TA X_{max} and σ(p-air)

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for *The Telescope Array Collaboration*

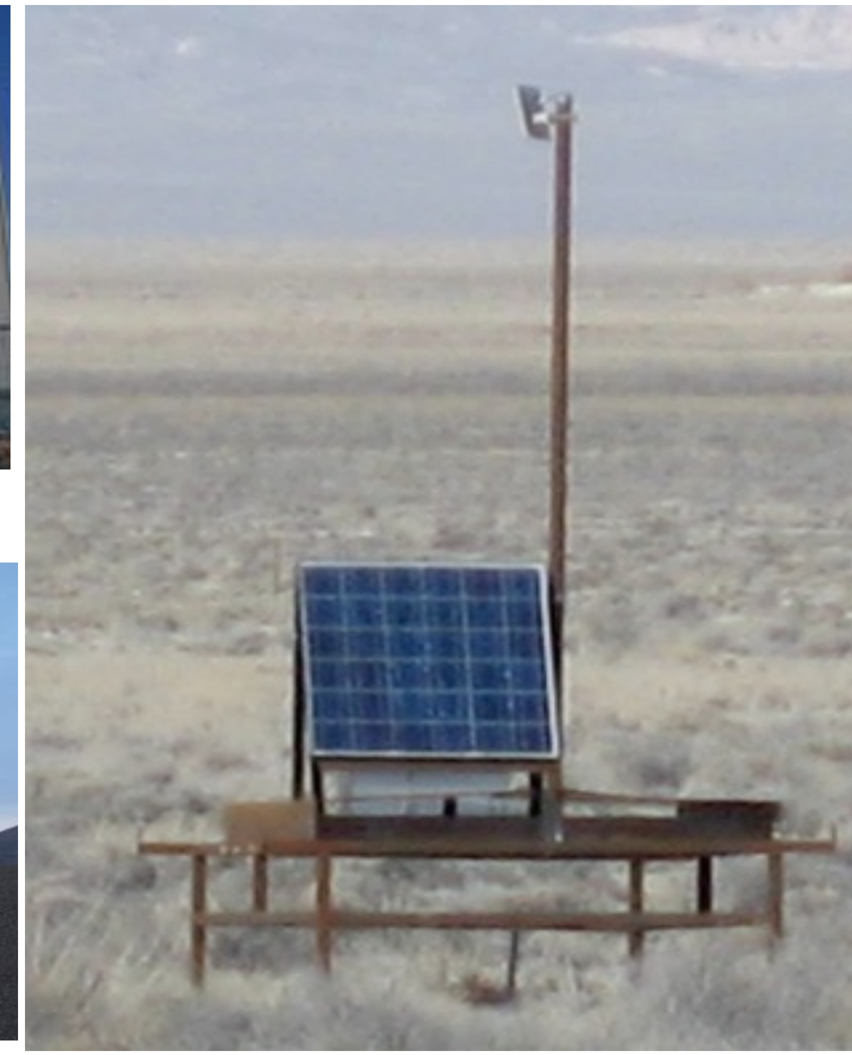
UHECR2014, Springdale, UT US, Oct 15 2014

TA Detectors

- **3 FD stations**
  - *Black Rock*
  - *Long Ridge*
  - *Middle Drum*

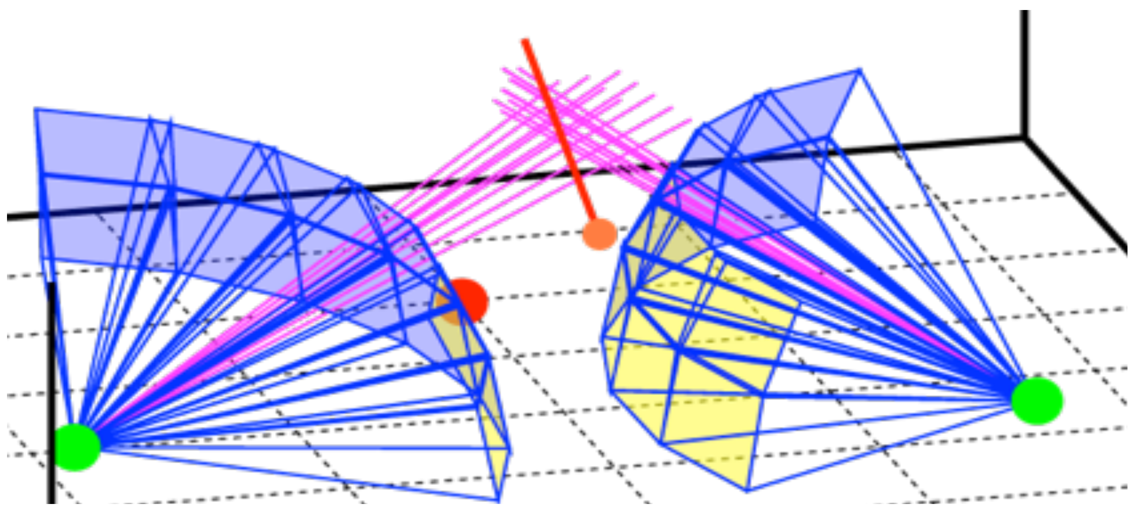
- **507 SDs**

- **X_{max} Analyses**
  - *Stereo*
  - FD/SD *Hybrid*

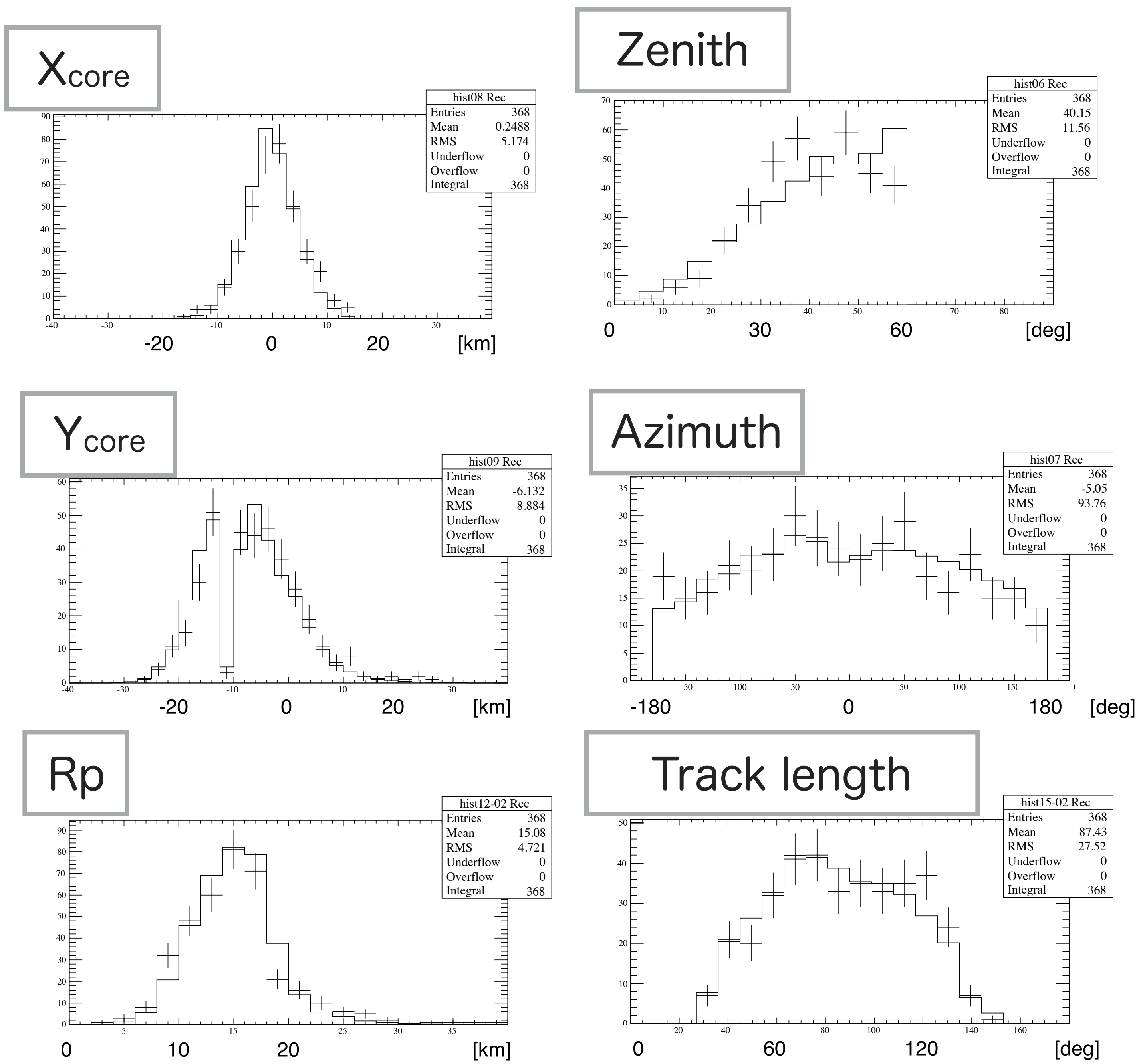


BR/LR/MD *Stereo* Reconstruction

- Use X_{max}: most efficient shower parameter to determine primary nuclear type
- Accuracy in geometry determination is crucial
  - Use FD data individually triggered by 2>= detectors: *Stereo* data
    - Each station defines a shower detector plane (SDP)
    - Intersection of the two SDPs well determines shower geometry
- Nov 2007 ~ Mar 2014: 6.3-year data

