Technology Progress Report of the ILC

Brian Foster (Oxford & GDE)

CERN 17/2/09

Overview

- Current status – the GDE, the RDR in brief and goals of TDR.
- Major R&D Goals & Progress
  - Superconducting RF
  - Accelerator Systems
  - CF&S
- Summary & Outlook

ILC Parameters

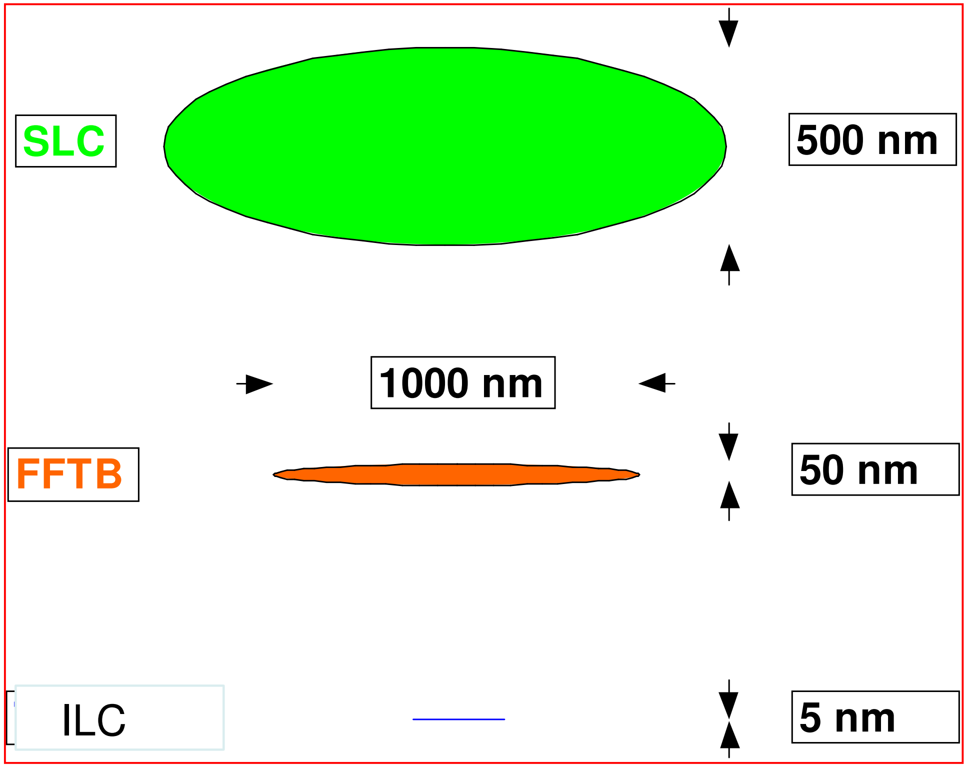
- E_{cm} adjustable from 200 – 500 GeV
- Luminosity $\int L dt = 500\ \mathrm{fb}^{-1}$ in 4 years

  (corresponds to $2 \times 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)
- 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**

ILC Parameters

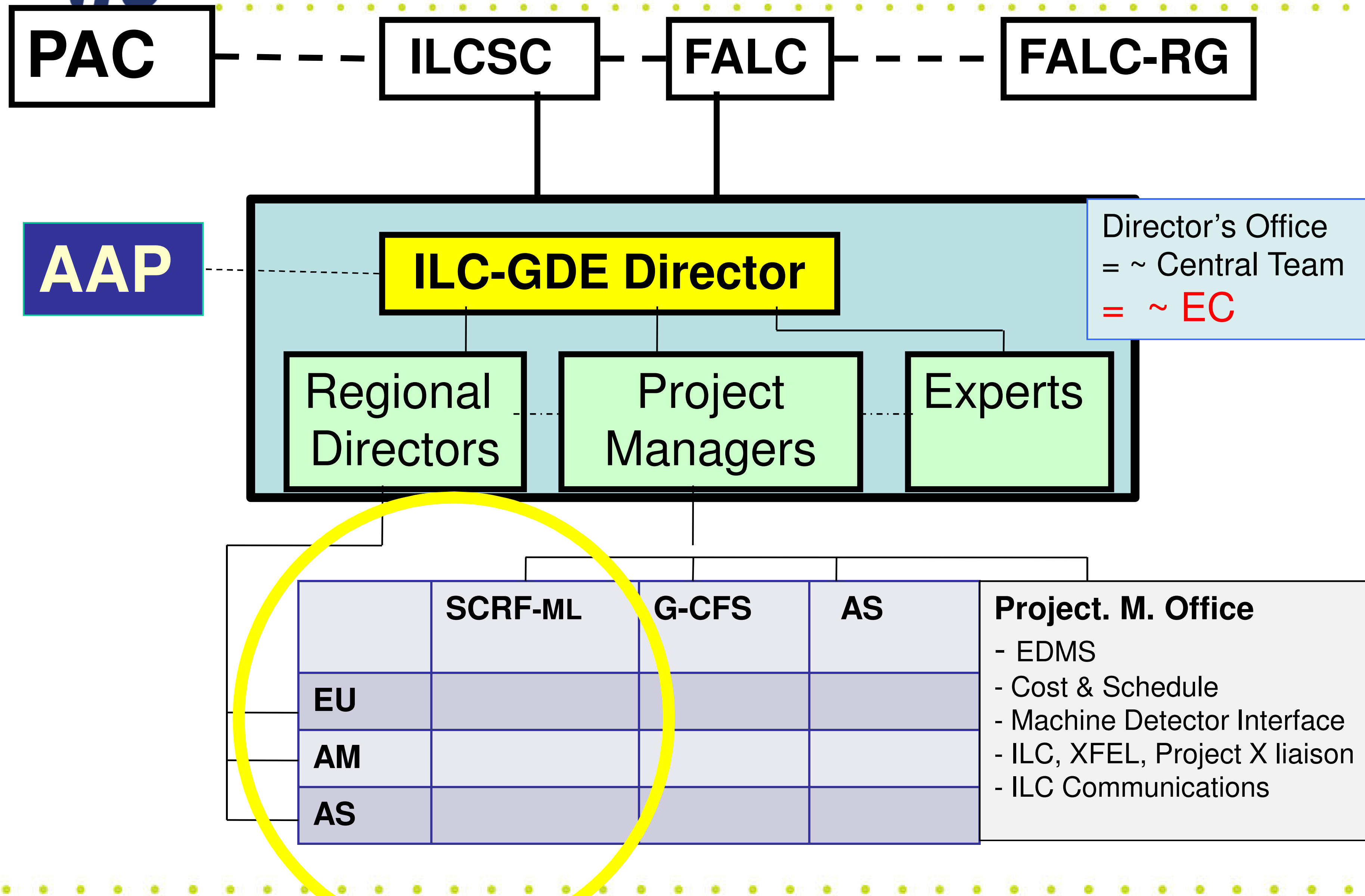
- **The scale of the problem**



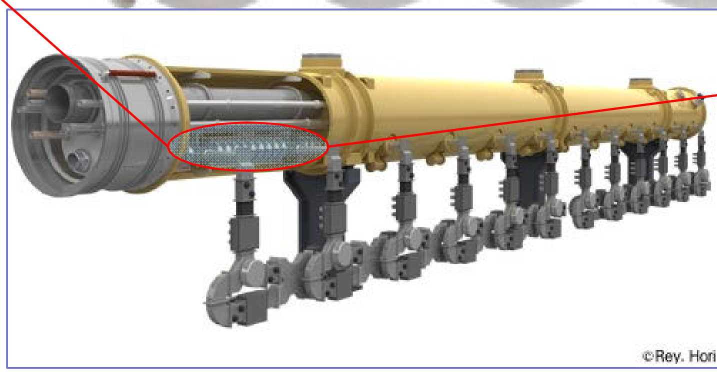
Global Design Effort Mission

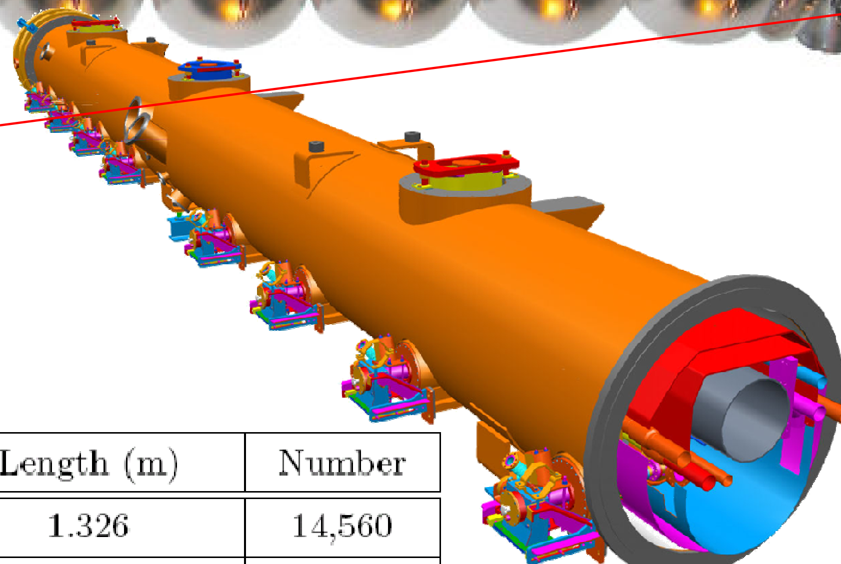
- Produce a design for the ILC that includes a detailed design concept, performance assessments, reliable international costing, an industrialization plan, siting analysis, as well as detector concepts and scope.
- Coordinate worldwide prioritized proposal driven R & D efforts (to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc.)
- B. Barish is GDE Director, assisted by 3 regional directors: BF (Europe); K. Yokoya (Asia); M. Harrison (Americas). 3 PMs – Marc Ross (Americas); N. Walker (Europe); A.Yamamoto (Asia). GDE (> 30% FTE)- currently 480 GDE members worldwide.

ILC-GDE Organization Chart



ILC's Workhorse - SCRF

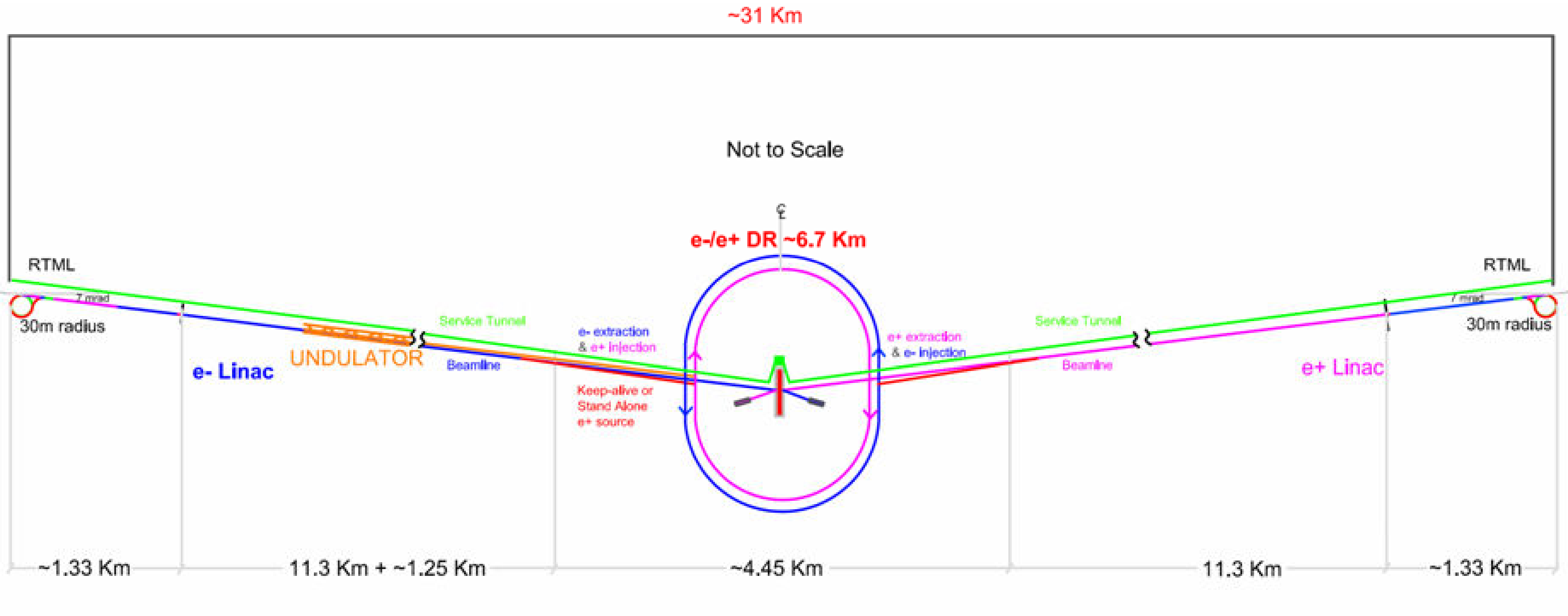




Subdivision	Length (m)	Number
Cavities (9 cells + ends)	1.326	14,560
Cryomodule (9 cavities or 8 cavities + quad)	12.652	1,680
RF unit (3 cryomodules)	37.956	560
Cryo-string of 4 RF units (3 RF units)	154.3 (116.4)	71 (6)
Cryogenic unit with 10 to 16 strings	1,546 to 2,472	10
Electron (positron) linac	10,917 (10,770)	1 (1)

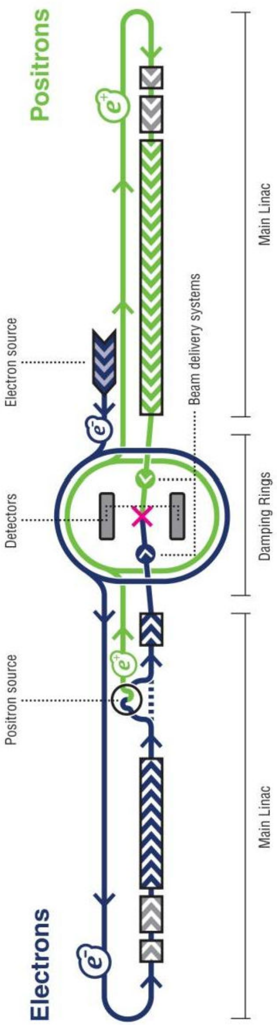
Overall ILC Layout from RDR

1st Stage: 500 GeV; central DR et al. campus; 2 “push-pull” detectors in 14 mrad IR.

