

# The Rapid Atmospheric Monitoring Program for the Pierre Auger Observatory

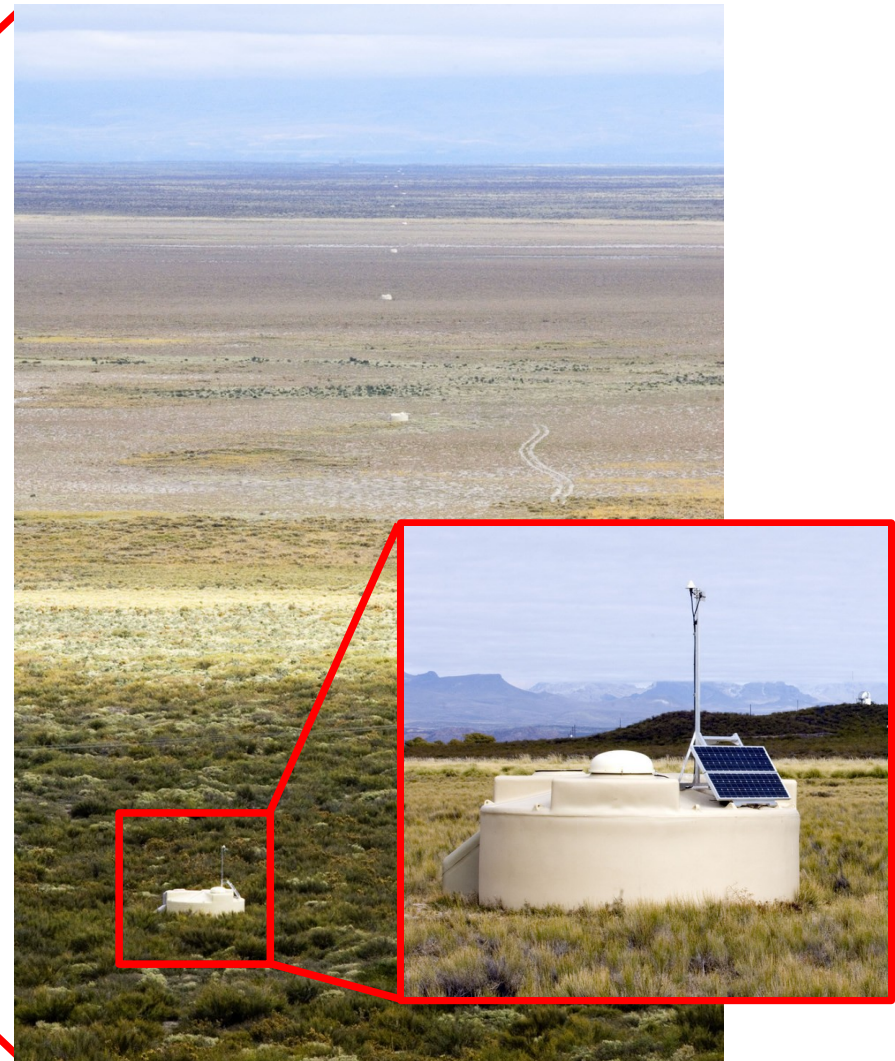
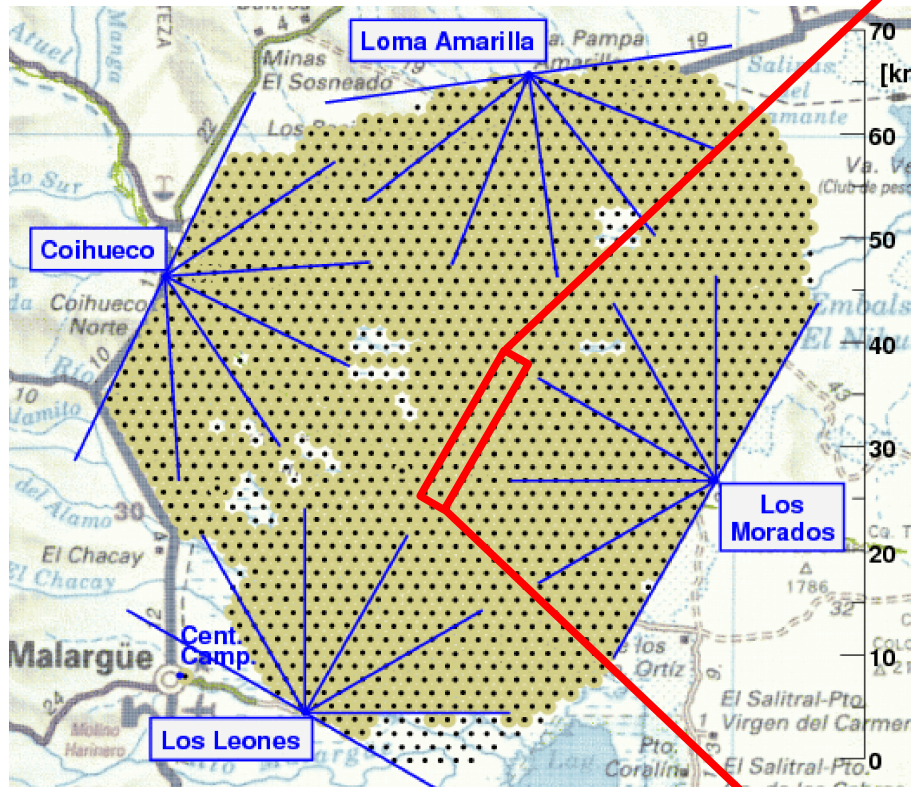
Martin Will  
for the Pierre Auger Collaboration

2nd Workshop on Atmospheric Monitoring in Astroparticle Physics and Astronomy



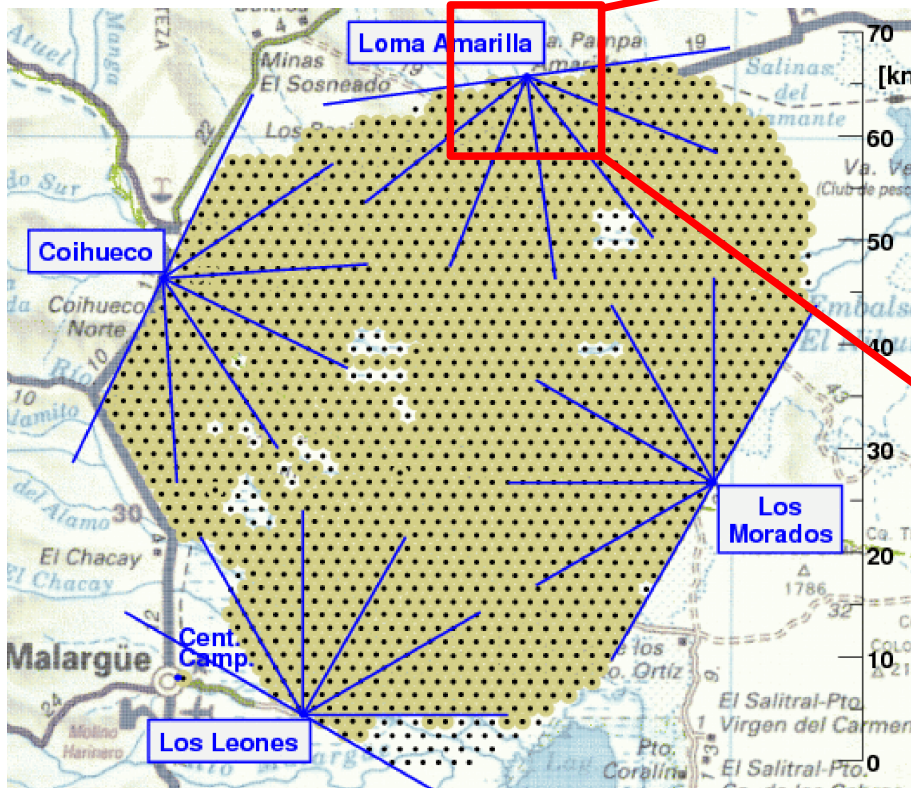


# Surface Detector



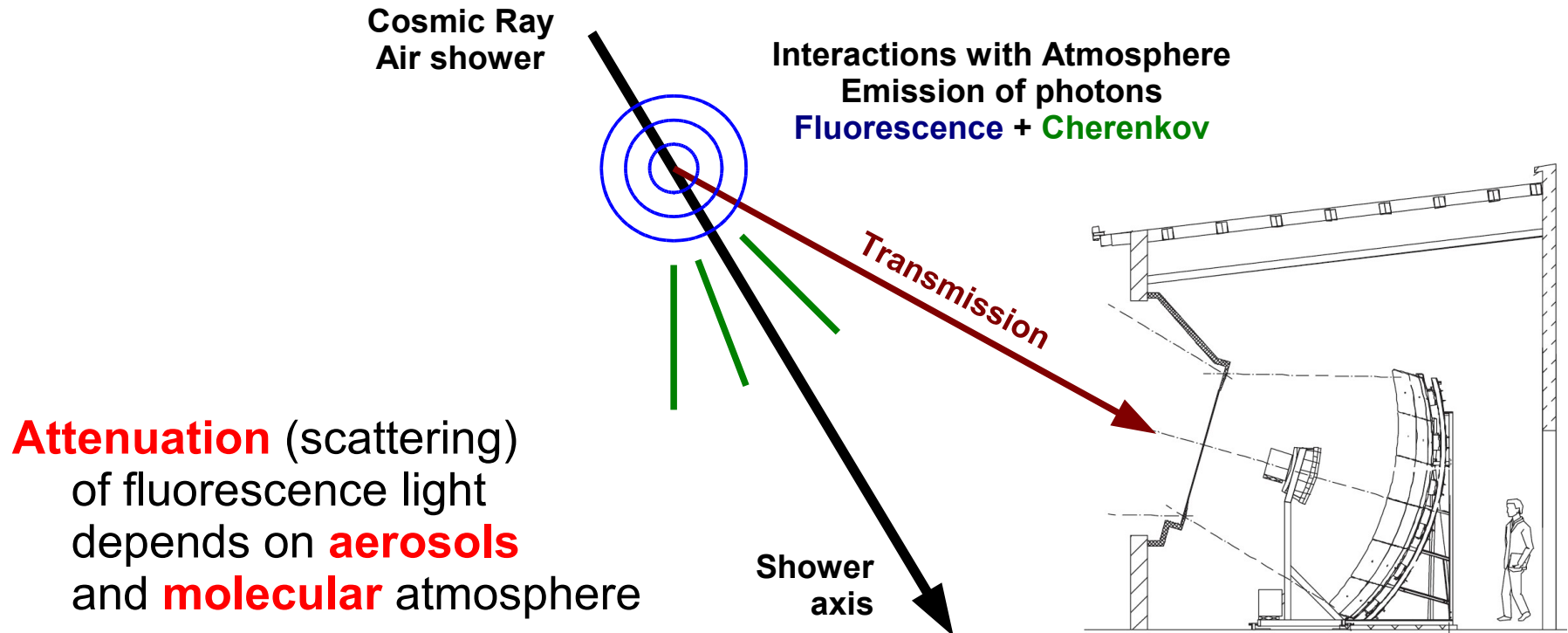


# Fluorescence Detector





# Atmosphere



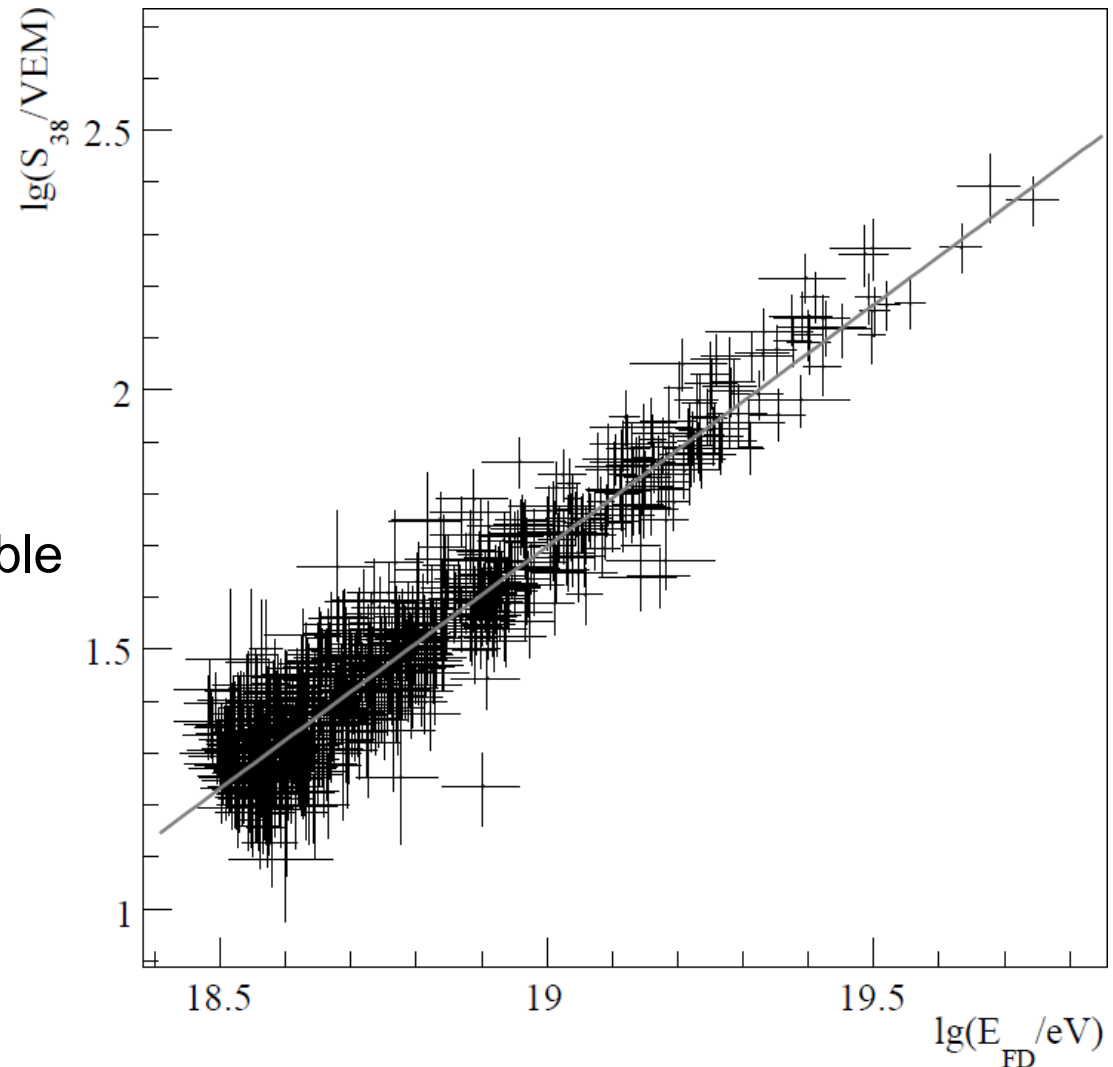
$$I_{det} \propto I_{emit} \cdot e^{-\tau_{mol}(T, p, e)/\sin \psi} \cdot e^{-VAOD(h)/\sin \psi}$$

