Incontri di Fisica delle Alte Energie 2007

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The International Linear Collider

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Outline

- The International Linear Collider

  All **three** words are important !!!

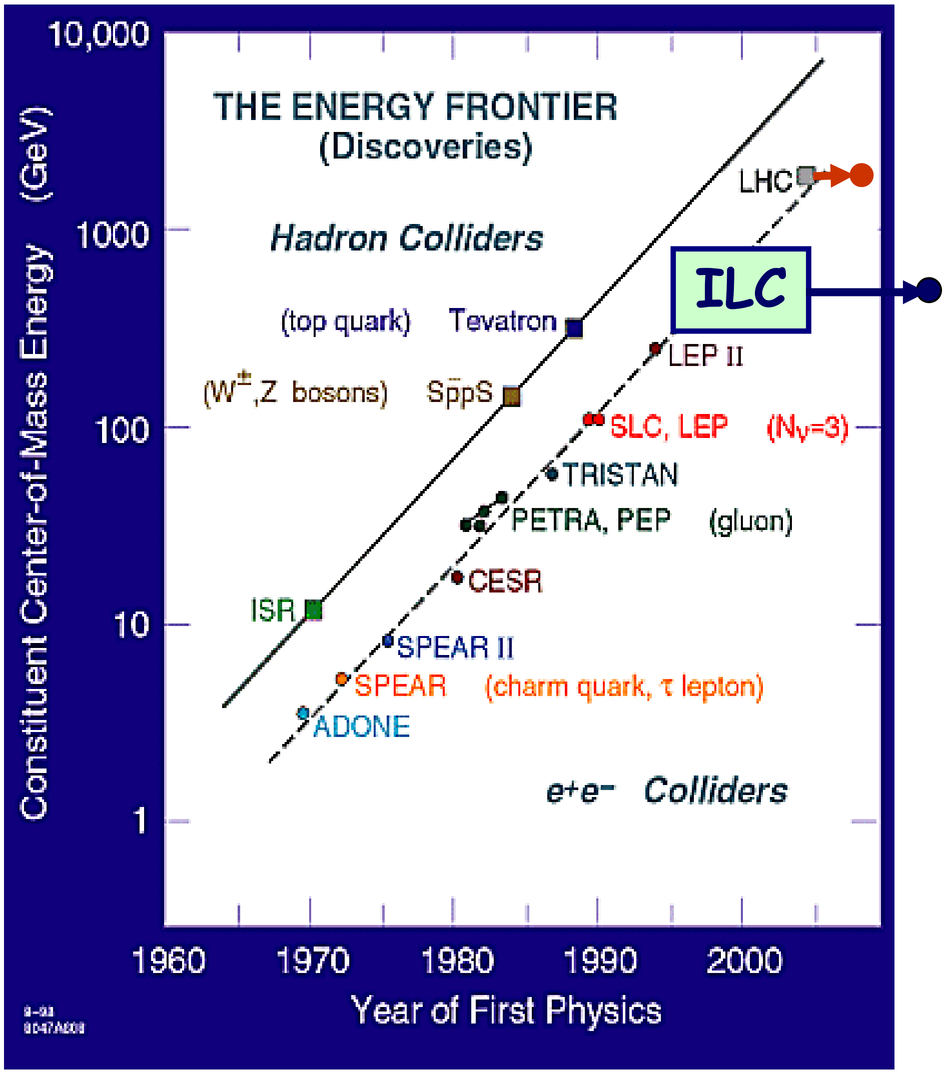
- In this talk I will cover

  – What the ILC machine is

  – Where the project stands and where is going

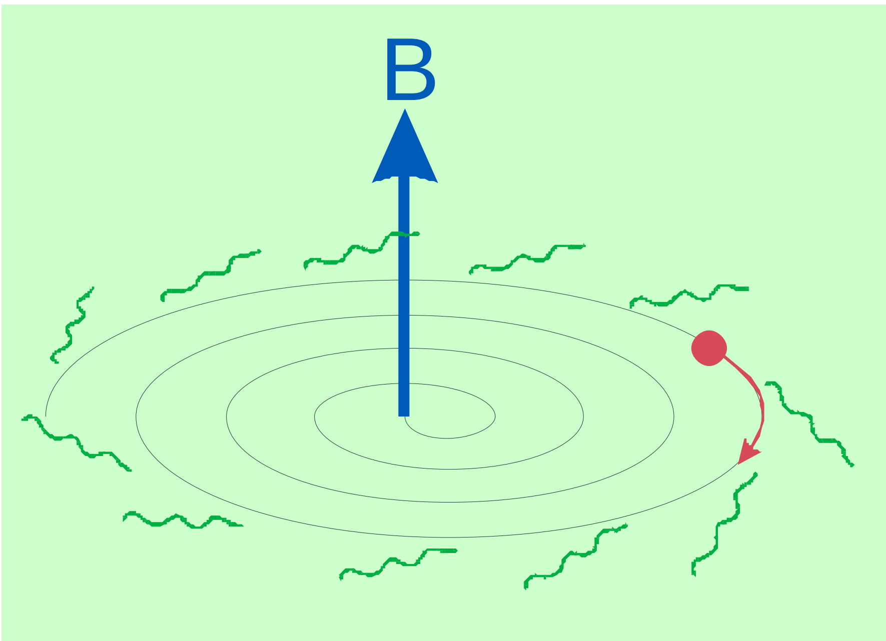
  –Which are the challenges for the machine

Energy Frontier and e^+e^- Colliders



No Circular e^+e^- Collider after LEP

Synchrotron Radiation:
charged particle in a magnetic field:



Energy loss replaced by RF power
cost scaling $\$ \propto E_{cm}^2$

Energy loss dramatic for electrons

$$U_{SR}[\text{GeV}] = 6 \cdot 10^{-21} \cdot \gamma^4 \cdot 1/r[km]$$

U_{SR} = energy loss per turn
γ = relativistic factor
r = machine radius

$$\gamma_{proton} / \gamma_{electron} \approx 2000$$

A Simple Exercise

- Synchrotron Radiation (SR) becomes prohibitive for electrons in a circular machine above LEP energies:

$$U_{SR}[\text{GeV}] = 6 \cdot 10^{-21} \cdot \gamma^4 \cdot \frac{1}{r[\text{km}]}$$

U_{SR} = energy loss per turn
γ = relativistic factor
r = machine radius

- RF system must replace this loss, and r scale as E^2
- LEP @ 100 GeV/beam: 27 km around, 2 GeV/turn lost
- Possible scale to 250 GeV/beam i.e. **E_{cm} = 500 GeV**:
  - **170 km** around
  - **13 GeV/turn** lost

$\gamma_{250GeV} = 4.9 \cdot 10^5$

- Consider also the luminosity
  - For a luminosity of ~ $10^{34}/\text{cm}^2$/second, scaling from b-factories gives ~ 1 Ampere of beam current
  - 13 GeV/turn x 2 amperes = **26 GW RF power**
  - Because of conversion efficiency, this collider would consume more power than the state of **California in summer: ~ 45 GW**

Circulating beam power = 500 GW

- Both size and power seem excessive

Origin of the Linear Collider Idea

M. Tigner,
Nuovo Cimento **37** (1965) 1228

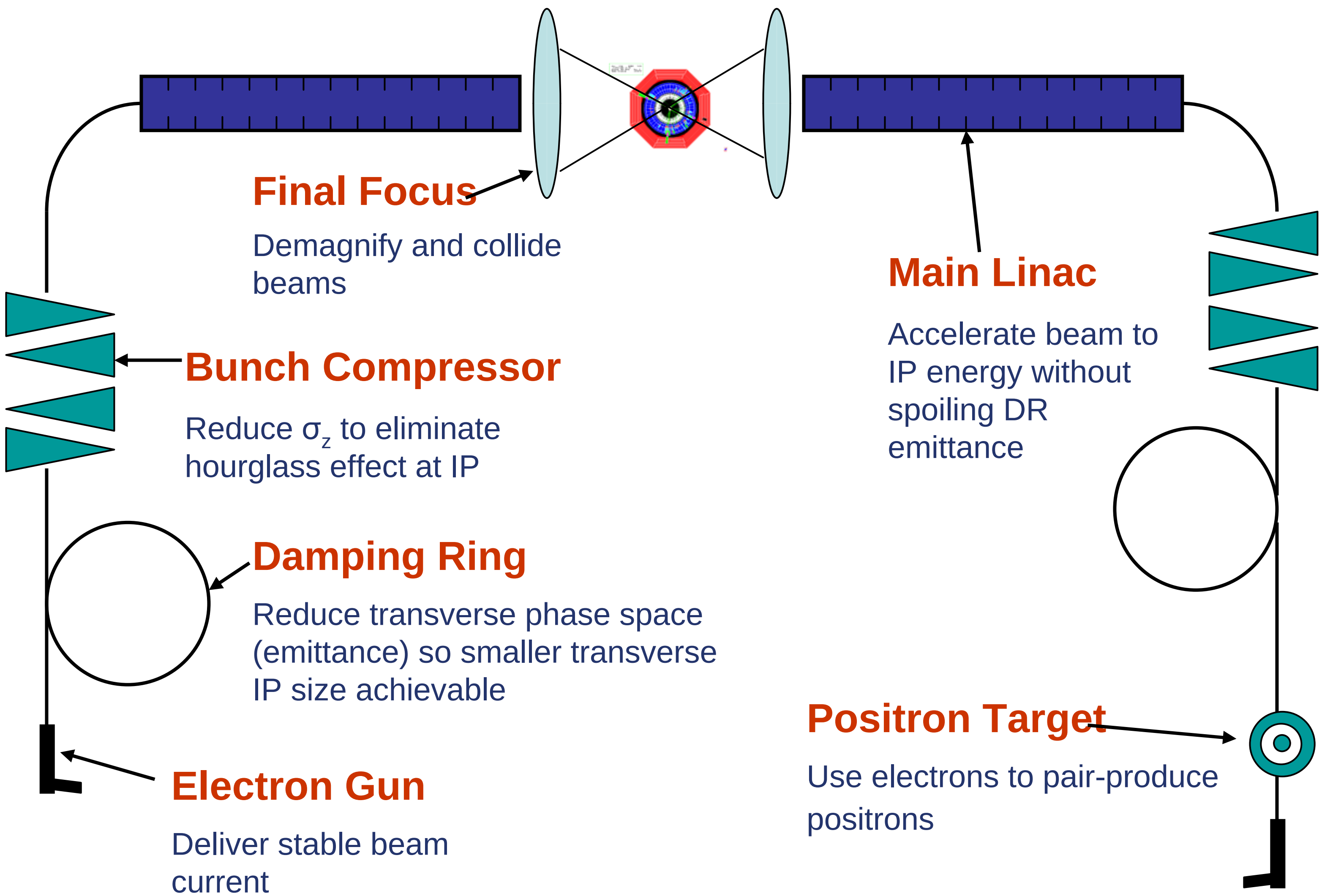
A Possible Apparatus for Electron-Clashing Experiments (*).

