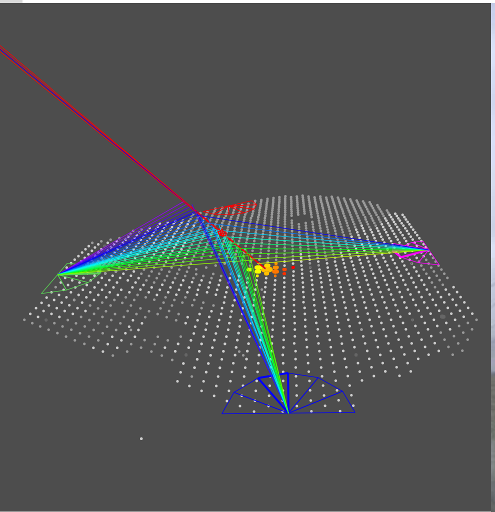
Atmosphere-Dependent Fluorescence Calculation in Air Shower Reconstruction

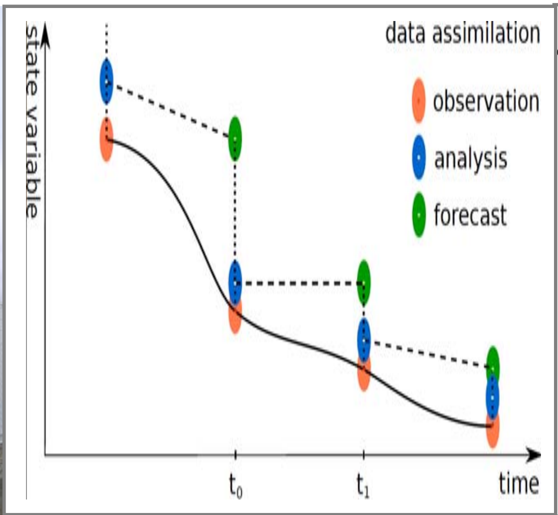
B. Keilhauer for the Pierre Auger Collaboration

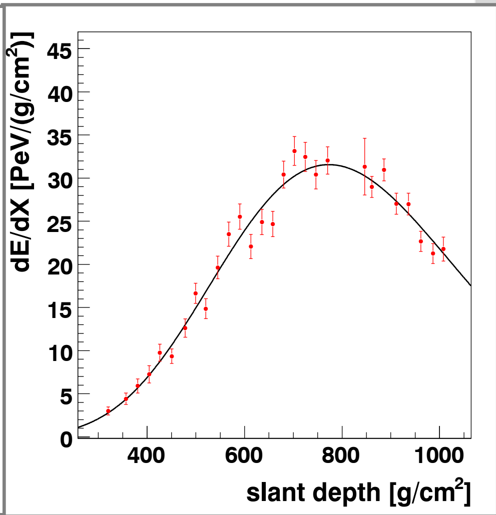
7th Air Fluorescence Workshop – Coimbra, Portugal

Overview

- Pierre Auger Observatory and its Reconstruction Procedure
- Meteorological Radio Soundings
  - Application to Air Shower Reconstruction
- Data from a Global Data Assimilation System
  - Application to Air Shower Reconstruction







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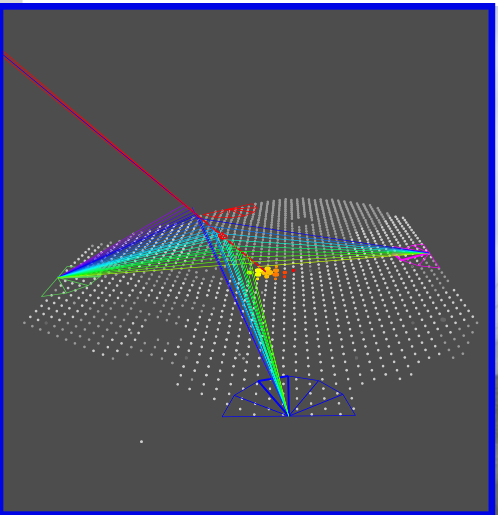
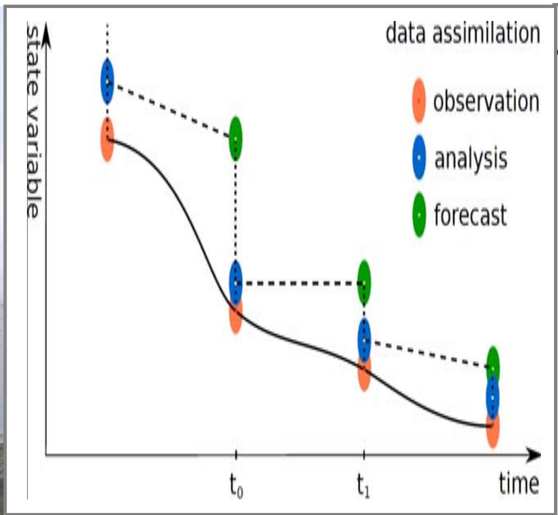
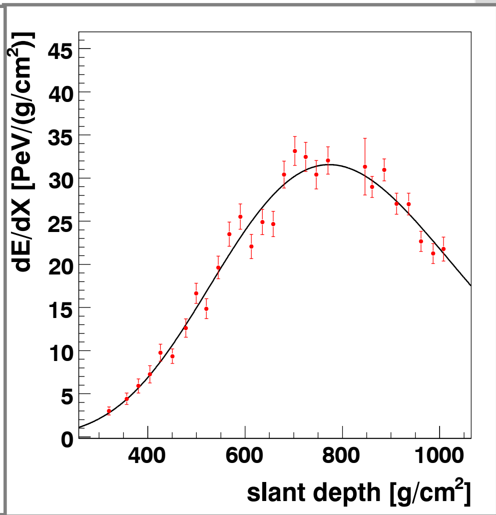
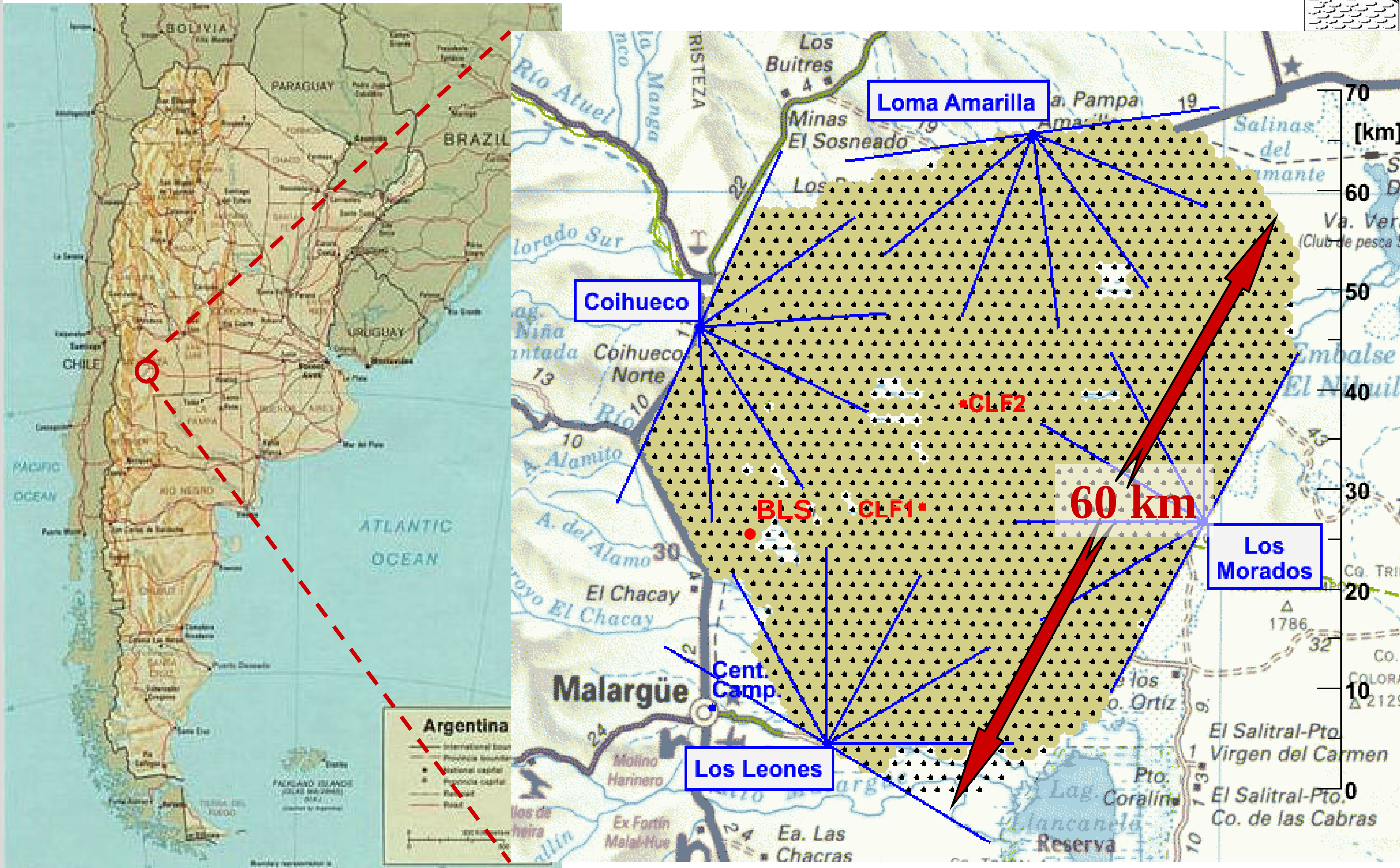






The Southern Pierre Auger Observatory



Why Hybrid Detection Technique ?

