Accelerator Design and R&D for the International Linear Collider

Nan Phinney
SLAC
2006 April APS Meeting, Dallas TX
April 22, 2006

Outline

1) Global Design Effort

2) Accelerator Configuration

3) Status of the Design and R&D

The 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, and a 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 Structure and Organization

Executive Committee for Baseline Configuration

GDE Director

- Barish

Regional Directors

- Dugan – Americas
- Foster – Europe
- Takasaki – Asia

Accelerator Leaders

- Yokoya - Asia
- Raubenheimer - Americas
- Walker - Europe

GDE Executive Committee

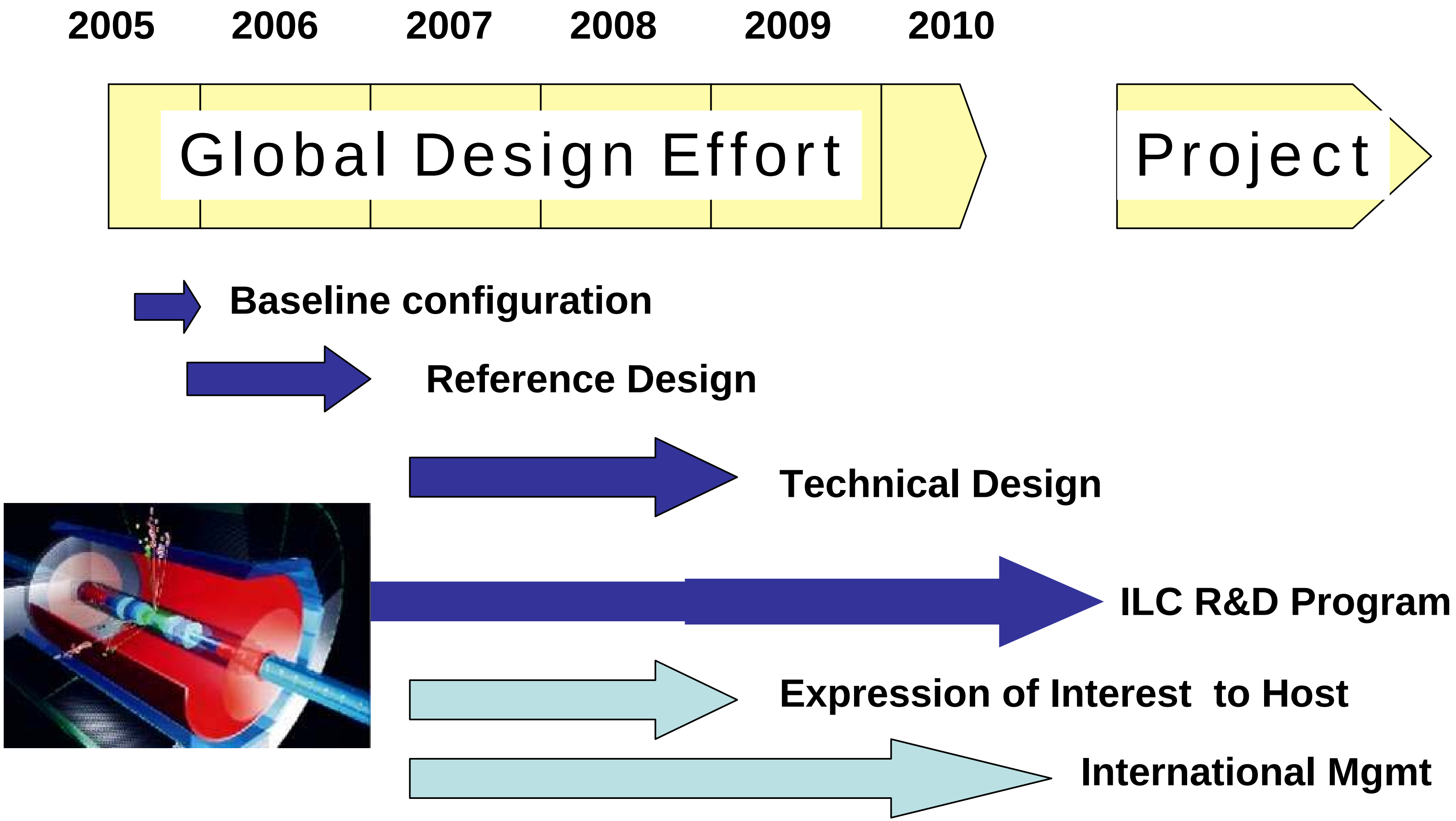
Responsible for top-level decisions for the Baseline Configuration Document (BCD) and Reference Design Report (RDR)

GDE Organization (2)

GDE Groups

- Cost Engineers
  - Shidara – Asia
  - Bialowons – Europe
  - Garbincius – Americas
- Conventional Facilities and Siting
  - Baldy - Europe
  - Enomoto – Asia
  - Kuchler – Amercas
- Physics / Detectors (WWS chairs)
  - Brau - Americas
  - Richard - Europe
  - Yamamoto - Asia
- Accelerator Experts (~66 GDE members)

ILC Timeline



2005 2006 2007 2008 2009 2010

Global Design Effort

Project

Baseline configuration

Reference Design

Technical Design

ILC R&D Program

Expression of Interest to Host

International Mgmt

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

The ILC Accelerator

2nd generation electron-positron Linear Collider

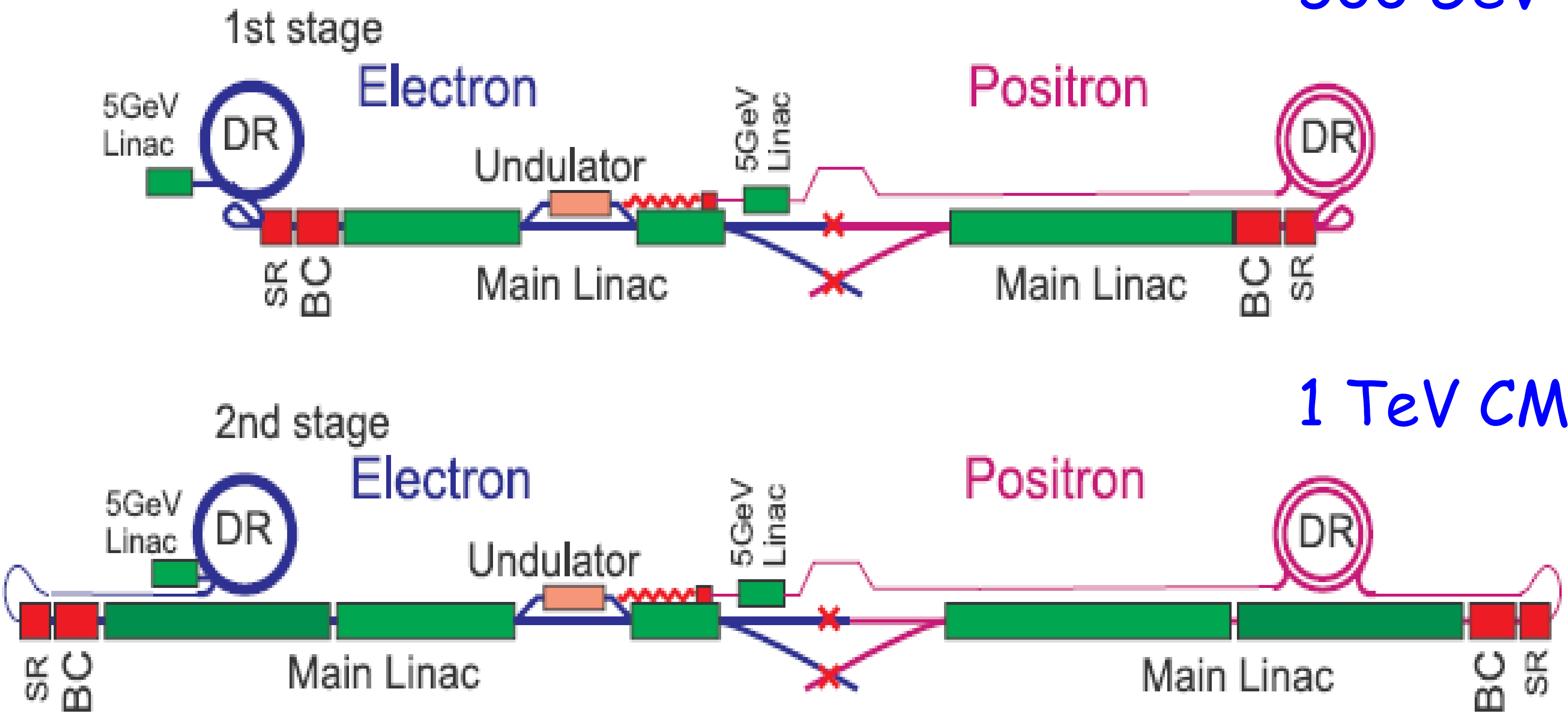
Parameter specification

- 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 γ–γ collisions
- The machine must be upgradeable to 1 TeV

Three big challenges: energy, luminosity, and cost

Baseline Configuration - Schematic

500 GeV CM



1 TeV CM

Scope of the 500 GeV machine

Main linacs length ~ 21 km, 16,000 RF cavities (total)

RF power ~ 640 10-MW klystrons and modulators (total)

Cryoplants ~ 11 plants, cooling power 24 kW (@4K) each

Beam delivery length ~ 5 km, ~ 500 magnets (per IR)

Damping ring circumference ~ 6.6 km, ~400 magnets each

Beam power ~ 22 MW total

Site power ~ 200 MW total

Site footprint length ~ 47 km (for future upgrade > 1 TeV)

Bunch profile at IP ~ 500 x 6 nm, 300 microns long

Accelerator physics & engineering challenges

Developing efficient high gradient superconducting RF sys

Requires efficient RF systems, capable of accelerating high power beams (~MW)

(Topic for next talk)

Achieving nm scale high-power beam spots

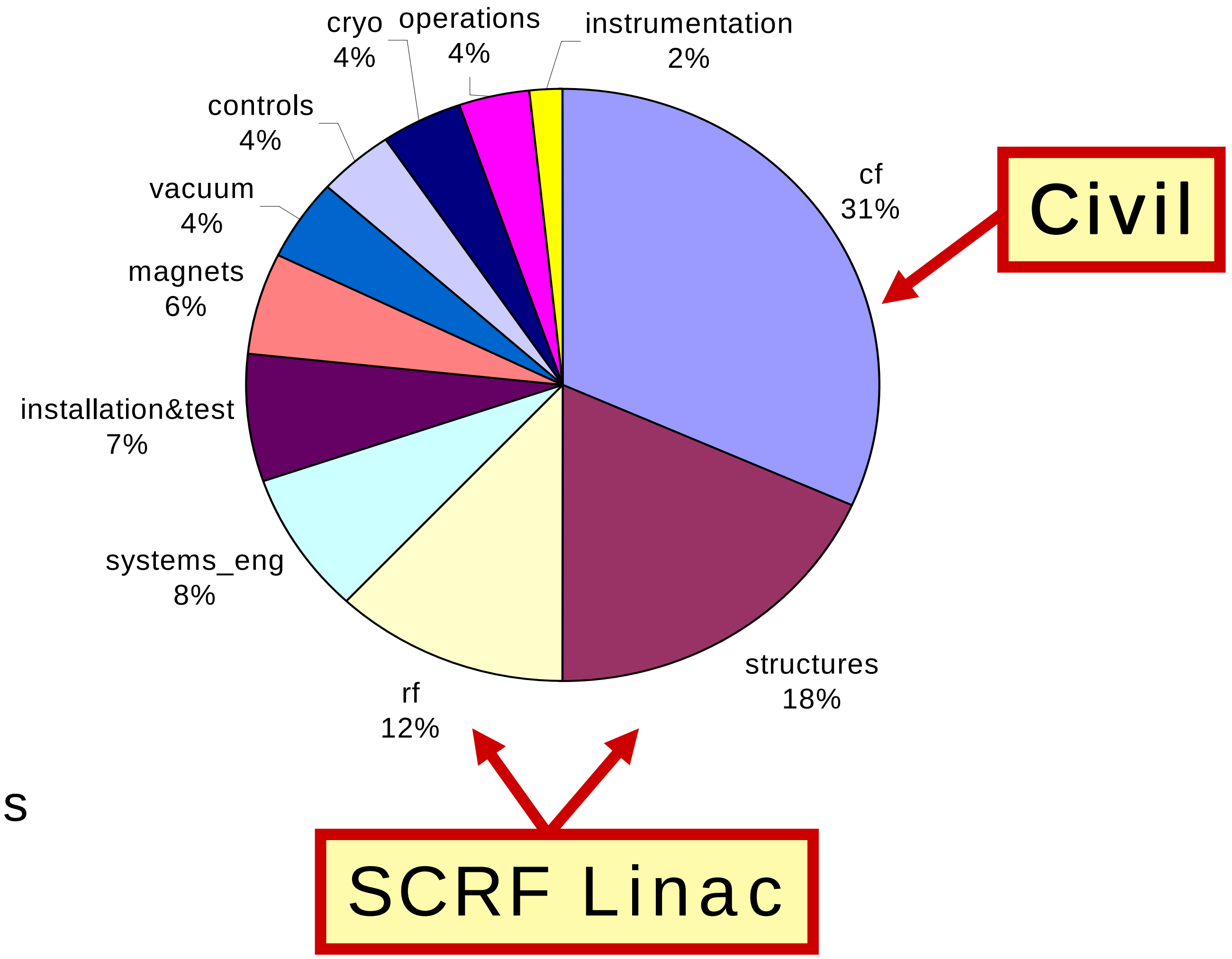
Requires generating high intensity beams of electrons and positrons