M. Tigner

Laboratory of Nuclear Studies. Cornell University - Ithaca, N.Y.

"While the storage ring concept for providing clashing-beam experiments ([1]) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant and superficially more complex may prove more tractable."

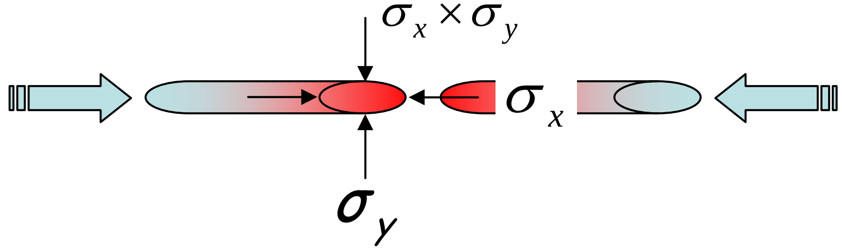
LC conceptual scheme



Fighting for Luminosity

$$L \propto \frac{N_e^2}{\sigma_x \sigma_y}$$

$$L \propto \frac{n_b \times N_e^2 \times f_{rep}}{\sigma_x \times \sigma_y} \times H_D$$



$$L \propto n_b \times f_{rep}$$

L = Luminosity

N_e = # of electron per bunch

$\sigma_{x,y}$ = beam sizes at IP

IP = interaction point

$$L \propto \frac{P_b}{E_{c.m.}} \times \frac{N_e}{\sigma_x \sigma_y}$$

n_b = # of bunches per pulse

f_{rep} = pulse repetition rate

P_b = beam power

$E_{c.m.}$ = center of mass energy

Parameters to play with

↓ Reduce **beam emittance** ($\varepsilon_x \cdot \varepsilon_y$) for smaller beam size ($\sigma_x \cdot \sigma_y$)

↑ Increase bunch population (N_e)

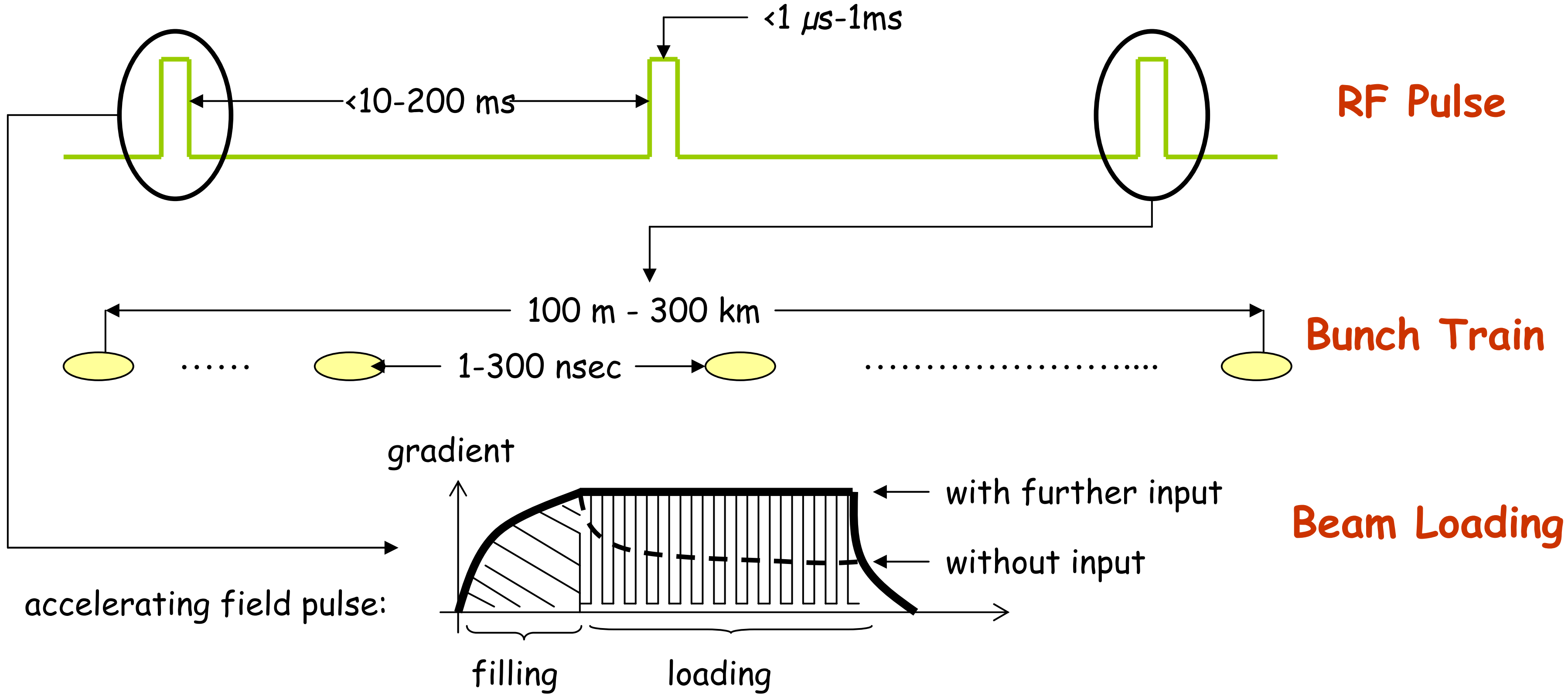
↑ Increase beam power $\left(P_b = E_{cm} \times N_e \times n_b \times f_{rep}\right)$

↑ Increase **beam to-plug power efficiency** for cost $P_{plug} = \eta P_b$

Linear Colliders are pulsed

LCs are pulsed machines to improve efficiency. As a result:

- duty factors are small
- pulse peak powers can be very large



Linacs are made of RF cavities

- To give energy to a charged particle beam, apart from “details”, you need to let him move across a region in which an electric field exists and is directed as the particle motion.

$$\Delta E_{particle} = \int \vec{F}_{Lorentz} \cdot d\vec{s} = q \int \vec{E} \cdot \vec{v}\, dt$$

- In the accelerator’s world RF take care of all the variety of items that are required to accomplish this task of creating a region filled of electromagnetic energy that can be sucked by the beam while crossing it.
- An “RF power source” is used to fill, via a “coupler”, the “RF cavity”, or resonator that is the e.m. energy container from which the beam is taking its energy.
- What we ask to a good cavity?

High Q for losses:

U = stored energy
P_{diss} = dissipated power

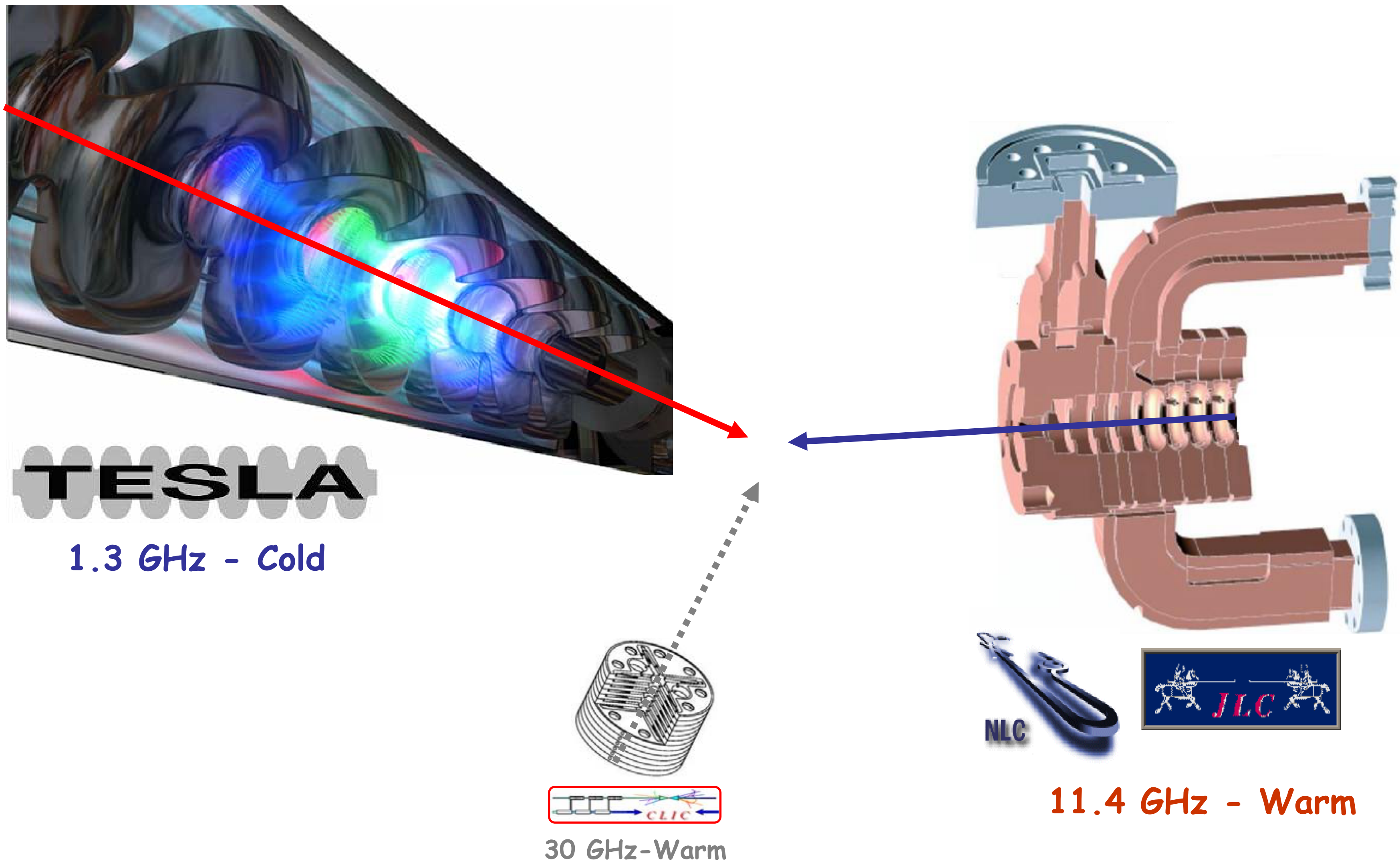
$$Q = \omega \frac{U}{P_{diss}}$$

Small R_s for high Q:

R_s = surface resistance
G = cavity geometrical factor

$$Q = \frac{G}{R_s}$$

Competing technologies



Technology Choice: NLC/JLC or TESLA

The International Linear Collider Steering Committee (ILCSC) selected the twelve members of the International Technology Recommendation Panel (**ITRP**) at the end of 2003:

Asia:	**Europe:**	**North America:**
G.S. Lee	J-E Augustin	J. Bagger
A. Masaike	G. Bellettini	**B. Barish (Chair)**
K. Oide	G. Kalmus	P. Grannis
H. Sugawara	V. Soergel	N. Holtkamp

First meeting end of January 2004 at RAL

Mission: one technology by end 2004

Result: recommendation on 19 August 2004

From the ILC Birthday

The Recommendation

- We recommend that the linear collider be based on superconducting rf technology (from Exec. Summary)
  - This recommendation is made with the understanding that we are recommending a technology, not a design. We expect the final design to be developed by a team drawn from the combined warm and cold linear collider communities, taking full advantage of the experience and expertise of both (from the Executive Summary).
  - We submit the Executive Summary today to ILCSC & ICFA
  - Details of the assessment will be presented in the body of the ITRP report to be published around mid September
  - The superconducting technology has features that tipped the balance in its favor. They follow in part from the low rf frequency.

19-Aug-04 ITRP - LC Technology Recommendation 13

From the ILC Birthday

Some of the Features of SC Technology

- The large cavity aperture and long bunch interval reduce the complexity of operations, reduce the sensitivity to ground motion, permit inter-bunch feedback and may enable increased beam current.
- The main linac rf systems, the single largest technical cost elements, are of comparatively lower risk.
- The construction of the superconducting XFEL free electron laser will provide prototypes and test many aspects of the linac.
- The industrialization of most major components of the linac is underway.
- The use of superconducting cavities significantly reduces power consumption.

Both technologies have wider impact beyond particle physics. The superconducting rf technology has applications in other fields of accelerator-based research, while the X-band rf technology has applications in medicine and other areas.

19-Aug-04 ITRP - LC Technology Recommendation 14

How is spent the cold advantage?

The gain in RF power dissipation with respect to a normal-conducting structure is spent in different ways

$$W \geq Q \frac{T_h - T_c}{T_c}$$

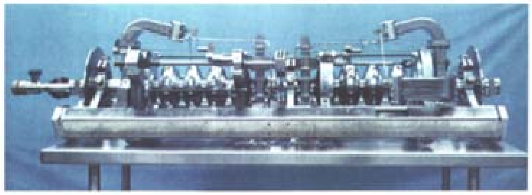
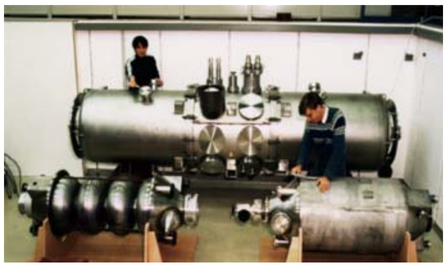
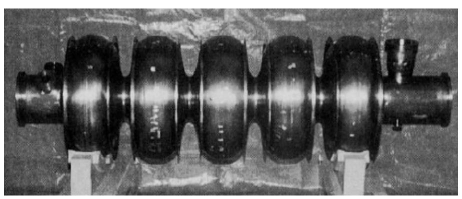
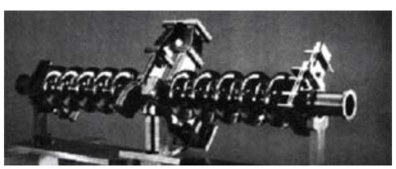
- Paying the price of supplying coolant at 2K
  - **This include ideal Carnot cycle efficiency**
  - **Mechanical efficiency of compressors and refrigeration items**
  - **Cryo-losses for supplying and transport of cryogenics coolants**
  - **Static losses to maintain the linac cold**
- Increasing of the duty cycle (percentage of RF field on)
  - **Longer beam pulses, larger bunch separation, but also**
  - **Larger and more challenging Damping Rings**
- Increasing the beam power (for the same plug power)
  - **Good for Luminosity**

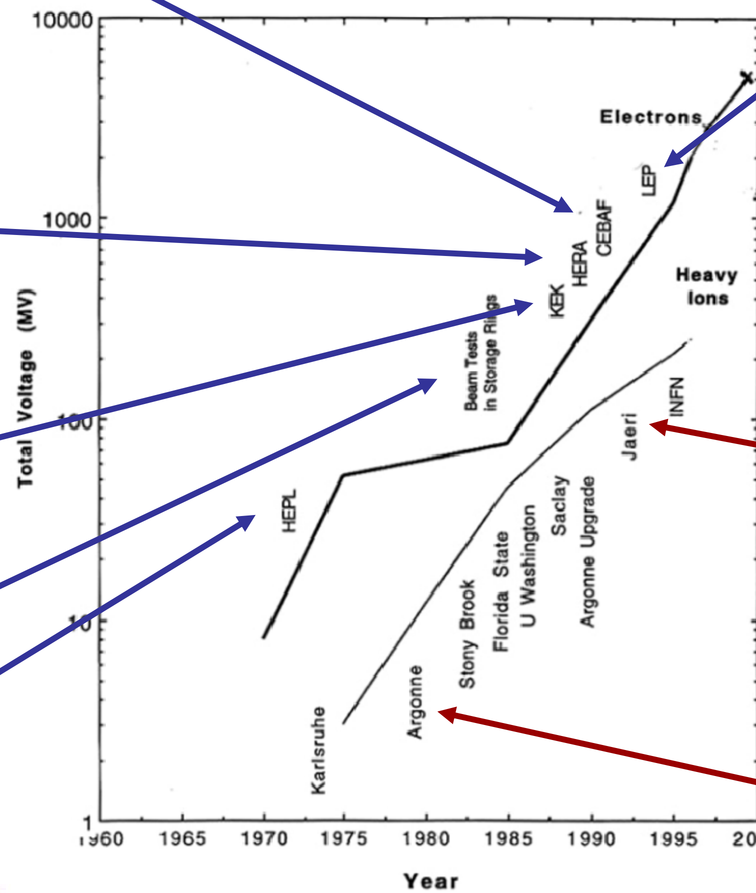
SRF before TESLA

"Livingston Plot" from Hasan Padamsee

Total Installation > 1000 m

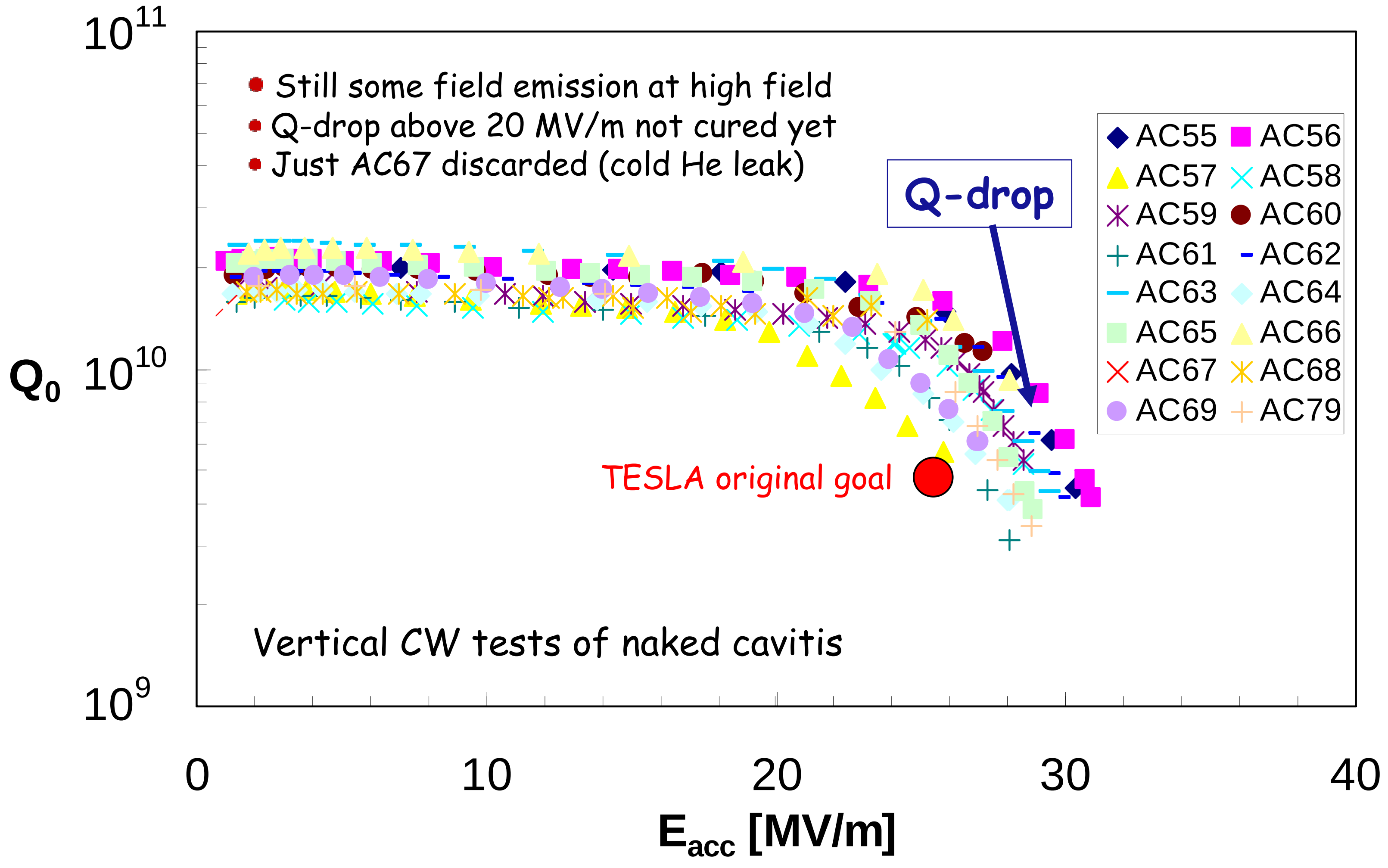
Provided > 5 GV






3rd cavity production with BCP



EP & Baking for 35 MV/m

Electro-Polishing (EP)

instead of

Buffered Chemical Polishing (BCP)

