Cosmic rays from space with AMS and future experiments

P. Saouter, Université de Genève

2015 CHIPP Annual Plenary Meeting

1 July 2015, Château de Bossey.

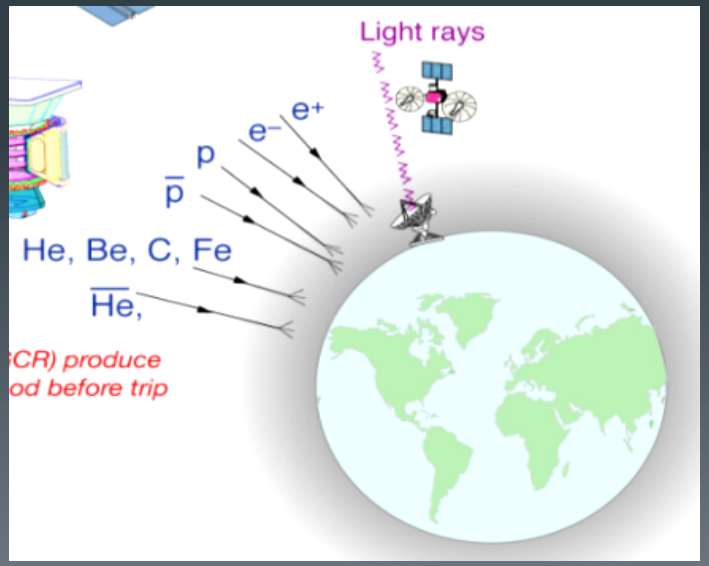
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Section de physique

Cosmic Rays from Space

A. Neutral cosmic rays (light rays and neutrinos):
measured for many years (Hubble, COBE, EGRET, WMAP, Planck, Fermi-LAT and Super Kamiokande, IceCube, HESS, …). Fundamental discoveries have been made.

B. Charged cosmic rays:
Following the pioneering experiments with balloons and satellites (ACE/CRIS, ATIC, BESS, CREAM, HEAT, PAMELA, …), using a magnetic spectrometer (AMS) on ISS is a unique way to provide **precision long term** (10-20 years) measurements of primordial high energy charged cosmic rays.

Measuring local properties of CRs around earth → information about the origin, propagation and acceleration of CRs. Potential for new physics as well.



Installed on the ISS in May 2011

DPNC involved since the beginning :

- Silicon Tracker Construction
- Commissioning
- Detector Operations
- Tracker Calibration
- Analysis

300,000 electronic channels
650 processors

5m x 4m x 3m
7.5 tons

AMS Results after 4 years of operation

In 4 years on ISS, AMS has collected > 60 billion cosmic rays.

Published results:

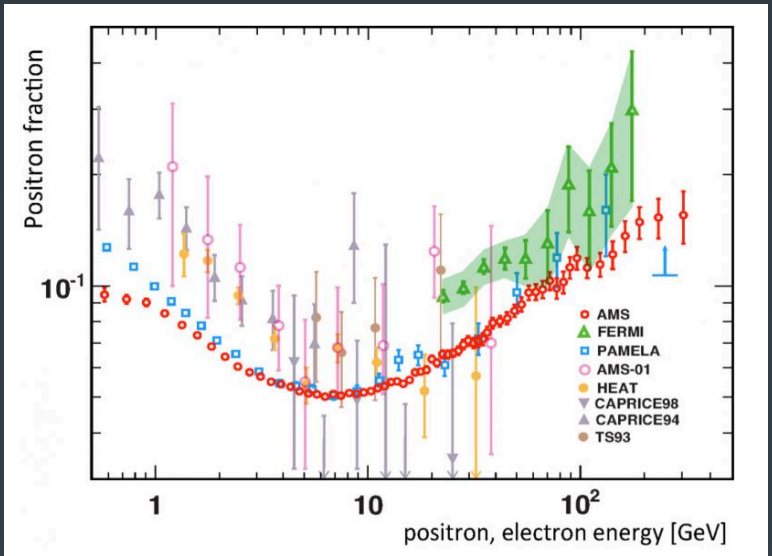
- **Positron Fraction** (0.5–350 [2013] 0.5-500 GeV [2014])
- **Electron** (0.5–700 GeV) and **Positron Fluxes** (0.5–500 GeV)
- **All electrons Flux** (0.5 GeV – 1 TeV)
- **Proton Flux** (1 GV – 1.8 TV)

Upcoming results (shown at AMS days in April 2015):

- **He fluxes**
- **anti-proton/proton ratio**
- **B, C, Li, O … ratio / fluxes**
- **Flux time variations / Solar Modulation**

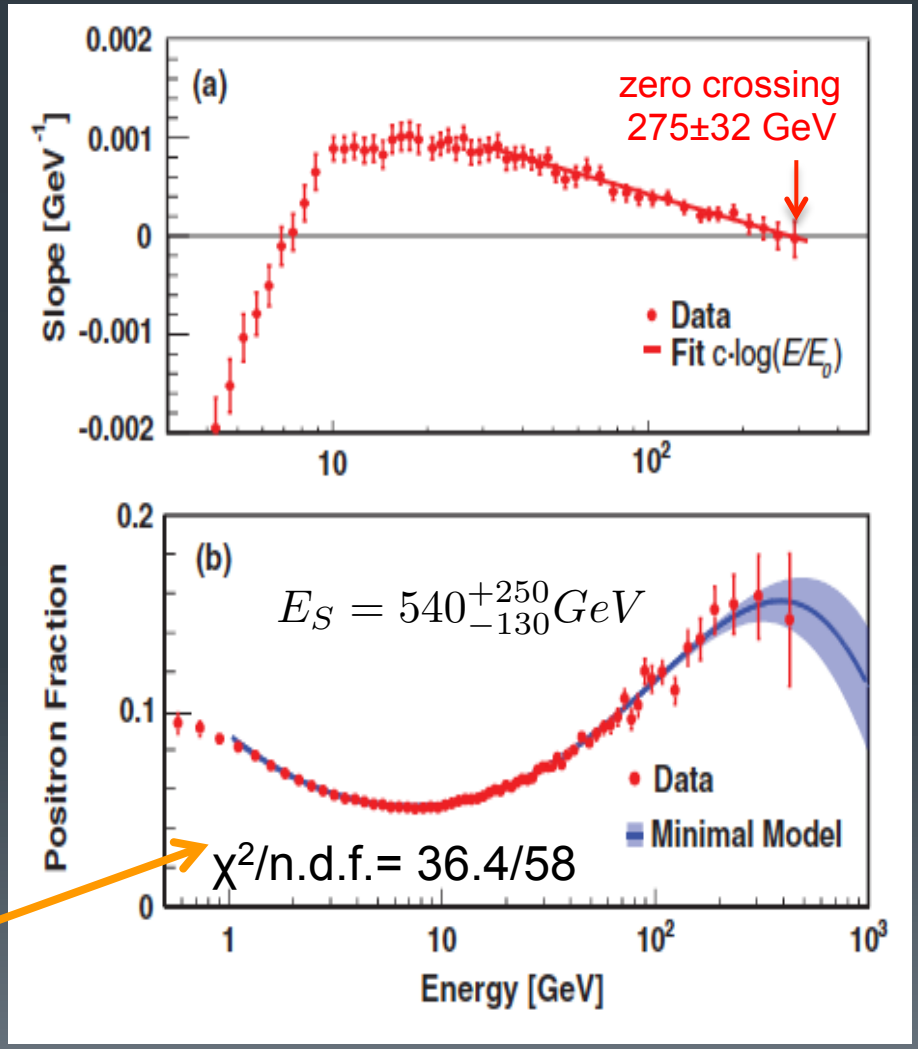
AMS Lepton Results (1)

Positron fraction from 0.5 GeV to 500 GeV (10.9 million electrons and positrons)



Positron fraction stops rising.
Maximum achieved…?
No fine structures observed,
no anisotropies.