Damping the beams to ultra-low emittance in damping rings

Transporting the beams to the collision point without significant emittance growth or uncontrolled beam jitter

Cleanly dumping the used beams

Affordability Challenges

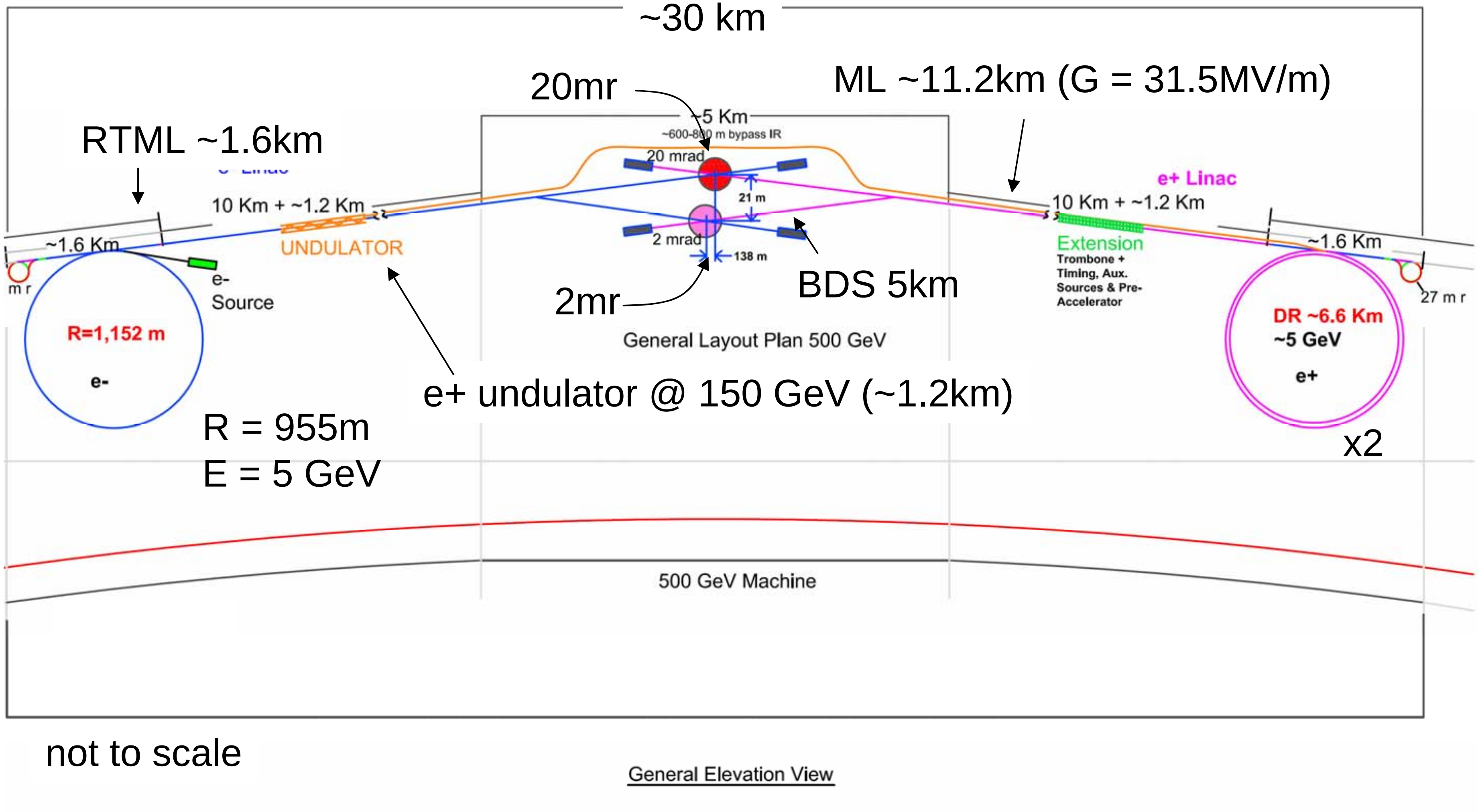


Civil

SCRF Linac

Pie chart
From US
Tech. Options
Study

The Baseline Machine (500GeV)



~30 km

20mr

ML ~11.2km (G = 31.5MV/m)

RTML ~1.6km

BDS 5km

2mr

e+ undulator @ 150 GeV (~1.2km)

R = 955m
E = 5 GeV

x2

not to scale

Elements of the BCD

Parameter plane established

- TESLA designed for 3.4e34 but had a very narrow operating range
- 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
  - Beam power between ~5 and 11 MW

Superconducting linac at 31.5 MV/m

- Cavities qualified at 35 MV/m in vertical tests
- Expect an average gradient of 31.5 MV/m to be achieved
  - Rf system must be able to support 35 MV/m cryomodules
- This still requires extensive R&D on cavities and rf sources

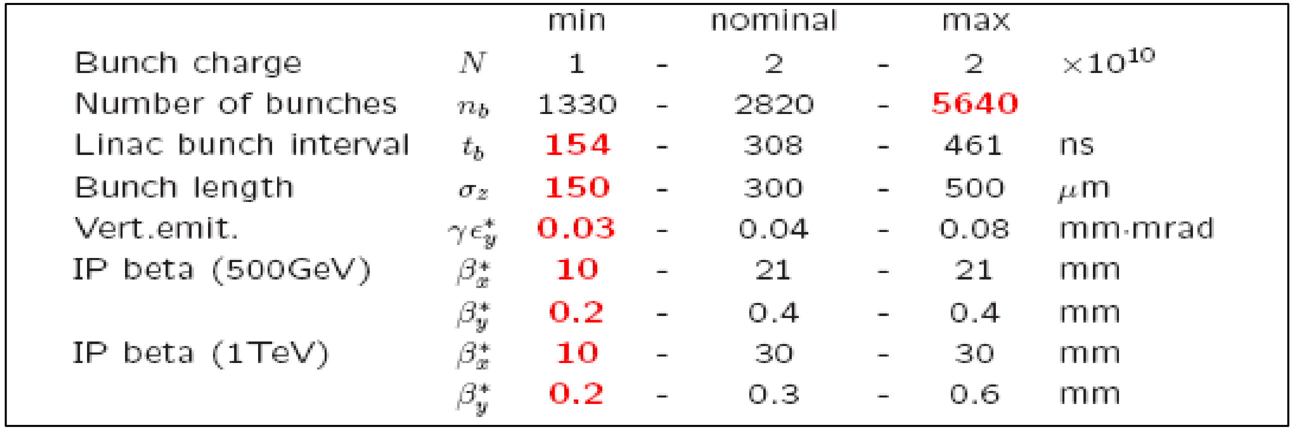
Parameter Plane

Parameter Trade-Offs

Linac
(relaxed within limits)

Damping Ring
(sources)

IR (IP)
Beam extraction



		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

Walker / Raubenheimer

Elements of the BCD (2)

Circular damping rings 6.6 km in circumference

- 5 GeV ring like TESLA and USTOS but shorter
- Rf frequency of 650 MHz = ½ main linac 1.3 GHz
  - Allows for greater flexibility in bunch train format
  - Allows for larger ion and electron cloud clearing gaps
- Shorter rings have large dynamic aperture compared to dogbone
- Single electron ring; two rings for the positrons

Dual stage bunch compressor

- Dual stage system provides flexibility in IP bunch length
- Allows for longer damping ring bunch length
- Turn-around allows for feed-forward from damping ring to ease kicker tolerances
- Pre-linac collimation system to remove beam tails at low energy

Elements of the BCD (3)

Positron source based on planar undulator

- Undulator located at ~150 GeV for energy flexibility and tuning stability
- Keep-alive source located on e+ side to provide positrons when problems with electron beam
  - Provide sufficient charge to operate diagnostics well
  - Also e- source for commissioning, eventual e-e- runs

Dual interaction regions

- Crossing angles of 2mrad and 20 mrad
  - 2 mrad has better hermaticity while 20 mrad has better accelerator performance
- Optimize both to understand performance trade-offs
- Regions separated longitudinally as well as transversely

High Availability Design

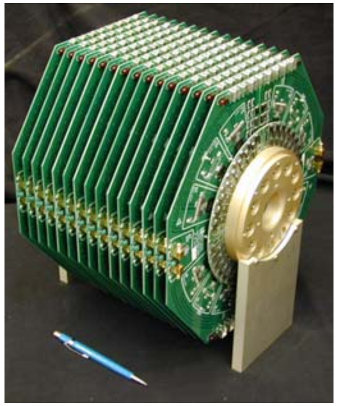
System availability studies (SLAC, DESY)

Design of high availability hardware (SLAC, LLNL)

Kickers, Power supplies, diagnostics, and control system

Modular 4 of 5 power supply with auto-failover

Fast (redundant) kicker for DR

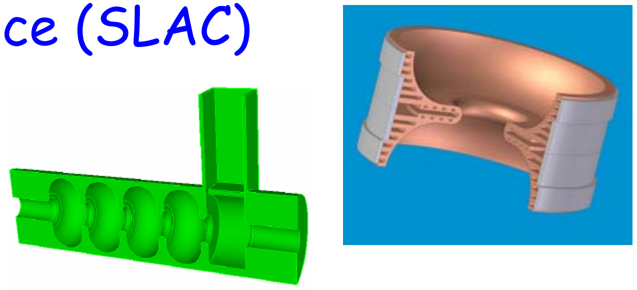


General control system design (ANL, FNAL, SLAC, …)

Sources R&D

Laser and cathode for polarized electron source (SLAC)

NC structures: design and test (SLAC)



Positron capture structures

E166 pol. e+ production (SLAC, many others)

Undulator design (Cornell, UK)

Positron Source simulations (ANL)

A comprehensive start-to-end simulation of conventional, polarized, and keep-alive sources.

