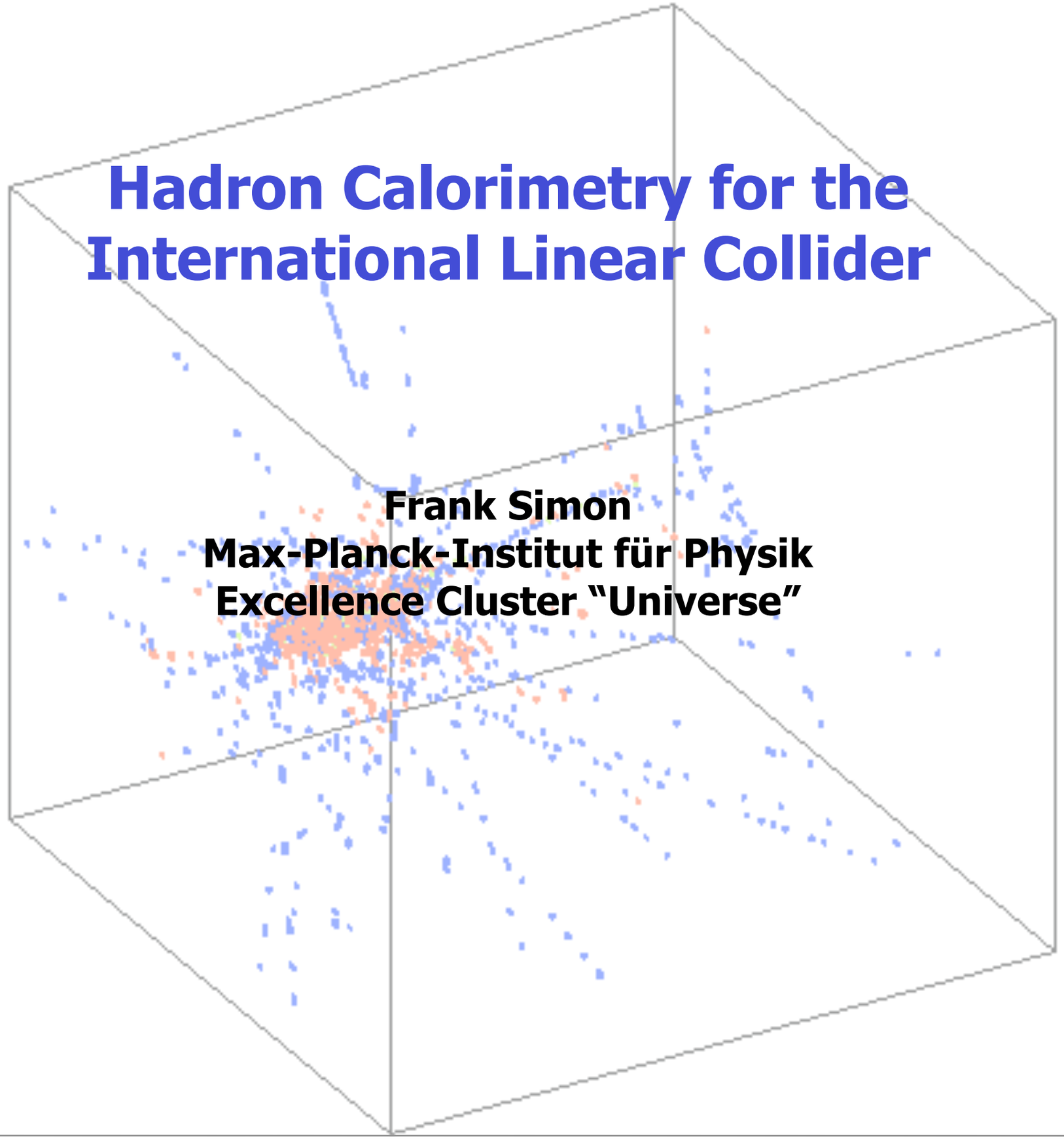
Hadron Calorimetry for the International Linear Collider



Frank Simon
Max-Planck-Institut für Physik
Excellence Cluster "Universe"

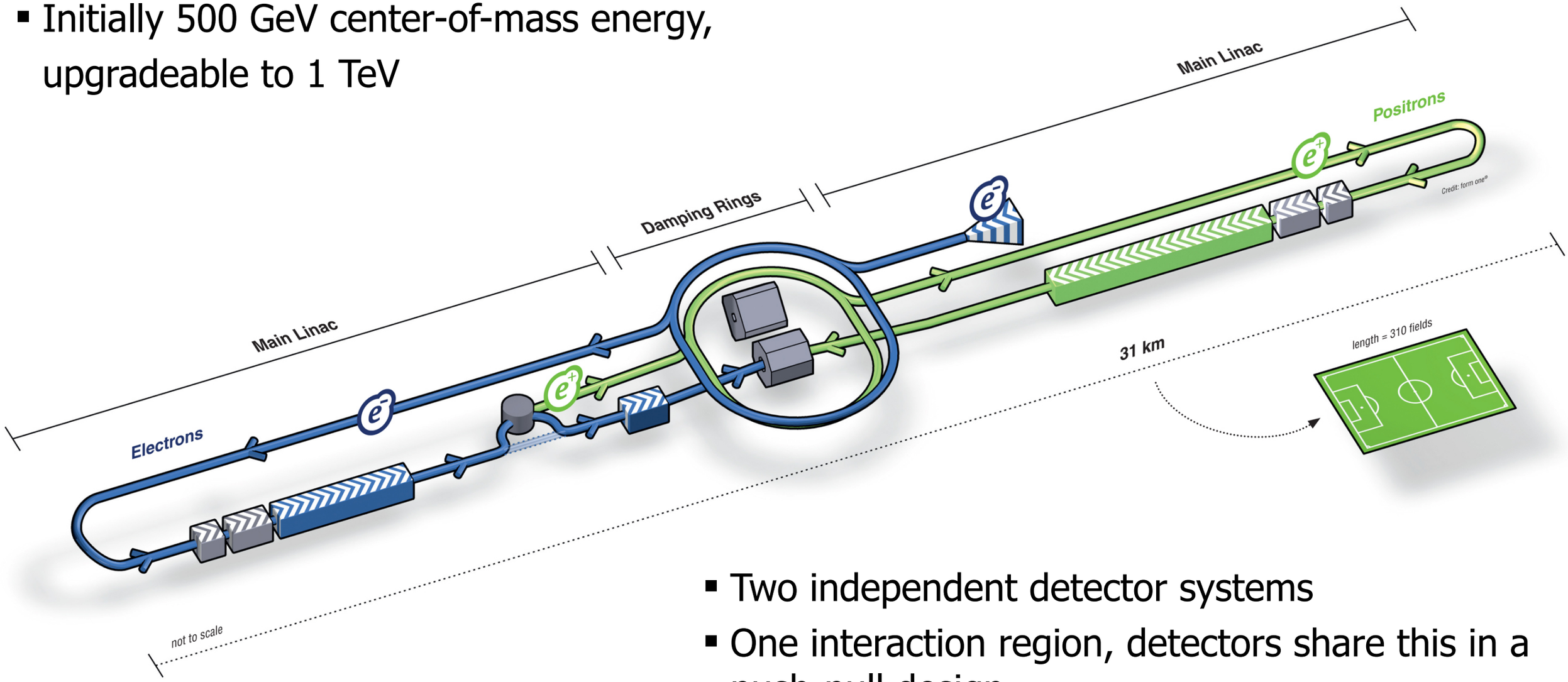
Outline

- The International Linear Collider: Requirements for Calorimetry
- The CALICE HCAL Prototype
- Test Beam Data
- Study of SiPMs
- An Idea for Digital Hadron Calorimetry
- Conclusion and Outlook

The Team: A. Frey, C. Kiesling, V. Morgunov, K. Prothmann, O. Reimann, F. Simon
... and more to come!

The International Linear Collider ILC

- Two superconducting linear accelerators, one for e^-, one for e^+
- Initially 500 GeV center-of-mass energy, upgradeable to 1 TeV



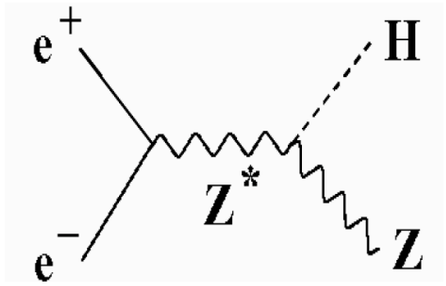
- Two independent detector systems
- One interaction region, detectors share this in a push-pull design

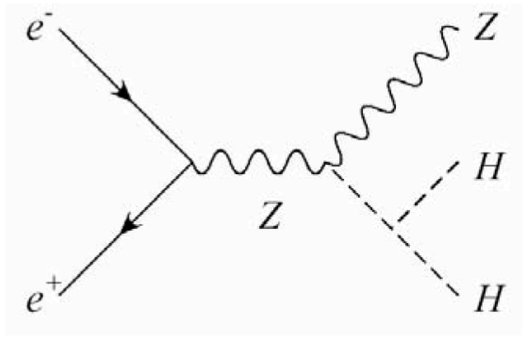
ILC Physics

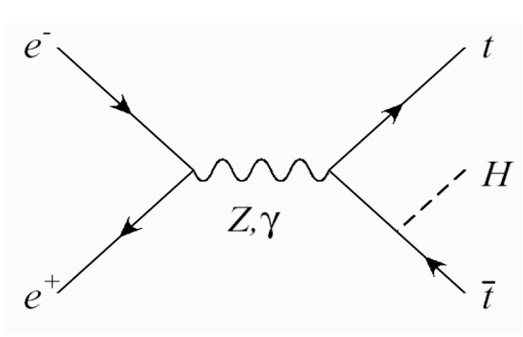
- Very rich program, depends on what LHC will find!

Examples:

- Precision Higgs studies







- Supersymmetry:
  - detailed measurement of the spectrum of supersymmetric particles
- Precision Standard Model Measurements: W, Z, top mass, α_s ...

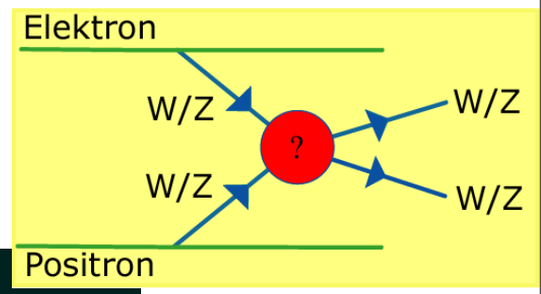
⇨typically large hadronic branching fractions

⇨ excellent jet energy resolution!

