The International Linear Collider:

A Brief History, Present Status and Future Plans

L. Warren Funk
Jefferson Lab / GDE
(with extensive borrowing from other GDE team members)

Outline

- **The case for the ILC**
- **A brief historical review †**
  - **A ‘global’ decision**
  - **A technology choice**
  - **A parameter set**
  - **A director and a project organization – a global effort**
  - **A set of key decisions**
  - **A baseline configuration**
- **Present status†**
  - **Reference design**
  - **Cost estimate**
  - **R&D programs**
- **Future prospects †**

† with JLab highlights

The Physics Case for the ILC

Joseph Lykken
Fermilab

Vancouver Linear Collider Workshop 19-22 July 2006

On 3 slides …. one

discover the secrets of the Terascale

- ***Something*** generates mass: either a "simple" Higgs, a complicated "Higgs sector", or a "something else".
- Precision detectors at a 500 GeV ILC are the ideal instruments to discover what is happening in the first two cases, and will be indispensable in all cases.
- ***Something*** creates the Terascale: supersymmetry, extra dimensions, new forces, ...
- At the ILC, observing new particles, and new interactions of known particles, will reveal the secrets of this larger universe.

J. Lykken The Physics Case for the ILC

… two …

shed light on dark matter

- More than 80% of the matter in the universe is cold dark matter. Probably it consists of more than one stable component. Probably at least one is a thermal “WIMP” relic.
- To discover the identity of such dark matter, we must know how it interacted with itself and other exotics after the Big Bang.
- ILC can produce such particles and the other most relevant exotics.
- ILC measurements will have the precision to identify the fingerprints of dark matter

J. Lykken The Physics Case for the ILC

… and three

reveal the ultimate unified theory

- Discoveries at the ILC, the LHC and elsewhere will give us a more fundamental understanding of the laws of nature and of the origin of the universe. How far can we go?
- With supersymmetry, precision measurements at the Terascale become a telescope to the energies of ultimate unification.
- ILC measurements could reveal unification of forces, unification of matter, signals of extra dimensions, and other telltale clues of superstrings.

Well presented, the story has a lot of appeal. It even gives lip service to LHC "and elsewhere", but …

J. Lykken *The Physics Case for the ILC*

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A Brief History …

- **ILC seen since the beginning as a project too large for any single country – planning and organization have been global in nature. Unlike the SSC, the ILC remains (so far) a global project.**
- **IUPAP → ICFA, ICFA → ILCSC, ILCSG → regional SGs, to recognize that resources are regional (Europe) and national (Americas and Asia)**
- **Technology:**
  - superconducting L-band and normal-conducting X-band
  - head-to-head competition in 2004
  - jury of 12 (4 from each region, chaired by Barish (Americas))
  - **SRF selected**
  - **DESY (SRF) and SLAC/KEK (NC) were main proponents**
  - **JLab supported the SRF position with presentations on our expertise and capability at DESY and CalTech; implication that our resources were at the service of the community might have contributed to subsequent difficulties**

The Project Accelerates

- 2004 August: ICFA accepts ITRP recommendation and creates Global Design Effort (GDE)
  November: First global ILC workshop (KEK)
- 2005 March: Barry Barish becomes Global director
  June: Regional Directors named
  August: Second global workshop (Snowmass)
  GDE initial membership announced (1 from JLab)
  December: First GDE meeting (Frascati)

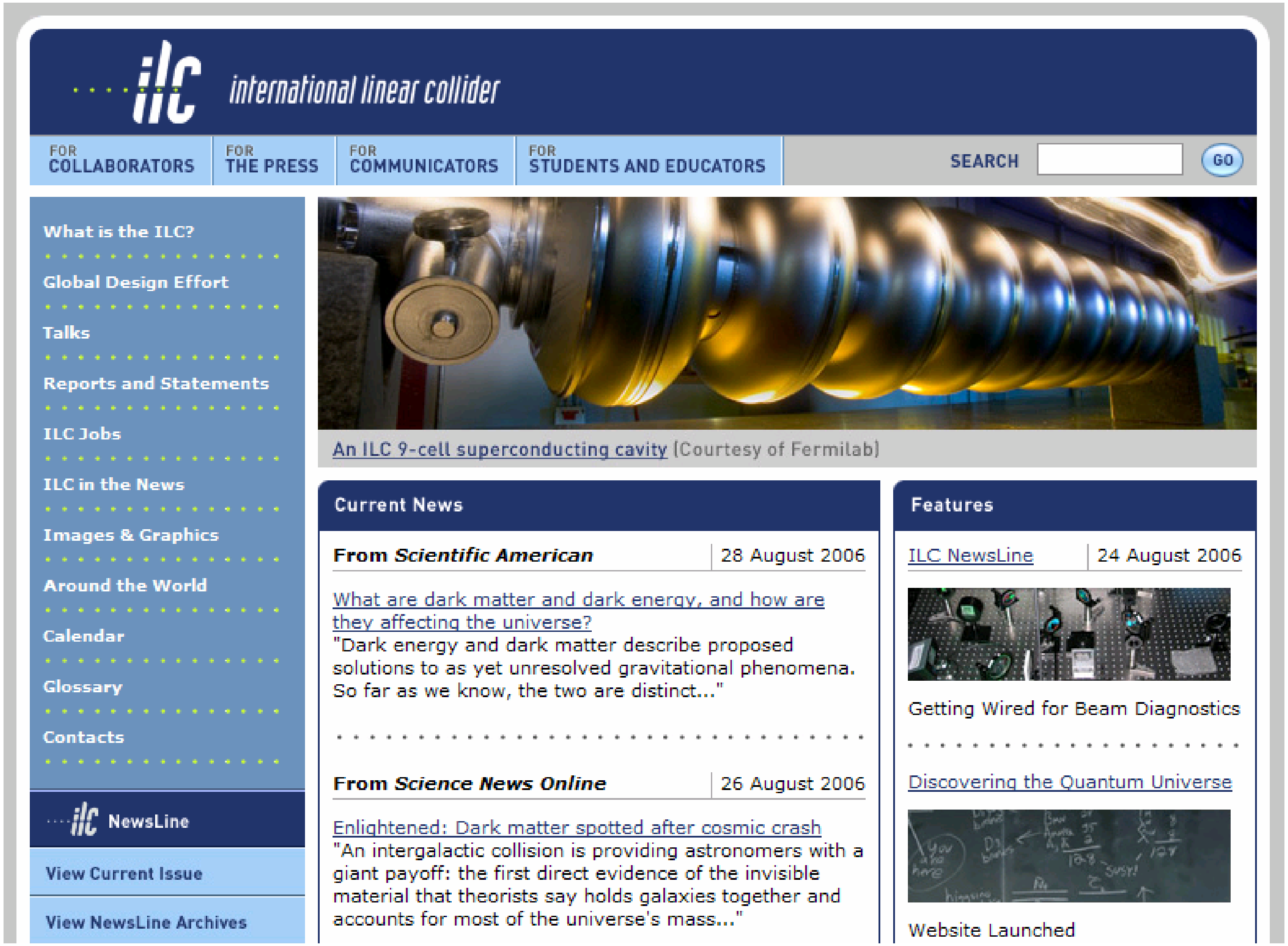
GDE Mission:

1. 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.
2. Coordinate worldwide prioritized proposal driven R&D efforts (to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc.)

GDE Composition:

Roughly equal representation from the three Regions (initially ~60, growing)

Working in the Open



http://www.linearcollider.org

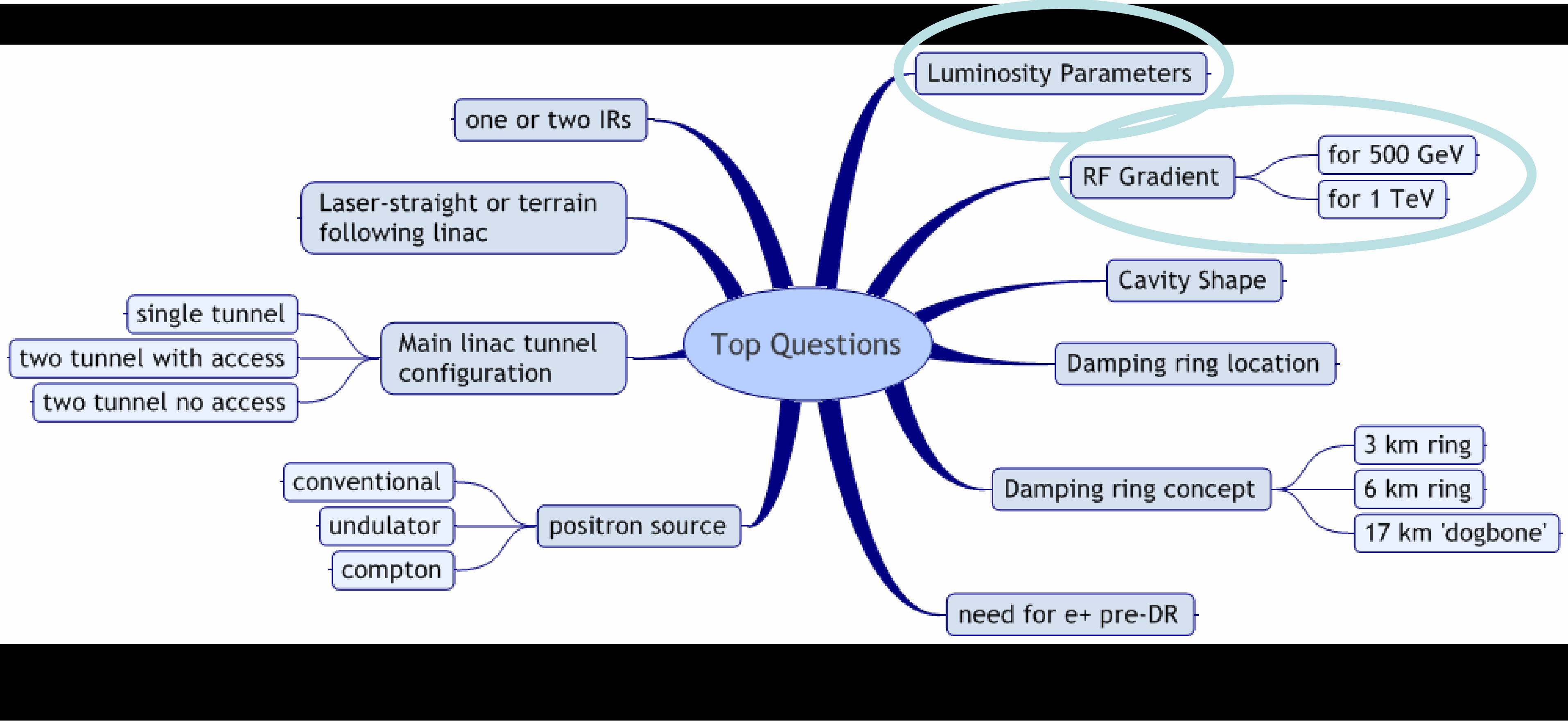
Parameters for the ILC

World Wide Study establishes parameters:

- e^+ »« e^-
- E_{cm} adjustable from 200 – 500 GeV
- $\int \mathscr{L} dt$ = 500 fb^{-1} in 4 years
- Energy stability and precision better than 0.1%
- Electron polarization of at least 80% (positron polarization, if possible)
- upgradeable to 1 TeV