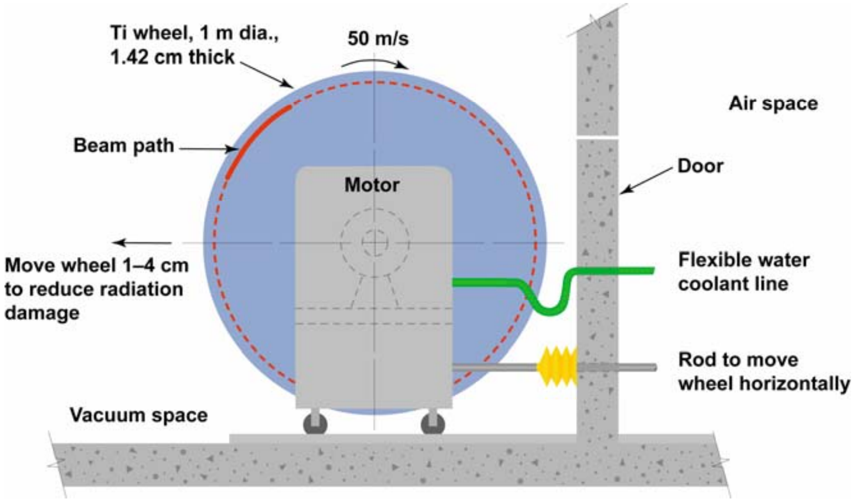
Positron target design (LLNL, UK)

Detailed engineering

Target simulations

Energy deposition, radiation damage, activation (LLNL, SLAC)

Compton source R&D (KEK)



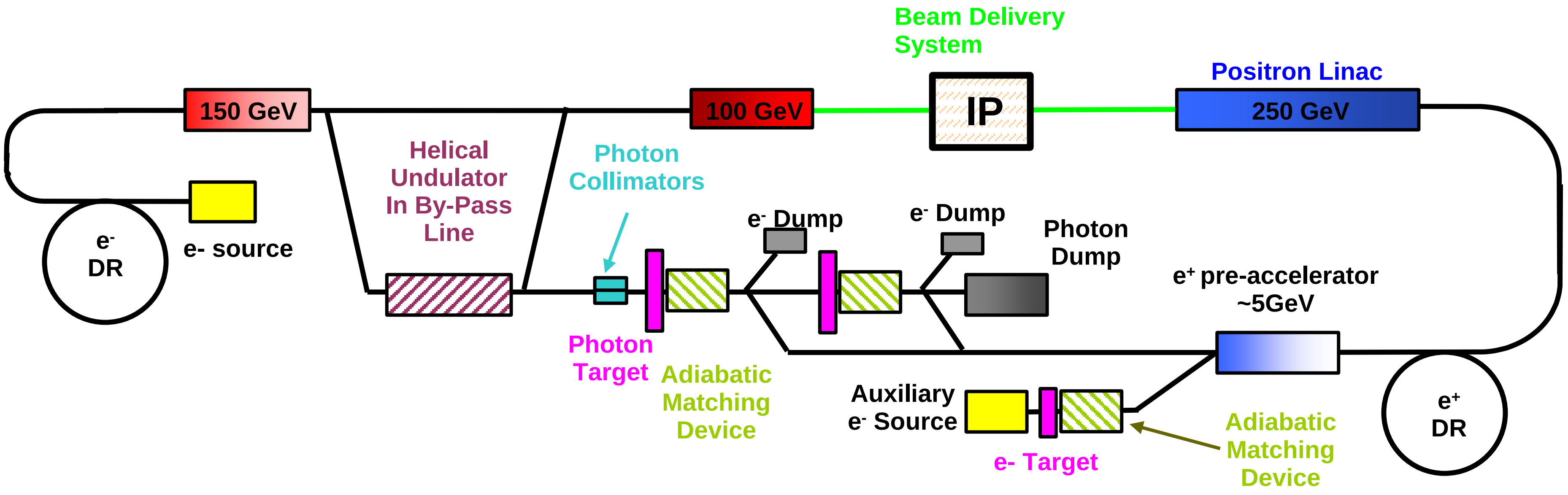
Layout of ILC Positron Source

Photon production at 150 GeV electron energy

K=1, λ=1 cm, 200 m long helical undulator

Two e+ production stations including a back up

Keep alive auxiliary source is e+ side, also e- source

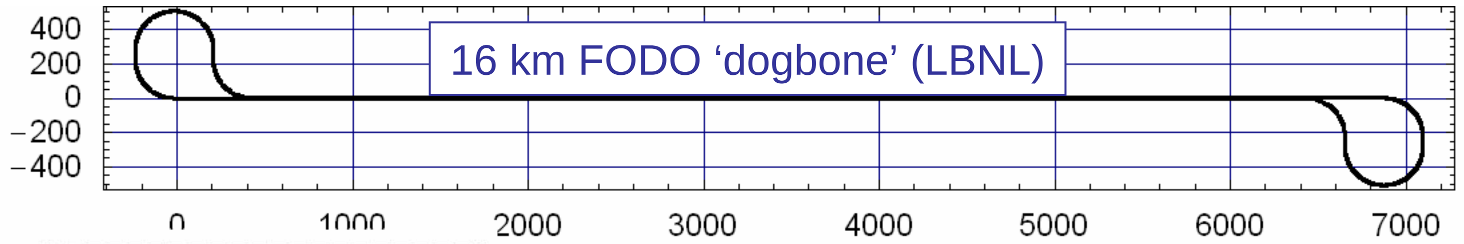


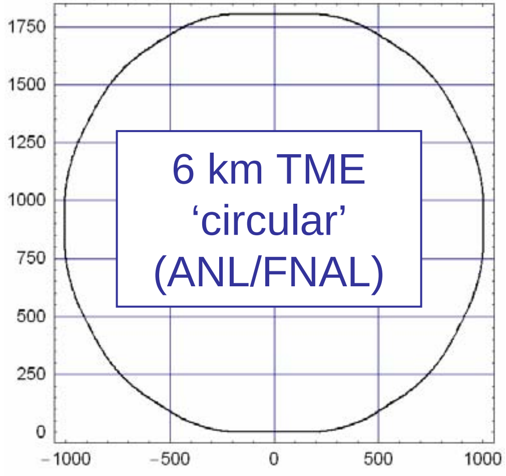
M. Kuriki, KEK

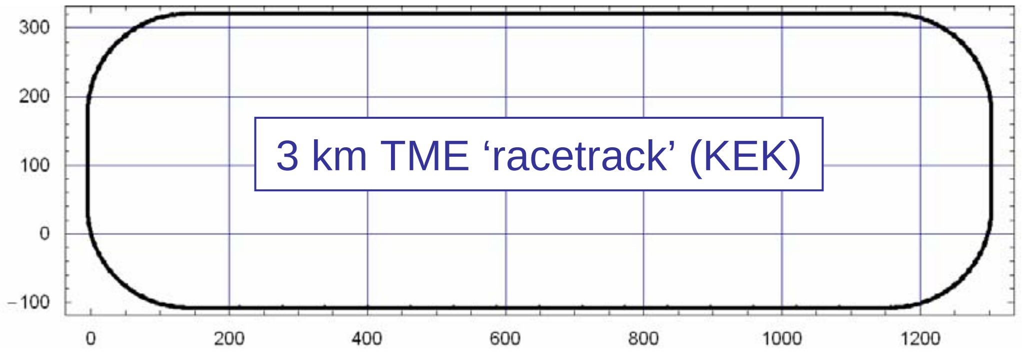
Comparative Study of Possible ILC DRs

A major activity in 2005

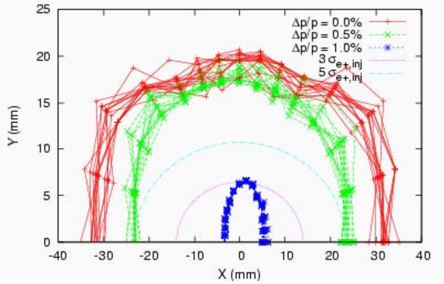
Explore different configuration options (including lattice styles) for the damping rings.


16 km FODO ‘dogbone’ (LBNL)

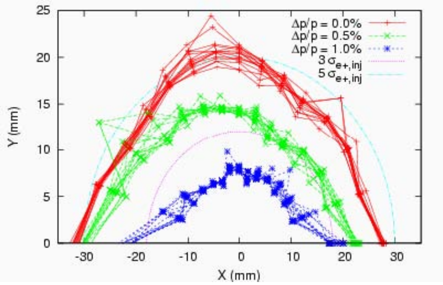

6 km TME ‘circular’ (ANL/FNAL)


3 km TME ‘racetrack’ (KEK)

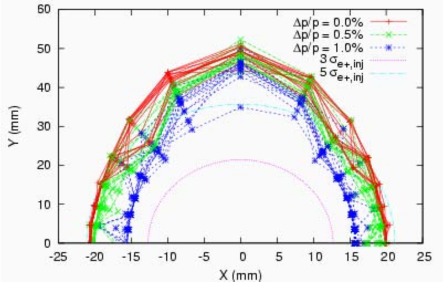
Dynamic Aperture in the Reference Lattices with Ideal Nonlinear Wiggler Model and 15 Seeds of Multipole Errors, computed with BMAD *(from Config Studies& Recomm Report)*



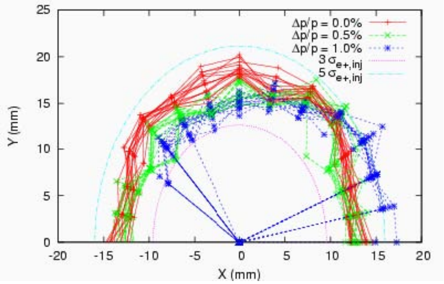
(a) PPA



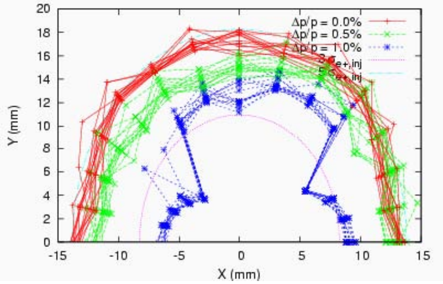
(b) OTW



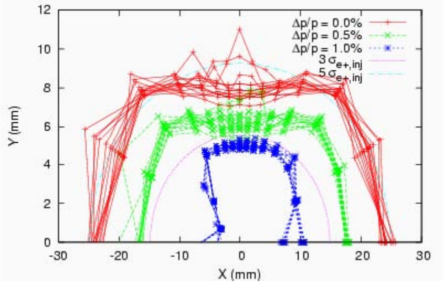
(c) OCS



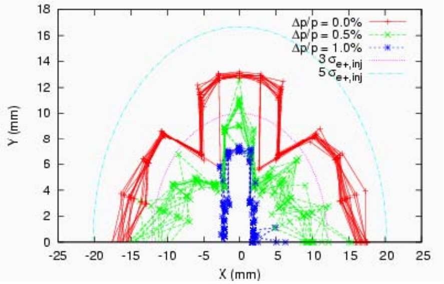
(d) BRU



(e) MCH



(f) DAS



(g) TESLA

Good agreement between results by different groups using different codes; *elegant*, Merlin, LEGO

Damping Rings

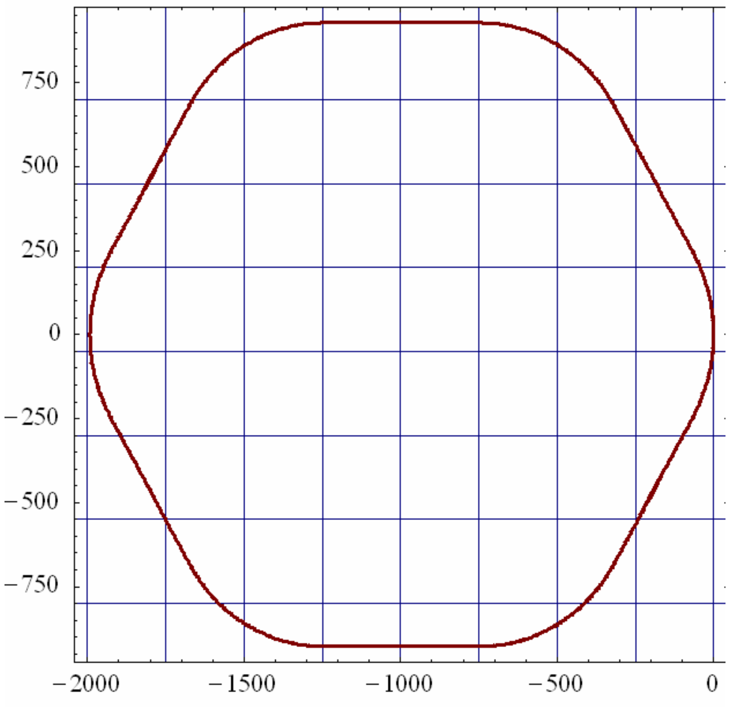
Positrons:

Two rings of ~6 km circumference in a single tunnel

Two rings are needed to reduce e-cloud effects unless significant progress can be made with mitigation techniques

Preferred to 17 km dogbone for:

- Space-charge effects
- Acceptance
- Tunnel layout (commissioning time, stray fields)



Electrons:

One 6 km ring

Damping ring R&D

Extensive program worldwide incl. KEK, UK, Frascati, IHEP

DR component optimization: wigglers, fast kickers; (Cornell) studies of the use of CESR as a DR test facility (in 2008)

Damping Ring Design and Optimization (ANL)

Lattice design and optimization; studies of ion instability in the APS ring; design of a hybrid wiggler

SEY, FII simulations, experiments in PEP-II (SLAC)

ATF damping ring experiments (SLAC, LBNL, Cornell)

Lattice designs for damping rings and injection/extraction lines; characterization of collective effects; stripline kickers for single-bunch extraction at KEK-ATF (LBNL)

SLAC: E-cloud R&D Program

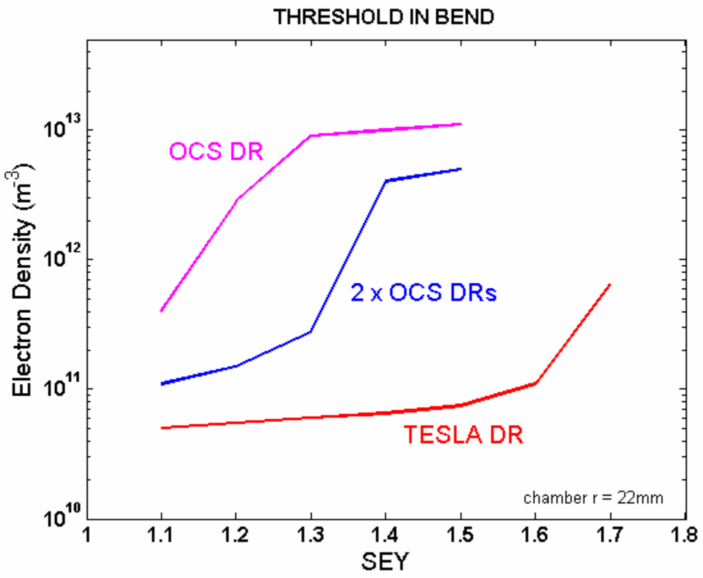
Multi-pronged program

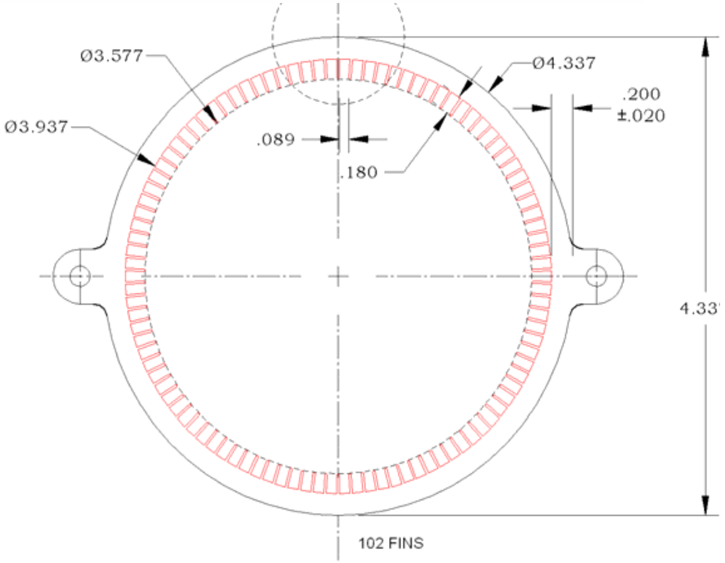
Simulations (SLAC, KEK, LBNL)

Secondary Yield studies

Test sample chamber in PEP-II

Chambers with fins to trap e-



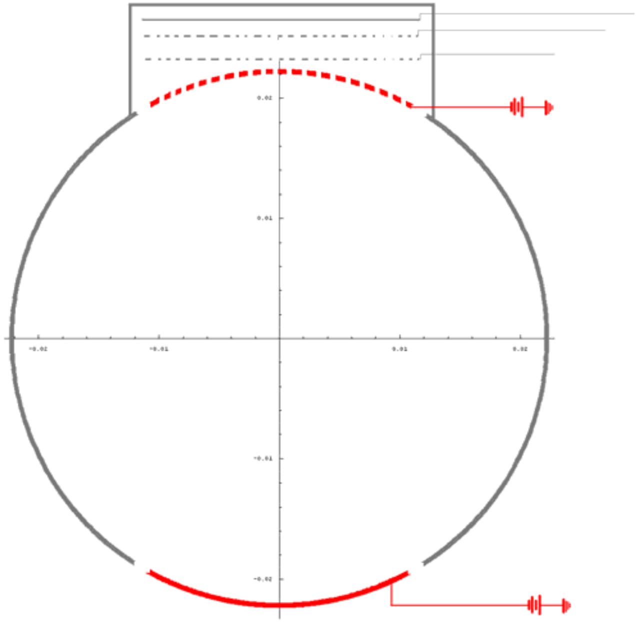


Mauro Pivi

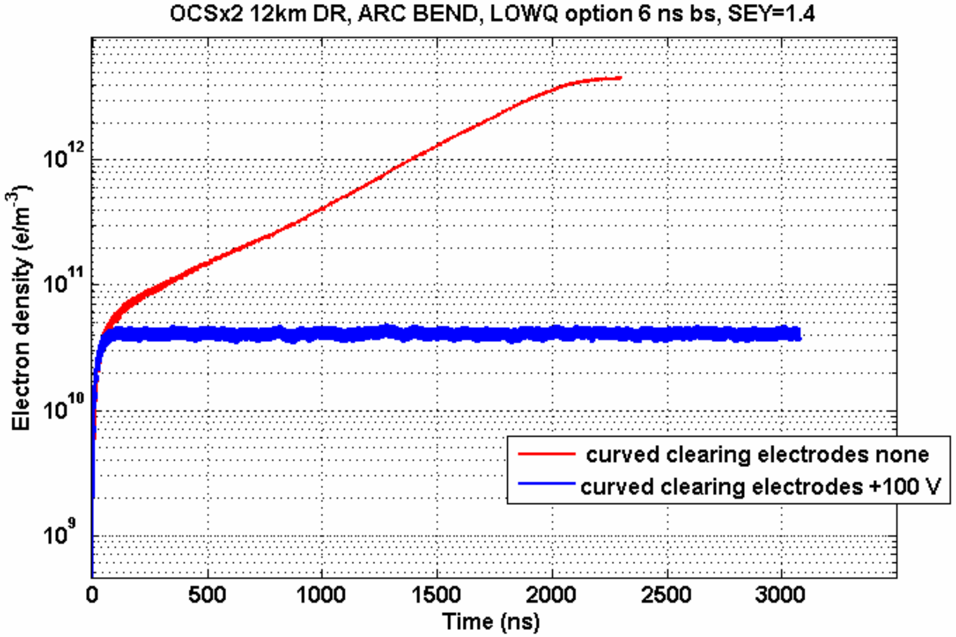
SLAC: E-cloud R&D Program (2)

Curved clearing electrodes

M. Pivi – L. Wang – T. Raubenheimer - P. Raimondi, SLAC. Mar 2006



Layout of the clearing electrodes in ILC DR BEND vacuum chamber



+100V clearing electrodes suppress electron cloud buildup

RTML and Main Linac Optics, beam dynamics, instrumentation

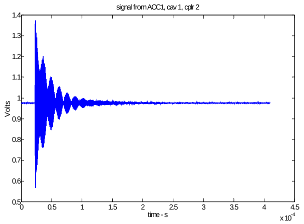
RTML (bunch compressor) design (SLAC, Cornell, PAL)

Main linac optics design (SLAC, Fermilab)

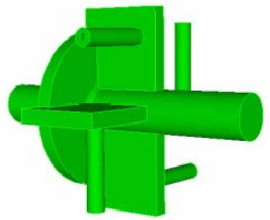
Low emittance transport simulations and BBA design (SLAC, Fermilab, Cornell, KEK, CERN, DESY)

Wakefield calculations (SLAC)

Linac beamline Instrumentation (SLAC)

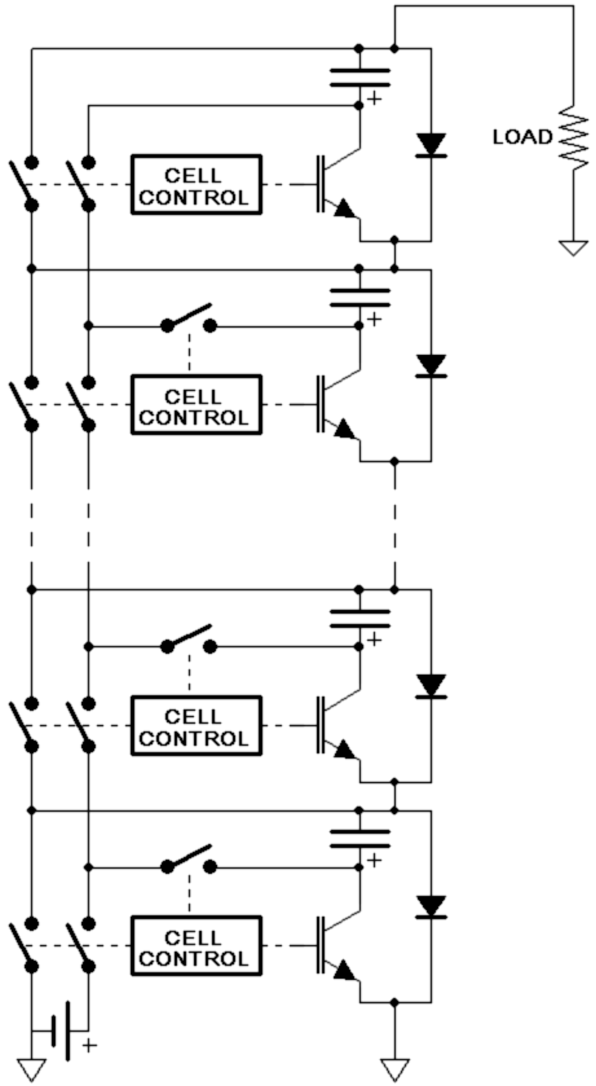


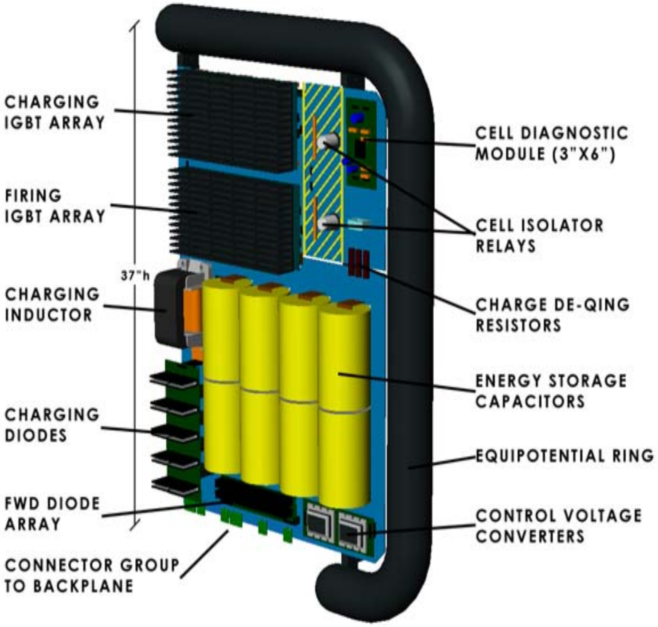
TTF HOM Signal 800 monitors installed



RF BPM for linac

Marx Generator Modulator





12kV MARX CELL, FRONT VIEW

12 kV Marx Cell (1 of 16)

