UNIVERSITÉ DE GENÈVE

erc

Direct detection of TeV-PeV cosmic rays in space

DAMPE, HERD and connection with CRMC

Andrii Kotenko, 12 - 15 of July 2022, Heidelberg, Germany

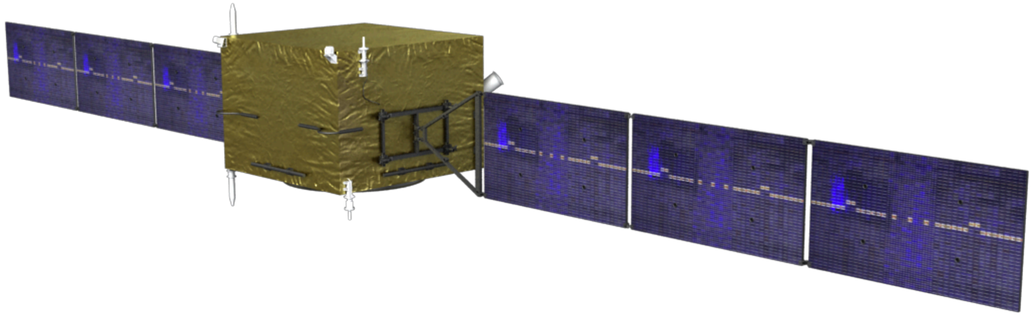
DAMPE experiment

DArk **M**atter **P**article **E**xplorer is a space experiment for direct cosmic and gamma ray detection.

Collaboration consists of Chinese, Italian and Swiss institutions.

Launched on 17th of December 2015.

Sun-synchronous orbit at the altitude of 500km.



DAMPE scientific objectives

- Studying cosmic ray propagation and acceleration in the Milky Way
- Probing the nature of dark matter
- Examining Galactic and extragalactic gamma-ray emission

DAMPE detector

Plastic Scintillator Detector (PSD):

- 82 plastic scintillator bars arranged in 2 double-layer planes
- Z measurement
- gamma-ray anti-coincidence

Silicon-Tungsten Tracker (STK):

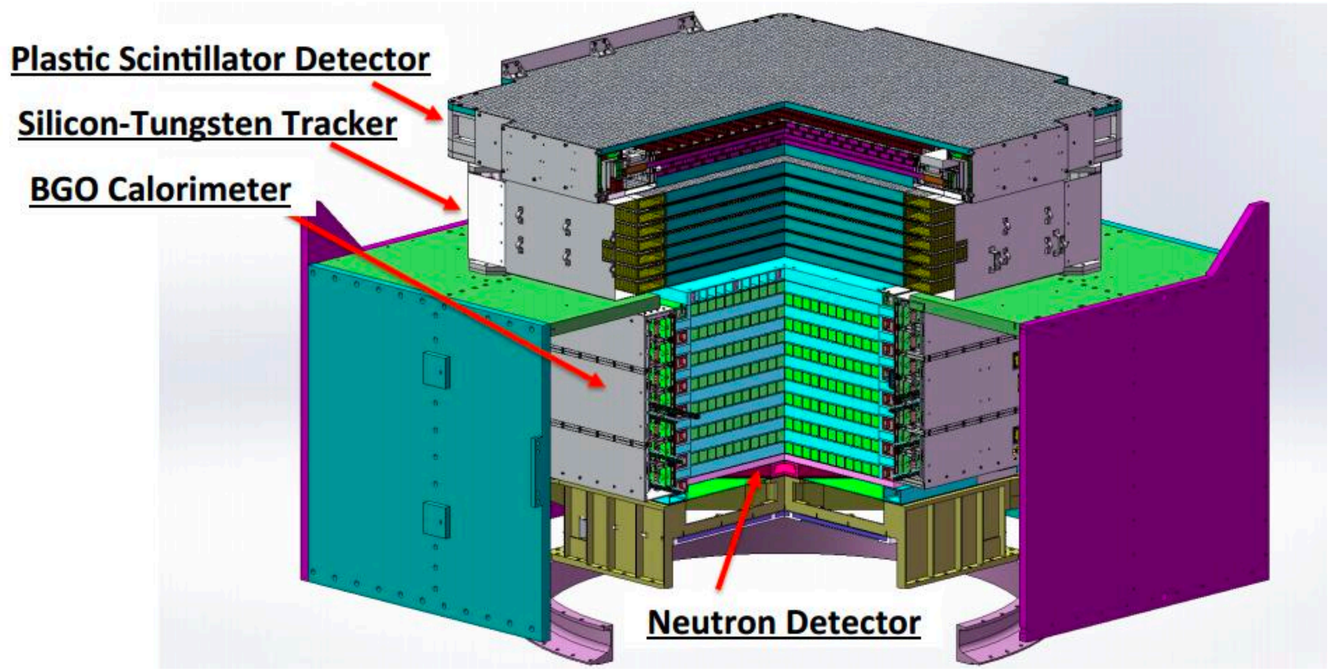
- 6 double-layers with <80 μm resolution
- 3 tungsten conversion plates
- precise track reconstruction
- Z measurement

BGO calorimeter:

- 14 layers 22 bars each arranged hodoscopically
- 32 radiation lengths, 1.7 interaction lengths
- The biggest calorimeter currently in space!
- trigger
- tracker seed
- energy measurement
- electron/hadron separation

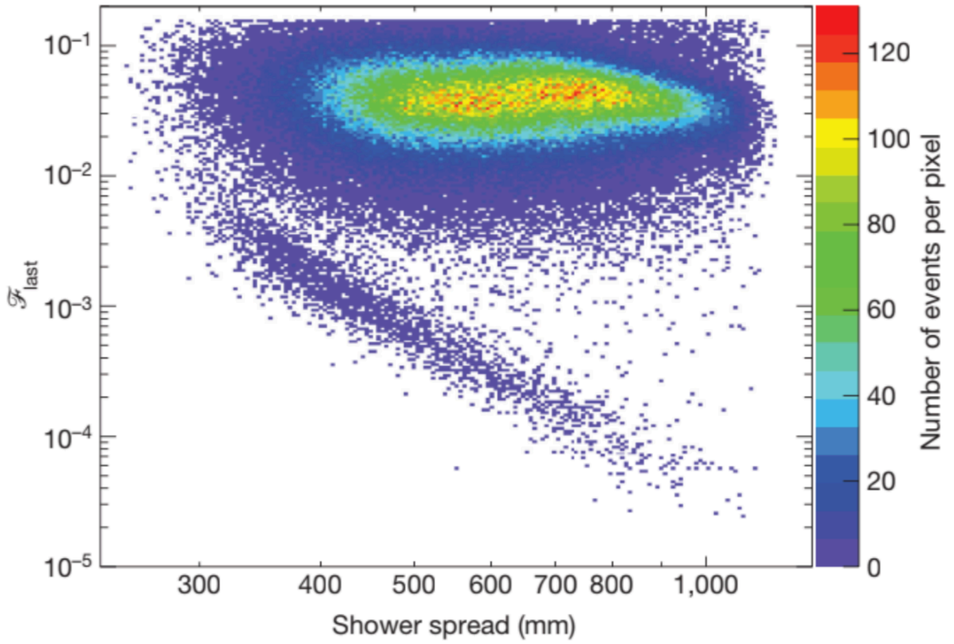
Neutron Detector (NUD):