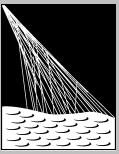
VAOD = Vertical Aerosol Optical Depth



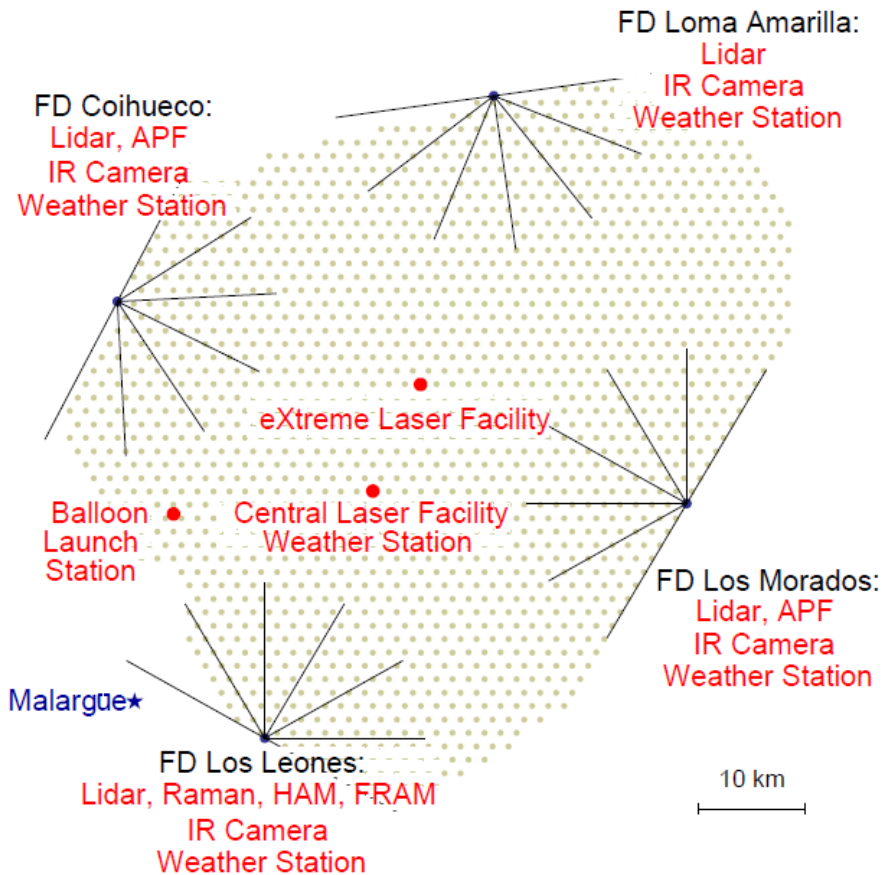
# Energy Calibration

- Calibration of SD energy
  - Depends on **high-energy** events
  - Need actual atmospheric conditions as **fast** as possible
- **Rapid atmospheric monitoring**

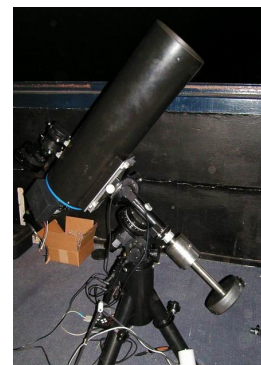
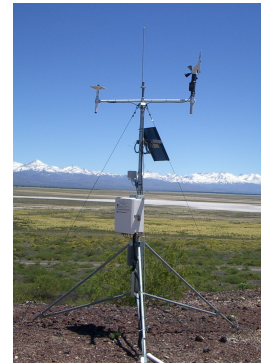
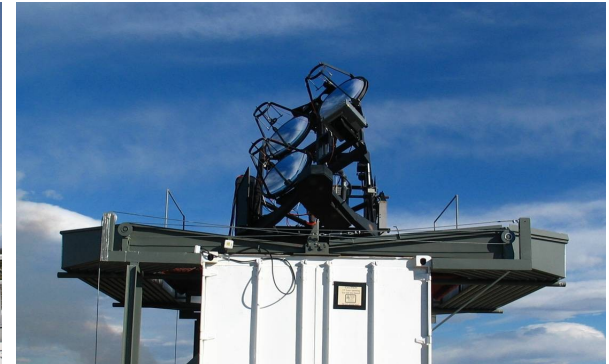


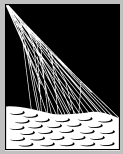


# Atmospheric Monitoring



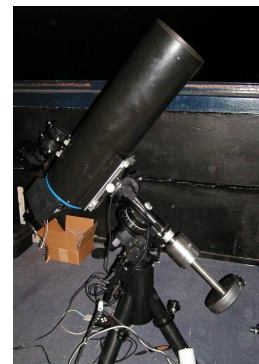
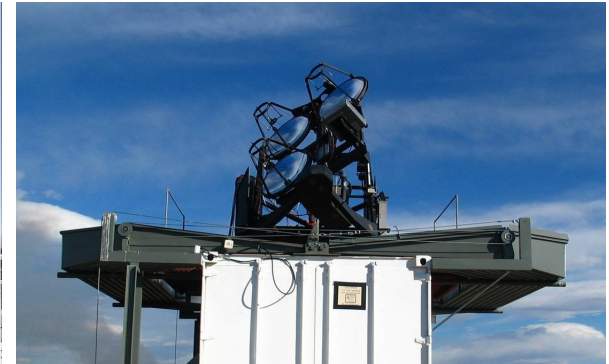
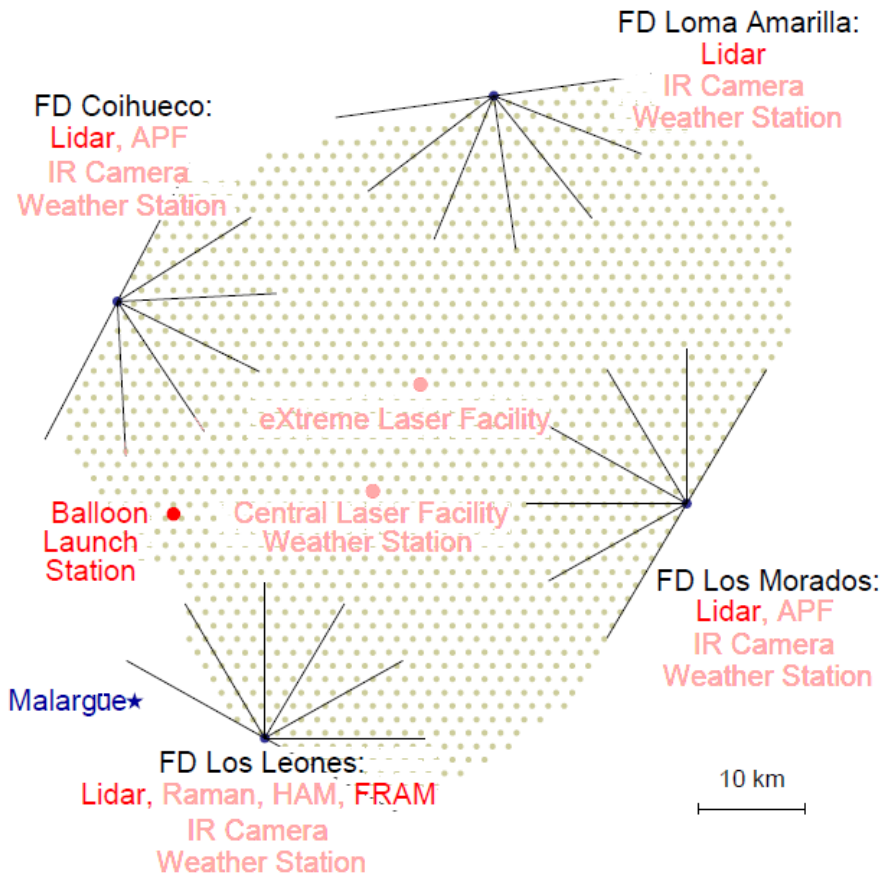
see talk #13, L. Wiencke





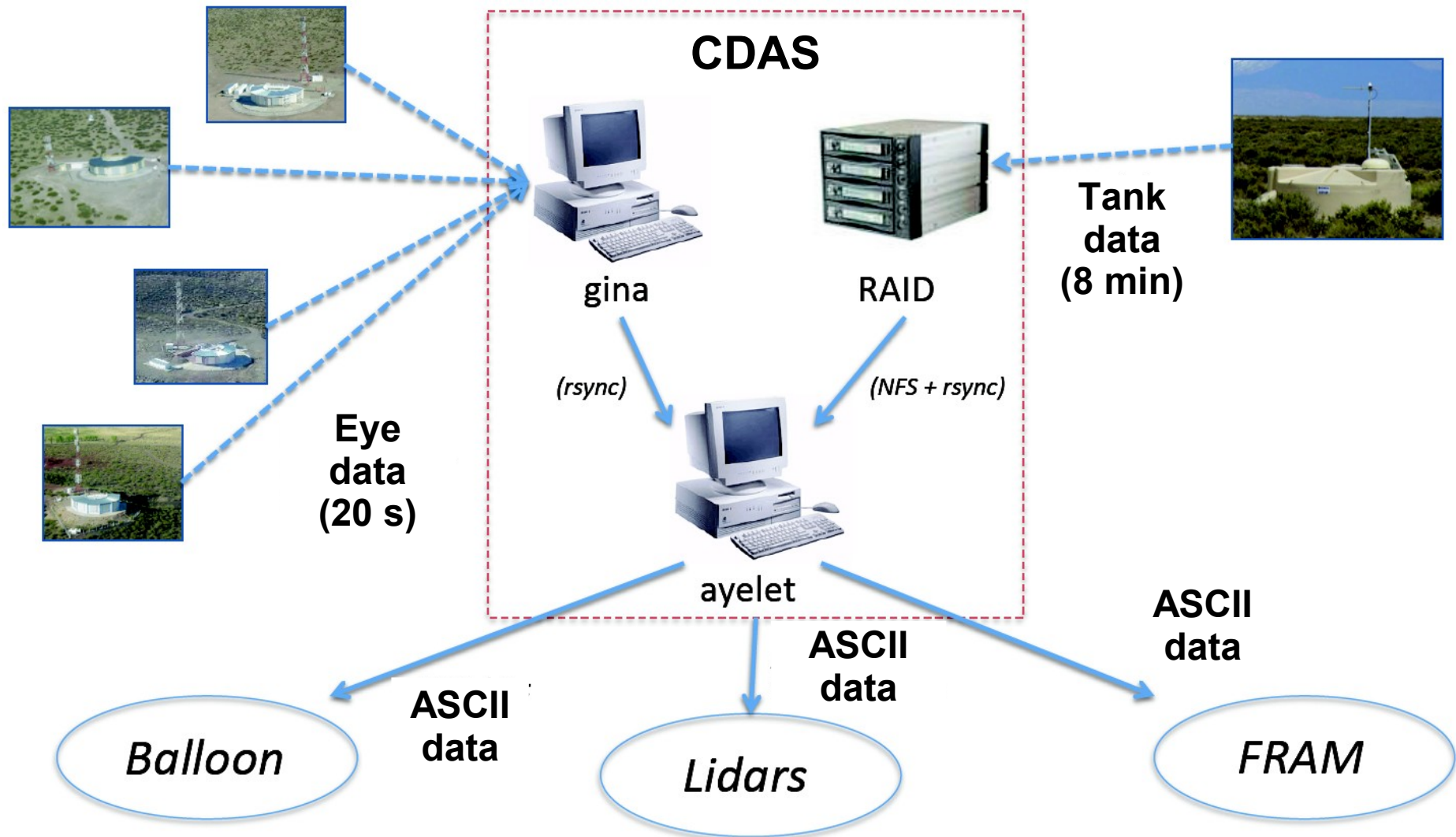
**Rapid**

# Atmospheric Monitoring



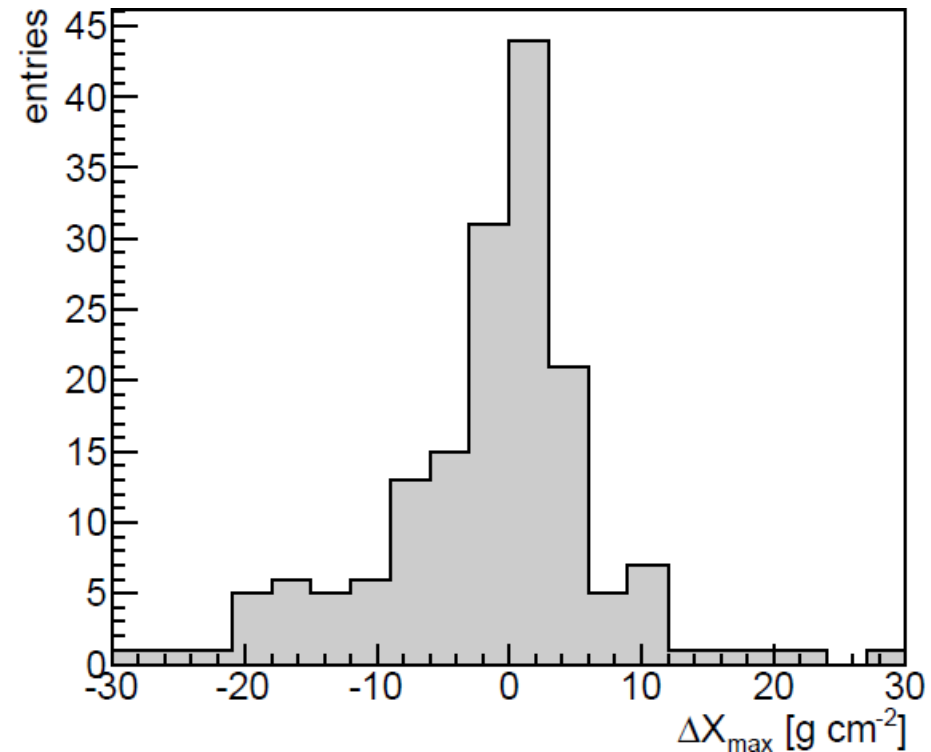
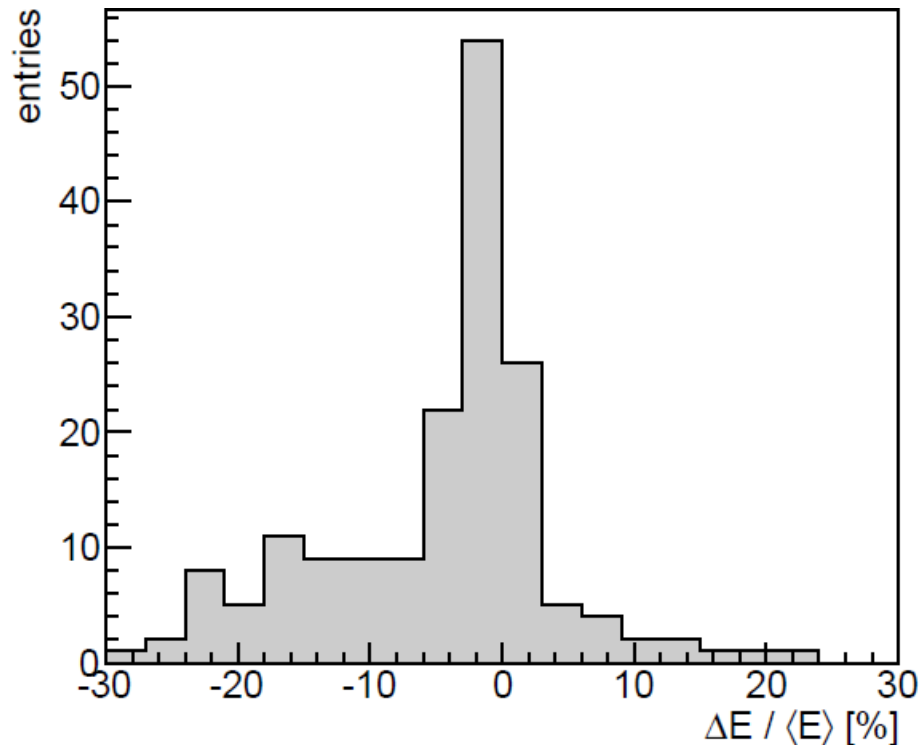


