Hadronic interaction models in simulations for UHECR composition studies

Eun-Joo Ahn

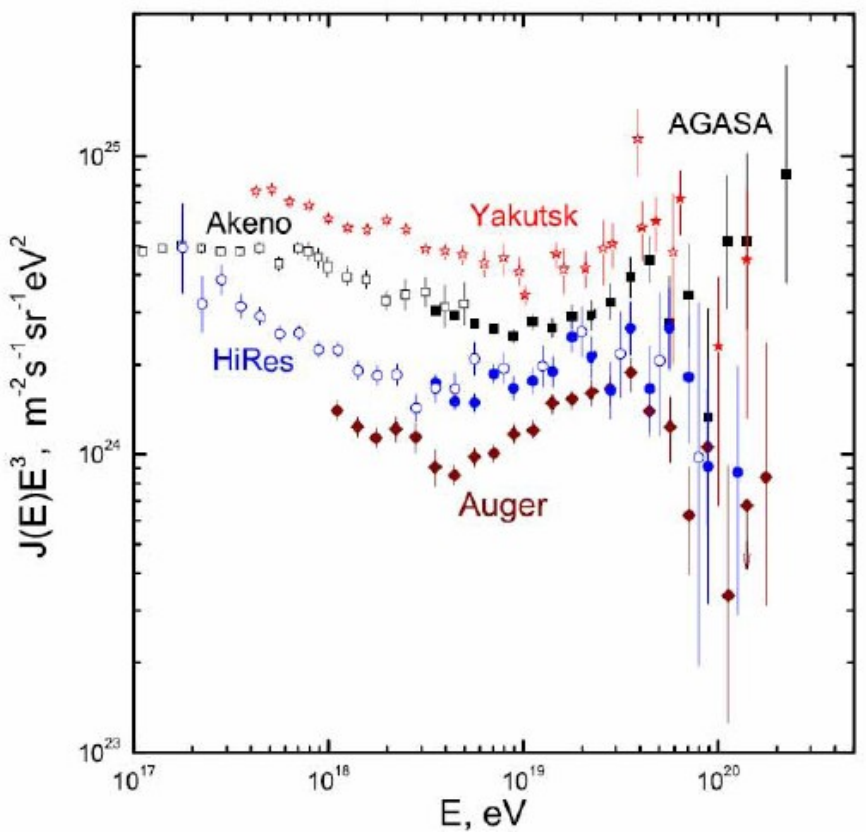
Fermi Center for Particle Astrophysics

Fermilab

TeVPA08 Beijing, Sept 26th 2008

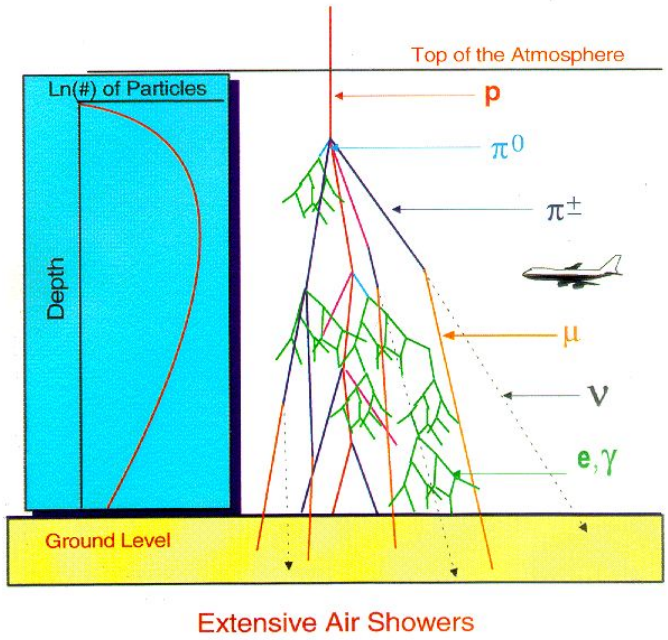
Ultra high energy cosmic rays

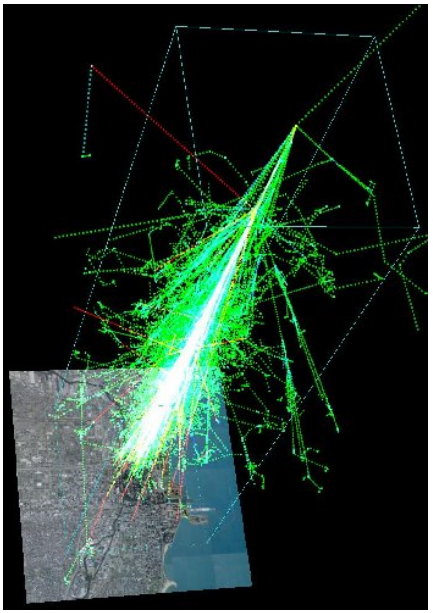
- low flux - indirect detection;
- observe extensive air shower;
- Monte Carlo required to interpret observation.



(V. Berezinsky ICRC 2007)

Air shower cascade





(UChicago COSMUS)

1. CR - air interaction $\rightarrow$ fragment into secondaries.
2. Secondaries propagate, interact/fragment, propagate etc. etc.
3. Number of particles reach maximum at X_m, then decrease.

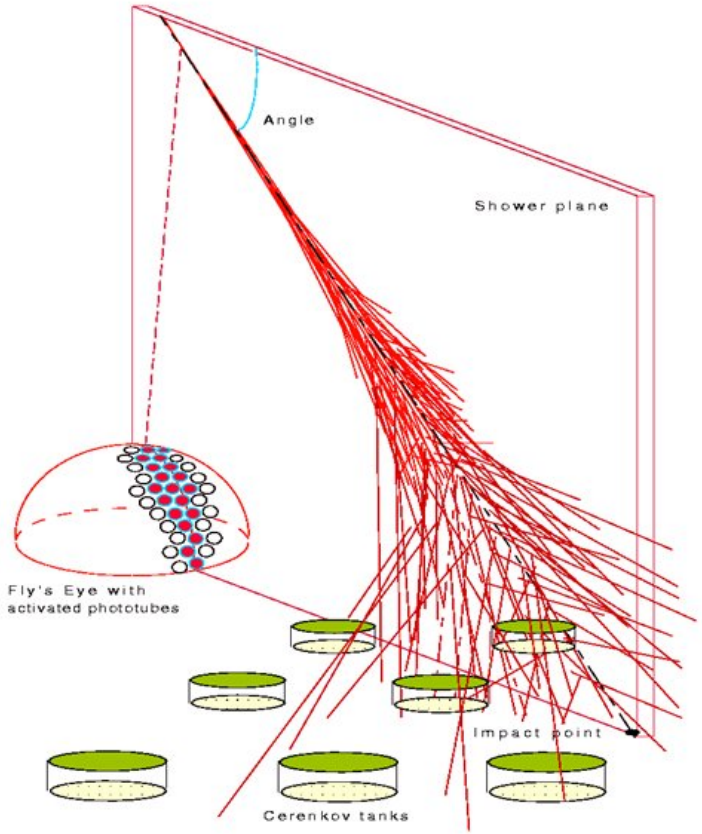
Air shower MC (CORSIKA, AIRES)

- Hadronic interaction / electromagnetic model - produce secondaries;
- Propagate secondaries in given atmosphere model;
- Secondaries interact again, with hi/em model;
- Decay secondaries.
- Thinning etc. to reduce time.

