STACEE

The Solar Tower Atmospheric Cherenkov Effect Experiment

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on behalf of the STACEE Collaboration

Overview

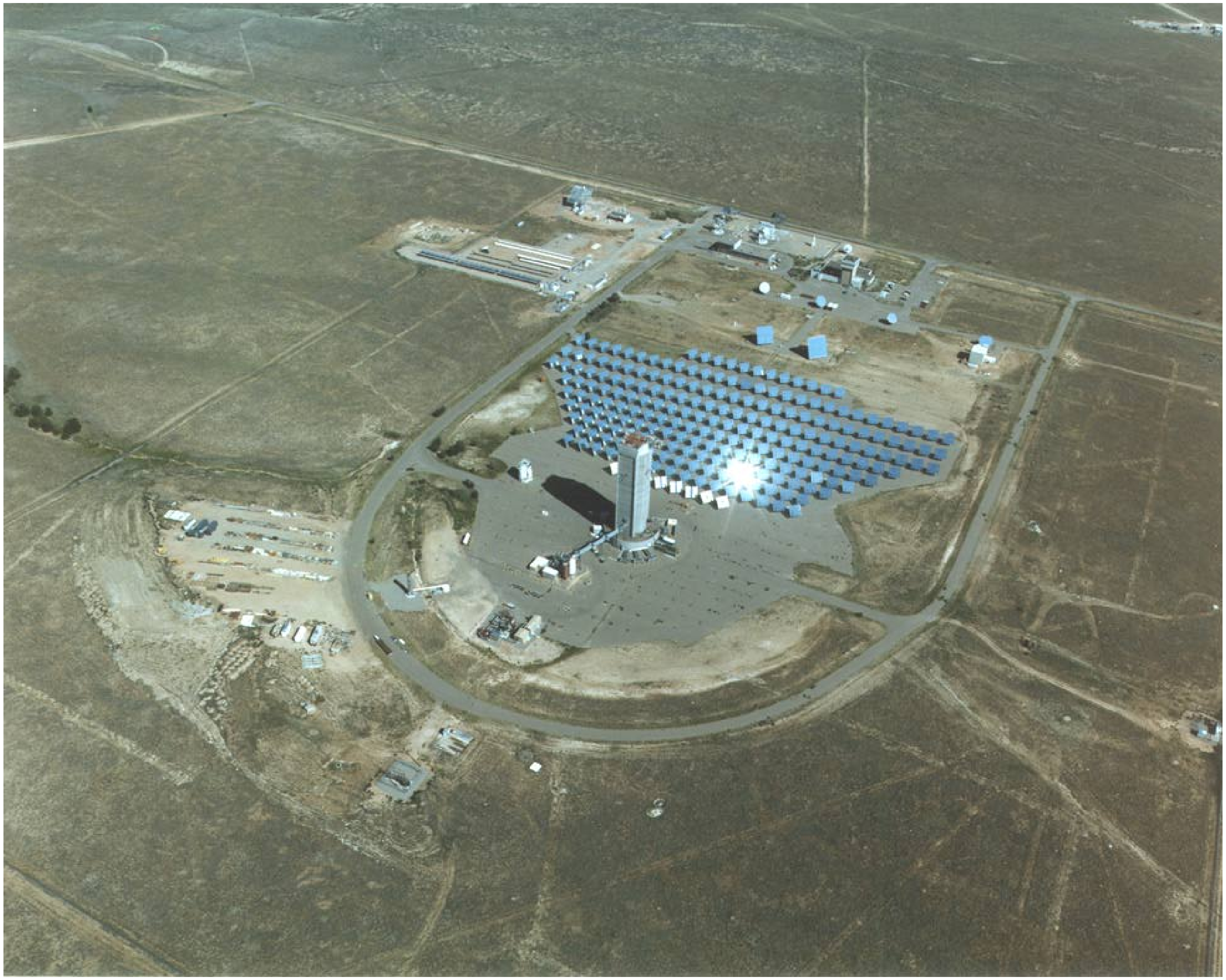
- Who, what, and where
  — the STACEE Collaboration
- How and why
  — the solar tower γ-ray observatory concept
  — STACEE observations
- Detector and data analysis
  — a tour of STACEE
  — the nitty gritty of detecting γ-rays
- Results and Future
  — where now with STACEE

Who?

The STACEE Collaboration

Case Western Reserve University
McGill University
University of California, Los Angeles
Columbia University
University of Alberta
University of California, Santa Cruz

The STACEE Experiment

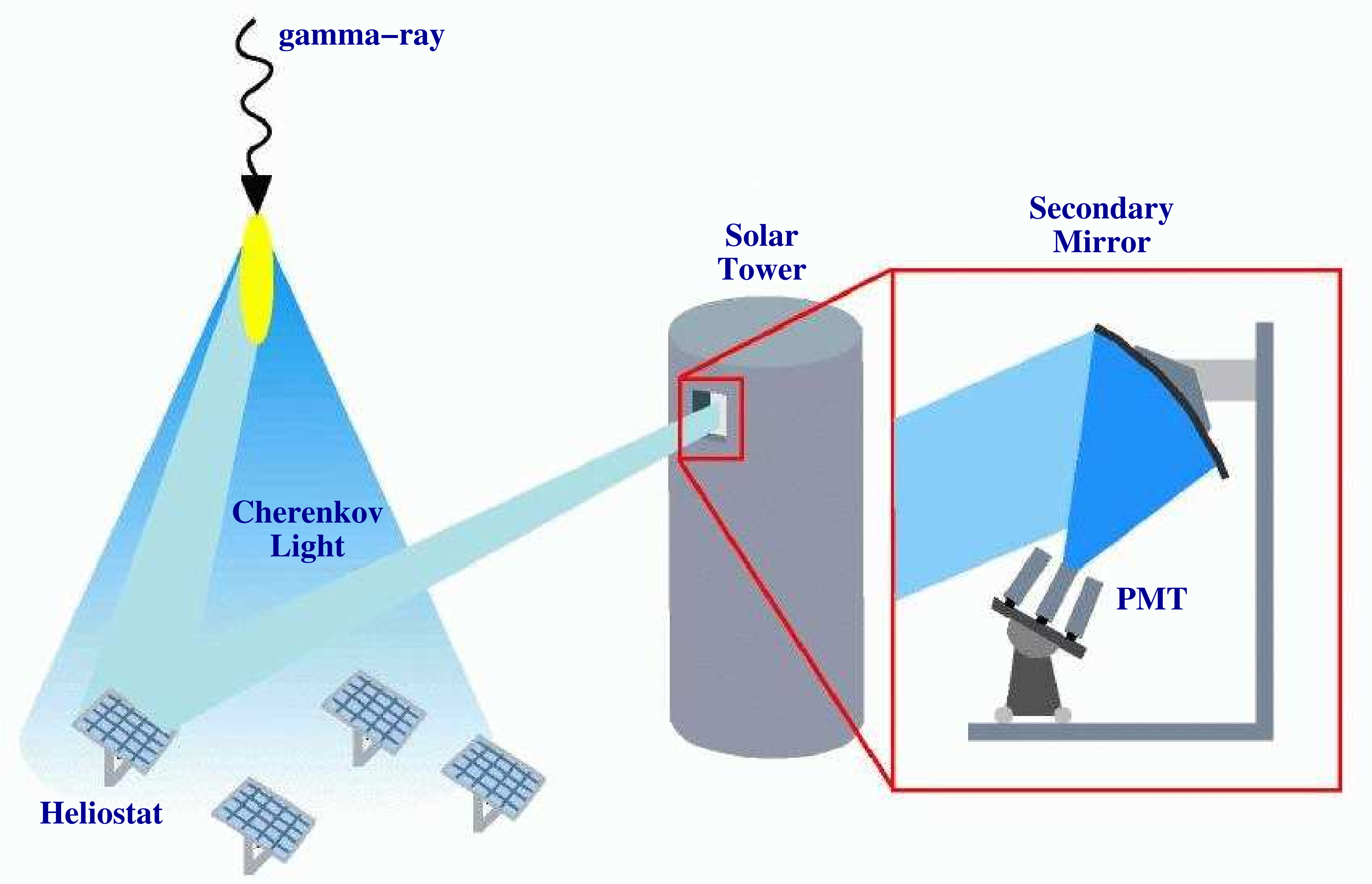


- National Solar Thermal Test Facility (NSTTF)
  — Sandia National laboratories, Albuquerque, New Mexico
  (US national facility for solar energy research)

The STACEE Experiment

- Central Receiver Test Facility (CRTF)
  — central tower ($\sim$200 ft) and $\sim$200 steerable heliostat mirrors
- Purpose
  — research centre for solar thermal electric power (by day!)
  — detector for atmospheric Cherenkov flashes (by night!)

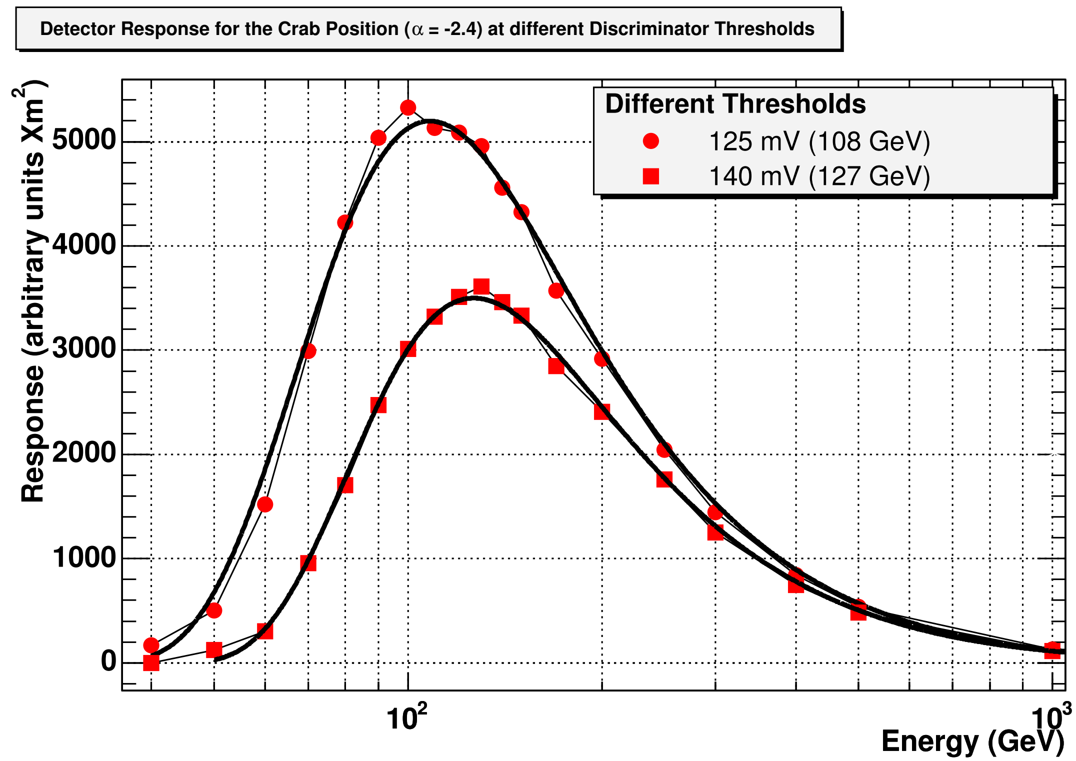
The Solar Tower Technique



- A Cherenkov light collector

  — detect γ-rays by sampling the Cherenkov front

Why use a Solar Tower?



