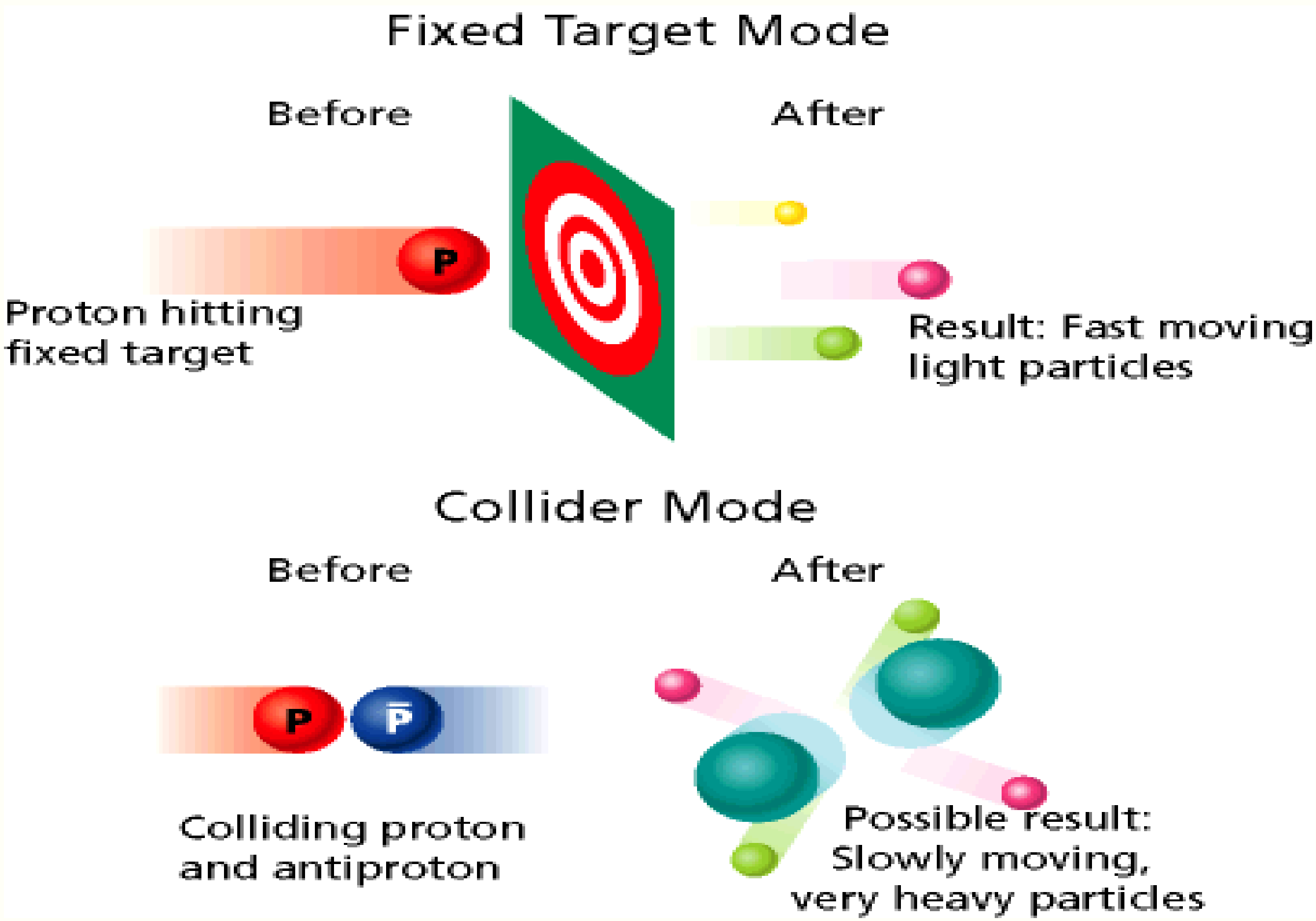
Introduction to the ILC

Lecture I-2

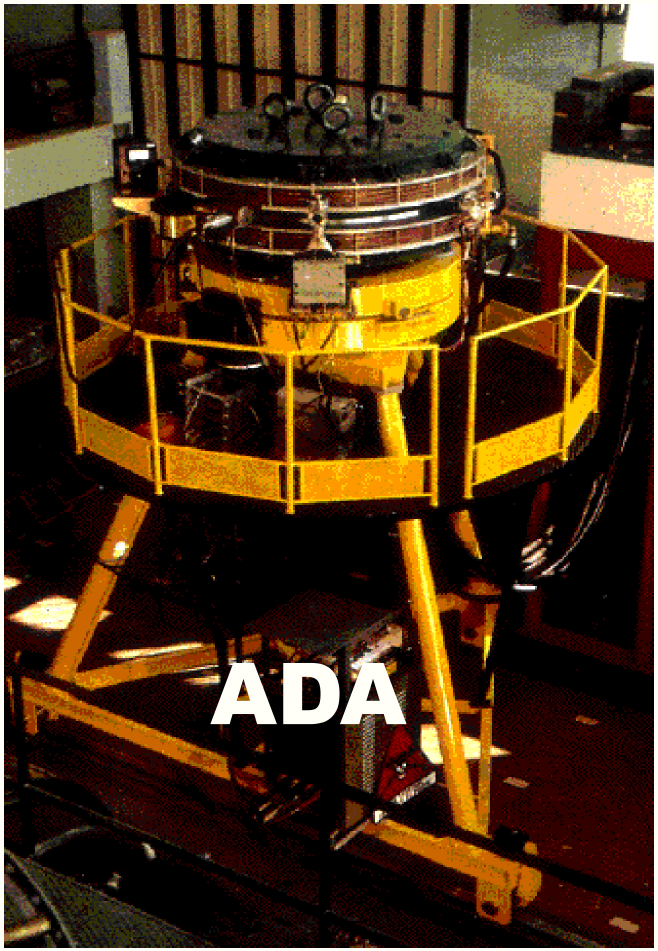


Barry Barish

Caltech / GDE

26-Oct-10

Electron-Positron Colliders

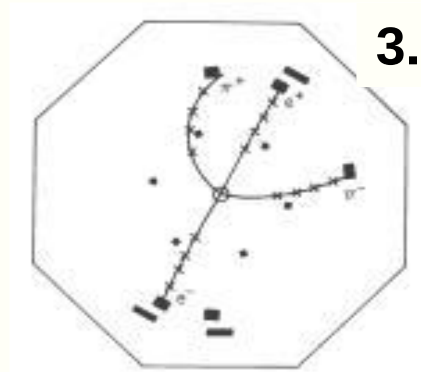


Bruno Touschek built the first successful electron-positron collider at Frascati, Italy (1960)

Eventually, went up to 3 GeV

But, not quite high enough energy ….

SPEAR at SLAC

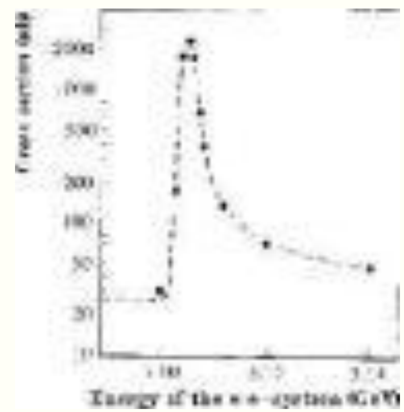


3.1 GeV

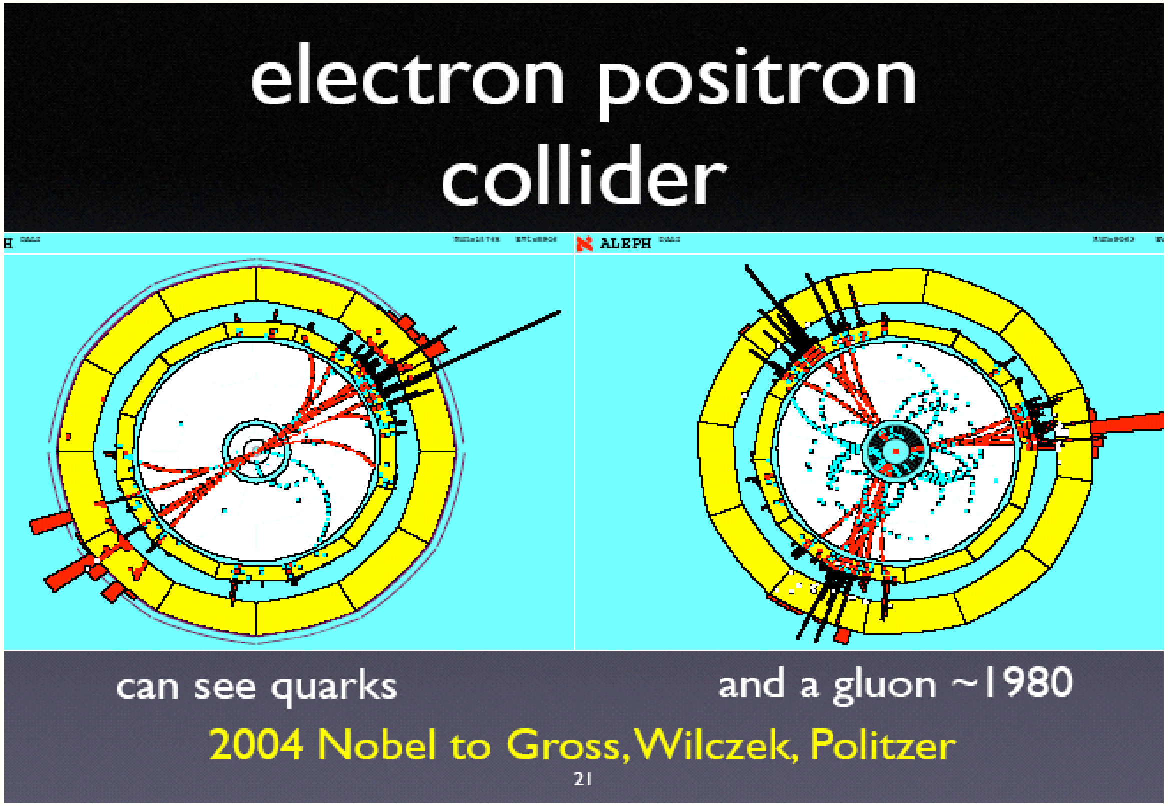
Burt Richter
Nobel Prize

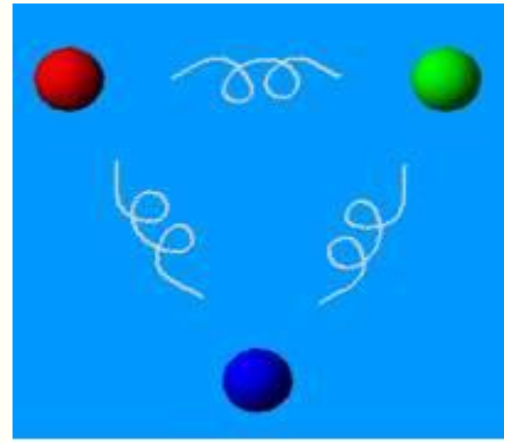
and

Discovery
Of
Charm
Particles



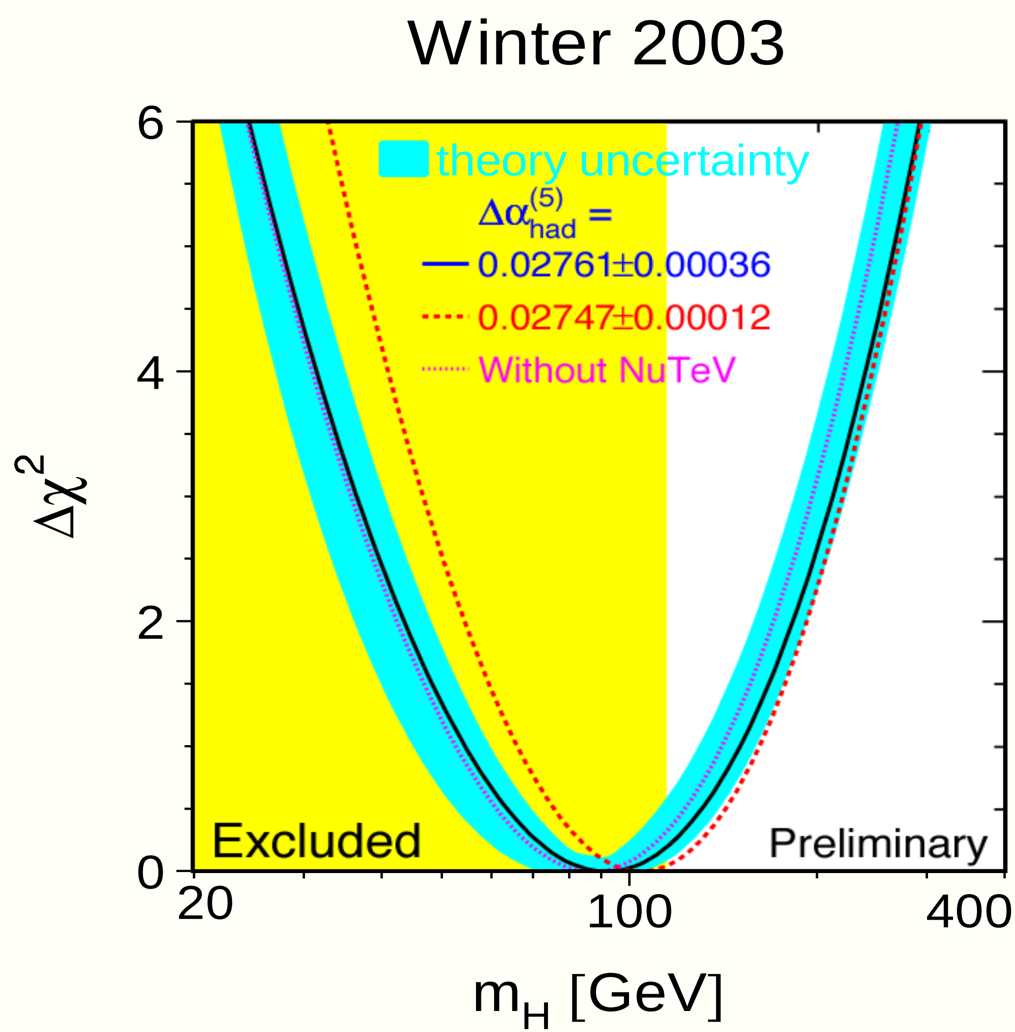
The rich history for e^+e^- continued as higher energies were achieved …





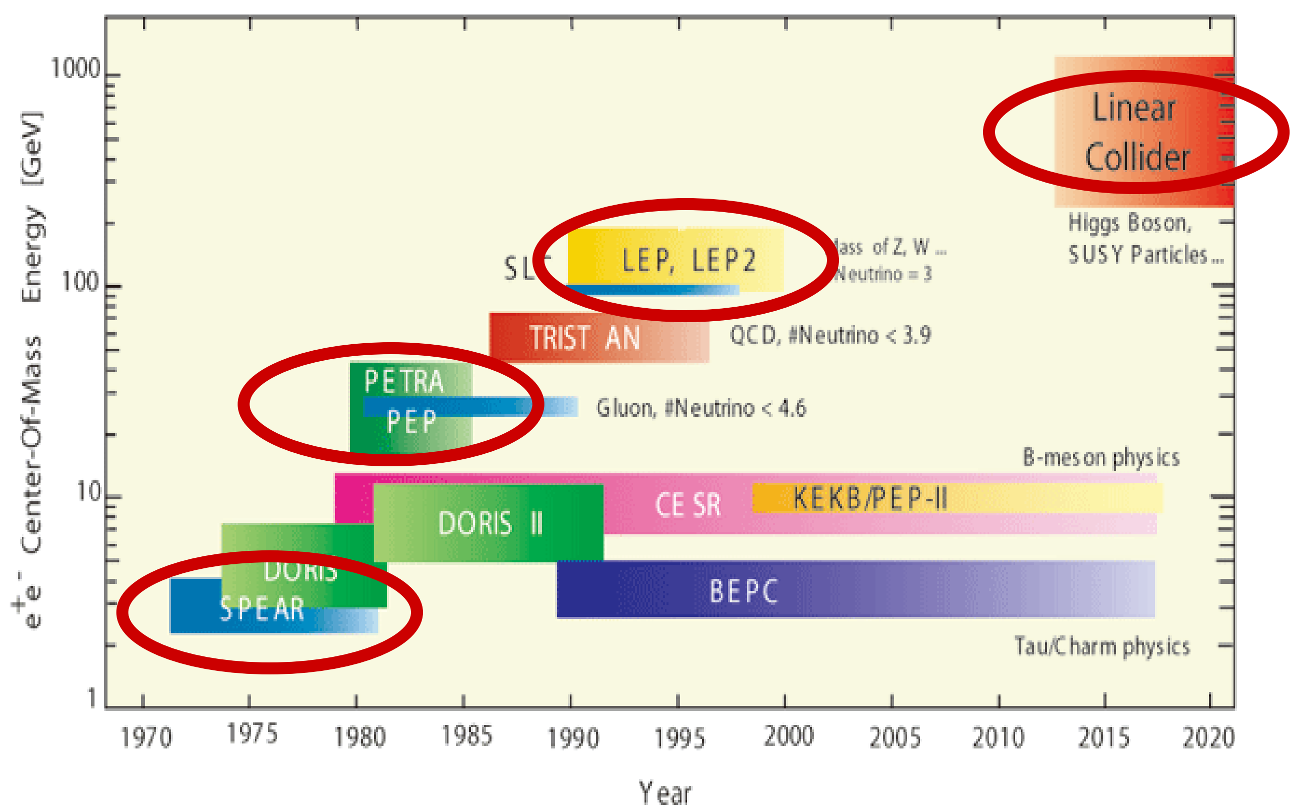
DESY PETRA Collider

LEP: Electroweak Precision Measurements



Three Generations of e^+e^- Colliders

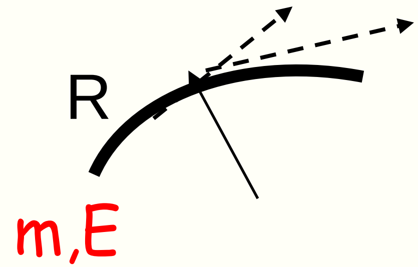
The Energy Frontier



Fourth Generation?

Circular or Linear Collider?

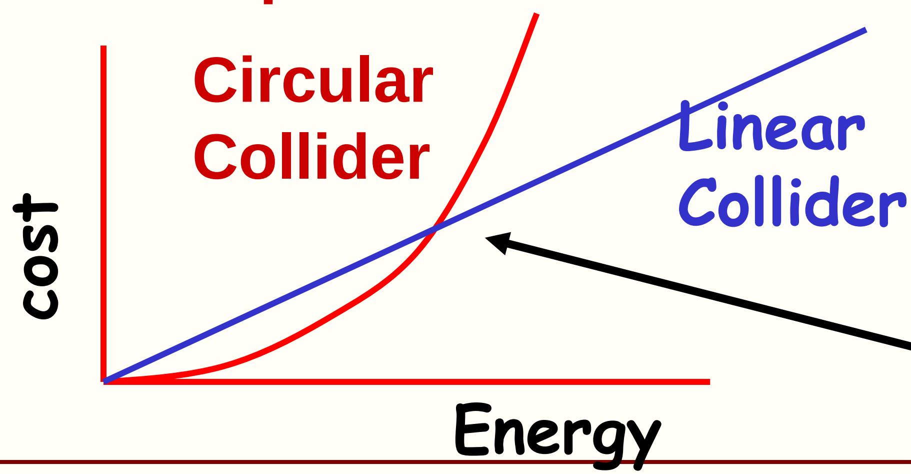
- **Circular Machine**



Synchrotron Radiation

  - $\Delta E \sim (E^4/m^4 R)$
  - Cost $\sim a R + b\, \Delta E$

    $\sim a R + b\, (E^4/m^4 R)$
  - **Optimization : $R \sim E^2 \Rightarrow$ Cost $\sim c\, E^2$**



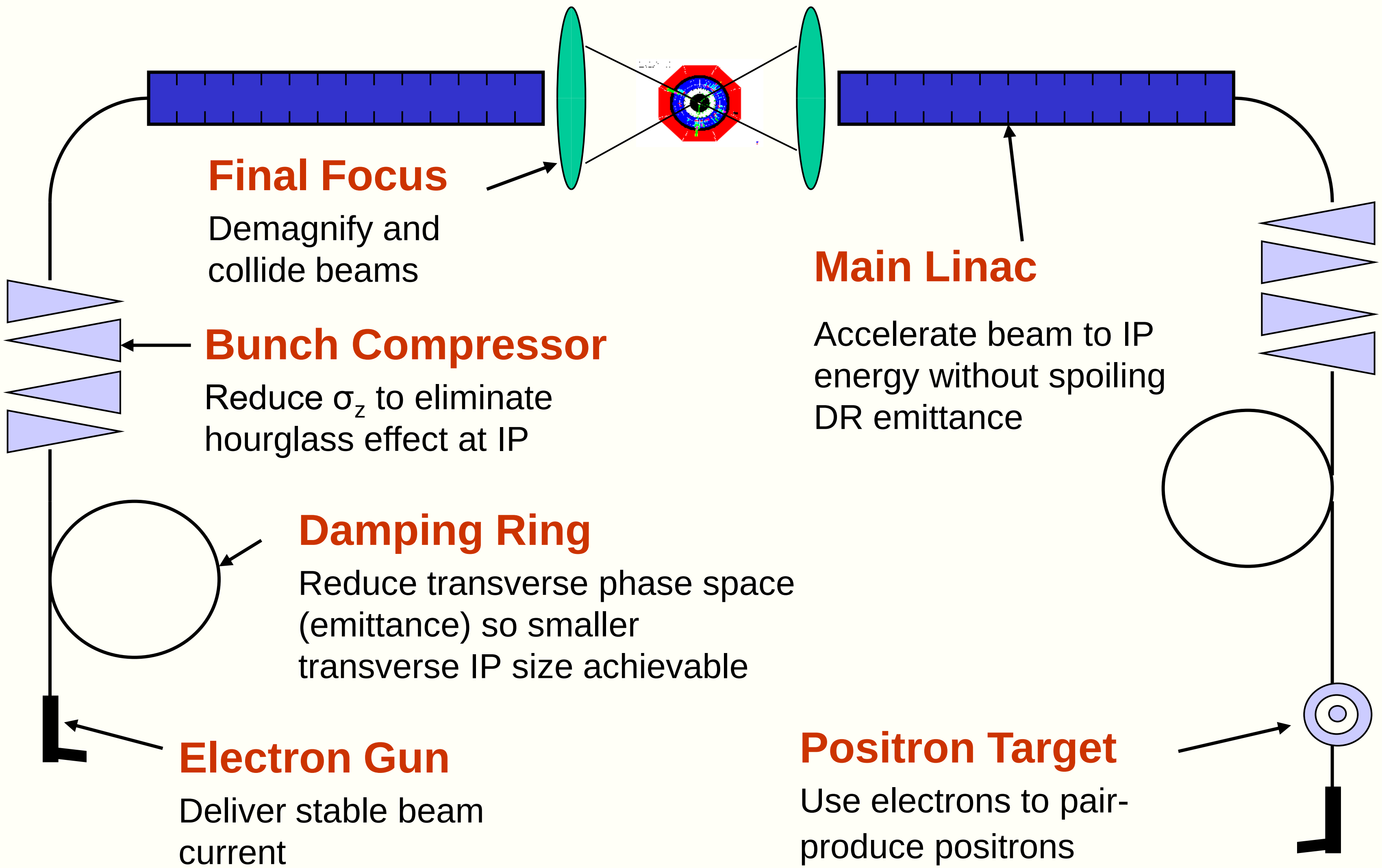
- Cost (linear) $\sim a' L$
- where $L \sim E$

~ 200 GeV

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



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.

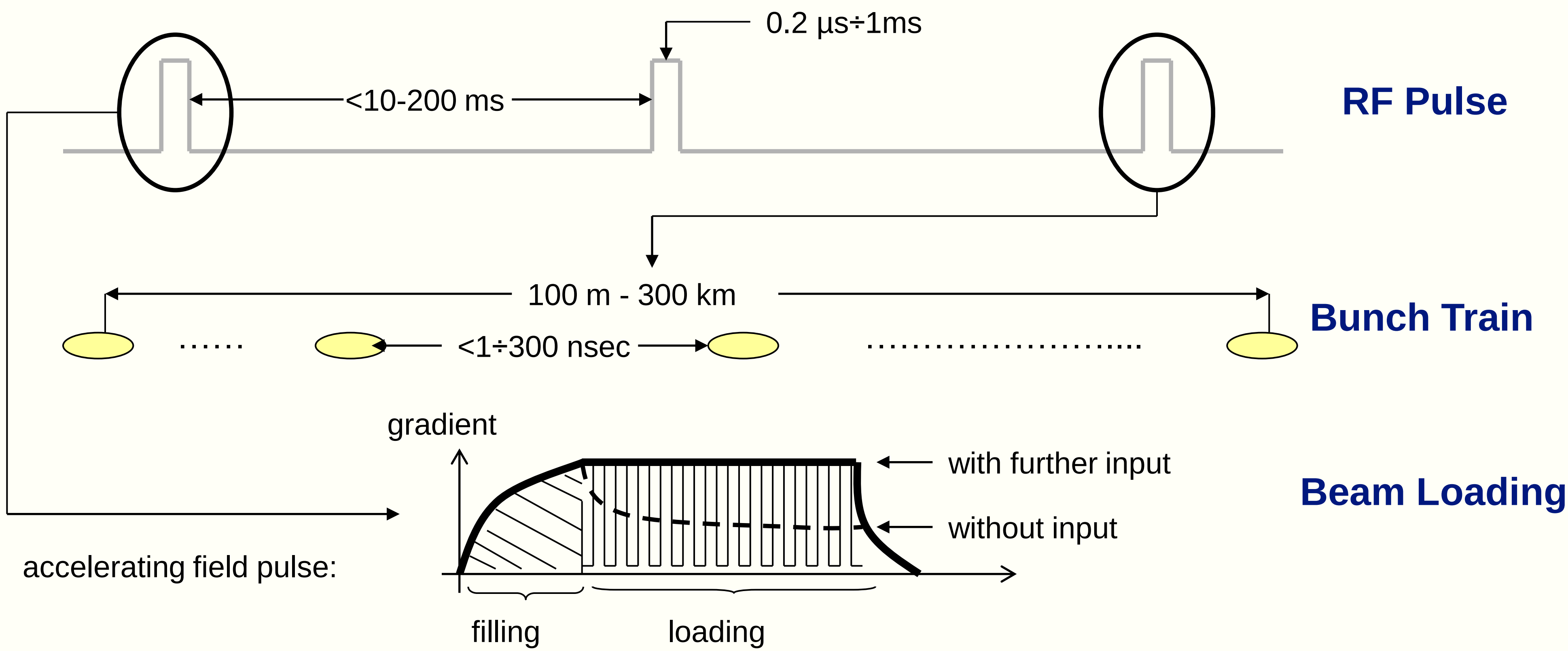
- **Beam Delivery System**

  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.

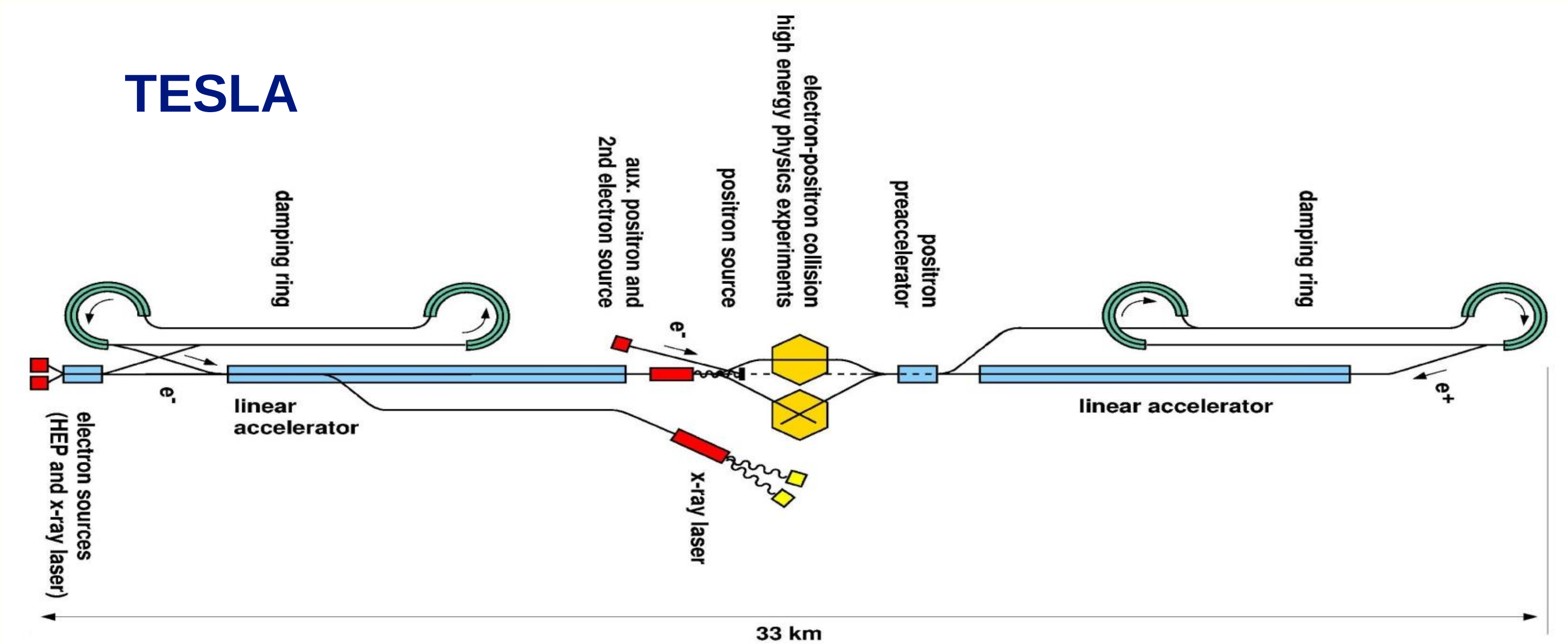
Linear Colliders are pulsed

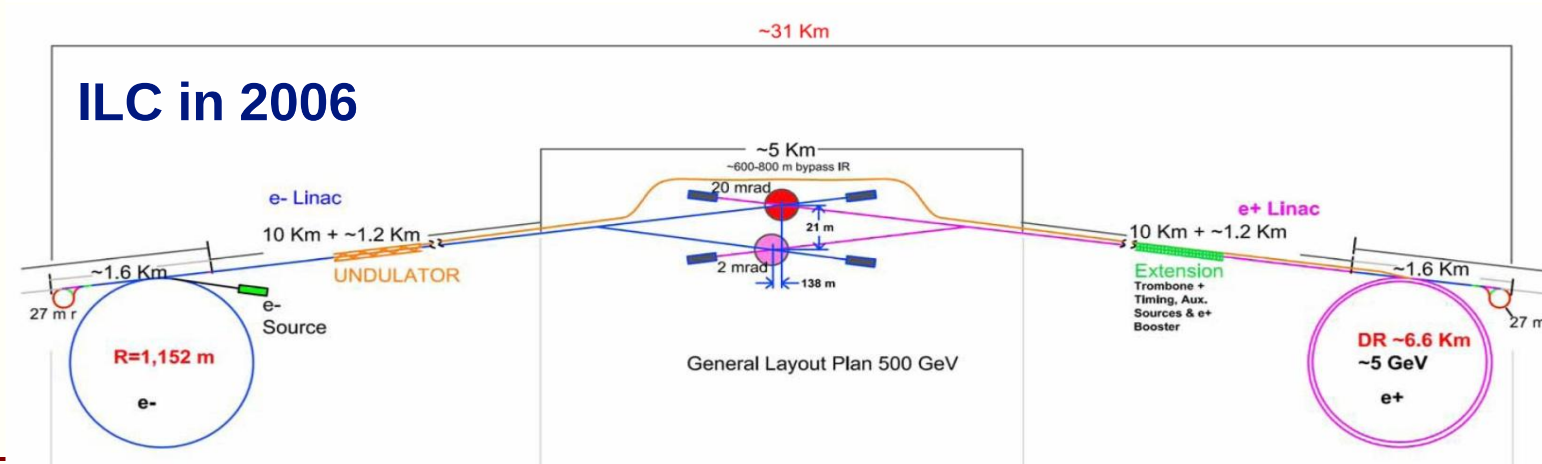
All LCs are pulsed machines to improve efficiency. As a result:

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

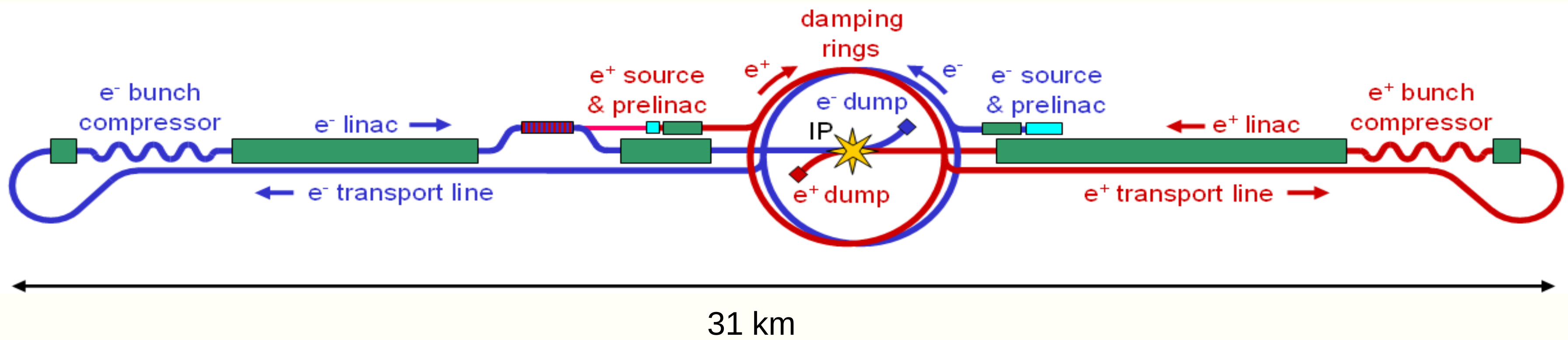


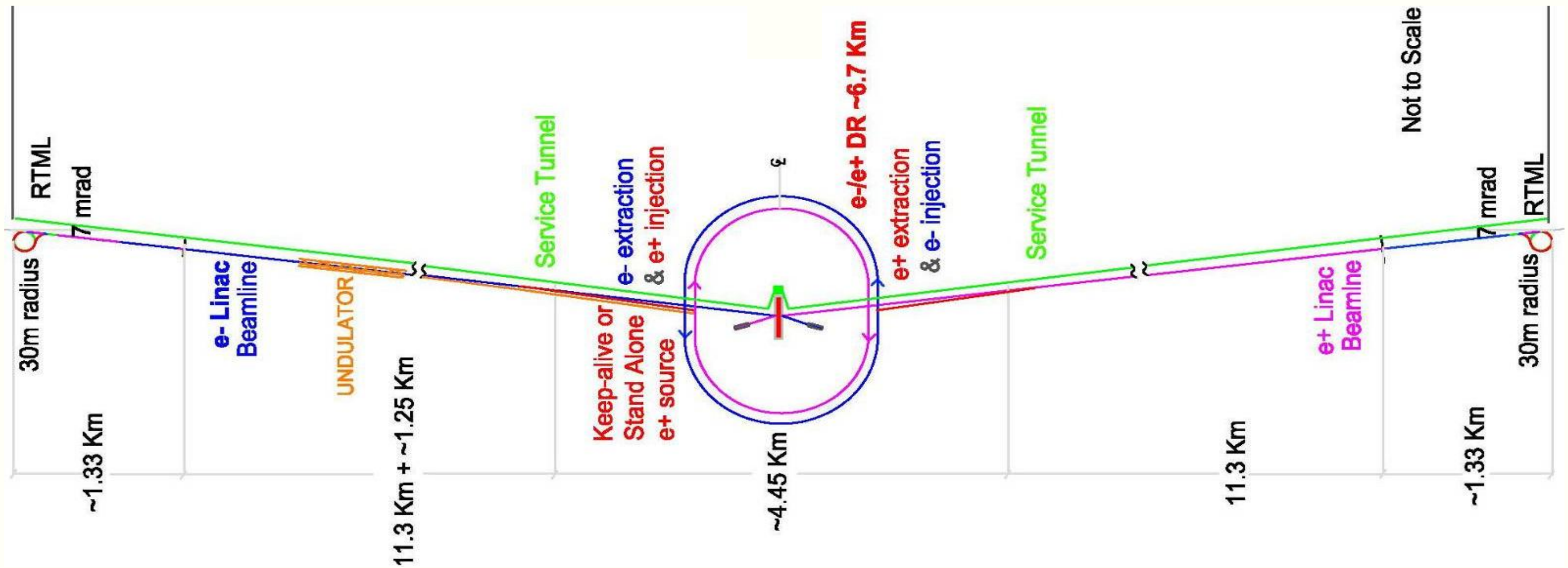
ILC Design Evolution



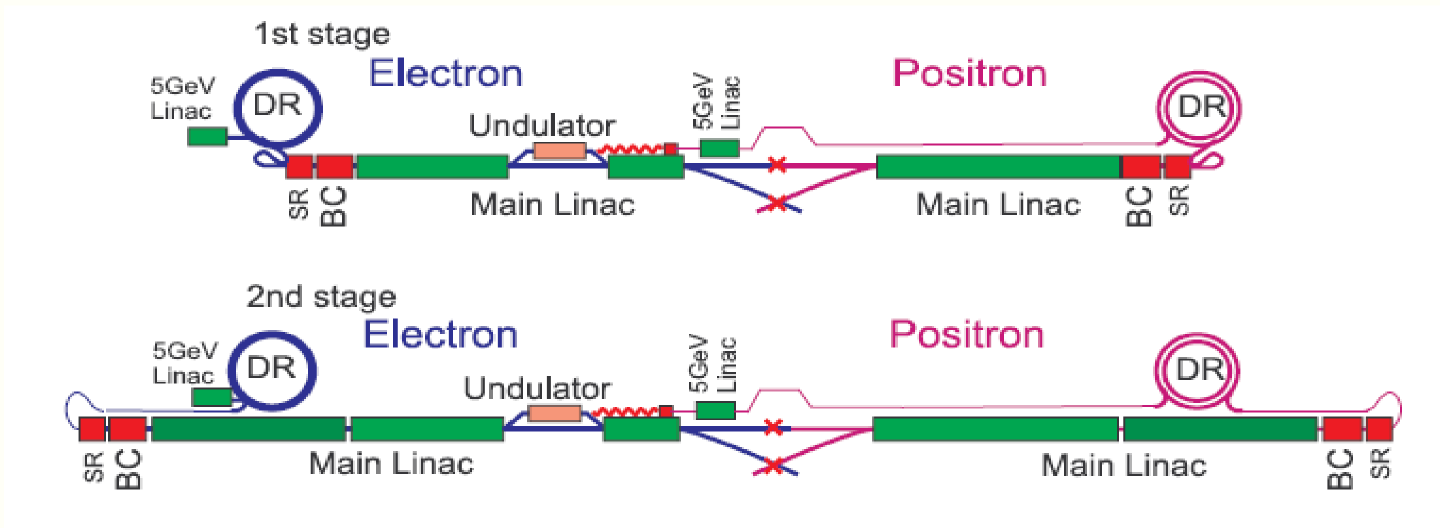


The ILC Reference Design





ILC Baseline Configuration

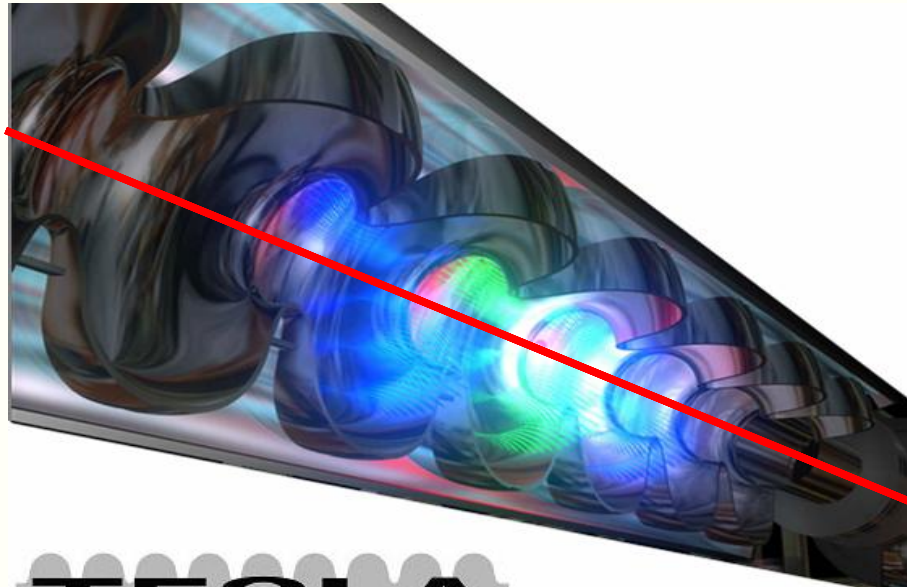


		min		nominal		max	
Bunch charge	N	1	-	2	-	2	$\times 10^{10}$
Number of bunches	n_b	1330	-	2820	-	5640	
Linac bunch interval	t_b	154	-	308	-	461	ns
Bunch length	σ_z	150	-	300	-	500	μm
Vert.emit.	$\gamma\epsilon_y^*$	0.03	-	0.04	-	0.08	mm·mrad
IP beta (500GeV)	β_x^*	10	-	21	-	21	mm
	β_y^*	0.2	-	0.4	-	0.4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

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.

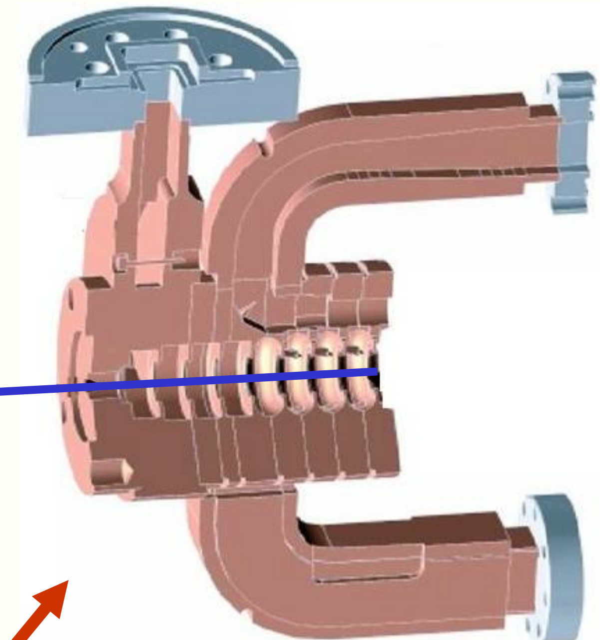
Linear Collier: Competing Technologies



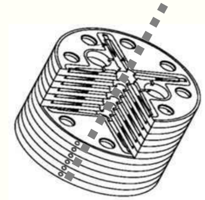
1.3 GHz - Cold

Evolution from: CEBAF & LEPII
+ TRISTAN, HERA, etc.

