Highly granular silicon-tungsten EM calorimetry

Daniel Jeans

LLR – École polytechnique, IN2P3/CNRS

Motivations for fine granularity @ future colliders

General design considerations

Photon reconstruction

CALICE ECAL prototypes

Main motivation:

- Precision measurement of hadronically decaying states
  - at future lepton colliders (ILC/CLIC)
    - W, Z... tagging
      - requires very good jet energy resolution (~2x better than today)

Use particle flow technique:

- Identify and measure each particle in the final state
  - (don't integrate over particles within hadronic jet)

- Use momentum measurement to get charged energy
  - ~65% on average
  - High precision
- Use calos only for neutral energy measurement
  - ~25% gamma, ~10% neutral hadrons
  - much lower precision (particularly for hadrons)

Main consequences:

- Pattern recognition more important than energy resolution
  - high granularity -> imaging calorimetry
- Main limitation to energy resolution is confusion between particle showers
  - rather than single particle resolution

Highly granular calorimeters developed within CALICE collaboration

- >300 physicists/engineers, >50 institutes, >15 countries, 4 regions

SiW ECAL design

Main task (for hadronic jets)
- Identify and measure photon energy deposits
- Minimise confusion from charged hadrons

Require:
- Excellent pattern recognition/Imaging: multi-particle separation
- Physically thin (inside solenoid)
- Reasonably good energy resolution for photons/electrons

Sampling calorimeter
- naturally gives longitudinal segmentation
- pattern recognition
- # samples ~ energy resolution

Tungsten absorber
- Small X_0 (3.5mm) – compact calo
- Small $R_{\text{Molière}}$ (9 mm)– compact EM showers
- Small X_0/Lambda (3.5/99) – longitudinal separation of EM and Had

~30 layers of silicon sensors
- Matrices of PIN diodes in high res Si (300-500 microns thick)
- Readout granularity 5x5 ~ 10x10 mm^2

Integrated low-power electronics
- Dynamic range 0.5 MIP -> 2500 MIP

Total thickness ~23X_0, 1 lambda, 20 cm
- Effective R_M ~ 19mm

For application @ CHIC,

- have somewhat similar requirements

- identify photons from chi_c decay
  - in sea of pi0->2 gamma
    - average gamma-gamma sep ~ 2->4 cm

- veto gammas from pi0 decays
  - gamma-gamma invariant mass
    - energy resolution has a rôle

- Also large number of charged hadrons
  - reject deposits from pi+-

Denser environment than ILC:

- in high energy jets (250 GeV), typical gamma-gamma distance ~ 5-15 cm
  - CHIC somewhat more challenging

Photon reconstruction

(GARLIC algorithm)

Identify photons within hadronic jets

Veto hits along extrapolated tracks

Project first 10 ECAL layers onto front surface

Find peaks = cluster seeds

Build narrow shower core around seeds

Window ~1.5 x cell size

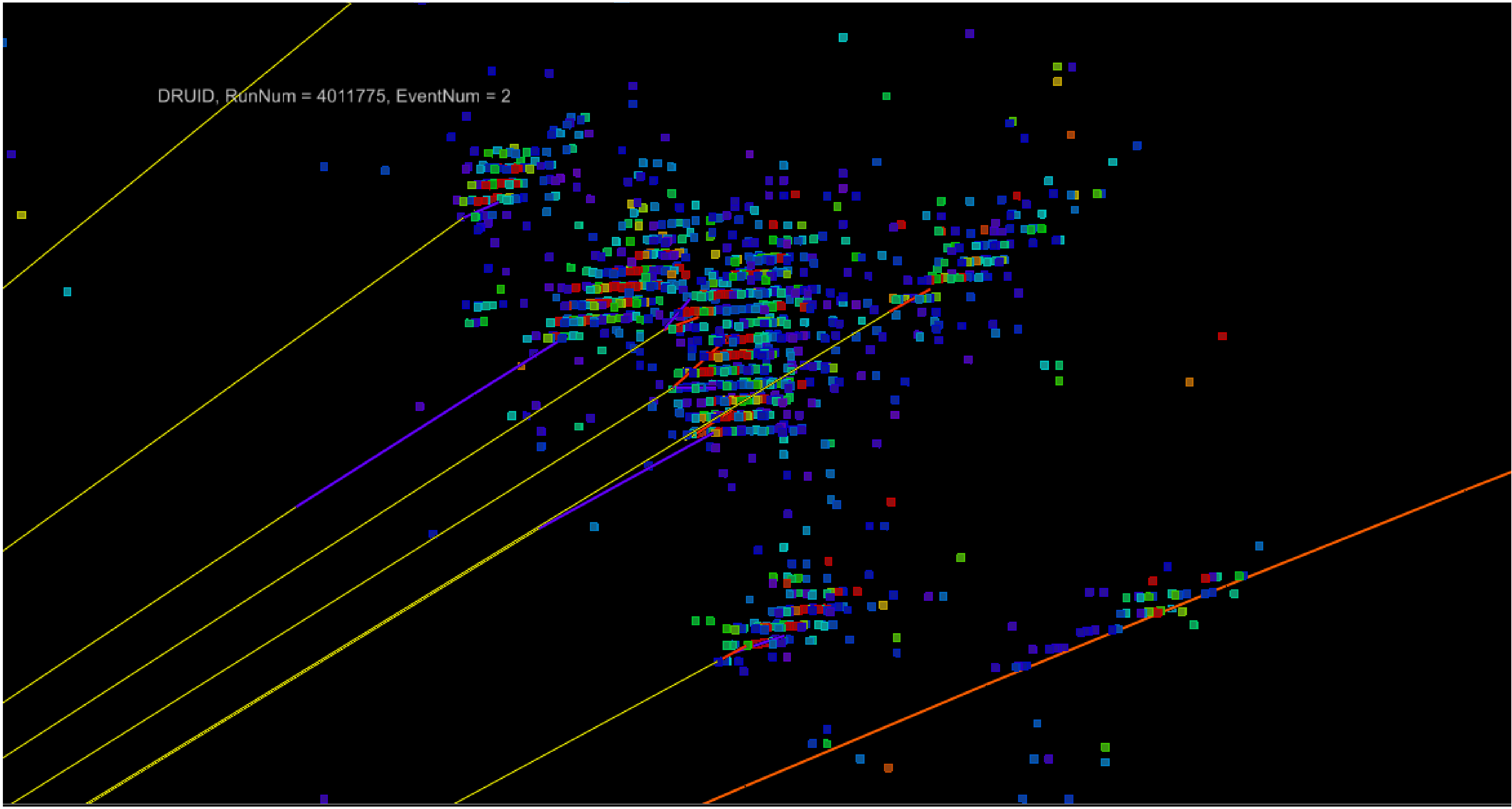
Grow clusters around cores

neighbouring cells up to 1~2 Molière radius

Merge closely touching clusters

Neural Network decides if clusters looks like photon

Small section of e+e- -> qq event at 500 GeV



Yellow lines = paths of photons, coloured boxes = calorimeter hits (colour ~ energy)

Photon reconstruction

(GARLIC algorithm)