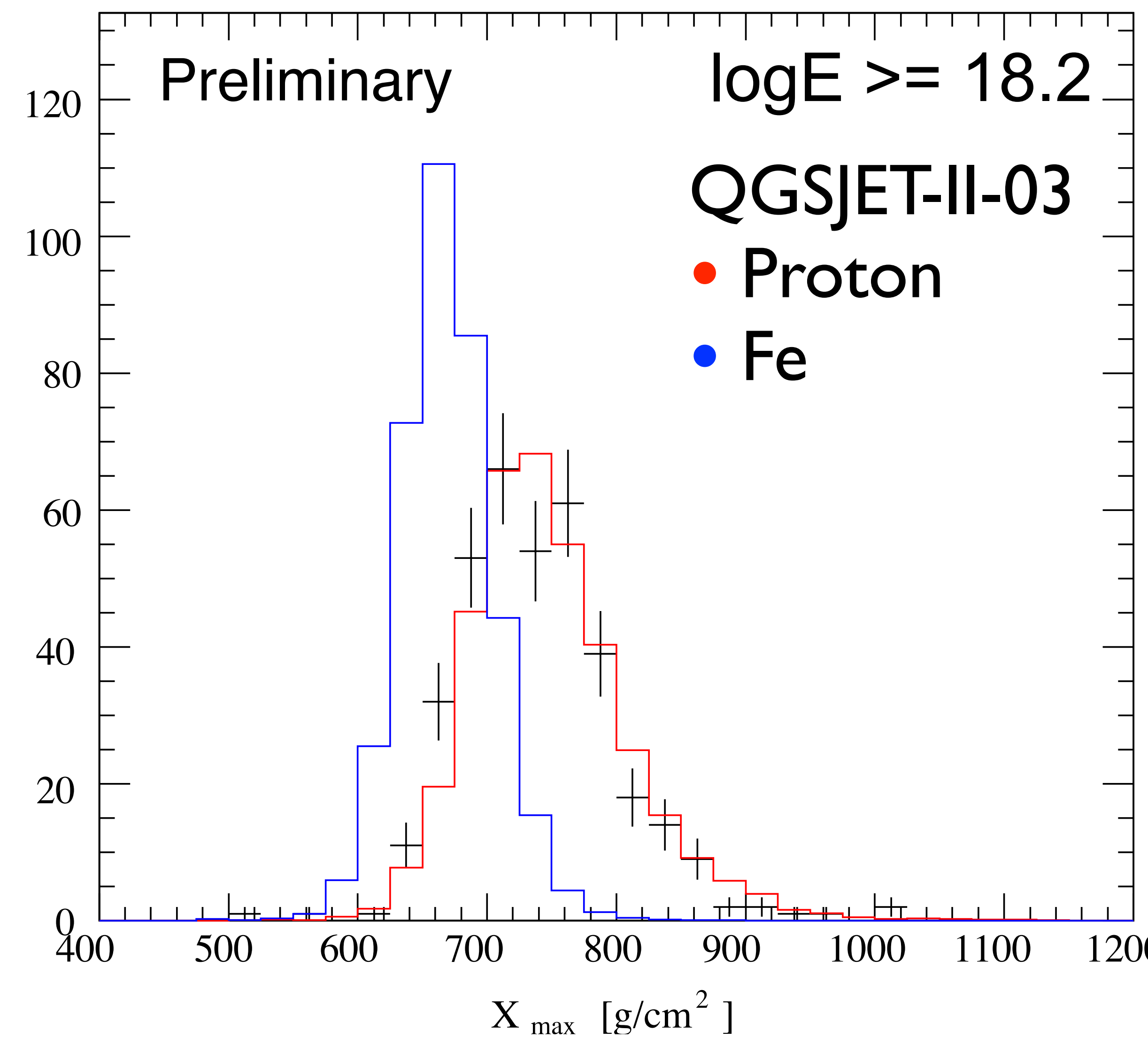


BR/LR Stereo X_{max}



BR/LR *stereo*

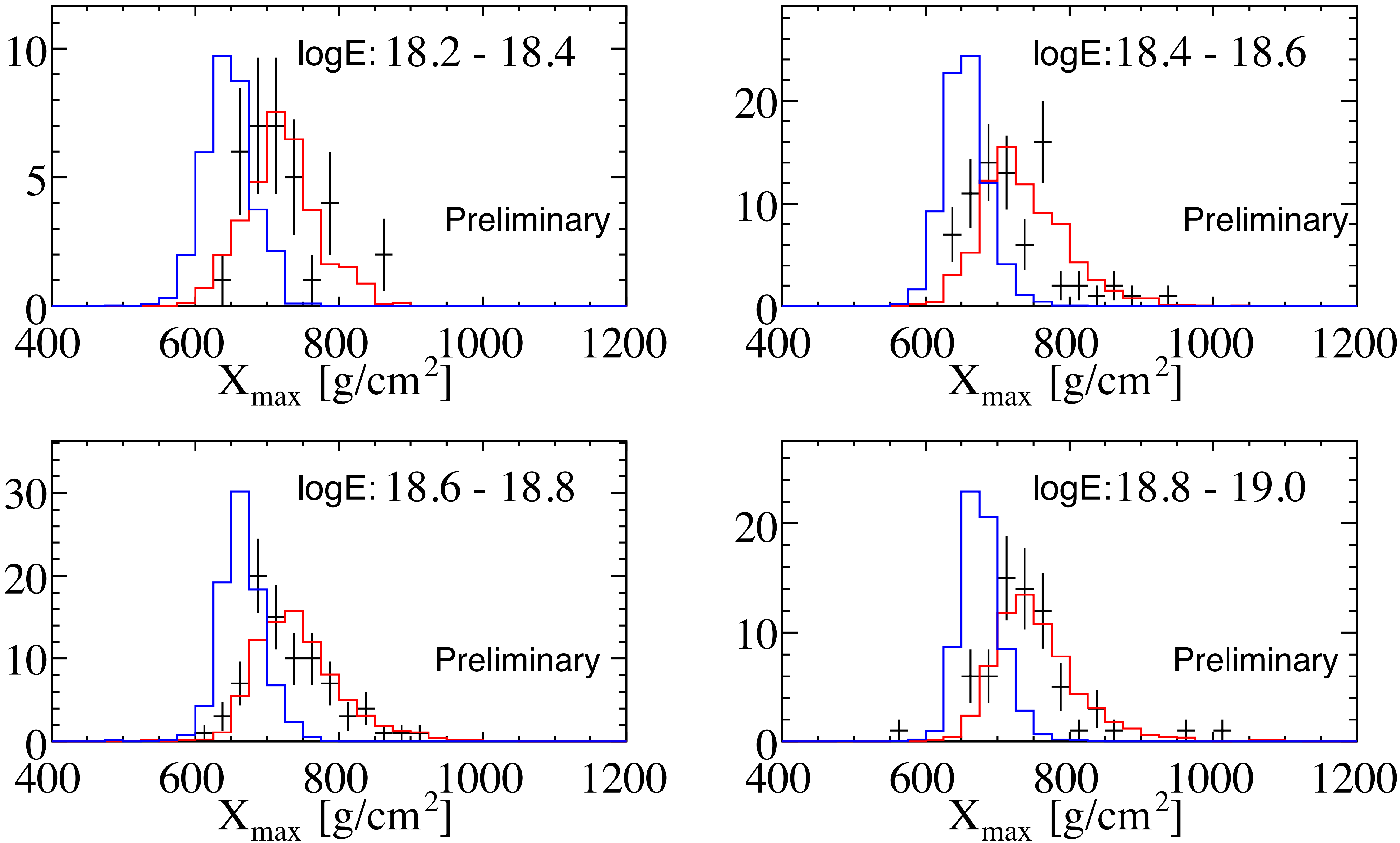
Nov 2007 ~ Mar 2014: 6.3-year data



X_{max} Distributions

TA BR/LR *Stereo* Preliminary

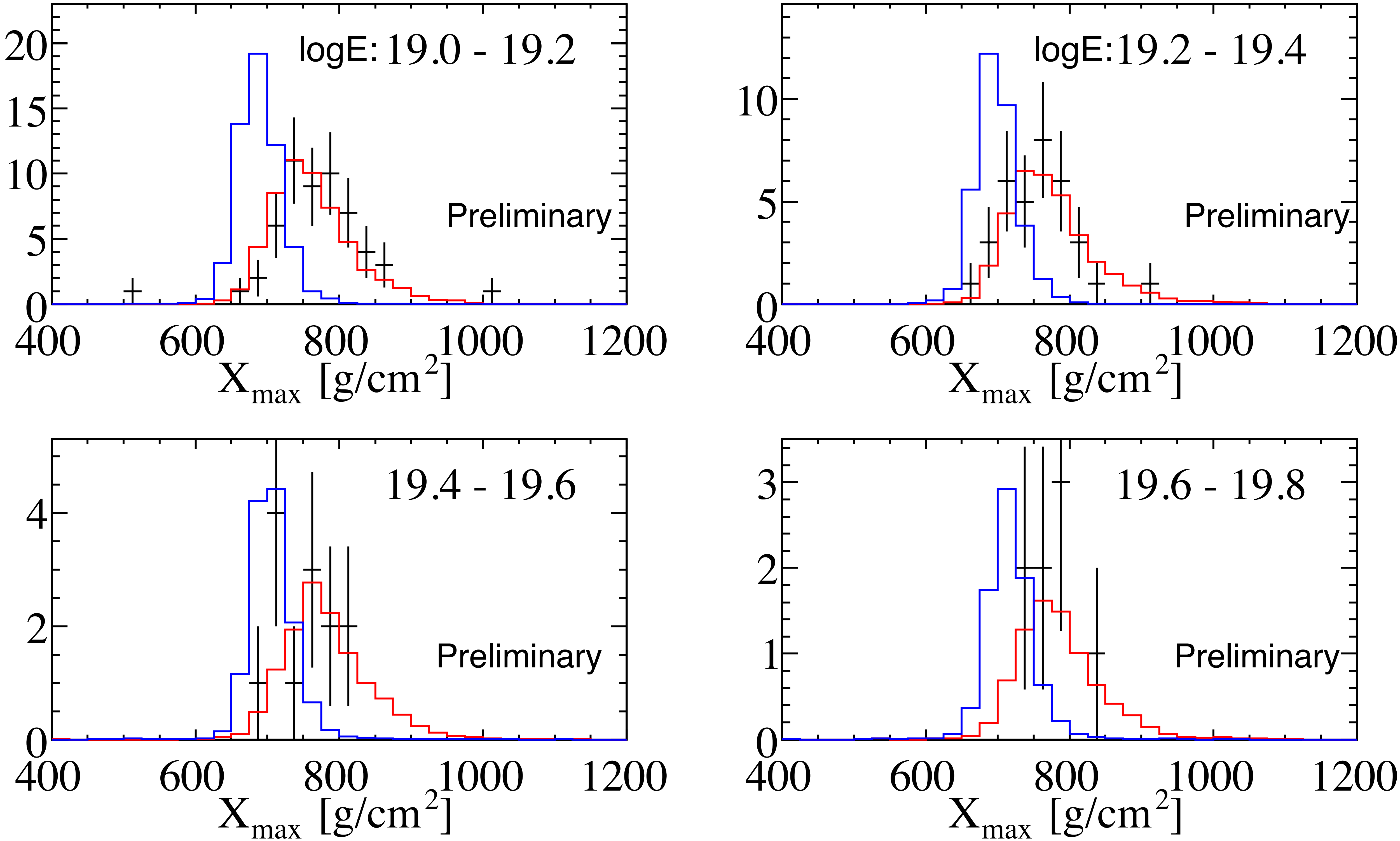
MC: QGSJET-II-03



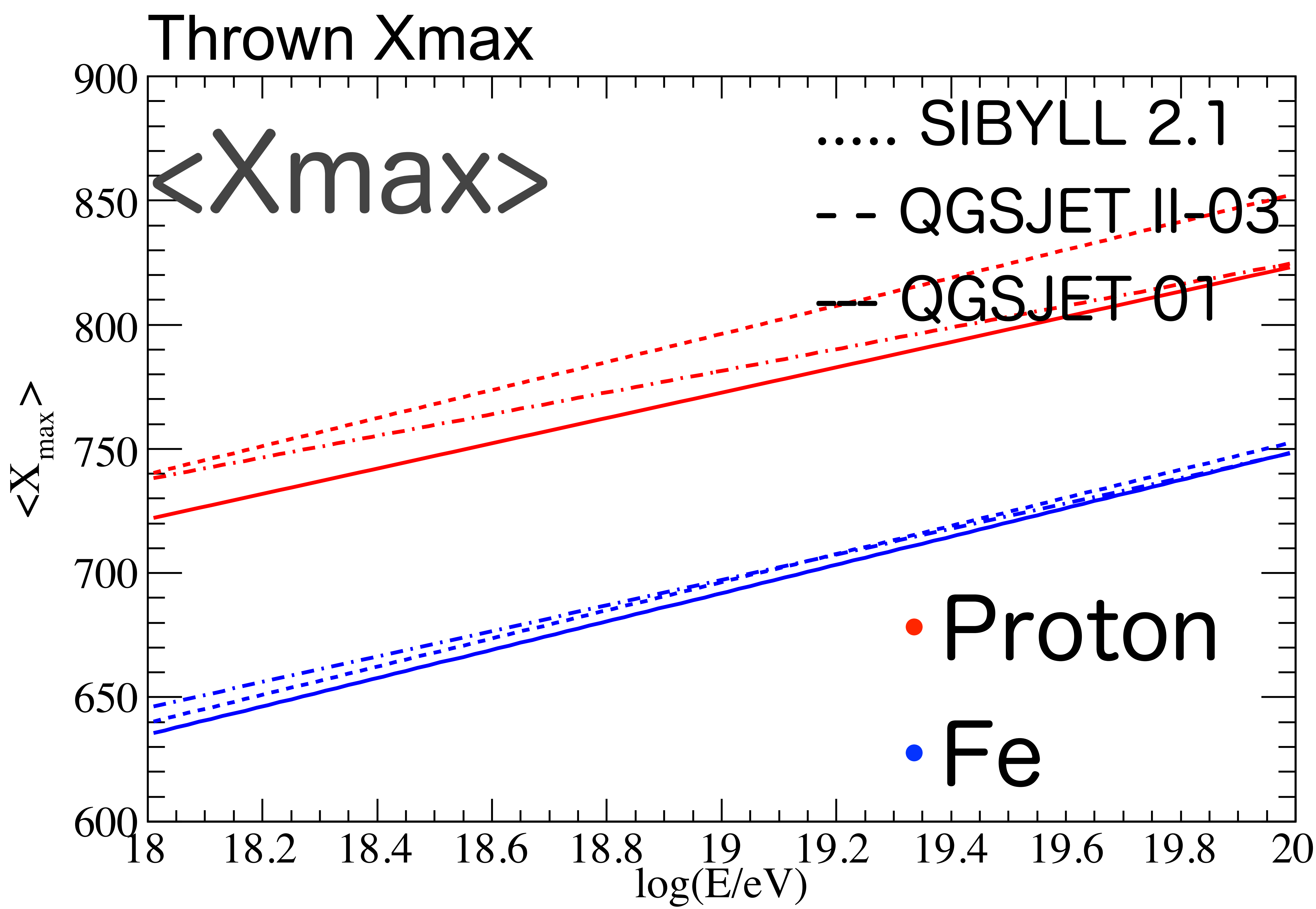
X_{max} Distributions

TA BR/LR *Stereo* Preliminary

MC: QGSJET-II-03

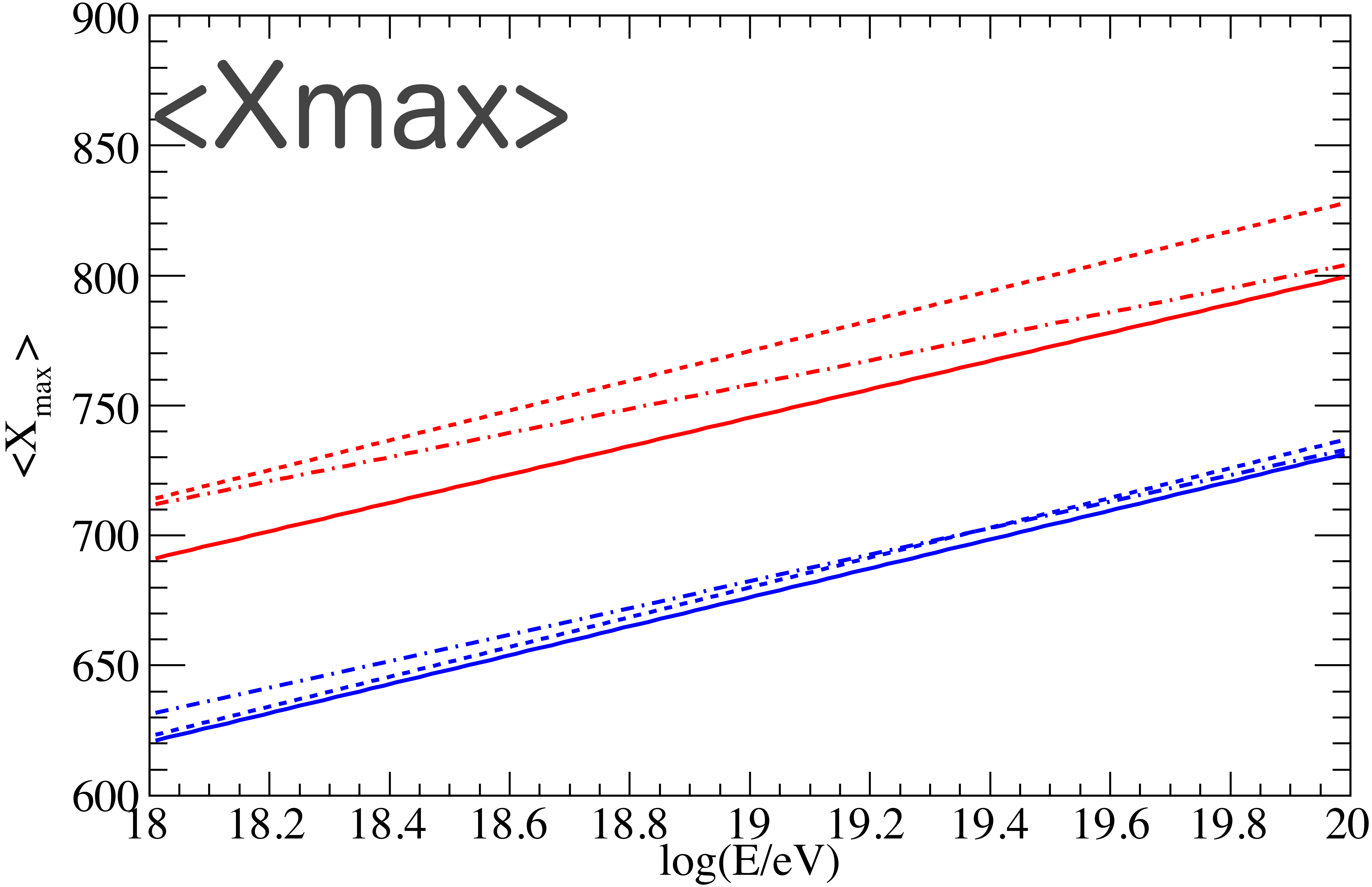


Acceptance Bias



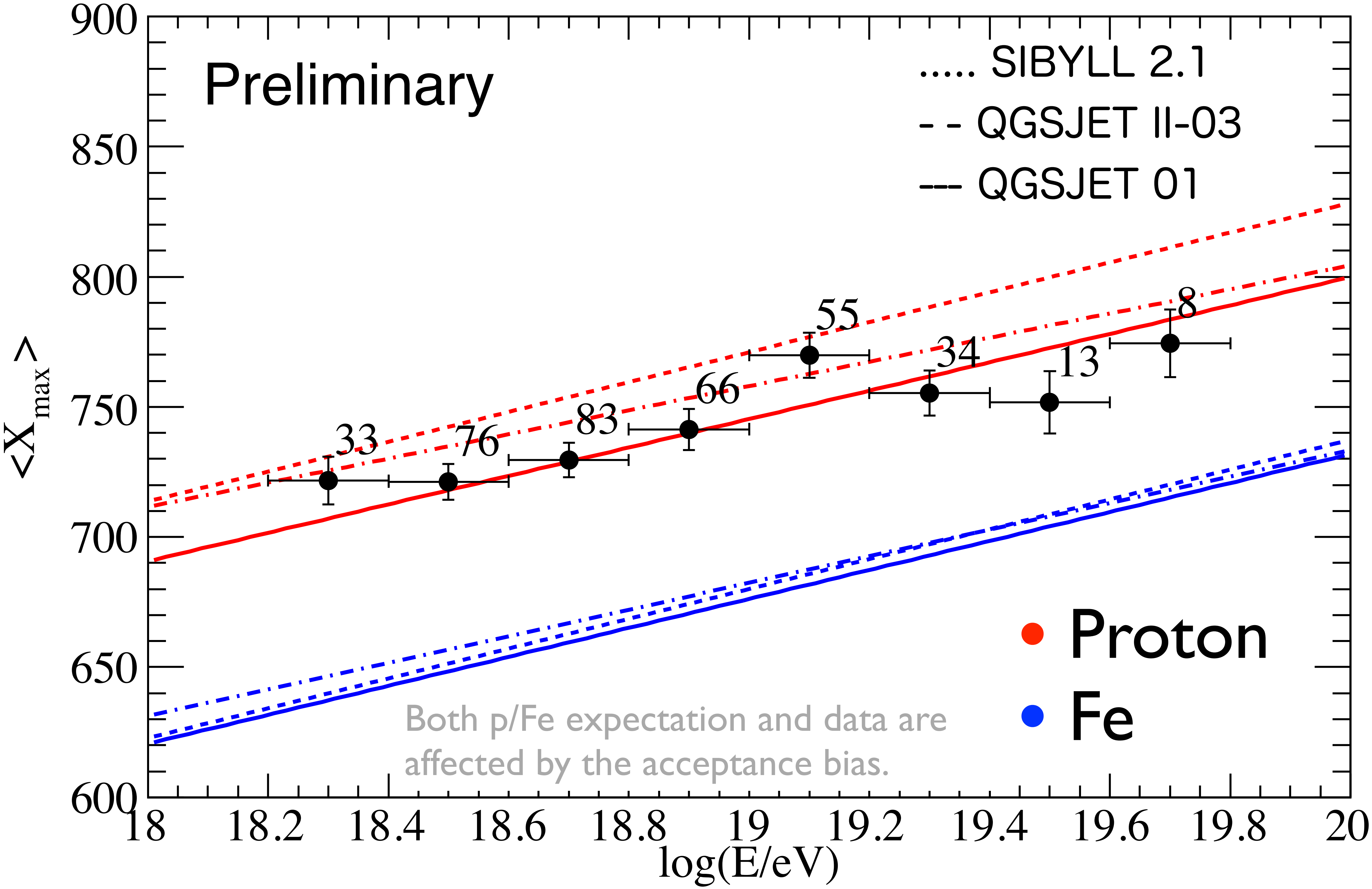
Acceptance Bias

After trigger/reconstruction/selection