Evolution from: SLAC & SLC

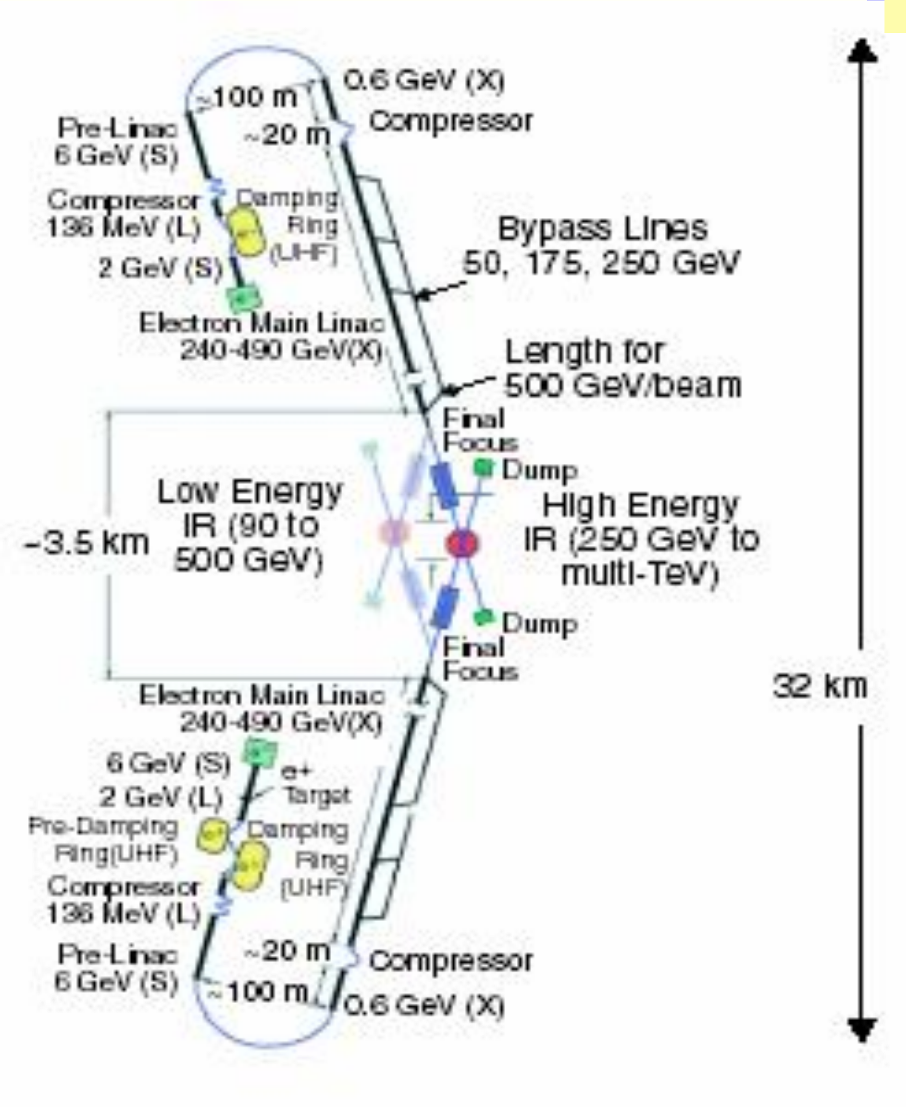


11.4 GHz - Warm



12 GHz - Warm

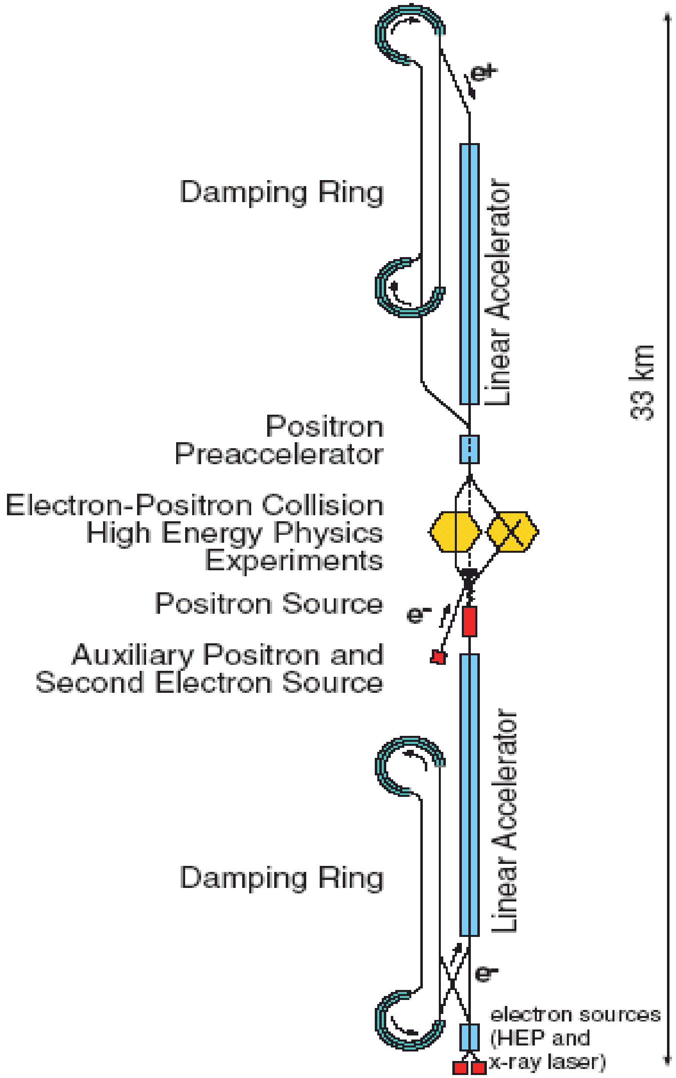
GLC



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.



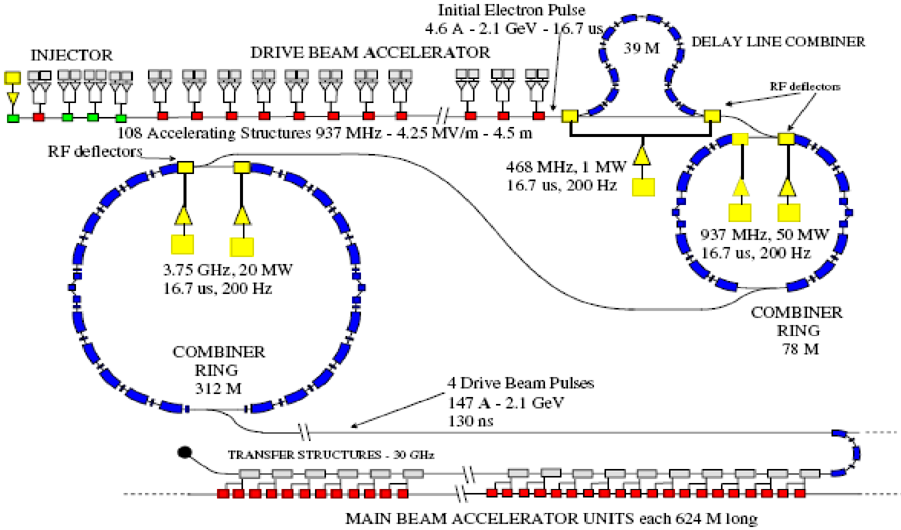
TESLA Concept

The main linacs based on 1.3 GHz superconducting technology operating at 2 K.

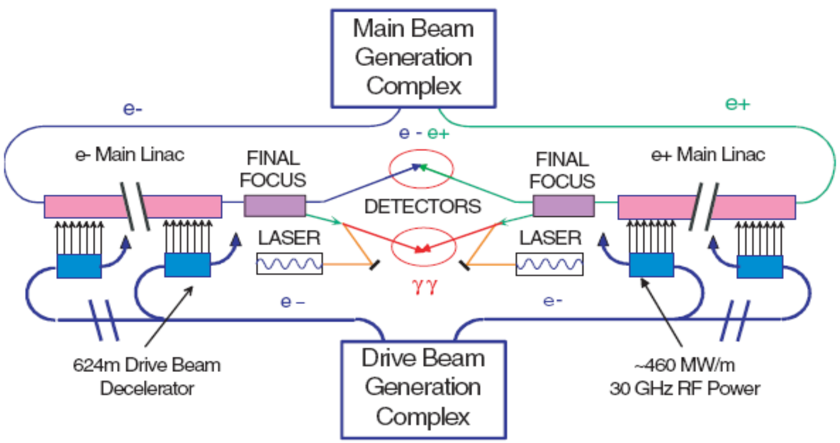
The cryoplant, is of a size comparable to that of the LHC, consisting of seven subsystems strung along the machines every 5 km.

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 ~2010

Technical Review Committee

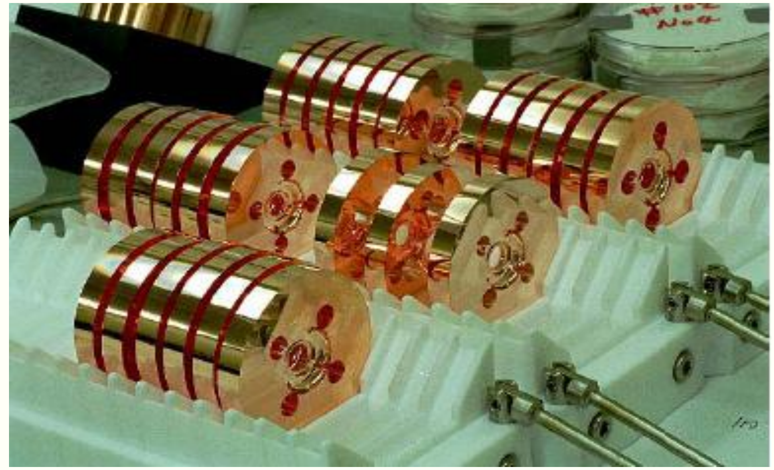
In Feb. 2001, ICFA charged a Technology Review Committee, chaired by Greg Loew of SLAC to review the critical R&D readiness issues.

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

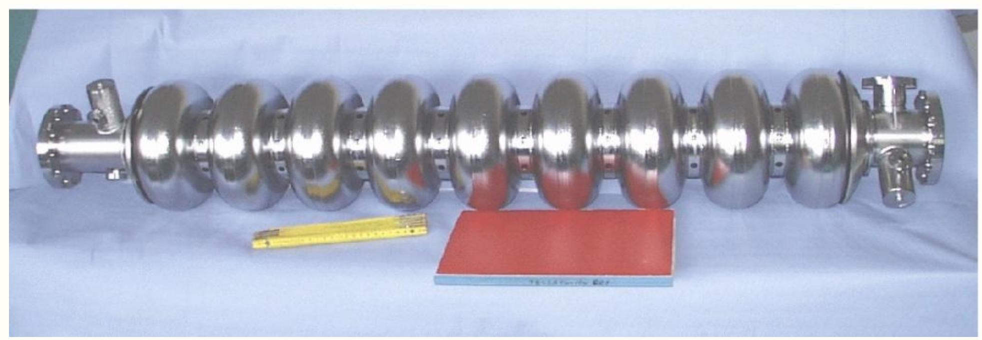
ILC – Underlying Technology

- 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

Superconducting RF Technology

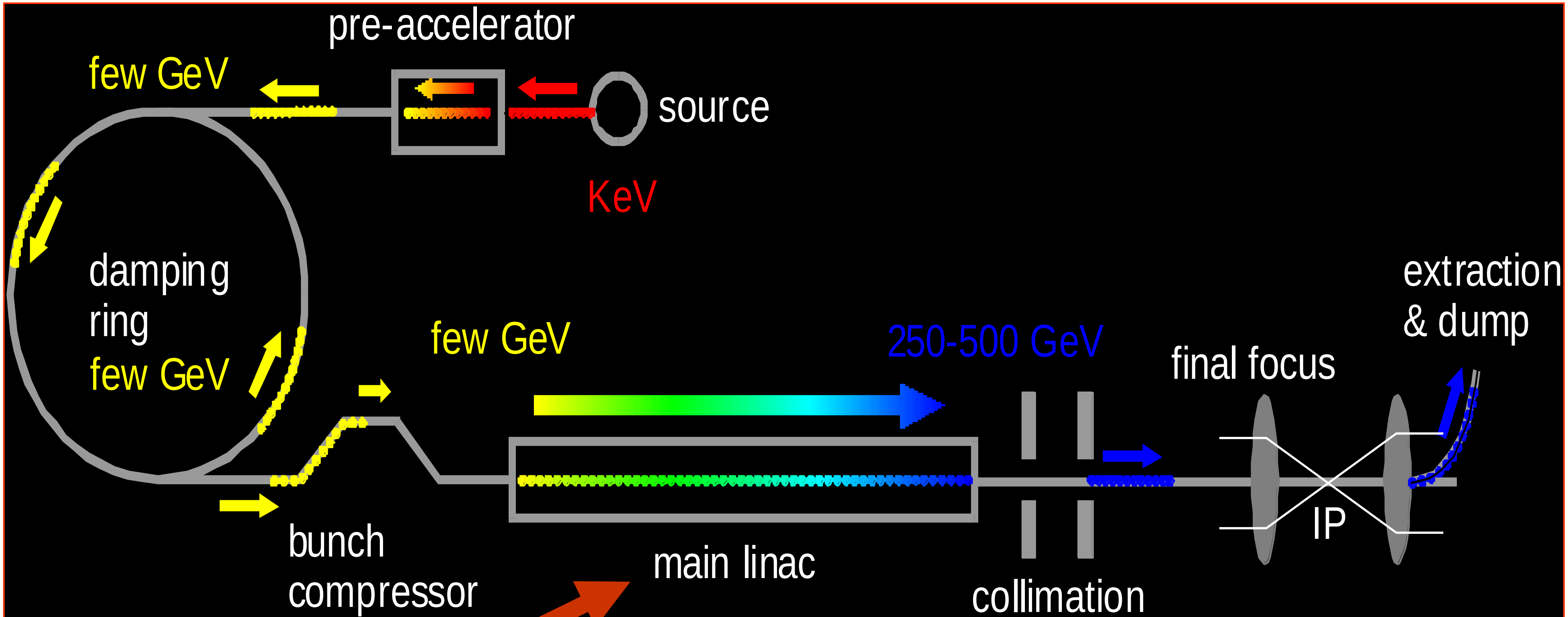
- **Forward looking technology for the next generation of particle accelerators: particle physics; nuclear physics; materials; medicine**
- **The ILC R&D is leading the way Superconducting RF technology**
  - **high gradients; low noise; precision optics**

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

Designing a Linear Collider



Superconducting RF Main Linac

The Community Self-Organized

Nov 13-15, 2004

~ 220 participants from 3 regions, most of them accelerator experts

15

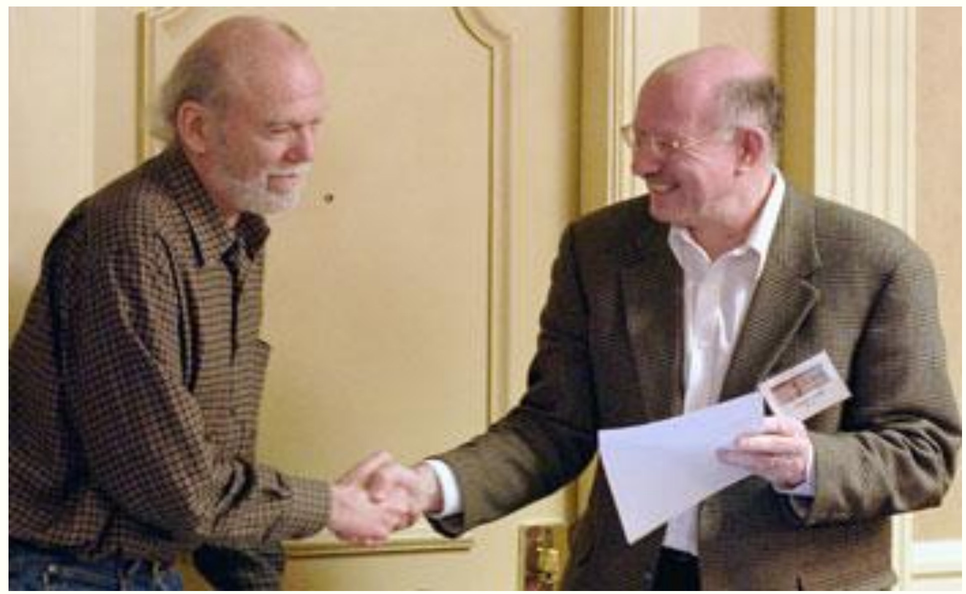
Self Organization following Technology Decision

- 1st ILC workshop at KEK November 2004
- ILCSC forms 5 technical WG + 1 communications and outreach WG
  - WG1 Parameters & General Layout
  - WG2 Main Linac
  - WG3 Injectors
  - WG4 Beam Delivery & MDI
  - WG5 High gradient SCRF
  - WG6 Communications

Global Design Effort (GDE)

- February 2005, at TRIUMF, ILCSC and ICFA endorsed the search committee choice for GDE Director

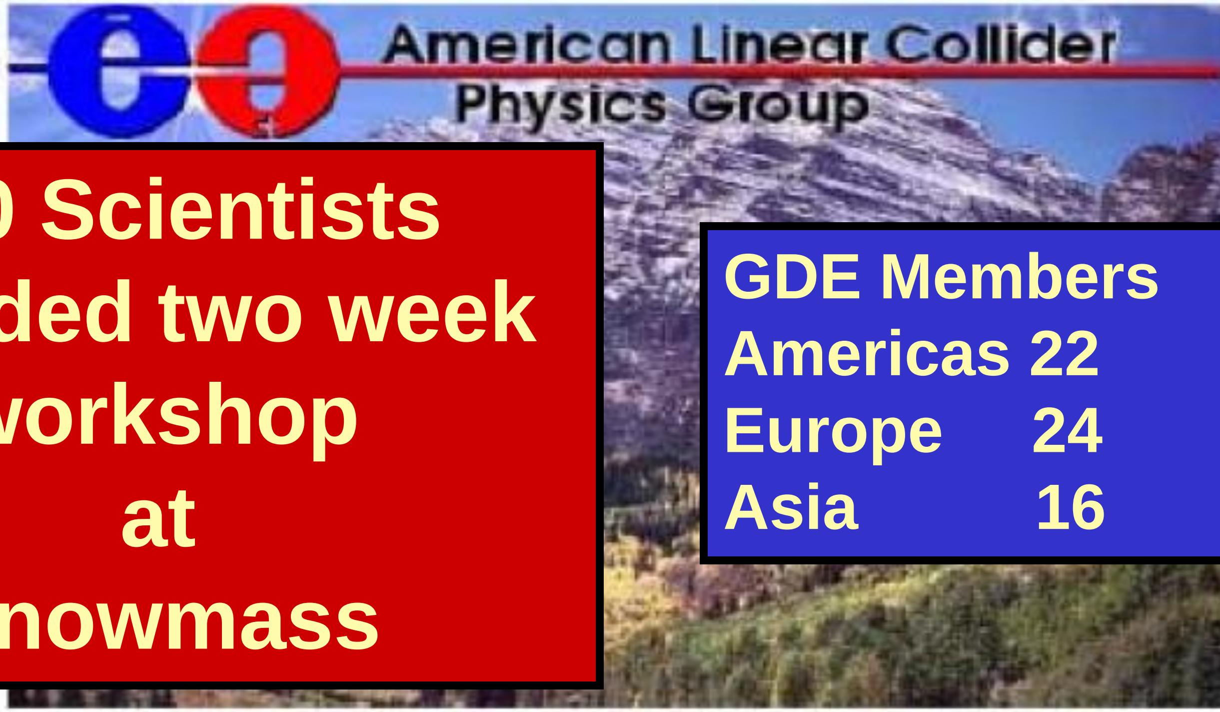
- On March 18, 2005, I officially accepted the position at the opening of LCWS 05 meeting at Stanford



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.)

GDE Begins at Snowmass



670 Scientists attended two week workshop at Snowmass

GDE Members
Americas 22
Europe 24
Asia 16

2005 International Linear Collider Physics and Detector Workshop and Second ILC Accelerator Workshop

Snowmass, Colorado, August 14-27, 2005

Enter the GDE - Snowmass

Birth of the GDE and Preparation for Snowmass

- WG1 Parms & layout
- WG2 Linac
- WG3 Injectors
- WG4 Beam Delivery
- WG5 High Grad. SCRF
- WG6 Communications

Introduction of **G**lobal **G**roups
transition workshop → project

- WG1 LET beam dynamics
- WG2 Main Linac
- WG3a Sources
- WG3b Damping Rings
- WG4 Beam Delivery
- WG5 SCRF Cavity Package
- WG6 Communications
- **GG1 Parameters & Layout**
- **GG2 Instrumentation**
- **GG3 Operations & Reliability**
- **GG4 Cost Engineering**
- **GG5 Conventional Facilities**
- **GG6 Physics Options**

GDE Organization for Snowmass

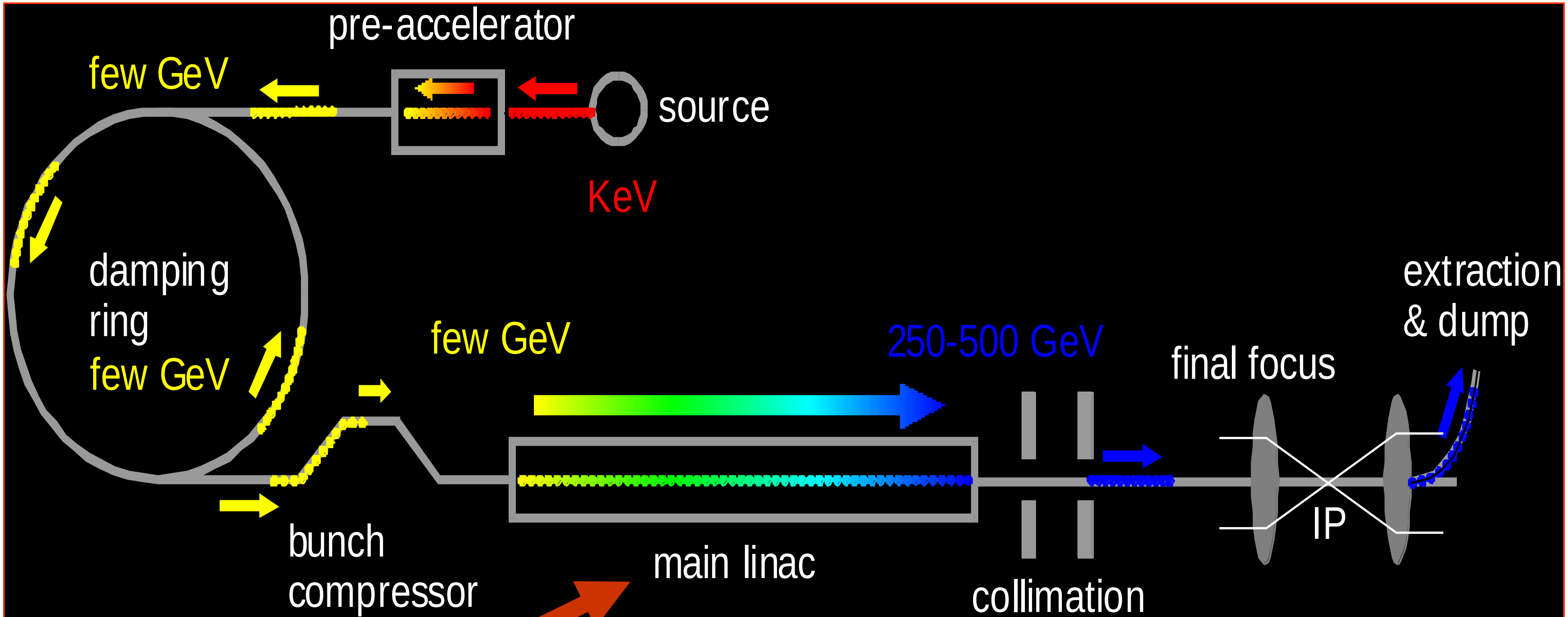
Technical sub-system Working Groups

Provide input

Global Group

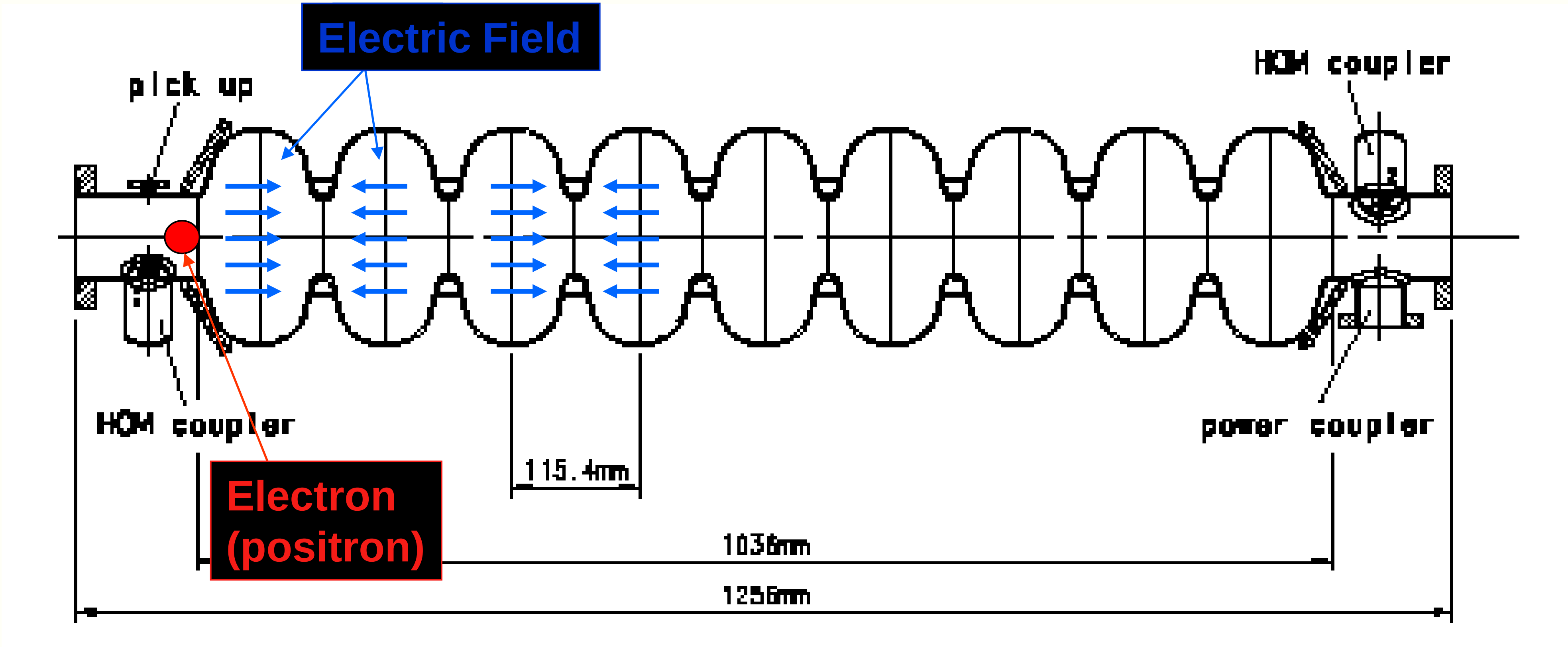
	WG5 Cavity	WG4 BDS	WG3b DR	WG3a Sources	WG2 Main Linac	WG1 LET bdyn.
GG1 Parameters						
GG2 Instrumentation						
GG3 Operations & Reliability						
GG4 Cost & Engineering						
GG5 Conventional Facilities						
GG6 Physics Options						

Designing a Linear Collider



Superconducting RF Main Linac

Technical Challenges: High Grad SCRF

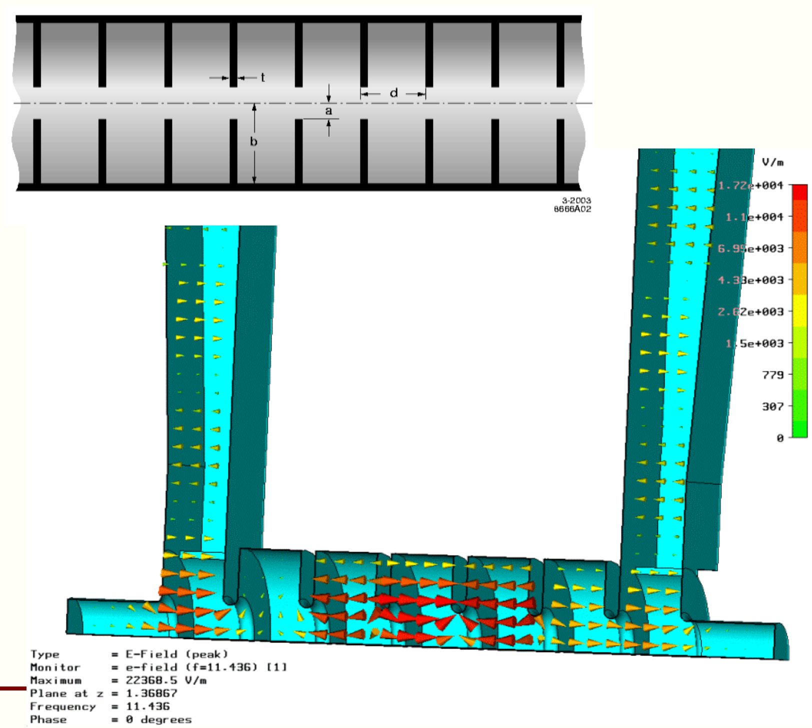


Real Accelerating Structures: Cavities

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 $v_{ph} \leq c$

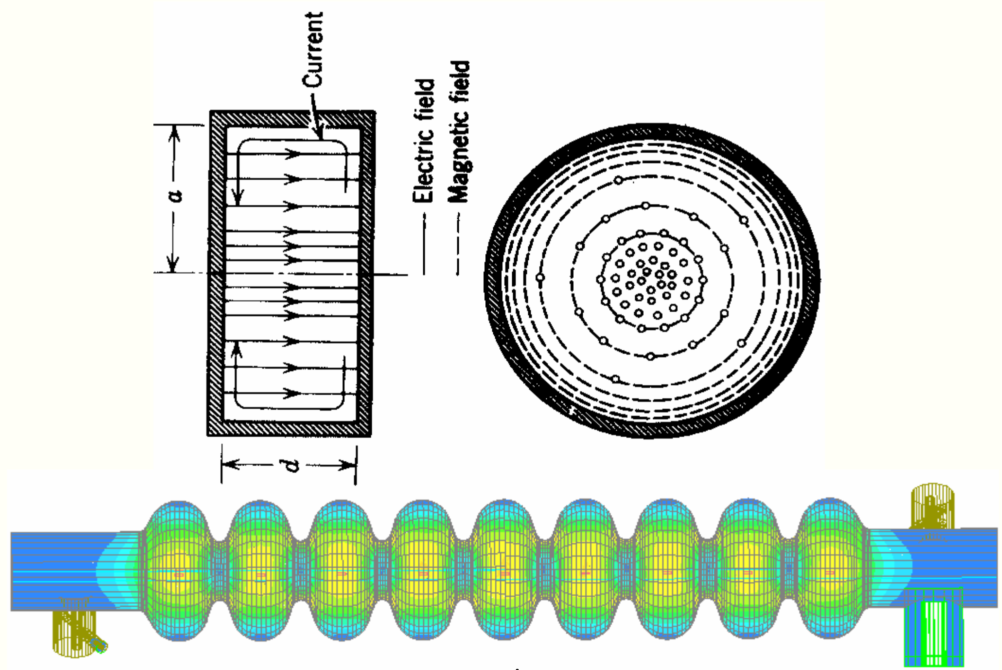
Traveling wave structure

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



Standing wave structure

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



π mode

Example of 9-cell cavity performance.

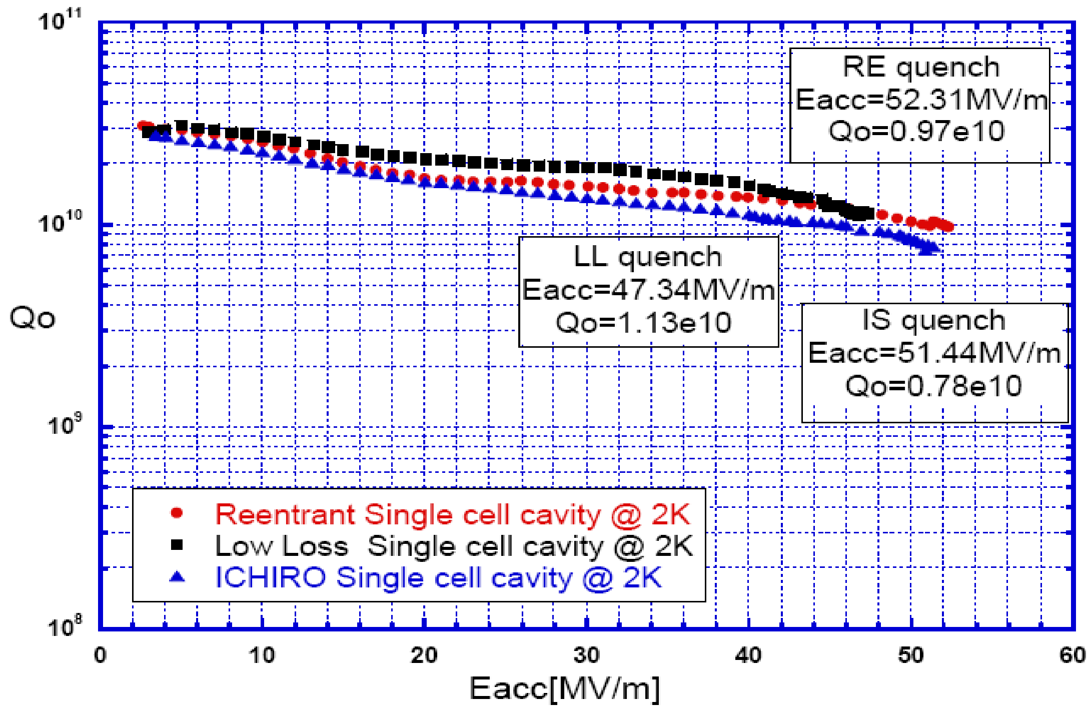
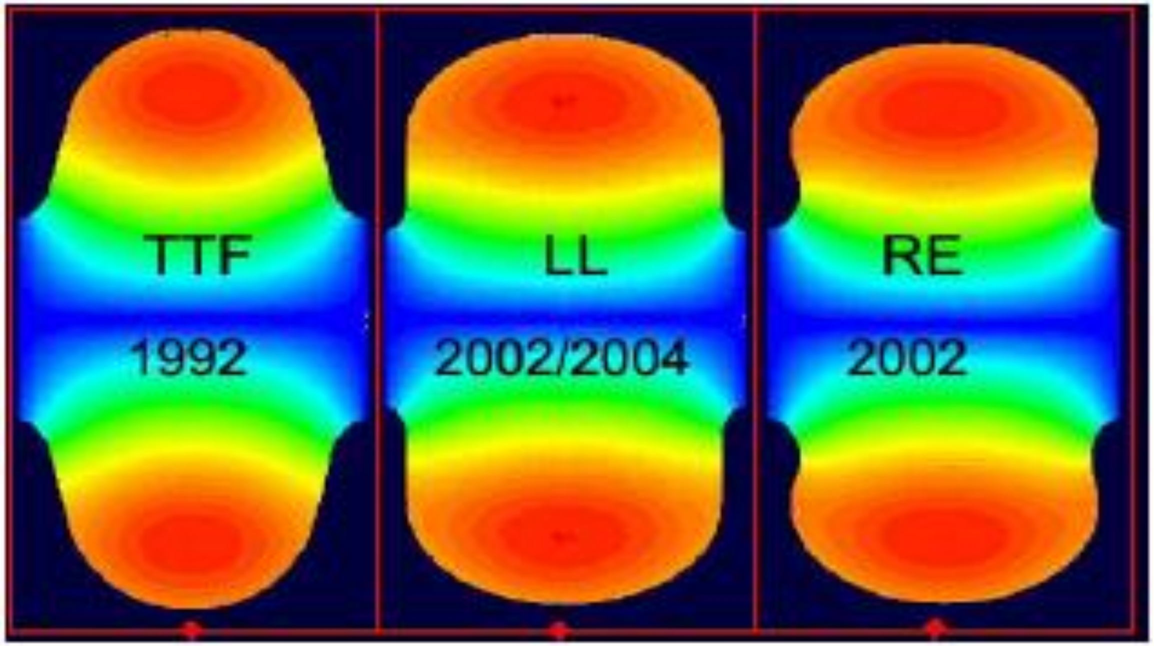


Figure 3: The results of high gradient measurements.

- **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

Luminosity & Beam Size

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

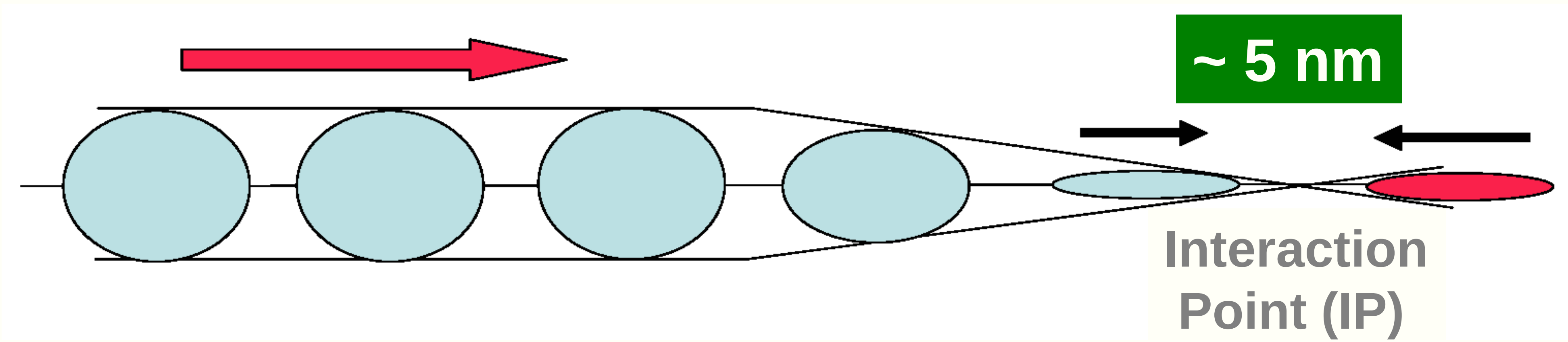
- f_{rep} * n_b tends to be low in a linear collider

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

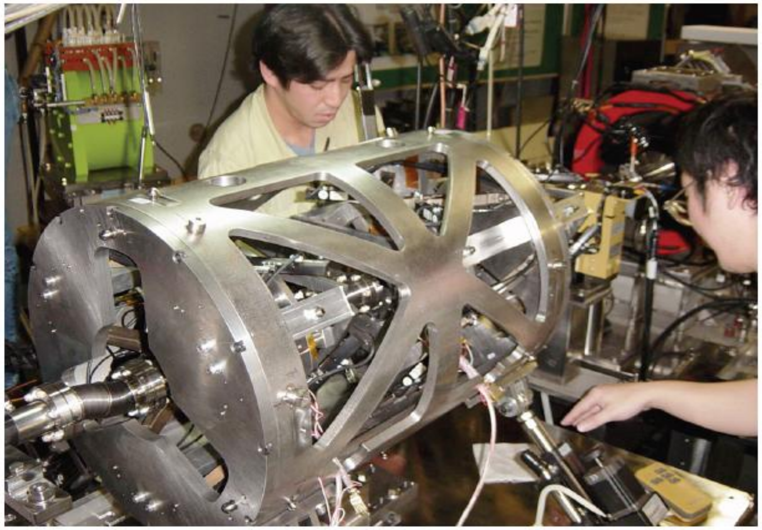
- Achieve luminosity with spot size and bunch charge

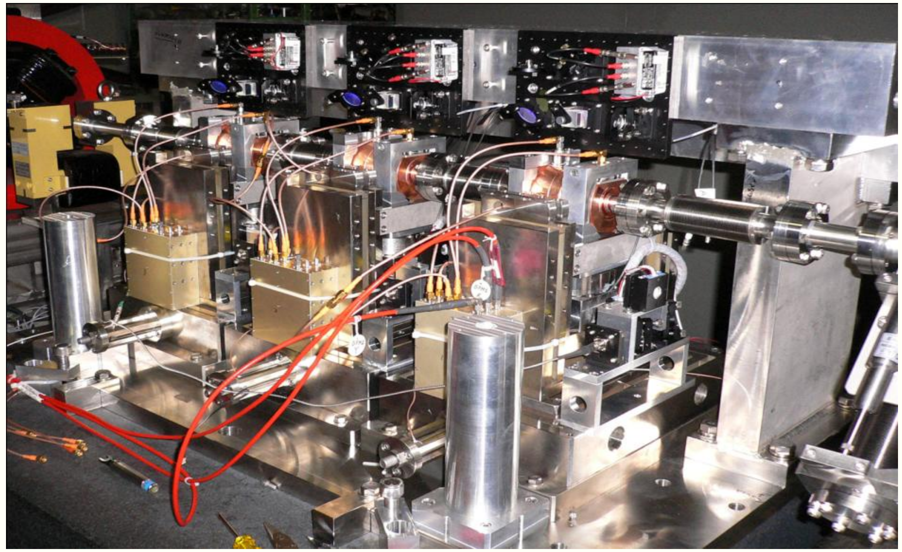
Achieving High Luminosity

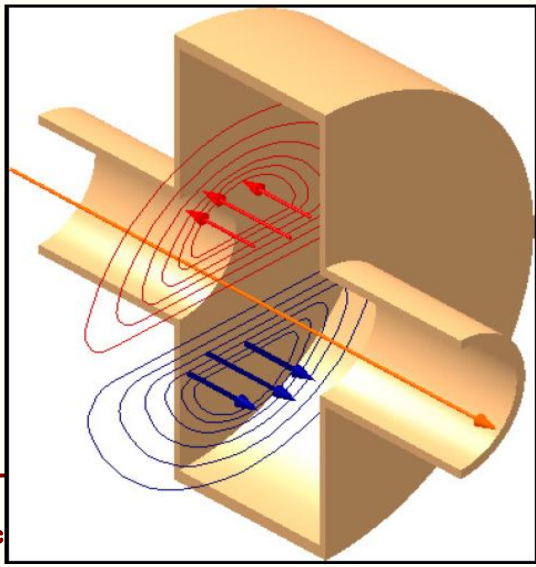
- Low emittance machine optics
- Contain emittance growth
- Squeeze the beam as small as possible

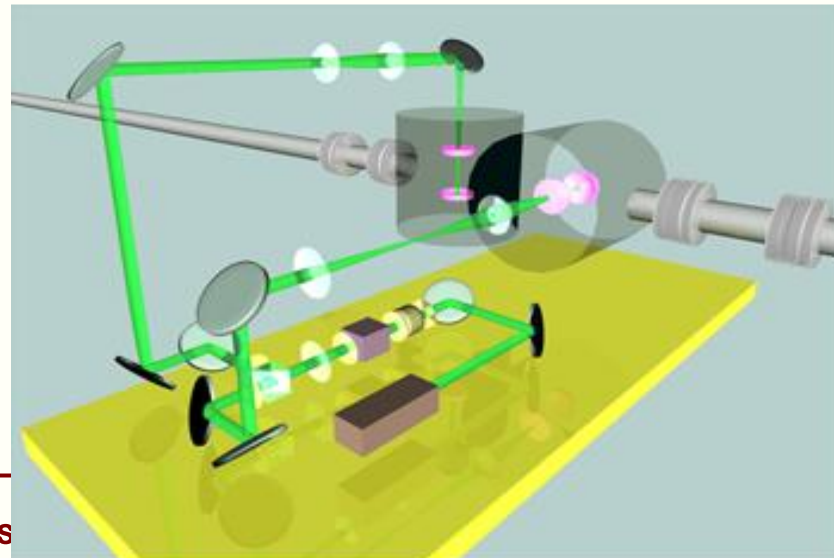


Making Very Small Emittance
(Beam Sizes at Collision)

