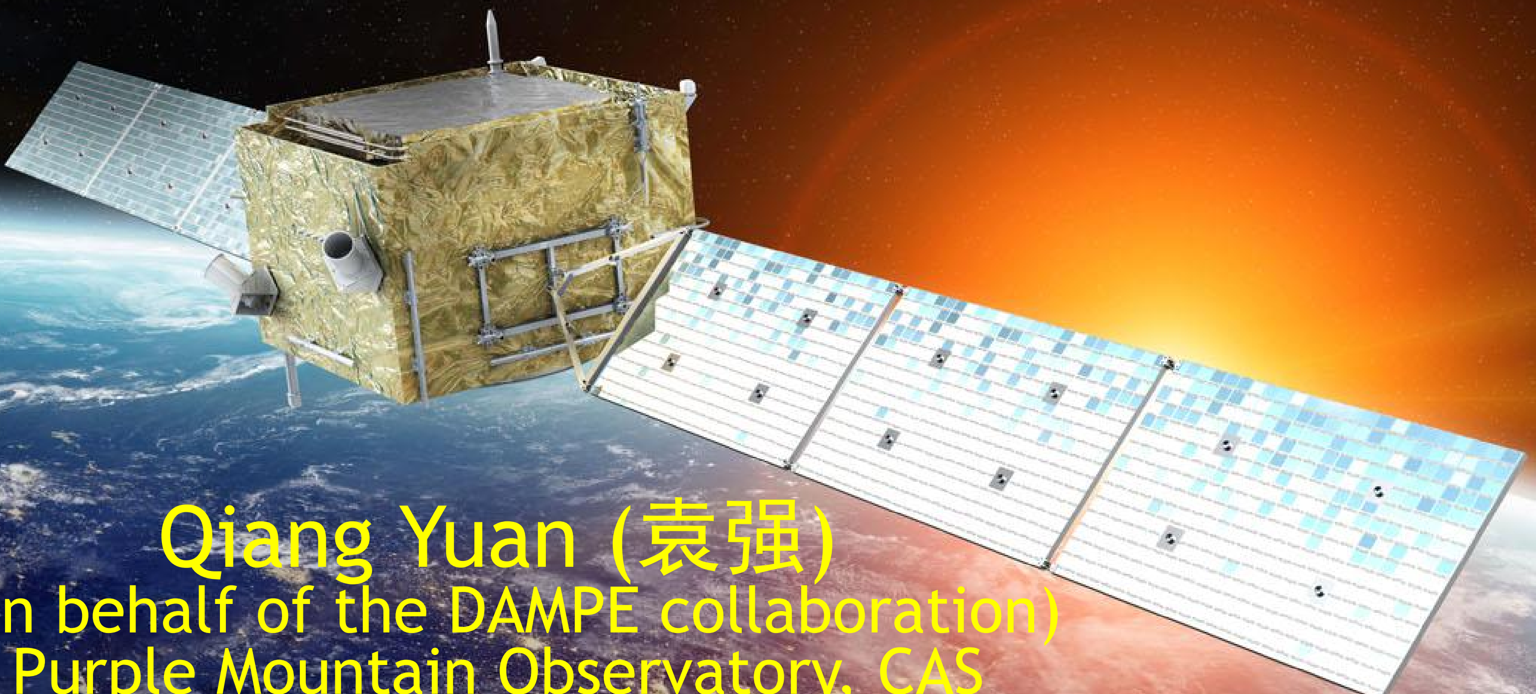
DAMPE experiment and its latest results



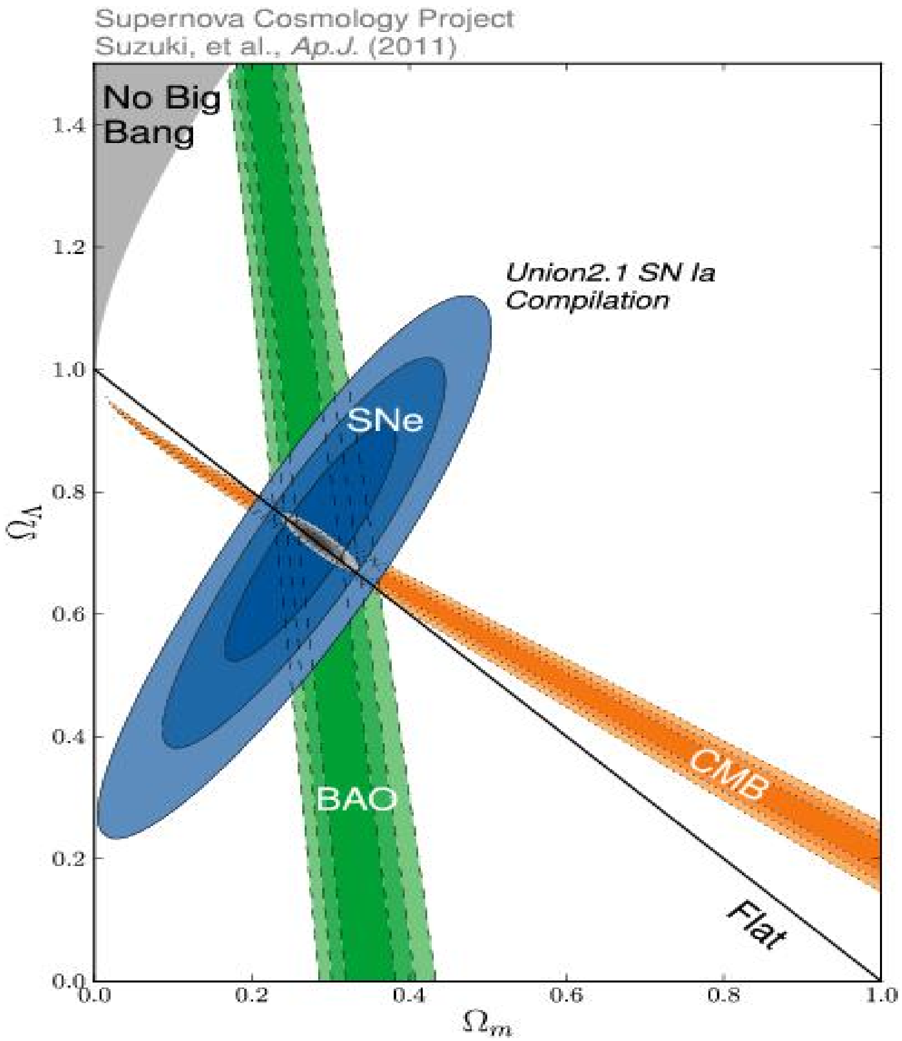
Qiang Yuan (袁强)
(On behalf of the DAMPE collaboration)
Purple Mountain Observatory, CAS

2018-10-11 @ NTU

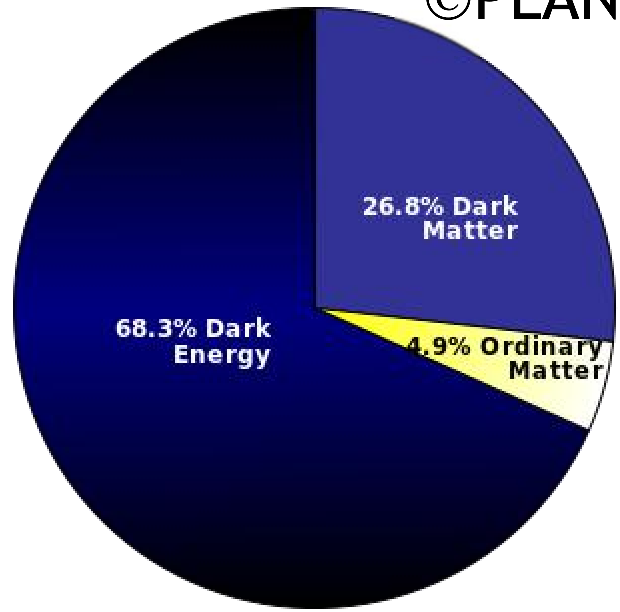
Outline

- Overview of dark matter indirect detection
- Dark matter particle explorer (DAMPE)
    - DAMPE experiment
    - Status and on-orbit performance
    - Physical results
- Summary

Composition of the Universe



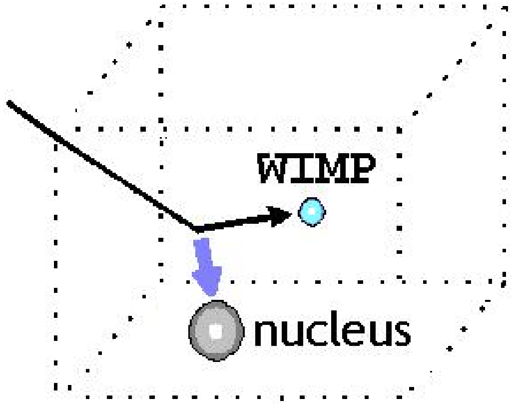
©PLANCK



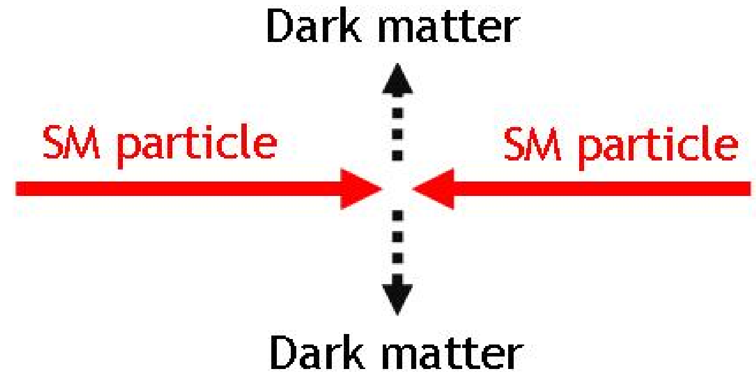
- The universe is made up of 68% dark energy, 27% dark matter and 5% ordinary matter
- We know little about the Universe!

