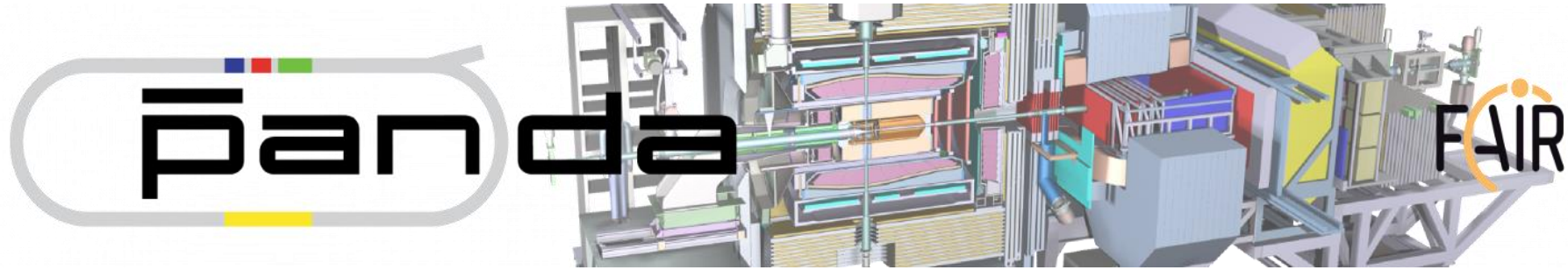
PID with the



EMC

Markus Moritz

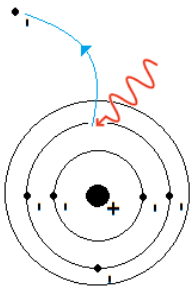
03.05.2018 PID Workshop

Calorimetry

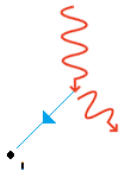
"…Calorimetry is the measurement of energy via "complete" absorption."

Tree fundamental processes for photons:

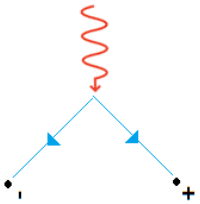
- **Photoelectric effect**
  - dominates at low energies
  - photons completely absorbed by a bound electron
  - cross section ~Z^{4-5}



- **Compton Scattering**
  - only a part of the energy is transferred to a bound electron
  - cross section ~Z



- **Pair Production**
  - above 1.022 MeV conversion into an electron-positron pair within the coulomb field from the nucleus
  - cross section ~Z^2



Calorimetry

"…Calorimetry is the measurement of energy via "complete" absorption."

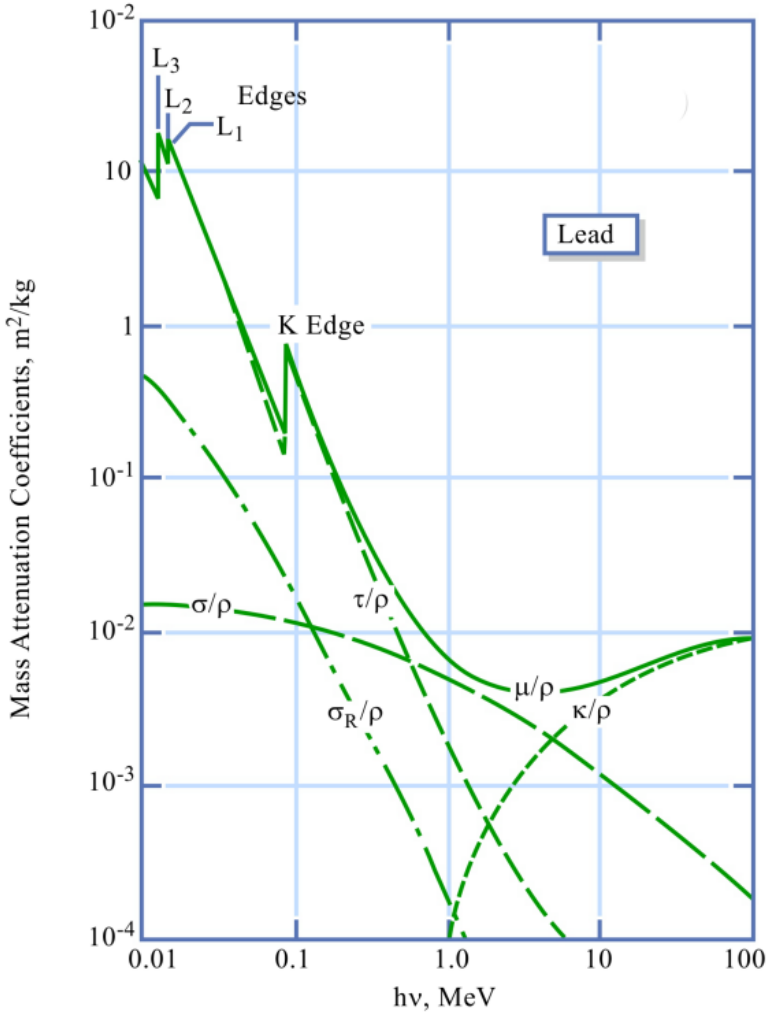
$$I(x) = I_0 \cdot e^{-(\tau+\sigma+\kappa)\cdot x}$$

with the coefficients:
τ photoelectric effect
σ Compton scattering
κ pair production

- **Mean free path of a photon:**

  length of the material where the number of primary photons is reduced by a factor 1/e

$$\Lambda_p = \frac{9}{7} X_0$$



Calorimetry

"…Calorimetry is the measurement of energy via "complete" absorption."

Interaction of charged particles:

Bethe Bloch

- **inelastic coulomb scattering**

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2}\frac{nz^2}{\beta^2}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\ln\frac{2m_e c^2\beta^2}{I(1-\beta^2)} - \beta^2\right]$$

with $\beta = v/c$, z the particle charge, n the electron density of the target, I the mean excitation potential of the target

- **Bremsstrahlung**
  - due to deflection and therefore acceleration by the coulomb field of the absorber
  - cross section ~1/m^2 of the penetrating particle
  - above critical energy $E_c \approx 550$ MeV/Z domination process
  - energy loss $-\frac{dE}{dx} = \frac{E}{X_0}$

$$E_c(PbWO_4) \approx 9.5\ MeV$$

- **Radiation length X_0 of a high energetic charged particle:**
  fraction of 1/e from the mean free path

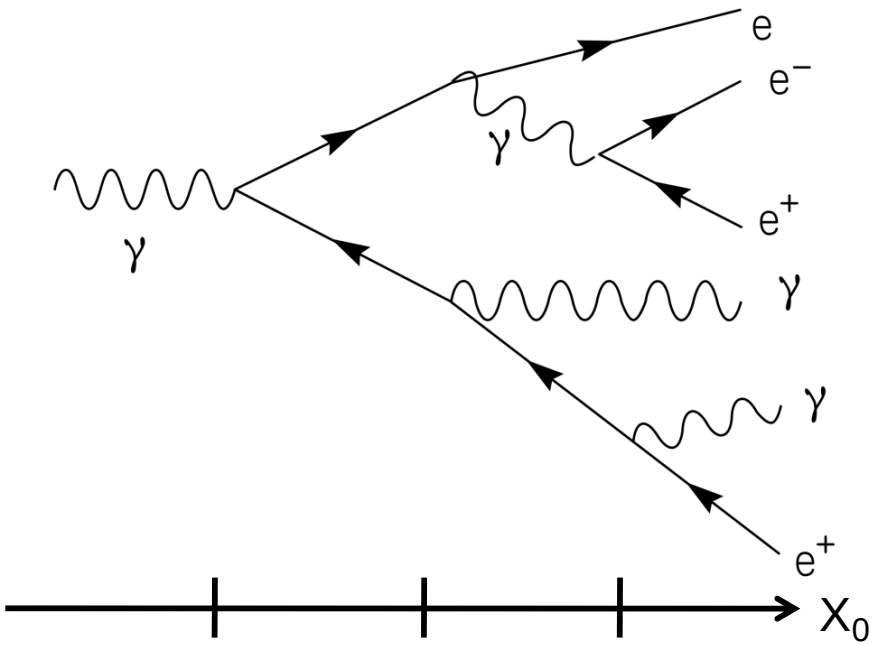
$$X_0 = \frac{A}{4\alpha N_a Z^2 r_e^2 \ln\left(183 Z^{-\frac{1}{3}}\right)} \approx \frac{1}{Z^2}$$

with N_a Avogadro constant, r_e the classical electron radius and α the Sommerfeld's fine-structure constant

$$X_0(PbWO_4) \approx 0.89\ cm$$

Calorimetry

Combination of all effects: **Electromagnetic shower development**



Amount of particles roughly doubles each radiation length

transversal spread
due to multiple scattering processes

$$R_M \approx \frac{21MeV}{E_c} \cdot X_0$$

- 10 % outside cylinder with radius R_M
- 99% contained inside 3.5 R_M
- $R_M(PbWO_4)$=2 cm

