Karlsruhe Institute of Technology

Measurements at LHC an their relevance for air shower physics

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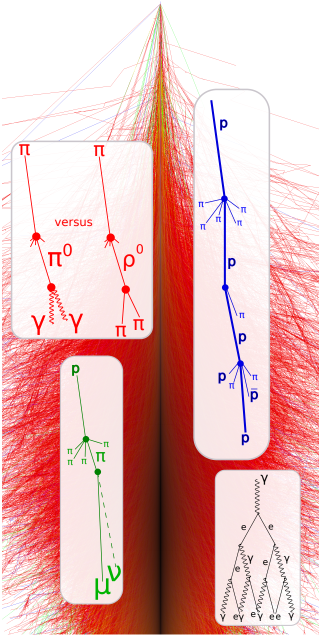
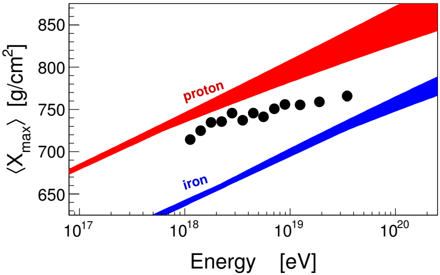
ISMD, 6. October 2015, Wildbad Kreuth

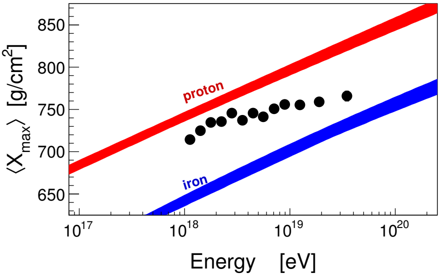
Ultra-high energy cosmic ray extensive air showers



- Huge coupled cascading process
- Conversion of primary energy into
  - Electrons/ photons
  - Muons
  - Low energy hadrons
- Most relevant observables are:
  - Depth of shower maximum
  - Muon content
- Precise modelling is mandatory for a cosmic ray mass measurement

EPOS 1.99 → **EPOS LHC**
QGSJetII.3 → **QGSJetII.4**

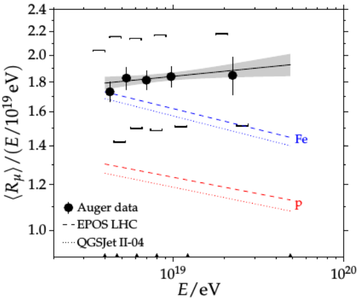


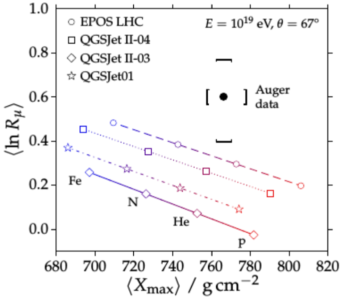


Tuning impact:

- Obvious apparent improved model predictions
- But is this really a quantitative indication of a better understanding?

Muon content of air showers at ground level





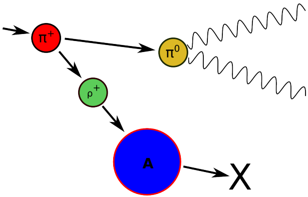
Auger, arXiv-1408.1421 [atro-ph]

- More muons in air shower data than expected
- No consistency between different observables can be achieved

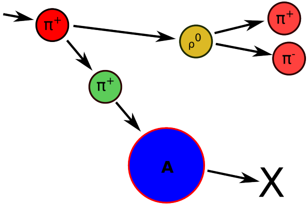
$\rightarrow$ Interaction physics in air shower models still not accurate

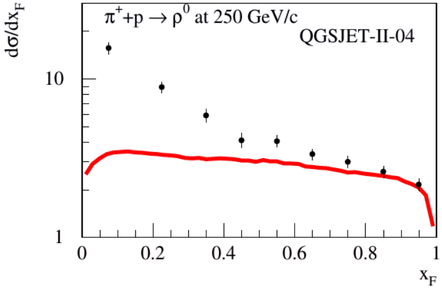
Forward ρ^0 Production, QGSJetII.3→QGSJetII.4

