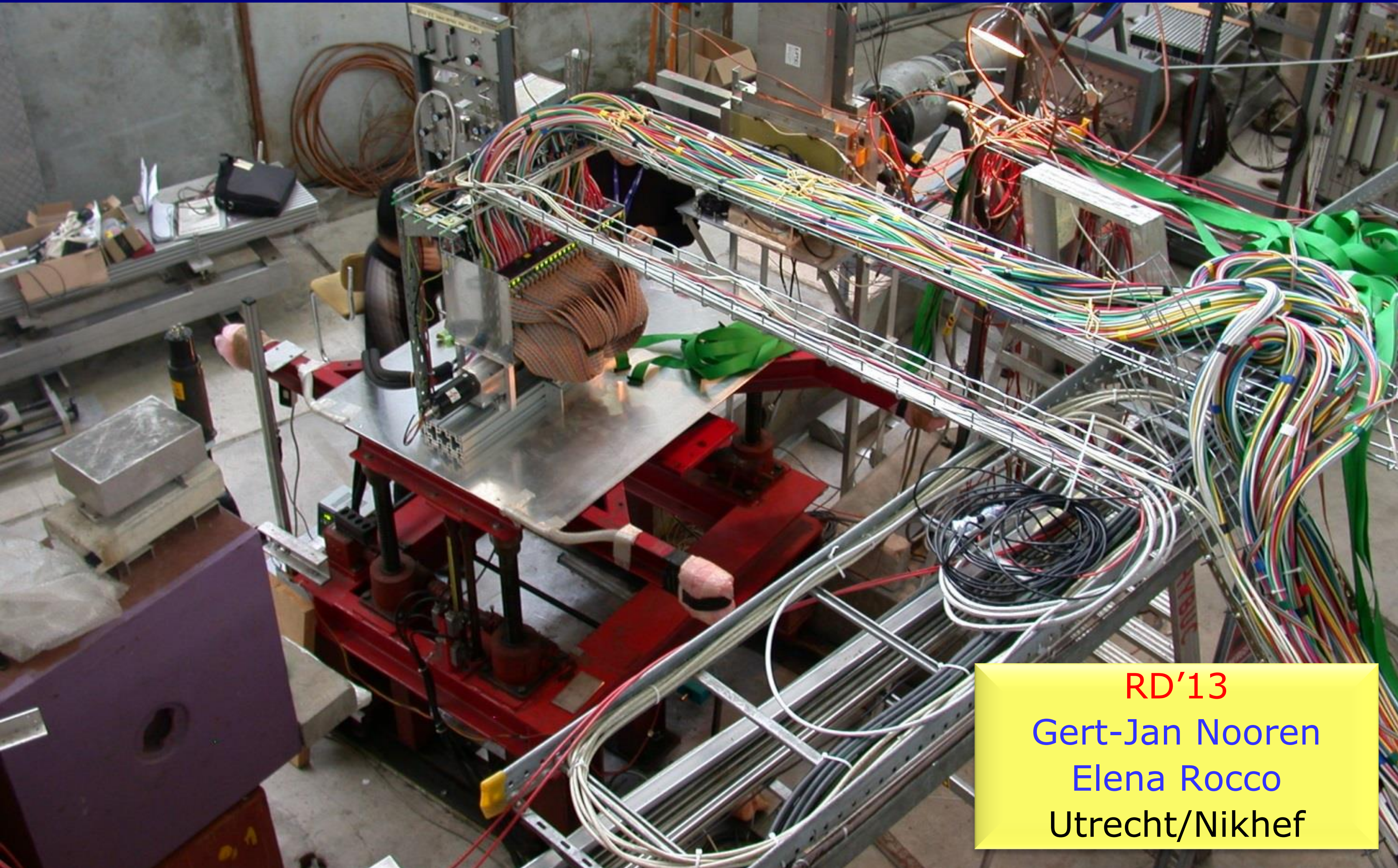
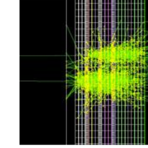
First results of beamtests of a MAPS based ElectroMagnetic calorimeter



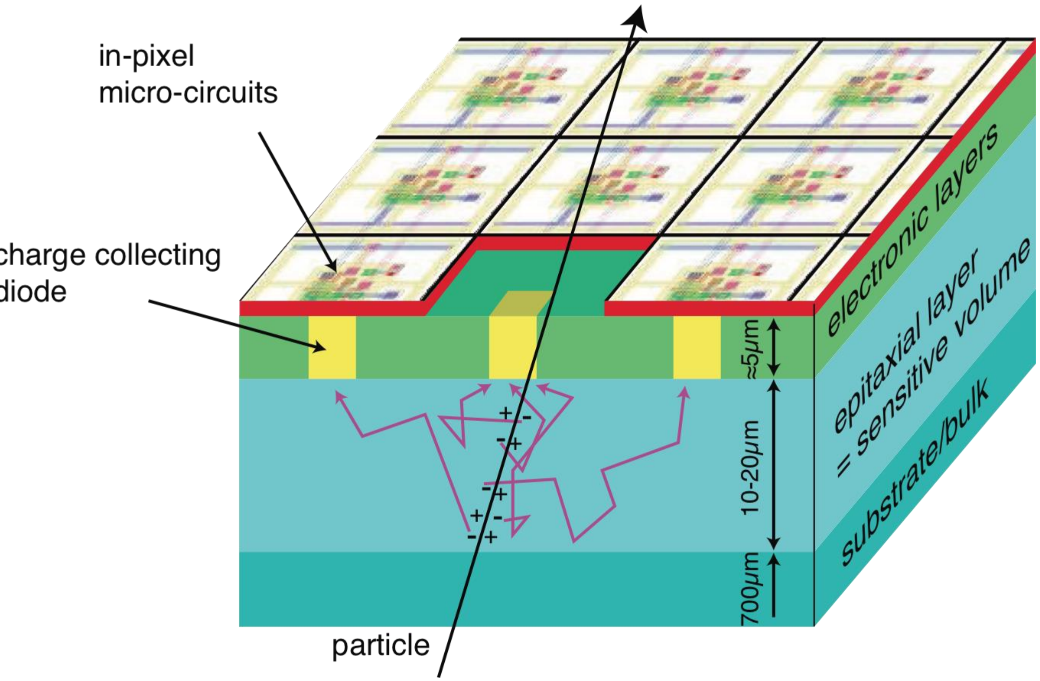
RD'13

Gert-Jan Nooren
Elena Rocco
Utrecht/Nikhef

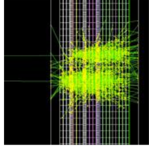


an EM calorimeter with MAPS?

- why
  1. particle flow: need to track particles
  2. shower shape analysis
  3. separate π^0 decay photons from direct photons
- what
  - lateral 1 mm, longitudinal 1 X_0
  - small Moliere radius → compact, W + silicon
- many channels
  - only feasible with digital calorimetry, i.e. particle counting
    - particle density 10^3 mm^{-2}
    - may need even more, smaller pixels!



Monolithic Active Pixel Sensor

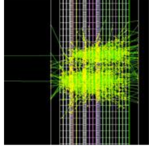


- ☺ solves the connection problem between sensor and front-end
- ☺ short input connections -> extremely low noise: tens of electrons

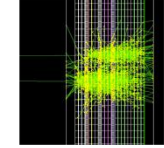
1 MIP = 80 e/h-pairs per micron

- ☹ high power density in sensor: dark current, cooling
- ☹ relatively slow -> not selftriggering
- ☹ charge collection
- ☹ radiation tolerance
- 😐 thin active layer
- ☺ intense development at several places, like RAL, IPHC, CERN

Beam test prototype objectives

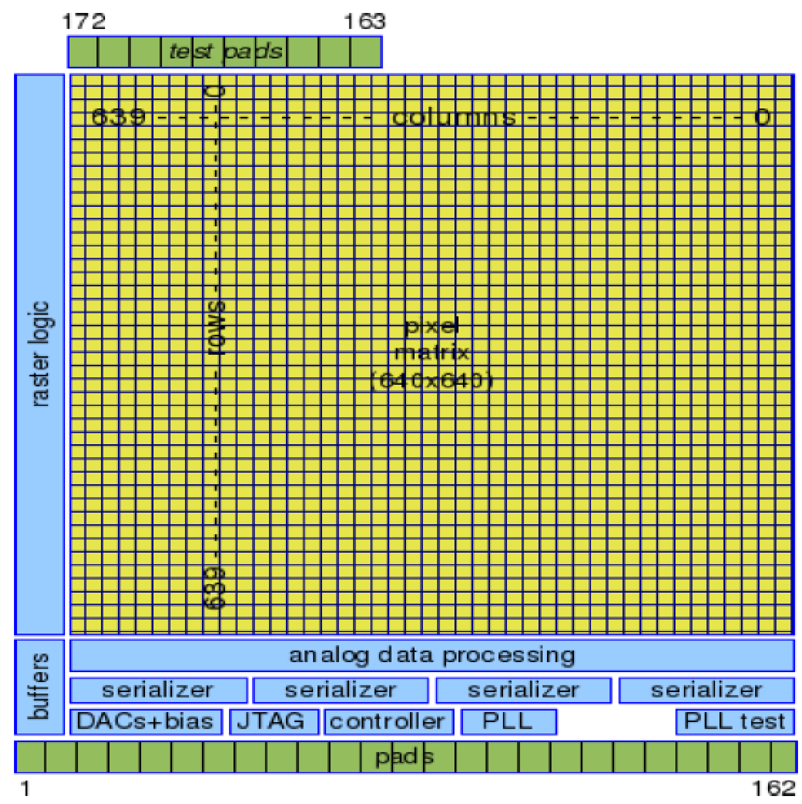


- YES:
  - proof-of-principle
    - resolution
    - Moliere radius
  - technology demonstrator
    - manage read-out at GB/s
    - cooling
    - integration
    - overlap, needed because of dead zones
  - collect data for study of
    - data volume/flow, data reduction
    - pixel size
- NO:
  - final chip, use what is on the market
  - rad hard

