Calorimeter Test Beam Requirements for ILC Detectors

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With thanks to:

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Paul Dauncey, John Hauptman, Marcel Reinhard,…

for helpful thoughts, comments etc.

…and apologies to those I did not talk to…

Outline

A series of questions:

- What tests have been made so far – some examples of results

- What do we need to test next?

- What test beam facilities do we have?

- What extra facilities do we need?

- When might we need them?

- How far do we need to go in tuning our simulations to match test beam data?

What tests have been made so far - some examples of results

Overview of ILC Calorimeter development

1) Electromagnetic calorimetry

- CALICE Si-W
- CALICE Scintillator –W
- Oregon-SLAC-BNL Si-W
- CALICE MAPS DECAL

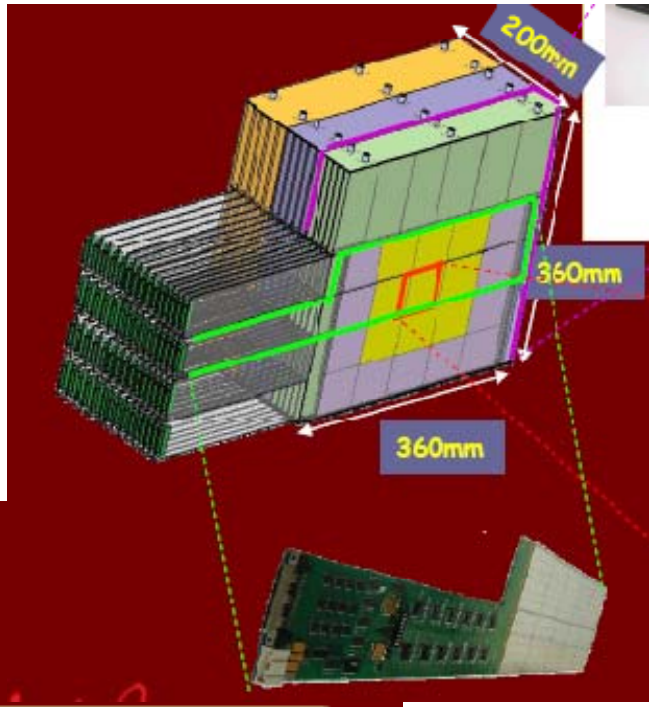
2) Hadron calorimetry

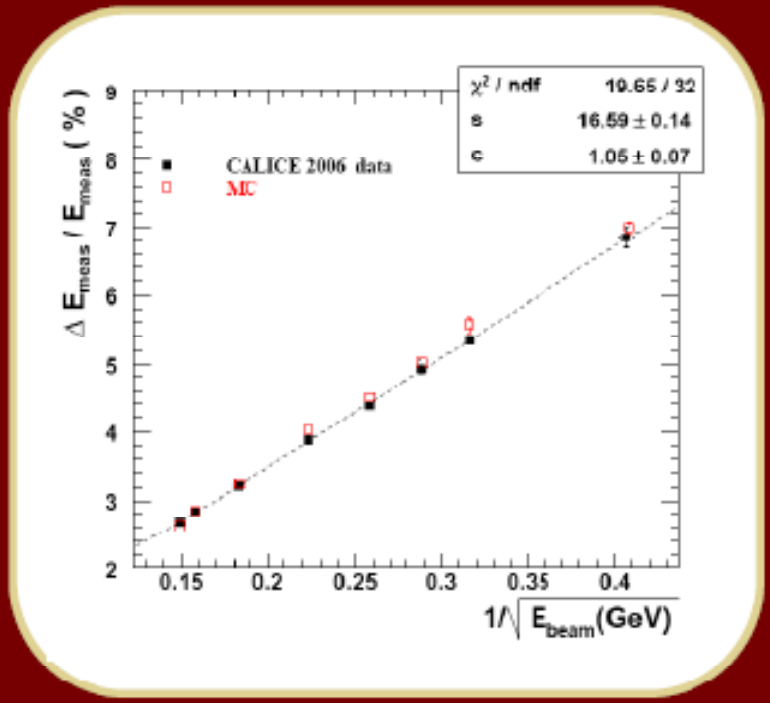
- CALICE Scintillator-Steel AHCAL
- CALICE RPC-Steel DHCAL U.S.
- CALICE RPC-Steel DHCAL Europe
- CALICE GEM-Steel DHCAL
- CALICE Micromegas-Steel DHCAL

3) Dual readout – ECal + HCal

Example: CALICE test beams at DESY, CERN

(1) Si-W ECal 2006/7



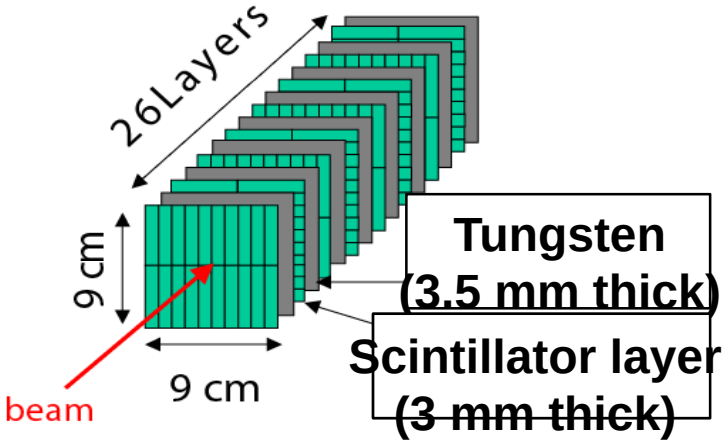


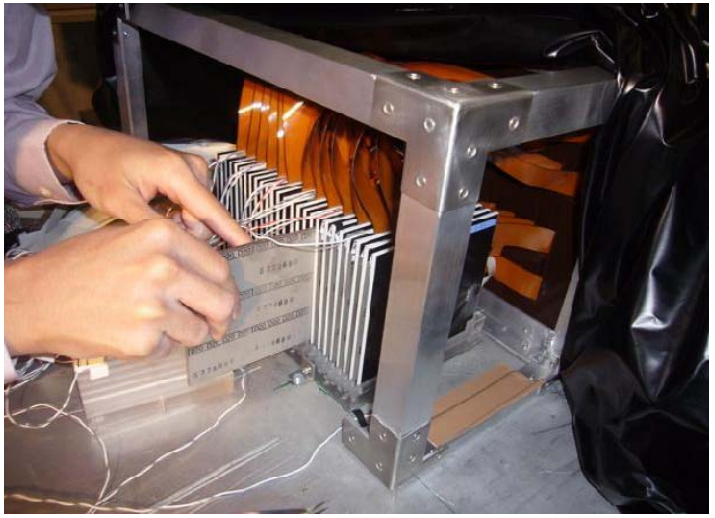
$$\frac{\Delta E_{meas}}{E_{meas}} = \left(\frac{16.6 \pm 0.1}{\sqrt{E(GeV)}} \oplus 1.1 \pm 0.1 \right) \%$$