Hadronic interaction model (Sibyll, QGSJET, EPOS)

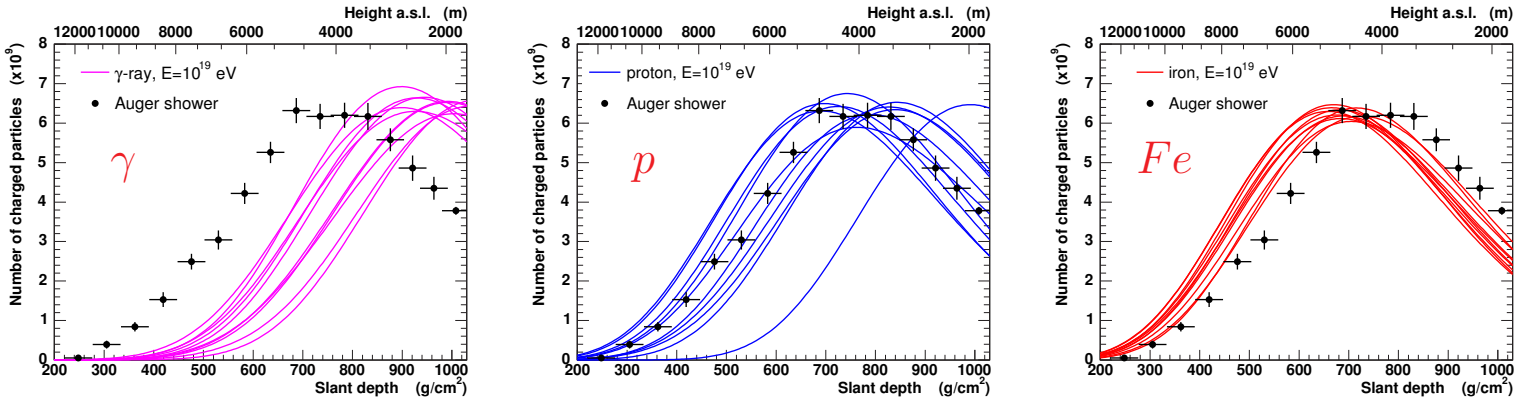
- input: projectile, target, E_{CM}
- output: fragmented particles
  cross sections

Pierre Auger Observatory

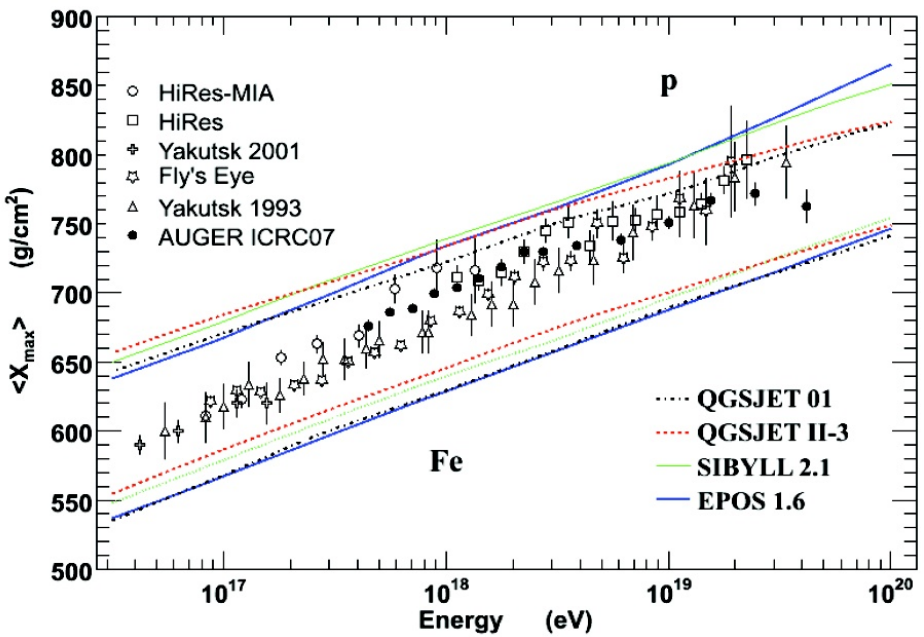


(PAO)

1. Fluorescence detector



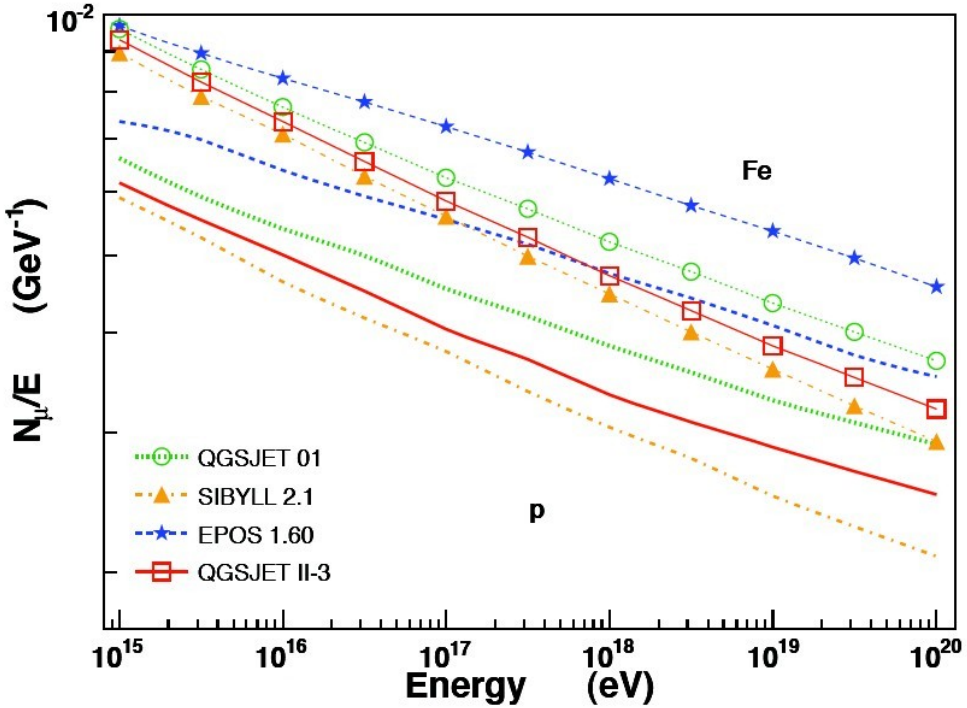
(R. Engel ICRC 2007)



- h.i. model required to determine composition;
- h.i. models slightly differ.