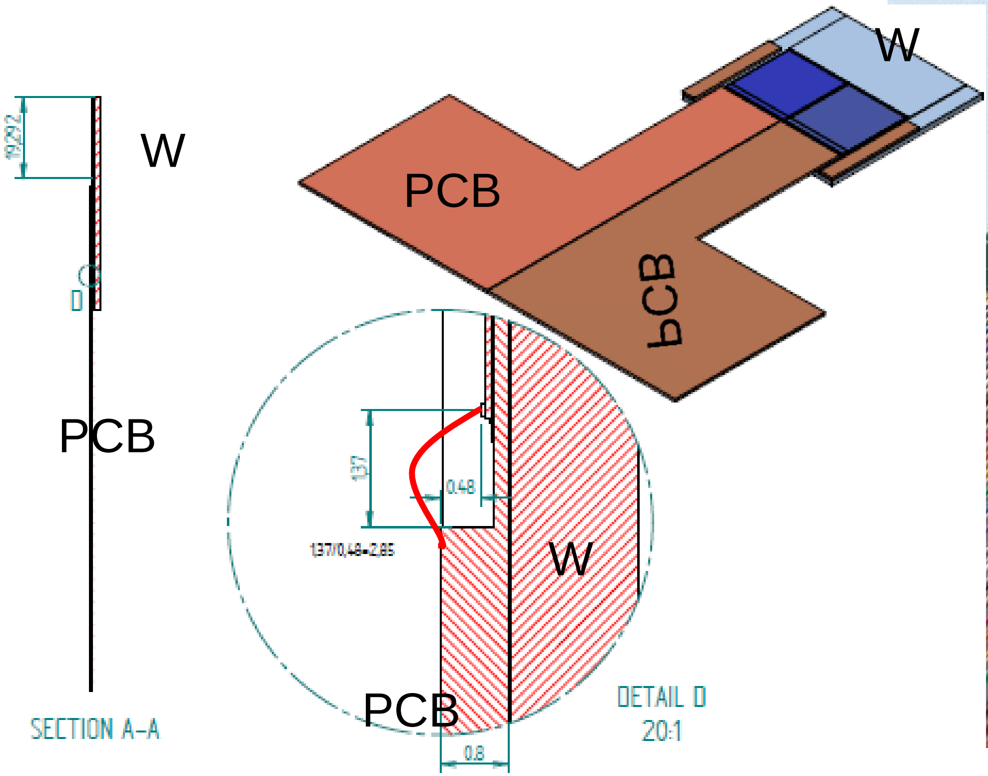


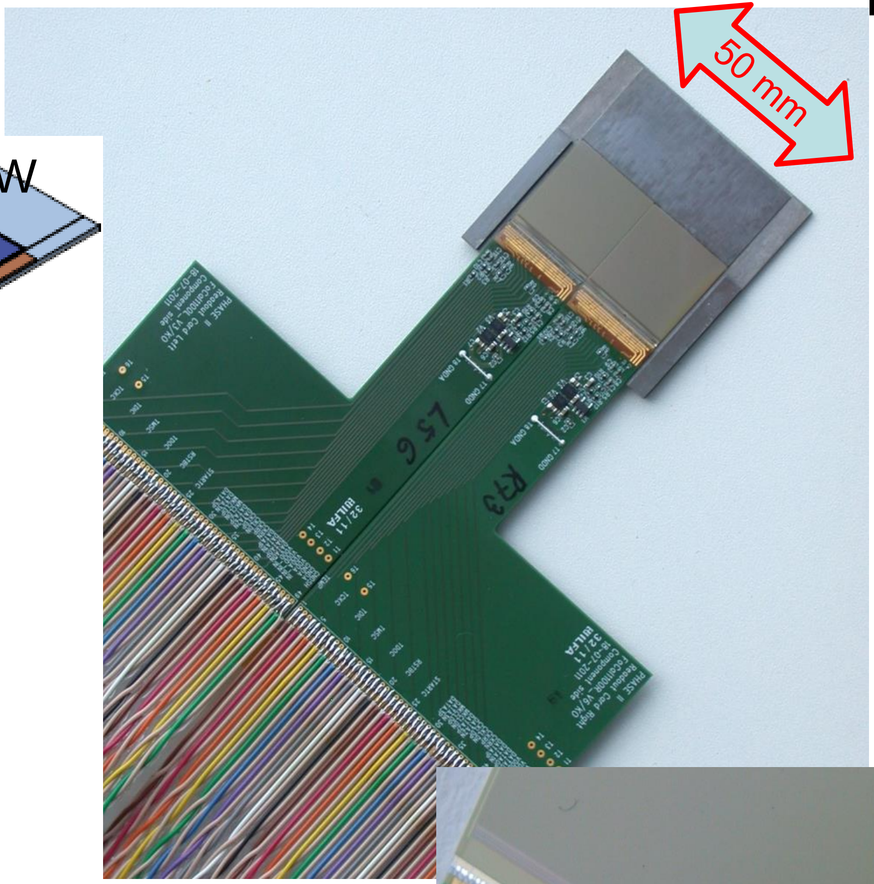
prototype features

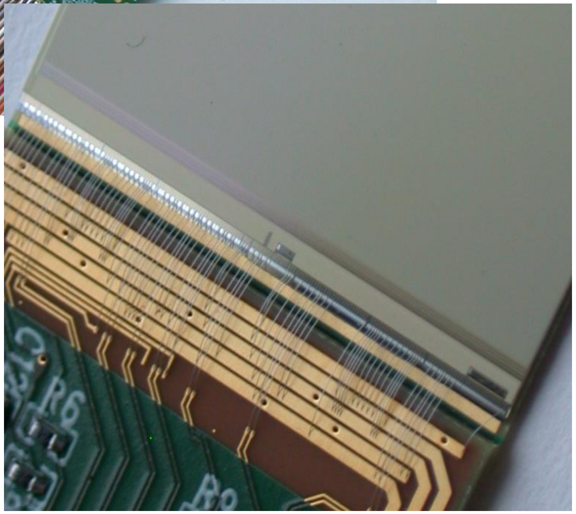
- PHASE2/MIMOSA23
  - 640 * 640 pixels, 30 µm pitch
  - high resistivity (400 Ωcm) epilayer, 15 and 20 µm
  - 1 MHz rolling shutter → 640 µs integration time
  - 160 MHz read-out clock
  - no data reduction on board
  - radiation tolerance < 1 Mrad
- thinned to 120 µm
  - total sensor layer thickness 1 mm
  - estimated R_M < 15 mm
- 4 PHASE1 per layer:
  - 4 * 4 cm^2 active area: ~3 R_M
  - overlap dead areas
- 24 layers 3.4 mm W
- challenges
  - largest MAPS application
  - data volume + rate

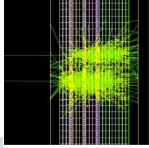


one module with two chips

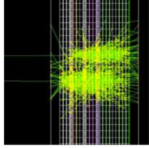




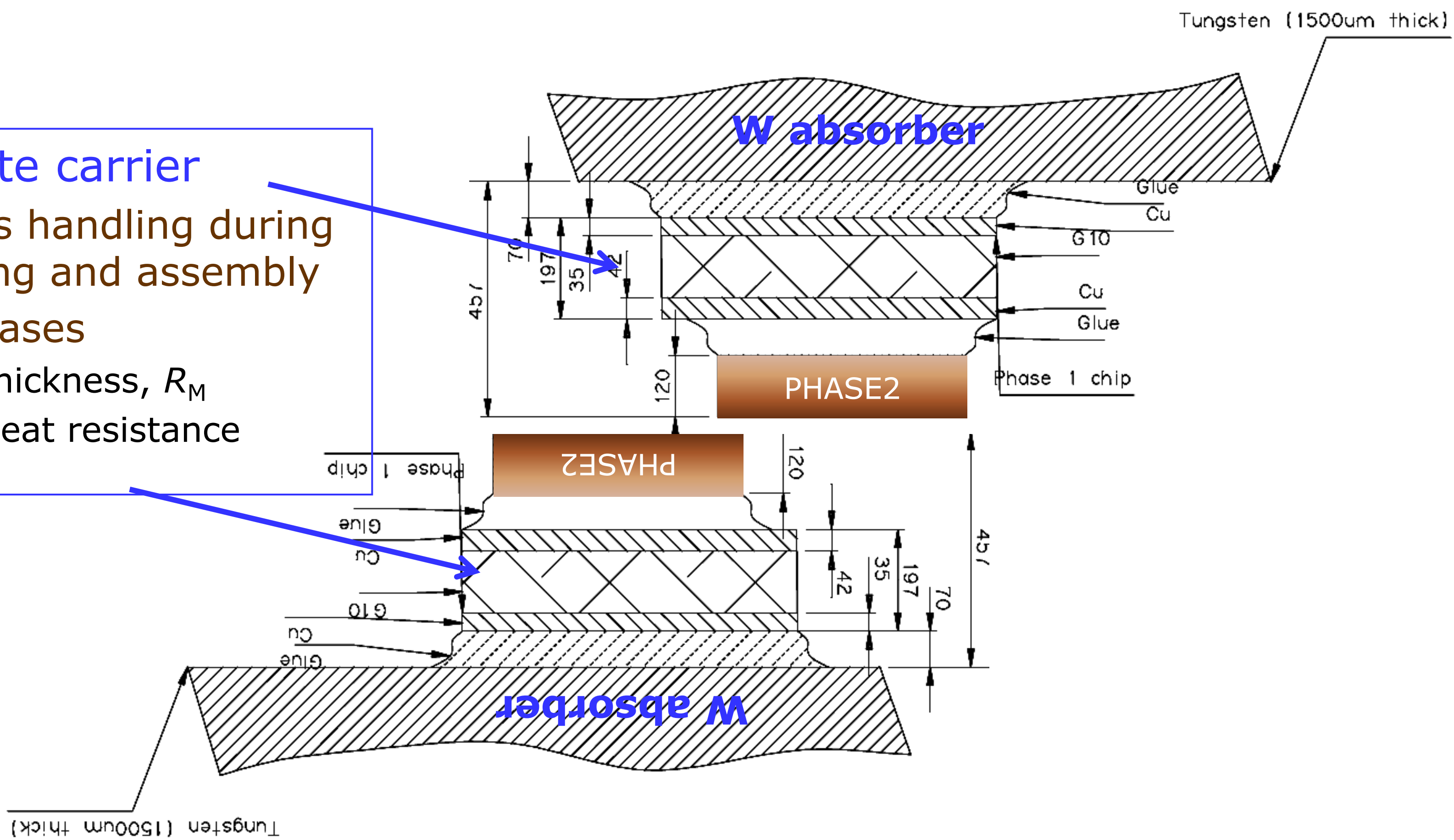




some details



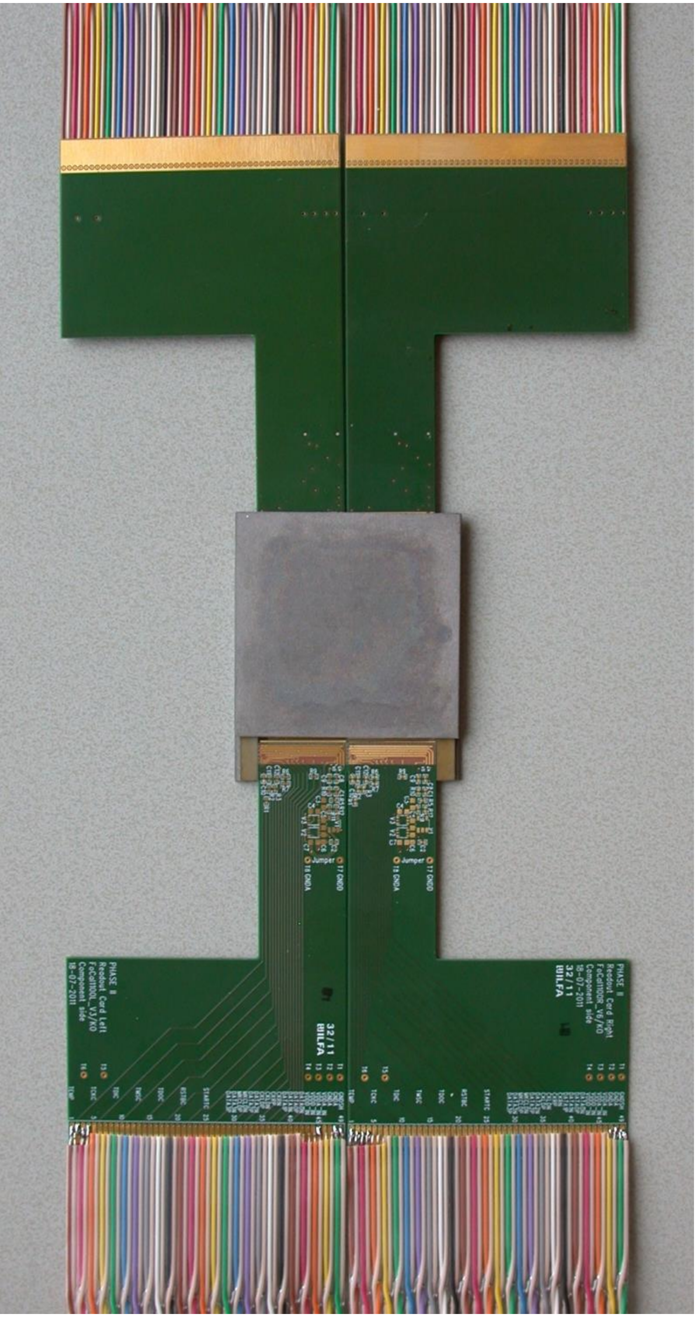
small overlap of top rows 100 µm



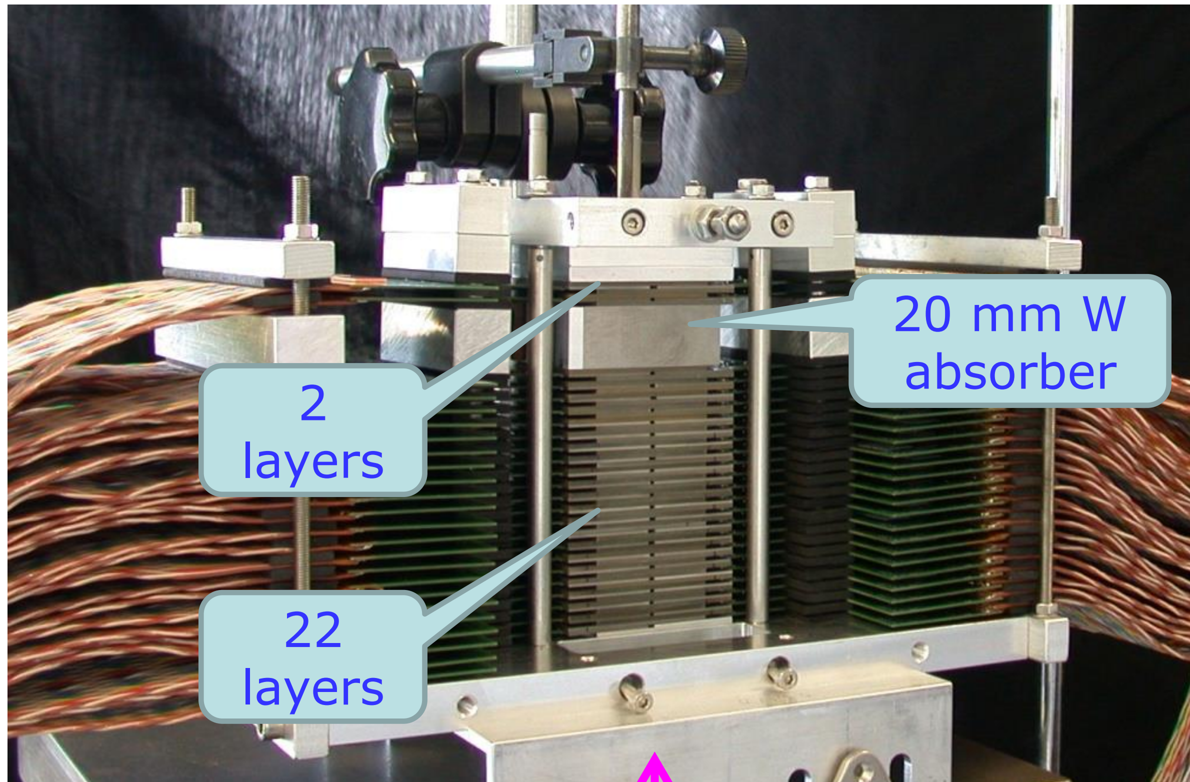
intermediate carrier

- eases handling during testing and assembly
- increases
  - thickness, R_M
  - heat resistance

