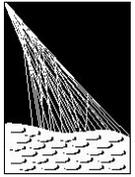


Global Atmospheric Model Data for the Pierre Auger Observatory

B. Keilhauer, D. Epperlein, M. Will for the Pierre Auger Collaboration

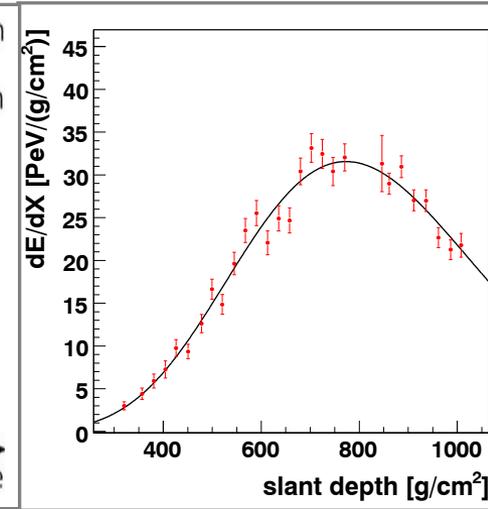
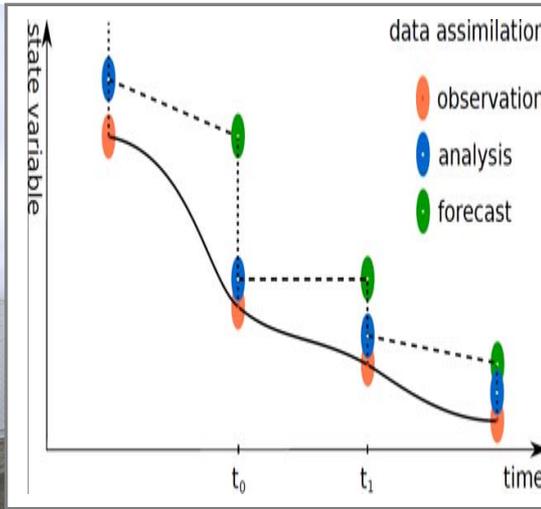
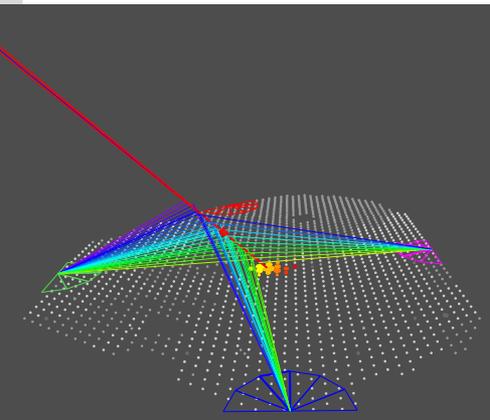
2nd Workshop on Atmospheric Monitoring in Astroparticle Physics and Astronomy

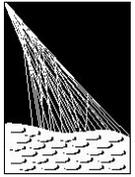




Overview

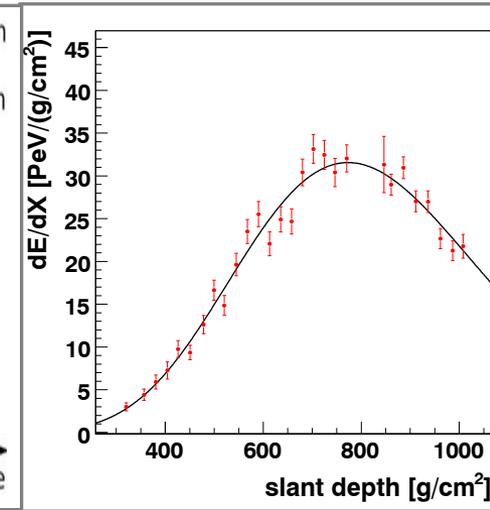
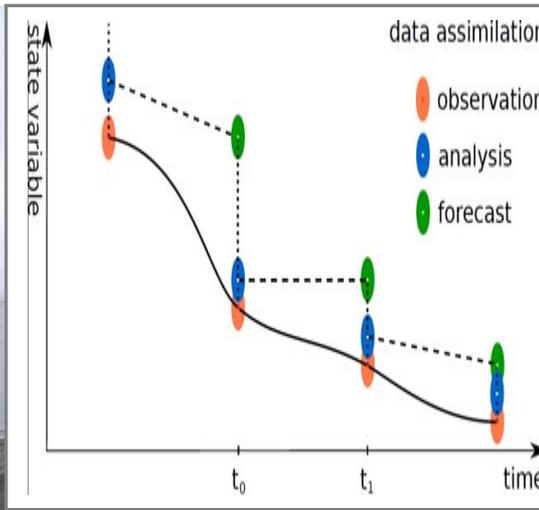
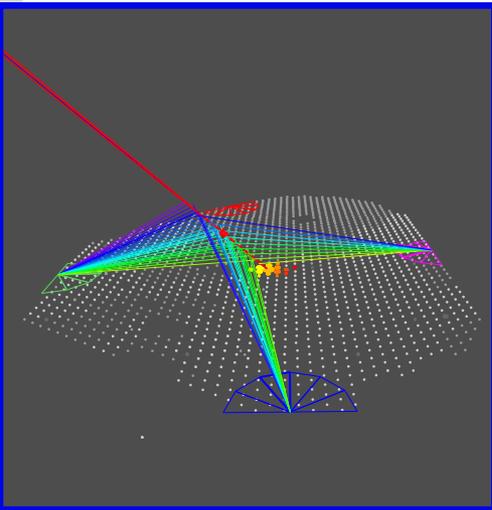
- Introduction to Cosmic Rays and the Pierre Auger Observatory
- Meteorological Radio Soundings
- Data from a Global Data Assimilation System
- Application to Air Shower Reconstruction





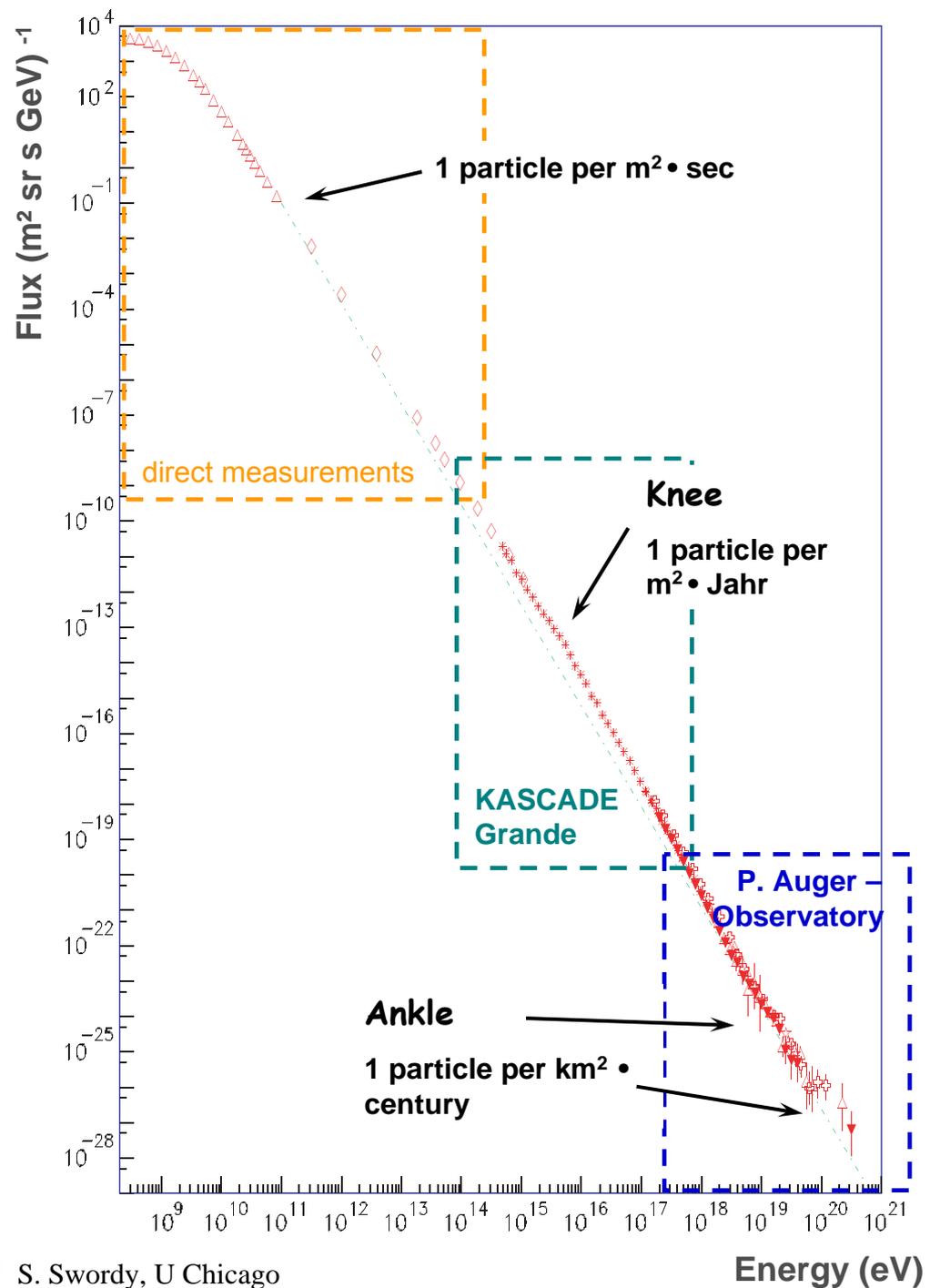
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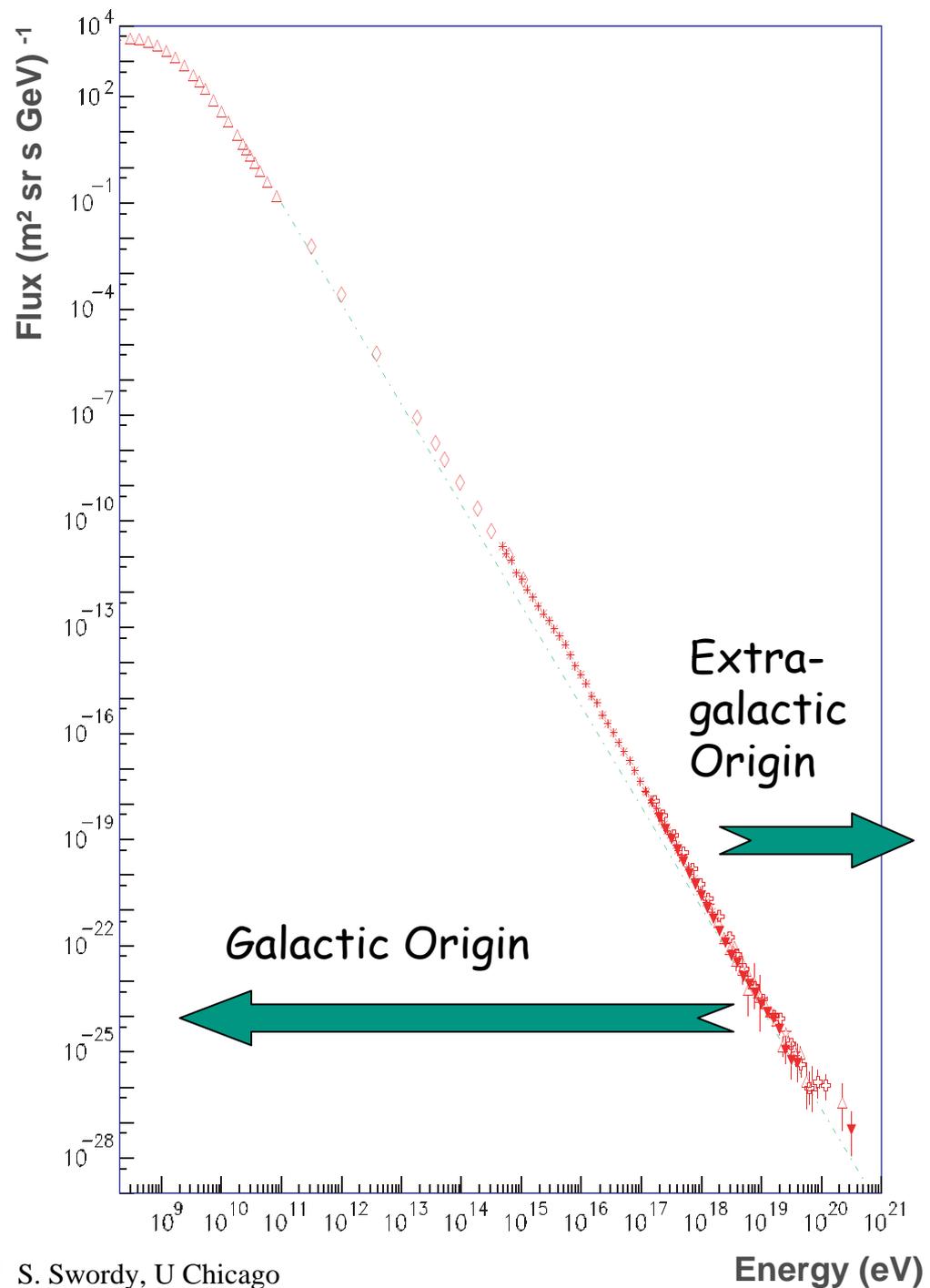
Cosmic Rays

- high energy particles from the Universe
- mostly full-ionized nuclei
- covering all elements of the periodic table of the elements, classically up to iron

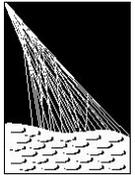


Cosmic Rays

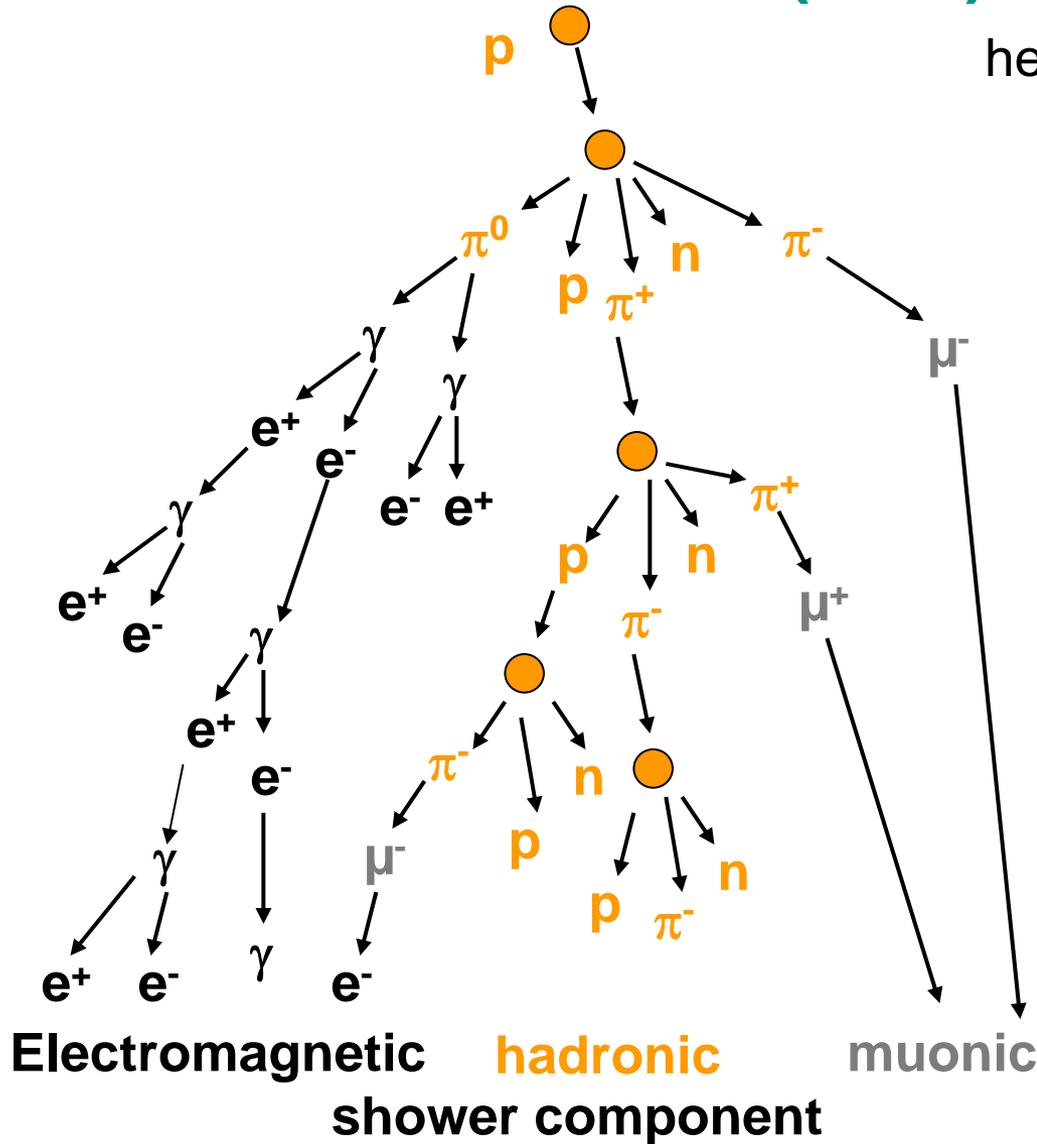
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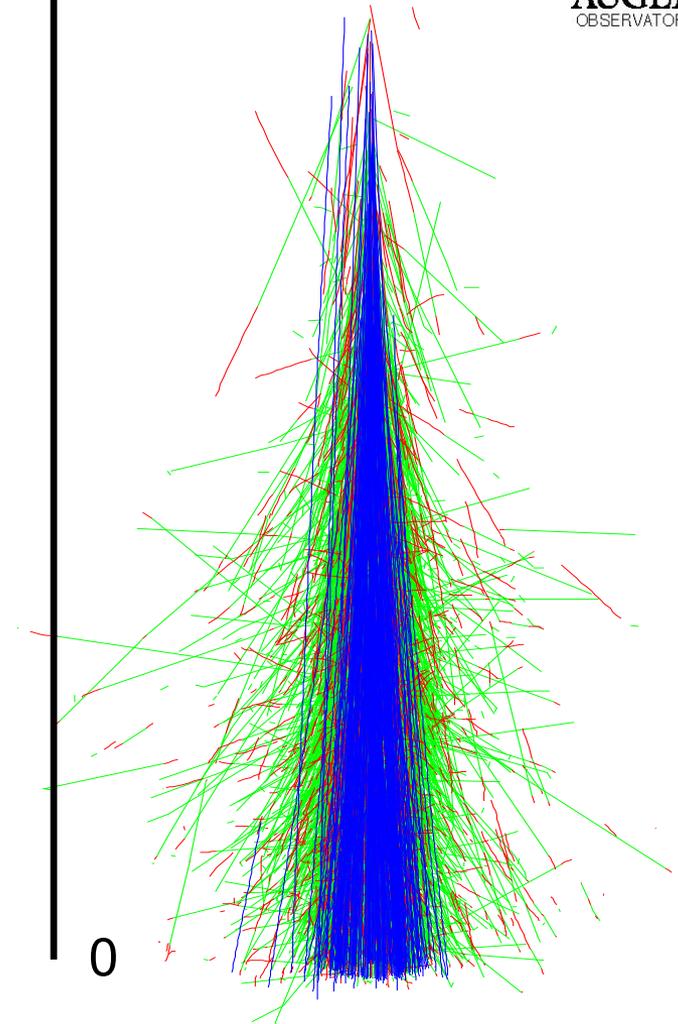
Extensive Air Shower (EAS)



