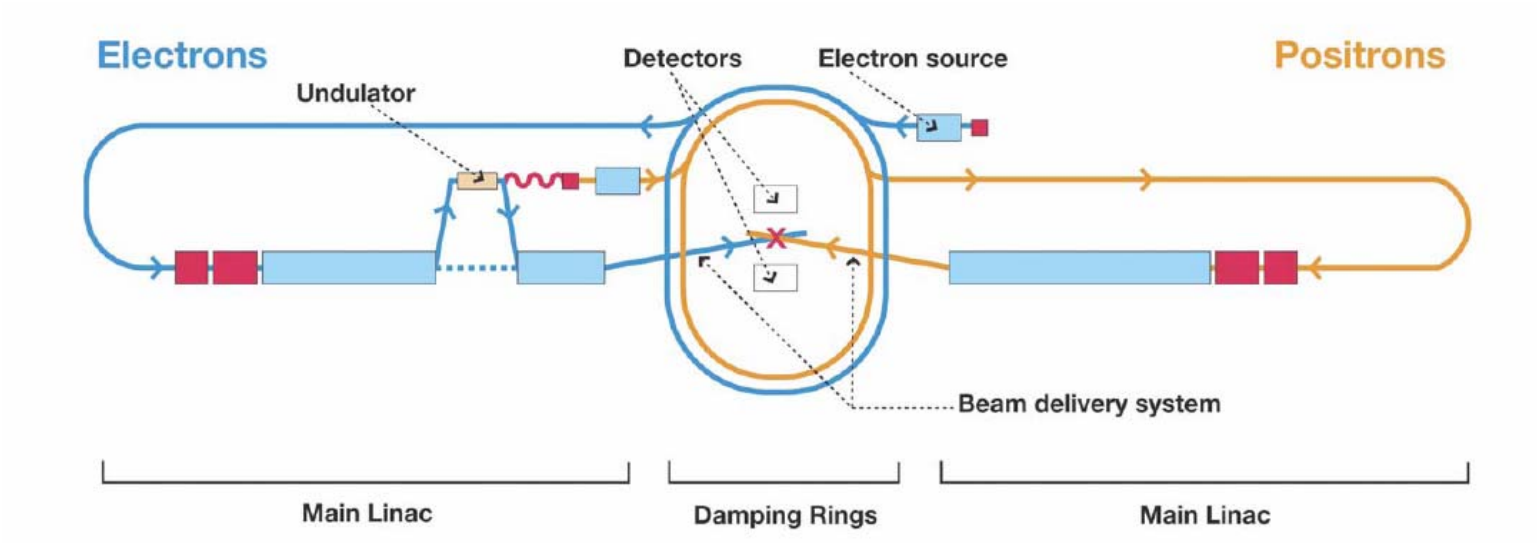
International Linear Collider



Barry Barish

7-March-07

Global Design Effort

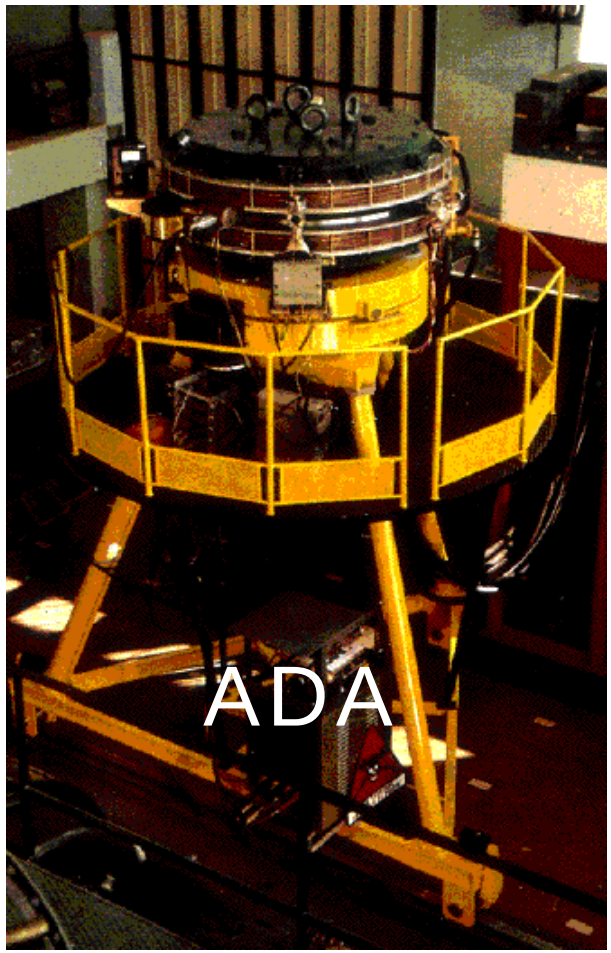
Introduction to the ILC

- Terascale science and how the ILC will complement the LHC?
- Why linear? What technology to employ?
- Designing the ILC -- a new paradigm in international collaboration.
- A thumbnail description of the ILC Reference Design and Cost?
- The path forward

Exploring the Terascale
the tools

- The LHC
  - **It will lead the way and has large reach**
  - **Quark-quark, quark-gluon and gluon-gluon collisions at 0.5 - 5 TeV**
  - **Broadband initial state**
- The ILC
  - **A second view with high precision**
  - **Electron-positron collisions with fixed energies, adjustable between 0.1 and 1.0 TeV**
  - **Well defined initial state**
- Together, these are our tools for the terascale

Electron-Positron Colliders

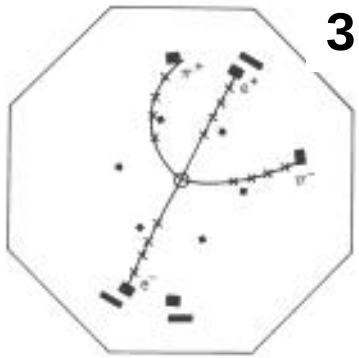


Bruno Touschek built the first successful electron-positron collider at Frascati, Italy (1960)

Eventually, went up to 3 GeV

But, not quite enough energy ….

SPEAR at SLAC

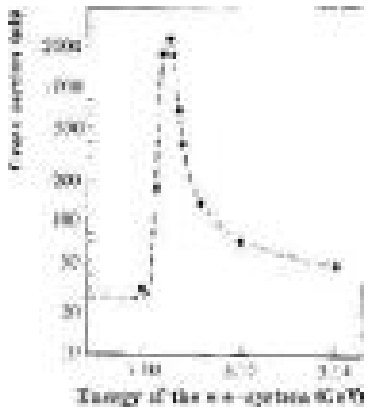


3.1 GeV

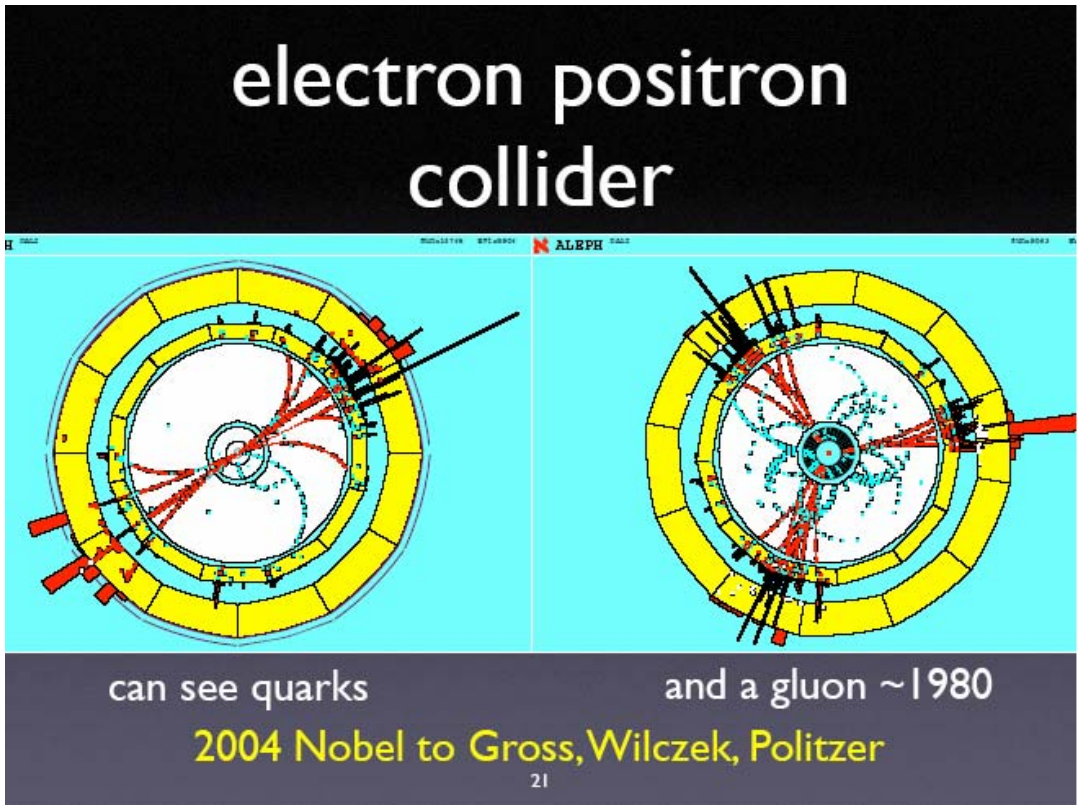
Burt Richter
Nobel Prize

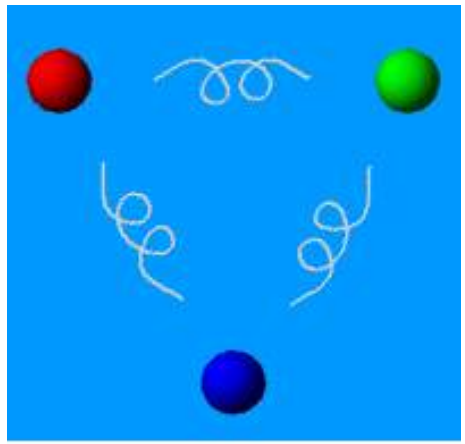
and

Discovery
Of
Charm
Particles



The rich history for e^+e^- continued as higher energies were achieved …

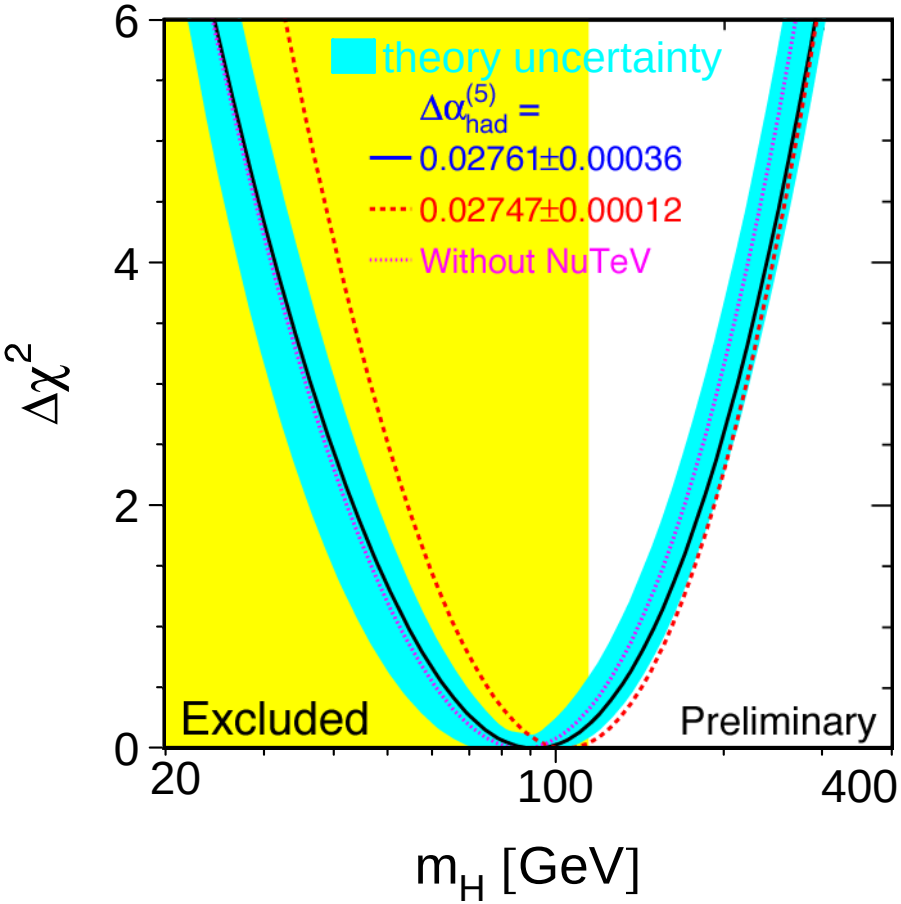




DESY PETRA Collider

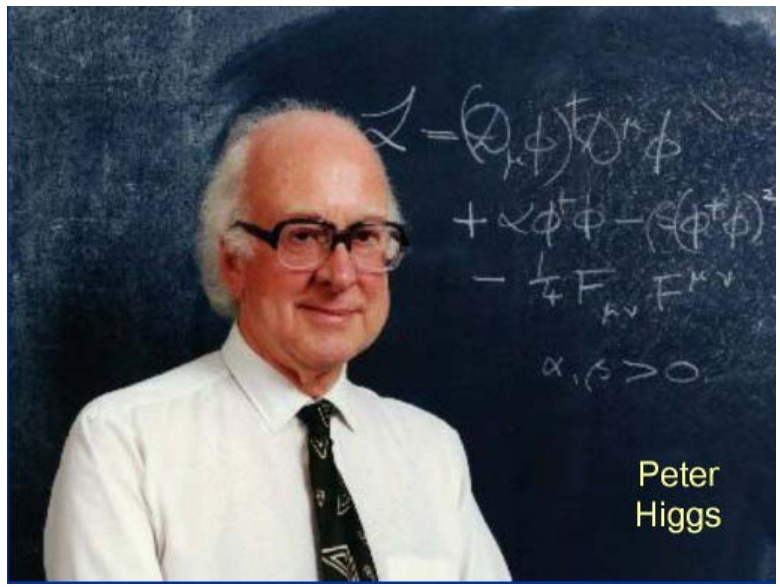
And also at LEP, where the stage has been set for the terascale