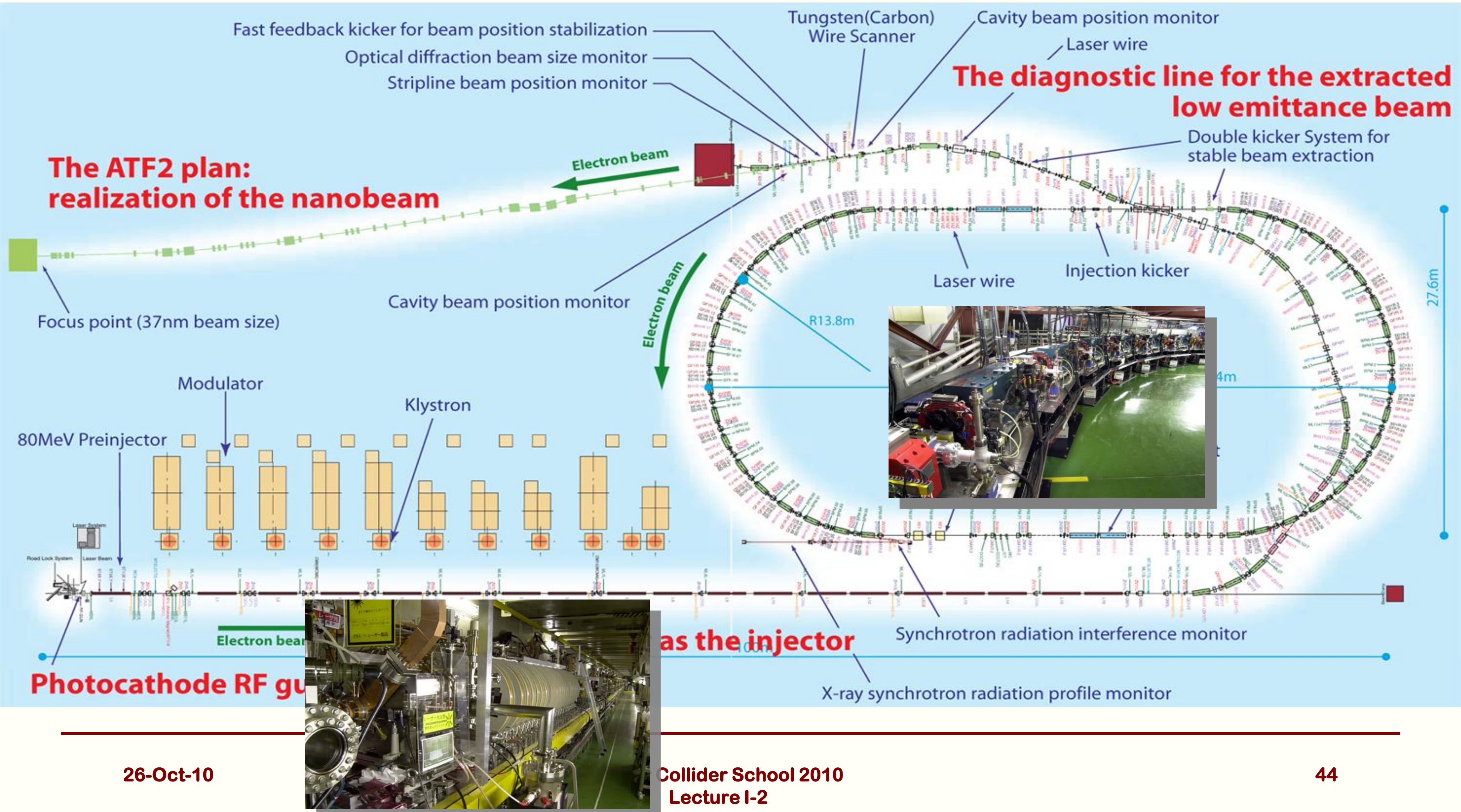




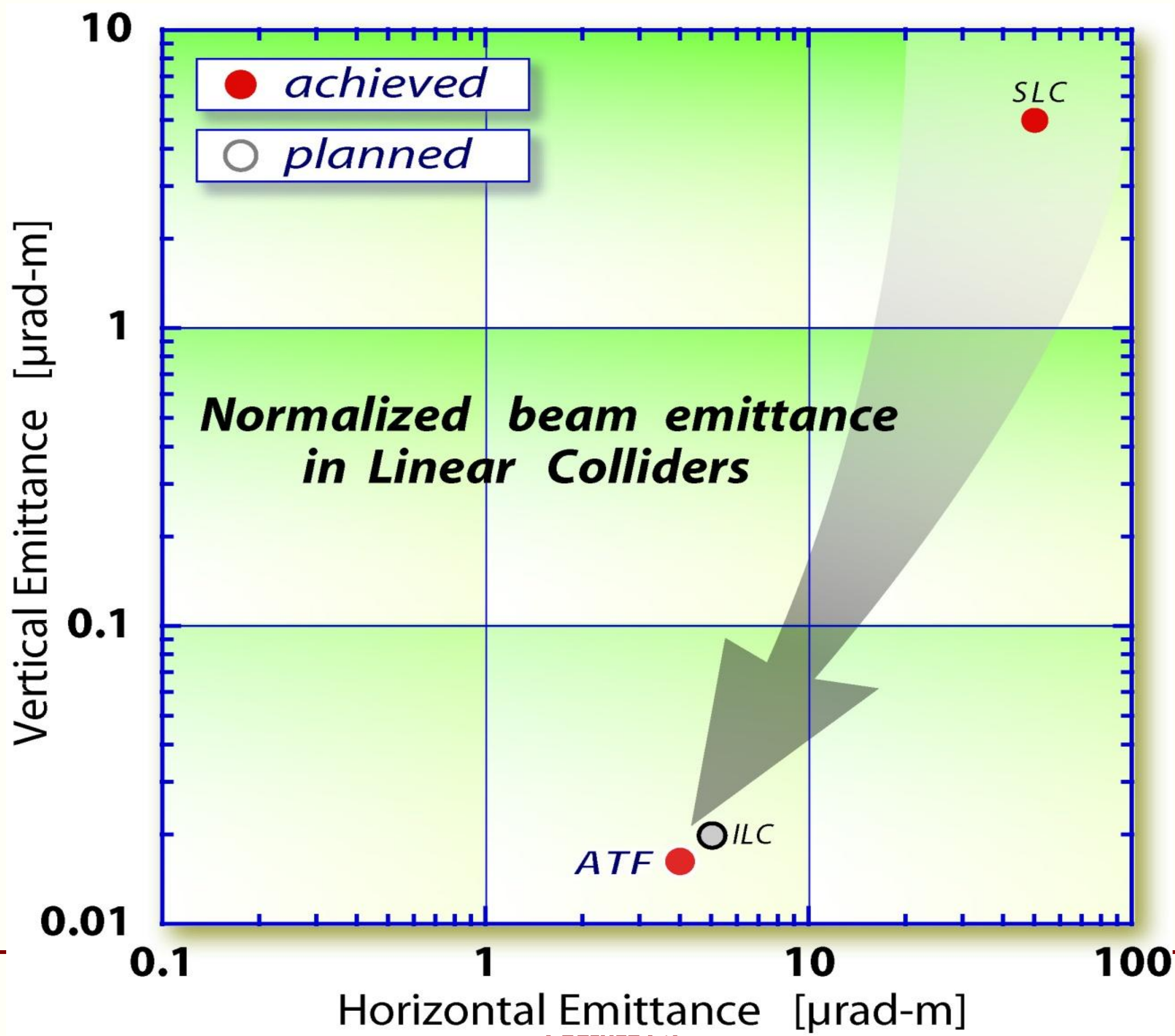




ATF
Accelerator Test Facility

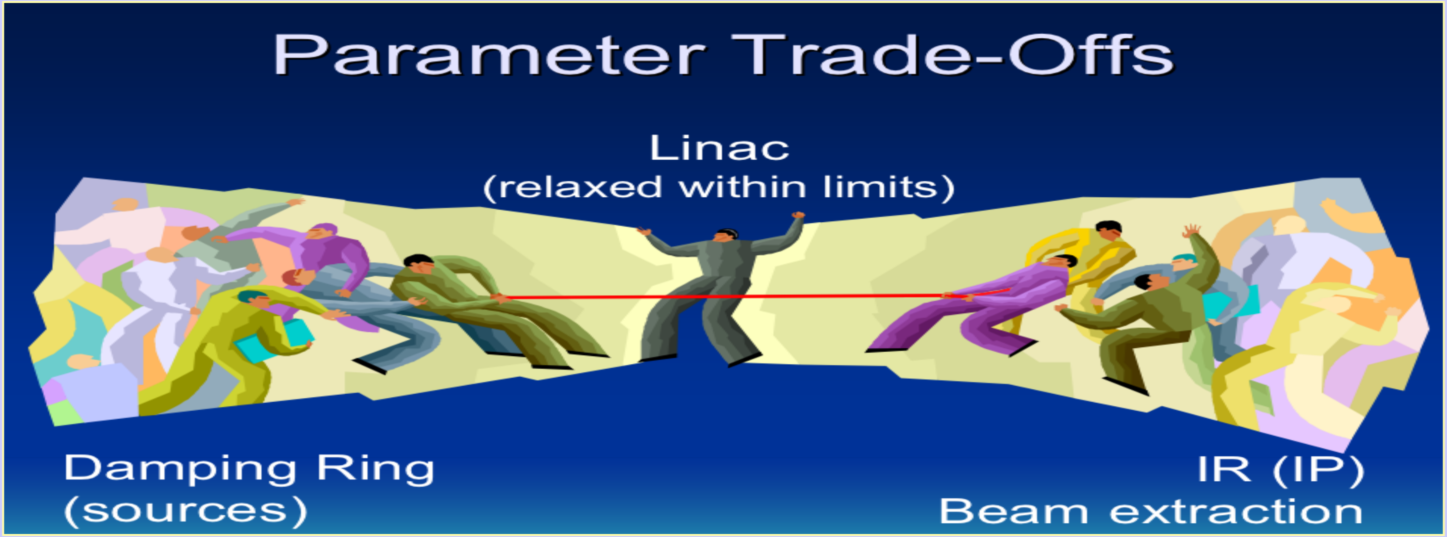


It seems that we have technology in hand to squeeze beam down to the required size.



Parametric Approach

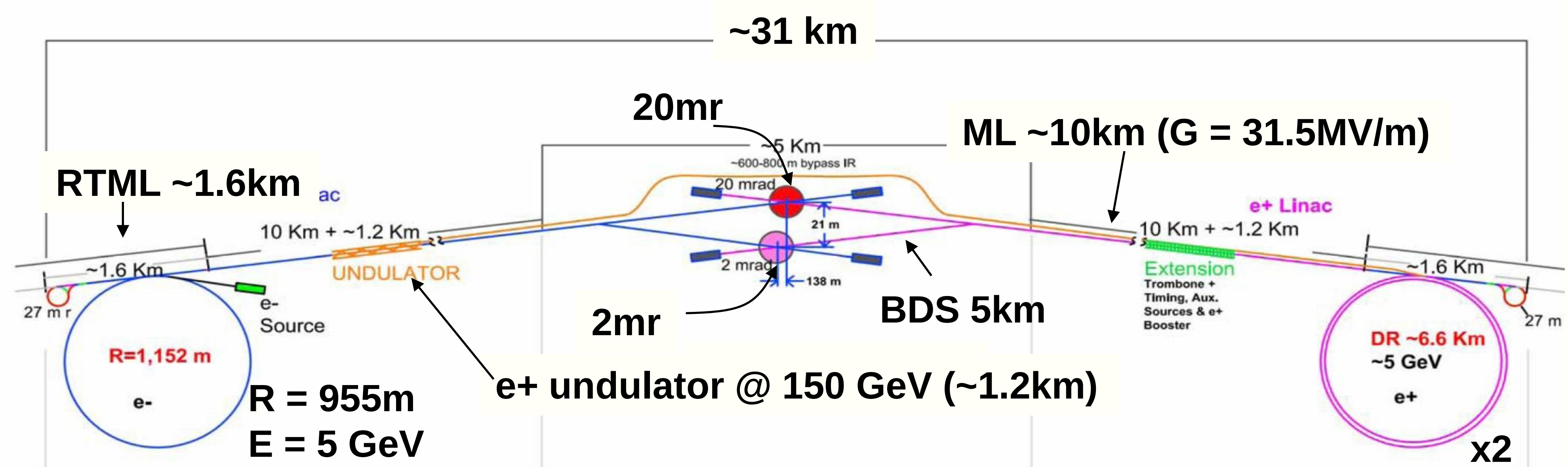
- **A working space - optimize machine for cost/performance**



		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

The Baseline Machine (500GeV)

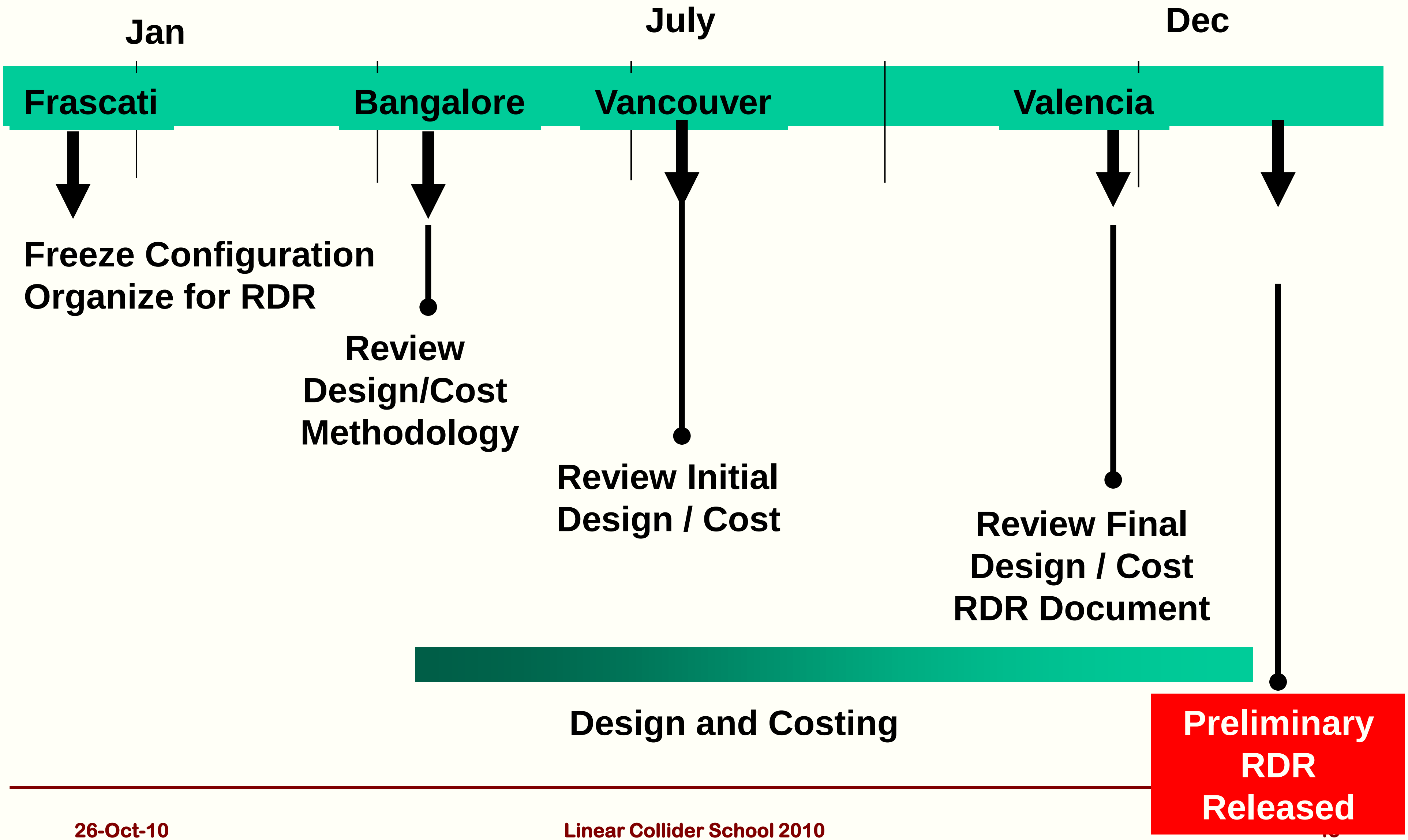
January 2006



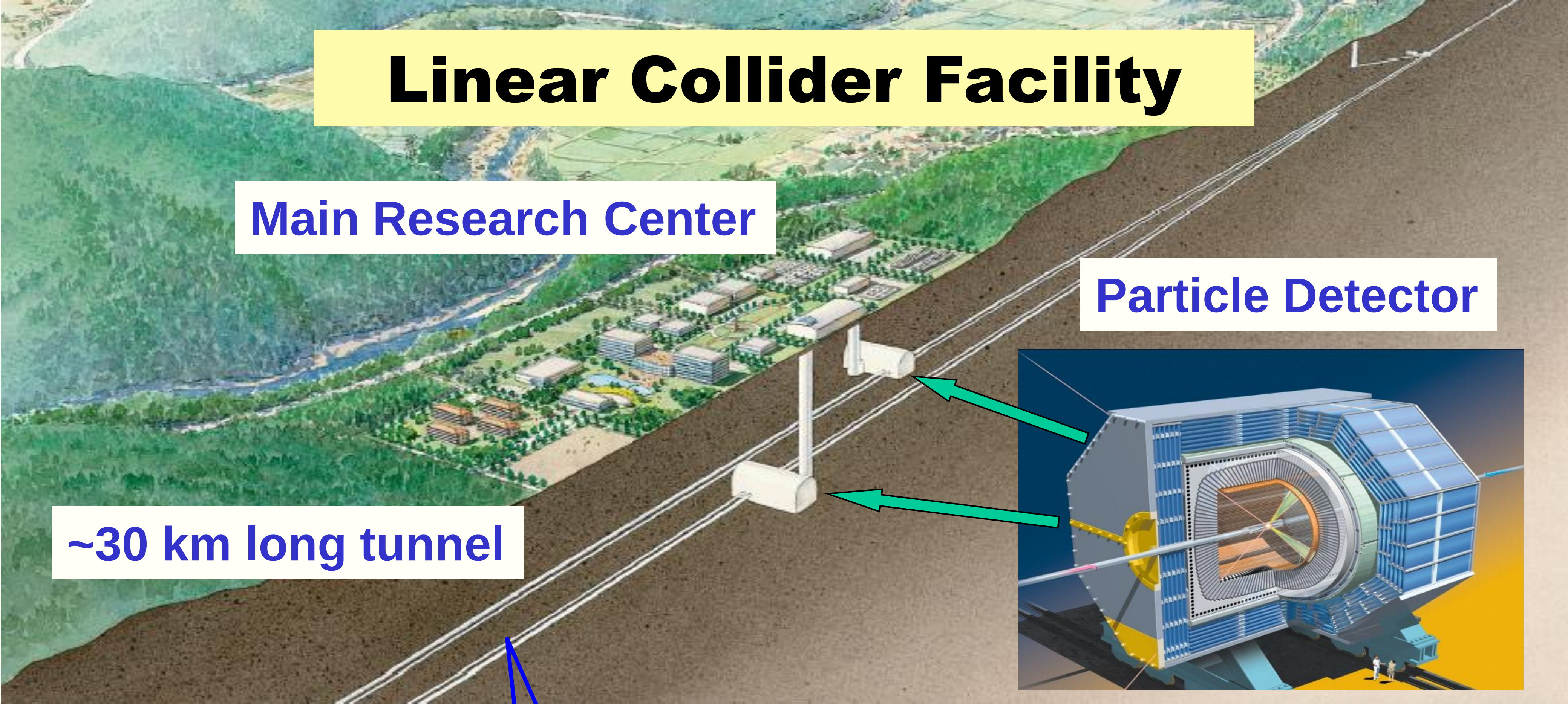
not to scale

From Baseline to a RDR

2006



Linear Collider Facility



Two tunnels

- accelerator units
- other for services -   RF power

Conventional Facilities

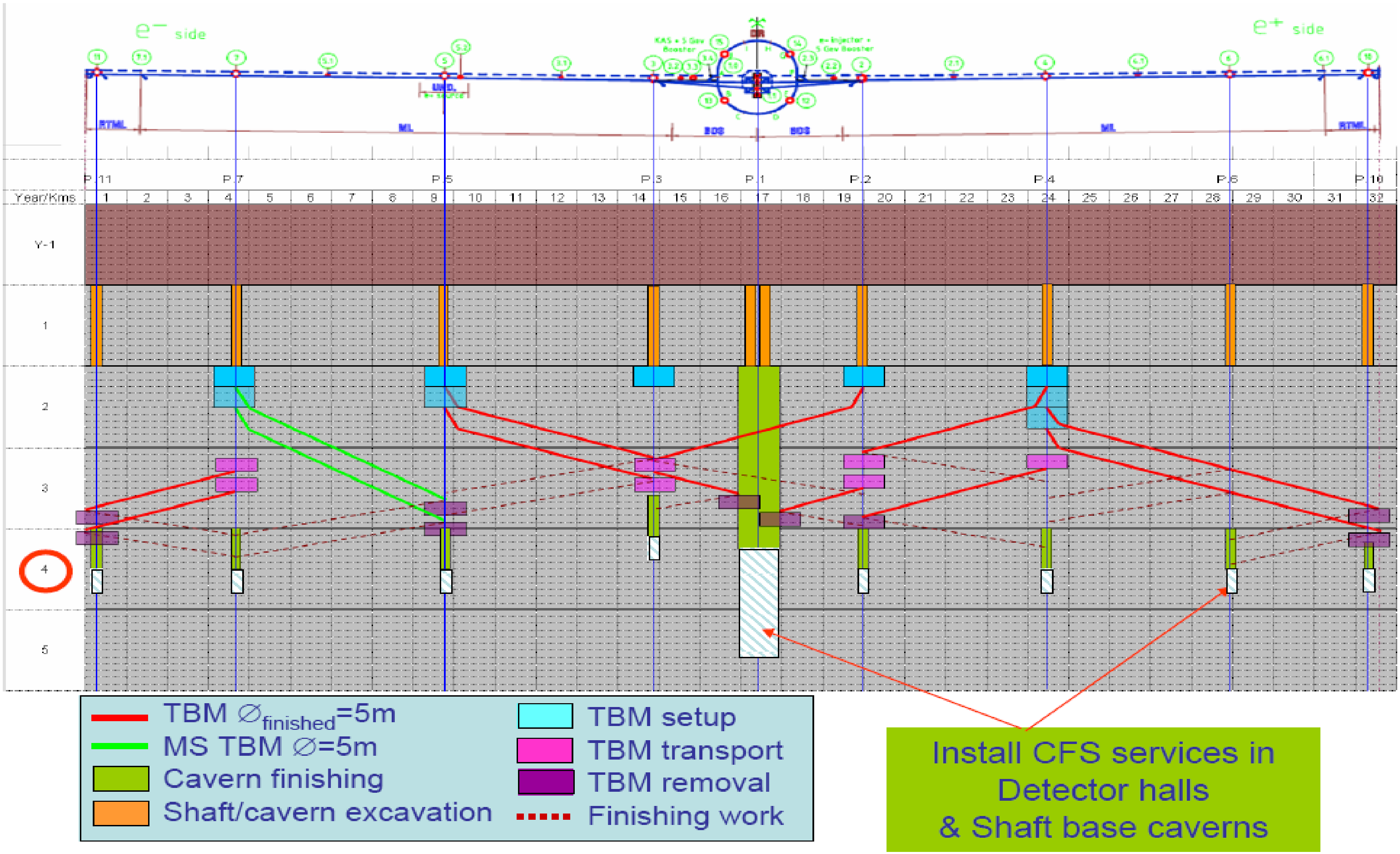
72.5 km tunnels ~ 100-150 meters underground

13 major shafts $\geq$ 9 meter diameter

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

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

Civil Construction Timeline

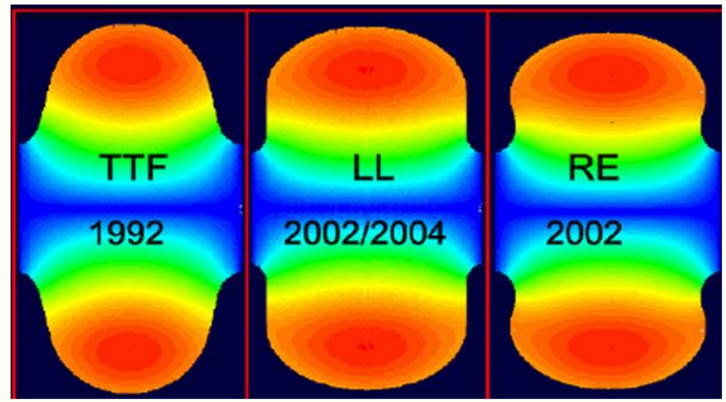


Superconducting RF Technology

- **Forward looking technology for the next generation of particle accelerators: particle physics; nuclear physics; materials; medicine**

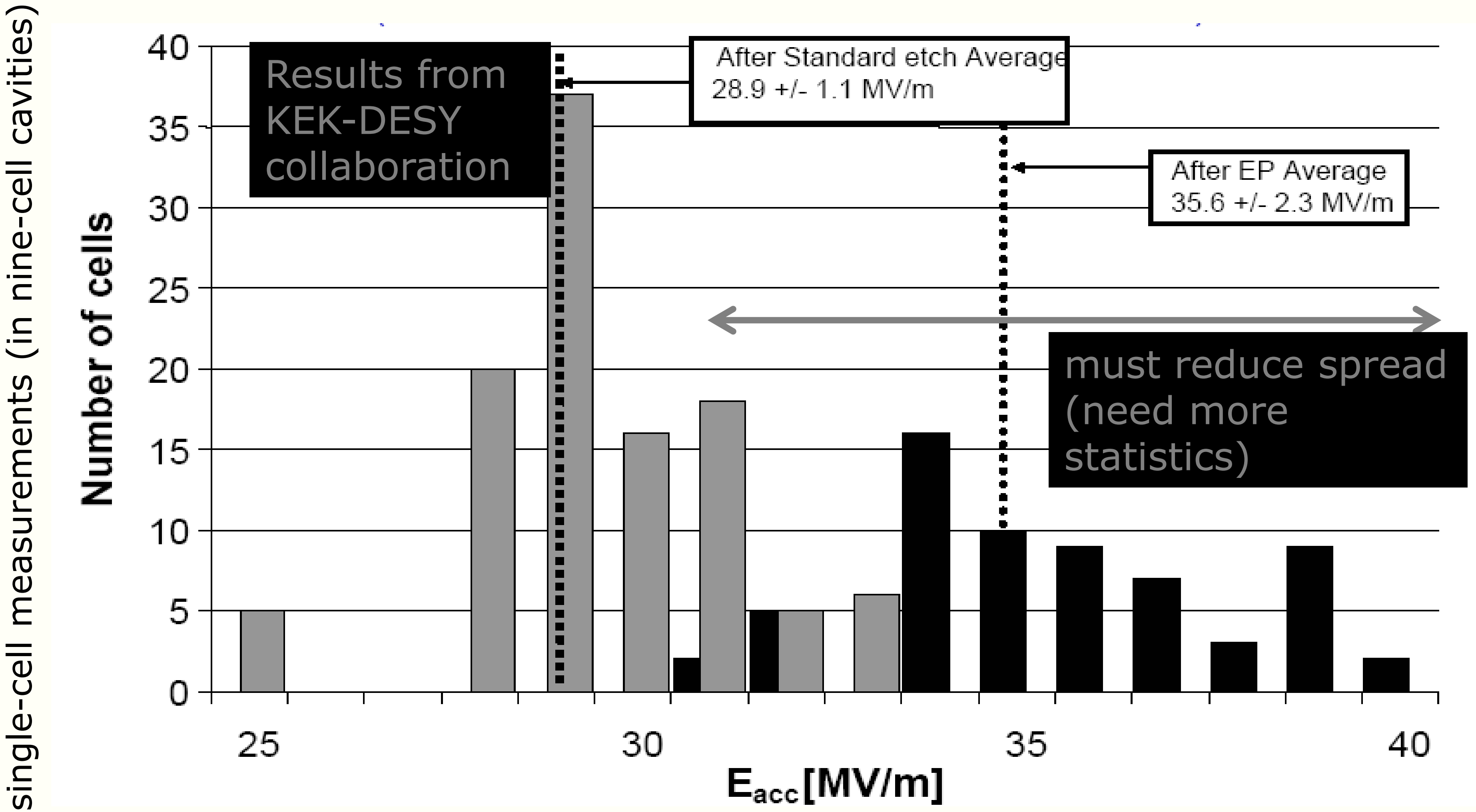
- **The ILC R&D is leading the way Superconducting RF technology**
  - **high gradients; low noise; precision optics**

Superconducting RF Cavities



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

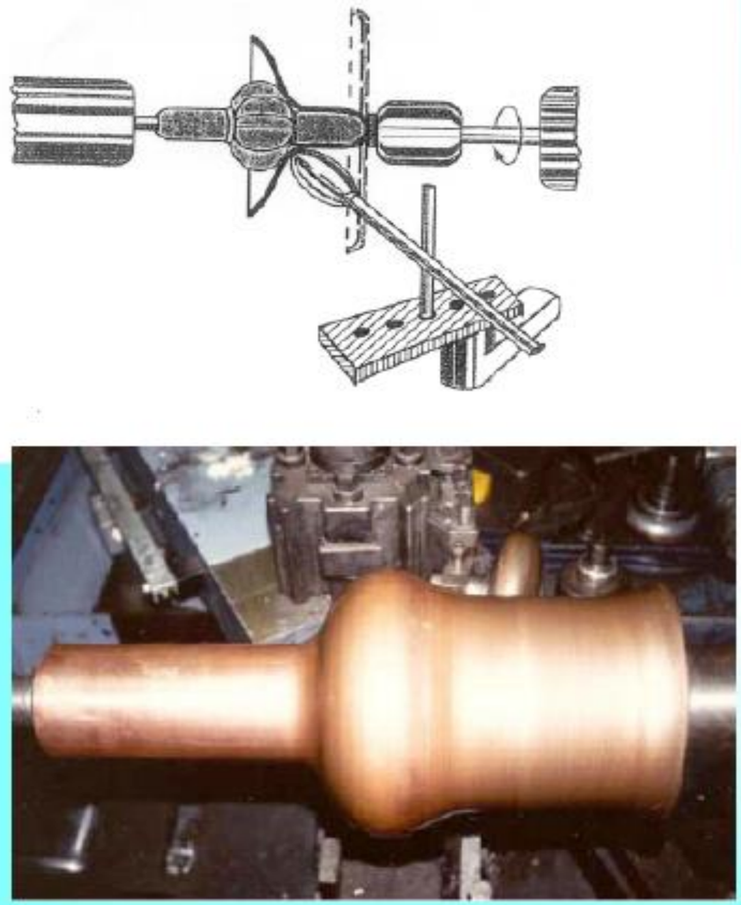
Gradient



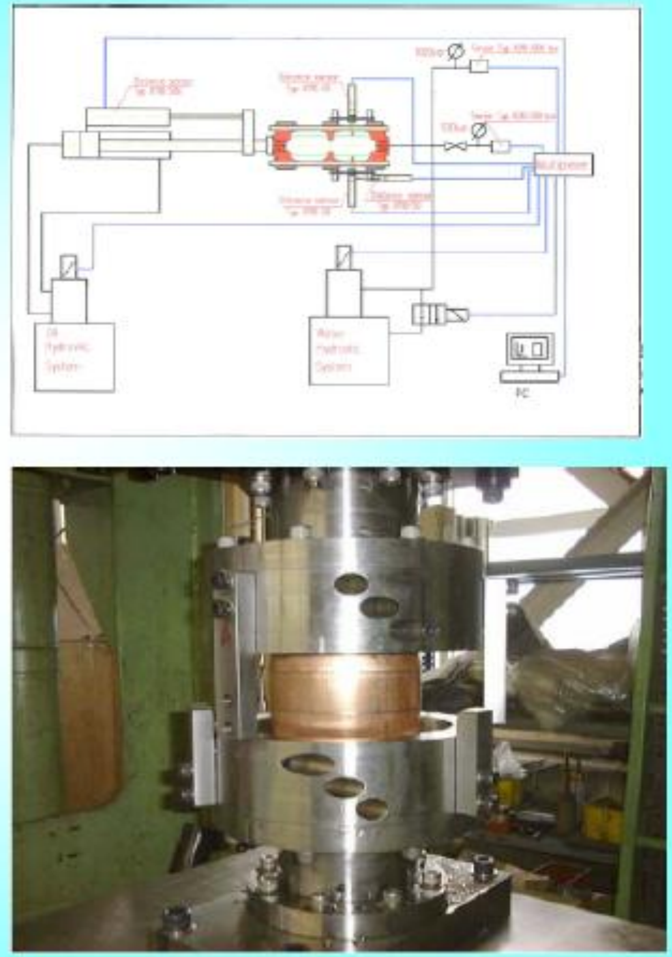
single-cell measurements (in nine-cell cavities)
Number of cells
40
35
30
25
20
15
10
5
0
Results from KEK-DESY collaboration
After Standard etch Average 28.9 +/- 1.1 MV/m
After EP Average 35.6 +/- 2.3 MV/m
must reduce spread (need more statistics)
25
30
35
40
E_{acc}[MV/m]

Improved Fabrication

Spinning (V.Palmieri,INFN Legnaro)



Hydroforming, DESY, KEK



Improved Processing
Electropolishing

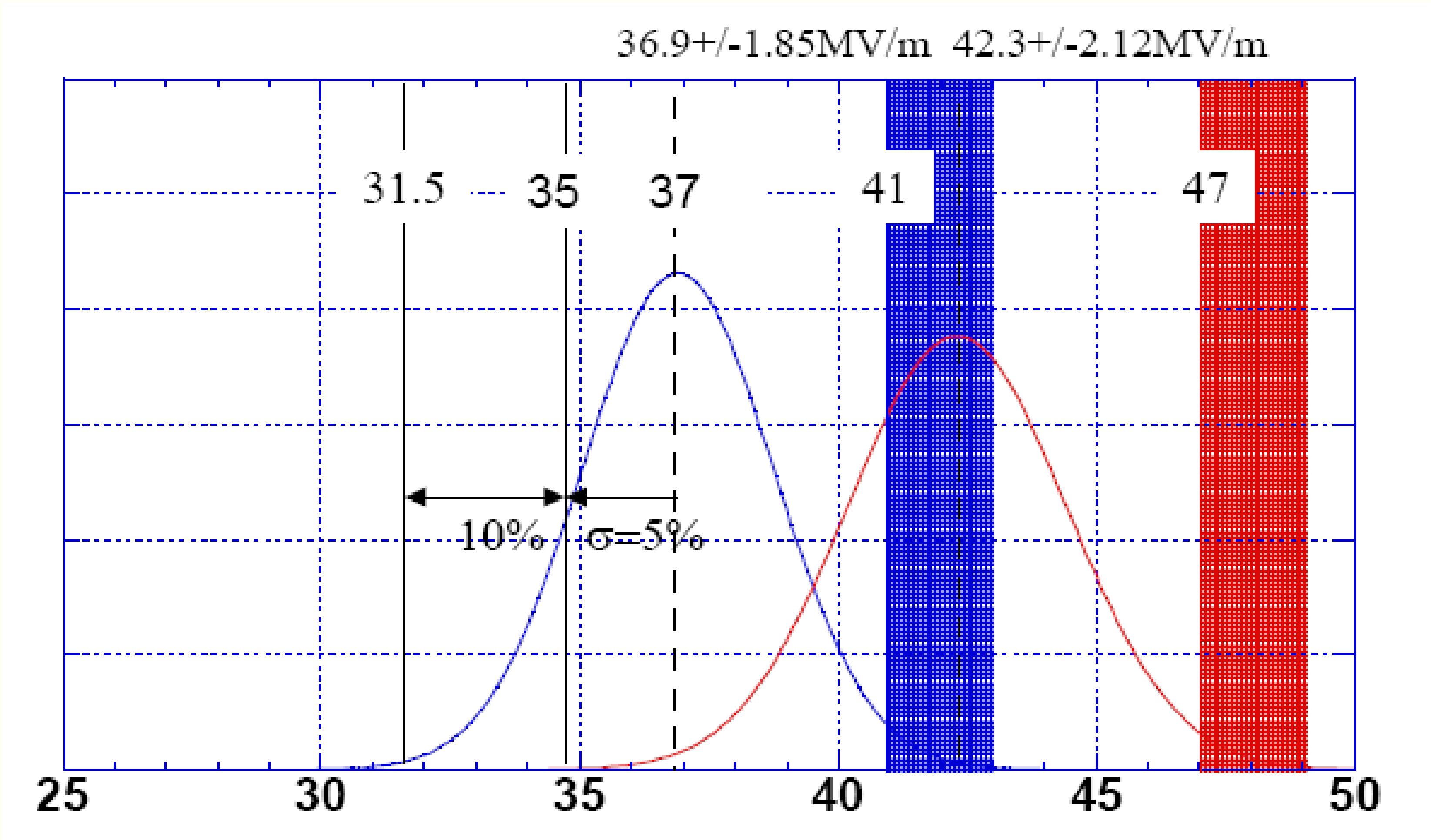
KEK / Nomura EP

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

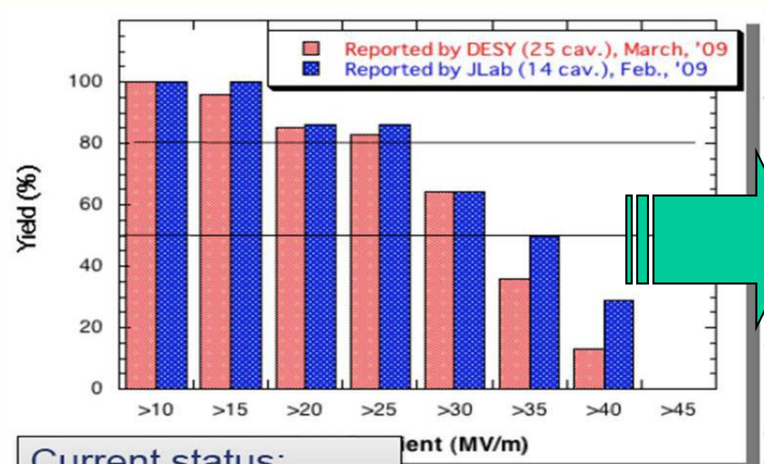
Yield Plot

- The gradients for DESY data were off by +2MV/m
- Not 08/09: large component of 2007, and very small component of 2009
- Not 1st or 2nd test: instead, last (DESY) or best (JLab)
- Included cavities fabricated by ACCEL, ZANON, AES, JLab-2, KEK-Ichiro

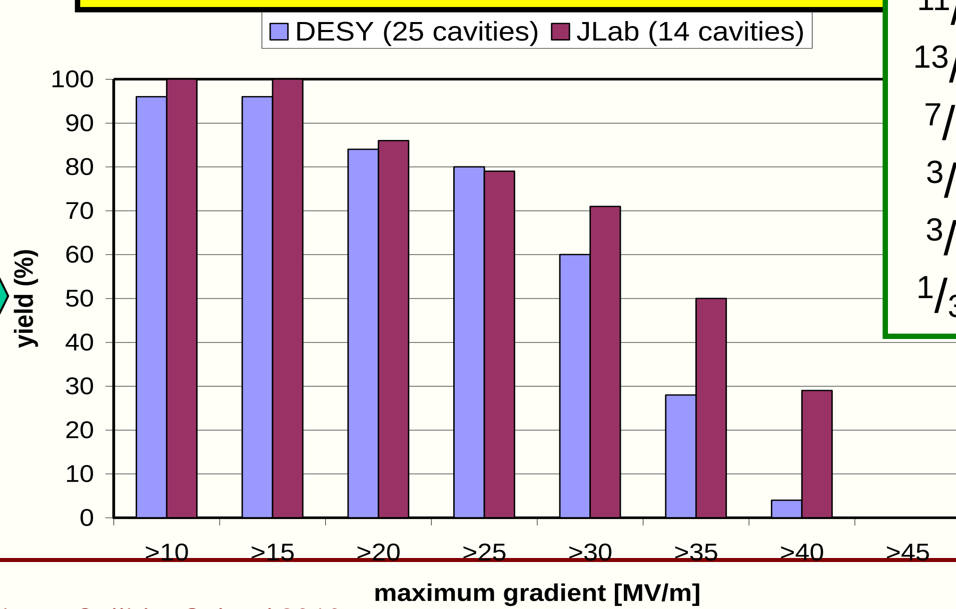
This is not the ideal data selection from which to infer a production yield

Old version, shown at PAC, 2009

Revised version (corrected only for mistakes)
- same data shown



Current status:
50% yield at ~ 33 MV/m;
(80% >25MV/m)



11/39 1st test
13/39 2nd test
7/39 3rd test
3/39 4th test
3/39 5th test
1/39 8th test

Definition of ‘Yield’

- Original S0 concept assumed:
  - Surface can be reset according to the EP process, and
  - Multiple processes may be integrated for statistics.
- Several years of experience shows
  - Repeat processing may cause degradation
- Processing and Test recipe has been updated
  - Complete the process and test only with the first cycle
    - no further processing if the results are acceptable
- Revision of the definition of ‘yield’ is required
  - Process (R&D) and Production definitions are different
  - A common means for collection and evaluation of the data is required

Creation of a Global Database

Activity Plan in 2009:

- Mid-July: Initial report to FALC
- End July:
  - Determine whether DESY-DB is viable option (DONE→YES!)
- Aug. 19: (ILCSC)
  - Status to be reported
- Sept. 28 - Oct. 2, 2009: (ALCPG/GDE)
  - Dataset web-based
    - to be Supported by FNAL-TD or DESY
  - Explainable, and near-final plots, available, such as
    - Production (and process) yield with Qualified vendors and/or All vendors, and time evolution
- End Nov. 2009, with input from a broader group of colleagues, finalize:
  - DB tool, web I/F, standard plots, w/ longer-term improvement plan

Proposed Global Data Collection - 1

- Proposition 1: all cavities fabricated and processed according to the following rough steps
  - Fine grain sheet material
  - Deep drawing & EBW
  - Initial field flatness tuning
  - Bulk EP for heavy removal
  - H_2 removal with vacuum furnace
  - Final tuning field flatness (and frequency)
  - Final EP for light removal
  - Post-EP cleaning
  - Clean room assembly
  - Low temperature bake-out
  - 2K RF test

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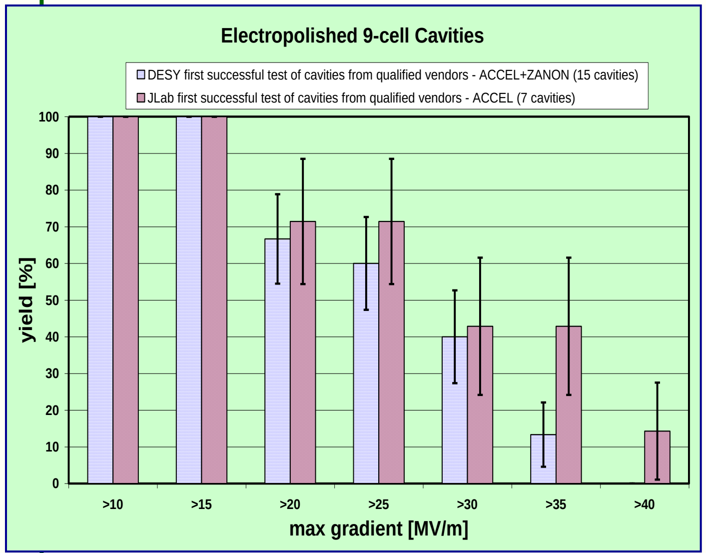
Proposed Global Data Collection -2

- **Proposition 2: accept understood variations, and combine samples to maximize statistics, for example:**
  - **Fine grain niobium irrespective of vendor**
  - **EBW irrespective of prep design welding parameter**
  - **Cavities with or without helium tank**
  - **With or without pre-EP treatment (BCP, CBP…)**
  - **EP irrespective of parameters & protocols**
    - **Horizontal or (future) vertical EP**
    - **H_2SO_4/HF/H_2O ratio, pre-mixing or on-site mixing**
    - **Cell temp. control or return acid temp. control**
    - **With or without acid circulation after voltage shut off**
    - **Post-EP cleaning: Ethanol rinse or Ultrasonic cleaning or H_2O_2 rinsing**
  - **H2 out-gassing irrespective of temp. & time**
  - **HPR irrespective of nozzle style, HPR time**
  - **Clean Room assembly irrespective of practice variability**
- *Additional note: The variations of BCP/EP, fine-grain/large-grain are not considered as acceptable variation in this statistical evaluation.*

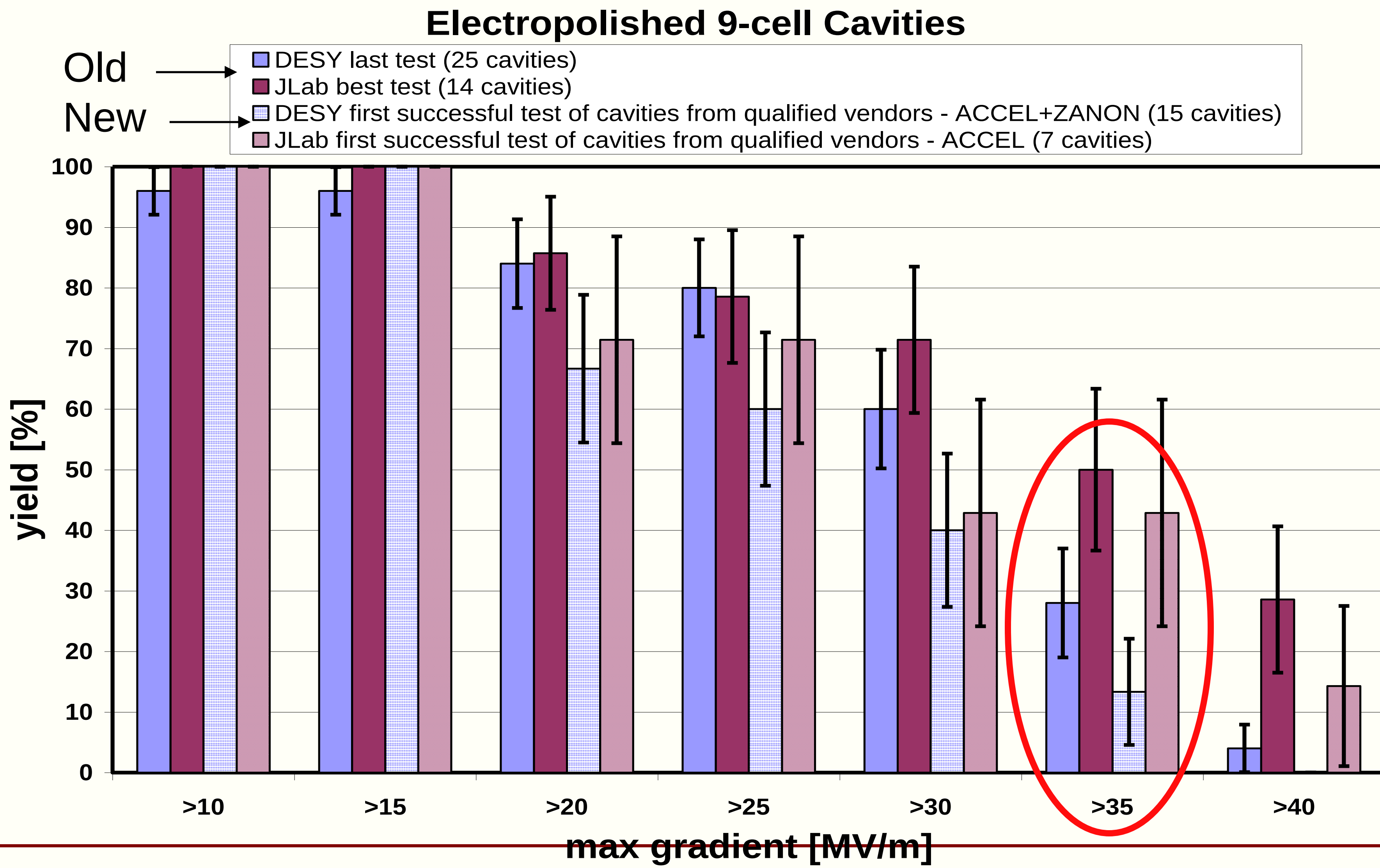
Example New Yield Plot

- **Vertical axis:** fraction of cavities satisfying criteria where:
  - **Denominator (logical and of the following):**
    - Fabricated by <u>ACCEL or ZANON</u>
    - Delivered to labs within last 2-3 years
    - <u>Electro-polished</u>
    - Fine-grain material
  - **Numerator (logical and of the following):**
    - Denominator
    - Accepted by the lab after incoming inspection
    - 1st successful vertical RF test,
      - excluding any test with system failure, has max gradient > (horizontal axis bin) MV/m;
      - ignore Q-disease and field emission (to be implemented in future)
- **Horizontal axis:** max gradient MV/m
- Exclude cavities which are work-in-progress, i.e., before rejection or 1st successful RF test