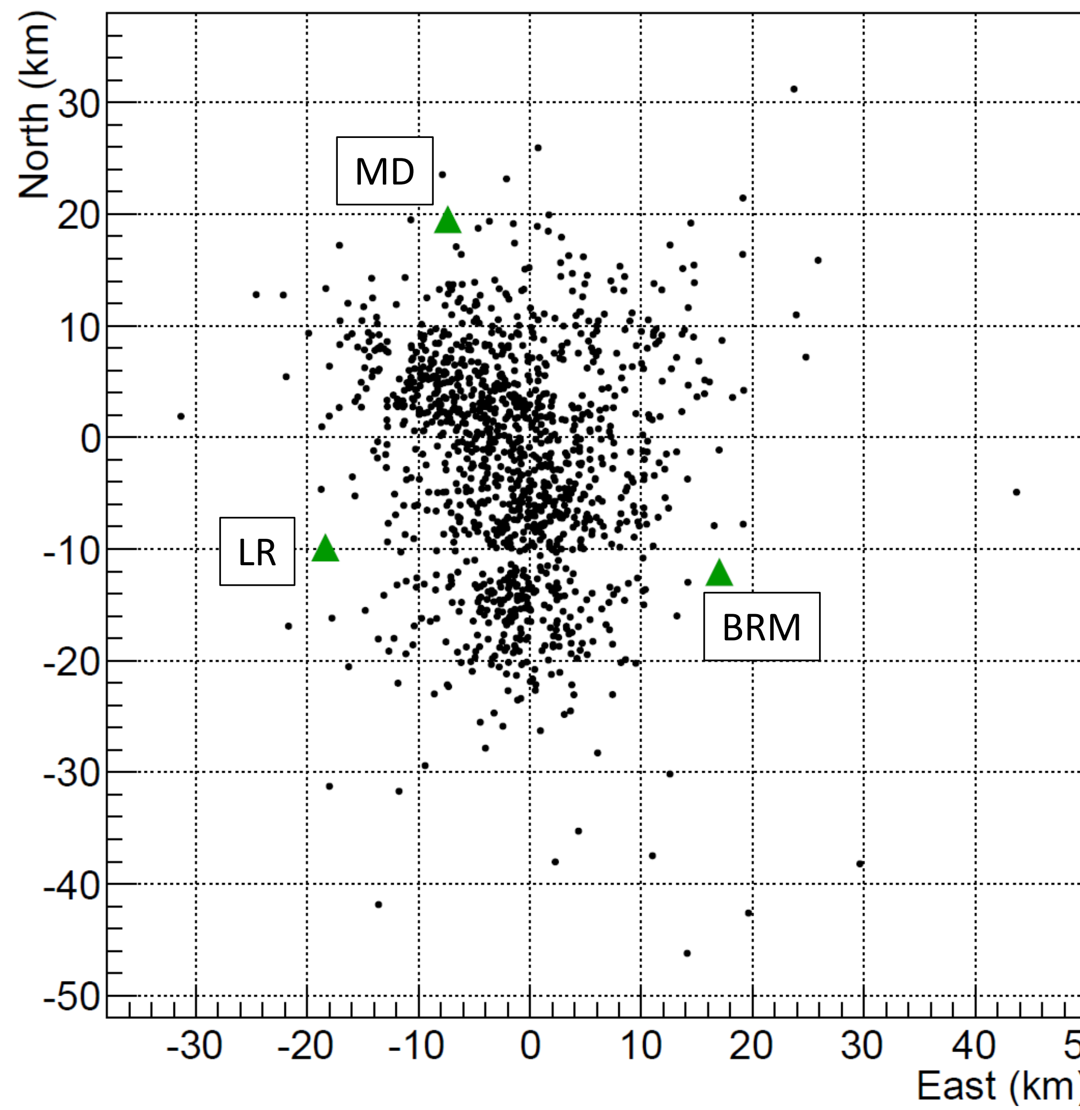
<X_{max}> vs log*E*

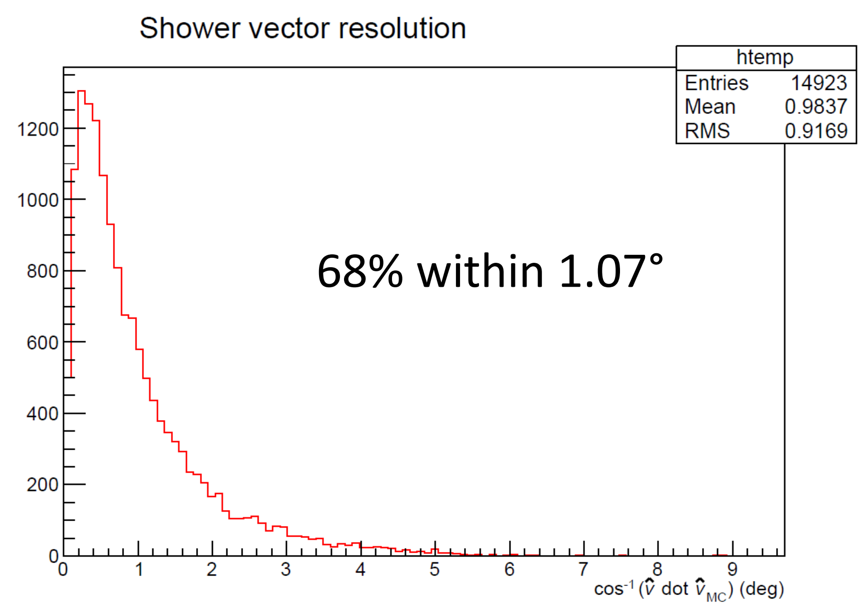
TA BR/LR *Stereo* Preliminary

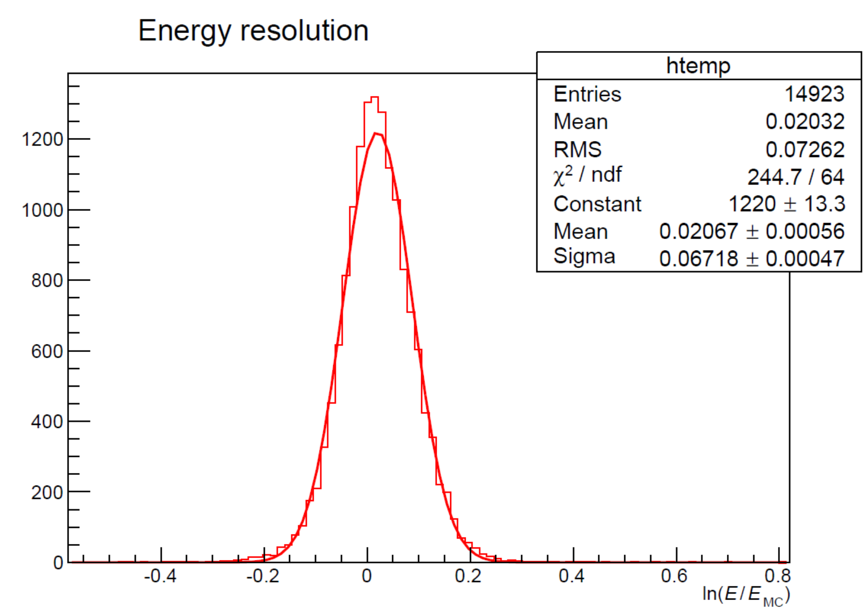


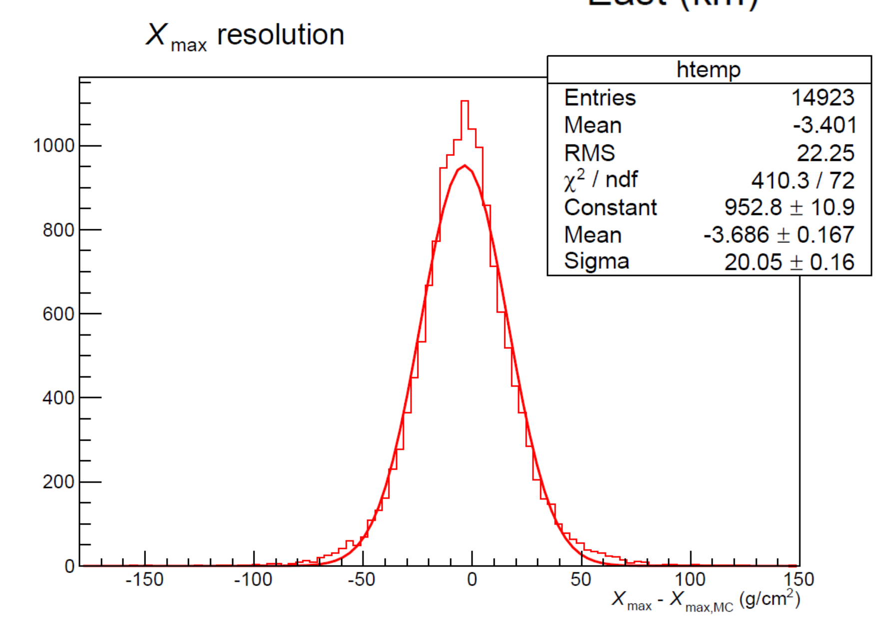
BR/LR/MD Stereo Events

- Now stereo reconstruction for all the 3 FD combinations possible
- Shower profiles calculated using the stereo geometry
  - Require successful reconstruction at both sites
  - Use BR/LR profiles for *triple stereo* events even if the MD SDP used
- (Unweighted) mean X_{max}