- Low energy threshold
  - — $E_{threshold} \sim \frac{1}{\sqrt{Area_{mirror}}}$
  - — heliostats provide mirror area
  - — STACEE total mirror surface $\simeq$ 2400 m^2 ($\sim$ 100 m^2 for IACT)

Figure: P. Fortin, McGill

Where does STACEE fit in?

Space telescopes

(Below 50 GeV)

Atmospheric Cherenkov Detectors

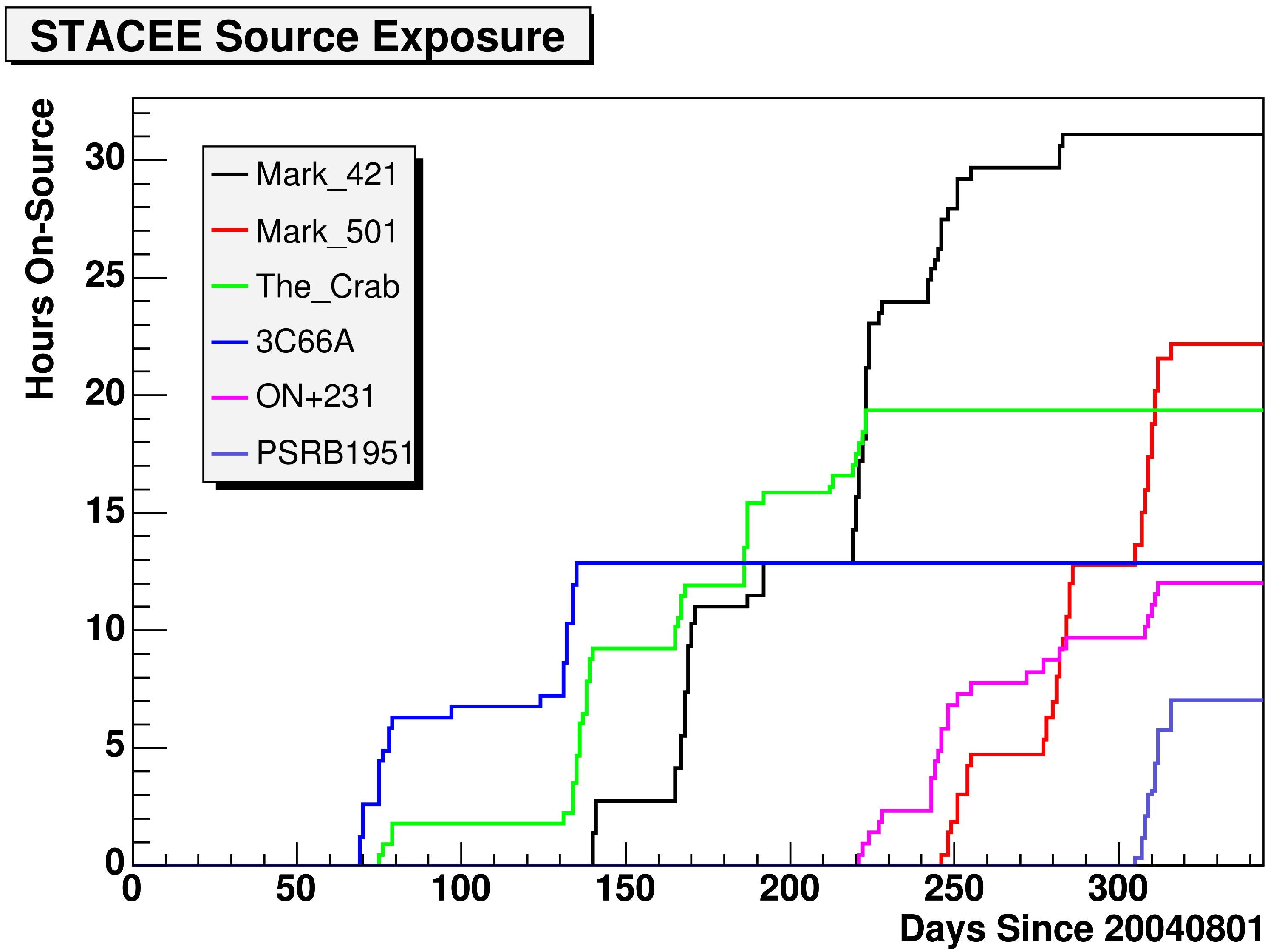
(50 GeV – 50 TeV)

Air shower arrays

(Above 50 TeV)

- The open window (10–200 GeV)
  - — STACEE attempts to close the window between space telescopes and the IACTs
  - — GLAST and MAGIC will ultimately fill the gap

STACEE Observations



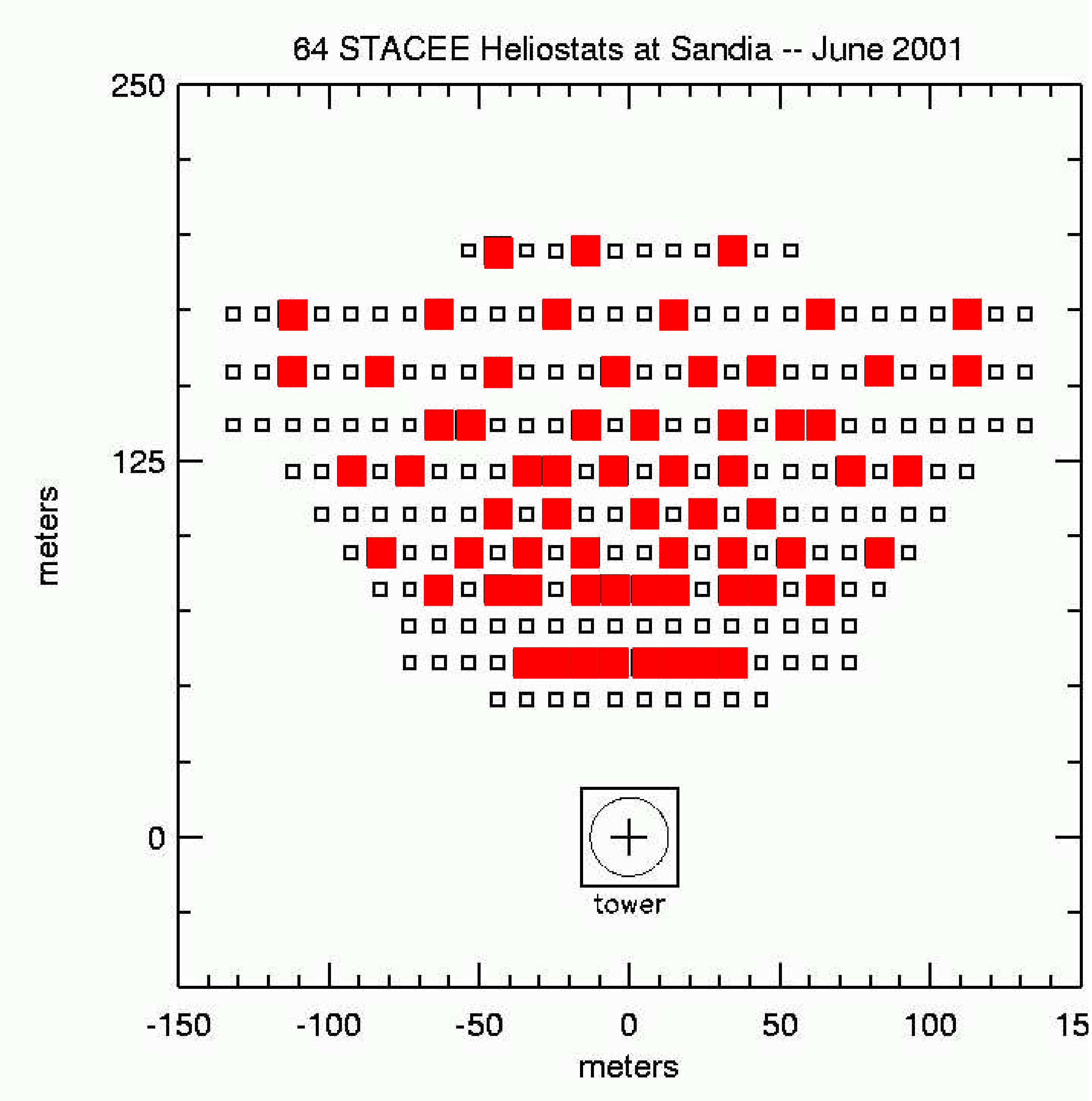
- Observations of AGN, pulsars and GRBs
  — on/off mode