- less local field enhancement
- High Pressure Rinsing more effective
- **Field Emission onset at higher field**

In Situ Baking

@ 120-140 ° C for 24-48 hours

- to re-distribute oxygen at the surface
- **cures Q drop at high field**

The AC 70 example

EP at the DESY plant

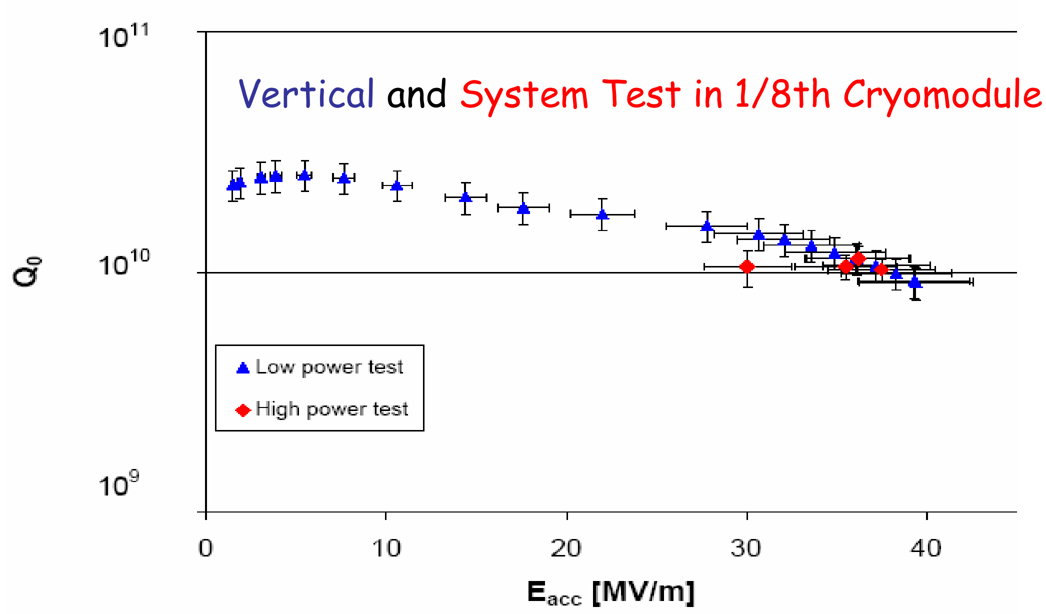
- **Low Field Emission**

800°C annealing

120°C, 24 h, Baking

- high field Q drop cured

High Pressure Water Rinsing

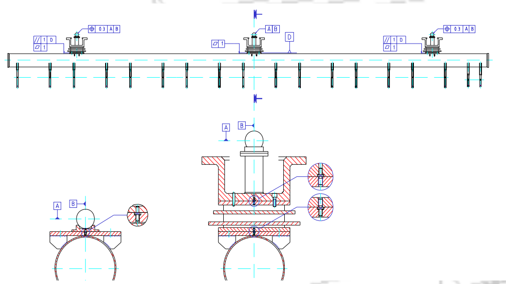


Performing Cryomodules

Three cryomodule generations to:

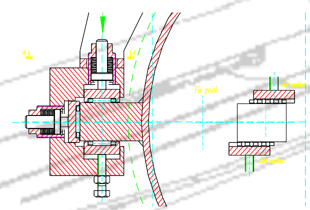
- improve simplicity and performances
- minimize costs

Reliable Alignment Strategy



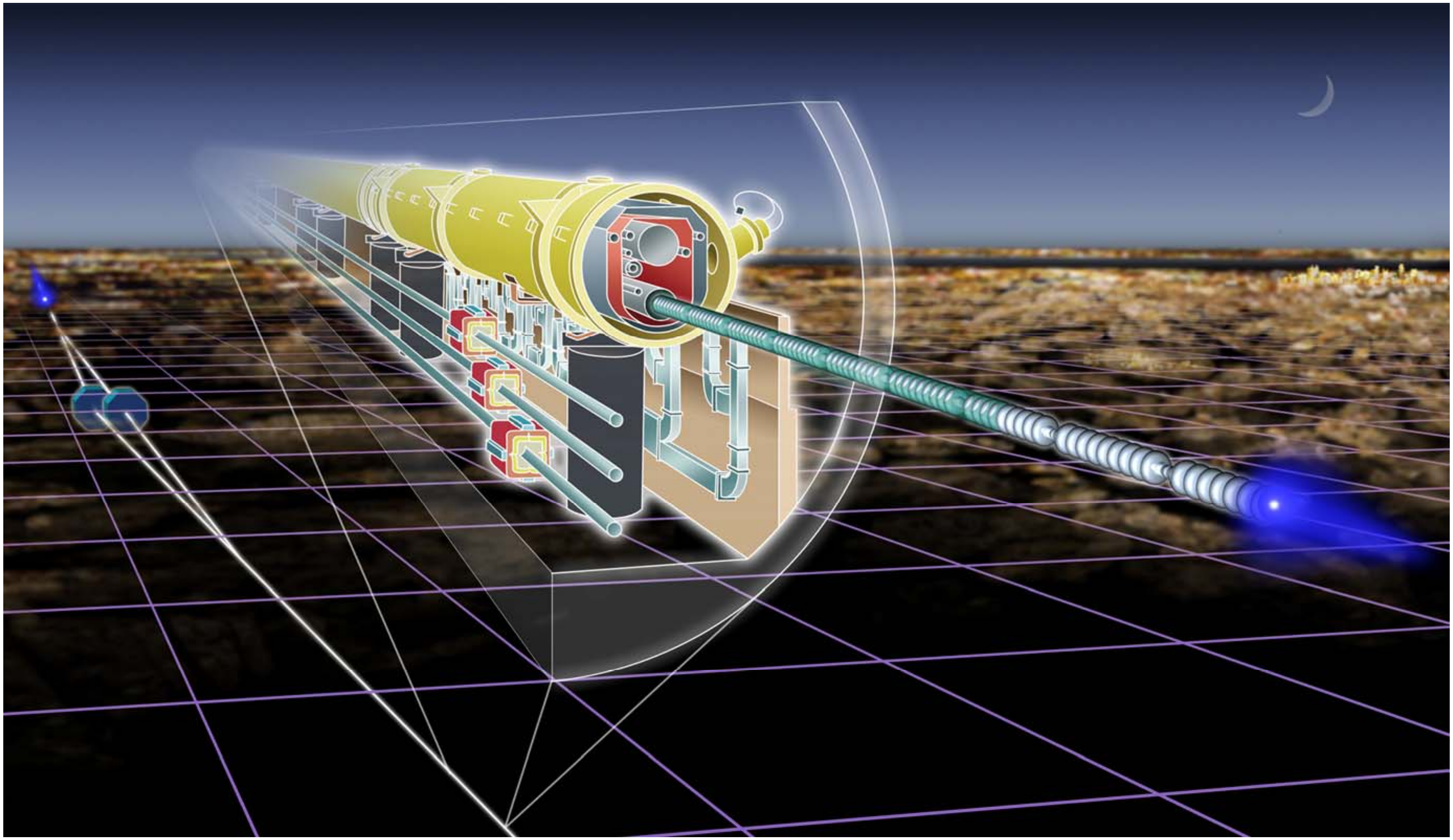
"Finger Welded" Shields

Sliding Fixtures @ 2 K

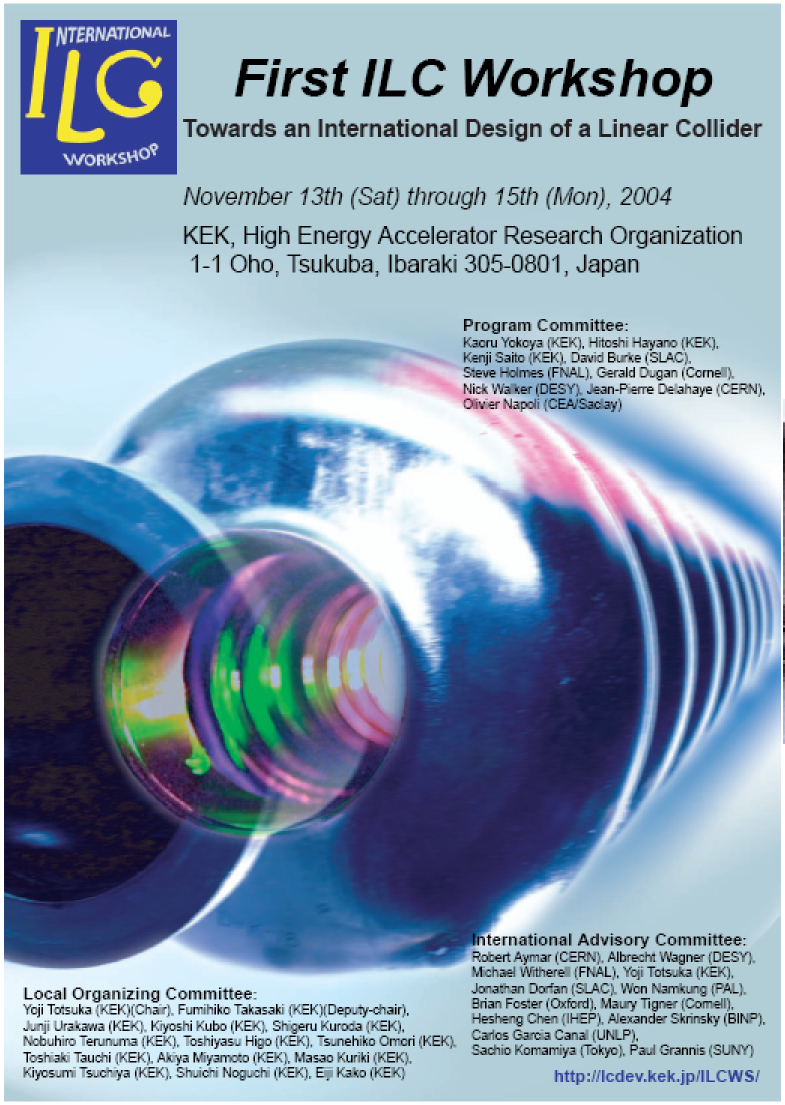


Required plug power for static losses < 5 kW/(12 m module)