(T. Pierog ICRC 2007)

2. Surface detector



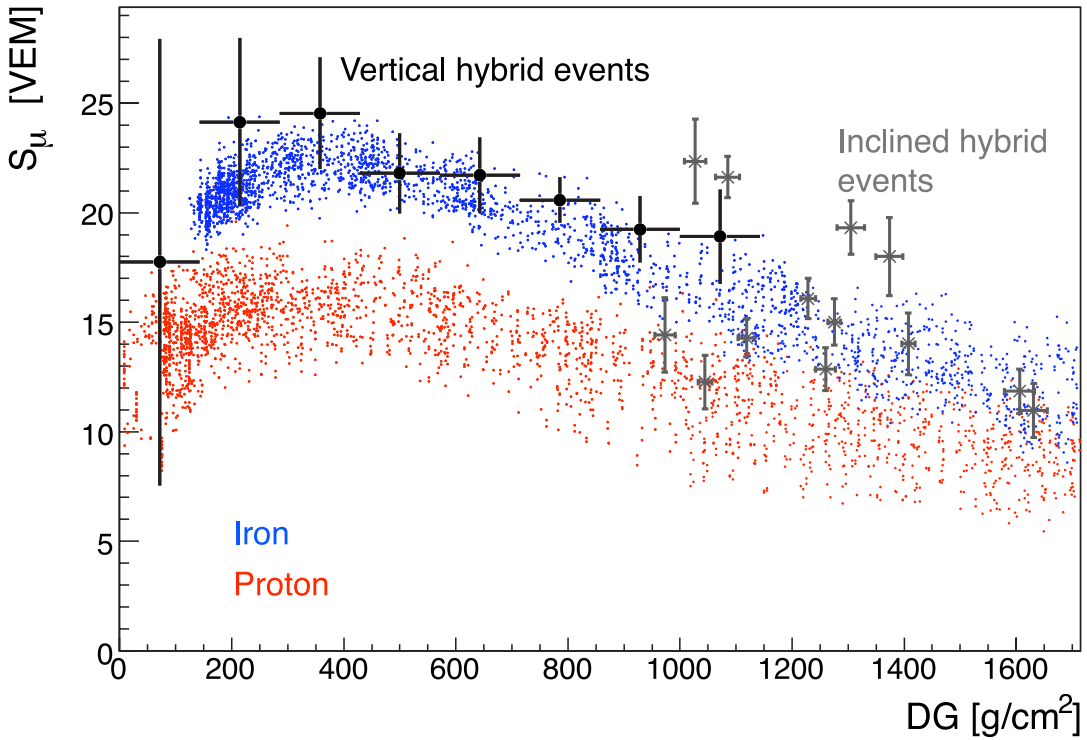
(R. Engel)

Number of muons differ for

- different compositions;
- different h.i. models.

	$N_\mu(p)$	$N_\mu(Fe)$
SIBYLL	small	small
QGSJET	medium	small
EPOS	v. high	v. high

2. Surface detector



(Auger Collab. ICRC 2007) (QGSJET II)

Number of muons differ for

- different compositions;
- different h.i. models.

	$N_\mu(p)$	$N_\mu(Fe)$
SIBYLL	small	small
QGSJET	medium	small
EPOS	v. high	v. high

Wiggle room for hadronic interaction models

- QCD + other phenomenology based - free parameters and extrapolation.
- Flexibility/robustness important.
- Must agree with low energy fixed target, collider data.

Wiggle room for hadronic interaction models

- QCD + other phenomenology based - free parameters and extrapolation.
- Flexibility/robustness important.
- Must agree with low energy fixed target, collider data.

♠ Leave model alone, change outcome $\propto$ energy (R. Ulrich, PhD thesis etc)

- vary cross section, multiplicity, inelasticity $\propto \log E$
- effect on observable (X_{max}, N_e, N_μ)
- not realistic, but *good understanding* of characteristics

Wiggle room for hadronic interaction models

- QCD + other phenomenology based - free parameters and extrapolation.
- Flexibility/robustness important.
- Must agree with low energy fixed target, collider data.

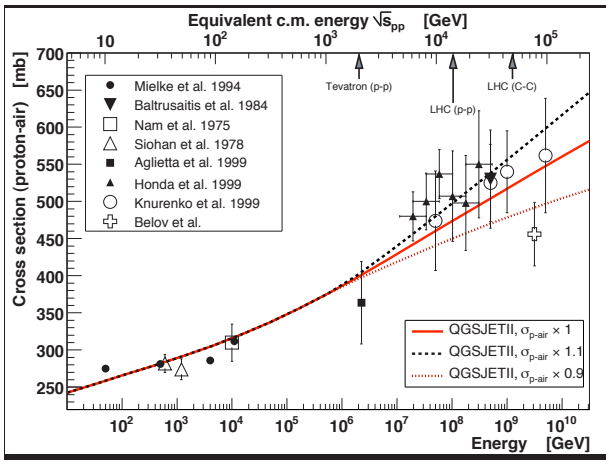
♠ Leave model alone, change outcome $\propto$ energy (R. Ulrich, PhD thesis etc)

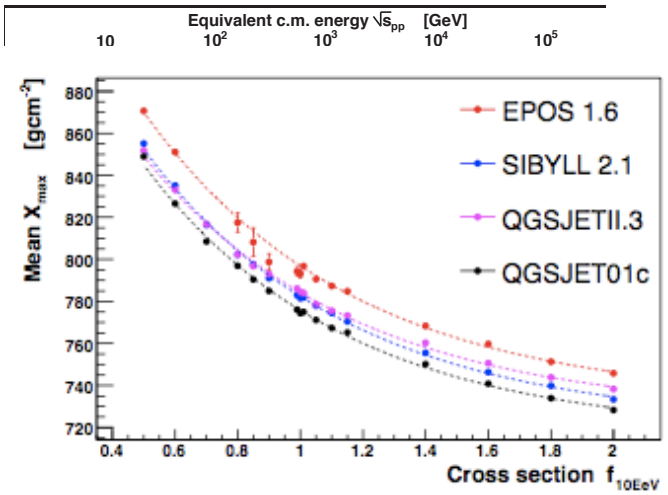
- vary cross section, multiplicity, inelasticity $\propto \log E$
- effect on observable (X_{max}, N_e, N_μ)
- not realistic, but *good understanding* of characteristics