Charge Exchange, Leading π^0/ρ^0 production:



versus



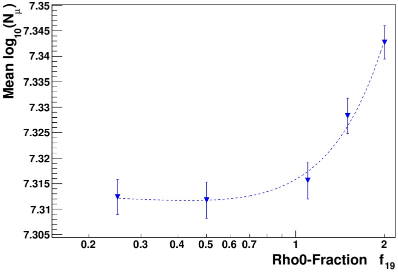


S. Ostapchenko, ISVHECRI 2012

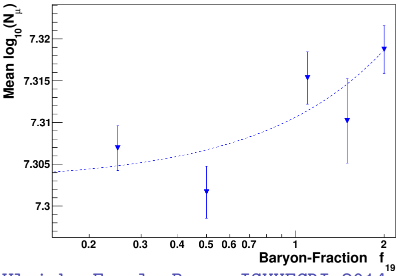
Impact on muons in air showers

Systematically change the

- leading π^0/ρ^0 ratio:



- baryon/anti-baryon production:



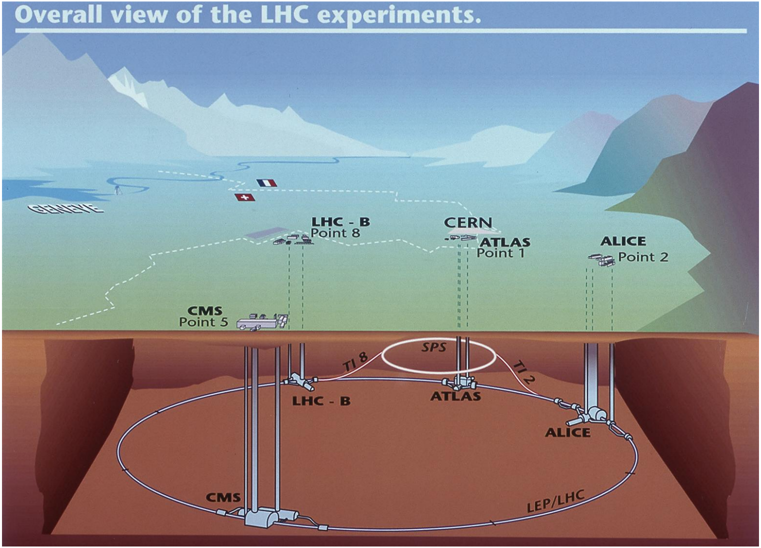
Ulrich, Engel, Baus, ISVHECRI 2014

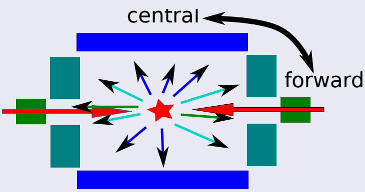
(SIBYLL, protons, $10^{19.5}$ eV)

(f19 is the scaling factor for ρ^0 and baryons at 10^{19} eV)

($\alpha^{\text{modified}}(\mathbf{E}) = \alpha^{\text{orig}}(\mathbf{E}) \cdot \left(\mathbf{1} + (\mathbf{f}_{19} - \mathbf{1}) \cdot \frac{\log_{10}(\mathbf{E}/10^{15}\ \mathbf{eV})}{\log_{10}(10^{19}\ \mathbf{eV}/10^{15}\ \mathbf{eV})}\right)$)