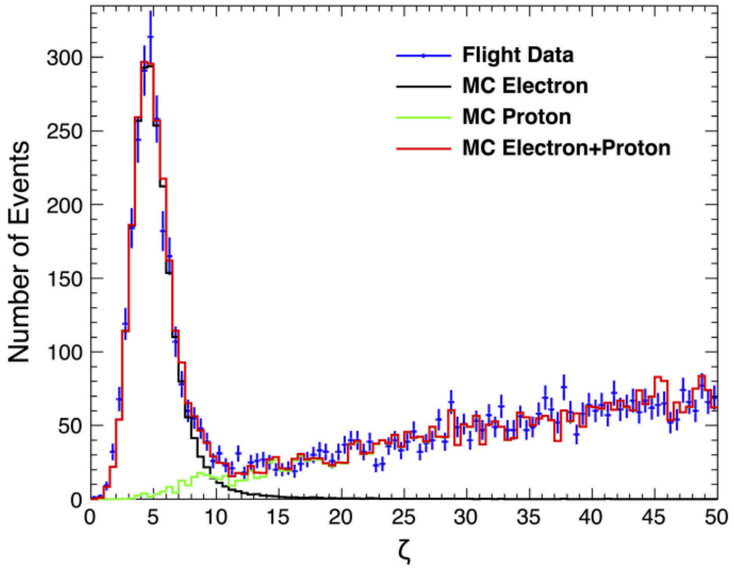
- electron/hadron separation



DAMPE electron-positron flux

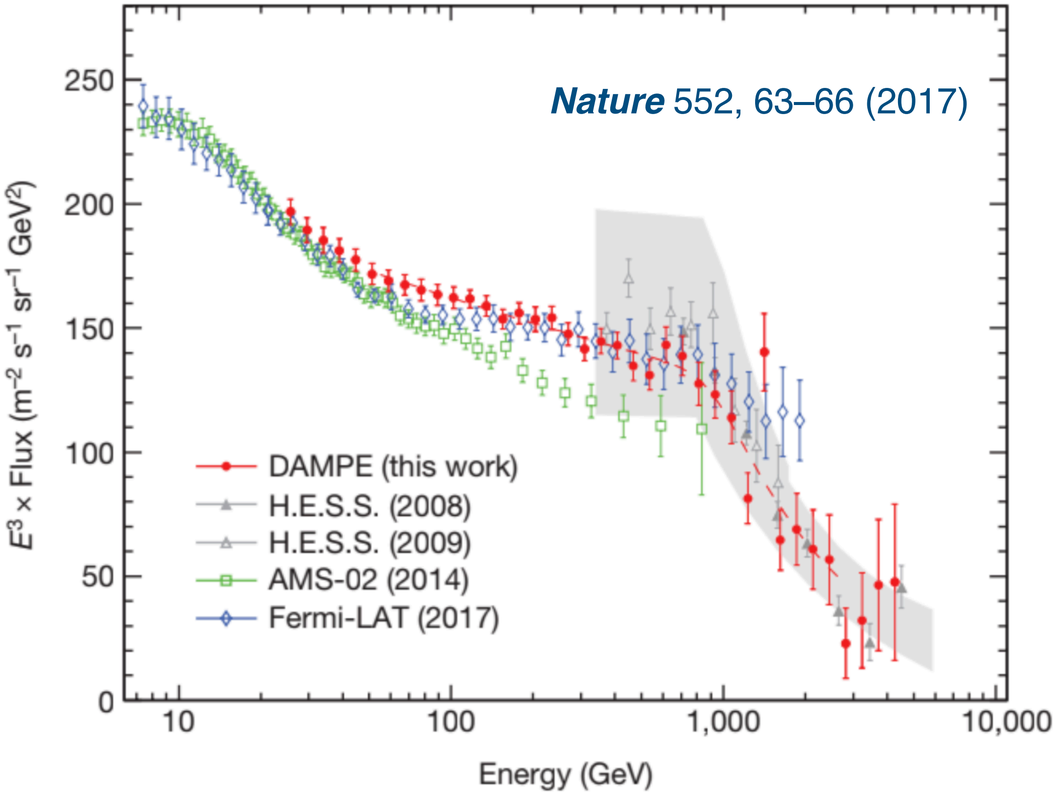
- Electrons deposit practically all their energy in the calorimeter
- DAMPE imaging calorimeter allows measuring the shape of electromagnetic shower, thus good background rejection from hadrons (protons/ions)
- Geant4 is used for simulations
- Good data/MC matching





DAMPE electron-positron flux

- Flux measured up to few TeV's
- Less than 3% background below 1TeV
- Hadronic simulations of proton background with different Geant4 models don't differ not much (<10%)
- Spectral hardening from at ~50GeV in agreement with other experiments
- Spectral break at around ~0.9TeV



Hadronic fluxes measurements

- While electrons deposit >90% of their energy in the calorimeter, hadrons on average deposit only a third of their energy.

