The CALICE test beam activities

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(for the CALICE collaboration)

ALCPG07, FNAL, Chicago, 22nd October 2007

The CALICE collaboration

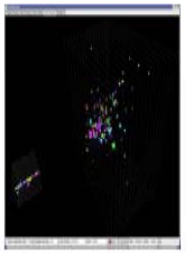
12 countries,
45 laboratories,
225 physicists/engineers ,

CALICE collaboration

CAlorimeter for the LInear Collider Experiment

A high granularity calorimeter optimised for the Particle Flow measurement of multi-jets final state at the International Linear Collider running at a center-of-mass between 90 GeV and 1 TeV

- Last Meeting : electronics in CALICE, CERN-meeting , 23 March 2007 agenda and slides
- Last CALICE week was in KOBE University (Japan) 10-12th May 2007 web site
- NEXT CALICE week will be held in PRAGUE (**Czech Rep.**) **11-13th September 2007** web site



re to have more pictures from the test beam at CERN / Summer- Fall 2006

n The ECAL project

- High granularity calorimeters for precision physics
- Study of particle flow for $\sigma_E/E \sim 30\%/\sqrt{E}$
- Validation of hadronic interaction models in MC

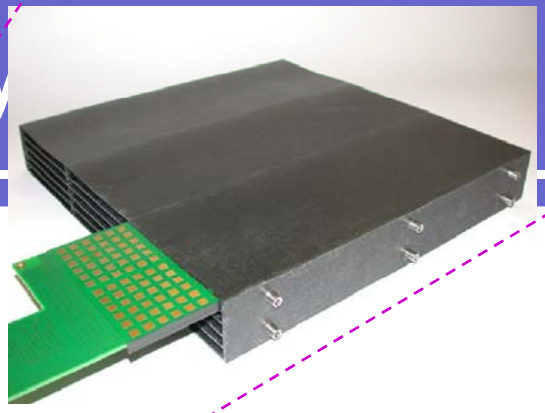
Calorimetry at ILC

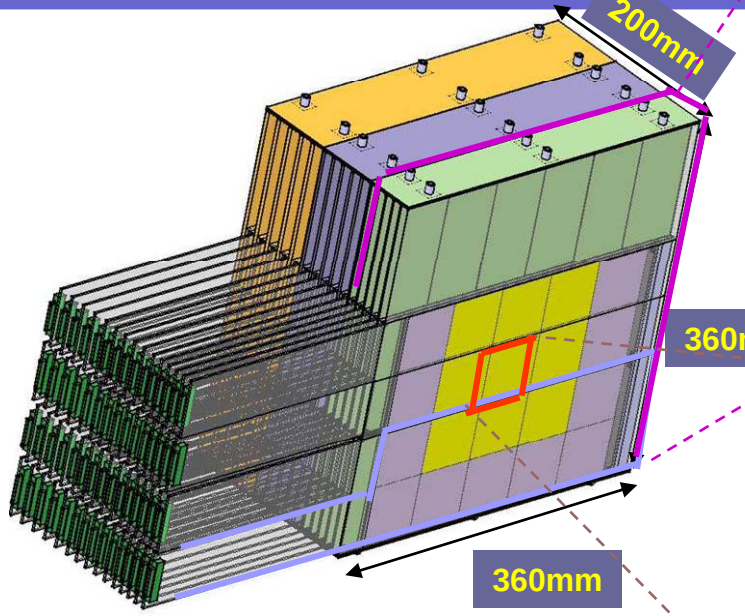
- Calorimetry is one of key ingredients for a high-specs detector at the ILC
  - Need high granularity for precise jet energy resolution
  - $\sigma_{jet} = \sigma_{ch\,\mathrm{arg}} \oplus \sigma_{phot} \oplus \sigma_{neut} \oplus \sigma_{confusion}$
- Design, build and operate a novel detector which fulfils stringent requirements: $\sigma_{jet} = 30\%/\sqrt{E}$

CALICE: build prototypes and perform an intensive test beam programme to characterize various calorimeter concepts

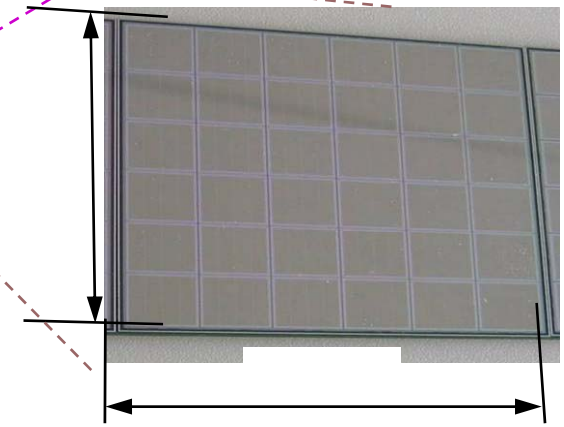
neutral hadrons	10 %	HCAL+ECAL	$\frac{\sigma_E}{E} \sim 45\%/\sqrt{E}$	$\sim 15\%/\sqrt{E_{jet}}$

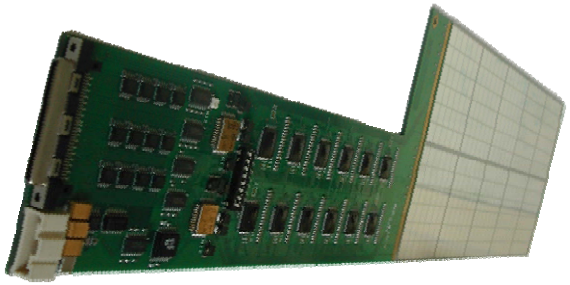
SiW ECAL prototy





- 6x6 1x1cm² Si pads
- Conductively glued to PCB

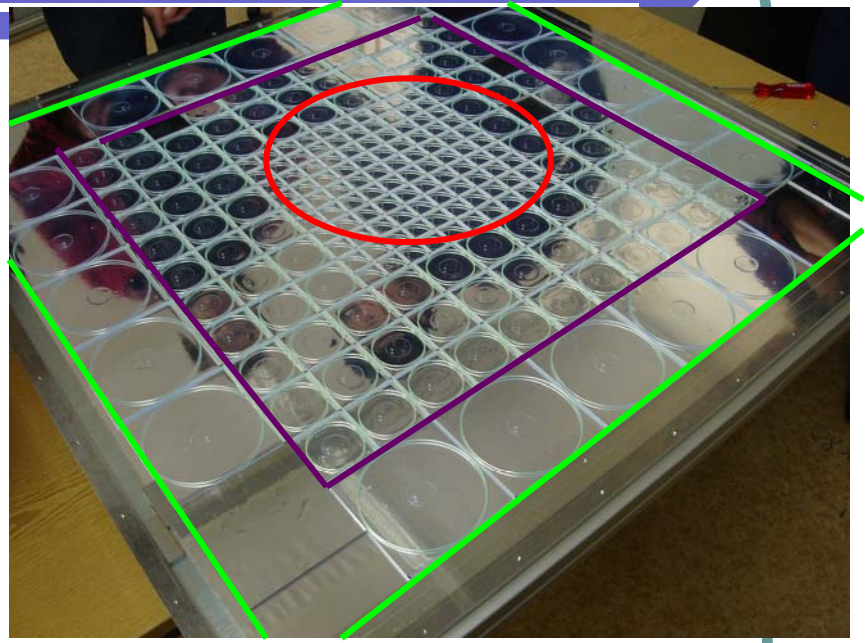




- W layers wrapped in carbon fibre
- 3 modules with different tungsten thickness, total = 24 X_0
- Active silicon layers interleaved: PCB+Si+W+Si+PCB layers = 8.5 mm
- FE chip and readout on PCB board

Analog HCAL prototype

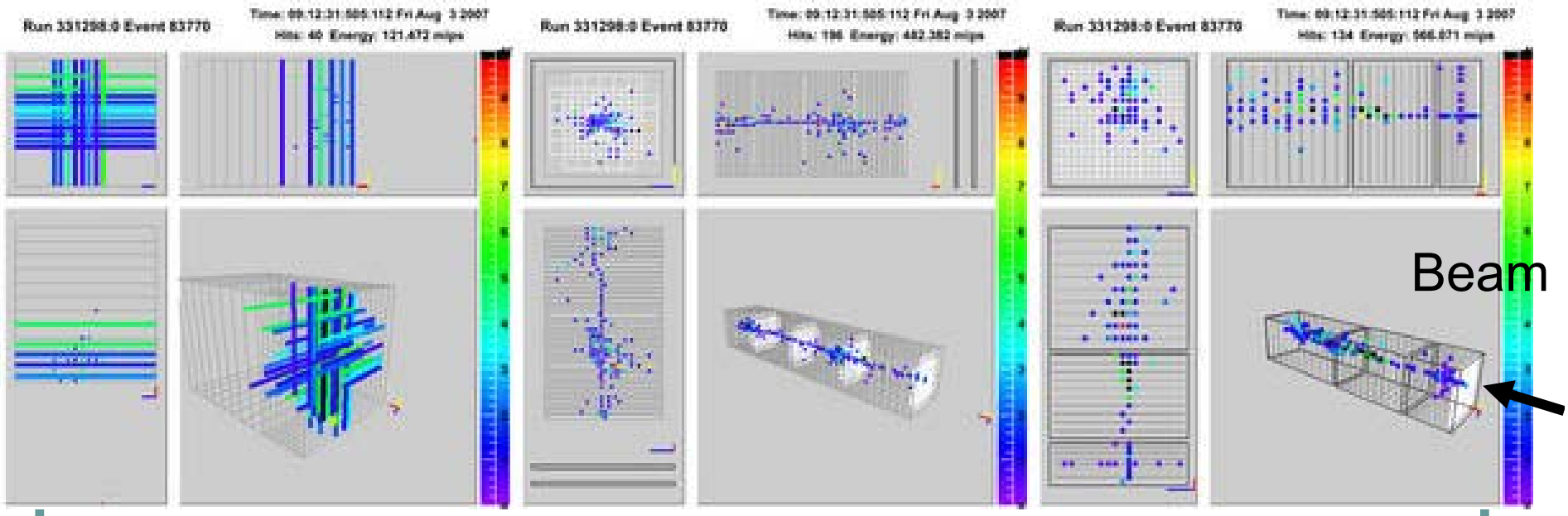
- 38 layers of scintillator tiles (90x90 cm^2) with steel absorber (15 in 2006 tb)
- High granularity
  - 3x3 + 6x6 + 12x12 cm^2 tiles
  - 30 modules with fine granularity (216 tiles) and 8 with coarse granularity (141 tiles)
  - 7608 readout channels (SiPM)
  - Total interaction length = 4.5 λ
- Common DAQ for ECAL+AHCAL+TCMT



- Measurements of shower leakage and μ identification provided by Tail Catcher + Muon Tracker (TCMT)
  - 96 cm of iron absorber with 16 layers of 5*50mm^2 scintillator strips (~10 λ)

A real tracking calorimeter

We are working towards prototyping calorimeters for particle flow algorithms for the ILC !



