ILC Accelerator Design: Status and Politics

Loopfest V

SLAC

June 19th, 2006

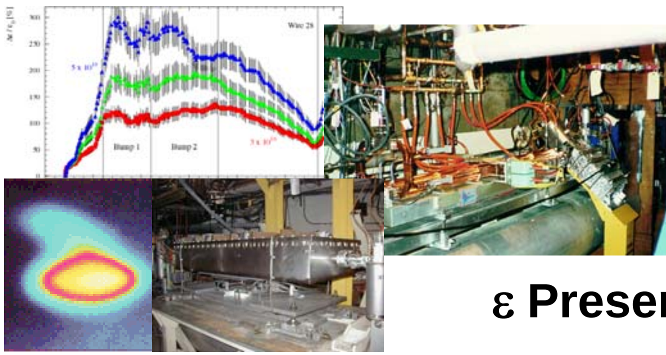
Tor Raubenheimer

The ILC Accelerator

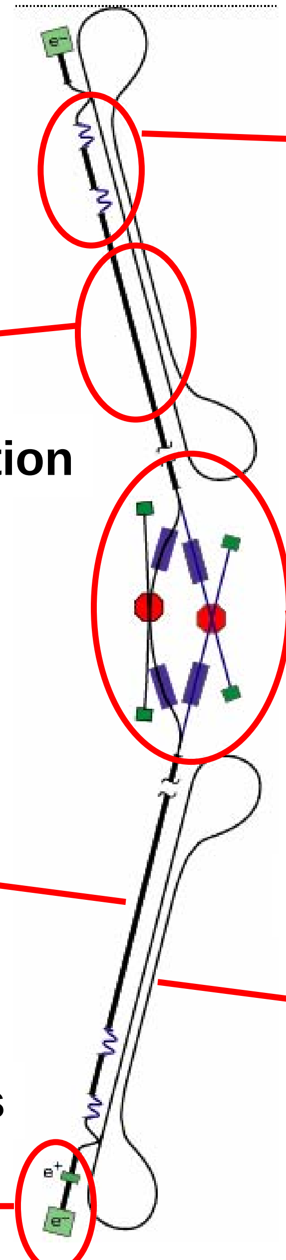
- 2nd generation electron-positron Linear Collider
- Parameter specification
  - E_{cms} adjustable from 200 – 500 GeV
  - Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
  - Ability to scan between 200 and 500 GeV
  - Energy stability and precision below 0.1%
  - Electron polarization of at least 80%
  - Options for electron-electron and $\gamma-\gamma$ collisions
  - The machine must be upgradeable to 1 TeV
- Three big challenges: energy, luminosity, and cost

Experimental Basis for the ILC Design

SLC, FFTB, ASSET, E-158



ε Preservation



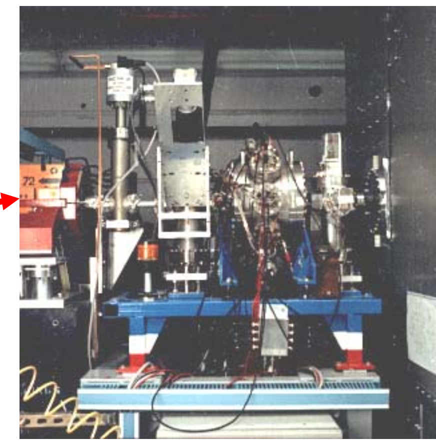
Bunch Compression

SLC and FEL's

SLC and FFTB

(ATF2 in the future)

BDS & IR



TESLA Test Facility

(SMTF & STF in the future)