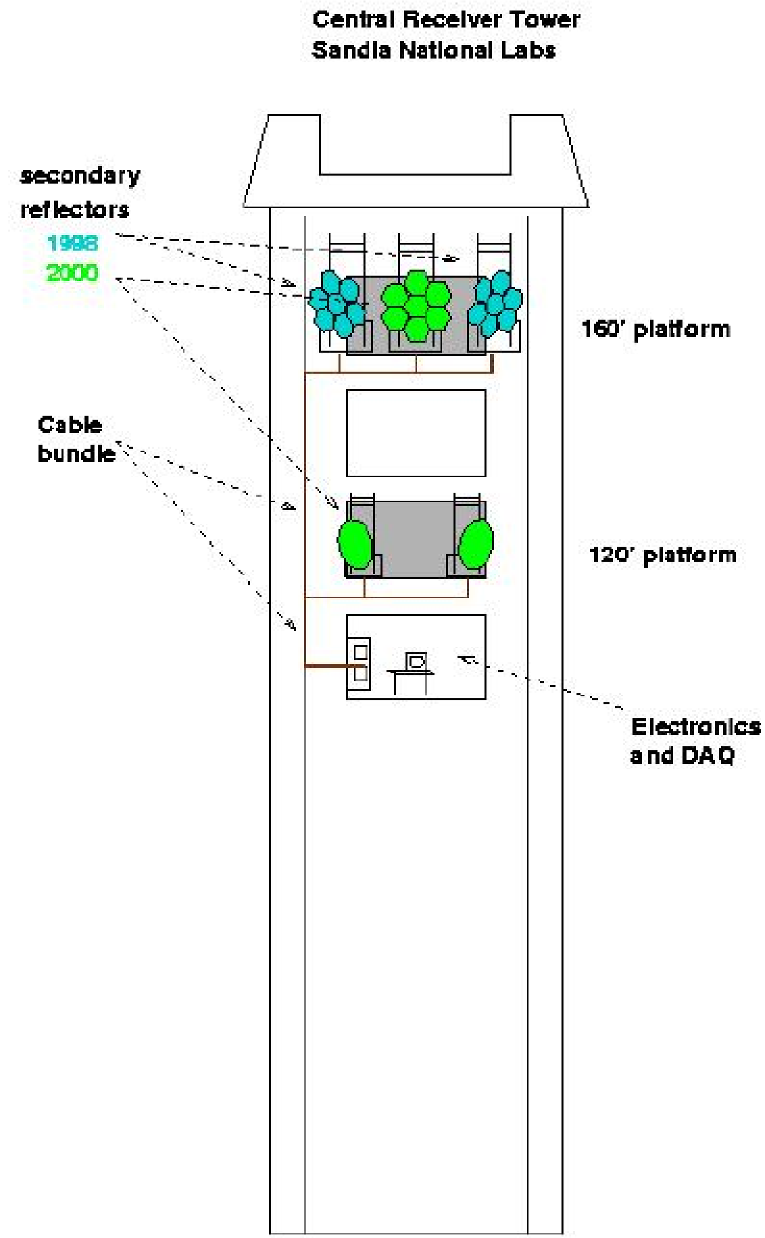
STACEE GRB Observations

- Follow-up observations of 14 bursts since 2002
- Recent heliostat motor upgrade
  — faster slewing, one minute to GRB location

Burst ID	Time to Target (min)	Initial Elevation	Approx. Live-time On Source (min)	Preliminary Significance
021112	217	73°	66	0.2
030324	123	31°	0^a	na
030501	369	47°	0^b	na
031220	310	59°	0^c	na
040422	95	35°	20	-0.7
040916	104	46°	na^d	na
041016	142	51°	16	-1.8
050209	146	56°	22	1.1
050402	3.8	49°	0^e	na
050408	640	43°	20	-1.0
050412	5.7	54°	na^f	na
050509B	20	83°	25	0.45
050509A	480	53°	15	0.1
050607	3.2	62°	19	-0.9

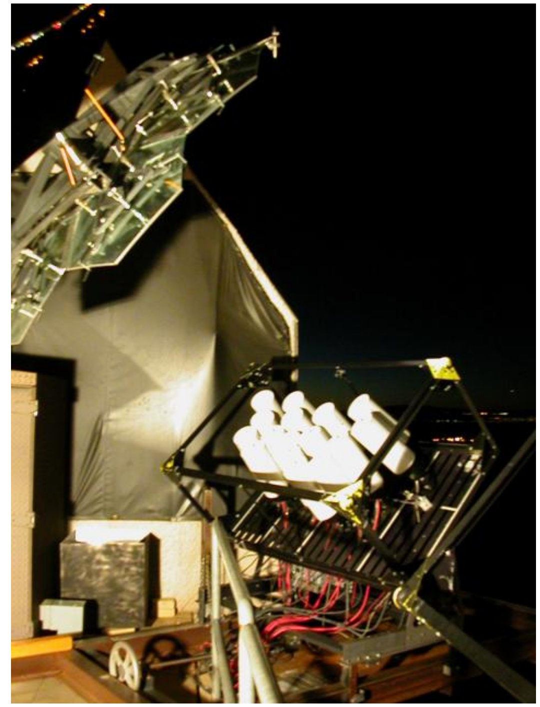
A Tour of STACEE





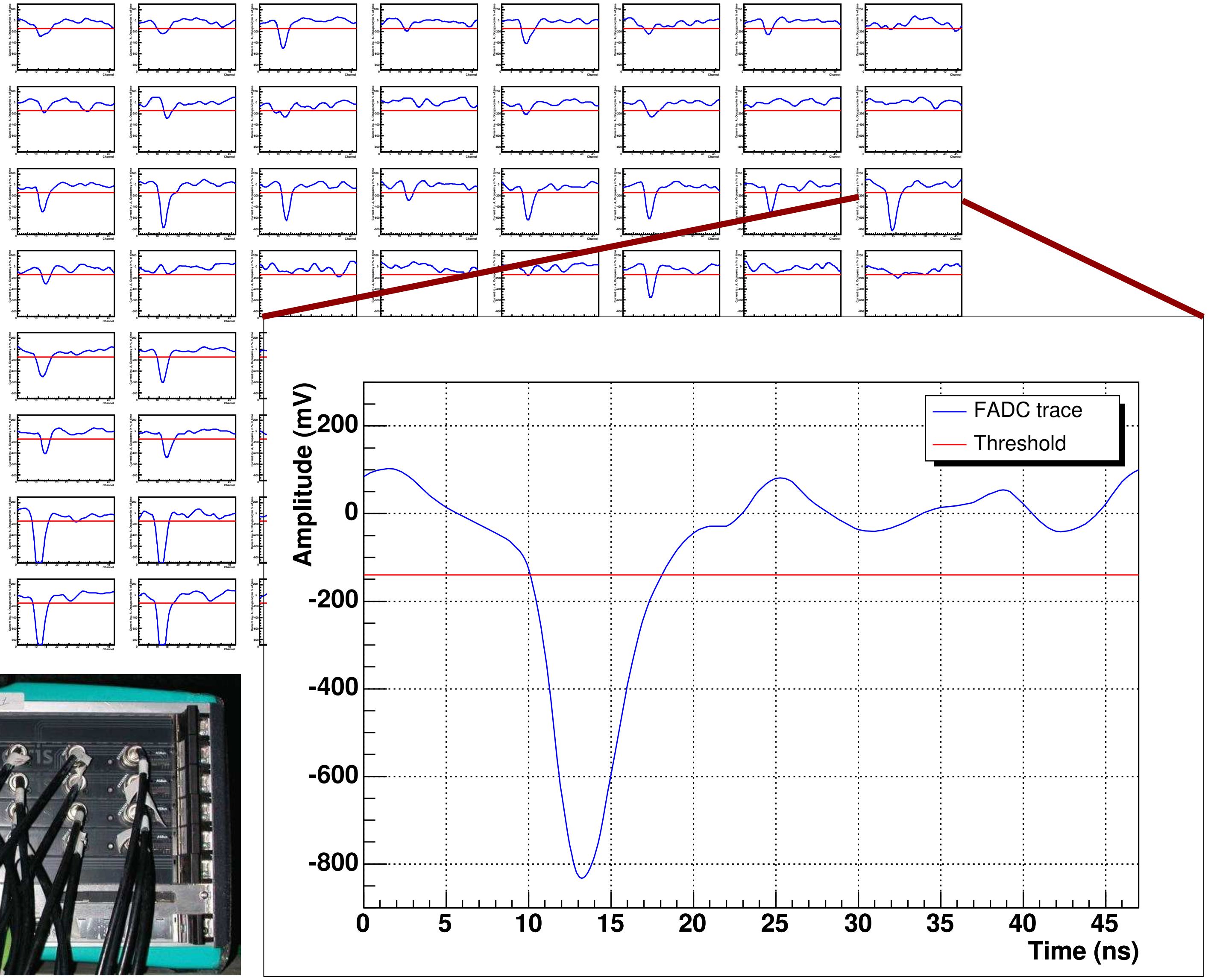
- 64 heliostats (solar mirrors), 200 ft tower

STACEE Secondary Optics and Camera



- Secondary optics
  - — 120-foot platform: 1-meter secondaries (2), 16 channels
  - — 160-foot platform: 2-meter secondaries (3), 48 channels
- Photomultiplier tubes (51 mm)
  - — one-to-one mapping of heliostats and PMTs
  - — 64 independent samples of Cherenkov light pool

STACEE FADCs



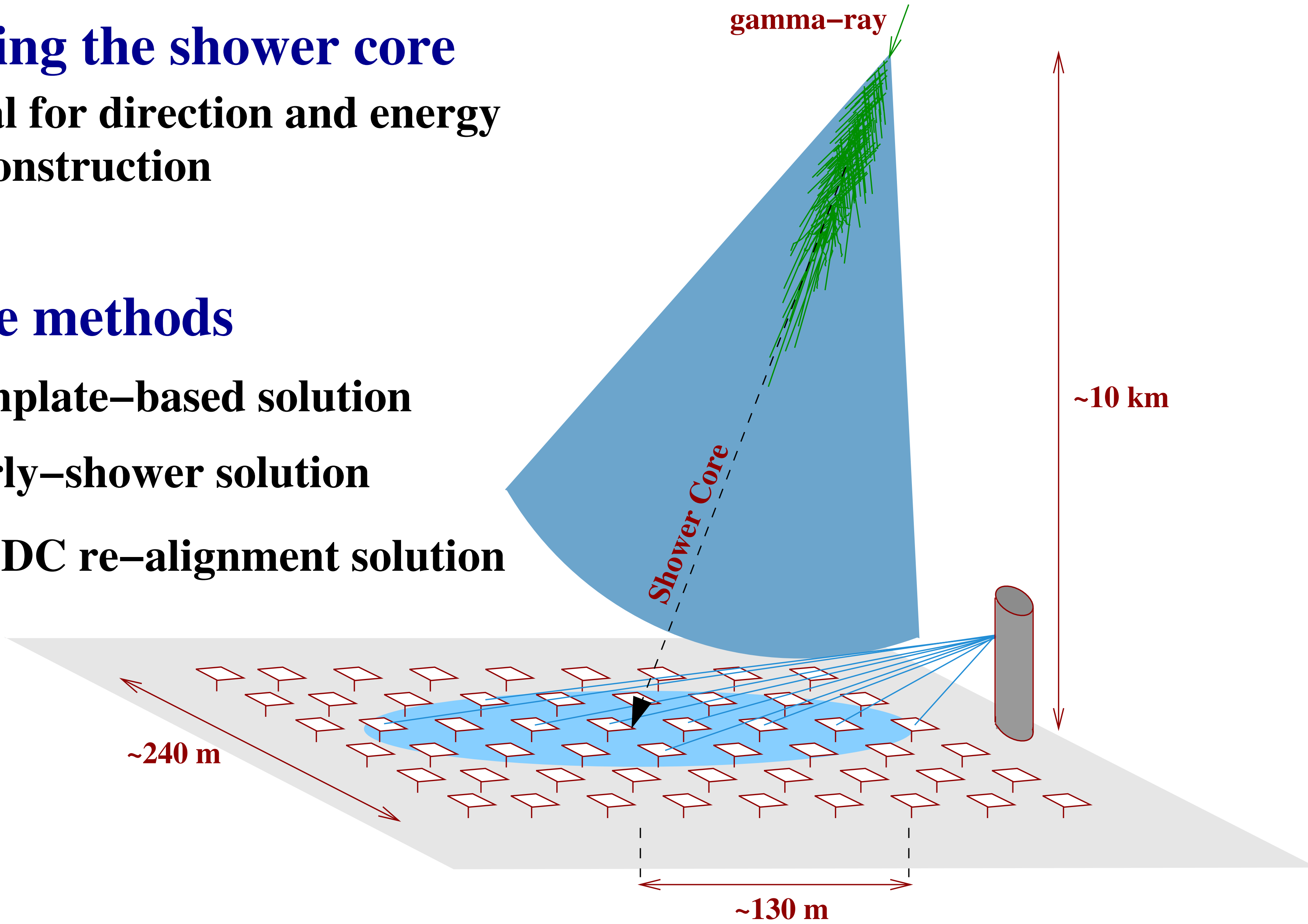
- 8 bit Flash ADCs, one per channel
  - — commercial units under real-time linux
  - — 1 GSample/second, 0.5 V dynamic range