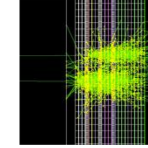
one layer -> 24 layers



assembly without cooling blocks

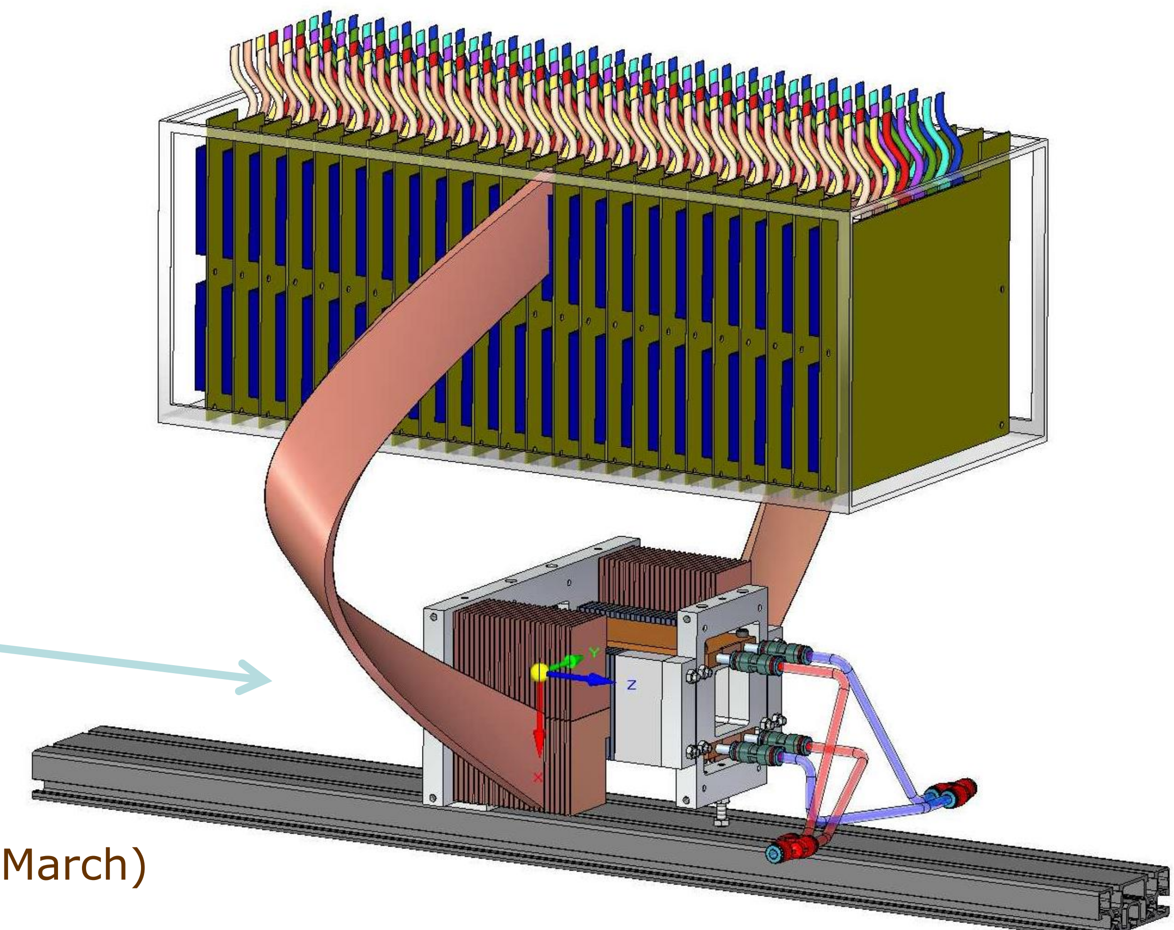


beam direction



beam test prototype

- 4 PHASE2 per layer: 24 * 4 cables from tower to read-out
- 39 M pixels → total 61 Gb/s
- several FPGA’s to manage this:
  - keep only 2 frames per trigger
  - big local buffer storage
  - small duty factor of PS/SPS

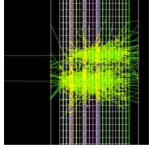


electron beam

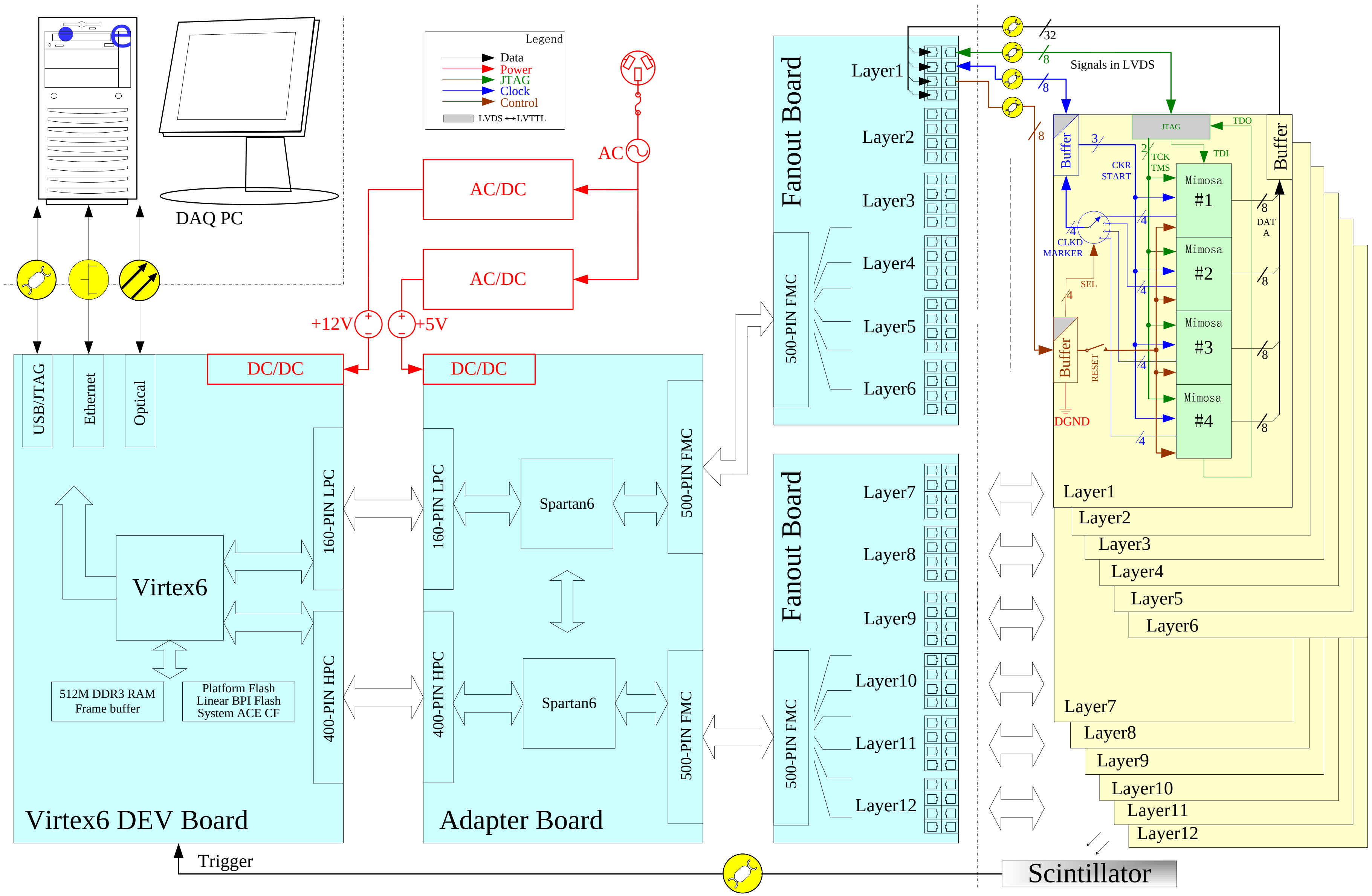
- DESY 2 .. 5 GeV
- CERN 30 .. 200 GeV

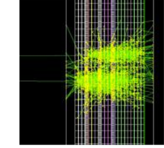
- cosmics (continuous since March)

read-out electronics (one half)