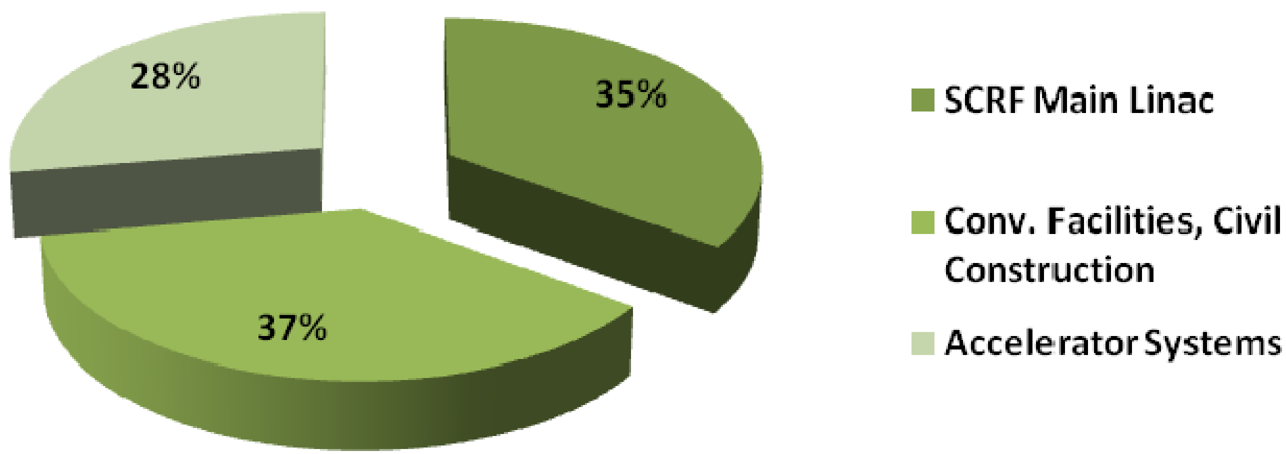


Schematic Layout of the 500 GeV Machine

RDR cost estimate

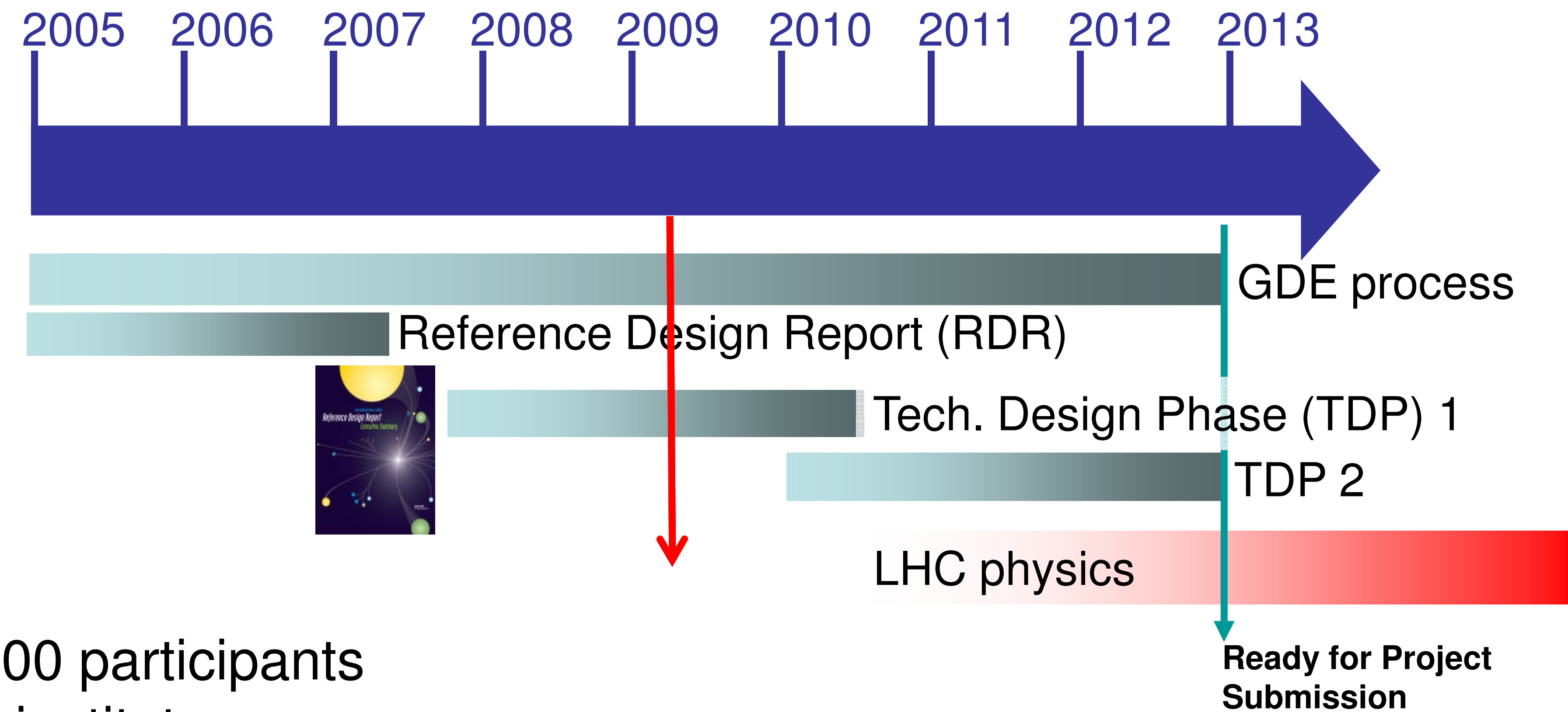


- Estimated cost (2007) ~6.7 Billion ILCU*
  - **4.87 BILCU shared**
  - **1.78 BILCU site-specific**



- 10,000 person-years “implicit” labour

GDE ILC Timeline



~100 participants
55 institutes
12 countries
3 regions

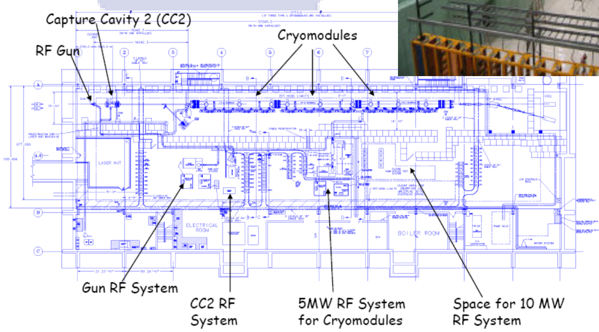
TDR R&D Plans

- Particular concentration in early phase of TP is on cost reduction. "Minimum machine" concept attempts to retain performance goals with less redundancy and cost.

- Concentrate on "cost drivers" – SCRF, CF&S – but significant R&D progress required for most other systems. Nevertheless, ILC could be built now – if money was available.

SRF Test Facilities

FNAL

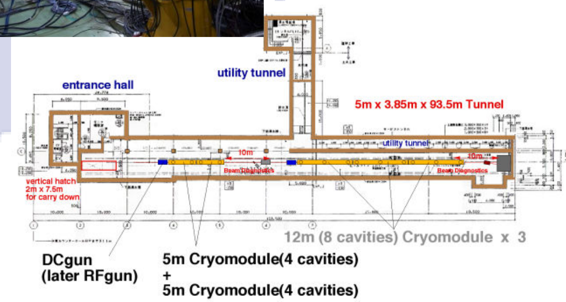


NML facility
Under construction
first beam 2010
ILC RF unit test

DESY

TTF/FLASH
~1 GeV
ILC-like beam
ILC RF unit
(* lower gradient)

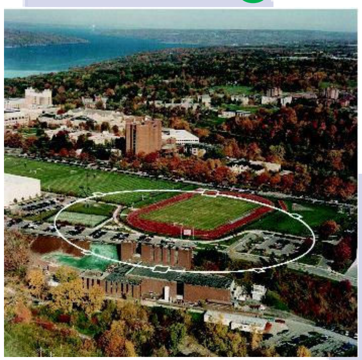
KEK, Japan



STF (phase I & II)
Under construction
first beam 2011
ILC RF unit test

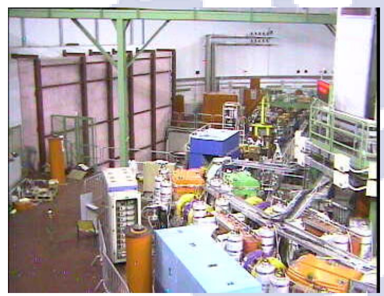
Other Test Facilities

Cornell



CesrTA (Cornell)
electron cloud
low emittance

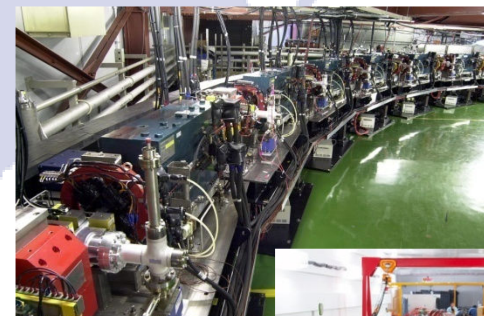
INFN Frascati

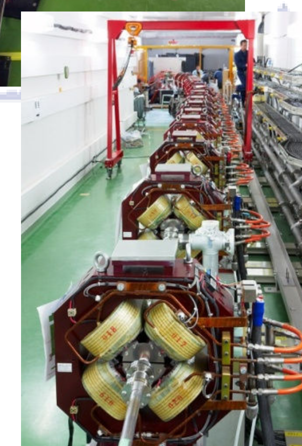


DAϕNE (INFN Frascati)
kicker development
electron cloud

<u>ATF</u> & ATF2 (KEK)
ultra-low emittance
Final Focus optics

KEK, Japan





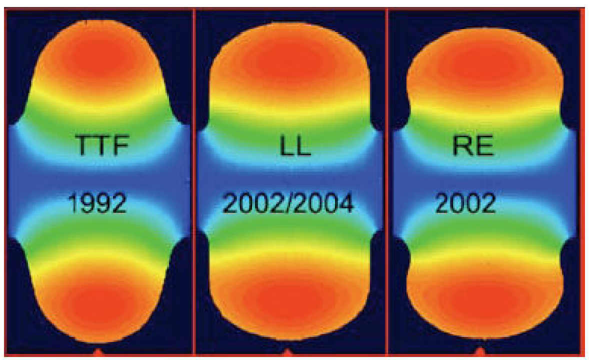
TDP Goals of ILC-SCRF R&D

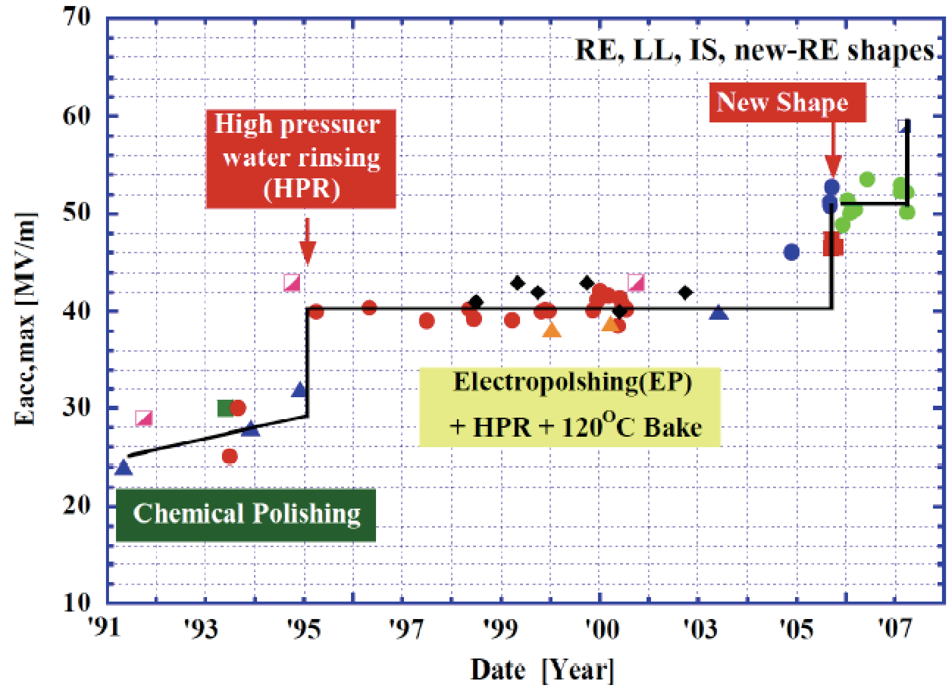
- **Field Gradient**
  - 35 MV/m for cavity performance in vertical test (S0)
  - 31.5 MV/m for operational gradient in cryomodule
    - to build two x 11 km SCRF main linacs
- **Cavity Integration with Cryomodule**
  - **"Plug-compatible" development to:**
    - Encourage "improvement" and creative work in R&D phase
    - Motivate practical 'Project Implementation' with sharing intellectual work in global effort
- **Accelerator System Engineering and Tests**
  - Cavity-string test in one cryomodule (S1, S1-global)
  - Cryomodule-string test with Beam Acceleration (S2)
    - With one RF-unit containing 3 crymodule

Progress in Single Cell Cavity

TABLE II. CAVITY SHAPES STUDIED FOR THE ILC.

Parameter	TESLA	LL/IS	RE
Iris aperture (mm)	70	60/61	66
E_{peak}/E_{acc}	1.98	2.36/2.02	2.21
B_{peak}/E_{acc} (mT/(MV/m))	4.15	3.61/3.56	3.76
Char. shunt impedance: R/Q (Ω)	114	134/138	127
Geometric factor: G (Ω)	271	284/285	277
G × R/Q (Ω × Ω × 10^5)	3.08	3.80/3.93	3.51





- Record of **59 MV/m** achieved with the RE cavity with EP, BCP and pure-water rinsing with collaboration of Cornell and KEK

Cavity Shape Design Investigated

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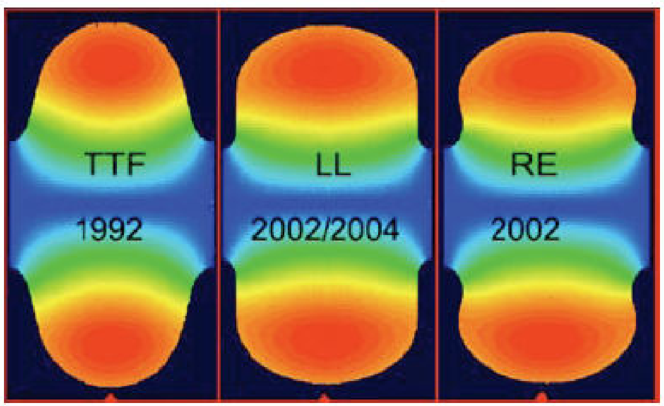
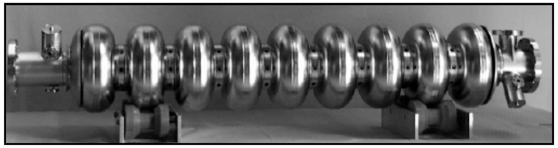


- TESLA
  - **Lower E-peak**
  - **Lower risk of field emission**
- LL/IS, RE
  - **Lower B-peak**
  - **Potential to reach higher gradient**

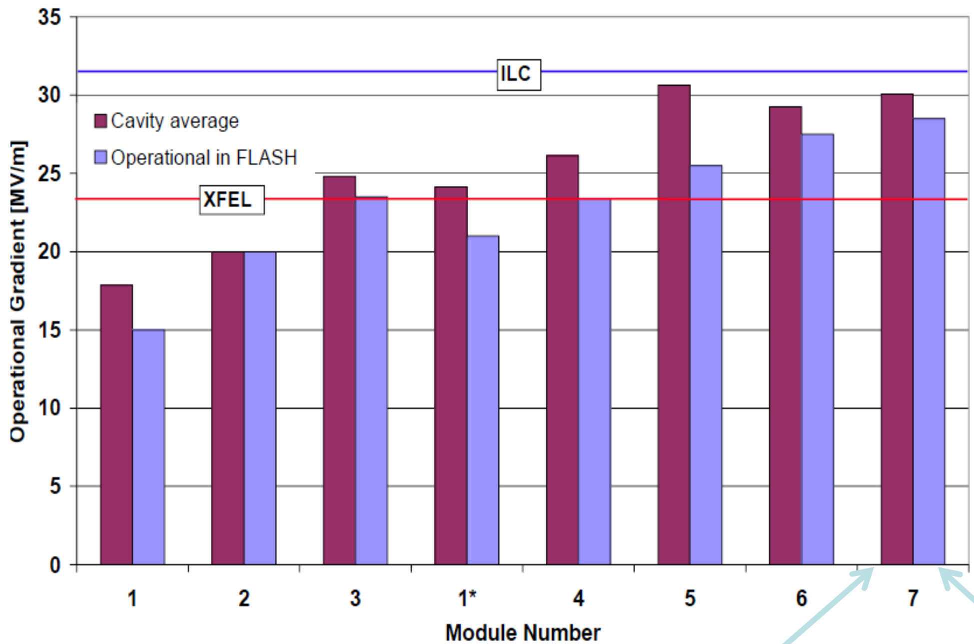
LL: low-loss, IS: Ichiro-shape, RE: re-entrant

