IceTop Energy Reconstruction

… a status report (IceTop-26)

Fabian Kislat

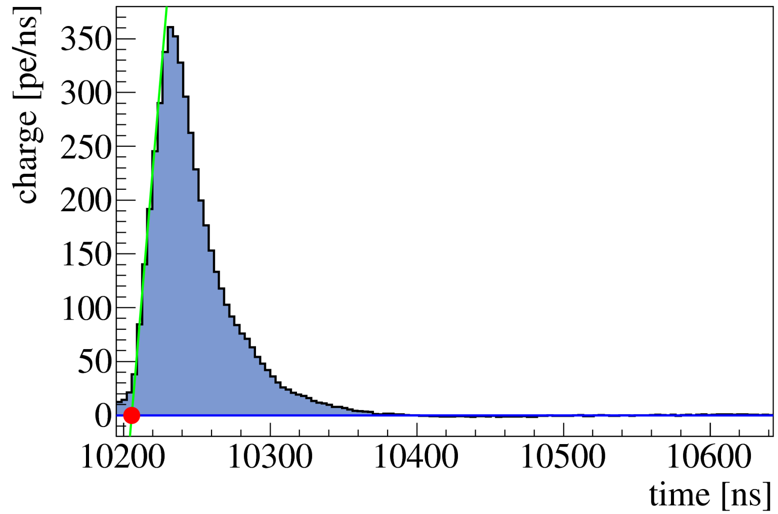
Cosmic Ray Workshop, Zeuthen
02/23/2010

Outline

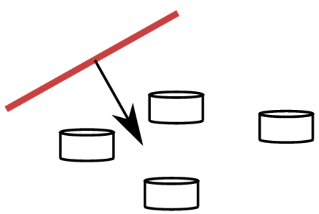
- Lateral Distribution Function
- Energy calculation
  - Unfolding Method
  - Parametric Method
- Systematic Uncertainties

Reconstruction Chain

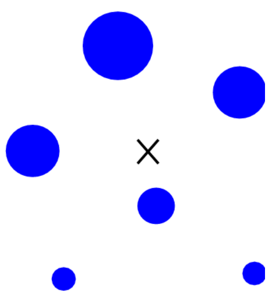
1. Extract Charge and time



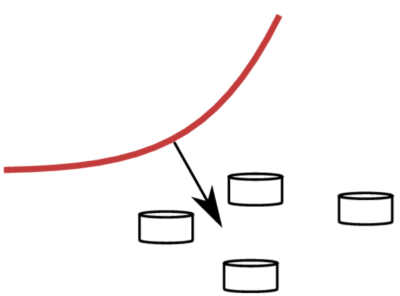
2. Plane fit direction first guess

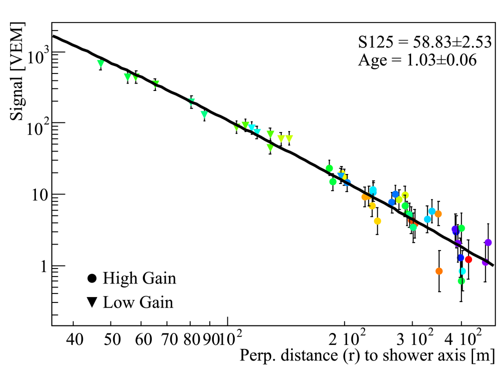


3. Centre Of Gravity core first guess

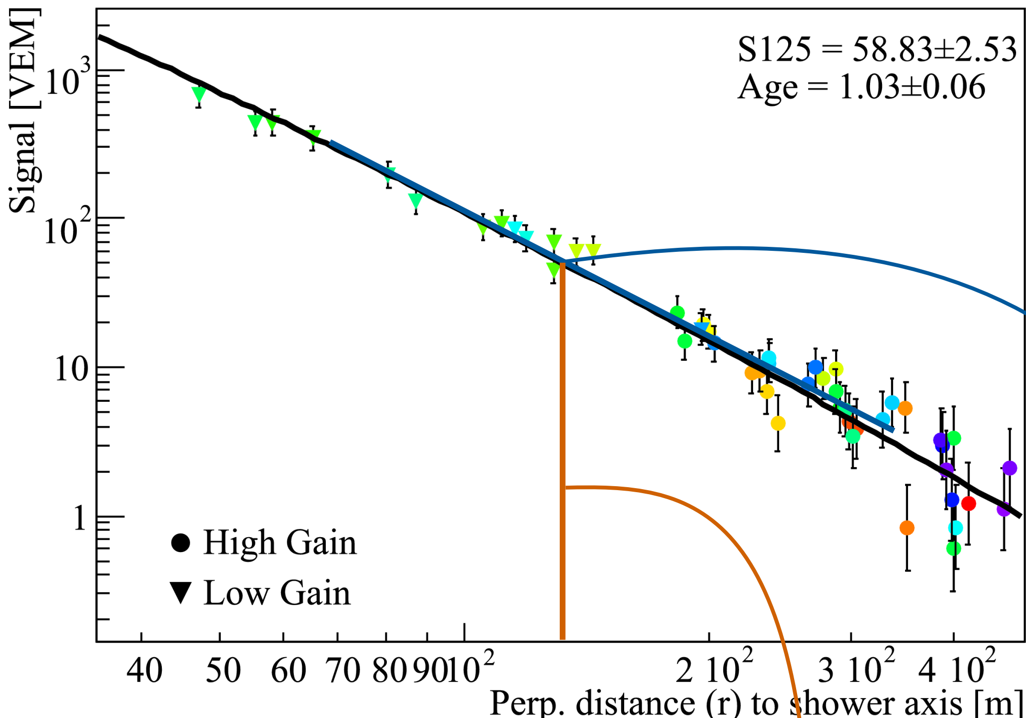


4. Lateral fit, combined with curved shower front fit, several iterations → likelihood reconstruction





Lateral Distribution Function



Slope at R = 125m

= 0.303 const.

Signal expectation at R = 125m

$$S(R) = S_{ref}\left(\frac{R}{R_{ref}}\right)^{-\beta-\kappa\log(R/R_{ref})}$$

= 125 m

→ 4 free parameters: S_{125}, β, x_c, y_c

Unfolding vs. Parametric Method

Unfolding Method

1. Calculate energy, proton based: $E_{rec}(S_{125}, \theta)$ from MC
2. Create proton-based energy spectrum
3. Monte Carlo → Energy response: $\log(E_{rec}/E_{true})$
   Different primary types
4. Use bias, resolution and efficiency to unfold the original spectrum