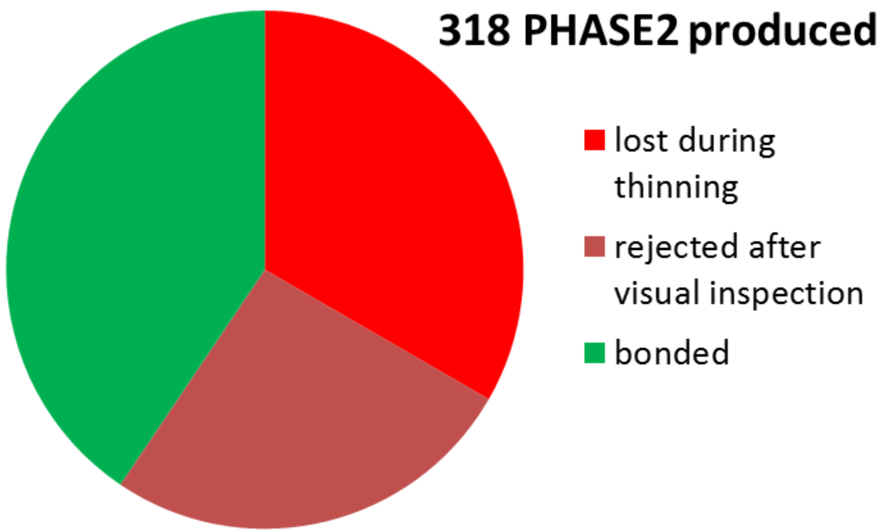
2013 JINST 8 P03015

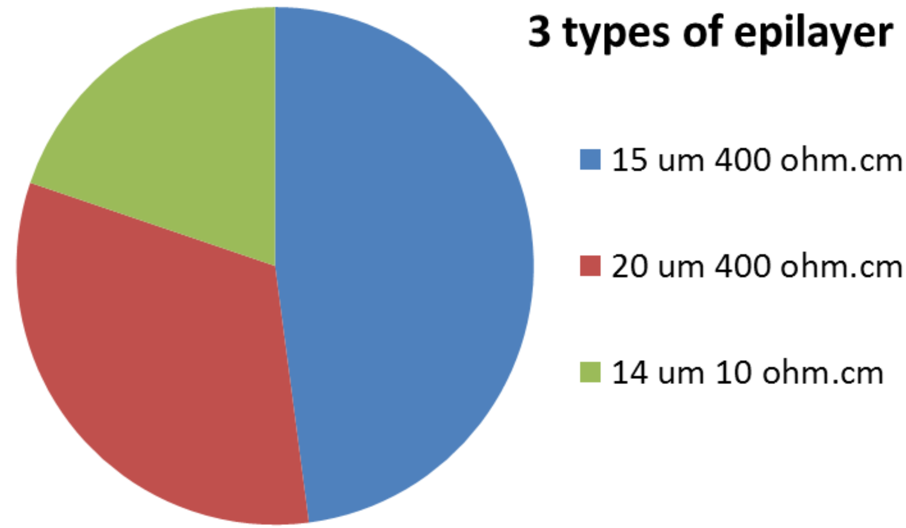




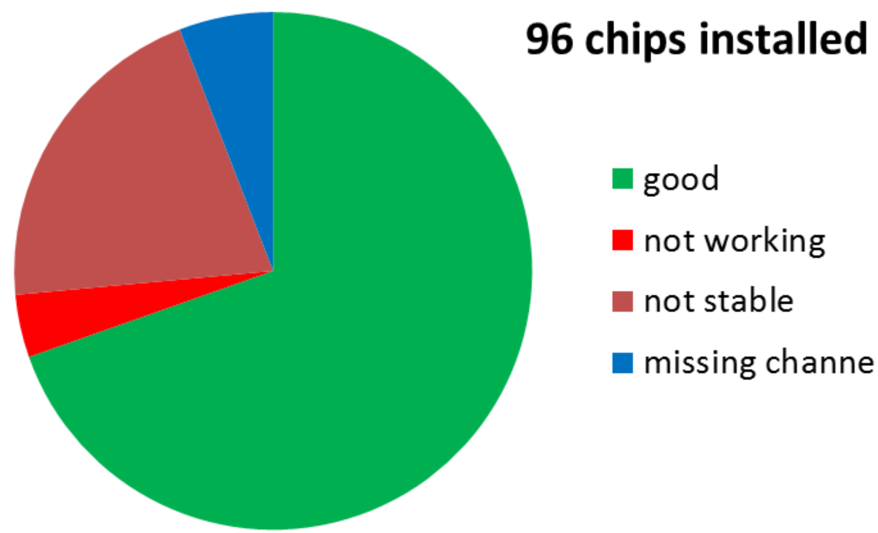
detector as built

low thinning yield

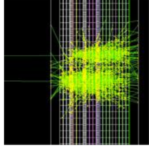




lost chips during/after assembly

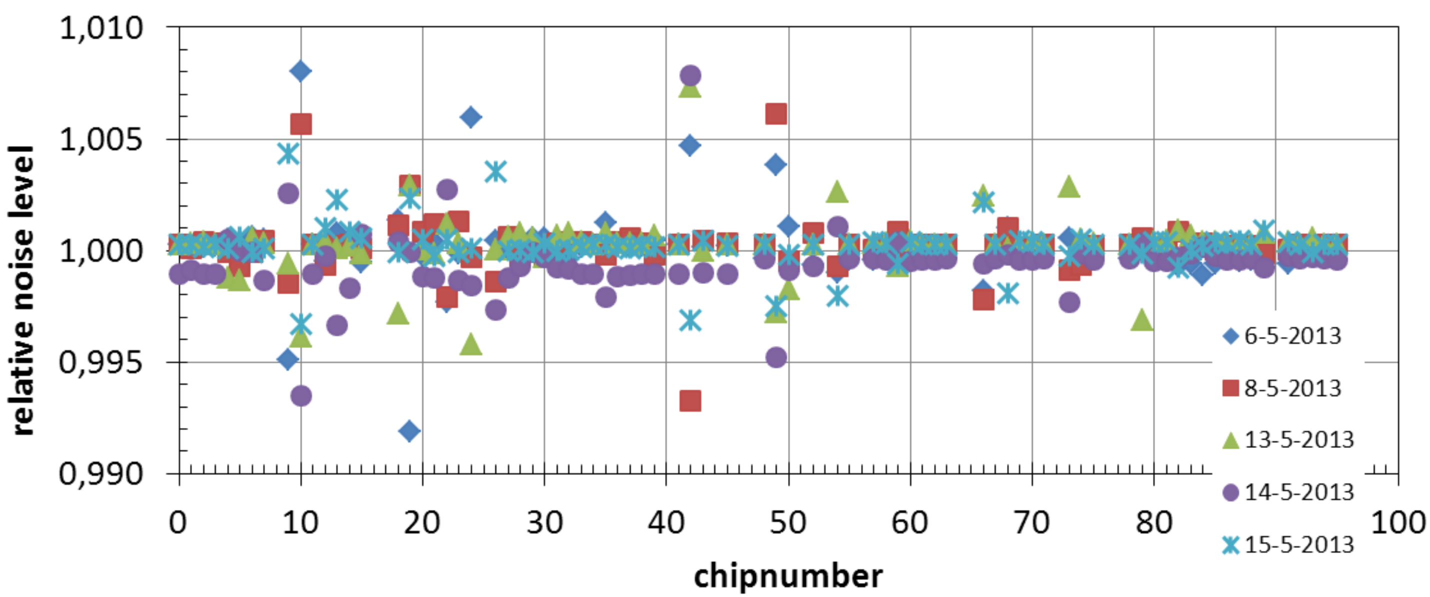


operation

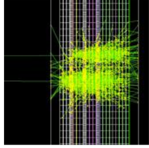


- flawless operation during 30 days of beamtests
  - occasional DAQ reset

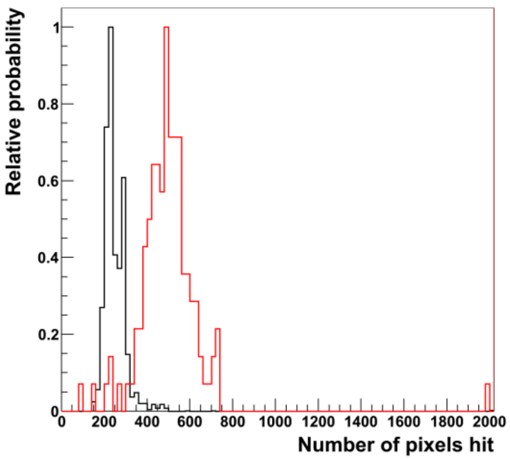
- continuous operation since March cosmics data taking
  - stable (10^{-3}) noise levels

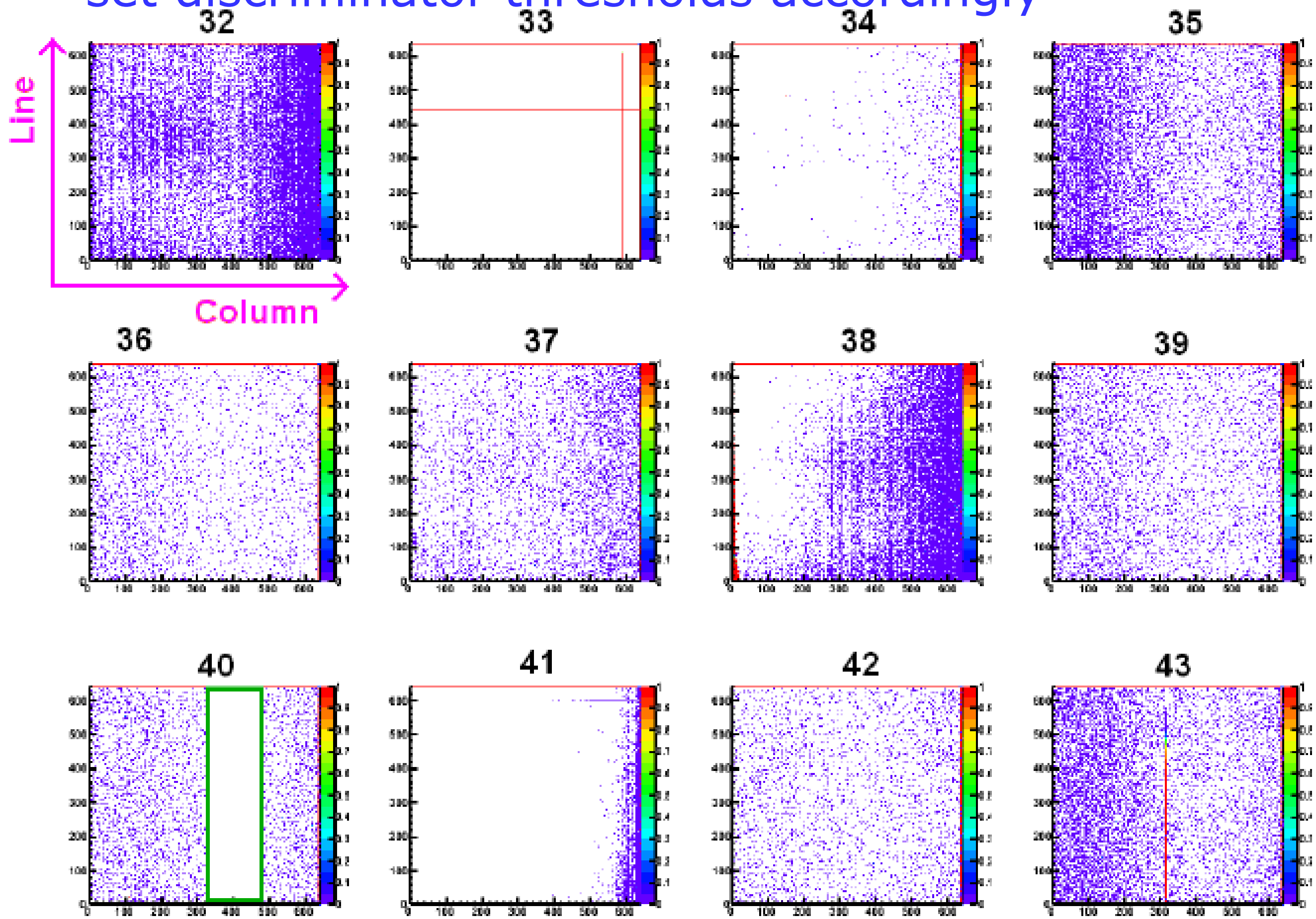


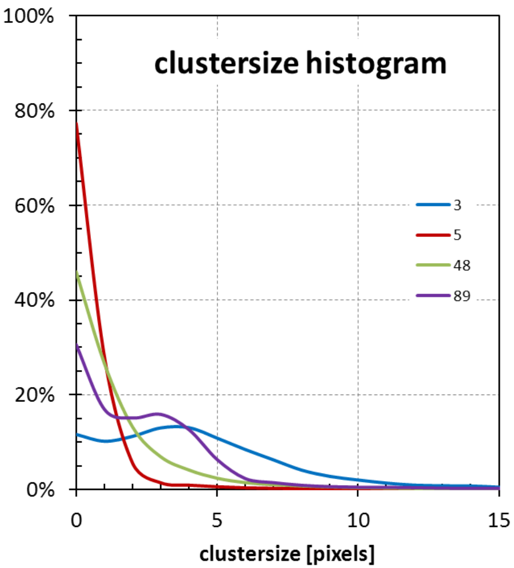
adjusting the discriminators
one per chip (409600 pixels)



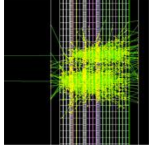
- different from tracker application!
- S/N ~2 at 2 GeV → noise 260 pixels → 10^{-5}
- set discriminator thresholds accordingly





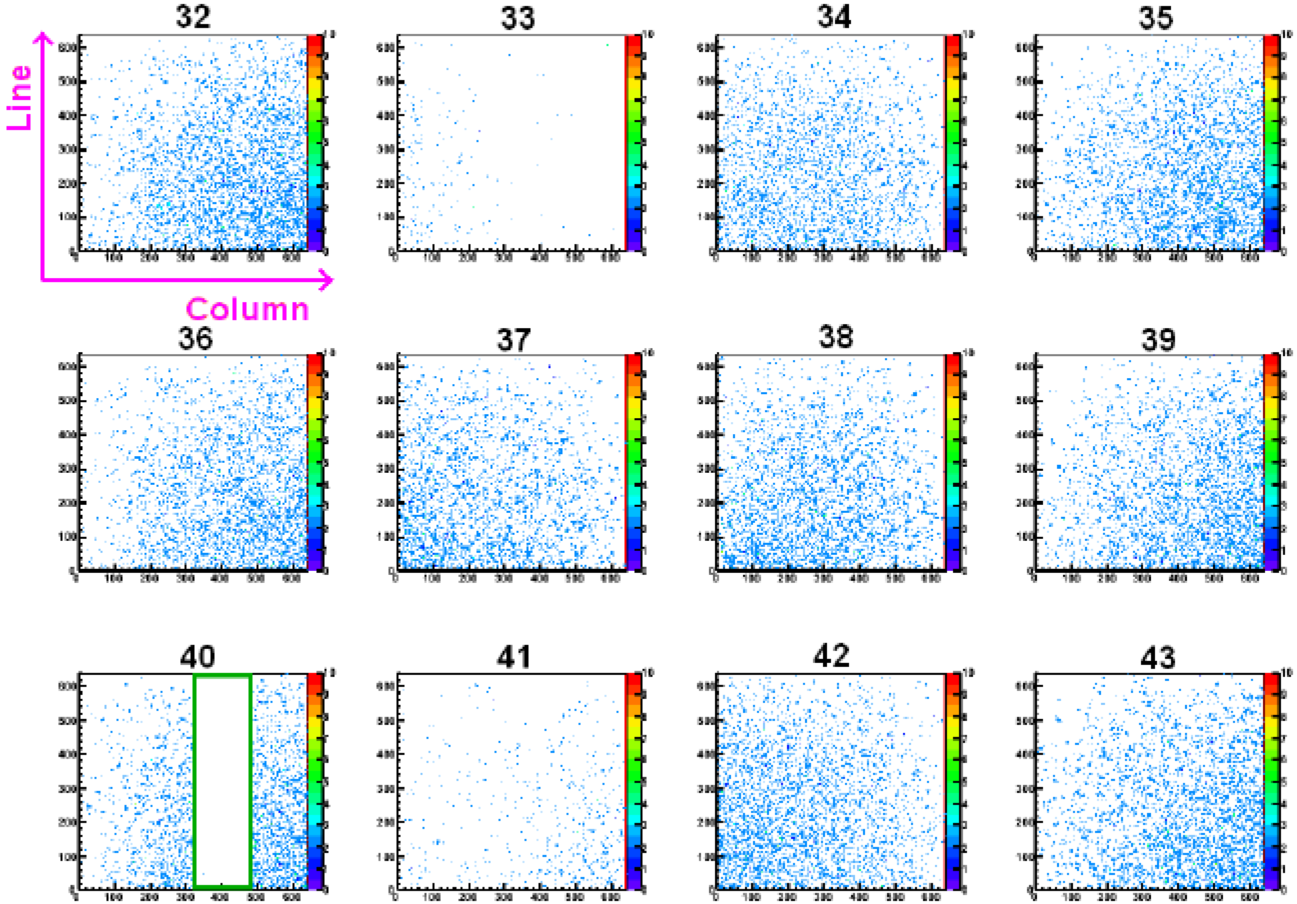


← near MPV peak → lose part of signal



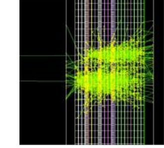
examples of raw data

hit patterns from cosmics (13 k triggers)