Winter 2003



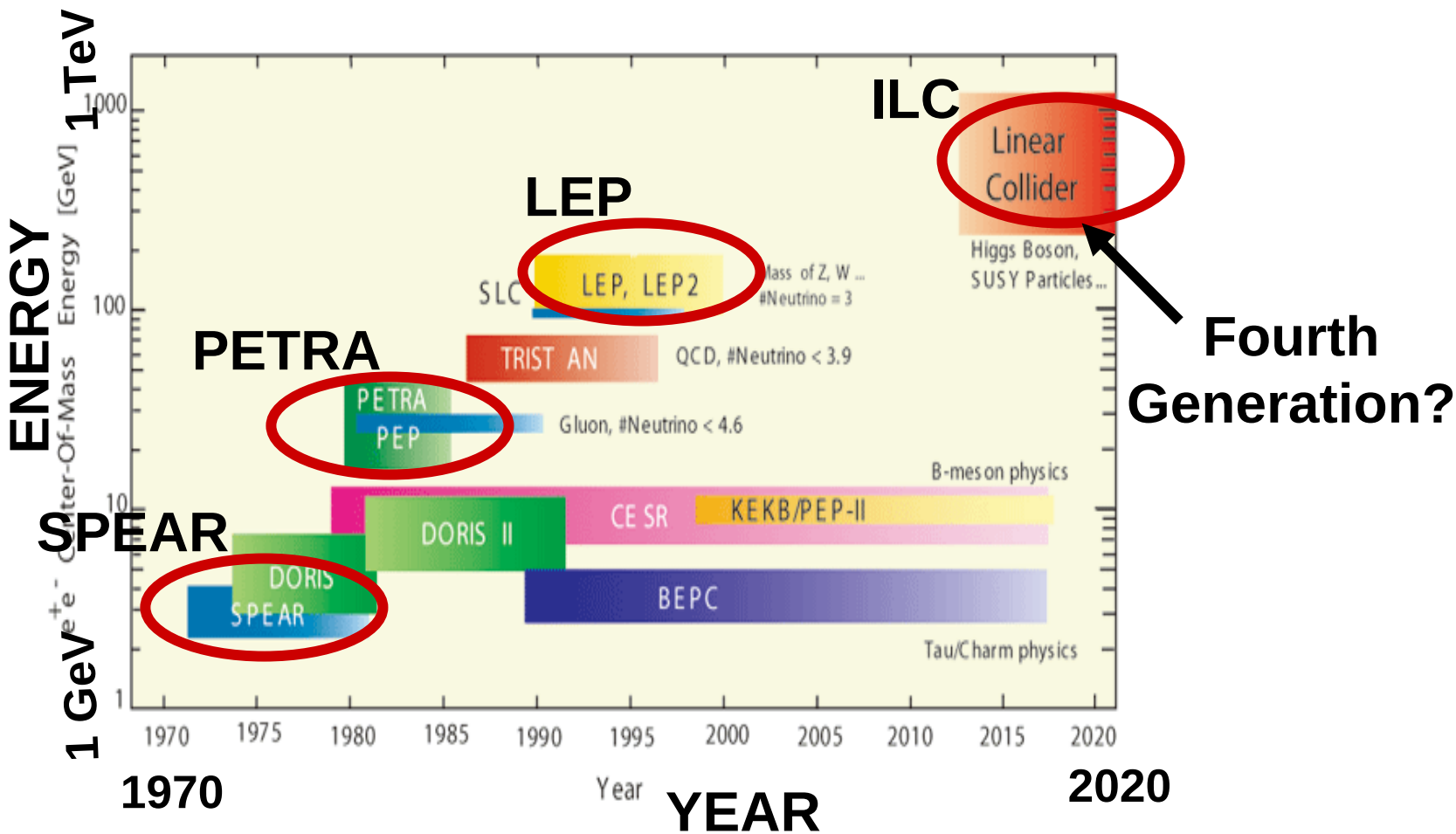
What causes mass??

The mechanism – Higgs or alternative appears around the corner



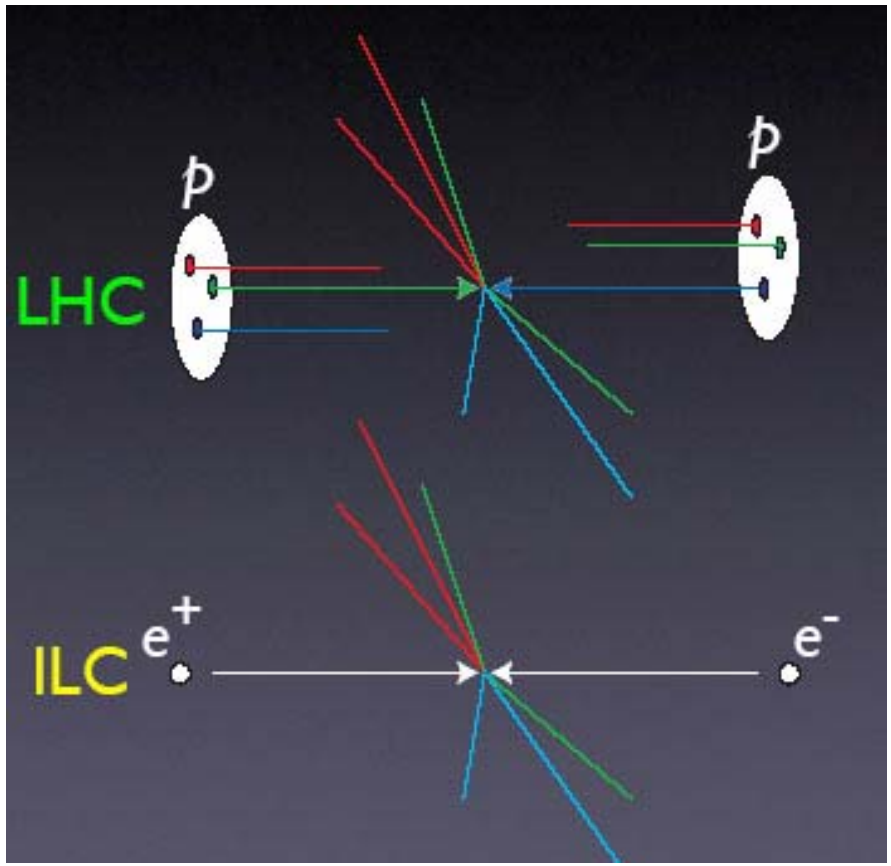
Three Generations of e^+e^- Colliders

The Energy Frontier



Why e^+e^- Collisions?

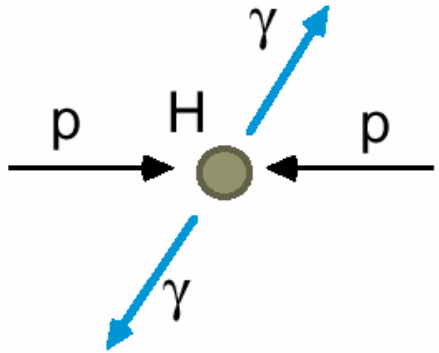
- elementary particles
- well-defined
  - **energy,**
  - **angular momentum**
- uses full COM energy
- produces particles democratically
- can mostly fully reconstruct events

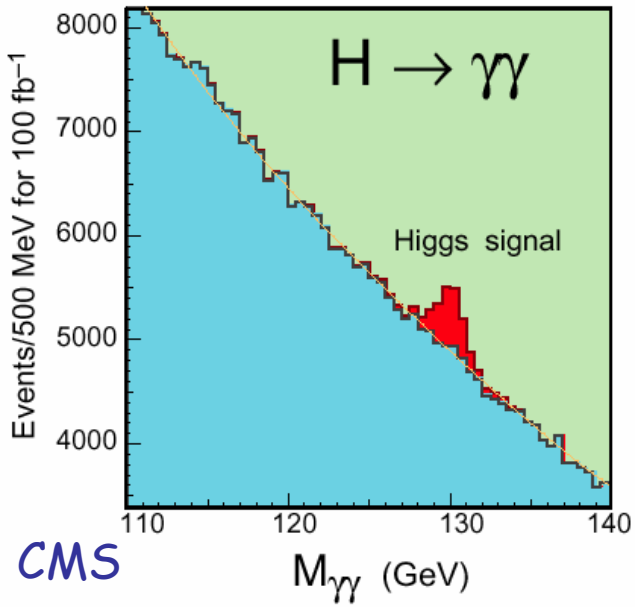


LHC: Low mass Higgs: $H \rightarrow \gamma\gamma$

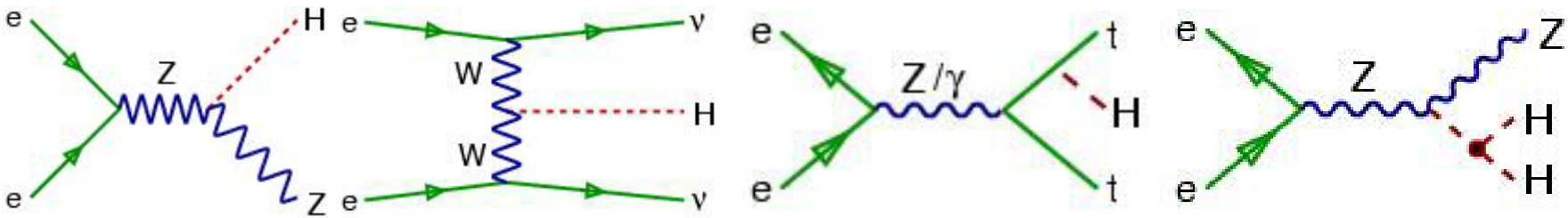
$M_H < 150$ GeV/c^2

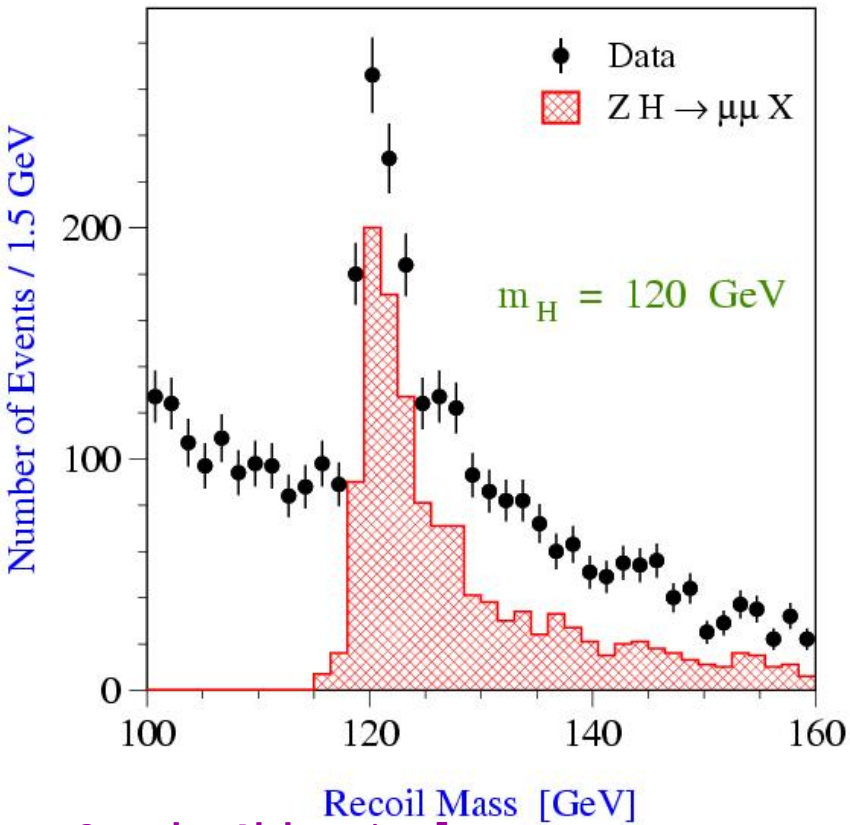
- Rare decay channel: BR~10^{-3}
- Requires excellent electromagnetic calorimeter performance
  - **acceptance, energy and angle resolution,**
  - **g/jet and g/p^0 separation**
  - **Motivation for LAr/$PbWO_4$ calorimeters for CMS**
- Resolution at 100 GeV: $\sigma \approx 1$ GeV
- Background large: S/B ≈ 1:20, but can estimate from non signal areas