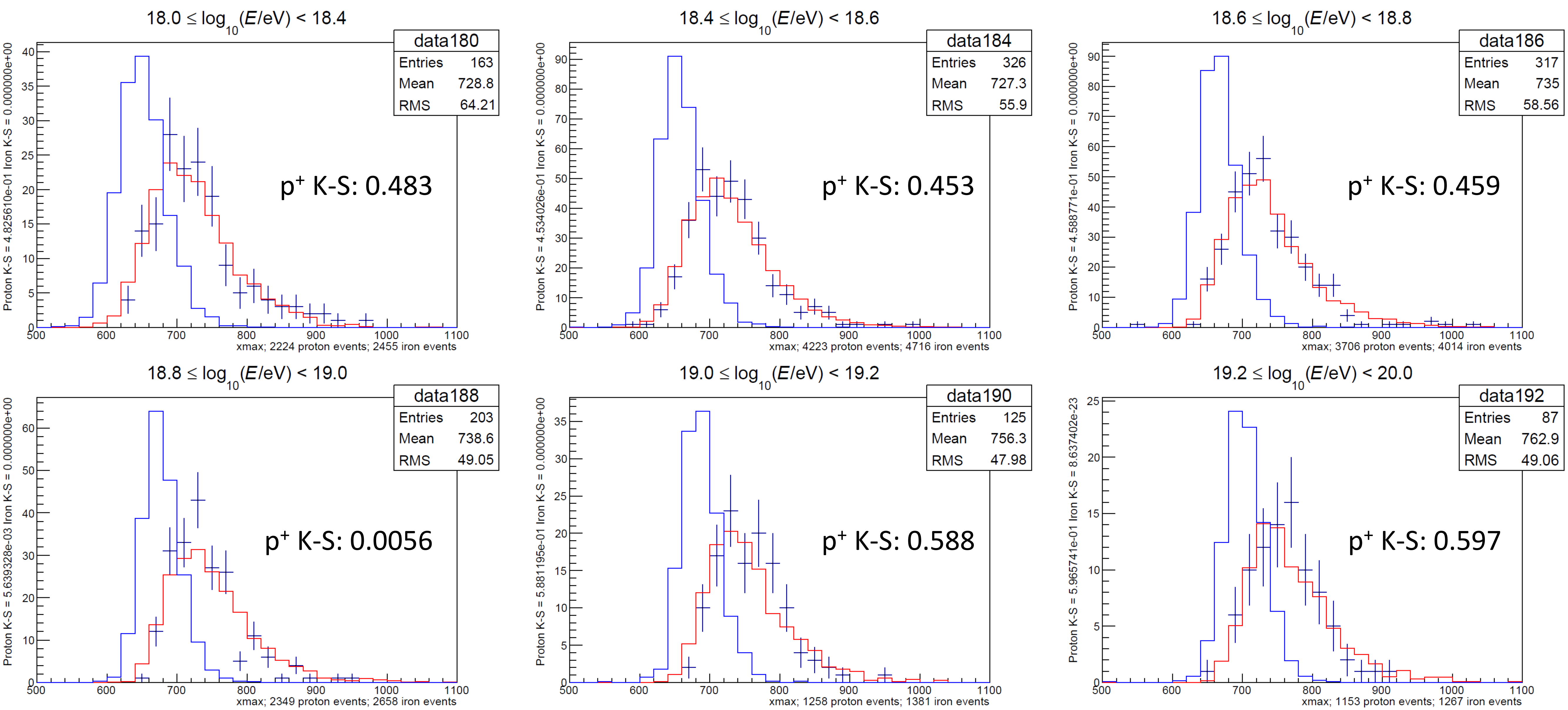
X_{max} Distributions

Proton

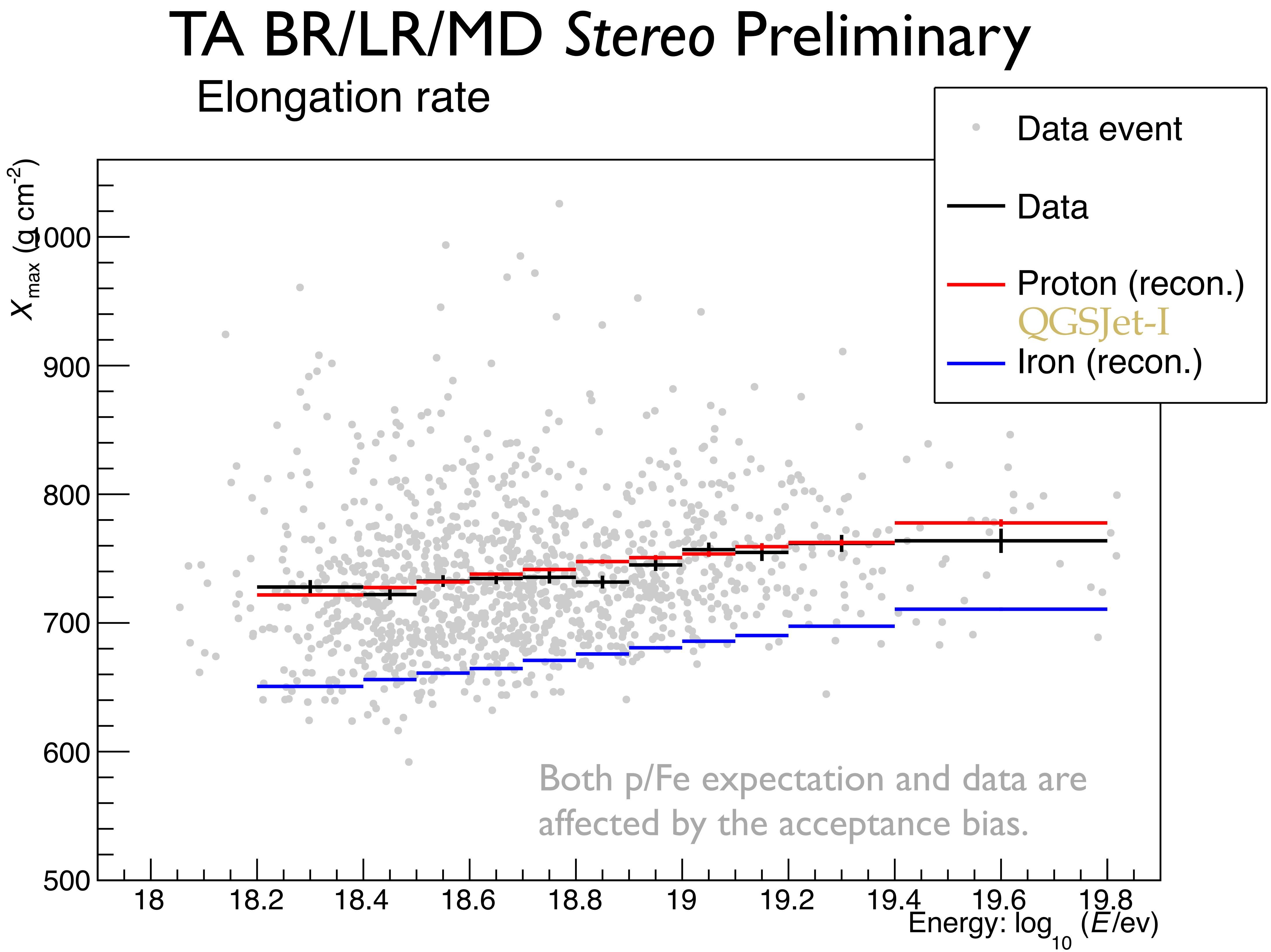
Iron

TA BR/LR/MD *Stereo* Preliminary

MC: QGSJET-I



<X_{max}> vs log*E*



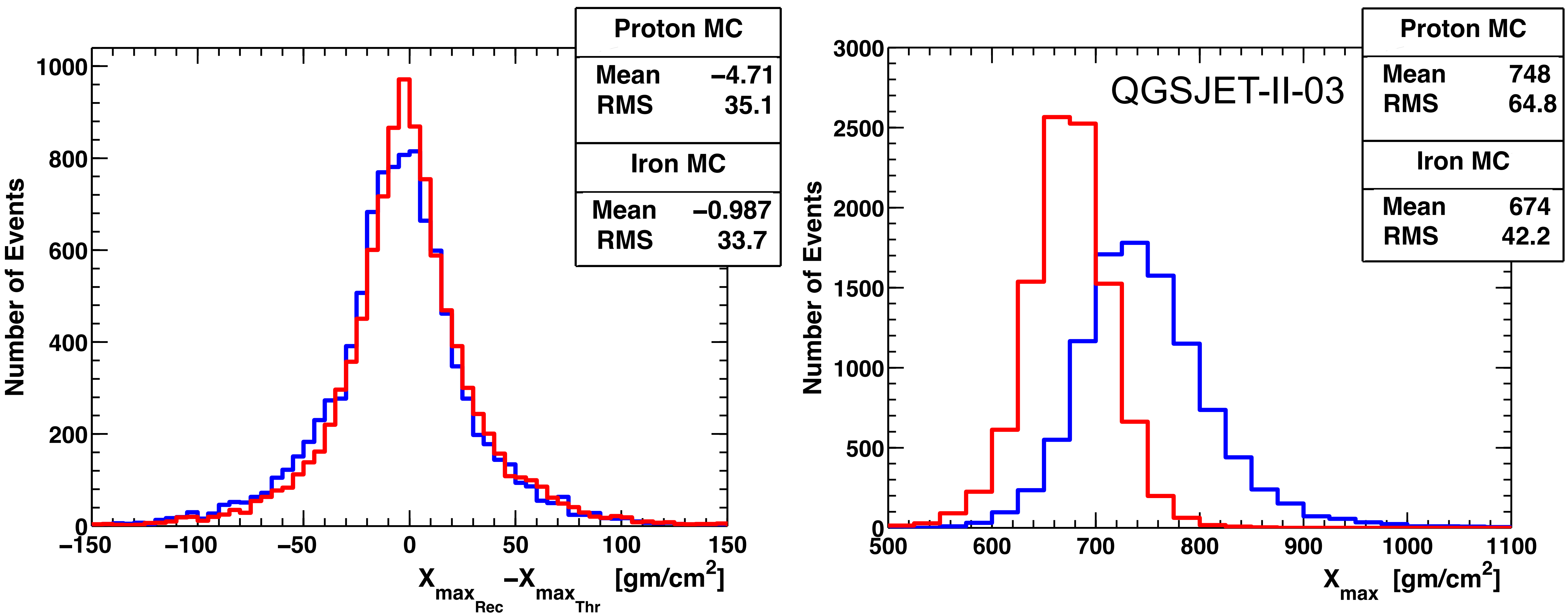
TA BR/LR/MD *Stereo* Preliminary
Elongation rate
Data event
Data
Proton (recon.)
QGSJet-I
Iron (recon.)
X_{max} (g cm^{-2})
1000
900
800
700
600
500
18
18.2
18.4
18.6
18.8
19
19.2
19.4
19.6
19.8
Energy: $\log_{10}$ (E/ev)
Both p/Fe expectation and data are
affected by the acceptance bias.

