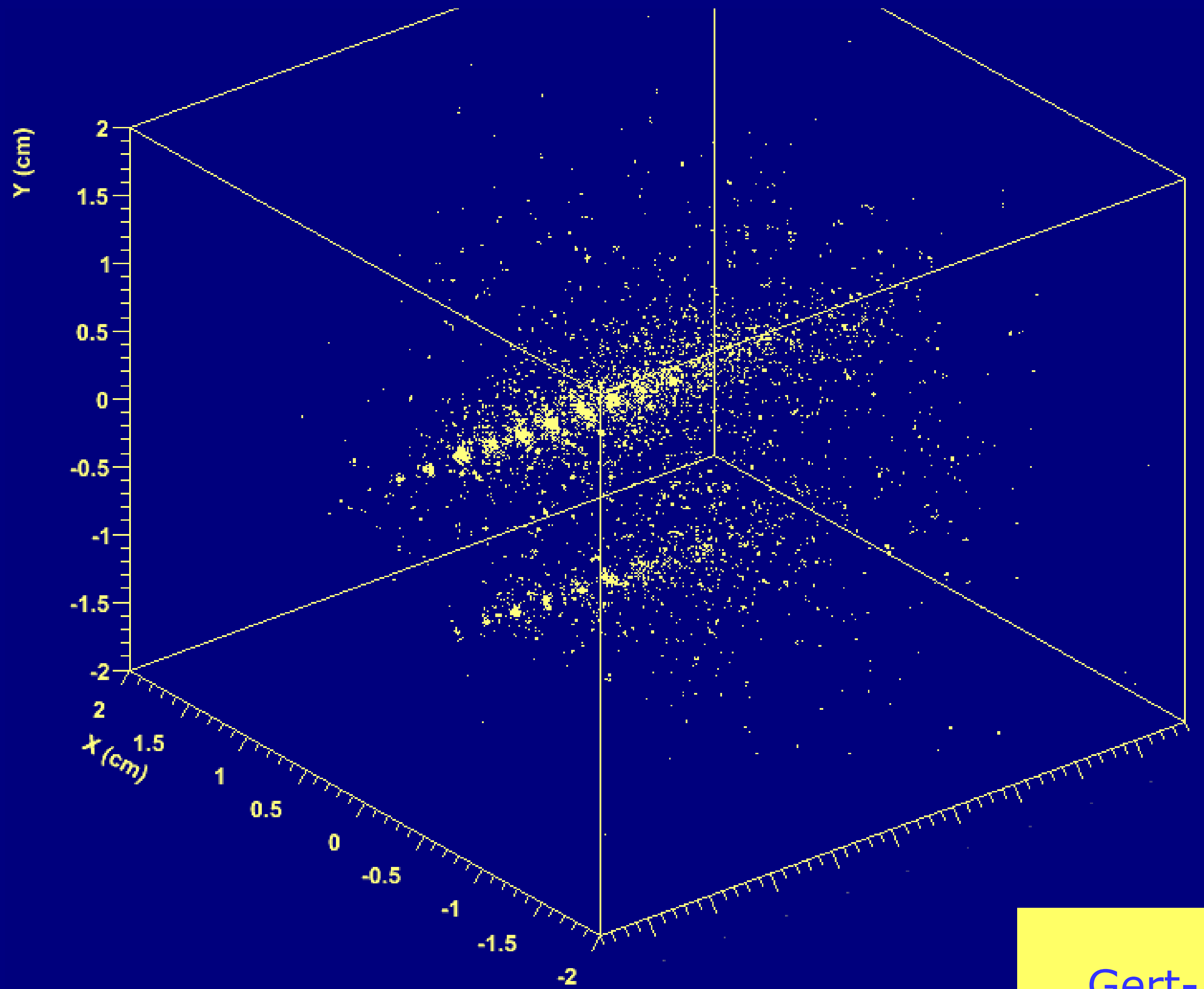
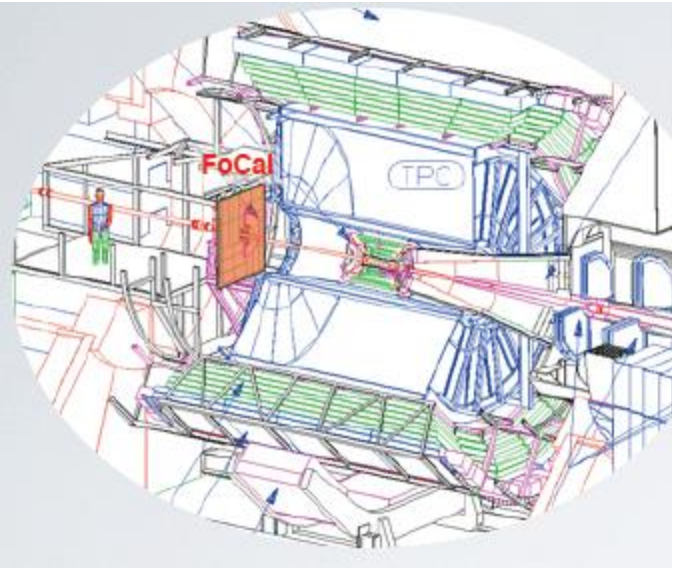
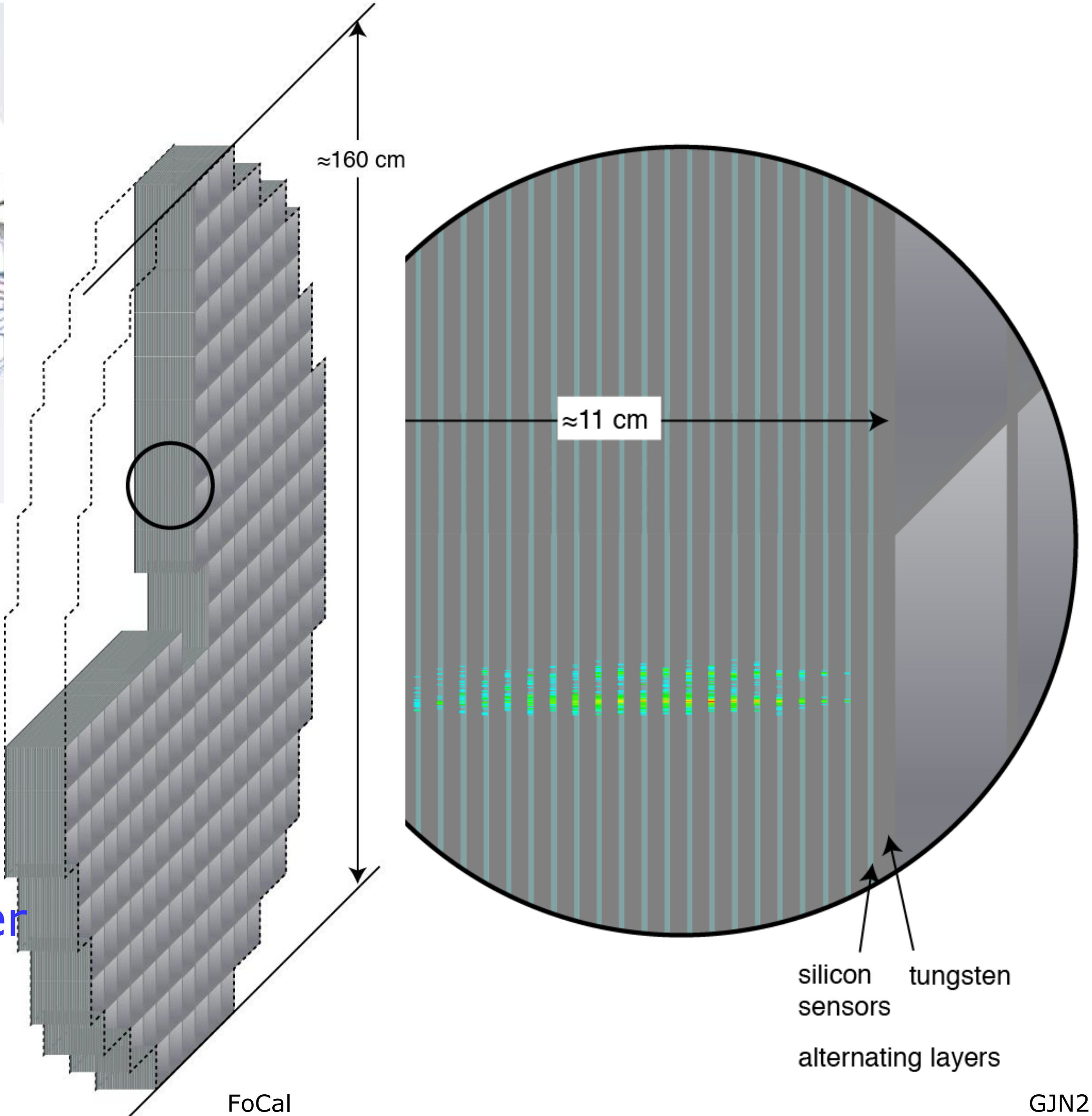
FoCal calorimetry introduction



Gert-Jan Nooren

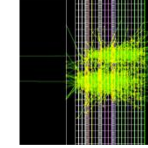
FoCal detector
for direct photons originating in the QGP



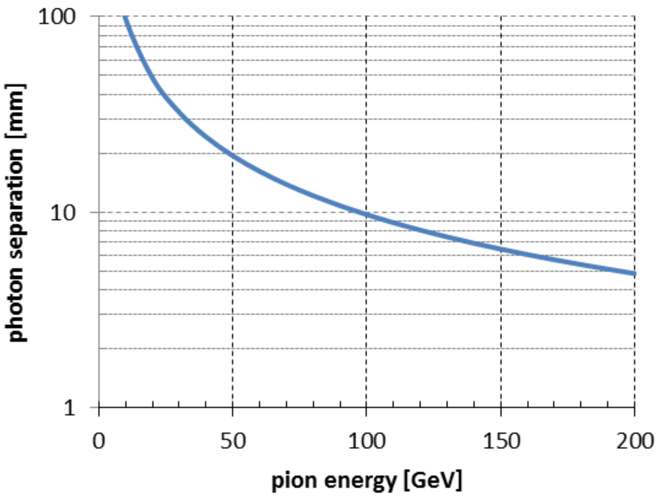


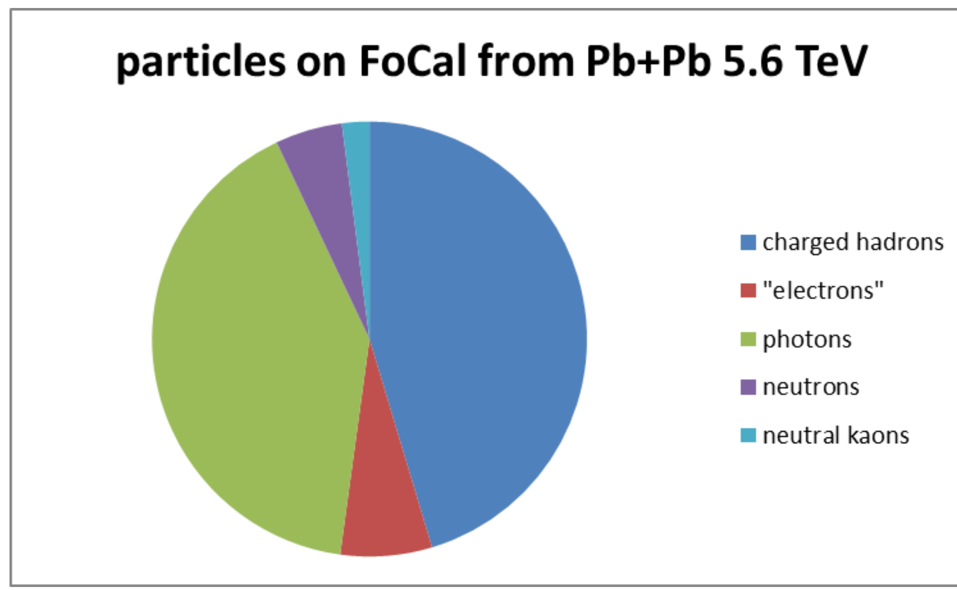
- 2 m² sensors per layer
- 3 ton

FoCal detector
for direct photons originating in the QGP



- ☹ there are other particles:
  - charged hadrons, mostly pions
  - muons and electrons
  - neutral particles
- ☹ there are other photons
  - scattering and radiation in the medium
  - *idem* in ALICE materials
  - from decay, mostly π^0