ILC: Precision Higgs physics

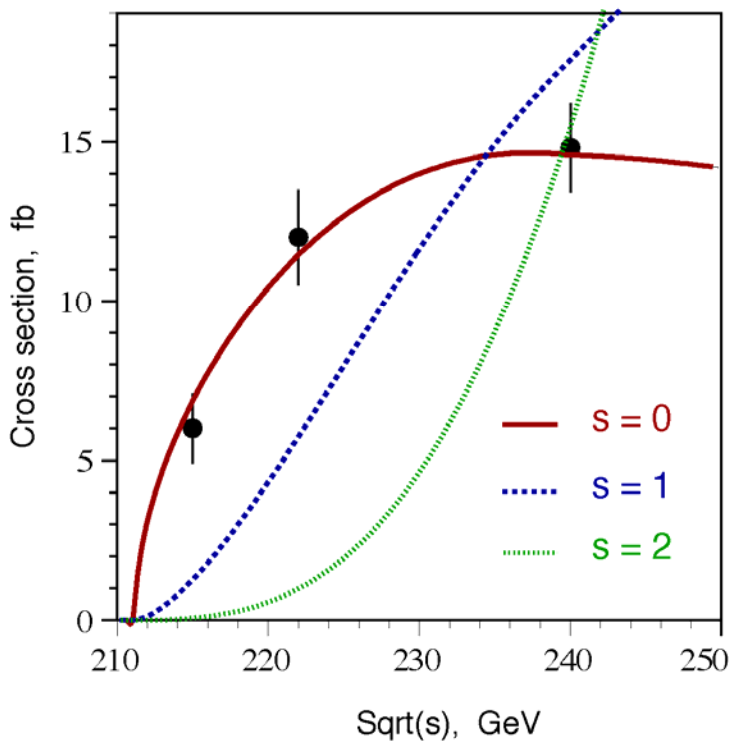




Garcia-Abia et al

- **Model-independent Studies**
  - **mass**
  - **absolute branching ratios**
  - **total width**
  - **spin**
  - **top Yukawa coupling**
  - **self coupling**
- **Precision Measurements**

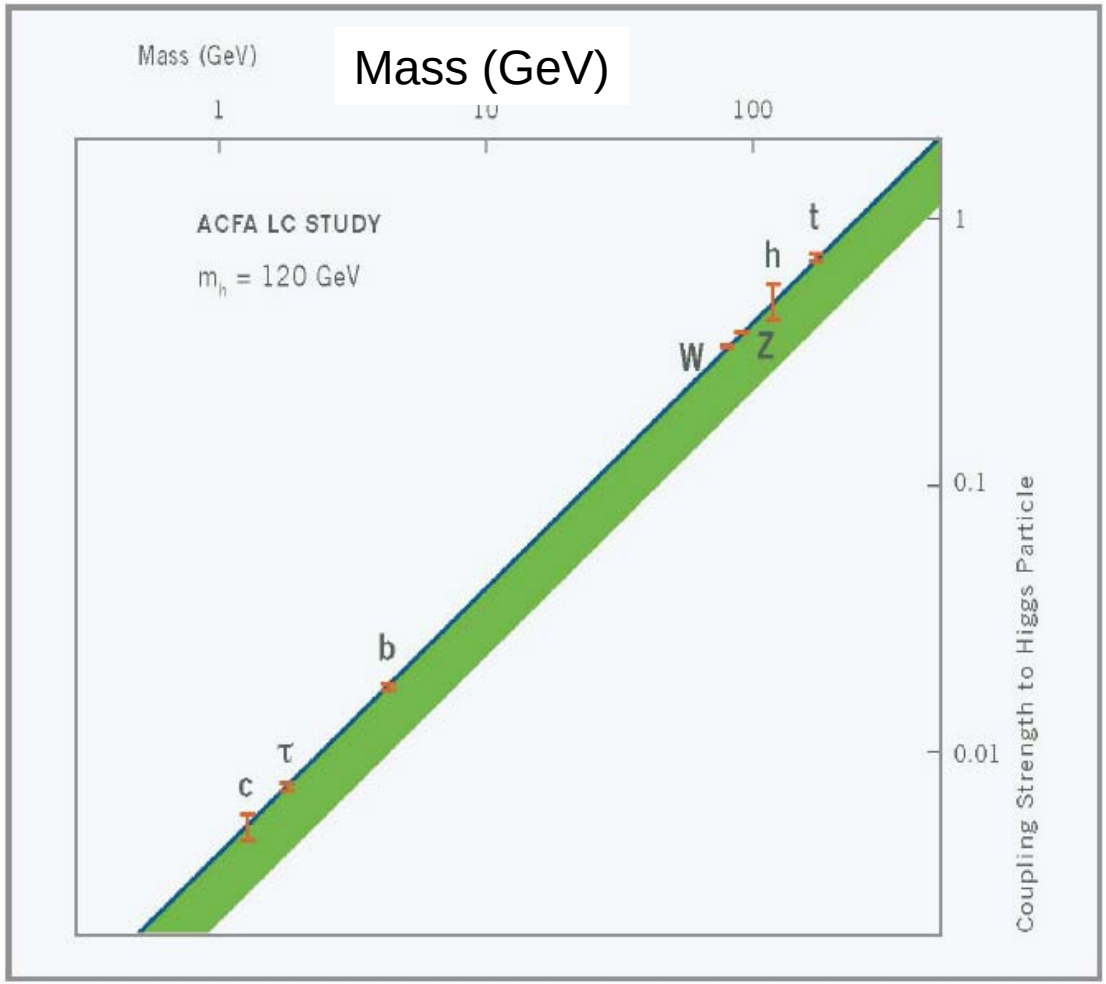
Is it really the Higgs ?



Measure the quantum numbers. The Higgs must have spin zero !

The linear collider will measure the spin of any Higgs it can produce by measuring the energy dependence from threshold

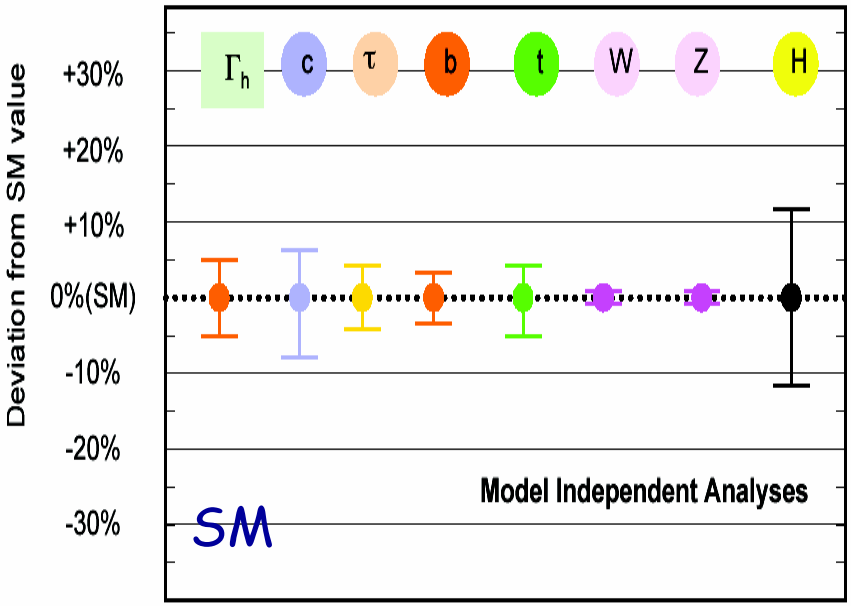
Higgs Couplings at the ILC



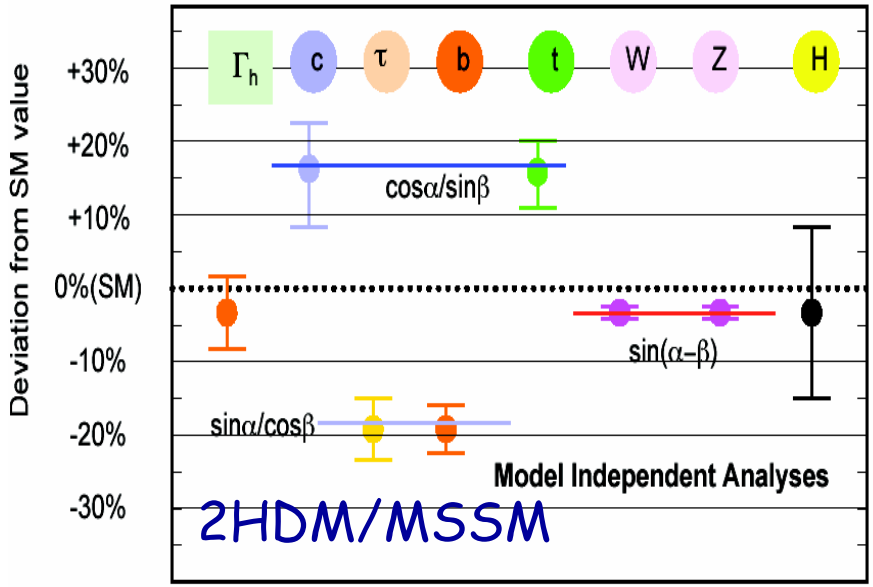
Higgs Coupling strength is proportional to Mass

e^+e^- : Studying the Higgs

determine the underlying model



Yamashita et al

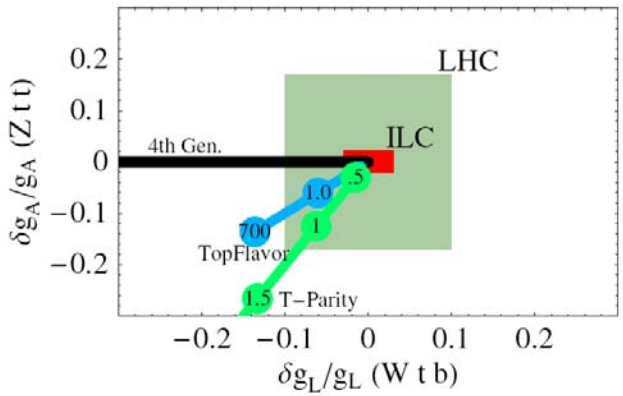


Zivkovic et al

More ILC Terascale Physics

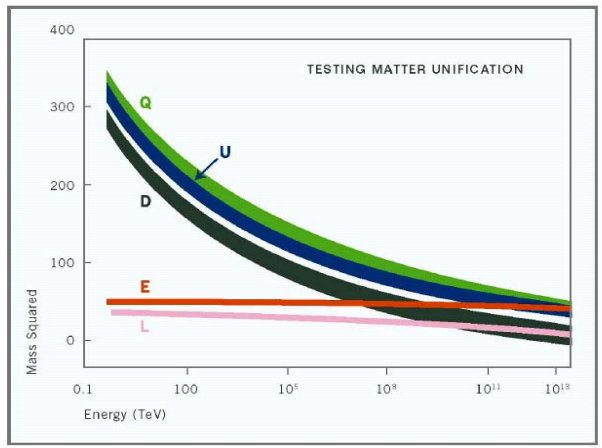
- **The Top Quark**

(precision top physics)



- **Supersymmetry**

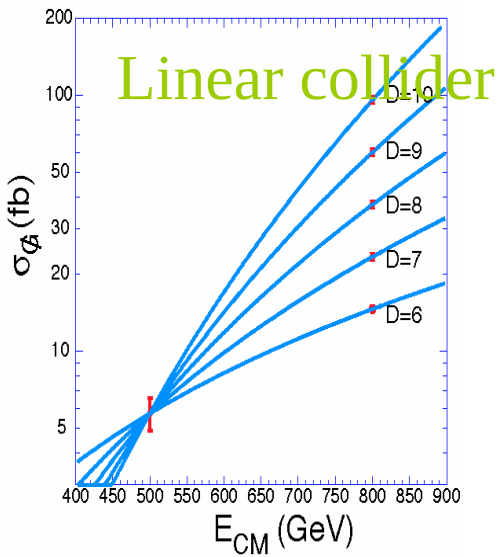
(Do quarks and leptons unify?)