Hadronic shower

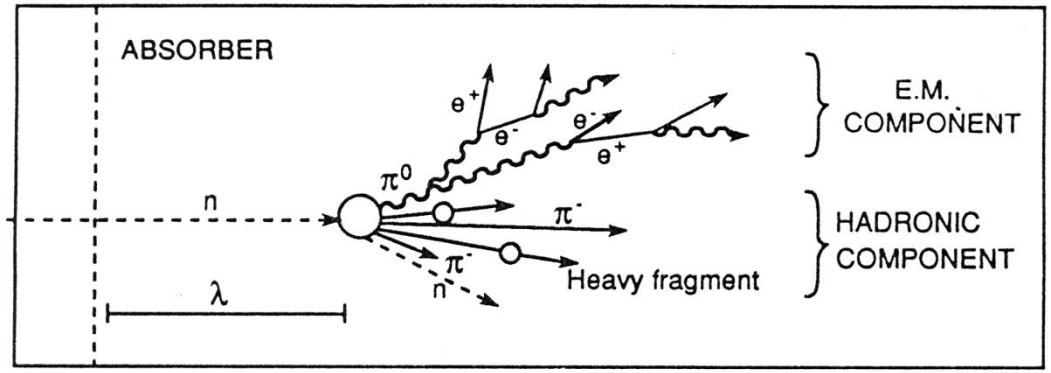
Impinging hadron creates a cascade of inelastic hadronic interactions with the nuclei and nucleons of the absorber material.

→ new hadrons (mainly pions) can be created $\pi^0 \rightarrow \gamma\gamma \rightarrow$ new EM-shower

Hadronic absorption length

$$\lambda_{had} = \frac{A}{N_A \rho \sigma_\mu}$$

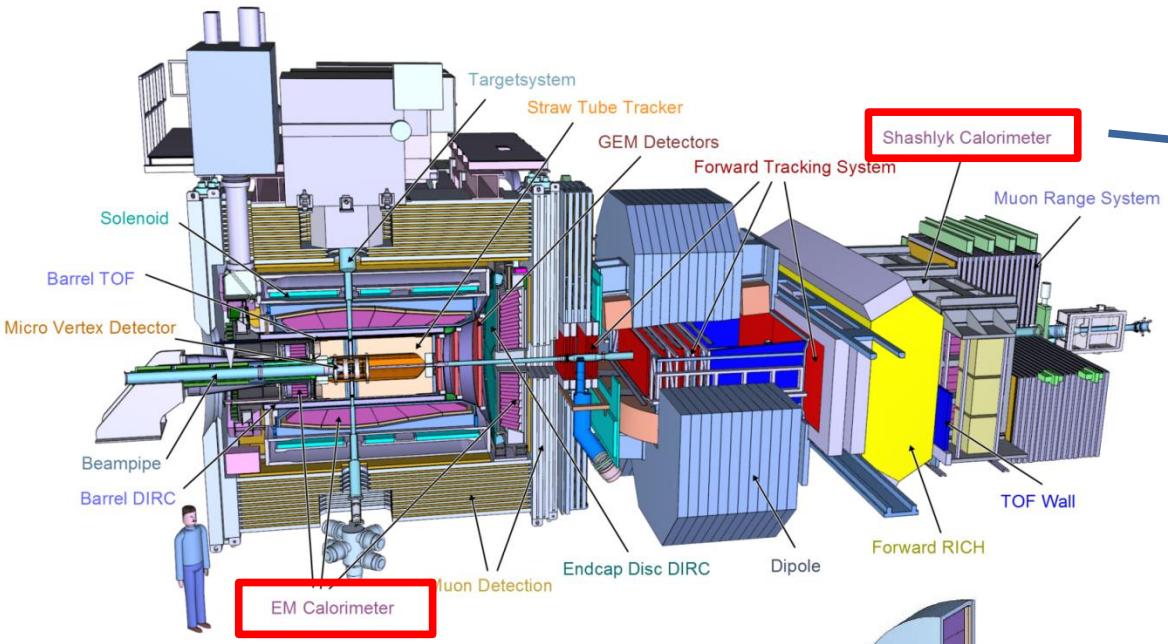
with N_a Avogadro constant, ρ the absorber density and σ_μ the cross section for inelastic interactions

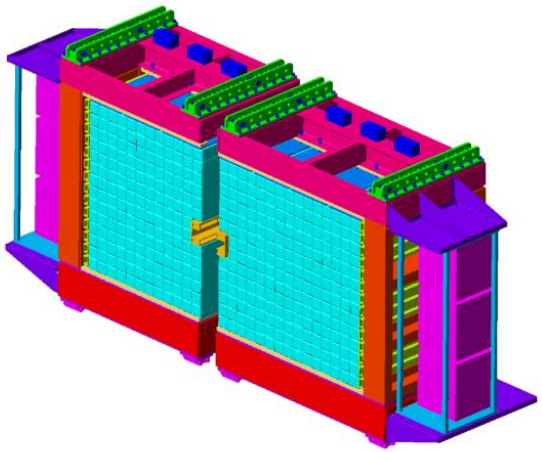


Short range of strong interaction

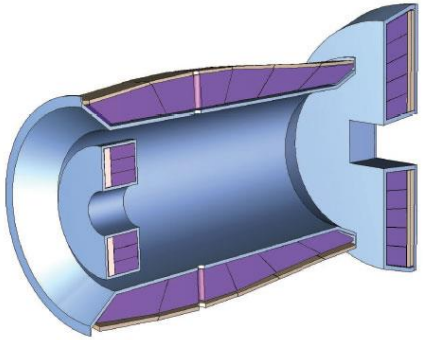
- absorption length much longer $\lambda >> X_0$
- hadronic shower less "concentrated", than EM-shower **->PID!**
- inelasticity < 50% of the energy are carried by secondaries
- non visible energy: binding energy, nuclear fragments neutral particles

The Electromagnetic Calorimeter





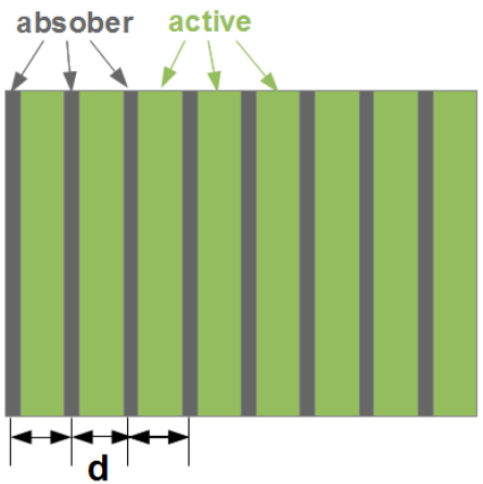
Forward Calorimeter based on 1512 Modules with alternating layers of lead sheets and organic plastic scintillator tiles