# Online Reconstruction



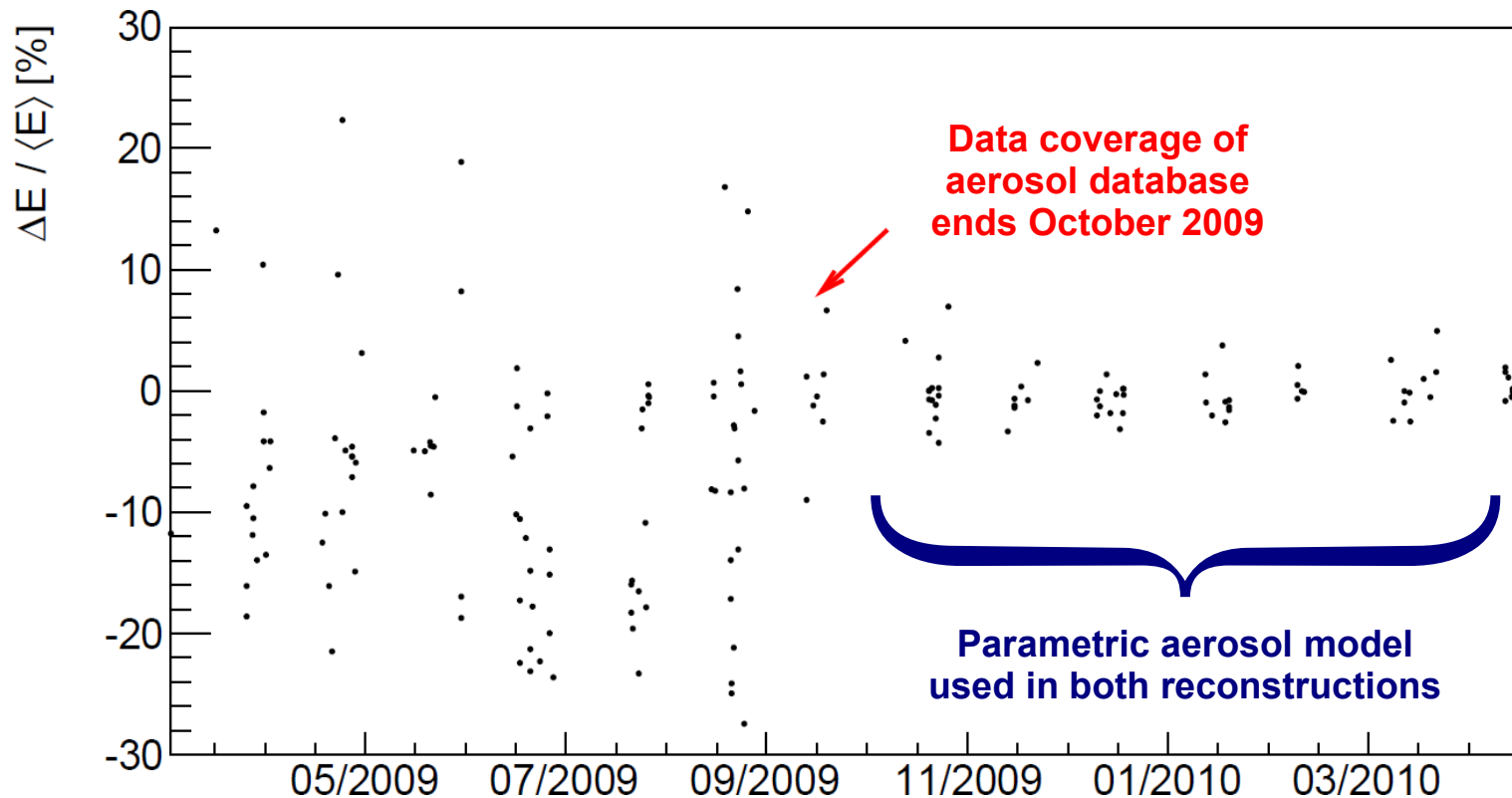


- Differences between online and “official” offline reconstruction





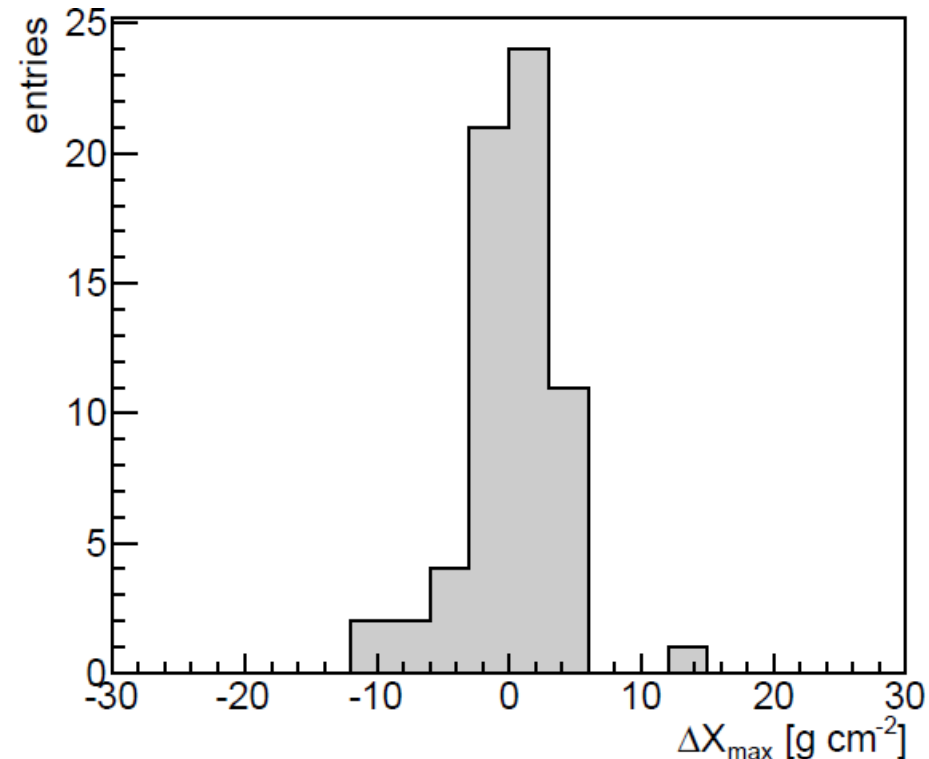
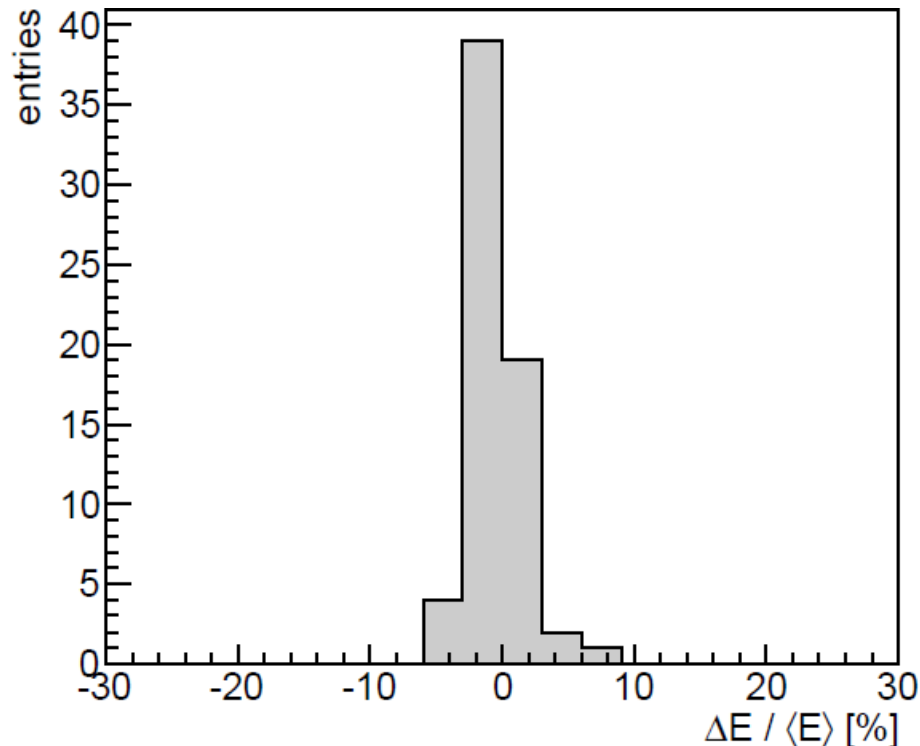
# Online Reconstruction

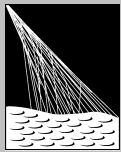




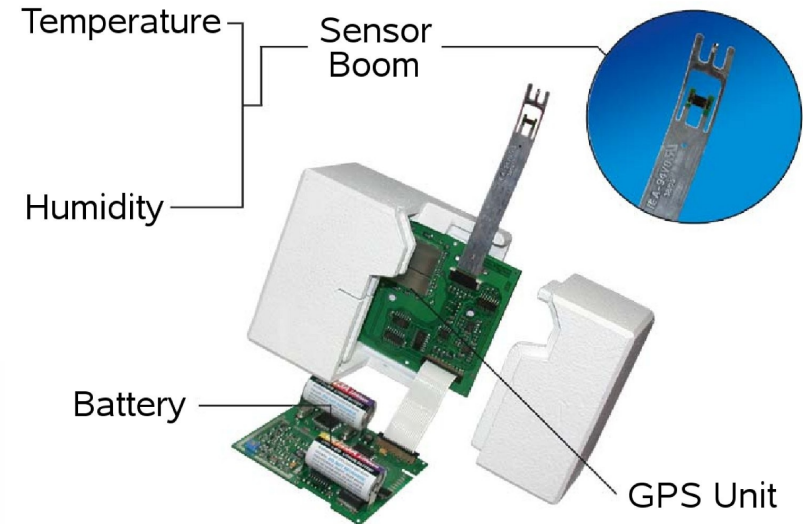
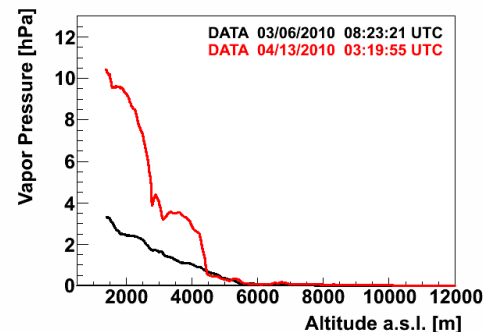
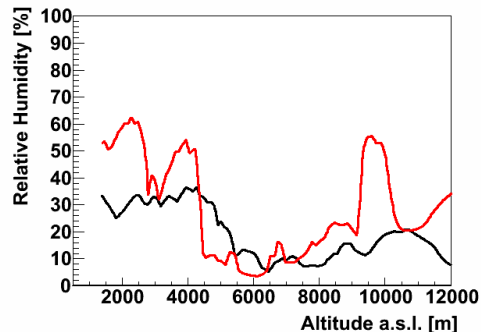
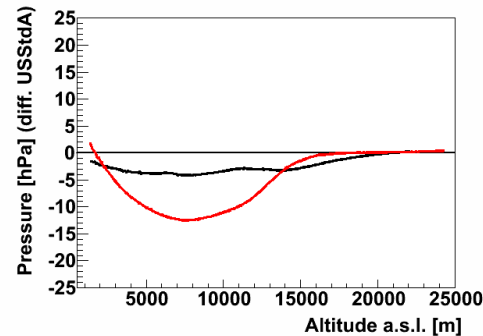
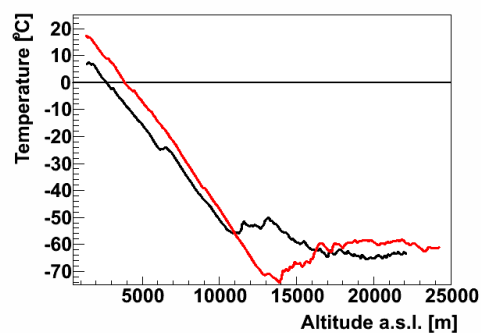
# Online Reconstruction

- After October 2009
  - Both reconstructions use same aerosol data
  - Good agreement of reconstructed parameters
  - Need for better parametric aerosol model





# Balloon-the-Shower (BtS)



## Measured

## Derived

- Temperature
- Pressure
- Rel. humidity
- Wind

- Vapor pres.
- Density
- Atm. depth



# BtS Chain

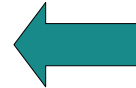
Online hybrid  
reconstruction



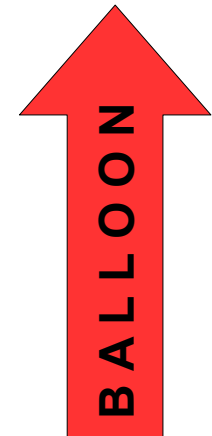
Shell script starts  
analysis program  
every 15 minutes



