Introduction to the ILC BCD

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Baseline Configuration (BCD)

- BCD developed by ILC Working Groups established at KEK ILC Workshop (2004)
  - Many working meetings during 2005
  - Discussed extensively at Snowmass ILC Workshop (2005)
    - Working groups summarized Snowmass Workshop with bulk of the BCD
  - White papers on contentious issues by GDE members in fall 2005
    - Energy upgrade; Positron source; Number of tunnels; Interaction region configuration; Laser straight versus curved or terrain following tunnels
  - Basic form ratified at Frascati GDE meeting
- BCD is not a cost-optimized design
  - BCD will evolve via a formal change control process as the cost estimates are developed
  - Evolution will also occur through the Alternate Configurations (ACD), included in the baseline document
  - The ACD are alternate technology paths which offer the possibility of cost reduction or performance enhancement, but require more R&D before they can be adopted as baseline

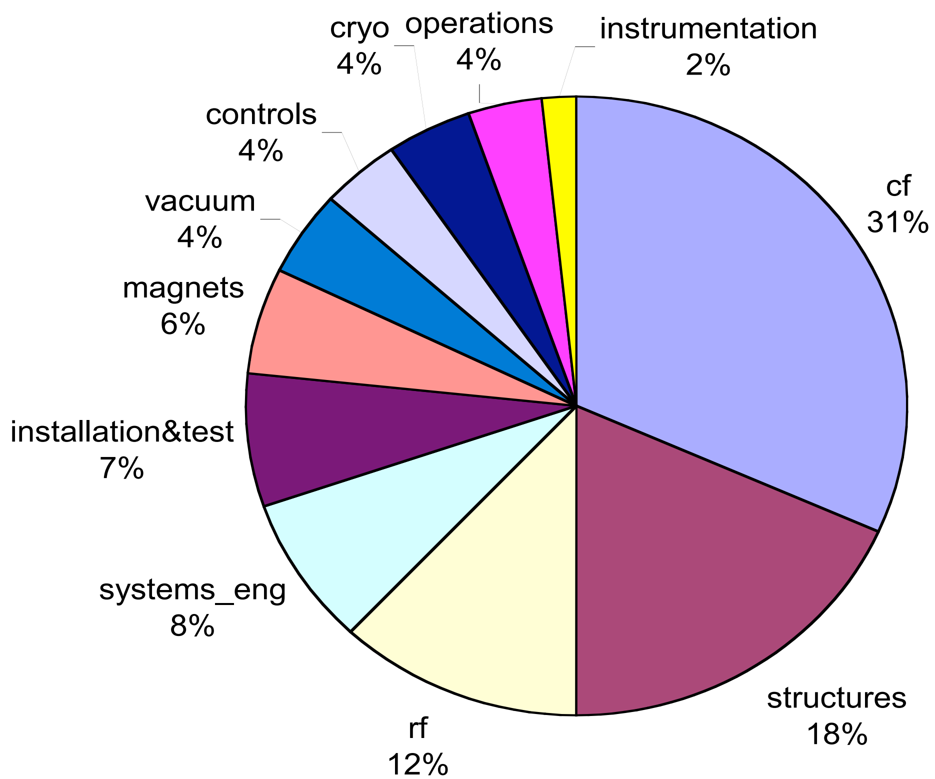
The ILC Accelerator

- 2^{nd} generation electron-positron Linear Collider
- Parameter specification
  - E_{cms} adjustable from 200 – 500 GeV
  - Luminosity → $\int Ldt = 500\ fb^{-1}$ 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

Energy and luminosity challenges

- Beam energy (E_{cm} of 500 GeV – biggest portion of cost)
  - RF system and acceleration cavities accelerate the beams
- AC power efficiency
  - Efficiency of the accelerator rf system – need high beam power
- Luminosity ($2x10^{34}$ $cm^{-2}s^{-1}$ – "only" 7000x higher than SLC)
  - Beam power (actually P_B * N) ~150x SLC
  - Requires very high density beams at collision
  - Limited by beam-beam effects and backgrounds

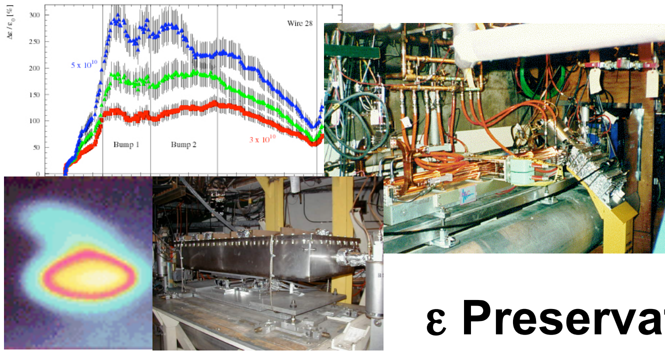
Cost Challenges



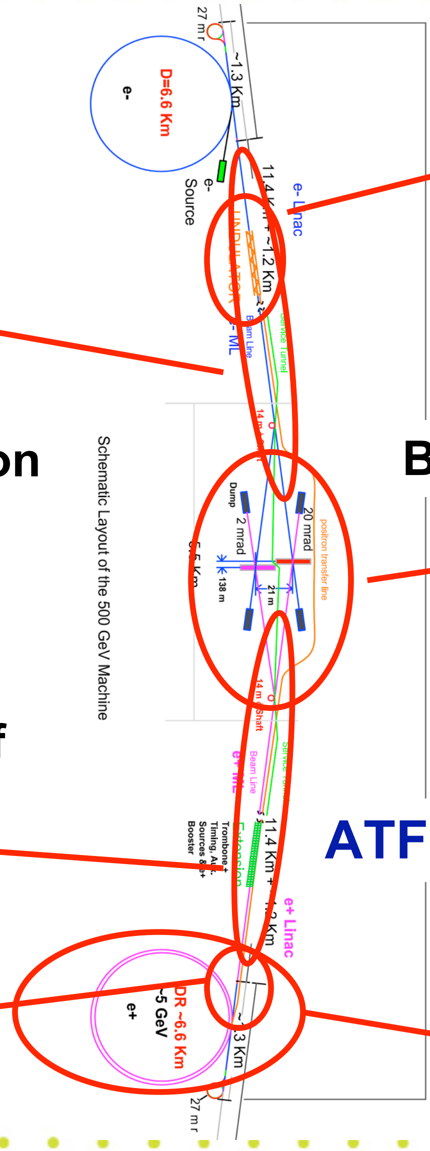
- Cost breakdown from US Technology Options Study
  - http://www-project.slac.stanford.edu/ilc/techinfo/USLCTOS/default.htm
  - Depends on costing practices (different in US, Europe, & Asia)

Experimental Basis for the ILC BCD

SLC, FFTB, ASSET, E-158

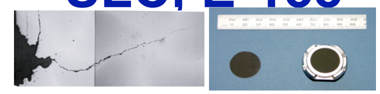


ε Preservation

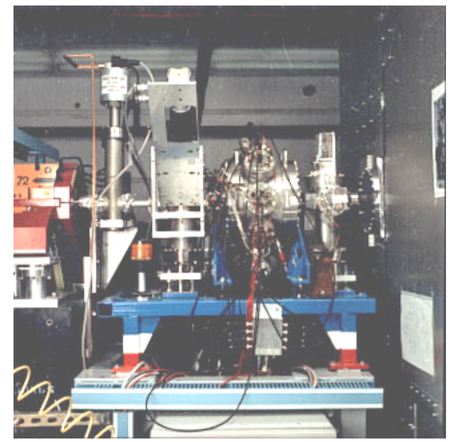


e+ / e- Sources

SLC, E-158



SLC and FFTB
(ATF2 in the future)



BDS & IR

TESLA Test Facility
(SMTF & STF in the future)