  Statistical unfolding required so precise energy deposition simulation needed

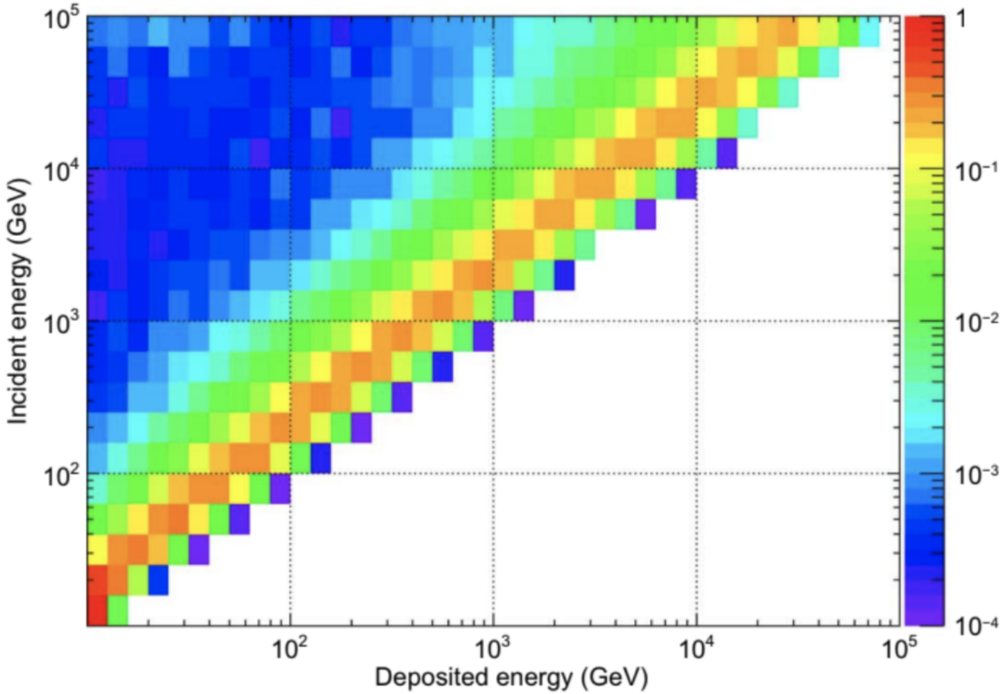
- Hadronic fluxes are 1-2 orders of magnitude bigger and also harder, they can be measured well into TeV-PeV energies

  Geant4 models work only up to 100TeV, so external generator was needed

- There is no fixed target lab data above ~TeV

  Results have to be compared with few generators to estimate systematics

MC responce matrix



Cosmic Ray Monte Carlo Package, CRMC

Ulrich, Ralf; Pierog, Tanguy; Baus, Colin

The program "crmc" (Cosmic Ray Monte Carlo) is an interface giving access to different cosmic ray and non cosmic ray event generators by an easy-to-use command line interface. The output can be stored in different formats, i.e. in a root TTree or HepMC3 event file. It can also be directly used for Rivet analyses.

Submit feature requests and bug reports at https://gitlab.ikp.kit.edu/AirShowerPhysics/crmc/-/issues

Supported models:

* Post LHC : EPOS LHC, QGSJETII-04, SIBYLL2.3d, DPMJETIII 2017-1

* Pre LHC : DPMJET 3.06, EPOS 1.99, QGSJET01, QGSJETII-03

* Further model: FLUKA, Gheisha, UrQMD, Pythia6, HiJING, phojet

https://doi.org/10.5281/zenodo.4558705

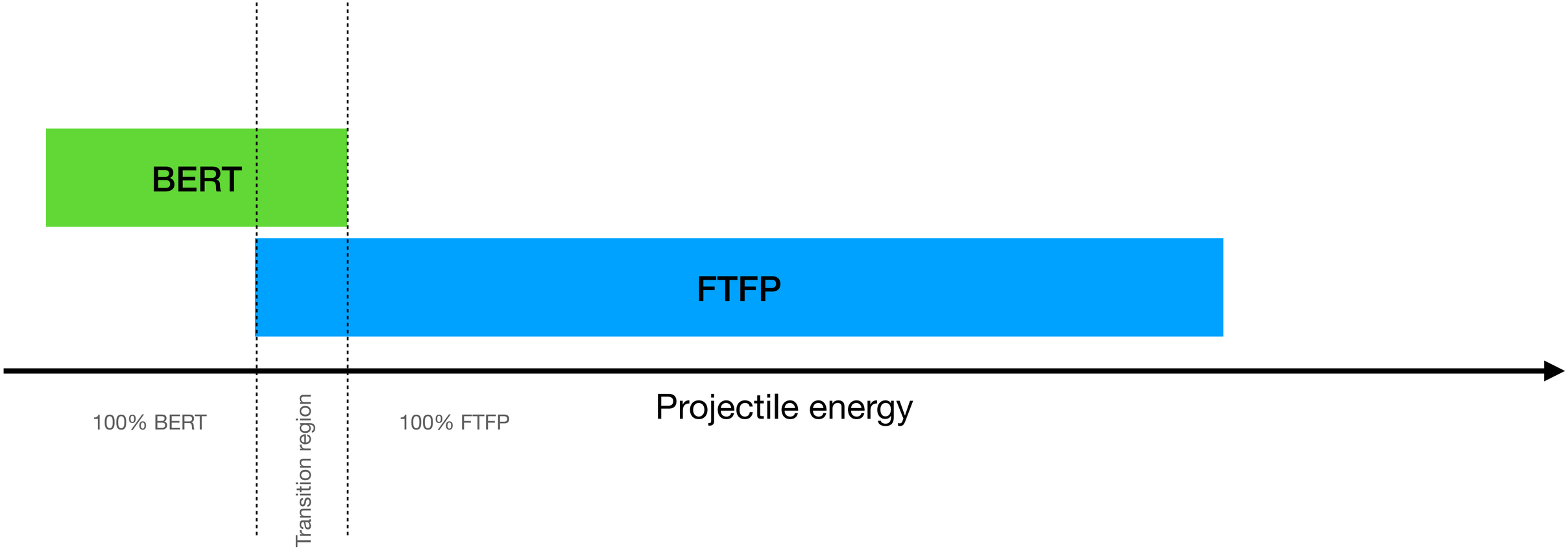
https://gitlab.iap.kit.edu/AirShowerPhysics/crmc

Geant4-CRMC interface

- Provides an interface to CRMC from Geant4 allowing usage of CRMC generators at the highest energies
- Initially created by Andrii Tykhonov (University of Geneva) as a part of DAMPE software code
- Later was became a separate branch of CRMC repository
- Was integrated into CRMC starting ver.2.0.0 (latest version so far)