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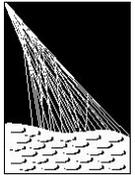


height \uparrow θ (25 km NN)

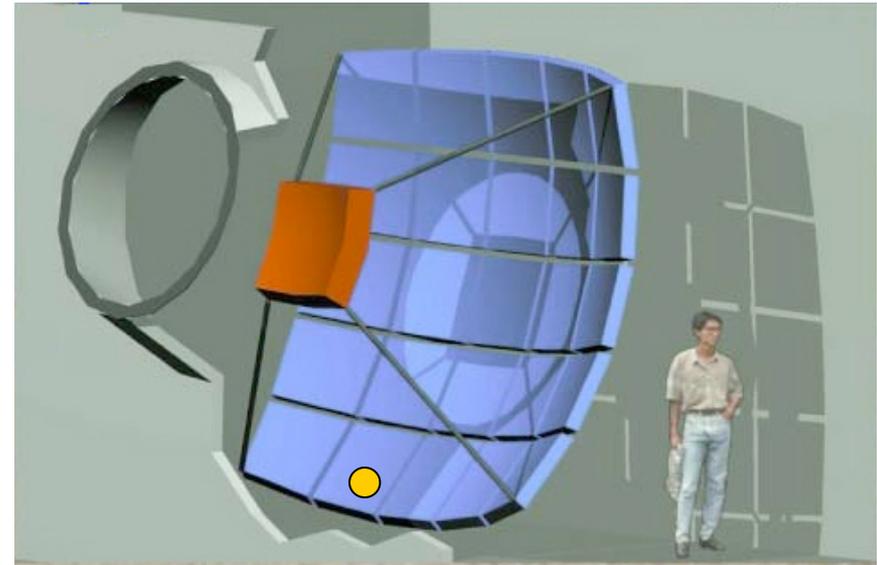
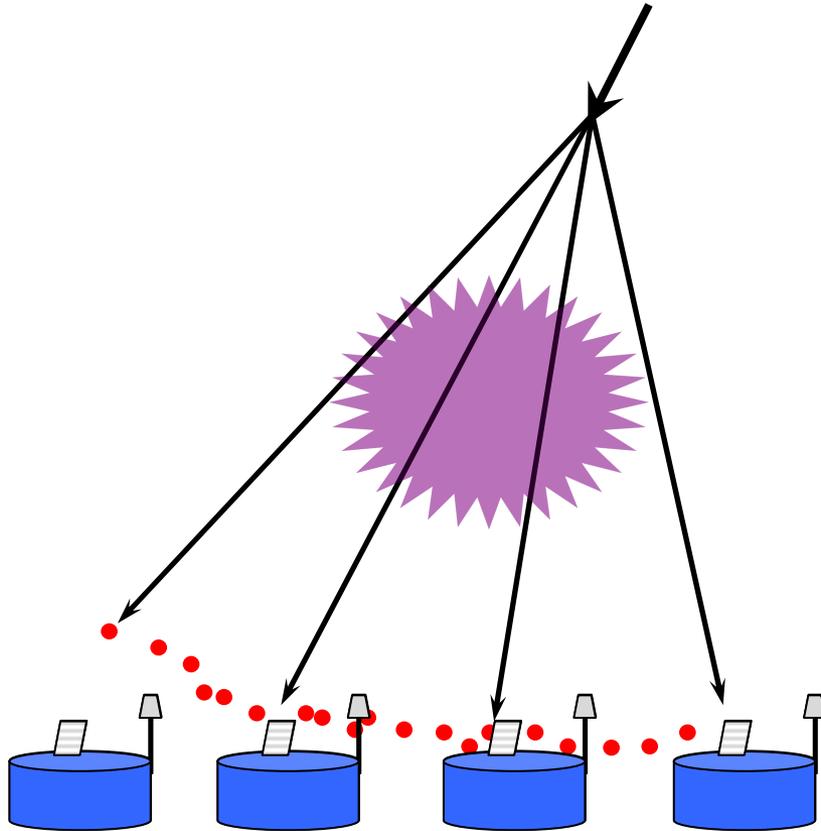


Hybrid Detection Technique

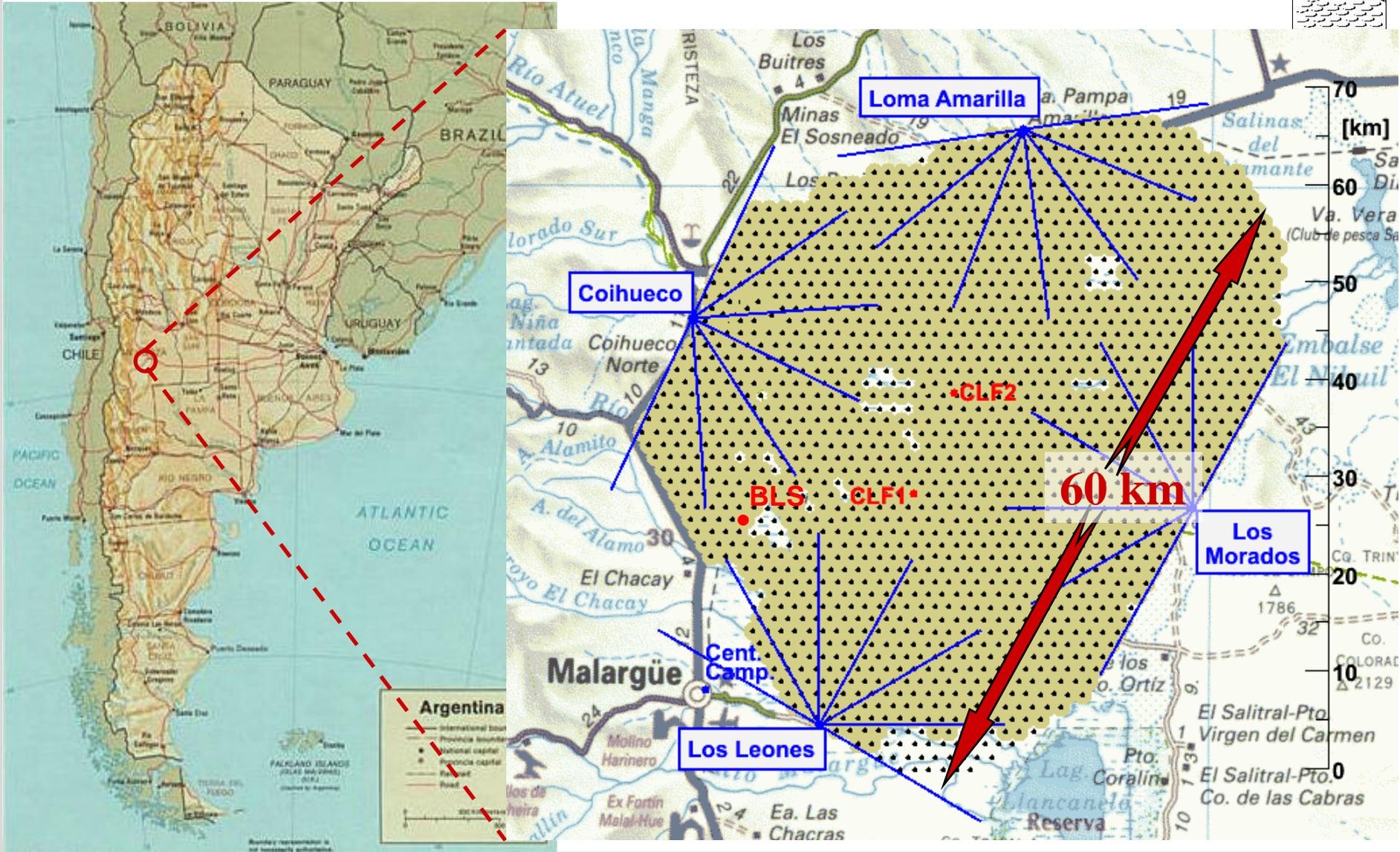
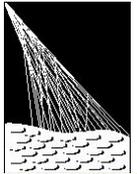
- longitudinal shower profiles by fluorescence light in atmosphere
- lateral particle distribution at ground



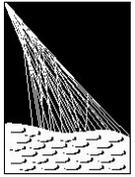
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The Southern Pierre Auger Observatory



Why Hybrid Detection Technique ?



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Surface Detectors

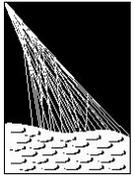
- ↑ 100 % duty cycle
- ↑ acceptance = geometric
- ↓ only last stage of shower development observed
- ↓ energy scale model dependent

Fluorescence Detectors

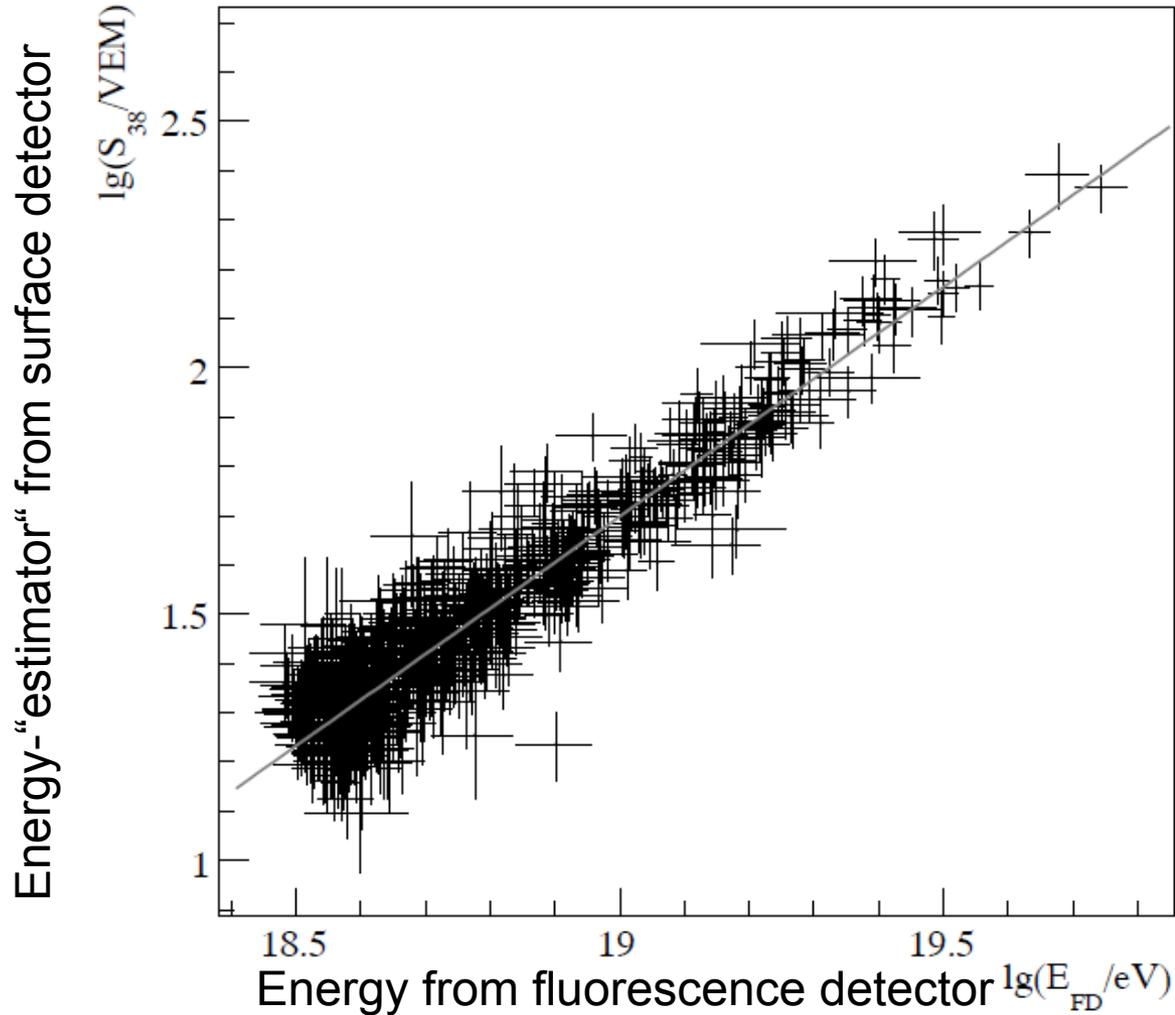
- ↓ ≈ 15 % duty cycle
- ↓ acceptance depends on distance and atmosphere
- ↑ observation of longitudinal shower development
- ↑ (almost) model independent



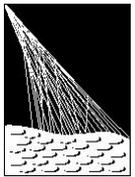
Energy Calibration



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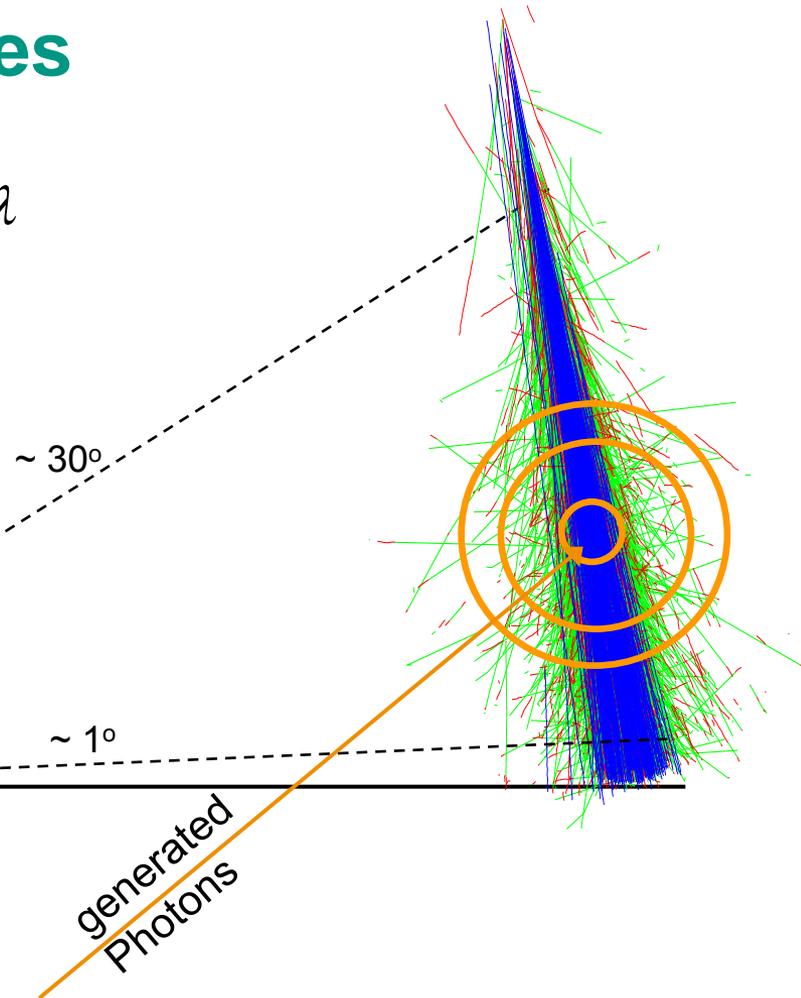
Measuring Principle of EAS with Fluorescence Telescopes



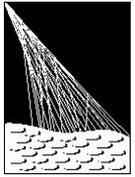
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$$\frac{dN_\gamma}{dX} = \int \frac{d^2 N_\gamma^0}{dX d\lambda} \cdot \varepsilon_{FD}(\lambda) \cdot \tau_{atm}(\lambda, X) d\lambda$$

Photons
at Detector

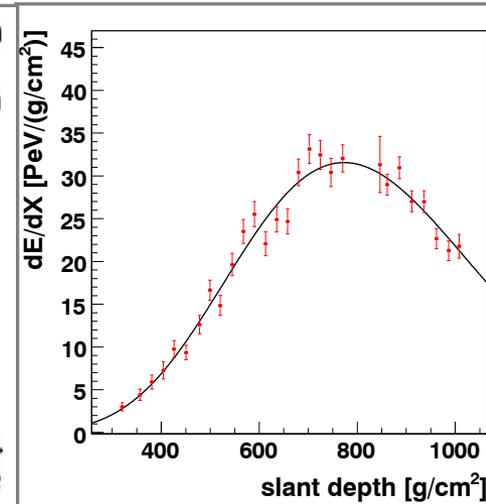
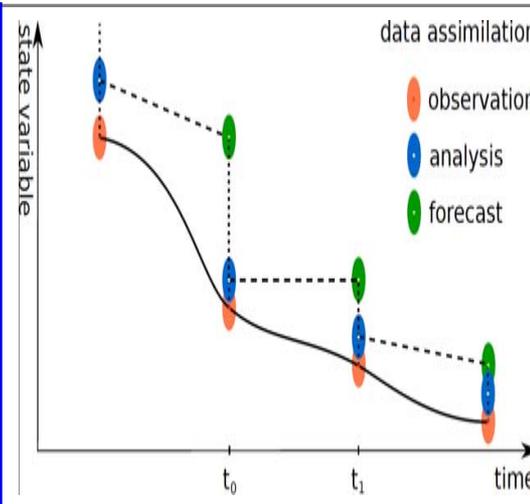
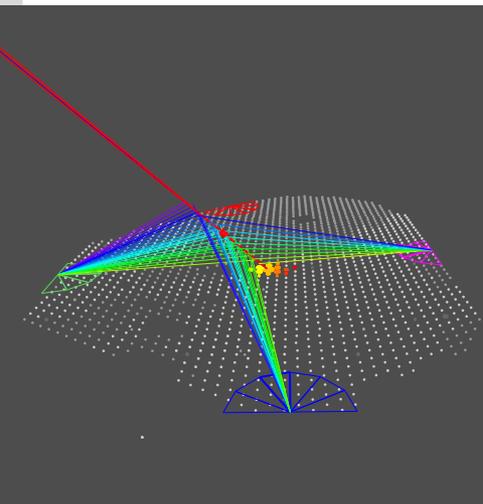


$$\frac{d^2 N_\gamma^0}{dX d\lambda} = \int Y(\lambda, P, T, u, E) \cdot \frac{dN_e(X)}{dE} \cdot \frac{dE_{dep}}{dE} dE$$



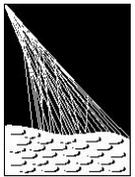
Overview

- Introduction to Cosmic Rays and the Pierre Auger Observatory
- **Meteorological Radio Soundings**
- Data from a Global Data Assimilation System
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Meteorological Radio Soundings

- Measurements of air pressure (p),
of air temperature (T),
of humidity (u)
- in dependence of altitude
- every 5 seconds readout of all data
- from ground up to about 23 km a.s.l.



