# Neutral Particle Identification in the $\overline{\text{P}}$ANDA Electromagnetic Calorimeter

Bachelor's Thesis (Physics)

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KVI

university of groningen

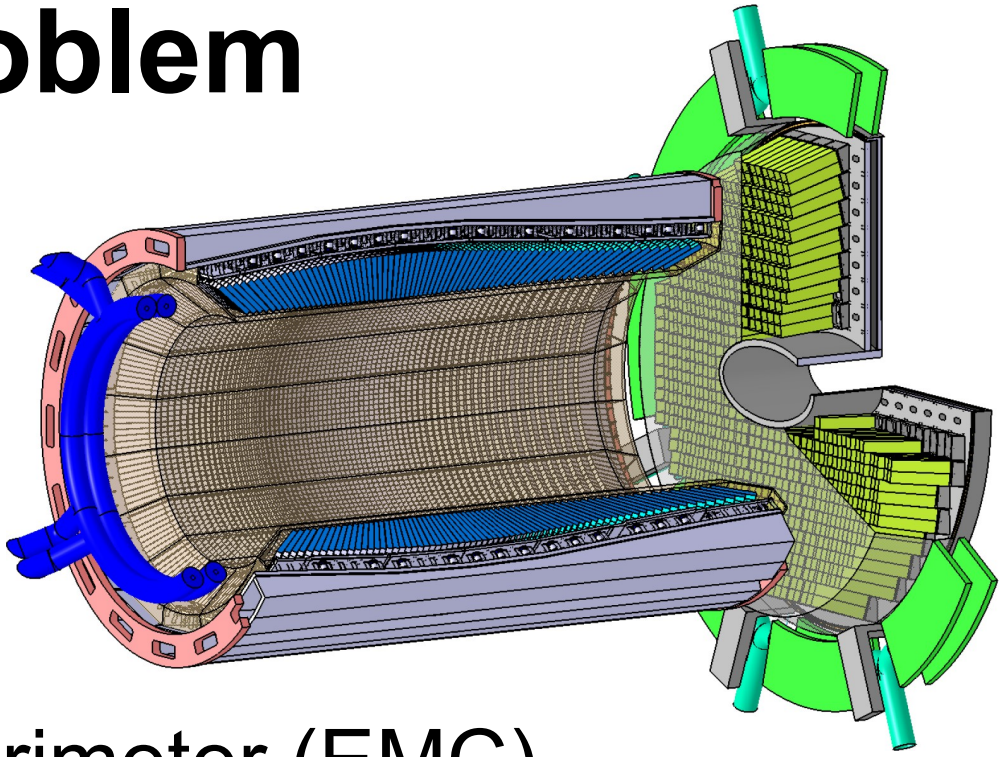
panda

# Outline

- Identification of neutral particle clusters in the $\overline{\text{P}}$ANDA electromagnetic calorimeter (EMC)
- What parameters to use?
- Multi-variate analysis
- Conclusions

# Problem

EMC of the target spectrometer



- Electromagnetic calorimeter (EMC)
  - Detects (neutral) particles by electromagnetic showers in lead-tungstate crystals
- Neutral particles
  - **photon**, **neutral pion**, (**neutron)**
  - Not detected by other $\overline{\text{P}}$ANDA subdetectors

# **Problem** – Neutral pion

- Decays quickly into 2 photons at target with opening angle $\theta$

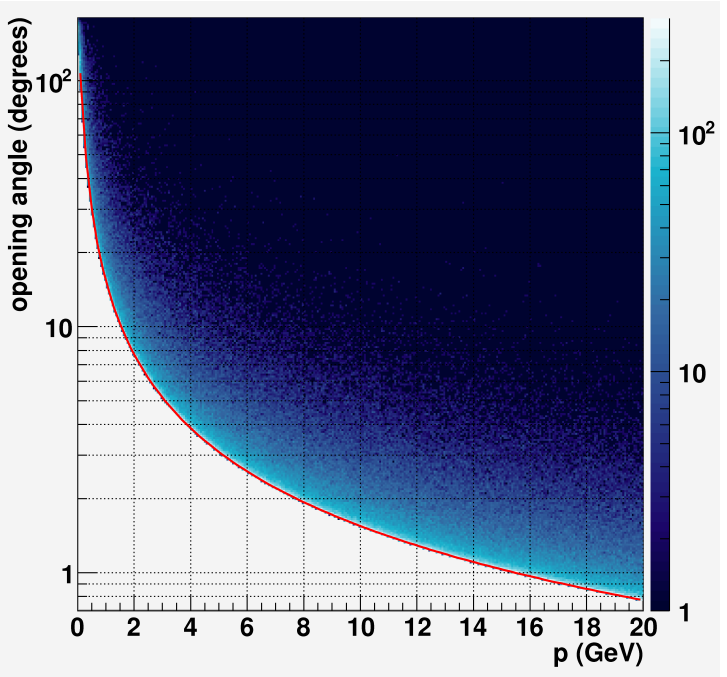
$$t_{1/2} = 8.4 \cdot 10^{-17}\ \mathrm{s}$$