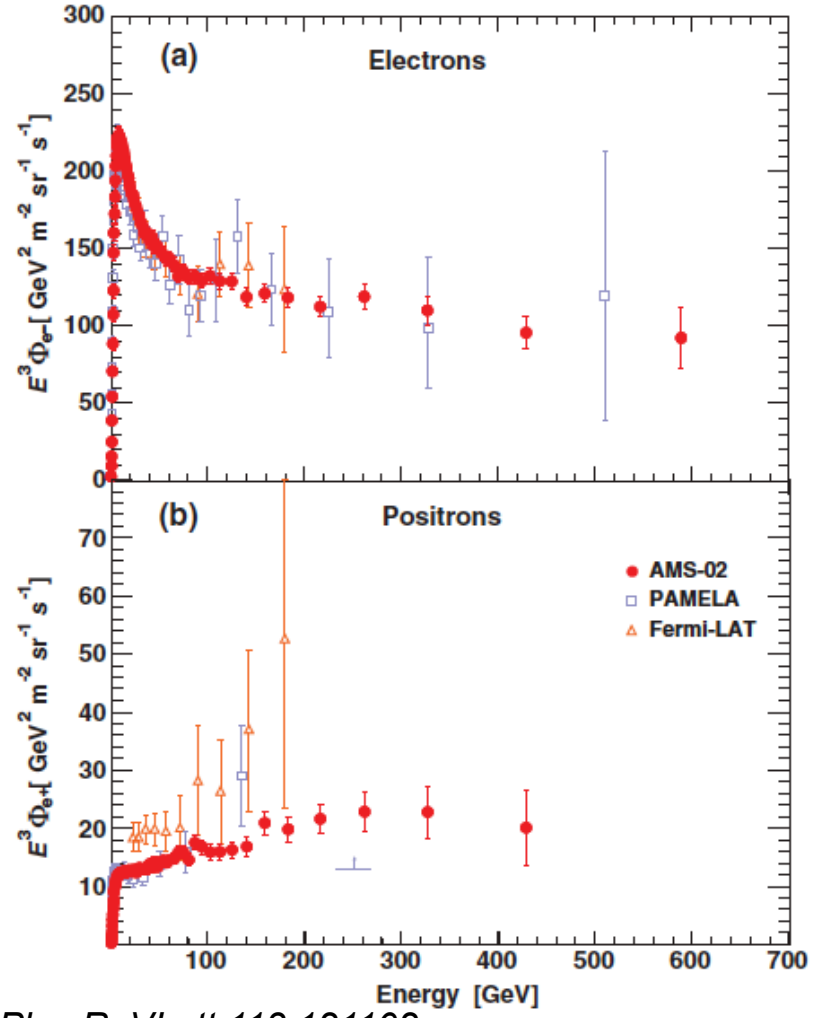
$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_S E^{-\gamma_S} e^{-E/E_S}$$
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_S E^{-\gamma_S} e^{-E/E_S}$$

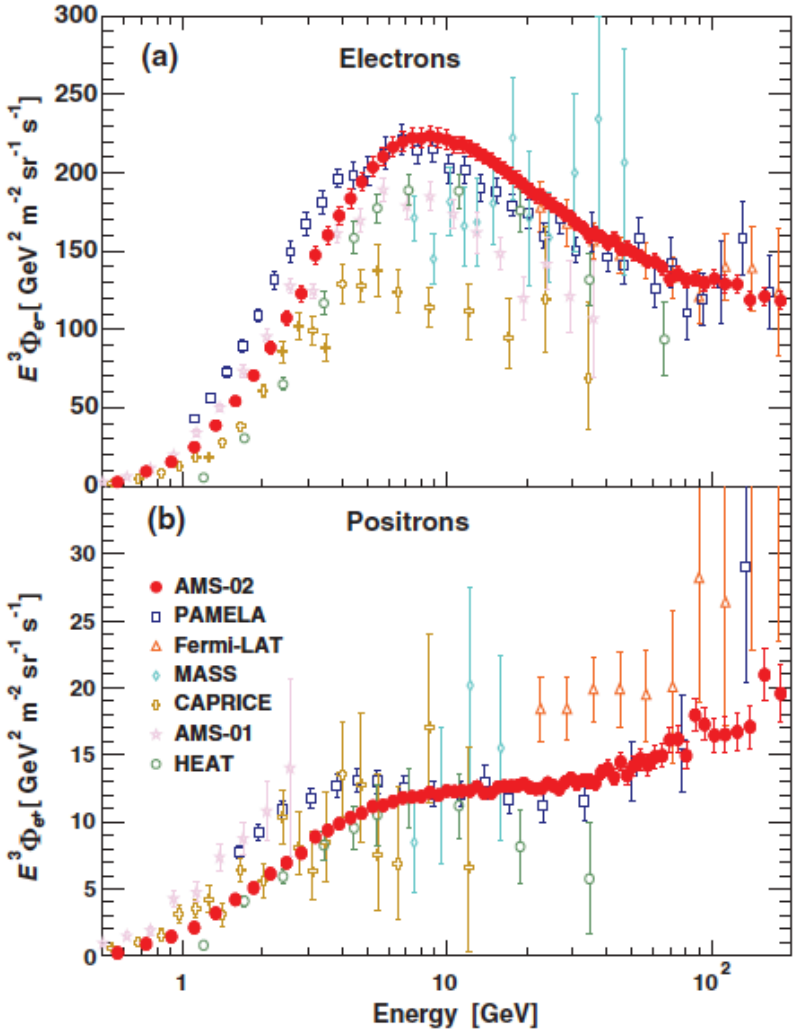


PhysReVLett.113.121101

AMS Lepton Results (2)

Positron (0.5 to 500 GeV) and Electron (0.5 to 700 GeV) Fluxes





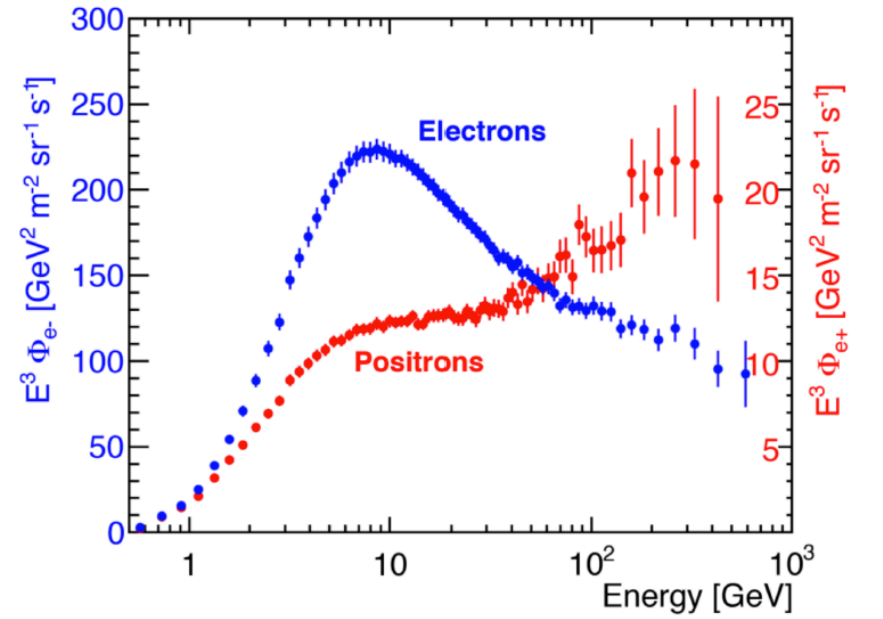
PhysReVLett.113.121102

AMS Lepton Results (2)