Outline

- The 2006 CERN test beam
  - Data taking summary
  - Preliminary ECAL and AHCAL results
- The 2007 CERN test beam
  - Installation
  - Data taking overview
  - Detectors' performances
- Future test beam plans
- Conclusions and Outlook

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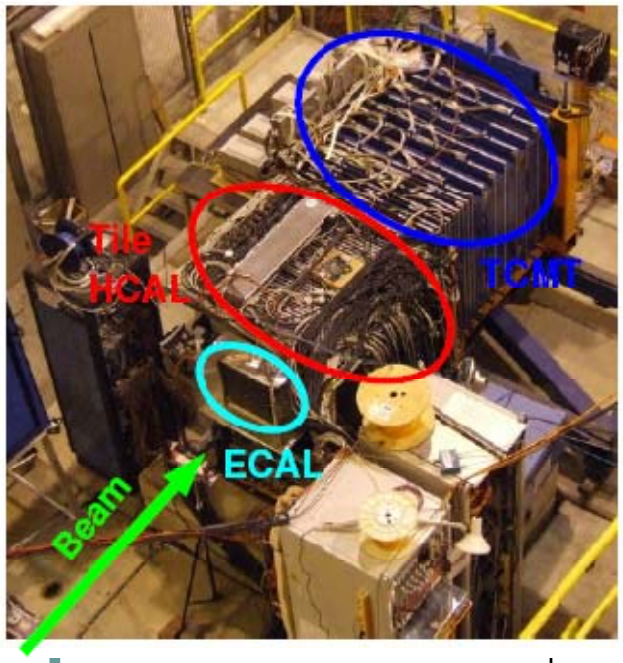
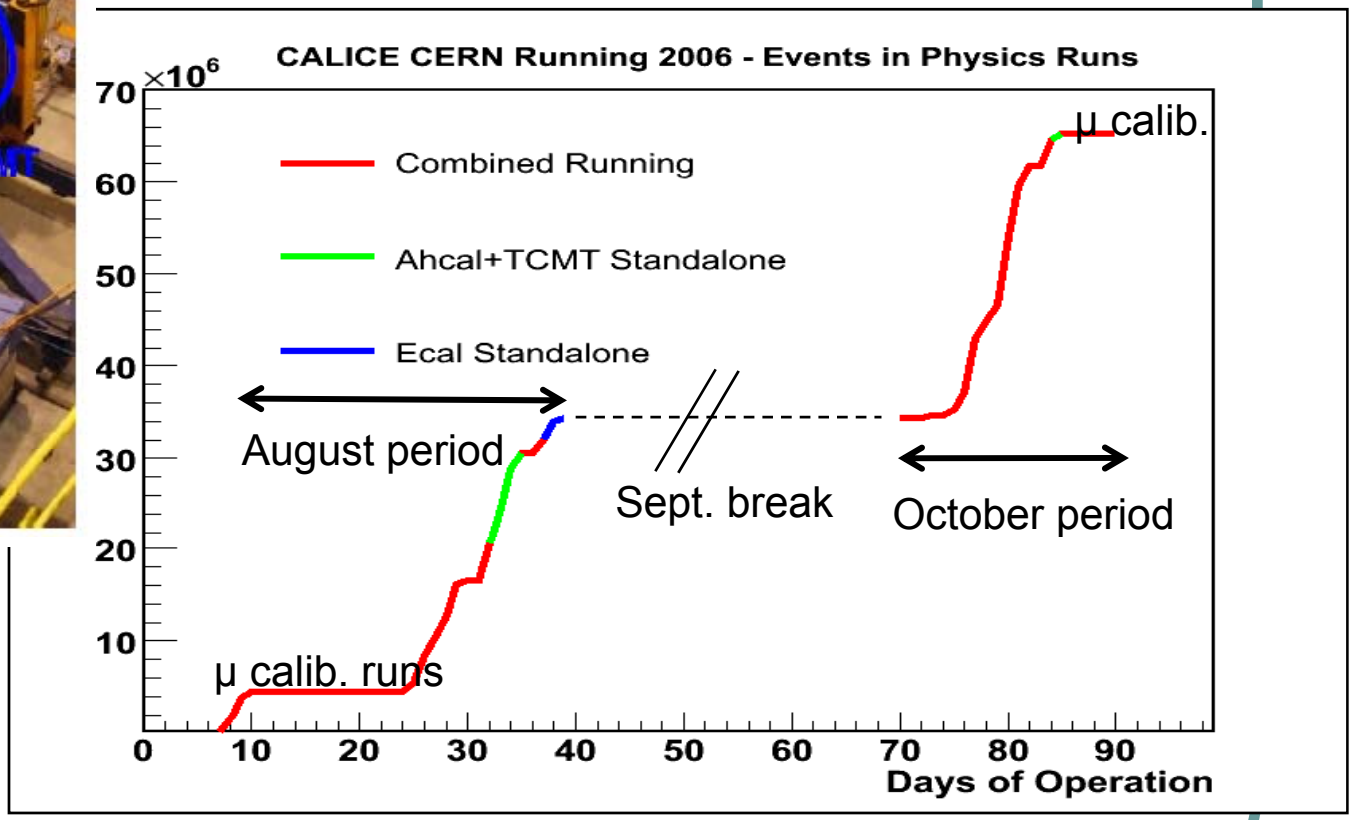
The 2006 CERN test beam

- Two beam periods
  - Aug 25th → Sept 6th
    - ECAL+AHCAL
      - 1.7M triggers
      - π beam
      - 5 E points (30-80 GeV), 3 angles
    - ECAL alone
      - 8.6M triggers
      - e⁻ beam
      - 6 E points (10-45 GeV), 4 angles
  - Oct 11th → Oct 30th
    - ECAL+AHCAL+TCMT
      - e± beams 3.8M trig., 10 E points (6-45) GeV
      - π± beams 2.2M trig., 11 E points (6-60) GeV
- 70M muon events for calibration

Preliminary results presented at LCWS07
arXiv:Physics.ins-det.0709.2516

Summary of the data taken



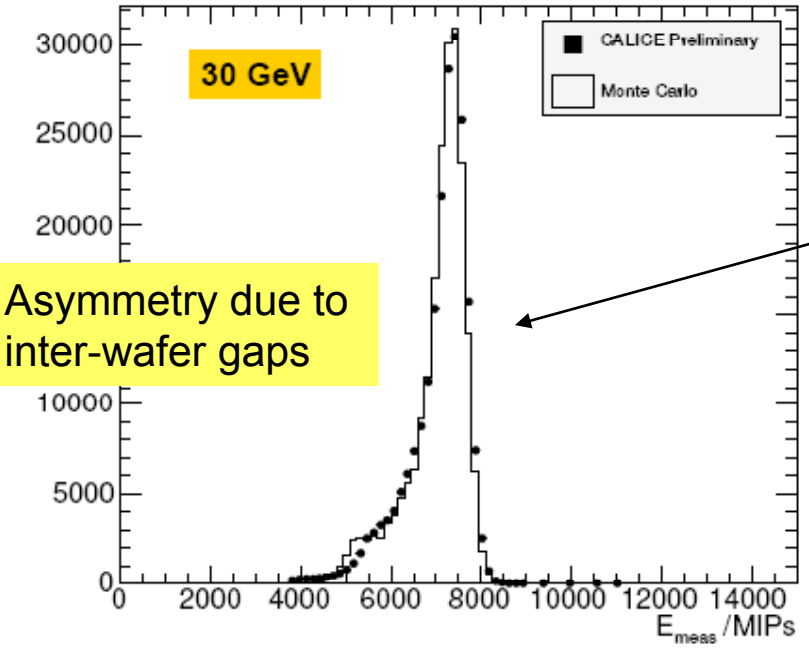


Size on disk: ~ 40 kB/evt

➔ 65M events = 2.5 TB for CERN Physics runs

➔ + 70 M = 3 TB for muon calibration runs

Preliminary results of ECAL analysis

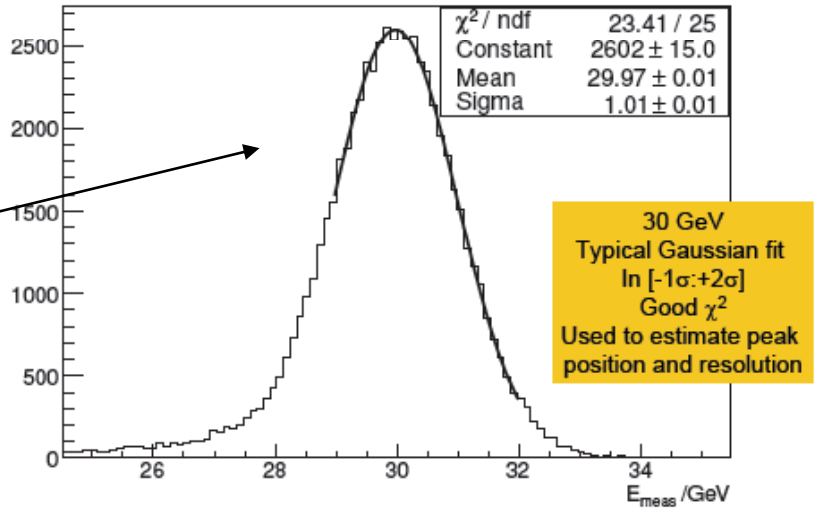


Asymmetry due to inter-wafer gaps

Raw energy spectrum

$E_{meas} = (\alpha_1 E(1\text{-}10) + \alpha_2 E(10\text{-}20) + \alpha_3 E(21\text{-}30)) / \beta$