Status of 9-Cell Cavity



- Europe
  - “Gradient” (<31.5> MV/m) with Ethanol rinse (DESY):
  - Industrial (bulk) EP demonstrated (<36> MV/m) (DESY)
  - Large-grain cavity (DESY)
  - Surface process with baking in Ar-gas (Saclay)
- America(s)
  - Gradient distributed (20 – 40 MV/m) with various surface process (Cornell, JLab, Fermilab)
  - Field emission reduced with Ultrasonic Degreasing using Detergent, and “Gradient” improved (JLab)
- Asia
  - “Gradient”, 36 MV/m (LL, KEK-JLab), 32 MV/m (TESLA-like, KEK)
  - Effort in Chinese laboratories in cooperation with KEK, Fermilab, Jlab, and DESY
  - Effort in Indian laboratories in cooperation with Fermilab, KEK

Field Gradient progressed at DESY

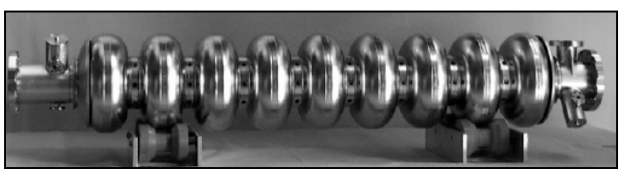


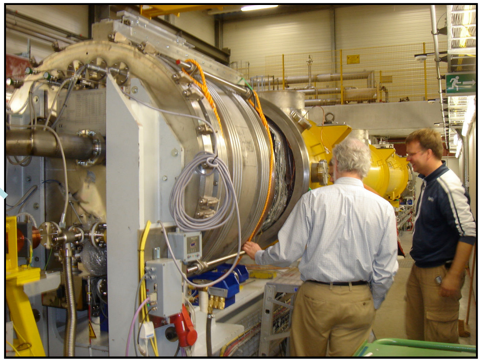
ILC operation :

- <31.5> MV/m

R&D Status :

- ~ 30 MV/m to meet XFEL requirement



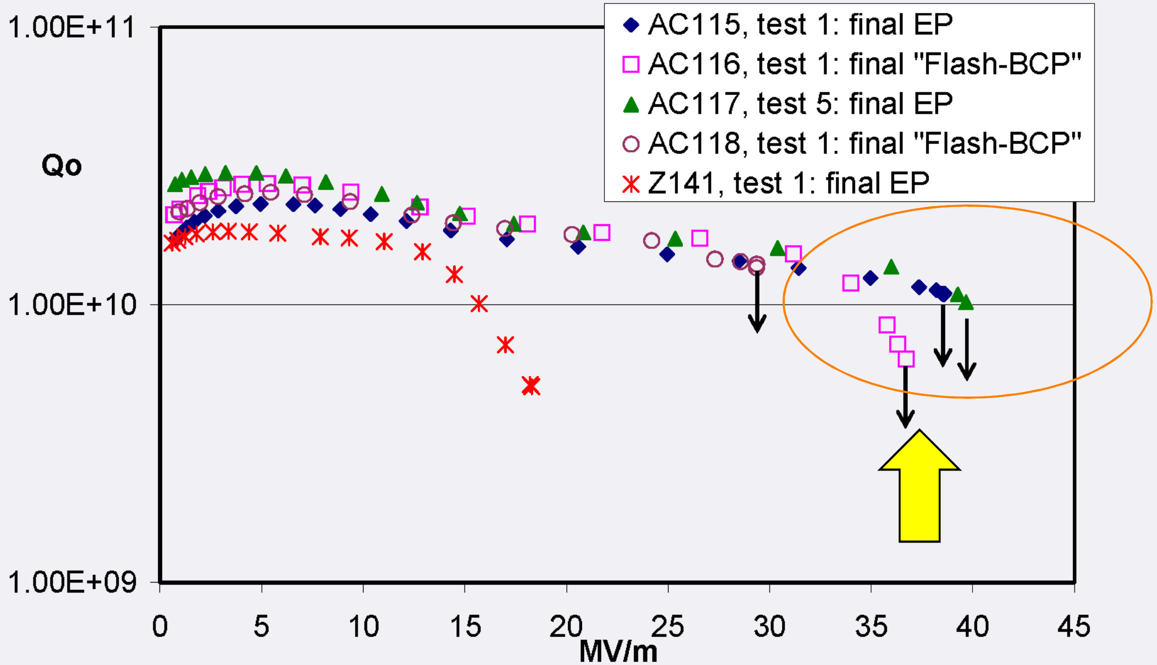


•**20 % improvement required for ILC**

Industrial EP at DESY/Plansee

6th cavity production – rf results

- excellent + promising first results including first Plansee nine-cell (AC115)
- Z141 as first cavity with surfaces damages after fabrication under investigation



Detlef Reschke, DESY
MAC DESY, May 08, 2008

HELMHOLTZ GEMEINSCHAFT

- The average gradient, **36 MV/m, achieved** with AC115-118

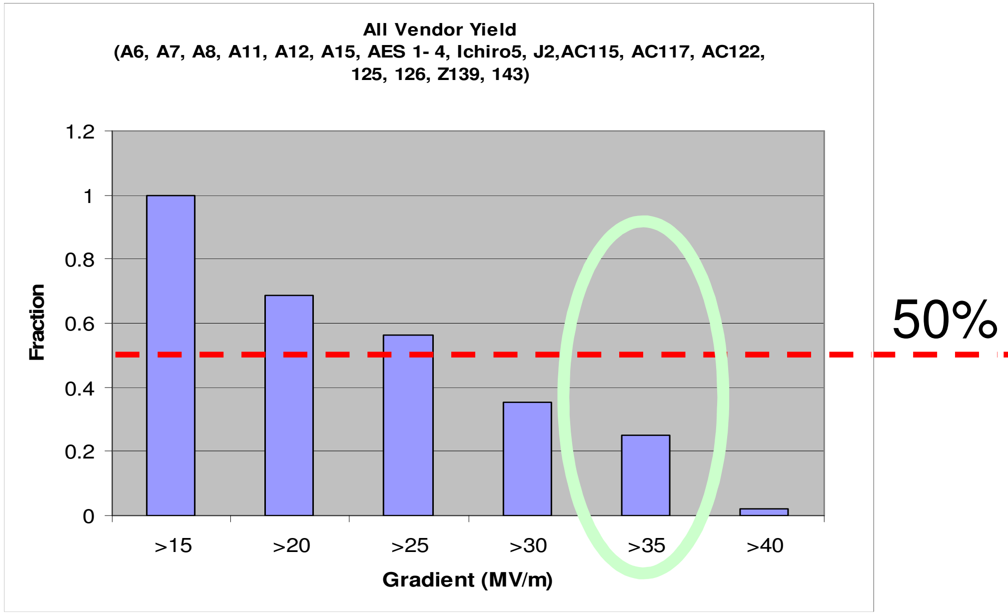
Combined Yield of Jlab and DESY Tests

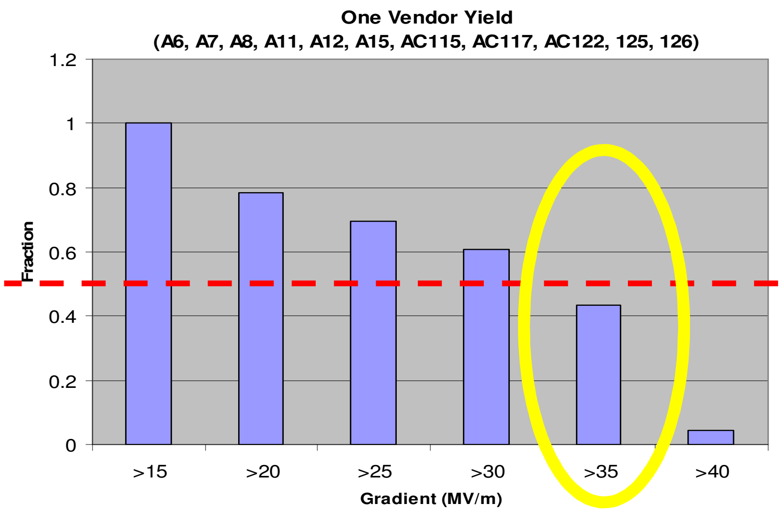
48 Tests, 19 cavities

ACCEL, AES, Zanon, Ichiro, Jlab

23 tests, 11 cavities

One Vendor





Yield 45 % at 35 MV/m being achieved by cavities with a qualified vendor !!

Plan for High Gradient R&D

1: **Research**/**find cause** of gradient limit

high resolution camera

surface analysis

2: **develop countermeasures**

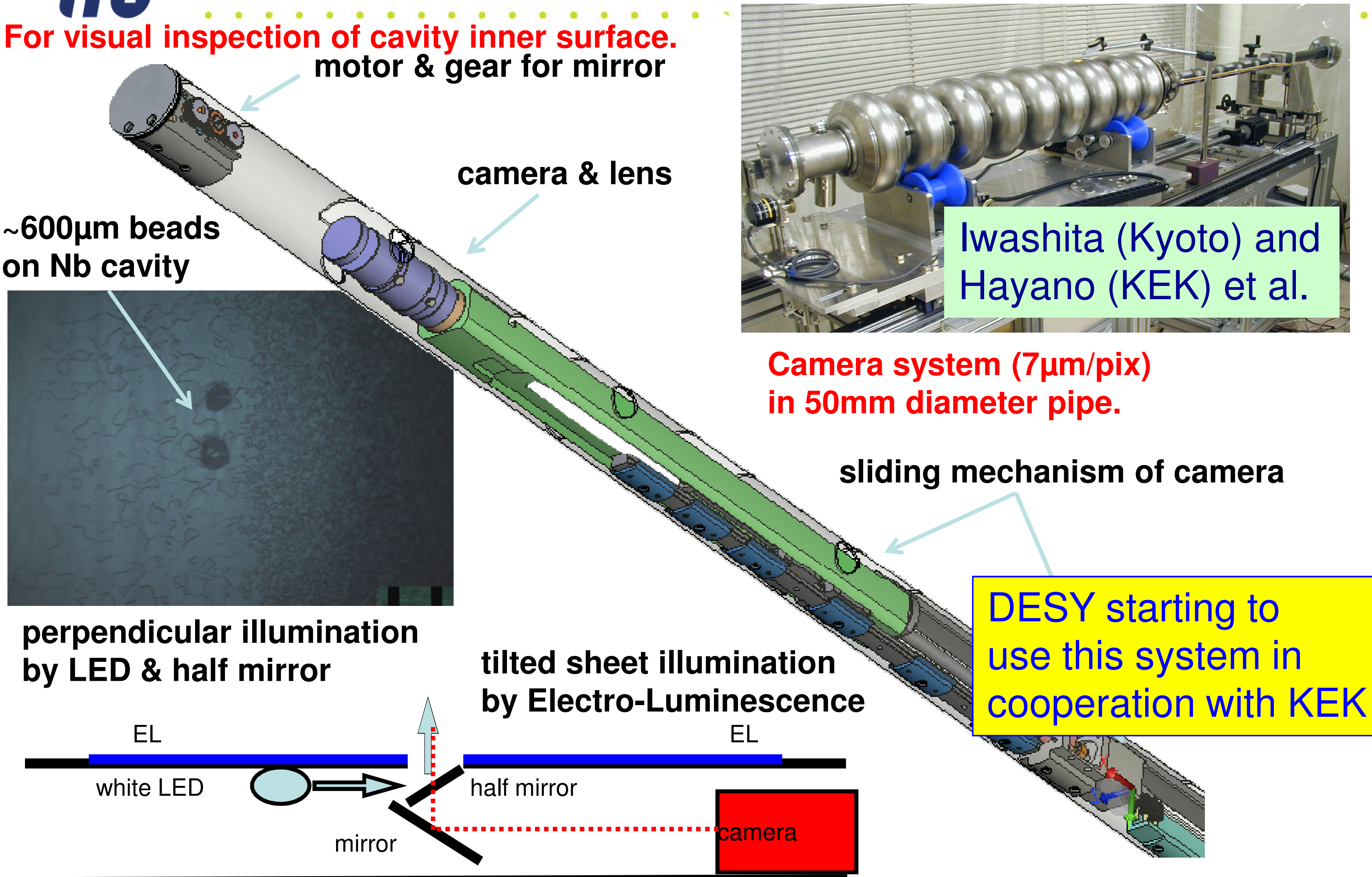
remove beads & pits,

establish surface process

3: **verify and integrate** countermeasures

get **statistics**

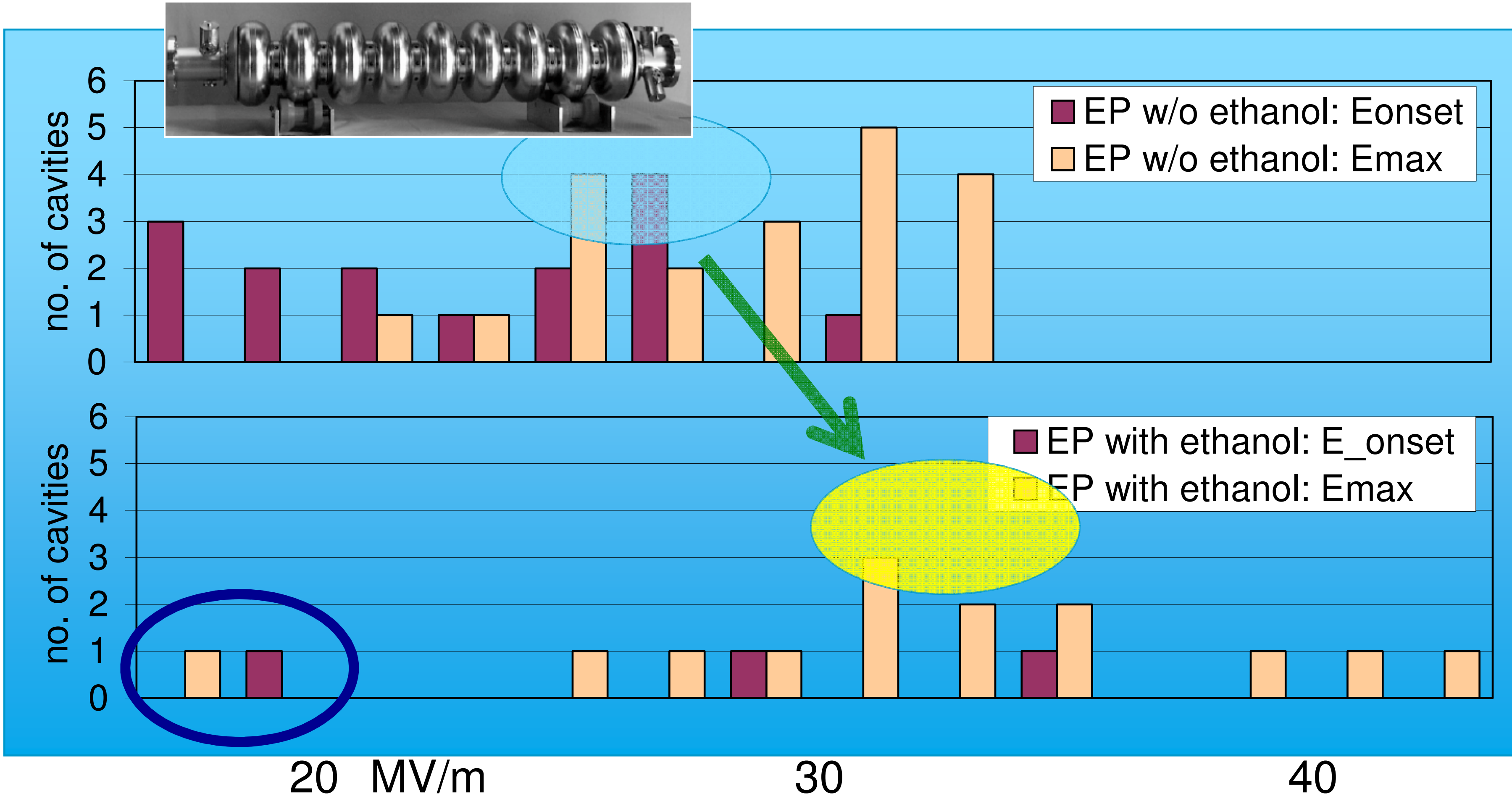
A New High Resolution, Optical Inspection