ILC Pictorial View



Start of the Global Design Initiative

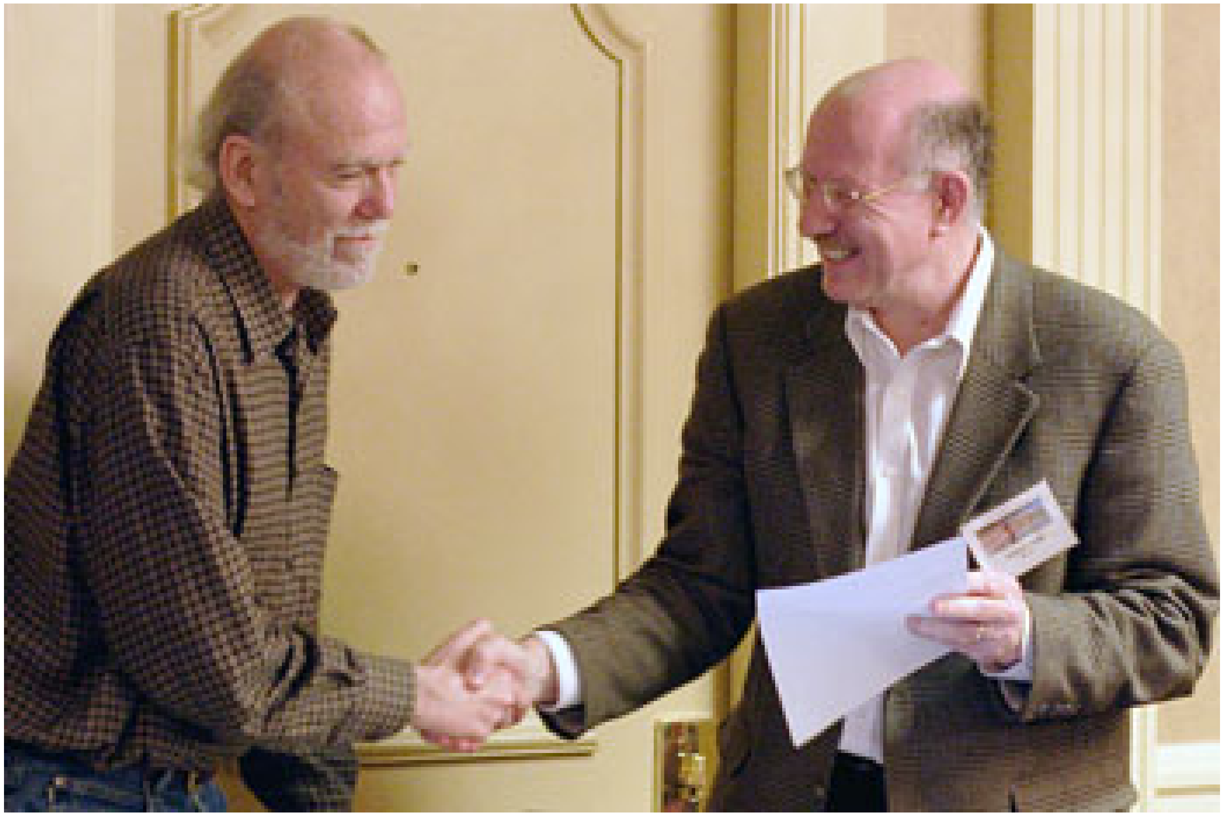


~ 220 participants from 3 regions

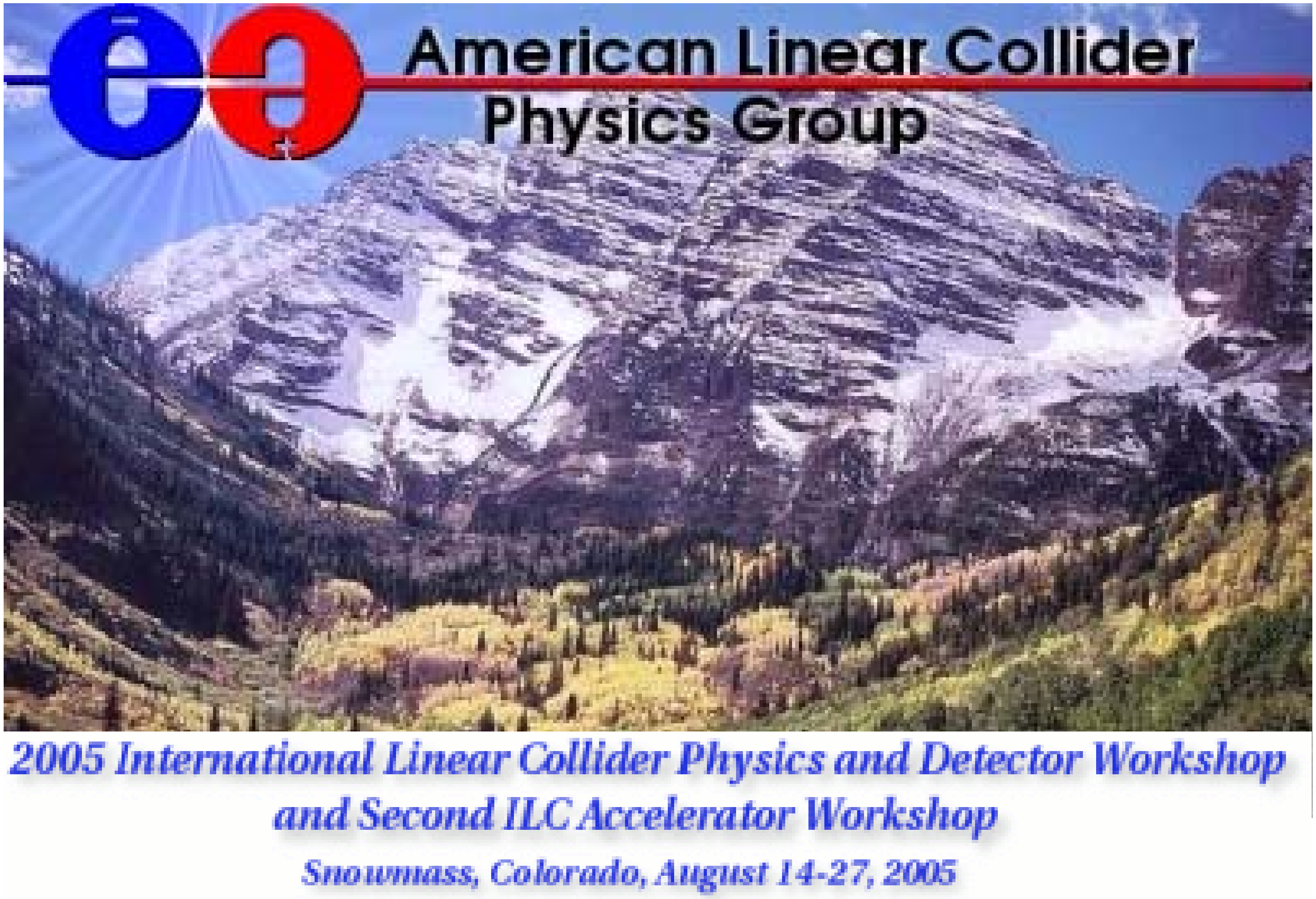
most of them accelerator experts

Global Design Effort (GDE)

On March 18, 2005, during the opening of *LCWS05* workshop at Stanford University, **Barry Barish** officially accepted the position of Director of the **G**lobal **D**esign **E**ffort, **GDE** (yet to be formed)