Detection of (WIMP) dark matter particles

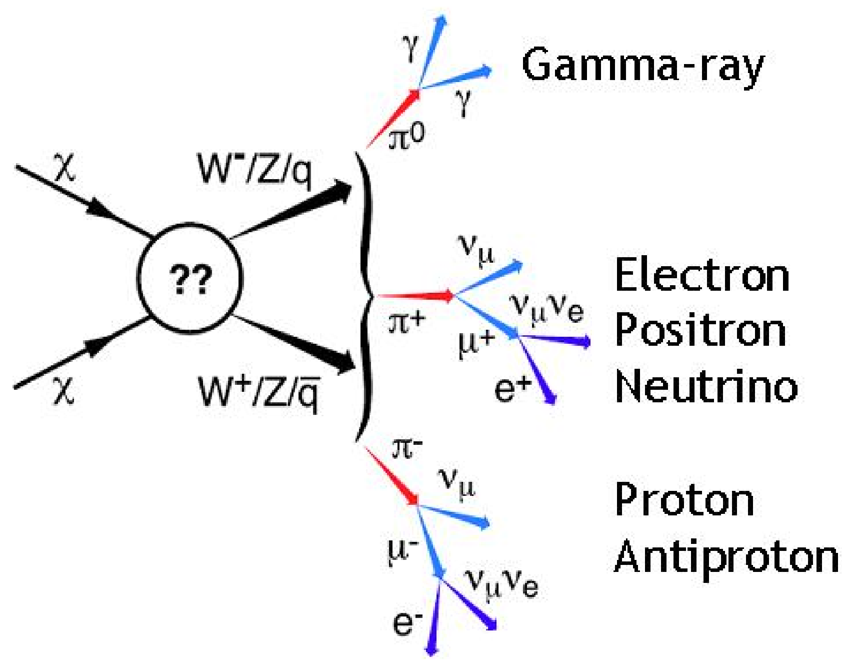
(a) Direct detection



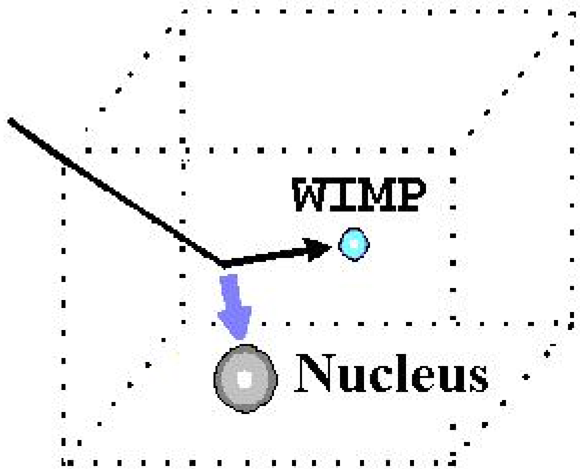
(b) Collider detection



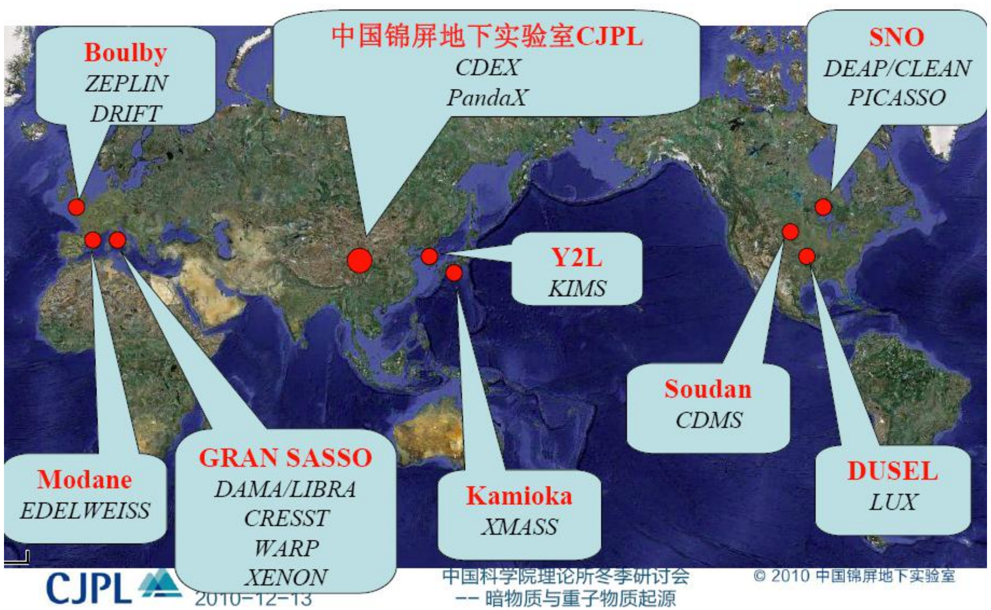
(c) Indirect detection

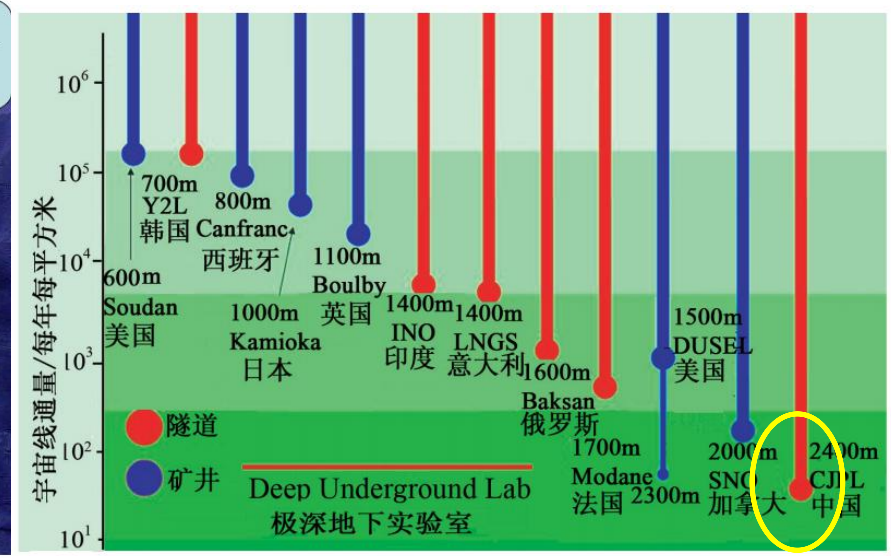


Underground direct detection

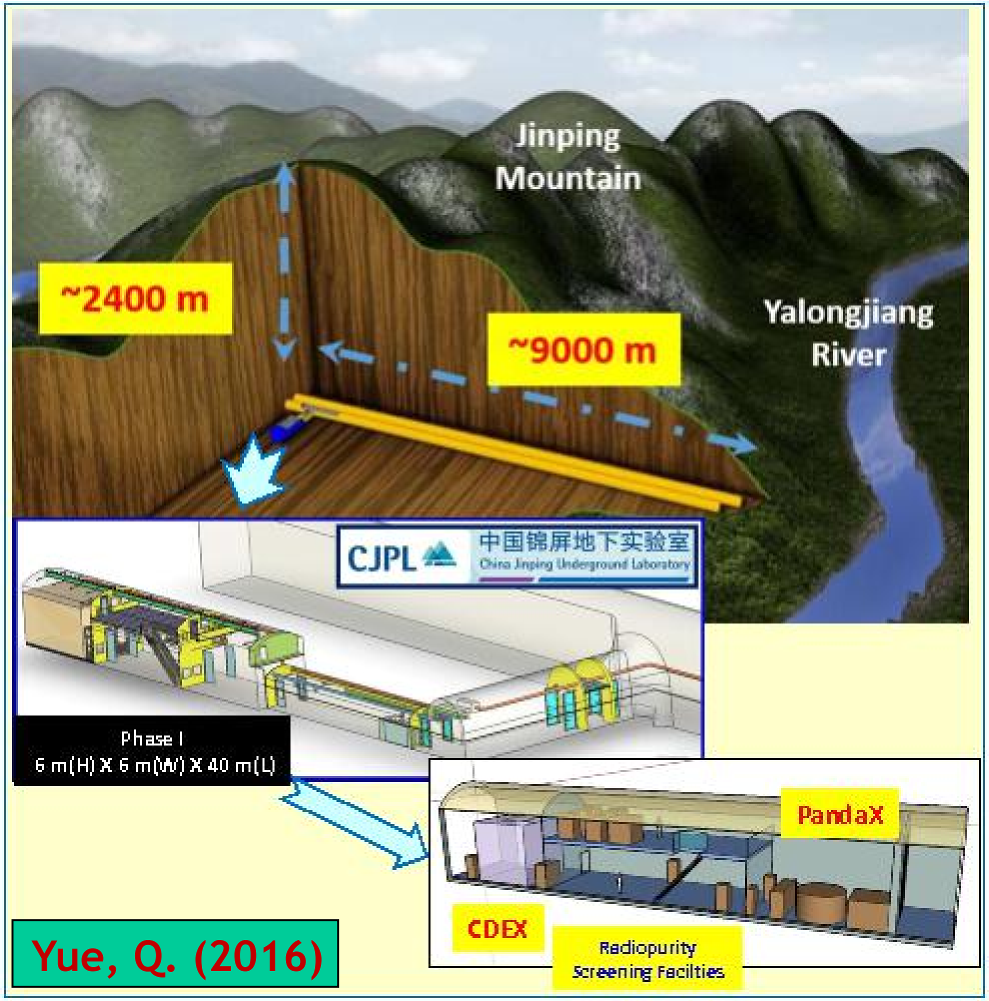


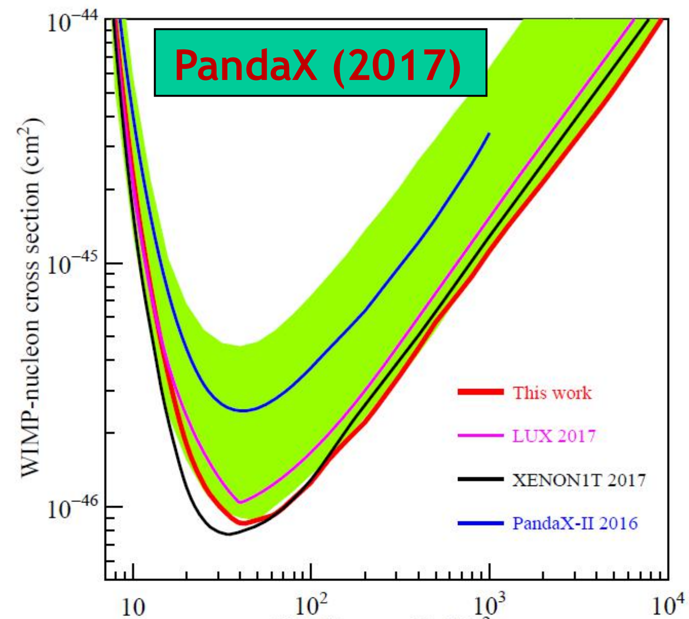
- Nuclear recoil from WIMP-nuclei collision
- Placed in deep underground laboratory to shield cosmic ray backgrounds

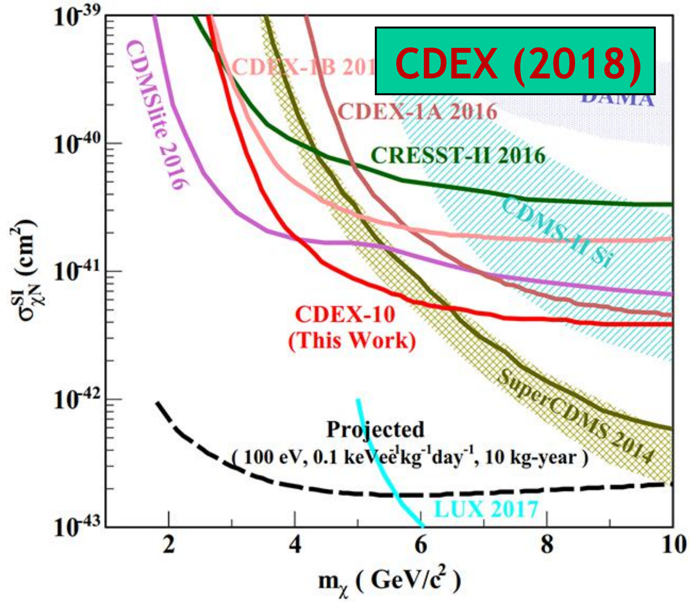




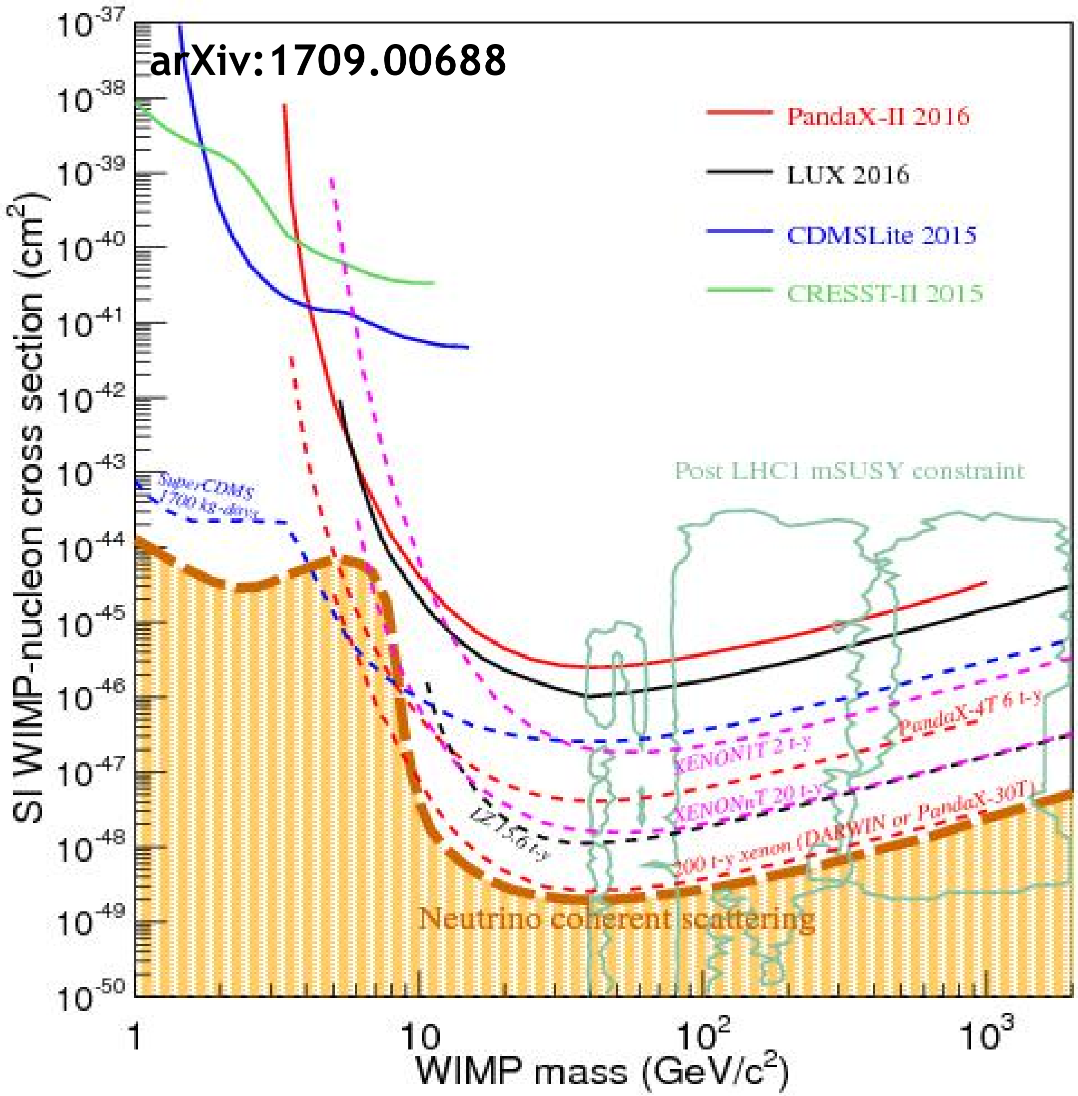
Jinping dark matter experiments





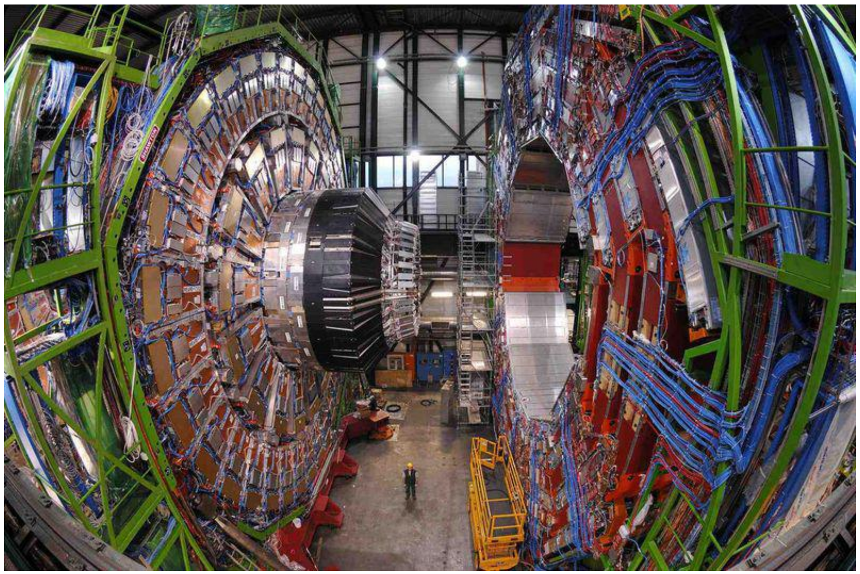


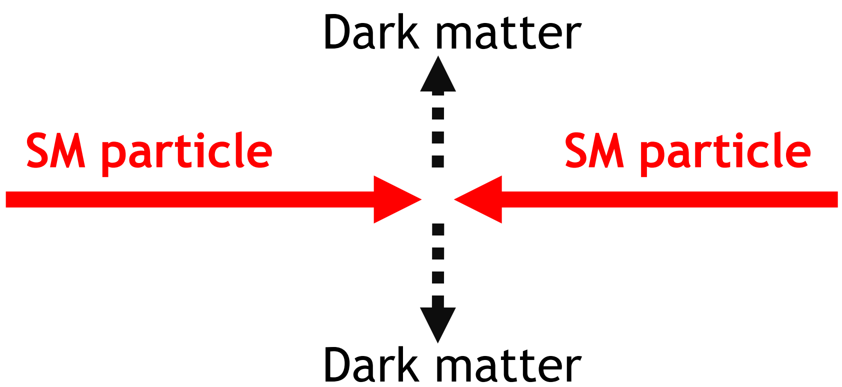
Current status



No signal has been successfully found. Stringent limits are placed.

Collider detection





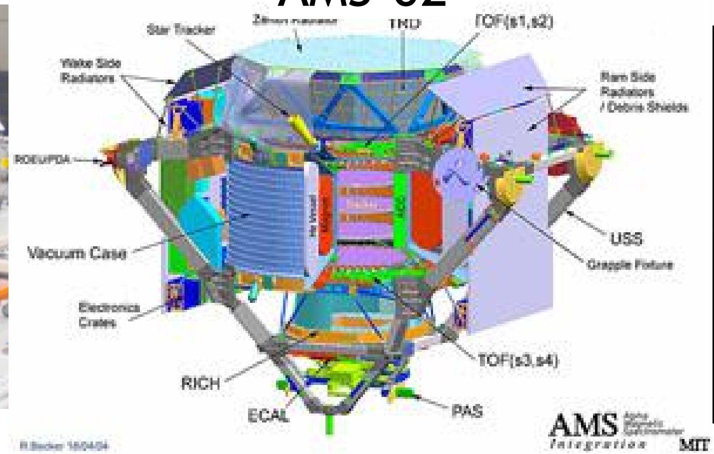
Missing energy events.

No signal of dark matter production has been identified yet in many colliders.