Short message to  
on-site technician



Quality cuts on  
rec. parameters &  
energy threshold



Technician drives to BLS,  
performs sounding  
(~ 30 min. drive,  
15 min. preparations)



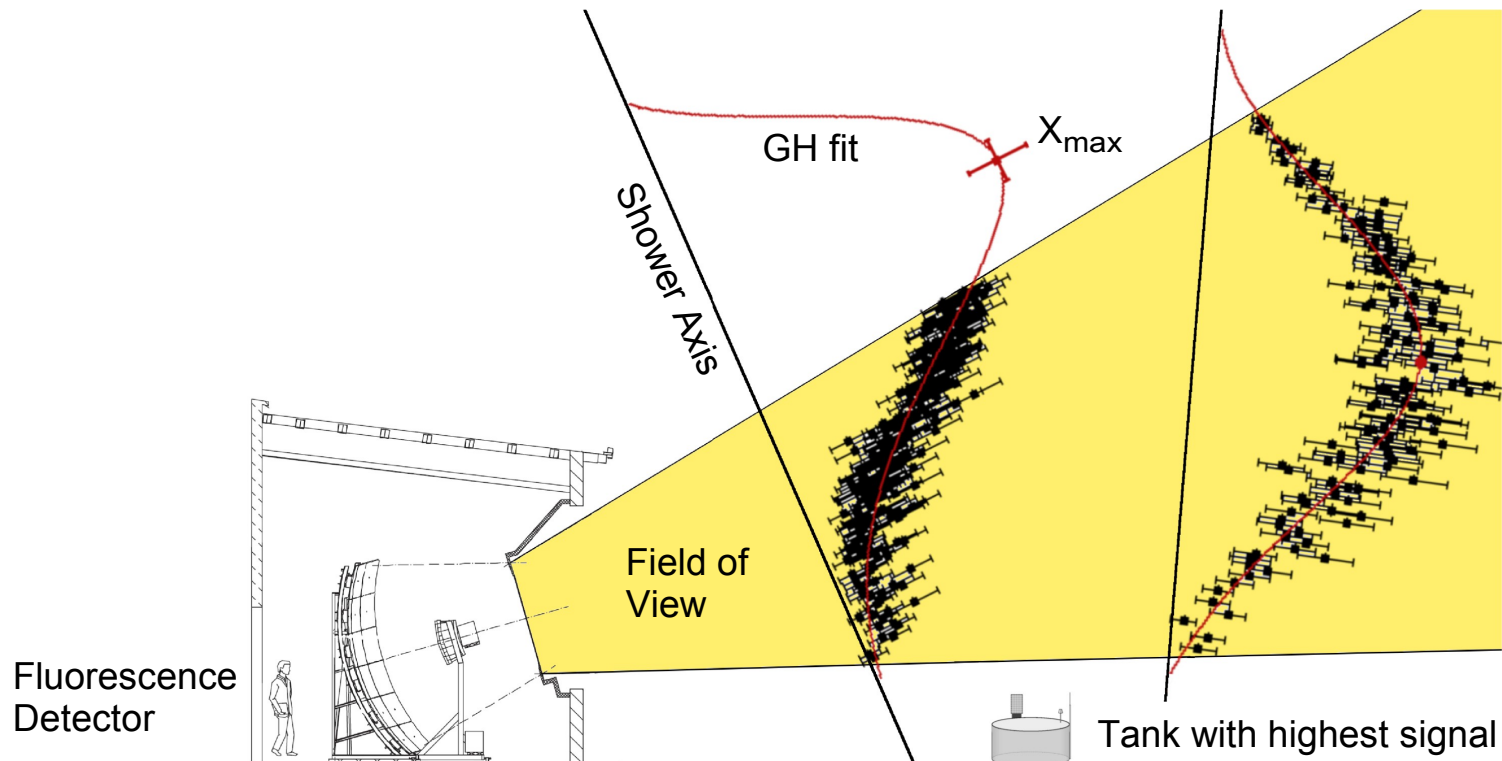
**Balloon in the air within  
2 hours after detection of  
interesting event**





# BtS Cuts

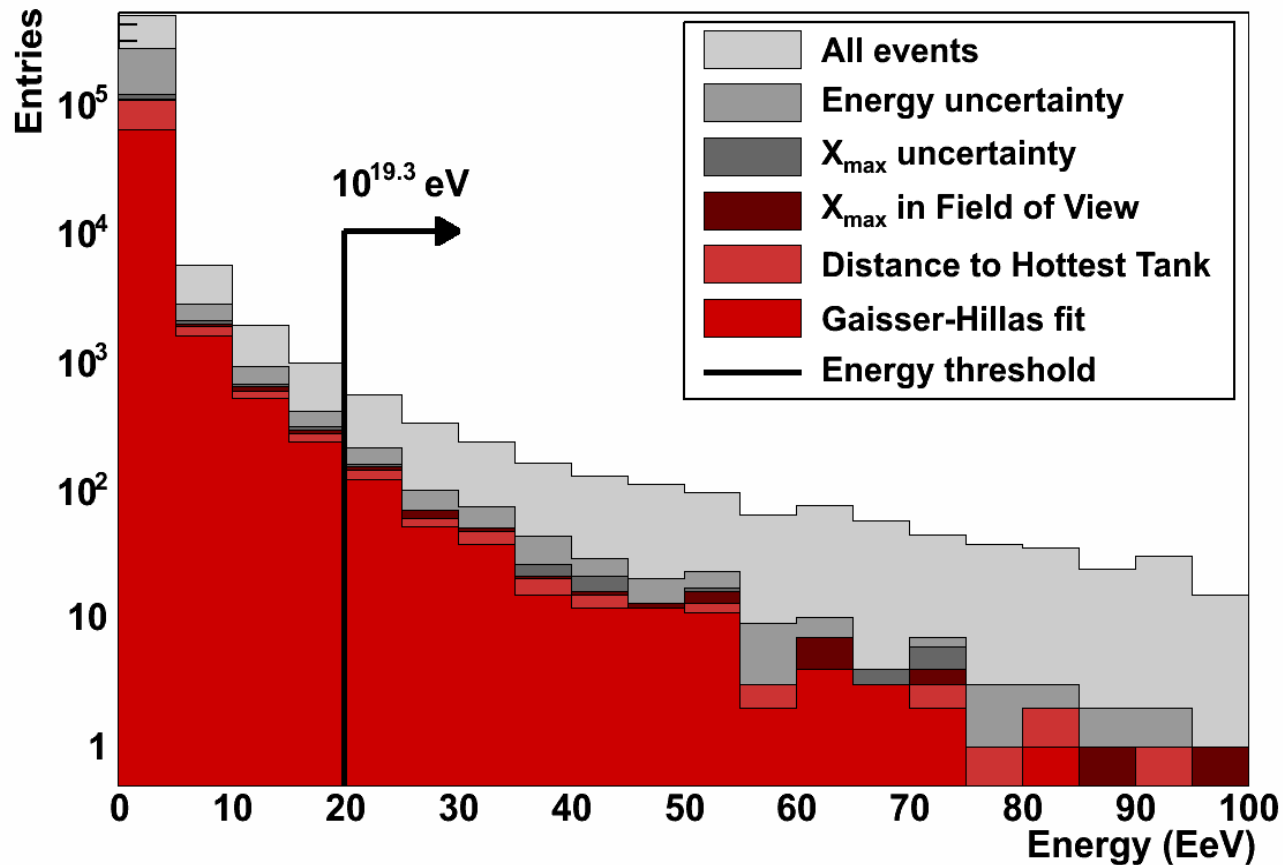
- Uncertainty of energy  $< 20\%$
- Uncertainty of  $X_{\max}$   $< 40 \text{ g cm}^{-2}$
- $X_{\max}$  well within of observed track
- Shower axis – SD tank  $< 1500 \text{ m}$
- $\chi^2(\text{Gaisser-Hillas fit}) / N_{\text{dof}} < 2.5$
- $\chi^2(\text{GH fit}) - \chi^2(\text{linear fit}) < 4$





# BtS Energy Threshold

## Expected BtS triggers 2006–2009



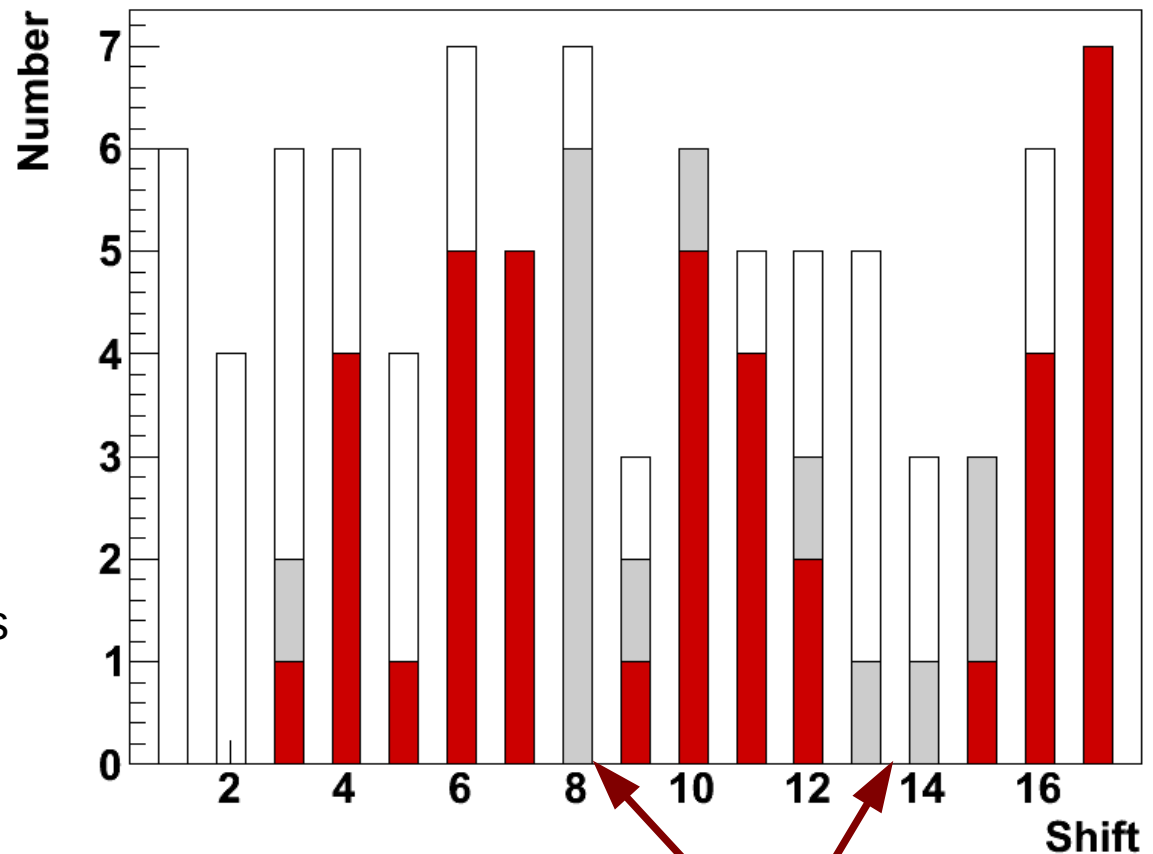
between 2 and 5 per shift



# BtS Statistics

Jan 2009 – May 2010

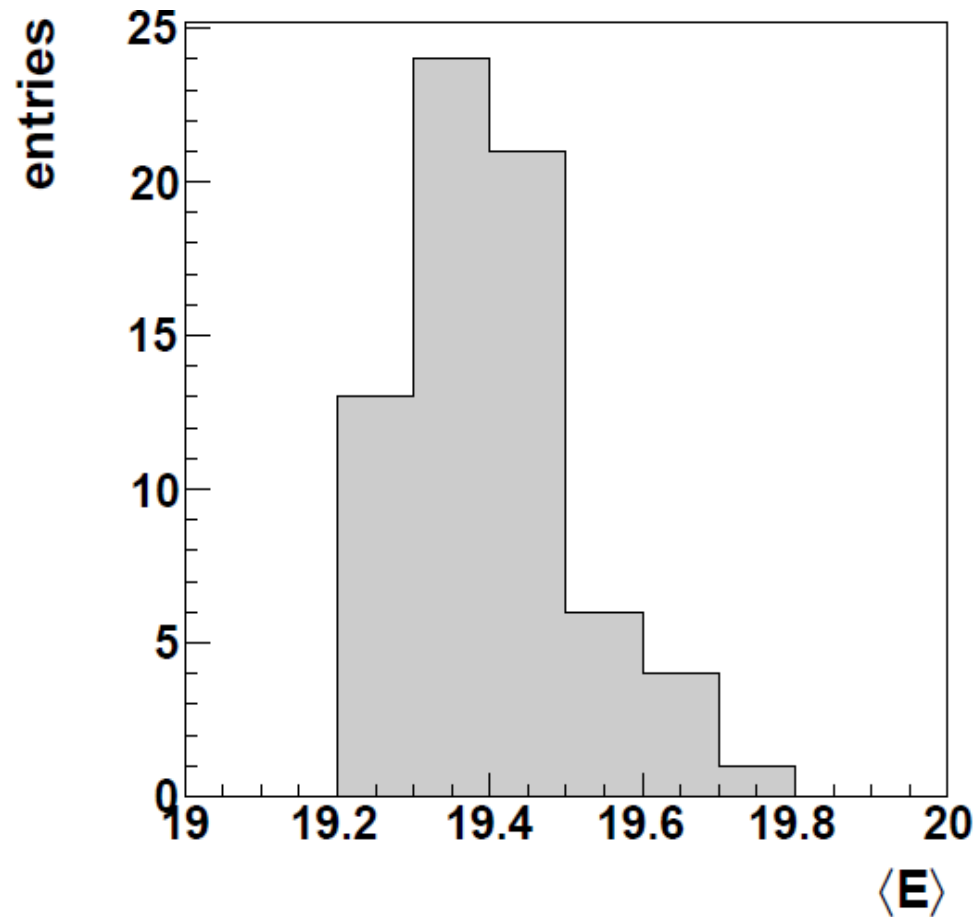
- White: Number of offline rec. showers that pass BtS cuts
- Grey: Number of texts sent after one of those events
- Red: Number of launches after one of those messages



Hardware and software problems at BLS, etc.

