ILC R&D

H.Weerts

Michigan State University / Fermilab

ILC = International Linear Collider

Introduction

Why am I giving this talk ?? Marcela asked me……

In the past have worked on (old) neutrino program at Fermilab and in last 20 years on Dzero at Tevatron.

There is life beyond the Tevatron………

Important for progress and future of particle physics in world and Fermilab to pursue International Linear Collider

Am on a sabbatical leave at Fermi to work on ILC, with an emphasis on detectors for ILC.

Started 10 months ago and am still learning, so this talk is incomplete (ask questions !), but it has been fun to work on something totally different and start at the beginning with everybody else (e^+e^- and new physics & detector)

Your convictions should guide your actions……..

New director made it clear at EPP2010 and elsewhere that the ILC is a major priority for Fermilab. (so we are not alone anymore….)

Intro ILC I

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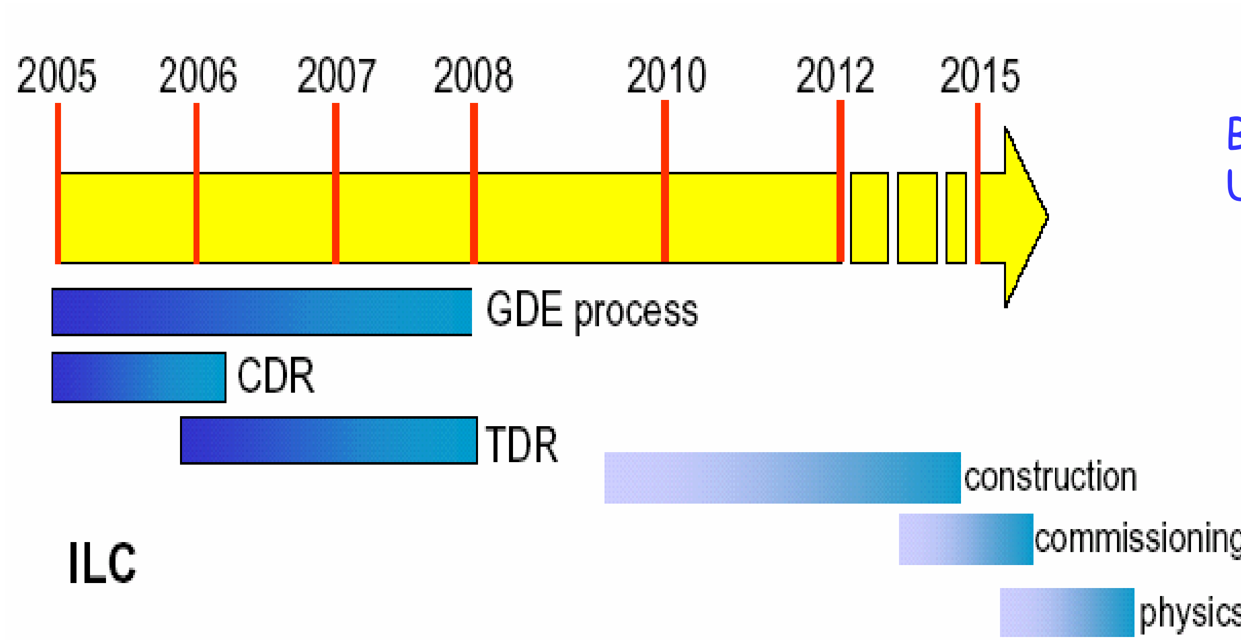
ILC is far away in time, not exactly around the corner.
Even LHC, which is next, has not even turned on

Timescale:



Barish @
Users Mtg.

Technically Driven Schedule

Formal organization started at LCWS 05 at Stanford
in March 2005 when Barish became director of the GDE

Many other factors will influence this schedule

ILC Intro II

State of the ILC

Few of us have ever been at the state of a physics facility like this........

Not a world, where physicists (by training) thrive →

- Everything is uncertain
- Nobody knows what will happen
- A few of us "plow ahead".....
- Decisions are made outside of our field
- Public relations & perception are important
- It will be truly international
- The outcome is uncertain........

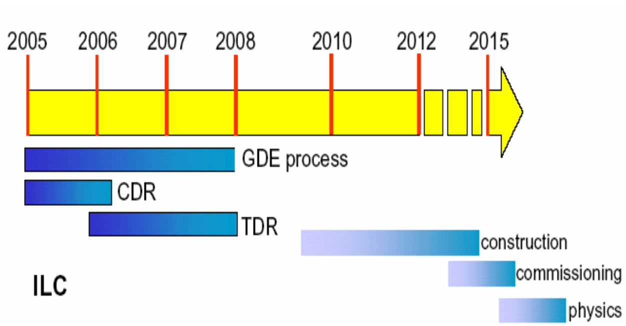
Not exactly the items that are in our standard Physics textbooks, where the world is methodical, objective and logical and even far outside CDF & DZero in their current status

But it is an important part of our science that is not taught anywhere, but in "the field" (every 20 years or so) and it requires communication with "the rest of the world".

BUT: **In addition to other professionals, physicists have to be involved**

otherwise it will not happen

ILC Intro III



Next 4-5 years:

today

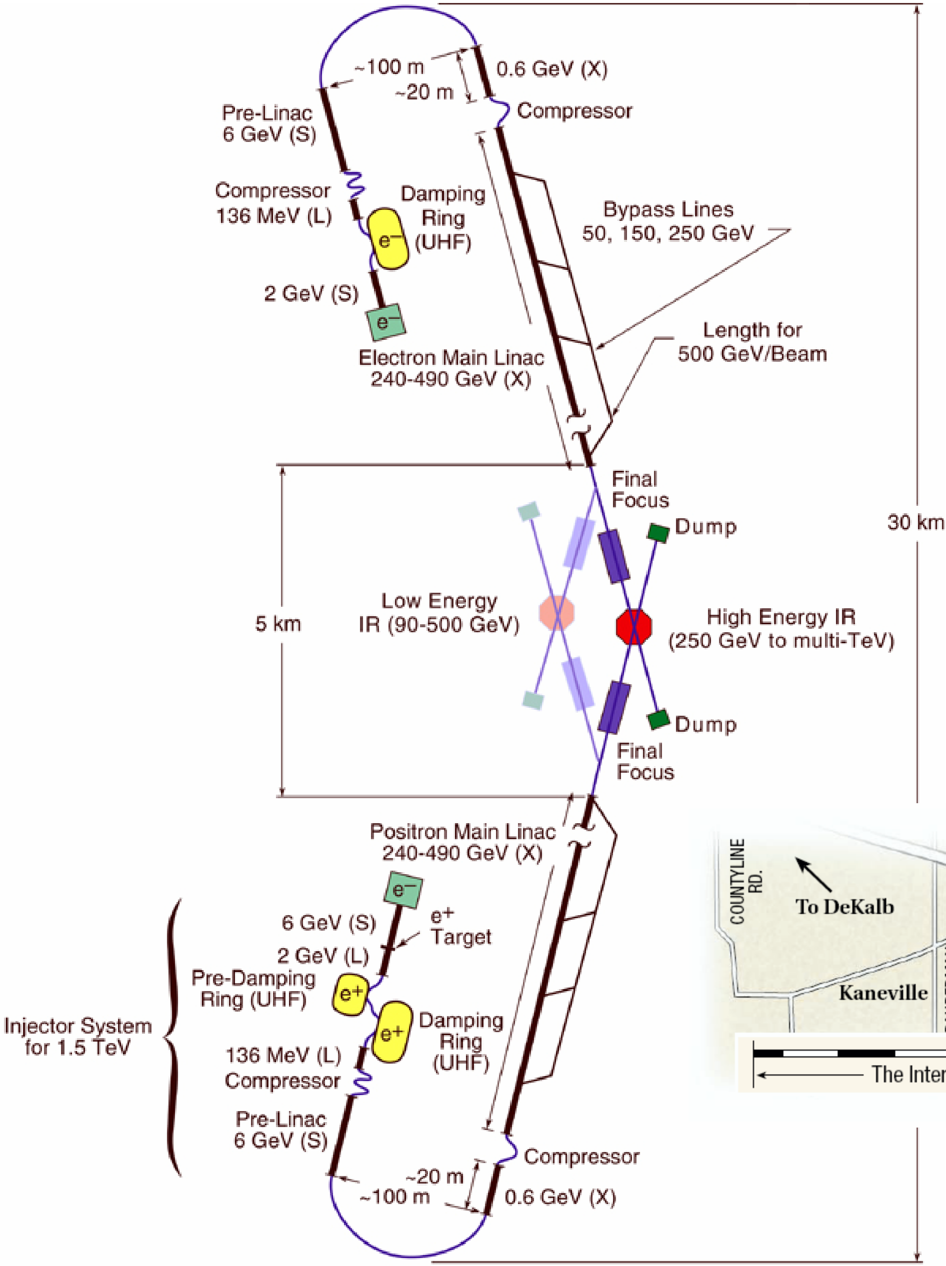
- R&D and design on accelerator
- Civil & site studies
- Detector R&D and design
- Make physics case stronger

To be able to write a TDR and enable a construction decision, next 4-5 years are a critical R&D phase.
Need funds to do this and manpower (including physicists i.e you !!)

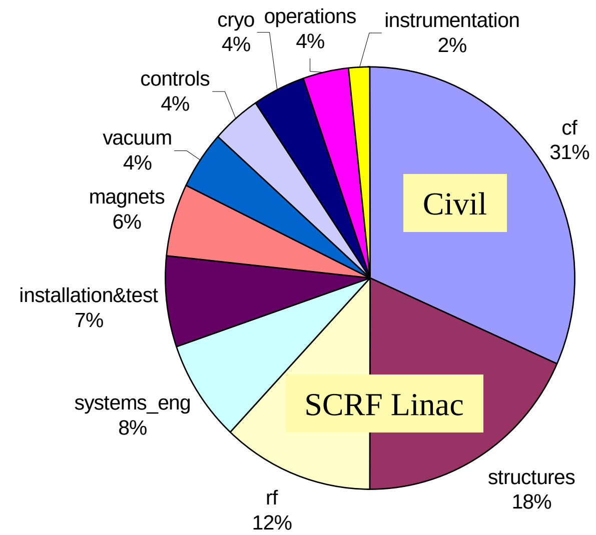
There is one more critical ingredient…………

Communication

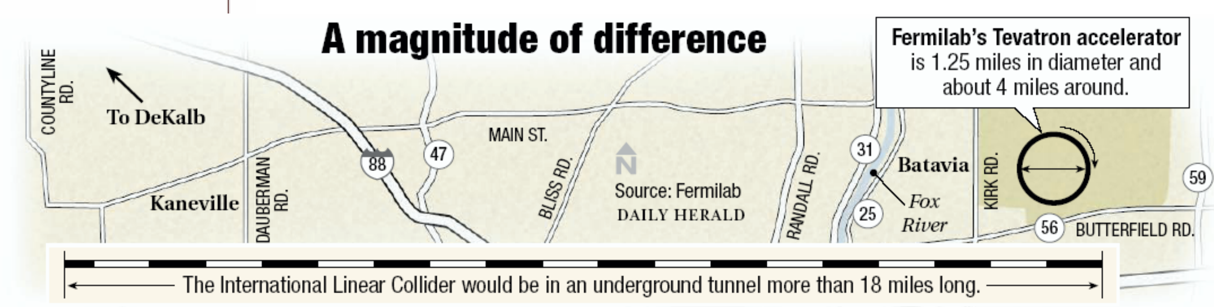
ILC overview; accelerator



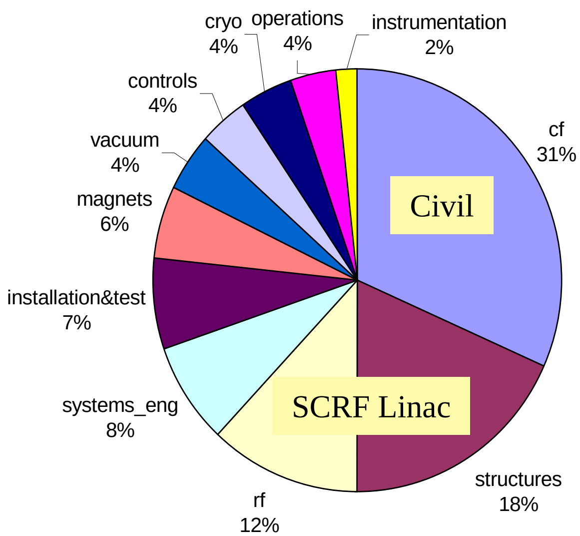
Cost drivers for ILC



This talk will cover R&D, largest cost item and covered by Fermilab & others.



ILC accelerator R&D at Fermilab



LINAC & accelerating structure obviously critical part of ILC.

Fermilab is concentrating its R&D efforts in this area. Formed a collaboration with many other institutions: Superconducting Module Test Facility (SMTF).

Goal: Build & test the SCRF structures for the ILC LINAC.

