An A-Z Guide to the Linear Collider

Steve Playfer

University of Edinburgh

Report on the ILC Forum,

Cosener's House, May 2006

Fermilab Today

April 1, 2006

April Fools' Edition

Calendar

Friday, April 1

10:00 a.m.-12:00 a.m. National Theory Appreciation Day

In honor of National Theory Appreciation Day, the Fermilab Theory Department will be serving free coffee and chocolates on the 3rd floor of Wilson Hall.

3:30 p.m. DIRECTOR'S WINE TASTING

4:00 p.m. Joint Experimental Theoretical Physics Seminar

Speaker: BingXin Gong

Title: The Uncertainty Principle is Untenable

Monday, April 4

3:30 p.m. DIRECTOR'S KEG PARTY

8:21 p.m. Special Arts Series Event:

The final game of the Men's NCAA

CDF, DZero to Trade Spaces

Spokespersons say CDF will freshen up DZero's image.

In an effort to spruce up their respective experiments and to maintain the highest standards of scientific objectivity, the

ILC NewsLine

FNAL's Mishra chosen to chair the ILC GDE's Acronym Recommendation Group

With the completion of the BCD and work well underway on RDR, the ILC GDE's EC has formed an Acronym Recommendation Group (ARG). Chaired by FNAL's Shekhar Mishra, the ARG will ensure that ILC design progress proceeds unimpeded by complications of combinations and permutations.

Shekhar Mishra

Welcome to TLA-land …

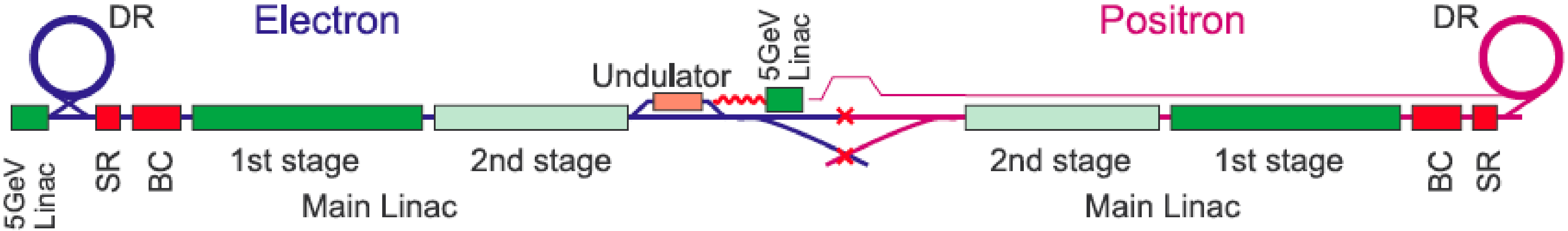
- I (international)
- L (inear)
- C (ollider)

- G (lobal)
- D (esign)
- E (ffort)

- R (eference)
- D (esign)
- R (eport)

- B (aseline)
- C (onceptual)
- D (esign)

I(nternational) L(inear) C(ollider)

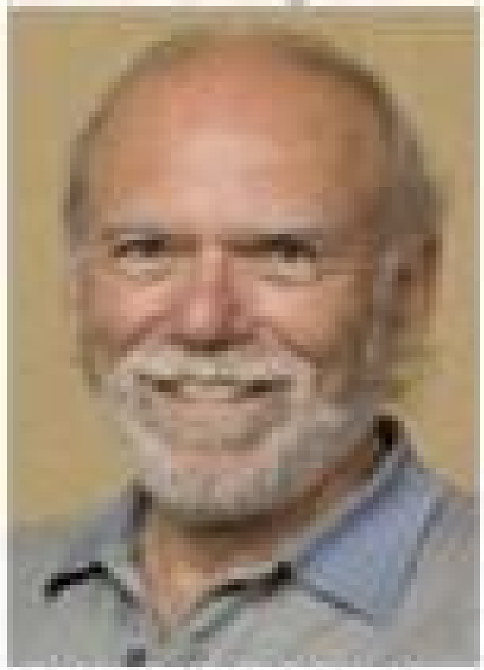


First stage CM energy = 500 GeV

Second stage CM Energy = 1 TeV

G(lobal) D(esign) E(ffort)

Director



Barry Barish

Regional Director-Americas

Gerald Dugan

Regional Director-Europe

Brian Foster

Regional Director-Asia

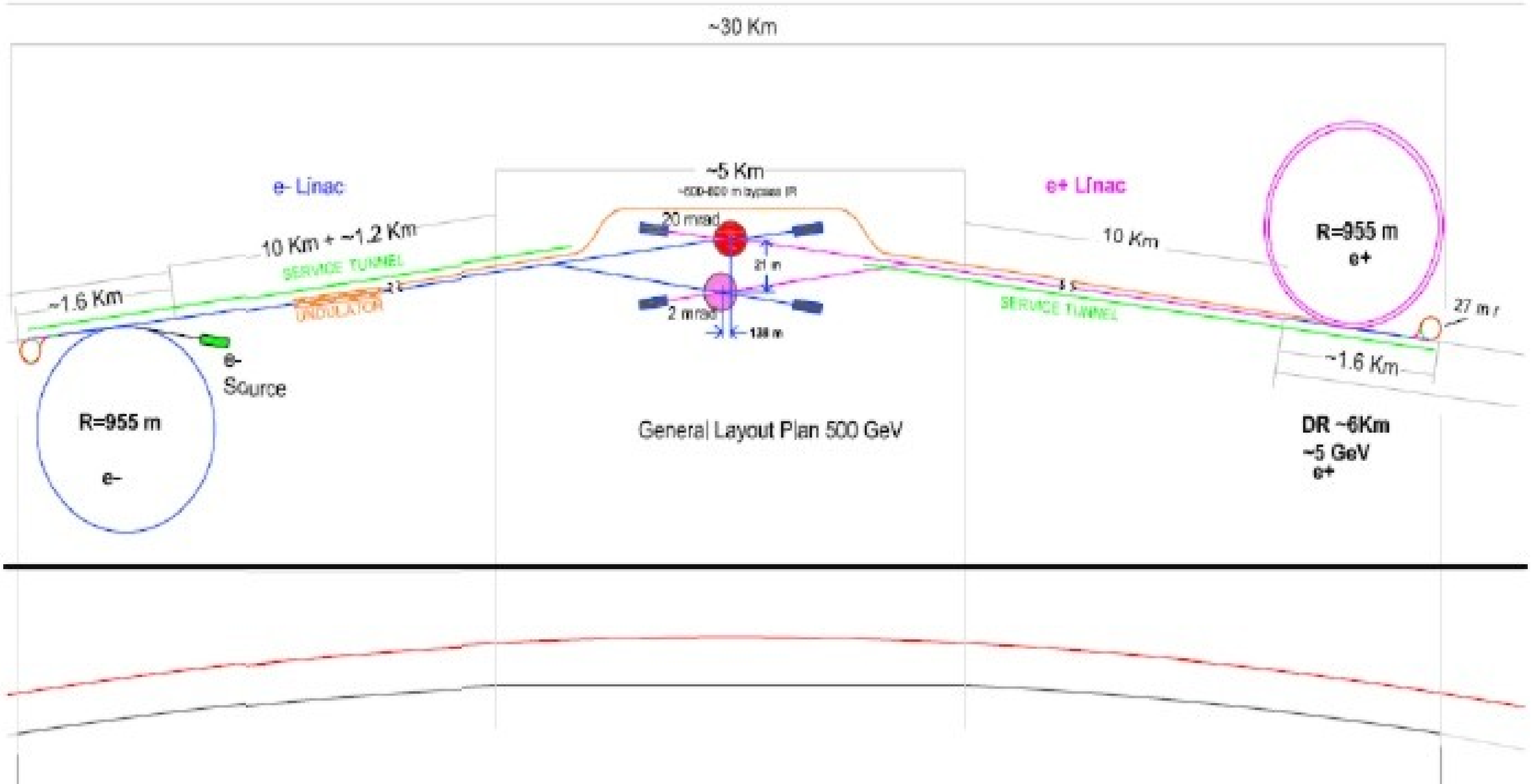
Mitsuaki Nozaki

+ about 60 people distributed equally over the three regions

B(aseline) C(onceptual) D(esign)

