Observations of the Crab Nebula and Pulsar

with

the Solar Tower Atmospheric Cherenkov Effect Experiment

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on behalf of the STACEE Collaboration

STACEE Crab Nebula/Pulsar Observations

- Previous STACEE observations (1998, 1999)
  - — 6.8σ detection in 42 hours on-source (Oser et al., 2001)
  - — 32-heliostat detector

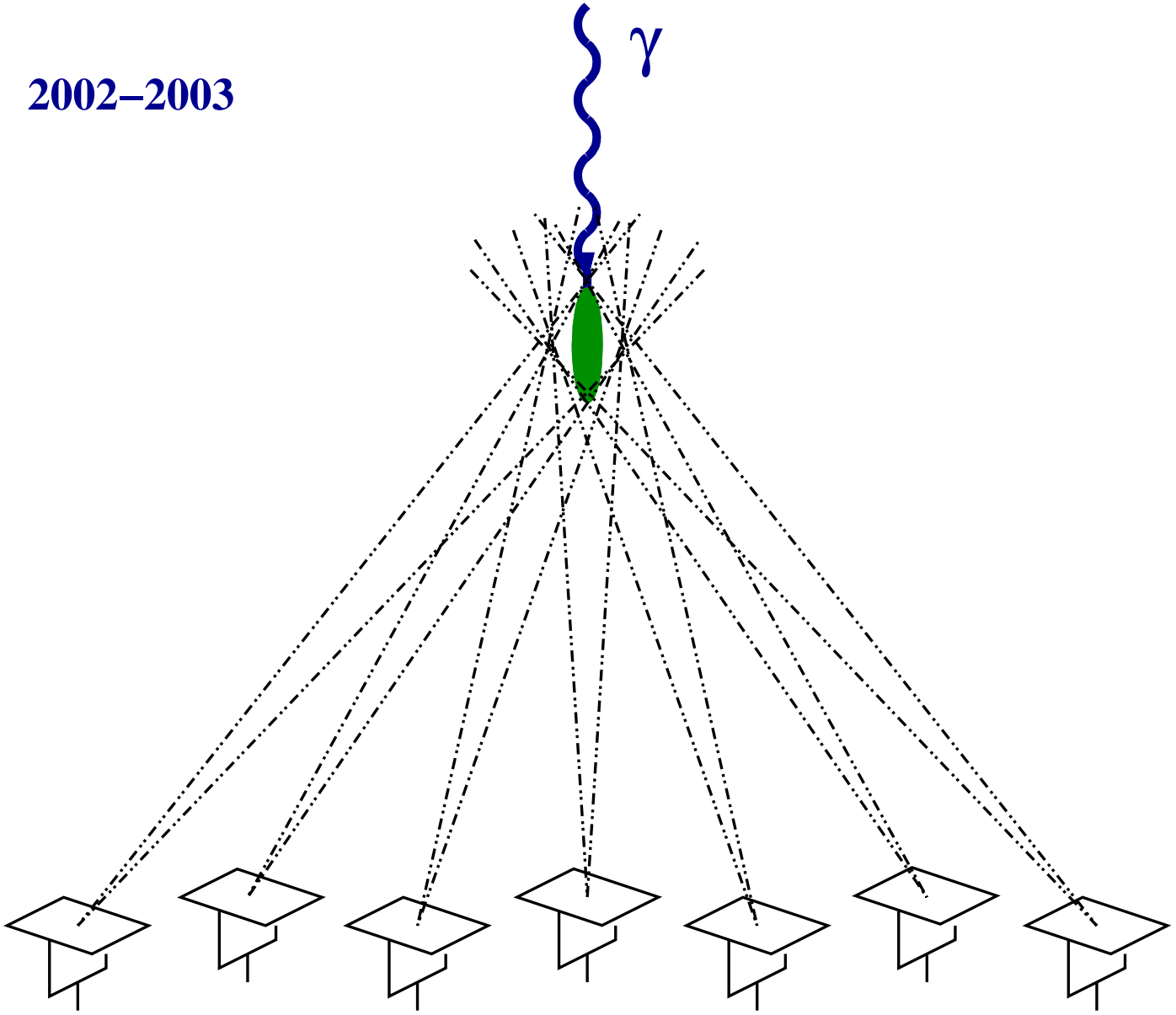
- Motivations for present observations
  - (a) characterize new detector/analysis, now 64 heliostats
  - (b) search for Crab Pulsar
  - (c) differential Crab Nebula spectrum down to 100 GeV

- Dataset (21.2 hrs total)
  - — 2002-2003: 7.2 hours on-source
  - — 2003-2004: 14.0 hours on-source
  - — equal amounts of off-source data

- ON/OFF brightness differences
  - — accounted for offline using padding procedure