From Barry Barish

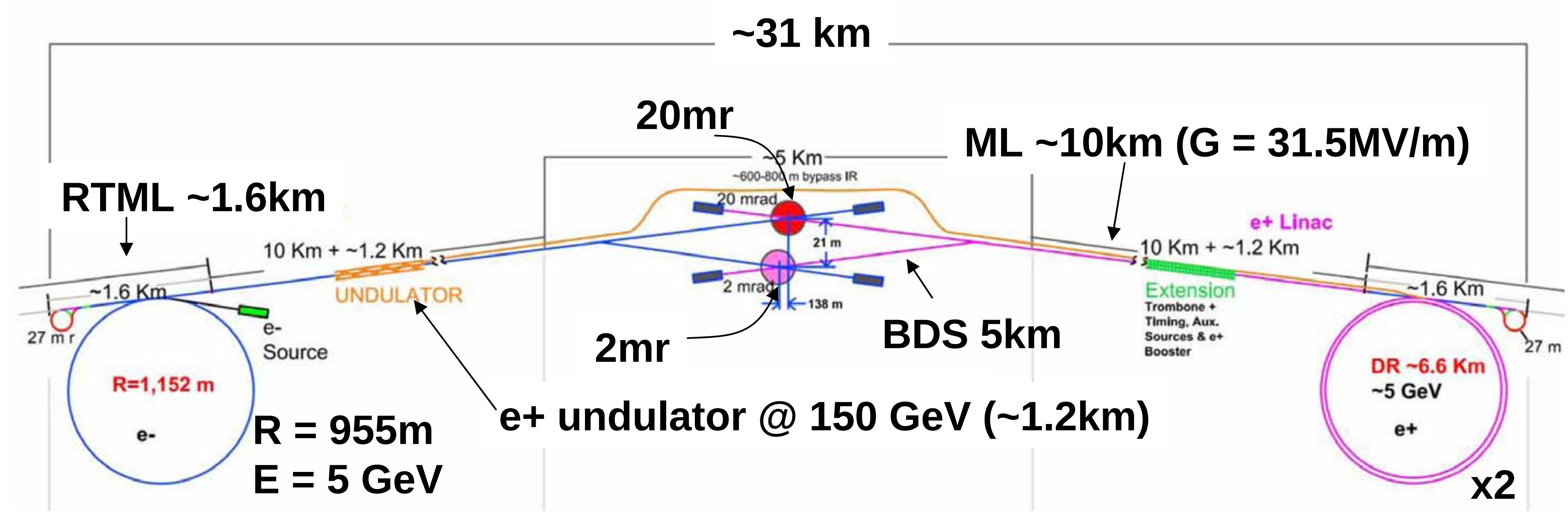
The Key Decisions



Critical choices: luminosity parameters & gradient

From Barry Barish

The Baseline Machine



not to scale

From Barry Barish

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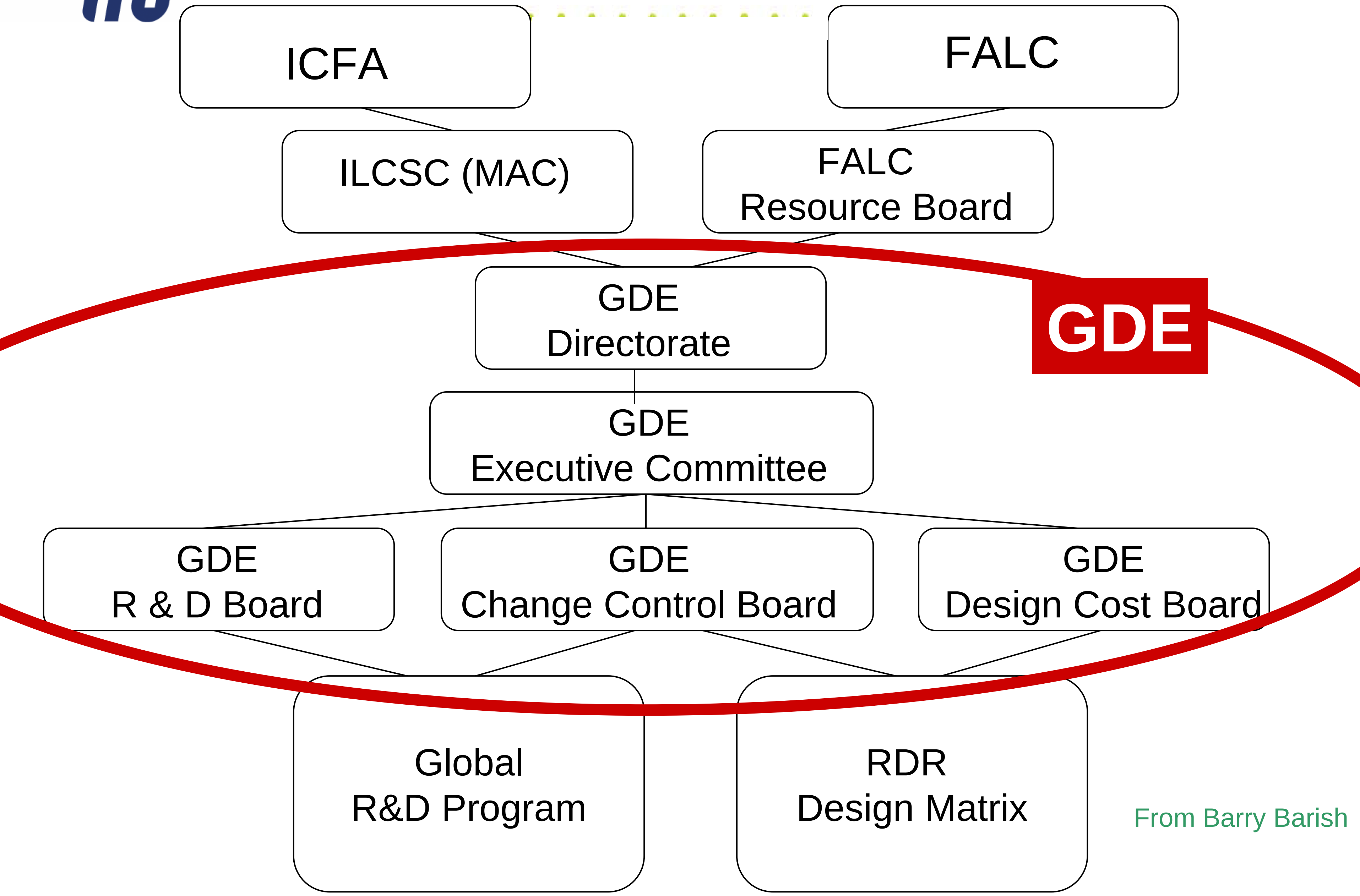
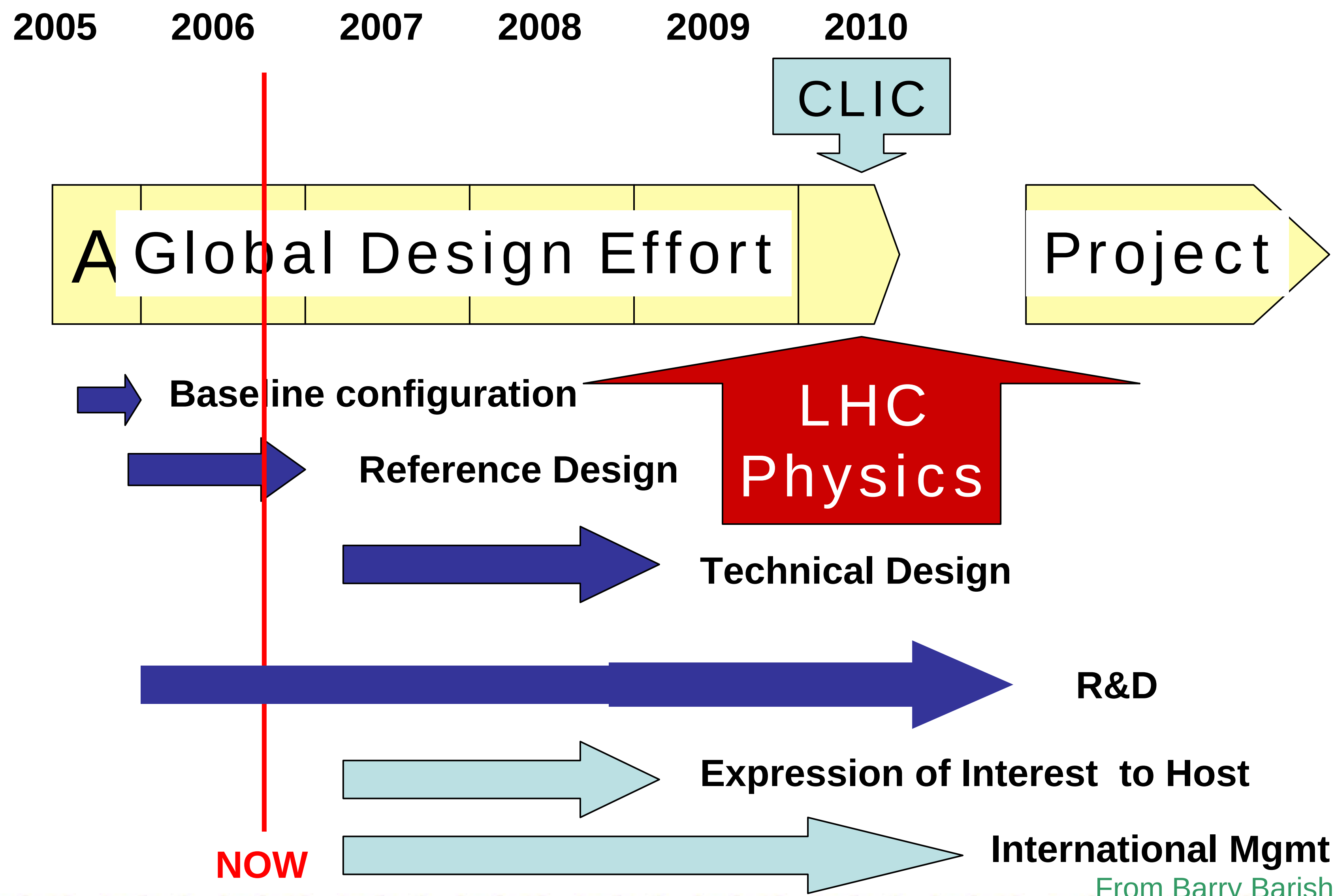
GDE RDR / R&D Organization