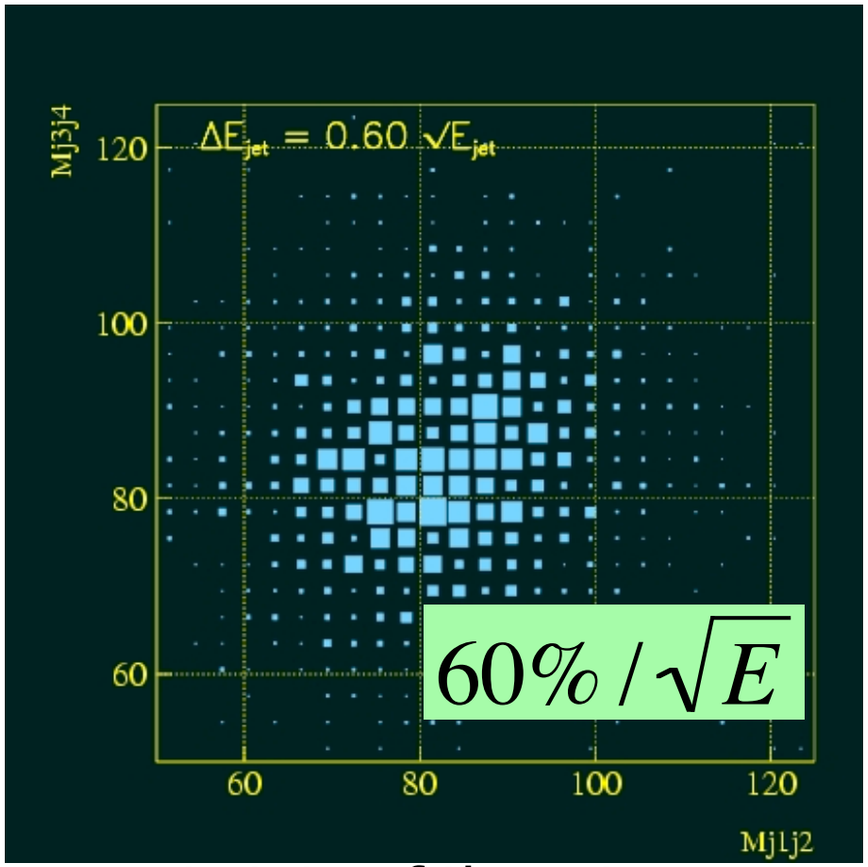
Required Jet Energy resolution

- Many final states of interest have multiple jets

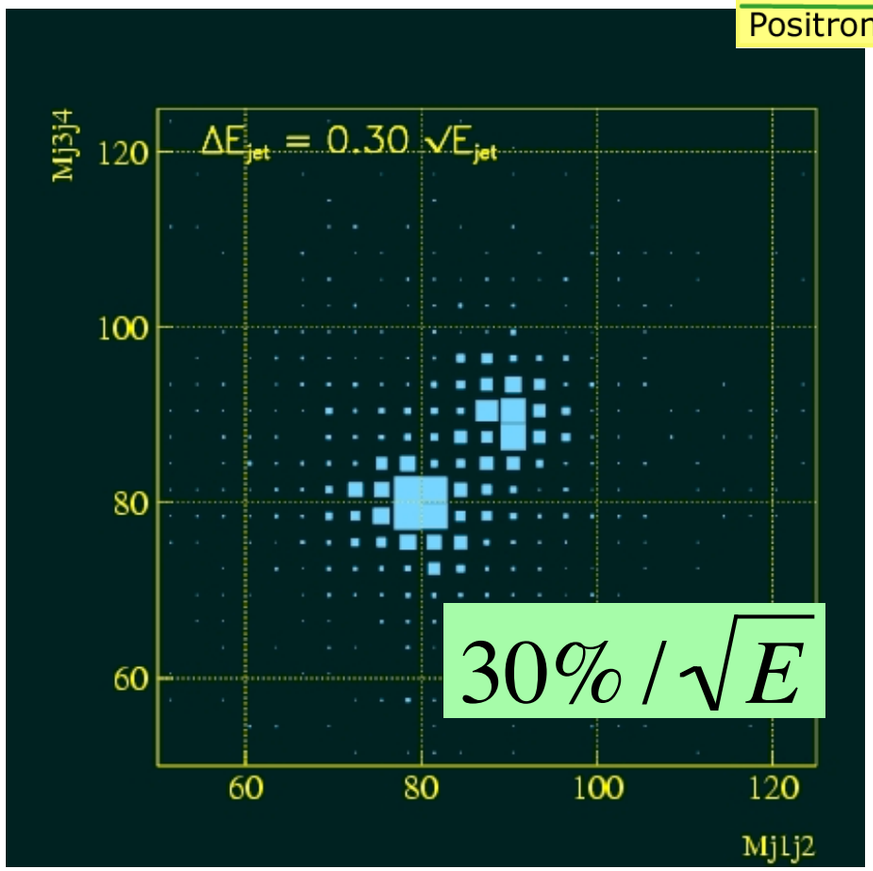
⇨Good jet energy resolution required, for example to distinguish W and Z in their hadronic decay modes



WW vs ZZ final states



present state of the art (LEP, LHC)



