宇宙線と0度測定
Cosmic rays and 0-degree measurements

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“WS for zero-deg ”

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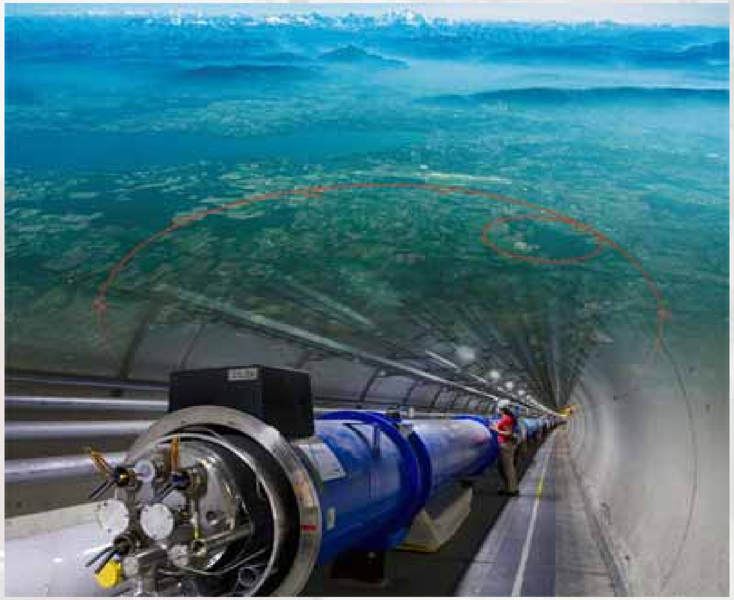
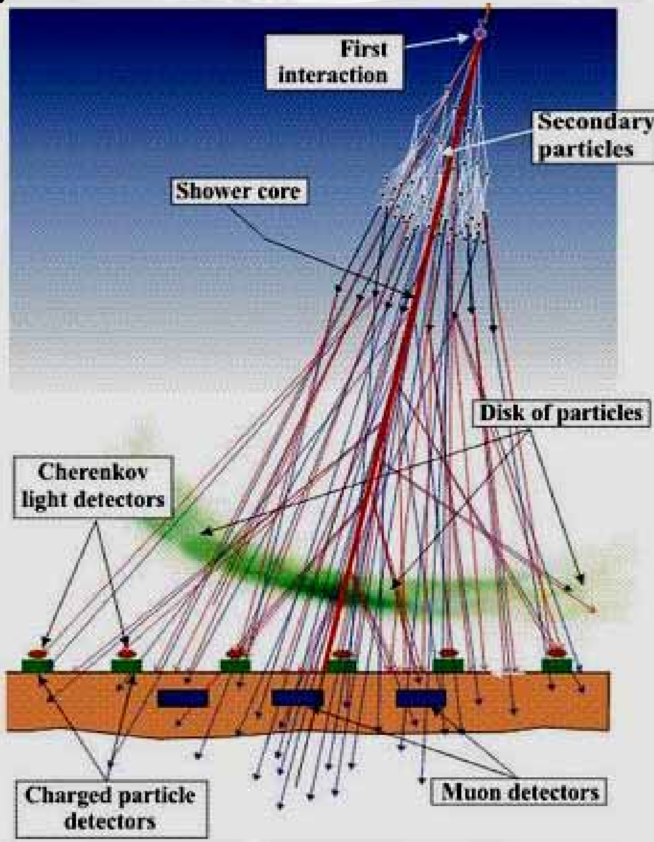
STEL

Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

Hadron interactions at ultra high energy
Accelerator ⇔ Cosmic rays





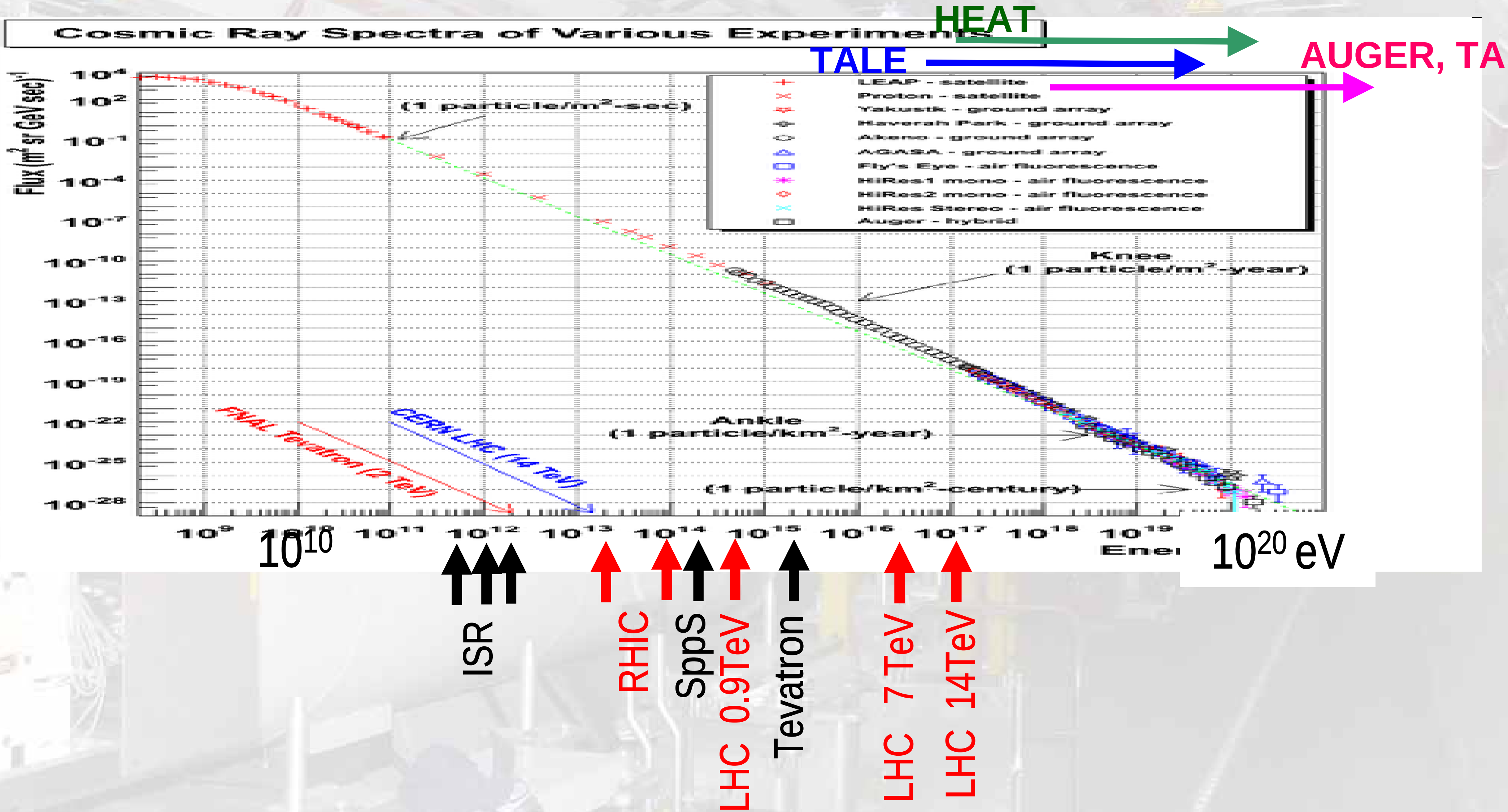
→ Precision improvement

← Hint for interactions at ultra-ultra high energy

$$E_{CM} \sim (2 \times E_{lab} \times M_p)^{1/2}$$

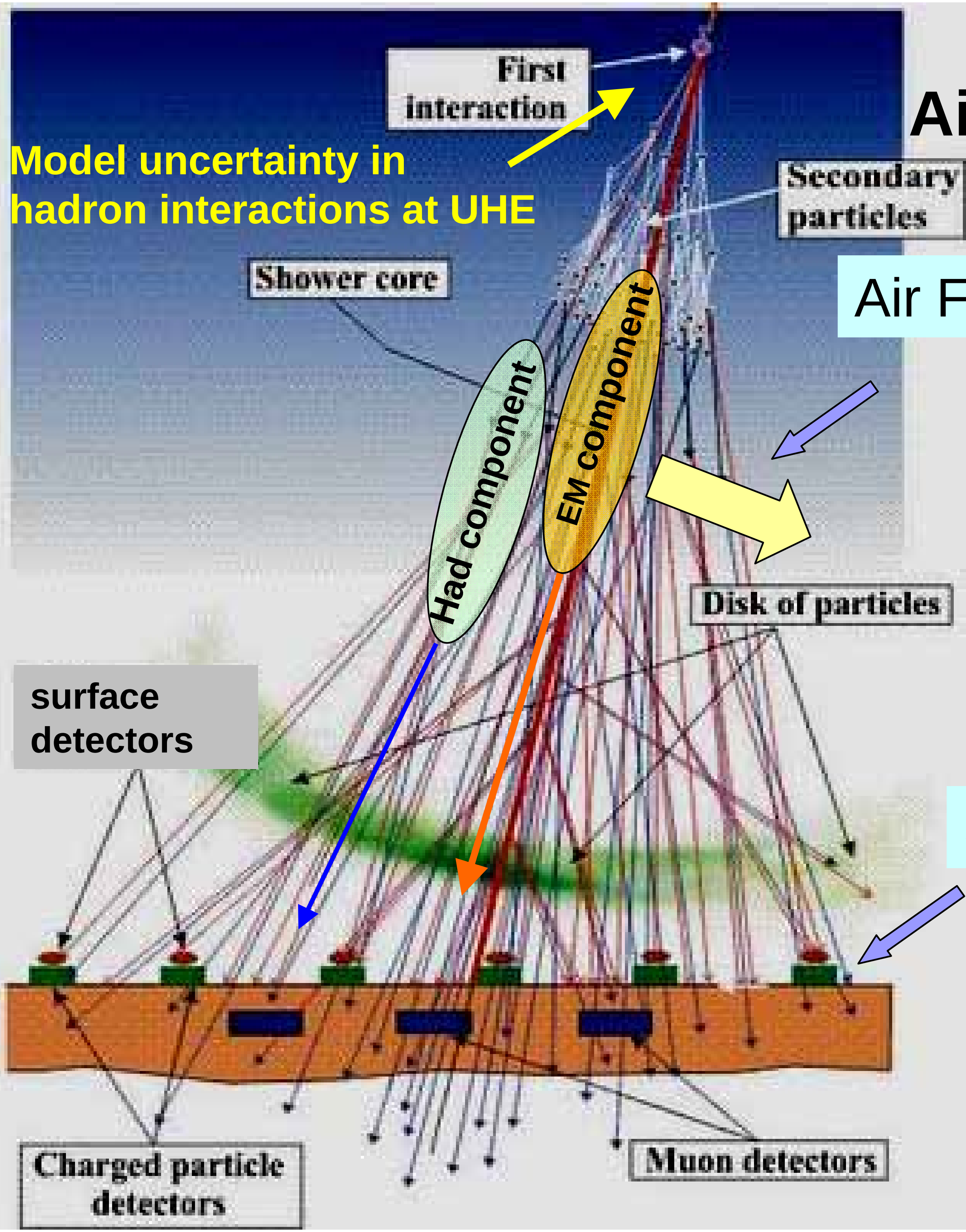
$\sqrt{s}$=14TeV collision at LHC
→10^{17}eV cosmic rays

Cosmic ray spectrum & historical colliders



>40 yrs legacy of wisdom for interactions available !

Air shower observation



Air Florescence telescope (FD)

EM component
(most of energy)

Scintillation lights
Shower directions
Shower max altitude

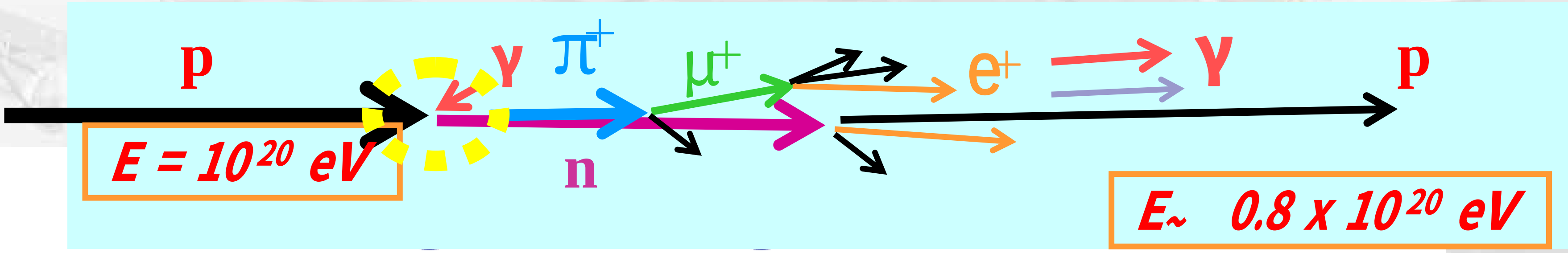
✓ Robust against interaction model.
✓ Detector systematics

Surface Detectors (SD)

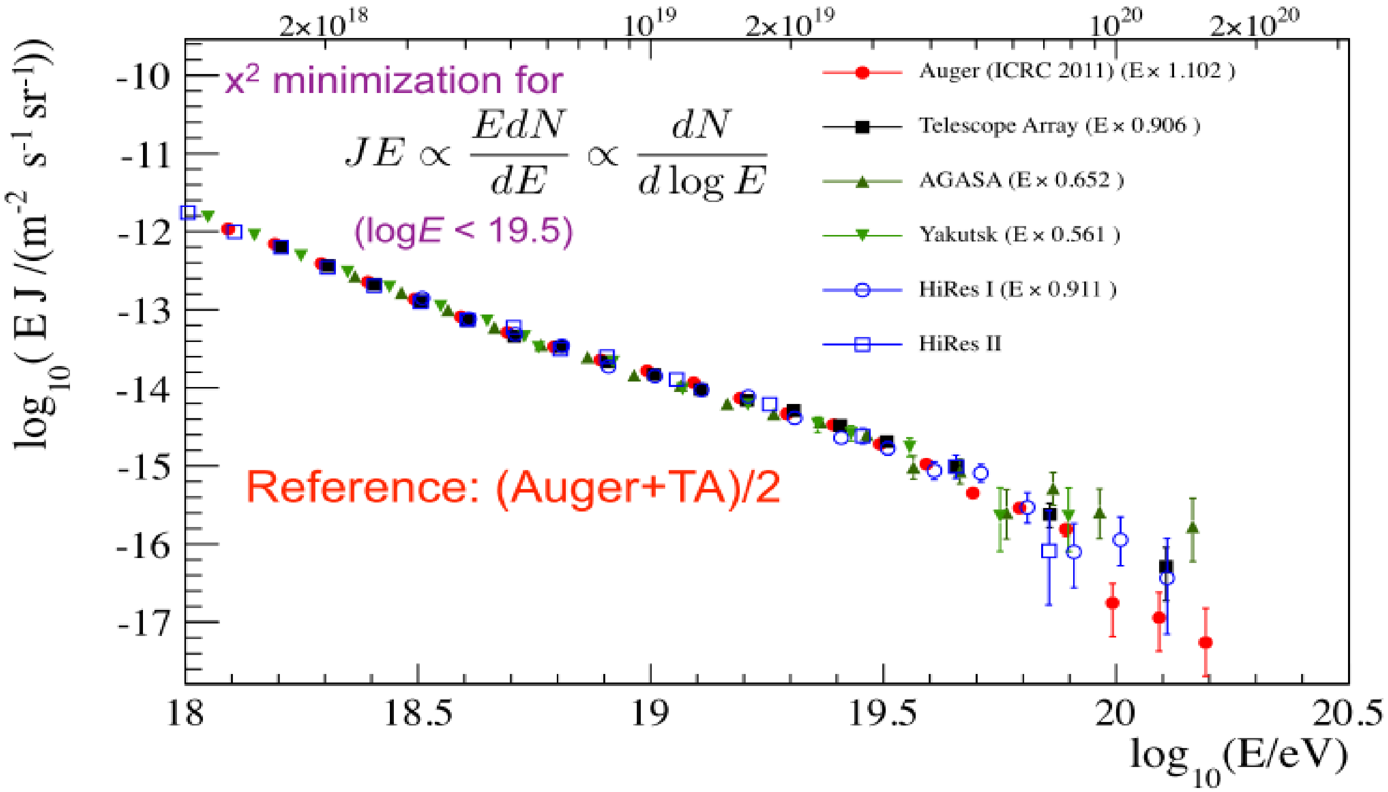
Number of particles
Arrival timing
Muon or EM component
(at given altitude)

✓ interaction model dependence.

