Gamma-Hadron Separation using Distribution of Light in HAWC Tanks

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- Erice

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HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Max-Planck-Institut
für Kernphysik

Contents:

Ground based detection of VHE gamma-rays:

(1) Shower Particle Detectors

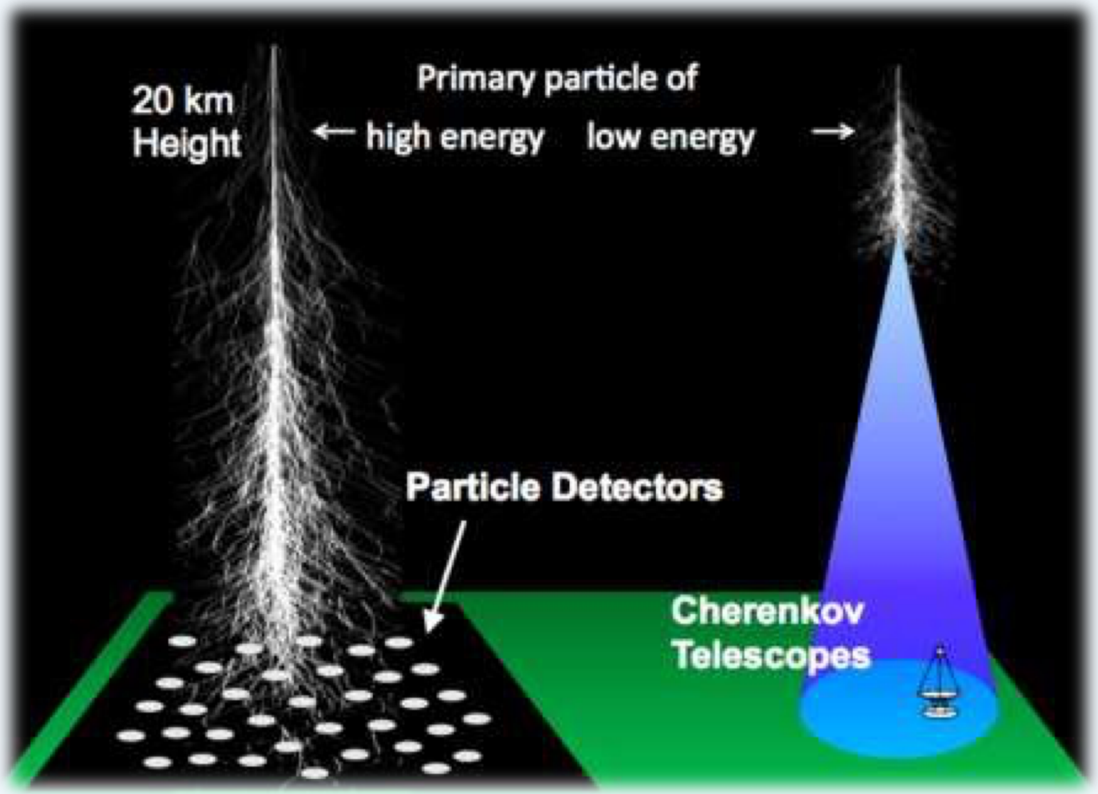
- Measure particles of the shower tail which reaches the ground
- Snapshot of the shower when it reaches the ground

(2) Cherenkov Telescopes

- Observe showers that die out before reaching ground
- Uses the full atmosphere as calorimeter

(3) Fluorescent light detectors

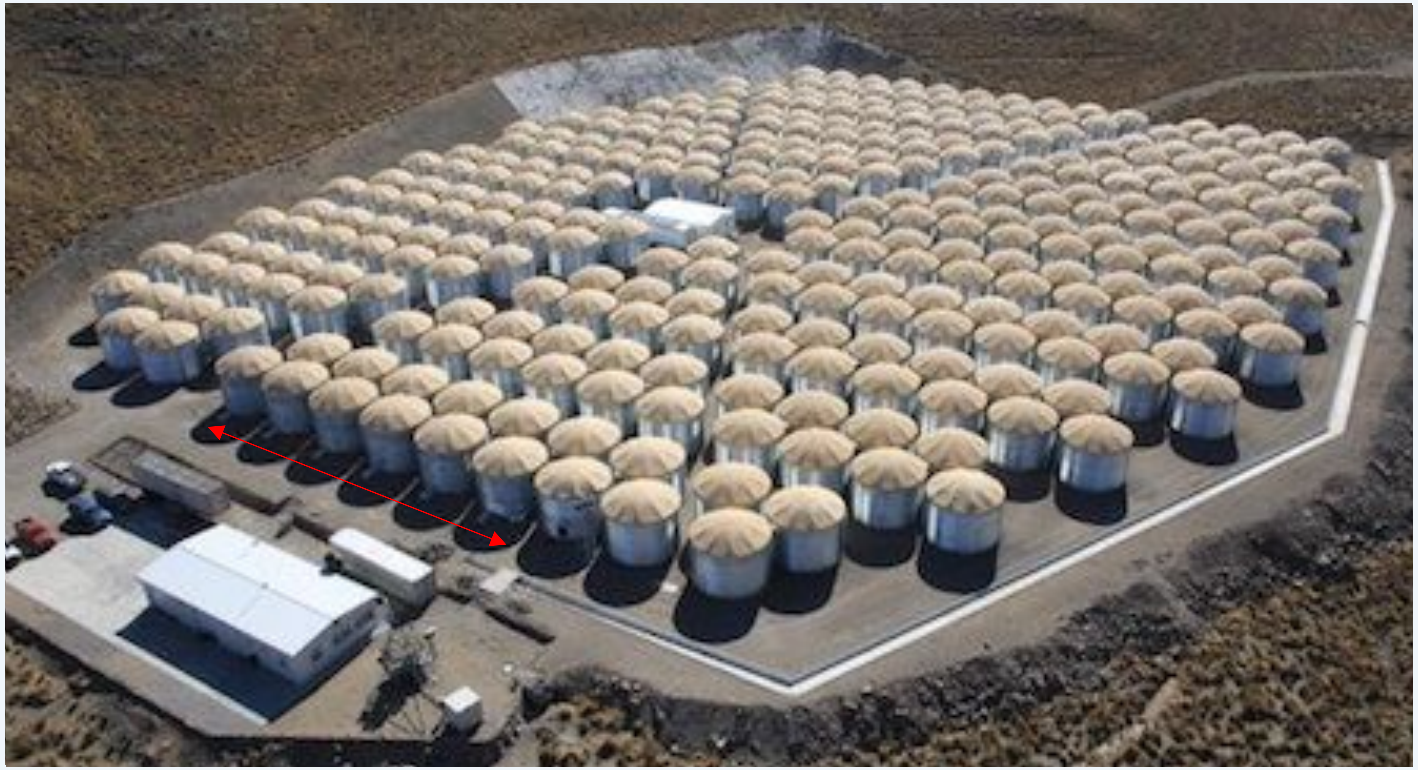
- Records the longitudinal profile of the shower development through the atmosphere