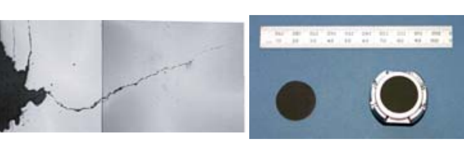
Linac rf system

ATF, 3rd Gen Light Sources, SLC

Damping Rings

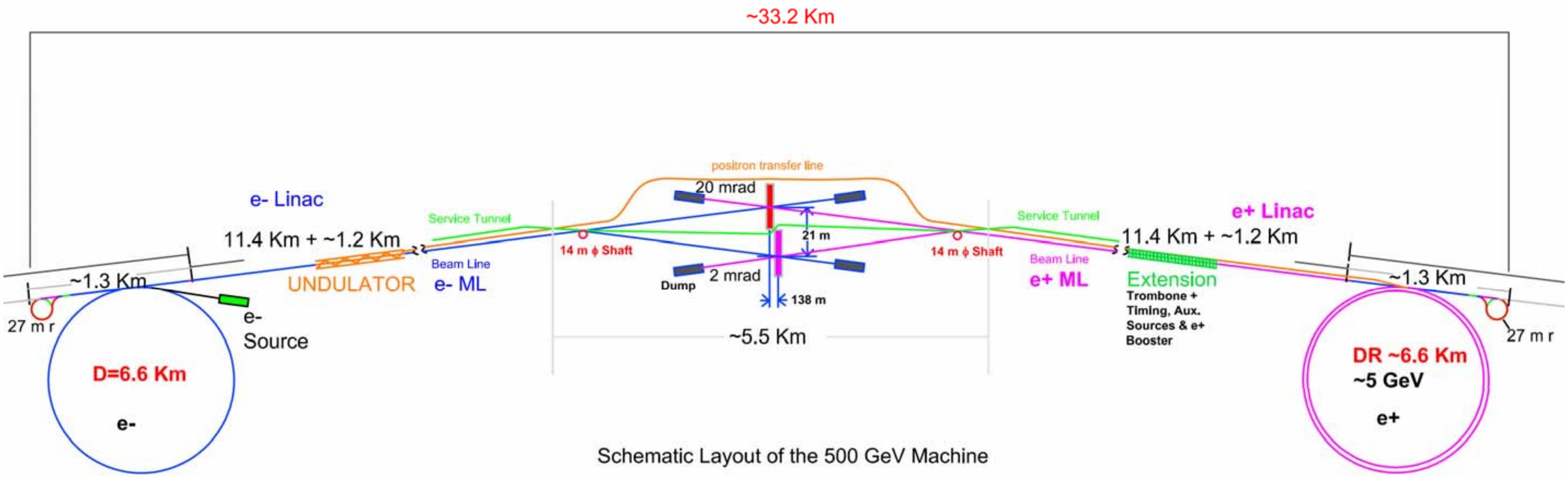
SLC, E-158

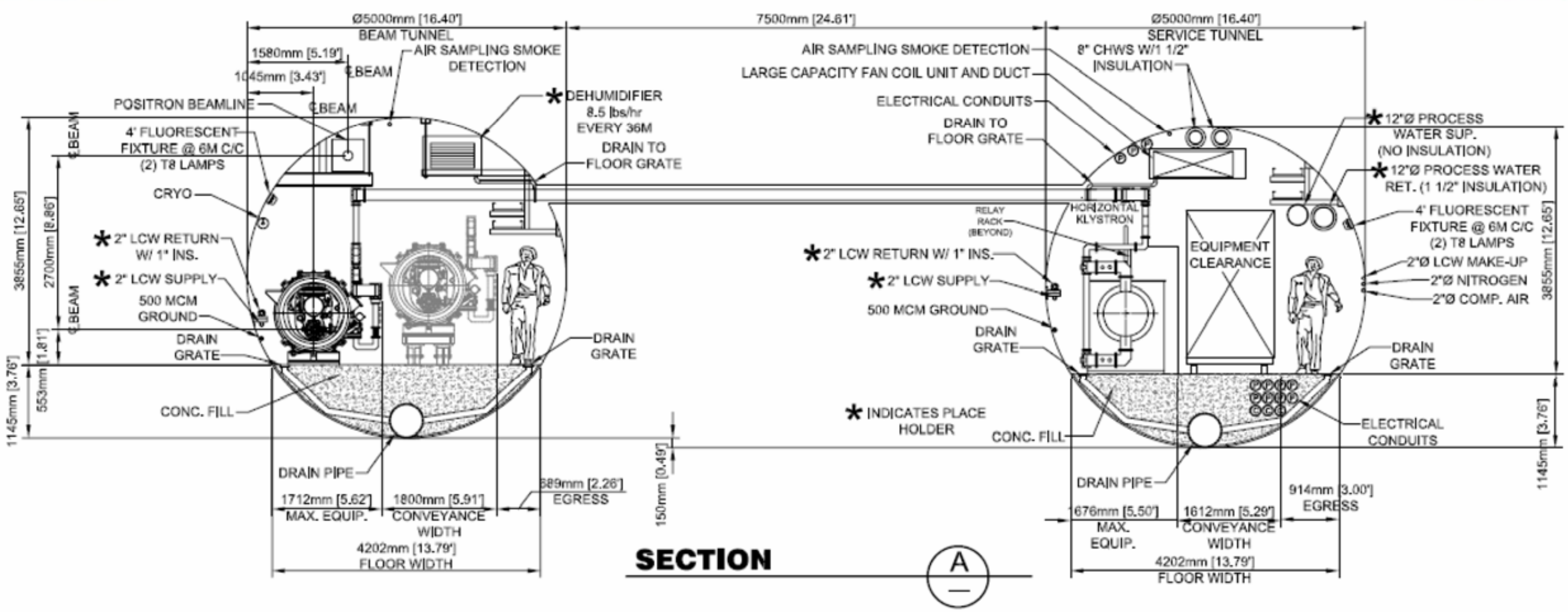
e+ / e- Sources



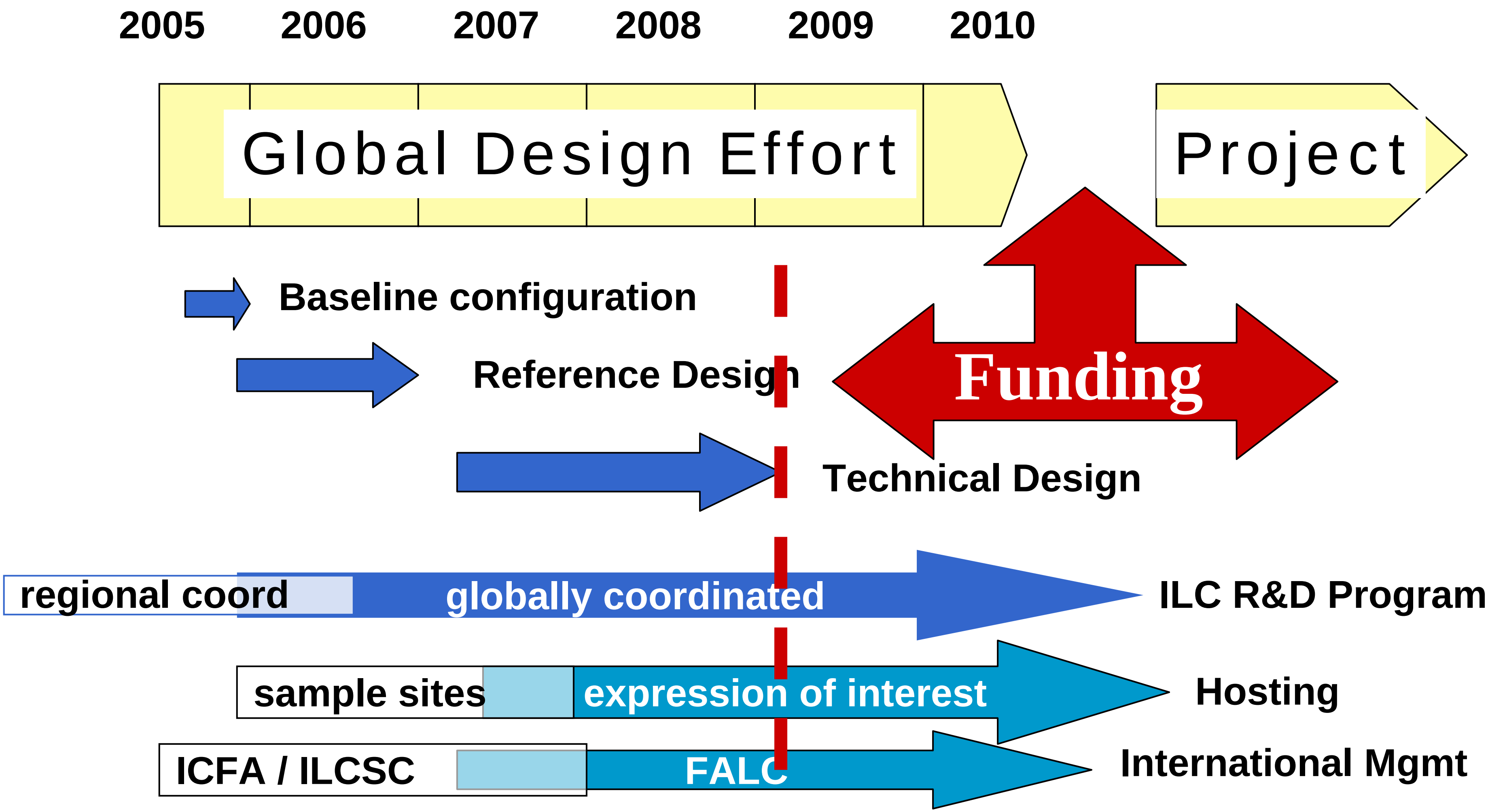
ILC Schematic and Tunnels

International Linear Collider – Americas

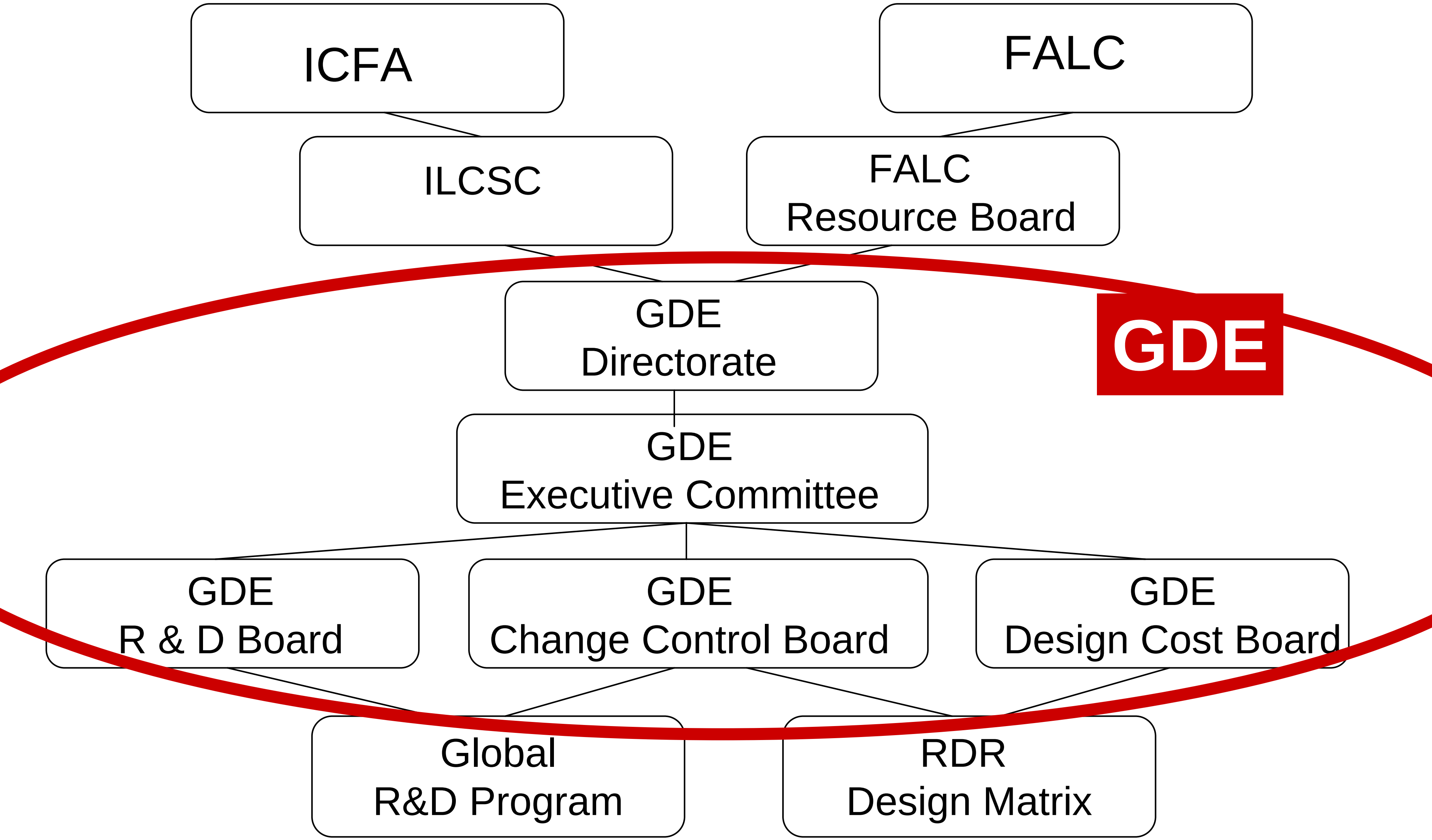




Global Design Effort Schedule



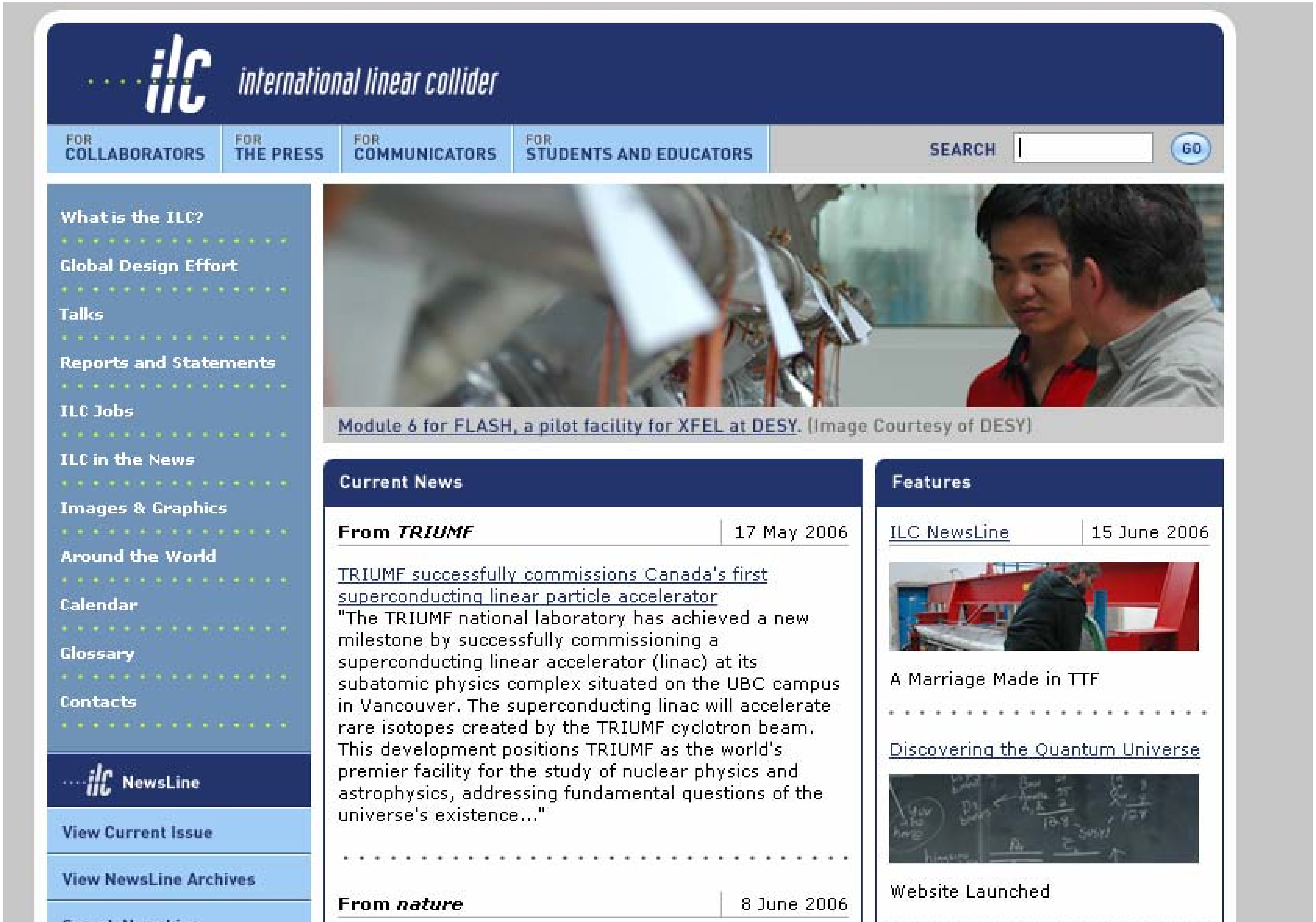
Global Design Effort



ILC International Linear Collider – Americas

Global Design Effort

http://www.linearcollider.org/



The GDE Boards

R&D Board
- Chris Damerell
- Eckhard Elsen
- Terry Garvey
- Hitoshi Hayano
- Toshiyasu Higo
- Tom Himel
- Lutz Lilje
- Hasan Padamsee
- Marc Ross
- <u>Bill Willis</u>
- Andy Wolski

Design Board
- W. Bialowons
- J.P. Delahaye
- A. Enomoto
- <u>P. Garbincius</u>
- R. Kephart
- A. Mueller
- J.M. Paterson
- N. Phinney
- T. Shidara
- N. Terunuma

Config Board
- C. Pagani
- G. Blair
- D. Schulte
- T. Markiewicz
- S. Mishra
- W. Funk
- K. Kubo
- M. Kuriki
- <u>N. Toge</u>

ILC GDE Program

- The present GDE ILC program has two portions:
  - Reference Design Report (RDR)
    - A conceptual design based on sample sites with a cost estimate
    - Accelerator physics and engineering efforts are being developed
  - R&D Program
    - Presently administered through the different regions
    - ILC Global Design Effort will coordinate effort more globally
- ILC design timeline
  - RDR at end of CY2006
  - TDR based on supporting R&D in ~2009
- ILC Americas
  - Effort spread between RDR and R&D programs
  - Coordinated by Gerry Dugan – MOUs between GDE and labs
    http://www.lns.cornell.edu/~dugan/LC/Labs/

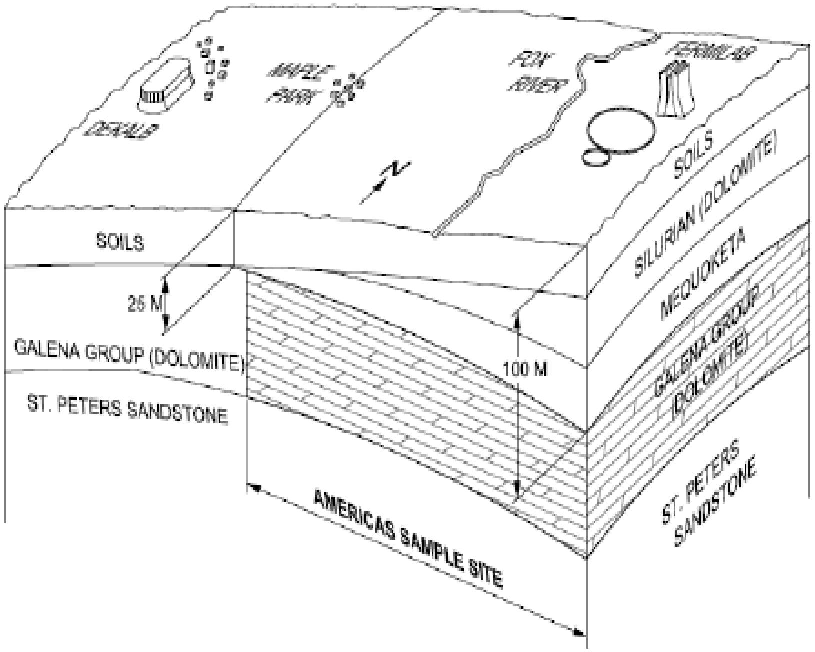
Reference Design Report

- What exactly is the RDR?
  - A 1st attempt at an international cost estimate for the ILC using 'reasonable' extrapolations from present technology