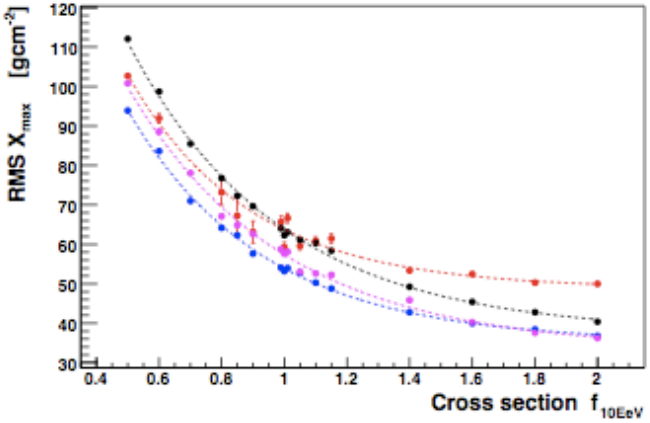
♠ Change model itself (work in progress)

- change intrinsic parameters
- more realistic

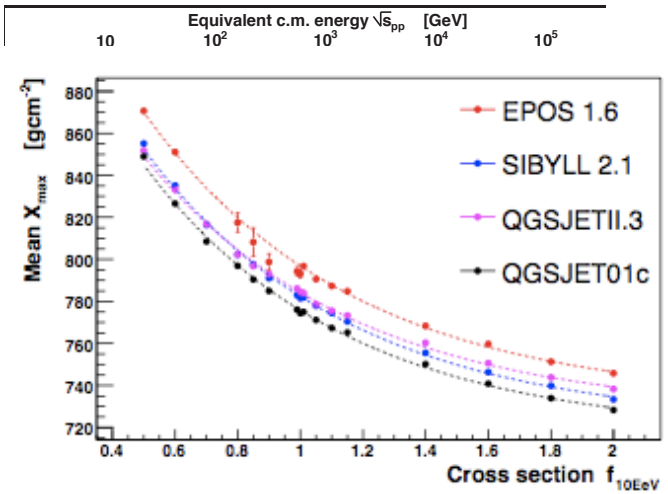
R. Ulrich

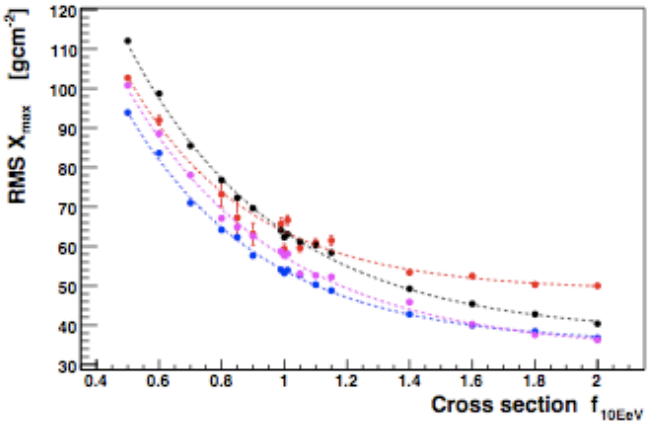

Equivalent c.m. energy $\sqrt{s}_{pp}$ [GeV]
10
10^2
10^3
10^4
10^5
Cross section (proton-air) [mb]
700
650
600
550
500
450
400
350
300
250
Tevatron (p-p)
LHC (p-p)
LHC (C-C)
Mielke et al. 1994
Baltrusaitis et al. 1984
Nam et al. 1975
Siohan et al. 1978
Aglietta et al. 1999
Honda et al. 1999
Knurenko et al. 1999
Belov et al.
QGSJETII, $\sigma_{p\text{-}air}$ × 1
QGSJETII, $\sigma_{p\text{-}air}$ × 1.1
QGSJETII, $\sigma_{p\text{-}air}$ × 0.9
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
Energy [GeV]


Equivalent c.m. energy $\sqrt{s}_{pp}$ [GeV]
10
10^2
10^3
10^4
10^5
Mean X_{max} [gcm^{-2}]
EPOS 1.6
SIBYLL 2.1
QGSJETII.3
QGSJET01c
Cross section f_{10EeV}

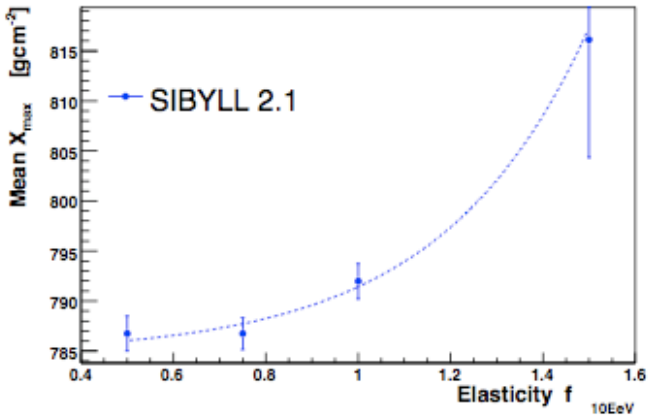

RMS X_{max} [gcm^{-2}]
Cross section f_{10EeV}

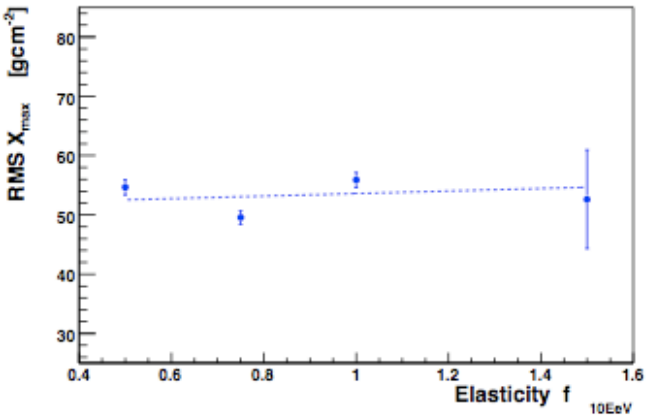
R. Ulrich





Elasticity $K_{el} = E_{max}/E_{tot}$





Sibyll

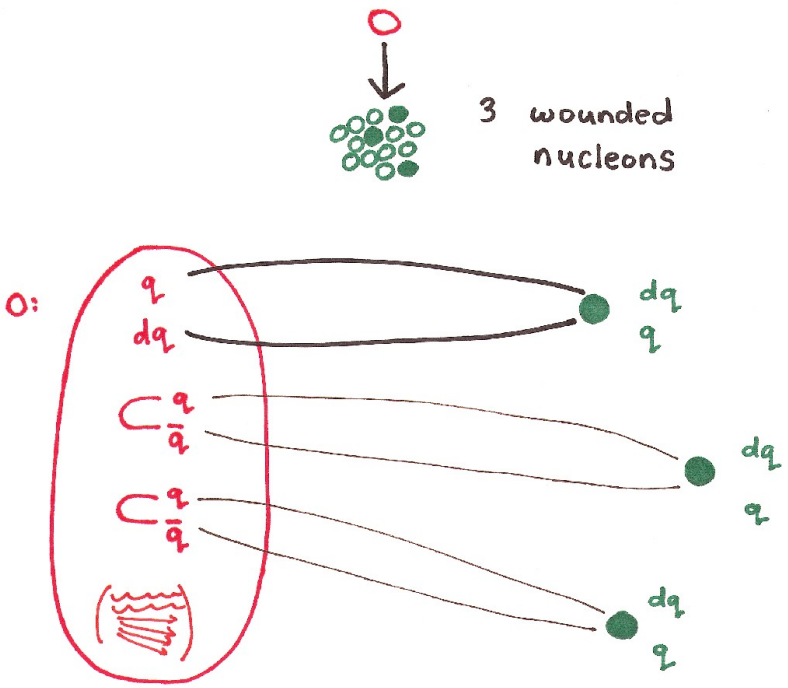
(EJA, R. Engel, R. Fletcher, T. Gaisser, P. Lipari, T. Stanev)