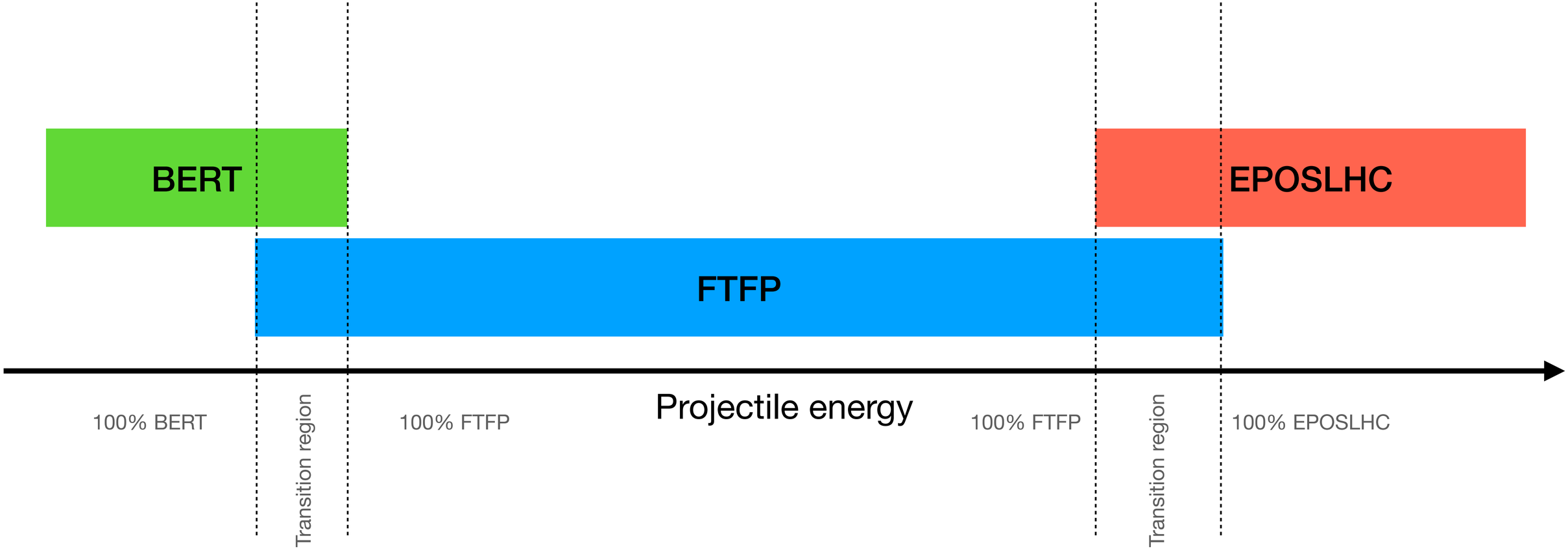
Geant4-CRMC interface

Geant4: “FTFP_BERT” Physics list



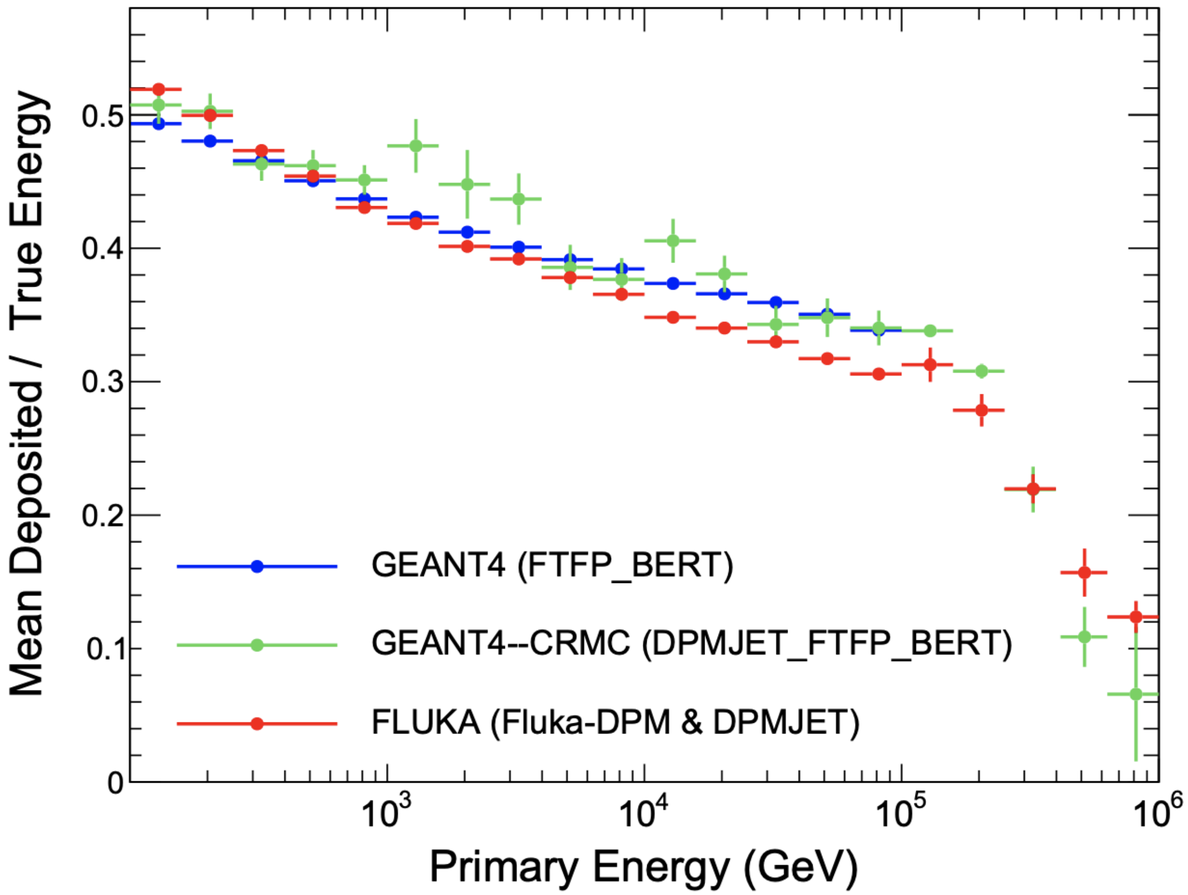
Geant4-CRMC interface

Geant4-CRMC: “EPOSLHC_FTFP_BERT” Physics list



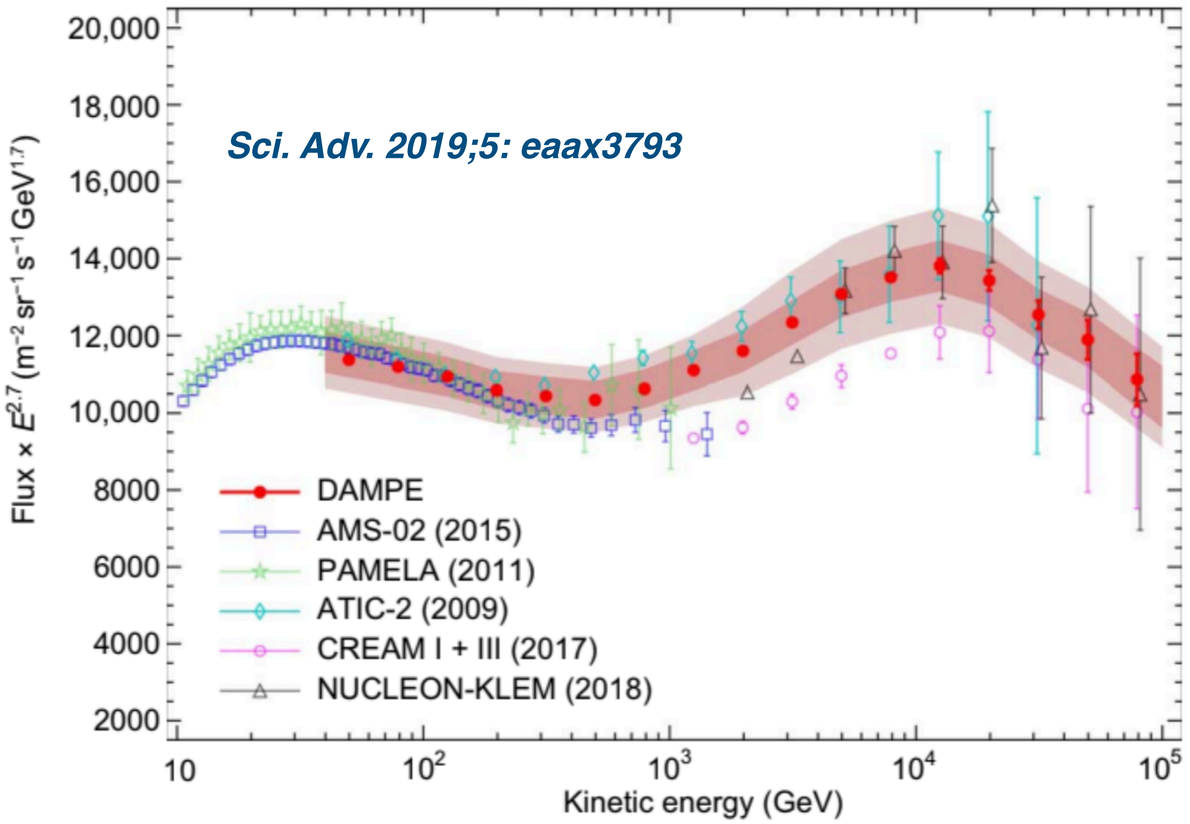
DAMPE simulations

- Geant4 is the default simulation tool in DAMPE
- DAMPE also uses FLUKA for simulations to estimate hadronic uncertainties
- Some difference in energy deposition at the highest energies is observed