Described in 300 page document released in December 2005

http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home



Accelerator Requirements

- Luminosity = 500/fb over 4 years
- Ability to scan CM energy from 200-500GeV
- Energy stability and precision 0.1%
- Electron beam polarizable >80%
- Options for e^-e^- and $\gamma\gamma$ collisions
- Must be upgradeable to 1TeV

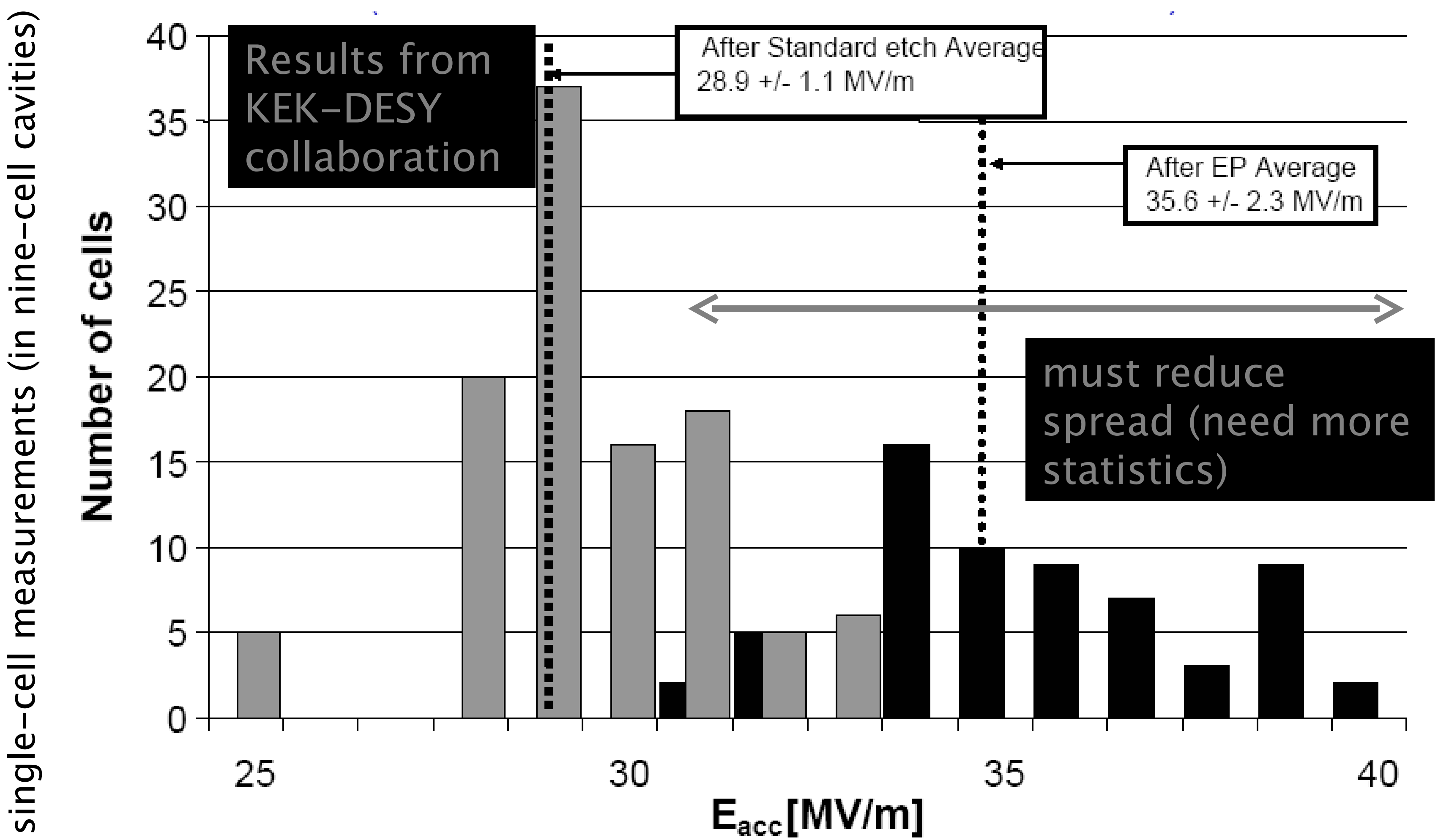
Operating Parameters

- Instantaneous luminosity $2x10^{34}/cm^2/s$
- 1000-6000 bunches with $1\text{-}2x10^{10}$ e
- Short bunch length σ_z =150-500 μm
- Final focus σ_x=500 nm, σ_y=4-8 nm
- Beam power 5-11 MW
- Linac accelerating gradient 31.5MV/m

In terms of numbers of components the ILC is 10x larger than any previous accelerator - reliability is an issue!

S(uper)C(onducting) R(adio)F(requency) cavities

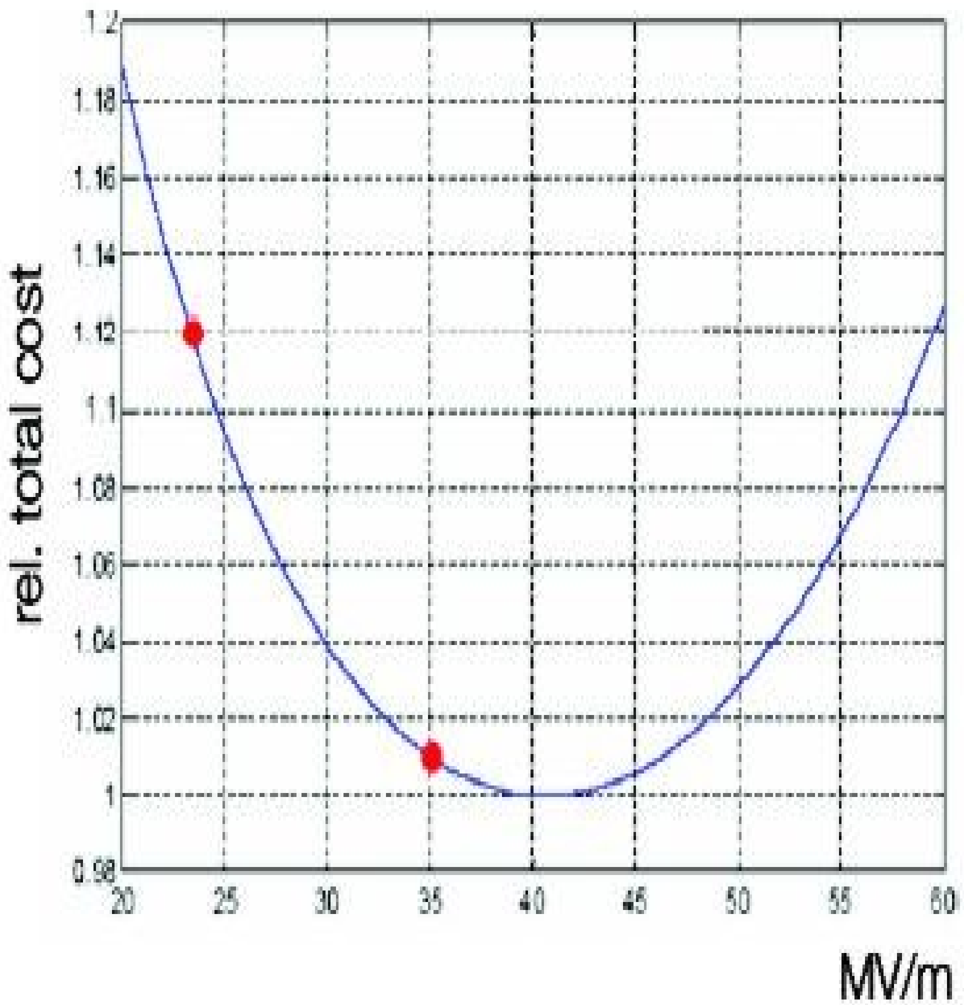
The 31.5MV/m Gradient is a problem!