Parametric Method

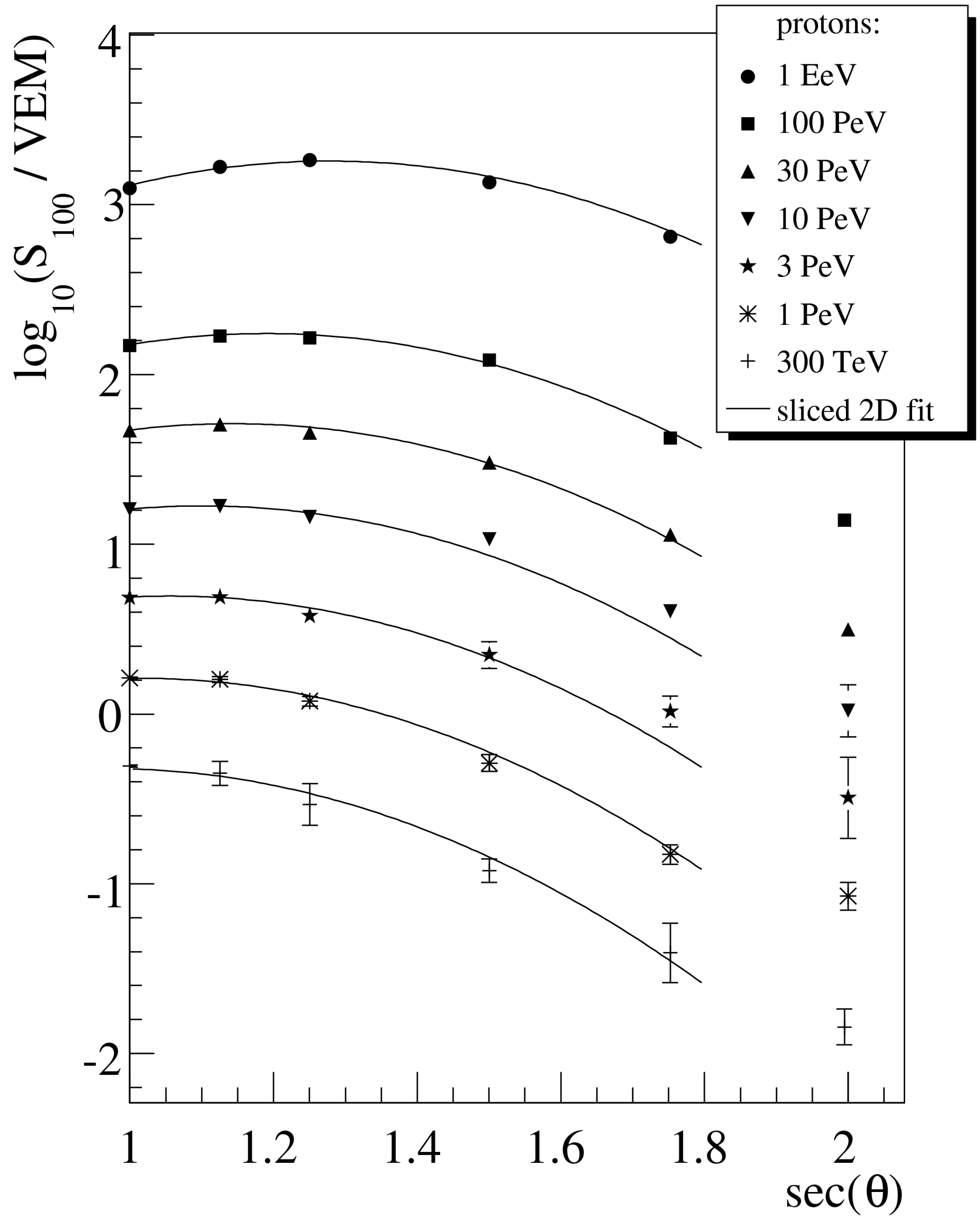
1. Monte Carlo → $E_{rec}(S_{125}, \theta)$
   For different primary assumptions
2. Get reconstruction efficiency from Monte Carlo
3. Create spectra for different composition assumptions
   (Correct for efficiency)

→ Result: Several Spectra for different composition assumptions

Unfolding Method

Part I: Energy Calculation

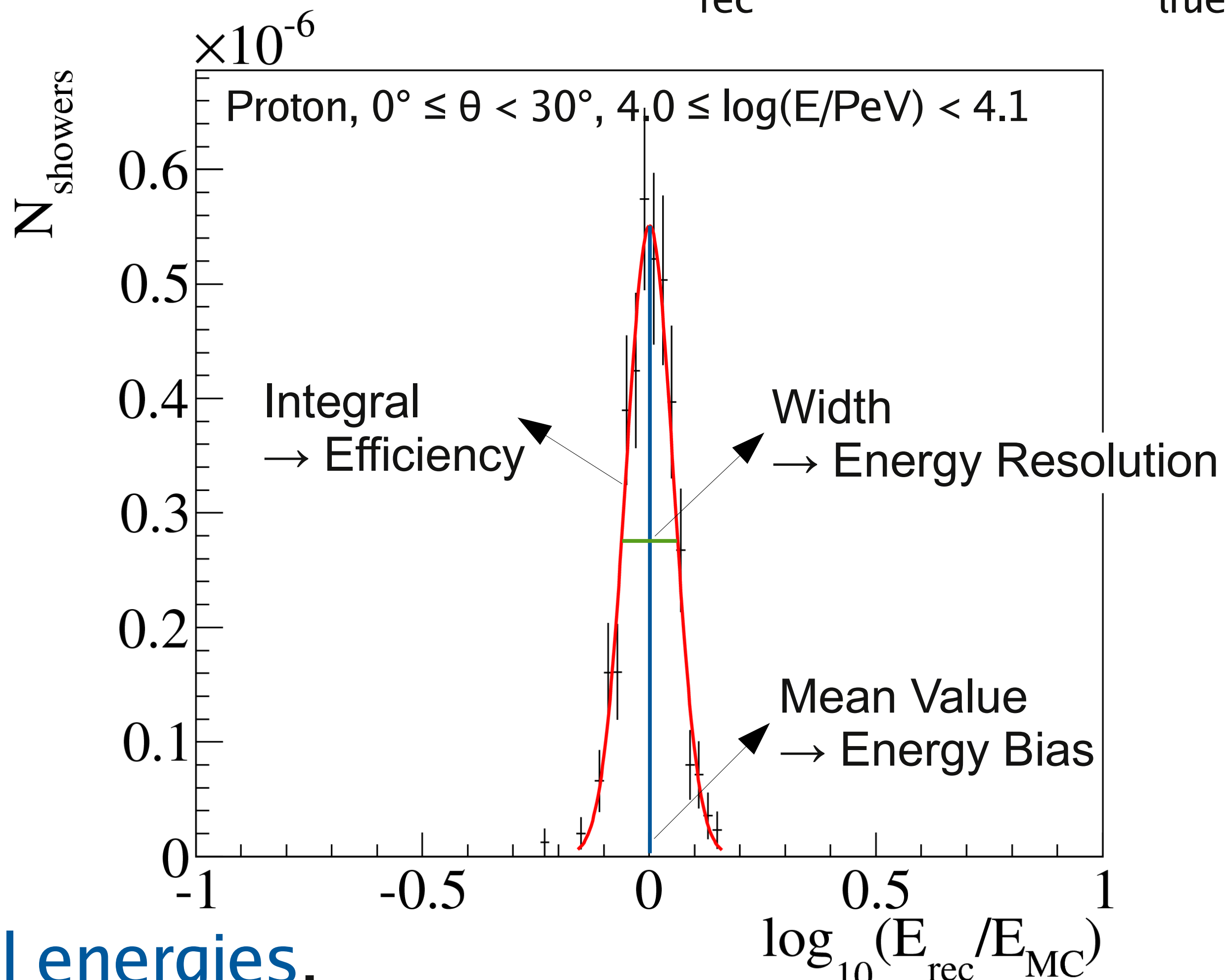
- Use MC to get a relation between
  - S_{125}
  - Zenith Angle
  - Primary Energy
- Uses full CORSIKA showers, no real detector simulation
- Use that to create a raw proton-based energy spectrum