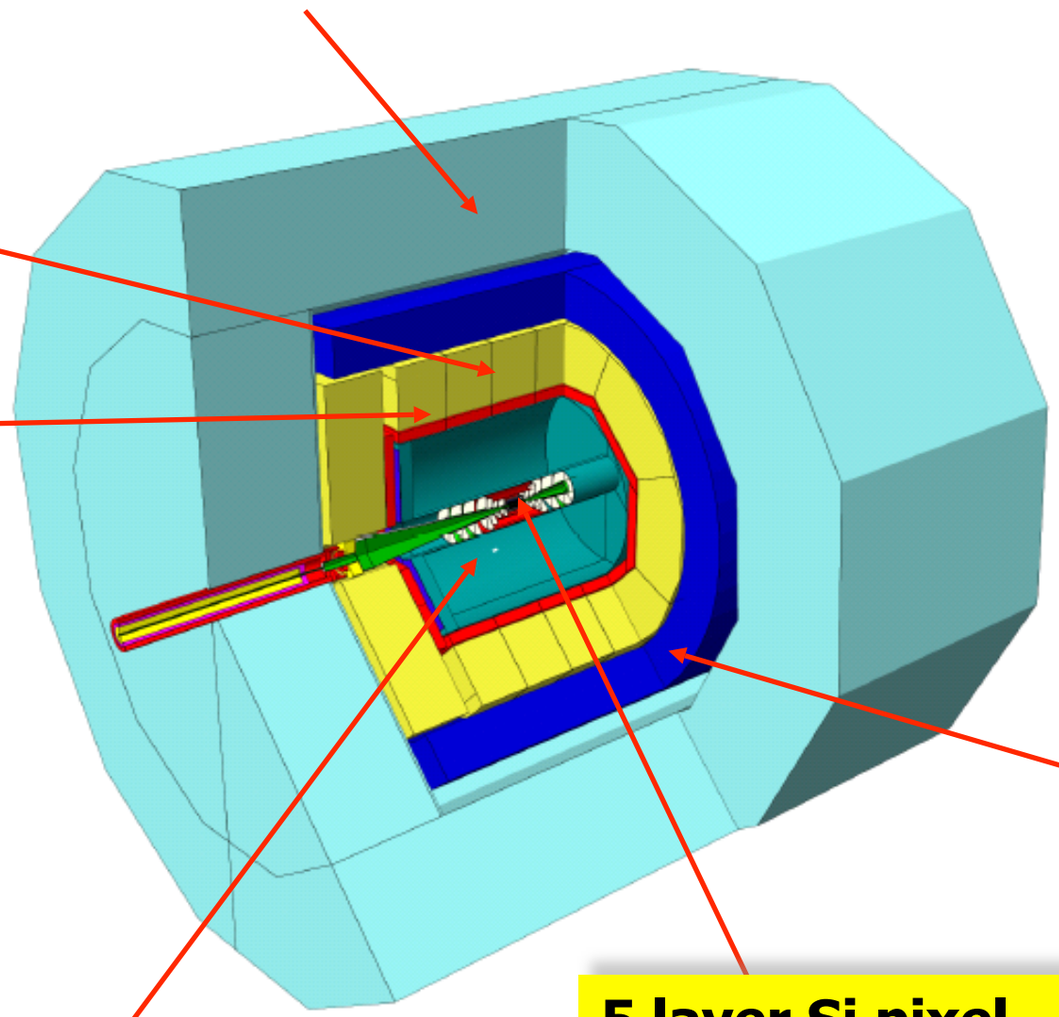
ILC goal

ILC Detector: Example LDC/ILD

Instrumented Iron Return Yoke

HCAL

ECAL

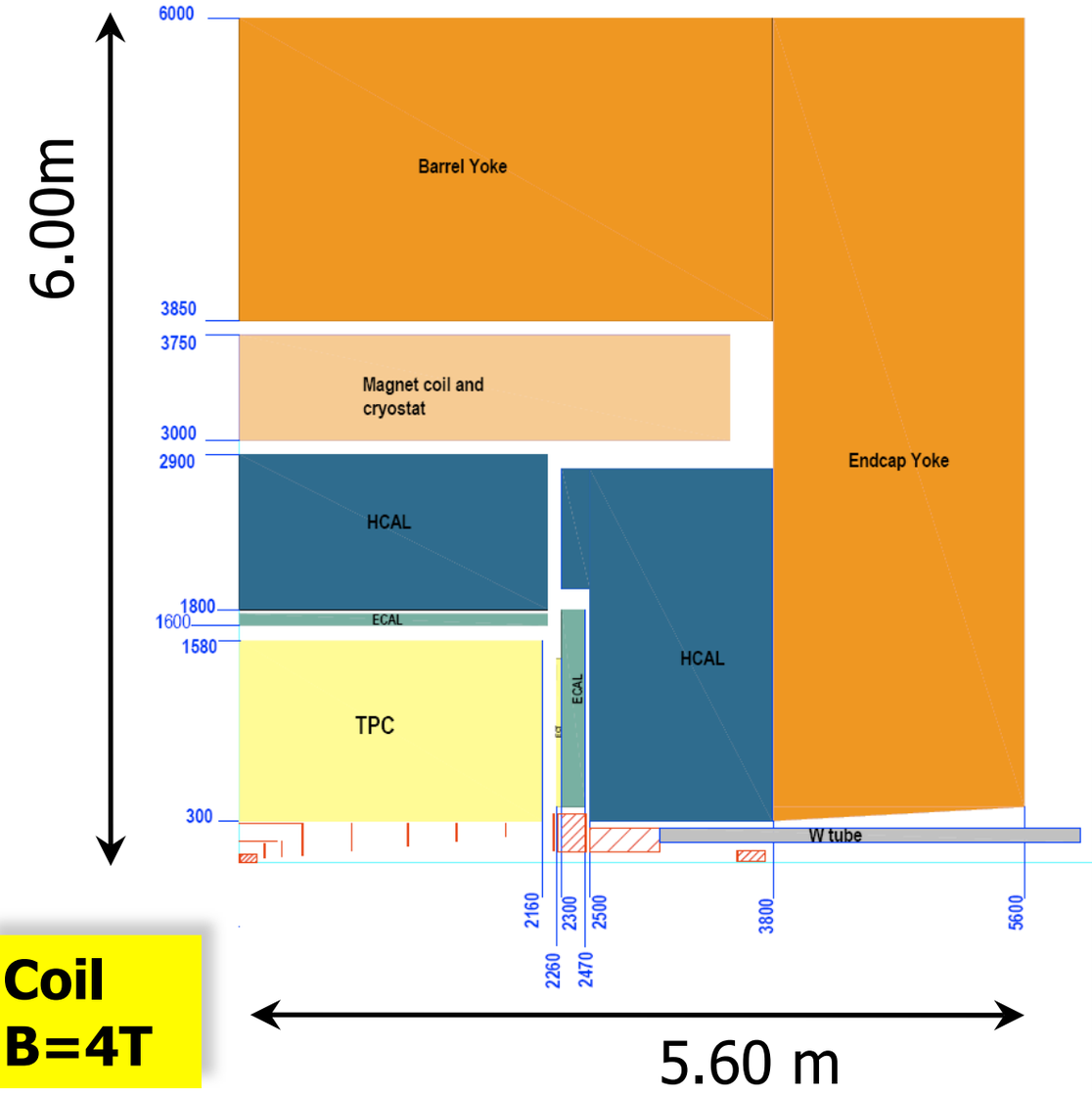


Coil B=4T

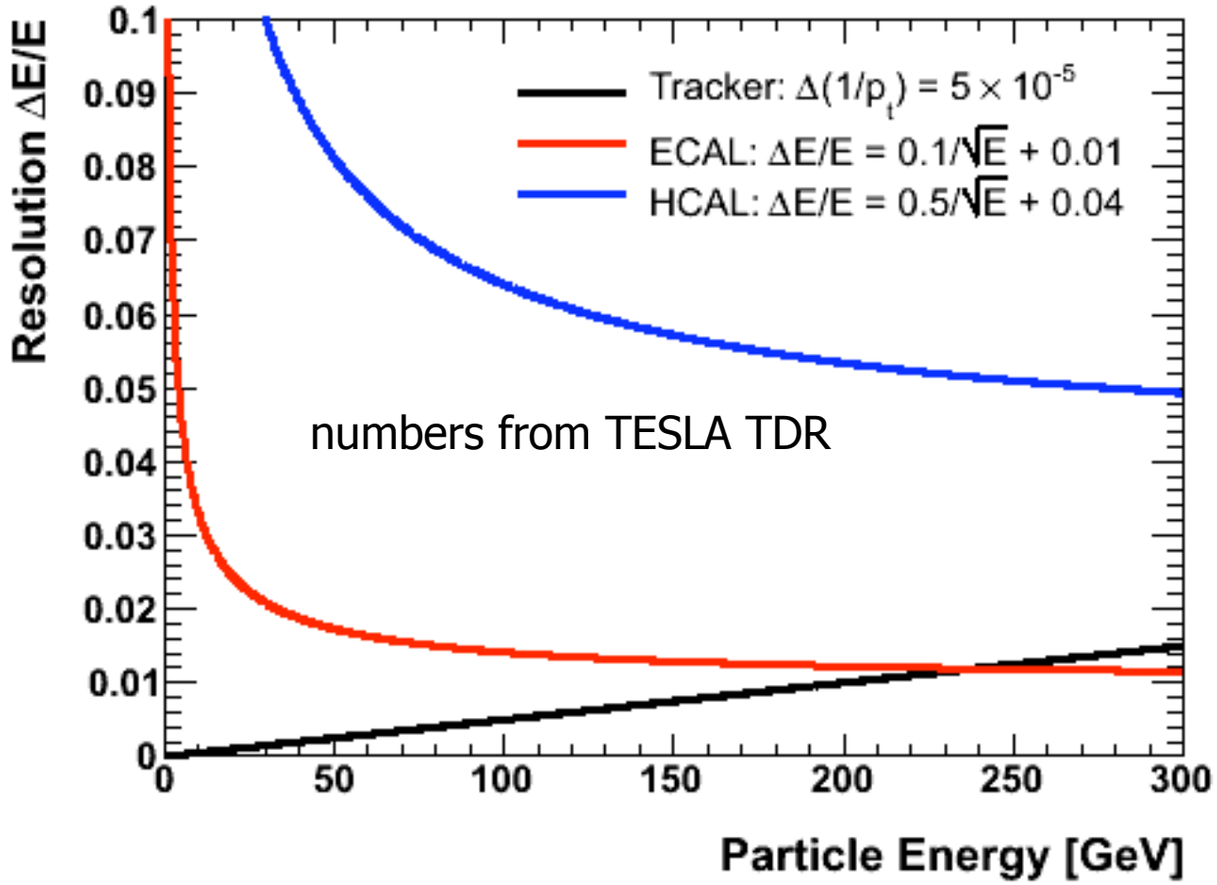
5 layer Si pixel

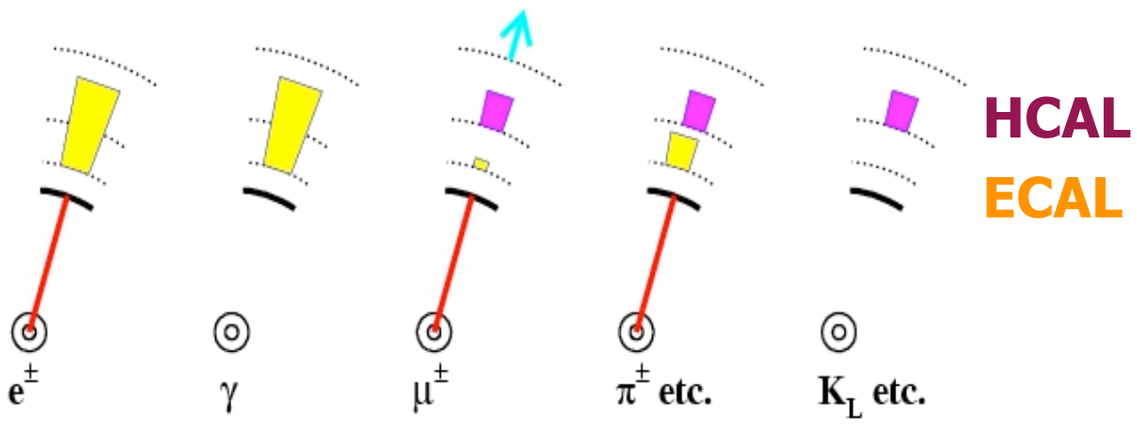
+ intermediate Si strips

Large TPC



Particle Flow: Optimized Jet Energy Measurement





- measure each particle type in the detector subsystem that provides the best resolution

  Tracker
  - charged hadrons
  - electrons
  - muons

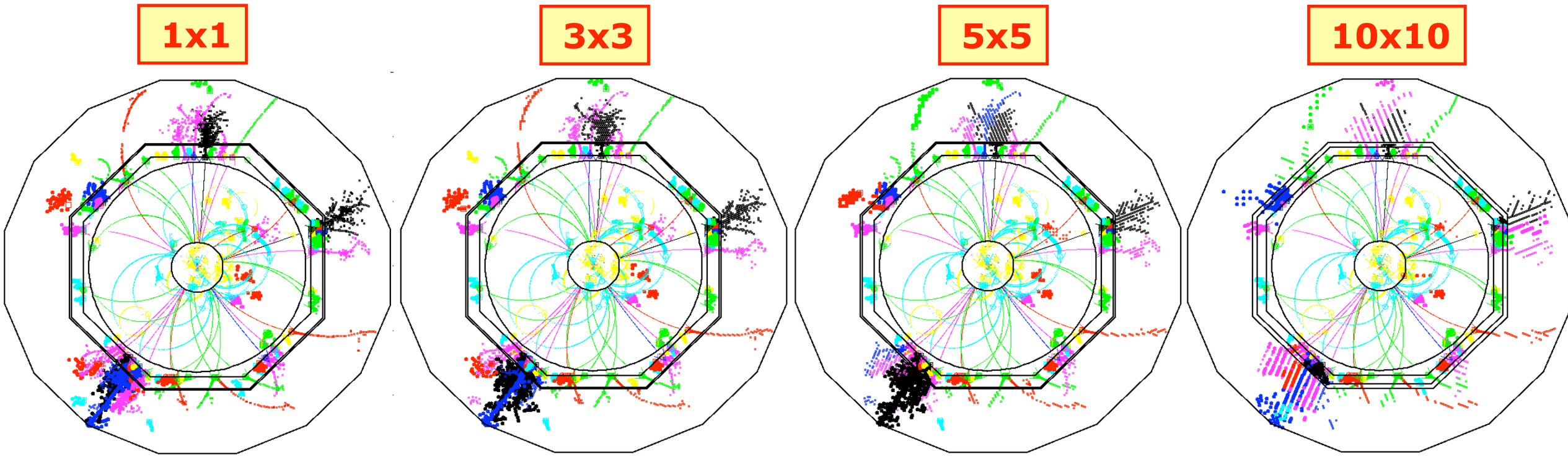
  Electromagnetic Calorimeter
  - photons
  - π^0

  Hadronic Calorimeter:
  - long-lived neutral hadrons

⇨ High granularity to disentangle individual particles

The Effect of Granularity in the HCAL

- Events as a function of HCAL granularity



Just by eye: You don't want to get larger than 3 x 3 cm^2

⇨ a technology is needed that allows such high granularity (and is affordable!)