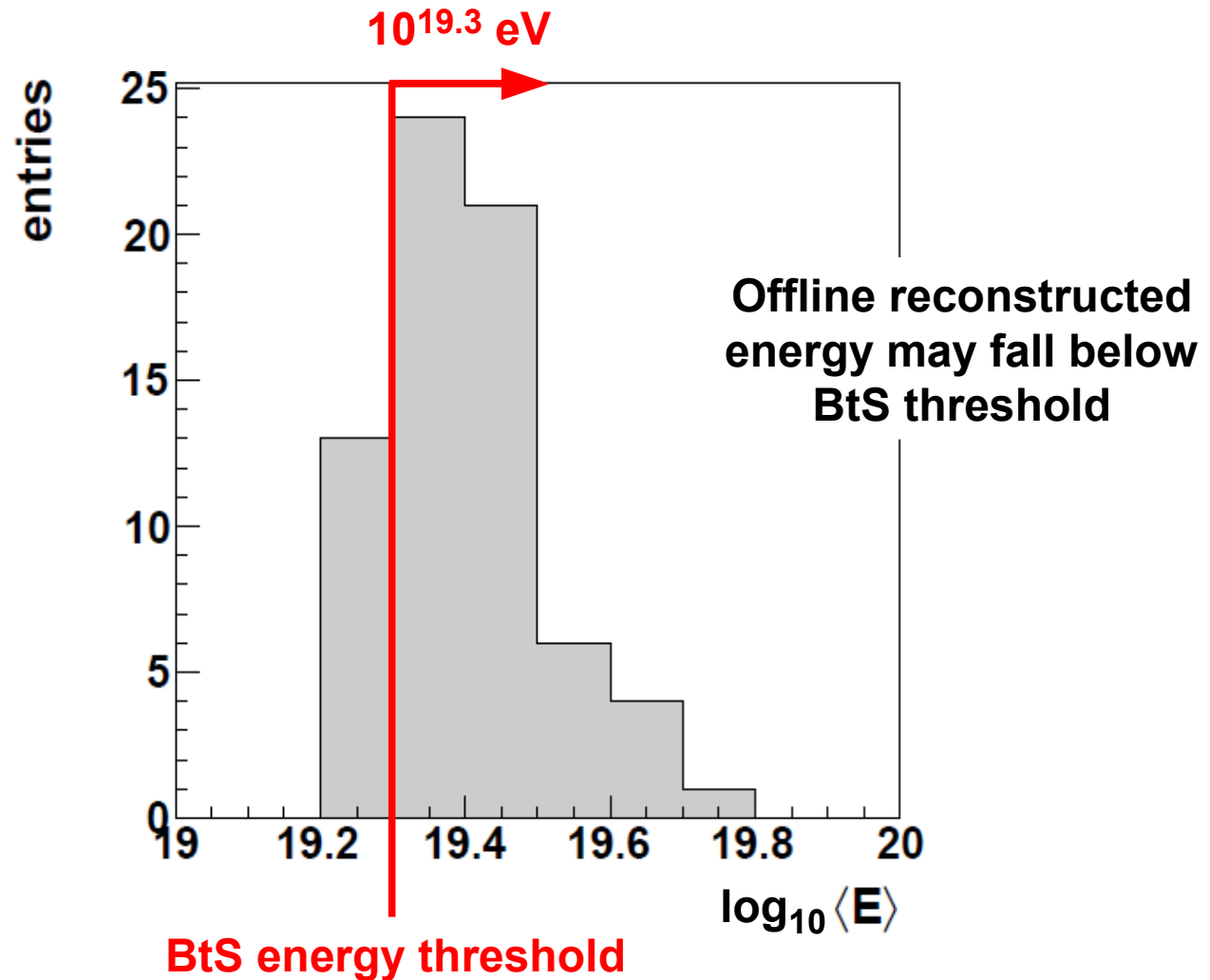


# Selected BtS Events





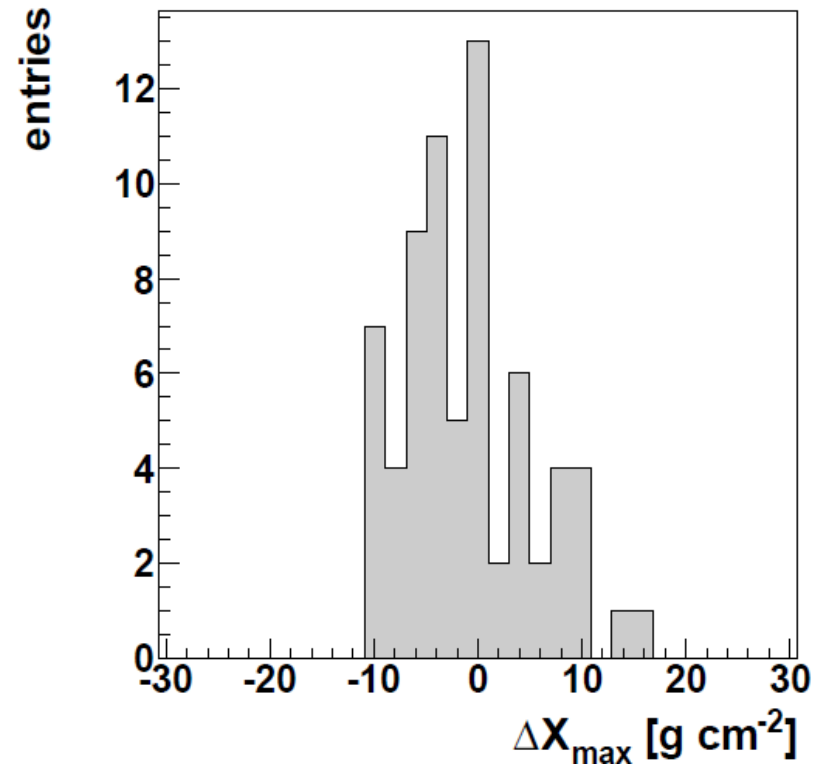
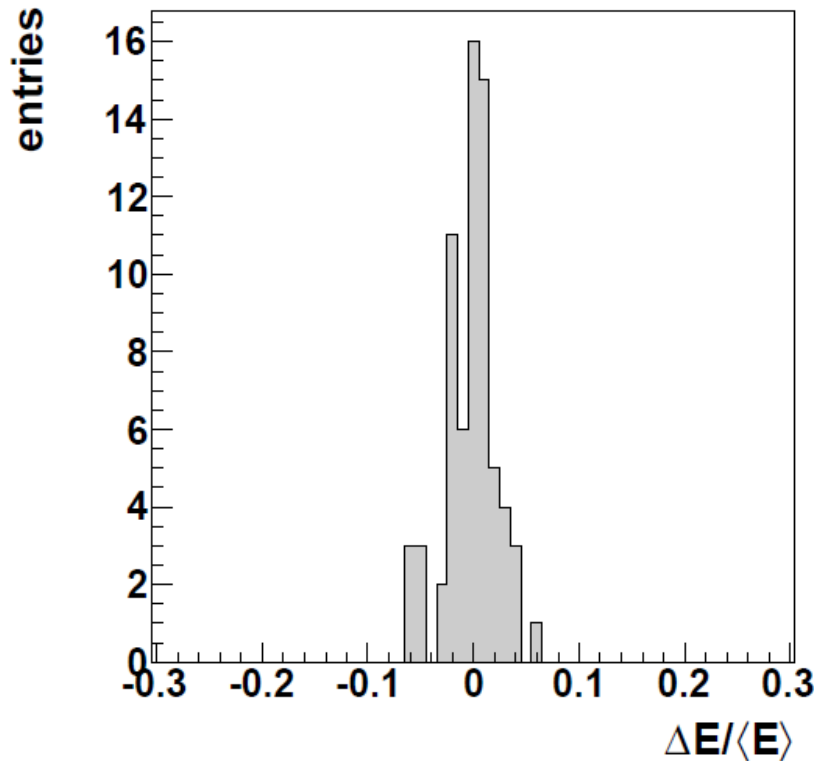
# Selected BtS Events

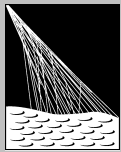




# Reconstructions with BtS

compared with monthly models



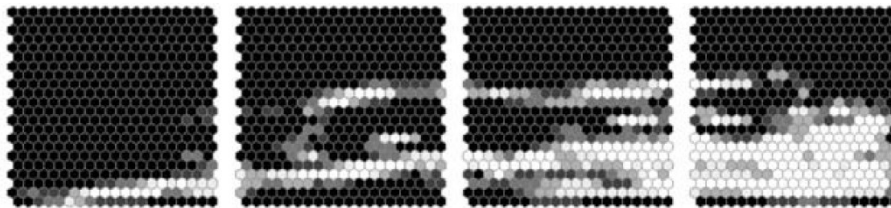


# Shoot-the-Shower (StS)

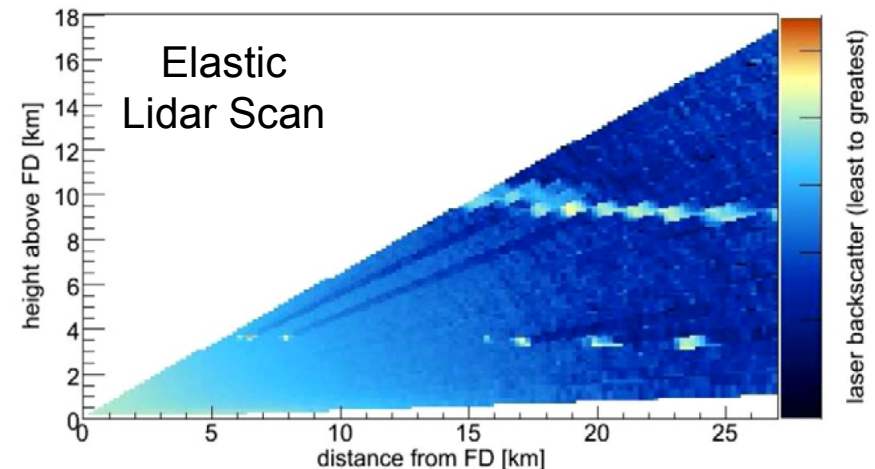
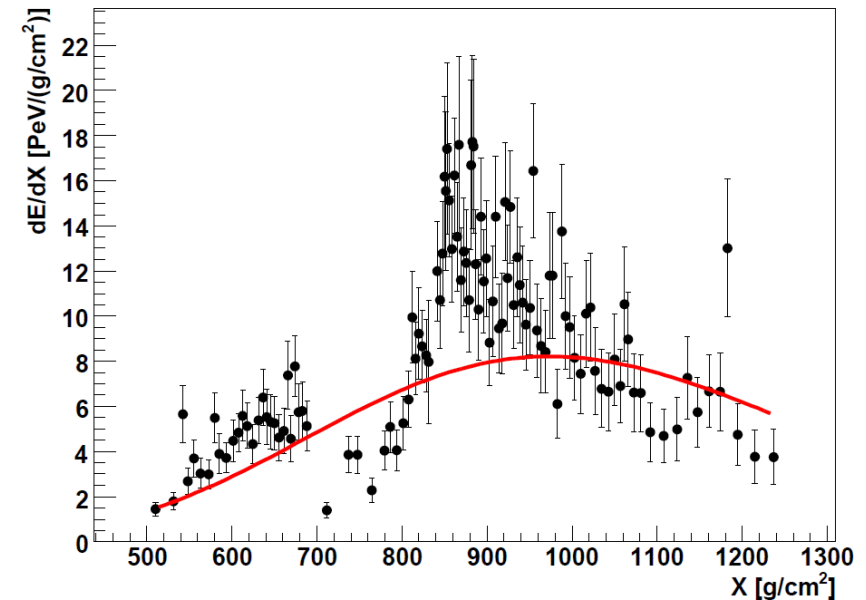
- Bumps, holes, spikes in light profile
  - Clouds obstructing light
  - Unusual particle interactions
  - Exotic particle interactions

- Was there a cloud in the FoV of a certain FD?

- Was it seen by the hourly scan?