- quark-diquark, strings, minijet, minimal pomerons, semi-superposition.
- PYTHIA-based, fragmentation region; ver 1.7, ver 2.1; fastest calc.

Sibyll

(EJA, R. Engel, R. Fletcher, T. Gaisser, P. Lipari, T. Stanev)

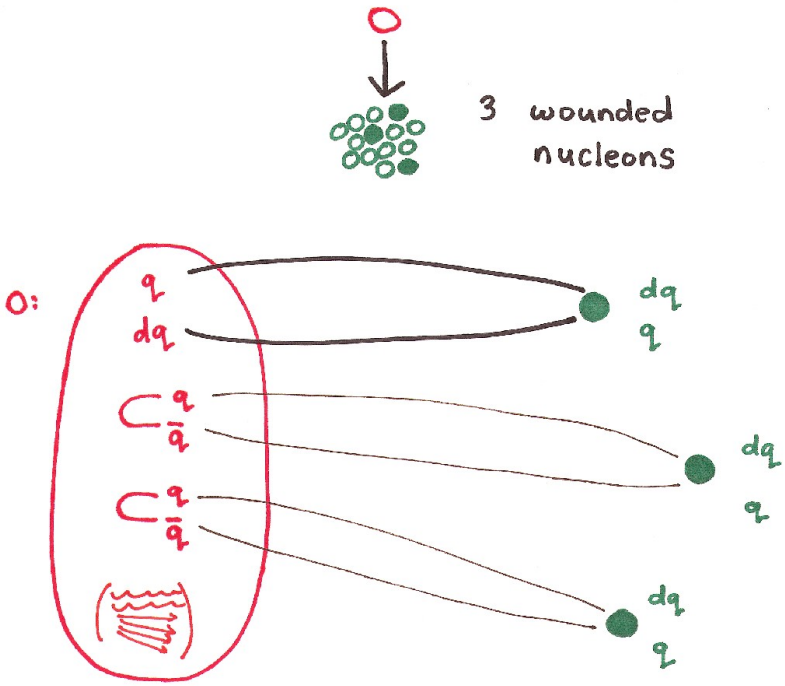
- quark-diquark, strings, minijet, minimal pomerons, semi-superposition.
- PYTHIA-based, fragmentation region; ver 1.7, ver 2.1; fastest calc.

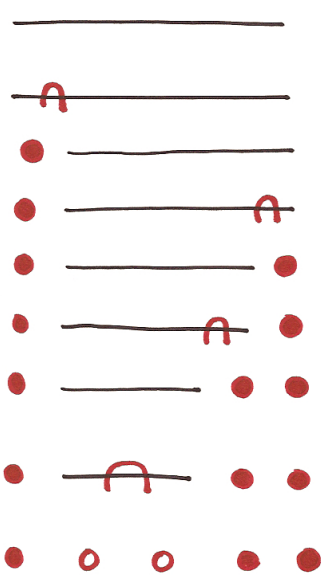


Sibyll

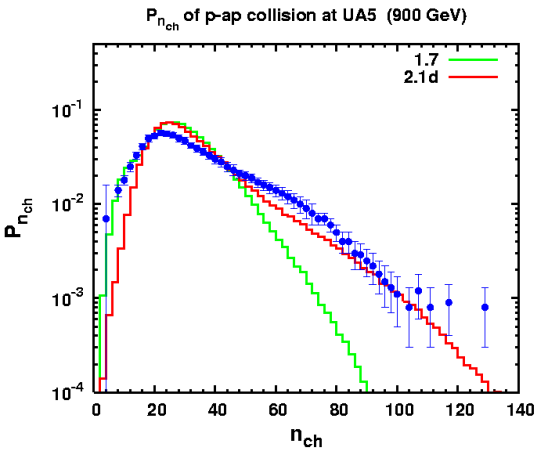
(EJA, R. Engel, R. Fletcher, T. Gaisser, P. Lipari, T. Stanev)

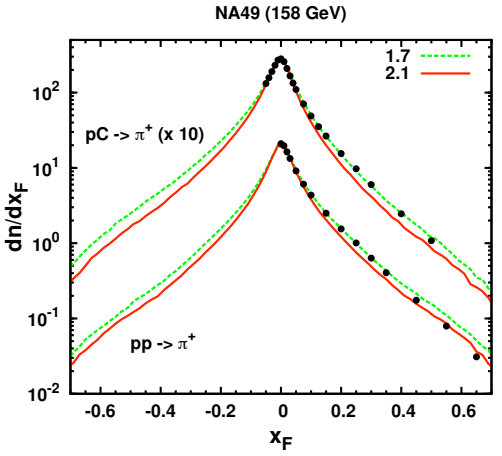
- quark-diquark, strings, minijet, minimal pomerons, semi-superposition.
- PYTHIA-based, fragmentation region; ver 1.7, ver 2.1; fastest calc.