Different Concepts for the HCAL

Analog Calorimeter

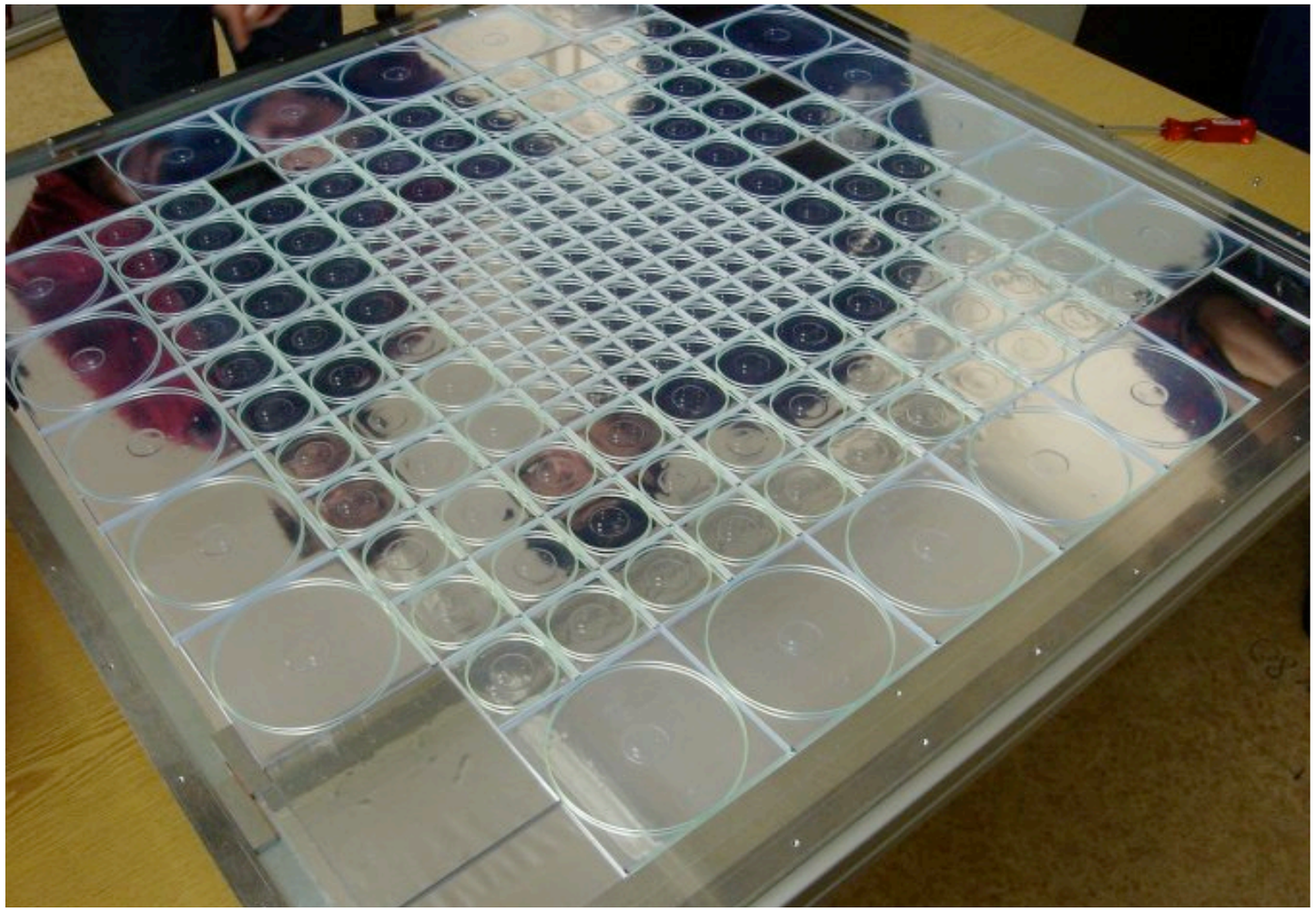
- Sampling calorimeter, plastic scintillator sandwiched between absorber layers
- Granularity achieved by using small scintillator tiles with individual readout
- Energy measurement uses the energy deposited in the scintillator

Digital Calorimeter

- Sampling calorimeter, active medium sandwiched between absorber layers
- Active Detectors under investigation:
  - Resistive Plate Chambers (RPC)
  - Gas Electron Multipliers (GEM,ThickGEM)
  - Micromegas
- Granularity achieved with small readout pads for each layer
- Energy measurement only uses the number of hit pads

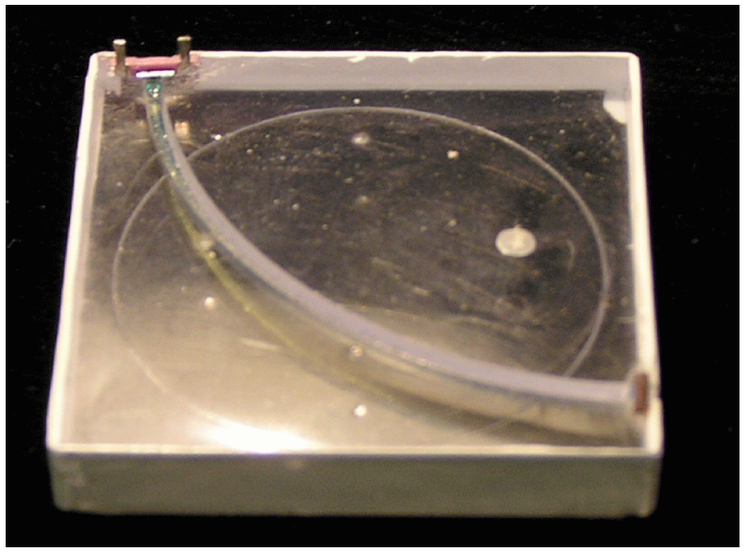
Tile HCAL Testbeam Prototype

- 1 cubic meter
- 38 layers, 2cm steel plates
- 7608 tiles with Silicon Photo-Multipliers

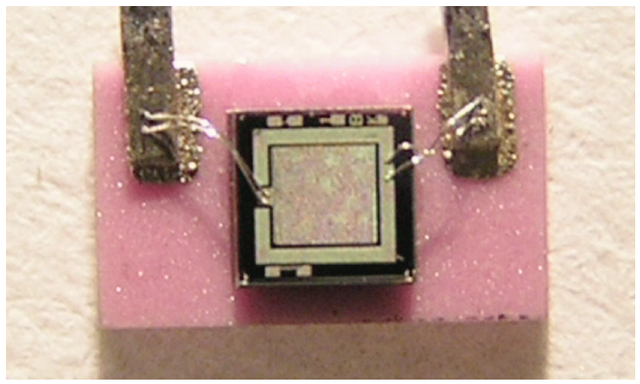


CALICE Calorimeter for ILC

one tile with WLS fiber



Silicon PM:



Test beam installation

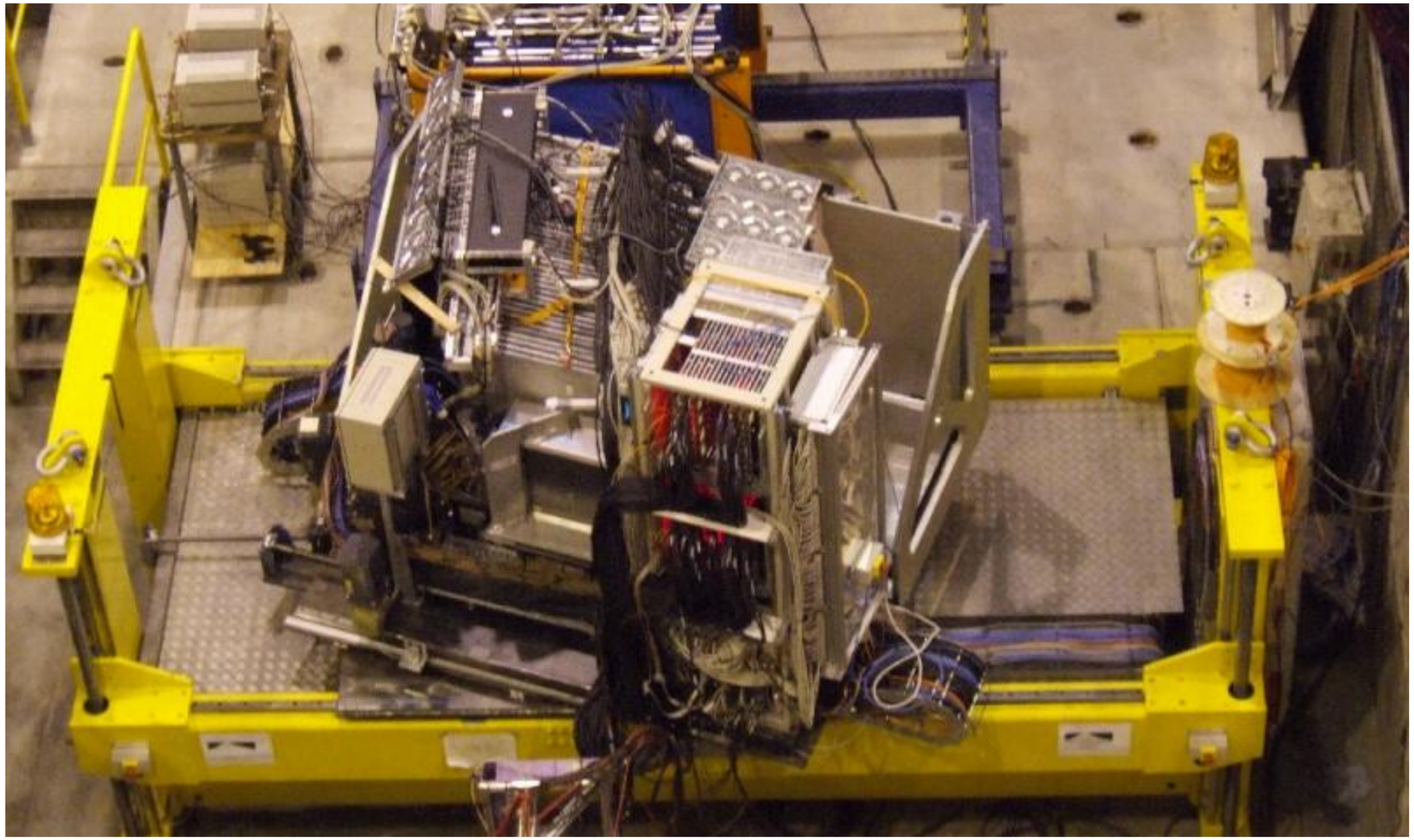
- Tested at the CERN SPS in 2006 and 2007