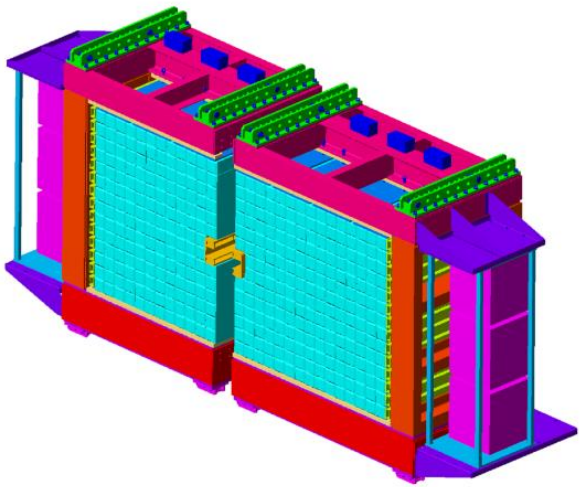
Target Calorimeter based on 15,740 PWO-II ($PbWO_4$) crystals

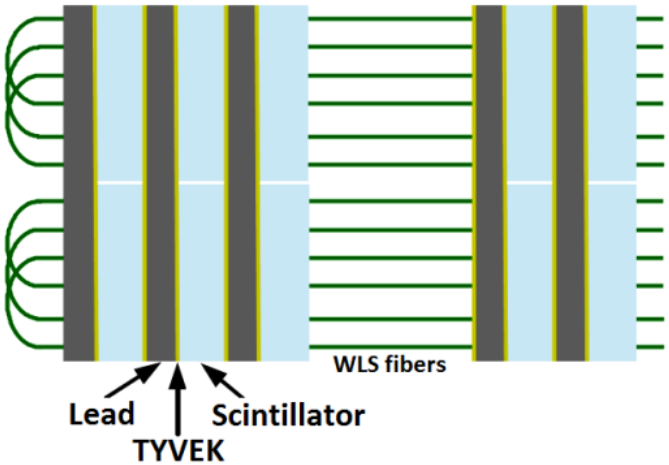
Dynamic range: 10 MeV-15 GeV

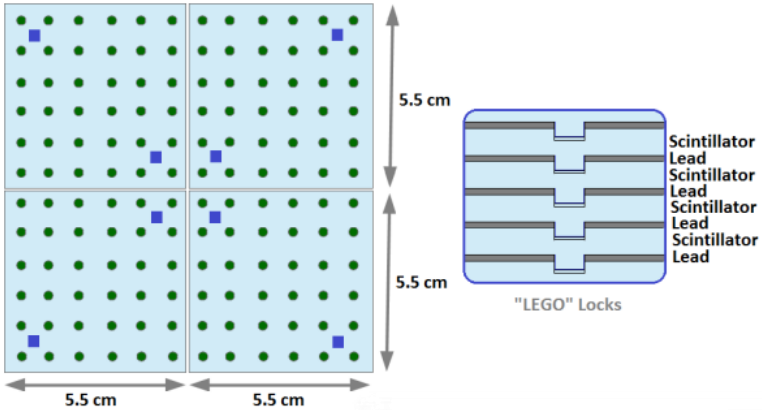
Forward Calorimeter Design



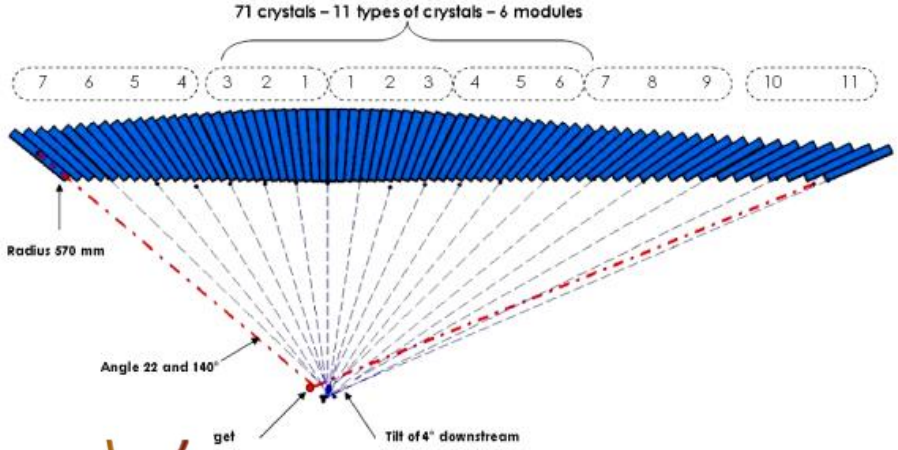
Longitudinal cross section
with alternating layers of 0.275 mm thick lead sheets and 1.5 mm thick scintillator tiles