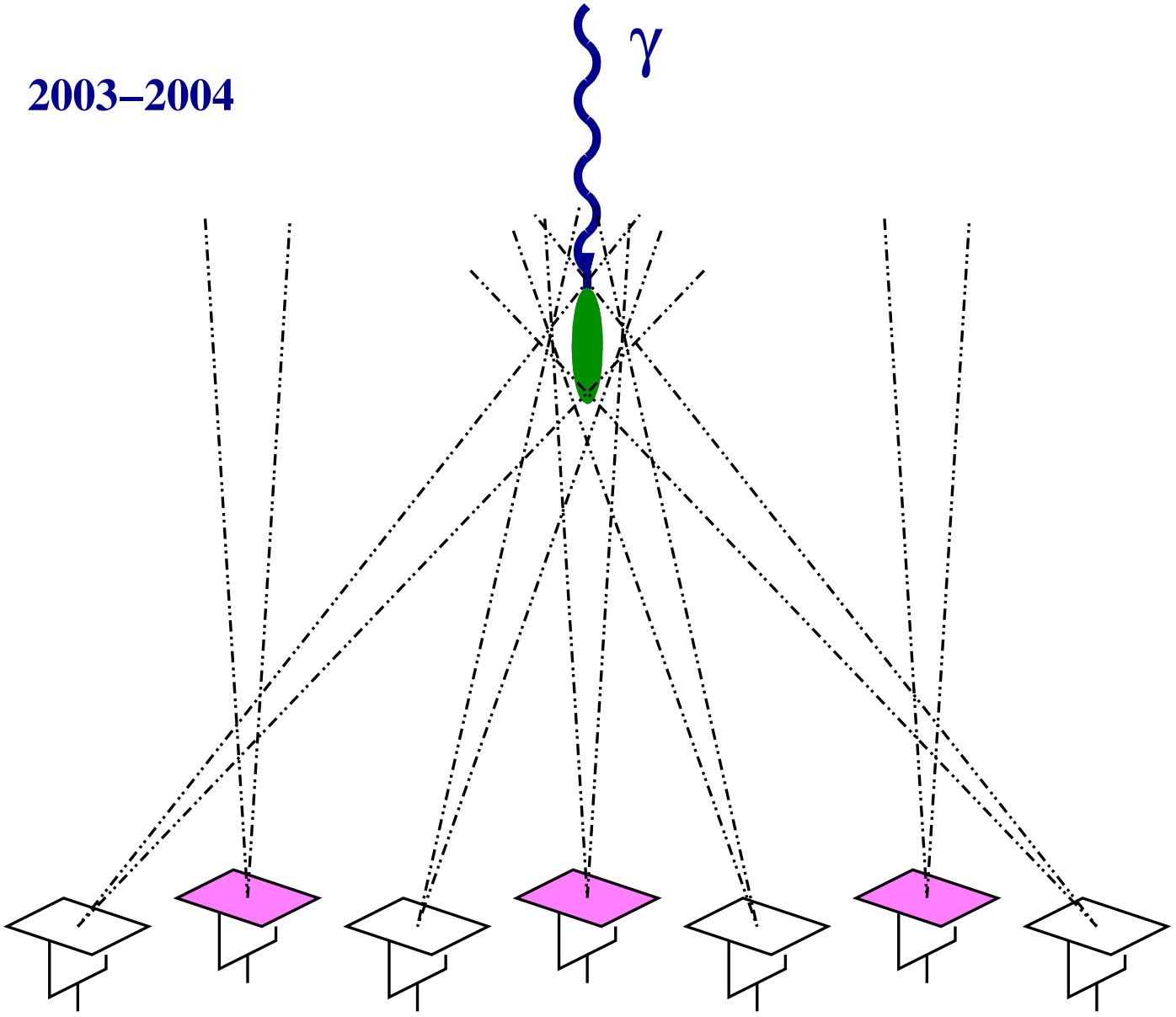
STACEE Observing modes – Monocanting

2002–2003



- All heliostats point toward expected shower location
  — maximizes light collected, good for dim showers

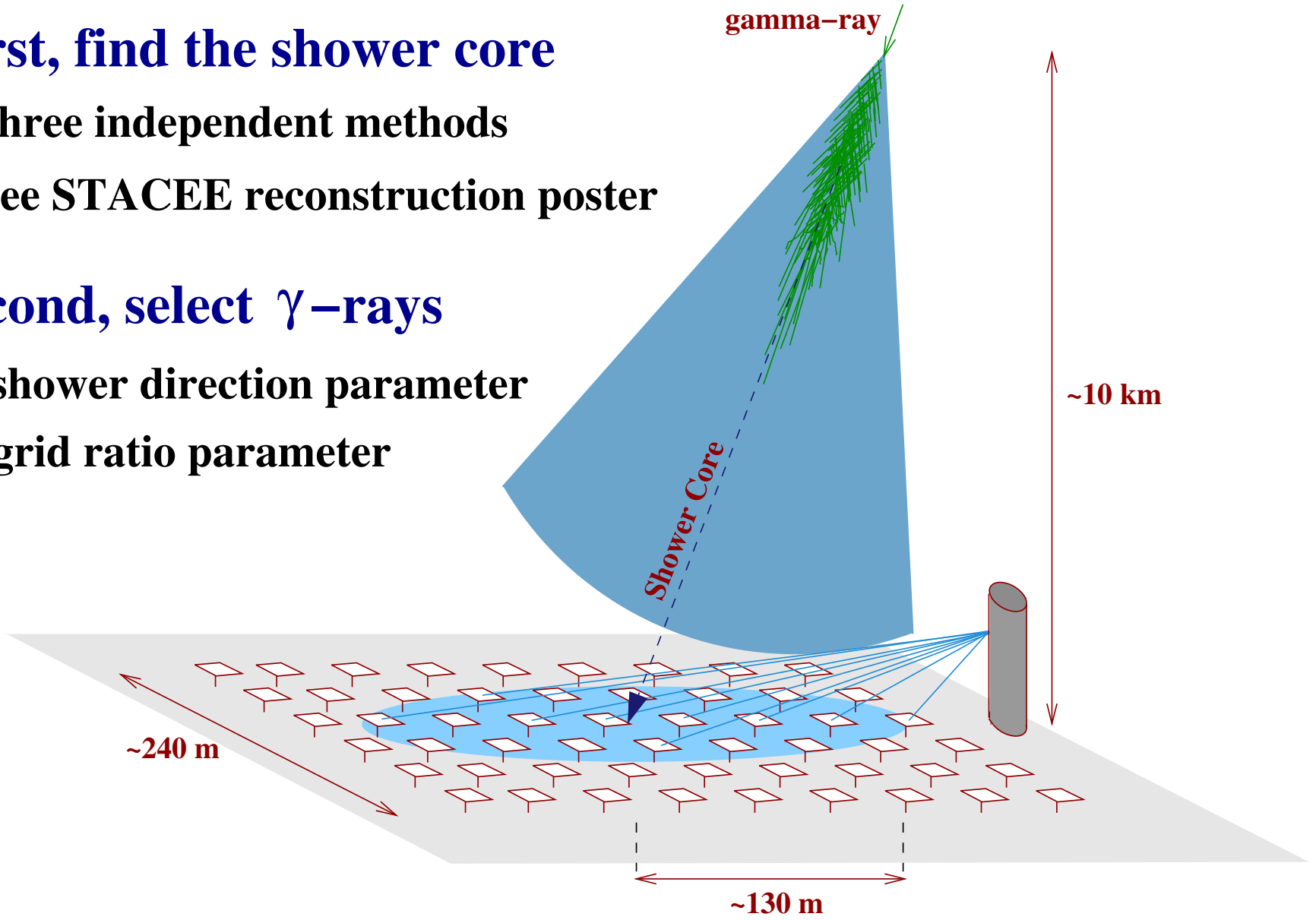
STACEE Observing modes – Paracanting



- Some point at expected shower location, some parallel
  — provides core information, superior reconstruction