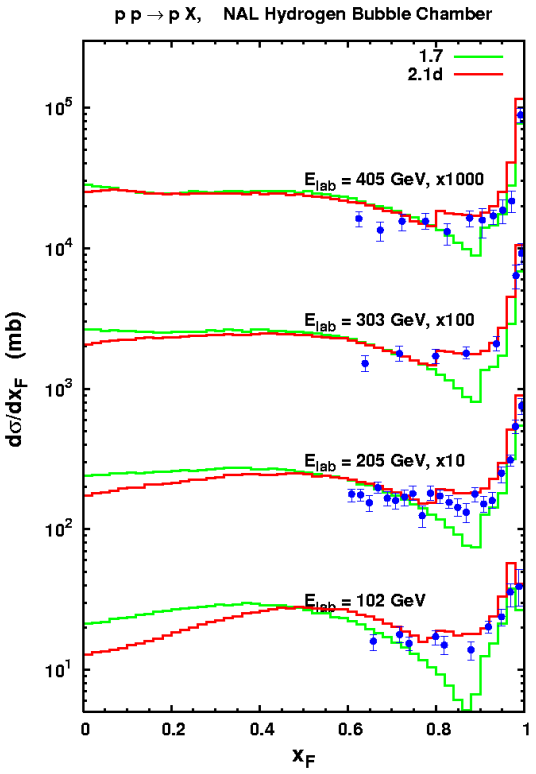




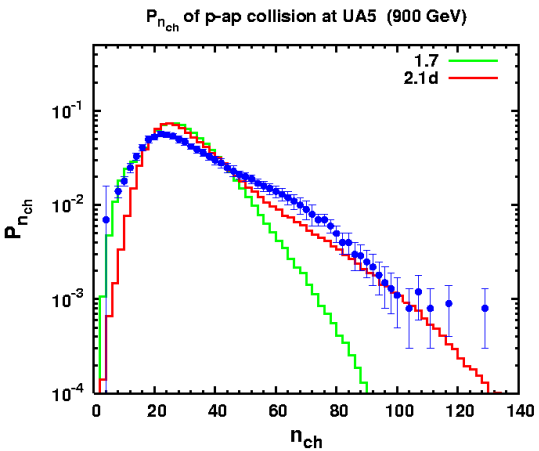
Good and not good agreement with data

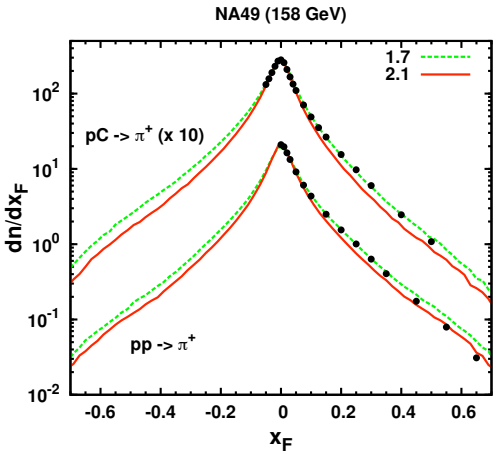


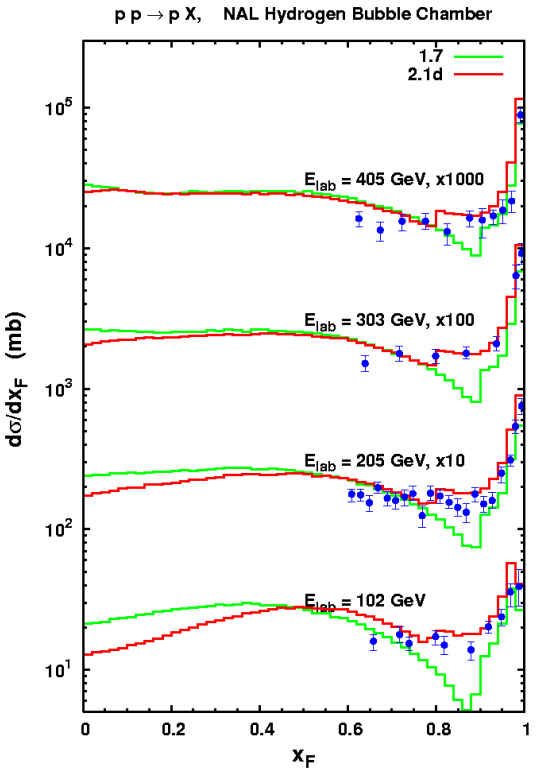


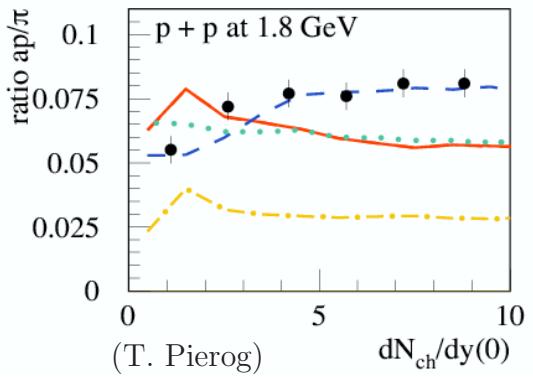


Good and not good agreement with data

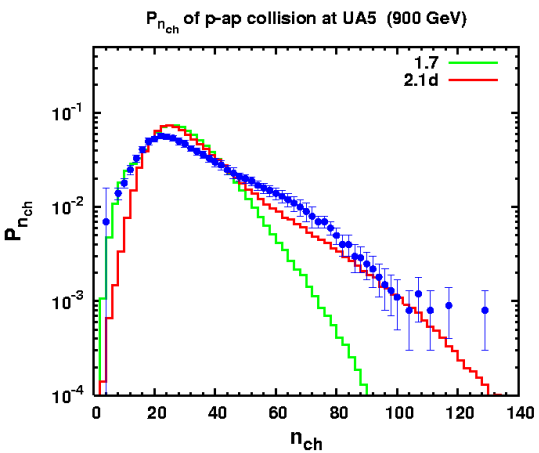


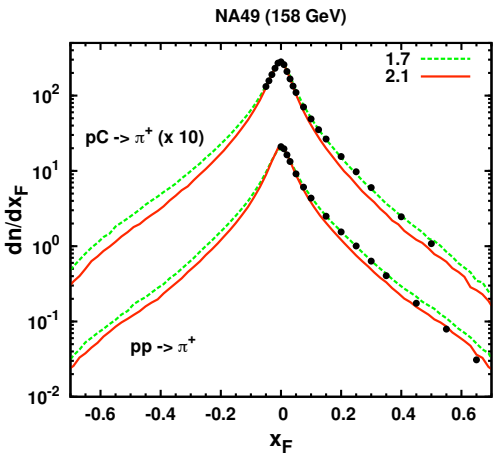


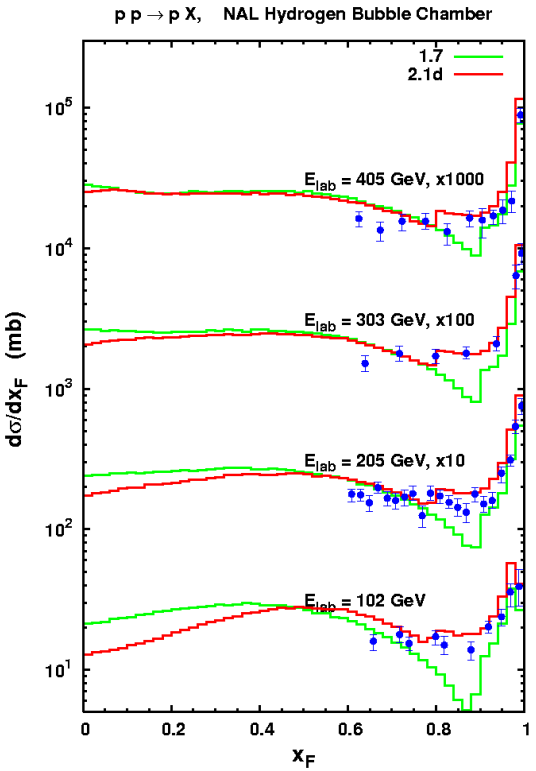




Good and not good agreement with data