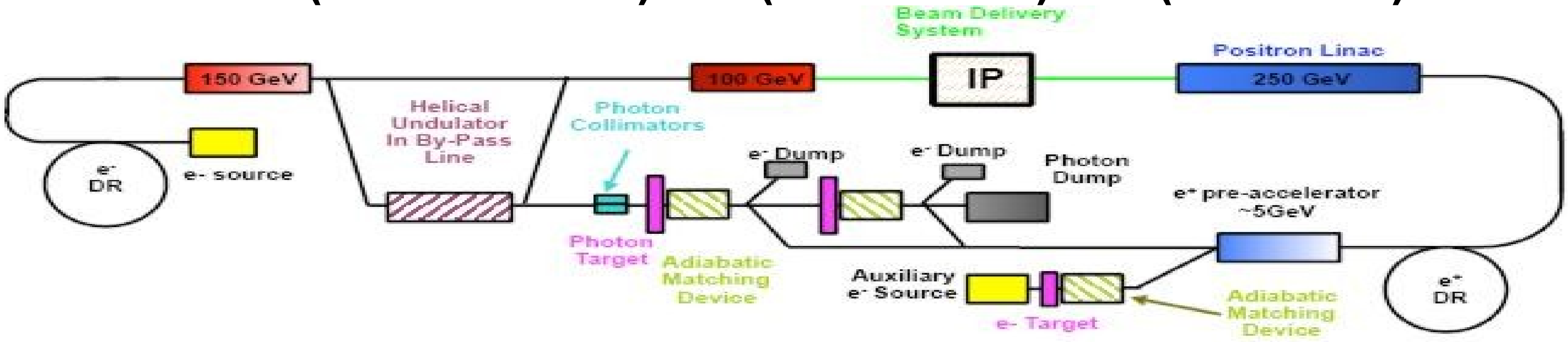
Test facilities being set up at DESY, Fermilab and KEK

Choice of Gradient

- Choice is almost cost neutral!
- Balance between length of tunnel and difficulty of making RF cavities
- Baseline design for 500GeV uses 31.5MV/m over 10.6km
- Upgrade plan to 1TeV assumes 36MV/m over 9.3km



U(ndulator) P(ositron) S(ource)



- Put 150GeV electrons through undulator
  - Possible to produce polarized positrons
- Convert synchrotron photons on a Ti target
  - Limited lifetime due to radiation damage
- Capture and focus positrons in 400MeV linac
- Accelerate to 5GeV in superconducting linac
- Inject into positron damping ring

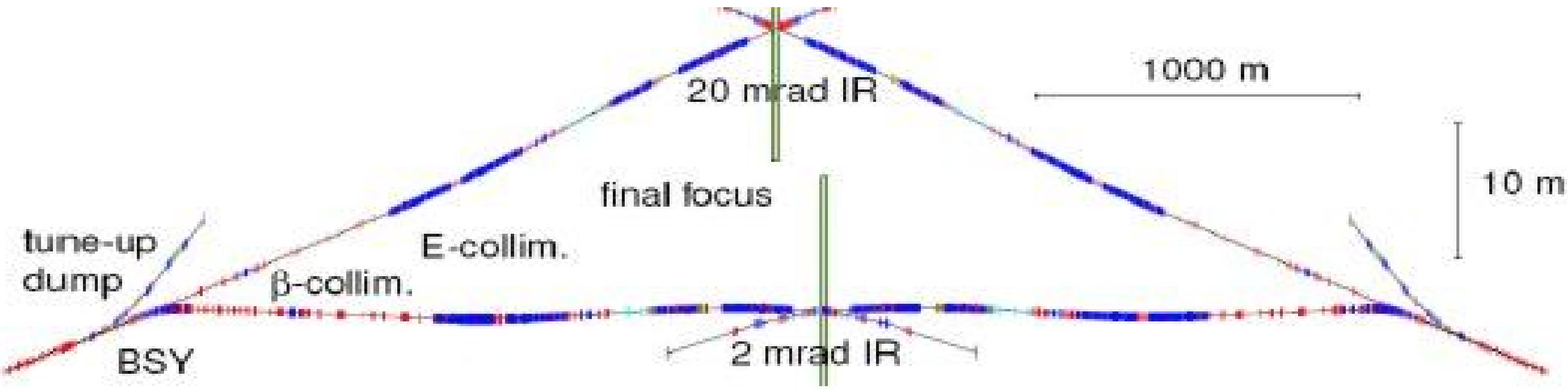
D(amping) R(ings)

- Circumference 6-12 km
- Beam energy 5GeV
- RF frequency 500-650MHz
- Use wigglers in straight sections to damp the emittance from 10^{-2} mrad to $\varepsilon_x=10^{-5}$, $\varepsilon_y=10^{-8}$
- Damping time 25 ms
- 3000 bunches of length 6mm in a 1ms train
- Currents x10 less than PEP-II/KEKB

Damping Ring Issues

- Hardest accelerator issues for ILC
  - Remember what happened at SLC!
- Need 99% availability
- Problems with collective instabilities
  - Electron cloud in positron ring
- Dynamic aperture is a challenge
- Need fast kickers for extraction into main linac
- Bunch compression to 500μm after extraction

B(eam) D(elivery) S(ystem)



- Plan for two interaction regions with 2mrad and 20mrad crossing angles
  - One of them for $\gamma\gamma$ as well as e^+e^-
  - Two detectors to cross-check results
  - No gain in integral luminosity!

I(nteraction) R(egions)

- Superconducting quadrupoles for final focus
  - Separate for each beam (20mrad crossing angle)
  - Common to both beams (2mrad crossing angle)
- Crab cavities needed for large crossing angle
  - 3.9GHz design being tested at Fermilab
- Main background is beamstrahlung (e^+e^- pairs)
  - Background similar for both crossing angles?
- Beam diagnostics important for ~nm beams
  - Fast feedback to adjust optics
  - Geological stability of site!

Physics at the ILC

- Precision measurements of electroweak symmetry breaking in the S(tandard) M(odel)
- Couplings and rare decays of Higgs boson(s)
- Couplings and rare decays of top quark
- Direct searches for N(ew) P(hysics), in particular SU(per)SY(mmetry)
- Indirect searches for NP through precision measurements
- Search for dark matter candidates

Interplay between LHC and ILC

G.Weiglein et al,hep-ph/0410364 (472 pages!)