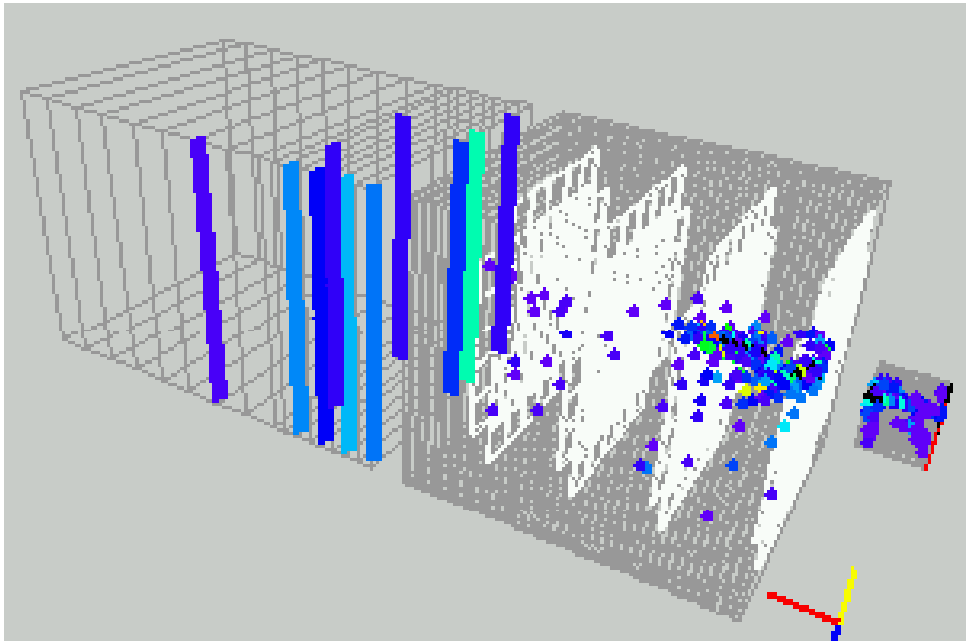
$$\frac{\Delta E_{meas}}{E_{meas}} = \left(\frac{17.3 \pm 0.1}{\sqrt{E(GeV)}} \oplus 0.5 \pm 0.1 \right) \%$$

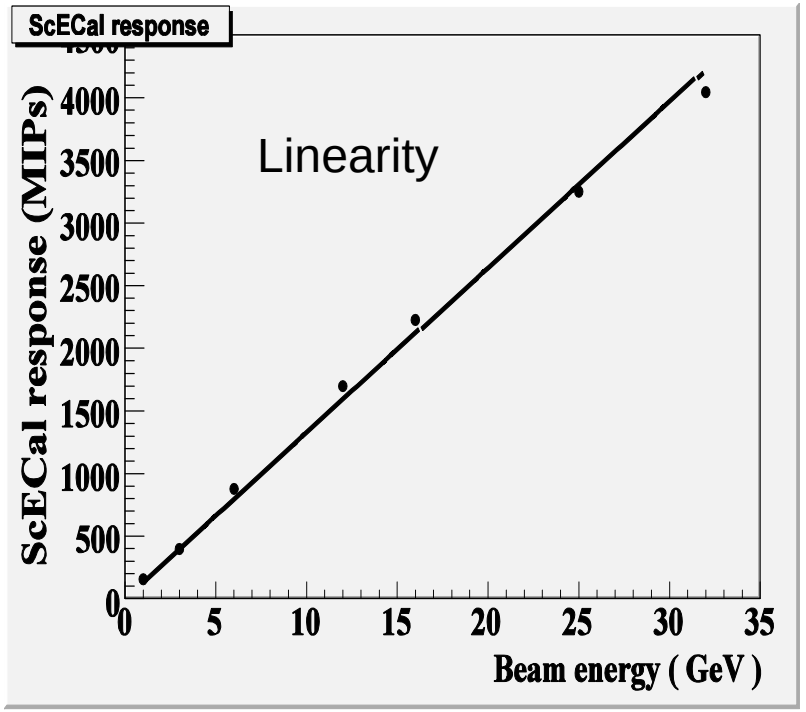
Example: CALICE test beams at FNAL

(2) ScECal 2008





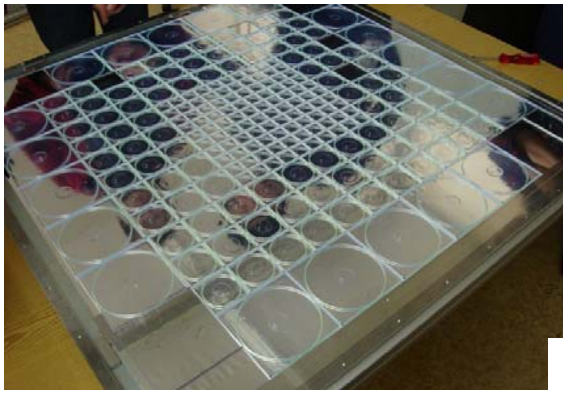




Example: CALICE test beams at CERN, FNAL

(3) Scintillator/SiPM AHCAL

-> results from CERN TB runs in 2006:



- Longitudinal shower profile

Using CERN 2006 data (23 layers)

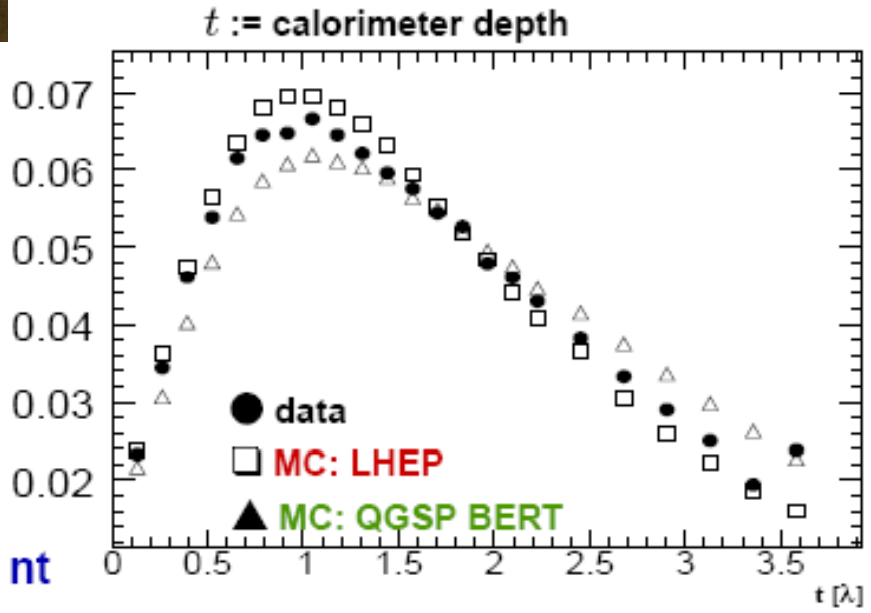
— combined AHCAL+TCMT data

— latest data corrections & MC digi

— Birks' law included in MC

⇒ longit. granularity can provide contraint

er models!