$$\pi^0 \rightarrow 2\gamma \qquad (98.8\%)$$

$$\pi^0 \rightarrow \mathrm{e}^+ + \mathrm{e}^- + \gamma \qquad (1.2\%)$$

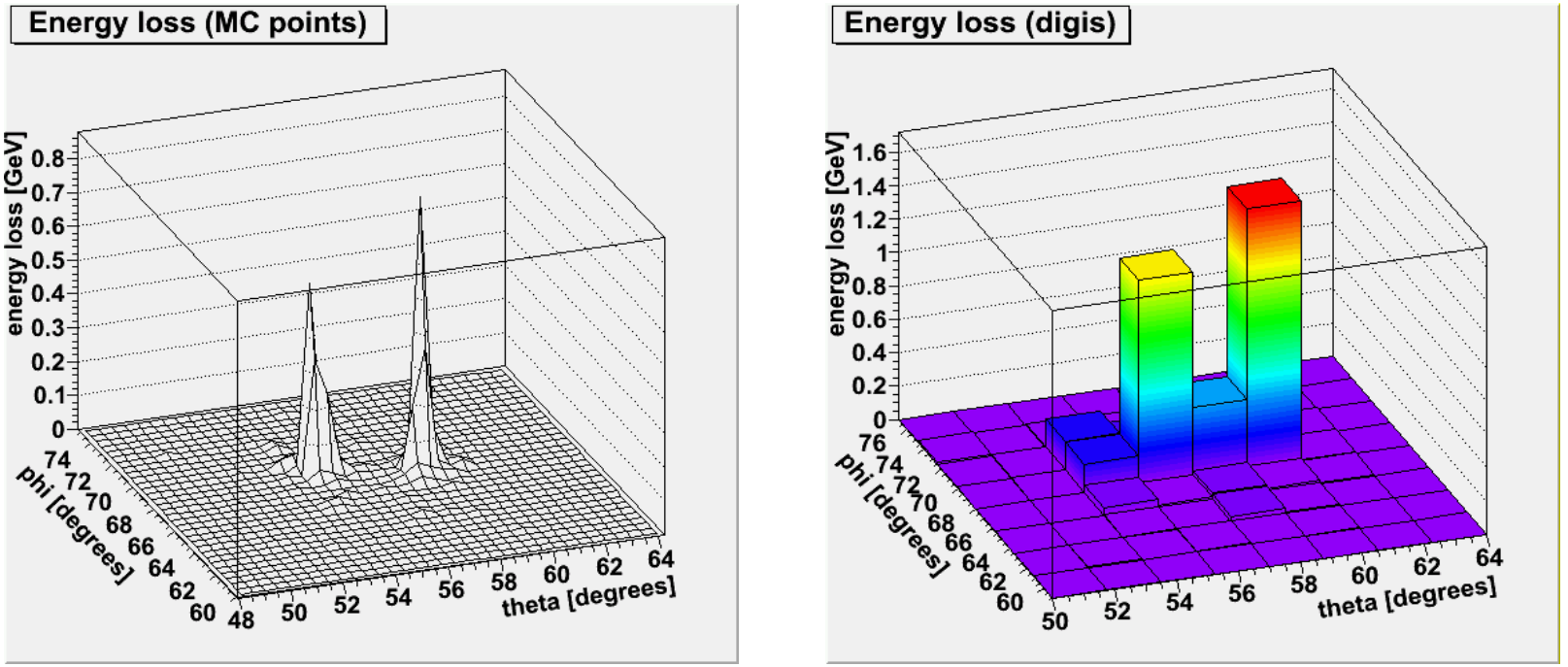
$$\theta_{\min}(p) = \cos^{-1}\left(1 - \frac{2m_{\pi^0}^2 c^2}{m_{\pi^0}^2 c^2 + p^2}\right)$$

$$\theta_{\max} = \pi$$




- Small opening angles at high momentum
  → *merged clusters* in EMC from 2 photons

# **Problem** – Merged Cluster Example

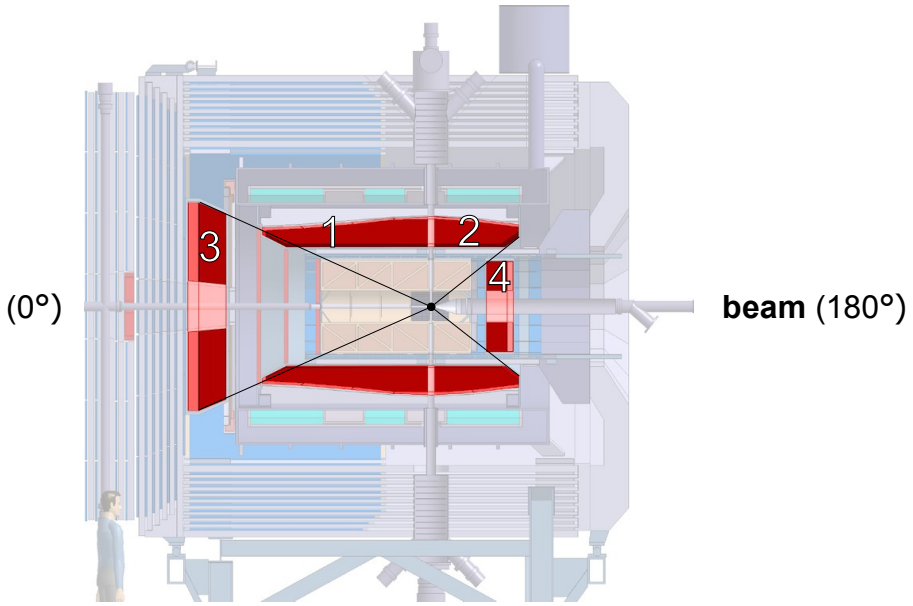



**4 GeV neutral pion event**

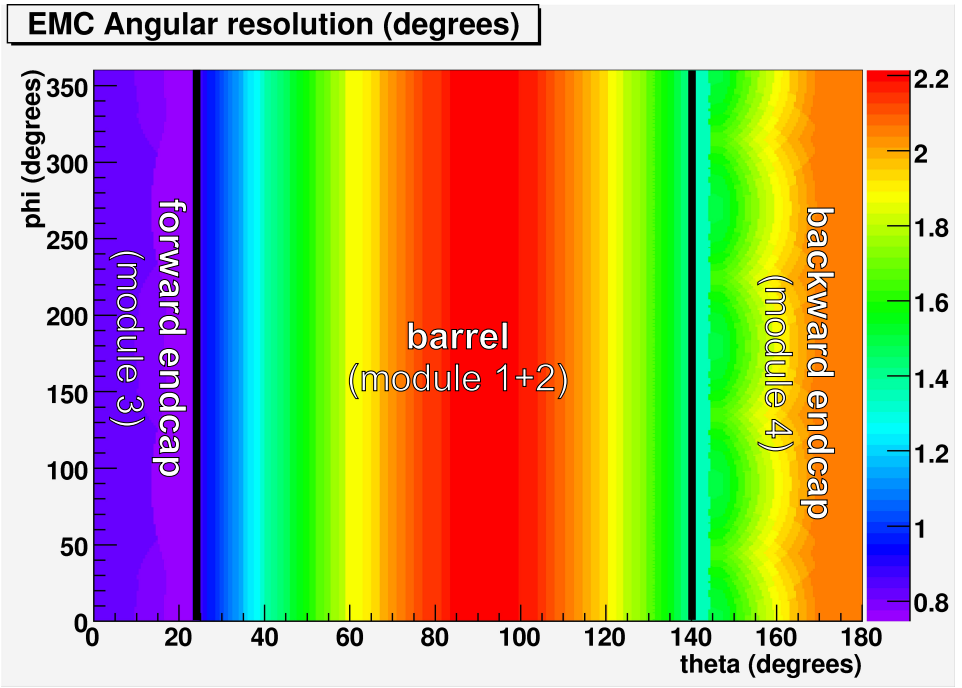
- Crystal energy depositions (**digis**)
  are grouped in **clusters** of neighboring crystals