Build means: develop capability in industry to build cavities and ultimately cryomodules, which contain them. CLEANING cavities is one of the critical components in this process. Needs understanding to get consistent gradients of 35MV/m

SMTF is a very large effort……. more on next pages

TESLA SCRF cavity

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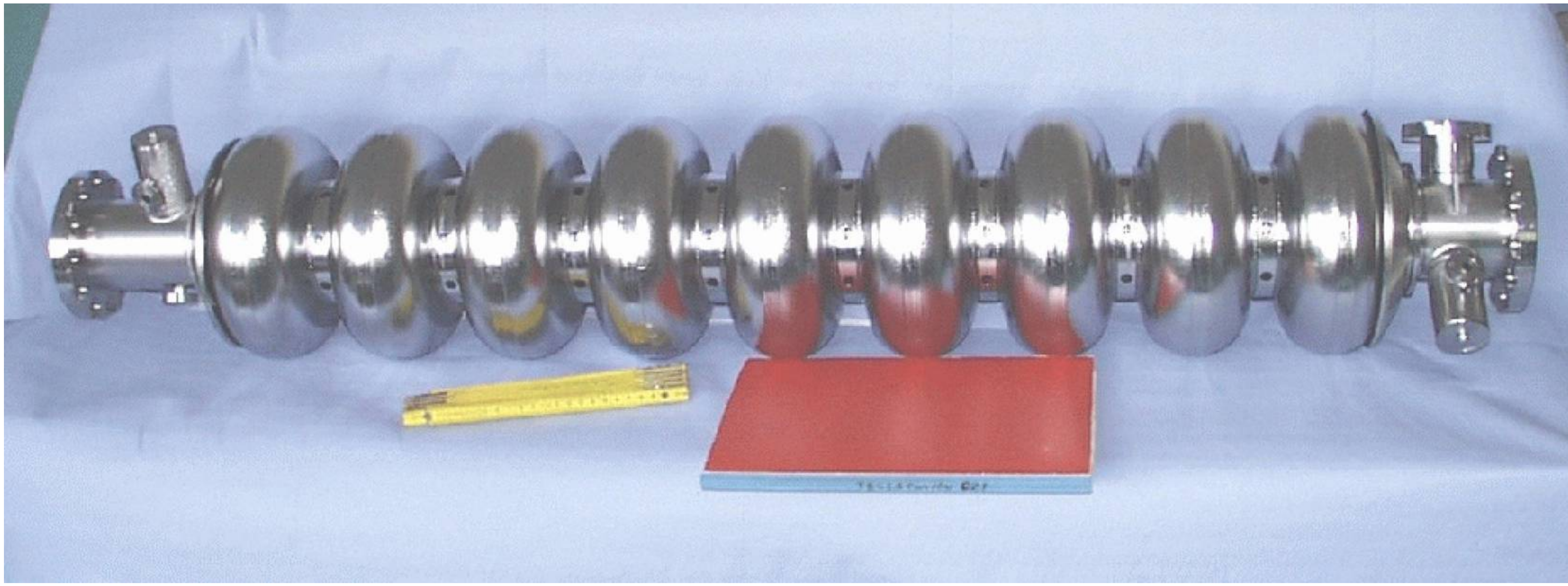
~1m



9-cell 1.3GHz Niobium Cavity

Reference design: has not been modified in 10 years

Cavities have been produced in industry in EU & tested at DESY.

Challenge: produce in other parts of world in industry & develop critical cleaning procedures (one of activities of SMTF at Fermilab).
Major FNAL goal: make cleaning and resulting gradient consistent.

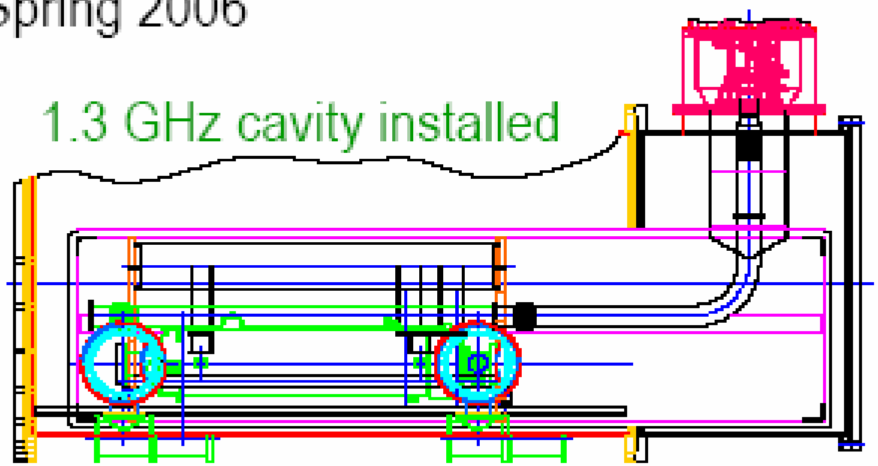
SMTF goals

Horizontal Test Cryostat, cont.

1.3 GHZ Cavity

- Design work will be completed in FY05
- Major components will be ordered early in FY06
- Planned to be operational in Spring 2006

1.3 GHz cavity installed



SMTF long term goals

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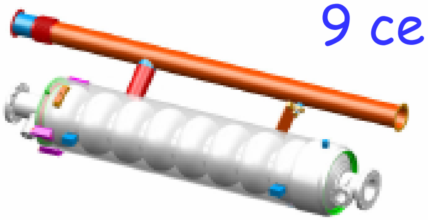
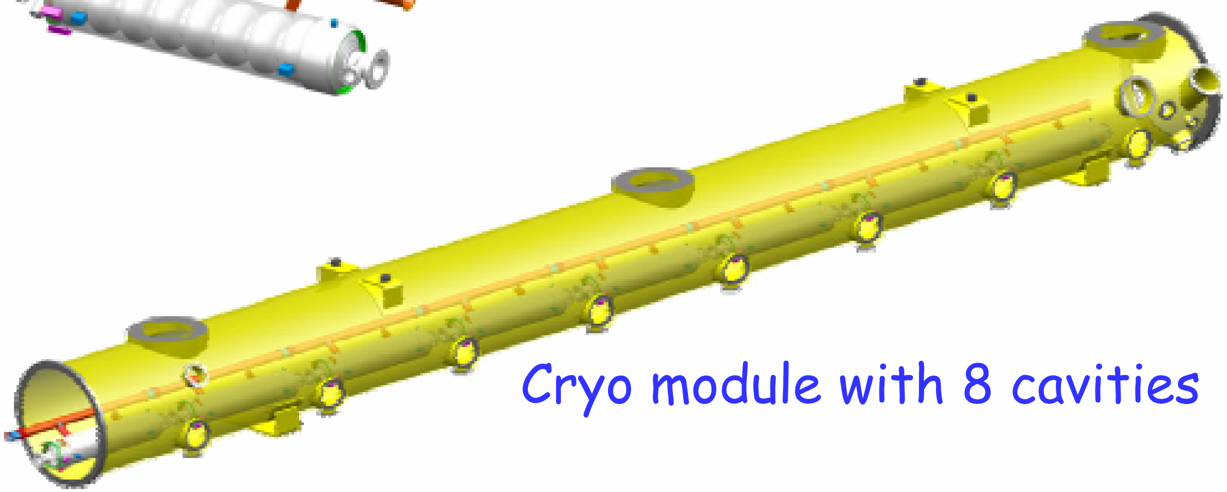
Goal for 2006…. produce 1 full working cryo module

Cavity and Cryomodule Fabrication Plans

9 cell cavity





Cryo module with 8 cavities

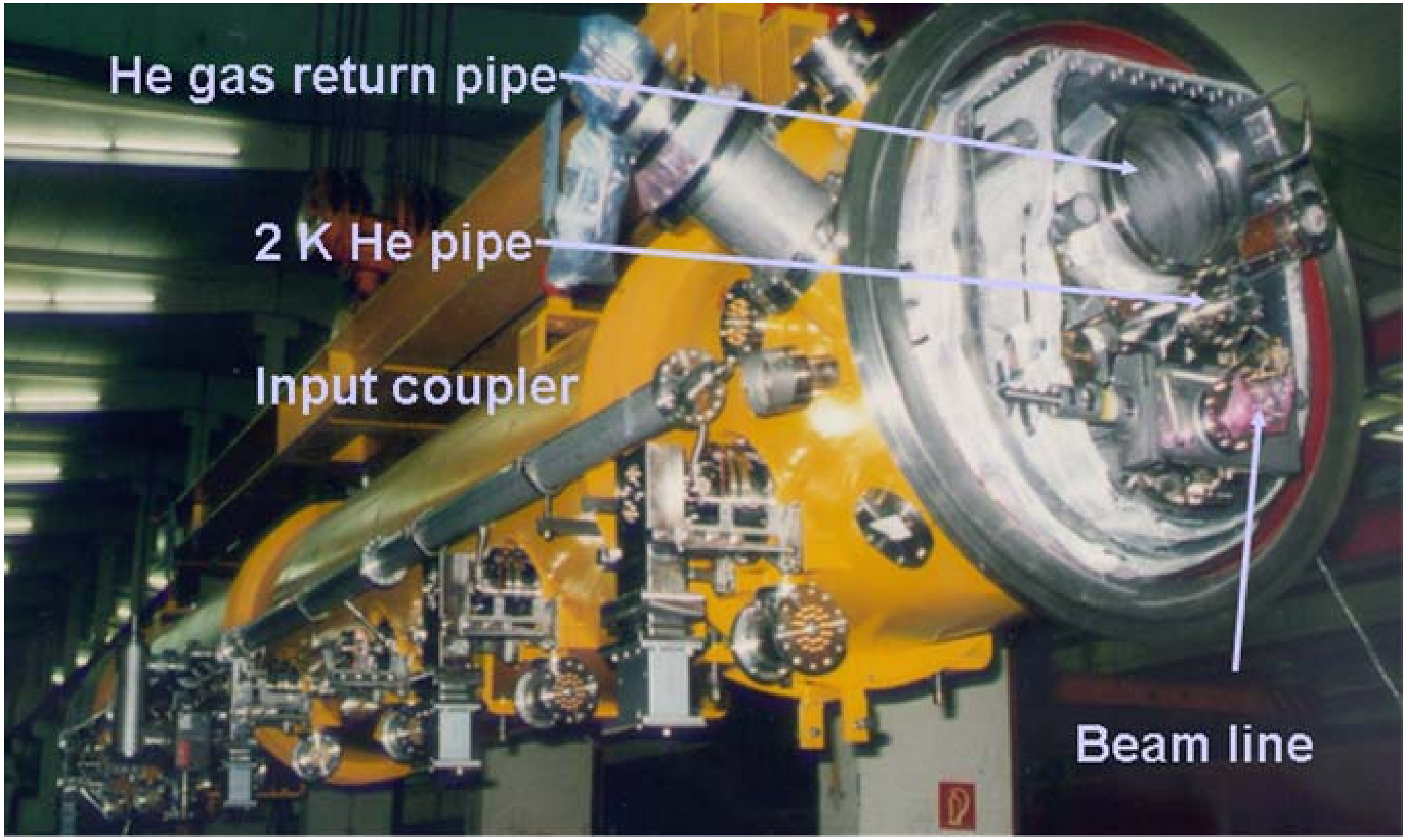
Initial cavities will come from DESY, KEK

Expect first 4 cavities from industry next year

Goal: By 2009 have built 6-7 cryomodules; finalized design; ready to built all components in industry.