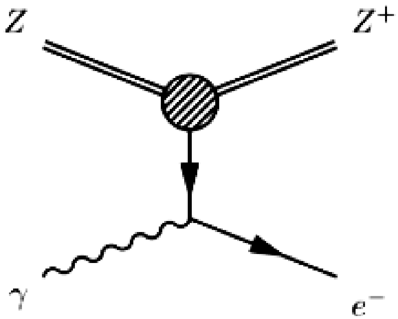


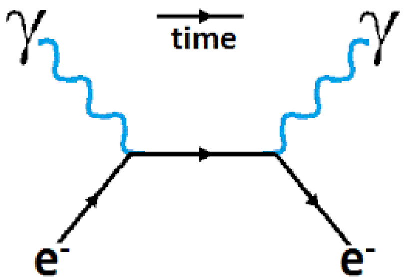


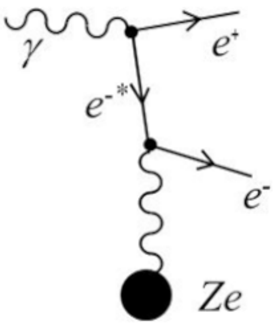
particle interactions (1)

- particle loses energy, is absorbed, particles created
- particle changes direction

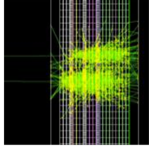
- neutral particles
  - nuclear interactions
  - photons: photo absorption, compton scattering, pair production





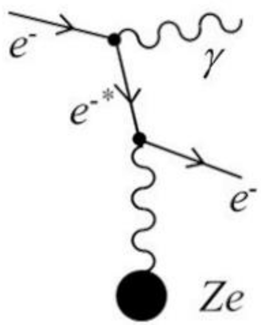


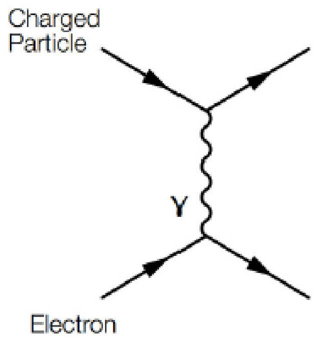
particle interactions (2)



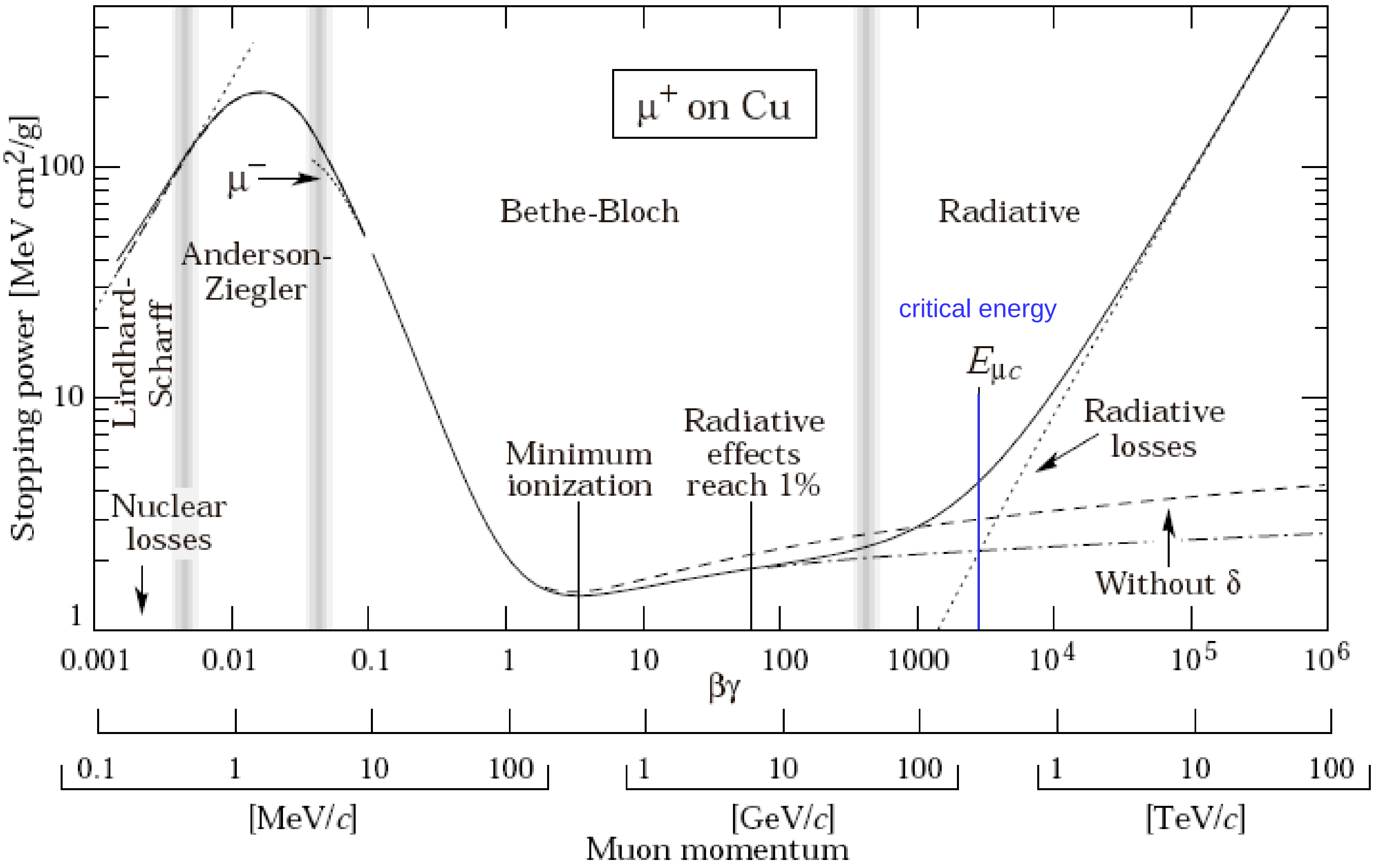
- ➢ particle loses energy, is absorbed, particles created
- ➢ particle changes direction

- charged particles
  - – nuclear interactions
  - – electromagnetic interactions:
    - at high momentum: radiative losses
    - energy loss via collisions “ionisation”

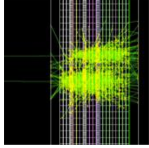




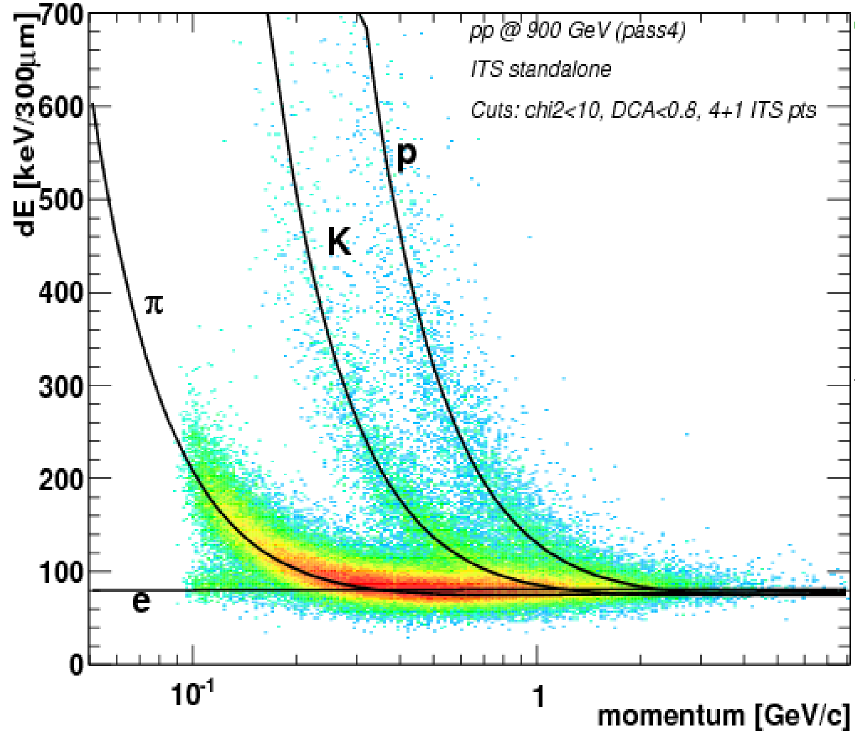
energy loss via collisions and radiation