- LHC
  - Composite protons
  - Strong interaction
  - E(CM)<14TeV
  - Selective triggers
  - Many jets
  - No polarization
- Direct discovery machine at high energy frontier

- ILC
  - Pointlike electrons
  - EM interaction
  - E(CM)=0.5-1TeV
  - All events trigger
  - Clean final state
  - Polarized beams
- High precision machine with tunable CM energy

Top Quark measurements

- m_t = 172.5(2.3)GeV at Tevatron

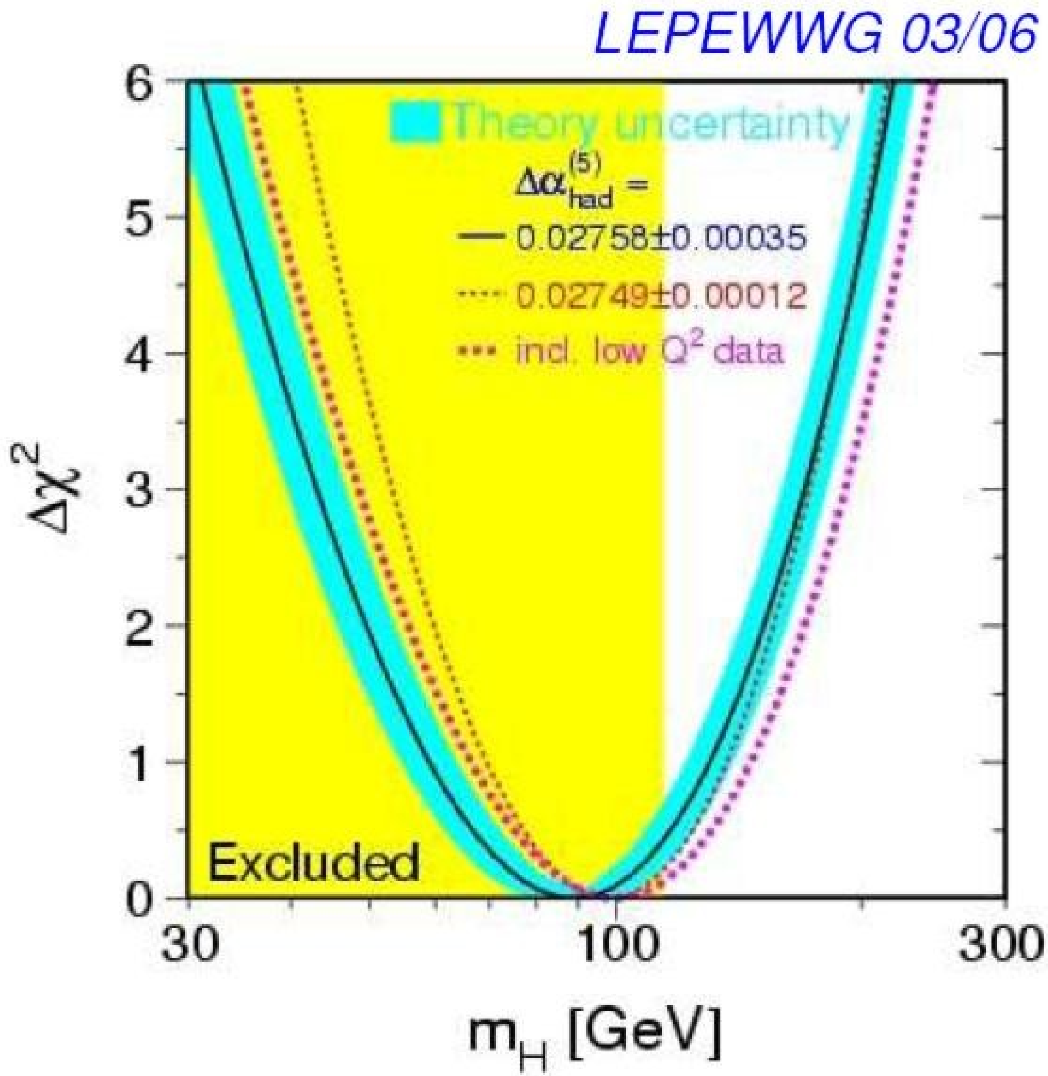
  Δm_t ~ 1 GeV at LHC

  Δm_t ~ 100 MeV at ILC (threshold scan)

  - Important input to Electroweak precision measurements (loop corrections)
- Test t couplings to γ, Z
- Measure H–>tt coupling
- Rare decays t–>s(d)

Standard Model Higgs Boson

- $114 < m_H < 207$GeV from LEP
  - $\Delta m_H \sim 150$ MeV at LHC
  - $\Delta m_H \sim 50$ MeV at ILC
- Verify spin S=0
- Measure Higgs couplings
  - 15-40% at LHC
  - 1-5% at ILC
- Triple Higgs self-coupling
  - ~20% at ILC
- CP properties of Higgs
- Disentangle SM Higgs from lightest SUSY Higgs

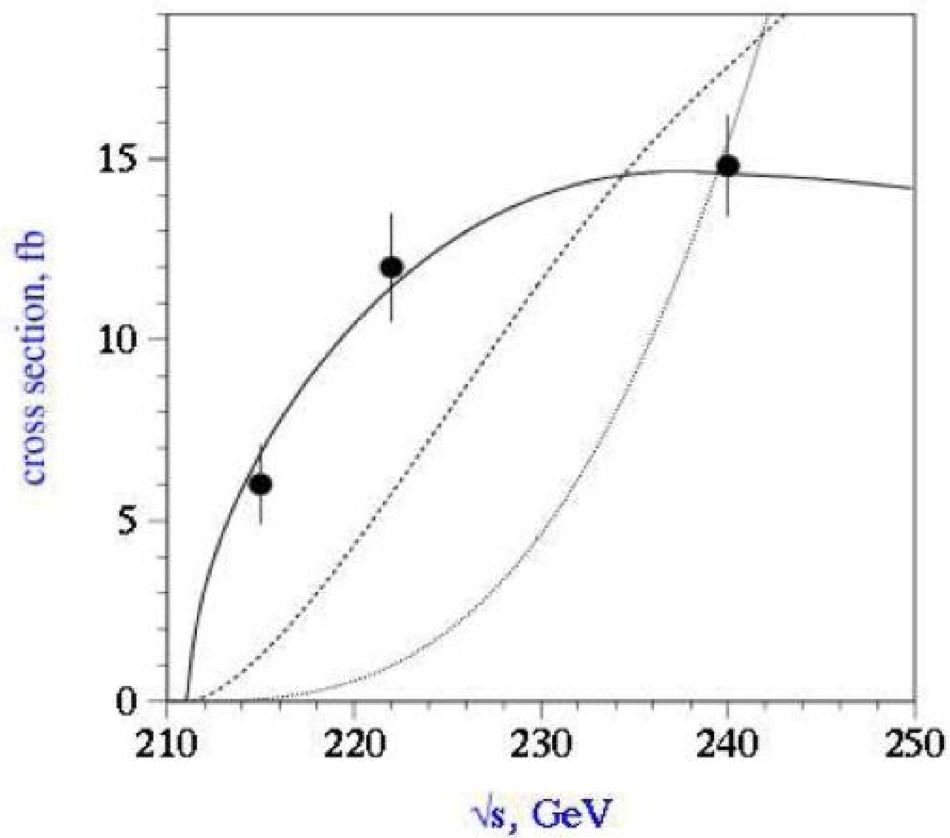


Higgs spin/parity

- Spin from threshold scan of

  $e^+e^- \to HZ$
- Parity from

  $H \to \tau\tau$ decay
- CP odd/even from angular distributions



Supersymmetry

- At least some light SUSY particles < 500GeV
  - LHC finds neutralino/charginos < 250GeV
  - LHC finds squarks/gluinos < 2TeV
  - ILC is better for sleptons/sneutrinos
- Measure L(ightest) S(upersymmetric) P(article) mass to accuracy of 0.3%
  - Use e^+e^- –> slepton pairs at threshold
  - Good dark matter candidate!
- Precise determination of 5 fundamental parameters of M(inimal) S(upersymmetric) S(tandard) M(odel) to few %

Extreme SUSY Challenge

- Squarks and sleptons heavy ~2 TeV
- Light gluino, chargino, neutralino
  - ILC only produces $e^+e^- \to \chi^+\chi^-$
  - LHC produces $\chi^0_{1,2}$ from gluino decay
- With polarized beams and excellent charm tagging at ILC can still measure all the MSSM parameters, and predict all the heavy mass partners!