- Muons, electrons, pions, protons

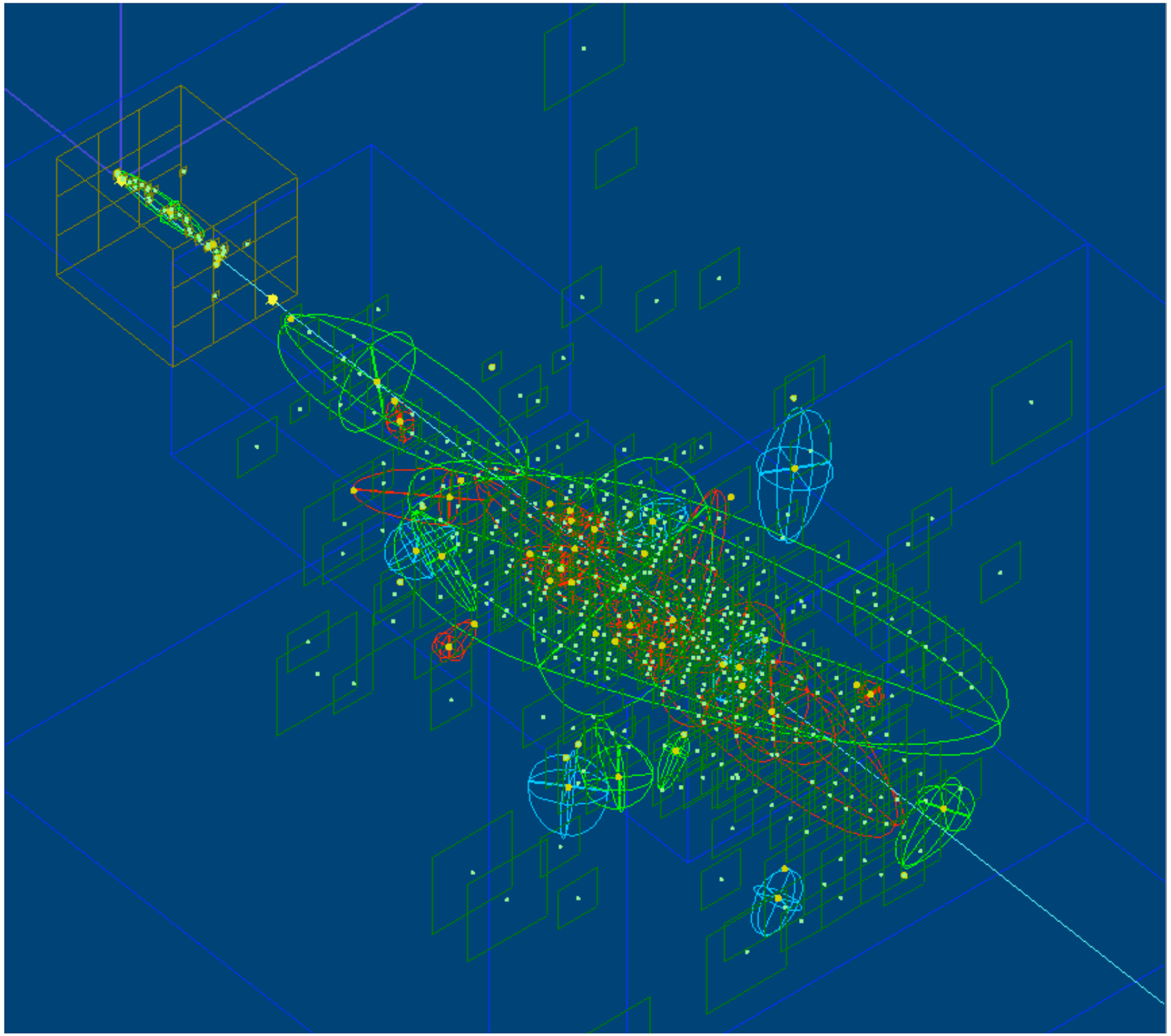
- 6-180 GeV

- ~ 200 million events

- With & w/o ECAL

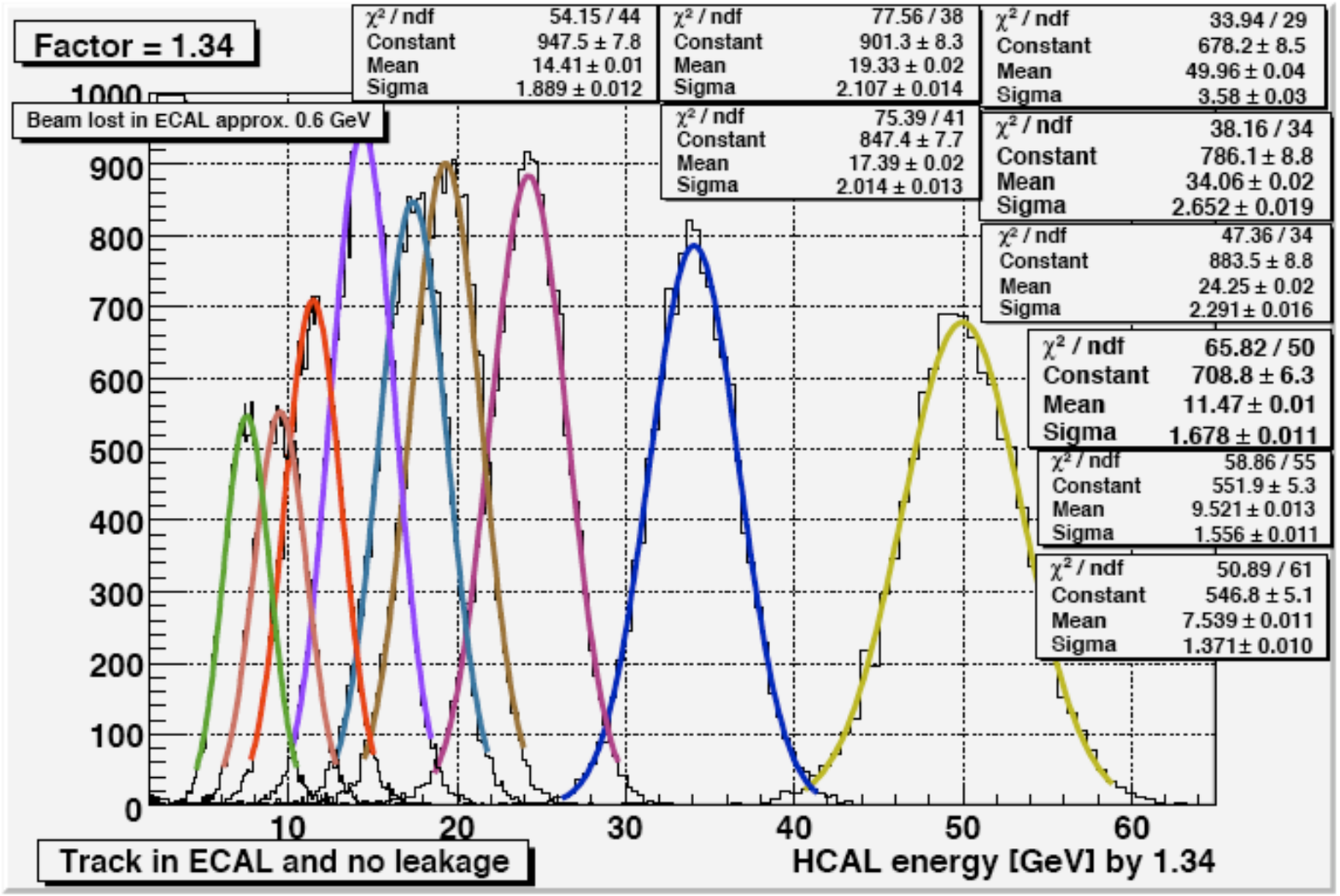


CALICE Test Beam



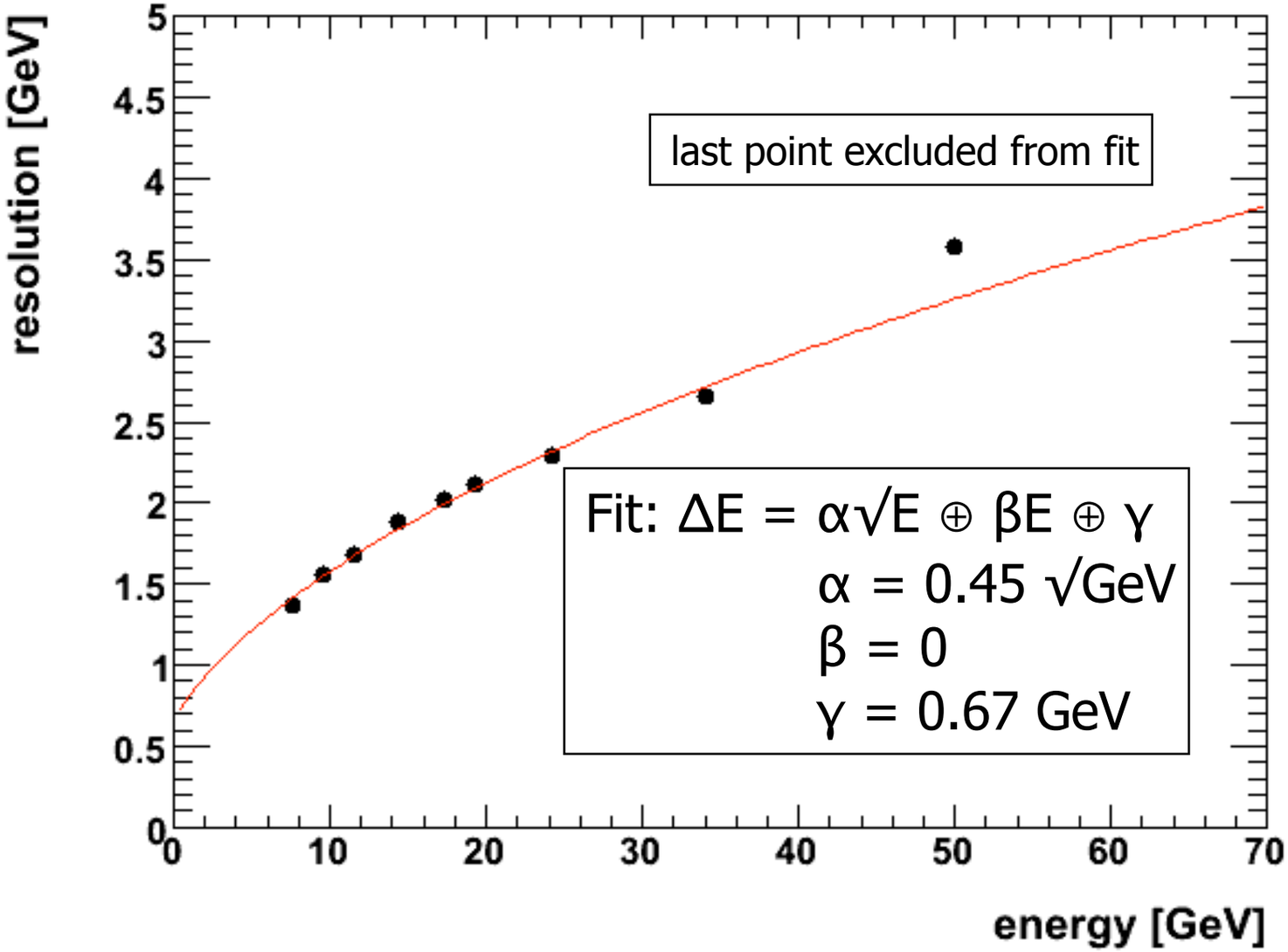
- 150 GeV π

CALICE Test Beam: First Results



- Reconstructed energy for contained hadronic showers
  - no weighting procedure applied
  - shower energy calculated directly from deposited energy in the calorimeter tiles

