Air Shower Development, Pion Interactions and Modified EPOS Model

Tanguy Pierog

Karlsruhe Institute of Technology, Institut für KernPhysik, Karlsruhe, Germany

K. Werner, B. Guiot, Subatech, Nantes, France

34th ICRC, The Hague, The Netherlands

July the 30th 2015

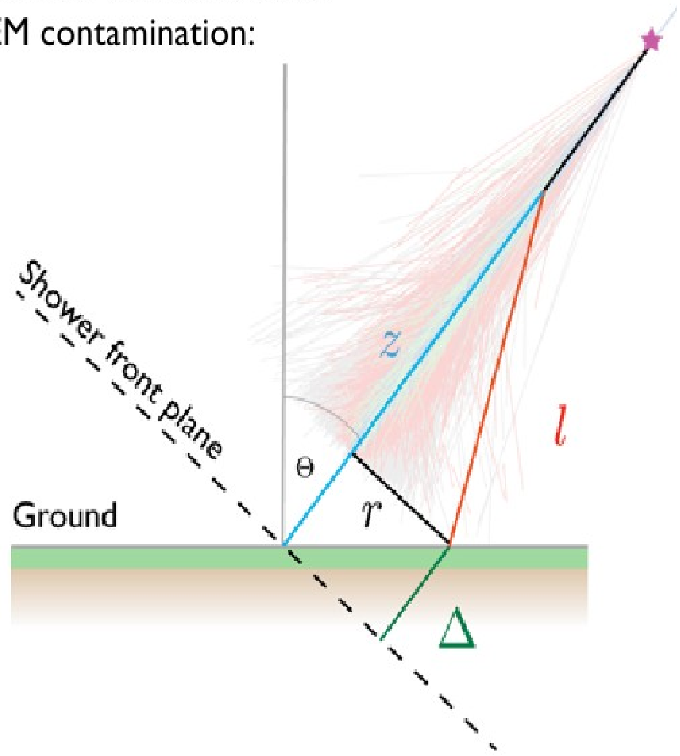
Outline

- Muon Production Depth (MPD) and EPOS
- Sensitivity to pion diffraction
- Results

Muon Production Depth is a very sensitive measurement to probe hadronic physics in air shower development.

Muon Production Depth measured by PAO

Inclined events to avoid EM contamination:



L. Cazon et al., Astropart.Phys. 36 (2012) 211–223

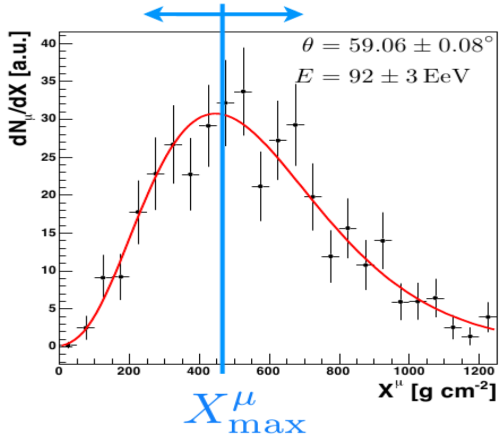
- **Independent surface detector measurement**
  - geometric delay of arriving muons

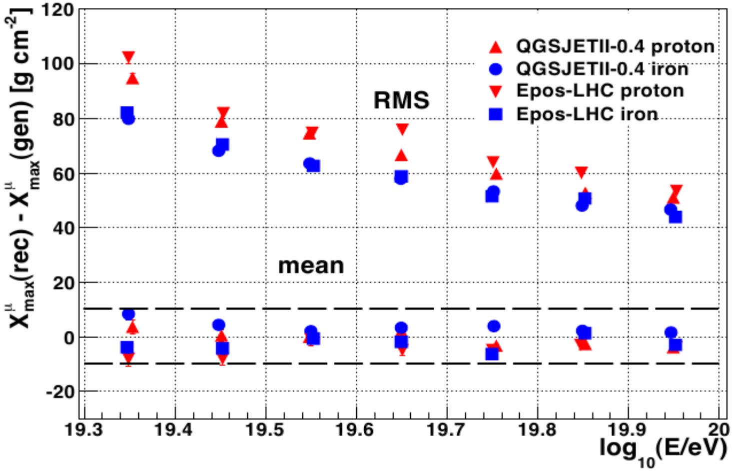
$$c \cdot t_g = l - (z - \Delta) = \sqrt{r^2 + (z-\Delta)^2} - (z - \Delta)$$