Shows the need and long time scale for R&D and industrialization of process

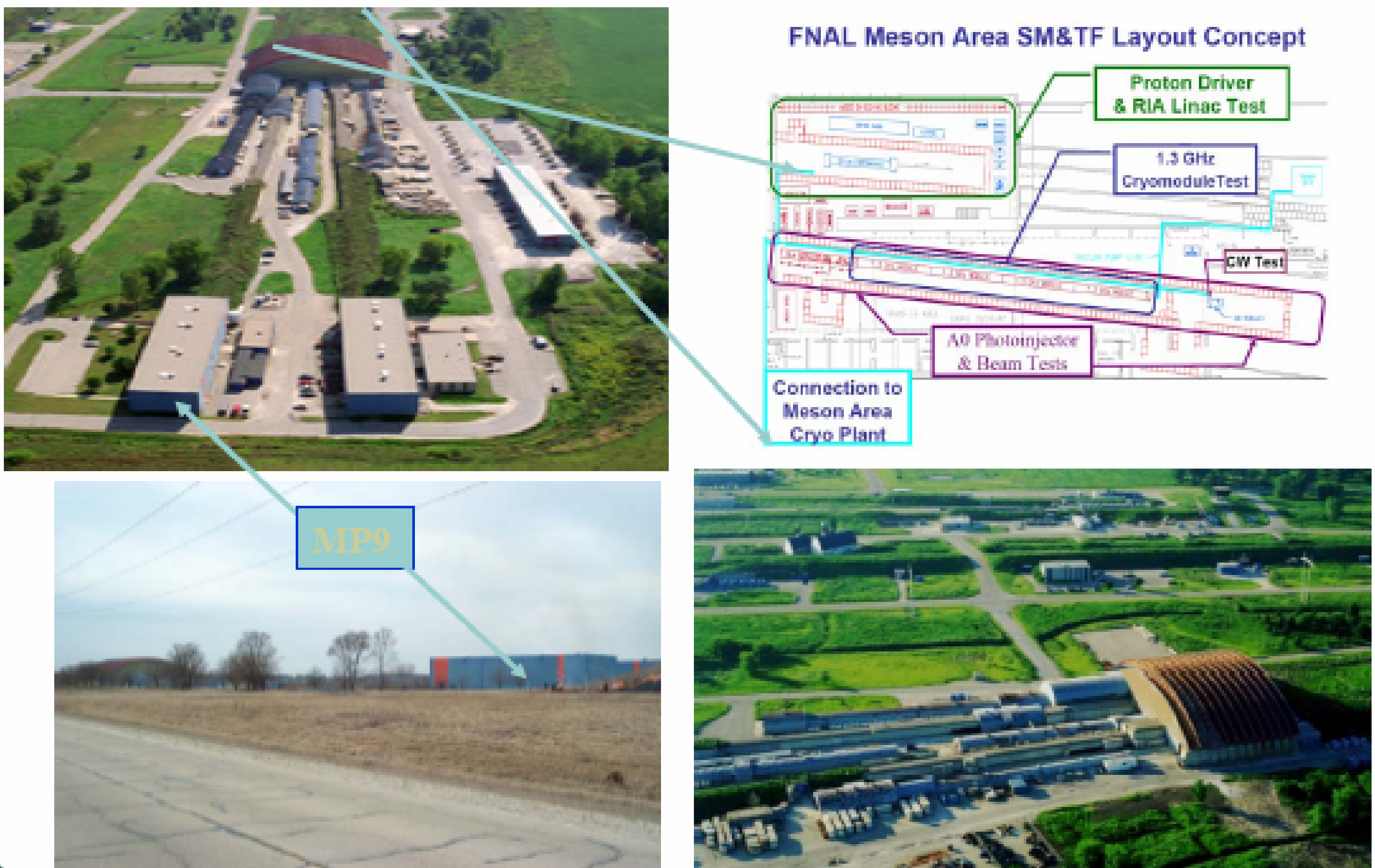
Image of a real cryomodule at DESY



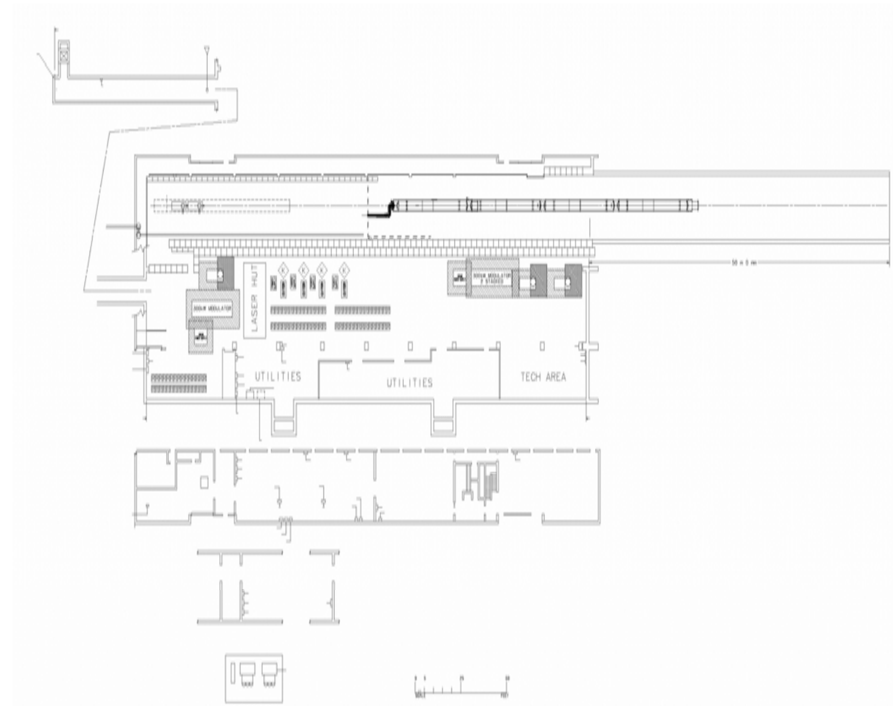
Cryomodule with only 4 cavities.
A cryomodule with 8 nine cell cavities has not been produced yet.

SMTF at Fermilab

MP9 Cryomodule Assembly Facility Development



ILC SMTF at Fermilab



- Plan is to set up ILC test area in the New Muon Lab and it will require some civil construction.
- This enables us to setup a single cryomodule test area in Meson and have enough room.

Accelerator R&D

Just given you a glimpse of some of the R&D and processes going on in development of accelerator components.
There are many more of them.

Need a separate talk to cover them all. An incomplete list:

Sources : electrons, positrons, polarized
Damping rings
SCRF LINAC
Beam Delivery and Interaction region
Large simulation efforts for all of these
Backgrounds in interaction regions
……….

This is an incredible task ahead of us.
Needs a large number of people and funding

R&D critical in next few years to be able to make a decision to build…….. it requires funds

Interested ? Contact : Shekhar Mishra and/or Nigel Lockyer

To do physics with ILC…..

Need detectors and current idealistic thinking is that there will be 2 interaction regions with detectors

Remainder of talk will concentrate what is happening in this area. This is area I am working in currently.

Why ILC detector R&D ?

From a naïve perspective looks like simple problem

	LHC	ILC
Bunch Crossing	25 ns (40 MHz); DC	337 ns 0.5% duty cycle
Triggering: L1, L2, and L3	40 MHz → 1 kHz → 100 Hz	No hardware trigger ~ 100 Hz Software
Radiation	1-100 MRad/yr	≤ 10 kRad/yr
Physics Occupancy Per bunch	23 min. bias; 100 tracks	0.3 $\gamma\gamma \rightarrow$ hadrons; 2 tracks

ILC

bunch spacing	337 nsec (176 ?)
#bunch/train	2820
length of train	950 μsec
#train/sec	5 Hz
train spacing	199 msec
crossing angle	0-20 mrad (25 for $\gamma\gamma$)

But there are other factors which require better performance.....

Intro I

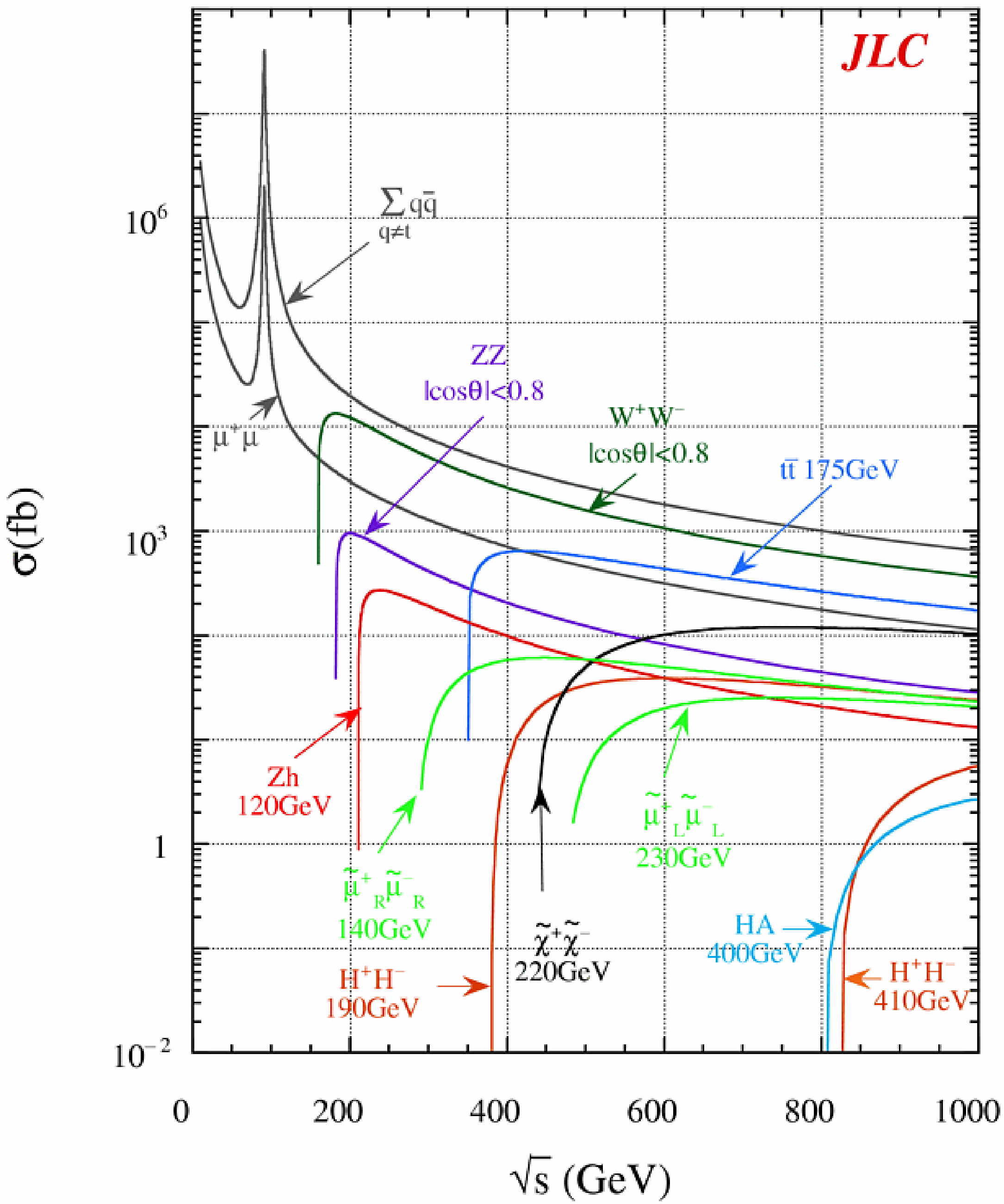


Illustration of final states expected at ILC vs. CMS energy

Observations:

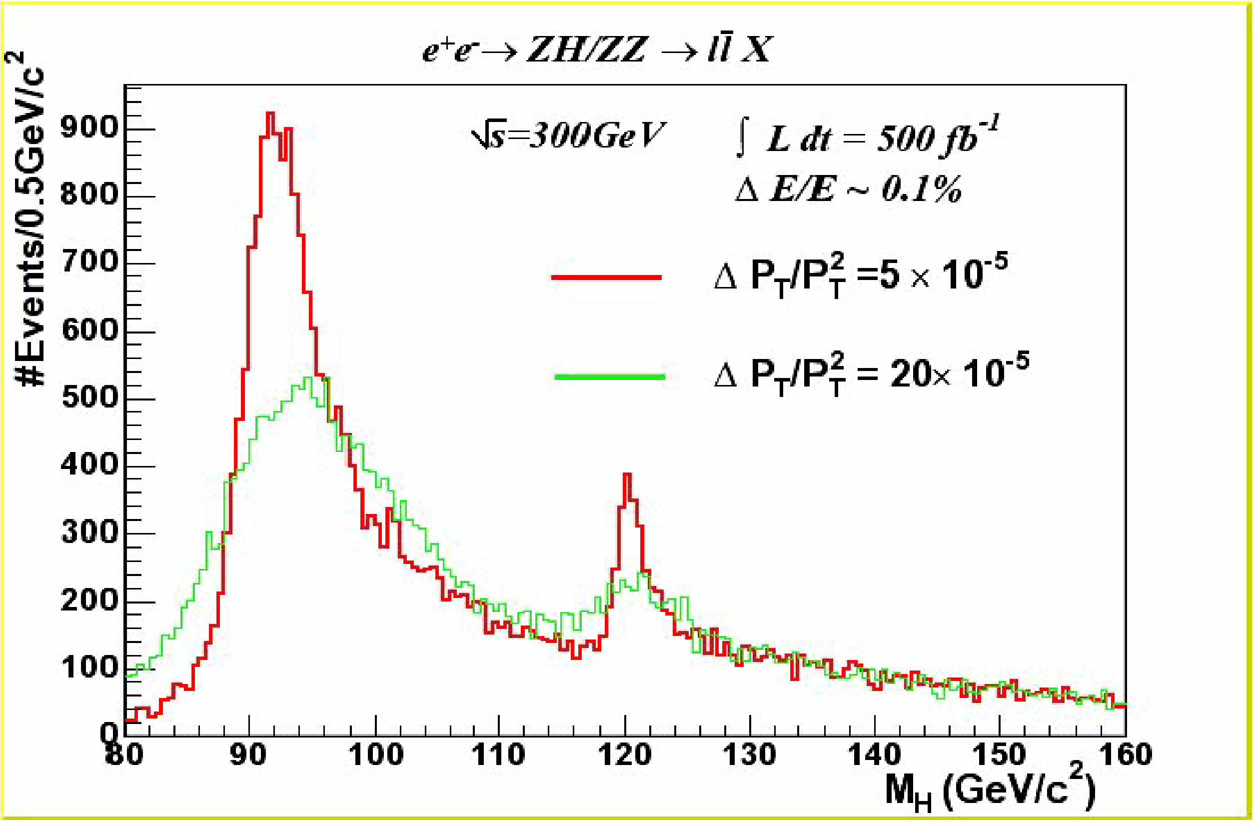
- No resonances (*Z* was last one)
- Need to reconstruct final states from leptons and/or jets
- *W* and *Z* become the main objects to reconstruct
- Measure missing energy (neutrinos +)

Quite different from usual e^+e^- detectors

Requirements 1

e.g: The Higgs tagging mode

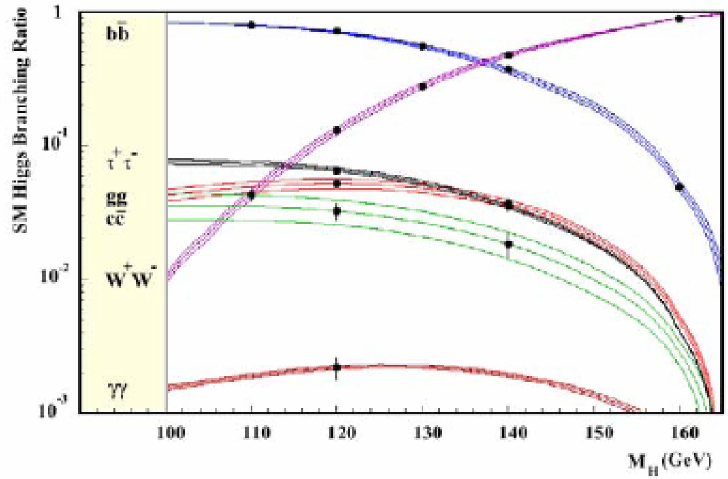
$$e^+e^- \rightarrow ZH, \quad Z \rightarrow \ell^+\ell^-$$

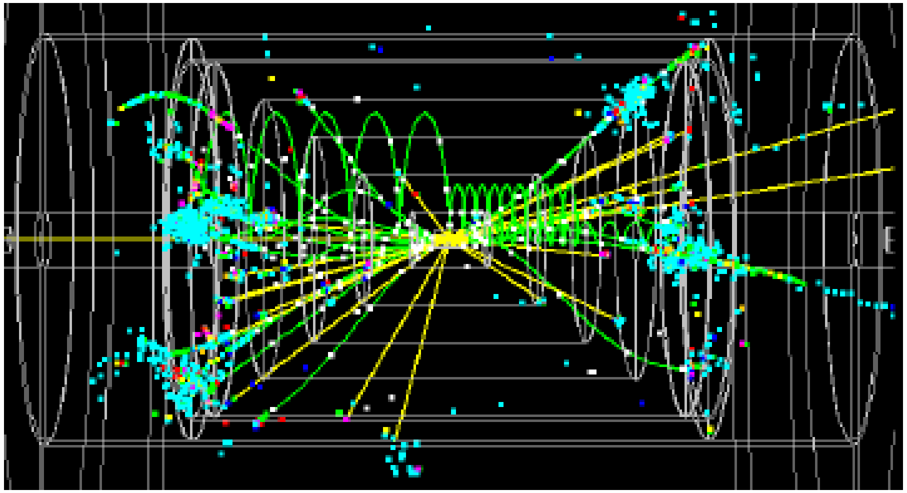


$\sigma_p/p^2 \sim 5 \times 10^{-5}$ is "necessary"