    1. Geometries used are not completely equivalent
    2. Geant4 and FLUKA use different sets of cross-sections



DAMPE proton flux

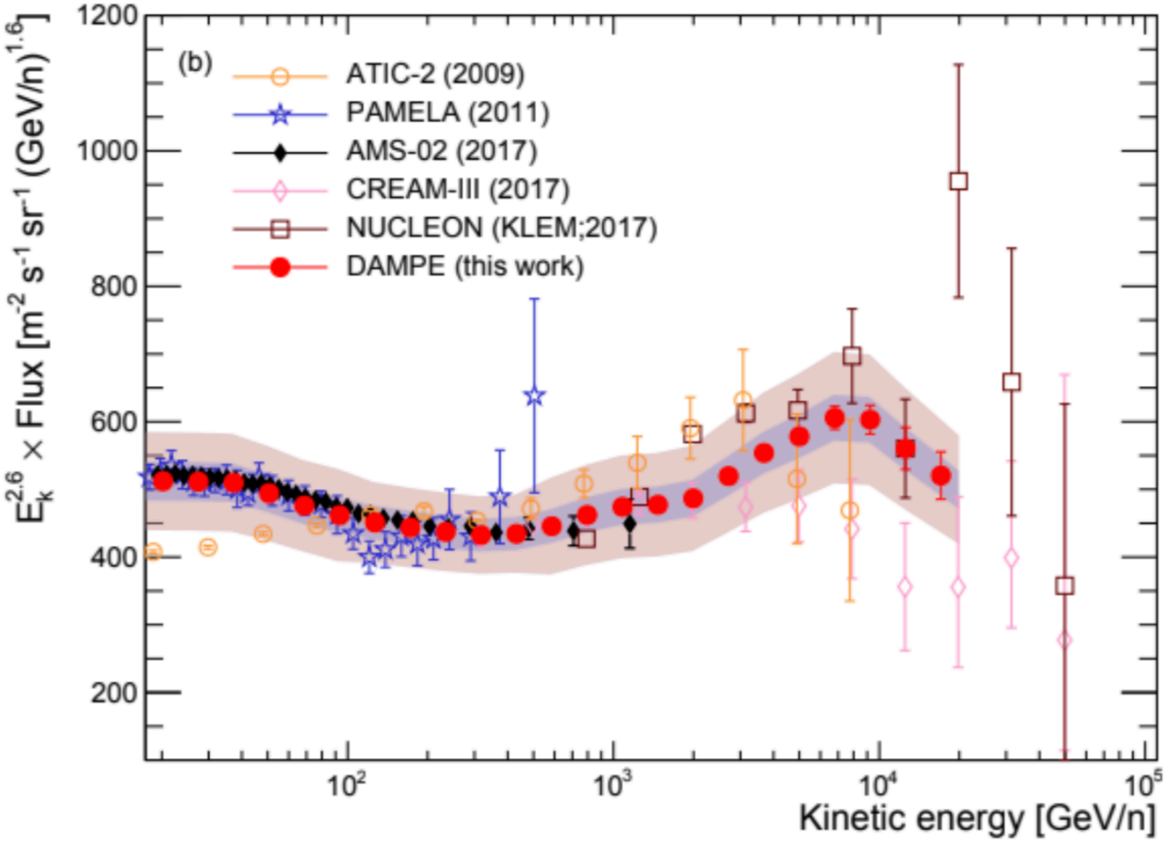
- High statistics for a direct measurement experiment
- Confirms spectra hardening at ~500GeV
- Reveals second break at ~14TeV
- Largely in agreement with other experiments
- Uncertainty is dominated by hadronic simulation systematics
- Hadronic uncertainties estimated as difference between Geant4 and FLUKA fluxes



