ERC PeVSPACE

Direct Detection of TeV–PeV Cosmic Rays in Space

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HERD collaboration meeting, Dec 16—18, 2019

Project in a nutshell

- In 2017 DAMPE collaboration achieved a breakthrough:

  Extended Cosmic Ray measurements beyond TeV
  with unprecedented energy resolution

- This opens a new field — Direct Cosmic Ray measurements in the transition from galactic to extragalactic origin

- PeVSPACE

  Fundamentally improve the measurement accuracy at highest energies (TeV—PeV) using state-of-the art Artificial Intelligence

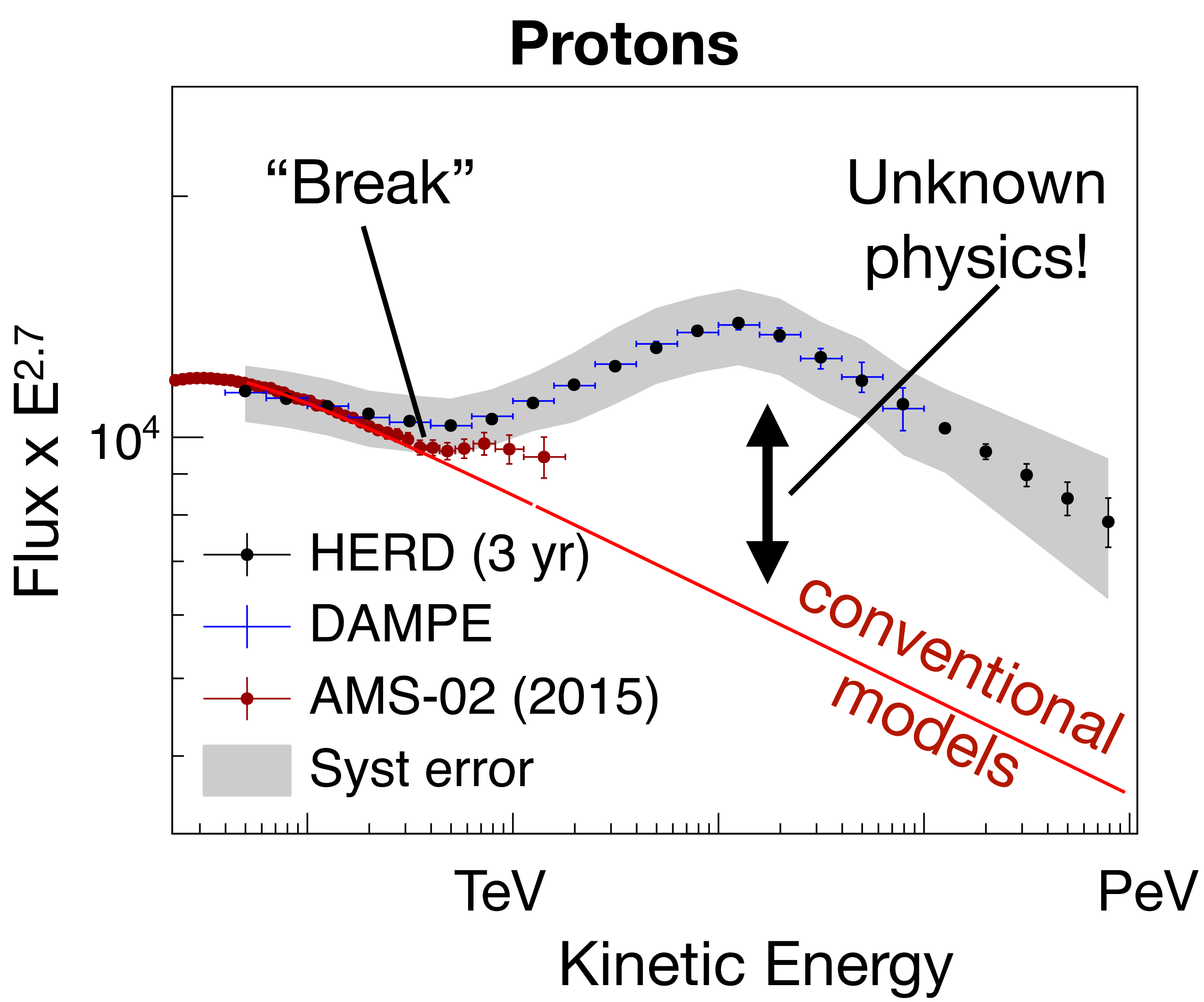
  To help solving key physics questions:

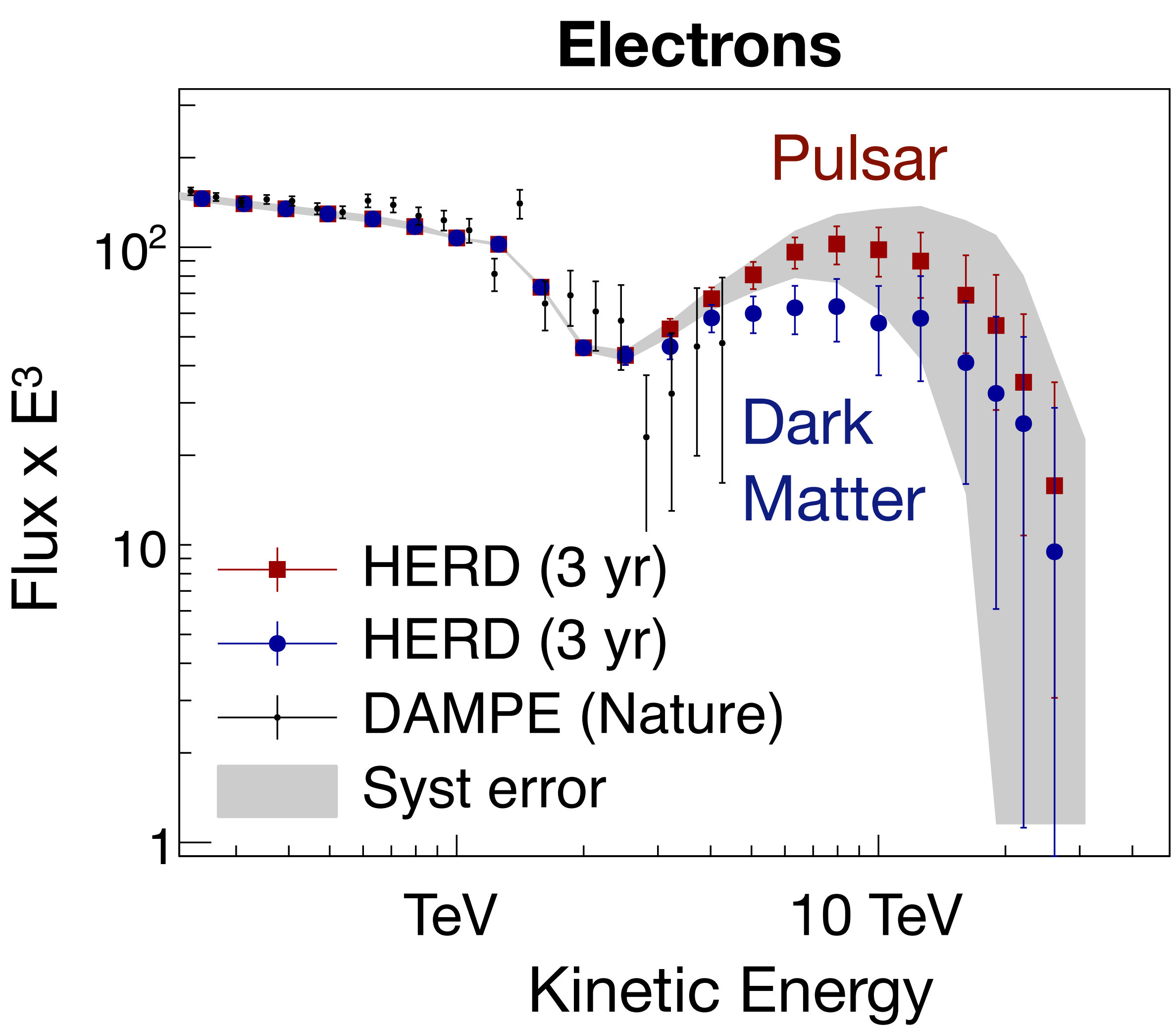
  nature of Cosmic Rays & Dark Matter

Project start in 2020, small group for 5 years (PI — Andrii Tykhonov)