MD/SD *Hybrid* Reconstruction

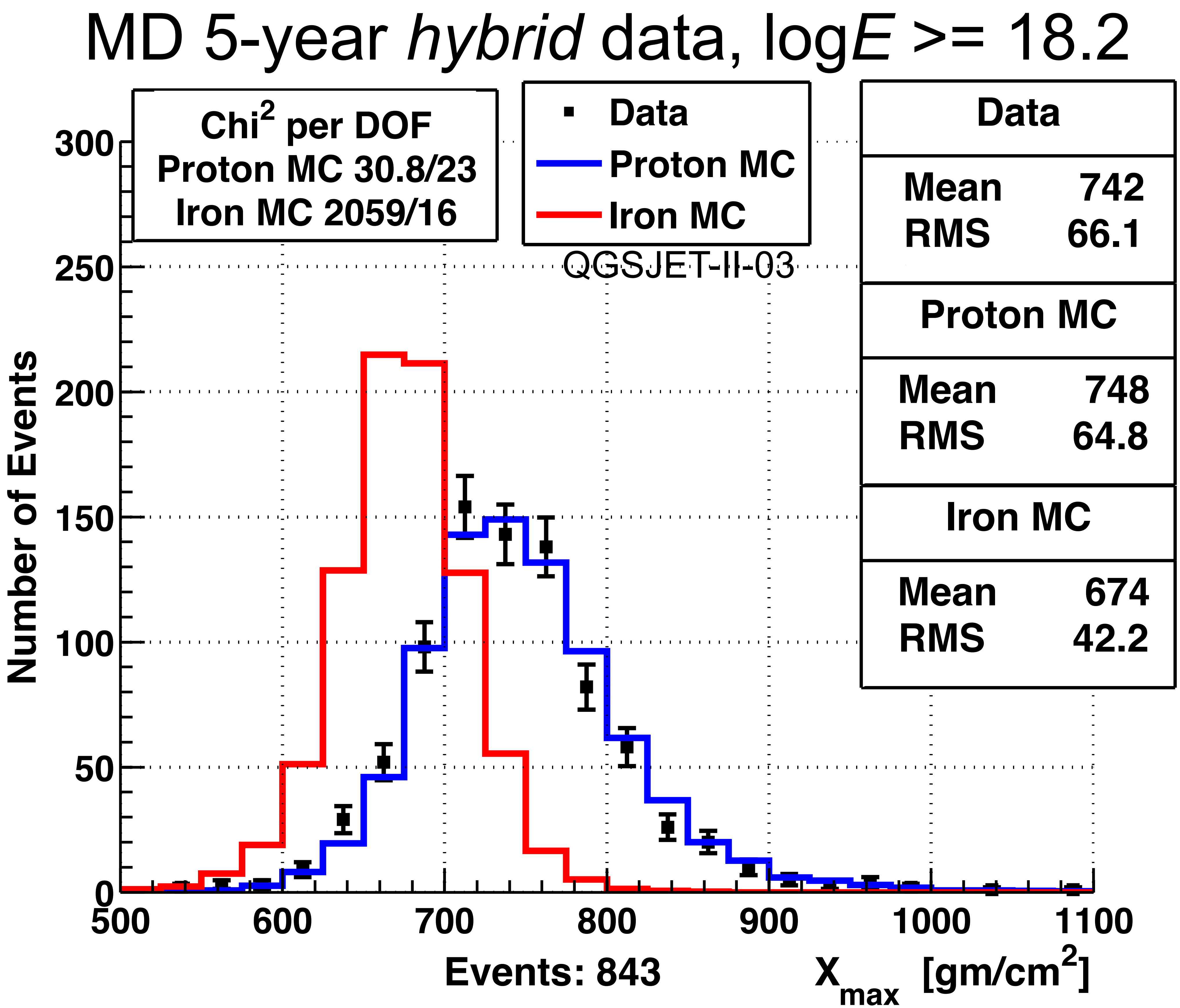
- **Independently triggered FD and SD data, time matching, use all SD information (FD SDP + FD timing + SD shower core) —> MD Hybrid**
- Independently triggered FD and SD data, time matching, use only single SD information (FD SDP + FD timing + SD timing/position) - in progress
- *Hybrid trigger*: External SD trigger by FD, use only single SD data, efficient in lower energies, implemented in late 2009 - in progress

MD/SD *Hybrid* Reconstruction

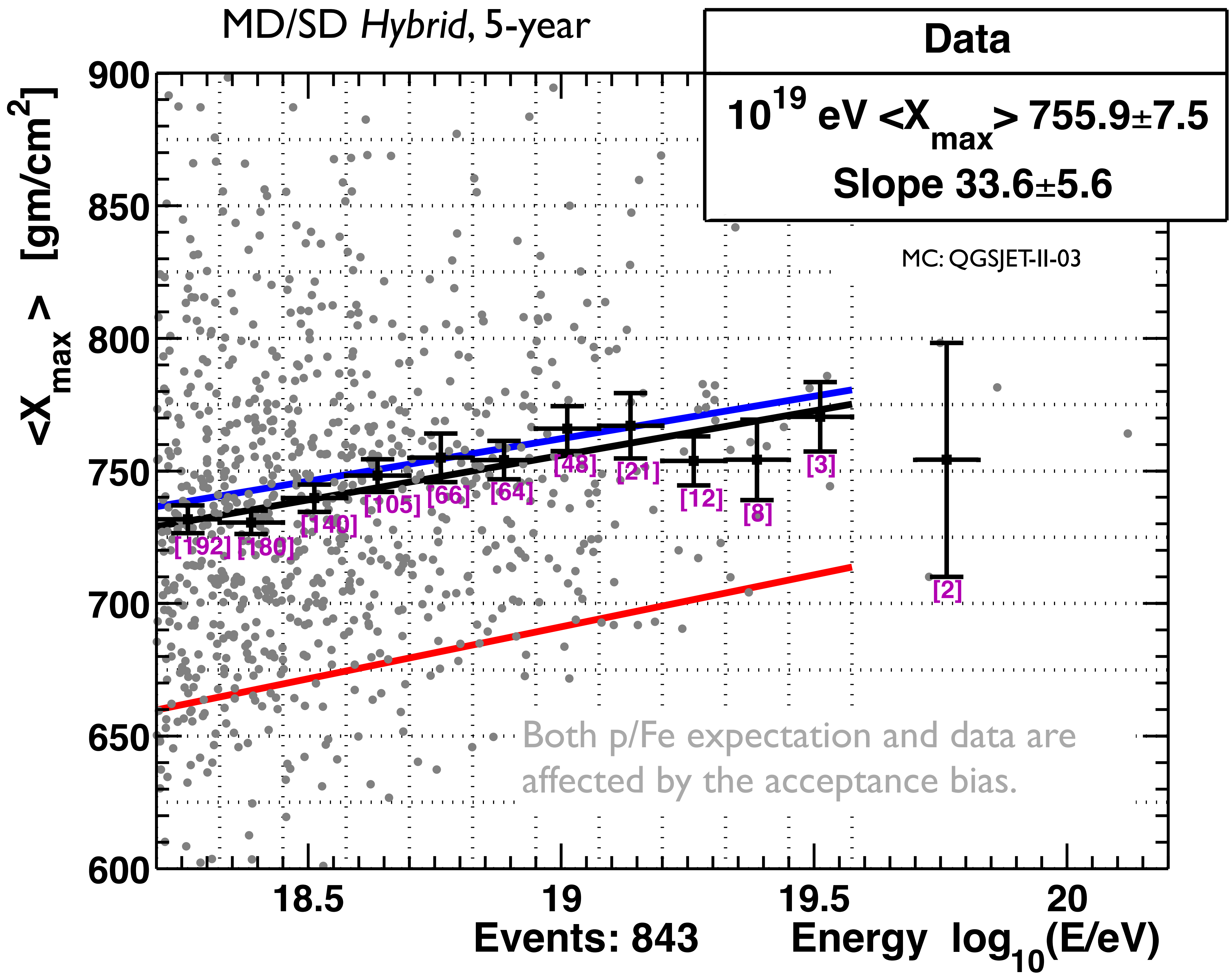
- MD-FD (refurbished HiRes-I detectors) + SD (>=3)
- SDP by FD + SD shower core
- 5-year data



MD/SD *Hybrid* X_{max}



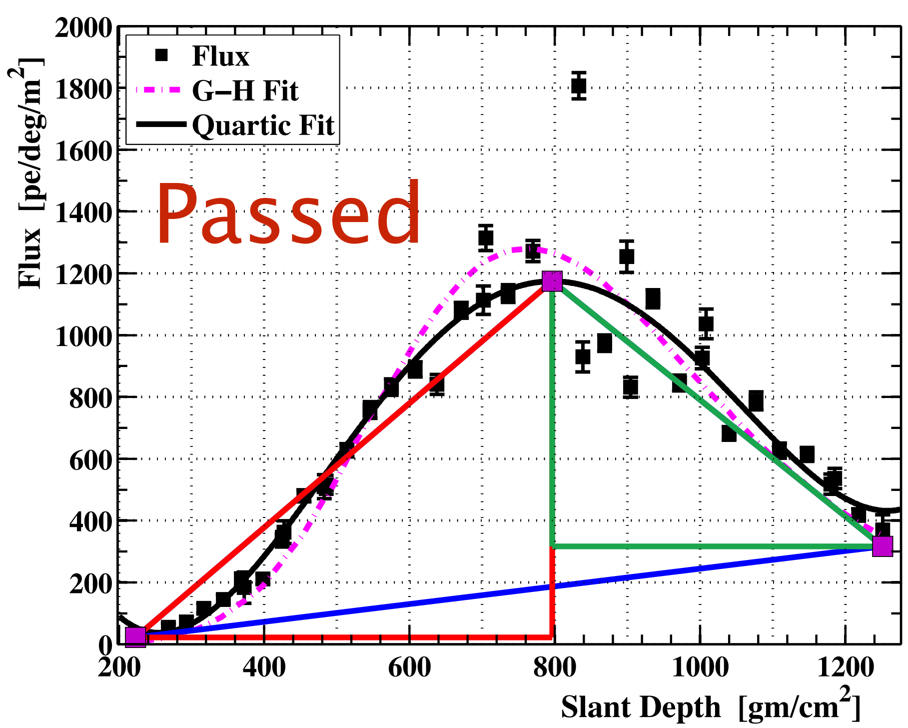
<X_{max}> vs log*E*

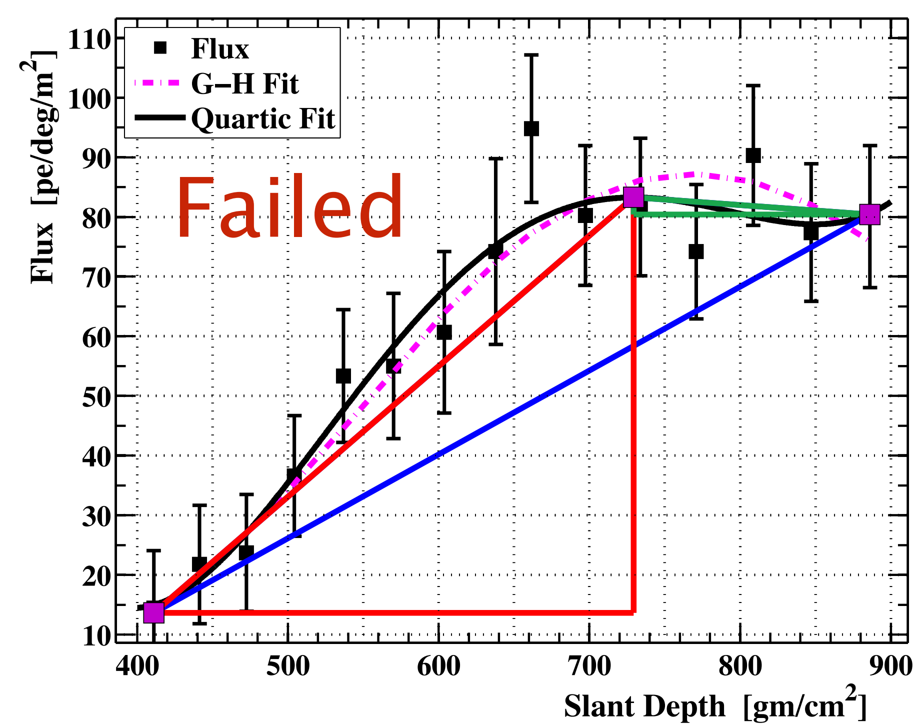


MD/SD Hybrid, 5-year
Data
10^19 eV <X_max> 755.9±7.5
Slope 33.6±5.6
MC: QGSJET-II-03
<X_max> [gm/cm^2]
900
850
800
750
700
650
600
18.5
19
19.5
20
Events: 843
Energy log_10(E/eV)
[192]
[180]
[140]
[105]
[66]
[64]
[48]
[21]
[12]
[8]
[3]
[2]
Both p/Fe expectation and data are
affected by the acceptance bias.