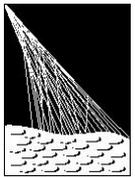
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Balloon Launching Station (BLS)

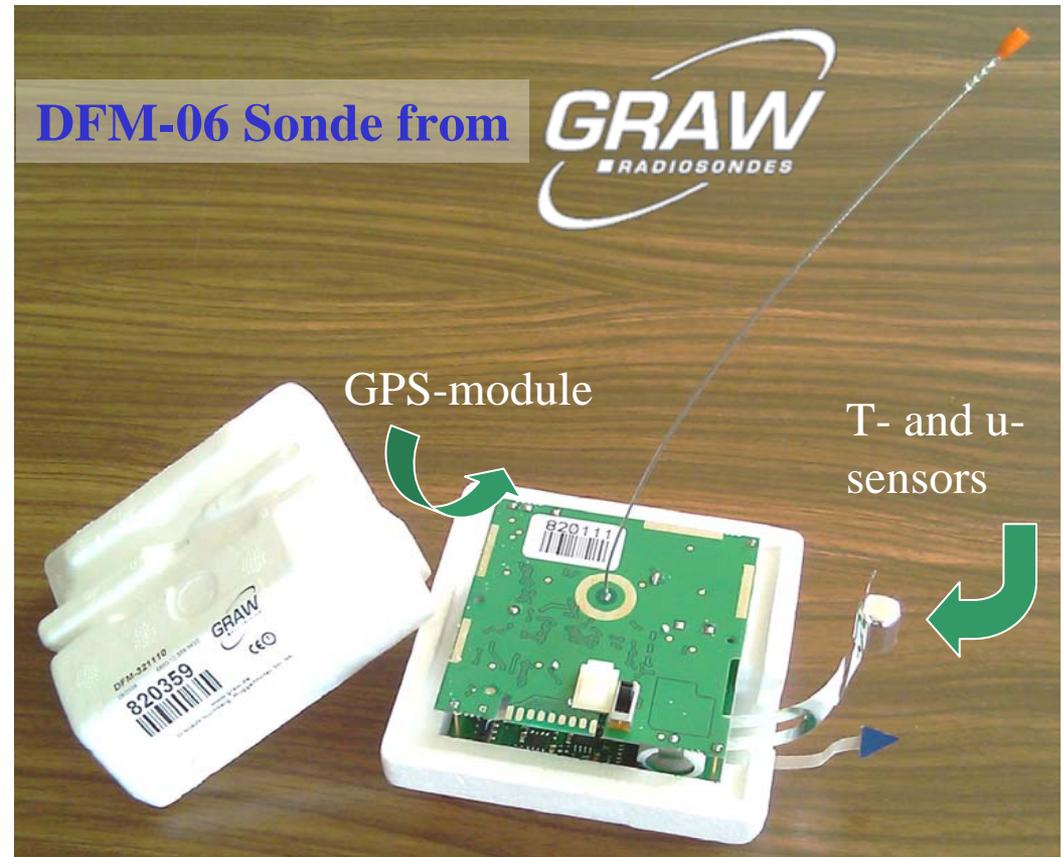


Radiosondes

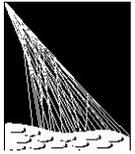
- altitude from GPS-module
- direct measurements of temperature and relative humidity
- pressure calculated iteratively from ground pressure and altitude



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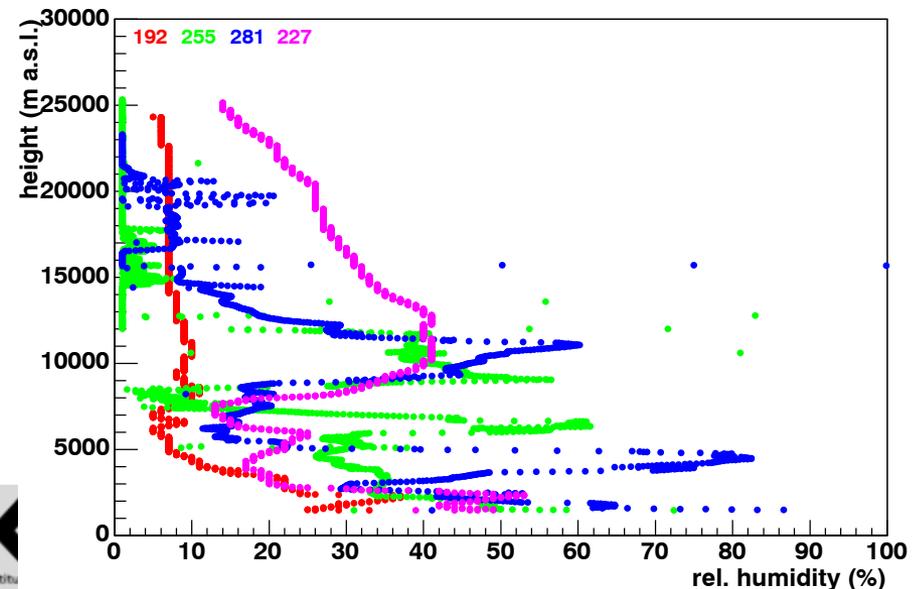
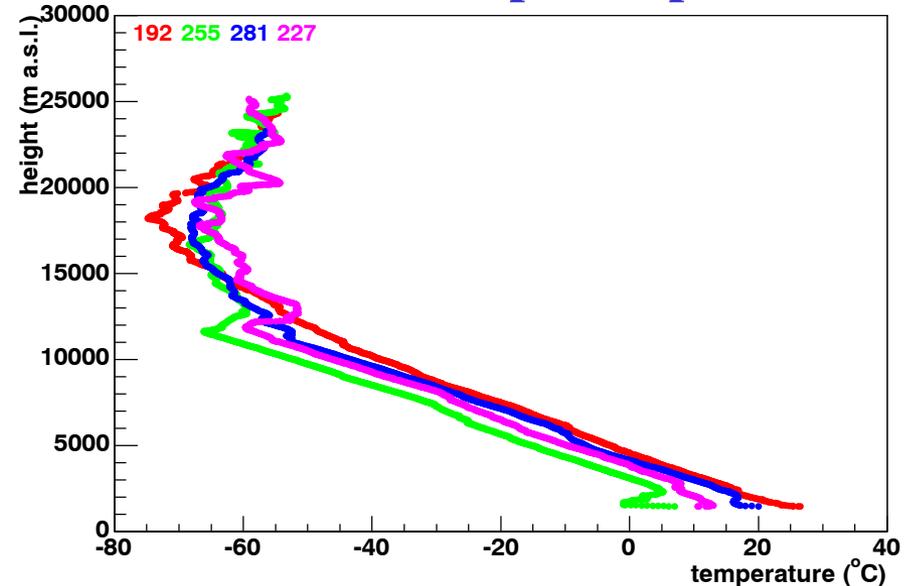
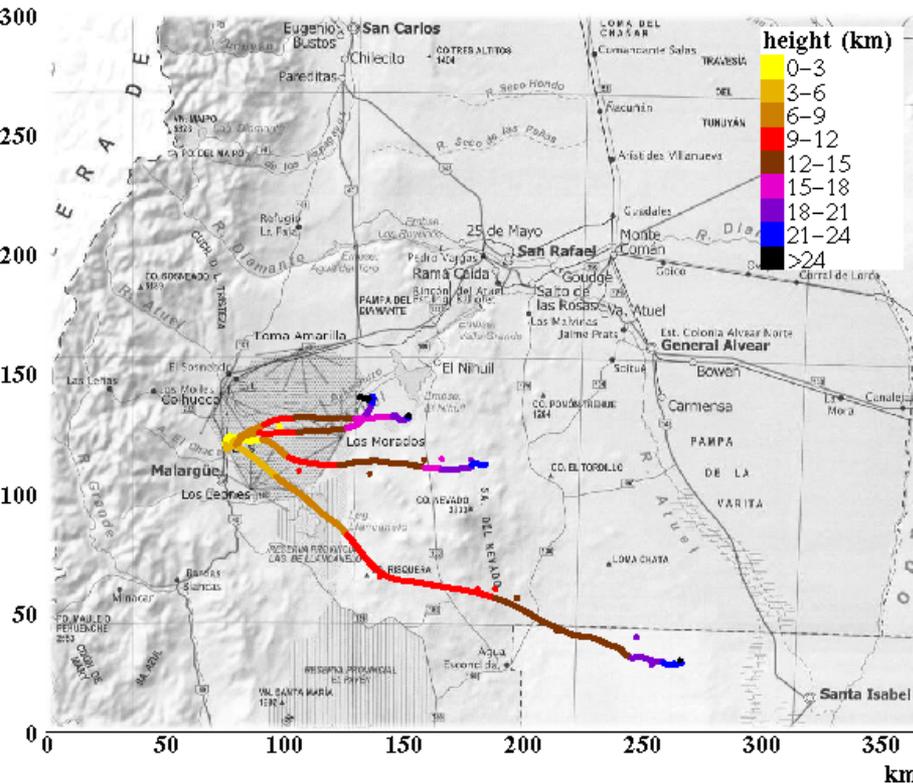


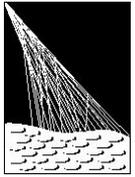
Radio Soundings at the Pampa Amarilla



measured atmospheric profiles

flight paths above the pampa





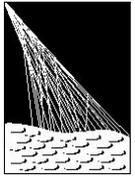
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Balloon-the-Shower

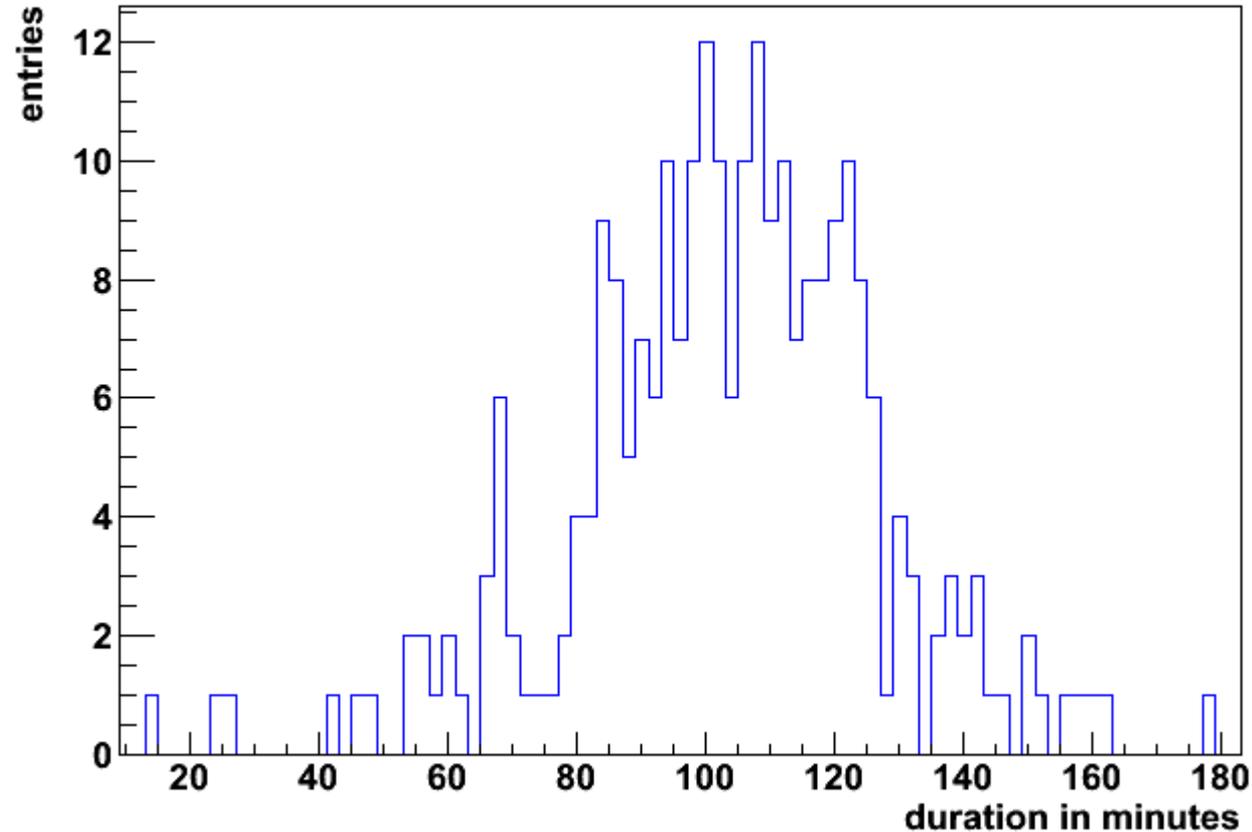
- No regular scheduled launches anymore
- high-energy, high-quality EAS initiate launch of weather balloon
- start of measurement within about 3 hours after EAS

- Balloon-the-Shower program started in March 2009 and will be terminated at the end of 2010

Duration of Soundings



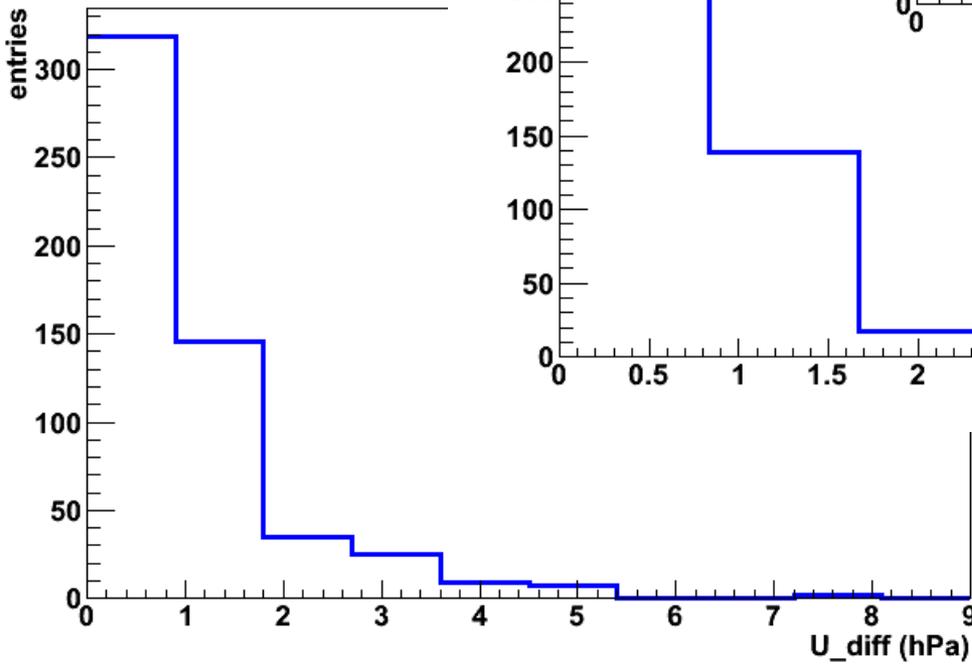
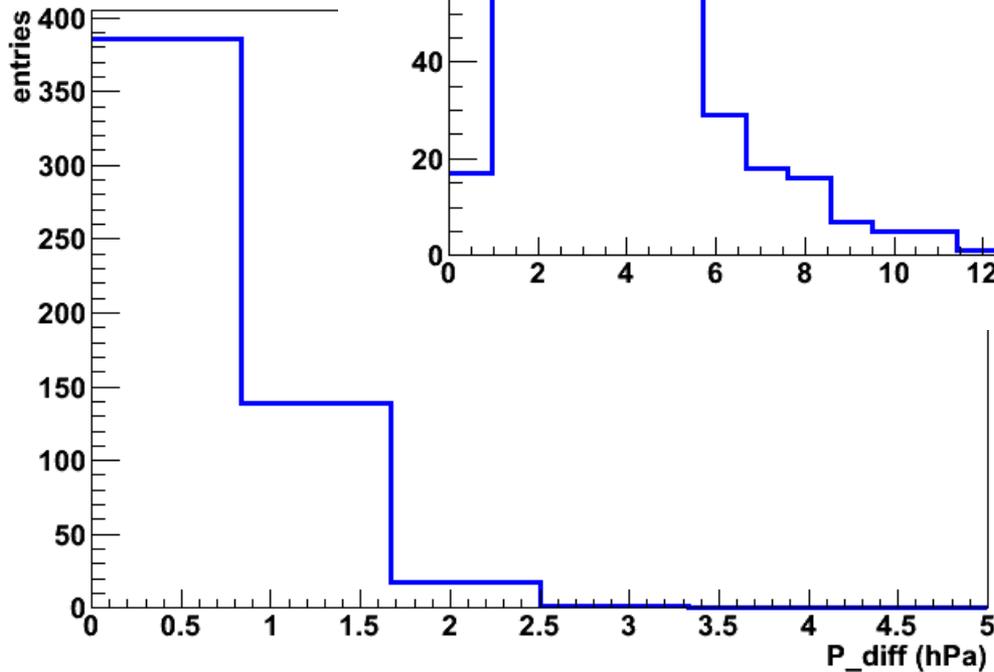
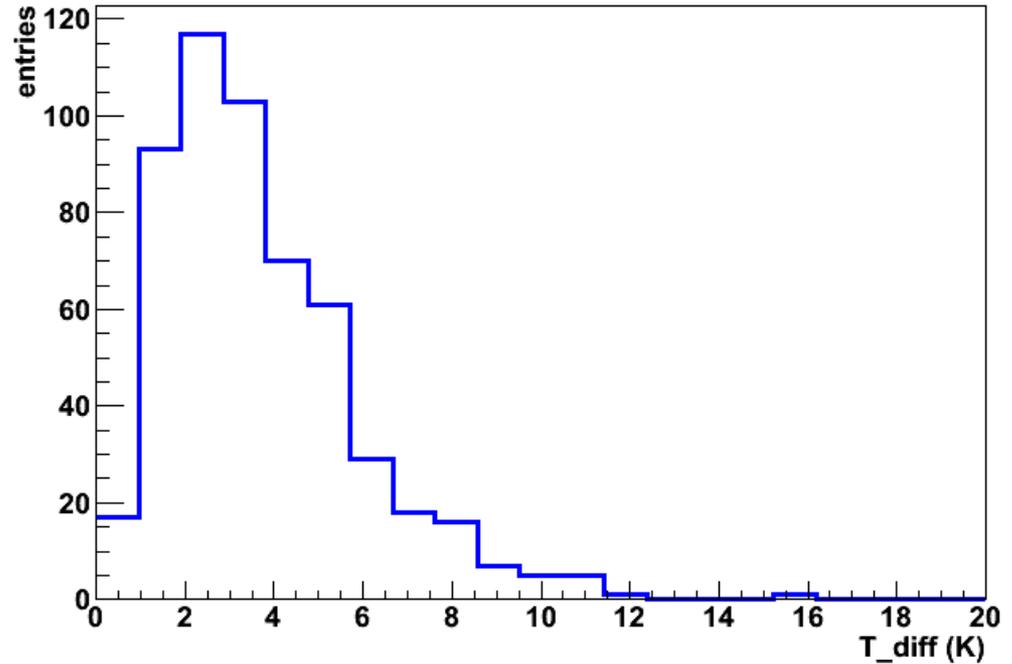
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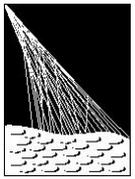
⇒ in average 103 min.

Variance of Observables

Differences between maximum and minimum of observable as found in weather station data during the time of a weather balloon launch.