Cosmic Rays

Measured with relatively low accuracy at TeV—PeV energies



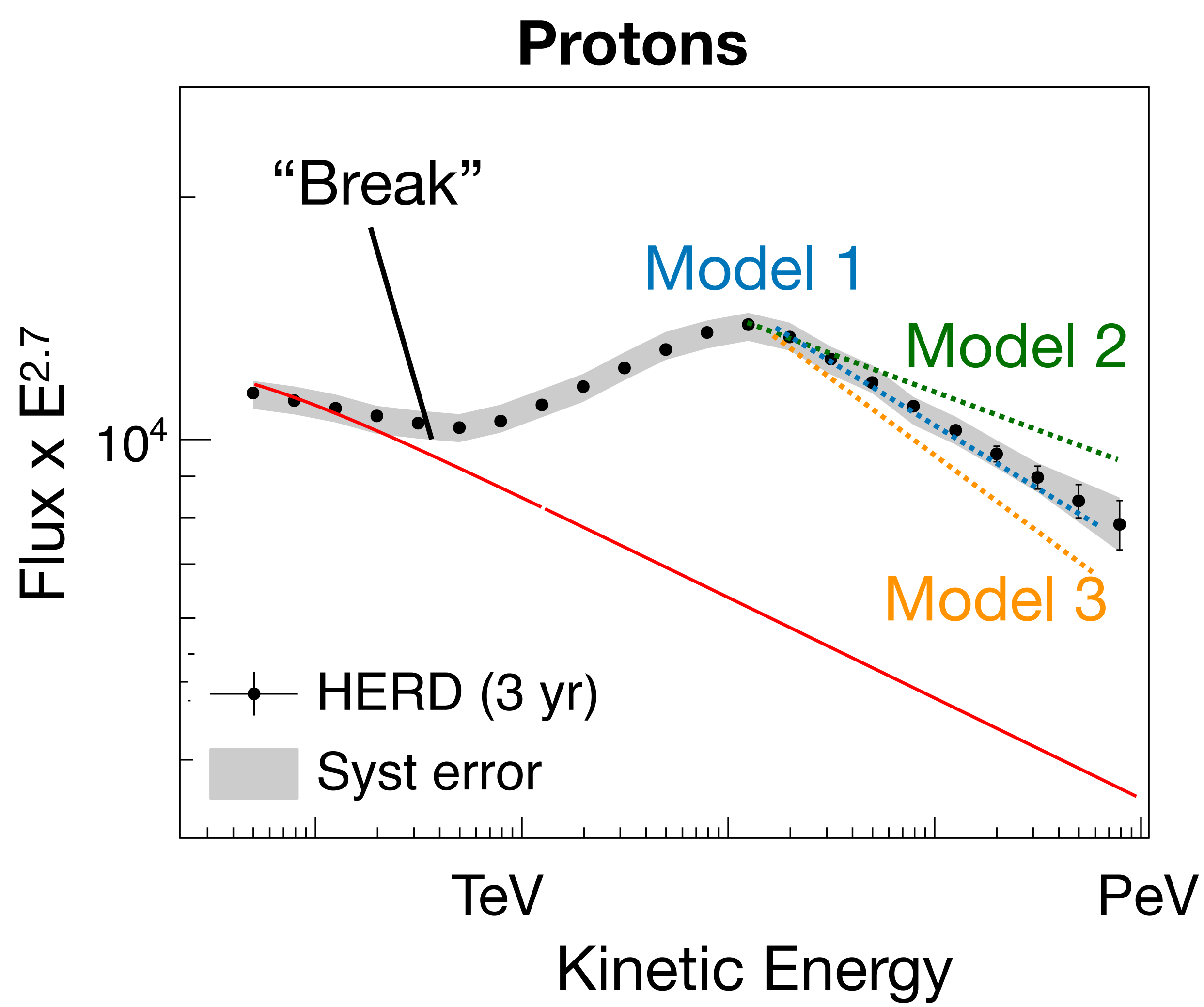


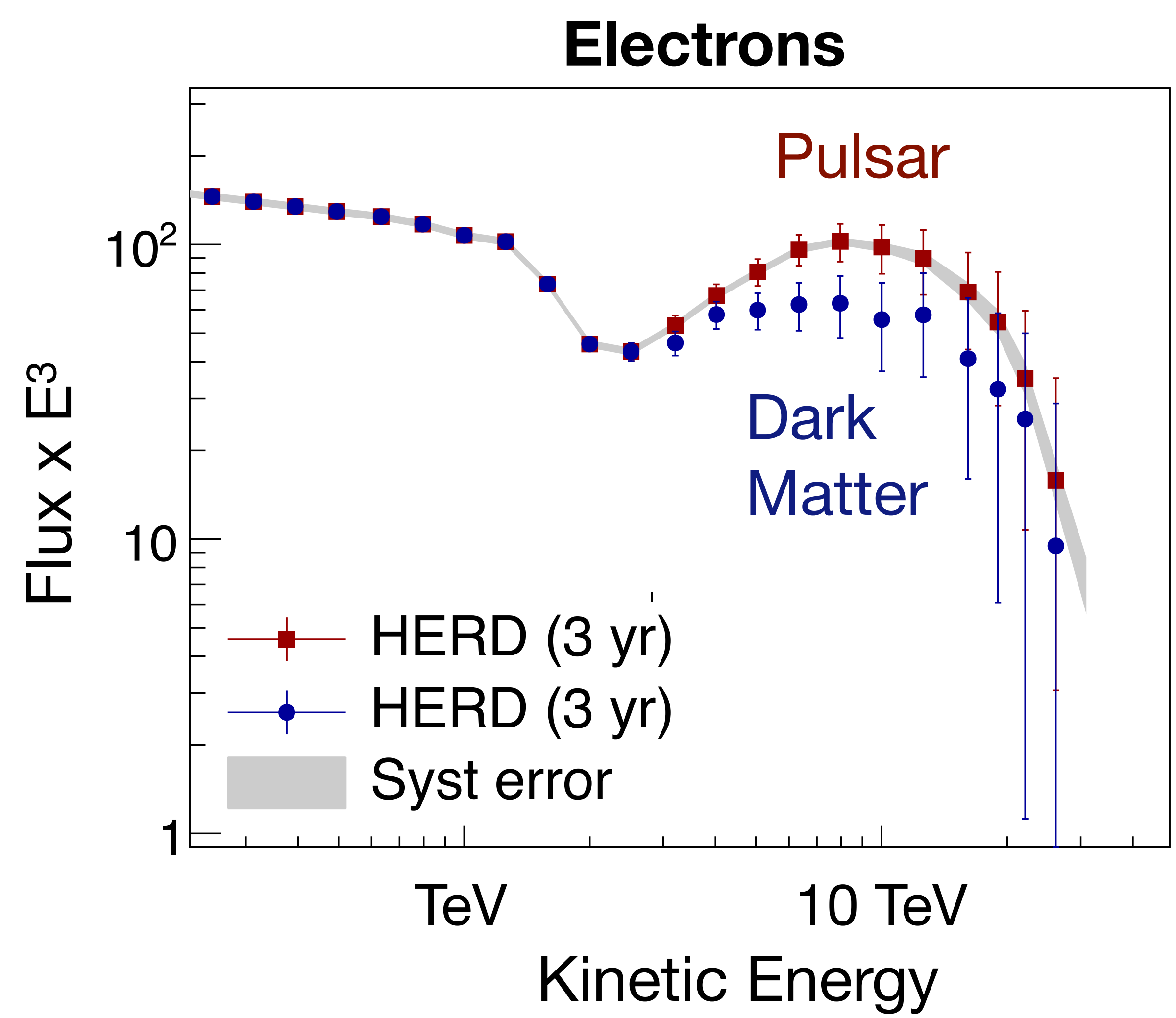
Key questions unanswered due to large systematic uncertainties

- Protons: origin of Cosmic Rays after the "break" at ~0.3 TeV?
- Electrons: Dark Matter contribution at multi-TeV energies?

