CRMC: an interface to cosmic ray event generators

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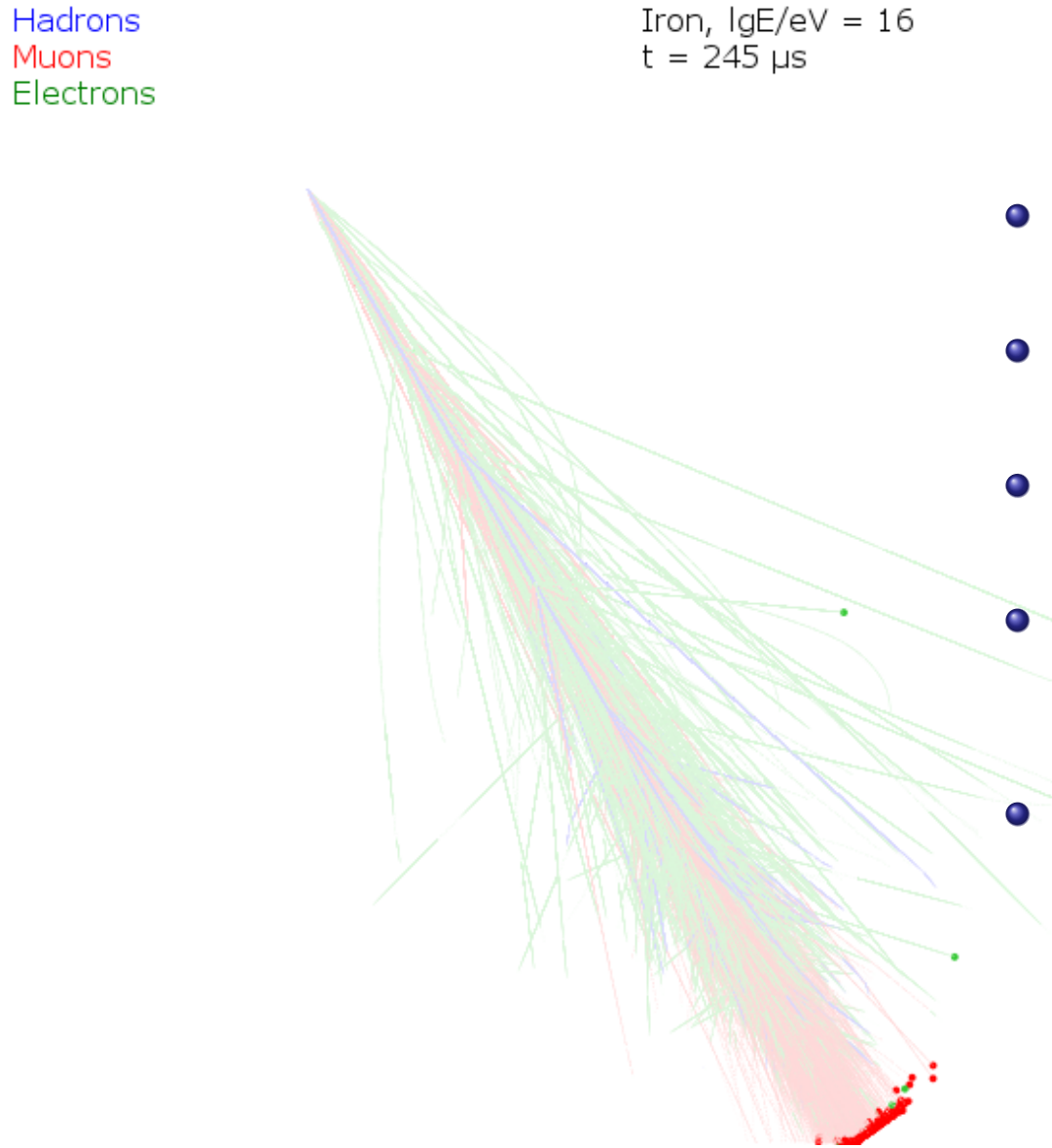
Outline

- Link between cosmic ray air showers and CERN
- Extensive air showers as Minimum-Bias laboratories
- The tool to run almost all cosmic ray event generators: **CRMC**
- Possible application: Resampling
- Impact of LHC measurements on air shower observables