“Don’t be afraid of heavy TeV particles!” (Gudi Moortgat-Pick)

Don’t have to produce them directly to determine their masses.

Other ILC Physics

- New sources of CP violation
- Extra Dimensions
  - K(aluza)-K(lein) states
  - Graviton by $e^+e^- \rightarrow \gamma G$
- Higher Z' resonances
- Improved limits on pointlike electrons
- Giga-Z production with polarized beams

  $\Delta \sin^2\theta_W = 1\text{-}5 \times 10^{-5}$

What if the LHC finds …?

(*An informal discussion led by Bill Murray)*

- Nothing
  - End of particle physics?
  - No ILC because top quark isn't worth $10B
- Standard Model Higgs
  - Boring but we should measure its properties
  - How much can LHC do?
  - Is the added precision of ILC worth the cost?
  - Unclear if ILC will be approved in this scenario
- New Physics (e.g. SUSY)
  - Dawn of golden age of particle physics
  - ILC approved and built as soon as possible
  - Lots of studies of the synergy between ILC and LHC for many New Physics scenarios

Welcome to ILC Detector-Land

- S (ilicon)
- i (nner)
- D (etector)

Led by US

- G (aseous)
- L (arge)
- D (etector)

Led by Japan

- L (arge)
- D (etector)
- C (oncept)

Led by Europe

+ 4th Detector Concept

(which nobody believes in)

SiD

From L–>R decreasing magnetic field from 5 –>3T and increasing solenoid radius from 2.5 –> 3.5m

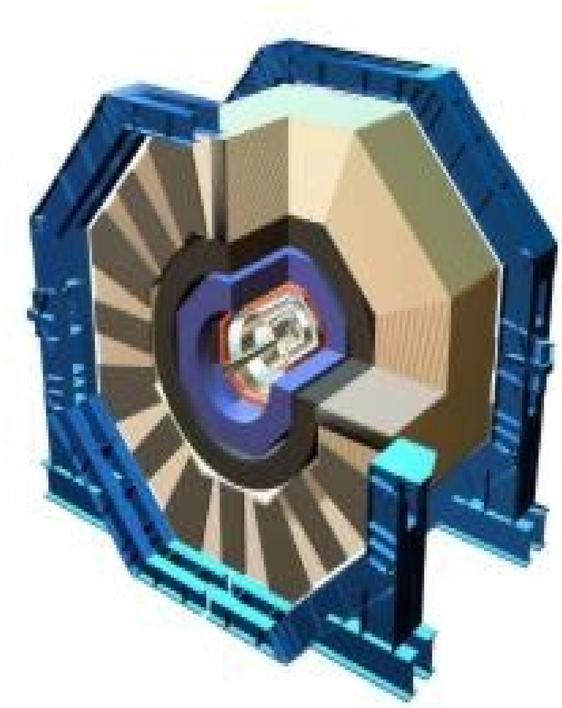
http://www-sid.slac.stanford.edu

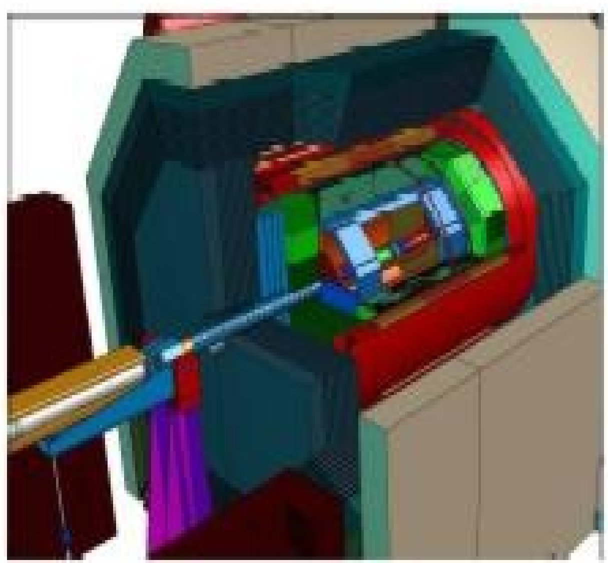
LDC

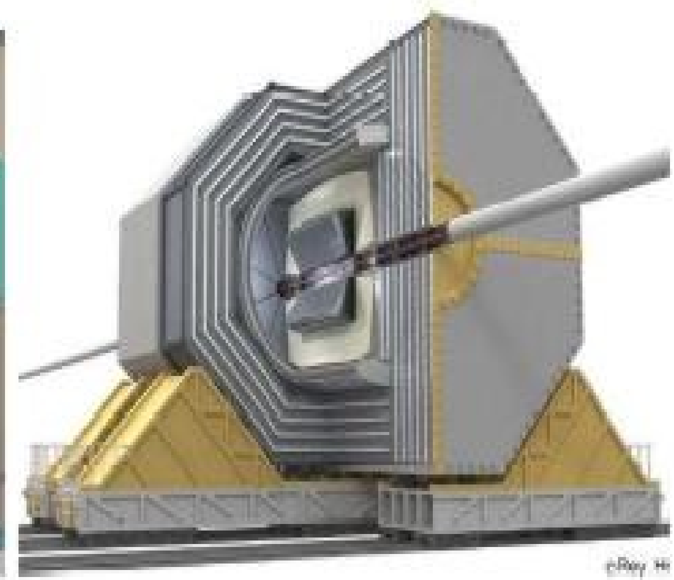
http://www.ilcldc.org

GLD

http://ilcphys.kek.jp/gld







Tasks for an ILC detector

- Reconstruct high momentum particles accurately
- Measure energies of hadronic jets accurately
- Be as hermetic as possible
- Identify long-lived particles (e,μ,π,K,p)
- Identify short-lived particles (b,c,τ)
- Reconstruct beam parameters as part of beam diagnostics
- Withstand large backgrounds at small radii

Momentum Resolution

- Want to reconstruct ZZH coupling from $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- X$ (recoil mass method)
  - Need $\sigma(1/p) \sim 4\times10^{-5}$/GeV to get $\Delta(M_Z)$=270MeV and $\Delta(M_H)$=1.2GeV

- Optimise detector resolution, number of points, magnetic field and tracking radius

$$\sigma(1/p) \sim \delta/R^2 B \mathrm{sqrt}(n)$$

Tracking Technologies

- Gaseous T(ime) P(rojection) C(hamber) with ~200 rows of pads (LDC/GLD)
  - Low material reduces multiple scattering and conversions
  - Robust pattern recognition with 2D points
  - Long drift time integrates over many bunch crossings

- All Silicon Detectors (SiD)
  - Better momentum resolution at high momenta
  - Fast readout reduces backgrounds
  - More material for secondary interactions
  - Pattern recognition hard with only a few layers