Guideline: Standard Procedure and Feedback Loop

	Standard Fabrication/Process	(Optional action)	Acceptance Test/Inspection
Fabrication	Nb-sheet purchasing		Chemical component analysis
	Component (Shape) Fabrication		Optical inspect., Eddy current
	Cavity assembly with EBW	(tumbling	Optical inspection
Process	EP-1 (Bulk: ~150um)		
	Ultrasonic degreasing (detergent) or ethanol rinse		
	High-pressure pure-water rinsing		Optical inspection
	Hydrogen degassing at 600 C (?)	750 C	
	Field flatness tuning		
	EP-2 (~20um)		
	Ultrasonic degreasing or ethanol	(Flash/Fresh EP) (~5um))	
	High-pressure pure-water rinsing		
	General assembly		
	Baking at 120 C		
Cold Test (vertical test)	Performance Test with temperature and mode measurement	Temp. mapping	If cavity not meet specification Optical inspection

DESY: Field Emission Analysis



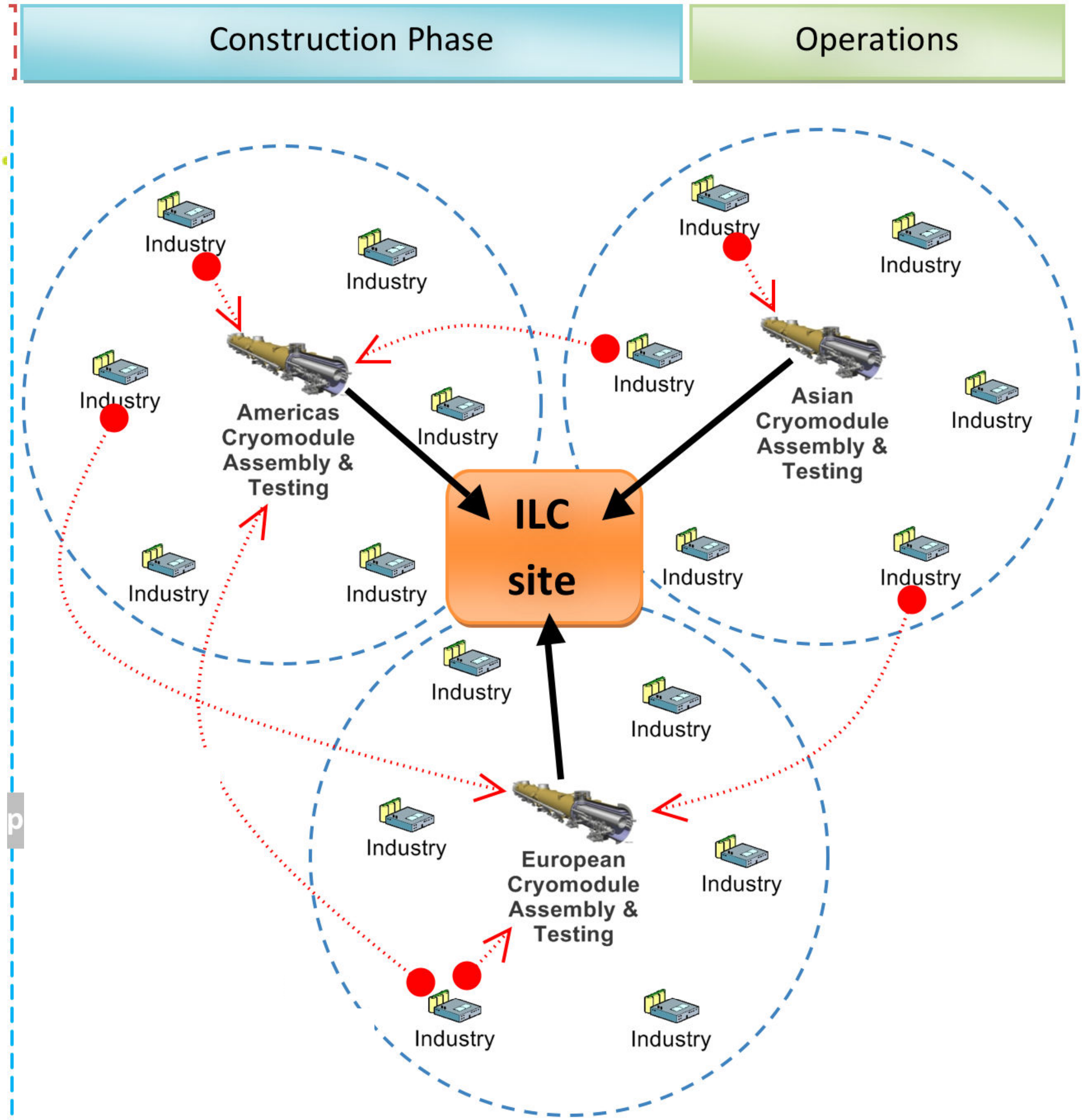
Cavity gradient shifted to High Gradient by 'ethanol rinse', except for "lowest two" (due to different reasons)

Cavity Integration and Tests

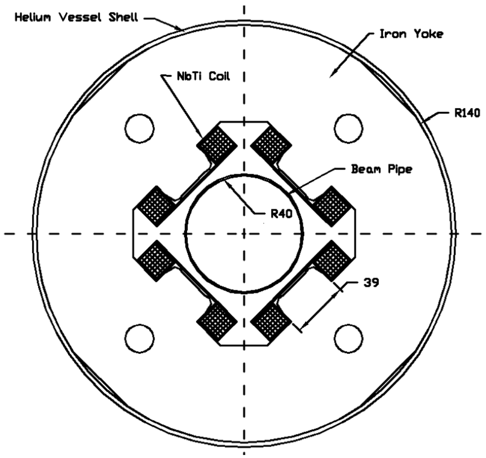
- **Europe (EU)**
  - **Cryomodule assembly plan for XFEL (DESY/INFN/CEA-Saclay)□□□**
  - **Input-coupler industrial assessment for XFEL (LAL-Orsay)**
  - **Cryomodule design for S1-global (INFN/KEK)**
  - **TTF- 9 mA Test**
- **America(s) (AMs)**
  - **Cryomodule design**
  - **Cryogenic engineering (FNAL in cooperation with CERN)**
  - **SCRF Test Facility (FNAL)**
- **Asia (AS)**
  - **Cryomodule engineering design (KEK/INFN, KEK/IHEP)**
  - **Superconducting test facility (KEK)**
- **Global effort for Cavity/Cryomodule Assembly**
  - **Plug-compatible integration and test :**

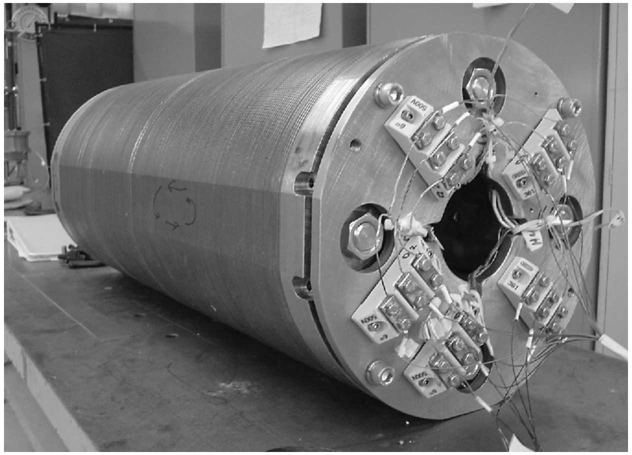
Global Production: Plug-Compatible Production

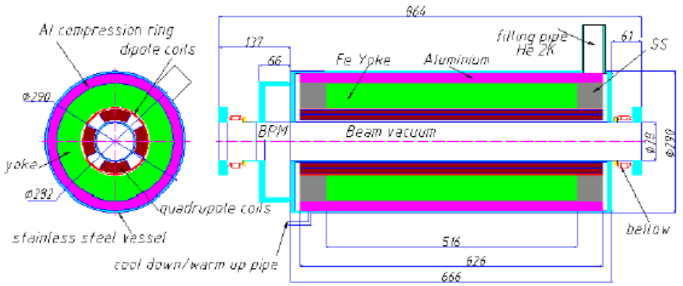
- Testing (QA/QC)
- Free 'global' market competition (lowest cost)
- Maintain intellectual regional expertise base



Quadrupole R&D Work







- Fermilab: V. Kashikhin et al.,
  - Test results of superconducting quadrupole model for linear colliders
  -
- SLAC/CIEMAT: C. Adolphsen et al

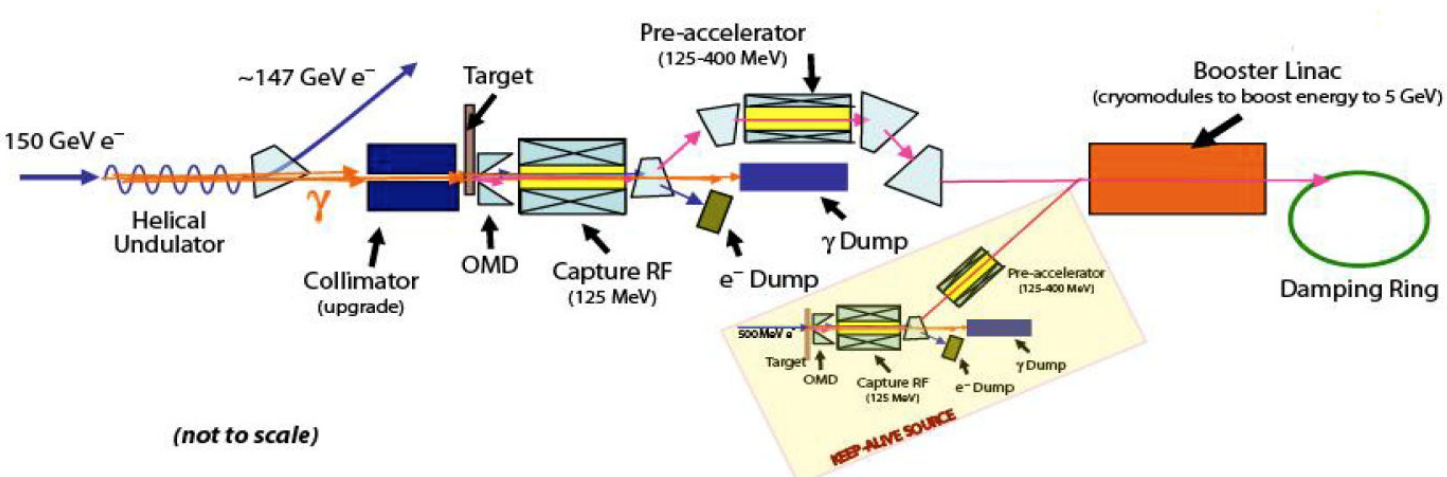
Non-SCRF R&D

- Electron source
- Positron source
- Damping ring
- Ring-to-Main-Linac (RTML)
- Beam Delivery System

Positron Source

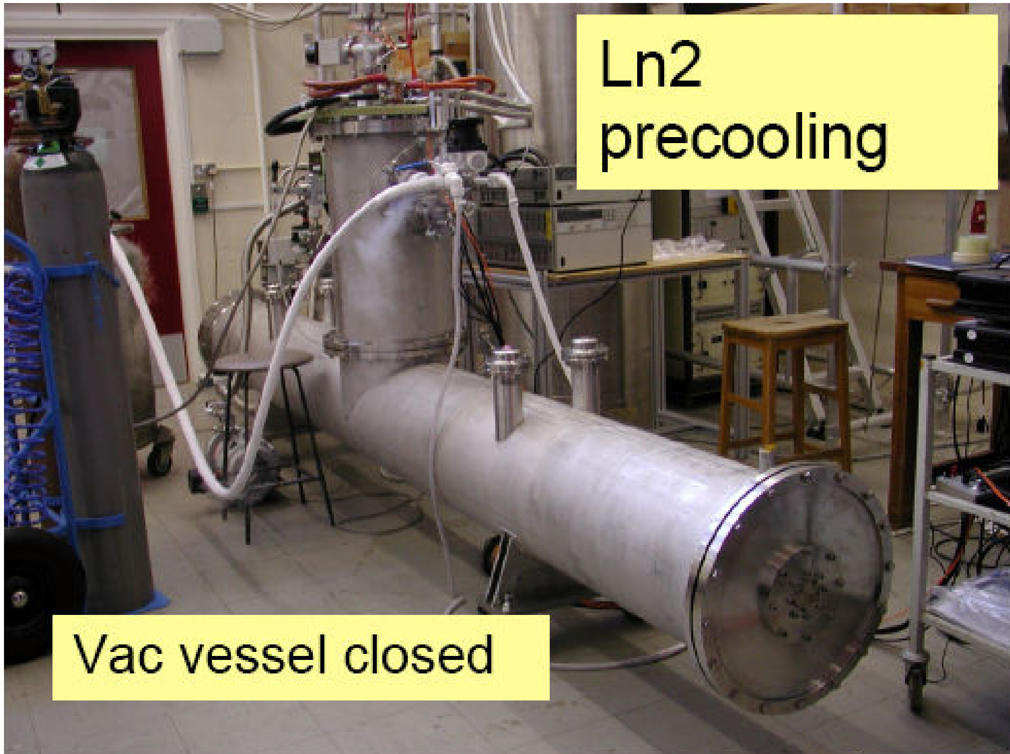
RDR Positron Source Layout

ASTeC Accelerator Science and Technology Cent



- R & D Priorities –
  - Undulator (UK – RAL, Cornell – Mikailichenko)
  - Target (KEK, BINP – Logachev)
  - Matching Device - replacement for ‘Flux Concentrator’
    - Liquid Lithium Lens (KEK, BINP – Logachev)

Positron Source



Constructed by Rutherford Appleton Lab.

First cooldown of complete system early Sept 08.