[Lorenz & Wagner 2012]

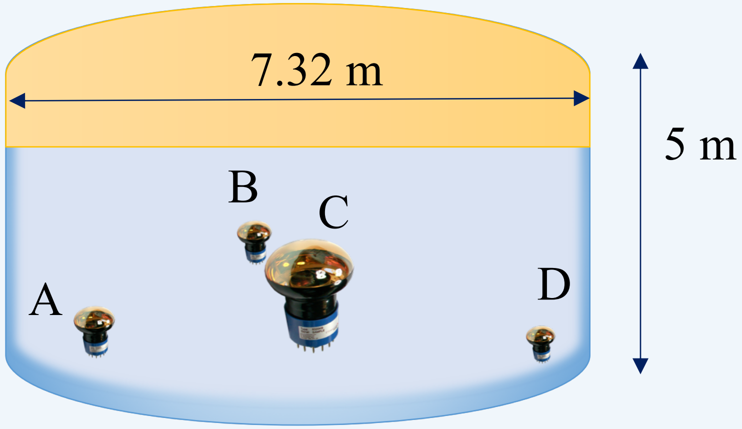
HAWC – High Altitude Water Cherenkov Gamma-ray Observatory

- On the flanks of Sierra Negra volcano near Puebla, Mexico (18°59′41″ N, 97°18′30″ W)
- Designed to observe high-energy γ-rays: 100 GeV – 100 TeV
- Altitude: 4100 m a.s.l.
- 22,000 m^2 on ground
- Crab detected in 1 transit
- Field of view of ~ sr,
- Continuous monitoring of the sky
- $-25° <$ declination $< +65°$



~50 m

HAWC



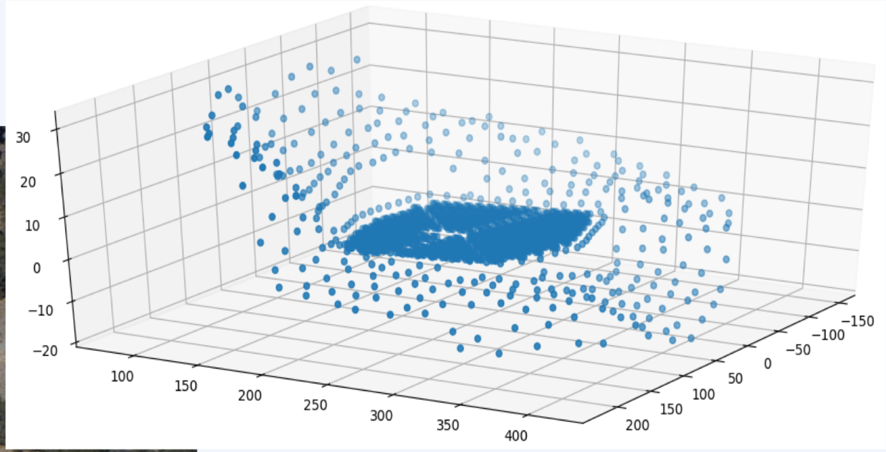
- 300 Water Cherenkov Detectors (WCDs)

  - 188,000 L

  - 4 Photomultiplier Tubes (PMTs: 3 peripheral 8" & 1 central 10" Hamamatsu)
- Cherenkov cone in water is 41°
- Denser medium so that rays interact more quickly to create high energy $e^{-}e^{+}$
- Outriggers – smaller WCDs around main array