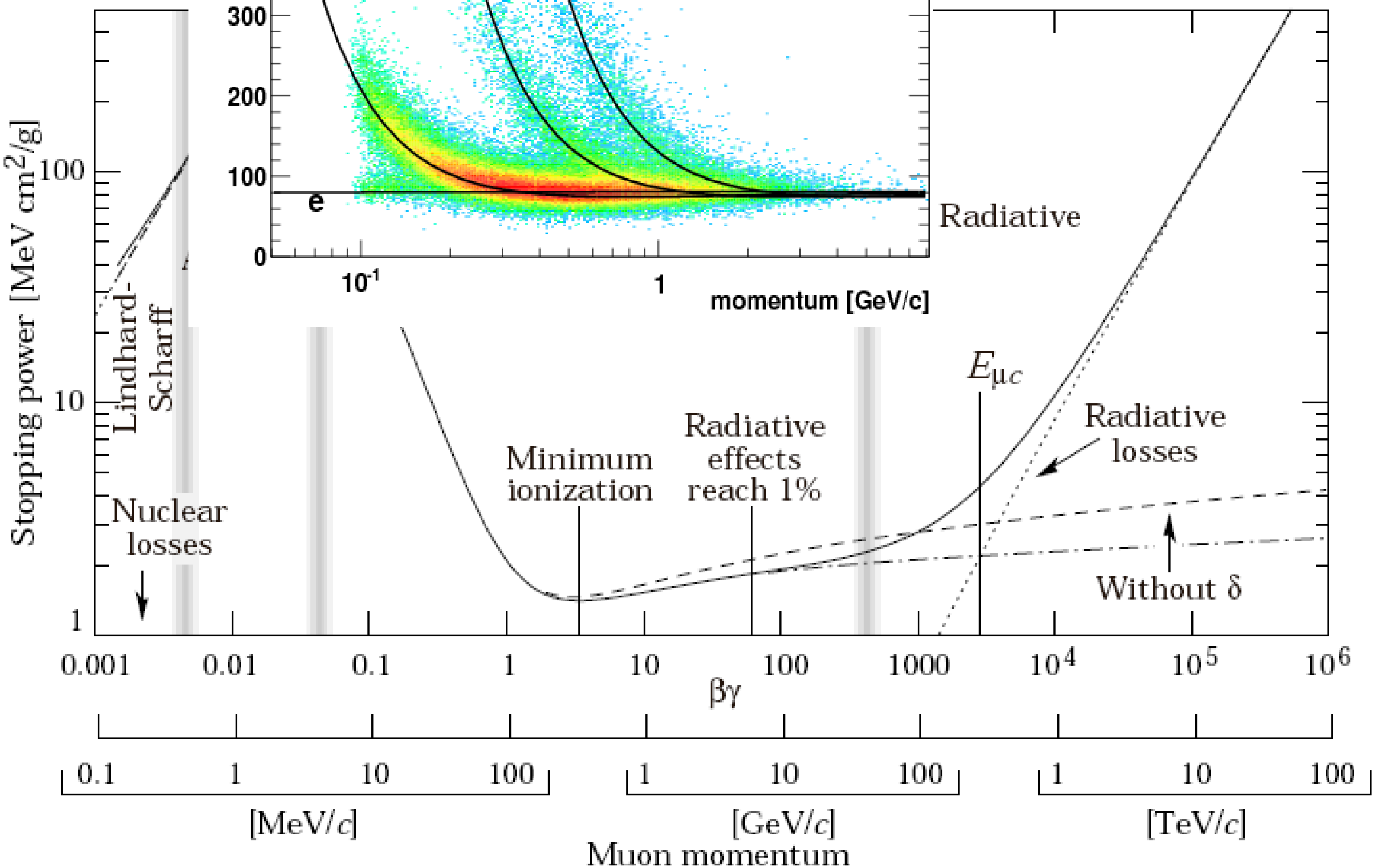
energy ... nd radiation



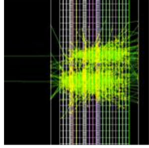
M. Chojnacki, E. Biolcati

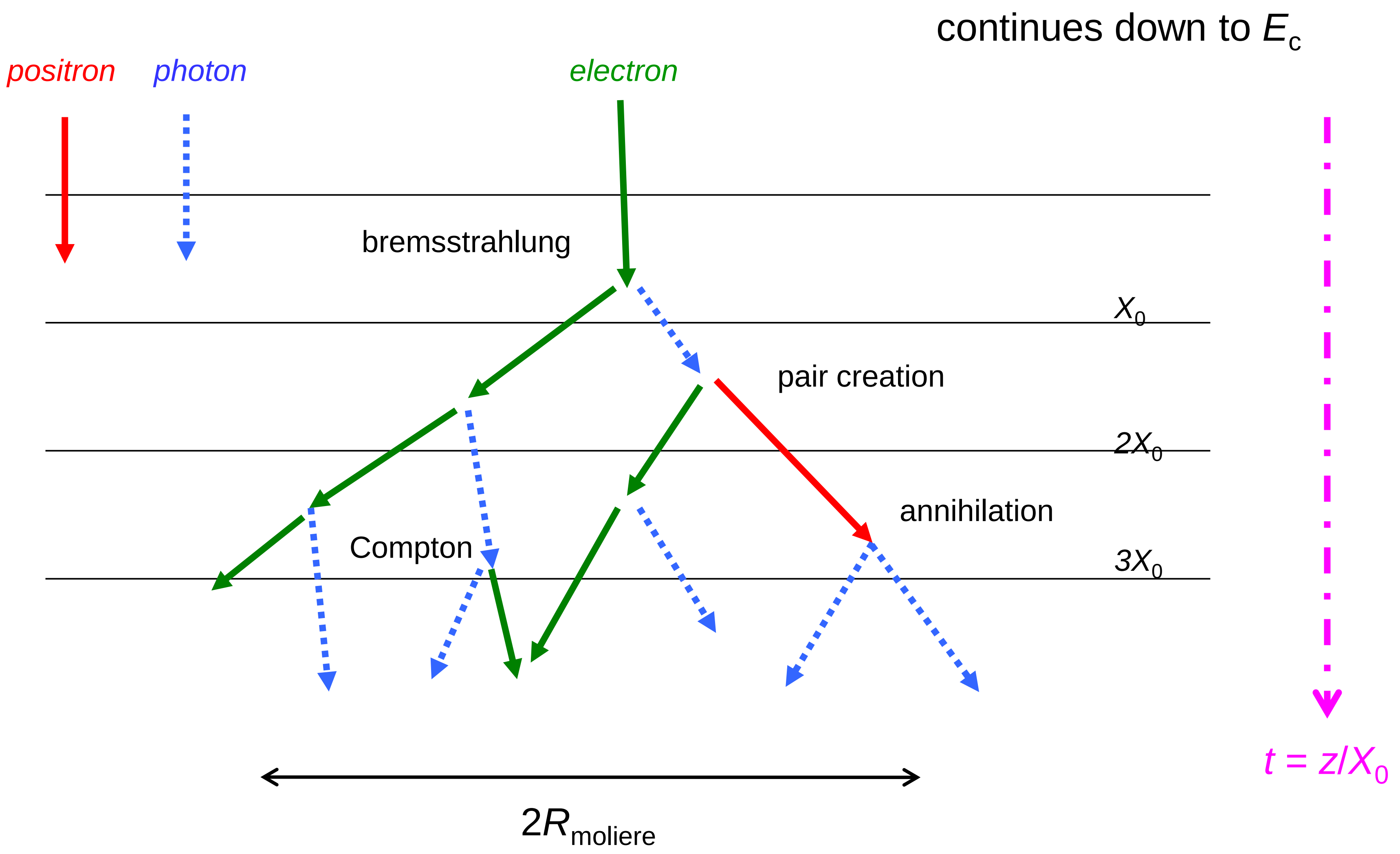


ITS
particle identification



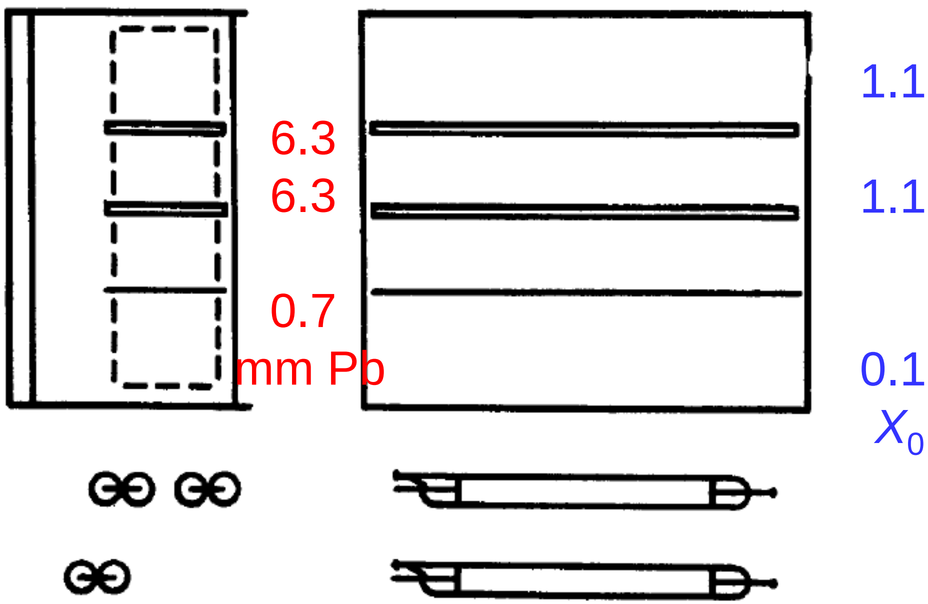
E.M. cascade “shower”



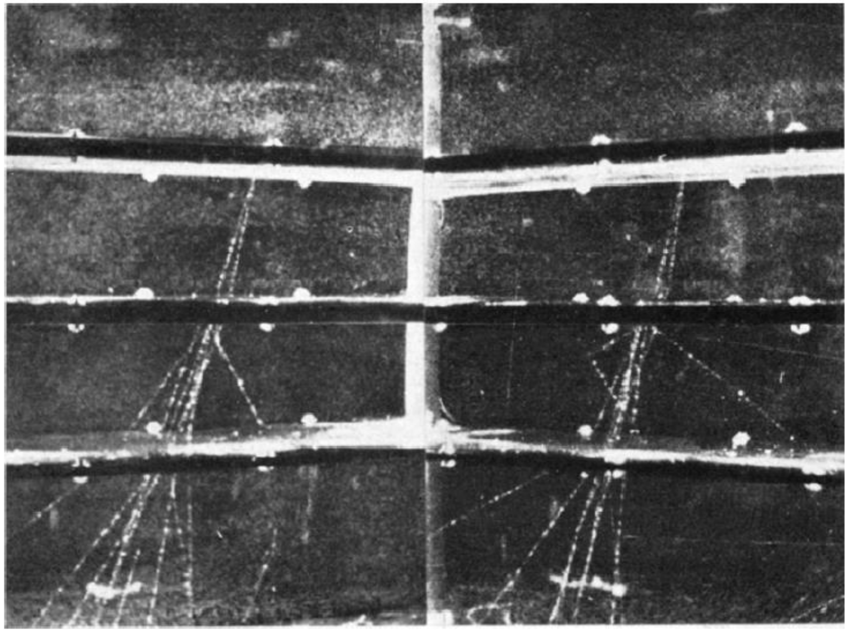


J. C. Street, Journ.FranklinInstitute 227, 6 (1939), 765

FIG. 5.

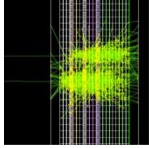


The arrangement of apparatus for the study of shower processes. The cloud chamber is expanded immediately following a coincident discharge of the Geiger counters.



Wilson cloud chamber with stereocamera triggered by Geiger tubes

Nikhef displays working cloud chamber in central hall



simple E.M. shower model of Heitler (1953)

- particle number doubles at each interaction

  $e \rightarrow e + \gamma$ and $\gamma \rightarrow e^- + e^+$

  ⇨ $N(t) = 2^t$

➢ average particle energy

  $\langle E \rangle = E_0 \,/\, N(t) \;= E_0 \,/\, 2^t$

- multiplication stops when

  $\langle E \rangle = E_c$ (critical energy)

➢ this depth is shower maximum

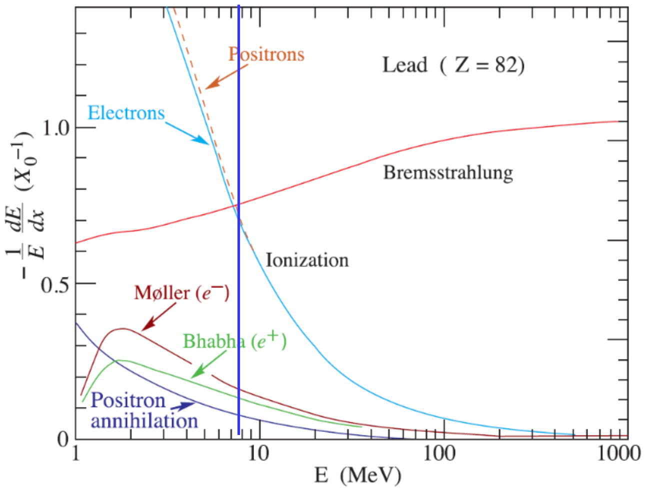
  $E_0 \,/\, 2^t = E_c$

  ⇨ $t_{max} = {}^2\log(E_0 / E_c)$

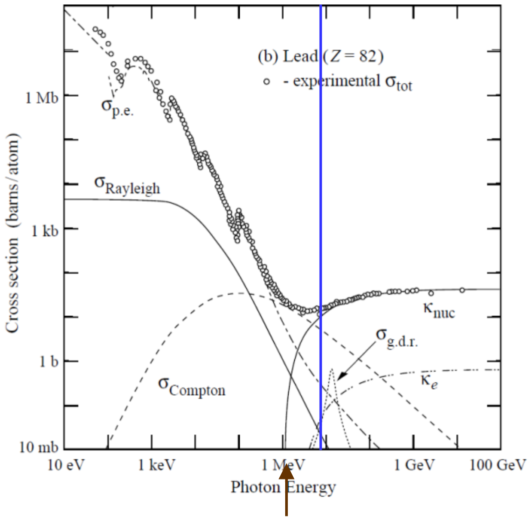
  ⇨ $N(t_{max}) = E_0 / E_c$

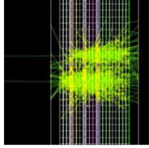
after shower maximum
particle energy < critical energy