Large Hadron Collider and Experiments

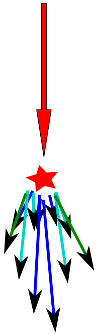




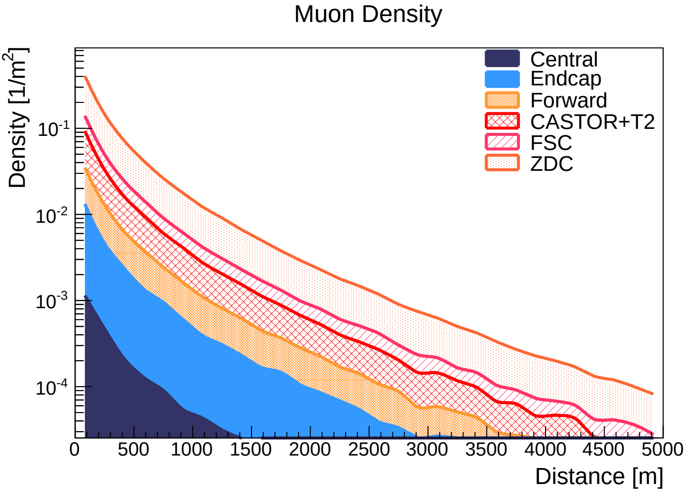
- Central ($|\eta| < 1$)
- Endcap ($1 < |\eta| < 3.5$)
- Forward ($3 < |\eta| < 5$), HF
- CASTOR+T2 ($5 < |\eta| < 6.6$)
- FSC ($6.6 < |\eta| < 8$)
- ZDC ($|\eta| > 8$), LHCf

- How relevant are specific detectors at LHC for air showers?

→ Simulate parts of shower individually.

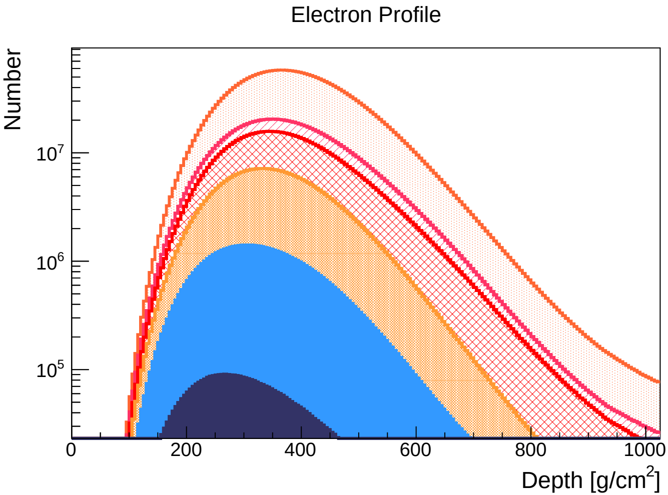


Lateral Particle Density on Ground Level



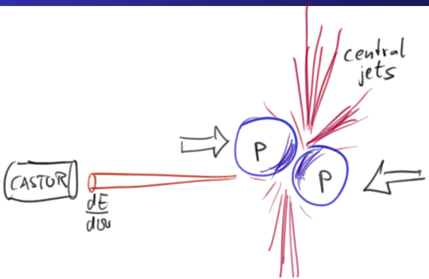
- Air shower models so far only tuned to about 10 % !
- Forward detectors are crucial.

Longitudinal Shower Development

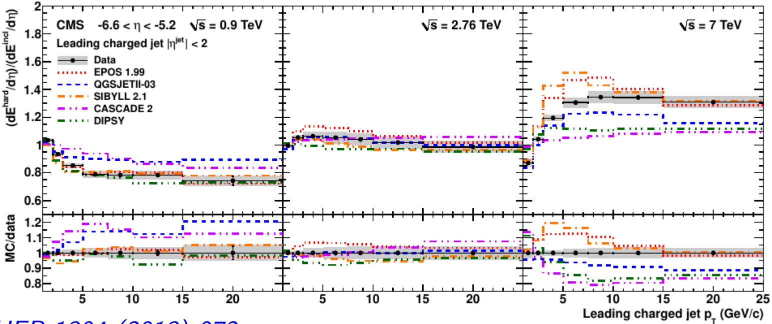


- Air shower models so far only tuned to about 10 % !
- Forward detectors are crucial.

Forward Energy as a Function of Central Activity

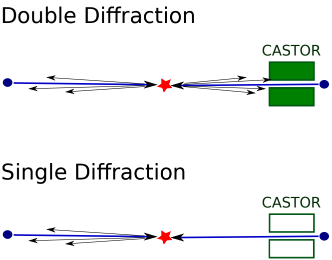


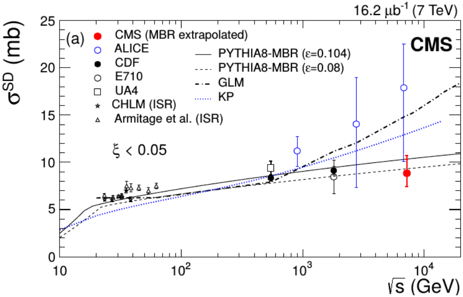
- **Forward energy** ∼ Remnant fragmentation
- **Central jets** ∼ String fragmentation
- "Underlying-Event" study in very forward direction