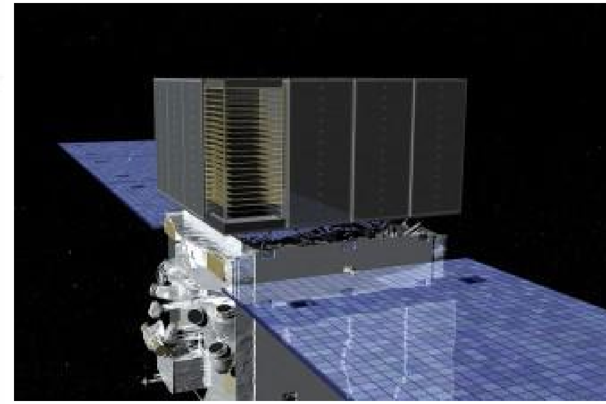
Some ongoing cosmic-ray/gamma-ray experiments

CALET

AMS-02



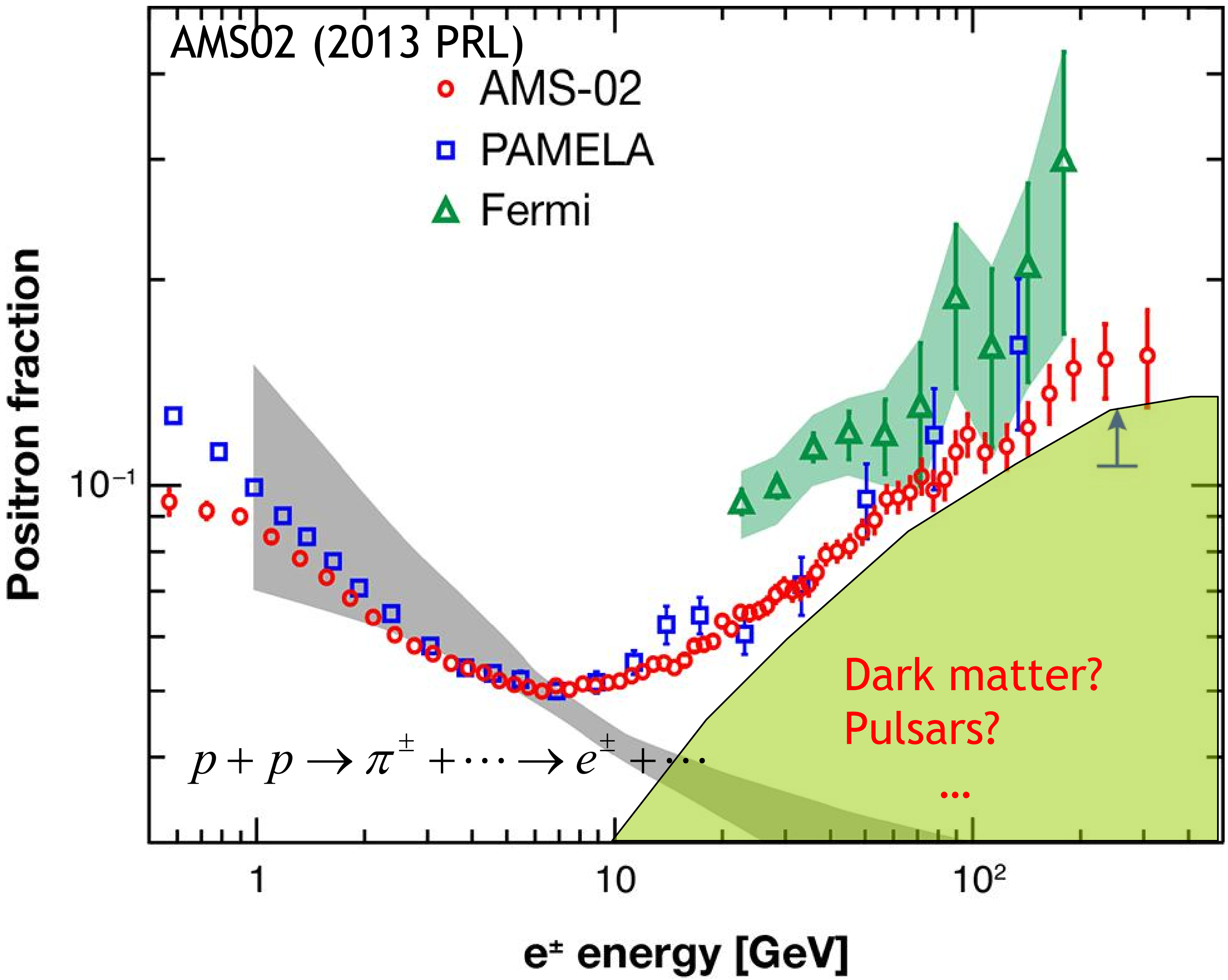
Fermi



Yangbajing/LHAASO

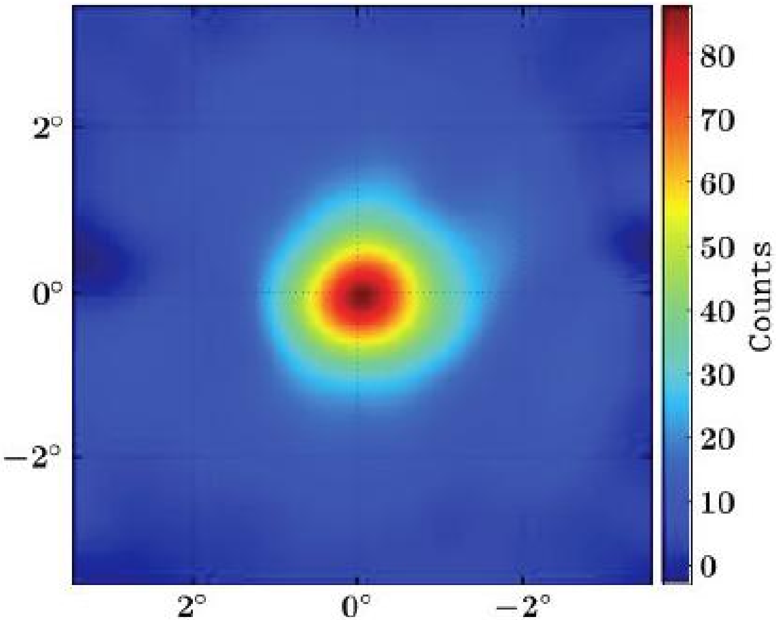
HESS/MAGIC/VERITAS/CTA

Excess of high energy positron fraction

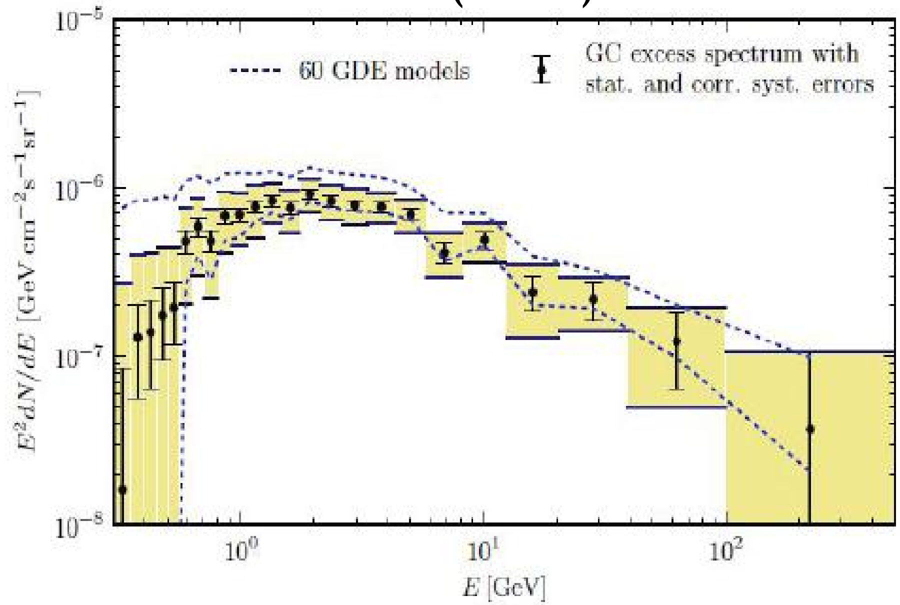


Gamma-ray excess from Galactic center

Gordon and Macias (2013)



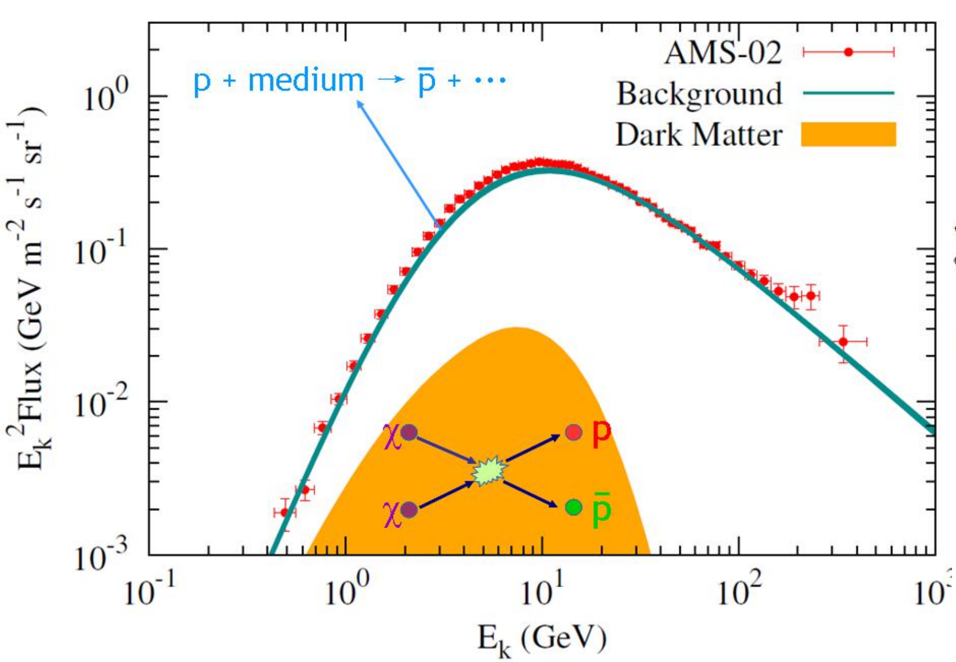
Calore et al. (2015)

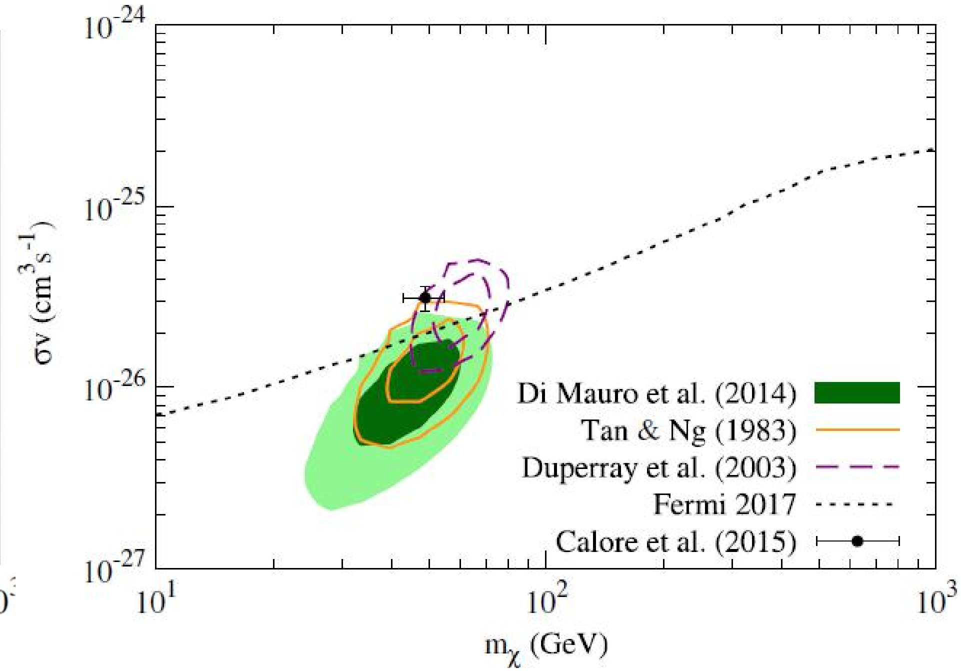


Goodenough & Hooper (2009)
Vitale & Morselli (2009)
Hooper & Goodenough (2011)
Hooper & Linden (2011)
Abazajian & Kaplinghat (2012)
Gordon & Macias (2013)
Huang et al. (2013)
Abazajian et al. (2014)
Daylan et al. (2014)
Zhou et al. (2014) ...

- Generalized NFW^2 distribution
- Spectrum peaks at 1-3 GeV
- Consistent with dark matter annihilation with 40 GeV mass and 10^{-26} cm^3/s cross section
- Millisecond pulsars?

Possible GeV antiproton excess?