Identify photons within hadronic jets

Veto hits along extrapolated tracks

Project first 10 ECAL layers onto front surface

Find peaks = cluster seeds

Build narrow shower core around seeds

Window ~1.5 x cell size

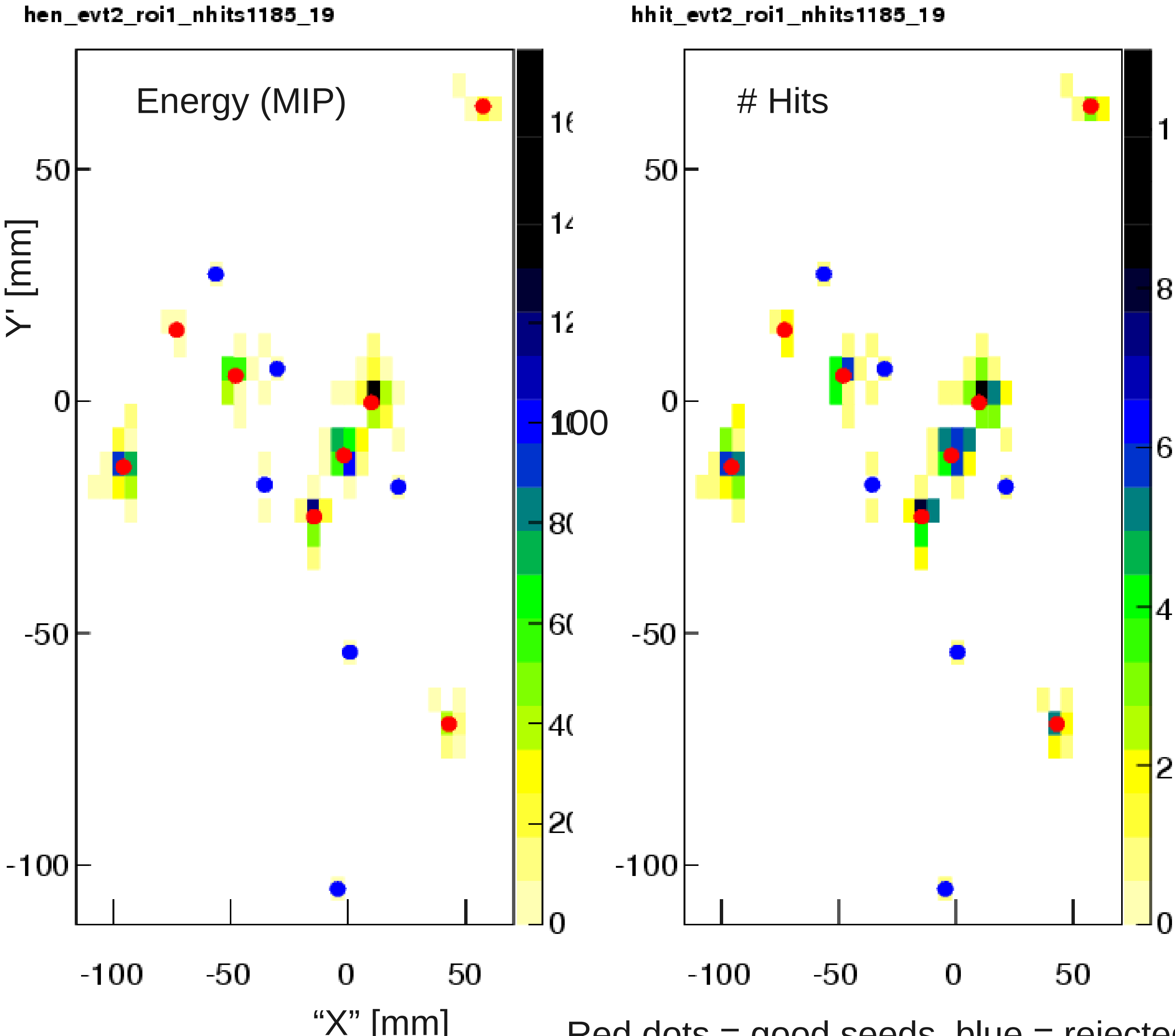
Grow clusters around cores

neighbouring cells up to 1~2 Molière radius

Merge closely touching clusters

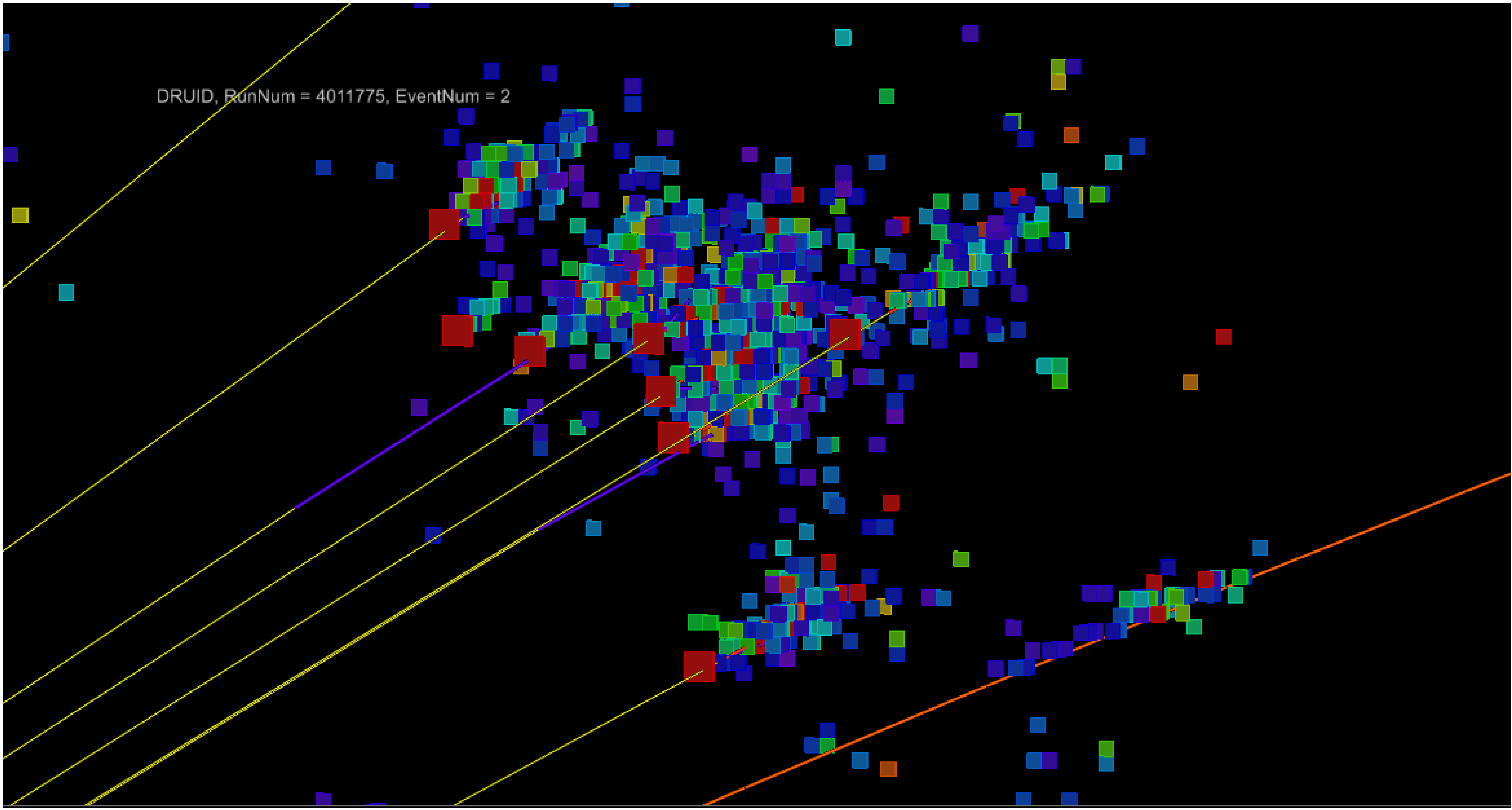
Neural Network decides if clusters looks like photon

Project hits in first 12 ECAL layers onto front face



Red dots = good seeds, blue = rejected seeds

Cluster seeds



Photon reconstruction

(GARLIC algorithm)