    - Baseline design mostly established at Snowmass, Aug. 2005
    - Not TESLA and not USTOS
  - Must document sufficiently to estimate cost
  - Cost estimate based on sample sites from different regions
  - Goal of completing the estimate in CY2006
    - Need to use existing information: TESLA TDR, USTOS, Japanese ITRP estimate
    - New information from US industrial estimates, DESY XFEL estimates, Japanese industrial estimates but most of these will be late → provide calibration but not a basis
    - Need to make laboratory estimates for cost drivers
- ***Highest priority for the GDE in 2006***

Sample Sites

- ***Sample sites located in US, Japan, Germany, and CERN.***
- ***Site located in northeast Illinois.***
- ***Tunnel placed in a north-south alignment, in the top half of the Galina/Platteville dolomite, limestone stratum. This rock stratum is structurally stable and relatively dry.***
- ***Potential sites under consideration range from being centered on Fermilab to a site 30 KM to the west of Fermilab.***

Americas Sample Plan / Section



RDR Working Groups

- Established working groups to complete RDR effort
  - Organized by Area around regional sections of LC
    - Sources; damping rings; main linac; beam delivery; …
  - Technical design provide by technical groups that reach across Areas
    - Coordinates technical resources but makes communication harder
    - Uniform technical standards applied across collider
    - Similar to style used for NLC Lehman design and TESLA TDR
  - Some groups provide technical support for Areas but also have system-wide responsibility → Global groups
    - Conventional Facilities and Siting (CF&S)
    - Control systems; Operations; Installation; …
  - Costs get rolled up to the Area groups so that they can study cost versus performance trades
  - Costs get output to Cost Engineers so they can study cost basis across systems

RDR Matrix (Organization to complete Design)