PIERRE AUGER OBSERVATORY

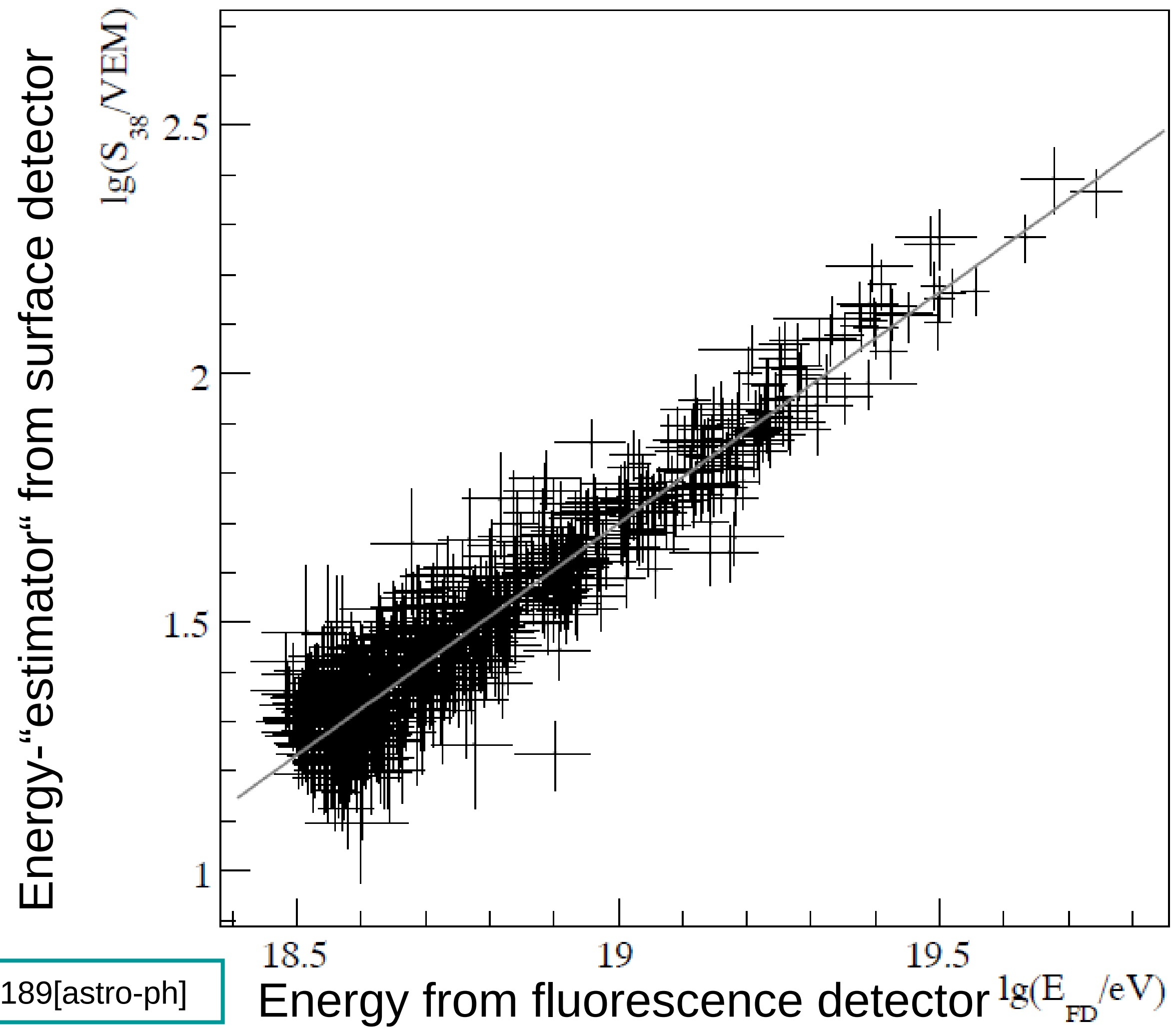
Surface Detectors

- ⬆ 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

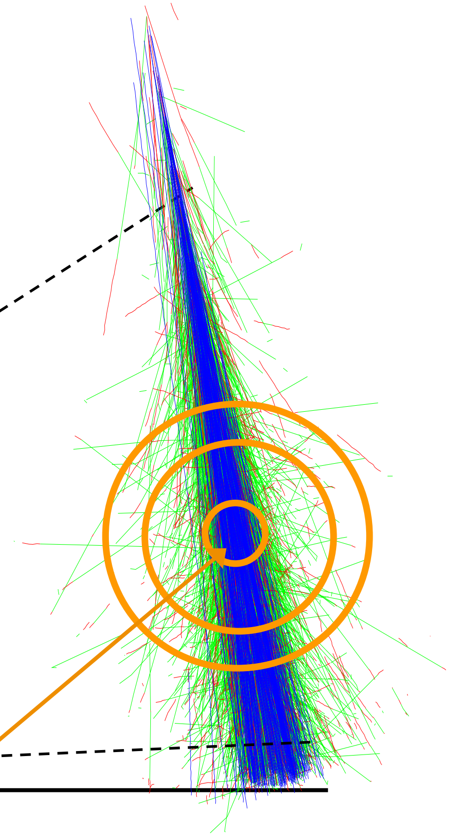
Energy Calibration



arXiv:0906.2189[astro-ph]

Measuring Principle of EAS with Fluorescence Telescopes

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



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

NIM A 597 (2008) 1

Standard Fluorescence Calculation

- AIRFLY parameterisation
- with normalisation of Y_{337} to that value from Nagano et al.
- spectrally resolved data, 34 transitions between 295 and 430 nm

$$Y_{\mathrm{air}}(\lambda, p, T) = Y_{\mathrm{air}}(337, p_0, T_0) \cdot I_\lambda(p_0, T_0) \times \frac{1 + \frac{p_0}{p'_{\mathrm{air}}(\lambda, T_0)}}{1 + \frac{p}{p'_{\mathrm{air}}(\lambda, T_0)\sqrt{\frac{T}{T_0}}\frac{H_\lambda(T_0)}{H_\lambda(T)}}}$$

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Atmosphere-Dependent Calculation -1-

PIERRE AUGER OBSERVATORY

- Temperature-dependent collisional cross sections

$$\frac{H_\lambda(T)}{H_\lambda(T_0)} = \left(\frac{T}{T_0}\right)^{\alpha_\lambda}$$

- With 14 α_λ for different wavelengths
  - 12 of the 2P system
  - 2 of the 1N system

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Atmosphere-Dependent Calculation -2-

PIERRE AUGER OBSERVATORY

- Quenching due to water vapour

$$\frac{1}{p'_{\mathrm{air}}} \to \frac{1}{p'_{\mathrm{air}}}\left(1 - \frac{p_{\mathrm{h}}}{p}\right) + \frac{1}{p'_{\mathrm{H_2O}}}\frac{p_{\mathrm{h}}}{p}$$

- With 14 $p'_{\mathrm{H_2O}}$ for different wavelengths
  - 12 of the 2P system
  - 2 of the 1N system

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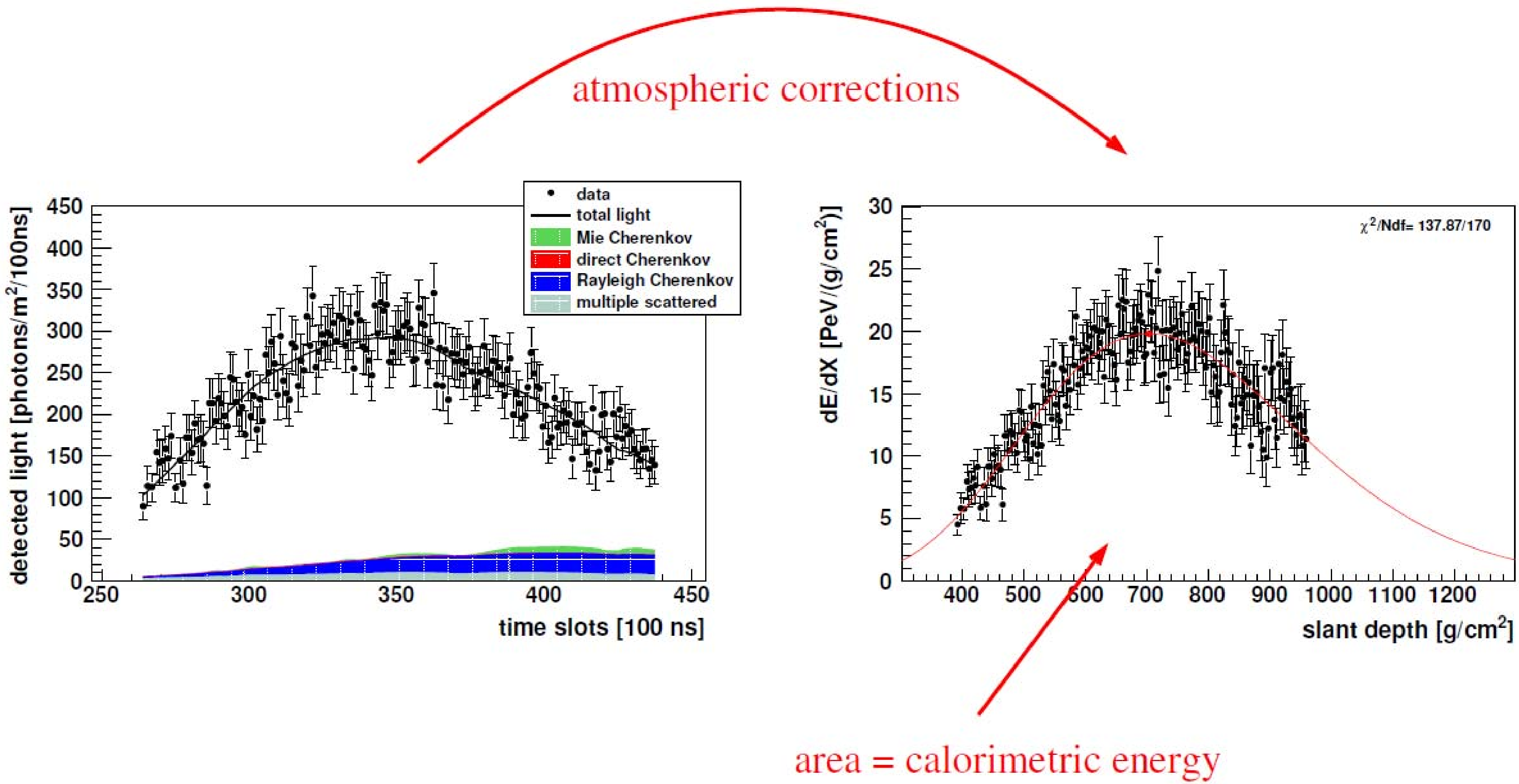
Air Shower Profile Reconstruction



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- **Meteorological Radio Soundings**
  - Application to Air Shower Reconstruction

- Data from a Global Data Assimilation System
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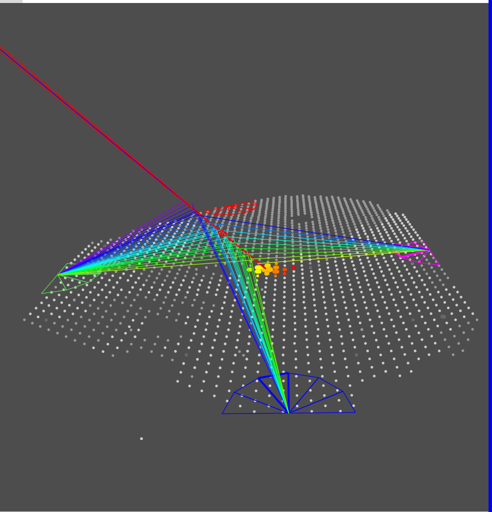
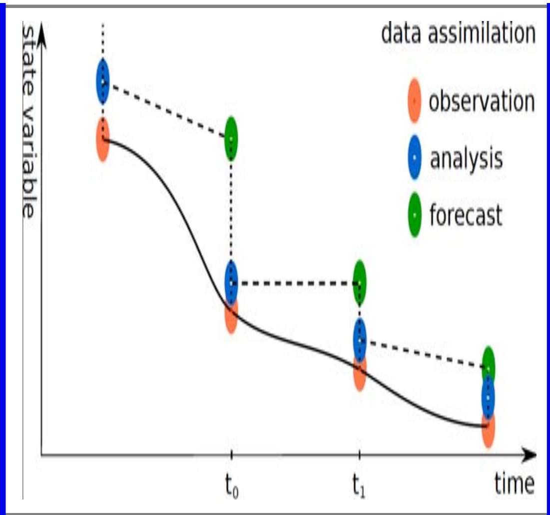
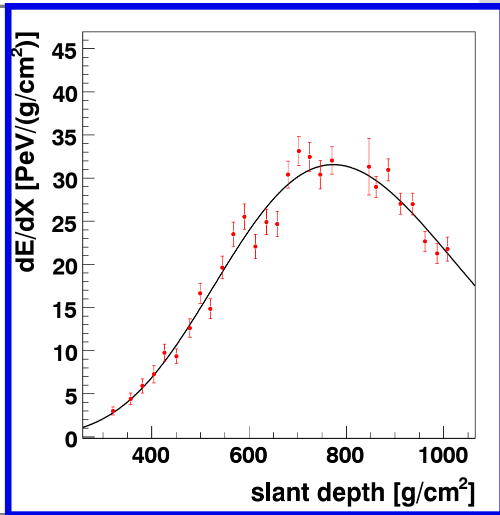