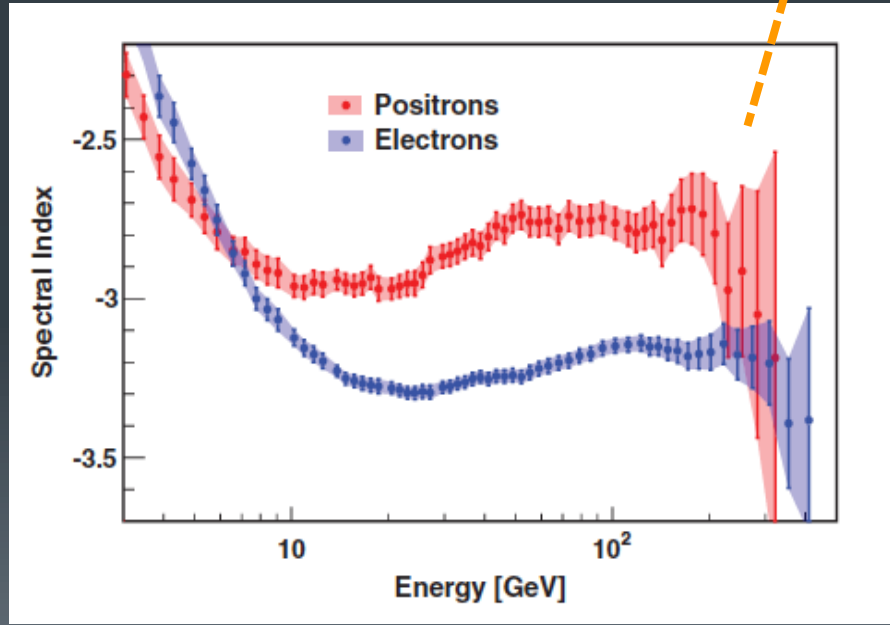
Positron (0.5 to 500 GeV) and Electron (0.5 to 700 GeV) Fluxes

Fit over sliding window to determine spectral index versus energy : $\Phi_{e^\pm} = C_{e^\pm} E^{\gamma_{e^\pm}}$

Above 10 GeV, increase positron fraction due excess of positrons.



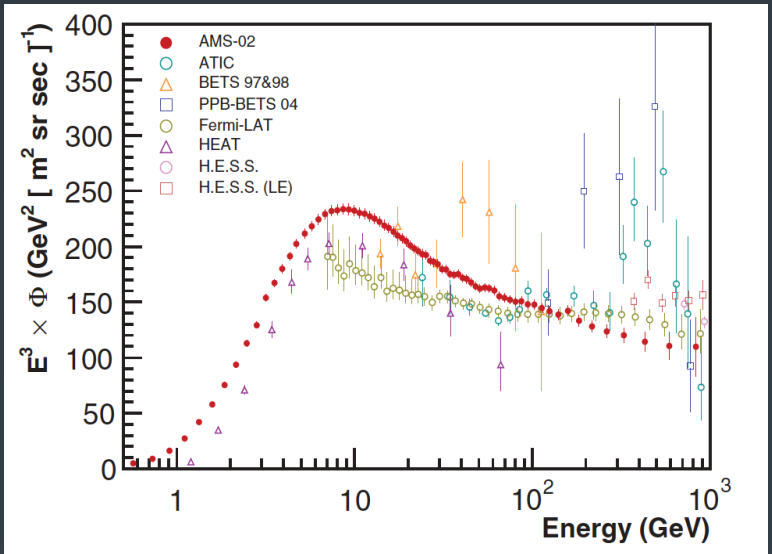
AMS Days, S. Schael



PhysReVLett.113.121102

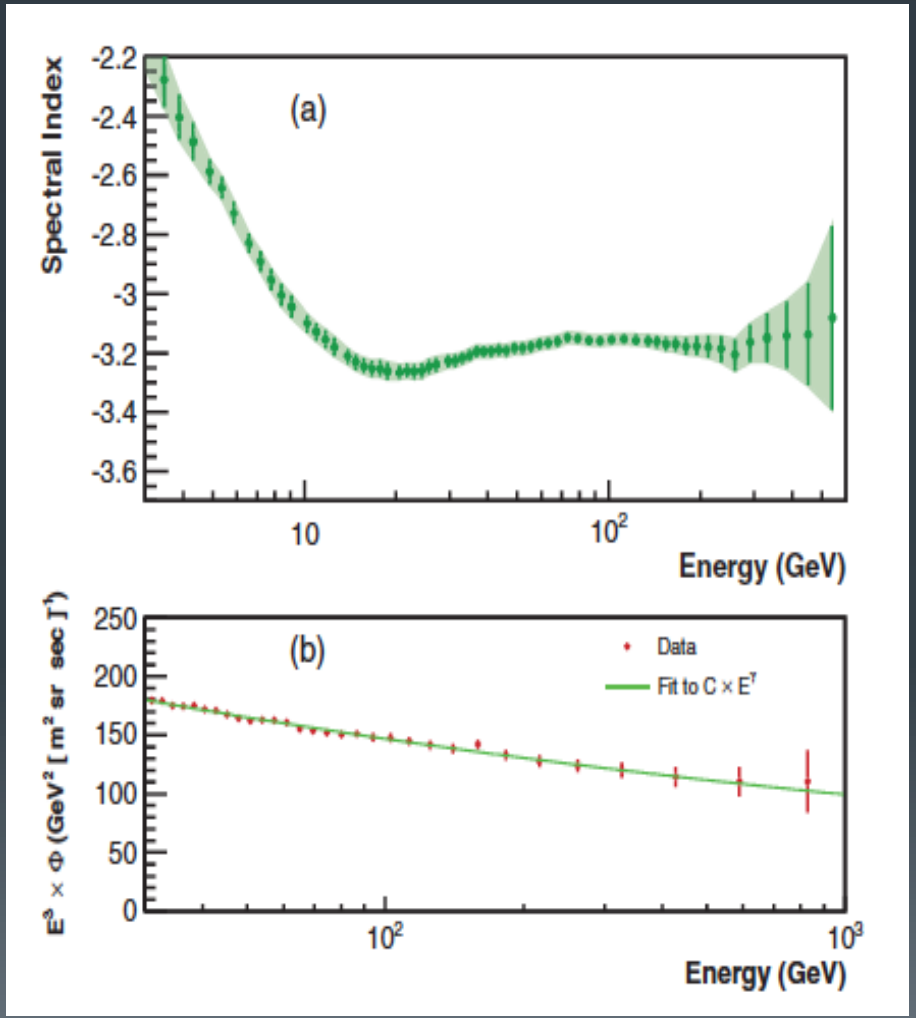
AMS Lepton Results (3)

All Electron ($e^+ + e^-$) flux up to 1 TeV



Flux smooth with no fine structures.
From 30.2 GeV to 1 TeV, single power law with index :