Vertical magnet tests successful – design field exceeded in both 1.75m undulators

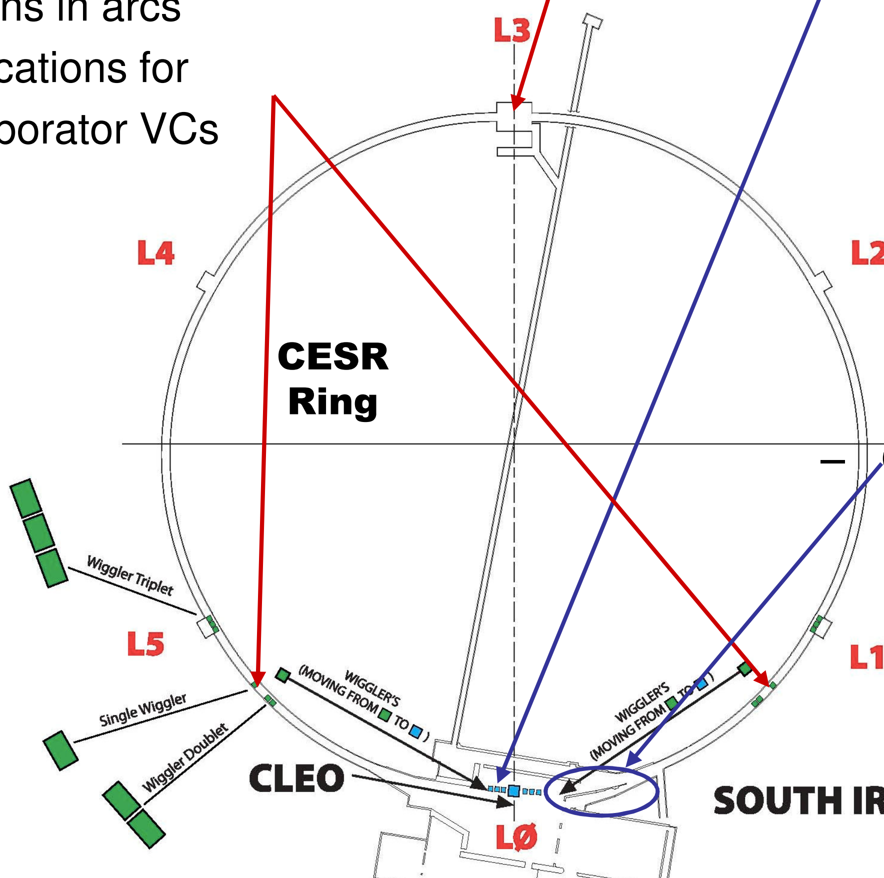
But, vacuum leak when cold – now being repaired – should be complete by Jan 09

Damping rings

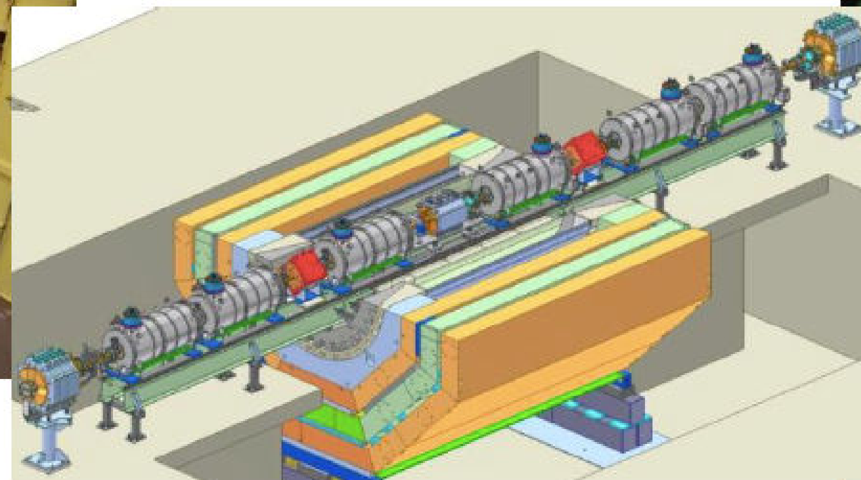
- One of the biggest problems is to cope with the electron cloud effect in the relatively small damping rings mandated by need to save costs.
- Electron cloud caused by electrons ejected from vacuum chamber walls by synchrotron photons and then accelerated by attraction of positron beams to give avalanche on striking walls. This cloud attracts & defocuses electron beam.

Damping rings – CESR

- Electron Cloud Diagnostics
  - L3 region prepped for arrival of PEP-II EC hardware including diagnostic chicane
  - New EC experimental regions in arcs w/ locations for collaborator VCs
  - L0 region reconfigured as a wiggler straight
    - Instrumented with EC diagnostics
    - Wiggler chambers with retarding field analyzers (fabricated at LBNL) – installed in later October
    - Chambers with EC mitigation (TiN coatings by SLAC)
  - CHESS D-line
    - Windowless (all vacuum) x-ray line upgrade
    - Addition of x-ray optics box
    - Detector setup in CHESS hutch
    - Option for longer optical lever arm by extending line to detector located in L0

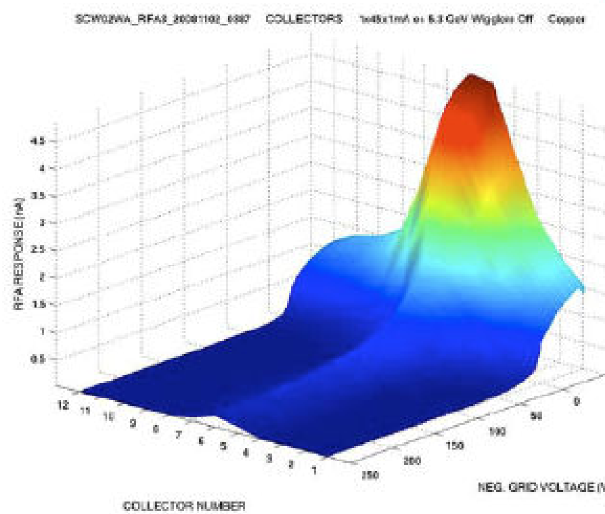


Damping rings – CESR



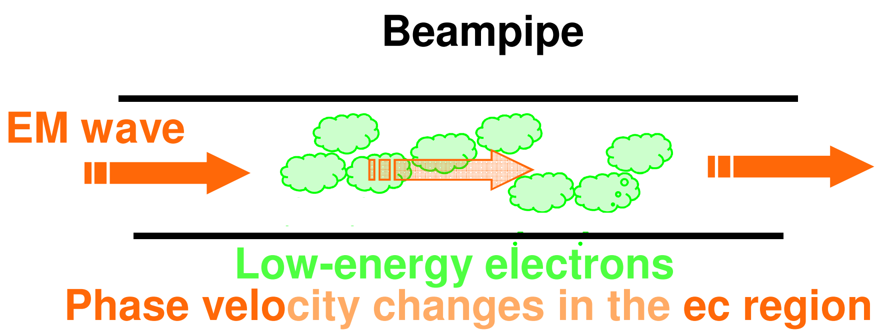
Installation of wigglers in former location of CLEO (above).

Retarding field analyzers in wiggler vacuum chambers, and first data (right).



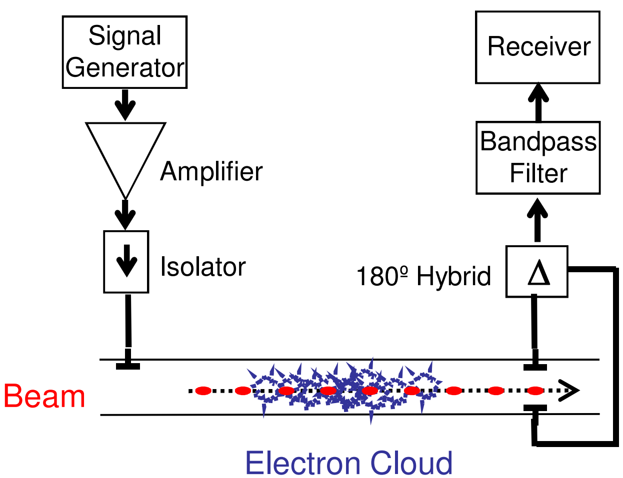
Damping rings – CESR

Induced phase modulation in the propagation of EM waves through beampipe

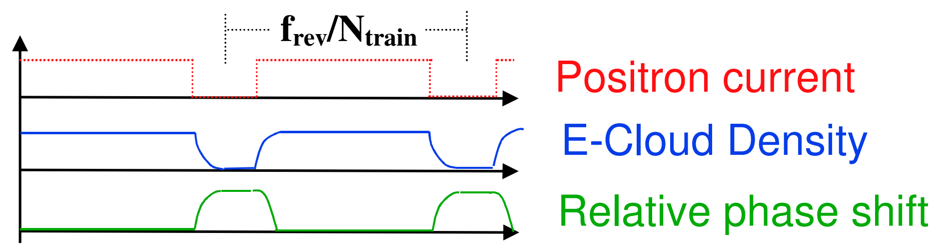


$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2}$$

plasma frequency
$2c(\pi \rho_e r_e)^{1/2}$



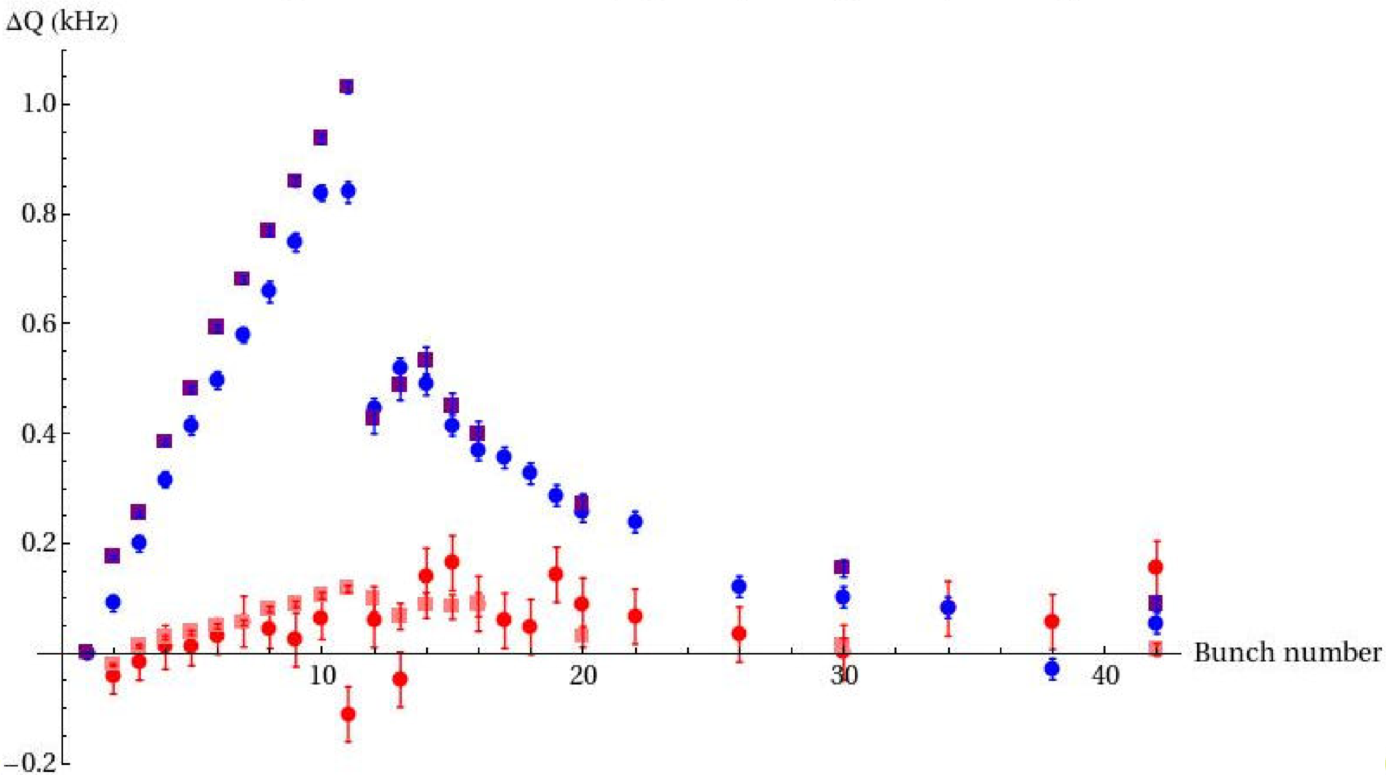
Experimental apparatus



Gaps in the fill pattern set the fundamental modulation frequency (1st sideband). Higher order components depend on the transient ecloud time evolution during the gap passage.

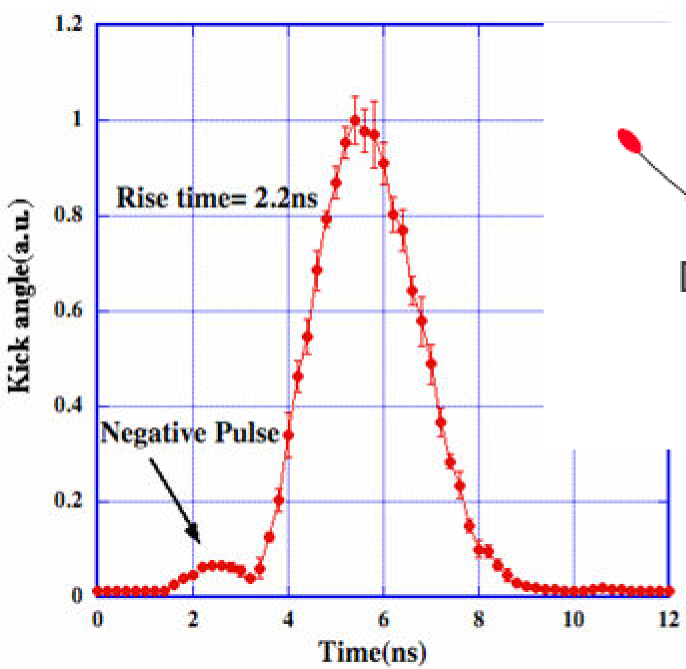
Damping rings – CESR

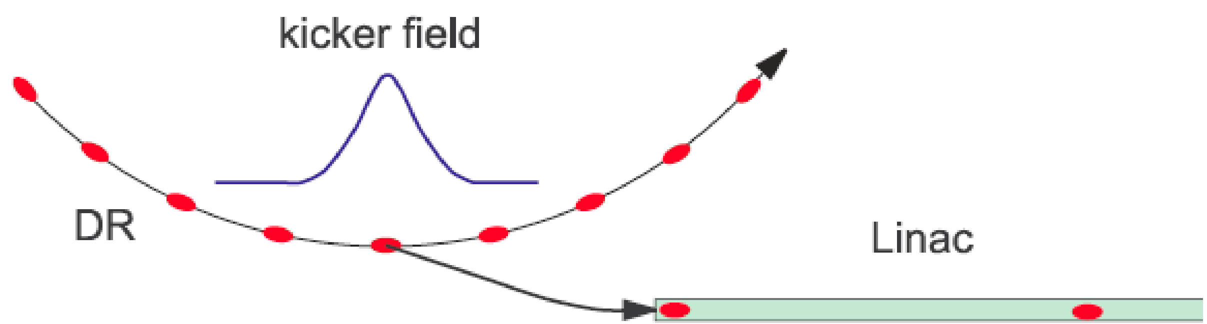
Coherent tune shift vs. bunch number
Tune shift data 1.885 GeV 10 bunch train 0.75 mA/bunch positrons 4/2/07
Purple Squares: Simulation, vertical tune shift
Blue Circles: data, vertical tune shift
Pink Squares: Simulation, horizontal tune shift
Red circles: data, horizontal tune shift
Simulation,
CESR–TA drift at 1.885 GeV: SEY=2.0, epk=310,r=15%, QE=12%,51 nicks,pa=1
CESR–TA dipole at 1.885 GeV: SEY=2.0, Epk=310, r=15%,QE=12%, 51 nicks, p