$(\alpha_1, \alpha_2, \alpha_3) = (1, 2, 3)$ $\beta=250$

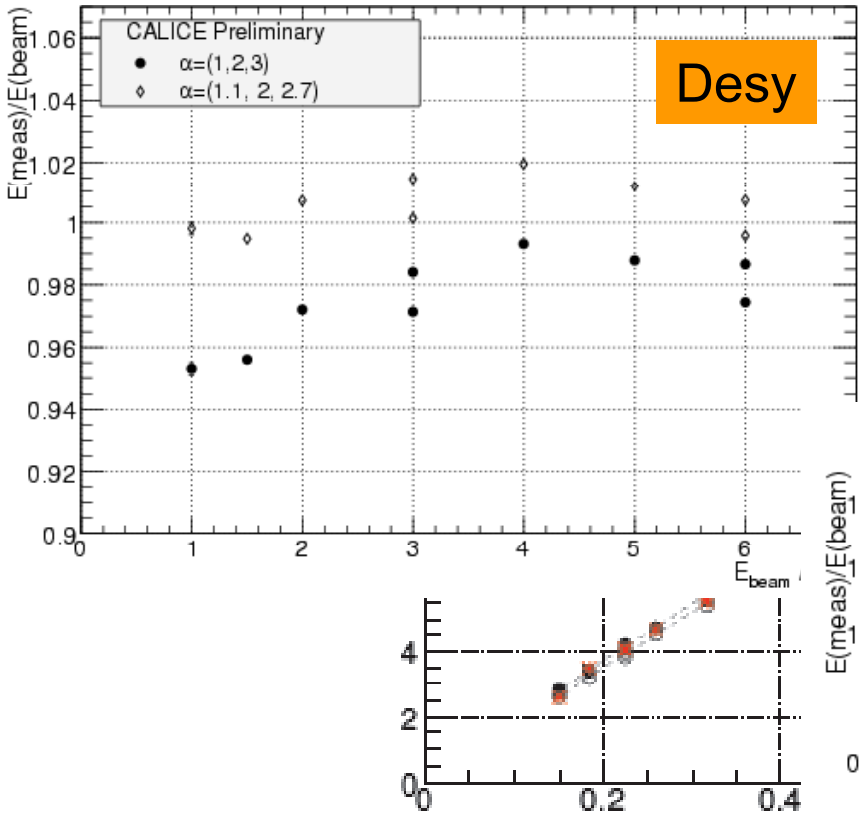


Spectrum after selecting events outside gaps

Optimised weights for resolution: (α_1, α_2, α_3) = (1.1, 2, 2.7)

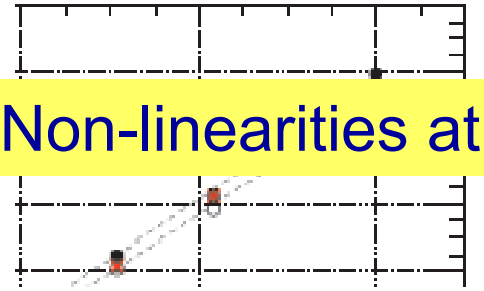
ECAL resolution and linearity

Linearity

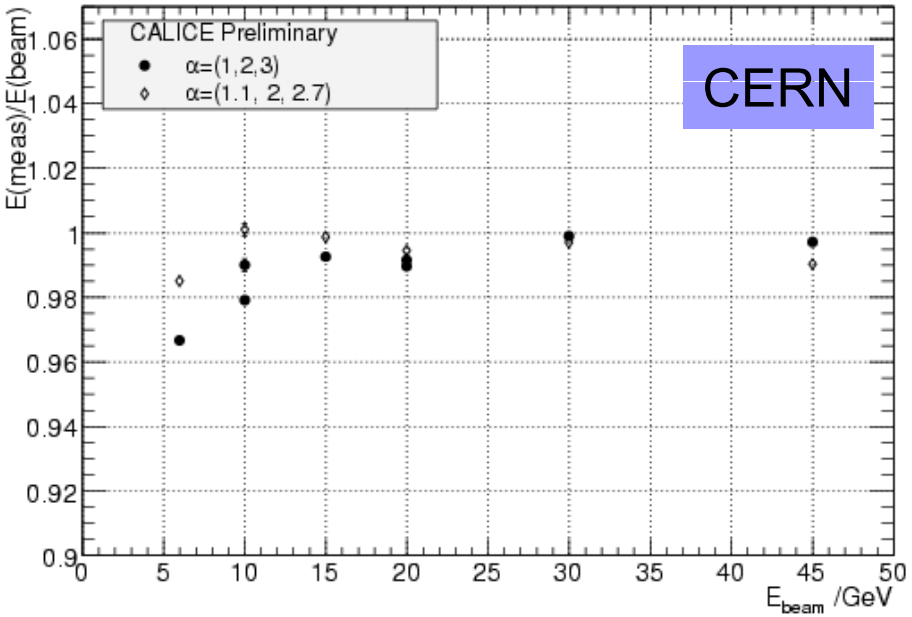


Desy

$(\alpha_1, \alpha_2, \alpha_3) = (1, 2, 3)$



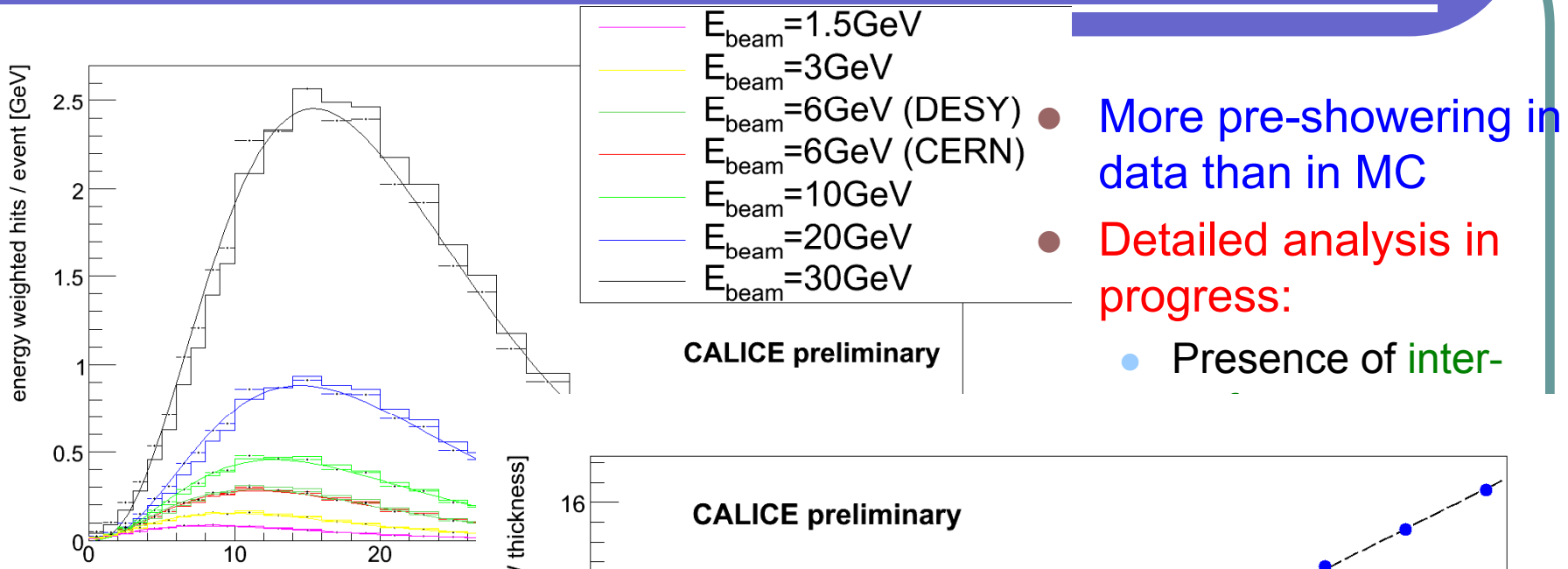
Non-linearities at few % level



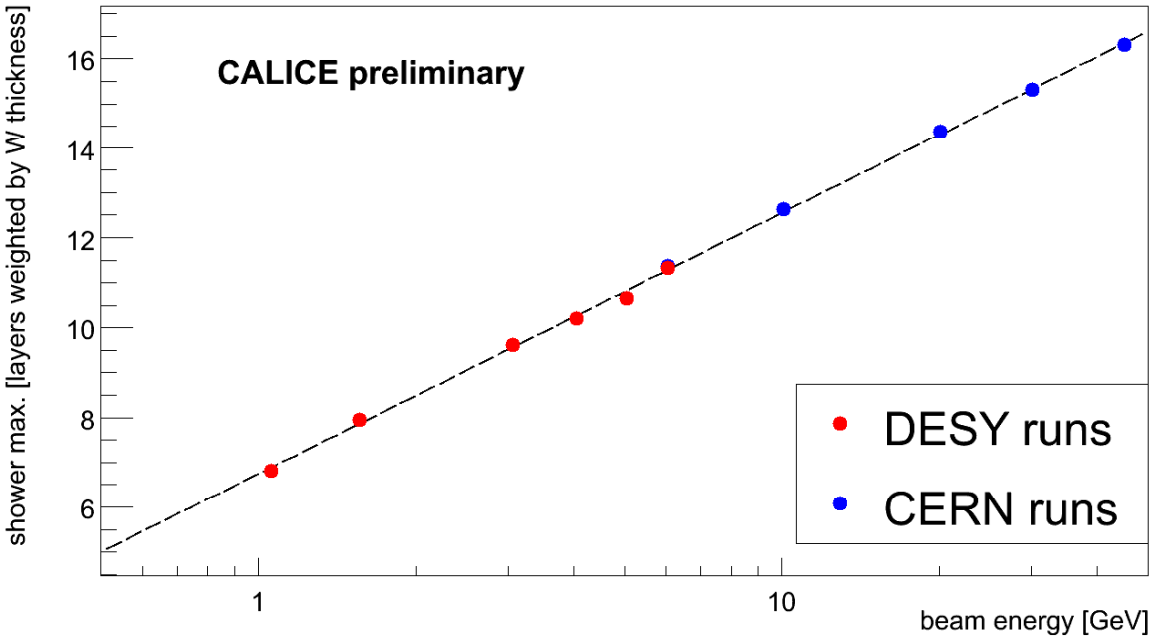
CERN

$$\frac{\Delta E}{E}(\%) = \frac{17.1 \pm 0.07}{\sqrt{E\,(\mathrm{GeV})}} \oplus (0.5 \pm$$

