ILC Calorimeter/Muon Detector Beam Test Program at Fermilab

FNAL PAC, April 7 – 9, 2005
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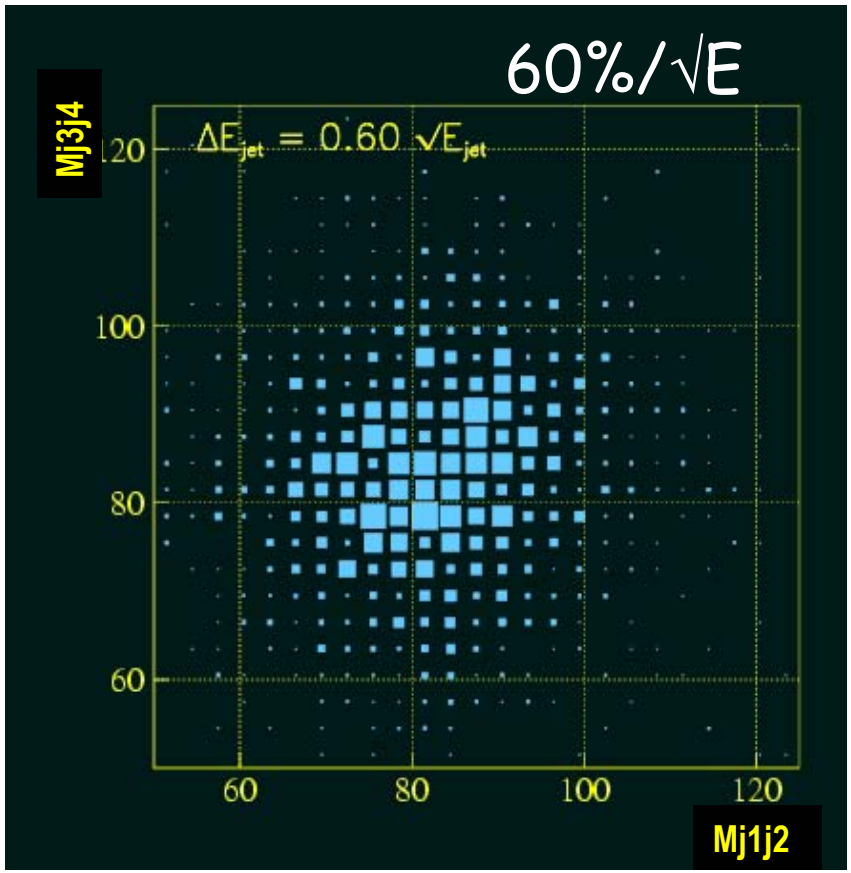
For the ILC TB Working Group

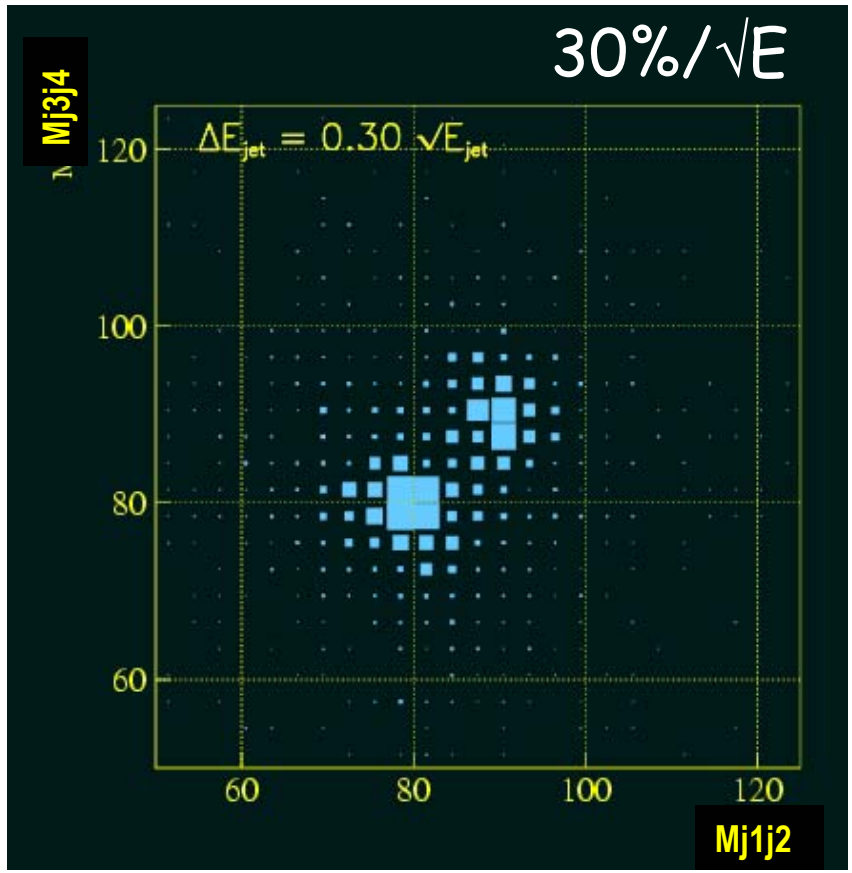
- Introduction
- ILC Beam Test Motivations and Goals
- Detector Technologies for Beam Test
- General Beam Test Plans
- CALICE Collaboration Detectors
- Concerns on Current Facility
- Beam Test Timeline
- Conclusions

Introduction

- International Linear Collider is the next generation machine for precision measurement in high $\sqrt{s}$
- Critical physics measurements
  - Higgs production e.g. $e^+ e^- \rightarrow Zh \rightarrow qqbb$
    - separate from WW, ZZ (in all jet modes)
  - Precision higgs couplings measurements
    - g_{tth} from $e^+ e^- \rightarrow tth \rightarrow WWbbbb \rightarrow qqqqbbbb$
    - g_{hhh} from $e^+ e^- \rightarrow Zhh \rightarrow qqbbbb$
  - Higgs branching ratios $h \rightarrow bb$, WW^*, cc, gg, $\tau\tau$
  - etc
- All of these physics goals demand
  - Efficient jet separation and reconstruction
  - Excellent jet energy resolution
  - Excellent jet-jet mass resolution

Can Traditional Calorimeter Meet the Requirements?





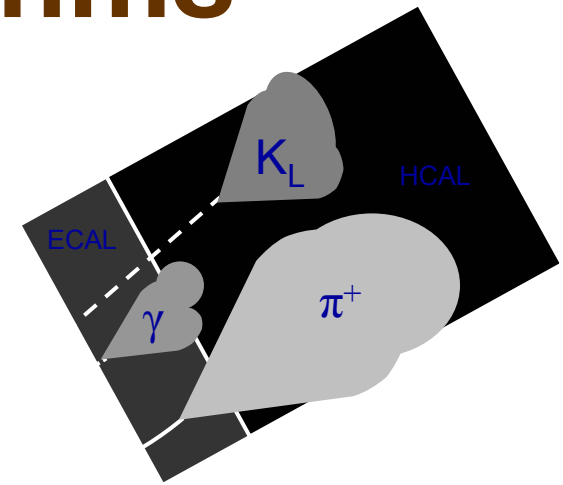
Traditional Calorimeter Systems

- Equalized EM and HAD responses ("compensation")
- Jets are measured through calorimeter alone
  - $E_{jet} = \sum E_{ECAL} + \sum E_{HCAL}$
- Optimized sampling fractions
  - ZEUS – Uranium /Scintillator
    - Single hadrons 35%/√E ⊕ 1%
    - Electrons 17%/√E ⊕ 1%
    - Jets 50%/√E
  - DØ – Uranium/Liquid Argon
    - Single hadrons 50%/√E ⊕ 4%
    - Jets 80%/√E
- Significant improvement is needed for LC
- New approach is necessary to meet the requirement

Particle Flow Algorithms

The idea…

Charged particles	measured with the	**Tracker**
Neutral particles		**Calorimeter**



$$E_{jet} = \sum_{\substack{Charged\\Particles}} P_{TRK} + \sum_{\substack{EM\\particles}} E_{ECAL} + \sum_{\substack{Neutral\\Hadrons}} E_{HCAL}$$

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion	Required for 30%/√E		**$\leq 0.24^2\ E_{jet}$**