Identify photons within hadronic jets

Veto hits along extrapolated tracks

Project first 10 ECAL layers onto front surface

Find peaks = cluster seeds

Build narrow shower core around seeds

Window ~1.5 x cell size

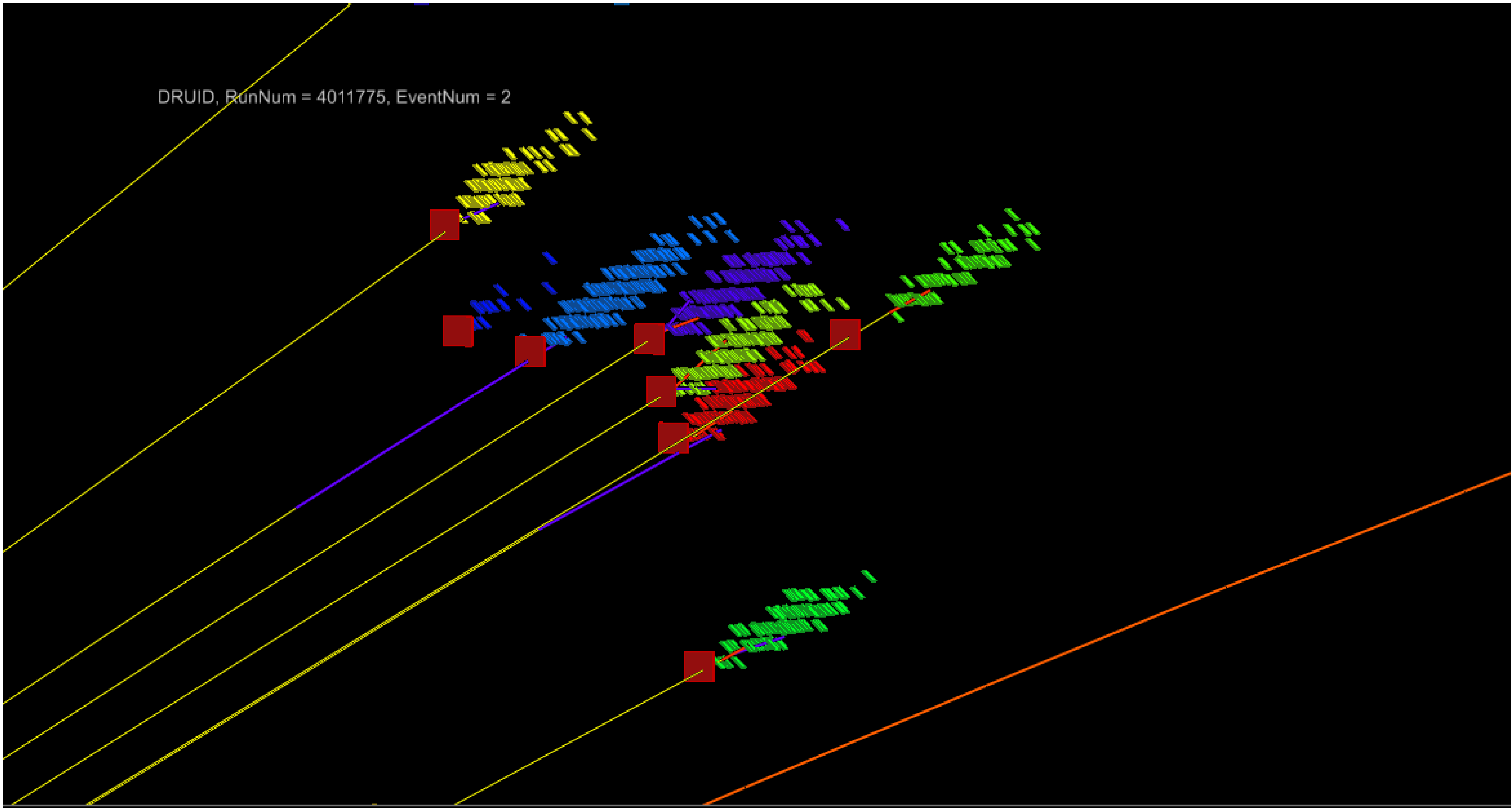
Grow clusters around cores

neighbouring cells up to 1~2 Molière radius

Merge closely touching clusters

Neural Network decides if clusters looks like photon

Build narrow cluster cores around seeds



Photon reconstruction

(GARLIC algorithm)

Identify photons within hadronic jets

Veto hits along extrapolated tracks

Project first 10 ECAL layers onto front surface
    Find peaks = cluster seeds

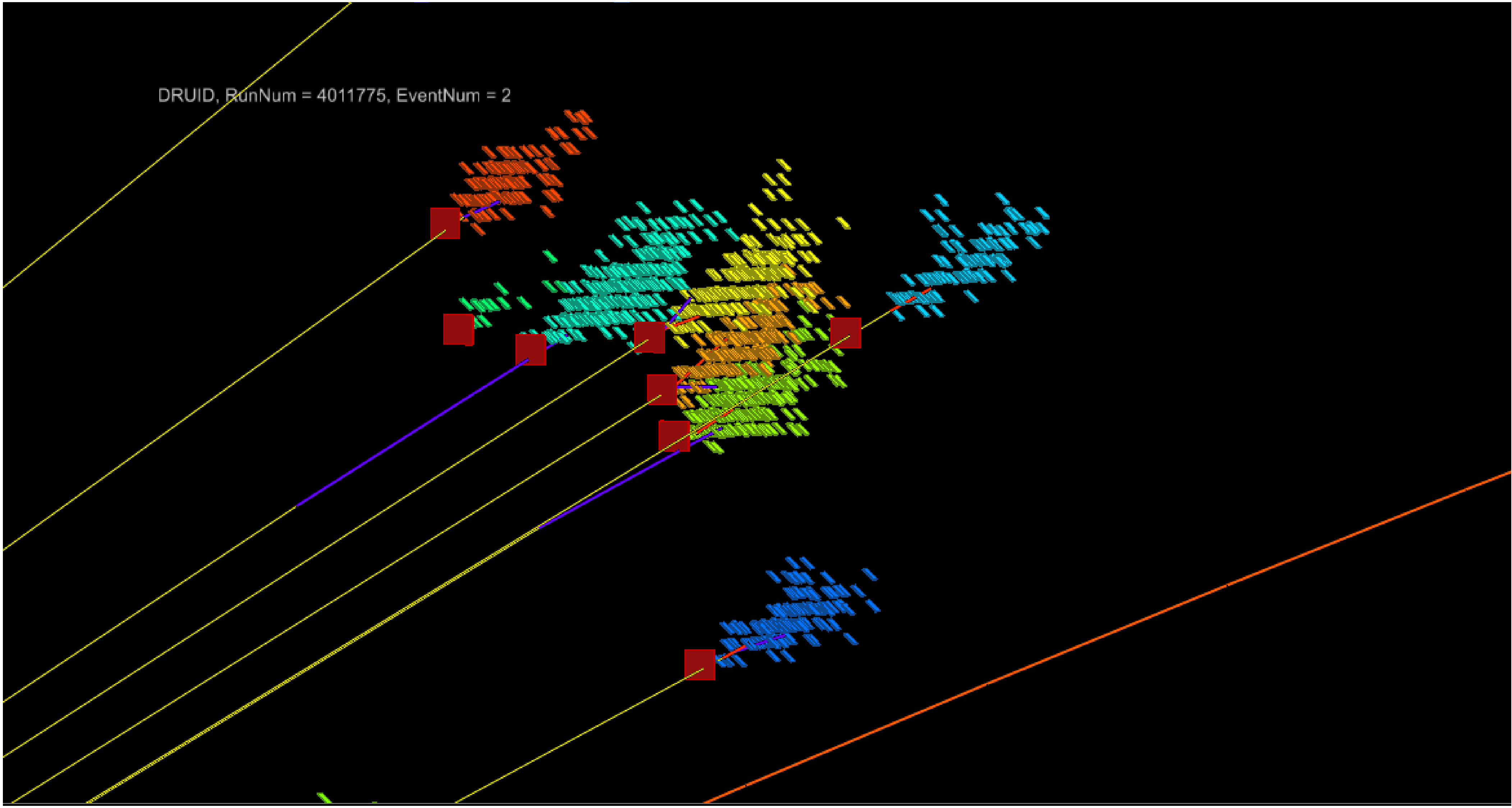
Build narrow shower core around seeds
    Window ~1.5 x cell size

Grow clusters around cores
    neighbouring cells up to 1~2 Molière radius

Merge closely touching clusters

Neural Network decides if clusters looks like photon

Build clusters around cores



Photon reconstruction

(GARLIC algorithm)