Kicker System

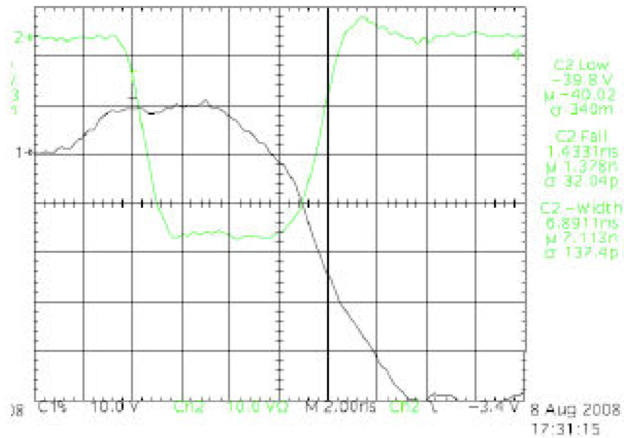
- Number of bunches 3000 (6000 desirable)
- 300ns interval in linac $\Rightarrow$ total length $\sim$1ms $\rightarrow$ 300km
- Store compactly in DR
  (circumference 20km $\rightarrow$ bunch interval $\sim$20ns, 6km $\rightarrow$ $\sim$6ns)
- Bunch by bunch extraction at 300ns interval (injection, too)



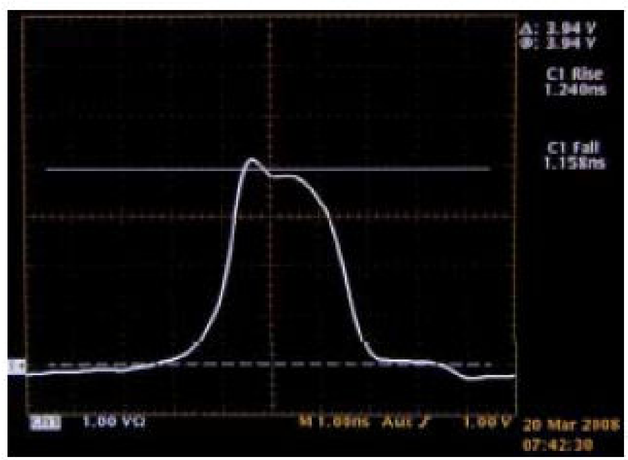


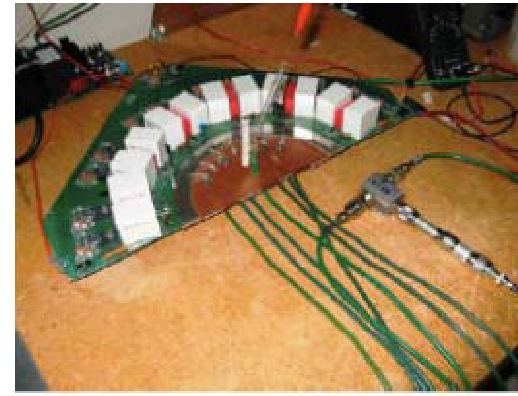
Kicker System R&D

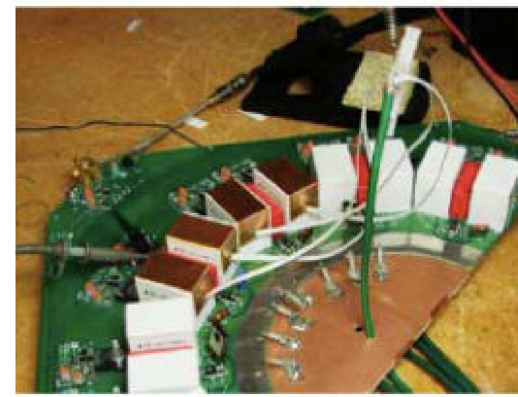
- Researchers at SLAC are investigating two possible technologies: MOSFET array, and *DSRD* fast switch.
- Both technologies provide attractive characteristics.
- A hybrid pulser may be the best solution.



V_{DS}=1kV, R_{Load}=10 ohm, I_D=68 A



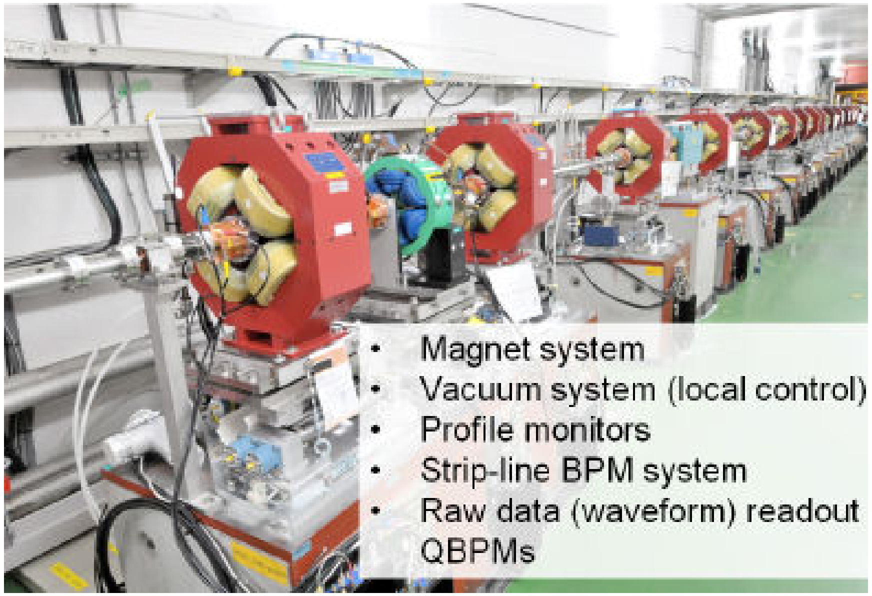




Beam Delivery System R&D

- Commissioning of ATF2 continuing - now home of almost all BDS instrumentation.
- Also looking at "minimal machine" optics, layout etc.
- Crab cavity
- Beam Dump
- Collimation

Finished works for ATF2 beamline



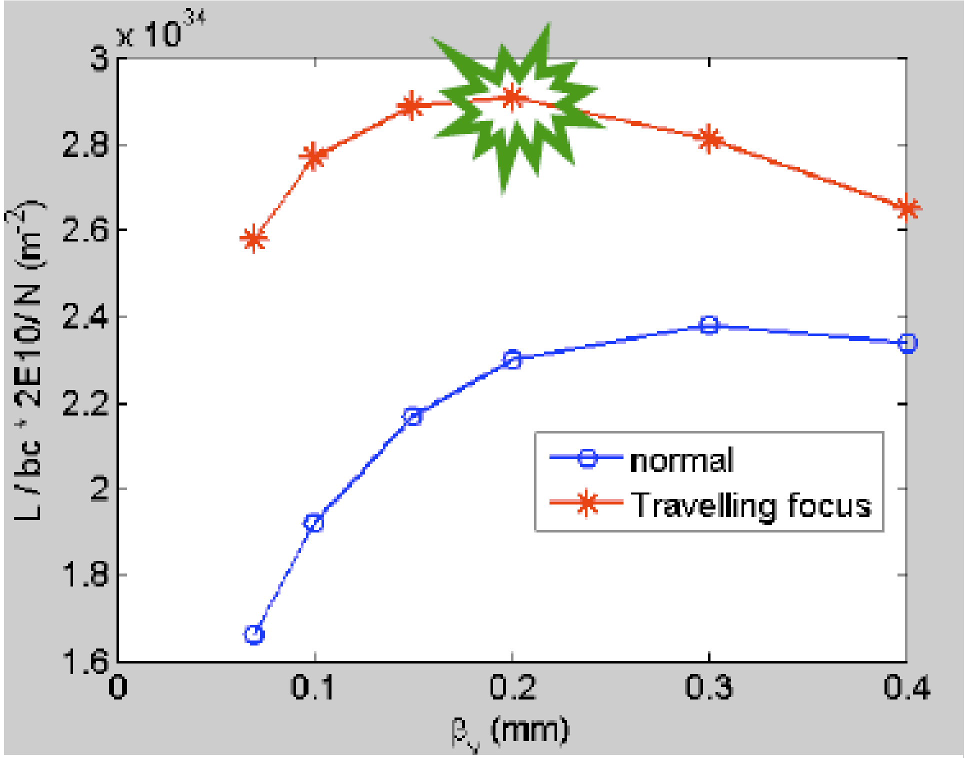
Beam Delivery System R&D

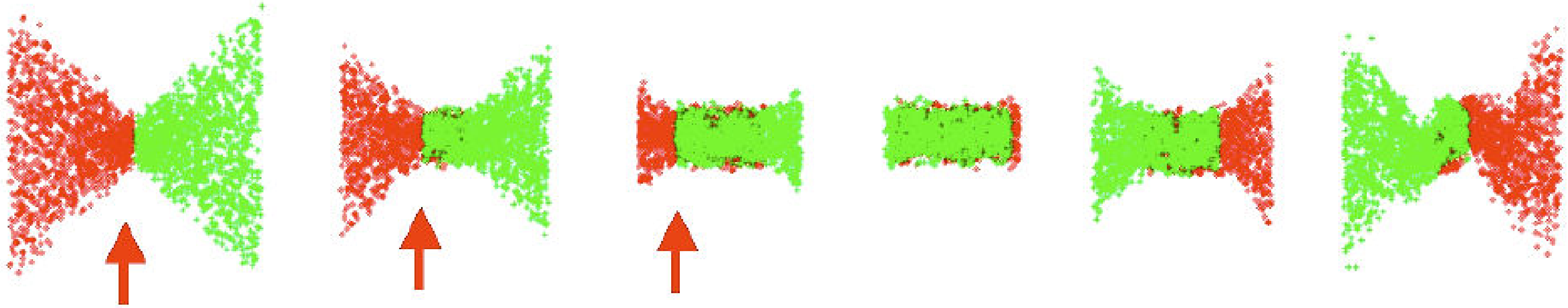
- "Low-power" parameter set.
- Use of "travelling focus" can regain substantial fraction of lumi.

	Nom. RDR	Low P RDR	new Low P
E CM (GeV)	500	500	500
N	2.0E+10	2.0E+10	2.0E+10
n_b	2625	1320	1320
F (Hz)	5	5	5
P_b (MW)	10.5	5.3	5.3
$\gamma\varepsilon_X$ (m)	1.0E-05	1.0E-05	1.0E-05
$\gamma\varepsilon_Y$ (m)	4.0E-08	3.6E-08	3.6E-08
βx (m)	2.0E-02	1.1E-02	1.1E-02
βy (m)	4.0E-04	2.0E-04	2.0E-04
Travelling focus	No	No	Yes
Z-distribution *	Gauss	Gauss	Gauss
σ_x (m)	6.39E-07	4.74E-07	4.74E-07
σ_y (m)	5.7E-09	3.8E-09	3.8E-09
σ_z (m)	3.0E-04	2.0E-04	3.0E-04
Guinea-Pig δE/E	0.023	0.045	0.036
Guinea-Pig L ($cm^{-2}s^{-1}$)	2.02E+34	1.86E+34	1.92E+34
Guinea-Pig Lumi in 1%	1.50E+34	1.09E+34	1.18E+34

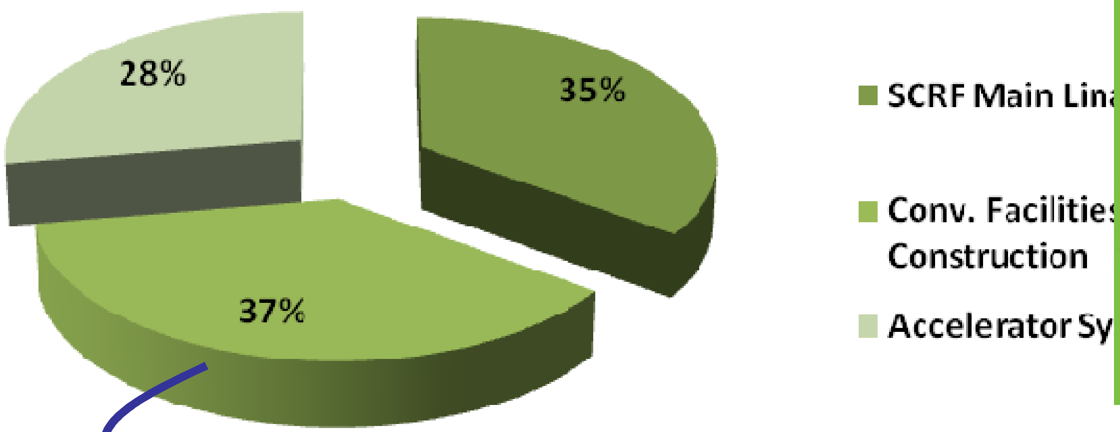
Travelling focus

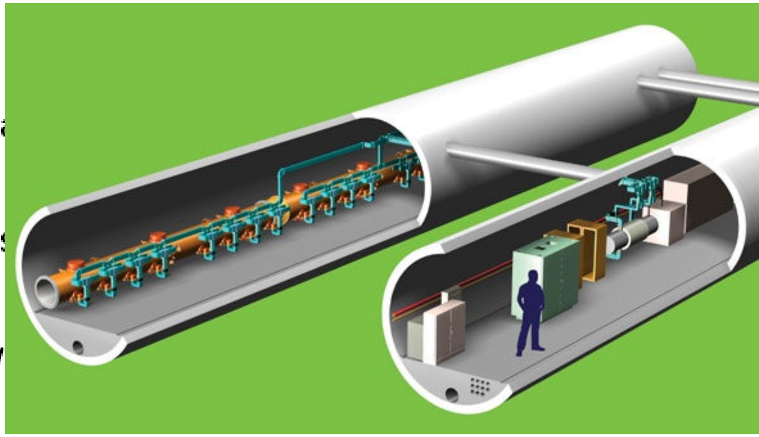
- Old idea - Balakin 1991.
- Uses beam-beam forces to given additional focussing.