Longitudinal shower development

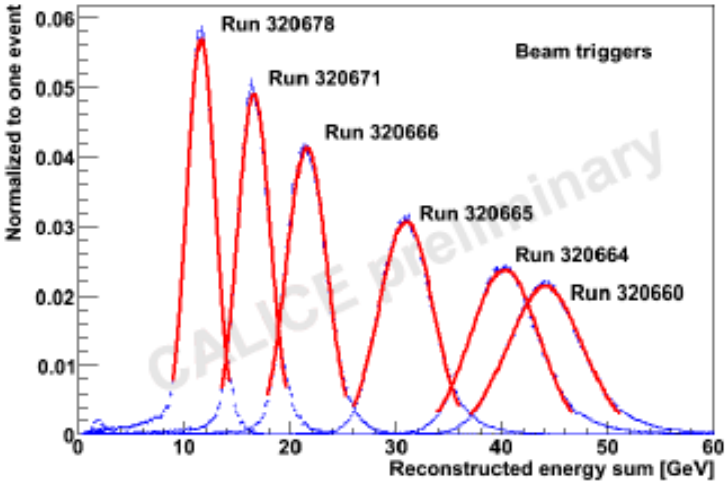


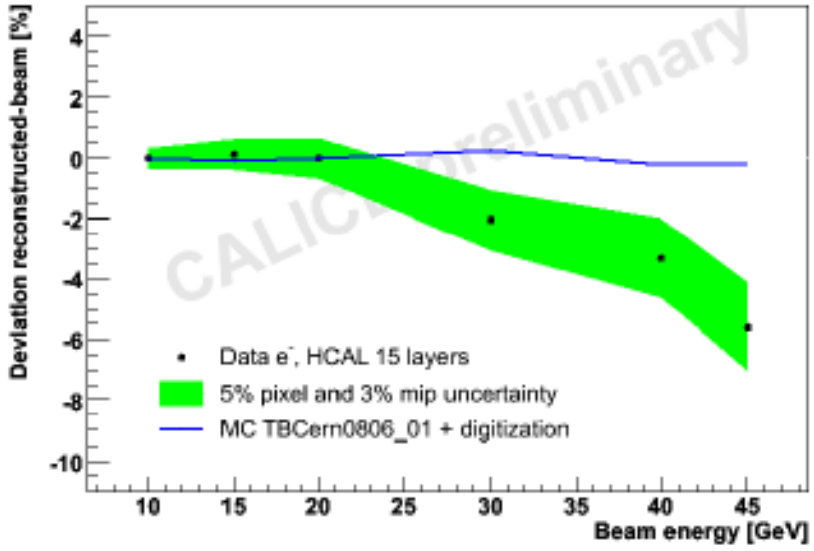
- More pre-showering in data than in MC
- Detailed analysis in progress:
  - Presence of inter-



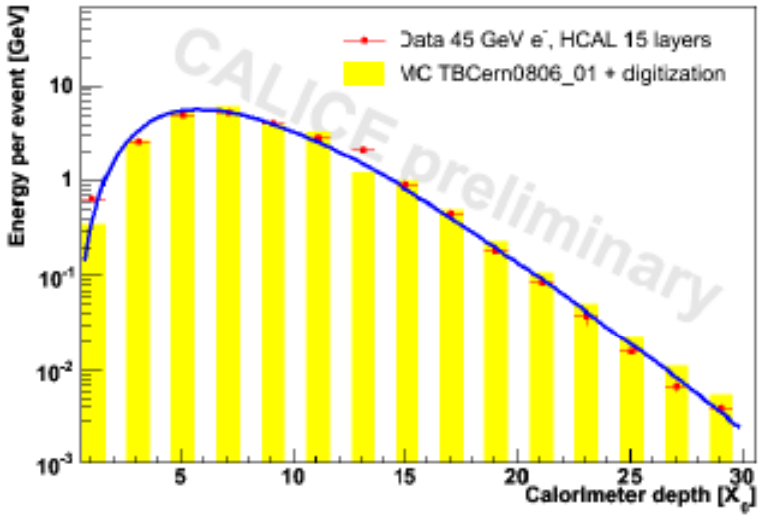
AHCAL response to electrons

- AHCAL alone (15 layers)
- Remove hits below 0.5 mip
- Energy sum of whole AHCAL, fit mean response
- Linearity better than 6%





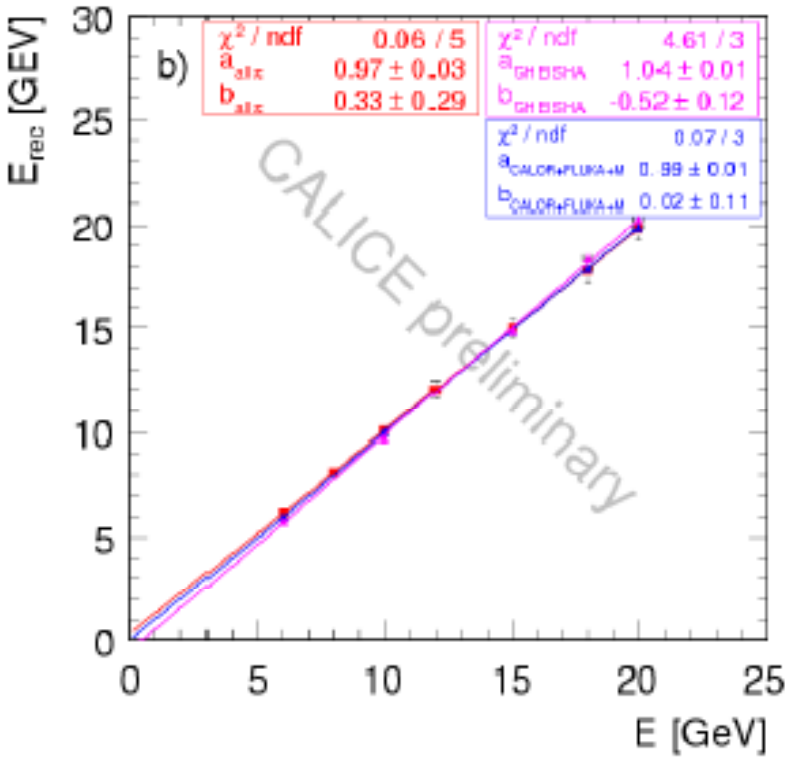
- Longitudinal energy profile



Salvatore, RH

Response to pions

- Energy sum compared between data and MC
  - GEISHA (no neutron transport)
  - GCALOR+FLUKA+MICAP (full neutron response)
- Linearity



Summary of 2006 test beam

- Analysis of 2006 data well under way
  - More than 9TB of data to analyze !
- Excellent performance of the ECAL
  - Very encouraging preliminary results on resolution, linearity and longitudinal shower development
- First results from e/π AHCAL results
  - Encouraging results for EM studies
  - Promising results from pion beam data
- Expect first publications by end of this year

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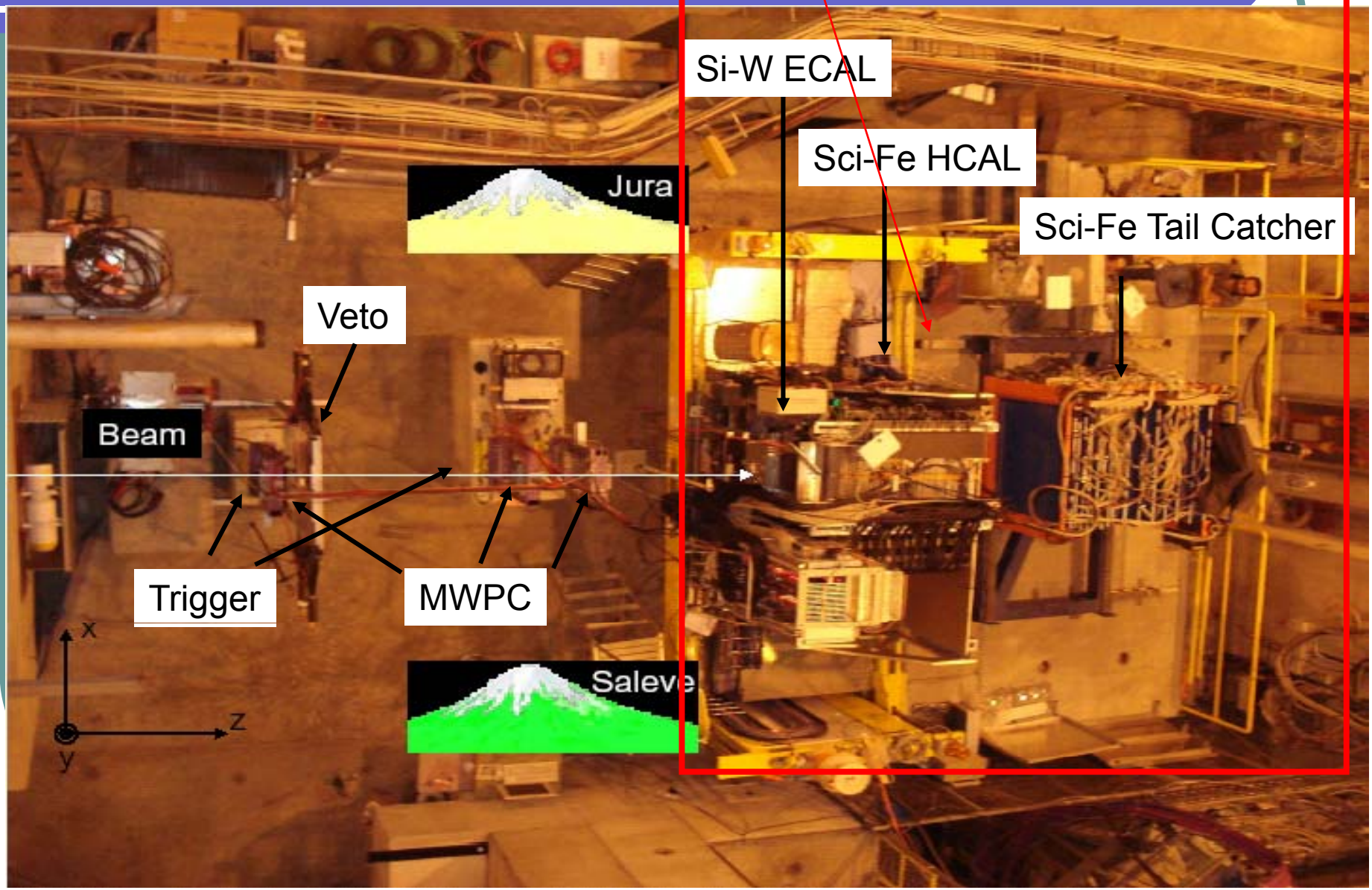
Beam line setup