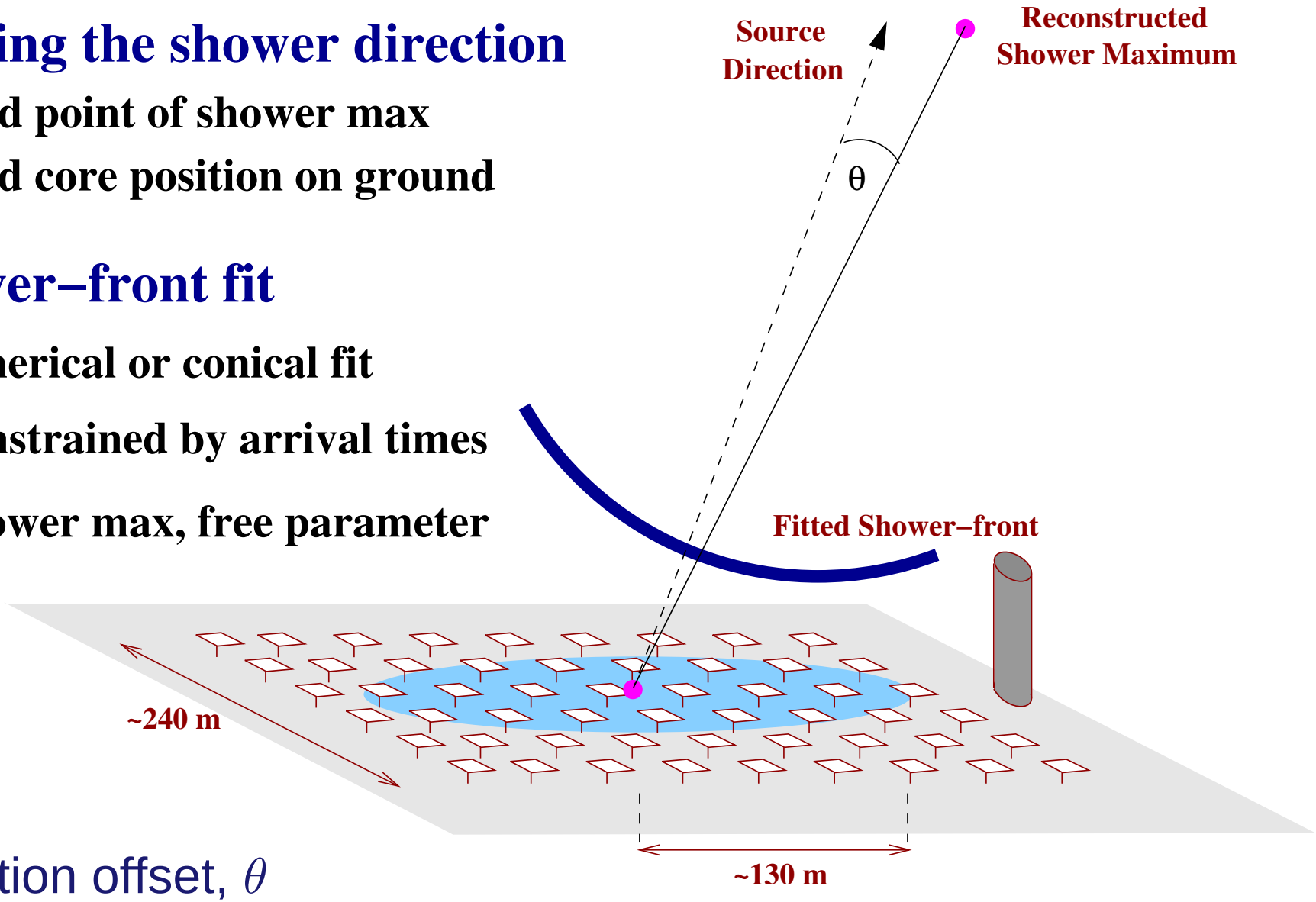
Shower Reconstruction and Gamma/Hadron Separation

- **First, find the shower core**
  - three independent methods
  - see STACEE reconstruction poster
- **Second, select γ–rays**
  - shower direction parameter
  - grid ratio parameter



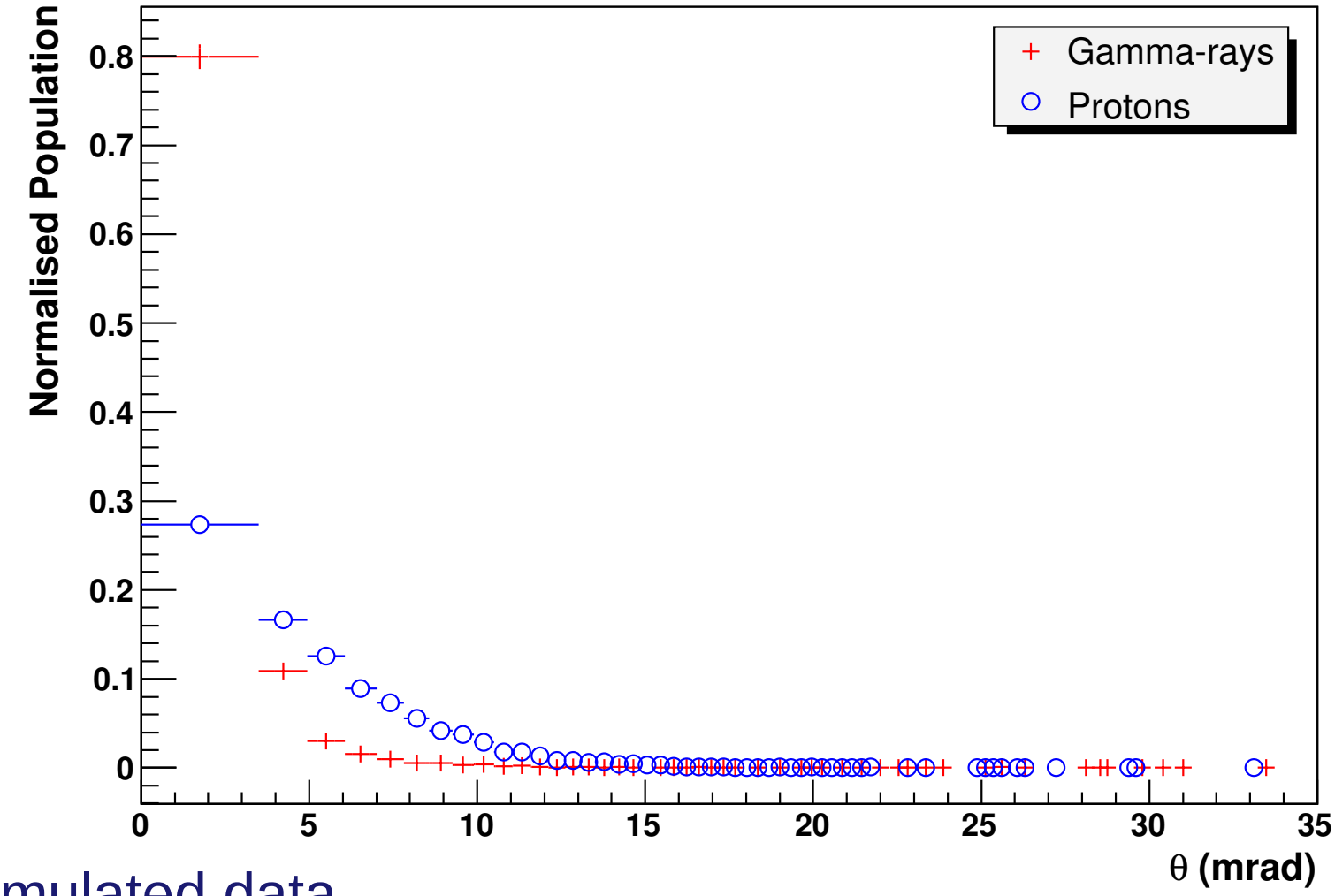
Event Reconstruction – Shower Direction

- **Finding the shower direction**
  - need point of shower max
  - need core position on ground
- **Shower–front fit**
  - spherical or conical fit
  - constrained by arrival times
  - shower max, free parameter