From Barry Barish

The Project Schedule



From Barry Barish

Reference Design

Deliverables:

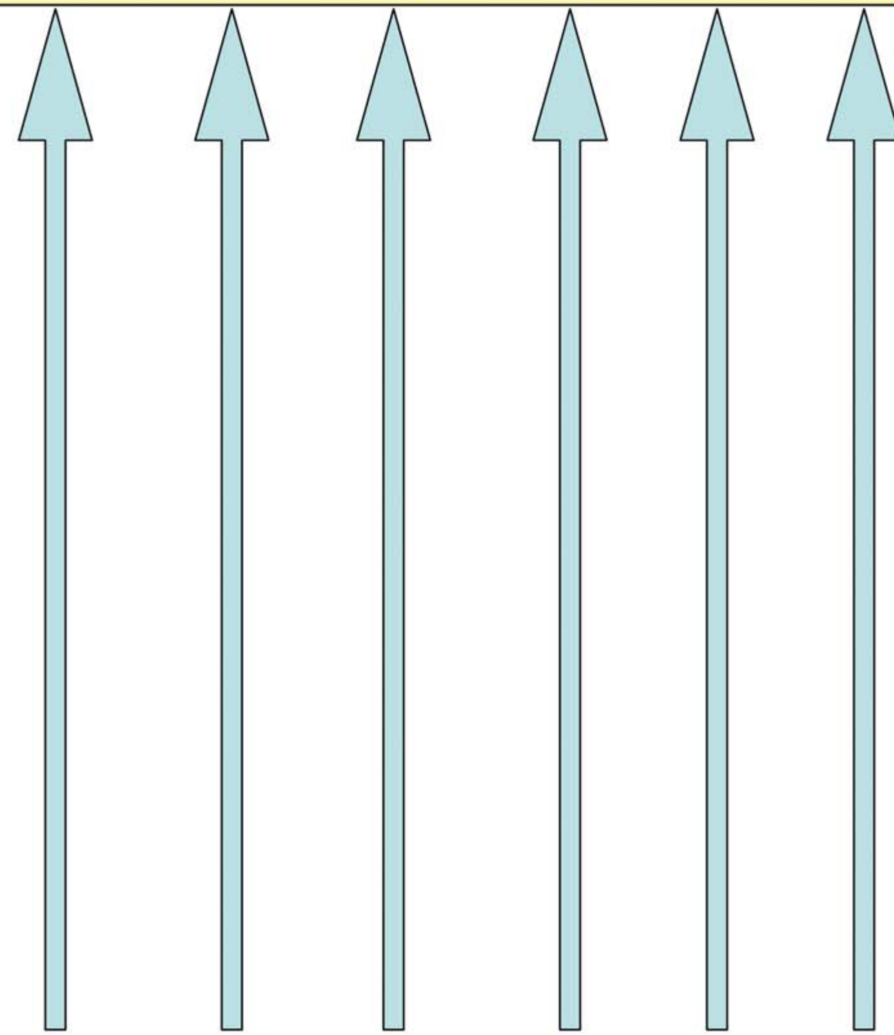
1. Detailed design report
   (level of detail somewhat less than a CDR would be for a DOE project)
2. “Glossy” executive summary
3. A cost estimate

The project is on schedule to complete these by the end of CY06.