Meteorological Radio Soundings

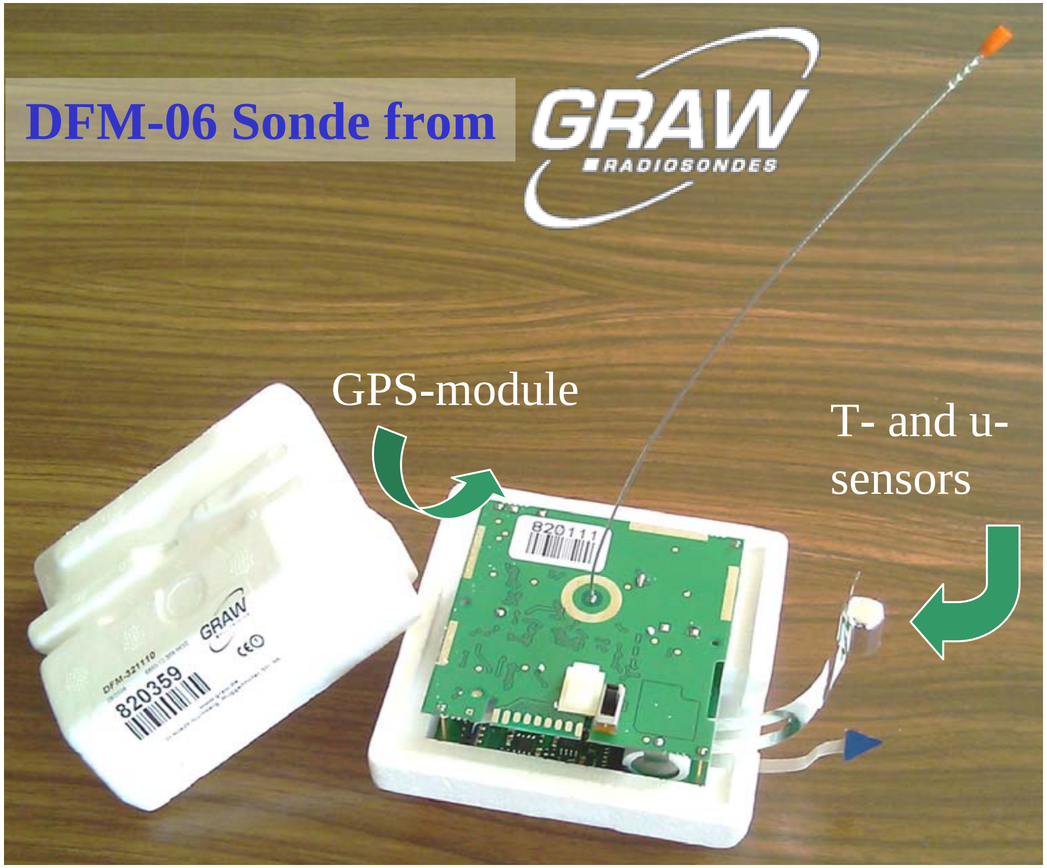
- Measurements of air pressure (p),
  of air temperature (T),
  of humidity (u)
- in dependence of altitude
- every 5 seconds readout of all data
- from ground up to about 23 km a.s.l.

Balloon Launching Station (BLS)

Start of a weather balloon

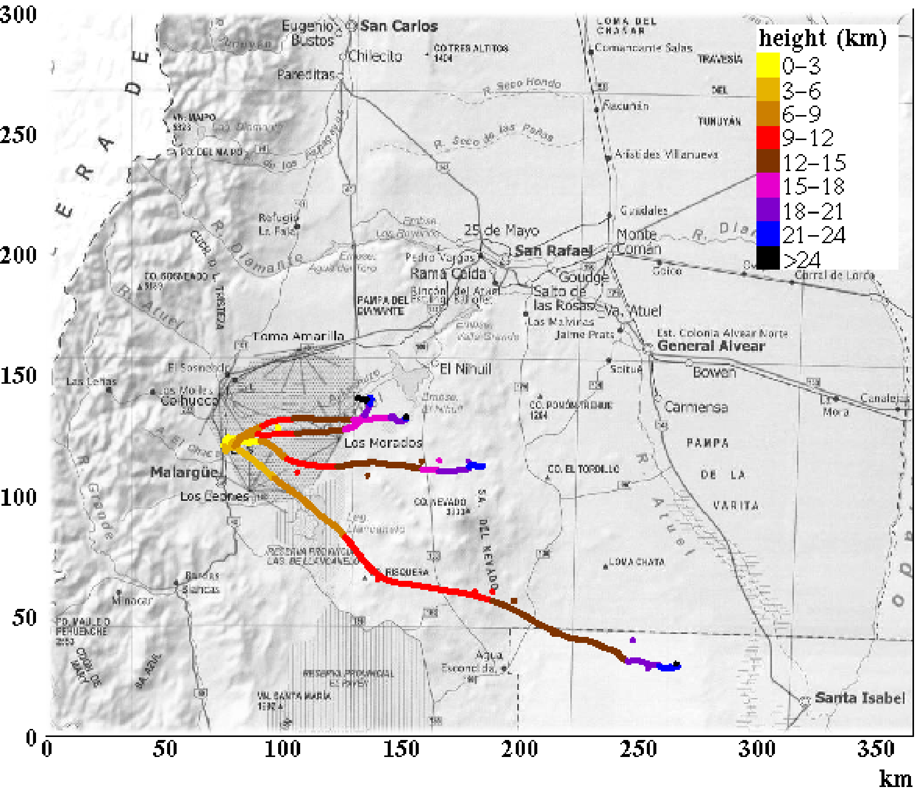
Radiosondes

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

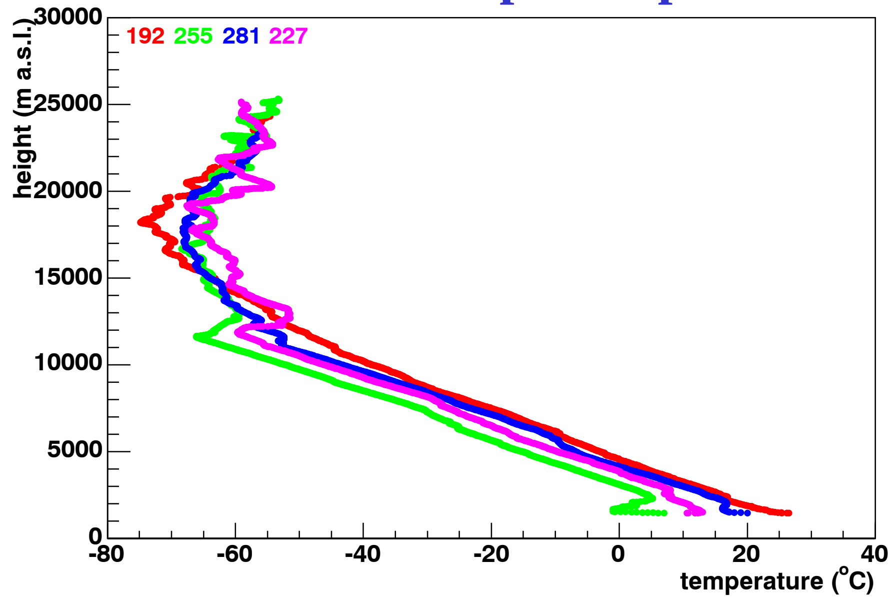


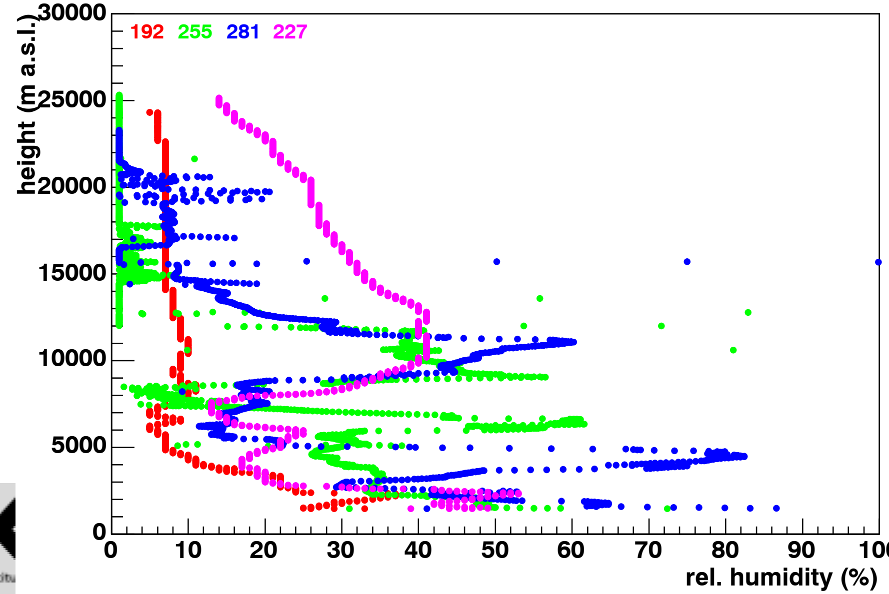
Radio Soundings at the Pampa Amarilla

flight paths above the pampa



measured atmospheric profiles





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

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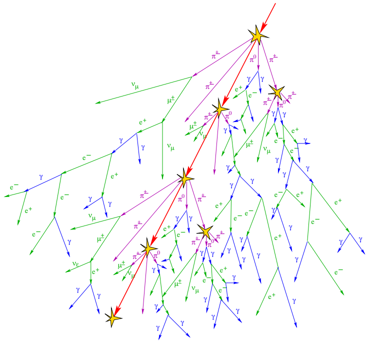
Balloon-the-Shower Chain



Online Hybrid Reconstruction

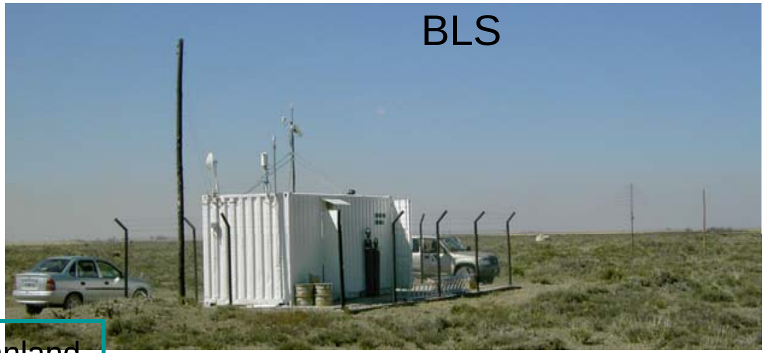
Analysis every 15 min.