IGBT switched

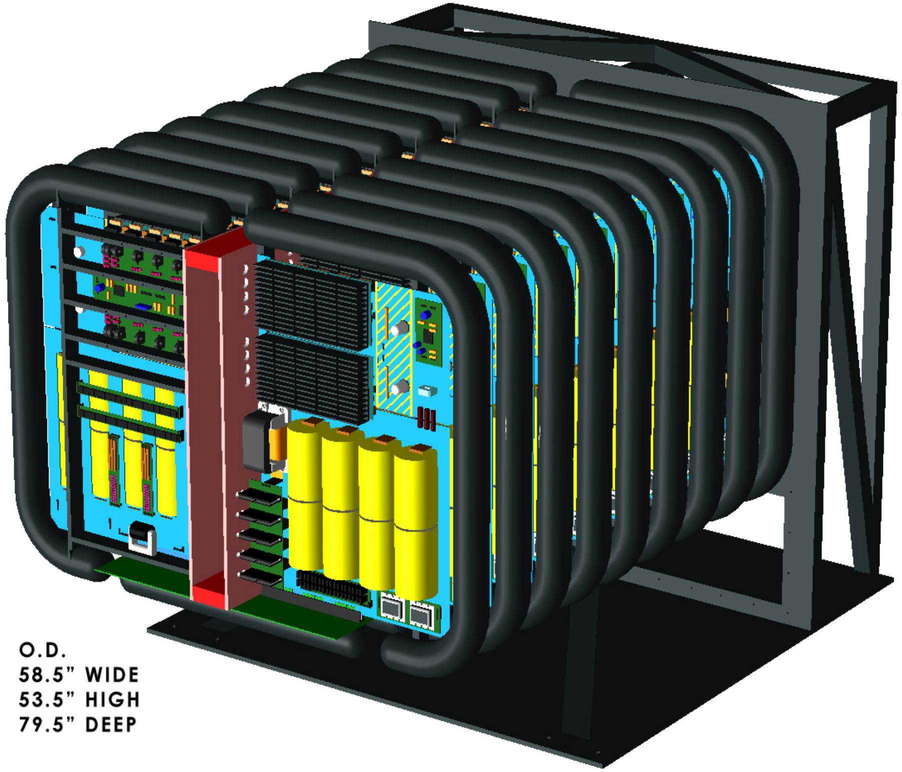
No magnetic core

Air cooled (no oil)

Greg Leyh

Marx Modulator (~ 2 m cubed)

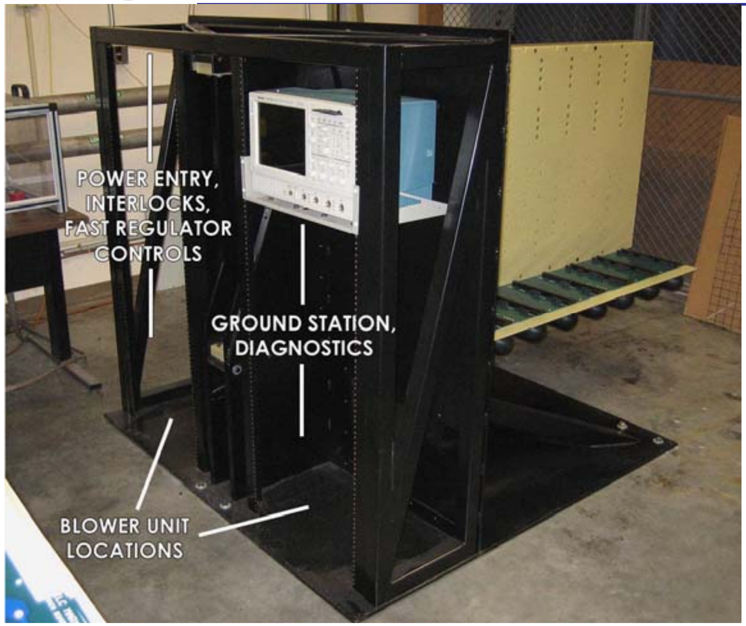
- Direct-coupled voltage stack of ten 12-kV cells producing 140A pk @ 1.5 msec
- IGBT switched
- Lower cost modular components
- Air cooled, no oil in tunnel
- Redundancy -> high availability
  - Cell can operate with failed components
  - Modulator functions with up to 2 failed drivers
- Vernier cells correct flat top to +/-0.5%

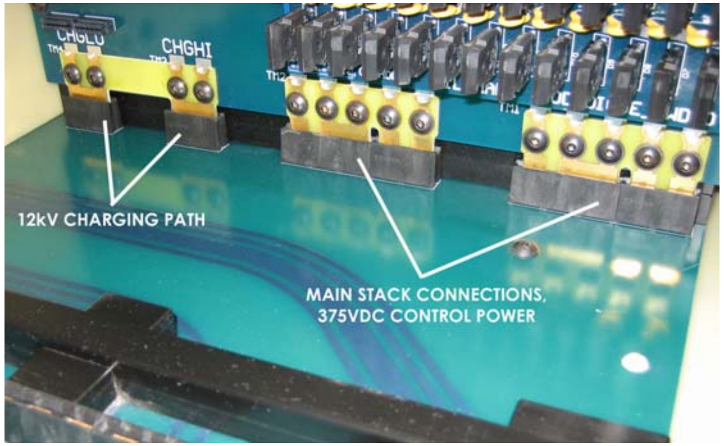


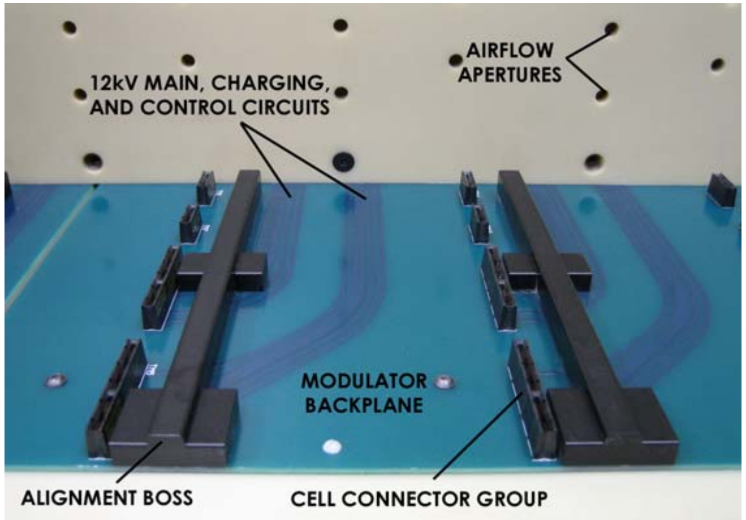
DETAIL, MARX MODULATOR CORE

Greg Leyh

Marx Modulator Prototype @ SLAC







RF Power: Baseline Klystrons


Thales


CPI


Toshiba

Specification:

10MW MBK

1.5ms pulse

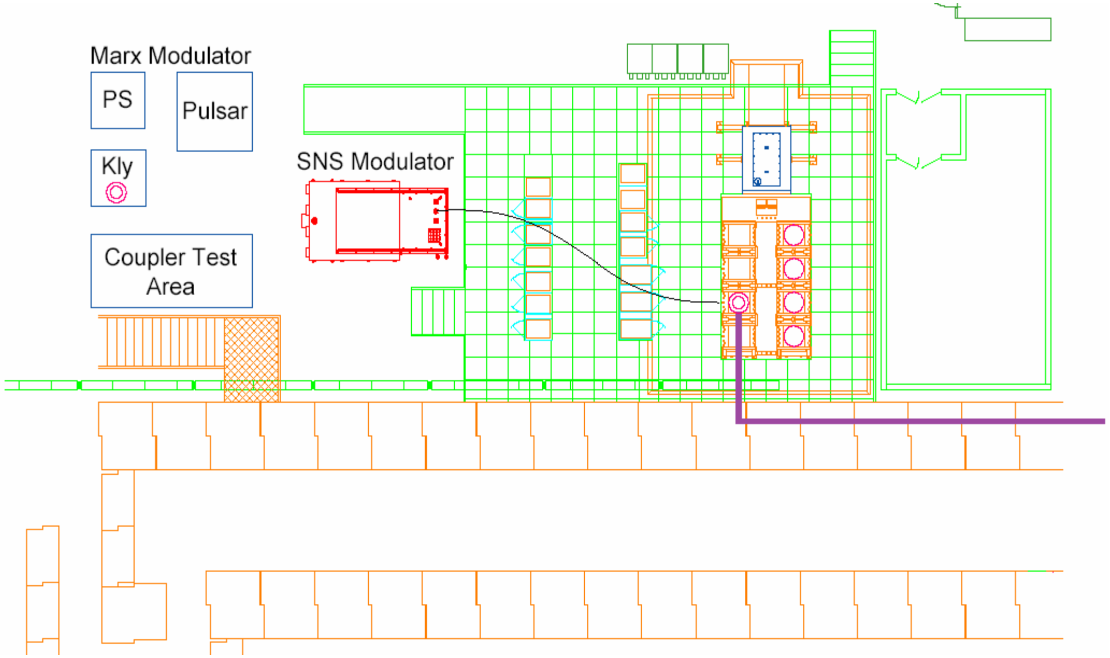
65% efficiency

None of these prototypes meet specifications yet

Urgent work needed

L-Band RF Test Facility

SLAC End Station B



5 MW station in FY06, with SNS modulator powering SDI legacy klystron

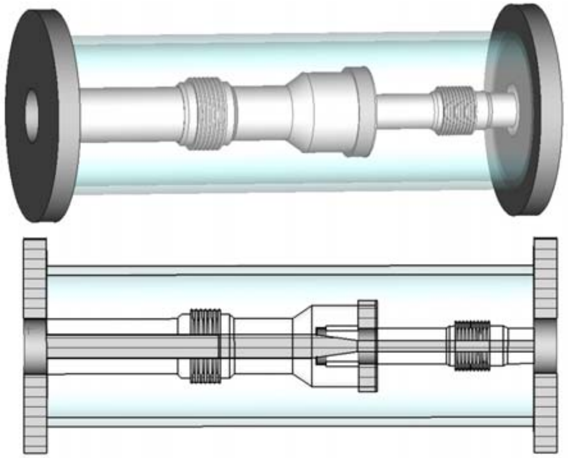
Test NC structures

Coupler test stand (LLNL)