JHEP 1304 (2013) 072

CMS/CASTOR Low-Mass Single Diffraction (pp, 7 TeV)

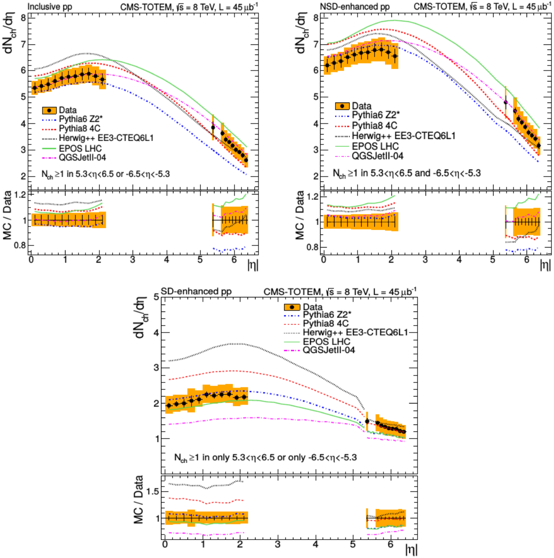




(submitted to PRD)

Separation of single- and double-diffraction only possible with CASTOR detector.

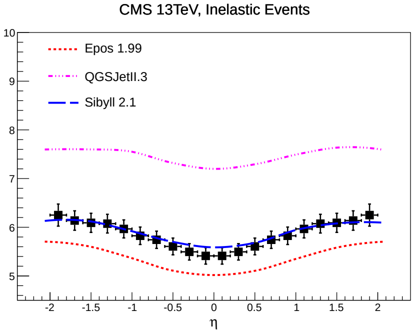
CMS + TOTEM Combined Multiplicity Data (pp, 8 TeV)