Main goal of the project

Substantially improve measurement accuracy at TeV—PeV energies





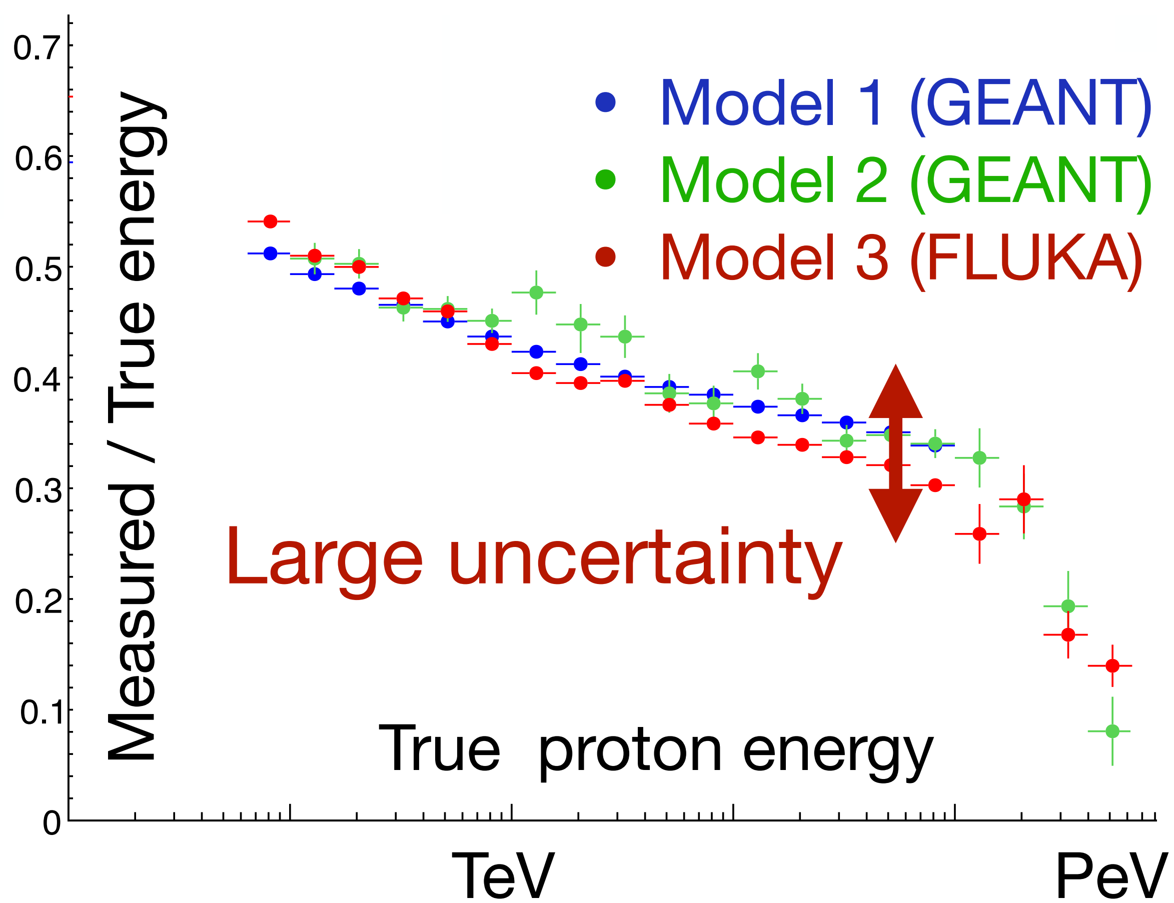
Help answering key physics questions

- Cosmic Ray origin and its effects on the Universe composition
- Nature of Dark Matter

Detection Challenge

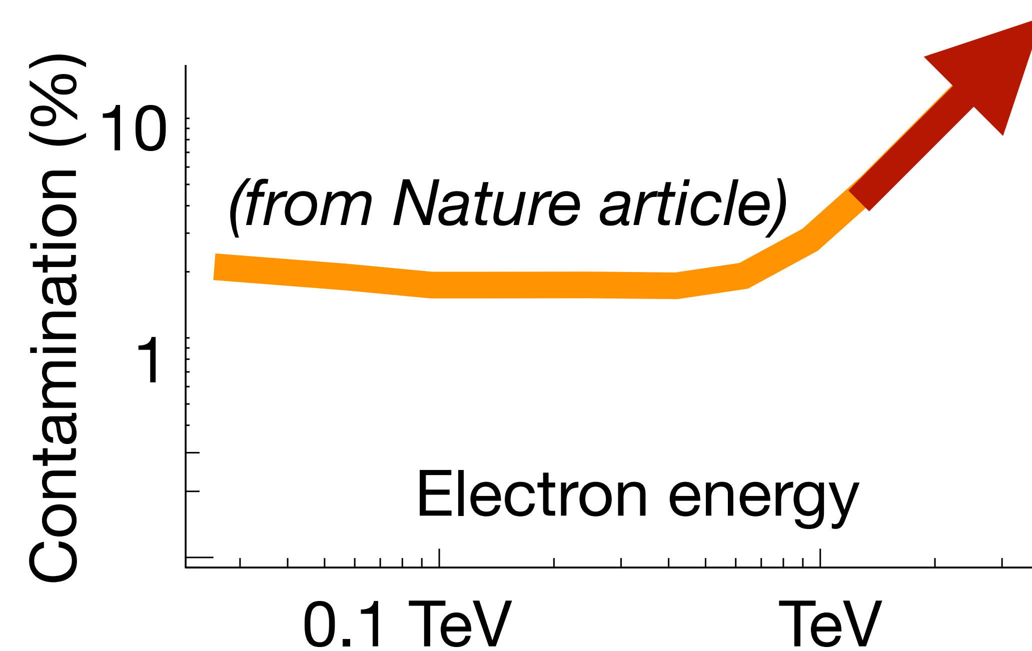
3 key factors affecting accuracy of Cosmic Ray detection in Space:

1. Limited accuracy of **hadronic simulations**



2. **Track reconstruction** & related charge (Z) estimation

3. High contamination of protons in **electron identification**



Approach

Problem	Approach	Expected Improvement	Innovation
Hadronic simulations	Identify and tune parameters of models & cross-sections using DAMPE & HERD data	Hadr. uncertainty from 15—20% to 1–5%	**First validation** of hadr. models at TeV—PeV energies
Track reconstruction	Apply Artificial Intelligence (AI) for particle hit classification	Charge estimation from 10—15% to 1–3%	**First application** of AI for particle tracking in Space
Electron identification	Apply Deep Learning to low-level data features for electron-proton discrimination	Proton rejection from 30% to 1–3%	**Unconventional** use of Machine Learning in Space

Reach at least one order of magnitude higher accuracy

Feasibility

- Improving accuracy of hadronic simulations
  - State-of-the-art models in DAMPE (cooperation with CERN, CORSIKA)

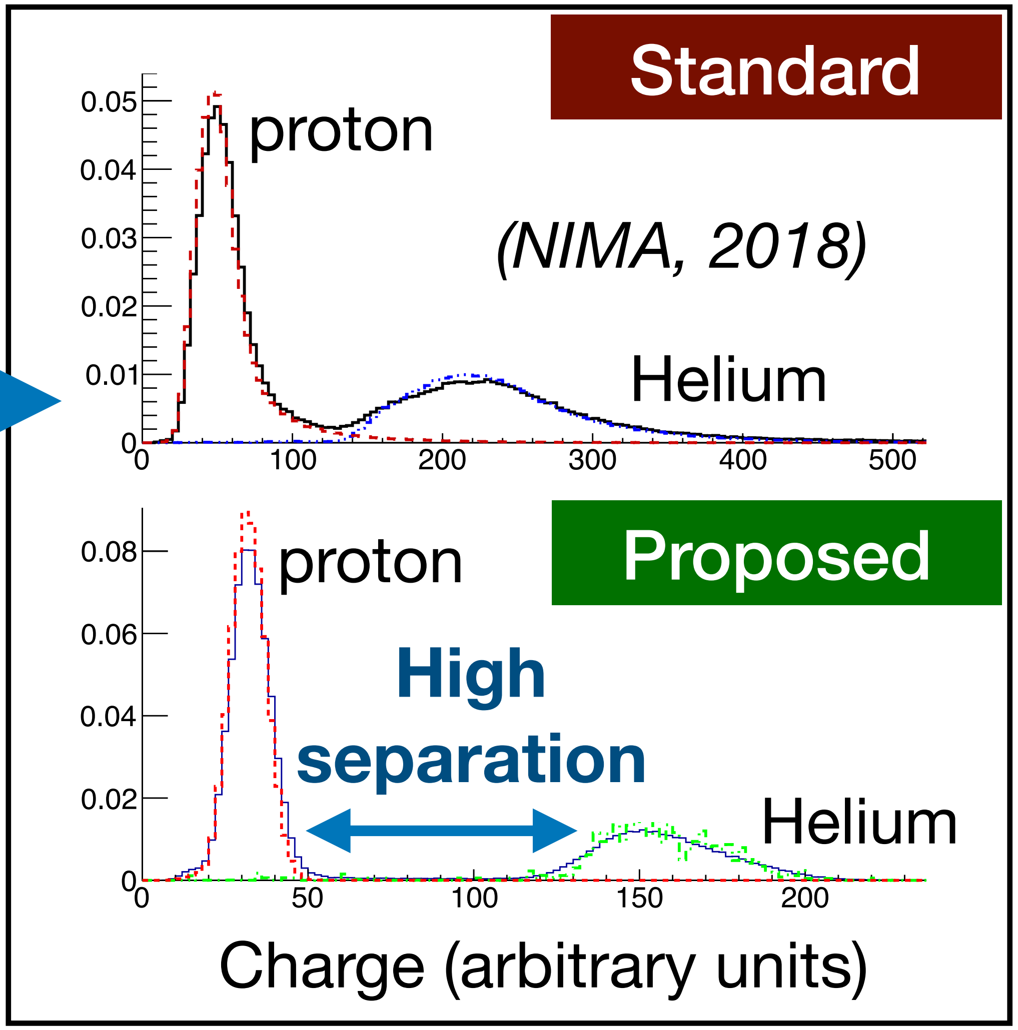
    … part of Geant4 release

- Proposed reconstruction approach
  - High proton/helium separation shown

- Electron identification
  - Implemented Neural/Convolutional Net

    ~2-3 times better proton rejection at 10 TeV

    (compared to *Nature* result)
  - Further improvement with more data



Expected results in physics

- Develop new Cosmic Ray detection techniques & methods
  - **Track reconstruction and electron identification**
  - Research program for improving **hadronic simulation**
- Measure Cosmic Ray Spectra (application to DAMPE)
  - **Electrons**, using developed electron/proton discrimination technique
  - **Protons**, using developed tracking & tuned hadronic models
- Long term (application to HERD)
  - Optimise developed techniques & methods for HERD