- average particle energy decreases
  - photons 'lose energy' via Compton scattering
  - electrons lose energy via ionization
- number of particles decreases slowly:
  - $\gamma \rightarrow e^- + e^+$ continues until 1.022 MeV, and
  - $e^+ \rightarrow \gamma + \gamma$ in electric field of nucleus
  - photons lost via photo-effect
  - electrons finally captured



critical energy



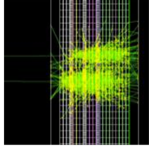


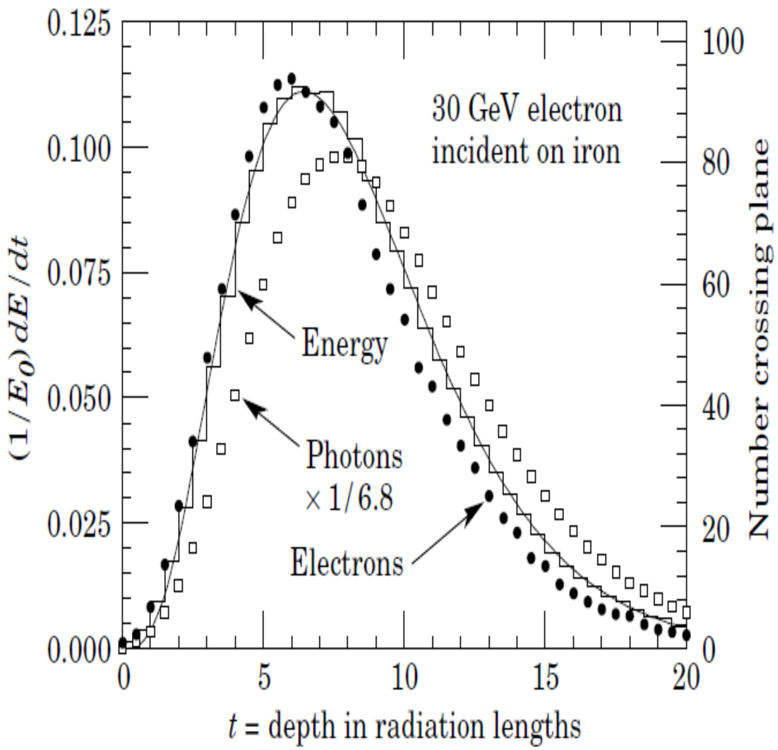
longitudinal profile E.M.

best fit of signal profiles, no theory!

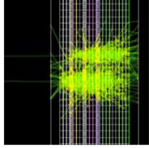
$$\frac{dN}{dt} = N_0 b \frac{(bt)^{a-1} exp(-bt)}{\Gamma(a)}$$

$$t_{max} = {}^2\log(E_0 / E_c) - 0.5 = (a\text{-}1)/b \quad b \approx 0.5$$





hadronic showers



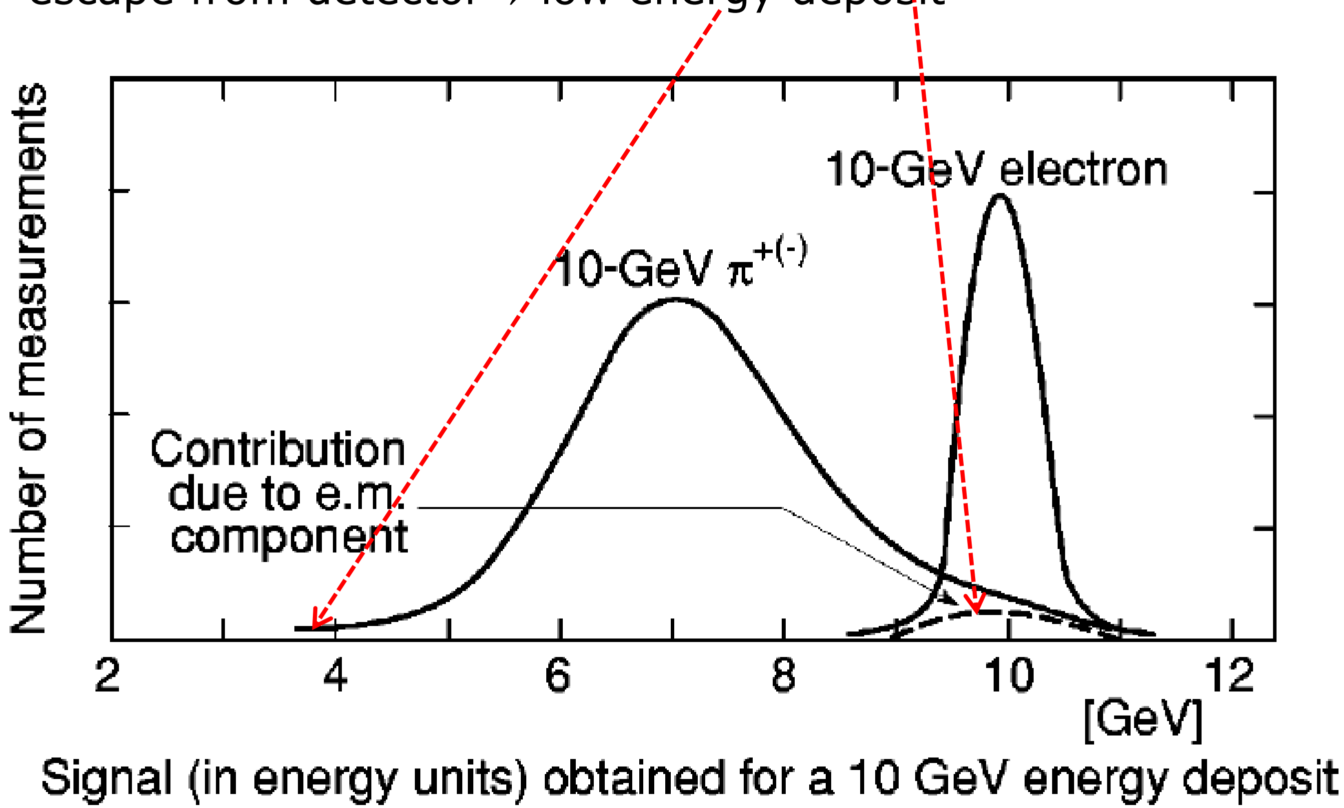
small interaction probability

very diverse shapes, extreme cases:

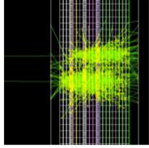
- pion can lose its charge in first collision $\pi^+ + A^Z \rightarrow \pi^0 + A^{Z+1}$

  π^0 decays to photons ($c\tau$ = 26 nm) → EM shower
- pion leads to spallation of a nucleus → many neutrons

  escape from detector→ low energy deposit



how to extract the signal



absorbing medium produces signal

homogeneous calorimeter

- semiconductor of heavy material direct electrical signal

Ge (X_0 = 2,3 cm)

- scintillator of heavy material needs photodetector

NaI (X_0 = 2,6 cm)

ALICE PHOS, CMS ECAL: $PbWO_4$ (X_0 = 0.9 cm)

☺ best resolution

😐 no spatial information

how to extract the signal

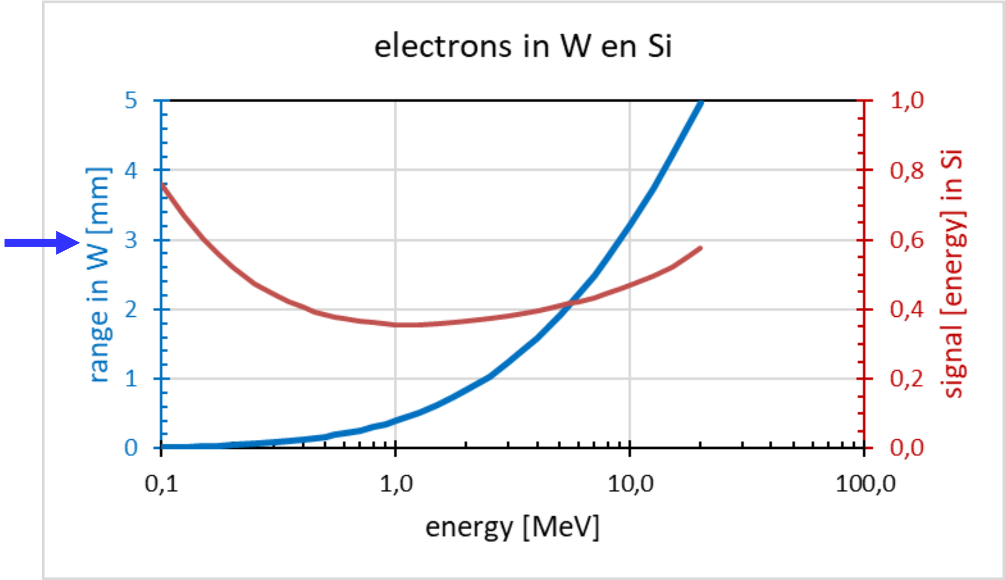
separated functions: absorber + detector

sampling calorimeter

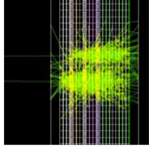
ALICE EMCAL: layers of Pb (X_0 = 0,6 cm) and scintillator