Unfolding Method

Part II: Energy Response

- Energy response = Distribution of E_{rec} for a given E_{true}

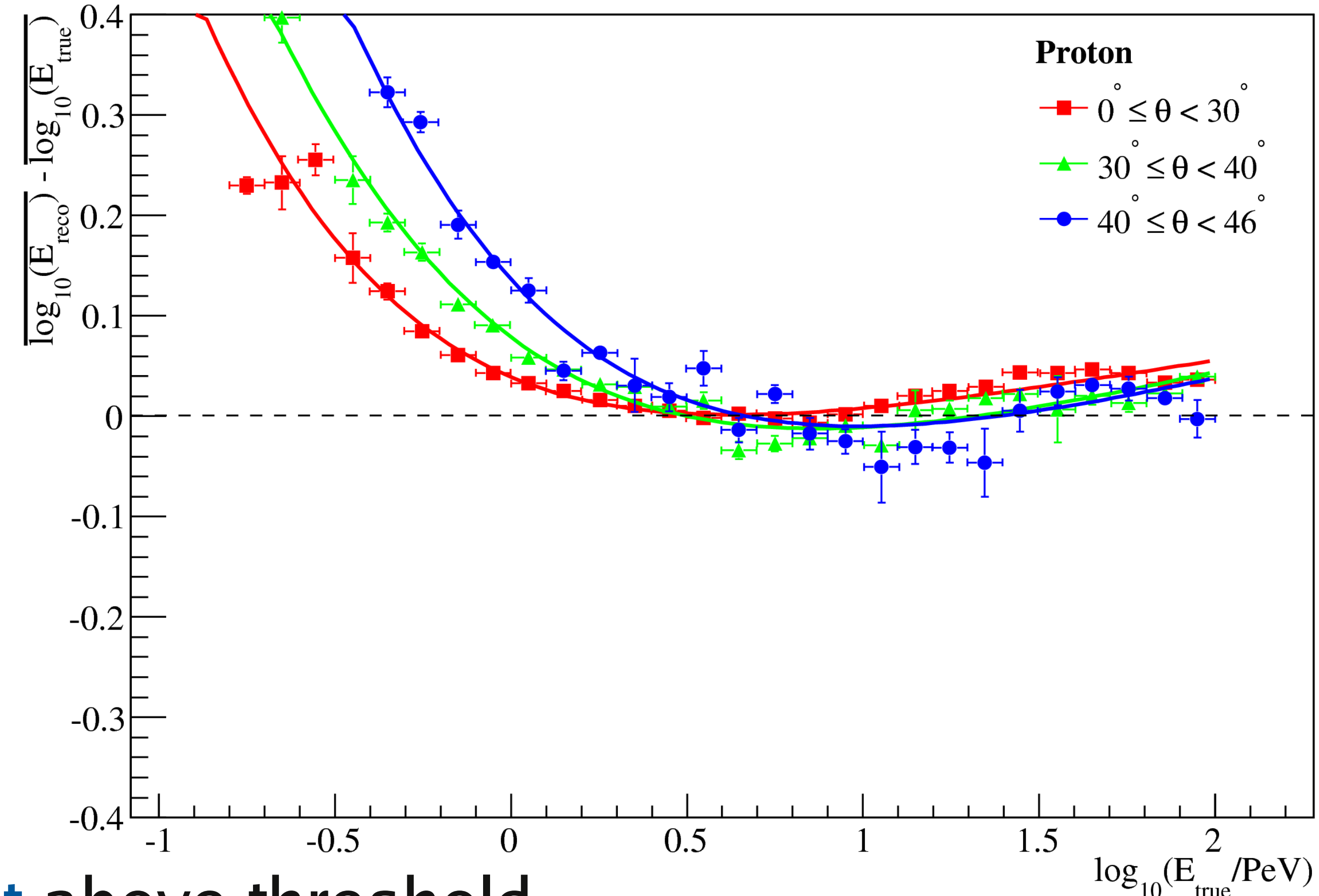


- Do this for all energies, different primaries, different zenith angles

Unfolding Method

Part III: Energy Bias

- Energy bias for proton showers:

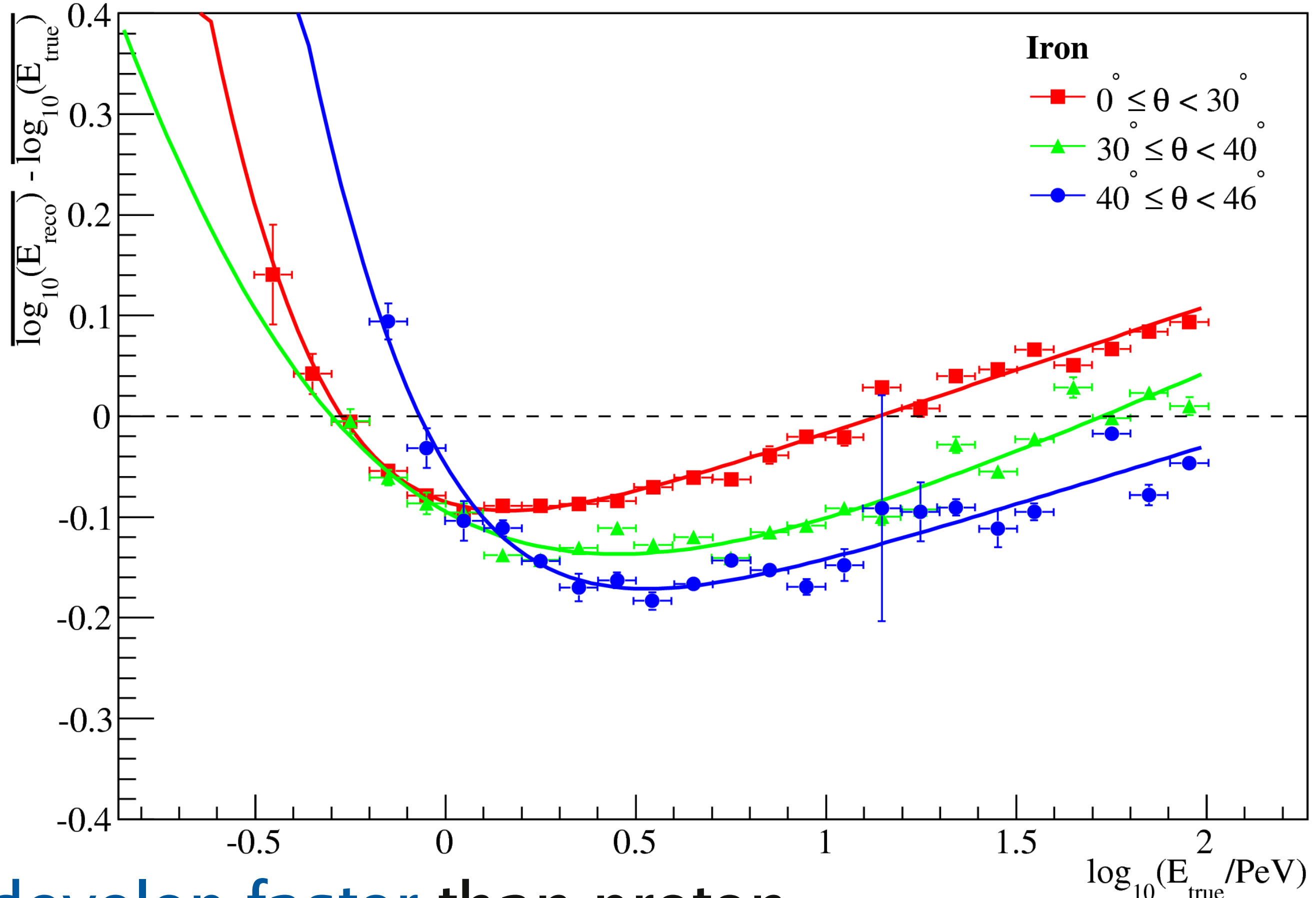


- Nearly flat above threshold
- Increase below threshold:
  Cutoff effect, only showers that fluctuate upwards trigger

Unfolding Method

Part III: Energy Bias

- Energy bias for iron showers:



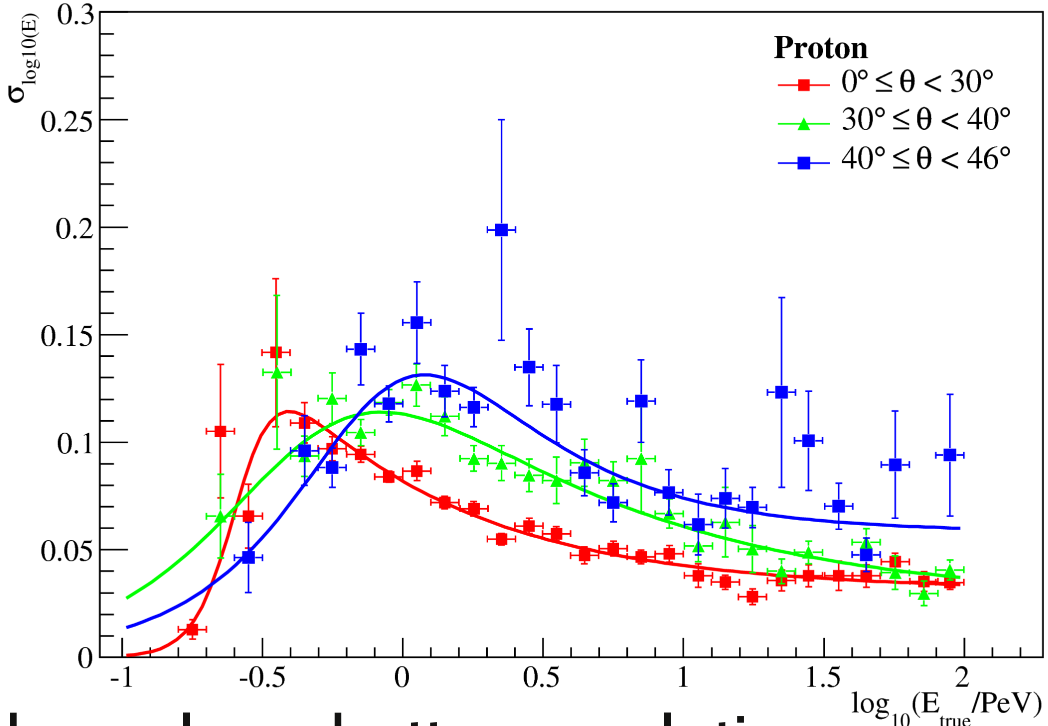
- Showers develop faster than proton

  → Zenith and energy dependent bias

Unfolding Method

Part IV: Energy Resolution

- Energy resolution for proton showers:

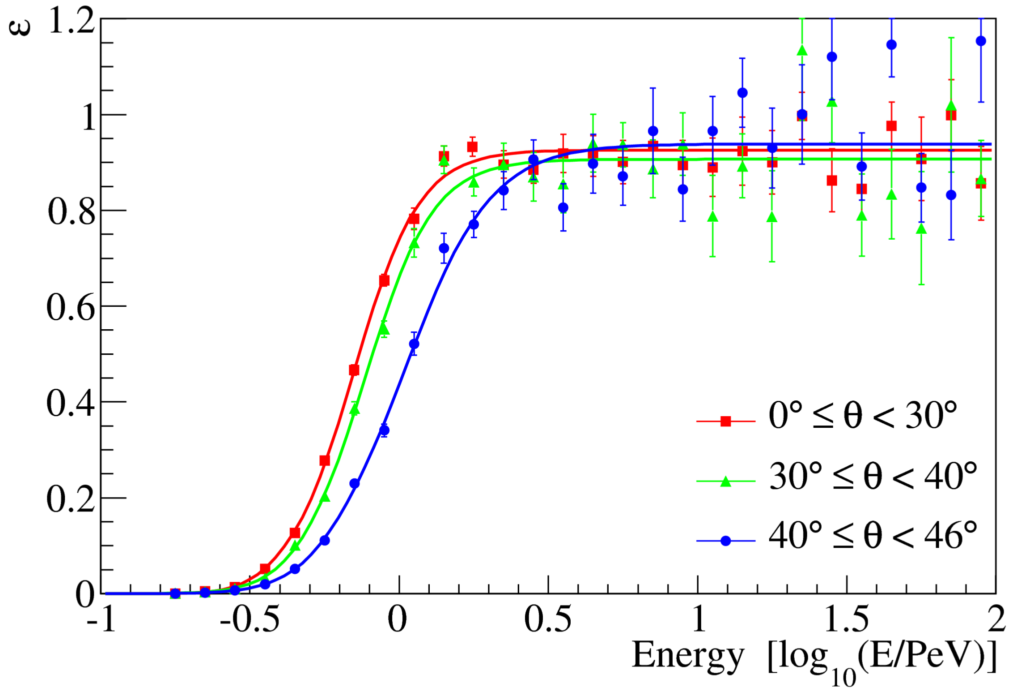


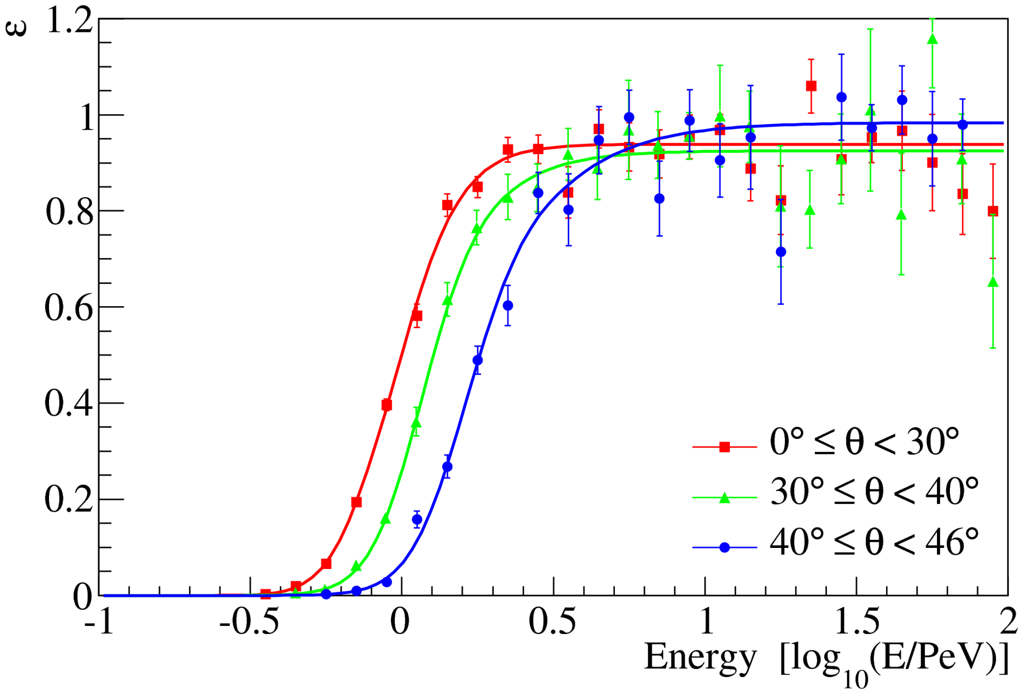
- Smaller zenith angle → better resolution
- Higher energy → better resolution
- Improvement in the threshold region:
  Cutoff effect, showers that fluctuate downwards do not trigger

Unfolding Method

Part V: Efficiency

- Reconstruction efficiency for proton and iron showers:





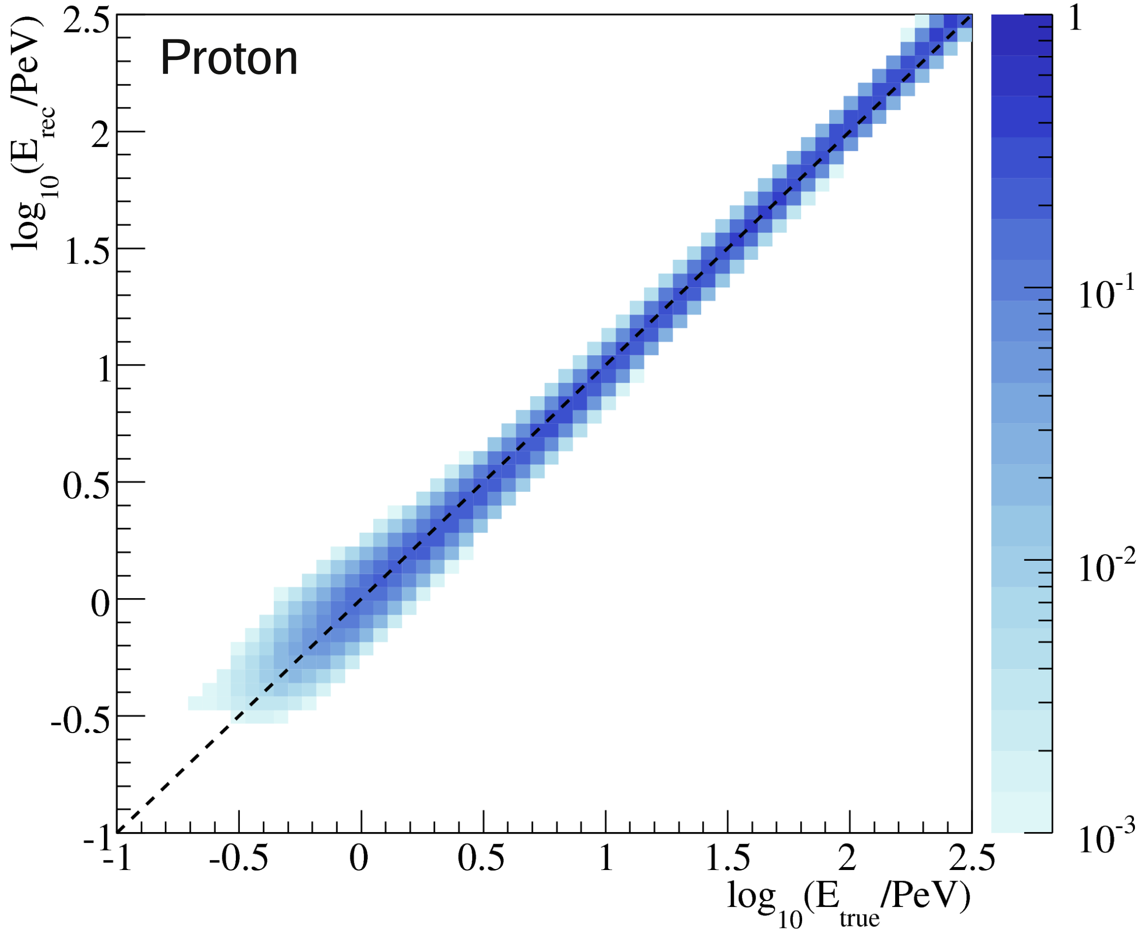
- Similar efficiency, nearly independent of zenith
- Iron: higher threshold
- Efficiency can be larger than 100% because of migration