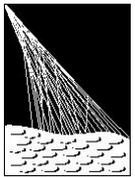
Adjustment



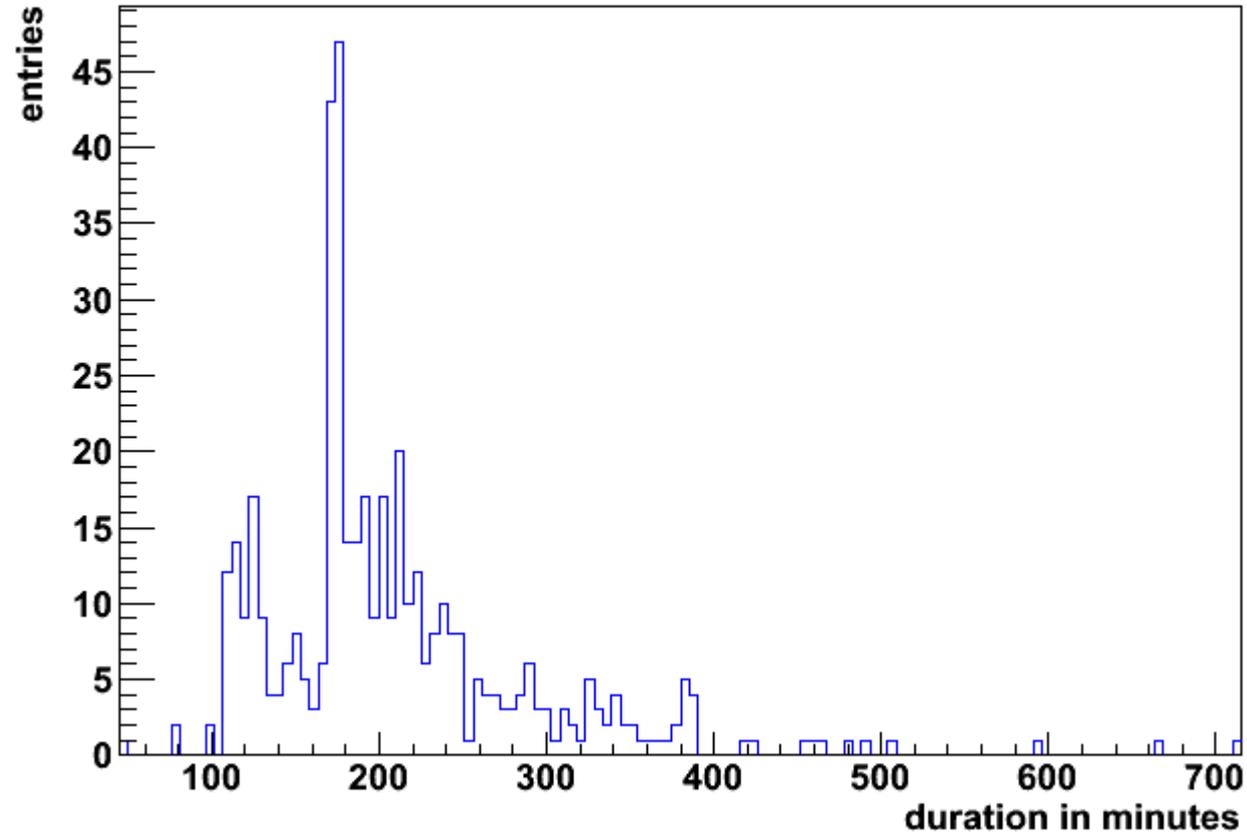
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Temperature:	$\Delta T < 4 \text{ K}$	$\rightarrow T_{\max / \min} = \bar{T} + / - 2 \text{ K}$
	$4 \text{ K} \leq \Delta T < 9 \text{ K}$	\rightarrow Launch is valid as obtained by the weather station scan
	$\Delta T \geq 9 \text{ K}$	\rightarrow Launch only valid during data taking
Pressure:	$\Delta p < 1 \text{ hPa}$	$\rightarrow p_{\max / \min} = \bar{p} + / - 1 \text{ hPa}$
	$1 \text{ hPa} \leq \Delta p < 3 \text{ hPa}$	\rightarrow Launch is valid as obtained by the weather station scan
	$\Delta p \geq 3 \text{ hPa}$	\rightarrow Launch only valid during data taking
Humidity:	$\Delta e < 0.8 \text{ hPa}$	$\rightarrow e_{\max / \min} = \bar{e} + / - 0.4 \text{ hPa}$
	$0.8 \text{ hPa} \leq \Delta e < 4.0 \text{ hPa}$	\rightarrow Launch is valid as obtained by the weather station scan
	$\Delta e \geq 4.0 \text{ hPa}$	\rightarrow Launch only valid during data taking

New Duration of Soundings

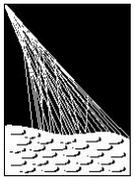


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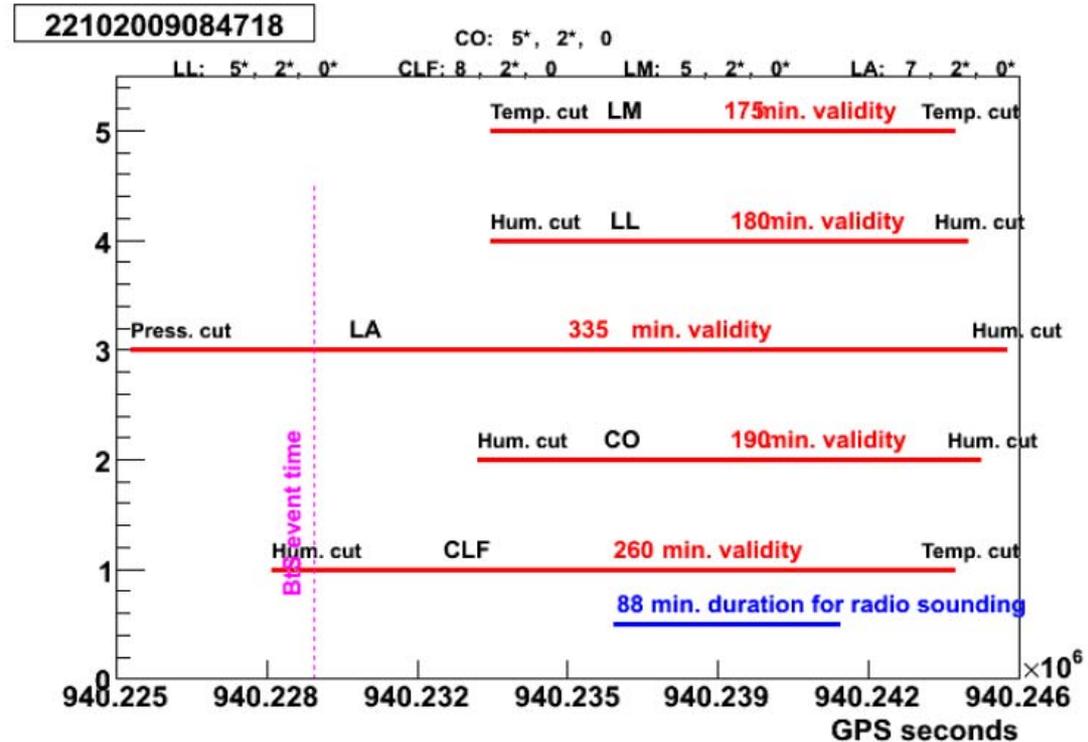
⇒ in average 209 min.

Critical Aspects of Technique

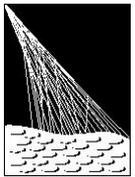


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(a) 2 weather station (LA and CLF) would label the radio sounding data as valid at the time of the *BtS* event, the other three not.

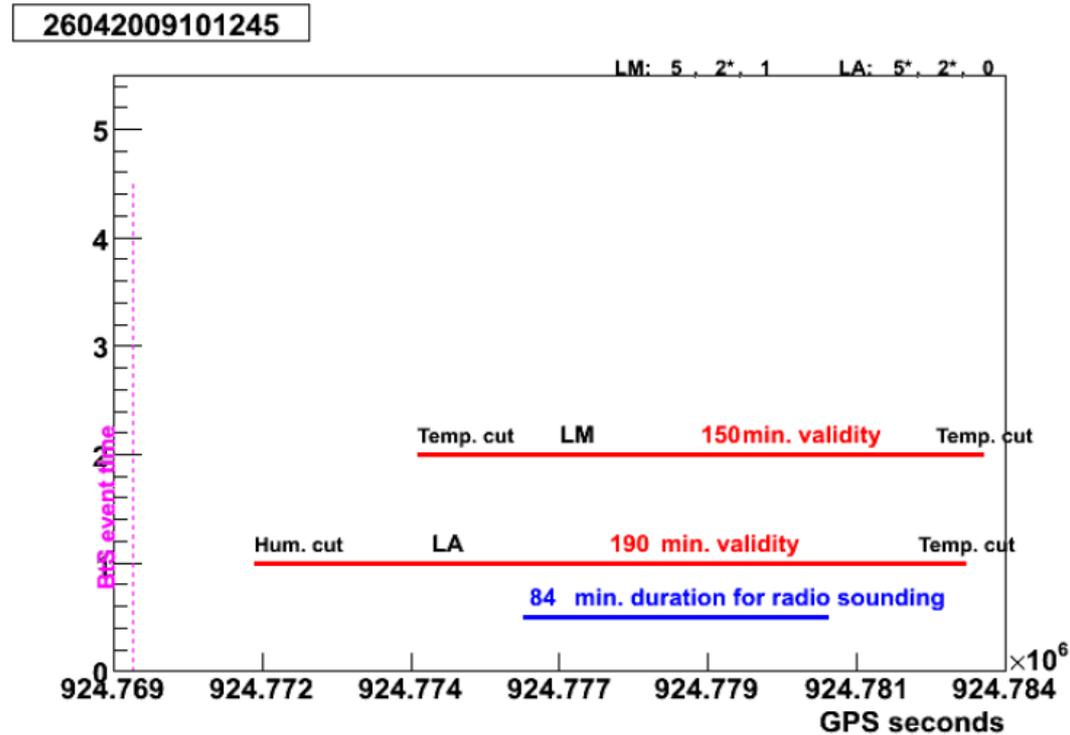


Critical Aspects of Technique

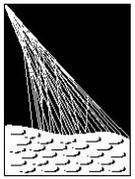


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(b) No weather station would label the radio sounding data as valid at the time of the *BtS* event.

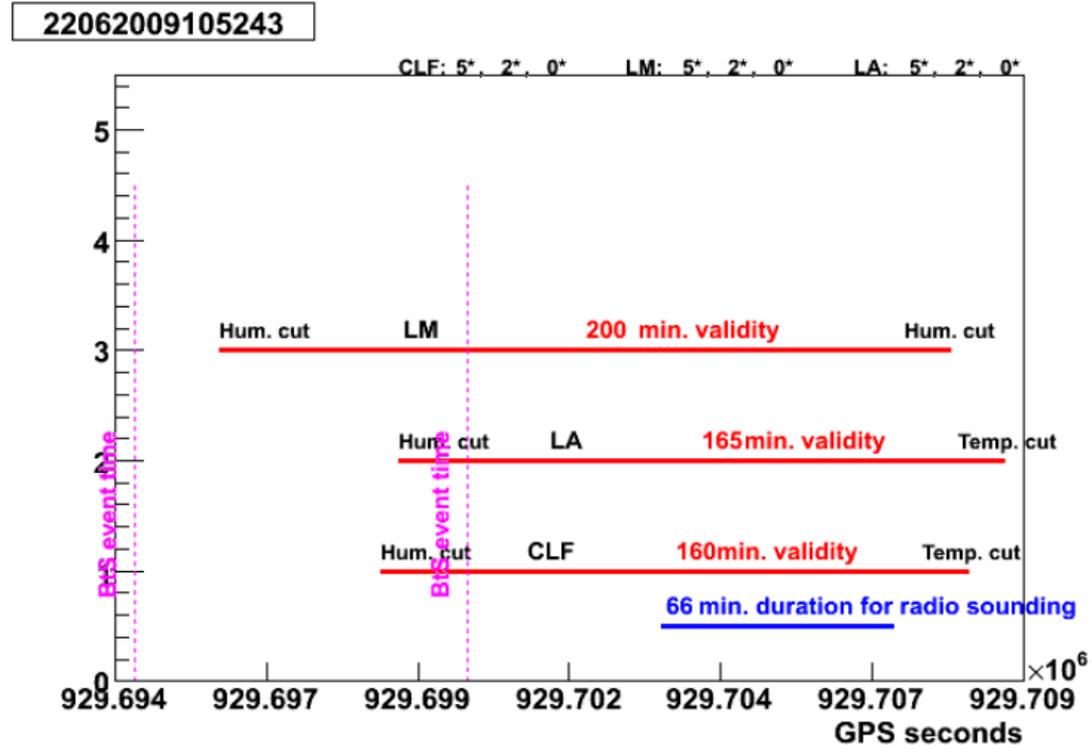


Critical Aspects of Technique

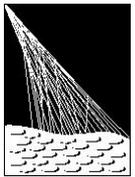


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(c) The radio sounding is initiated by the first *BtS* event, but would not be valid for that event. However, a second event could be reconstructed using the initiated radio sounding data.



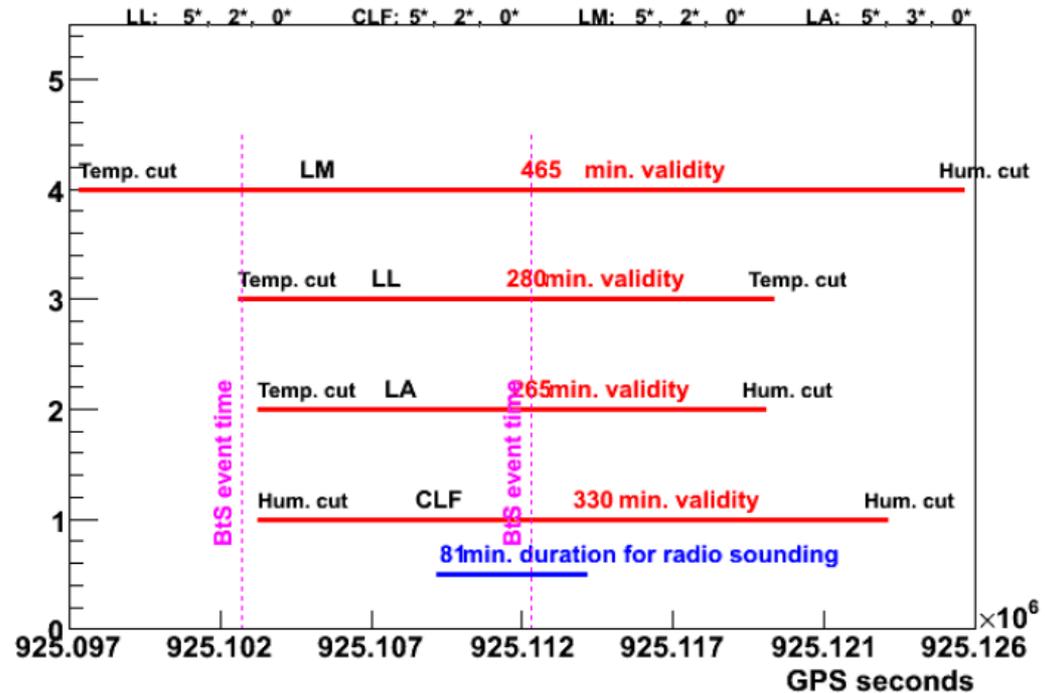
Critical Aspects of Technique



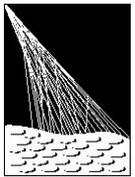
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30042009064242

(d) The radio sounding is initiated by the first *BtS* event and two weather station (LL and LM) would label the data as valid at the time of the *BtS* event. A second high-energy event was observed during the sounding.

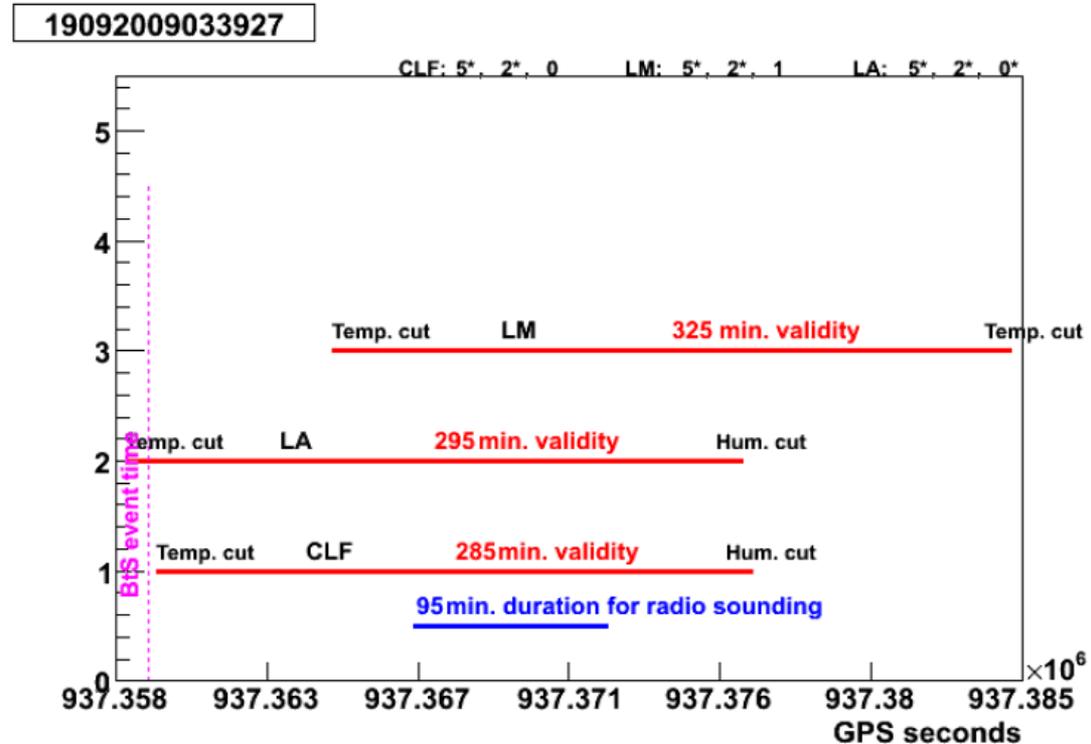


Critical Aspects of Technique

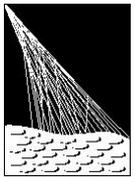


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(e) This example reveals that sometimes one weather station shows a shifted validity time compared with the other stations for the same launch.