Note: These are results from the vertical CW test at DESY and JLab

Comparison 'Old' vs 'New' Yield Plots



Preliminary Conclusions

- The global database team has been formed to
  - Understand the cavity gradient status in a common-way, world wide
- The effort has started with
  - Checking of the 'old' yield plot presented in PAC, Vancouver
  - Revision of the yield plot with some correction:
    - The yield at 35 MV/m in a vertical test remains 50+/-13% for JLab results, and is corrected to 28+/-9% for DESY results
  - Agreement to use the DESY Database system for superconducting cavities
- A new 'production yield' is being defined with the 1st pass (and 2nd pass)
  - Introduced and under evaluation.
    - The yield at 35 MV/m in a vertical test remains 43+/-19% for JLab results, and is corrected to 13+/-9% for DESY results

26-Oct-10
Linear Collider School 2010
Lecture I-2
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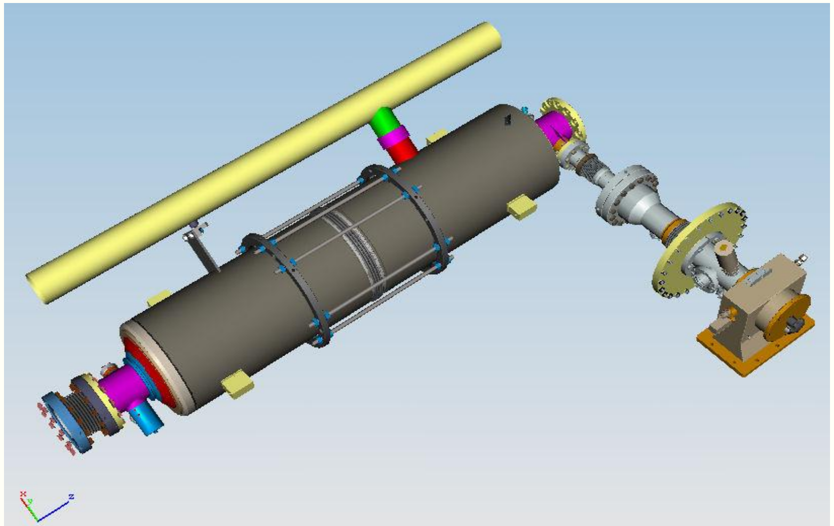
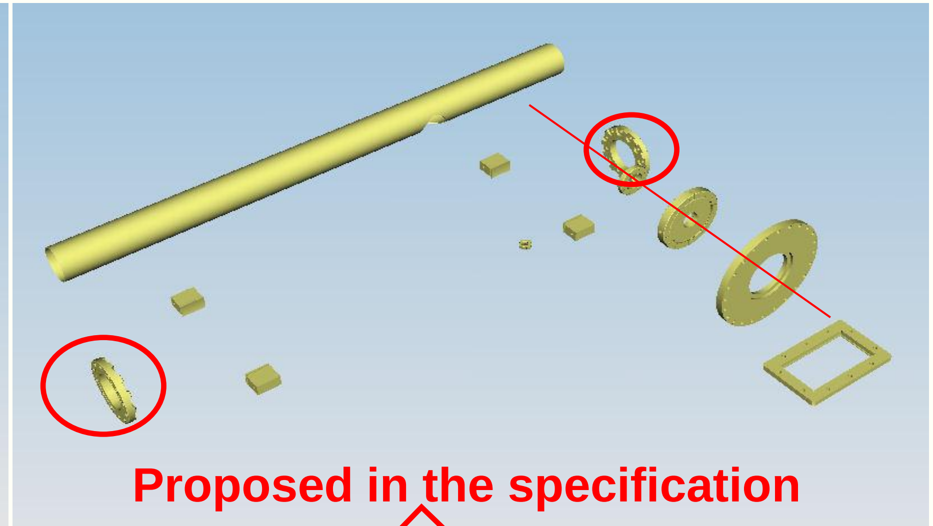
Plug Compatibility Concept

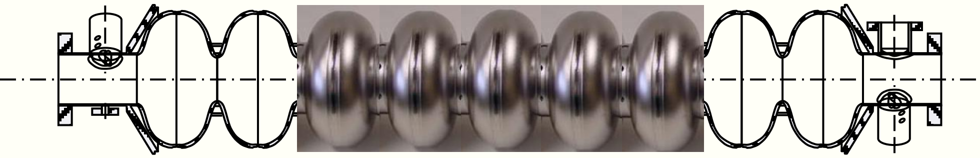


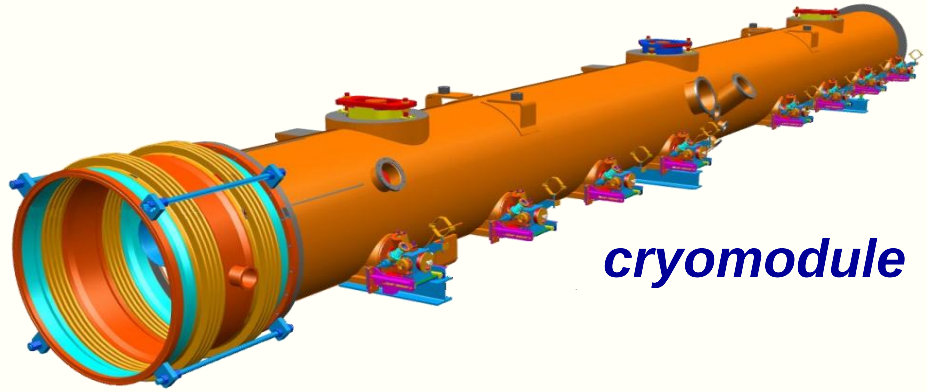


Helium Vessel Body		KEK-STF-BL	KEK-STF-LL	FNAL-T4CM	DESY-XFEL
Helium Jacket	Material	Ti	SUS	Ti	Ti
	Slot length, mm	1337	1337	1326.7	(1382:Type3)
	Distance between beam pipe flanges, m	1258.6	1254.5	1247.4	1283.4
	Distance between bellows flanges, mm	78.4	85,2	80.49 (cold)	
	Outer diameter, mm	242	236	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

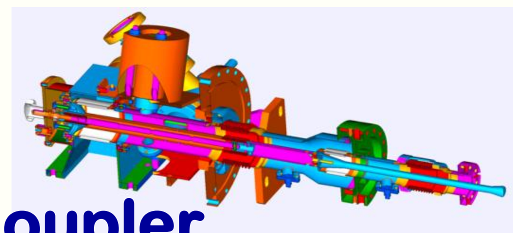
cavity



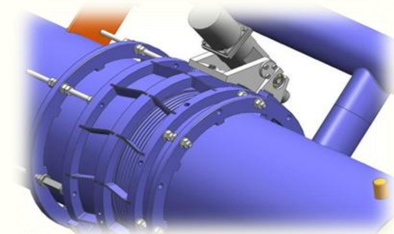


cryomodule

SCRF Linac Technology

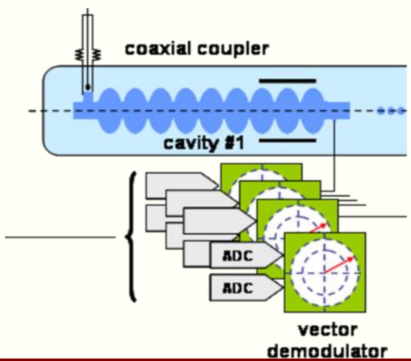


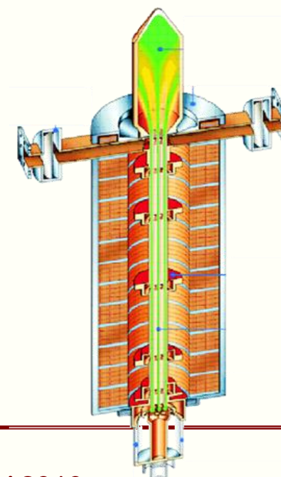
coupler



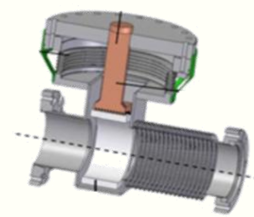
tuner

LLRF





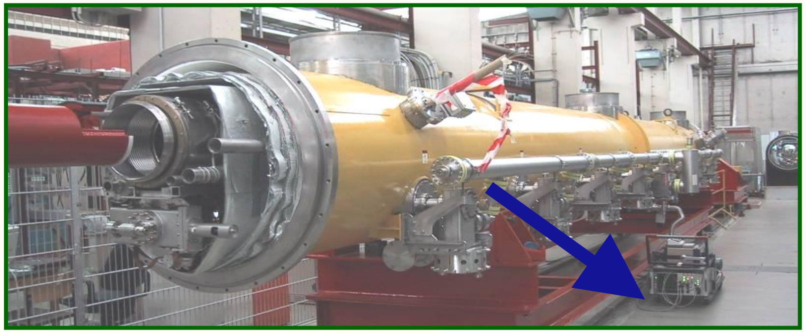
RF

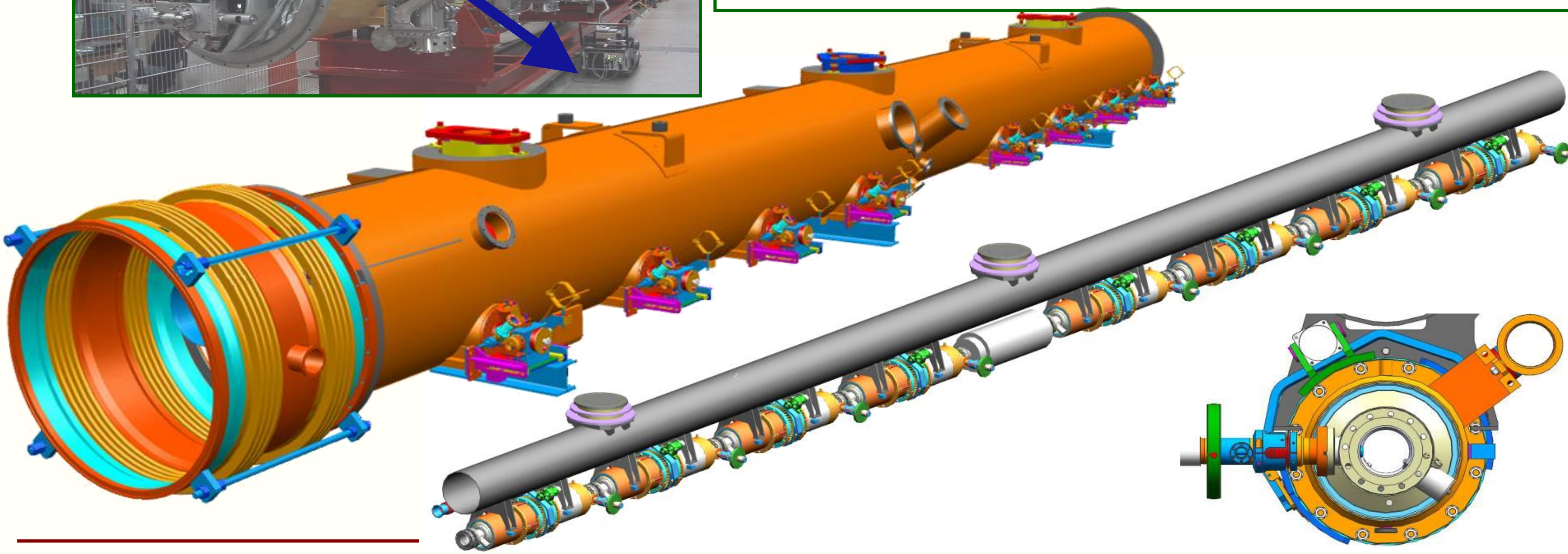


HOMs

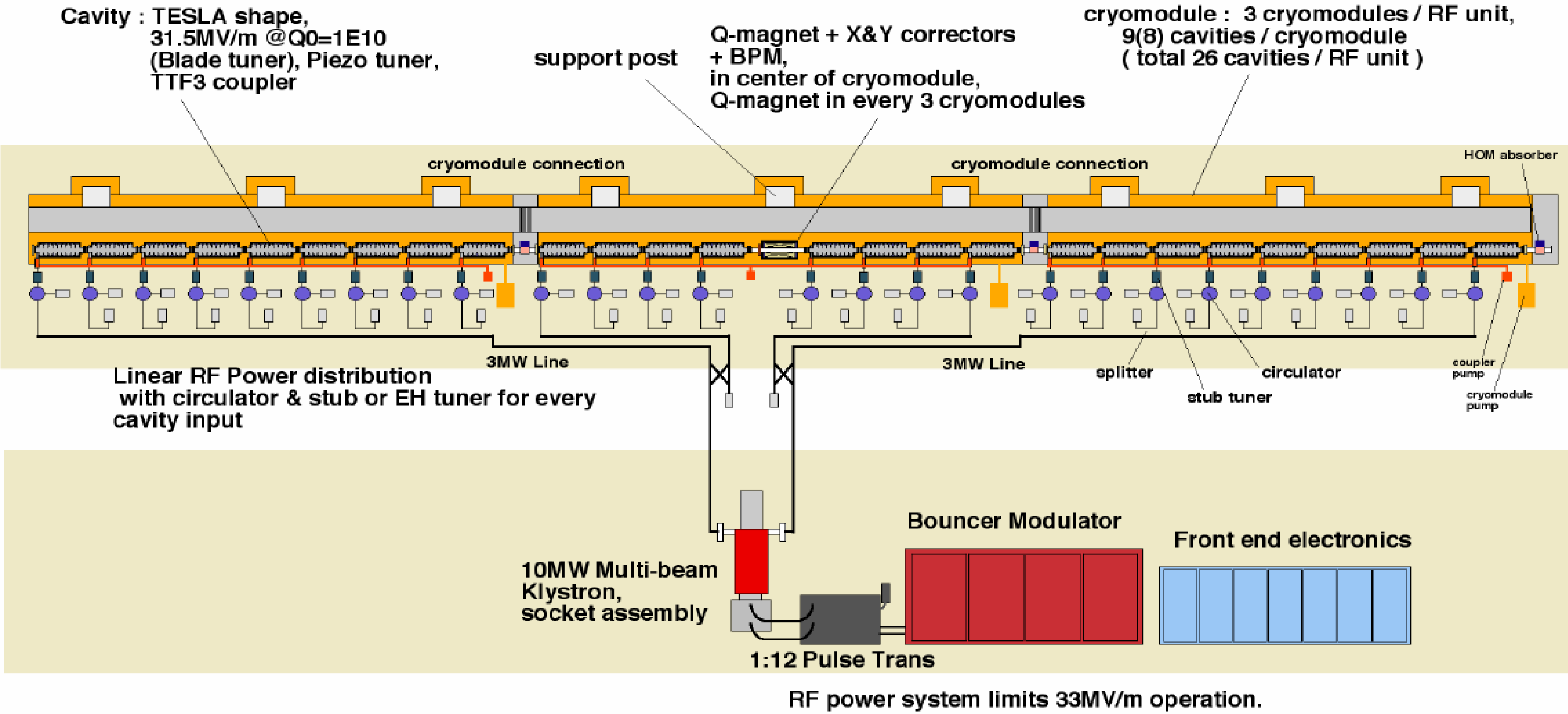
ILC Reference Cryomodule

- 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)**





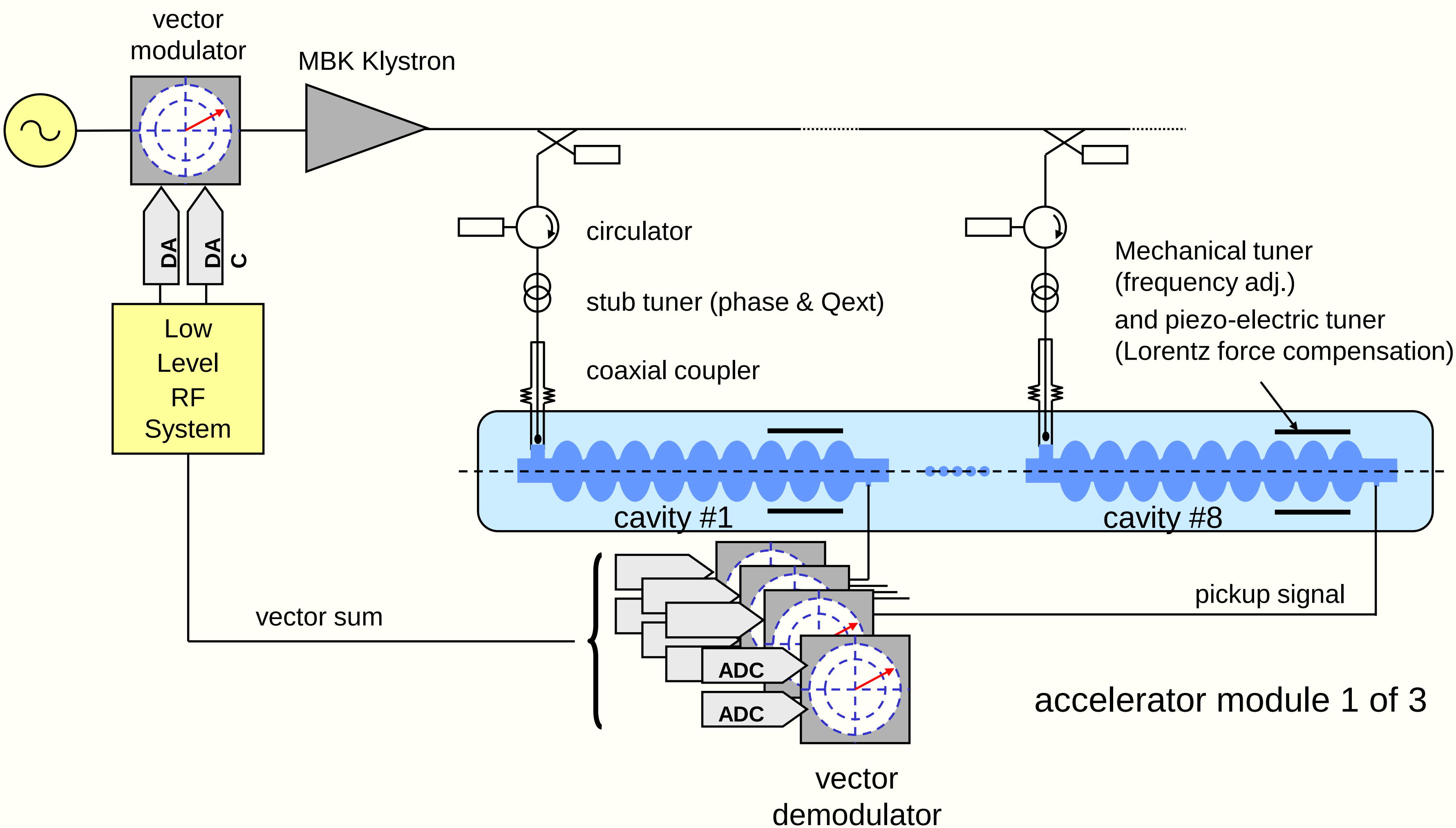
One ILC Linac RF Unit



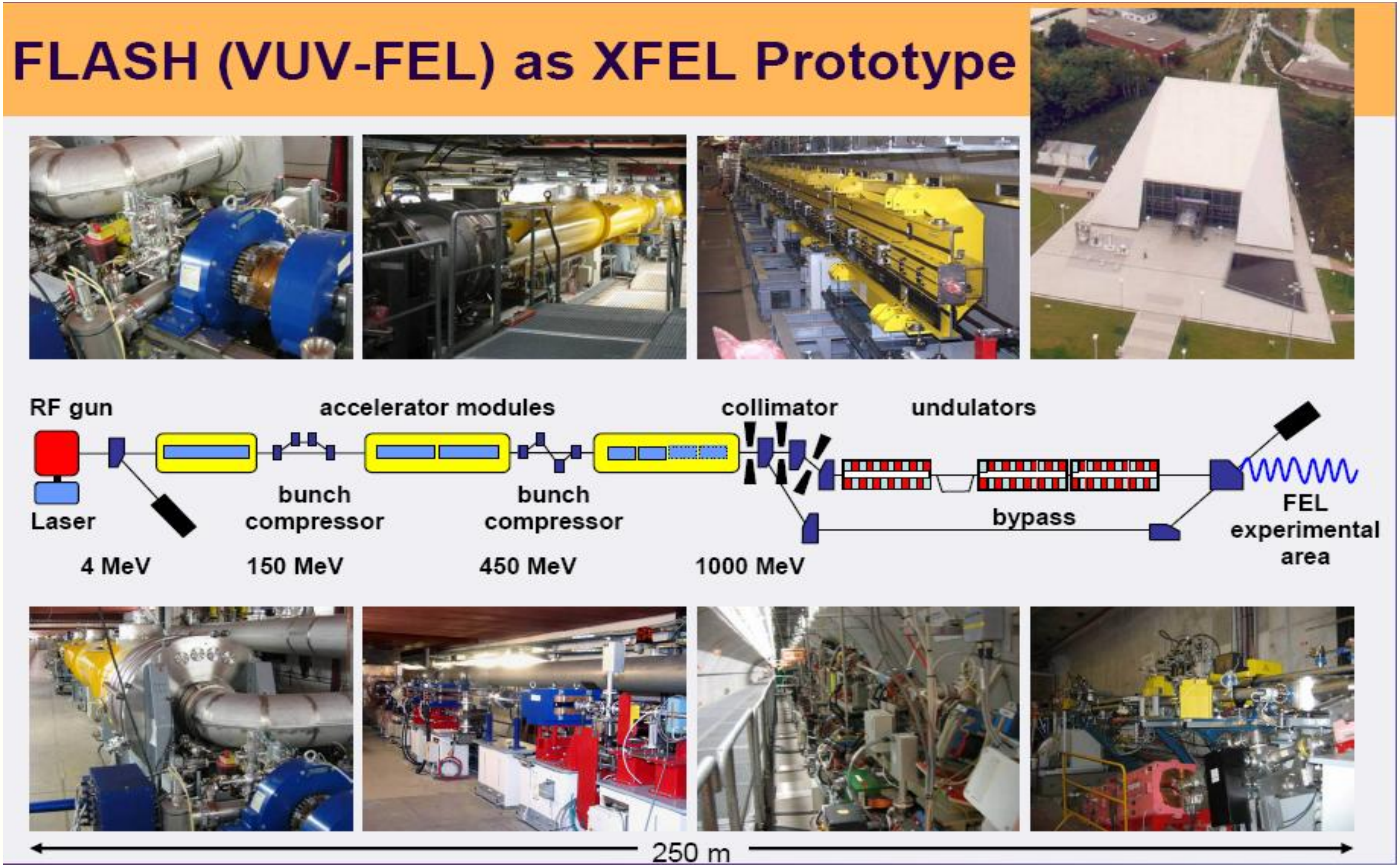
RDR configuration

Standard ILC RF Unit

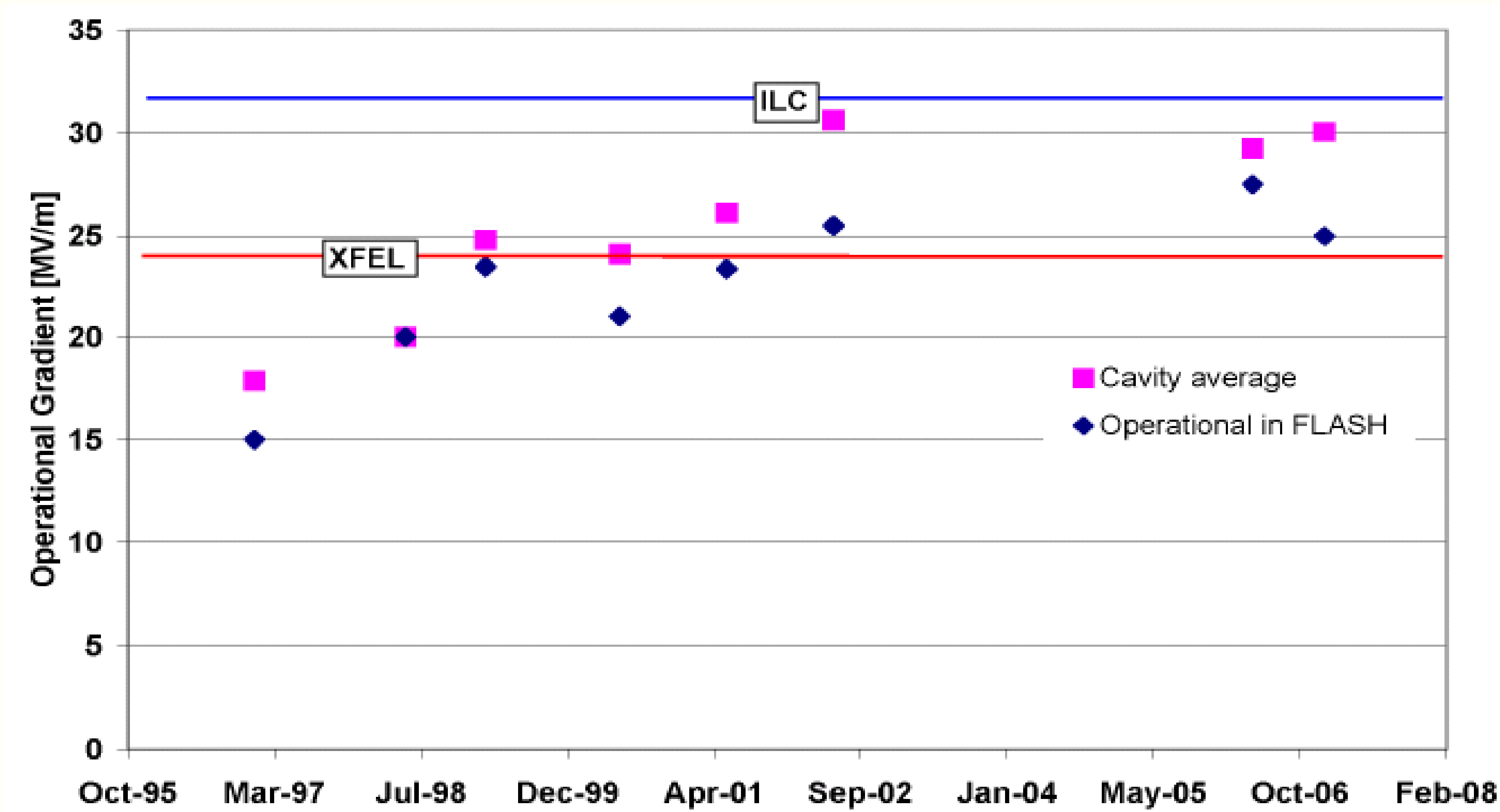
1 klystron for 3 accelerating modules, 9-8-9 nine-cell cavities each



The Existing FLASH at DESY



TTF-FLASH System Performance

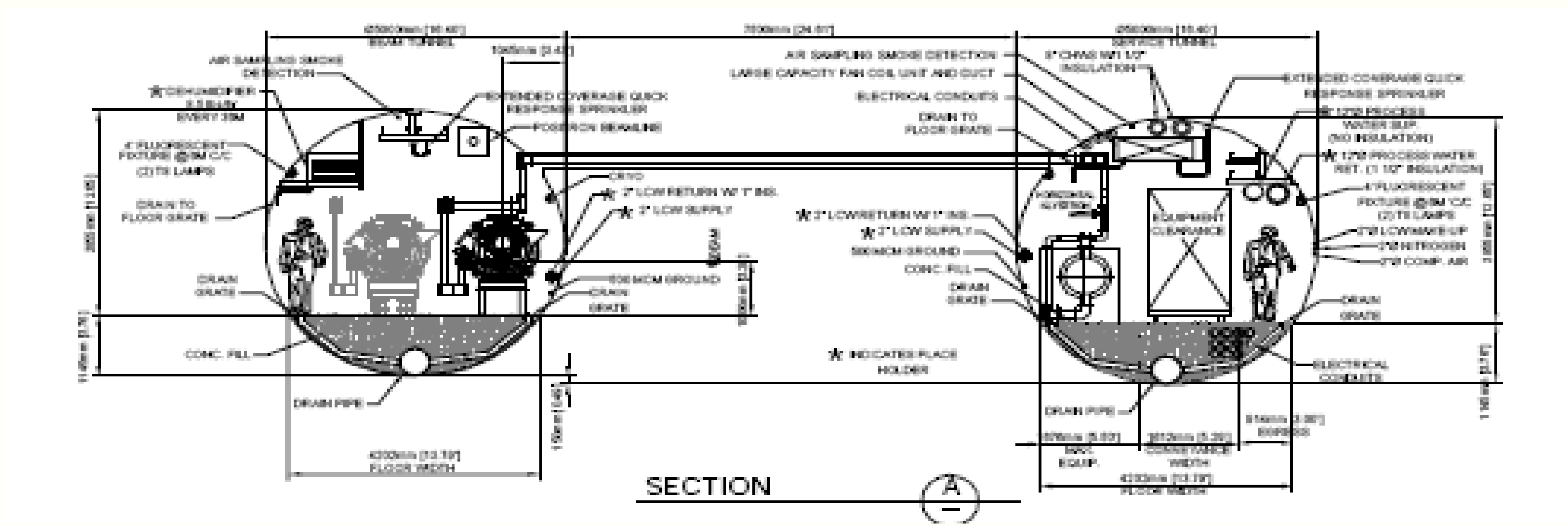


A more flexible RF Distribution System will allow higher operation gradient

Reference Design – Regional Differences

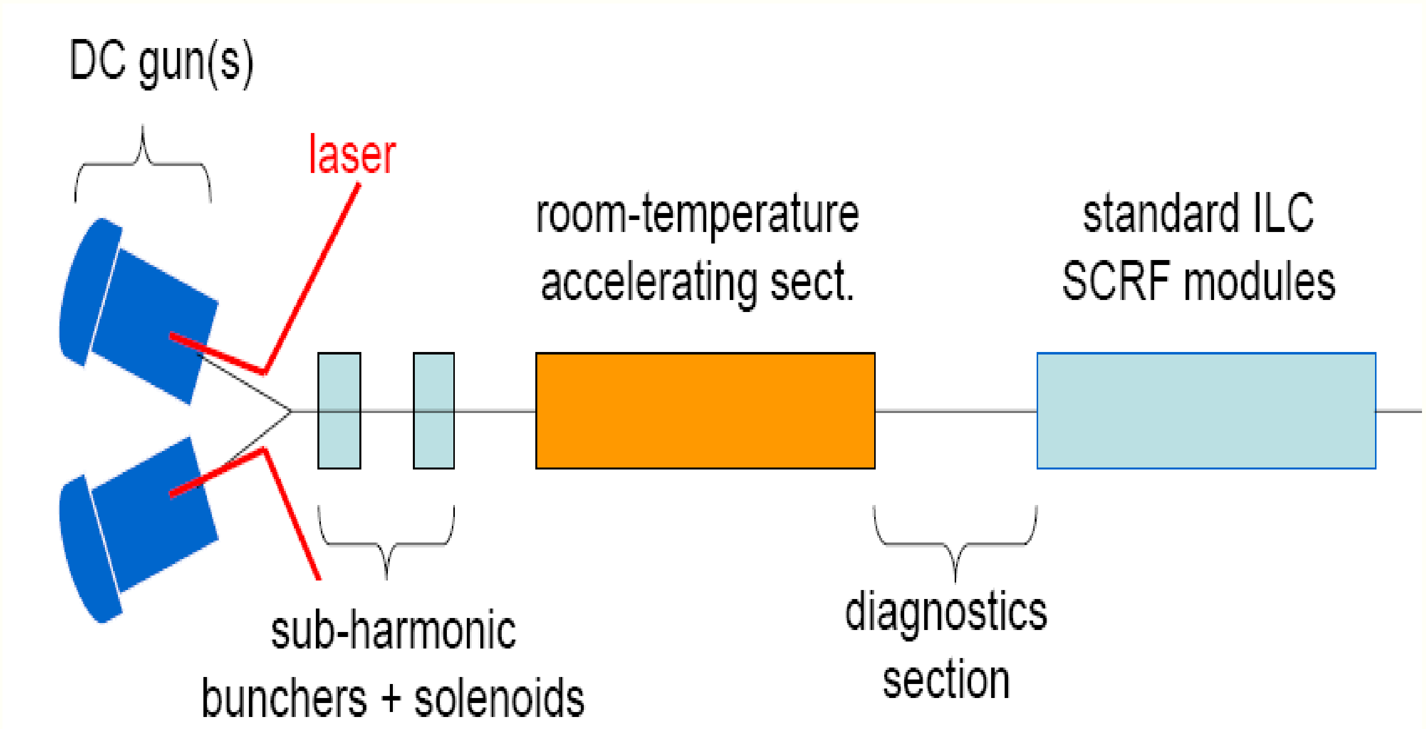
Tunnel Diameter

- Both tunnels are 5 meter diameter (Fixed)
- 5 meters in Asia & 7.5 meters elsewhere between tunnels (for structural reasons)
- 5 meters between tunnels required for shielding



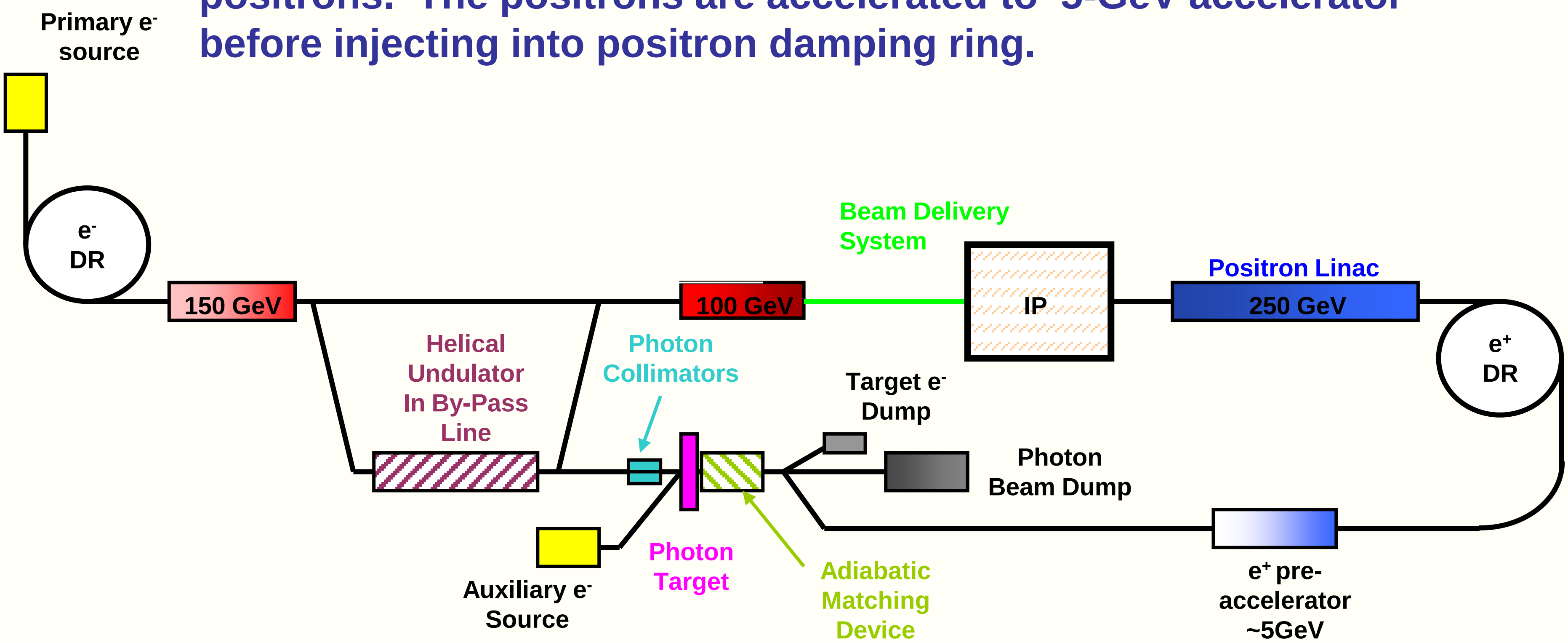
Baseline Features – Electron Source

- **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

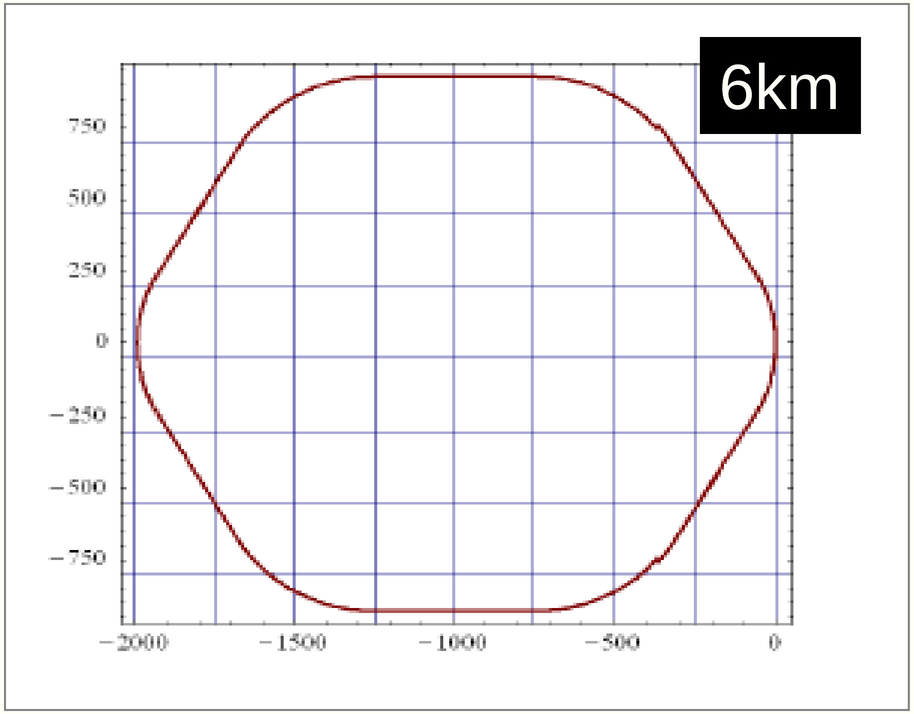


Baseline Features – Positron Source

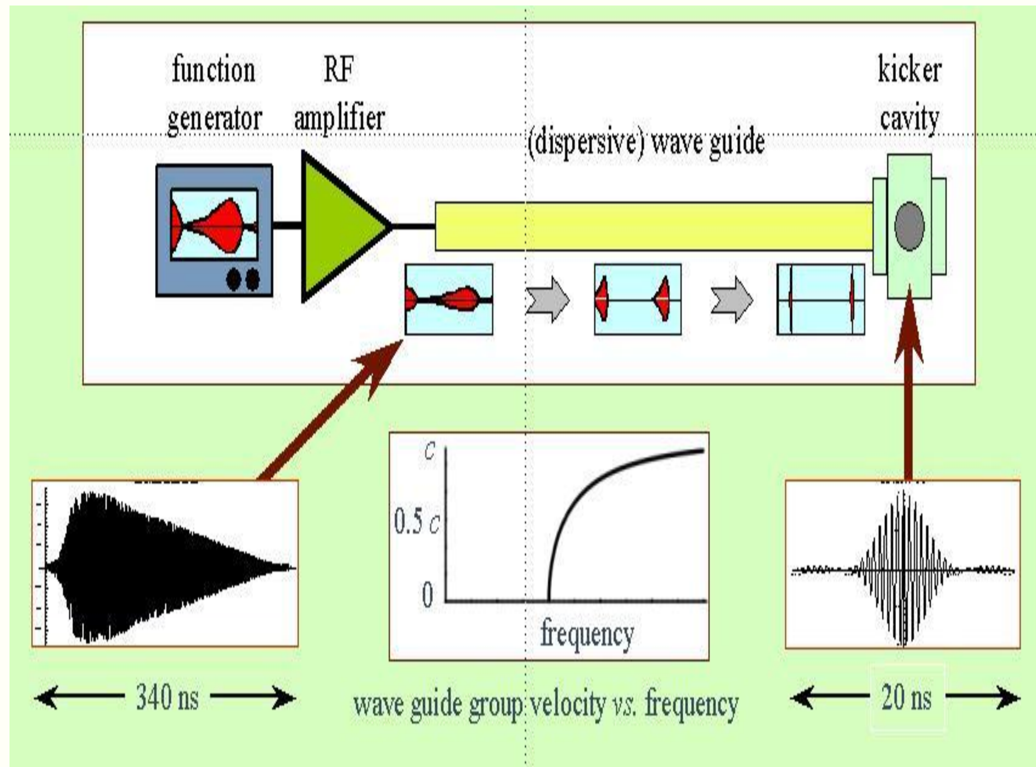
- **Positron Source – Helical Undulator with Polarized beams –** 150 Gev electron beam goes through a 200m undulator ing making photons that hit a 0.5 rl titanium alloy target to produce positrons. The positrons are accelerated to 5-GeV accelerator before injecting into positron damping ring.