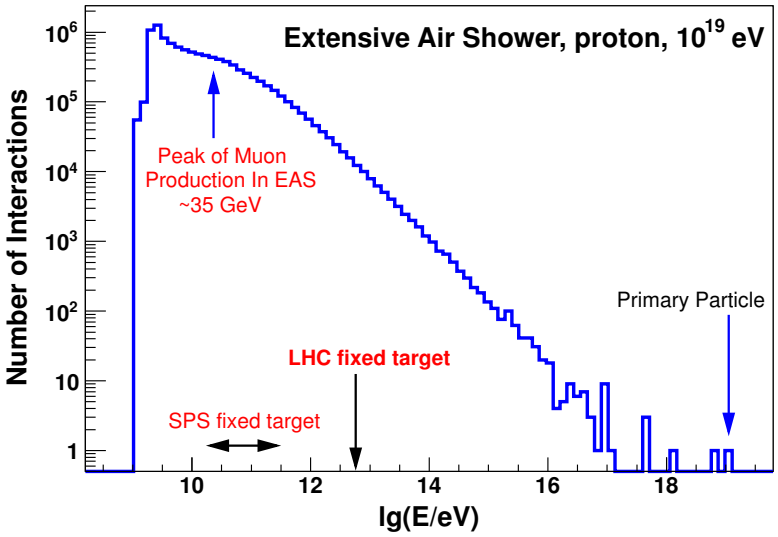
Extensive Air Shower

Extensive Air Shower



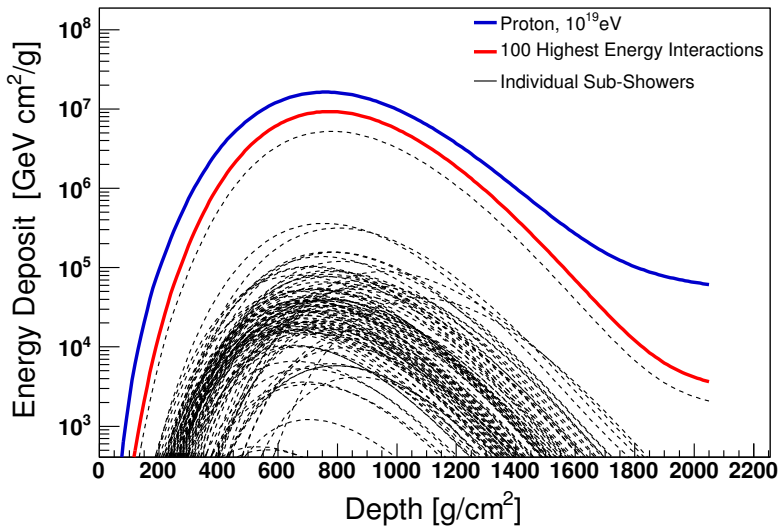
- CORSIKA+COAST
- Billions of interactions
- All energies
- No energy is lost, just transported
- **Forward physics matters**

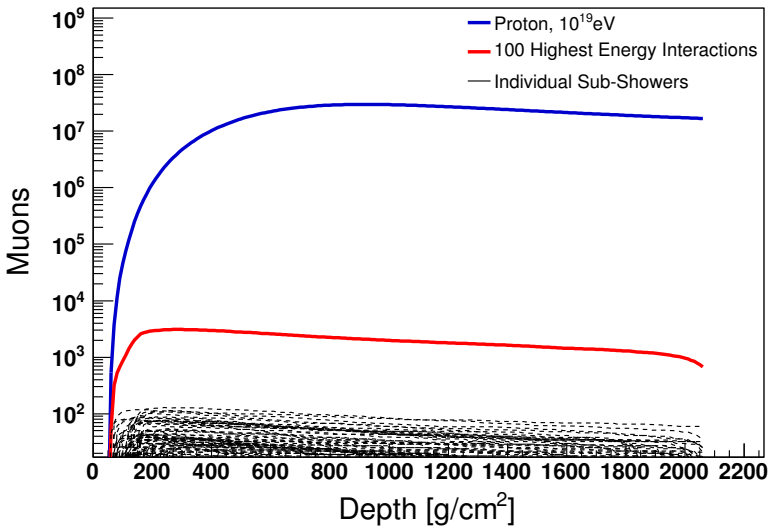
Interactions in Extensive Air Shower



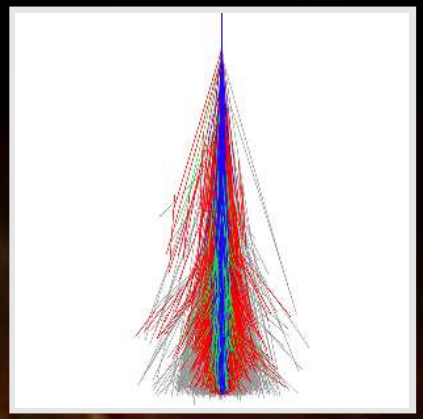
- Energies beyond accelerators
- However, mostly in SPS range
- Uncertainty: extrapolation of hadronic interactions
  - Phase space (!)
  - Energy

→ Very different impact on different EAS observables





"Astrophysics" at LHC – Air-Showers + Forward Physics



Astrophysical Neutrinos

- The first two real astrophysical neutrino candidates
- PeV energies
- Electron neutrino structure
- Atmospheric prompt charm production ?

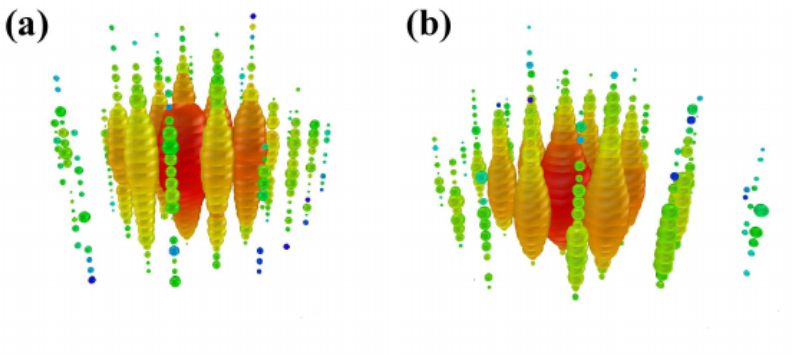
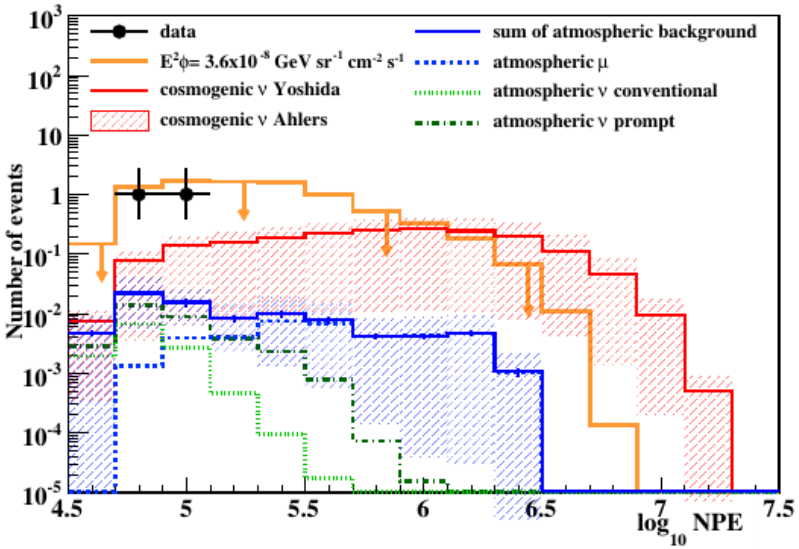


