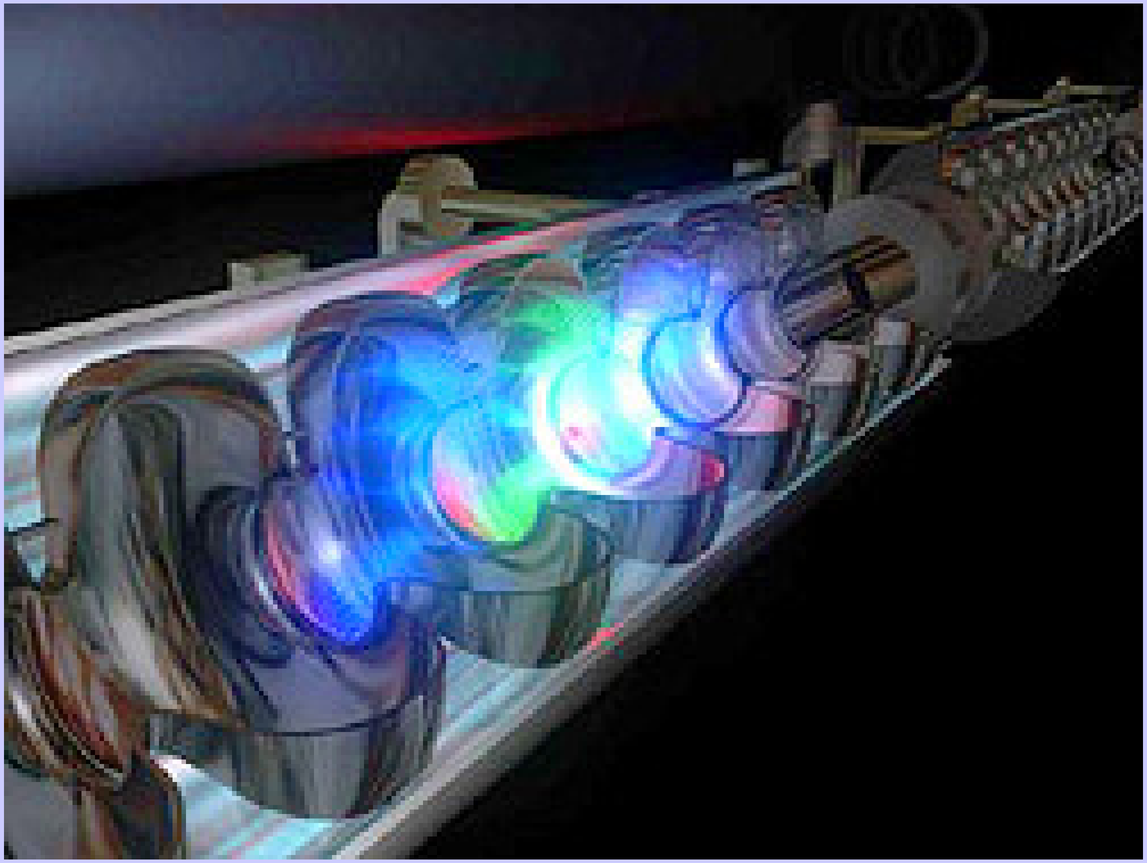
Introduction to the ILC

Lecture I-2

Linear Collider School 2012

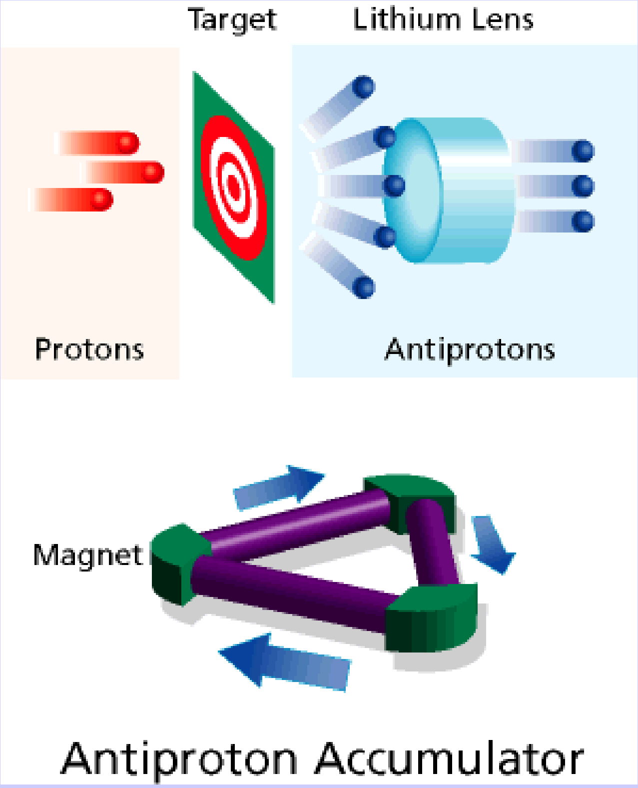


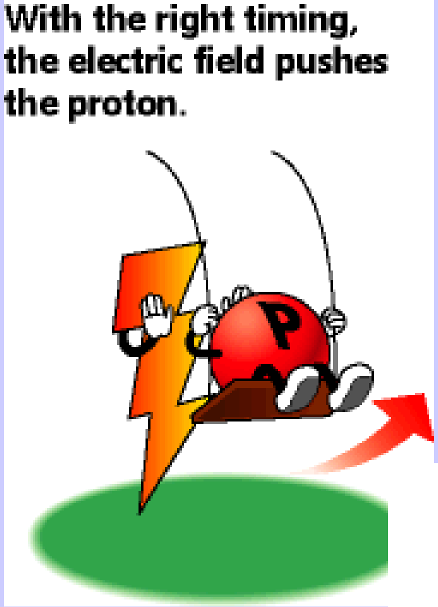
Barry Barish

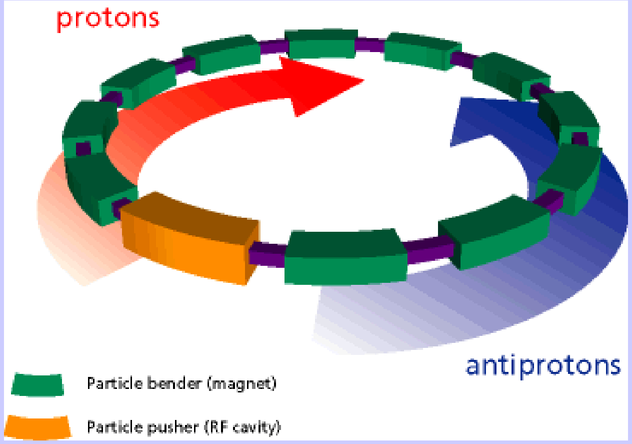
Caltech / GDE

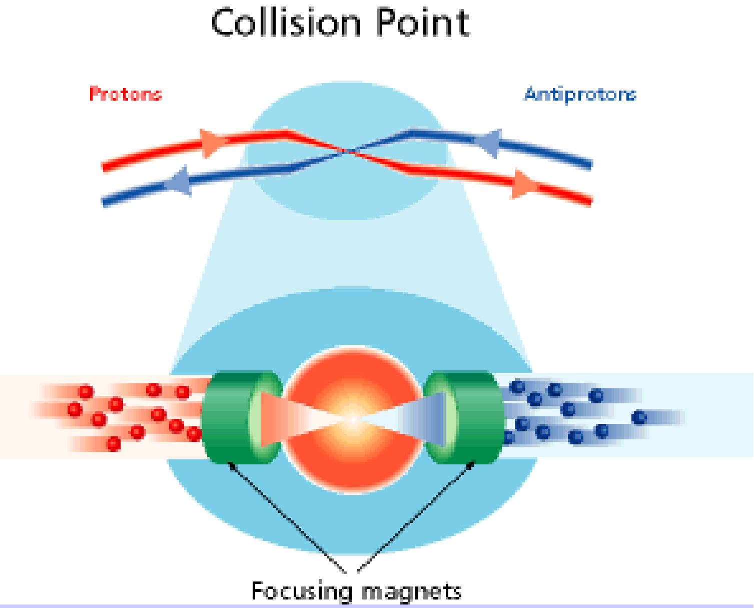
28-Nov-12

Particle Colliders

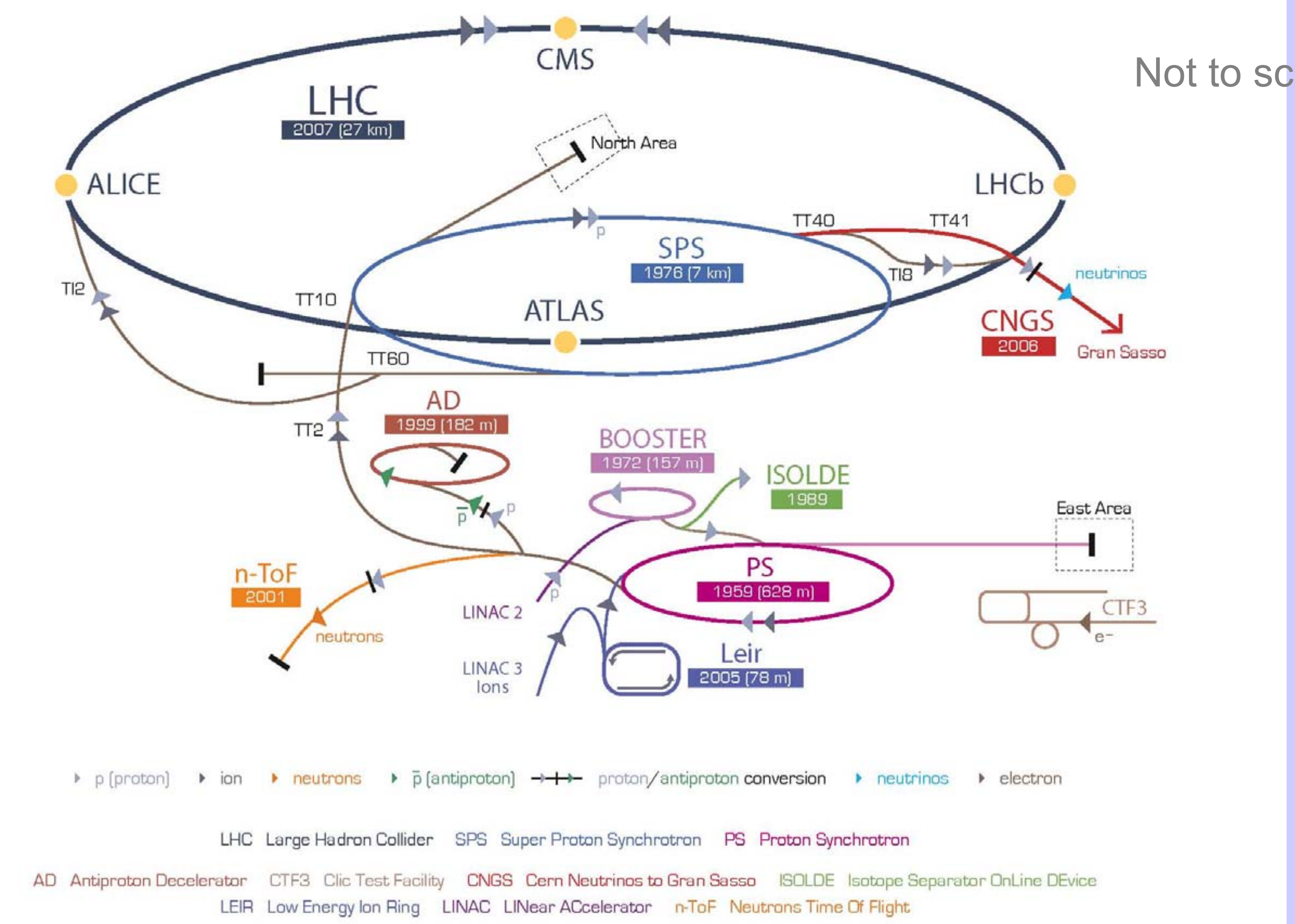



With the right timing, the electric field pushes the proton.



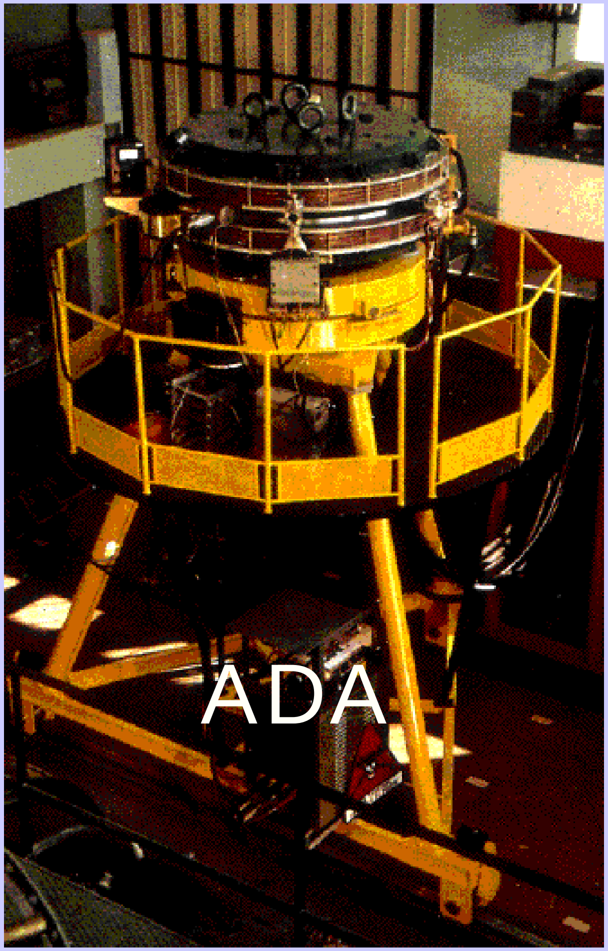


LHC – CERN Accelerator Complex



Not to scale

Electron-Positron Colliders

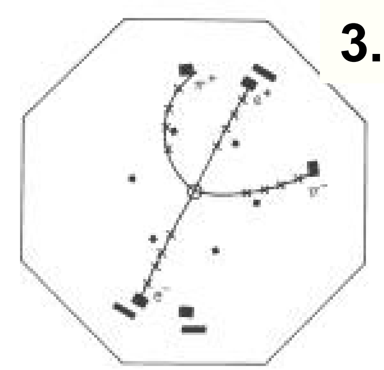


Bruno Touschek built the first successful electron-positron collider at Frascati, Italy (1960)

Eventually, went up to 3 GeV

But, not quite high enough energy ….

SPEAR at SLAC

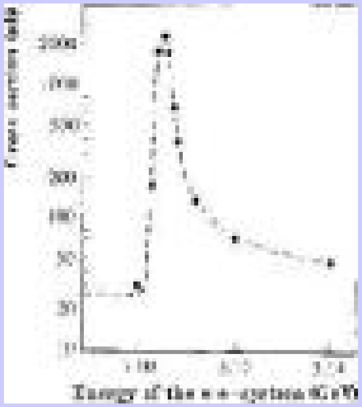


3.1 GeV

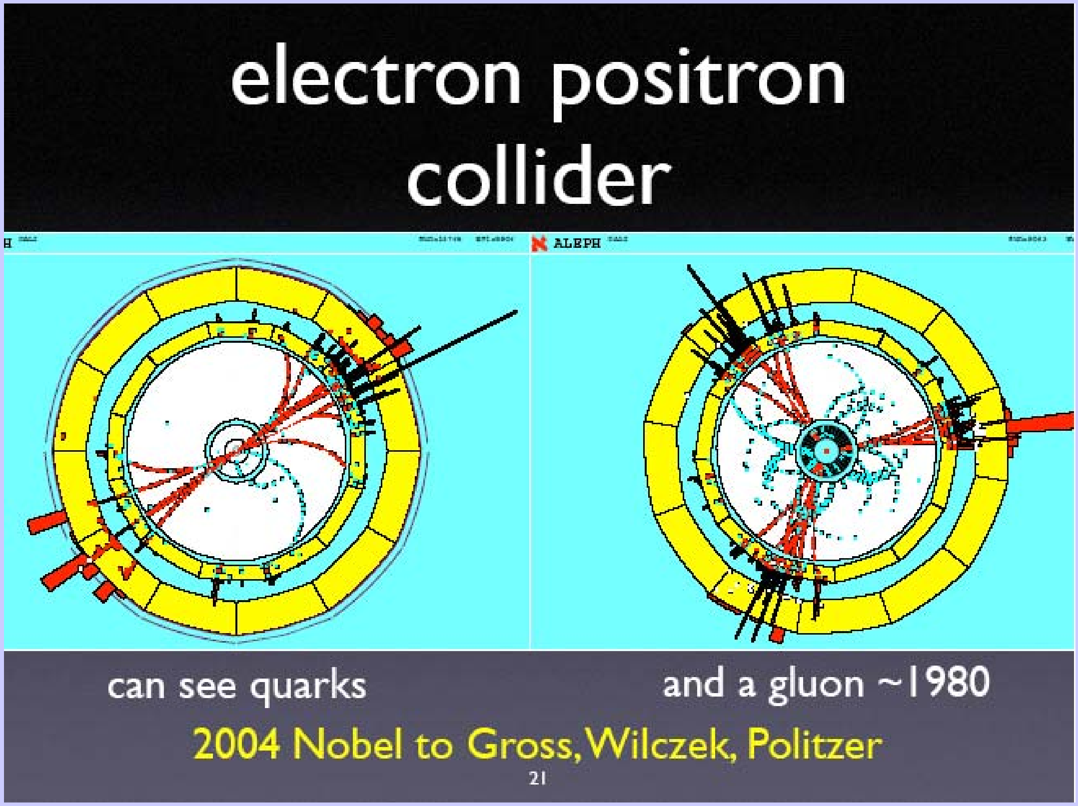
Burt Richter
Nobel Prize

and

Discovery
Of
Charm
Particles



The rich history for e^+e^- continued as higher energies were achieved …



electron positron collider

can see quarks

and a gluon ~1980

2004 Nobel to Gross, Wilczek, Politzer

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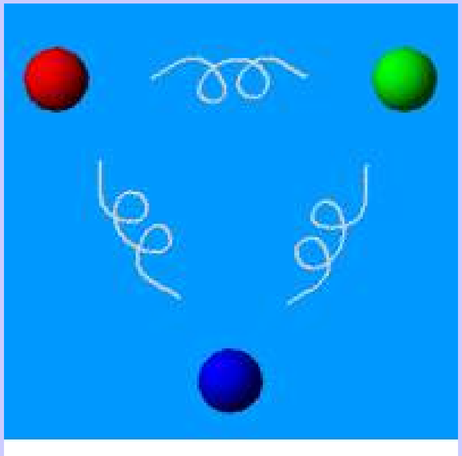
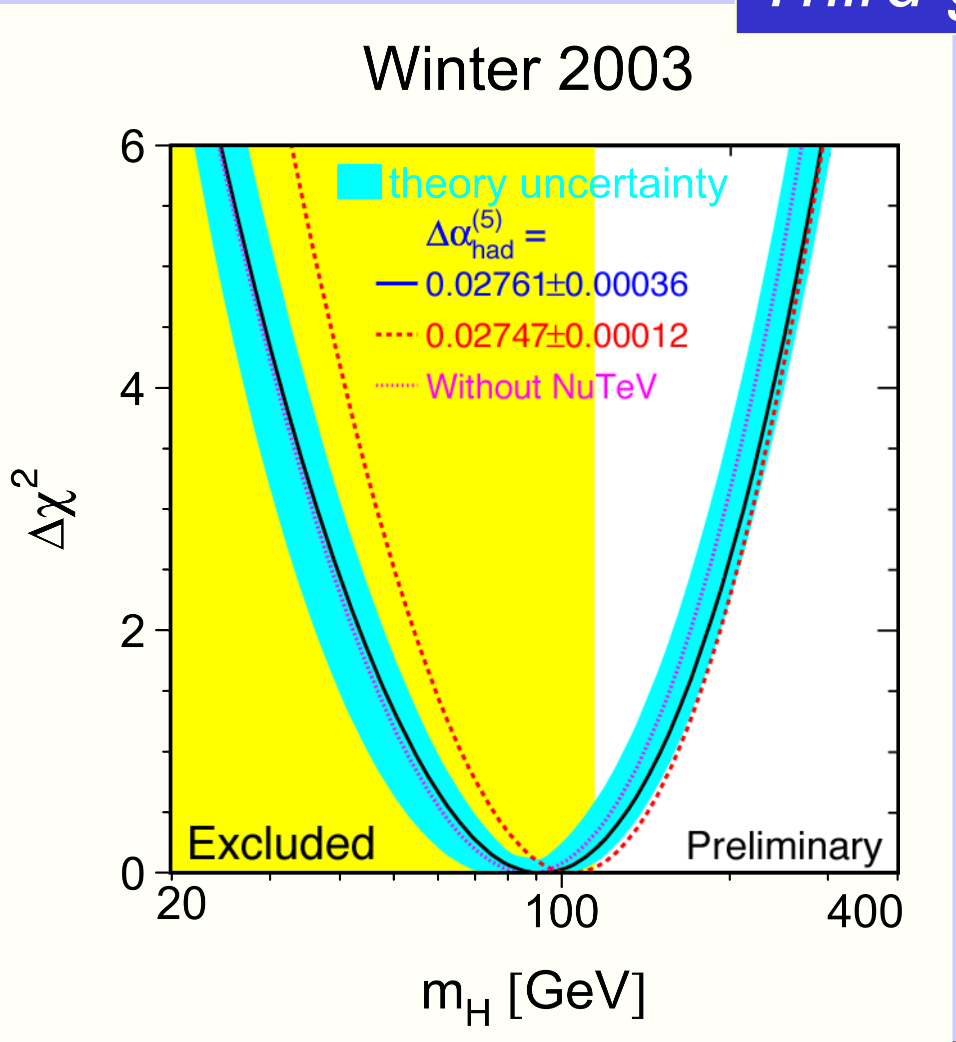


DESY PETRA Collider

Precision Measurements

Third generation

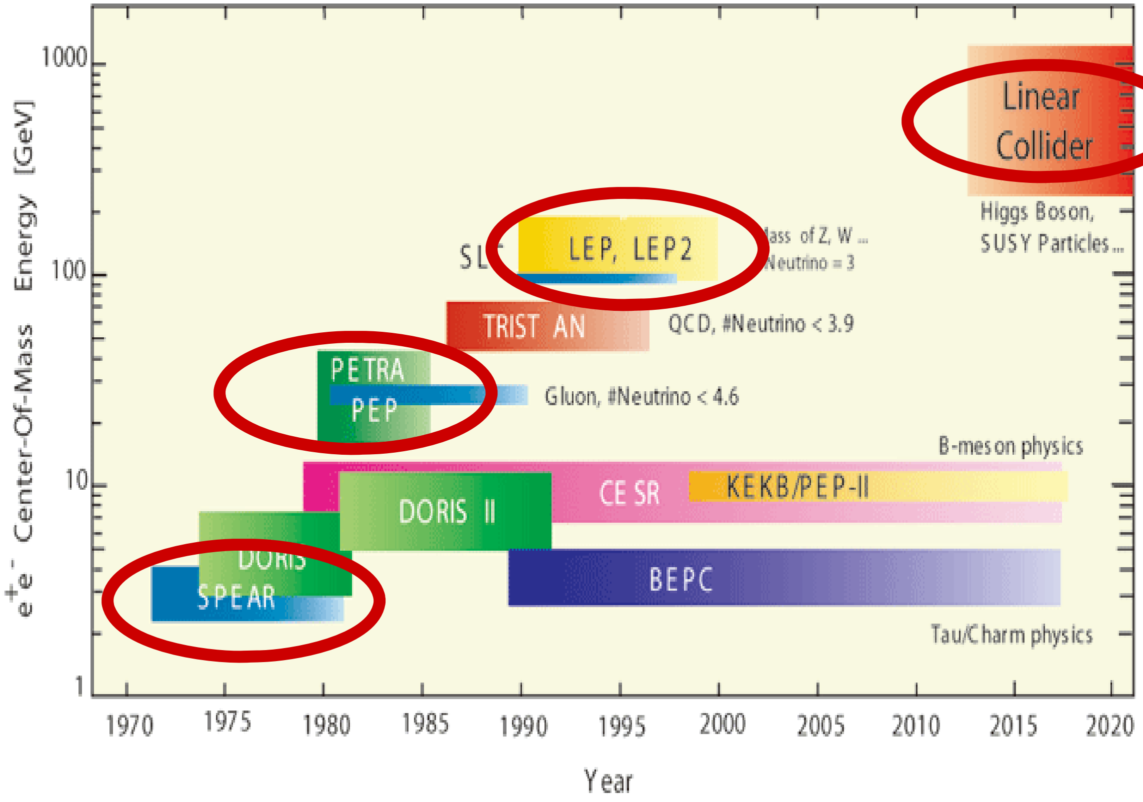


CERN's LEP Collider set the stage for Terascale physics

- **Reveal the origin of quark and lepton mass**
- **Produce dark matter in the laboratory**
- **Test exotic theories of space and time**

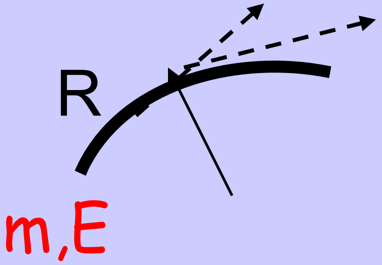
Three Generations of e^+e^- Colliders

The Energy Frontier



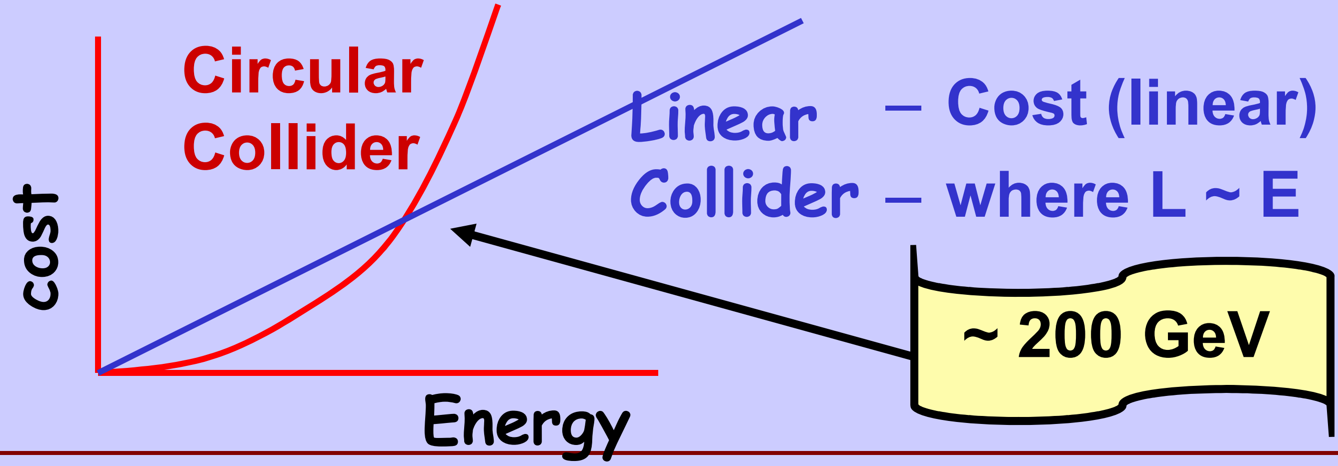
Fourth Generation?

Circular or Linear Collider?



Synchrotron Radiation

- **Circular Machine**
  - $\Delta E \sim (E^4 / m^4 R)$
  - Cost $\sim a R + b \Delta E$
    $\sim a R + b (E^4 / m^4 R)$
  - Optimization : $R \sim E^2$ ⇒ Cost $\sim c E^2$

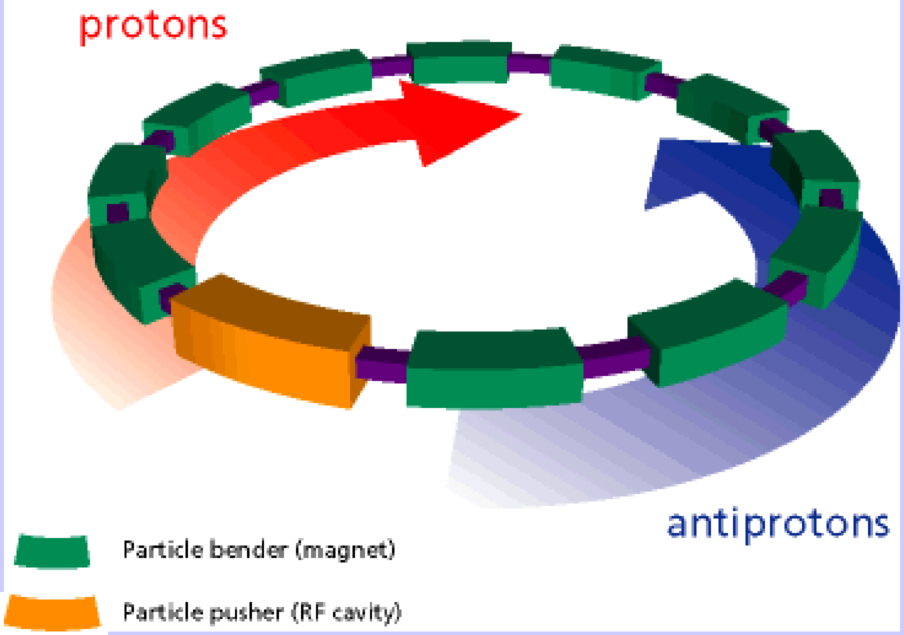


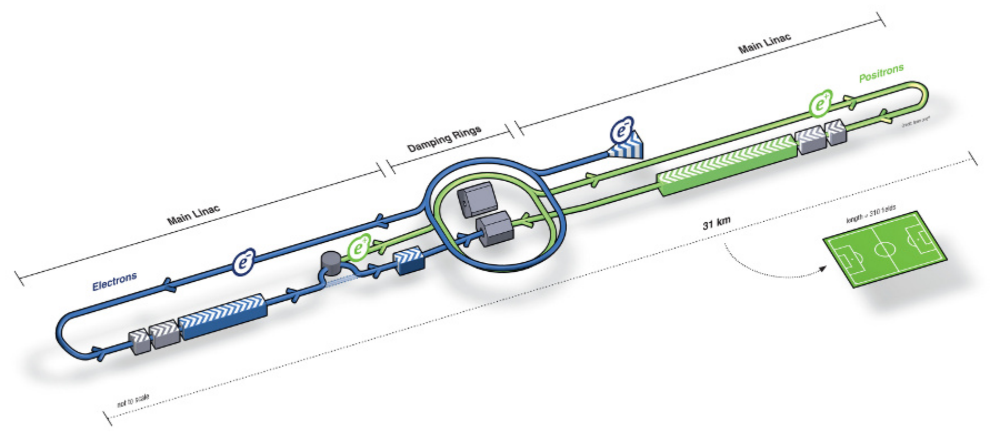
- Cost (linear) $\sim a' L$
- where $L \sim E$

Particle Colliders

Hadron colliders:

Higher energies, but energy of collision of point-like constitutents have large variance.

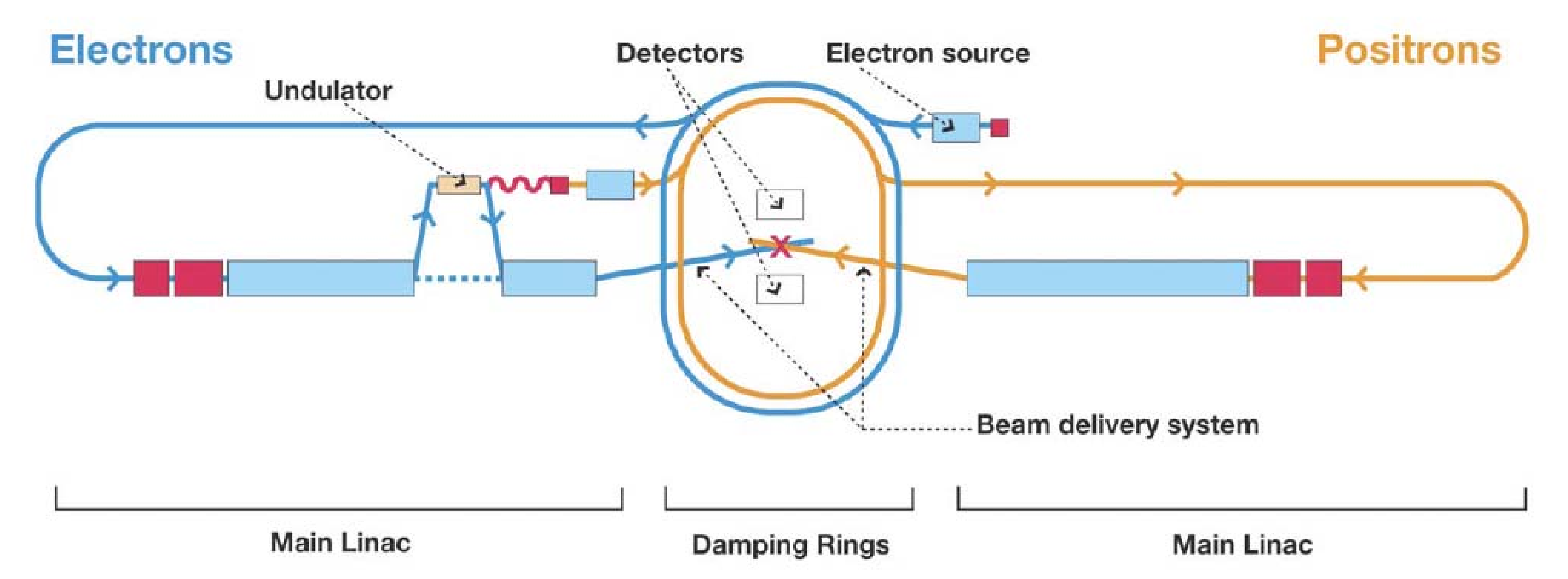




Lepton (ep) colliders:

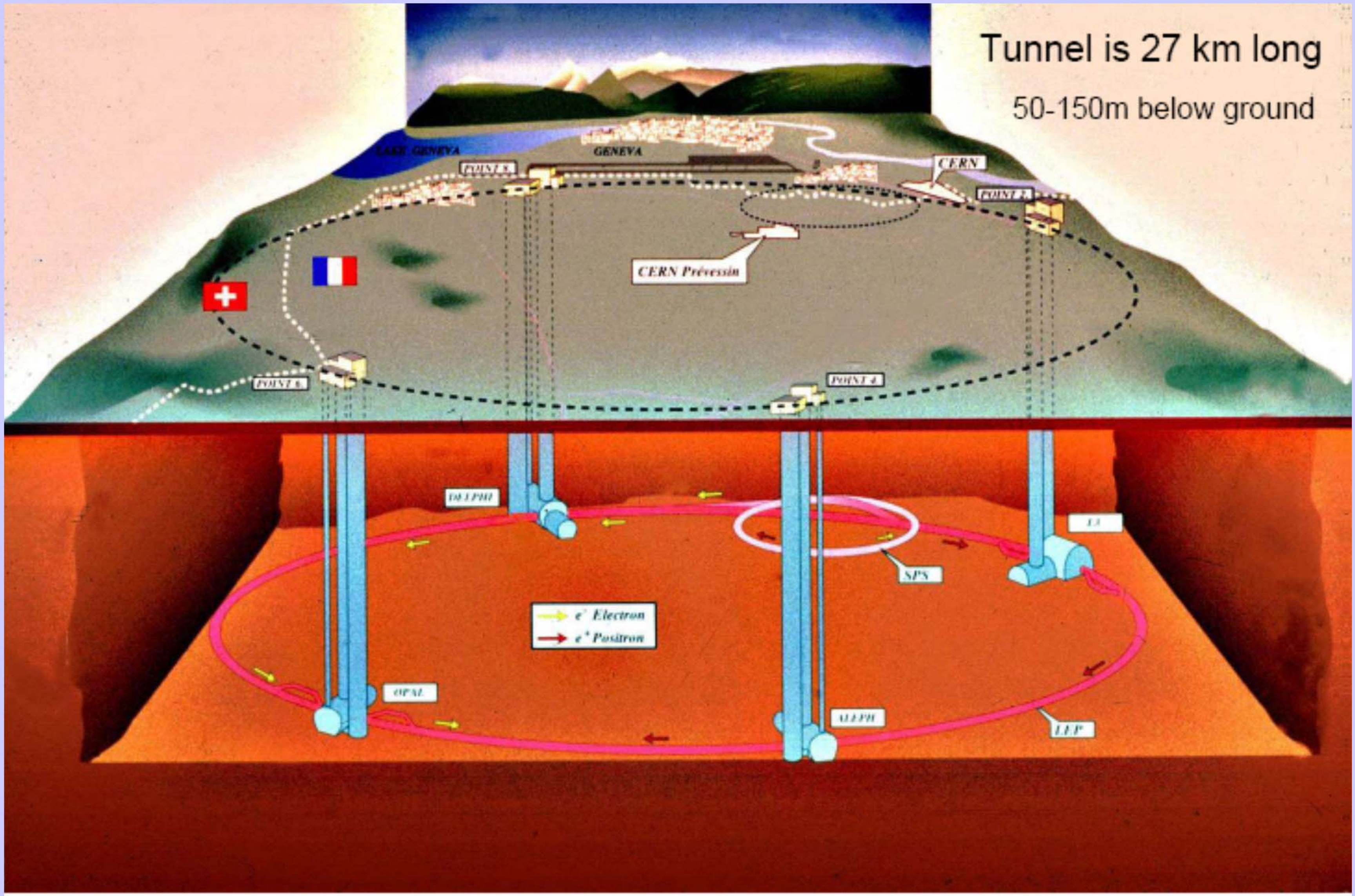
Lower energies, but well-known, controllable E_{CM} of collisions, much cleaner final states.

The ILC

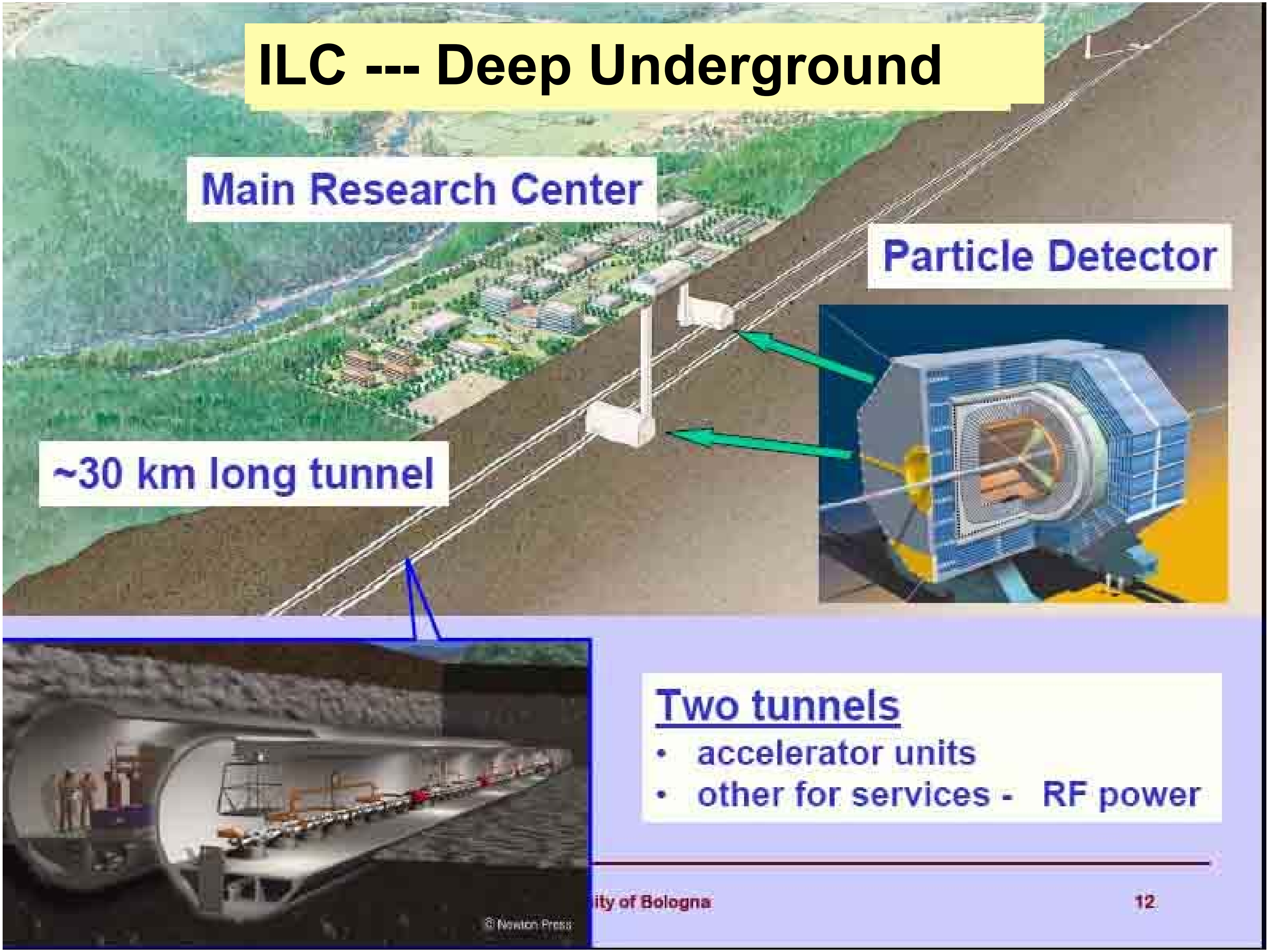


- **Two linear accelerators, with tiny intense beams of electrons and positrons colliding head-on-head**
- **Total length ~ 30 km long (comparable scale to LHC)**
- **COM energy = 500 GeV, upgradeable to 1 TeV**

LHC --- Deep Underground


Tunnel is 27 km long

50-150m below ground



ILC --- Deep Underground

Main Research Center

Particle Detector

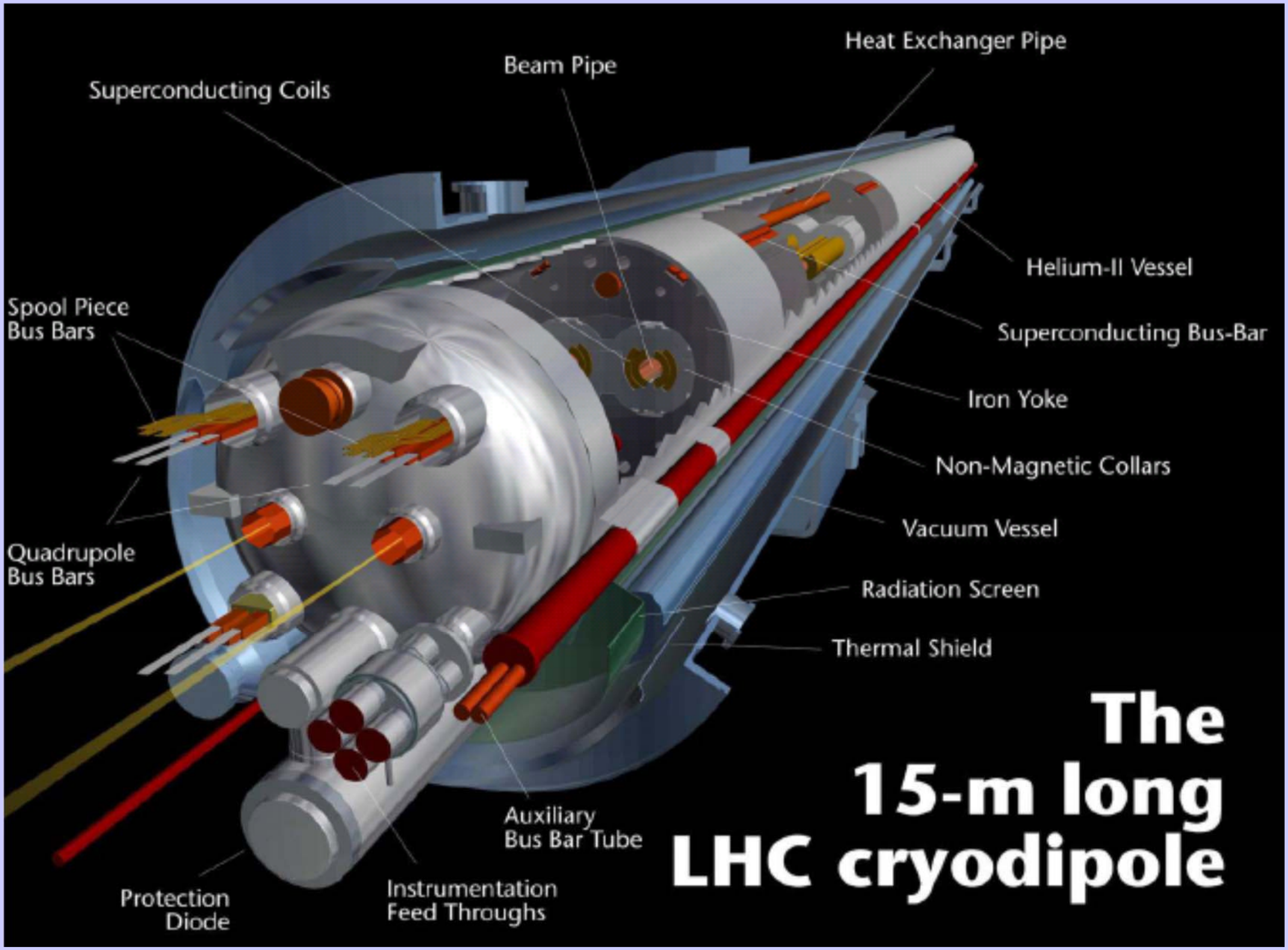
~30 km long tunnel

Two tunnels

- accelerator units
- other for services - RF power

© Newton Press

LHC --- Superconducting Magnet



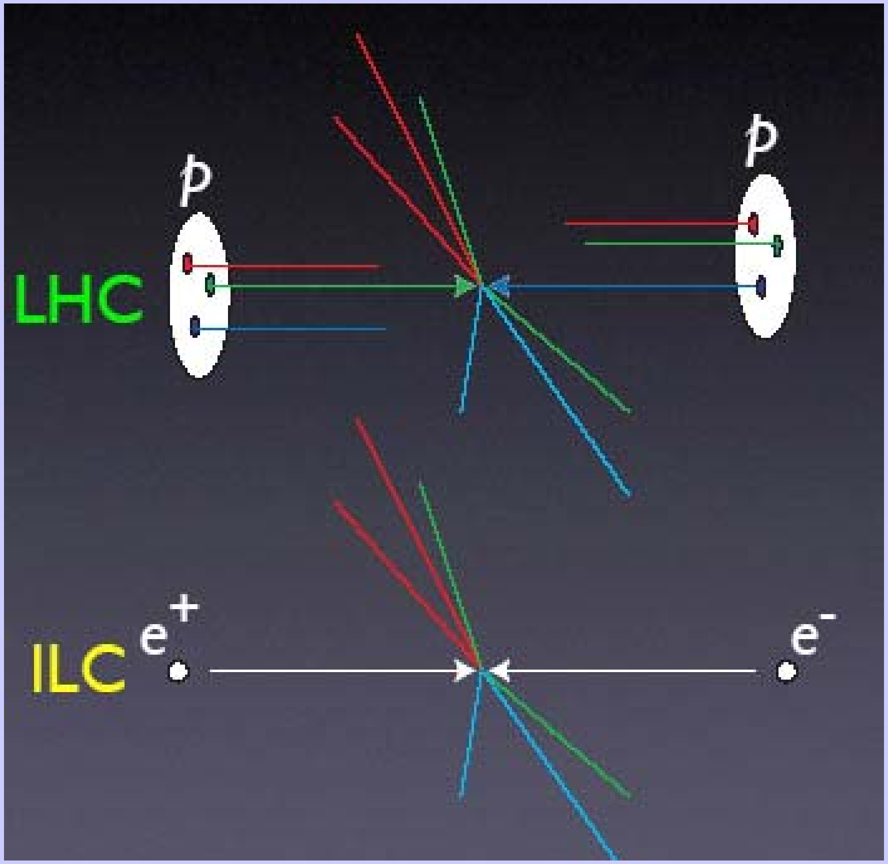
ILC - Superconducting RF Cryomodule

Comparison: ILC and LHC

	ILC	LHC
Beam Particle :	Electron x Positron	Proton x Proton
CMS Energy :	0.5 – 1 TeV	14 TeV
Luminosity Goal :	2×10^{34} /cm^2/sec	1×10^{34} /cm^2/sec
Accelerator Type :	Linear	Circular Storage Rings
Technology :	Supercond. RF	Supercond. Magnet

Advantages of e^+e^- Collisions ?

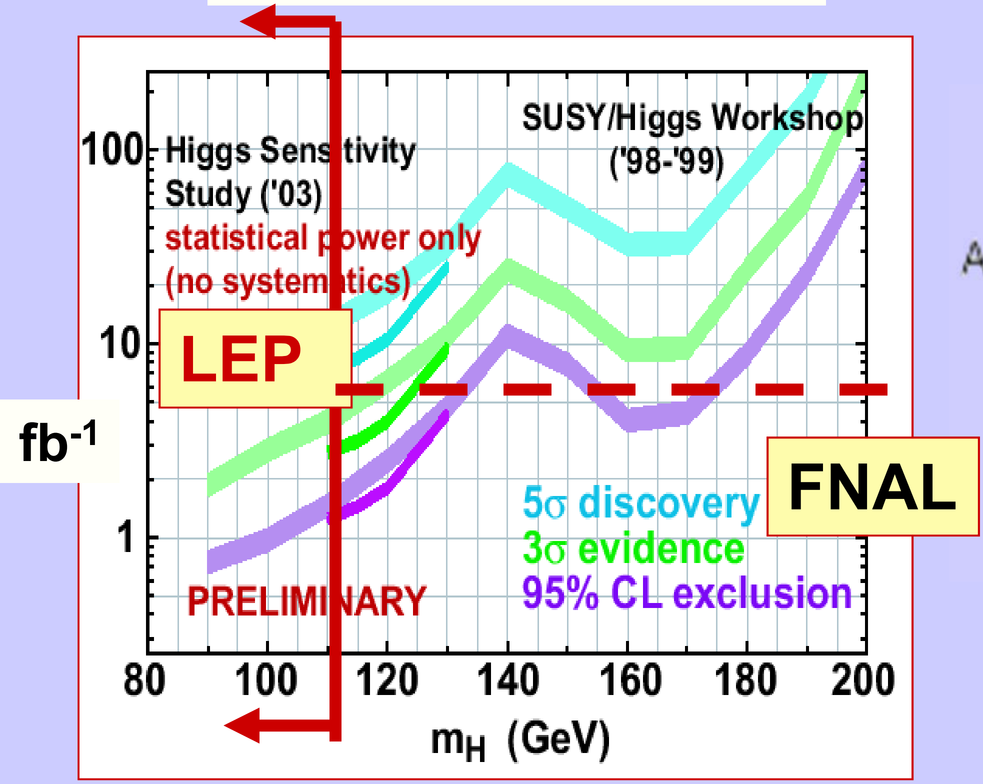
- elementary particles
- well-defined
  - energy,
  - angular momentum
- uses full COM energy
- produces particles democratically
- can mostly fully reconstruct events



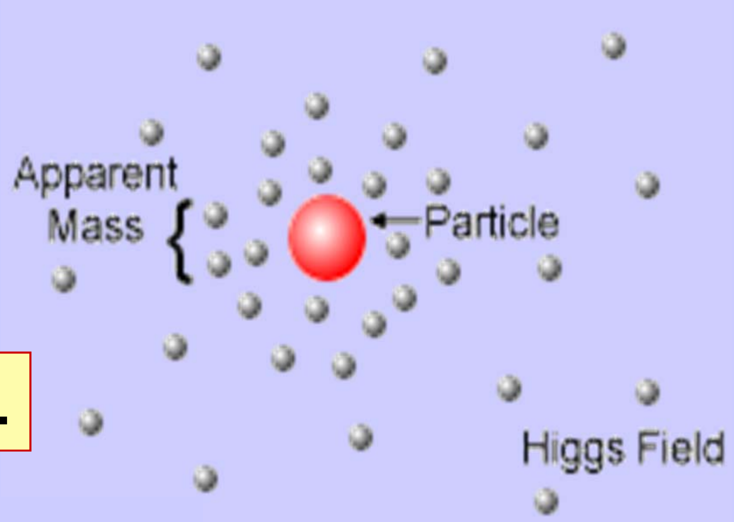
LHC and the Energy Frontier

Source of Particle Mass

Discover the Higgs



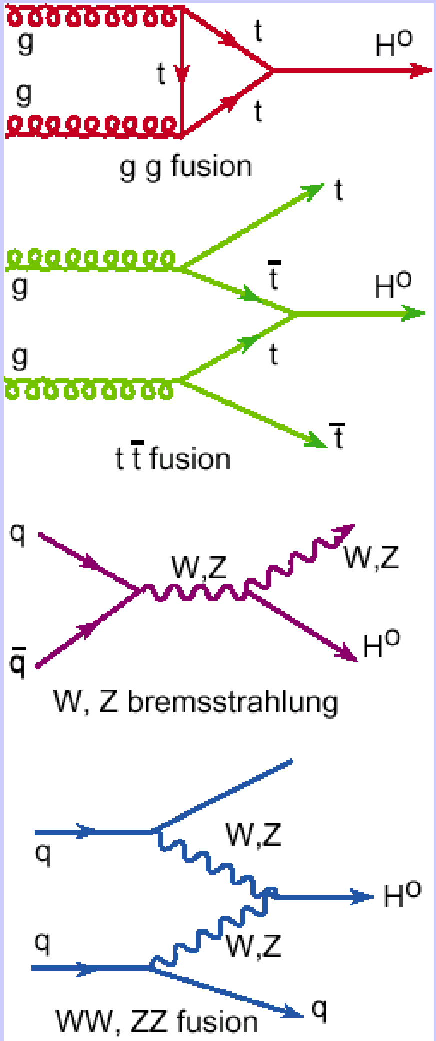
The Higgs Field

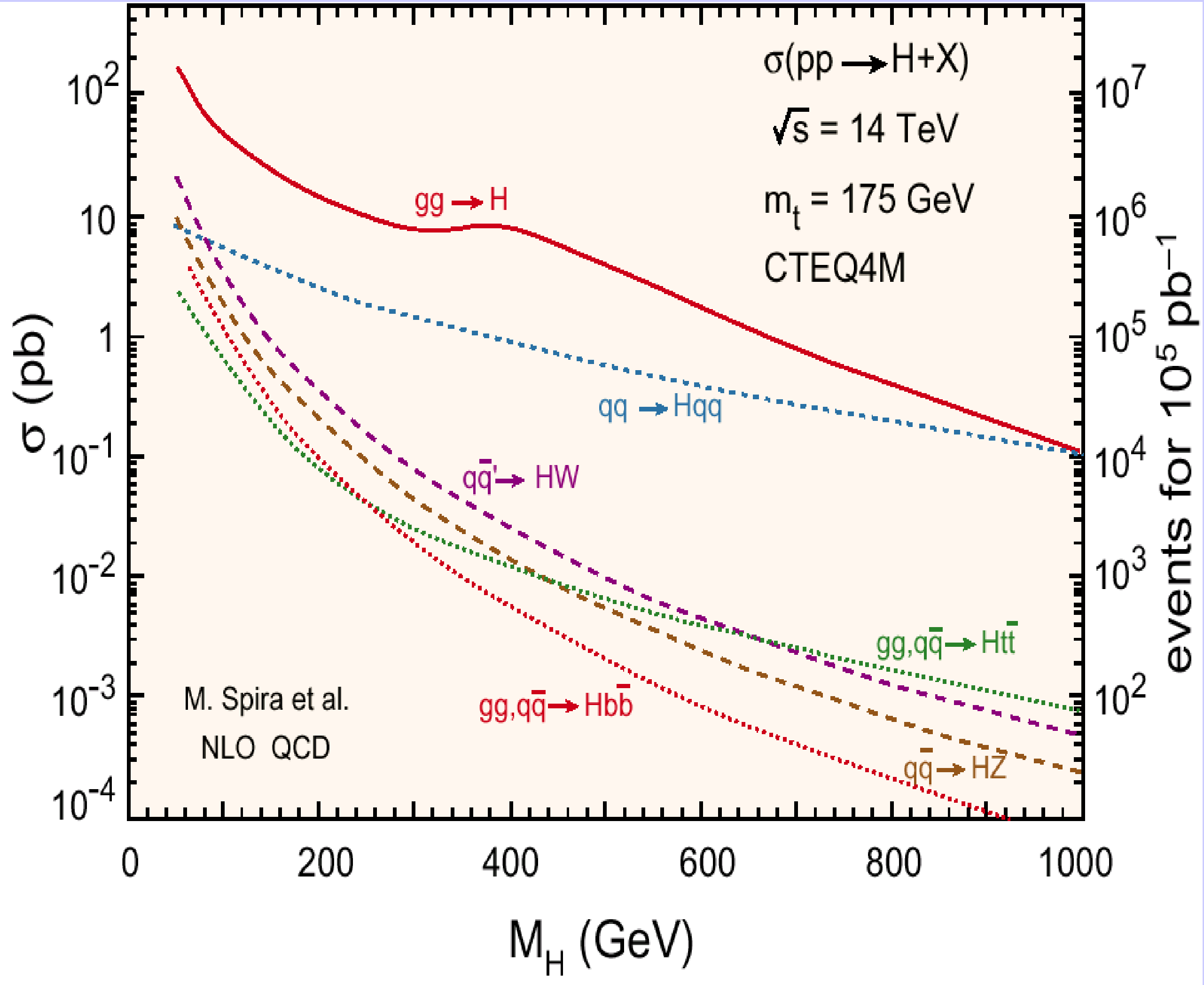


or variants or ???

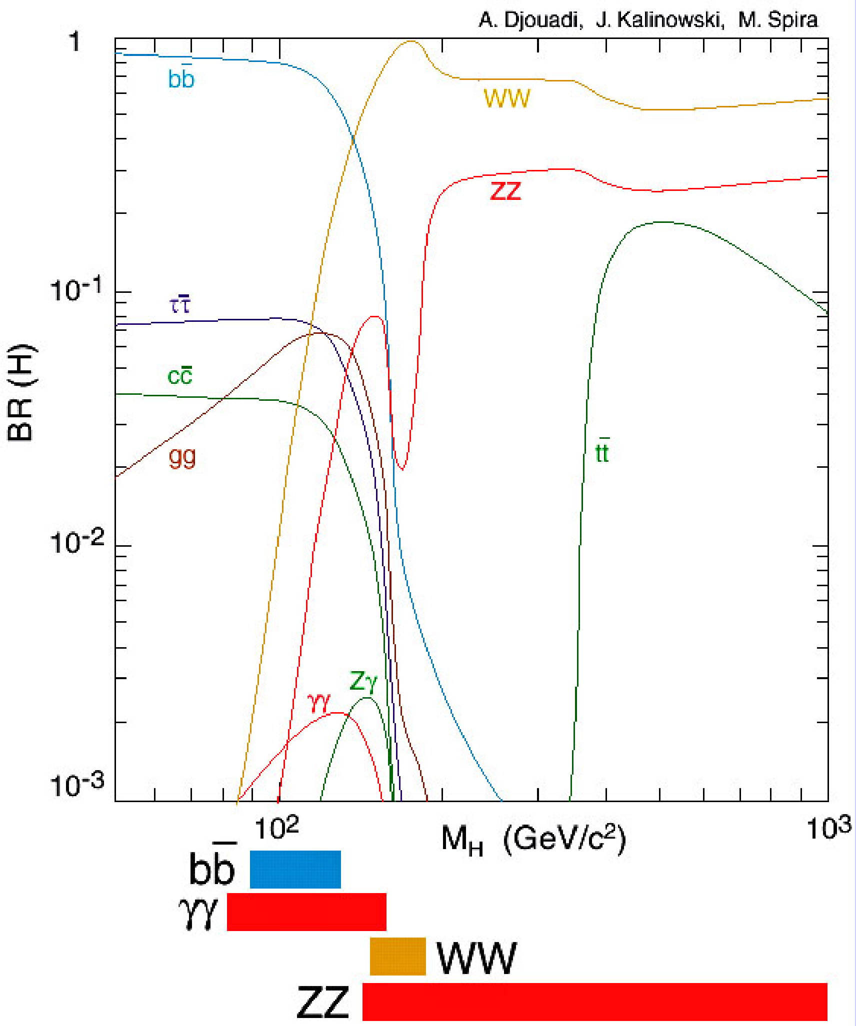
LHC - Higgs Production and Cross Section

four production mechanisms





LHC - Higgs Discovery Channels



Higgs coupling proportional to $m_{f,}$ therefore b-quark dominates until reach WW, ZZ thresholds

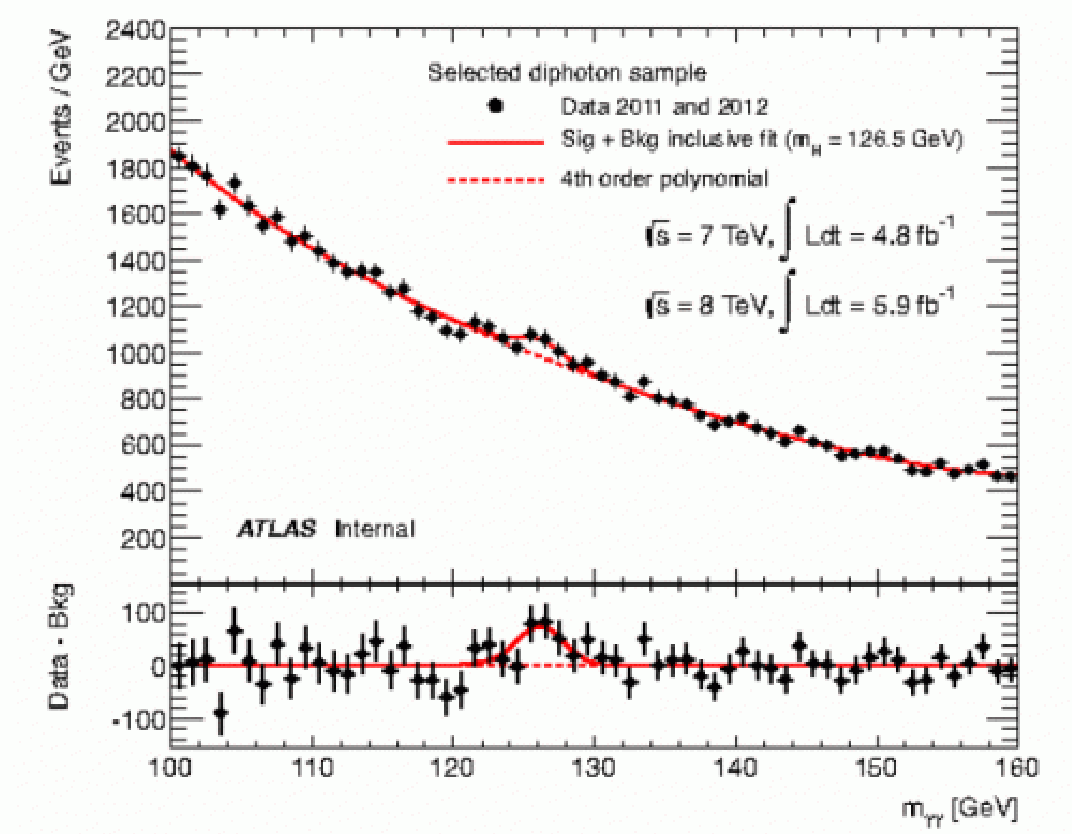
Large QCD backgrounds:

σ (H → bb) ≈ 20 pb
(for M_H =120 GeV)

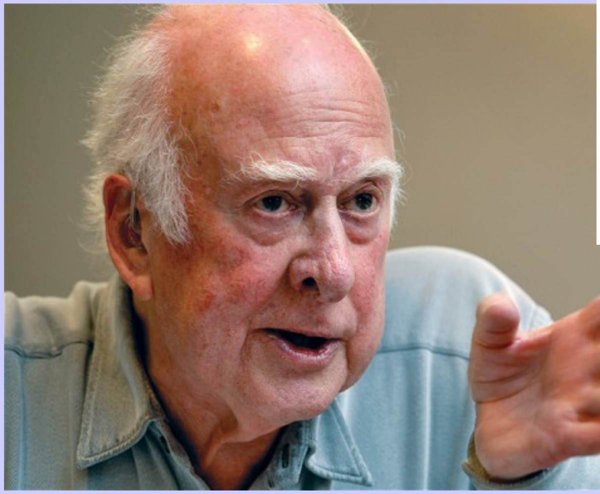
σ (bb) ≈ 500 mb

Search for ℓ, γ final states

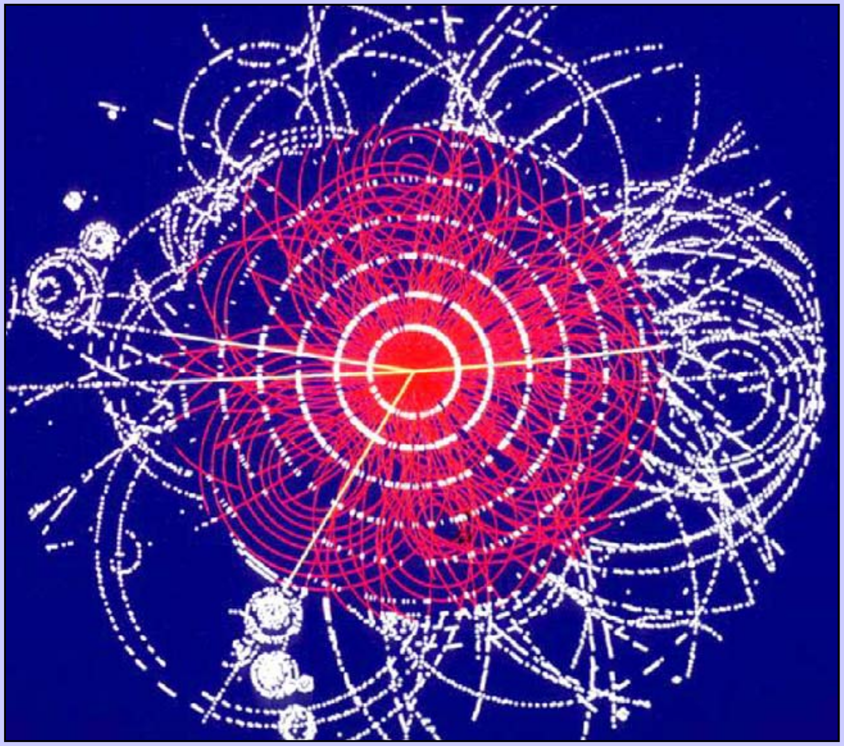
Discovery of Higg-like particle



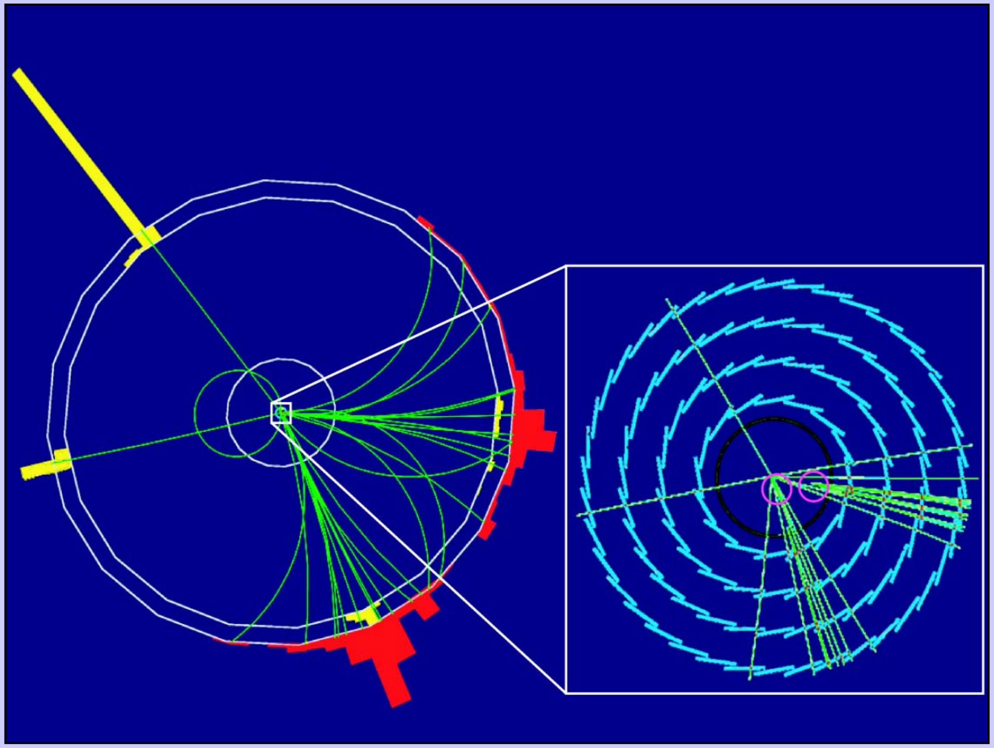
Peter Higgs



LHC/ILC Higgs Event Comparison



LHC

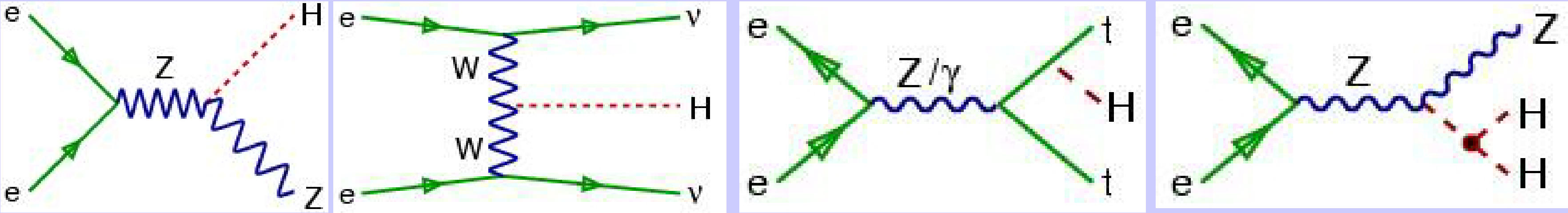


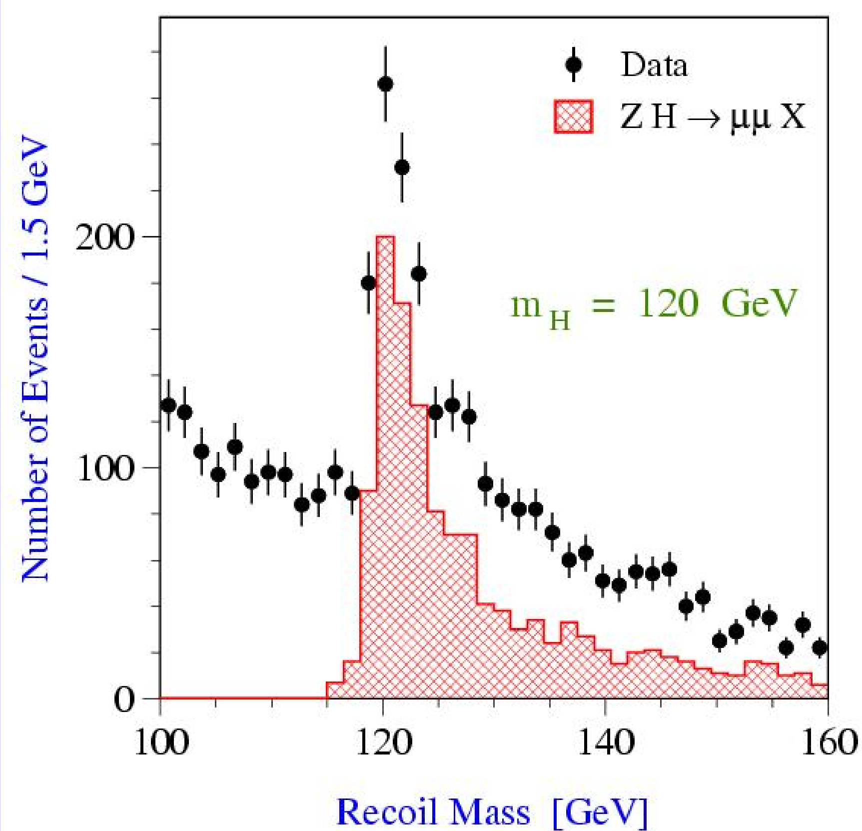
ILC

$e^+ e^- \rightarrow Z\, H$

$Z \rightarrow e^+ e^-,\ H \rightarrow \bar{b} b$ …

ILC Precision Higgs physics



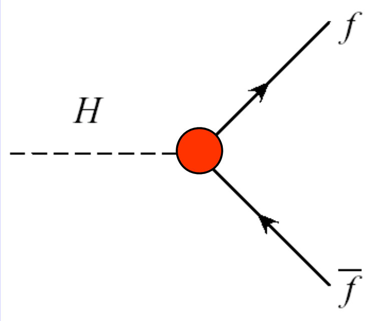


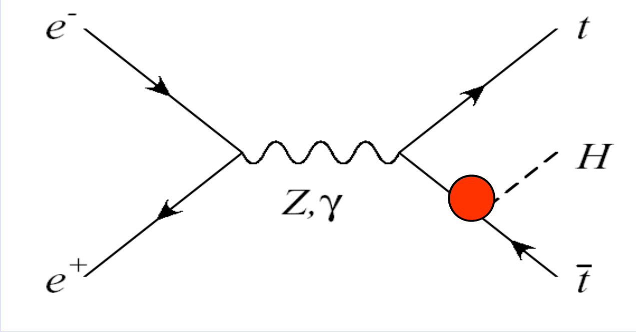
Garcia-Abia et al

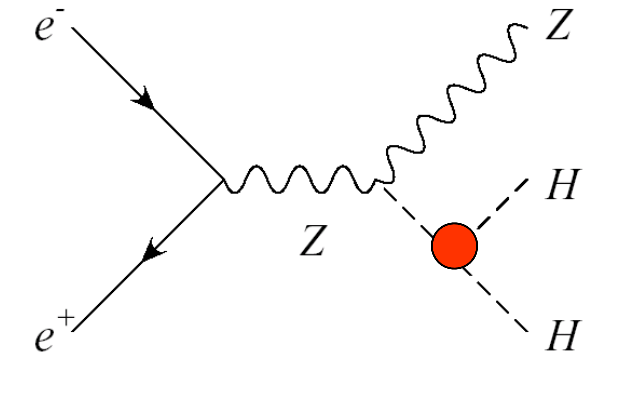
- **Model-independent Studies**
  - **mass**
  - **absolute branching ratios**
  - **total width**
  - **spin**
  - **top Yukawa coupling**
  - **self coupling**
- **Precision Measurements**

Remember - the Higgs is a Different!