} 18%/√E

Requirements on detector

→ Need excellent tracker and high B – field

→ Large R_I of calorimeter

→ Calorimeter inside coil

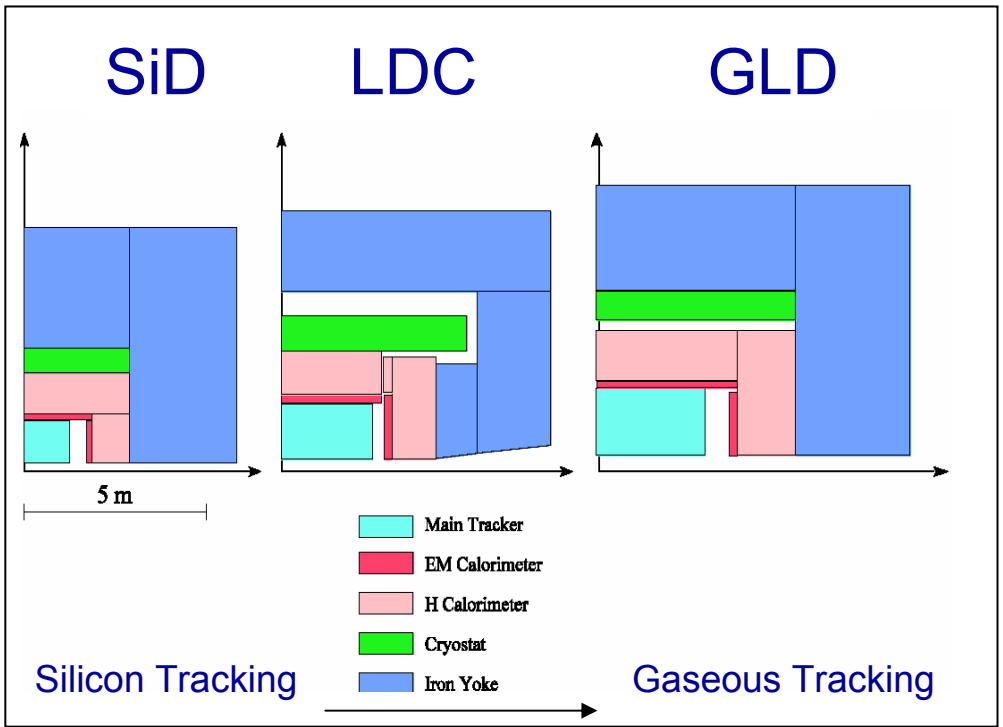
→ Calorimeter with extremely fine segmentation

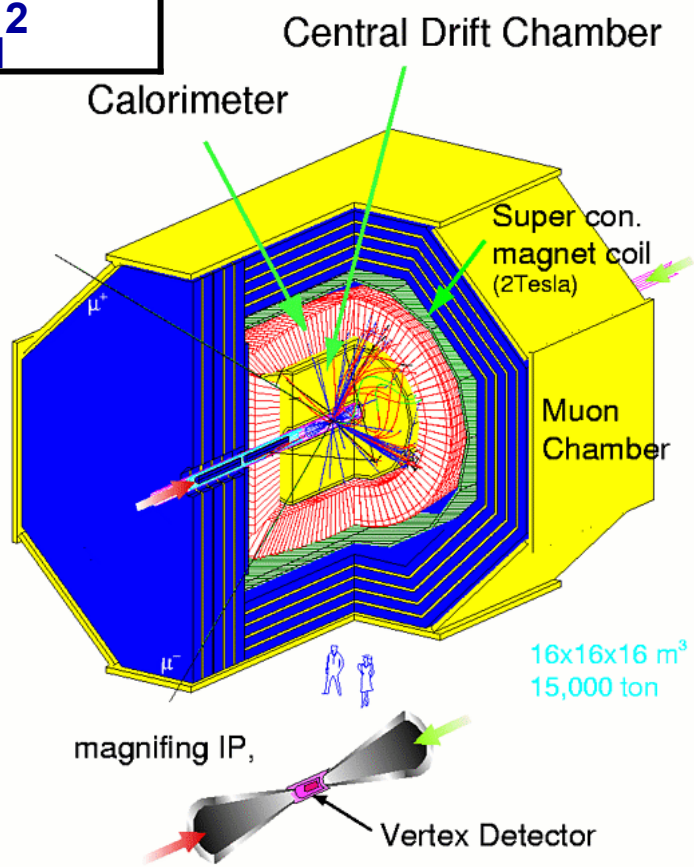
Figure of merit BR_I^2

ILC Detector Concepts

Identical concepts
Different dimensions
Different technologies

Design study	Centered in	Figure of merit
Silicon Detector Design	N America	$\mathbf{B}\cdot R_I^2$
Large Detector Concept	Europe	$B\cdot R_I^2$
Large/Huge Detector	Asia	$B\cdot \mathbf{R_I^2}$



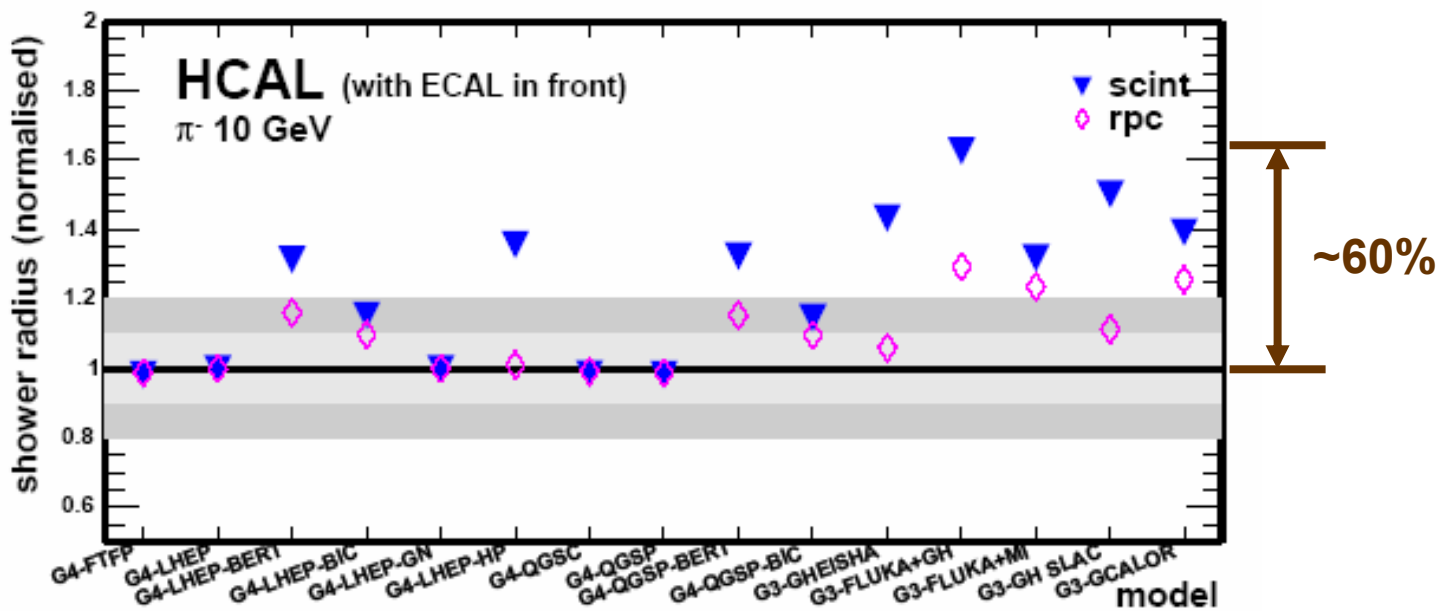


Motivations for ILC Beam Tests

- Detector R&D activities maturing rapidly
  - Many of them need beyond-the-prototype-and-cosmic-ray testing
- Integrated detector concepts being developed
  - Suitable technology choice necessary
  - Measure performances
- Expeditious development of PFA necessary
  - Suitable simulation tools are critical
- ILC Community has made a few critical decisions
  - Choice of accelerator technology
  - Accelerator TDR timeline puts urgency on detector R&D

ILC Beam Test Goals

- Detector performance measurement – Phase I
  - Necessary to choose good detector technologies that meets the requirements optimized for PFA
- Better simulation tools for more sophisticated PFA development
  - Hadronic shower needs better understanding