Quality cuts

```
...
  && EnergyErr / Energy < 0.2
  && XmaxErr < 40.
  && Xmax > minFOV + 10.
  && Xmax < maxFOV – 10.
  && StationAxisDistance < 2000.
  && GHFitChi2 / GHFitNDF < 2.5
  && LineFitChi2 – GHFitChi2 > 4.
...
```

Shower above Energy threshold triggers technician via SMS

Technician drives to the BLS and launches balloon



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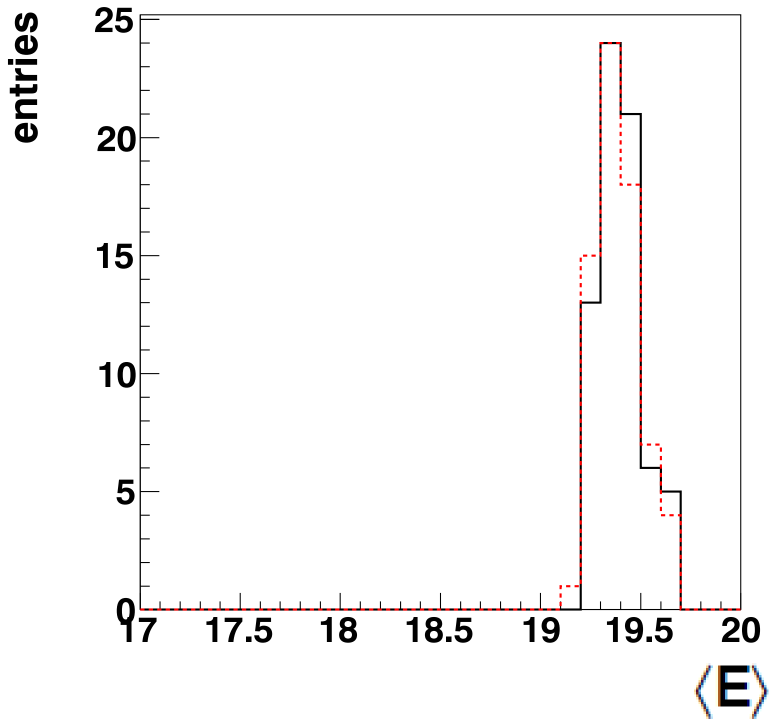
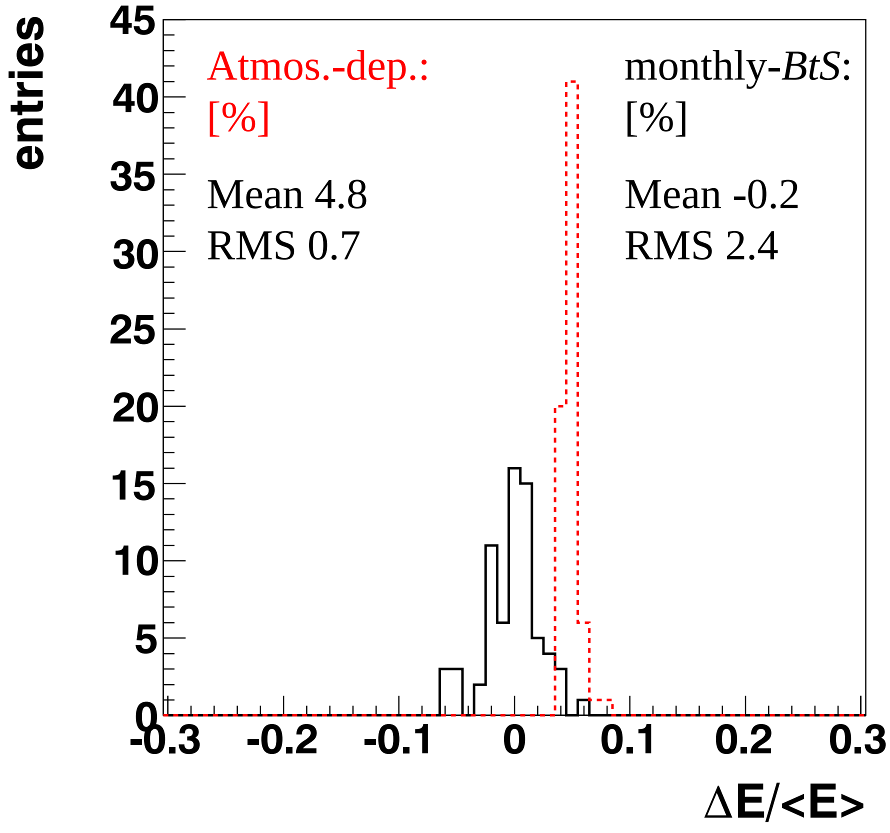
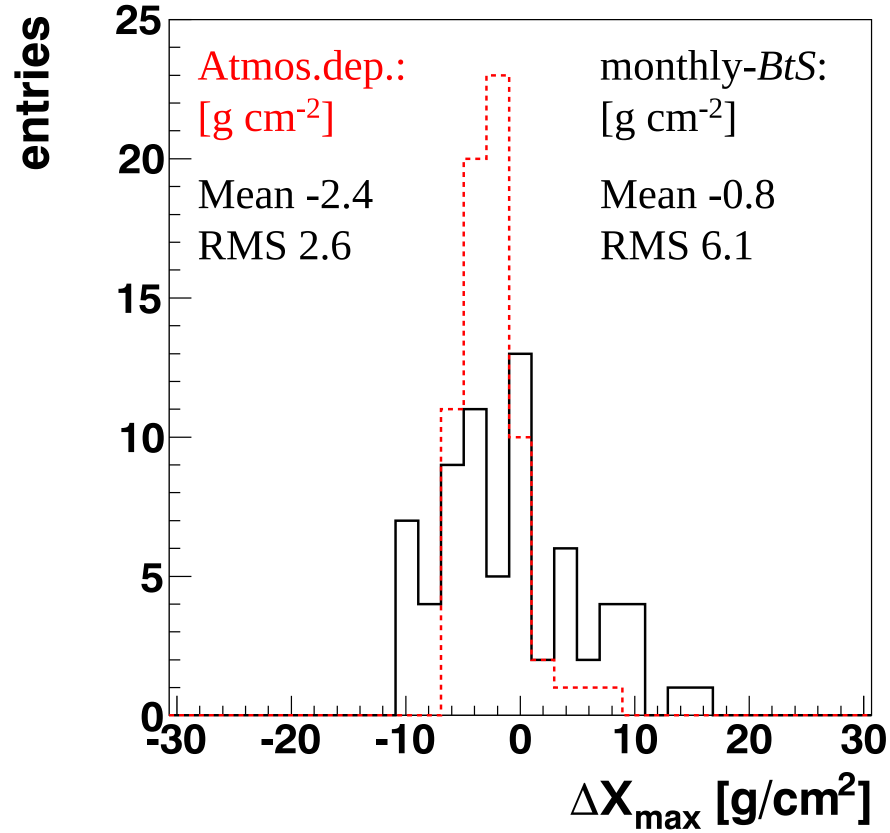
Reconstruction Analysis

- all EAS from 2009 until mid 2010 which initiated a BtS
- In RED reconstruction with local atmospheric monthly models, FIRST without – SECOND with atmosphere-dependence
- In BLACK reconstruction with atmosphere-dependence FIRST with local monthly models – SECOND with BtS atmospheres