Identify photons within hadronic jets

Veto hits along extrapolated tracks

Project first 10 ECAL layers onto front surface

Find peaks = cluster seeds

Build narrow shower core around seeds

Window ~1.5 x cell size

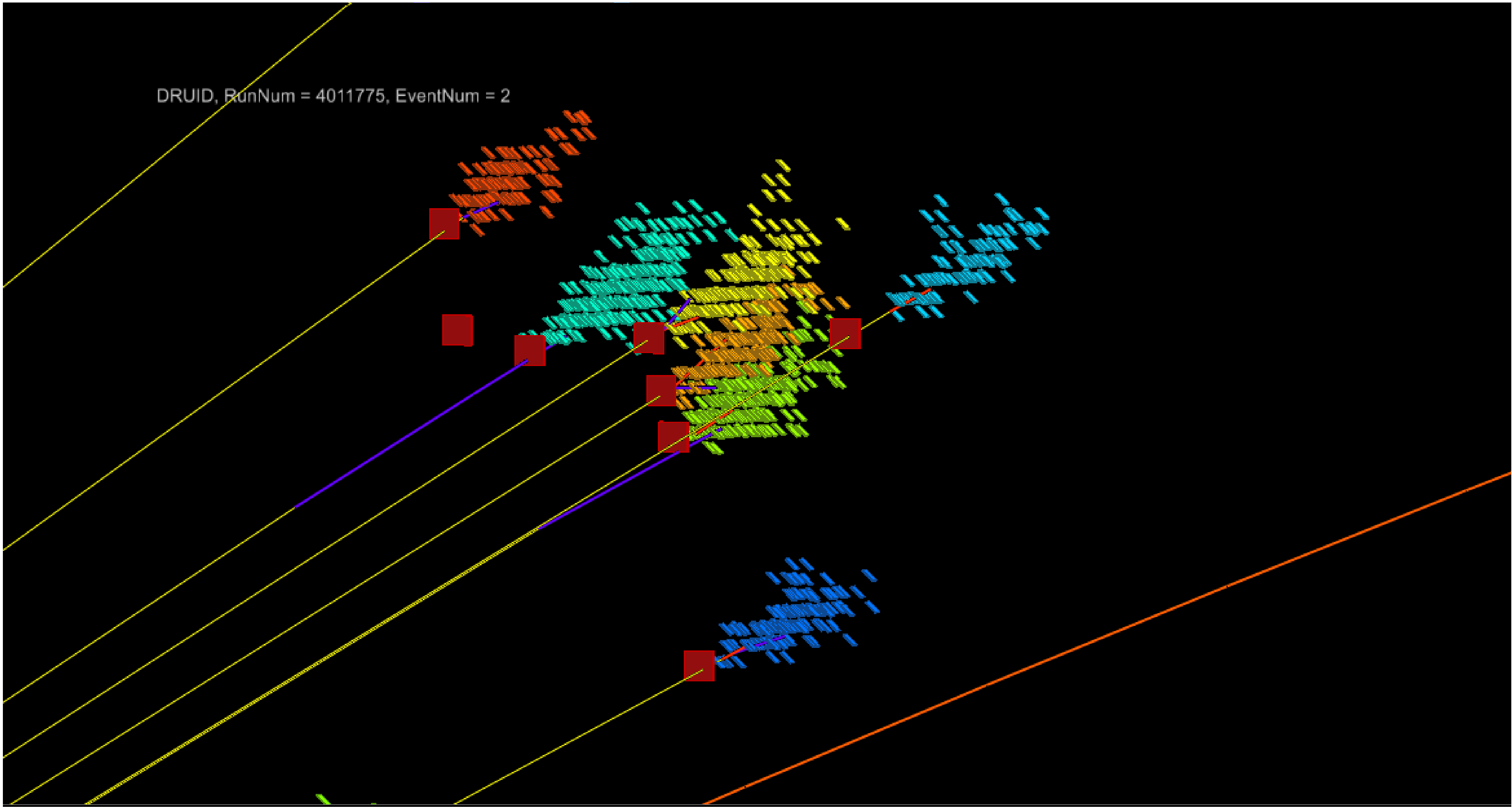
Grow clusters around cores

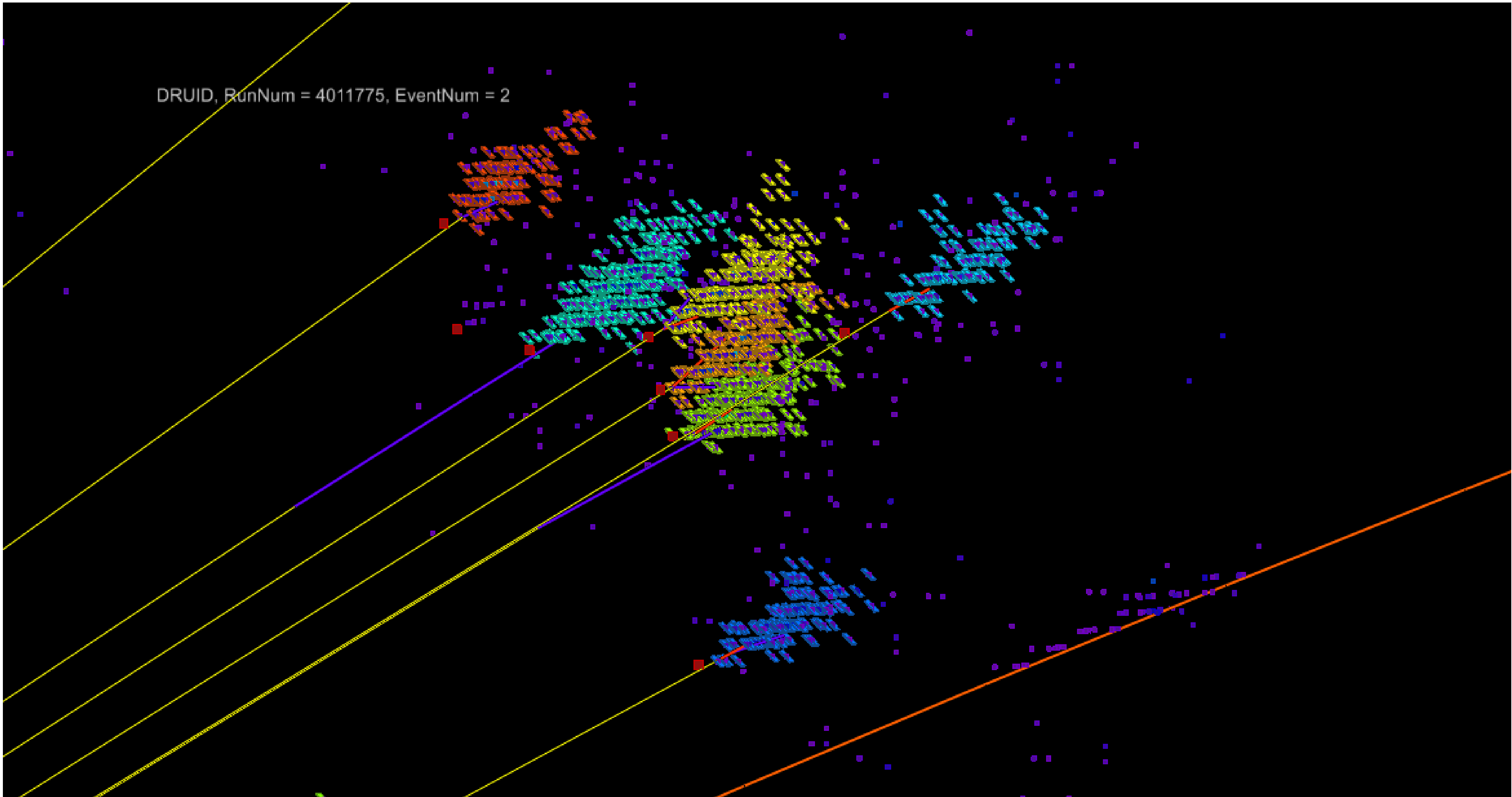
neighbouring cells up to 1~2 Molière radius

Merge closely touching clusters

Neural Network decides if clusters looks like photon

Select photon-like clusters





Photons separated by ~2cm can be separated
some overlap of energy deposition -> will effect energy resolution

Separation of 2 photons @ ~2cm is possible with such an ECAL

But don't forget:

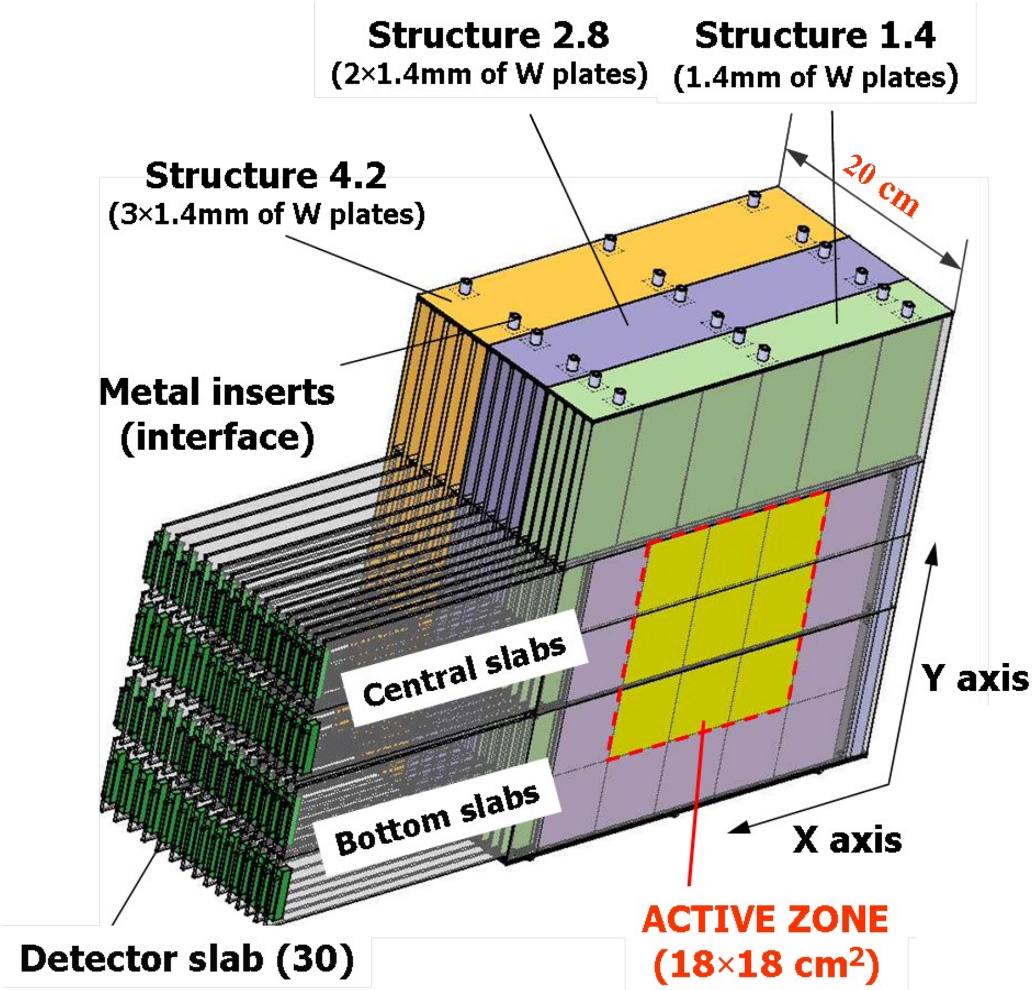
- large # of superimposed pi+-
- if “average” gamma-gamma distance is 2cm,
  ~ half are closer than 2 cm...