STACEE Data Analysis

- Much progress...
  — significant advances in data analysis over the past year
  — using full power of FADC data - invaluable!
- Event reconstruction
  — core reconstruction to within $\sim$15 m
- Currently two main gamma/hadron separation parameters
  — Shower direction offset, θ
  — *Grid ratio*
- Development ongoing
  — investigating several other possible parameters

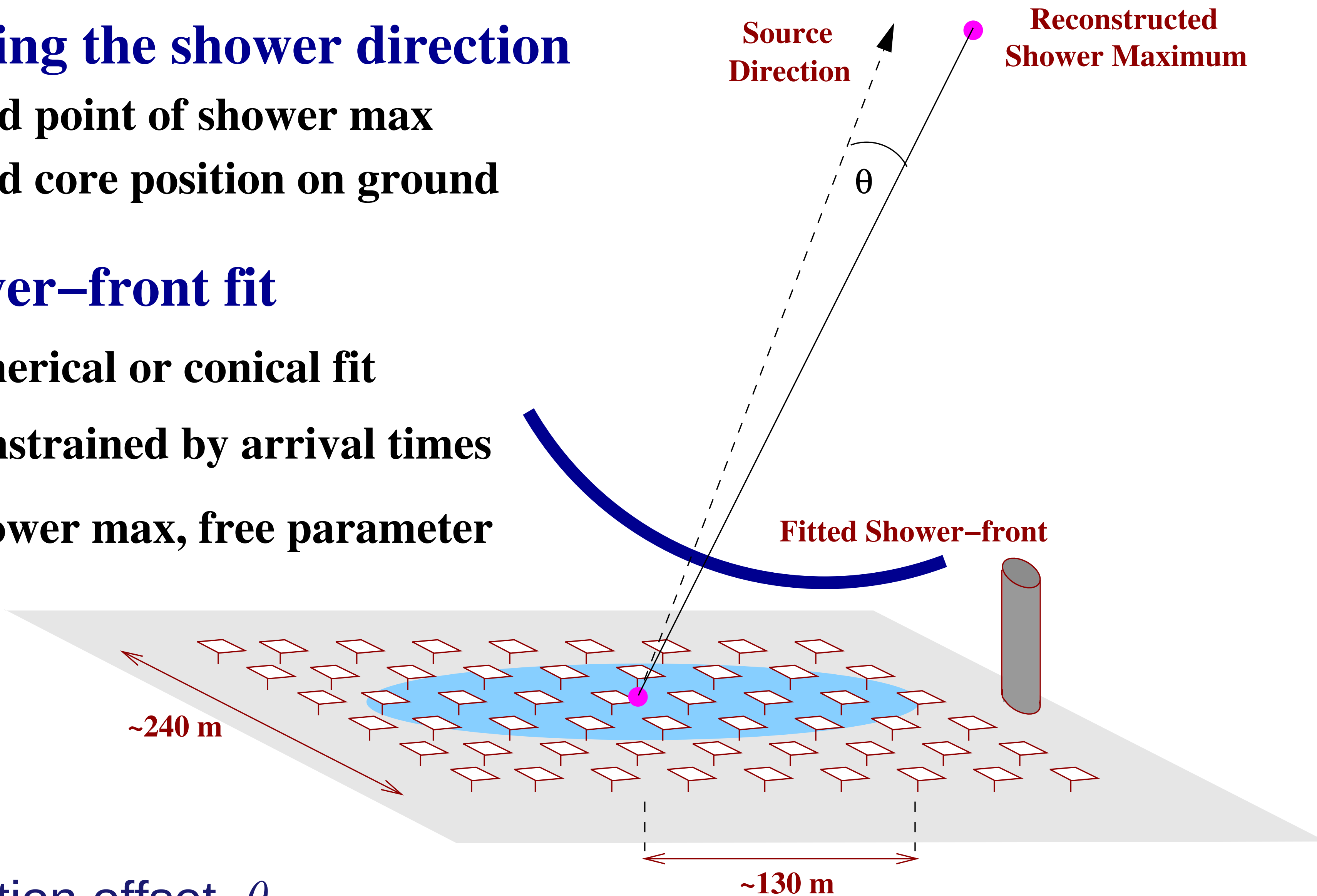
STACEE Event Reconstruction – the Shower Core

- **Finding the shower core**
  - vital for direction and energy reconstruction
- **Three methods**
  - template–based solution
  - early–shower solution
  - FADC re–alignment solution



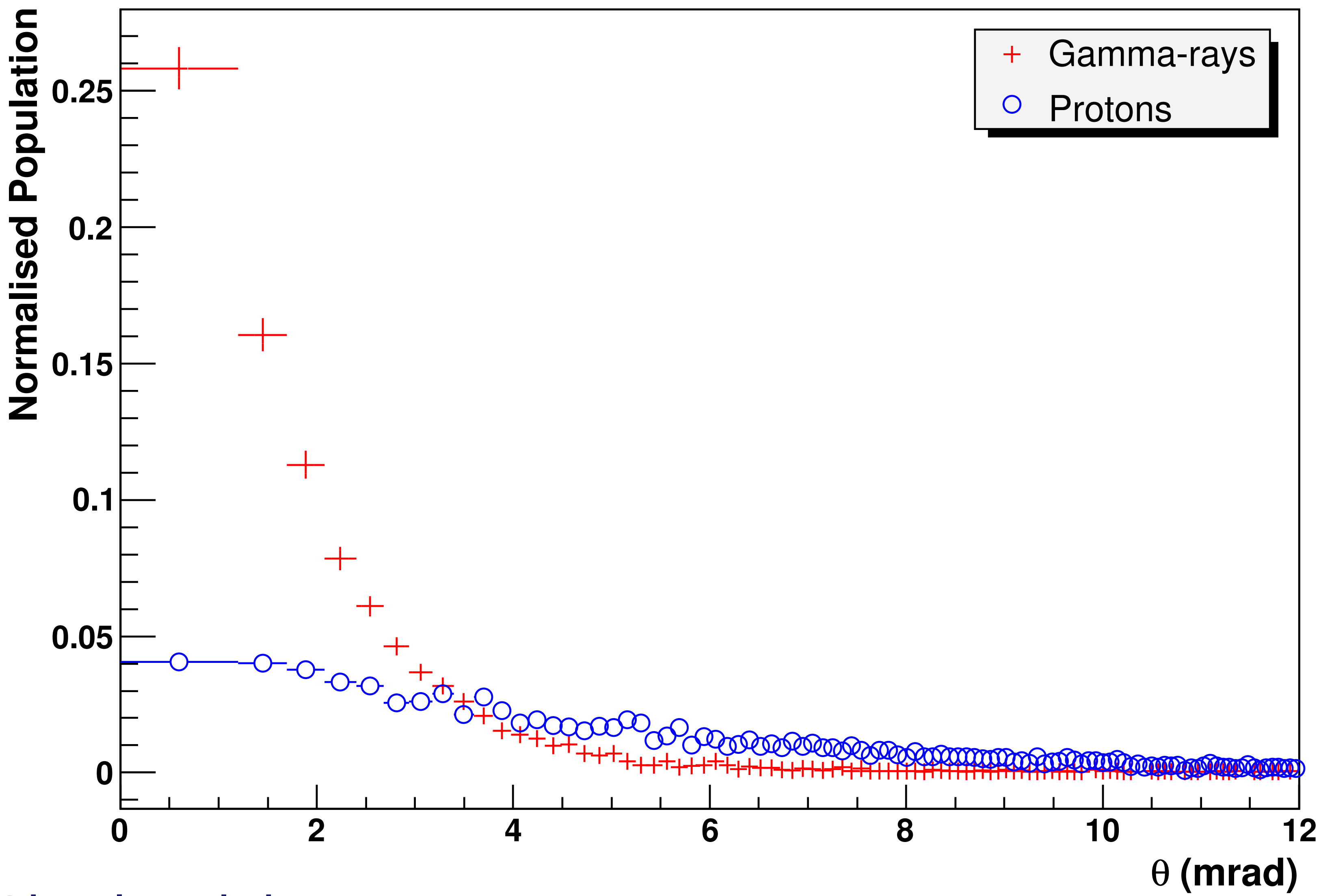
Event Reconstruction – Direction Reconstruction