- The standard background model under-predicts cosmic ray antipotons in 1-10 GeV band, which could be explained by ~50 GeV dark matter annihilation
- Uncertainties of hadronic/nuclear interactions and solar modulation

Cui, QY et al. (2017)
Cuoco et al. (2017)

Summary of dark matter searches

- Collider：Null！
- Direct：Null！
- Indirect：

  1. positron exess
  2. gamma-ray excess
  3. antiproton excess

  Inconclusive！

Summary of dark matter searches

- Collider： Null！
- Direct： Null！
- Indirect：
  1. positron exess
  2. gamma-ray excess
  3. antiproton excess

  Inconclusive！

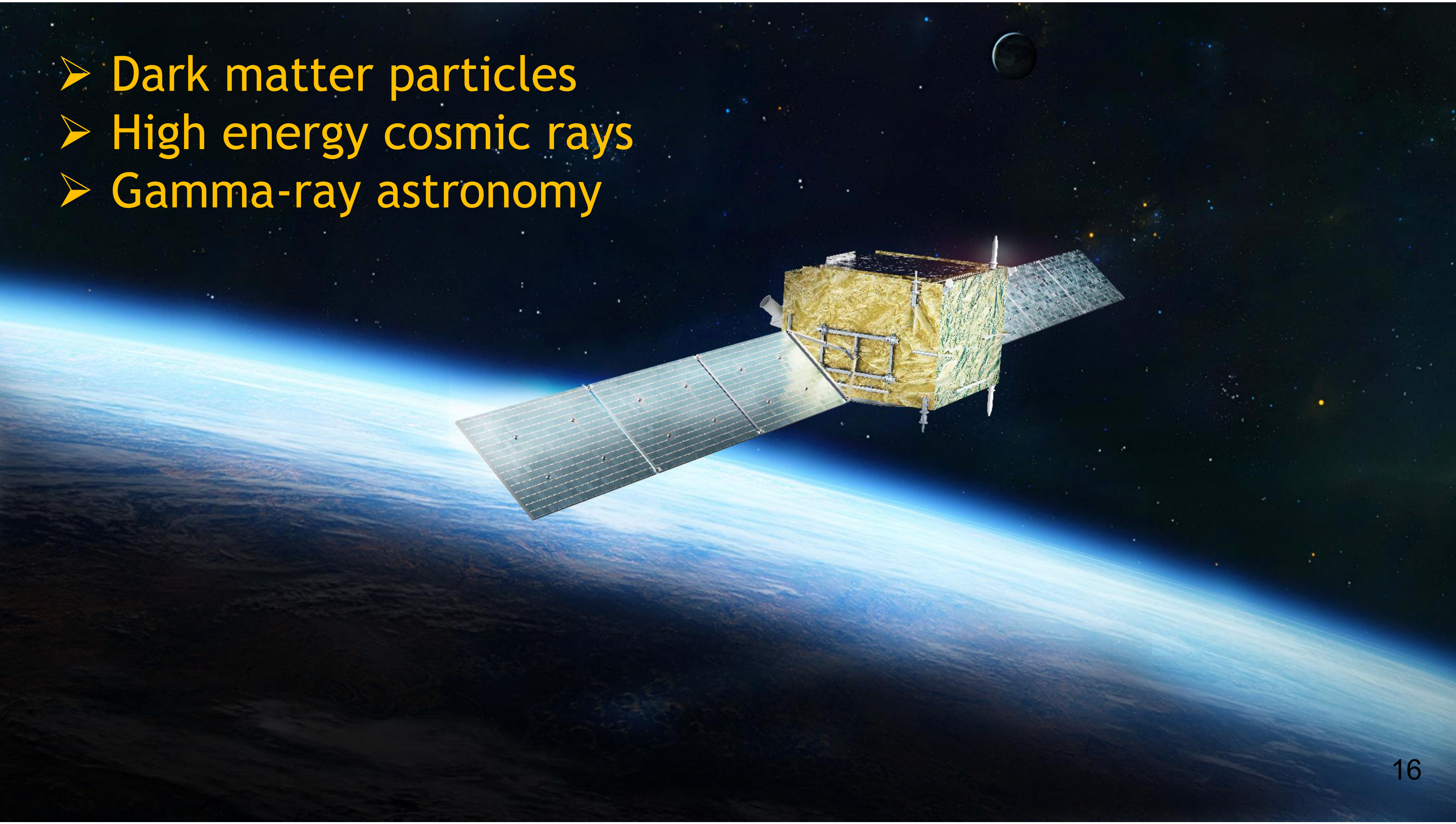
- Astronomers can not see dark matter, but they discover dark matter
- Physicsts can in principle “see” dark matter, but they find nothing yet

Outline

- Overview of dark matter indirect detection
- Dark matter particle explorer (DAMPE)
  - ➢ DAMPE experiment
  - ➢ Status and on-orbit performance
  - ➢ Physical results
- Summary

Dark Matter Particle Explorer: probe the high-energy window with higher energy resolution, higher energy reach, and clearer particle ID

- Dark matter particles
- High energy cosmic rays
- Gamma-ray astronomy



The DAMPE collaboration

- China
  - Purple Mountain Observatory, CAS
  - University of Science and Technology of China
  - Institute of High Energy Physics, CAS
  - Institute of Modern Physics, CAS
  - National Space Science Center, CAS

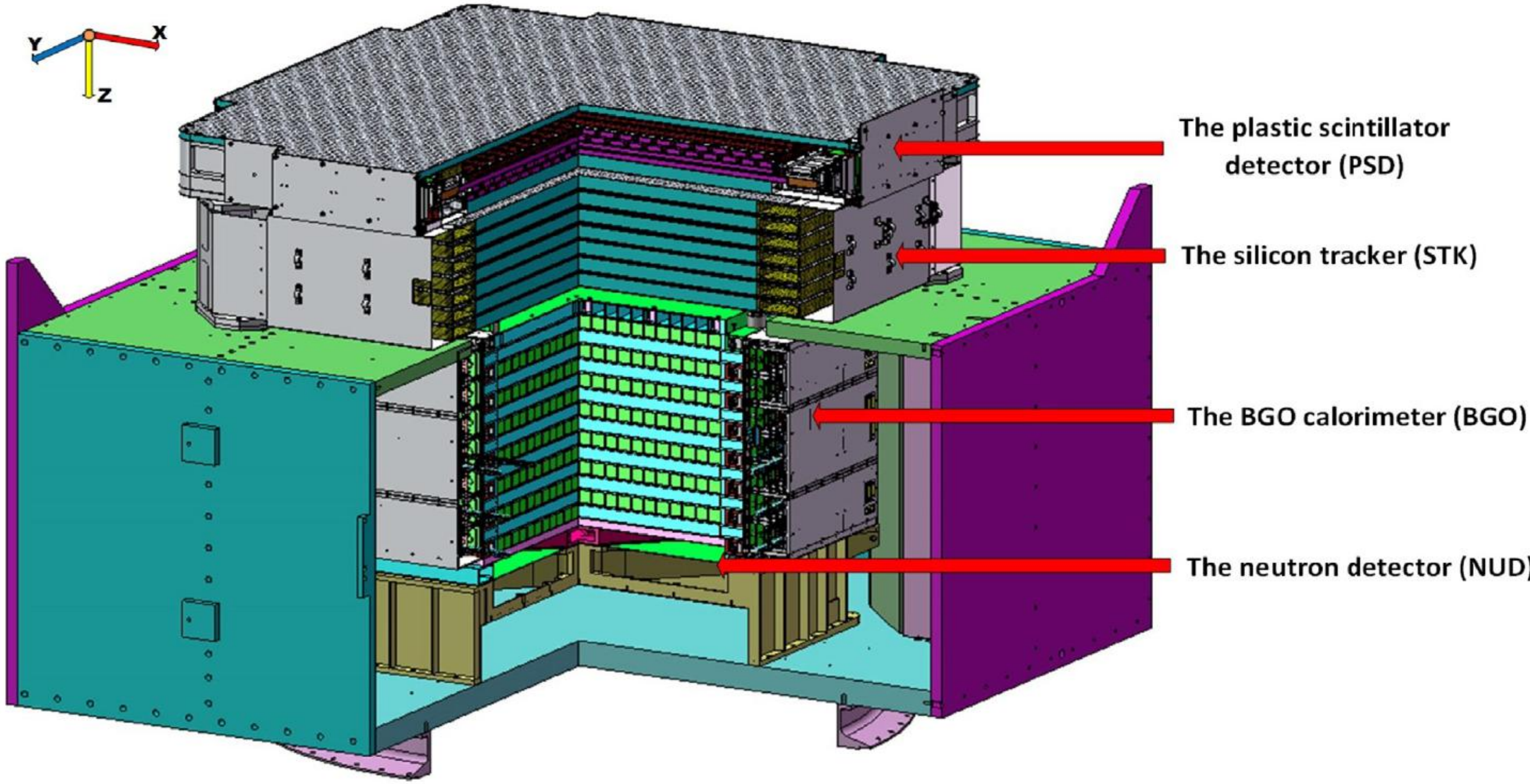
- Italy
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento

- Switzerland
  - University of Geneva

Launched on Dec. 17, 2015, at JiuQuan satellite launch center

Named as “Wukong”

DAMPE detector

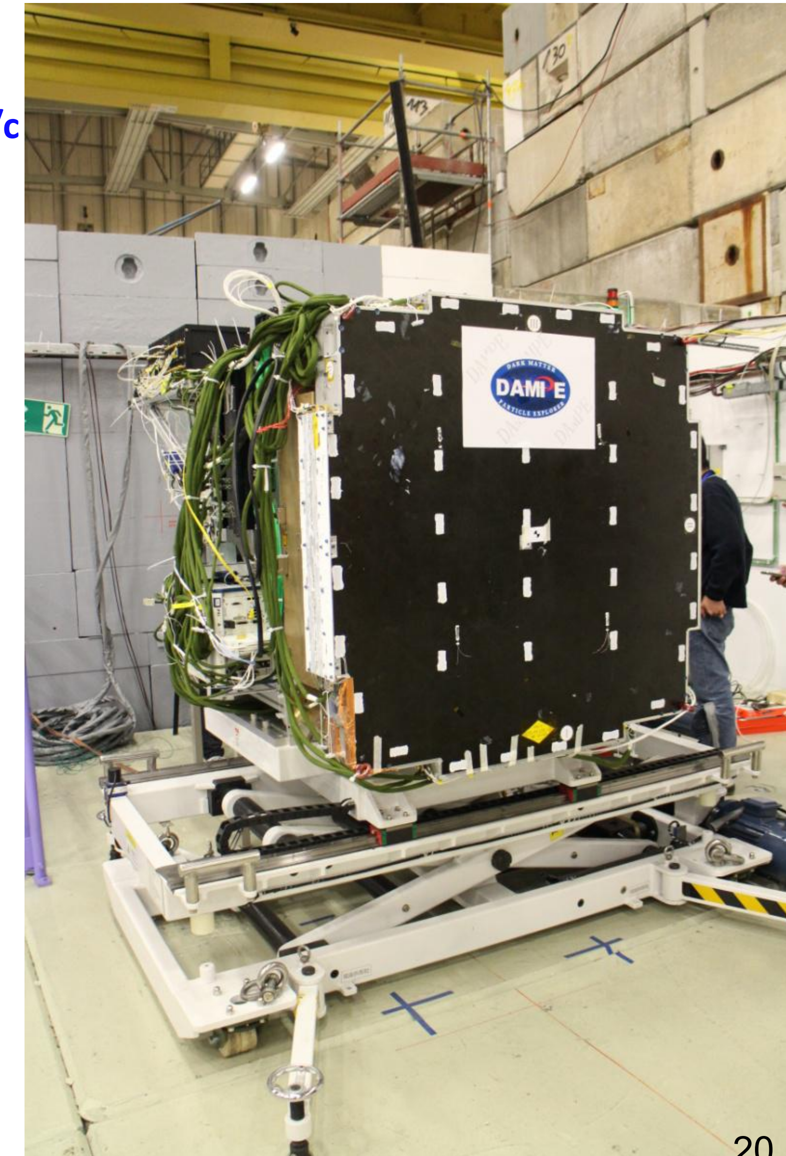


- Charge (dE/dx in PSD, STK and BGO)
- Track (STK and BGO)
- Energy (BGO)
- Particle identity (BGO and NUD)

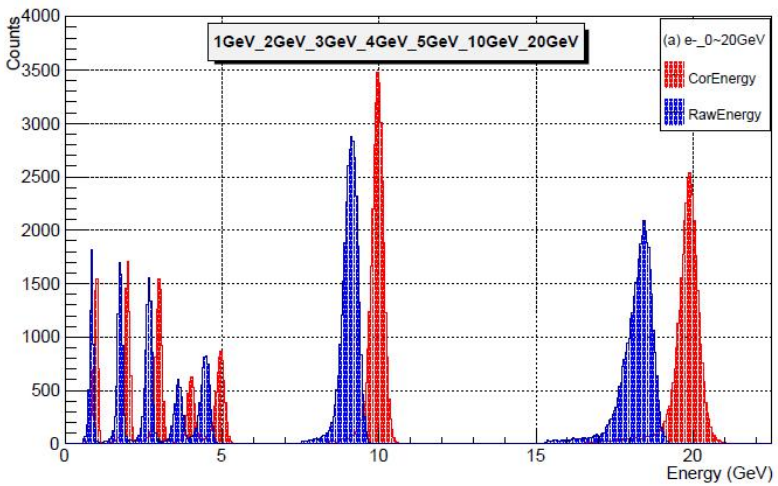
Chang et al. (2017, Astropart. Phys.)

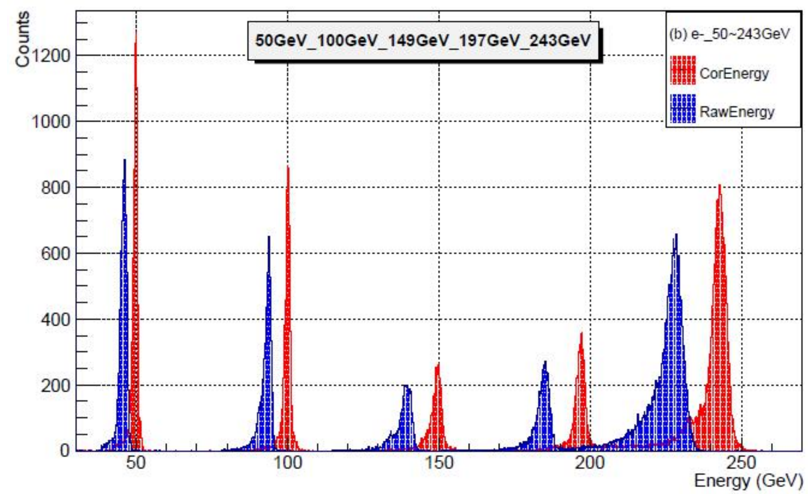
Beam tests at CERN

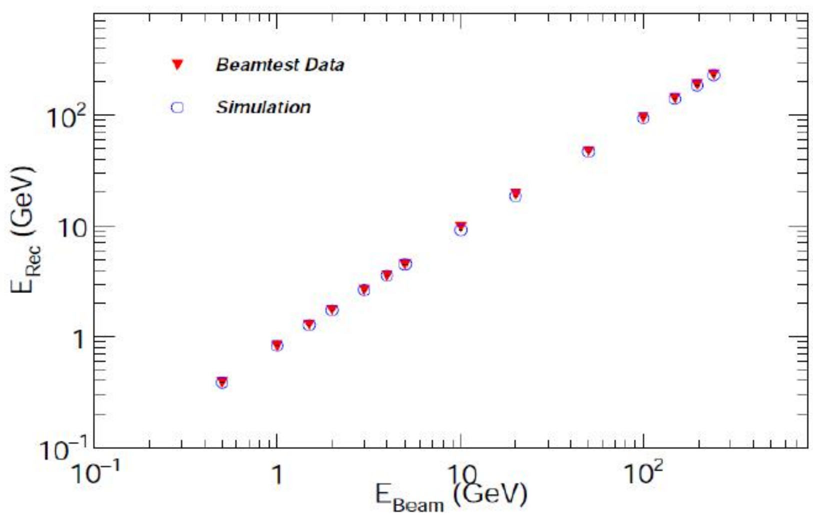
- 14days@PS， 29/10-11/11 2014
  - e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  - p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  - π-@ 3GeV/c, 10GeV/c
  - γ @ 0.5-3GeV/c
- 8days@SPS， 12/11-19/11 2014
  - e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
  - p @ 400GeV/c (SPS primary beam)
  - γ @ 3-20GeV/c
  - μ @ 150GeV/c,
- 17days@SPS， 16/3-1/4 2015
  - Fragments： 66.67-88.89-166.67GeV/c
  - Argon： 30A- 40A- 75AGeV/c
  - Proton： 30GeV/c， 40GeV/c
- 21days@SPS， 10/6-1/7 2015
  - Primary Proton: 400GeV/c
  - Electrons @ 20, 100, 150 GeV/c
  - γ @ 50, 75 , 150 GeV/c
  - μ @ 150 GeV /c
  - π+ @10, 20, 50, 100 GeV/c
- 6days@SPS, 20/11-25/11 2015
  - -- Pb 030 AGeV/c (and fragments）