Full detector simulations and
re-optimised reconstruction algorithms
required to come to definitive conclusions

CALICE silicon tungsten ECAL prototypes

“physics prototype”
demonstrate feasibility of technique

“technical prototype”
develop technical solutions towards final detector



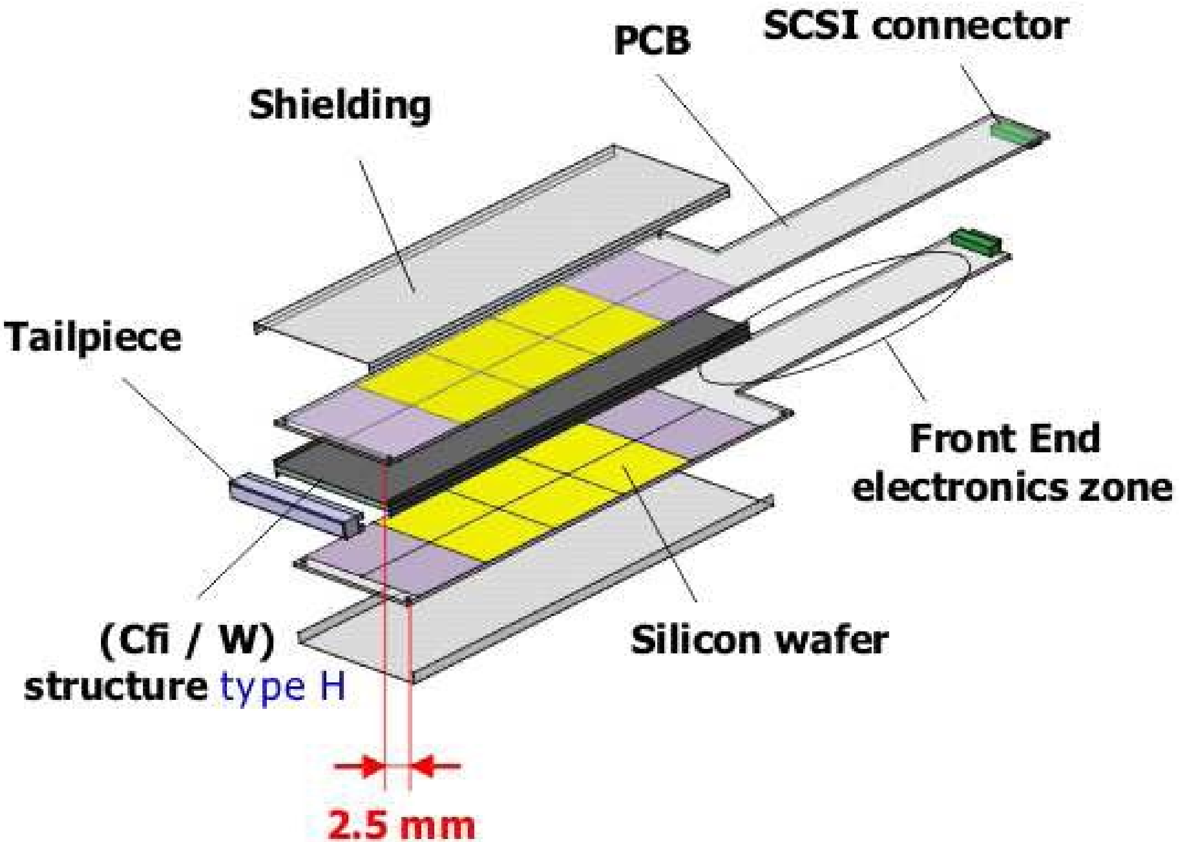
"Physics" prototype

30 detection layers

Carbon-fibre composite/tungsten
mechanical structure

18x18cm² active area

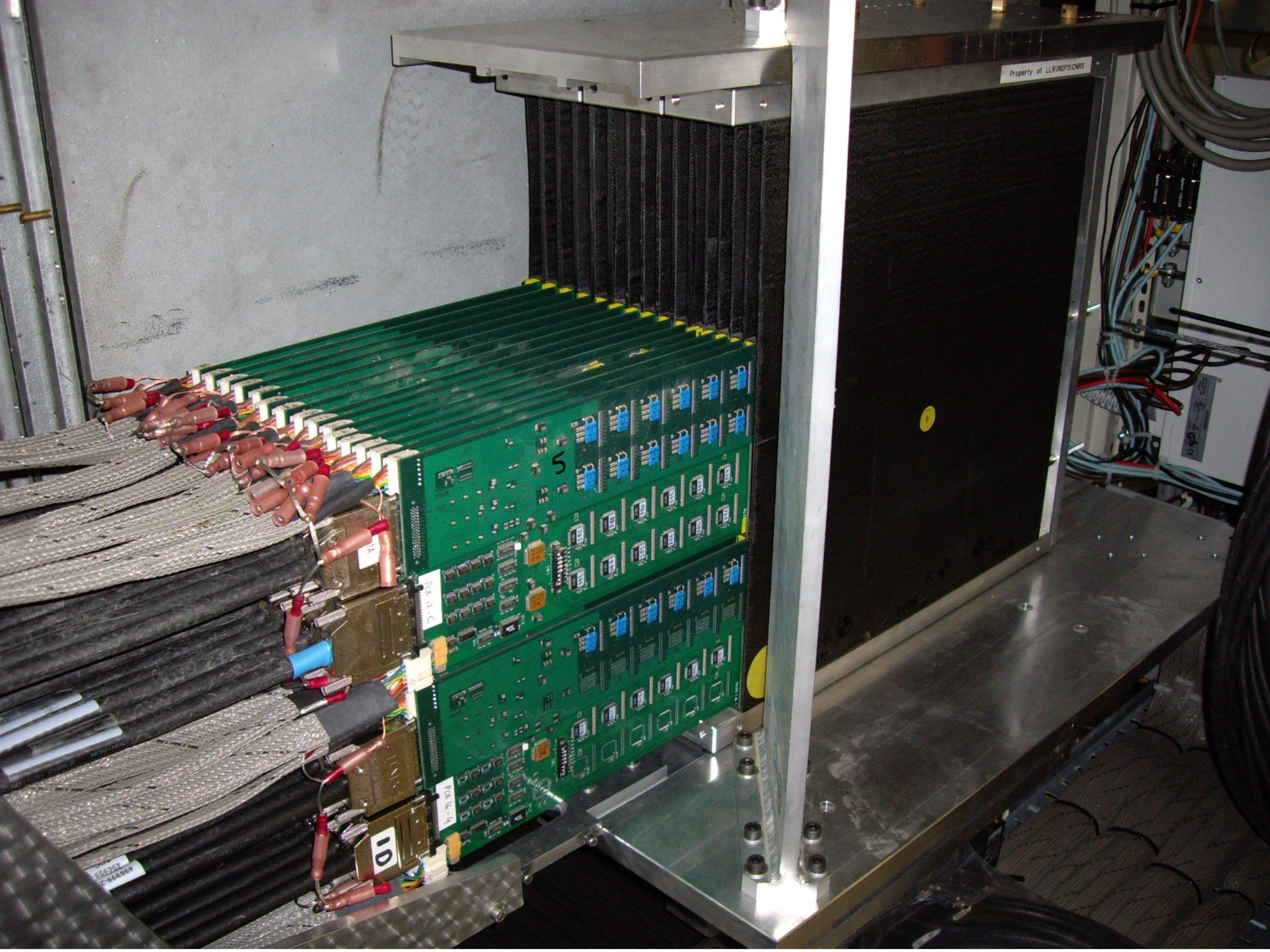
~10k readout channels



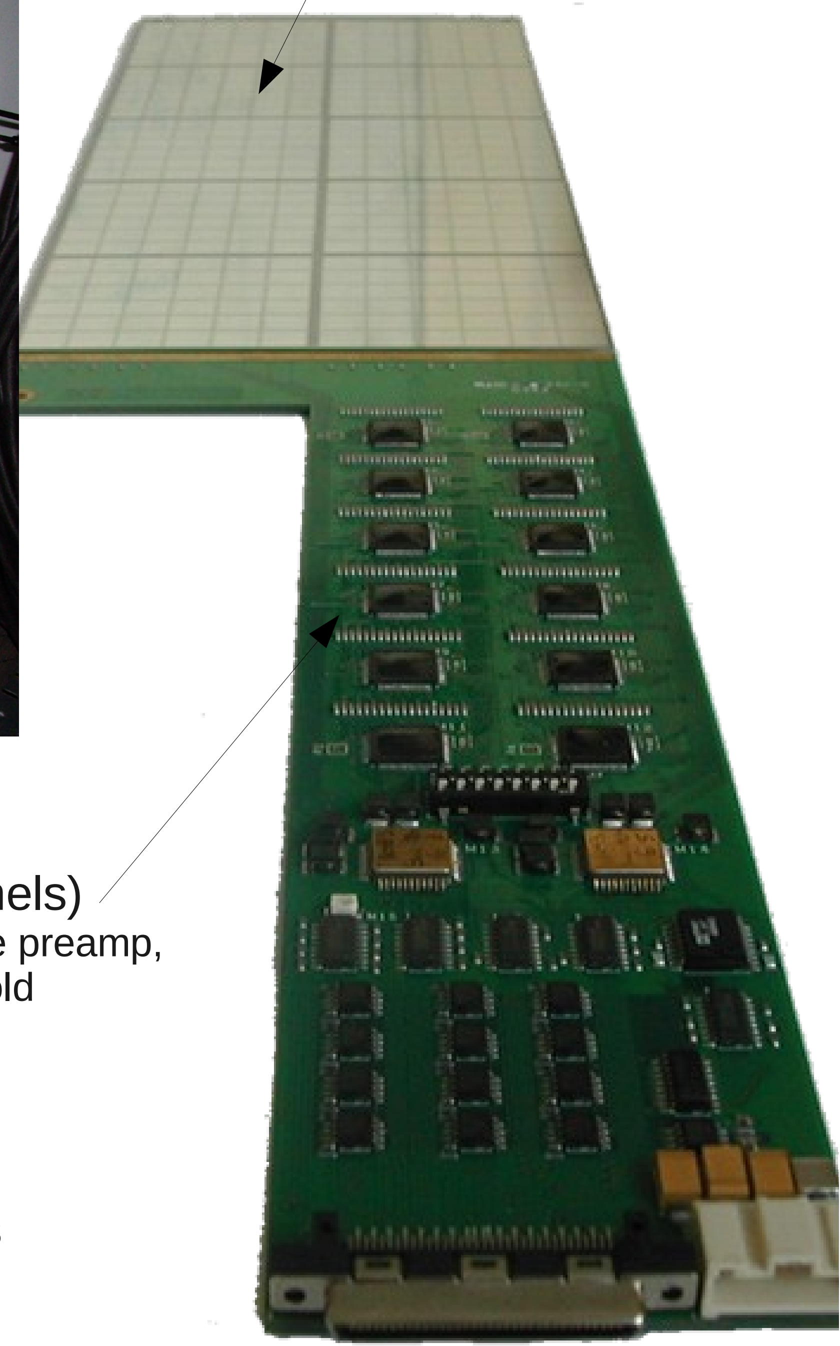
Based around detector slab

2 detection layers sandwiched around
layer of tungsten

Silicon sensor:
Matrix of 1x1cm² PIN diodes