Linac rf system

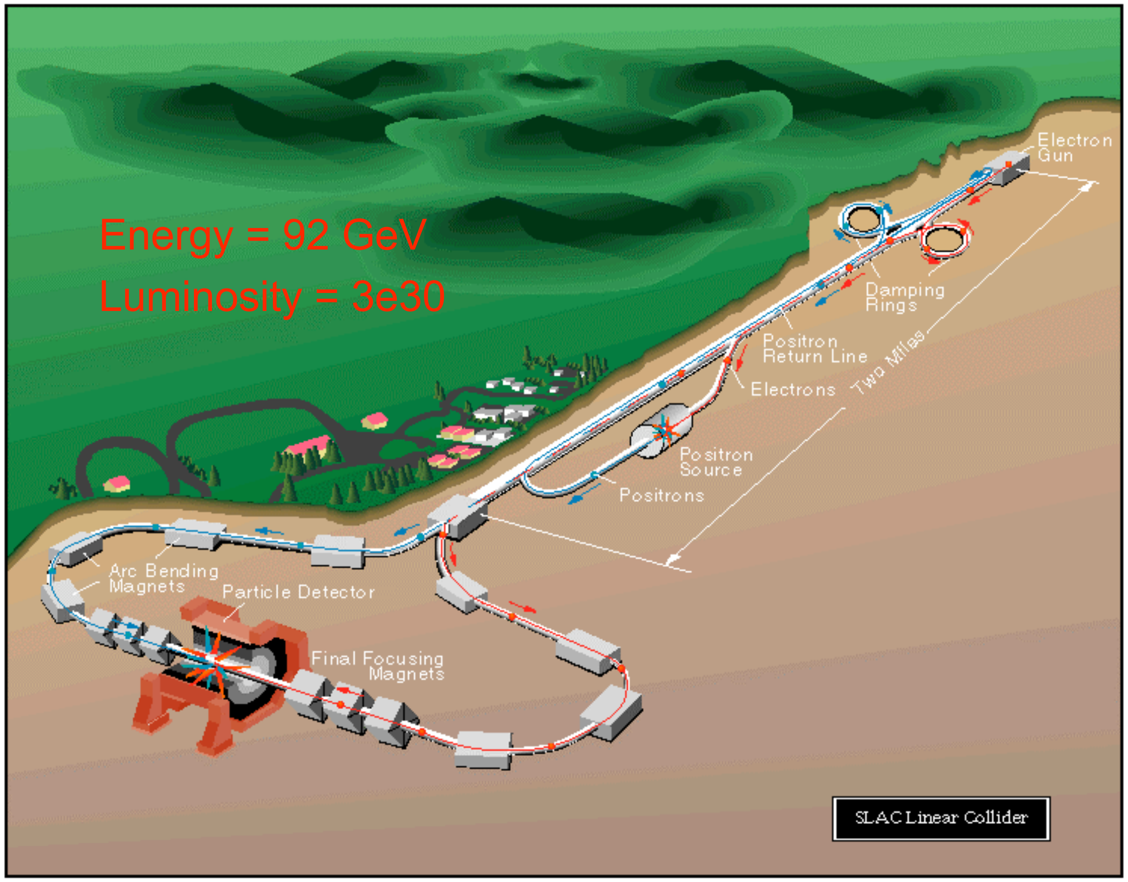
ATF, 3rd Gen Light Sources, SLC

Damping Rings

Bunch Compression

SLC and FEL's

SLC: The 1st Linear Collider



Many Lessons Learned:

- Extensive diagnostics for troubleshooting and tuning
- Reliable and stable operation
- Well designed collimation to limit backgrounds
- **Flexible design to allow parameter optimization**

- Built to study the Z_0 and demonstrate linear collider feasibility
- Had all the features of a 2nd gen. LC, except both e+ and e- shared the same linac

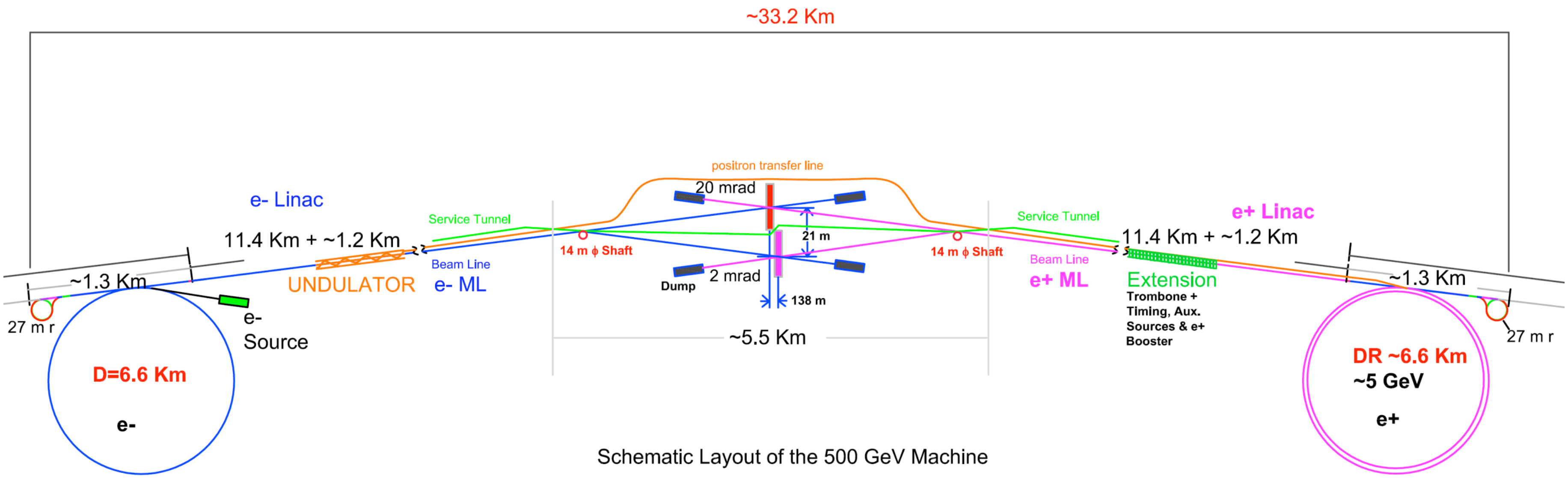
Design flexibility: ILC Parameter Plane

- Parameter plane established
  - TESLA TDR specified luminosity at 3.4×10^{34} but had a very narrow operating range
    - Designed for single operating point
  - ILC luminosity of 2×10^{34} is designed to be achievable over a wide range of operating parameters
    - Bunch length between 500 and 150 um
    - Bunch charge between 2×10^{10} and 1×10^{10}
    - 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

Energy Upgrade Path

- Linac energy upgrade path based on empty tunnels hard to ‘sell’
  - Empty tunnels obvious cost reduction
- Energy upgrade based on 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

ILC BCD Layout



Schematic Layout of the 500 GeV Machine

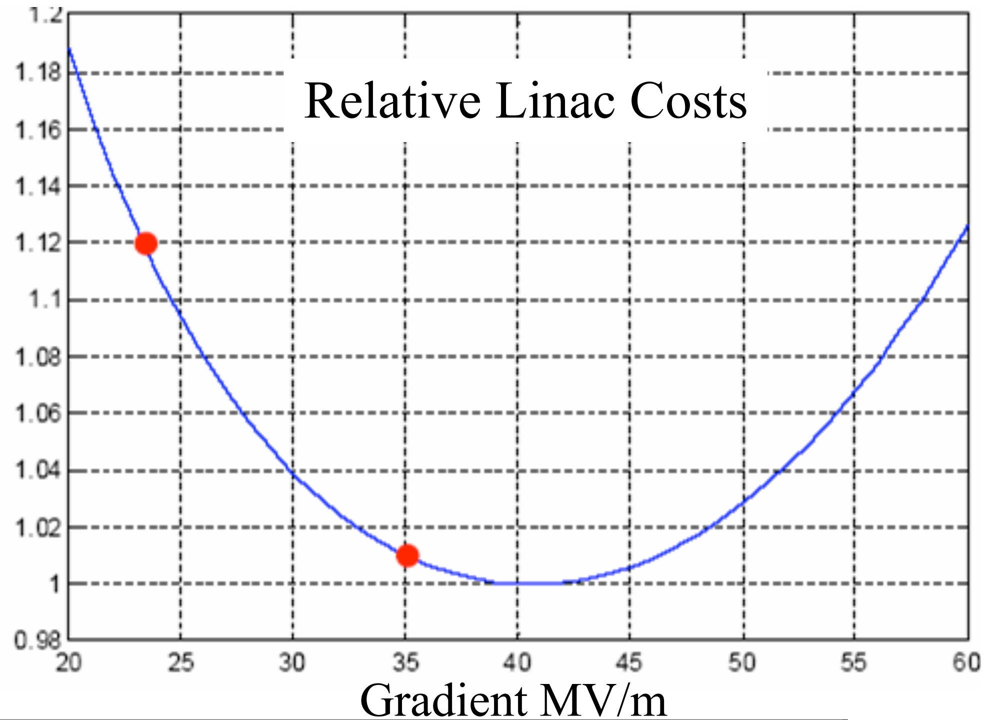
Main Linac

Main features:

- Cryomodule operating gradient of 31.5 MV/m
  - Qualify cavities at 35 MV/m in vertical tests
  - ~5% overhead for variation in installed cryomodules
  - ~5% overhead for operations (1~2 MV/m below quench)
- Packing fraction ~70%
  - Based on Type-IV cryomodule
    - Shorter cavity-cavity spacing (1.2λ vs $3\lambda/2$)
    - Quadrupole in center of cryomodule
  - Design evolution from Type-III cryomodules installed in TTF
- Installed RF power capable of 35 MV/m operation
  - 9.5 mA average current
- 3% additional rf units for repair & feedback

Operating Gradient Choice

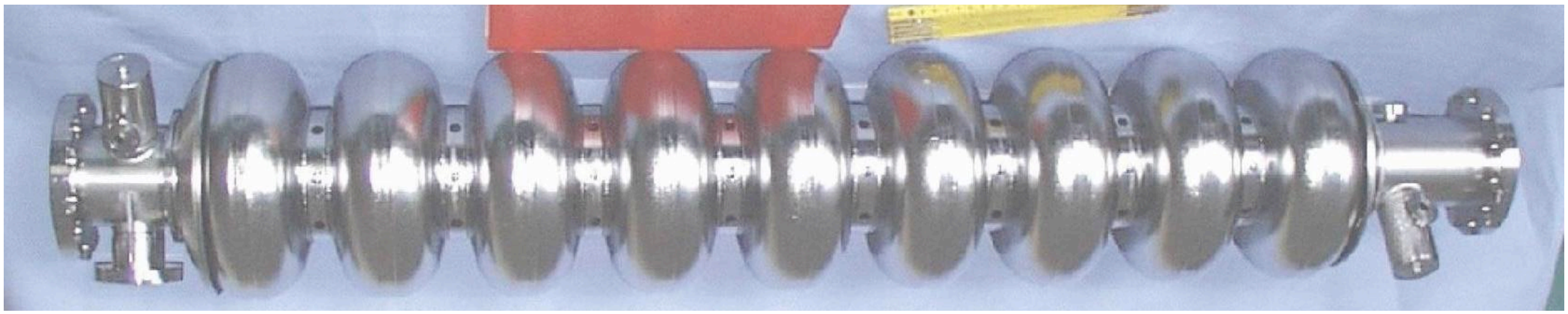
- Balance between cost per unit length of linac, the available technology, and the cryogenic costs
- Optimum is fairly flat and depends on details of technology



	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

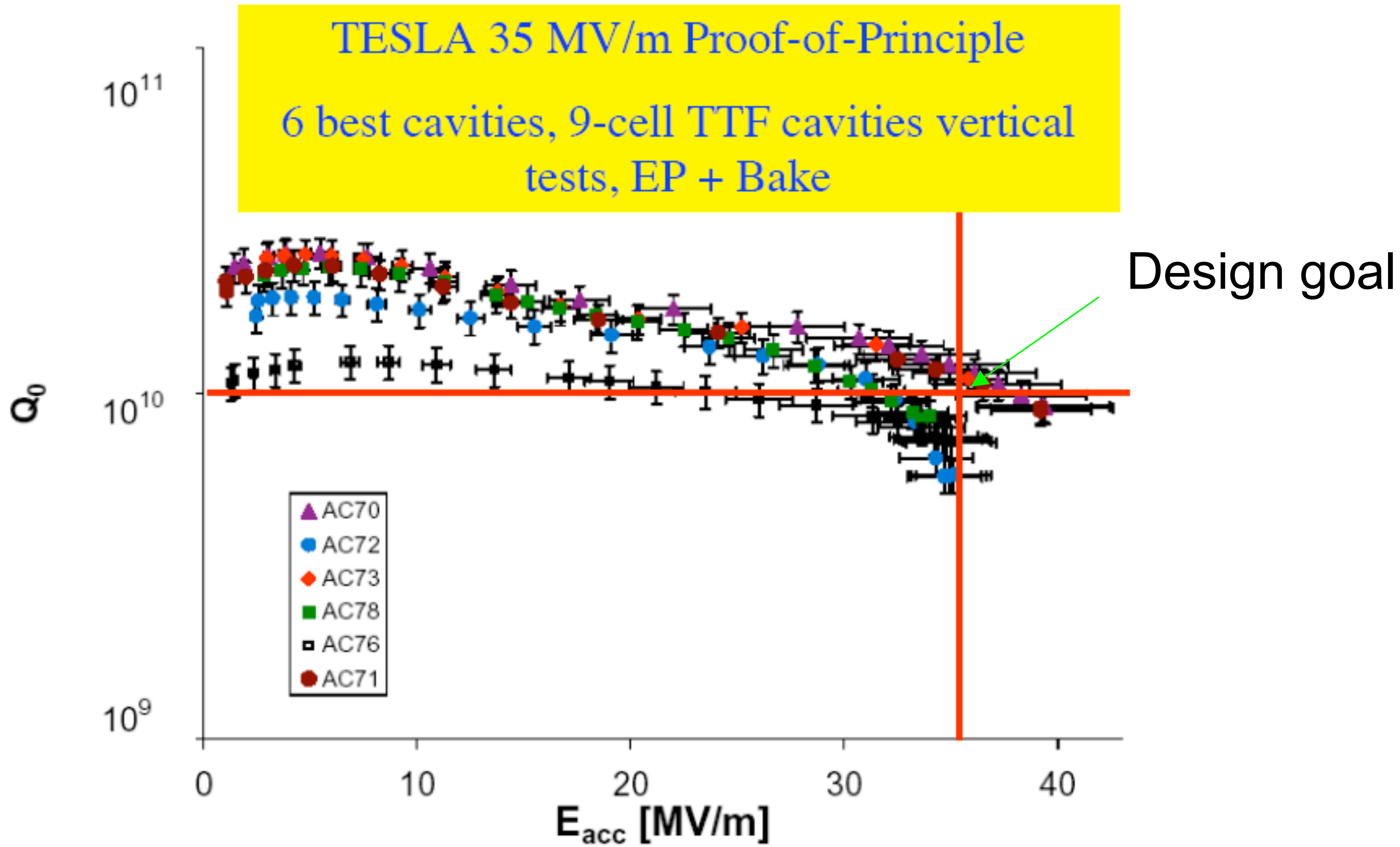
Superconducting RF Cavities

- SC cavities are center-piece technology for the ILC
  - Extensive R&D to understand fabrication techniques, increase gradients and Q's, and reduce costs