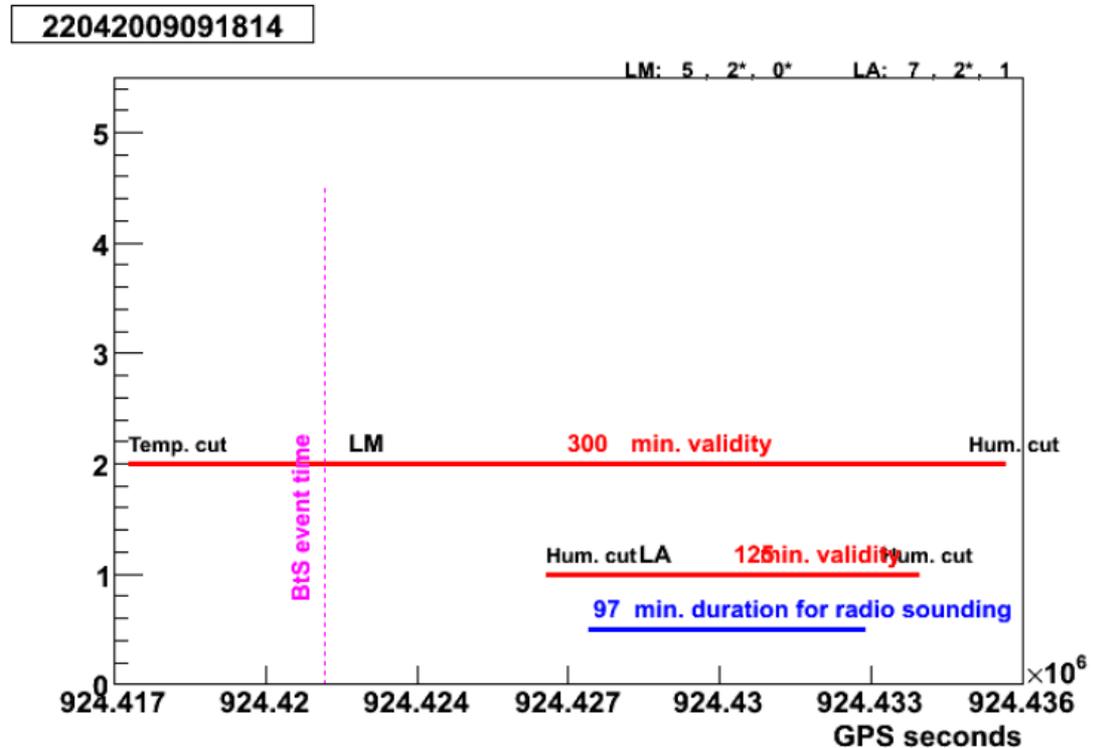


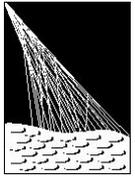
Critical Aspects of Technique



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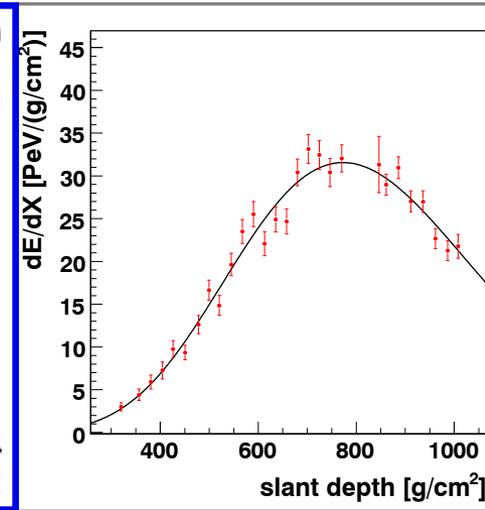
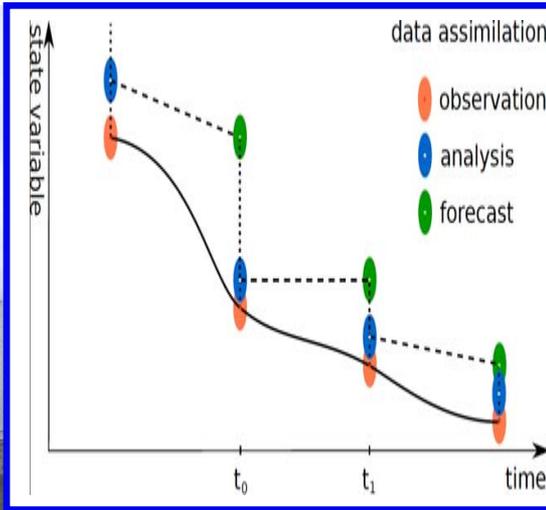
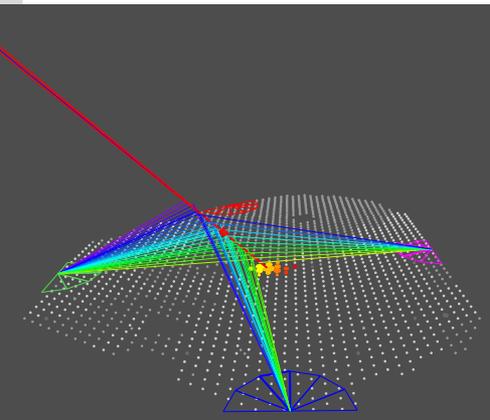
(f) Here, one station indicates a quite long period of validity while the other station suffers strict cuts, in this case for the humidity.



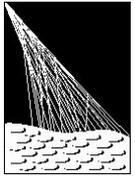


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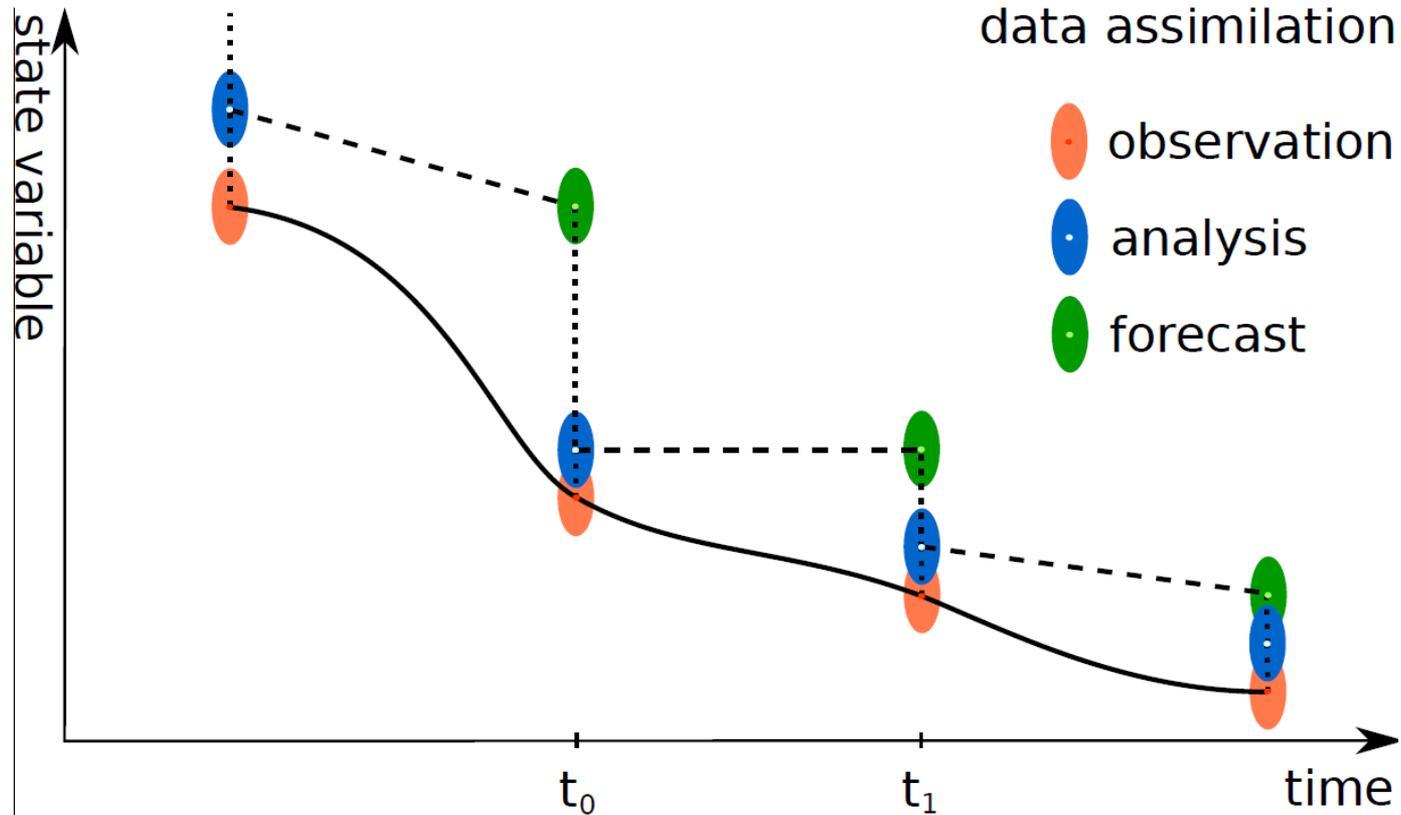
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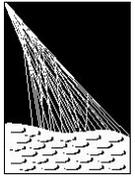
Global Data Assimilation System (GDAS)



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GDAS

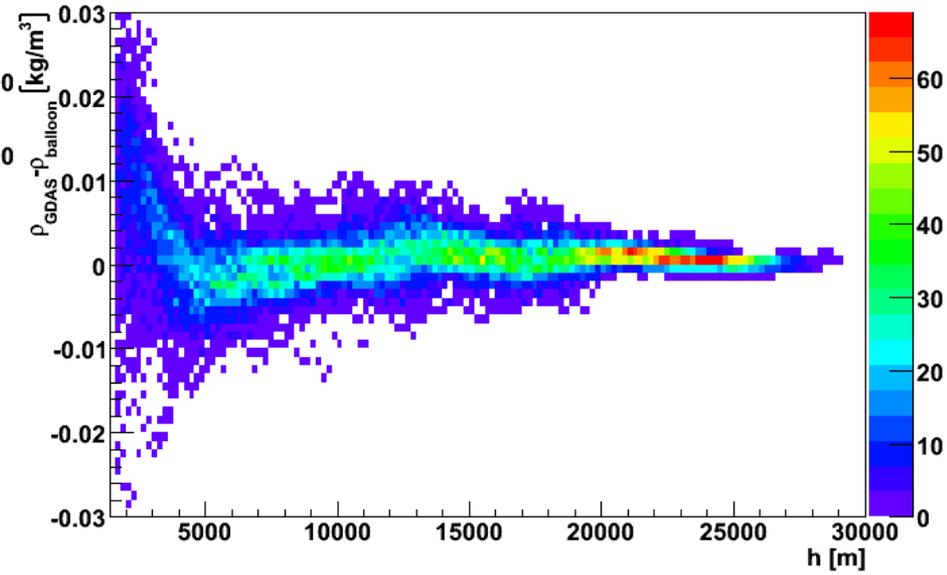
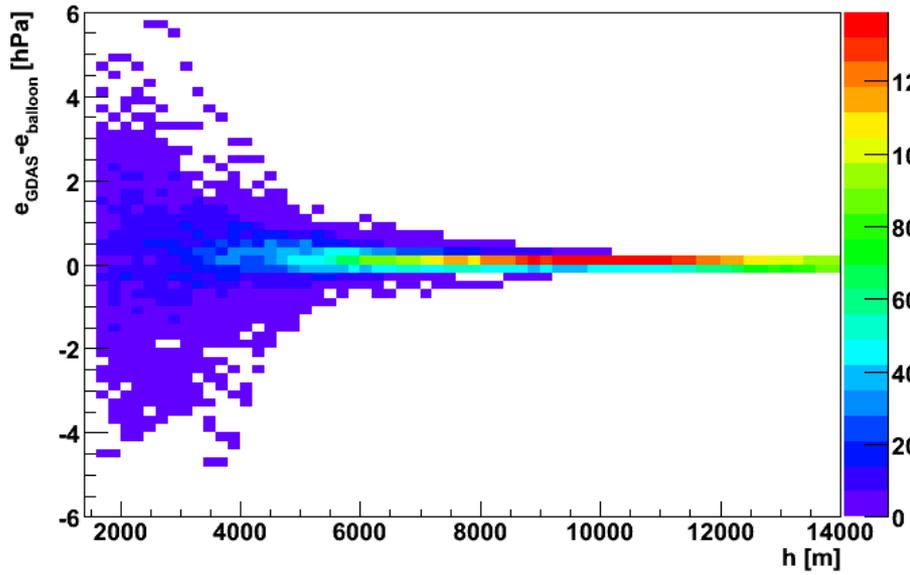
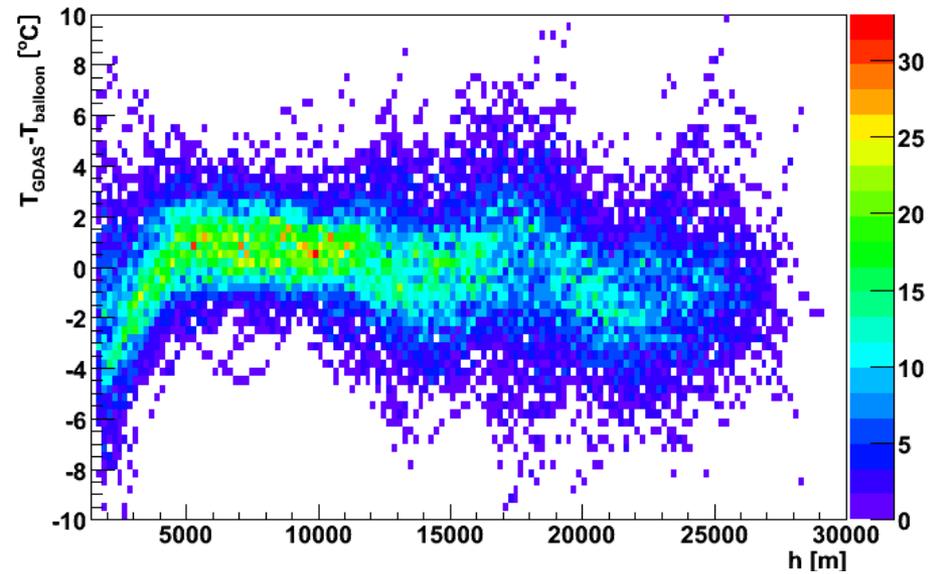
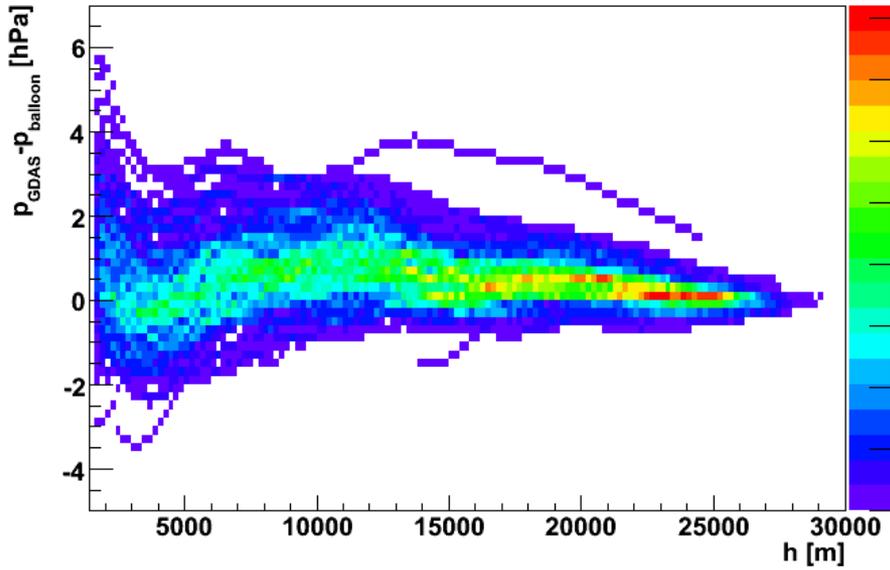


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- global atmospheric model developed at NCEP
National Centers for Environmental Prediction (NCEP) at NOAA –
National Oceanic and Atmospheric Administration
- vertical atmospheric profiles for height, temperature, humidity
at 23 constant pressure levels every 3 hours since Dec. 2004
- global data publicly available at <http://ready.ar1.noaa.gov>