Unfolding Method

- For every bin there is a distribution $p(E_{rec} \mid E_{true}, \theta, \text{type})$
  → Energy response curves: bias, resolution, efficiency
- From the true spectrum I to the measured spectrum S
  → fold with response matrix

$$S_i = R_{ij} I_j$$

- Unfolding ↔ Invert R_{ij}
- Use Bayesian method to do this
  G. D'Agostini



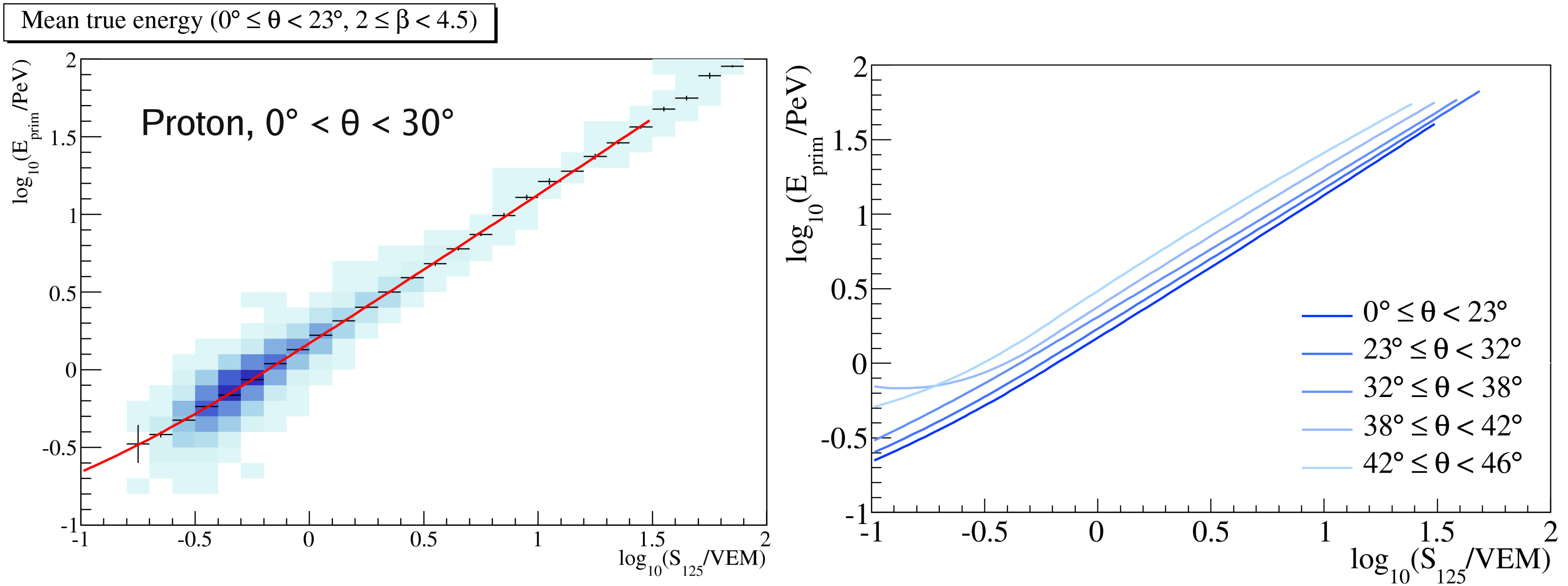
Unfolding Method

Part V

- Automatically corrects for efficiency
- Takes bin-to-bin migration into account
- Used here to account for different primary assumptions
- Problem: when using a different assumption than protons a large shift (bias) needs to be corrected for

Parametric Method

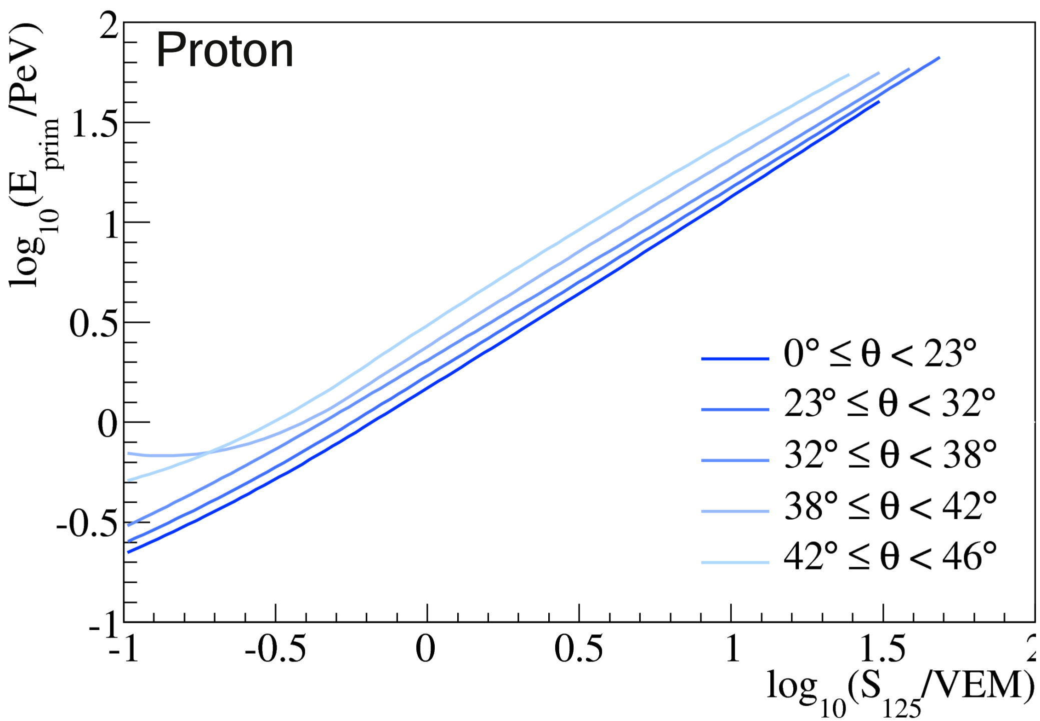
Part I: Energy Calculation I

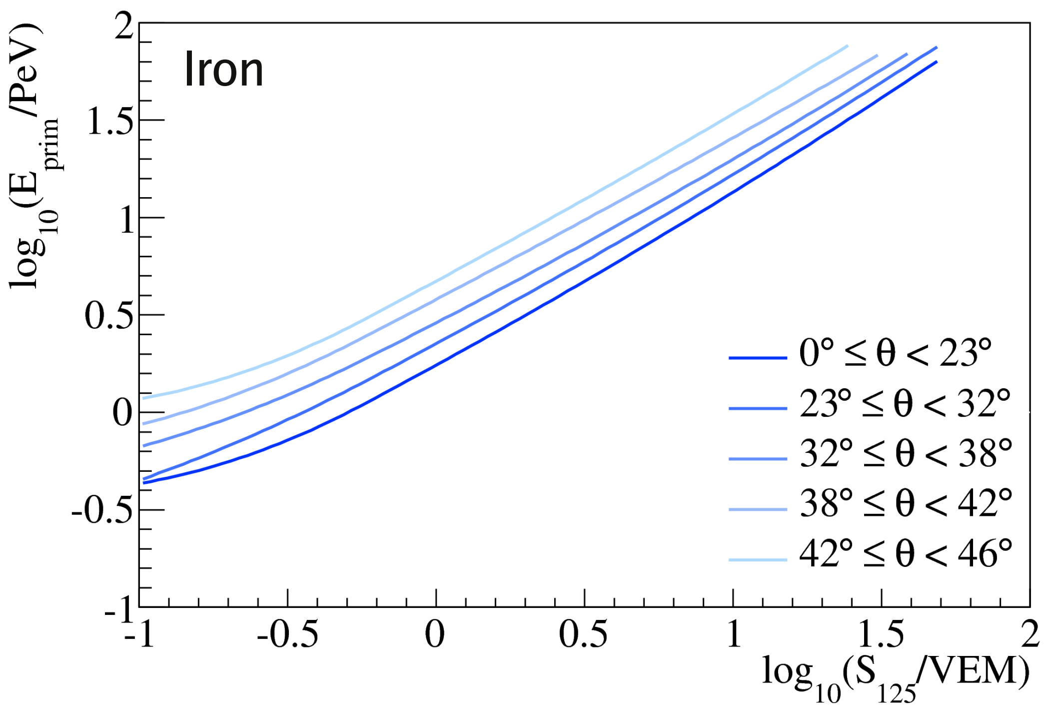


- Simulate CORSIKA showers and full detector
- Create these plots for different
  - zenith ranges
  - primary composition assumptions