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CALICE/FNAL summer 2008

Run Plan – Accomplishments

4.-7. July: Muon Calib. — accomplished 9/7/08
At two different holds

8.-9.July: Dedicated Ecal Running — accomplished 13/7/08
with trigger optimized Ecal

> 9. July: Running with slow trigger

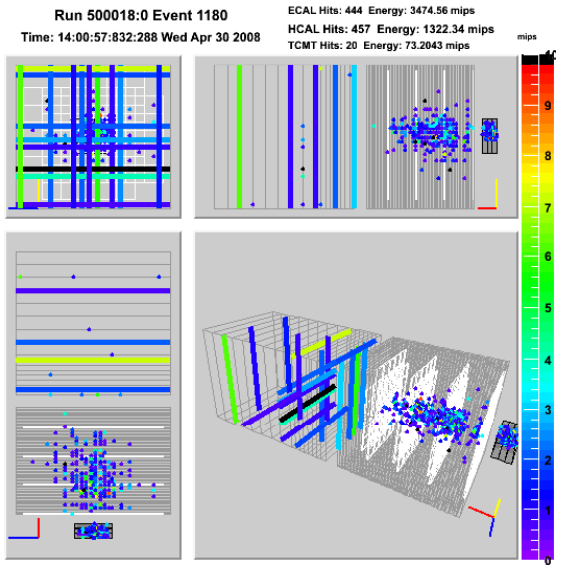
10.-16. July: Completion of — accomplished 20/7/08
(low energy) pion program

17. July: Running with Hcal and Ecal — accomplished 22/7/08
shifted w.r.t beam and to each other

18.-24. July: Running at rotated position — accomplished 26/7/08
10 (20) and 30 degrees — 20 and 30 Degrees
Cover the full energy range
(but not all points)

25.-26.July: Spare Time for
combined program
or low energy proton running

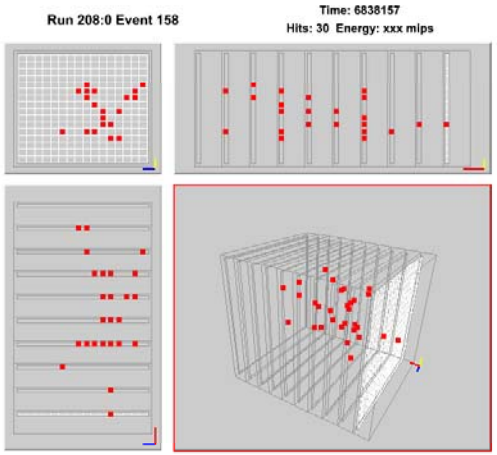
27. July – 1. August Hcal Only Running

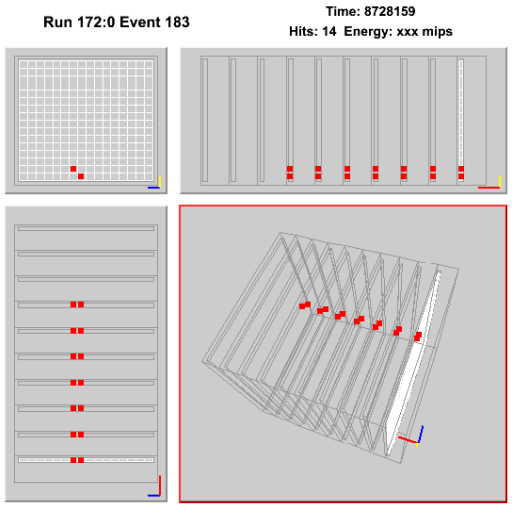


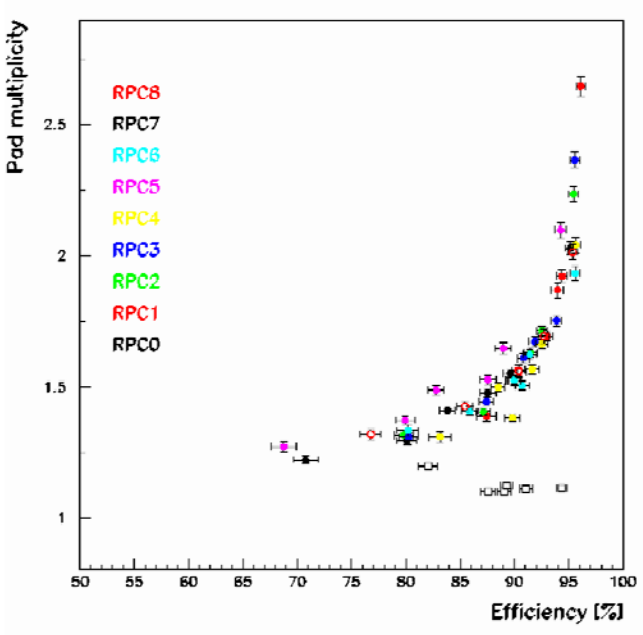
A 120 GeV proton shower recorded by W/Si Ecal+steel/scintil.Hcal+TailCatcher. (Wed 30 Apr 2008)

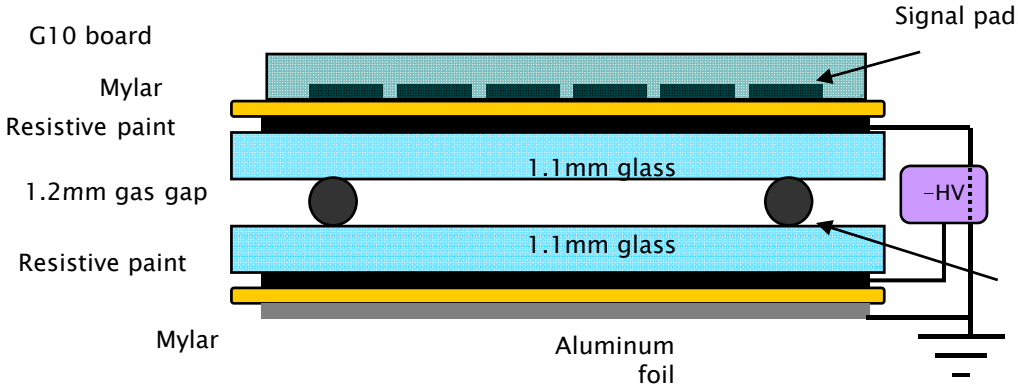
Example: CALICE test beams at FNAL

(4) RPC/Steel DHCAL (U.S.)





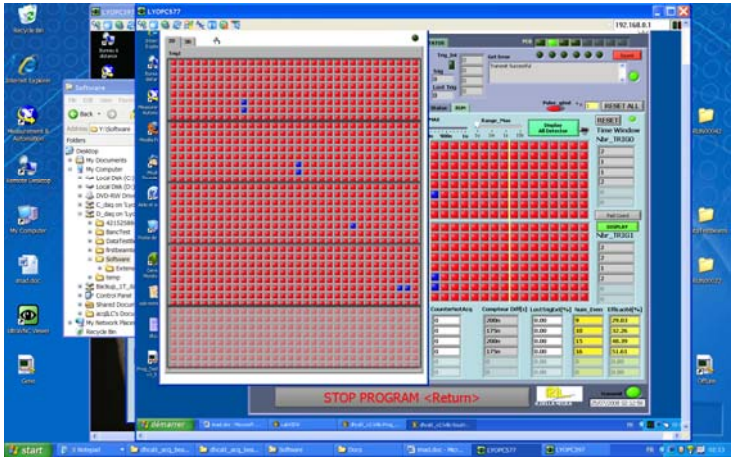


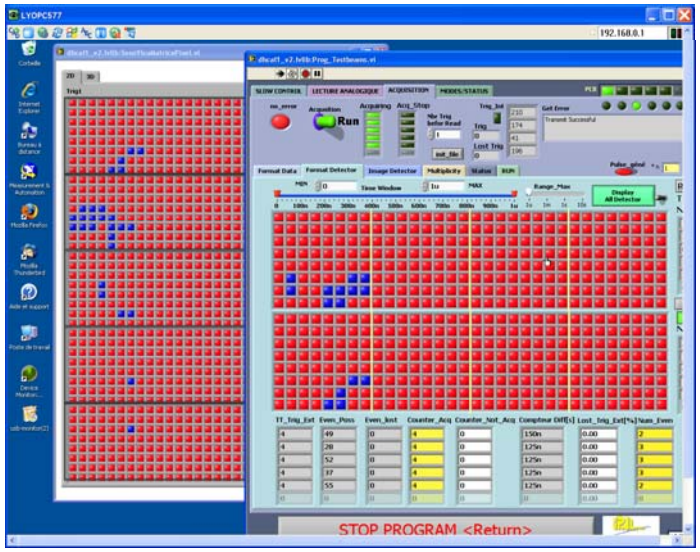


Example: CALICE test beams at CERN

(5) RPC/Steel DHCAL (Europe)