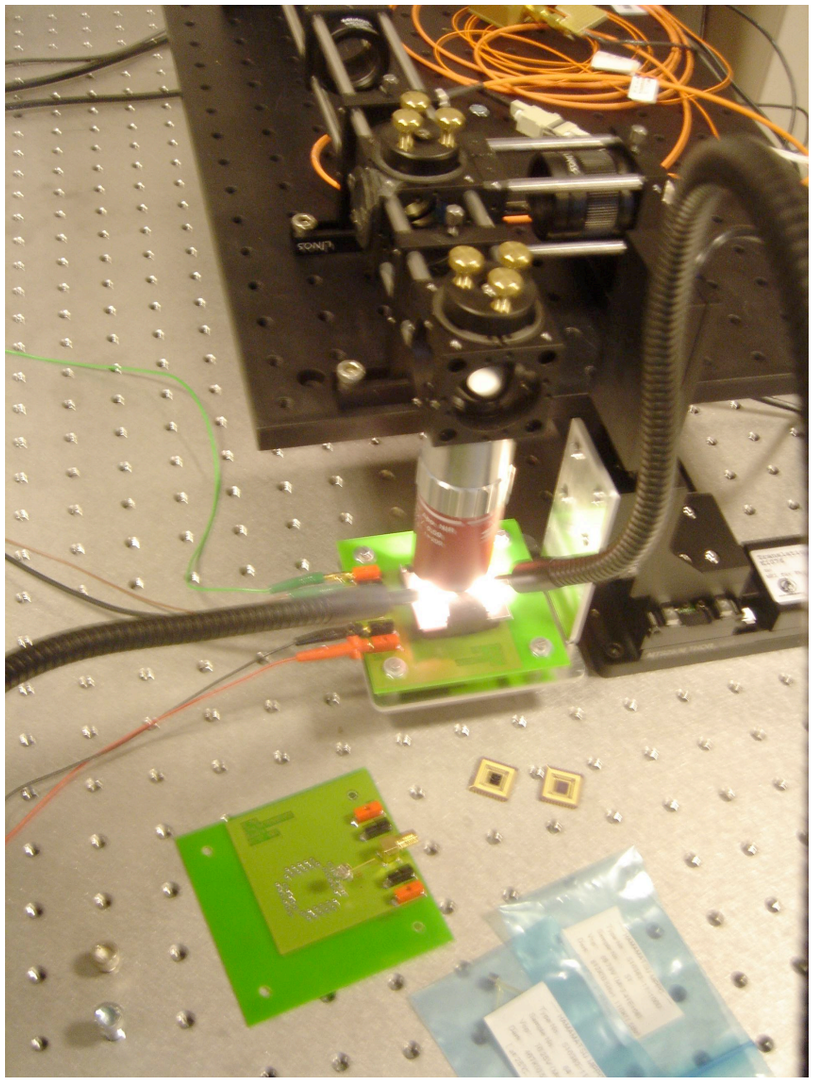
First Results: Energy Resolution

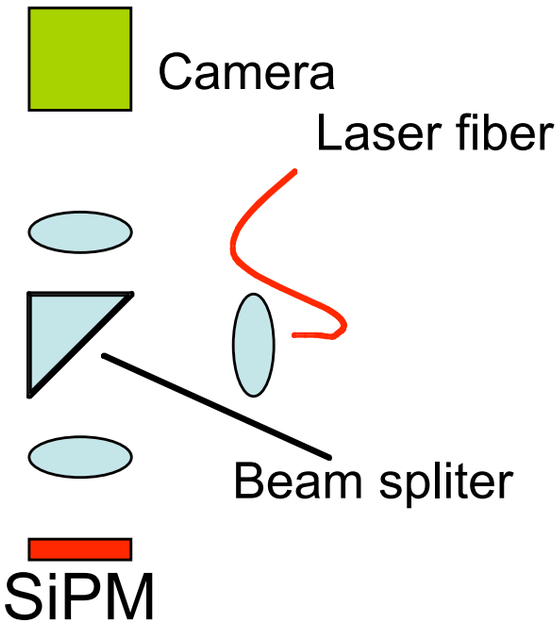


- Energy resolution for fully contained showers (tail-catcher < 1 GeV)
- Energy determined from energy deposit in scintillator, e/π calibration and MIP calibration

Study of Silicon Photomultipliers

- Test setup for SiPMs

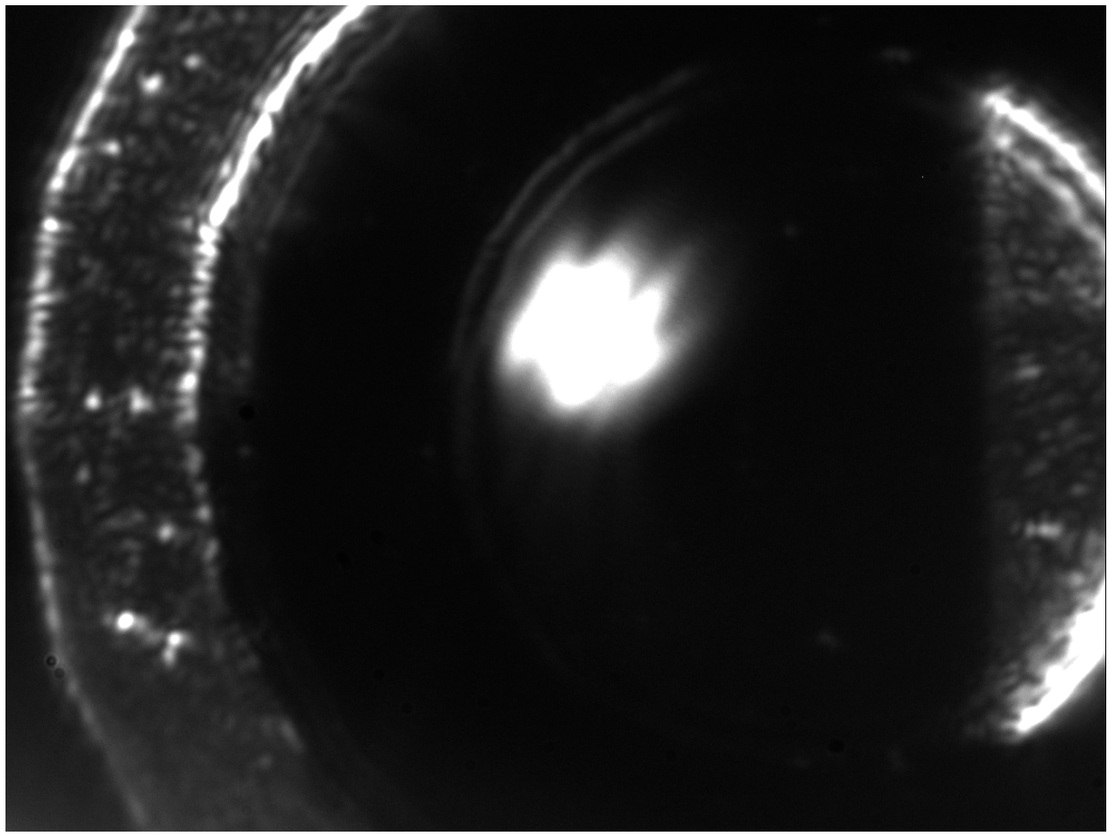




850nm laser spot on SiPM pixel
Sensitive area of pixel $(25\mu m)^2$

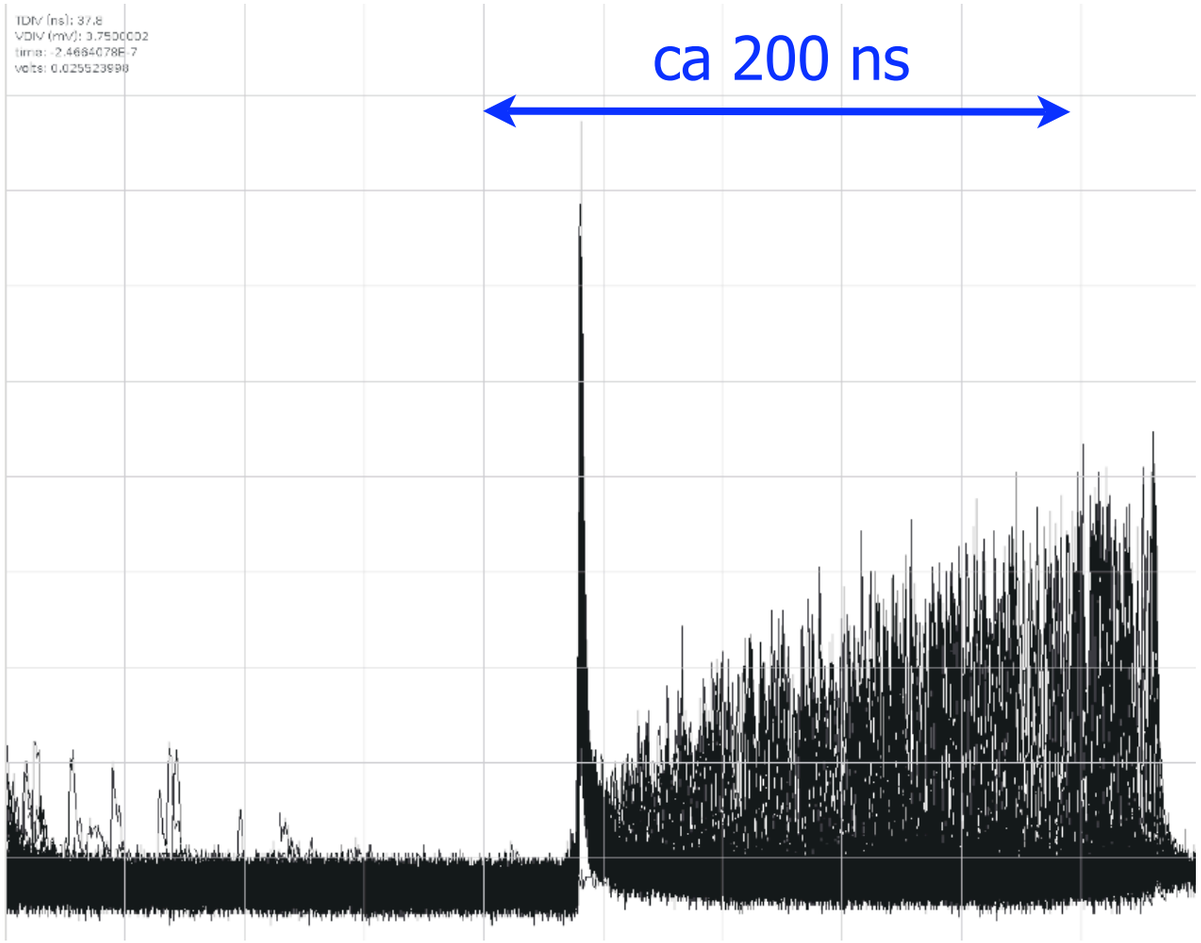
Scanning over pixel to characterize the response (uniformity etc.)