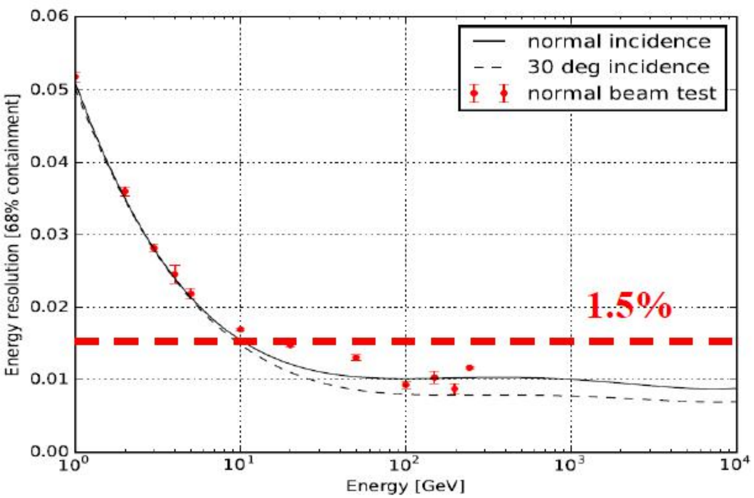


Beam tests of electrons



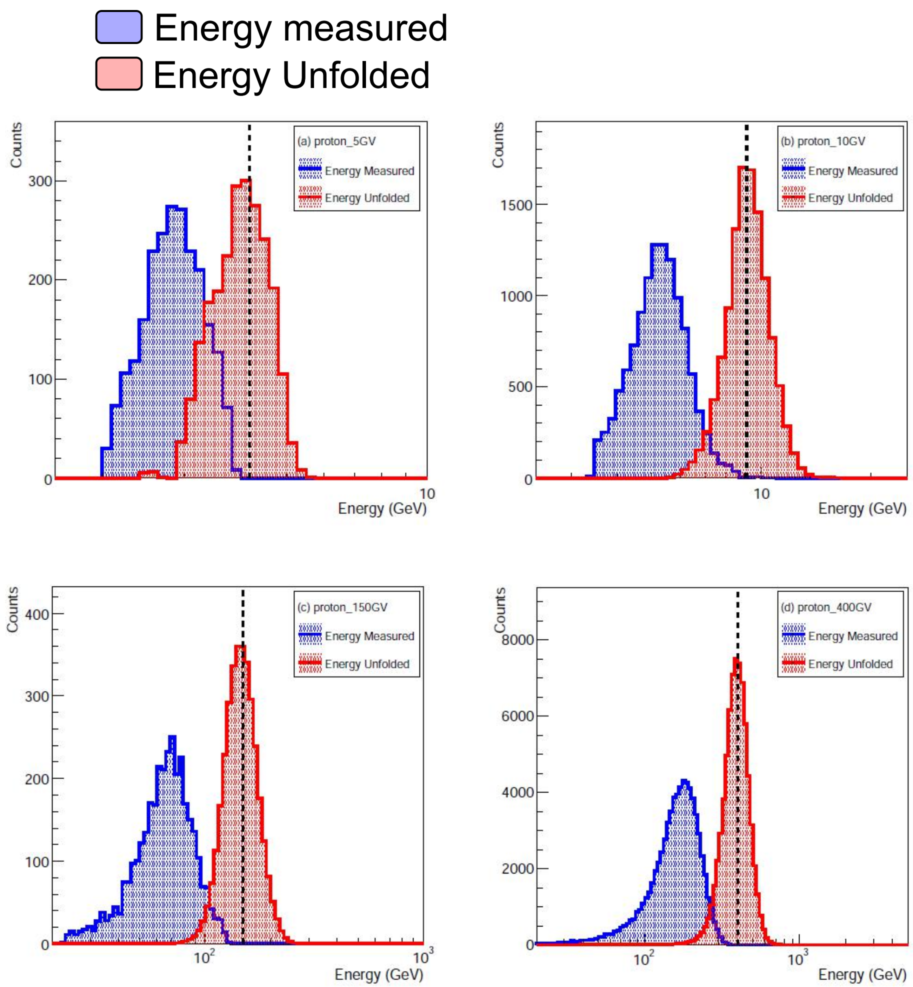


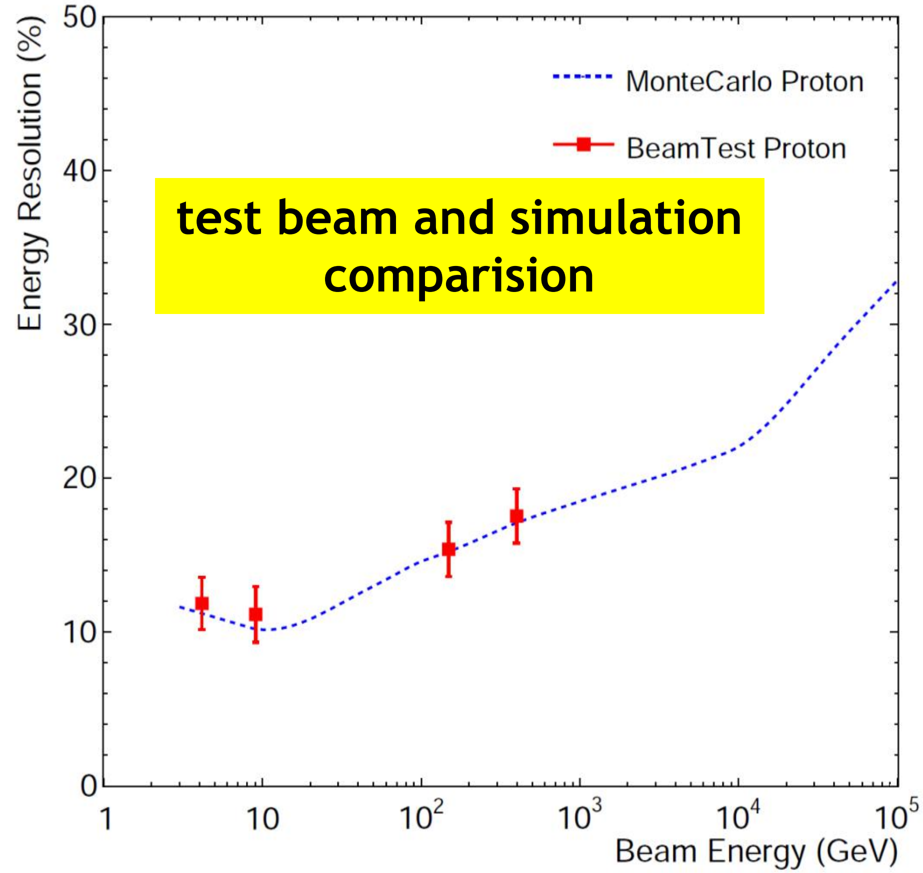




Chang et al. (2017, Astropart. Phys.)

Beam tests of protons





Chang et al. (2017, Astropart. Phys.)

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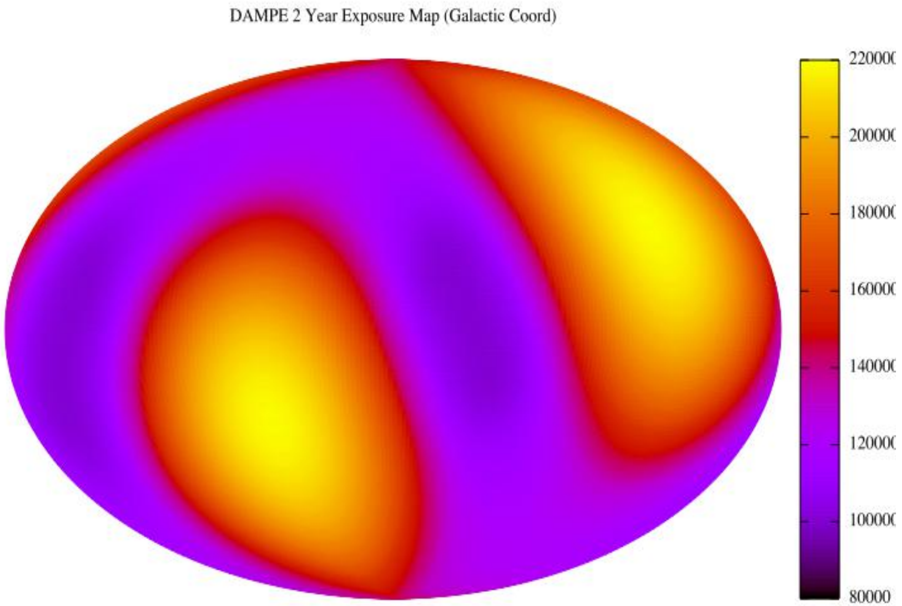
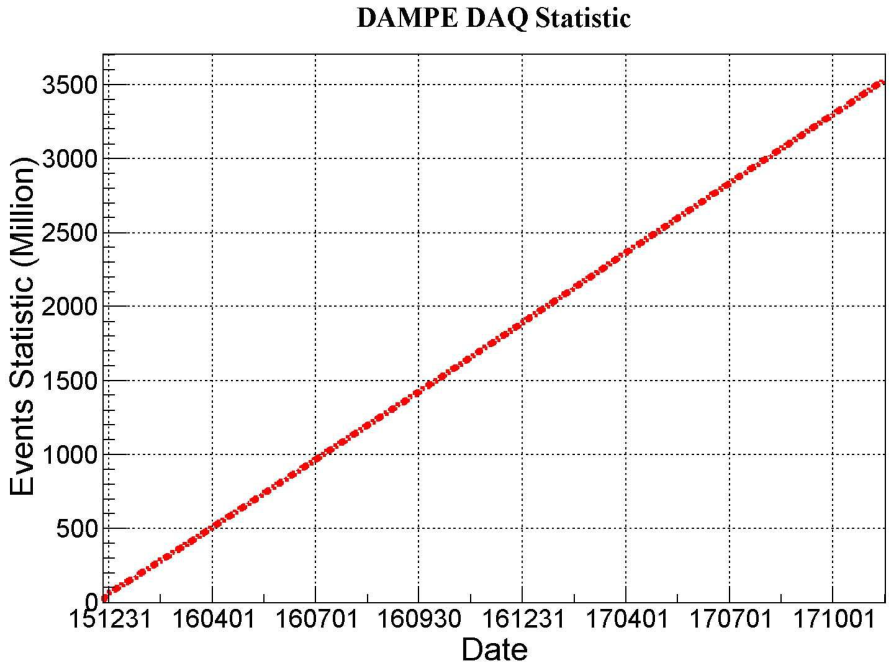
Observation overview