- **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

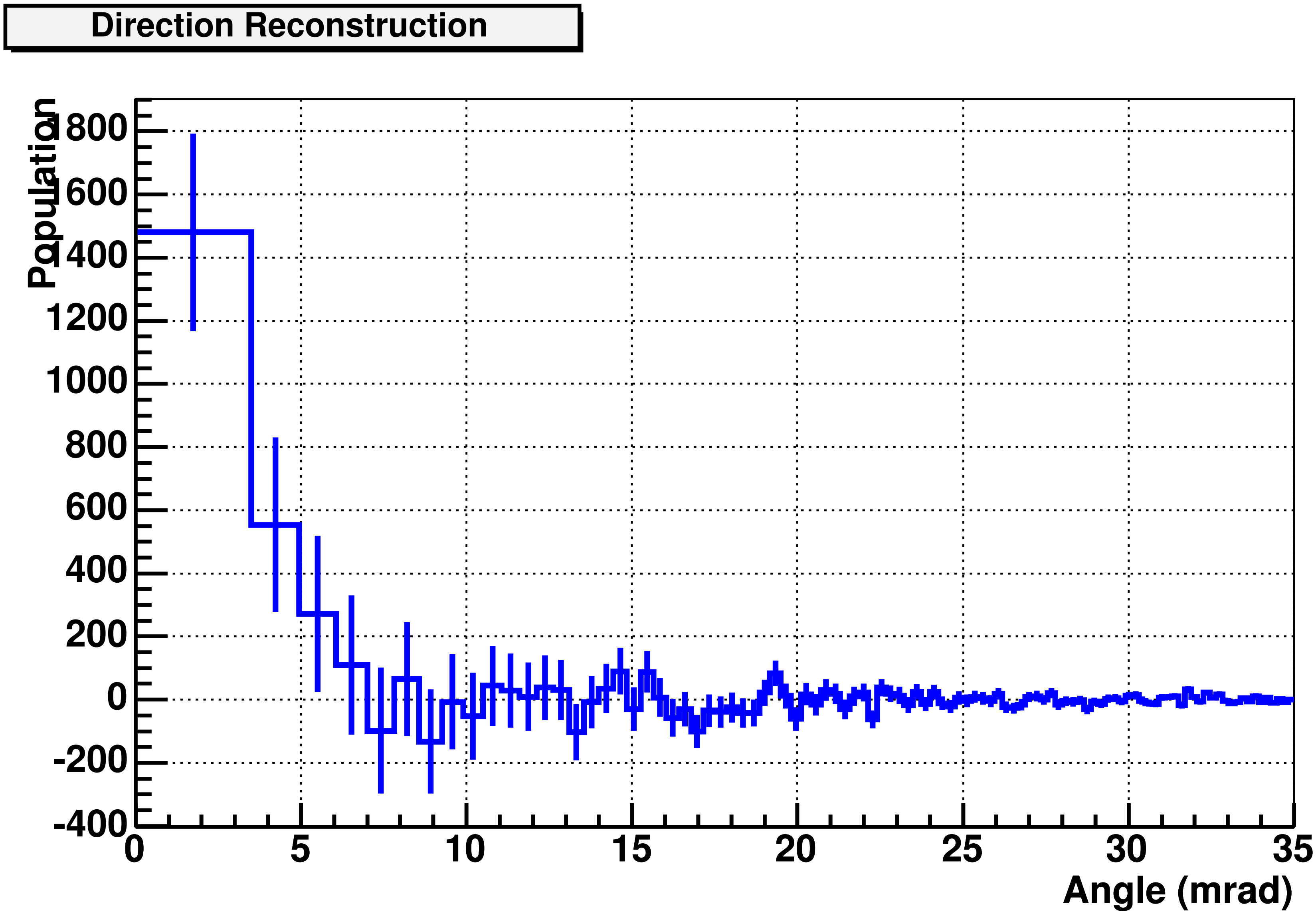
Gamma/Hadron Separation – Direction Reconstruction



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

Bins have equal area on the sky

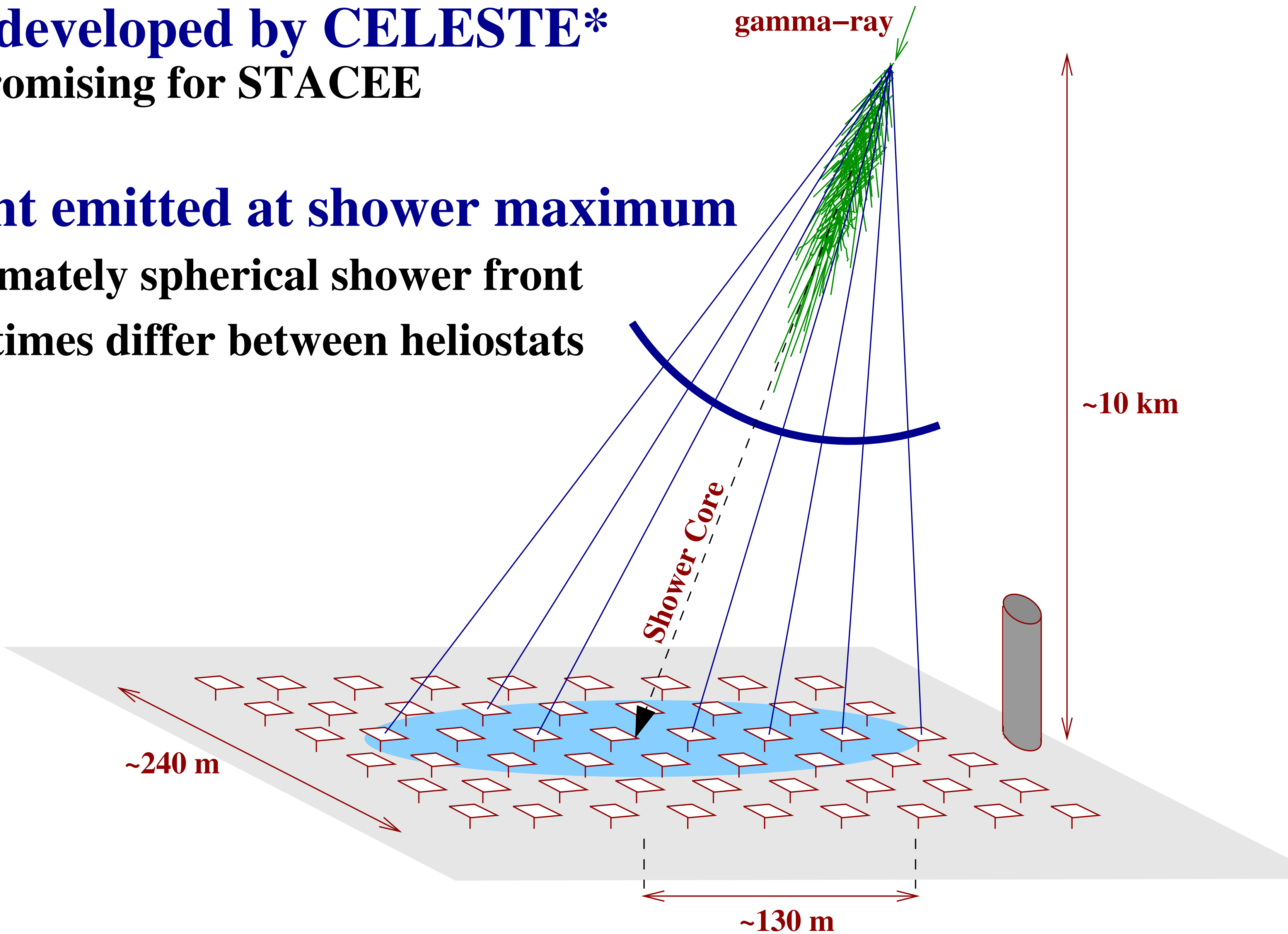
Gamma/Hadron Separation – Direction Reconstruction



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

Event Reconstruction – Grid Alignment

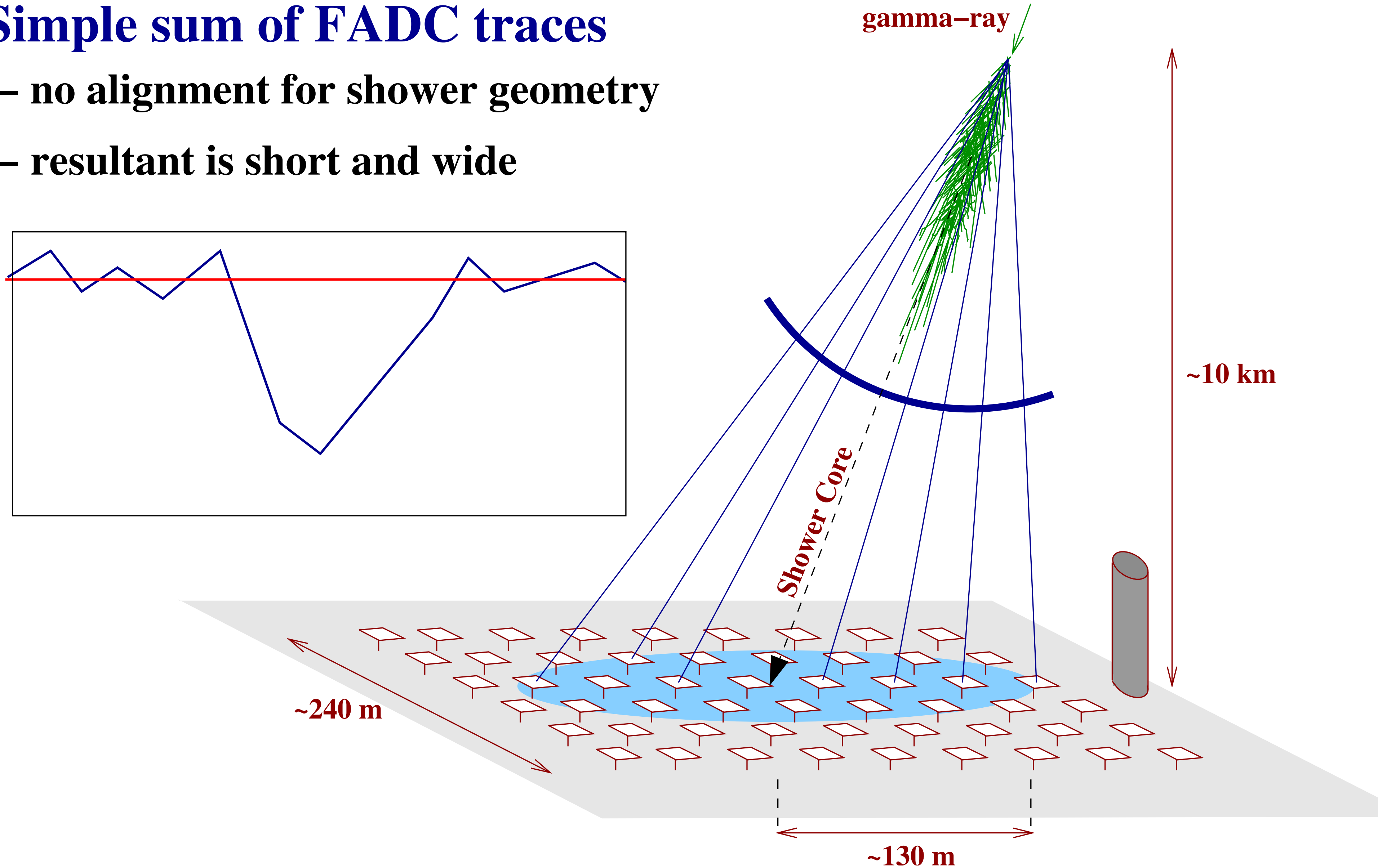
- **Method developed by CELESTE***
  - **looks promising for STACEE**
- **Most light emitted at shower maximum**
  - **approximately spherical shower front**
  - **arrival times differ between heliostats**