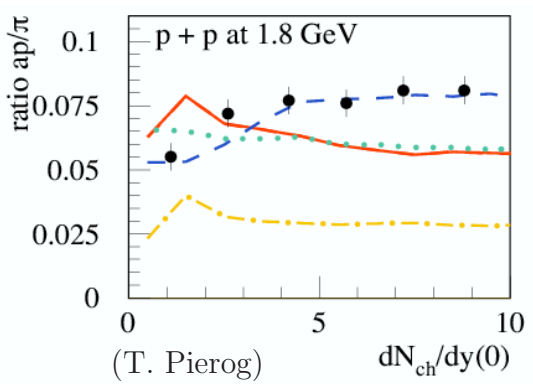






More improvement needed:

- larger kaon production, correct anti-baryon;
- improve diffraction, nucleus-nucleus;
- improve discrimination of hard/soft interaction;
- etc.

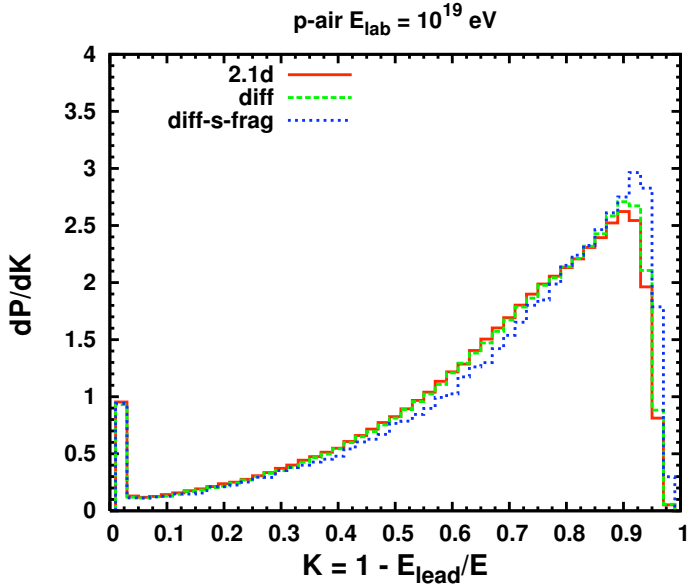


Improvement

- smoother transition to diffraction;
- larger s quark fraction;
- small bugfix;

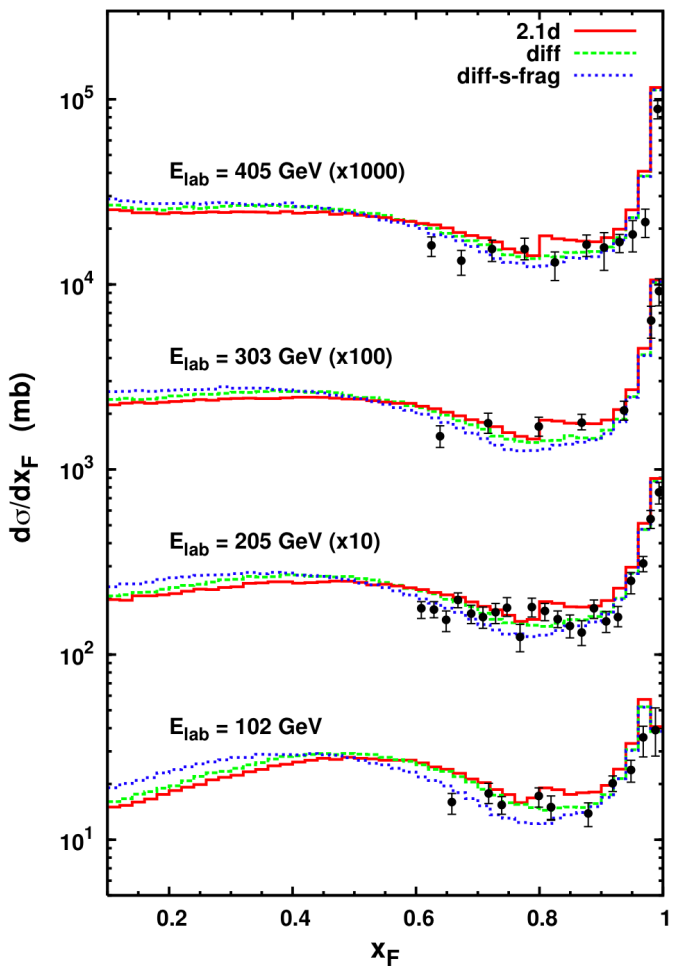
Variation

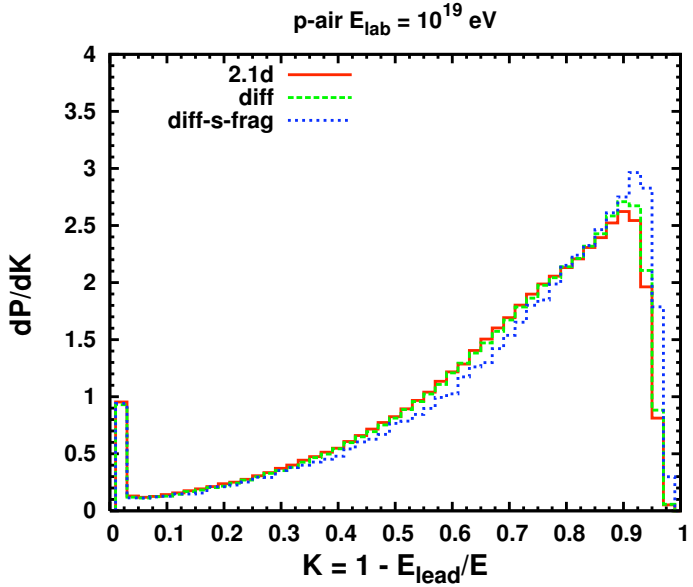
- inelasticity (fragmentation func).