The CERN beam

- Excellent beam set-up
  - Super-cycle: { 14 bp/16.8 sec — day; (17 bp/20.4 sec from 15/08); 12 bp/14.4 sec — night/w-e
- Secondary beam energies:

-80 GeV wobbling	π^- (40-100 GeV) and e^- (15-50 GeV)
-10 GeV wobbling	π^- and e^- (6-25 GeV)
+60 GeV wobbling	π^+/p(30-80 GeV) and e^+ (10-50 GeV)
-130 GeV wobbling	π^- (60-180 GeV) and e^- (70-90 GeV)

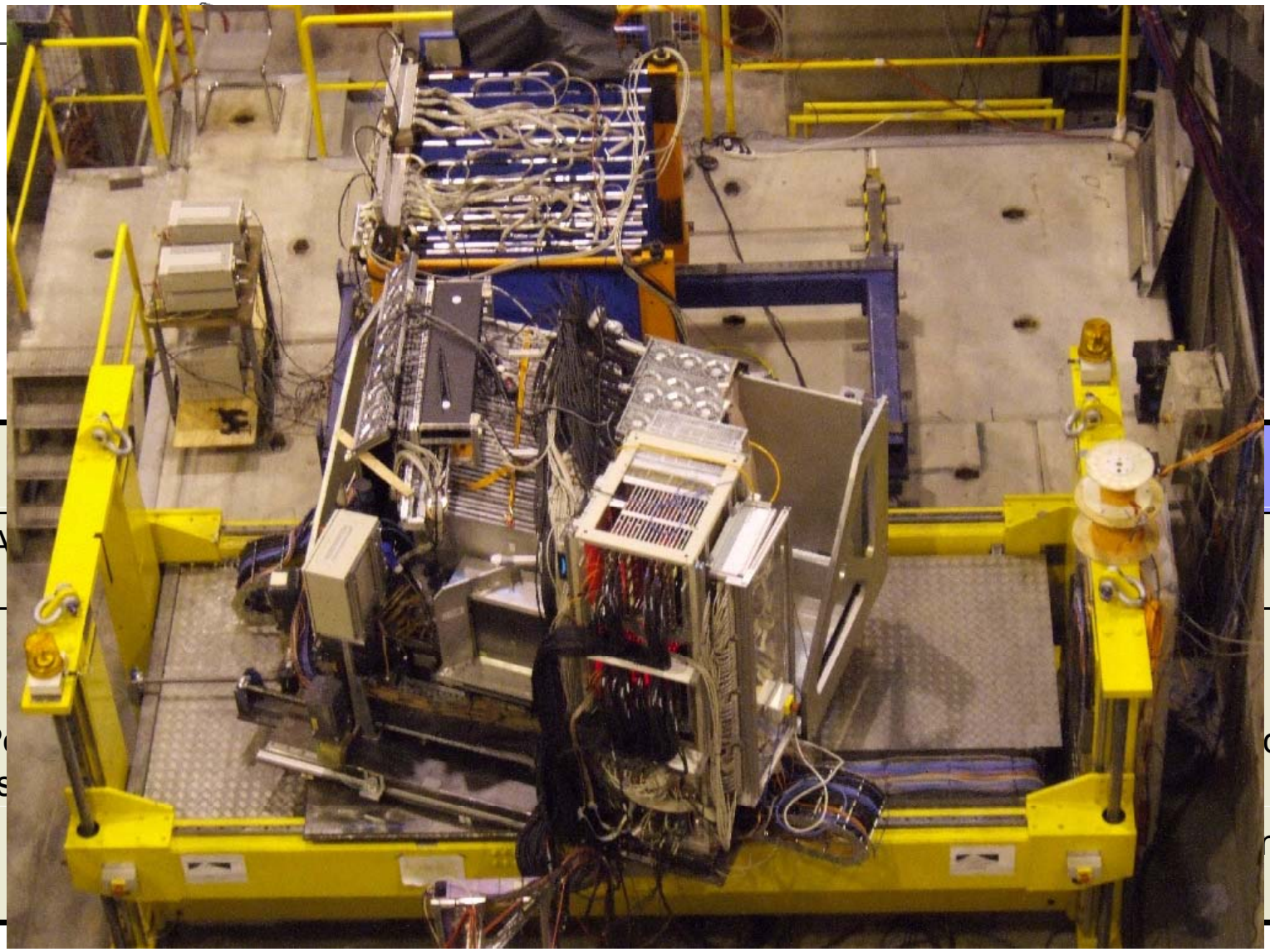
The test beam programme: energies and particle types

- Very intense test beam programme
  - 7 weeks of continuous data taking
    (July 5th → August 22nd)

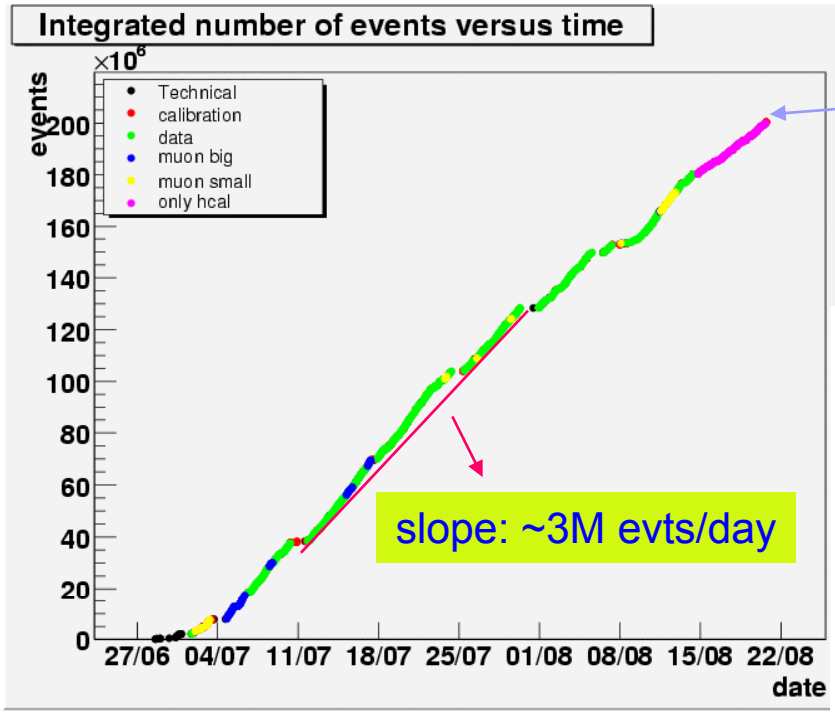
	Proposed in TB plan	Collected during TB
Energy (GeV)	6,8,10,12,15,18,20,25,30,40,50,60,80	6,8,10,12,15,18,20,25,30,40,50, 60,80,100,120,130,150,180
Particles	$\pi^{\pm}/e^{\pm}$	$\pi^{\pm}/e^{\pm}$/protons

- π/e (π/p) separation achieved using Cherenkov threshold detector filled with He (N_2) gas
  - Possible to distinguish π from e(p) for energies from 25 to 6 (80 to 30) GeV