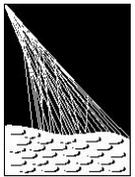
Comparison of GDAS with Sounding Data

- using fitting technique -

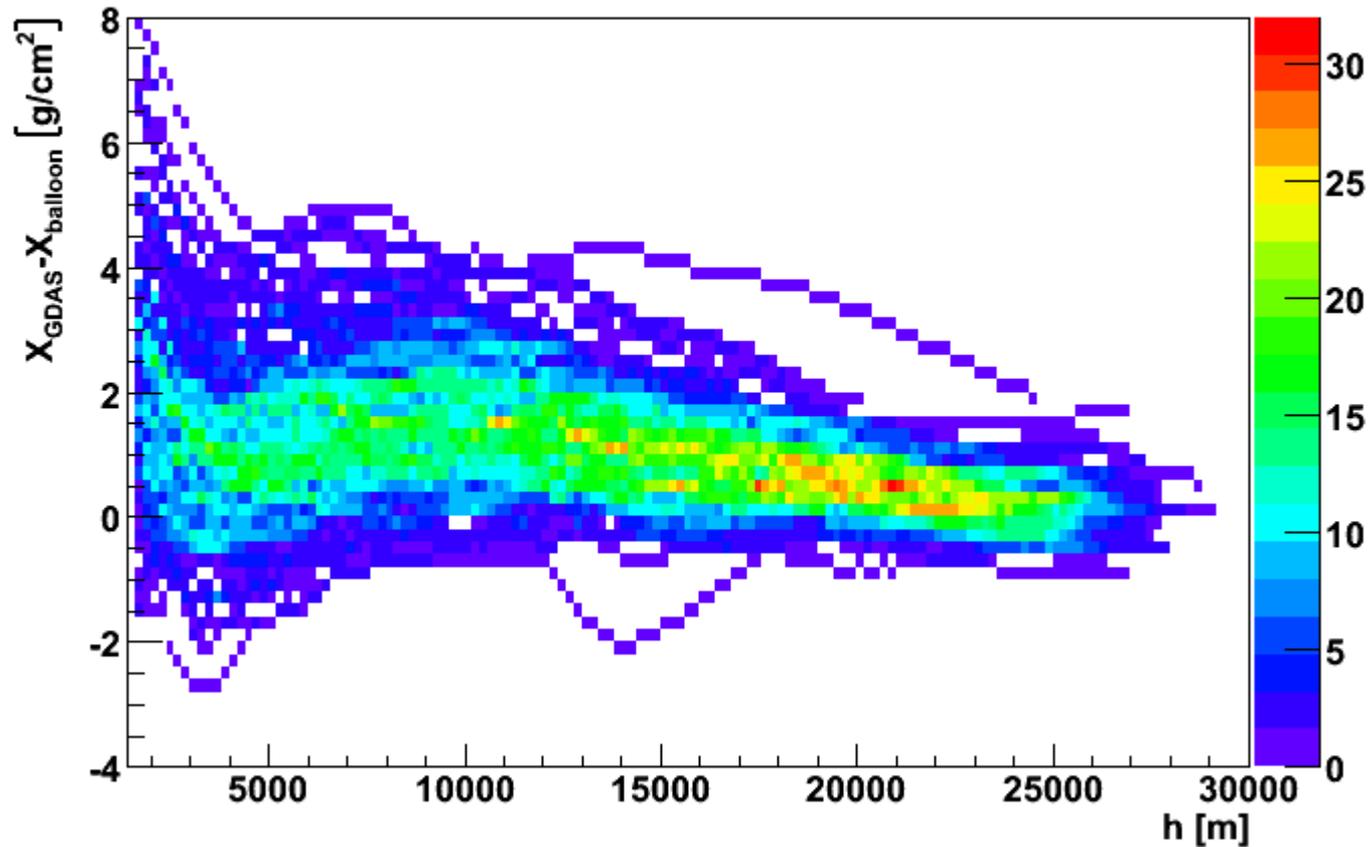


Comparison of GDAS with Sounding Data

- using fitting technique -



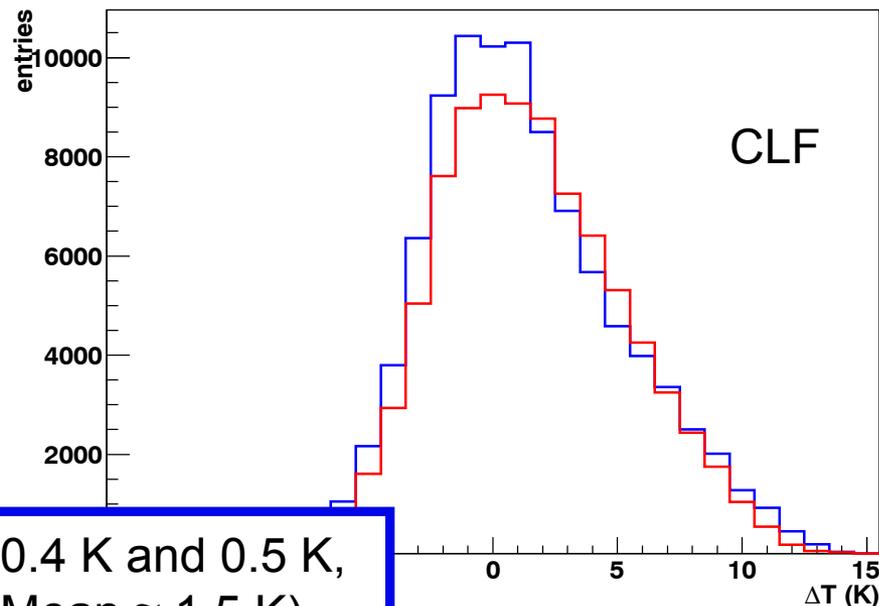
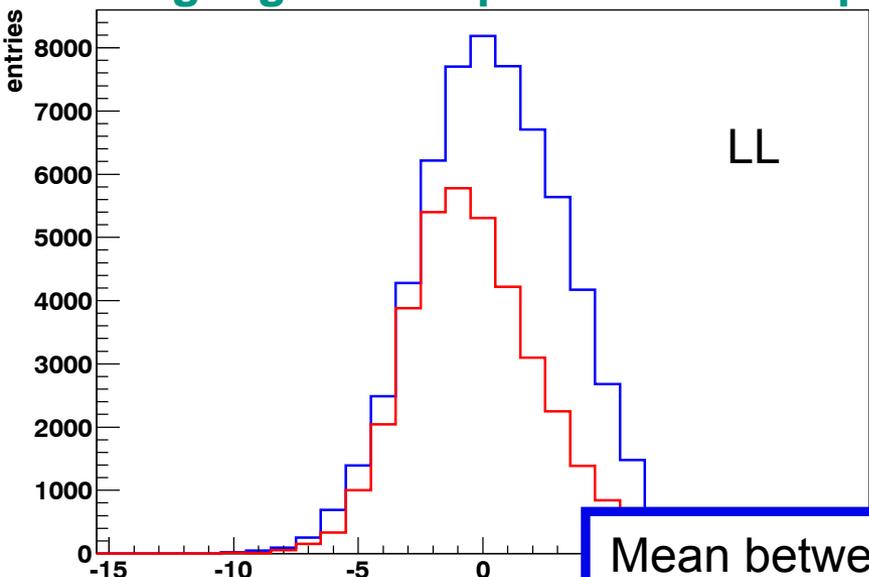
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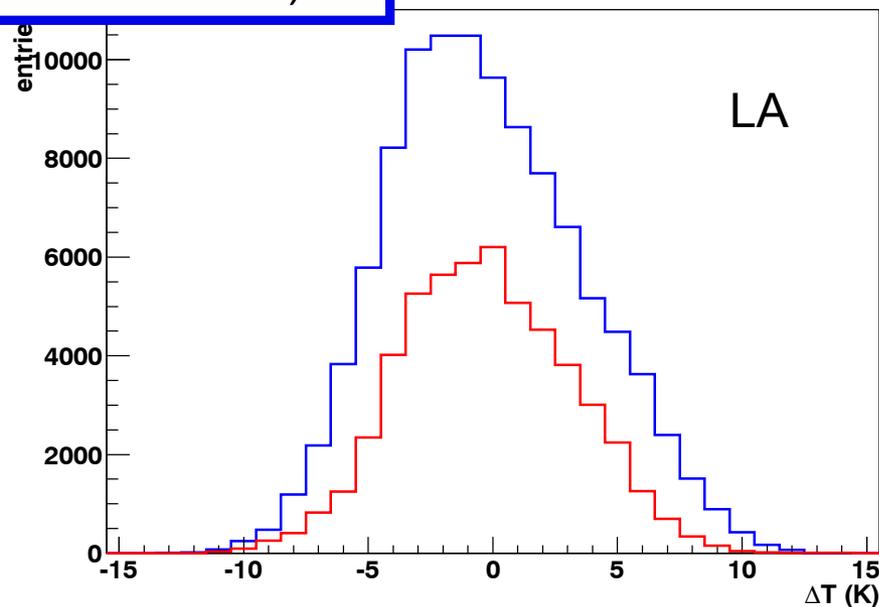
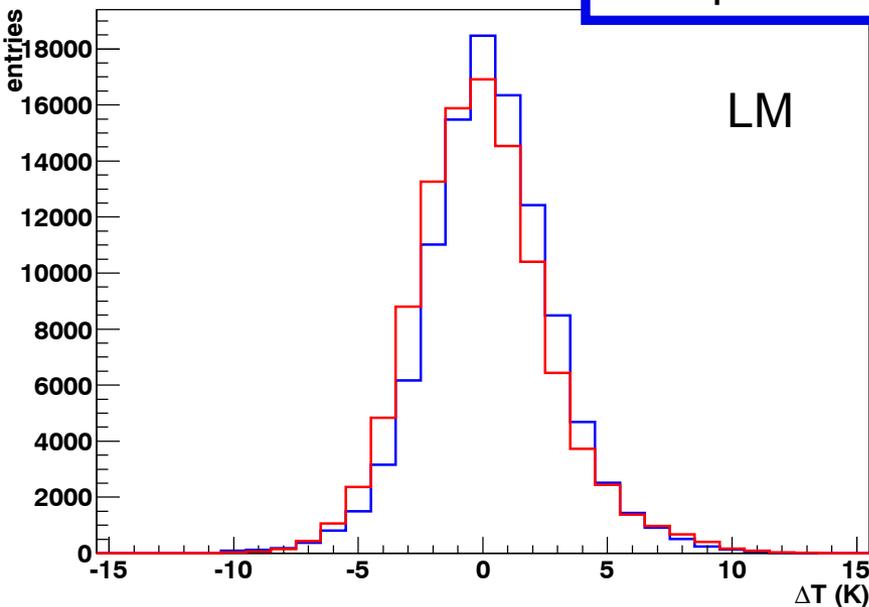
Comparison of GDAS with Weather Station Data



- using log/lin-interpolation technique -



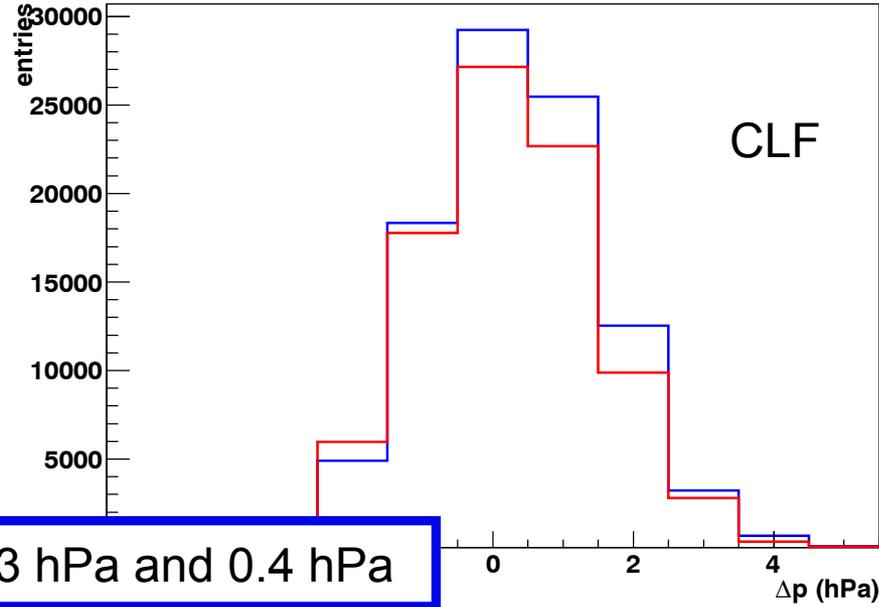
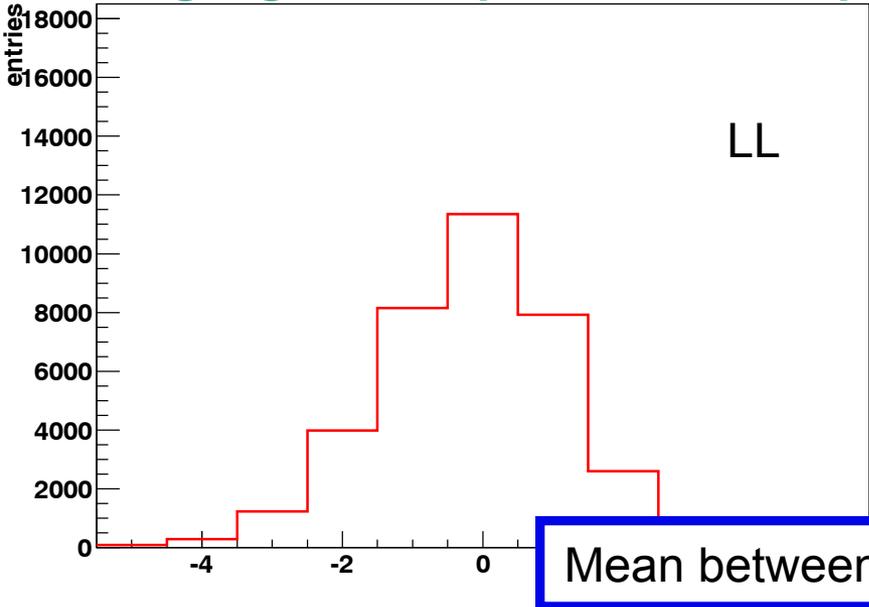
Mean between -0.4 K and 0.5 K,
except for CLF (Mean \approx 1.5 K)



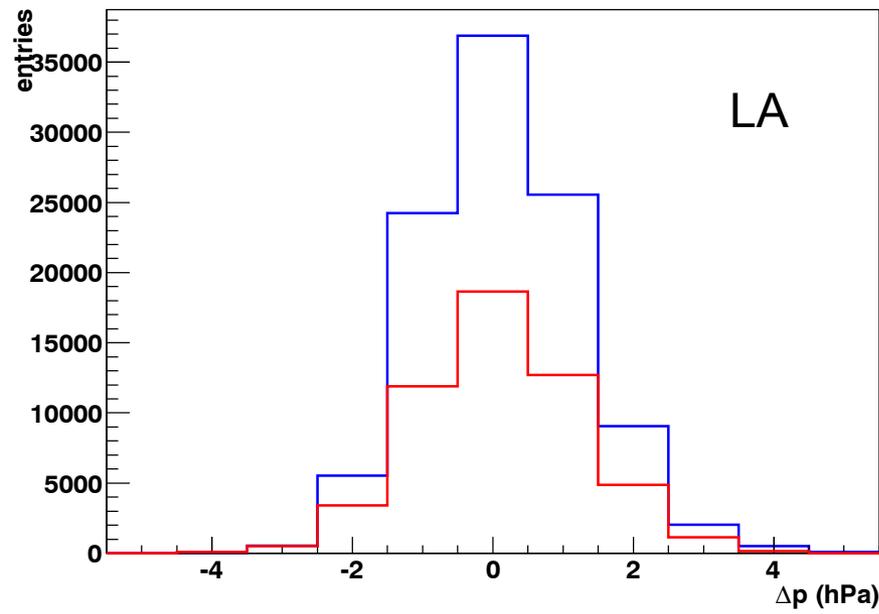
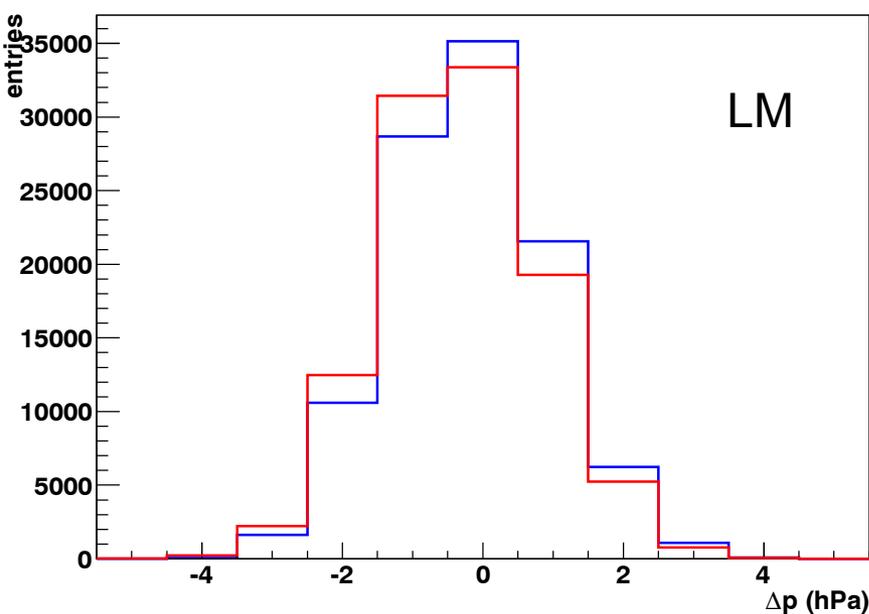
Comparison of GDAS with Weather Station Data



- using log/lin-interpolation technique -



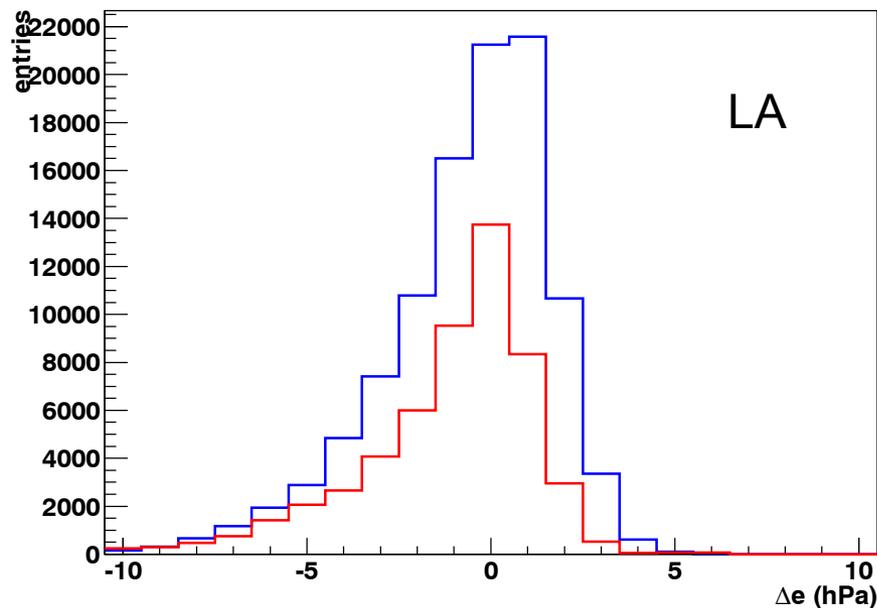
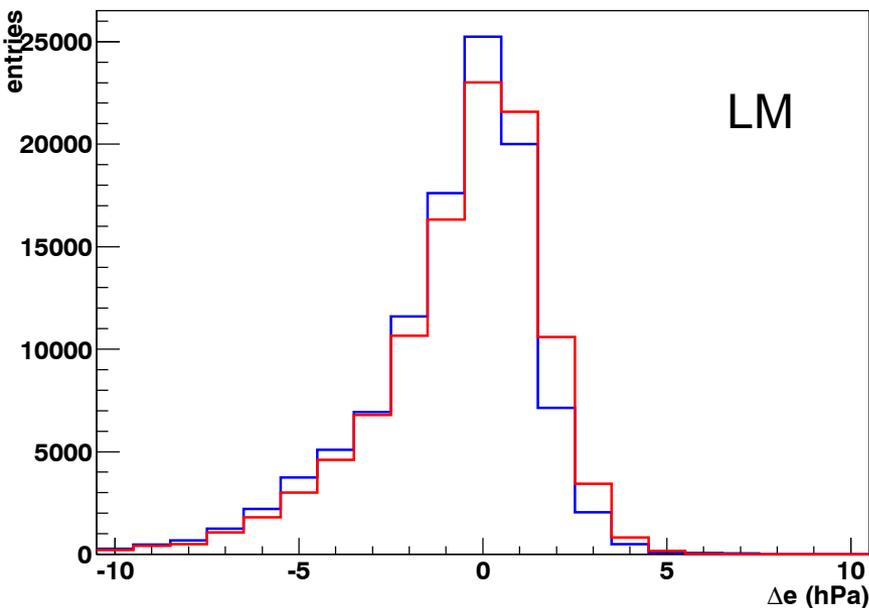
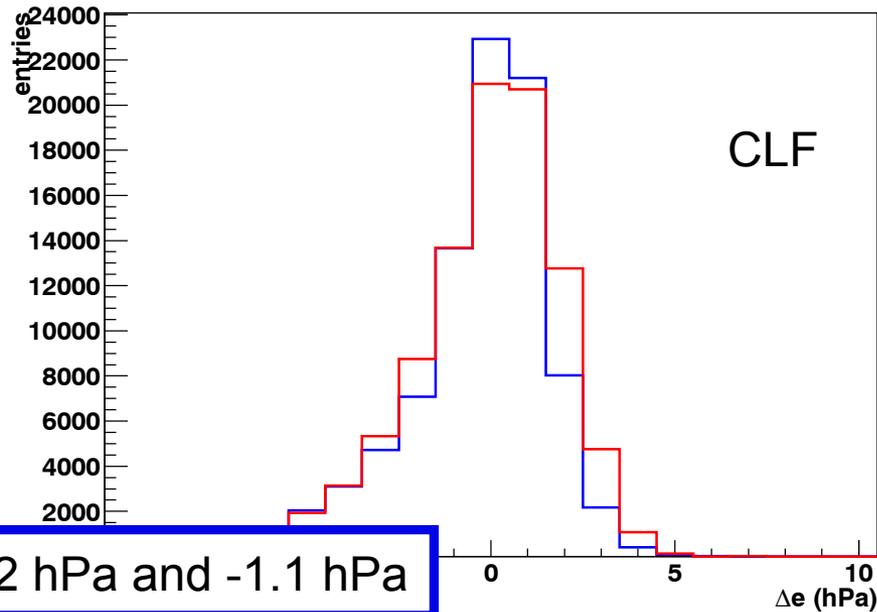
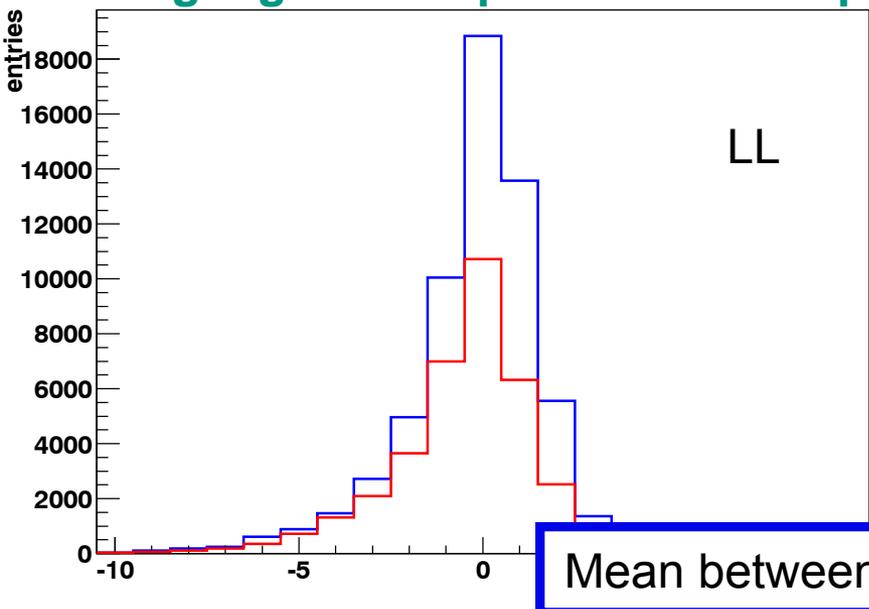
Mean between -0.3 hPa and 0.4 hPa