Test a mini DHCAL with new generation embedded electronics readout in beam conditions for the first time

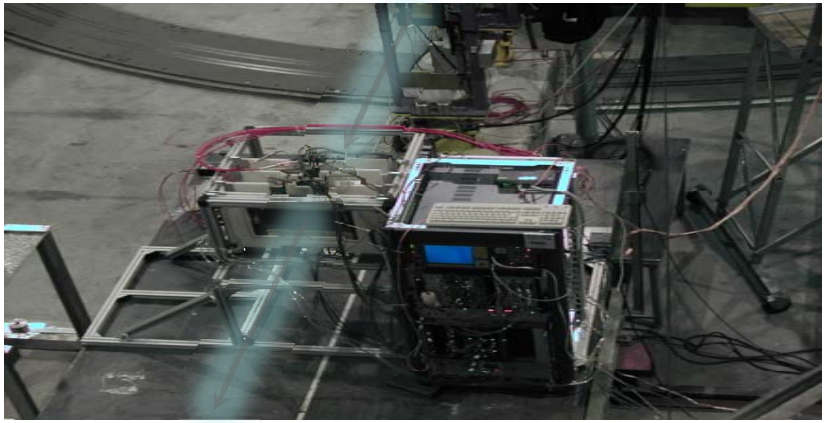




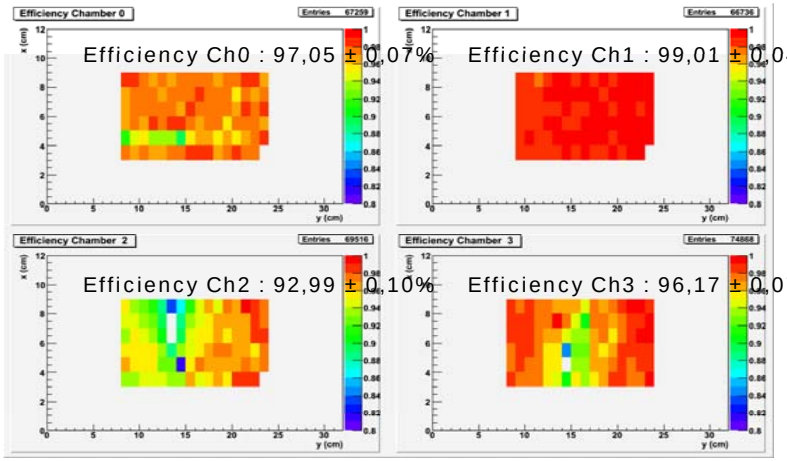
With 2 cm Steel slabs and one λ I.L (Tungsten)

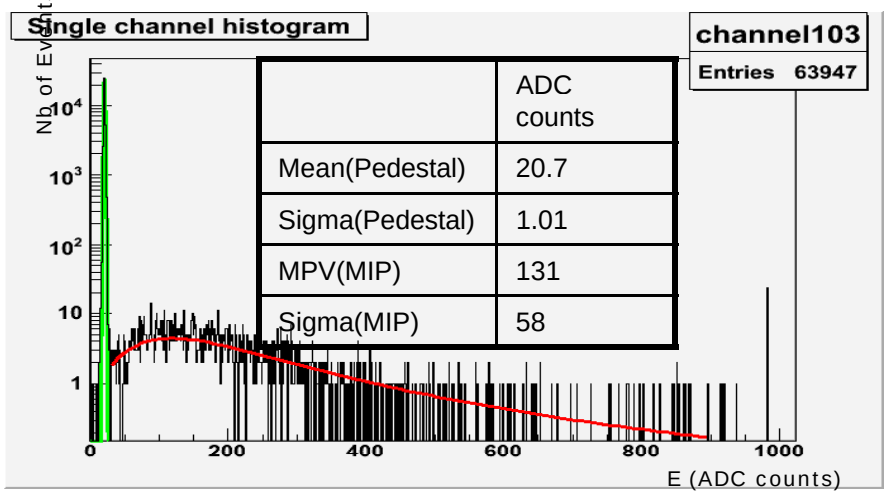
Example: CALICE test beams at CERN

(6) Micromegas DHCAL (Europe)



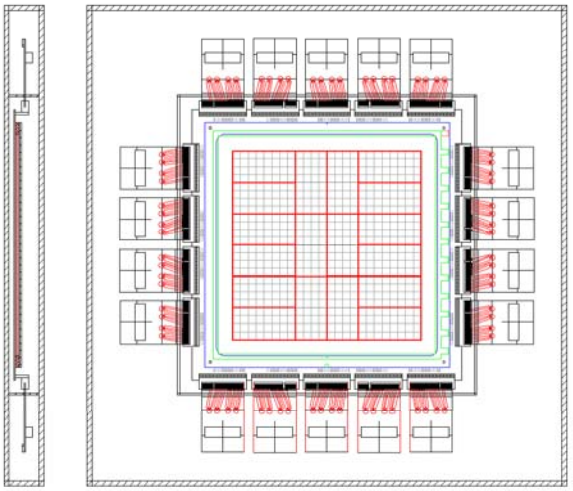
- The data (CERN H2B)
  - 6-7 August Muons & Pions (Gain inter-calibration)
  - 14-15 August : 205 000 Muons
- 15 August : 150 000 Pions