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

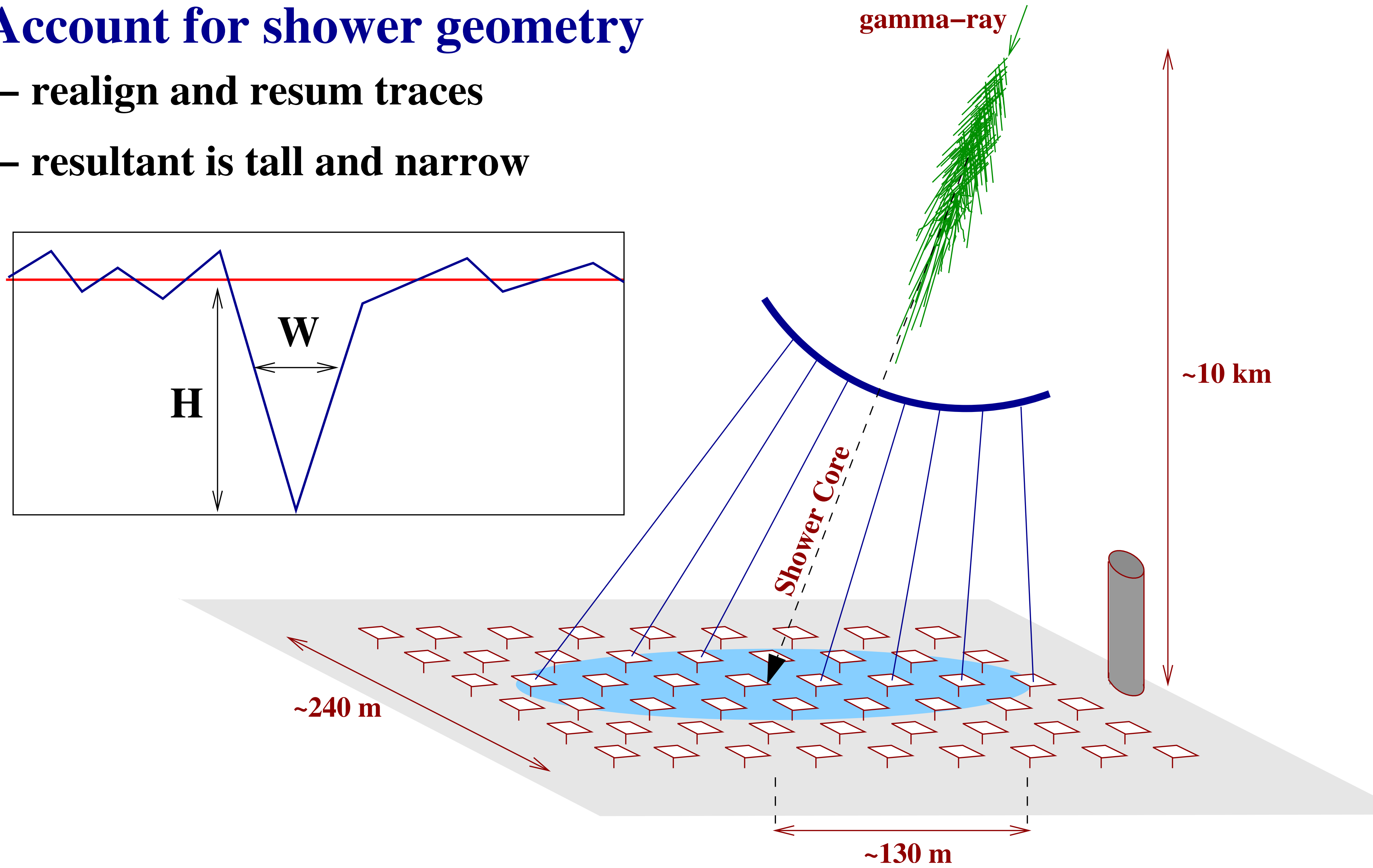
Event Reconstruction – Grid Alignment

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



Event Reconstruction – Grid Alignment

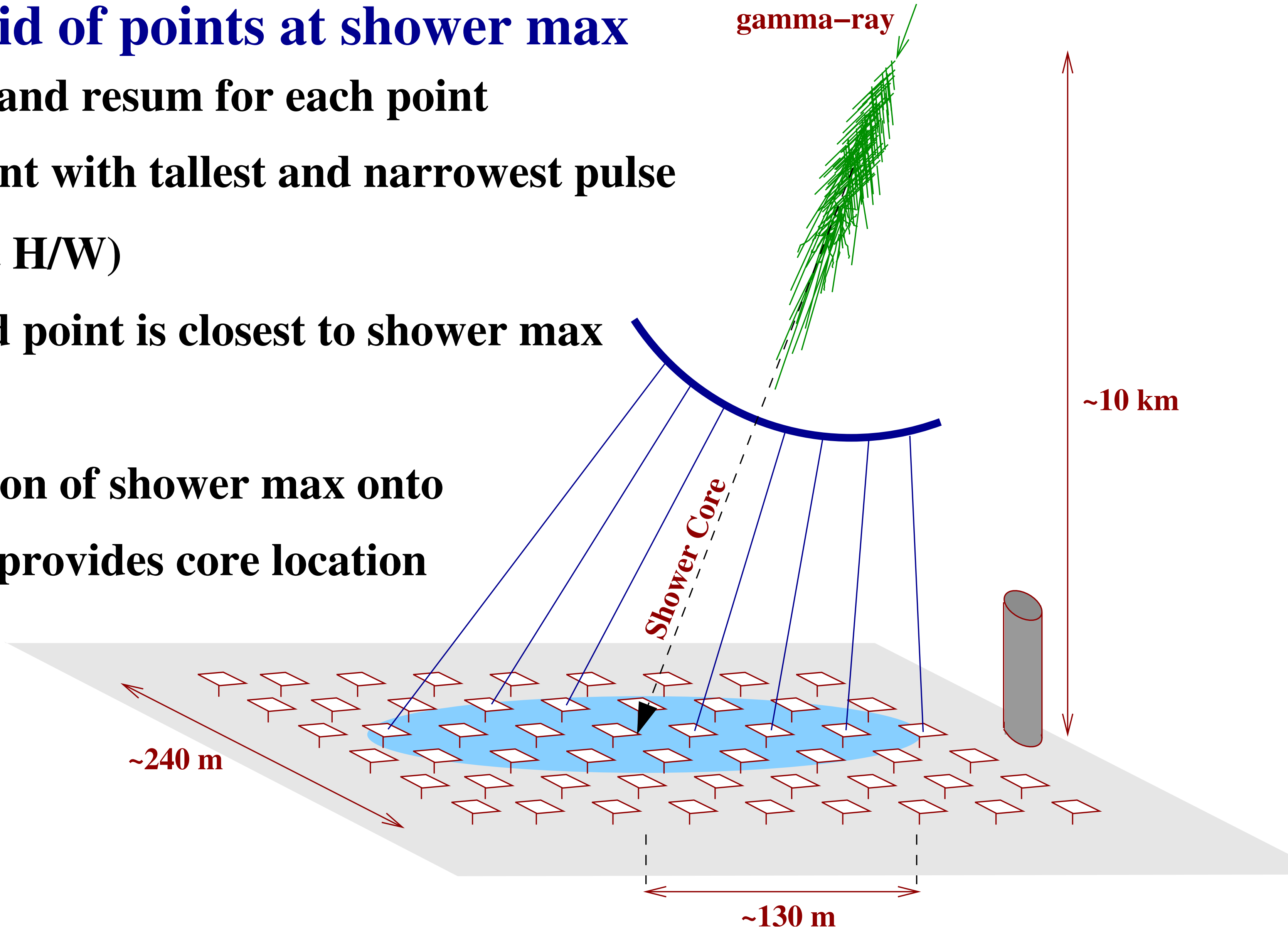
- **Account for shower geometry**
  - **realign and resum traces**
  - **resultant is tall and narrow**



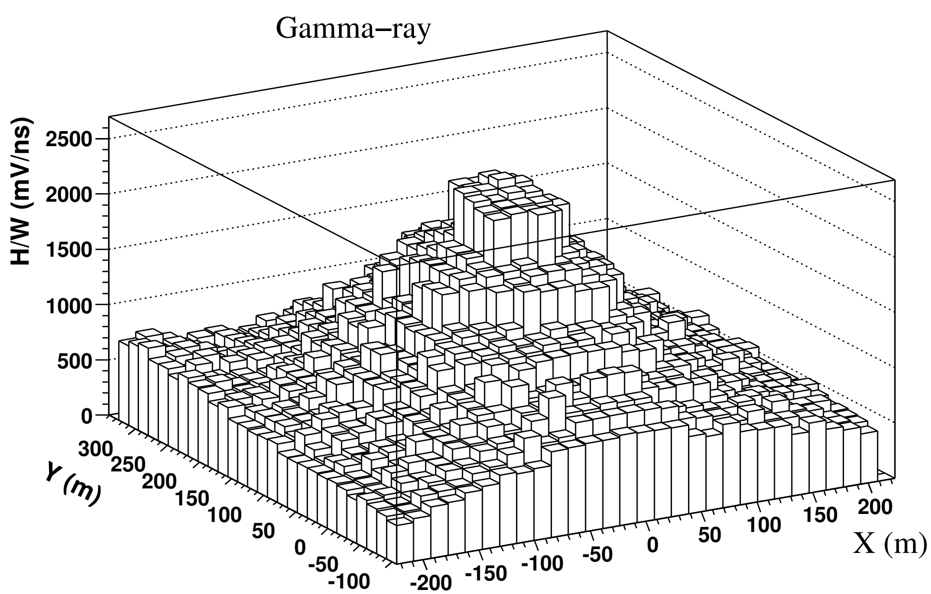
— of course, we don't know where the shower max is!