- Direction offset, θ
  — gamma rays from source, have small values of θ

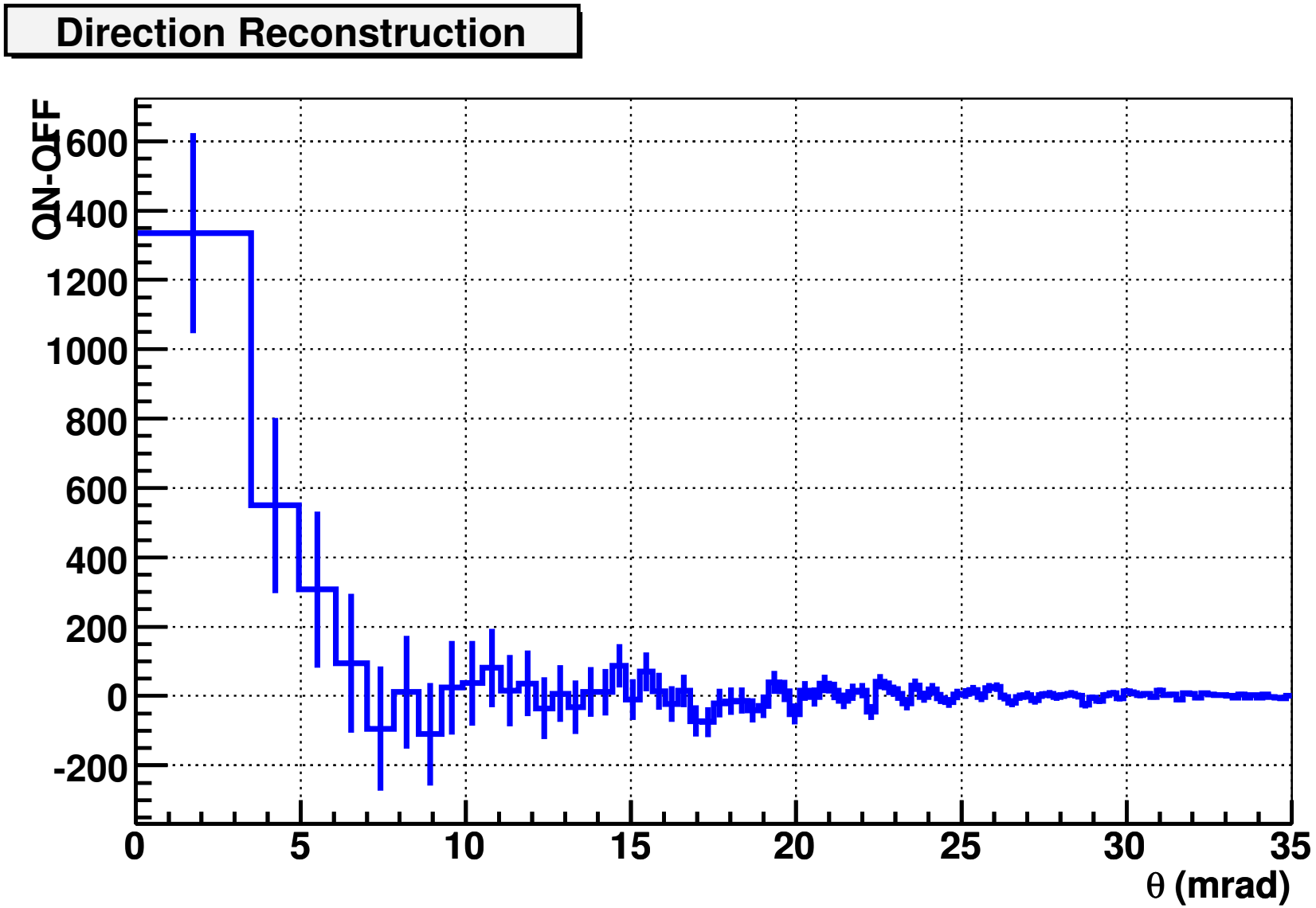
Gamma/Hadron Separation – Shower Direction