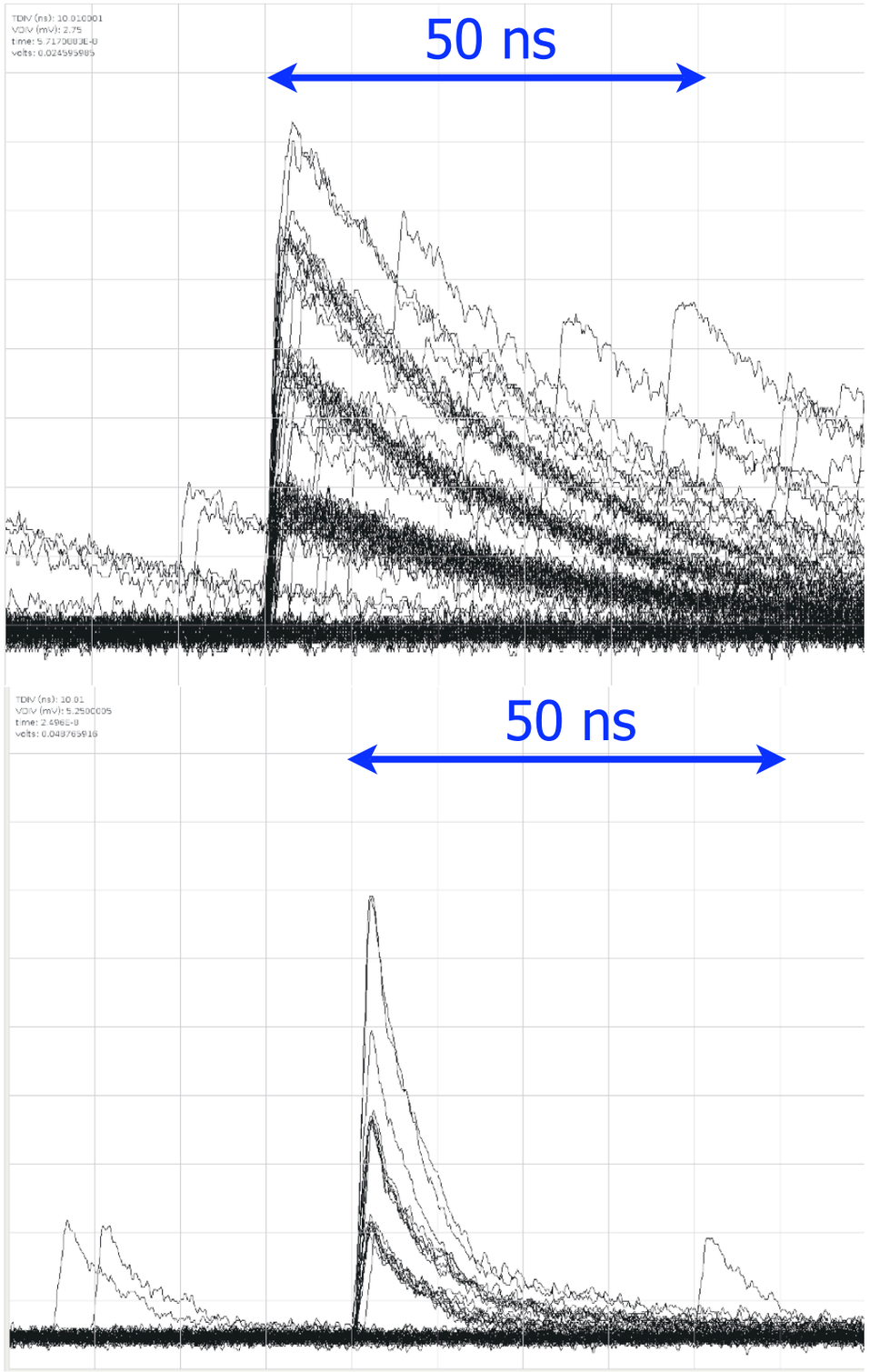
XYZ Stage
Laser and Fiber Collimator
sensitive to NIR microscope optics



SiPM Response to short Laser Pulse

Amplitude dependence on time between pulses (recovery time)