Parametric Method

Part II: Different Composition Assumptions



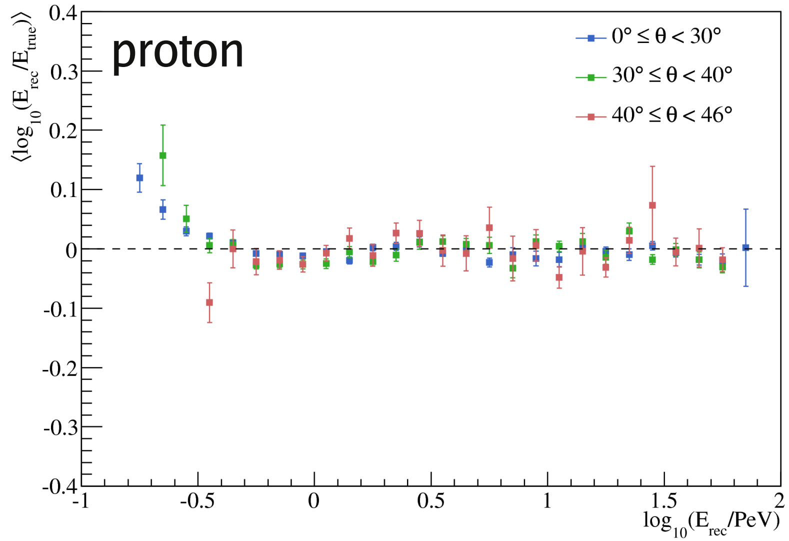


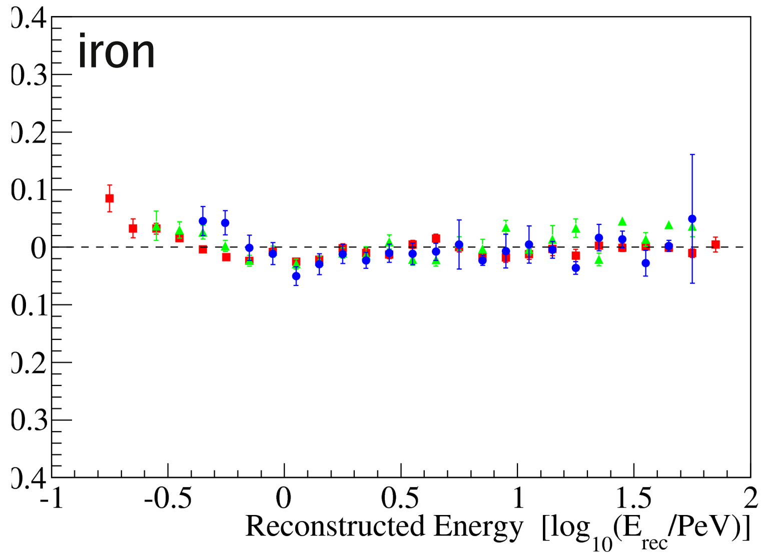
- Spacing of iron curves larger → stronger attenuation
- Iron curves at larger values → smaller shower size