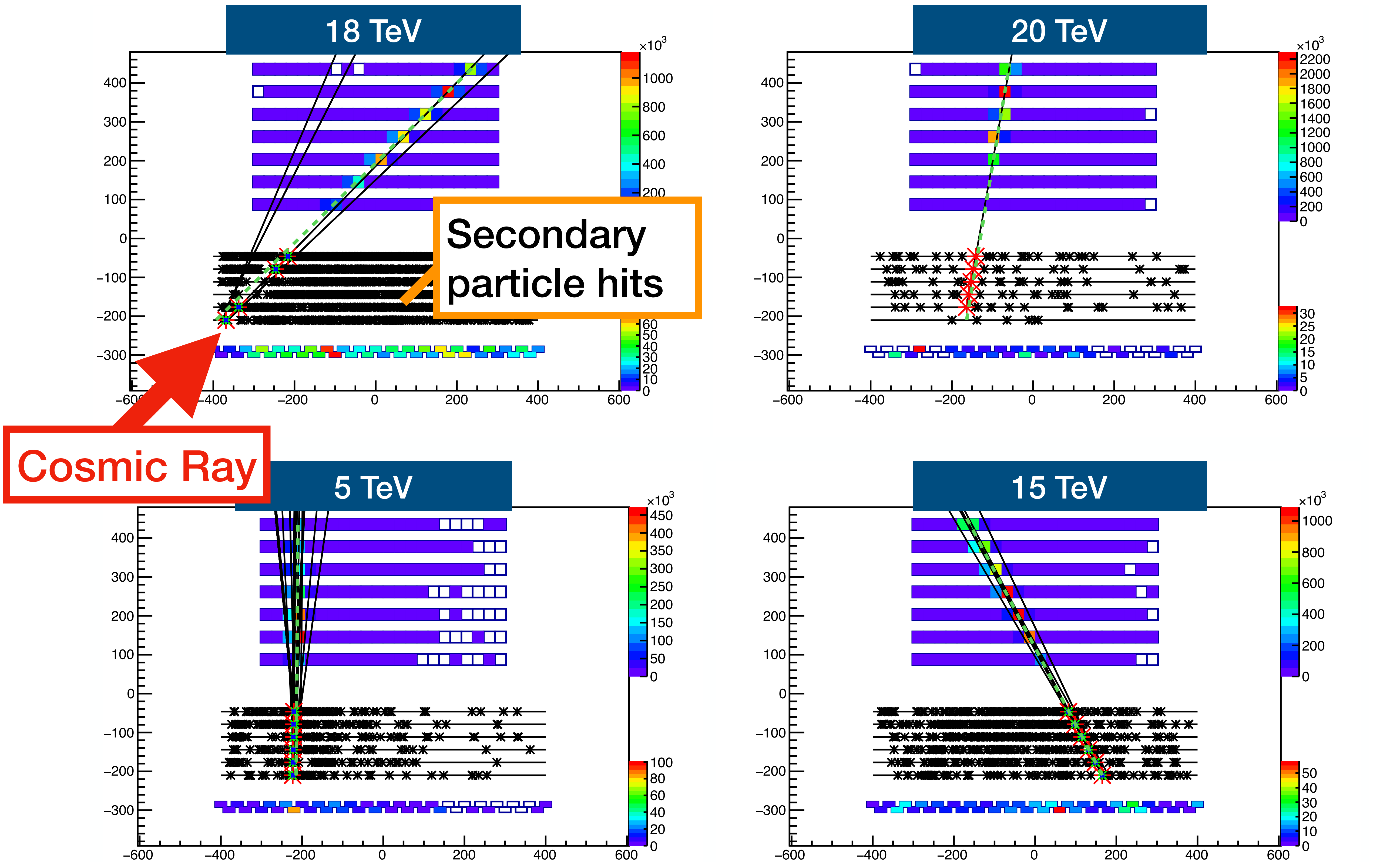
Summary

- Core — precision measurements of TeV—PeV Cosmic Rays
- Aim — help understanding origin of Cosmic Rays and Dark Matter
- Plan
  - Develop reconstruction & identification techniques
  - Set up research program for improving hadronic simulations
  - Apply to DAMPE data
  - **Long-term**: apply to HERD
- Feasibility — demonstrated with DAMPE data and simulation
- Interdisciplinary — physics, computer science