DAMPE He4 flux

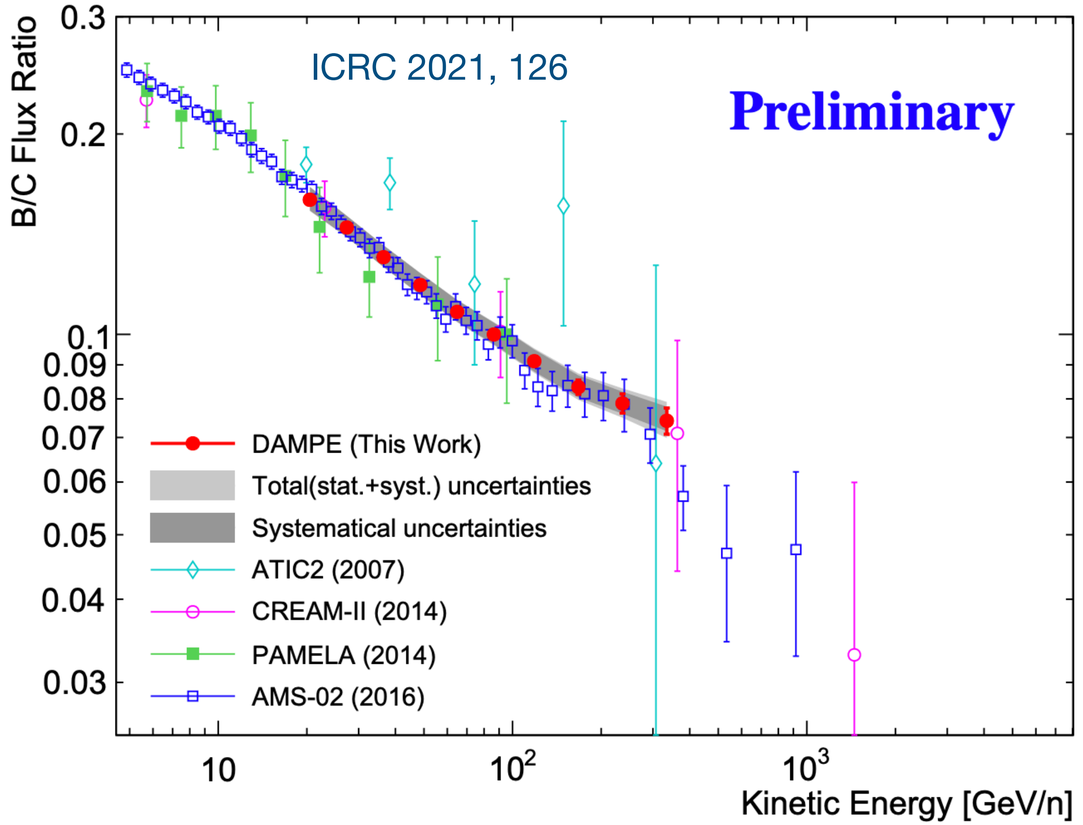
- Hardening at ~1TeV
- Reveals second break at ~34TeV
- Agreement with other experiments
- Uncertainty is dominated by hadronic physics simulation uncertainty
- Hadronic uncertainties estimated as difference between Geant4+EPOSLHC and FLUKA fluxes

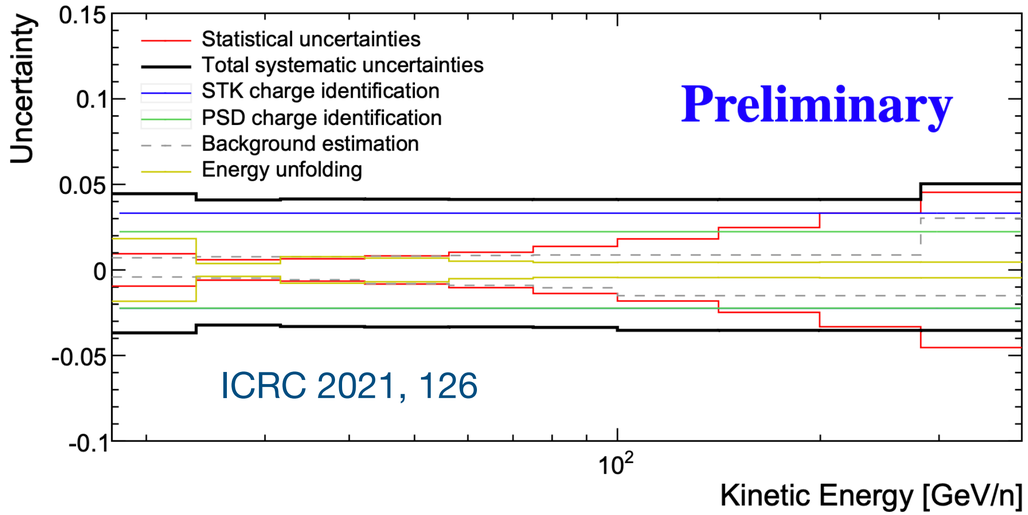
Phys. Rev. Lett. **126**, 201102



DAMPE B/C flux ratio

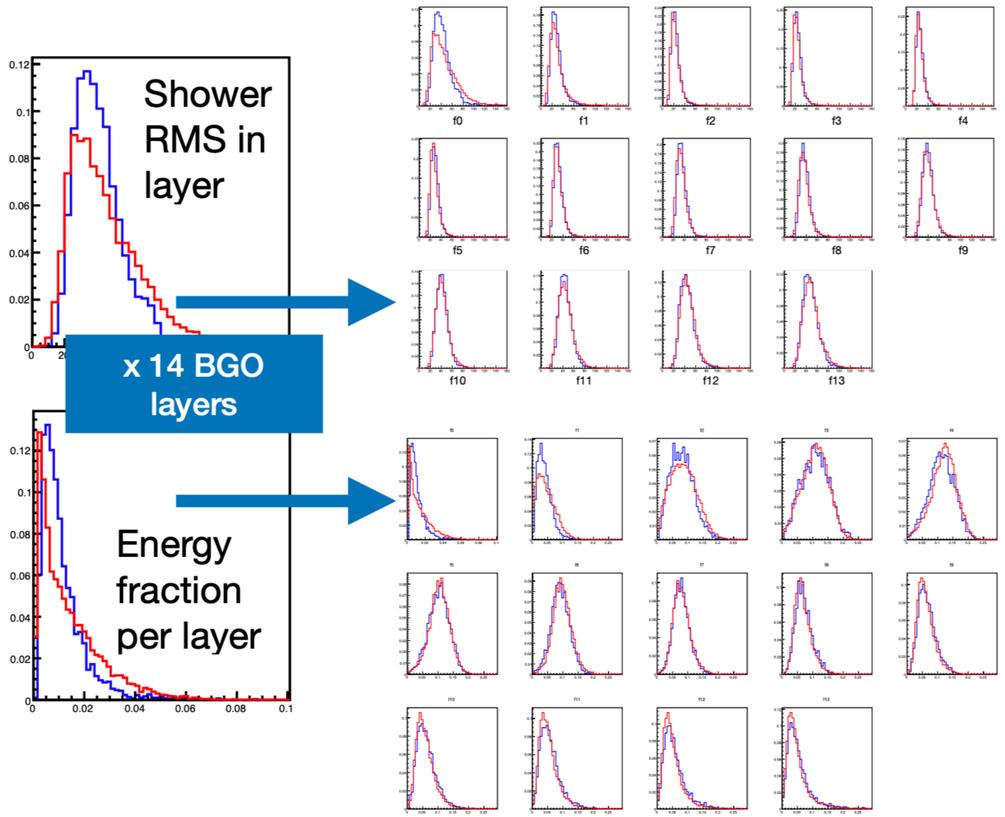
- Important result for understanding cosmic ray propagation
- Values are consistent with AMS and PAMELA
- Partial compensation of hadronic uncertainties