- Matrix of Area Systems and Technical Systems to develop cost estimate
  - International representation in all working groups

	Area Systems					
	e- source	e+ source	Damping Rings	RTML	Main Linac	BDS
		Kiriki	Gao	ES Kim	Hayano	Yamamoto
			Guiducci		Lilje	Angal-Kalinin
	Brachmann	Sheppard	Wolski	Tenenbaum	Adolphsen	Seryi
	Logachev		Zisman		Solyak	
Technical Systems						
Vacuum systems	Suetsugu	Michelato	Noonan			
Magnet systems	Sugahara		Thomkins			
Cryomodule	Ohuchi	Pagani	Carter			
Cavity Package	Saito	Proch	Mammosser			
RF Power	Fukuda		Larsen			
Instrumentation	Urakawa	Burrows	Ross			
Dumps and Collimators	Ban		Markiewicz			
Accelerator Physics	Kubo	Schulte				
Global Systems						
Commissioning, Operations & Reliability	Teranuma	Elsen	Himel			
Control System	Michizono	Simrock	Carwardine			
Cryogenics	Hosoyama	Tavian	Peterson			
CF&S	Enomoto	Baldy	Kuchler			
Installation	Shidara	Bialwons	Asiri			

RDR Management group:
Nick Walker, Tor Raubenheimer, Kaoru Yokoya, Ewan Paterson, Wilhelm Bialowons, Peter Garbincius, Tetsuo Shidara

RDR Costing

- Use the spirit of ITER "Value" methodology
  - Doesn't include labor costs, but estimates of institutional labor effort in person-hours
  - Doesn't include contingency – need to subtract this cleanly from regional estimates
  - Will need a risk assessment for costs
  - Costs for raw materials will be standardized across project
- Use TESLA TDR, DESY XFEL, and USTOS costing
  - Get additional industrial estimates to support laboratory #s
- Insufficient time to develop a loaded schedule
  - Assume a 7 year construction period
    - Construction starts with the 1st contracts and finishing with the installation of the final components

RDR Schedule

- RDR Matrix – established @ Frascati (12/05)
  - Area Systems meeting @ KEK (1/06)
  - Area & Technical Systems meeting @ FNAL (2/06)
- GDE Meeting @ Bangalore (3/06)
  - Weekly review of different Area Systems
  - Linac Systems meeting @ DESY (5/06)
  - Weekly review of different Technical Systems
  - First pass at cost estimates to AS and DCB by June 25th
- GDE Meeting @ Vancouver (7/06)
  - Iterate on main cost drivers and estimates
  - Complete written drafts of RDR
  - Probable RDR meetings in early fall
- GDE Meeting @ Valencia (11/06)
  - First draft of RDR and cost estimate → complete in early 2007

Parameter Plane

- Parameter plane established
  - – TESLA designed for 3.4e34 but had a very narrow operating range
    - Designed for single operating point
  - – ILC luminosity of 2e34 over a wide range of operating parameters
    - Bunch length between 500 and 150 um
    - Bunch charge between 2e10 and 1e10
    - Number of bunches between ~1000 and ~6000
      - – Significant flexibility in damping ring fill patterns
      - – Vary rf pulse length
      - – Change linac currents
    - Beam power between ~5 and 11 MW
  - – Thought to have small cost impact – to be checked

Parameters

Parameter range established to allow operating optimization

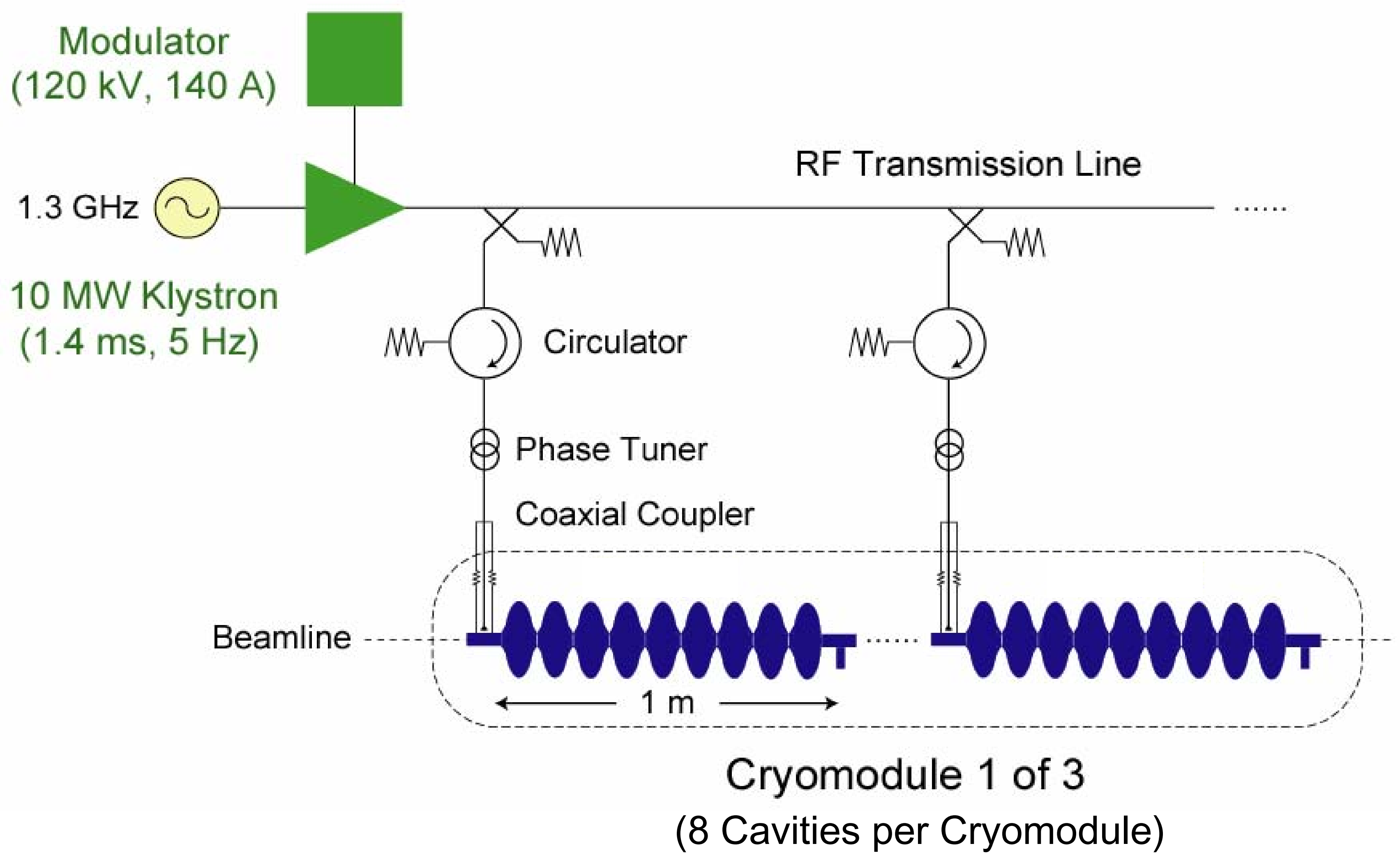
		nom	low N	lrg Y	low P	High L
N	$\times 10^{10}$	2	1	2	2	2
n_b		2820	5640	2820	1330	2820
$\varepsilon_{x,y}$	μm, nm	9.6, 40	10, 30	12, 80	10,35	10,30
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2	1, 0.2
$\sigma_{x,y}$	nm	543, 5.7	495, 3.5	495, 8	452, 3.8	452, 3.5
D_y		18.5	10	28.6	27	22
δ_{BS}	%	2.2	1.8	2.4	5.7	7
σ_z	μm	300	150	500	200	150
P_{beam}	MW	11	11	11	5.3	11

Energy Upgrade Path

- Linac energy upgrade path based on empty tunnels hard to ‘sell’
  - Empty tunnels obvious cost reduction
- Lower initial gradient increases capital costs