→ cluster identification is needed

# EMC Design




EMC modules in the target spectrometer




Approximation of angular granularity as seen from target

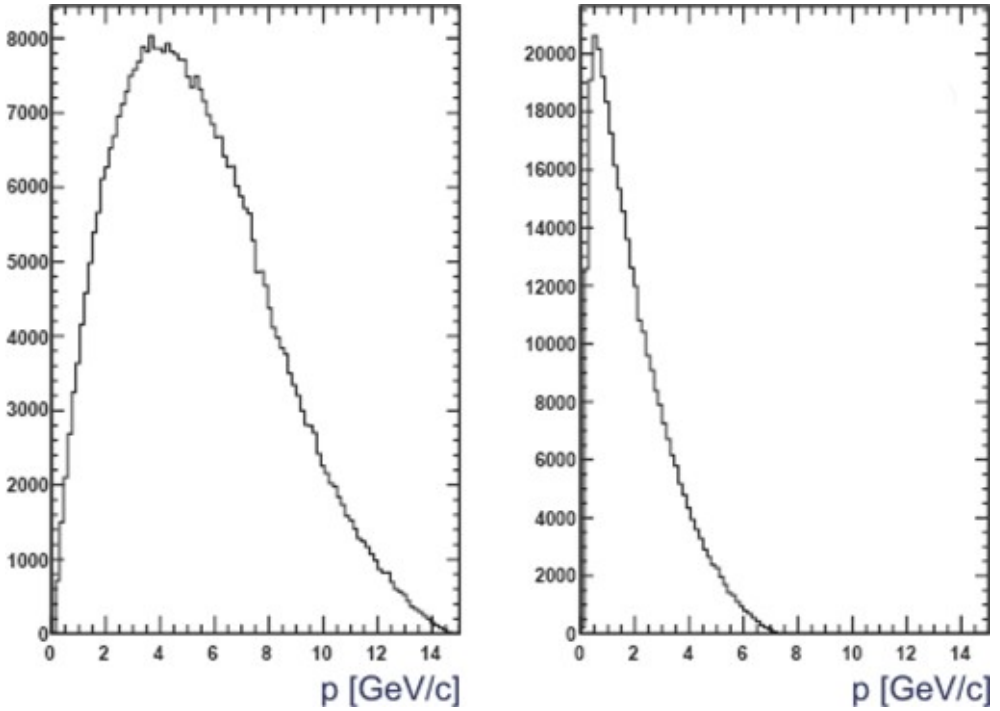
- Angular granularity seen from target depends strongly on theta
  - Important for neutral pion events

# EMC Design

- High-momentum pions are boosted in forward direction

Simulated neutral pion momentum spectrum
(15 GeV beam momentum)

**forward endcap**




**barrel**

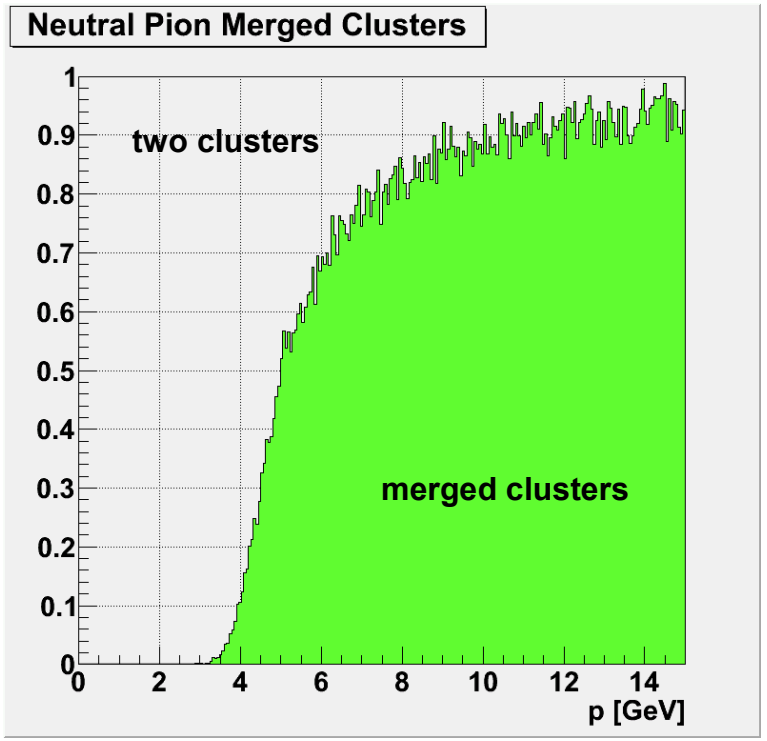
Source: EMC Design Report (2008)