500 micron thick high resistivity silicon



PIN diode matrices

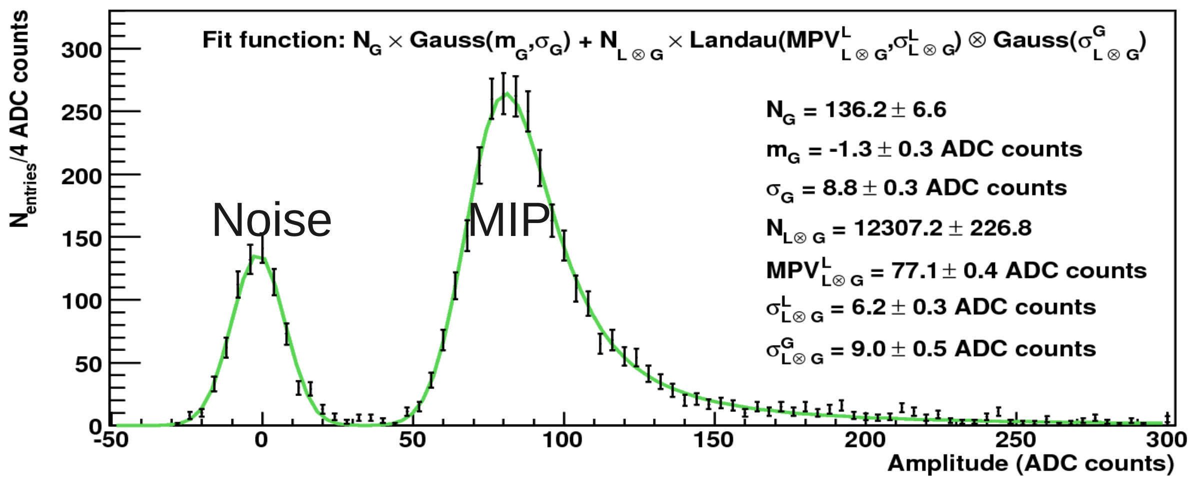


flc_phy3 ASIC (18 channels)
Variable gain charge sensitive preamp, followed by sample & hold

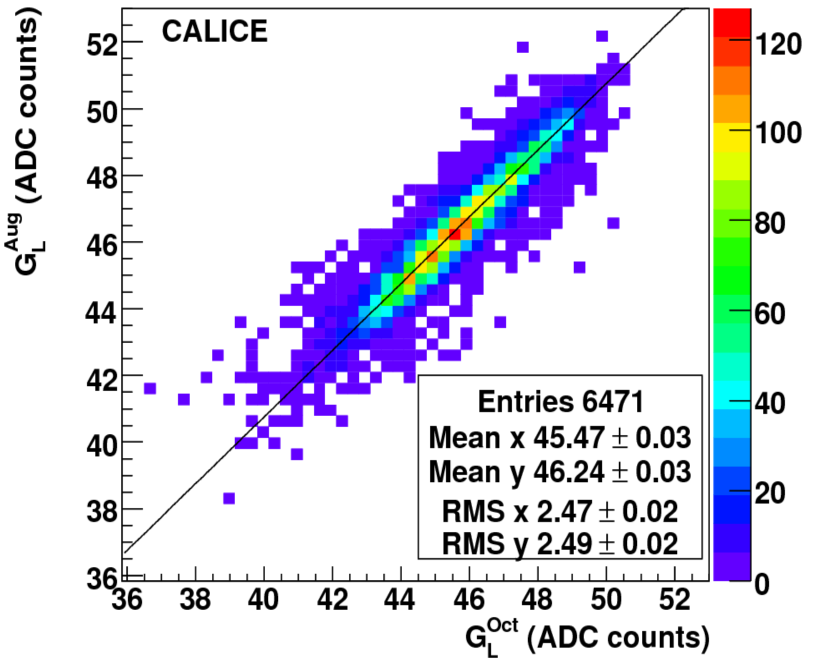
running in test beams 2006-2011

- stable calibration
- performance well described by GEANT4 simulations
- energy resolution sigE/E ~ 16.6% / sqrt(E) + 1.0%

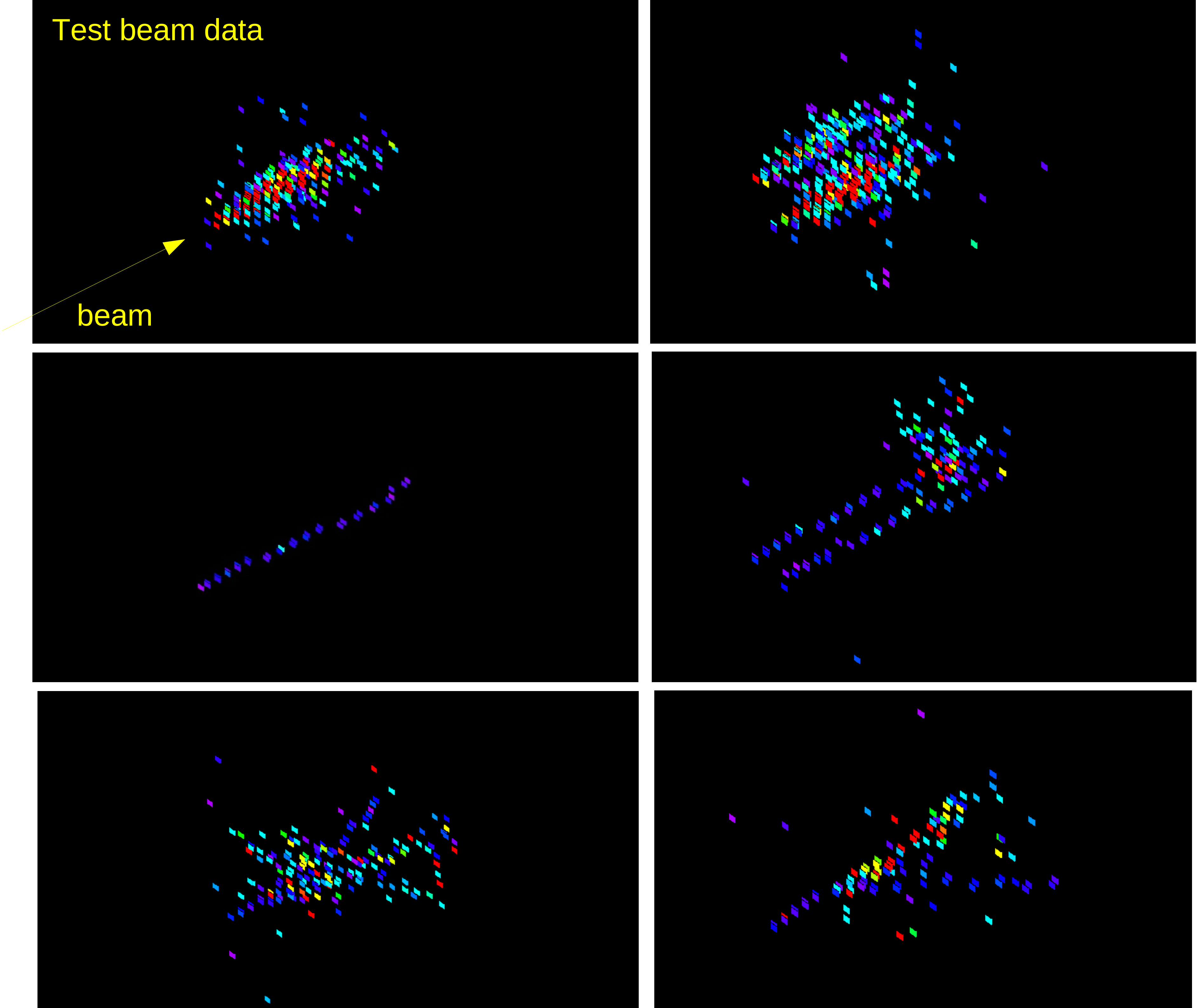
Detector calibration



S/N ~ 7.5 for single MIP



Calibration of each channel in different data-taking periods


Test beam data
beam

Developments in progress

“Technical prototype”
    prepare for detector integration into ILC-like detector