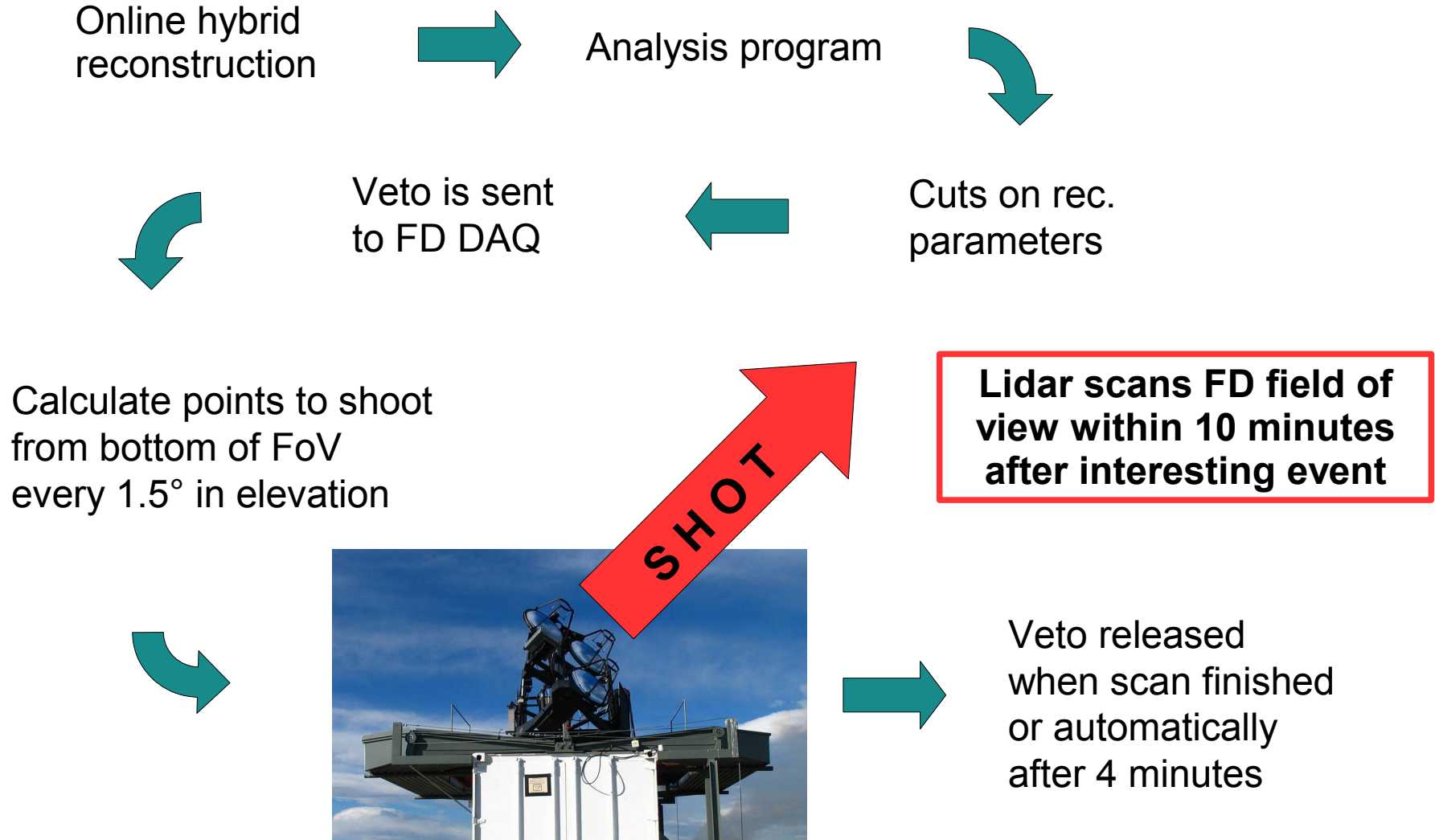


IR Cloud Camera





# StS Chain





# StS Cuts

## High-quality, high-energetic showers

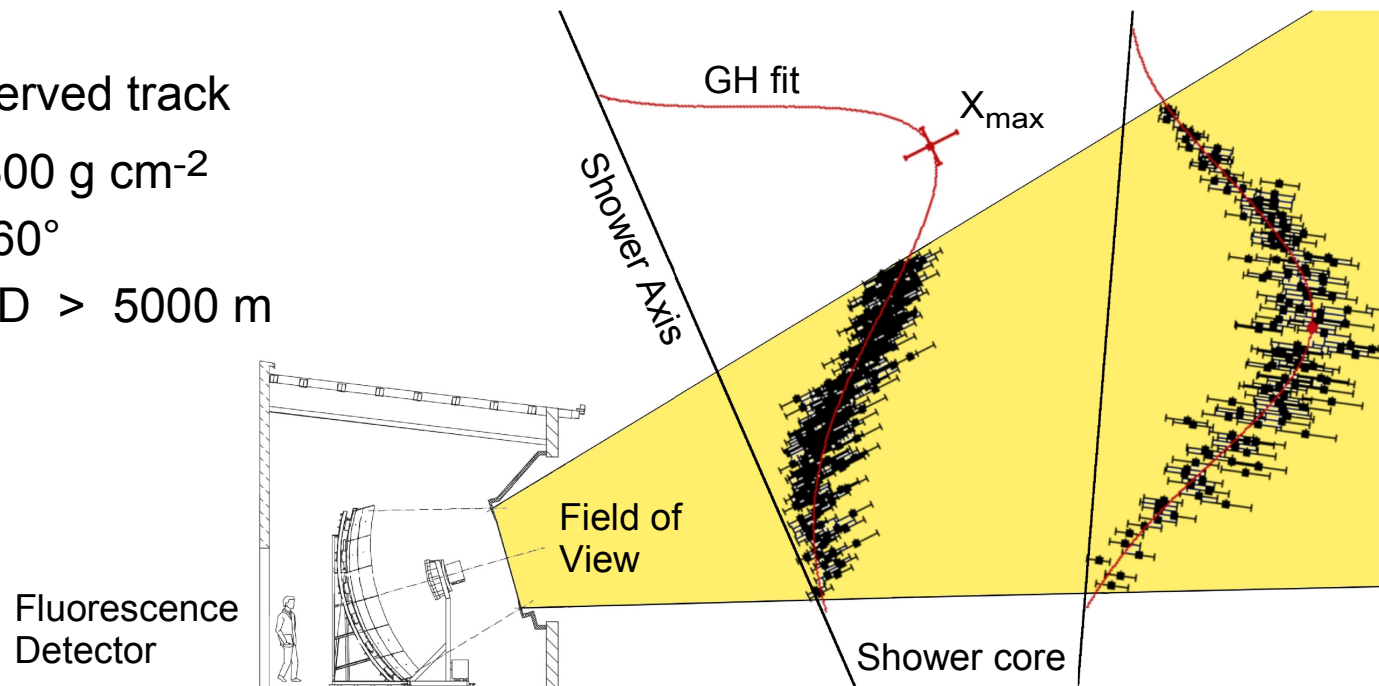
- Energy  $\geq 20$  EeV
- Uncertainty of energy  $\leq 20\%$
- $\chi^2(\text{Gaisser-Hillas fit}) / N_{\text{dof}} < 2.5$
- $\chi^2(\text{GH fit}) < \chi^2(\text{linear fit})$

## Showers with interesting profiles

- Energy  $\geq 15$  EeV
- Uncertainty of energy  $> 25\%$
- $\chi^2(\text{Gaisser-Hillas fit}) / N_{\text{dof}} \geq 2.5$
- $\chi^2(\text{GH fit}) < 2 \cdot \chi^2(\text{linear fit})$

## Additional cuts

- $X_{\text{max}}$  part of observed track
- Track length  $\geq 300 \text{ g cm}^{-2}$
- Zenith angle  $\leq 60^\circ$
- Shower core – FD  $> 5000 \text{ m}$





# StS Cuts

## High-quality, high-energetic showers

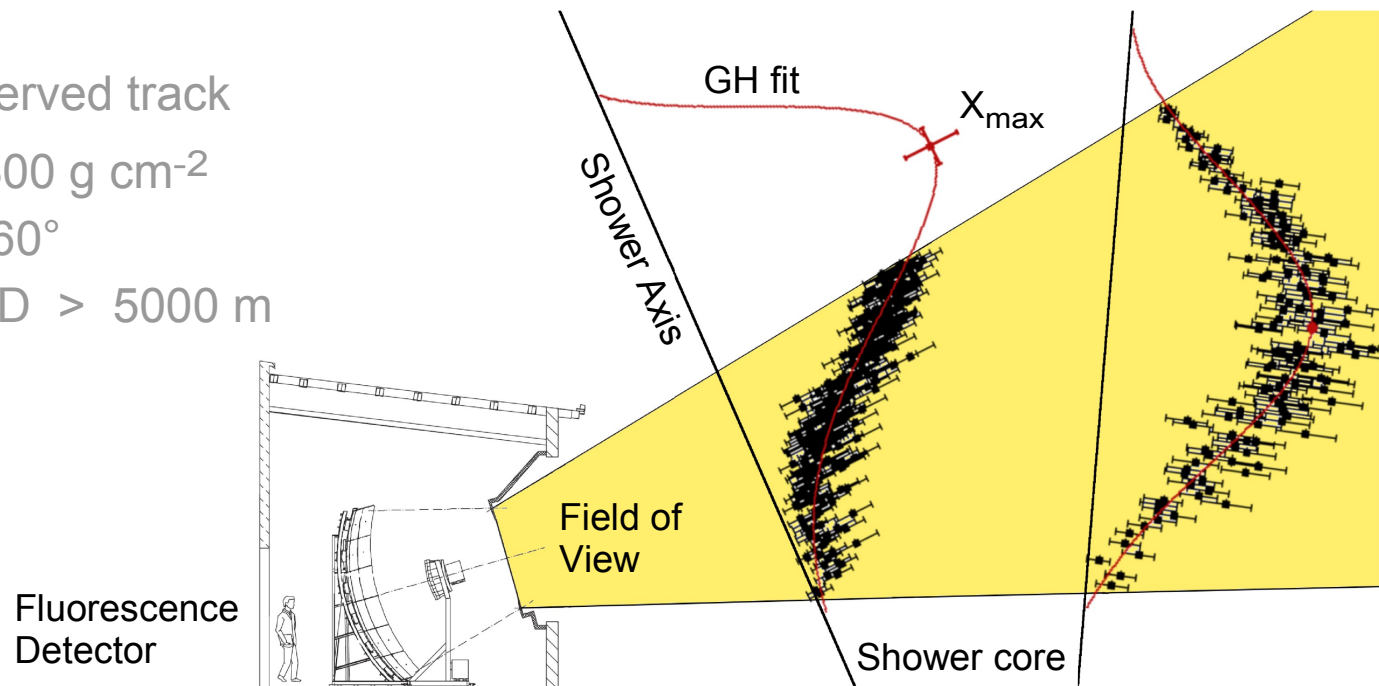
- Energy  $\geq 20$  EeV
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- $\chi^2(\text{Gaisser-Hillas fit}) / N_{\text{dof}} < 2.5$
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## Additional cuts

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## Showers with interesting profiles

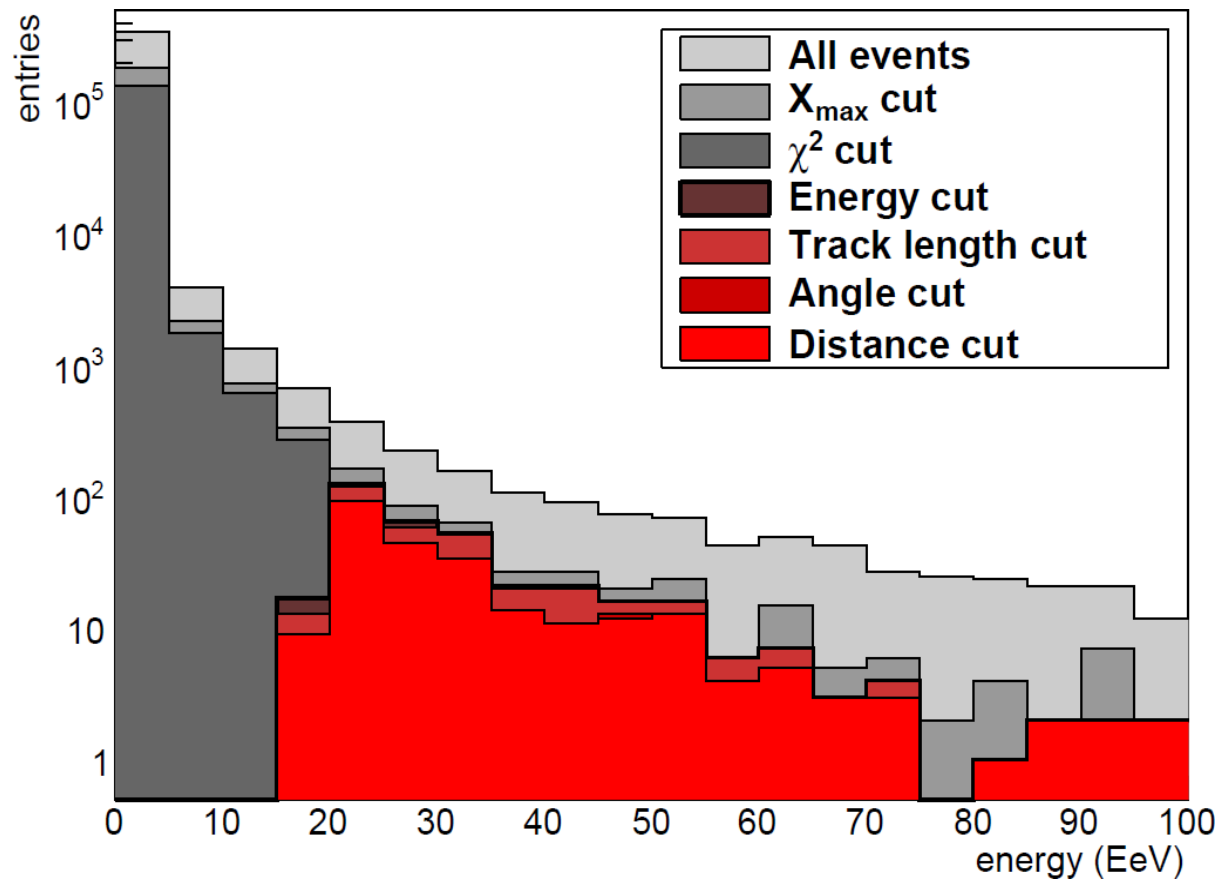
- Energy  $\geq 15$  EeV
- Uncertainty of energy  $> 25\%$
- $\chi^2(\text{Gaisser-Hillas fit}) / N_{\text{dof}} \geq 2.5$
- $\chi^2(\text{GH fit}) < 2 \cdot \chi^2(\text{linear fit})$





# StS Cuts

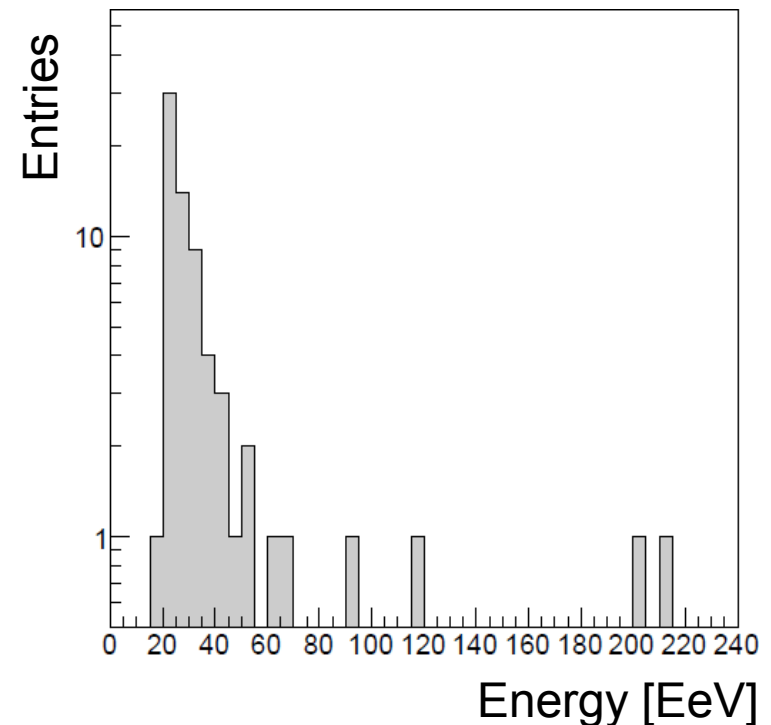
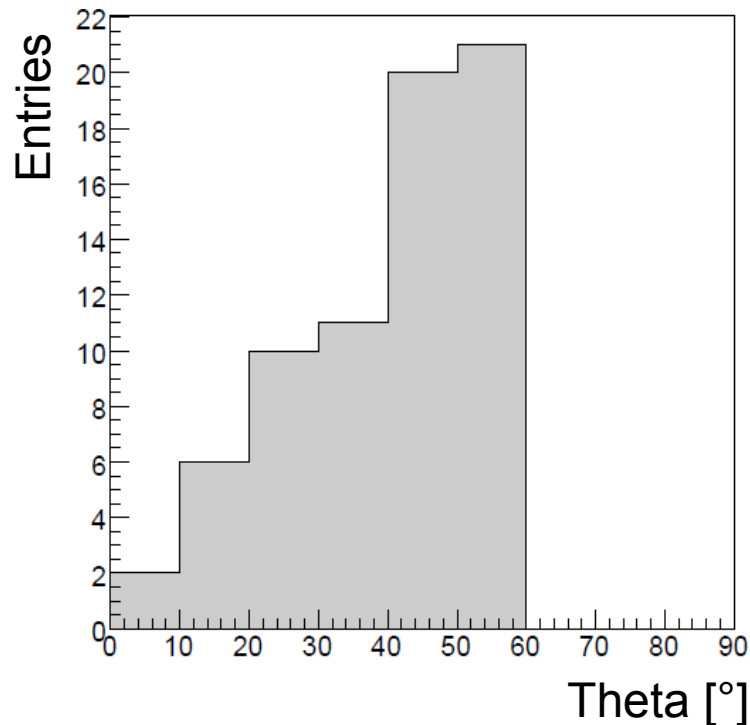
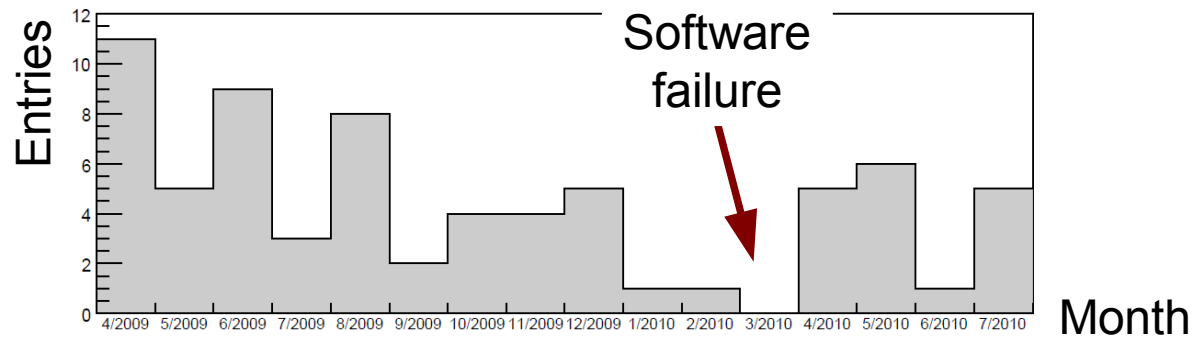
## Expected StS triggers 2006–2008