- It is a zero spin particle that fills the vacuum
- It couples to mass; masses and decay rates are related



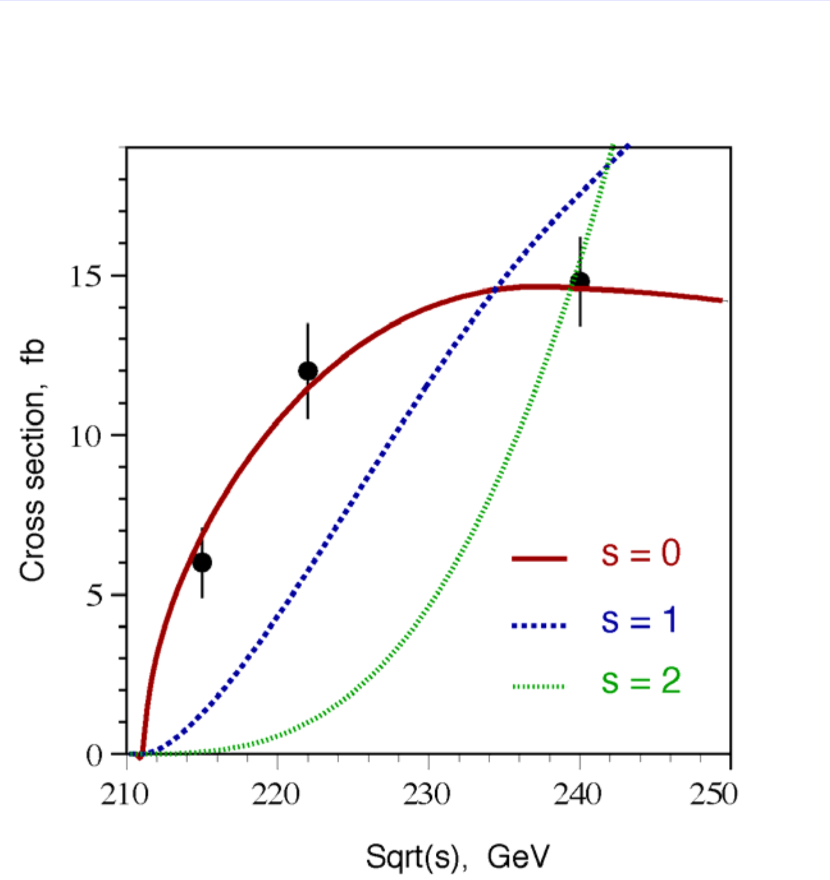




Higgs Coupling-mass relation

$$m_i = v \times \kappa_i$$

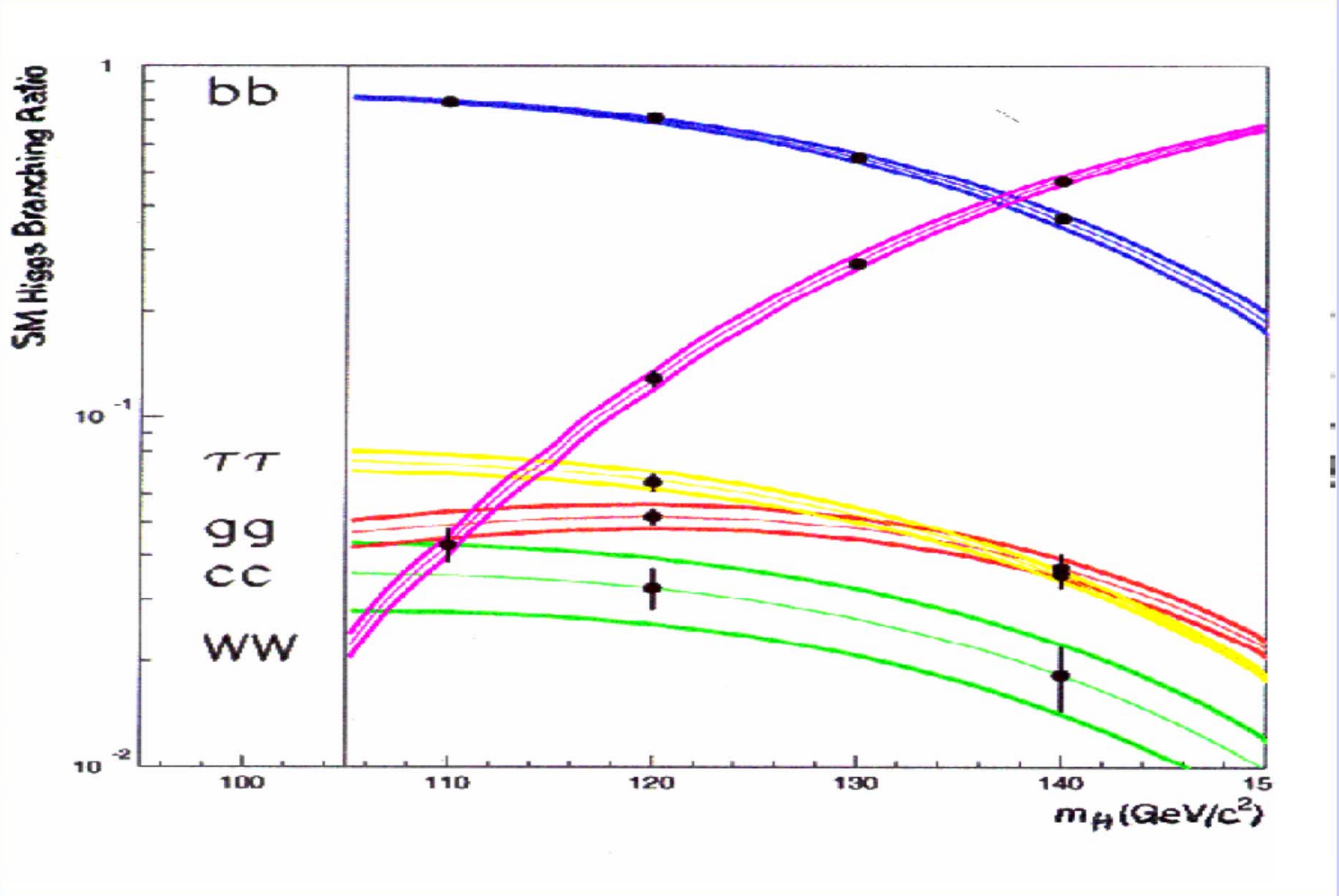
ILC: Is it really the Higgs ?



Measure the quantum numbers. The Higgs must have spin zero !

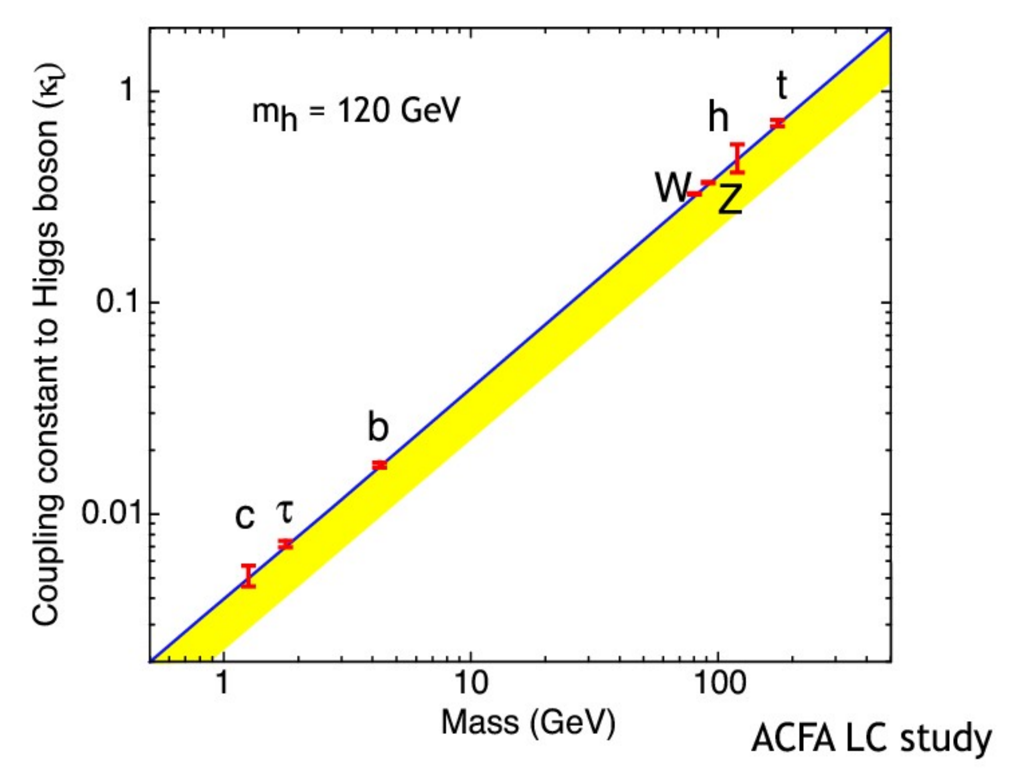
The linear collider will measure the spin of any Higgs it can produce by measuring the energy dependence from threshold

Higgs Branching Ratios



What can we learn from the Higgs?

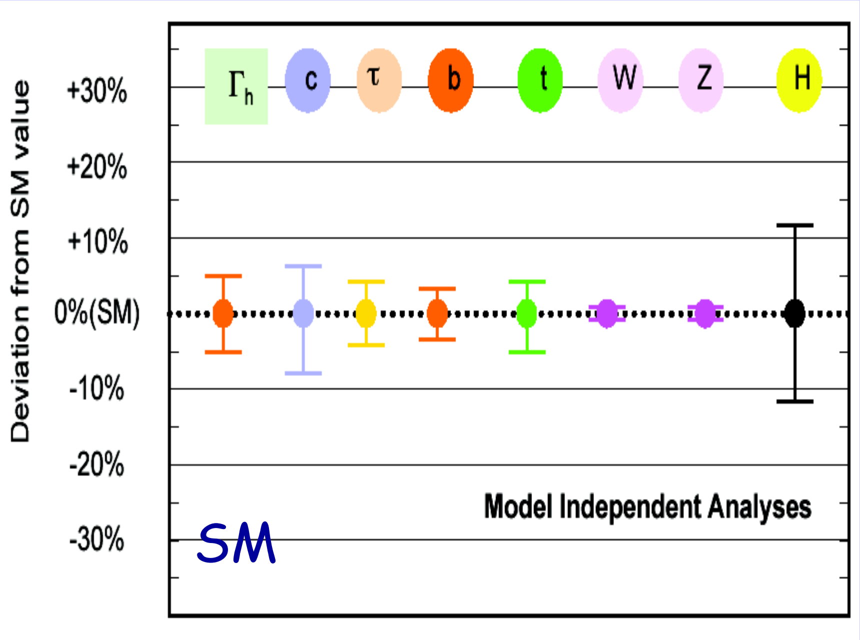
Precision measurements of Higgs coupling

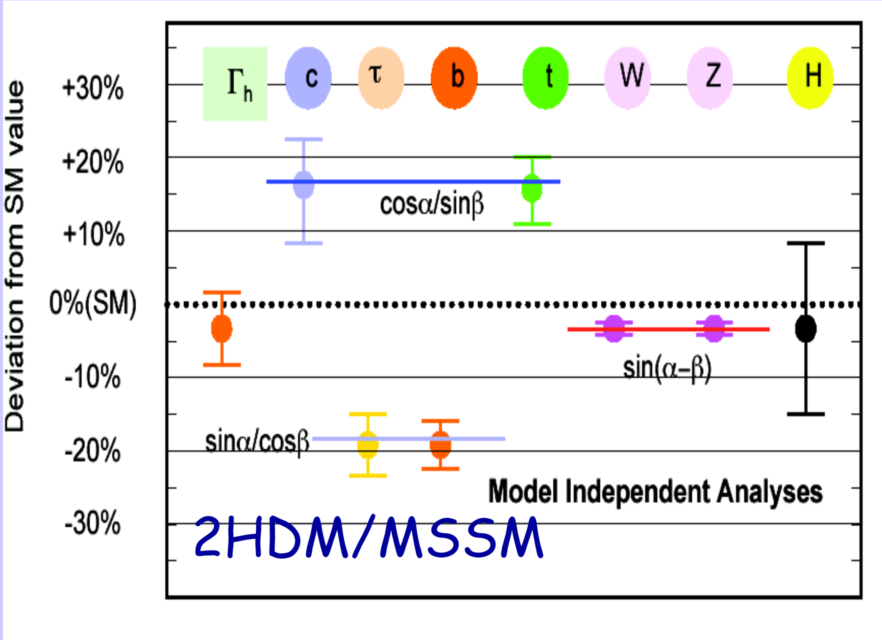


Higgs Coupling strength is proportional to Mass

e^+e^- : Studying the Higgs

determine the underlying model





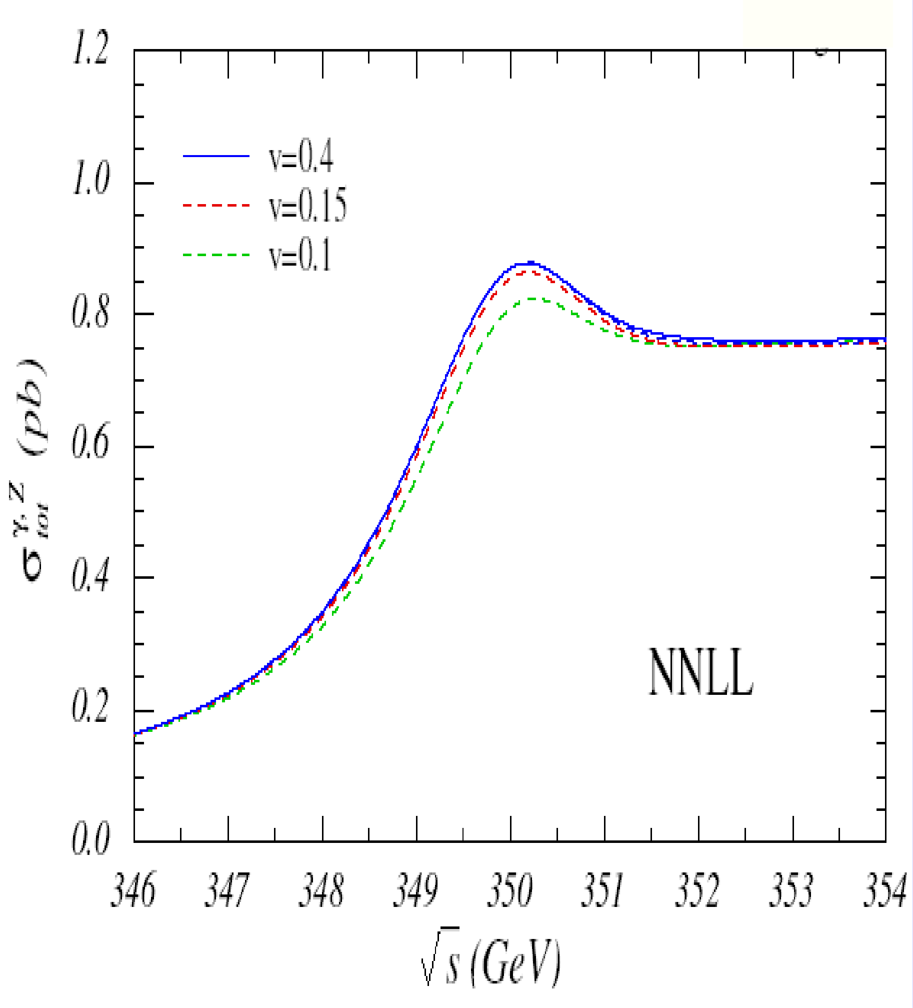
Yamashita et al

Zivkovic et al

Top Quark Measurements

Threshold scan provides mass measurement

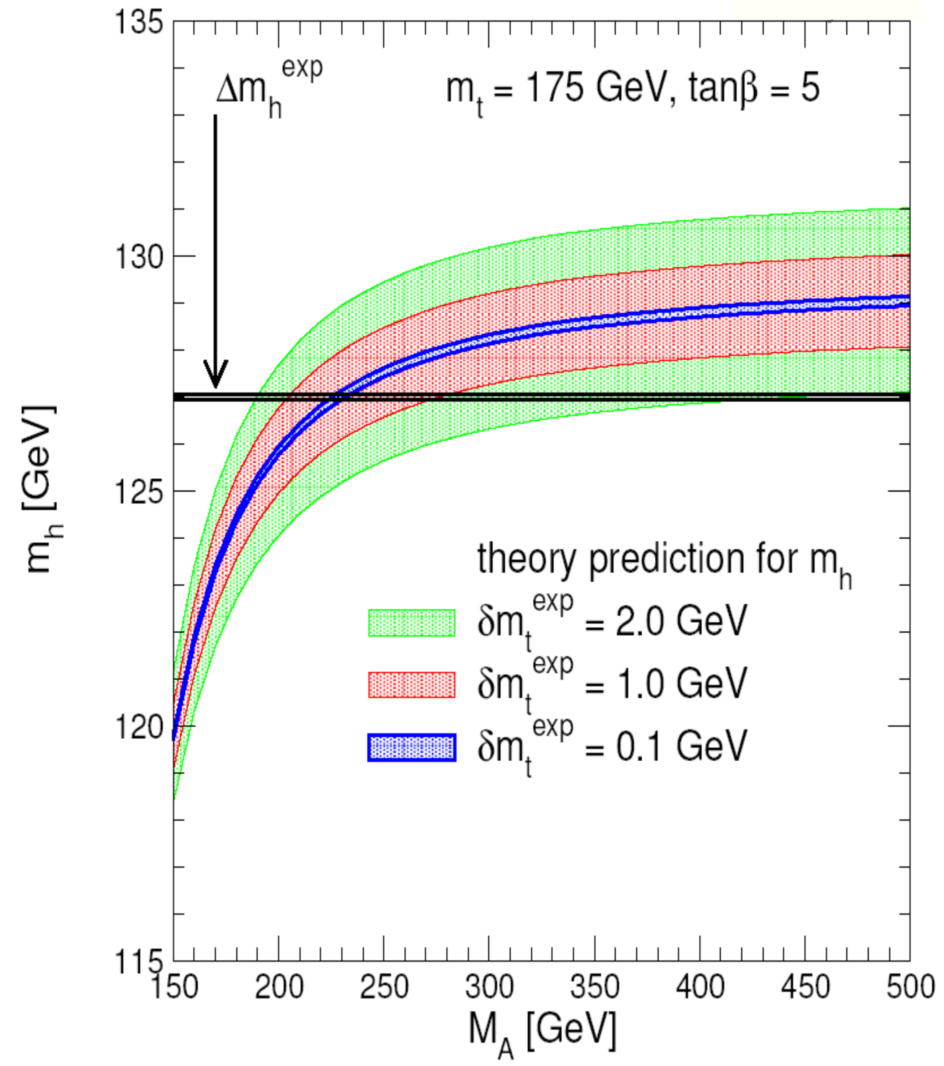
Theory (NNLL) controls m_t(MS) to 100 MeV



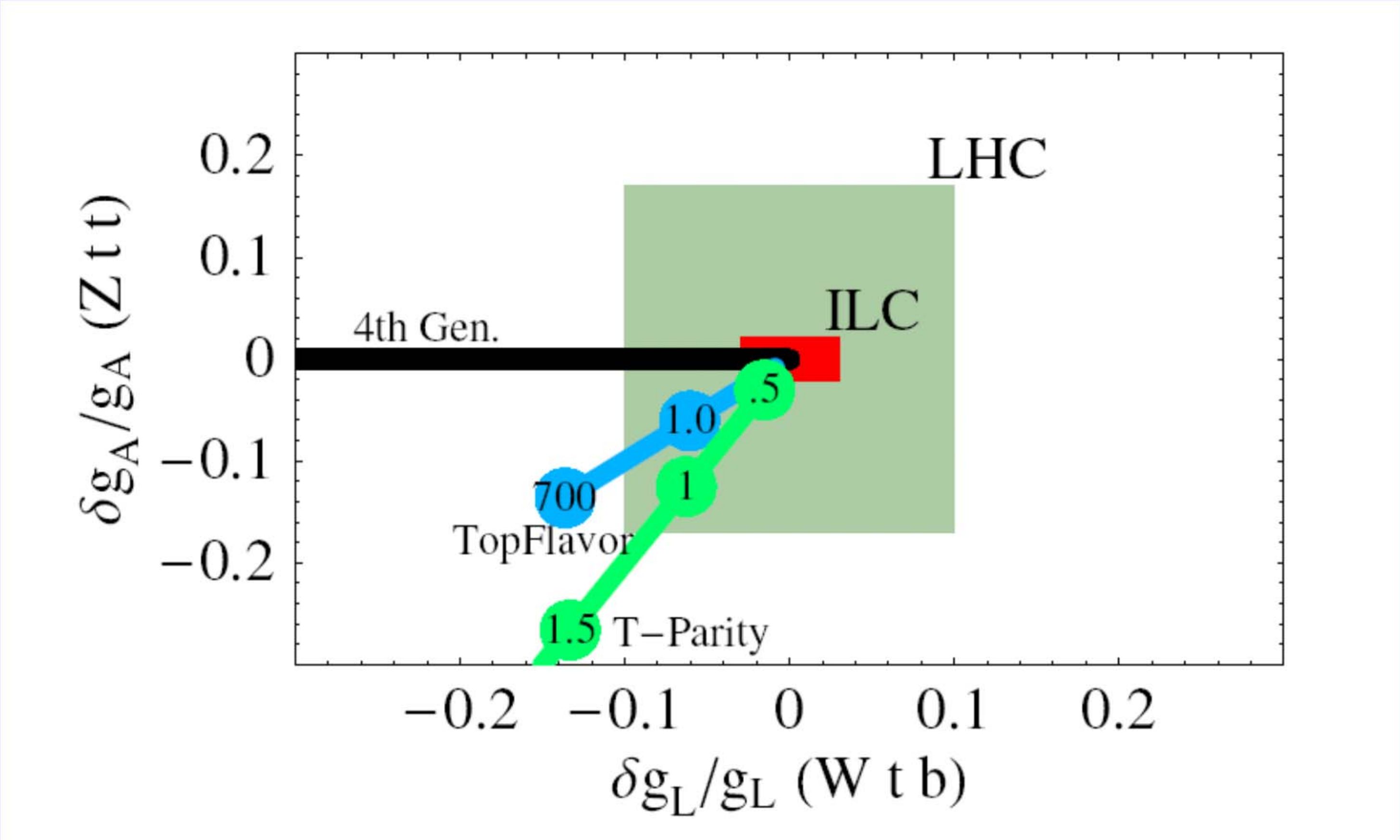
Top Quark Measurements

Precision top mass

- Improved Standard Model fits
- MSSM (m_h prediction)
- …

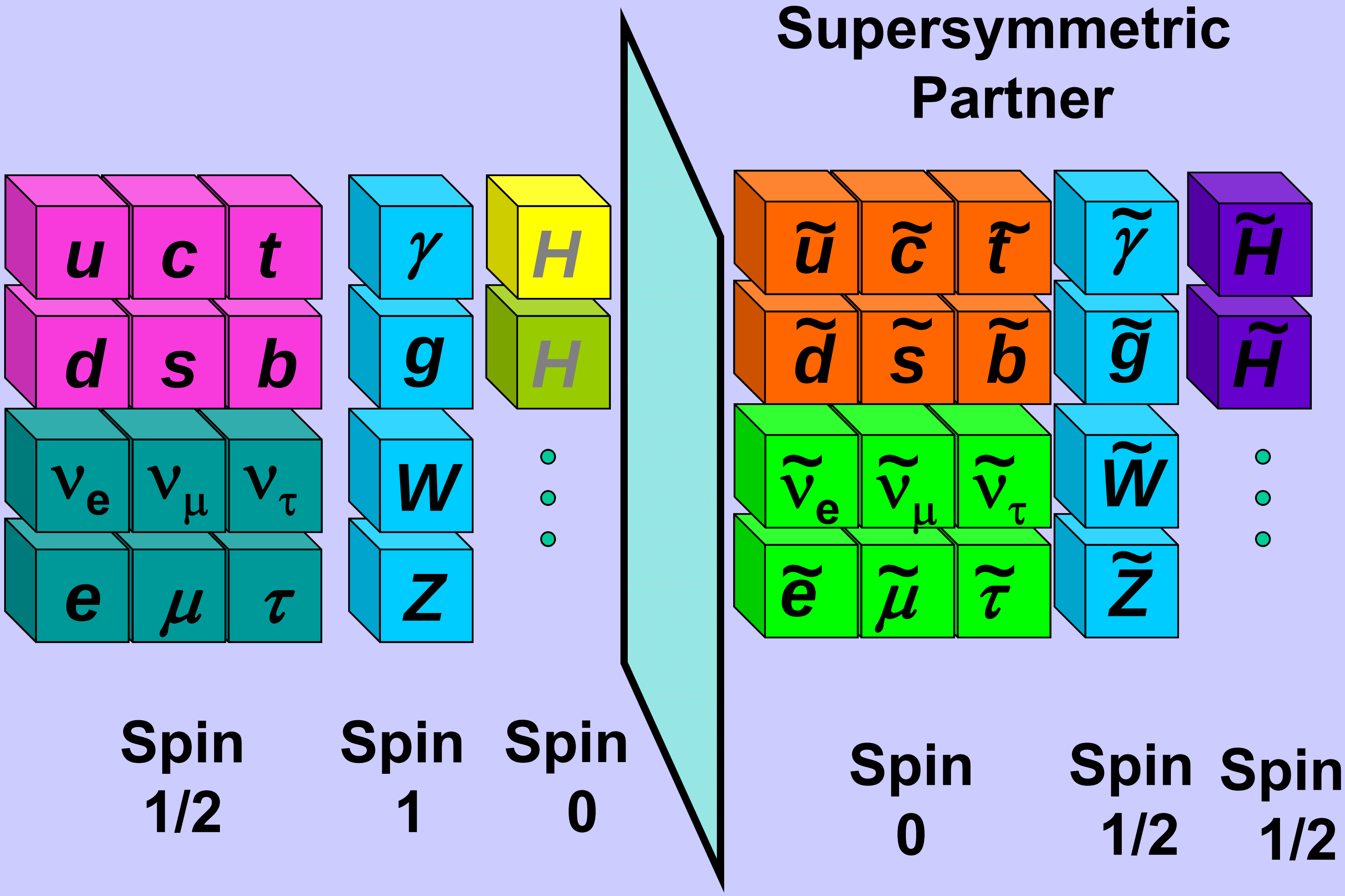


Top Quark Measurements



Bounds on axial ttbarZ and left handed tbW for LHC and ILC compared to deviations in various models

Supersymmetry

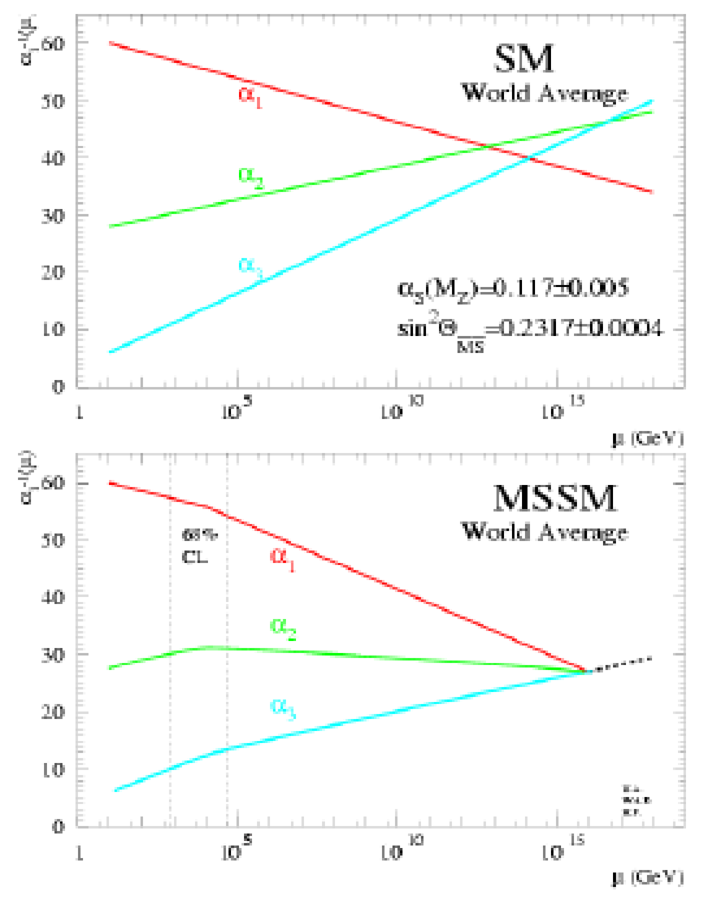


Is there a New Symmetry in Nature?

Bosons ↔ **Fermions**

Integer Spin: 0, 1,..

Half integer Spin: 1/2, 3/2,..

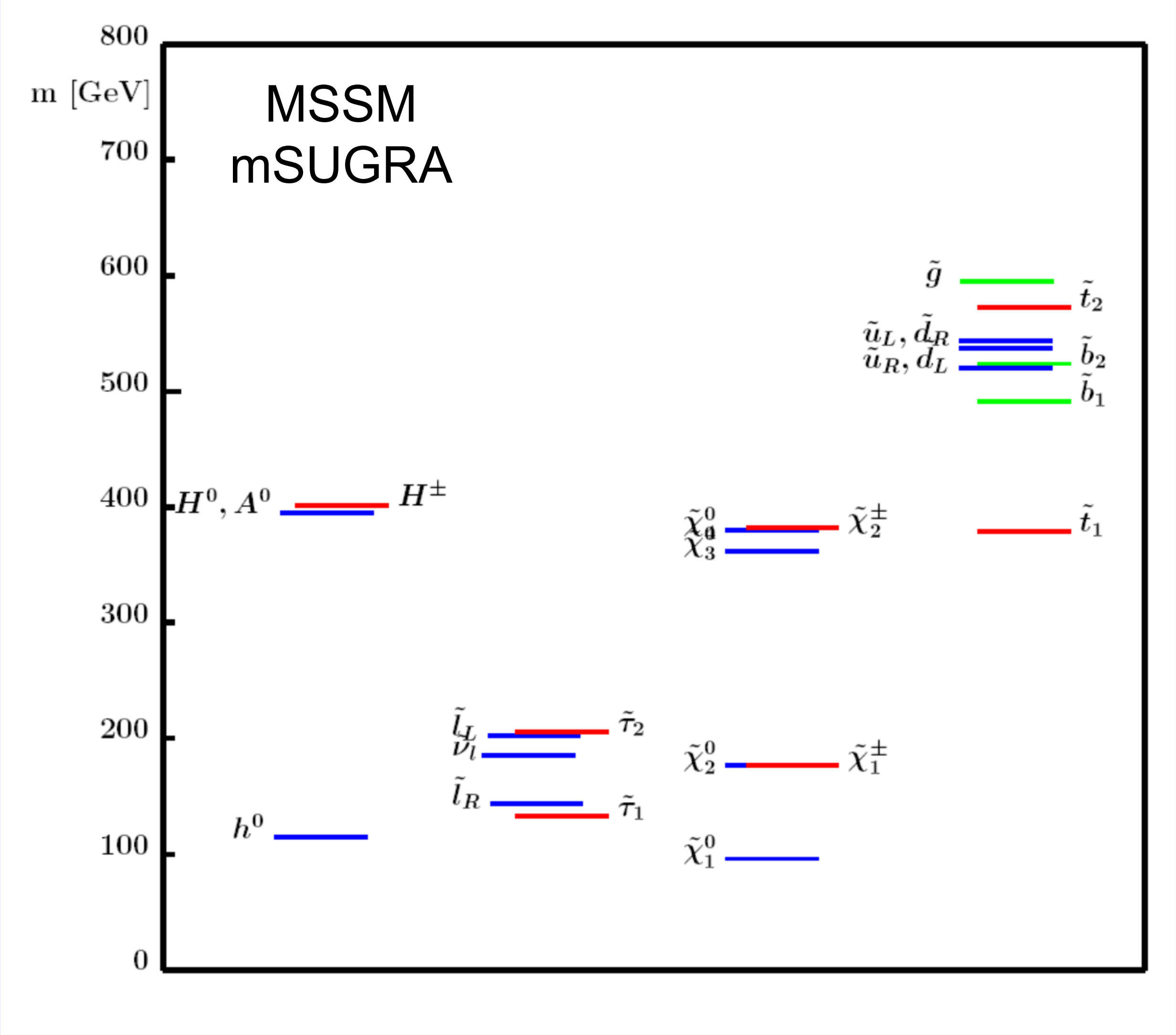


The virtues of Super-symmetry:

- **Unification of Forces**
- **The Hierarchy Problem**
- **Candidate for the Dark Matter**

…

Spectrum of Supersymmetric Particles



squarks and sgluons heavy yielding long decay chains ending with LSP neutrilino

Superstring Theory

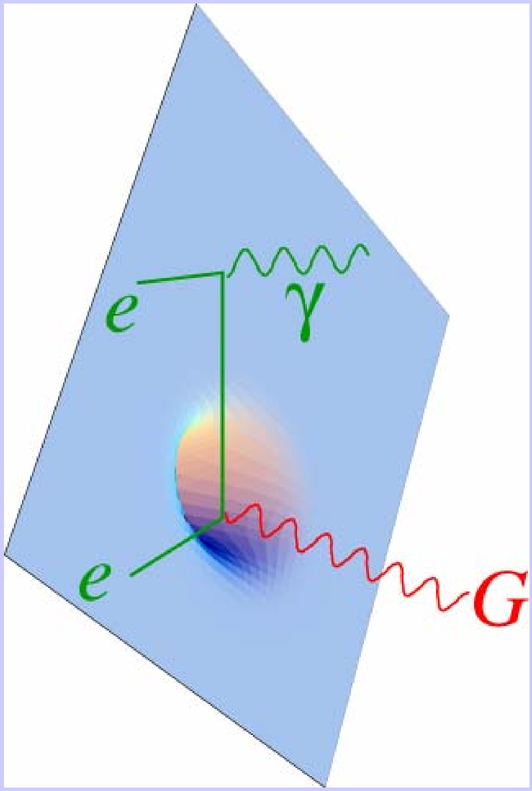
extra dimensions

- **In addition to the 3+1 dimensional space-time, extra space-dimensions exist, presumably curled into a small space size.**

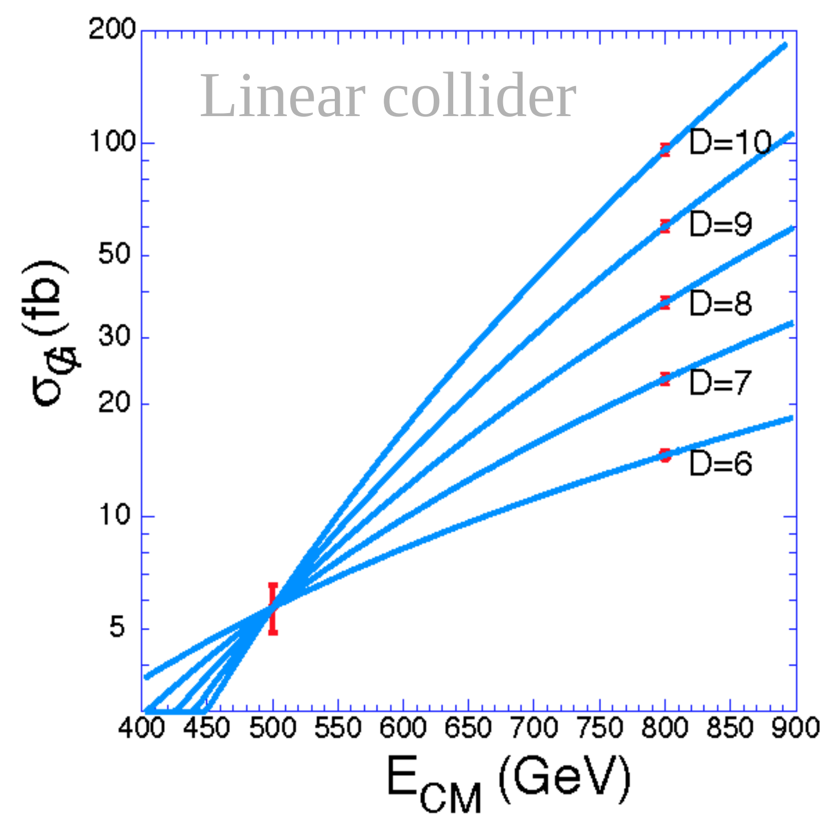
Internal quantum numbers of elementary particles are determined by the geometrical structure of the extra dimensions

Kaluza-Klein - Bosonic partners

Direct production from extra dimensions ?

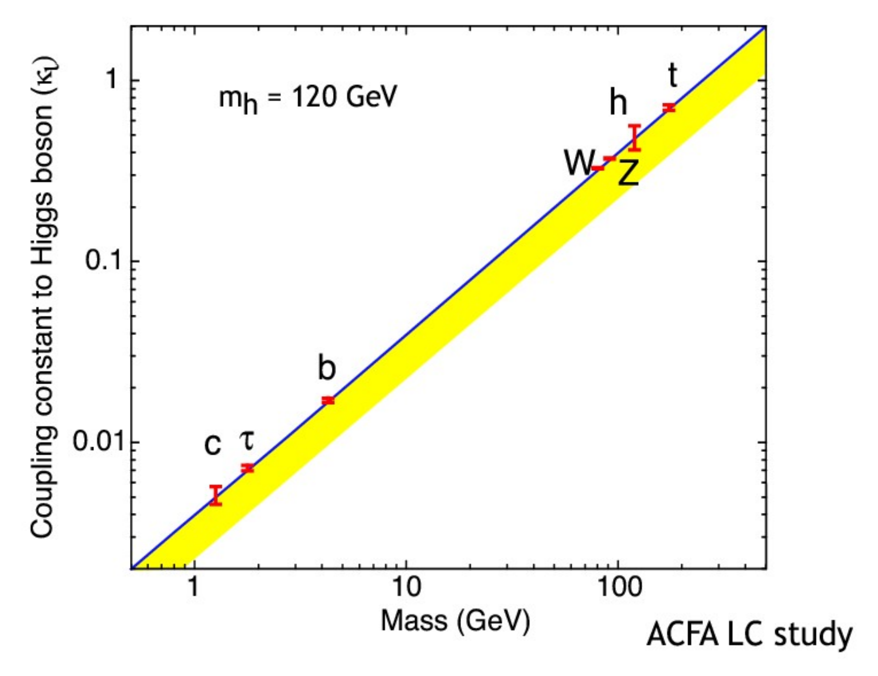


New space-time dimensions can be mapped by studying the emission of gravitons into the extra dimensions, together with a photon or jets emitted into the normal dimensions.



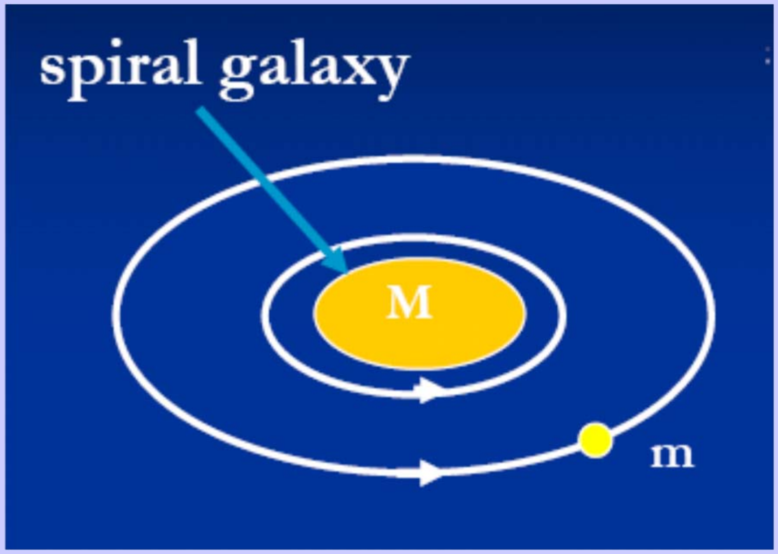
Extra dimensions and the Higgs?

Precision measurements of Higgs coupling can reveal extra dimensions in nature



ACFA LC study

- Straight blue line gives the standard model predictions.
- Range of predictions in models with extra dimensions -- yellow band, (at most 30% below the Standard Model
- The red error bars indicate the level of precision attainable at the ILC for each particle



Dark Matter

- **gravity = centrifugal**

  $GMm/r^2 = mv/r^2$

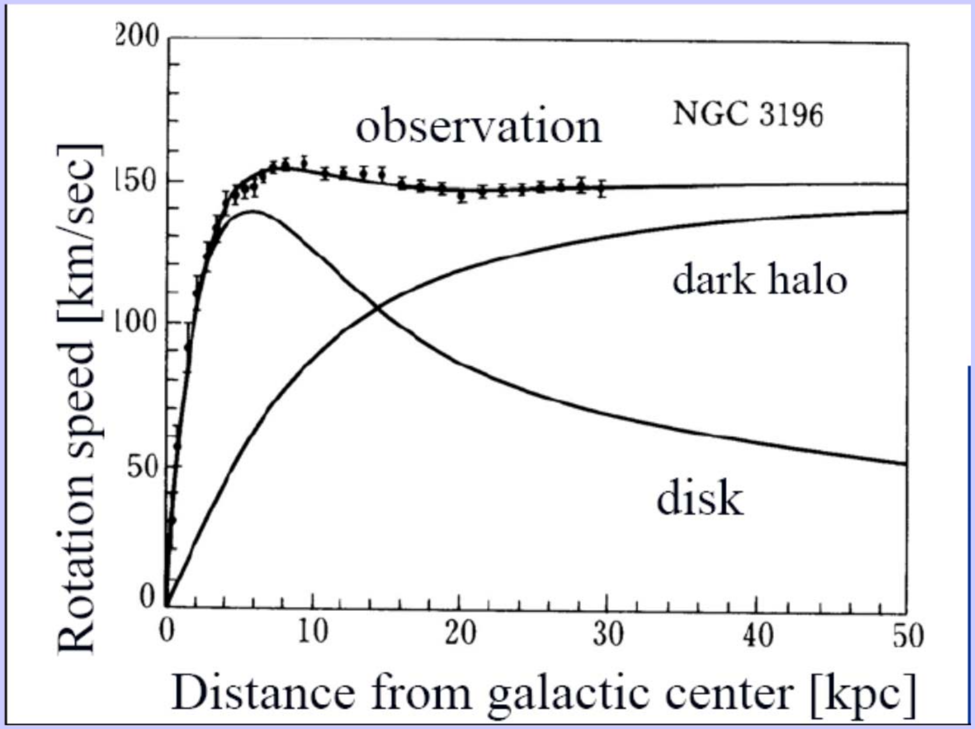
- **outside of galaxy**

  $v = \sqrt{GM/r}$

- **inside of galaxy**

  $v = \sqrt{4\pi G\rho/3}\ r$

Dark Matter in our Galaxy



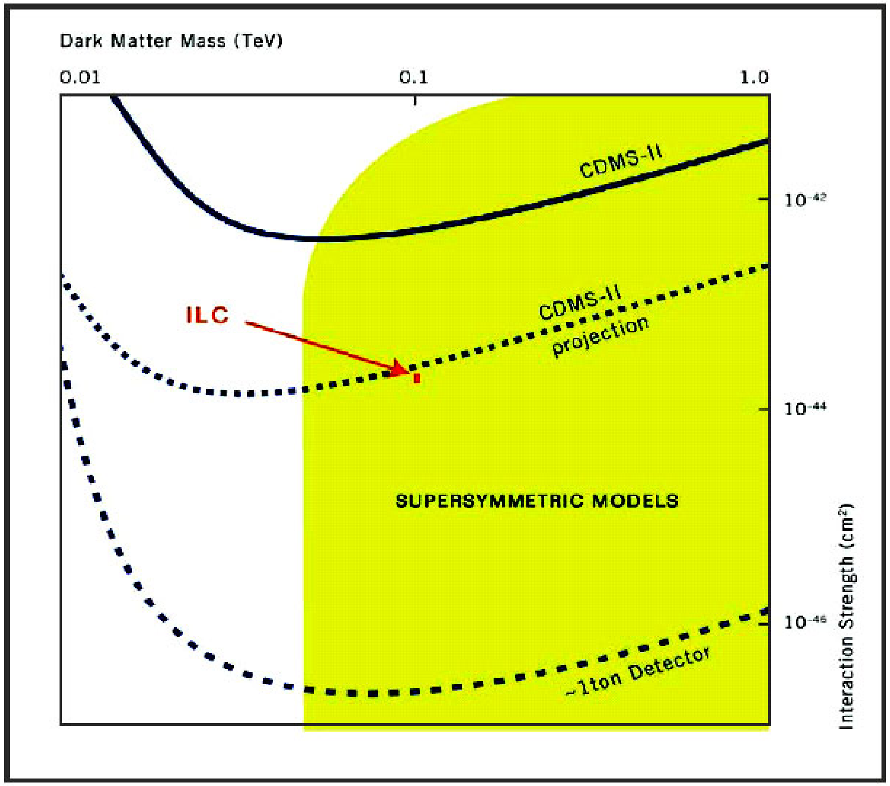
- Rotation speed of the spiral is almost constant over wide distance from the center

→ ~ 0.3 GeV/cm of Dark Matter exists in our Galaxy

Dark Matter Candidates
LSP

The most attractive candidate for the dark matter is the lightest SUSY particle

- **The abundance of the LSP as dark matter can be precisely calculated, if the mass and particle species are given.**
- **ILC can precisely measure the mass and the coupling of the LSP**
- **The Dark Matter density in the universe and in our Galaxy can be calculated.**

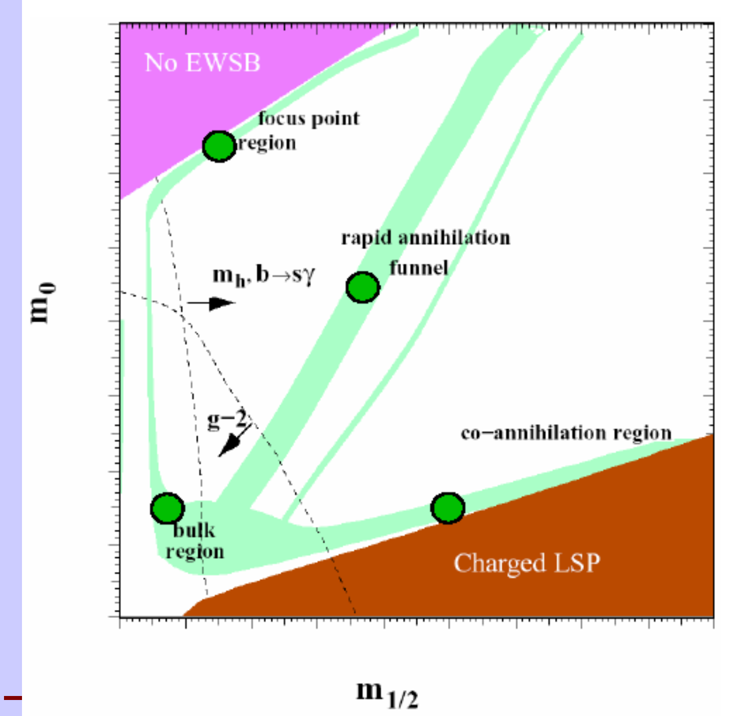


The Cosmic Connection

SUSY provides excellent candidate for dark matter (LSP)

Other models also provide TeV-scale WIMPs

How well can the properties of the DM-candidates (to be found at accelerators) be compared to the properties of the real DM (inferred from astrophysical measurements) ?



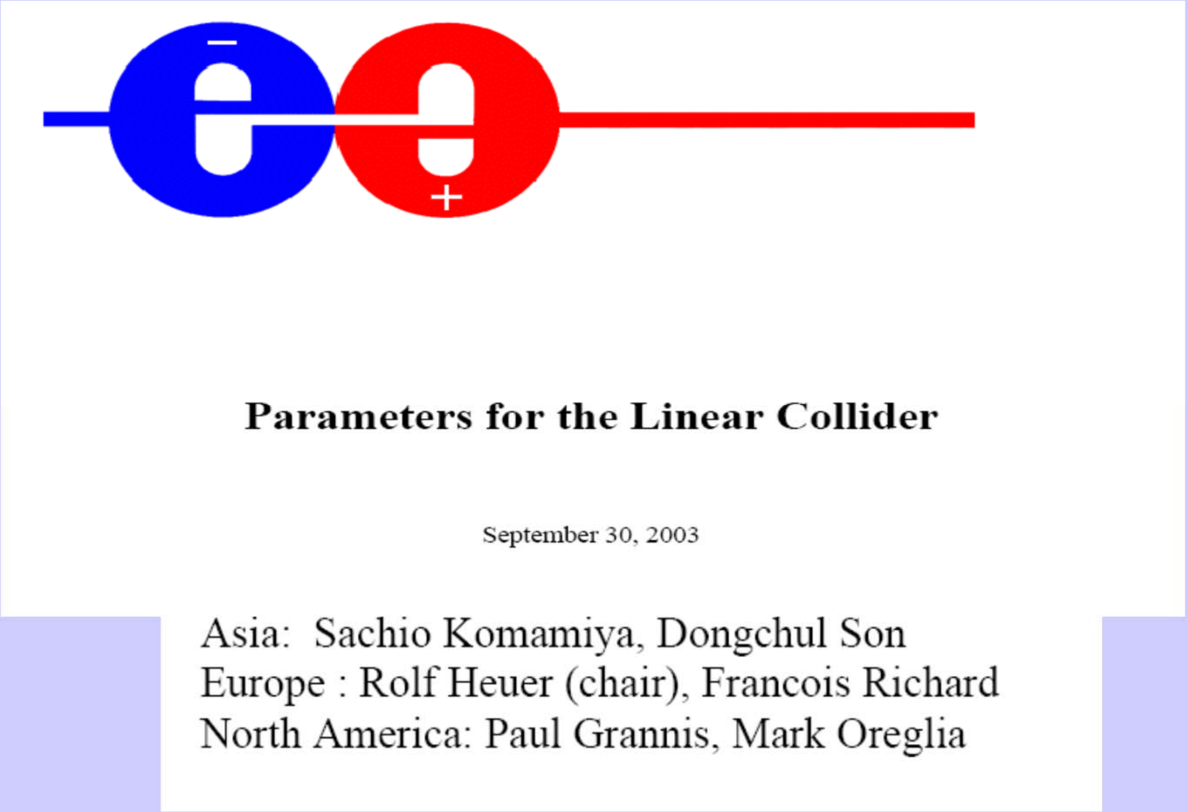
	$\Delta\Omega_{DM}/\Omega_{DM}$	main sensitivity
bulk	3.5%	$\tilde{\chi}_1^0, \tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_1$
focus	1.9%	$\tilde{\chi}_1^0, \tilde{\chi}_2^0 - \tilde{\chi}_1^0, \tilde{\chi}_3^0 - \tilde{\chi}_1^0, \tilde{\chi}_1^+ - \tilde{\chi}_1^0, \sigma(\tilde{\chi}_1^+ \tilde{\chi}_1^-)$
co-ann.	6.5%	$\tilde{\chi}_1^0, \tilde{\chi}_1^0 - \tilde{\tau}_1$
funnel	3.1%	$A^0, \tilde{\chi}_1^0, \tilde{\tau}_1$

Matches precision of future CMB exp.

How the physics defines the ILC

ICFA International Committee for Future Accelerators

Sponsored by the Particles and Fields Commission of IUPAP



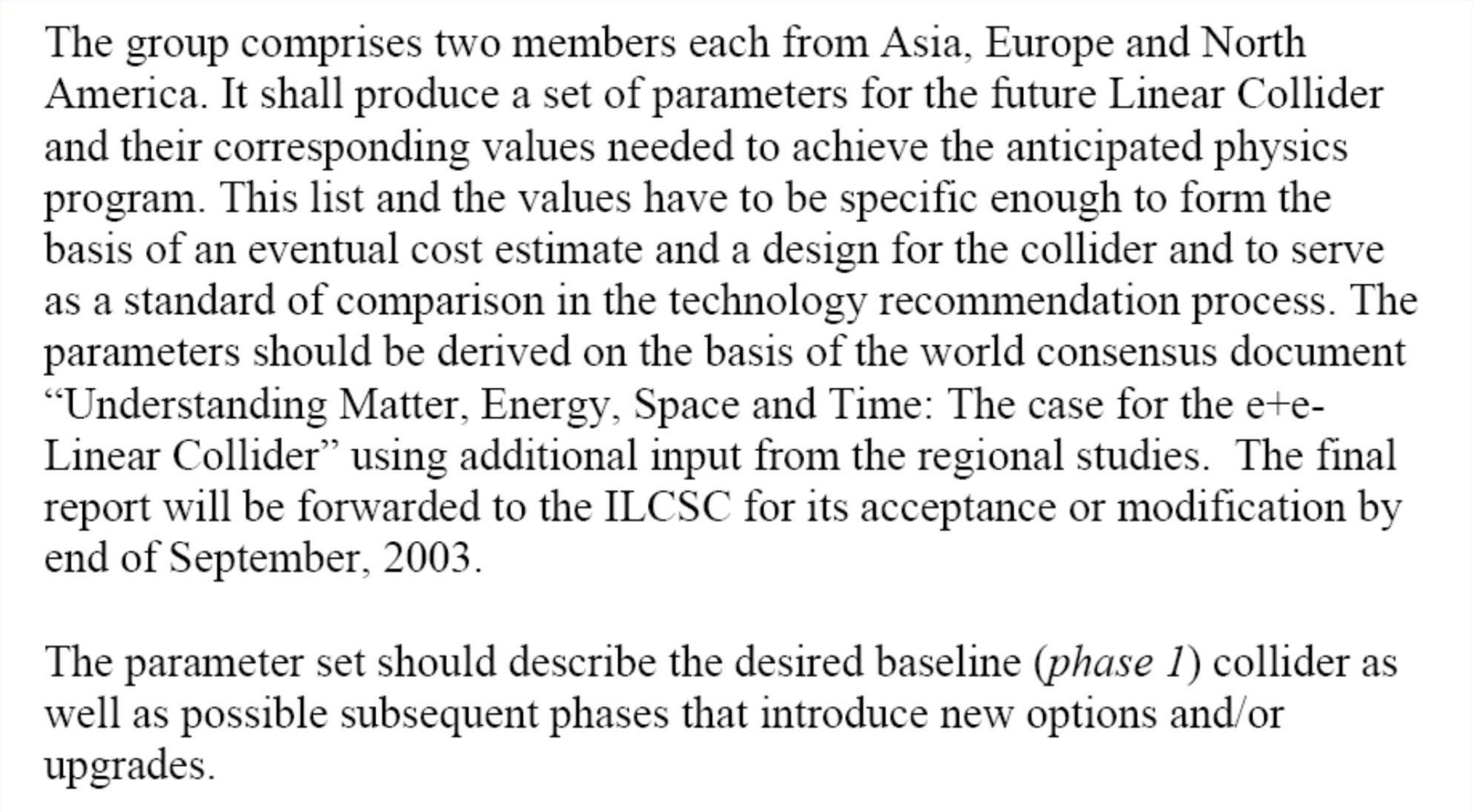
Parameters for the Linear Collider

September 30, 2003

Asia: Sachio Komamiya, Dongchul Son
Europe : Rolf Heuer (chair), Francois Richard
North America: Paul Grannis, Mark Oreglia

How the physics defines the ILC

charge

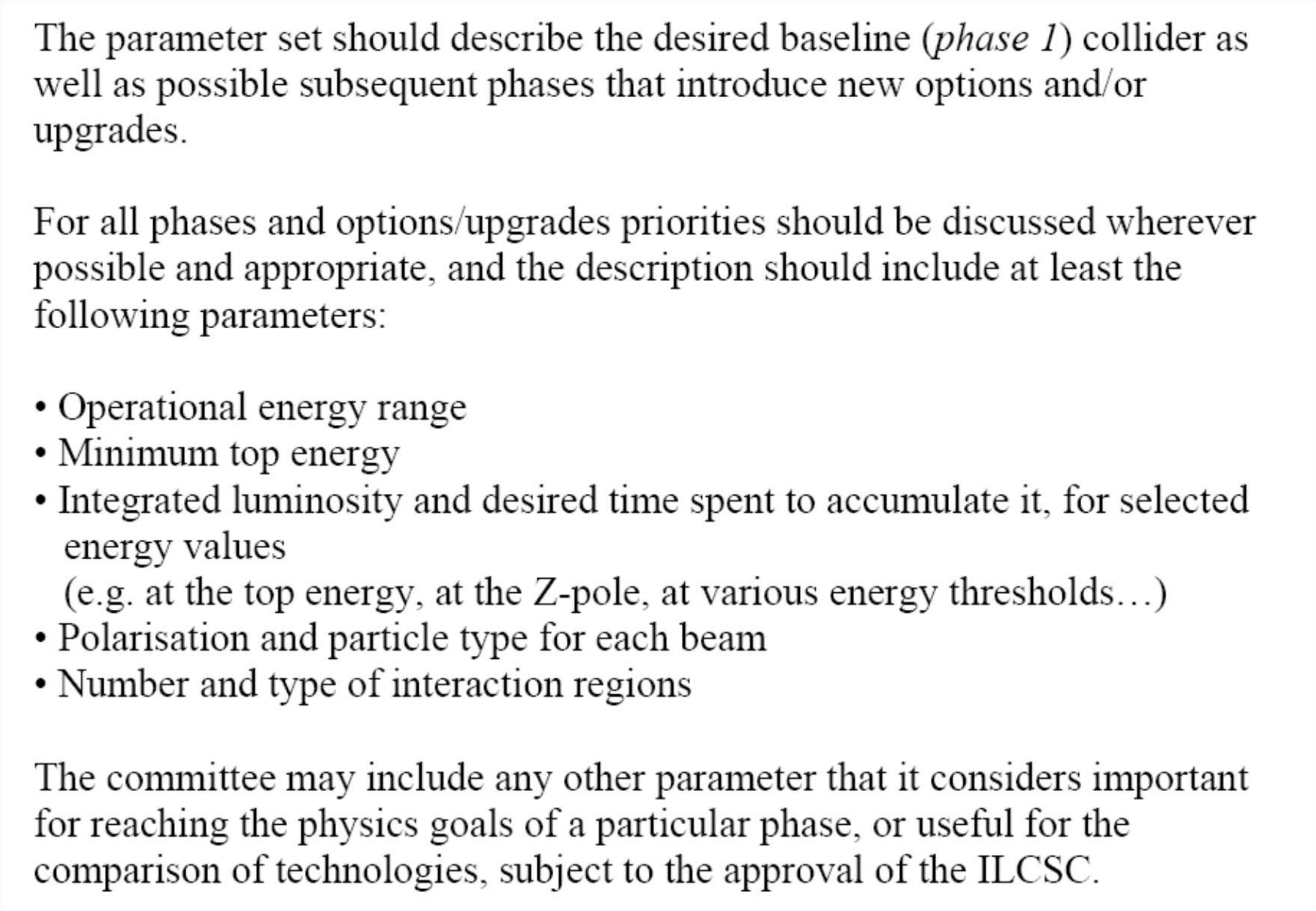


The group comprises two members each from Asia, Europe and North America. It shall produce a set of parameters for the future Linear Collider and their corresponding values needed to achieve the anticipated physics program. This list and the values have to be specific enough to form the basis of an eventual cost estimate and a design for the collider and to serve as a standard of comparison in the technology recommendation process. The parameters should be derived on the basis of the world consensus document "Understanding Matter, Energy, Space and Time: The case for the e+e- Linear Collider" using additional input from the regional studies. The final report will be forwarded to the ILCSC for its acceptance or modification by end of September, 2003.

The parameter set should describe the desired baseline (*phase 1*) collider as well as possible subsequent phases that introduce new options and/or upgrades.

How the physics defines the ILC?

charge (continued)



The parameter set should describe the desired baseline (*phase 1*) collider as well as possible subsequent phases that introduce new options and/or upgrades.

For all phases and options/upgrades priorities should be discussed wherever possible and appropriate, and the description should include at least the following parameters:

- Operational energy range
- Minimum top energy
- Integrated luminosity and desired time spent to accumulate it, for selected energy values
  (e.g. at the top energy, at the Z-pole, at various energy thresholds…)
- Polarisation and particle type for each beam
- Number and type of interaction regions

The committee may include any other parameter that it considers important for reaching the physics goals of a particular phase, or useful for the comparison of technologies, subject to the approval of the ILCSC.

Parameters for the ILC

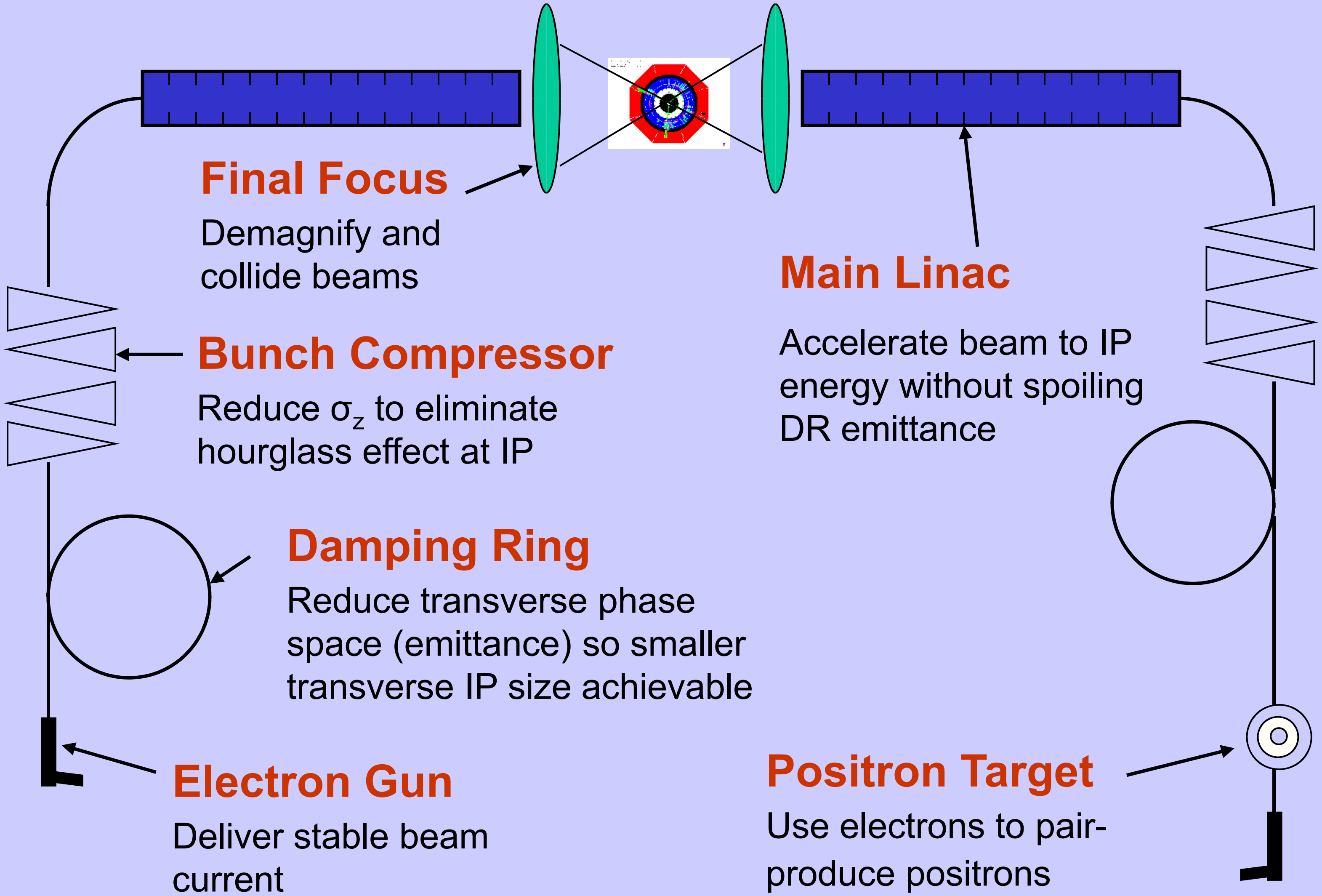
- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV

A TeV Scale e^+e^- Accelerator?