  - mapped to muon production distance

$$z = \frac{1}{2}\left(\frac{r^2}{ct_g} - ct_g\right) + \Delta$$

  - decent resolution and no bias

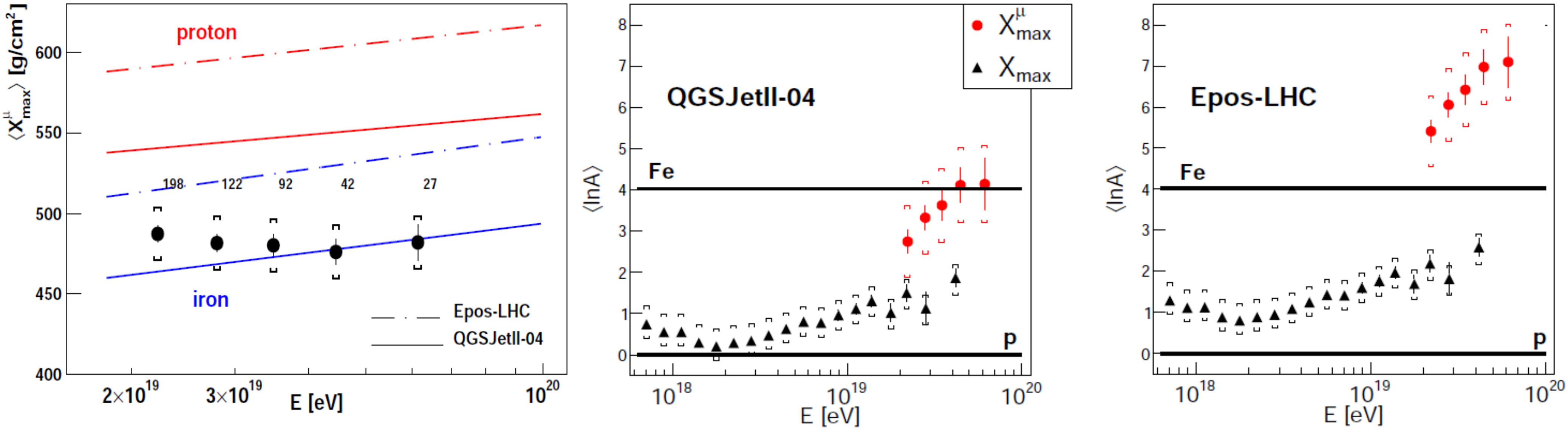




Muon Production Depth and EPOS

- **2 independent mass composition measurements <X_{max}> and <X^{μ}_{max}>**
  - both results should be between p and Fe
  - both results should give the same mean logarithmic mass for the same model
  - problem with EPOS appears after corrections motivated by LHC data

L. Collica's talk Monday CR14

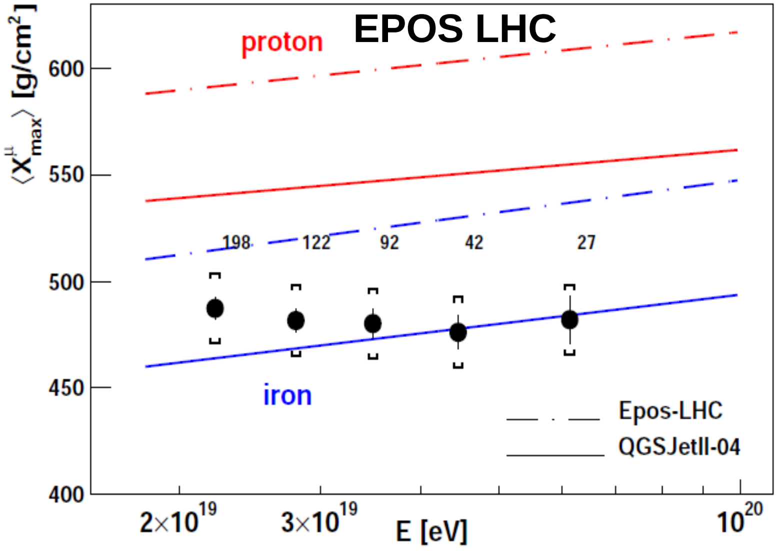


Pierre Auger Collaboration, Phys. Rev. D90 (2014), no. 1 012012, [arXiv:1407.5919]. [Erratum: Phys. Rev.D92,019903(2015)].

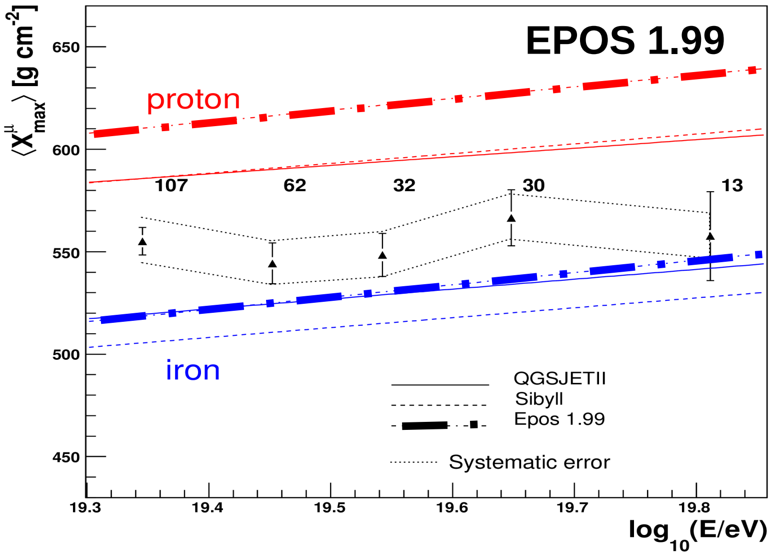
Muon Production Depth and EPOS

- **2 independent mass composition measurements $<X_{max}>$ and $<X^{\mu}_{max}>$**
  - both results should be between p and Fe
  - both results should give the same mean logarithmic mass for the same model
  - problem with EPOS appears after corrections motivated by LHC data