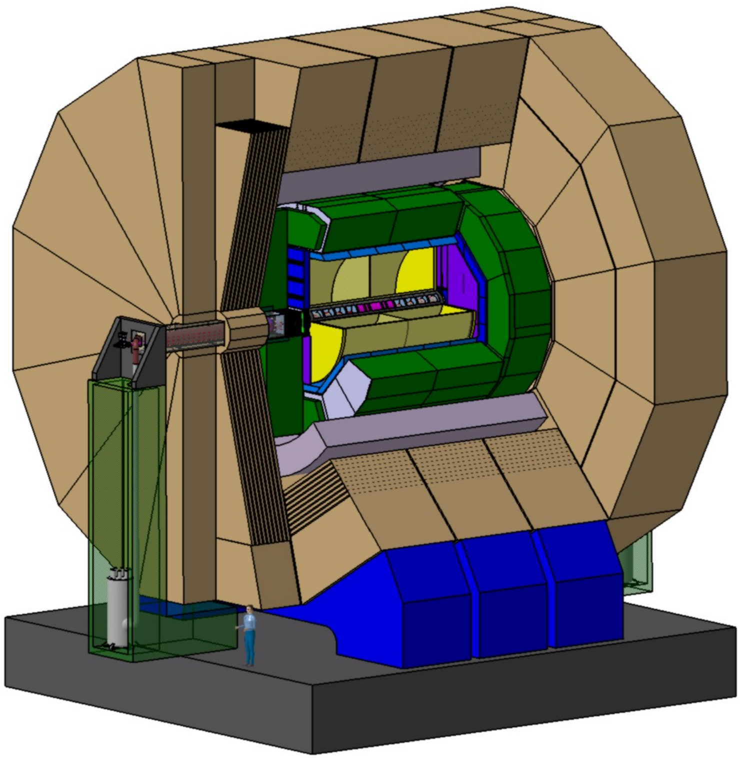
Sensors with smaller dead areas, reduced x-talk
    5mm pixel size

Low power ASICs
    including ADC, zero suppression, ...

Integration of ASICs into detector volume

Realistic mechanical structures

Cooling schemes



France: LAL, LLR, LPC, LPNHE, Omega
Japan: Kobe, Shinshu
Korea: SKKU

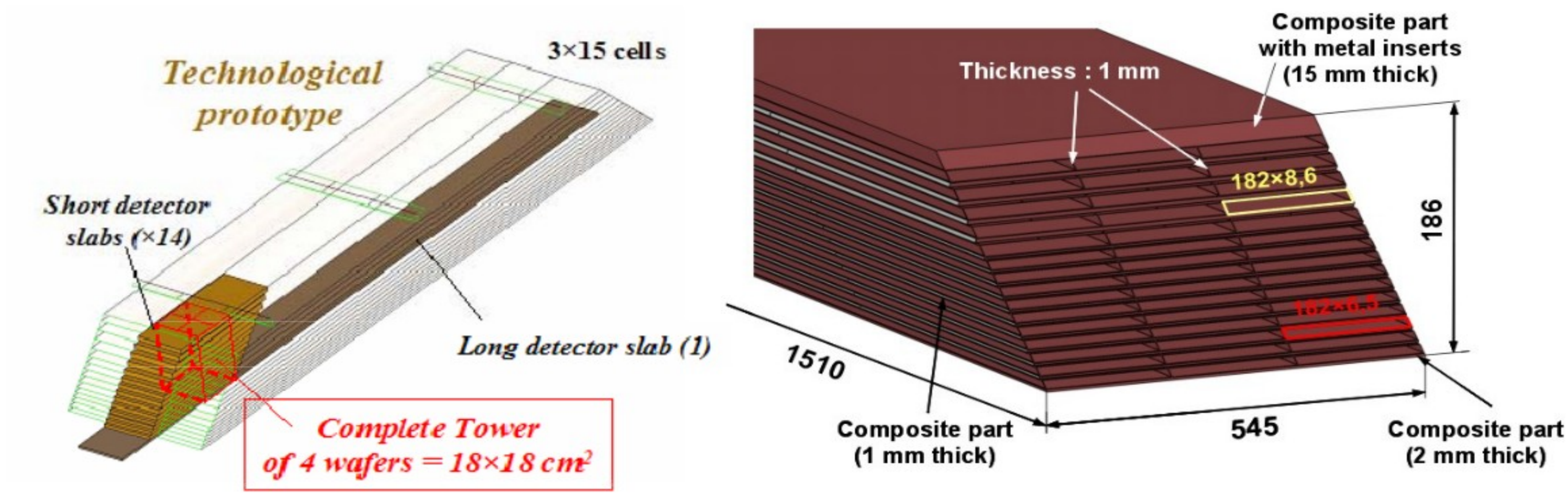
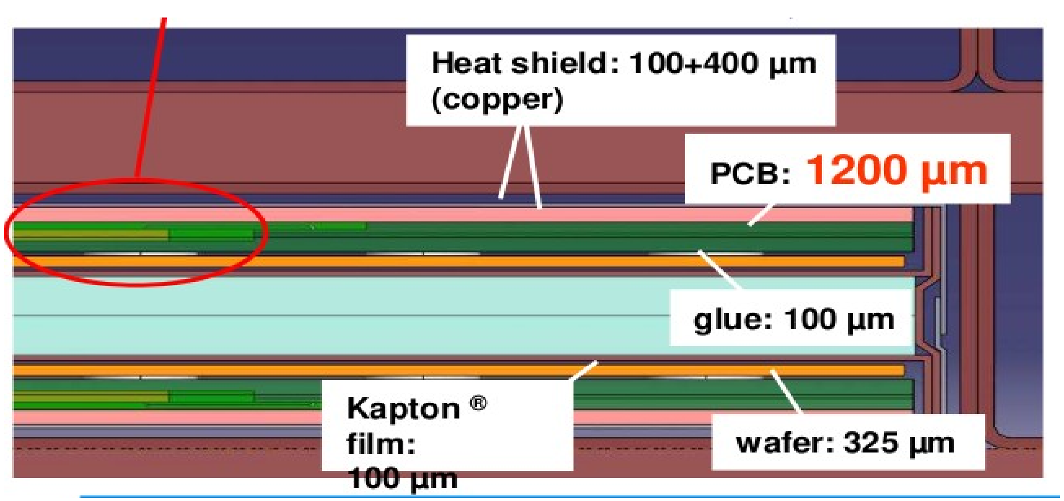
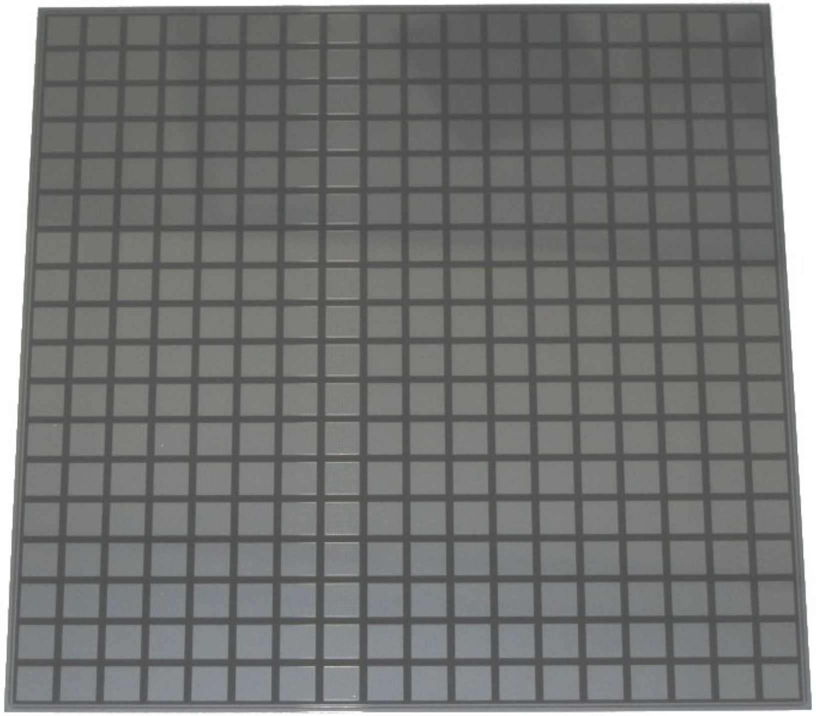
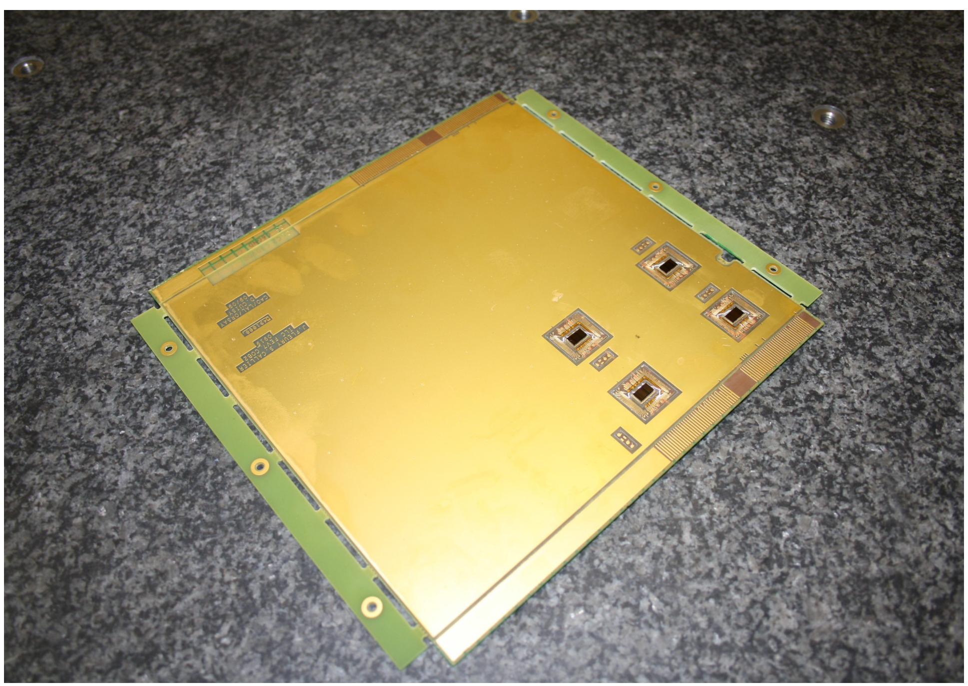
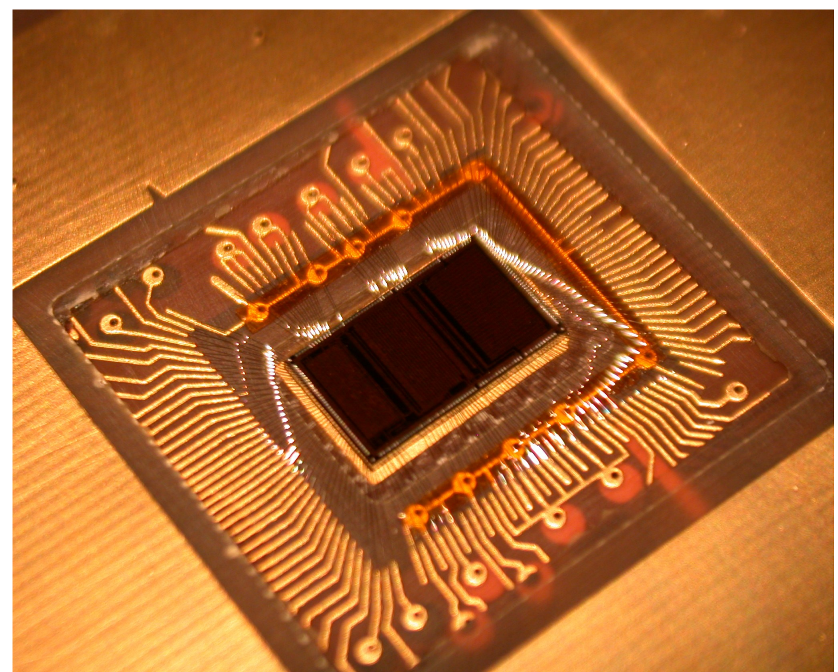