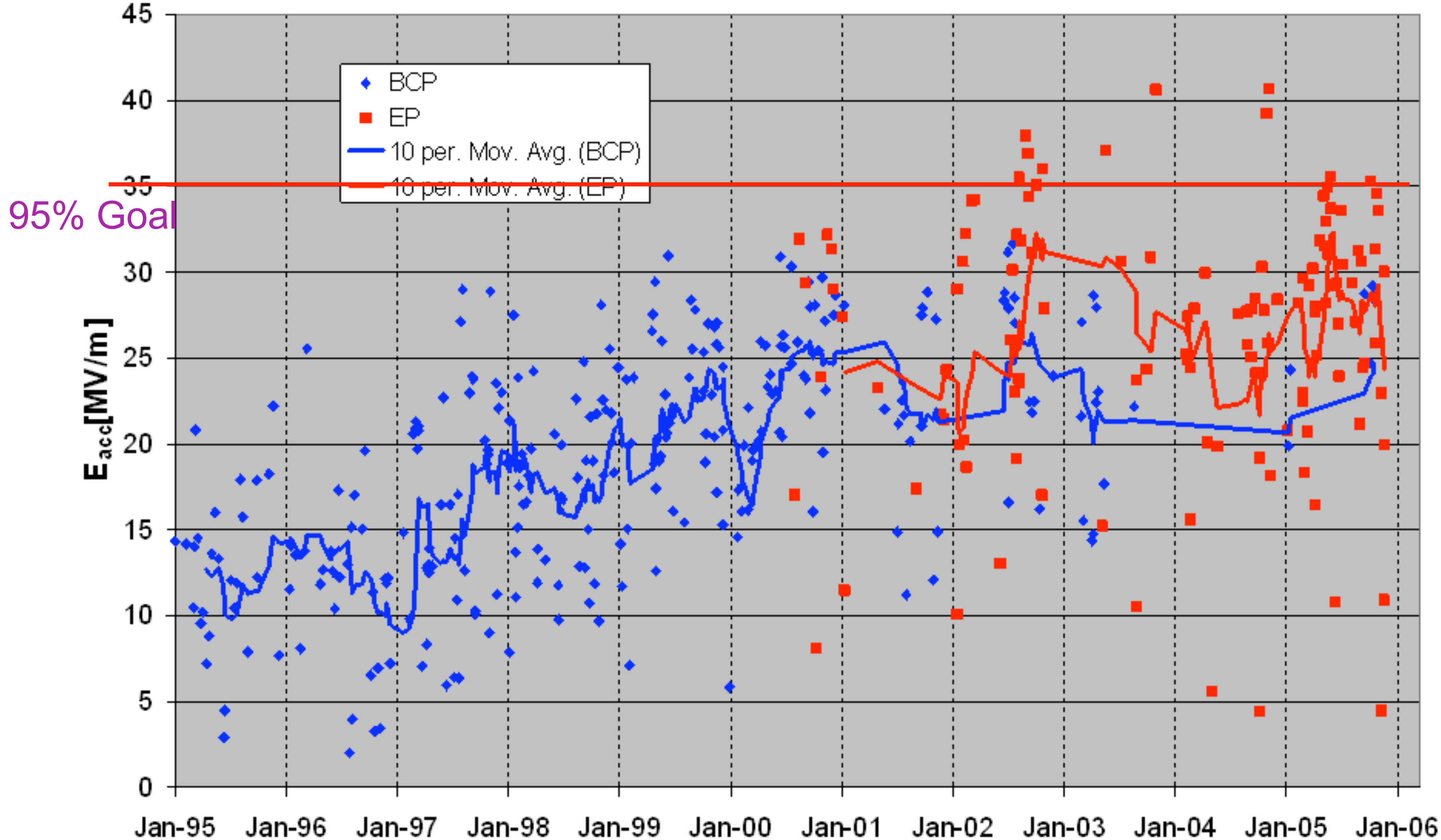


- TESLA SC cavities are well benchmarked
  - Working to fully understand process control and yield
- New concepts (ACD) are being investigated
  - Cavity shapes to optimize electromagnetic fields
  - Alternate materials to simplify processing or operate at higher fields

TESLA Style-Cavities

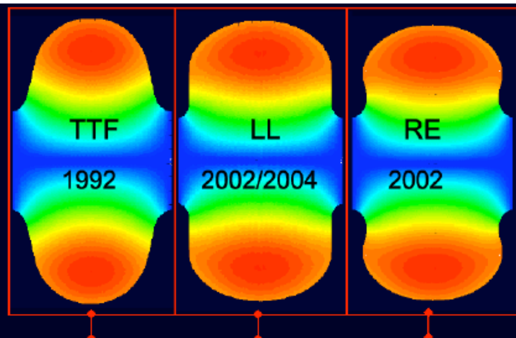


Achieved Cavity Gradients at DESY

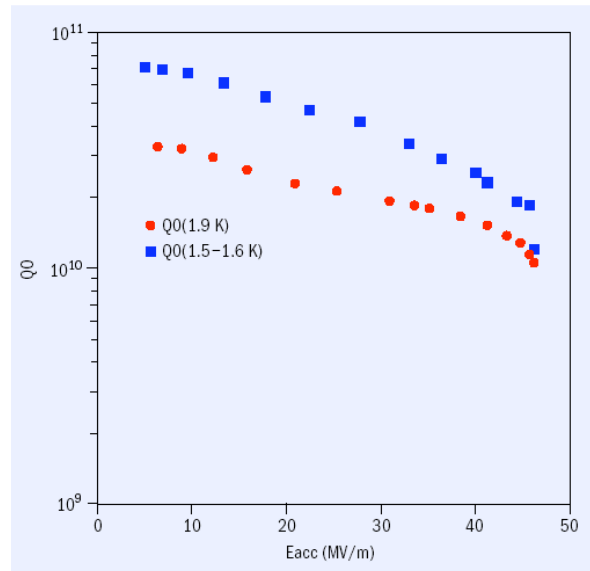


ACD-Improved Cavity Shapes and new materials

- Present SC rf cavity gradients are limited by high magnetic fields
  - Trade magnetic for electric fields by modification of cavity shape– single cavities ~ 50 MV/m



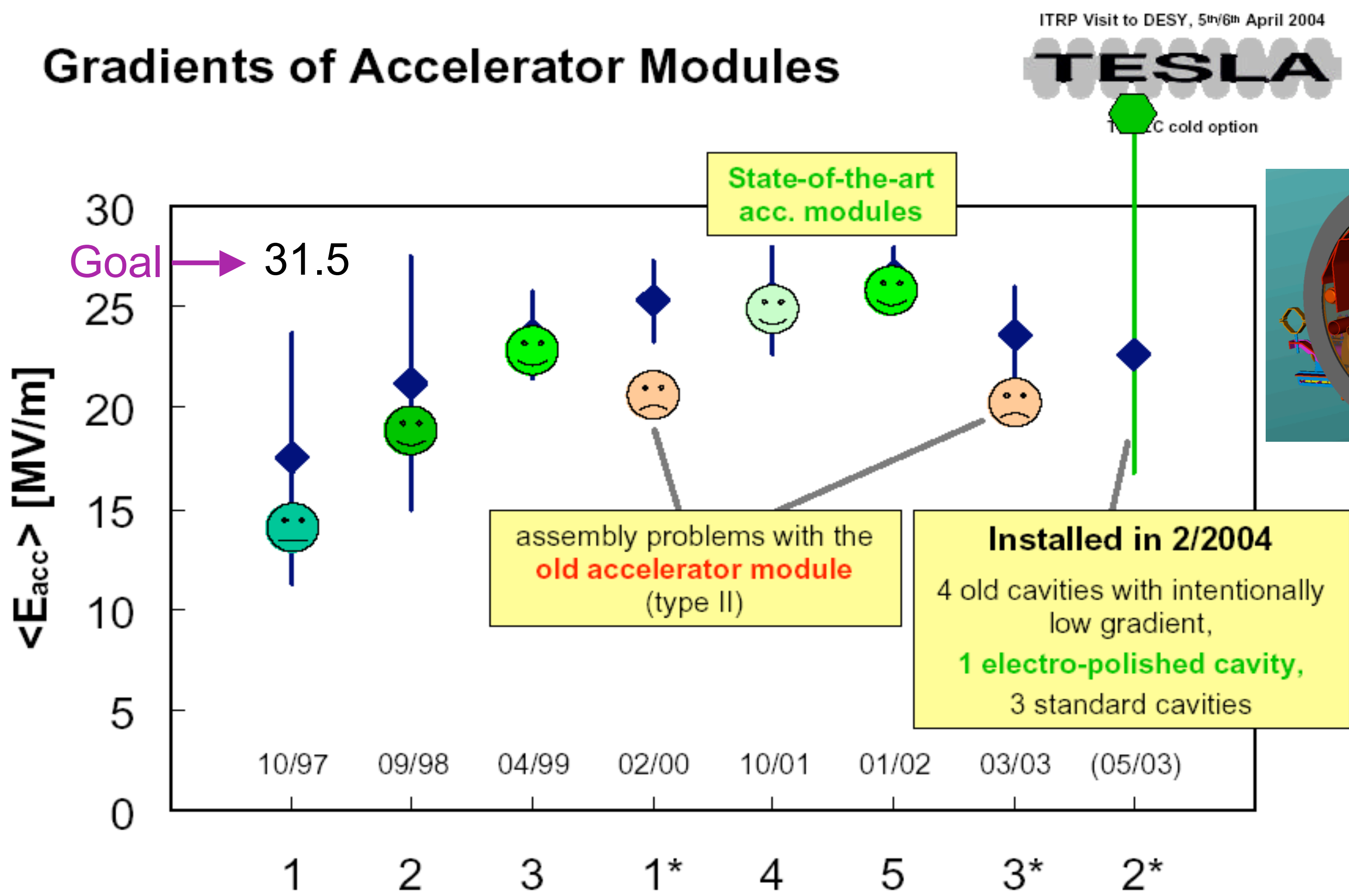
		TTF	LL	RE	
r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo limit)