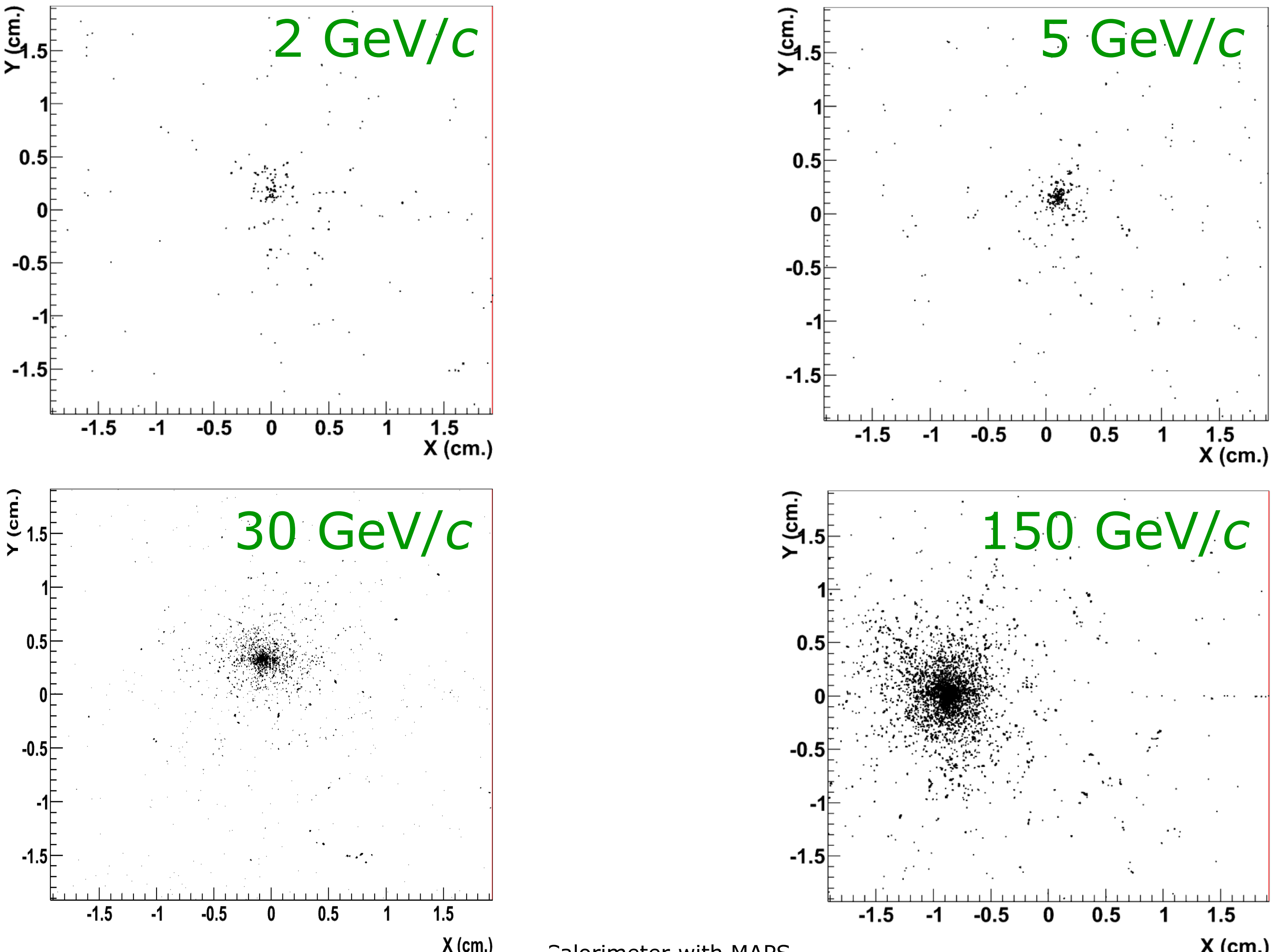


4 chips per layer, next plots

- not aligned, only oriented
- hot pixels / columns masked



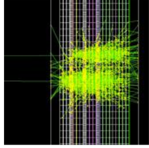
all hits generated by a single electron of