The test beam programme: angles and position scans



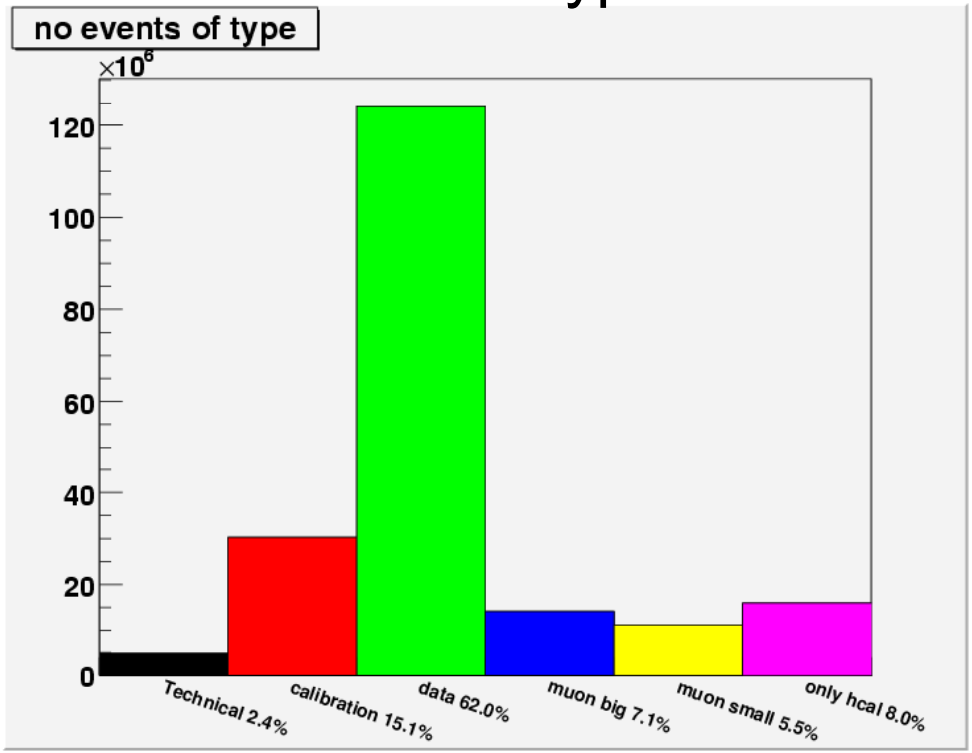
Total events collected



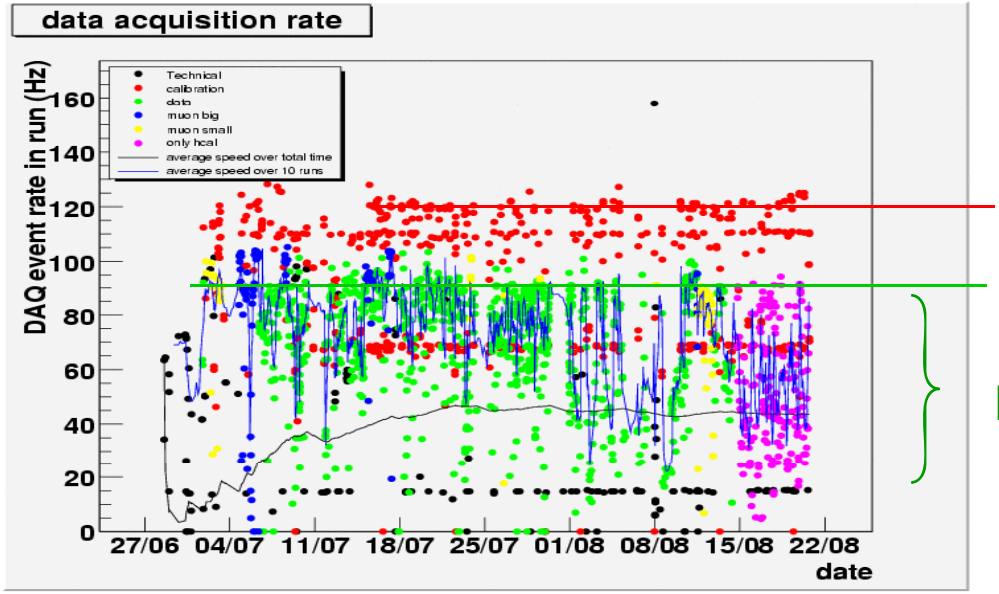
200M triggers !!!

Total Events vs Time

Event Types



DAQ rate

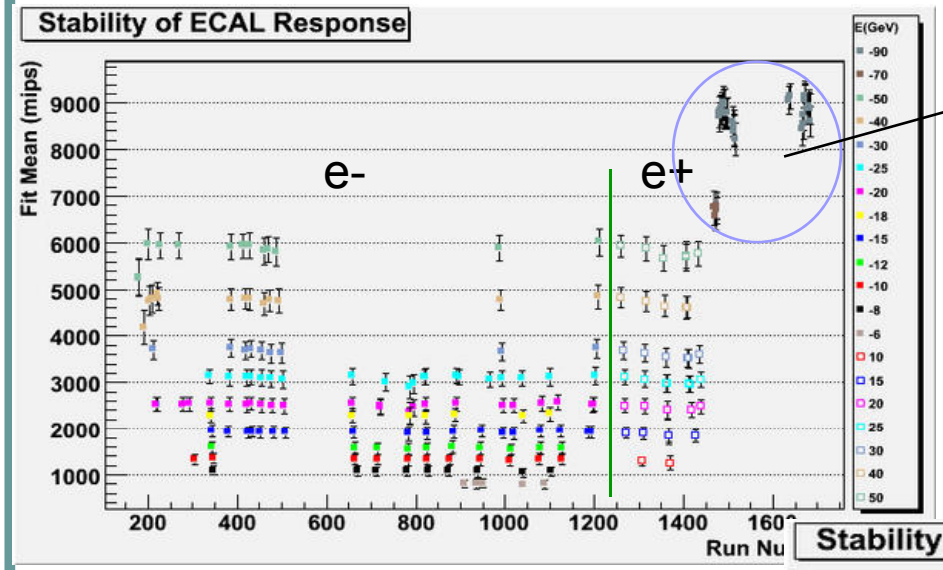


120 Hz limit of DAQ out of spill

90 Hz limit of DAQ in spill limited by beam rate

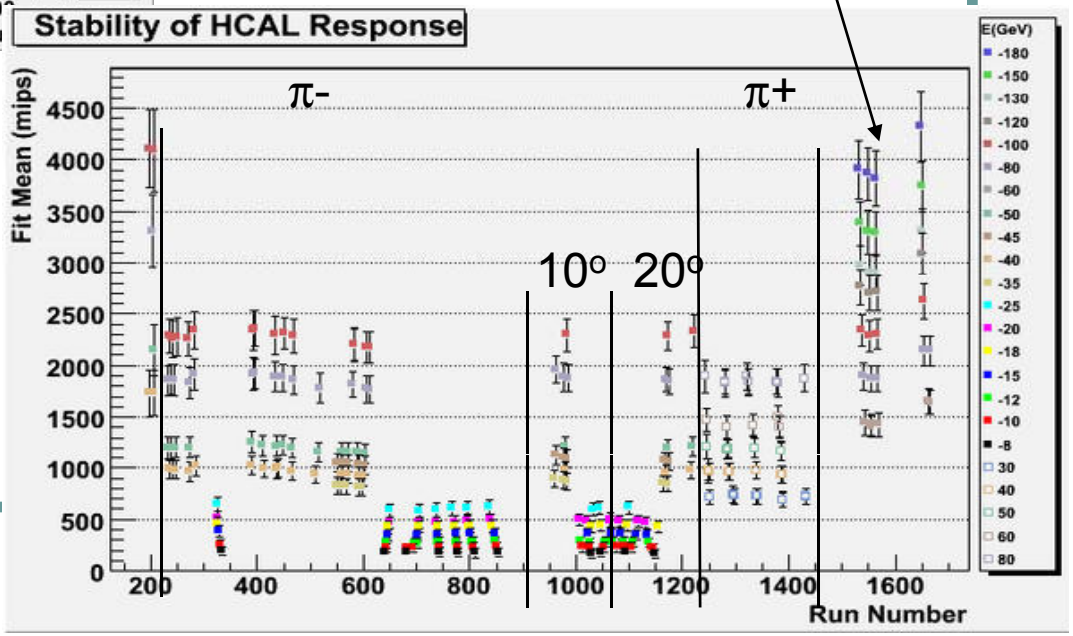
- Low energy beams (6-25 GeV)
  - Trigger rate on 10x10 adjusted in beam files using available collimators
    - Average rate ~ 600 pps@ 6 GeV, ~1-3K pps@ 8-25 GeV
  - DAQ rate ~35-60 Hz
- High energy beams (30-180 GeV)
  - Trigger rate on 10x10 set to <10K pps to prevent damage to the detectors
    - Average rate ~8K pps
  - DAQ rate ~70-80 Hz

ECAL and AHCAL response



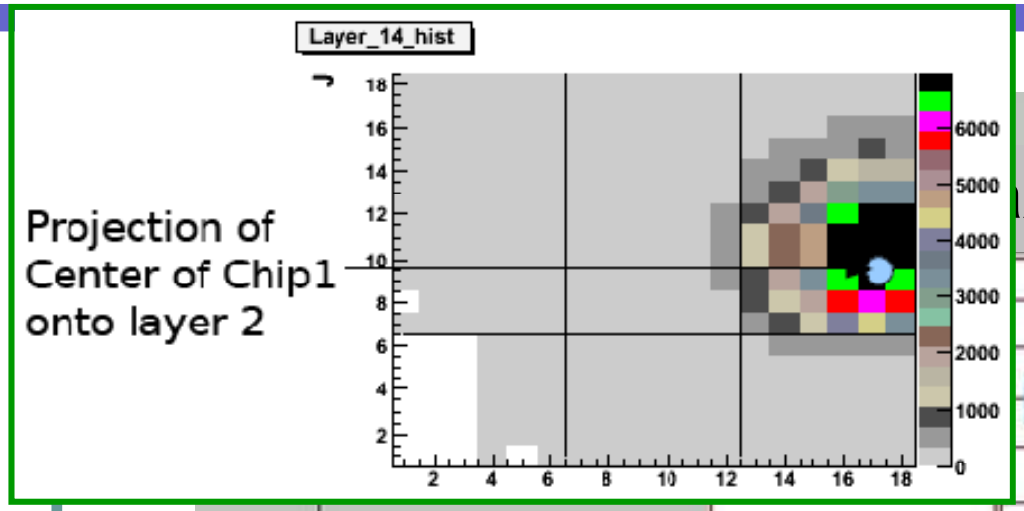
Irradiation of one PCB
(see next slide)