# Event Generation

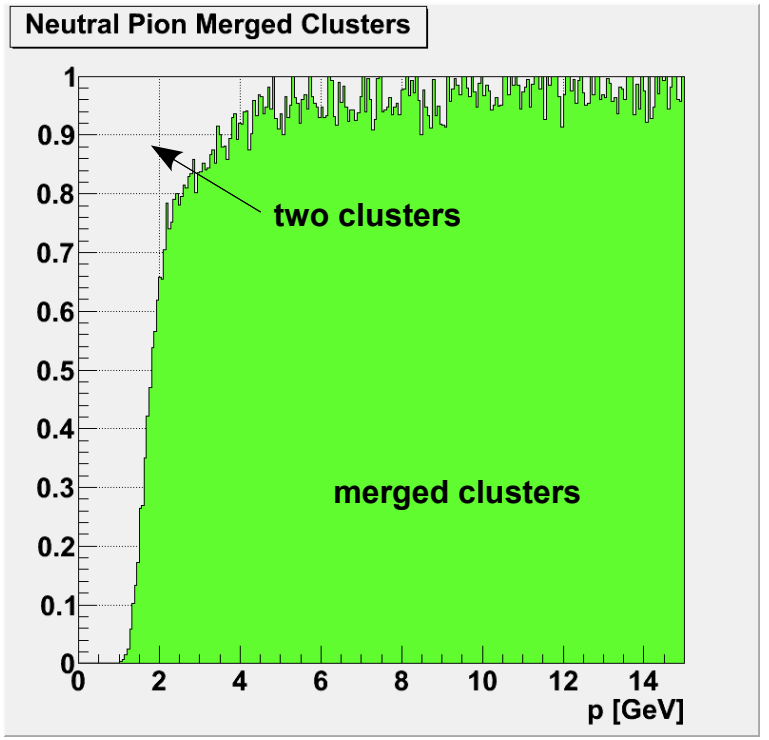
- PandaRoot
- Particles: gamma, neutral pion, (neutron)
- $2 \cdot 10^5$ events per class
- Momentum = 0 - 15 GeV (uniform)
- Theta = 14° (forward endcap); 80°-100° (barrel)
- Phi = 0° - 360°
- GEANT3

# **Event Selection** – Neutral Pions

## Simulated neutral pion events




forward endcap




barrel

Neutral pion merged clusters selected

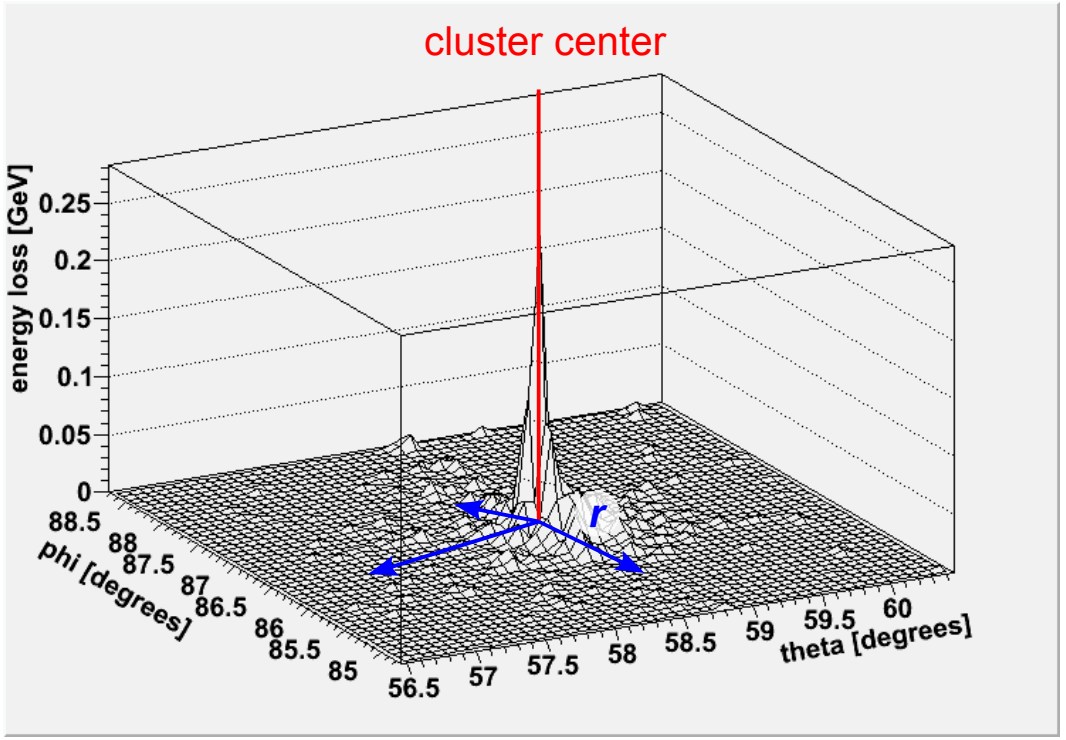
forward endcap > ~5 GeV; barrel > ~2 GeV

# Parameters

- Parameters investigated for cluster identification include:
  - Cluster energy, cluster 'mass' ..... `PndEmcCluster`
  - Cluster moments ..... `PndEmcClusterMoments`
  - Major/minor axis moments of clusters ..... (`PndEmcClusterMoments`)
  - Zernike moments ..... `PndEmcXClMoments`
  - Energy fraction in *n* most energetic digis
  - Neutral pion invariant mass reconstruction
  - Number/energy of bumps within cluster
  - ...
- Many highly correlated
- Best single parameter will be presented:
  $2^{nd}$ cluster moment