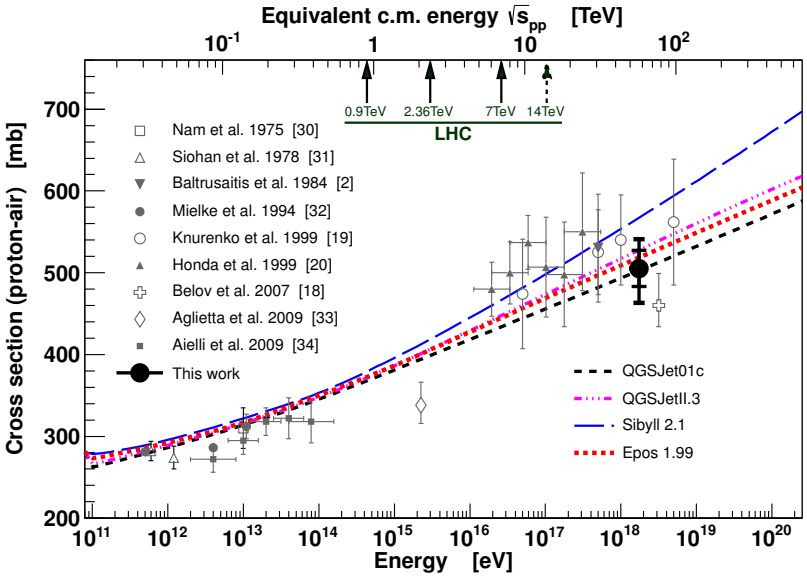
FIG. 4. The two observed events from (a) August 2011 and (b) January 2012. Each sphere represents a DOM. Colors represent the arrival times of the photons where red indicates early and blue late times. The size of the spheres is a measure for the recorded number of photo-electrons.

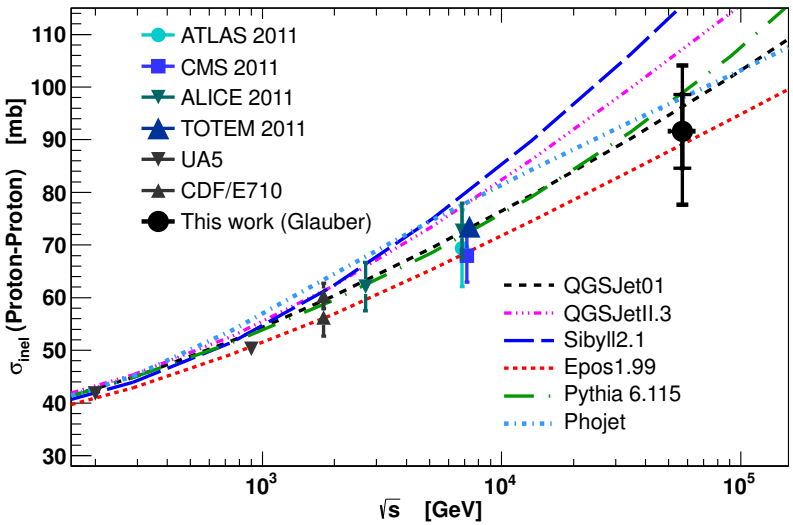


ICECUBE: *Phys. Rev. Lett. 111, 021103 (2013)*

Direct Sensitivity to Particle Physics

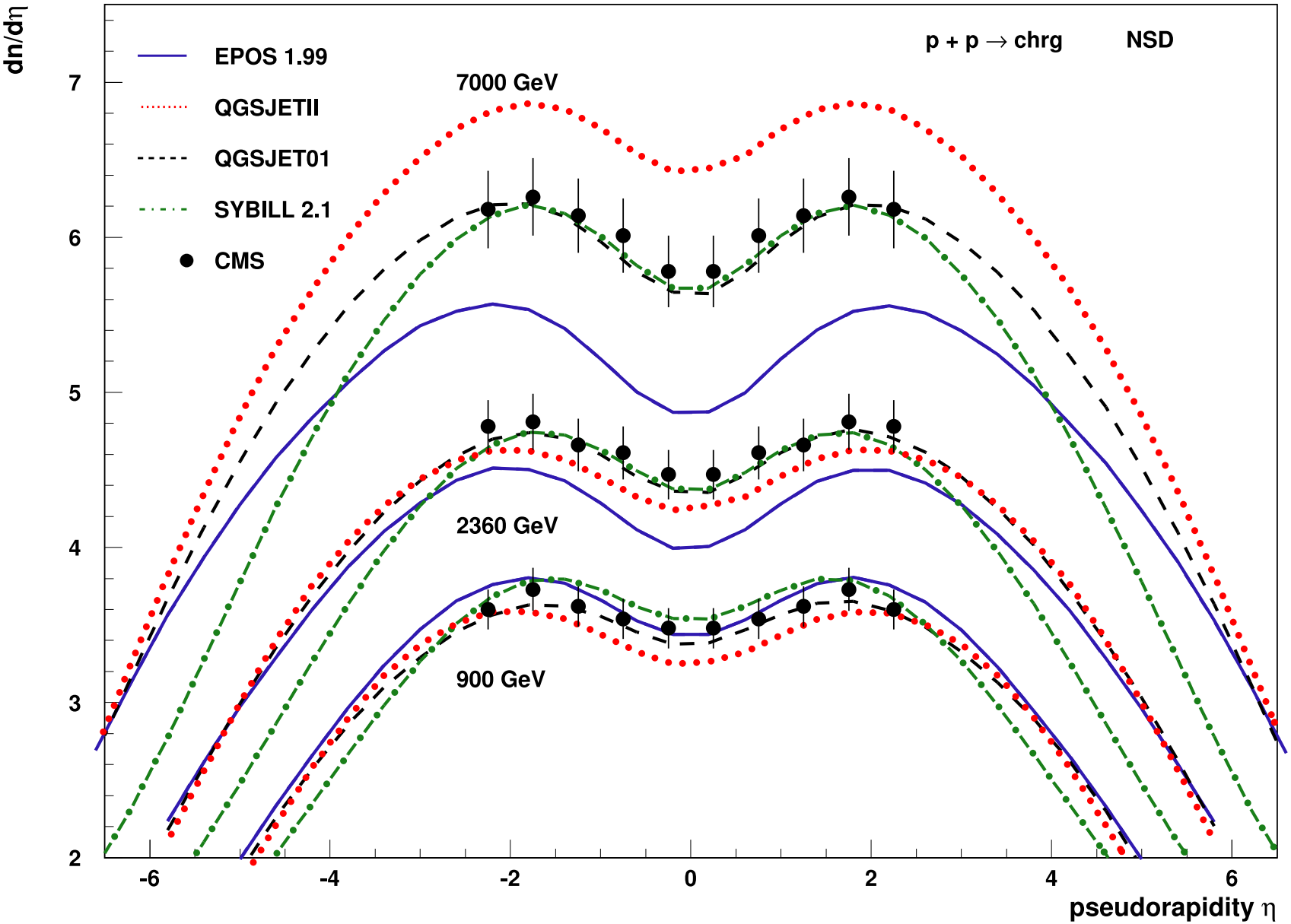
- Measure cross sections in extensive air showers from fluctuations
- TeV to PeV energies
- Possible with high quality air shower observations