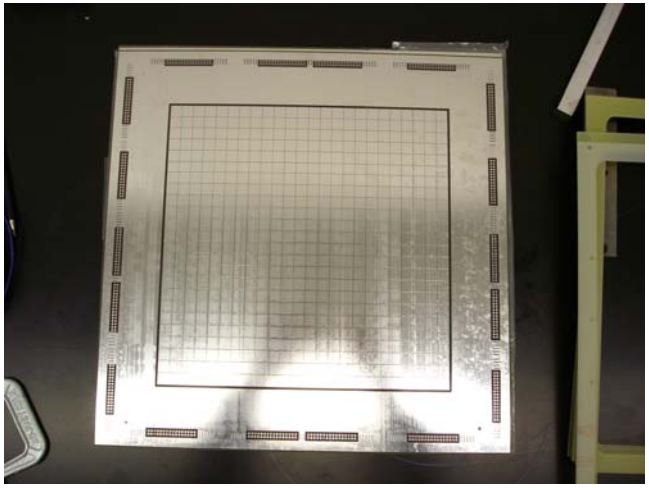


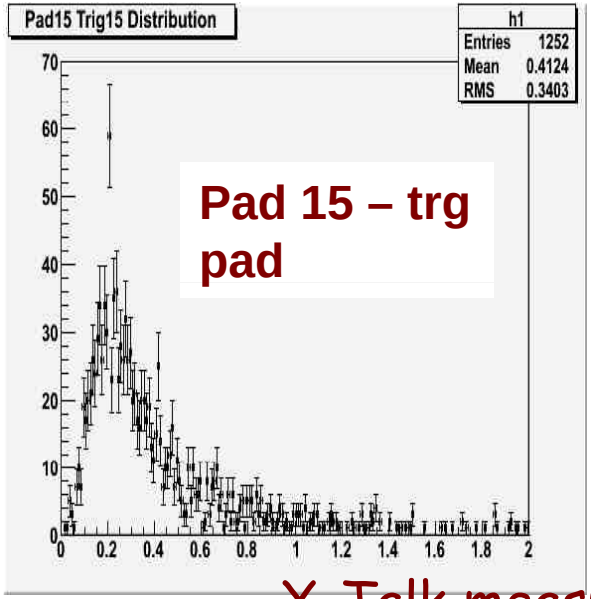


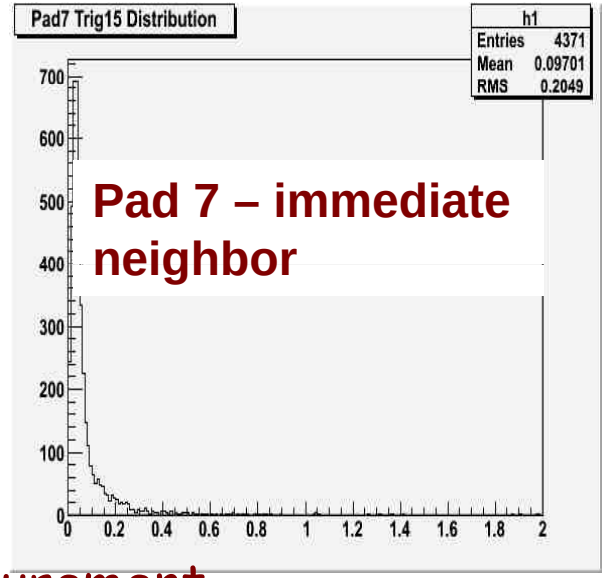
Example: CALICE test beams at FNAL

(7) GEM-DHCAL 2007









X-Talk measurement

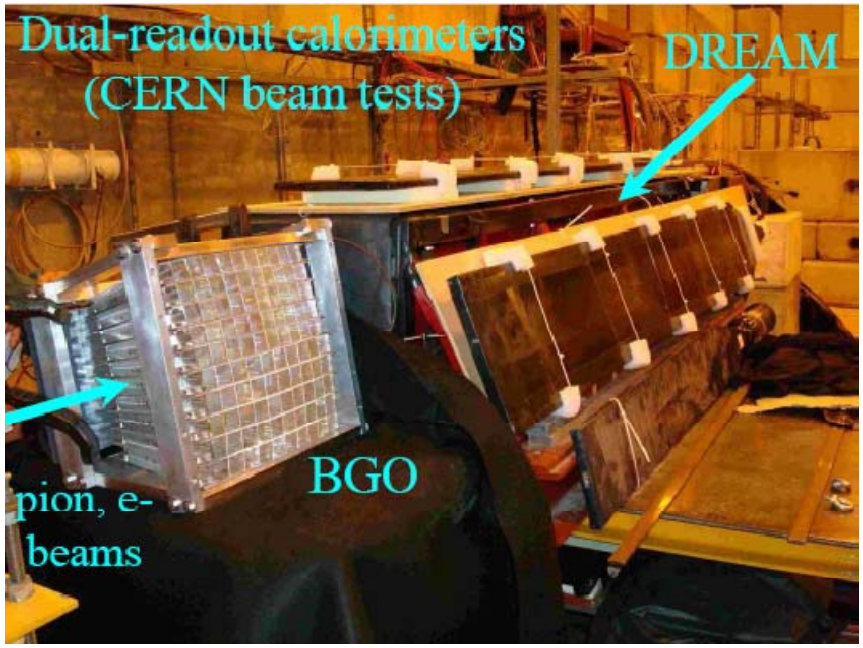
Example: 4th Concept

- L3 BGO crystals in front of small DREAM module

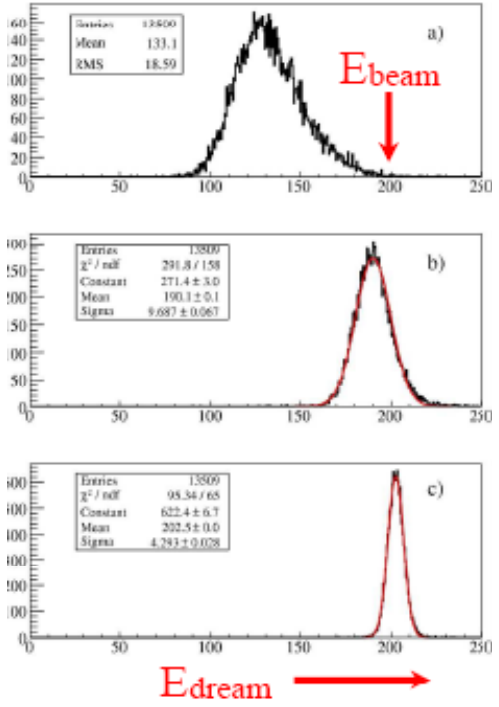
  -> August 2008 data analysis in progress.

  -> Two papers expected

  -> Small module => no hadron containment



Hadronic energy resolution (fibers)



What test beam facilities do we have?

See previous talks +...

Test Beam Facilities as of mid-2007 – needs update!

Facility	Primary beam energy (GeV)	Particle types	Beam lines	Beam Instr.	Availability and plans
CERN PS	1–15	e, h, μ	4	Cerenkov, TOF, MWPC	Available, but reduced services during LHC commissioning
CERN SPS	10–400	e, h, μ	4	Cherenkov, TOF, MWPC	Available, but reduced services during LHC commissioning
DESY	1–6	e	3	Pixels	Available over 3 mo/yr
FNAL-MTBF	1–120	p, e, h, μ	1	Cherenkov, TOF, MWPC, Si strips, pixels	Continuous at 5% duty factor, except for summer shutdowns
Frascati	0.25–0.75	e	1		Available 6 mo/yr
IHEP-Beijing	1.1–1.5 0.4–1.2 (secondary)	e e, π, p	3	Cherenkov, TOF, MWPC	Available in March 2008 or later
IHEP-Protvino	1–45	e, h, μ	4	Cherenkov, TOF, MWPC	Two one-month periods per year
KEK-Fuji	0.5–3.4	e	1		Available in fall 2007, for 8 mo/yr, as long as KEKB operates
LBNL	1.5; <0.06; <0.03	e; p; n	1	Pixels	Continuous
SLAC	28.5 1–20 (secondary)	e e, π, p	1		Shutdown in 2008-2009, with uncertain plans beyond

From Fermilab-TM-2392-AD-DO-E Roadmap TB document, 2007

What do we need to test next?
Short/medium term

CALICE 2008-2010

SiW ECAL + SciFe HCAL: essentially compete

SciW ECAL + SciFe HCAL: one more beam period at MTBF in spring or early summer 2009, maybe including some HCAL standalone runs with e-

Any ECAL, most likely SiW, + RPCFe HCAL(US): start integration and first runs with sub-set of ~ 10 layers in 2009 at MTBF, hopefully to be completed with fully equipped cubic-meter in first half of 2010 - including tests with GEM replacement layers in $1m^3$ – later in 2010.