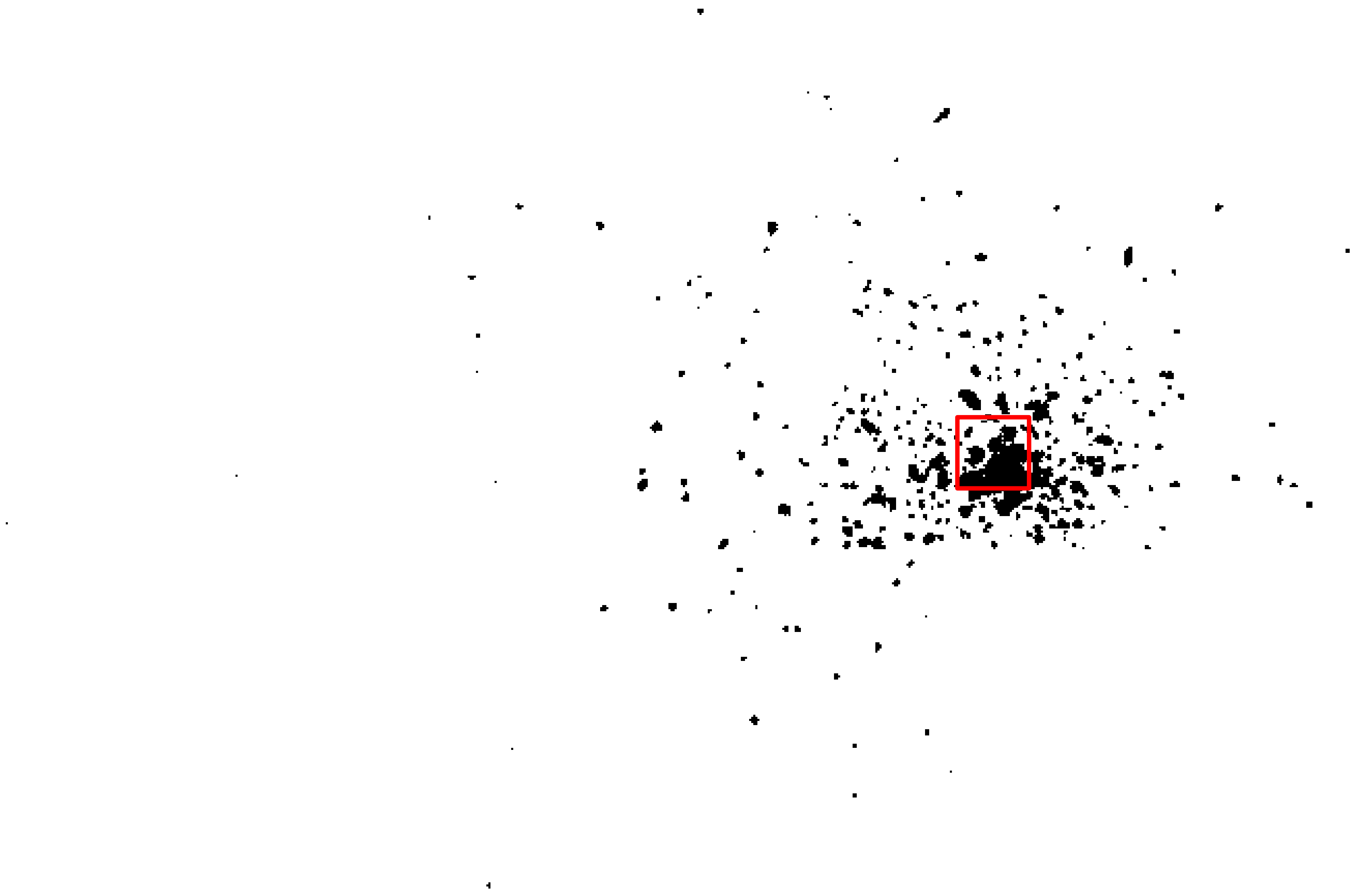


hit density

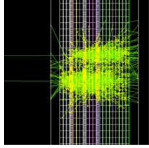
single electron 150 GeV/c

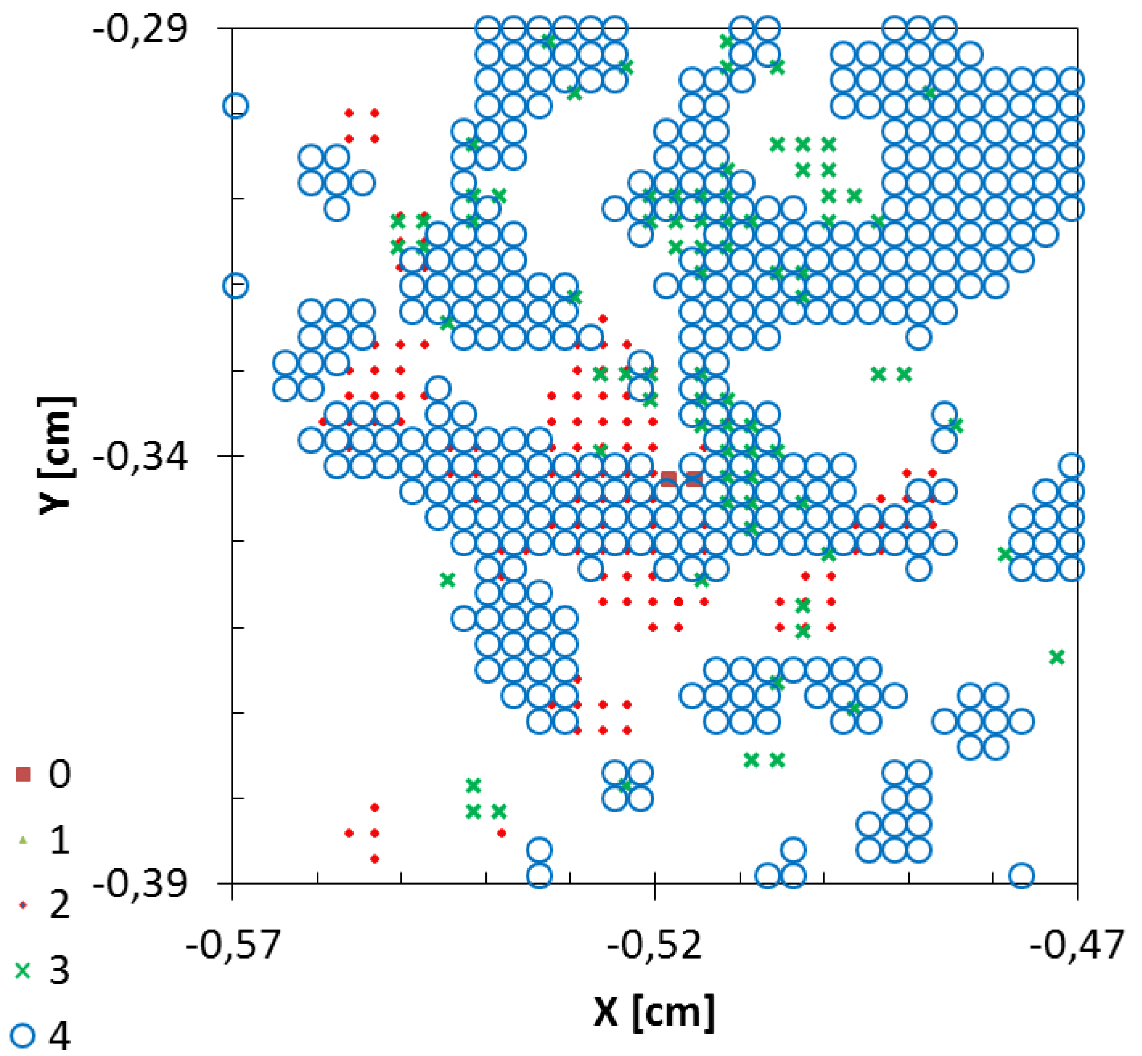
layer 6 5.9 X_0 square is 1 mm



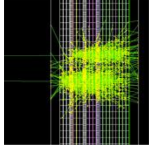


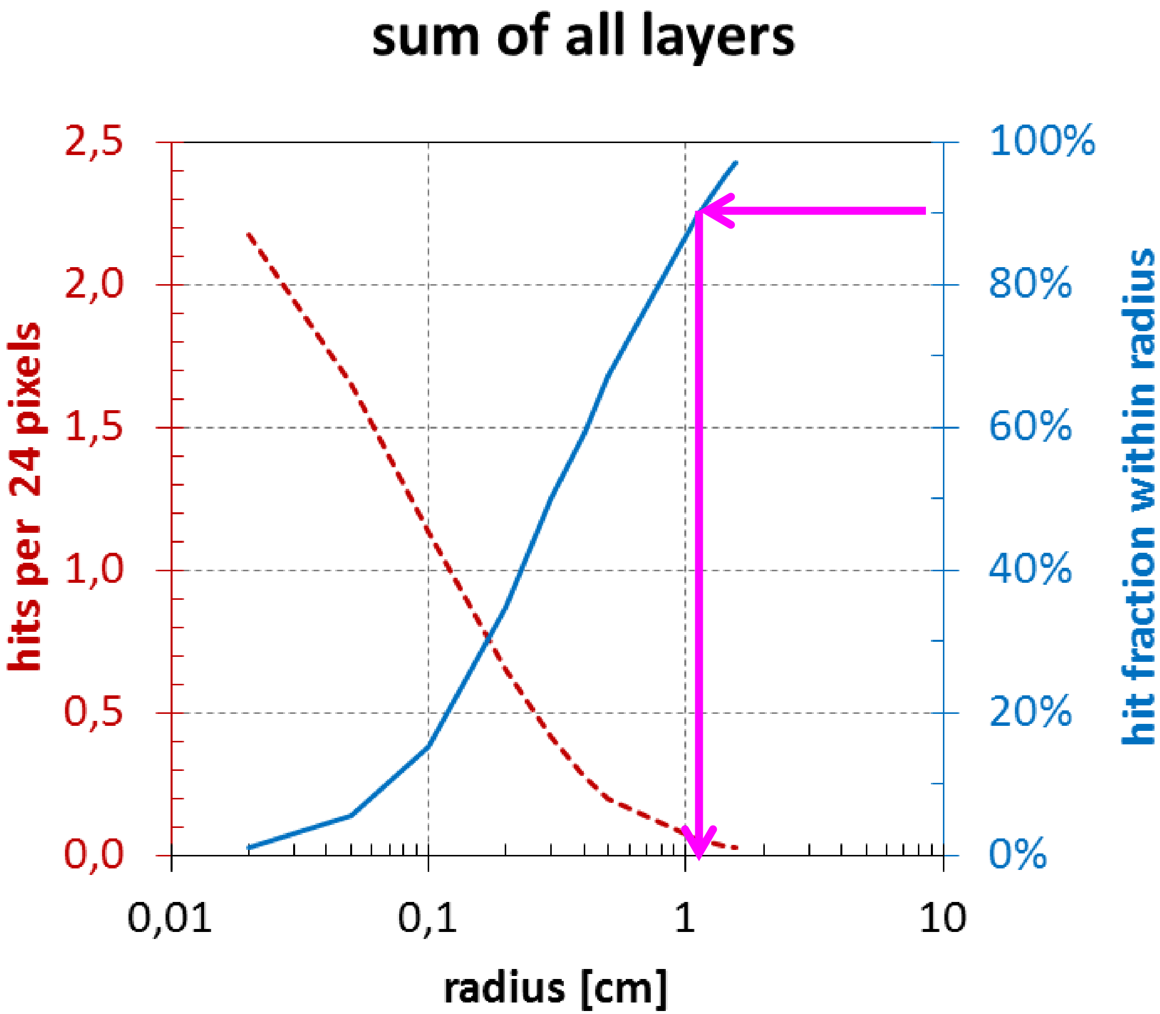
close look at showercore
200 GeV/*c* positron, 30 um pixels



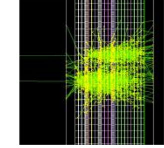


close look at showercore
Moliere radius



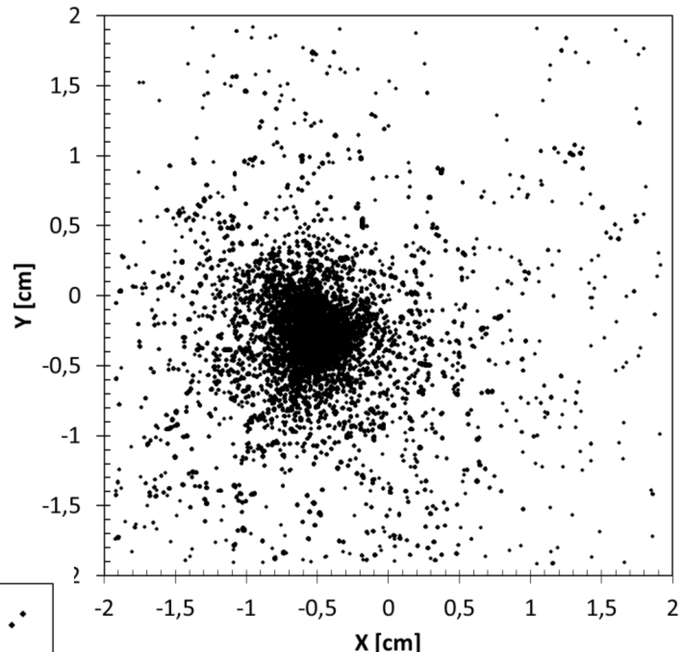


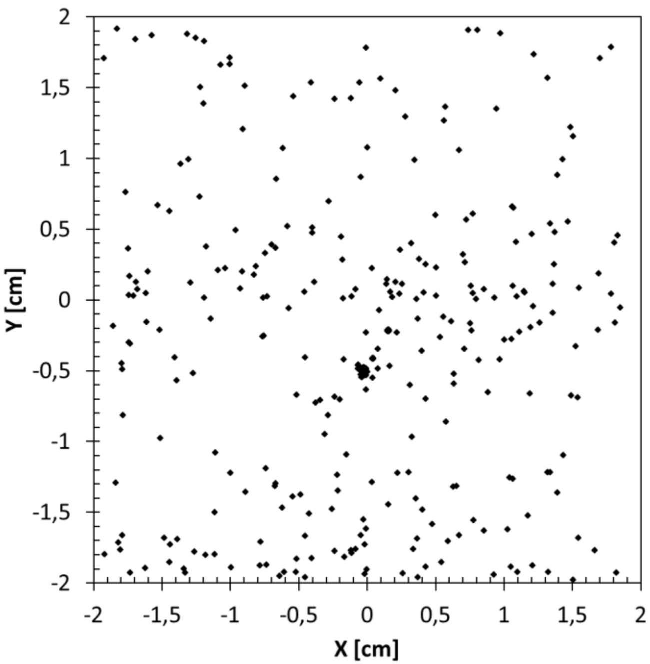
all hits generated by a single particle



200 GeV/c positron

26022 hits

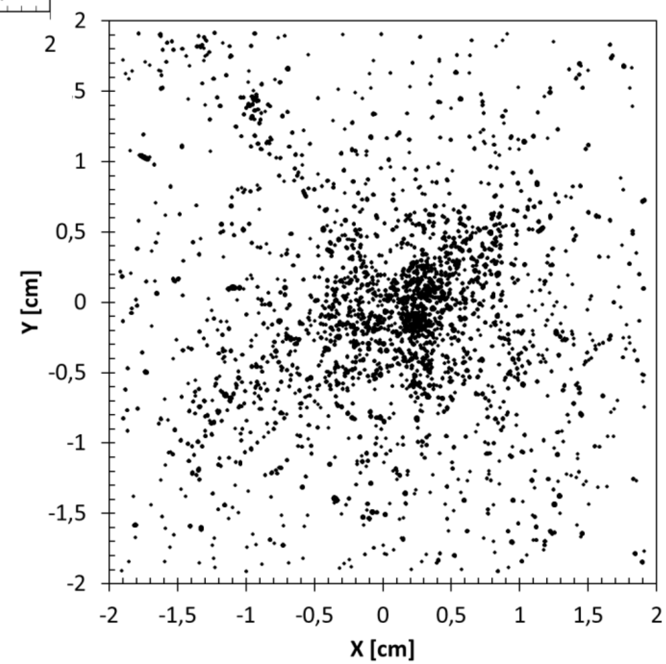




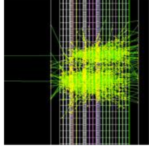
200 GeV/c pion

415 hits

12238 hits

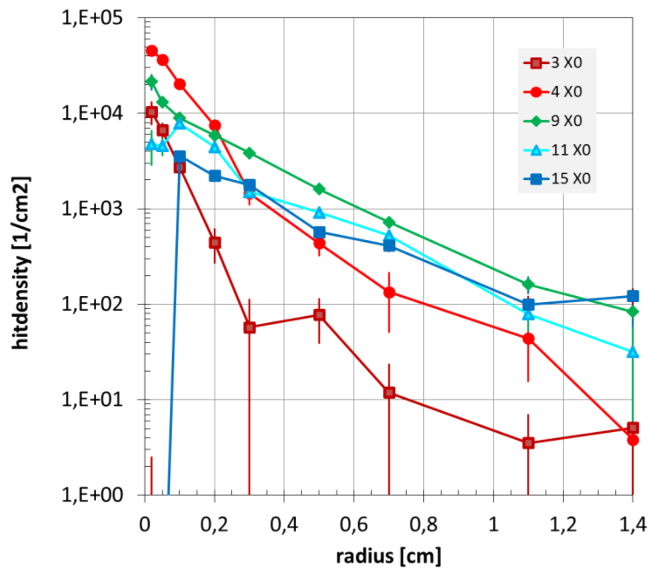


hit profiles of a single particle



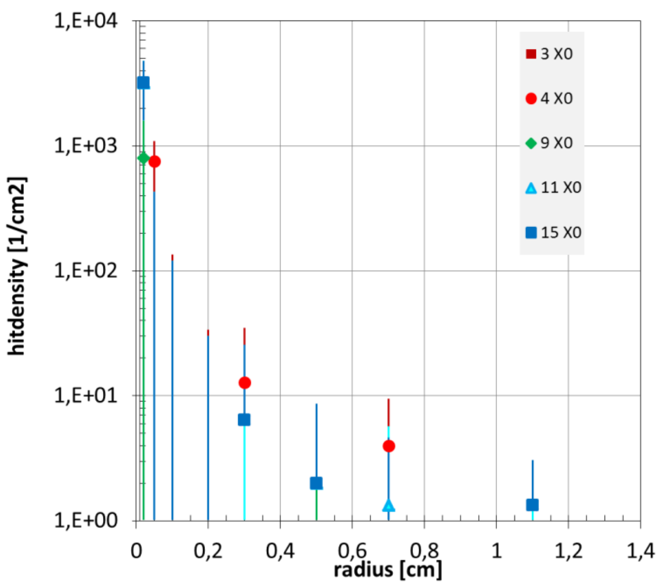
200 GeV/c positron

EM shower

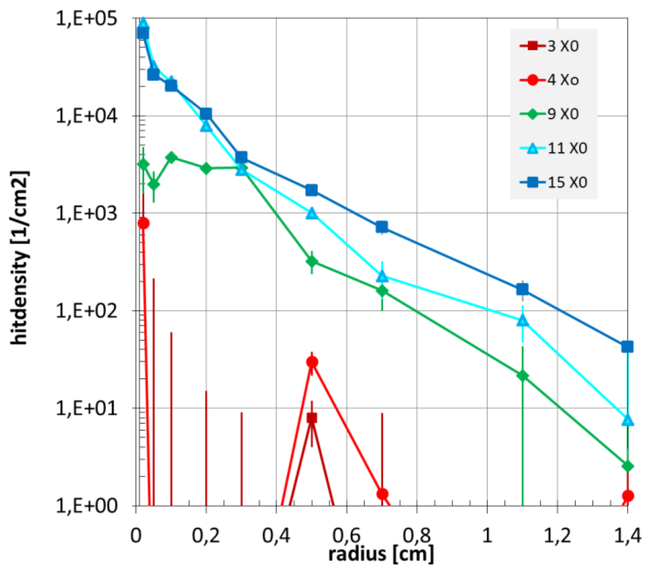


200 GeV/c pion

track

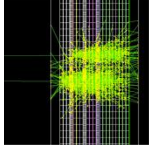


hadronic shower



noise hit density 1 cm^{-2}

special features: large clusters, lines,..