10 MW station later with new klystron

Test rf system components

Reuses extensive infrastructure

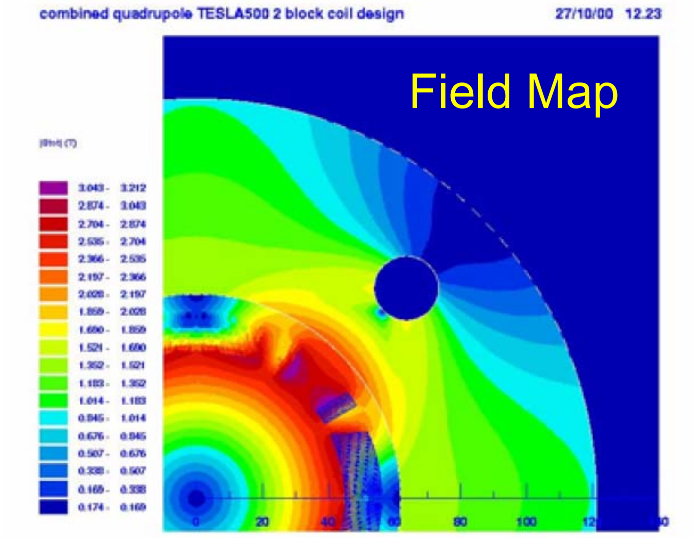


Coupler test assembly

Linac SC Quad/BPM Evaluation

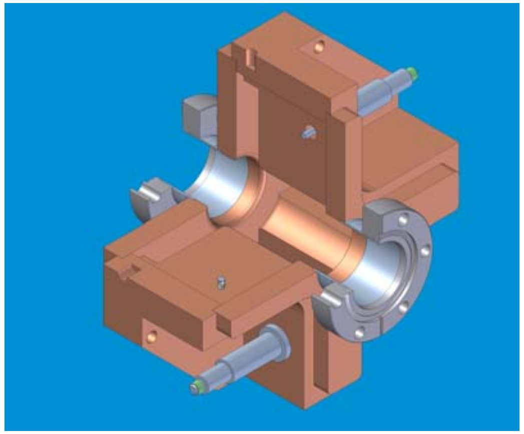
Cos(2Φ) SC Quad

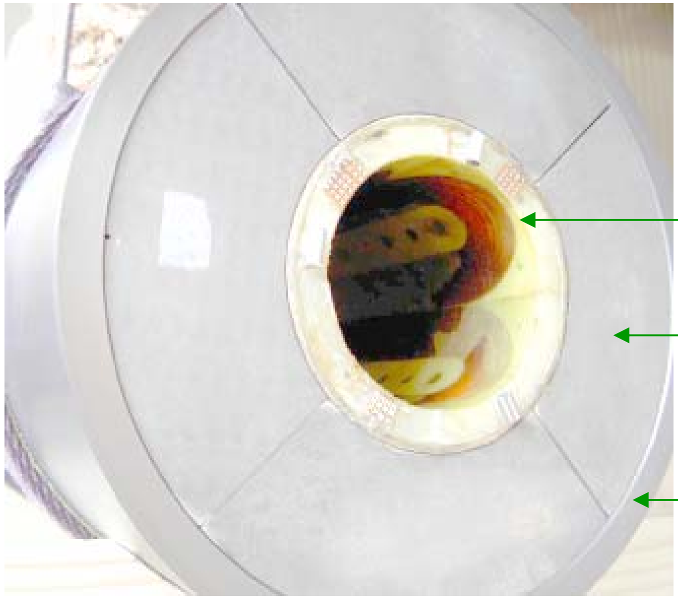
(~ 0.7 m long)



S-Band BPM Design

(36 mm ID, 126 mm OD)



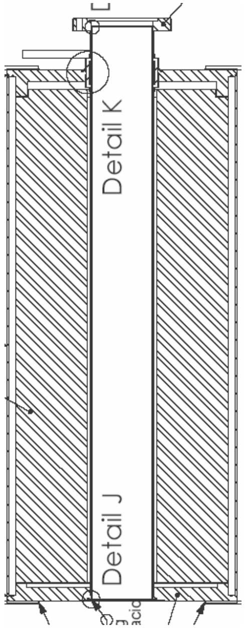


He Vessel →

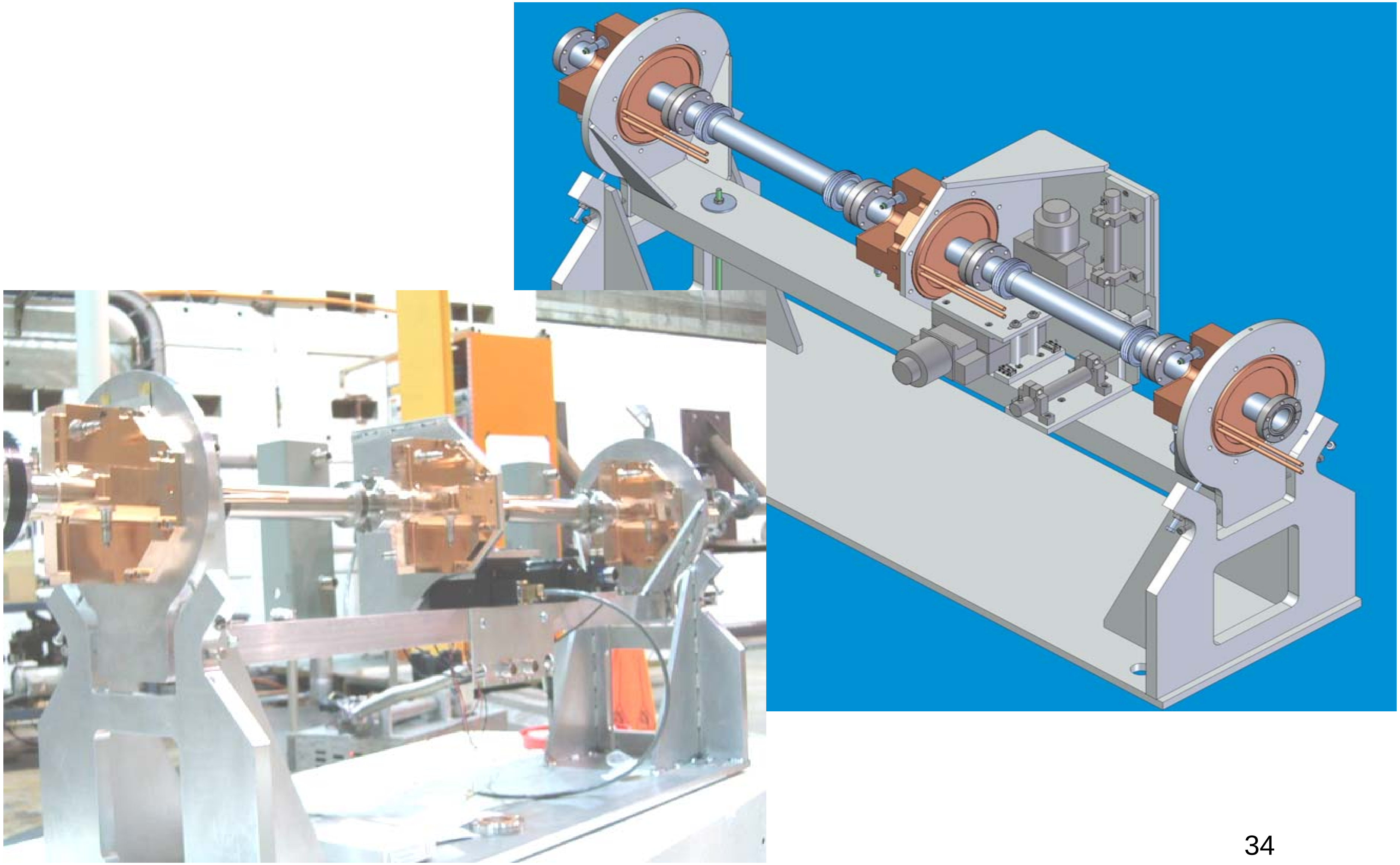
SC Coils

Iron Yoke Block

Al Cylinder



BPM Triplet to be Tested with Beam



Beam Delivery System

Beam delivery system design (SLAC, Daresbury)

ATF-2 (KEK, SLAC, UK, DESY, CERN, etc.)

- Construction of magnets, PS, and instrumentation

ESA MDI Test Facility (SLAC)

NanoBPM for ATF2 (LLNL, KEK)

20 mrad compact SC FF magnet development (BNL)

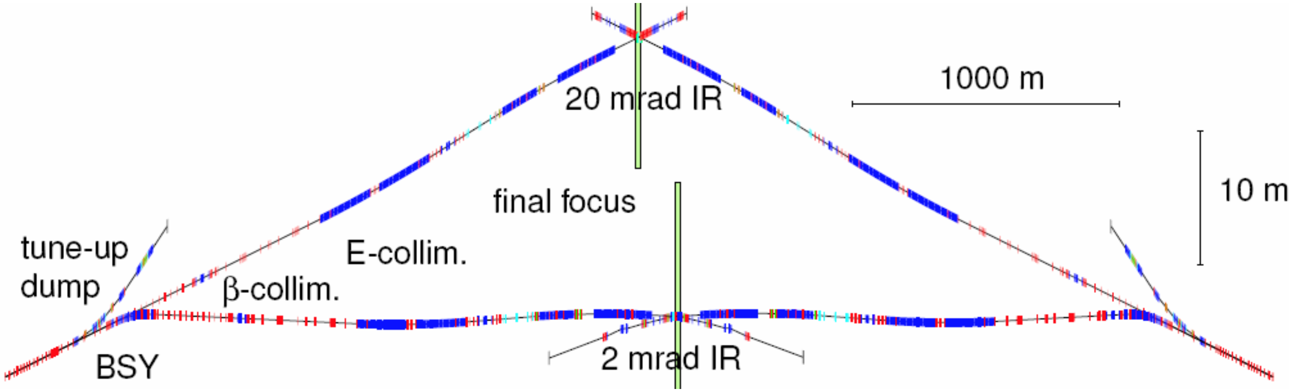
- Fabricate and test a short proof of principle shielded final-focus-like quadrupole coil

2 mrad large-bore SC magnet development (Saclay/Orsay)

- Based on LHC Magnet design

Crab Cavity Development (FNAL, SLAC, UK)

Beam Delivery System



Baseline (supported, at the moment, by GDE exec)