# **Parameters** – 2nd Cluster Moment

- Average squared distance from cluster center, weighed by digi energy

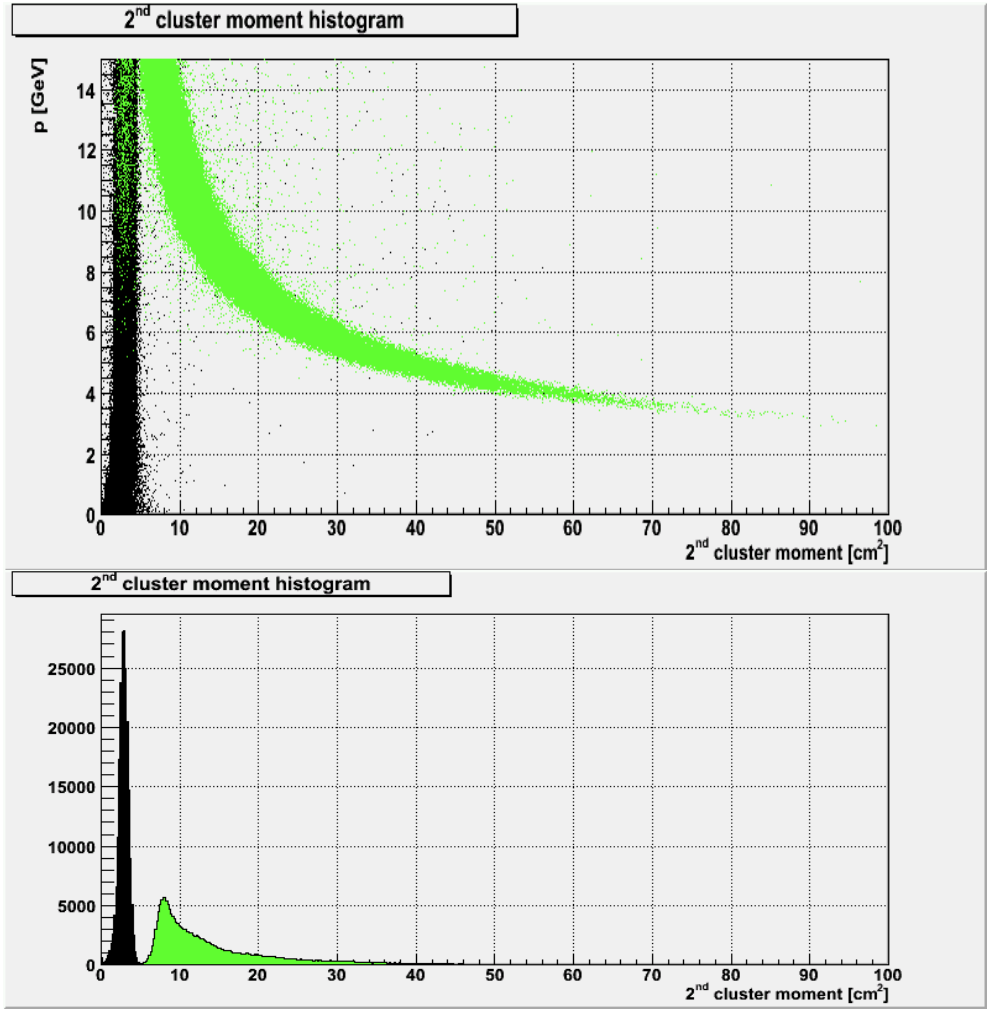



$$r_d = ||\boldsymbol{x}_d - \boldsymbol{x}_{\text{cluster}}||$$

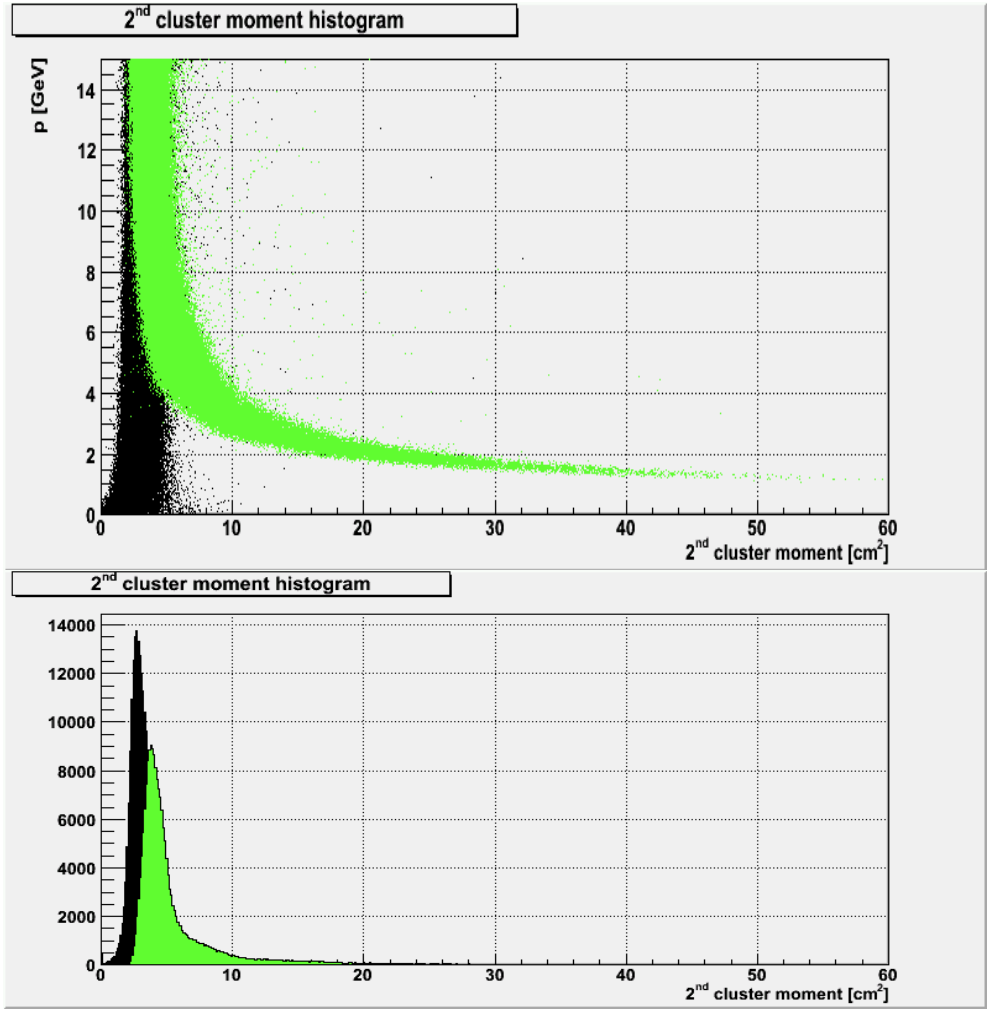
$$\langle r^2 \rangle = \frac{1}{E_{\text{cluster}}} \sum_d E_d r_d^2$$