- Two parallel developments over the 1990s (the science & the technology)
  - Two alternate designs -- “warm” and “cold” had come to the stage where the “show stoppers” had been eliminated and the concepts were well understood.
  - A major step toward a new international machine required uniting behind one technology, and then make a unified global design based on the recommended technology.

Linear Collider Conceptual Scheme



Final Focus

Demagnify and collide beams

Main Linac

Accelerate beam to IP energy without spoiling DR emittance

Bunch Compressor

Reduce σ_z to eliminate hourglass effect at IP

Damping Ring

Reduce transverse phase space (emittance) so smaller transverse IP size achievable

Electron Gun

Deliver stable beam current

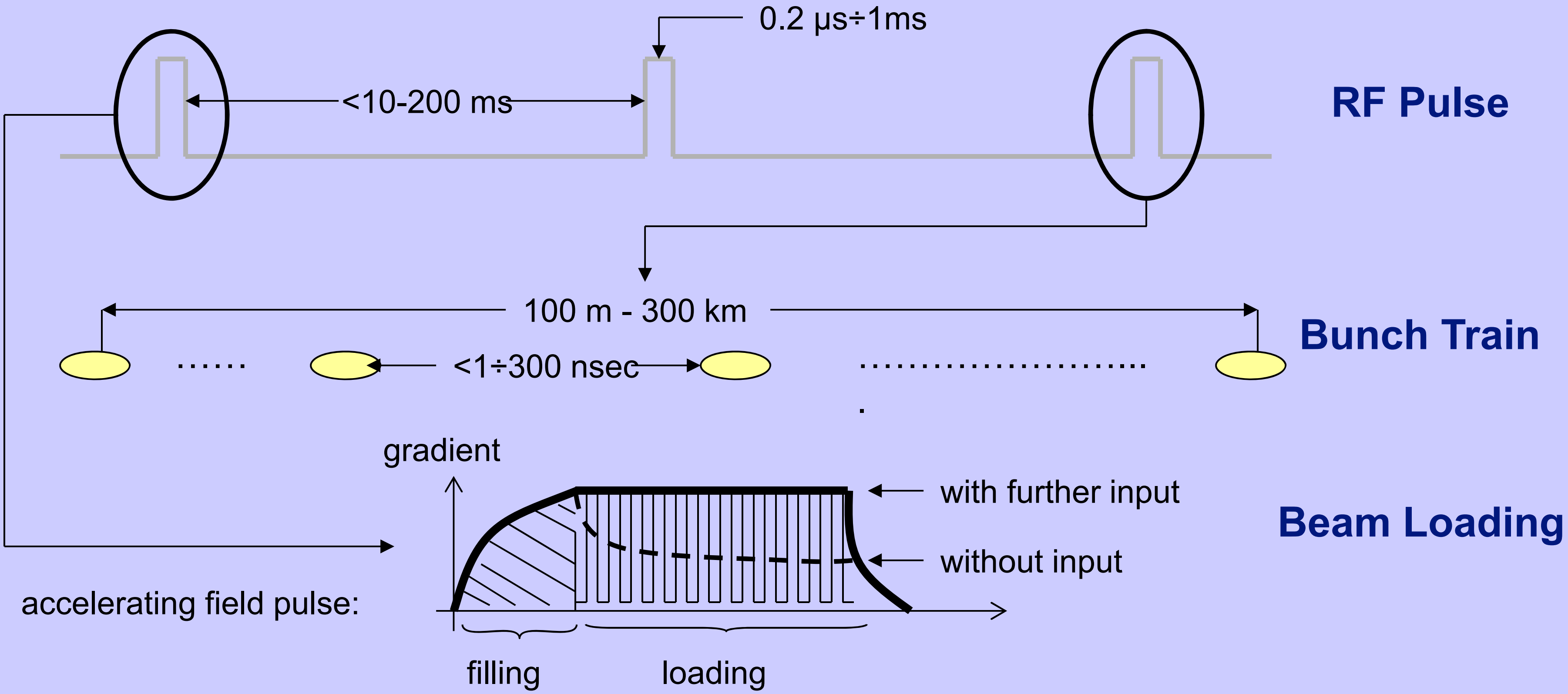
Positron Target

Use electrons to pair-produce positrons

Linear Colliders are pulsed

All LCs are pulsed machines to improve efficiency. As a result:

- **duty factors are small**
- **pulse peak powers can be very large**



ILC Subsystems

- **Electron source**

  To produce electrons, light from a titanium-sapphire laser hit a target and knock out electrons. The laser emits 2-ns "flashes," each creating billions of electrons. An electric field "sucks" each bunch of particles into a 250-meter-long linear accelerator that speeds up the particles to 5 GeV.

- **Positron source**

  To produce positron, electron beam go through an undulator. Then, photons, produced in an undulator, hit a titanium alloy target to generate positrons. A 5-GeV accelerator shoots the positrons to the first of two positron damping rings.

- **Damping Ring for electron beam**

  In the 6-kilometer-long damping ring, the electron bunches traverse a wiggler leading to a more uniform, compact spatial distribution of particles. Each bunch spends roughly 0.2 sec in the ring, making about 10,000 turns before being kicked out. Exiting the damping ring, the bunches are about 6 mm long and thinner than a human hair.

- **Damping Ring for positron beam**

  To minimize the "electron cloud effects," positron bunches are injected alternately into either one of two identical positron damping rings with 6-kilometer circumference.

- **Main Linac**

  Two main linear accelerators, one for electrons and one for positrons, accelerate bunches of particlesup to 250 GeV with 8000 superconducting cavities nestled within cryomodules. The modules use liquid helium to cool the cavities to - 2° K. Two 12-km-long tunnel segments, about 100 meters below ground, house the two accelerators. An adjacent tunnel provides space for support instrumentation, allowing for the maintenance of equipment while the accelerator is running. Superconducting RF system accelerate electrons and positrons up to 250 GeV.

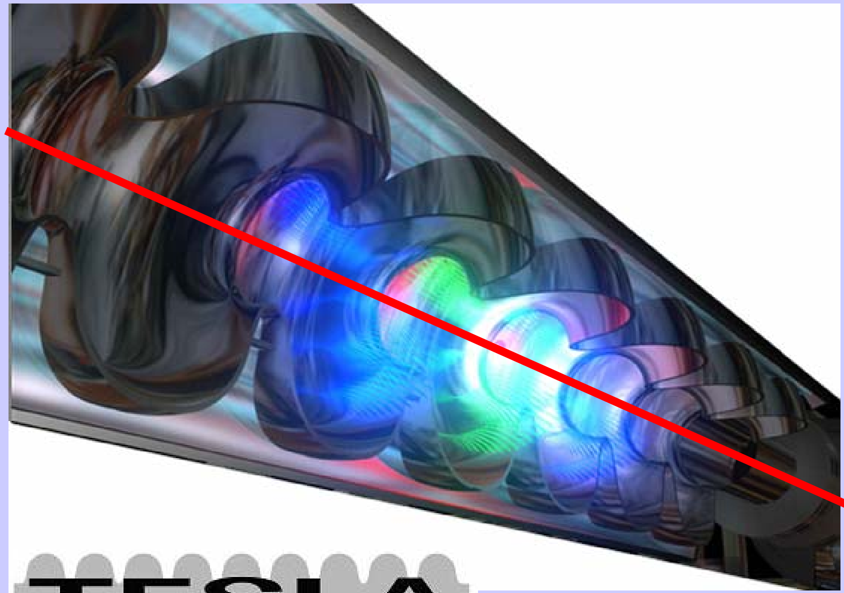
- **Beam Delivery System**

  Traveling toward each other, electron and positron bunches collide at 500 GeV. The baseline configuration of the ILC provides for two collision points, offering space for two detectors.

A TeV Scale e^+e^- Accelerator?

- **Two parallel developments over the 1990s (the science & the technology)**
  - **Two alternate designs -- “warm” and “cold” had come to the stage where the “show stoppers” had been eliminated and the concepts were well understood.**
  - **A major step toward a new international machine required uniting behind one technology, and then make a unified global design based on the recommended technology.**

Linear Collier: Competing Technologies



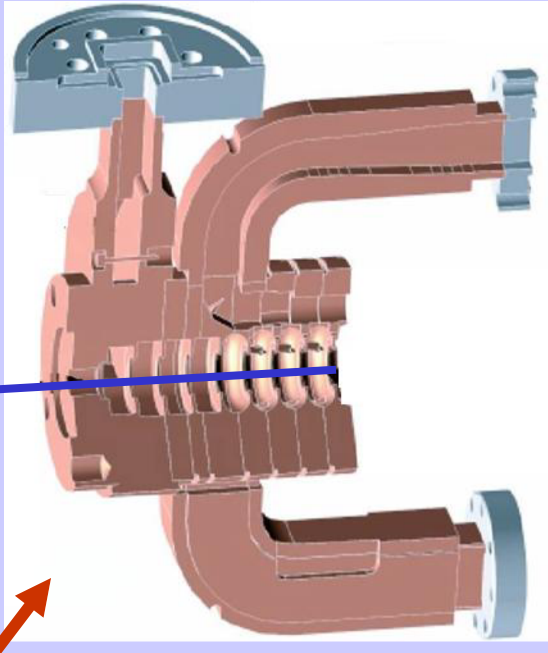
TESLA

1.3 GHz - Cold

Evolution from: CEBAF & LEPII

+ TRISTAN, HERA, etc.

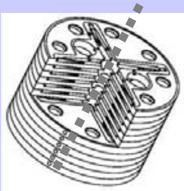
Evolution from: SLAC & SLC



NLC

JLC

11.4 GHz - Warm

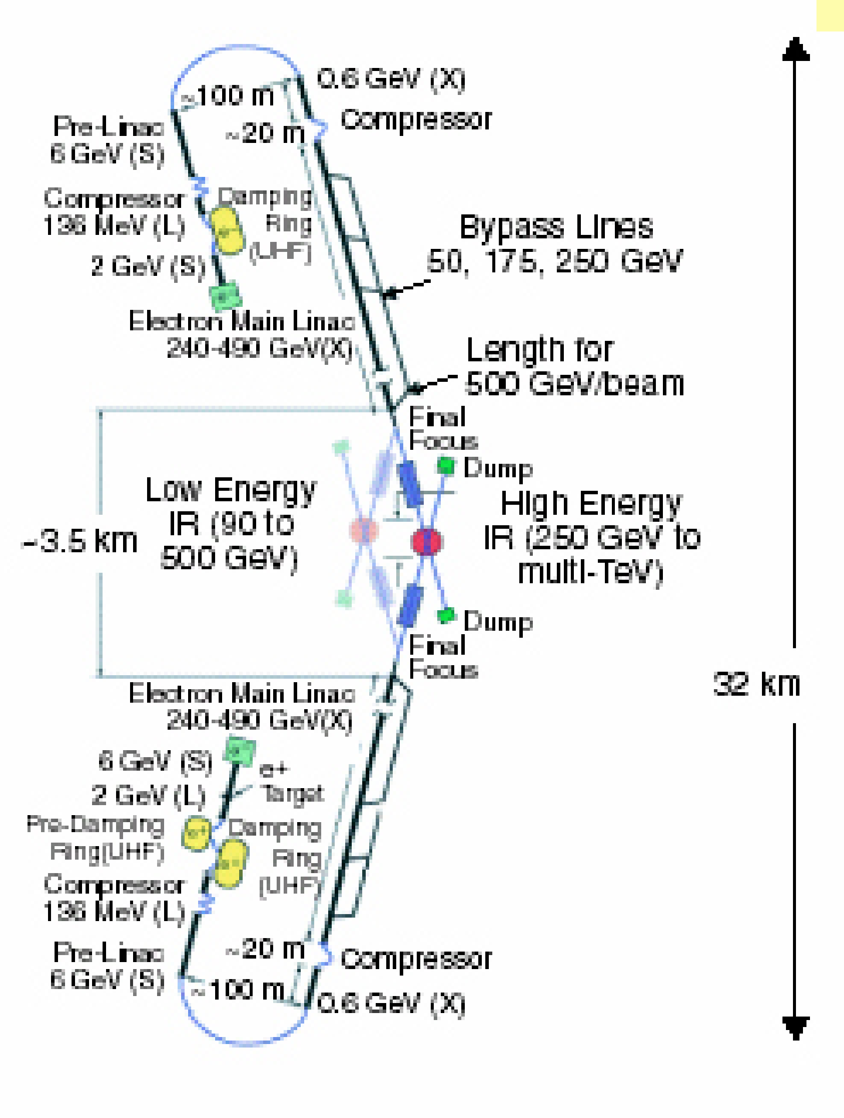


CLIC

12 GHz - Warm

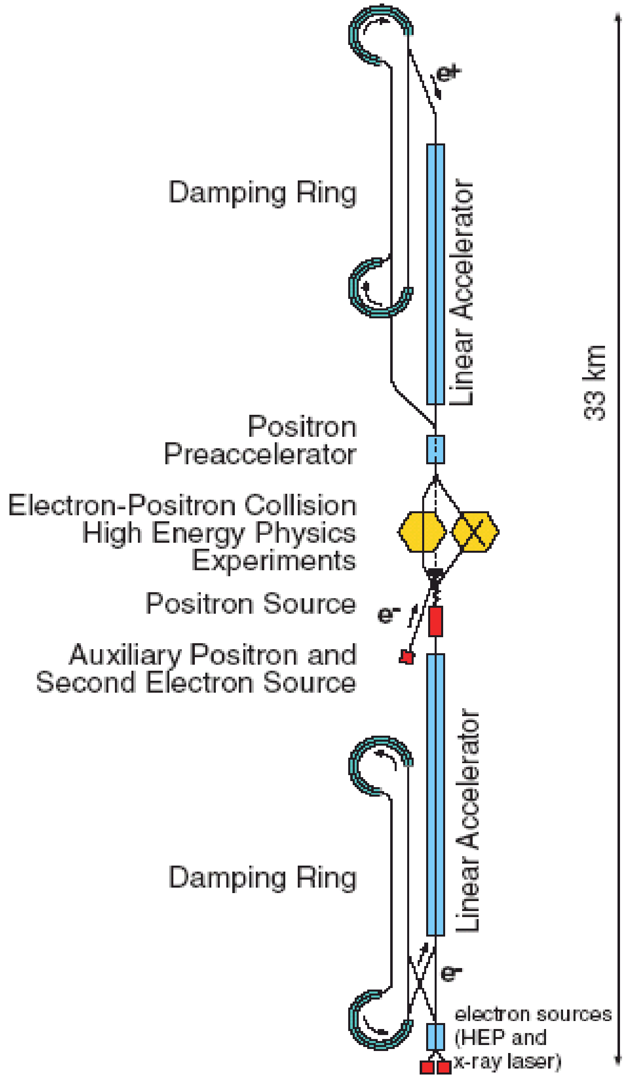
GLC

GLC/NLC Concept



The JLC-X and NLC essentially a unified single design with common parameters

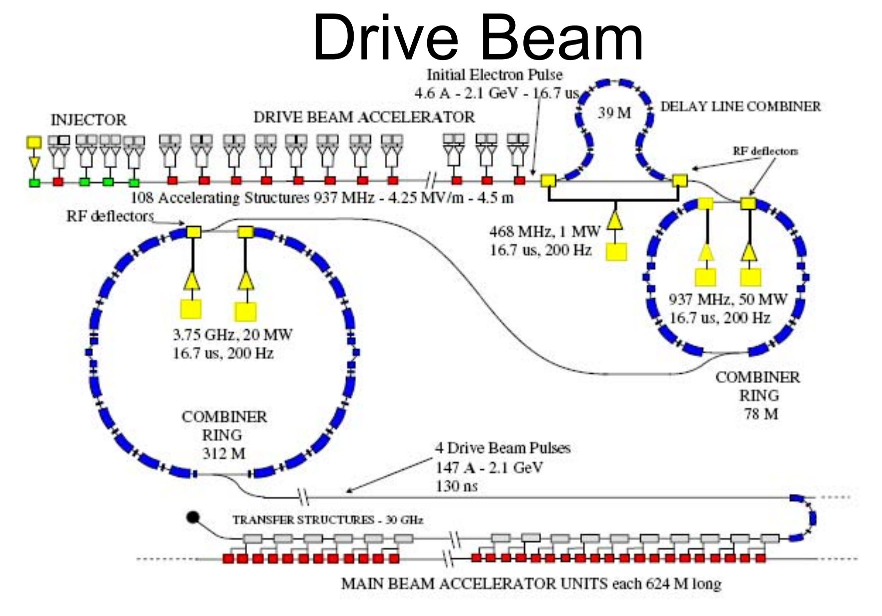
The main linacs based on 11.4 GHz, room temperature copper technology.

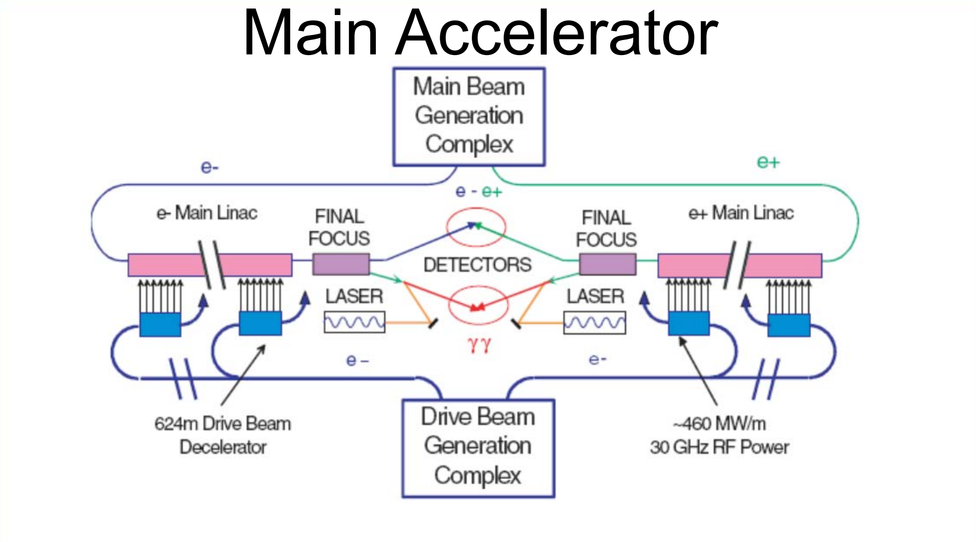


TESLA Concept

- The main linacs based on 1.3 GHz superconducting technology operating at 2 K.
- The cryoplant, is of a size comparable to that of the LHC, consisting of seven subsystems strung along the machines every 5 km.

CLIC Concept


Drive Beam


Main Accelerator

The main linac rf power is produced by decelerating a high-current (150 A) low-energy (2.1 GeV) drive beam

Nominal accelerating gradient of 150 MV/m

GOAL

Proof of concept

Technical Review Committee

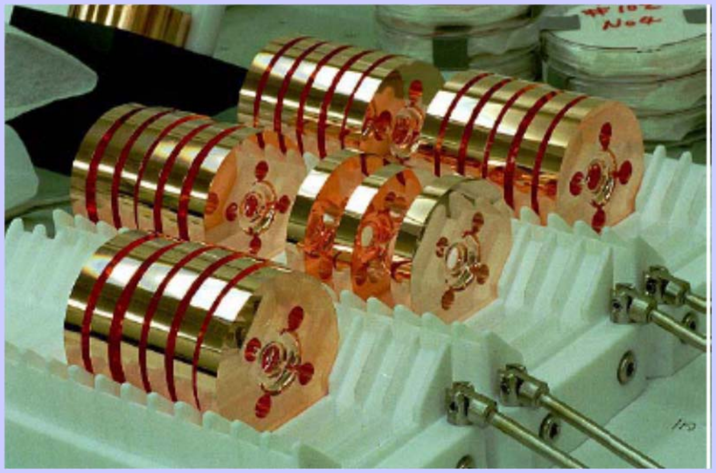
In Feb. 2001, ICFA charged a Technology Review Committee, chaired by Greg Loew of SLAC to review the critical R&D readiness issues.

The TRC report in 2003 gave a series of R&D issues for L-band (superconducting rf TESLA), X-band (NLC and GLC), C-band and CLIC. The most important were the R1's: those issues needing resolution for design feasibility.

R1 issues pretty much satisfied by mid-2004

ILC – Underlying Technology

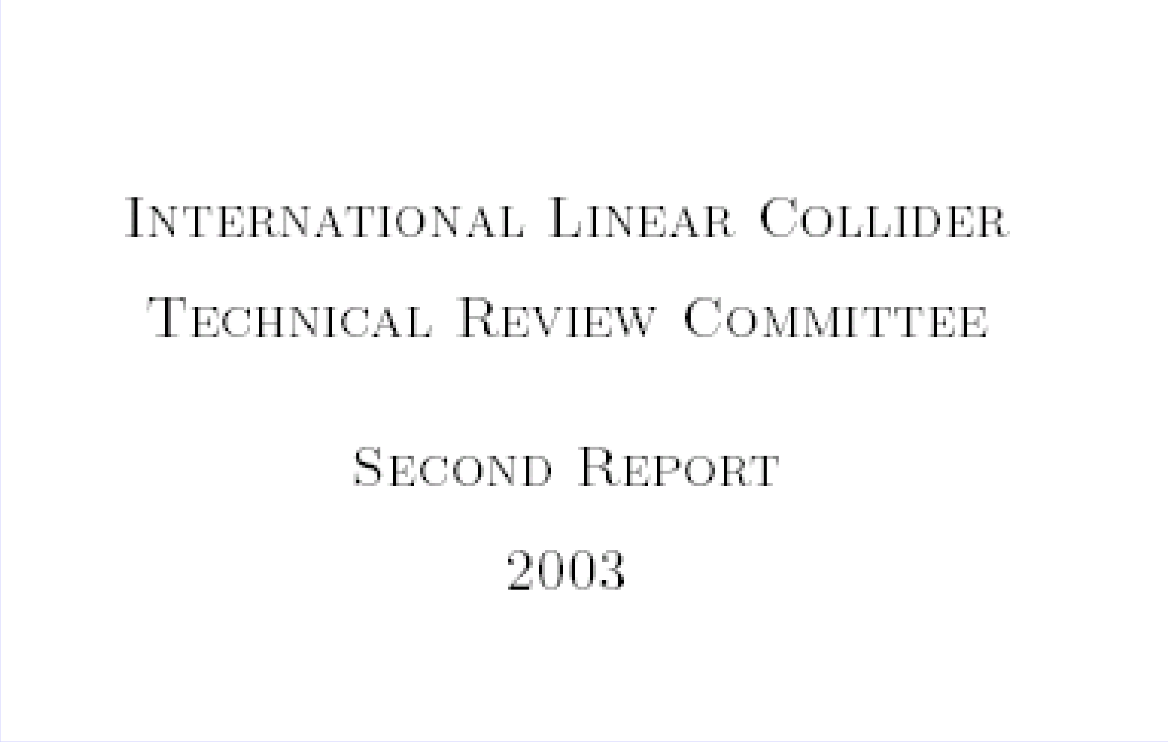
- **Room temperature copper structures**



OR

- **Superconducting RF cavities**

ICFA/ILCSC
Evaluation of the Technologies



INTERNATIONAL LINEAR COLLIDER
TECHNICAL REVIEW COMMITTEE

SECOND REPORT
2003

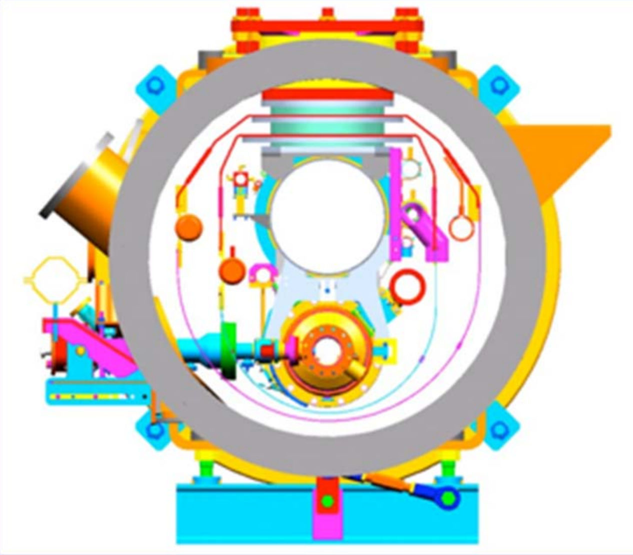
The Report Validated the Readiness of L-band and X-band Concepts

ITRP in Korea

International Technology Recommendation Panel Meeting
August 11 ~ 13, 2004. Republic of Korea

Recommendation: Superconducting *(SCRF)*

- **Advantages:**
  - Small RF surface resistance
  - Large Resonance value: Q
  - <u>Low frequency and Large aperture</u> and
  - Small beam loss



- **Additional effort required:**
  - Cryomodule (thermal insultation)
  - Cryogenics,

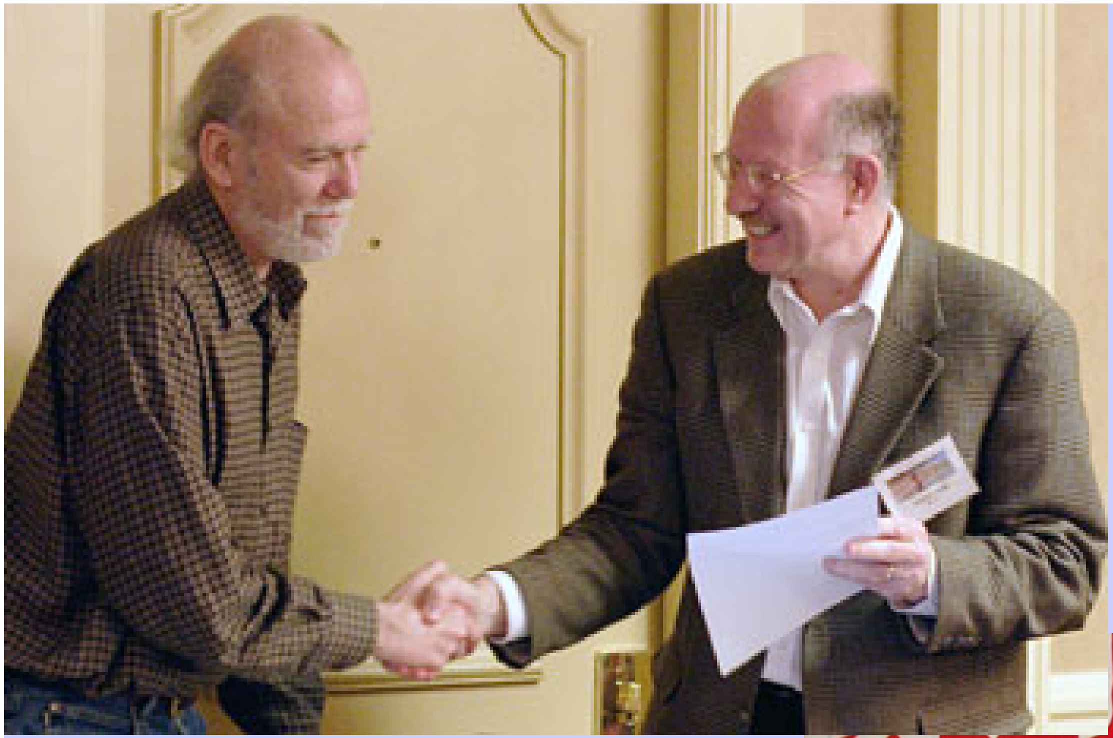
SCRF Technology Recommendation

- The recommendation of ITRP was presented to ILCSC & ICFA on August 19, 2004 in a joint meeting in Beijing.

- ICFA unanimously endorsed the ITRP's recommendation on August 20, 2004

Global Design Effort

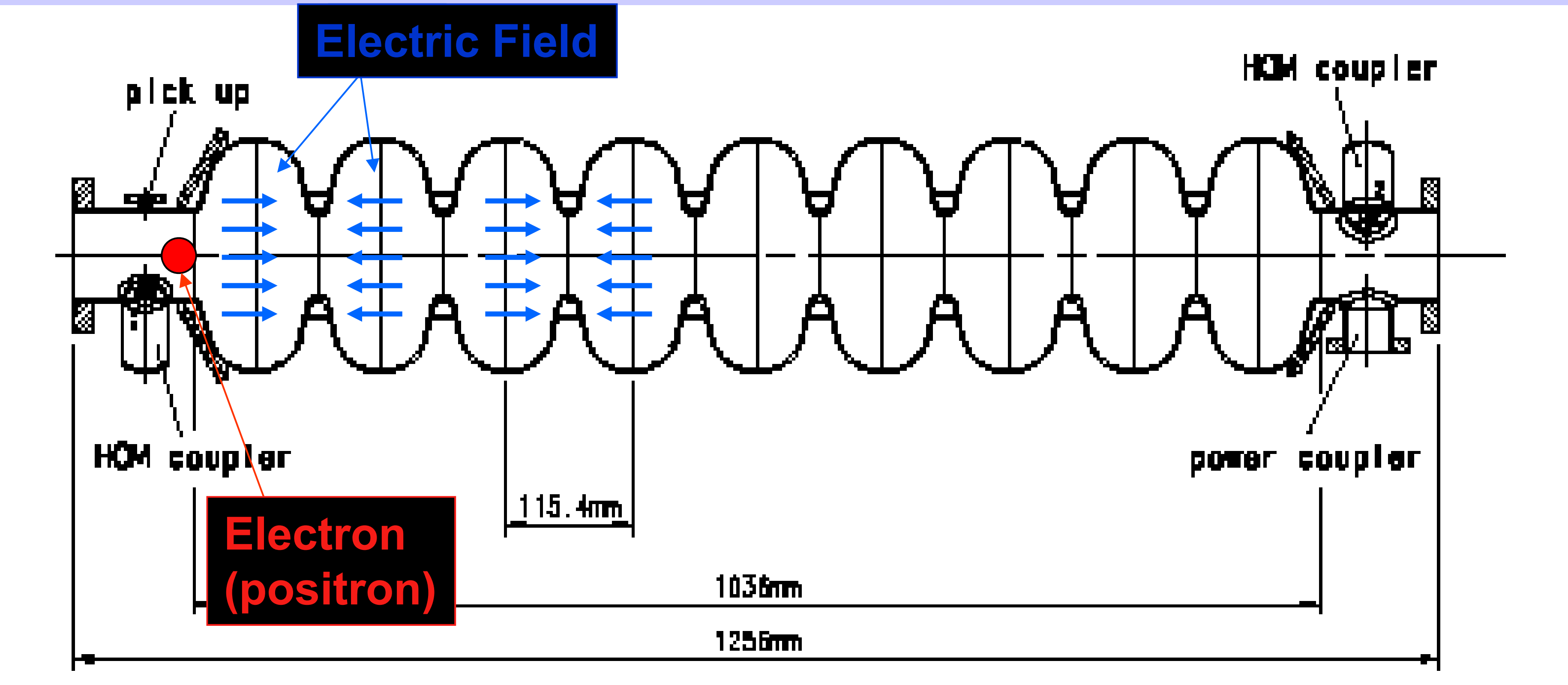
- The Mission of the GDE
  - Produce a design for the ILC that includes a detailed design concept, performance assessments, reliable international costing, an industrialization plan , siting analysis, as well as detector concepts and scope.
  - Coordinate worldwide prioritized proposal driven R & D efforts (to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc.)



March 2005
I accepted
GDE job

Feb 2007
Reference Design
Presented to
ICFA/ILCSC

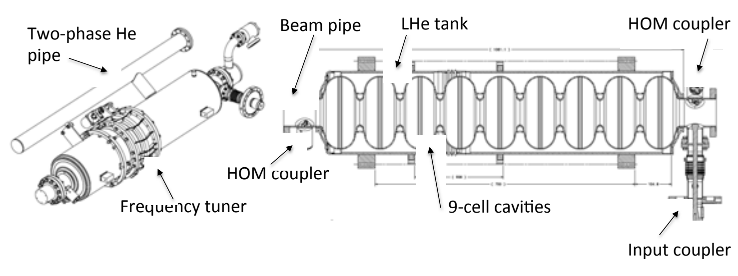
Technical Challenges: High Grad SCRF



Electric Field

Electron (positron)

SCRF Linac Technology




©Rey.Hori/KEK

1.3 GHz Nb 9-cellCavities	16,024
Cryomodules	1,855
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	436 / 471 *

* site dependent

Approximately 20 years of R&D worldwide
→ Mature technology

Main Linac Parameters

Average accelerating gradient	31.5 (±20%)	MV/m
Cavity Q_0	10^{10}	
(Cavity qualification gradient	35 (±20%)	MV/m)
Beam current	5.8	mA
Number of bunches per pulse	1312	
Charge per bunch	3.2	nC
Bunch spacing	554	ns
Beam pulse length	730	μs
RF pulse length (incl. fill time)	1.65	ms
Pulse repetition rate	5	Hz
Beam power per cavity (peak)	190*	kW

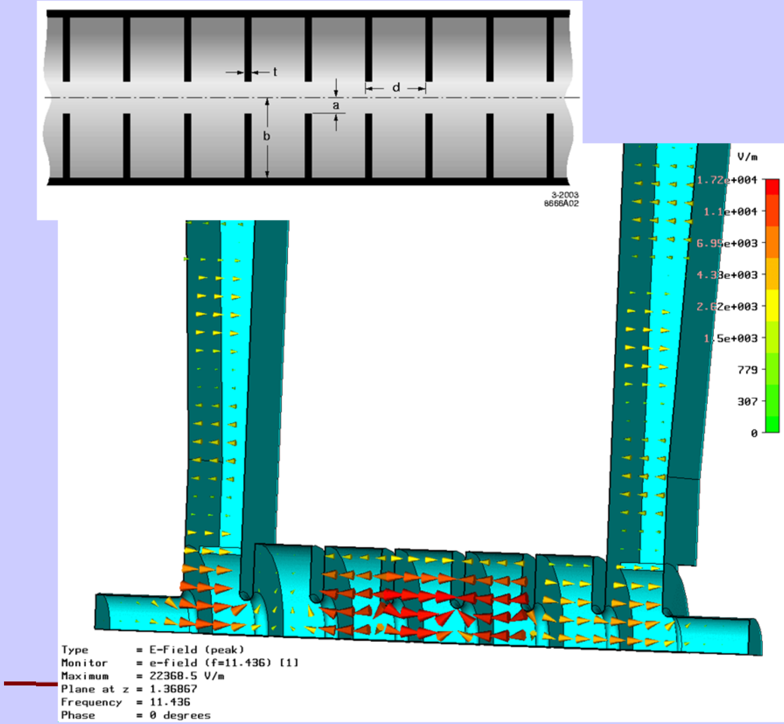
* at 31.5 MV/m

Real Accelerating Structures: Cavities

Imposing boundary condition in the longitudinal direction, z, we have for each mode (for example the TM_{01}) two waves: rightward-propagating (+z) wave and a leftward-propagating wave The combination can give a wave with phase velocity $v_{ph} \leq c$

Traveling wave structure

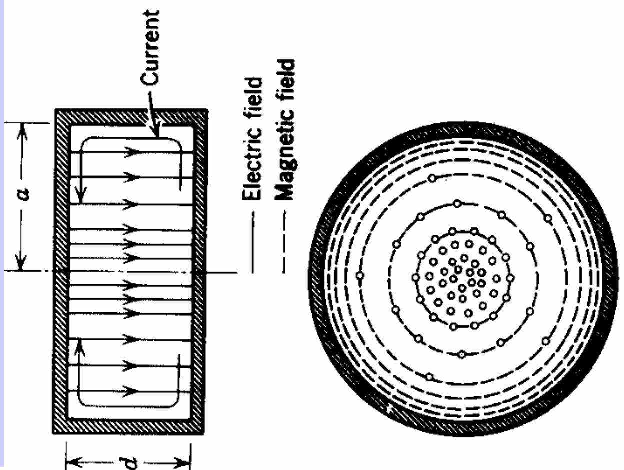
$V_{ph} \approx c$ and $Vg < c$

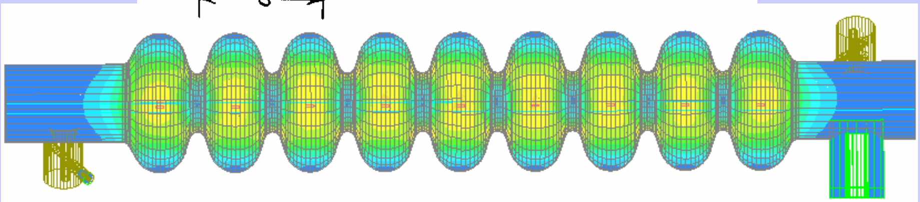


```
Type        = E-Field (peak)
Monitor     = e-field (f=11.436) [1]
Maximum     = 22368.5 V/m
Plane at z = 1.36867
Frequency   = 11.436
Phase       = 0 degrees
```

Standing wave structure

$V_{ph} = 0$ and $Vg = 0$





π mode

Example of 9-cell cavity performance

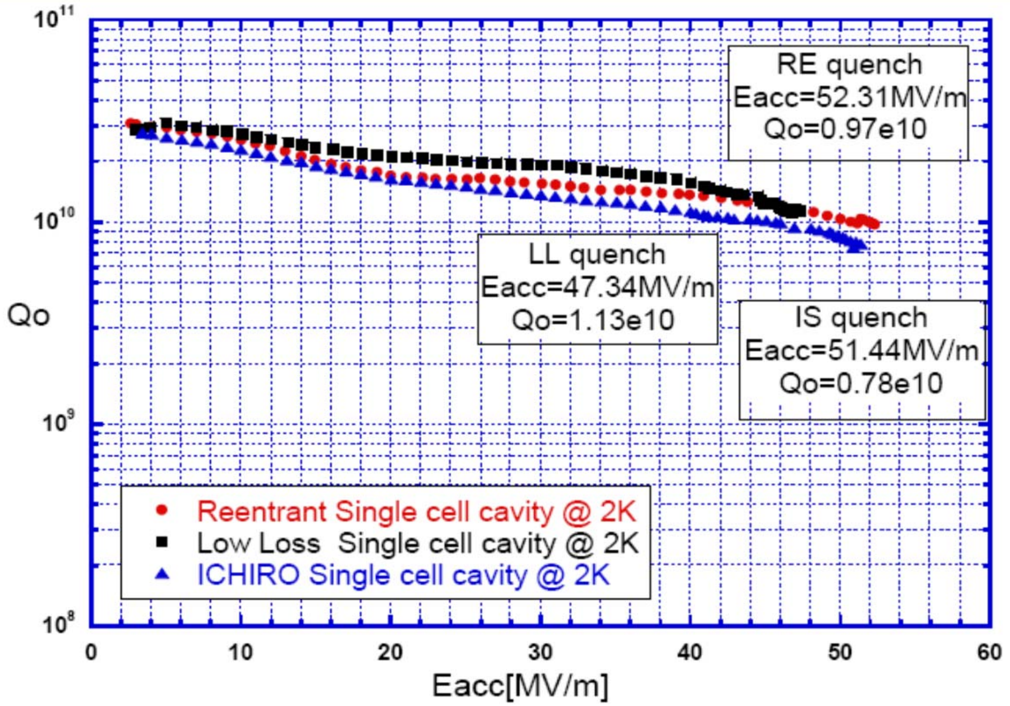
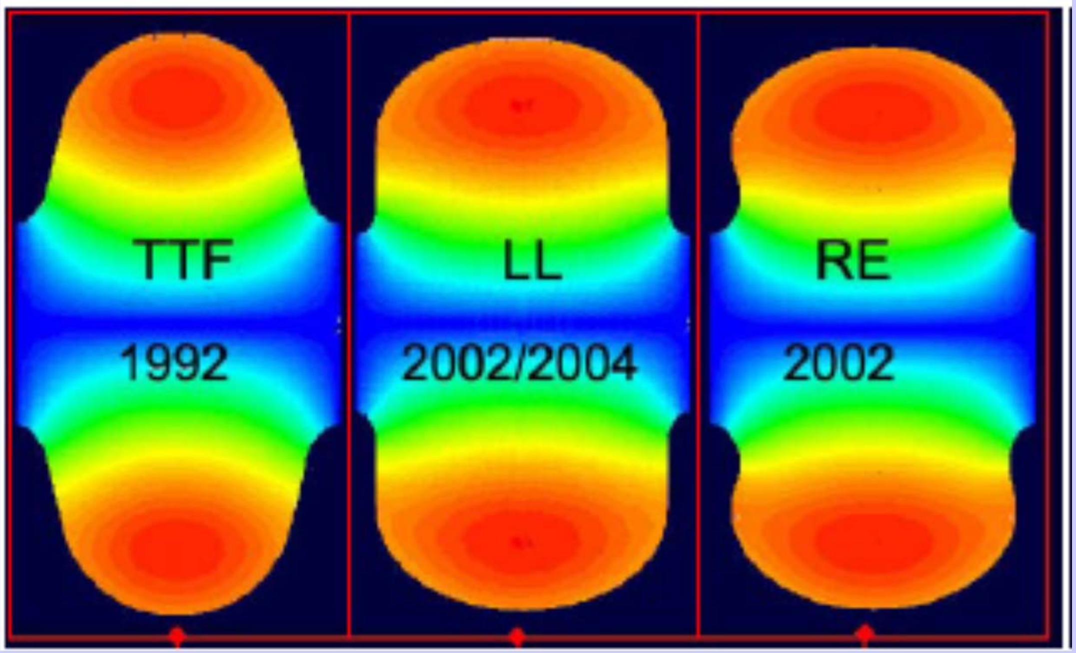


Figure 3: The results of high gradient measurements.

- Enormous R&D efforts have been made world wide to establish SCRF acceleration technology.

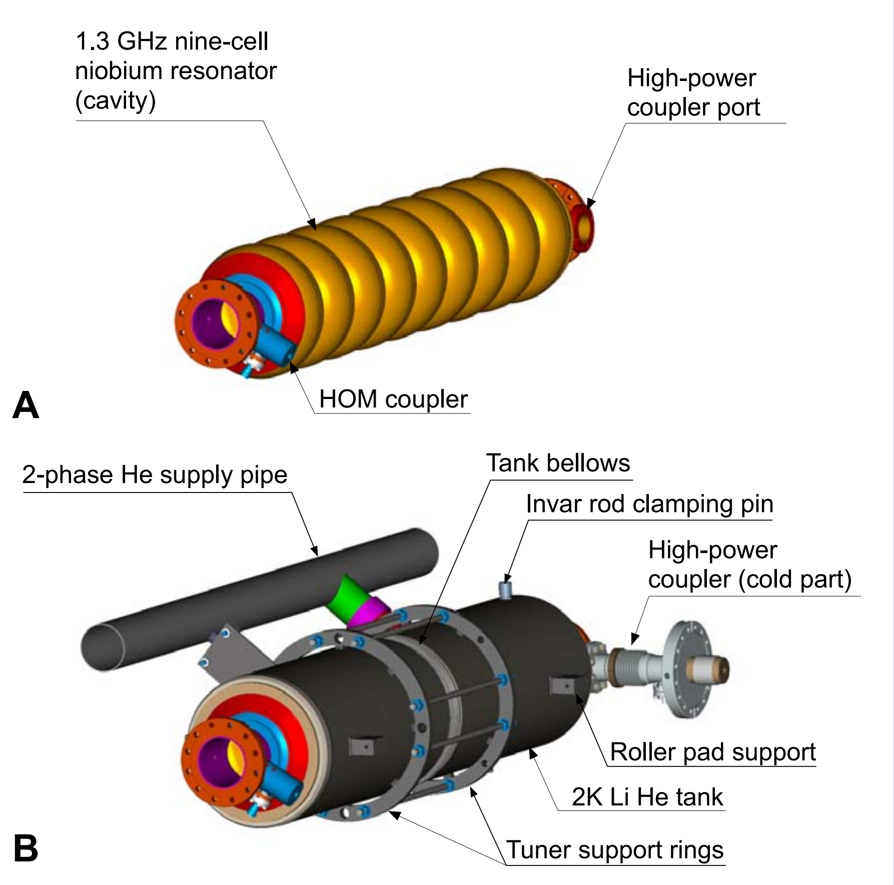
- We need more than 10,000 units of this kind of cavity assembled in the cryomodule.

Cavity Shape Optimization



	TESLA	LL	RE
Aperture, mm	70	60	70
k_c,%	1.9	1.52	2.38
K_e = E/Eacc	1.98	2.36	2.39
k_m, mT/(MeV/m)	4.15	3.61	3.78
(r/Q), Ω	113.8	133.7	120.6
G, Ohm	271	284	280

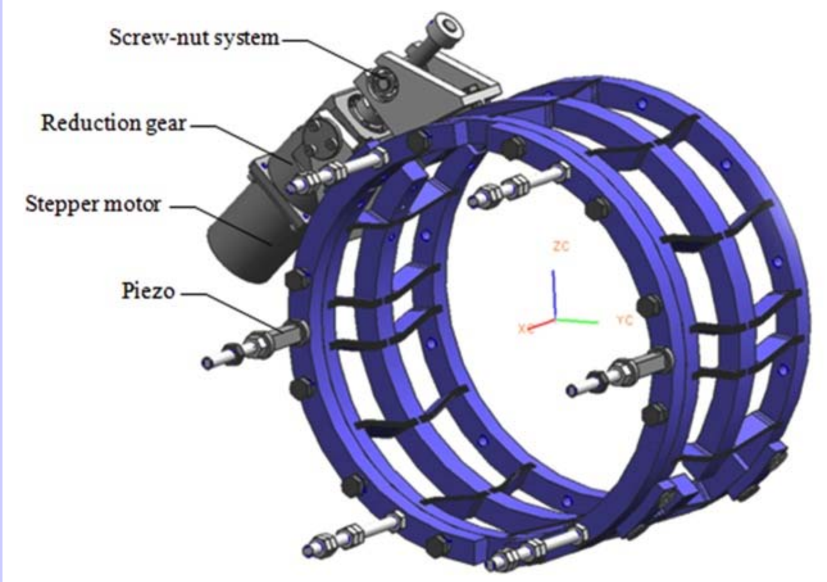
1.3 GHz Nine-Cell Cavities



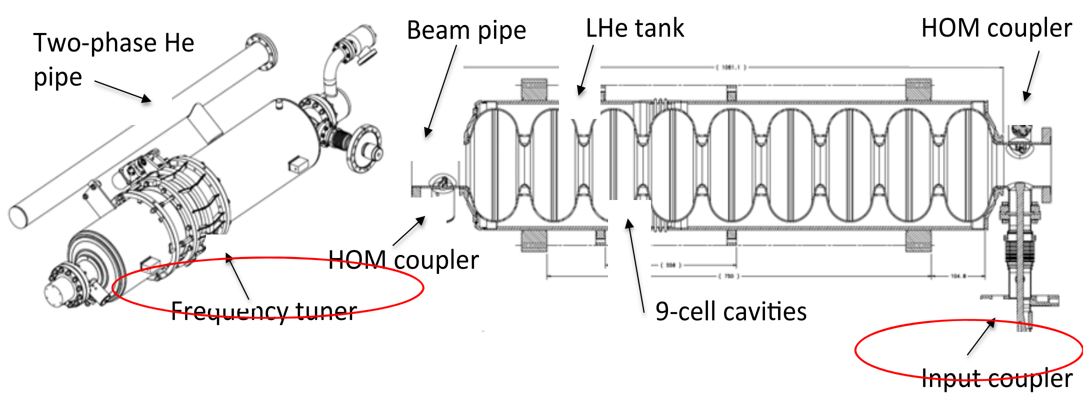
- **Solid high-grade niobium**
  - **RRR ≥300**
- **Mechanical fabrication**
  - **deep drawing**
  - **electron-beam welding**
- **Surface preparation**
  - **electro-polishing**
  - **High-pressure rinsing**
  - **800 deg C bake**
- **Cavity package:**
  - **HOM couplers (x2)**
  - **High-power input coupler**
  - **Ti-Nb Helium tank (cryostat)**
  - **Mechanical tuner**

Ultra-Clean Environment

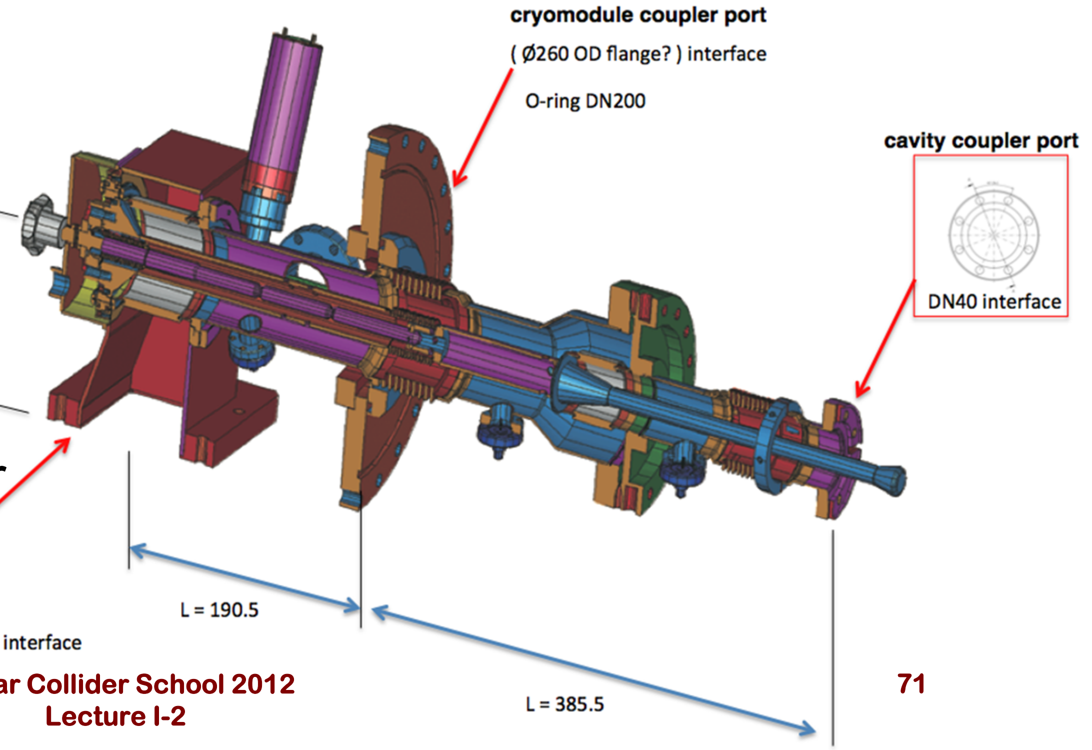
Cavity Package



Frequency (“blade”) tuner



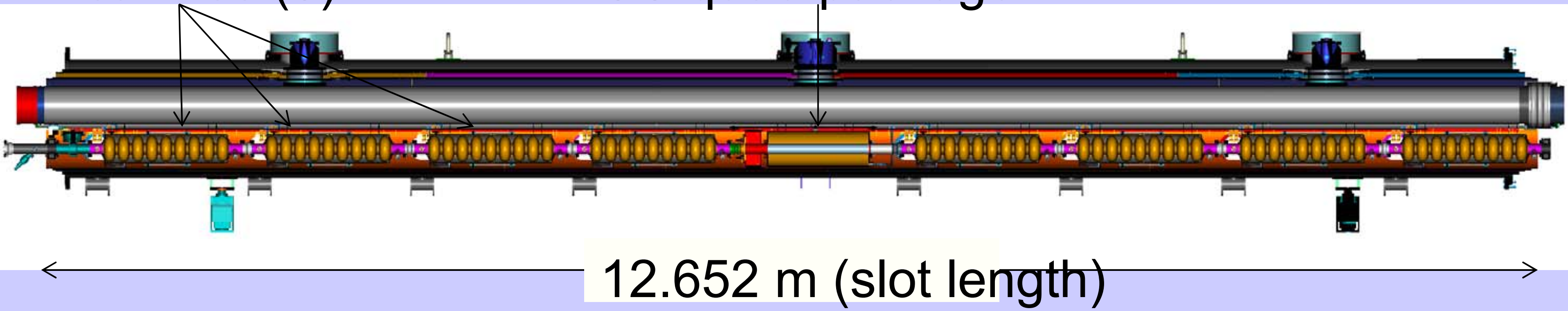
High-power coaxial input coupler



Cryomodule

Type-B module

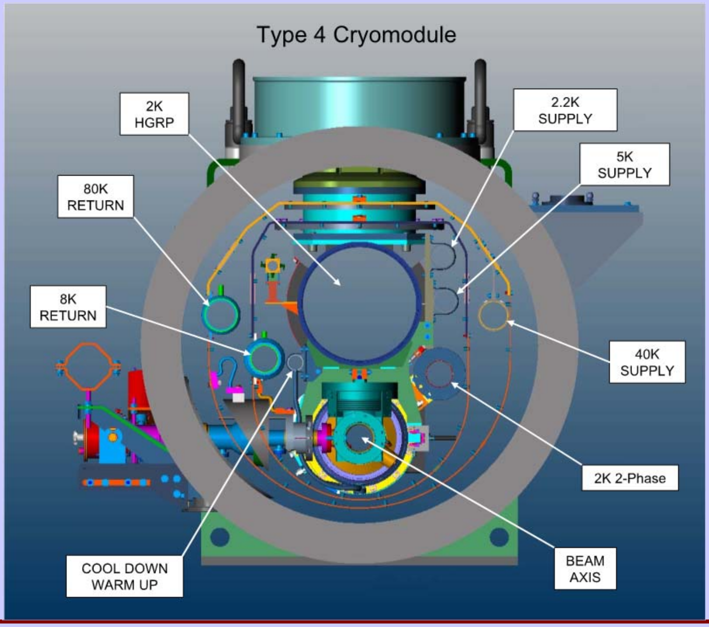
Type-A has 9 cavities and no quadrupole



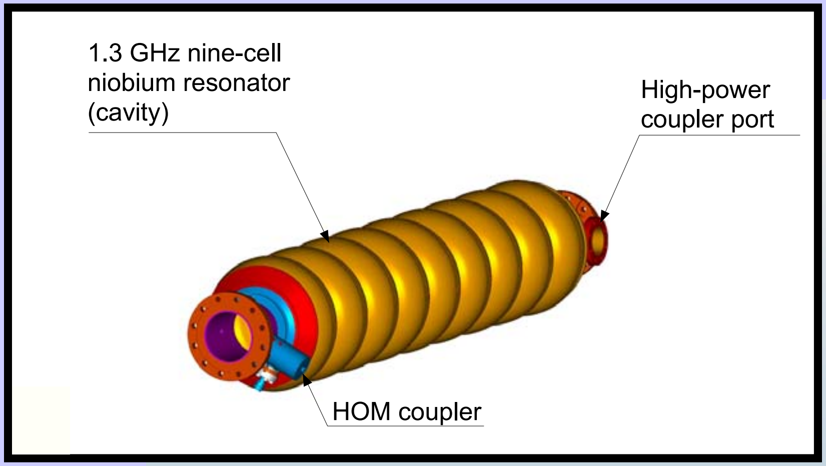
cavities (8)

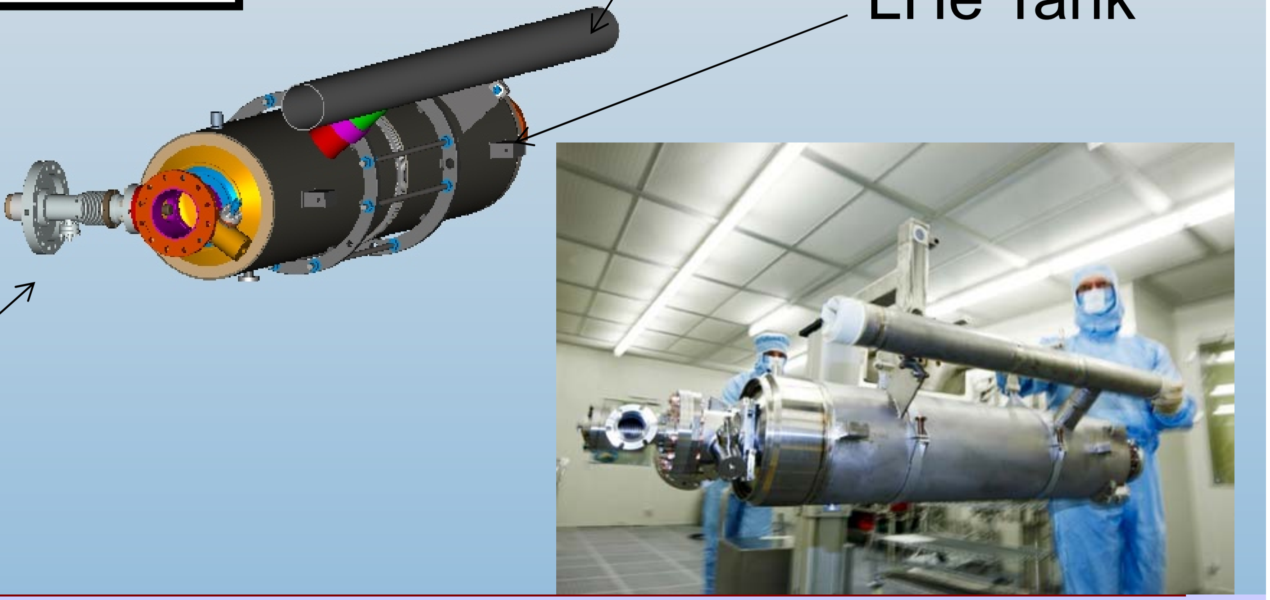
SC quad package

12.652 m (slot length)