- Simulated data
  - — θ is a good gamma/hadron separation parameter for STACEE

Bins have equal area on the sky

Gamma/Hadron Separation – Shower Direction

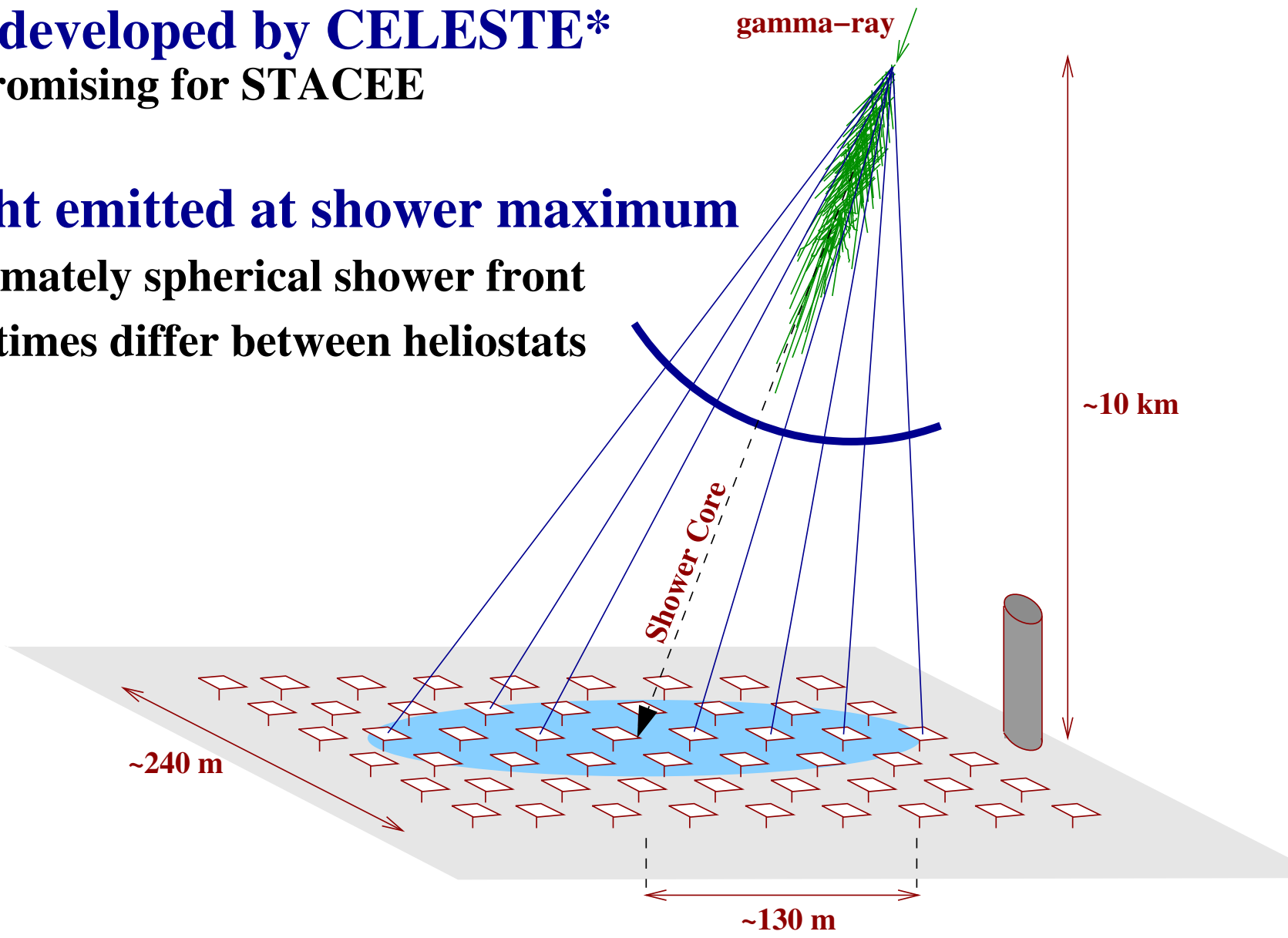


- Crab Nebula data (ON-OFF distribution)
  - — Clear excess at low θ

Bins have equal area on the sky

Event Reconstruction – Grid Alignment

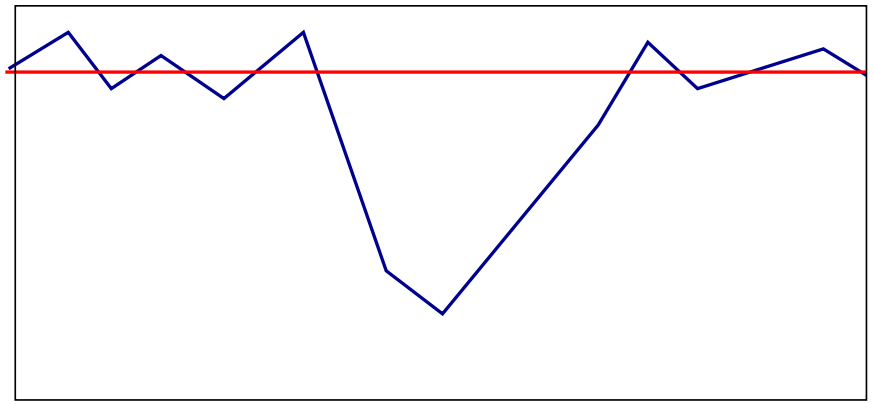
- **Method developed by CELESTE***
  - **looks promising for STACEE**
- **Most light emitted at shower maximum**
  - **approximately spherical shower front**
  - **arrival times differ between heliostats**



* Bruel, P., et al., 2004, Proceedings of Frontier Science 2004, Physics & Astrophysics in Space

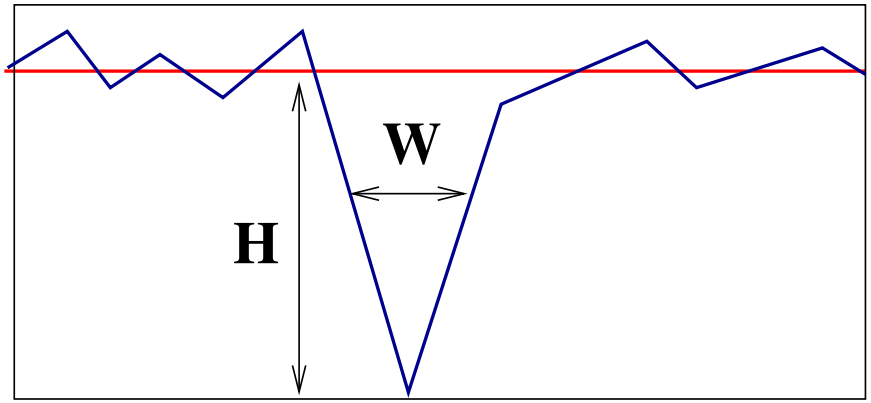
Event Reconstruction – Grid Alignment

- **Simple sum of FADC traces**
  - **no alignment for shower geometry**
  - **resultant is short and wide**



Event Reconstruction – Grid Alignment

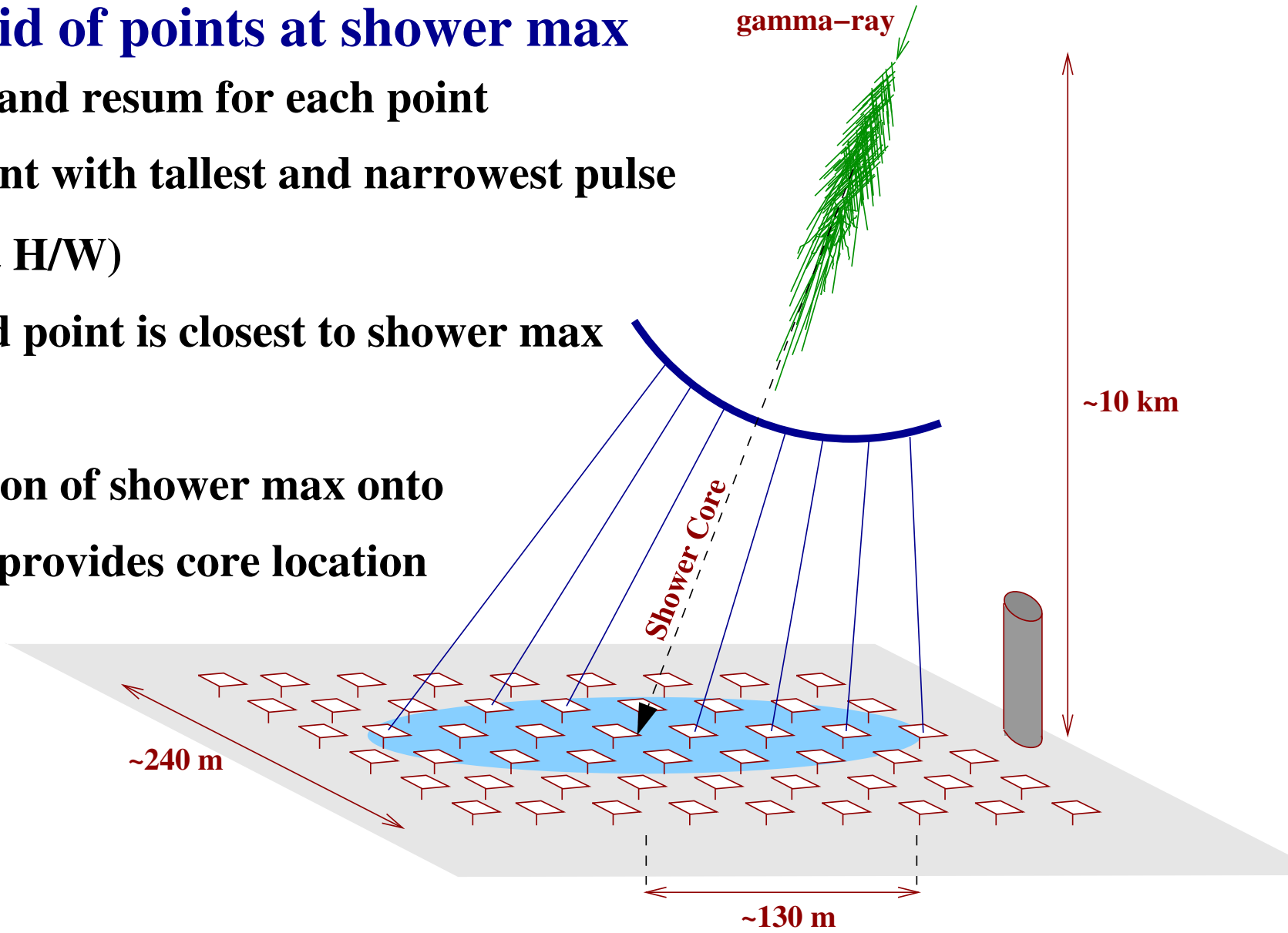
- **Account for shower geometry**
  - **realign and resum traces**
  - **resultant is tall and narrow**