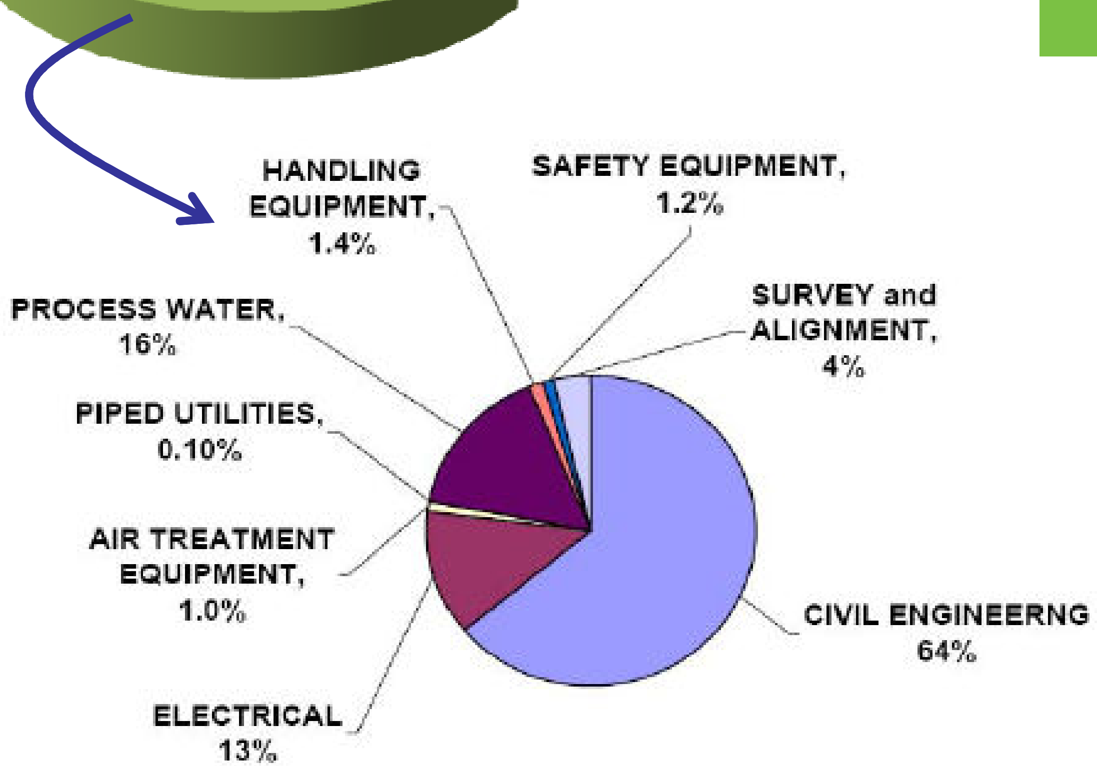




CF&S Work



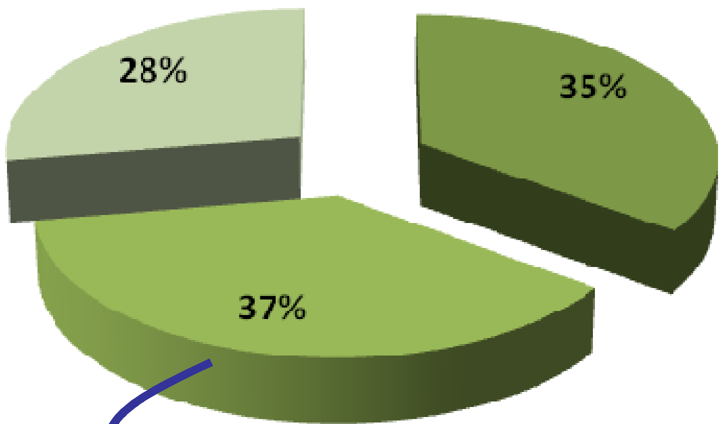


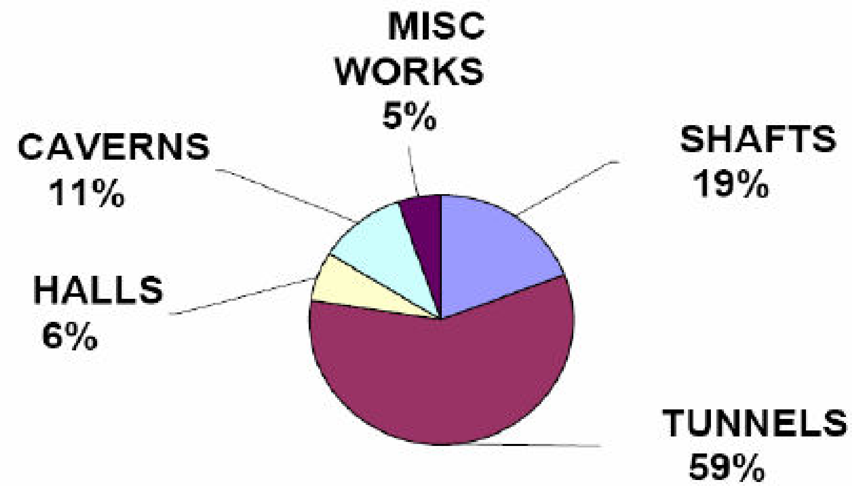


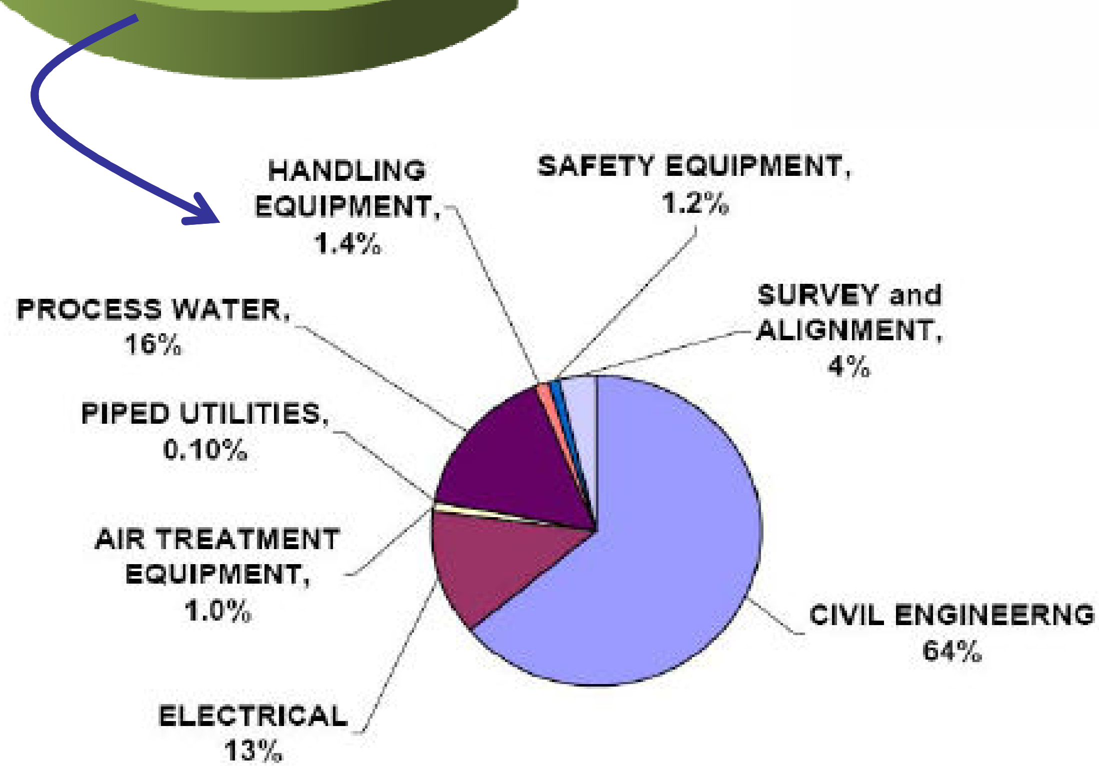
CFS identified as a major cost driver with high-potential for cost-saving

CFS requirements driven by machine design & layout

CF&S Work



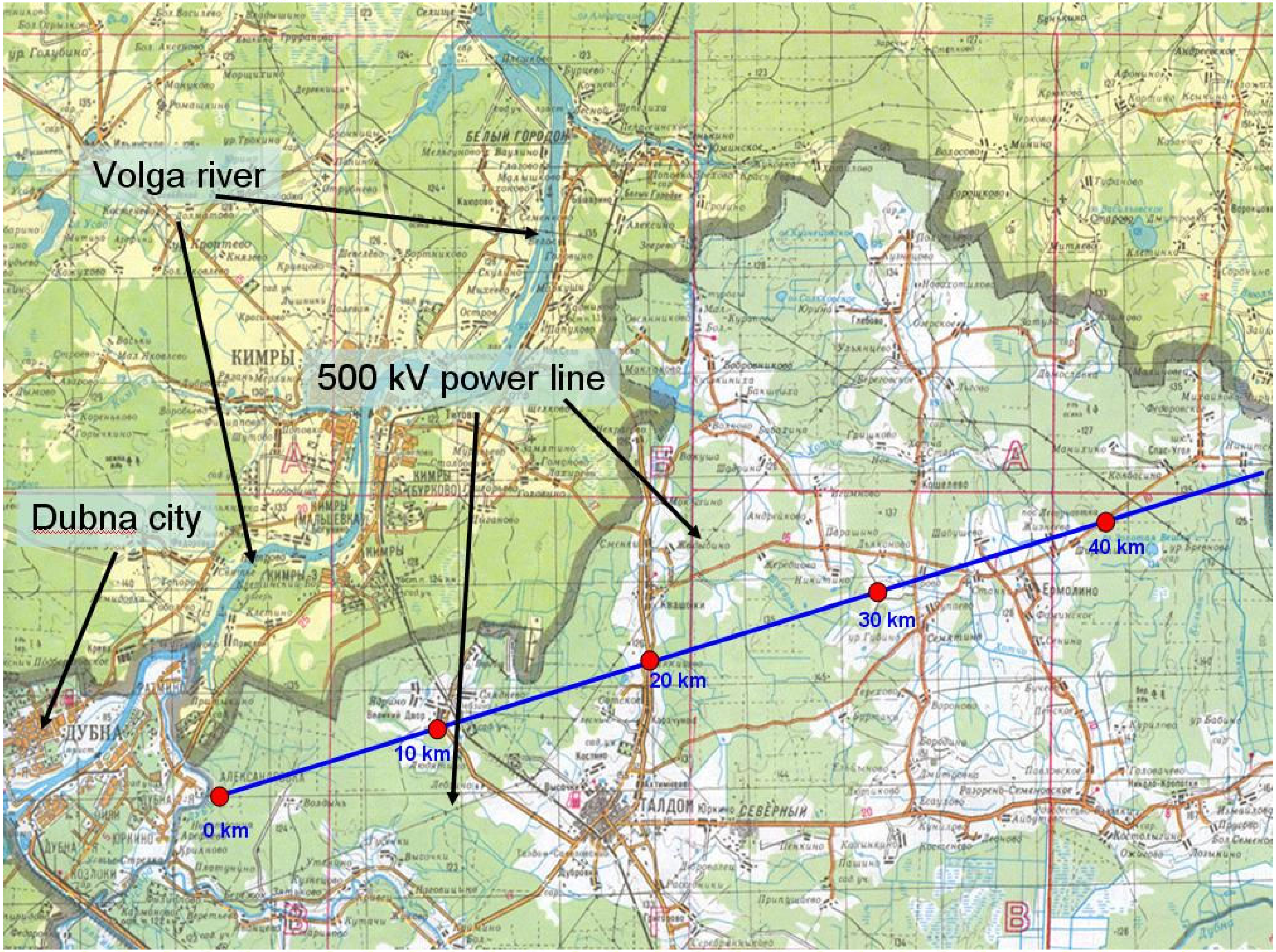




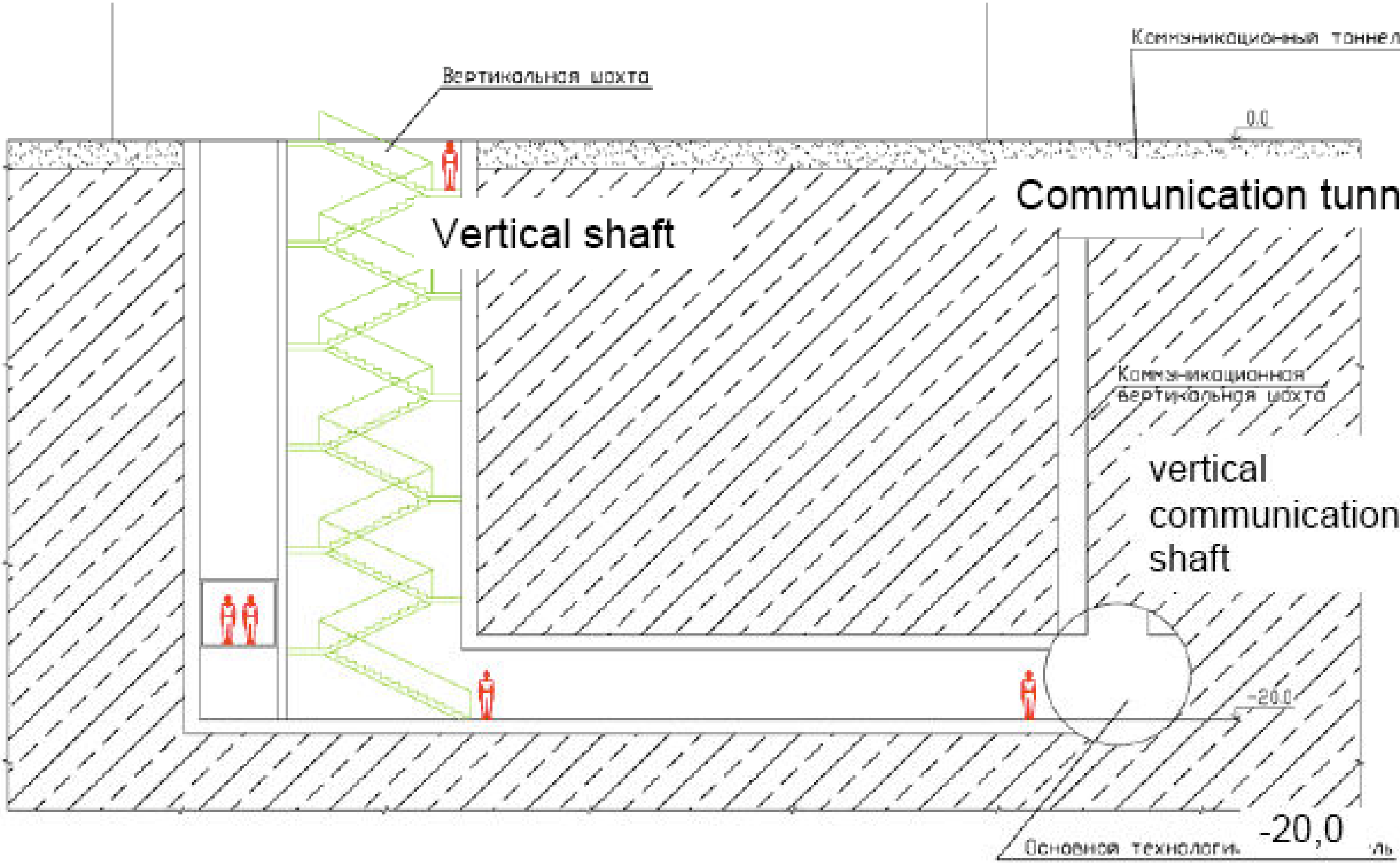
CFS identified as a major cost driver with high-potential for cost-saving