FoCal: layers of W (X_0 = 0,35 cm) and silicon

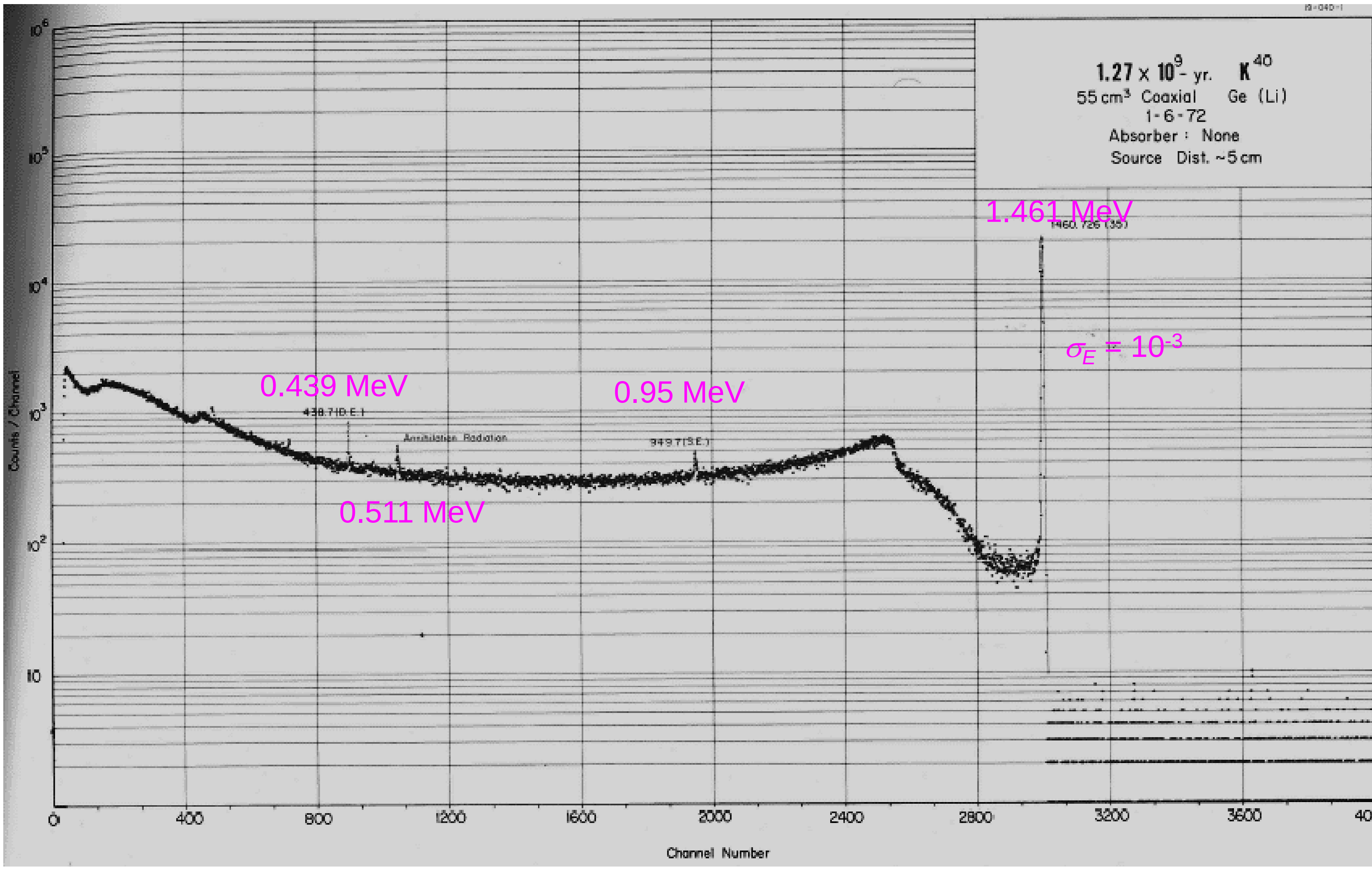
signal development different from homogeneous calorimeter

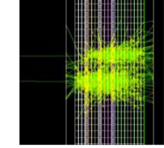


gammaspectrum ^{40}K E_γ = 1.461 MeV



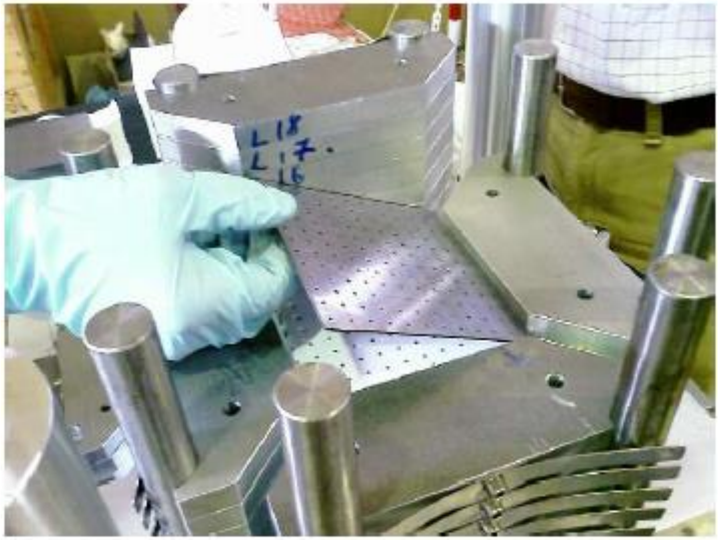
- no showering: E_c = 18 MeV
- pair production, Compton scattering, photo-effect





EMCAL

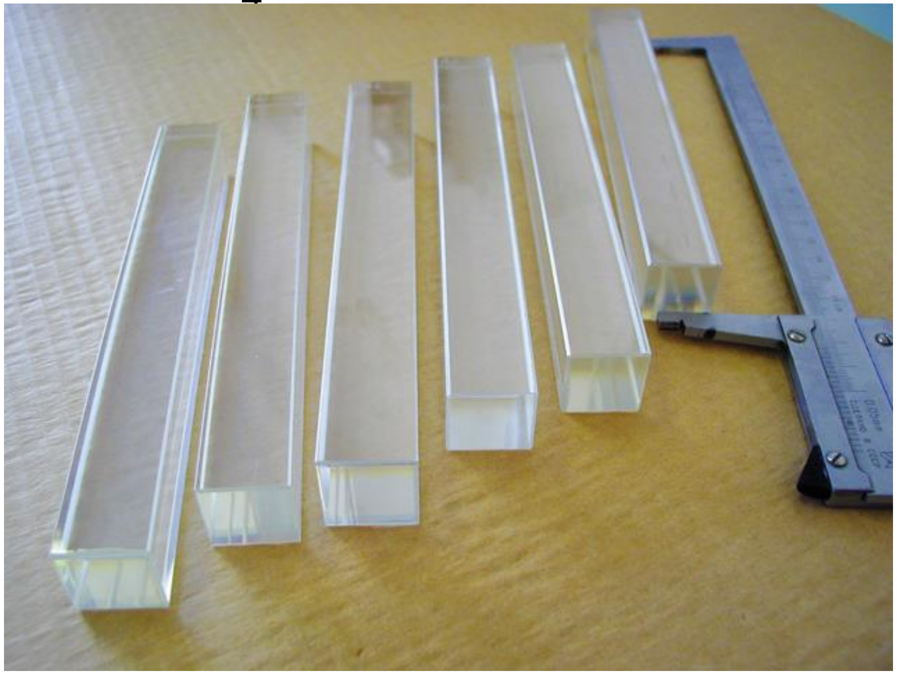
- absorber 1.44 mm Pb
- scintillator 1.76 mm plastic
- 77 layers 25 cm 20 X_0
- fibers + APD

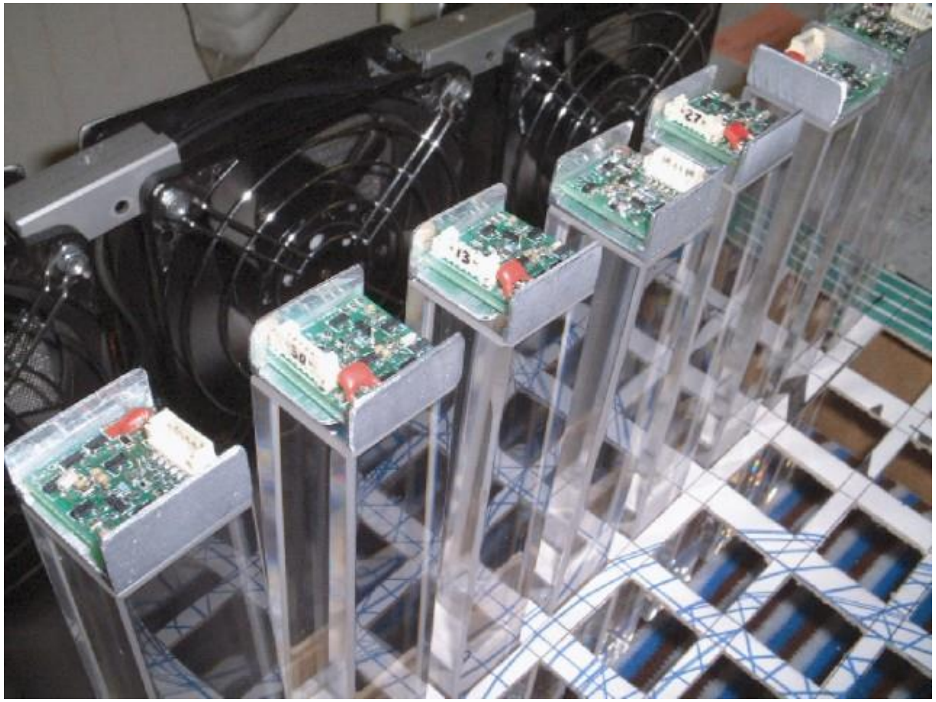


PHOS

- crystal coupled to APD
- 18 cm 20 X_0

$PbWO_4$





what is measured?