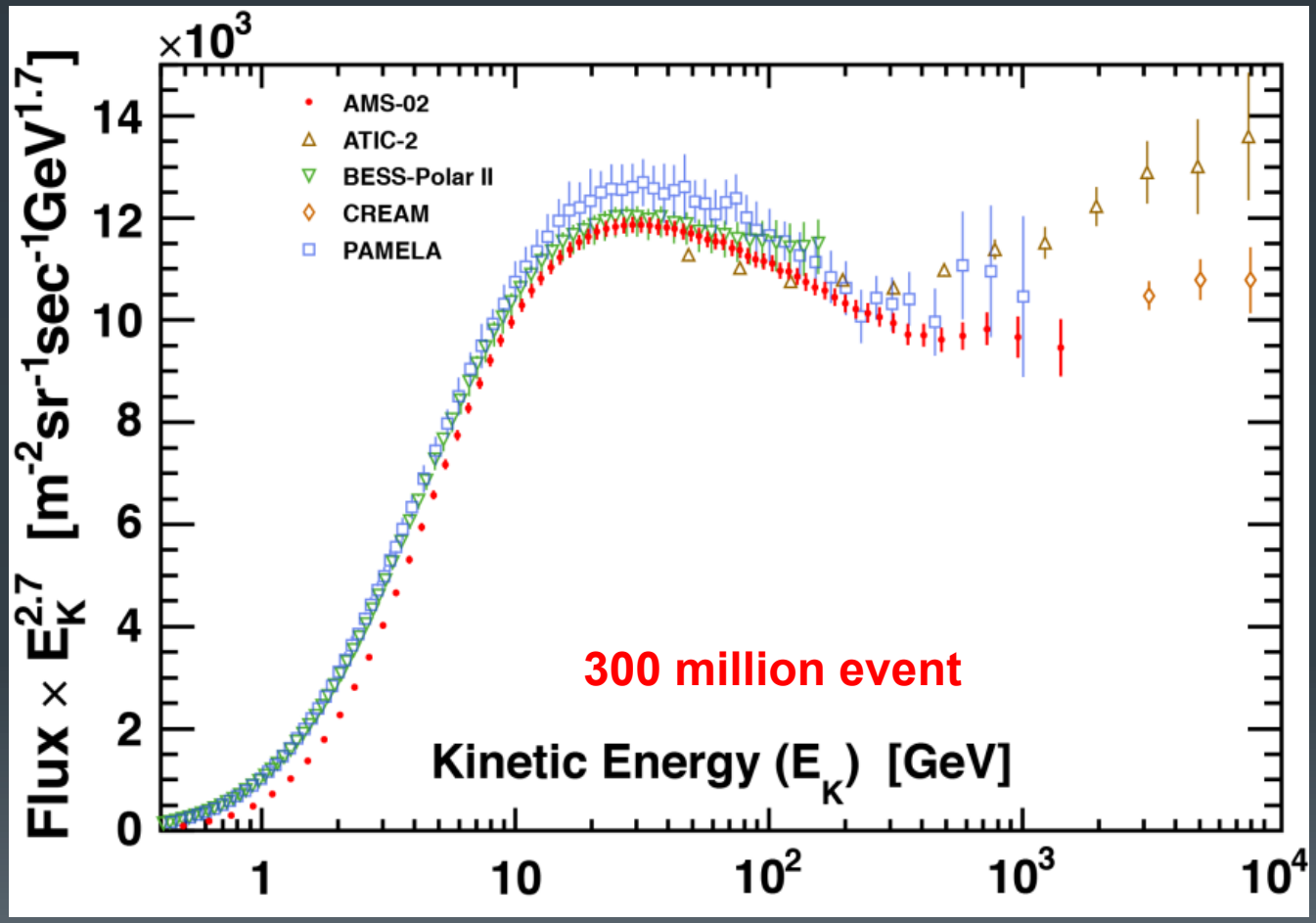
$$\gamma = -3.170 \pm 0.008(\text{stat+sys}) \pm 0.008(\text{E scale})$$



PhysReVLett.113.221103

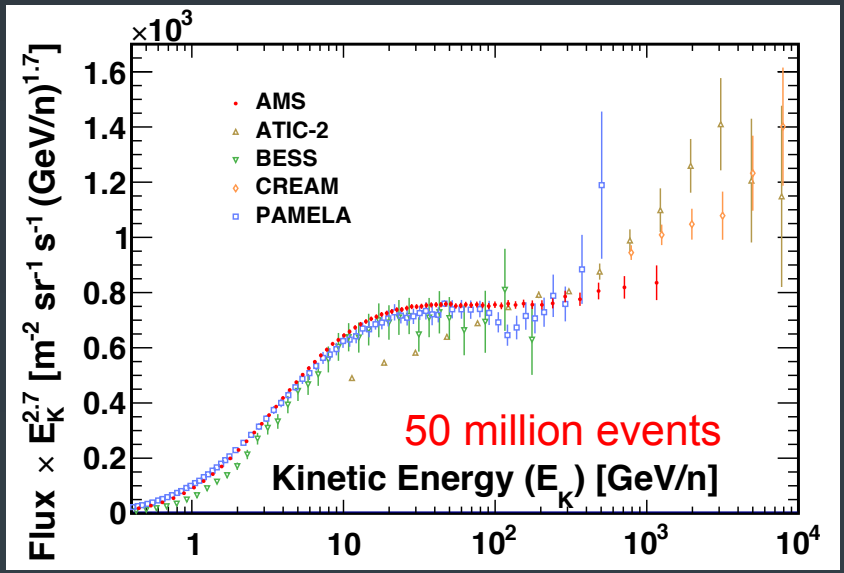
AMS Proton Flux

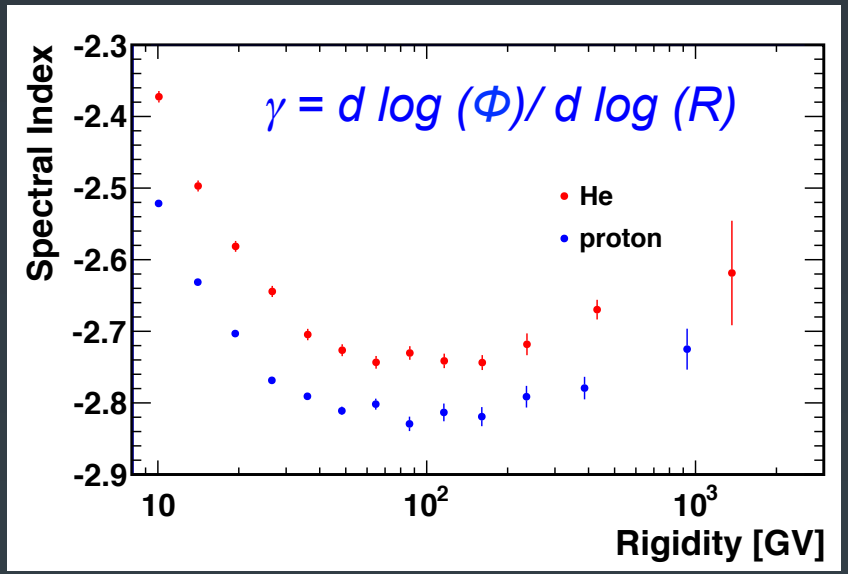
Proton flux from 1 GV to 1.8 TV (300 million events)



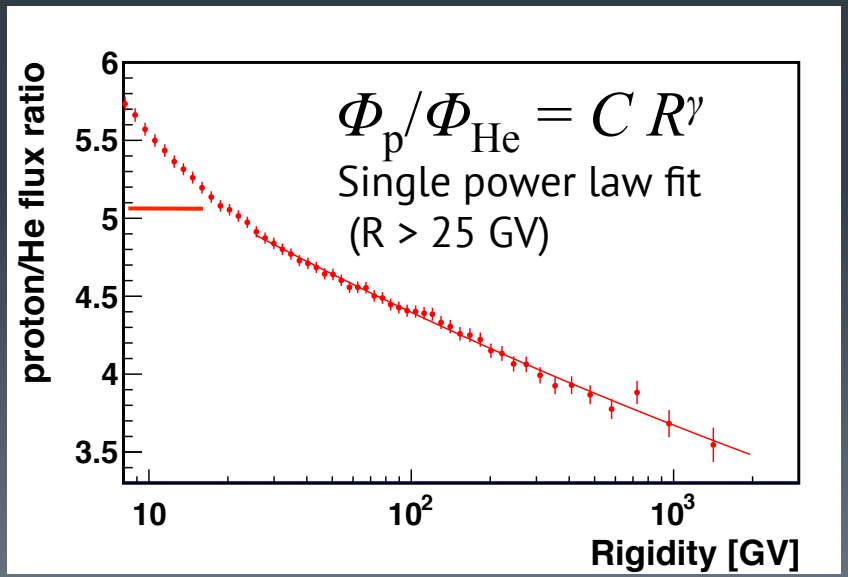
To match the statistics, the study of systematic errors have become crucial!