Auger: *Phys. Rev. Lett. 109, 062002 (2012)*

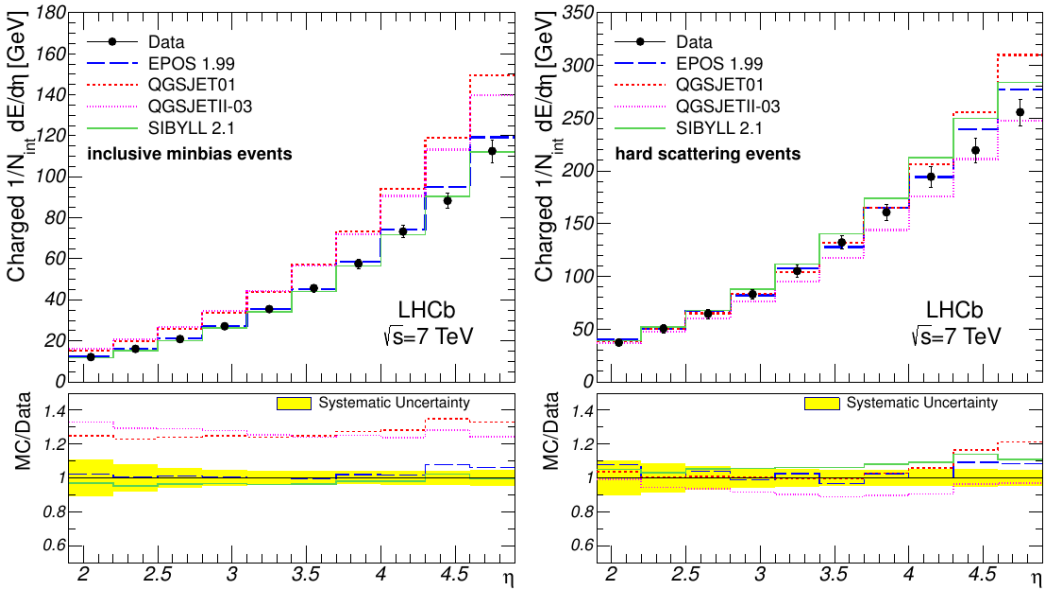
Cosmic Ray Models and First LHC Data



Astropart.Phys. 35 (2011) 98-113

Cosmic Ray Models and Recent LHC Data: LHCb

e.g.



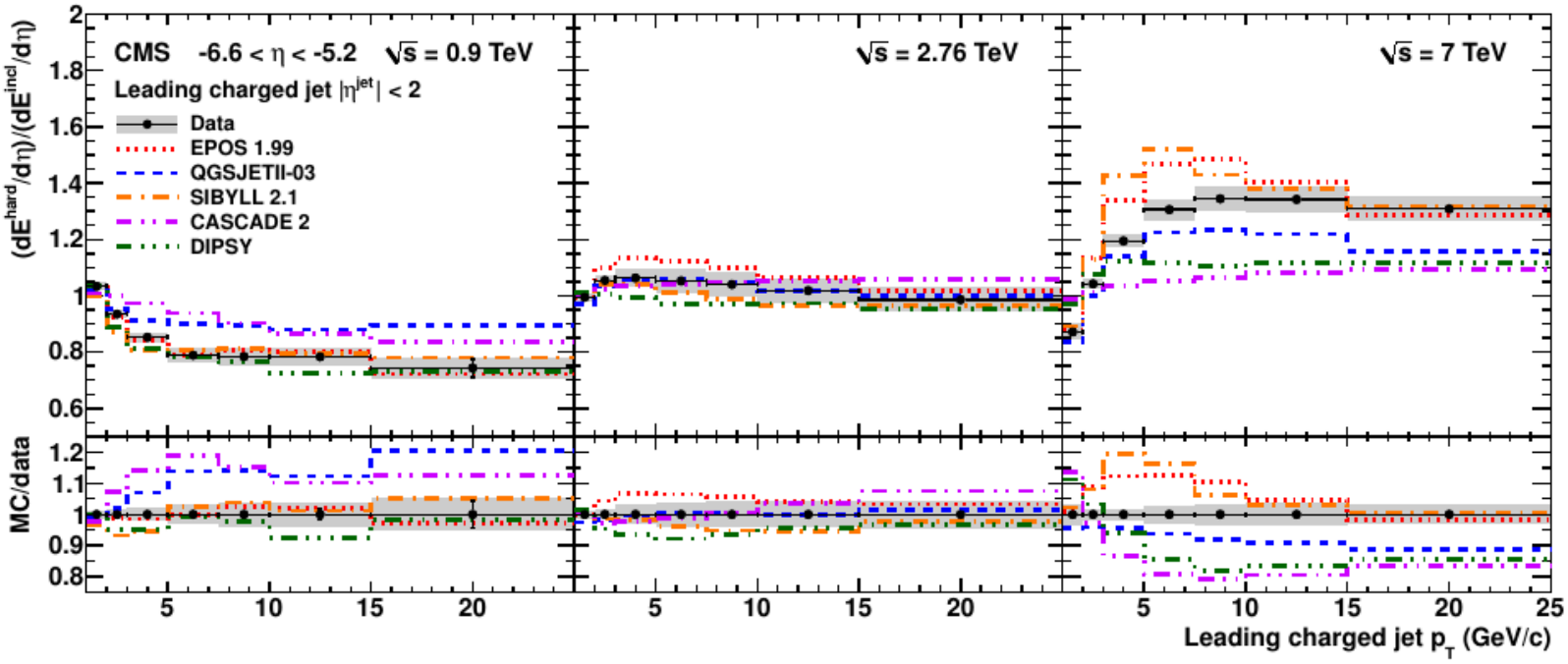
Comparison on event generator level:

- Forward energy flow
- Forward Lambda production, strangeness
- More in preparation...

Eur.Phys.J. C73 (2013) 2421

Cosmic Ray Models and Recent LHC Data: CMS

Very forward underlying event:

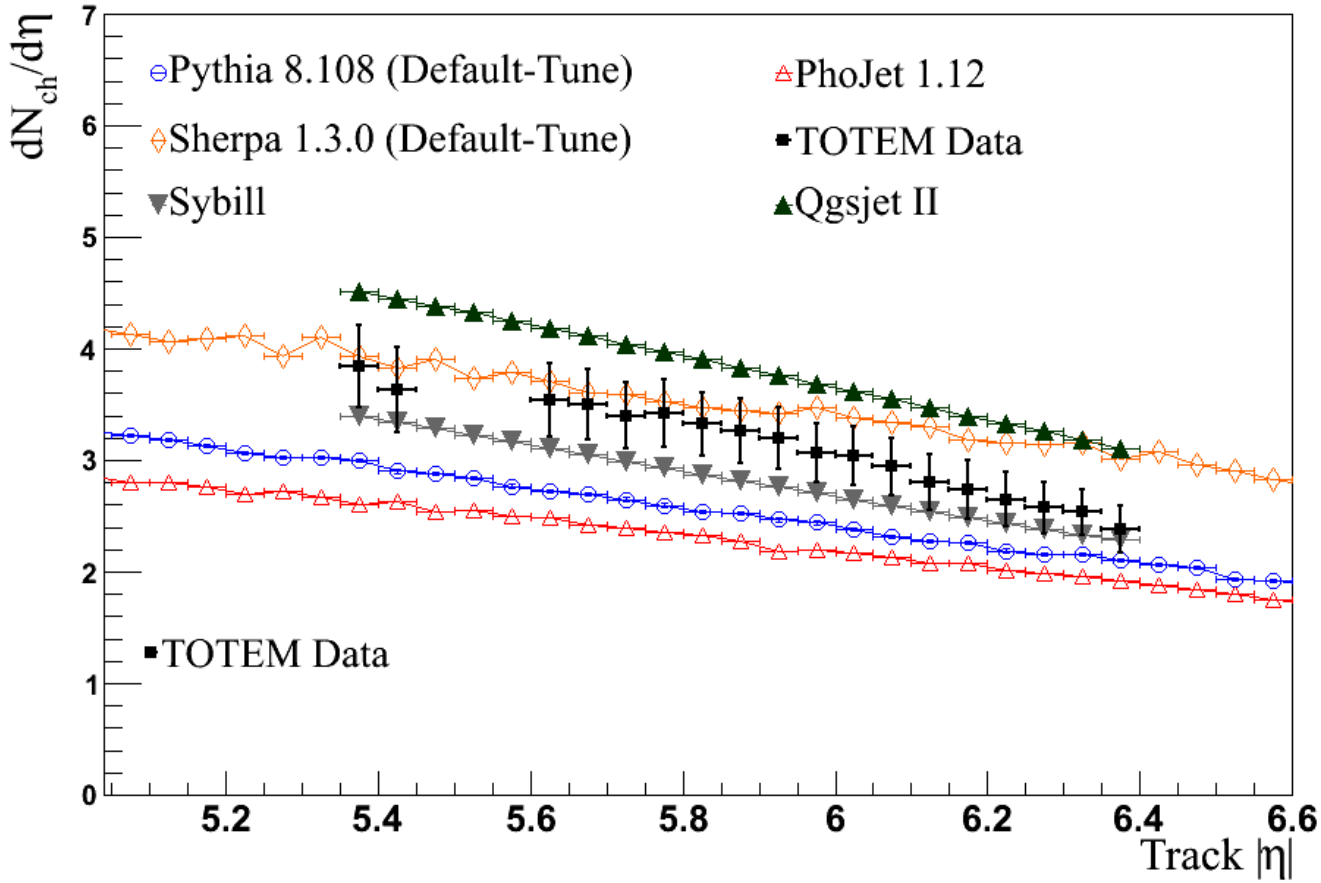


JHEP 1304 (2013) 072

In CMS:

- Used for pPb and PbPb (and forward pp) detector studies and correction factors
- Where relevant, also event generator comparisons are performed

Cosmic Ray Models and Recent LHC Data: TOTEM



Forward charged multiplicities: *Europhys.Lett. 98 (2012) 31002*

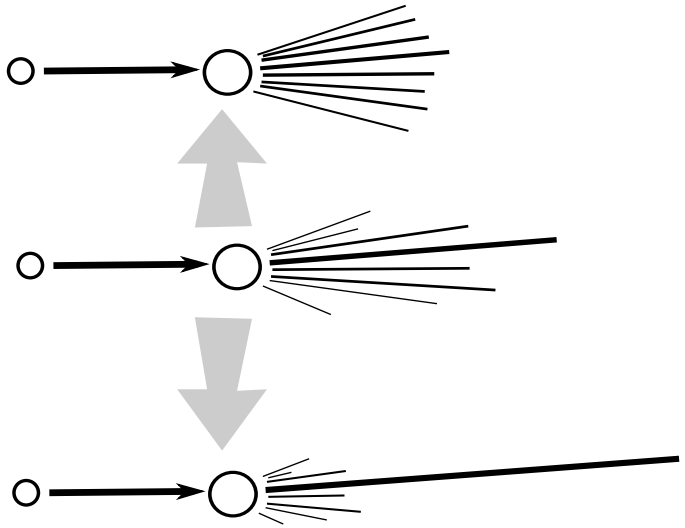
Status

- Good description of main hadronic particle production
- Constrains from Modeling (mainly Glauber+Gribov) AND extensive air shower data work and are useful at LHC
- Models work over wide range in primary energies and for a variety projectile/target combinations (without re-tuning)
- Widely used already now: CMS, LHCb, also ATLAS, TOTEM (and ALICE ?)