Organization for Design

Area Systems

e- source	e+ source	damping rings	RTML	main linac	BDS



Technical Systems

- Vacuum systems
- Magnet systems
- Cryomodule
- Cavity Package
- RF Power
- Instrumentation
- Dumps and Collimators
- Accelerator Physics

Global Systems

- Commissioning, Operations & Reliability
- Control System
- Cryogenics
- CF&S

From Barry Barish

RDR Cost Estimating

- **500 GeV BCD machine + “essentials” for 1 TeV**
- **Follow ITER “Value” & CERN “CORE” model for International Projects**
  – Provides basic agreed to costs [common “value” + in-house labor (FTE)]
- **RDR will provide information for translation into any country’s cost estimating metric, e.g. Basis of Estimate => contingency estimate, in-house labor, G&A, escalation, R&D, pre-construction, commissioning, etc.**
- **Assumes a 7 year construction phase**

From Barry Barish

ILC Cost Estimate

- **Based on a call for world-wide tender:**
  lowest reasonable price for required quality
- **Classes of items in cost estimate:**
  - Site-Specific (separate estimates for each site)
  - Conventional – global capability (single world est.)
  - High Tech – cavities, cryomodules, regional estimates
- **Cost Engineers will determine how to combine and present multiple estimates**
- **WBS ; WBS Dictionary; Costing Guidelines are mature enough - cost estimating is underway**
- **Initial estimate assembly at Vancouver: successful**
- **Next steps: value engineer**
- **Don’t ask me! Only 4 people know for sure!**

From Barry Barish

Elements of the ILC R&D Program

- **R&D in support of the baseline**
  - Technical developments, demonstration experiments, industrialization, etc.

- **R&D in support of alternatives to the baseline**
  - Proposals for potential improvements to the baseline, resources required, time scale, etc.
  - Guidance from Change Control Board

- **DETECTOR R&D program aimed at technical developments needed to reach combined design performance goals**

From Barry Barish

Developing Global R&D Plan

- **High priority items first**
  - Advice for US R&D Funding
- **Initiating two SRF task forces**
  - S0 / S1 to demonstrate gradient and yield
  - S2 to develop system tests
- **Coordinate R&D on “alternatives” to the Baseline**
  - CCB will define goals to replace the baseline
  - RDB will determine program – milestones, resources, etc

From Barry Barish

The JLab Role: Negotiating the Rapids

- **Our challenges:**
  - **Meeting expectations to apply our core competencies (SRF, electron sources and cryogenics) to the ILC**
  - **Achieve the first without compromising our support our NP mission**
  - **Managing success**
- **Our approach:**
  - **Find/fashion situations where meeting an expressed ILC need supports achievement of our internal objectives: win-win**
  - **We're being clear about:**
    - our desire to support ILC developments, and
    - need for direct HEP funding for additional tasks that rise above occasional expert consultations.

FY06 Funded Projects

- **Two types of projects meet the criteria and are underway this year:**
  - **Investigation of new materials and methods:**
    - **Large- or single-grain Nb and superstructures (cheaper cavities)**
      - **directly funded by HEP**
    - **Electropolishing (increased gradient reach)**
      - **funded through MOU with FNAL -- MPO**
  - **Use (and support) of SRF infrastructure and technical expertise**
    - **Fabrication of 9-cell, 1.3 GHz cavities (e-beam welder)**
      - **funded through MOU with FNAL -- MPO**
    - **Preparation of cavity string production cost estimate**
      - **funded through MOU with FNAL -- MPO**

- **We have seen significant growth in interest in taking advantage of our core competencies.**

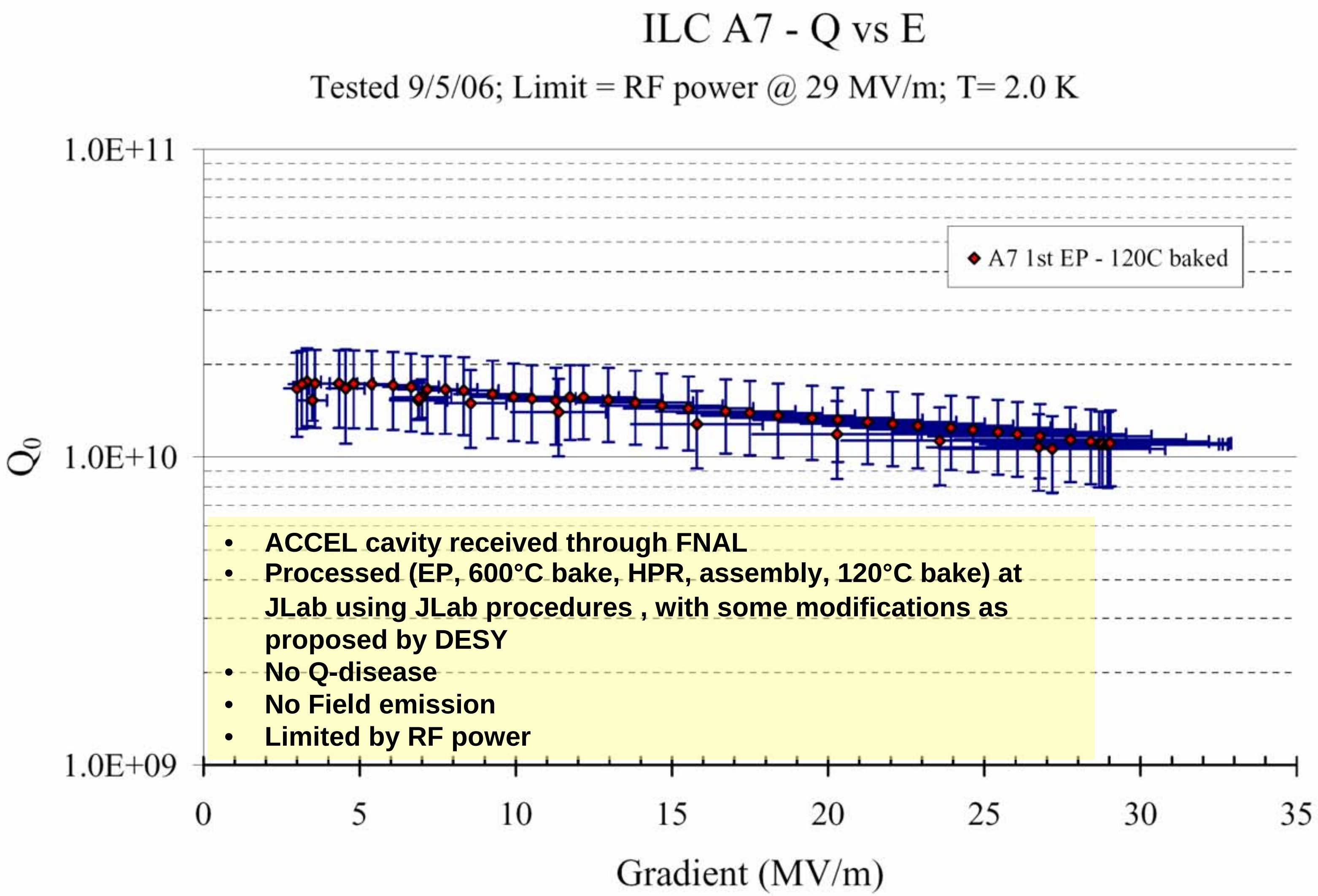
FY07 Proposals and Aspirations

(to be understood in the context of requests for R&D support 3x the anticipated ILC accelerator R&D budget)