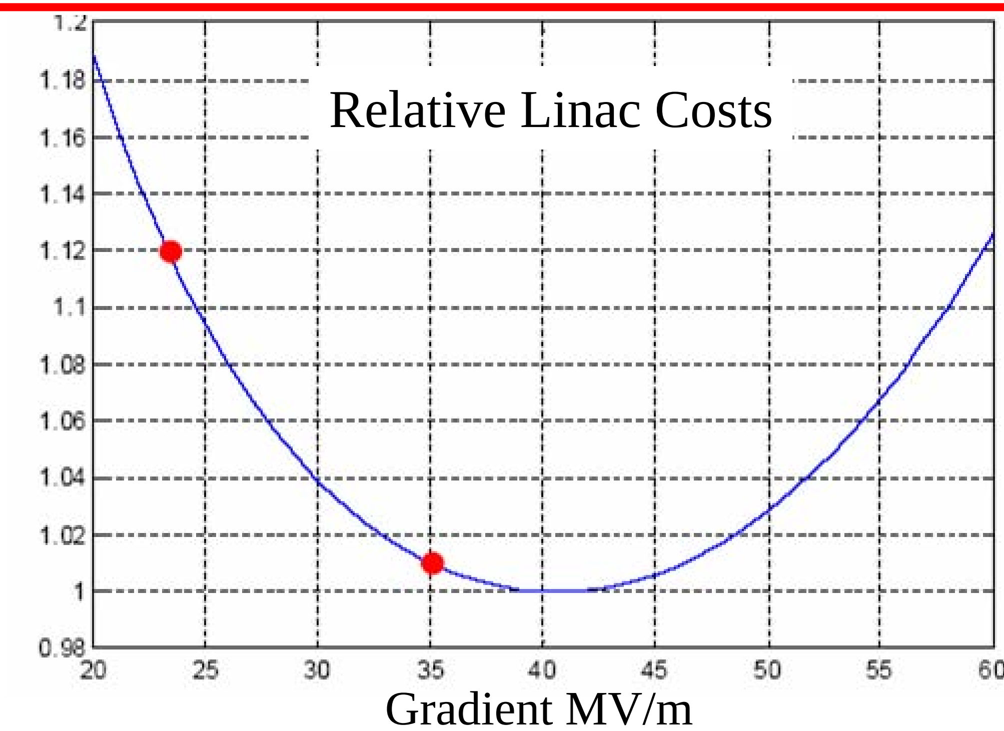
- Baseline has tunnels for 500 GeV cms with a linac gradient of 31.5 MV/m
- Geometry of beam delivery system adequate for 1 TeV cms
  - Require extending linac tunnels past damping rings, adding transport lines, and moving turn-around → ~50 km site

RF System


Modulator
(120 kV, 140 A)
RF Transmission Line
1.3 GHz
10 MW Klystron
(1.4 ms, 5 Hz)
Circulator
Phase Tuner
Coaxial Coupler
Beamline
1 m
Cryomodule 1 of 3
(8 Cavities per Cryomodule)

Gradient Choice

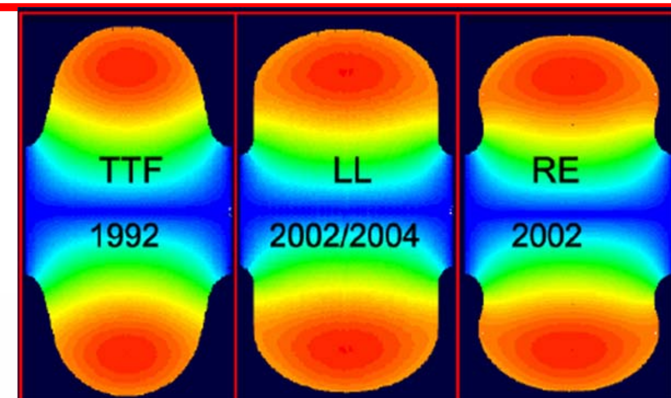
- Balance between cost per unit length of linac, the available technology, and the cryogenic costs
- Optimum is fairly flat and depends on details of technology

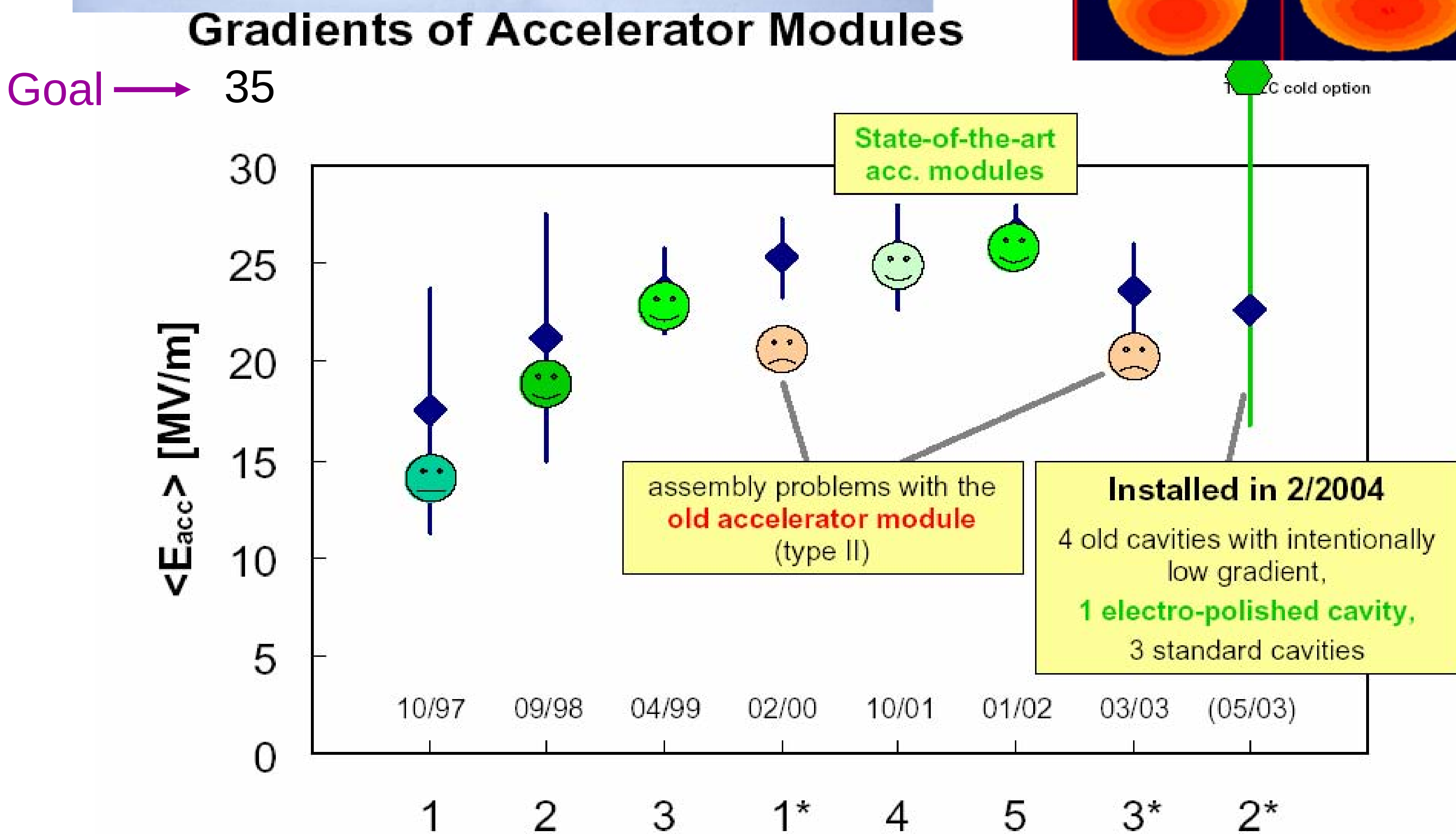


	Cavity type	Qualified gradient MV/m	Operational gradient MV/m	Length Km	Energy GeV
initial	TESLA	35	31.5	10.6	250
upgrade	LL	40	36.0	+9.3	500