2014



2011

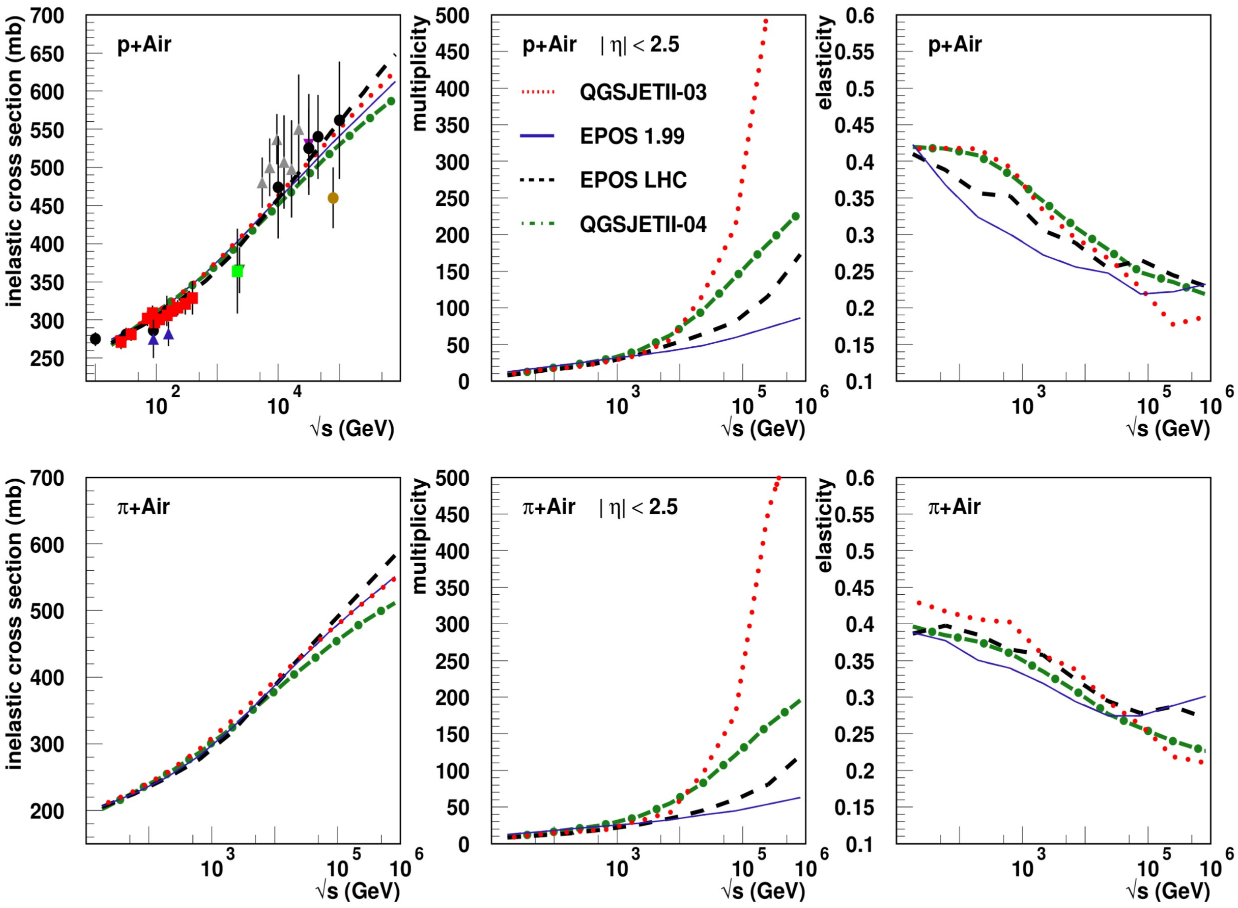


Former EPOS 1.99 compatible with data !

EPOS 1.99 used as reference for the rest of the talk

Pierre Auger Collaboration, Phys. Rev. D90 (2014), no. 1 012012, [arXiv:1407.5919]. [Erratum: Phys. Rev.D92,019903(2015)].

Difference EPOS 1.99/EPOS LHC



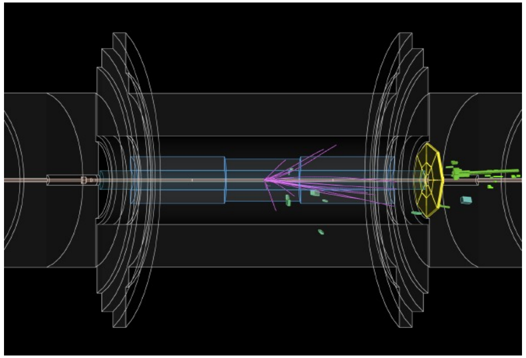
- **EPOS 1.99 to EPOS LHC**
  - tune cross section to TOTEM value
  - ~~change old flow calculation to a more realistic one~~
  - introduce central diffraction and improve rapidity gap distributions
- **Effect on MPD:**
  - shallower MPD
    - larger multiplicity
    - larger cross-section
  - deeper MPD
    - larger elasticity

?