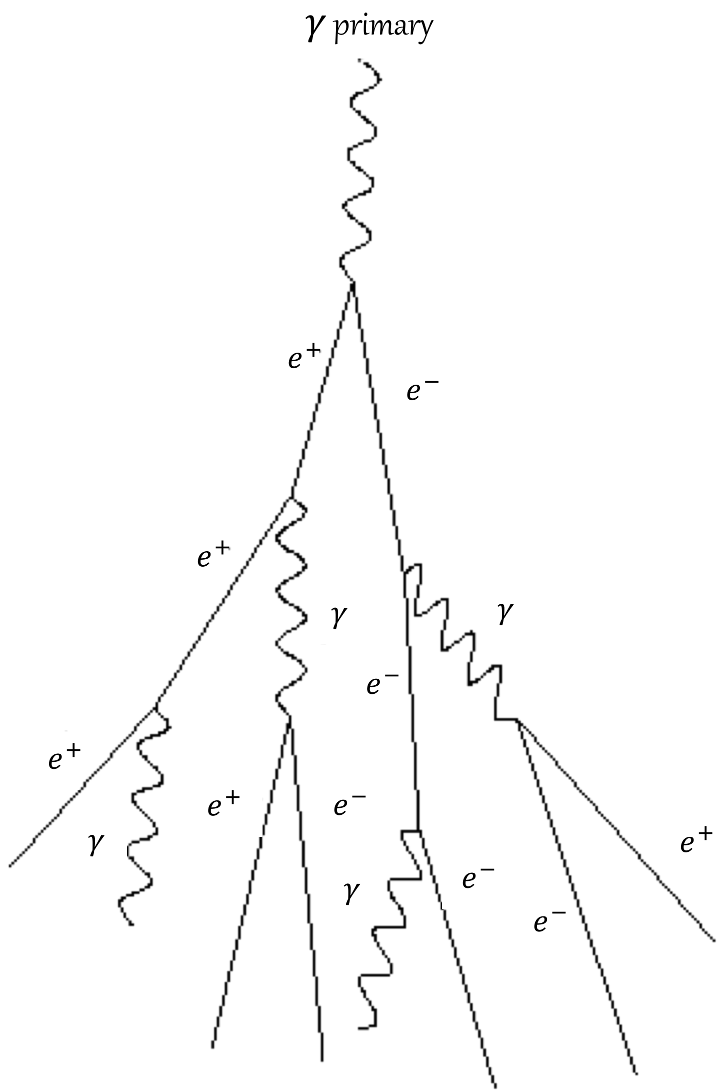
  – Improve sensitivity

HAWC



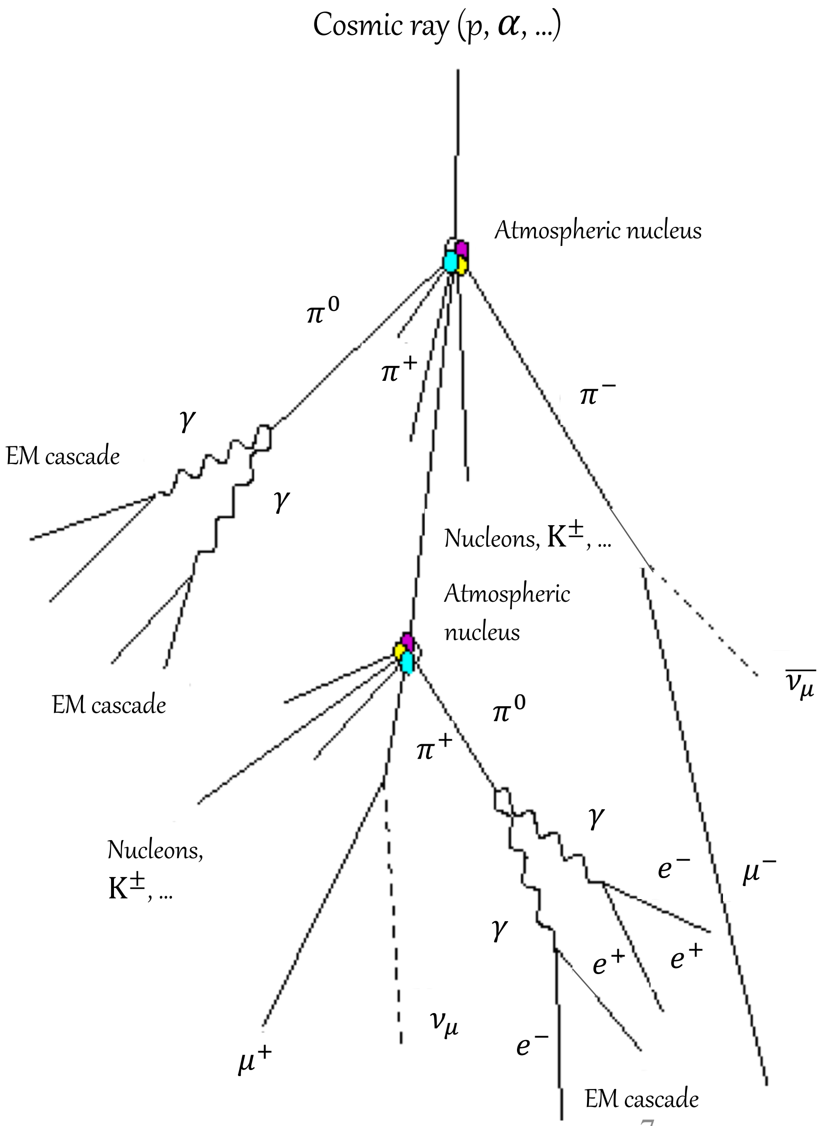
30
20
10
0
−10
−20
100
150
200
250
300
350
400
−150
−100
−50
0
50
100
150
200

Gamma vs Hadrons:

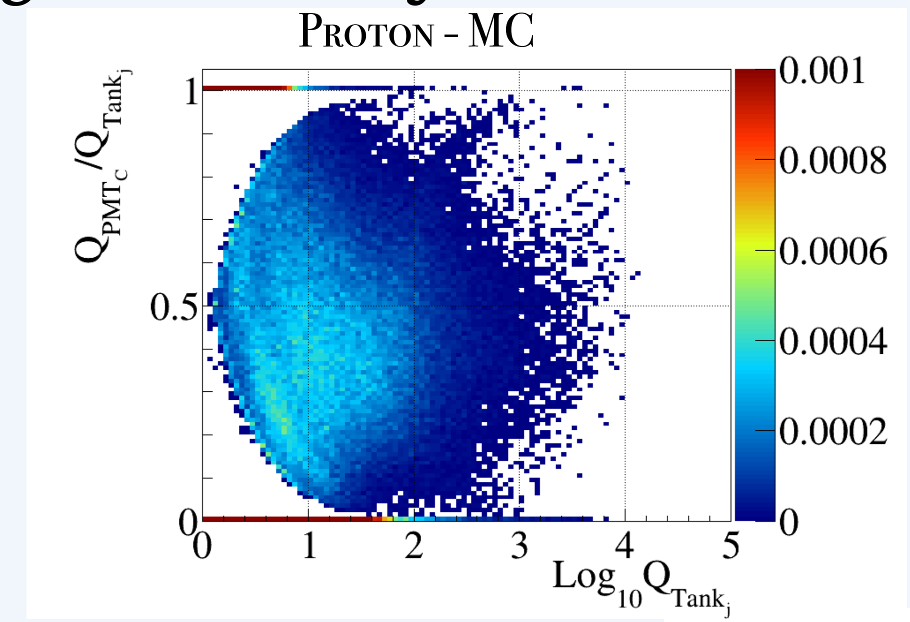


- Charged cosmic rays also produce EAS
- Enormous background compared to genuine γ-ray-induced cascades

Bin No.	Percentage of PMTs hit out of 1200 (%)
0	$0.0 \leq Tank_{hit} < 8.4$
1	$8.4 \leq Tank_{hit} < 16.7$
2	$16.7 \leq Tank_{hit} < 25.0$
3	$25.0 \leq Tank_{hit} < 33.4$
4	$33.4 \leq Tank_{hit} < 41.7$
5	$41.7 \leq Tank_{hit} < 50.0$
6	$50.0 \leq Tank_{hit} < 58.4$
7	$58.4 \leq Tank_{hit} < 66.7$
8	$66.7 \leq Tank_{hit} < 75.0$
9	$75.0 \leq Tank_{hit} < 83.4$
10	$83.4 \leq Tank_{hit} < 91.7$
11	$91.7 \leq Tank_{hit} \leq 100$



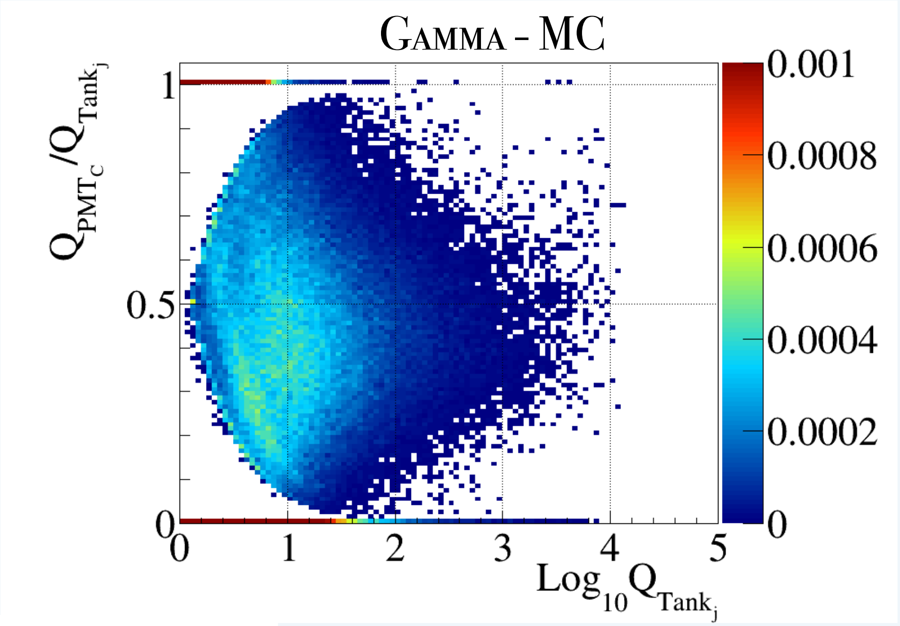
Light distribution for MC and data:



P_p

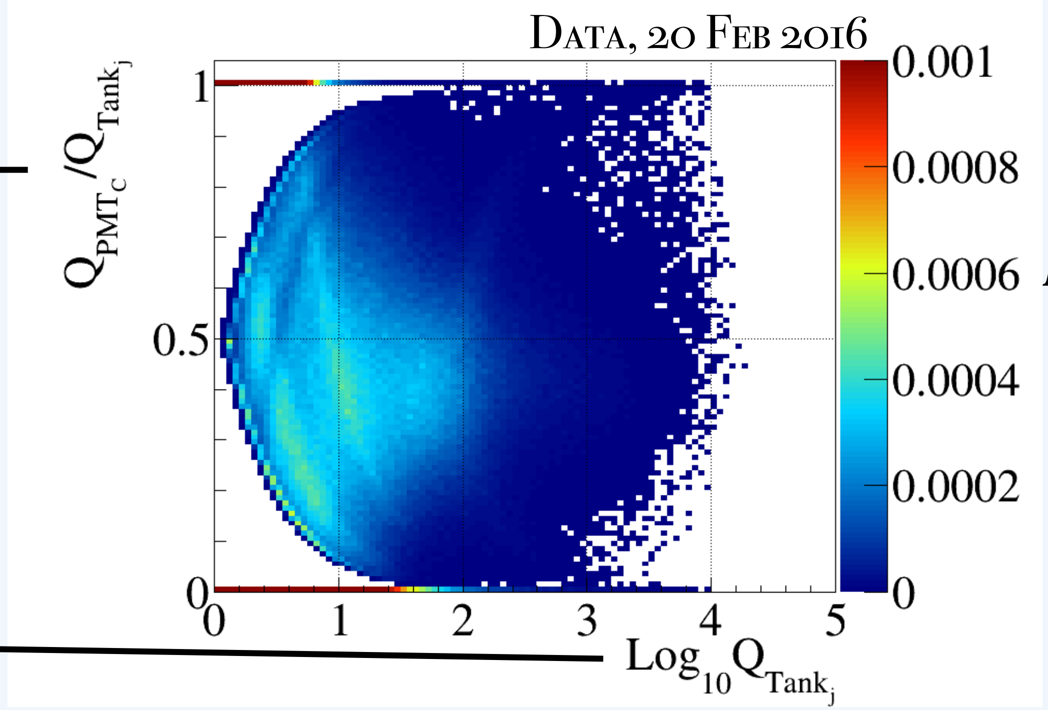
Probability density function

Bin5
PMT C



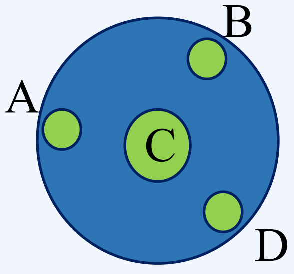
P_γ

Charge 'seen' by PMT i (Here C) as a fraction of total charge 'seen' by tank j



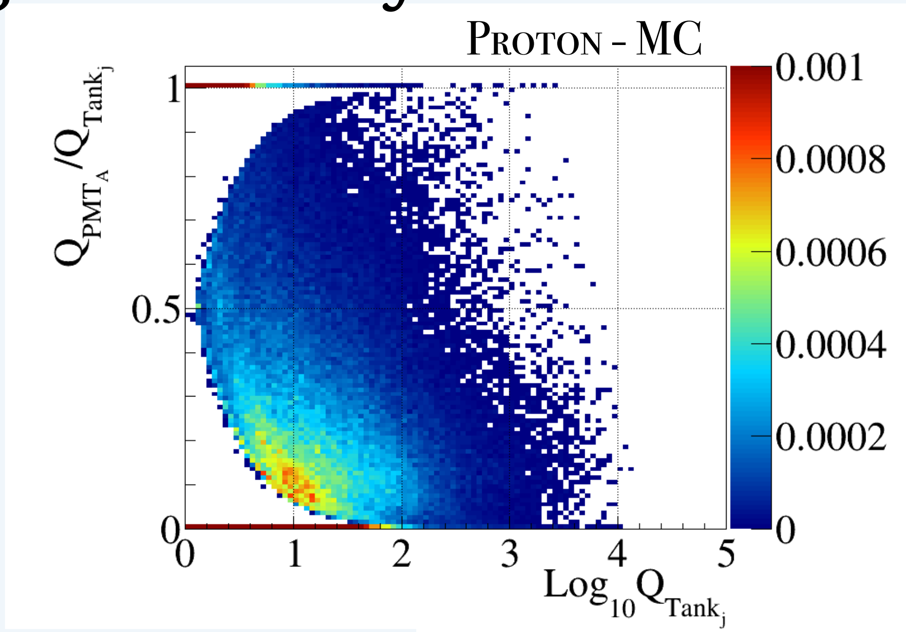
P_d

Total charge 'seen' by tank j
$\sum_i Q_{\mathrm{PMT}_i}$



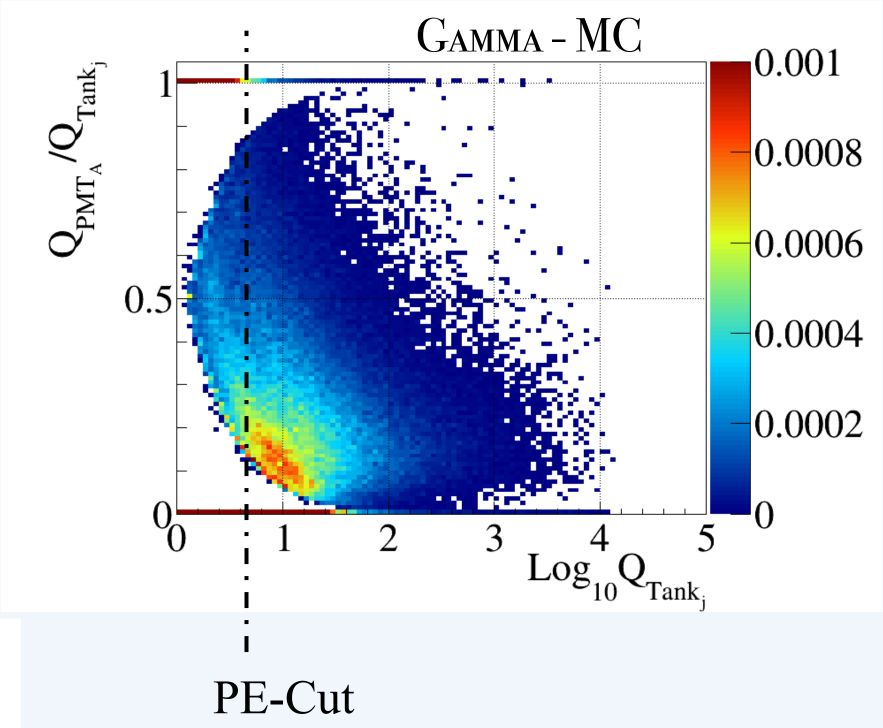
Tank j (1 – 300) with PMT i (A, B, C, D)

Light distribution for MC and data:

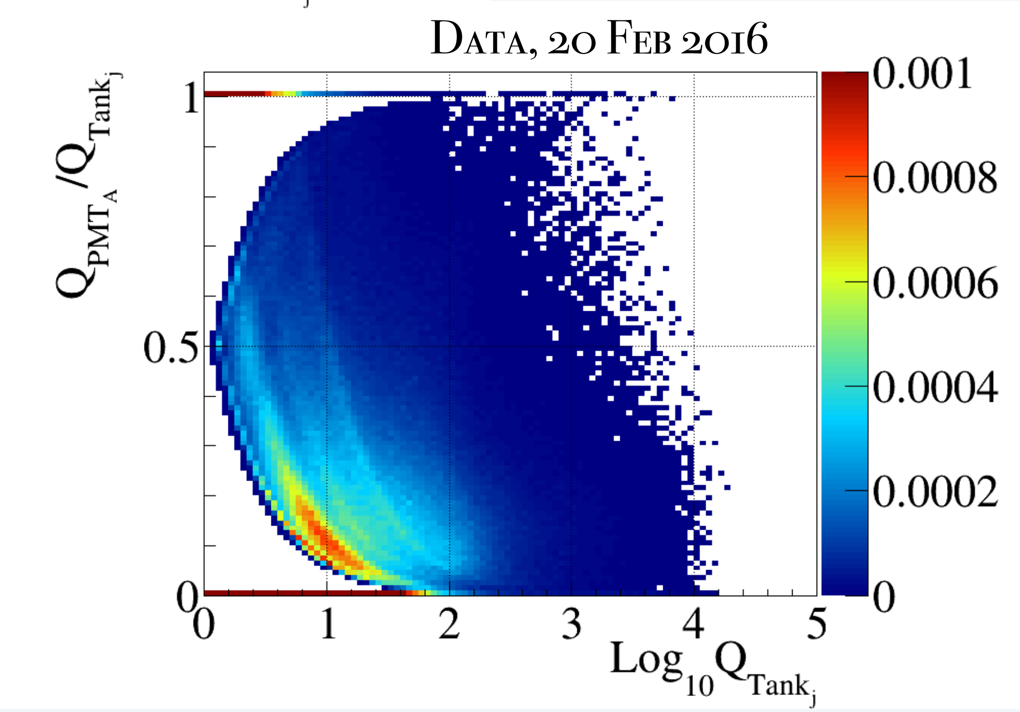


P_p

Bin5
PMT A



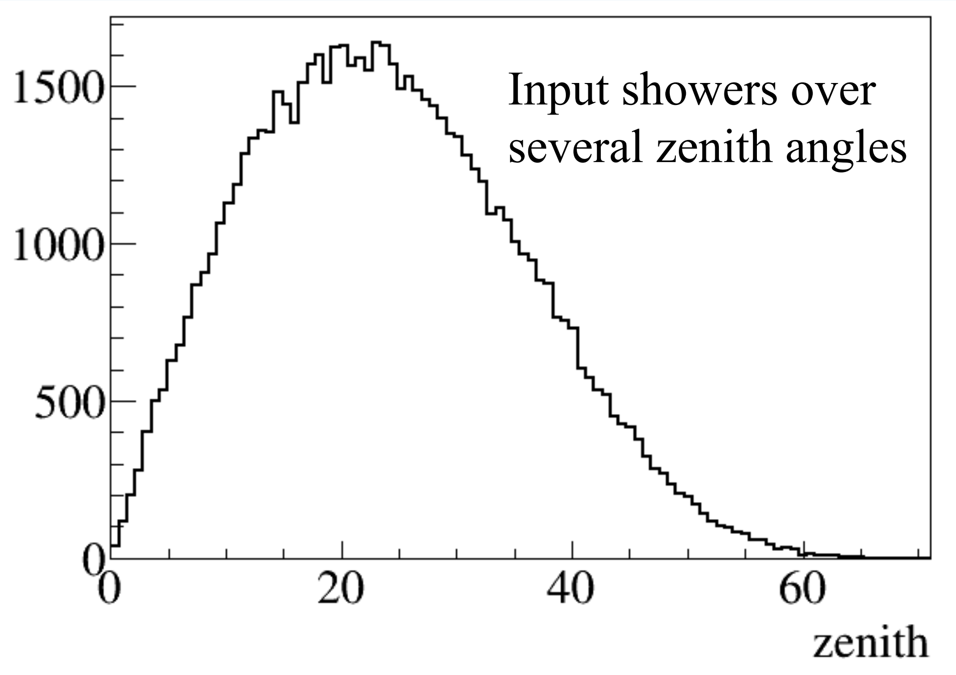
P_γ

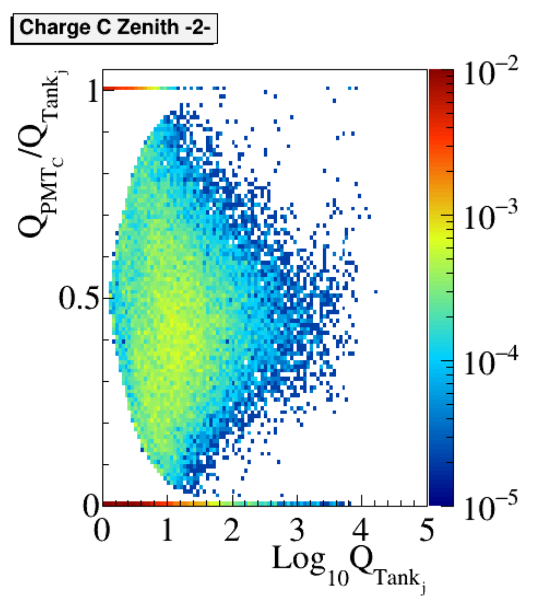


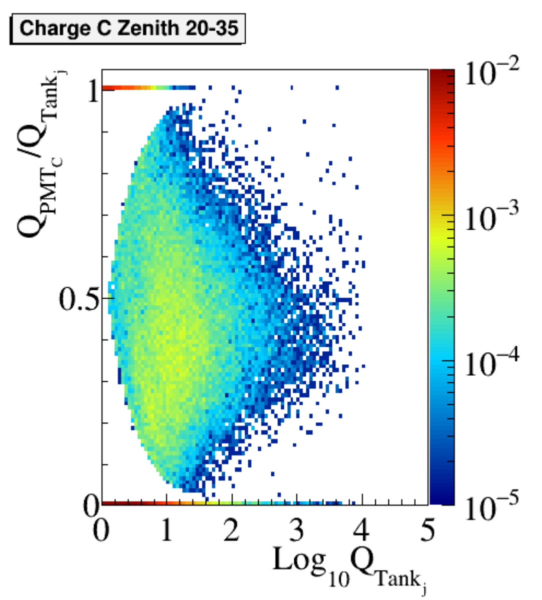
P_d

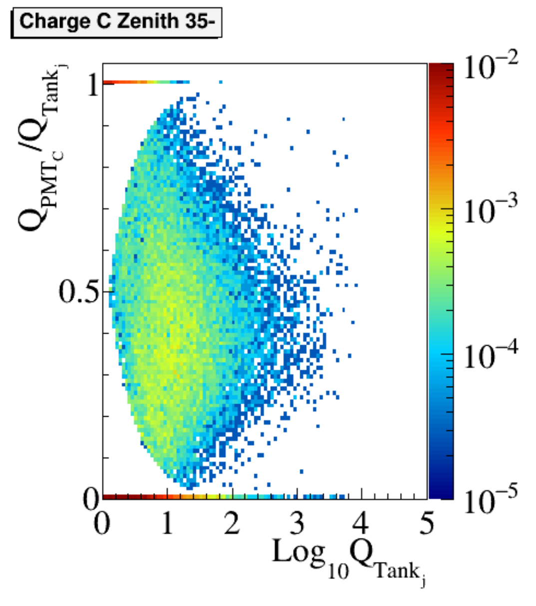
Zenith Angle Dependence:

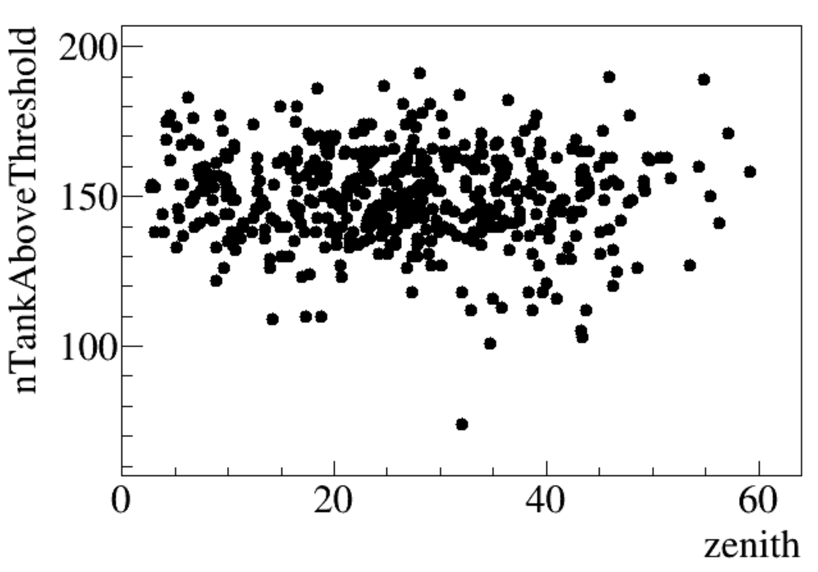
Bins have no dramatic dependence on zenith











Likelihood Ratio:

For one event, (log-)likelihood for a shower to be gamma induced:

$$L_\gamma = \sum_j \sum_i \ln P_\gamma\left(\frac{Q_{\mathrm{PMT}_i}}{Q_{\mathrm{Tank}_j}}, Q_{\mathrm{Tank}_j}\right)$$

For one event, (log-)likelihood for a shower to be proton induced:

$$L_\mathrm{p} = \sum_j \sum_i \ln P_\mathrm{p}\left(\frac{Q_{\mathrm{PMT}_i}}{Q_{\mathrm{Tank}_j}}, Q_{\mathrm{Tank}_j}\right)$$

Likelihood ratio:

$$R_{\mathrm{p}/\gamma} = L_\mathrm{p} - L_\gamma$$

Calculate L_p & L_γ for $Q_{\mathrm{Tank}_j} \geq$ PE-Cut (Configurable)

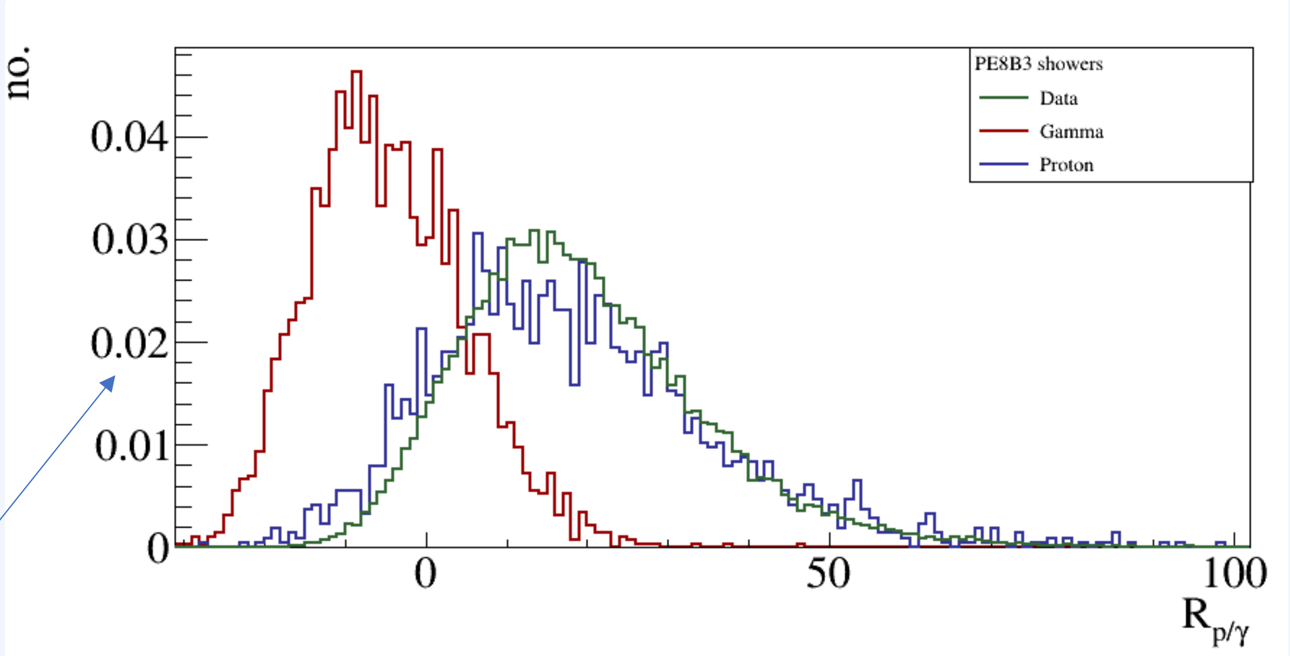
Likelihood Ratio (All Events):