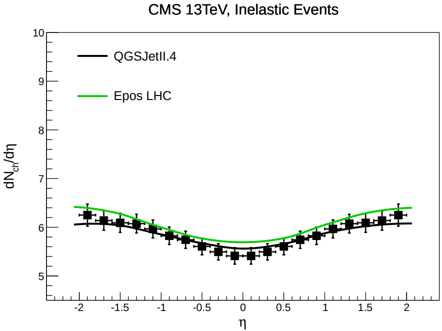


The European Physical Journal C, Oct 2014, 74:3053

Multiplicity measurements at 13TeV

pre-LHC models → **Models tuned at 7 TeV**

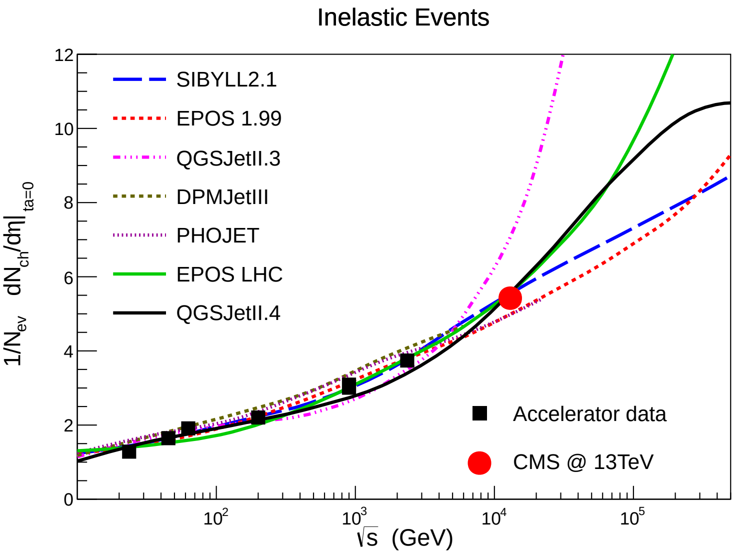




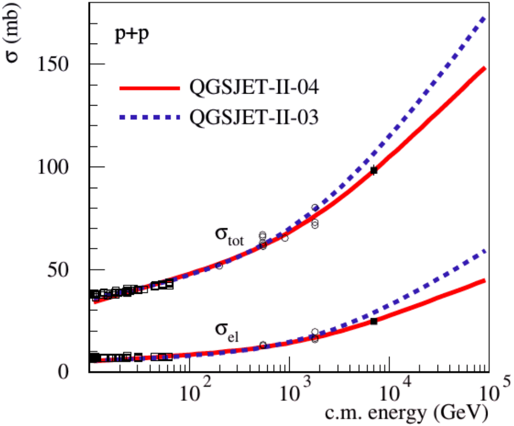
CMS data: arXiv:1507.05915, accepted at PLB

- Good extrapolation over factor ≈2 in $\sqrt{s}$
- Poorly contraint for factor > 10 in $\sqrt{s}$

Extrapolation to ultra-high energies



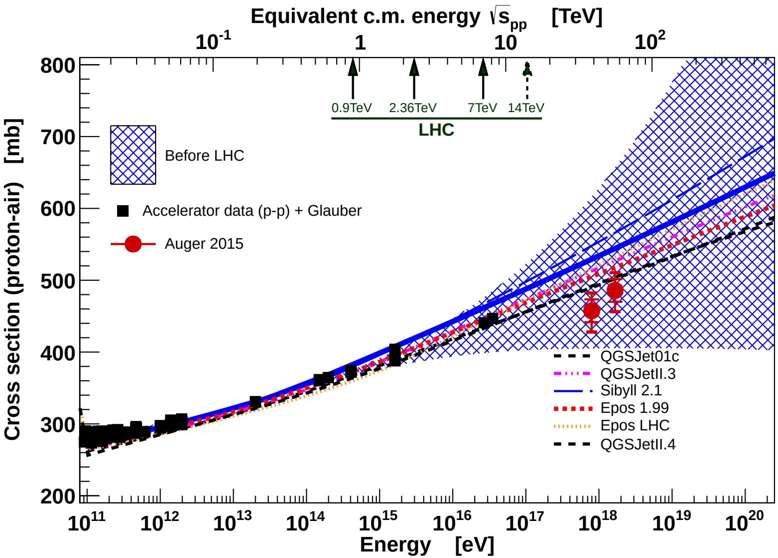
Cross section data



S. Ostapchenko, ISVHECRI 2014

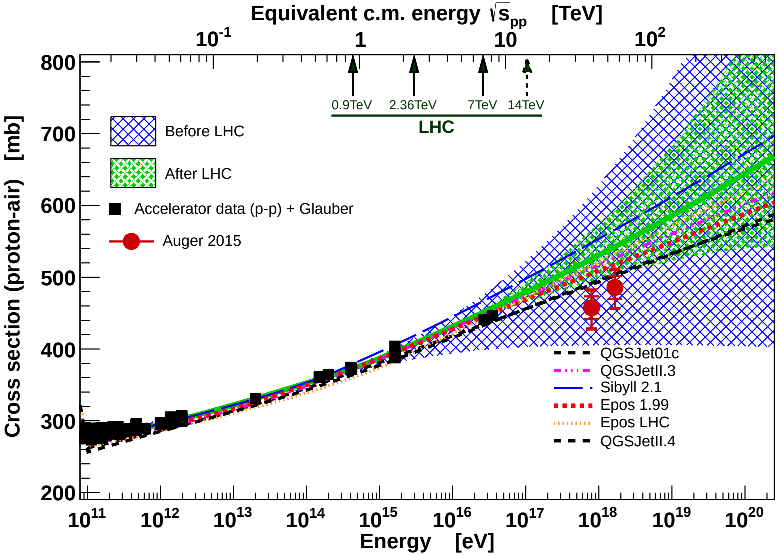
Proton-Air cross section is one of the most important quantities for air shower modeling