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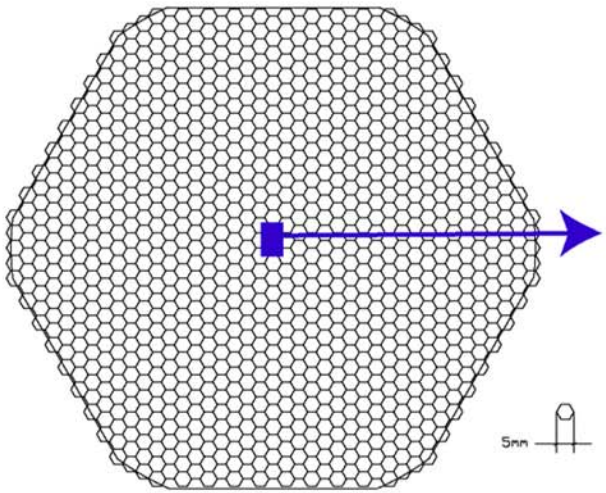
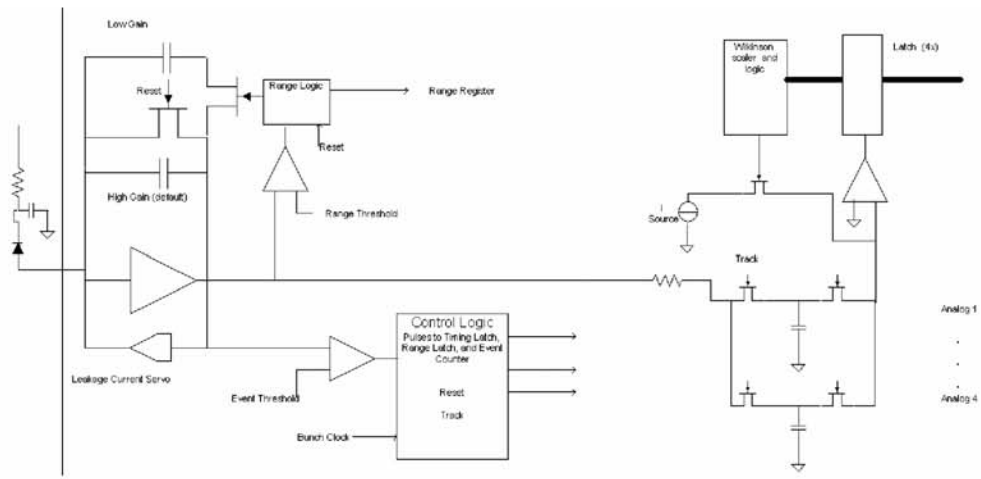
Detector Technologies - ECAL

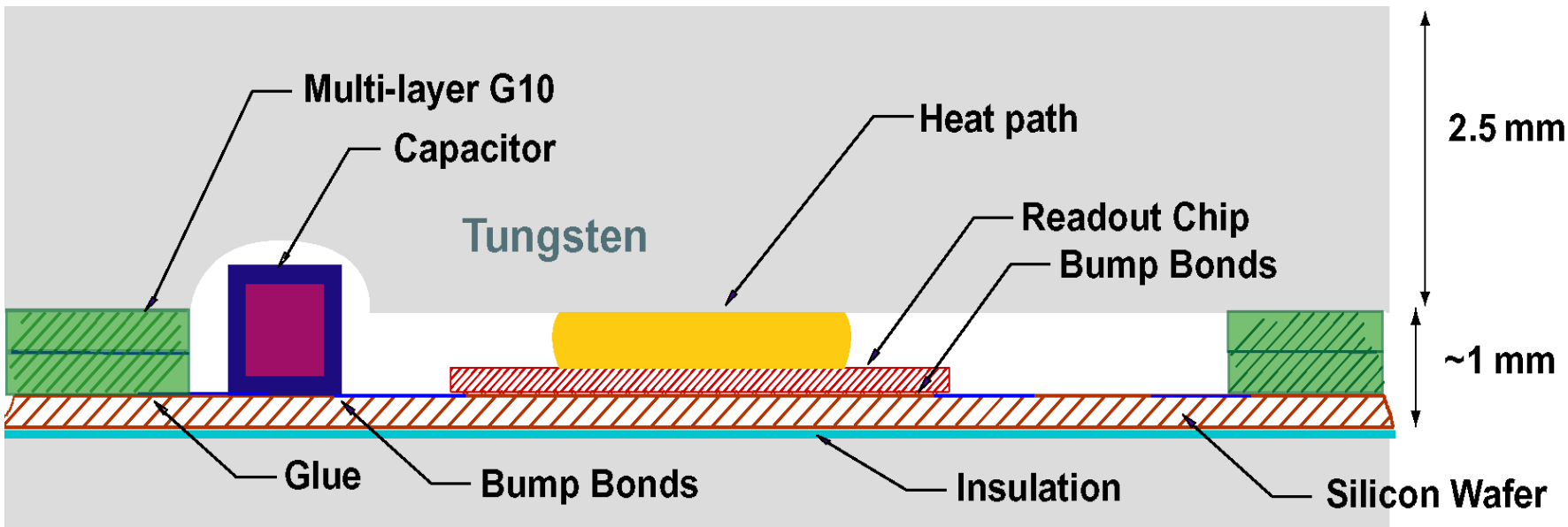
- Compact EM shower for high resolvability
  - High density, short X_0 material: Tungsten
  - Thin layers to keep shower from spreading
    - Silicon in the sensitive gap w/ embedded FE
- Major efforts in Si-W ECAL development
  - US: Oregon, SLAC and BNL
    - Sensitive gap with integrated readout being developed (~1mm thin)
    - **Funding for beam test requested through NSF–MRI**
  - EU: CALICE-EU Collaboration ECAL
    - Performed an electronic TB run at DESY in Jan – Feb. 2005
      - Took a total of $2*10^7$ events in 6 weeks
  - Asia: Ehwa University
    - Performed a test module run at CERN late 2004
- Other technologies
  - Scintillator-W: Colorado (US) and Shinshu (Japan)
  - Scintillator-Si-W hybrid: KU (US) and Padova (Italy)
    - Padova (LC-CAL) module has been tested at CERN in 2003

Oregon-SLAC-BNL (OSB) Si-W ECAL





Si Waffer w/ ~ 1k 1x1cm^2 pixels



Detector Technologies - HCAL

- All HCAL groups are working in CALICE collaboration
- High granularity for higher shower resolving power
- Two readout technologies being looked into
  - Analog: Scintillator-Steel, CALICE-AHCAL
    - Varying tile sizes to 3x3 cm^2 the finest to explore possible digital options
    - Uses SiPM for readout
    - Test beam module construction to complete by the end of 2005
  - Digital: RPC-Steel (ANL, etc) and GEM-Steel (UTA, etc)
    - $1m^3$ module with Anode pad sizes of $1x1cm^2$
    - Basic R&D for RPC and most for GEM complete
    - ASIC being jointed developed with Fermilab
    - **Funding for beam test requested through NSF–MRI**
- Tail Catcher – Muon Chamber construction to complete by the end of 2005
  - Joint effort between NIU, Fermilab and DESY

Total of 12 Projects

Calorimeter		Project	Lead institution
ECAL	1	Silicon-Tungsten (CALICE)	LLR
	3	Silicon-Tungsten (US)	SLAC, Oregon
	2	Silicon-Tungsten (Asia)	Ehwa Univ., Korea
	2	Scintillator-Tungsten	Shinshu
		Scintillator-Tungsten	Colorado
		Scintillator-Silicon-Tungsten	Kansas
		Scintillator-Silicon-Lead	Padova
HCAL	1	Scintillator-Steel (CALICE)	DESY
	2	RPC-Steel (CALICE)	ITEP, ANL
	3	GEM-Steel (CALICE)	UTA
Muon-detectors/tail catch	1	Scintillator-Steel (CALICE)	NIU/DESY/FNAL
	2	Scintillator-Steel	FNAL/UCD/IU/NIU / Notre Dame
	3	RPC-Steel	Frascati

29 institutions from 3 regions

General Plans for ECAL

- Small and easily transportable
- Large fraction of “standalone” tests can be performed at DESY or SLAC
  - CALICE–ECAL: Construction to complete in Fall 2005
    - Use DESY positron beam in 1 – 6 GeV range for
      - Electronics commissioning
      - “Standalone” performance testing
    - Transport to Fermilab late 2005 or early 2006
      - Depending on Tevatron shutdown progress
  - OSB ECAL: Ready for beam by mid 2007
    - Use SLAC electron beam in 1 – 25 GeV for
      - Electronics commissioning
      - “Standalone” performance testing
  - Ehwa ECAL: Ready for beam sometime in 2007
  - Shinshu Scintillator-Tungsten ECAL: Late 2006

General Plans for ECAL

- Use overlapping energy regions of Fermilab electron beams to cross calibrate the detector
- Perform combined testing with the available HCAL for integrated performance testing
- Participate in hadronic shower runs
- Perform regular calibration runs w/ beam

General Plans for HCAL

- Use cosmic ray for initial calibration
- CALICE collaboration constructing
  - Mechanical support to hold the integrated ECAL and HCAL structures
    - A joint effort between ME to make the structure fit to Fermilab safety and other requirements started
  - 1x1x1 m^3 Hanging file style absorber plate structure (40 layers)
    - For three different sensitive gap technologies to be tested w/ one common absorber
  - Transport the mechanical structure to Fermilab late 2005 or early 2006
  - Standalone testing w/ hadron beams followed by angle and energy scans
- Scintillator-steel in early to mid-2006 followed by RPC (mid-2007) and GEM (late 2007) digital