The highest energy CR; GZK cut off



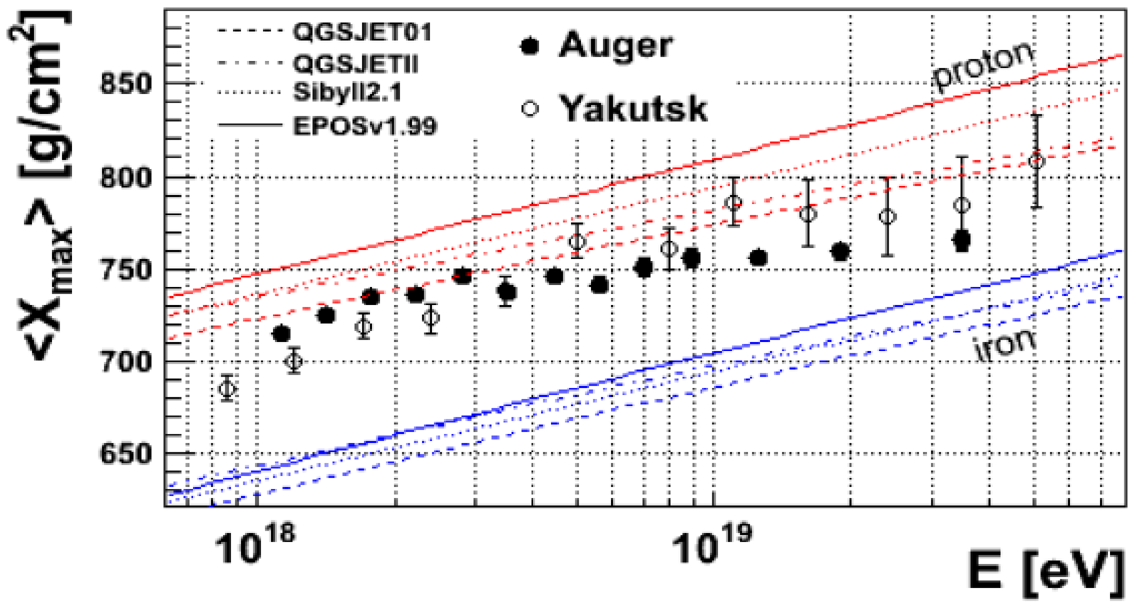
GZK cut off

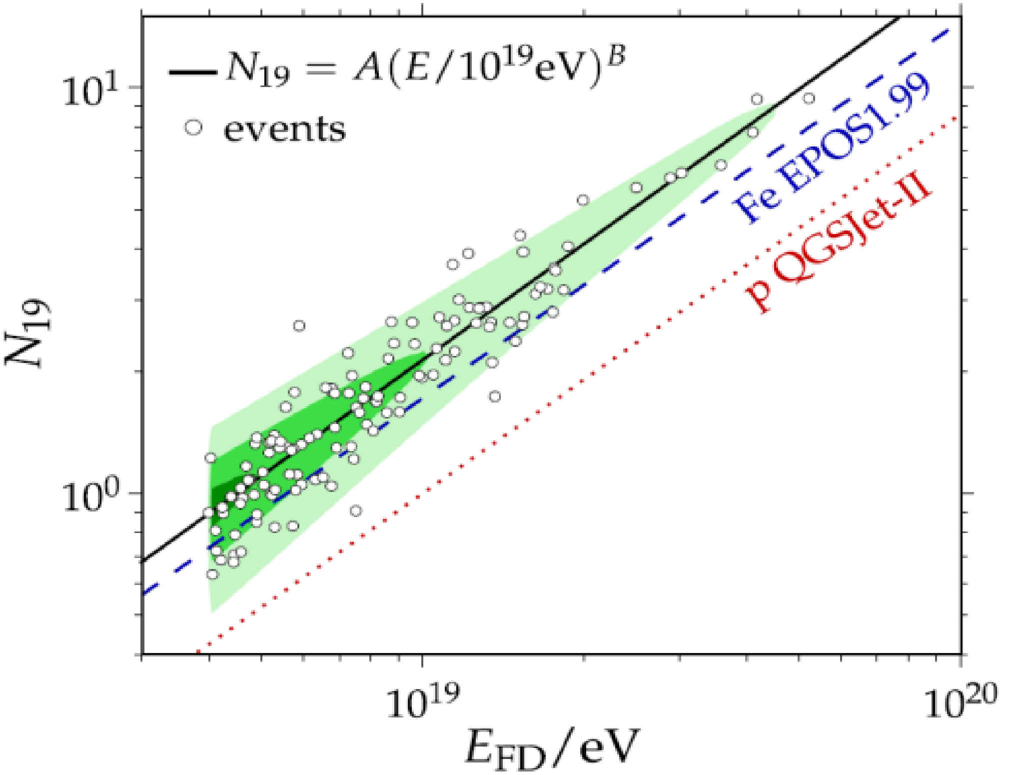


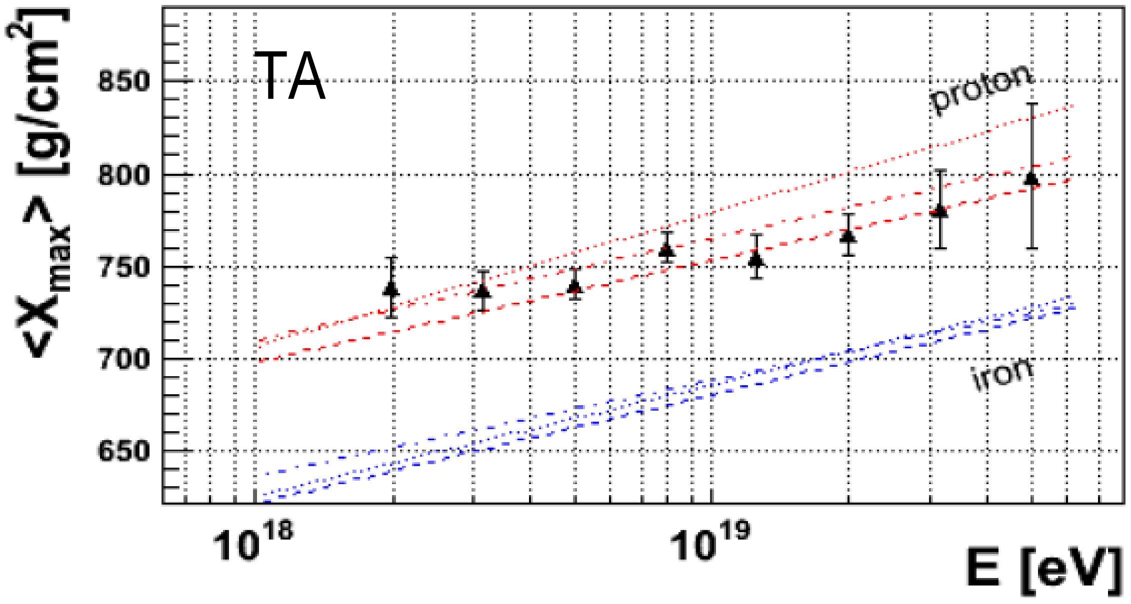
Tunesada, UHECR2012

	Auger	TA	HiRes	AGASA	Yakutsk
$\log_{10} \alpha$ Relative to (Auger+TA)/2	-0.042 (0.003)	+0.042 (0.003)	+0.041 (0.005)	+0.19 ( )	+0.26 (0.004)