CFS requirements driven by machine design & layout

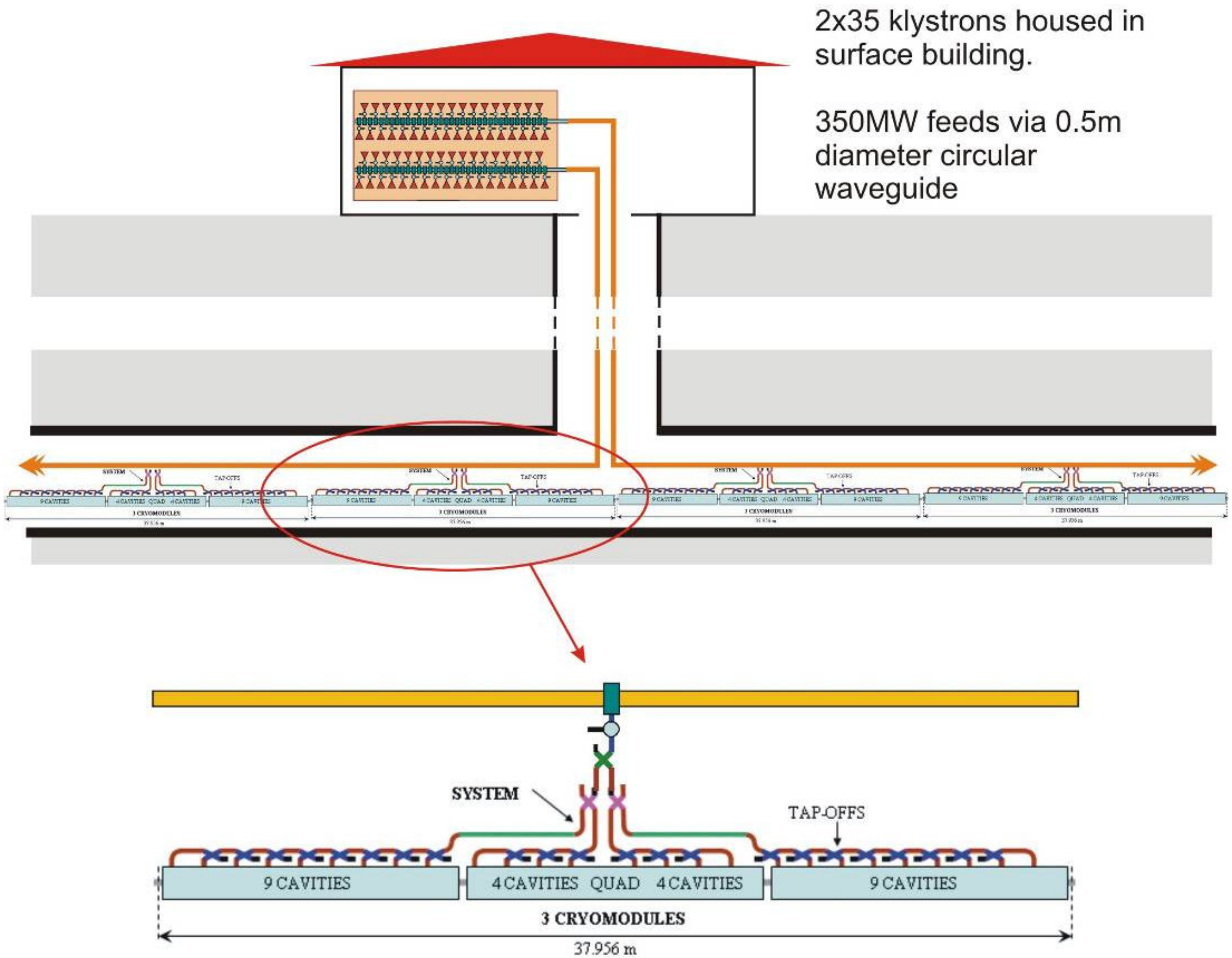
CF&S – Shallow site



Dubna CF


Вертикальная шахта
Коммуникационный тоннель
0.0
Communication tunnel
Vertical shaft
Коммуникационная
вертикальная шахта
vertical
communication
shaft
-20.0
-20,0
Основной технологи

CF&S

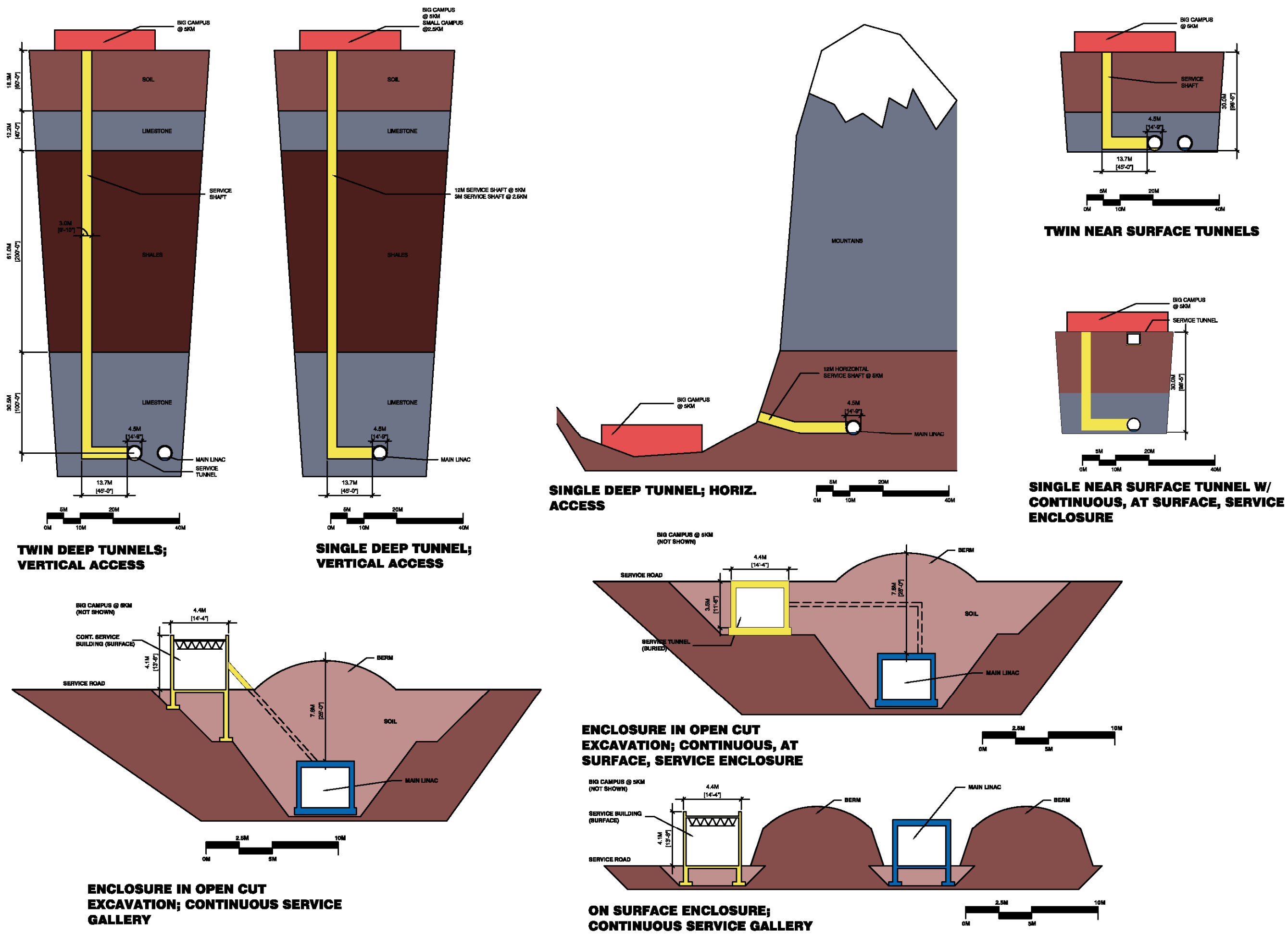


Each tap-off from the main waveguide feeds 10 MW through a high power window and probably a circulator or switch to a local PDS for a 3 cryomodule, 26 cavity RF unit (RDR baseline).

- Klystron cluster concept - keep access with 1 tunnel
- R&D needed to show power handling
  - **Planned (SLAC, KEK)**

CF&S

- Work proceeds on examples of all types of sites.

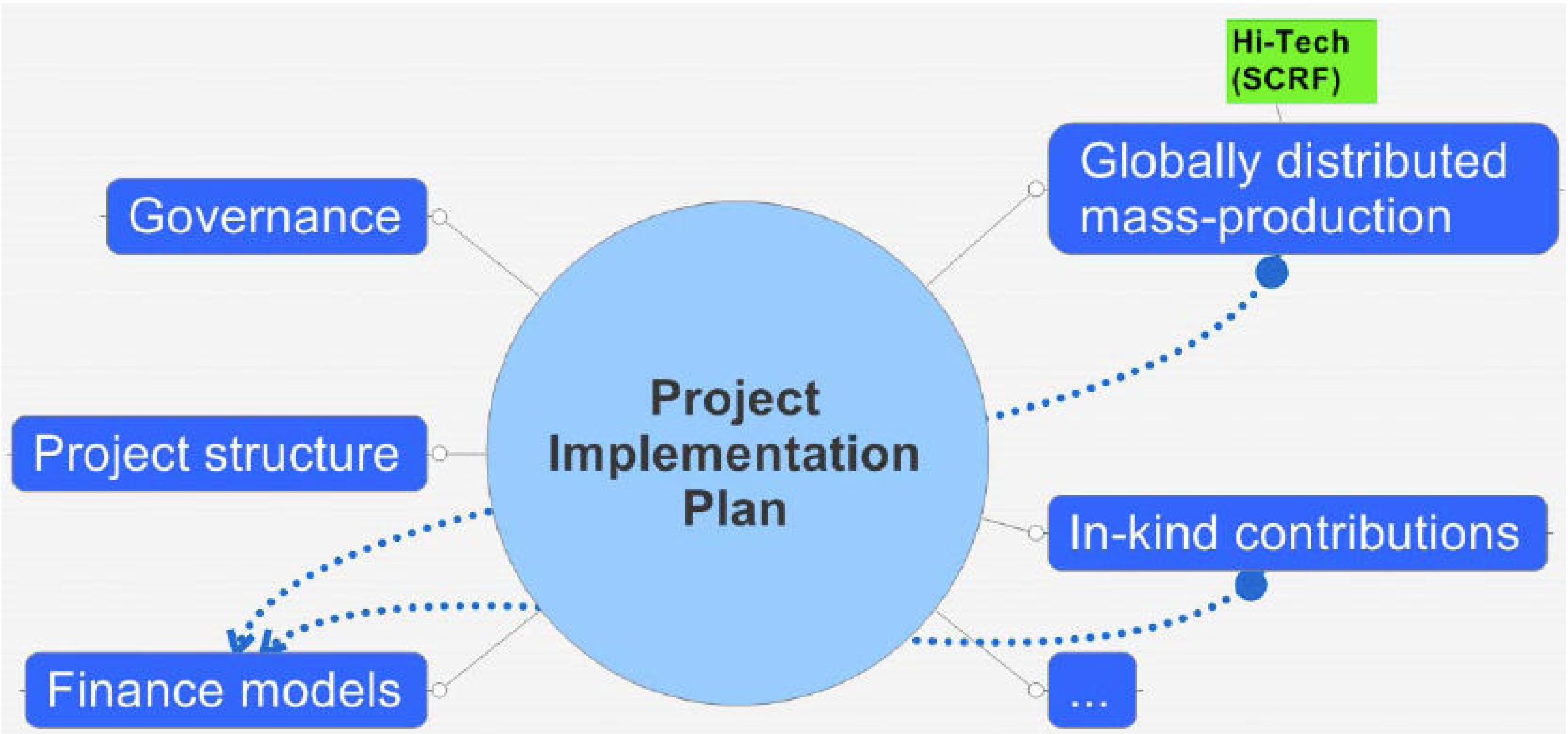


Resources available

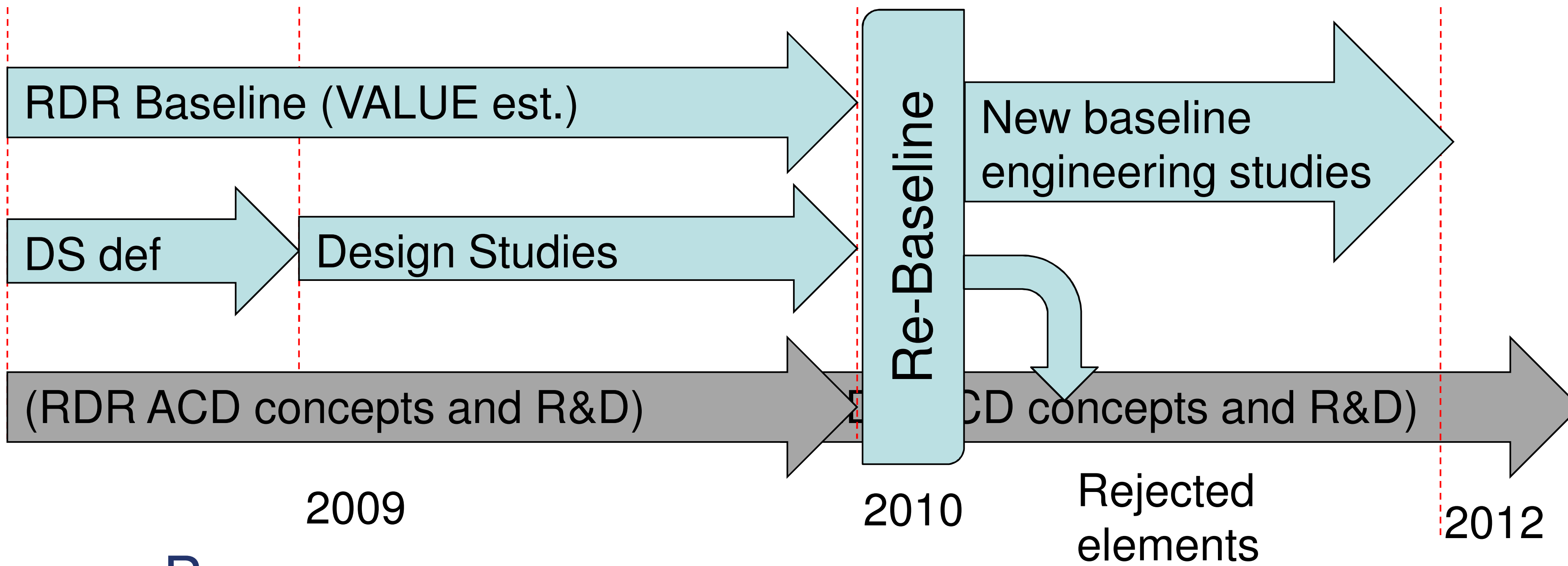
- (summarized in R & D Plan; published 2008.06)
- 2007-2010 → 4 years

Technical Area:	Effort (years * people)	Funds (M$)
Superconducting RF Tech	615	90
CFS / Global	112	4
Accelerator Systems	415	27
Total	1142	121

Project Implementation plan



Towards a Re-Baselining in 2010



- Process
  - **RDR baseline & VALUE element are maintained**
    - Formal baseline
  - **Formal review and re-baseline process beginning of 2010**
    - Exact process needs definition
    - Community sign-off mandatory

ILC-CLIC collaboration

- Co-conveners - CLIC-ILC working groups
  - **Civil Engineering and Conventional Facilities (CFS):** Claude Hauviller/CERN, John Osborne/CERN, Vic Kuchler (FNAL)
  - **Beam Delivery Systems and Machine Detector Interface:** D.Schulte/CERN, Brett Parker (BNL), Andrei Seryi (SLAC),, Emmanuel Tsesmelis/CERN
  - **Detectors:** L.Linssen/CERN, Francois Richard/LAL, Dieter.Schlatter/CERN, Sakue Yamada/KEK
  - **Cost & Schedule:** John Carwardine (ANL), Katy Foraz/CERN, Peter Garbincius (FNAL), Tetsuo Shidara (KEK), Sylvain Weisz/CERN
  - **Beam Dynamics:** A.Latina/FNAL), Kiyoshi Kubo (KEK), D.Schulte/CERN, Nick Walker (DESY)
- + two new groups in e^+ sources, damping rings.

Summary and Outlook

- The RDR describes a machine that could be built tomorrow – but it is expensive.
- Significant R&D is under way to produce savings while maintaining the physics specifications – much has already been achieved.
- Collaboration with CLIC is close and growing. We will build the best machine whenever - and wherever – political will and funding becomes available.
- It is our job to be ready, and to oil the wheels, whenever exciting results at LHC give us the lubrication.