AMS Helium Flux (un-published)

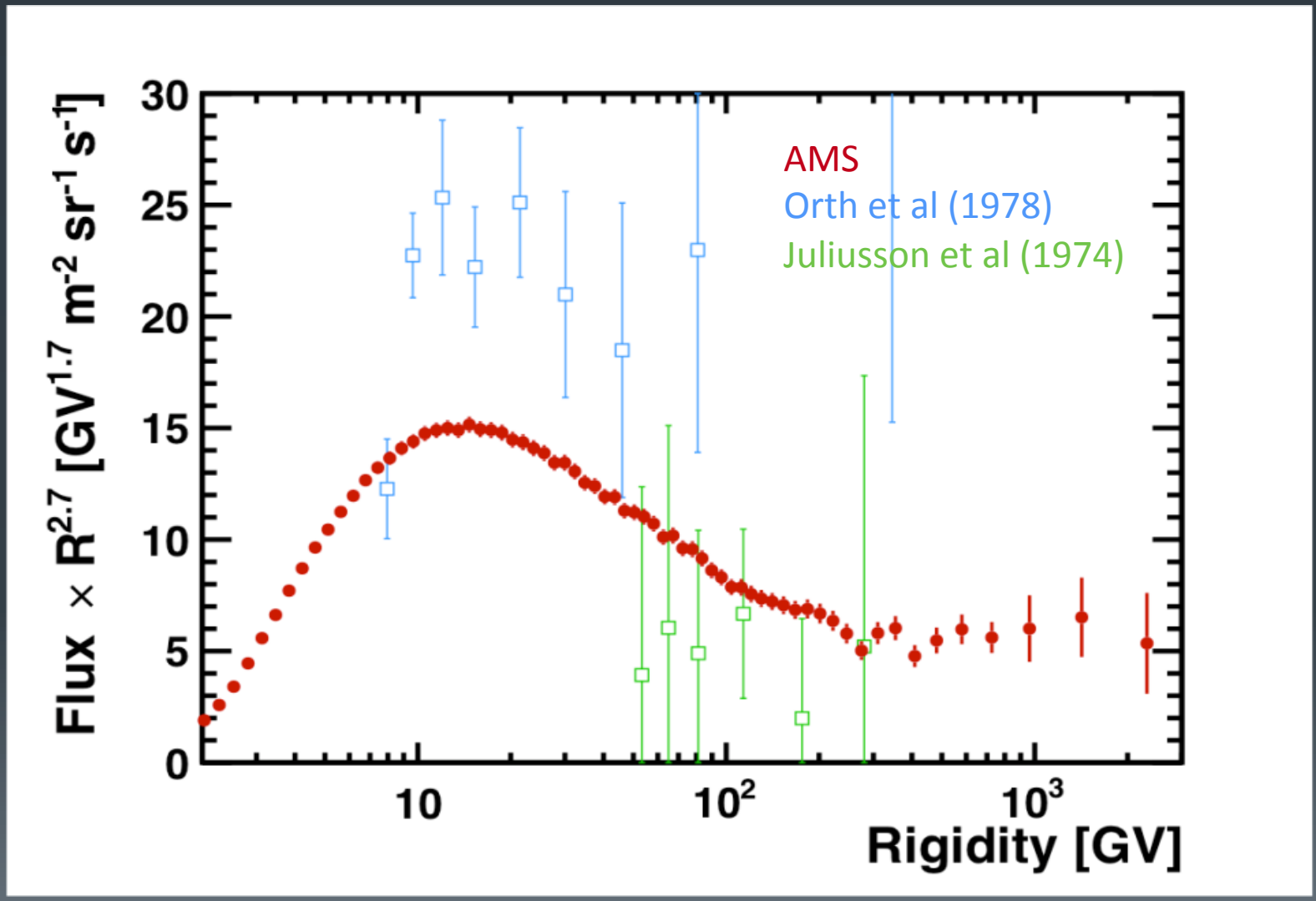




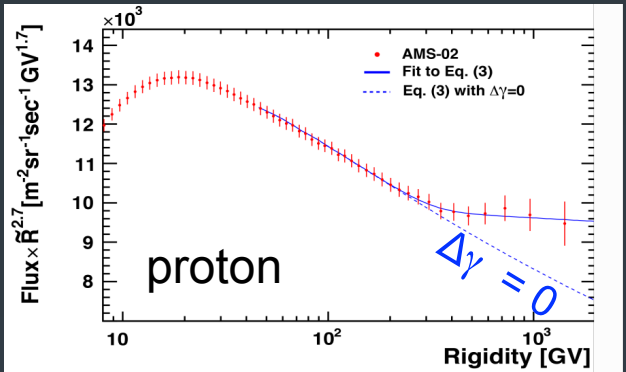
Variation of proton and helium spectral index very similar. Progressive hardening starts around 100 GV.

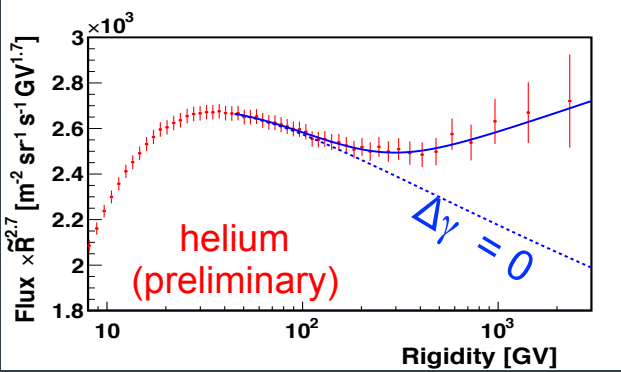


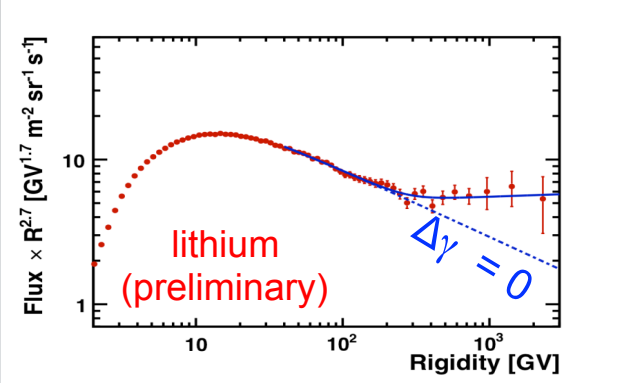
AMS Lithium Flux (current status)



AMS Nuclei Fluxes (H, He, Li)







$$\Phi = C\left(\frac{R}{45\mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

Solid curve fit of Eq. Φ to the data.
Fit to data above 45 GV:

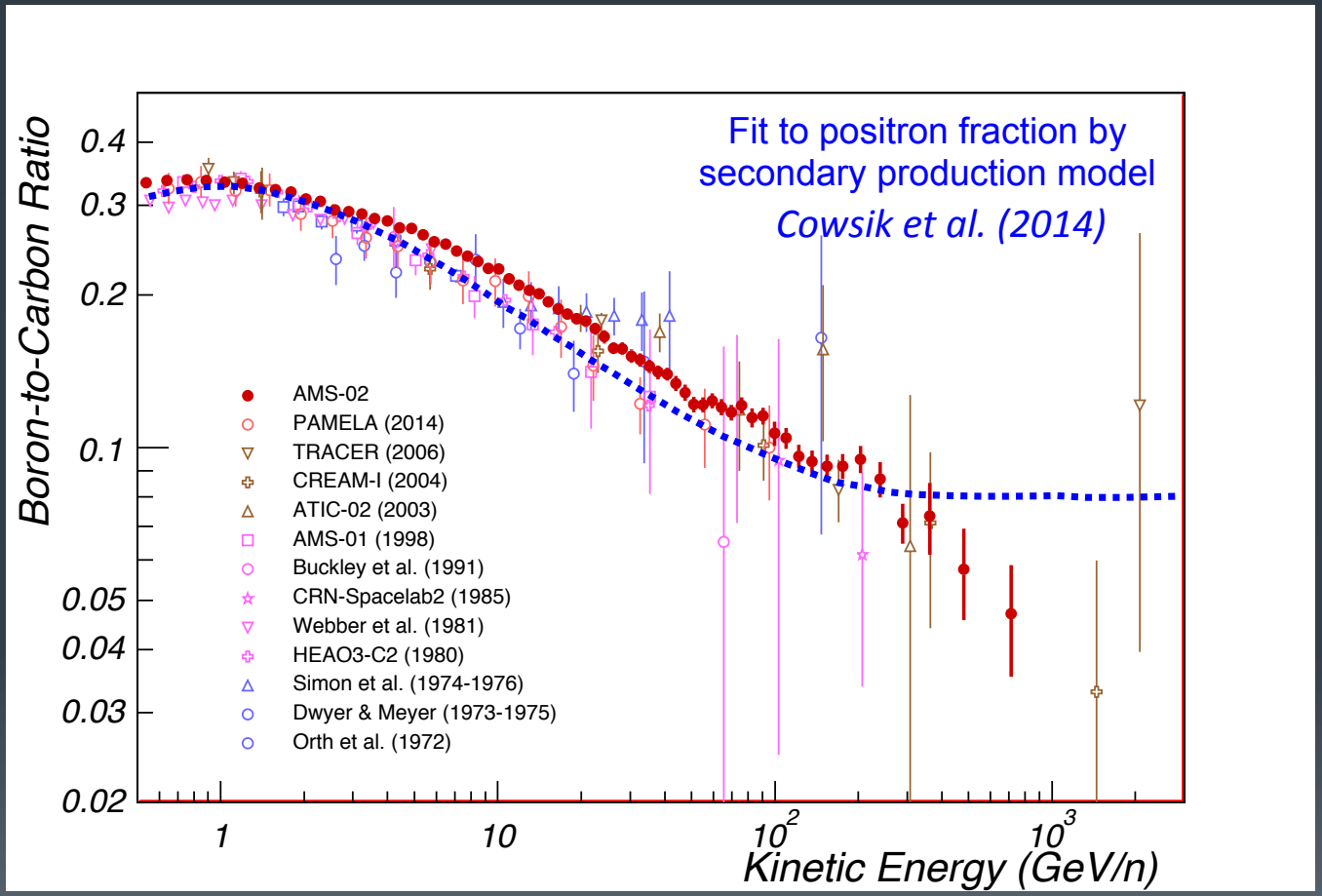
- proton : χ^2/d.f.= 25 /26
- helium : χ^2/d.f.= 20.5 /27

Dashed curve uses the same fit values but with Δγ set to zero.

Slope changes at about the same rigidity for proton, helium and lithium…
What will we see for heavier nuclei?

Boron over Carbon Ratio (current status)

Exposure time of 40 months, 7M Carbons, 2M Borons



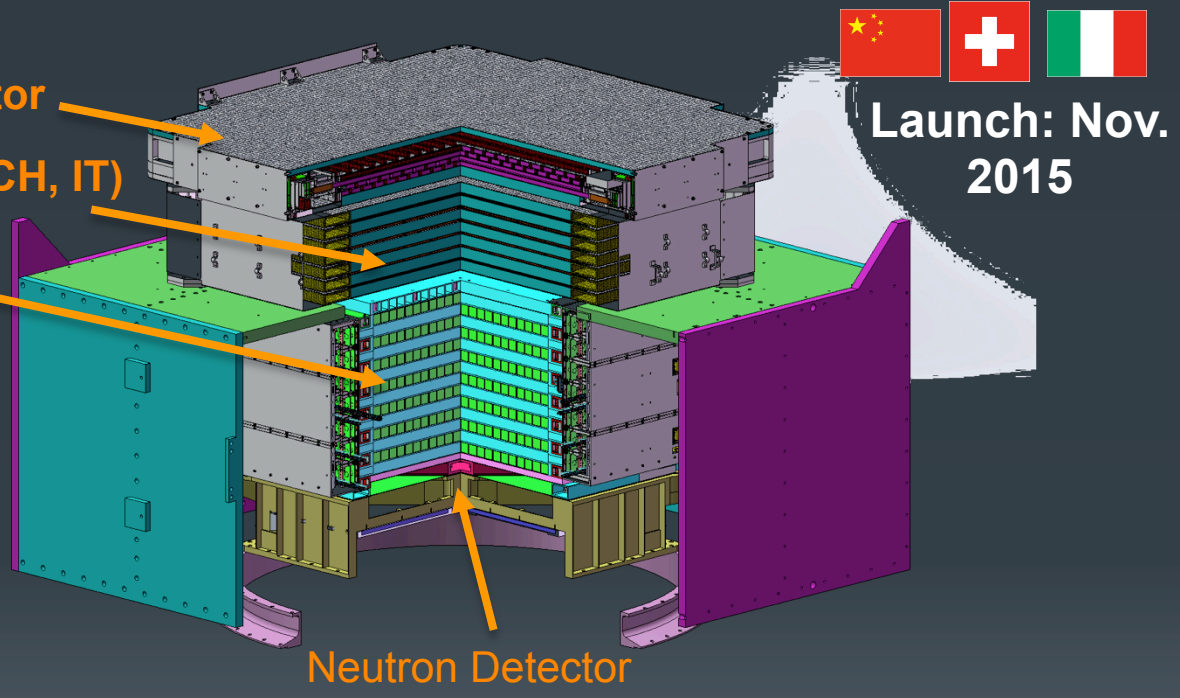
Precision and extended energy range of AMS B/C will help better constraining propagation models.