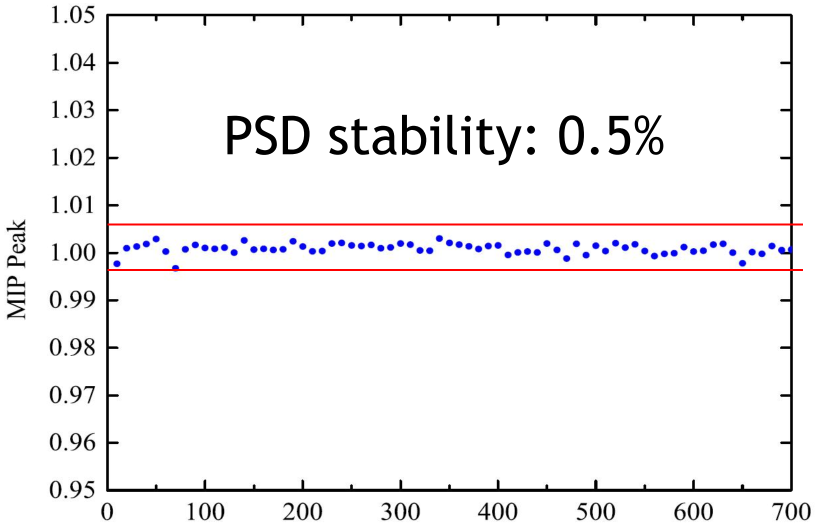




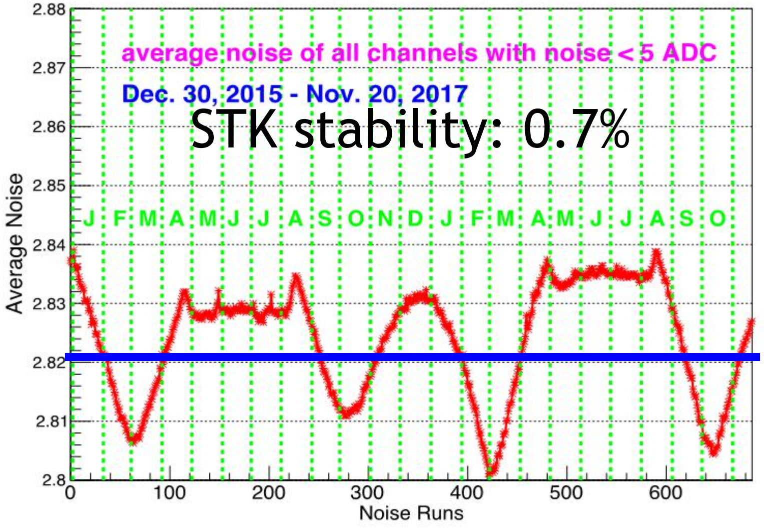
5 full scans of the sky

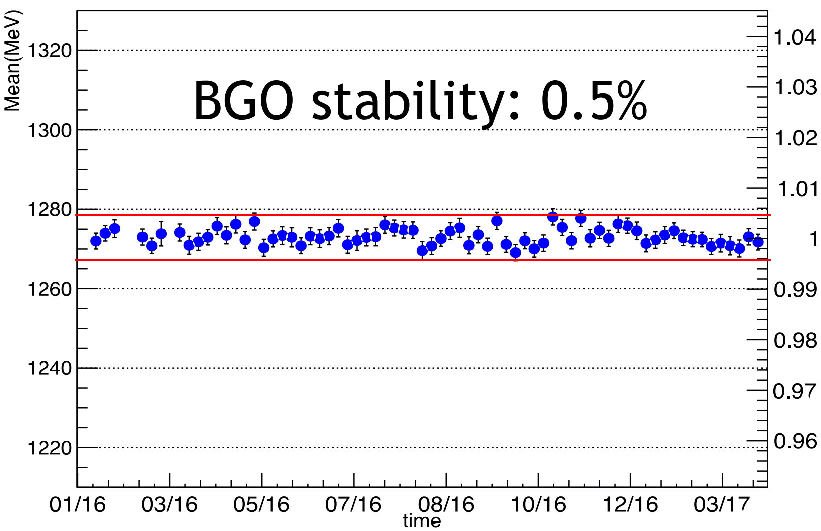
5M events/day
4.6 billion in total

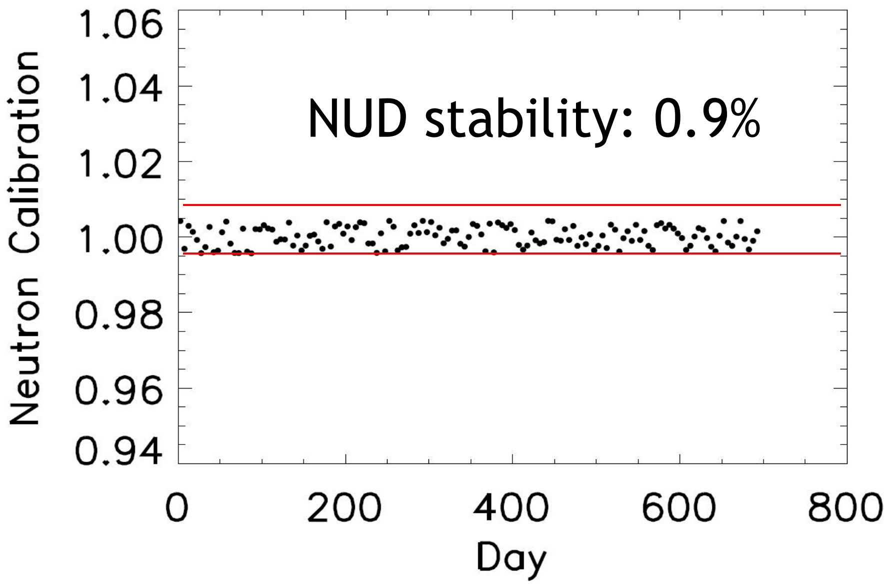
On-orbit performance



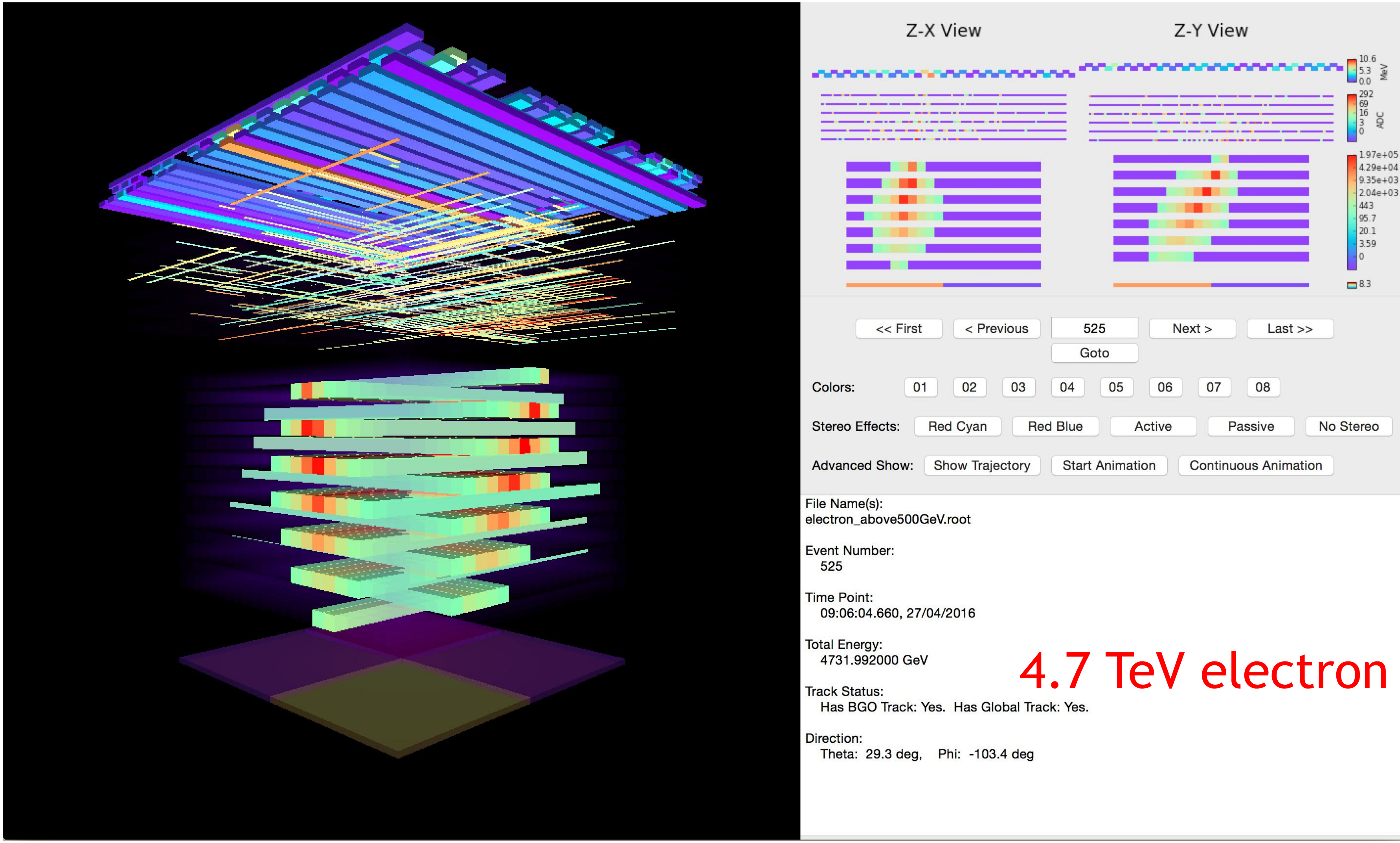
Stability of Helium MIPs





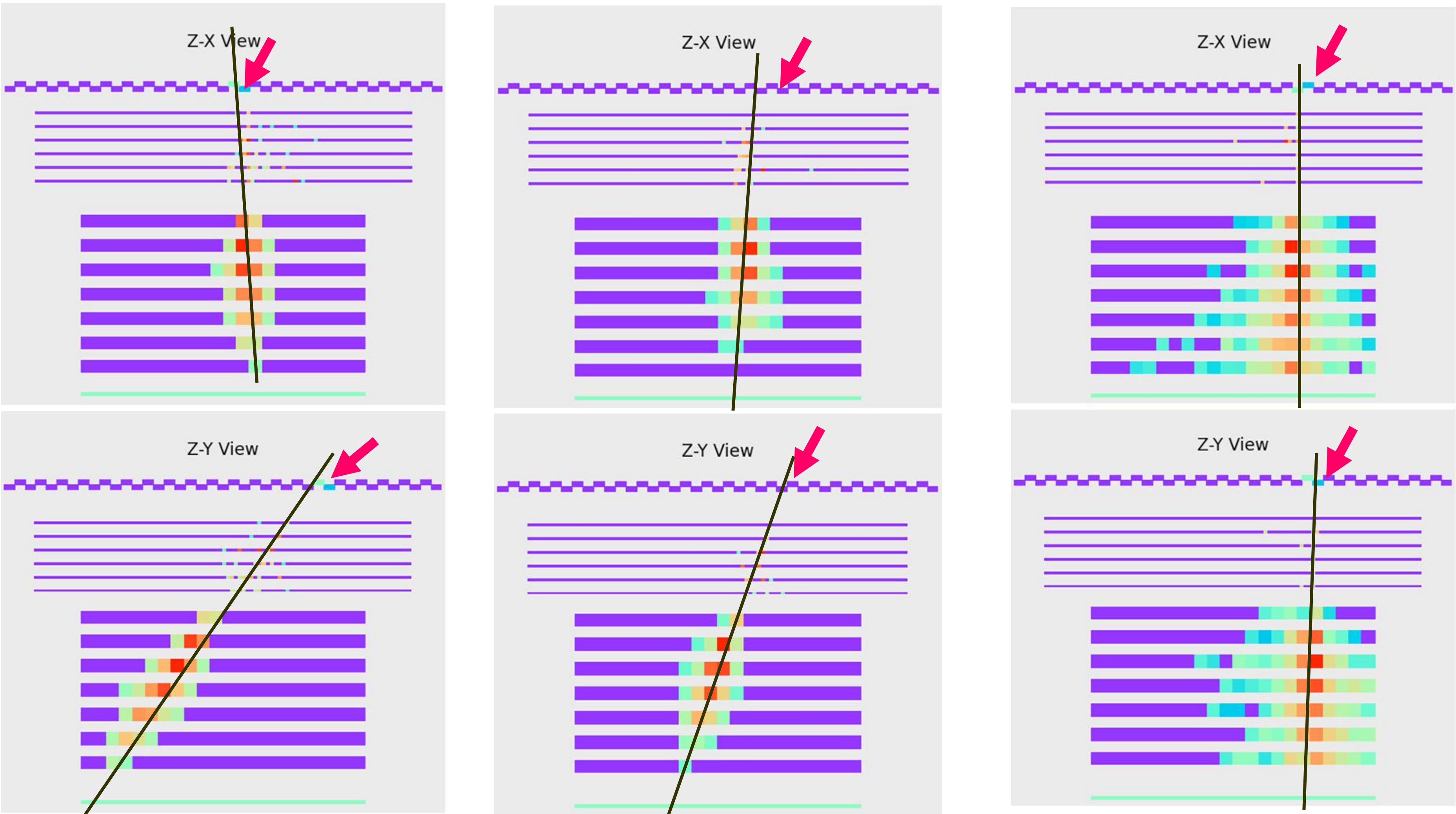


Typical DAMPE event

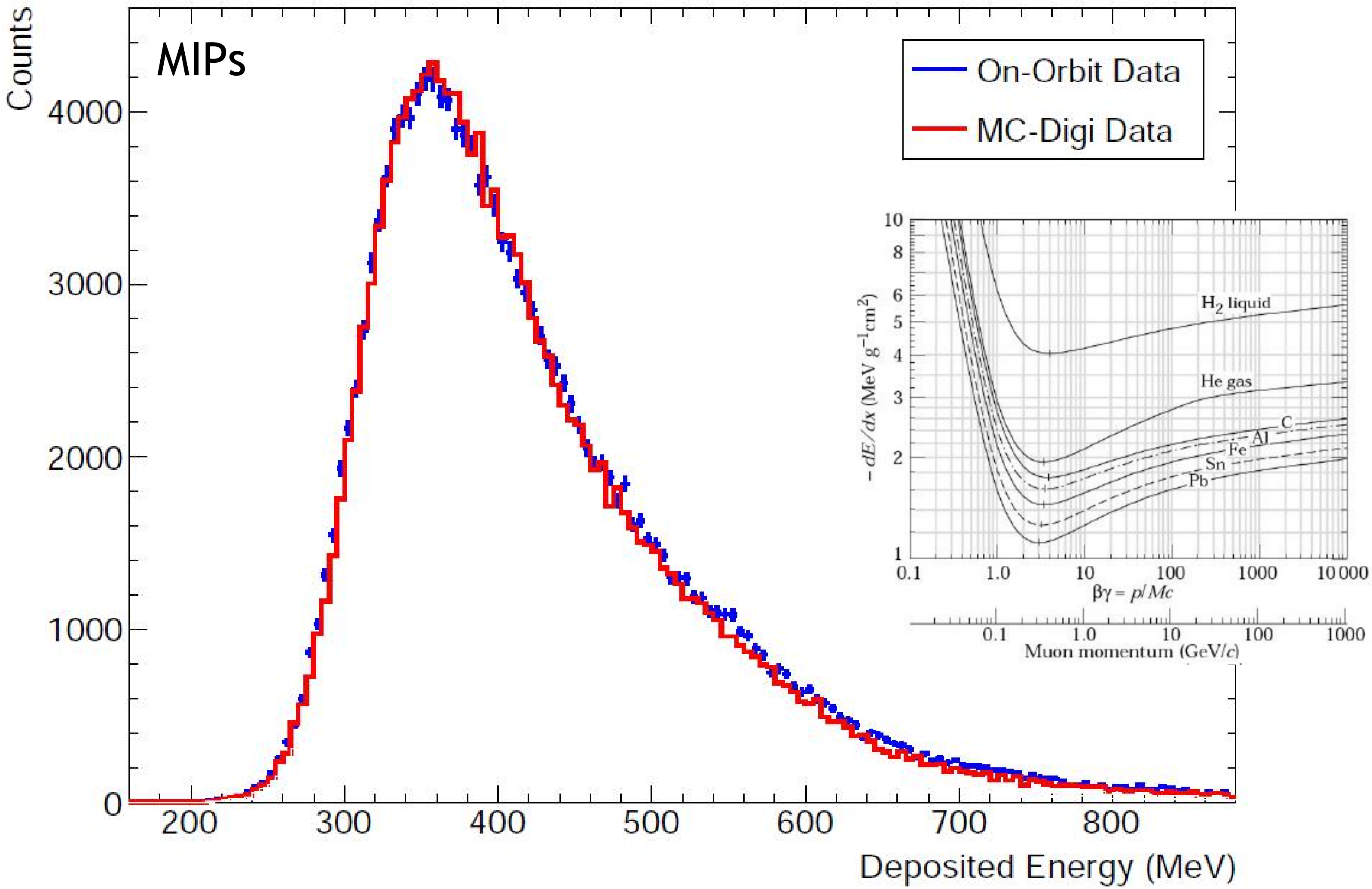


Typical DAMPE events

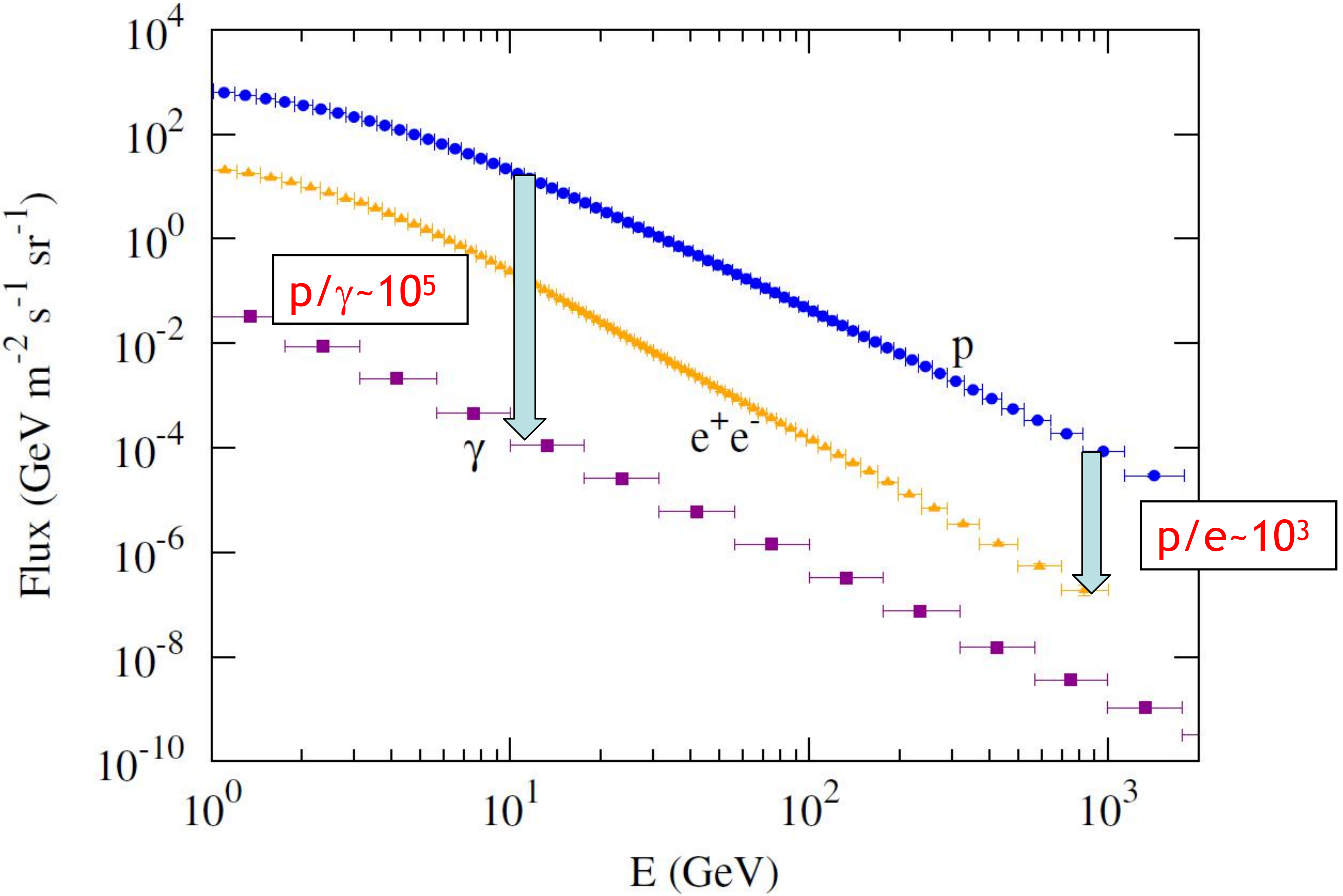
Electron Gamma Proton



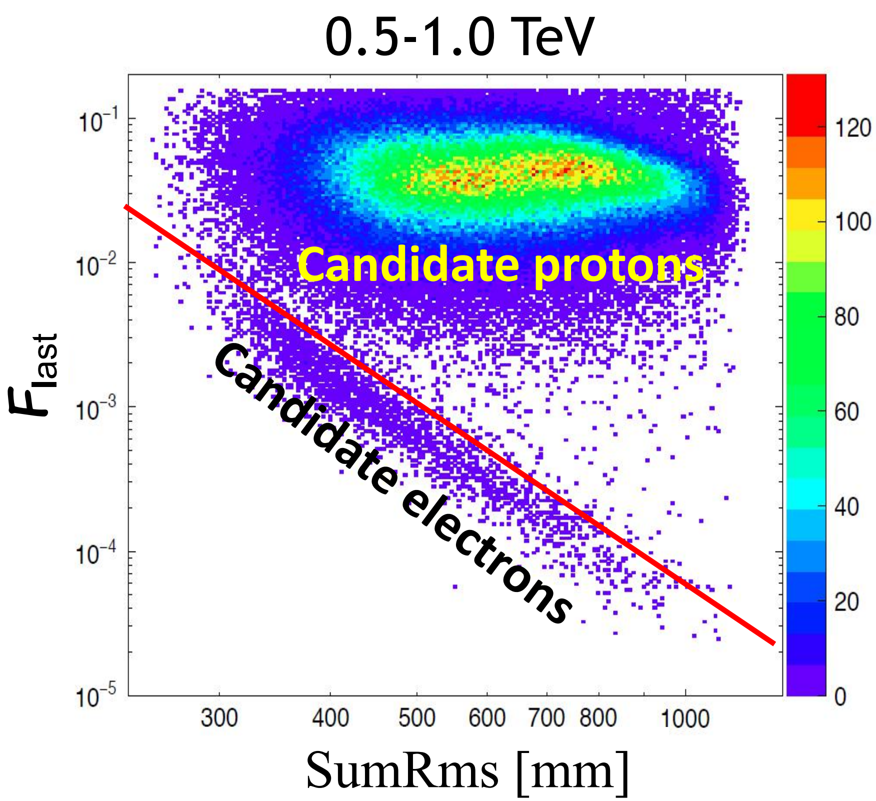
On-orbit performance: energy calibration

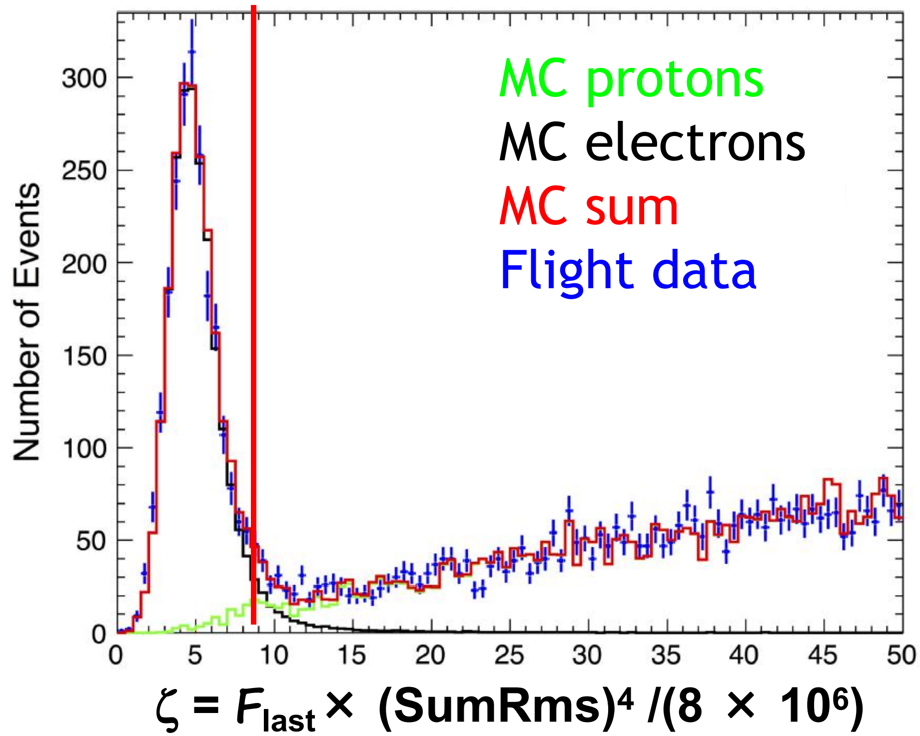


Particle identification is crucial