- Available in PandaRoot as `PndEmcClusterMoments::SecondMoment()`

# **Results** – 2nd Cluster Moment




**forward endcap** 0-15 GeV



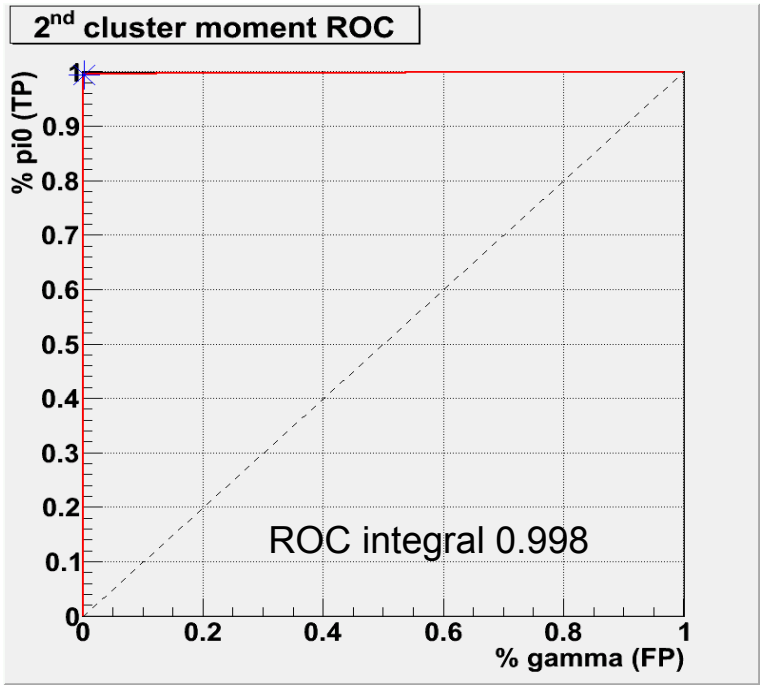

**barrel** 0-15 GeV

**gamma**
**neutral pion**

# **Results** – 2nd Cluster Moment

## ROC curves

(fraction of events classified as pion is plotted)

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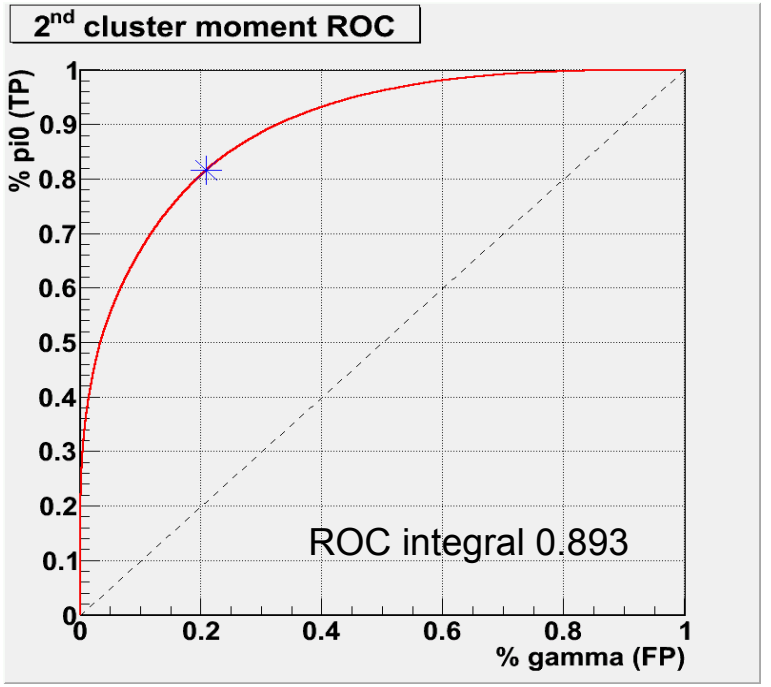
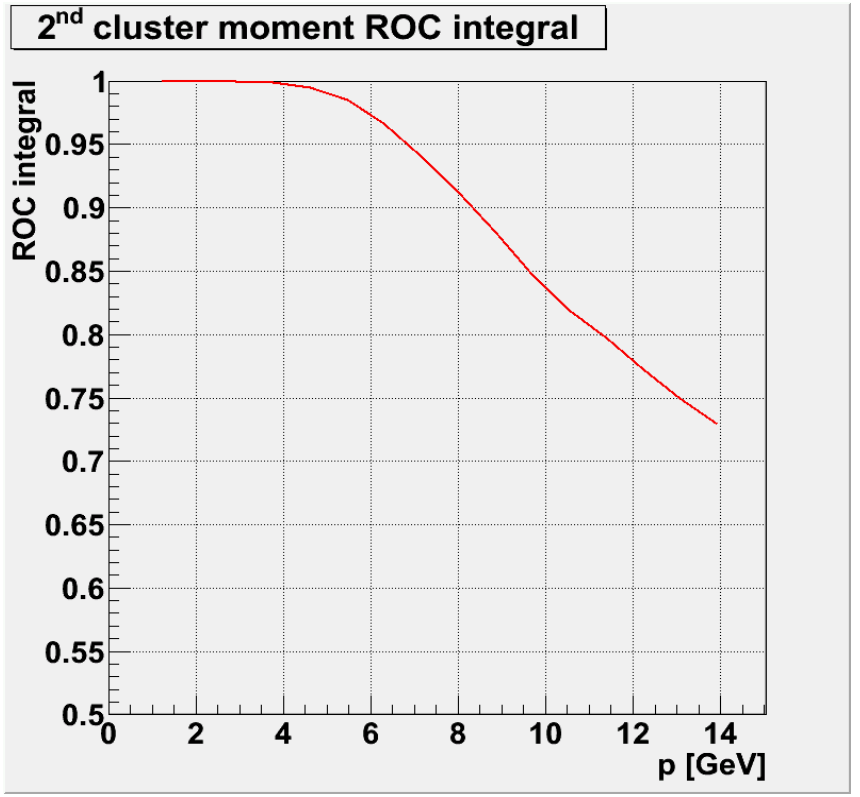



**barrel** 0-15 GeV

- *Single cut* (can be adjusted)
  - forward endcap: 0.995 TP rate, 0.003 FP rate
  - barrel: 0.816 TP rate, 0.209 FP rate

# **Results** – 2nd Cluster Moment (Barrel)

- Momentum dependence 2nd cluster moment separation power
- More parameters?