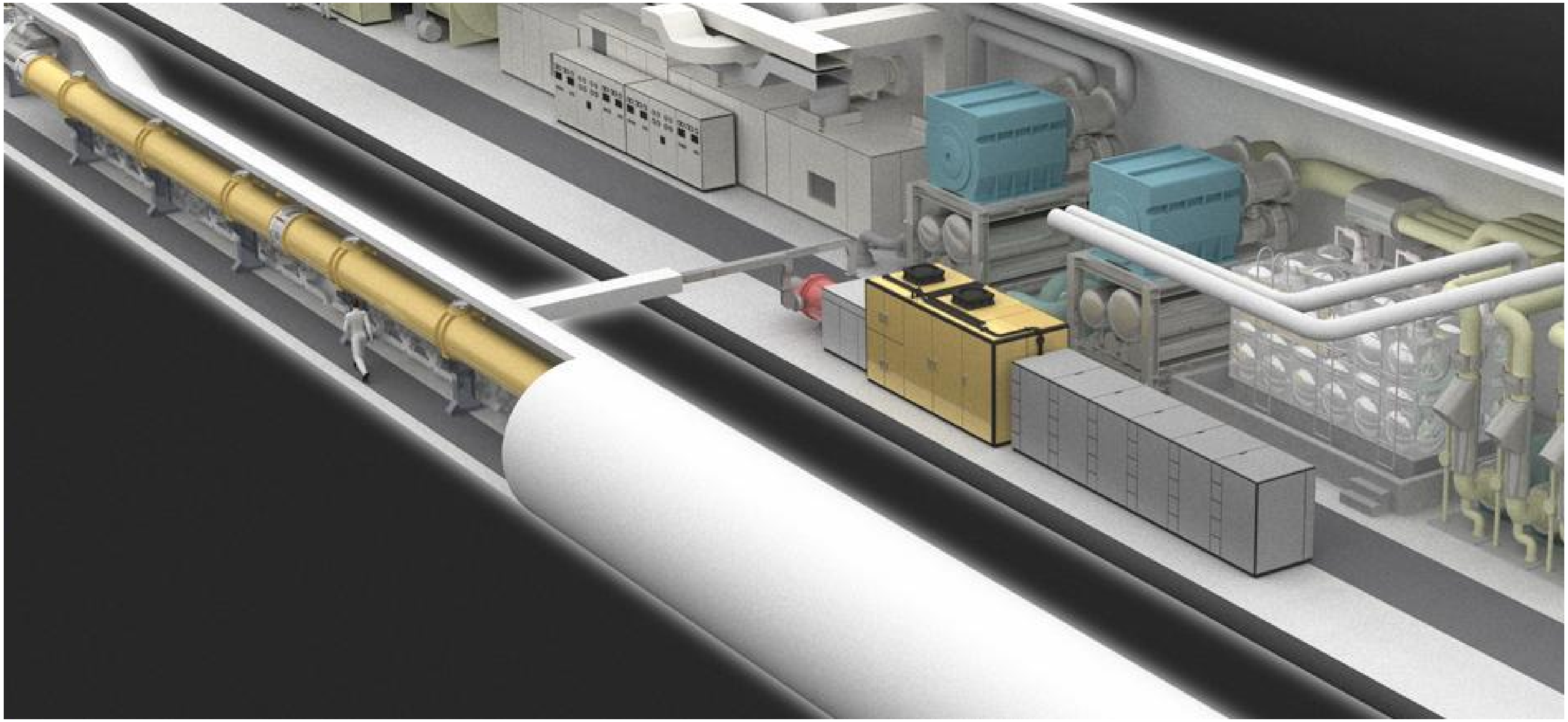
International Linear Collider – Americas

Superconducting Cavities





Main Linac Layout

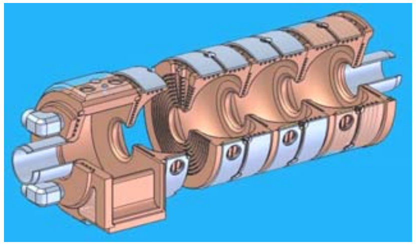


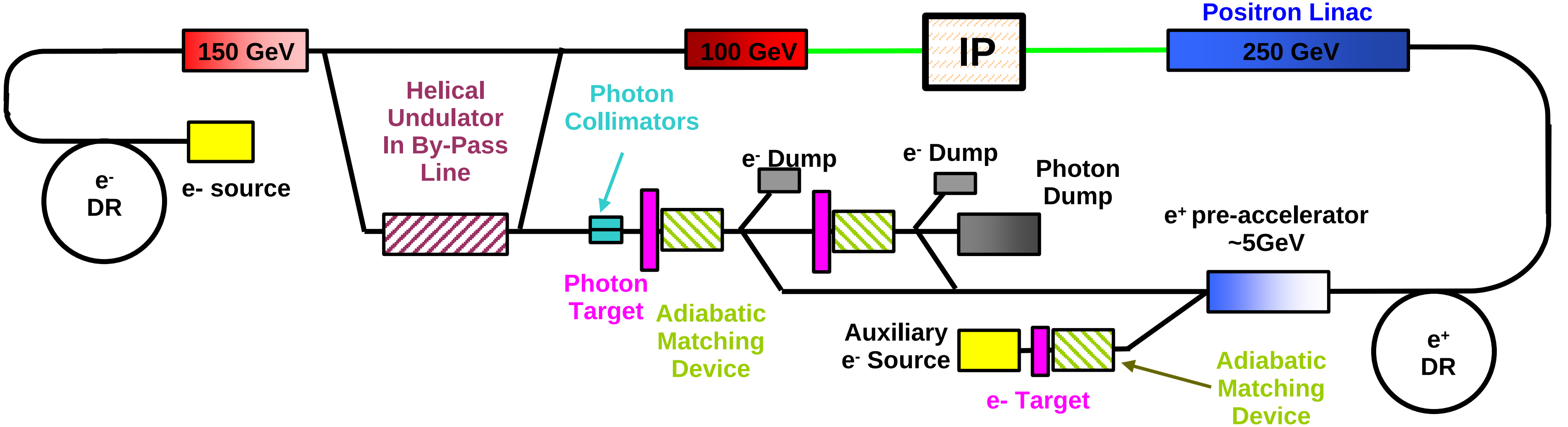
Positron Source Choice

- Snowmass debate between conventional, undulator, and Compton sources
  - Snowmass recommendation of undulator source with Compton source as ACD
- Conventional source
  - Reduces operational coupling
- Undulator-based positron source
  - Much lower radiation environment
  - Smaller e+ emittance for given yield
  - Similar target and capture system to conventional
  - Easy path to polarized positrons Photon production at 150 GeV electron energy
- Compton source
  - Requires large laser system and/or capture ring

Positron Source

- Positron source
  - SLAC is coordinating the positron source development
  - Undulator-based positron source is a large system
  - Focused on systems design and capture structure R&D
    - Working with LLNL on target design
    - Working with ANL on AMD and capture simulations
    - Working with UK and ANL/LBNL on undulator design





Damping Ring Requirements

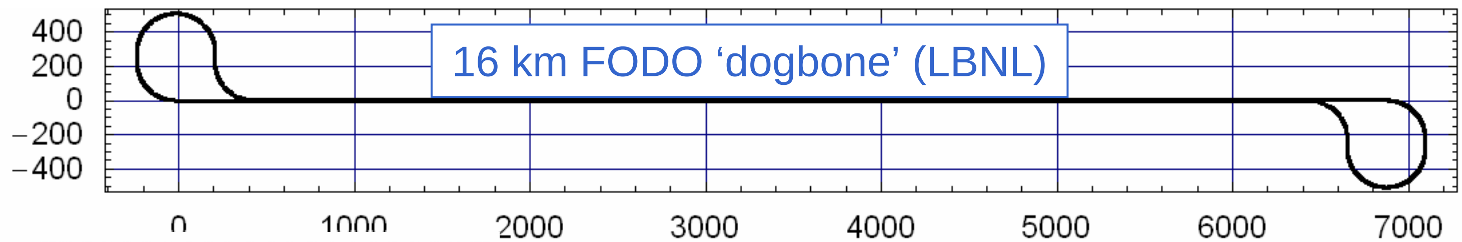
- Compress 1 ms linac bunch train in to a “reasonable size” ring
  - Fast kicker (ns)
- Damping of $\gamma\varepsilon_{x,y}= 10^{-2}$ m-rad positron beams to $(\gamma\varepsilon_x, \gamma\varepsilon_y)=(8 \times 10^{-6}, 2 \times 10^{-8})$ m-rad
  - Low emittance, diagnostics
- Cycle time 0.2 sec (5 Hz rep rate)→ τ = 25 ms
  - Damping wiggler
- 2820 bunches, 2×10^{10} electrons or positrons per bunch, bunch length= 6 mm
  - Instabilities (classical, electron cloud, fast ion)
- Beam power > 220 kW
  - Injection efficiency, dynamic aperture

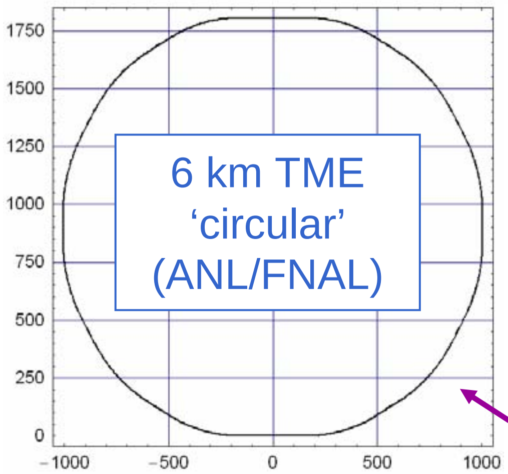
Damping Ring Issues

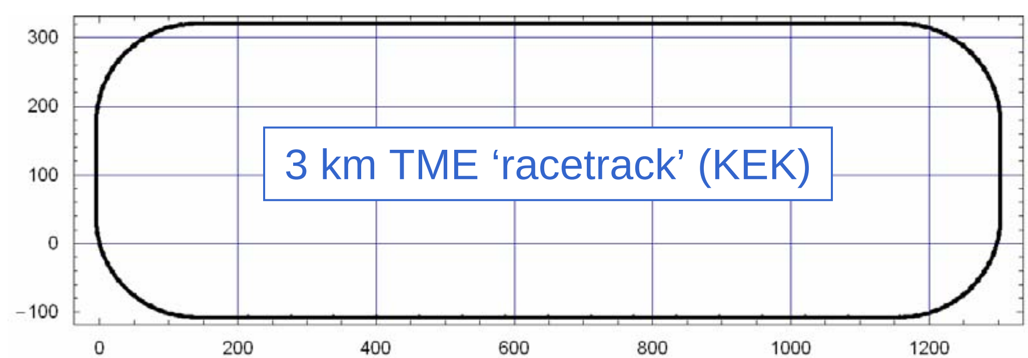
- Damping rings have most accelerator physics in ILC
- Required to:
  1. Damp beam emittances and incoming transients
  2. Provide a stable platform for downstream systems
  3. Have excellent availability ~99% (best of 3rd generation SRS)
- Mixed experience with SLC damping rings:
  – Referred to as the “The source of all Evil”
  – Collective instabilities, dynamic aperture and stability were all hard
- ILC damping rings have lower current than B-factories
  – More difficult systems feedback because of very small extracted beam sizes in constant re-injection (operate with small S/N)
  – More sensitive to instabilities – effects amplified downstream