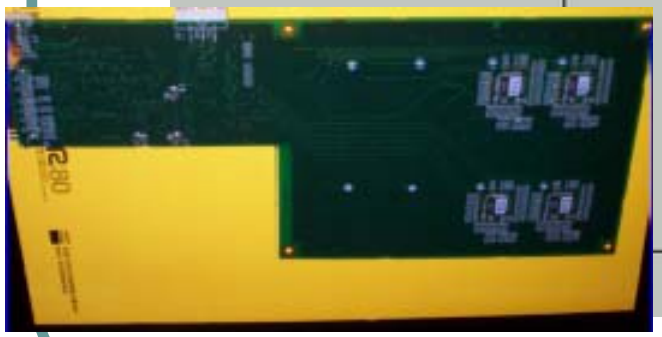
AHCAL alone runs



Plots made during shifts,
no corrections applied

Irradiation of ECAL PCB





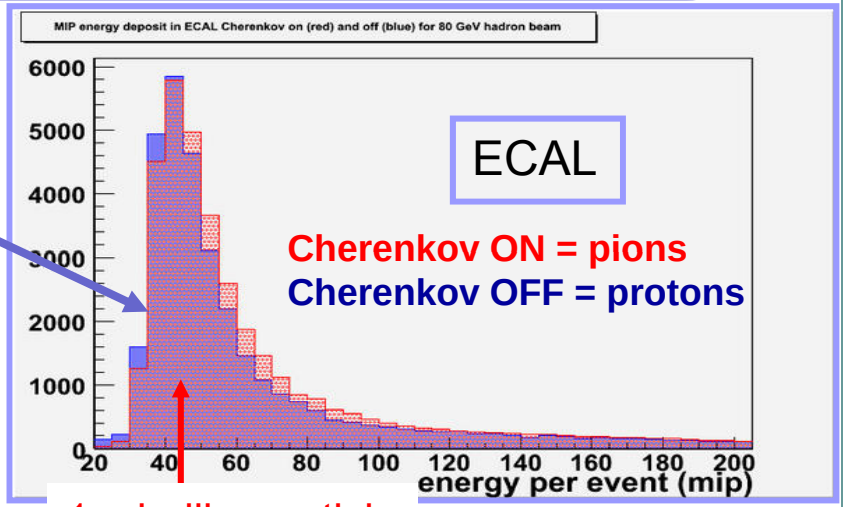
Test of one PCB with embedded electronics

5 position scan for each of the 4 chips on the special ECAL slab
- 90 (and 70) GeV electron beam used
~1.2 M events per chip

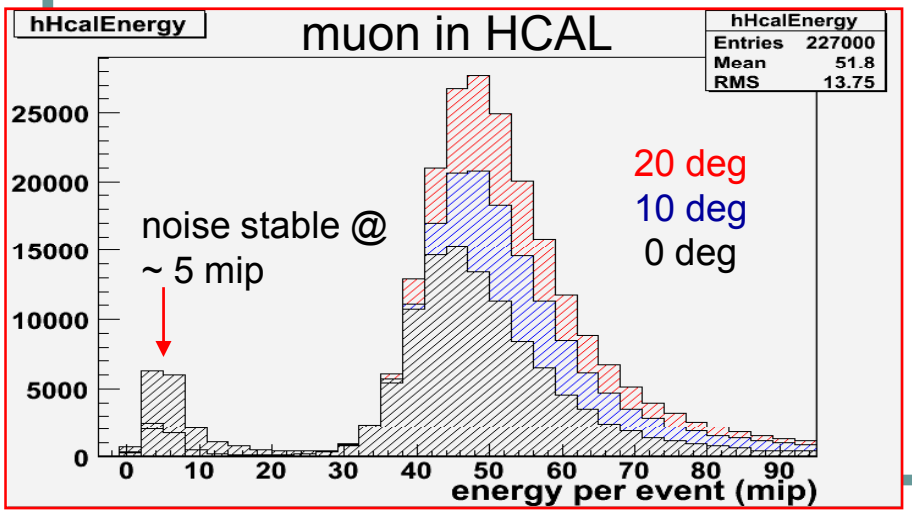
CALO response to p/μ beam

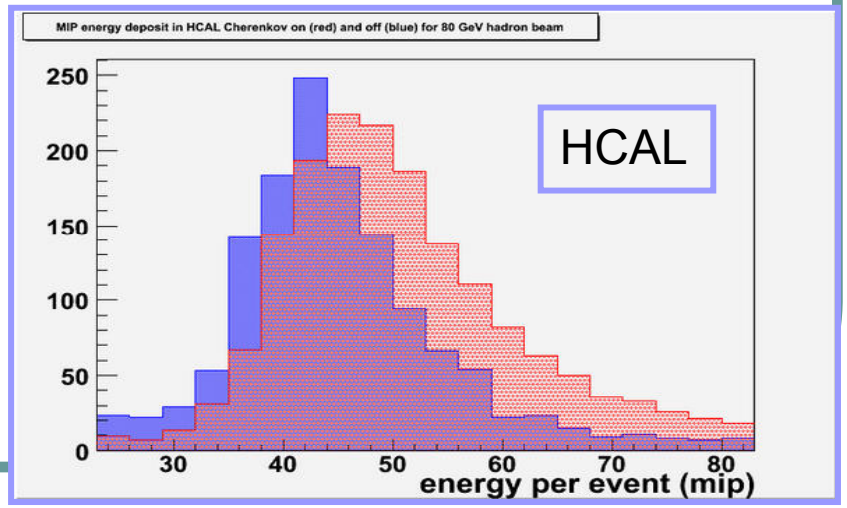
ECAL and AHCAL response to π and protons, distinguished using signal from Cherenkov detector

AHCAL calibration performed using samples of several million muons at the different angles

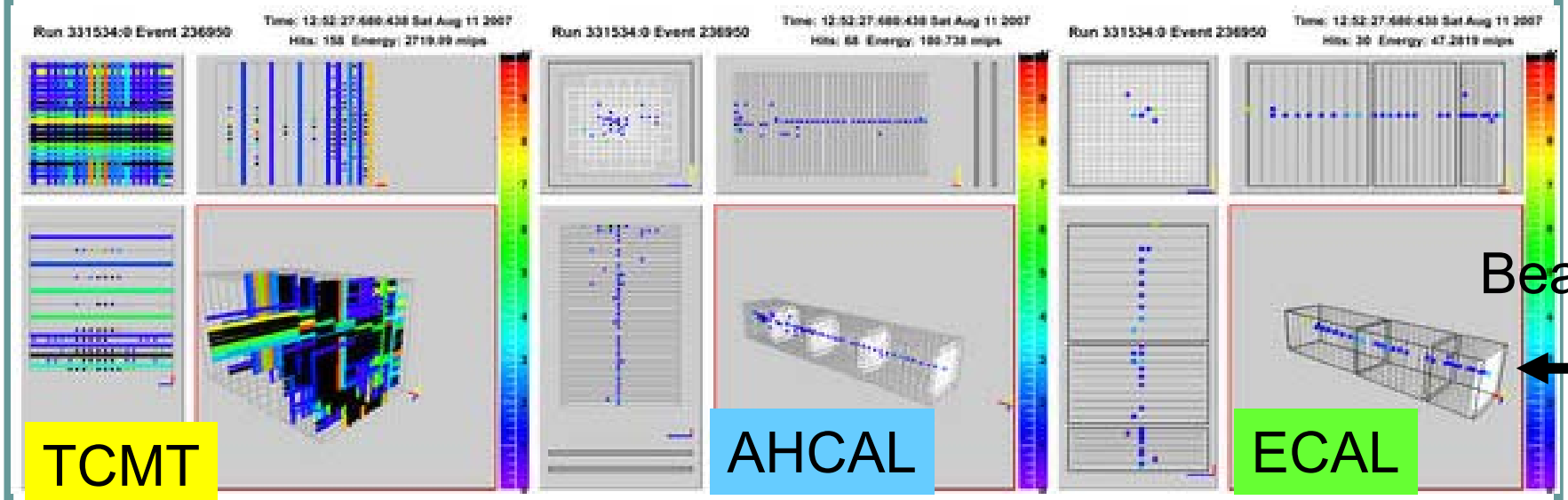


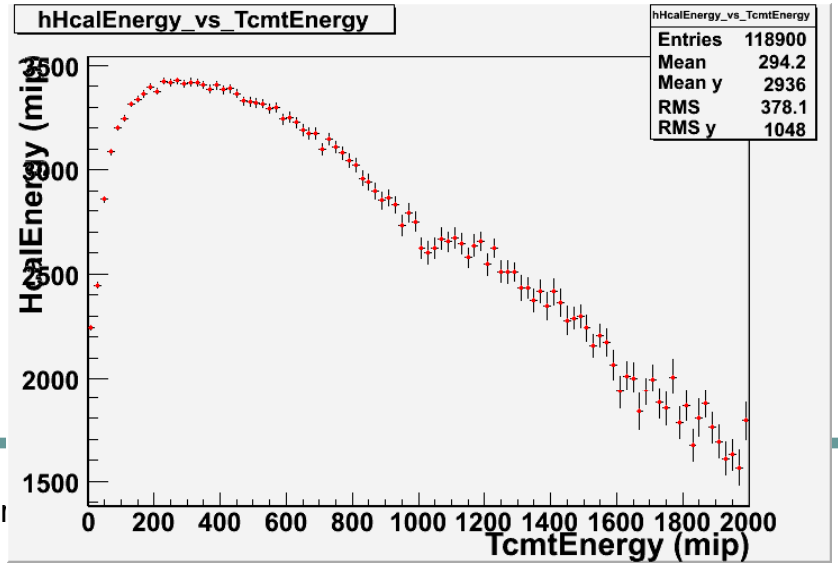
1 mip-like particle





TCMT response





180 GeV pion
strong AHCAL-TCMT
anti-correlation

Summary of data taking time

Time since 5th of July	4 147 200 sec
14.4s super-cycle	2 389 798 sec
16.6s (20.4s) super-cycle	889 829 sec
Power cuts	86 400 sec
Summer students	57 600 sec
π/e/p data	1 790 698 sec
muons (100x100)	153 976 sec
muons (20x20)	131 752 sec
AHCAL only	365 195 sec
Calibration	318 447 sec
SPS up-time	79.1%
Beam controlled by H6B	76.1% (96.2% of up-time)
DAQ taking analysis data	62% (81.5% of beam in H6B)
DAQ on calibration	15.1%

Summary of the 2007 test beam

- This year's test beam has been a huge success !
  - All active elements of calorimeters completed
  - Movable mechanics commissioned
- The test beam programme has been completely fulfilled, thanks to the hard work of everyone involved and to the extra weeks given to us by CERN
- The participation in the test beam has been incredible and full of enthusiasm from everyone in the collaboration
- We have ~14 TB of data available on the grid ready to be analyzed

Analysis of 2007 data under way

- Analysis of 2007 test beam data has started
  - ECAL
    - Physics performances: linearity and resol
    - Detector performances: study of noi ctors
    - Irradiation of test PCB with in tronics
    - Particle flow algorithm B data
  - AHCAL+TCMT
    - Detector s: calibration of SiPM
      emperature dependence of SiPM signal
      erformances: linearity and resolution
      mparison with existing MC models: characterization of electromagnetic and hadronic showers

Eagerly awaited by all ILC community !

