
# AMS-02 in space

## physics results overview and challenges

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LPSC Grenoble 01 December 2014

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# The AMS Project

**Particle physics detector conceived for high precision study of CRs at TV energy**

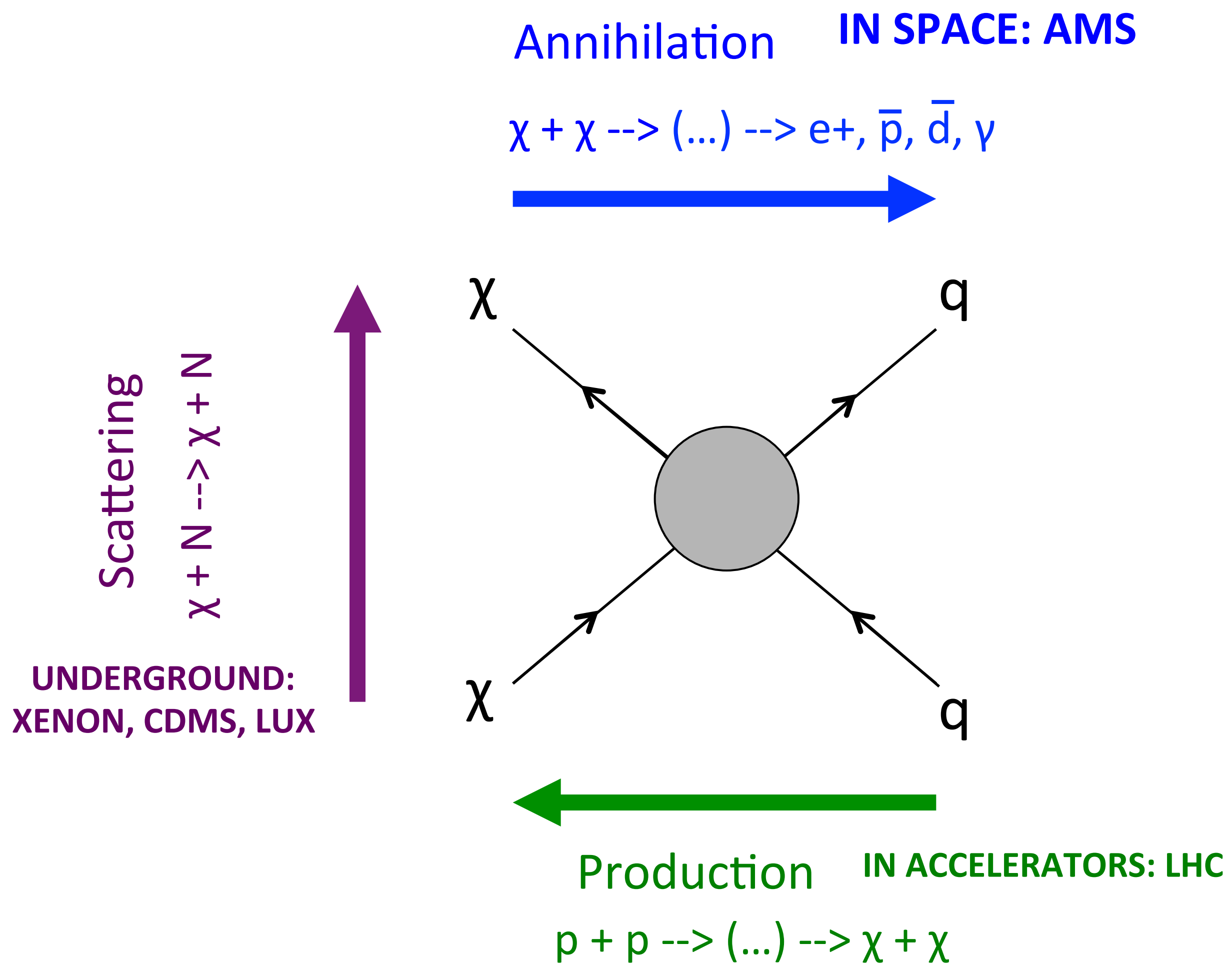
## Physics goals

- ✓ **Antimatter search (|Z|>1 anti-nuclei)**
- ✓ **Dark Matter (light anti-matter & γ-rays)**
- ✓ **Exotic signals?**
- ✓ **GCR & γ-rays astrophysics**
- ✓ **Solar Physics (modulation & SEP)**
- ✓ **Magnetospheric physics**