Comparison of GDAS with Weather Station Data



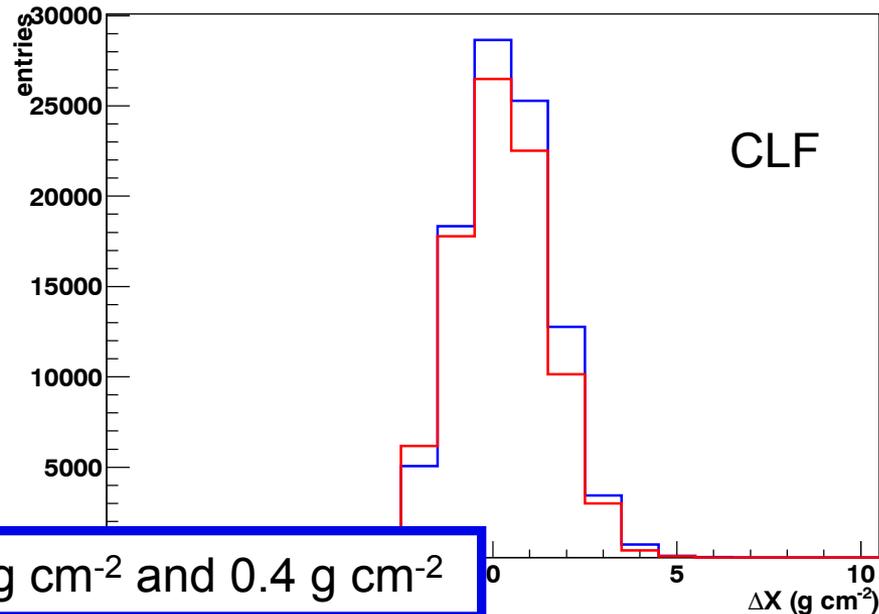
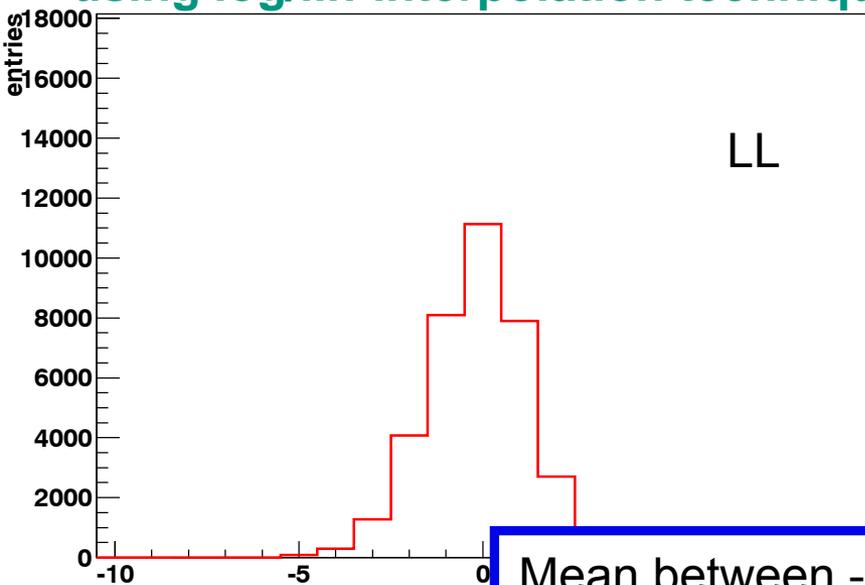
- using log/lin-interpolation technique -



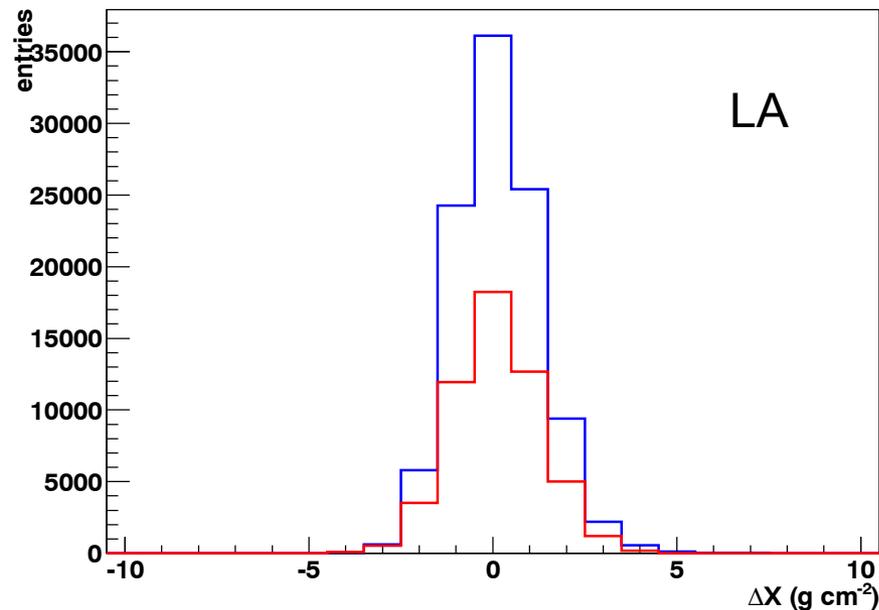
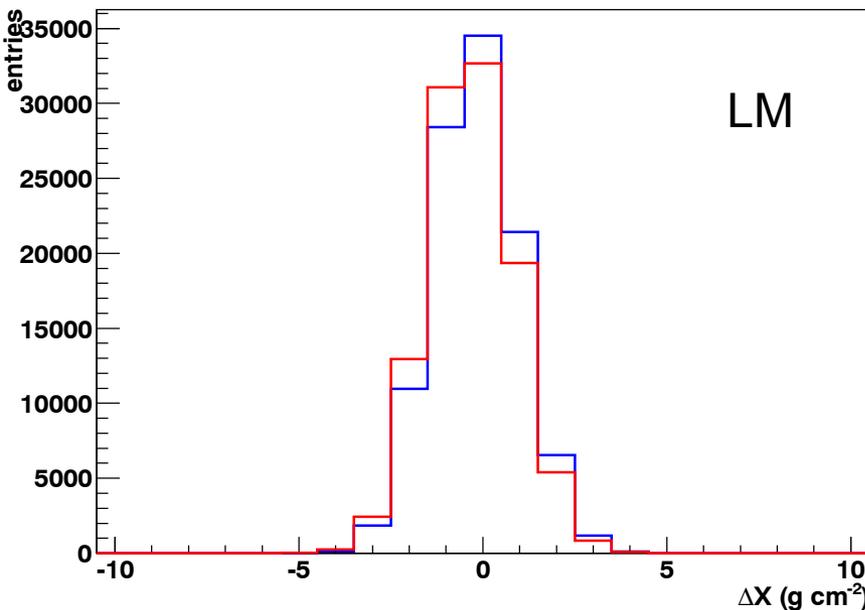
Comparison of GDAS with Weather Station Data

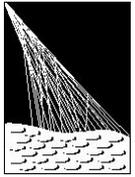


- using log/lin-interpolation technique -



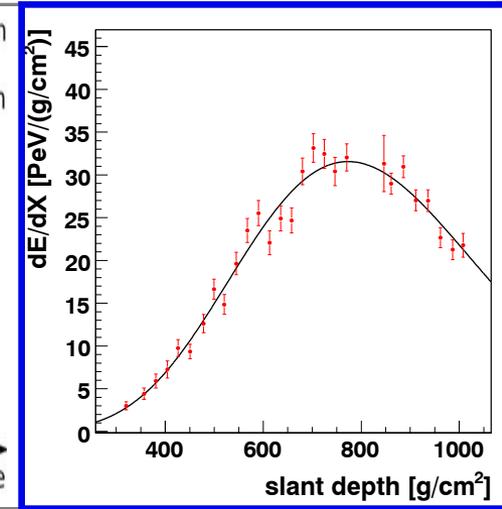
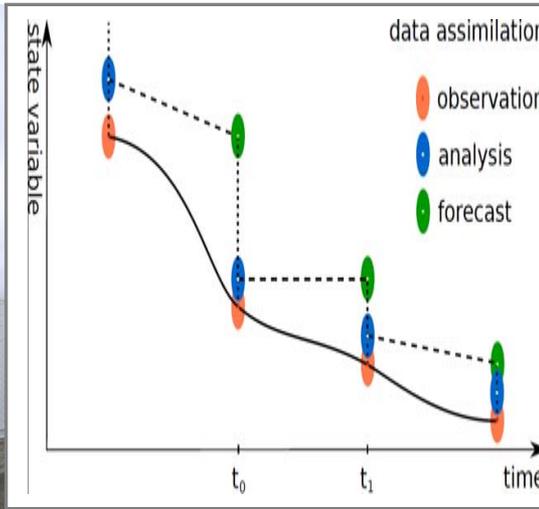
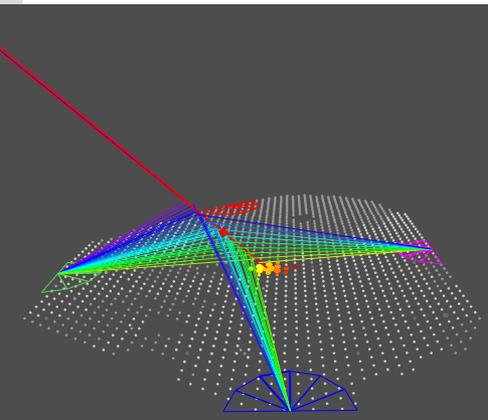
Mean between -0.3 g cm^{-2} and 0.4 g cm^{-2}



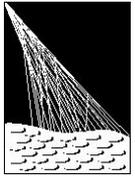


Overview

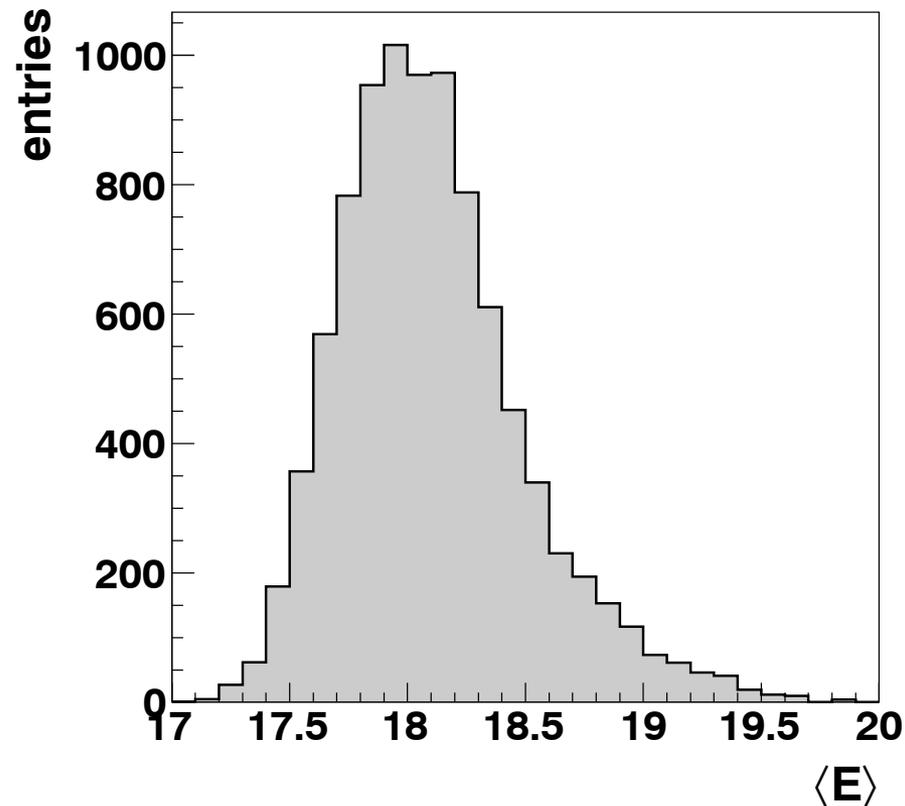
- Introduction to Cosmic Rays and the Pierre Auger Observatory
- Meteorological Radio Soundings
- Data from a Global Data Assimilation System
- **Application to Air Shower Reconstruction**



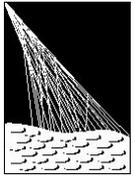
Reconstruction Analysis



- all EAS from 2009 are reconstructed
- FIRST reconstruction with local atmospheric monthly models
- SECOND reconstruction with GDAS atmospheric data

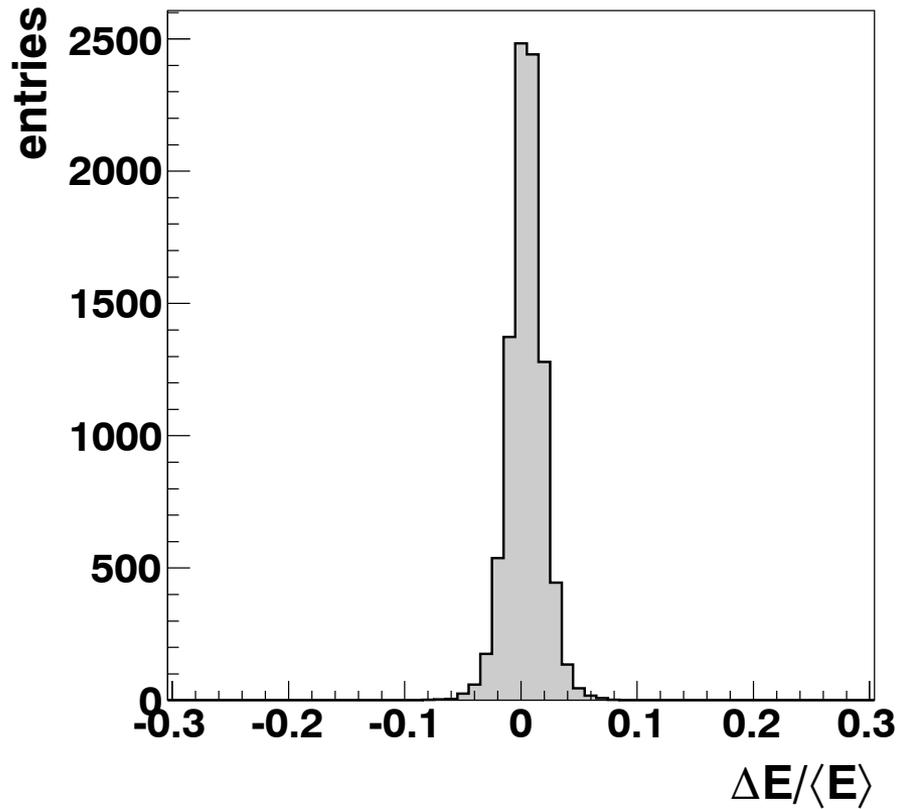


Reconstruction Differences

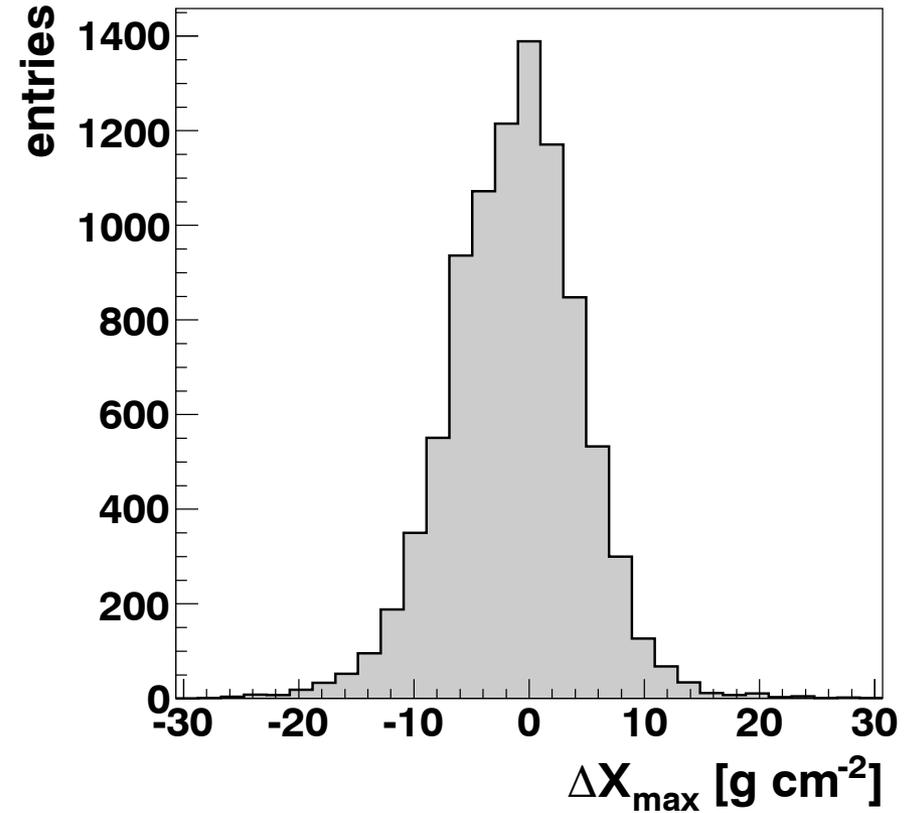


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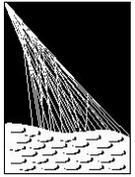
Mean 0.4 %