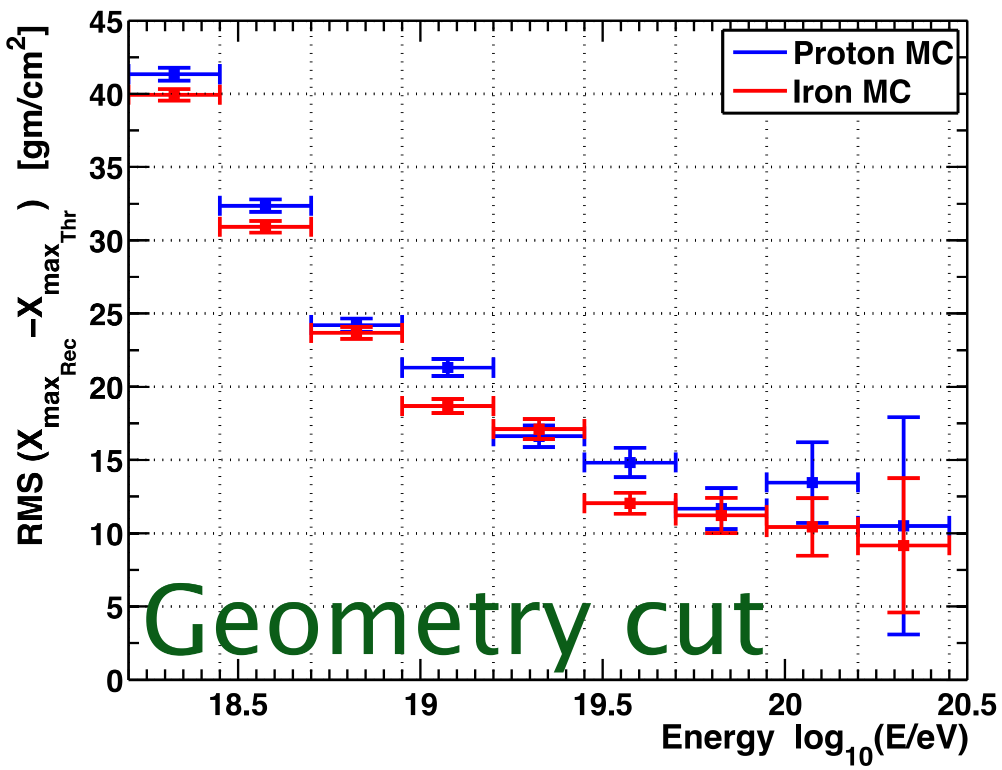
Pattern Recognitions for Shower Profiles

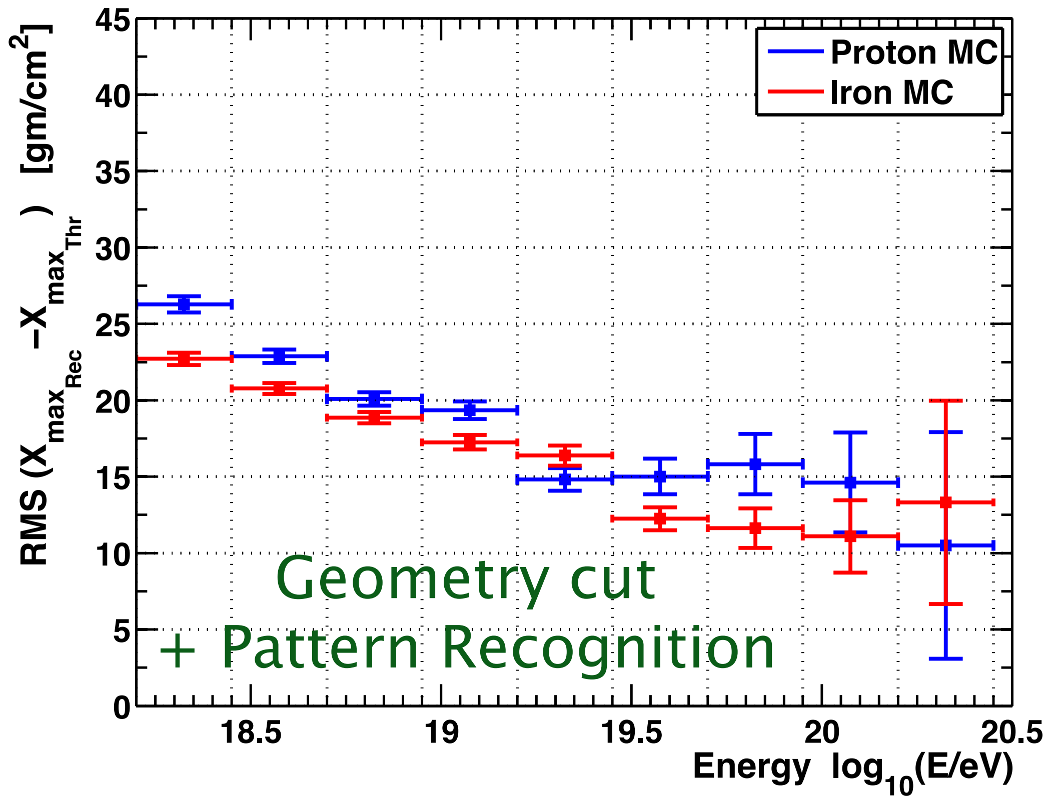
- Motivation: improve X_{max} resolution and its energy dependence
- Use only events with a clear rise and fall in FoV
    - Low-energy flat profile events are of poor X_{max} resolution (with rather good χ^2)
  - A machine-learning approach: Pattern recognition to select events with a rise and fall using the simplest templates: triangle.