Apply PE-Cuts: 0.1, 1 – 20, 25, 30, 35, 40, 50, 100

Find likelihood ratio using gamma showers and proton showers

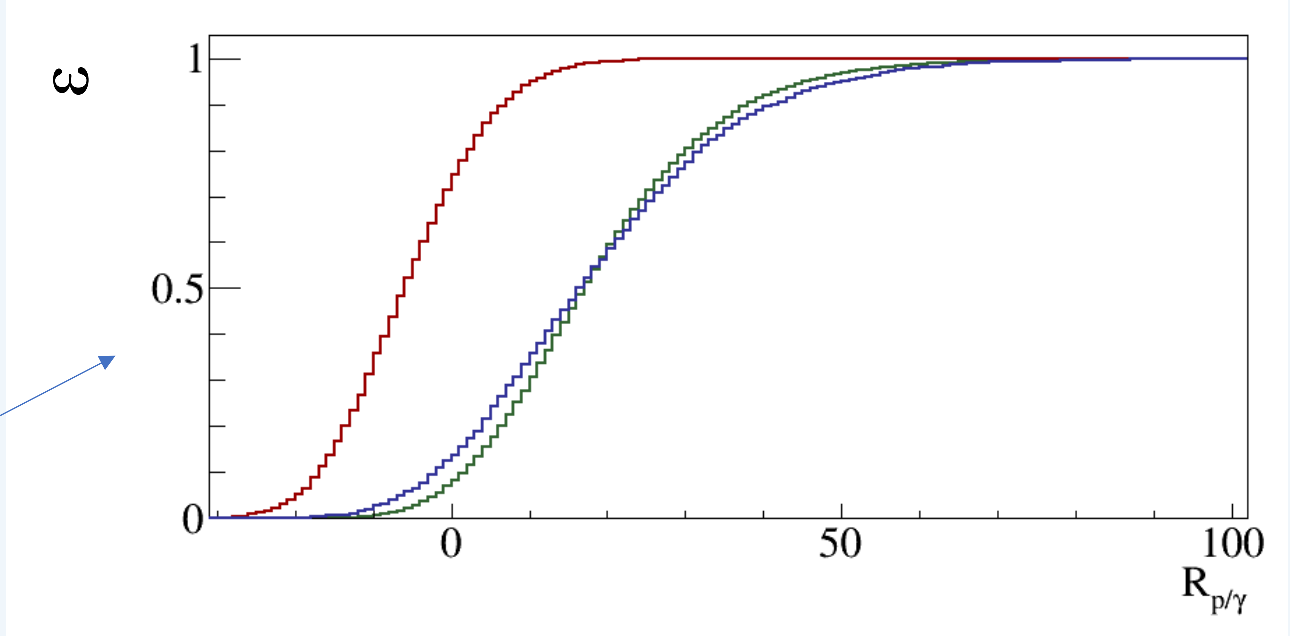
Find likelihood ratio using gamma showers and data