More ILC Terascale Physics

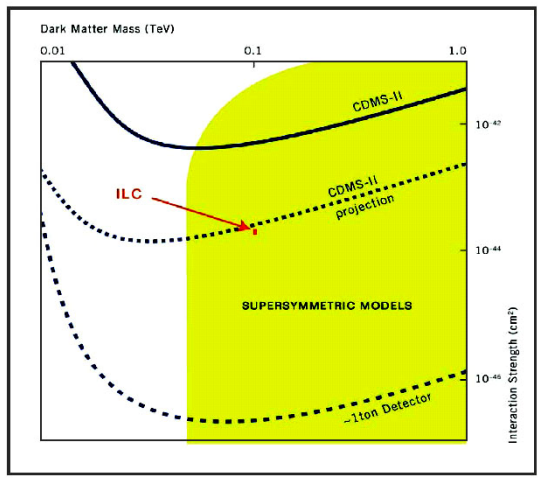
- **Extra Dimensions**

(how many dimensions in nature)



- **Dark Matter**

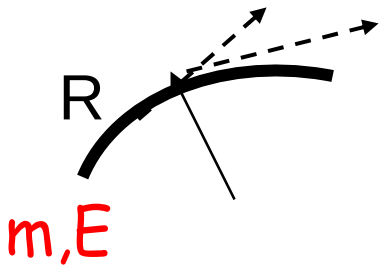
(comparable sensitivity to direct searches – determine mass and coupling of LSP)



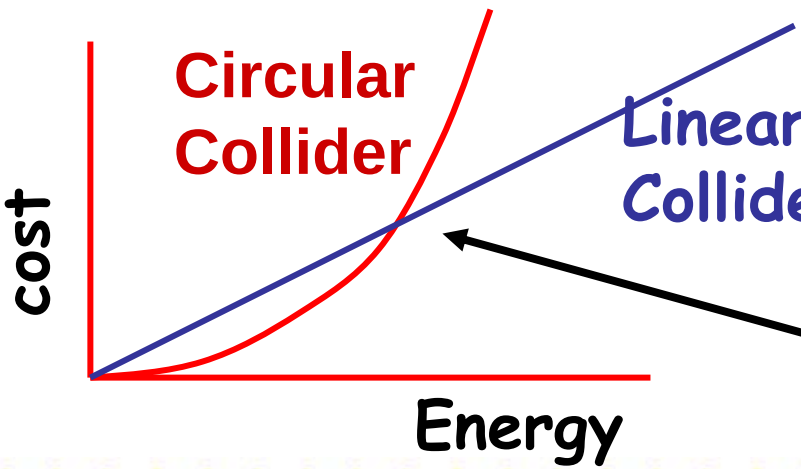
Why Linear?

- Circular Machine
  - $\Delta E \sim (E^4 / m^4 R)$
  - Cost $\sim a R + b \Delta E$

    $\sim a R + b (E^4 / m^4 R)$
  - **Optimization : $R \sim E^2 \Rightarrow$ Cost $\sim c E^2$**



Synchrotron Radiation



– Cost (linear) $\sim a' L$

– where $L \sim E$

~ 200 GeV

How the physics defines the ILC

Parameters for the Linear Collider

September 30, 2003

Asia: Sachio Komamiya, Dongchul Son
Europe : Rolf Heuer (chair), Francois Richard
North America: Paul Grannis, Mark Oreglia

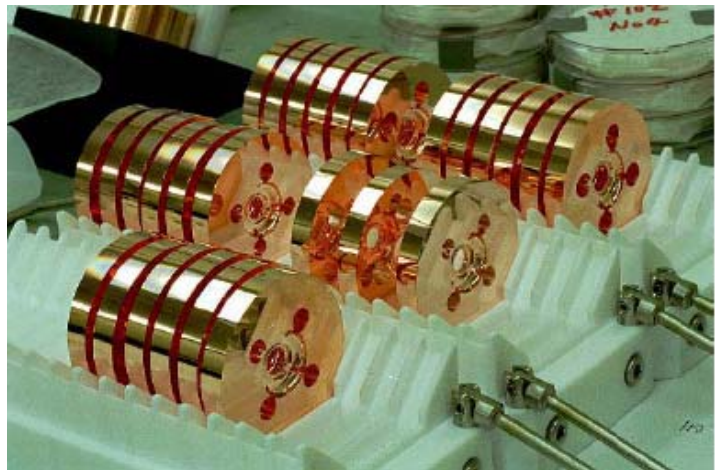
Parameters for the ILC

- E_{cm} 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%

- The machine must be upgradeable to 1 TeV

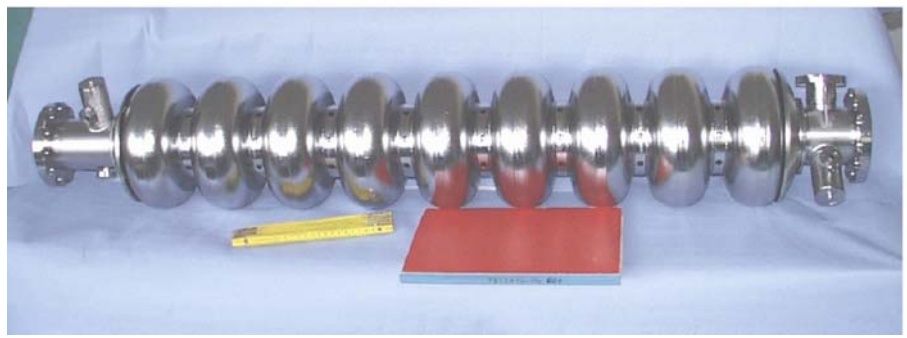
ILC – Underlying Technology

- Room temperature copper structures



OR

- Superconducting RF cavities

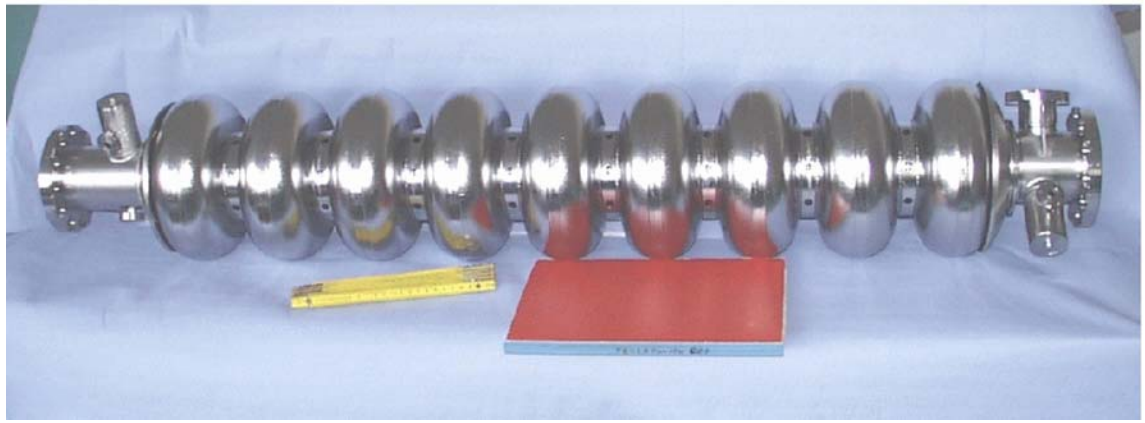


SCRF Technology Recommendation

- The recommendation of ITRP was presented to ILCSC & ICFA on August 19, 2004 in a joint meeting in Beijing.

- ICFA unanimously endorsed the ITRP's recommendation on August 20, 2004

Superconducting RF Technology



- Forward looking technology for the next generation of particle accelerators: particle physics; nuclear physics; materials; medicine

- The ILC R&D is leading the way Superconducting RF technology
  - **high gradients; low noise; precision optics**

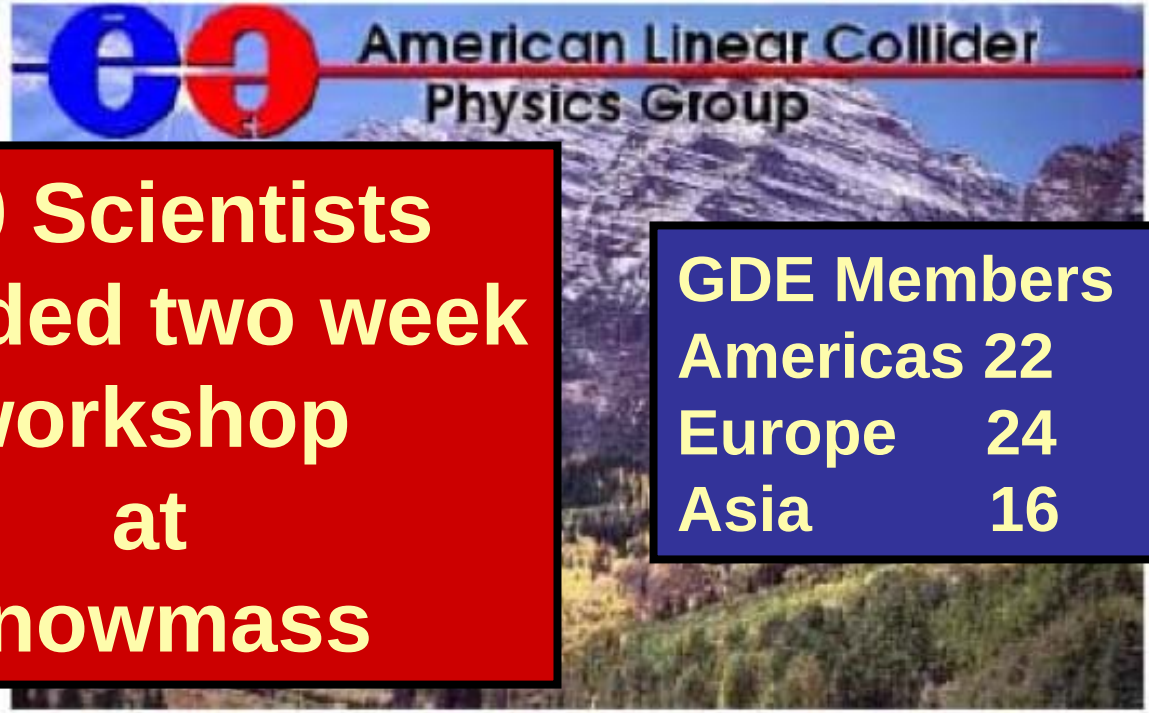
The Community Self-Organized

Nov 13-15, 2004

~ 220 participants from 3 regions, most of them accelerator experts

15

GDE Began at Snowmass



670 Scientists attended two week workshop at Snowmass

GDE Members

Americas	22
Europe	24
Asia	16

2005 International Linear Collider Physics and Detector Workshop and Second ILC Accelerator Workshop

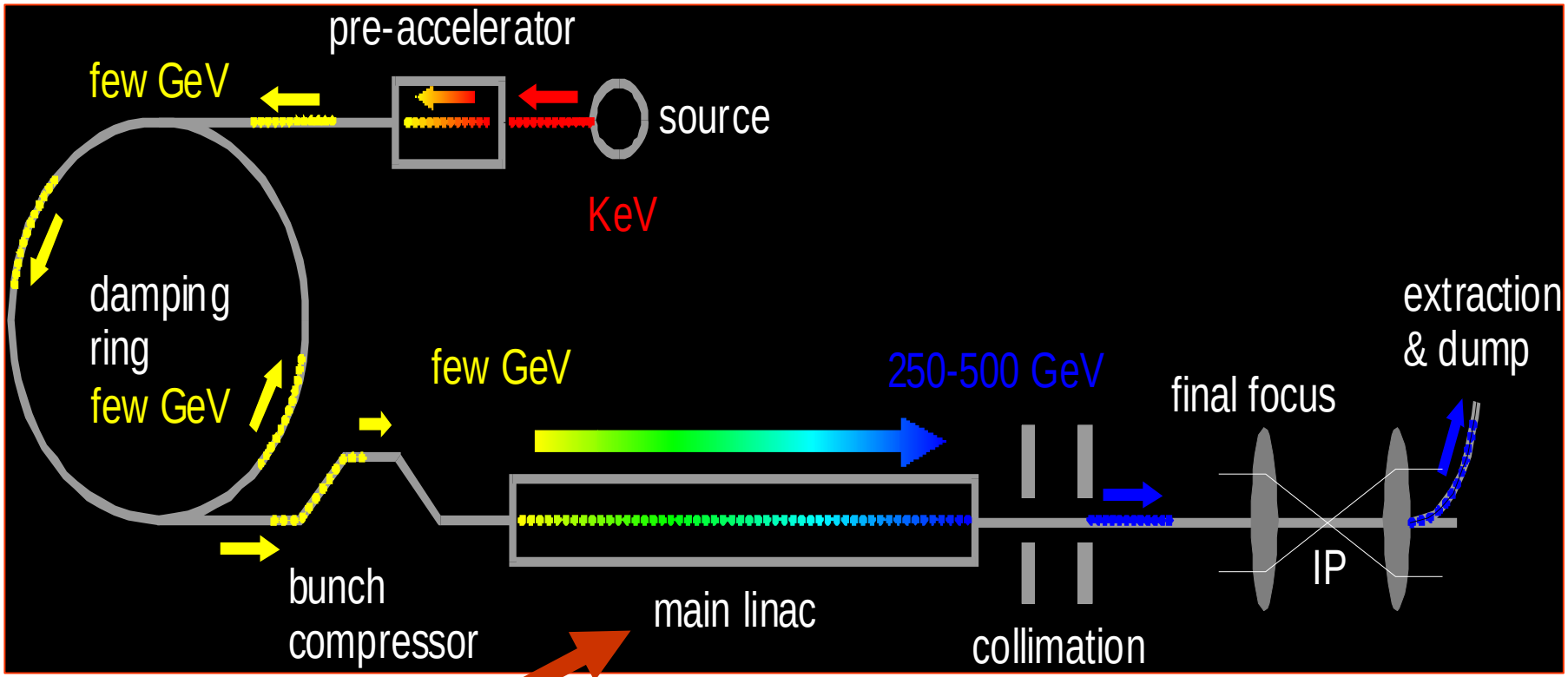
Snowmass, Colorado, August 14-27, 2005

Global Design Effort

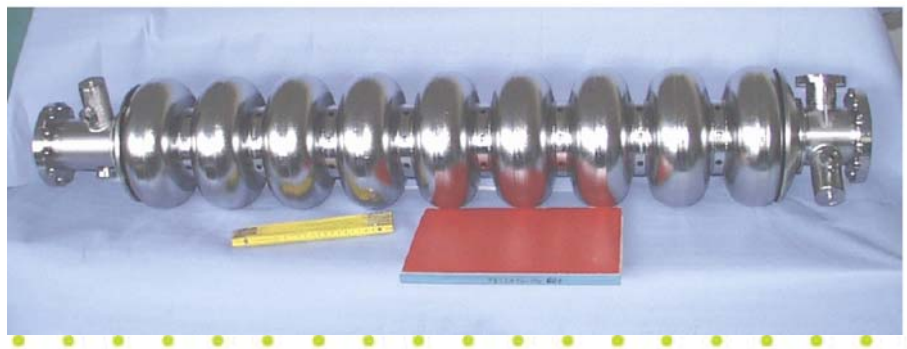
– **The Mission of the GDE**

- Produce a design for the ILC that includes a detailed design concept, performance assessments, reliable international costing, an industrialization plan , 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 -- Designing a Linear Collider