Elasticity should be the source of the difference

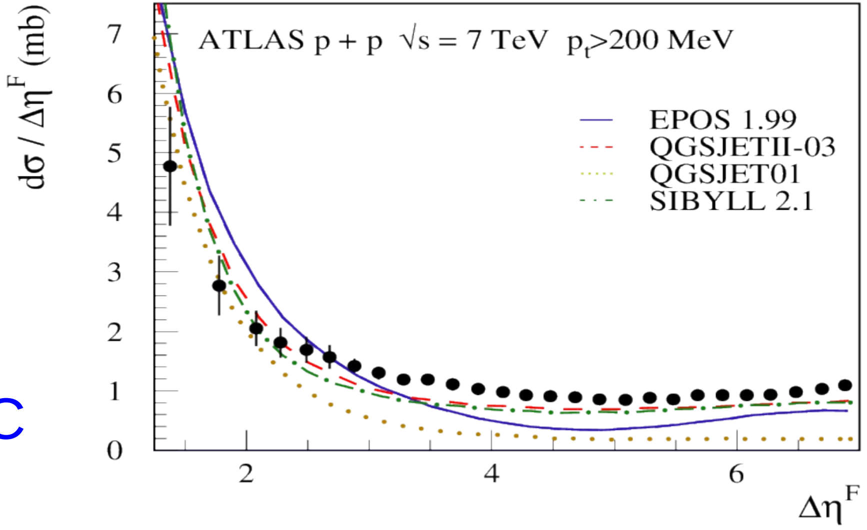
(In)elasticity

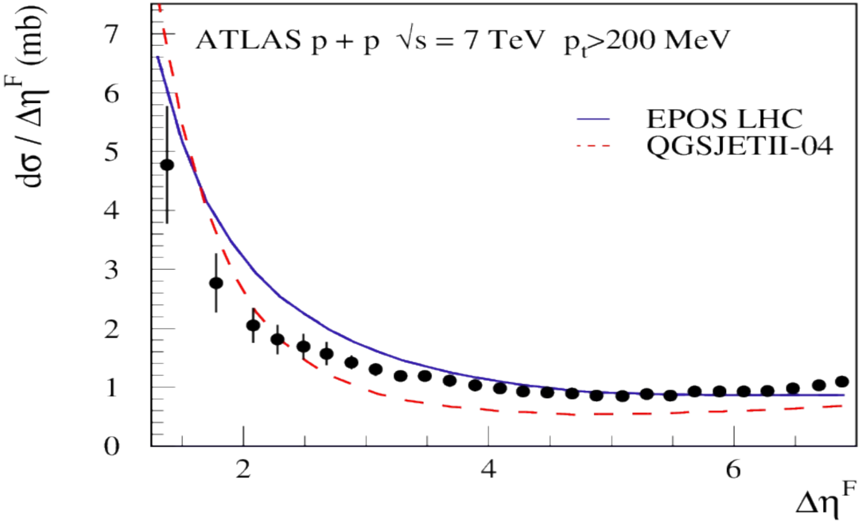
- **Difficult to measure ⇒ large uncertainty**
  - Difference in diffraction
    - low mass / high mass / central diffraction
  - difference for pions/Kaons/nucleons
    - very few data (and at low energy)
  - Rapidity gap : first precise measurement at high energy