- 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

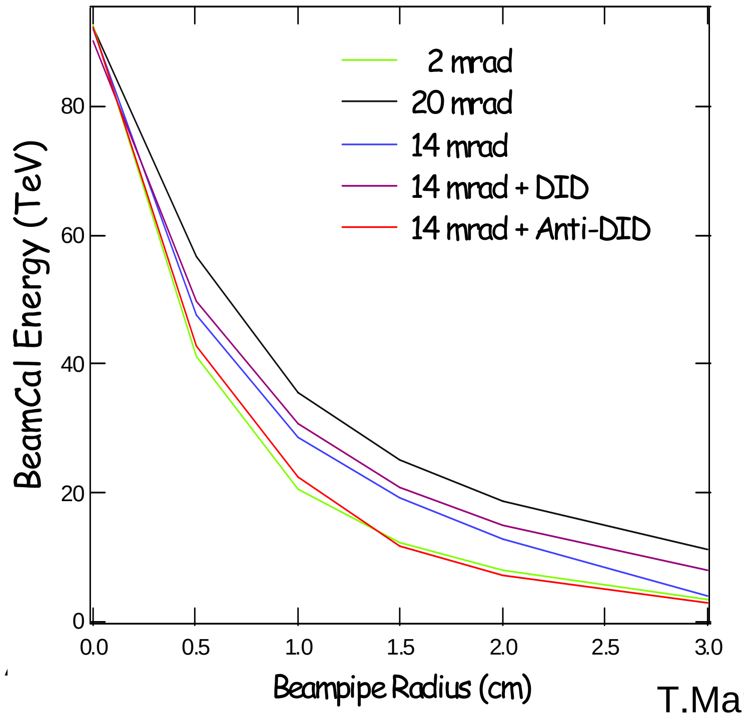
Alternative 2

- single IR/BDS, collider hall long enough for two push-pull detectors

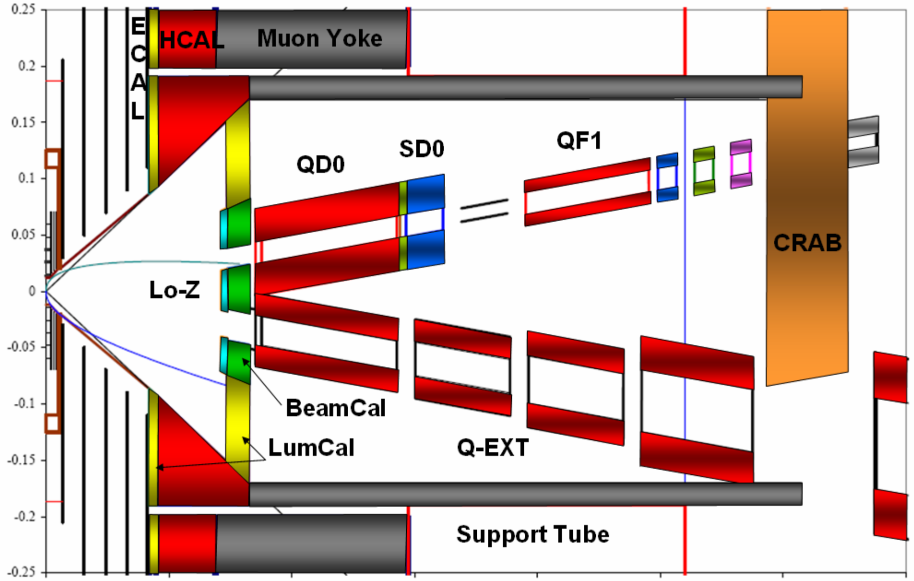
Andrei Seryi

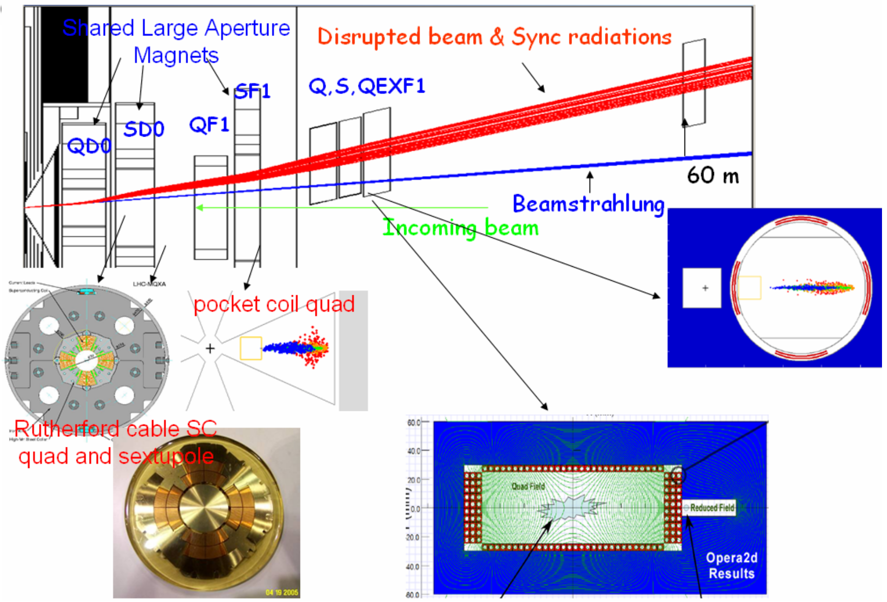
IR Design

- Design of IR for both small and large crossing angles
- Optimization of IR, masking, instrumentation, background evaluation
- Design of detector solenoid compensation



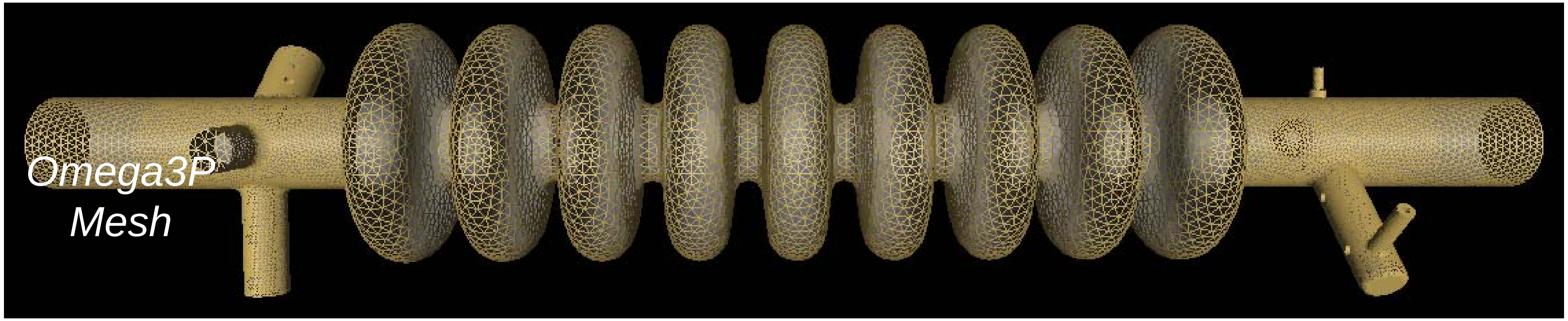
T.Maruyama et al

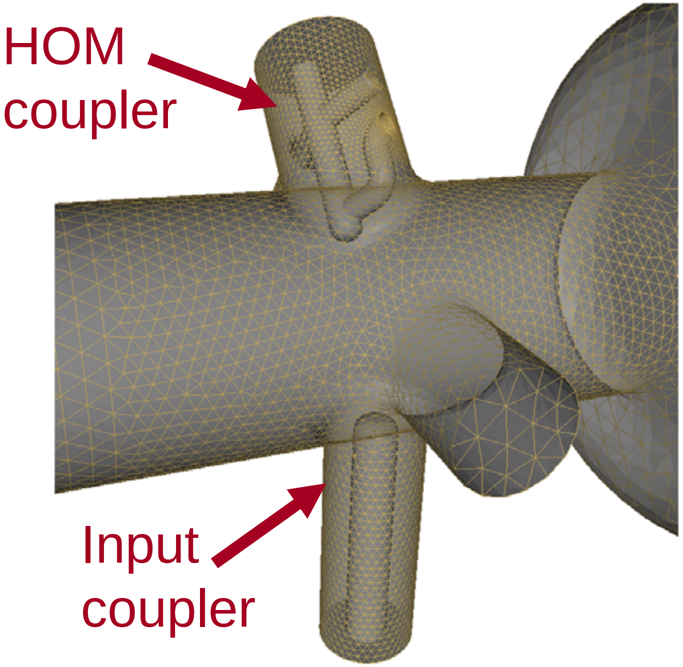


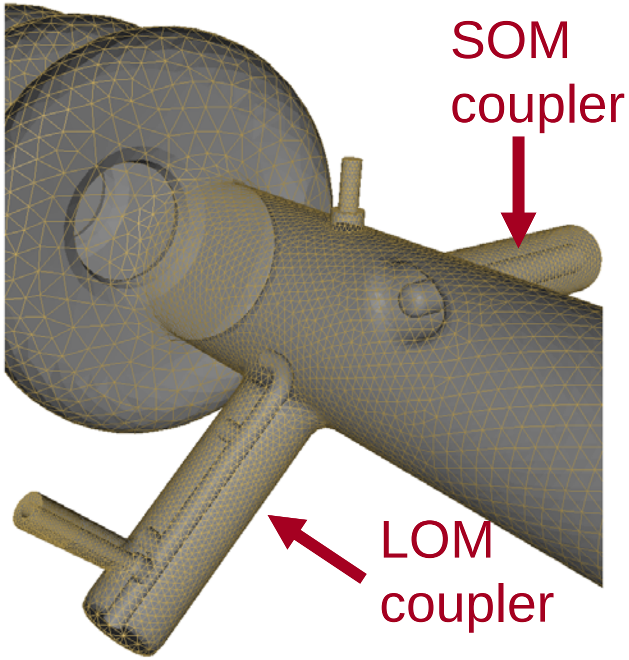


B.Parker, Y.Nosochkov, T.Markiewicz,C.Spencer, SLAC-UK-France task force, et al

3.9 GHz Crab Cavity (FNAL Design)



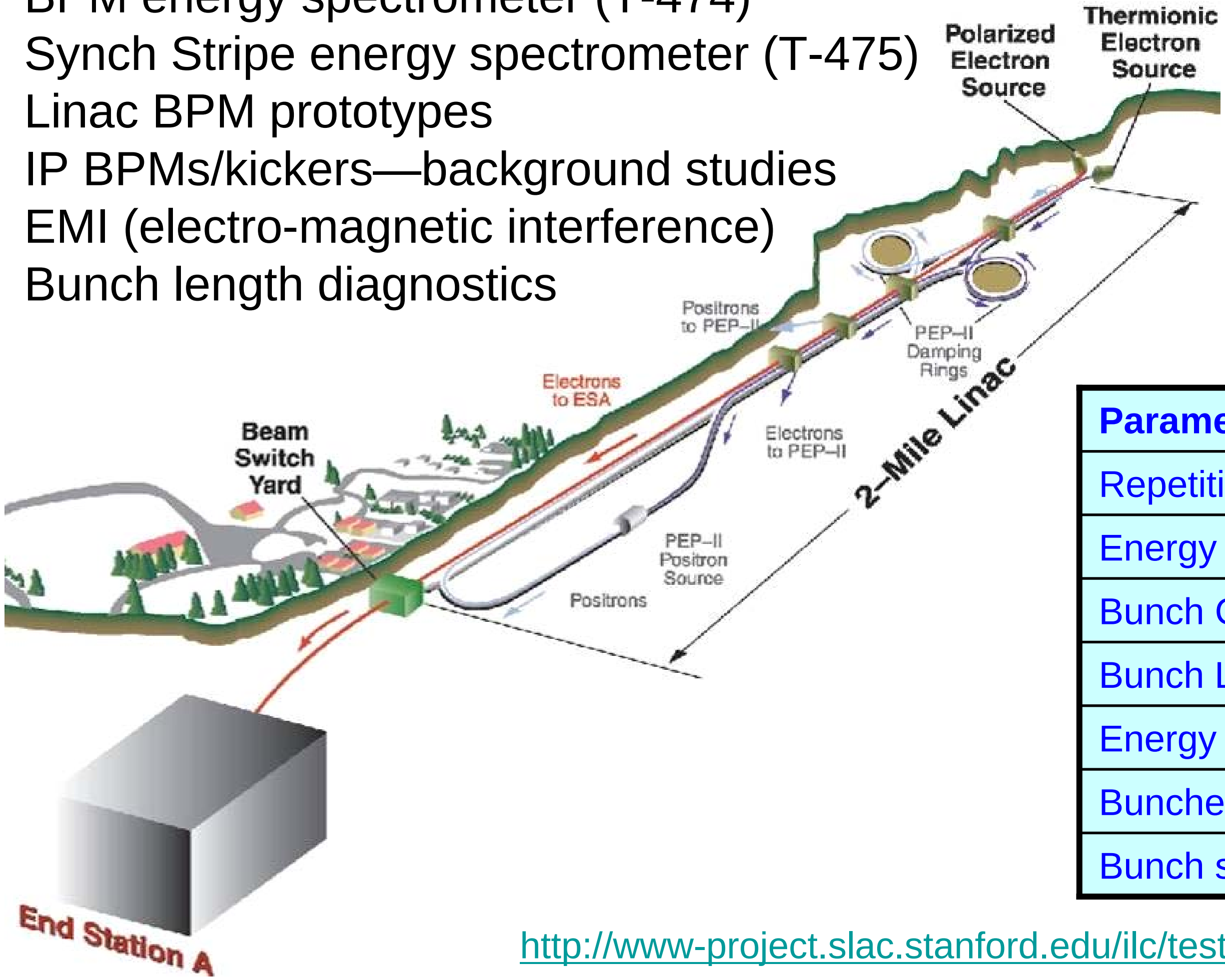




Collaboration : FNAL, Daresbury, SLAC

ILC Beam Tests in End Station A

Collimator design, wakefields (T-480)
BPM energy spectrometer (T-474)
Synch Stripe energy spectrometer (T-475)
Linac BPM prototypes
IP BPMs/kickers—background studies
EMI (electro-magnetic interference)
Bunch length diagnostics