Superconducting RF Main Linac



Luminosity & Beam Size

$$L = \frac{n_b N^2 f_{rep}}{2\pi \Sigma_x \Sigma_y} H_D$$

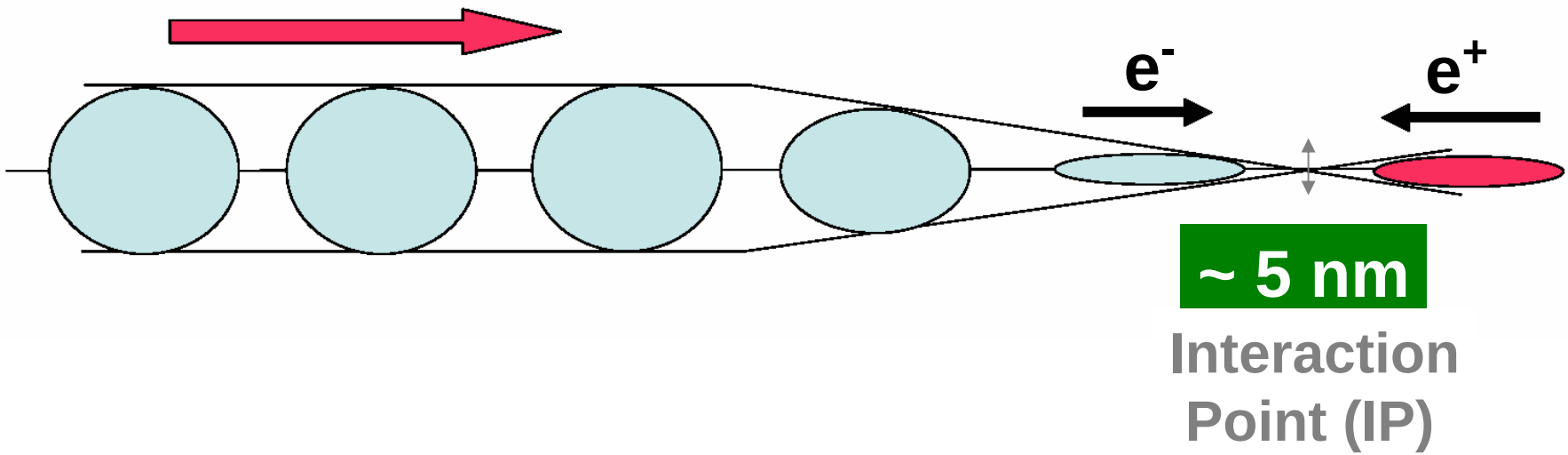
- f_{rep} * n_b tends to be low in a linear collider

	L	f_{rep} [Hz]	n_b	N [10^{10}]	σ_x [μm]	σy [μm]
ILC	$2x10^{34}$	5	3000	2	0.5	0.005
SLC	$2x10^{30}$	120	1	4	1.5	0.5
LEP2	$5x10^{31}$	10,000	8	30	240	4
PEP-II	$1x10^{34}$	140,000	1700	6	155	4

- Achieve luminosity with spot size and bunch charge

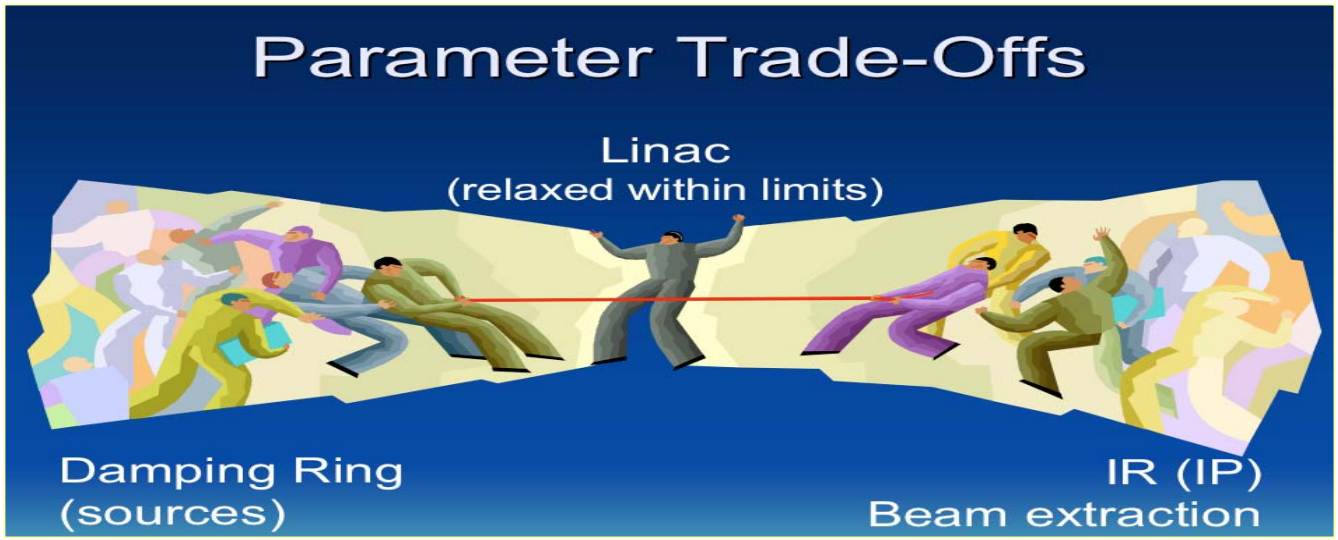
Achieving High Luminosity

- Low emittance machine optics
- Contain emittance growth
- Squeeze the beam as small as possible



Parametric Approach

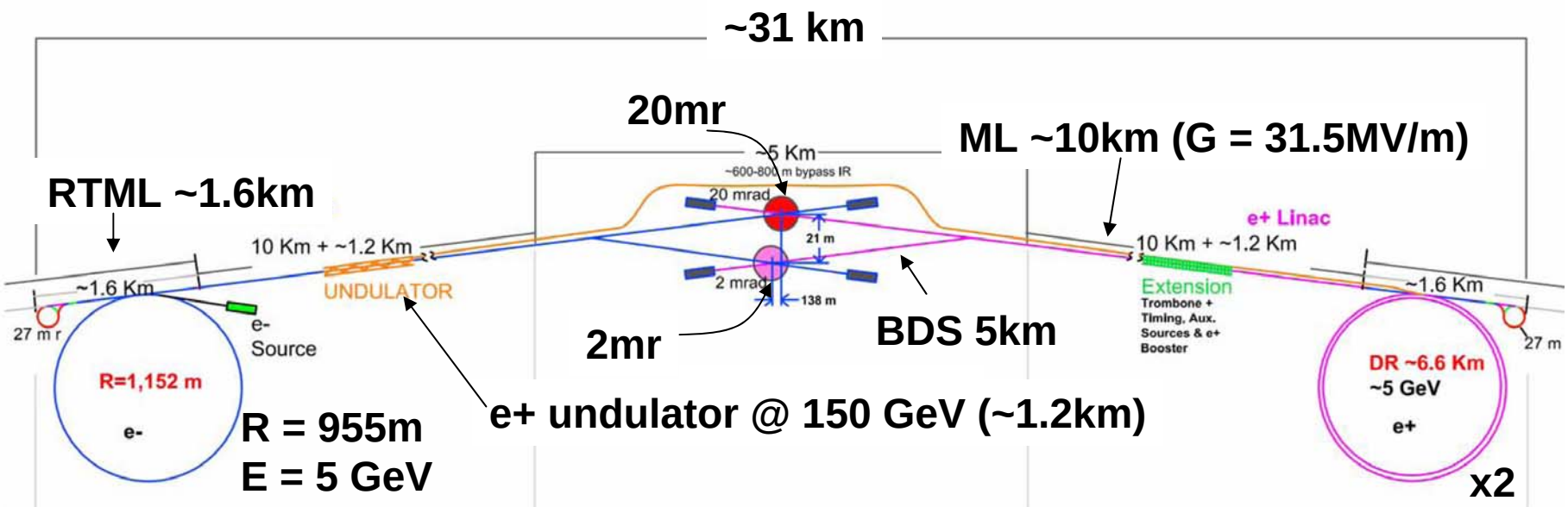
- A working space - optimize machine for cost/performance



		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

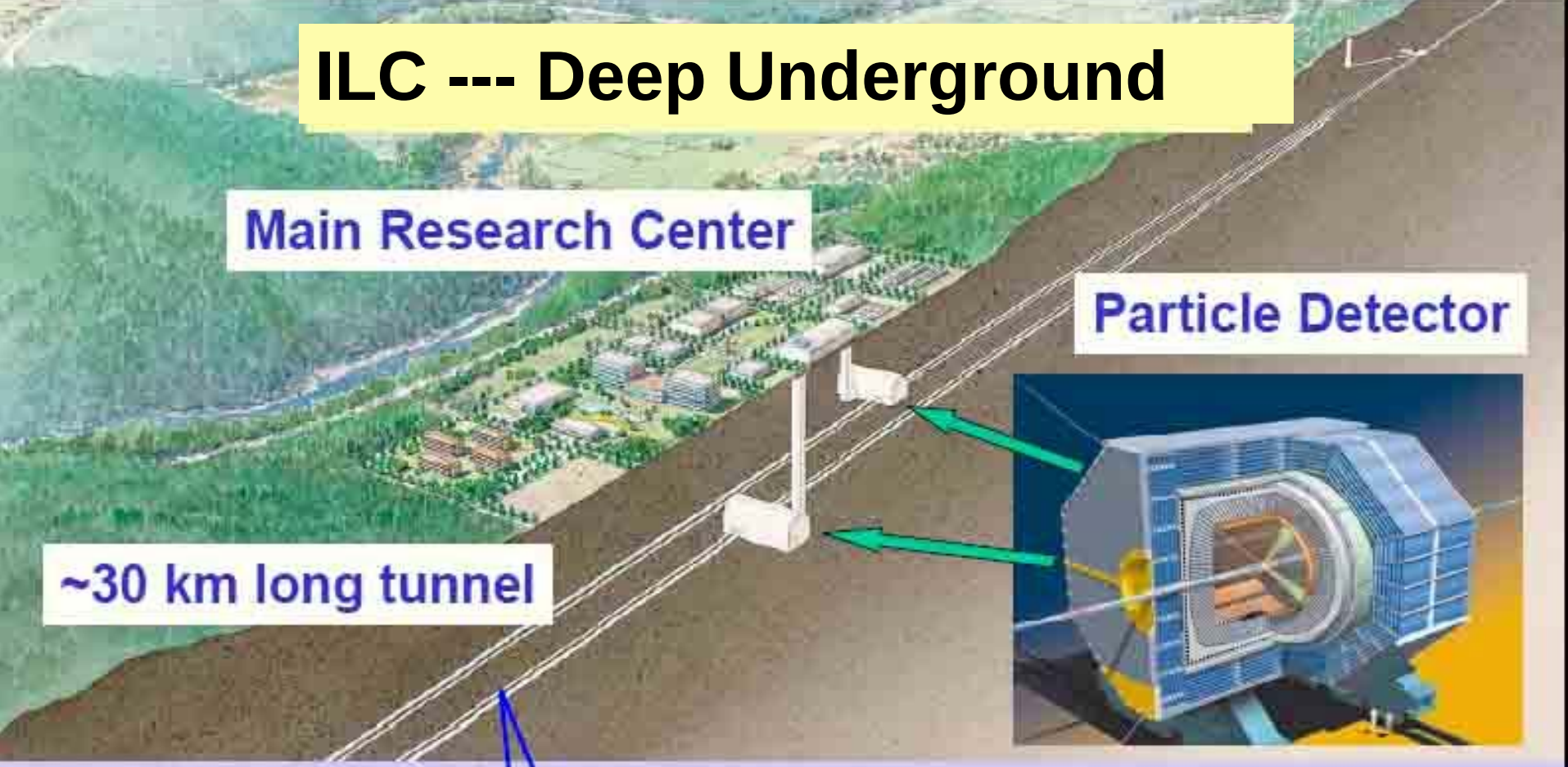
The Baseline Machine (500GeV)