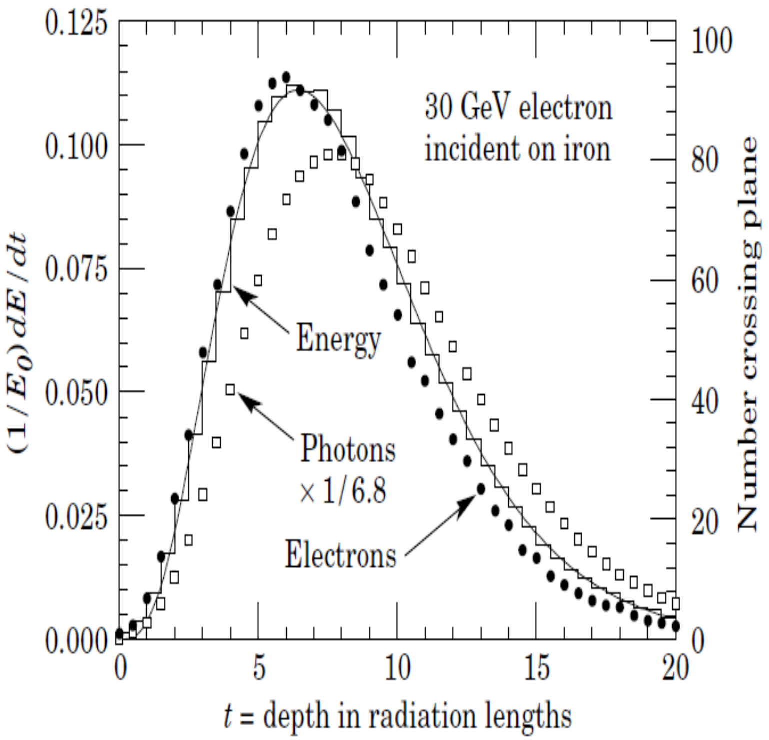
A energy / analog

- amount of light from scintillator
- charge from PIN detector

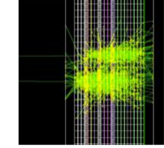
OR

D number of particles / digital

- count hits from pixel detector



Particle Data Book at http://pdg.lbl.gov/

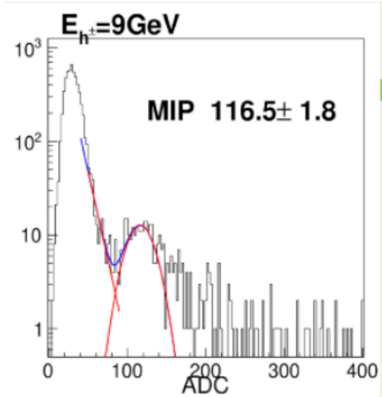


analog

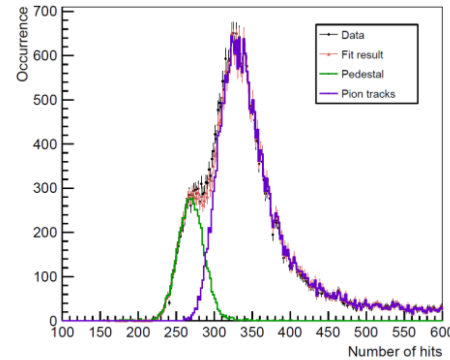
digital

smallest signal

noise, dark current

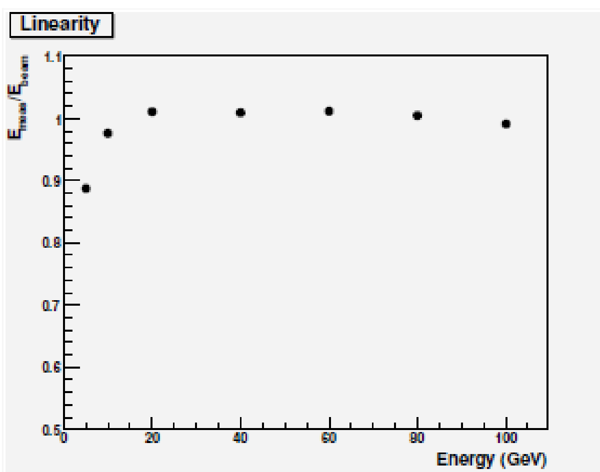


spontaneous hits

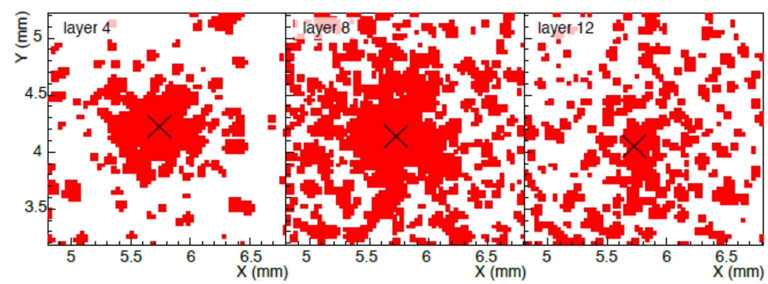


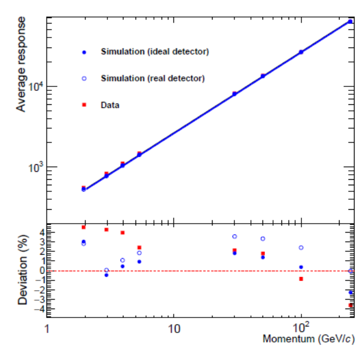
large signal, linearity

saturation

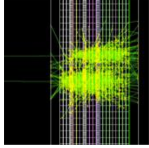


overlapping hits

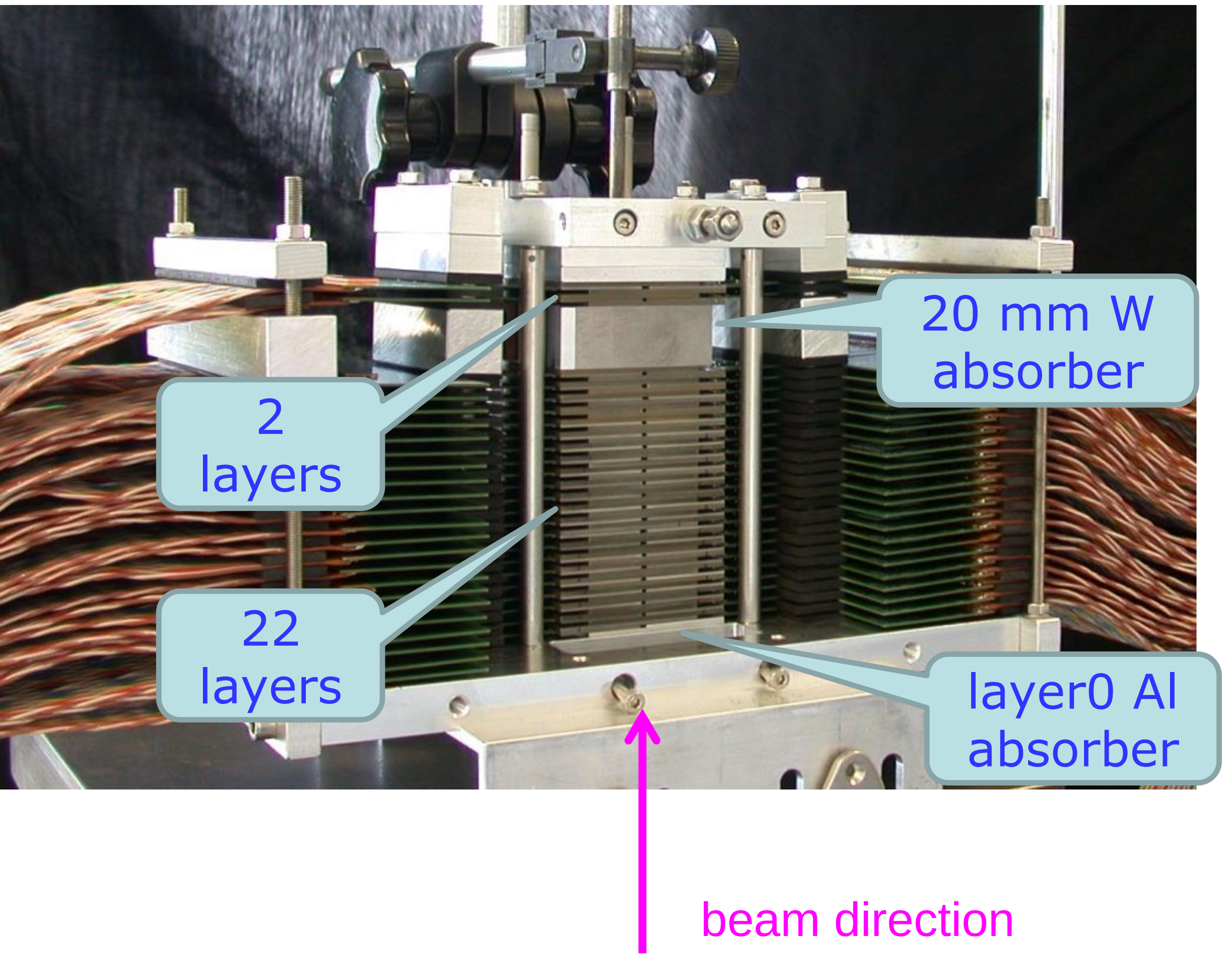


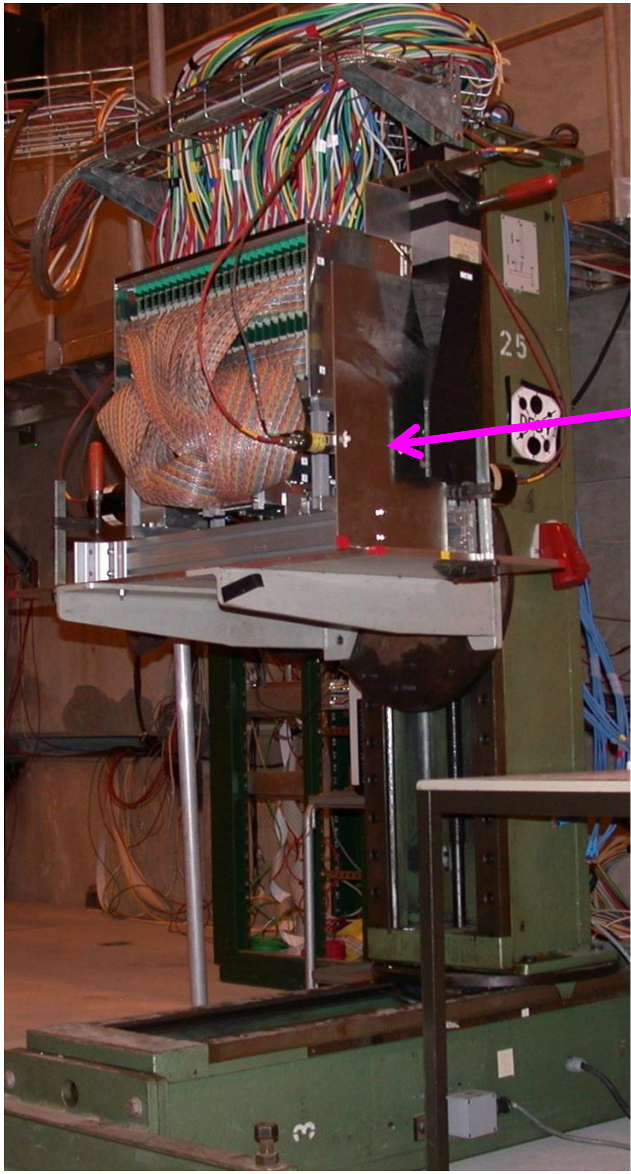