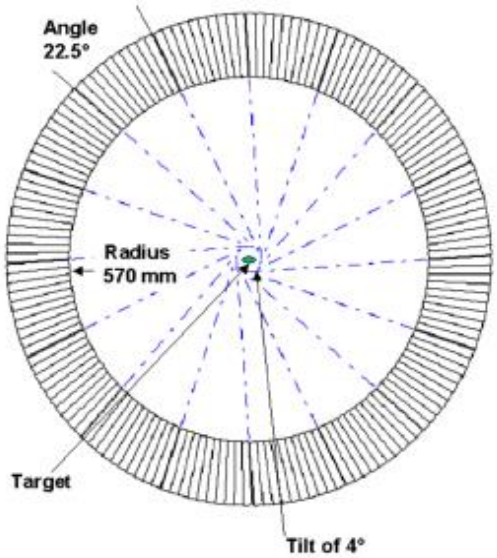


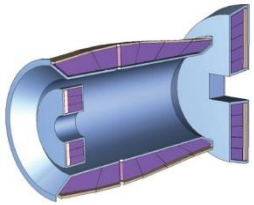


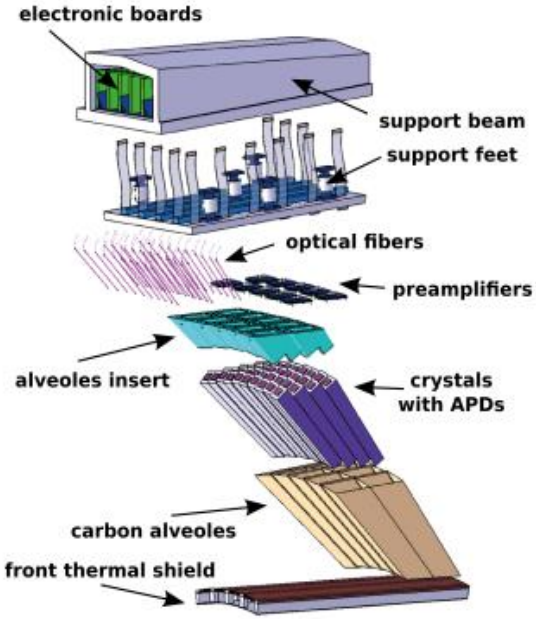


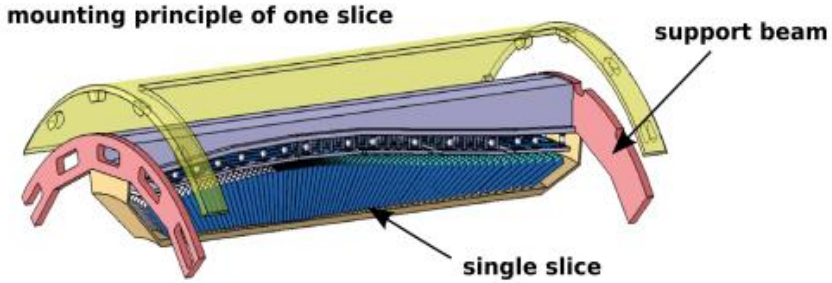
Target Calorimeter Design









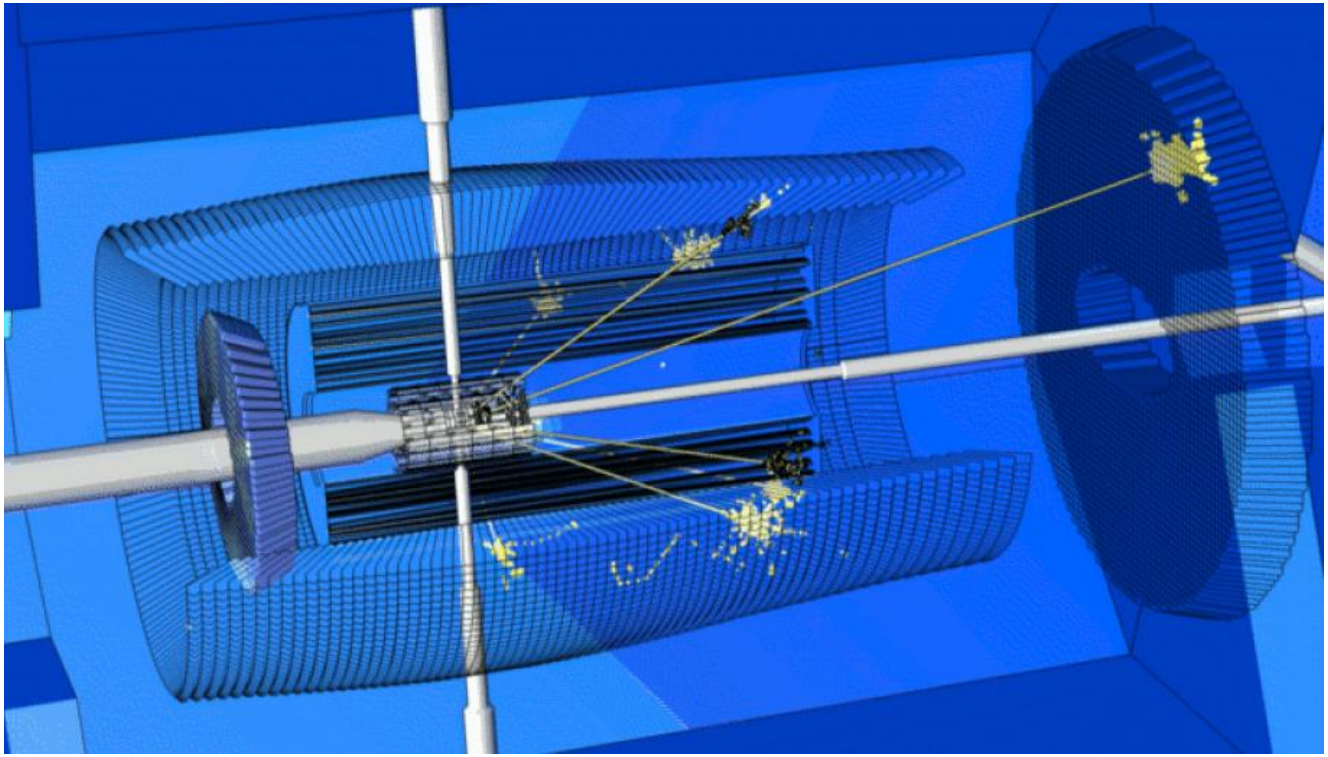


Photon Reconstruction

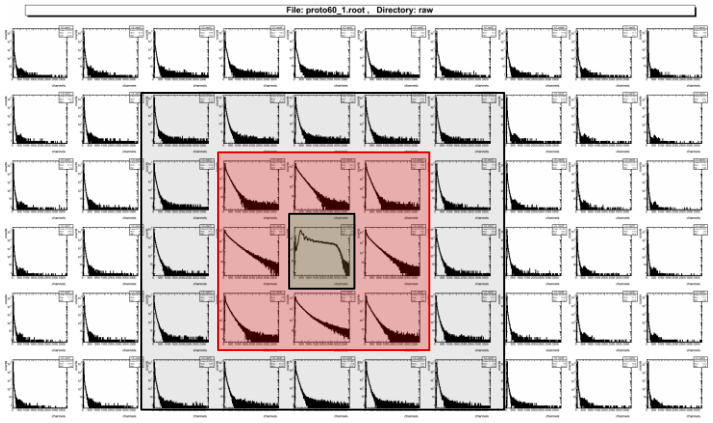
Energy of each gamma distributes over several crystals

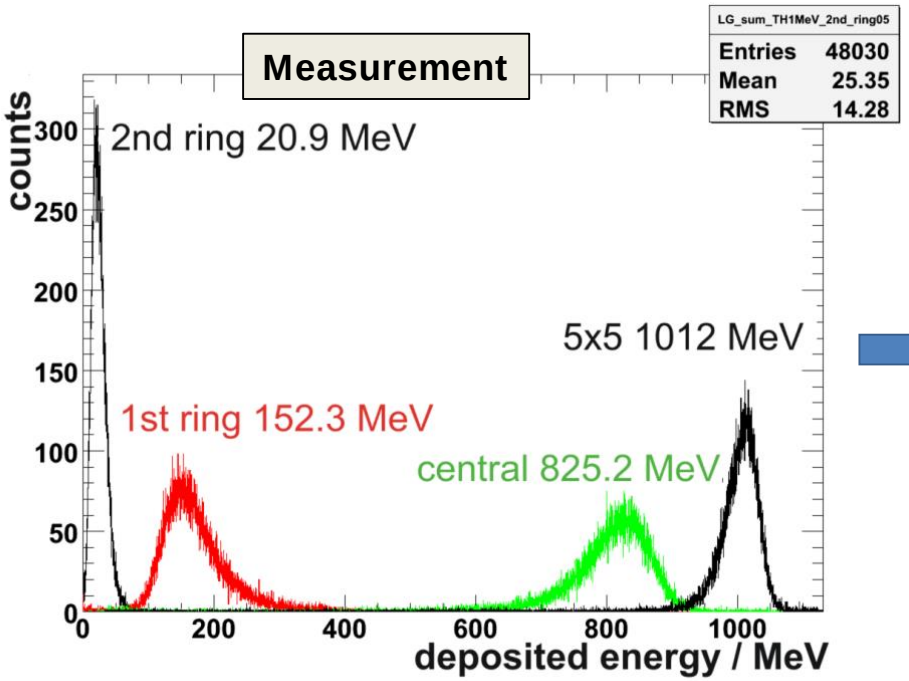
→ Energy sum over for each cluster necessary

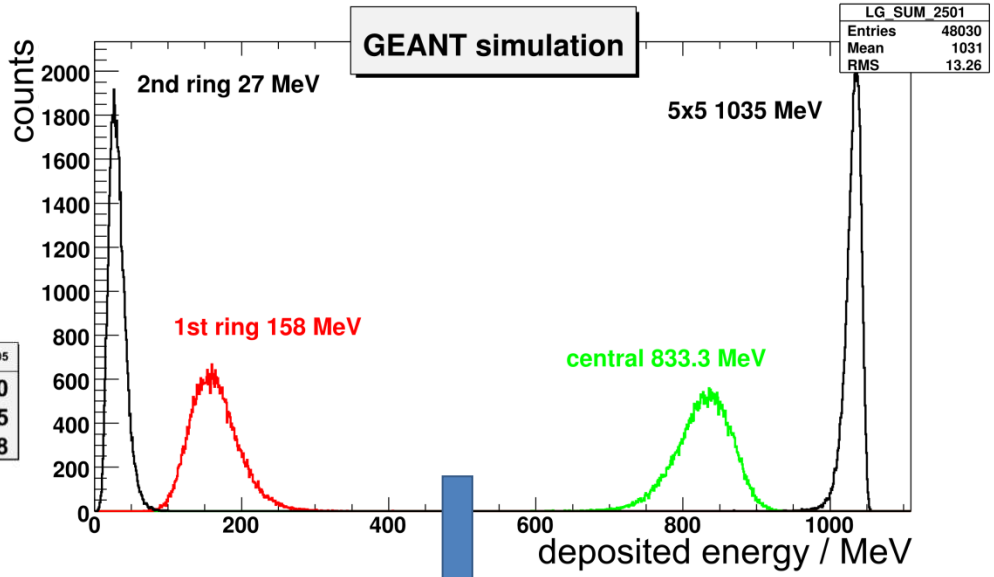
EMC with a six gamma event



Example: Experiment with 1057.7 MeV γ's







No full energy reconstruction

Correction of few percent necessary

$$E_{\gamma,cor} = E \cdot f(\ln E, \theta)$$

$$f(lnE,\theta) = exp(a_0 + a_1\, lnE + a_2\, ln^2 E + a_3\, ln^3 E + a_4\, \cos(\theta) + a_5\, \cos^2(\theta) + a_6\, \cos^3(\theta) + a_7\, \cos^4(\theta) + a_8\, \cos^5(\theta) + a_9\, lnE\, \cos(\theta))$$