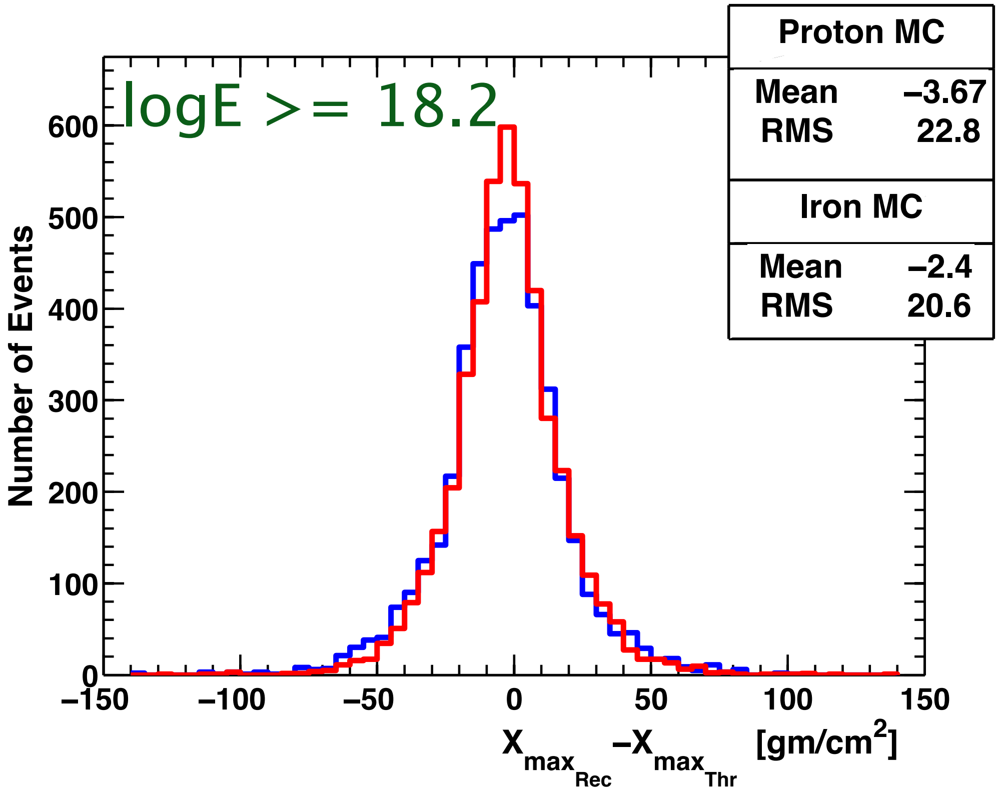




X_{max} Resolution after Geometrical and Pattern Recognition Cuts

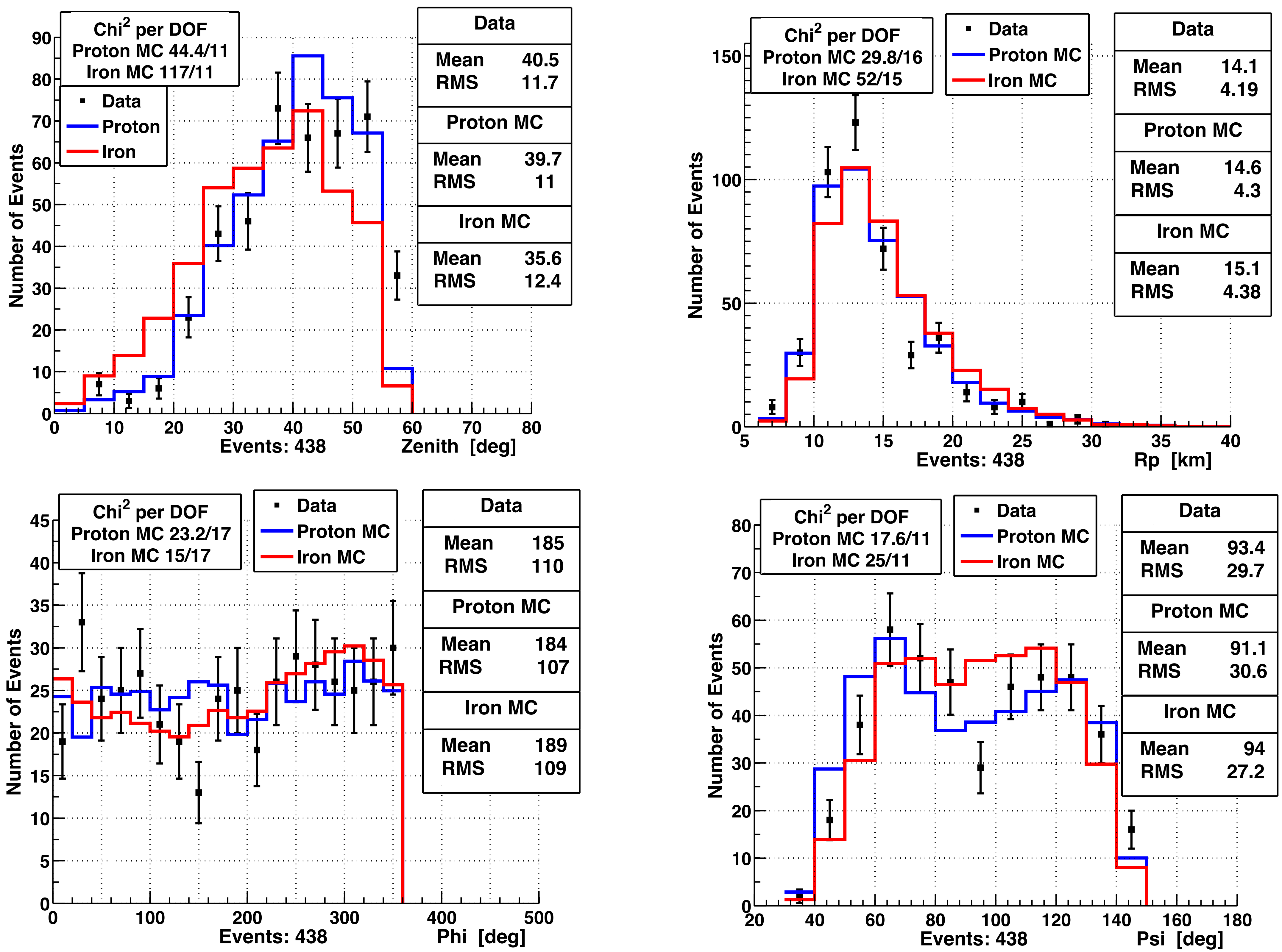






Data/MC Comparisons after Geometrical and Pattern Recognition Cuts

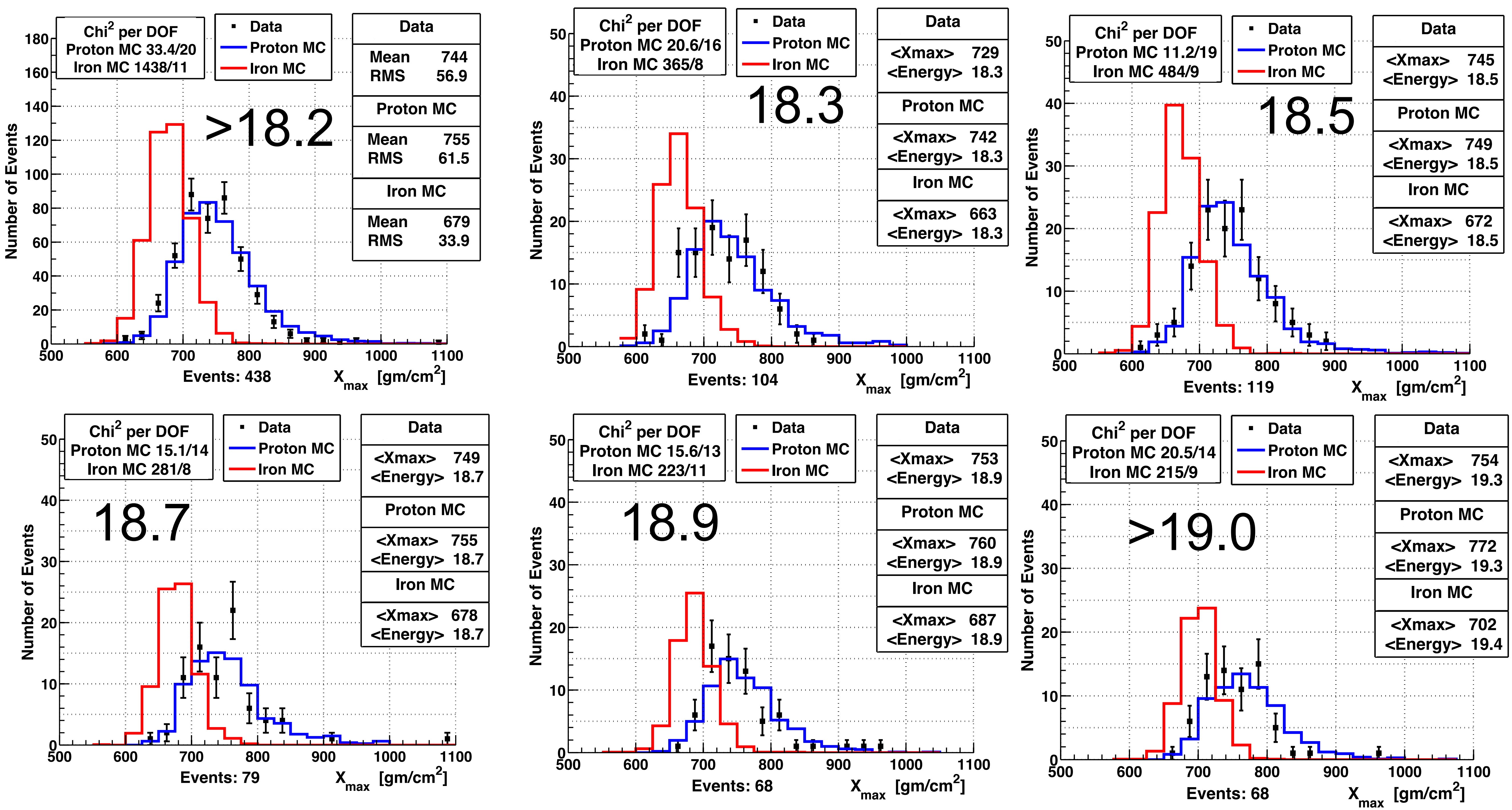
MC: QGSJET-II-03



X_{max} Distributions

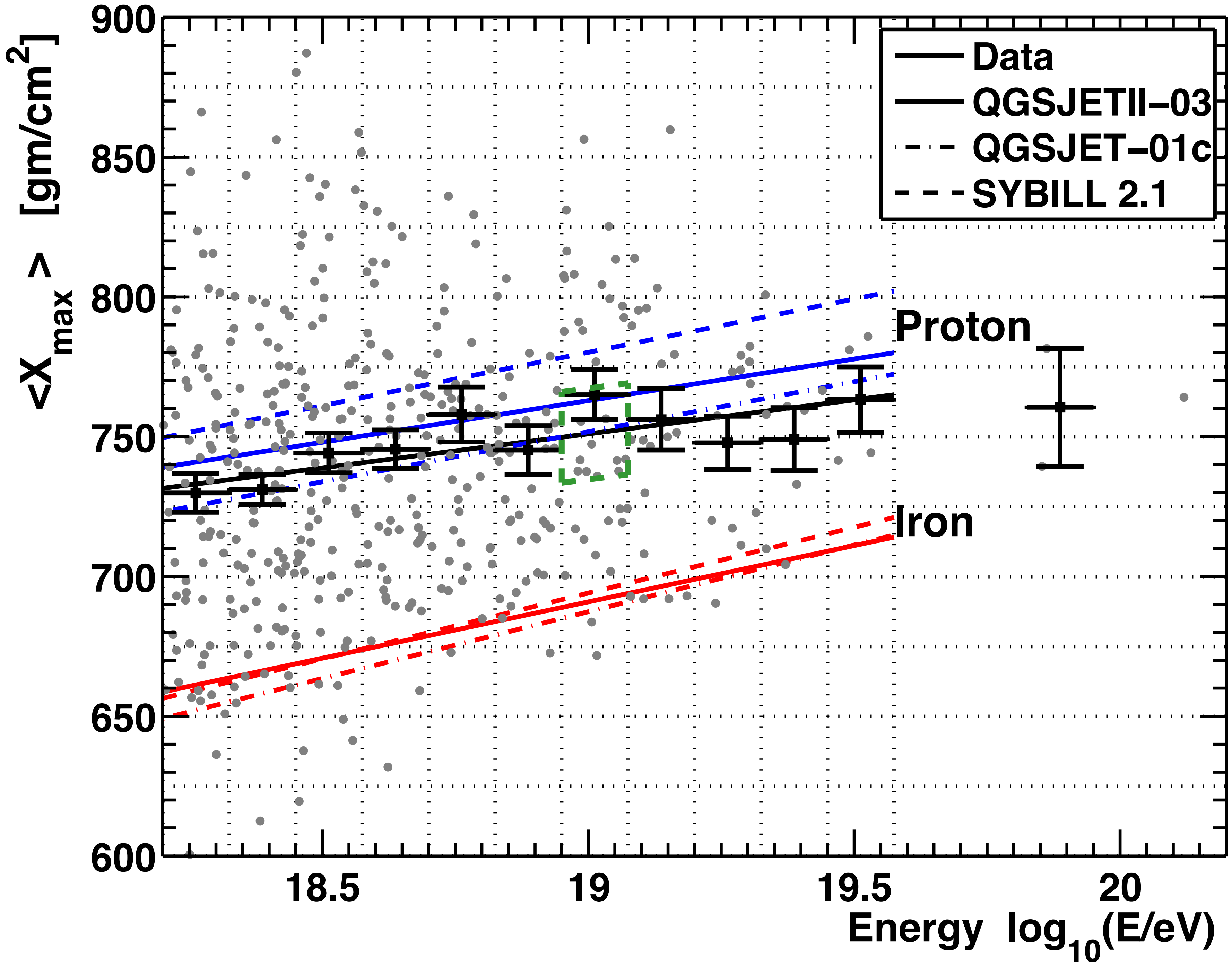
MD/SD *Hybrid*, 5-year, with geometrical + pattern recognition cuts

MC: QGSJET-II-03

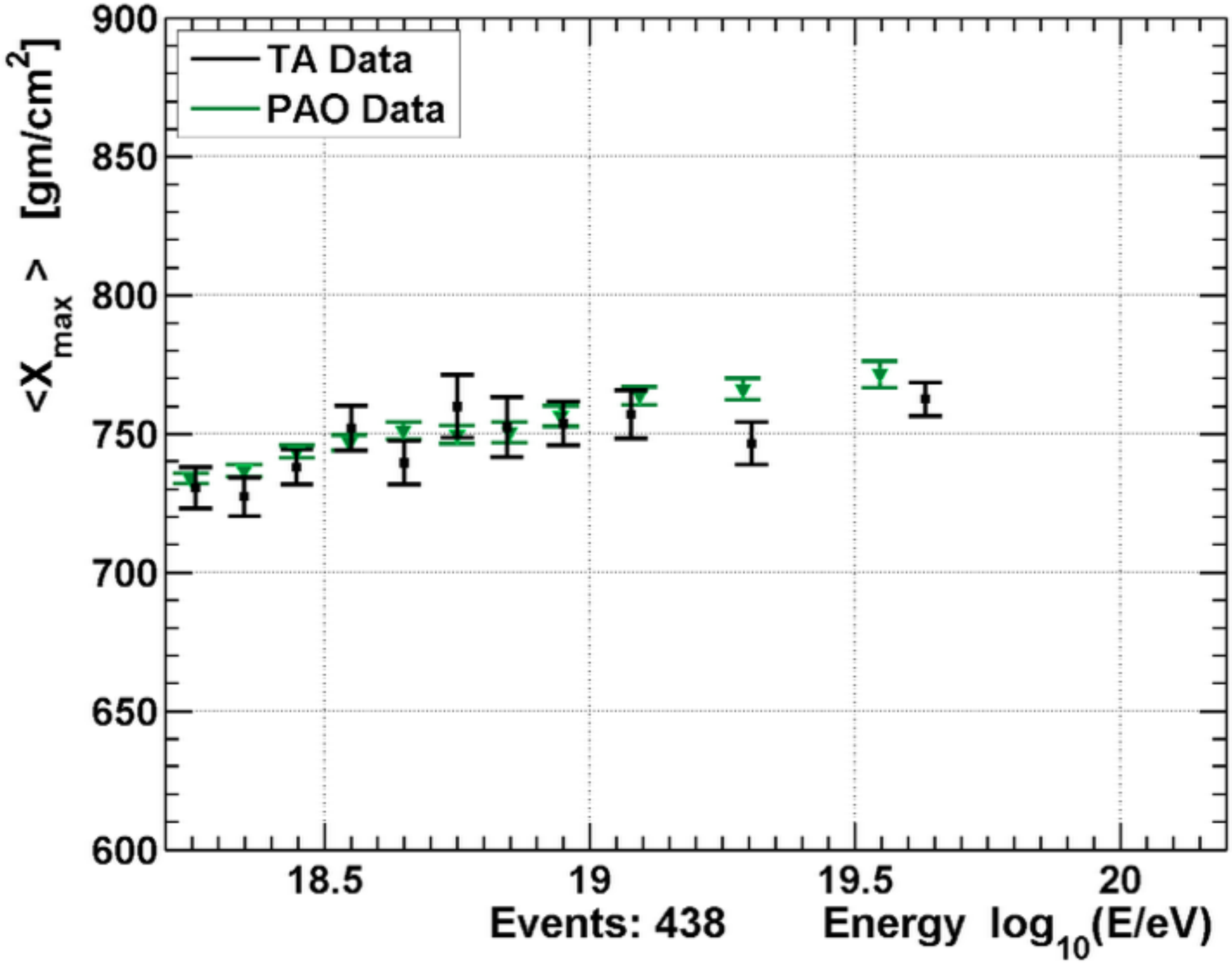


<X$_{max}$> vs log*E*

MD/SD *Hybrid*, 5-year, with geometrical + pattern recognition cuts

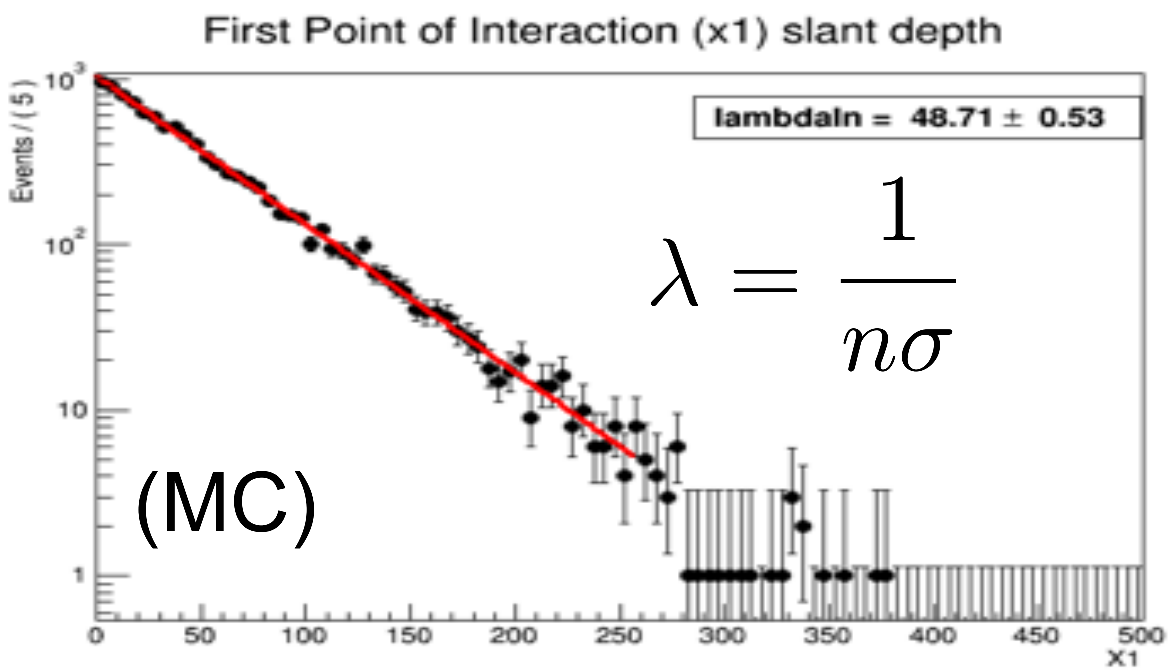


$<X_{max}>$ vs log*E*

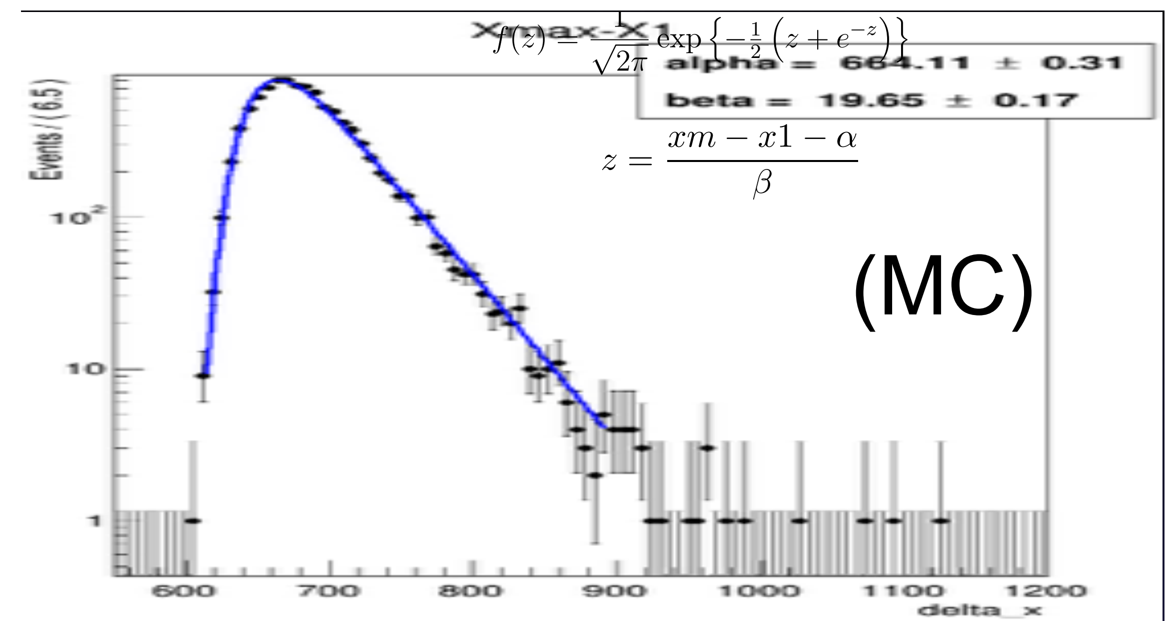

TA Data
PAO Data
900
850
800
750
700
650
600
$<X_{max}>$ [gm/cm^2]
18.5
19
19.5
20
Events: 438
Energy $\log_{10}$(E/eV)