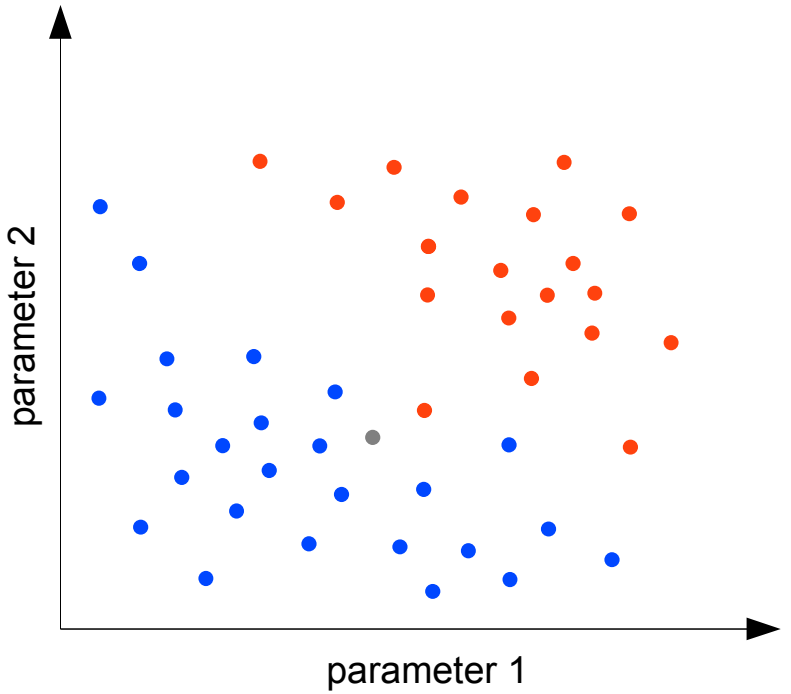


# **Analysis** – MVA

- Multivariate analysis (MVA) using **k-Nearest Neighbours algorithm** (KNN)
- Allows combination of multiple parameters (multi-dimensional density estimator)

- events of class 1
- events of class 2
- to be classified

**2-dimensional example**



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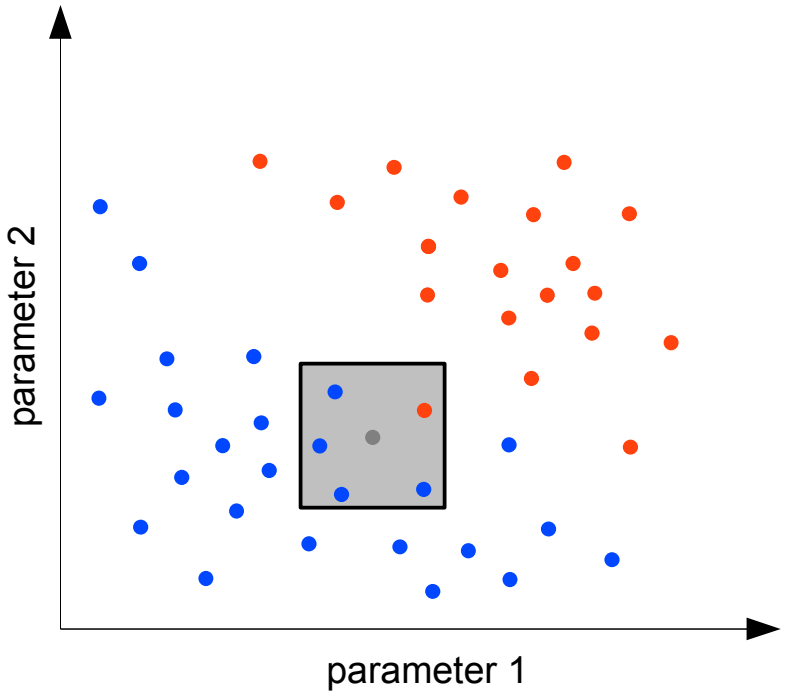



**Classification results (k = 5)**

20% class 1
80% class 2

# **Analysis** – MVA

- 90% of events used to approximate distribution in chosen parameter-space
- 10% of events classified
- Best *k* depends on number of events and parameters (dimension)

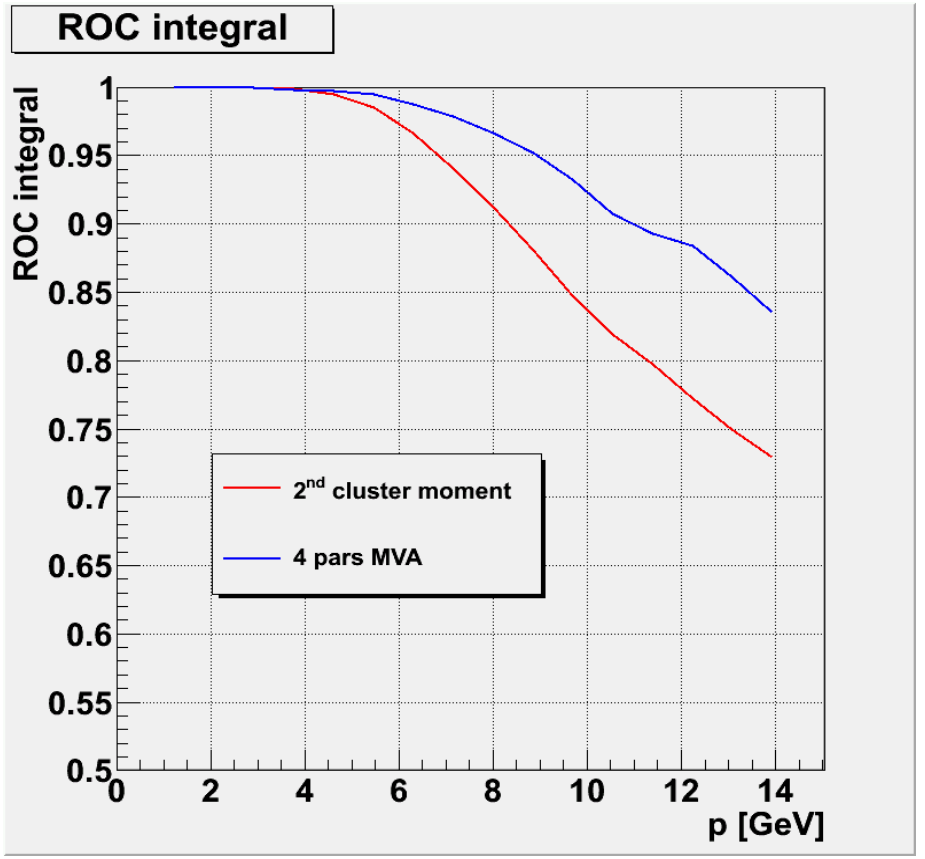
- KNN (and other MVA algorithms) are available in PandaRoot under `pid/PidClassifier`
  - M. Babai