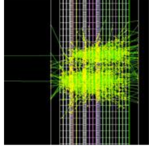


objects larger than single particle hits:

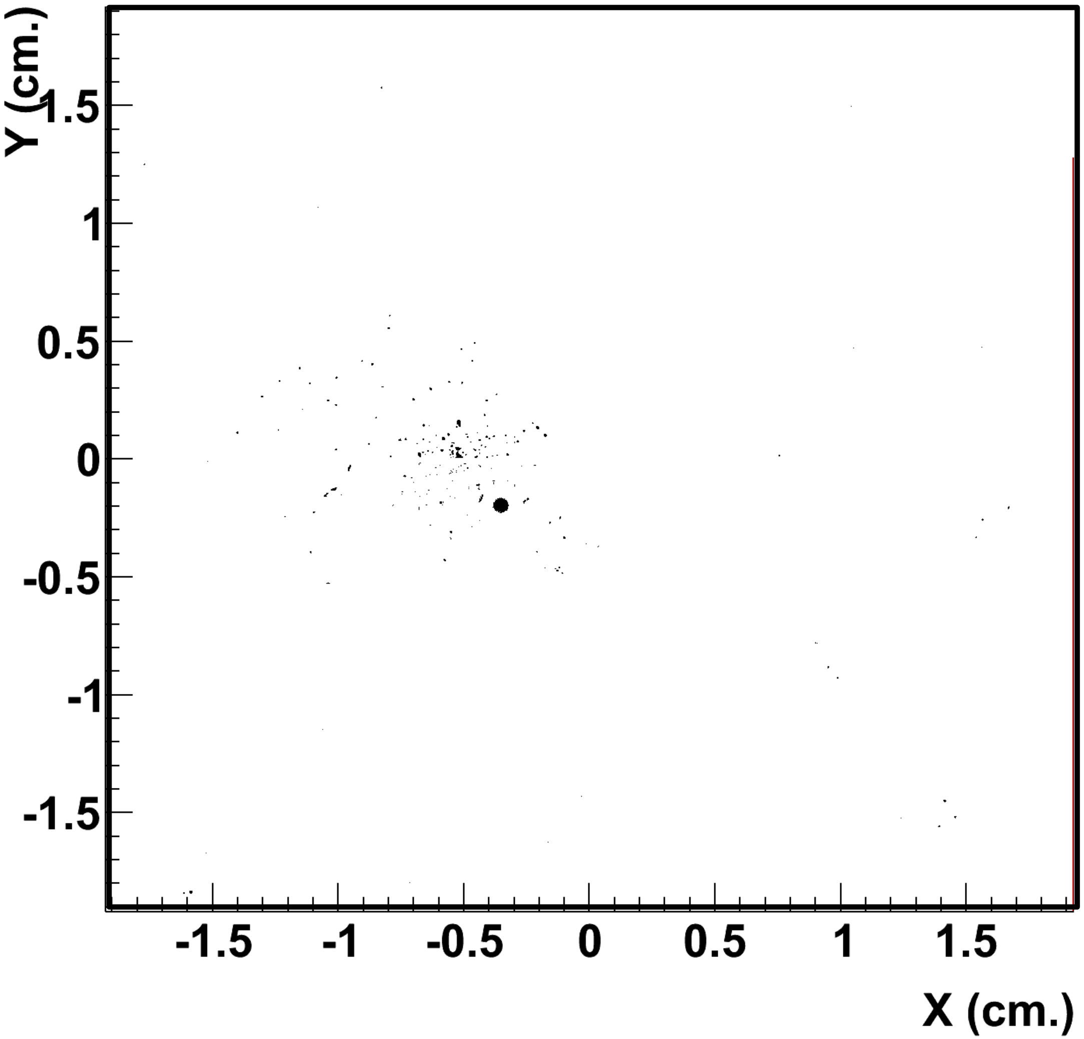
  - clustersize >5
  - linear

- observed in ‘all’ showers, never associated with pion tracks
- shapes
  - largest object: 0.8 mm Ø disc
  - line 1.3 mm
  - curved lines *r* ~ mm

positron 200 GeV/c

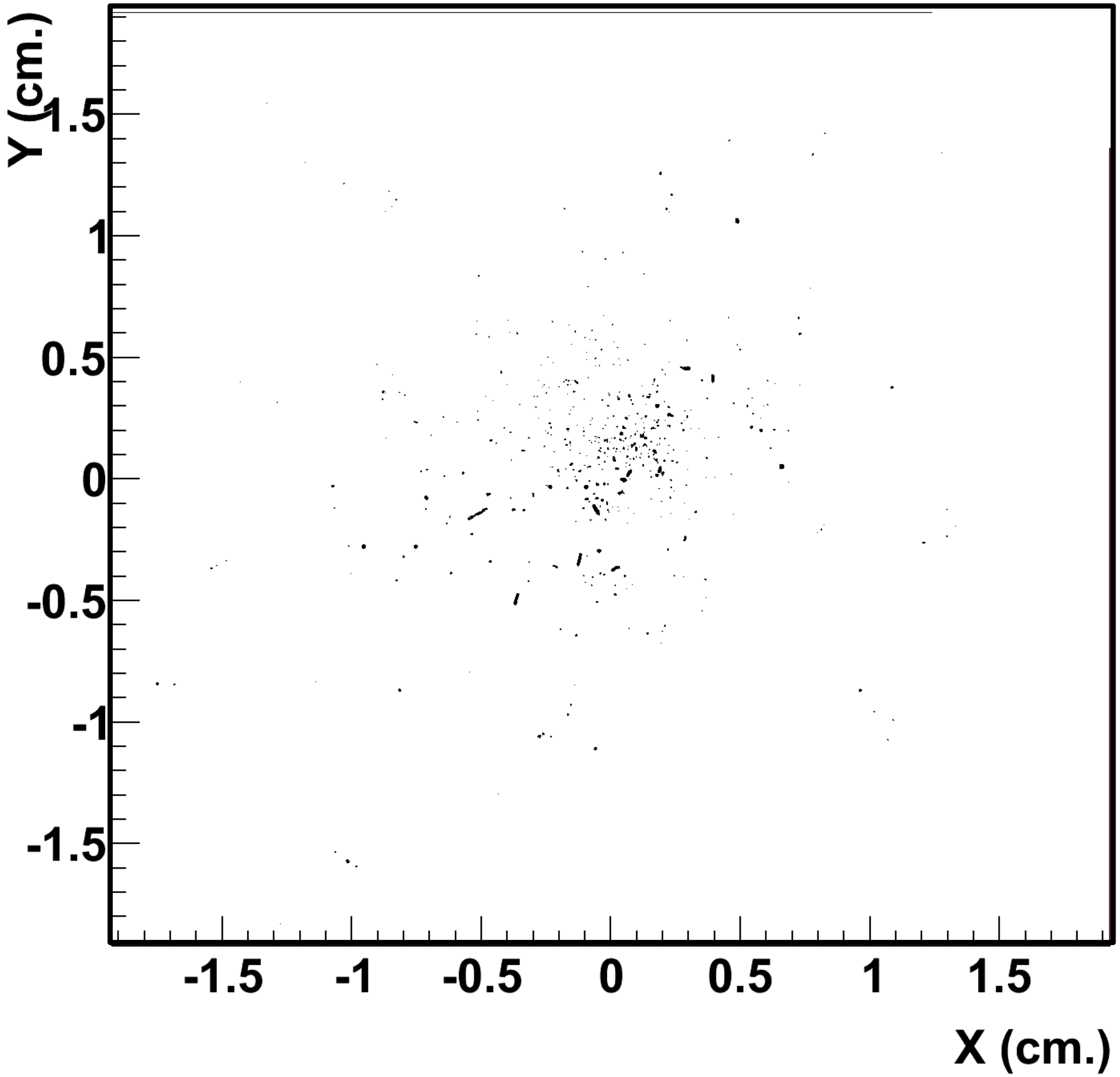


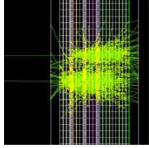
layer 9 8.8 X_0



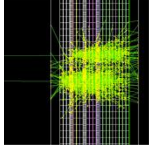
electron -50 GeV/*c*)

layer 15 15 X_0

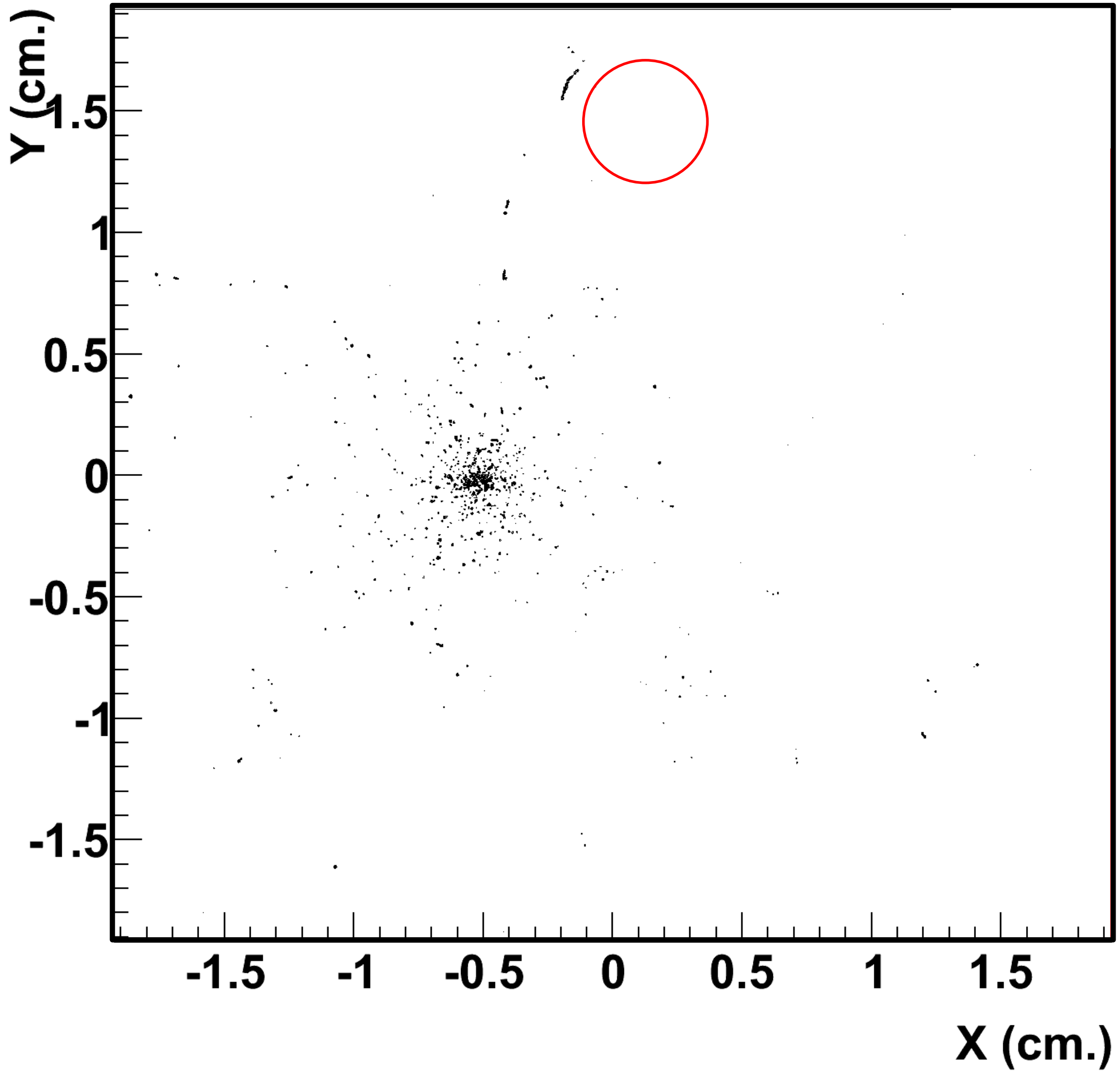


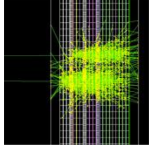


positron 200 GeV/c)