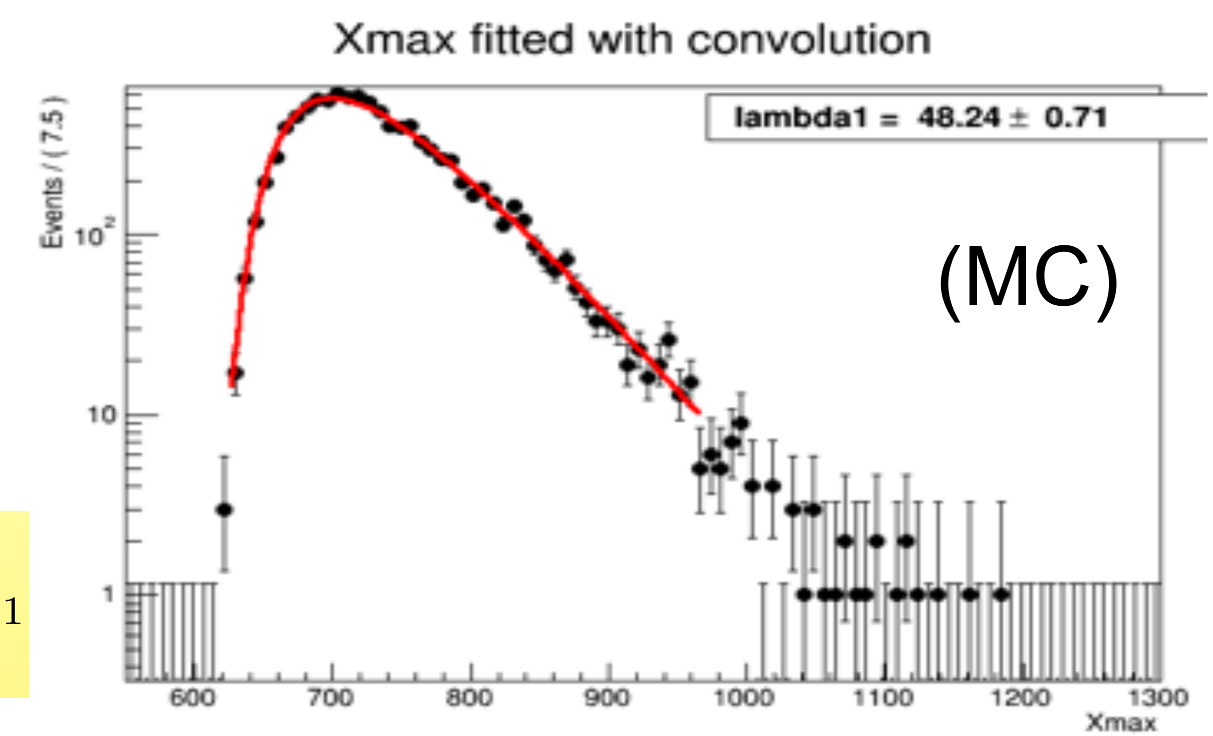
p-Air Cross Section

Measuring p-air cross section with FD data



$\otimes$





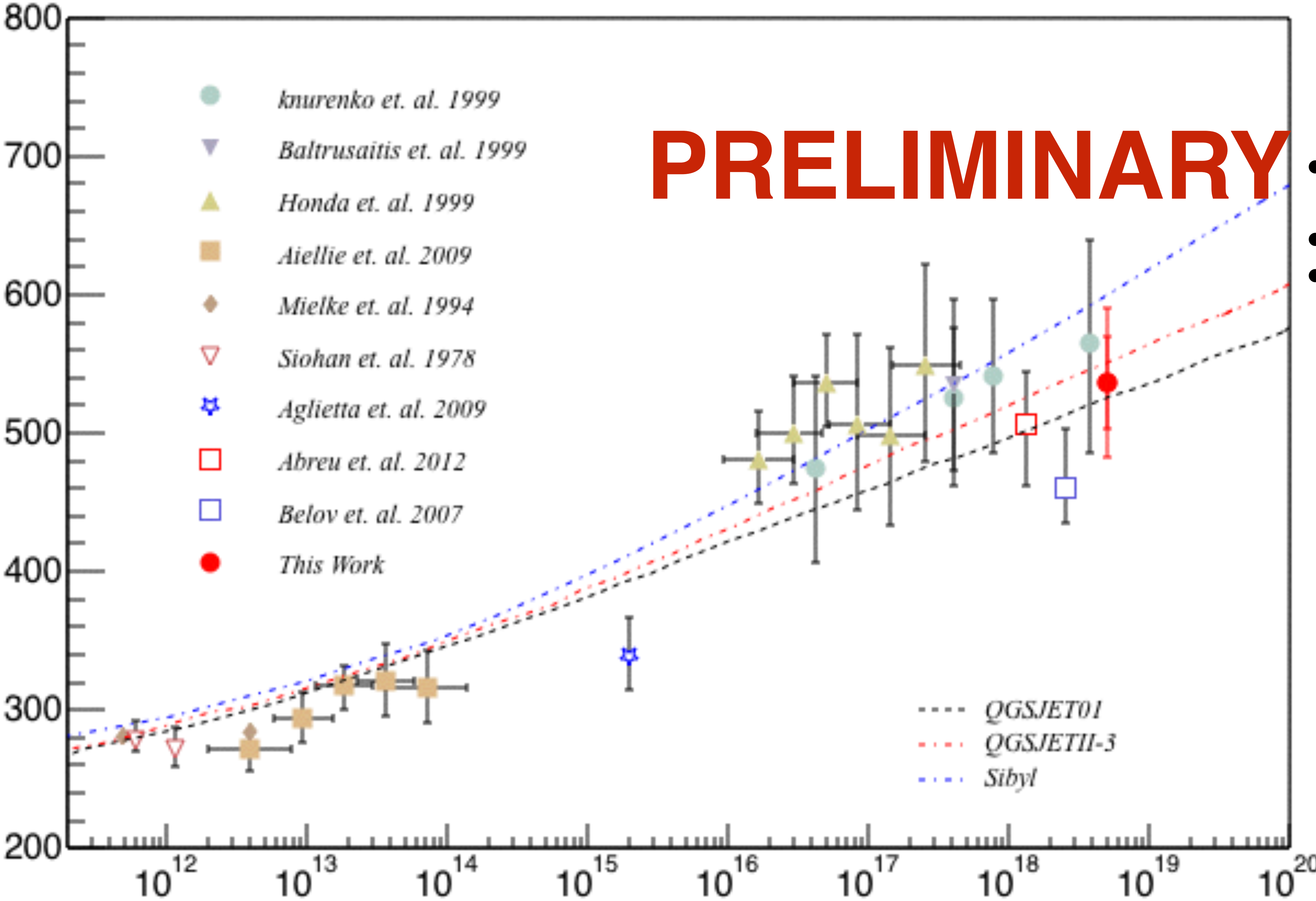
$$\frac{1}{\beta\sqrt{2\pi}}\int_0^{x_m}\frac{1}{\lambda_{p-air}}e^{-x_1/\lambda_{p-air}}e^{\frac{1}{2}[\frac{x_m-x_1-\alpha}{\beta}+e^{-[\frac{x_m-x_1-\alpha}{\beta}]}]}dx_1$$

σ(p-air): Data

- MD/SD hybrid, 5-year
  - Geometrical + pattern recognition cuts
  - logE = 18.3 - 19.3, <logE> = 18.7
  - 439 events
  - X_{max} resolution: 23.5 g/cm^2

σ(p-air) from MD Hybrid

(Average of σ(QGSJET-I) and σ(QGSJET-II)



Systematic errors:

- Different primary contamination ~10%: 30mb
- Detector bias: 33mb
- Model dependence: 33mb

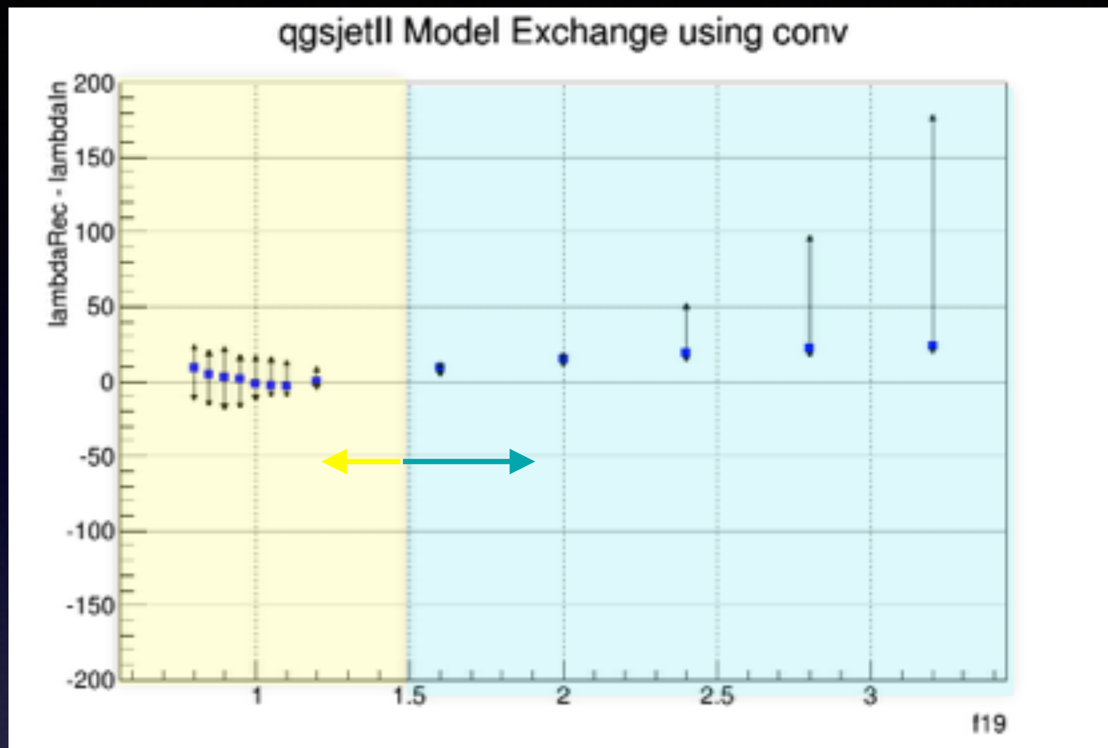
$$\sigma_{\mathrm{p-air}} = 536.2 \pm 33.4(\mathrm{stat}) \pm 55.4(\mathrm{sys})\ [\mathrm{mb}]$$

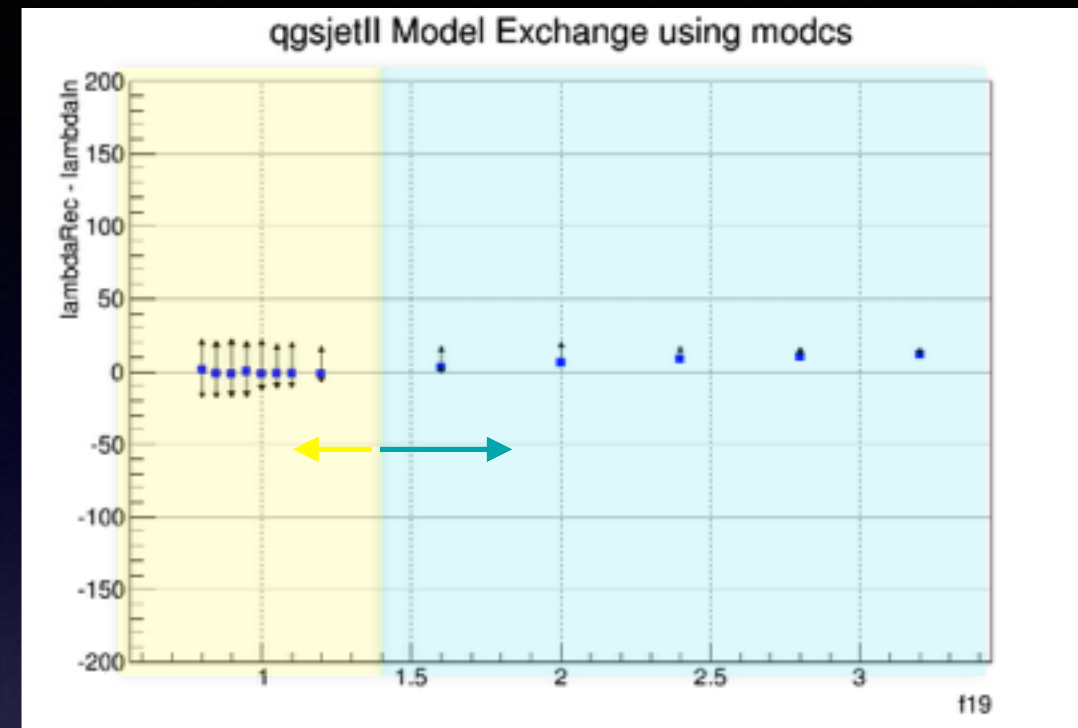
Conclusions

- TA X_{max} measurements
  - BR/LR/MD *stereo* reconstruction: 6.3-year data
  - MD *hybrid* reconstruction: 5-year data
    - Paper submitted to APP
- TA composition results indicate light composition below 10^{19}eV
  - Statistics is low in higher energies
- First result of the p-air cross section at $10^{18.7}$eV with MD hybrid

$$\sigma_{\mathrm{p-air}} = 536.2 \pm 33.4(\mathrm{stat}) \pm 55.4(\mathrm{sys})\ [\mathrm{mb}]$$

Convolution vs. MCS





(lambda rec - lambda model) vs. the fraction by which cross section is modified.

→ **advantage of MCS at high values of f19: 50% or higher also at -20% or lower.**

→ **Does this still applies at 5%,10%..etc where it is more realistically the case**

Comparison at 5,10,15, and 20% modification level

qgsjet II4