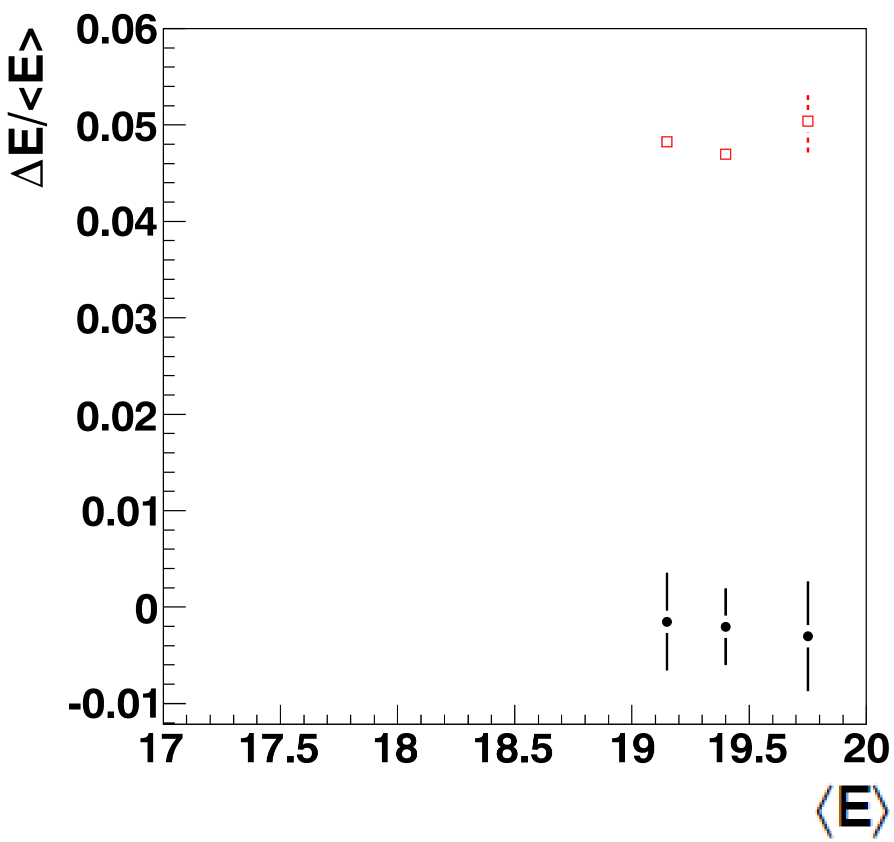


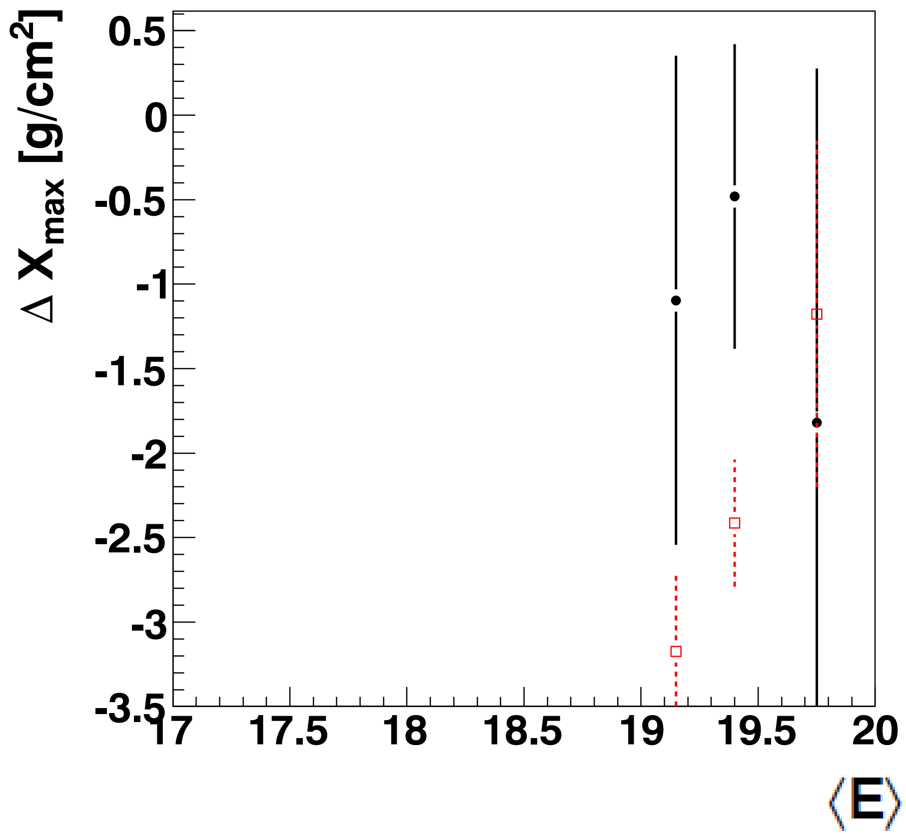
Reconstruction Differences



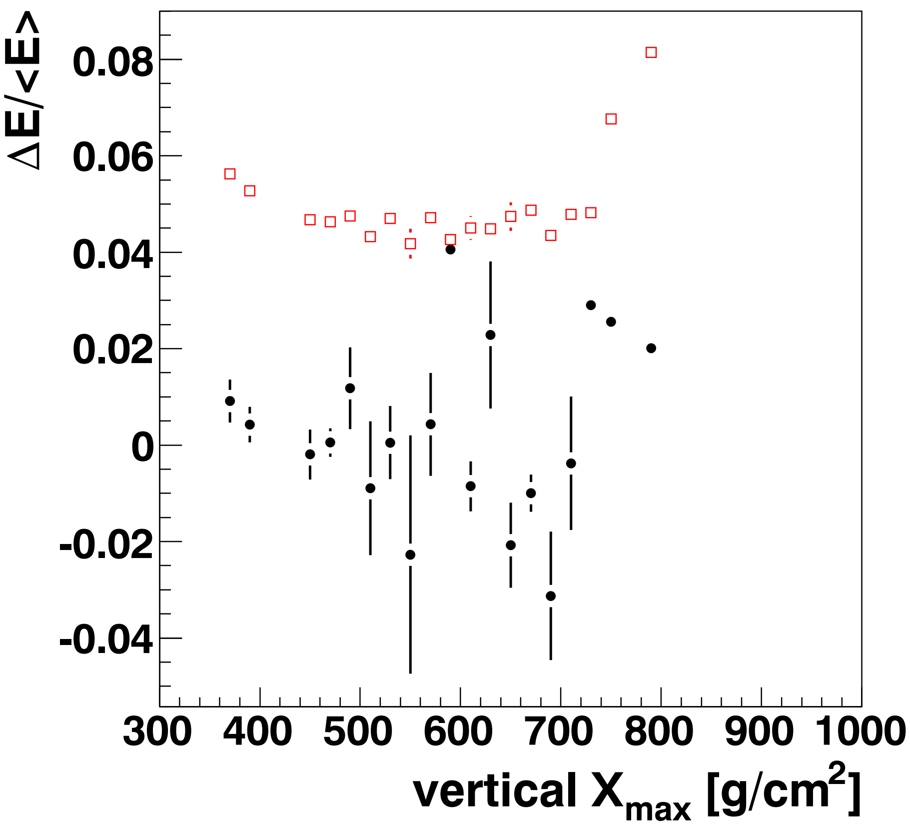


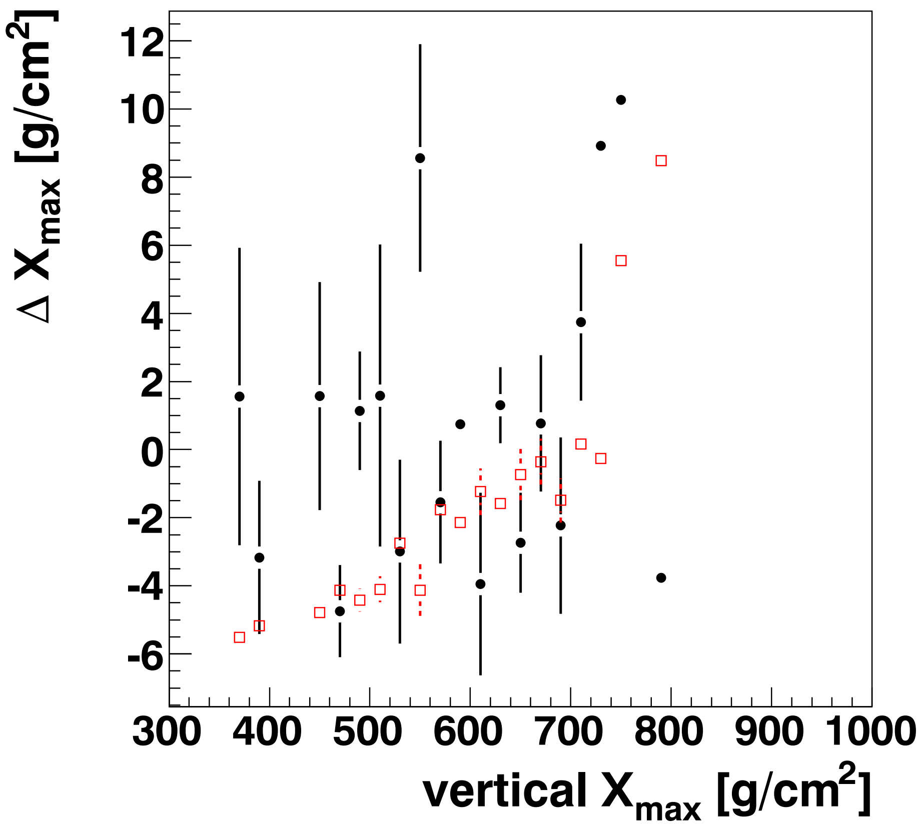
Reconstruction Differences vs. <E>





Reconstruction Differences vs. vertical X_{max}





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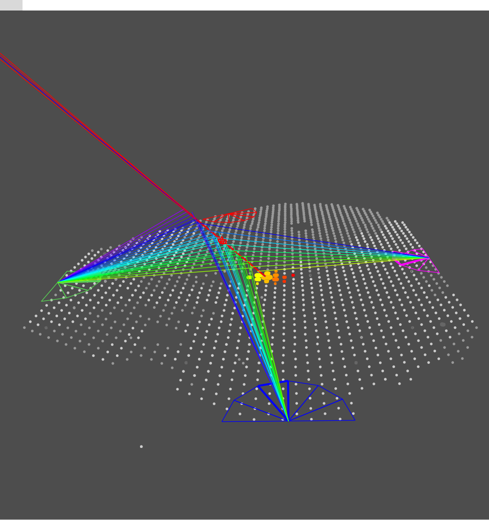
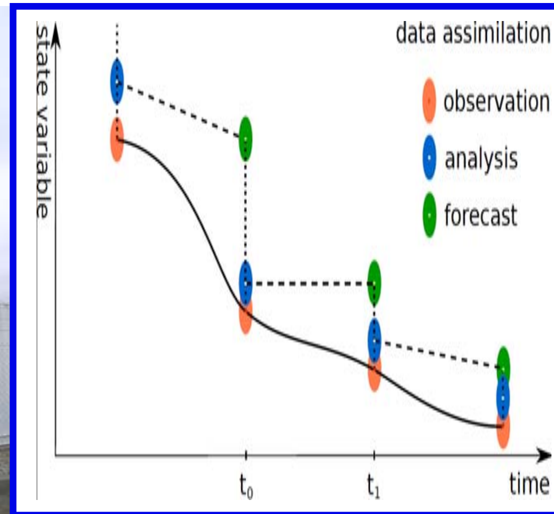
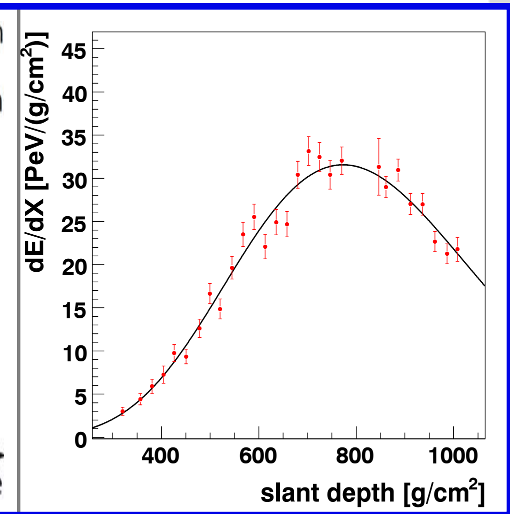
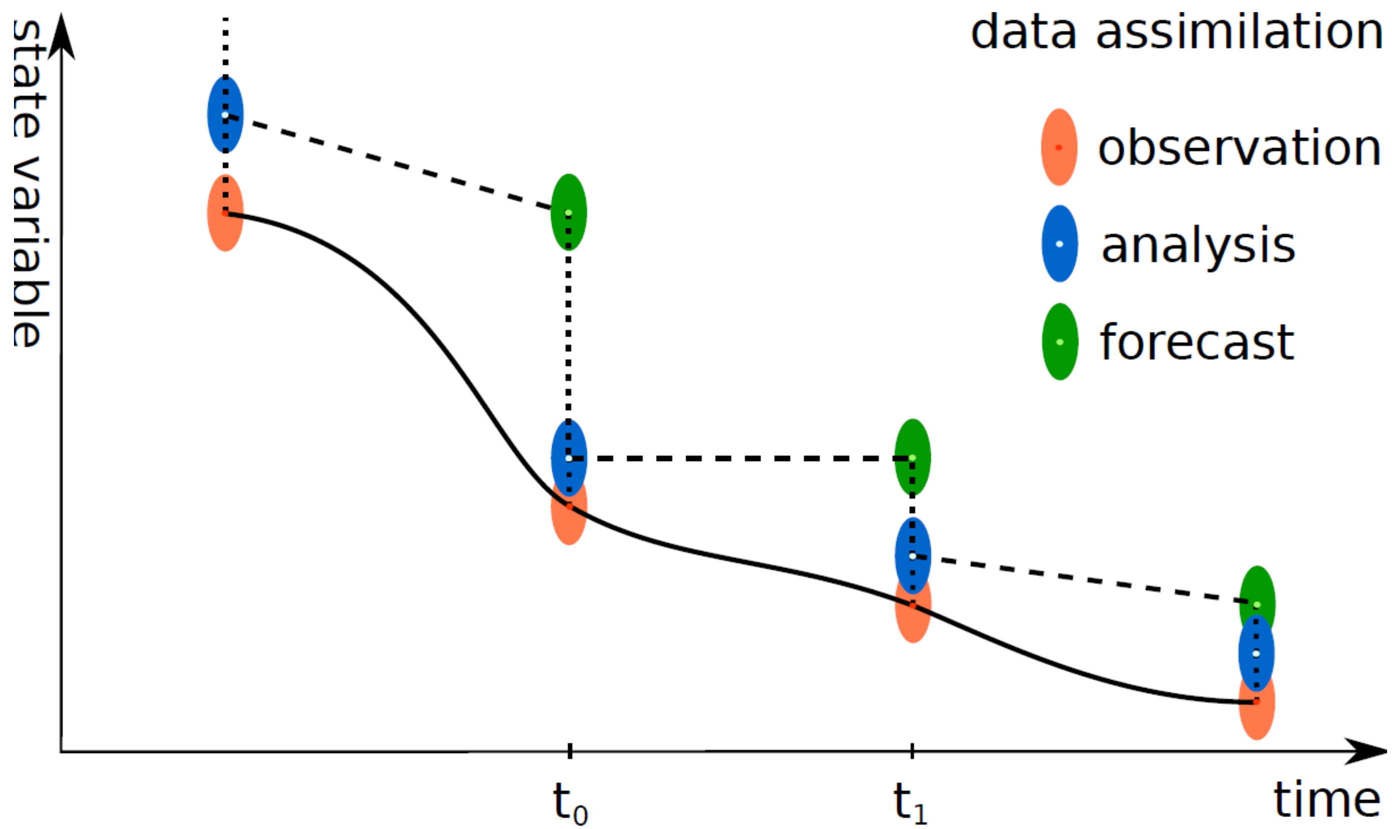