**between 2 per night in winter and 2 per shift in summer**

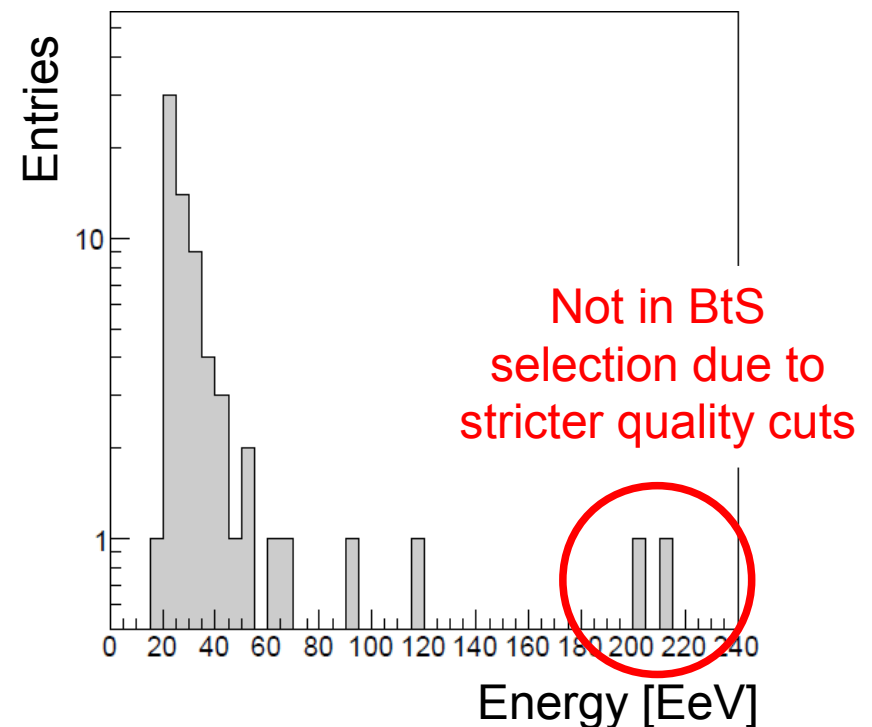
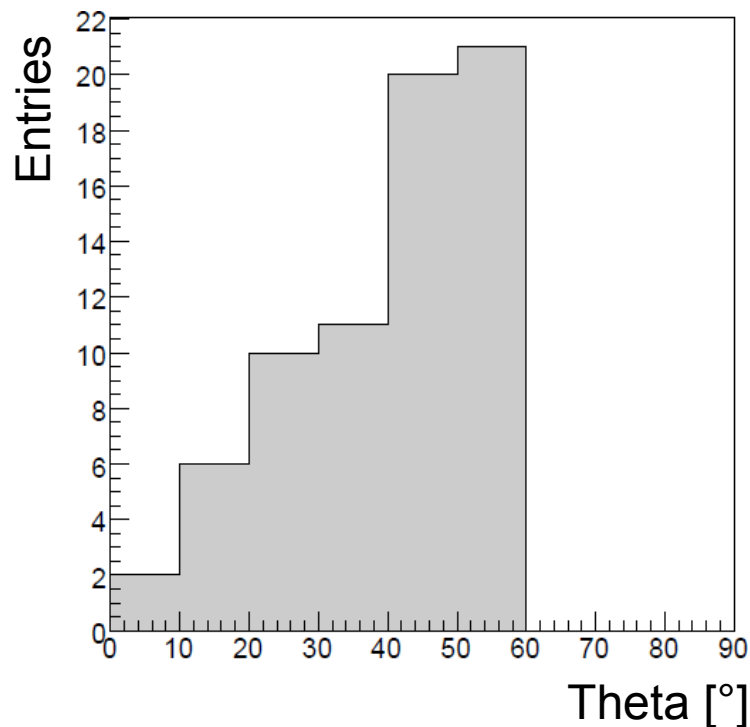
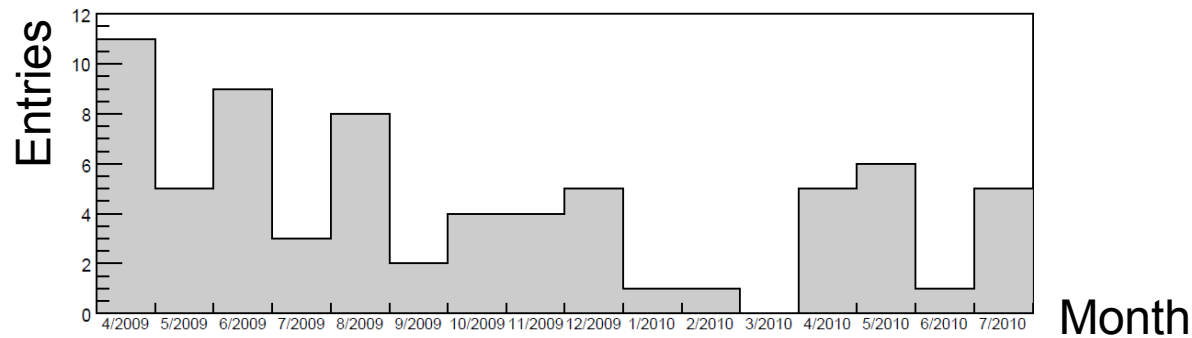


# StS Statistics



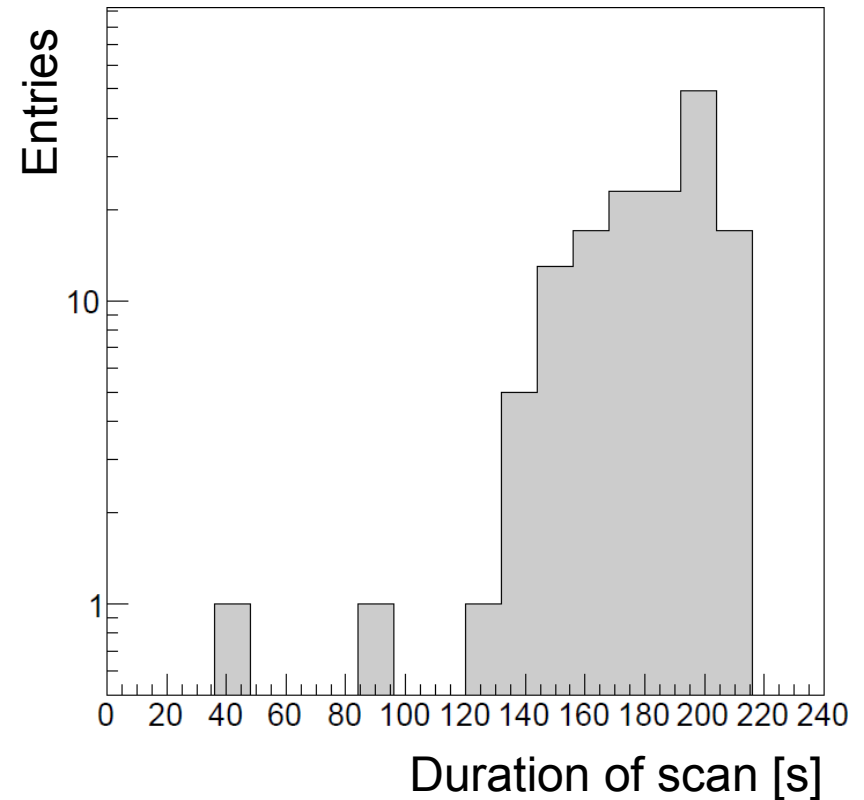
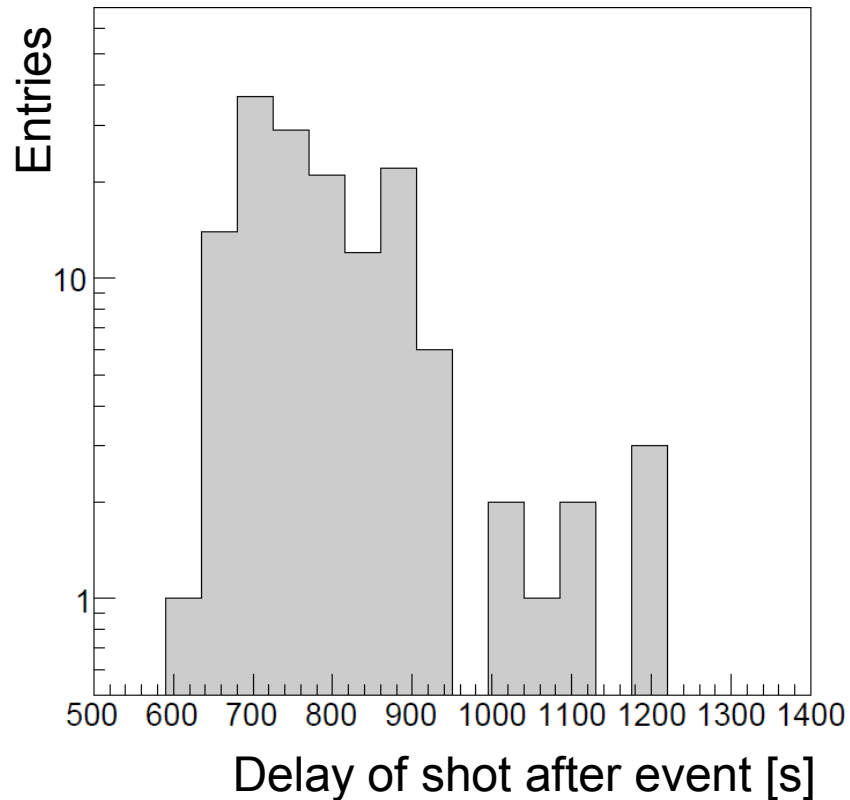


# StS Statistics





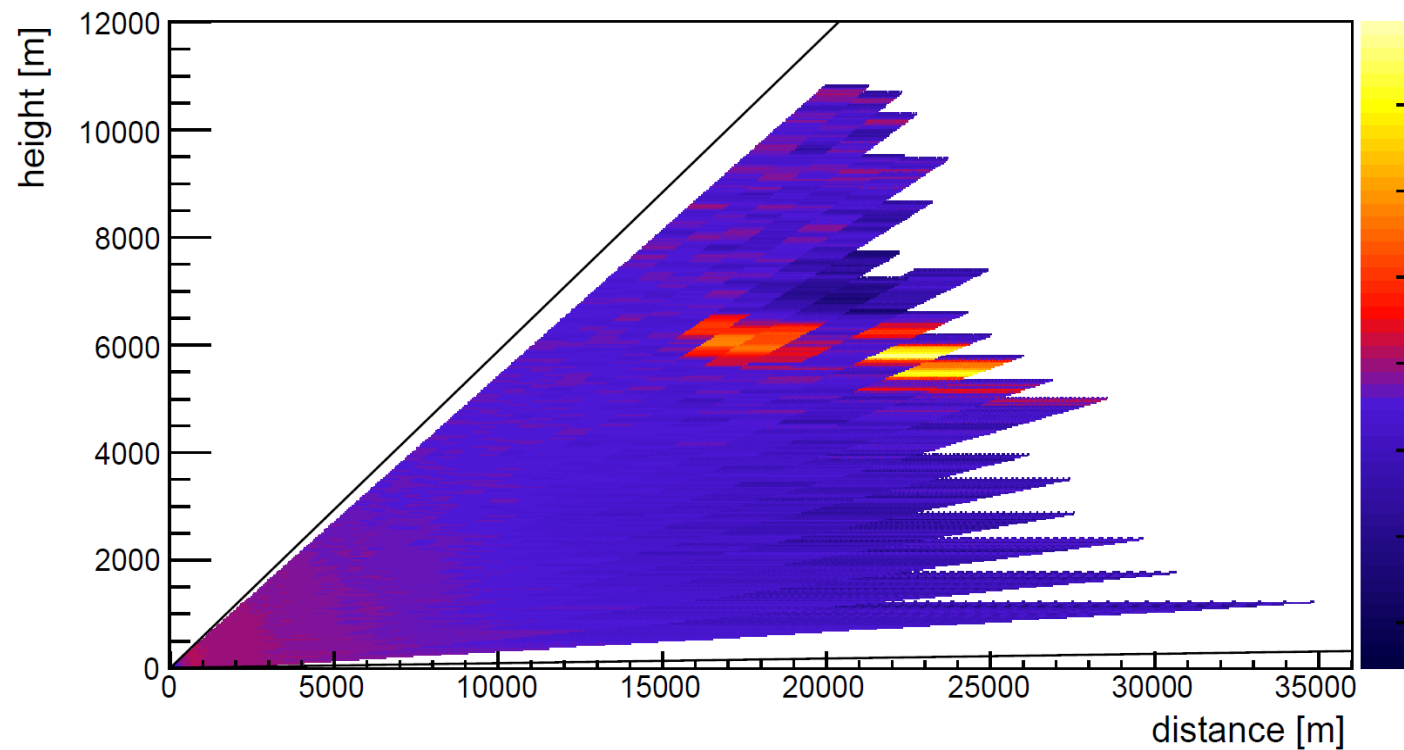
# StS Statistics





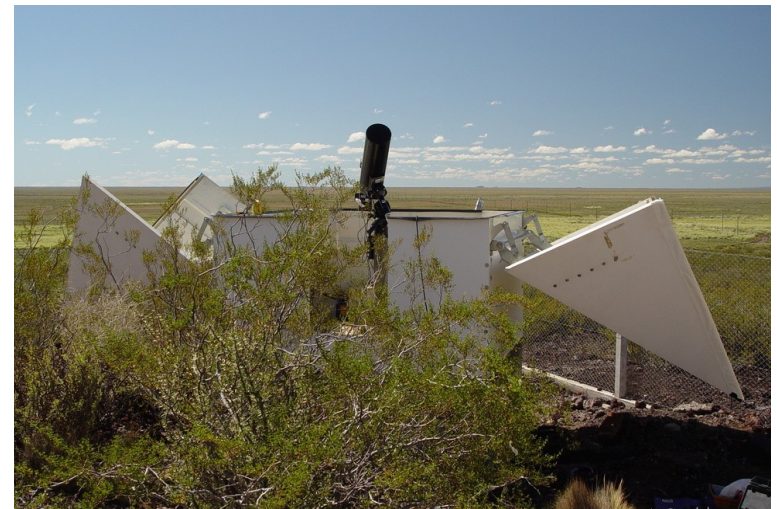
# StS Results

- Several clouds were identified in the FoV
- Some in periods of  $< 20\%$  cloud coverage
- Smaller, localized clouds