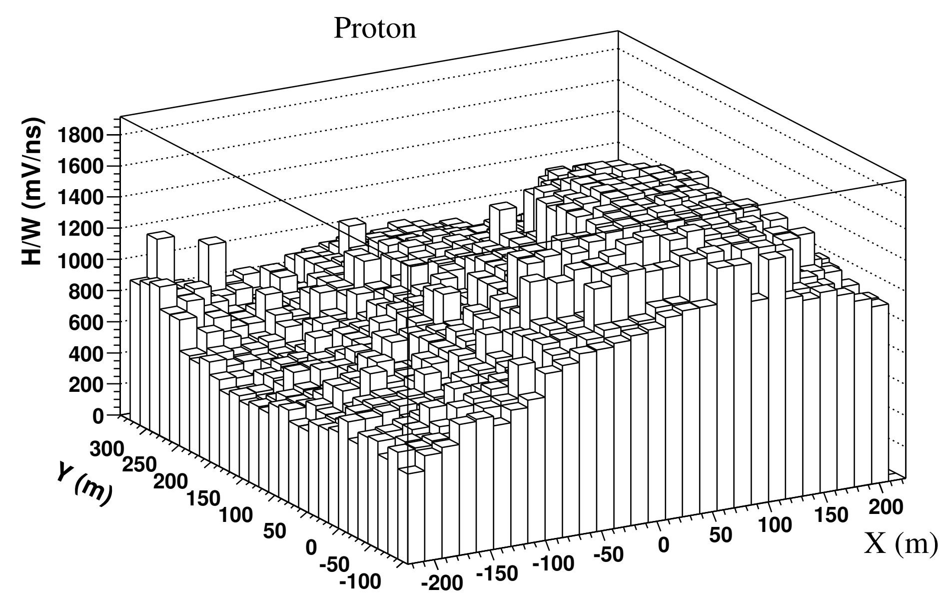
Event Reconstruction – Grid Alignment

- **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

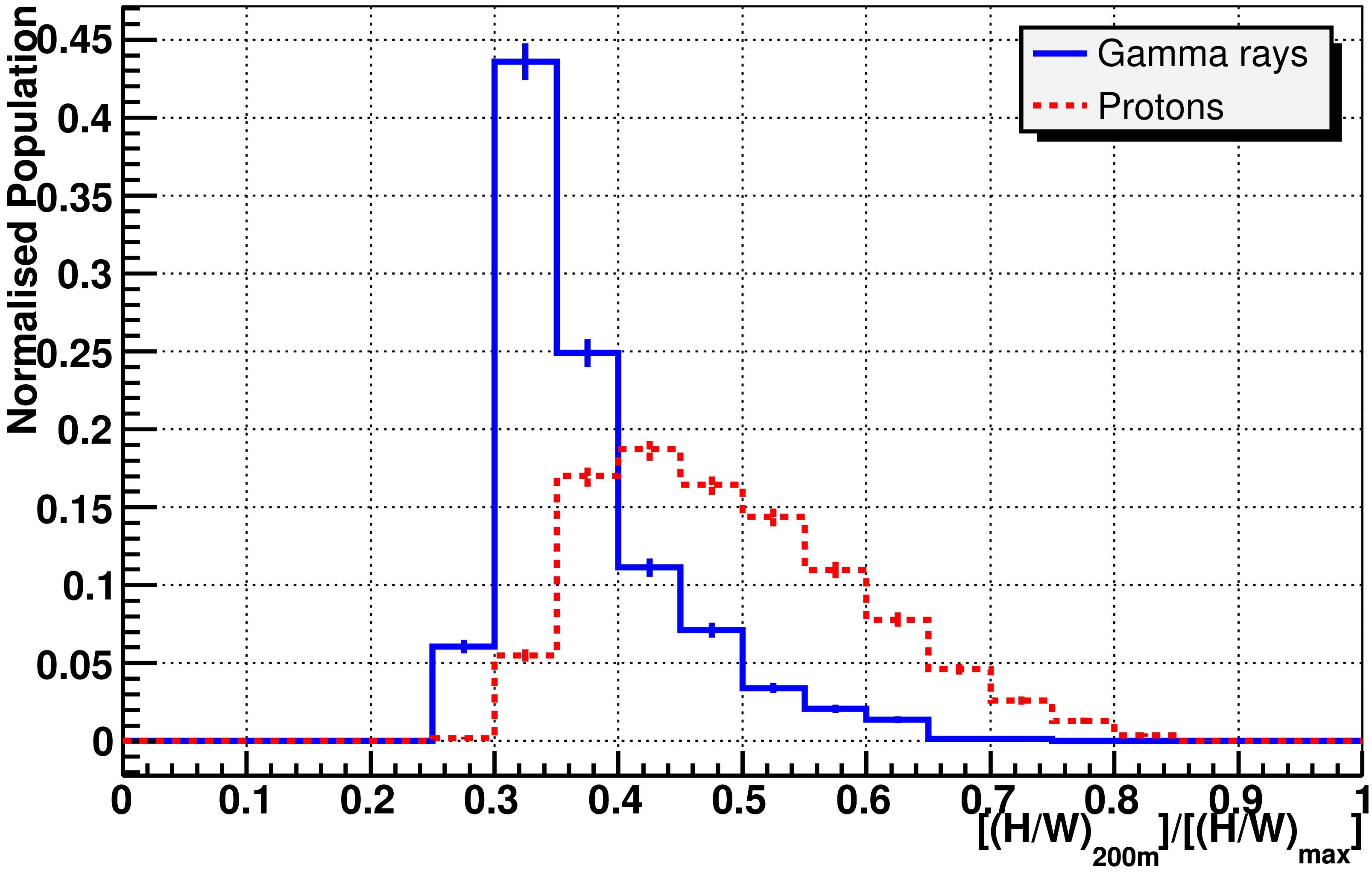




- Distribution of H/W for each grid point
  — peak provides core location

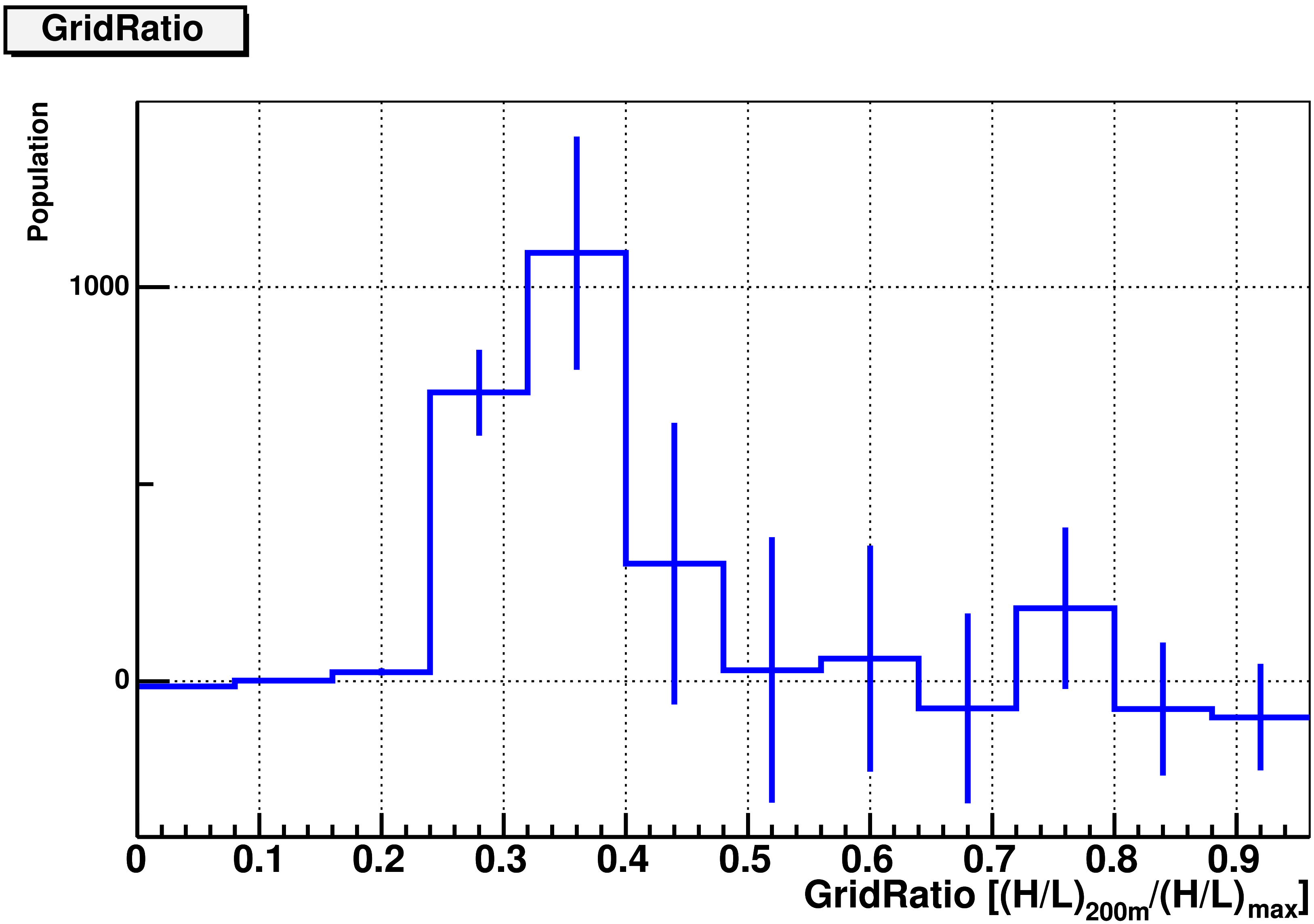
- Gamma/hadron separation
  — distribution very different for gamma rays and protons
  — gamma-ray pulses quickly fall out alignment away from shower max
  — parameterize shape of H/W distribution as *grid ratio*, $\{\frac{(H/W)_{200m}}{(H/W)_{max}}\}$

Gamma/Hadron Separation – Grid Alignment



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

Gamma/Hadron Separation – Grid Alignment



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

STACEE Milestones

- 2000: Crab nebula detection
  - — 190 GeV, 32-channel detector (Oser et al., 2001, ApJ, 547:949)
  - — Crab pulsar upper limit–constraint on outer gap model
- 2001: Detection of Mrk 421 flares
  - — (Boone et al., 2002, ApJ, 579:L5)
- 2002: STACEE-64 commissioned
  - — 64 heliostats, 64 FADCs
- 2003: WComae (ON+231) upper limits
  - — Scalzo et al., ApJ, 607:778-787 (2004)
  - — an EGRET blazar, hard (α = 1.73) spectrum (undetected by IACTs)
  - — 10.5 hours of ON-source data
  - — flux upper limits above 100 GeV for leptonic models, above 150 GeV for hadronic models (lowest yet for WComae)
  - — strongly constrain EGRET power law extrapolation
  - — upper limit below SPB 2 hadronic model prediction