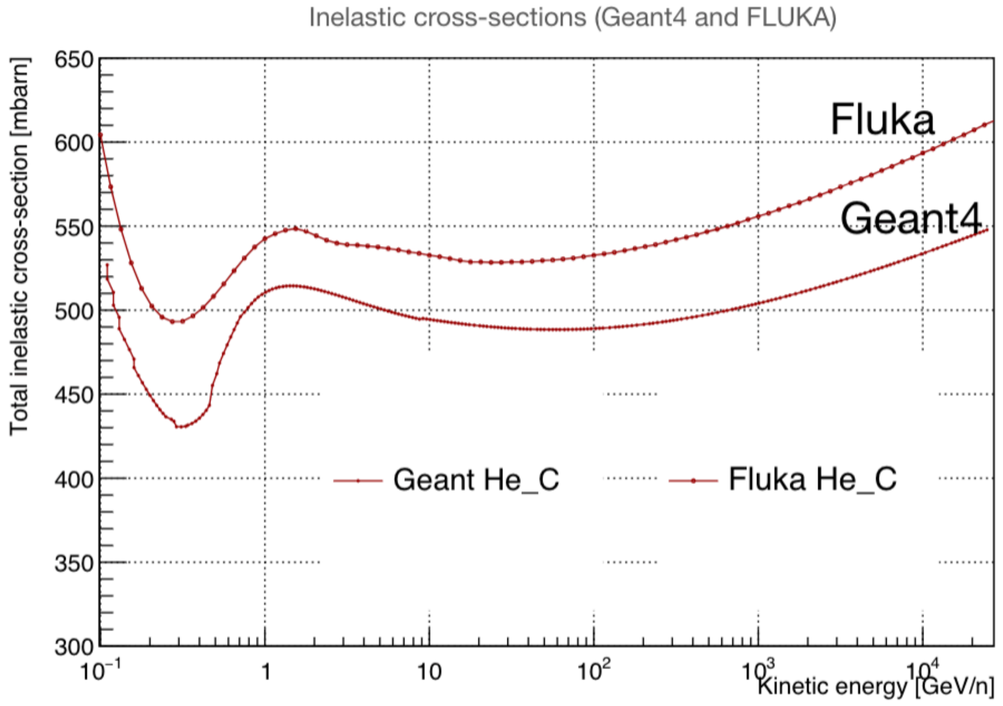




Hadronic systematics

What is the source of systematics from hadronic modelling and how to reduce it?





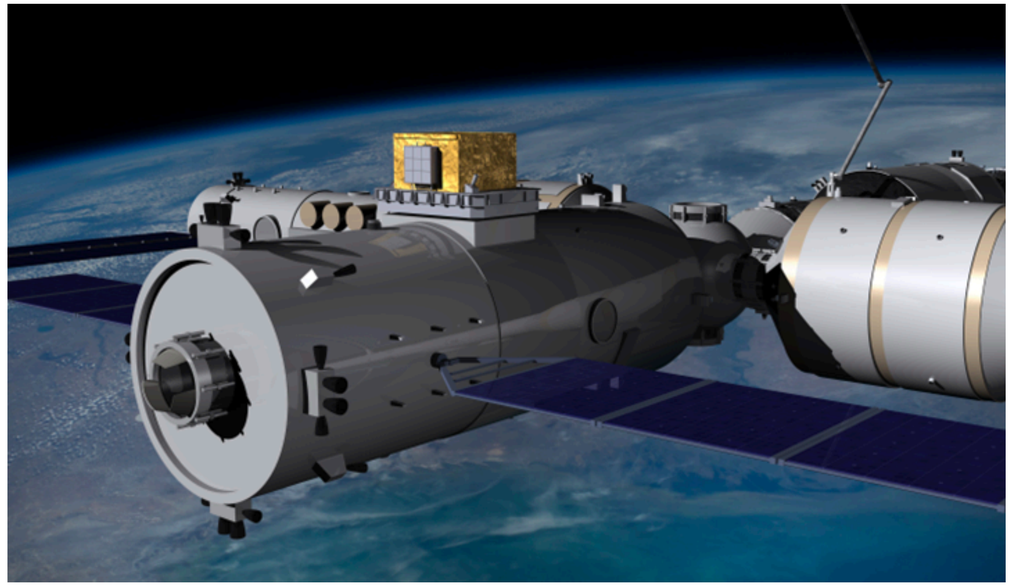
HERD experiment

High Energy Cosmic **R**adiation **D**etection facility is next-gen direct cosmic ray experiment which would allow measurements at PeV energies.

Collaboration consists of Chinese, Italian, Swiss and Spanish institutions.

Planned to start data taking in 2027.

The detector will be mounted at CSS.



HERD detector

Silicon Charge Detector (SCD):

- Assures the best charge measurement

Plastic Scintillator Detector (PSD):

- Z measurement
- gamma-ray anti-coincidence

Fiber Tracker (FIT):

- precise track reconstruction
- Z measurement

Calorimeter (CALO):

- 7500 LYSO cubes
- 55 radiation lengths, 3 interaction lengths (!)
- shower direction
- energy measurement