Photon Reconstruction

PANDA Reconstruction Algorithm

1. Finding of a continuous area of scintillator modules with energy deposition

PnDEmc2DLocMaxMaxFinder:

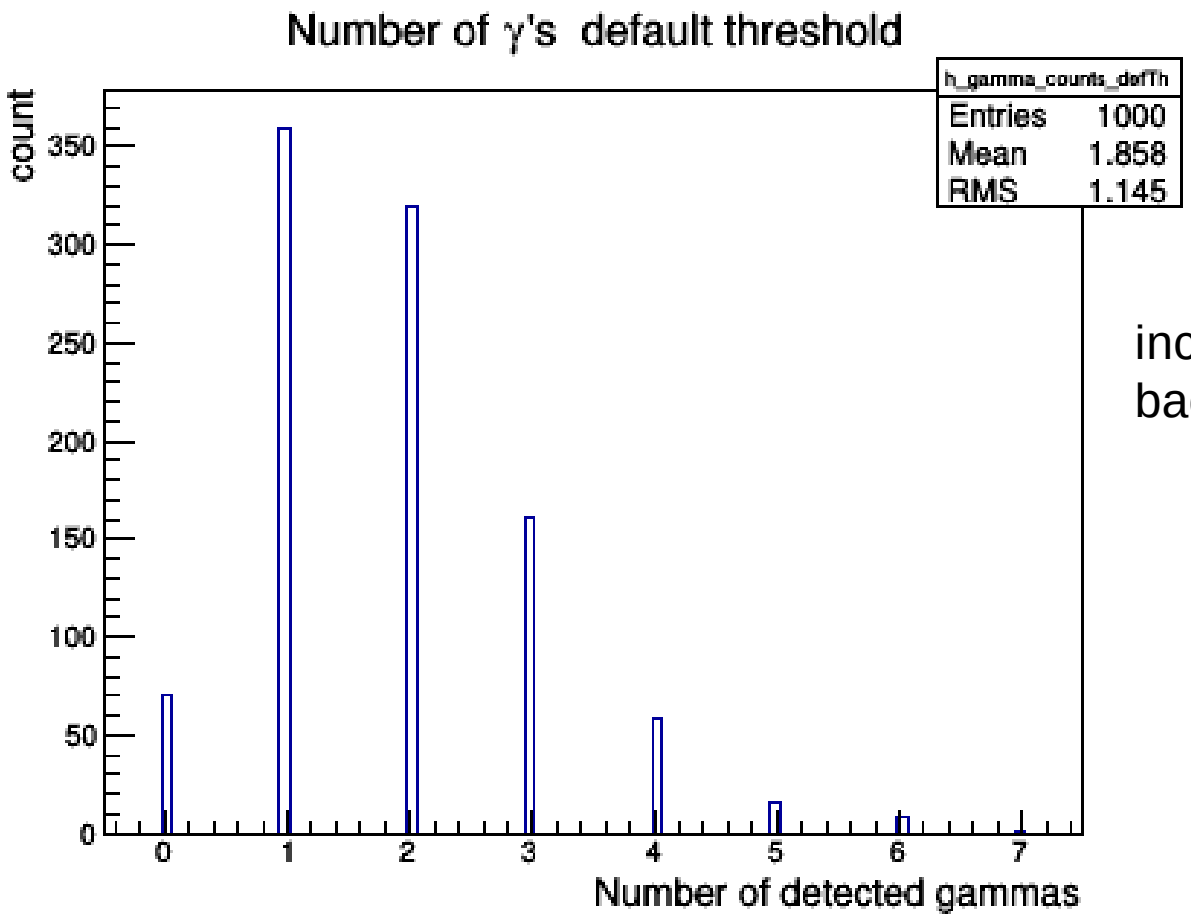
- Start at module with largest energy deposit
- Add neighbors if $E > E_{th,xtl}$
- Stop if no more neighbor above $E_{th,xtl}$
- Accept Cluster if $E_{sum} > E_{th,cl}$

	TS EMC	FW EMC
E_{xtl}	3 MeV	8 MeV
E_{cl}	10 MeV	15 MeV
E_{max}	20 MeV	10 MeV

user has to take care ?!?

Photon Reconstruction

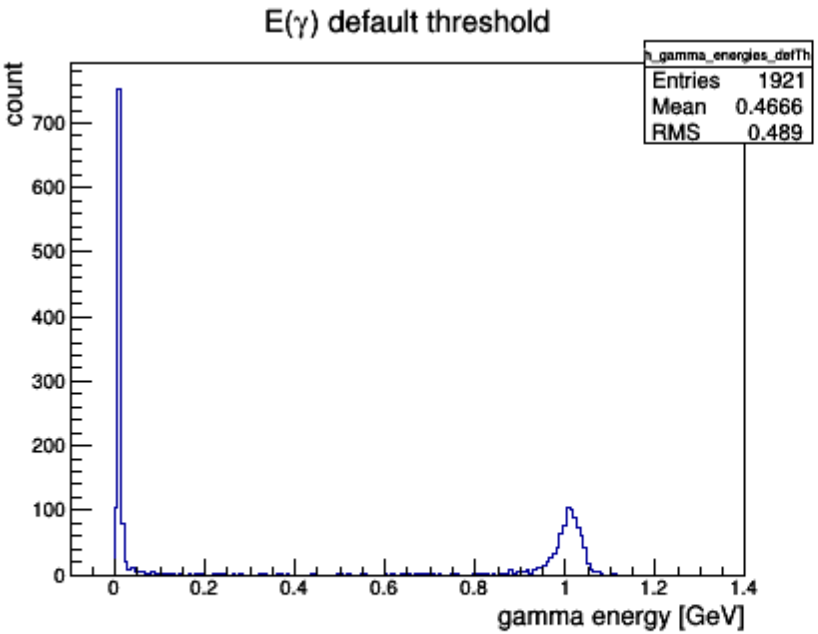
1000 1GeV single-photon events with the particle gun (**PndBoxGenerator**)



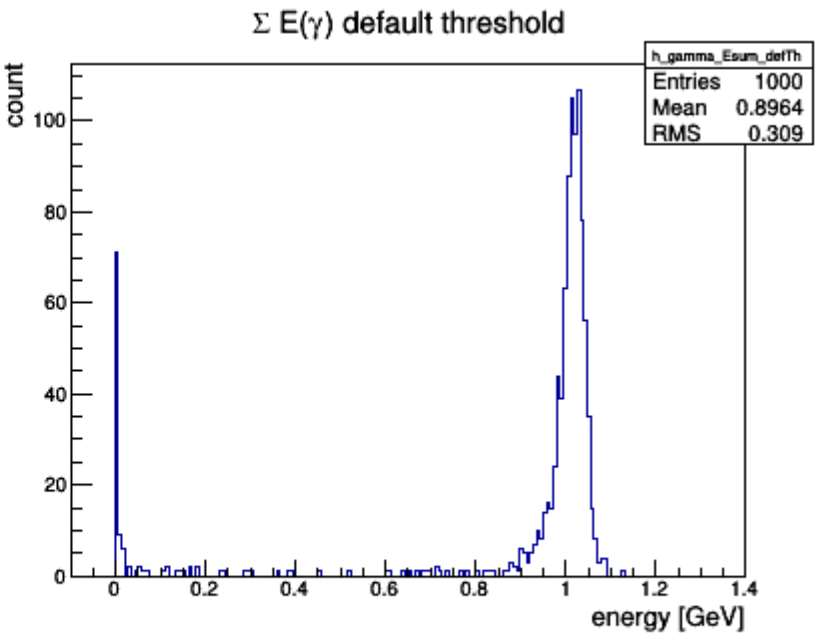
increases (combinatorial) background drastically !