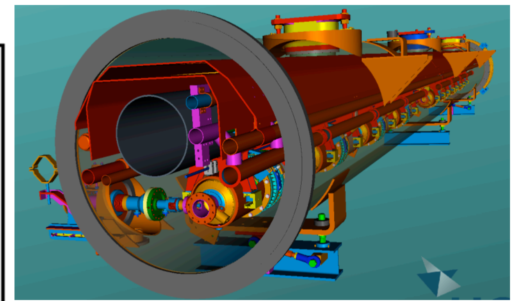


- Fabrication from large grain or single-crystal Nb discs:

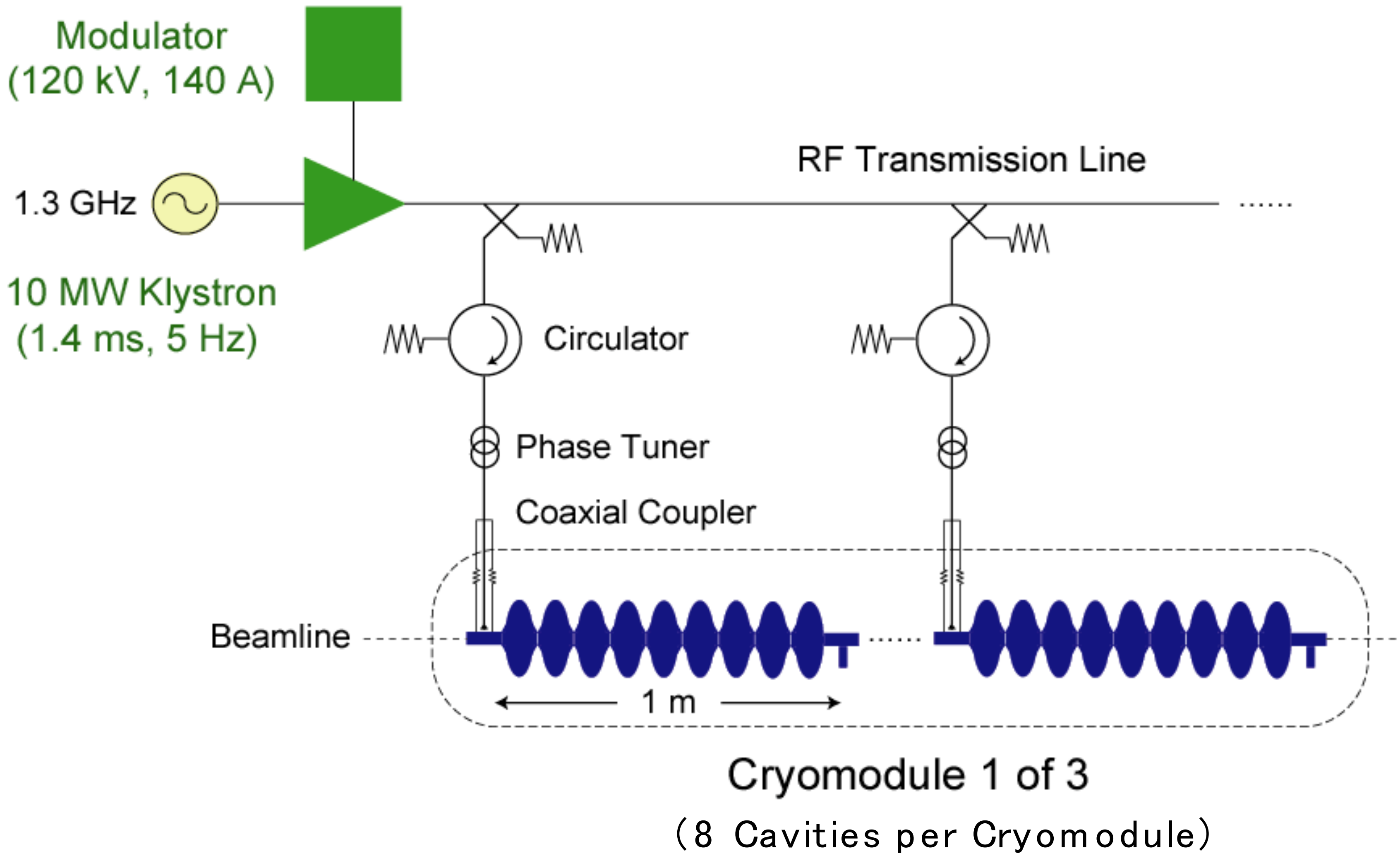
- May remove the need for electropolishing(↓ cost!)

Cryomodule performance



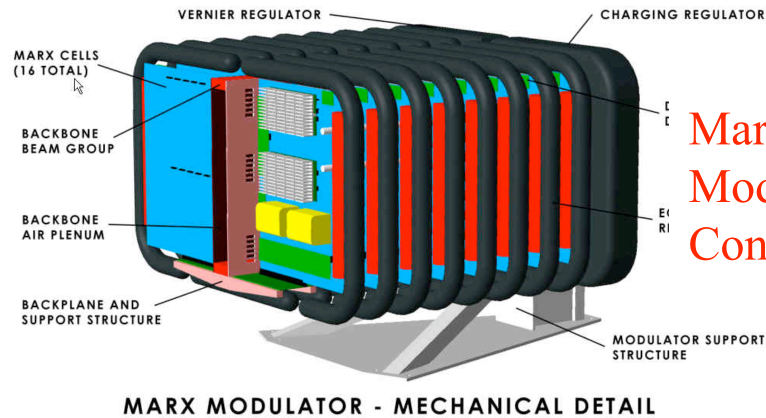


RF System


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

Modulators: Line AC →Pulsed DC

- Modulators create the 1.5 ms 120 kV DC pulses that drive the klystrons (switched capacitor banks)



Marx Modulator Concept-ACD

FNAL/TTF Modulator

Baseline

SNS Modulator

Baseline Klystron

- Multi-beam 10MW klystron for high efficiency in a cost effective package
  - Klystron efficiency depends on space charge forces ~ I / $V^{3/2}$

Thales

CPI

Toshiba

Specification:

10MW MBK

120 kV

1.5ms pulse

65% efficiency

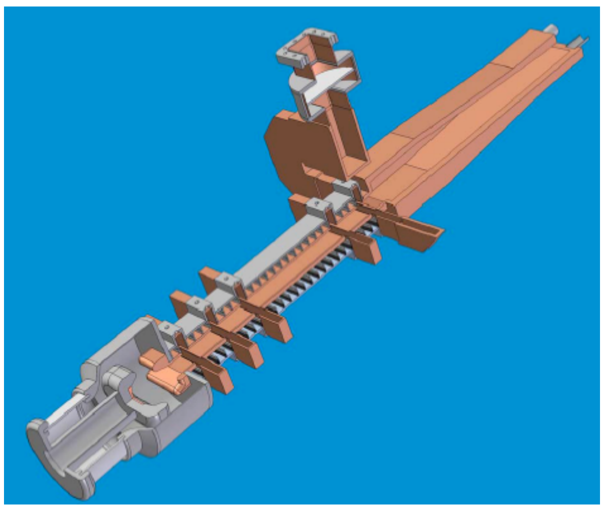
50,000+ MTBF

Requirements have not yet been met

ACD Klystron Options

10 MW Sheet Beam Klystron (SBK)

Parameters similar to
10 MW MBK but flat
beam reduces space charge

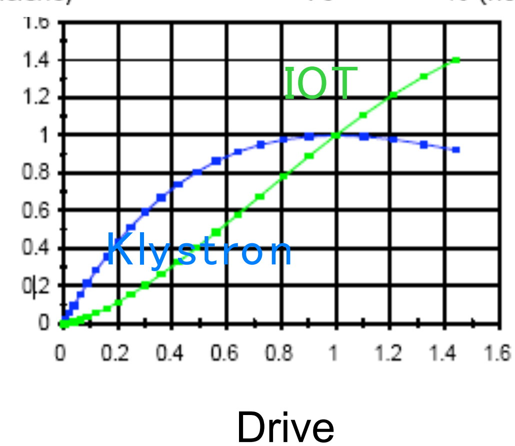


5 MW Single Beam Klystron

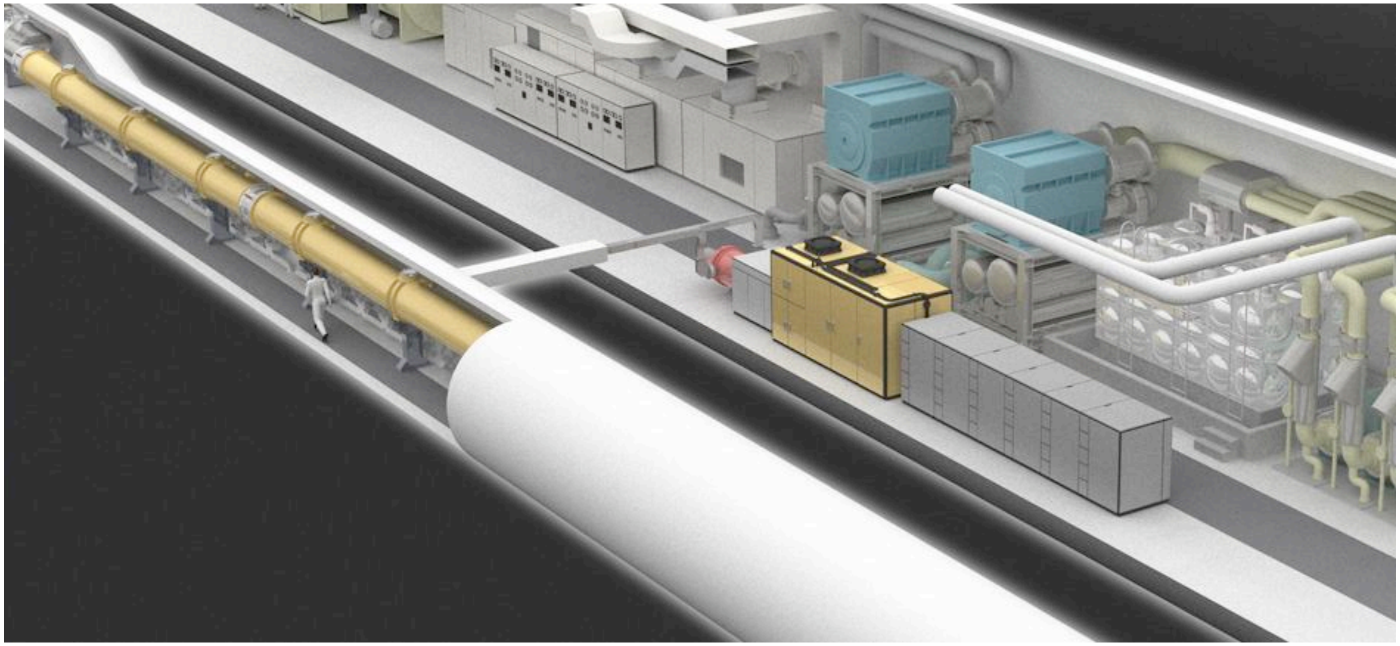
Higher voltage and lower current for low perviance and high efficiency

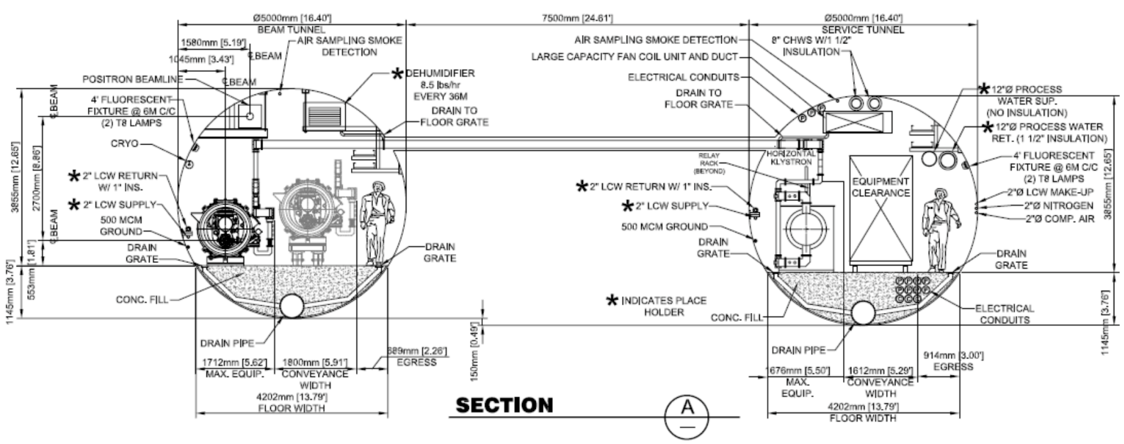
5 MW Inductive Output Tube (IOT)

Peak Output Power	5	MW (min)
Average Output Power	75	kW (min)
Beam Voltage	115	kV (nom)
Beam Current	62	A (nom)
Current per Beam	5.17	A (nom)
Number of Beams	12	---
Frequency	1300	MHz
1dB Bandwidth	4	MHz (min)
Gain	22	dB (min)
Efficiency	70	% (nom)



Main Linac Layout

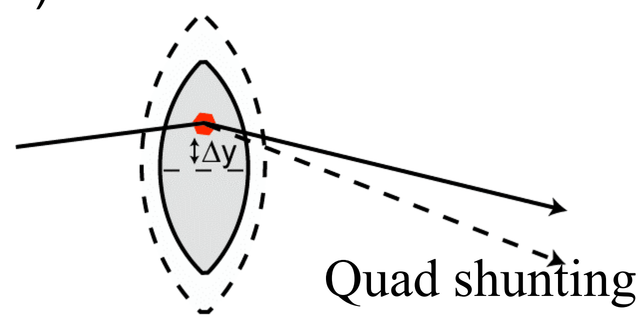




•Two tunnels: chosen to improve reliability and minimize surface presence
•Terrain-following

Linac Beam Dynamics

- Tolerances are comparable to those in SLC
  - 200~300 μm on the structures and 25 μm on the quadrupoles
- Structure alignment has been measured at TTF
  - Will get additional experience with new test facilities
  - Could be improved using beam-based diagnostics
- Multiple quadrupole beam-based alignment techniques
  - Quad-shunting (used in many places; FFTB demonstrated <7 μm)
  - Dispersion-Free Steering (tested on SLAC linac)
  - Ballistic alignment (tested in SLC)
  - Emittance bumps (used routinely in SLC)
- Should not prove to be an important limitation
  - Need stable magnetic centers
  - Present SC quadrupole probably will require stiffening

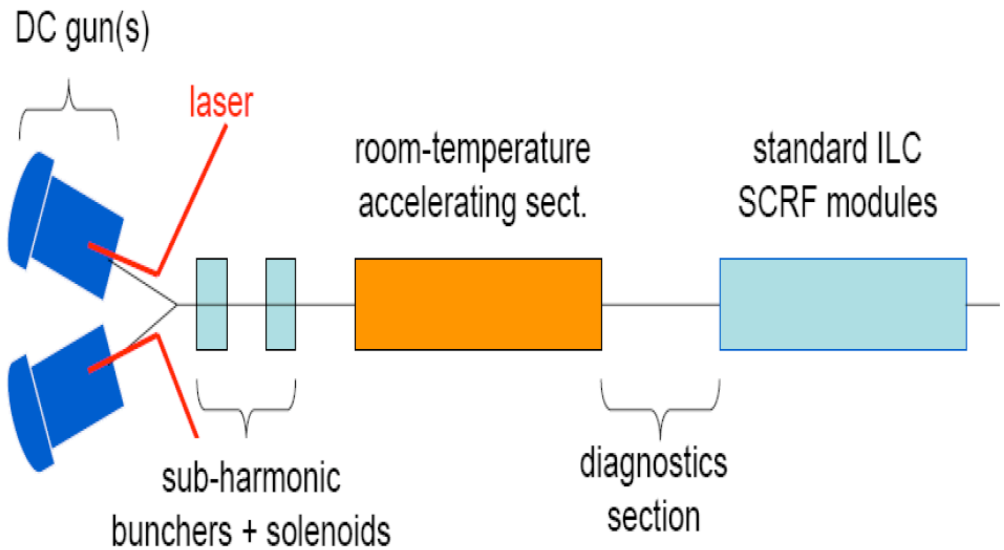


Linac Summary

- Extensive rf system technology development aimed at:
  - Demonstrating baseline (klystrons and cavities)
  - ACD options to improve efficiency and reduce cost (klystrons, modulator, RF distribution, and cavities)
- Two-tunnel, terrain-following layout
- Linac beam dynamics
  - Problems are relaxed compared to SLC and other sections of LC
    - Tight alignment tolerances within cryomodules
    - Beam-based alignment solutions exist
    - Instrumentation is key to understanding and diagnosing problems