General Plans for HCAL

- Standalone performance runs
- Incident angle scans: 3 angles at minimum 3 ~ 4 energy points
- Muon Responses: Momentum tagged 3 – 20 GeV muons for detection efficiency measurements and calibration
- Energy scan/hadronic shower behavior runs w/ pions and protons in both polarities
  - 1~2 – 66GeV for pions + protons
  - Also utilize 120 GeV protons

CAlorimeter for the **LI**near **C**ollider with **E**lectrons

CALICE Collaboration: http://polywww.in2p3.fr/flc/calice.html

170 Physicists from **27** Institutes in **8** Countries in **3** Regions

Germany DESY , Univ. Hamburg

Korea Kangnung NU. , Seoul NU. EESC,
In progress to join *Ewha U. , SNU-physics Dept*

France LAL-Orsay, LLR-X, PICM-X, LPC-Ct ,
LAPP-Annecy , LPSC-Grenoble within the next month

Czech rep. Univ. Charles-Prague, IOP-ASCR

Russia ITEP, IHEP-Protvino, LPI, Univ. Moscow, MEPHI,

UK Birmingham, Cambridge, Imperial Coll, Manchester, UCL, RHUL, RAL
Edinburgh in discussion

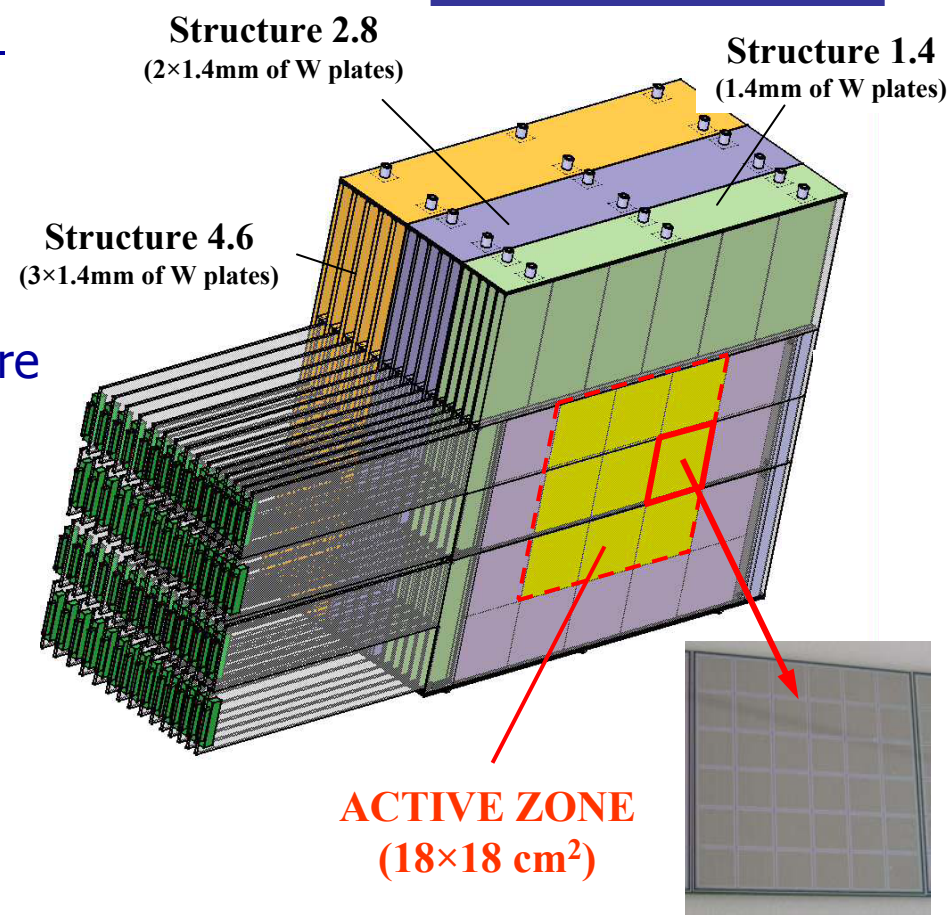
USA ANL, UT Arlington, NIU, U. of Iowa

CALICE ECAL

Design and Prod : LLR
Integration : LLR

Multi-layer (30) W-Si Prototype :

- 3 independent C-W alveolar structures according to the thickness of tungsten plates (1.4, 2.8 and 4.2 mm)
- 30 detector slabs which are slid into central and bottom cells of each structure
- Active zone : 3×3 wafers × 30 layers



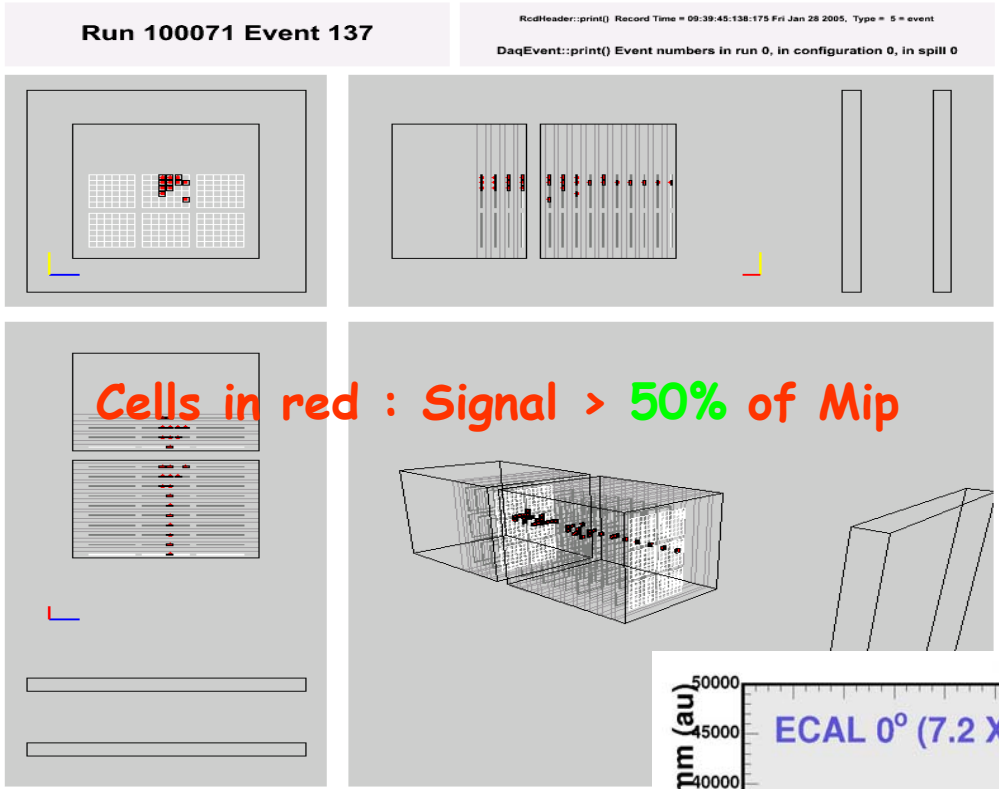
270 Wafers Si with 6×6 pads (10×10 mm²)

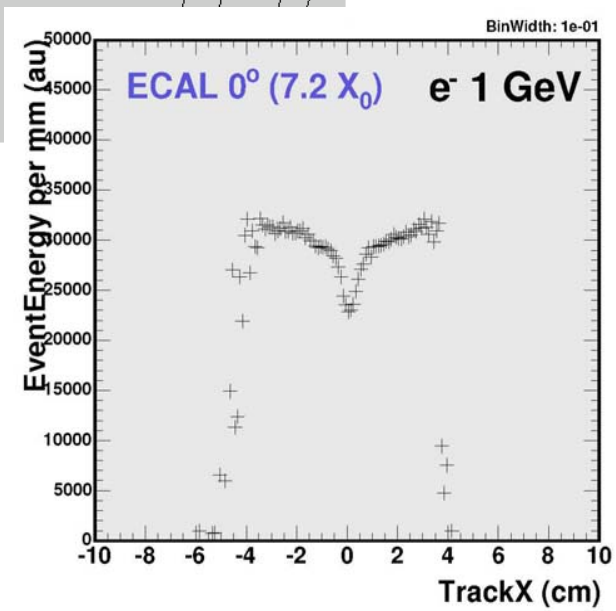
- 3 structures W-CFi (1,2,3 x1.4mm)
- 30 detector slabs
- Dimension 200x180x180 mm