The next test beam at FNAL

CERN test	Proposed plan for the test beam (4 weeks)	Achieved results at the test beam (7 weeks)
Particle type	$\pi^-(\pi^+)$, $e^-(e^+)$	$\pi^{+/-}$, $e^{+/-}$, protons.
Energy points (GeV)	6 - 80	6 - 180
Angles (deg)	0, 10, 15, 20, 30	0, 10, 20, 30

Preliminary ideas for the test at FermiLab:

- Low energy points: E < 6 GeV, e/π/p (minimum E = 0.5 GeV)
- Integration of prototypes: test of SiW/SciW-ECAL+AHCAL/DHCAL
- Physics program: establish data set for comparison with CERN data and AHCAL/DHCAL data
- Angles: 15 deg. (missing in 07 tb), 30 deg. ECAL+AHCAL
- Technical studies: ECAL noise, integrated chip, AHCAL long term stability…
- …

Conclusions and Outlook

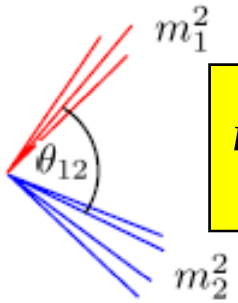
- The collaboration is very healthy !
- We are entering in the publications phase
  - Two papers are being prepared on the 2006 test beam, and will be out by the end of the year
  - Analysis on the 2007 data is well under way
    - Still a lot to do, but it is really worth doing it !
- We are growing !
  - Three new institutes asked to join last month
- Ready for our next phase of beam tests
  - Preliminary discussion on next year's tb programme already started

Looking forward to being at FNAL next spring !

Backup slides

Why 30%/√E ?

- Aiming at jet energy resolution giving di-jet mass resolution similar to Gauge boson widths



$$m^2 = m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta_{12}) \Rightarrow \frac{\sigma_m}{m} \approx \frac{\Gamma_{W/Z}}{m_{W/Z}} \approx 0.027$$

$$\frac{\sigma_{E_{jet}}}{E_{jet}} < 3.8\% \quad + \text{term due to } \theta_{12} \text{ uncertainty}$$

- Assuming $\sigma_E/E=\alpha(E)/\sqrt{E}$ (GeV)

$\Rightarrow \sigma_m/m \approx \alpha(E_j)/\sqrt{E_{jj}}$ (GeV)

$\Rightarrow \alpha(E_j) < 0.027\ \sqrt{E_{jj}}$ (GeV)

Tipical di-jet energies at ILC:

E_{jj}/GeV	$\alpha(E_{jj})$
100	< 27 %
200	< 38 %

$$\sigma_E / E = 0.30 / \sqrt{E_{jj}(GeV)}$$

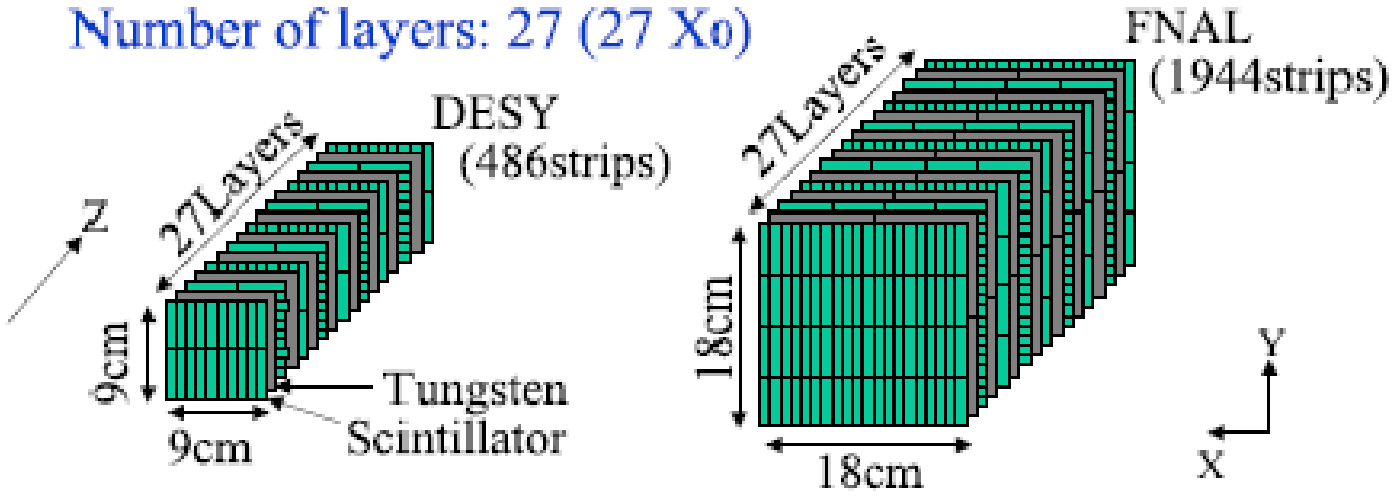
SciW ECAL prototype

Prototype ECAL - MPPC readout

Tungsten:3.5mm Sci. strip:3mm

Strip size: 1cm (width) x 4.5cm (length)

Number of layers: 27 (27 X0)



Cross section 9cmx9cm Test@DESY(This winter)

-> In EM shower (Non linearity of MPPC)

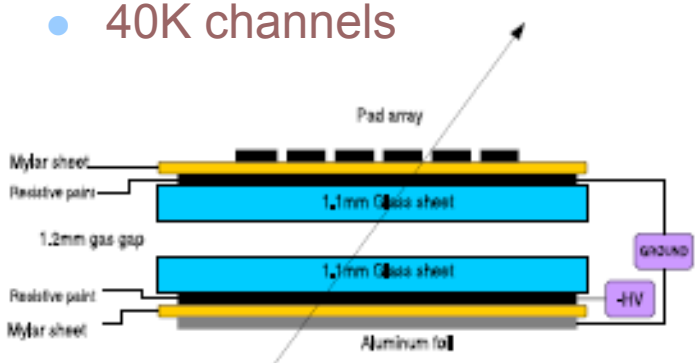
Cross section 18cmx18cm Test@Fermilab(2007)

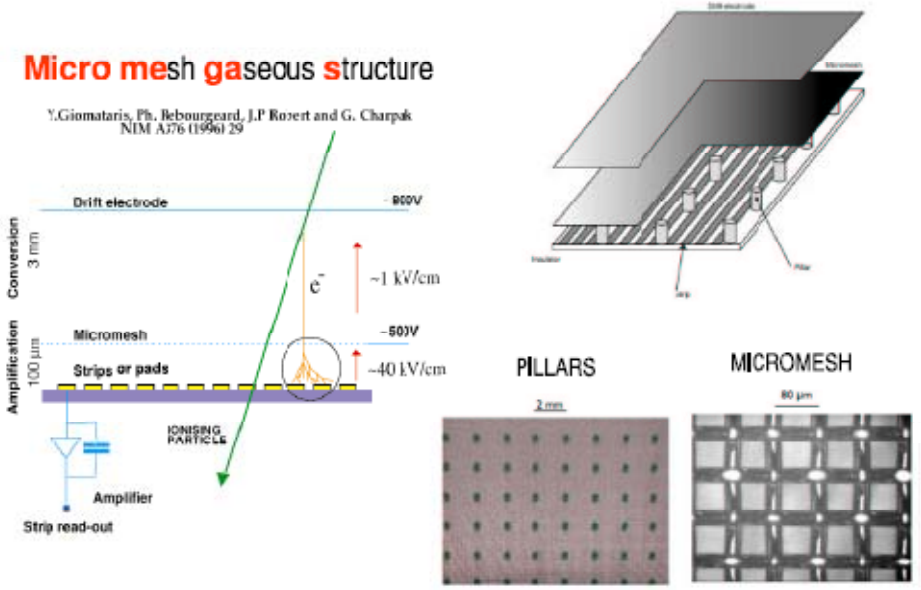
-> In multi particle injection / Pi0 reconstruction

(slide by T.Takeshita)

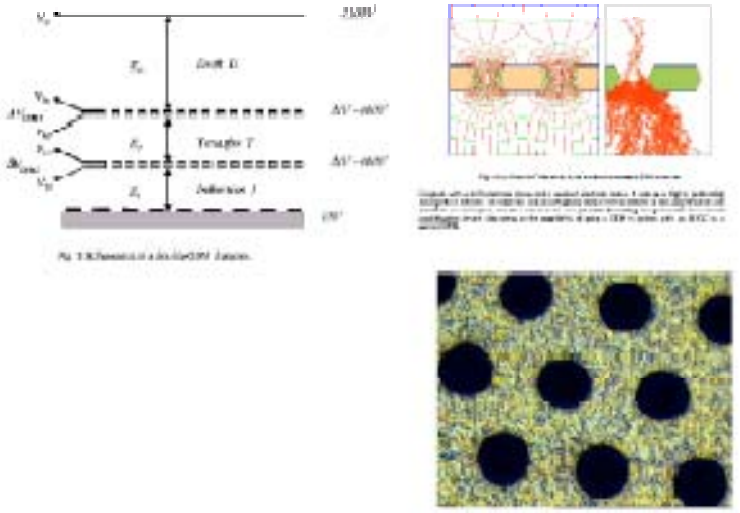
DHCAL prototypes

- RPC + steel absorber (1x1 cm^2)
  - 1m^3 prototype, 4.5 λ_I
  - 40K channels





- GEMs + steel absorber (1x1 cm^2)
  - 1m^3 prototype, 4.5 λ_I
  - 40K channels



- Layers equipped with Micro MEsh GAseous Structure chambers
  - Readout by pads or strips