Composition / μ excess problems

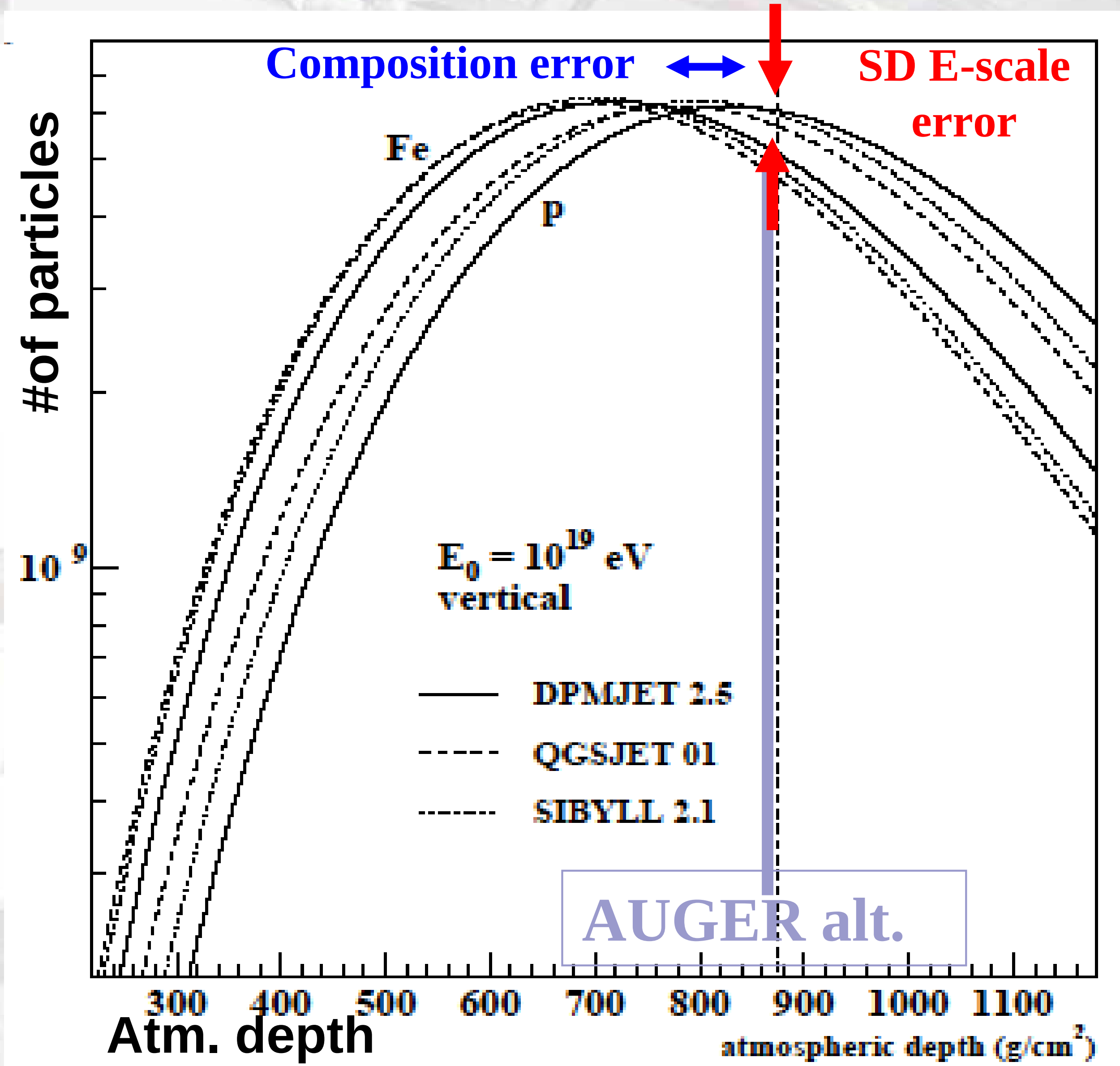




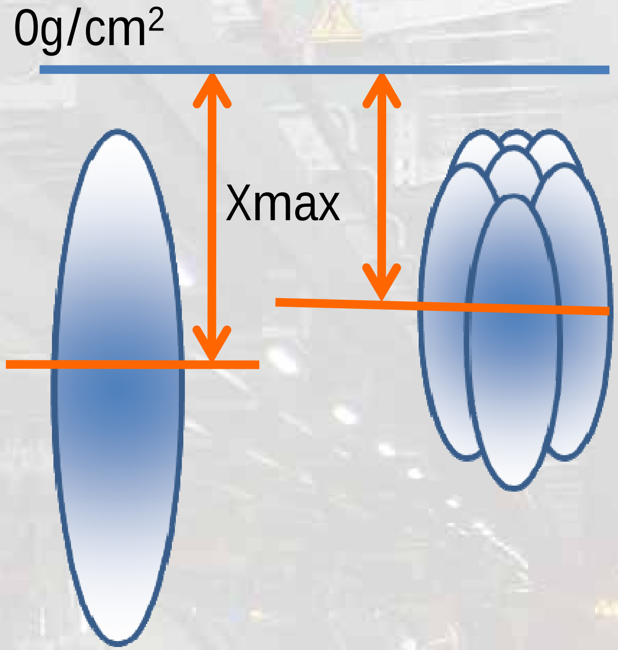


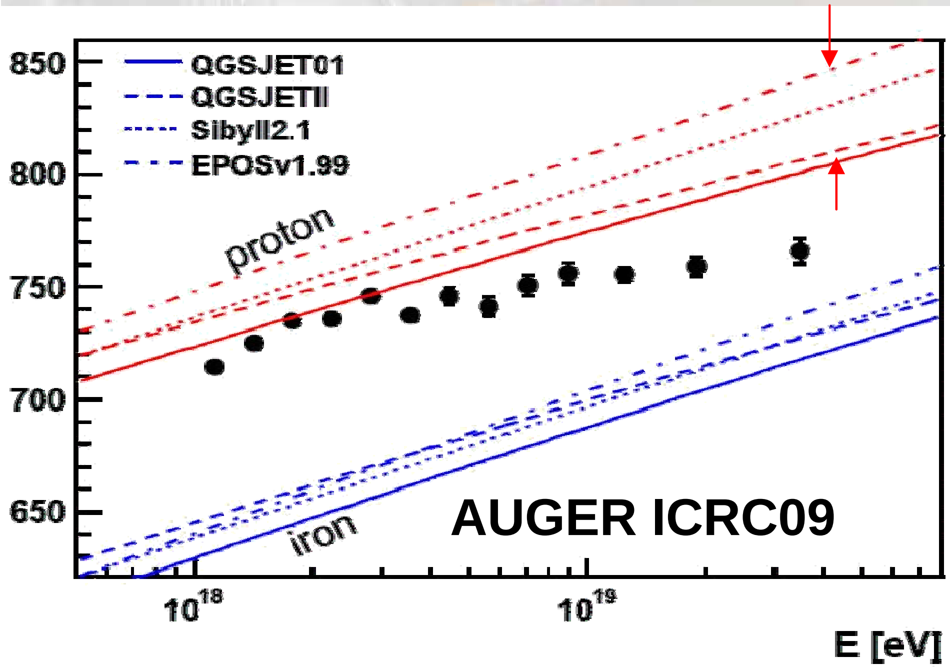
μ excess anomaly ?

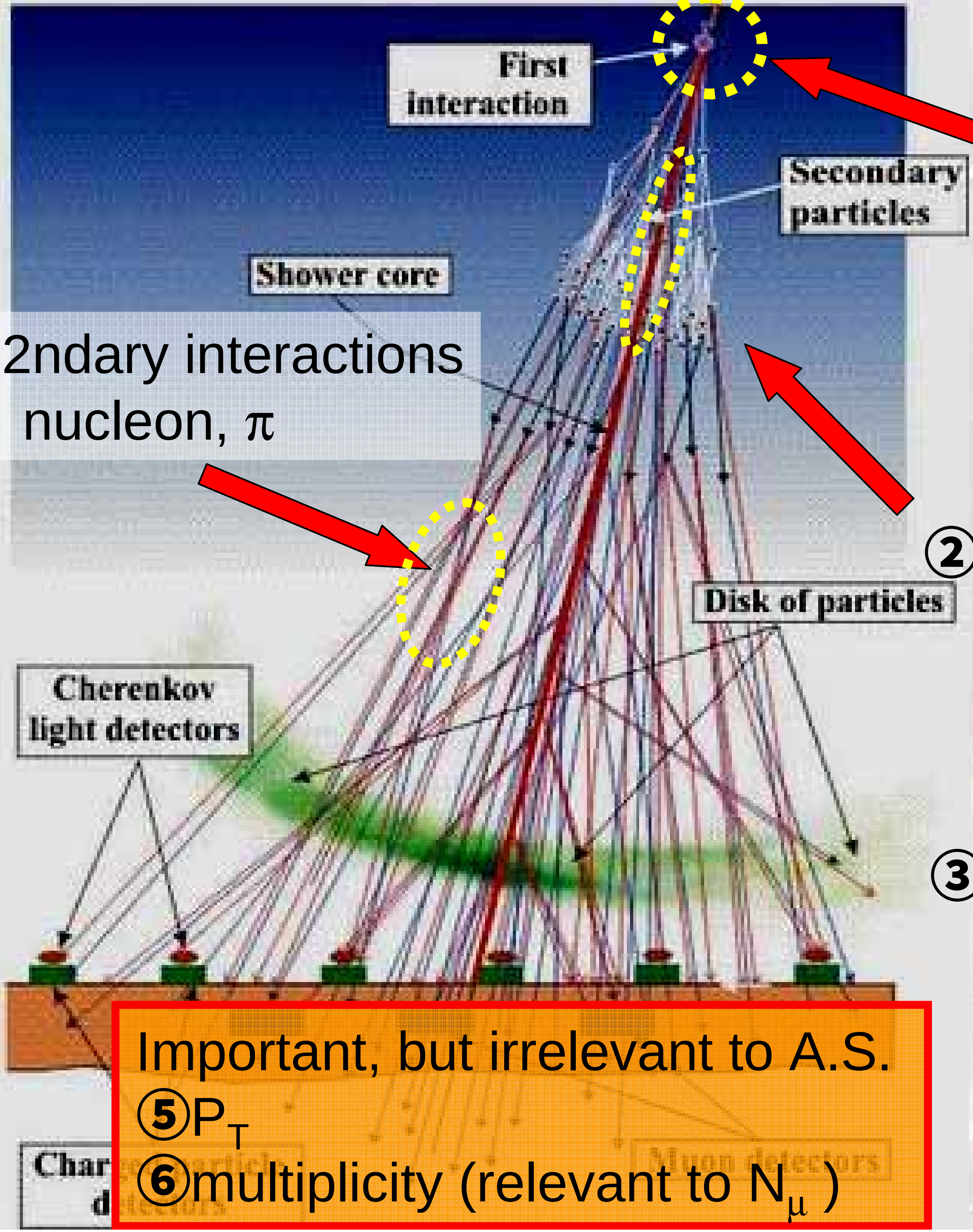
Impact of shower development uncertainty on E-scale/composition