Requirements 2

- Tracking is to be an integrated system with combined optimization of:
  - the inner tracking (vertex detection)
    - Precision measurements of Higgs branching fractions test SM symmetry breaking; need ultimate b-tagging capability
      - CCD's provide superb resolution (pixel size 20 μm), but are too slow
  - the central tracking
    - Higgs recoil mass resolution improves until $\Delta p/p^2 \sim 5 \times 10^{-5}$
      - Tracker resolution improvement is 10x LEP/SLC and 3x CMS





No proven solution currently ➔ R&D

Requirements 3

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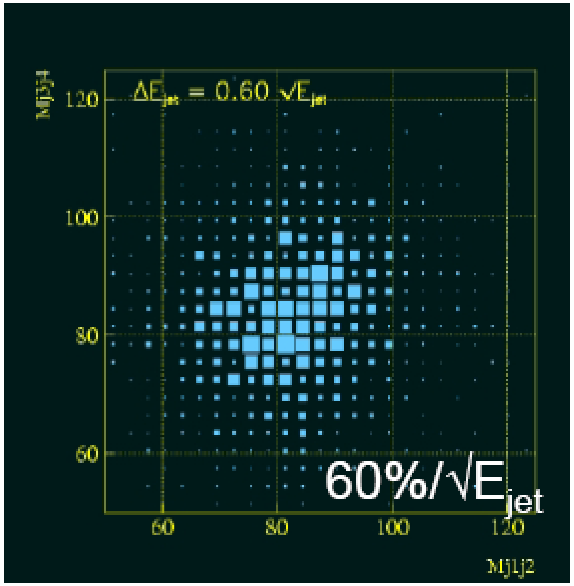
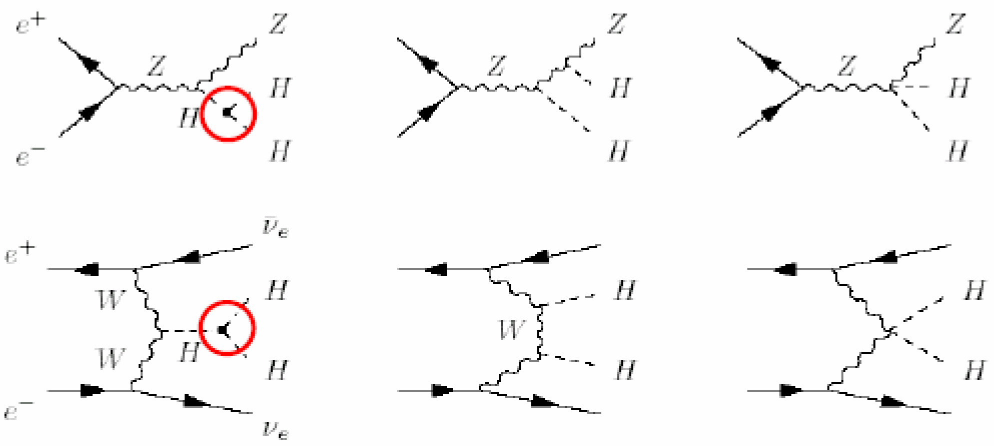
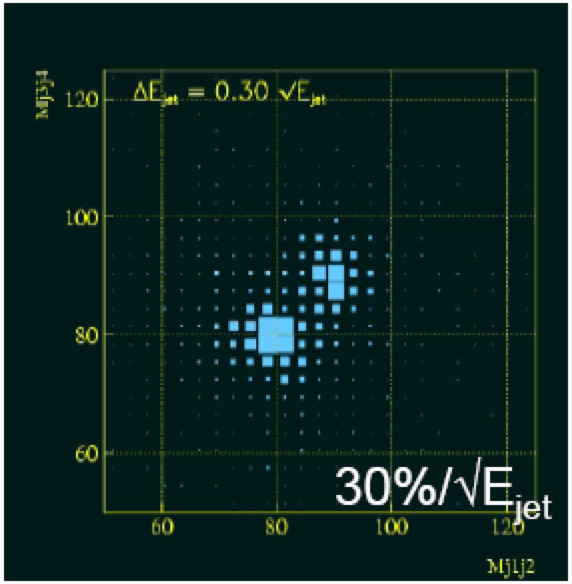
- Many processes have W and Z bosons in the final state; events need to discriminate
- Need for precision calorimetry
  - $e^+e^- \rightarrow WW\nu\nu$, $WZe\nu$ and $ZZ\nu\nu$ events
    - Can be indicative of strong EWSB
  - Measure Higgs Self-coupling λ_{HHH}
    - Two production processes
      - ZHH and W-fusion
    - Small cross section on large multijet background;
    - need high resolution calorimetry to identify







Goal: excellent, never before achieved jet energy resolution: ~30%/ $\sqrt{E}$

Design Driver

To be able to achieve the jet resolution can NOT simply use calorimeters as sampling devices.

$$\frac{\sigma_E}{E} \cong 0.30 \frac{1}{\sqrt{E(GeV)}}$$

Have to use "energy/particle flow". Technique has been used to improve jet resolution of existing calorimeters.

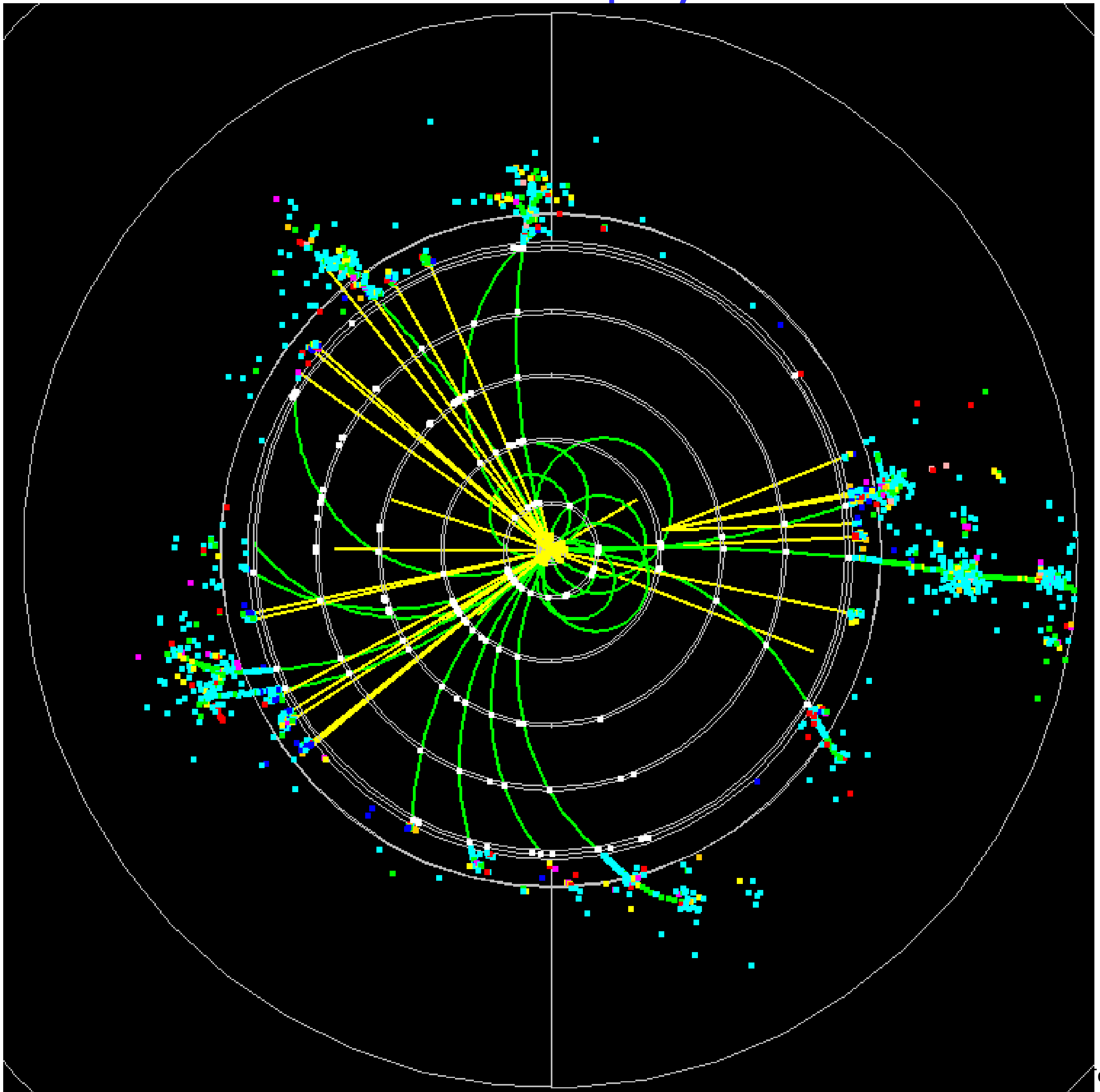
Algorithm:

- use EM calorimeter (EMCAL) to measure photons and electrons;
- track charged hadrons from tracker through EMCAL,
- identify energy deposition in hadron calorimeter (HCAL) with charged hadrons & replace deposition with measured momentum (very good)
- When completed only E of neutral hadrons (K's, Lambda's) is left in HCAL. Use HCAL as sampling cal for that.

Require:

Imaging cal (use as tracker = like bubble chamber),
➔ very fine transverse & longitudinal segmentation
Large dynamic range: MIP…. to …..shower
Excellent EM resolution

Event display



Design Driver

Requirements for optimal "energy/particle flow" now drive the calorimeter design and drive it to extremes in terms of sampling transversely and longitudinally.

However do not know where break even point is i.e. resolution is limited by algorithm and not the detector.

Studies are underway:

- Develop and test algorithm
- Develop and measure response of calorimeters
- Push limits of our current understanding of hadron showers
- Large R&D program including testbeam work with test calorimeters in planning

→ @Fermilab

Summary of requirements

Detector performance goals (Int'l R&D review)

Reference CMS

• central tracking:

$\sigma(1/pt) \leq 5 \times 10^{-5}(\mathrm{GeV/c})^{-1}$ — 7×10^{-4}

(~1/10 LHC; 1/6 material in tracking volume.)

• Jet energy:

Drives design →

$$\frac{\sigma_E}{E} \cong 0.30 \frac{1}{\sqrt{E(GeV)}}$$ — 0.86

(1/200 calorimeter granularity w.r.t. LHC)

• vertexing:

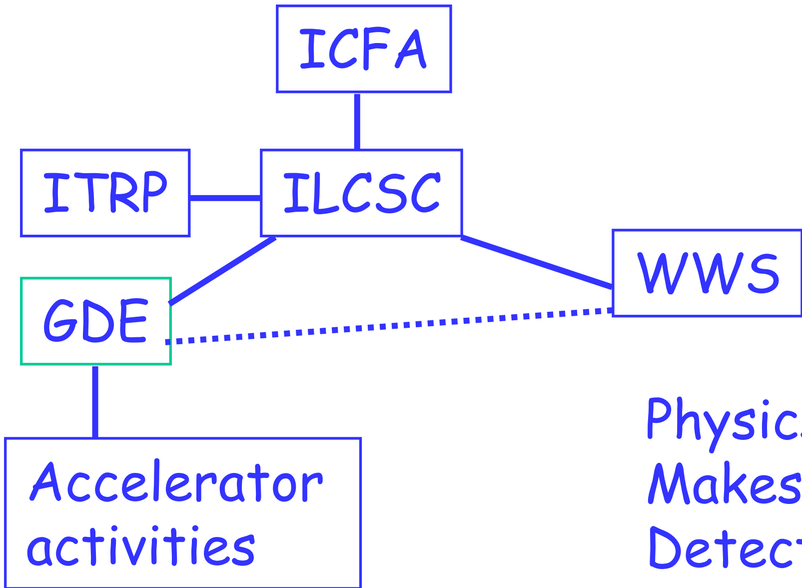
$$\sigma_{r\phi,z}(ip) \leq 5\mu m \oplus \frac{10\,\mu m Gev/c}{p \sin^{3/2}\theta}$$

(1/5 $r_{beampipe}$, 1/30 pixel size, 1/30 thin w.r.t LHC)

Exploits the clean environments of LC.
Not a luxury, but needed for LC to do its physics.

Pushes detector performance into unexplored territory

ILC detector history I



= Worldwide Study of the Physics and Detectors for Future Linear $e^+ e^-$ Colliders

Physics & Detectors
Makes physics case
Detector development; up to now mainly "generic" detector R&D

R& D activities:
- Silicon (SiLC)
- TPC/Jet chambers
- Vertex detectors
- Calorimetry (CALICE) (EM & HAD)
- Muon System -- at FNAL
- .....

There was a TESLA detector design

This was situation up to Spring 2004

ILC detector history II

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In February 2004 ILCSC asked WWS to develop a plan for detectors corresponding to machine schedule/plan

Machine schedule/plan

2004 International technology selection.
Initiate the Global Design Effort.
2005 Complete the accelerator **CDR**, including site requirements, and initial cost and schedule plan.
2006 Initiate detailed engineering designs under the leadership of the CentralTeam.
2007 A complete detailed accelerator TDR with the cost and schedule plan,establish the roles & responsibilities of regions, and begin the process for site proposals.
2008 Site selection and approval of international roles & responsibilities by the governments.

....

2009 Start construction
2015 Start operation

WWS plan/answer:

2005 Preliminary costing of **at least two whole detector concepts** (single joint document with performance estimates for each concept, plus R&D done and still required.) Produce in time to be included in the Accelerator CDR process of the GDI.

2007 Detector CDRs –Conceptual Design Reports for experiments (could be different from concepts above) with specification of physics performance on key benchmarks, technical feasibility, and refined cost. Individuals encouraged to sign more than one CDR.

2008 Proposals – Groups united around CDR detector concepts submit Letters of Intent for proposals (including performance, costs, and technical feasibility) to the Global Lab, which will invite some of the groups to produce TDRs.

Now in hands of GDE……..