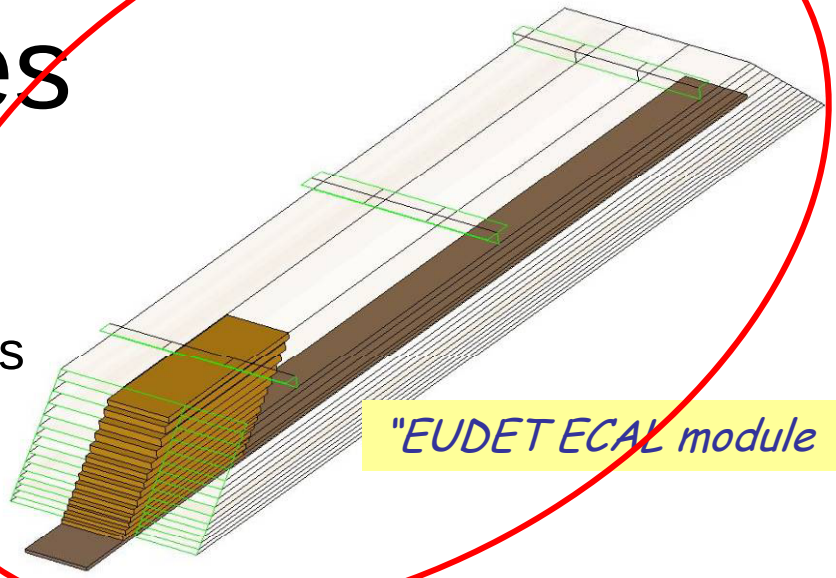
European DHCAL: individual/few layers in 2009; full scale prototype in late 2009/early 2010 (at CERN ?)

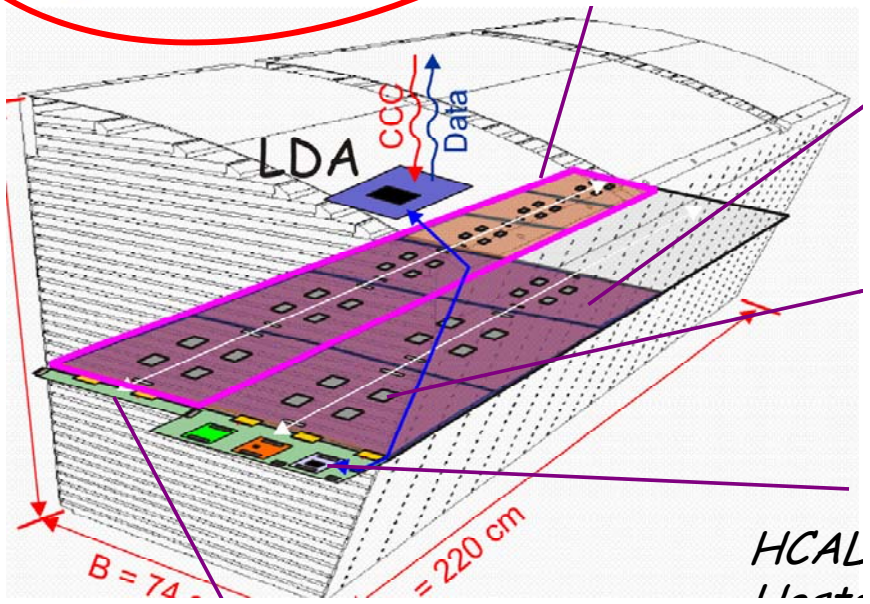
ECal EUDET Module: complete by end 2009 -> beam tests in 2010

SciFE HCAL: multiple integrated layers in 2010?

EUDET module FEE : main issues

- Technical prototype
- Test many technical issues
  - “stictchable” motherboards
  - Minimize connections between boards
  - Reduce PCB thickness to <1mm
  - Internal supplies decoupling
  - Mixed signal issues
  - Digital activity with sensistive analog front-end
  - Pulsed power issues
  - Electronics stability
  - Thermal effects
  - To be validated in beam





4th Concept

- Plans (from 2006) for $1m^3$ module construction at Fermilab. …but…no funding.

- Current aim: $1m^3$ dual readout fiber module (10λ) + dual readout crystal calorimeter ($25X_0$) in front – 1 month test.

- Adam Para – total absorption calorimeter/dual readout;

  EM section crystals/Si pixel layers/Hadronic section with larger crystals

  Timescale for tests?

What do we need to test next? Short/medium term

It appears that this program can be achieved with existing test beam facilities.

What do we need to test next? Long term

Will depend on technology choices and other concept-dependent issues…a few items may be anticipated…

SiD Si-W Electromagnetic Calorimeter

R&D needed to demonstrate readiness for "RDR" (2012):

- Fabricate a functional test module with the real elements, KPiX-1024 bump-bonded to sensors