# **Results** – Barrel MVA

- Multivariate analysis using KNN with 4 parameters:
  - Cluster energy
  - $2^{nd}$ cluster moment
  - Energy fraction in 4 most energetic digis
  - Zernike moment (5, 3)

# **Results** – Barrel MVA

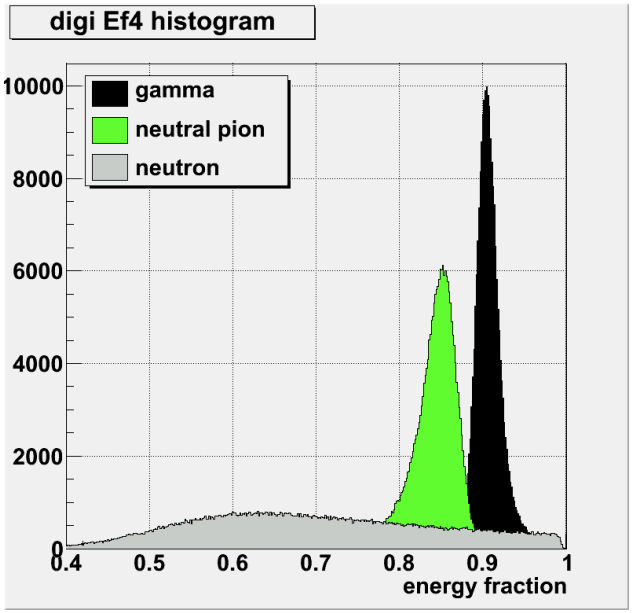
- KNN (4 parameters):
  - Cluster energy
  - 2nd cluster moment
  - Energy fraction in 4 most energetic digis
  - Zernike moment (5, 3)



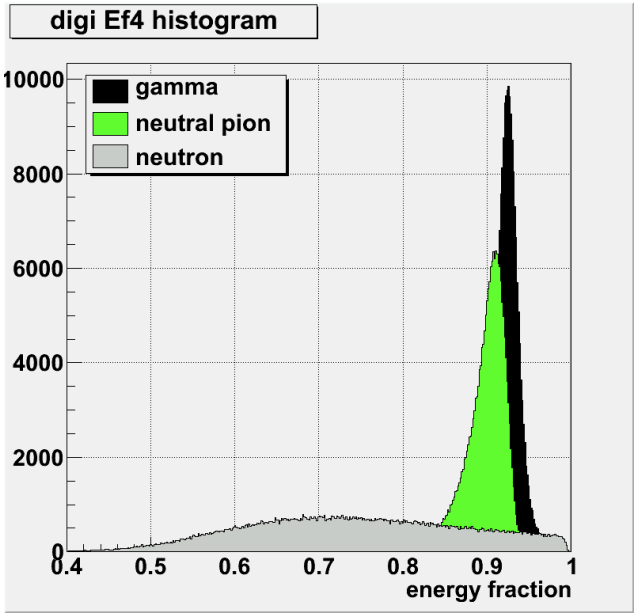

→ *KNN analysis* improves separation for high-momentum events

# **Results** – Adding Neutrons

- Example parameter:
  **energy fraction in 4 most energetic digis**




**forward endcap**




**barrel**

# **Results** – Adding Neutrons

- MVA (4 parameters):
  - Cluster energy
  - 2nd cluster moment
  - Energy fraction in 4 most energetic digis
  - Zernike moment (5, 3)
- *KNN analysis* classification results

**forward endcap**

| event type \ classified as (%) | $\gamma$ | $\pi_0$ | n |
|---|---|---|---|
| $\gamma$ | 96.2 | 0.2 | **3.6** |
| $\pi_0$ | 0.5 | 99.3 | 0.2 |
| n | **3.1** | 0.2 | 96.8 |

**barrel**

| event type \ classified as (%) | $\gamma$ | $\pi_0$ | n |
|---|---|---|---|
| $\gamma$ | 84.8 | **11.0** | 4.1 |
| $\pi_0$ | **10.6** | 88.4 | 1.0 |
| n | 3.0 | 2.0 | 95.0 |

# Conclusions

- EMC cluster separation efficiency depends on theta

  - **Forward endcap**
    - Good separation of neutral pion and gamma events up to highest momenta using **2$^{nd}$ cluster moment**
  - **Barrel**
    - Good separation of neutral pion and gamma events up to medium momenta by **combining ~4 parameters**
      - More parameters yield only small improvements
      - High-momentum events should be rare for barrel part

# Discussion

- Use a realistic event generator
  - Realistic momentum spectrum?
  - Realistic number of particles of each class?
- Other applications?
  - Converted photons?
- Particles not produced at the target?

# Technical issues

- Some bugs in EMC code were fixed
- Open problem: lifetime of cluster moments objects
  - `PndEmcClusterDistances;`
    `PndEmcClusterEnergySums;`
    `PndEmcClusterMoments;`
    `PndEmcXClMoments`
  - See thread on forum
- Multi-class MVA tools now available in PandaRoot

# Questions?

Thanks for your attention!