Fig.1 – Schematic 3D view of the prototype and design of the alveolar structure





Cost guesstimate

Price is dominated by the silicon sensors

for small (~0.1 m^2) test production from Hamamatsu PK,
we pay ~ 10 euro / cm^2 (excluding NRE)

proposed CHIC ECAL

Ring structure, 30 detection layers
A) R_{in} ~ 15 cm, R_{out} ~ 40 cm, A ~ 0.43 m^2, A_{si} ~ 13 m^2
B) R_{in} ~ 30 cm, R_{out} ~ 55 cm, A ~ 0.67 m^2, A_{si} ~ 20 m^2

Silicon sensor cost ~ 10-20 * 10^4 * 10 * f_{scale} Euro
~ 1-2 * f_{scale} M Euro
[f_{scale} < 1
economies of scale in sensor production,
different manufacturers...]

+ electronics, mechanics, DAQ...

Summary

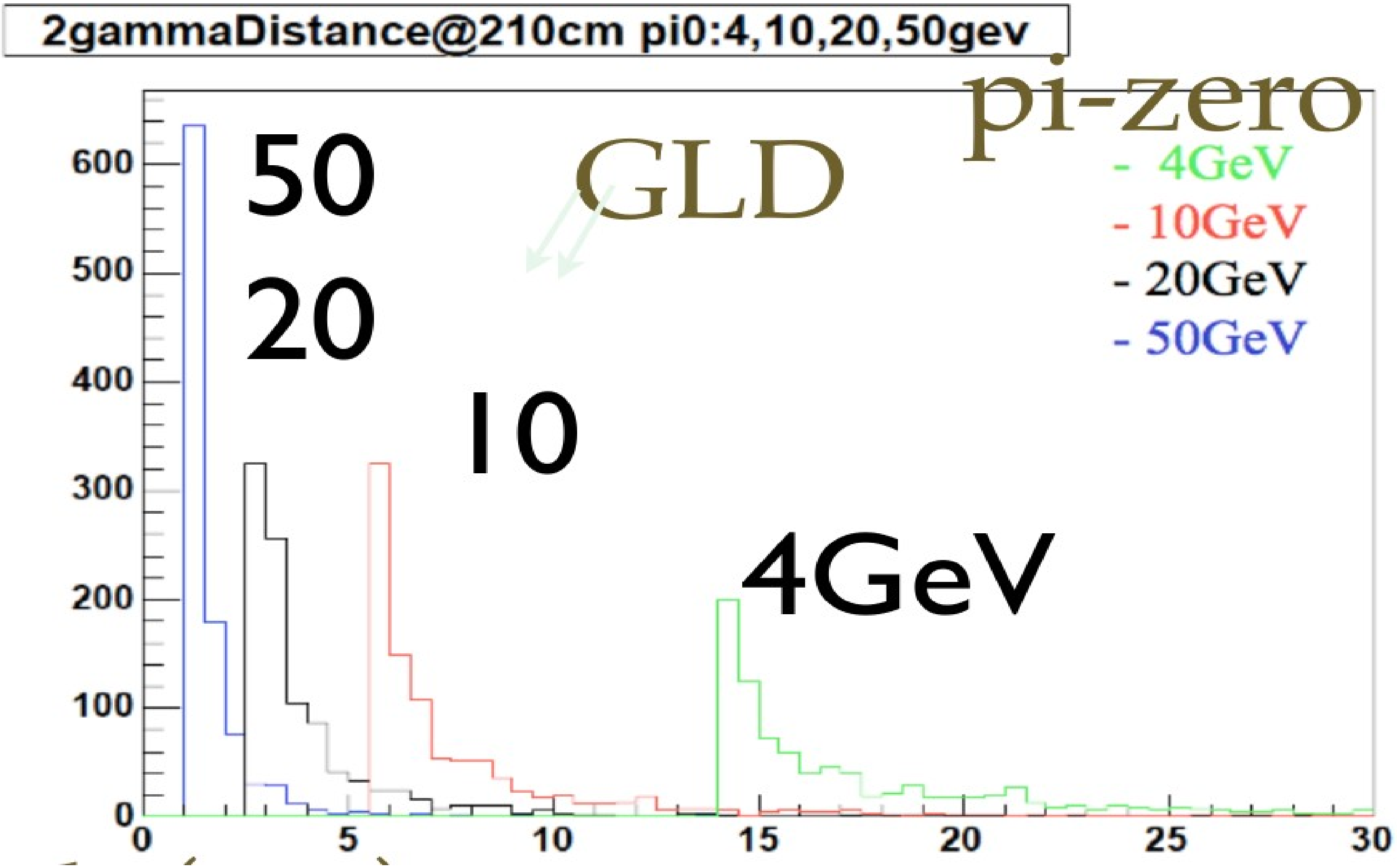
High granularity calorimetry being developed for
- future collider detectors (particle flow approach to jet energy measurement)

Silicon-tungsten ECAL suitable for this
- specific photon reconstruction algorithms developed

Si-W ECAL principle well established and tested
- technical developments continuing,
  - geared towards integration into large collider detector

CHIC application
- high granularity to deal with high particle densities
  - more dense environment than for ILC
- SiW ECAL seems suitable
  - needs detailed simulation and reconstruction to verify

backup



Photon separation at ECAL front face (2.1 m) [cm]