ATLAS Collaboration

Pre LHC

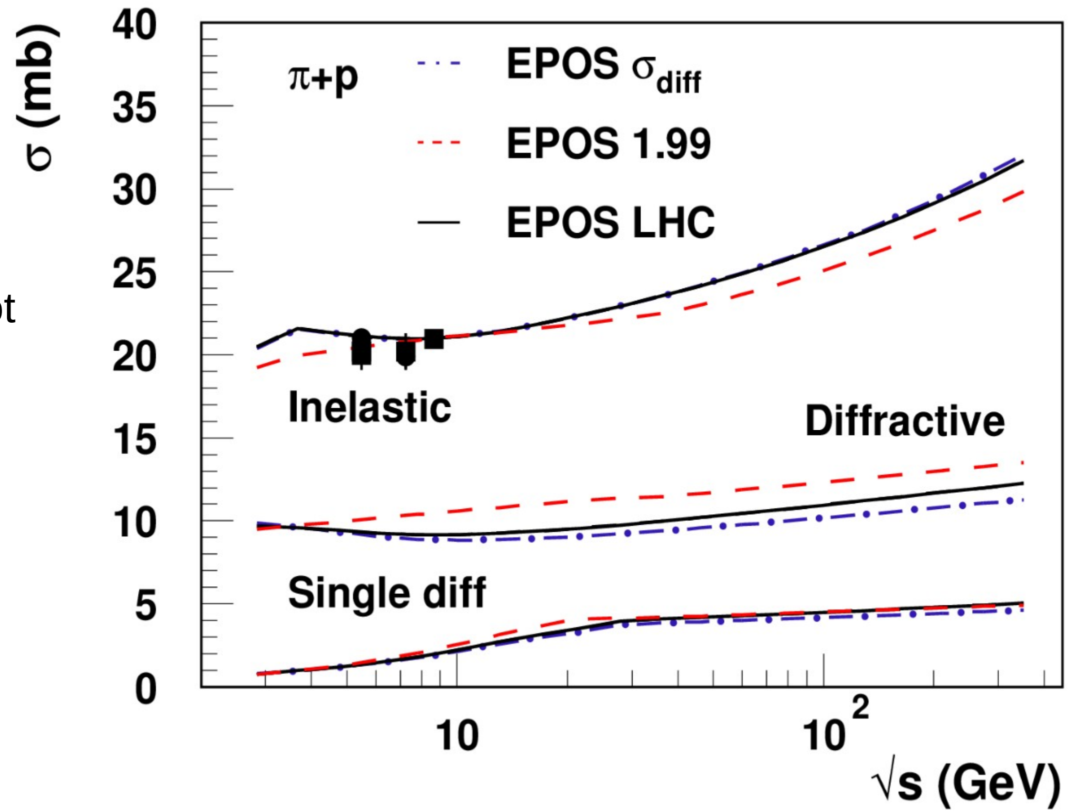




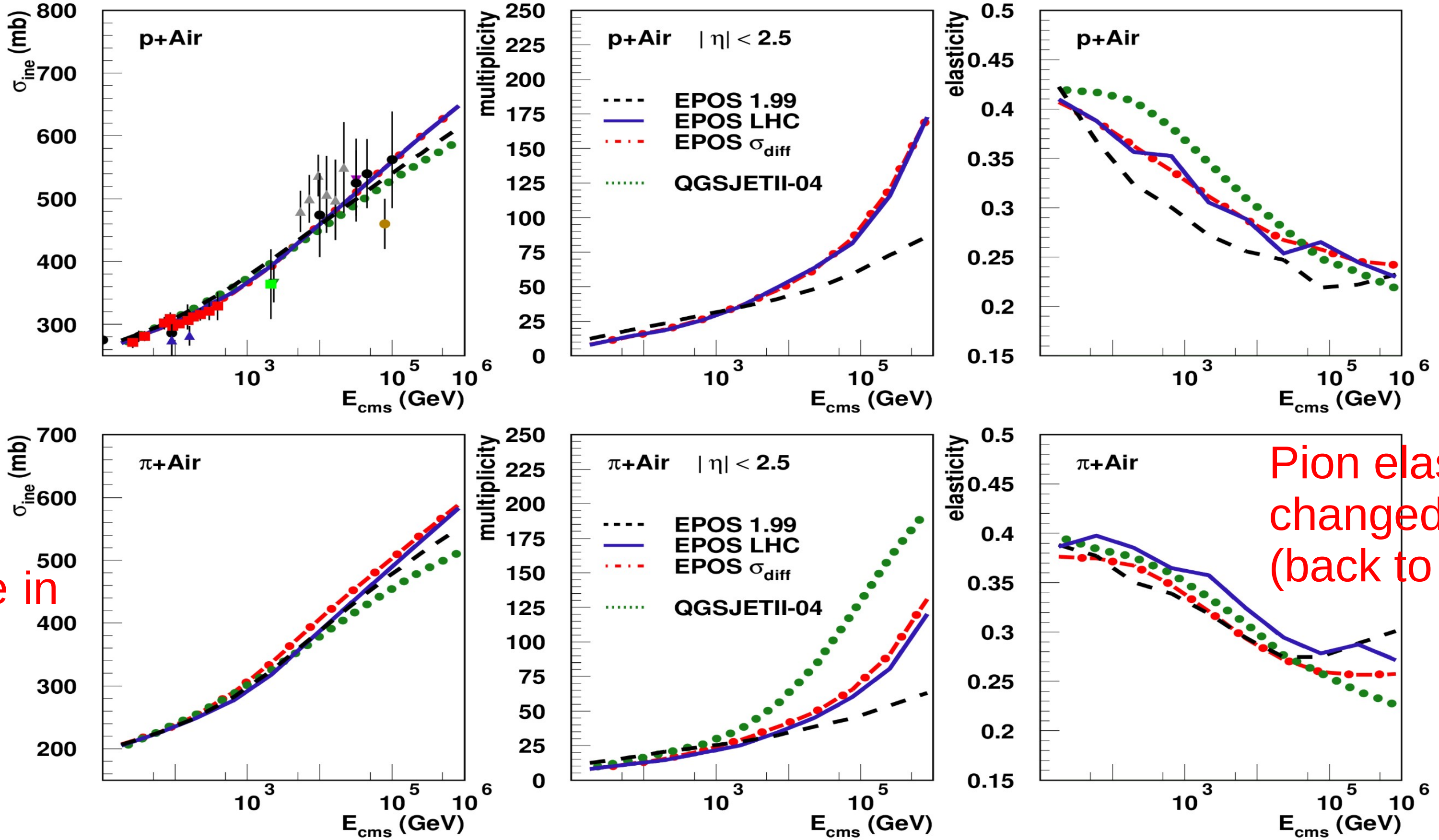
Post LHC

Pion Diffraction and MPD

- **Rapidity gap measurement fixed by LHC**
  - one should not change proton interactions
- **MPD driven by long chain of pion-Air interaction**
  - Modify in EPOS pion diffraction only
  - Change total diffractive cross-section but not inelastic and single diffractive (existing measurements)
  - first check existing pion data to tune parameter to REDUCE pion diffraction
- **new “tune”**
  - EPOS (LHC) σ_{diff} : reduce diffractive cross section (small effect ~ 10%)