Parametric Method

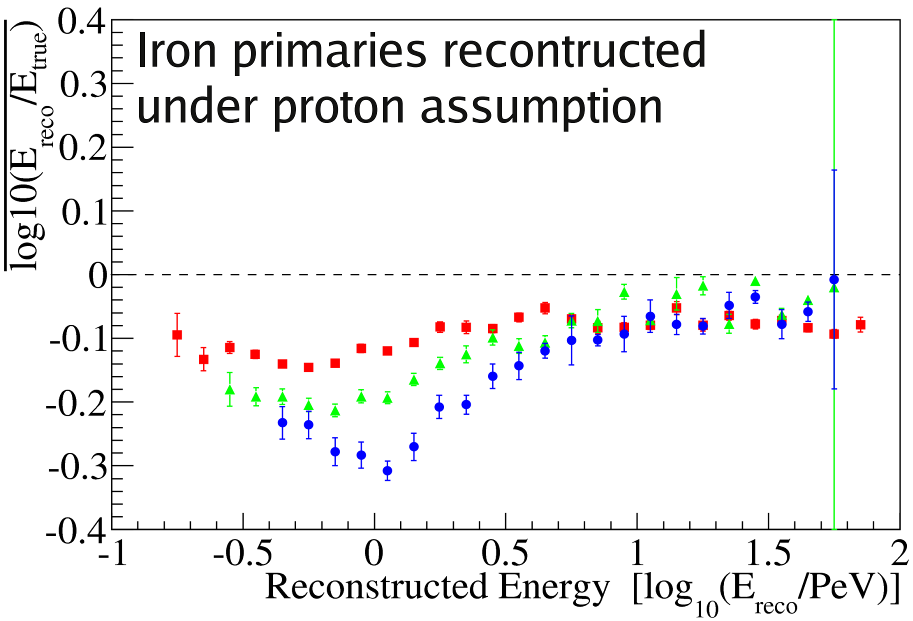
Part III: Resulting Bias

- Small bias for both proton and iron primaries





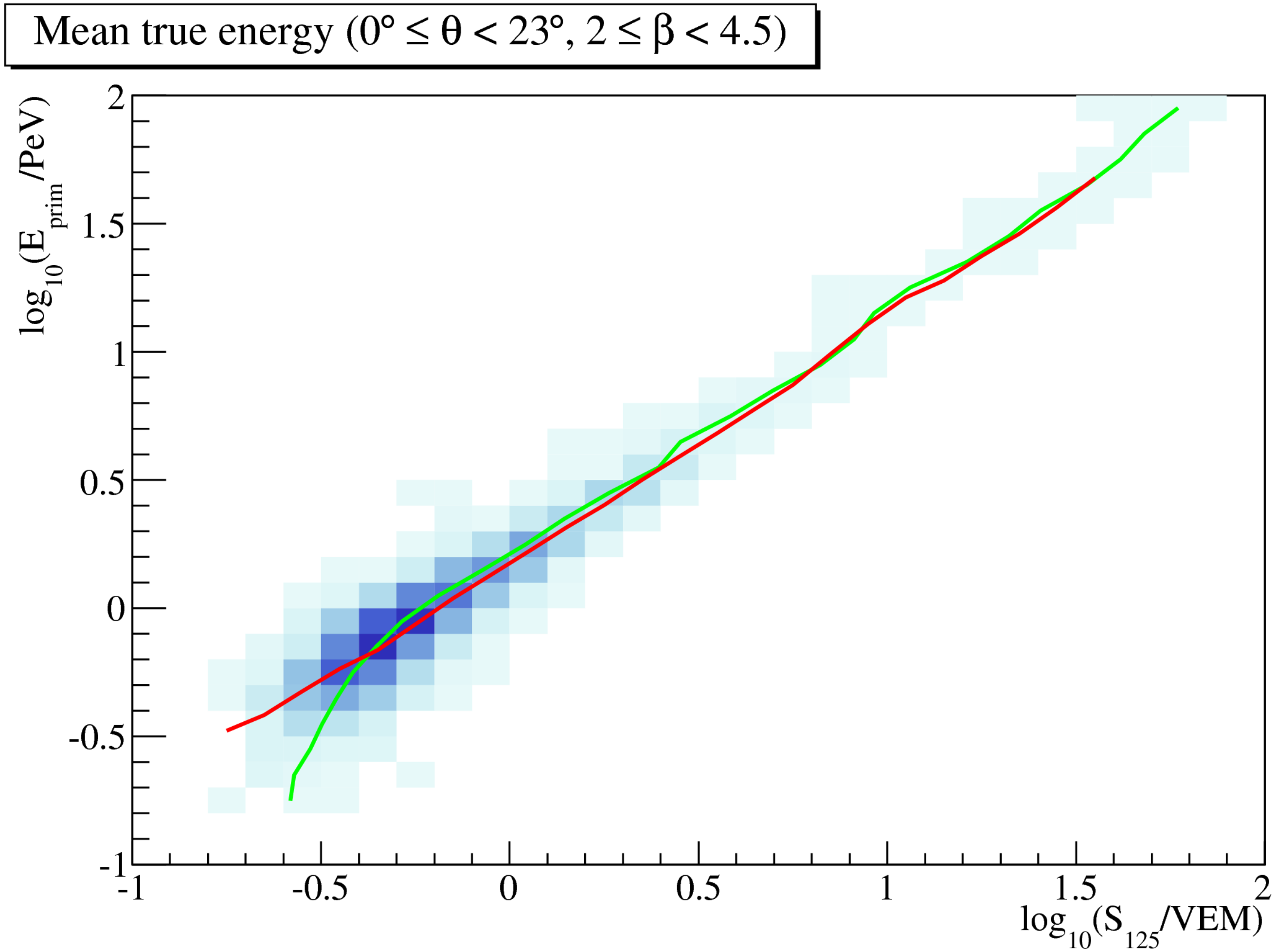
- Large, zenith and energy dependent bias when reconstructing with the wrong primary assumption



Parametric Method

Part IV: More thoughts on the bias

- Steep input spectrum
  $\rightarrow \langle E(S_{125}) \rangle \neq \langle S_{125}(E) \rangle$
- Two ways to average:
  $\rightarrow$ a) Bias(E_{rec}) ~ 0
  or
  $\rightarrow$ b) Bias(E_{true}) ~ 0
- Another Problem:
  Input spectrum will bias final result



Efficiency Calculation

- Events can migrate into or out of contained area → ε > 1 possible
- Efficiency:

$$\varepsilon = \frac{\sum_{in,rec} w_i}{\sum_{in,gen} w_i}$$

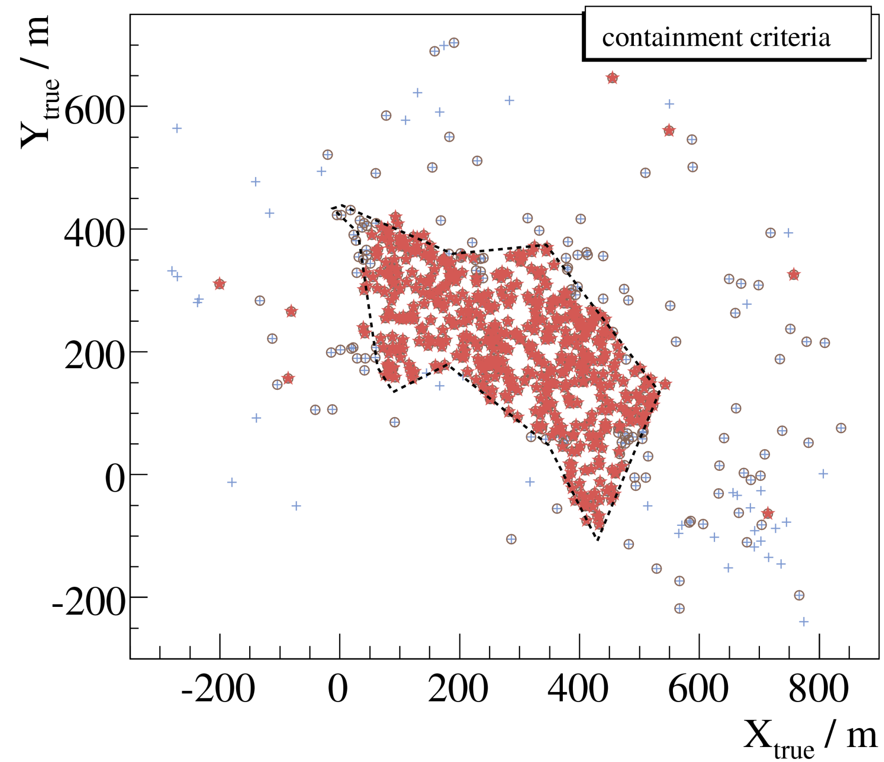
- Error of that:

$$\sigma_\varepsilon = \sqrt{\sigma^2_{\varepsilon_{in}} + \left(\frac{\sum_{out,gen} w_i}{\sum_{in,gen} w_i} \sigma_{\varepsilon_{out}} \right)^2}$$

Poissonian error of the probability that a contained events passes the cuts

Poissonian error of the probability that an outside event remains in the sample

$$\sigma_{\varepsilon_x} = \sqrt{\varepsilon_x (1 - \varepsilon_x)} \cdot \left(\frac{\sum_{gen,x} w_i^2}{\left(\sum_{gen,x} w_i\right)^2} \right)^{\frac{1}{2}}$$



Model Dependency

- Assumptions in simulation:
  - Interaction model
  - Atmosphere parametrisation
  - Input flux (spectrum)
- Unfolding method:
  - Energy estimator
  - Response matrix: bias, resolution (fluctuations!)
- Parametric method:
  - Energy estimator
  - Simulated spectrum → Bias on the result? Migration not corrected.
- Treatment of snow is a major issue (→ separate discussion)

Systematic Uncertainties

- Interaction Model
- Atmosphere:
  deviation from model, short term variations
- Method:
  - Unfolding algorithm, iterations, etc...
  - Parametric method: simulated spectrum
- Snow:
  - Treatment of snow in simulation / reconstruction
  - Unknown / varying snow depth
    (we only have snow measurements once a year)
- Simulation: saturation, threshold description
- Detector calibration