J.Knapp Astropart. Phys.19 (2003) 77







④ 2ndary interactions
nucleon, π

① Inelastic cross section

If large σ
rapid development
If small σ
deep penetrating

② <u>Forward energy spectrum</u>

If softer
shallow development
If harder
deep penetrating

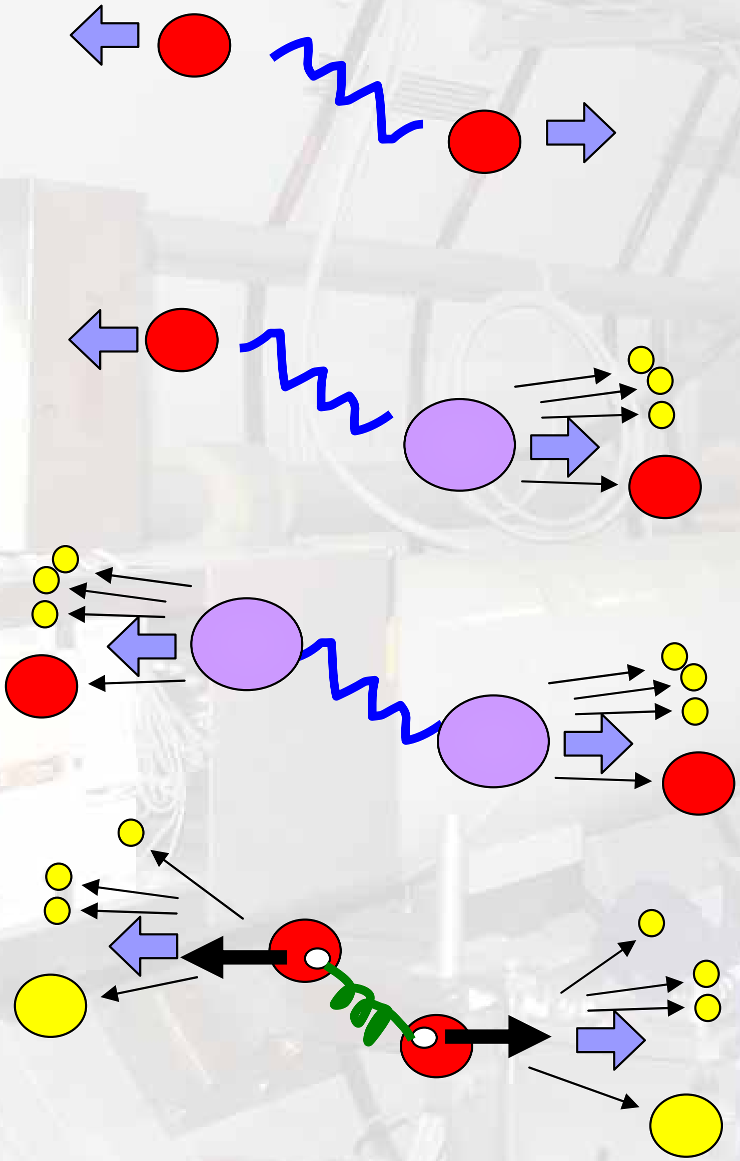
③ Inelasticity $k = 1 - p_{lead}/p_{beam}$

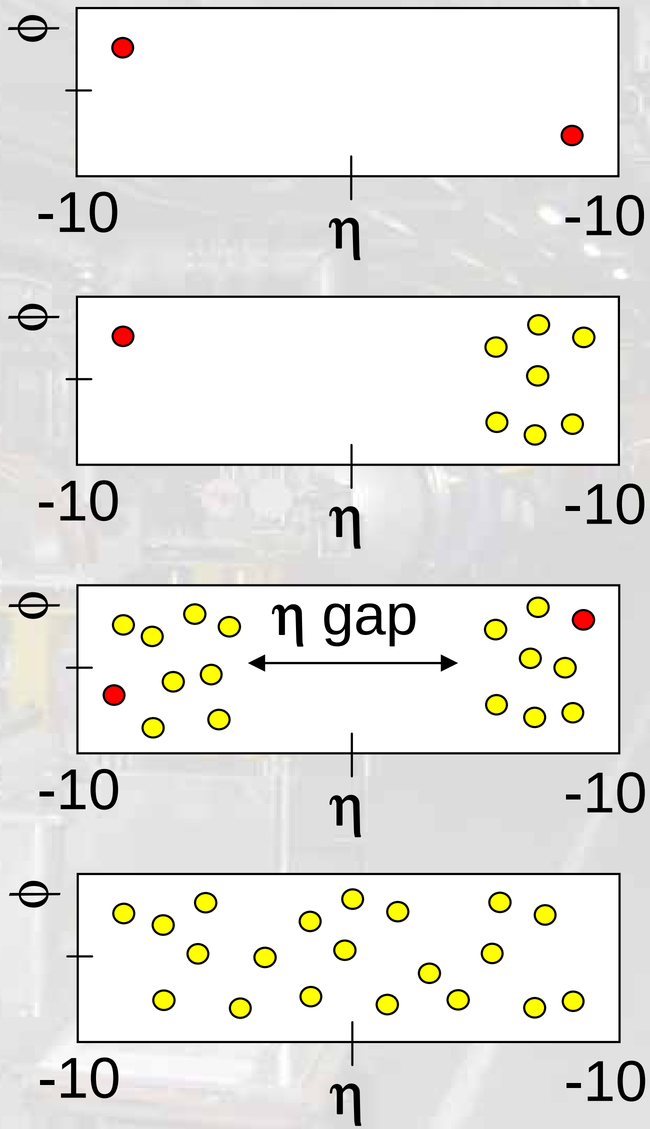
If large k
rapid development
If small k
deep penetrating

Important, but irrelevant to A.S.
⑤ P_T
⑥ multiplicity (relevant to N_μ)

pseudorapidity and interactions

σ @7TeV

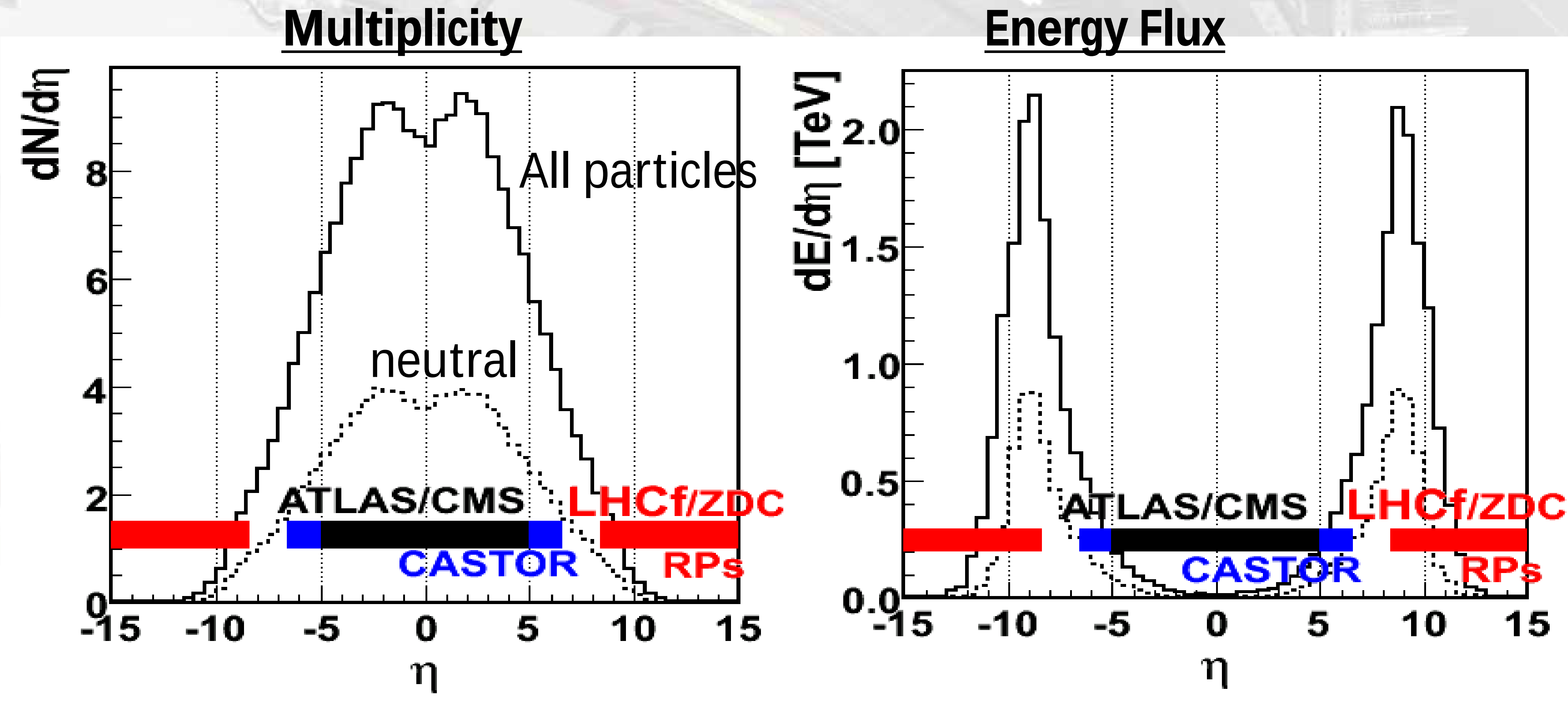




	σ @7TeV
Elastic	~25mb
Single diffractive	~10mb
Double diffractive	~10mb
Non-diffractive	~50mb