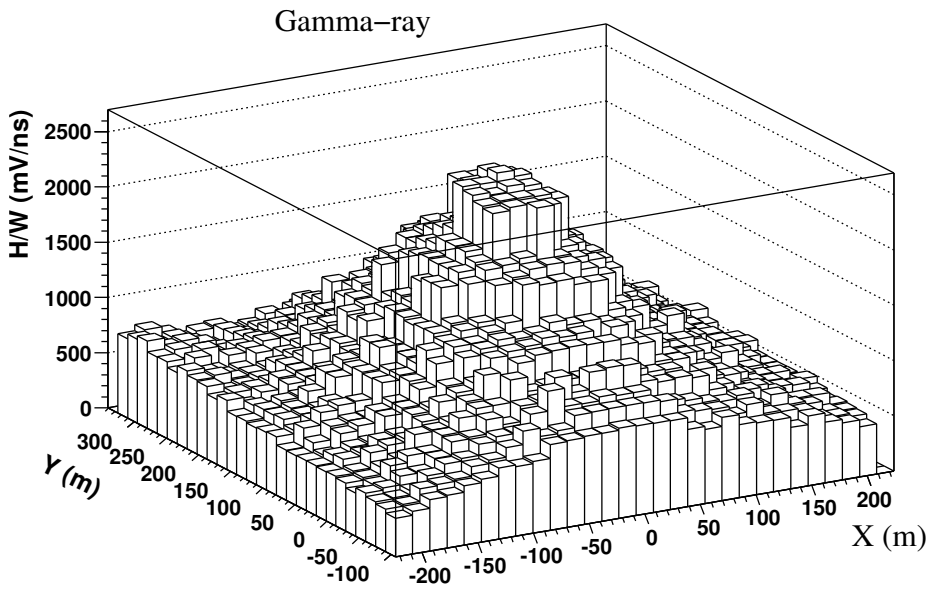
— of course, we don't know where the shower max is!

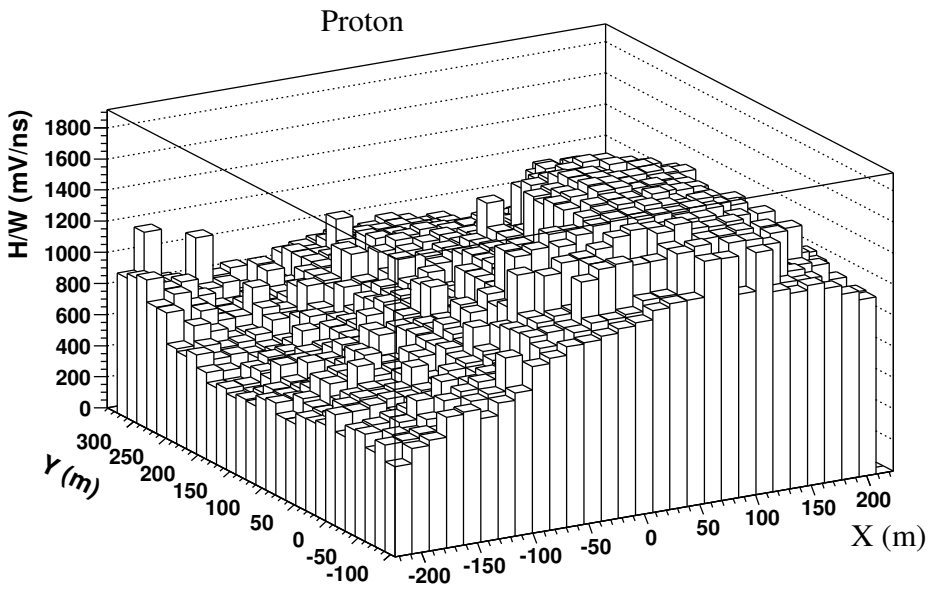
Event Reconstruction – Grid Alignment

- **Form grid of points at shower max**
  - **realign and resum for each point**
  - **find point with tallest and narrowest pulse (largest H/W)**
  - **this grid point is closest to shower max**
  - **projection of shower max onto ground provides core location**