Photon Reconstruction

1000 1GeV single-photon events with the particle gun (**PndBoxGenerator**)



Photon energy distribution

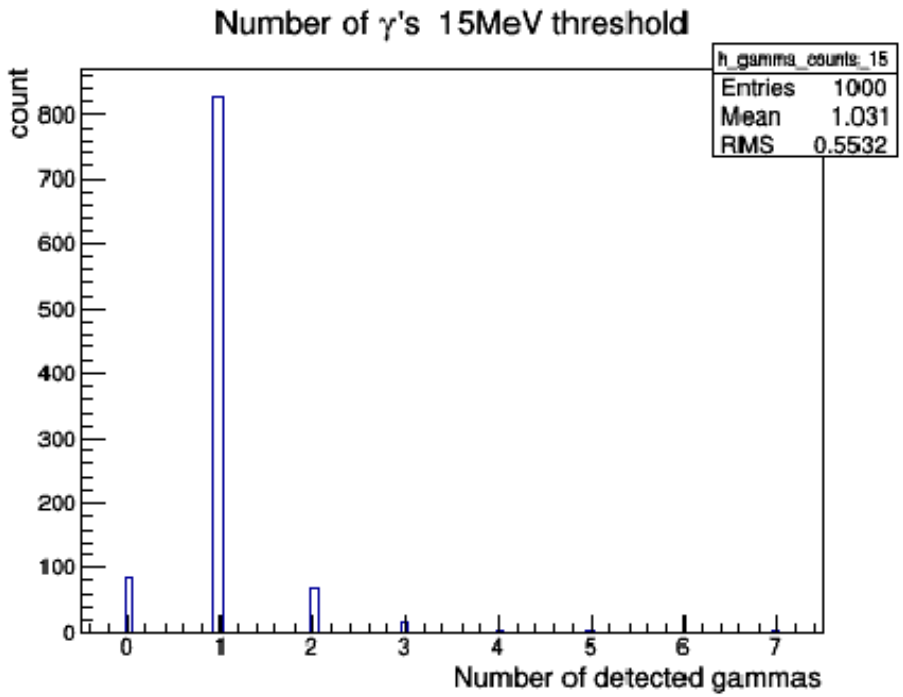


Energy sum within one event

Photon Reconstruction

1000 1GeV single-photon events with the particle gun (**PndBoxGenerator**)

➡ User cluster threshold necessary

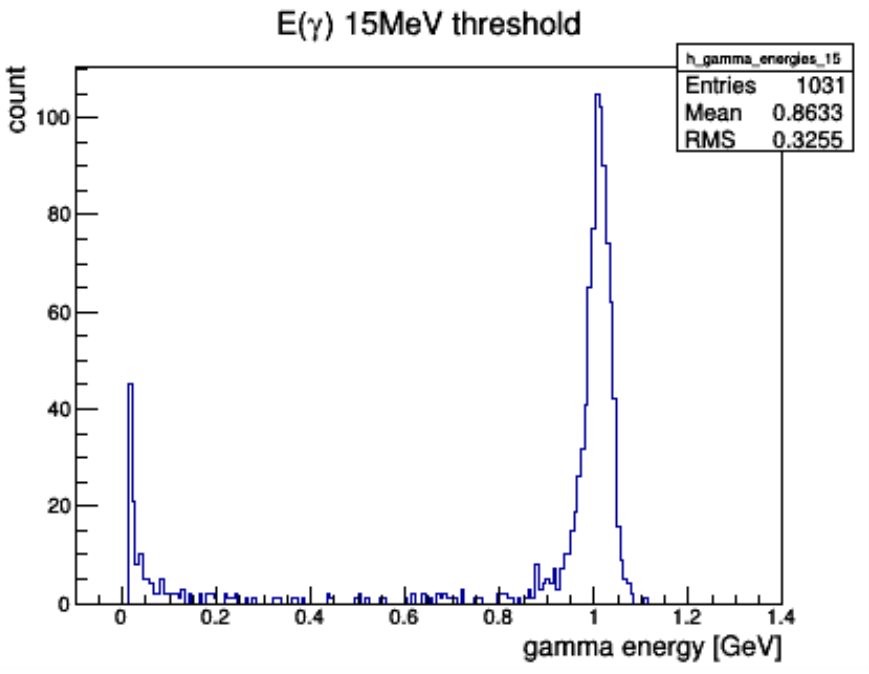


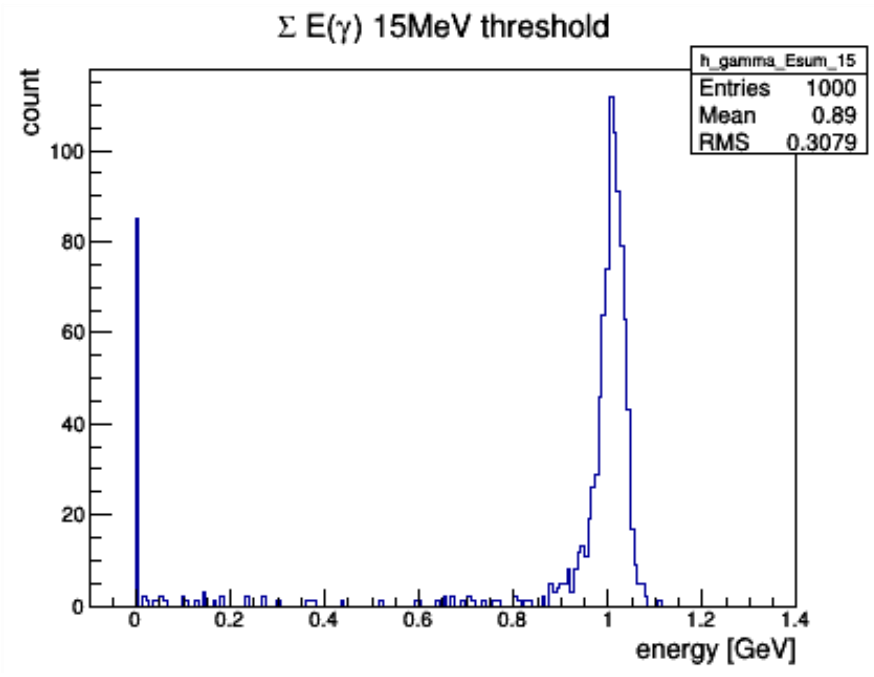
Threshold	Detected 1-Photon-events
Default (3 MeV)	~ 35%
10 MeV	~ 73%
15 MeV	~ 82%
20 MeV	~ 86%

Photon Reconstruction

1000 1GeV single-photon events with the particle gun (**PndBoxGenerator**)

User cluster threshold necessary



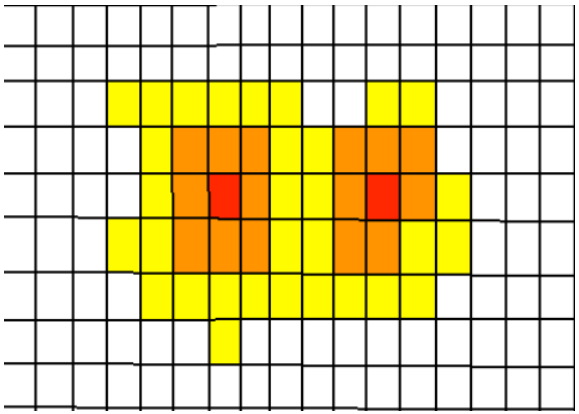


Energy sum nearly unaffected

Photon Reconstruction

2. Search for bumps within each cluster
   - A cluster can be formed by more than one particle if the angular distances of the particles are small

   ➡ **bump splitting PndEmcMakeBump**



2 GeV pi0

Bump: - a local maximum inside the cluster while all neighbors smaller $E_{LocalMax} > E_{max}$

- Highest Energy E_{NMax} of any of the N neighbors must fulfill: $0.5(N-2.5) > E_{NMax}/E_{LocalMax}$