6 Km Damping Ring



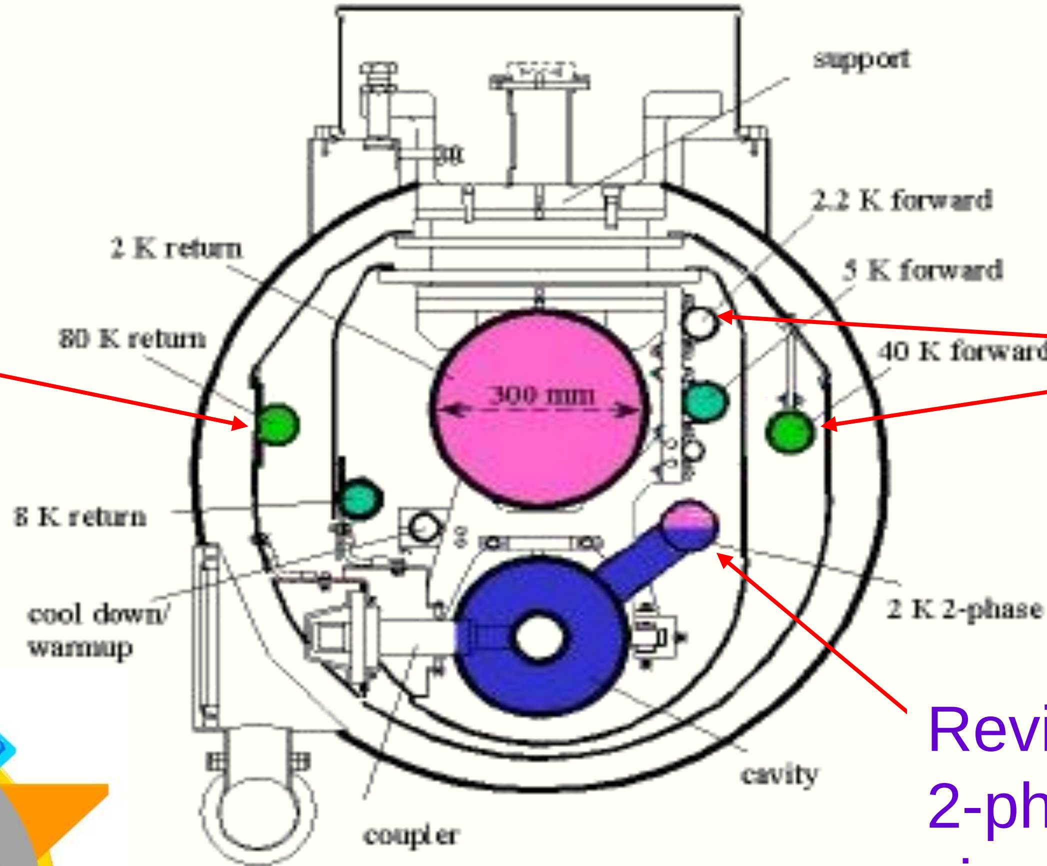
Requires Fast Kicker 5 nsec rise and 30 nsec fall time



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

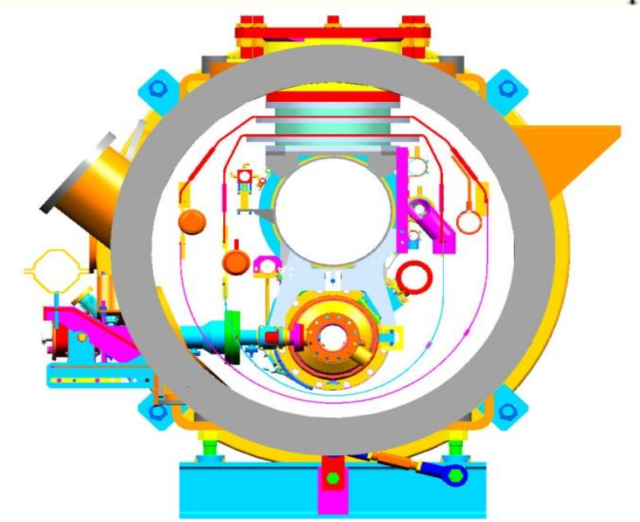
ILC Cryomodule

Increase diameter beyond X-FEL

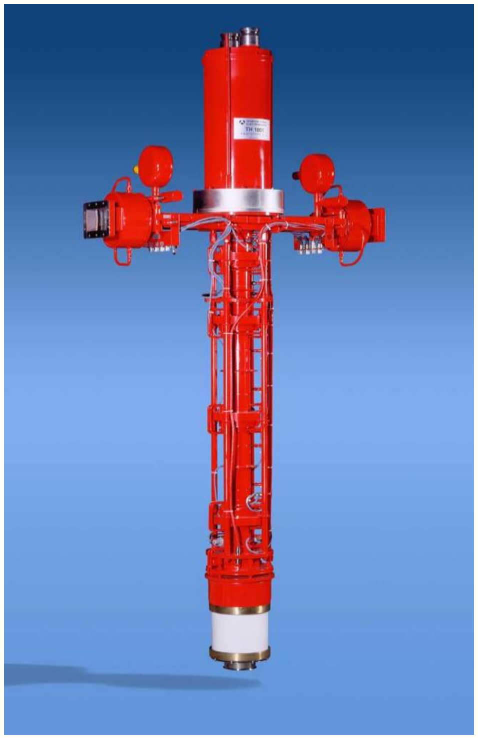


Increase diameter beyond X-FEL

Review 2-phase pipe size and effect of slope



RF Power: Baseline Klystrons



Thales

CPI

Toshiba

Specification:

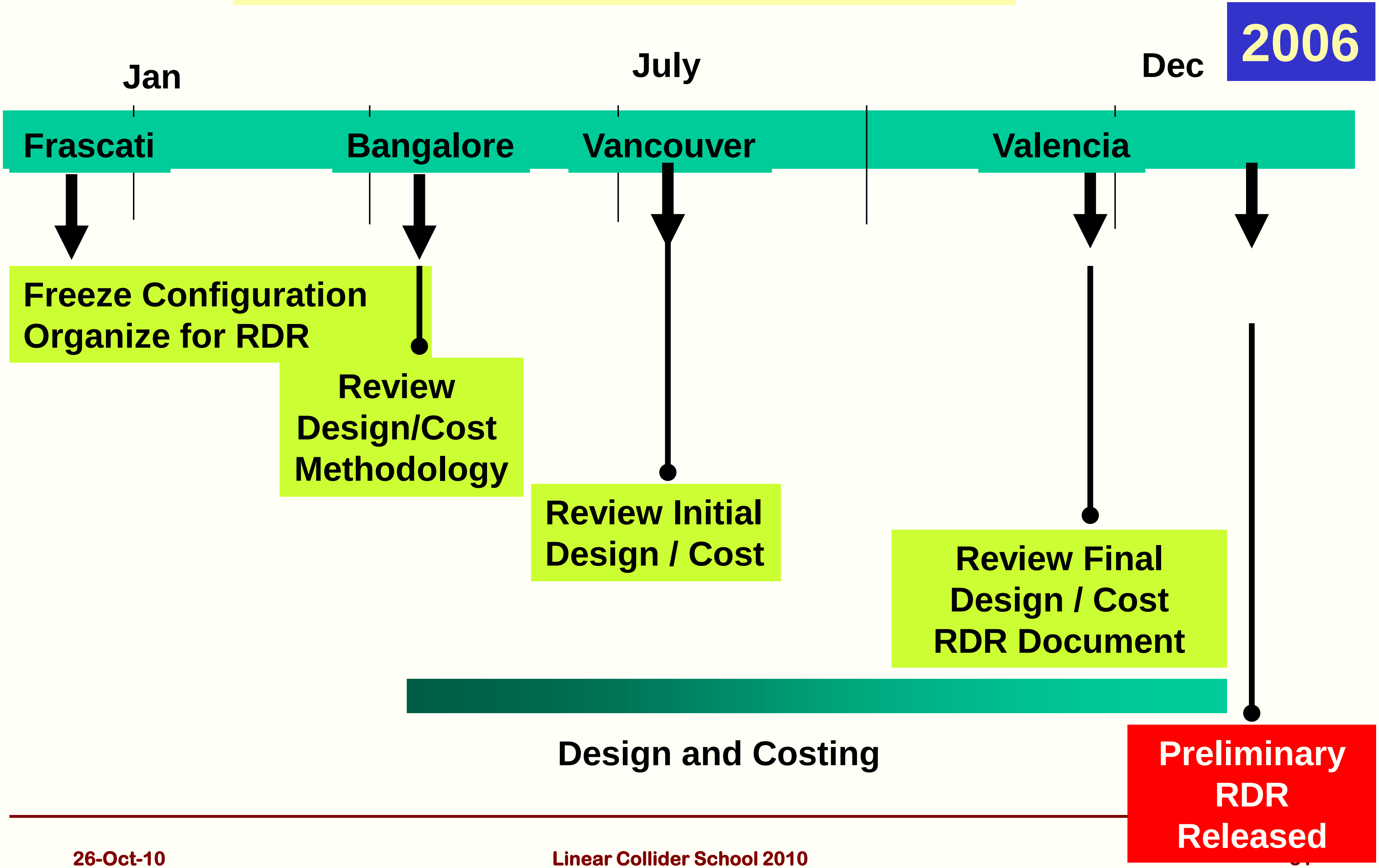
10MW MBK

1.5ms pulse

65% efficiency

BREAK

Baseline to a RDR

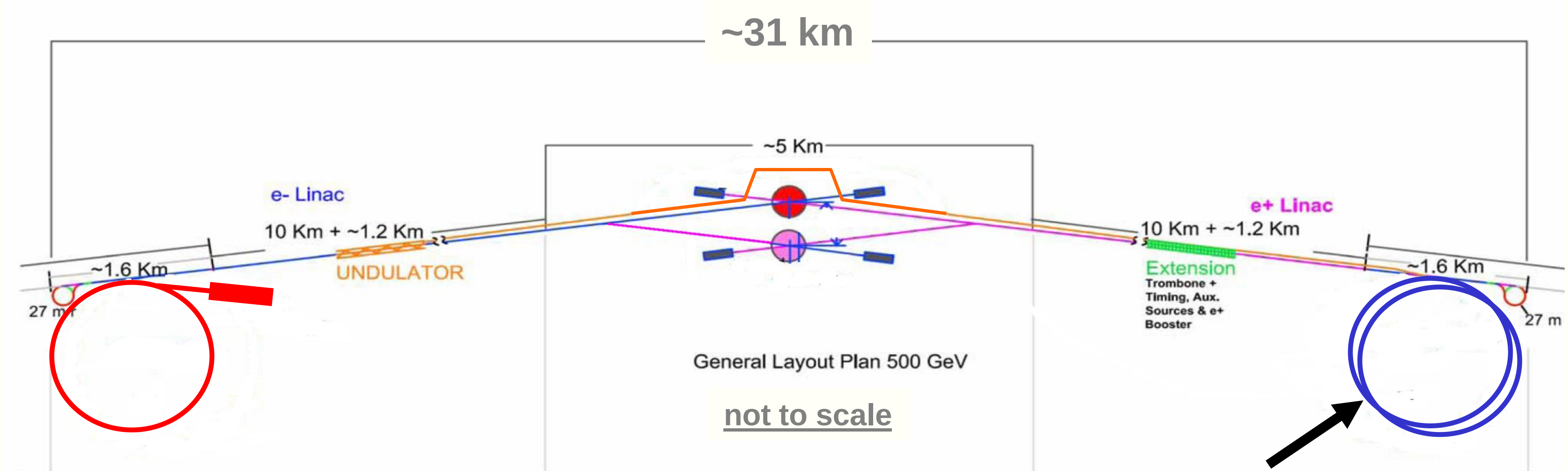


Cost-Driven Design Changes

Area		RDR MB	CCR	CCB	approx. Δ$
BDS	2´14mr IRs	supported	14	✓	~170 M$
	Single IR with push-pull detector	supported	23	✓	~200 M$
	Removal of 2nd muon wall	supported	16	✓	~40 M$
ML	Removal of service tunnel	rejected			~150 M$
	RF unit modifications (24 → 26 cav/klys)	supported			~50 M$
	Reduced static cryo overhead	supported	20	✘	~150 M$
	Removal linac RF overhead	supported			~20 M$
	Adoption of Marx modulator (alternate)	rejected			~180 M$
RTML	Single-stage bunch compressor	rejected			~80 M$
	Miscellaneous cost reduction modifications	supported	19	✓	~150 M$
Sources	Conventional e+ source	rejected			<100M$
	Single e+ target	supported	*in prep*		~30 M$
	e- source common pre-accelerator	supported	22	✓	~50 M$
DR	Single e+ ring	supported	15	✓	~160 M$
	Reduced RF in DR (6 → 9mm σ_z)	supported	*in prep*		~40 M$
	DR consolidated lattice (CFS)	supported	*in prep*		~50 M$
General	Central injector complex	supported	18(19)	✓	~180 M$

The Evolving Baseline

Baseline Configuration

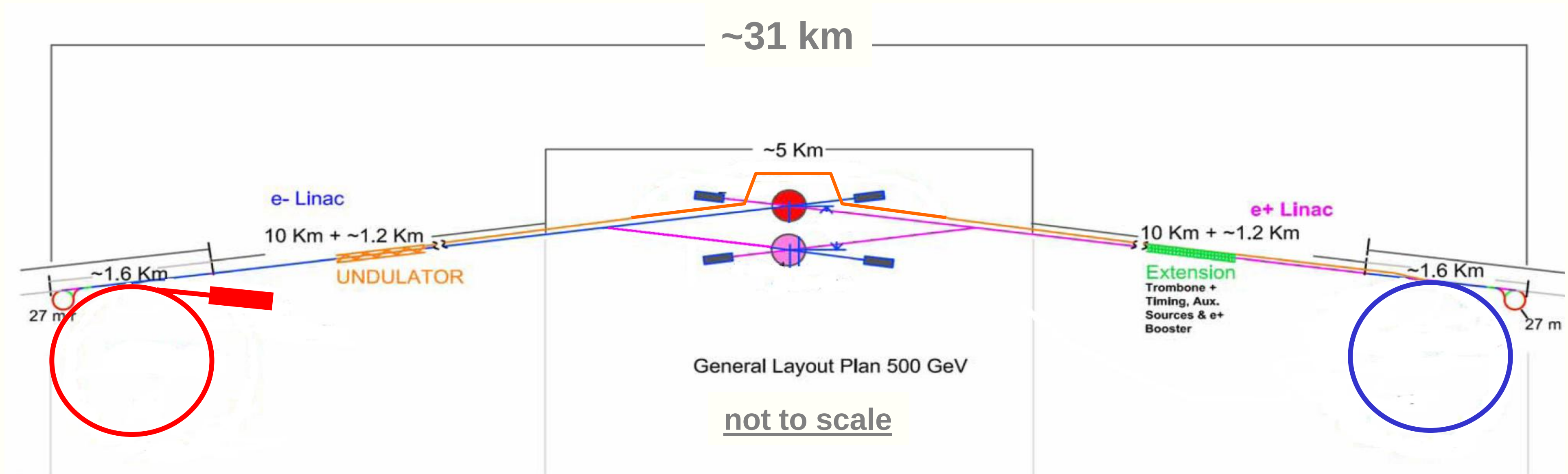


Removal of second e+ ring

The Evolving Baseline

Damping Ring

Baseline Configuration



Removal of second e+ ring

simulations of effect of clearing electrodes on **Electron Cloud** instability suggests that a **single e+ ring** will be sufficient

The Evolving Baseline

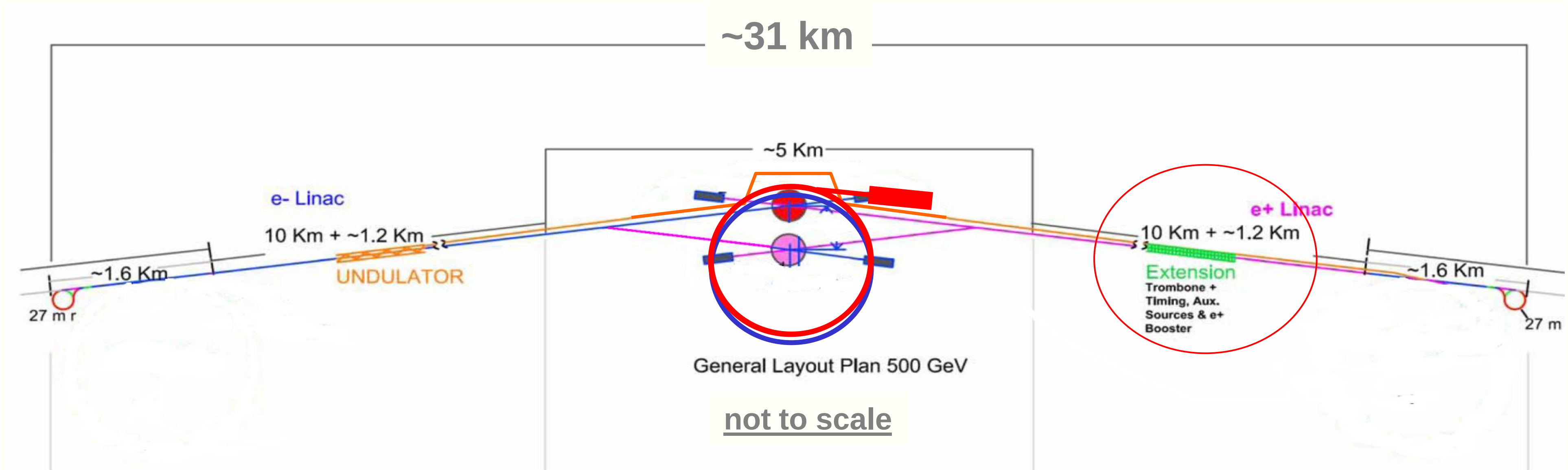
Baseline Configuration

Centralised injectors

Place both e+ and e- ring in single centralized tunnel

The Evolving Baseline

Baseline Configuration



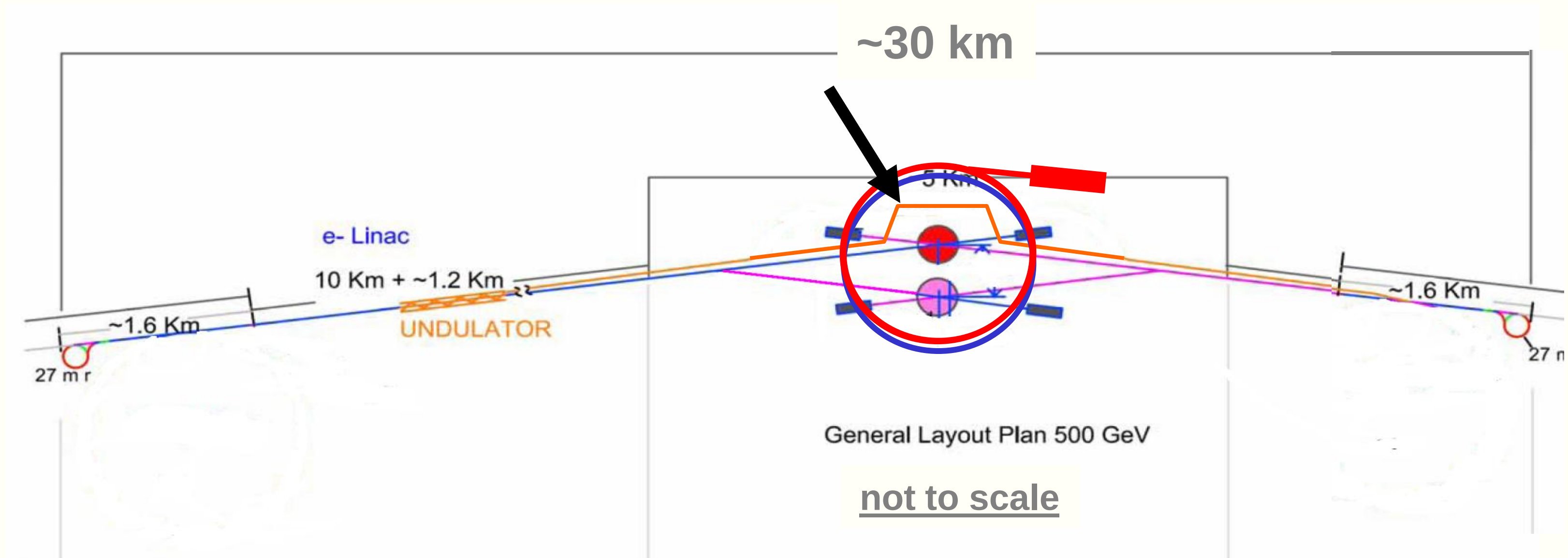
Centralised injectors

Place both e+ and e- ring in single centralized tunnel

Adjust timing (remove timing insert in e+ linac)

The Evolving Baseline

Baseline Configuration



Centralised injectors

Place both e+ and e- ring in single centralized tunnel

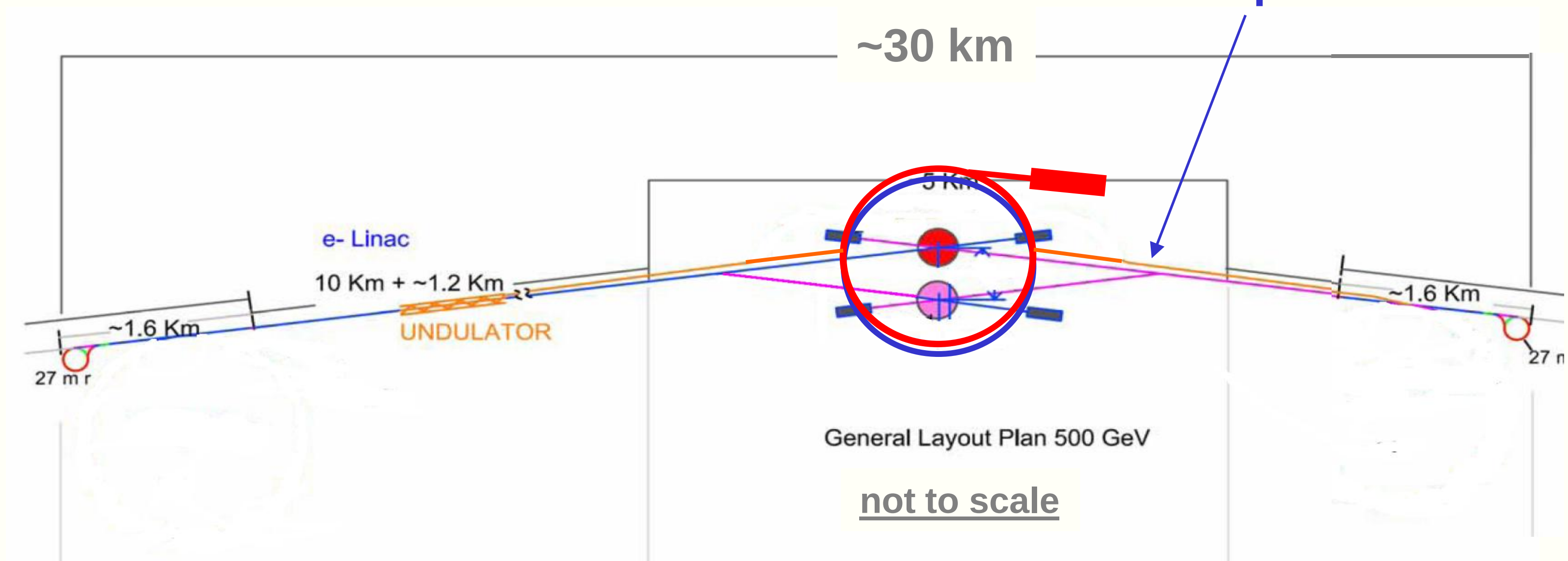
Adjust timing (remove timing insert in e+ linac)

Remove BDS e+ bypass

The Evolving Baseline

Baseline Configuration

Long 5GeV low-emittance transport lines now required



Centralised injectors

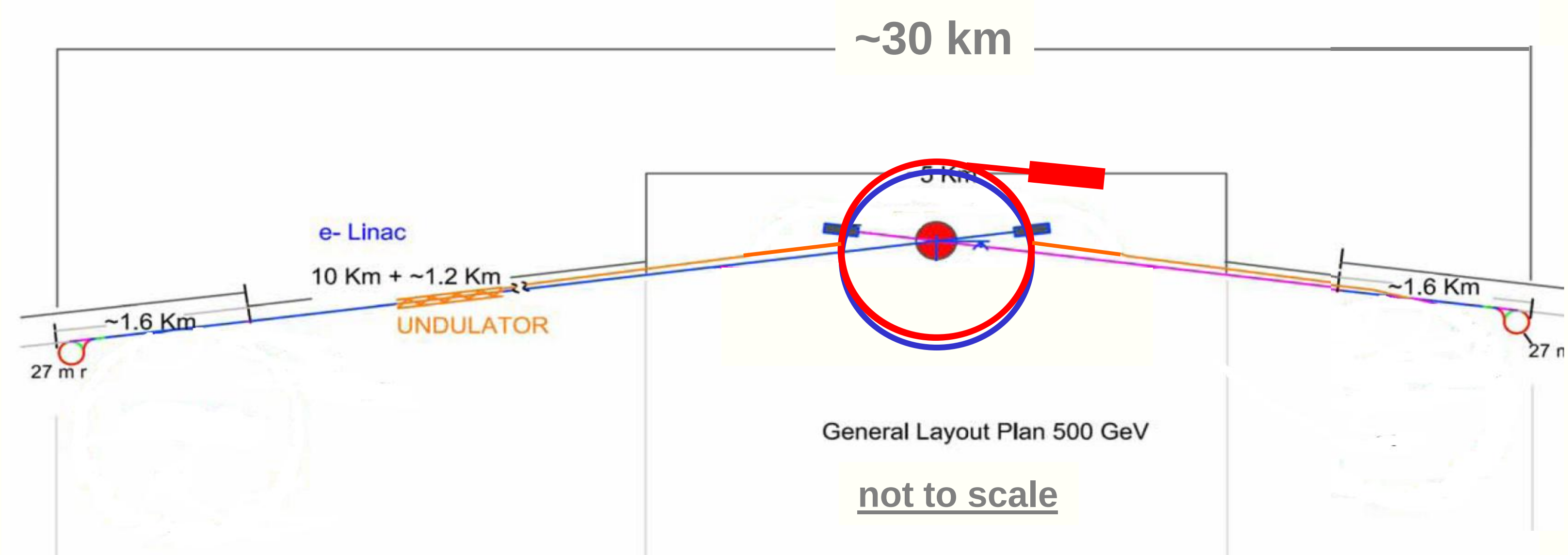
Place both e+ and e- ring in single centralized tunnel

Adjust timing (remove timing insert in e+ linac)

Remove BDS e+ bypass

The Evolving Baseline

Baseline Configuration

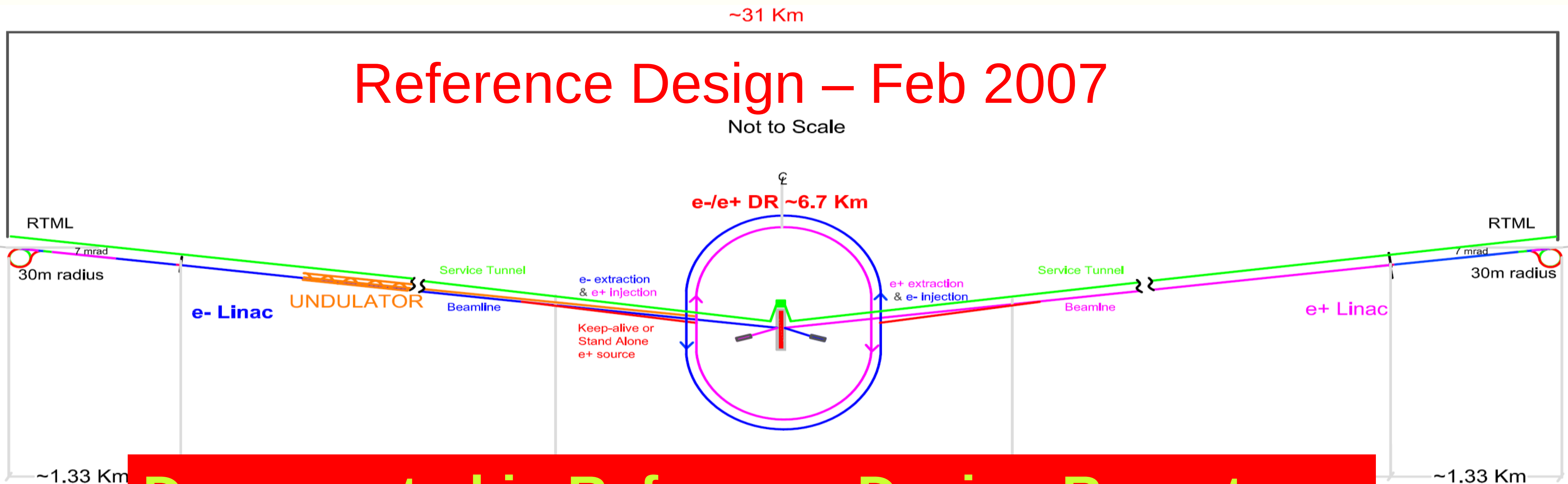


Single IR with Push-Pull Detector

Final RDR baseline

ILC Reference Design

- 11km SC linacs operating at 31.5 MV/m for 500 GeV
- Centralized injector
  - Circular damping rings for electrons and positrons
  - Undulator-based positron source
- Single IR with 14 mrad crossing angle
- Dual tunnel configuration for safety and availability



Documented in Reference Design Report

Parameters Report Revisited

- **The ILCSC Parameters Group has given updated selected clarification on accelerator requirements, based on achieving ILC science goals:**
  - **Removing safety margins in the energy reach is acceptable but should be recoverable without extra construction. The max luminosity is not needed at the top energy (500 GeV), however …..**
  - **The interaction region (IR) should allow for two experiments ….. the two experiments could share a common IR, provided that the detector changeover can be accomplished in approximately 1 week.**

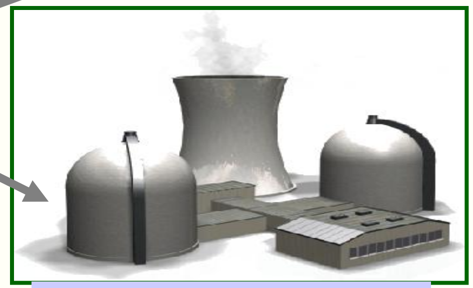
RDR Design Parameters

Max. Center-of-mass energy	500	GeV
Peak Luminosity	~2×10^{34}	$1/cm^2s$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW

ILC site power: ~ 230MW

Main Linacs
140 MW

Sub-Systems 90 MW



RF
100 MW

78%

Cryogenics:
40 MW

Injectors

Damping rings

BDS

Auxiliaries

65%

60%

Beam Power
22 MW

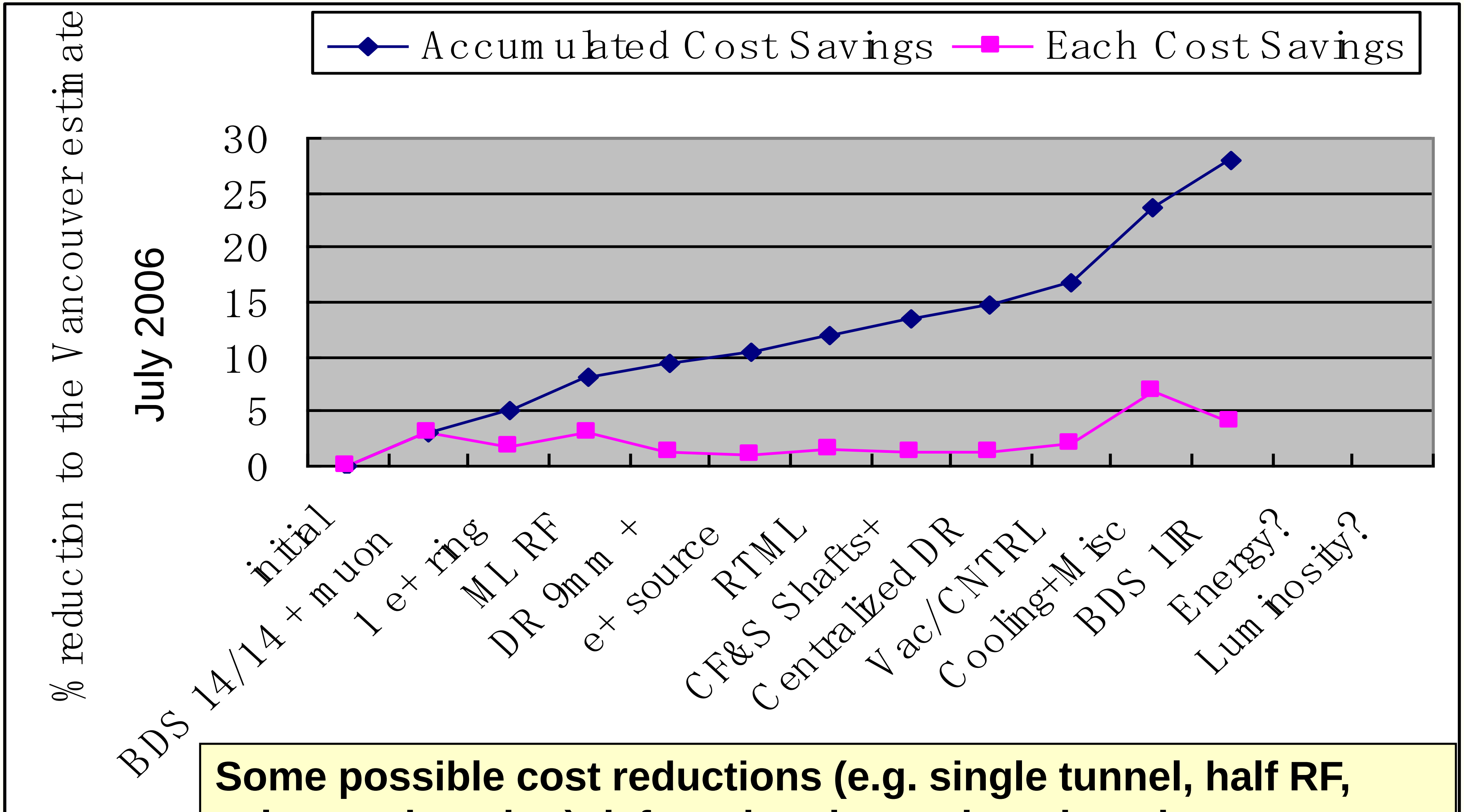
RDR Cost Estimating

- "Value" Costing System: International costing for International Project
  - Provides basic agreed to "value" costs
  - Provides estimate of "explicit" labor (man-hr)]

- Based on a call for world-wide tender:
  lowest reasonable price for required quality

- Classes of items in cost estimate:
  - Site-Specific: separate estimate for each sample site
  - Conventional: global capability (single world est.)
  - High Tech: cavities, cryomodules (regional estimates)

Evolving Design → Cost Reductions



Some possible cost reductions (e.g. single tunnel, half RF, value engineering) deferred to the engineering phase

RDR Design & “Value” Costs

The reference design was “frozen” as of 1-Dec-06 for the purpose of producing the RDR, including costs.

It is important to recognize this is a snapshot and the design will continue to evolve, due to results of the R&D, accelerator studies and value engineering

The value costs have already been reviewed three time

- 3 day “internal review” in Dec
- ILCSC MAC review in Jan
- International Cost Review (May)

Σ Value = 6.62 B ILC Units

Summary
RDR “Value” Costs

Total Value Cost (FY07)

4.80 B ILC Units Shared

+

1.82 B Units Site Specific

+

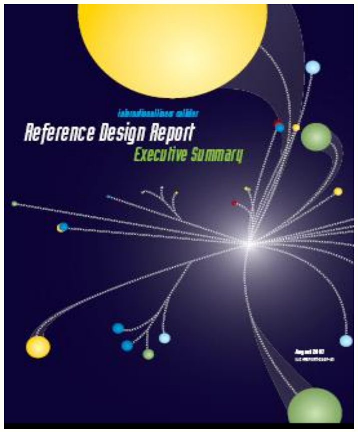
14.1 K person-years

(“explicit” labor = 24.0 M person-hrs @ 1,700 hrs/yr)

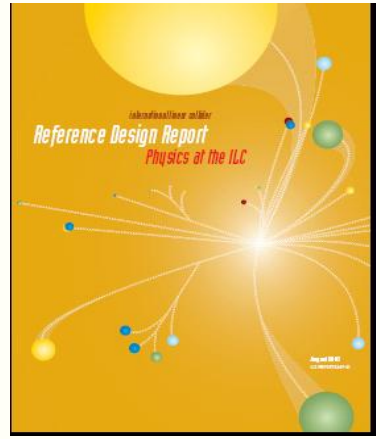
1 ILC Unit = $ 1 (2007)

RDR Complete

- Reference Design Report (4 volumes)

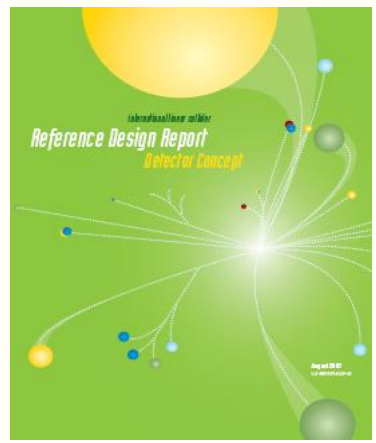


Executive Summary



Physics at the ILC

Accelerator



Detectors

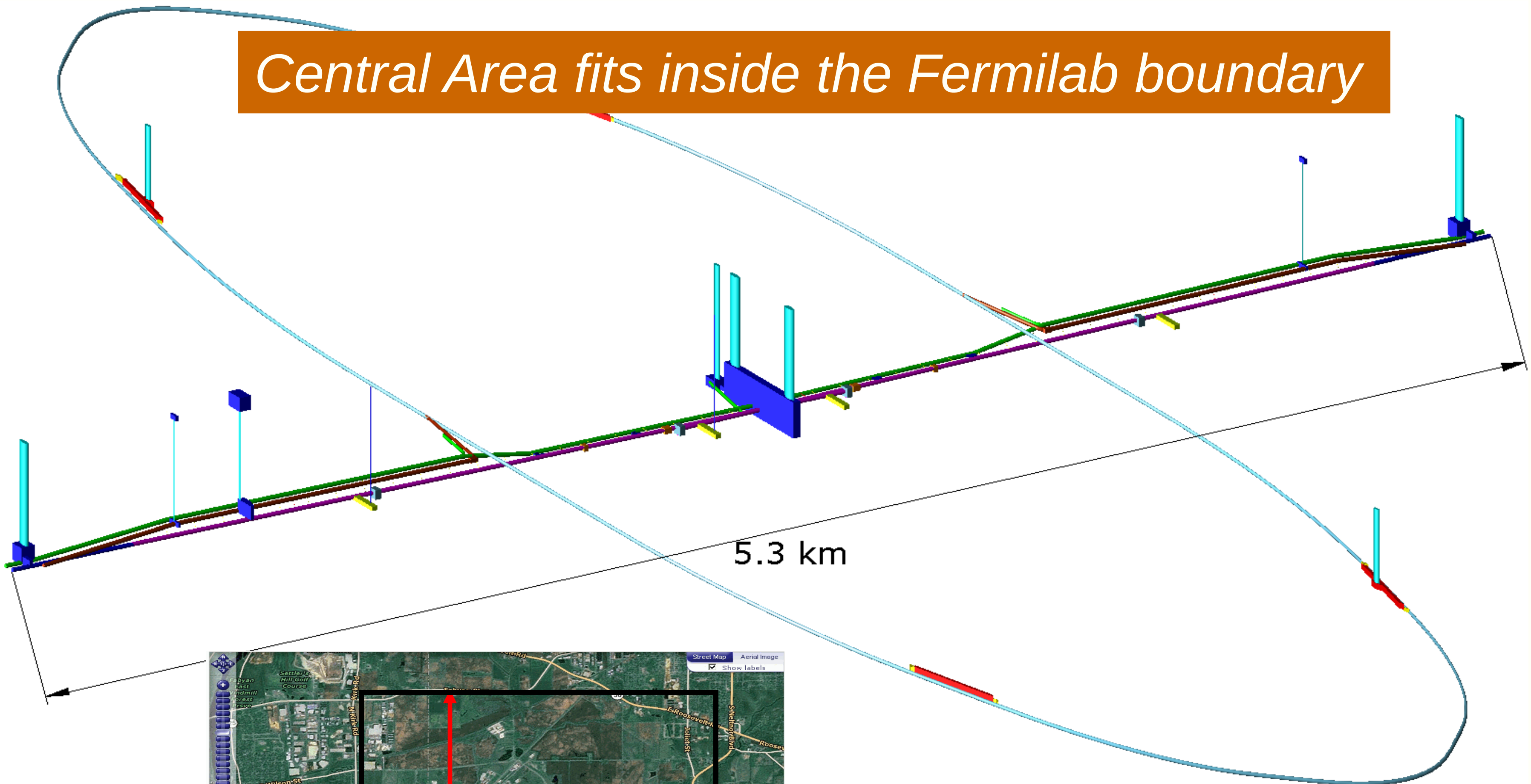
RDR vs ICFA Parameters

- 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%

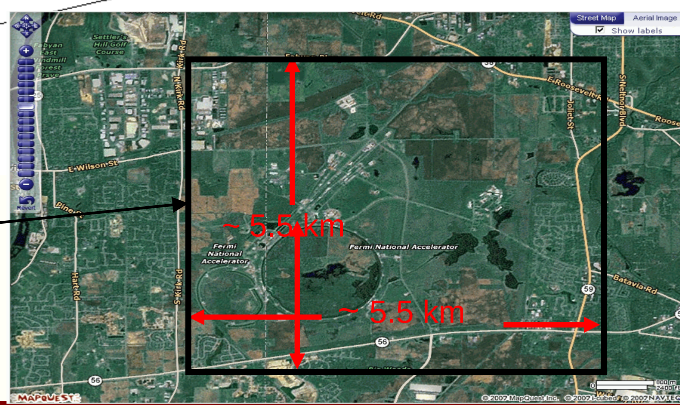
The RDR Design meets these "requirements," including the recent update and clarifications of the reconvened ILCSC Parameters group!