Future Space Missions

In which DPNC and/or ISDC and/or PSI are involved
(as well as other Swiss institutes)

DAMPE (DArk Matter Particle Explorer)

- **High priority satellite project of Chinese Academy of Sciences (CAS)**
- Collaboration: DPNC, Perugia, Bari, Lecce, IHEP, PMO, USTC, IMP, NSSC
- CERN recognized experiment since March 2014



Launch: Nov. 2015

~3x GF of AMS-02 !
~ 33 X_0
deepest space CALO

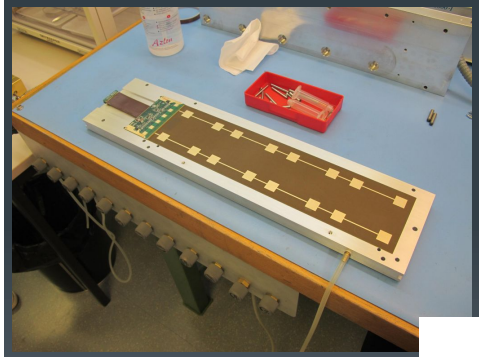
Detection of 5 GeV - 10 TeV e/γ, 100 GeV - 100 TeV CR
Complementary to Fermi, AMS-02, CALET, ISS-CREAM

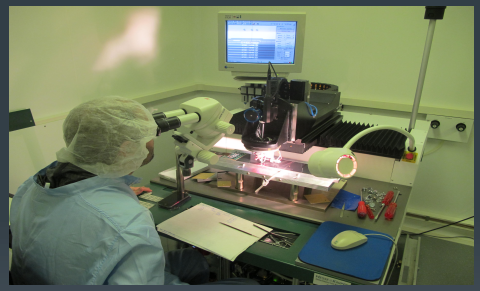
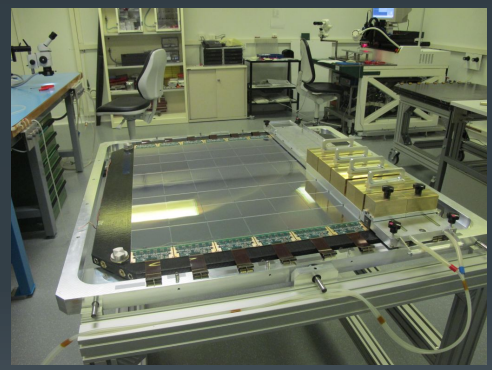
W converter + thick calorimeter (total 32 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

DAMPE Silicon Tungsten Tracker

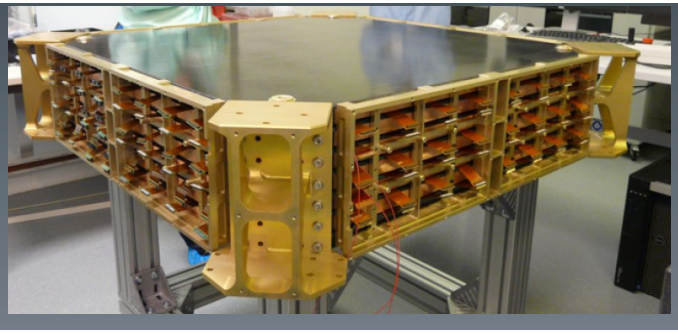
- ✓ **DPNC proposed and leads the Silicon-Tungsten Tracker project**:
  Main design, production, integration, test activities done at DPNC
- ✓ **STK completed, qualified and delivered**
  74k channels: noisy channels <0.5%

Status : Satellite integration in Shanghai in progress.
Current effort on calibration, commissioning, software, science preparation
Plan to play major roles in data reconstruction and analysis



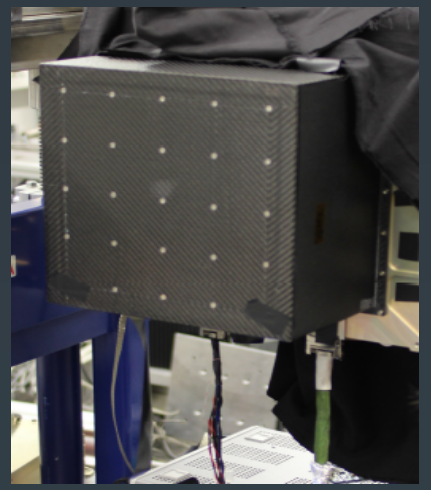
2 years of intensive effort at DPNC Geneva


POLAR (Polarimeter)

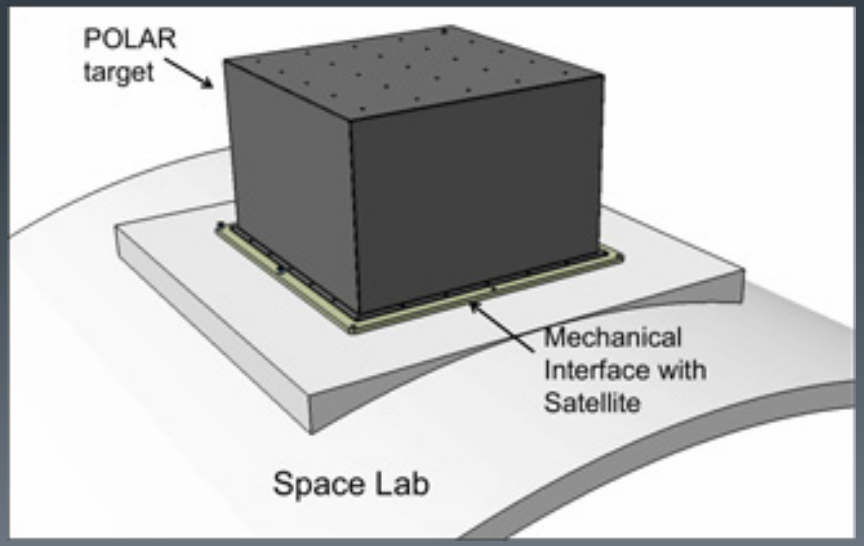
Gamma Ray Bursts (GRBs) are the most energetic electromagnetic events.

- POLAR measures polarization to 10% to distinguish models of GRBs (50-500 keV photons).
- On board the Chinese Tiangong-2 space lab, 30 kg module
- Original proposal from DPNC+ISDC
  International collaboration: DPNC, ISDC, PSI, NCBI Warsaw, IHEP
- DPNC : responsibility for detector design and construction



Status :

- **Construction completed**
  - Final calibration at ESRF in May 2015
  - Final acceptance tests at Terni in June
  - Shipment to China in July
  - Launch in Summer 2016
- **Plan to play a major role in data analysis**
  - In close collaboration with ISDC

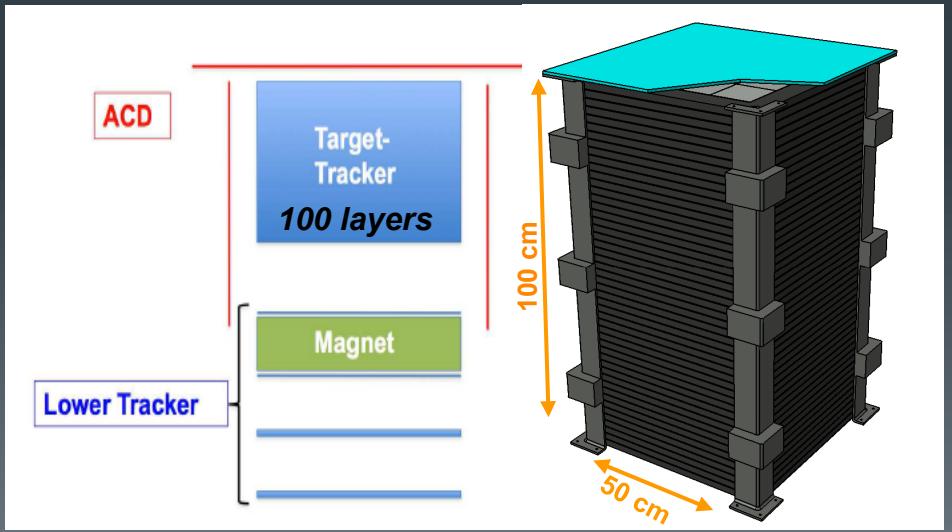


PANGU: PAir-productioN Gamma-ray Unit

A High Resolution Gamma-Ray Space Telescope in 10 MeV - 1 GeV range.
Submitted in March 2015 to the ESA-CAS Call for Joint Small Space Mission
Mission concept proposed by DPNC