Global Data Assimilation System (GDAS)



GDAS

- global atmospheric model developed at NCEP

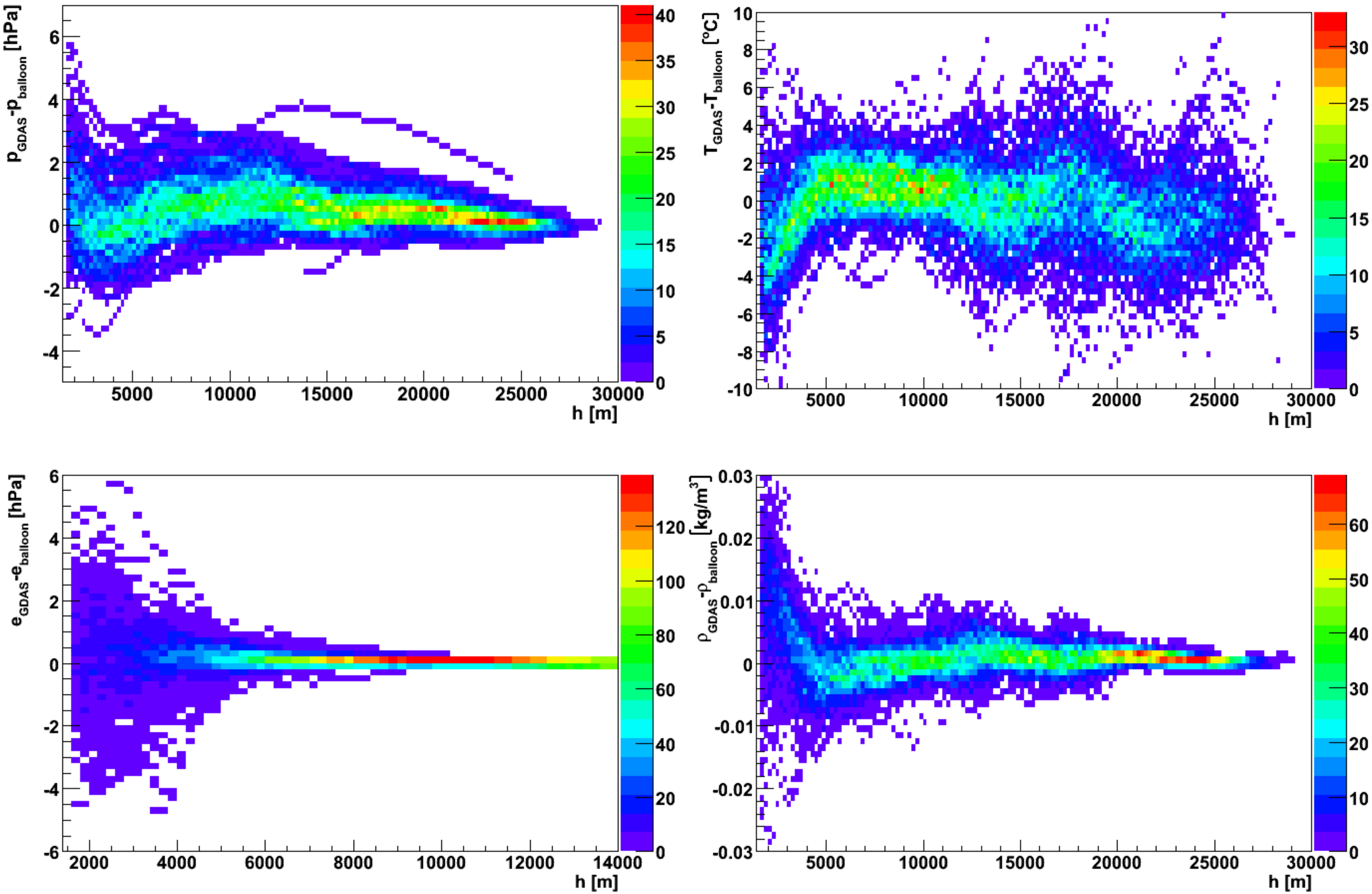
  National Centers for Environmental Prediction (NCEP) at NOAA – National Oceanic and Atmospheric Administration

- 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.arl.noaa.gov`**

Comparison of GDAS with Sounding Data

- using fitting technique -



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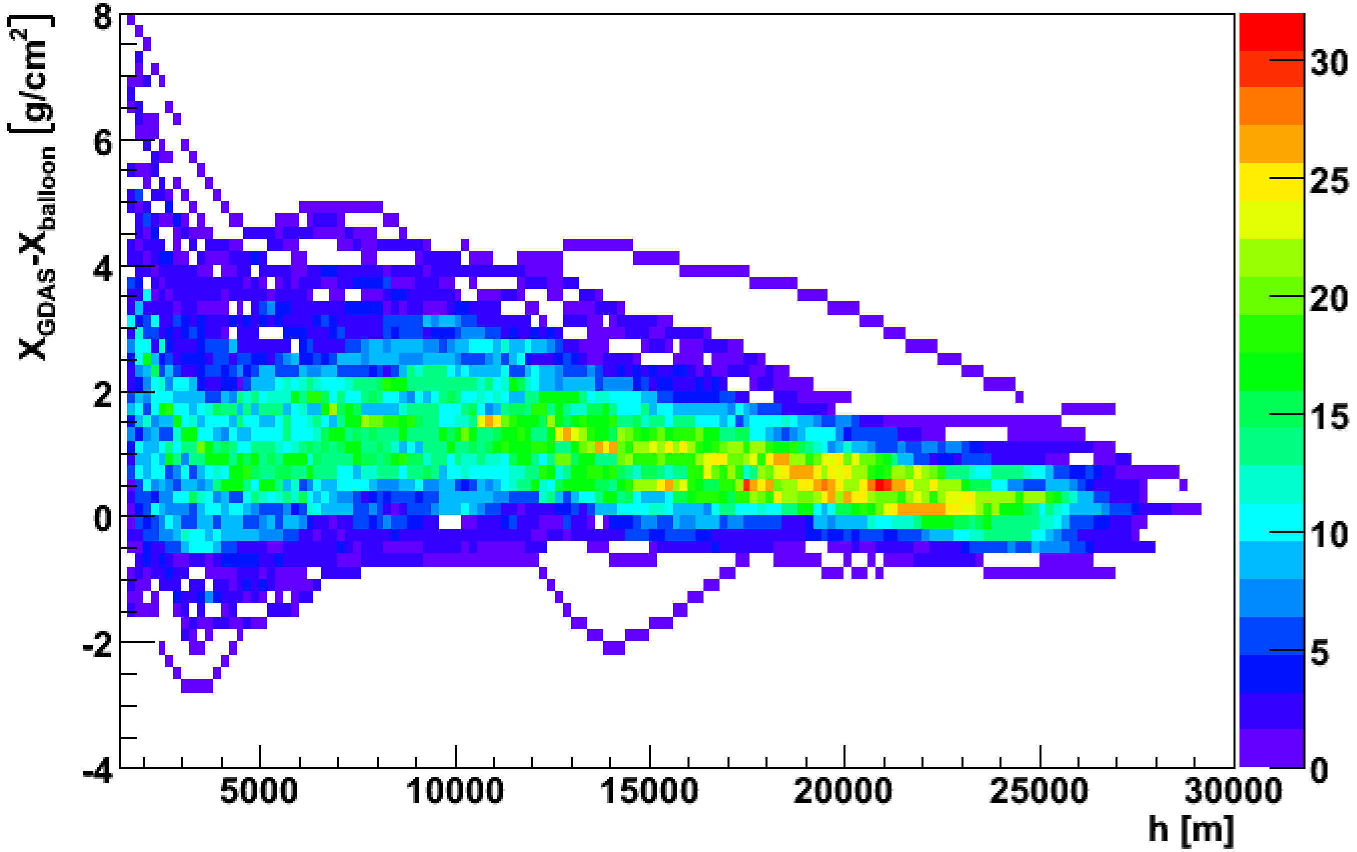
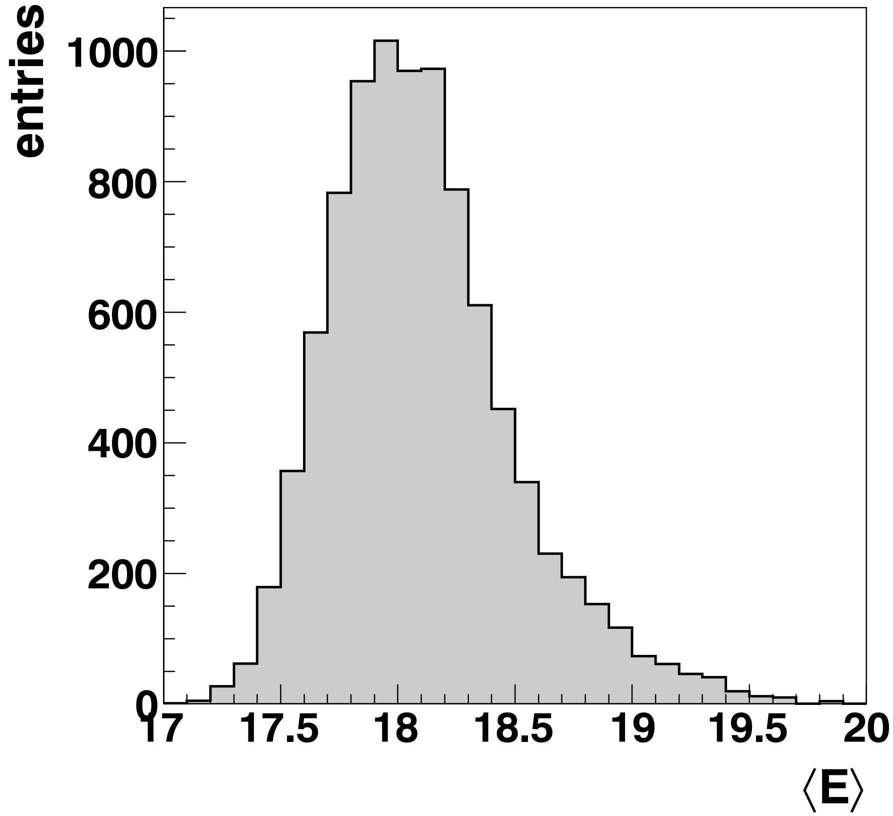