Preconstruction Plan for Fermilab

Central Area fits inside the Fermilab boundary



~ Boundary of Fermilab



Site Characterization of the Central Area can be done

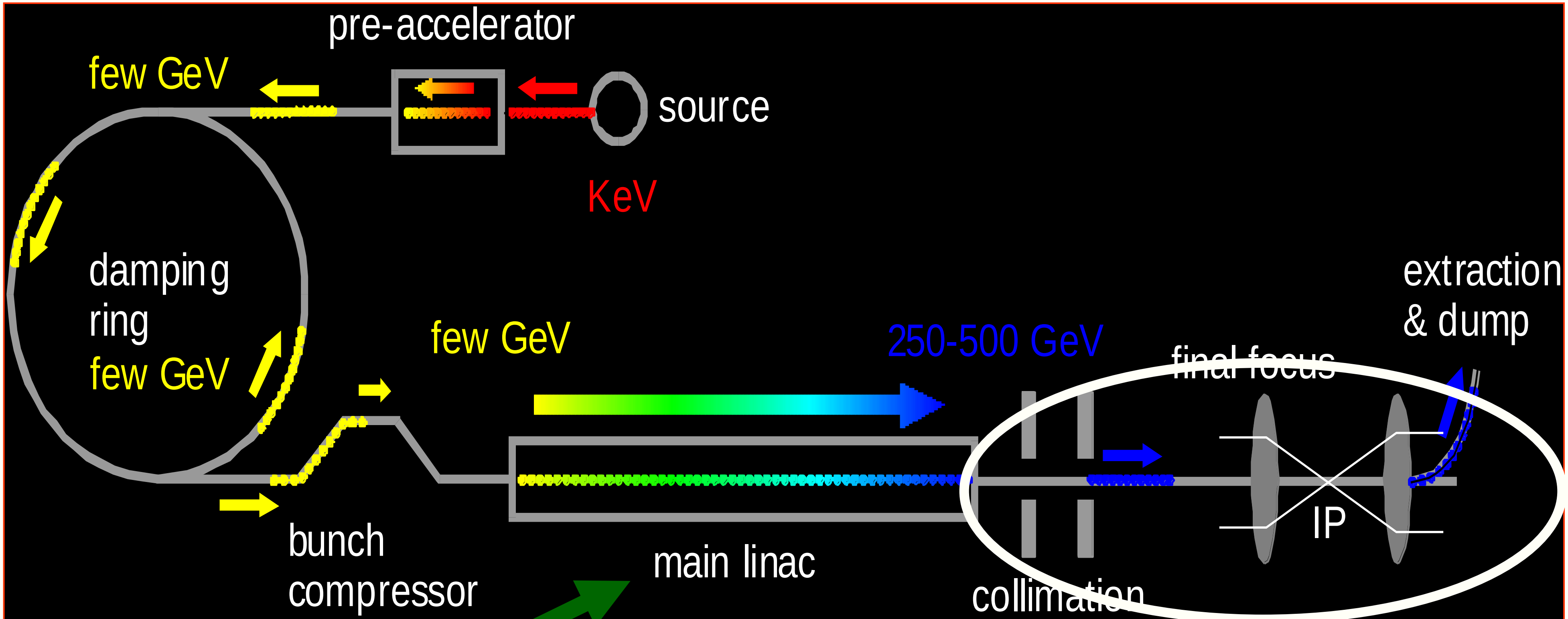
RDR Milestone Achieved

- **"Draft" Reference Design Report (RDR) was released and presented to ICFA as a ~300 page report at Beijing**
- **"Preliminary" International Value Costing presented**
- **This report and costing will serve as the foundation for the development of an Engineering Design Report that will define the ILC construction proposal. The reference design will guide:**
  - **The R&D program demonstrating the design or validating alternatives that improve performance or reduce risk**
  - **The Engineering Design Effort and especially the value engineering will be guided by the RDR.**

March 2005
I accepted
GDE job

Feb 2007
Reference Design
Presented to
ICFA/ILCSC

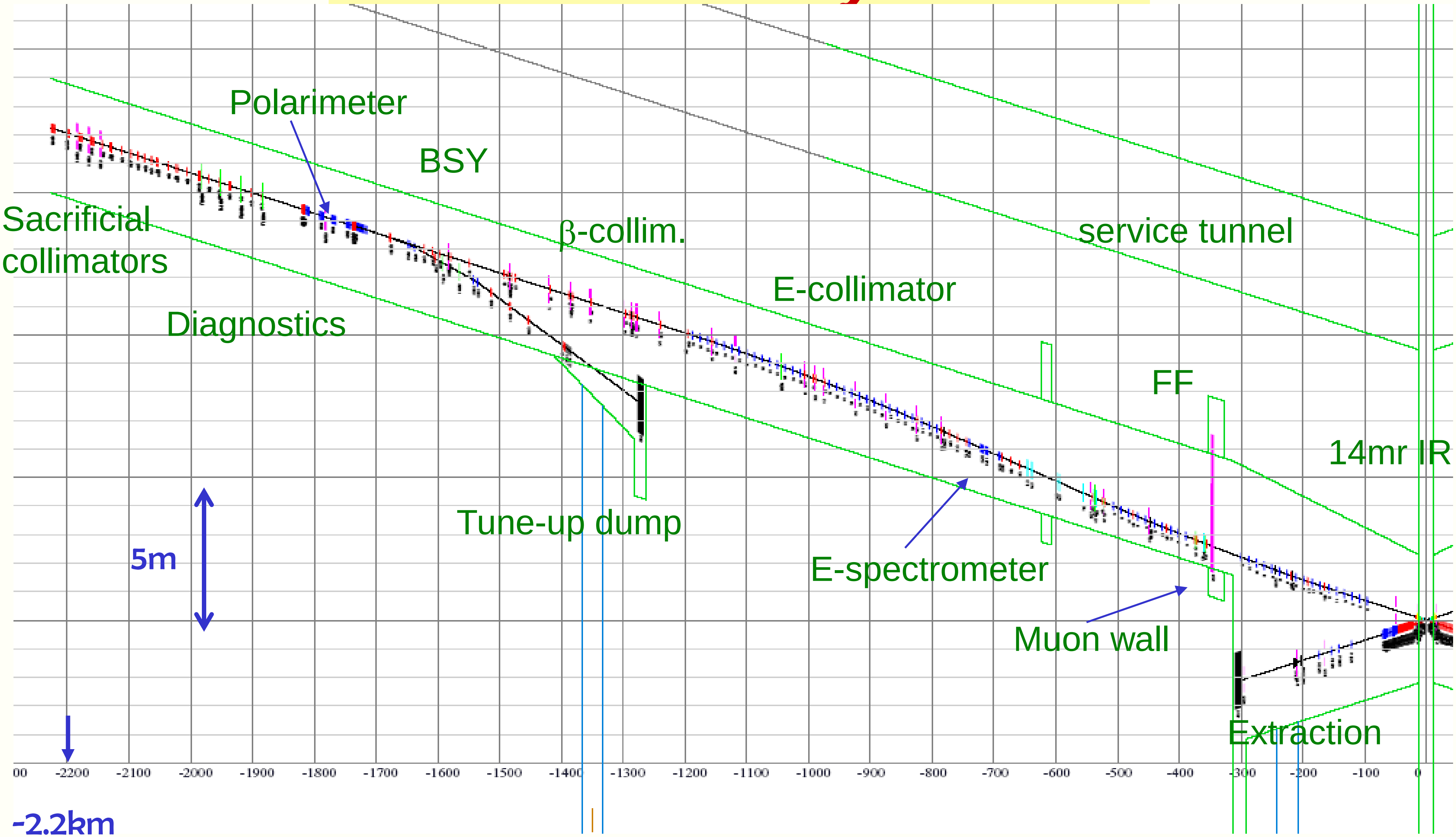
Designing a Linear Collider



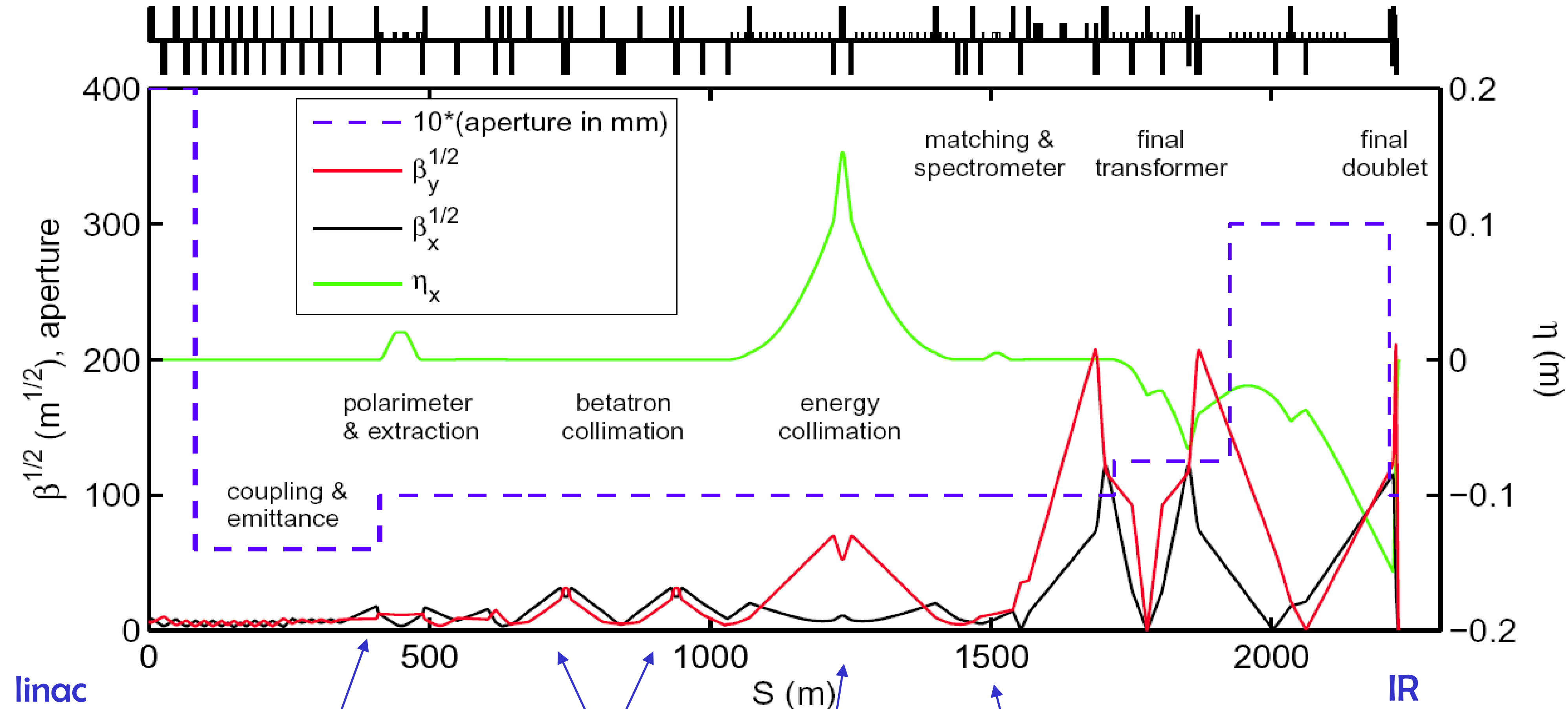
Superconducting RF Main Linac

Beam Delivery System

beam-line layout



Beam Delivery System Optics

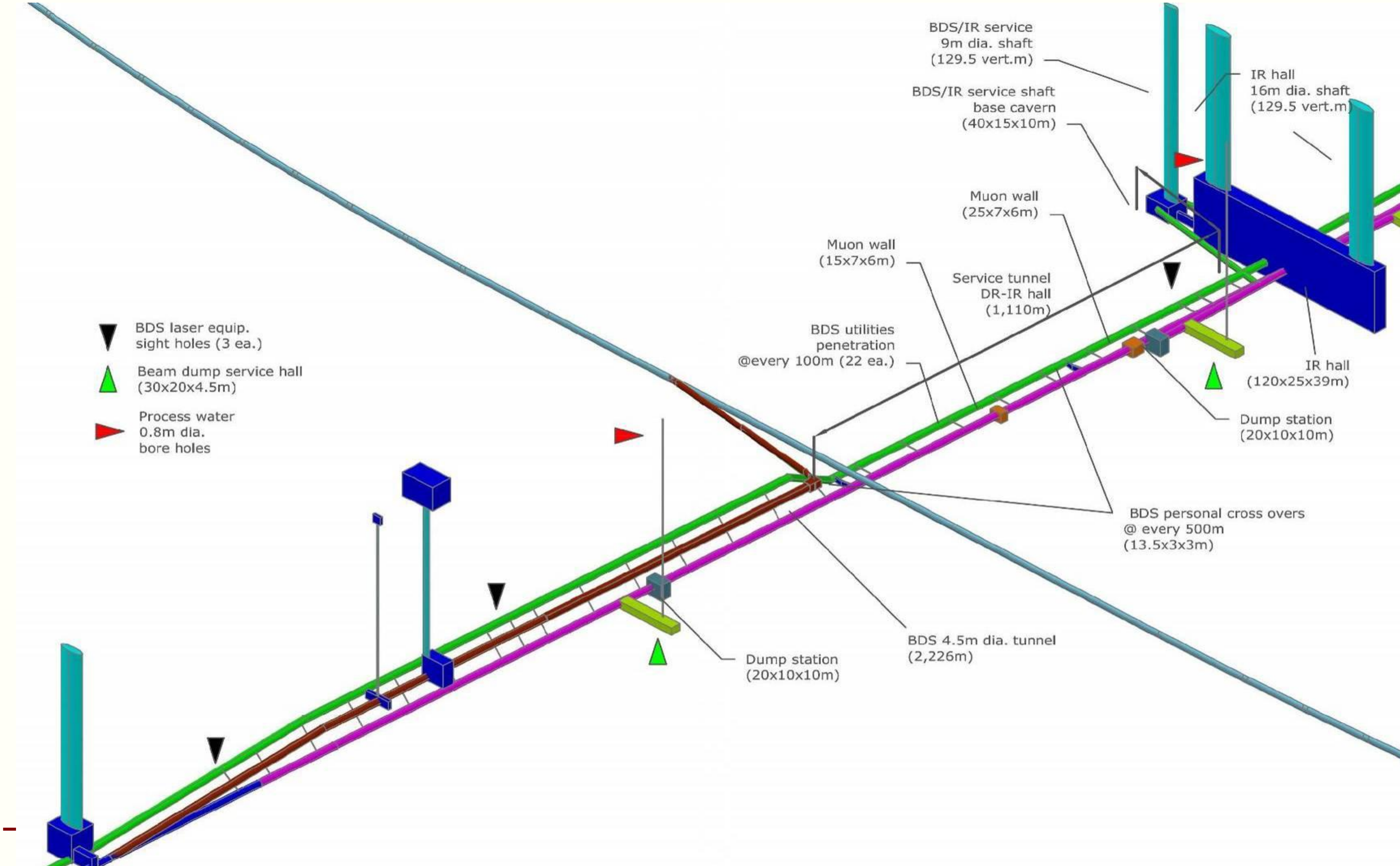


Upstream polarimeter; β & E –collimation ; Energy spectrometers are of particular Machine Detector Interface interest

Beam Delivery System
parameters

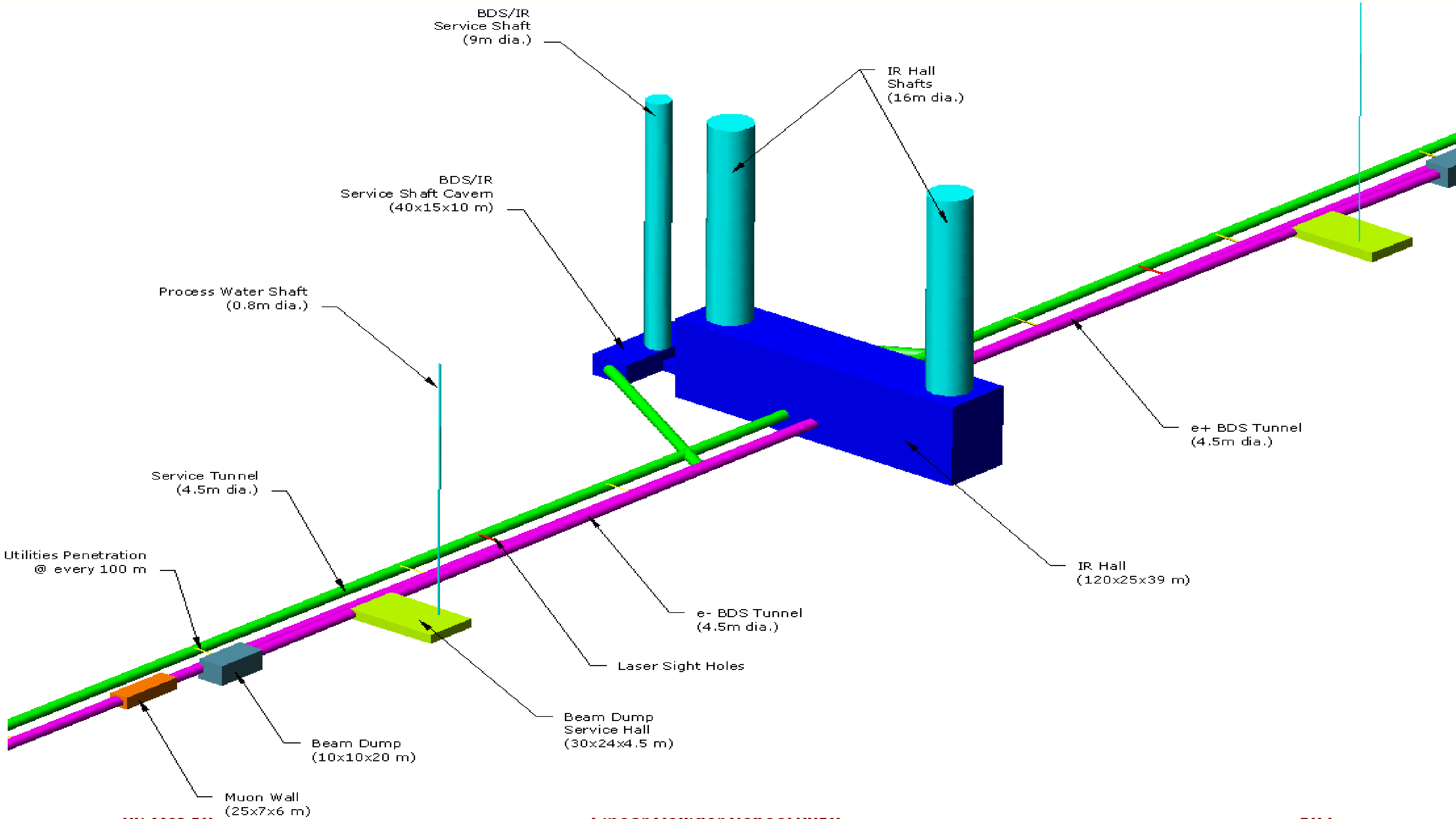
Length (linac exit to IP distance)/side	m	2226
Length of main (tune-up) extraction line	m	300 (467)
Max Energy/beam (with more magnets)	GeV	250 (500)
Distance from IP to first quad, L*	m	3.5-(4.5)
Crossing angle at the IP	mrad	14
Nominal beam size at IP, σ^*, x/y	nm	639/5.7
Nominal beam divergence at IP, θ^*, x/y	μrad	32/14
Nominal beta-function at IP, β^*, x/y	mm	20/0.4
Nominal bunch length, σ_z	μm	300
Nominal disruption parameters, x/y		0.17/19.4
Nominal bunch population, N		2.05×10^{10}
Beam power in each beam	MW	11.3
Preferred entrance train to train jitter	σ	< 0.5
Preferred entrance bunch to bunch jitter	σ	< 0.1
Typical nominal collimation depth, x/y		8–10/60
Vacuum pressure level, near/far from IP	nTorr	1/50

BDS layout

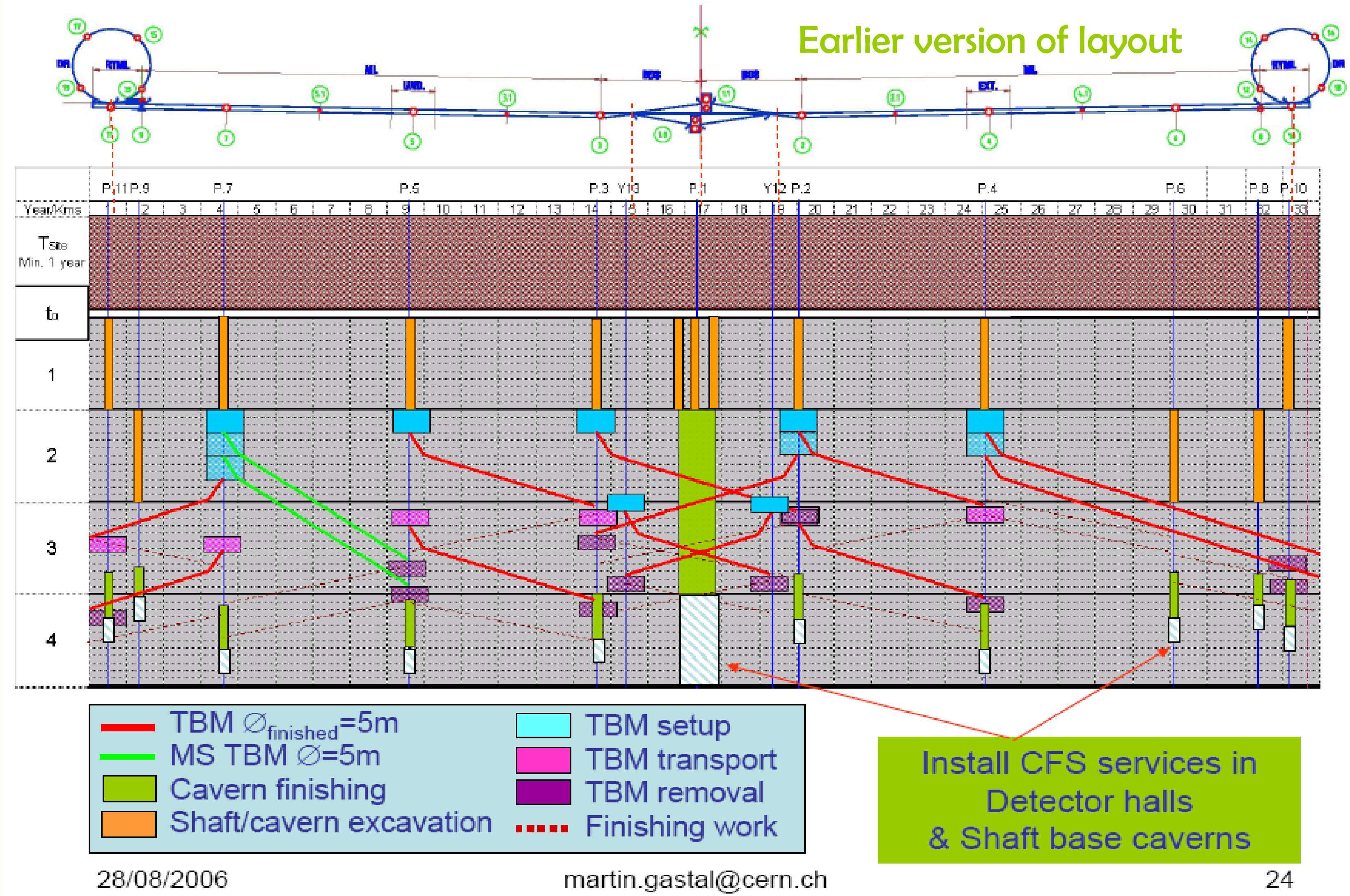


BDS/IR service
9m dia. shaft
(129.5 vert.m)
IR hall
16m dia. shaft
(129.5 vert.m)
BDS/IR service shaft
base cavern
(40x15x10m)
Muon wall
(25x7x6m)
Muon wall
(15x7x6m)
Service tunnel
DR-IR hall
(1,110m)
BDS utilities
penetration
@every 100m (22 ea.)
BDS laser equip.
sight holes (3 ea.)
Beam dump service hall
(30x20x4.5m)
Process water
0.8m dia.
bore holes
IR hall
(120x25x39m)
Dump station
(20x10x10m)
BDS personal cross overs
@ every 500m
(13.5x3x3m)
BDS 4.5m dia. tunnel
(2,226m)
Dump station
(20x10x10m)

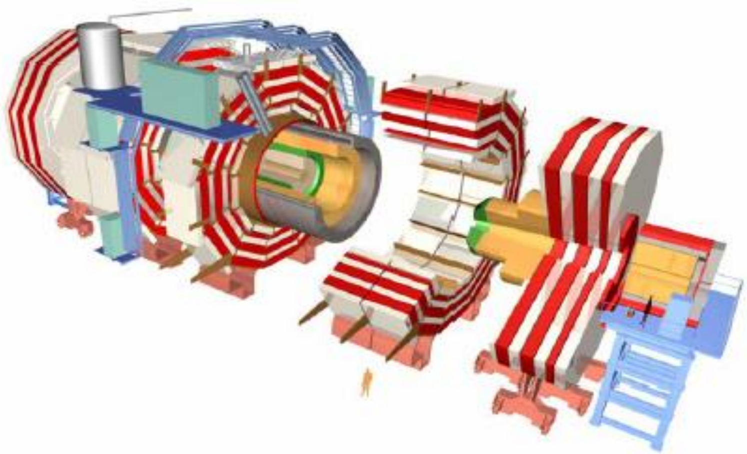
IR hall region

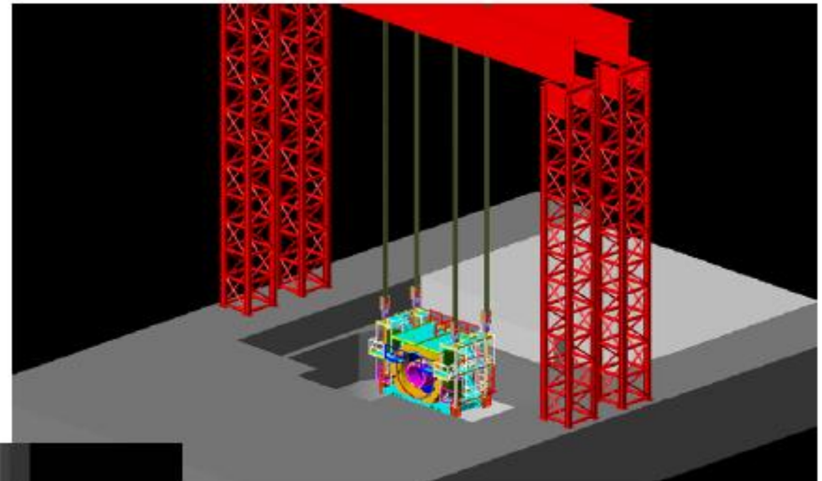


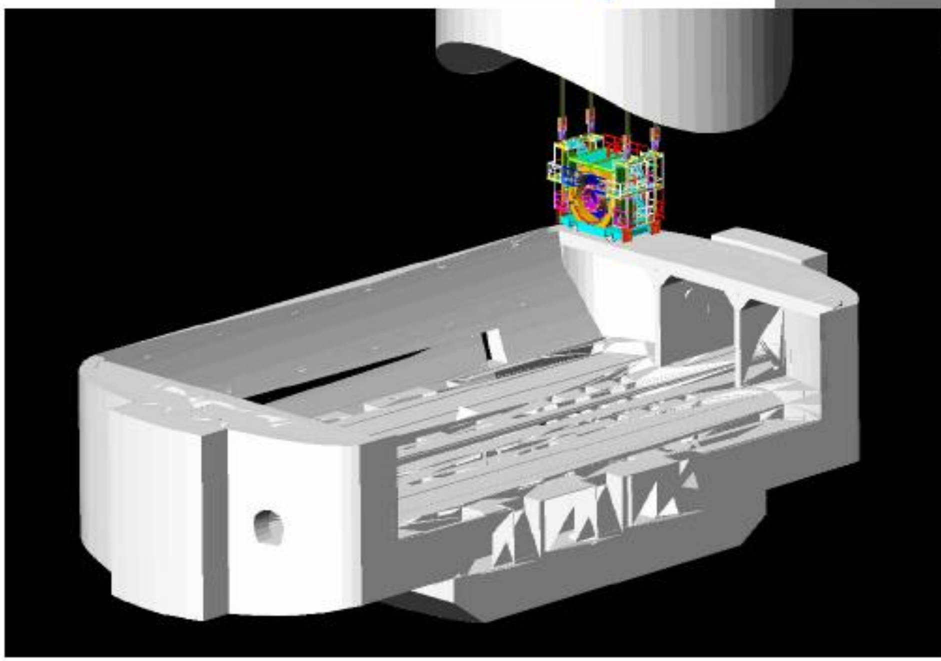
ILC Underground Construction Schedule



On-surface Detector Assembly
CMS approach



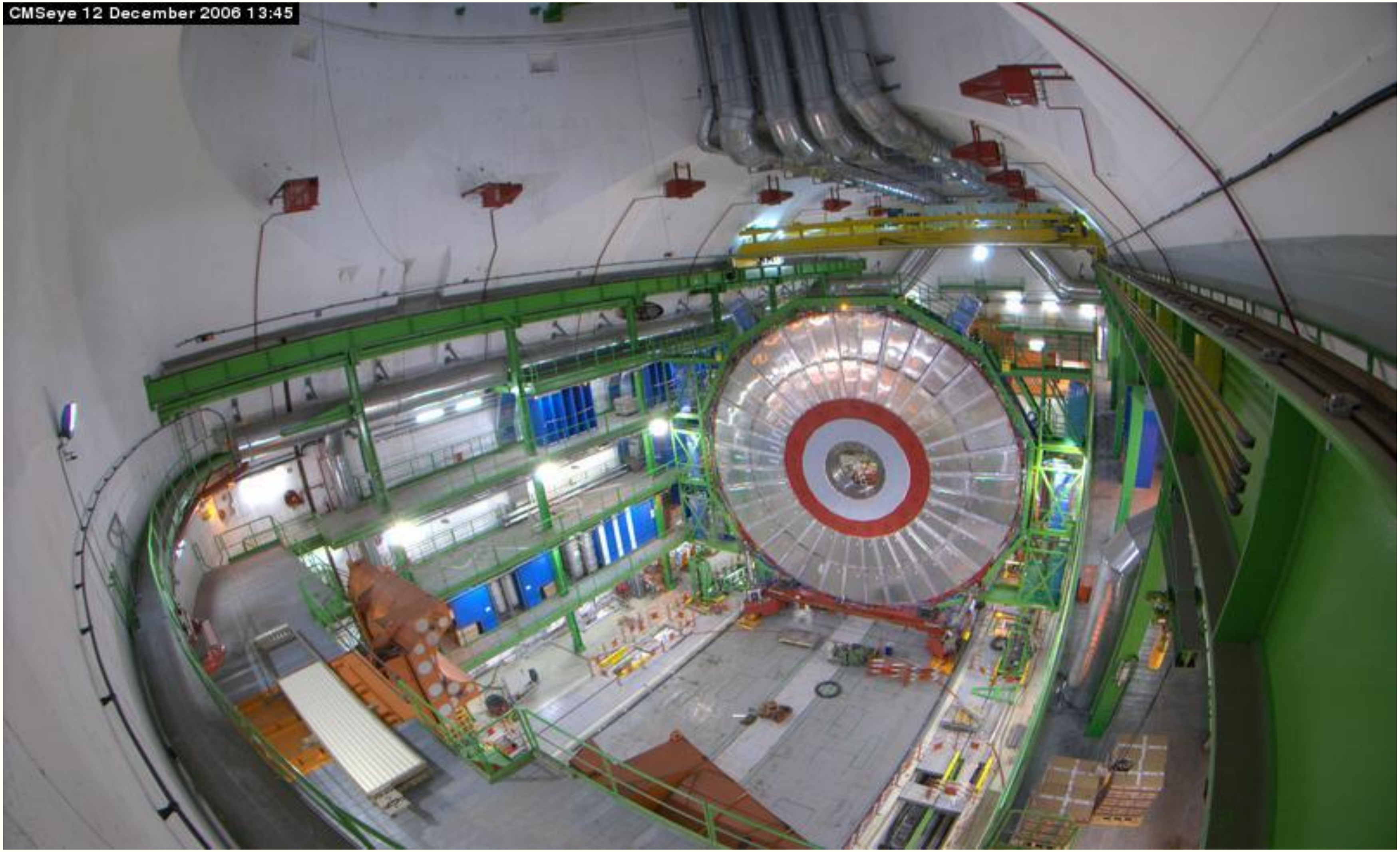




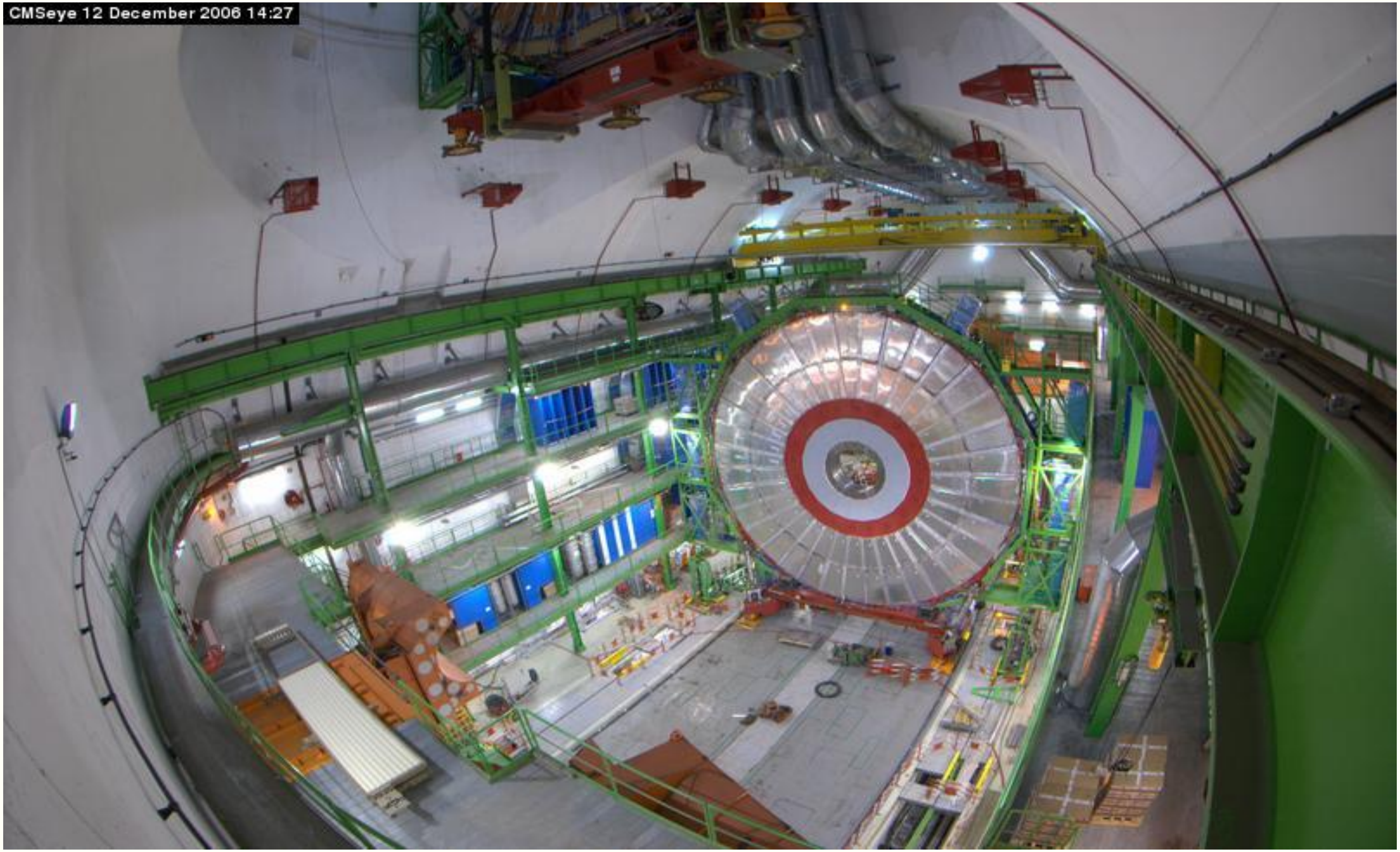
CMS assembly approach:

- 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

CMS Assembly

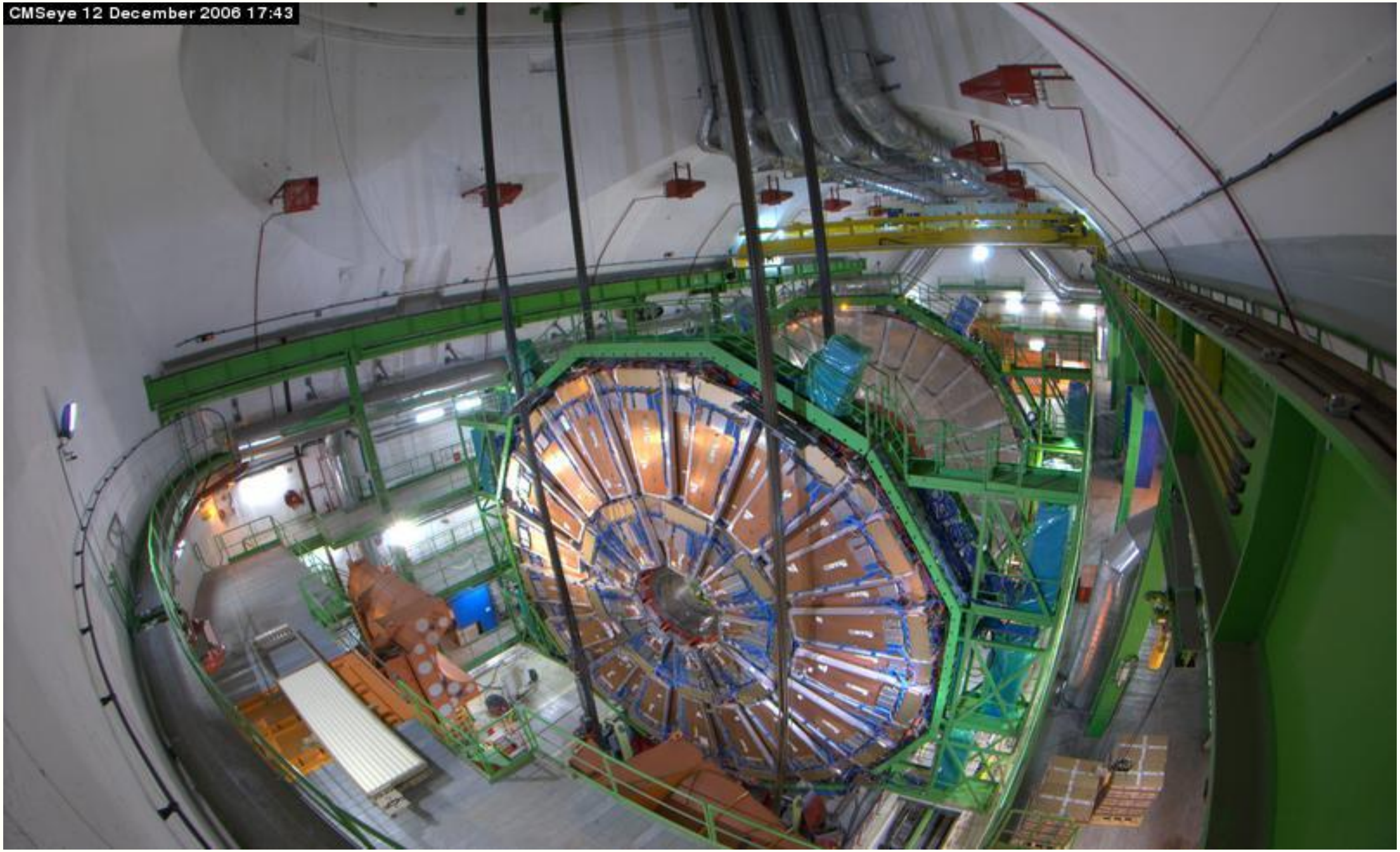


CMS Assembly

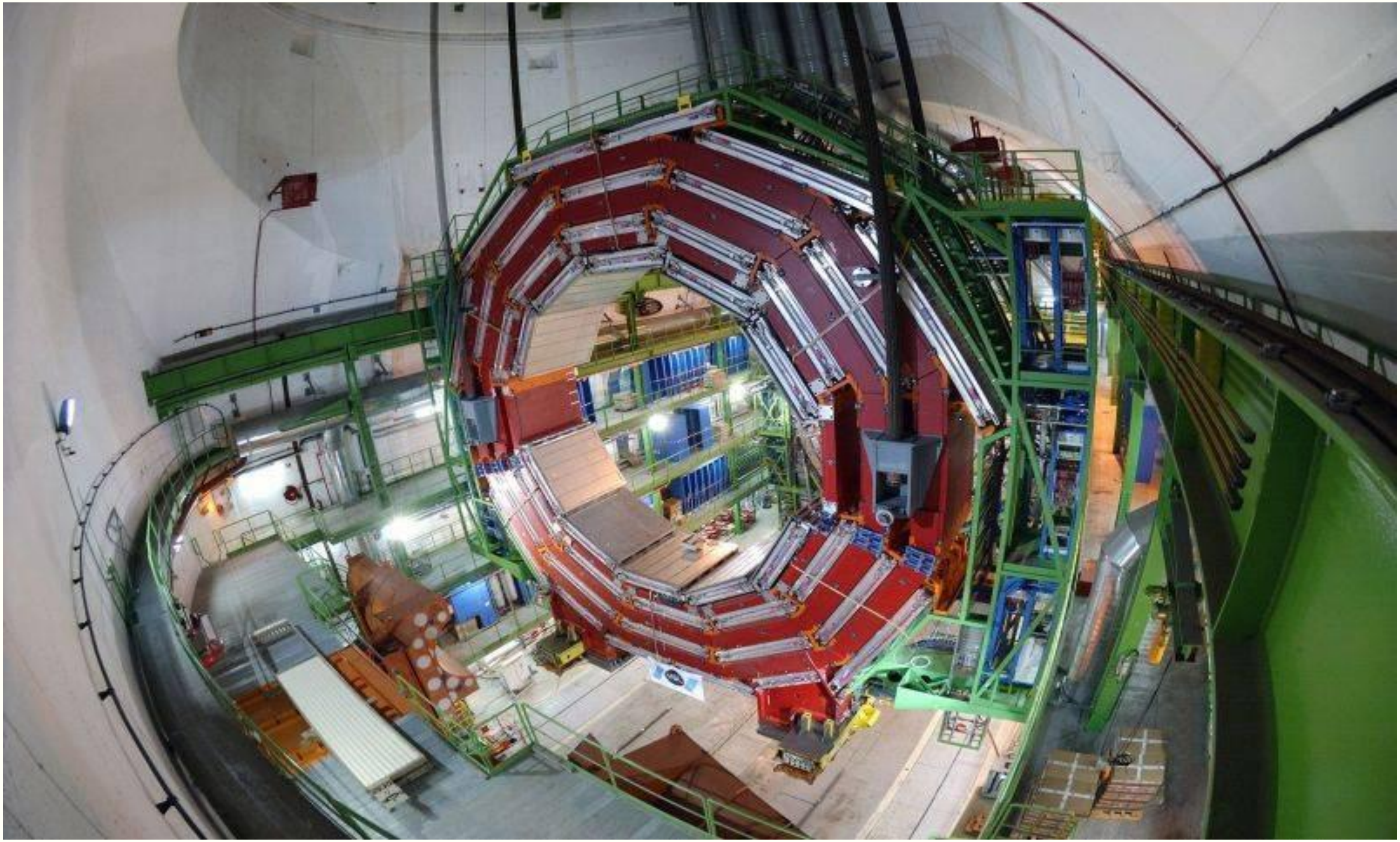


CMS Assembly

CMS Assembly

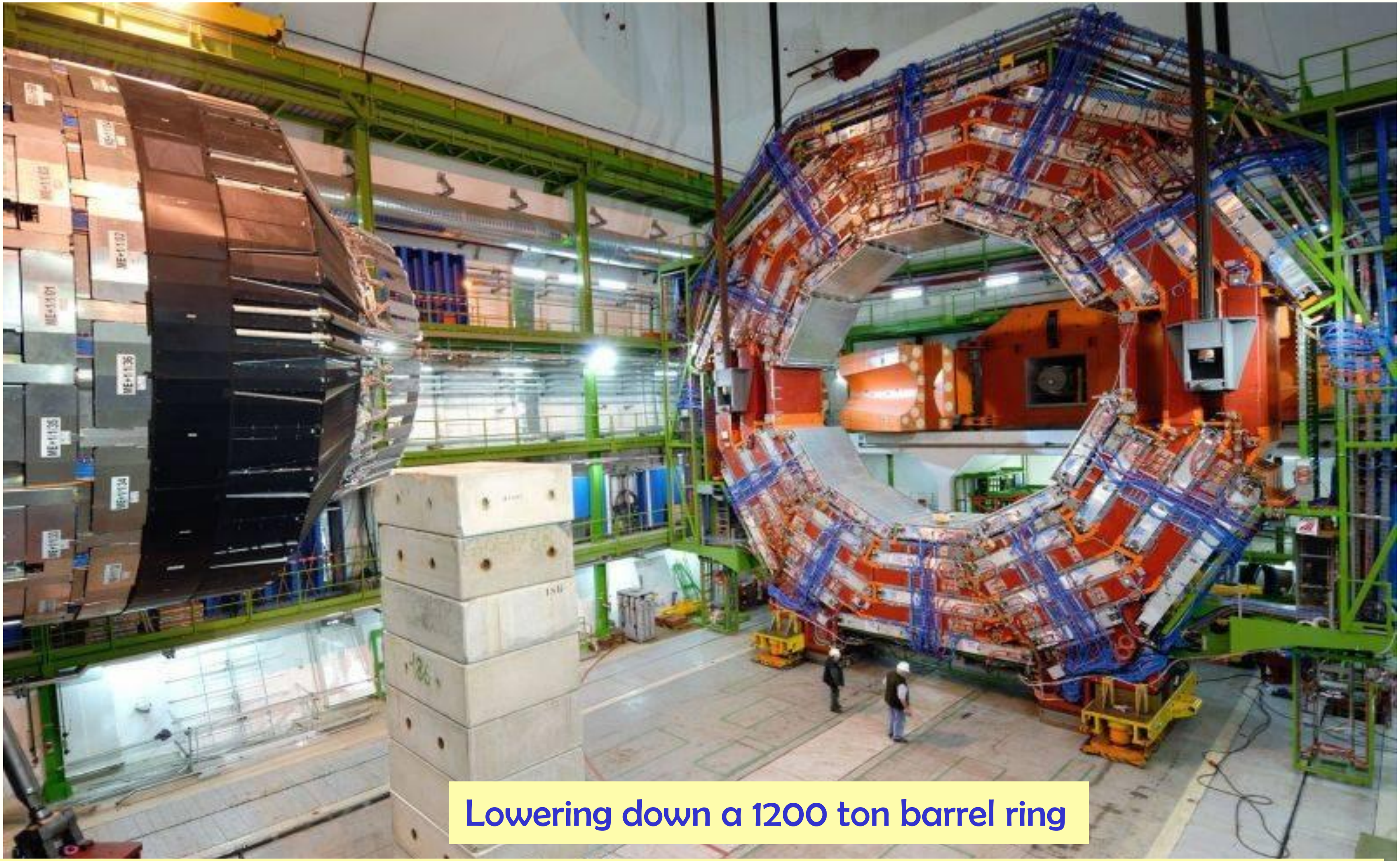


CMS Assembly



February 1. Lowering down a 1200 ton barrel ring.   Photo and info courtesy Alain Herve