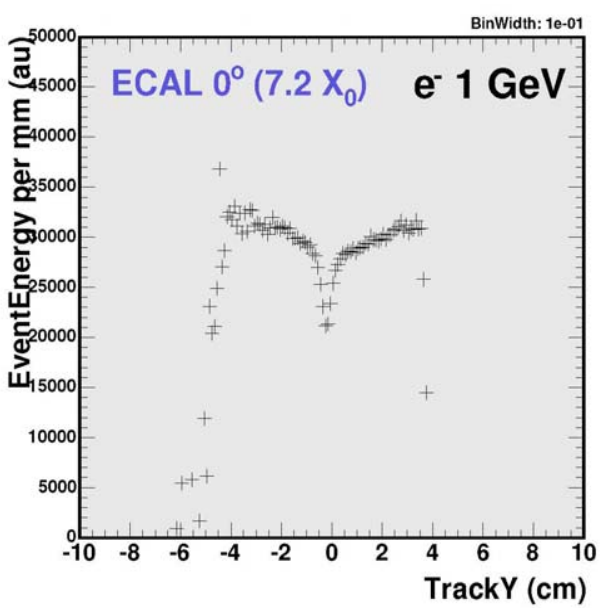
➔ **9720 channels in the proto.**

Prod : 150 MSU (Russia)
150 IOP (Czech republic)