Time line

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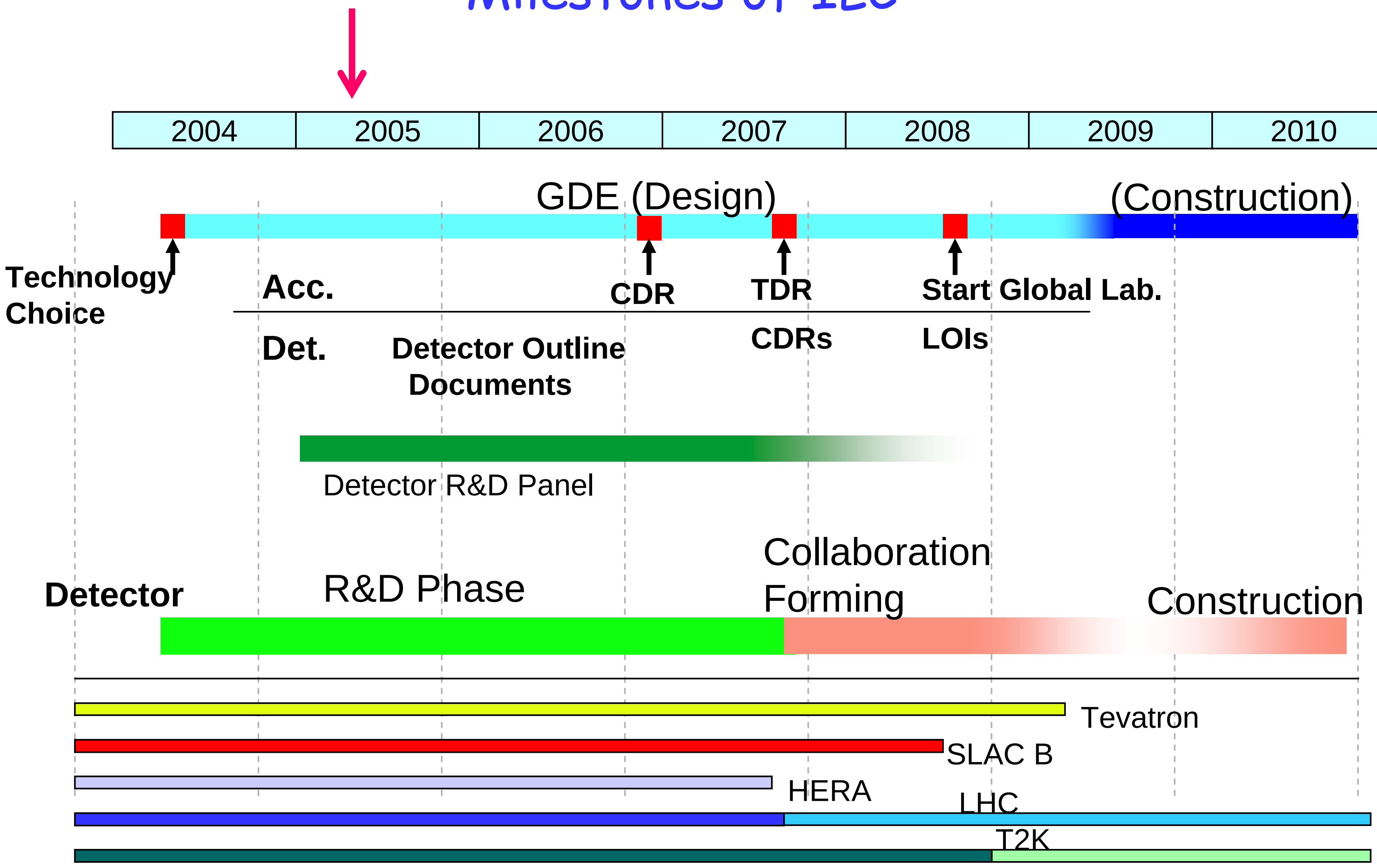
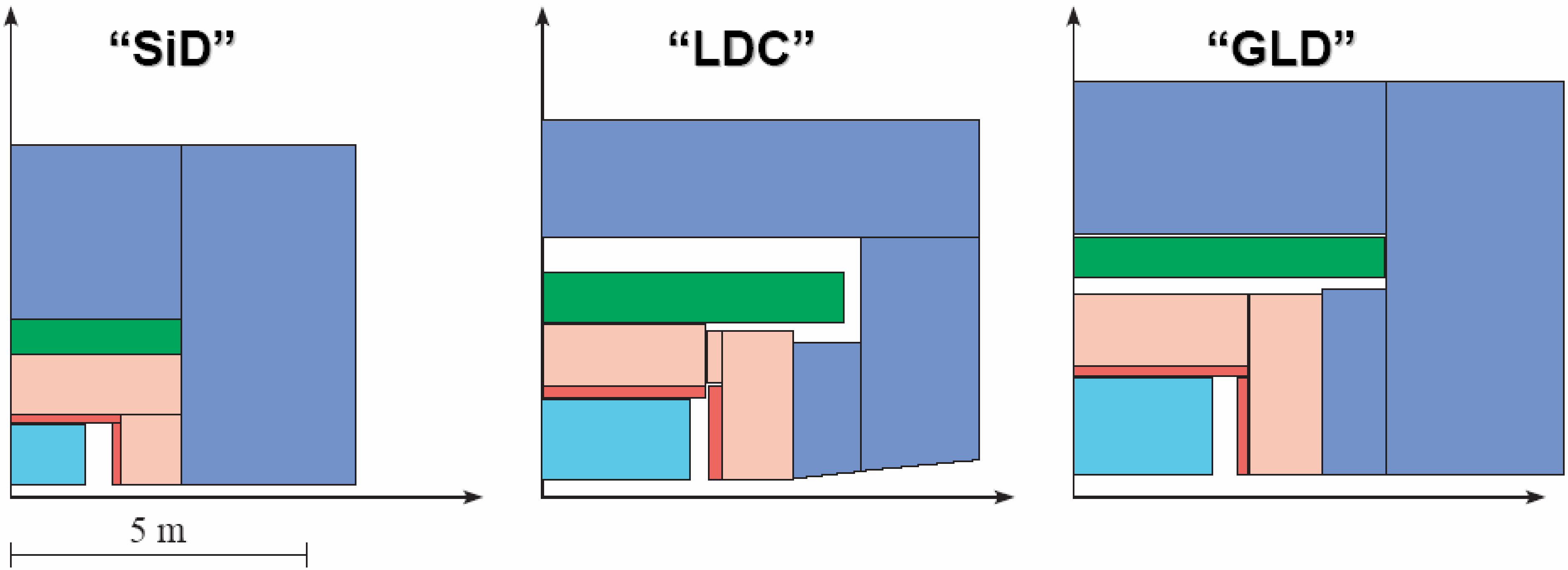
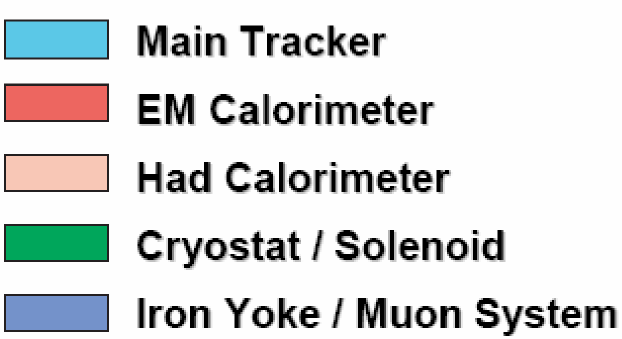
Milestones of ILC



Detector Concepts

- Three detector concepts





- SiD: Silicon Detector — SiD: **B** $\mathbf{R}^2$
  - Small, ‘all’ silicon
- LDC: Large Detector Concept — LDC: **B** $\mathbf{R}^2$
  - TPC based
- GLD: Global Large Detector — GLD: **B** $\mathbf{R}^2$

Detector R&D efforts & Design Studies

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	Vxd 4-5	SiLC	T P C	J e t	Calic e EM	Cali ce HA D	LC cal	Cal Asia	EM OR/ SLAC	EM hybri d	muo n
SiD	X	X			X	X		X	X	X	X
LDC	X	X	X	X	X	X	X	X	X	X	X
GLD	X	?	X	X		X	X	X			X

	Fwd trac	Fwd cal	Fwd Che	DA Q	γγ	BD IR
SiD	X	X		X		X
LDC	X	X	?	X		X
GLD	X	X	?	X		X

Nearly all detector R&D efforts are represented in the Design Studies (DS)

FNAL involvement in "Design Studies" and in more generic R&D

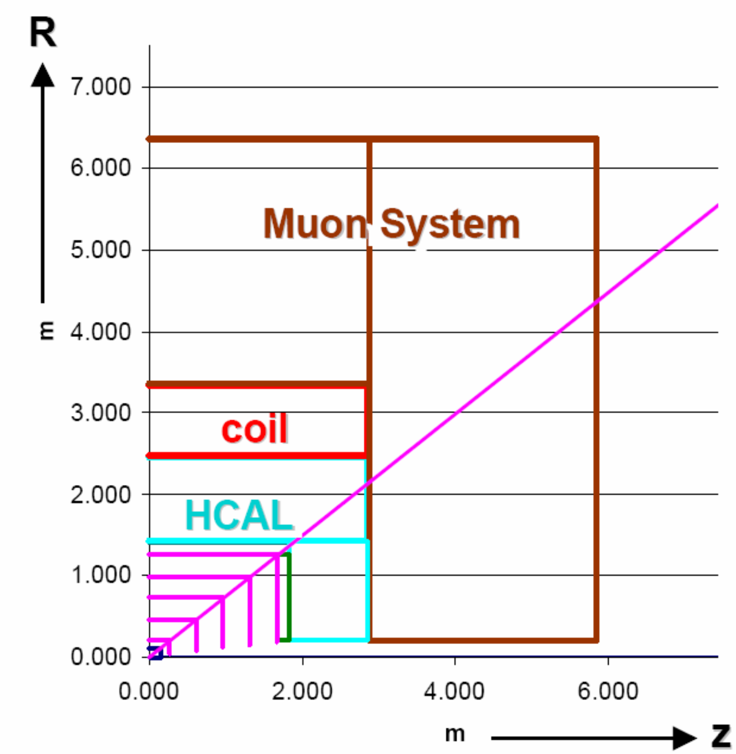
SiD Concept Overview/Status

- Focus at Fermilab is on SiD concept

  Effort at FNAL & SLAC with many other US & world institutions

  (Jaros & Weerts leading design study)

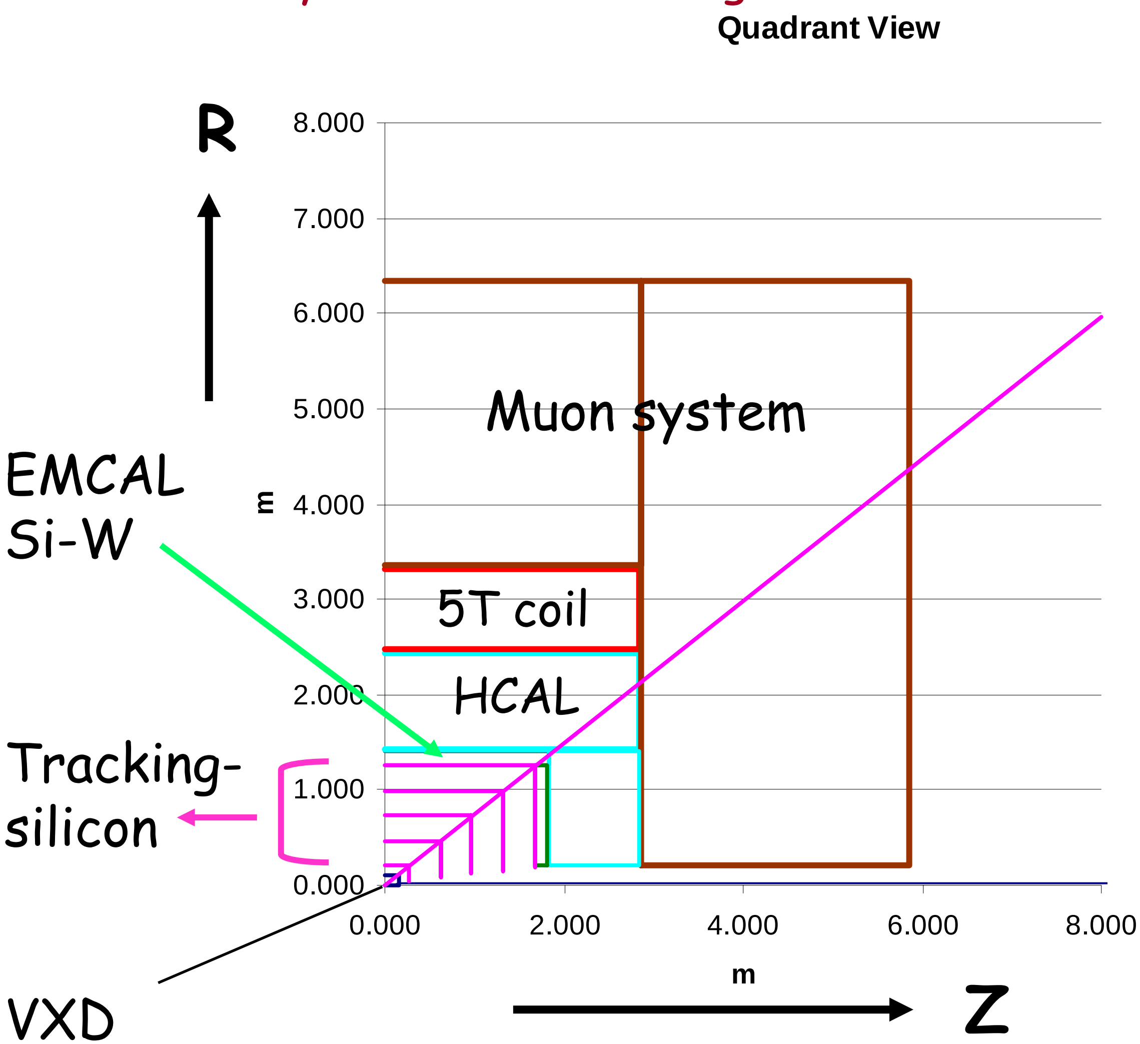
- Assumptions behind SiD concept
  - Particle Flow Algorithm will deliver best performance, use as base
  - Si/W is right technology for EMCAL
  - Limit tracking radius/EMCAL to limit costs
  - Increase B field to maintain BR^2
  - Use Si tracking only, for best $\delta p/p$ and low mass
  - Use pixel vertex detector for best pattern recognition
  - Emphasize integrated, hermetic detector design