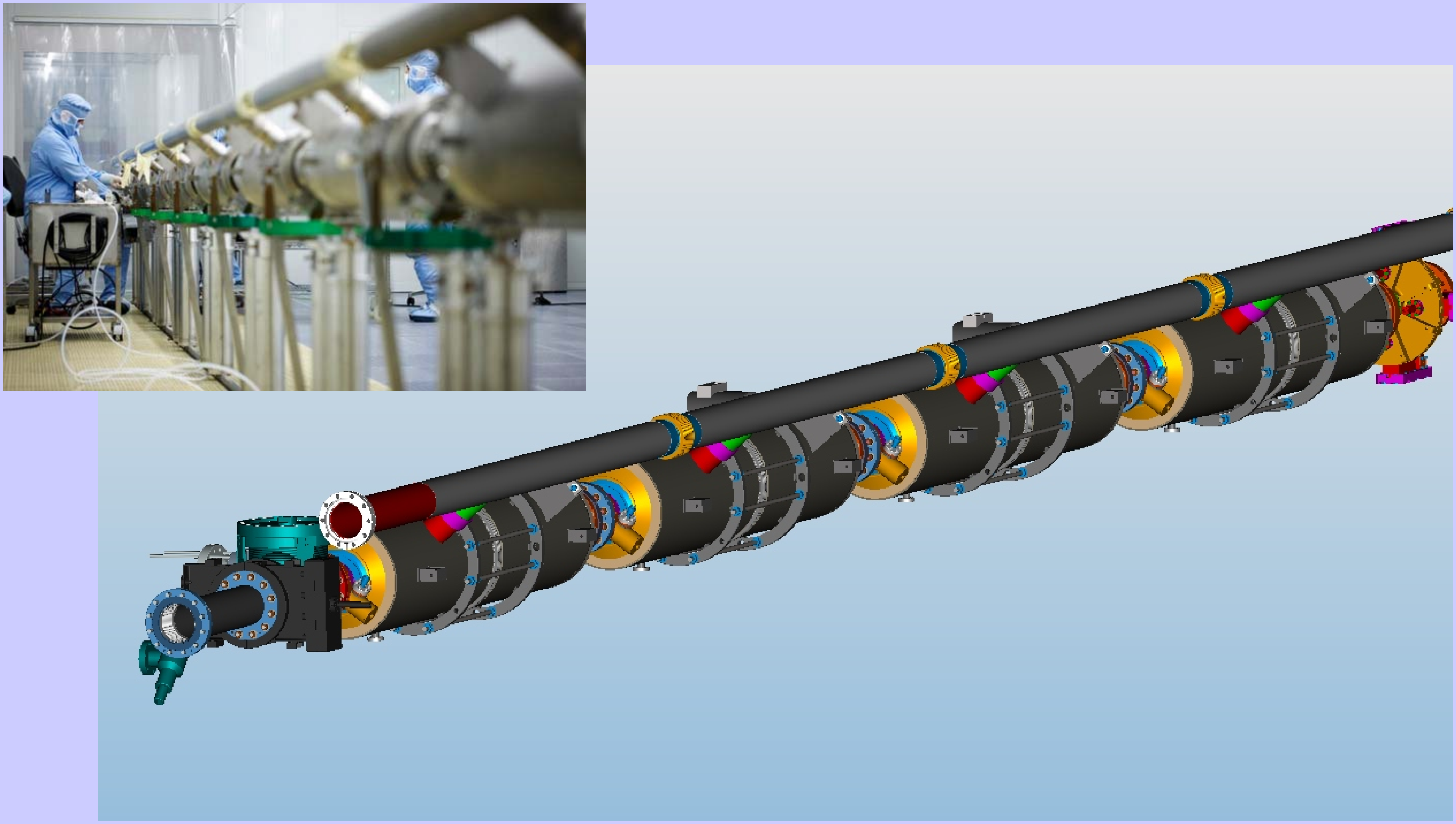


Cavity Package

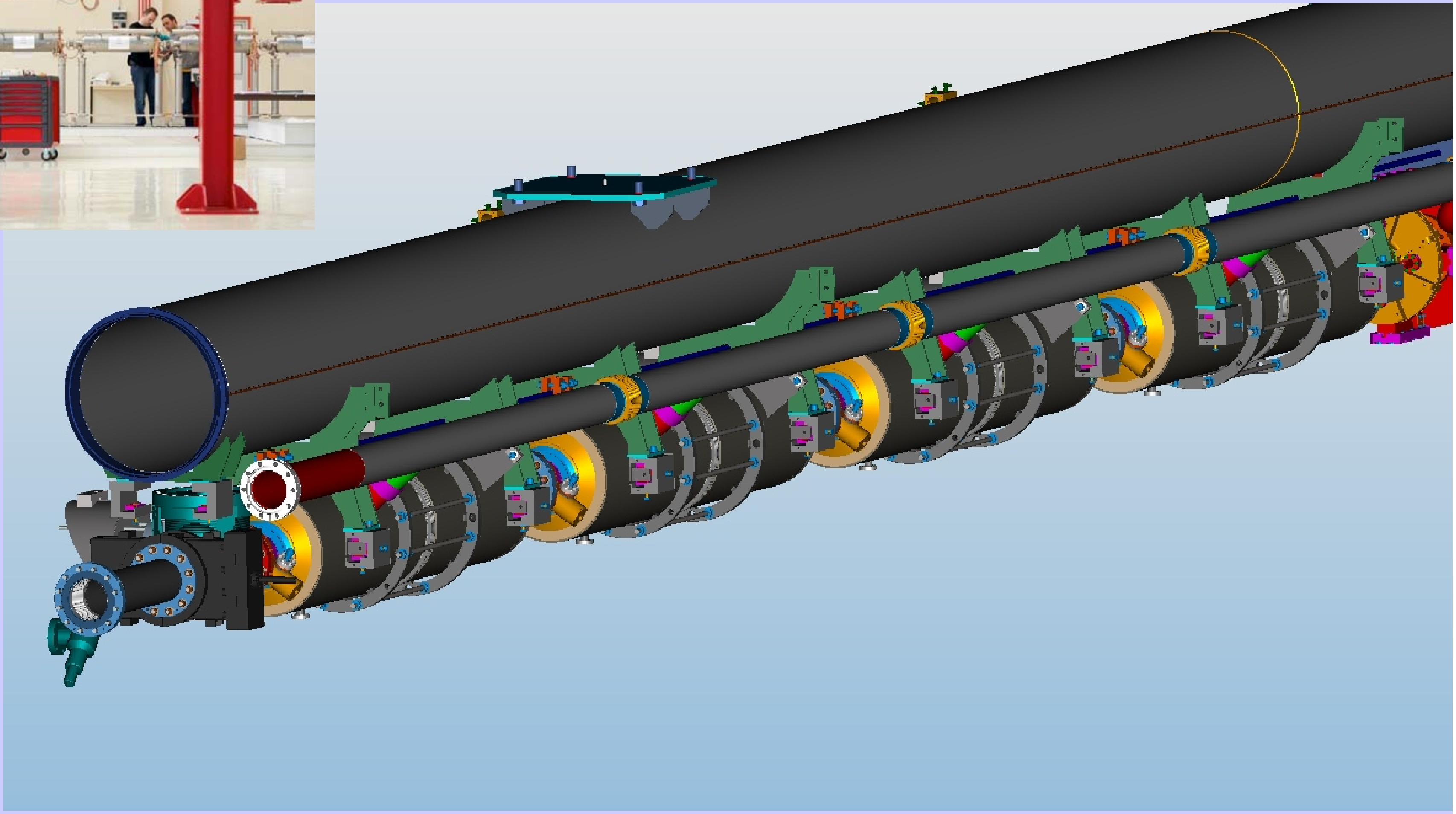




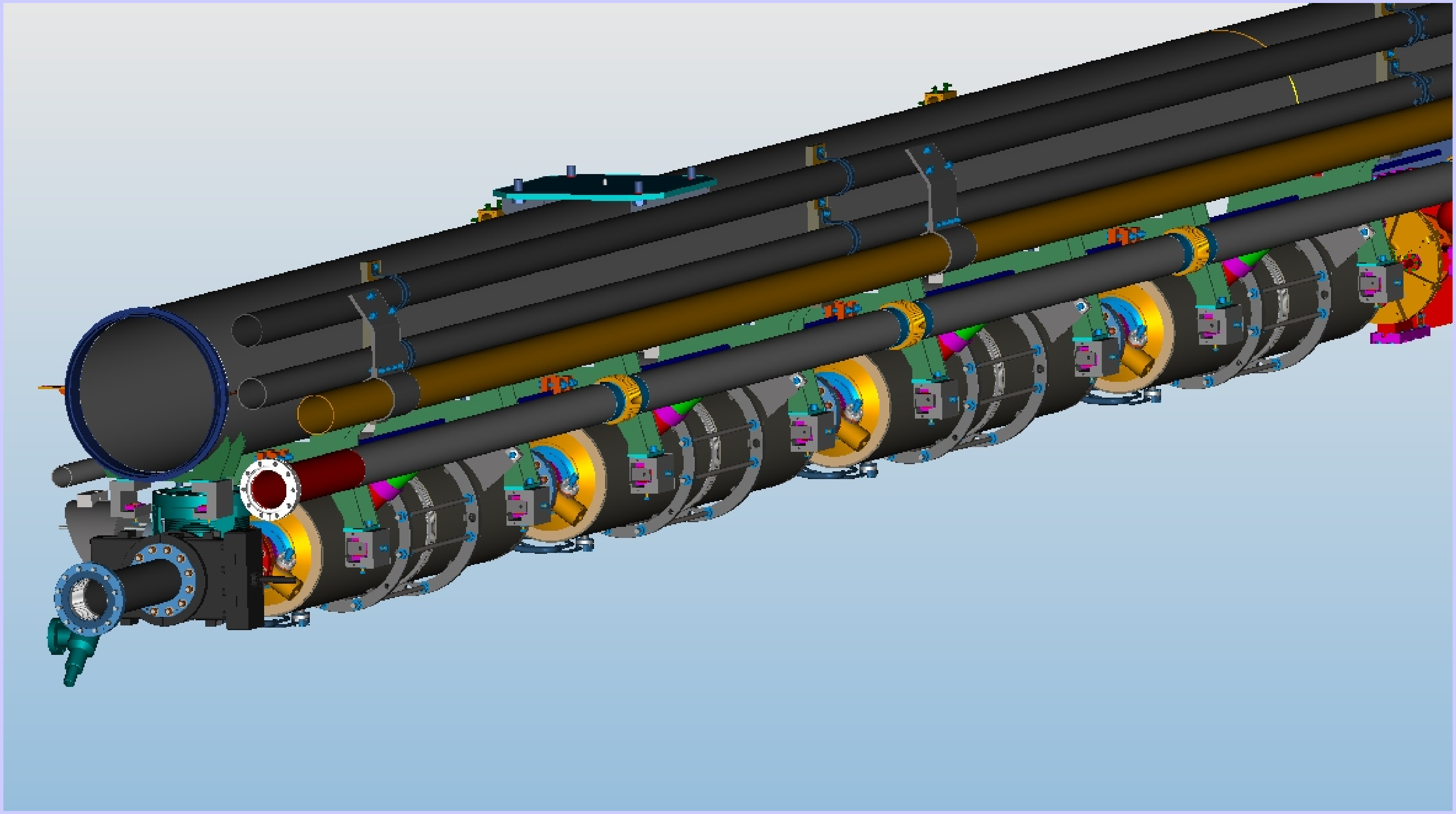
String Assembly



Mounted to Gas Return Pipe



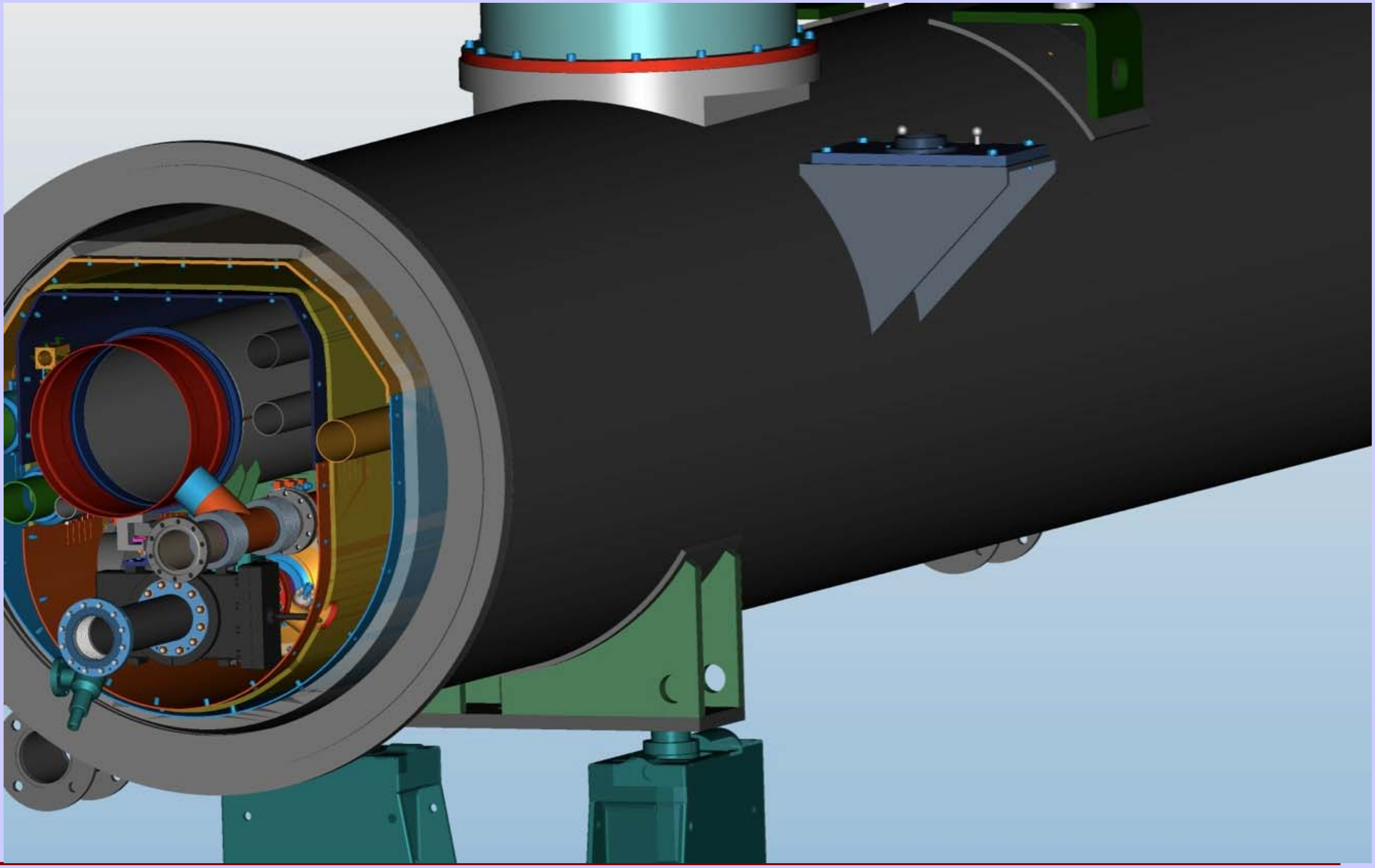
Add Piping



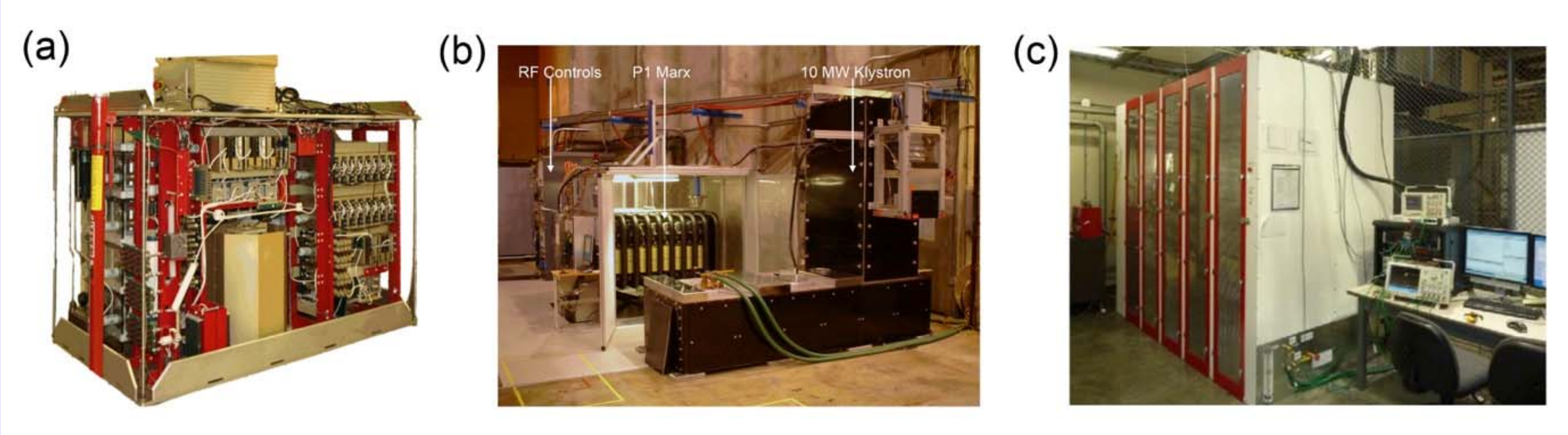
5K and 70K Thermal Shields

and insulation

Insertion into outer vacuum vessel



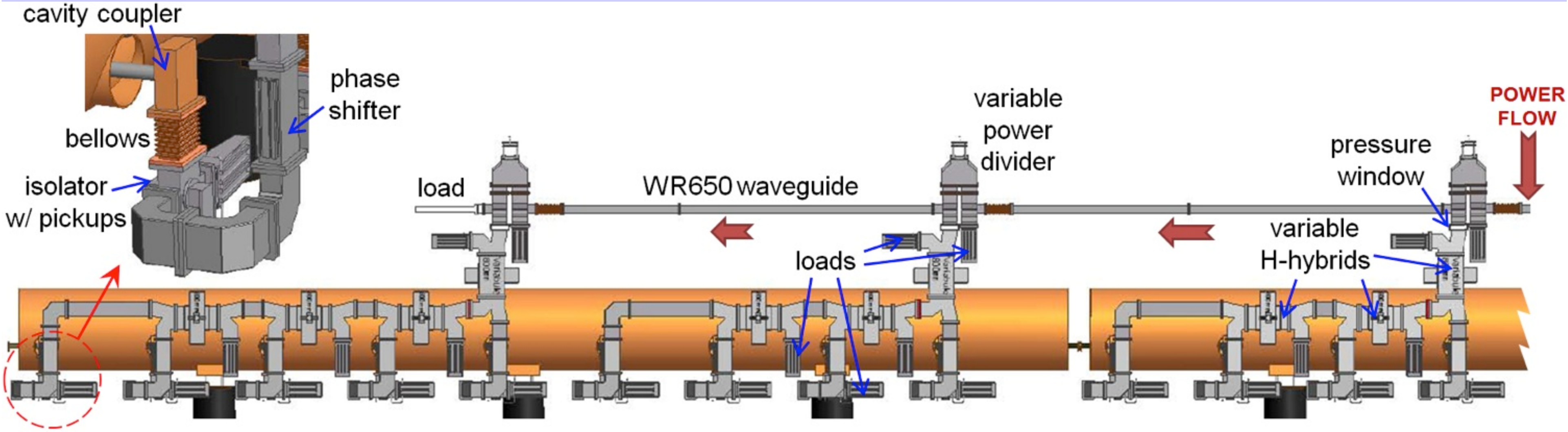
RF Power Source



Marx modulator

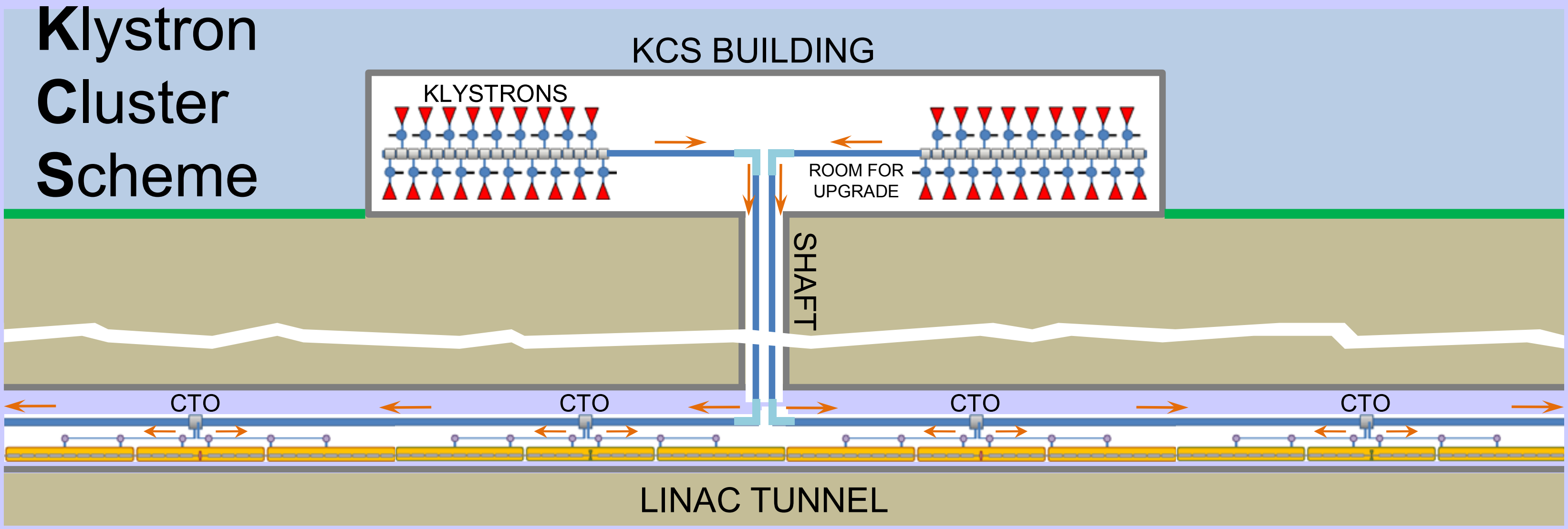
10MW MB
Klystron

RF Power Distribution (in tunnel)



- One ‘source’ drives many cavities (26/39)
- Power distribution system divides and distributes power to individual cavities
- Automated adjustment (splitters, phase shifters) allow individual adjustment of power to each cavity
- Can be tailored to accommodate the expected ±20% in cavity gradient performance
- Remote adjustability gives flexibility and maximises energy reach – but at a cost.

Site Dependence I: KCS


Klystron **C**luster **S**cheme

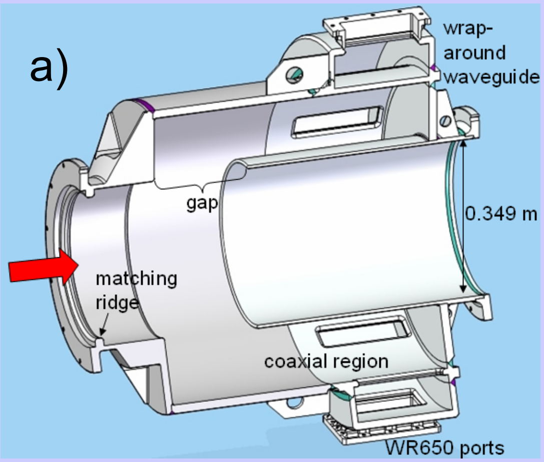
Novel system

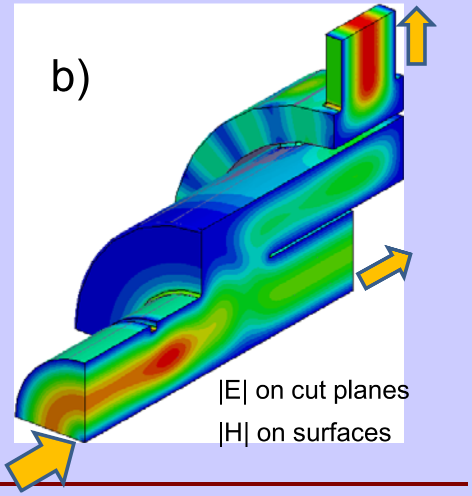
35×10 MW MBK → 350 MW

Feeds ~1 km of linac via over-moded circular WG (ø 48 cm)

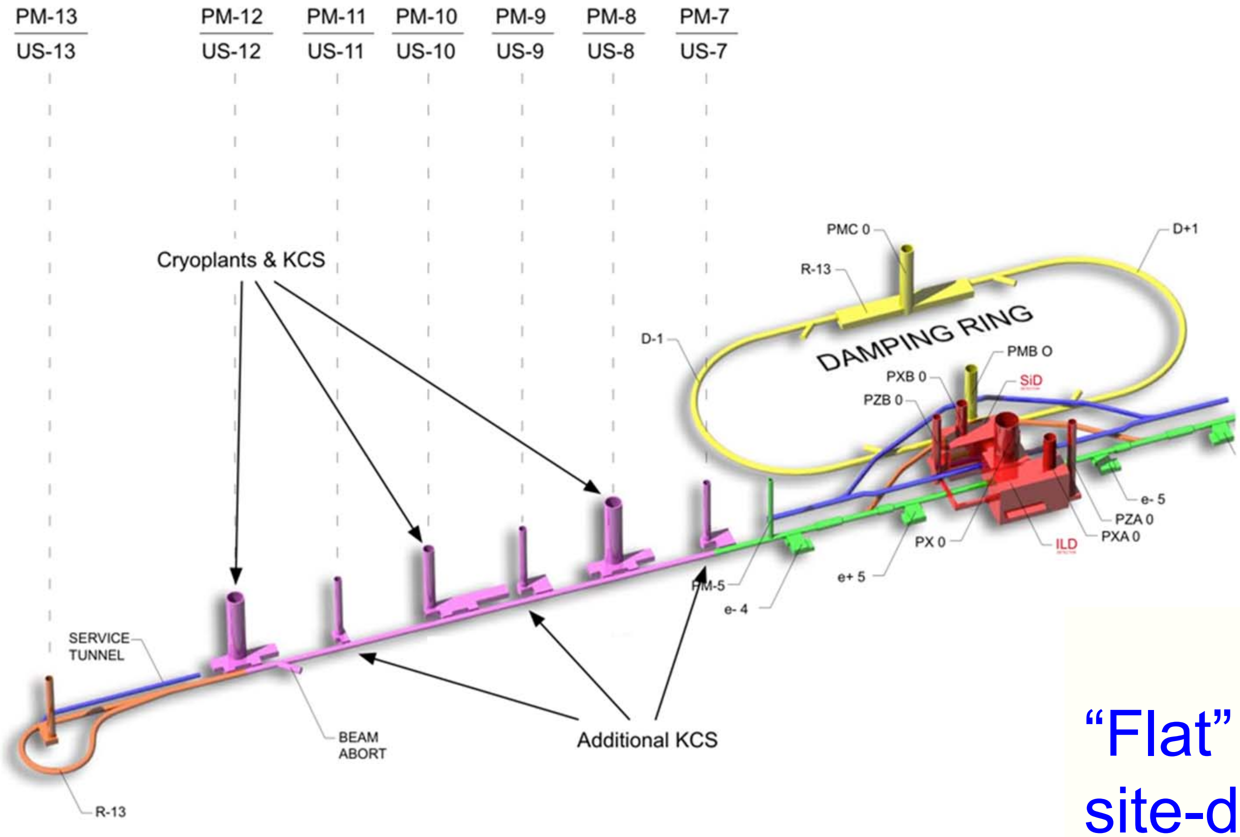
~8 MW ‘taped-off’ every 26 cavities

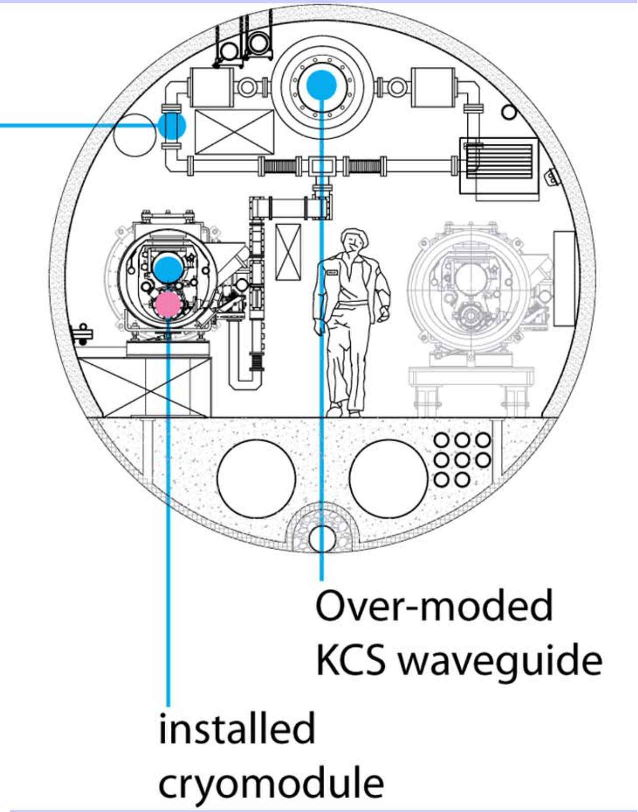
Special **C**oxaxial **T**ap-**O**ffs (CTO) used for both combining and splitting





Site Dependence I: KCS

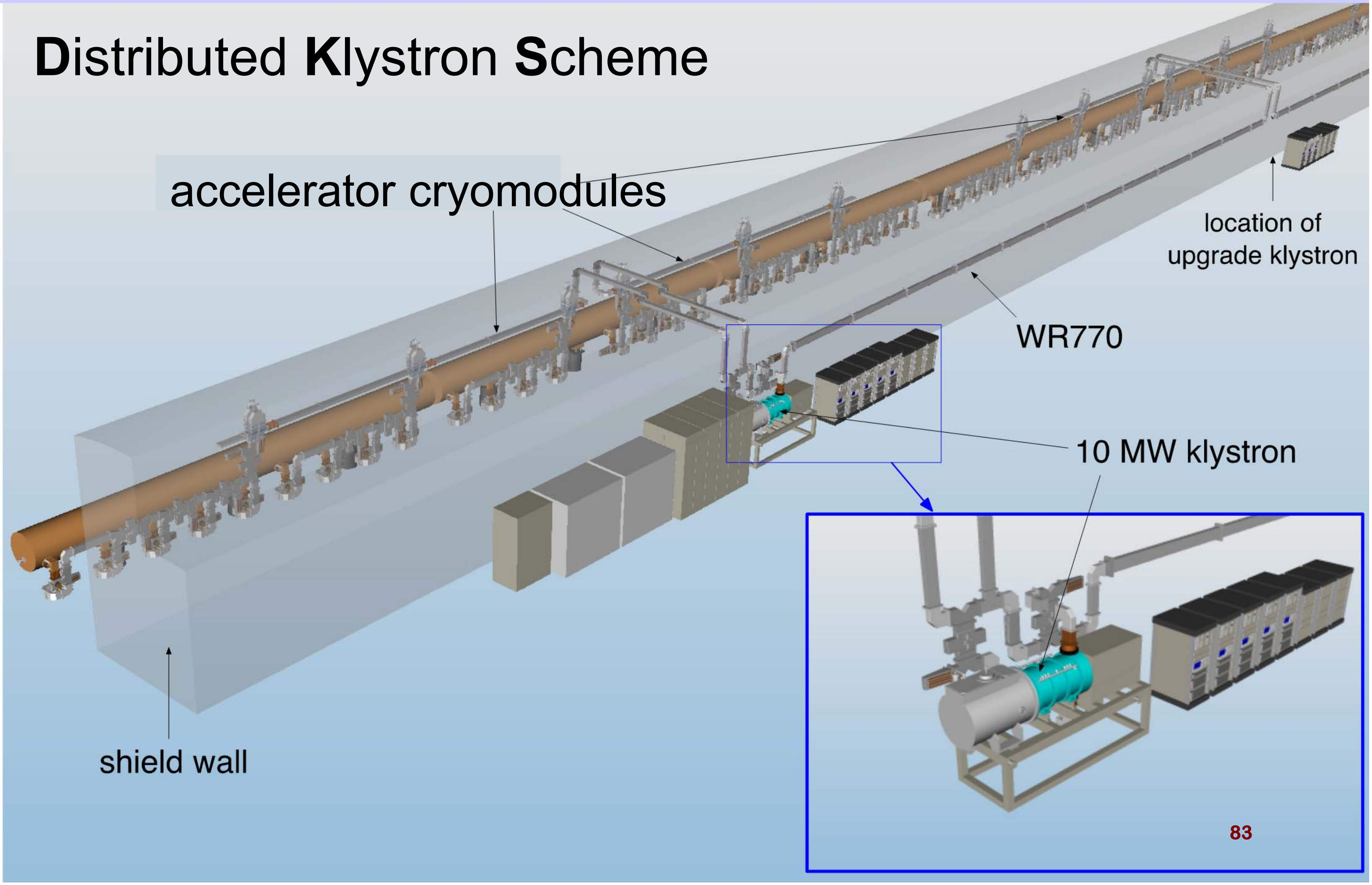




“Flat” topography
site-dependent design

Site Dependence II: DKS

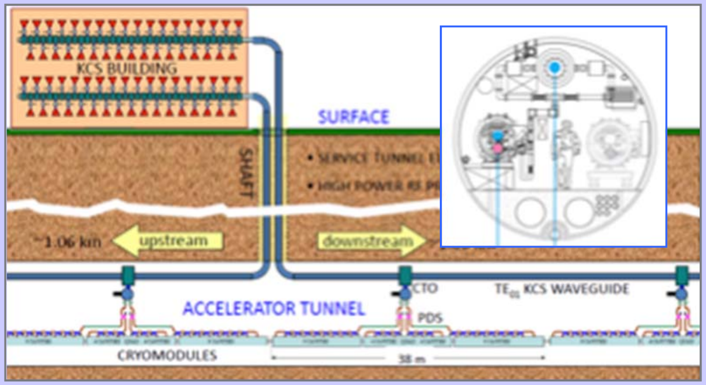
Distributed **K**lystron **S**cheme



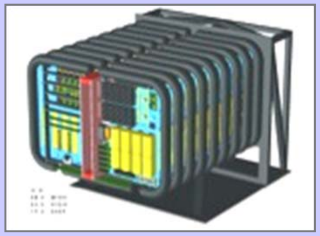
HLRF Power Distribution Design

Klystron Cluster Scheme (KCS)

- **Marx Modulators**
- **Clusters of klystrons**
  (2 × ~ 30 10-MW MBK) on surface
- **RF power distribution via major waveguide (300 MW)**



Distributed Klystron Scheme (DKS)



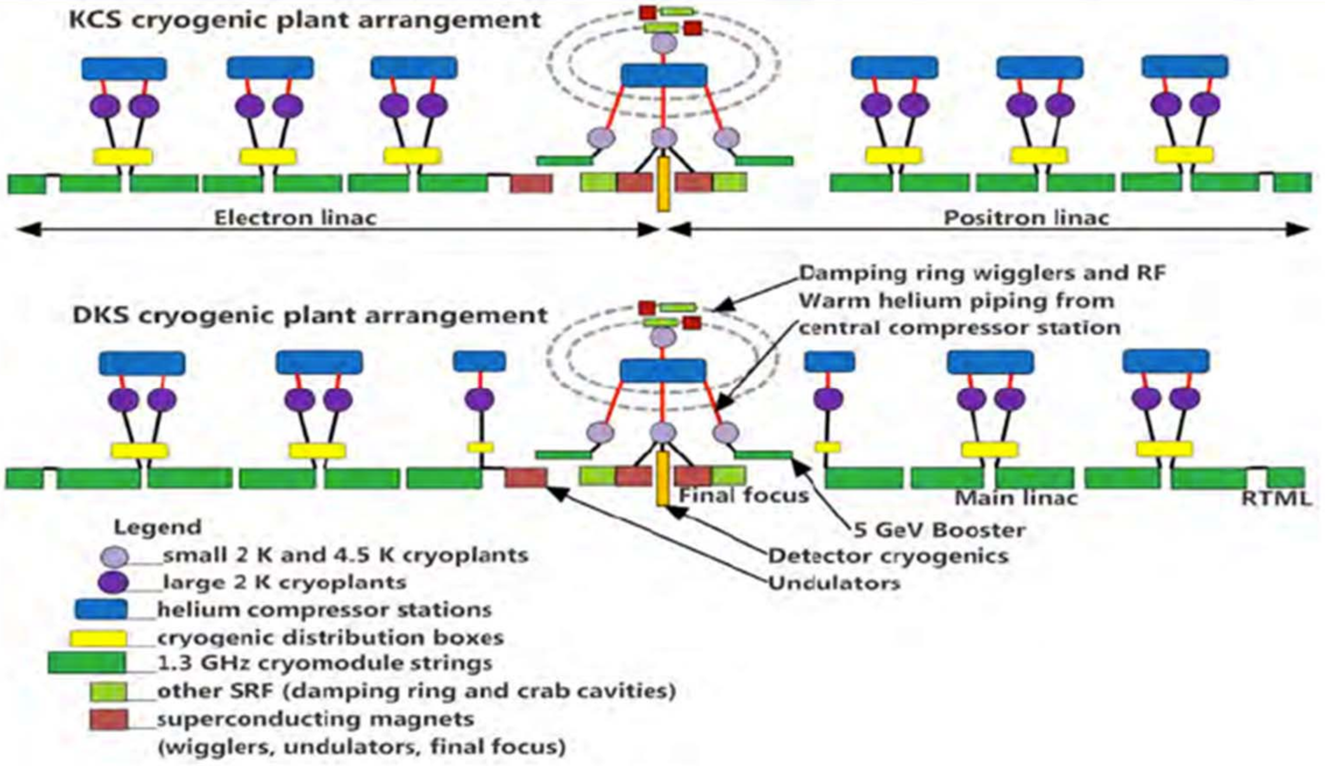
- **Marx modulator**
- **10-MW MBK per 39 cavities**
- **Everything in tunnel**

Slide 84

NJW1 Will mention verbally the on-going SLAC R&D (and recenet high-power result) and that DRFS concept will be tested at S1G.

Nicholas Walker, 10/4/2010

Cryogenics Designs

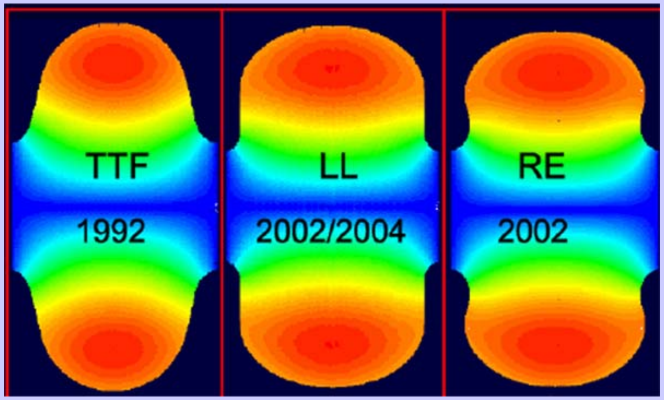


Volumes	Numbers	Liq. He (L) equivalent	Tevatron eq.	LHC Eq.
One module		346.1		
String	12 modules	4,153	0.1	
Cryo. unit	14-16 strings	62,992	1.0	0.1
ILC ML	2 x 5 cryo. units	630,261	10.5	0.9

Global Plan for SCRF R&D

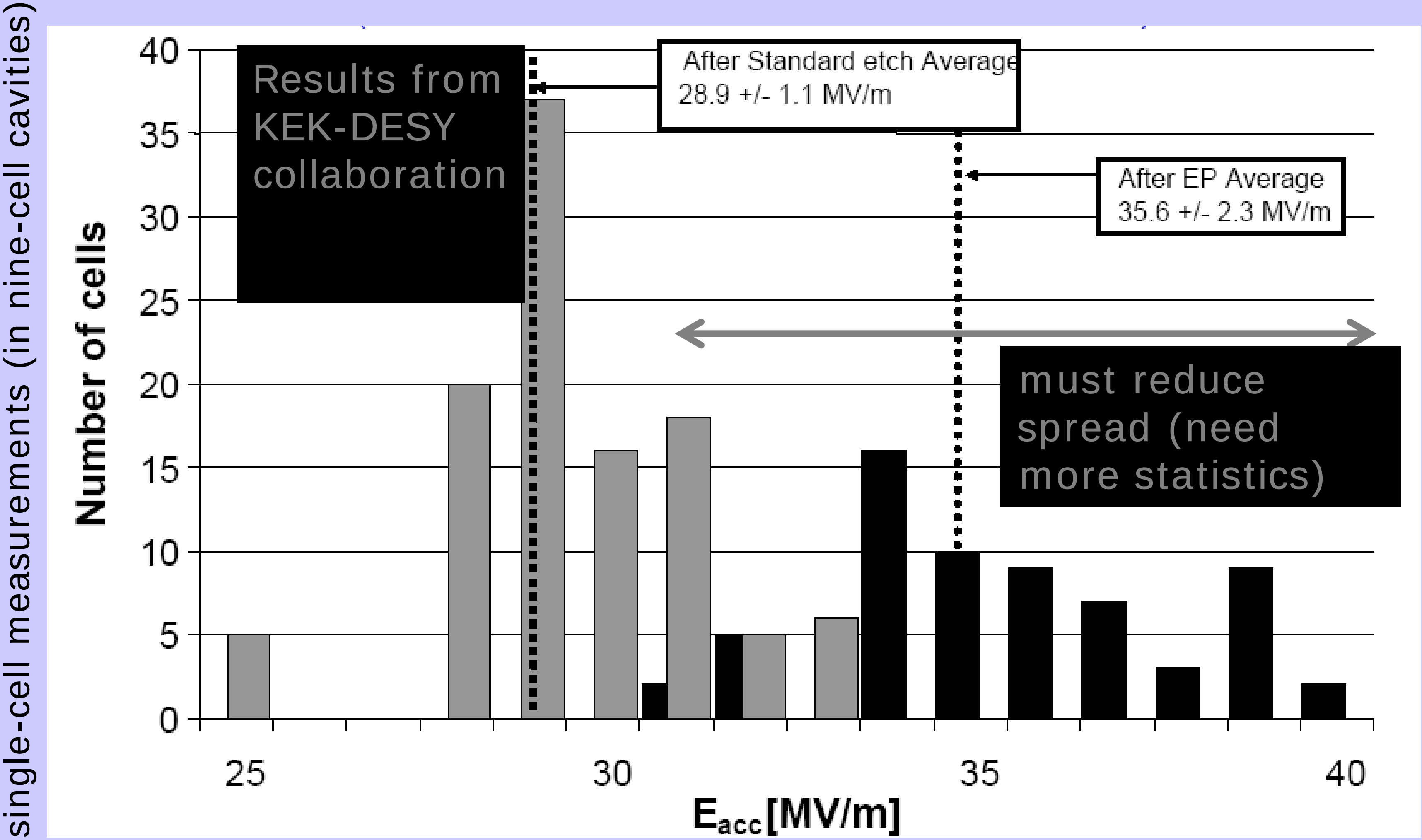
Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in v. test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		**Global effort for string assembly and test** (DESY, FNAL, INFN, KEK)			We are here	
System Test with beam acceleration		**FLASH (DESY) , NML/ASTA (FNAL)** **QB, STF2 (KEK)**				
Preparation for Industrialization			**Production Technology R&D**			
Communication with industry:	1st Visit Vendors (2009), Organize Workshop (2010) 2nd visit and communication, Organize 2nd workshop (2011) 3rd communication and study contracted with selected vendors (2011-2012)					

Superconducting RF Cavities



High Gradient Accelerator
35 MV/meter -- 40 km linear collider

Gradient

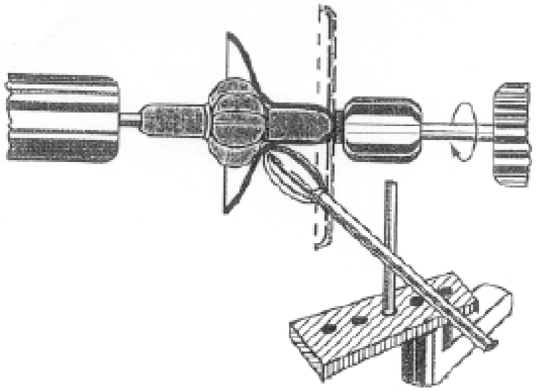


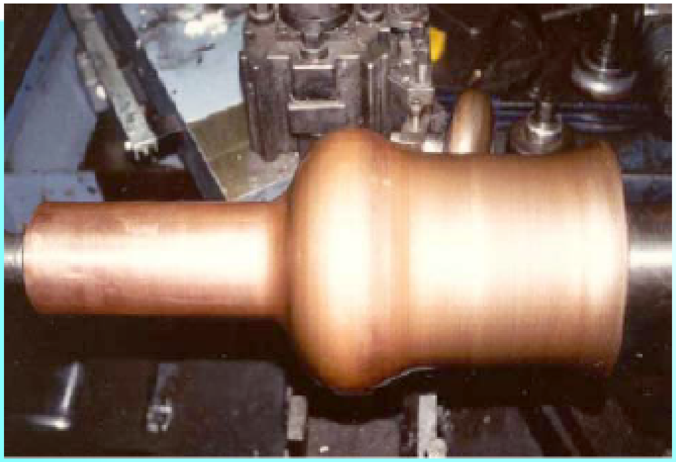
Results from KEK-DESY collaboration

must reduce spread (need more statistics)

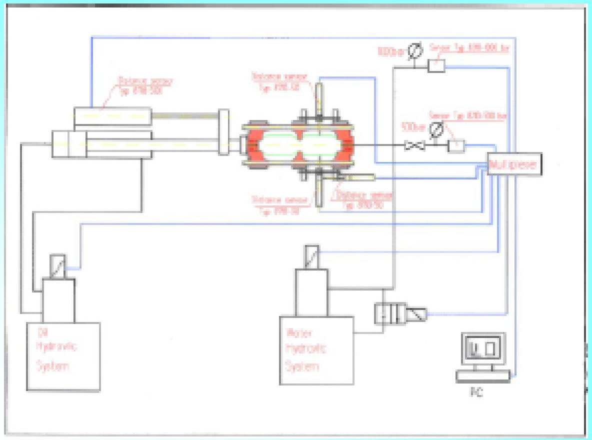
Improved Fabrication

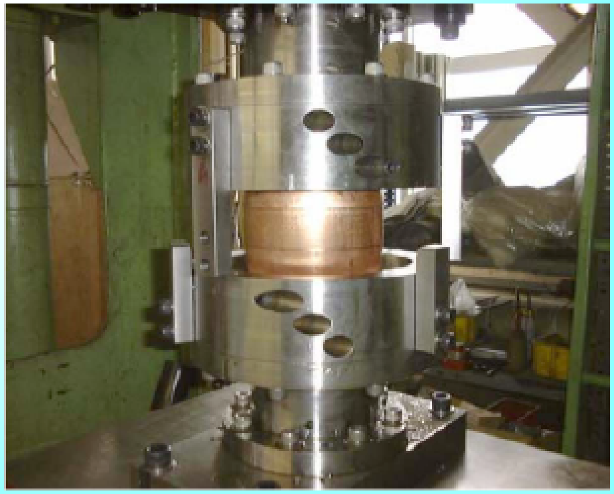
Spinning (V.Palmieri,INFN Legnaro)





Hydroforming, DESY, KEK





Improved Processing Electropolishing

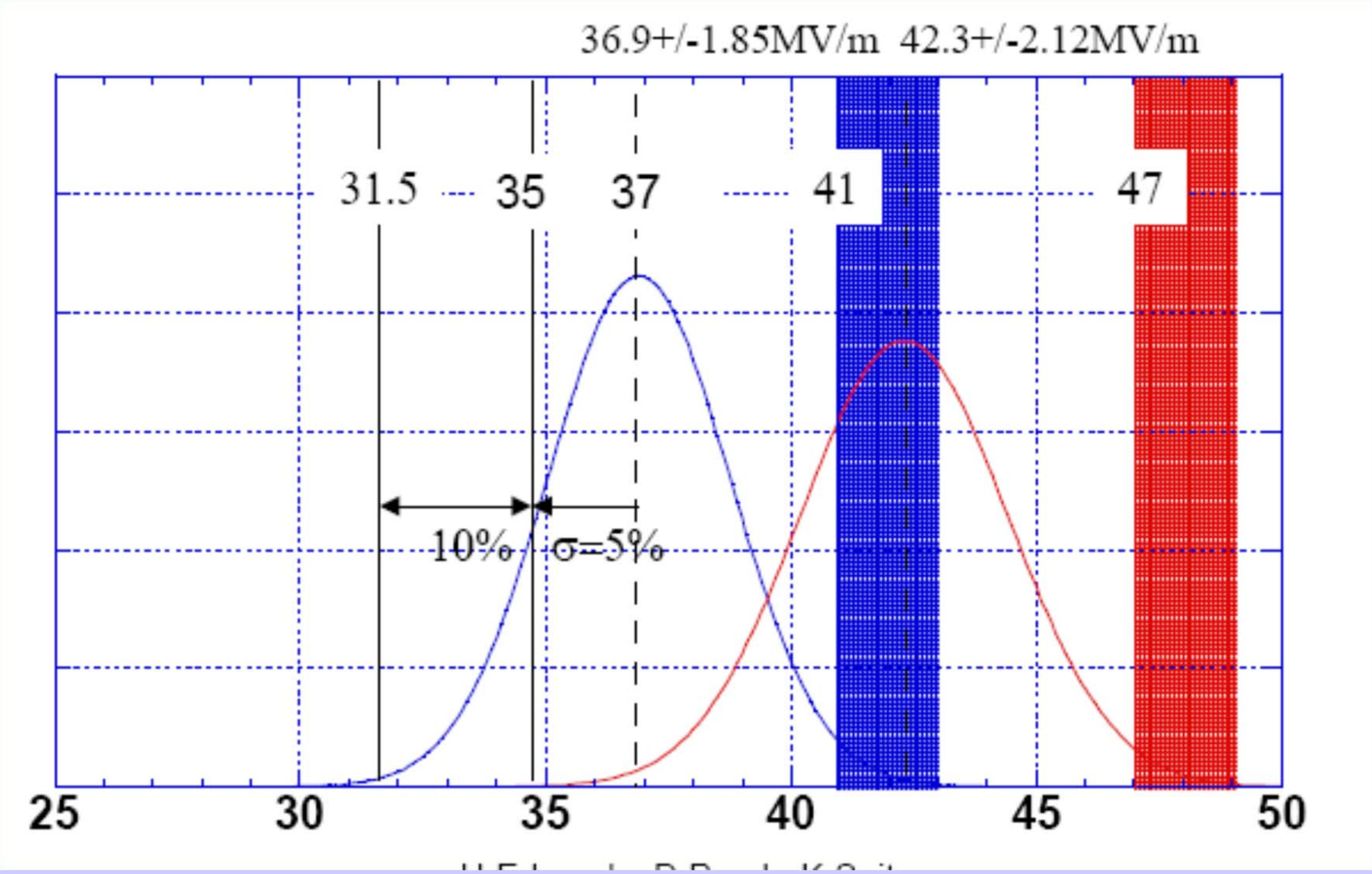
KEK / Nomura EP

DESY EP

Chemical Polish

Electro Polish

Baseline Gradient



The ILC SCRF Cavity

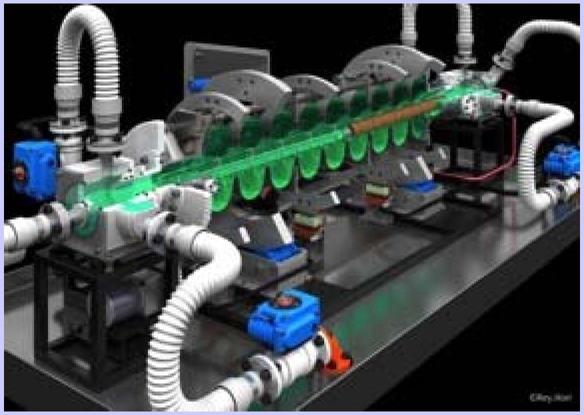
Figure 1.2-1: A TESLA nine-cell 1.3 GHz superconducting niobium cavity.

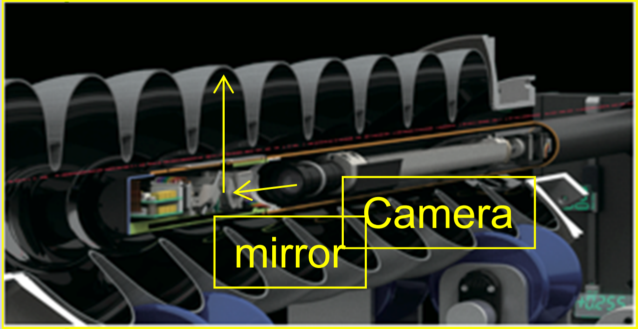
- Achieve high gradient (35MV/m); develop multiple vendors; make cost effective, etc

- Focus is on high gradient; production yields; cryogenic losses; radiation; system performance

Cavity R&D Efforts

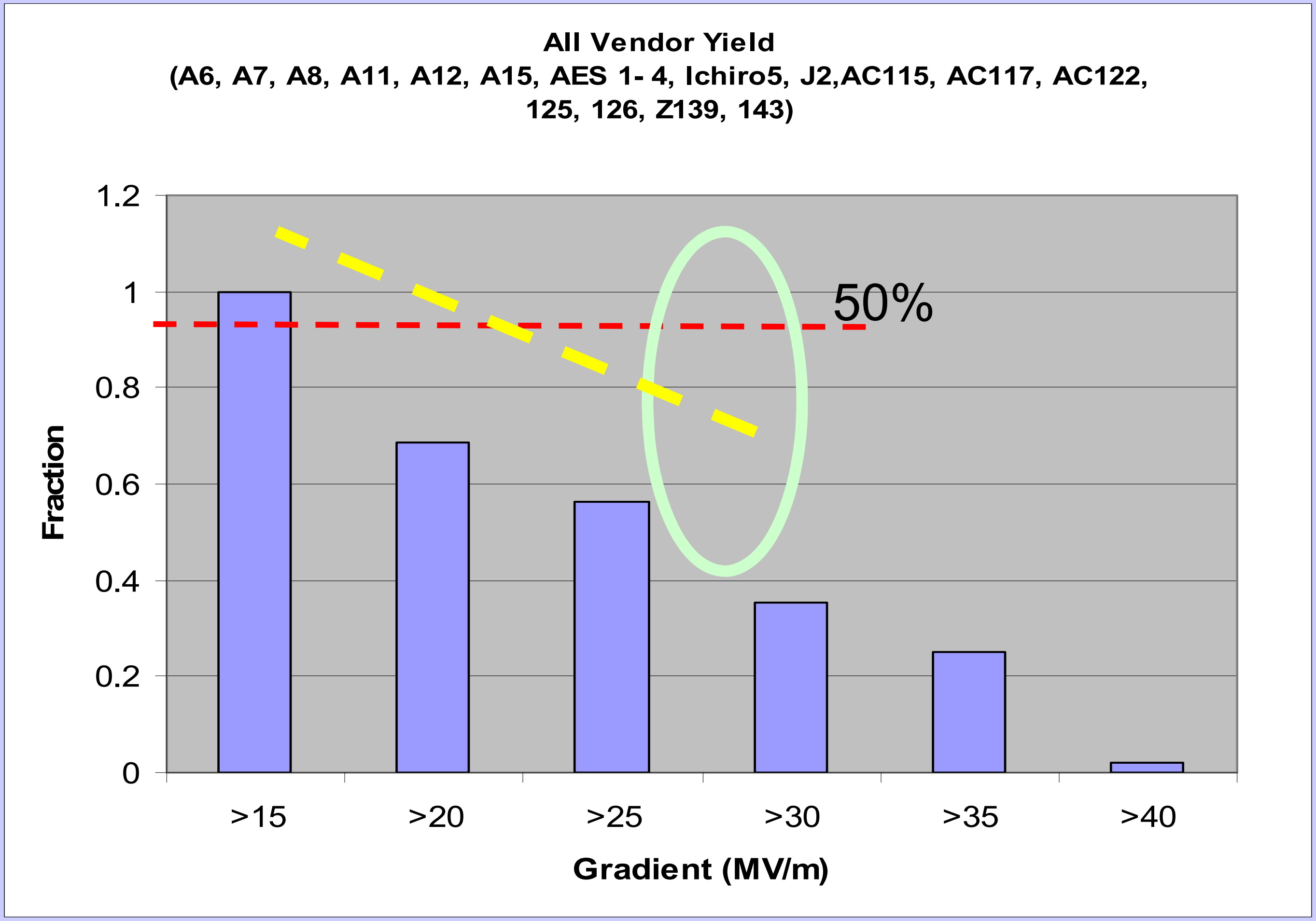
- **Fabrication:**
  - Forming and welding (EBW)
- **Surface Process:**
  - Chemical etching
    - Electro-polishing
  - Cleaning
    - Ethanol, Detergent, Micro-EP
    - High pressure rinsing
- **Inspection/Tests:**
  - Optical Inspection (warm)
  - Tests and thermometry (cold)





Cavity Process Yield in 2008

Process Yield: **~ 23 %** @ 35 MV/m, based on 48 Tests for19 cavities


All Vendor Yield
(A6, A7, A8, A11, A12, A15, AES 1- 4, Ichiro5, J2,AC115, AC117, AC122, 125, 126, Z139, 143)

- Manufactured by ACCEL, AES, Zanon, KEK (Ichiro-type), and JLab

Tested at DESY and JLab

Standard Procedure Established

allow twice

	Standard Fabrication/Process
Fabrication	Nb-sheet purchasing
	Component Fabrication
	Cavity assembly with EBW
Process	EP-1 (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	EP-2 (~20um)
	Ultrasonic degreasing or ethanol (or EP 5 um with fresh acid)
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Cold Test (vertical test)	Performance Test with temperature and mode measurement

Fabrication

- Material
- EBW
- Shape

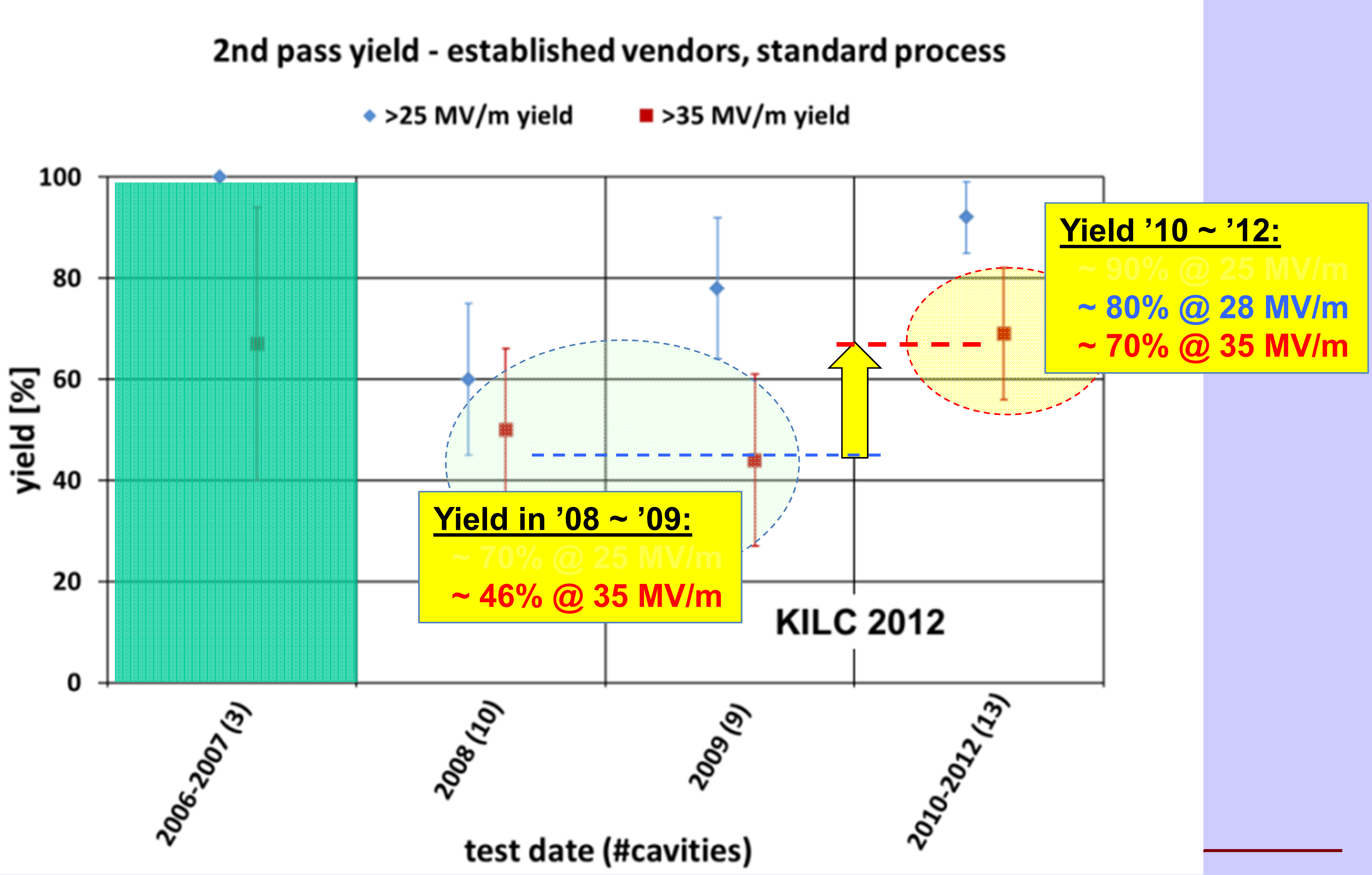
Process

- Electro-Polishing

- Ethanol Rinsing or
- Ultra sonic. + Detergent Rins.

- High Pr. Pure Water cleaning

Yearly Progress in Cavity Gradient Yield



Yield '08 ~ '09:

~ 70% @ 25 MV/m

~ 46% @ 35 MV/m

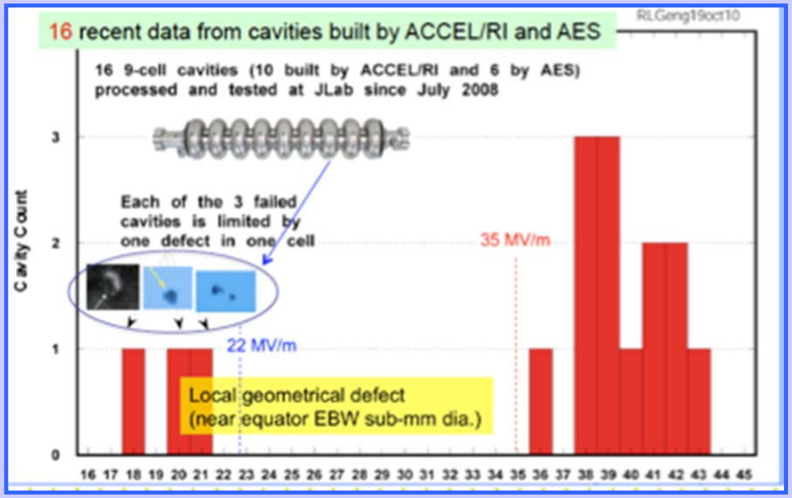
Yield '10 ~ '12:

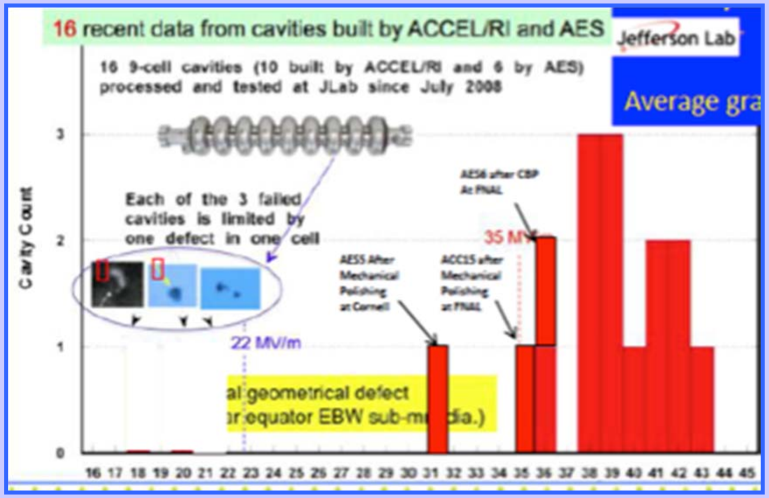
~ 90% @ 25 MV/m

~ 80% @ 28 MV/m

~ 70% @ 35 MV/m

Experience
JLab, Fermilab, Cornell Collaboration





- Type-A: quench limit occurs in a gradient range of < 25 MV/m.
  - Often correlated with sub-mm sized geometrical defects at or near the equator EB welding.
  - Repeated EP has no or little effect in improving the quench limit, suggesting the permanent nature of these defects
- Type-B: quench limit occurs at a gradient > 25 MV/m.
  - Normally no observable feature at the quench site
  - Often, a second EP effectively improves the quench limit to > 30 MV/m.

Reasons to limit the field gradient

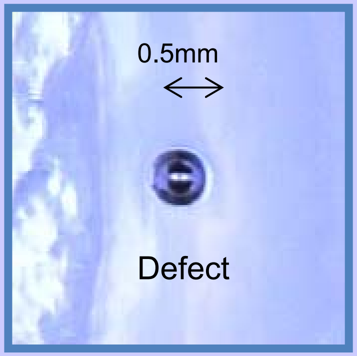
A: Caused in Fabrication

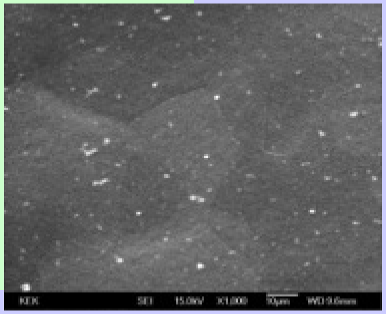
--> Defect in material and from EBW

B: Caused in Surface Treatment

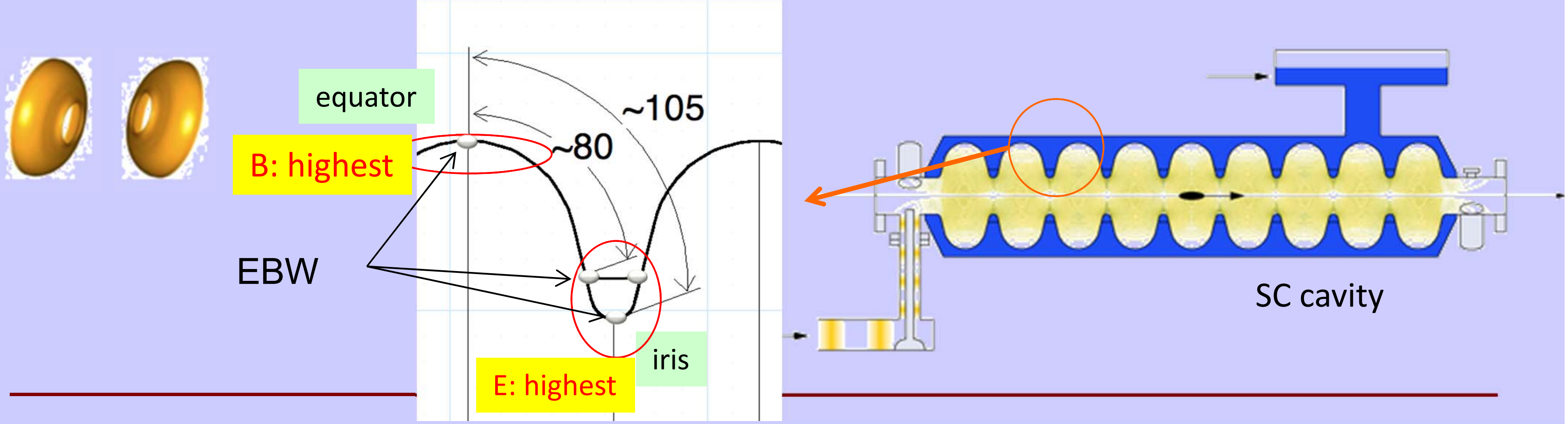
--> Enhancement of material defect

--> Residual contamination





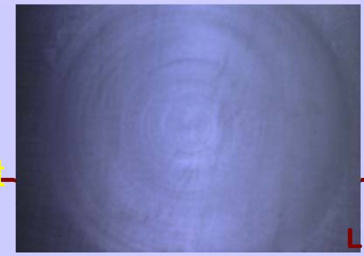
Contamination on Nb surface
(~ a few 10μm)



Inspection and Repairing Technology may improve the Yield

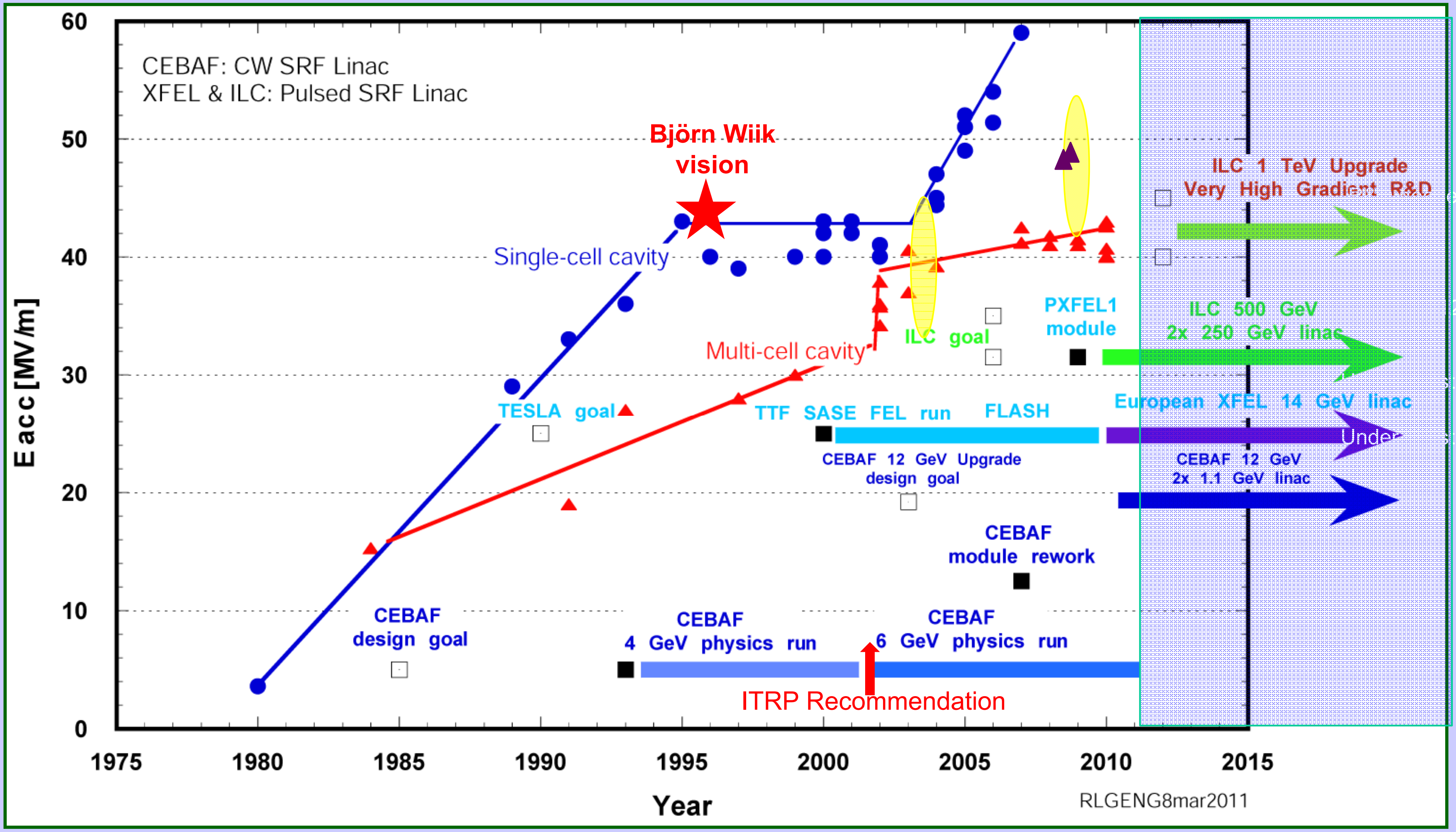
Technology in progress:

- **Localization during test**
  - **+ Optical inspection**
    - **+ Repairing**



Cavity	Repaired at (EP/ MT/ LG)	Tested at	Bef.	Aft.	Year
AES-5	Cornell (EP)	JLab	20	31	2010
AES-6	FNAL (Tumbling)	JLab	21	36	2011
ACC-15	FNAL (Tumbling)	JLab/FNAL	18	35	2011?
LG#1	JLab-KEK (LG)	JLab	31	(42)	2010?
MHI-08	KEK (LG)	KEK	16	27	2009
MHI-14	KEK (LG)	KEK	13	37	2011
MHI-15-1	KEK (LG)	KEK	23	33	2011
MHI-15-2	KEK (LG)	KEK	29	36	2011
MHI-15-3	KEK (LG)	KEK	18	36	2012
MHI-16	KEK (LG)	KEK	21	34	2012
MHI-19	KEK (LG)	KEK	26	37	2012
HIT-2	KEK (LG)	KEK	35	41	2012

SCRF Cavity Gradient Progress



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SCRF Accelerator Test Facilities

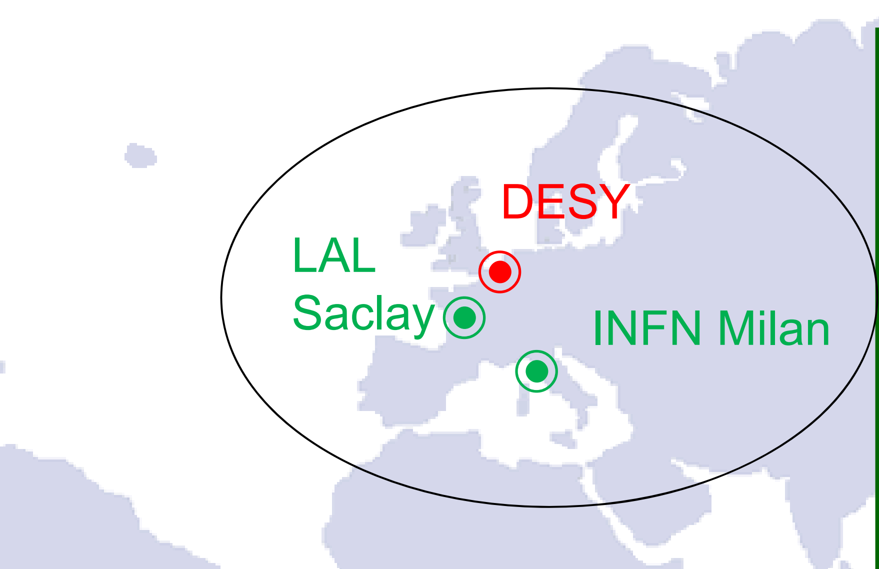
- **In progress for SCRF beam accelerator**

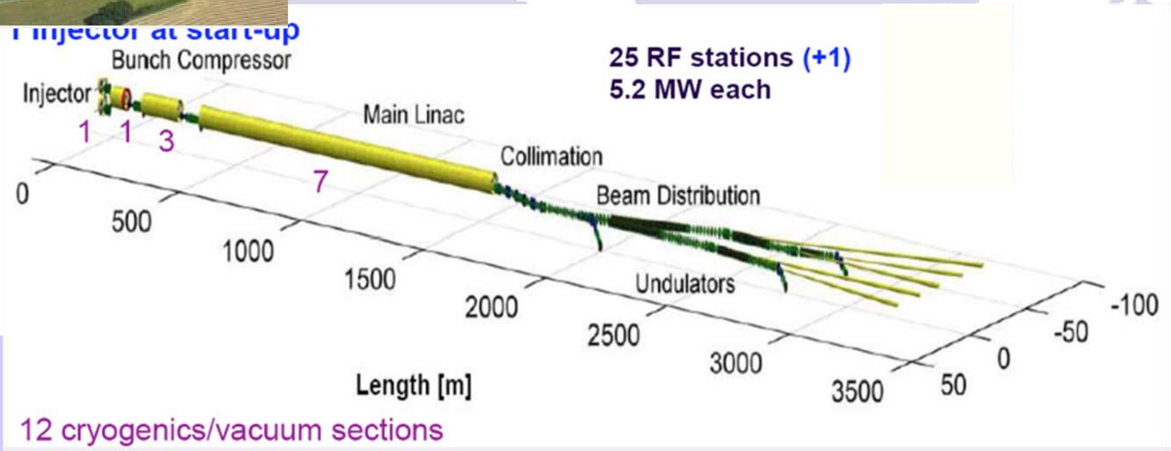
FLASH@DESY

STF@KEK

ASTA@FNAL

European XFEL

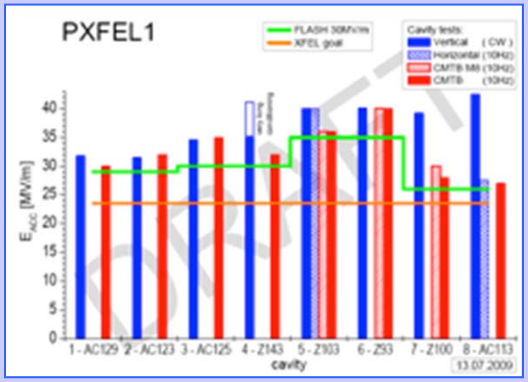


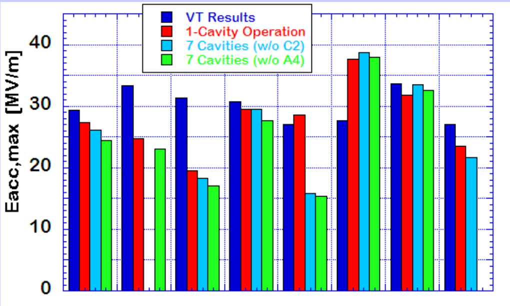


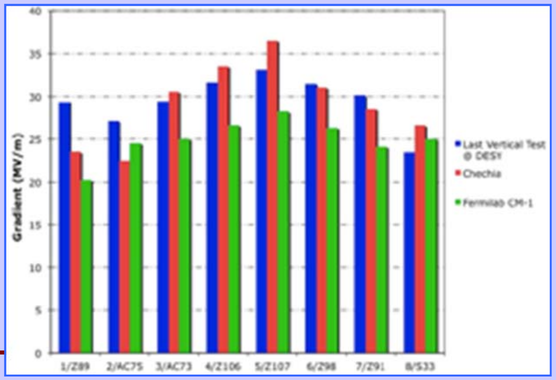
- **17.5 GeV (20 GeV)**
- **100 Cryomodules**
- **800 cavities**
- **Gradient:**
  - **23.5 MV/m**
  - **(28 MV/m)**
- **Industrialisation & mass production**
  - **1 CM / week**
- **“In-kind” international model**

Progress in SCRF System Tests

- **DESY: FLASH**
  - **SRF-CM string + Beam,**
    - **ACC7/PXFEL1 < 32 MV/m >**
  - **9 mA beam, 2009**
  - **800μs, 4.5mA beam, 2012**
- **KEK: STF**
  - **S1-Global: complete, 2010**
    - **Cavity string : < 26 MV/m>**
  - **Quantum Beam : 1 ms**
  - **CM1 + Beam, in 2014**
- **FNAL: NML/ASTA**
  - **CM1 test complete**
  - **CM2 operation, in 2013**
  - **CM2 + Beam, beyond 2013**



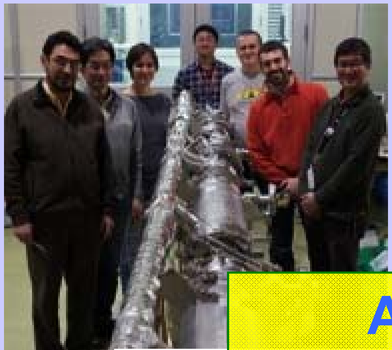


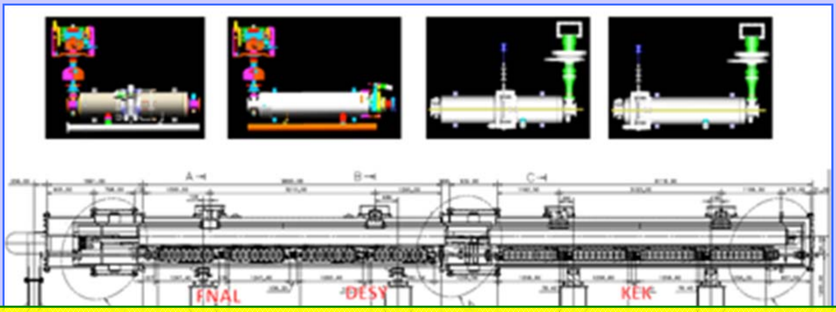


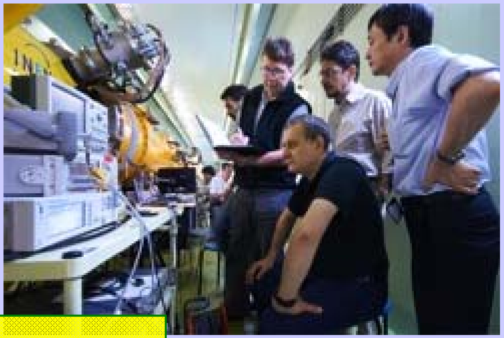
S1-Global Assembly/Test with Global Effort

DESY, FNAL, Jan., 2010

DESY, Sept. 2010







AL & INFN, July, 2010

A practice for Global Cooperation with Plug-compatibility !