CALICE ECAL TB at DESY

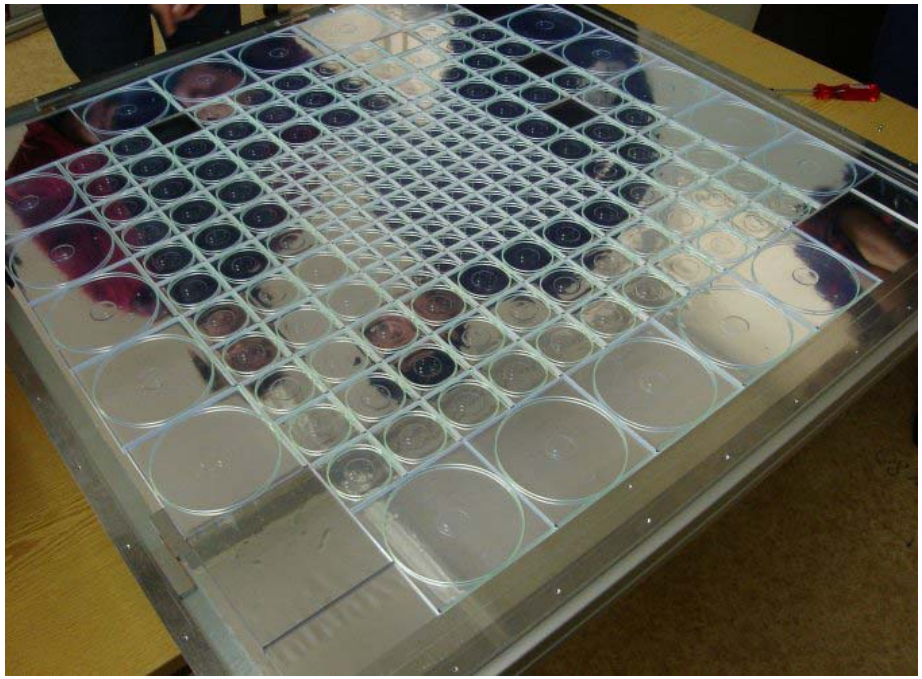


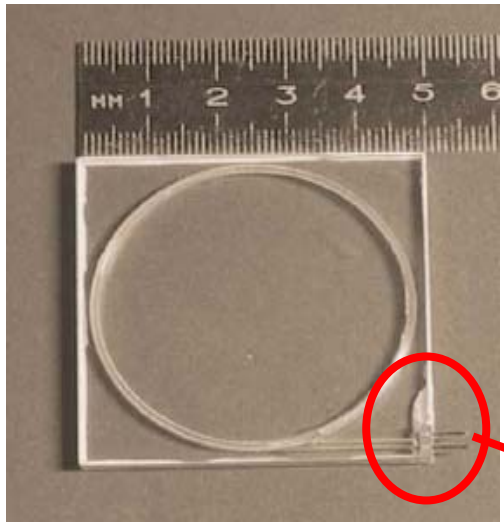




Position Scan

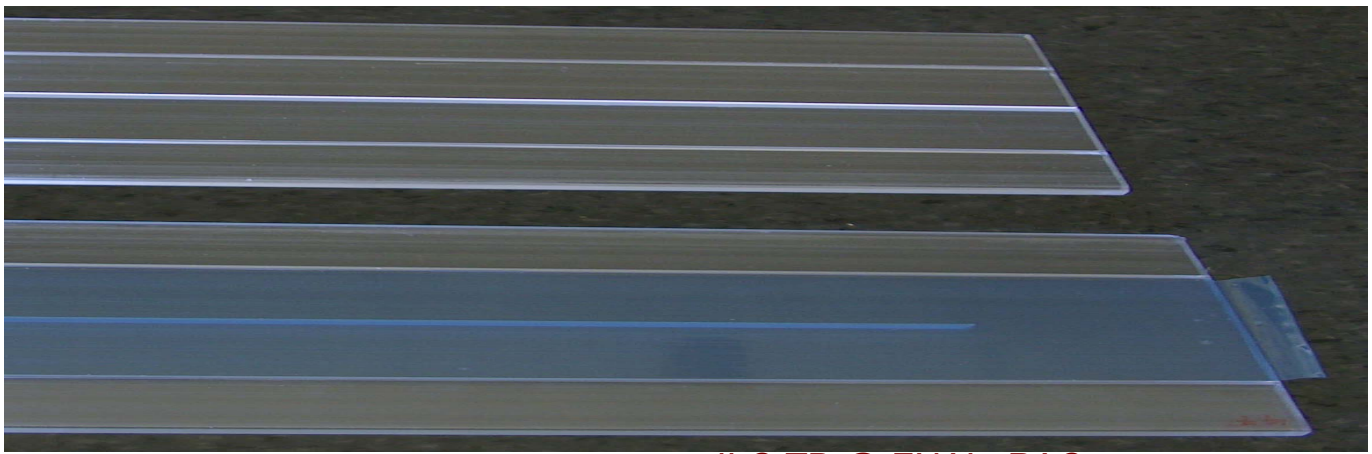
CALICE AHCAL & TCMT





- AHCAL-Scintillator tiles w/ SiPM
- 40 layers in 1m^3 module

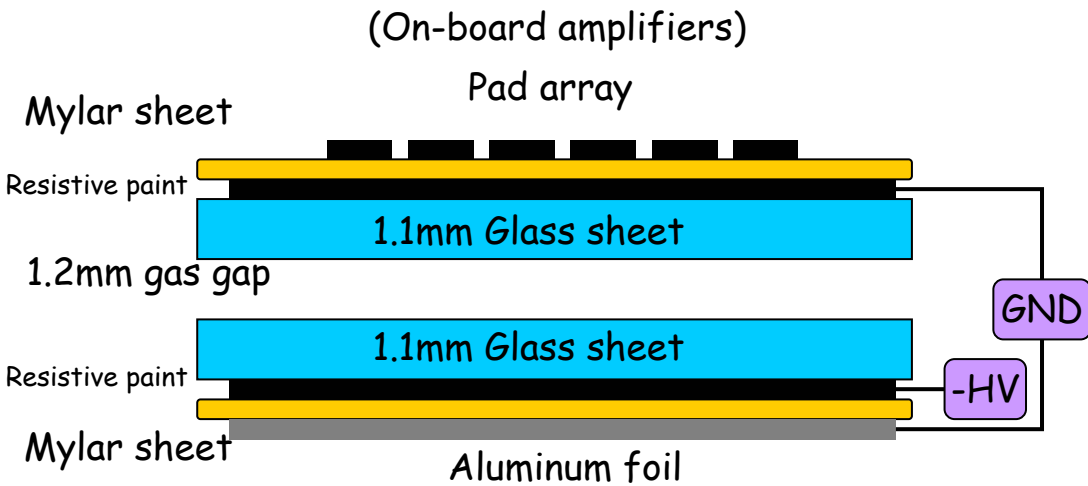
Si PM

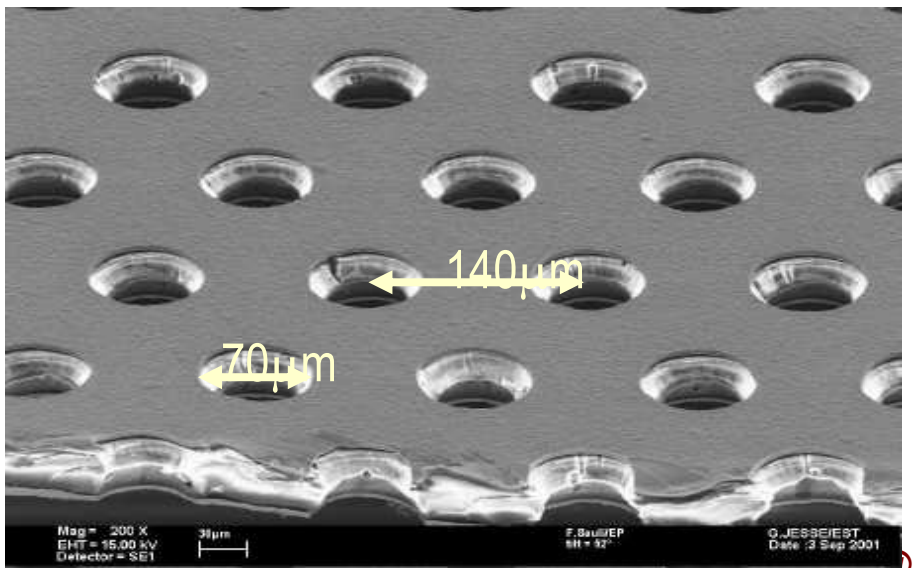


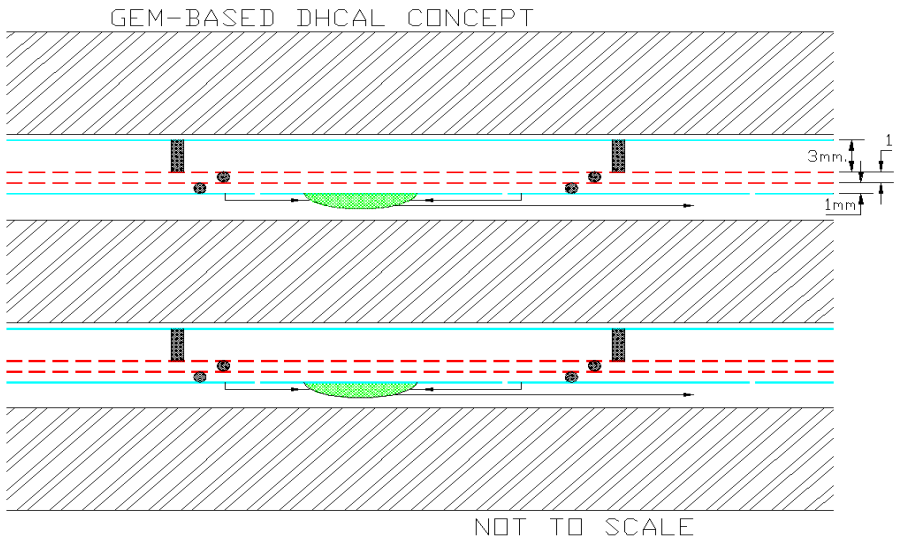
TCMT-Extruded Scintillators w/ SiPM

CALICE DHCALs

- Construct sensitive gap chambers using RPCs and GEM detectors
- Slide them into hanging file absorber structure
- ASICs being developed jointly with FNAL



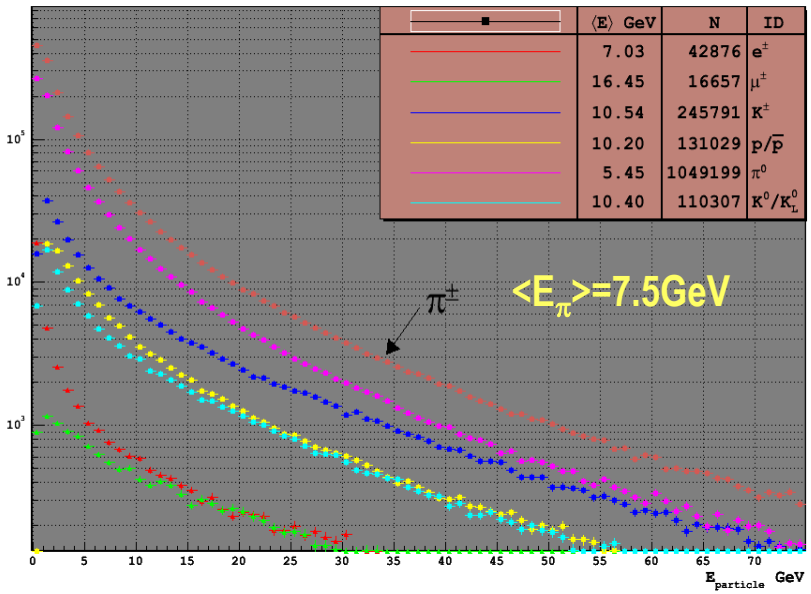


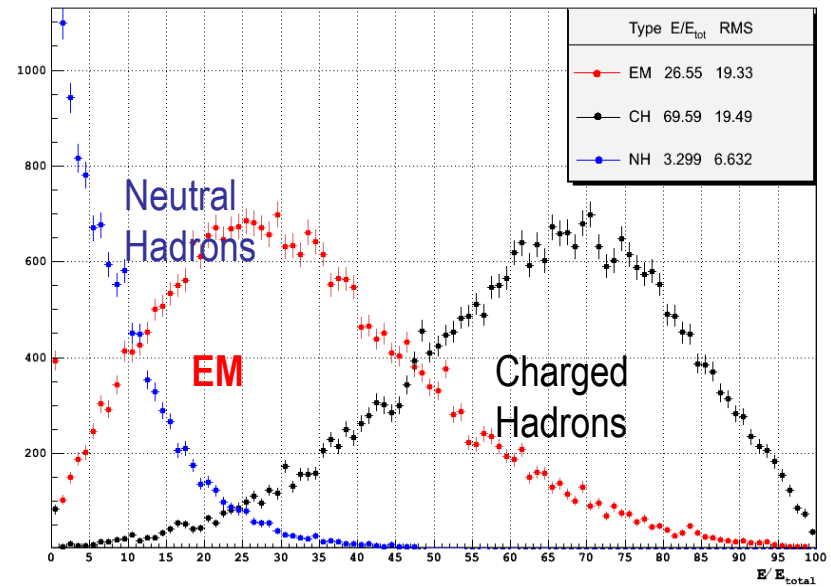


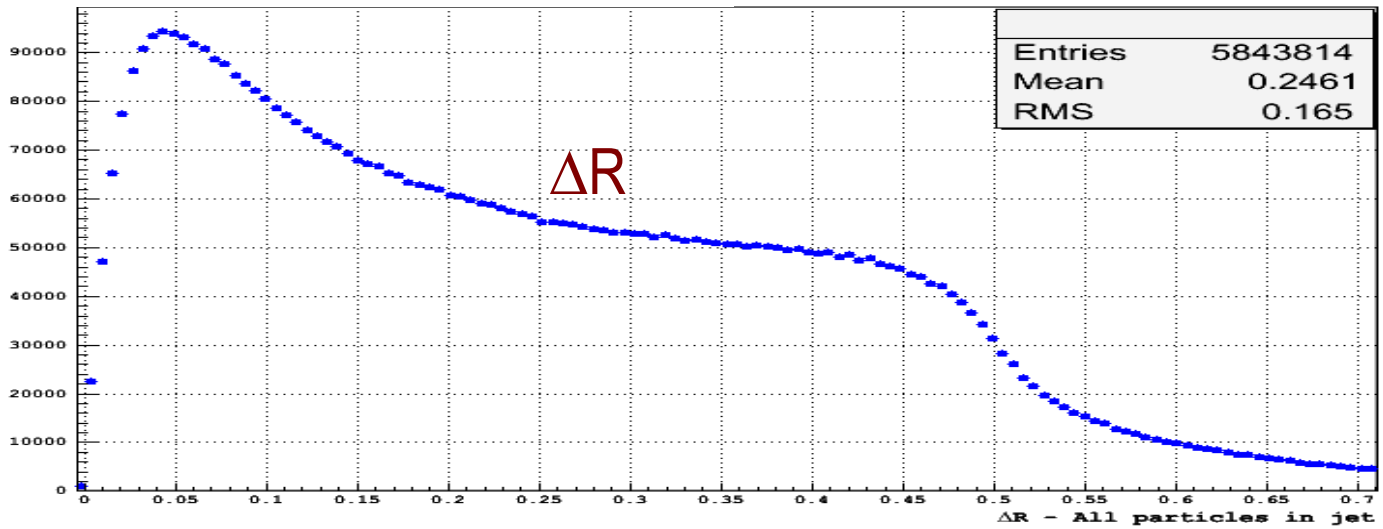
Total Number of Channels in CALICE

- CALICE ECAL
  - ~10k readout channels
- CALICE HCALs
  - AHCAL: 8 ~ 9k analog readout
  - RPC and GEM DHCAL: 400k digital readout
- CALICE TCMT
  - Total of 0.5k analog readout
- Total number of channels span
  - ~25k to 0.5M
  - Recall D0 Run I had some 100k readout