Hamamatsu 100UI

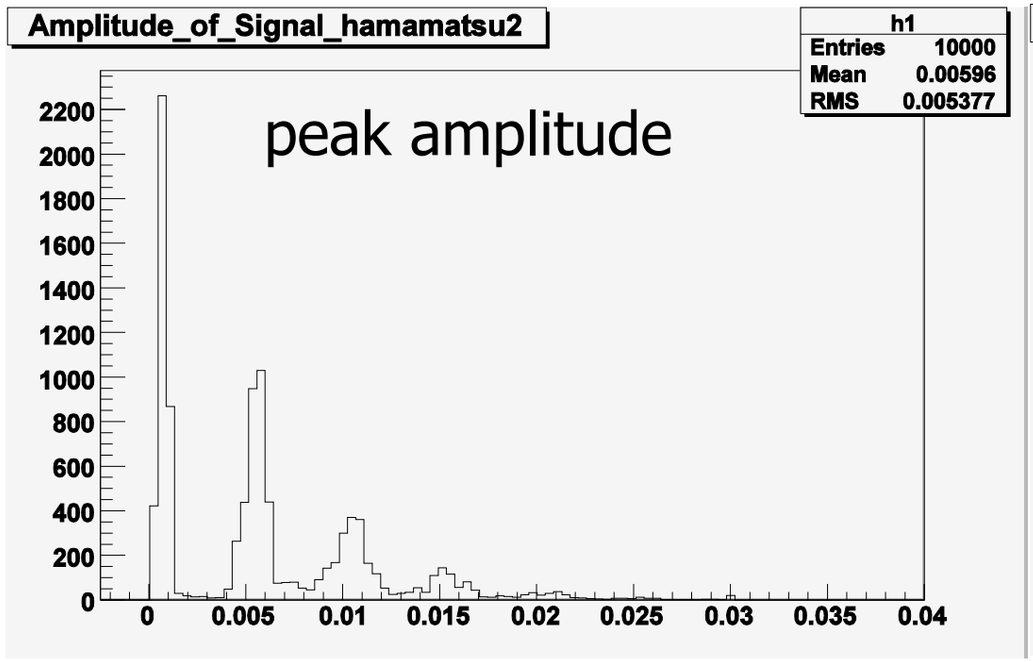
100 Events

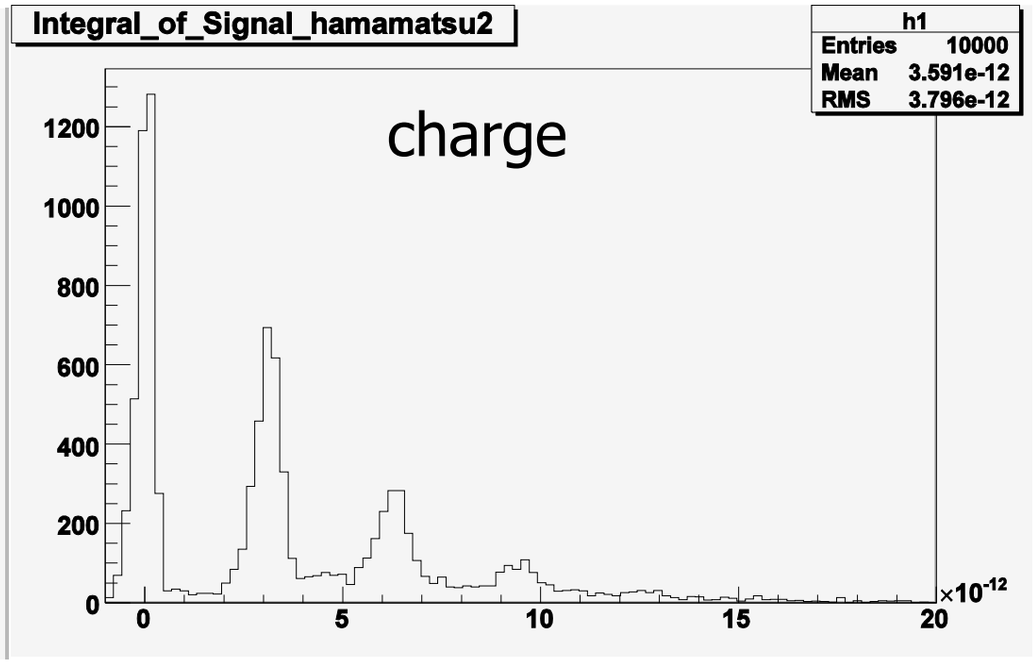
HLL Test array

100 Events

- different SiPMs:
  - different pixel size
  - different quenching resistor

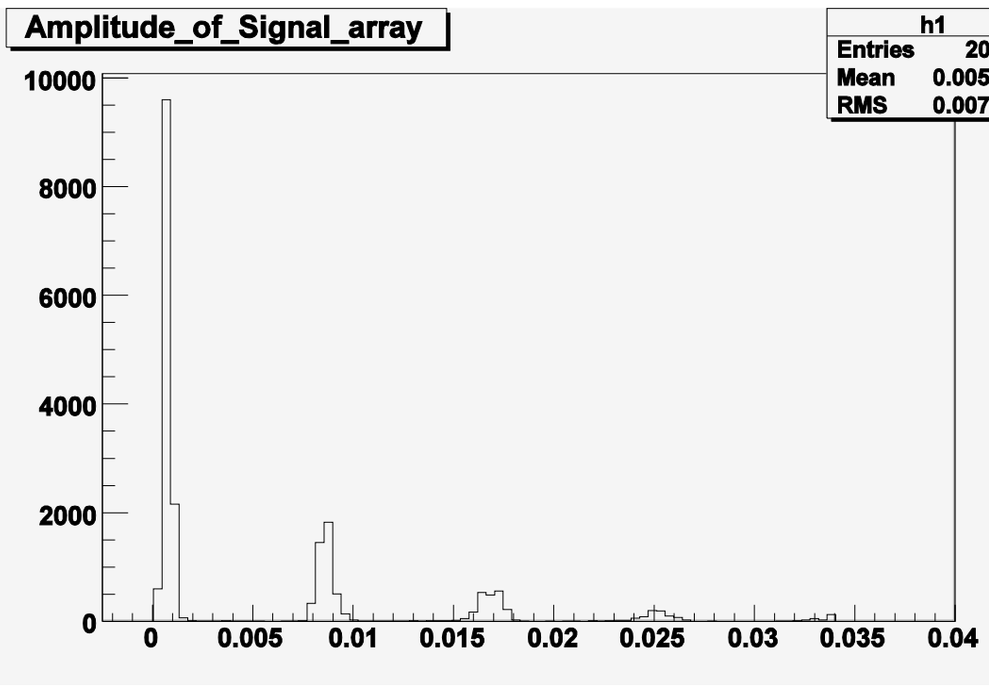
Amplitude and Charge

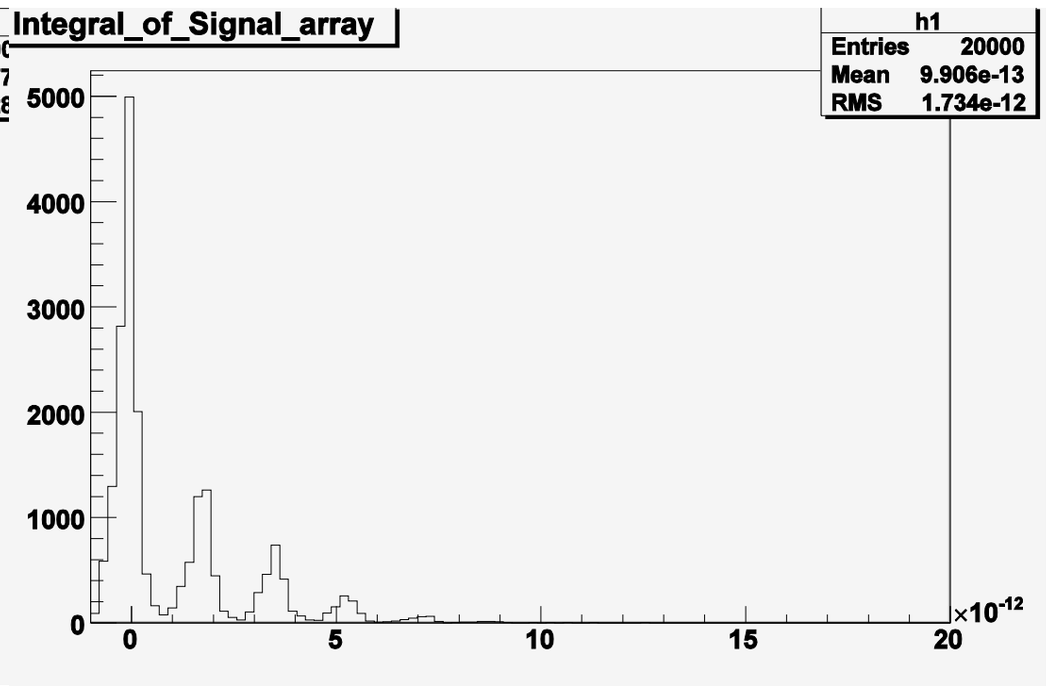




SiPM

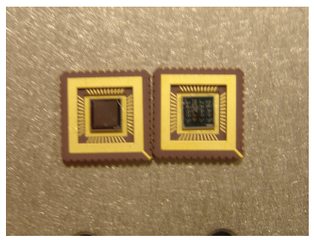
Hamamatsu 100U





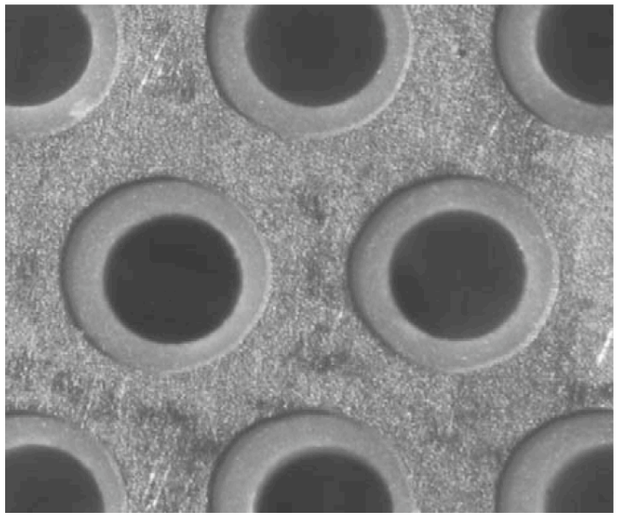
SiPM

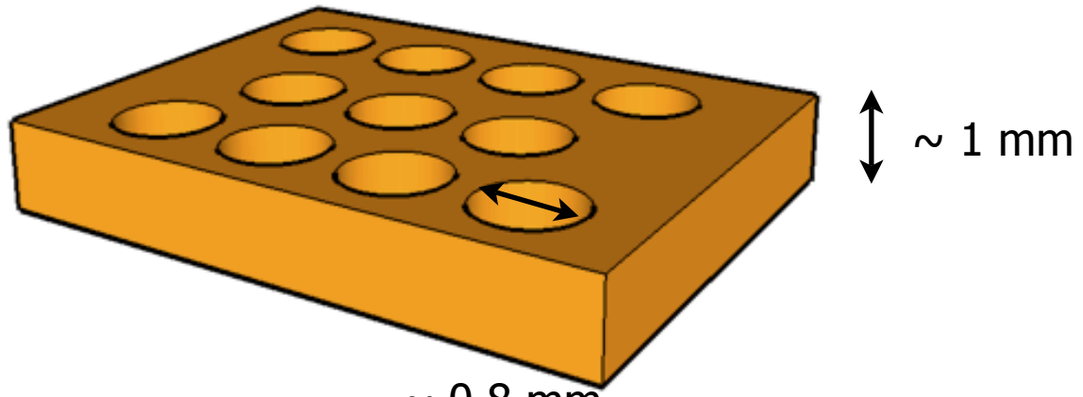
HLL Test Array

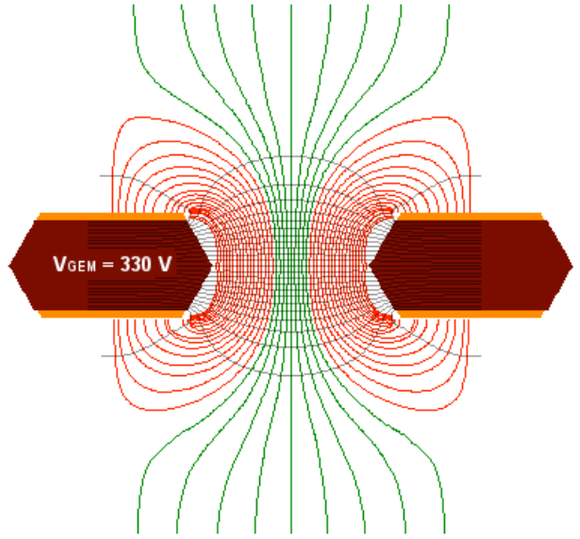


ThickGEMs for a Digital HCAL

- Printed circuit board or other insulator with conducting layer on both sides
- perforated with many small holes (diameter ~ thickness)
- produced by mechanical drilling and additional etching around the holes





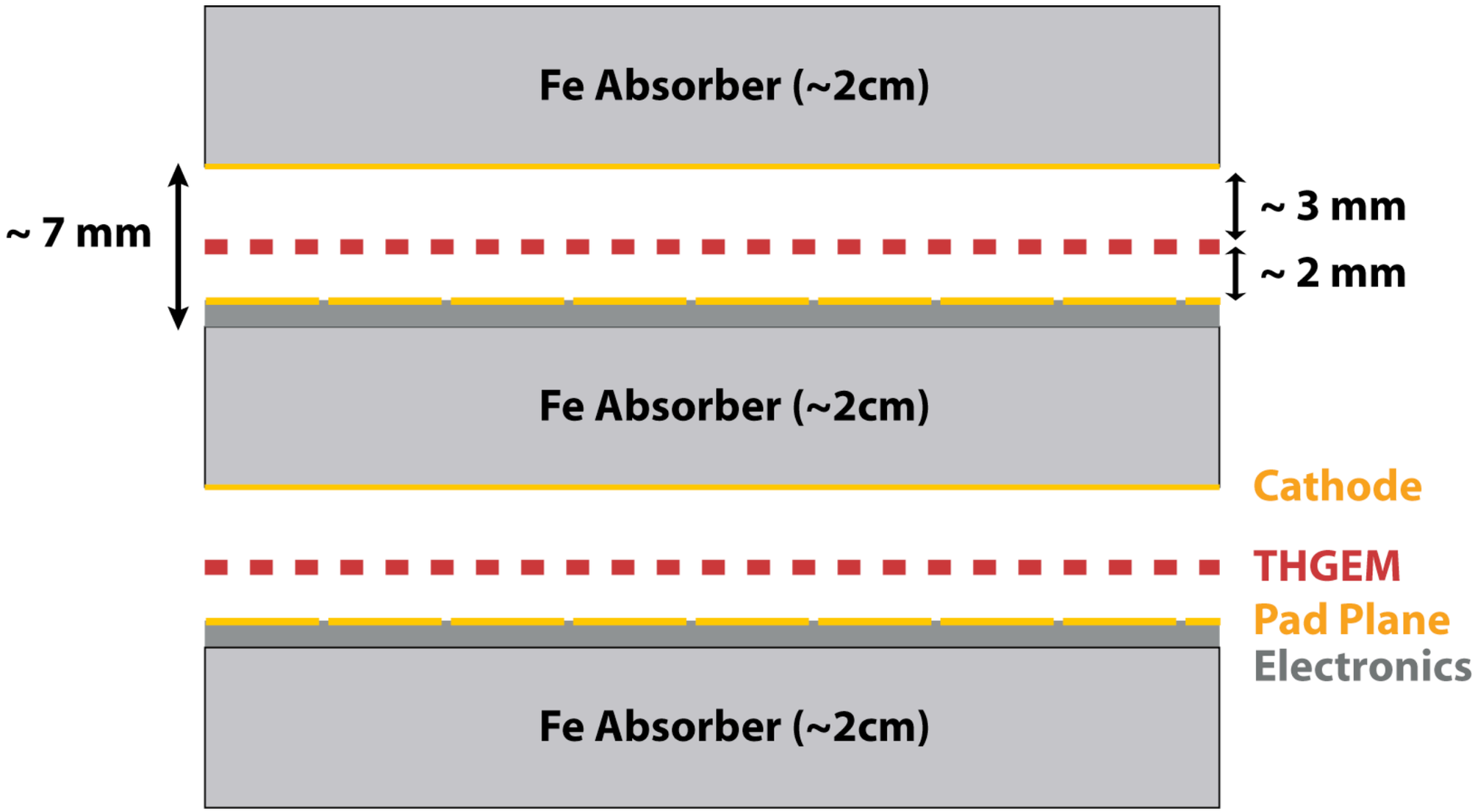


⇨high gain (> 10^4) with a single multiplication stage
⇨readout with 1 x 1 cm^2 pads

Explore other possibilities, such as resistive layers...

C. Shalem et al., NIM A558, 475 (2006)

ThickGEM based Digital HCal



- Active layers sandwiched between ~1 X_0 of Fe absorber
- In a realistic ILC detector the HCAL is limited to a thickness of 1m

⇨about 40 layers, thickness ~4.7 λ_I

Conclusion and Outlook

- Since this year the MPI is a member of the CALICE collaboration
- A large dataset is available from a test beam with a 1 m^3 scintillator prototype
- New activities at the Institute:
  - Test beam data analysis
  - Study of SiPMs for scintillator tile calorimeters
  - Investigation of gas detectors for a digital calorimeter