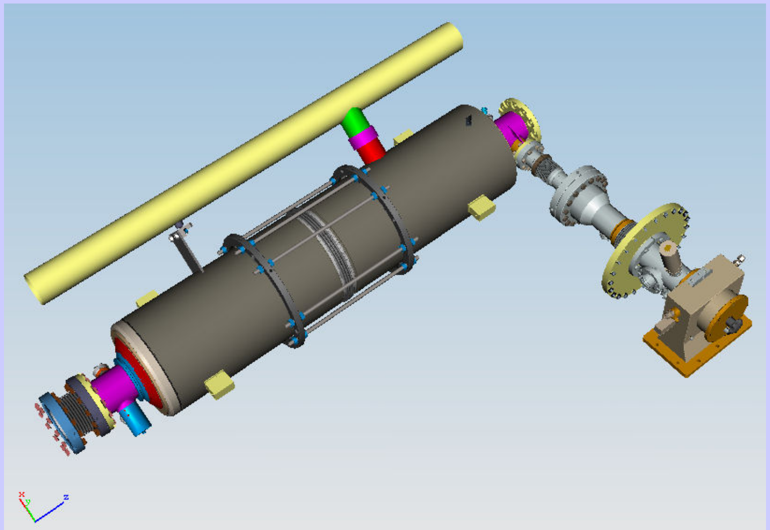
INFN
and
FNAL
Feb.
2010

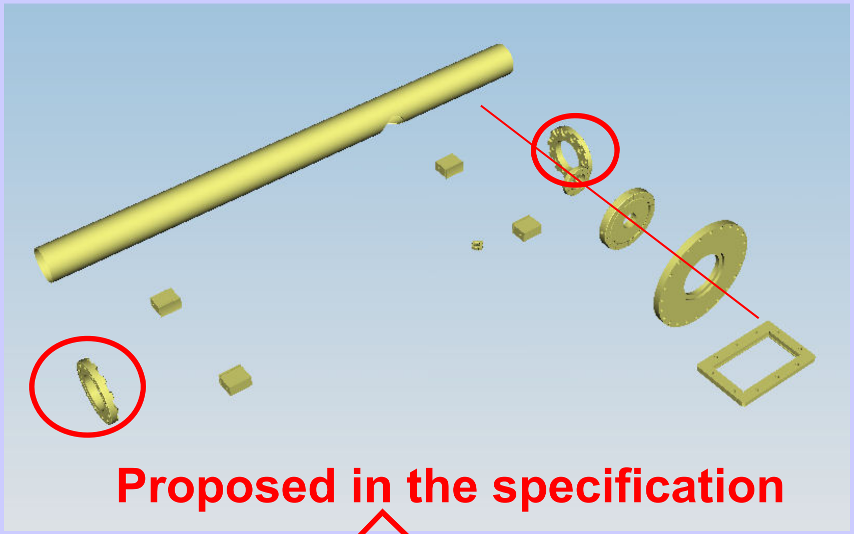
March, 2010

DESY, May, 2010

June, 2010 ~

Plug Compatibility Concept



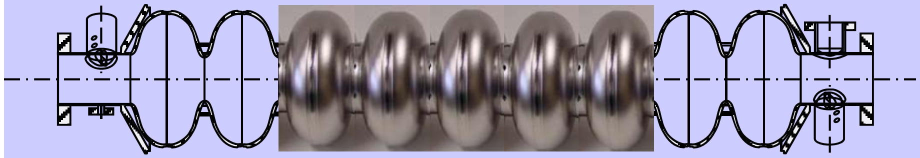


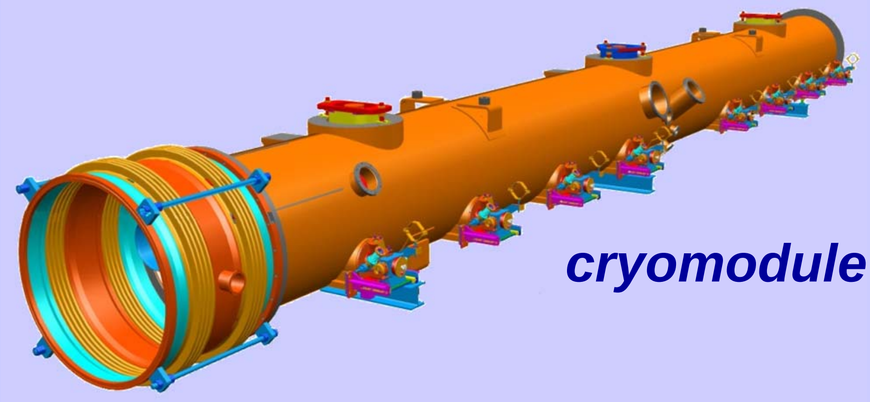
Proposed in the specification

Helium Vessel Body		KEK-STF-BL	KEK-STF-LL	FNAL-T4CM	DESY-XFEL
Helium Jacket	Material	Ti	SUS	Ti	Ti
	Slot length, mm	1337	1337	1326.7	(1382:Type3)
	Distance between beam pipe flanges, m	1258.6	1254.5	1247.4	1283.4
	Distance between bellows flanges, mm	78.4	85,2	80.49 (cold)	
	Outer diameter, mm	242	236	240	240
Beam Pipe Flange	Material	NbTi	Ti	NbTi	NbTi
	Outer diameter, mm	130	140	140	140
	Inner diameter, mm	84	80	82.8	82.8
	Thickness, mm	14	17.5	17.5	17.5
	PCD, bolts	ϕ115, 16-ϕ9	ϕ120, 16-ϕ9	12, M8 SS studs	12, M8 SS studs
	Sealing	Helicoflex	M-O seal	Al Hex Seals	Hexagonal Al ring
	Distances between the connection surface and input coupler axis	62, -1196.6	58.1, -1213.9	60.6, -1186.8	60.6, -1222.8

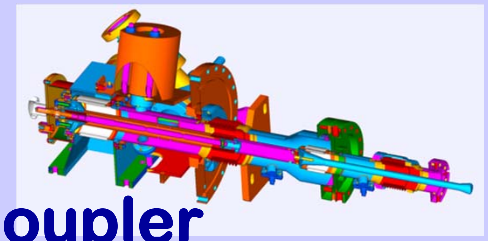
Superconducting RF Linac Technology

cavity



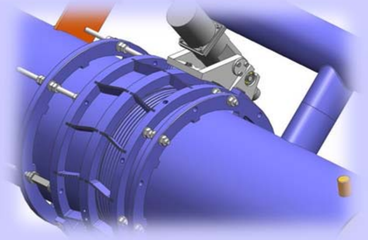


cryomodule



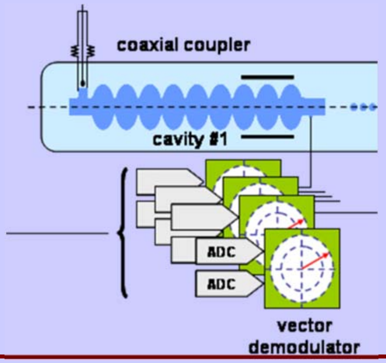
coupler

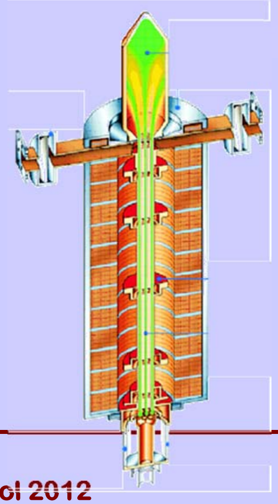
SCRF Linac Technology



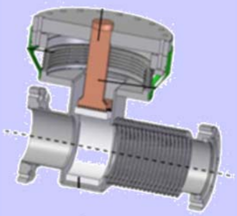
tuner

LLRF





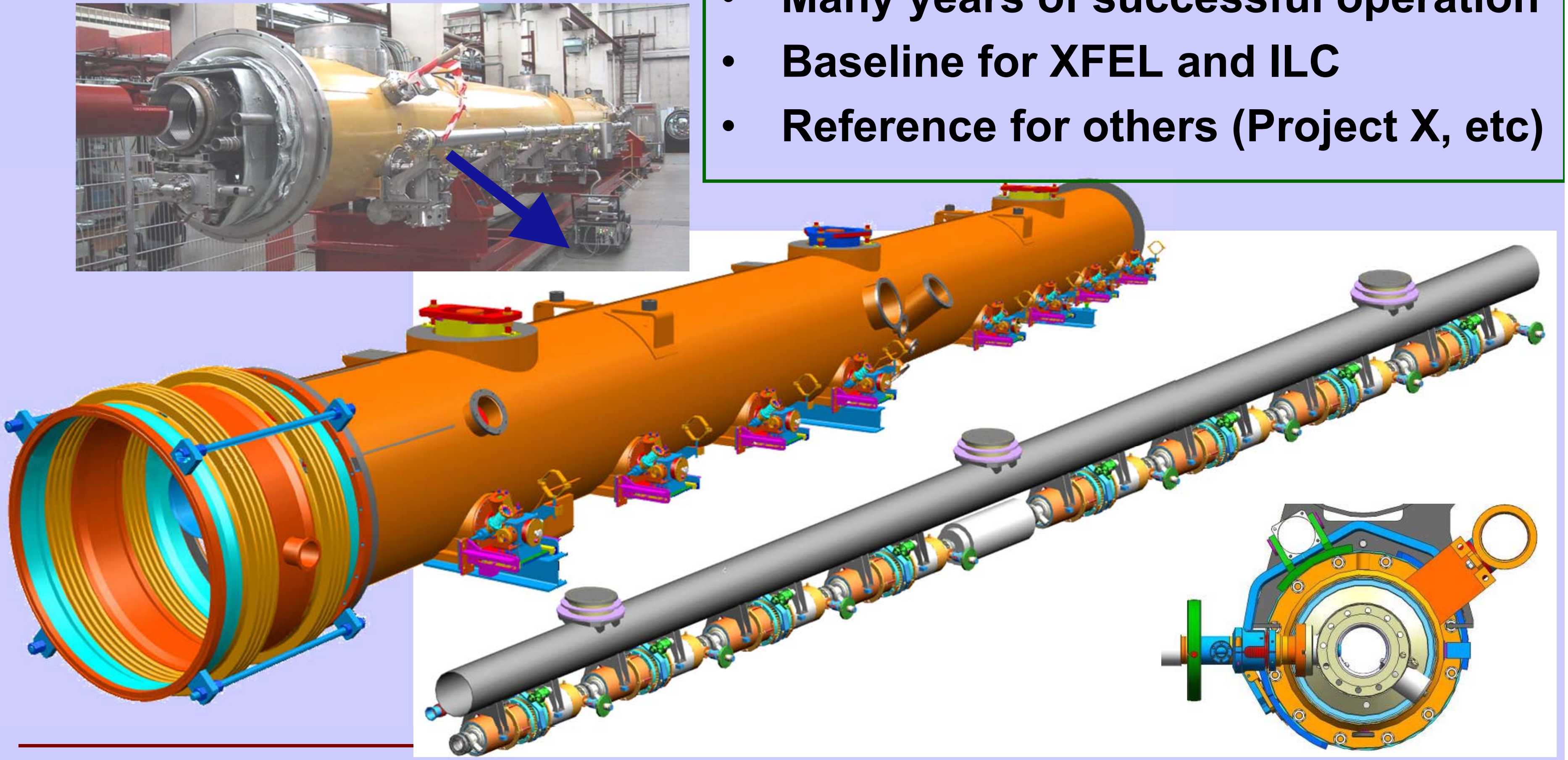
RF



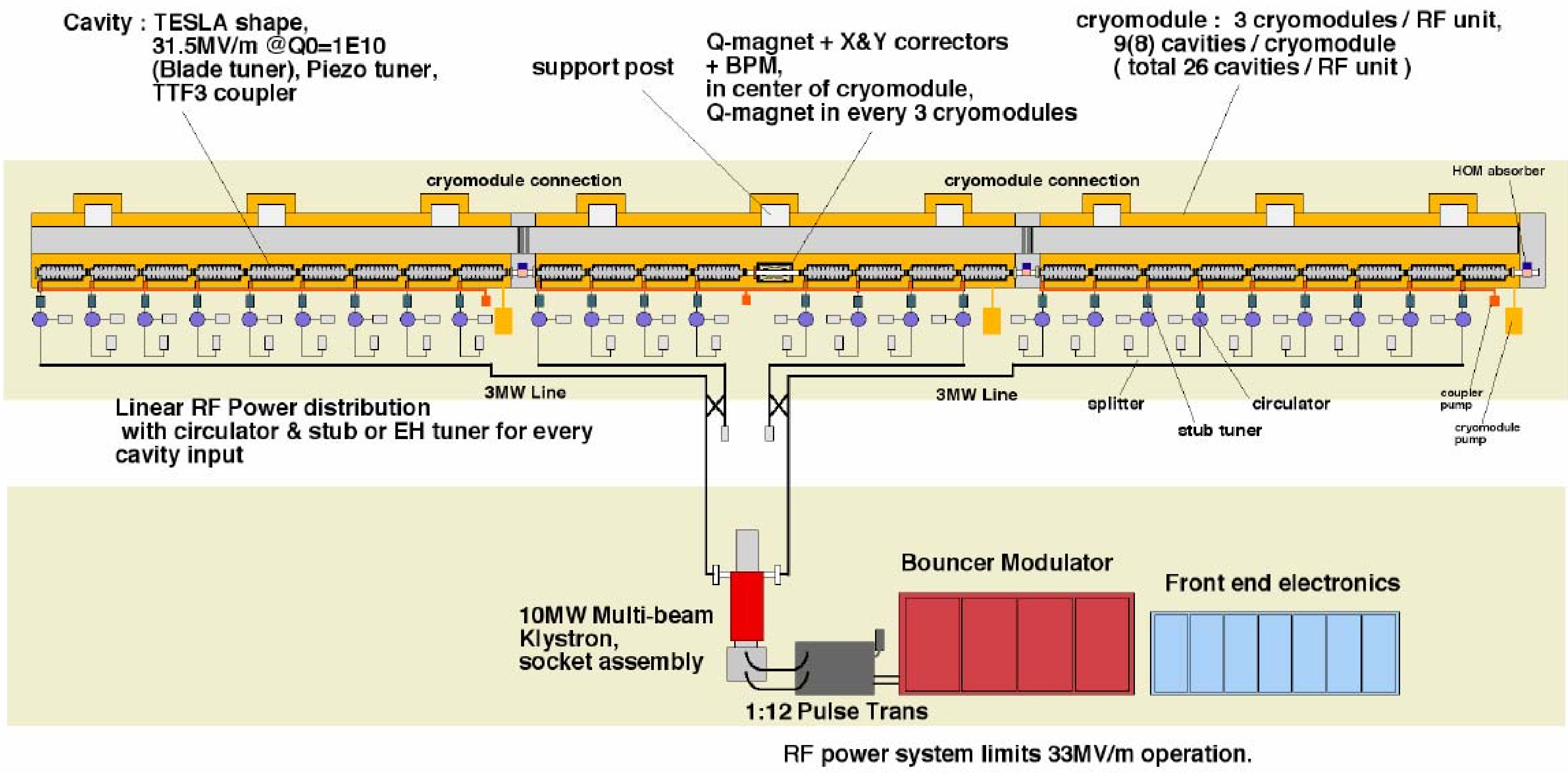
HOMs

ILC Reference Cryomodule

- Developed by INFN for TTF-TESLA
- **3rd generation of improvements**
- **Many years of successful operation**
- **Baseline for XFEL and ILC**
- **Reference for others (Project X, etc)**



One ILC Linac RF Unit



Cavity : TESLA shape,
31.5MV/m @Q0=1E10
(Blade tuner), Piezo tuner,
TTF3 coupler

support post

Q-magnet + X&Y correctors
+ BPM,
in center of cryomodule,
Q-magnet in every 3 cryomodules

cryomodule : 3 cryomodules / RF unit,
9(8) cavities / cryomodule
(total 26 cavities / RF unit)

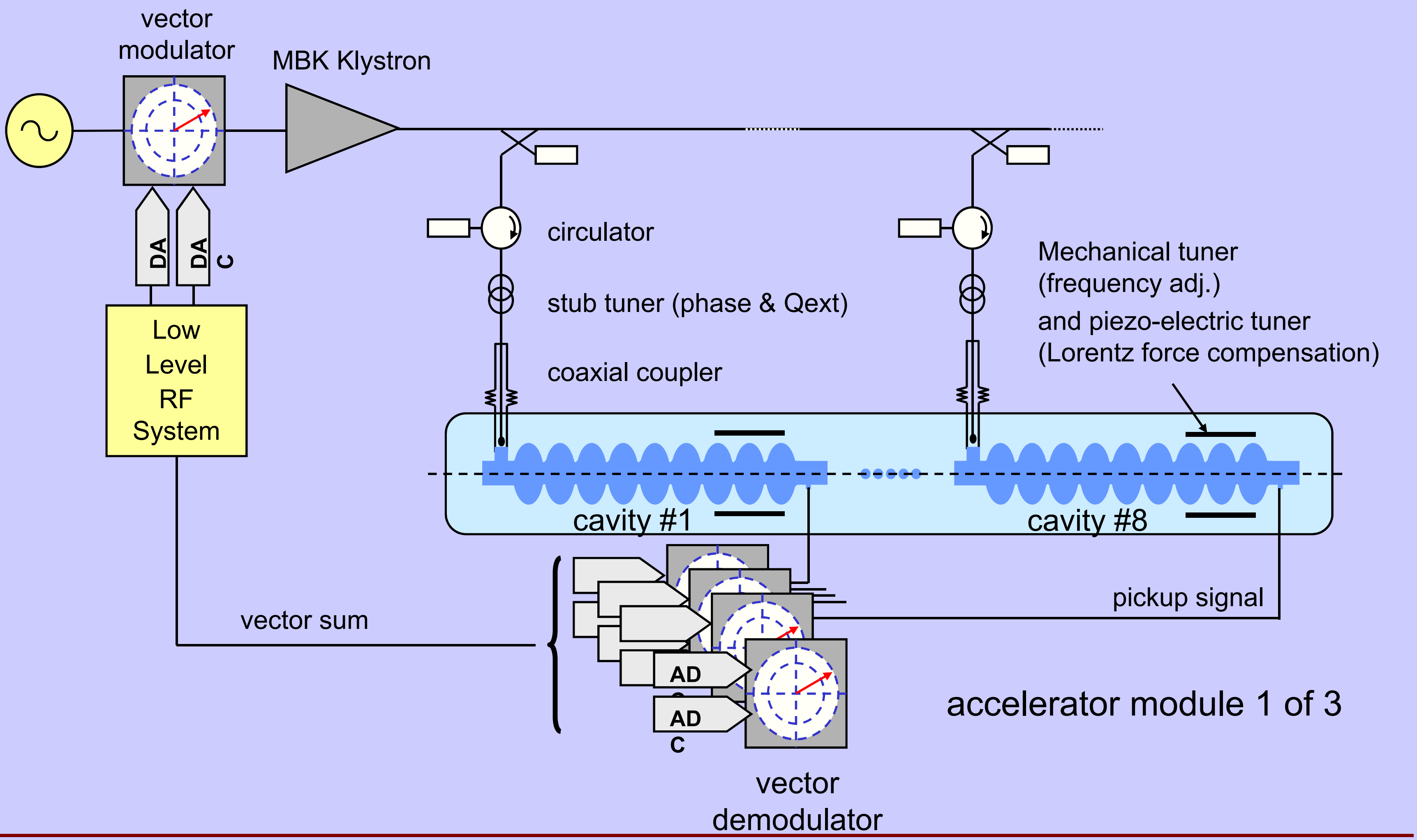
Linear RF Power distribution
with circulator & stub or EH tuner for every
cavity input

RF power system limits 33MV/m operation.

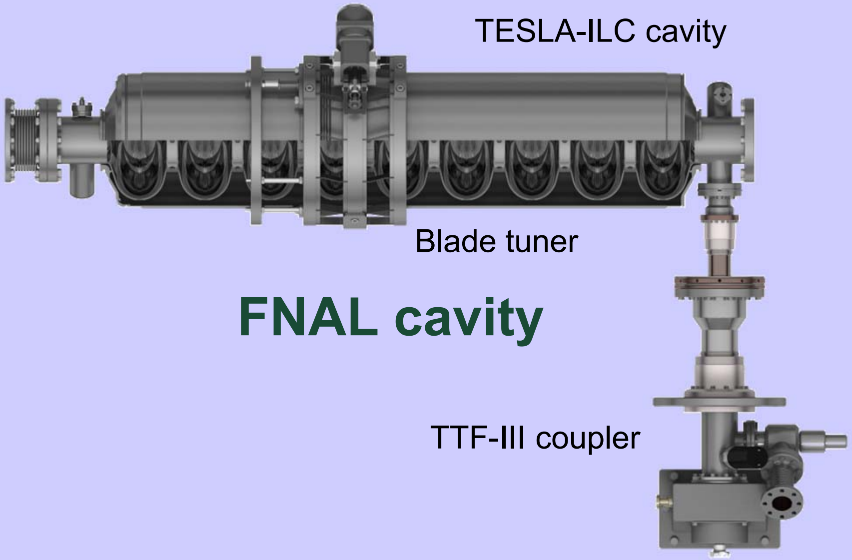
RDR configuration

Standard ILC RF Unit

1 klystron for 3 accelerating modules, 9-8-9 nine-cell cavities each

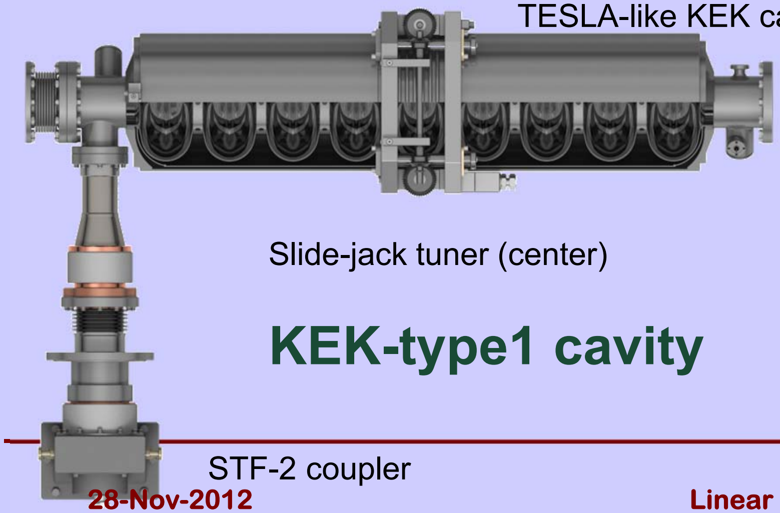


S1-Global Cavity Packages



FNAL cavity

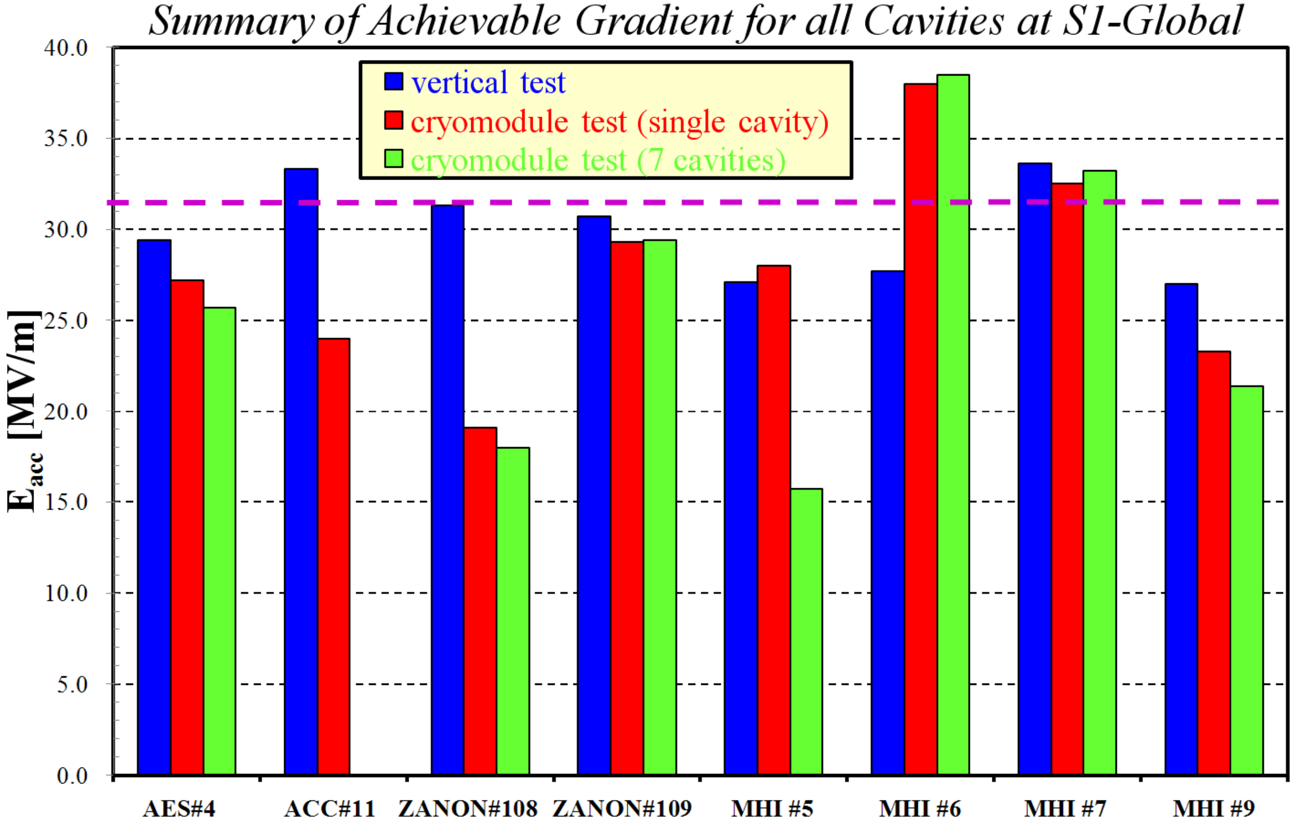
DESY cavity



KEK-type1 cavity

KEK-type2 cavity

Cavities Performance:



Gradient

31.5 MV/m

C1 C2 C3 C4 A1 A2 A3 A4

🟦 Before cryomodule installation Average 30.0MV/m

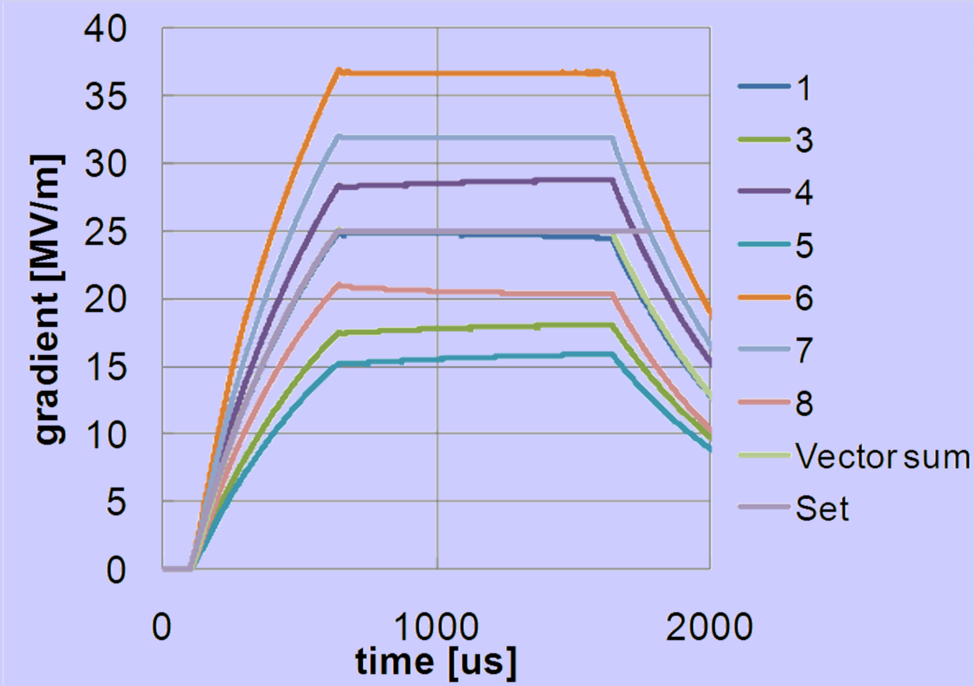
🟥 after cryomodule installation Average 27.7MV/m

🟩 7 cavities combined operation Average 26.0MV/m

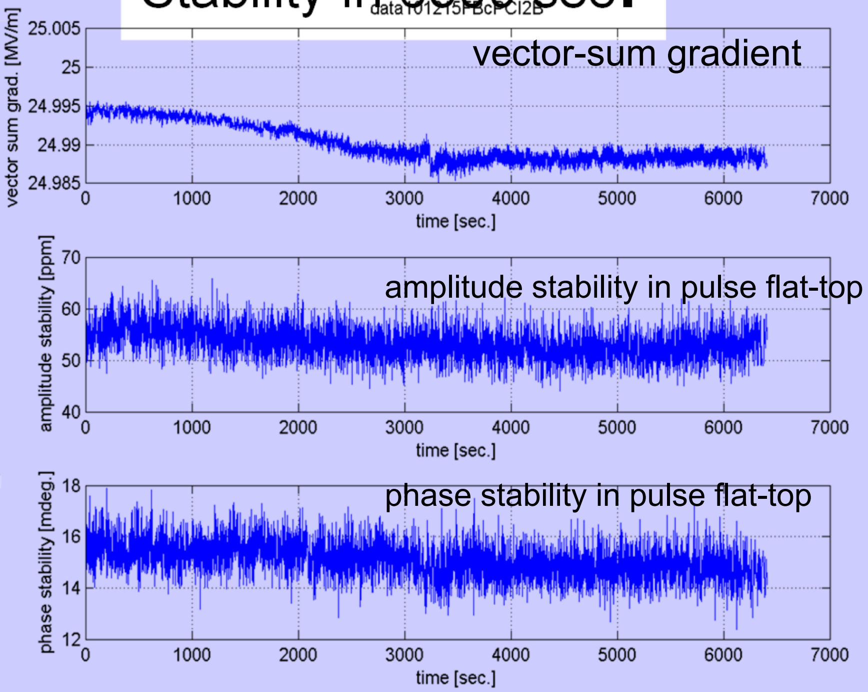
Seven-cavity operation by digital LLRF

LLRF stability study with 7 cavities operation at 25MV/m

Field Waveform of each cavity



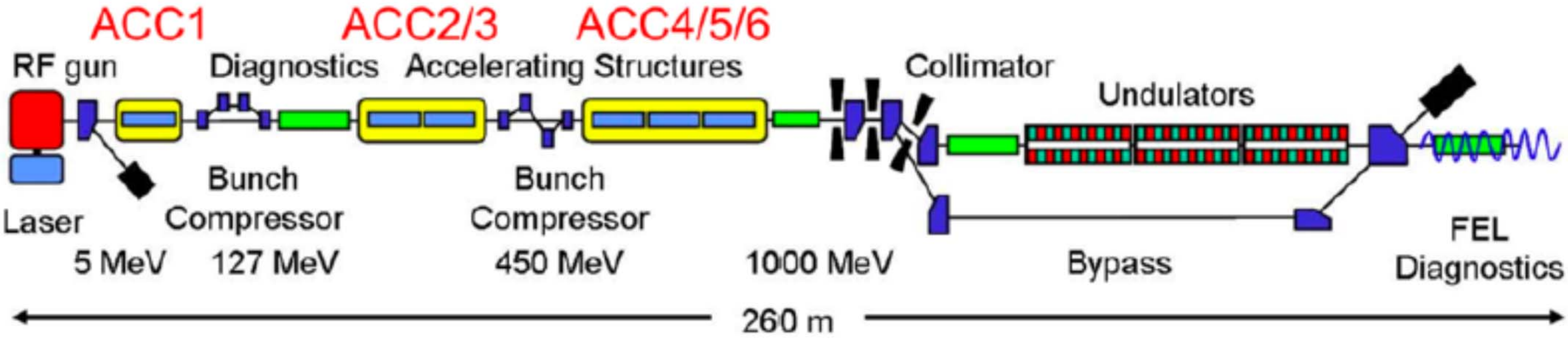
Stability in 6300 sec.



- Vector-sum stability: 24.995MV/m ~ 24.988MV/m (~0.03%)
- Amplitude stability in pulse flat-top: < 60ppm=0.006%rms
- Phase stability in pulse flat-top: < 0.0017 degree.rms

TTF/FLASH 9mA Experiment

Full beam-loading long pulse operation → "S2"

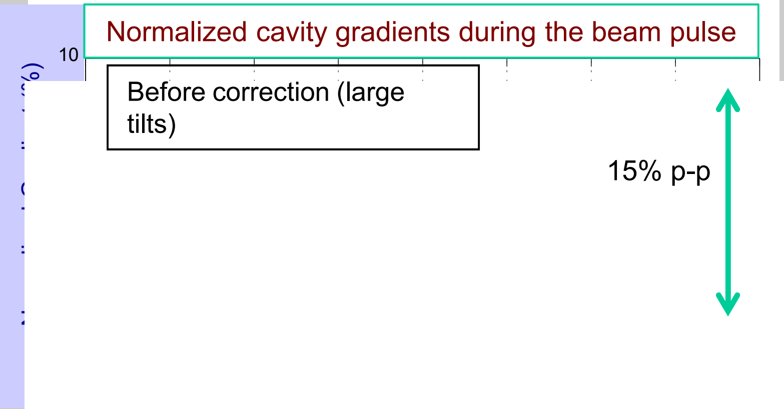


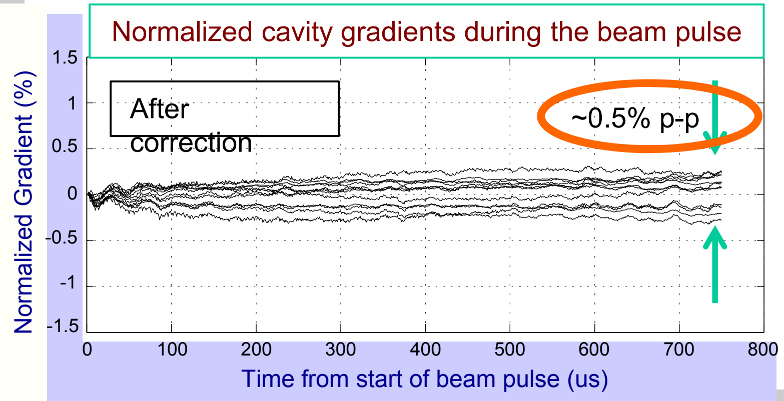
		XFEL	ILC	FLASH design	9mA studies
Bunch charge	nC	1	3.2	1	3
# bunches		3250	2625	7200'	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9

- Stable 800 bunches, 3 nC at 1MHz (800 µs pulse) for over 15 hours (uninterrupted)
- Several hours ~1600 bunches, ~2.5 nC at 3MHz (530 µs pulse)
- >2200 bunches @ 3nC (3MHz) for short periods

FLASH 9mA Studies: Beam operation close to cavity gradient limits (4.5mA/800us bunch trains)

Tailored cavity Loaded-Qs to cancel beam-loading induced gradient tilts


Normalized cavity gradients during the beam pulse


Normalized cavity gradients during the beam pulse

Operation at 380MeV on ACC67

(13 cavities)

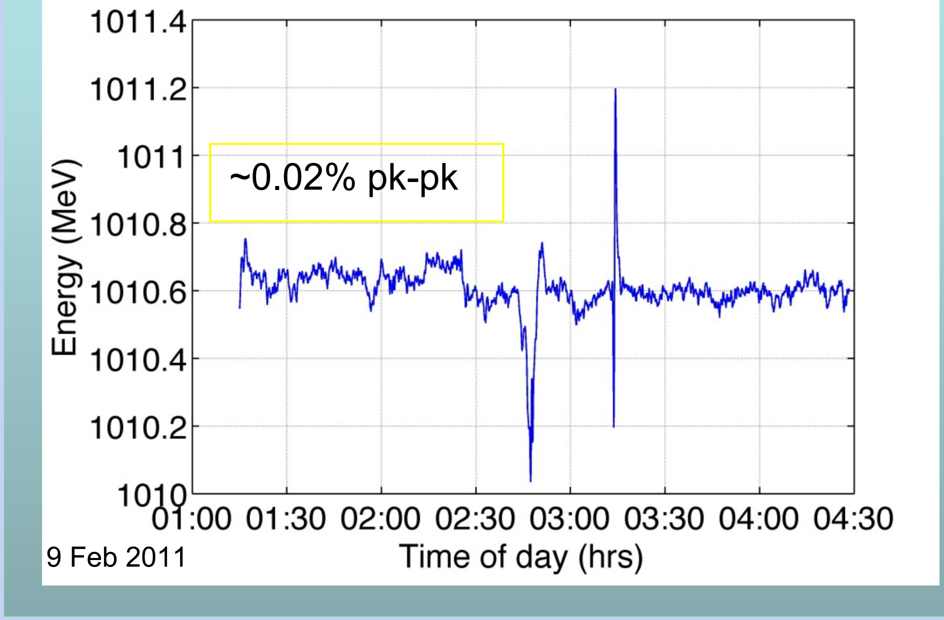
The limiting cavity is within 5% of quench

- Flattened individual gradients to **<<1% p-p,**
- Several cavities within 10% of quench ,

- ‘Cavity gradient limiter’ to dynamically prevent quenching without turning off the RF.

FLASH: Stability

Energy stability over 3hrs with 4.5mA



- **15 consecutive studies shifts (120hrs), and with no downtime**
- **Time to restore 400us bunch-trains after beam-off studies: ~10mins**
- **Energy stability with beam loading over periods of hours: ~0.02%**
- **Individual cavity "tilts" equally stable**

FLASH 9mA Expt achievements: 2009-mid 2012

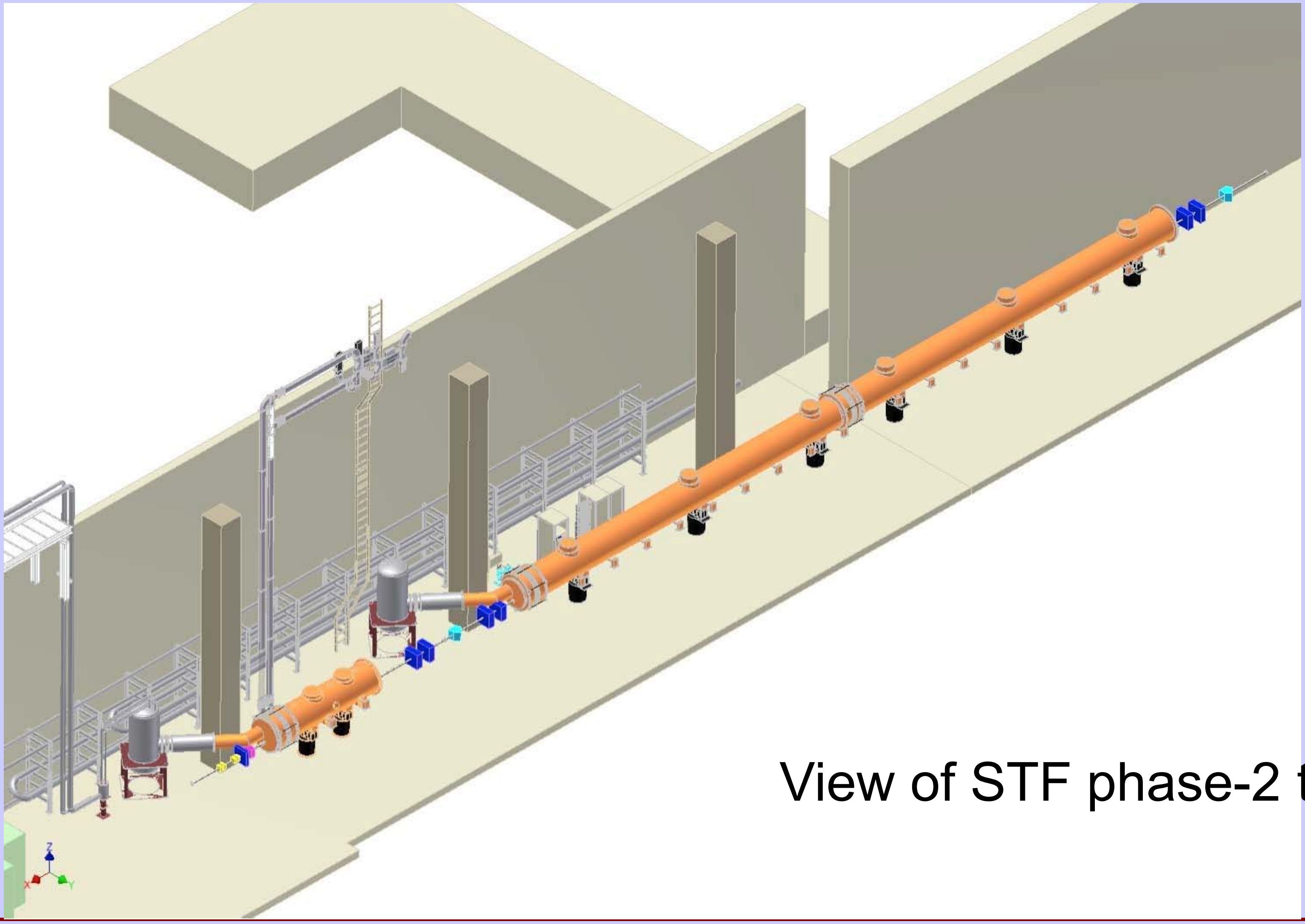
High beam power and long bunch-trains *(Sept 2009)*

Metric	ILC Goal	Achieved
Macro-pulse current	9mA	9mA
Bunches per pulse	2400 x 3nC (3MHz)	1800 x 3nC 2400 x 2nC
Cavities operating at high gradients, close to quench	31.5MV/m +/-20%	4 cavities > 30MV/m

Gradient operating margins *(Feb 2012)*

Metric	ILC Goal	Achieved
Cavity gradient flatness (all cavities in vector sum)	2% ΔV/V (800μs, 5.8mA) (800μs, 9mA)	<0.3% ΔV/V (800μs, 4.5mA) *First tests of automation for Pk/Ql control*
Gradient operating margin	All cavities operating within 3% of quench limits	Some cavities within ~5% of quench (800us, 4.5mA) *First tests of operations strategies for gradients close to quench*
Energy Stability	0.1% rms at 250GeV	<0.15% p-p (0.4ms) <0.02% rms (5Hz)

STF Systems Tests at KEK



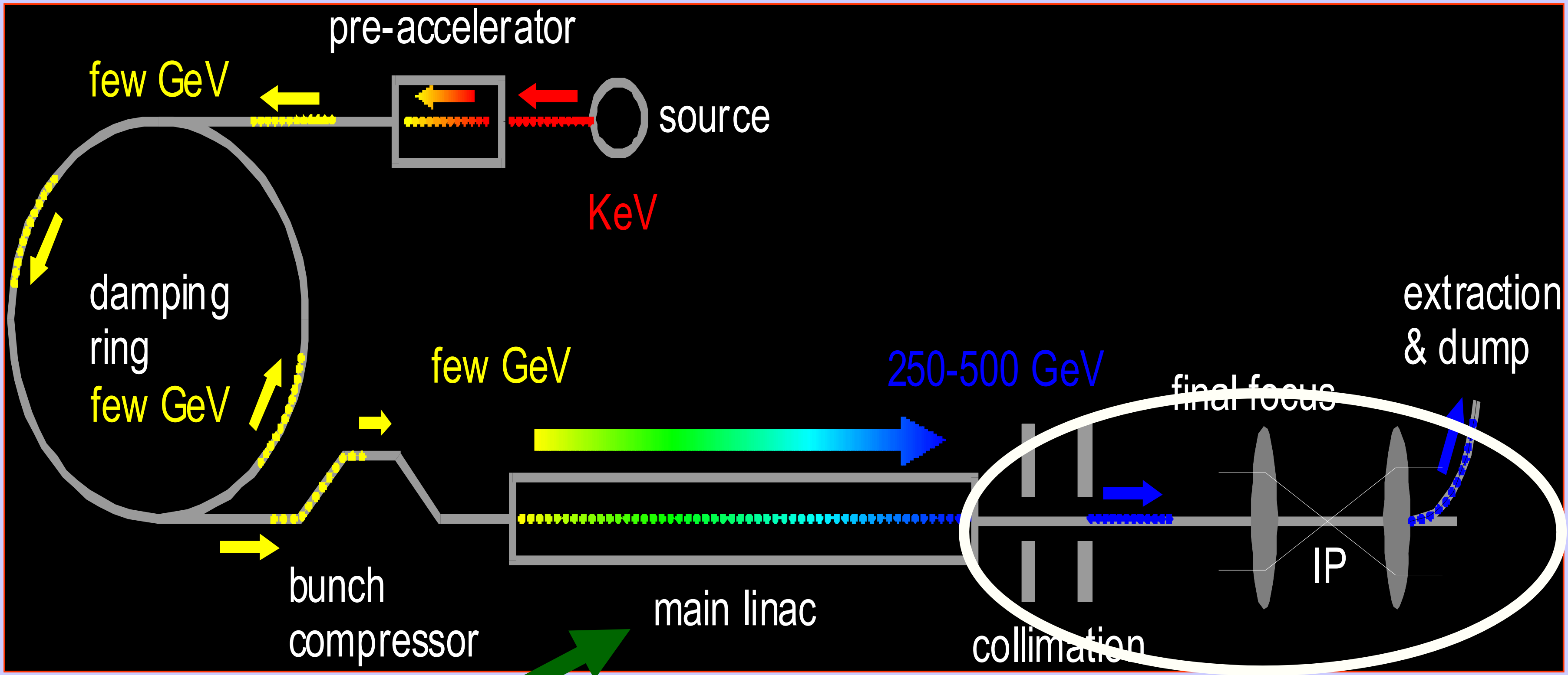
View of STF phase-2 tunnel

Fermilab – NML SRF

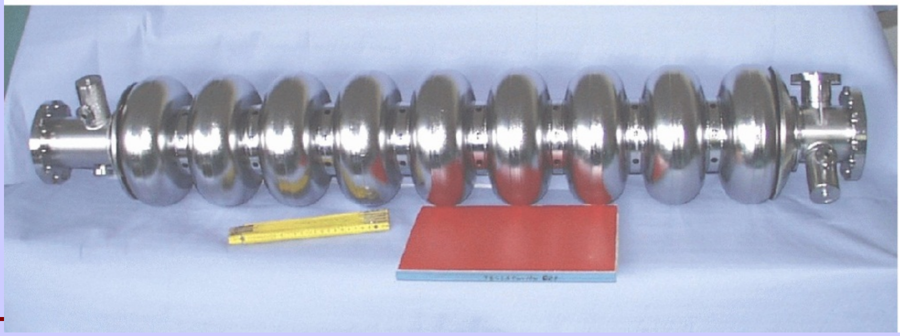
Systems Tests

Fermilab NML: RF Unit Test Facility

Designing a Linear Collider



Superconducting RF Main Linac



Luminosity & Beam Size

$$L = \frac{n_b N^2 f_{rep}}{2\pi\sigma_x\sigma_y} H_D$$

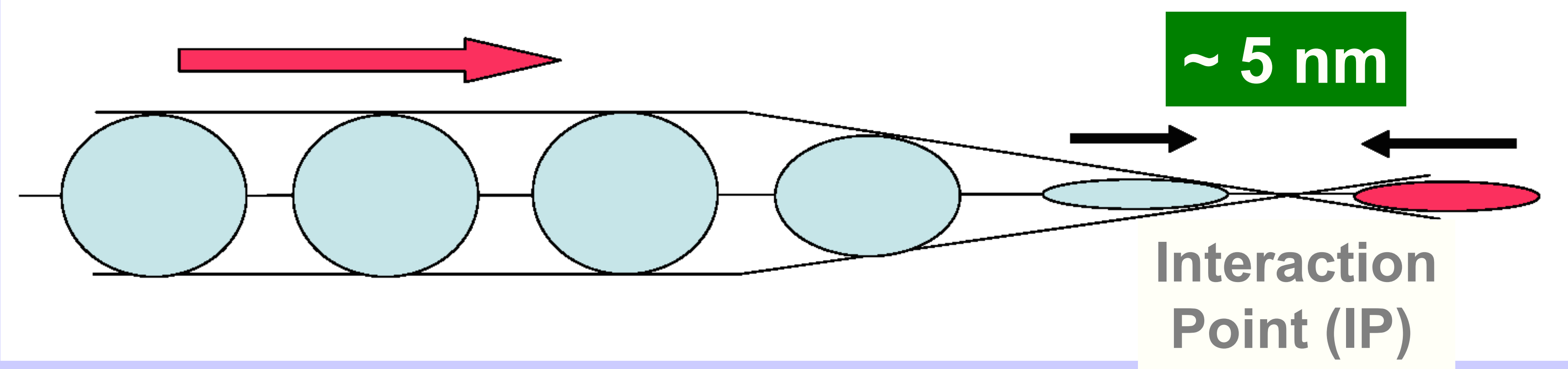
- f_{rep} * n_b tends to be low in a linear collider

	L	f_{rep} [Hz]	n_b	N [10^{10}]	σ_x [μm]	σy [μm]
ILC	$2\text{x}10^{34}$	5	3000	2	0.5	0.005
SLC	$2\text{x}10^{30}$	120	1	4	1.5	0.5
LEP2	$5\text{x}10^{31}$	10,000	8	30	240	4
PEP-II	$1\text{x}10^{34}$	140,000	1700	6	155	4

- Achieve luminosity with spot size and bunch charge

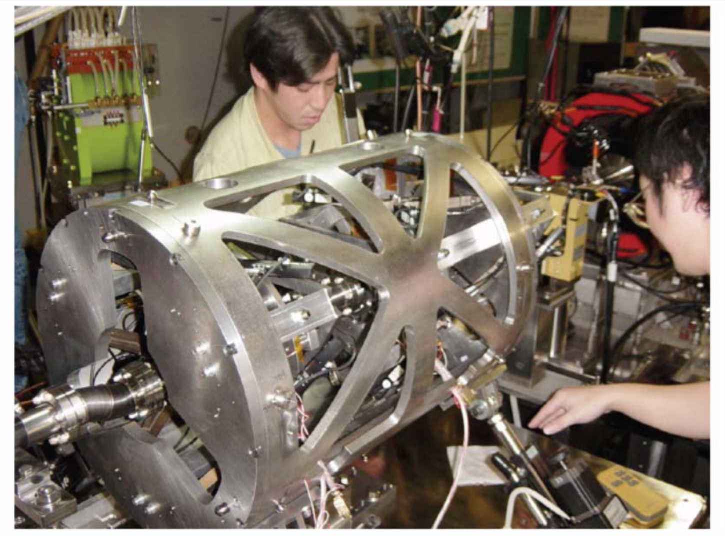
Achieving High Luminosity

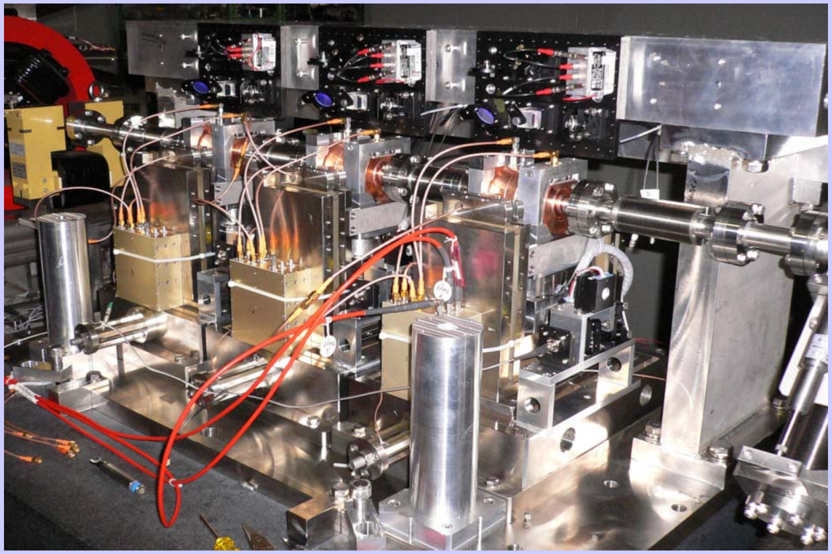
- Low emittance machine optics
- Contain emittance growth
- Squeeze the beam as small as possible

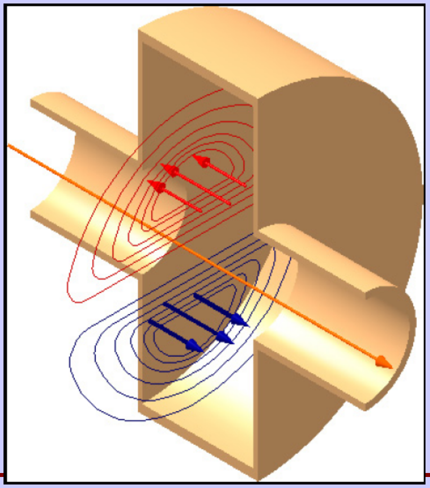


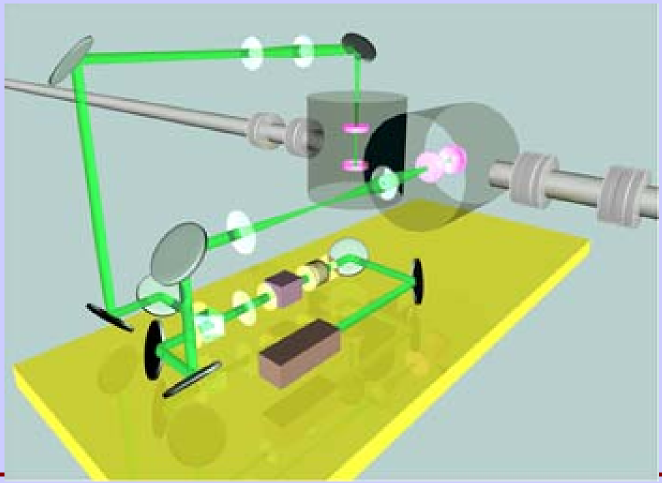
Making Very Small Emittance

(Beam Sizes at Collision)

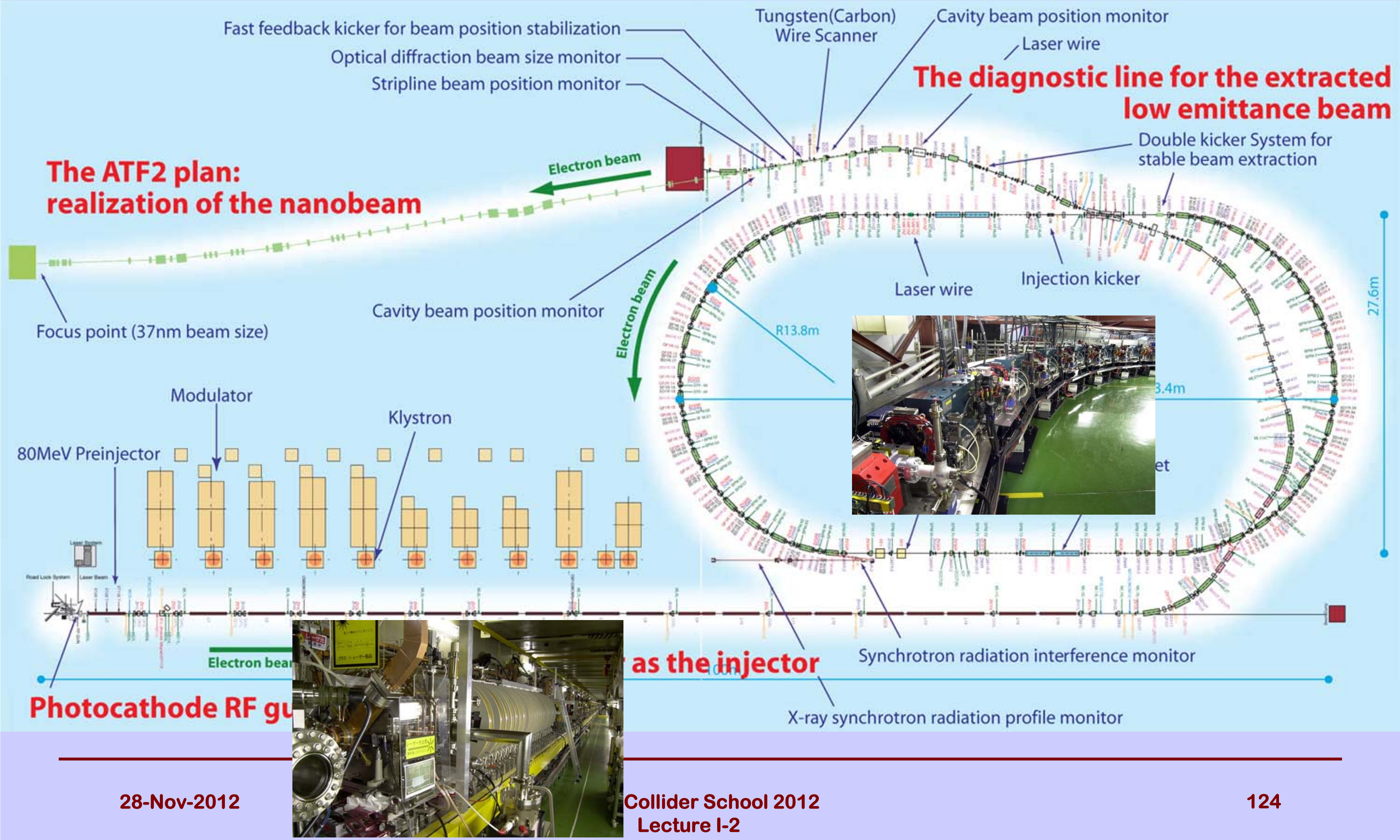




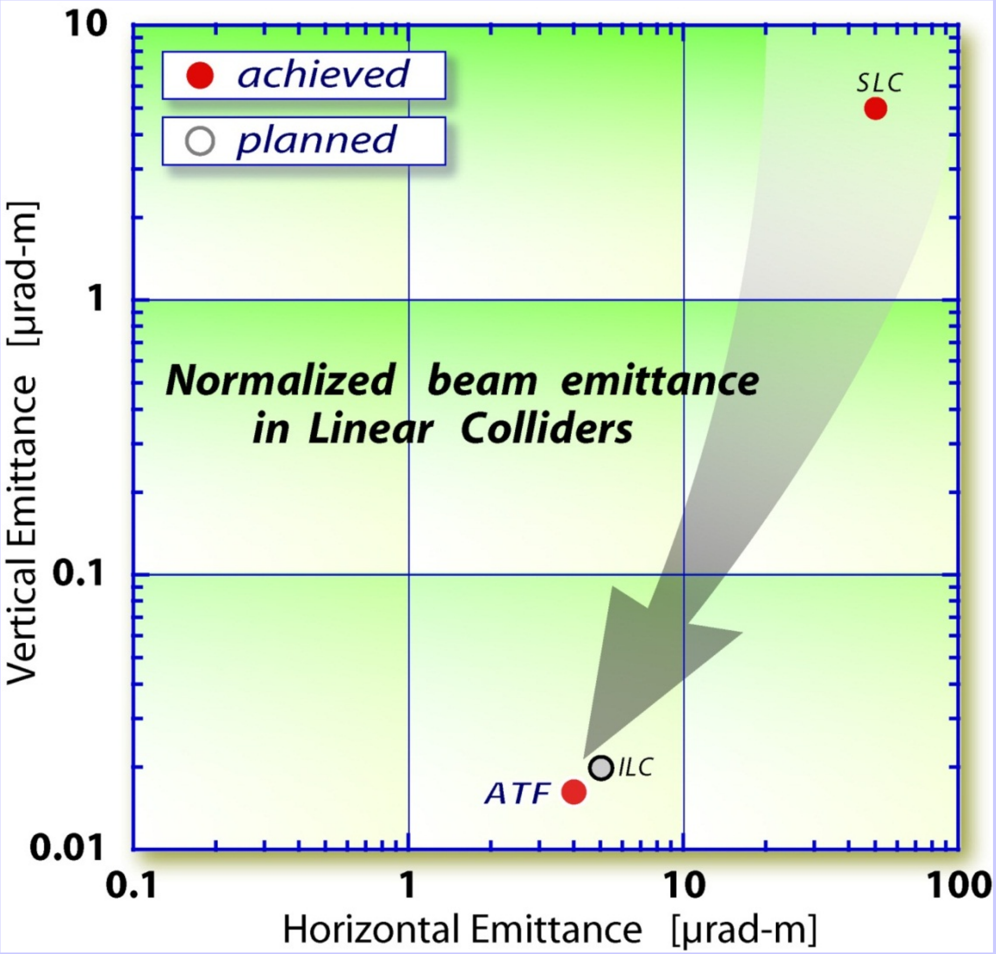




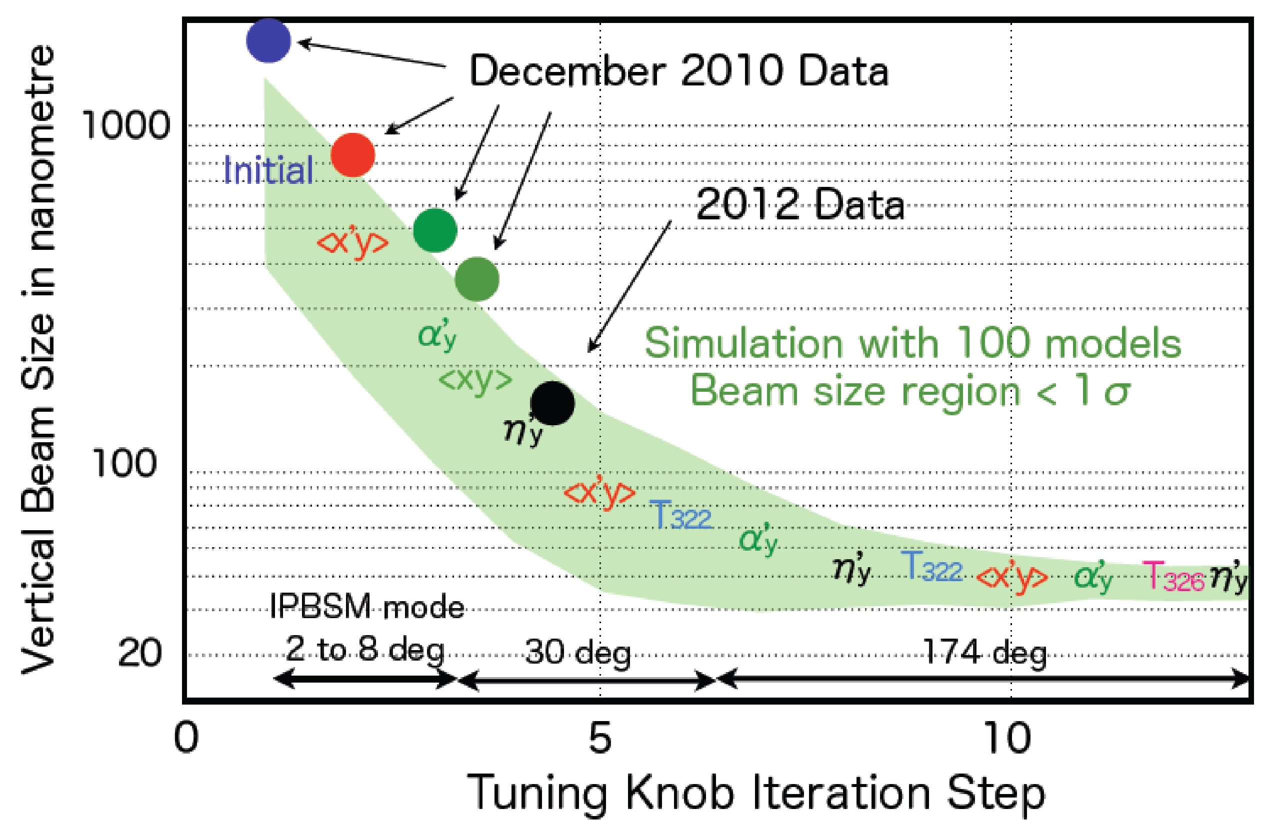
Accelerator Test Facility (ATF)



We believe we have technology in hand to squeeze beam down to the required size.