January 2006



not to scale

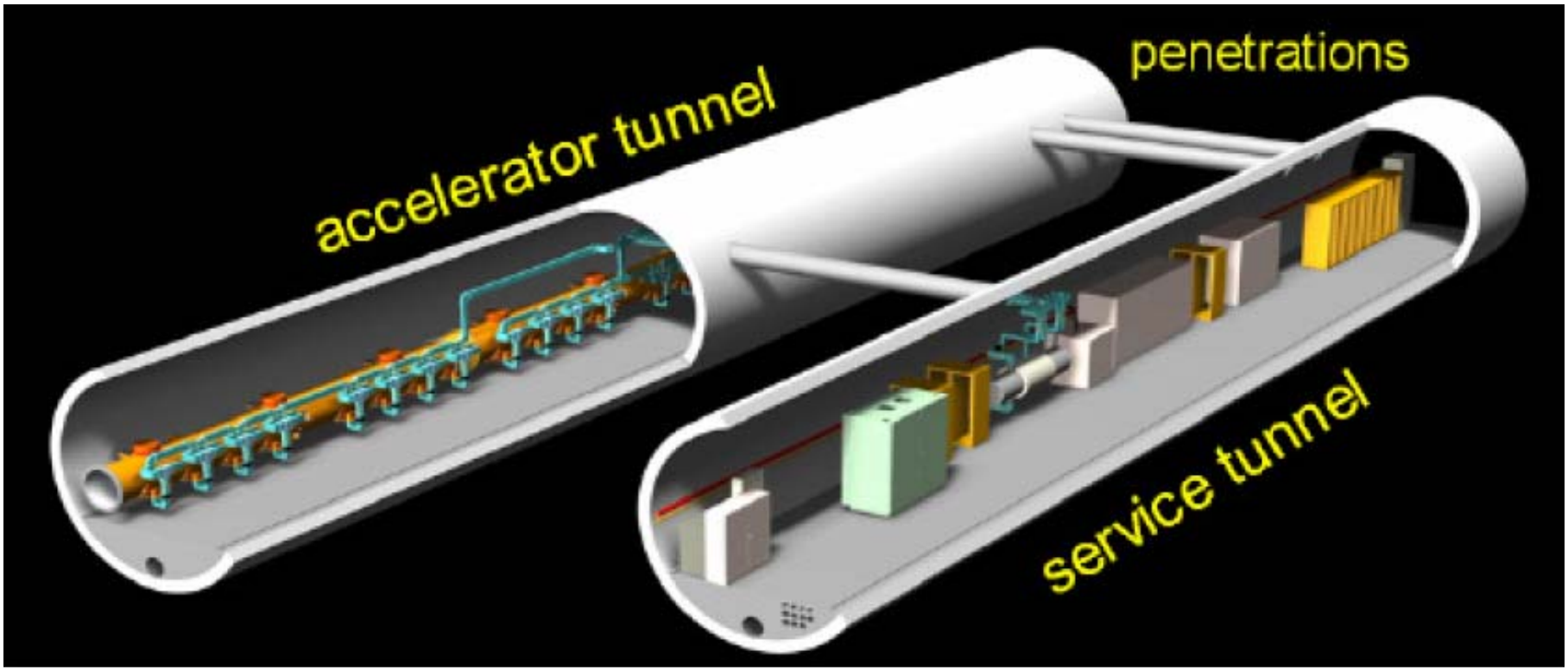
ILC --- Deep Underground



Two tunnels

- accelerator units
- other for services - RF power

Main Linac Double Tunnel



- Three RF/cable penetrations every rf unit
- Safety crossovers every 500 m
- 34 kV power distribution

Superconducting RF Cryomodule

RDR Cost Estimating

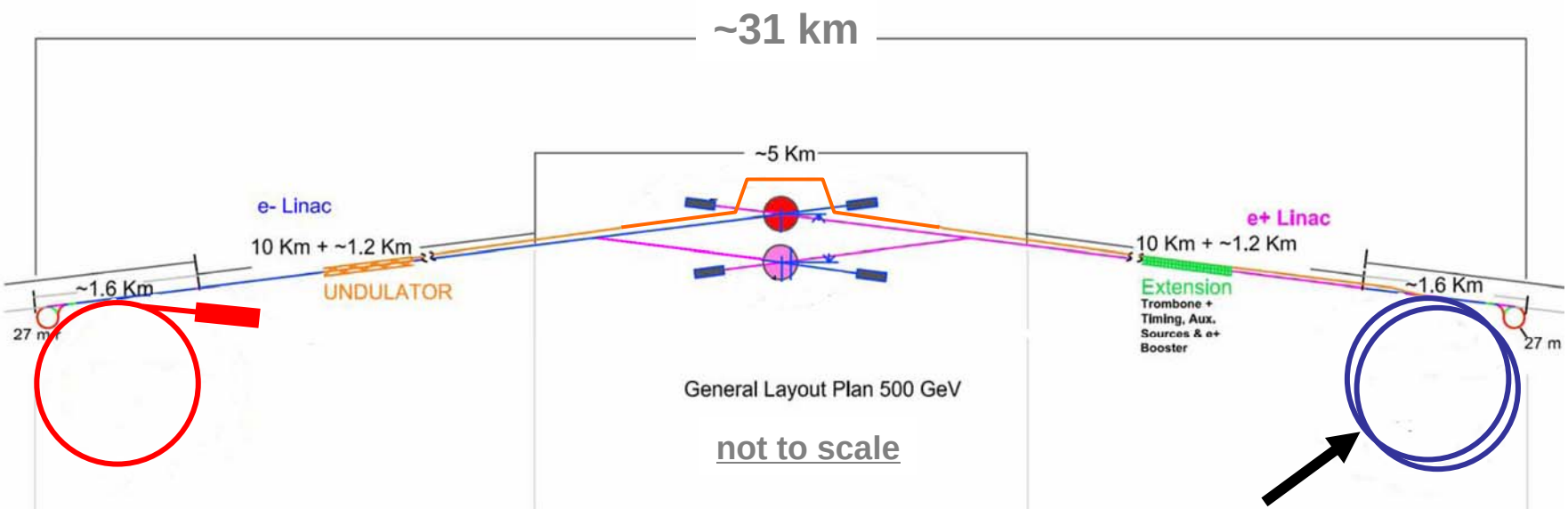
- "Value" Costing System: International costing for International Project
  - **Provides basic agreed to "value" costs**
  - **Provides estimate of "explicit" labor (man-hr)]**
- Based on a call for world-wide tender:
  lowest reasonable price for required quality
- Classes of items in cost estimate:
  - **Site-Specific: separate estimate for each sample site**
  - **Conventional: global capability (single world est.)**
  - **High Tech: cavities, cryomodules (regional estimates)**

Cost-Driven Design Changes

Area		RDR MB	CCR	CCB	approx. Δ$
BDS	2´14mr IRs	supported	14	yes	~170 M$
	Single IR with push-pull detector	supported	23	yes	~200 M$
	Removal of 2nd muon wall	supported	16	yes	~40 M$
ML	Removal of service tunnel	**rejected**			~150 M$
	RF unit modifications (24 ® 26 cav/klys)	supported			~50 M$
	Reduced static cryo overhead	supported	20	yes	~150 M$
	Removal linac RF overhead	supported			~20 M$
	Adoption of Marx modulator (alternate)	**rejected**			~180 M$
RTML	Single-stage bunch compressor	**rejected**			~80 M$
	Miscellaneous cost reduction modifications	supported	19	yes	~150 M$
Sources	Conventional e+ source	**rejected**			<100M$
	Single e+ target	supported	*in prep*		~30 M$
	e- source common pre-accelerator	supported	22	yes	~50 M$
DR	Single e+ ring	supported	15	yes	~160 M$
	Reduced RF in DR (6 ® 9mm σz)	supported	*in prep*		~40 M$
	DR consolidated lattice (CFS)	supported	*in prep*		~50 M$
General	Central injector complex	supported	18(19)	yes	~180 M$

The Evolving Baseline

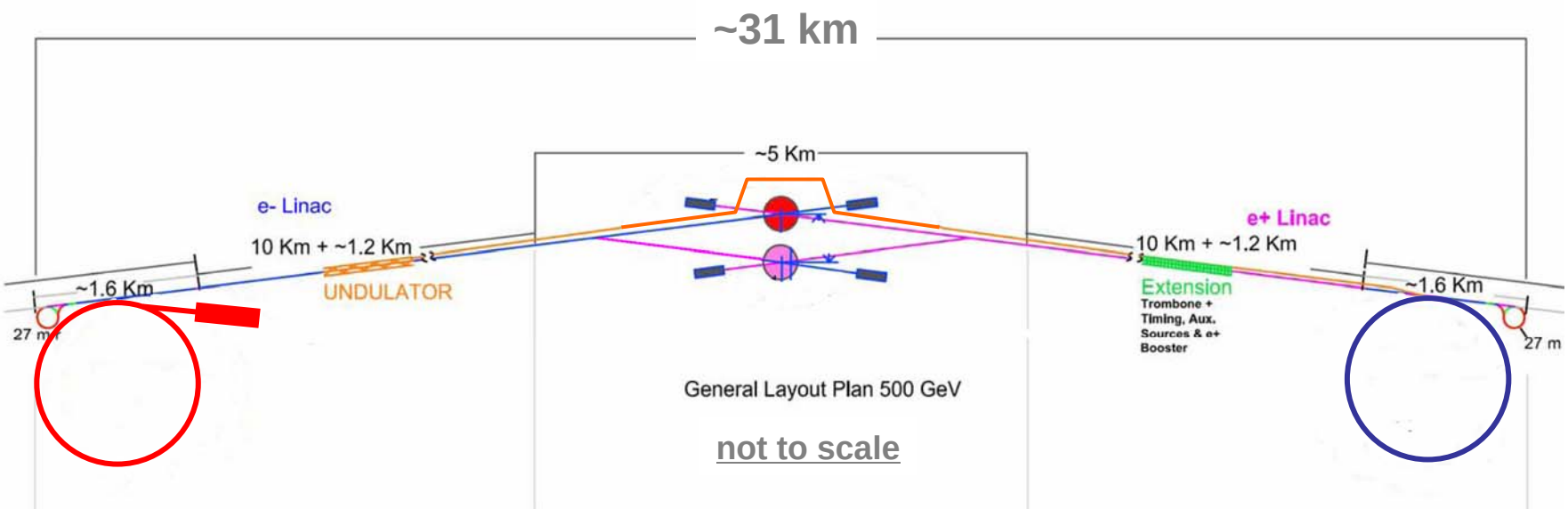
Baseline Configuration



Removal of second e+ ring

The Evolving Baseline

Baseline Configuration

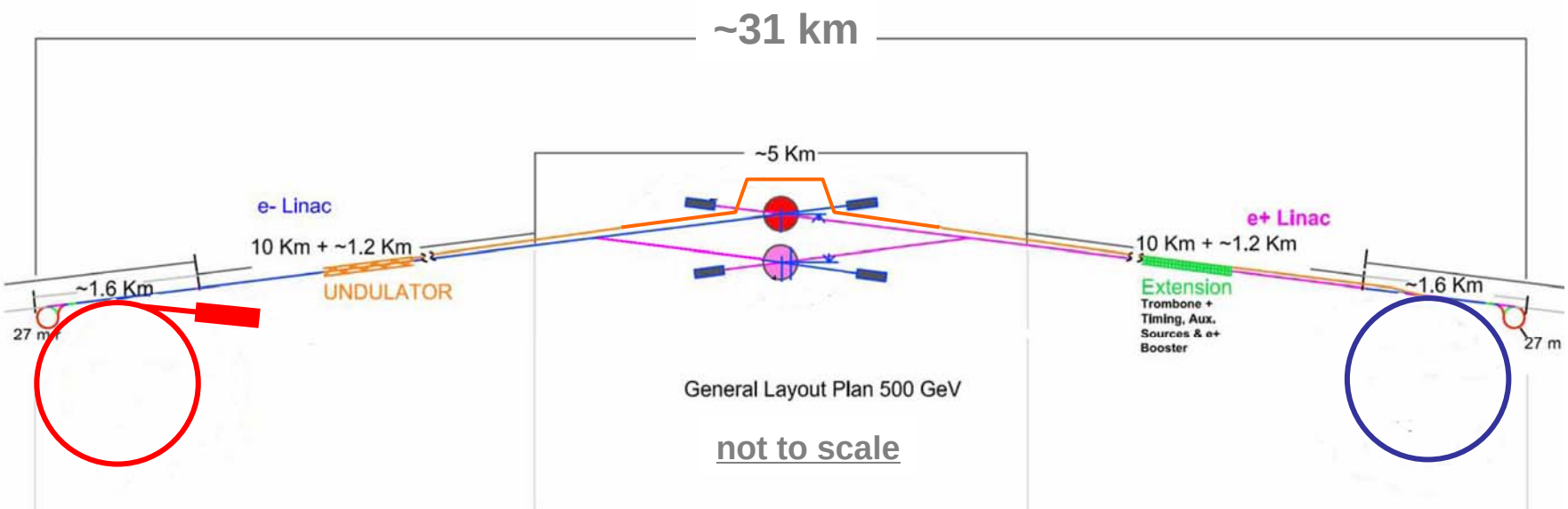


Removal of second e+ ring

simulations of effect of clearing electrodes on **Electron Cloud** instability suggests that a **single e+ ring** will be sufficient