Particle Properties in a jet







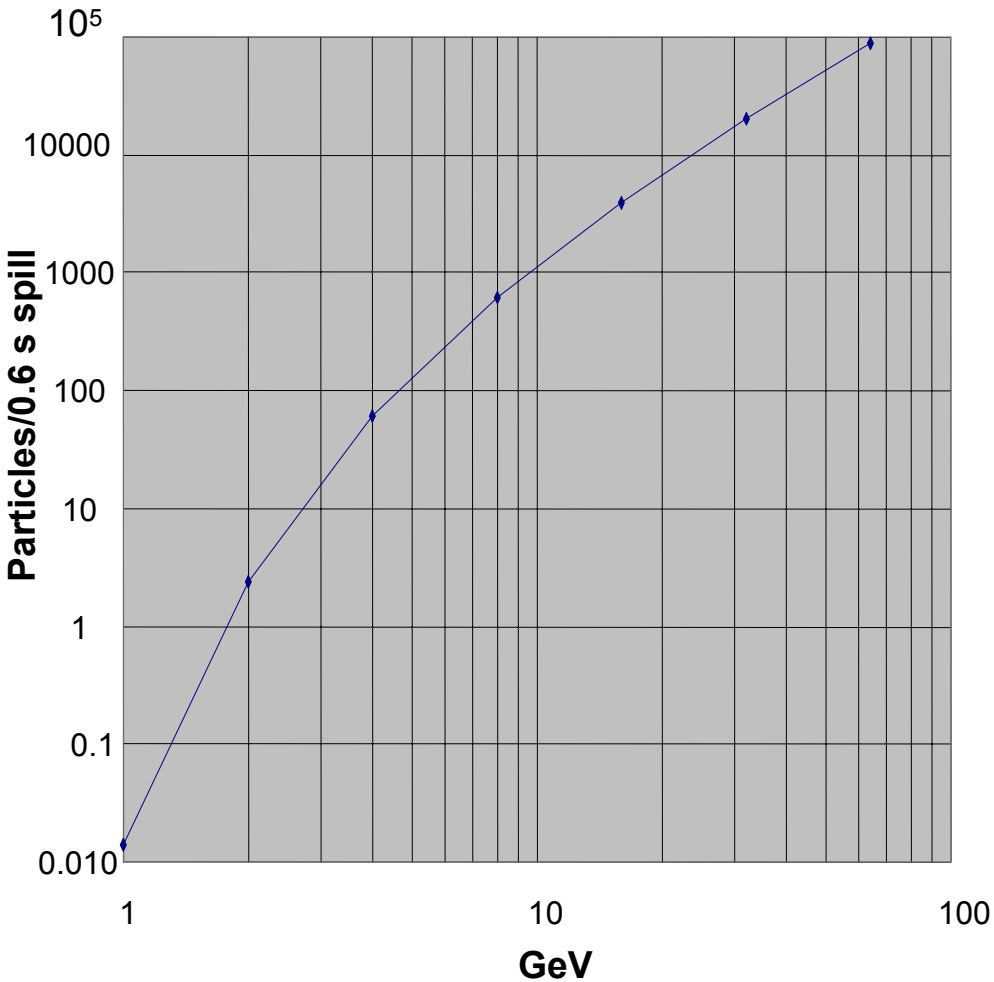
Beam Requirements

Particle	Energy range
Electrons	3 – 20 GeV → 3 – 25 GeV
Pions	3 – 66 GeV → 1~2 – 66 GeV
Protons	3 – 66 GeV, 120 GeV
Muons	3 – 20 GeV, momentum selected
Muons	Not momentum selected

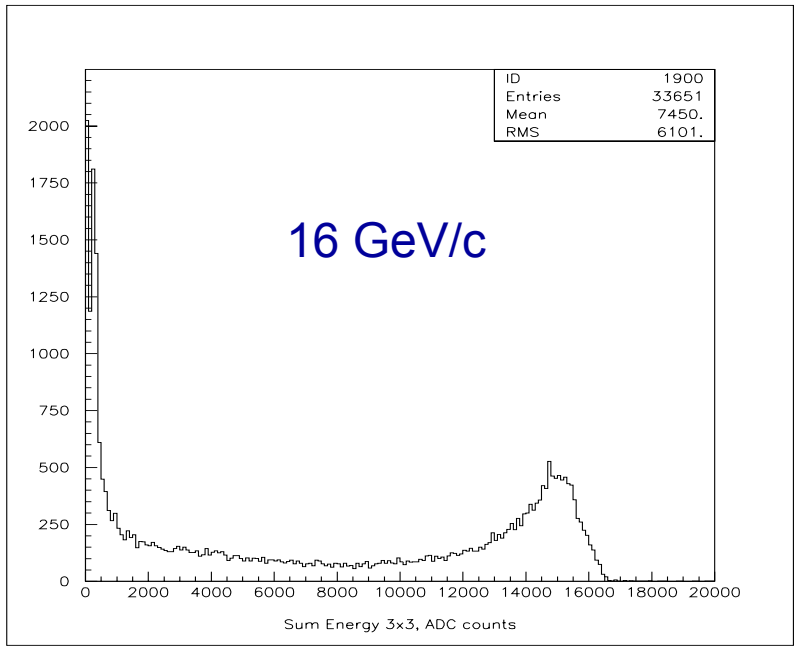
Both polarities
Momentum bite less than ½ the detector resolution (1.5 ~ 4%)
Rates in part not to exceed 2000 event for non-RPC and 100 Hz for RPC

Beam Rates at MTBF

Pion flux as a function of energy



Electron purity and rate



E_e	Purity (%)	N_e/ 0.6s spill
4	25	10 – 20
8	10	~40
16	2	~90

Example CALICE Run Table for RPC

Run type	particles	Momenta (GeV/c)	targeted stat. prec.	Nevt (k events)	Beam Rate (4 s flattop)	Max Det rates (Hz)	Ndays
Energy Scan	Electrons	4	1%	100	100	100	1.4
		7.5	1%	300	267	100	1.6
		10	1%	100	400	100	0.3
		15	1%	100	600	100	0.3
		20	1%	300	600	100	1
		25	1%	100	600	100	0.3
	Hadrons	3	1%	3000	133	100	31.3
		5	1%	1000	1000	100	3.5
		7.5	1%	3000	>2k	100	10.4
		10	1%	1000	>2k	100	3.5
		15	1%	1000	>2k	100	3.5
		20	1%	3000	>2k	100	10.4
		30	1%	1000	>2k	100	3.5
		45	1%	1000	>2k	100	3.5
		60	1%	3000	>2k	100	10.4
		120	1%	1000	>2k	100	3.5

Beam rate is scaled up to 4s from the number of particles in 0.6 s spills.

Anticipated Duration of Data Taking

- CALICE ECAL
  - Commissioning w/ beam 2 weeks
  - Cross calibration of electron energy points at minimum two low energy to provide good overlap regions
    - Need ~20k events for each of two energy points
    - 3~4GeV seems reasonable: expect about 75/spill every 2 min in the current 4s flattop structure
      - Takes 200spills * 2min =400 min or ~7 hours for 20k events/ energy point ➔ 14 hours for two energy points
  - CALICE ECAL electron Energy scan: Targeted stat. precision 1% puts the total number of days for electrons runs at ~5*3=~15 days for all CALICE combinations