Ambitious (borderline of risky) project with immediate science impact

Problem of track reconstruction

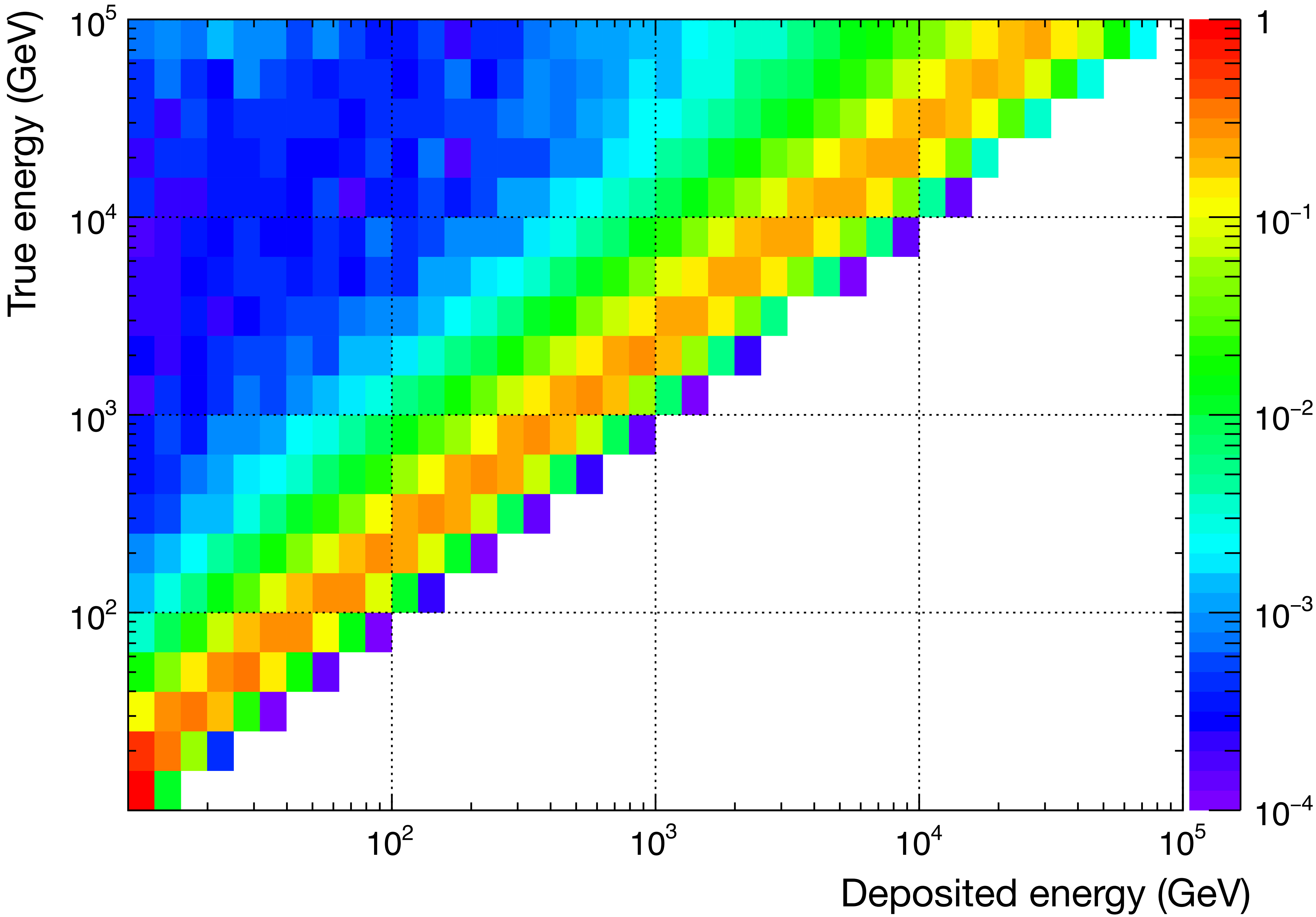
BACKUP SLIDES



BACKUP SLIDES

Problem of energy estimation

- Relation between true and deposited proton energy in DAMPE detector



Problem of energy estimation

- Relation between true and deposited proton energy in DAMPE detector
  - **Example**: one bin of deposited energy, 40—63 TeV
  - Obtained form simulation with 3 different spectral indices (2.7, 2.8, 2.6)