Reconstruction Analysis

- 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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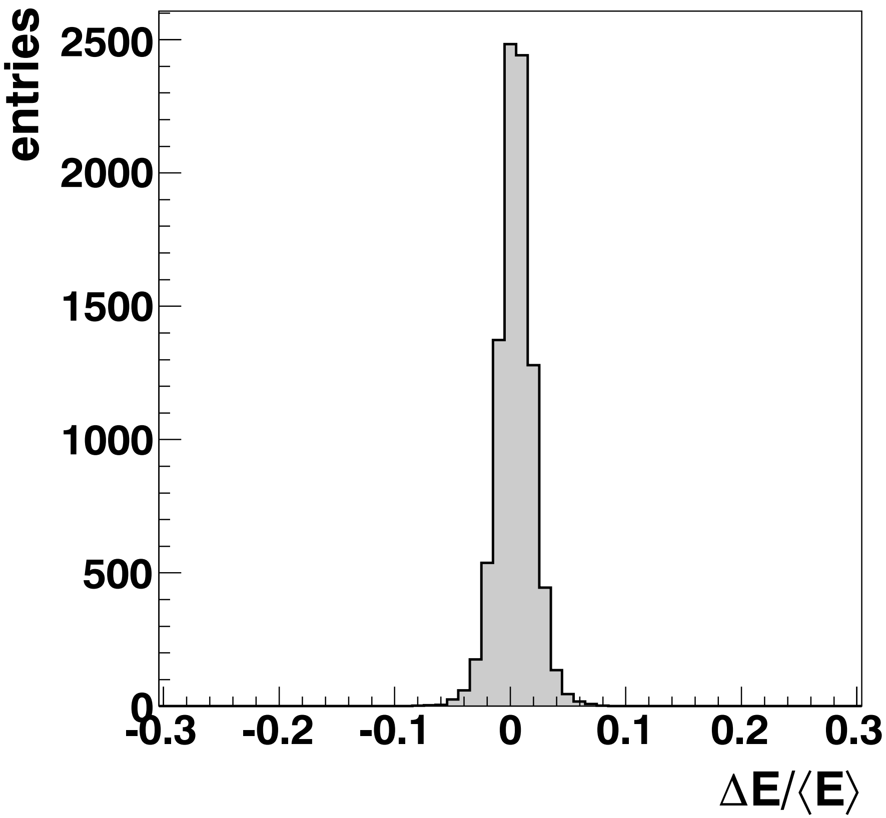
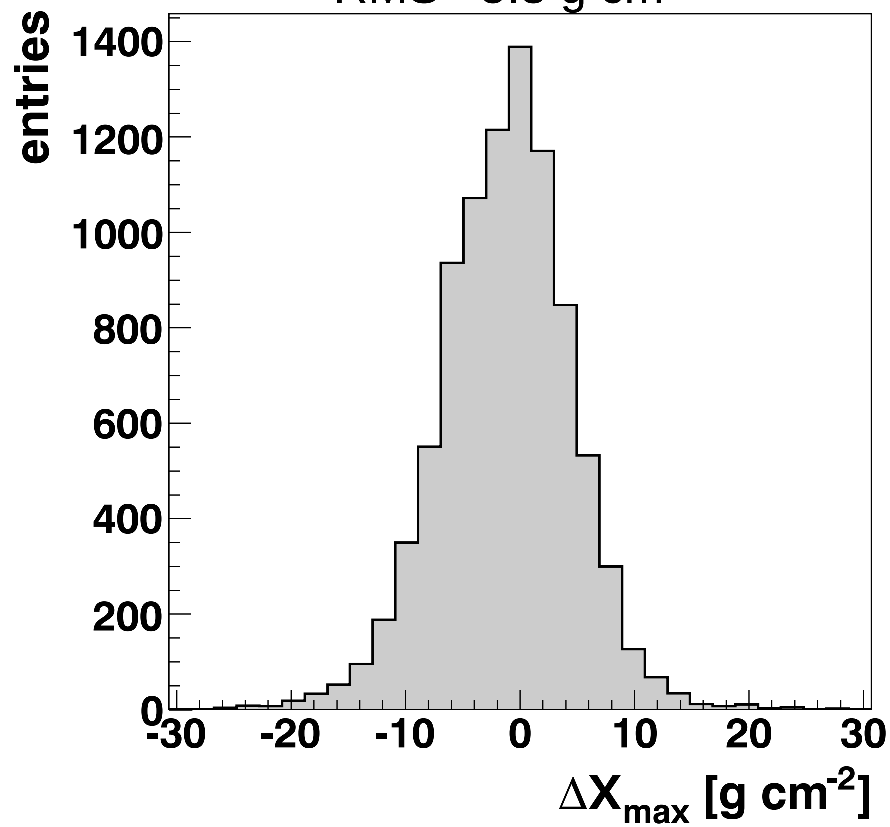
Mean 0.4 %
RMS 1.5 %



Mean -1.3 g cm^{-2}
RMS 5.8 g cm^{-2}



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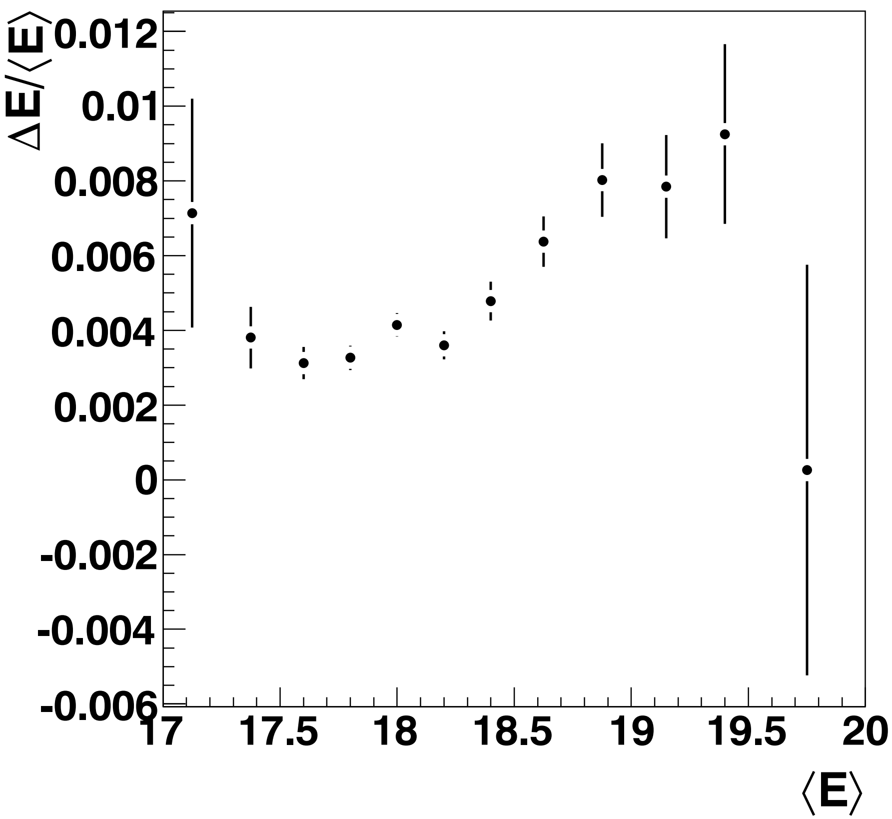

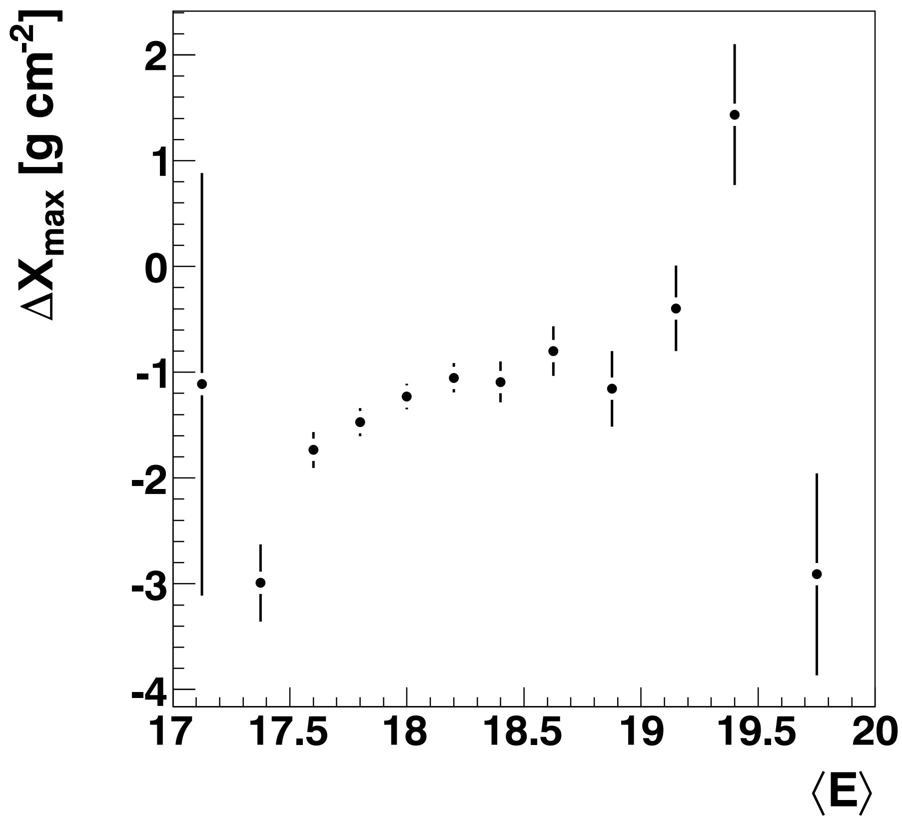

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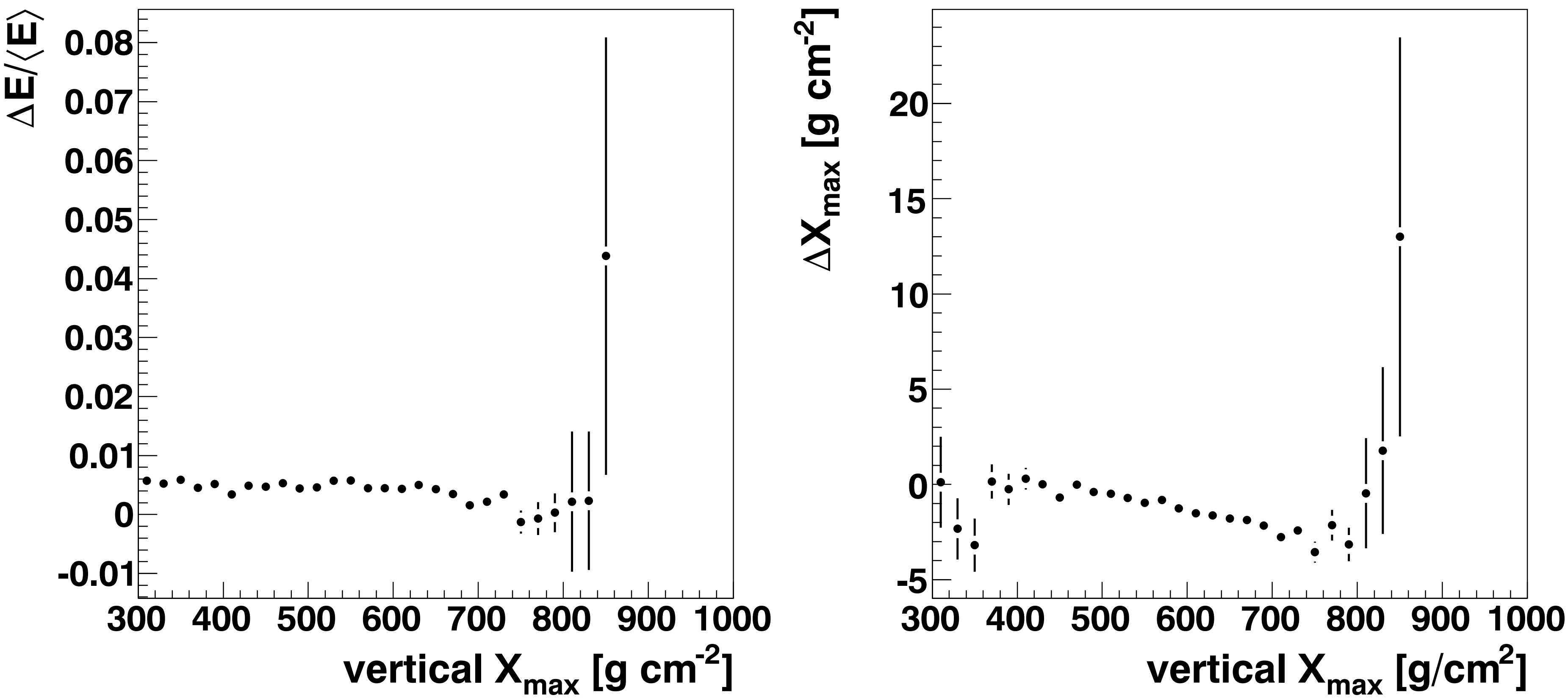