Technical Information

- Available event generators:
  `QGSJet01, QGJSetII.3, QGSJetII.4, EPOS1.99, EPOS1.99lhc, SIBYLL2.1, DPMJETIII,` and some others
- Example to generate 100 4.4 ATeV pPb collisions with QGSJetII-04:
  `bin/crmc -o hepmc -p3500 -P-1380 -n100 -m7 -i2112 -I822080`
- Output: `hepmc, hepmc.gz, lhe, lhe.gz, root`
- Authors: Colin Baus, Tanguy Pierog, Ralf Ulrich
  email to: `colin.baus@kit.edu`
- Package also available by default in the:
  - From: `http://www.auger.de/~rulrich`
  - CMSSW framework as GribovGlauberInterface
  - In the `genser` package:
    `/afs/cern.ch/sw/lcg/external/MCGenerators_lcgcmt65/crmc/1.0/x86_64-slc5-gcc47-opt/bin/crmc`
  - Via `genser` in the ATLAS offline software
- *Paper as documentation in preparation*

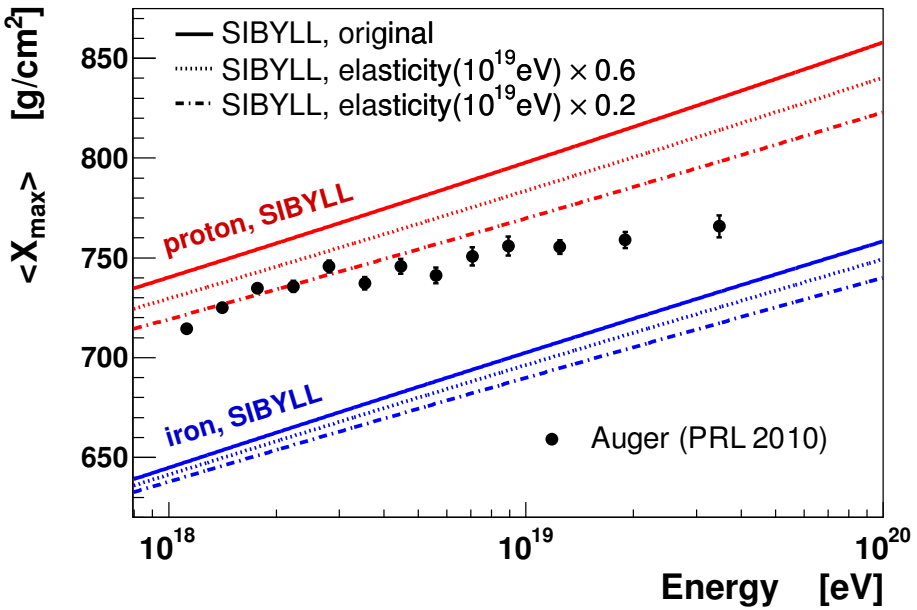
Resampling (e.g. Elasticity)



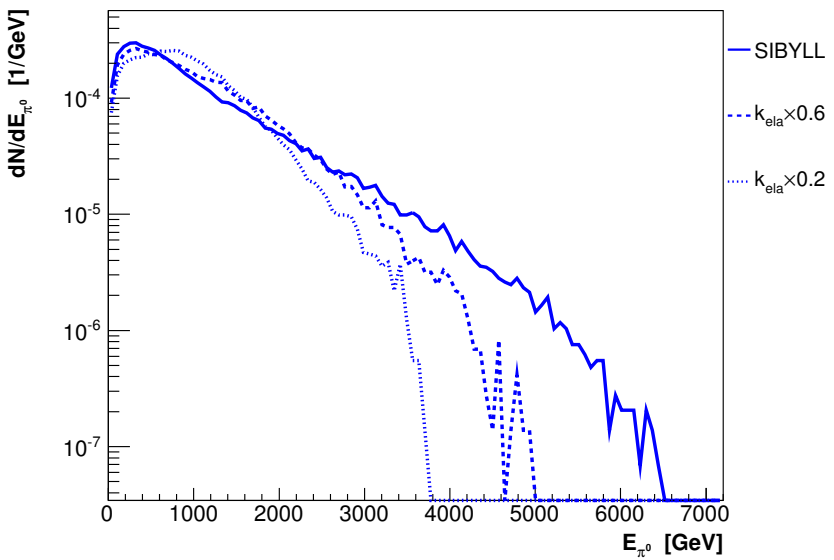
$$k_{\mathrm{inel}} = 1 - E_{\mathrm{max}}/E_{\mathrm{tot}}$$