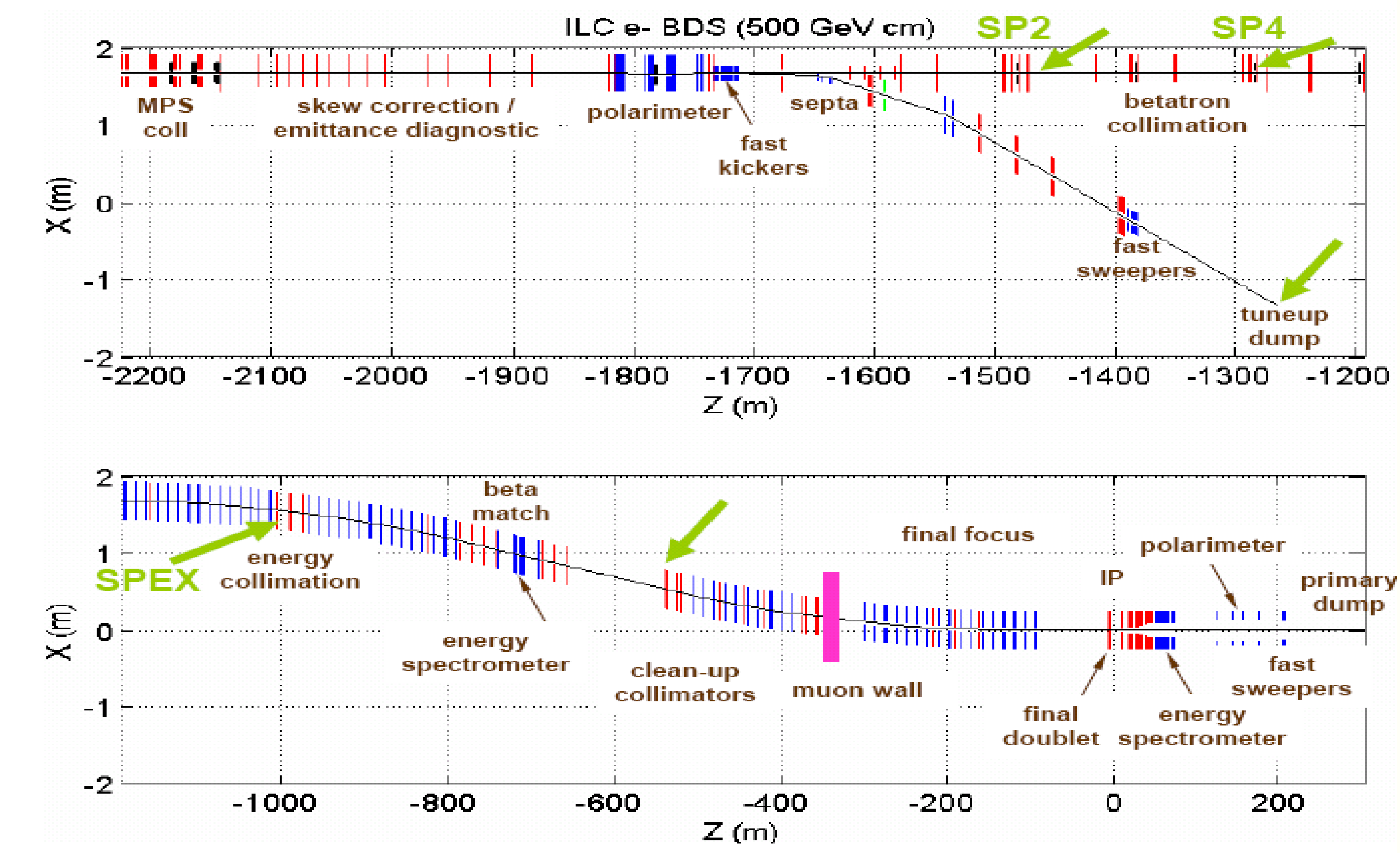
CMS Assembly



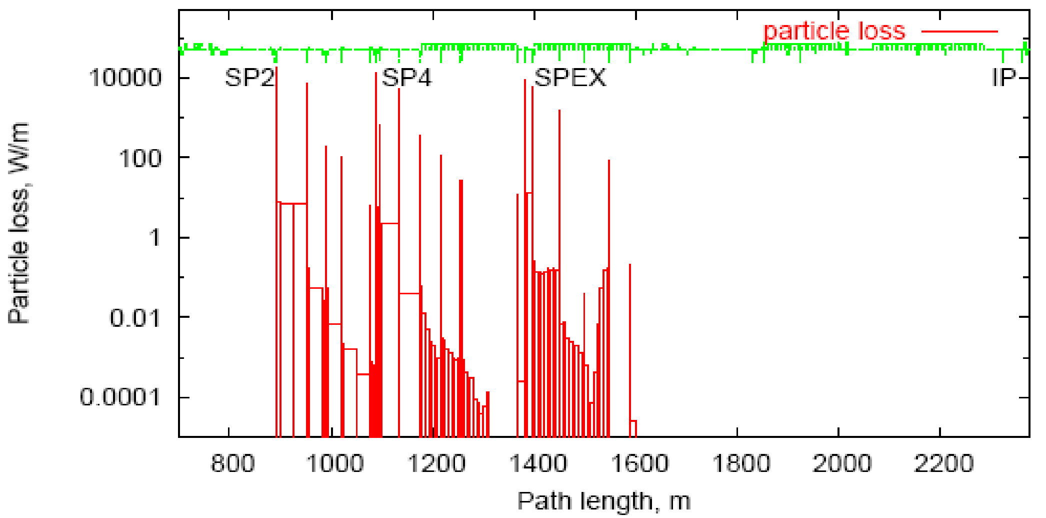
Lowering down a 1200 ton barrel ring

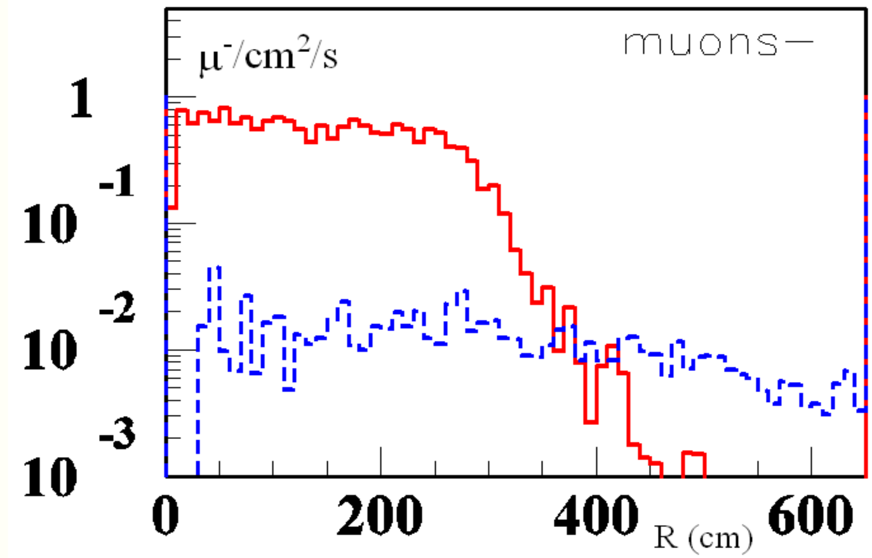
CMS is at half process. Next -- lowering 2kt central barrel by the end of February. **Alain Herve**

Possible Sources of Muons

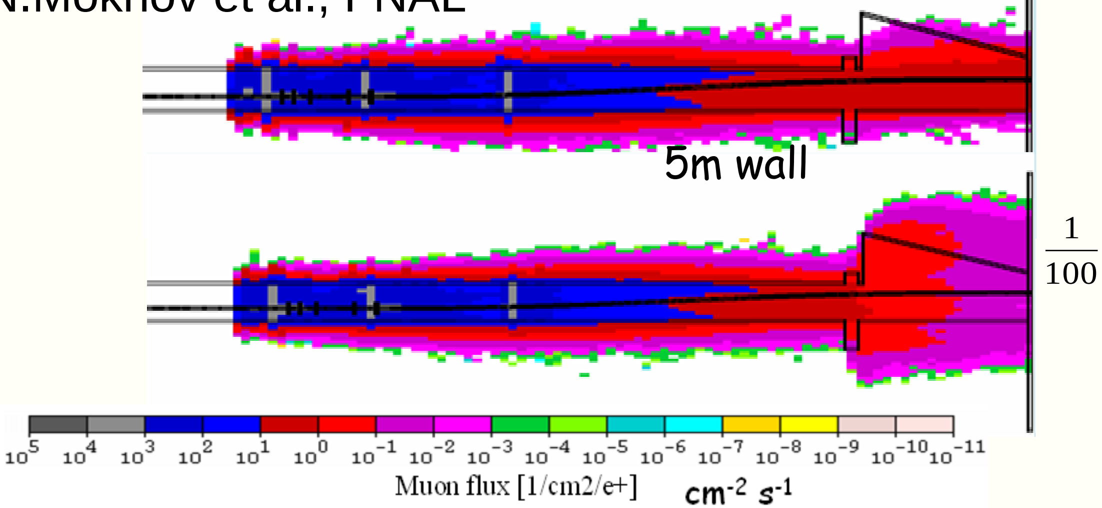


Muon Reduction





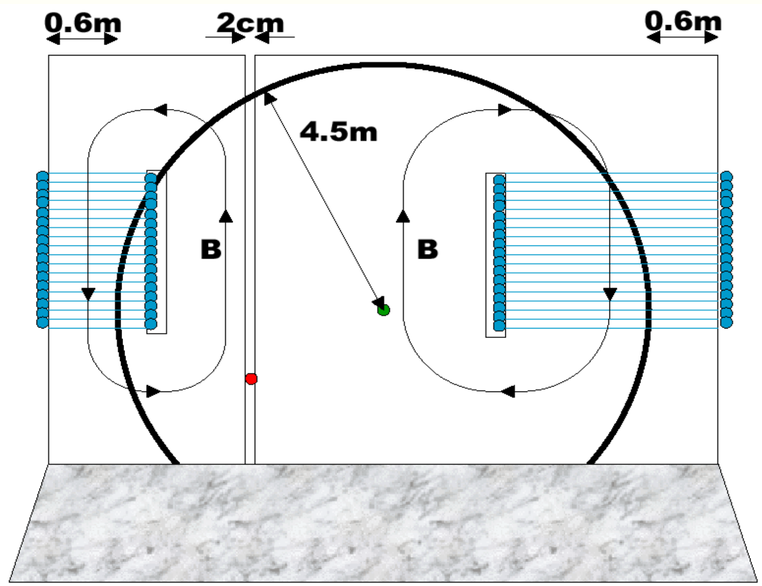
N.Mokhov et al., FNAL

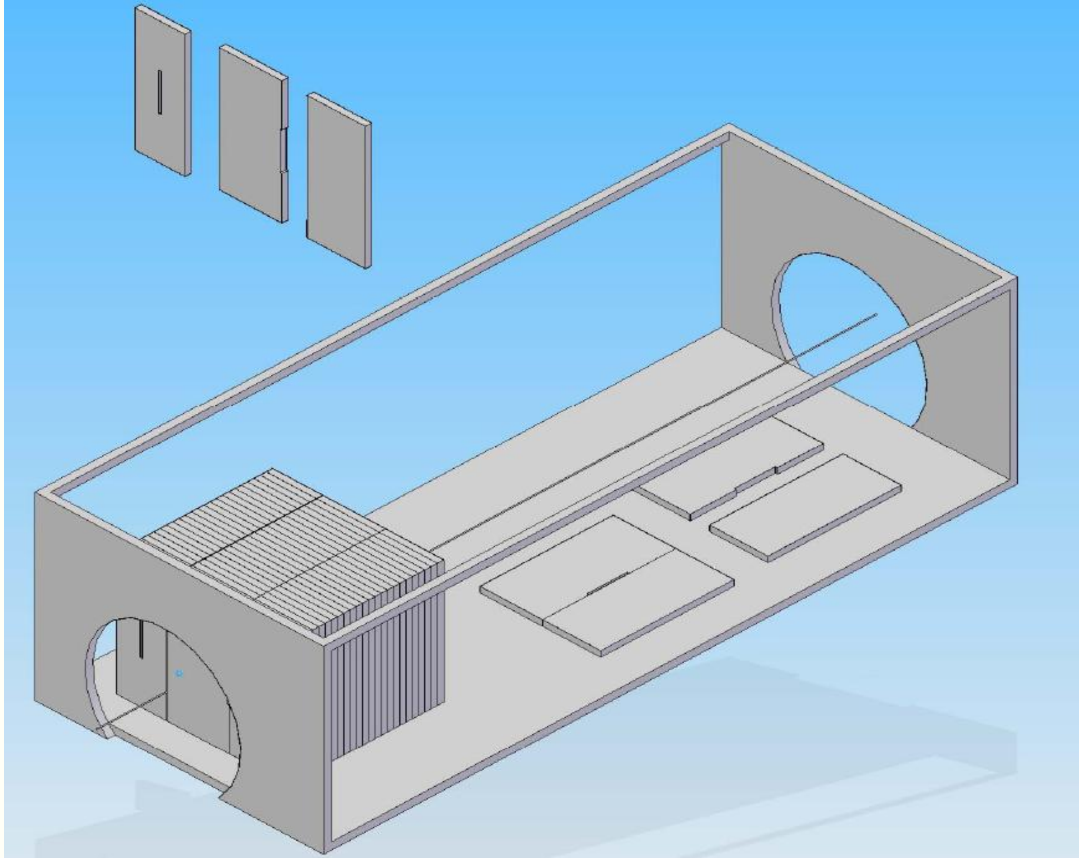


- **Muon flux in BDS & IR with and without 5m muon wall**
- **Allows reducing flux in TPC to a few m per ~100 bunches**

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**



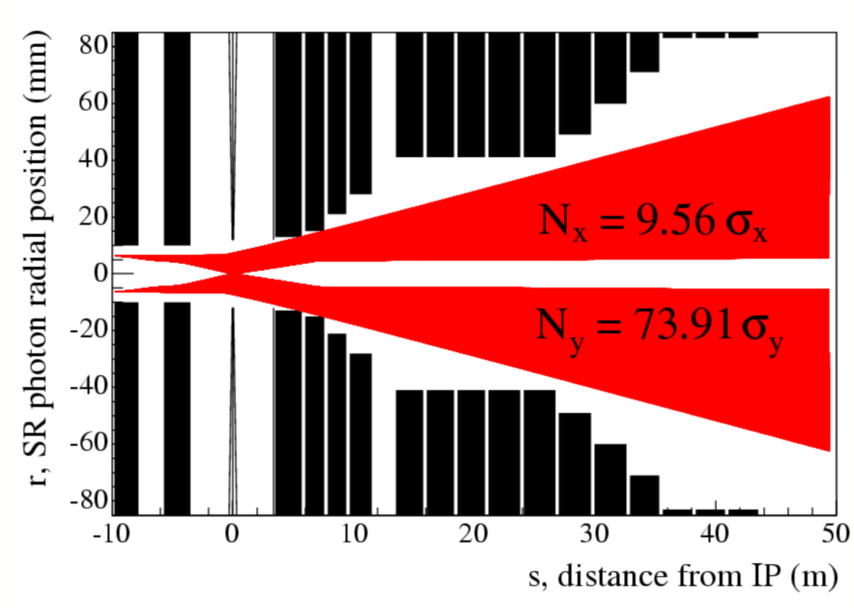


5m muon wall installed initially

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)

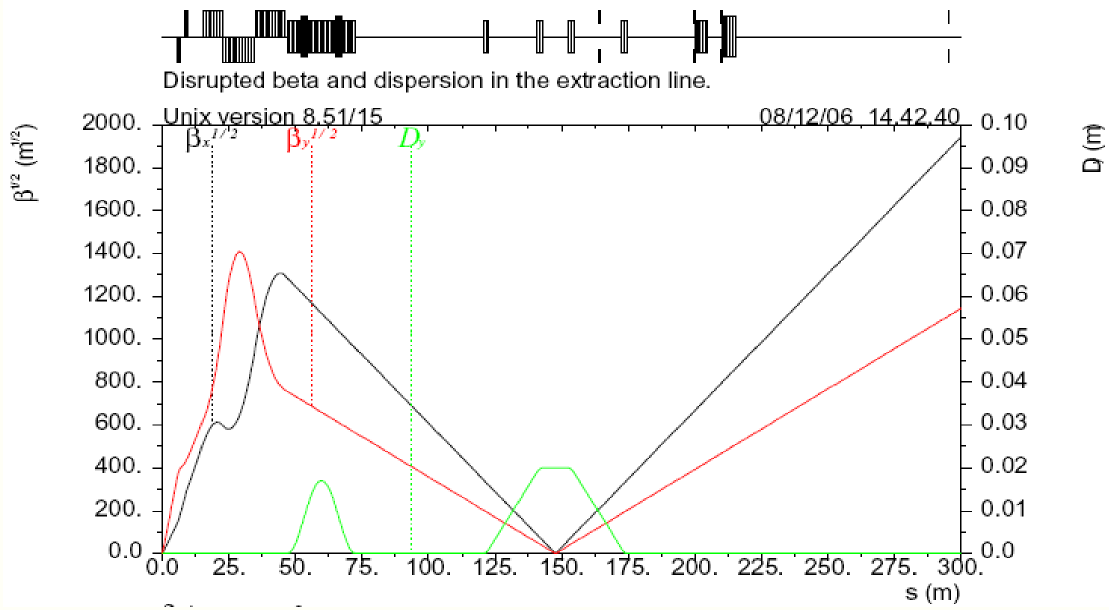
Beam Gas & Synchrotron Radiation in IR

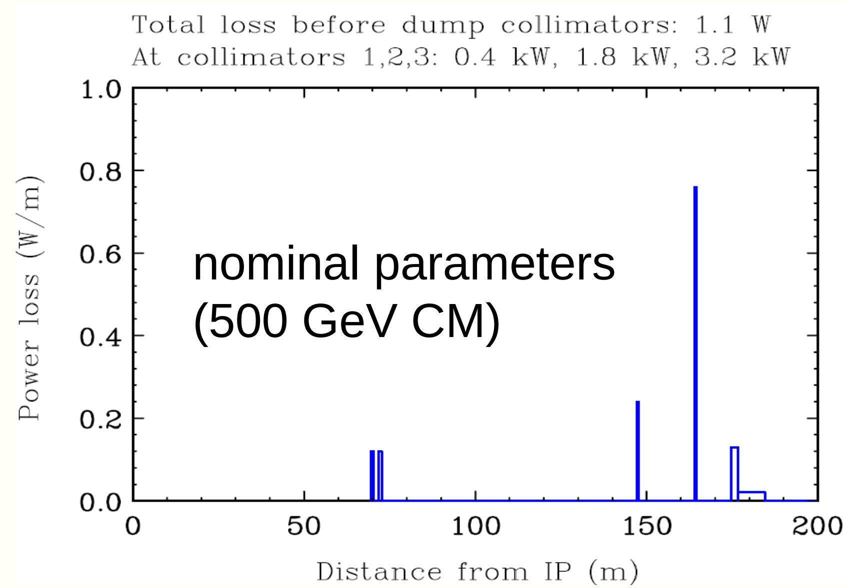
- **Beam gas**
  - is minimized by controlling the pressure near IP within 1nTorr level, 10nTorr in 200-800m from IP and ~50nTorr in the rest of the system
- **Synchrotron Radiation in IR**
  - due to upstream collimation is contained within a defined cone which is extracted away

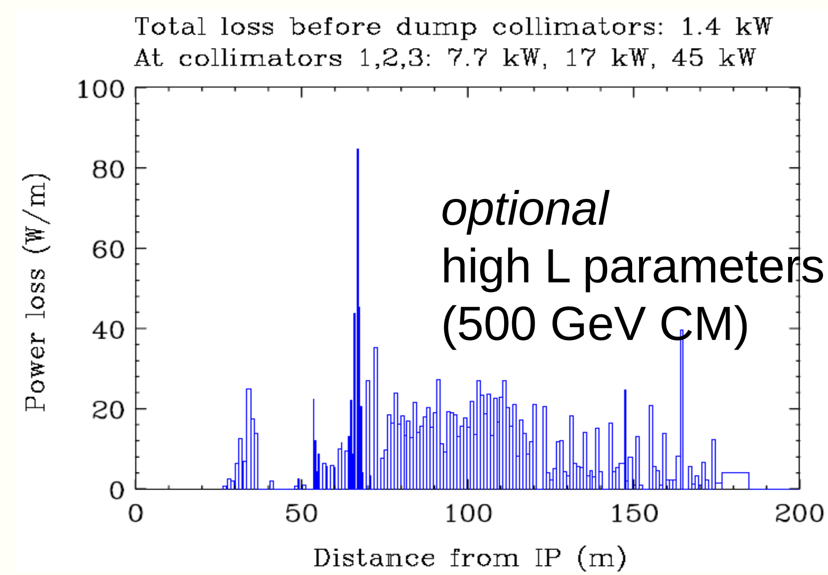


Example of SR rays from beam halo in IR apertures

Extraction Lines

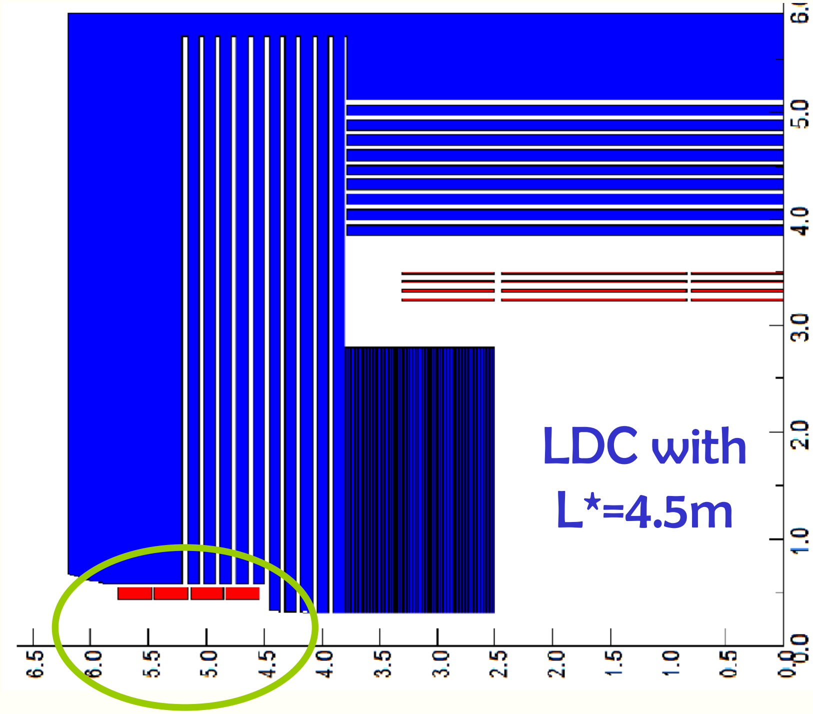


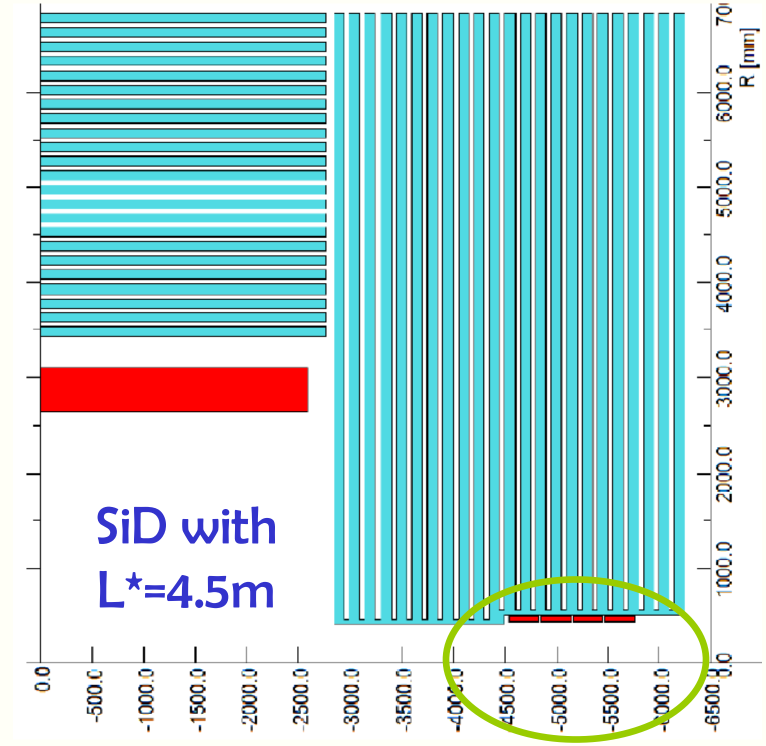




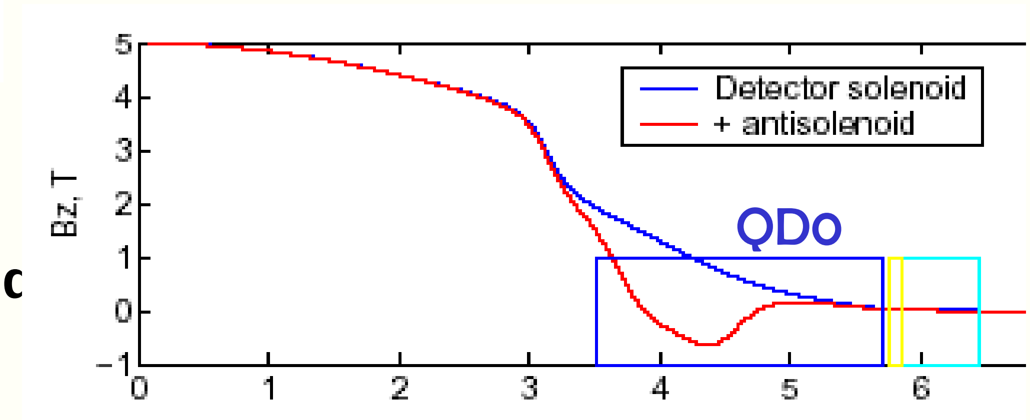
- **Losses for the nominal case are negligible (~1W for 200m from IP)**
- **Even for High L parameters is within acceptable levels**
- **Small losses in extraction and separation from dump are important to keep the back-shine low**

Antisolenoids





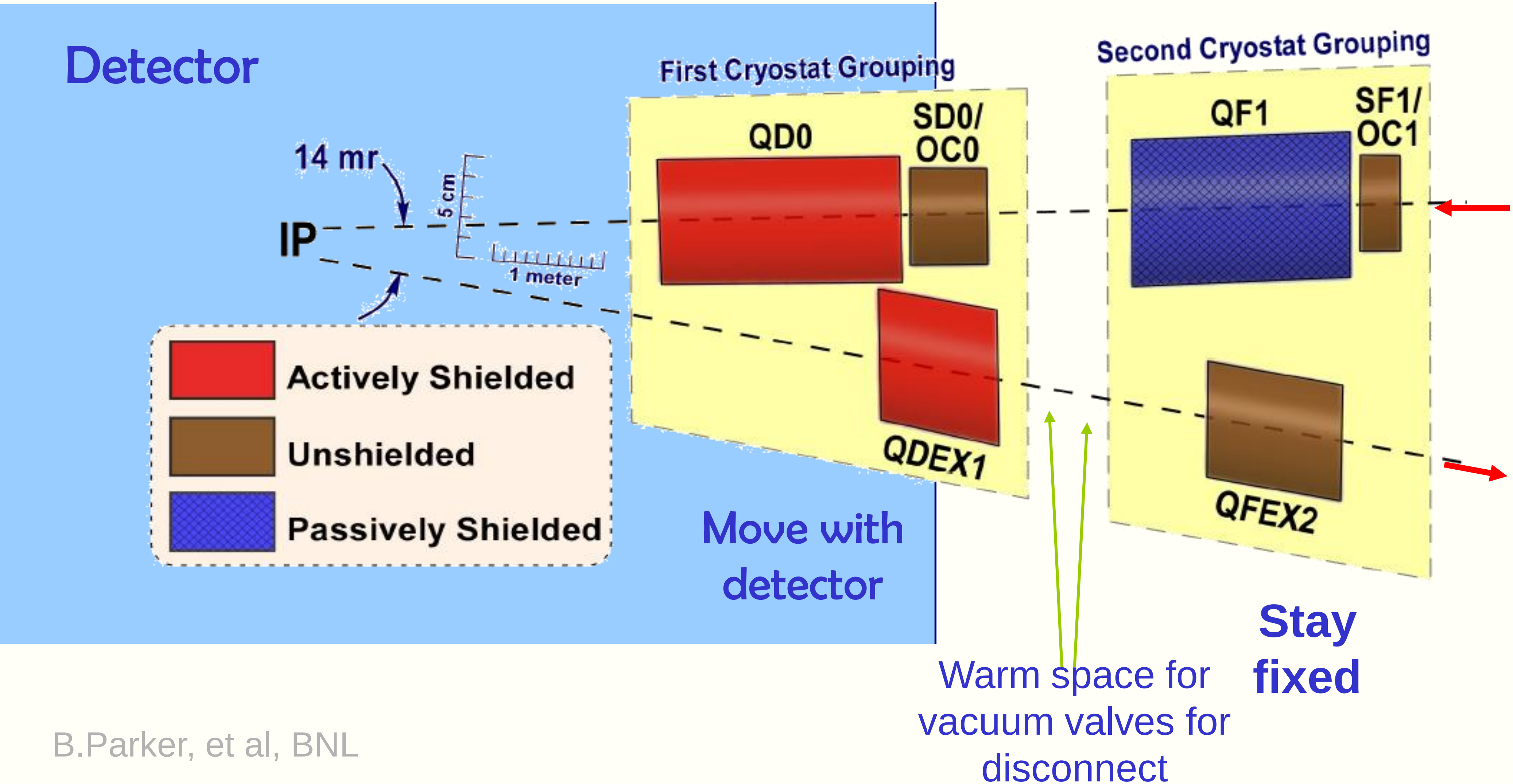
- Antisolenoids for local compensation of beam coupling
- Depend on all parameters (L*, field sizes, etc) and is a delicate MDI issue



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

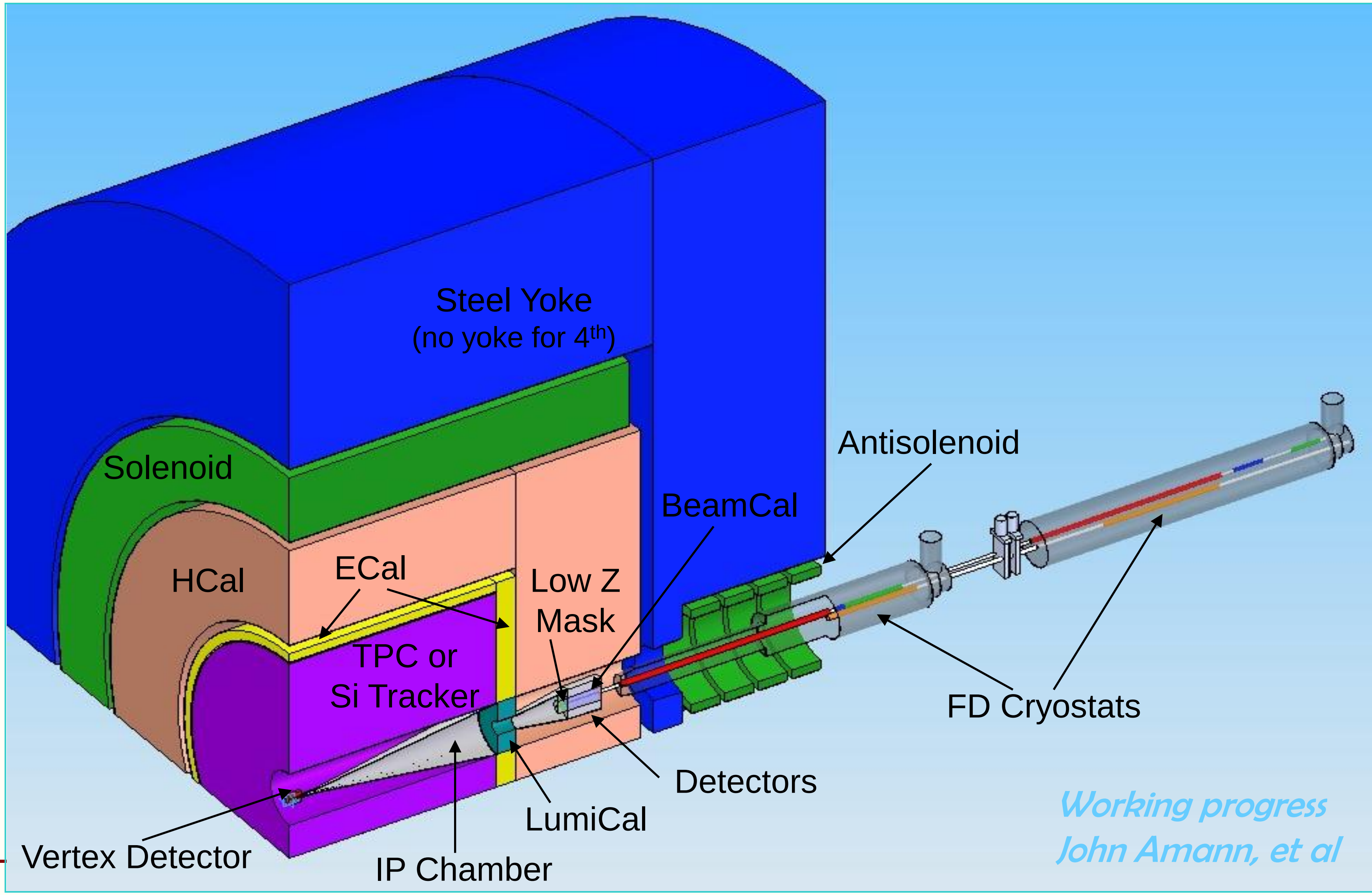
B.Parker, BNL

Interaction Region Conceptual Design

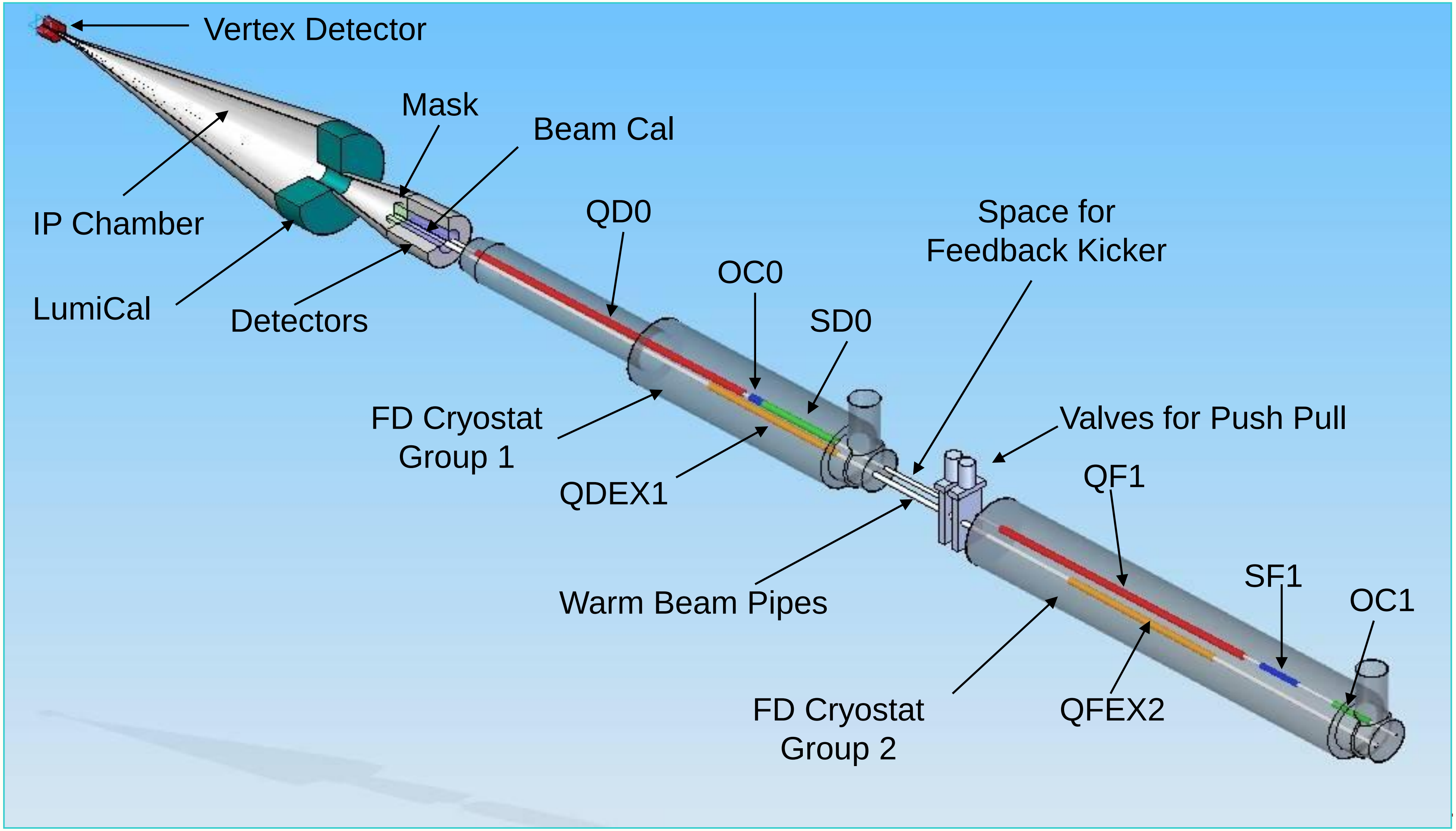


B.Parker, et al, BNL

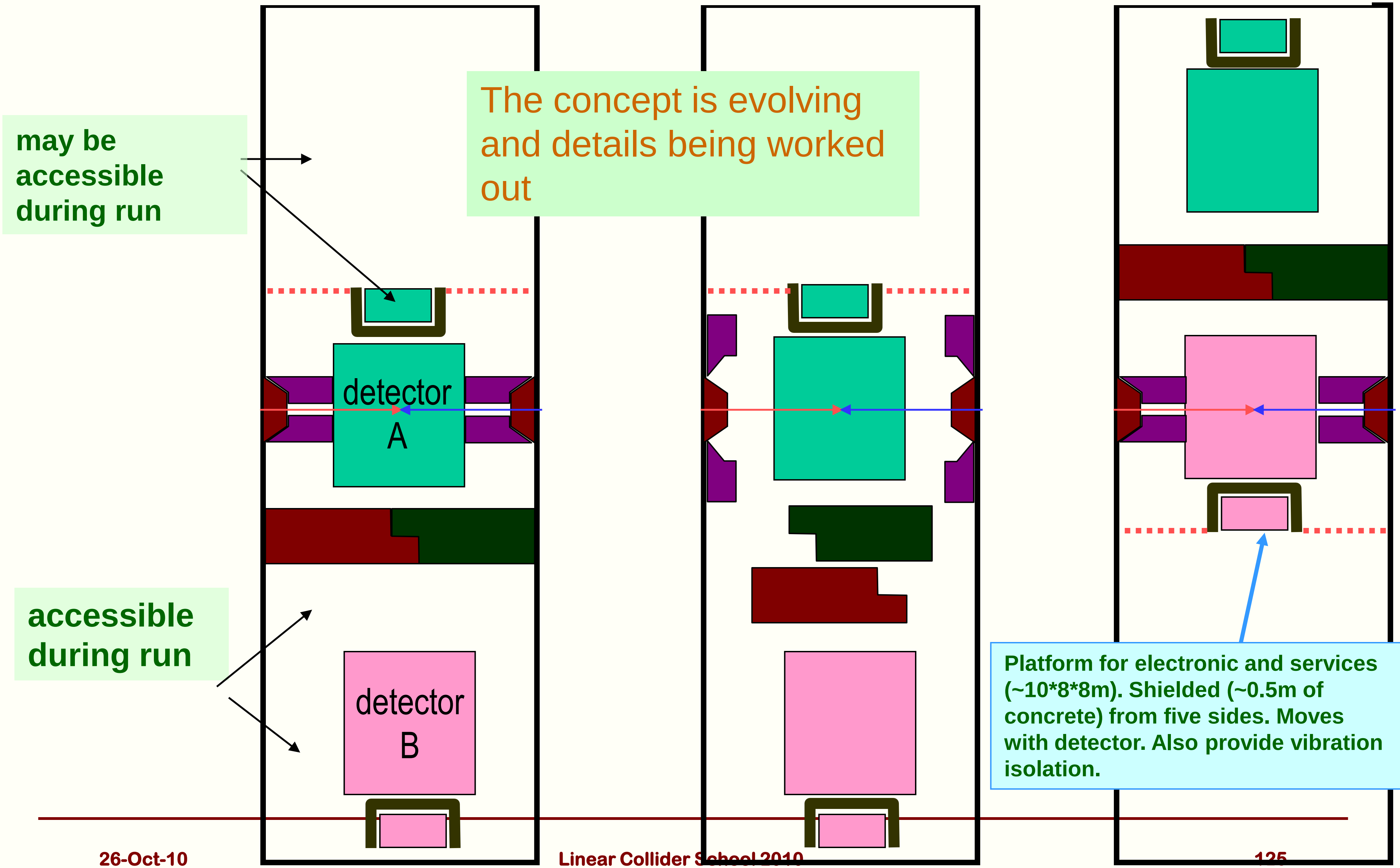
Generic Detector - IR Details



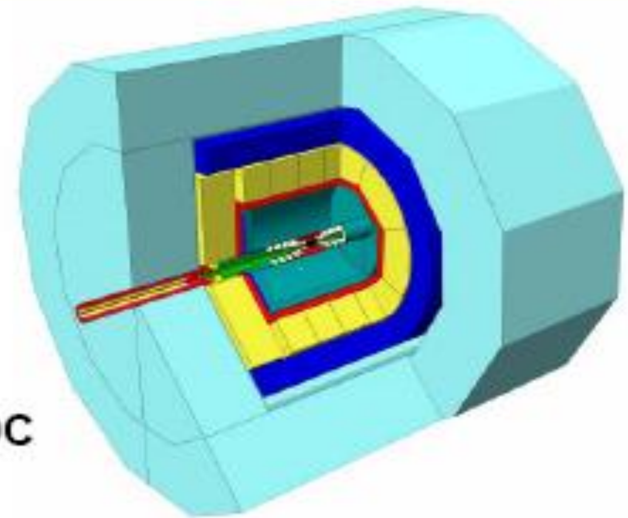
Generic IR layout

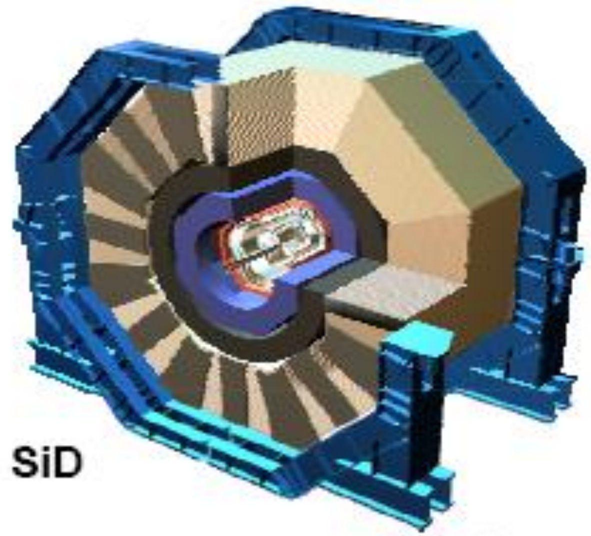


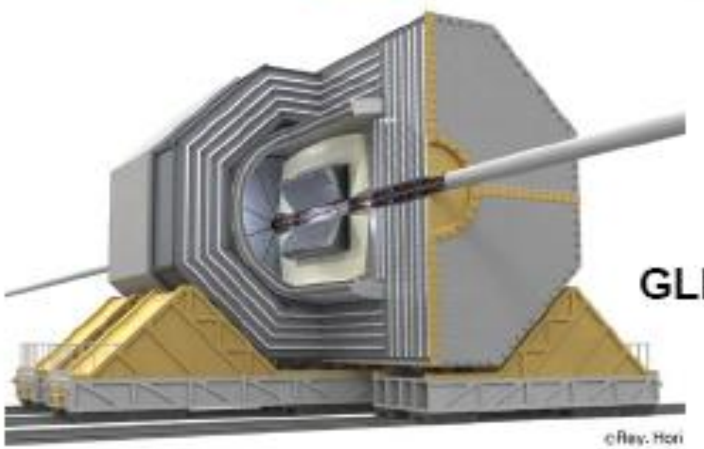
Concept of IR hall with two detectors



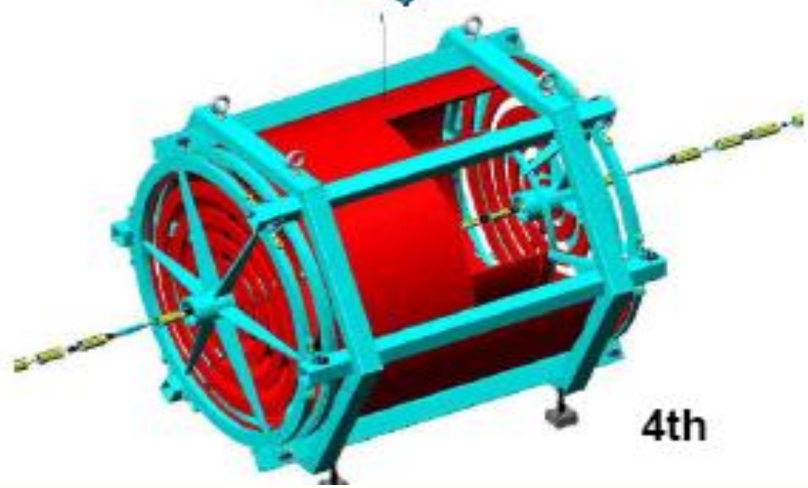
Detector Concepts


LDC


SiD



GLD


4th

Detector Philosophies

- **Detector designing philosophy is somewhat different for the three main concepts.**
  - **The small detector does not use gaseous tracker, since the operation of silicon tracker might be more robust. Also, in principle, smaller detector is inexpensive.**
  - **The large detectors use TPC for the main tracker, because of large number of hit points along a track in the TPC easier patte[illegible]ognition.**
  - **The separation of the charged particles and photons at the calorimeter inner surface is essential for the particle flow algorithm.**

- **The main differences of the three concepts are**

  (1) Use silicon detector alone or with TPC for the tracker

  (2) Use Si-W or Scintillator-W for ECAL

Detector Concepts

	Tracking	ECal Inner Radius	Solenoid	EM Cal	Hadron Cal	Other
SiD	silicon	1.27 m ↓	5 Tesla ↑	Si/W	Digital (RPC..)	Had cal inside coil
LCD	TPC gaseous	1.68 m ↓	4 Tesla ↑	Si/W	Digital or Analog	Had cal inside coil
GLD	TPC gaseous	2.1 m	3 Tesla	W/ Scin.	Pb/ Scin.	Had cal inside coil
4th	TPC gaseous			crystal	Compen-sating fiber	Double Solenoid (open mu)

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 $\Delta d = 5\ [\mu m] + 10\ [\mu m] / (p[GeV] \sin 3/2\theta)$