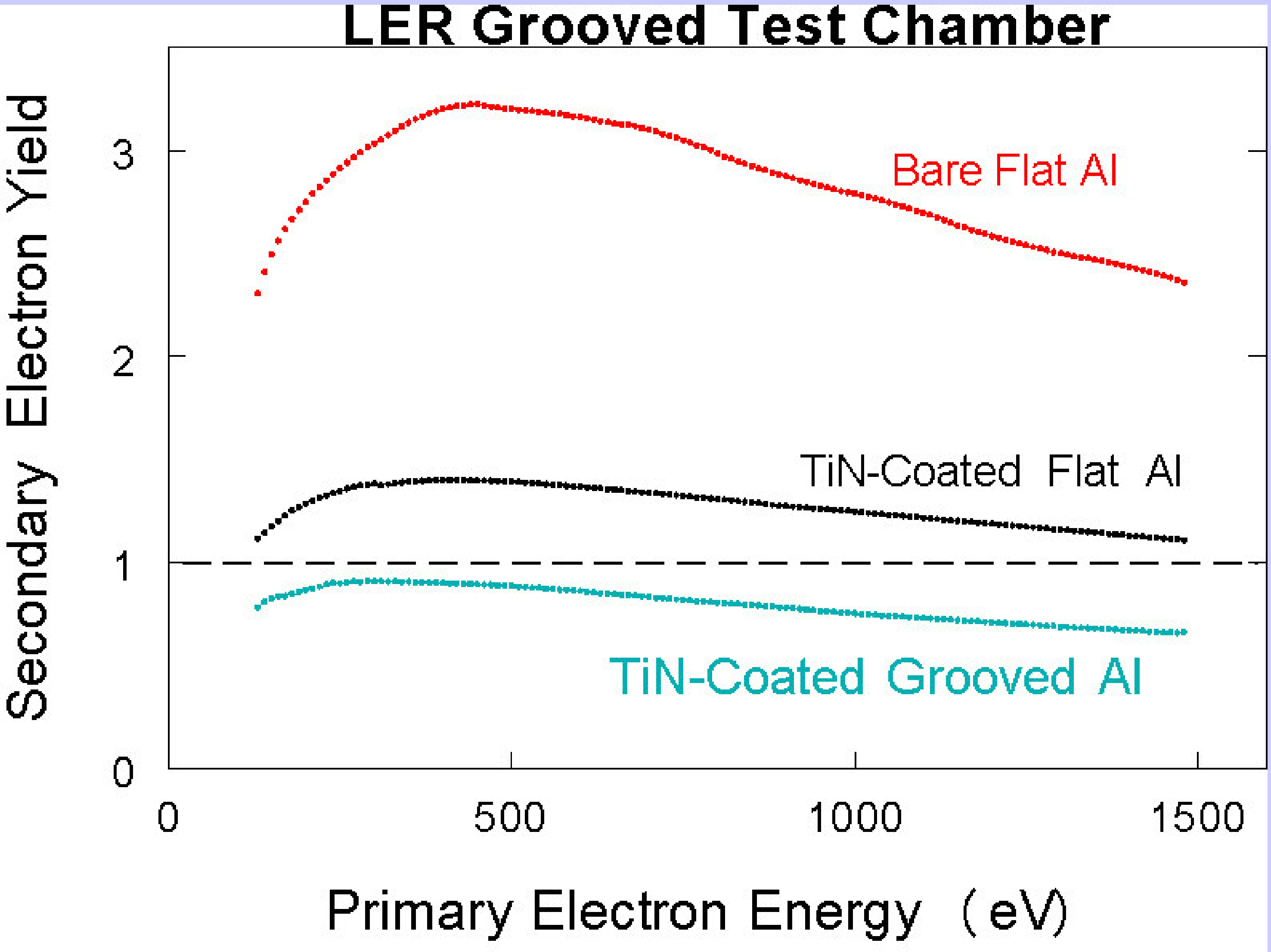


ATF-2 earthquake recovery

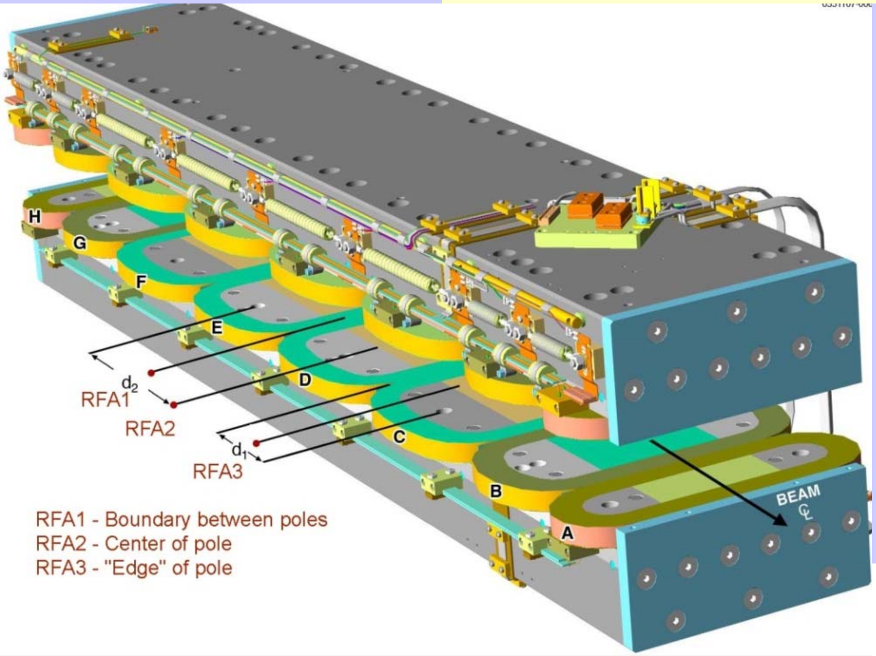


- Vertical beam size (2012) = 167.9 plus-minus nm
- 1 sigma Monte Carlo
- Post-TDR continue to ILC goal of 37 nm + fast kicker
- Stabilization studies

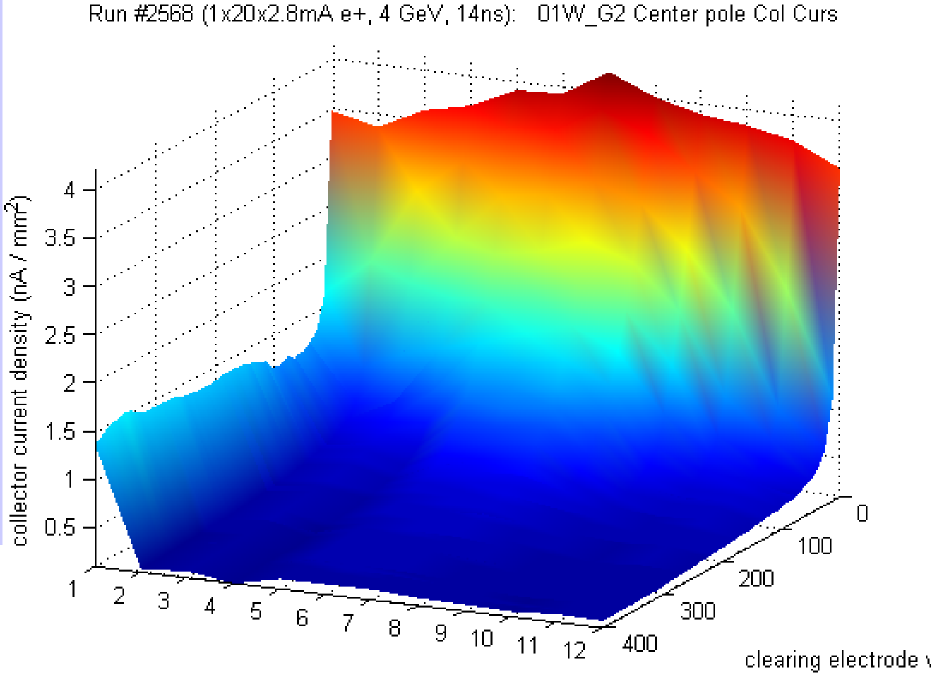
Mitigation - Simulation Studies

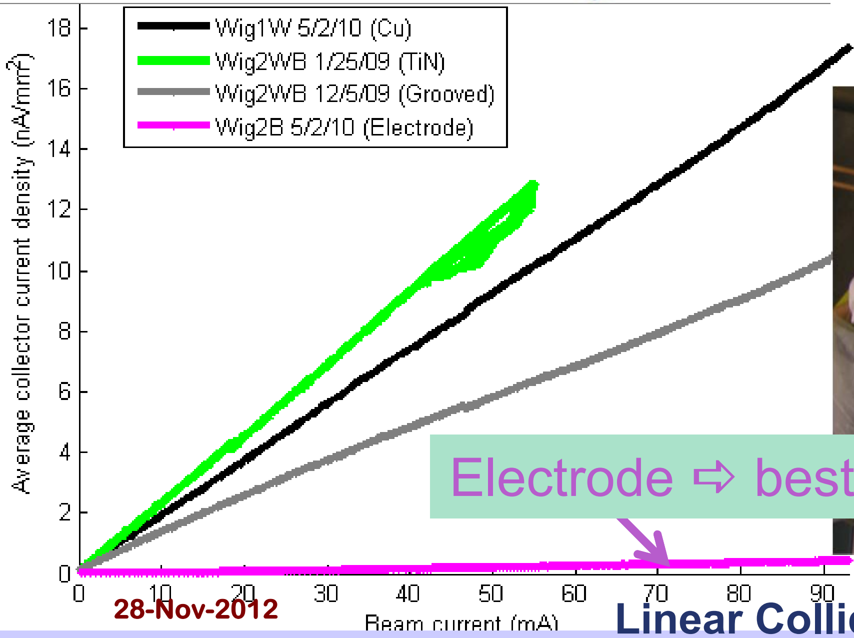


CesrTA - Wiggler Observations



RFA1 - Boundary between poles
RFA2 - Center of pole
RFA3 - "Edge" of pole





Electrode ⇨ best performance

Baseline Mitigation Plan

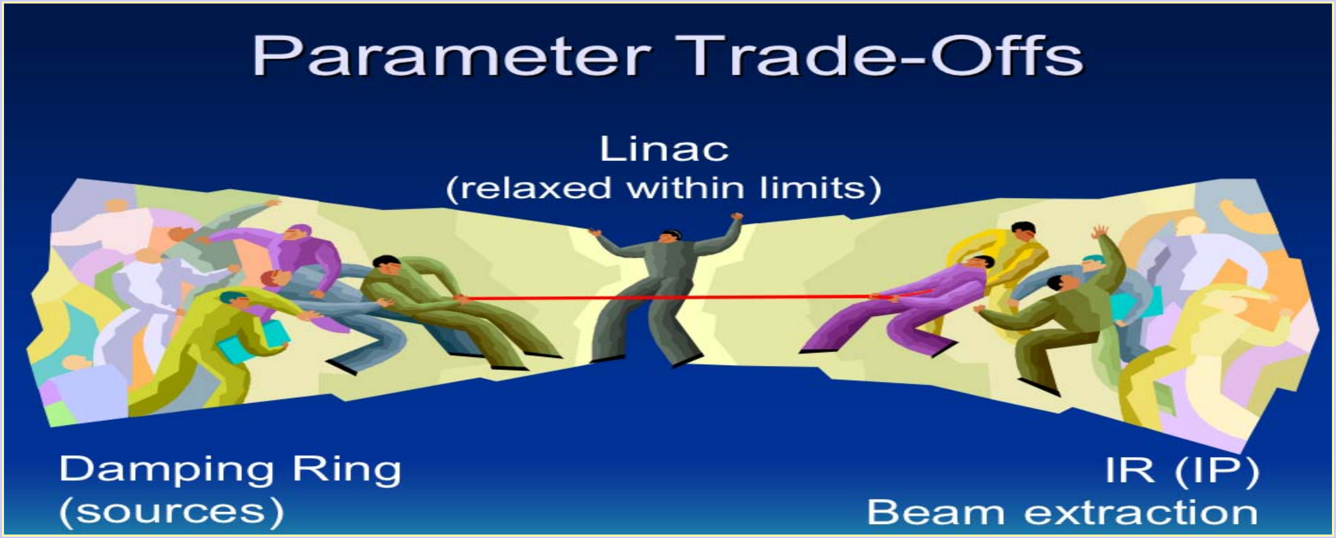
EC Working Group Baseline Mitigation Recommendation				
	Drift*	Dipole	Wiggler	Quadrupole*
Baseline Mitigation I	**TiN Coating**	**Grooves with TiN coating**	**Clearing Electrodes**	**TiN Coating**
Baseline Mitigation II	**Solenoid Windings**	**Antechamber**	**Antechamber**	
Alternate Mitigation	**NEG Coating**	**TiN Coating**	**Grooves with TiN Coating**	**Clearing Electrodes or Grooves**

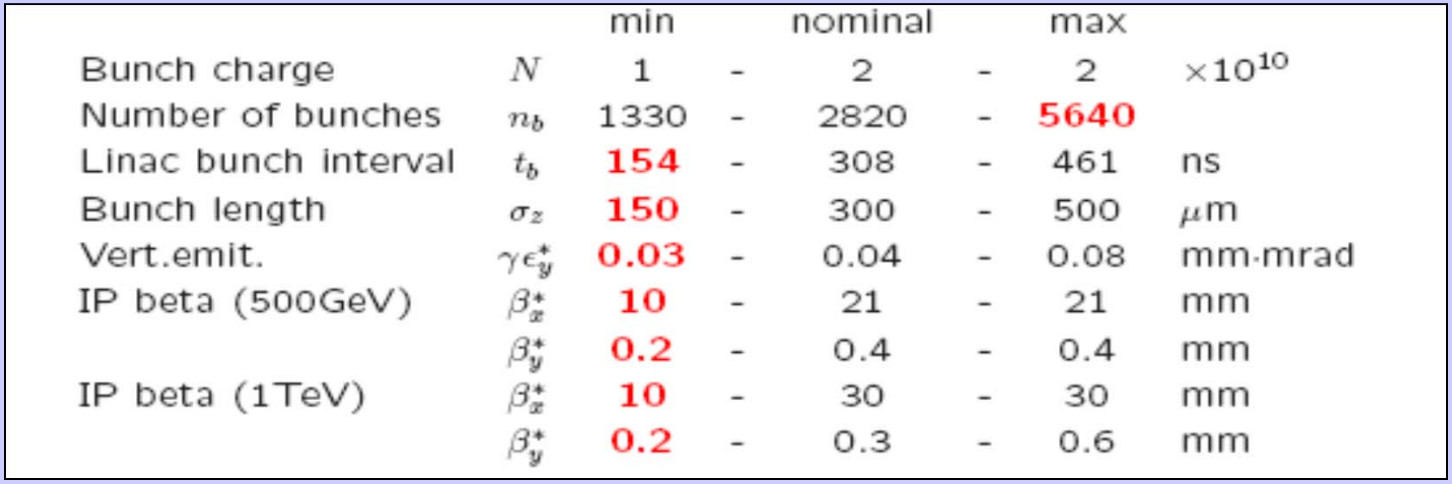
*Drift and Quadrupole chambers in arc and wiggler regions will incorporate antechambers

- Preliminary CESRTA results and simulations suggest the presence of *sub-threshold emittance growth*
  - Further investigation required
  - May require reduction in acceptable cloud density ⇨ reduction in safety margin
- An aggressive mitigation plan is required to obtain optimum performance from the 3.2km positron damping ring and to pursue the high current option

Parametric Approach

- **A working space - optimize machine for cost/performance**

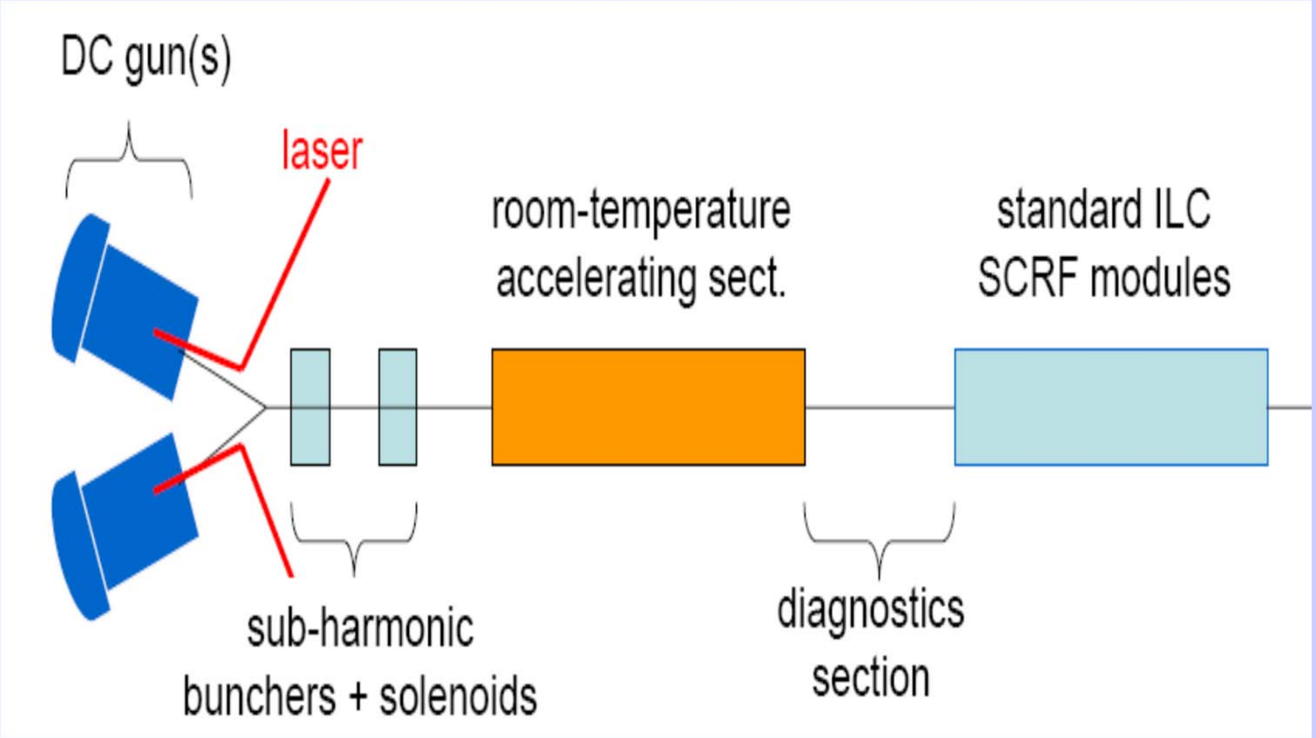




		min		nominal		max	
Bunch charge	N	1	-	2	-	2	$\times 10^{10}$
Number of bunches	n_b	1330	-	2820	-	**5640**	
Linac bunch interval	t_b	**154**	-	308	-	461	ns
Bunch length	σ_z	**150**	-	300	-	500	μm
Vert.emit.	$\gamma\epsilon_y^*$	**0.03**	-	0.04	-	0.08	mm·mrad
IP beta (500GeV)	β_x^*	**10**	-	21	-	21	mm
	β_y^*	**0.2**	-	0.4	-	0.4	mm
IP beta (1TeV)	β_x^*	**10**	-	30	-	30	mm
	β_y^*	**0.2**	-	0.3	-	0.6	mm

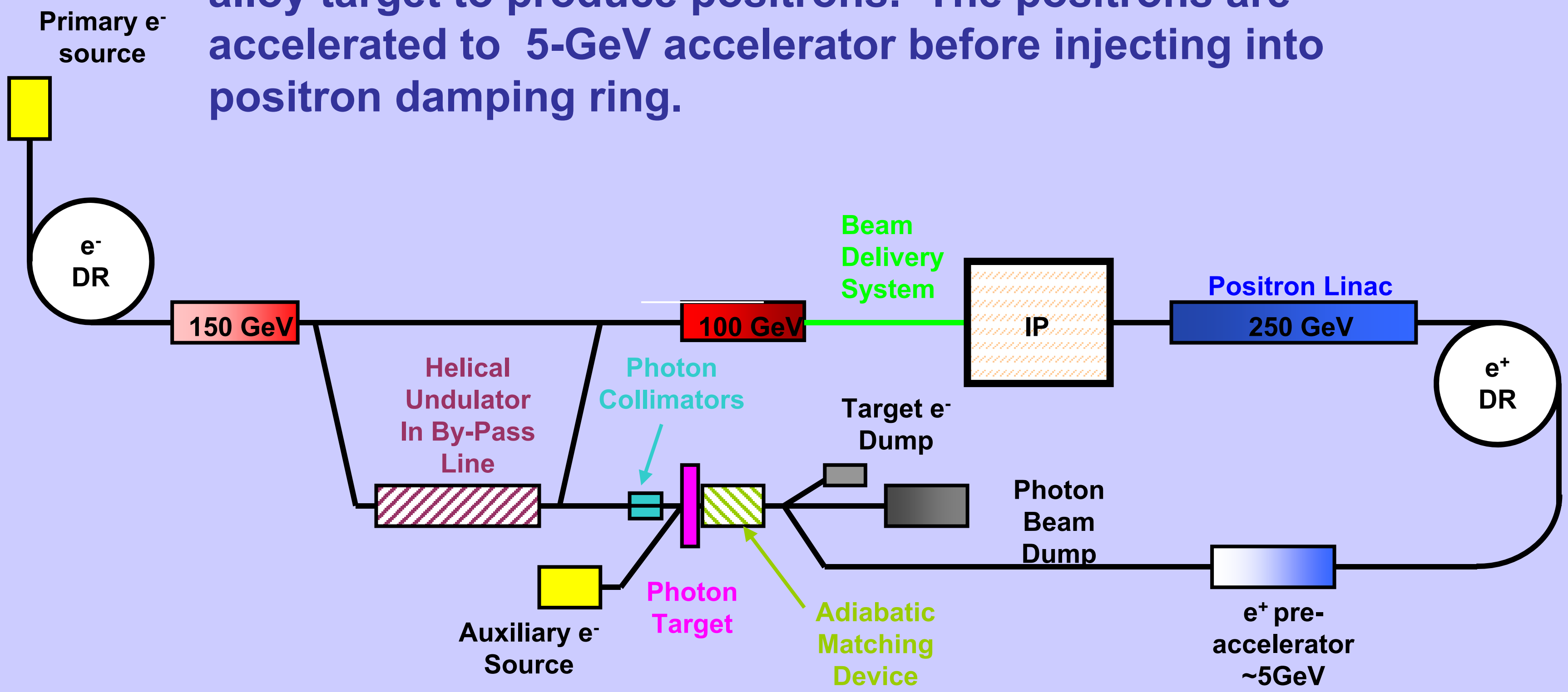
Baseline Features – Electron Source

- **Electron Source – Conventional Source using a DC** ----- **Titanium-sapphire laser emits 2-ns pulses that knock out electrons; electric field focuses each bunch into a 250-meter-long linear accelerator that accelerates up to 5 GeV**

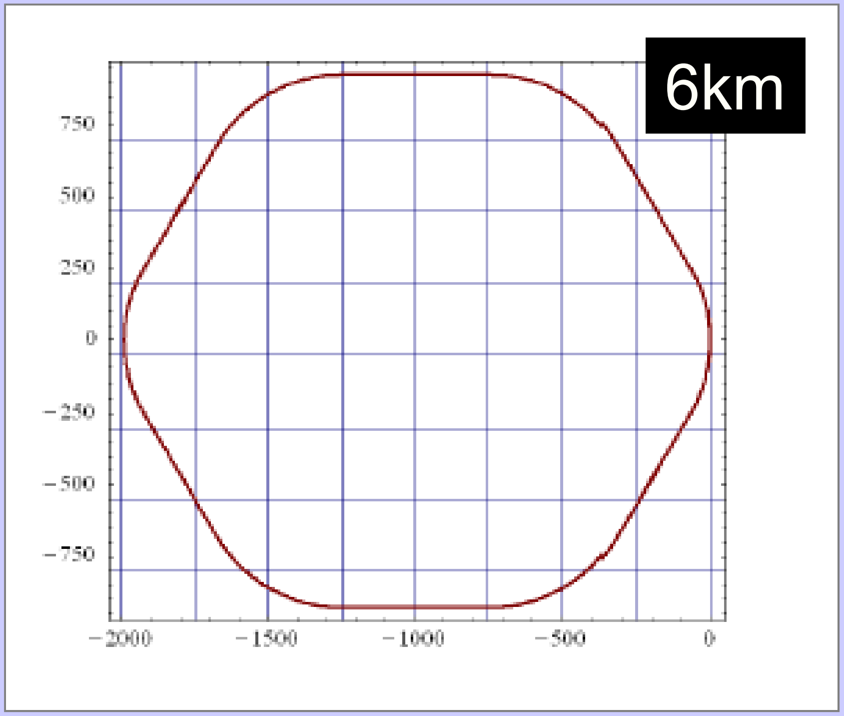


Baseline Features – Positron Source

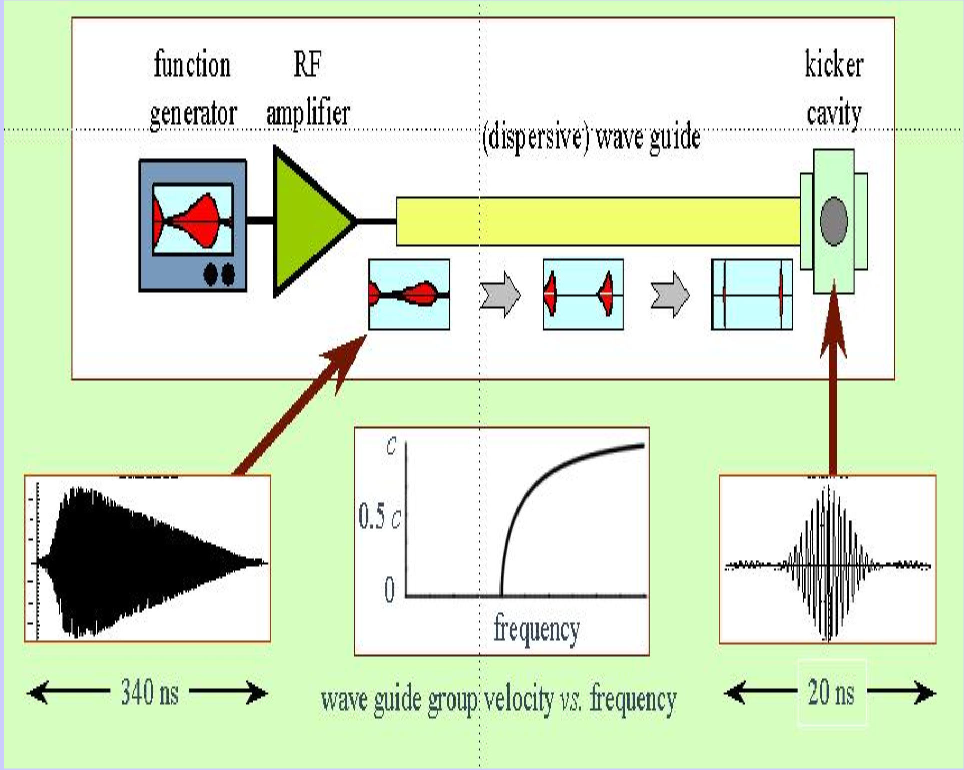
- **Positron Source – Helical Undulator with Polarized beams –** 150 Gev electron beam goes through a 200m undulator ing making photons that hit a 0.5 rl titanium alloy target to produce positrons. The positrons are accelerated to 5-GeV accelerator before injecting into positron damping ring.



6 Km Damping Ring

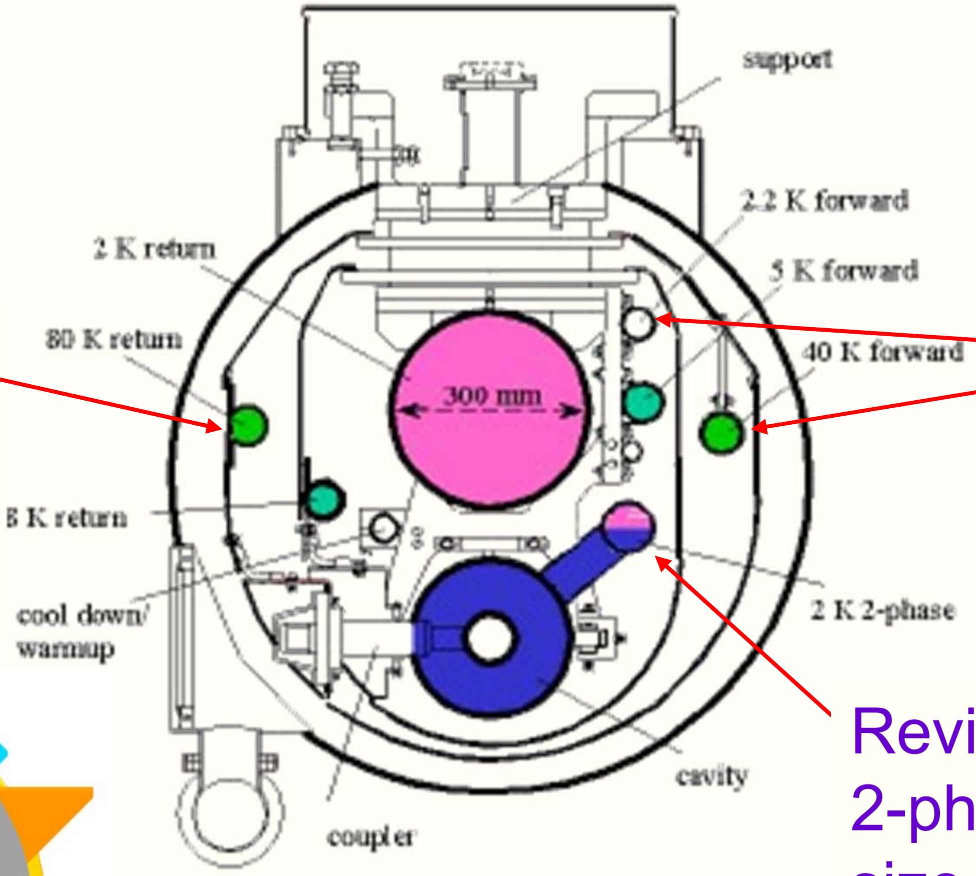


Requires Fast Kicker
5 nsec rise and 30 nsec fall time



The damping rings have more accelerator physics than the rest of the collider

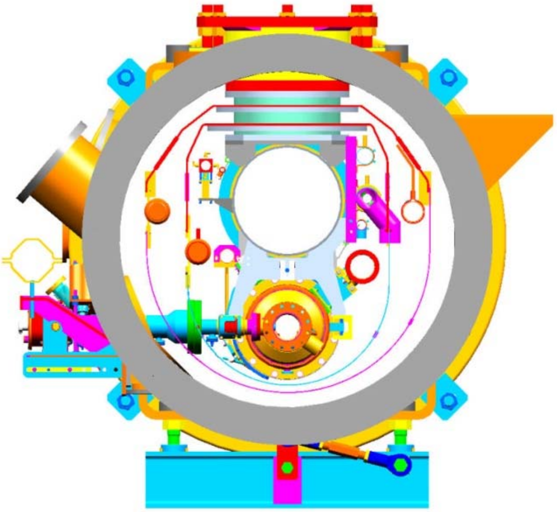
ILC Cryomodule



Increase
diameter
beyond
X-FEL

Increase
diameter
beyond
X-FEL

Review
2-phase pipe
size and
effect of slope

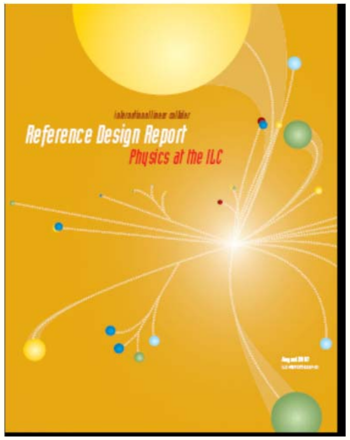


RDR Complete

- Reference Design Report (4 volumes)


Reference Design Report
Executive Summary

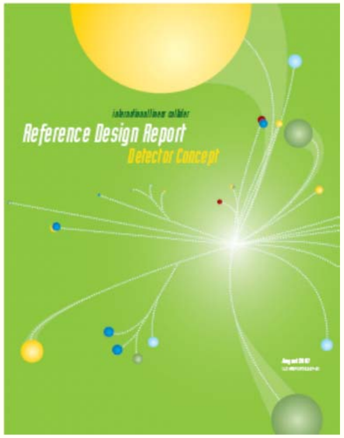
Executive
Summary


Reference Design Report
Physics at the ILC

Physics
at the
ILC


Reference Design Report
Accelerator

Accelerator


Reference Design Report
Detector Concept

Detectors

RDR vs ICFA Parameters

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

The RDR Design meets these "requirements," including the recent update and clarifications of the reconvened ILCSC Parameters group!

Why change from RDR design?

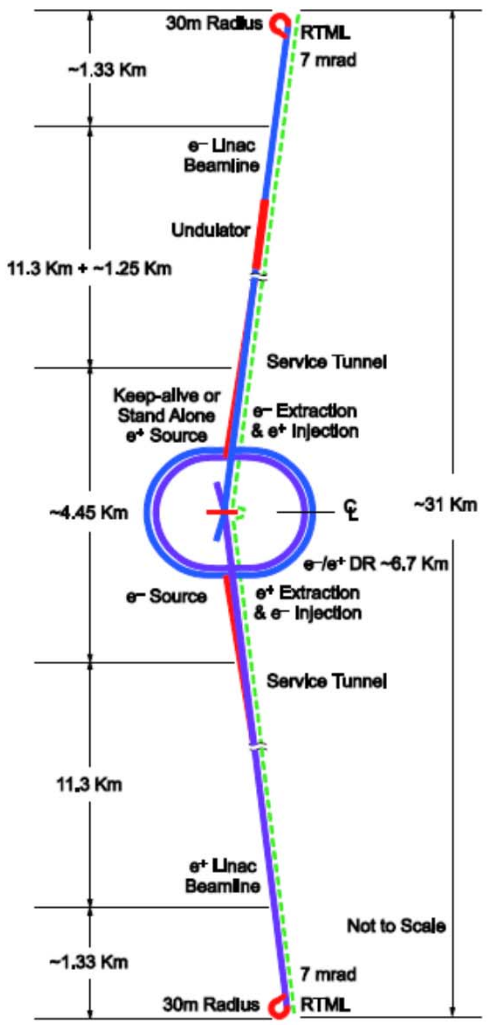
- Timescale of ILC demands we continually update the technologies and evolve the design to be prepared to build the most forward looking machine at the time of construction.

- Our next big milestone – the technical design (TDR) at end of 2012 should be as much as possible a “construction project ready” design with crucial R&D demonstrations complete and design optimised for performance to cost to risk.

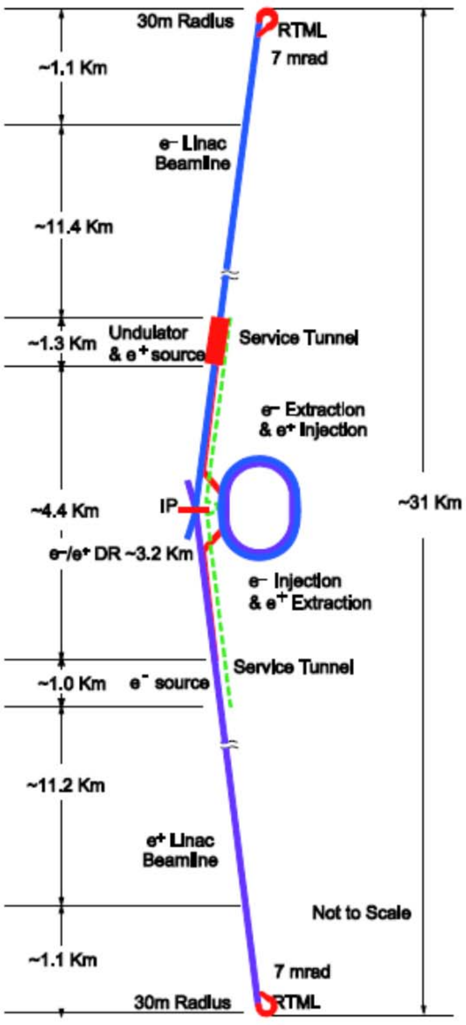
- Cost containment vs RDR costs is a crucial element. (Must identify costs savings that will compensate cost growth)

Proposed Design changes for TDR

RDR



SB2009

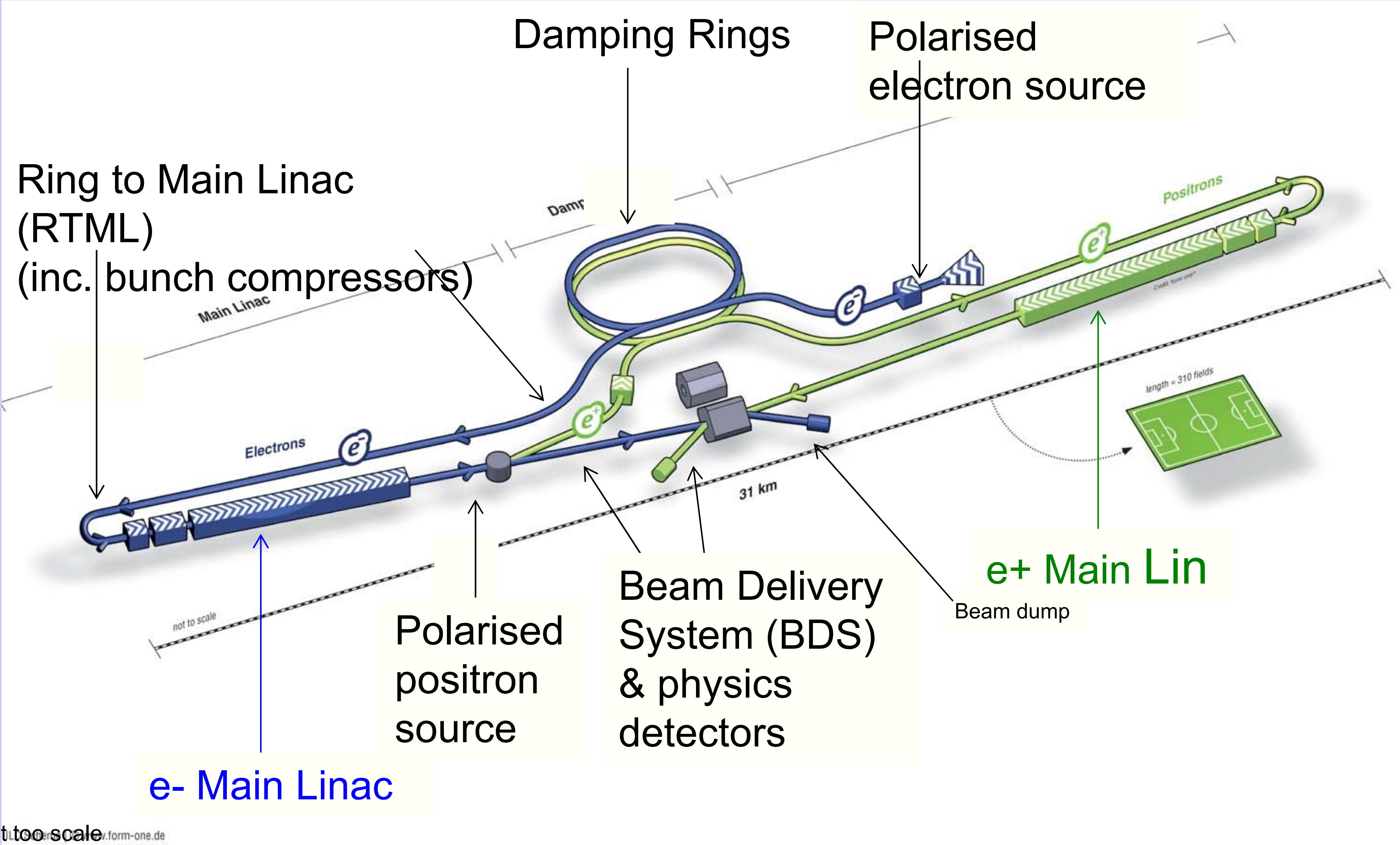


- Single Tunnel for main linac
- Move positron source to end of linac ***
- Reduce number of bunches factor of two (lower power) **
- Reduce size of damping rings (3.2km)
- Integrate central region
- Single stage bunch compressor

Scope of Design Changes

1. 31.5 MV/m average accelerating gradient including ±20% spread
2. Single tunnel for Main Linacs
3. Undulator-based e^+ source relocation to end of e^- Main Linac
4. Reduced beam-power parameter set
   - reduced klystron / modulator count
5. 3.2km circumference Damping Ring
6. Central region integration (general)

ILC General Layout



Damping Rings

Polarised electron source

Ring to Main Linac (RTML)
(inc. bunch compressors)

e- Main Linac

Polarised positron source

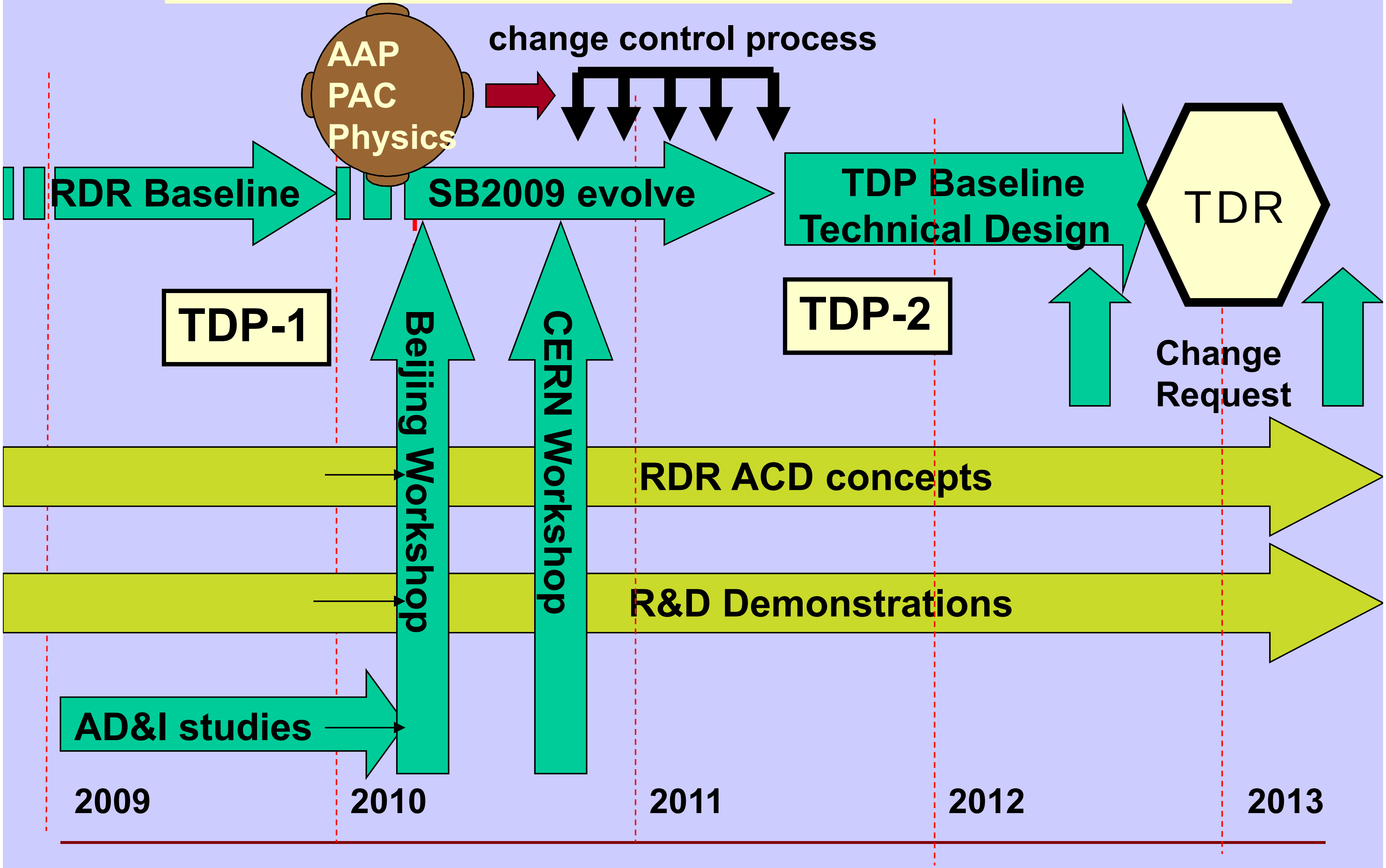
Beam Delivery System (BDS) & physics detectors

e+ Main Lin

Beam dump

not too scale

Technical Design Phase and Beyond



AAP
PAC
Physics

change control process

RDR Baseline

SB2009 evolve

TDP Baseline
Technical Design

TDR

TDP-1

TDP-2

Beijing Workshop

CERN Workshop

Change
Request

RDR ACD concepts

R&D Demonstrations

AD&I studies

2009

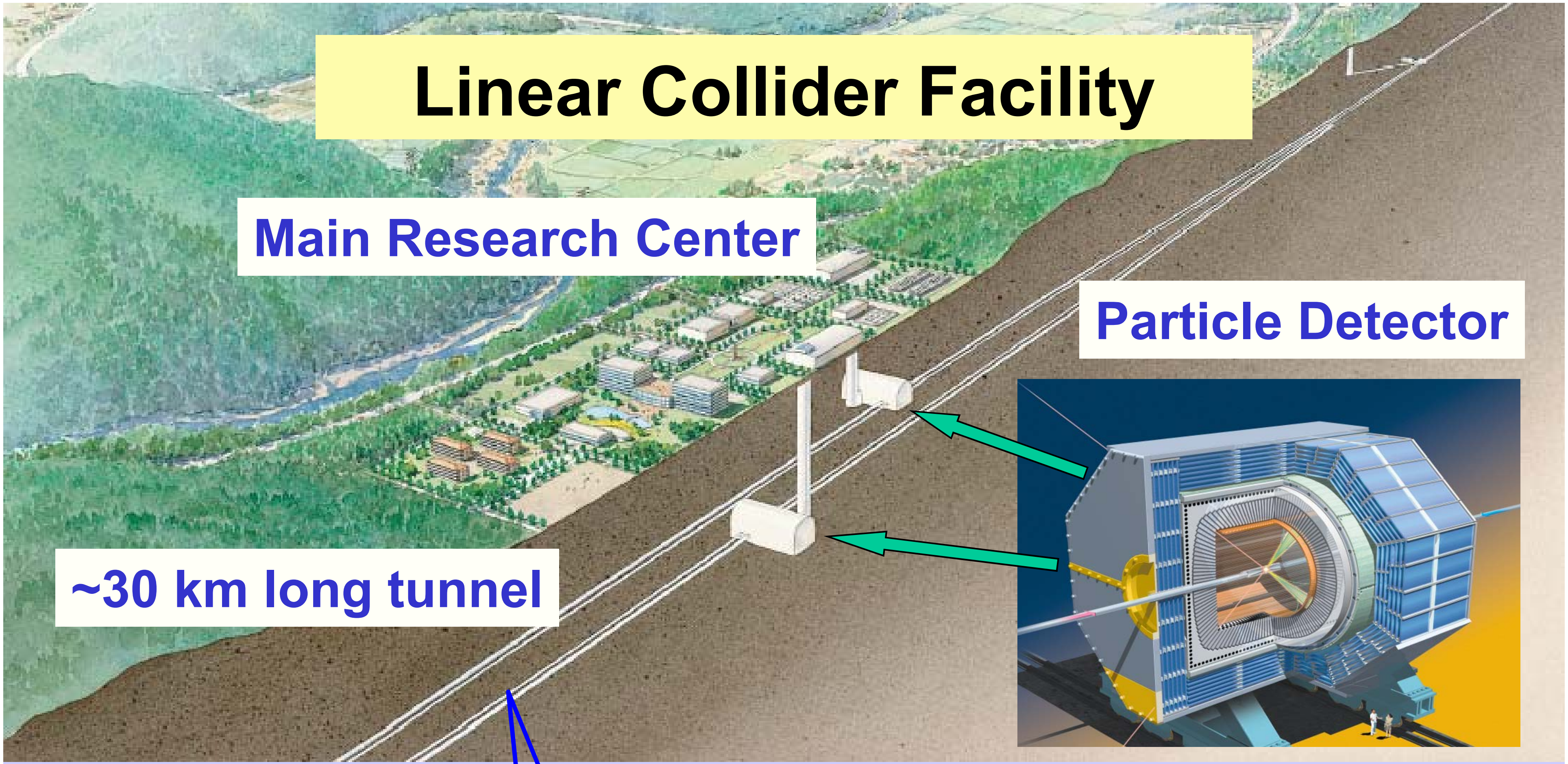
2010

2011

2012

2013

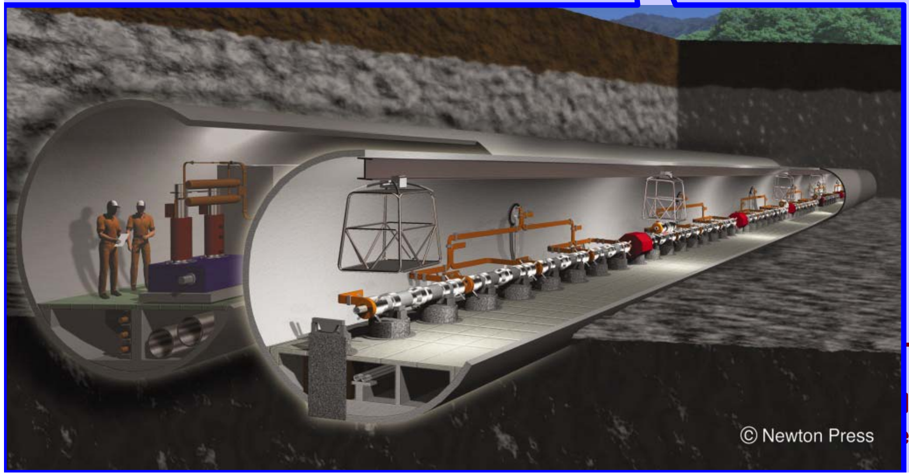
Linear Collider Facility



Main Research Center

Particle Detector

~30 km long tunnel



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Two tunnels

- accelerator units
- other for services - RF power

Conventional Facilities

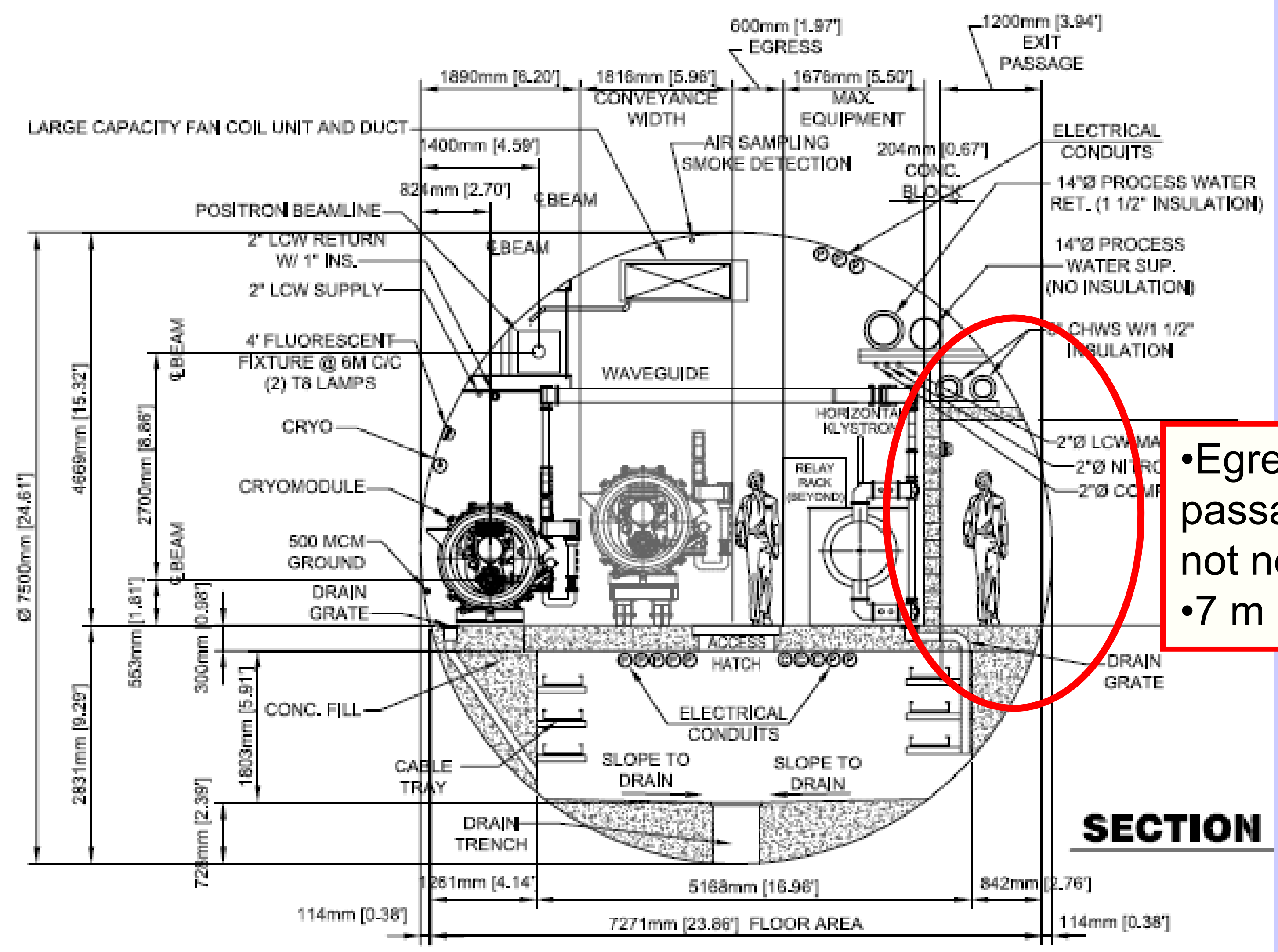
72.5 km tunnels ~ 100-150 meters underground

13 major shafts ≥ 9 meter diameter

443 K cu. m. underground excavation: caverns, alcoves, halls

92 surface “buildings”, 52.7 K sq. meters = 567 K sq-ft

7.5 m Diameter Single Tunnel



- Egress passageway not needed;
- 7 m Ø ok

7.5 m Diameter Single Tunnel

High-Level RF Solution

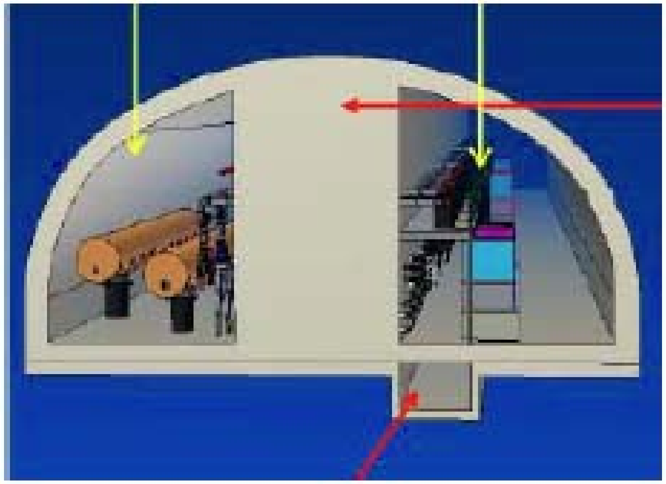
- Critical technical challenge for one-tunnel option is the high level RF distribution.
- Two proposed solutions :
  - **Distributed RF Source (DRFS)**
    - Small 750kW klystrons/modulators in tunnel
    - One klystron per four cavities
    - ~1880 klystrons per linac
    - Challenge is cost and reliability
  - **Klystron Cluster Scheme (KCS)**
    - RDR-like 10 MW Klystrons/modulators on surface
    - Surface building & shafts every ~2 km
    - Challenge is novel high-powered RF components (needs R&D)

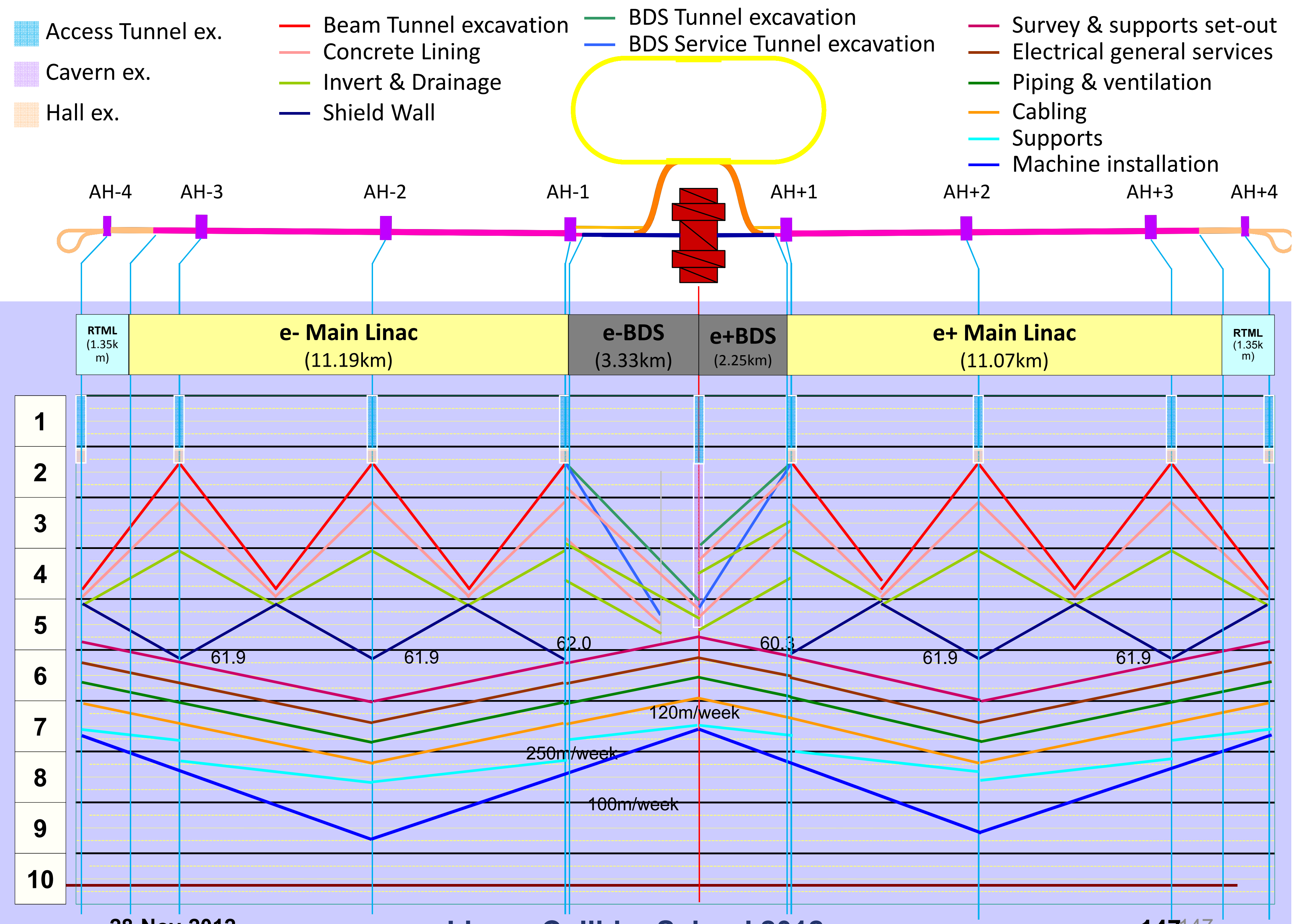
Conventional Facilities

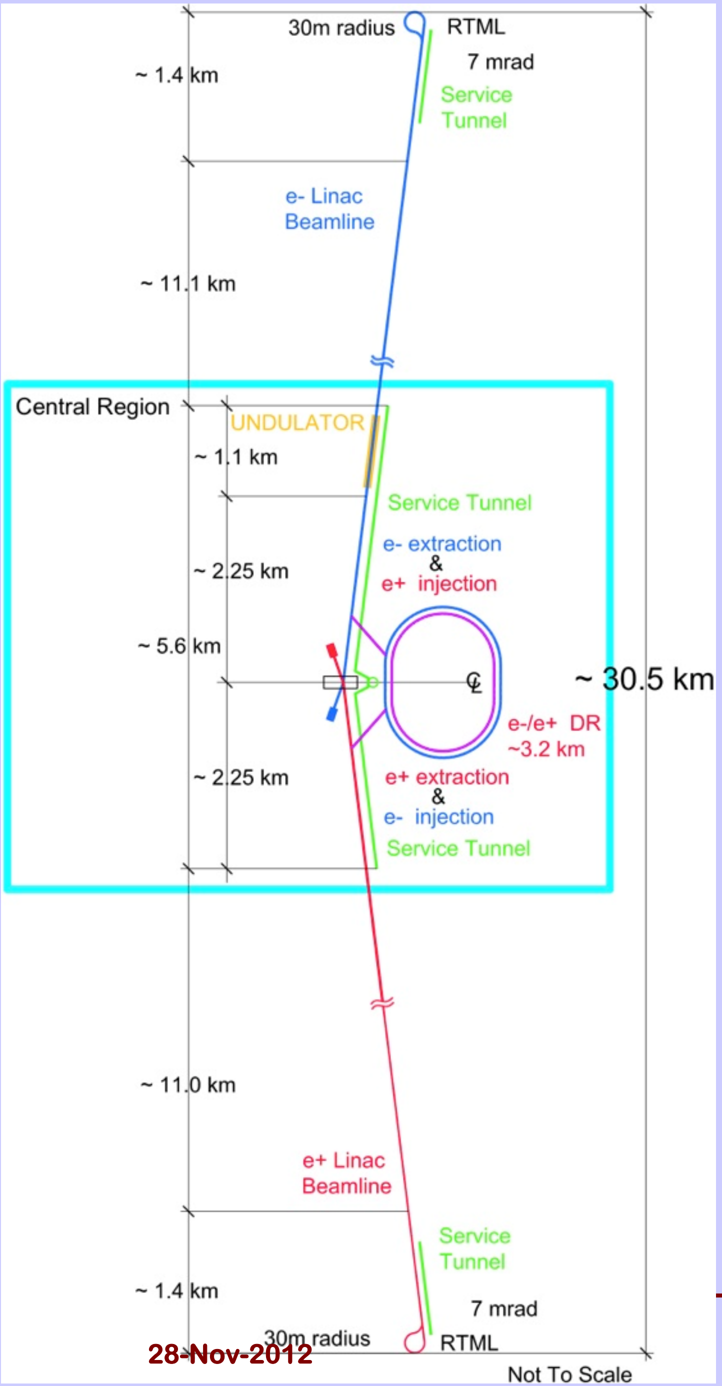
Japan -- New Tunnel Shape

RDR two tunnel design (2007)

TDR mountain sites




Access Tunnel ex.
Cavern ex.
Hall ex.
Beam Tunnel excavation
Concrete Lining
Invert & Drainage
Shield Wall
BDS Tunnel excavation
BDS Service Tunnel excavation
Survey & supports set-out
Electrical general services
Piping & ventilation
Cabling
Supports
Machine installation
AH-4
AH-3
AH-2
AH-1
AH+1
AH+2
AH+3
AH+4
RTML (1.35km)
e- Main Linac (11.19km)
e-BDS (3.33km)
e+BDS (2.25km)
e+ Main Linac (11.07km)
RTML (1.35km)
1
2
3
4
5
6
7
8
9
10
61.9
61.9
62.0
60.3
61.9
61.9
120m/week
250m/week
100m/week

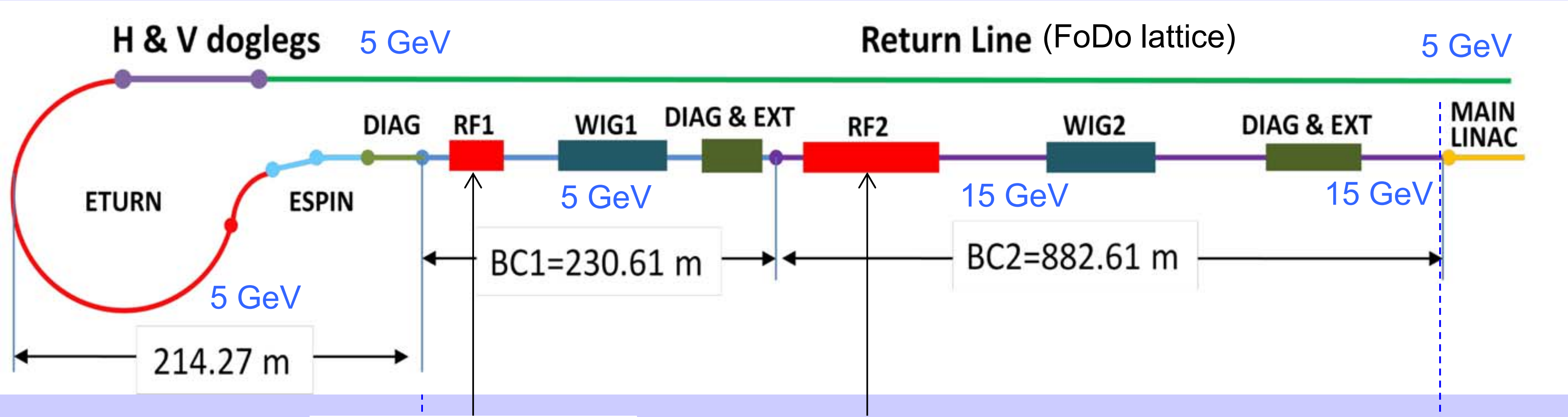


Footprint

Total site length (500 GeV CM)	30.5 km
SCRF Main Linacs	22.2 km
RTML (bunch compressors)	2.8 km
Positron source	1.1 km
BDS / IR	4.5 km
Damping Rings (circumference)	3.2 km

There are the SCRF main linacs….
… and there is everything else.