~$25M (FY06) ➔ $60M (FY07) (PB)

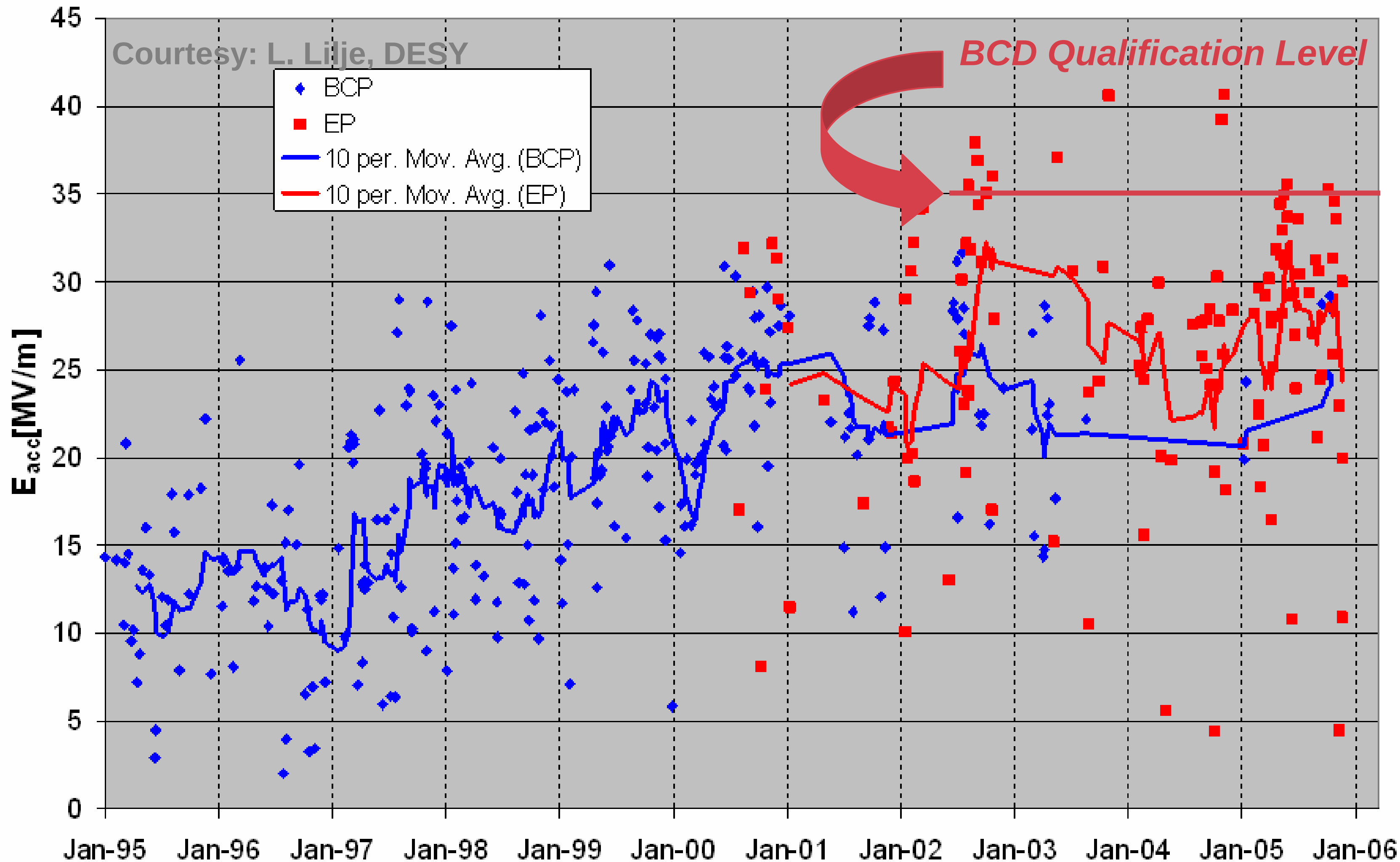
- **Extensions of all current projects (~$1,000k), plus**
- **Multi-layer (SIS) films ($350k)**
  - **assessed as generic, rather than ILC-specific**
- **Cryomodule value engineering ($200k)**
  - **Recommended for direct ILC funding at the $100k level**
- **Understanding/control/elimination of ‘dark current’ ($550k)**
  - **Rated “high” but assessed as generic, rather than ILC-specific**
  - **Extends existing JLab opportunistic program (IP^{3}I) – short term goal of better controlling processes, procedures & people to eliminate field emission (dark current source and important source of performance variability)**
  - **Working within US Regional Interest R&D Panel to elevate interest and priority for its contribution to technology industrialization**