On-orbit performance: particle identification





- We use the lateral (SumRMS) and longitudinal (energy ratio in last layer) developments of the showers to discriminate electrons from protons
- For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV

(Nature 552 (2017) 63-66)

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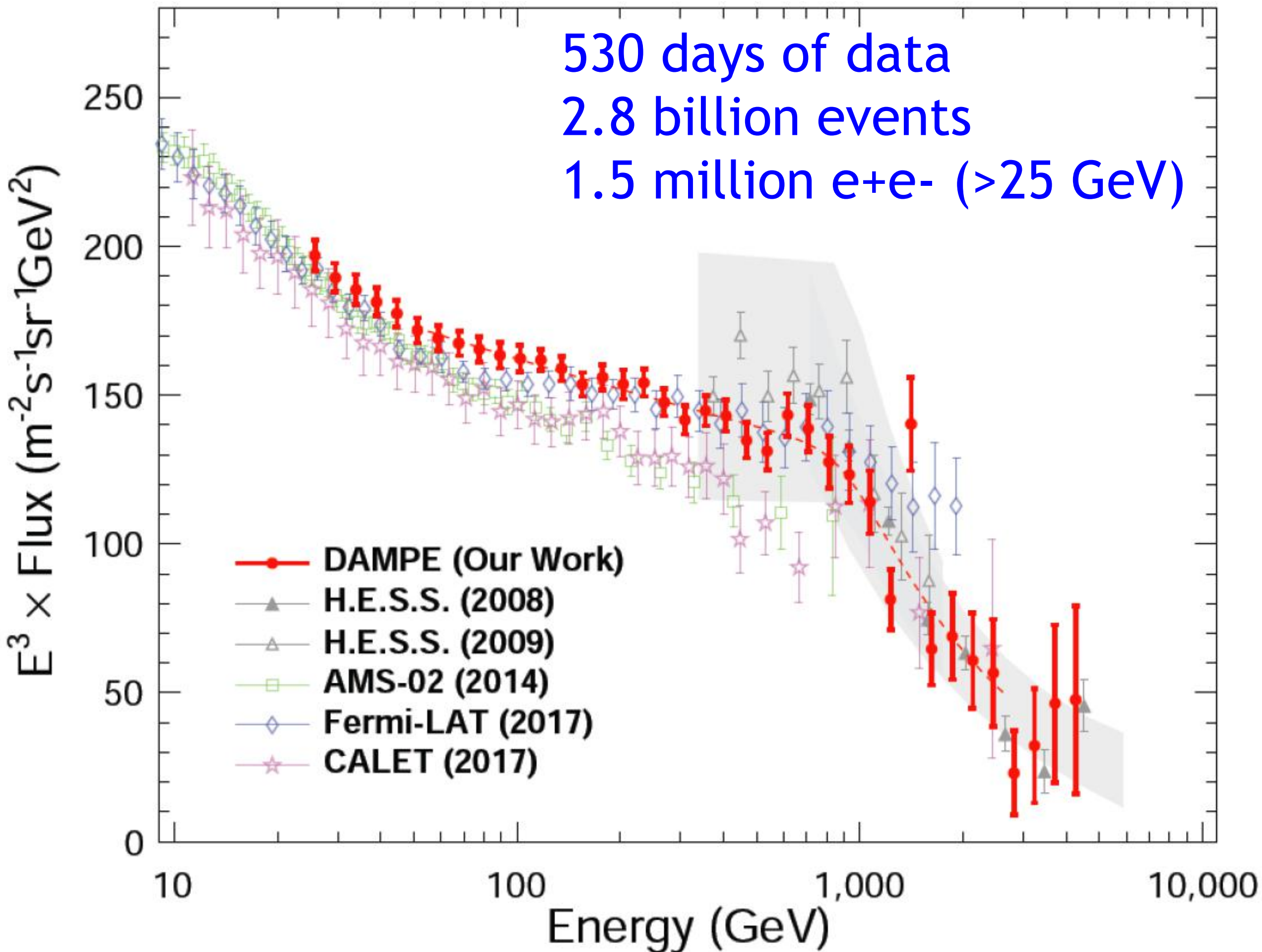
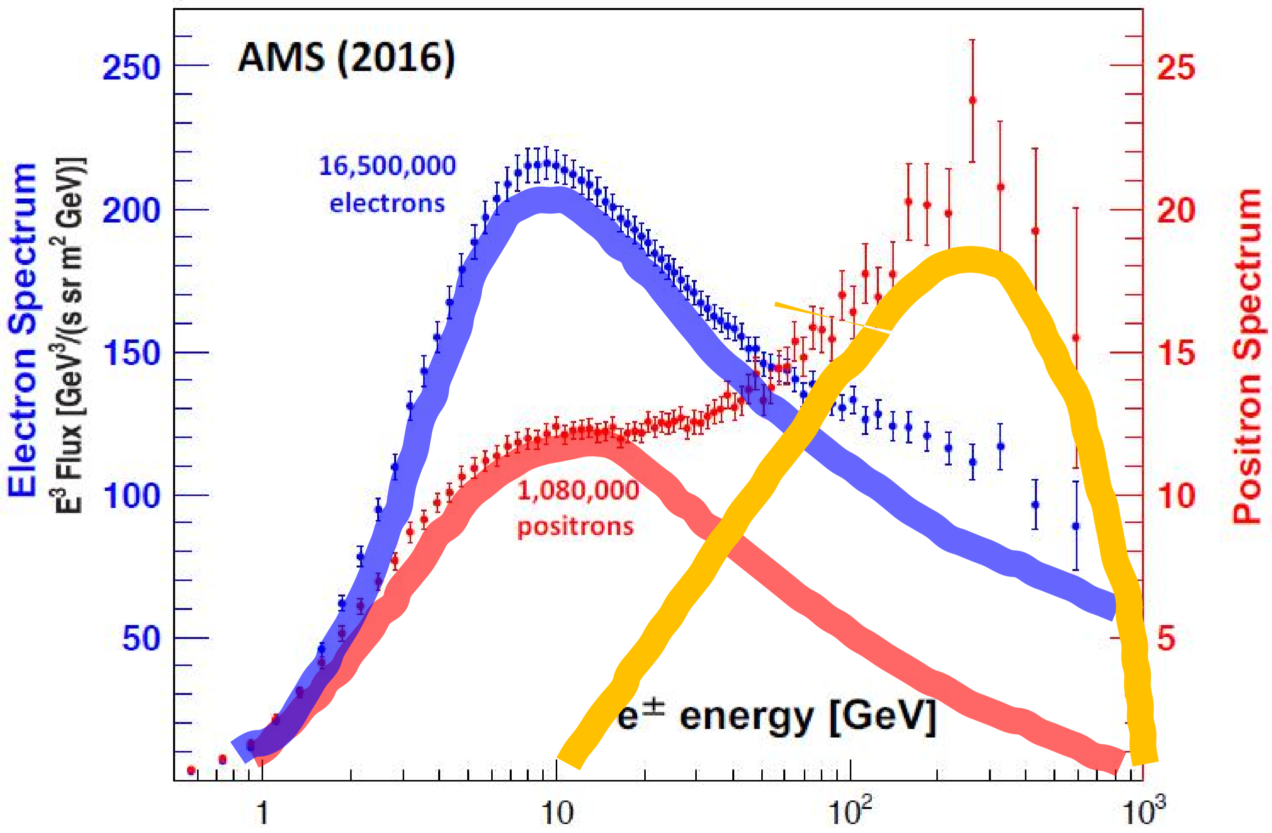
Physical results: electron+positron fluxes



- Highest precision and lowest background in TeV energy range
- Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level

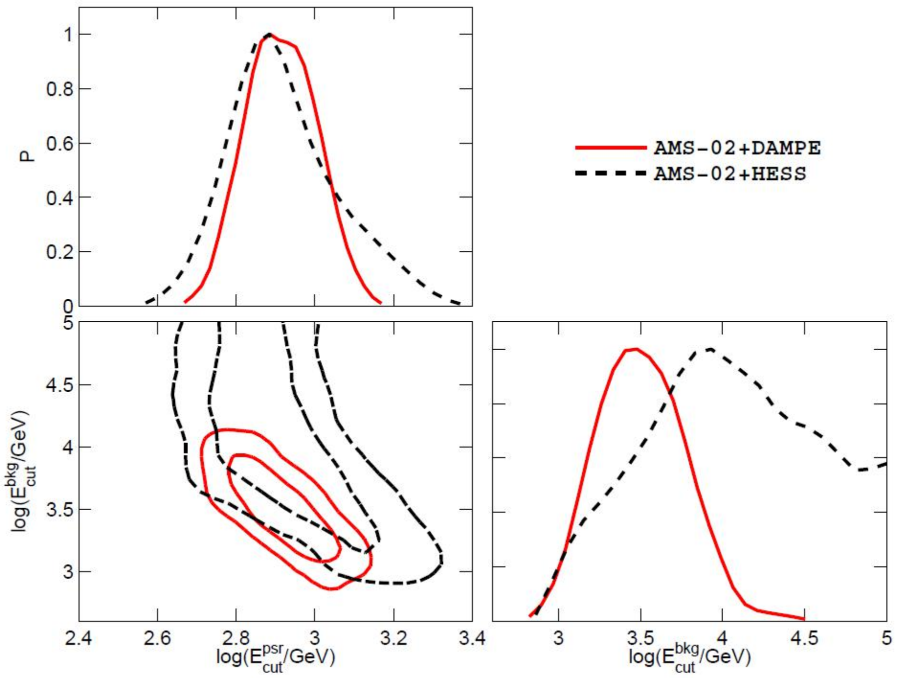
Ambrosi et al. (2017)