The Evolving Baseline

Baseline Configuration

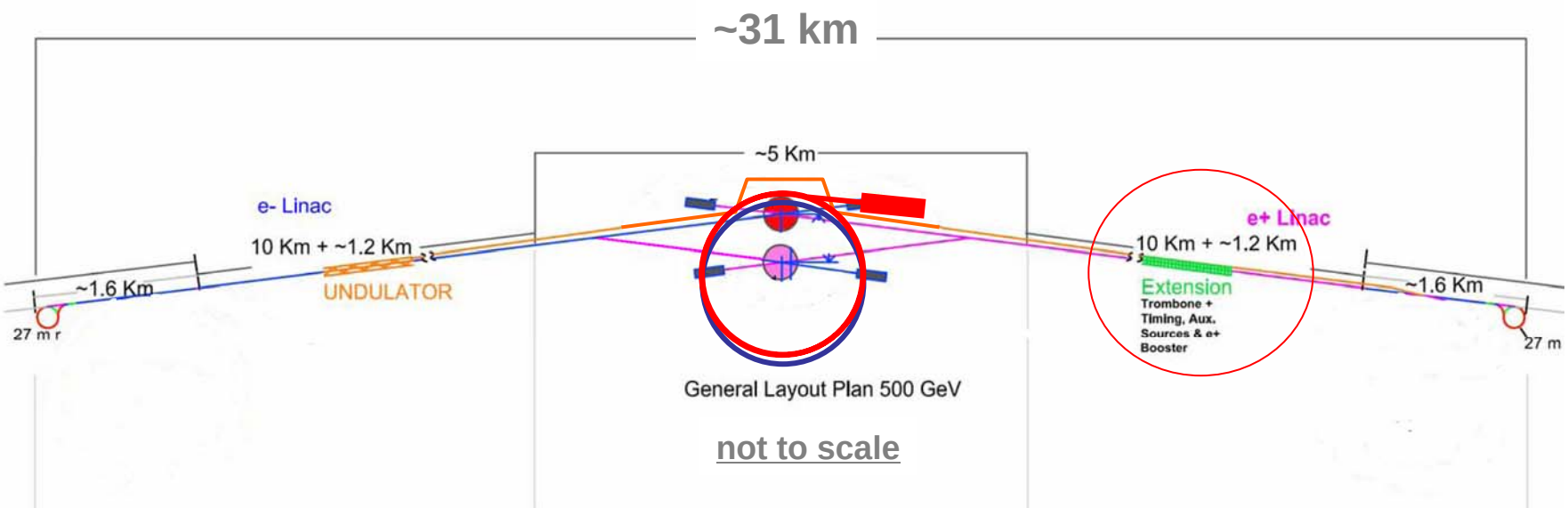


Centralised injectors

Place both e+ and e- ring in single centralized tunnel

The Evolving Baseline

Baseline Configuration



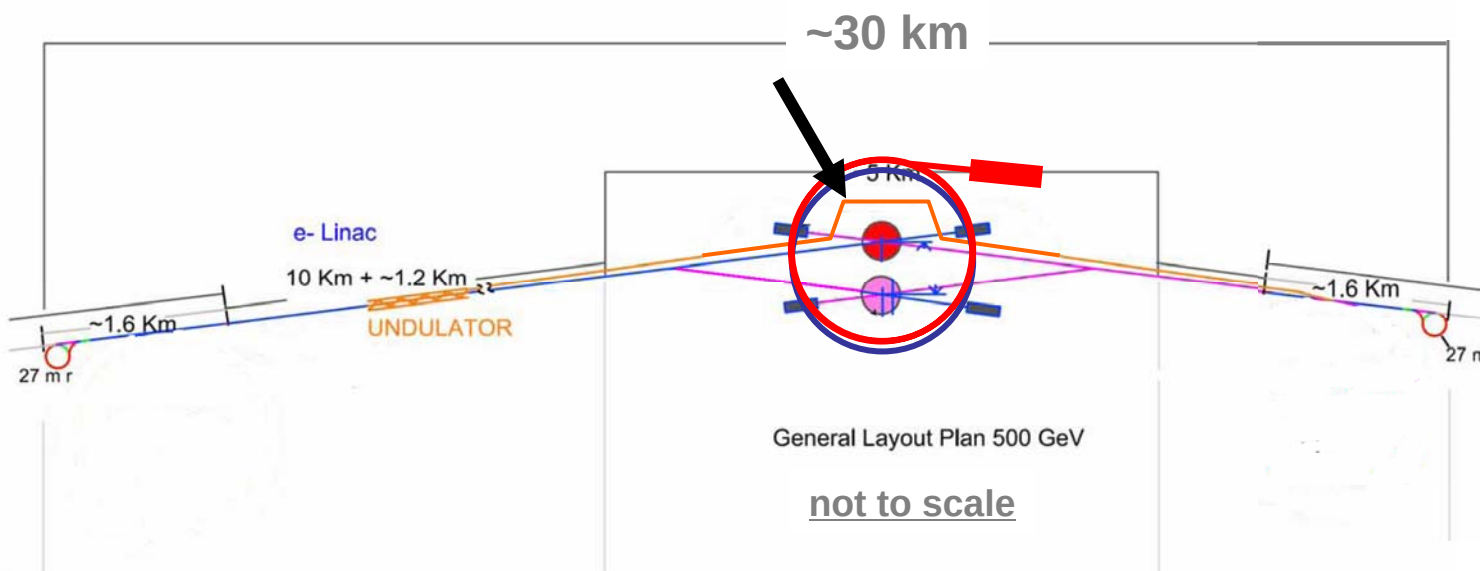
Centralised injectors

Place both e+ and e- ring in single centralized tunnel

Adjust timing (remove timing insert in e+ linac)

The Evolving Baseline

Baseline Configuration



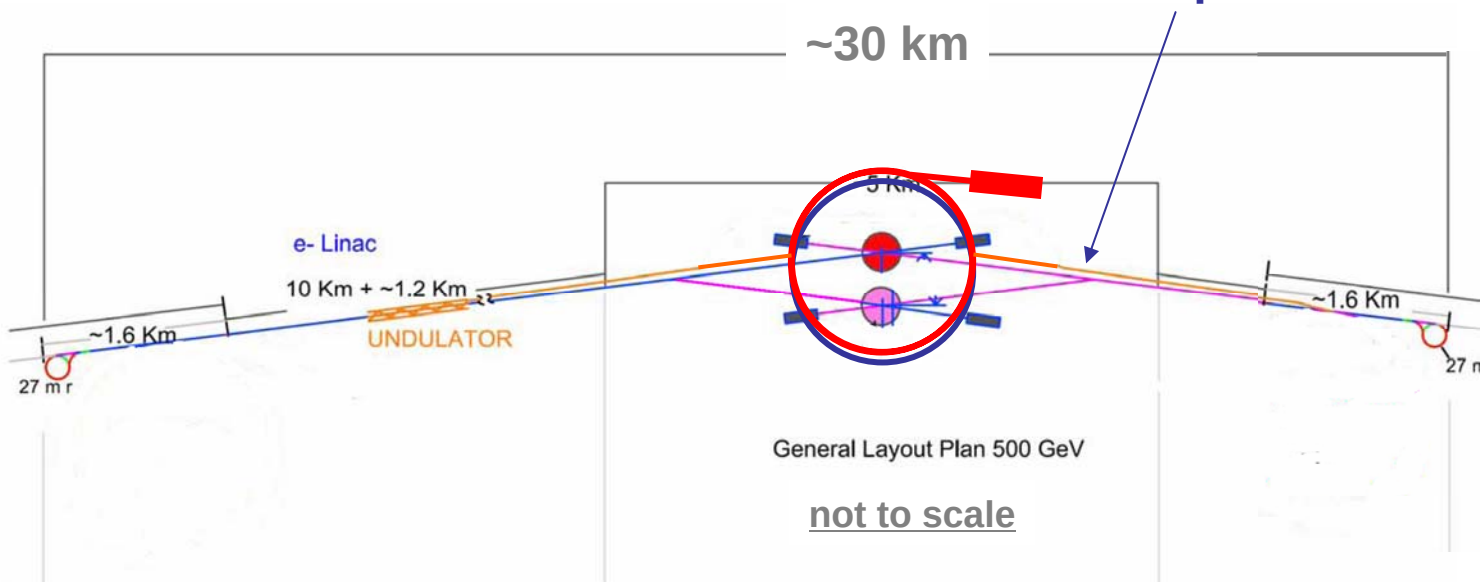
Centralised injectors

- Place both e+ and e- ring in single centralized tunnel
- Adjust timing (remove timing insert in e+ linac)
- Remove BDS e+ bypass

The Evolving Baseline

Baseline Configuration

Long 5GeV low-emittance transport lines now required



Centralised injectors

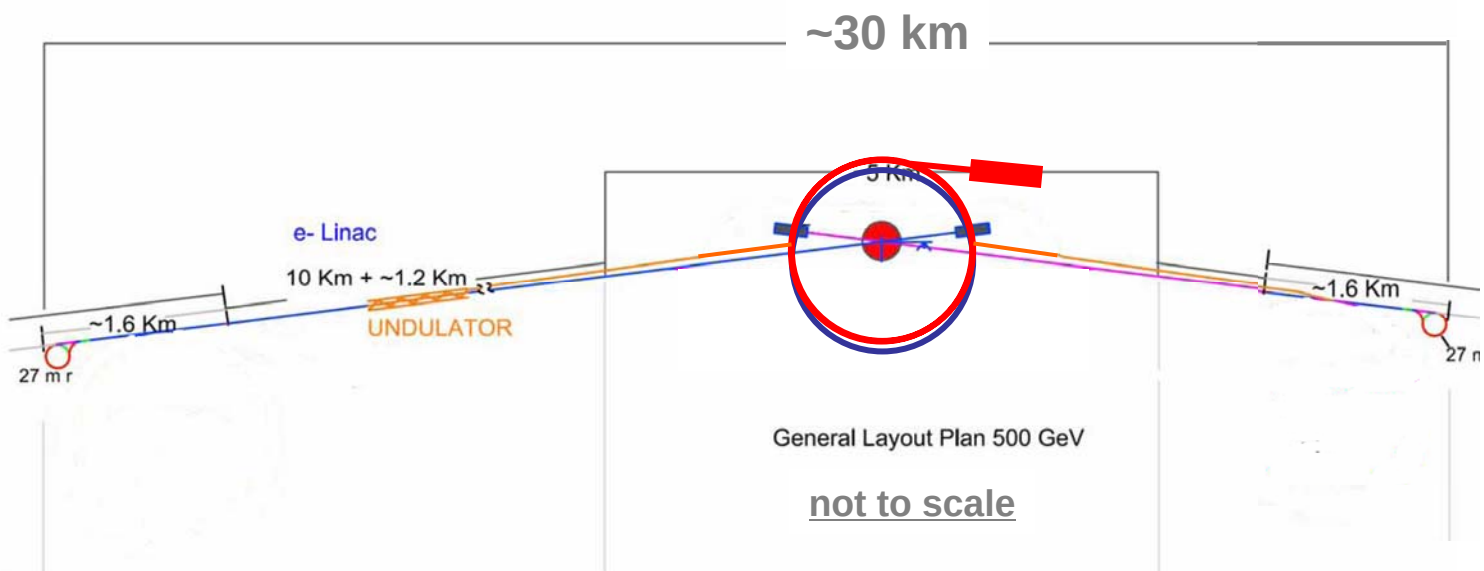
Place both e+ and e- ring in single centralized tunnel

Adjust timing (remove timing insert in e+ linac)