Vertex Detector requirements

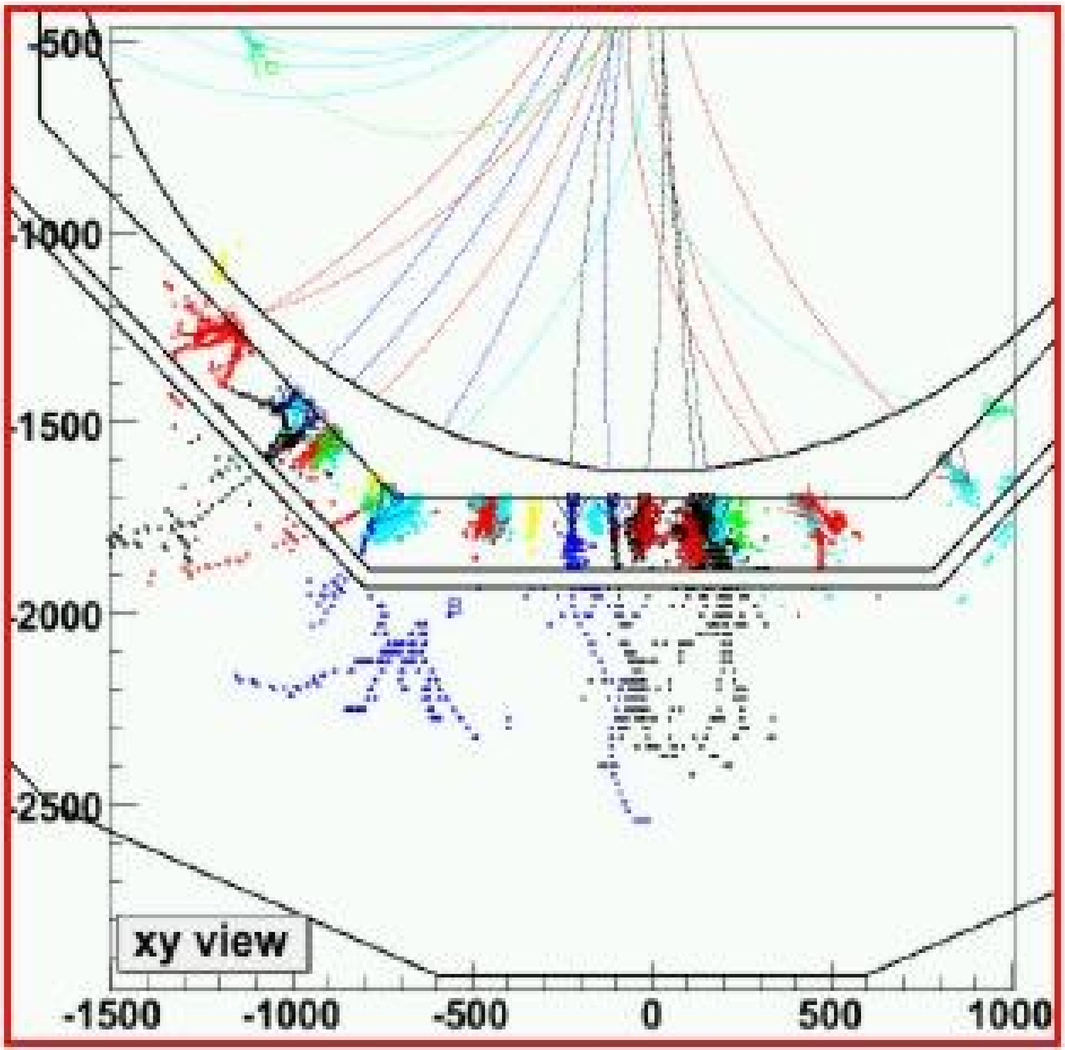
- Want to measure H–>cc which is <10% of H–> bb
  - Need vertex resolution ~5μm with a point resolution of ~3μm at R=1.5cm
  - Inner layer thickness ~0.2% X_0
- In principle not a big problem …

  … but the large backgrounds require fast pixel detectors (CCDs vs MAPs)

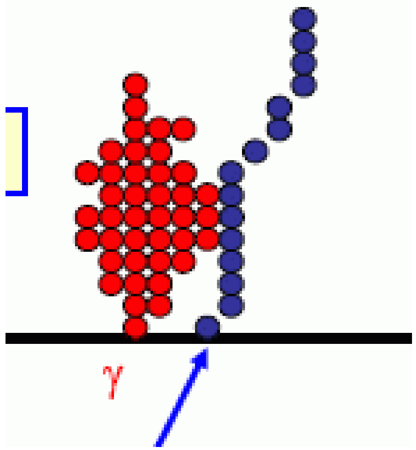
Calorimetry

- Need to separate WW and ZZ events with W,Z decays to hadronic jets
  - Need $\Delta E/E = 30\%/\text{sqrt}(E)$ (E in GeV)
  - Classical calorimetry is >45%/sqrt(E)
- New paradigm of P(article) F(low) C(alorimetry)
  - Count charged track, electromagnetic and neutral hadronic energy separately
  - Main problem is confusion due to overlapping particles in hadronic jets
  - Performance is not yet proven!

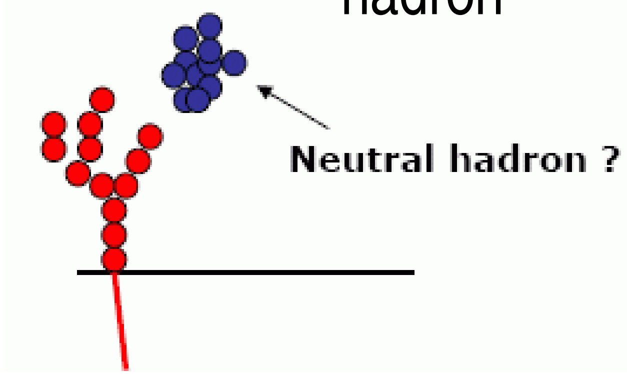
Granularity and Confusion



γ/track



γ/neutral
hadron



Calorimeter Designs

- All three detector designs assume fine-grained calorimeters with large numbers of readout channels
  - Tungsten/Lead/Iron absorbers for electromagnetic/hadronic calorimeters
  - Silicon pads for finest grain readout
  - Scintillators for coarser readout
- Transition between different designs depends on radius and cost

L(inear) C(ollider) UK R&D

- A(ccelerator) B(eam) D(elivery)
  - Collaboration between many universities and the two accelerator institutes (Adams and Cockcroft)
  - Mostly final focus and beam diagnostics
  - May be some damping ring work in the future
- L(inear) C(ollider) F(lavour) I(dentification)
  - Vertex detector R&D (mostly CCDs)
- CA(lorimetry for the) LI(near) C(ollider) E(xperiments)
  - Fine-grained calorimetry design and testing
  - Part of large international R&D collaboration

Here I was going to talk in more detail about the UK R&D actitivities …

But we already had seminars from:

Paul Dauncey (CALICE)
Chris Dammerel (LCFI)
Joel Goldstein (LCFI)