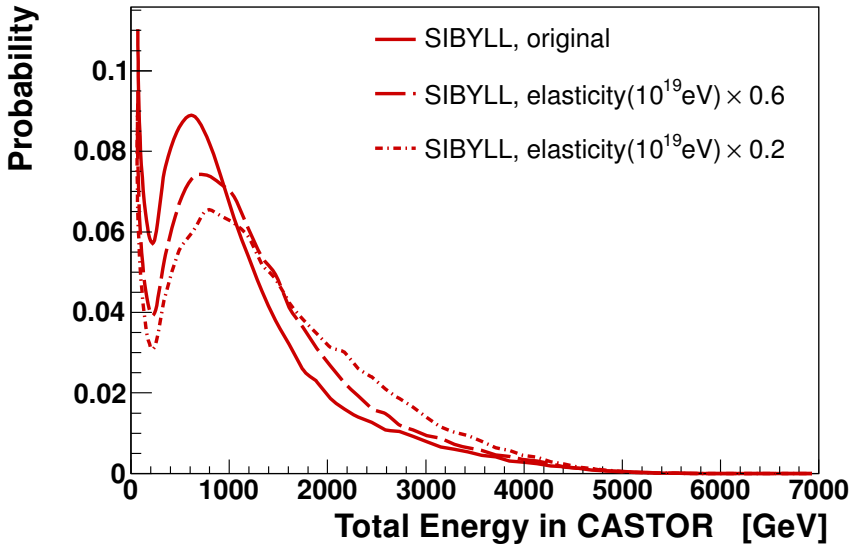
- **Redistributing** of energy among the leading particle and the other secondaries.
- Algorithm changes the interaction elasticity while conserving the total energy

Impact on Air Showers Observables

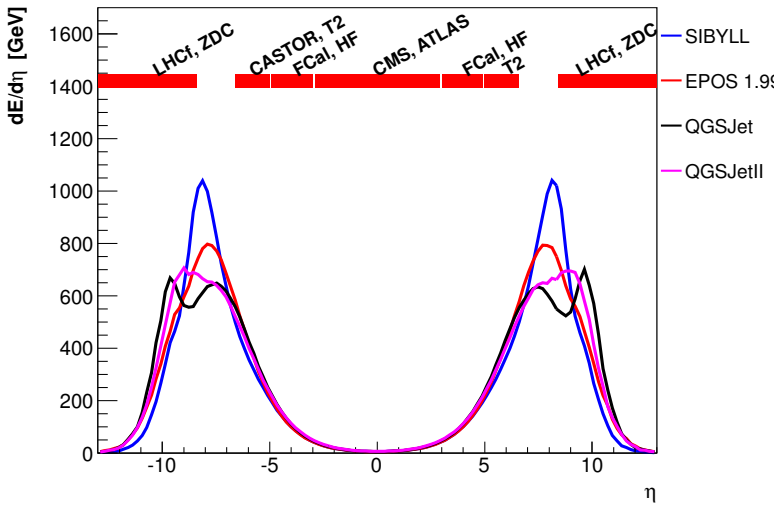


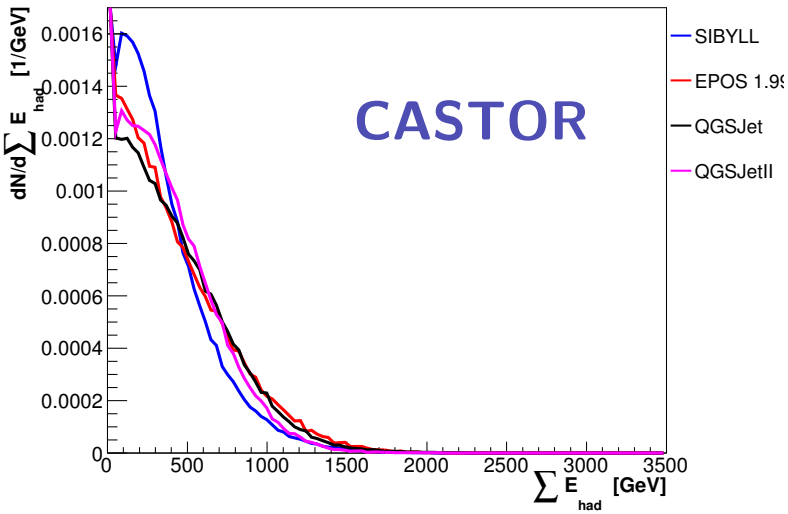
- Modifying the *elasticity*
- Observe impact at LHC **AND**
- in Extensive Air Showers