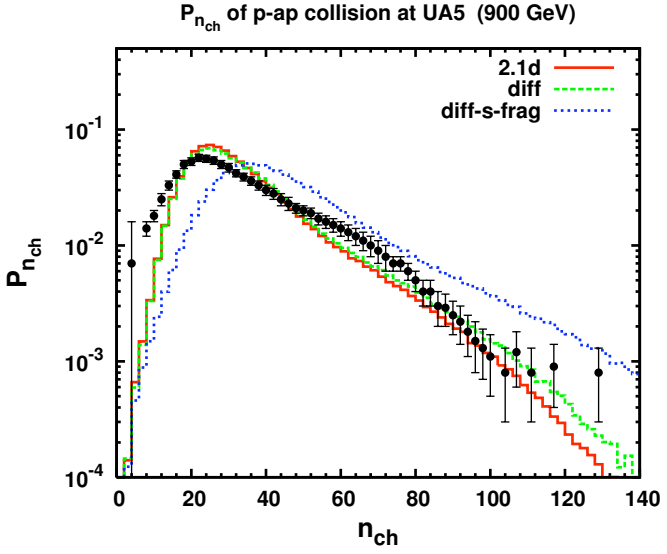


Improvement

- smoother transition to diffraction;

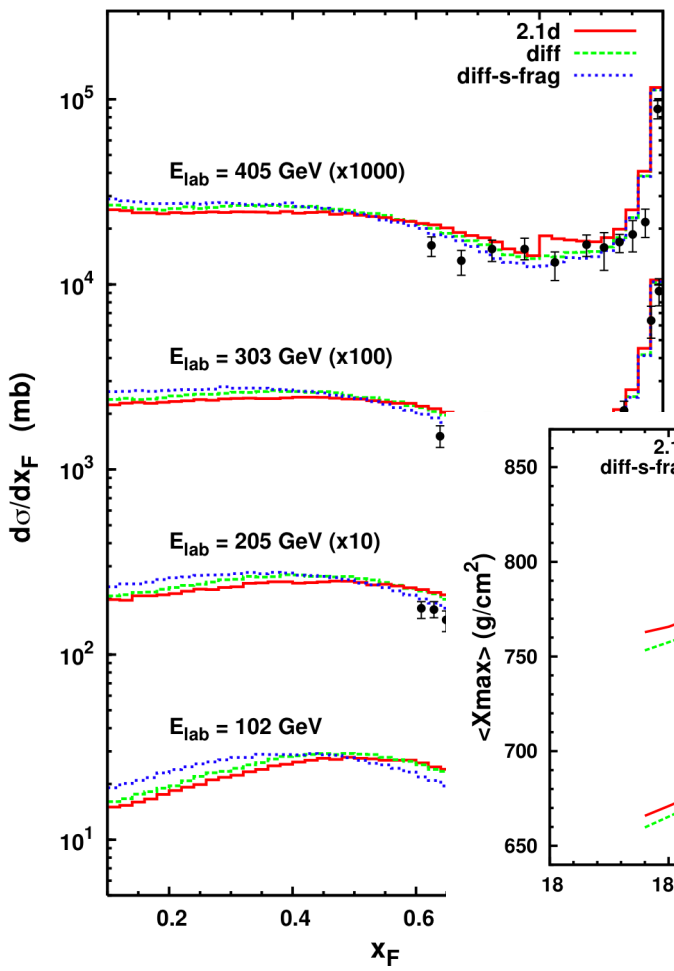


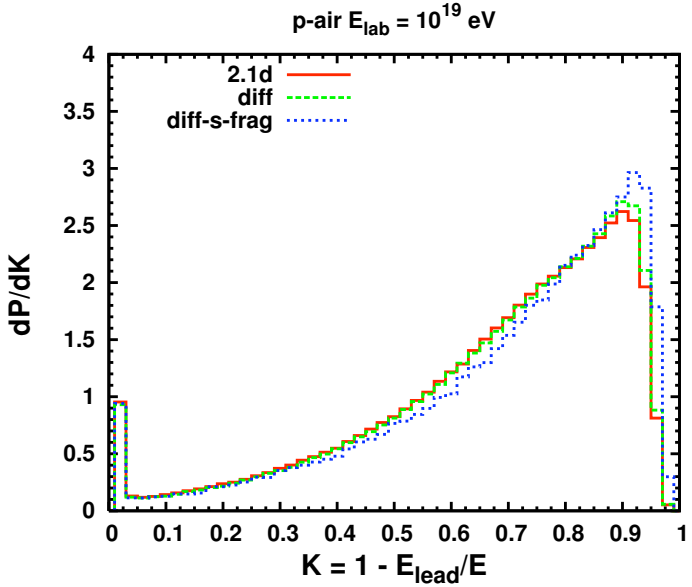


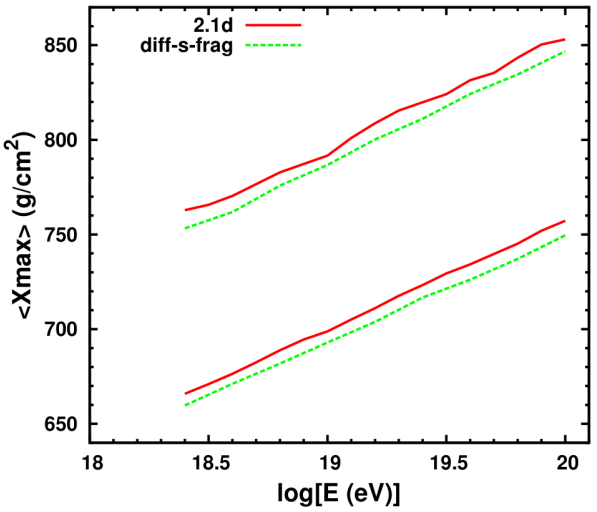


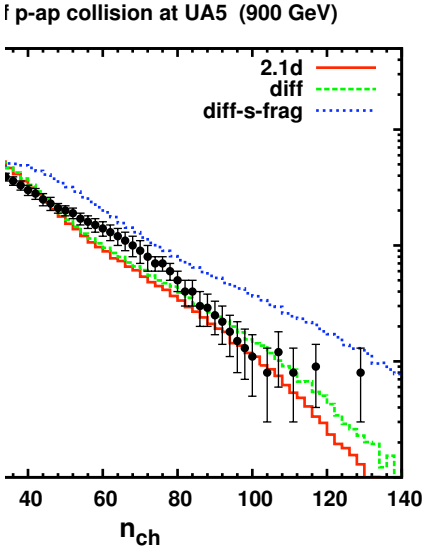
Improvement

- smoother transition to diffraction;









Conclusions

- Hadronic interaction models required to understand observation;
- Models are not rigid, are alright, need improvements;
- Large data accumulation - exciting time for UHECR study.

Conclusions

- Hadronic interaction models required to understand observation;
- Models are not rigid, are alright, need improvements;
- Large data accumulation - exciting time for UHECR study.

(Energy version of the "distance ladder" for interaction & cascade)

- direct detection (AMS, ATIC, BESS, CREAM, TRACER ...)
- low E indirection detection (ARGO-YBJ, MILAGRO (?), HAWC (?) ...)
- fixed target, collider (SPS, Tevatron, NA49, HARP ...)
- mid E indirect detection (IceTop-IceCube, Tibet, KASCADE, KASCADE-Grande, Auger ...)
- mid E collider (LHC)
- high E indirection detection (TA, Auger S & N, JEM/EUSO)