  - Test in a beam with good noise performance

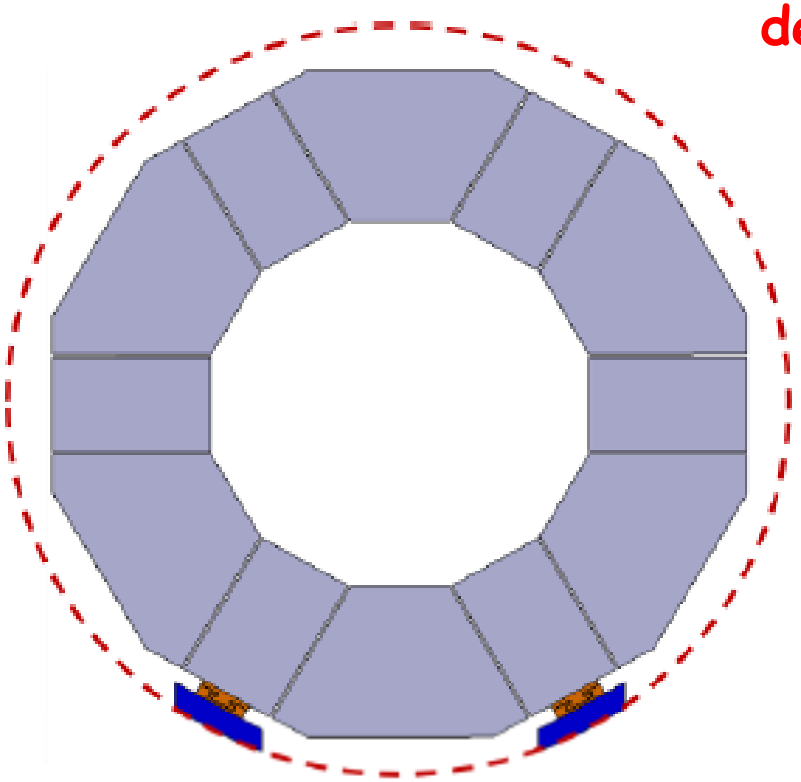
- Long flex-cables

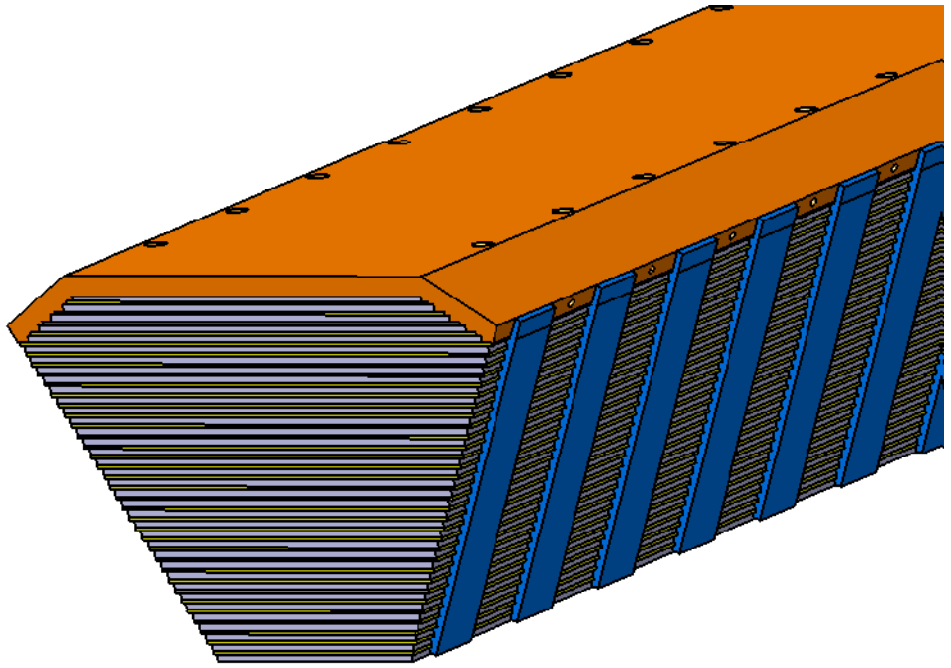
- Mechanical prototype (including thermal demonstration)

SiD HCal Engineering Design

Design work by Nicolas Geffroy (LAPP)

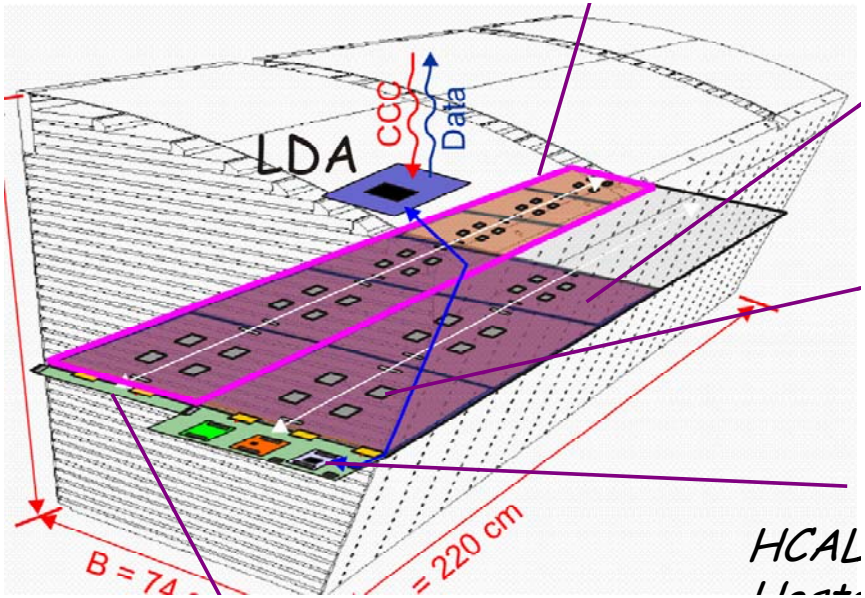
More realistic engineering designs are emerging – eventually we will need to **test complete modules, and complete detector slices in test beam(s)..201x**





CALICE

Full HCal module with existing absorber in 2011?



Full wedge (tracking, ECal, HCal,…) beam tests ??

-> PFA validation? B-field tests? …?

Particle ID

- Not discussed in ILC detector meetings recently
- What Particle ID does the ILC physics program need
- 4th Concept have their own view…

	Physical measurement	Particles/particles discriminated	Subsystems used	
1.	$\Sigma_i C_i$ *vs.* $\Sigma_i S_i$	$e^{\pm}$ *vs.* $\pi^{\pm}$ *vs.* $\mu^{\pm}$	dual-readout fiber (S and C) calorimeter	← *Beam test data*
2.	$\chi^2 \sim \frac{1}{n}\sum_i^n [C_i - S_i]^2/[k(C_i + S_i)]$ $(k \sim 0.10)$	EM *vs.* non-EM *vs.* "hadronic"	dual-readout fiber and crystal calorimeters	← *Beam test data*
3.	$f_n \sim E_n/E_{\rm shower}$ (slow n's)	"hadronic" *vs.* EM or "muonic"	scintilating fibers $S_{\rm pe}(t)$ long-time history	← *Beam test data*
4.	$(S - C)$ *vs.* $(S + C)$	μ *vs.* π *vs.*e	dual-readout fiber (S and C) calorimeter	← *Beam test data*
5.	Time-history of S fibers	EM *vs.* non-EM *vs.* "hadronic"	dual readout S fibers	← *Beam test data*
6.	dN/dx cluster counting	$e - \mu - \pi - K - p$ (few GeV)	CluCou tracking	← *Bench test data*
7.	EM calor + tracking	$e - \gamma$	CluCou tracking + dual-readout calor's	
8.	$p_{\rm tracking} \approx E_{\rm dual-readout} + p_{\rm muon}$	μ *vs.* punch-through tracks	CluCou, calor, muon	
9.	$\tau^{\pm} \to \rho^{\pm}\nu \to \pi^{\pm}\gamma\gamma$	τ *vs.* hadronic debris	BGO dual-readout CluCou, calor.	
0.	sub-ns time-of-flight	massive SUSY object	Čerenkov pulses in BGO and fiber calorimeter	← *Beam test data*
1.	$W, Z \to jj$ mass	W, Z *vs.* QCD jj	CluCou, jet finding, dual readout calor's	← *ILCroot*

Particle ID in 4th — John Hauptman – this meeting

Questions for the future

- Do we need to test technical prototype modules in magnetic fields?

  If so, how do we provide a large volume, high field region?

  → Size of effects – simulations?

  → Lead time for request to labs, agencies?

- Do we need higher energy beams than we have now? What if CLIC turns out to be the right machine?

  → New/heavy particle(s) may decay to multiple jets with not so high energies?

  → Depth of calorimetry/size of detector?

Questions for the future

- Do we still need to think about getting the shower model(s) in GEANT4 "right" ?

  → restrict range of models/parameters – constrain to test beam data ?

-…and, do we need a neutral beam?

  → if we have the charged component of showers correct, are there models for neutrals that are significantly different? Would this affect the PFA(s)?

  → large experimental effort on neutral beams – is it worth it?

Questions for the future

- what are the prospects for getting "synchronous" beams at CERN and/or MTBF?

  → for which aspects of detector development is this critical, and when?

- CALICE: test EUDET electronics with power-pulsing? CERN PS or Fermilab MTBF?