ε: Normalised Efficiency



Likelihood plot

PE-Cut = 8
Bin = 3



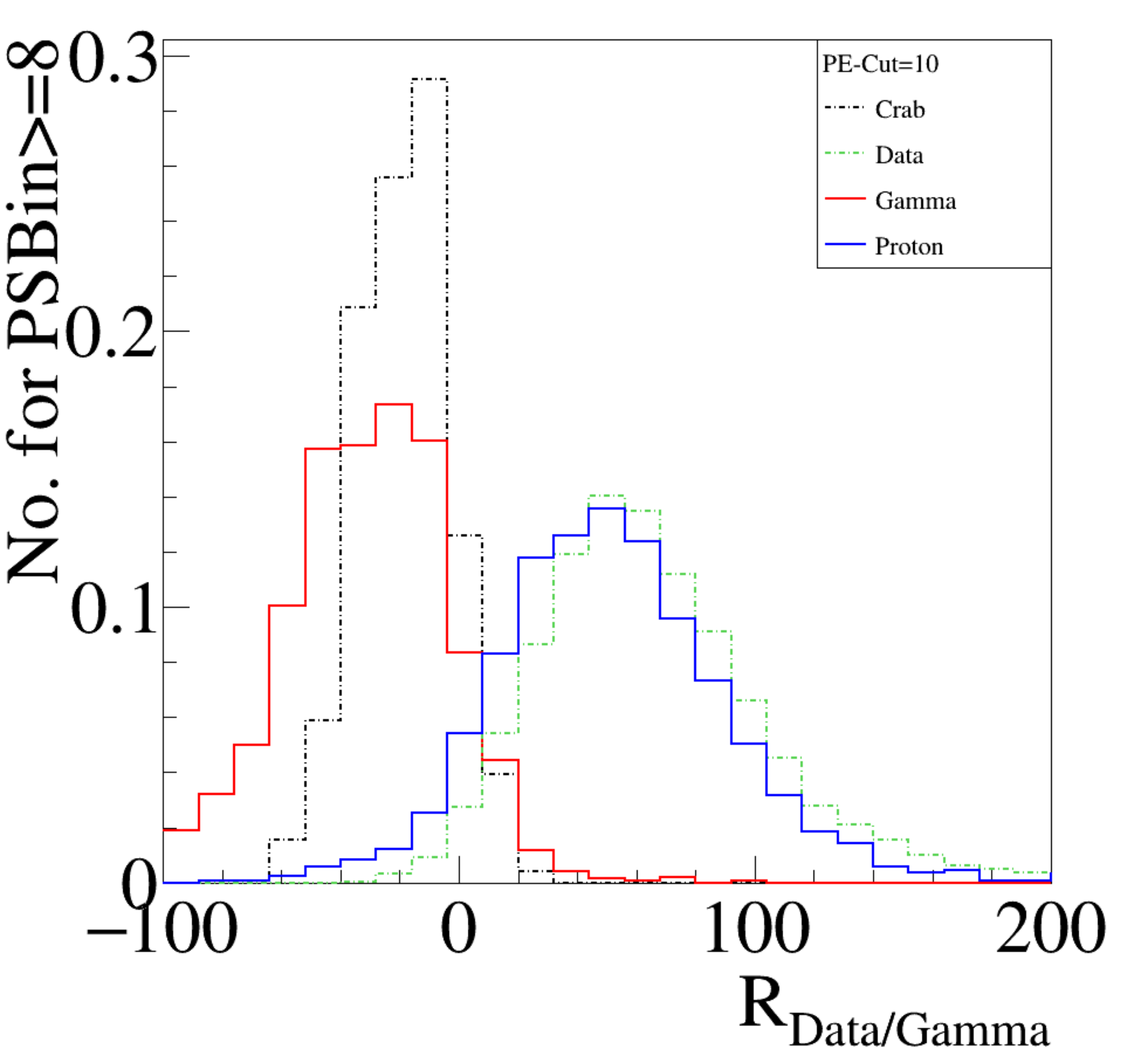
Efficiency plot

Comparison to Crab:

Gamma-hadron separation possible (shown) for bins 8 and above

Comparison is made between gamma simulations, proton simulations, HAWC data and events from the Crab as seen by HAWC plus hard G/H cuts

$$R_{p/\gamma} = L_p - L_\gamma$$



Signal–to–Noise Ratio

Apply cuts at different $R_{p/\gamma}$ values on efficiency plot

Signal–to–noise ratio is given as

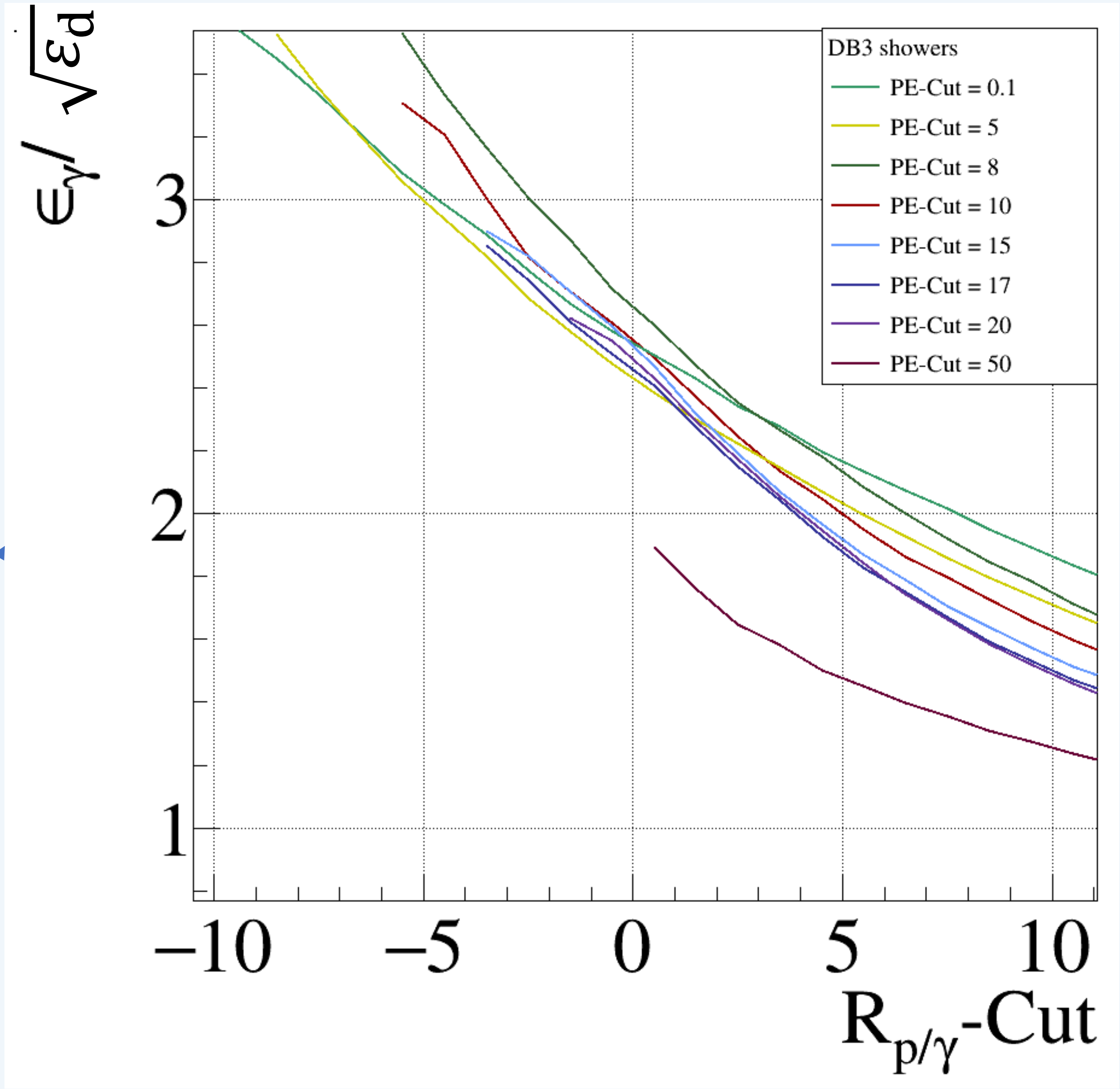
$$\frac{S}{\sqrt{N}} \sim \frac{\varepsilon_\gamma}{\sqrt{\varepsilon_P}}$$

Or $\sqrt{\varepsilon_d}$

Gamma showers compared to data (Bin 3)

Condition: $\varepsilon_\gamma > 0.5$

Optimal PE-Cut (at $R_{p/\gamma}$-Cut of 0) = 8



Summary & Outlook

- G/H method works independent of reconstruction, array geometry and no major zenith angle dependence

- Can be optimised based on shower sizes (bins) and optimised PE-Cut applied (trigger threshold implemented)

- Better G/H separation implies better significance of results which, in turn, implies better constraints about cosmic accelerators

Thank-you!