Gamma/Hadron Separation – Grid Alignment

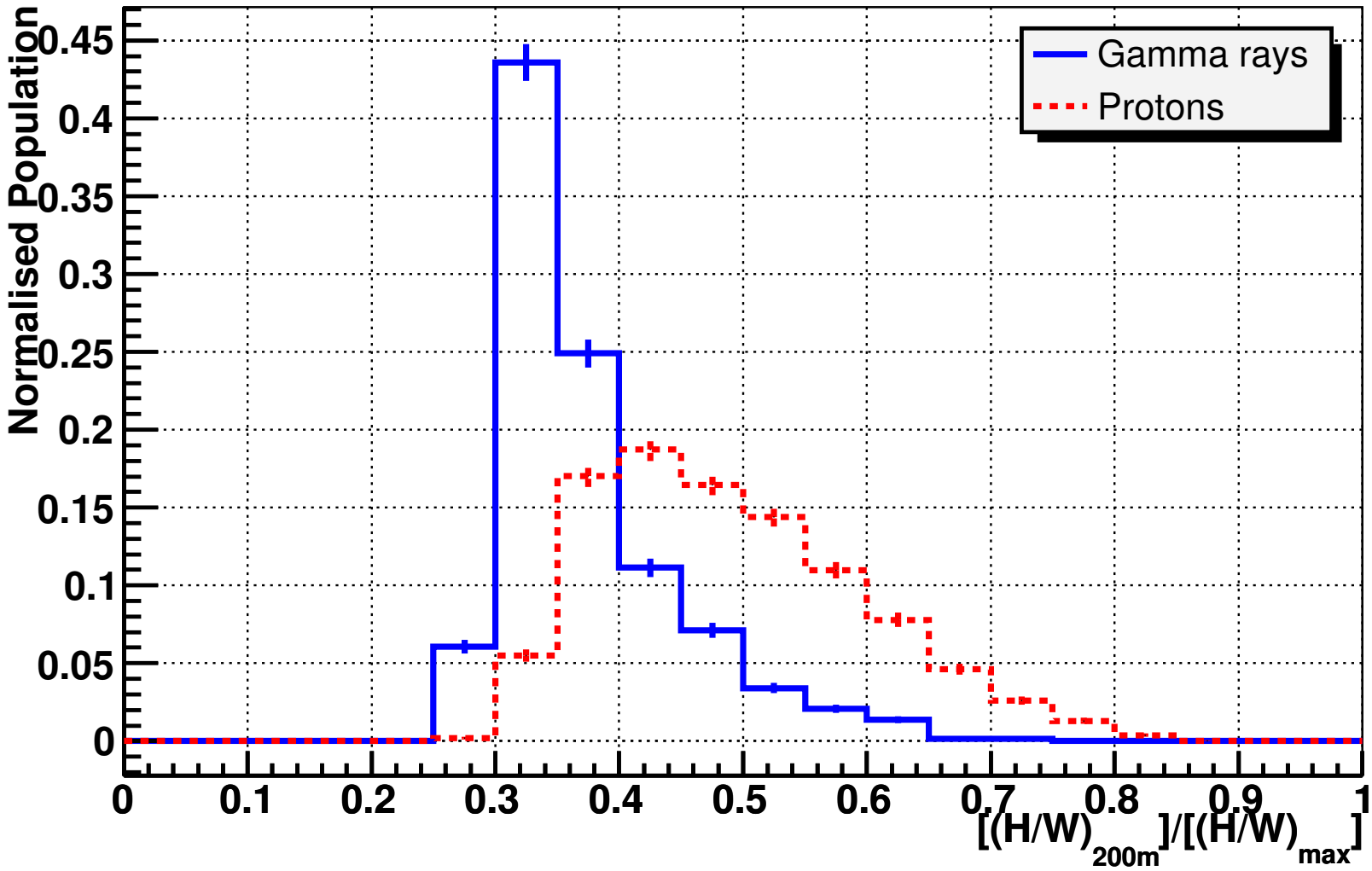




- Distribution of H/W for each grid point
  - — peak provides core location

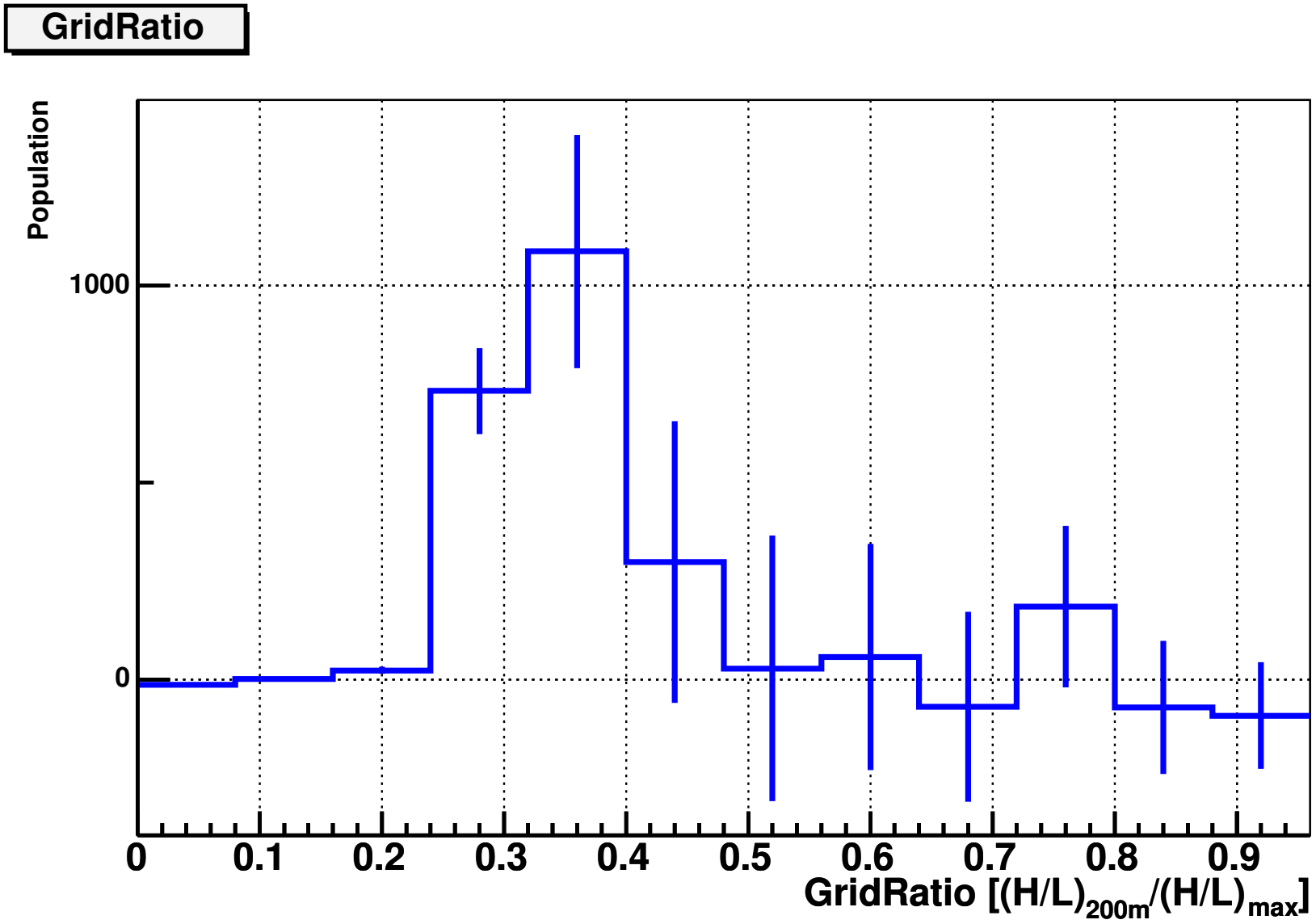
- Gamma/hadron separation
  - — distribution very different for gamma rays and protons
  - — gamma-ray pulses quickly fall out alignment away from shower max
  - — parameterize shape of H/W distribution as *grid ratio*, $\{\frac{(H/W)_{200m}}{(H/W)_{max}}\}$