Conclusions

- Vigorous test beam program in progress

- Extensions into 2009/2010

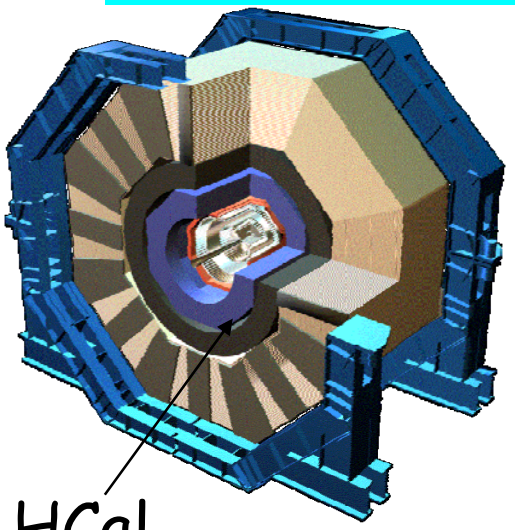
- Present facilities appear to accommodate the program through 2010

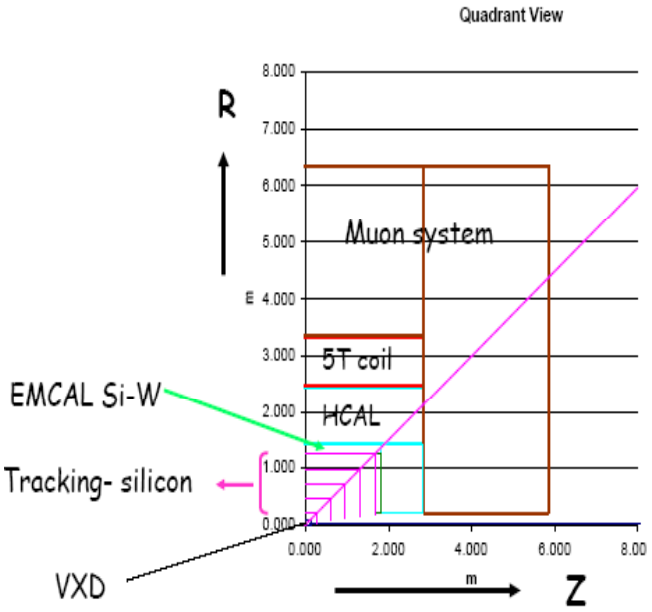
- Long term tests – not so well defined

- Need to decide soon (for funding, planning, construction,… lead time) if we need additional significant facilities and/or long term attack on GEANT4 shower model(s) issue.

Extra material

SiD HCal


HCal


Quadrant View
R
m
Muon system
5T coil
HCAL
EMCAL Si-W
Tracking- silicon
VXD
8.000
7.000
6.000
5.000
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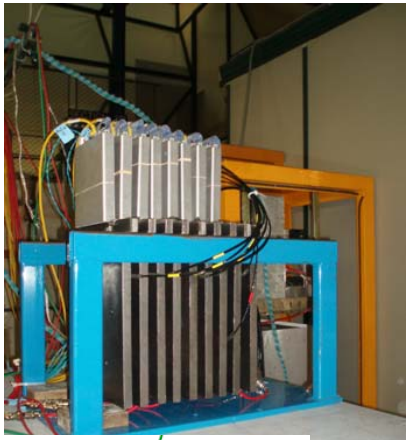
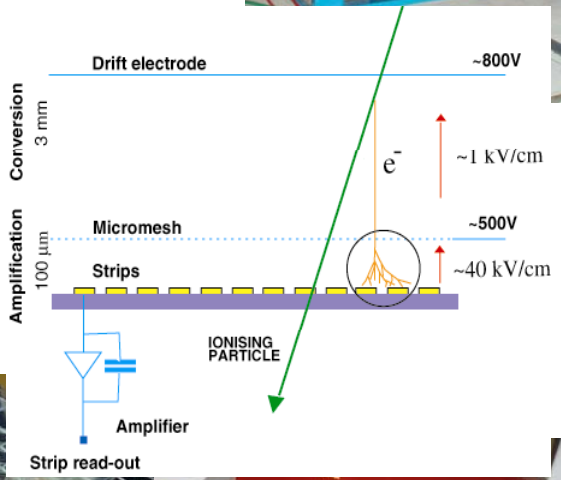
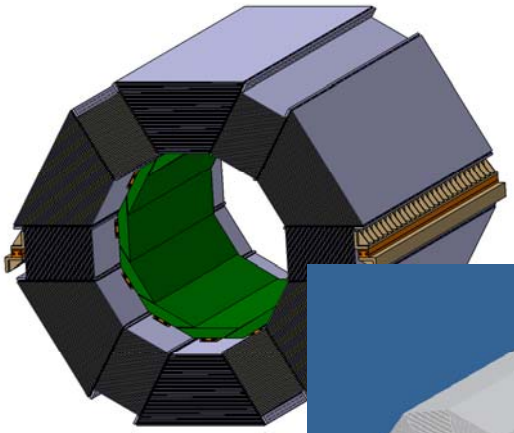
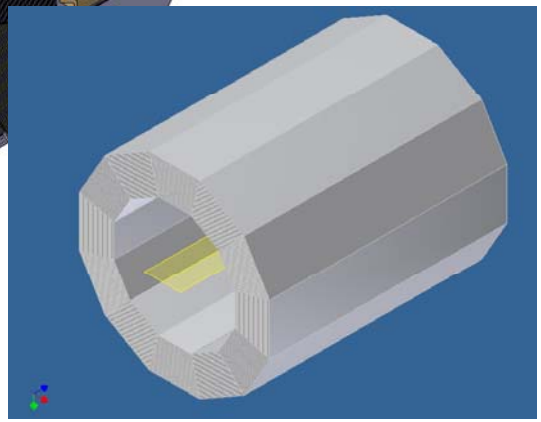
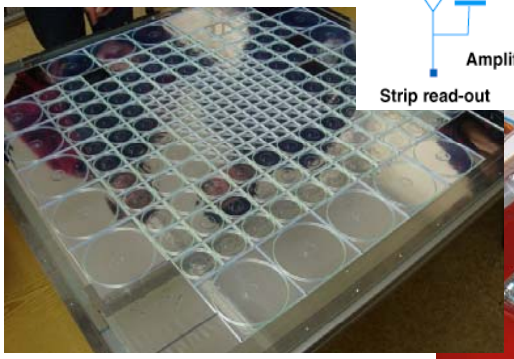
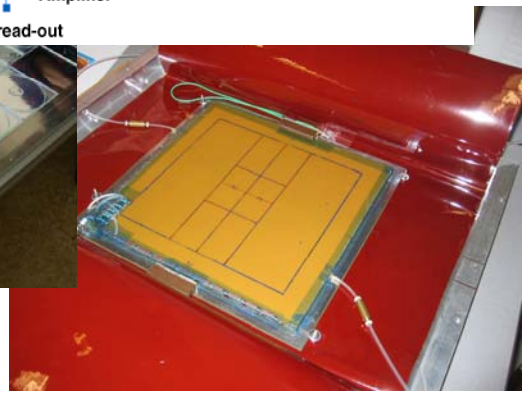



Drift electrode
~800V
Conversion
3 mm
e⁻
~1 kV/cm
Amplification
100 µm
Micromesh
~500V
Strips
~40 kV/cm
IONISING PARTICLE
Amplifier
Strip read-out









points (GeV)	40, 50, 60, 80	150, 180
(deg)	0, 10, 15, 20, 30	0, 10, 20, 30
med physics package; low energy programme	pi:- 500K evts@6/10/12/15/18/20GeV; 10, 15, 20, 30 deg	pi-: 400K evts @6/8/10/12/15/18/20 GeV deg; 1M evts @6 GeV; 500K ev @8-20 GeV @20 deg.
physics package; ns: low energy mme	e-: 1M evts@6/10/15(/20) GeV, 0 deg	e-: 500K evts @6 GeV @0 ~700K evts @8/10/12/15/1 GeV @0 deg. 1M evts @6 GeV @20 deg ~400K evts @8/10/12/15/1 GeV @10,20 deg
physics package; ns: high energy mme		e-: ~2M evts @25/30/40/50 @0 deg; ~200K evts @25/30/40/50 @10,20 deg.
physics package; ns: high energy mme		e-; scan of the bottom layer ECAL: 5 position points, ~250K evts @90 GeV @0 per position.
rradiation package;	e-: 1M evts@10/50 GeV,	e-: 1.1M evts @70 GeV @ position scannig;