  - ○ 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

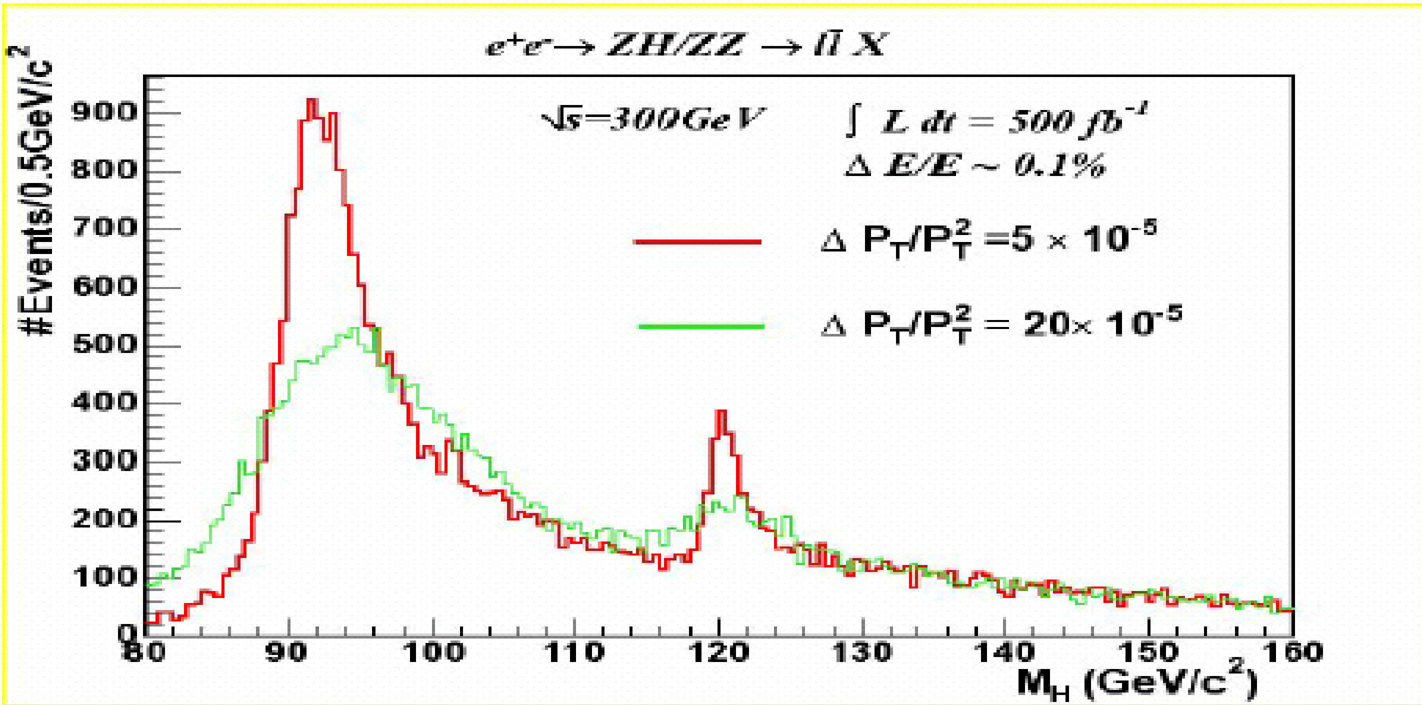
  Jet energy resolution $\Delta E_{jet} / E_{jet} = 0.3 / \sqrt{E_{jet}}$

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

Detector Performance Goals

e.g: The Higgs tagging mode

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



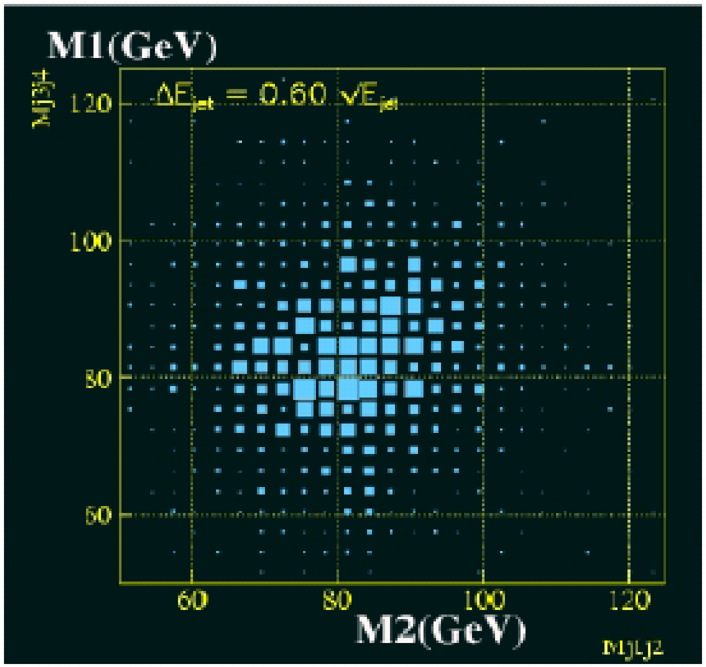
$\sigma_p/p^2 \sim 5 \times 10^{-5}$ is "necessary"

Detector Performance Goals

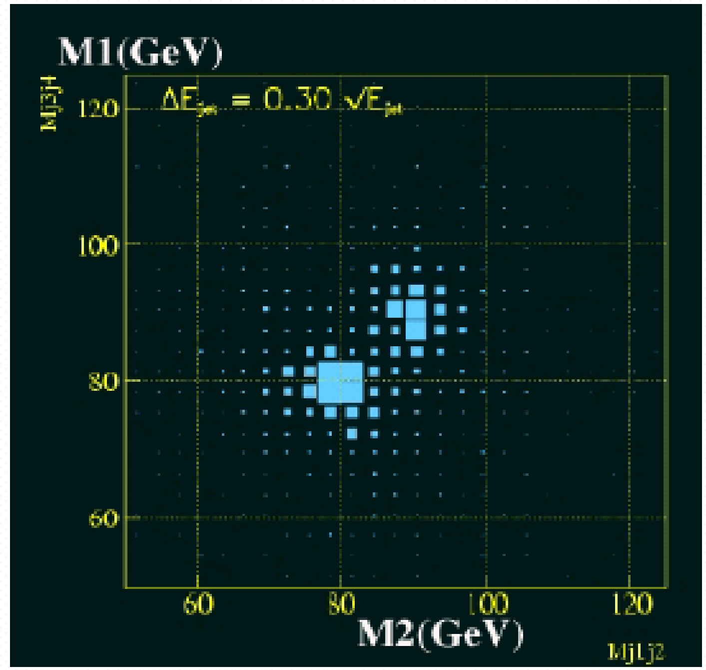
e.g: Separation of WW and ZZ

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

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



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



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

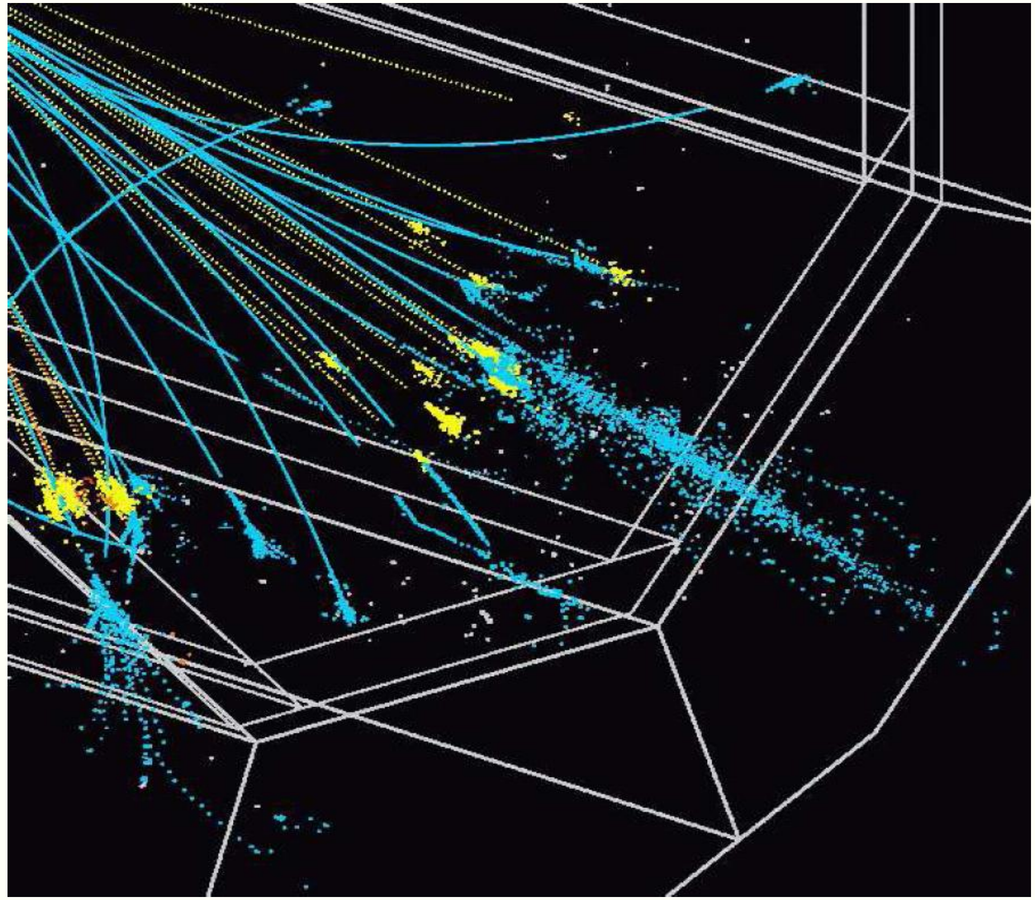
For jets !!!!

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.

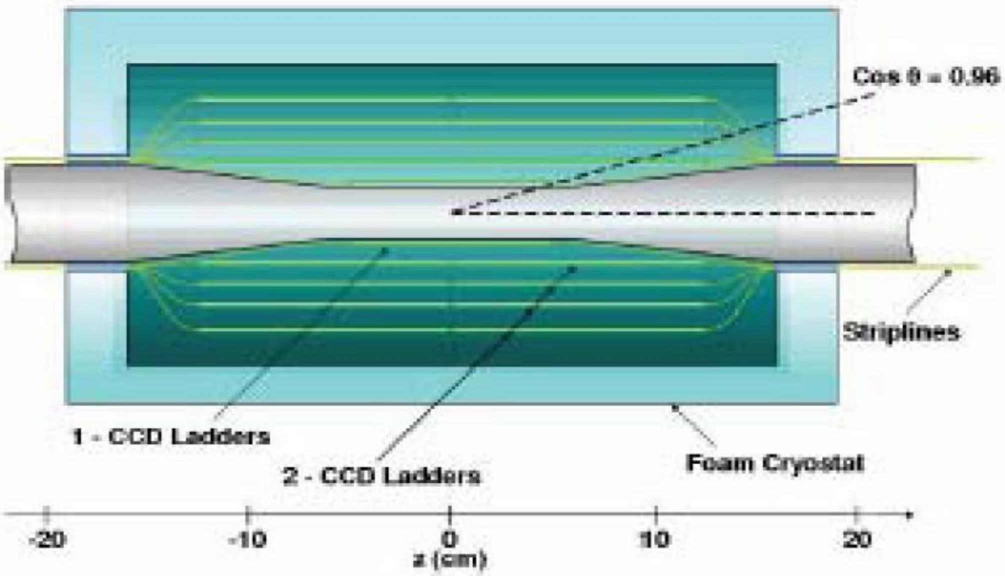
ILC Energy Flow Calorimetry

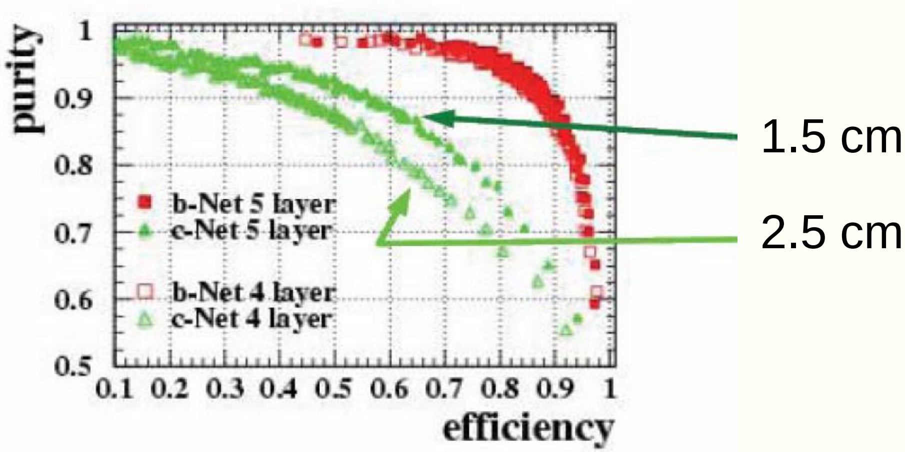
- Jet energy measurement is by the Energy/particle flow algorithm
- Charged particle momentum is measured by tracker
- Photon energy is measured by ECAL
- Neutral hadron (K_L n) energy is measured by HCAL(+ECAL)
- Separate these particles in the calorimeters

- $\sigma(E_{jet})^2 = \Sigma\Delta E_{ch}^2 + \Sigma\Delta E_{\gamma}^2 + \Sigma\Delta E_{neutral\ had}^2 + \Sigma\Delta_{confusion}^2$

- 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**

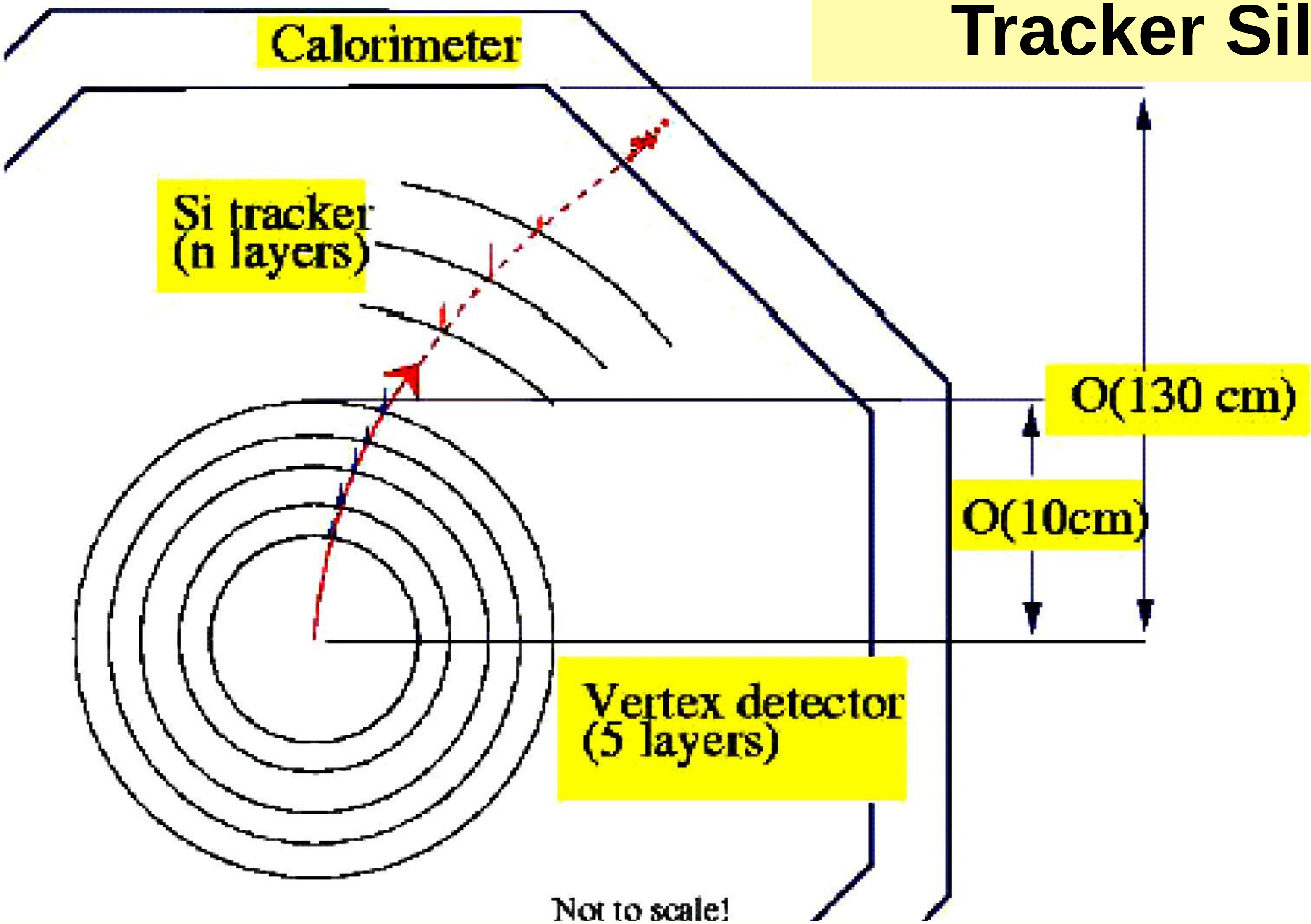
Tracking Considerations

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

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

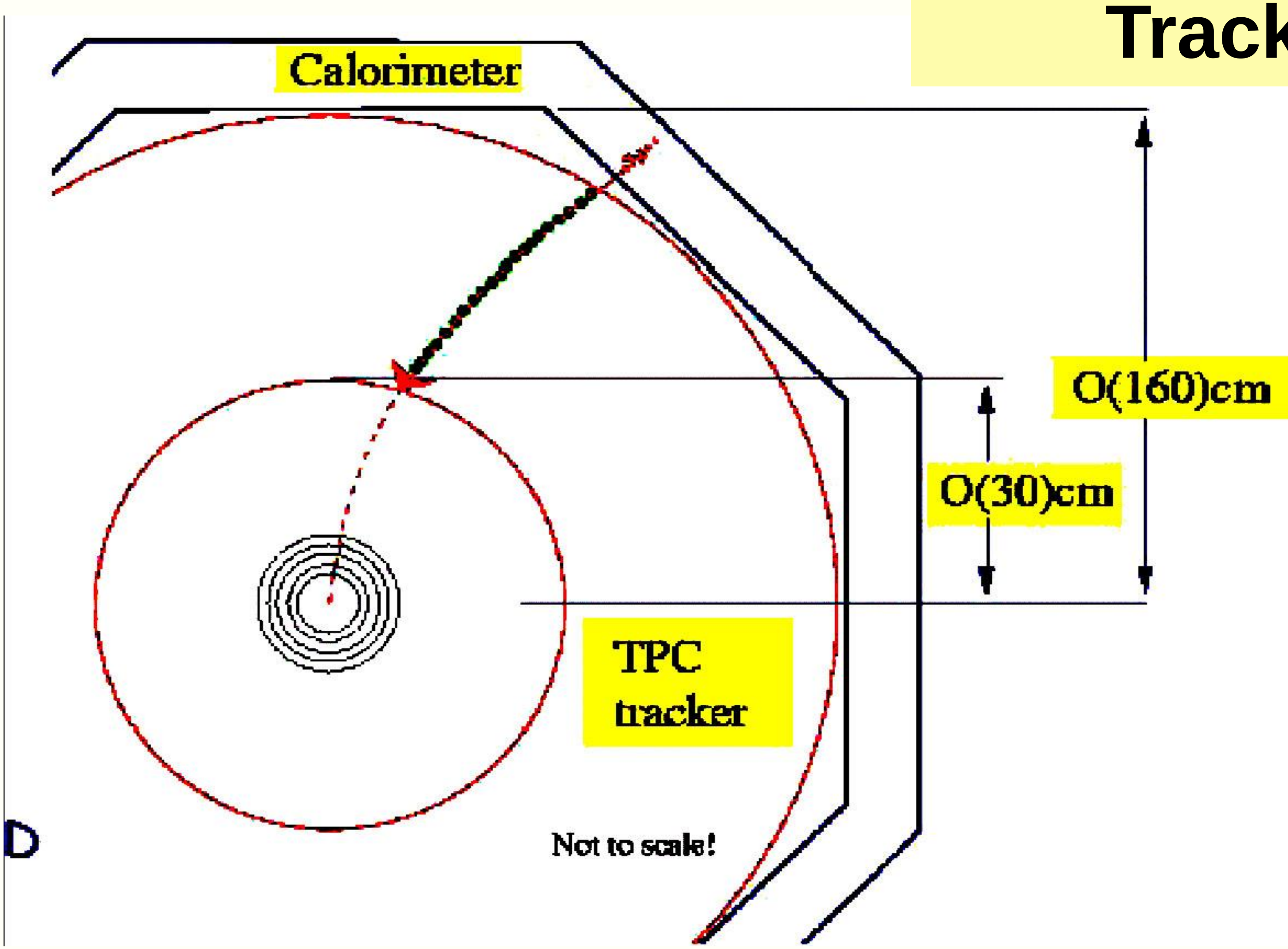
- Pattern recognition efficiency ~ N
- Need robustness vs background
- Two approaches in the Detector Concepts

Tracker Silicon



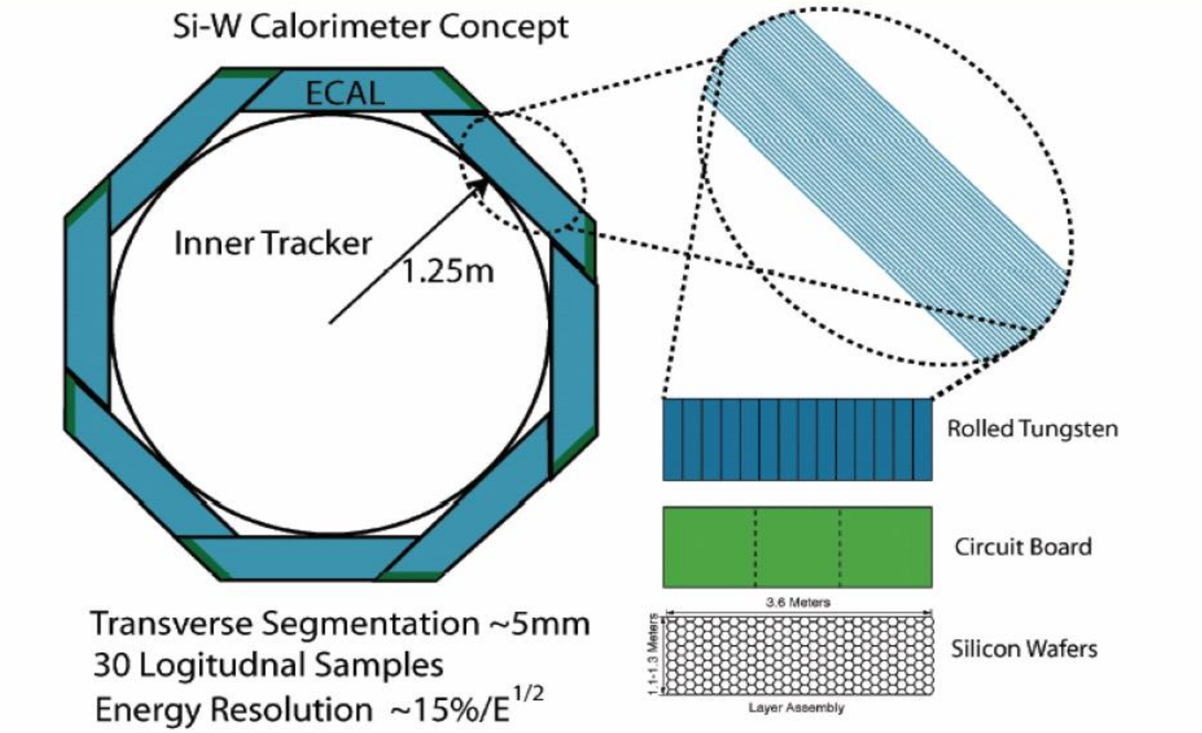
- 5 layers of pixel detectors and 5 layers of Si-strip

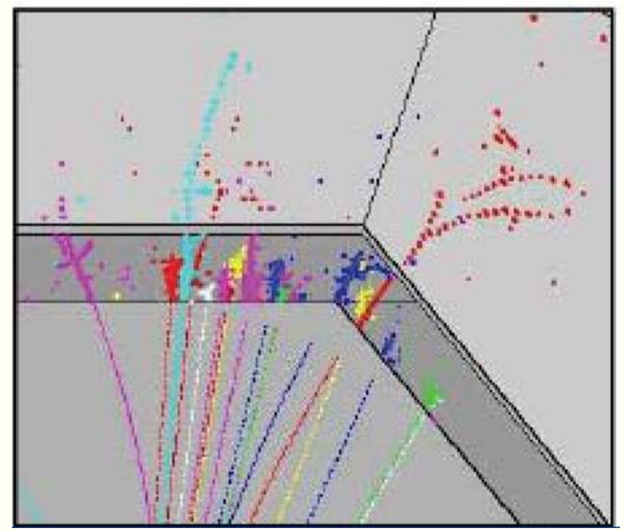
Tracker TPC



- $\mathcal{O}$(200pts) in TPC; 5 layers pixel vertex detectors; $\mathcal{O}$(2) Silicon tracking layers

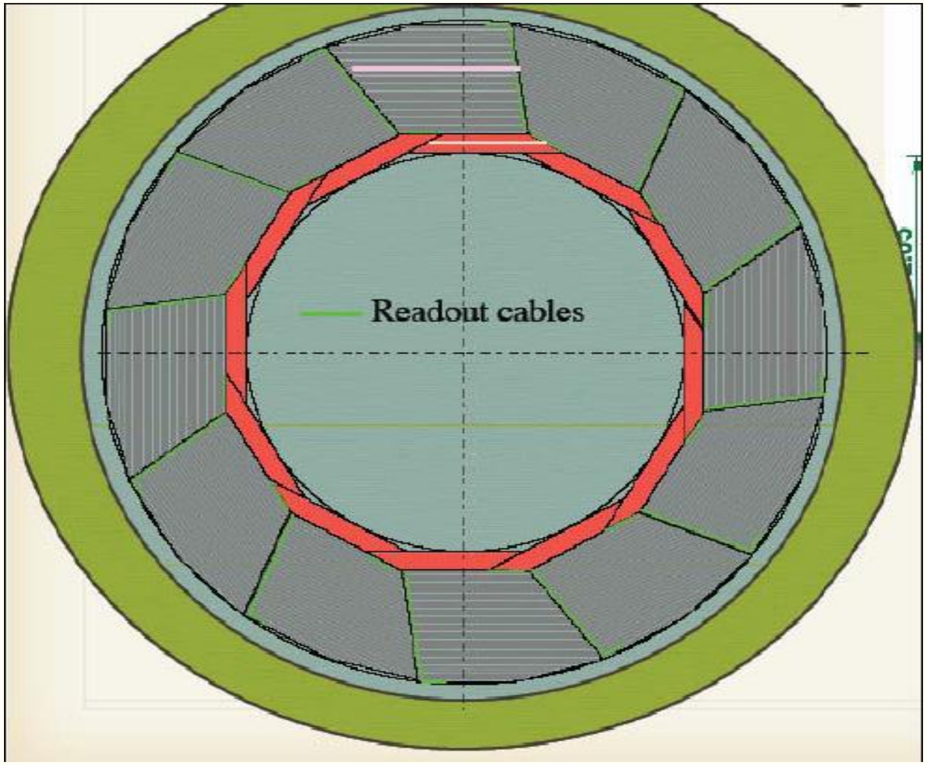
EM Calorimeter





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

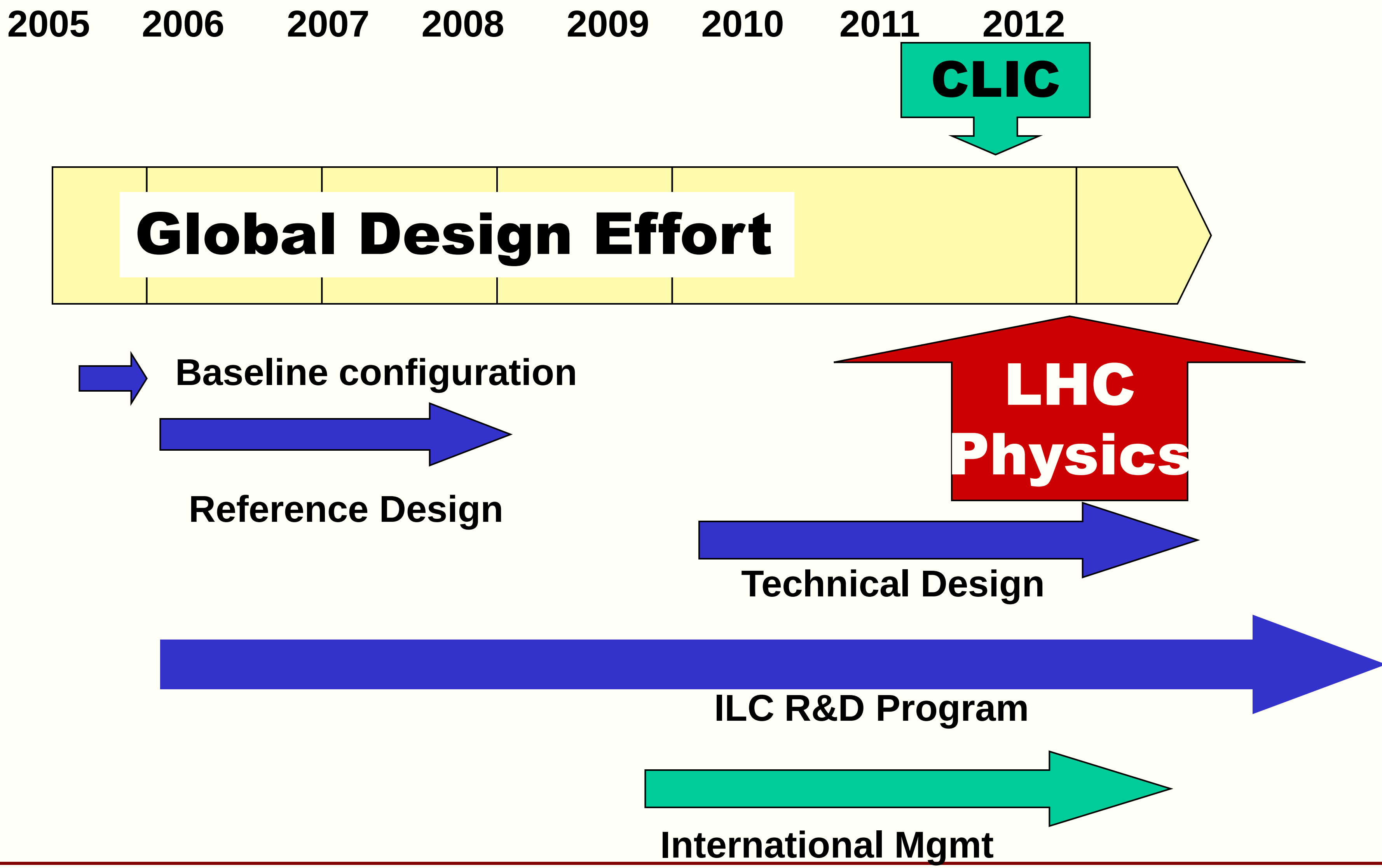
Hadronic Calorimeter



Hadron Calorimeter
Digital vs analog

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

The GDE Plan and Schedule



What's Next? - Technical Design Phase

ILC Research and Development Plan for the Technical Design Phase

Release 4

July 2009

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross, Nick Walker, Akira Yamamoto

Major TDP Goals:

- ILC design evolved for cost / performance optimization
- Complete crucial demonstration and risk-mitigating R&D
- Updated VALUE estimate and schedule
- Project Implementation Plan

Essential Elements of TDP

- **Optimize the design for cost / performance / risk**
  - Top down approach to 'minimum' design; value engineering; risk mitigation
- **Key Supporting R&D Program (priorities)**
  - High Gradient R&D - globally coordinated program to demonstrate gradient for TDR by 2010 with 50%yield
  - Electron Cloud Mitigation – Electron Cloud tests at Cornell to establish mitigation and verify one damping ring is sufficient.
  - Final Beam Optics – Tests at ATF-2 at KEK
- **GOAL – Bring us ready to propose a solid and defendable "construction project" to world's governments by 2012 (linked to LHC results)**

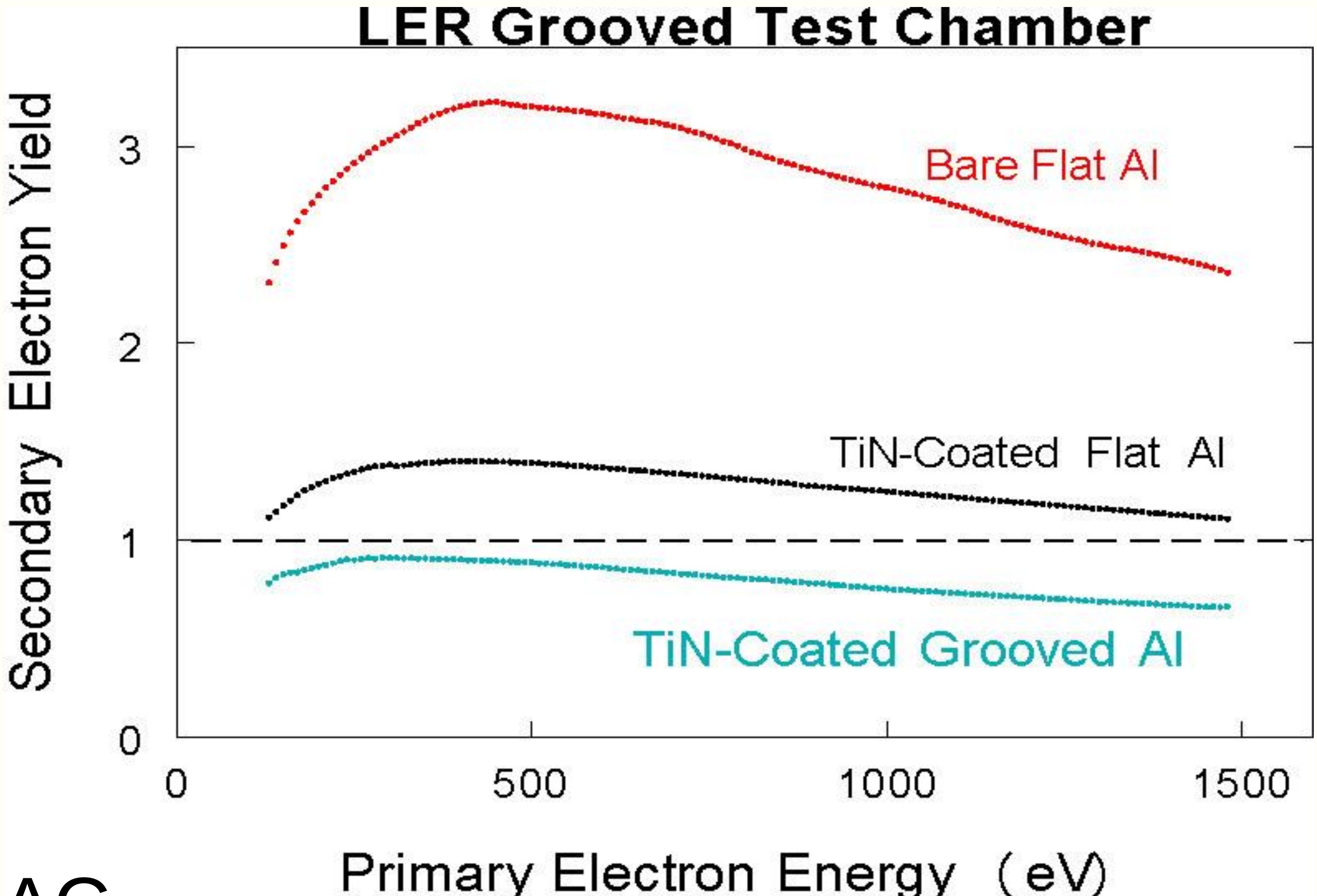
TD Phase 1

- **Timescale: Interim report mid 2010**
- **Major theme: High-priority risk-mitigating R&D**
  - Superconducting RF linac technology – technical demonstration of gradient, plug compatiblity and identifying potential cost reductions
  - Confirm mitigation of electron cloud effects
  - The re-baseline will take place after careful consideration and review of the results of the TD Phase 1 studies and the status of the critical R&D.

Electron cloud – Goal

- Ensure the e- cloud won't blow up the e+ beam emittance.
  - Do simulations (cheap)
  - Test vacuum pipe coatings, grooved chambers, and clearing electrodes effect on e- cloud buildup
  - Do above in ILC style wigglers with low emittance beam to minimize the extrapolation to the ILC.
  - Tset progam underway at CESR Cornell (CesrTA)

E Cloud – Results



SLAC

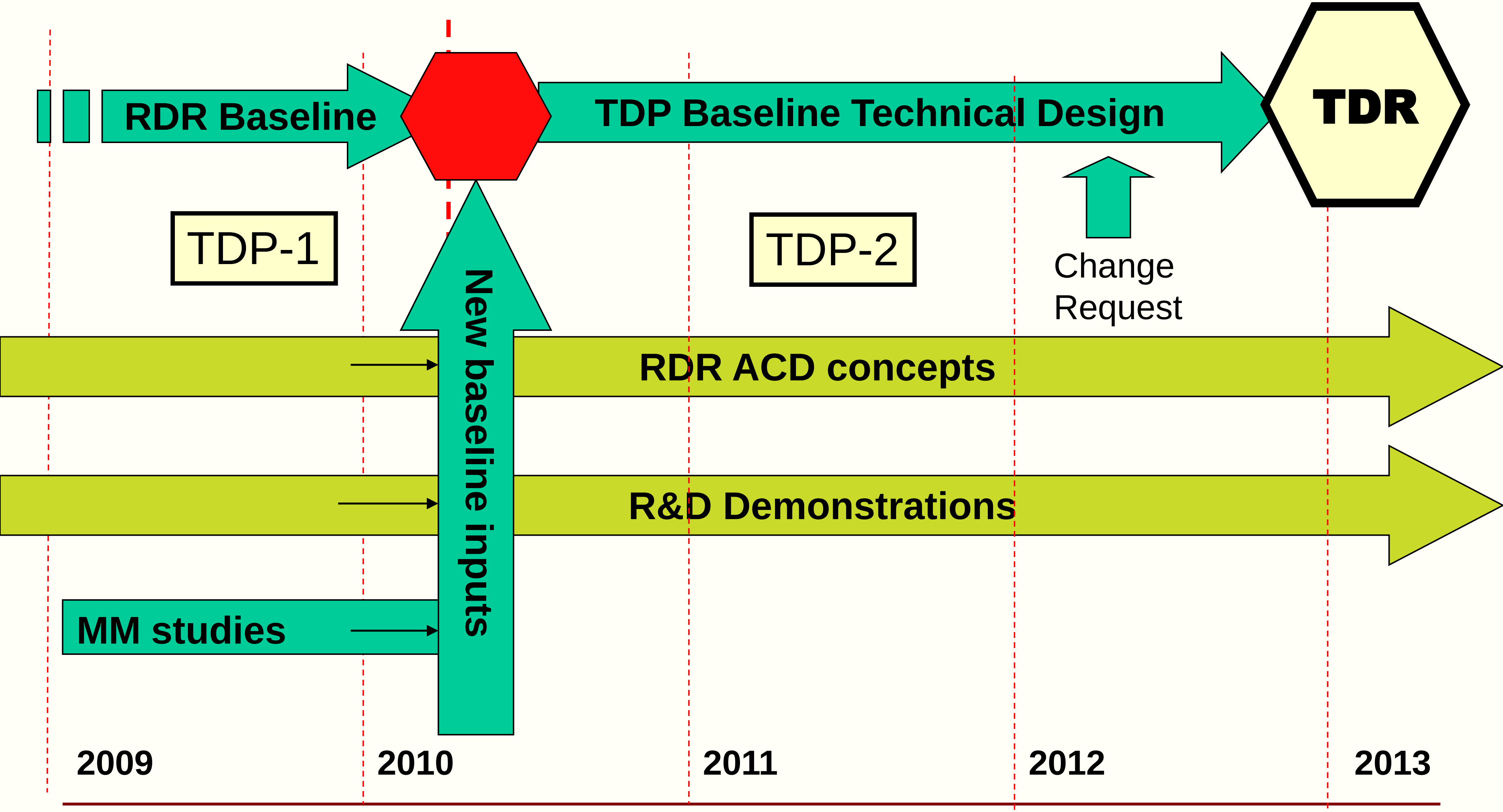
TD Phase 2

- **Timescale: Produce final reports mid-2012**
  - **Technical Design**
  - **Project Implementation**

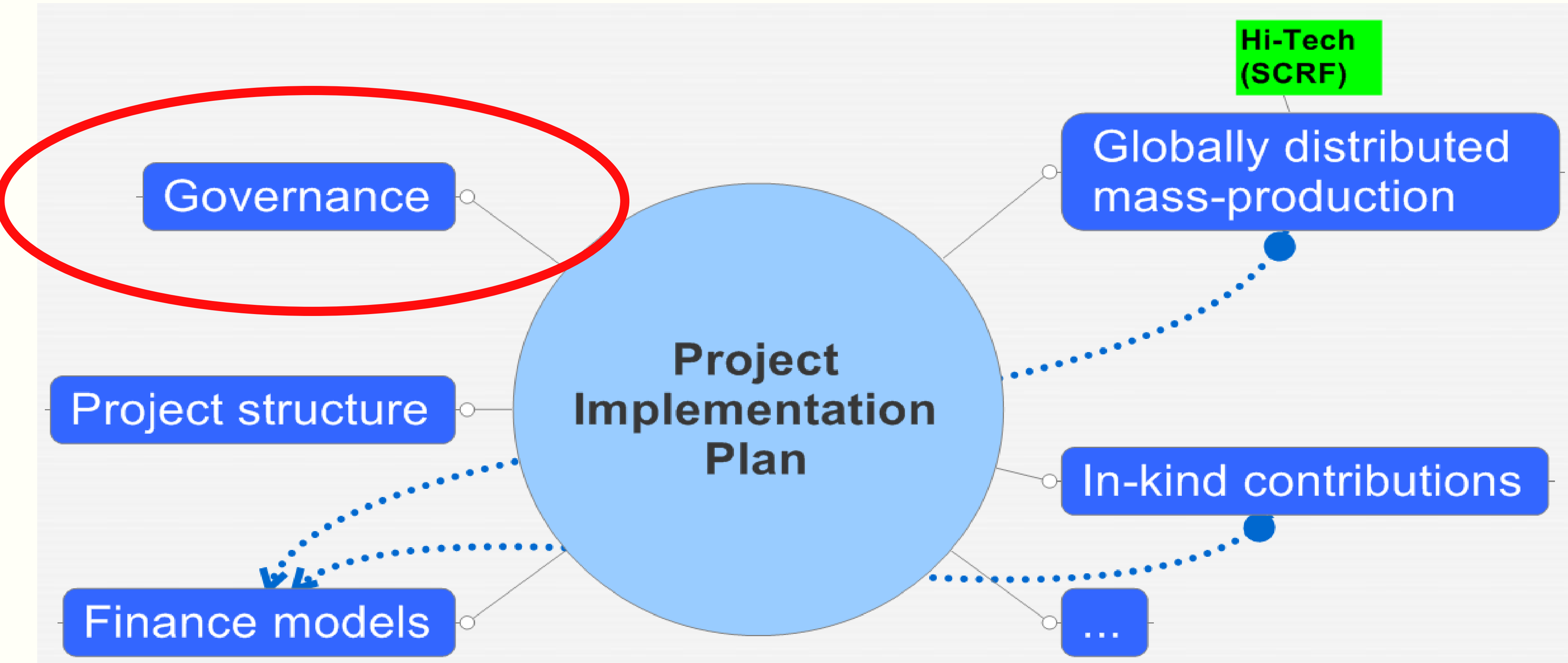
- First goal: **Technical Design**
  - **SCRF – S0 gradient and S1 Global Tests of one RF unit**
  - **Detailed technical design studies (minimum machine)**
  - **Updated VALUE estimate and schedule.**
  - **Remaining critical R&D and technology demonstration identified and planned**

- Second Goal: **Project Implementation Plan**
  - **Studies of governance; siting solicitation and site preparations; manufacturing; etc**

Technical Design Phase and Beyond



Project Implementation Plan



ILC R&D Beyond 2012 ?

- The AAP points to uncertainties beyond 2012 in their conclusions:
  - "Some aspects of the R&D for the ILC will have to continue beyond 2012."
  - "The milestone 2012 is however timely placed. The LHC will be providing operating experience of a large facility and with some luck the first physics discoveries will emerge."
  - "The HEP community is thus well prepared for the decision for the next facility. In a sense the construction of the ILC seems the natural evolution of that process, in which case the efforts for the ILC have to be ramped up without delay."
  - "Nature may be less kind or science policy makers not ready for a decision on the next big HEP project. In this case the large community must be engaged to facilitate the decision for the construction of the next HEP project."
- We need to prepare for uncertainties in the path to the ILC after 2012, including what LHC tells us.