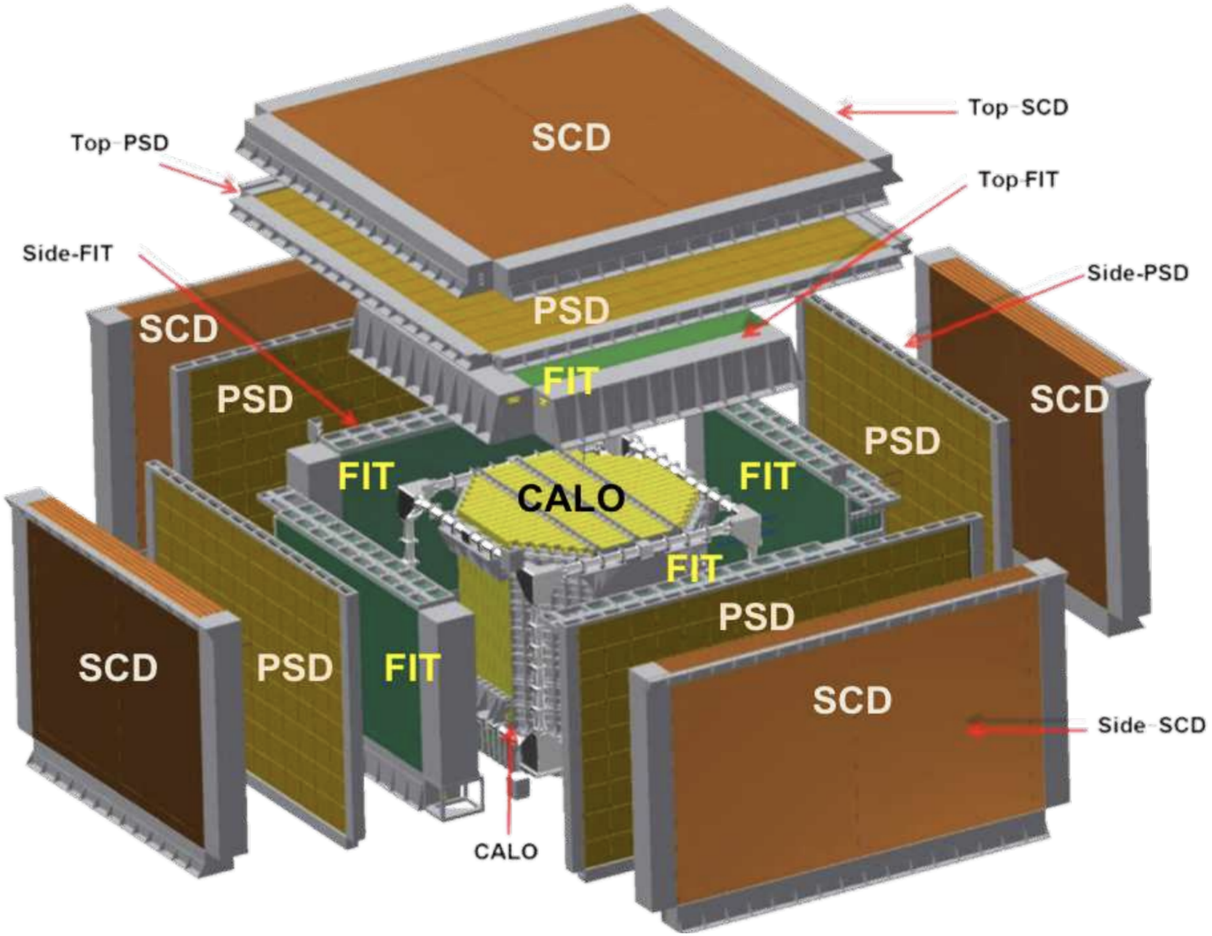
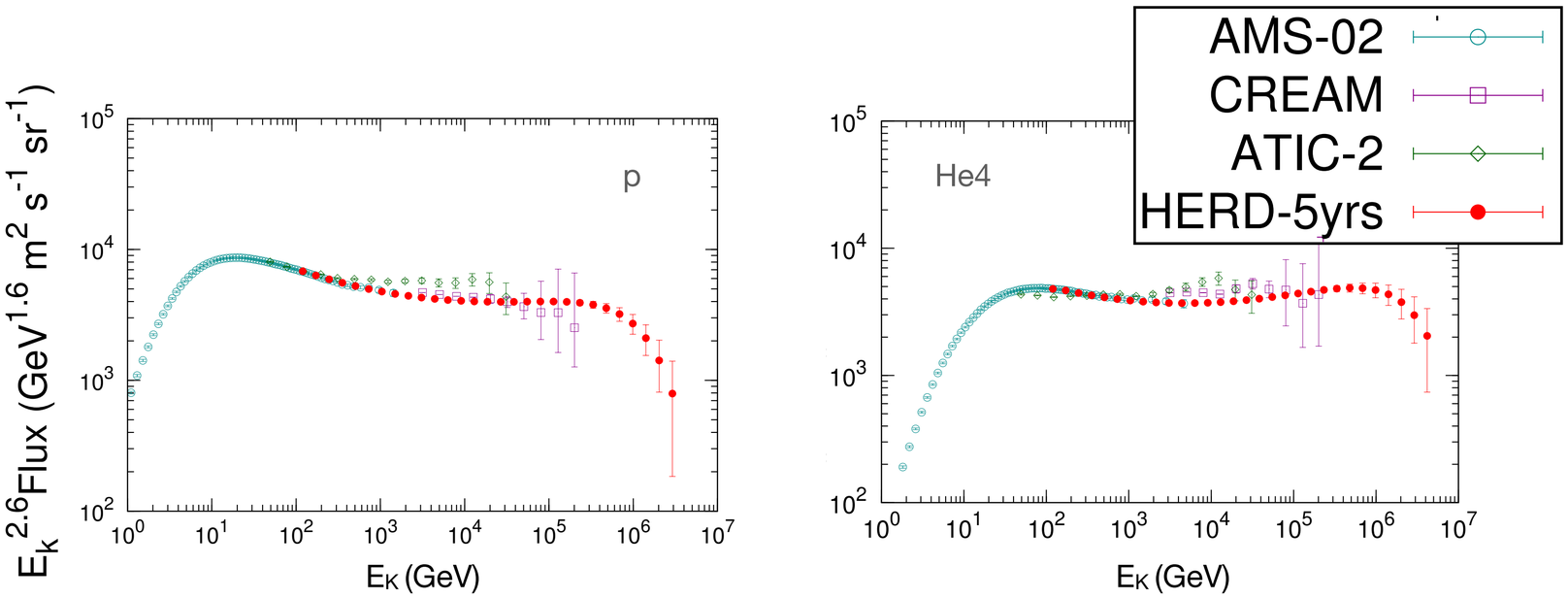


Image: D.Kyratzis, 15th meeting on advanced detectors

HERD expected performance

- Order of magnitude higher geometrical acceptance compared to DAMPE
- Would allow for electron measurements up to 100TeV and proton+ions up to PeVs



Only statistical errors are shown

Summary

- Measurements of hadronic fluxes are in TeV-PeV range require on hadronic simulations
- CRMC was used in published analyses and continues to be used other analyses
- Continuing collaboration :)