Ring To Main Linac (RTML)



3 cryomodules
1 klystron/modulator

48 cryomodules
(acceleration 5-15 GeV)
16 klystrons/modulators

Bunch Compression (6mm → 0.3mm)

Ring To Main Linac (RTML)

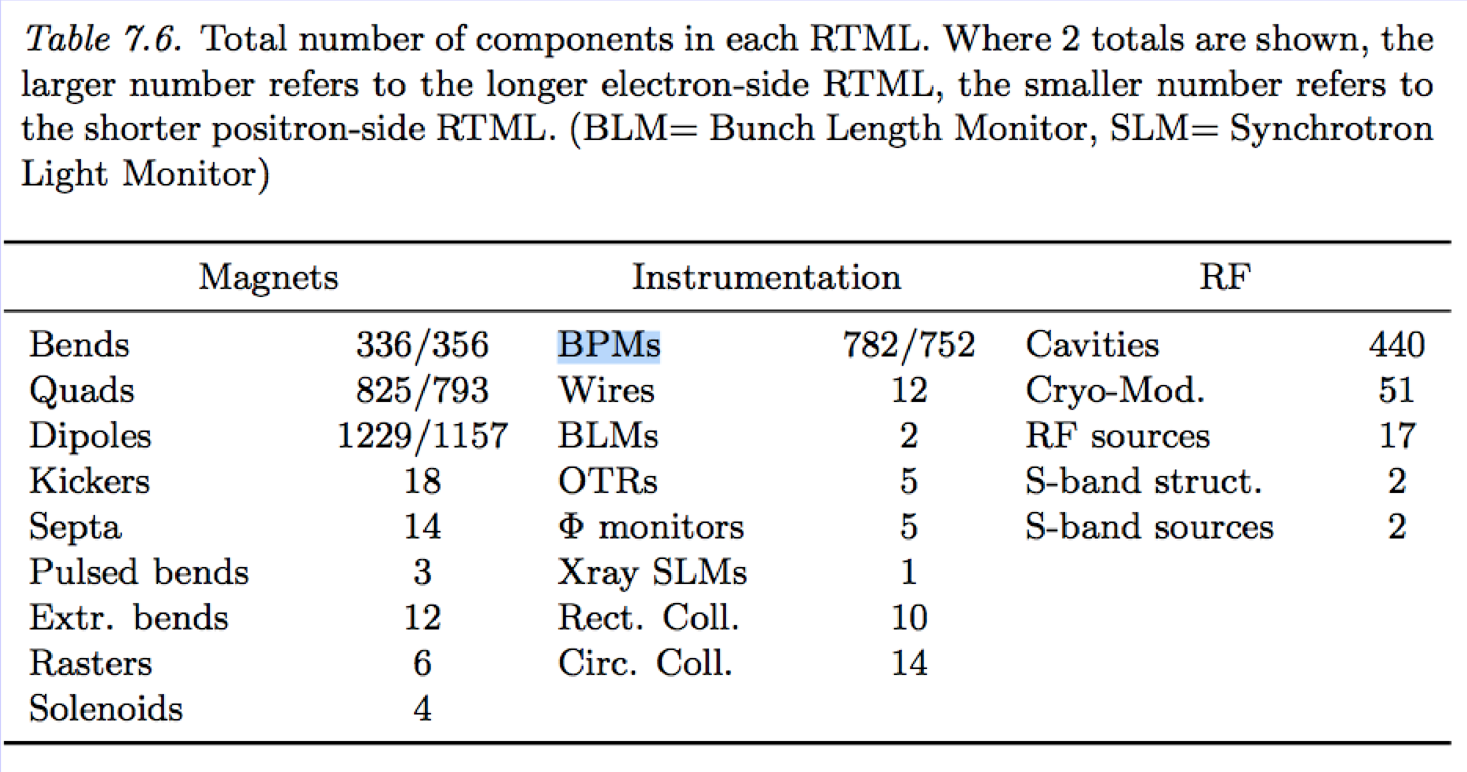
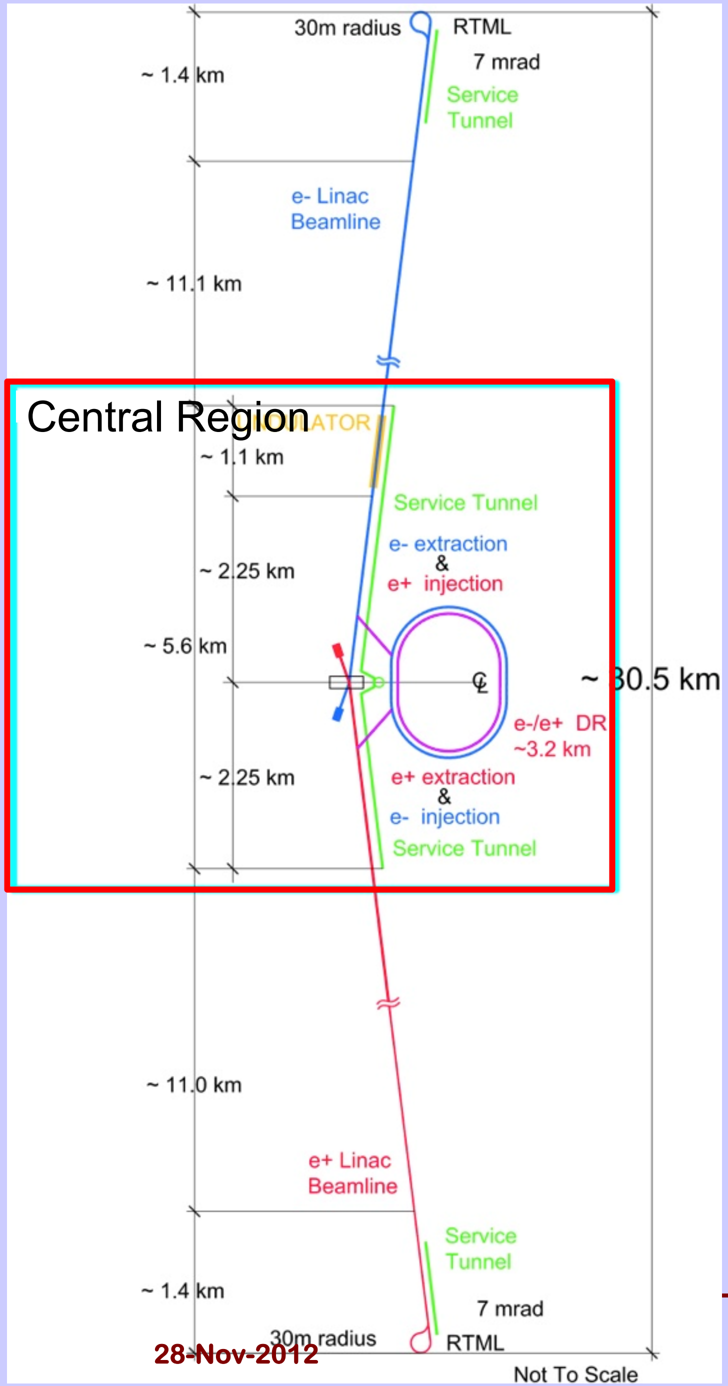


Table 7.6. Total number of components in each RTML. Where 2 totals are shown, the larger number refers to the longer electron-side RTML, the smaller number refers to the shorter positron-side RTML. (BLM= Bunch Length Monitor, SLM= Synchrotron Light Monitor)

Magnets		Instrumentation		RF	
Bends	336/356	BPMs	782/752	Cavities	440
Quads	825/793	Wires	12	Cryo-Mod.	51
Dipoles	1229/1157	BLMs	2	RF sources	17
Kickers	18	OTRs	5	S-band struct.	2
Septa	14	Φ monitors	5	S-band sources	2
Pulsed bends	3	Xray SLMs	1		
Extr. bends	12	Rect. Coll.	10		
Rasters	6	Circ. Coll.	14		
Solenoids	4				

Longest single system: 15.4 km (×2) (beamline length)



Central Region

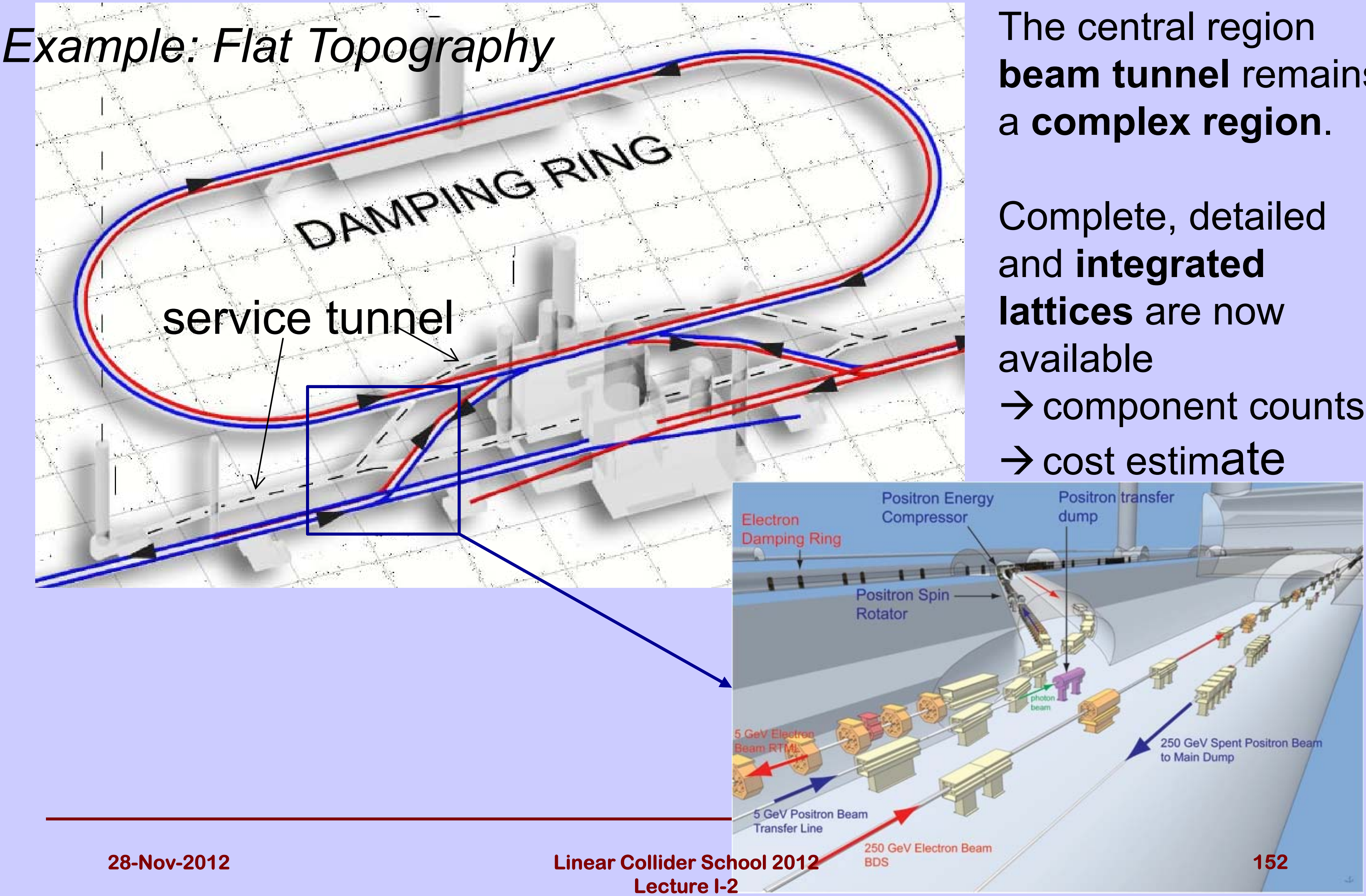
- **5.6 km region around IR**
- **Systems:**
  - **electron source**
  - **positron source**
  - **beam delivery system**
  - **RTML (return line)**
  - **IR (detector hall)**
  - **damping rings**

common tunnel

- **Complex and crowded area**

Central Region

Example: Flat Topography



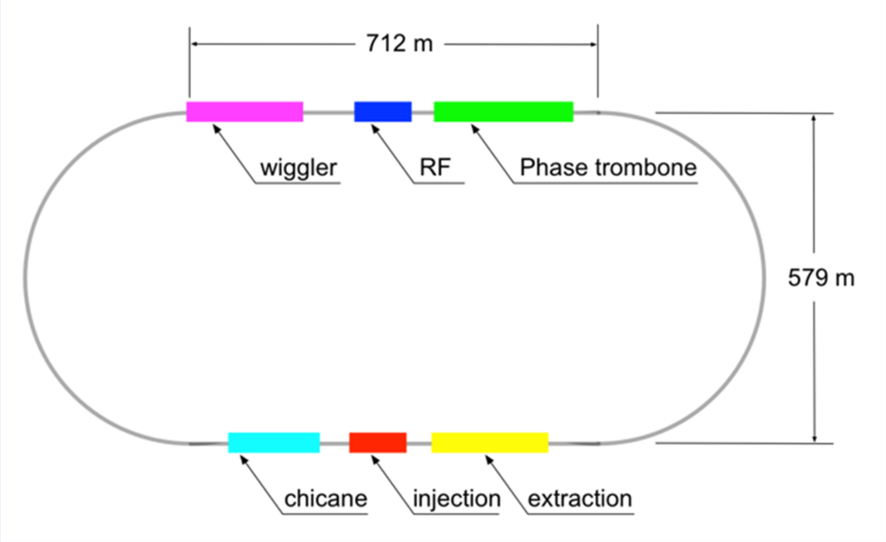
The central region **beam tunnel** remains a **complex region**.

Complete, detailed and **integrated lattices** are now available

→ component counts

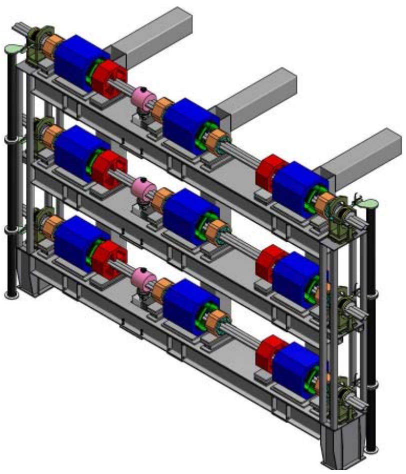
→ cost estimate

Damping Rings

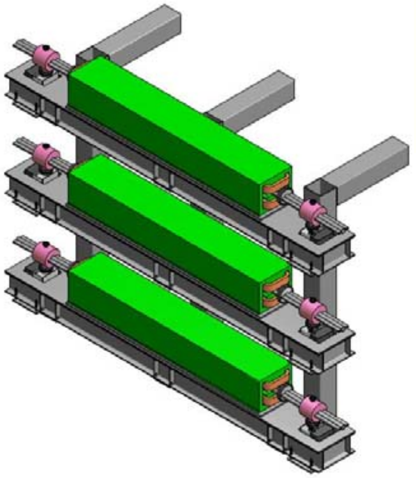


Circumference		3.2	km
Energy		5	GeV
RF frequency		650	MHz
Beam current		390	mA
Store time		200 (100)	ms
Trans. damping time		24 (13)	ms
Extracted emittance	x	5.5	µm
(normalised)	y	20	nm
No. cavities		10 (12)	
Total voltage		14 (22)	MV
RF power / coupler		176 (272)	kW
No.wiggler magnets		54	
Total length wiggler		113	m
Wiggler field		1.5 (2.2)	T
Beam power		1.76 (2.38)	MW

Values in () are for 10-Hz mode



Arc quadrupole section

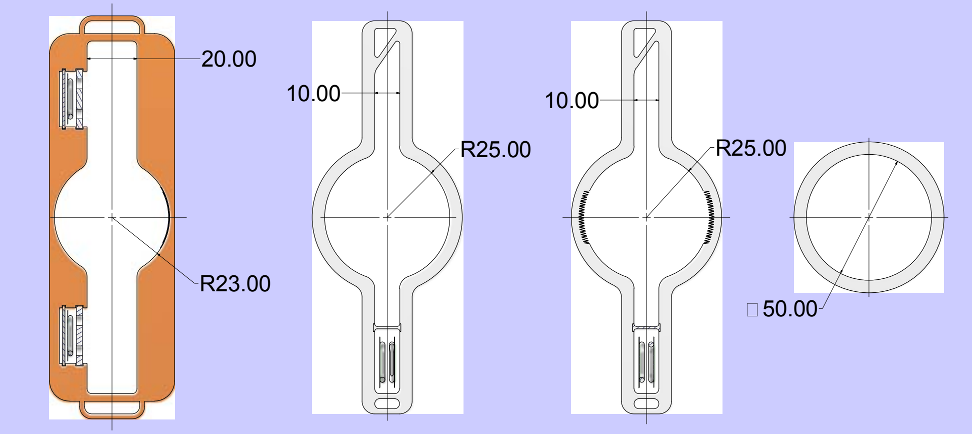


Dipole section

Many similarities to modern 3rd-generation light sources

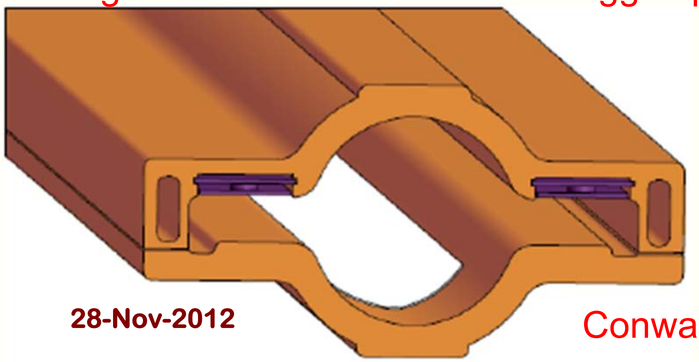
Damping Rings: Vacuum (Electron Cloud)

- **Reduction of electron cloud build-up in e+ ring critical for ILC parameters**
- **Full e-cloud mitigation concepts included into vacuum design**
  - **CesrTA (and other) R&D results**
- **Vacuum System Design/Costing**
  - **Super-KEK-B VCs in production with similar designs to ILC DR**



(a) WIGGLER CHAMBER (b) ARC CHAMBER (c) DIPOLE CHAMBER (d) DRIFT CHAMBER

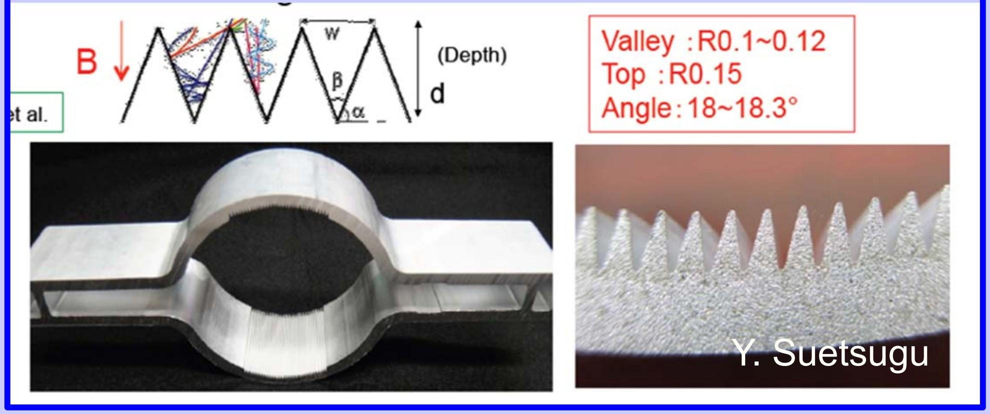
DR Wiggler chamber concept with thermal spray clearing electrode – 1 VC for each wiggler pair.



28-Nov-2012

Conway/Li

SuperKEKB Dipole Chamber Extrusion



Y. Suetsugu

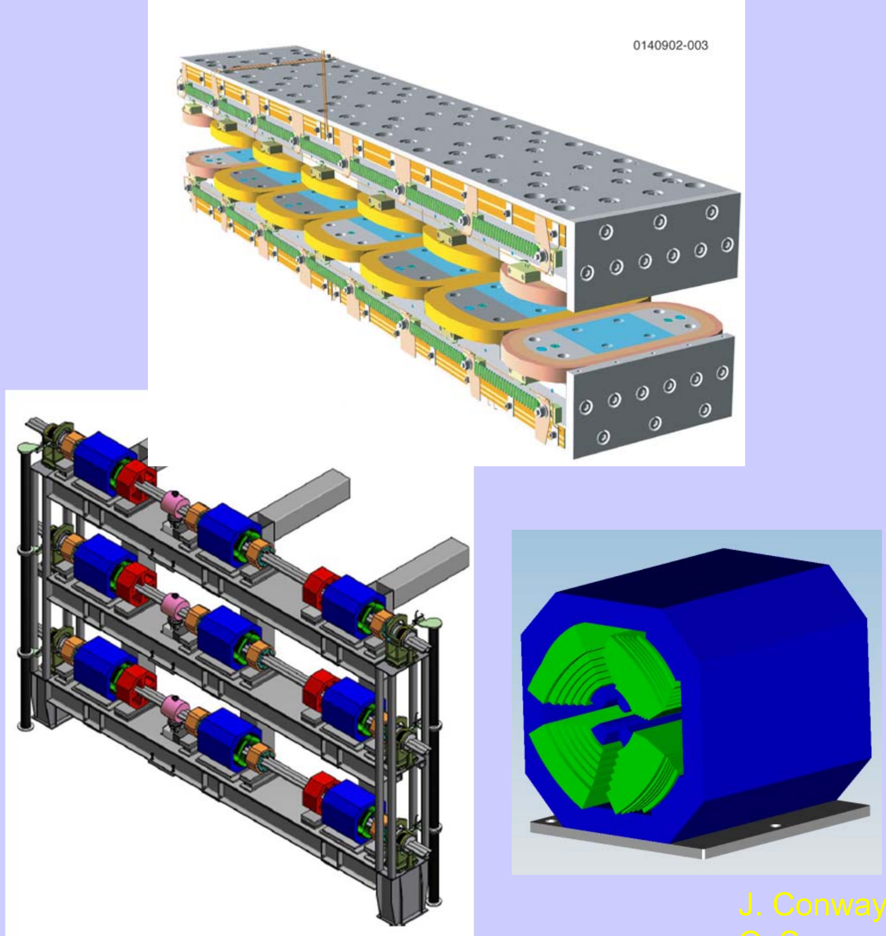
DR: Magnets & Power Supplies

Superferic SC wigglers

Parameter	Unit	CESR-c	ILC TDR
Peak Field	T	2.10	2.16
No. Poles		8	14
Length	m	1.3	1.875
Period	m	0.40	0.30
Pole Width	cm	23.8	23.8
Pole Gap	cm	7.6	7.6
$\Delta B/B\vert_{x=10\,\mathrm{mm}}$	%	0.0077	0.06
Coil Current	A	141	141
Beam Energy	GeV	1.5–2.5	5

room-temperature magnets

Magnet	Type	Eng. Style	Qty	Power Method
Dipoles:	Corrector	D60L250	304	Individual
	Chicane	D60L940	28	String
	Disp. Supp.	D60L1940	10	String
	Arc	D60L2940	150	String
Quadrupoles:	Arc	Q60L480	482	Individual
	Straight	Q60L700	121	Individual
	Wig/Inj/Ext	Q85L309	50	Individual
	Wiggler	Q85L600	30	Individual
Skew Quads	Corrector	Q60L250	158	Individual
Sextupoles	—	SX60L250	600	Individual
Wigglers	—	WG76L2100	54	Individual
Kickers	Inj/Ext	Striplines	42	Individual
Thin Pulsed Septa	Inj/Ext	—	2	Individual
Thick Pulsed Septa	Inj/Ext	—	2	Individual

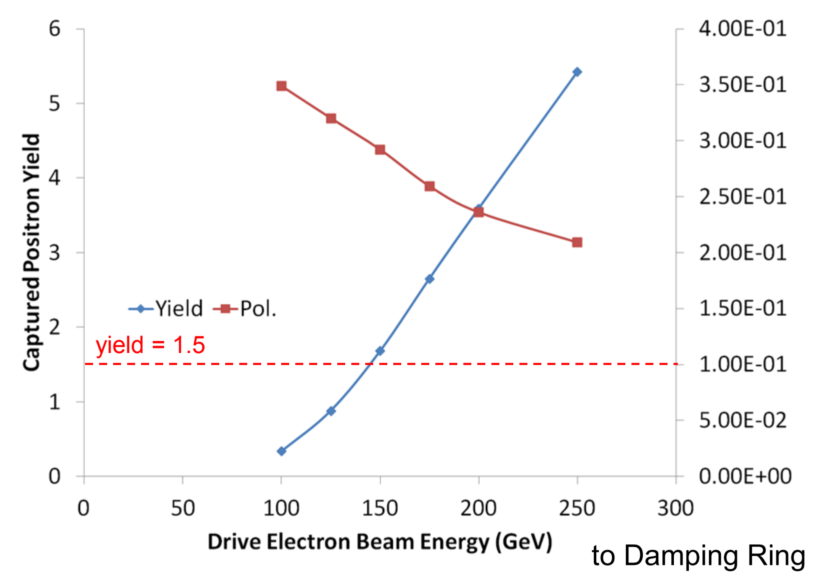


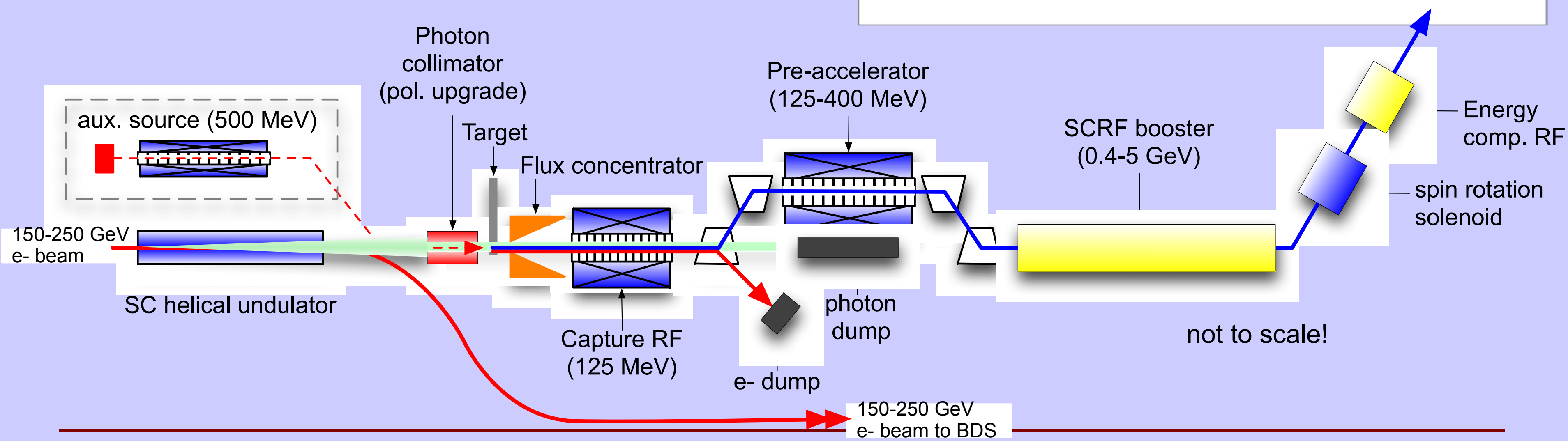
J. Conway
C. Spencer

Power system based on large DC supplies driving long bus bar, with local DC-to-DC converters at magnet locations (cost optimised)

Positron Source (central region)

- located at exit of electron Main Linac
- 147m SC helical undulator
- driven by primary electron beam (150-250 GeV)
- produces ~30 MeV photons
- converted in thin target into e+e- pairs



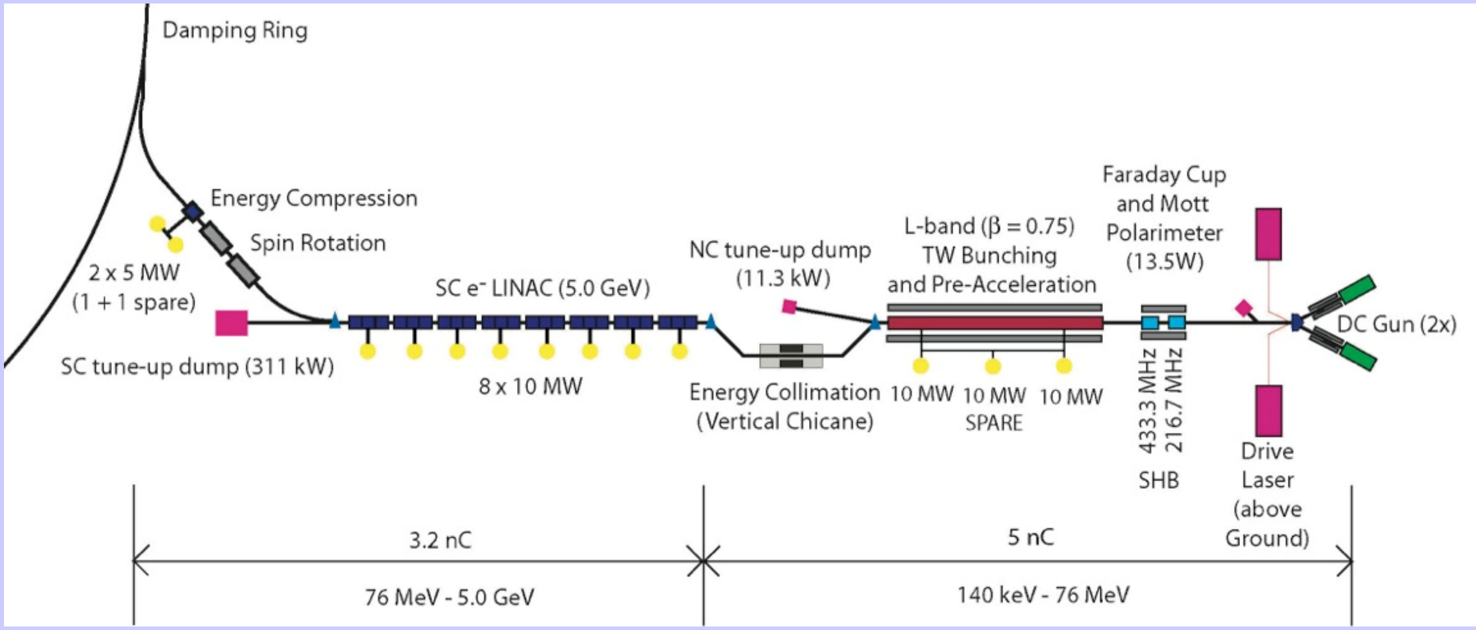


10Hz mode for e+ production

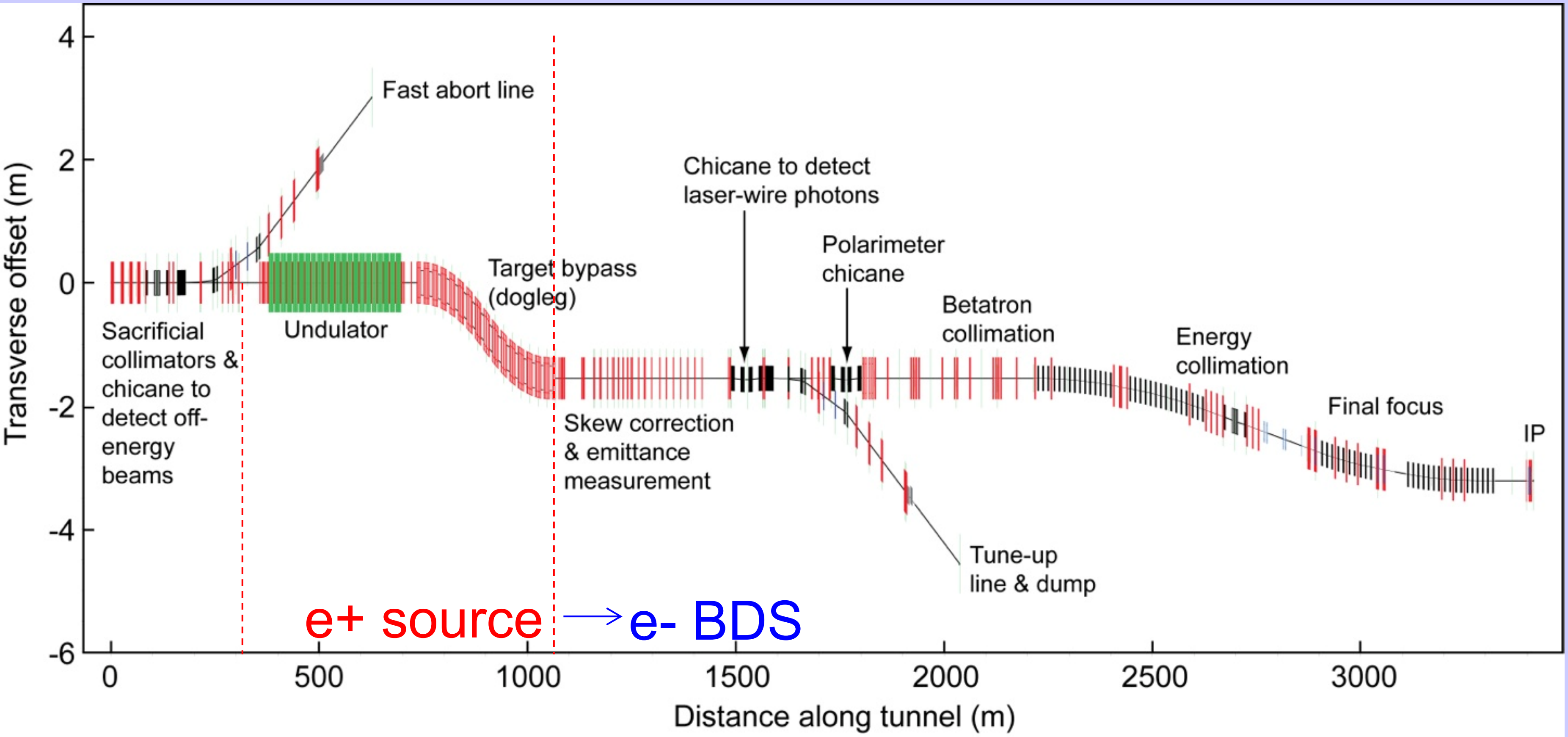
- Low E_{cm} running (≤250 GeV) → 10Hz mode
- Alternate pulses:
  - 150 GeV e- pulse to generate positrons
  - Ecm/2 e- pulse for luminosity
- Ramifications:
  - 100ms store time in DR → shorter damping times
  - Need to dump 150 GeV production pulse after undulator (new beamline, pulsed-magnet system)
  - Pulsed trajectory-correction system before undulator for 150 GeV production beam.
- Electron Main Linac requires no modification
  - Installed AC power sufficient for ~½ energy operation at 10Hz.

Polarised Electron Source

- Laser-driven photo cathode (GaAs)
- DC gun
- Integrated into common tunnel with positron BDS



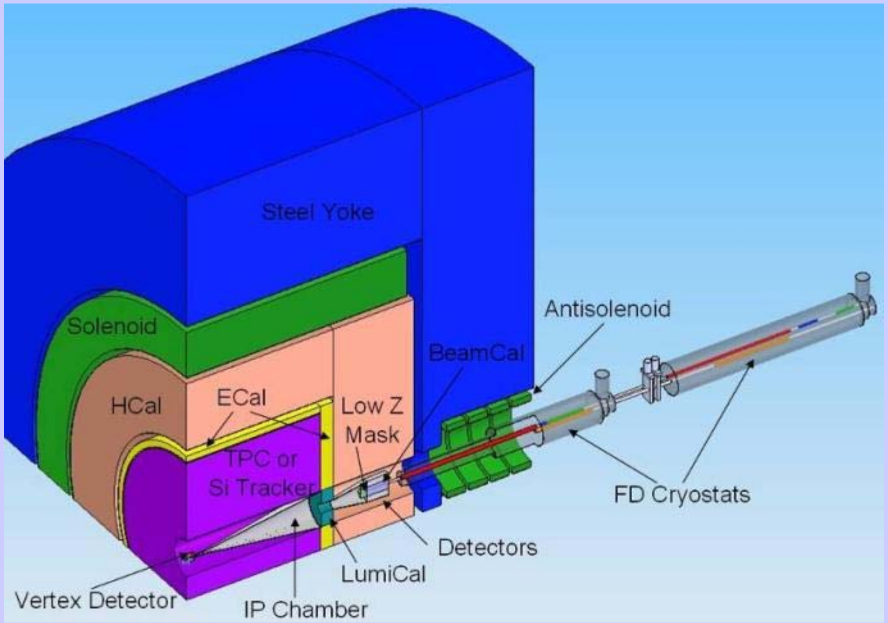
Beam Delivery System

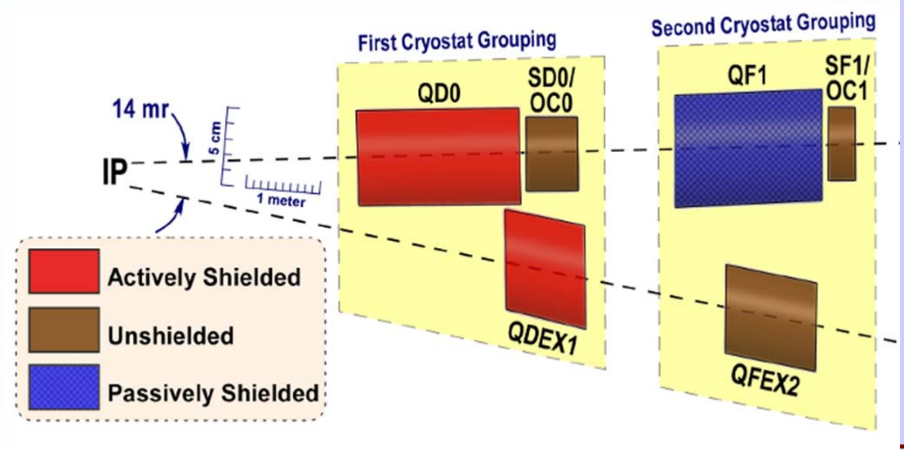


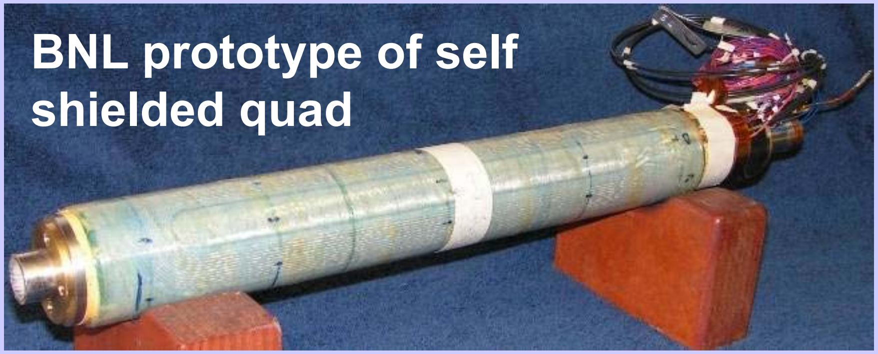
Electron Beam Delivery System

IR region (Final Doublet)

- FD arrangement for push pull
  - different L*
  - ILD 4.5m, SiD 3.5m
- Short FD for low E_{cm}
  - Reduced β_x*
    - increased collimation depth
  - “universal” FD
    - avoid the need to exchange FD
    - conceptual - requires study
- Many integration issues remain
  - requires engineering studies beyond TDR
  - No apparent show stoppers

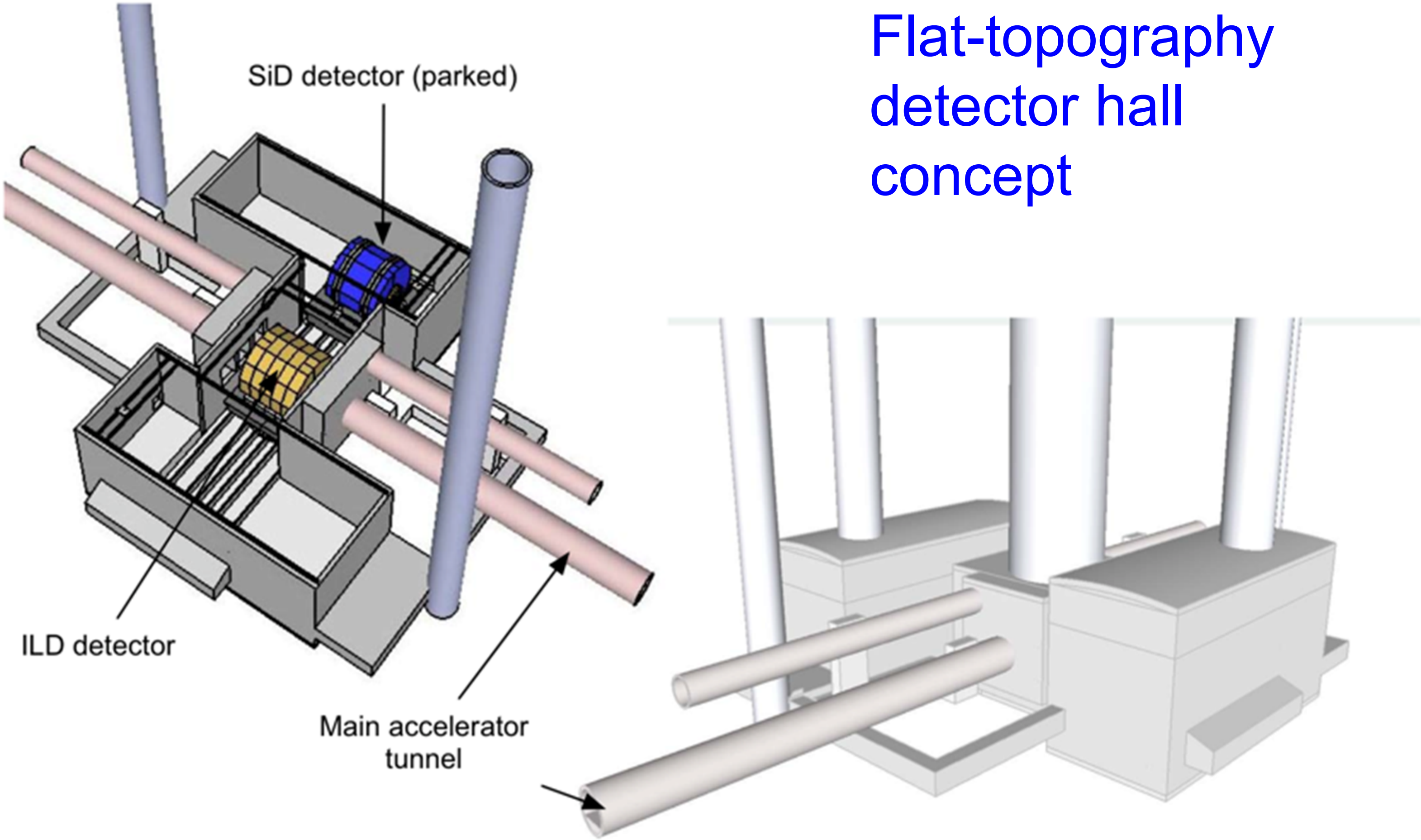






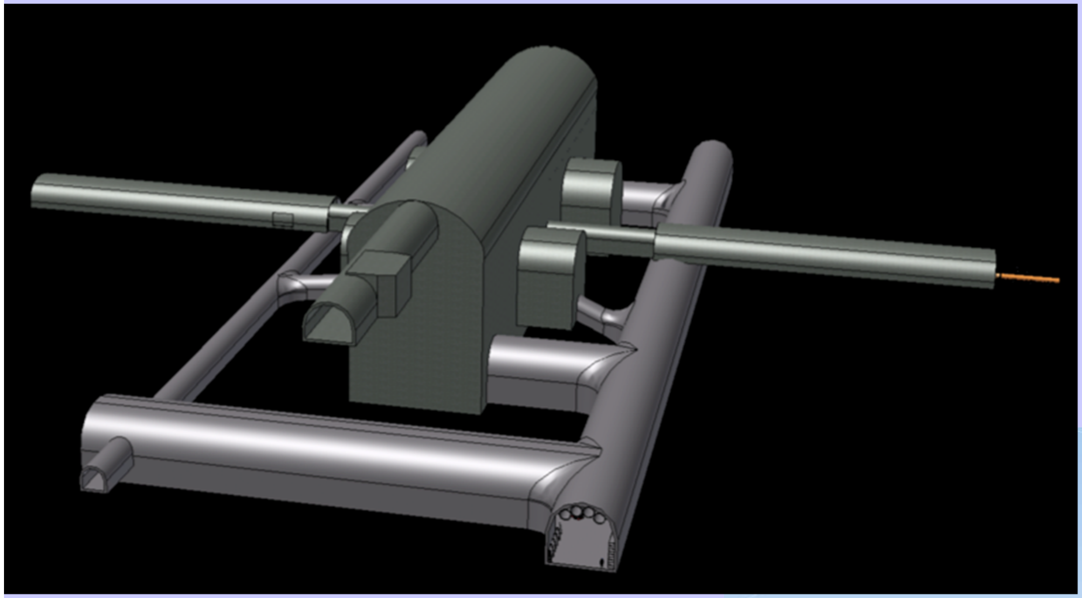
BNL prototype of self shielded quad

Detector Hall

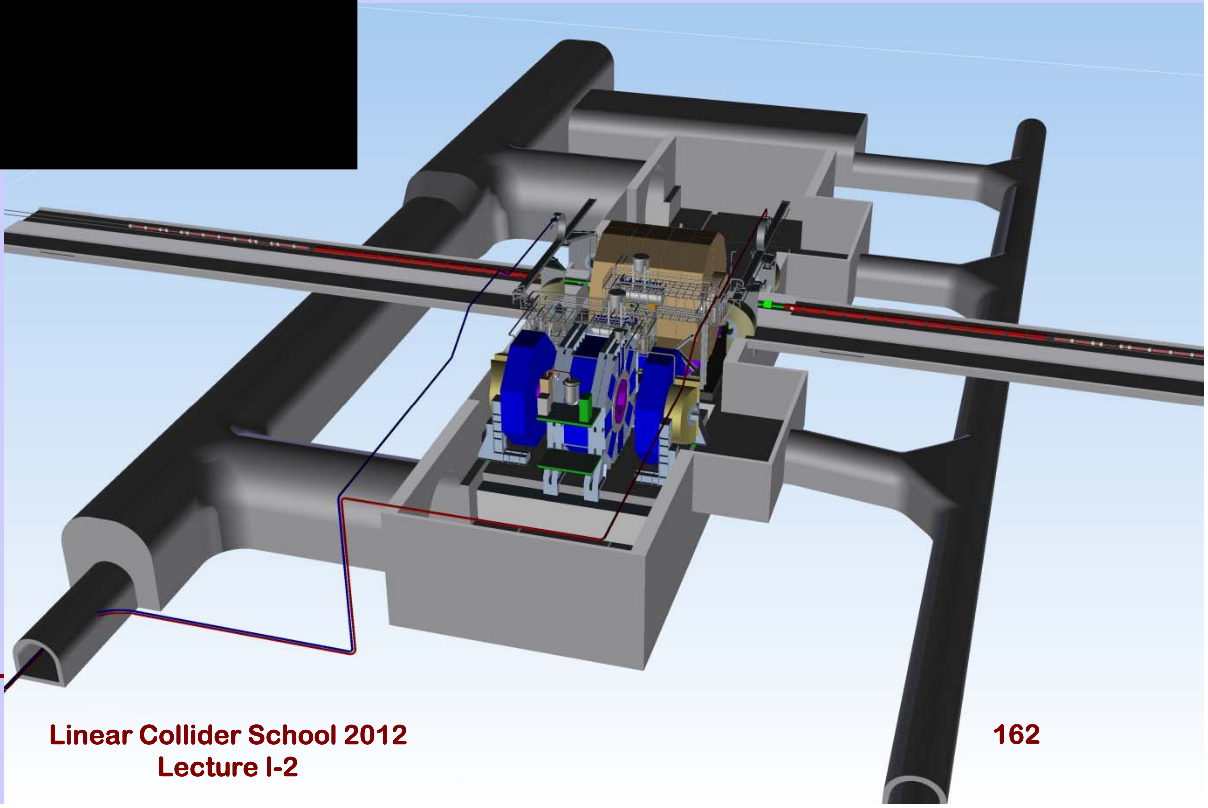


Flat-topography detector hall concept

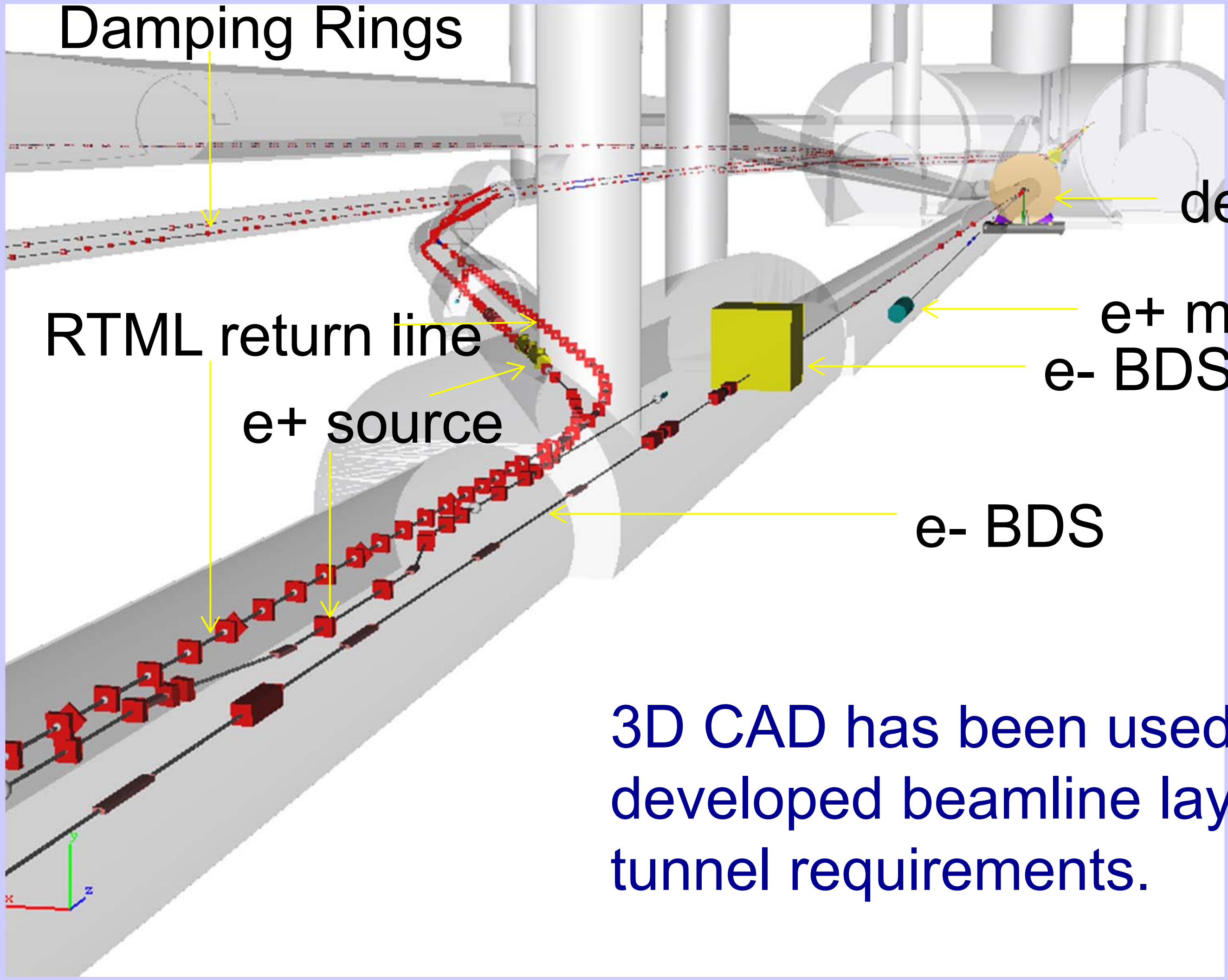
Detector Hall



Mountainous-topography detector hall concept



Central Region Integration

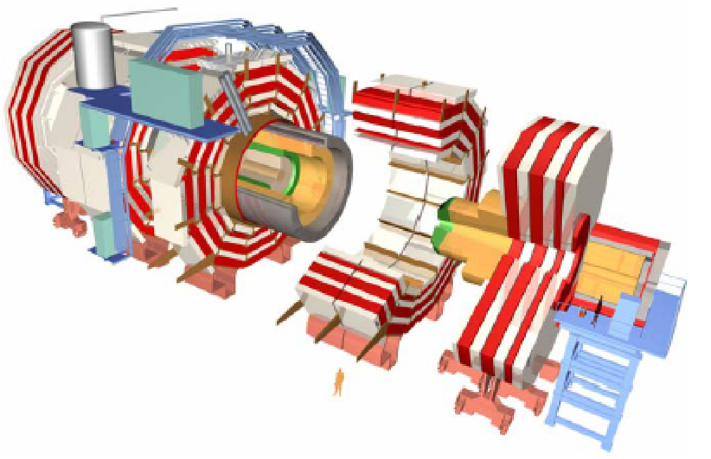


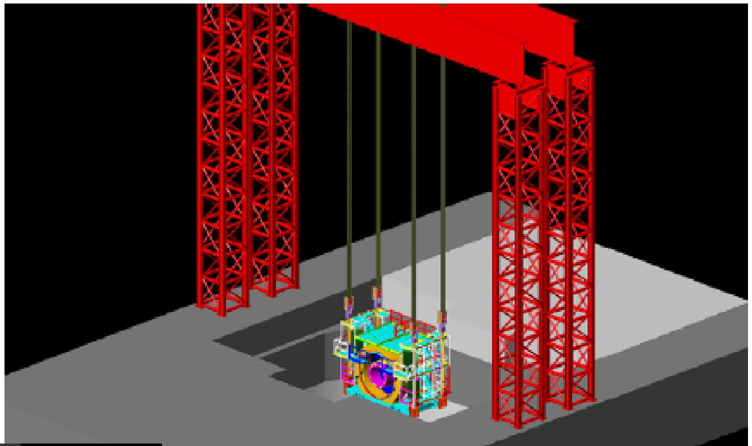
3D CAD has been used to developed beamline layouts and tunnel requirements.

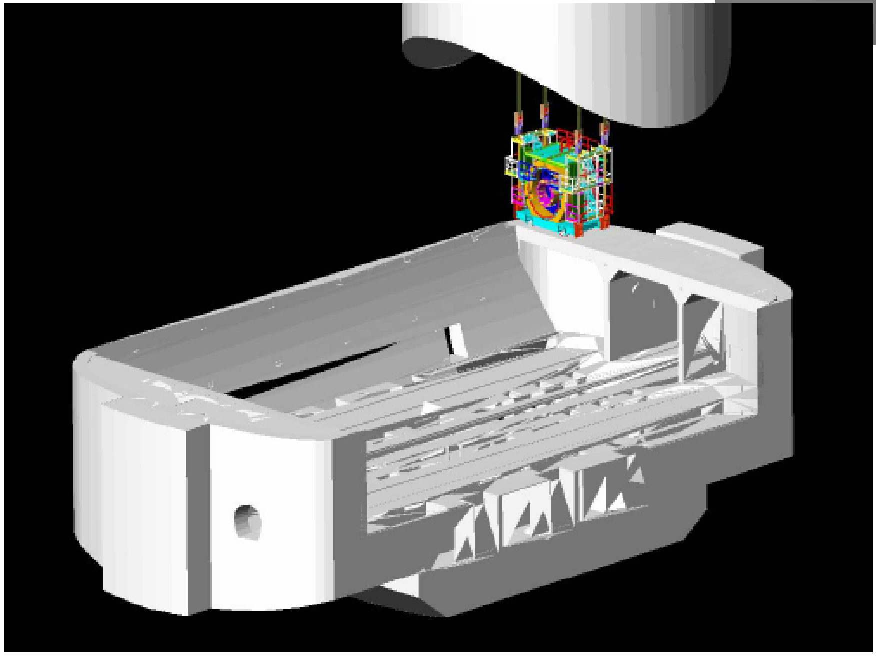
Complete model of ILC available.

On-surface Detector Assembly

CMS approach



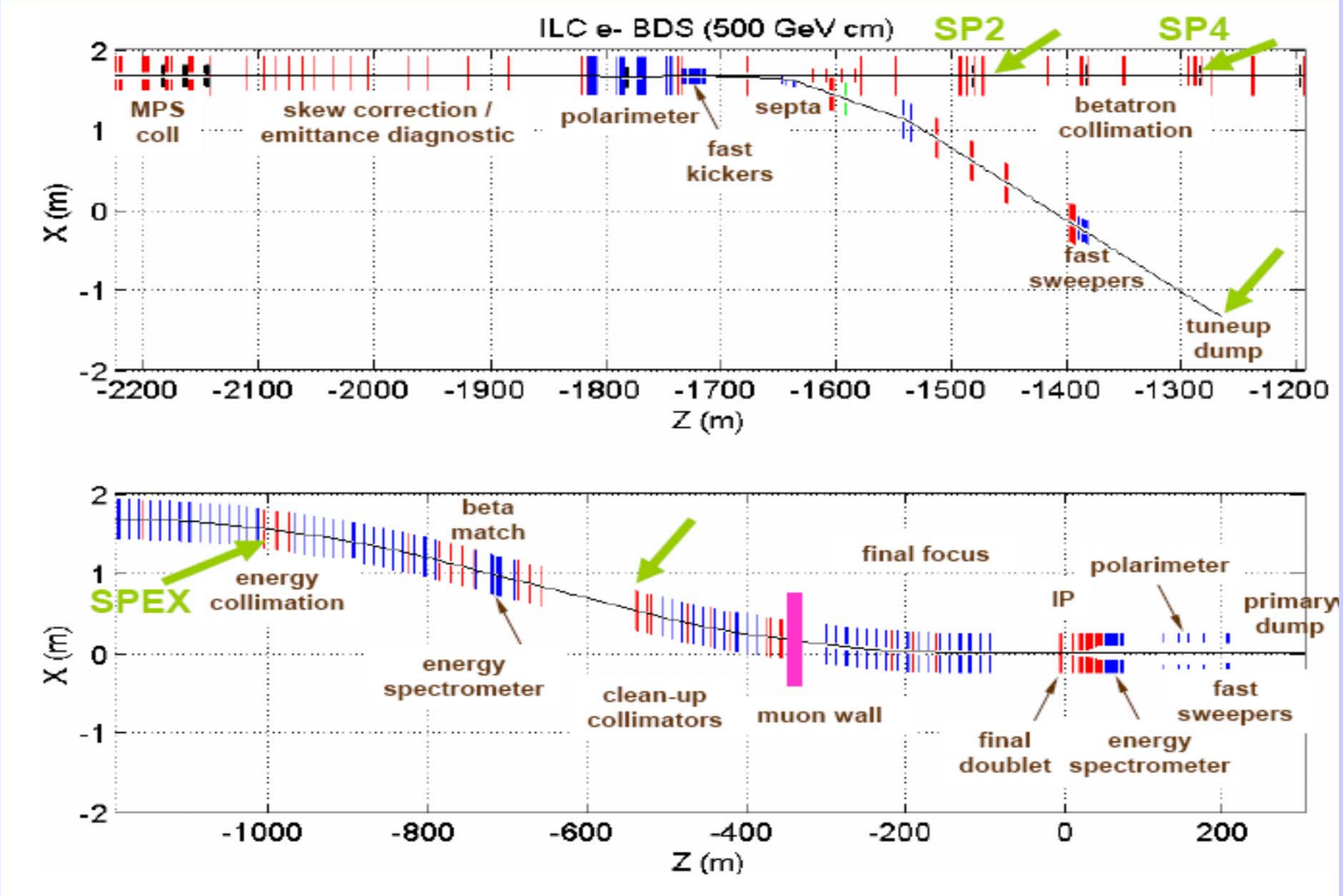




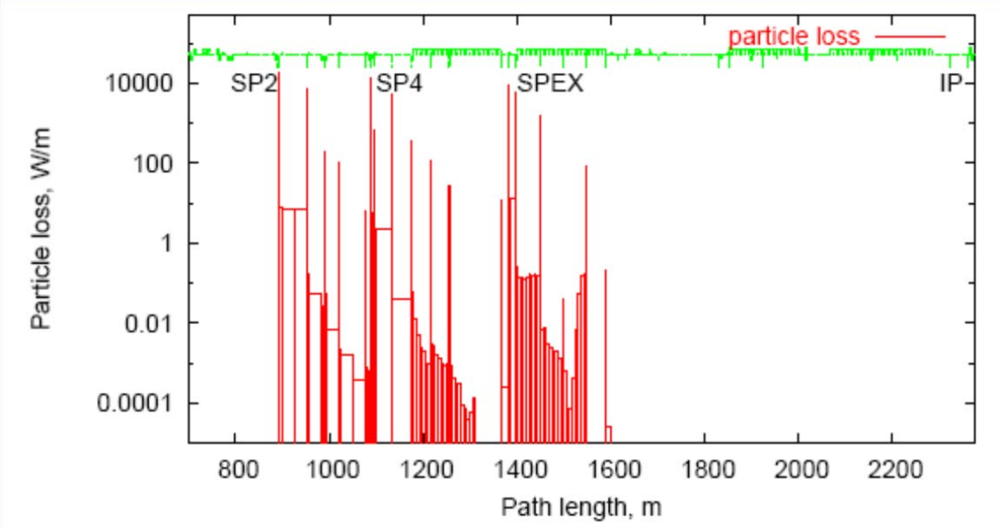
CMS assembly approach:

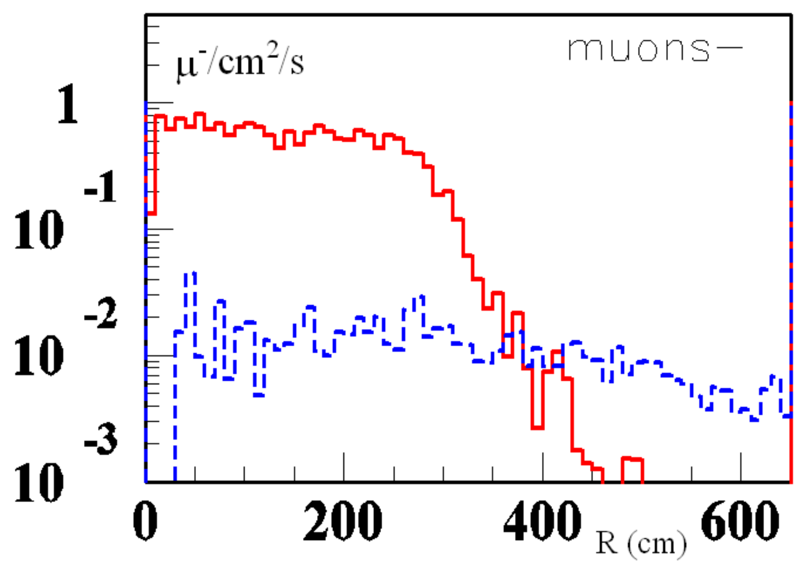
- Assembled on the surface in parallel with underground work
- Allows pre-commissioning before lowering
- Lowering using dedicated heavy lifting equipment
- Potential for big time saving
- Reduces size of required underground hall

Possible Sources of Muons

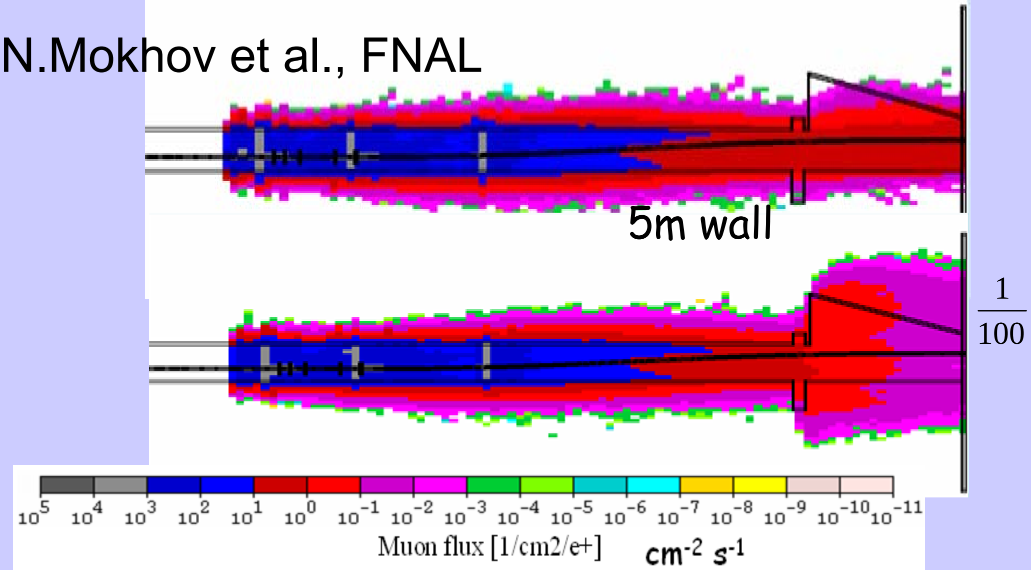


Muon Reduction





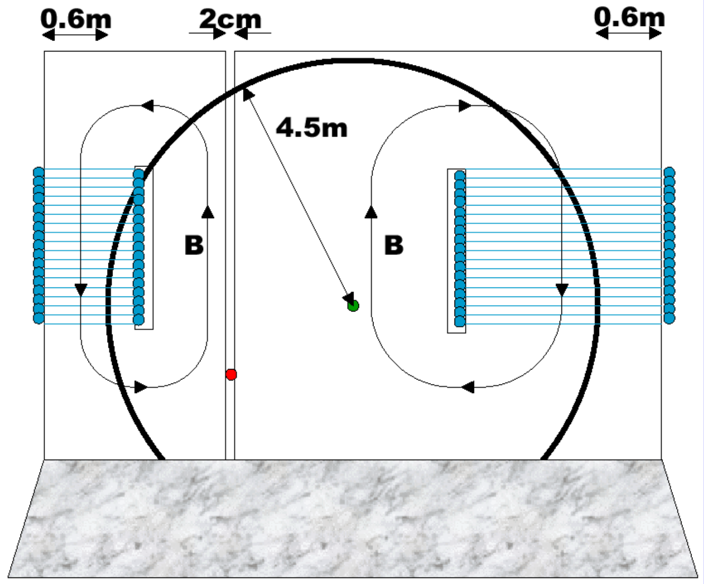
N.Mokhov et al., FNAL

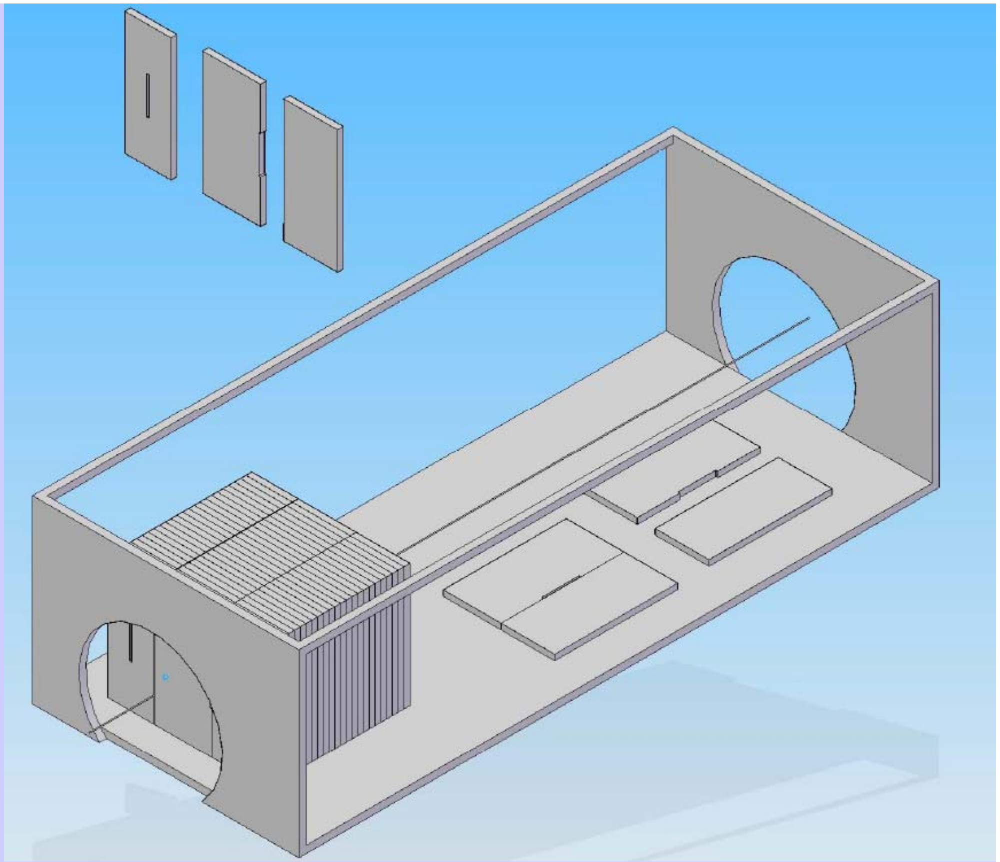


- **Muon flux in BDS & IR with and without 5m muon wall**
- **Allows reducing flux in TPC to a few m per ~100 bunches**

Muon walls

- **Purpose:**
  - **Personnel Protection: Limit dose rates in IR when beam sent to the tune-up beam dump**
  - **Physics: Reduce the muon background in the detectors**



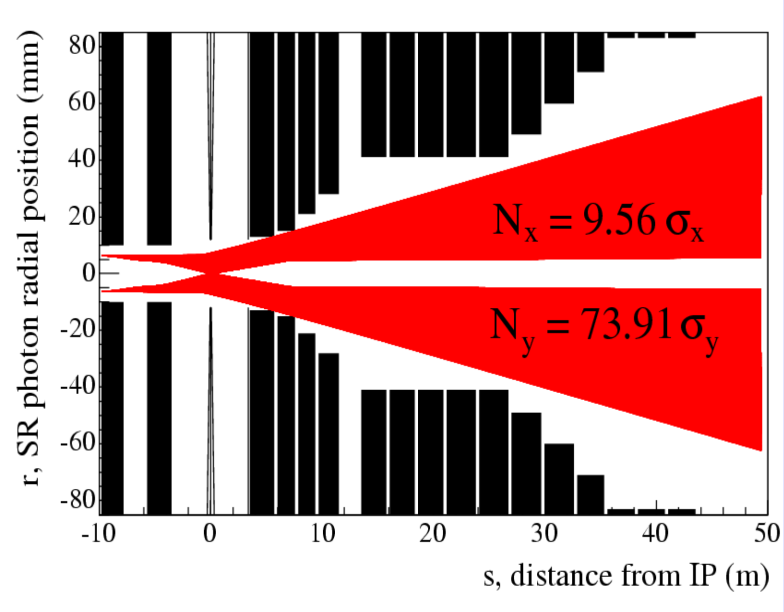


5m muon wall installed initially

If muon background measured too high, the 5m wall can be lengthened to 18m and additional 9m wall installed
(Local toroids could be used also)