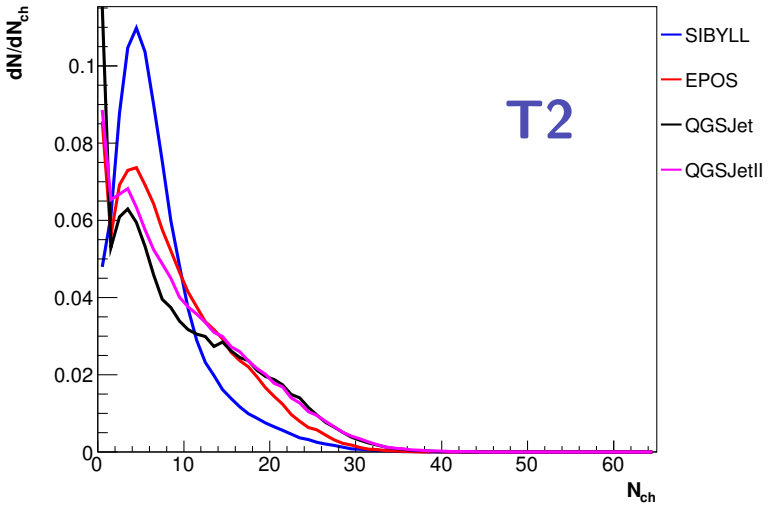


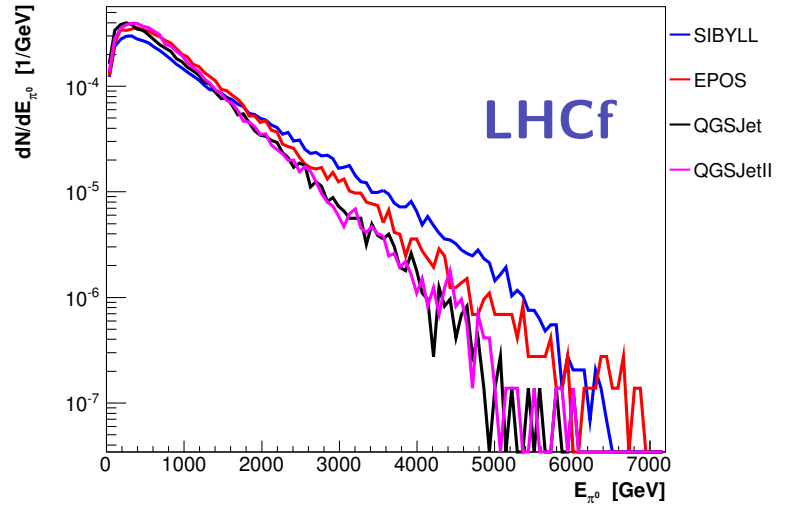


Model Differences in the Forward Detectors

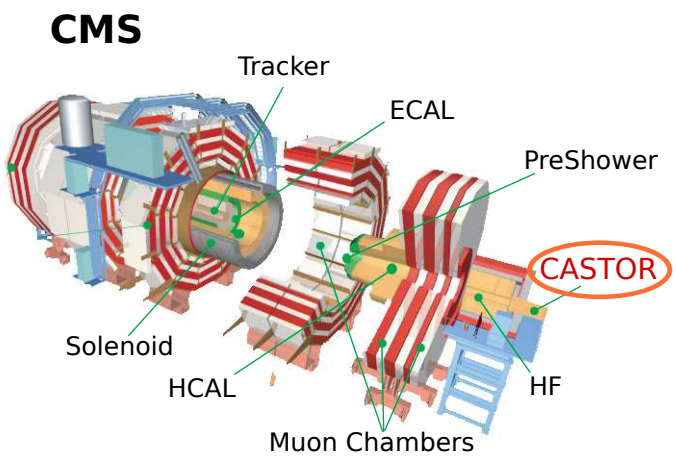


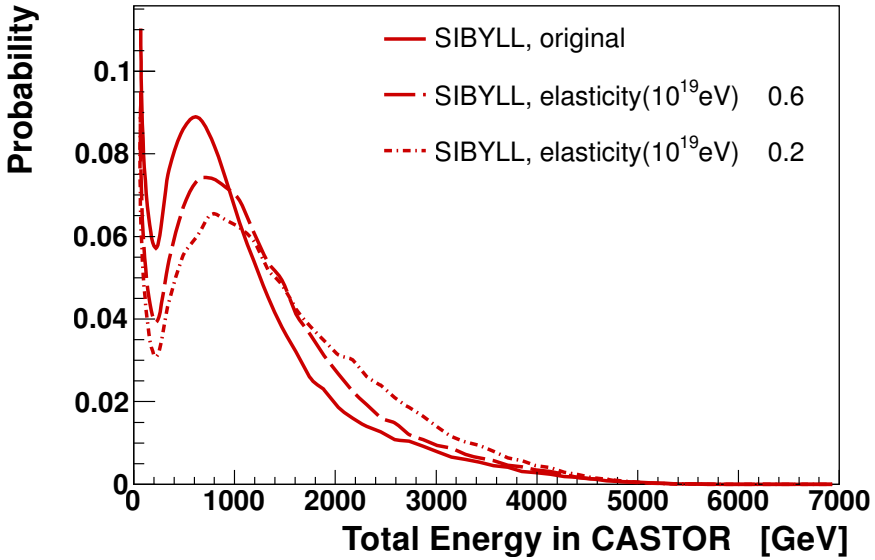


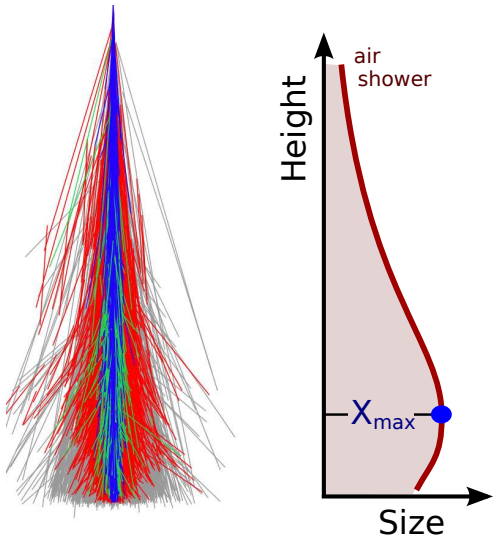


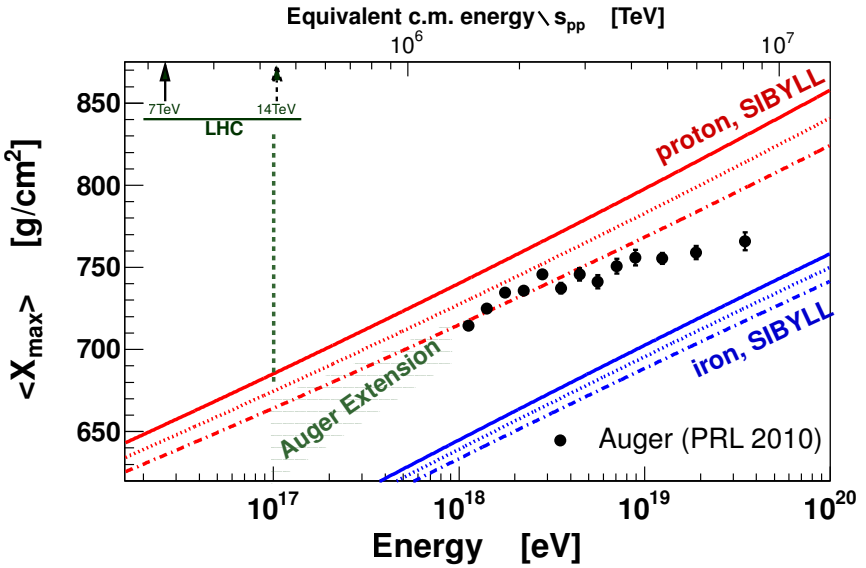


Connection to Air Shower Physics









Summary

- Extensive air shower data constrains event generators
- Cosmic ray models flexible and well suited to describe hadronic bulk particle production
- Cosmic ray models can be used at LHC for efficiency corrections
- Furthermore: many measurements can be compared directly to these models
- With CRMC the production of events is almost trivial
- Already used in many analyses