Parameter	SLAC ESA	ILC-500
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
Bunch Charge	2.0 x 10^{10}	2.0 x 10^{10}
Bunch Length	300 mm	300 mm
Energy Spread	0.2%	0.1%
Bunches / train	1 (2*)	2820
Bunch spacing	-(20-400ns*)	337 ns

http://www-project.slac.stanford.edu/ilc/testfac/ESA/esa.html

ESA runs in 2006


January 2006 Commissioning Run

ILC T-474, T-475, T-480:

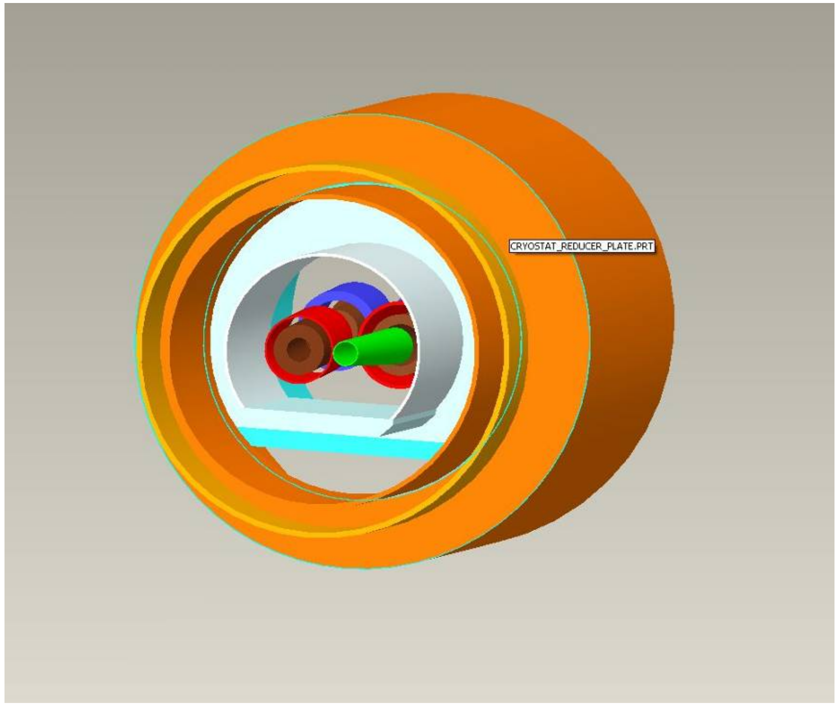
i) Commissioning run – January 4-9, 2006

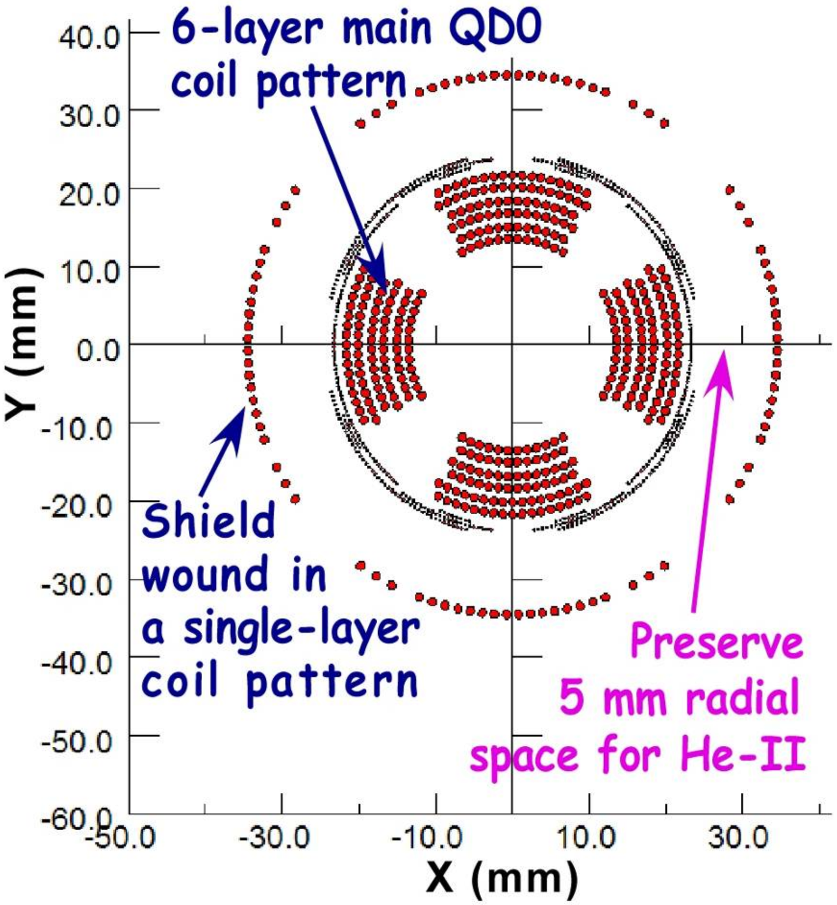
ii) April 24 – May 8, 2006

iii) July 3-17, 2006

ESA plans for FY07-08:
A few 2-week runs each year

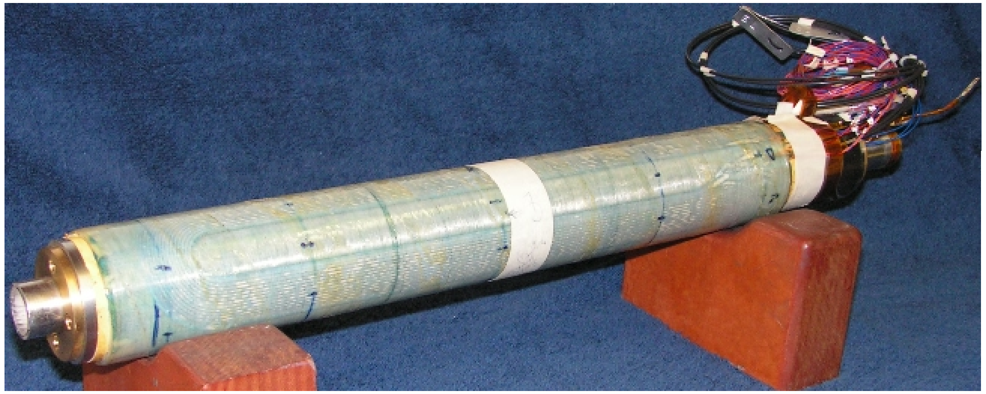
Compact FF Magnet R&D - FY06





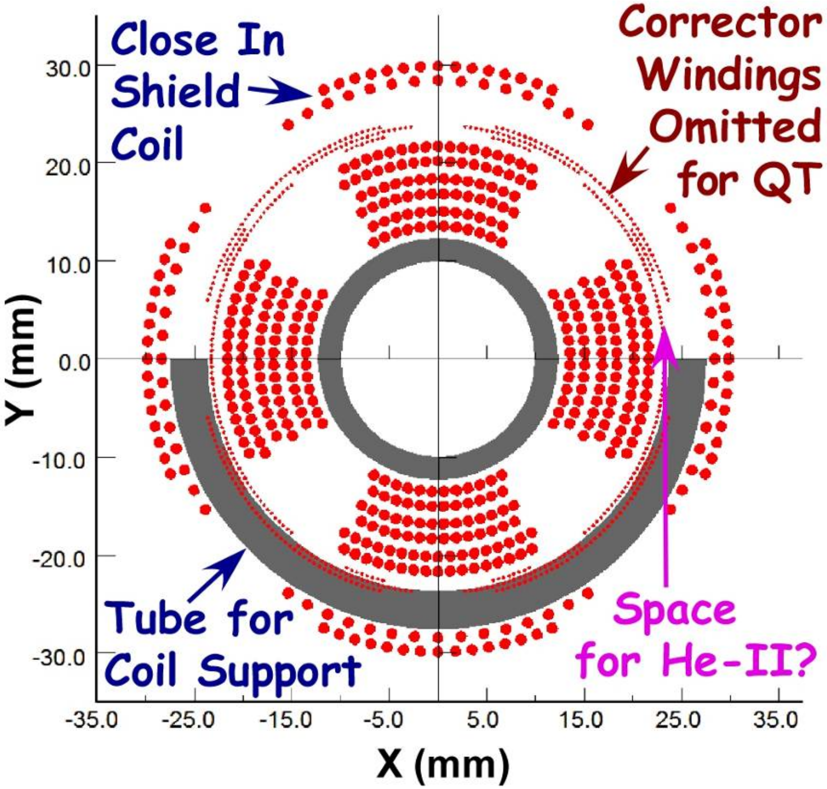
A Nb-Ti coil X-section with a 66 mm OD will meet the 144 T/m design gradient. Outgoing beam pipe is ~ 4 mm beyond the shield coil. All components are housed in a common cryostat. Magnet operates at 1.8K

FF Magnet Prototype



short (20 cm) proof of principle coil with desired quad X-section and the shield coil wound on a separate tube

QT (test coil) cross section



ILC Civil Design for the RDR

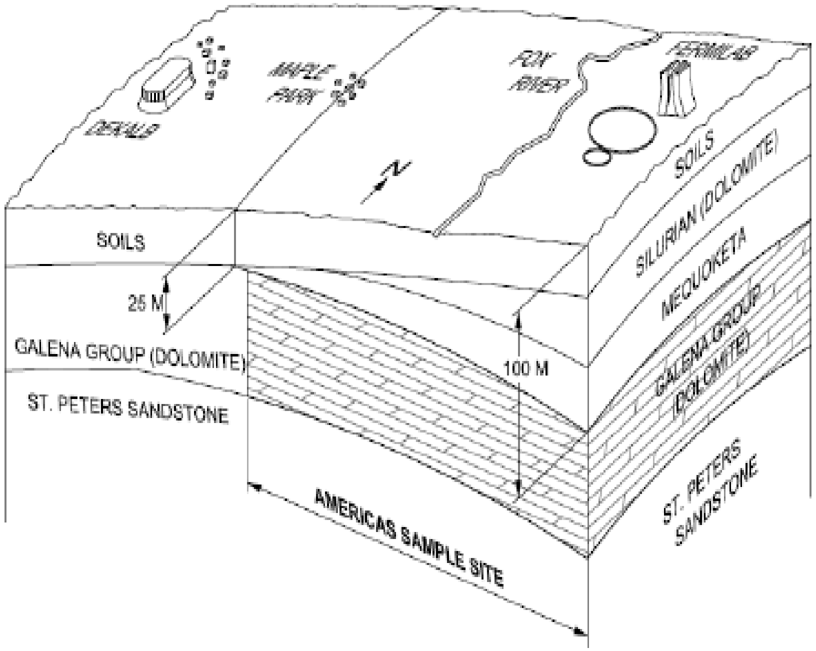
Design to "sample sites" from each region

- Americas – near Fermilab
- Japan
- Europe – CERN & DESY

Americas Site - in Illinois– location may vary from the Fermilab site west to near DeKalb

Design efforts ongoing at Fermilab and SLAC

Americas Sample Plan / Section



ILC-Americas University R&D - FY05

SCRF materials and surface preparation: Wisconsin ($64K), Northwestern($40K), Old Dominion ($58K)

RF power sources: Yale ($60K), MIT($30K)

Polarized electron source: Wisconsin ($35K)

Polarized positron source: Tennessee ($40K), Princeton

Damping rings: Illinois ($17K), Cornell ($75K, $46K) [NSF]

Instrumentation, diagnostics: Berkeley ($35K), Cornell ($24K) [NSF]

Mover systems: Colorado State ($49K) [NSF]

Radiation hard electronics: UC Davis ($38K), Ohio State ($75K)

Ground motion: Northwestern ($28K)

Linac beam dynamics design-Cornell ($21K)

High-gradient SCRF R&D- Cornell ($140K)

Gerry Dugan

Summary

Global Design Effort launched

Baseline Accelerator Configuration adopted

Reference Design Report with a preliminary cost estimate due by the end of 2006

Extensive worldwide effort on R&D to demonstrate design feasibility, find cost effective alternatives