FoCal digital prototype as proof-of-principle

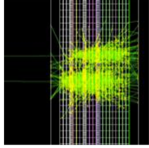


assembly without cooling

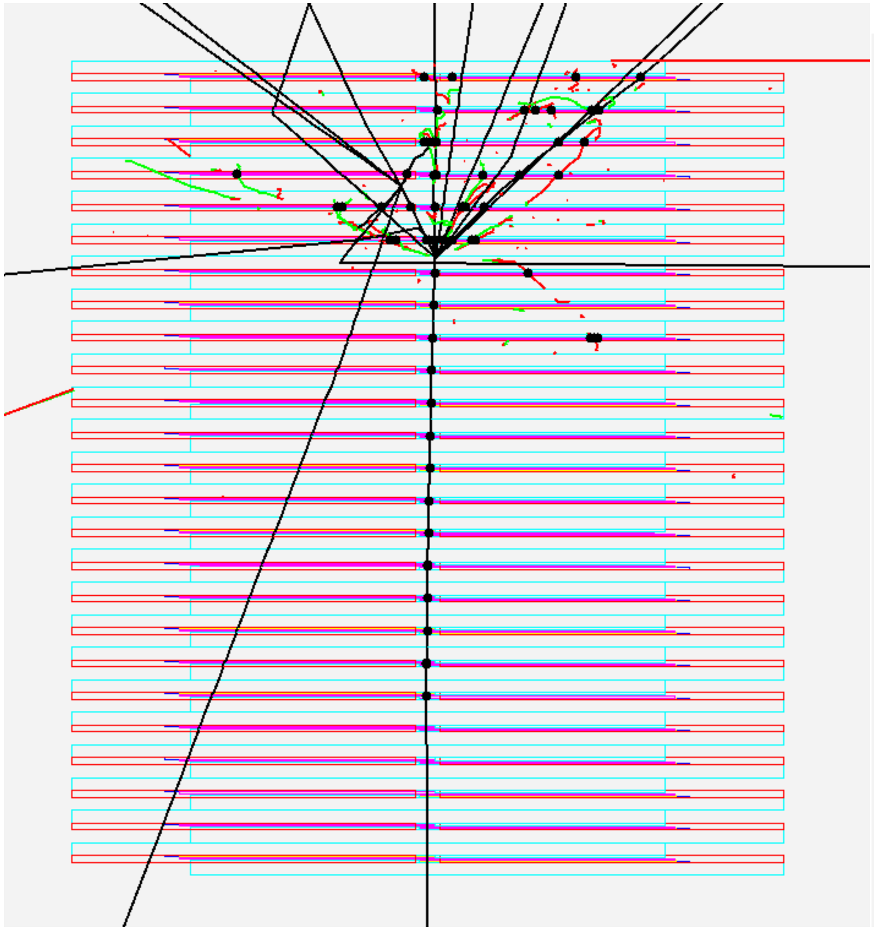


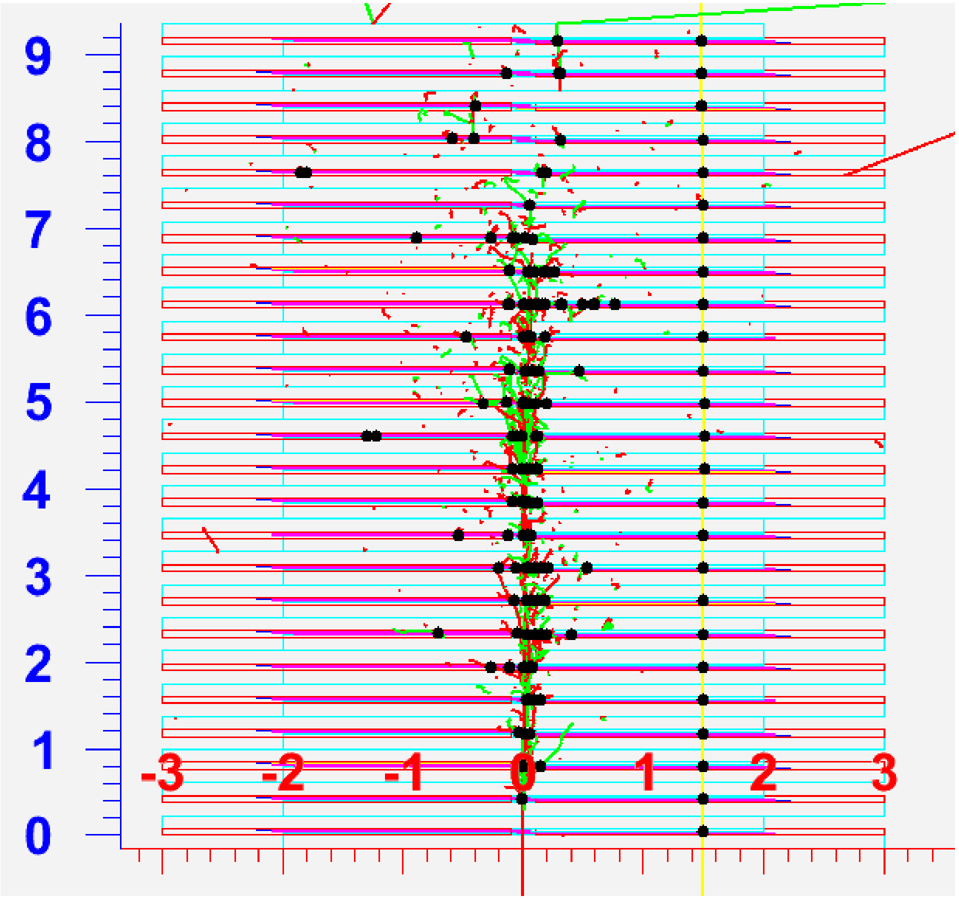


simulated response (GEANT)



5 GeV/*c* pion, 5 GeV/*c* electron, 10 GeV/*c* muon (Blenkers, 2012)





measured response 244 GeV/c

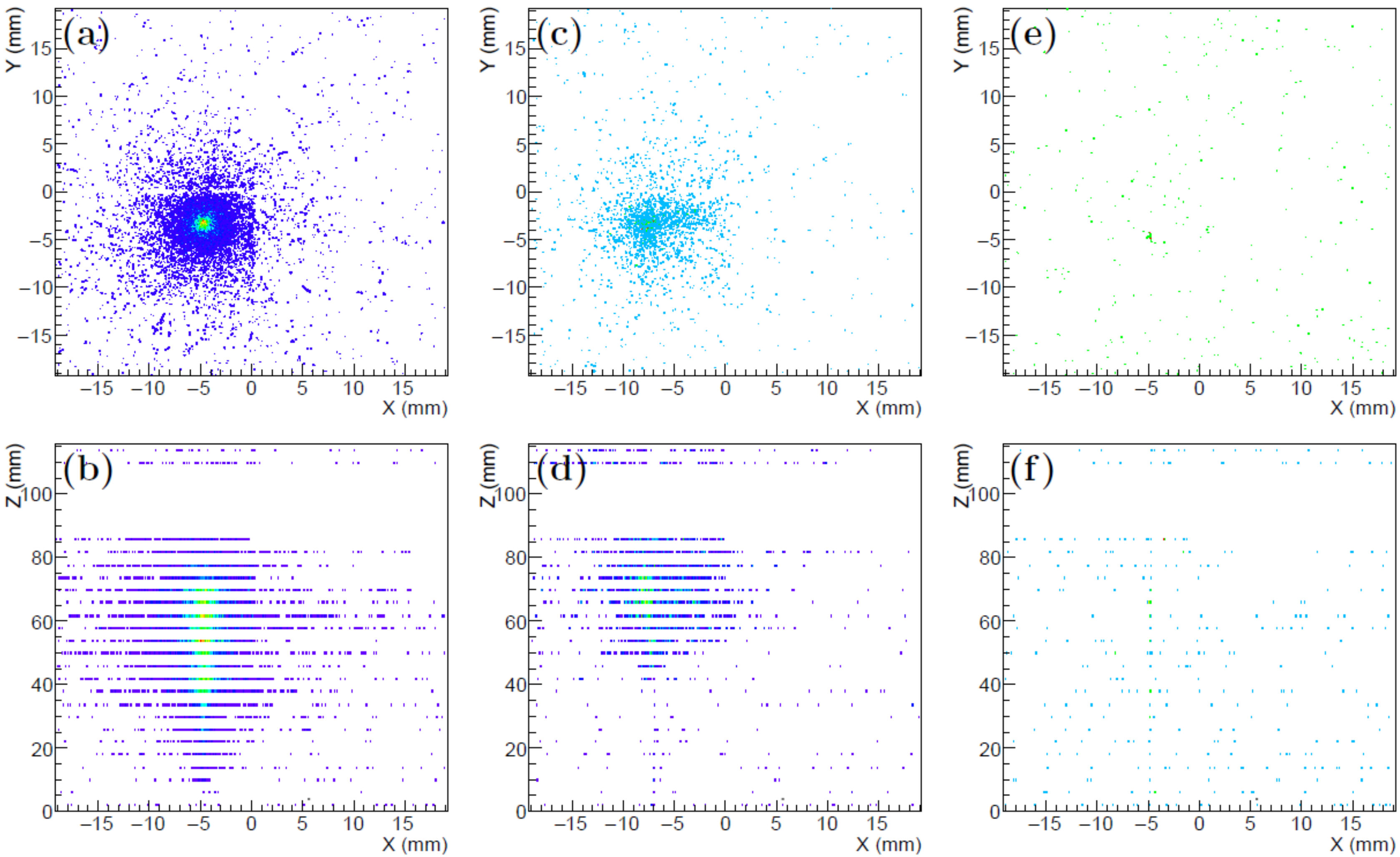
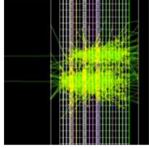
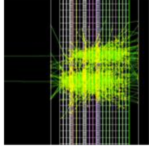


Figure 3.1: *Typical events display for 244 GeV EM shower in top and side view (a, b), for a hadronic shower in top and side view (c, d) and for a track in top and side view (e, f).*



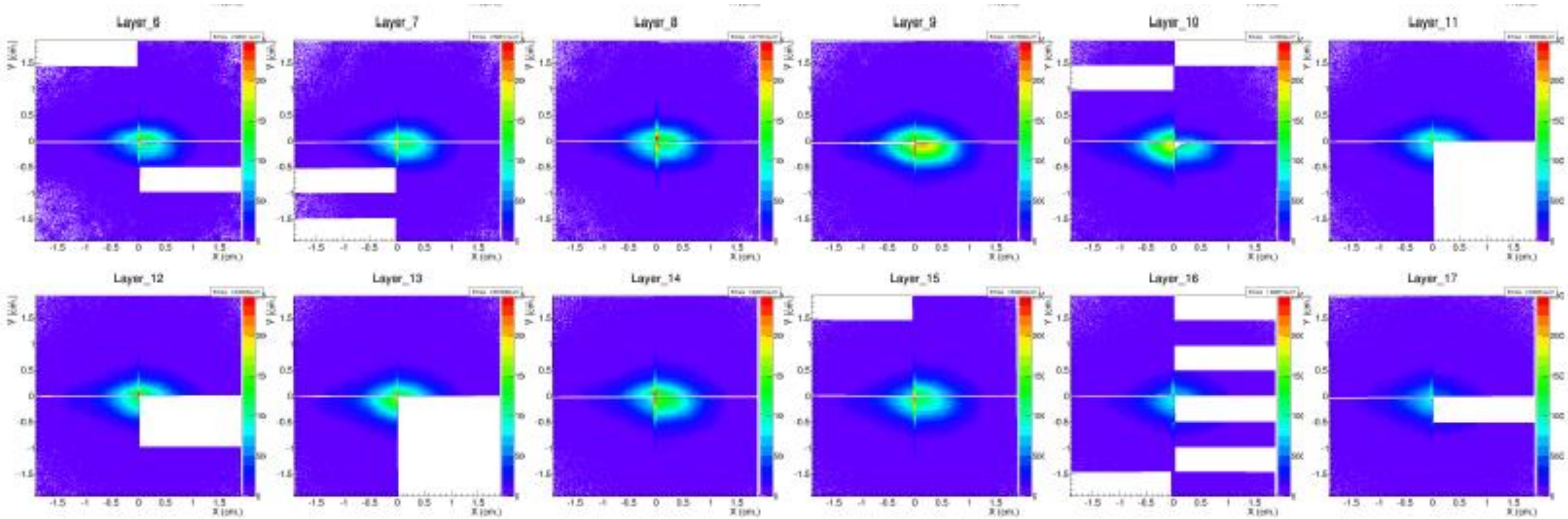


real life data

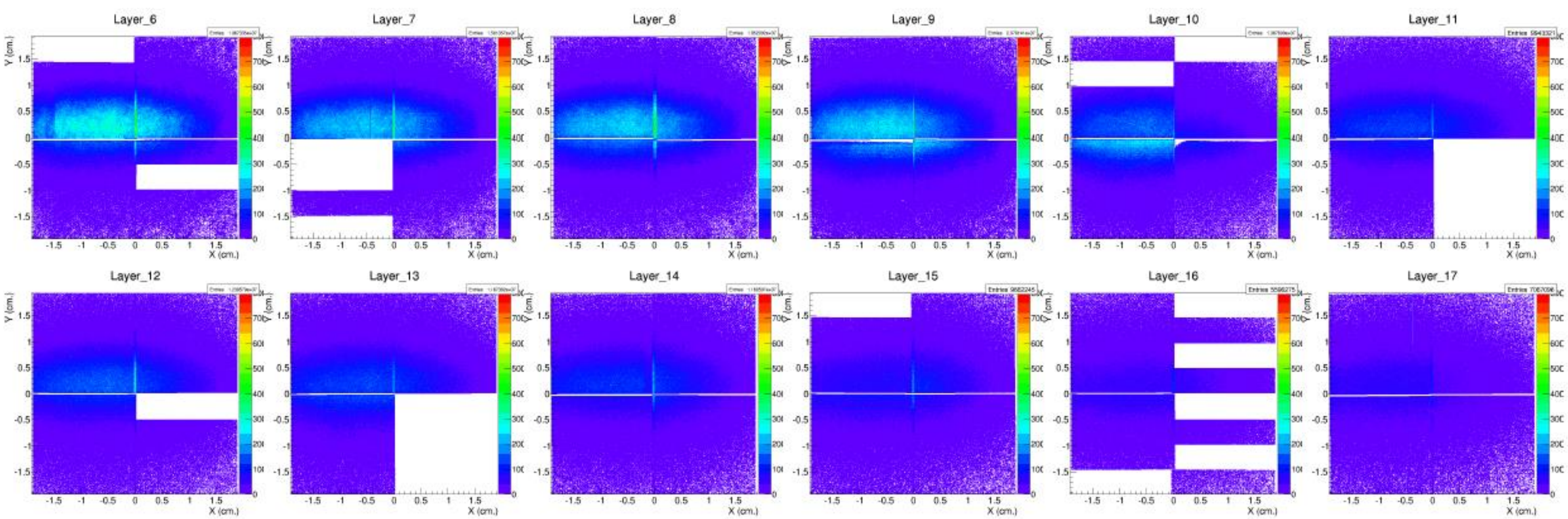
part of the detector is not working (correctly)