The 2nd ILC Workshop

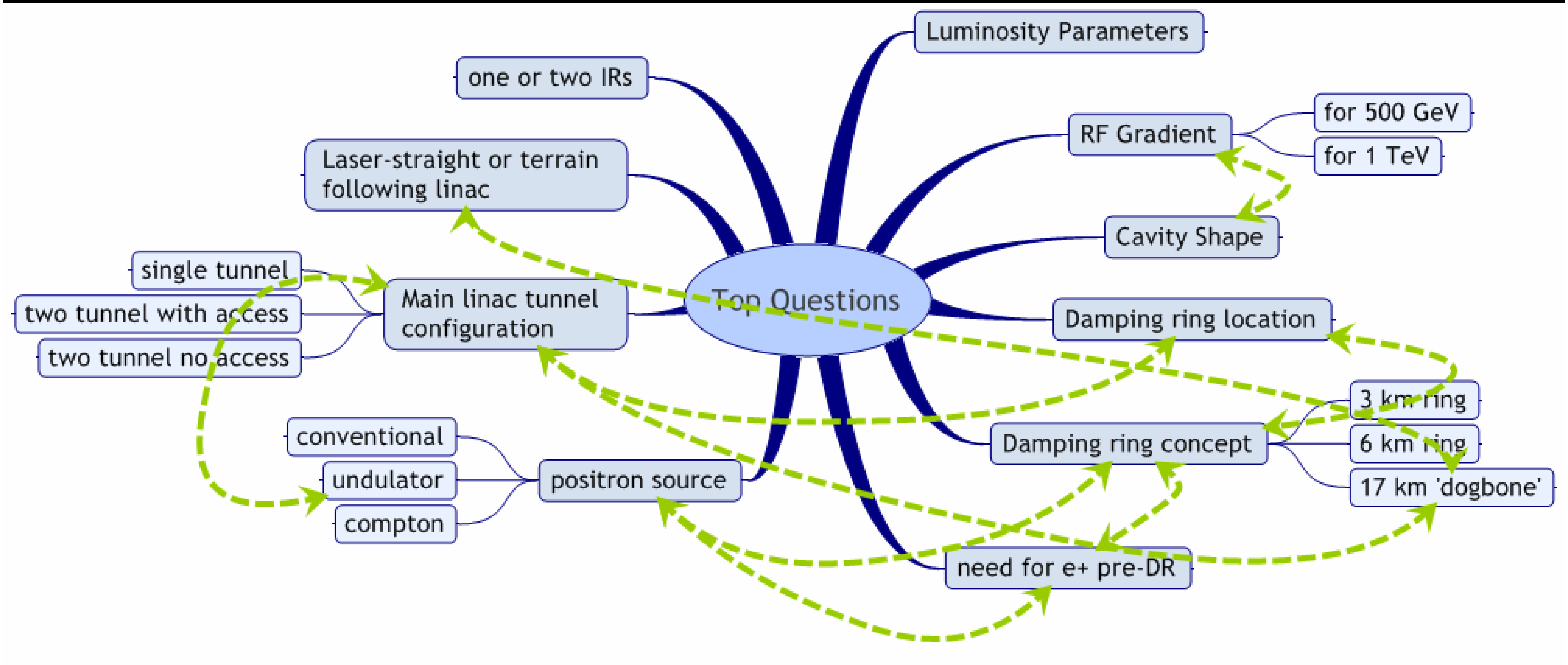


The Mission of the GDE

- 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.)

Making Choices – The Tradeoffs



Many decisions are interrelated and require input from several WG/GG groups

From Snowmass to a Baseline

2005

Snowmass

August | **September** | **October** | **November** | **December**

WW/GG summaries

Response to list of 40+ decisions

All documented 'recommendations available on ILC Website (request community feedback)

Review by BCD EC

BCD EC publishes 'strawman' BCD

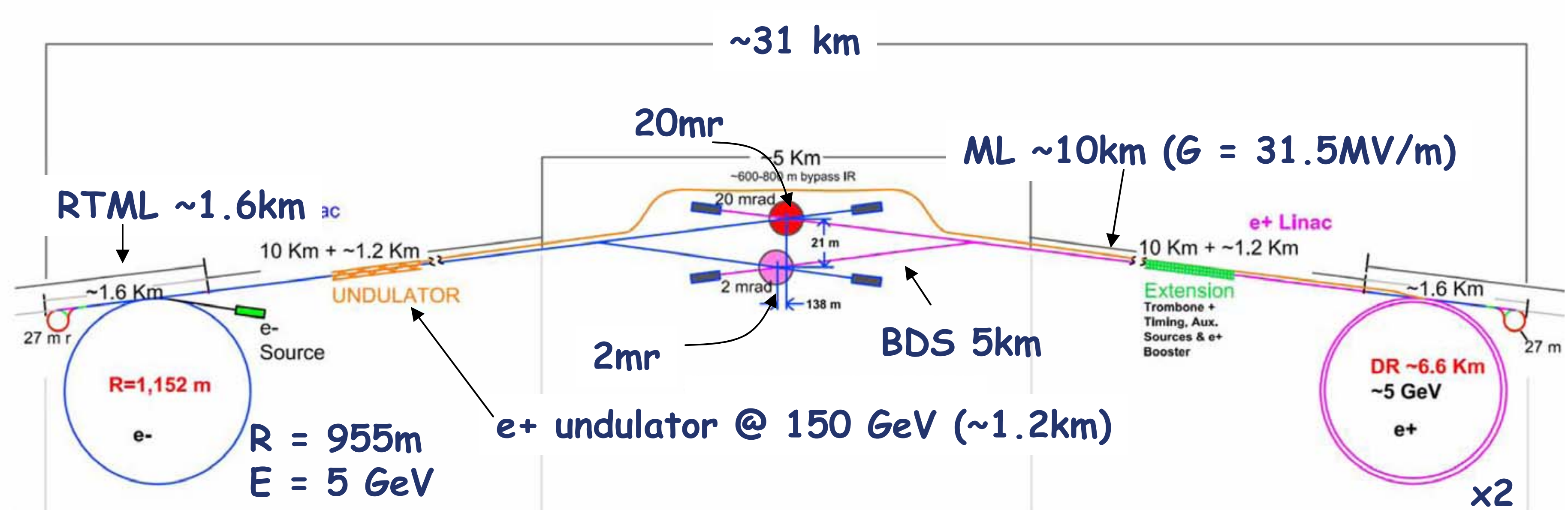
Public Review

Frascati GDE meeting

BCD Executive Committee:
Barish
Dugan, Foster, Takasaki
Raubenheimer, Yokoya, Walker

© Barry Barish

The Baseline Machine



A structured electronic document

Documentation (reports, drawings etc)

Technical specs.

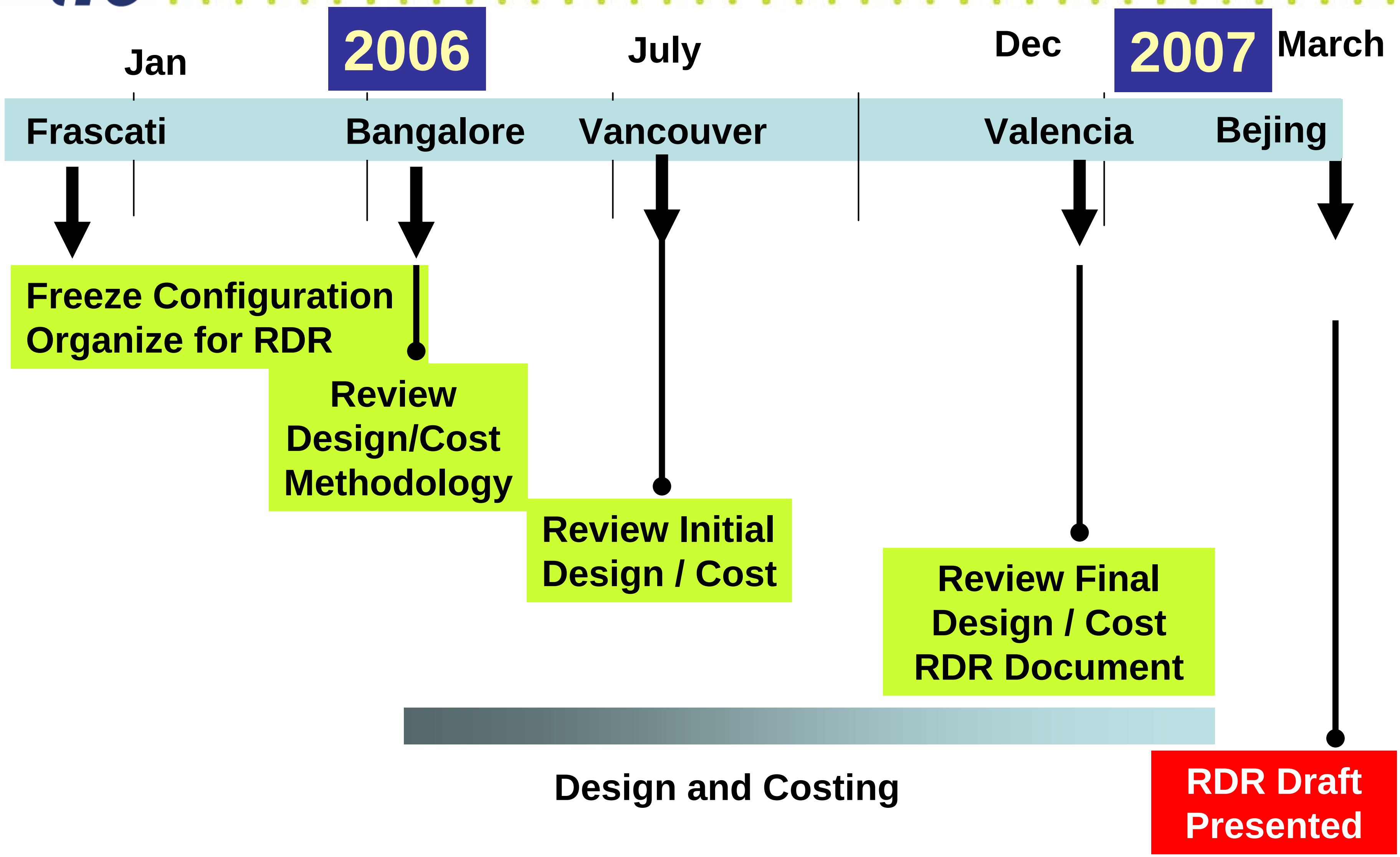
Parameter tables

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

GDE Organization for RDR

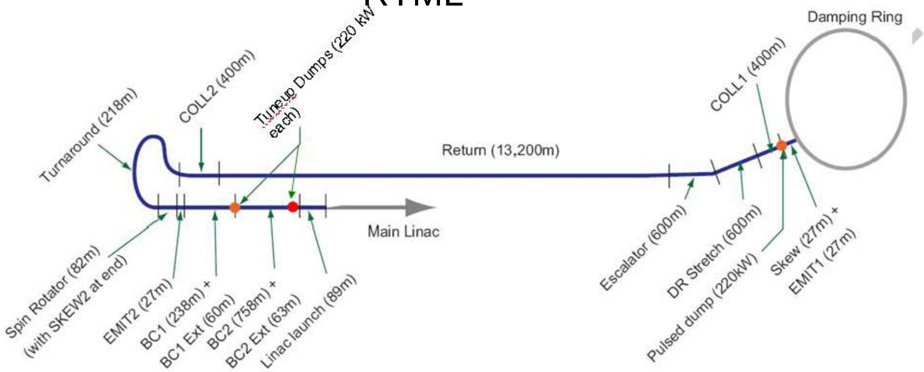
- **Selected some selected new members for the GDE following the BCD completion who have needed skills in design, engineering, costing, etc**
- **Change Control Board**
  - **The baseline will be put under configuration control and a Board with a single chair will be created with needed expertise.**
- **Design / Cost Board**
  - **A GDE Board with single chair will be established to coordinate the reference design effort, including coordinating the overall model for implementing the baseline ILC, coordinating the design tasks, costing, etc.**
- **R&D Board**
  - **A GDE Board will be created to evaluate, prioritize and coordinate the R&D program in support of the baseline and alternatives with a single chair**