… and I know a lot less than they do
so I refer you to their talks

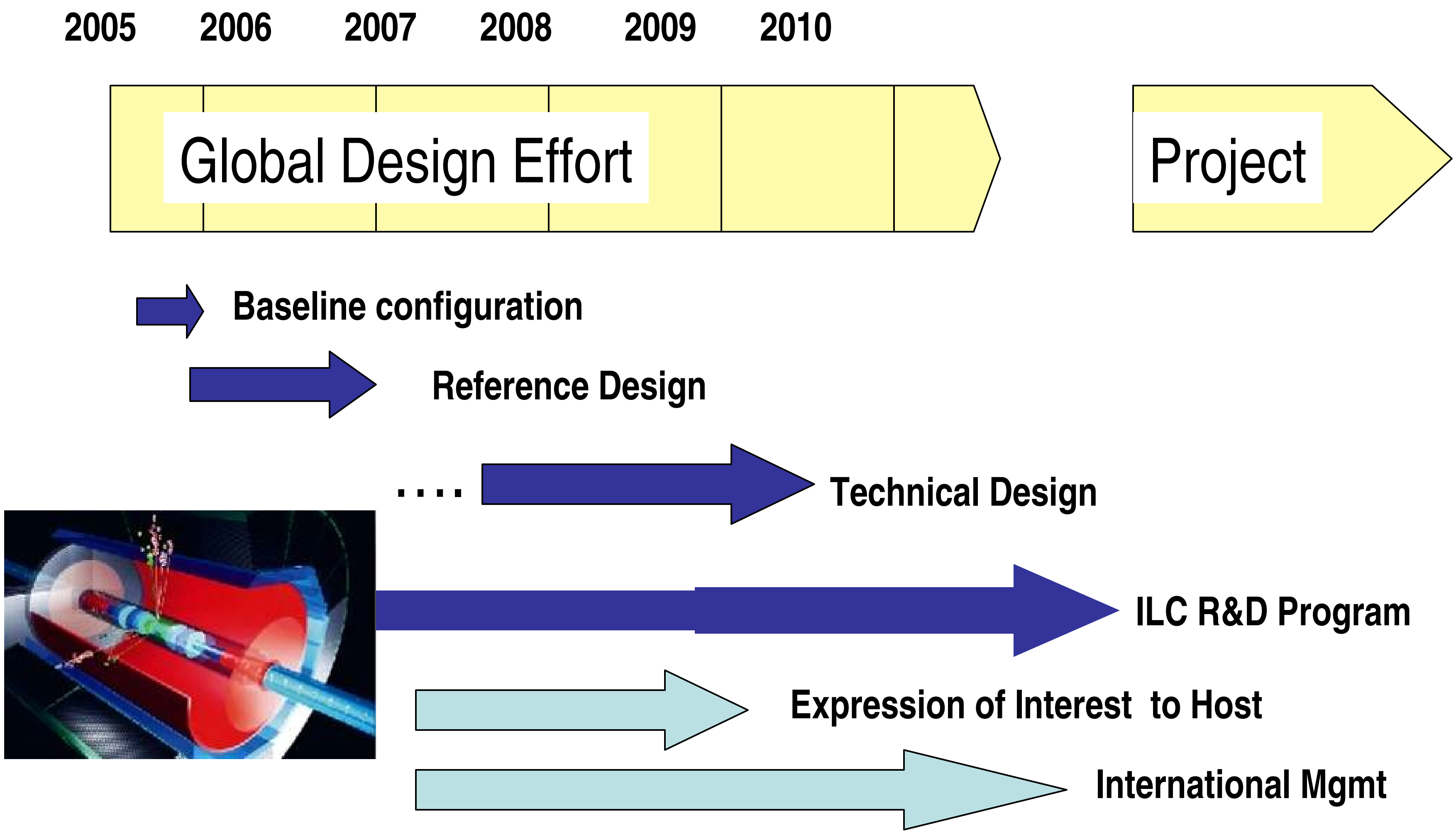
For UK-ABD there was a good talk by Phil Burrows at the Cosener's meeting
(but a bit technical for a general audience)

Status of UK R&D programme

- CALICE and LCFI have just been funded until January 2009
  - Funding has been flat since 2004
- UK-ABD is putting in a new proposal in July 2006
  - Also expecting flat funding

This is discouraging when other countries are rapidly expanding their R&D funding (particularily the USA)

ILC Timeline (Barry Barish)



R(eference) D(esign) R(eport)

- Due by the end of 2006
- Will include first estimate of the total cost of the ILC
  - Rumoured to be 8-12 Billion $
- Will include first detailed costings and D(escriptions) O(f) D(etectors)

T(echnical) D(esign) R(eport)

- Plan is to have this by the end of 2009
  - Seems optimistic. I would say 2010
- Will include full technical description of ILC
  - Based on several years of R&D
  - Forms the basis for approval and requests to the funding agencies
- Do we need to identify the site for the TDR?

Site Selection

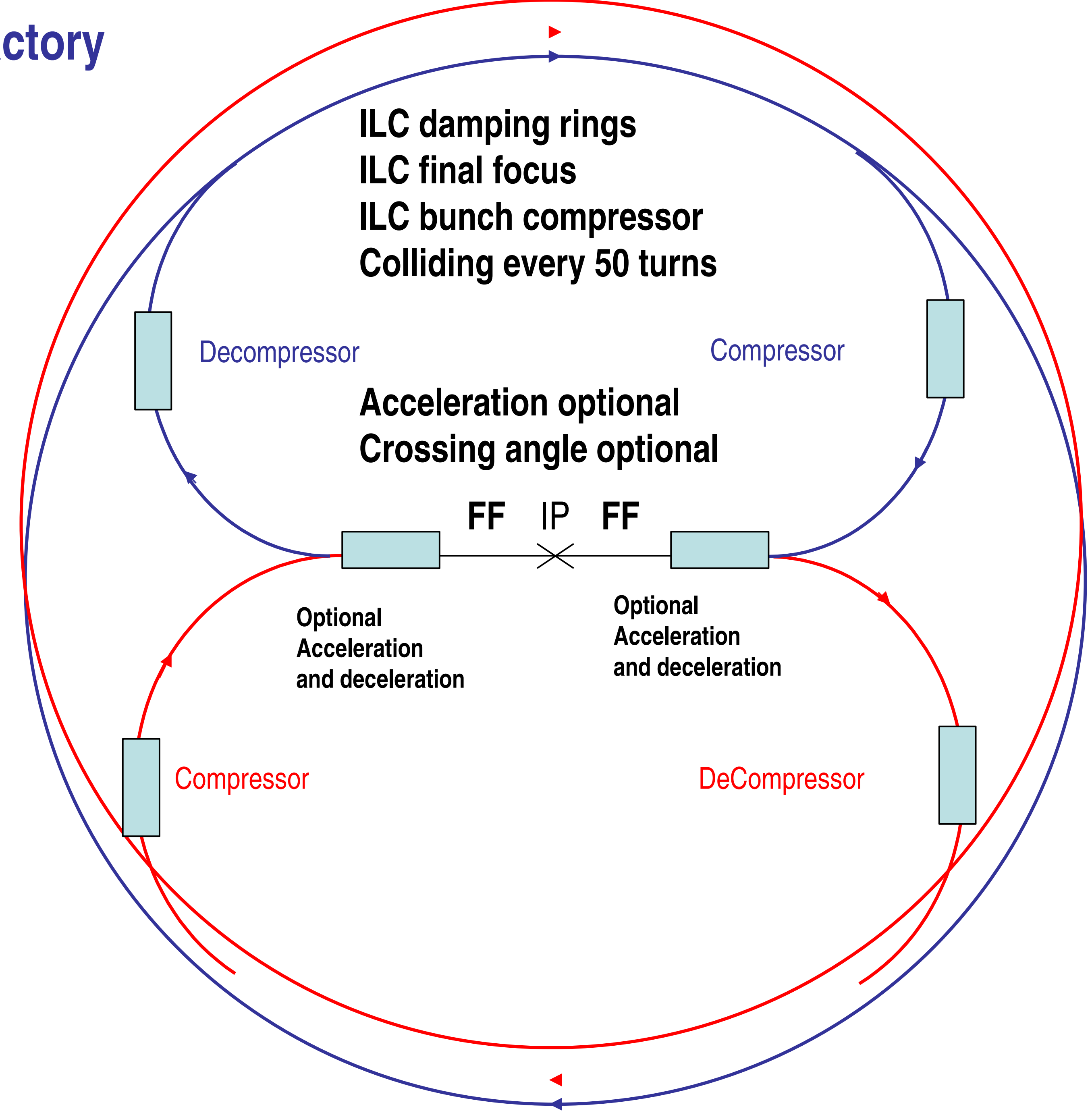
- There are four sites discussed in the BCD:
  - Fermilab, somewhere in the fields of DeKalb county west of the Tevatron
  - DESY, based on the TESLA proposal
  - CERN, along the foot of the Jura
  - Japan, somewhere up in the mountains (!)
- They will be asked to submit bids to a site selection process
- Fermilab is currently the hot favourite
- Host region expected to pay 50% of the cost

S(cottish) U(niversities) P(hysics) A(lliance)

- The Particle Physics theme has proposed a strong Scottish participation in the ILC as its main new initiative in the next 5 years
- Will be joint between Edinburgh & Glasgow
- Will probably be as part of LCFI
- How do we take a “clear role” in leading Linear Collider development work?
- What resources do we need to ask for?