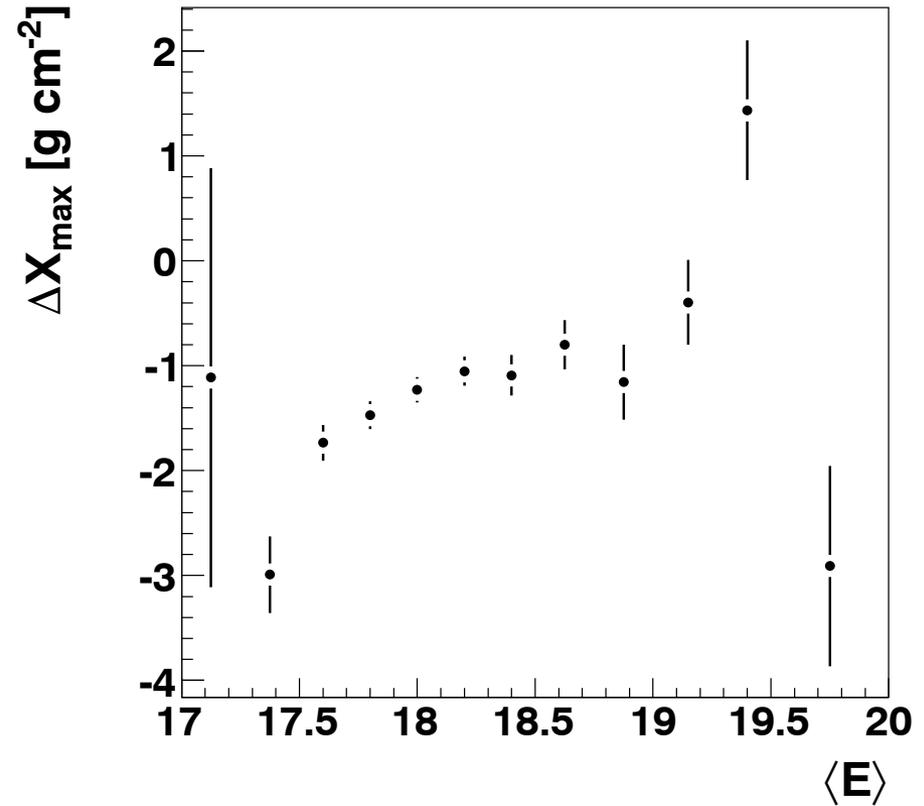
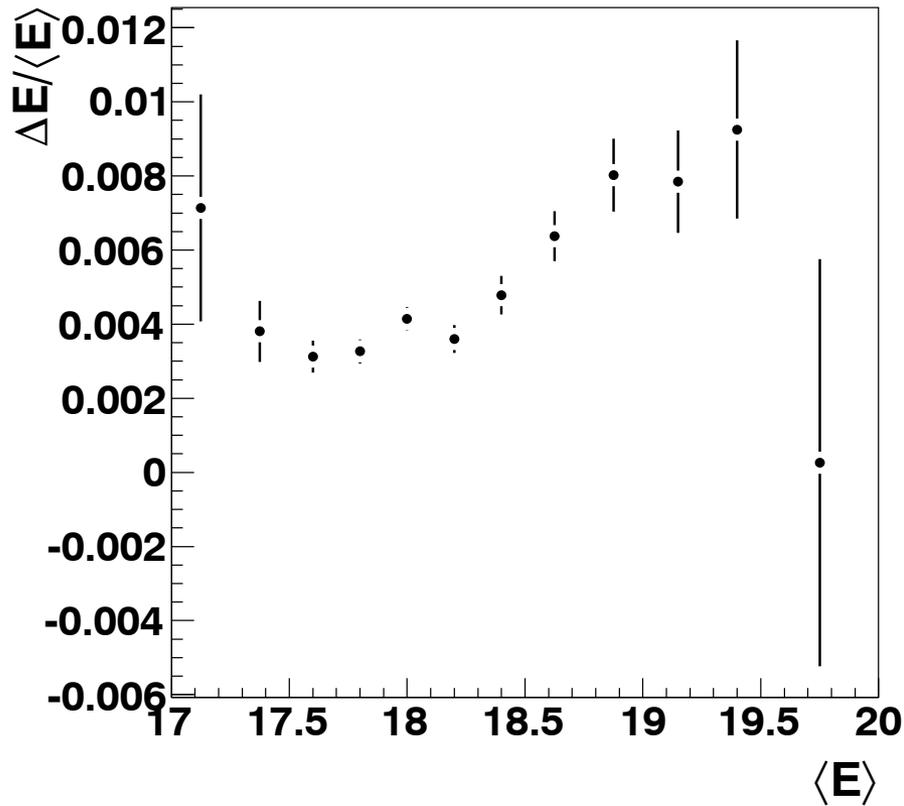
Mean -1.3 g cm⁻²



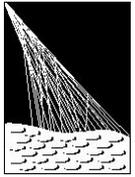
Reconstruction Differences vs. $\langle E \rangle$



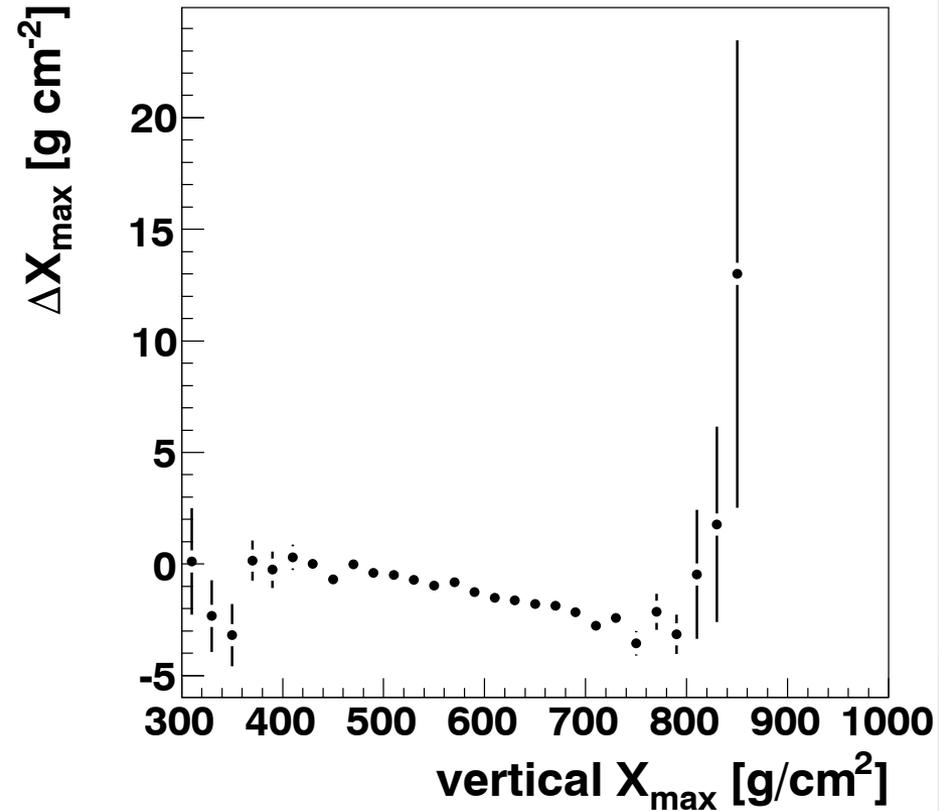
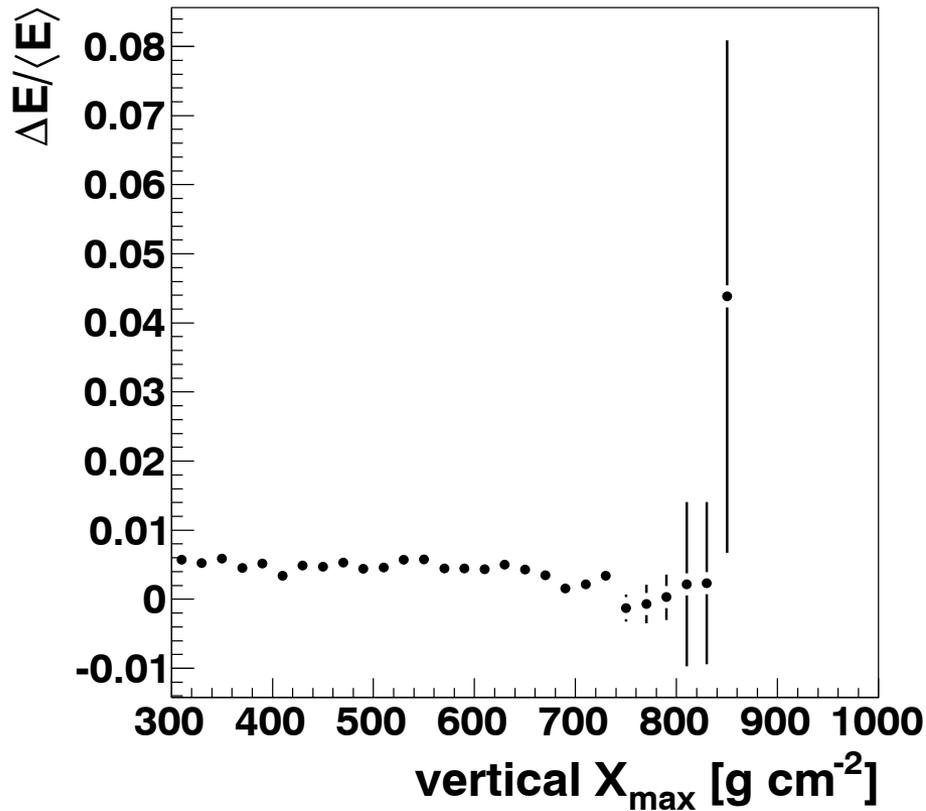
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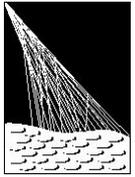
Reconstruction Differences vs. vertical X_{\max}



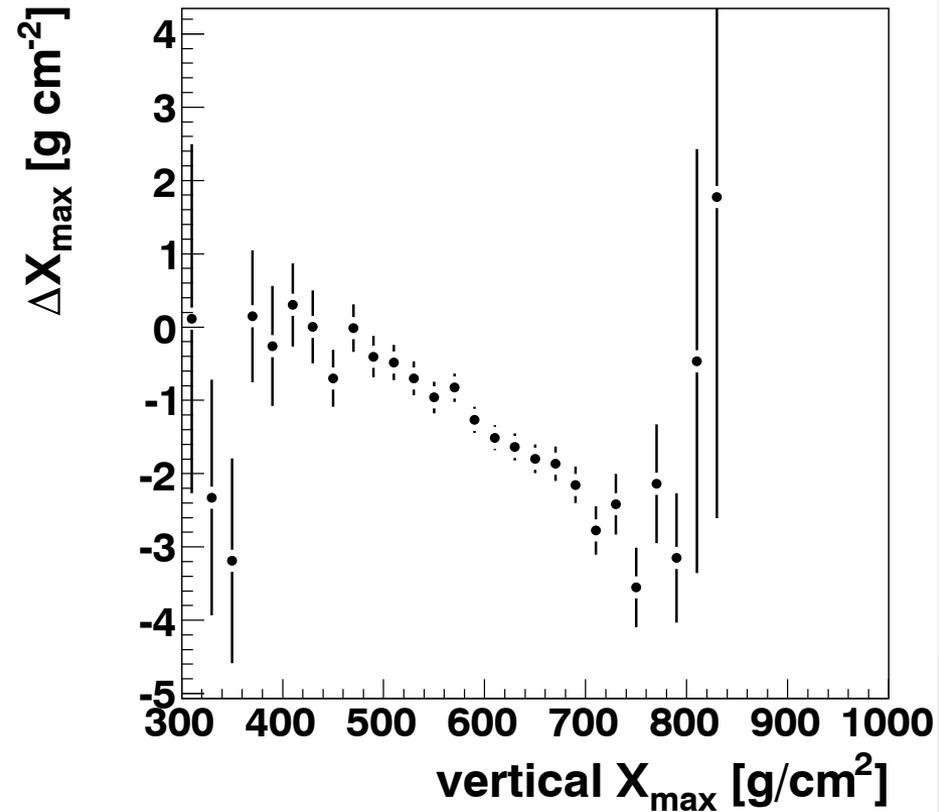
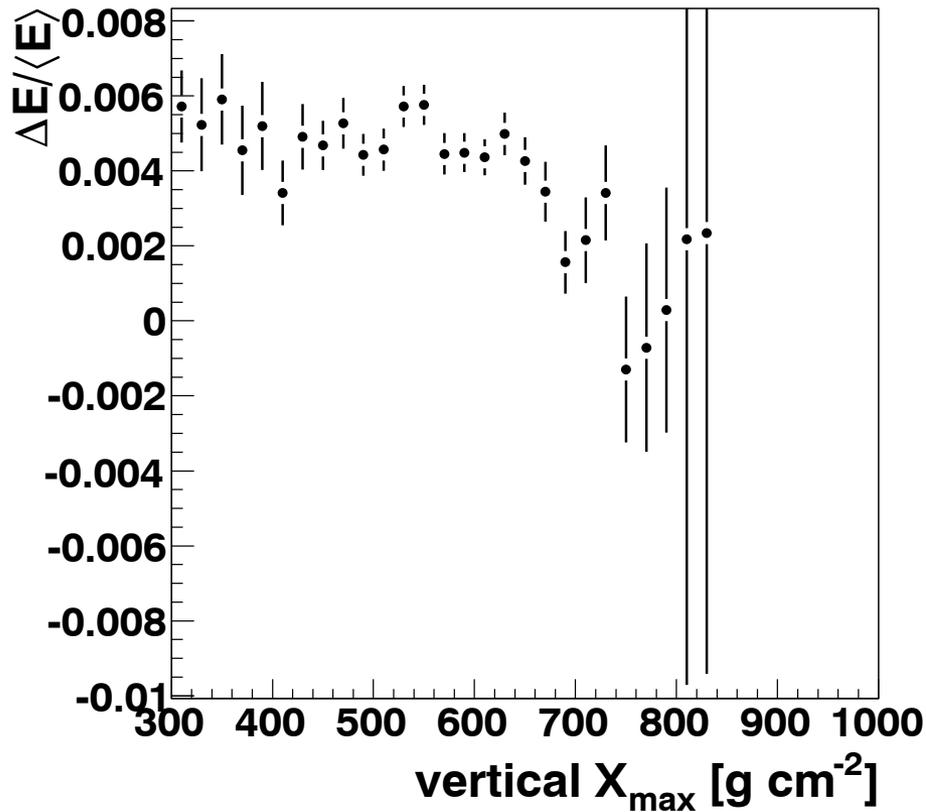
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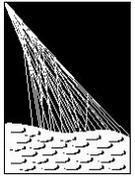
Reconstruction Differences vs. vertical X_{\max}



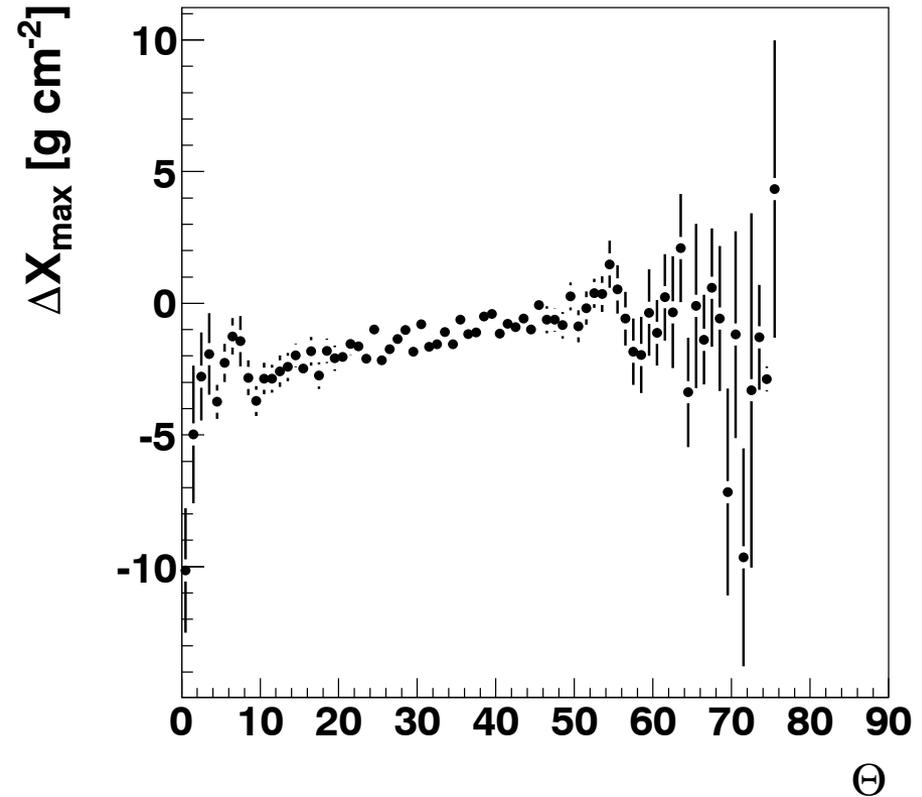
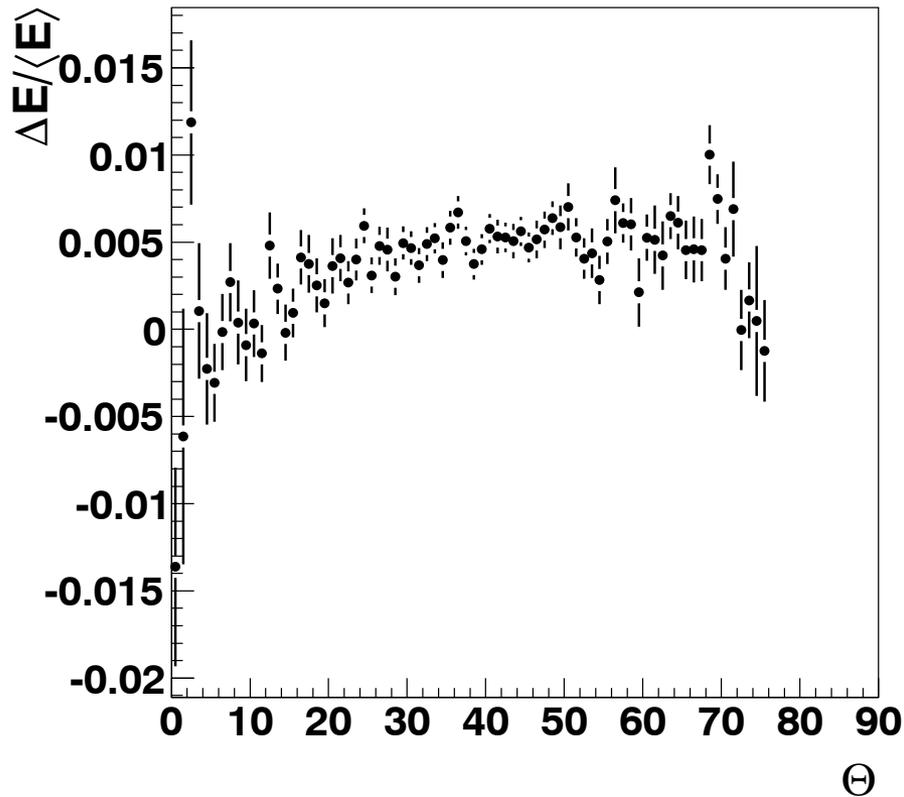
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Reconstruction Differences vs. zenith angle



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Summary

- Auger Observatory for investigation of **highest-energy cosmic rays**
- Actual **atmospheric profiles** must be known for a reliable EAS reconstruction
- **Local radio soundings** are inefficient and duration of validity is questionable
- **GDAS data** describe conditions at the (southern) Auger Observatory well
- **EAS reconstruction** reaches a higher level of precision