varies over experiments and even runs

244



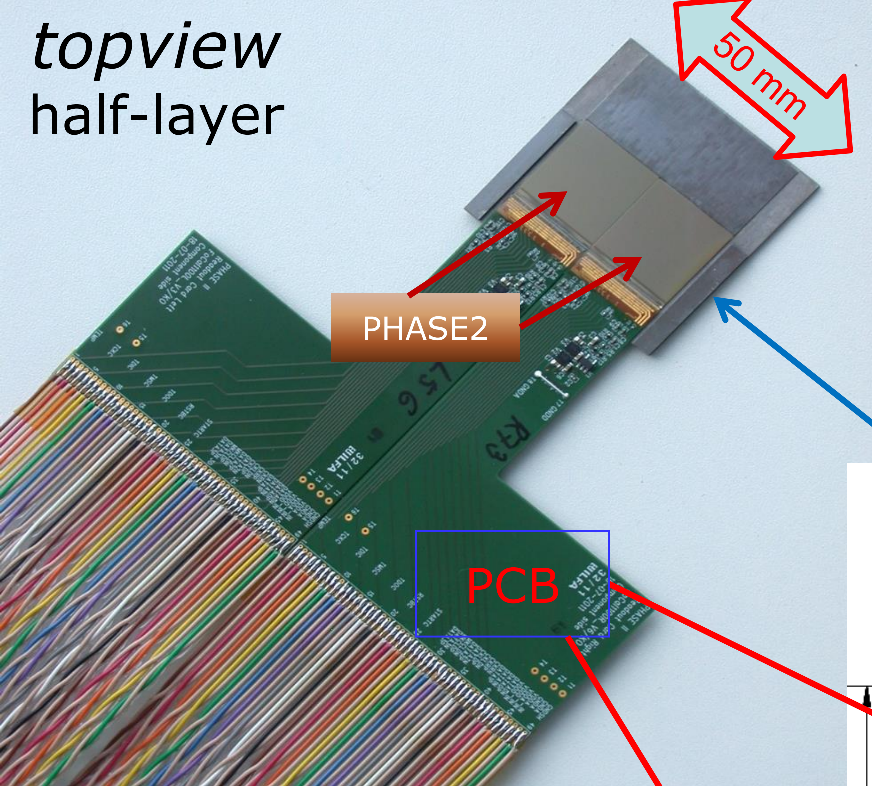
50

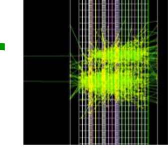


4 sensors in one layer

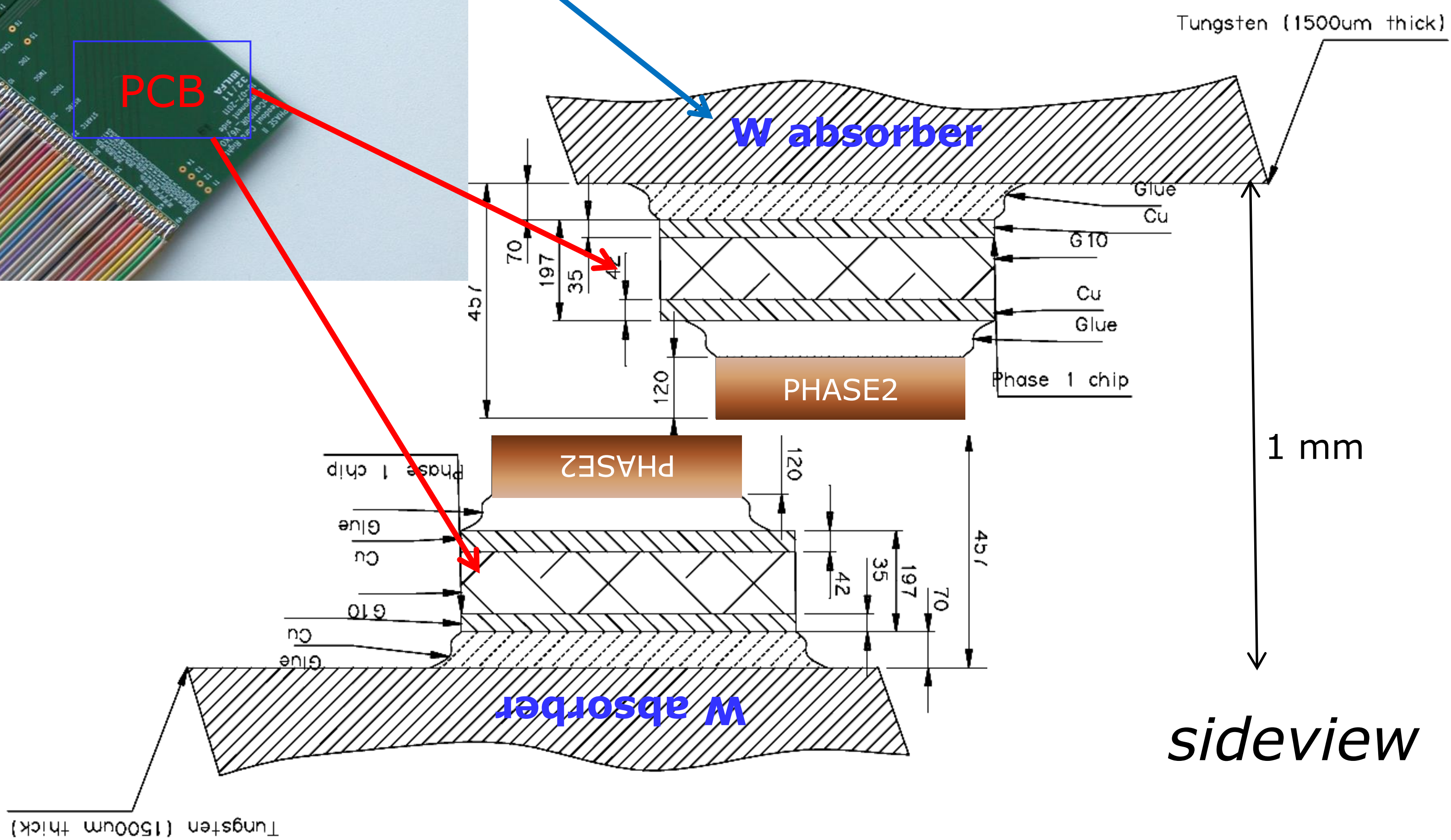
thinned to 120 µm

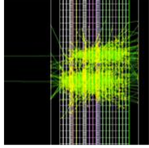
4 mm 0.97 X_0



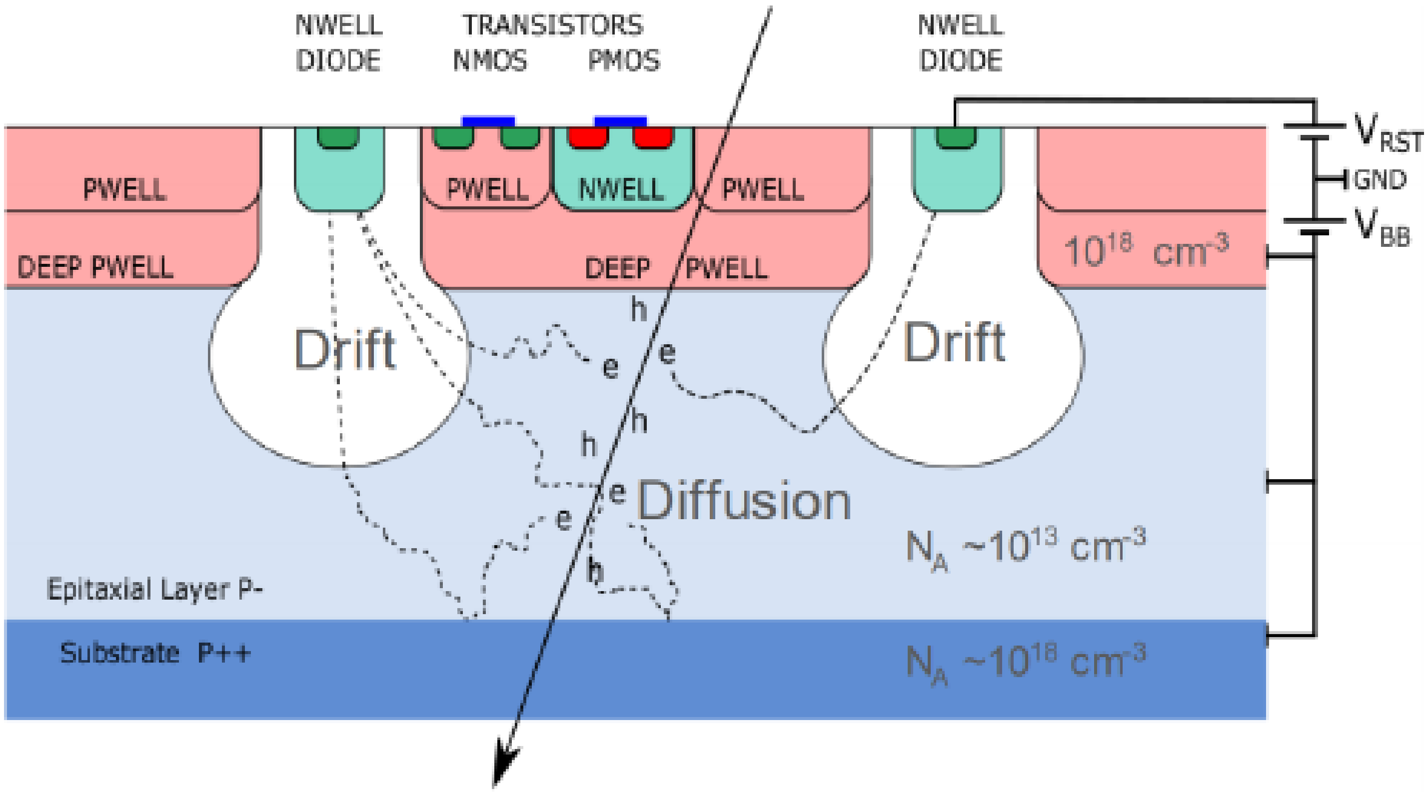


small overlap of top rows 100 µm





- ALPIDE


NWELL
DIODE
TRANSISTORS
NMOS
PMOS
NWELL
DIODE
PWELL
PWELL
NWELL
PWELL
DEEP PWELL
DEEP PWELL
V_{RST}
GND
V_{BB}
10^{18} cm^{-3}
Drift
Drift
h
e
e
h
h
e
e
h
Diffusion
N_A ~10^{13} cm^{-3}
Epitaxial Layer P-
Substrate P++
N_A ~10^{18} cm^{-3}