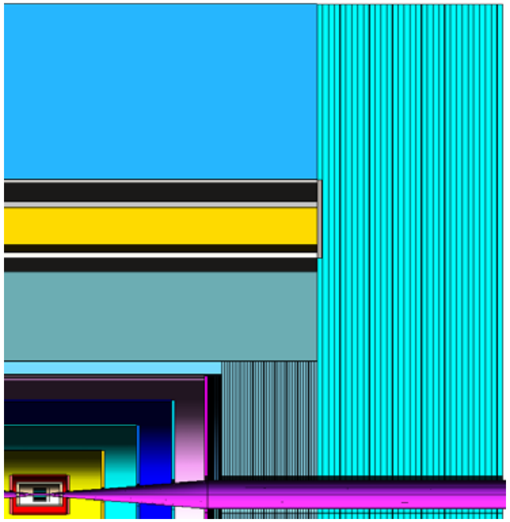


Result: most compact of 3 concepts

SiD FNAL involvement

Very schematic drawing





Status May 2005

Status July 2004

Overview of current SiD "baseline"

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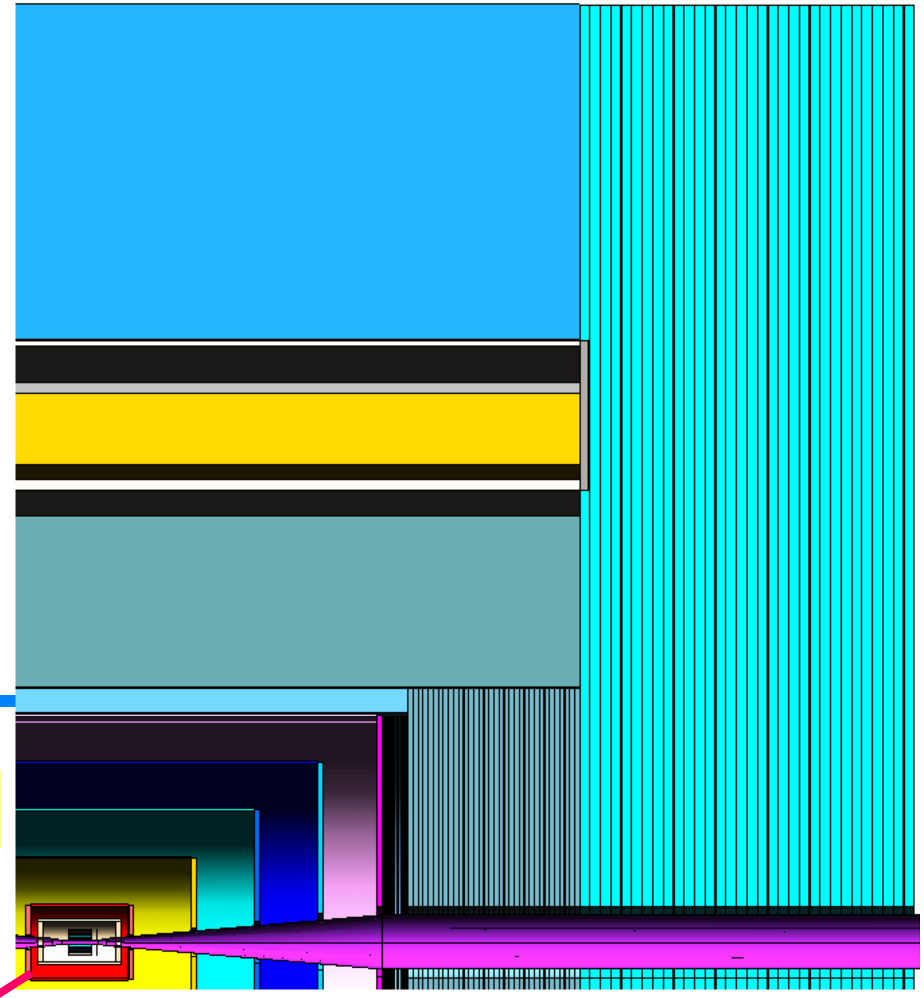


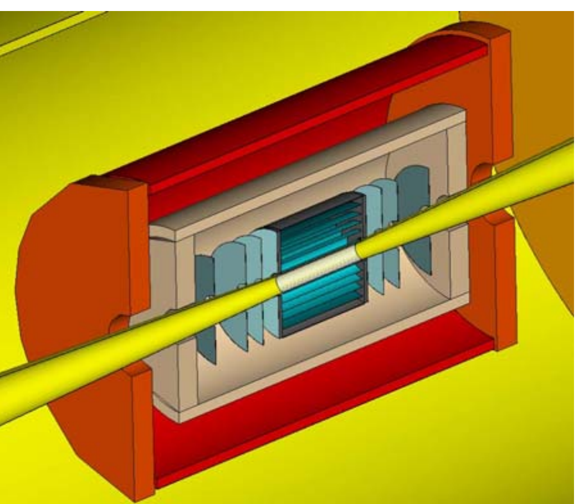
Flux return/muon Fe: 48 layers, R_{in}= 333 cm & R_{out}= 645 cm

Solenoid: 5 T; R_{in}= 250 cm

HCAL Fe: 34 layers; R_{in}= 138 cm

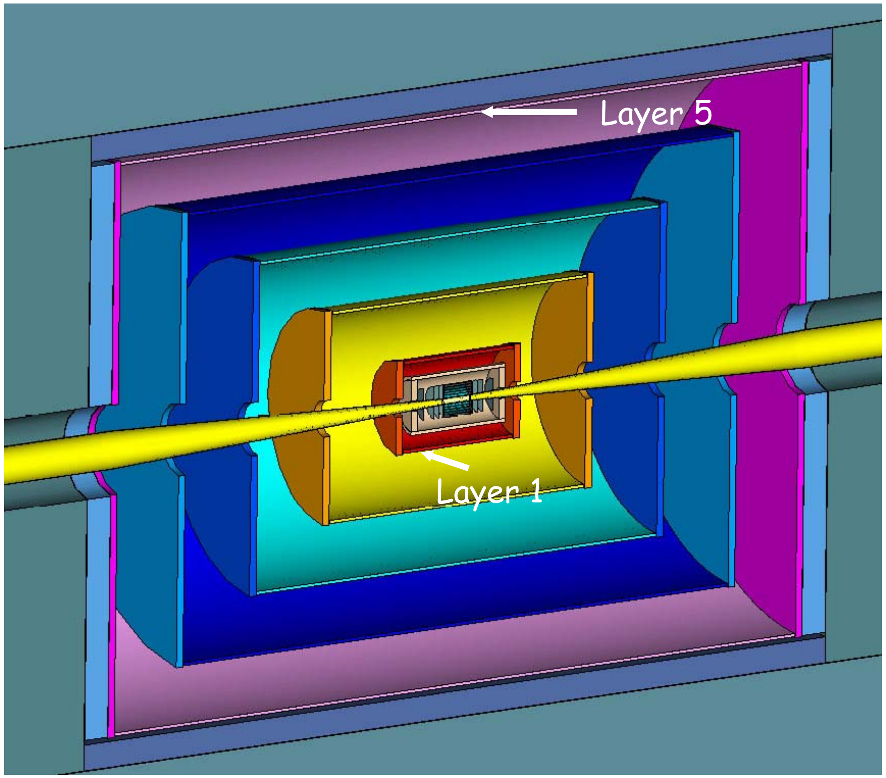
EMCAL Si/W: 30 layers; R_{in}= 125 cm

Si tracking: 5 layers; R_{in}= 18 cm



Vertex detector: 5 barrels, 4 disks; R_{in}= 1.4 cm

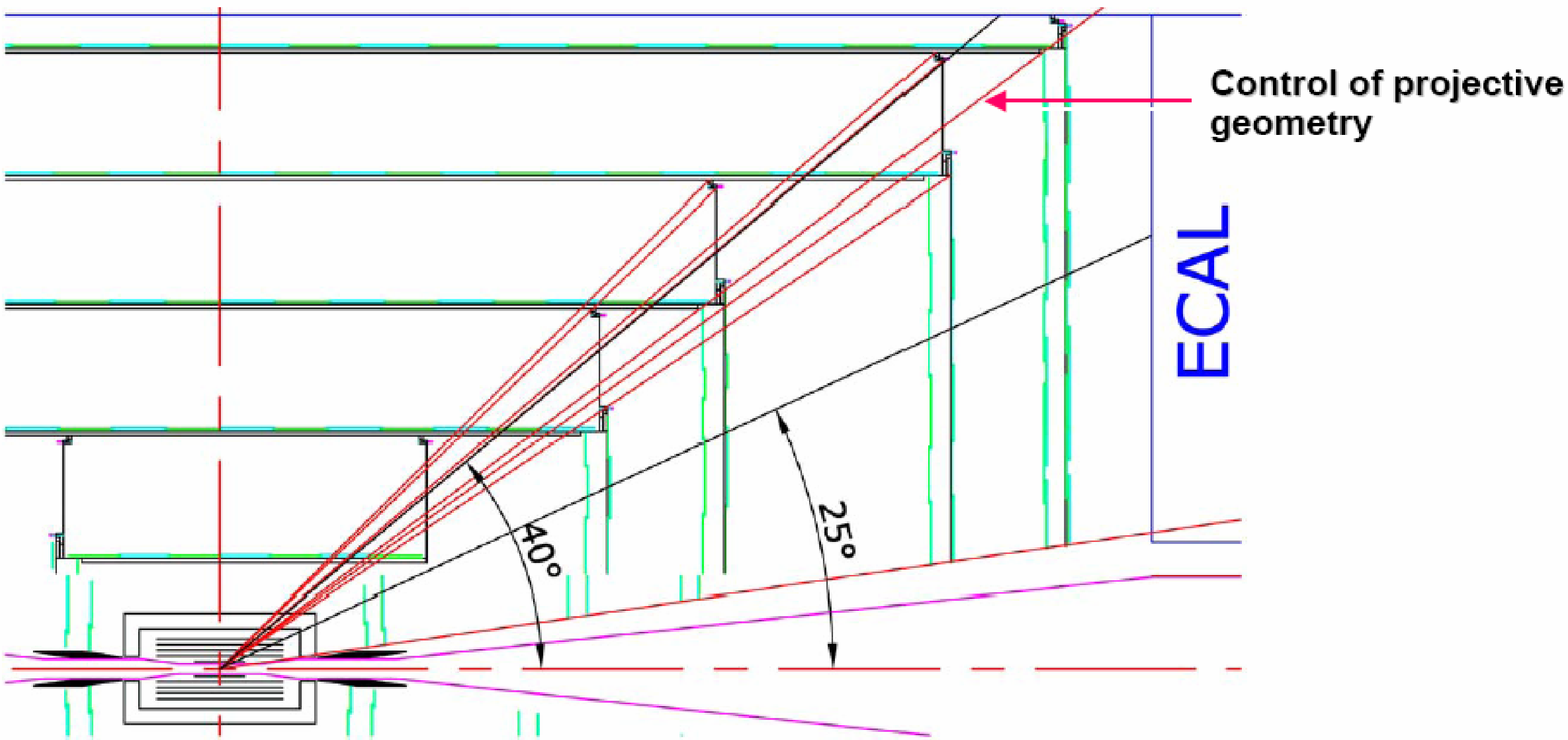
SiD Silicon tracker work at FNAL I



- Support
  - Double-walled CF cylinders
  - Allows full azimuthal and longitudinal coverage
- Barrels
  - Five barrels, measure Phi only
  - Eighty-fold phi segmentation
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- Disks
  - Five double-disks per end
  - Measure R and Phi
  - varying R segmentation
  - Disk radii increase with Z

SiD Silicon Tracker work at FNAL II

- Significant consideration given to mechanical engineering issues
  - Support of disks from barrels
  - minimization of material budget
    - Control projective geometry
    - Material budget of ~0.8% X0 possible for realistic design in barrel region
  - lay-up of carbon fiber-rohacell support cylinders and disks