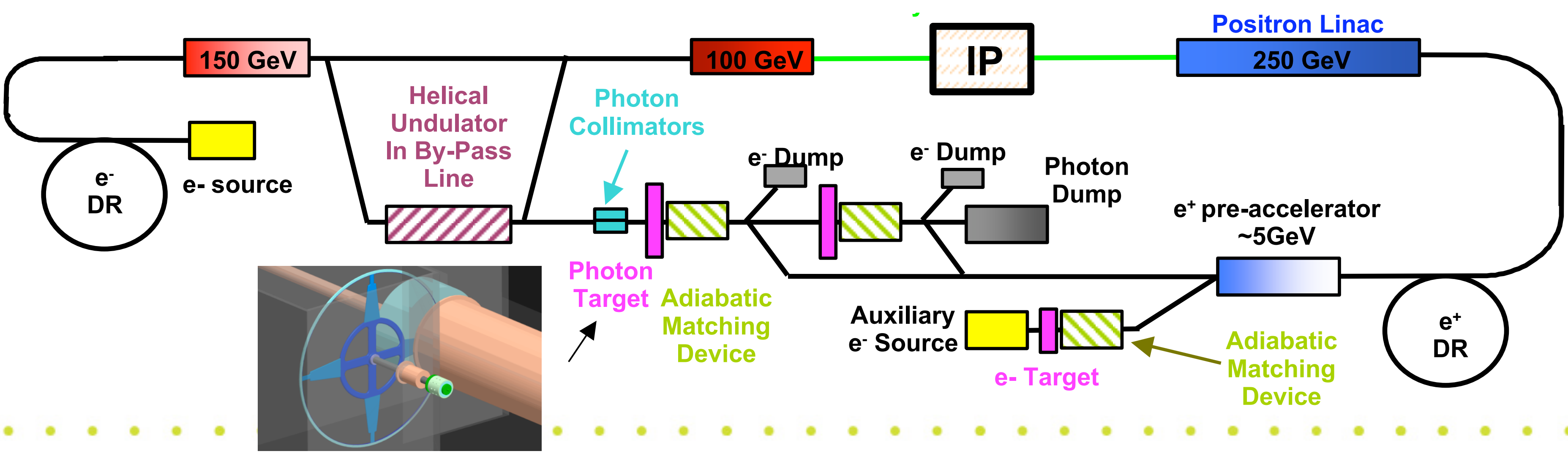
Electron Source baseline

- DC polarized photocathode electron source
- Titanium-sapphire laser emits 2-ns pulses that knock out electrons from a Ga-As photocathode; electric field focuses each bunch into a 250-meter long linear accelerator that accelerates up to 5 GeV
- Two guns for improved availability



Positron Source Baseline

- Snowmass debate between conventional, undulator, & Compton
- 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

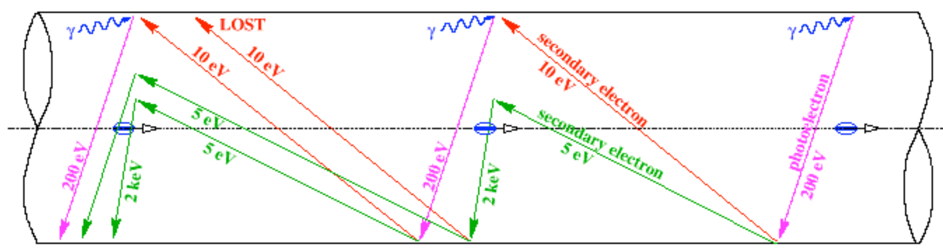


Damping Ring Issues

- Damping rings have many of the most difficult accelerator physics challenges in the ILC
- Required to:
  - Damp beam emittances and incoming transients
  - Provide a stable platform for downstream systems
  - 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 feedback systems because of very small extracted beam sizes and constant re-injection (operate with small S/N)
  - More sensitive to instabilities – effects amplified downstream

Collective Effects in ILC DR

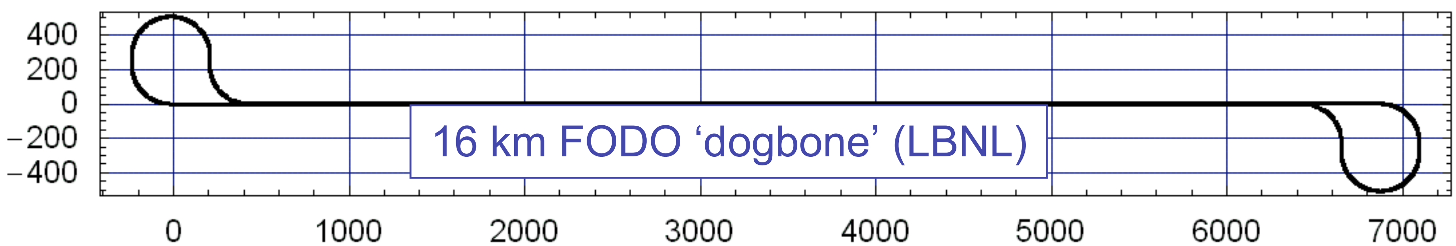
- Three main issues:
  - Classical single and coupled bunch instabilities
    - Effects well known but still hard to fully predict as they can depend on details in vacuum system design
  - Ion instabilities
    - Problem in the electron ring – requires gaps between trains
  - Electron cloud instability (ECI: specific to positron ring)
    - Secondary electrons from SR or scattered electrons can cascade



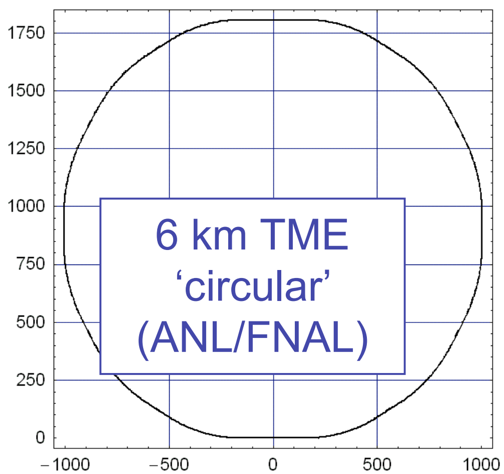
  - RF instabilities should be easier than in B-factories because of lower currents

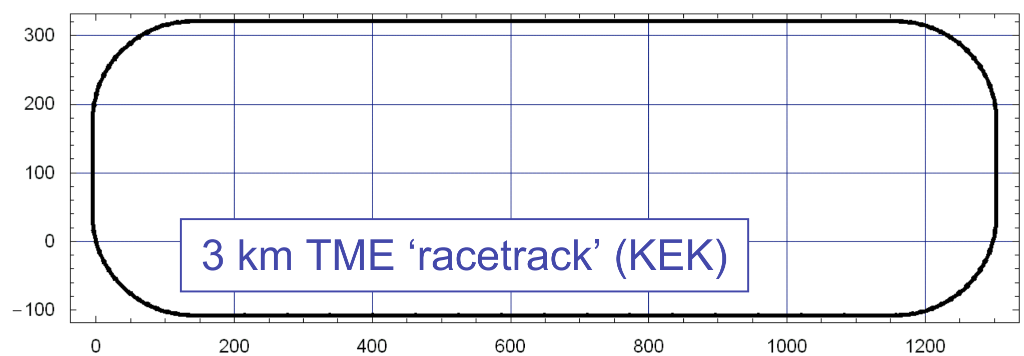
Damping Rings – BCD Choice

- In making the BCD choice, the DR group compared multiple lattice styles, looking at
  - Optics tuning and dynamic aperture
  - Collective instabilities (ECI, Ions, Space charge)
  - Cost