From Baseline to a RDR

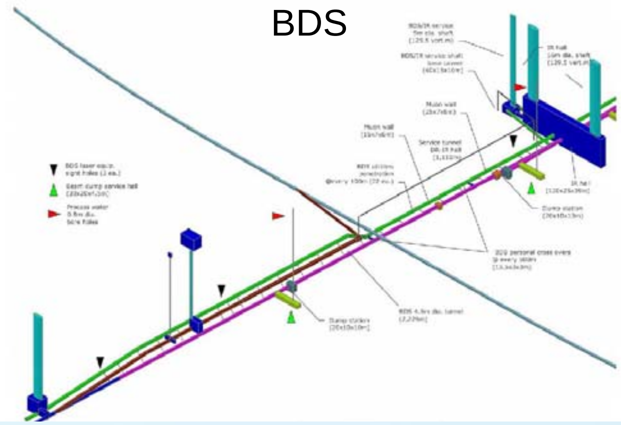


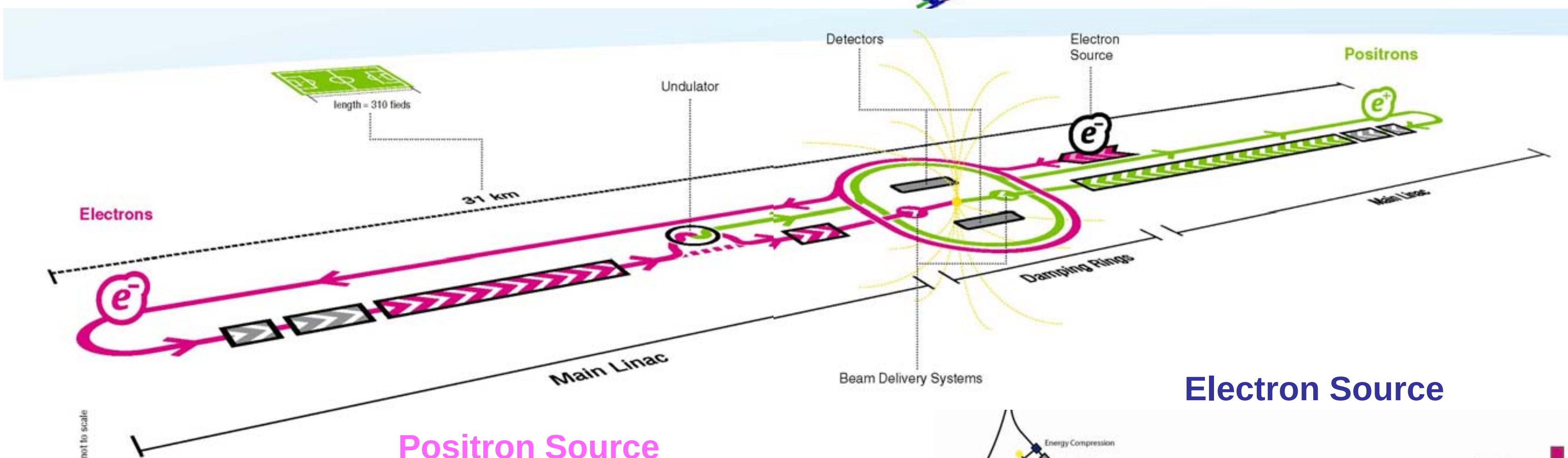
ILC as from RDR

RTML

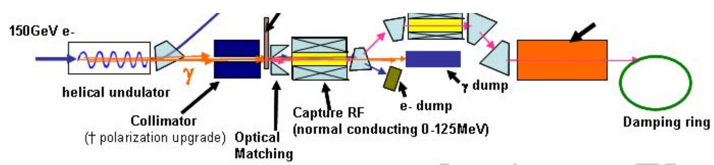


BDS

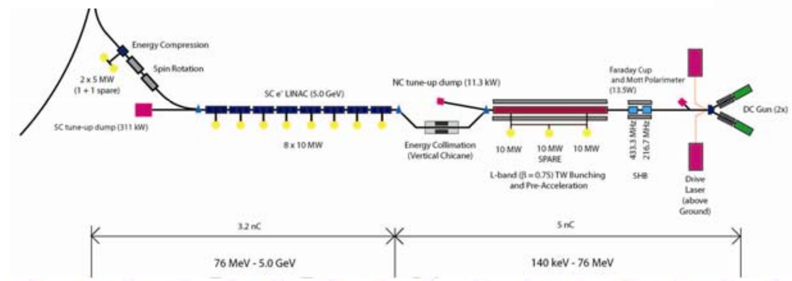




Positron Source

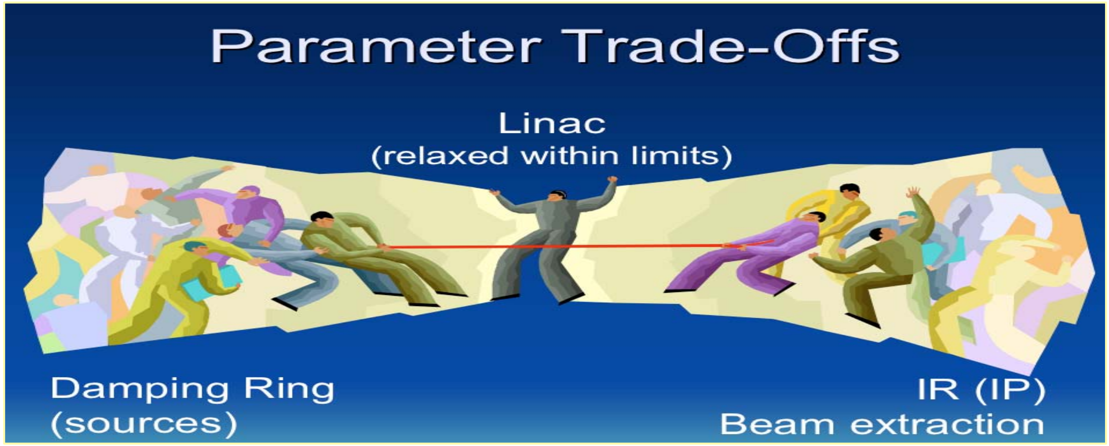


Electron Source



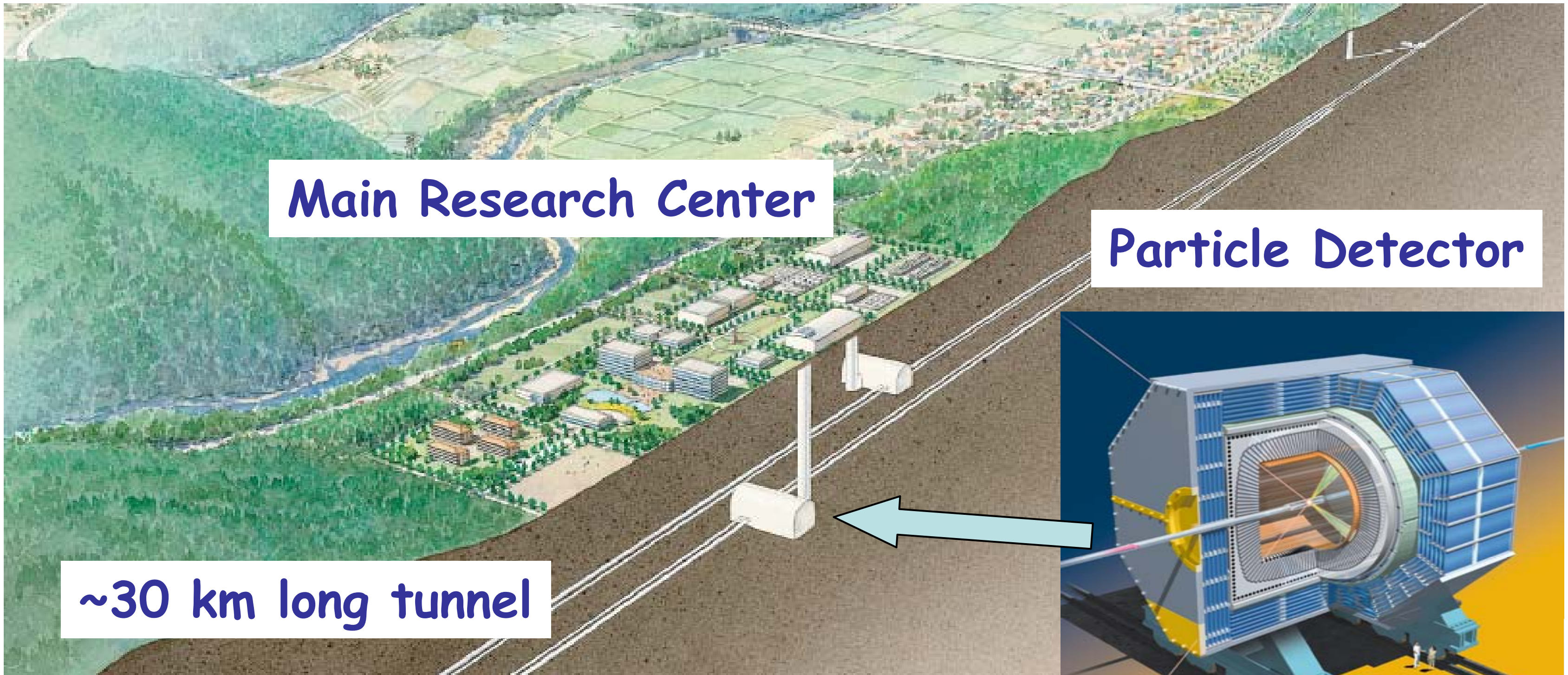
Parametric Approach

A working space - optimize machine for cost/performance



	min	nominal	max	
Number of particles	1	2	2	10^{10}
Number of bunches	1320	2625	5120	
Linac bunch interval	189	369	480	ns
DR bunch interval	3.08	6.15	12.3	ns
Bunch length	200	300	500	μm
Vertical emittance	0.03	0.04	0.08	μm
Beta at IP (x)	11	11	20	mm
Beta at IP (y)	0.2	0.4	0.6	mm
R.m.s beam size at IP σ_x		**636**		**nm**
R.m.s beam size at IP σ_y		**5.7**		**nm**