Early Result

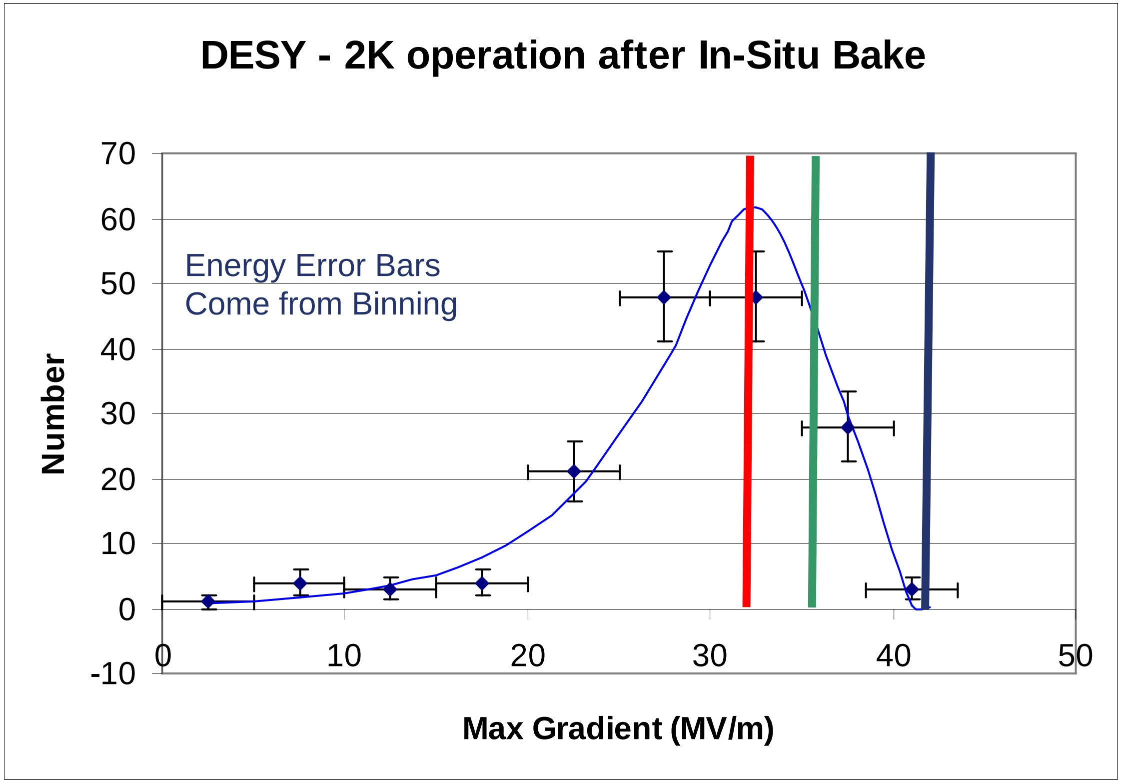


- **ACCEL cavity received through FNAL**
- **Processed (EP, 600°C bake, HPR, assembly, 120°C bake) at JLab using JLab procedures , with some modifications as proposed by DESY**
- **No Q-disease**
- **No Field emission**
- **Limited by RF power**

Cavity Gradient: Problem Statement



Focus on EP Results



- Not Gaussian!
- Lognormal fits well

$$P(x) = \frac{1}{S\sqrt{2\pi}\,x} e^{-(\ln x - M)^2/(2S^2)}$$

$$D(x) = \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{\ln x - M}{S\sqrt{2}}\right)\right],$$

- with $x = 42 - E_{acc}$; M = 2.41 and S = 0.520

Theoretical Limit for TESLA cavity shape @ ~42 MV/m

Cavity qualification gradient @ 35 MV/m

Cavity operating gradient @ 31.5 MV/m

Issues:

- **Yield of qualified cavities is too low**
- **Performance spread is too high: LLRF limitations are said to demand that all cavities operate at the same gradient ➔ each RF module (24 cavities) operates at the gradient of its worst-performing cavity!**

S0/S1 Task Force

- **H. Hayano, T. Higo, L. Lilje, J. Mammosser, H. Padamsee, M. Ross, K. Saito**

CHARGE

- *The RDB is asked to set up a Task Force to carry out a closely coordinated global execution of the work leading to the achievement of the accelerating gradient specified in the ILC Baseline.*
- *A definition of the R&D goals for the cavity performance in terms of gradient and yield and a plan for achieving them should be proposed by this group, which should take account of the global resources available and how they may be used most rapidly and efficiently.*
- *The accelerating gradient performance and yield should be specified for cavity production, and treatment process (S0), and for cryomodules (S1), and the plan should cover the demonstration of this performance in all cases.*
- *The GDE will facilitate the coordination at the global level to* **achieve this vital goal as soon as possible.**

From Barry Barish

S0/S1 R&D Framework

- The need of making gradients more reproducible is a top priority
- Single-cell cavities in various labs and also from industry obtain very high performance
  - Yield rates vary between labs
  - Probably we are not far away from the good parameter set
- Looking at the history of TTF some significant effort is needed to transfer results to multi-cells
  - Three cavity production cycles (20-30 each) were done to improve the gradient from the level of 5-10 MV/m to 25 MV/m with classical etching
    - This included especially the training of companies to provide the required niobium and electron beam weld quality
  - Currently, we are in EP Production cycle No.1 at DESY
  - Other regions are in the process of being able to do research, it is not yet a production cycle
- A dedicated facility in each region with sufficient redundancy and flexibility is desirable to have fast turn-around of cavity tests.
  - Waiting for the repair of infrastructure is painful
  - From the TTF experience the bottleneck is typically the cavity preparation, not the cryogenic testing

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Issues Overview

- S0
  - Achieve 35 MV/m in 9-cell cavity in vertical dewar tests (low-power) with a sufficient yield
  - Staged approach with intermediate goals to track progress
- S1
  - Achieve 31.5 operational as specified in the BCD in more than one accelerating module
  - … and enough overhead as described in the BCD.
- S2
  - a string of N modules with full xyz...by date ...
  - Need for a linac ?
  - Endurance testing

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Task Force Plans: I

- Accumulate information of regional programs (has started)
  - E.g. how many cavities are being fabricated
- Assessment of infrastructure (has started)
  - E.g. how many test stands are available
- Data assessment (has started)
  - What has been achieved where?
- Define tests needed on a multi-cell cavity (has started)
  - E.g. setting up temperature mapping for nine-cells
- Proposals on future work (has started)
  - Refine R&D plan and set goals (see below)
  - Definition of scope:
    - » Which parameter range should be pursued?
    - » How much room for alternatives (e.g. large-grain material)
  - Propose coordination:
    - » Distribution of work load

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S0 Ultimate Goals

- The cavity performance is influenced by the fabrication process and surface preparation process.
  – Effort in all the regions to qualify further vendors for cavities
- Preparation process and vertical test yield for 35 MV/m at $Q_0 = 10^{10}$ should be greater than 90% for a sufficiently large number (greater than 100) of preparation and test cycles.
  – There should be a complete description of the preparation and testing processes (reproducibility in other places). The time scale should be commensurate with the completion of the TDR (middle of 2009).