ACD



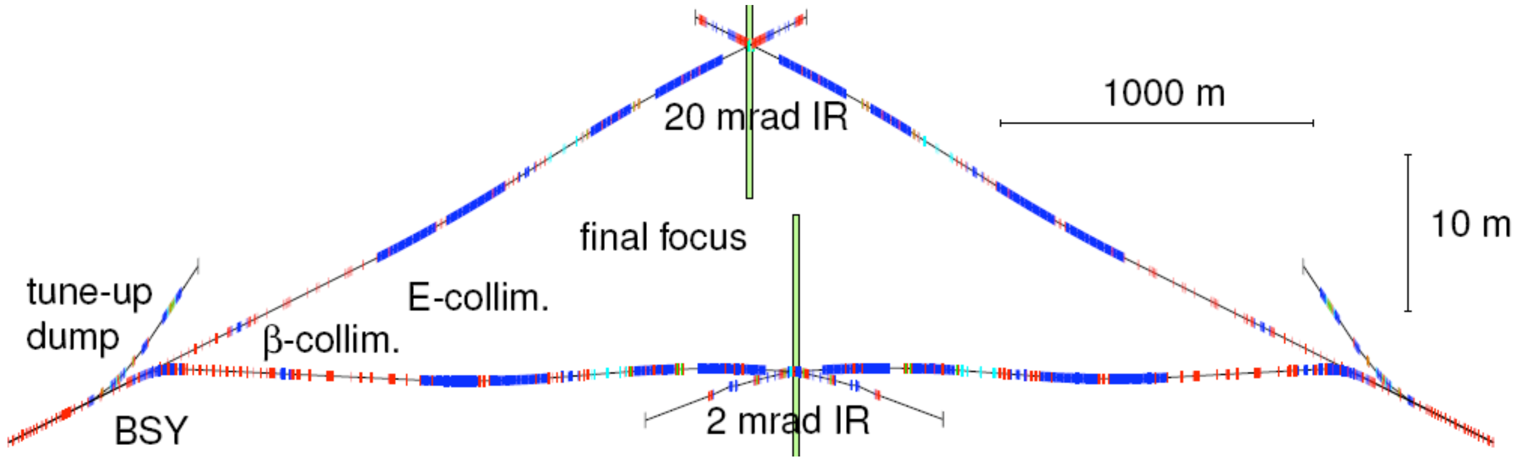


Baseline

Damping ring and bunch compressor baseline

- Circular damping rings 6.6 km in circumference
  - 5 GeV ring like TESLA and USTOS
  - 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 (to mitigate electron cloud issues)
- 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

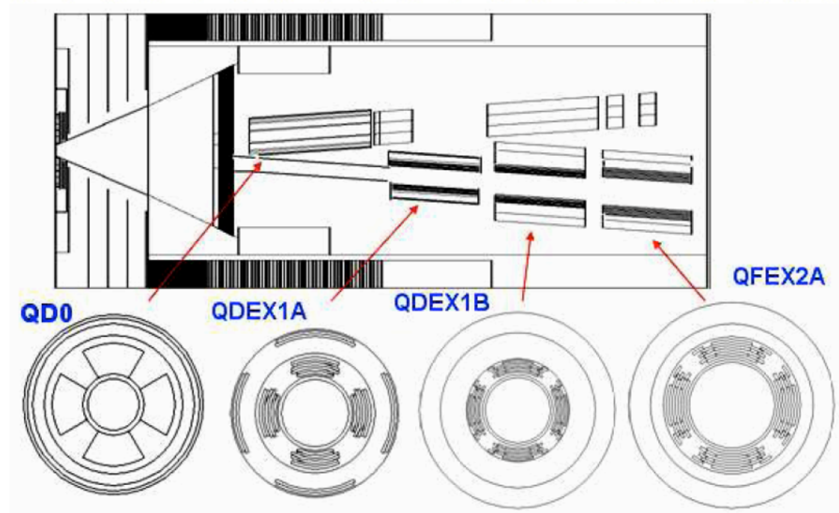
Beam Delivery System

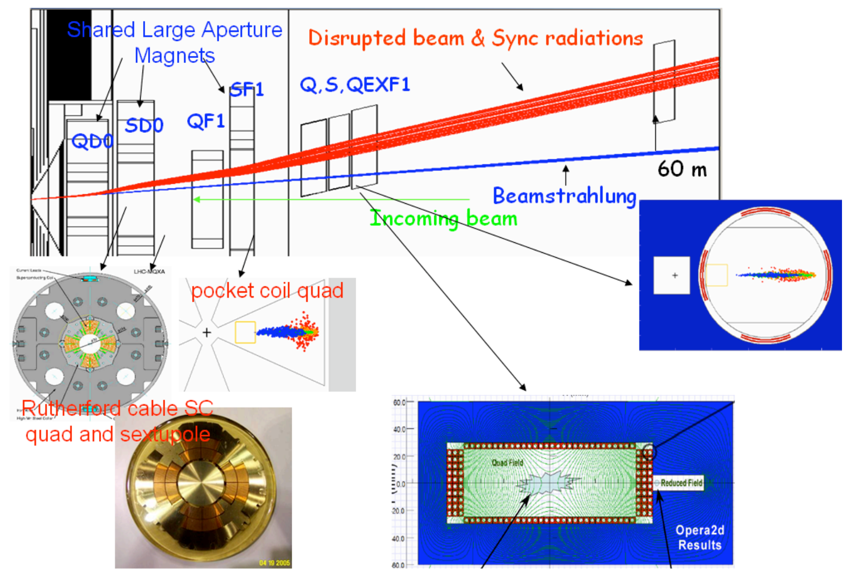


- Baseline
  - Two BDS's, 20/2mrad, 2 detectors, 2 longitudinally separated IR halls
  - Length is determined by synchrotron radiation: $\Delta\gamma\varepsilon \sim \gamma^6$
- ACD Alternative 1
  - Two BDS's, 20/2mrad, 2 detectors in single IR hall @ Z=0
- ACD Alternative 2
  - Single IR/BDS, collider hall long enough for two push-pull detectors

IR Design Issues

- Design of IR needed for both small and large crossing angles
- Pairs induced background similar in both cases
- Losses in extraction & background harder in 2 mrad
- Design optimization is ongoing – lots of work is needed
  - L*
  - Masking and collimation
  - Extraction line and dump design





Beam-Beam Force and Disruption

- Beam-beam force is a mixed blessing
  - Self-focusing increases luminosity ~ 1.7 for flat beams
    + Luminosity enhancement observed in SLC
  - Nonlinear focusing increases outgoing beam emittances
    - Larger aperture extraction lines – recapture difficult
  - Strong beam-beam forces lead to beamstrahlung → energy spread
    + Broad luminosity spectrum and increased energy aperture in extraction line
  - Beam-beam forces amplify offsets of beams
    + Allow for IP feedback at nm-level – essential for collisions
    - Two-stream instability (“kink”) can make collisions unstable
- Shorter bunches decrease disruption of opposing beam but increase EM fields and beamstrahlung
  - Optimization during operation is likely important

Operational Issues

- Integrated luminosity is the goal-baseline machine availability requirement is 75%
- Operational issues are hard to quantify
  - Beam and hardware diagnostics are crucial
  - We know that, to meet the availability spec, component MTBF must be much larger (~x10!) than in conventional accelerators
    - Design for high availability (HA) – lots of experience from industry
  - Operational experience from existing accelerators hard to interpret
    - Most operating accelerators have had diagnostic electronics accessible during operation
    - TESLA TDR based on a cheaper single tunnel concept but present baseline is based on a dual tunnel configuration
  - Need to understand HA designs, develop prototype electronics hardware, and develop detailed monte-carlo with modeled tuning times

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
- Active R&D program (baseline and ACD) to address technical and cost risks and improve the baseline
  – GDE Global R&D Board is working to coordinate the program