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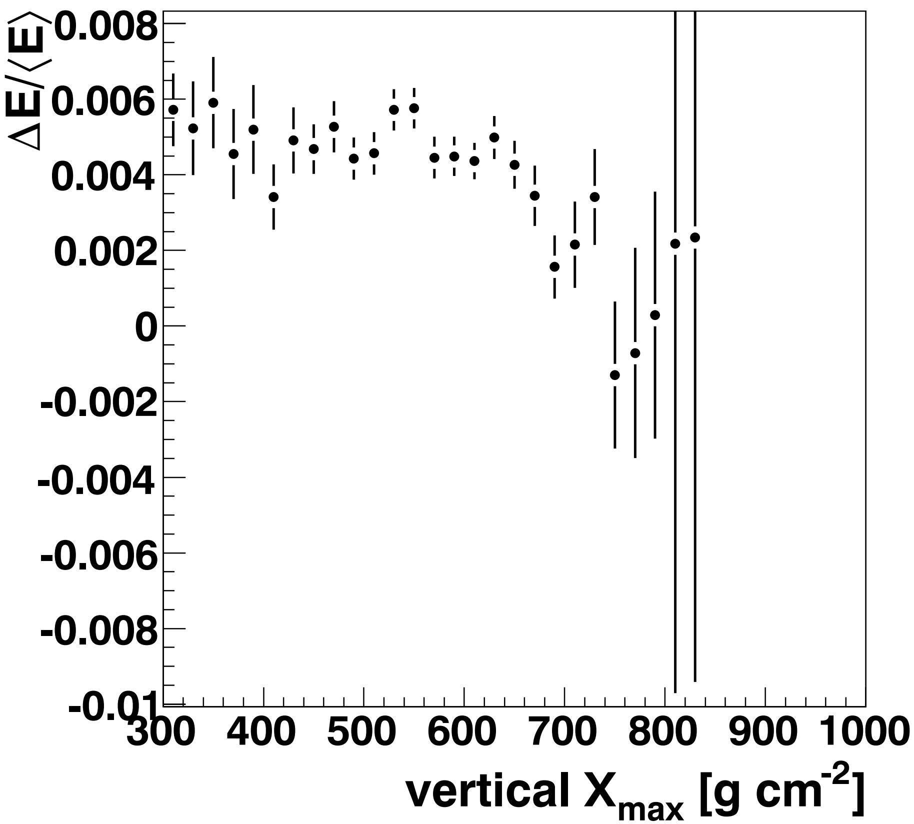
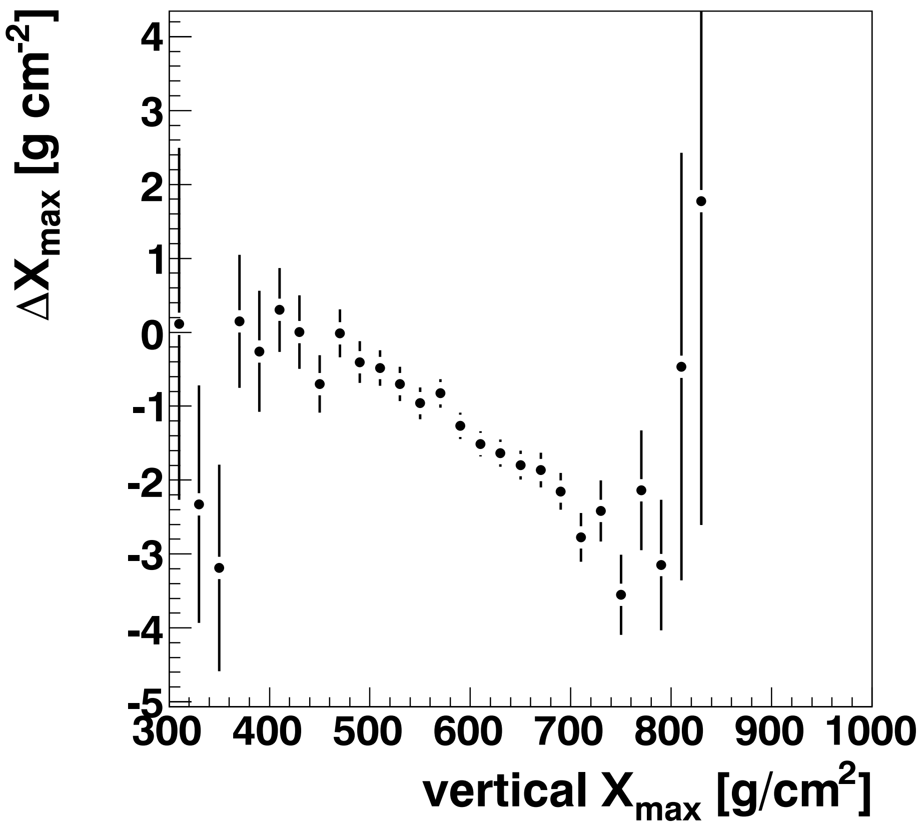
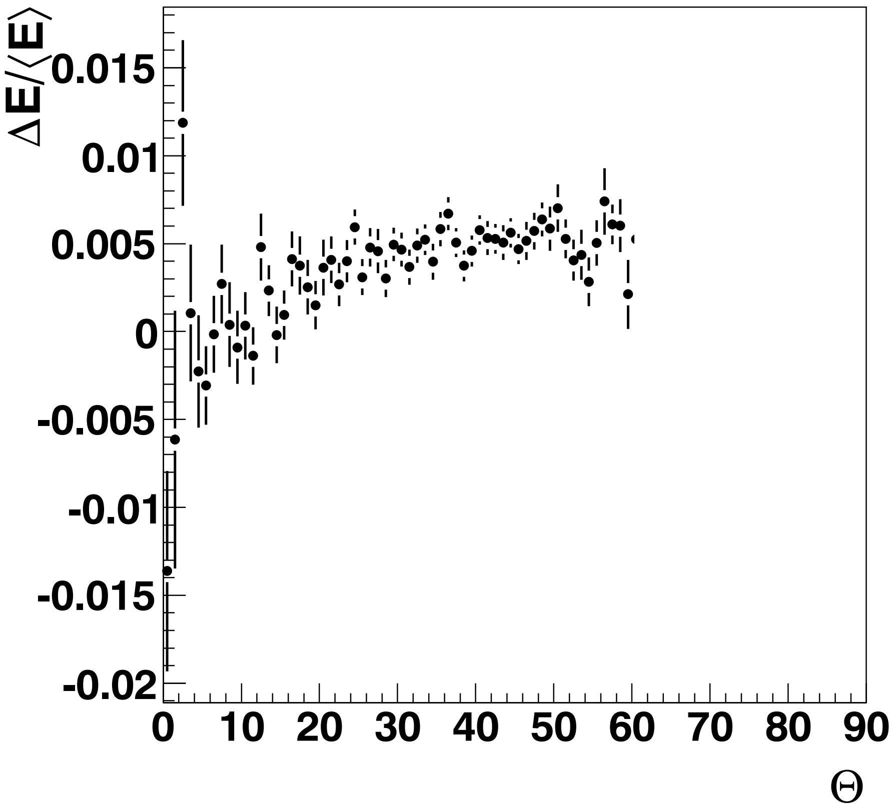
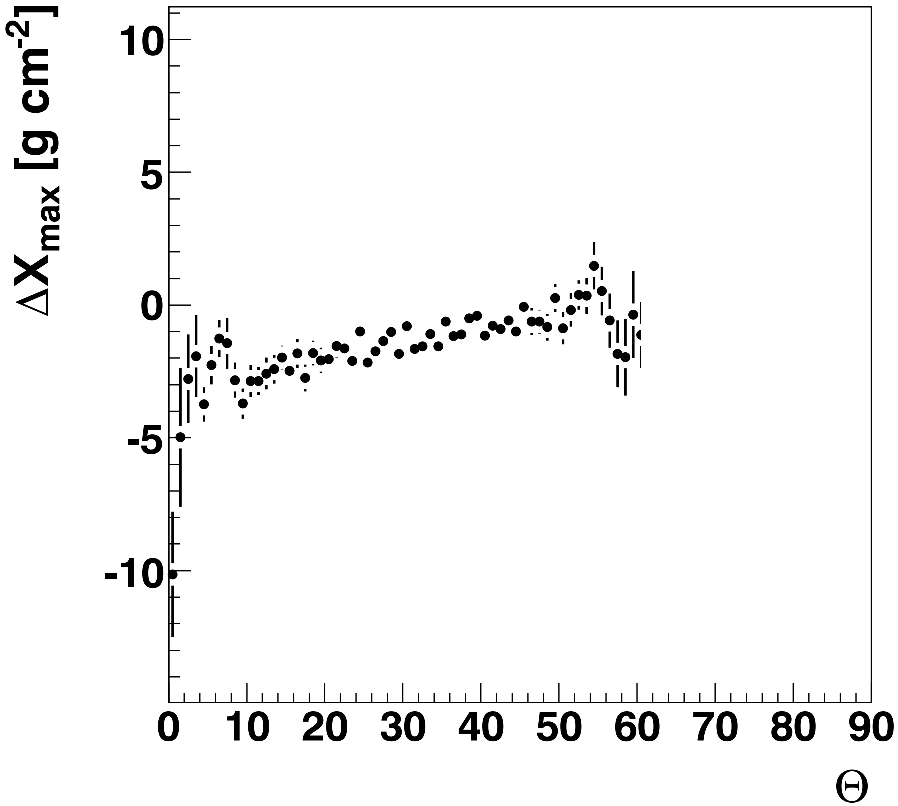




Reconstruction Differences vs. zenith angle





Summary

- Auger Observatory starts to implement atmosphere-dependent fluorescence calculation in reconstruction
- Current investigations consider local monthly models, local radio soundings, and GDAS data
- Clear shift in E_0 and X_{max} due to atmosphere-dependent calculation
- GDAS data describe conditions at the (southern) Auger Observatory well