Damping Rings – BCD Choice

- Compared multiple lattice styles
  - Optics tuning and dynamic aperture
  - Collective instabilities (ECI, Ions, Space charge)
  - Cost

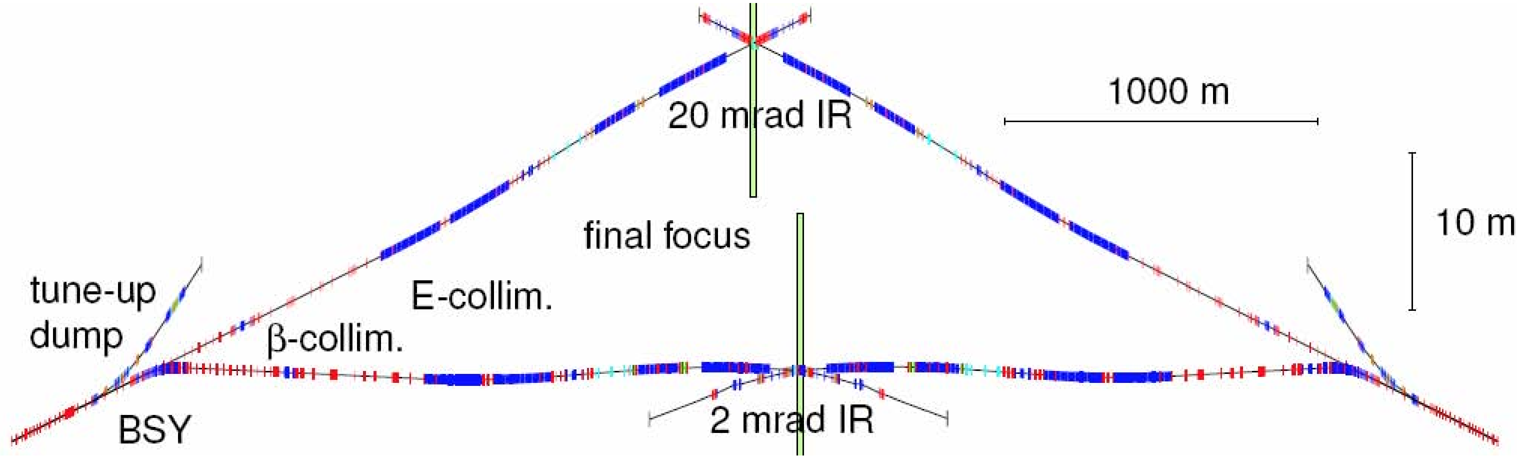






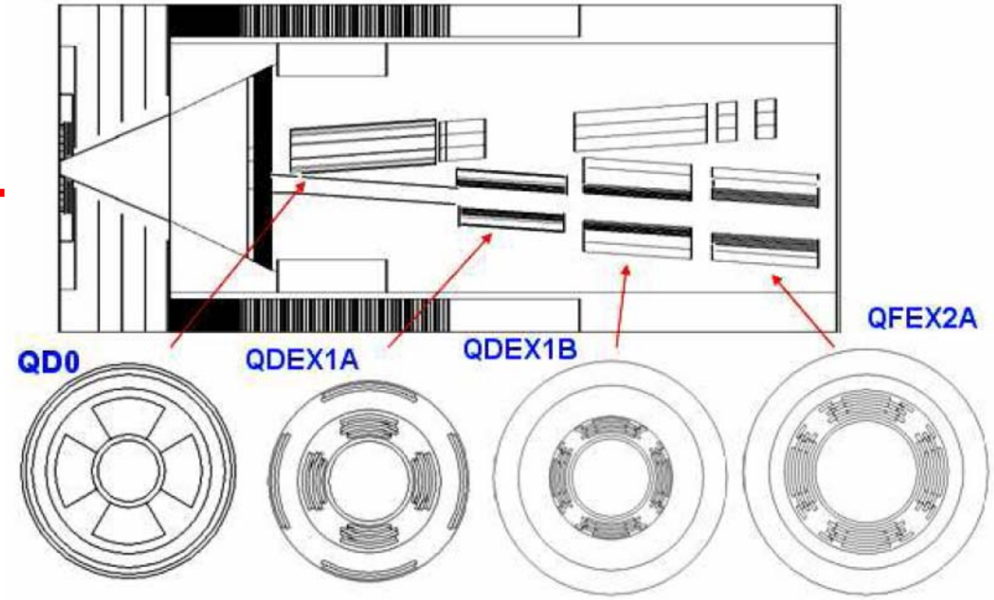
Baseline

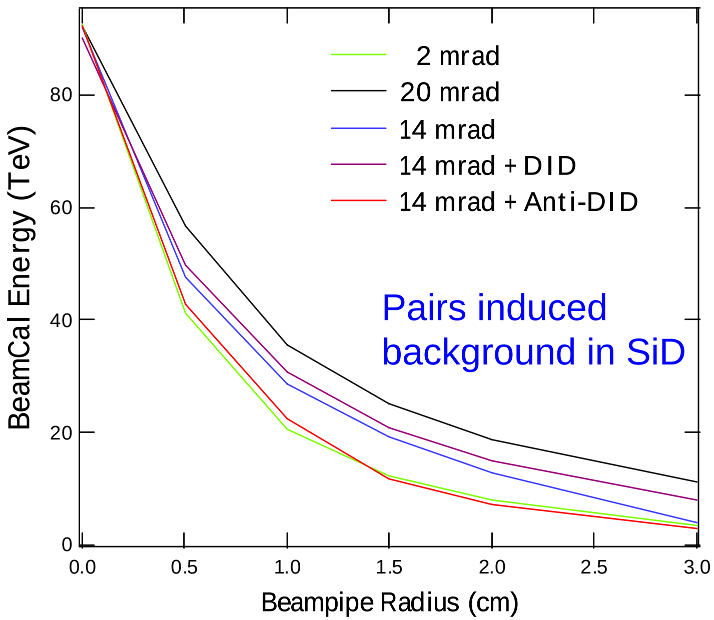
Beam Delivery System

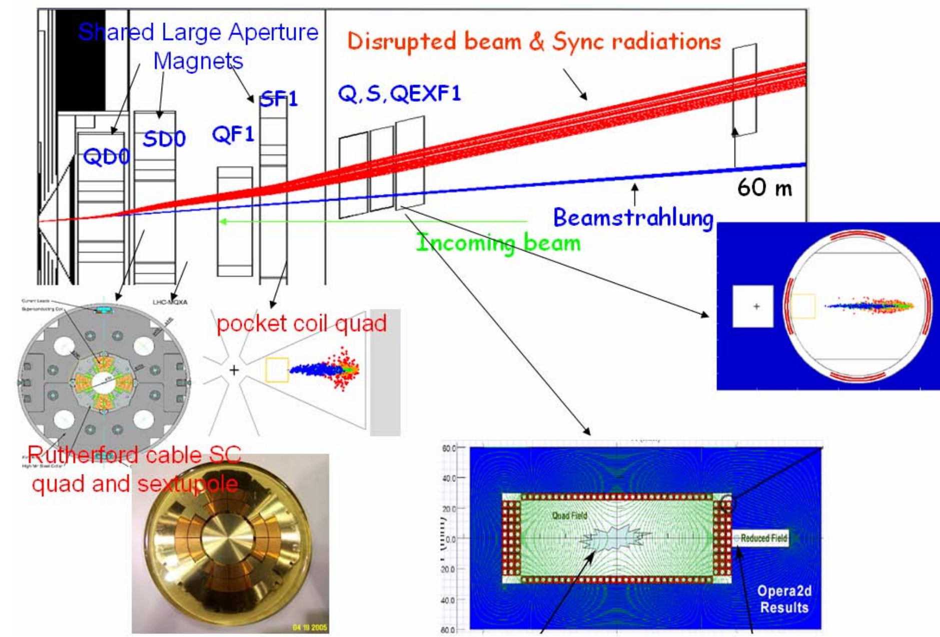


- Baseline
  - Two BDSs, 20/2mrad, 2 detectors, 2 longitudinally separated IR halls
- Alternative 1
  - Two BDSs, 20/2mrad, 2 detectors in single IR hall @ Z=0
- Alternative 2
  - Single IR/BDS, collider hall long enough for two push-pull detectors