Extrapolation to CR interactions

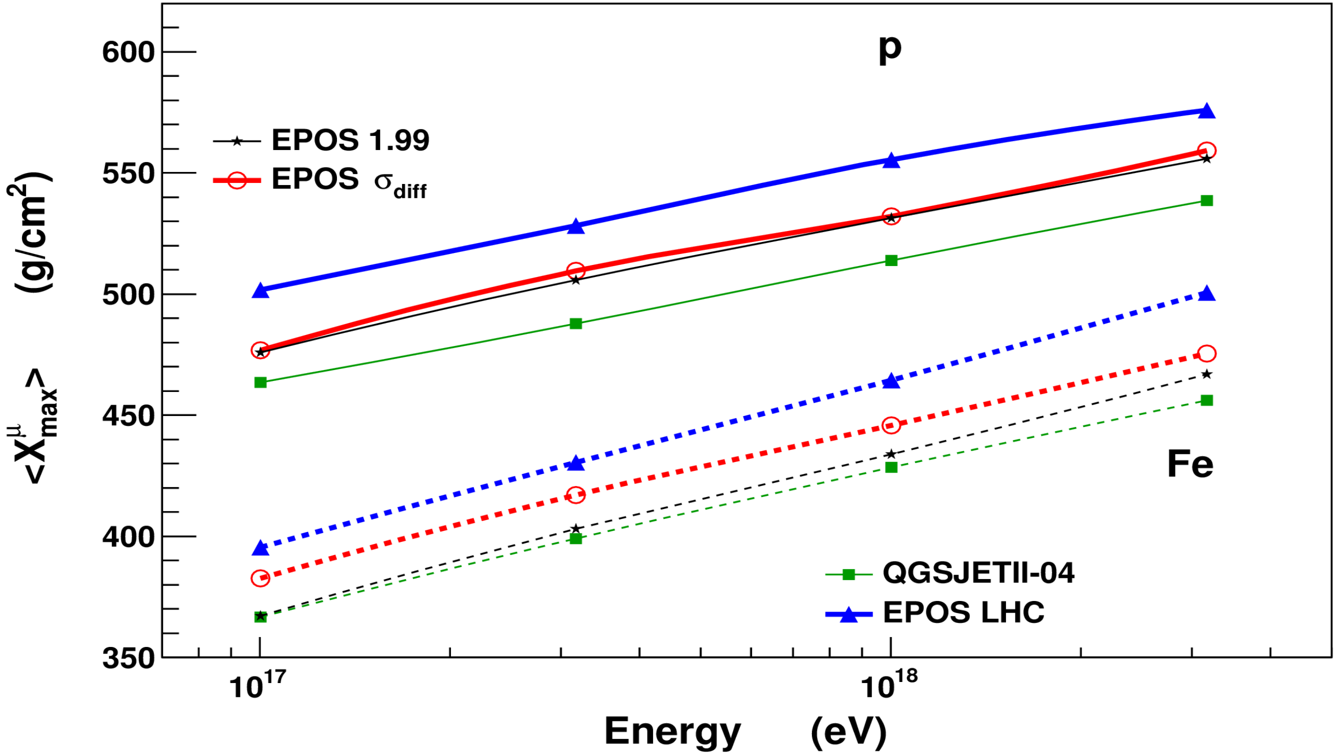


5% difference in cross section

Pion elasticity changed by 12.5 % (back to EPOS 1.99)

$<X^{\mu}_{max}>$

Not as measured … use EPOS 1.99 as reference ...