The seven LHC experiments

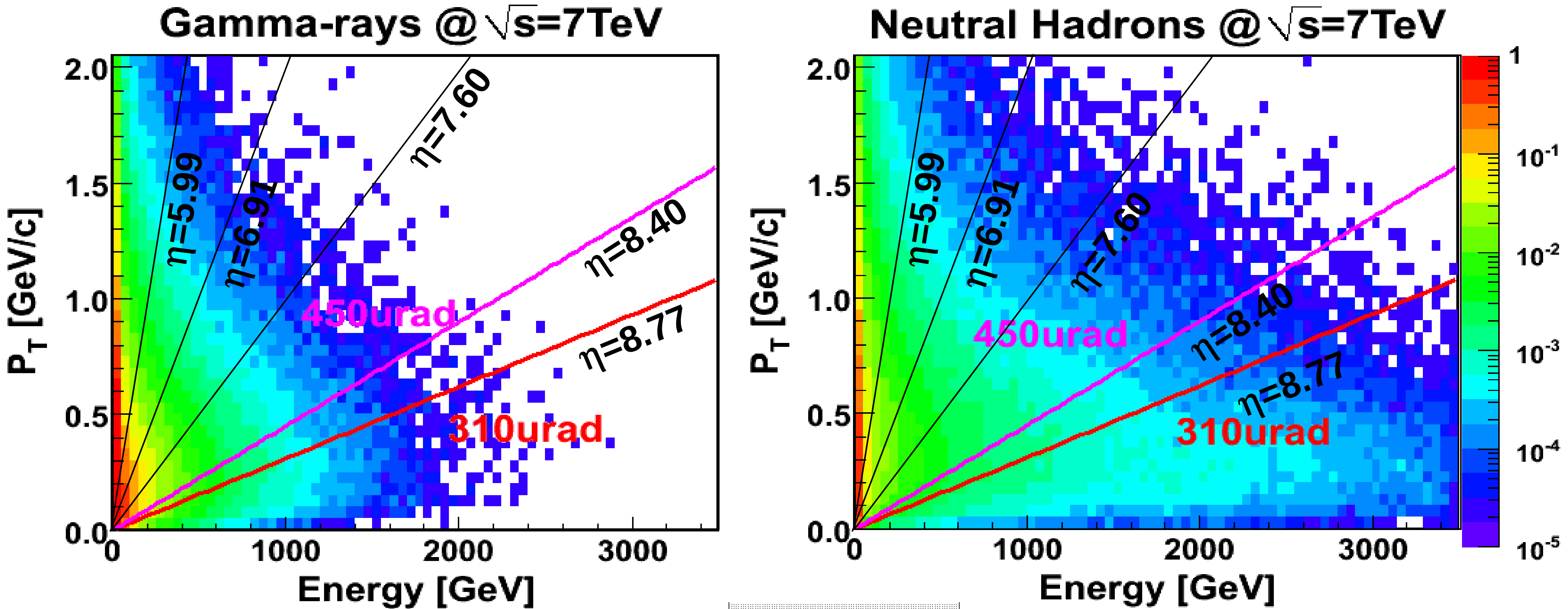
Very forward : Majority of energy flow ($\sqrt{s}$=14TeV)

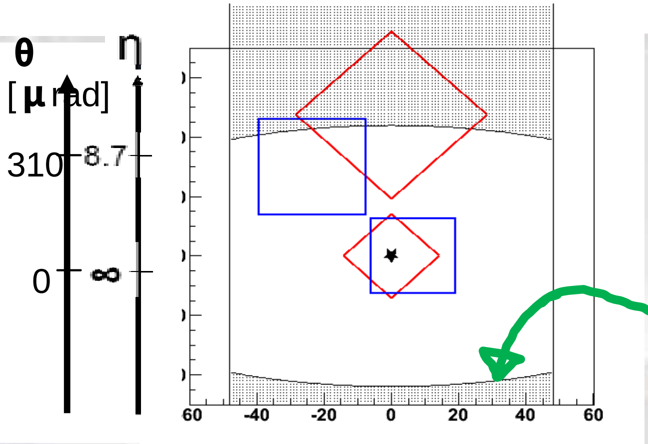


Most of the energy flows into very forward

(Particles of X_F > 0.1 contribute 50% of shower particles)

Rapidity vs Forward energy spectra

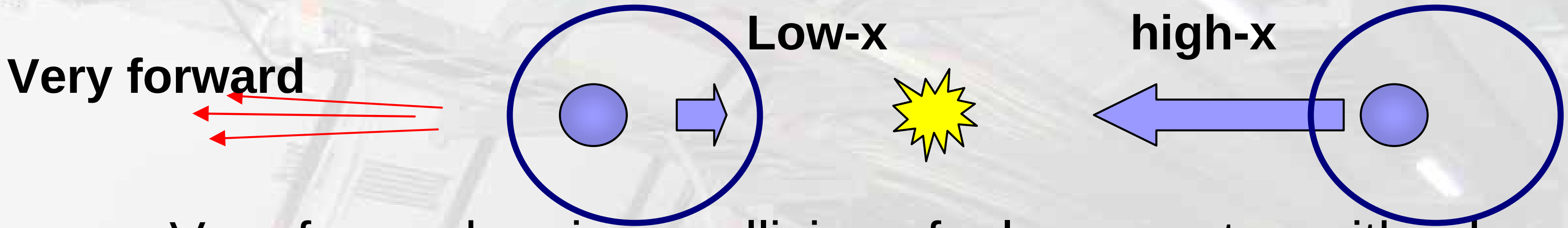




Viewed from IP1 (red:Arm1, blue:Arm2)

Projected edge of beam pipe

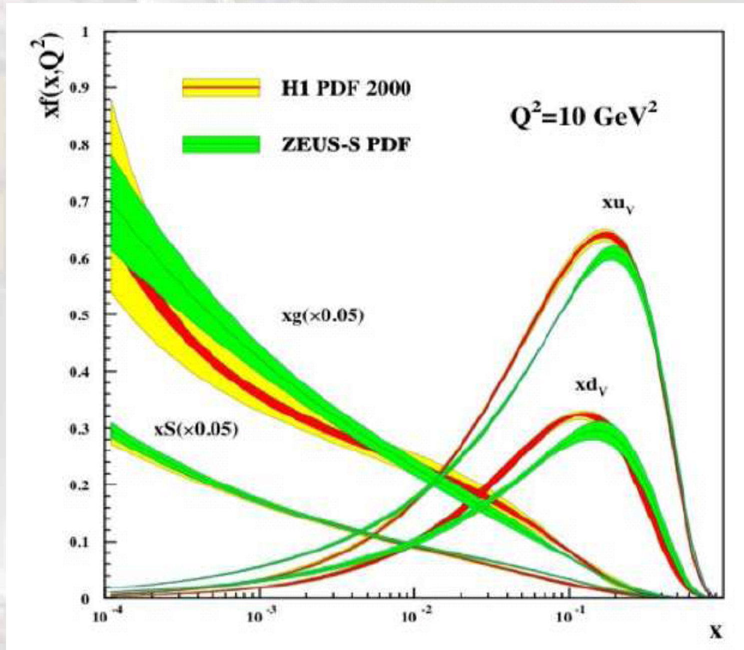
Very forward – connection to low-x physics



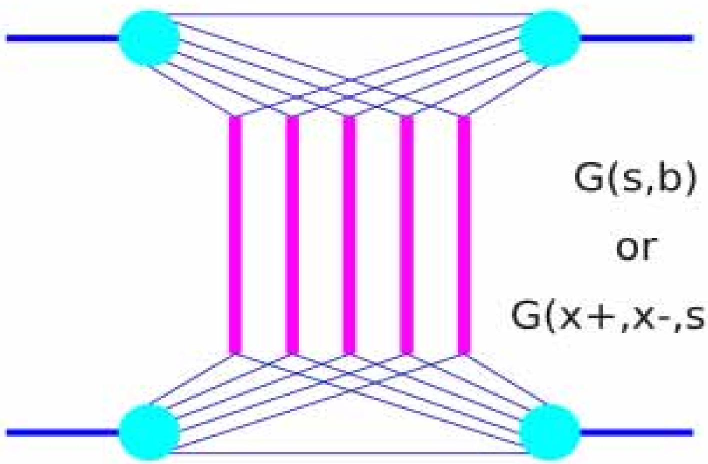
- Very forward region : collision of a low-x parton with a large-x parton
- Small-x gluon become dominating in higher energy collision by self interaction.
- But they may be saturated (Color Glass Condenstation)

Naively CGC-like suppression may occur in very forward at high energy

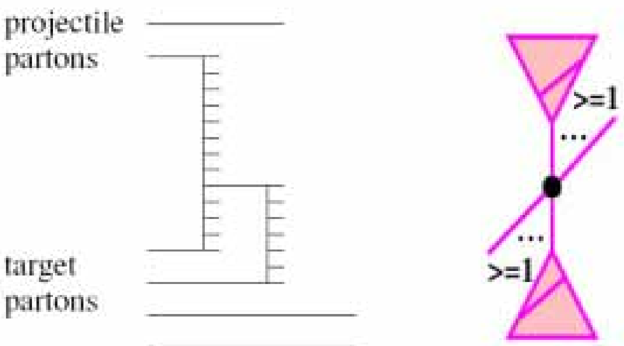
→ **However situation is more complex**
(not simple hard parton collsions,
but including soft + semi-hard)