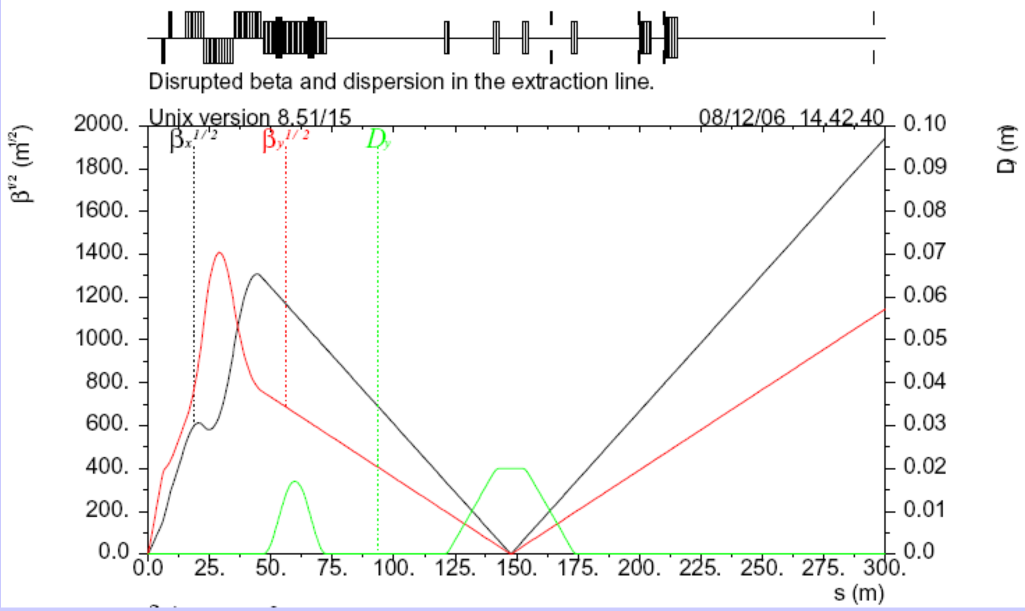
Beam Gas & Synchrotron Radiation in IR

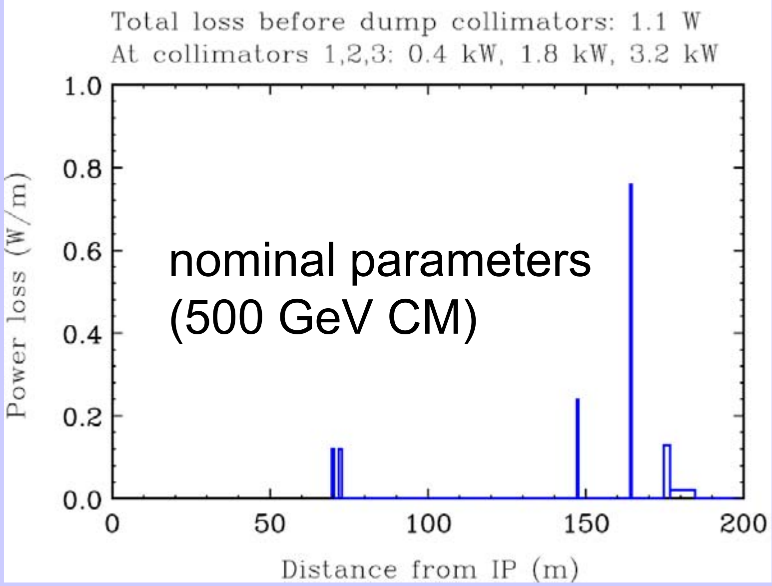
- **Beam gas**
  - is minimized by controlling the pressure near IP within 1nTorr level, 10nTorr in 200-800m from IP and ~50nTorr in the rest of the system
- **Synchrotron Radiation in IR**
  - due to upstream collimation is contained within a defined cone which is extracted away



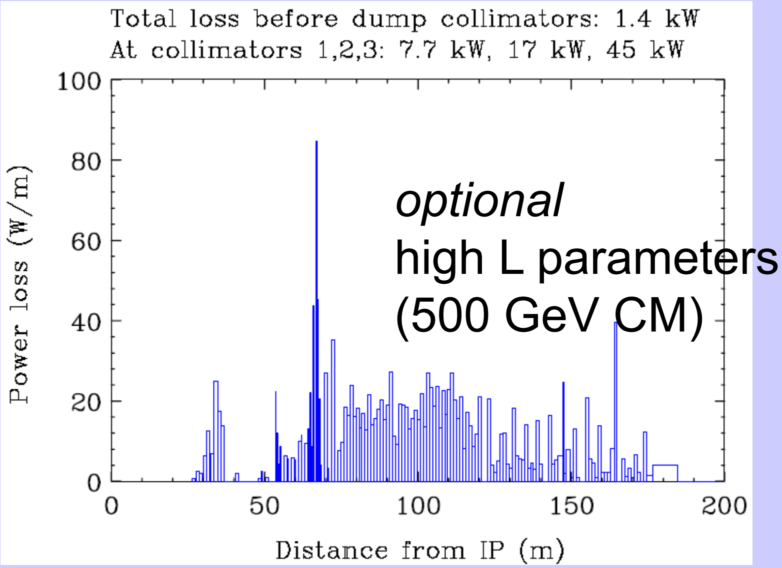
Example of SR rays from beam halo in IR apertures

Extraction Lines





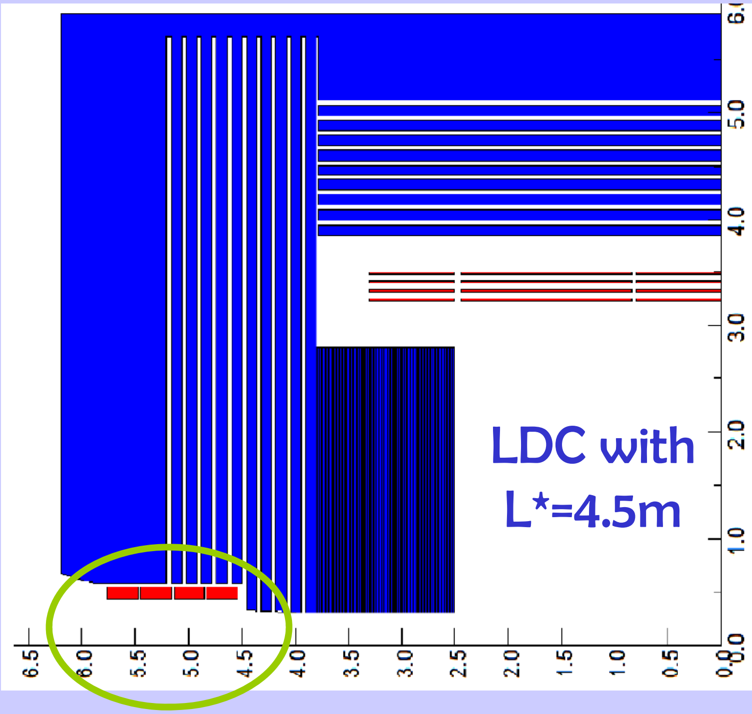
nominal parameters
(500 GeV CM)



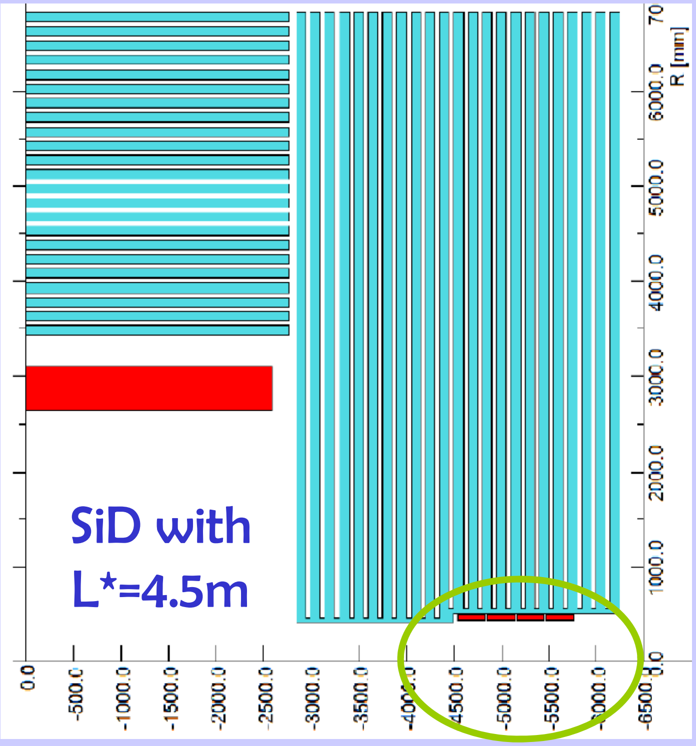
optional
high L parameters
(500 GeV CM)

- **Losses for the nominal case are negligible (~1W for 200m from IP)**
- **Even for High L parameters is within acceptable levels**
- **Small losses in extraction and separation from dump are important to keep the back-shine low**

Antisolenoids

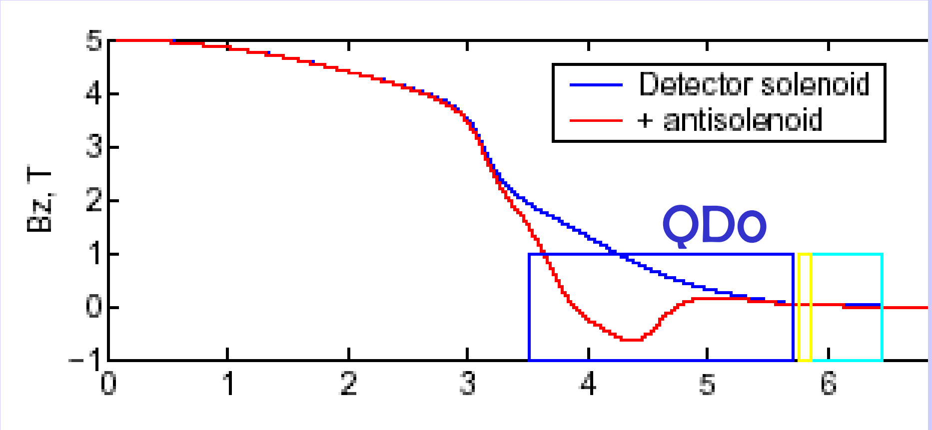


LDC with L*=4.5m



SiD with L*=4.5m

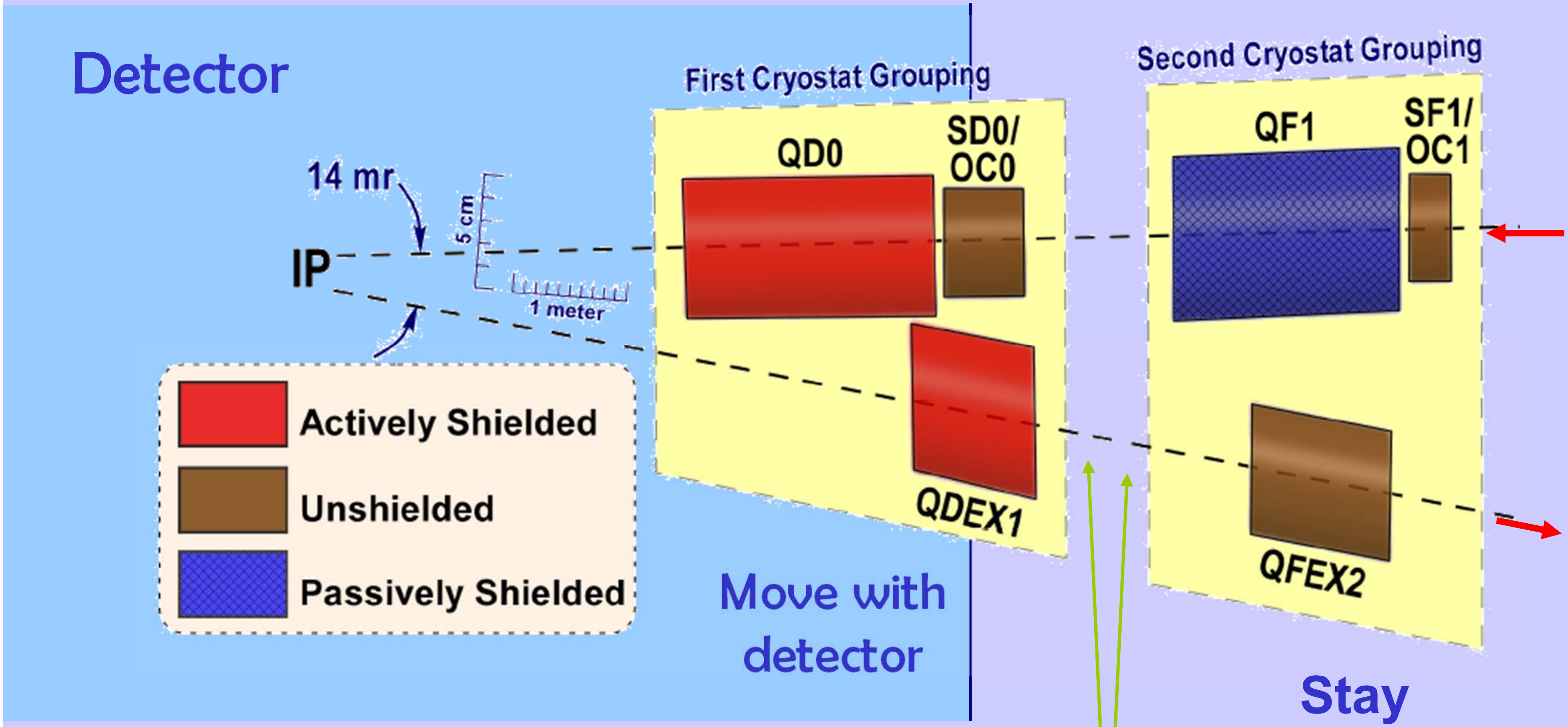
- **Antisolenoids for local compensation of beam coupling**
- **Depend on all parameters (L*, field, sizes, etc) and is a delicate MDI issue**



Example of optimal field for local compensation of coupling (SiD, L*=3.5m)

B.Parker, BNL

Interaction Region Conceptual Design



Detector

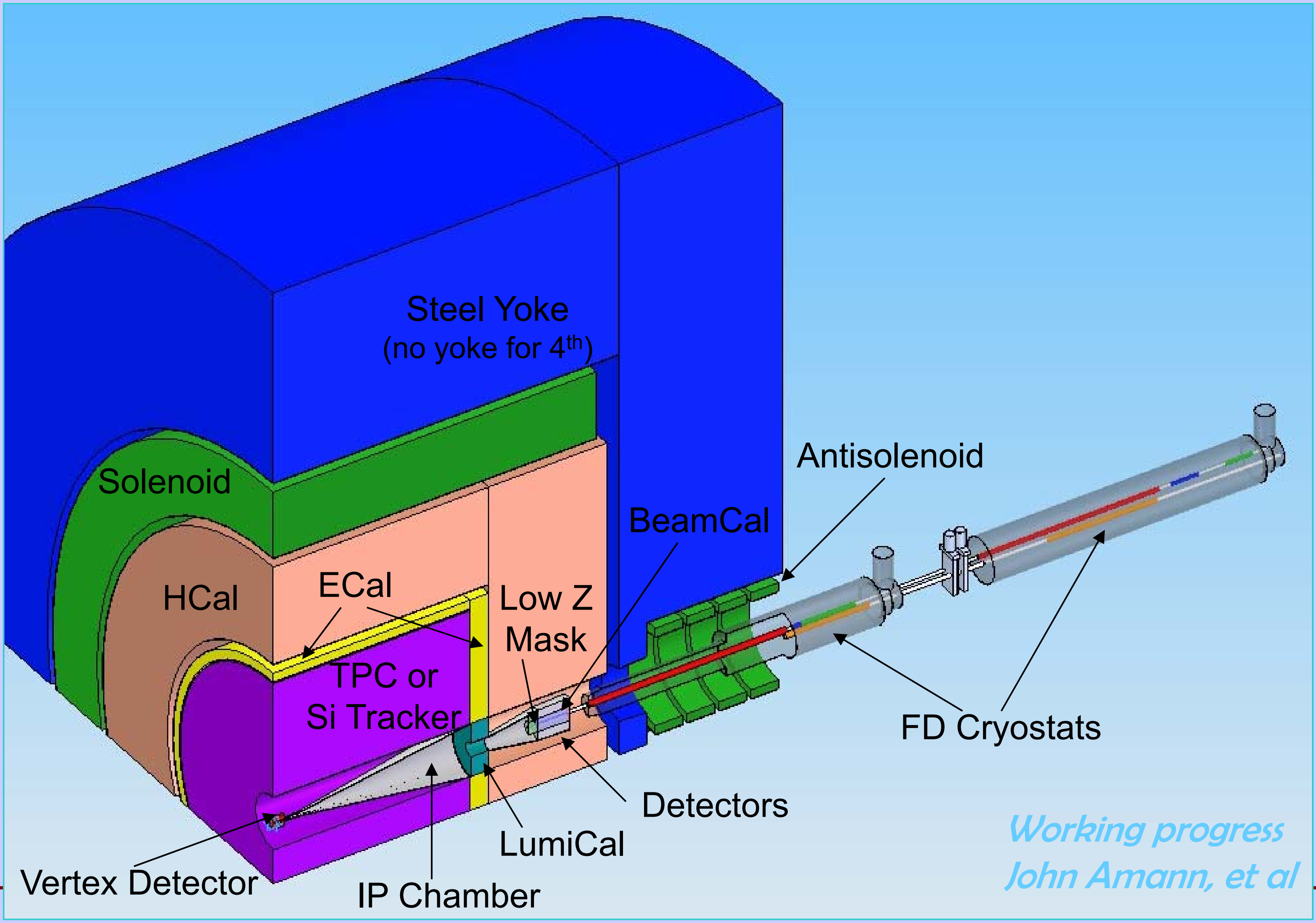
Move with detector

Stay fixed

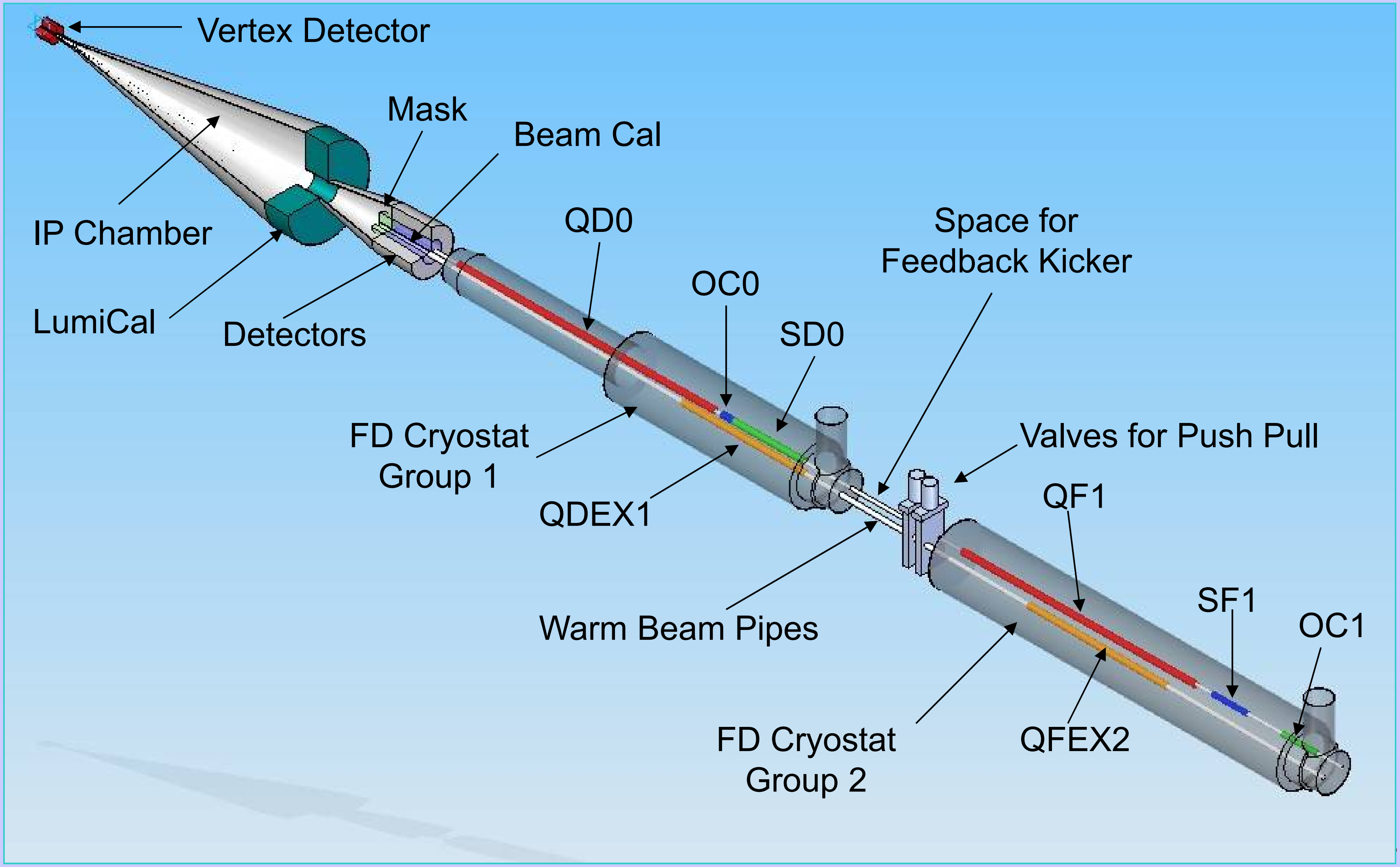
Warm space for vacuum valves for disconnect

B.Parker, et al, BNL

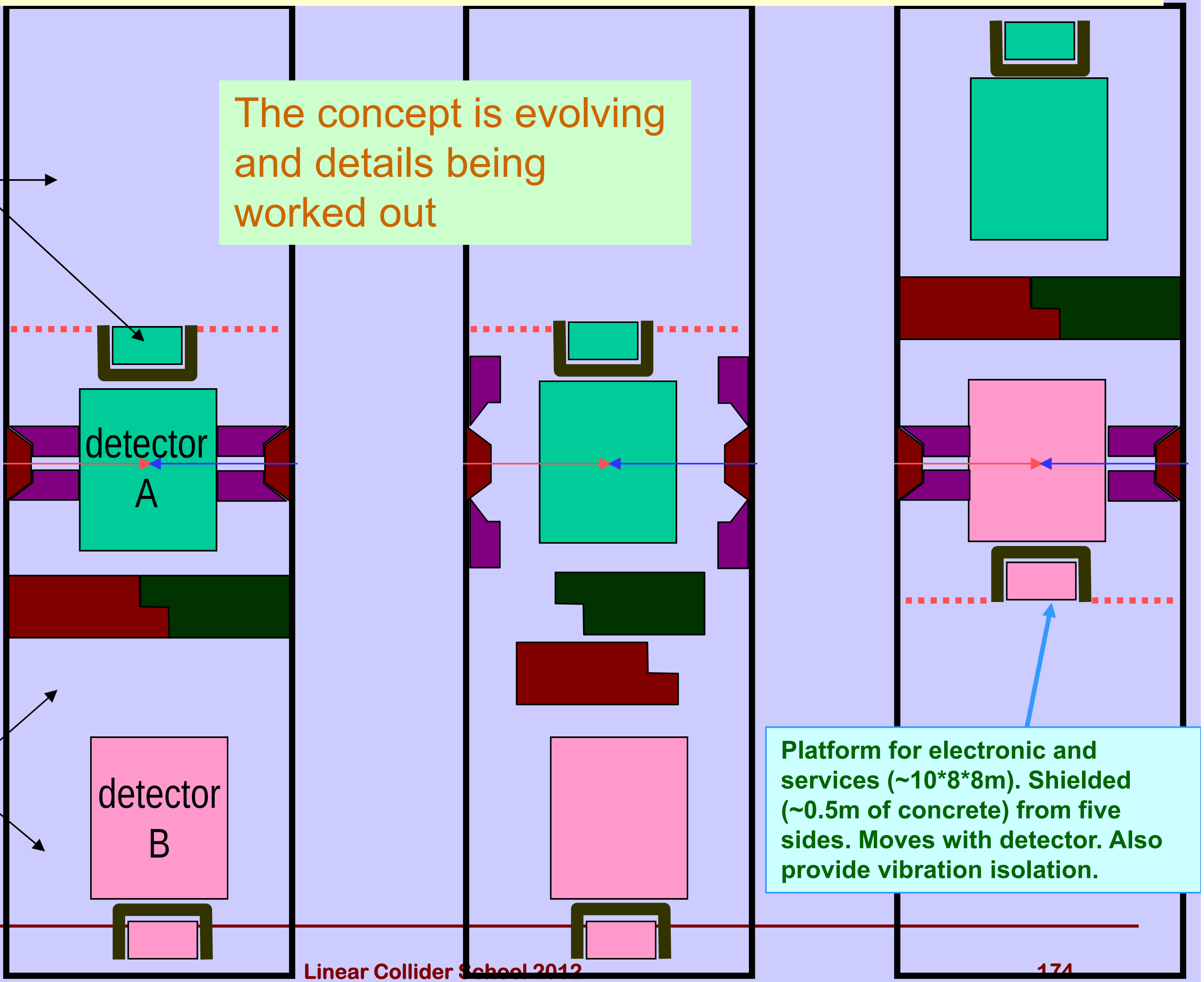
Generic Detector - IR Details



Generic IR layout



Concept of IR hall with two detectors



may be accessible during run

The concept is evolving and details being worked out

accessible during run

Platform for electronic and services (~10*8*8m). Shielded (~0.5m of concrete) from five sides. Moves with detector. Also provide vibration isolation.

Detector Performance Goals

- **ILC detector performance requirements and comparison to the LHC detectors:**
  - ○ Inner vertex layer ~ 3-6 times closer to IP
  - ○ Vertex pixel size ~ 30 times smaller
  - ○ Vertex detector layer ~ 30 times thinner

  Impact param resolution $\Delta d = 5\,[\mu m] \oplus 10\,[\mu m] / (p[GeV] \sin^{3/2}\theta)$

  - ○ Material in the tracker ~ 30 times less
  - ○ Track momentum resolution ~ 10 times better

  Momentum resolution $\Delta p / p^2 = 5 \times 10^{-5}\,[GeV^{-1}]$ central region

  $\Delta p / p^2 = 3 \times 10^{-5}\,[GeV^{-1}]$ forward region

  - ○ Granularity of EM calorimeter ~ 200 times better

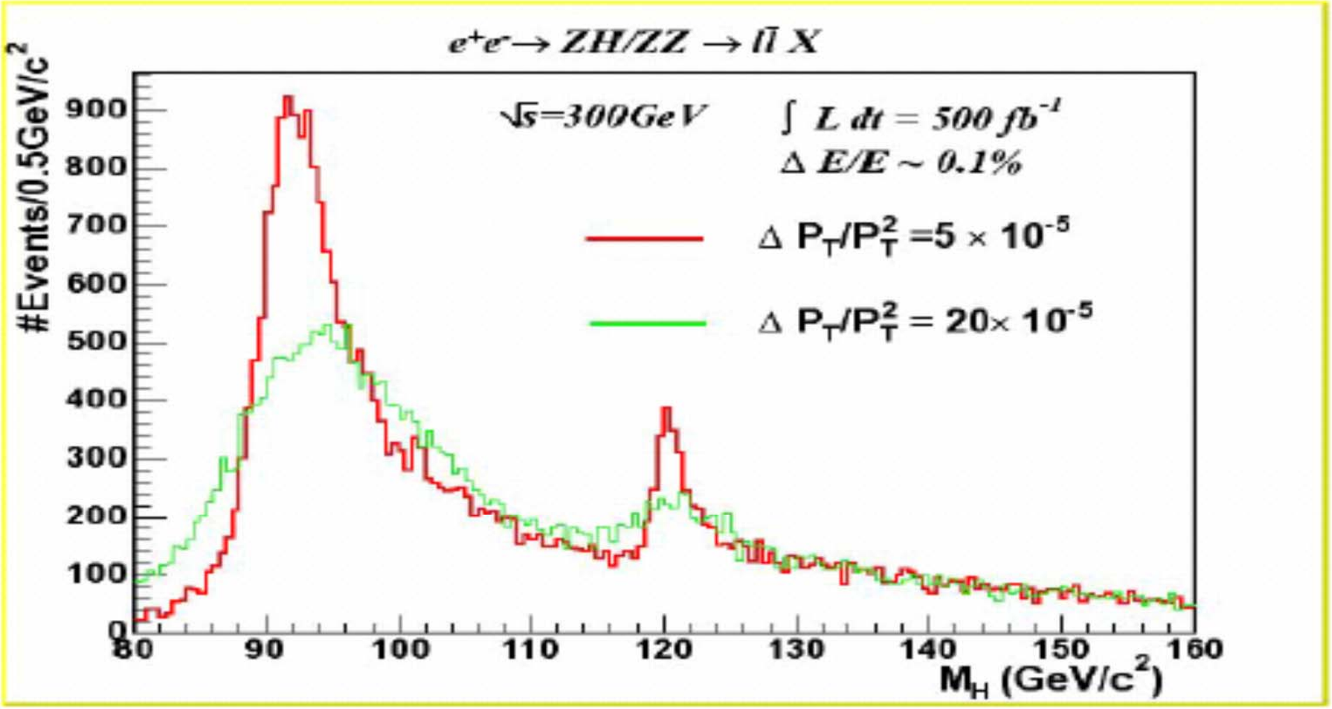
  Jet energy resolution $\Delta E_{jet} / E_{jet} = 0.3 / \sqrt{E_{jet}}$

  Forward Hermeticity down to $\theta = 5\text{-}10$ [mrad]

Detector Performance Goals

e.g: The Higgs tagging mode

$e^+e^- \to ZH, \quad Z \to \ell^+\ell^-$



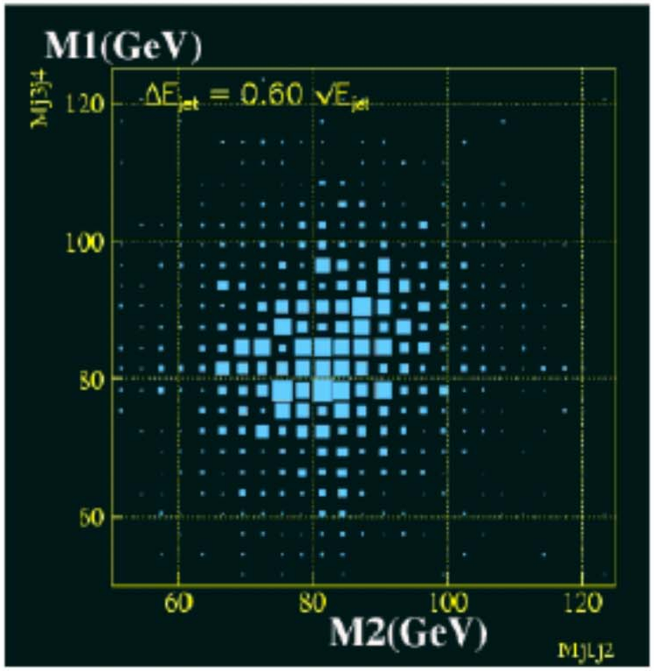
$\sigma_p/p^2 \sim 5\ \mathrm{x}10^{-5}$ is "necessary"

Detector Performance Goals

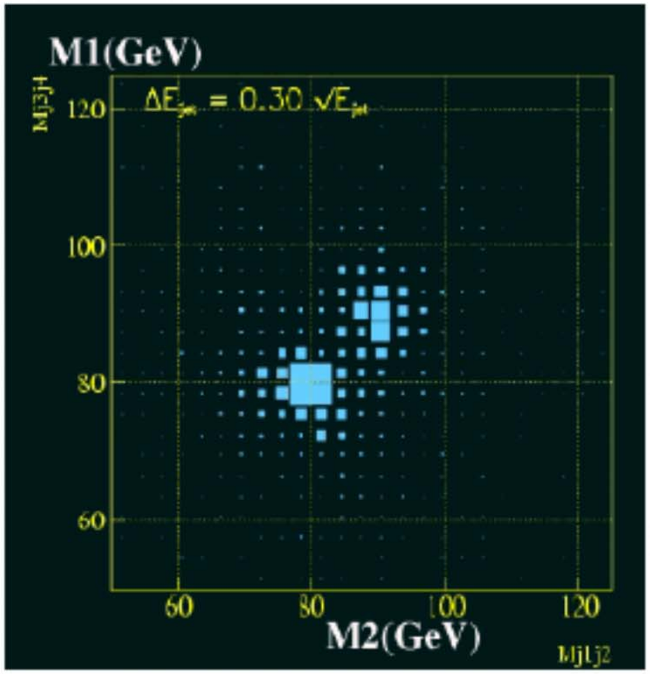
e.g: Separation of WW and ZZ

$$e^+e^- \to \nu\bar{\nu}W^+W^-, \nu\bar{\nu}ZZ\,, \quad W,Z \to 2\text{jets}$$

$$\frac{\sigma_E}{E} = \frac{0.6}{\sqrt{E}}$$



$$\frac{\sigma_E}{E} = \frac{0.3}{\sqrt{E}}$$



$\frac{\sigma_E}{E} \sim \frac{0.3}{\sqrt{E}}$ is ‘needed’.

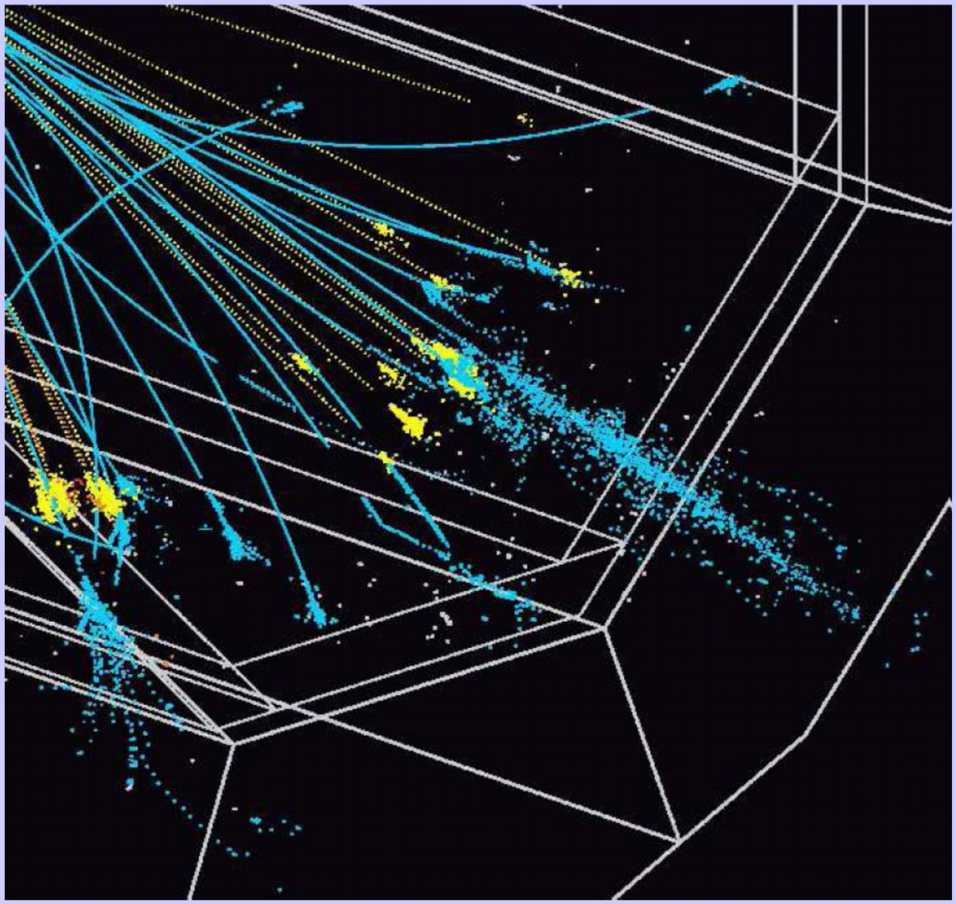
For jets !!!!

How to Achieve $\Delta E/E = 0.3/\sqrt{E}$

- **Must improve beyond sampling calorimeters**
- **Proposal → Use "energy / particle flow"**
  - **EM calorimeter (EMCAL) used to measure photons and electrons**
  - **Track charged hadrons from tracker through EMCAL**
  - **Identify energy deposition in hadron calorimeter (HCAL) with charged hadrons & replace deposition with measured momentum**
  - **The remaining energy of neutral hadrons (K's, Lambda's) is measured by sampling calorimetry**
- **Requires imaging calorimeter with very fine transverse segmentation and large dynamic range and EM resolution**

How to Achieve $\sigma_E/E = 0.3/\sqrt{E}$

- Simulation studies are underway to determine transverse and longitudinal sampling and test algorithms.
- Beam tests are needed to demonstrate the technique and resolutions achieved

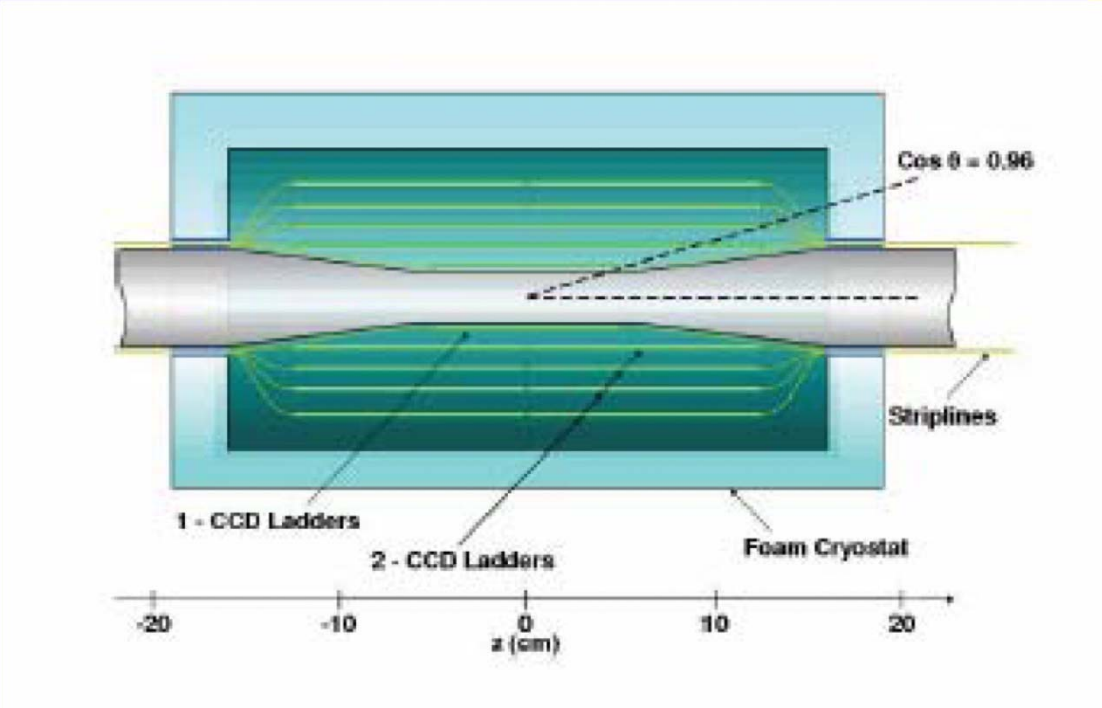


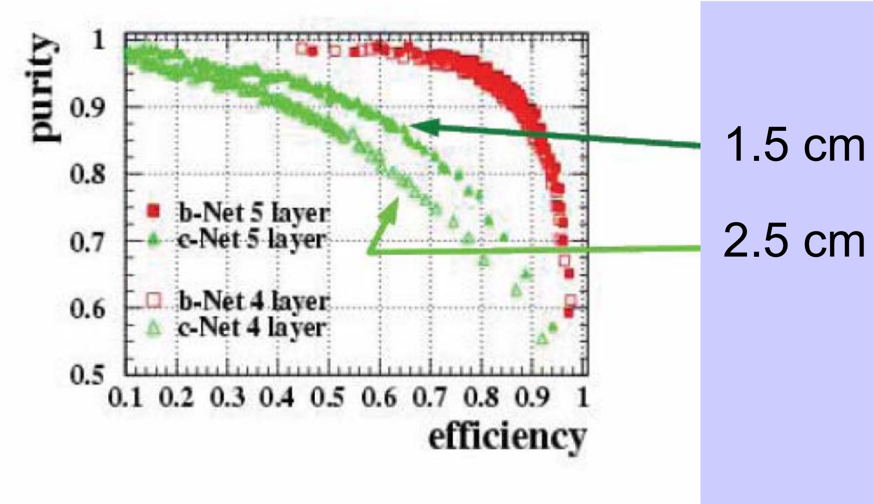
Imaging calorimeter, where spatial resolution becomes as important as energy resolution.

ILC Energy Flow Calorimetry

- Jet energy measurement is by the Energy/particle flow algorithm
- Charged particle momentum is measured by tracker
- Photon energy is measured by ECAL
- Neutral hadron (K_L n) energy is measured by HCAL(+ECAL)
- Separate these particles in the calorimeters
- $\sigma(E_{jet})^2 = \Sigma\Delta E_{ch}^2 + \Sigma\Delta E_\gamma^2 + \Sigma\Delta E_{neutral\ had}^2 + \Sigma\Delta_{confusion}^2$
- Due to high particle density in the core of jet and large fluctuation of HCAL energy flow, jet energy resolution is dominated by $\Delta E_{neutral\ had}$ and $\Delta_{confusion}$

Vertex Detectors





- Measurement of Higgs Boson coupling requires high purity and high efficiency b- and c-quark identification
- High occupancy due to soft e+e- pairs created by Beamstrahlung, therefore Si pixel detector
- The inner layers must be as thin close to the beam as possible

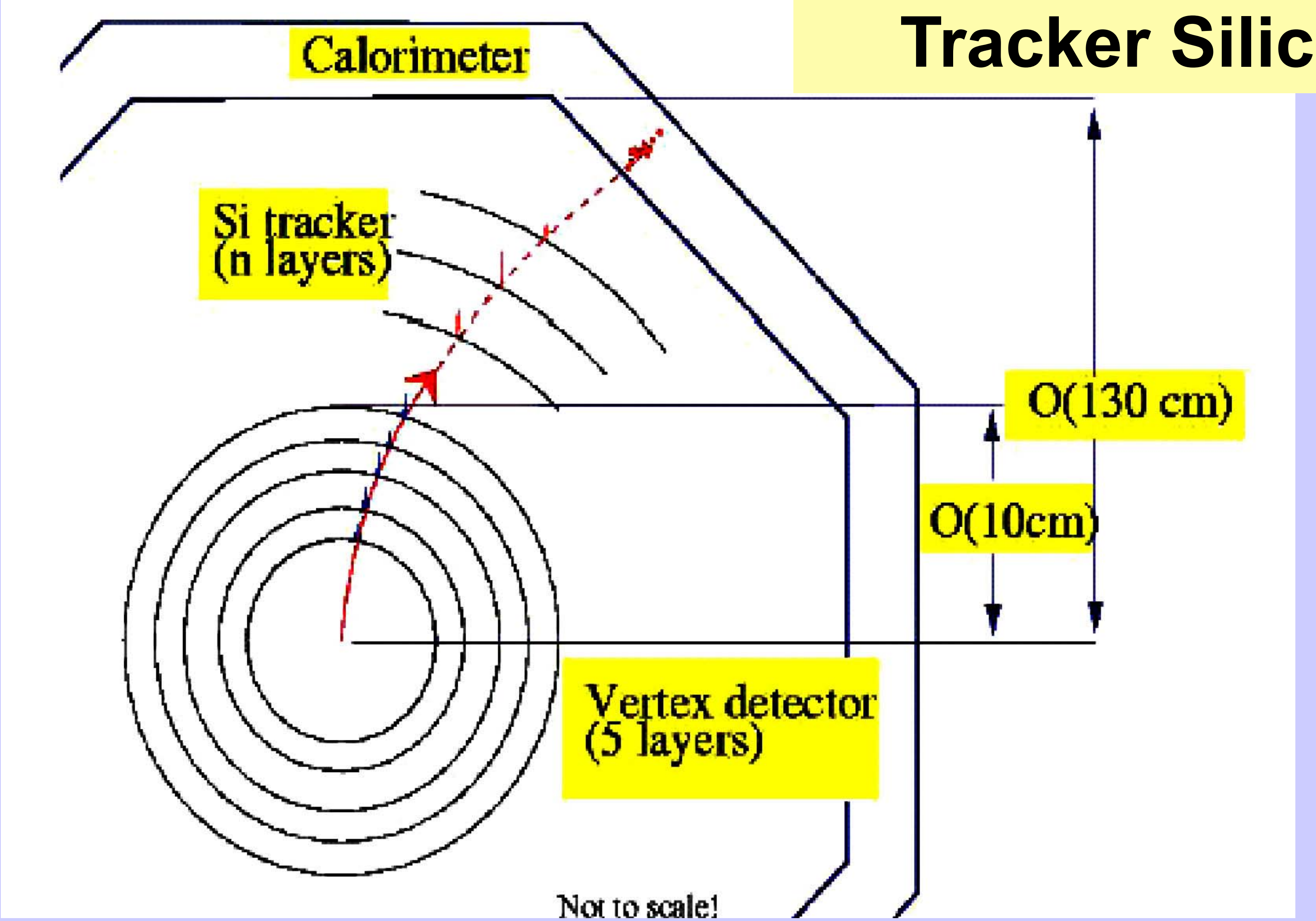
Tracking Considerations

- Momentum resolution (hit position accuracy, calibration, alignment)

$$\Delta p/p^2 \sim \sigma/R^2B\sqrt{N}$$

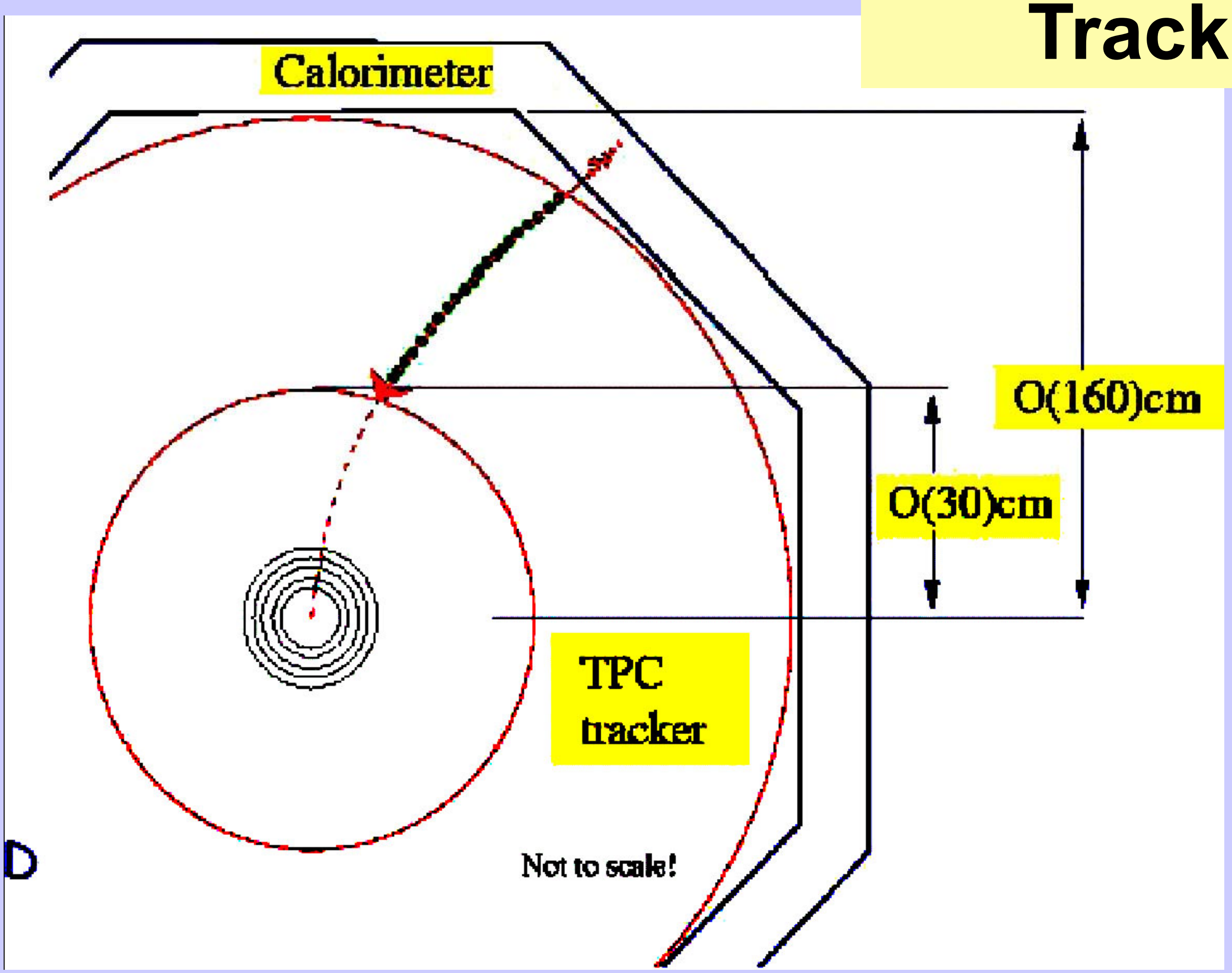
- Pattern recognition efficiency ~ N
- Need robustness vs background
- Two approaches in the Detector Concepts

Tracker Silicon



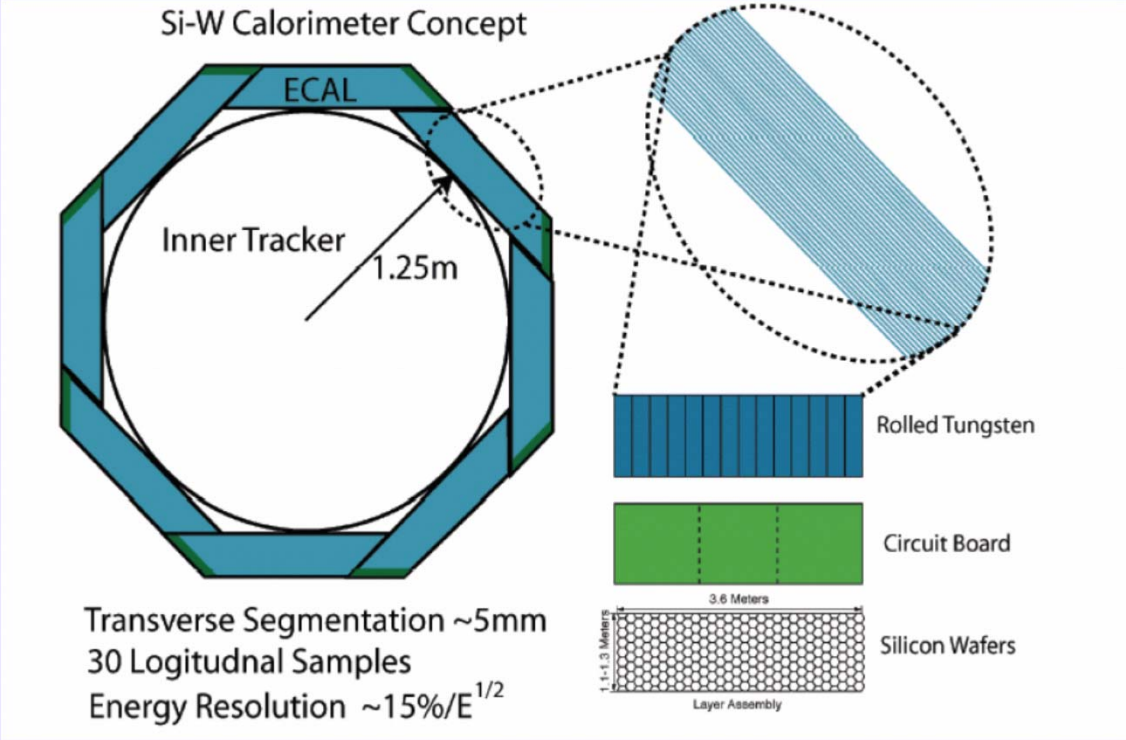
- **5 layers of pixel detectors and 5 layers of Si-strip**

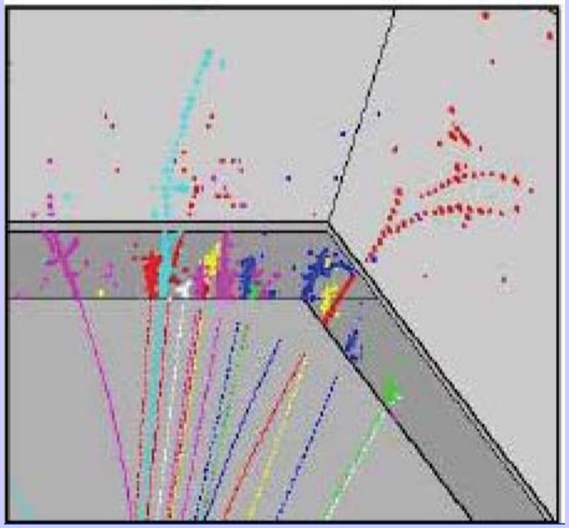
Tracker TPC



- *O*(200pts) in TPC; 5 layers pixel vertex detectors; *O*(2) Silicon tracking layers

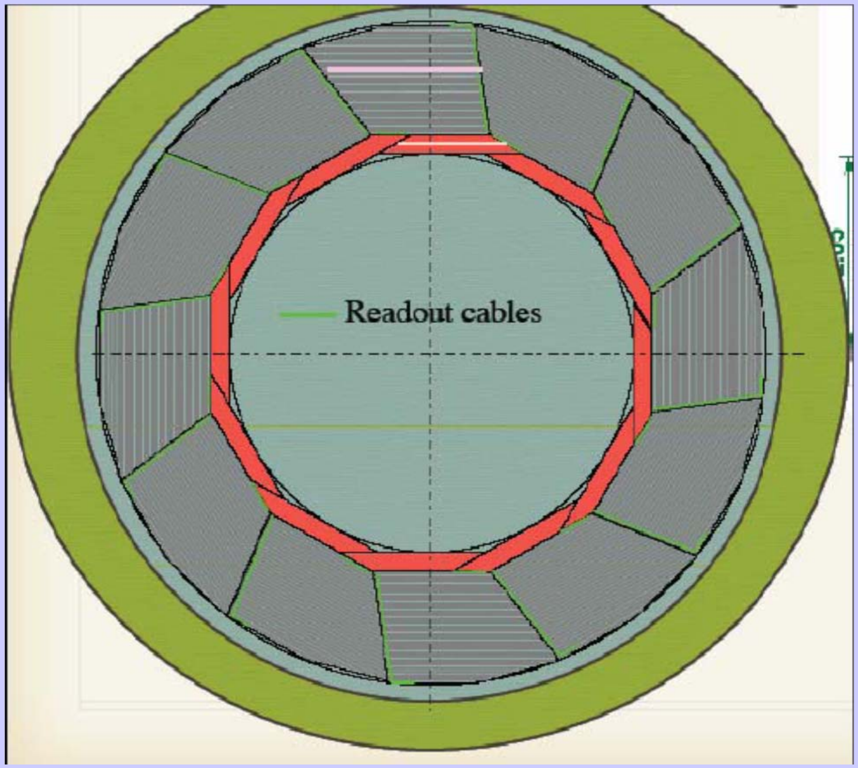
EM Calorimeter





- **Electro-magnetic Calorimeter Tungsten is an ideal material**
  - **short radiation length 3.5mm**
  - **small Moliere radius 9mm**
  - **Si-sensor / Si-PMT**

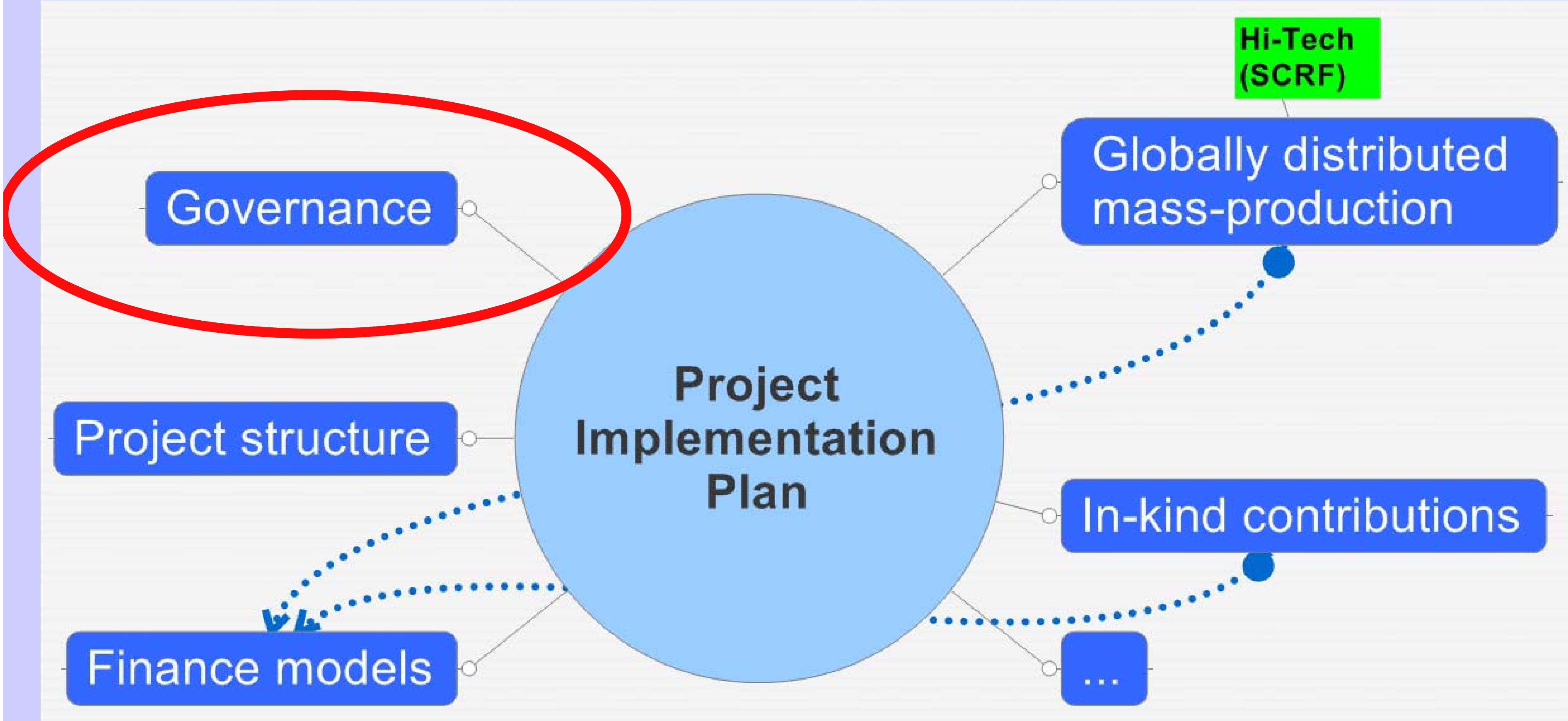
Hadronic Calorimeter



Hadron Calorimeter
Digital vs analog

- **Granularity, Hermeticity, Energy resolution, Thickness**

Project Implementation Plan



[redacted]

Higgs Factory – Energy

Staging / Upgrading

- ~125 GeV from LHC
  - 125+91=216 GeV cm → 250 GeV
- 173 GeV Top quark
  - 2x173=346 GeV cm → 350-400 GeV
- Higgs self coupling (t-coupling) ???
  - ≥ 500 CM (up to 650 ??)
- TeV and beyond….?

250 GeV CM (first stage)

Relative to TDR 500 GeV baseline

Two stage compressor (5-15 GeV)

Half linacs solution
G = 31.5 MV/m

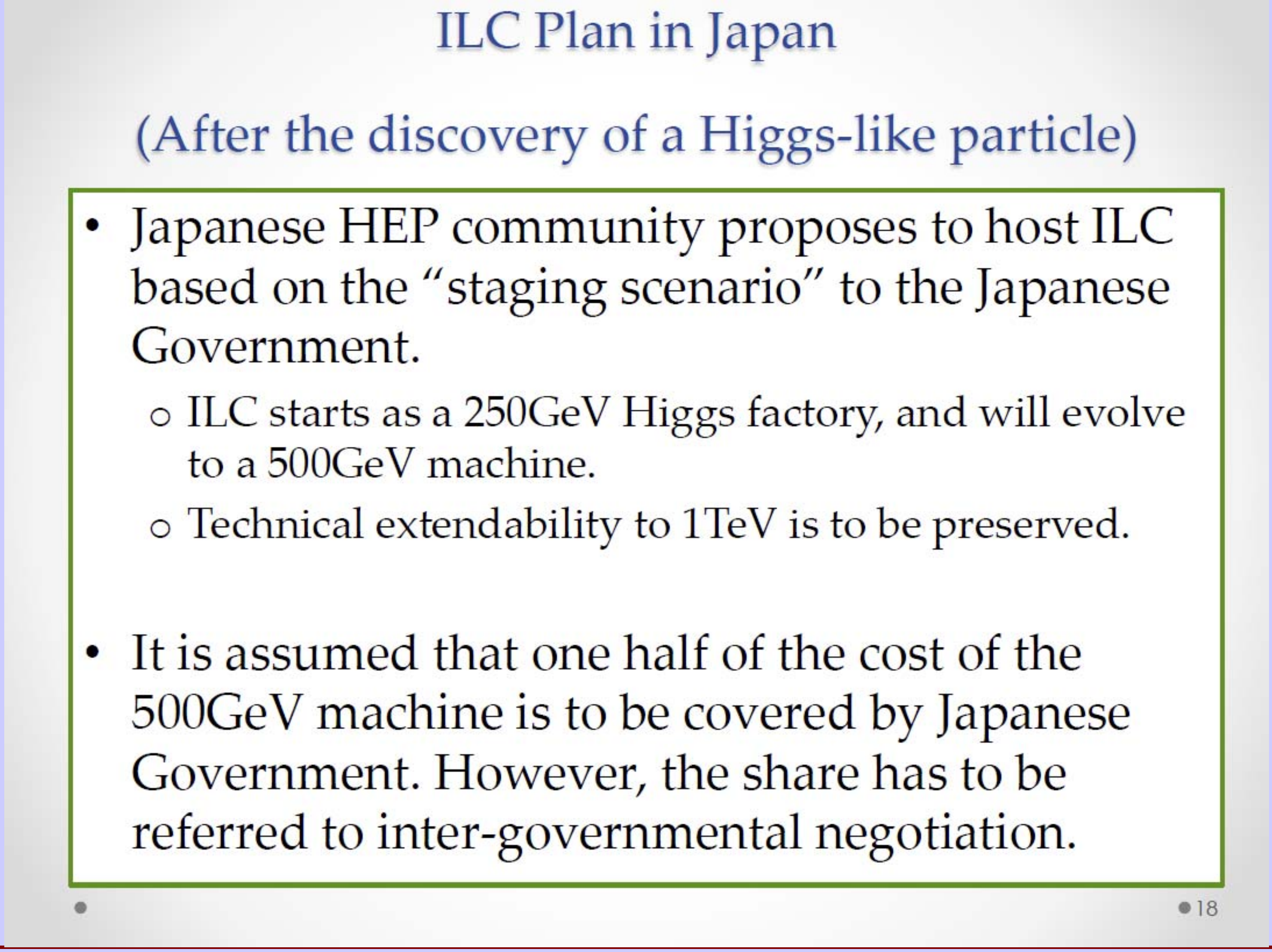
POSITRON linac straightforward
~50% ML linac cost (cryomodules, klystrons, cryo etc.)
~50% ML AC power

ELECTRON linac needs 10Hz mode for e+ production
ΔE = 135 GeV instead of 110 GeV (+25 GeV)
~57% ML linac cost (cryomodules, klystrons etc)

Main Linac infrastructure
Linac components: 50%
Cryogenics: 65%
RF AC power: 80%

10Hz needs (1/2 linac × 10Hz/5Hz):
100% ML AC power
(1/2 linac × 10Hz/5Hz)
80% cryo cost
(50% static + 100% dynamic)

Y. Okada @ Fermilab

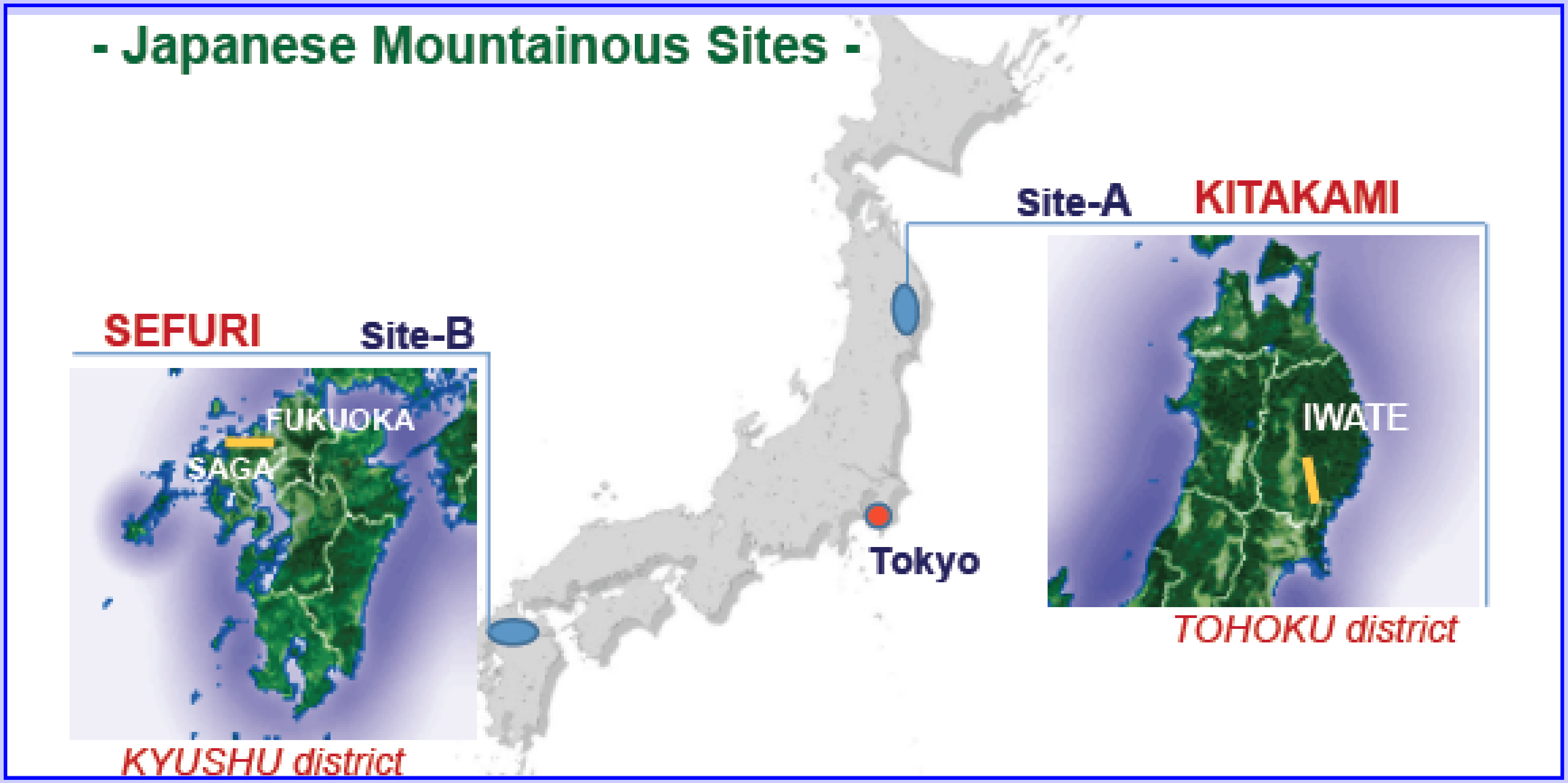


ILC Plan in Japan

(After the discovery of a Higgs-like particle)

- Japanese HEP community proposes to host ILC based on the "staging scenario" to the Japanese Government.
  - ILC starts as a 250GeV Higgs factory, and will evolve to a 500GeV machine.
  - Technical extendability to 1TeV is to be preserved.
- It is assumed that one half of the cost of the 500GeV machine is to be covered by Japanese Government. However, the share has to be referred to inter-governmental negotiation.

Two Candidate Sites in Asia/Japan



GDE Conclusions

- **The major R&D milestones for TDR are in-hand**
- **The TDR will be a self-contained comprehensive R&D report; with a design based on new baseline; a new value costing; and a section on project implementation planning**
- **Submit: Dec 2012; Reviews of technical design & costs;**
  - **Technical Review by augmented PAC (Dec 2012 at KEK)**
  - **Cost Review by international committee (Jan 2013 at Orsay)**
  - **TDR Overall Review by ILCSC (Feb 2013 at Vancouver)**
- **Revise, rewrite as needed; finalize and submit to ICFA at LP2013 (June 2013)**

GDE Mandate Complete

- **Post–TDR ILC program: 1) extend energy reach; 2) systems tests; 3) evolve design based on technology development and LHC results; consider staged design, beginning with Higgs Factory.**