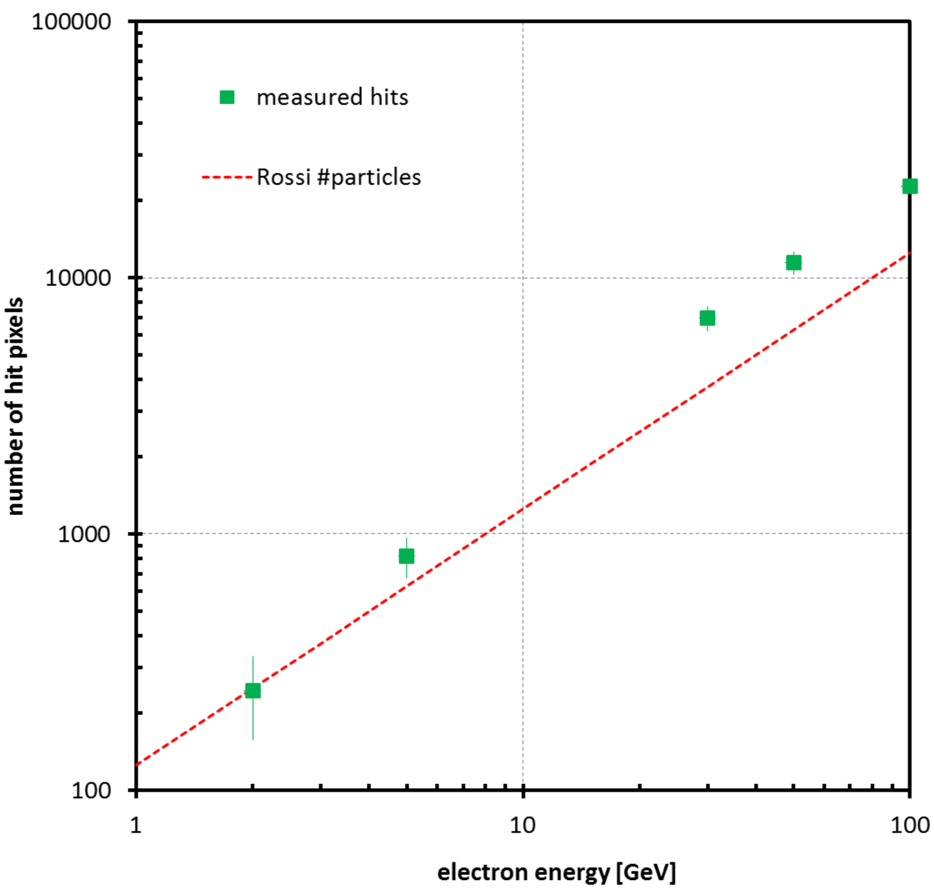


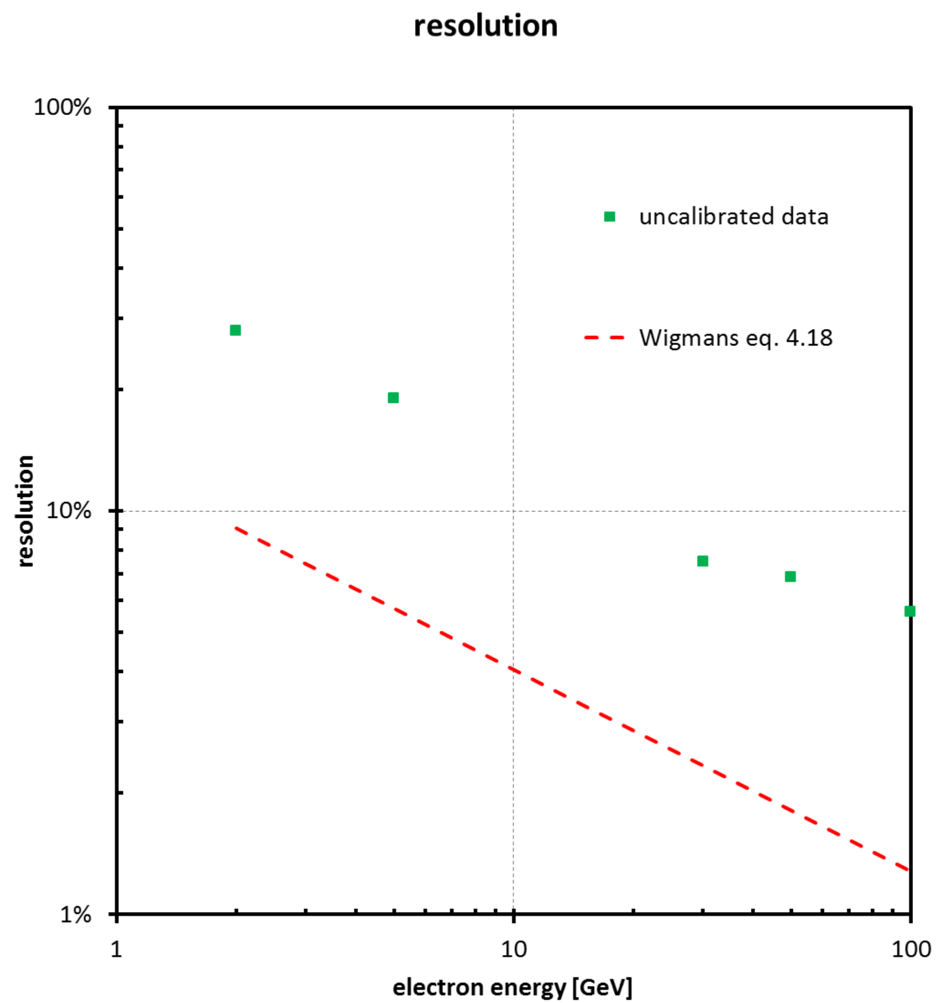
layer 12 12 X_0

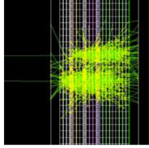




preliminary results
calibration in progress!

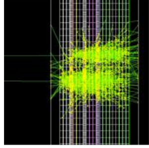






objectives reached?

- proof-of-principle
  - ➢ resolution to be improved
  - ✓ Moliere radius 11 mm
- technology demonstrator
  - ✓ manage read-out at GB/s
  - ✓ cooling
  - ✓ integration
  - ✓ overlap, needed because of dead zones
- collect data for study of
  - ✓ data volume/flow, data reduction
  - ✓ pixel size
- further work required
  - ➢ threshold tuning
  - ✓ unexplained features in EM showers



R. Wigmans, Calorimetry, energy measurement in particle physics,

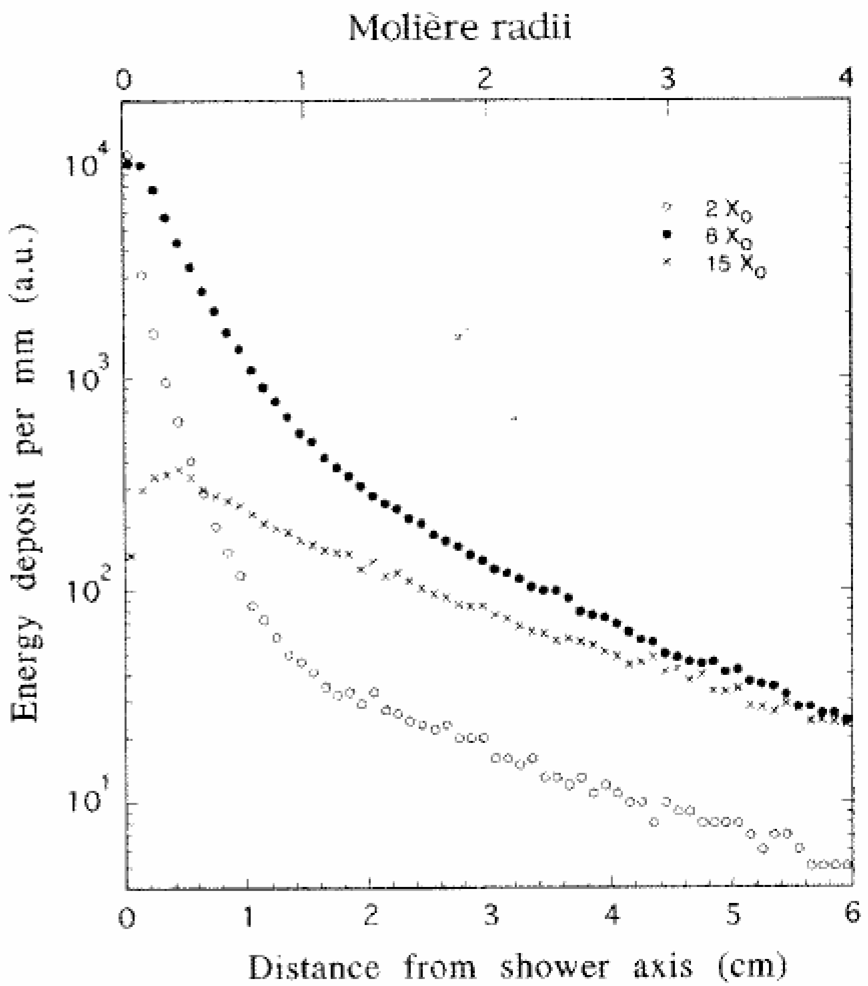
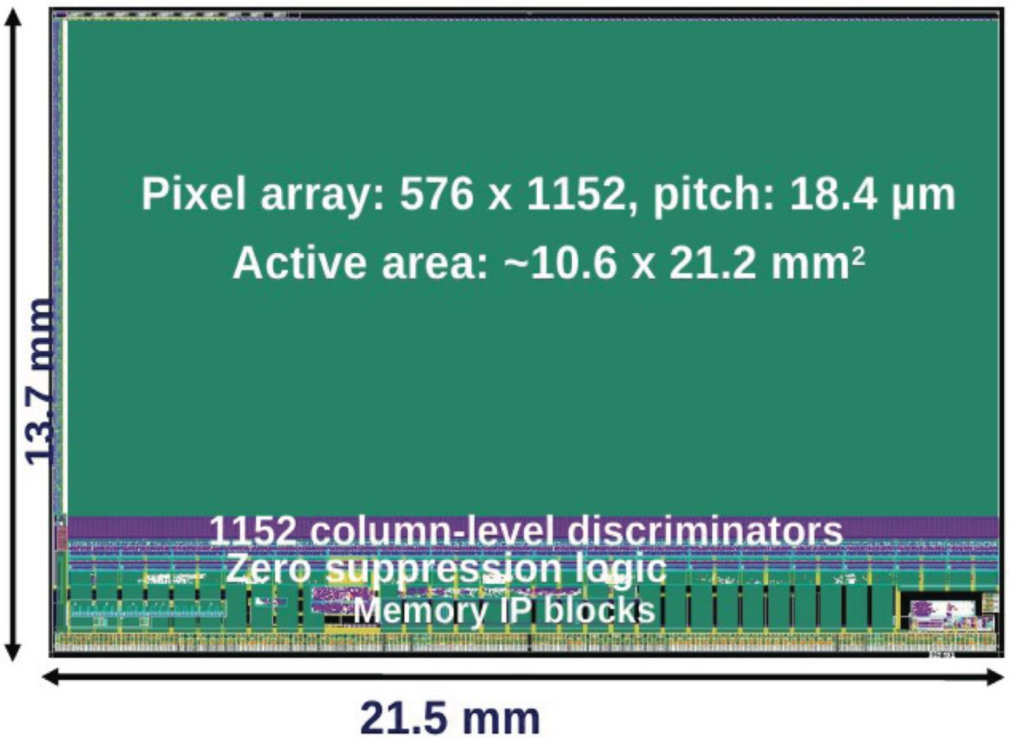
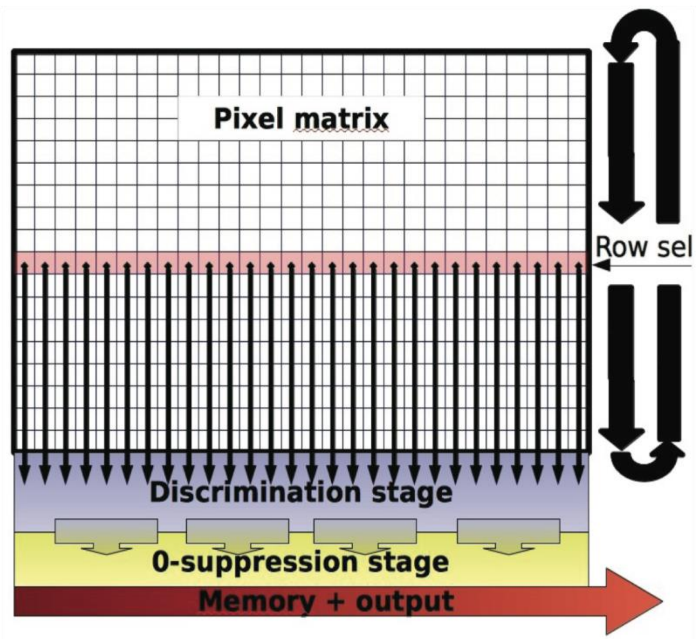


FIG. 2.13. The radial distributions of the energy deposited by 10 GeV electron showers in copper, at various depths. Results of EGS4 calculations.

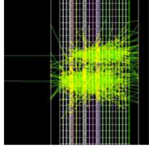
an implementation in 0.35 AMS: MIMOSA26



- “rolling shutter” readout
  - 115 μs per frame
  - 115 μs charge integration
- row-wise discrimination
- built-in zero suppression



DAQ during test beams



- rolling shutter 640 us
- 96 chips
- total datarate 61 Gbit/s

-> can store only 0.5 s of data in memory

takes ~2 minutes to transfer to disk

-> very low dutyfactor

- datacompression via Root: 10 – 50
- 7 TB disk space

➢ can store all raw data (1300 s livetime)

➢ select triggered frames off-line (231k triggers)