Proton-Air cross section, with Tevatron data



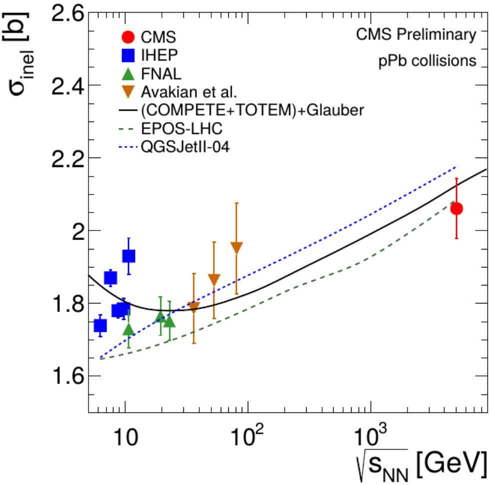
compare to Nucl.Phys.Proc.Suppl. 196 (2009) 335

Proton-Air cross section, with LHC data



⇒ Sign of a clear relevant improvement

Inelastic Proton-Lead Cross Section at 5.02 TeV



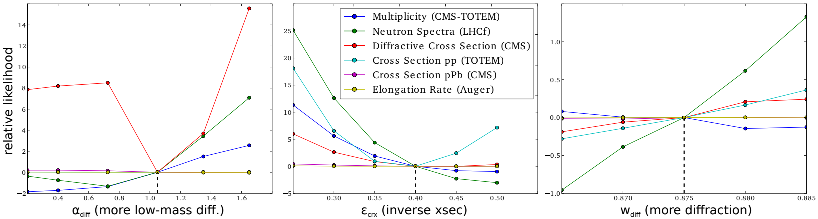
arXiv:1509.03893, submitted to PLB

- **Direct test of Glauber model (and extensions) at LHC**

Outlook: Global picture of Accelerator+CR data

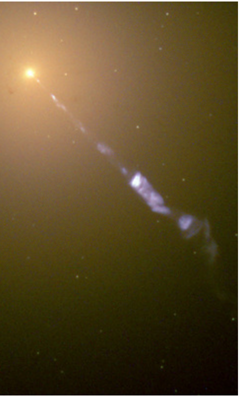
- Global likelihood: $\mathcal{L}_{\text{global}} = \mathcal{L}_{\text{Accelerators}} \cdot \mathcal{L}_{\text{CR}}$
- Exploit sensitivity of various data on model features: *marginalize* model differences

→ New analysis framework to perform automated large scale simulation productions in many dimensions of accelerator as well as cosmic ray observables



C. Baus et al., ICRC 2015

Summary



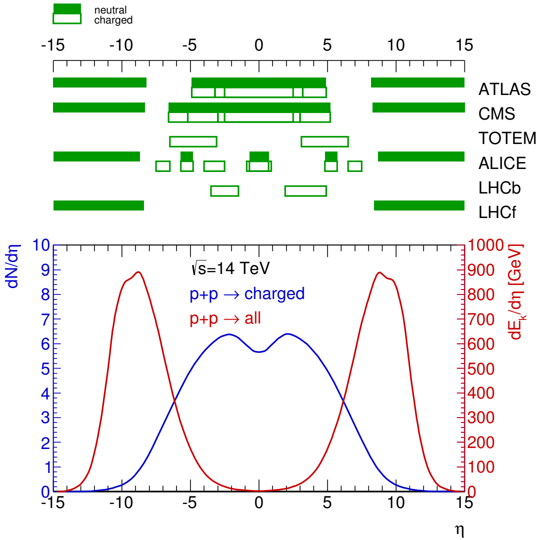
⇒ **LHC data extremely important ⇒ forward**

⇒ **Not yet derived maximum information gain**

⇒ **Global approach could provide ultimate insight**

Angular acceptance of LHC experiments

Definition of *pseudorapidity*: $\eta = -\log\tan(\theta/2)$



CMS Minijet Measurements (pp, 8 TeV)

$$\sigma_{QCD}(s, p_{T,min}) = \int_{p_{T,min}}^{\sqrt{s}/2} dp_T \int_{4p_T^2/s}^{1} dx_1 \int_{4p_T^2/(x_1 s)}^{1} dx_2 \sum_{ijkl} f_{i,A}(x_1, p_T^2)\, f_{j,B}(x_2, p_T^2)\, \frac{d\hat{\sigma}_{ij}^{kl}(\hat{s})}{dp_T}$$

p_T-Cutoff

Parton distribution functions, PDFs

Minijet Cross section

- Hadronization in string fragmentation, minijet production
- p_{T} threshold