SiD Silicon Tracker work at FNAL III

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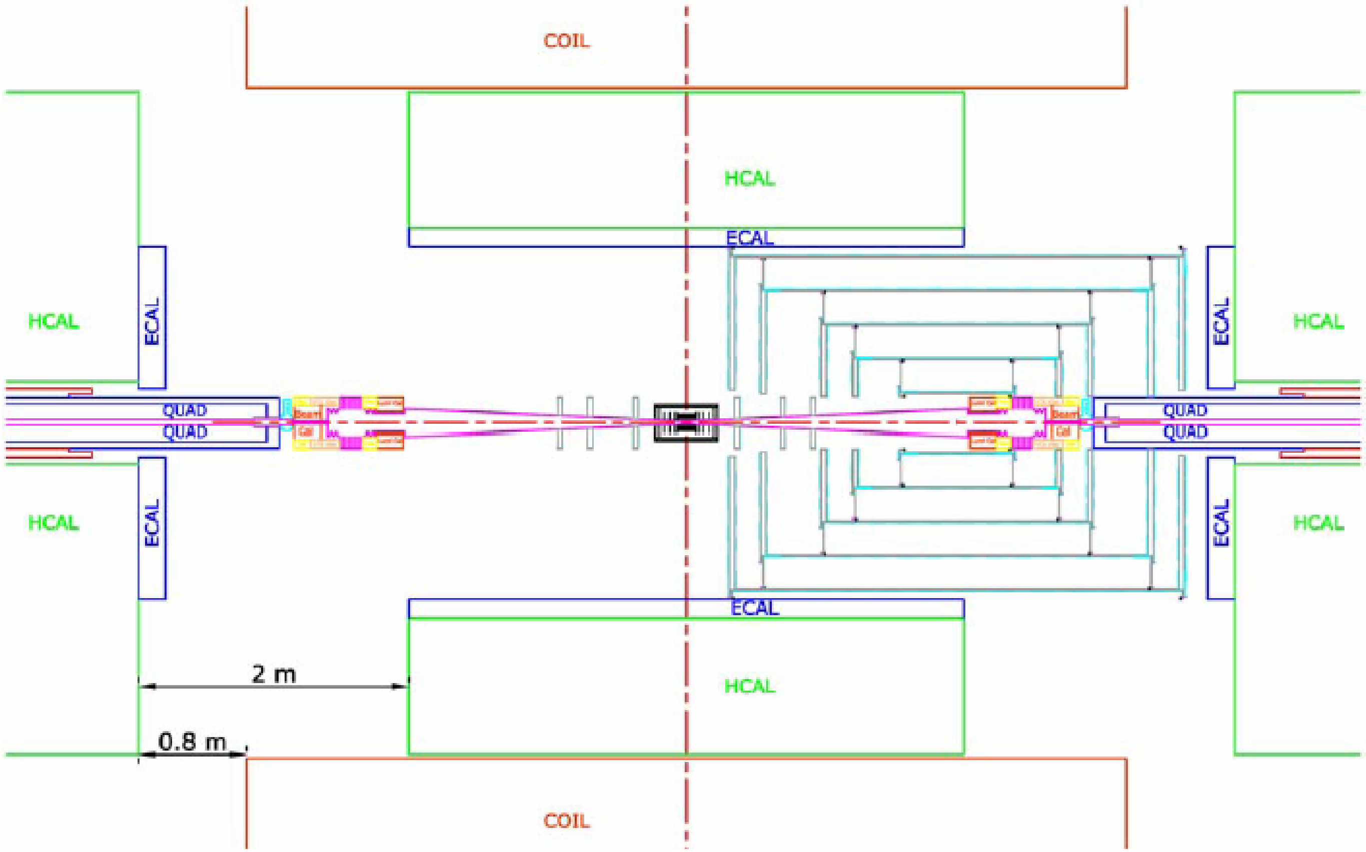
- Interface with vertex detector
  - Outer Si tracker separated into a portion supported from the ECAL and a portion supported from the beam pipe to allow servicing of the VXD; VXD stationary
  - Still full angular coverage by offsetting inner disks



ILC Muon R&D

Muon system; hardware @ FNAL

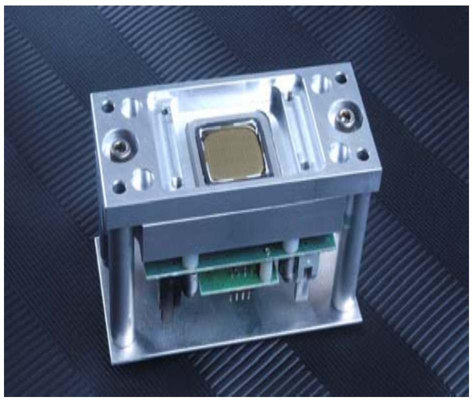
- Colo. State, UC Davis, Fermilab,
- Northern Illinois Univ.,
- Univ. of Notre Dame, Wayne State Univ.,
- Univ. of Texas Austin, INFN Frascati

- Scintillator strip panels

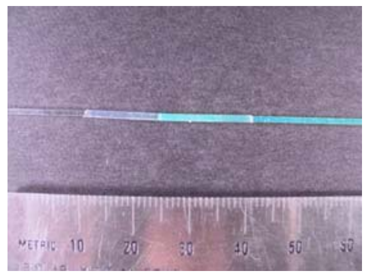
MINOS style: 4 cm X 1 cm

MAPMT 16 or 64 channels

4mm X 4mm pix / 16 ch

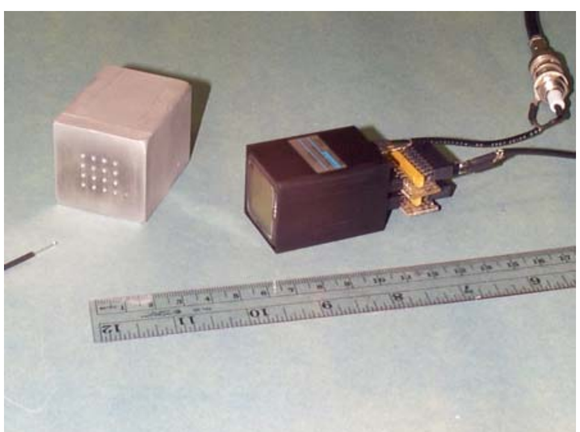


1.2mm fiber

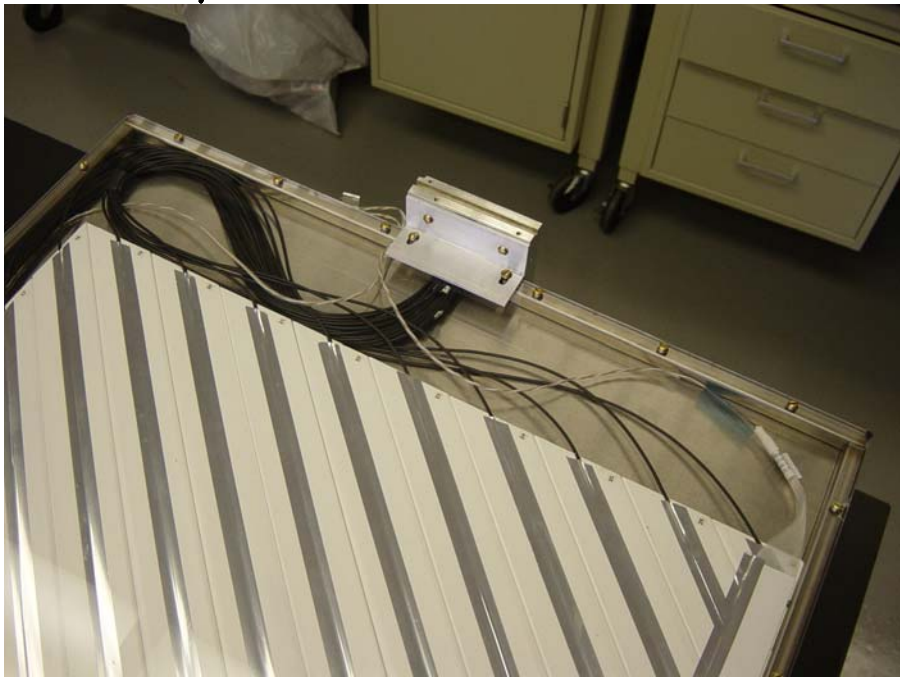


Thermally fused splice

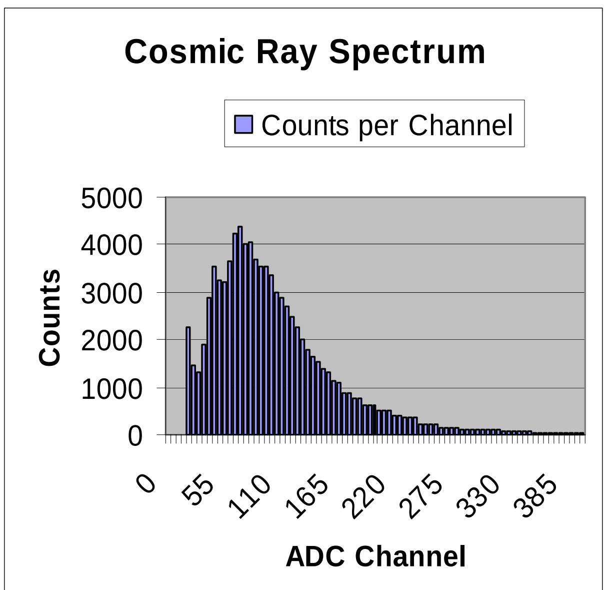
MAPMT



Muon system hardware



- Reduced Size Mechanical Preprototype for ¼ Scale Module
- Built by Notre Dame U.



Spectrum observed (at FNAL).
In initial stages.
Optically better module being built.

Results presented at LCWS, R.Abrams, Indiana

ILC Muon R&D

The latest in muon hardware….1/4 scale prototype 1.25x2.5m

Development of algorithms:

Tracking of muons through whole detector.

Improve simple stepper to a Kalman filter based method, incl. dE/dx along road.

Goal: first modules in testbeam 2006; improve algorithms

SiD solenoid

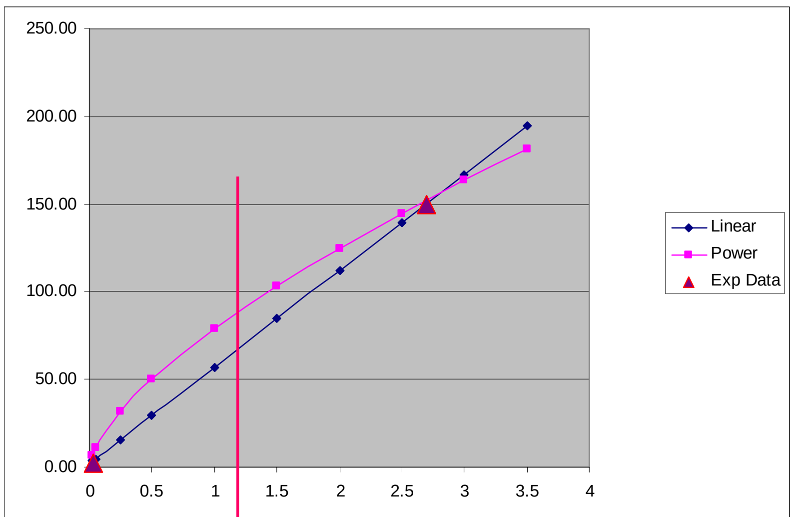
H.Weerts

This is what I used to show

Inner radius: ~ 2.5m to ~3.32m, L=5.4m; Stored energy ~ 1.2 GJ

Need feasibility study in next year to at least convince ourselves that this challenging 5T solenoid can be built .

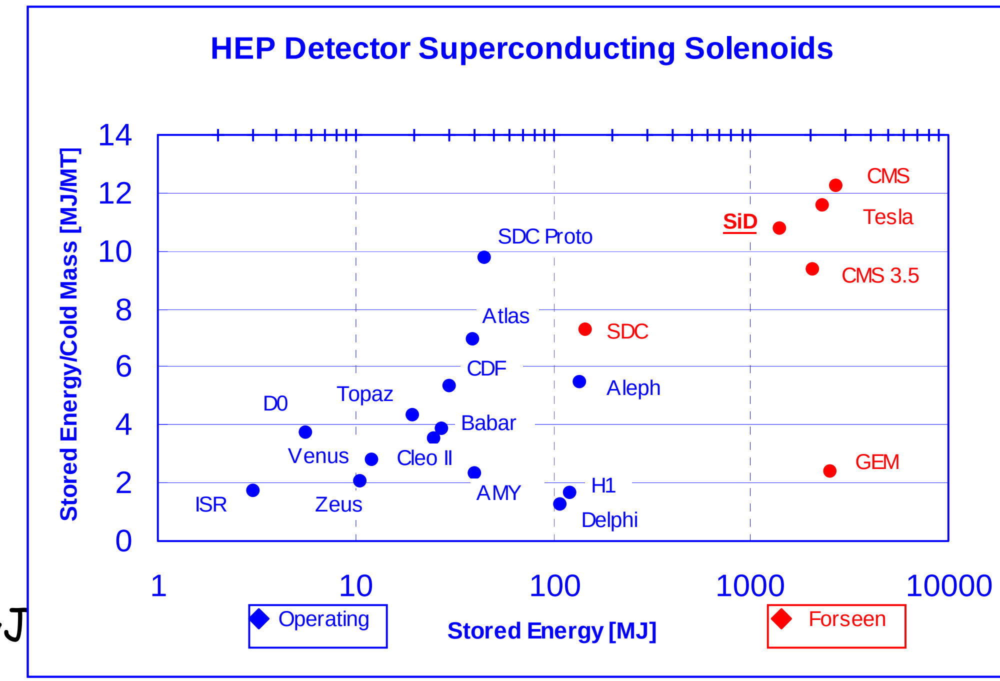
Expertise not readily available. CMS solenoid sets current scale.



Cost model

SiD

Energy [GJ]



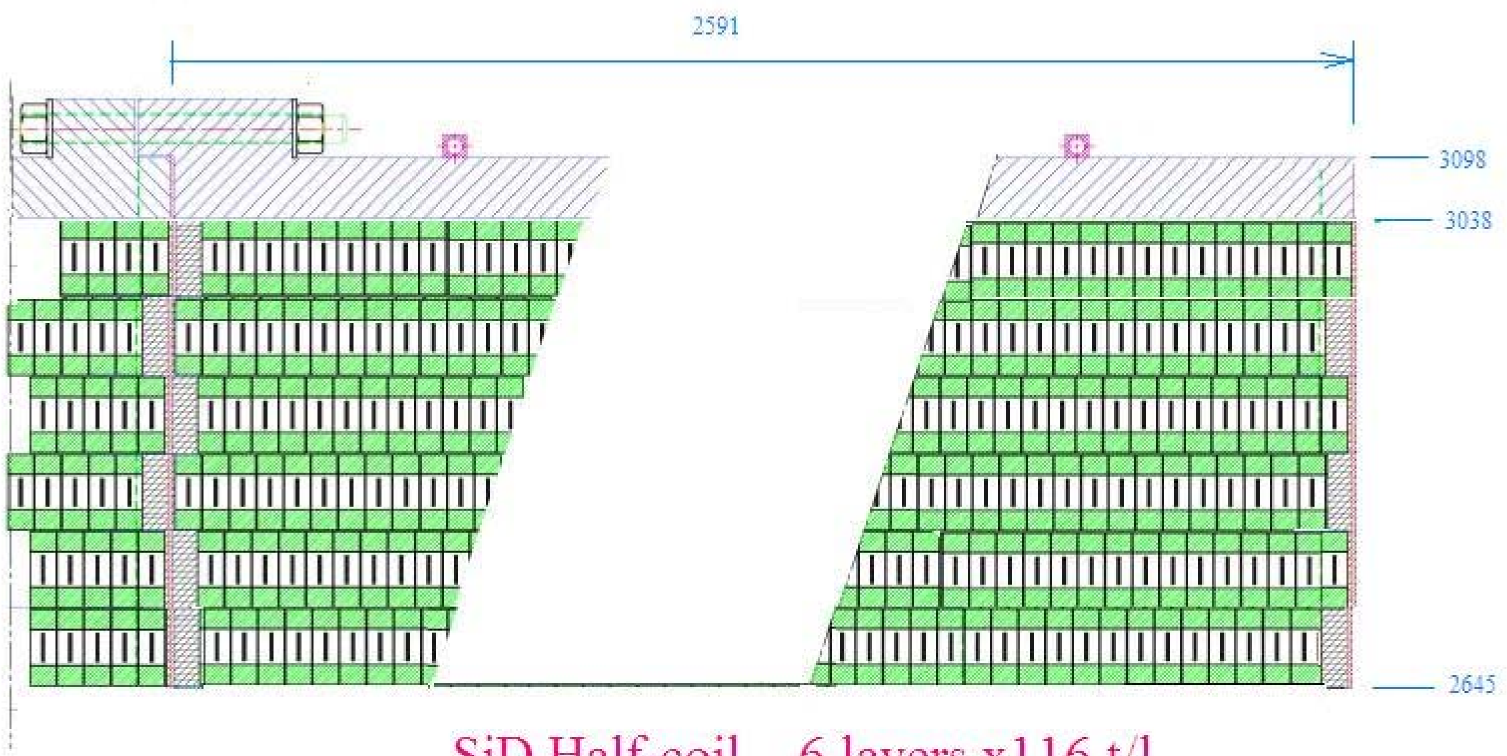
Does physics really require 5T?