- Design of IR for both small and large crossing angles
- Pairs induced background similar in both cases
- Losses in extraction & background harder in 2mrad



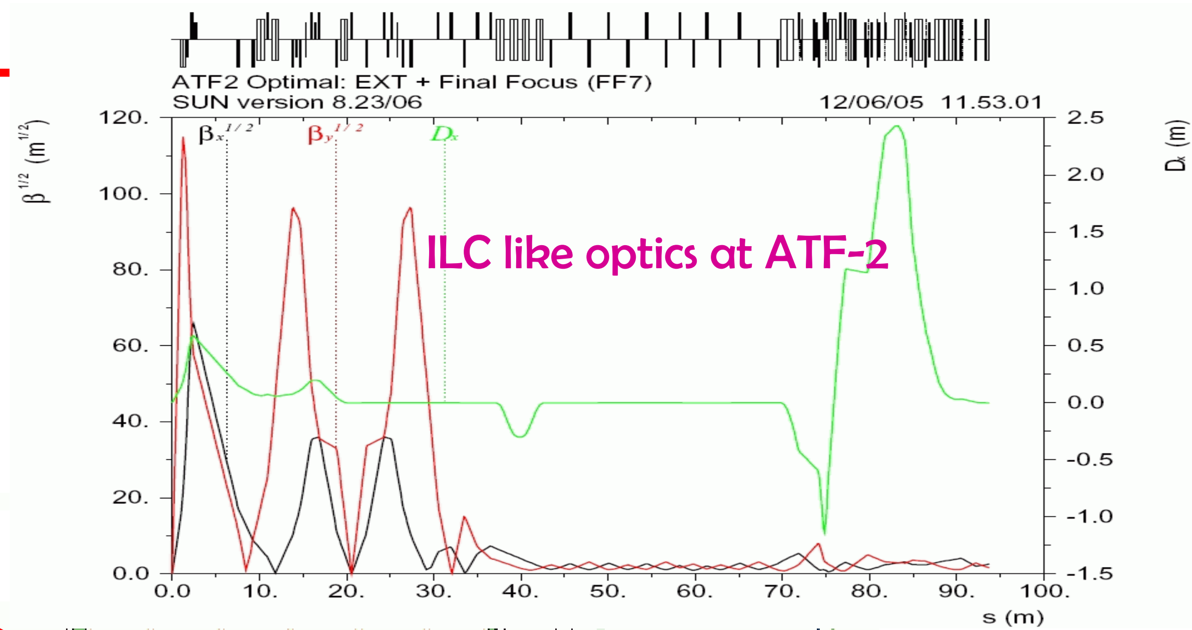


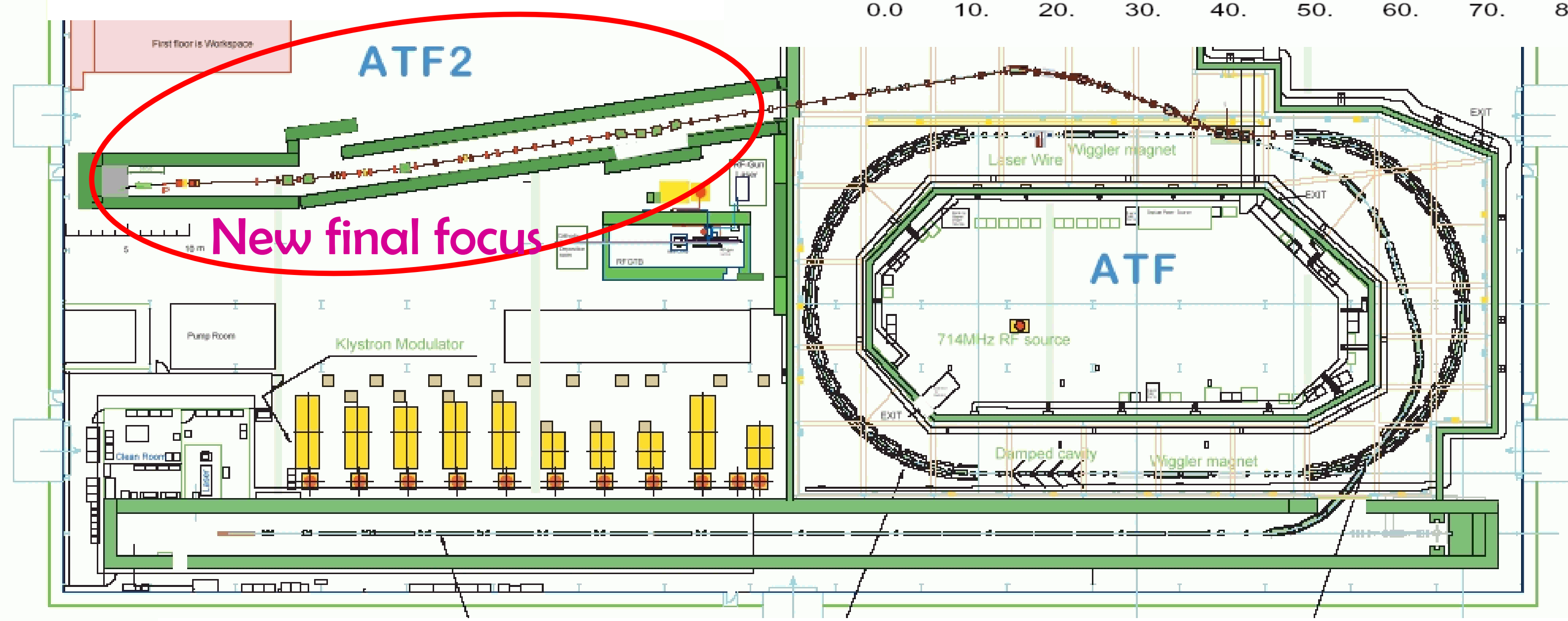


ILC International Linear Collider – Americas

ATF-2 at KEK

- ATF-2 would be the BDS test facility
  - Follow-on to FFTB
  - New FFS optics
  - Operational issues
  - Train next generation





http://lcdev.kek.jp/ILC-AsiaWG/WG4notes/atf2/proposal/public/atf2-web.pdf

ILC Technology Status

- Very High R&D priorities (categorized by Global Board):
  - Superconducting cavities and gradient
    - Gradient of 25 versus 35 MV/m
    - Cavity tuners
  - Rf sources
    - Klystrons do not meet spec
    - New modulator designs, eg Marx Generator
  - High availability hardware
    - Power supplies and magnets
  - Positron target
  - Instrumentation (BPMs, laser wires, and energy spectrometers)
  - Damping ring (collective effects, kickers and emittance)
  - Beam delivery system (crab cavity, feedback and tuning)

http://www.linearcollider.org/wiki/doku.php?id=rdb:rdb_external:rdb_external_home

Availability and Operations

- The ILC will be an order of magnitude more complex than any accelerator ever built
  - If it is built like present HEP accelerators, it will be down an order of magnitude more (essentially always down)
  - For reasonable uptime, component availability must be much better than ever before → requires serious R&D

Device	Required MTBF Improvement Factor	MTBF from Present Experience (khours)
magnets - water cooled	20	1,000
power supply controllers	**50**	100
flow switches	10	250
water instrumention near pump	10	30
power supplies	5	200
kicker pulser	5	100
coupler interlock sensors	5	1,000
collimators and beam stoppers	5	100
all electronics modules	**10**	100
AC breakers < 500 kW	**10**	360
vacuum valve controllers	**5**	190
regional MPS system	**5**	5
power supply - corrector	**3**	400
vacuum valves	**3**	1,000
water pumps	**3**	120
modulator		50
klystron - linac		40
coupler interlock electronics		1,000

Summary

- ILC baseline configuration is well thought out
  - Based on decades of R&D
  - Technology reasonable extrapolation of the R&D status
  - Inclusion of availability and operational considerations
  - Conservative choices (for the most part) to facilitate rapid cost evaluation
- International team will complete RDR by end of CY2006
  - Unknown review process afterwards
- Active R&D program to address technical and cost risks
  - Global R&D Board is working to coordinate the program