Proposal was “well thought of” by SUPA advisory panel (April 2006)

Super B Factory



Linear Collider B factory

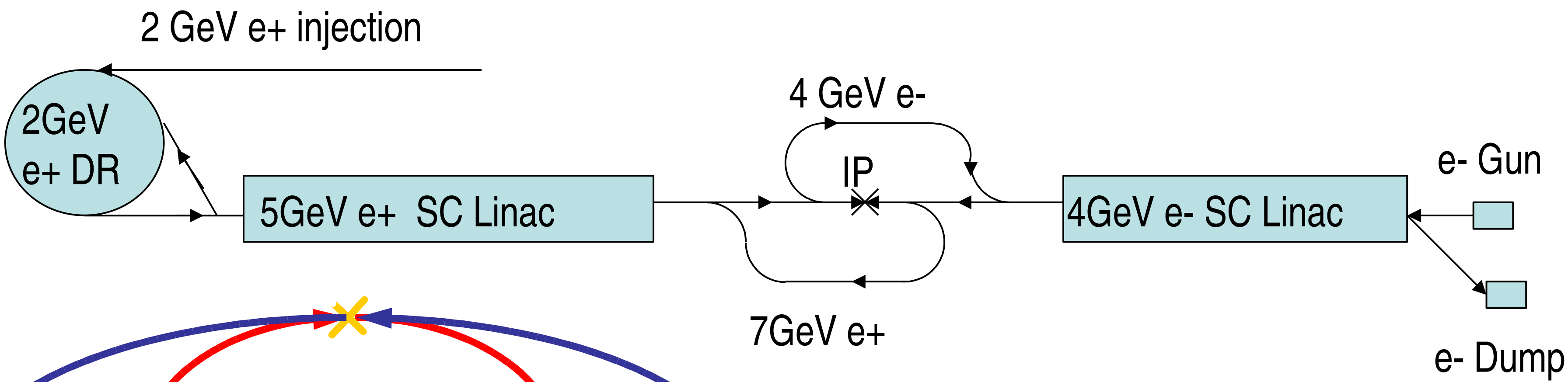
- "An electron-positron linear collider as a B-anti B Meson factory" (Amaldi & Coignet 1986)

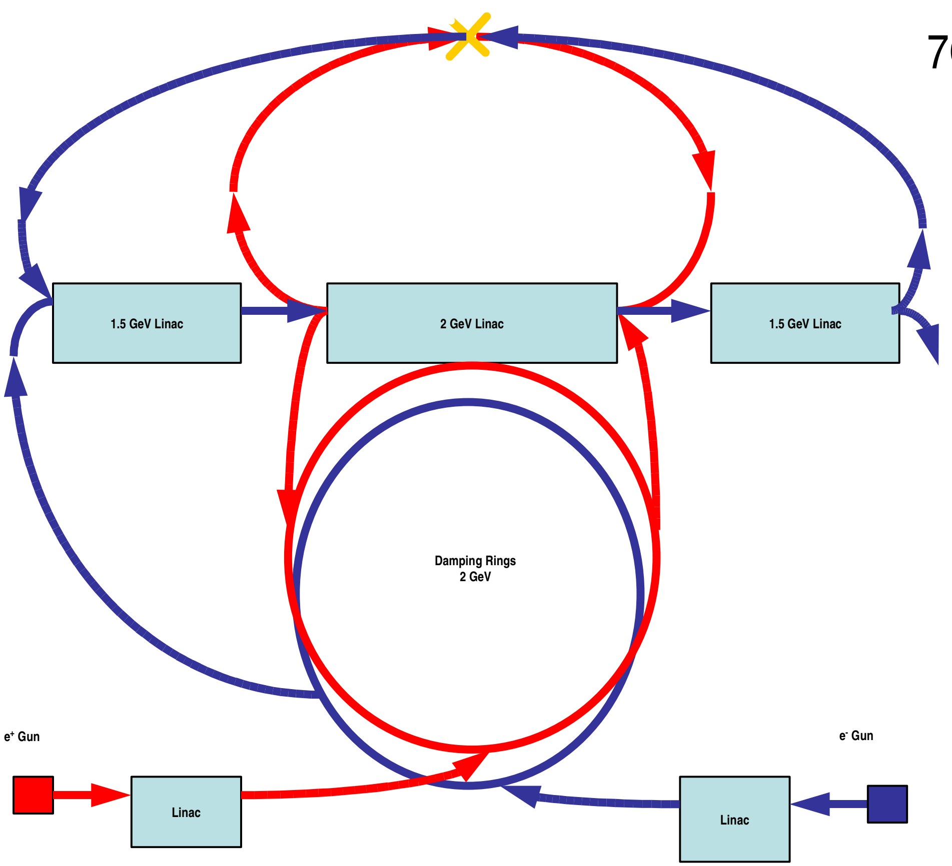
- Idea resurrected at Hawaii Super B workshop (Pantaleo Raimondi, April 2005)
- "Super B: a linear high luminosity B factory"
  (J.Albert et al, hep-physics/0512235)

Benefits from all the Linear Collider R&D that has been going on in the last 20 years.

Looks feasible to get luminosity of 1-2 x 10^{36} at Y(4S)

First Linear Super B scheme with acceleration and energy recovery (to reduce power)





- Use Superconducting Linacs to recover energy
- Use low energy damping rings to reduce synchrotron radiation
  - Maybe no e^- damping ring
- Use bunch compression and final focus a la ILC
- Energy and asymmetry tunable
- Polarized beams possible

Parameters of Super-B Designs

Collider		ξ_y	N	β_y^*	s	E	F	Lumin
Units			10^{10}	mm	m	GeV	(~Hd)	10^{35}
PEP-II	Normal	0.068	8	11	1.26	3.1	0.84	0.10
KEKB	Normal	0.065	5.8	6	2.1	3.5	0.76	0.16
Super-PEP-II	High I low βy	0.12	10	1.7	0.32	3.5	0.81	7
Super-KEKB	High I low βy	0.28	12	3	0.59	3.5	0.76	5
Linear SuperB	Single pass	29.	10	0.5	250	4	1.07	10
SuperB	Bunch shorten	0.14	6	0.4	0.63	4	0.75	10
SuperB	X'ing angle	0.045	2	0.08	0.5	5	0.8	9

John Seeman, FPCP 2006

Comparison of Rings (Andy Wolski)

	SuperB	ILC $e^-(e^+)$	PEP-II e+	PEP-II e-
Circumference	3 km	6.7 km	2.2 km	2.2 km
Beam energy	4(7) GeV	5 GeV	3.1 GeV	9 GeV
Bunch charge	2×10^{10}	1×10^{10}	6.9×10^{10}	4.3×10^{10}
N° bunches	5000	5800	1588	1588
Current	1.6 A	0.4(0.2) A	2.4 A	1.5 A
Bunch length	4 mm	6 mm	11 mm	11 mm
Energy spread	0.11%	0.13%	0.07%	0.07%
Horiz. emit.	0.4 nm	0.5 nm	35 nm	60 nm
Vert. emit.	0.002 nm	0.002 nm	1.4 nm	1.4 nm
Damping Time	10 ms	27 ms	70 ms	37 ms