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S0 Ultimate Goals

- After a viable cavity process has been determined through a series of preparations and vertical tests on a significant number of cavities, achieve 35 MV/m at $Q_0 = 10^{10}$ in a sufficiently large final sample (greater than 30) of nine-cell cavities in the low-power vertical dewar testing in a production-like operation e.g. all cavities get the same treatment.
  - The yield for the number of successful cavities of the final production batch should be larger than 80% in the first test. After re-processing the 20 % underperforming cavities the yield should go up to 95%. This is consistent with the assumption in the RDR costing exercise.

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S0 Intermediate Goals FY06-07

- Qualification of multi-cell setups and procedures (start now)
  - Improve process monitoring: e.g.
    - High pressure rinse parameters
    - Acid quality control
    - HF content
  - 'Tight-loop' processing of a few (1-4) cavities over and over again.
  - The goal is to demonstrate gradients after new 10 preparations are within less than 10% of the (acceptable) average gradient of each cavity.
- Definition of the single-cell effort has started by TTC and SMTF
  - Must be following the prioritized proposals
    - Multi-Lab participation possible
    - Processes must be transferable to multi-cells
  - Process monitoring
    - S-deposition studies
    - H- contamination studies
  - Limited room for basic studies is needed
    - Field emission studies
    - Control of particulate contamination
    - Material studies
  - Need to set a deadline to allow feedback into nine-cell process

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Final Process Reproducibility → FY08

- Stage 1: Tight-loop (finish mid-2007) :
  - Start with a batch of 20 cavities globally. Carry out the full treatment once.
  - Pick out the best 9 cavities and distribute 3 per location. These 9 cavities have a starting average gradient and spread.
  - Show reproducibility of "final process" with 3 best cavities at each location by using the tight loop EP 20 um/HPR/Test. 3 cavities x 3 cycles = 9 tests per location.
  - Determine spread and best gradient for final treatment process.
- Stage 2: Improved tight-loop (finish mid-2008):
  - Include improvements from the parallel/coupled R&D program.
  - Repeat the first stage with the same 9 cavities, get smaller spread with higher gradient.

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S1 Ultimate Goals

- Final goal (following the BCD definition):
  - Achieve 31.5 MV/m at a $Q_0=10^{10}$ as operational gradient as specified in the BCD in more than one module of 8 cavities including e.g. fast tuner operation and other features that could affect gradient performance
  - All cavities built into modules perform at 31.5 MV/m including enough overhead as described in the BCD. The cavities accepted in the low-power test should achieve 35 MV/m at $Q_0 = 10^{10}$ with a yield as described in the S0 definition (80% after first test, 95% after re-preparation).
  - At least three modules should achieve this performance. This could include re-assemblies of cryostats (e.g. exchange of cavities).
  - It does not need to be final module design. An operation for a few weeks should be performed.
- Intermediate goal
  - Achieve 31.5 MV/m average operational accelerating gradient in a single cryomodule as a proof-of- existence. In case of cavities performing below the average, this could be achieved by tweaking the RF distribution accordingly.

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S0/S1 Task Force Plans: II

- Involve TESLA Technology Collaboration
  - Can help in organizing forums
    - TTC Meetings
    - Monthly teleconference with America and Europe started, seeking to integrate Asia soon
    - A lot of expertise is accumulated there
  - E.g.: Steps towards accumulation of various parameters of EP has started, proposal for dedicated single-cell program
  - Make ILC R&D needs transparent
  - Stay online with developments in TTC
- Propose to involve Industry early in preparation processes
  - Based on the TTF experience this is probably just the right time
  - Need also preparation capacity
    - Started for XFEL in Europe, to some degree available in Japan, needs work in America
- Need feedback from GDE
  - WWW page will be setup with documents, talks and data on R&D board page
- First 'formalized' proposal to be finalized at LINAC06

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Refining the R&D Process

- Need for Intermediate Milestones
  - Ultimate Goals are long-term
  - allow for tracking of progress in cavity preparation cycle
  - Under discussion! Following slides are proposals and need careful evaluation
- Describe type measurement cycles
  - 'Tight-loop':
    - A few cavities over again, demonstrate that spread of process is small
    - Qualification of infrastructure and processes
    - Finally, the full process chain must be looped through
  - 'Production-like'
    - Batches of cavities treated in same manner
- Define measurement best practice e.g.
  - Passband mode measurements
  - Check for Q-disease
  - Temperature-mapping of the niobium surface for multi-cells in all regions
- Need estimation of capacities for testing and cavity production
  - A lot of the testing needs to be done on multi-cell cavities as assemblies and procedures are different for single-cells and multi-cells
  - Define single-cell measurements where they are useful
    - Programm must be integrated into nine-cell effort
  - Leave some room for alternatives (e.g. large-grain material)
    - Overall testing capacity will be limited

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Issues – from the ILC Perspective

- Variety of cavity types is not helpful in the long-run
  - Various lengths, flange systems, magnetic shielding, HOM damping etc.
  - For the ultimate goal a single cavity type is needed
    - Can be built and treated in different regions in parallel provided processes are transferable
- Variety of recipes and setups
  - Must develop protocols that guarantee transferable results
    - Monitoring of parameters should make processes more transparent (e.g. HF content)
    - Exchanging cavities can facilitate
  - Setups need to be qualified first (tight-loop)
- Many process steps from niobium to cavity in accelerating module
  - New vendors will have to learn
  - separate final process reproducibility from cavity reproducibility (includes fabrication)
- Cavity development is ongoing
  - Staging of cavity production is necessary to allow for evolution in cavity design and process improvements
- Ultimately the number of cavities being built and treated will be small compared to the ILC number of cavities

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Momentum Continues to Build

- Progress toward a Reference Design Report, including a cost estimate, continues on schedule
- Reviews of the physics opportunities and the potential of the ILC have been very favorable, particularly in the US
  - EPP2010
  - The ILC is recognized as essential to providing the vehicle for the training and development of future generations of scientists and engineers
  - Its potential contribution to strengthening the economy through technology development could be pivotal.

Personal Notes

- **Expect a new Americas Regional Director:**
  - Gerry Dugan has announced his retirement from his position as Americas Regional Director.
  - Search underway for replacement
- **Expect a new GDE organization**
  - RDR process has revealed weaknesses
    - **Access to resources**
    - **Communications and cultural differences**
    - **Project controls, management, accountability**
  - Possible as early as November (Valencia); probable by Feb-March (Beijing?)
- **Expect cost estimate to be too high for comfort**