Differences between Models



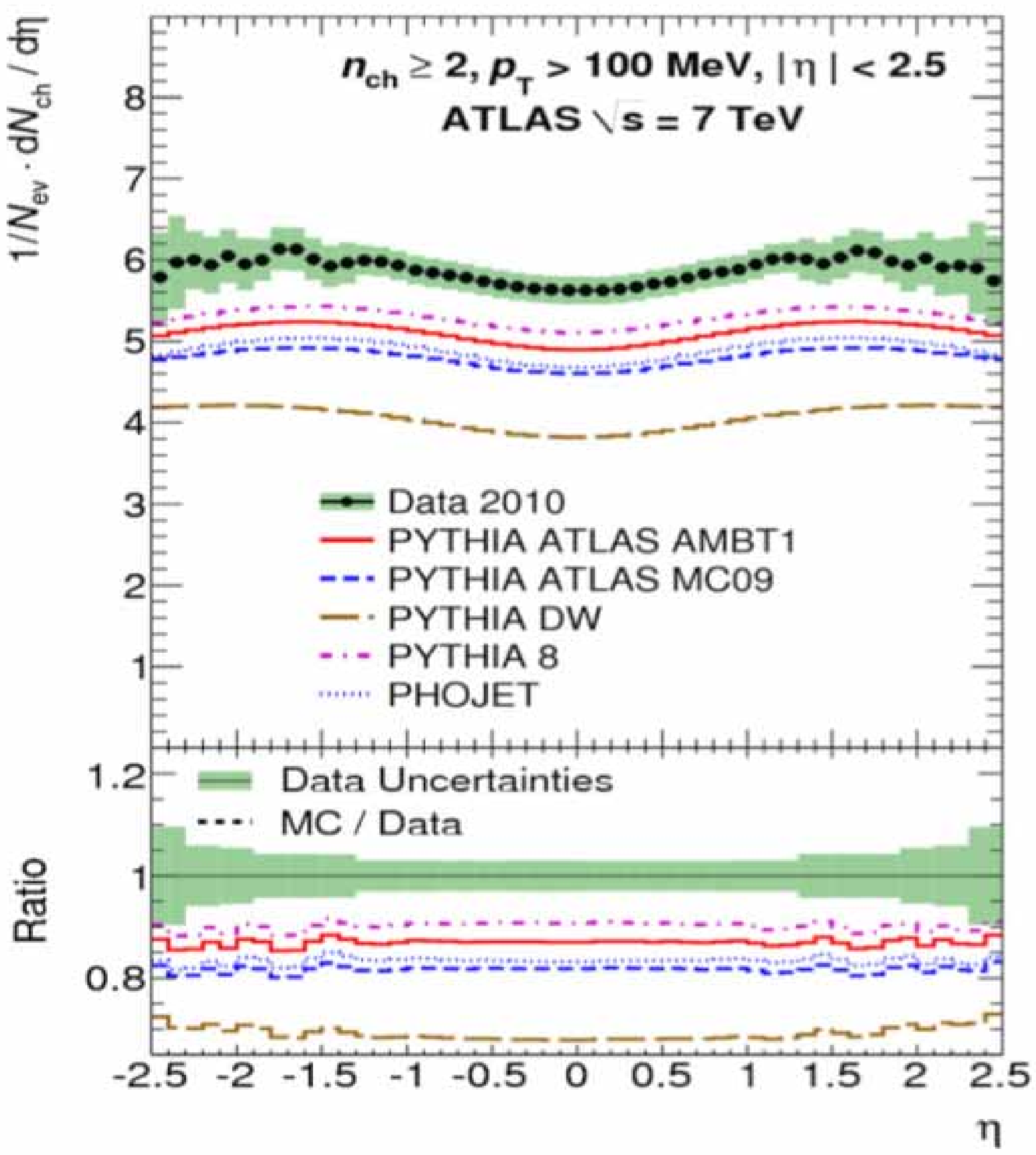
EPOS QGSJET II

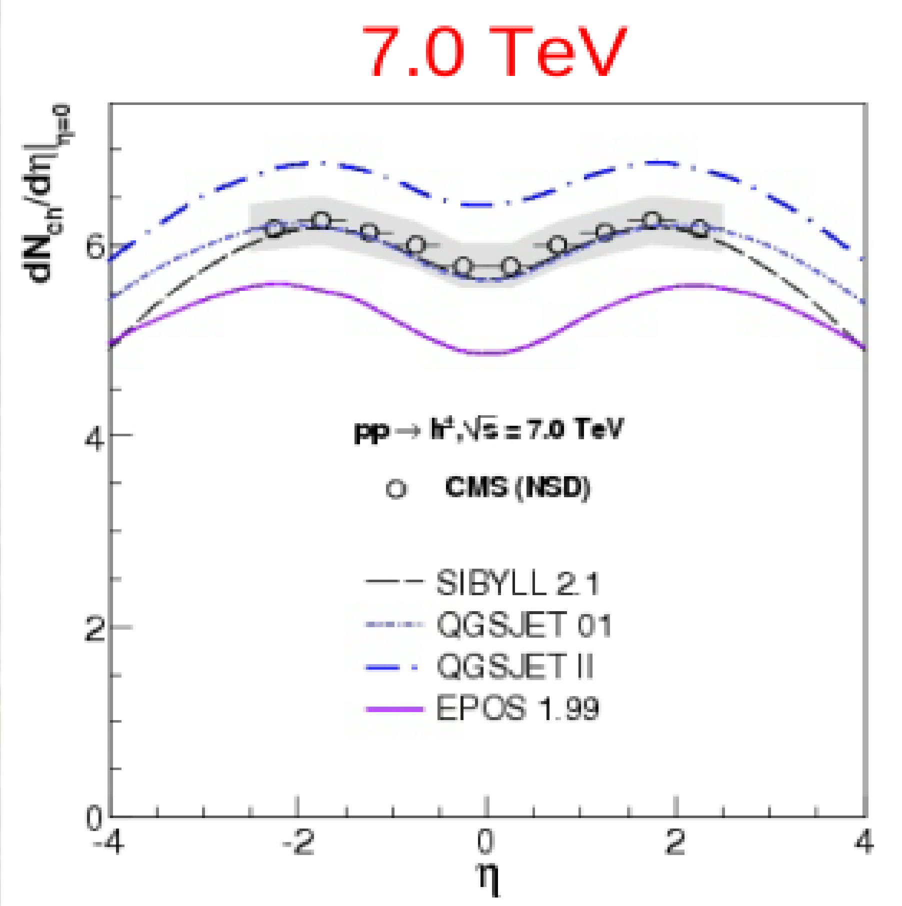


- **Gribov-Regge and optical theorem**
  - Basis of all models (multiple scattering) but
    - Classical approach for QGSJET and SIBYLL (no energy conservation for cross section calculation)
    - Parton based Gribov-Regge theory for EPOS (energy conservation at amplitude level)
- **pQCD**
  - Minijets with cutoff in SIBYLL
  - Same semi-hard Pomeron (DGLAP convoluted with soft part : not cutoff) in QGS and EPOS but
    - No enhanced diagram in Q01 (old PDF)
    - Generalized enhanced diagram in QII
    - Simplified non linear effect in EPOS
      - Phenomenological approach