SPB model: Mücke & Protheroe 2000; Aharonian 2000; Mücke et al., 2003

WComae Upper Limits

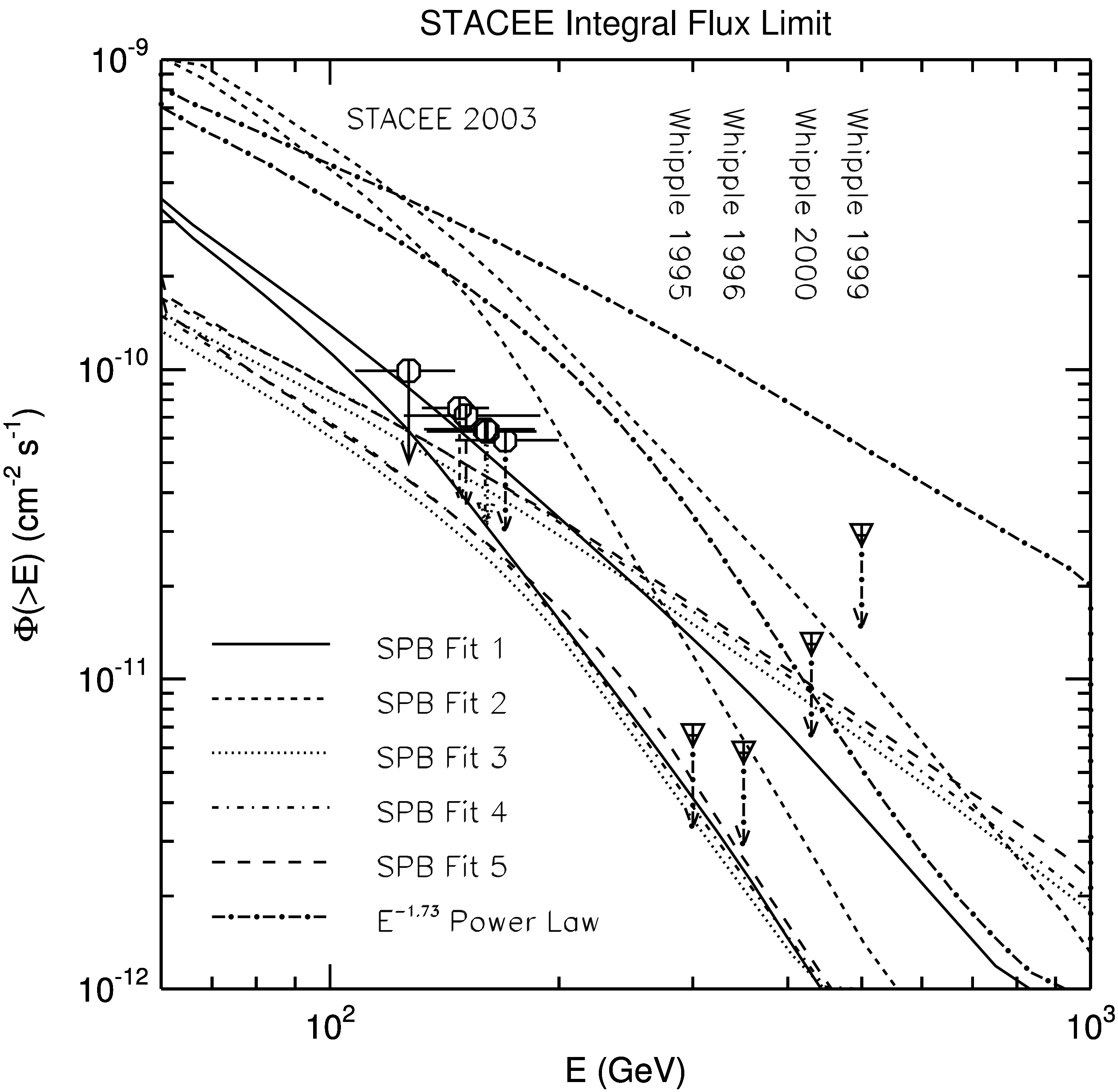
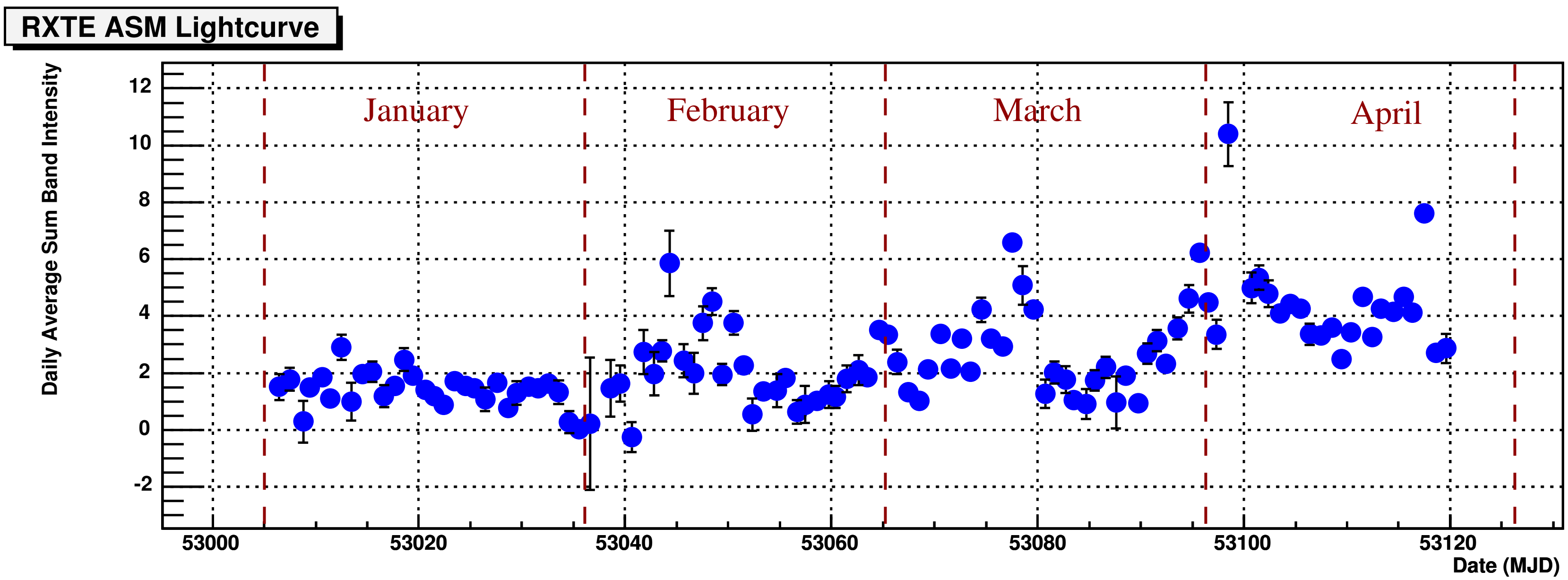
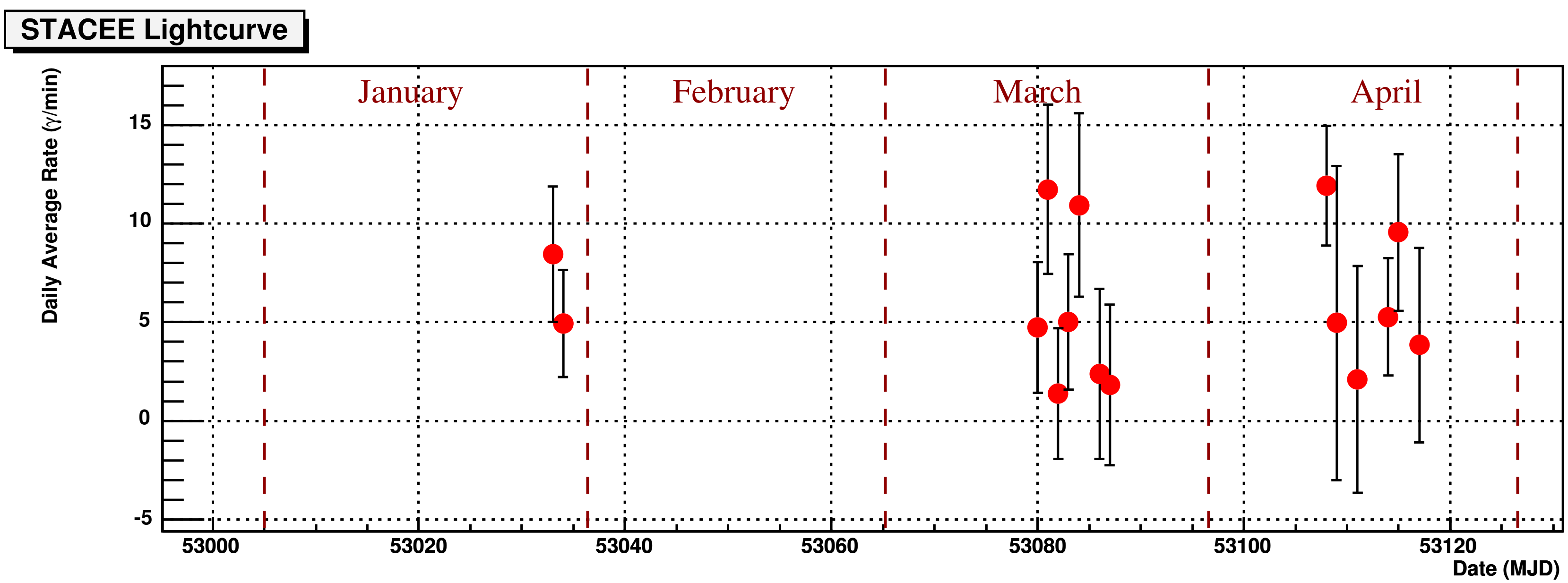


Figure: Scalzo et al. 2004

Markarian 421 2003/04 – Preliminary Results





— high state according to RXTE ASM during spring 2004

— 7.9 hours on source, combined significance of 5.9σ

— spectral analysis almost complete

STACEE Milestones

- 2004: 3C 66A upper limits
  - — Bramel et al., 2005, accepted for publication in ApJ
  - — LBL, associated with EGRET source 3EG J0222+4253
  - — repeated detections by Crimean group at 1 TeV*
  - — redshift quoted as 0.444, but uncertain
  - — 16.3 hours of on-source data, 2.2σ on-source excess
  - — flux upper limits above 147 GeV for various EBL absorbed power-law spectra,
  - — lowest energy upper limits yet for this object

* Nesphor et al., 1998, Stepanyan et al., 2002

Status/Future of STACEE

- Experiment status
  - — STACEE fully operational, stable, and taking data
- Analysis status
  - — continued improvements in data analysis methods, particularly advanced event reconstruction using FADCs and padding analysis (ON/OFF brightness equalisation)
  - — Spectral analyses under development
- Data to be re-analyzed with improved gamma/hadron separation
  - — H1426+428, 3C 66A, PSR B1951+32, WComae, GRBs
- Observations
  - — STACEE will continue to take data on known and potential γ-ray sources until mid-2006