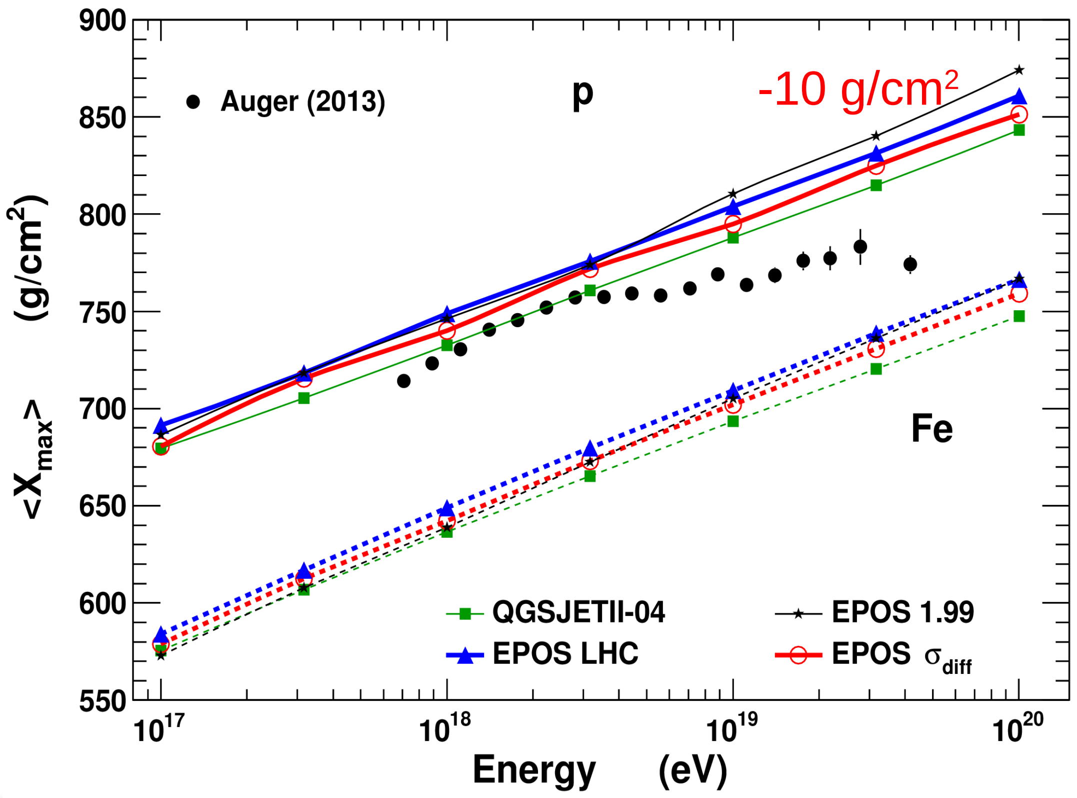
-30 g/cm² back to EPOS 1.99

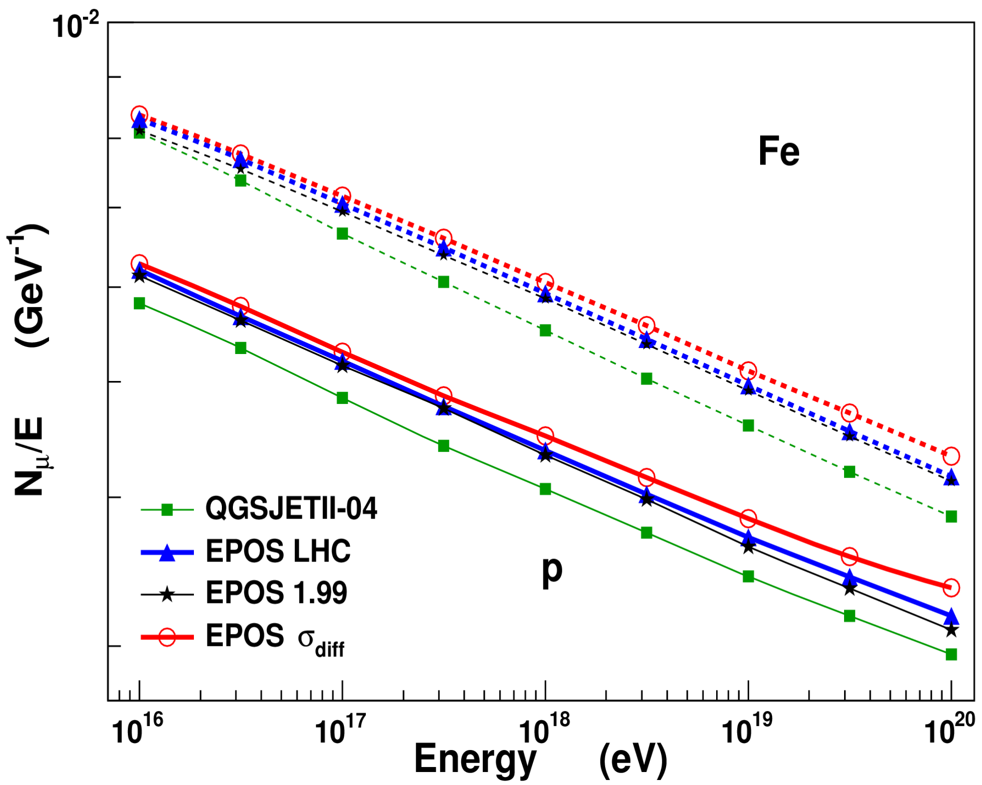
Strong effect of the change of pion-air elasticity in EPOS !

To be confirmed by test on reconstructed MPD (as measured by Pierre Auger Observatory)

$\langle X_{max} \rangle$ and N_μ

Diffractive cross-section change MPD but small effect on $\langle X_{max} \rangle$ (smaller) and N_μ (larger)