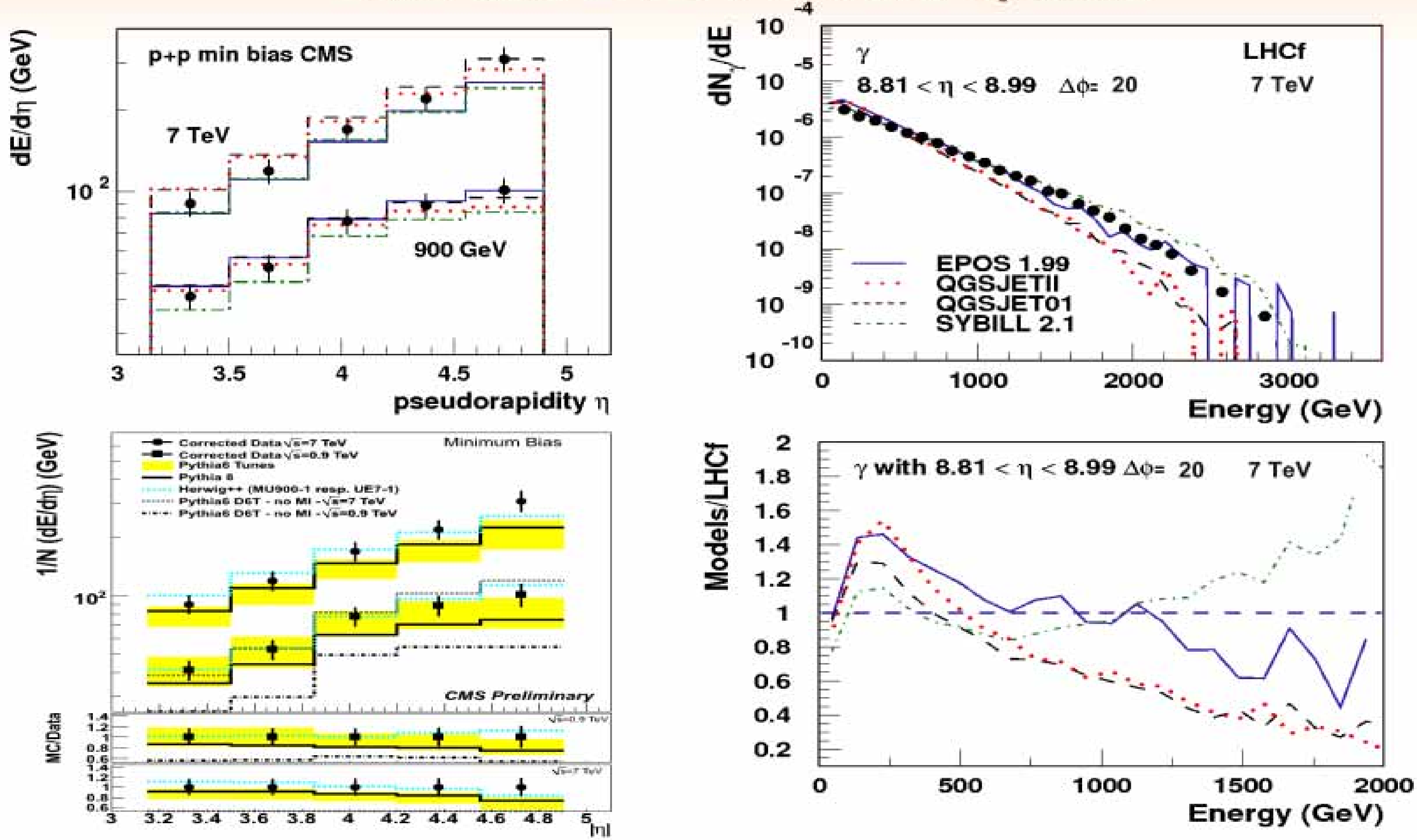
And SYBILL

LHC data vs PYTHIA/CR int. model



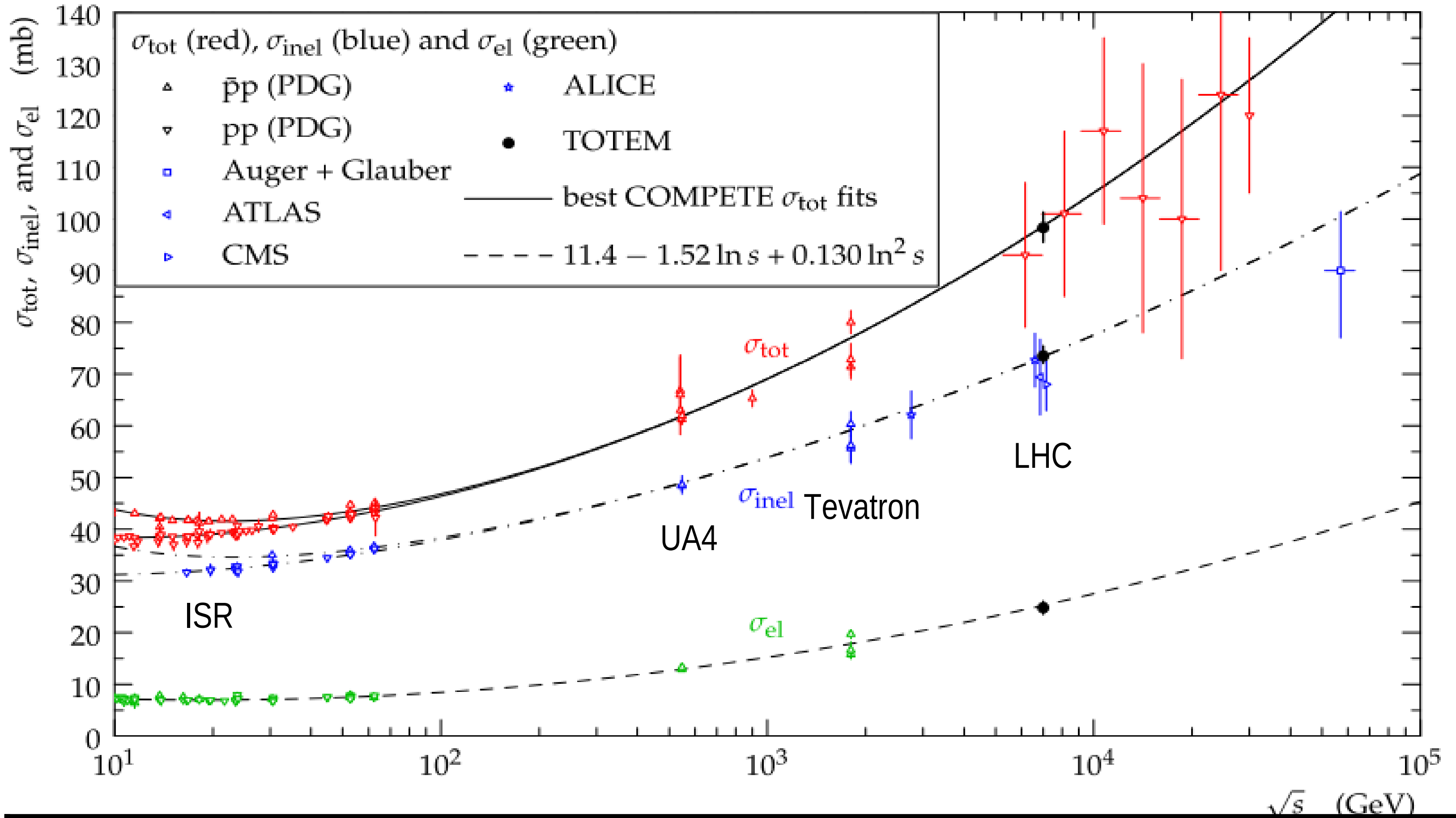


CMS and LHCf Forward Spectra



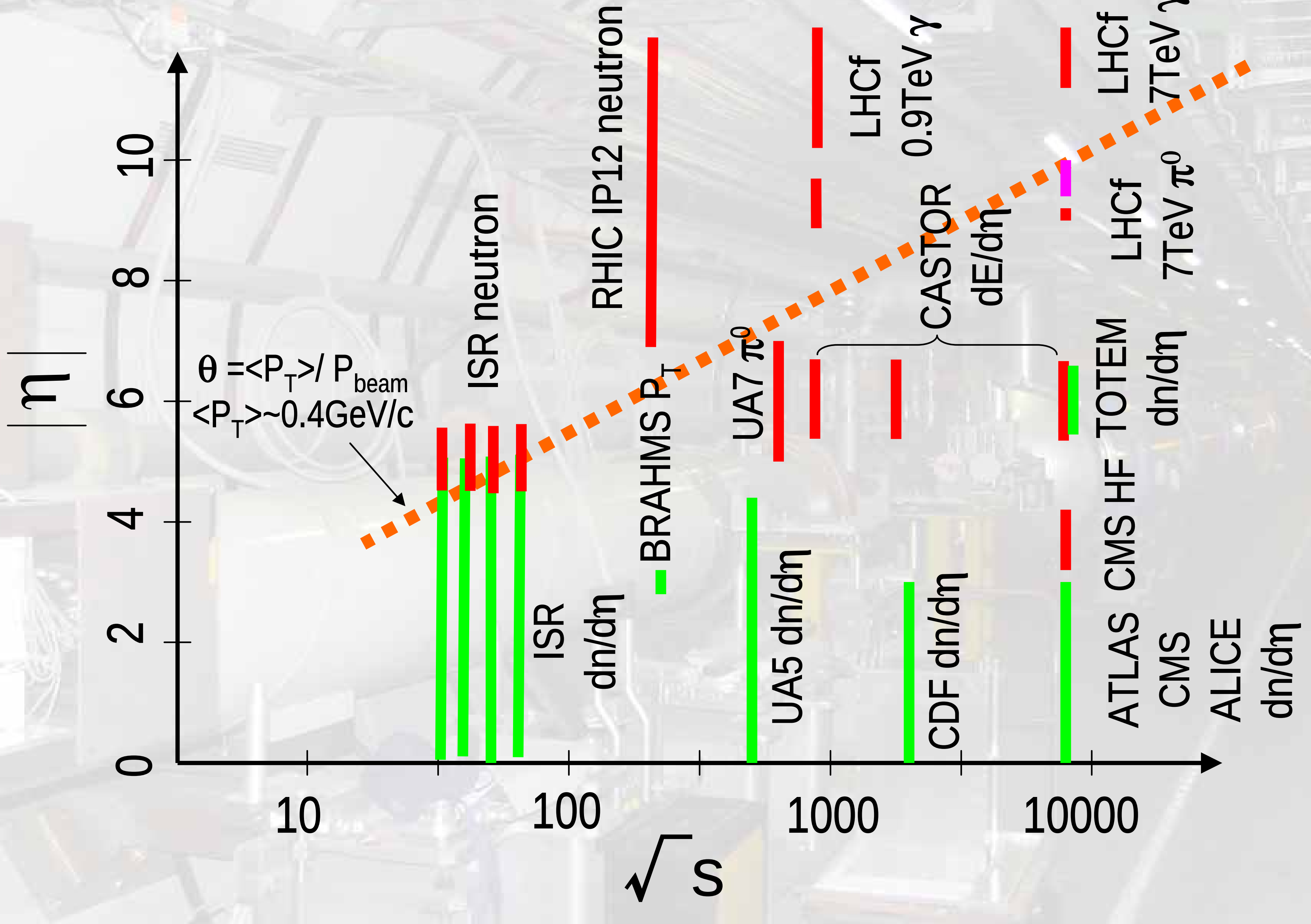
- Forward calorimeter → **better than HEP models**

σ_{inel} result @ 7TeV



TOTEM	73.5+-0.6+1.8-1.3 mb	dσ/dt(t=0)
ATLAS	69.4+-2.4+-6,9 mb	MBTS sample
CMS	68.0+-2.0+-2.4+-4 mb	Ntrk sample
ALICE	72.7+-1.1+-5.1 mb	VZERO sample

Summary : forward spectra coverage



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