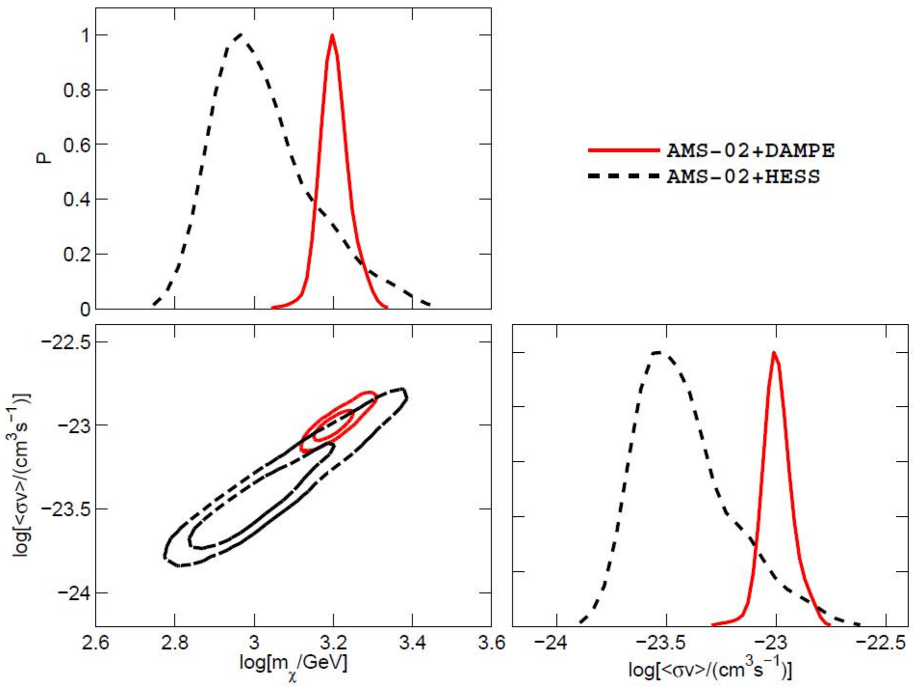
Three-component e+e- model



- Primary e- accelerated together with ions (in e.g., supernova remnants)
- Secondary e- and e+ from hadronic interaction of cosmic ray nuclei
- Additional e- and e+ from extra sources (e.g., pulsars, ...)

Implication of DAMPE data: improve constraints on model parameters of the 1st and 3rd components





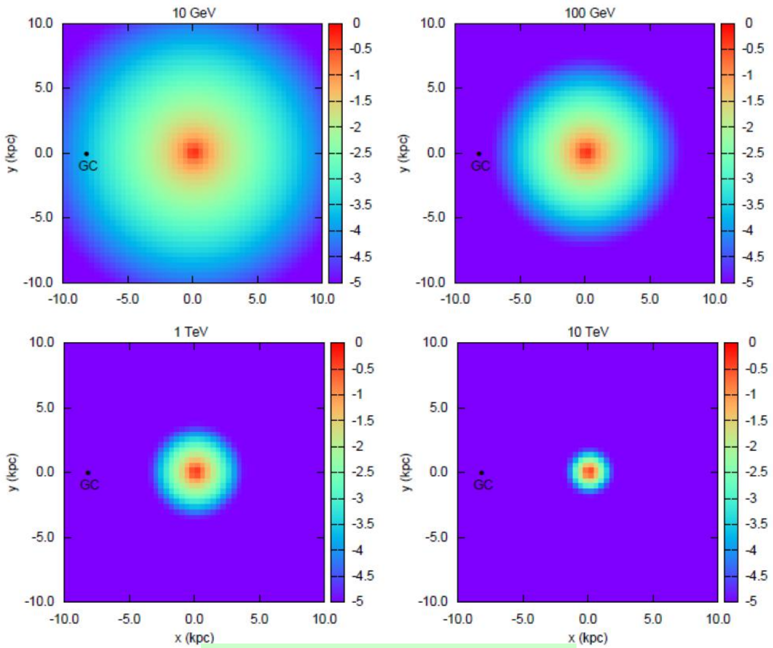
bkg cutoff energy vs. pulsar cutoff

mchi vs. <σv>

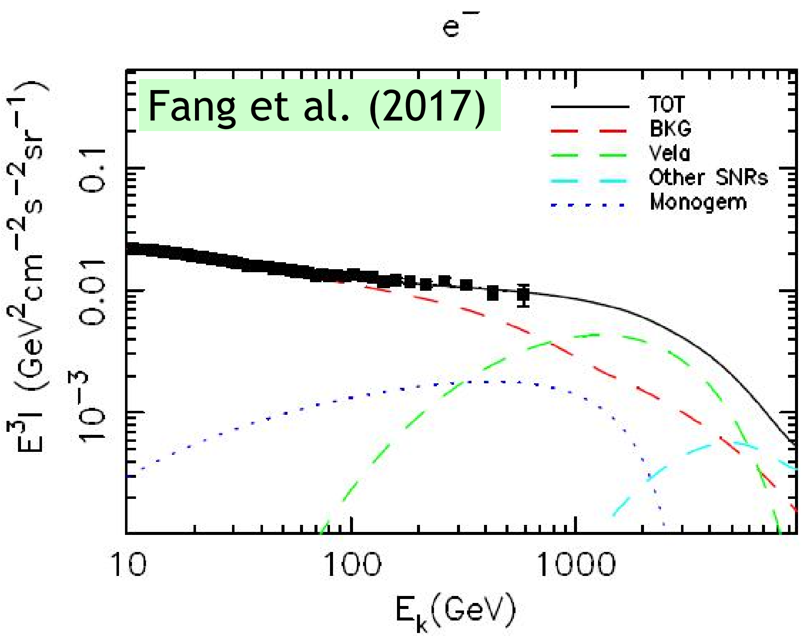
Yuan et al. (2017)
arXiv:1711.10989

Implication of the spectral break: break of continuous source distributions in space and time

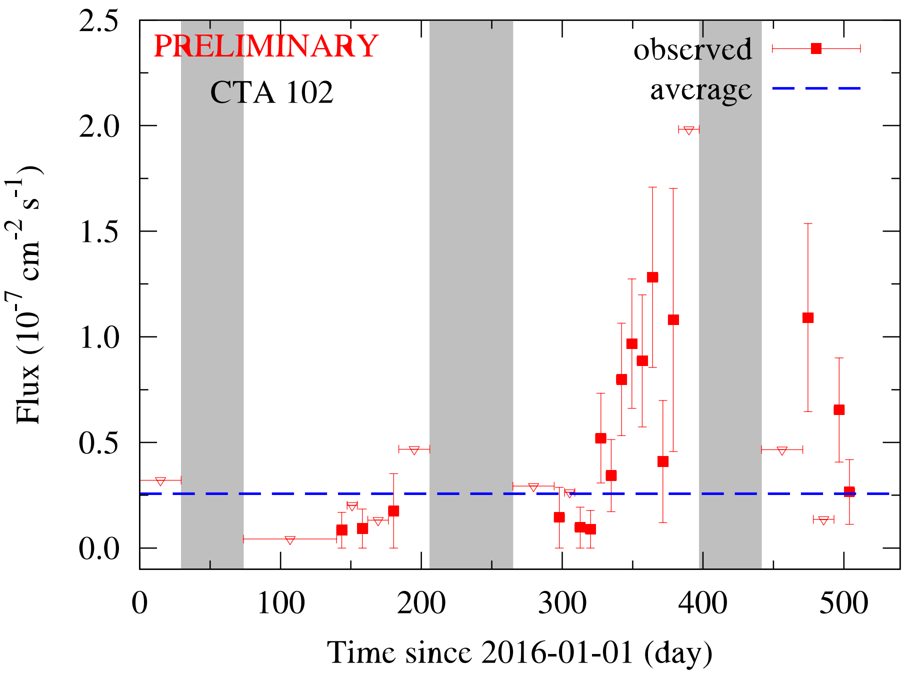
- Cooling time of TeV electrons ~ Myr, effective propagation range ~ kpc
- Assuming a total SN rate of 0.01 per year, the total number of SNRs within the effective volume and cooling time is O(10)

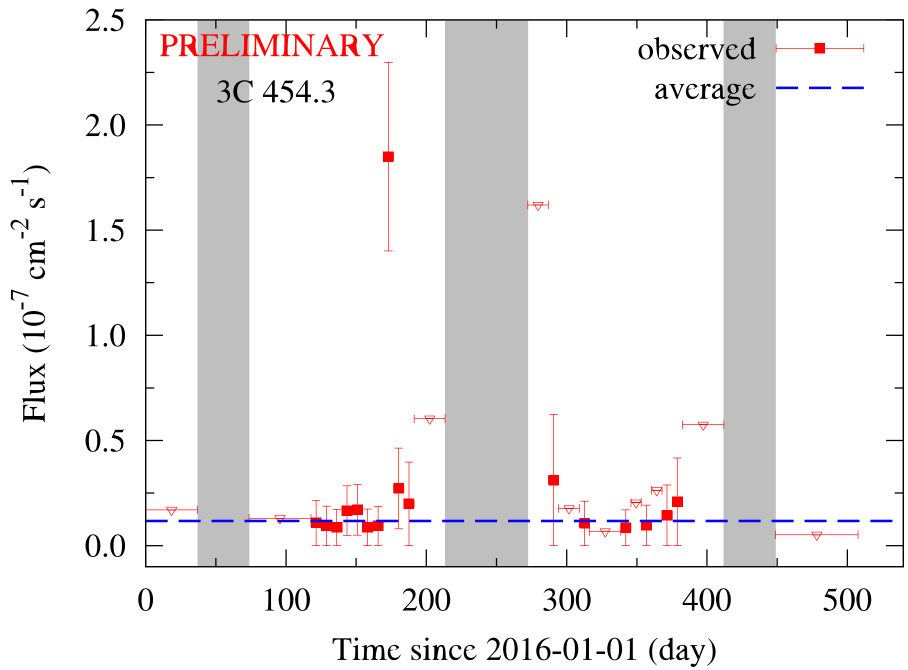


Yuan & Feng (2018)



Physical results: variable AGNs

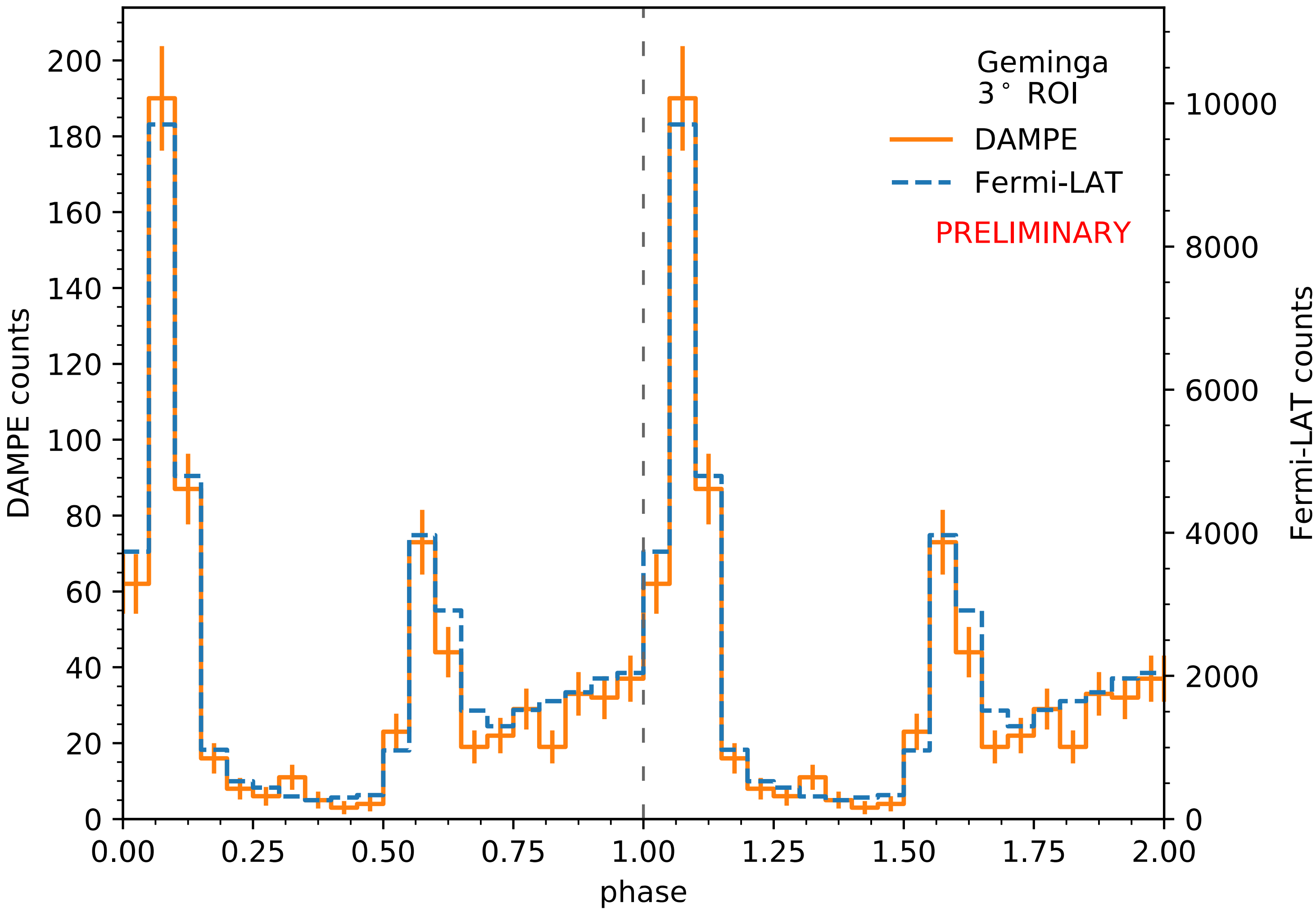




- DAMPE detected outbursts of CTA 102 and 3C 454.3
- Consistent with multi-wavelength observations

Yuan et al. (2017; ICRC)

Physical results: pulsars



Lei et al. (2017; ICRC)

Summary

- DAMPE detector is working extremely well since its launch more than 2 years ago
  - The electron + positron spectrum at TeV energies has been precisely measured → **as anticipated!**
    - A clear spectral break has been directly measured at ~ 1 TeV → **crucial to understanding some mysteries in cosmic ray physics!**
  - Nuclei measurements are ongoing
  - Photon detection capability is demonstrated but more statistics to profit the excellent energy resolution at high energy is needed

Thanks for your attention!