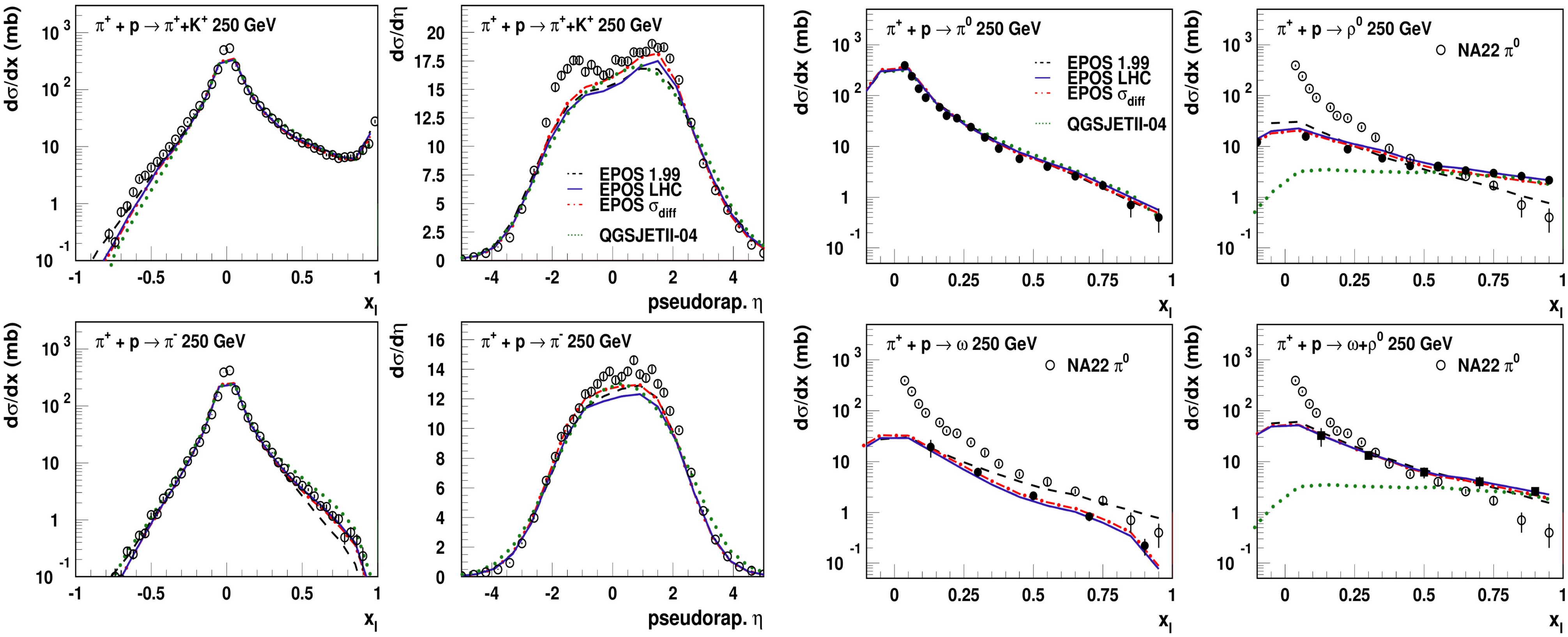




Summary

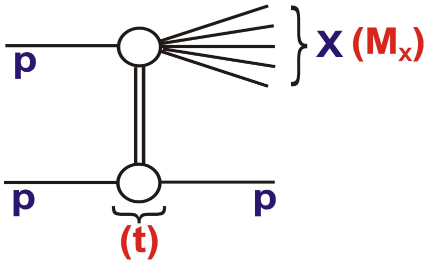
- **Inelasticity linked to diffraction**
  - weak influence on electromagnetic X_{max} since only 1st interaction really matters
  - cumulative effect for X^{μ}_{max} since muons produced at the end of hadronic sub-cascade
  - rapidity-gap in p-p @ LHC to be improved in models
  - lower pion diffraction cross-section reduce <u>a lot</u> X^{μ}_{max} with little effect on X_{max} and N_{μ}
  - very strong sensitivity of MPD on pion diffraction which is badly measured
    - **MPD can be used to constrain models**
    - then MPD can not be used for mass composition (X_{max} less sensitive to details) unless more accelerator data can constrain models
- **Outlook: new data from NA61 (this session)**
  - models under-predict ρ^0 production
  - possible source of discrepancy of muon production in EAS (more muons (less π^0 (to be confirmed with ω), larger attenuation length (larger mean energy), higher production high (MPD) (less generation))

Test with accelerator data

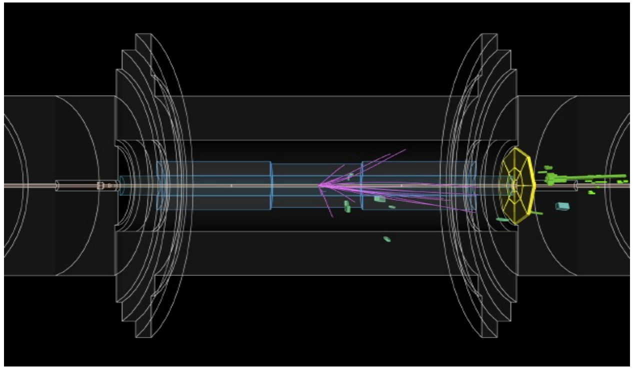


Rapidity Gap and (In)elasticity

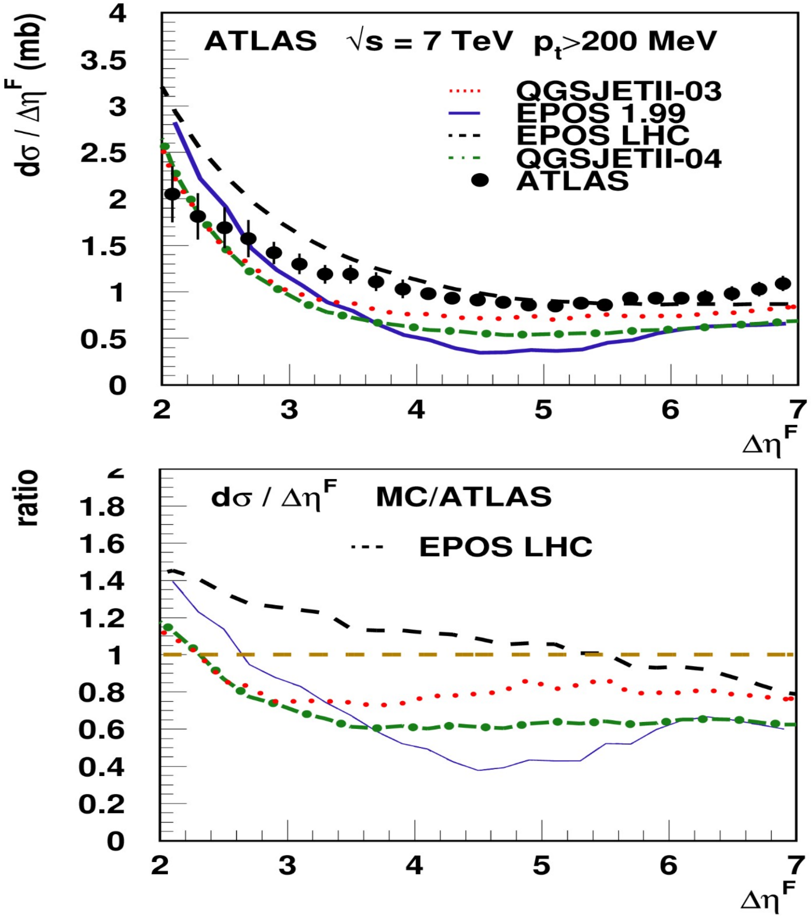
diffractive process



ATLAS detector



ATLAS Collaboration



- **Rapidity gap closely related to diffraction**
  - diffractive cross-section
  - AND diffractive mass distribution
- **Hard constraint for CR**
  - change (in)elasticity

Is X^{μ}_{max} Important for Muons at Ground ?

- **For EM particles : shift in X_{max} $\approx$ change in EM at ground**
  - strong atmospheric absorption
- **For muons : shift in X^{μ}_{max} $\not\approx$ change in muons at ground**
  - weak atmospheric absorption
  - model dependent energy spectra
  - distance to core dependence