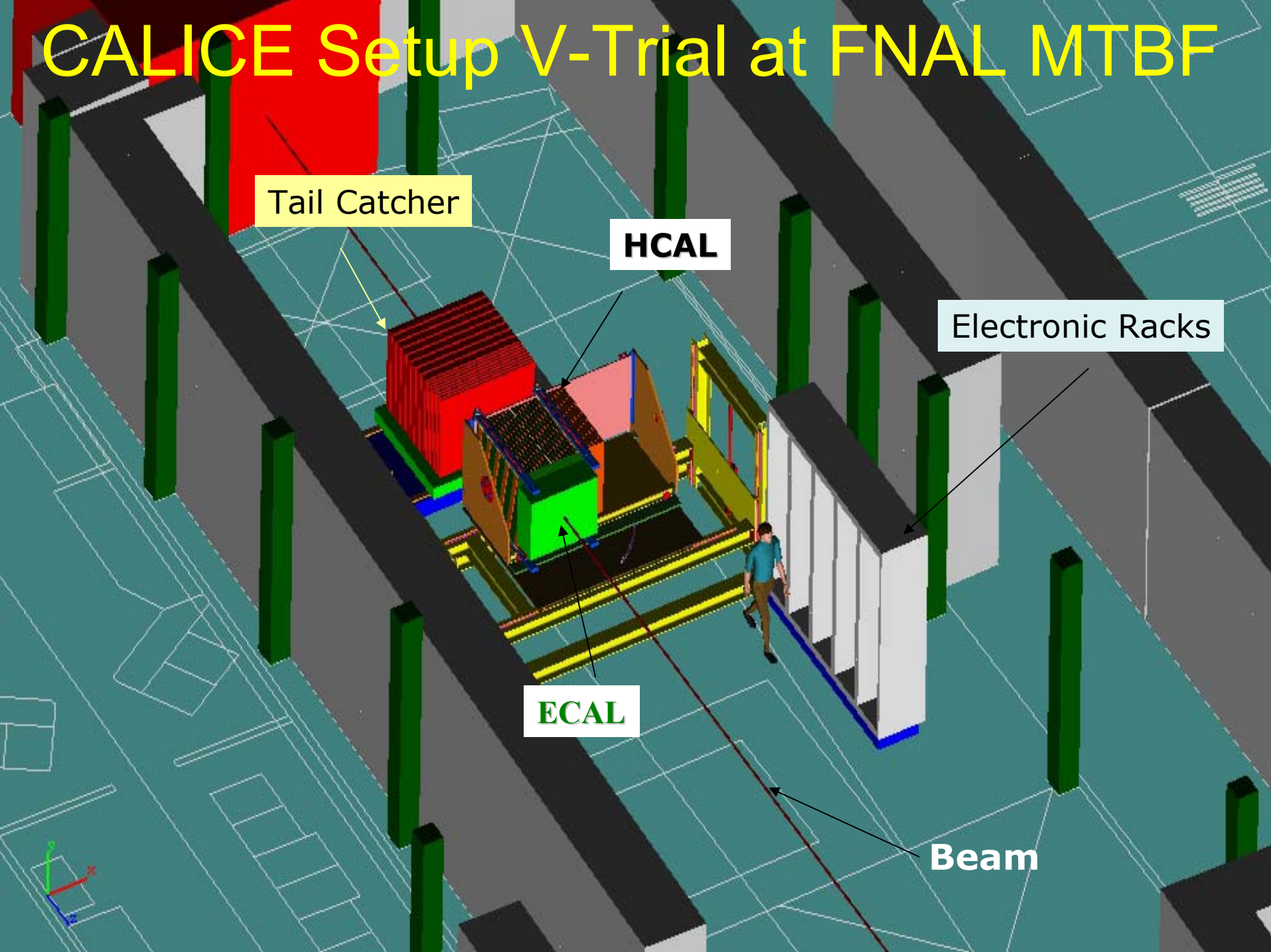
Anticipated Duration of Data Taking

- HCAL – Hadron energy scan and shower behavior runs
  - Commissioning w/ Beam: 2 weeks along with ECAL
  - Statistical precision at 1% for shower tails, requiring large number of events through the entire energy ranges
    - Hadron energy scans are used also for hadronic shower behavior runs
    - Takes 41, 41 and 84 days for Scintillator, GEM and RPC HCAL combination w/ ECAL, per each charge at 100% up time➔166 days*2 for all three CALICE setups for all charges
- Total for CALICE: ~ 360 days assuming 100% up time

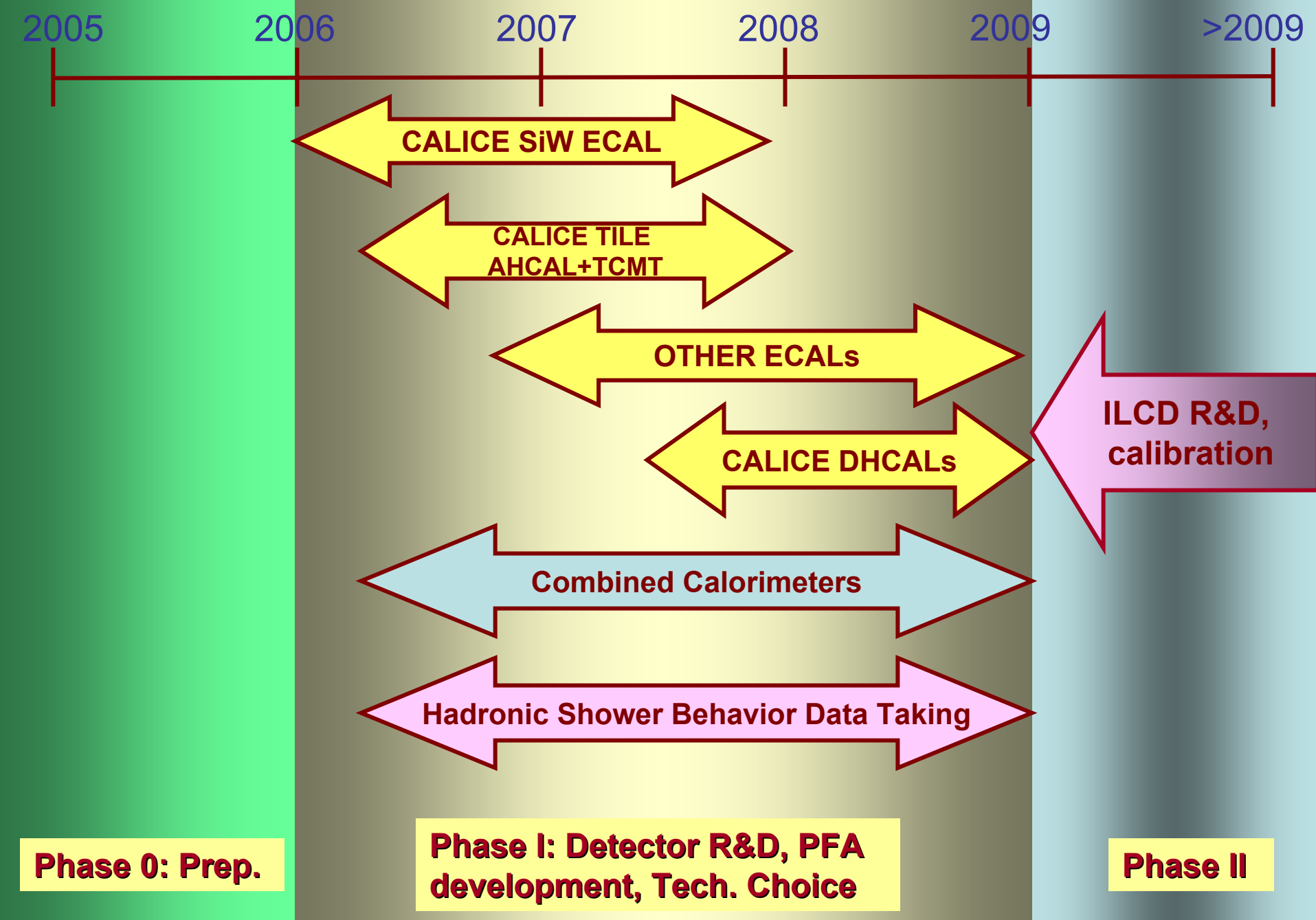
Concerns on Current Facility

- Spill structure of one 4 sec flattop every two minute not ideal (<5% duty cycle)
- MTB Facility
  - Small space w/ inclined beam
  - Rates in low energy hadron beams too low
  - Electron beam purity and rate too low
  - Can use more beam optimization
- Desire to have improvements for an optimization
  - ILC TB beam tests can start in late 2005 or early 2006 with what is available at MTBF
    - **CALICE ECAL, AHCAL and TCMT will be the first**
  - A new beam line w/ better rates and larger space in mid to late 2006?
- Beam time structure that mimics ILC desired

CALICE Setup V-Trial at FNAL MTBF



Timeline of ILC Beam Tests at FNAL



Conclusions

- ILC Accelerator and Detector R&D picking up momentum
- Large scale, long term detector test beam needed
  - The first beam test modules by CALICE collaboration expected by late 2005/early 2006
  - Will be followed by a few years of beam tests for other technologies and for understanding hadronic shower behavior for PFA
- An important step forward for ILC detector development and for the future of Fermilab
  - Fermilab has virtually the only possibility of dedicated TB Facility
- A new, more ideal, dedicated beam line along with an optimal spill structure would be of tremendous help
- Strong participation by Fermilab colleagues in this exciting endeavor would be critical