	TS EMC	FW EMC
E_{xtl}	3 MeV	8 MeV
E_{cl}	10 MeV	15 MeV
E_{max}	20 MeV	10 MeV

➡ If bump: total cluster energy has to be shared

Iterative algorithm assigns weight to each crystal:

$$E_{bumb} = \sum_i w_i E_i \qquad w_i = \frac{E_i \, exp(-2.5\, r_i \,/\, r_m)}{\sum_j E_j \, exp(-2.5\, r_j \,/\, r_m)}$$

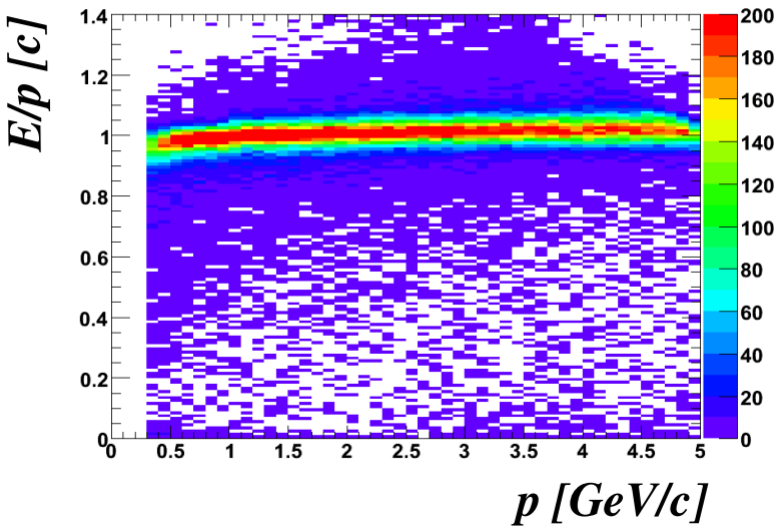
r_m = Molière radius
r_i, r_j = distance of the ith and jth crystal to the center of the bump
j = index over all crystals

…until position of bump center (via centre of gravity method) stays stable

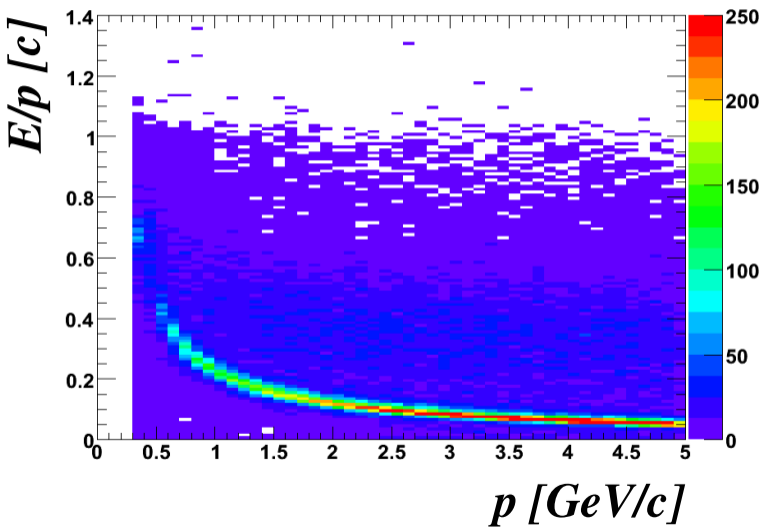
PID –Electrons-

- Most important measure: $E_{cluster}/p$
  - p: reconstructed momentum
  - $E_{cluster}$: deposited energy of charged particle
  - Electron: complete energy deposition within EMC $E_{cluster} / p \approx 1$
  - Hadrons and μ deposit only a fraction of their kin. energy

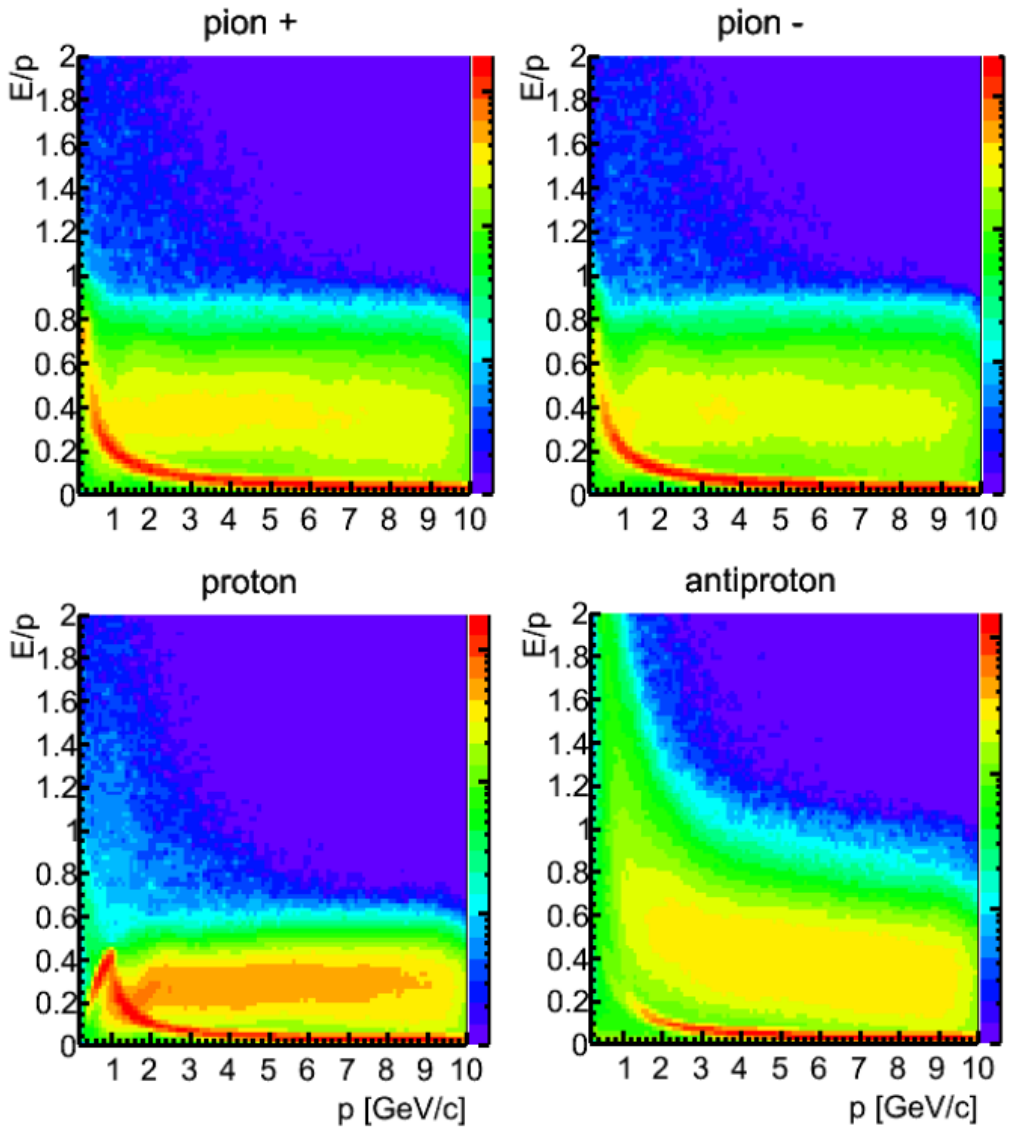
electron



pion



PID –E/p-



π+ is like π^-

different

PID –Electrons-

Further options:

- shower shape analysis
  - E_1/E_9
  - -> Energy central crystal / sum 3X3
- Lateral moment of the cluster:

$$mom_{LAT} = \sum_{i=3}^{n} E_i r_i^2 \Big/ \left(\sum_{i=3}^{n} E_i r_i^2 + E_1 r_0^2 + E_2 r_0^2 \right)$$