Remove BDS e+ bypass

The Evolving Baseline

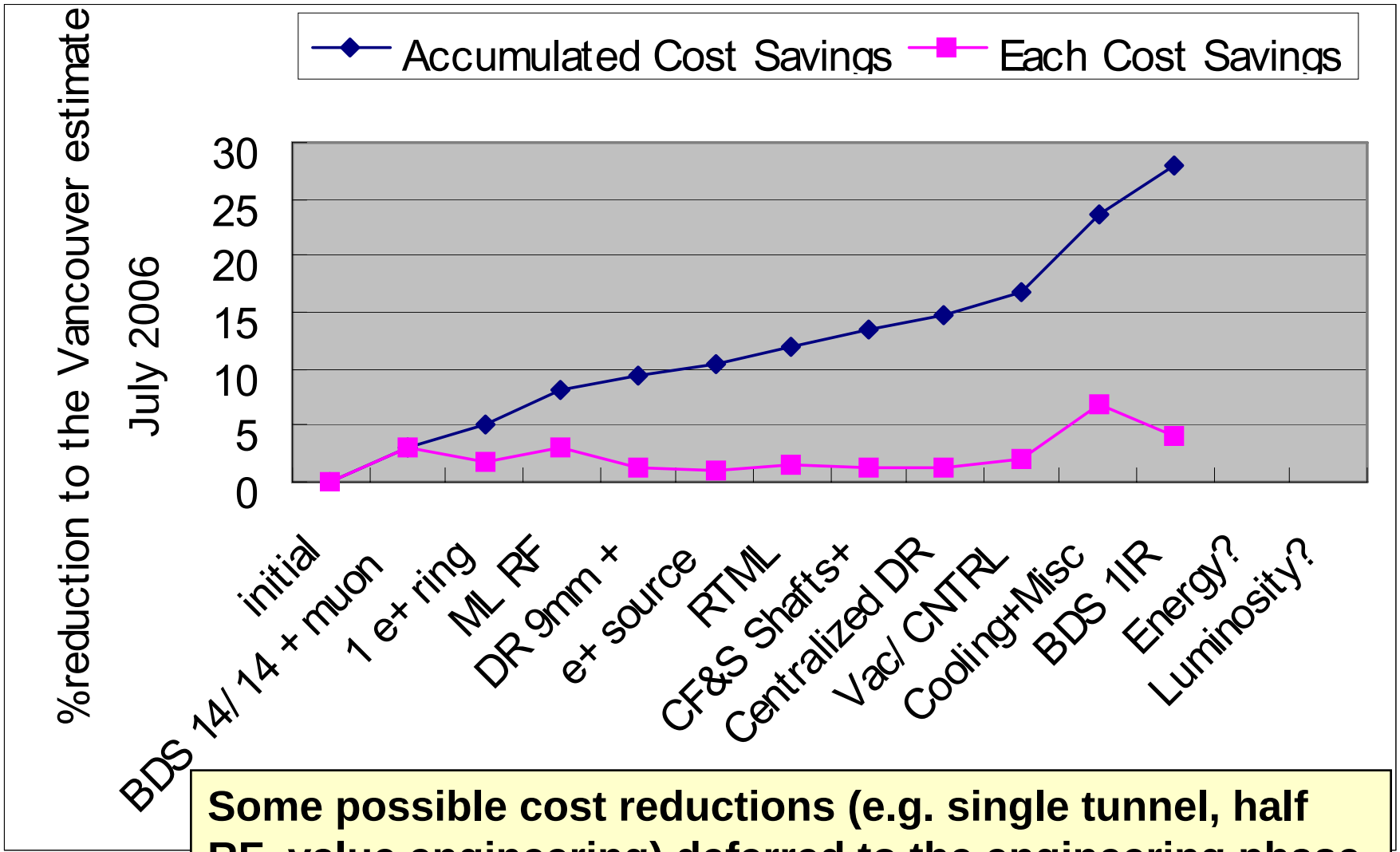
Baseline Configuration



Single IR with Push-Pull Detector

Final RDR baseline

Evolving Design → Cost Reductions



Some possible cost reductions (e.g. single tunnel, half RF, value engineering) deferred to the engineering phase

RDR Design & "Value" Costs

The reference design was "frozen" as of 1-Dec-06 for the purpose of producing the RDR, including costs.

It is important to recognize this is a snapshot and the design will continue to evolve, due to results of the R&D, accelerator studies and value engineering

Summary
RDR "Value" Costs

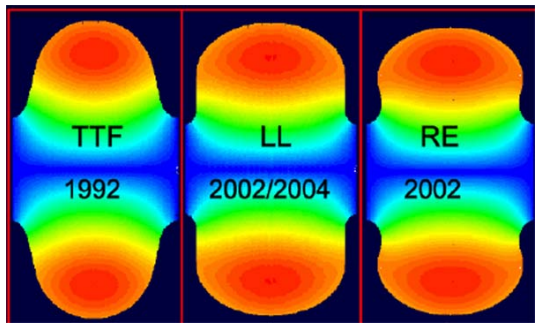
Total Value Cost (FY07)

4.87B ILC Units - Shared
+
1.78B ILC Units - Site Specific
+
13.0K person-years
("explicit" labor = 22.2 M person-hrs @ 1,700 hrs/yr)

For this estimate
1 ILC Unit = 1 US 2007$ (= 0.83 Euro = 117 Yen)

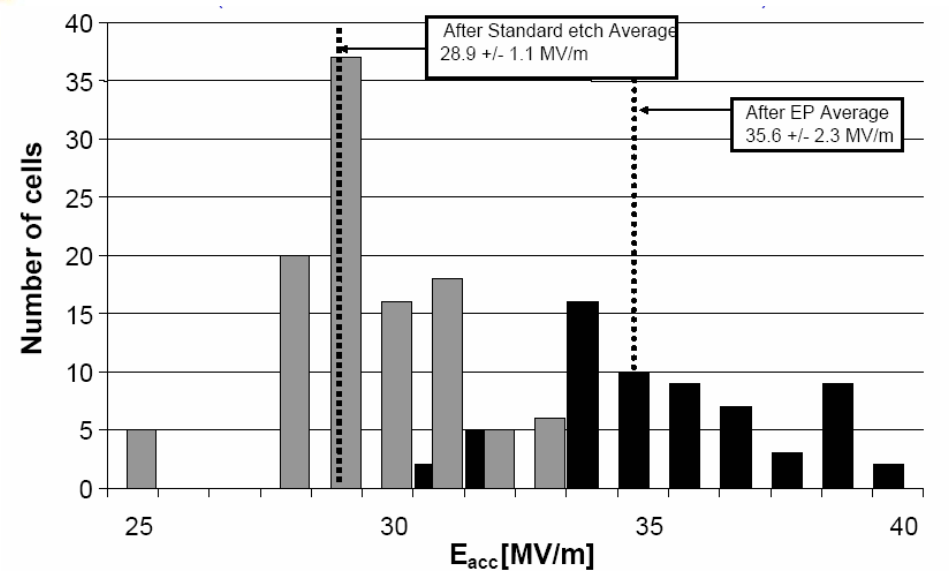
ILC Reference Design and Plan

Producing Cavities

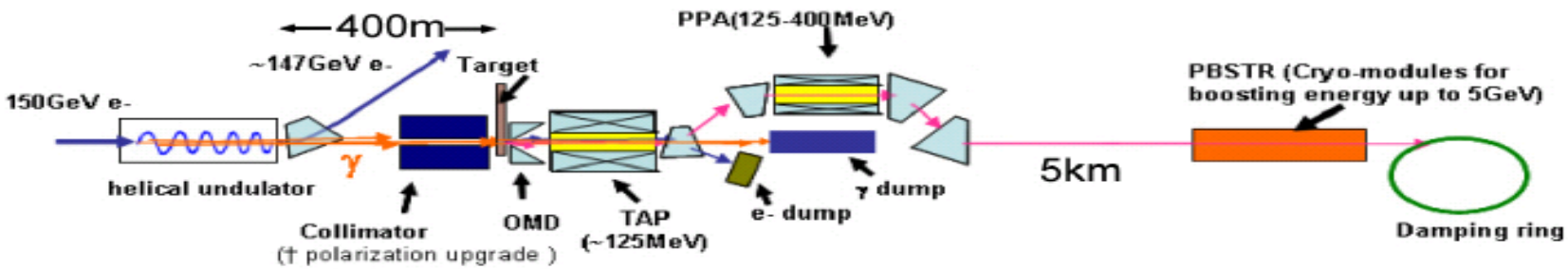


Cavity Shape

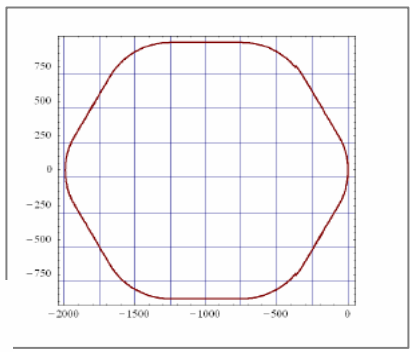
Obtaining Gradient



ILC Reference Design and Plan

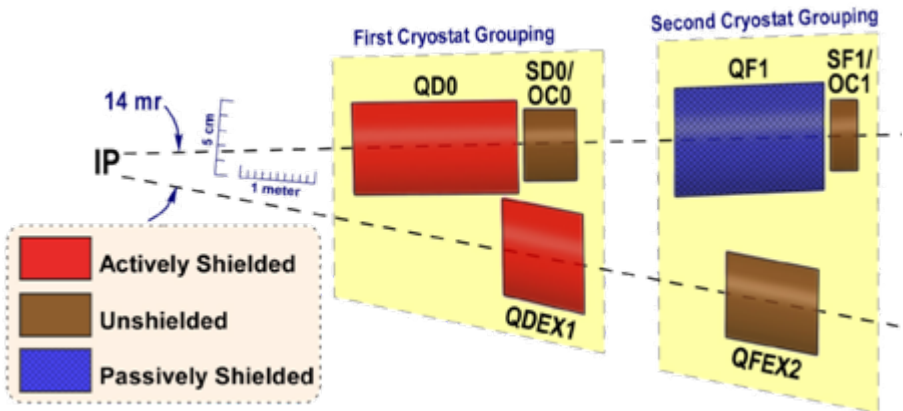


Making Positrons



6km
Damping
Ring

10MW
Klystrons



Beam Delivery and Interaction Point

ILC Reference Design
Technical Discussion

Marc Ross

Wine & Cheese Seminar

Friday March 9.

Final Reflections

- We have come a long way, and the connecting theme has been a strong physics case, coupled with the development of a coherent concept for the accelerator and the R&D technology demonstrations

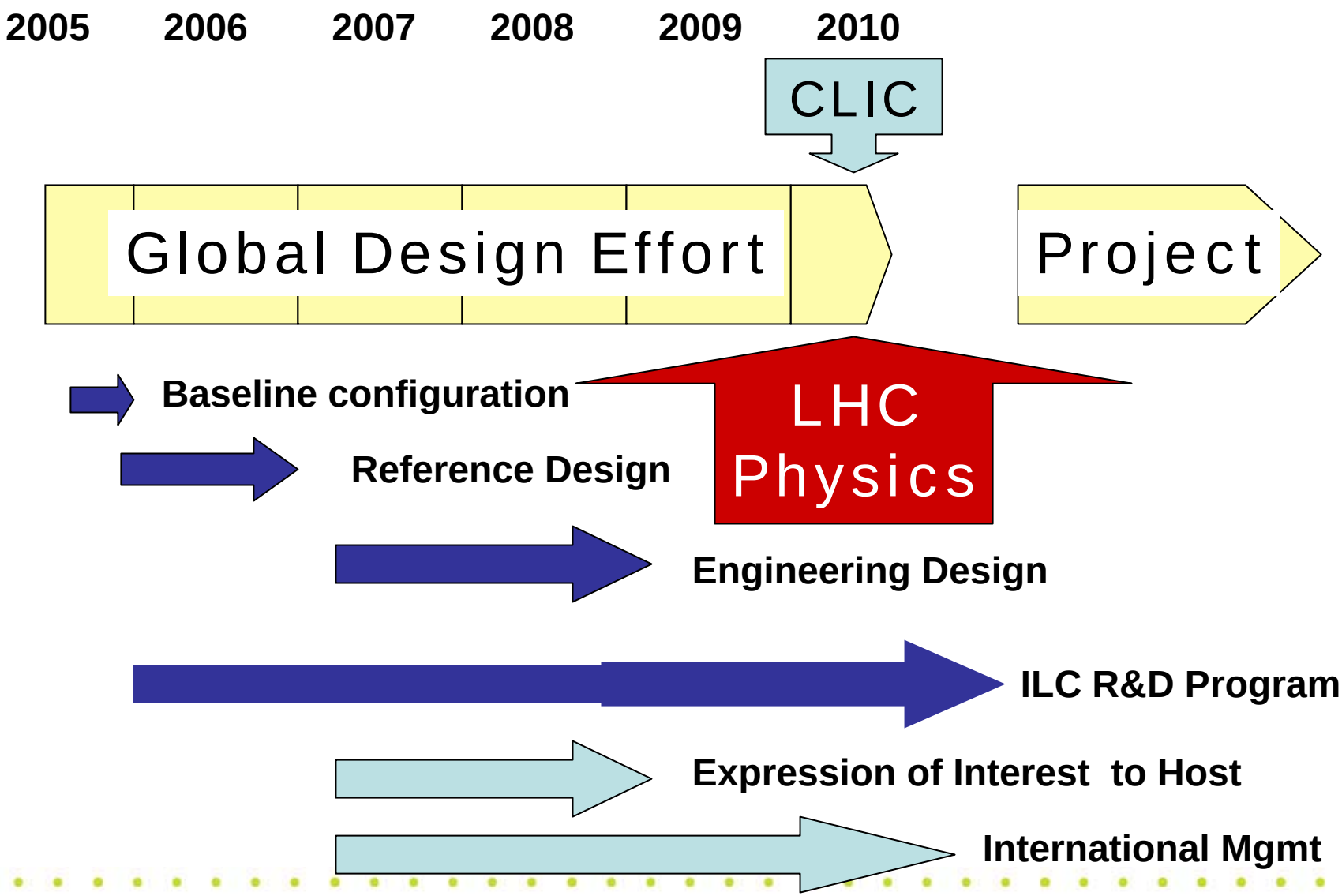
March 2005
I accepted
GDE job

Feb 2007
Reference Design
Presented to
ICFA/ILCSC

Final Reflections

- We have come a long way, and the connecting theme has been a strong physics case, coupled with the development of a coherent concept for the accelerator and the R&D technology demonstrations

- This provides a strong base for the future, but there are many hurdles ahead: costs, LHC results, international management, determining a host and site, funding, .

- Many things will converge in about 2010 and we want to be ready with the strongest construction proposal possible on that time scale.

The GDE Plan and Schedule