Solenoid

Feasibility study has been done at FNAL.

Use CMS conductor design and study stresses, in cooldown and energizing

4 layers in CMS, go to 6 layers for SiD

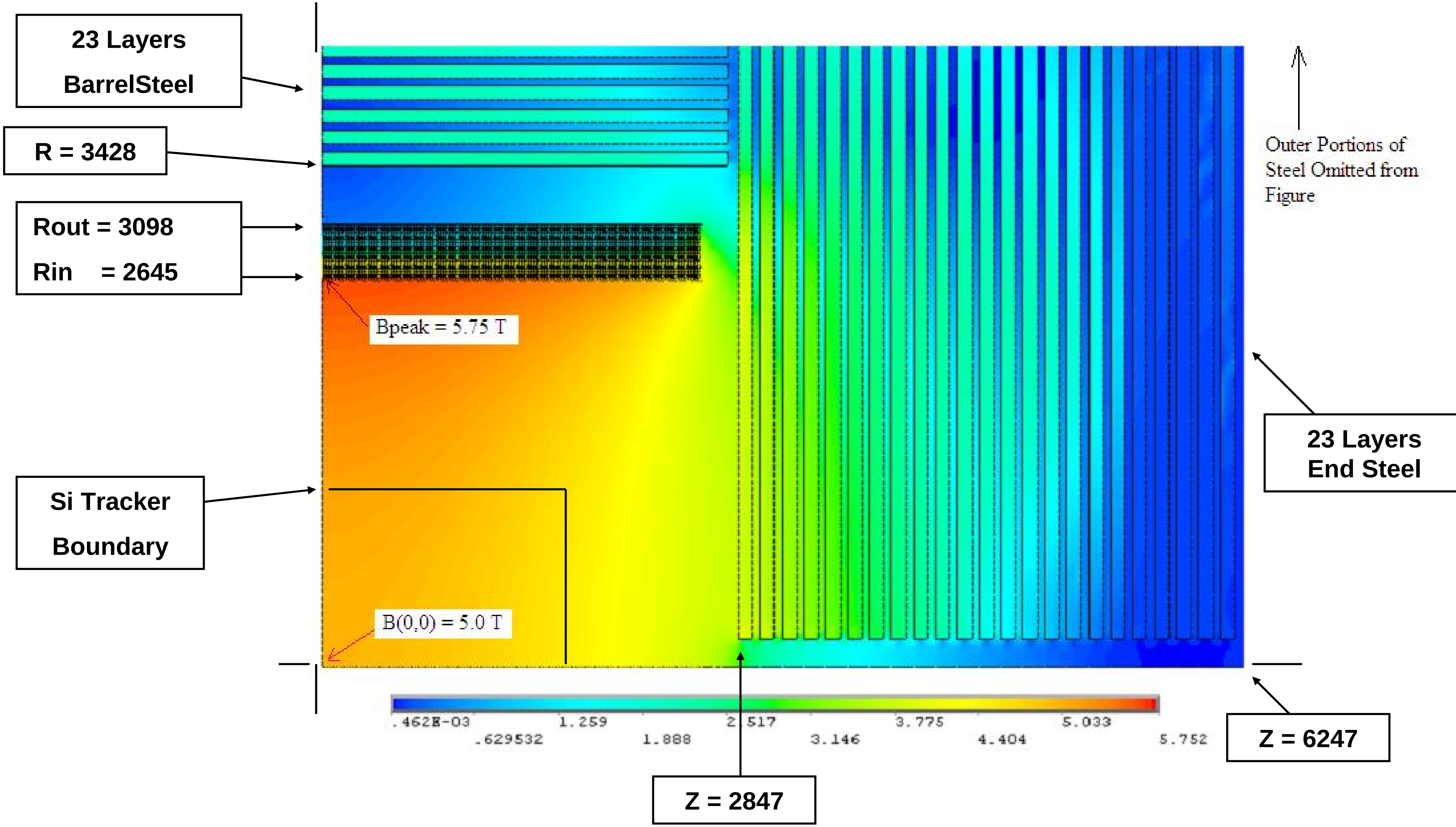


SiD Half-coil 6 layers x116 t/l

Very nice results, experts agree that it pushes technology, but feasible

Solenoid

First ANSYS 2D, 3D Modeling



Goal: Complete feasibility study, build & lead solenoid effort

Next: detector integrated dipole (DID) with BDIR-WG4

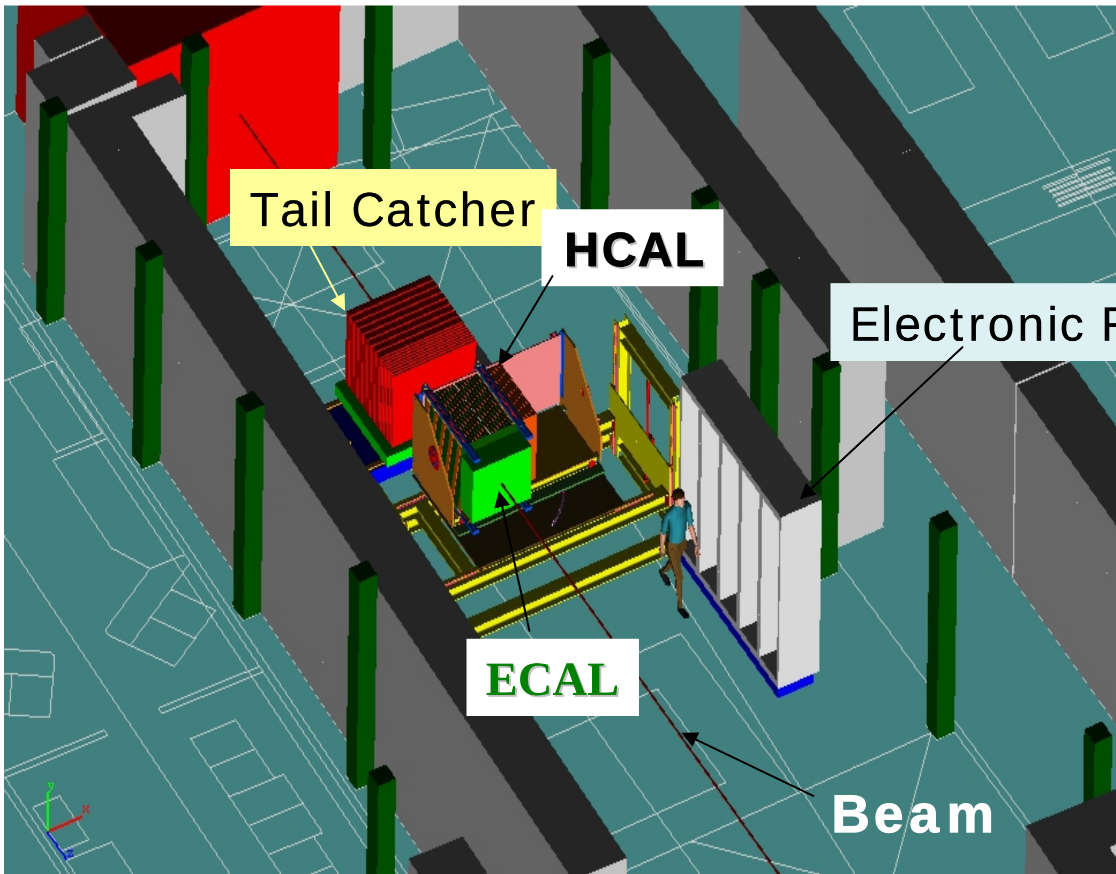
Calorimeter

Proposal to set up multi year testbeam program at Fermilab in MT6 for study of high performance calorimeters for ILC

CALICE collaboration

Program could start Jan 2006

Obvious area for Fermilab involvement



Beam parameters:

- Momentum between 5 and 120 GeV
- protons, pions, muons, electrons
- Resonant extraction
- Variable intensity
- Duty cycle low

A possible program in HCAL

H.Weerts

Areas of interest:

Development of PFA algorithms (all simulation)

- Do we really need 30%/$E^{0.5}$?
- Collaborate with NIU & ANL; already active

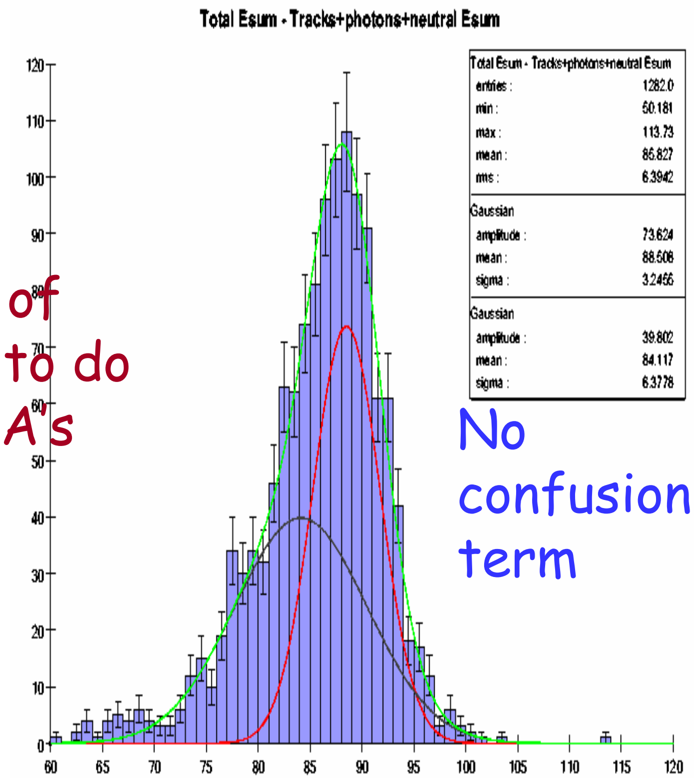
HCAL detector development within CALICE & SiD

- RPC/GEM detectors, using ASIC development as start
- Scintillator tile layout & readout with NIU

Testbeam is an obvious base for collaboration: CALICE

- hardware & software;
- feed results back into GEANT

Ideal PFA
-> W 28%/√E



A lot of work to do on PFA's

No confusion term

Challenging and interesting R&D area;
Group starting it should set direction;
Could be 60% or more simulation

Summary of detector R&D

Main areas of ILC detector R&D concentration at Fermilab:
(no order)

Silicon tracking and vertexing.

Includes everything from pixel development, to detector layout for tracking and vertexing, simulation, algorithm development etc. Not just for ILC.

Solenoid development

Build on work done already and expertise and existing collaboration in CMS. R&D on conductor; work on cryo system.

Muon detector & ID

Collaborate with universities on MINOS type scintillator.
Algorithm development

SiD involvement

Involved in SiD design study together with SLAC & many other institutions.

Hadron calorimetry

PFA development, involvement in CALICE testbeam; build up group that can make substantial contribution; collaborate NIU, ANL, UTA

Note: For next 2 years, THE emphasis is on simulation in all these areas……… need physicists

Conclusions & Summary

ILC R&D @ Fermilab with other institutions

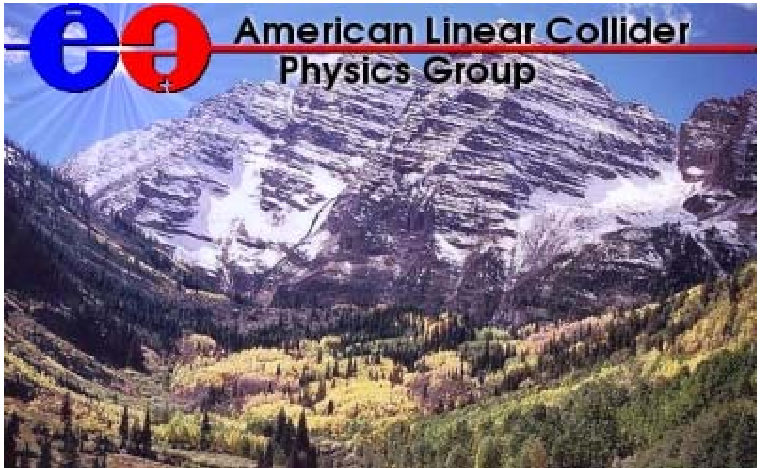
Very active and substantial program ramping up in ILC accelerator R&D

Emphasis on SCRF and structures, but others areas as well

Beginnings of a detector R&D program are in place, slope is positive, increasing interest.

Keep momentum going & increase effort

Next step for all ILC R&D:



ALCPG2005 @ Snowmass
August 14-27, 2005

The End