– n: number of modules associated to the shower

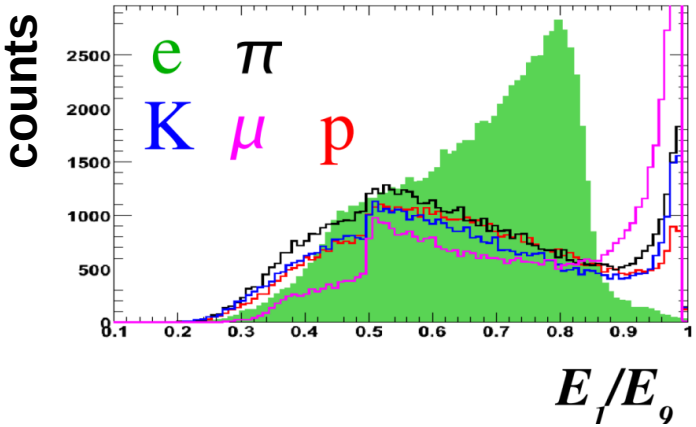
– E_i: deposited energy in the iTH module with $E_1 \geq E_2 \geq ... \geq E_n$

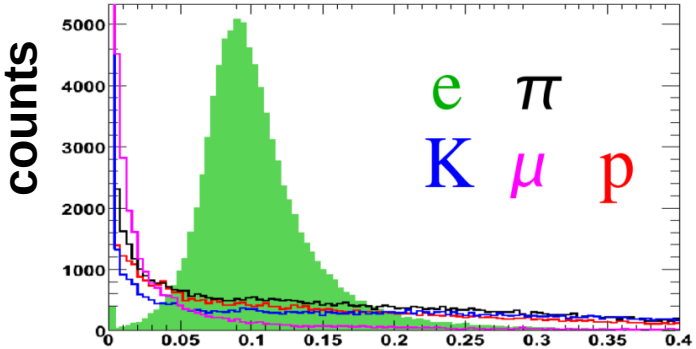
– r_i: lateral distance between the central and the iTH module

– r_0: the average distance between two modules.

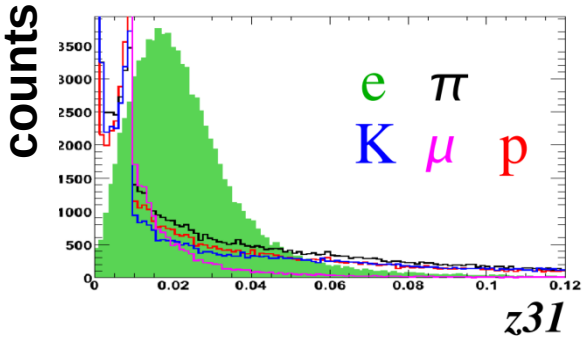
- Zernike moments

  Describing energy distribution within a cluster by radial and angular dependent polynomials





lateral energy distr.



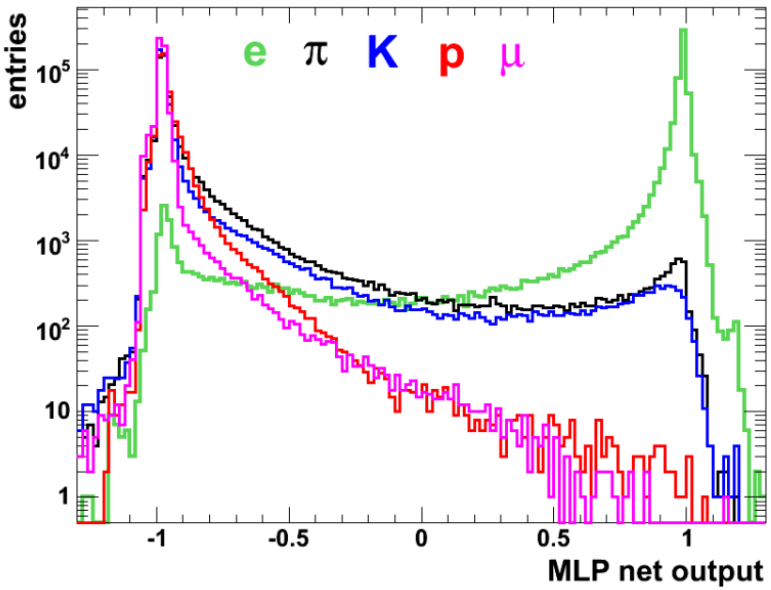
PID –Electrons-

- Lot of measures helpful for electron identification
  - How to find optimum selection criteria?

➡ neural network: Multilayer Perceptron (MLP)

  - Input for training:
    - 10^7 tracks of *e*, π, μ and *p*
    - *Momentum range: 0.2 – 15 GeV/c*
    - 10 Inputparameter:
      - E/p, E1/E9, E9/E25, lat. energy dist., Zernike moments
    - Answer: “1” for e and “-1” for π,K,μ,p

Test with 10^5 tracks 0.3-15 GeV/c



almost clean electron recognition with a quite small contamination of muons and hadrons can be obtained by applying a cut on the network output

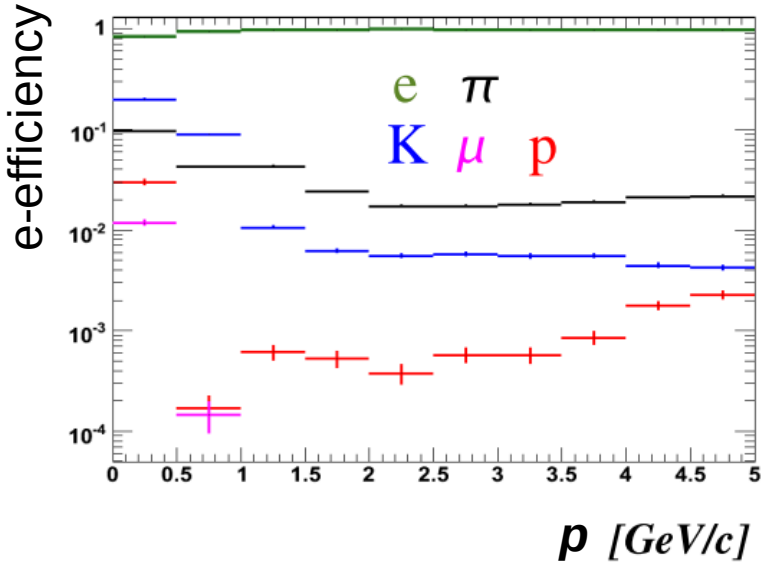
The electron efficiency and contamination rate

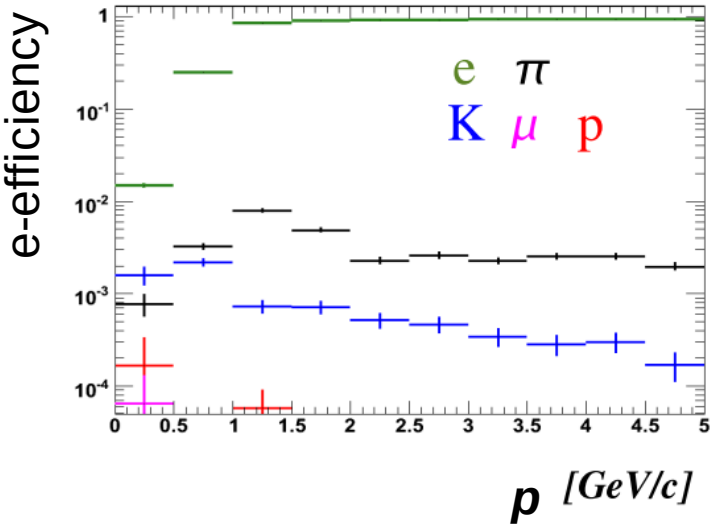
e-probability > 20%

- p>1GeV/c
  - efficiency >98%
  - misidentification $\pi = 2\%$
- p<1GeV/c
  - >= 85 % eff.
  - up to 20% miss id. K

e-probability > 95%

- p>1GeV/c
  - efficiency >90%
  - misidentification
    - $\pi = 0.2\%$
    - μ, p < 10^{-4}
- p<1GeV/c
  - low e eff. 3%-30%





Overal efficiencies

MC input

Reco & PID

	e	μ	π	K	p
e	95	0	2	2	2
μ	0	97	36	41	24
π	2	1	23	15	11
K	1	1	3	5	3
p	2	1	36	37	60

E and μ ok

μ impure

Annihilation

R.A. Kunne, IPN Orsay

Thank you for your attention