Gamma/Hadron Separation – Grid Ratio



- Simulated data
  - — *Grid ratio* is a good gamma/hadron separation parameter for STACEE

Gamma/Hadron Separation – Grid Ratio



- Crab Nebula data (ON-OFF distribution)
  — Clear excess at small values of the *grid ratio*

Crab Nebula Results

Cut	No. ON	No. OFF	ON–OFF	σ	γ Rate (min^{-1})
		2002-2003			
Raw	165773	164341	1432	2.6	3.3 ± 1.30
Re-trigger	137923	136237	1686	3.4	3.9 ± 1.20
Re-trigger + Direction	41440	40652	788	2.8	1.8 ± 0.67
Re-trigger + Grid Ratio	4452	3989	463	5.1	1.1 ± 0.21
		2003-2004			
Raw	290770	288641	2129	2.4	2.5 ± 0.89
Re-trigger	231269	228932	2337	3.1	2.7 ± 0.79
Re-trigger + Direction	75031	72818	2213	5.5	2.6 ± 0.45
Re-trigger + Grid Ratio	14331	13405	926	5.5	1.1 ± 0.19

- All cuts applied directly from simulations ($E_{th} \sim 170$ GeV)
  — no optimization at this stage

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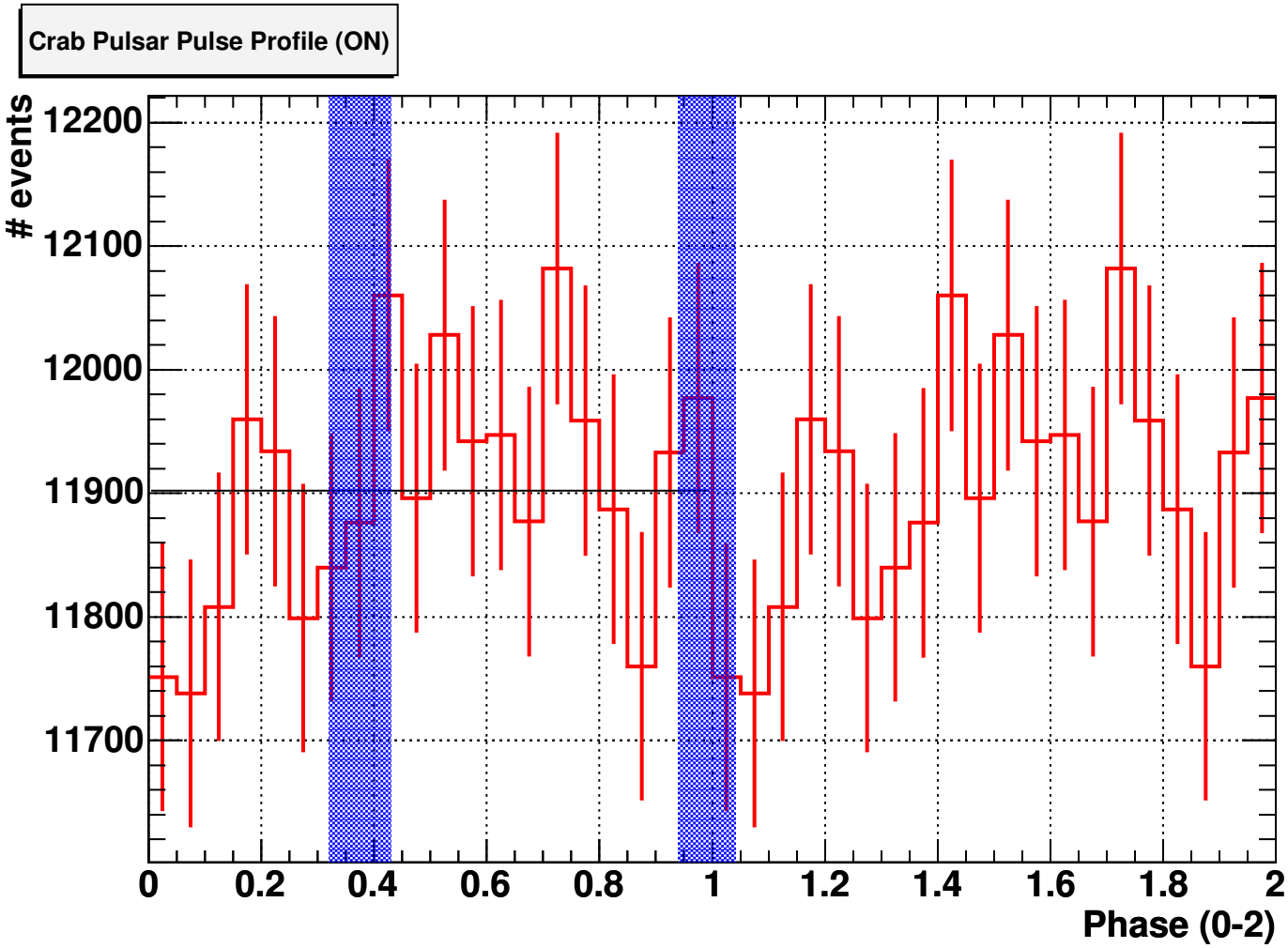
- All cuts applied directly from simulations ($E_{th} \sim 170$ GeV)
  — no optimization at this stage
- Improved direction reconstruction for paracanted data
  — as expected according to simulations
- Grid ratio very powerful
  — expect further improvement with optimization

Crab Pulsar Results



- Independent analysis (15 hrs of data)
  — PhD thesis of P. Fortin, McGill University

- Pulsed upper limit (at 185 $\pm$ 35 GeV)
  — 16.4% of unpulsed STACEE signal

Conclusions

- STACEE Crab Nebula detection
  - clear detection in both years with different pointing strategies
  - non-optimized cuts

- Crab Pulsar upper limits
  - 16.4% of unpulsed signal at 185 $\pm$ 35 GeV
  - expect improvement with low-energy event selection (down to $\sim$50 GeV)

- Looking ahead...
  - spectral analysis underway (see Mkn 421 talk by Jennifer Carson)
  - event reconstruction methods look promising
  - proceeding systematically (understand cuts, optimize, apply)
  - perform analysis on other sources