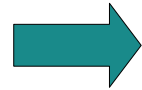
- **F/(Ph)otometric Robotic Atmospheric Monitor**
- Passive measurement
- 4° x 2.67° CCD camera
- For rapid monitoring: 435nm filter
  
- Capture picture of night sky
- Get Astrometry
  - Identify non-variable stars
  - Compare with catalog magnitude
- Calculate optical properties
  - $k = (m_{obs} - m_{tab}) / X_{airmass}$





# FRAM Chain

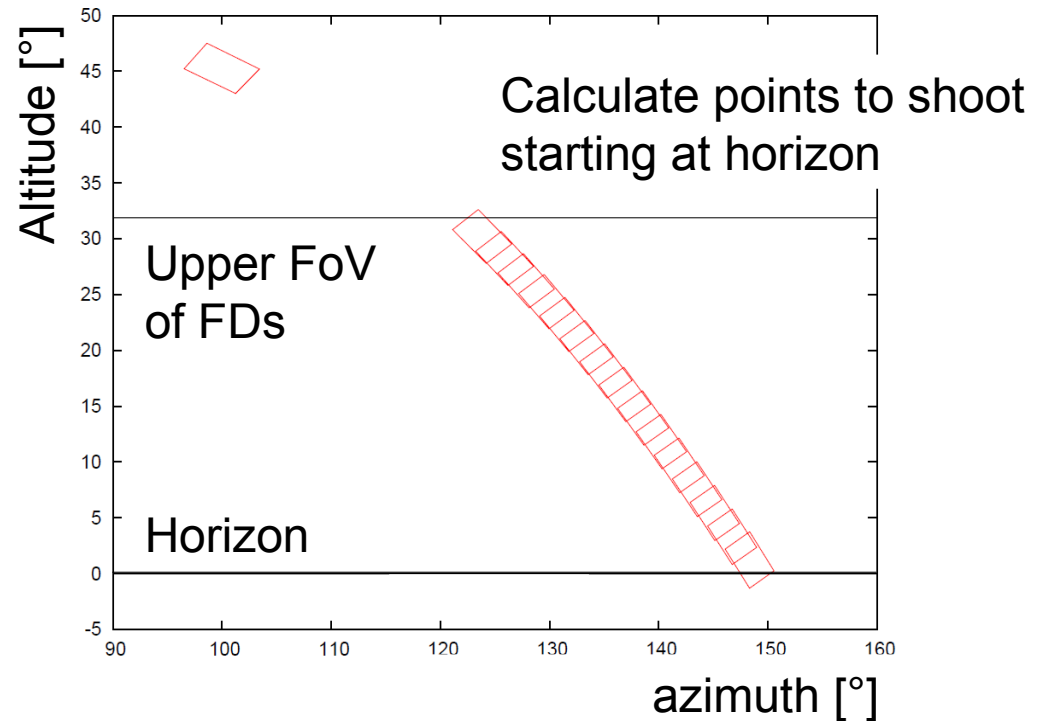
Online hybrid  
reconstruction



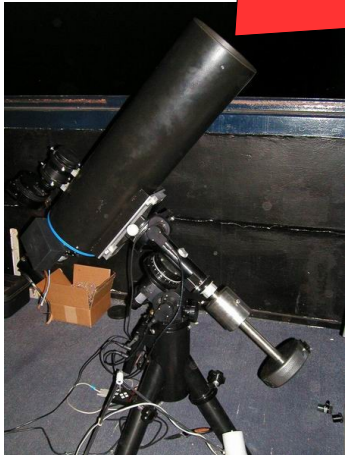
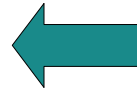
Analysis program



Cuts on rec.  
parameters



**STARLIGHT**



Get astrometry



Calculate extinction coefficient



# FRAM Cuts

- Shower observed by Los Leones FD
- Energy  $\geq 10$  EeV

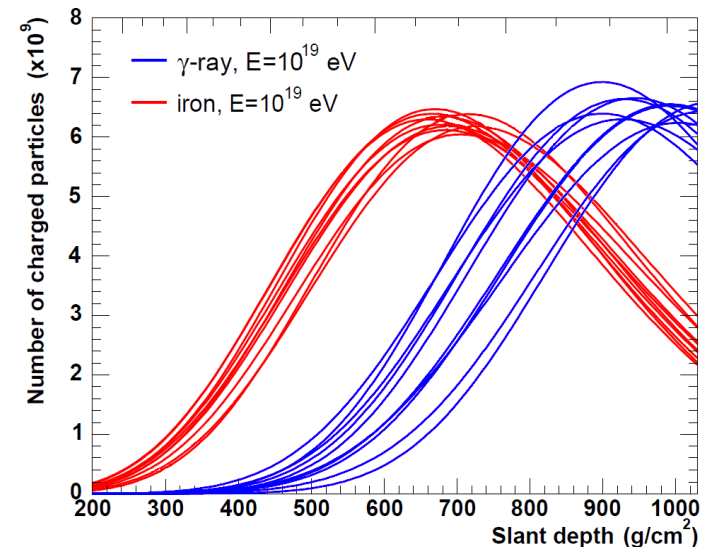
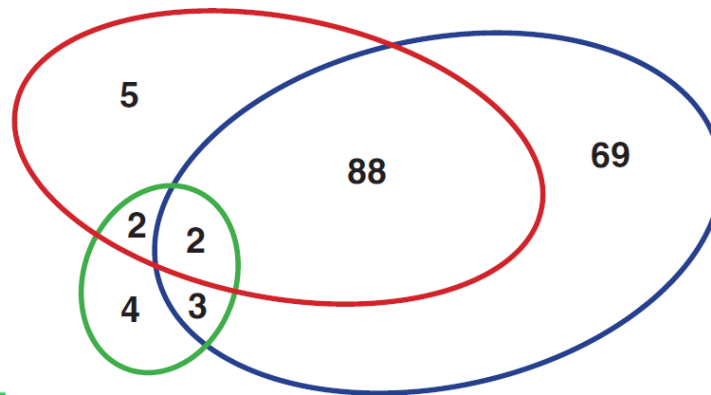
**Cut 1**  
**High-quality**

**Cut 2**  
**Photon-like**

**Cut 3**  
**Good-quality**

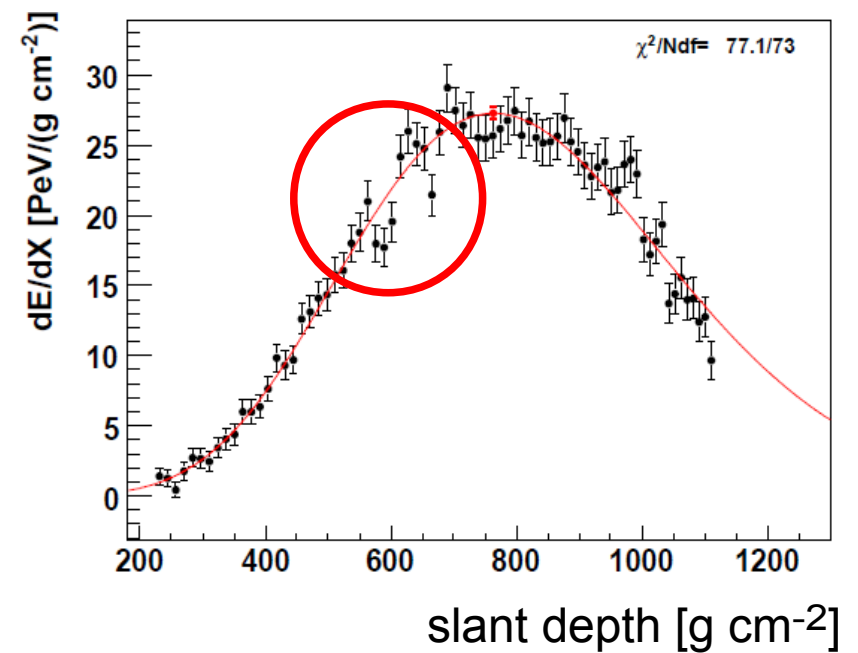
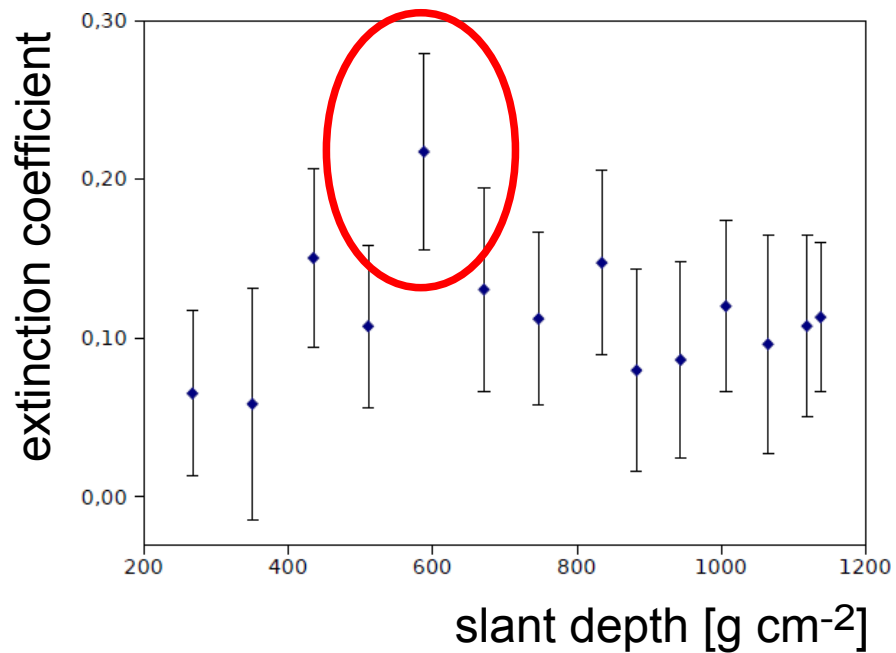
- Triggered FD PMTs  $\geq 10$

- Triggered FD PMTs  $\geq 6$
- Viewing angle  $> 15^\circ$
- Shower axis – SD tank  $< 1500$  m
- $\chi^2(\text{Gaisser-Hillas fit}) / N_{\text{dof}} < 6$
- $\chi^2(\text{GH fit}) / \chi^2(\text{linear fit}) < 0.9$





# FRAM Results

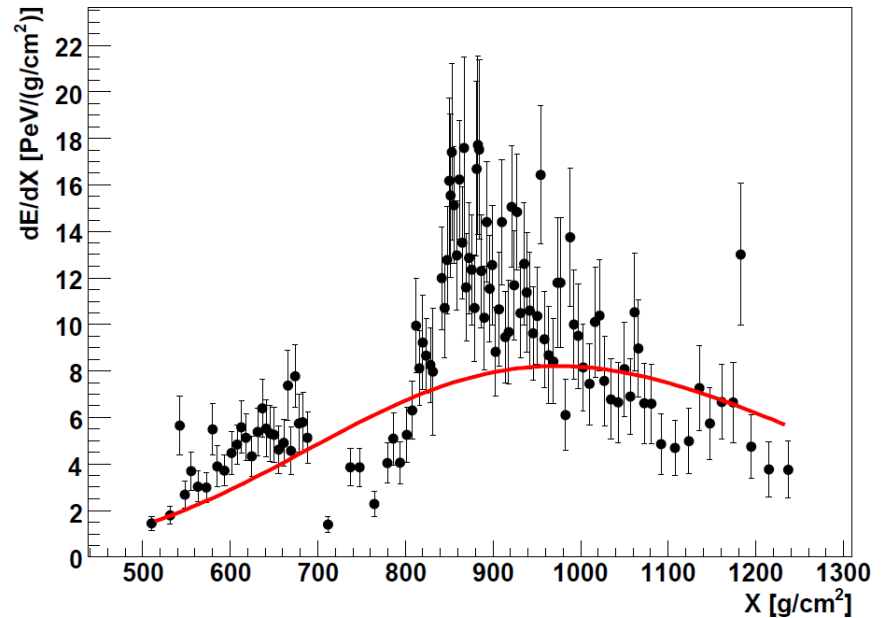




# Outlook

- Implement new triggers for **double bump showers** in StS and FRAM

- Fit two GH to profile



- Include **Raman lidar** in rapid monitoring
- BtS ends this year
  - Profiles provided by GDAS data
  - see talk #7, B. Keilhauer



# Summary

- Rapid atmospheric monitoring **started successfully in 2009**
- Online reconstruction **runs smoothly** without major disruptions
- BtS produced actual atmospheric profiles after **high-energy events**
- StS **identified clouds** that were not seen in routine scans
- FRAM data used to calculate extinction coefficient after high-quality and **photon-like events**



# BACKUP



# BtS Reconstructions