Linear Collider Facility



Two tunnels

- accelerator units
- other for services - RF power

Single IR @ 14 mrad with Push-Pull Detectors

RDR ILC Cost Estimate

- The reference design was "frozen" as of 1-Dec-06 for the purpose of producing the RDR, including cost.
- 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.
- The value costs have already been reviewed twice
  - **3 days "internal review" in Dec 2006**
  - **ILCSC MAC review in Jan 2007**

From GDE-Status-2007 presented at Bejing by Barry Barish

Summary RDR "Value" Costs

Total Value Cost (FY07)

1 ILC Unit = 1 US 2007$ = 0.83 € = 117 Yen

4.87B Shared

+

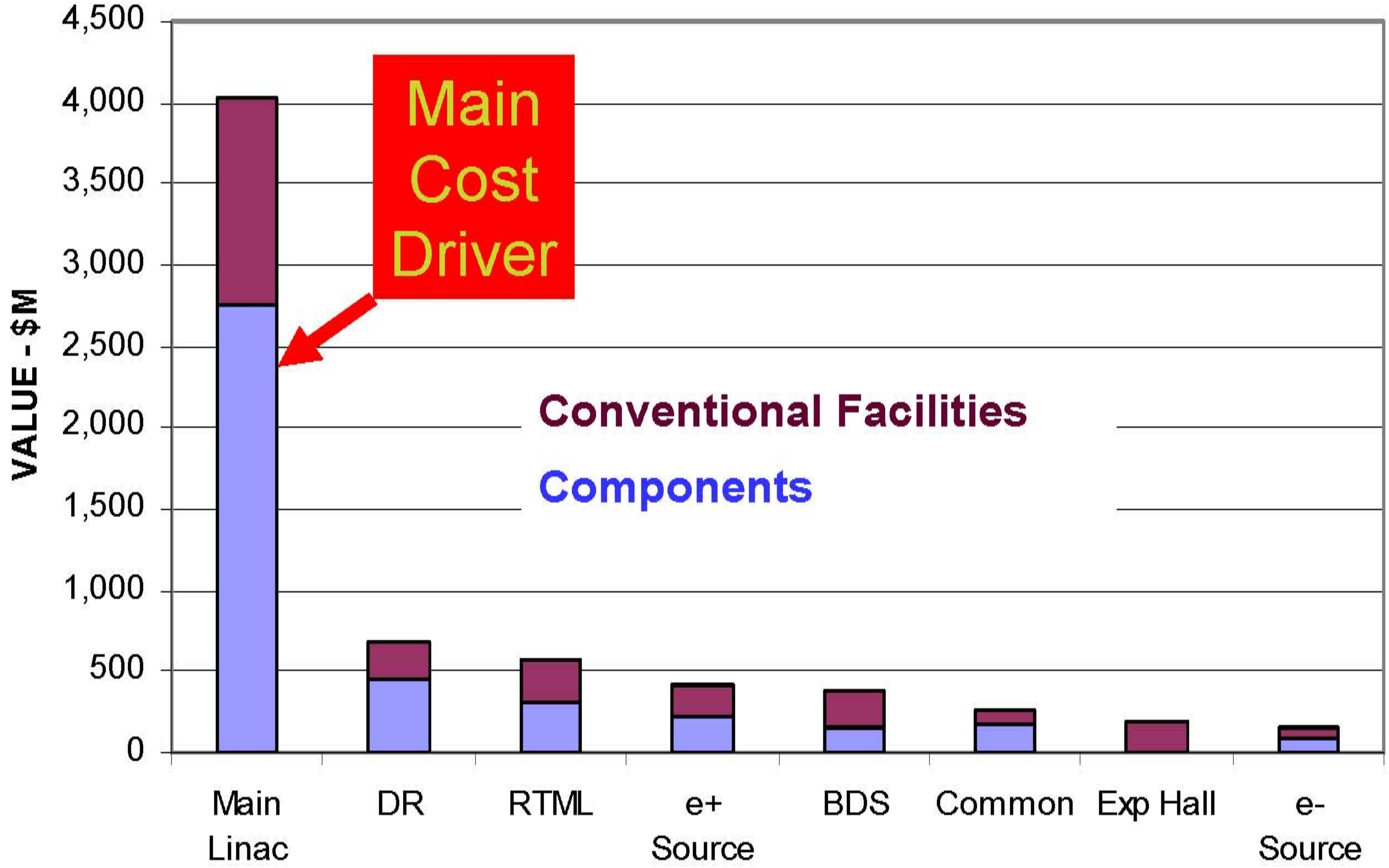
1.78B Site Specific

+

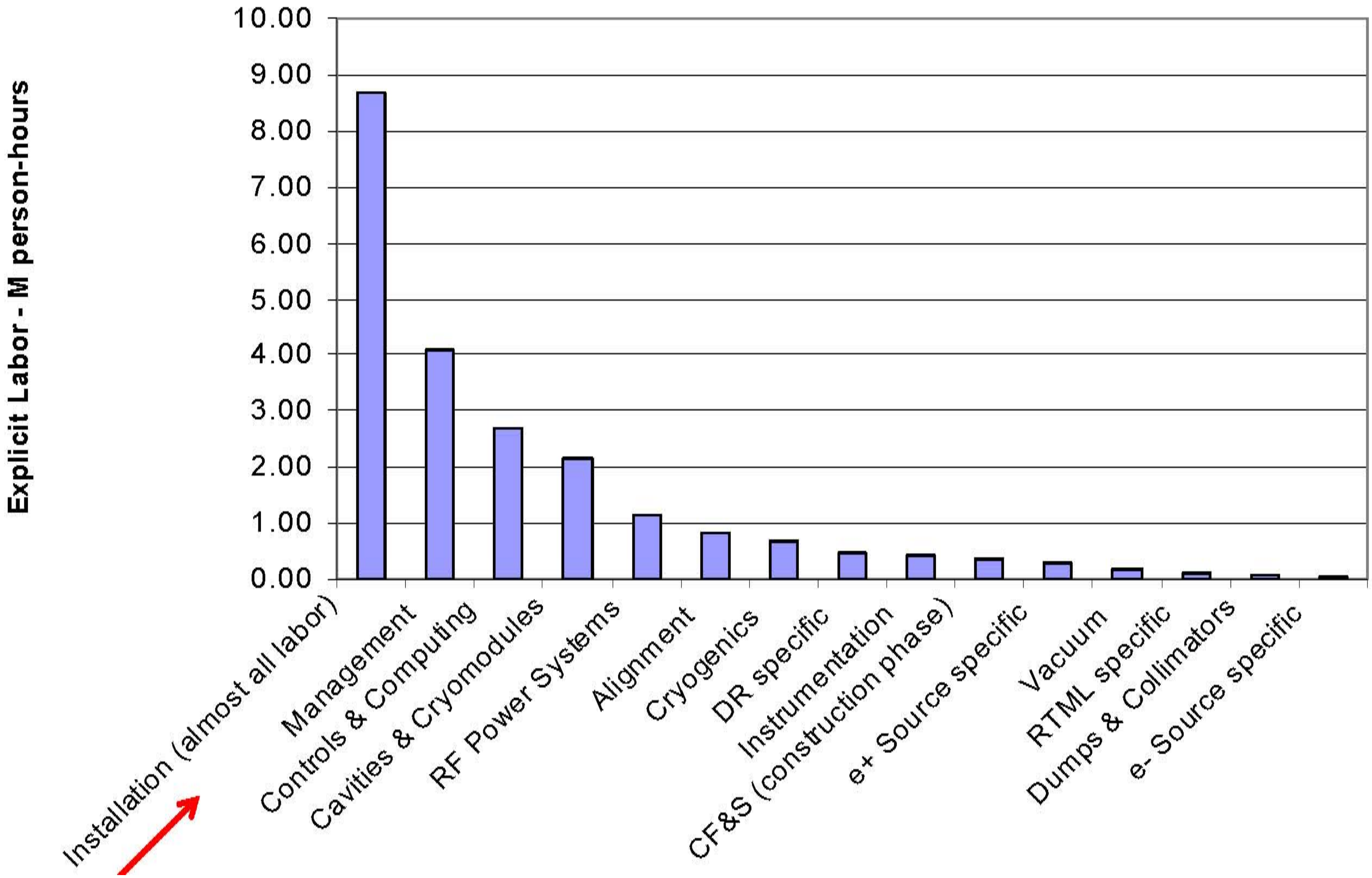
13.0 k person-years

("explicit" labor = 22.2 M person hrs @1700 hrs/yr)

ILC Value - by Area System



ILC Value – Explicit Manpower



"management" includes overhead

ILC Design Primary Challenges

- Availability
  - ILC has about 10 times more operating units compared to previous accelerators with similar availability goal (>75 %)
  - This requires significant improvements in.
    - Failure rates on components and sub-systems:
      - Magnets
      - Power Supplies
      - …
    - Redundancy
      - Power
      - Particle Sources
      - …
    - Access for maintenance and servicing
      - Double tunnel concept
- Damping Rings
  - Requires Fast Kicker (5 nsec rise and 30 nsec fall time)
  - Electron Cloud buildup in arc bend
- …

What's next

The nest step is the Engineering Design Report (EDR) due by 2010

A possible projected timeline for the ILC

How to be informed

- To be updated
  - **ILC newsLine** **http://www.linearcollider.org/newsline/**
- To know more
  - **ILC site** **http://www.linearcollider.org/**
- To learn more
  - **ILC School**
    - 2nd International Accelerator School for Linear Colliders
      Ettore Majorana Center, Erice,Italy
      1-10 October 2007

http://www.linearcolider.org/school/2007