- **International collaboration with strong core instrument teams led by DPNC**
  - Switzerland (DPNC, ISDC, PSI), Italy, Sweden, Irland, China
  - Endorsed by national agencies from Switzerland, Italy, Sweden and Ireland
  - 80 authors from 11 countries: CH, IT, SE, IE, CN, FR, DE, ES, PL, ZA, AT

- **Innovative payload concept for Small Mission (~60 kg, ~65W)**
  - Target Silicon Tracker + Spectrometer
  - Unprecedented angular resolution in 10 MeV - few GeV + polarimeter capability

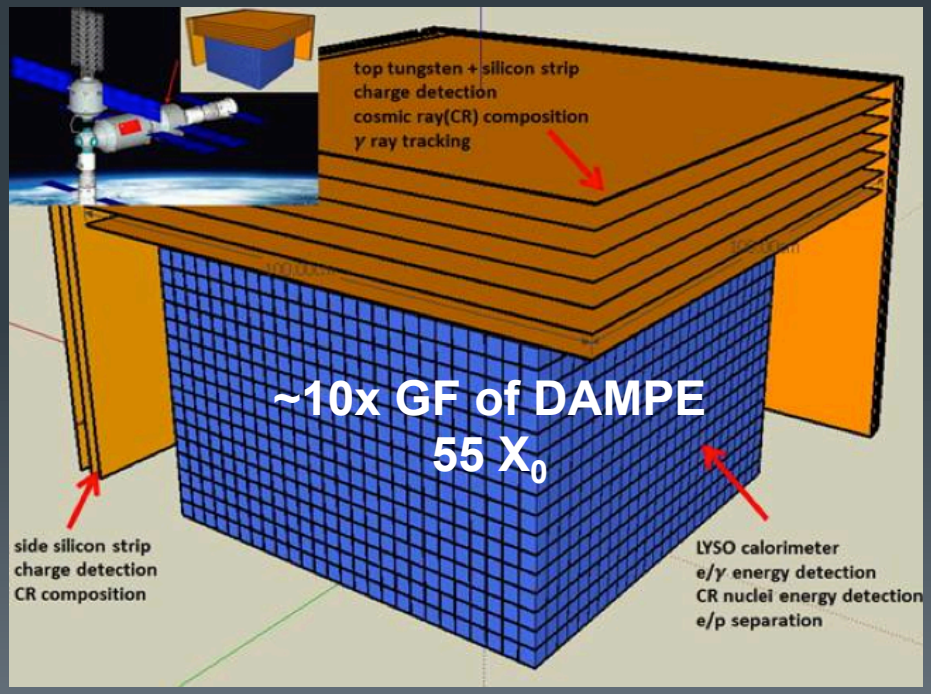


HERD : High Energy cosmic-Radiation Detection

Goal : Extend the science of AMS and DAMPE to much higher energy: CRs to the PeV region (γ's,e to TeV)

Proposal for the cosmic lighthouse program onboard China's Space Station

On board the Chinese Space Station, ~2025

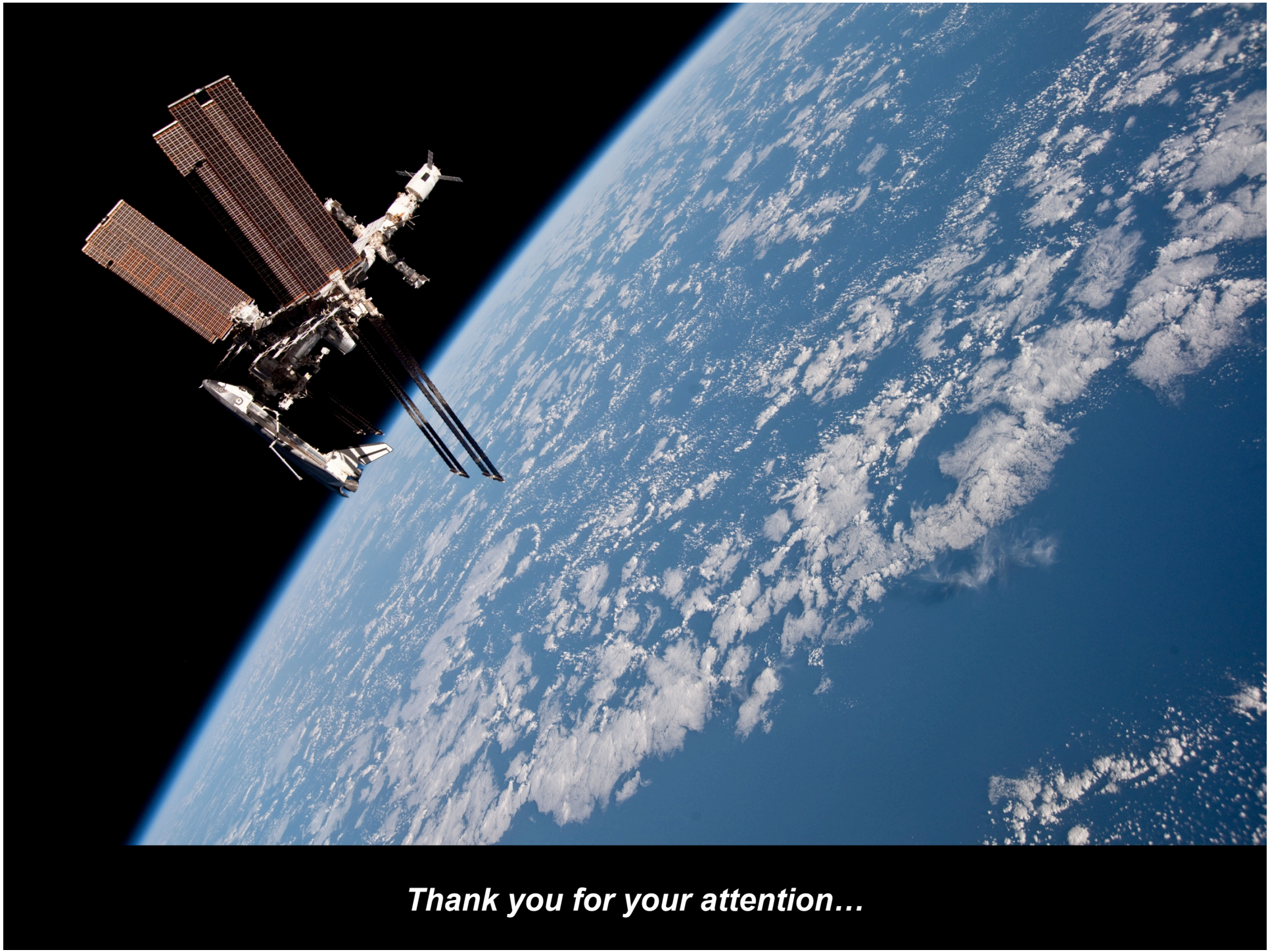


- > 2 tons and ~1.5x1.5x1.5 m^3
- **Key performance** :
  large acceptance ~2 m^2sr (nuclei)
- Deep cubic 3D Calorimeter
- 5 sides surrounded Si-W tracker
- TB of prototype calorimeter planned for November (e, p, ions)

DPNC proposed and involved in the Si-W Tracker + a sub-GeV γ-ray detector extension (eg. Fibers)

Conclusion

- In the past hundred years, measurements of charged cosmic rays by balloons and satellites have typically contained ~30% uncertainty.
- AMS is providing cosmic ray information with ~1% uncertainty which provides new type of constraints to theoretical models.
- Future experiments will extend AMS measurements to even higher energies, allowing to distinguish between different interpretations of the current data.
- DPNC/ISDC is actively involved and has gain a large expertise in the field of cosmic ray measurements from space.


Thank you for your attention…