## How it will fulfill these goals?

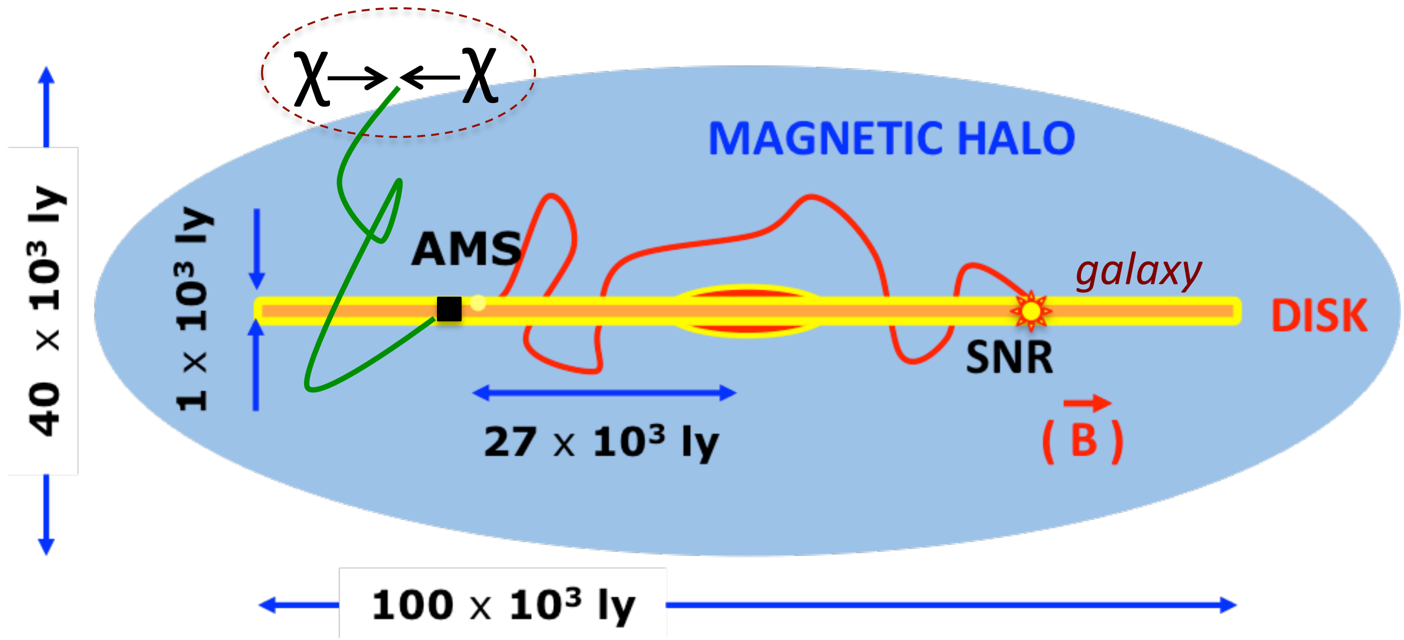
- **Large collaboration: 16 Countries, 60 Institutes and ~500+ Physicists**
- **Same concept (precision & capability) as the large state-of-the-art HEP detectors [but: fitting into the space shuttle & no human intervention after installation]**
- **Operation in space, ISS, at 400km, no backgrounds from atmospheric interactions [extensive multi-step space qualification tests]**
- **Collection power: geometrical factor (≈ 0.5 m2sr) X exposure time ( = ISS lifetime) [extensive calibration campaigns on ground]**

# Search for dark matter



# Dark matter and CR propagation physics

- ✓ *Background* from cosmic-ray sources (SNR) - No anti-matter expected
- ✓ *Background* from p+ISM collisions on disc: from propagation models
- ✓ *Signal* from DM annihilation χ + χ --> (...) --> antimatter




*DISC*

- *Sources (SNRs)*
- *Intestellar matter (ISM)*

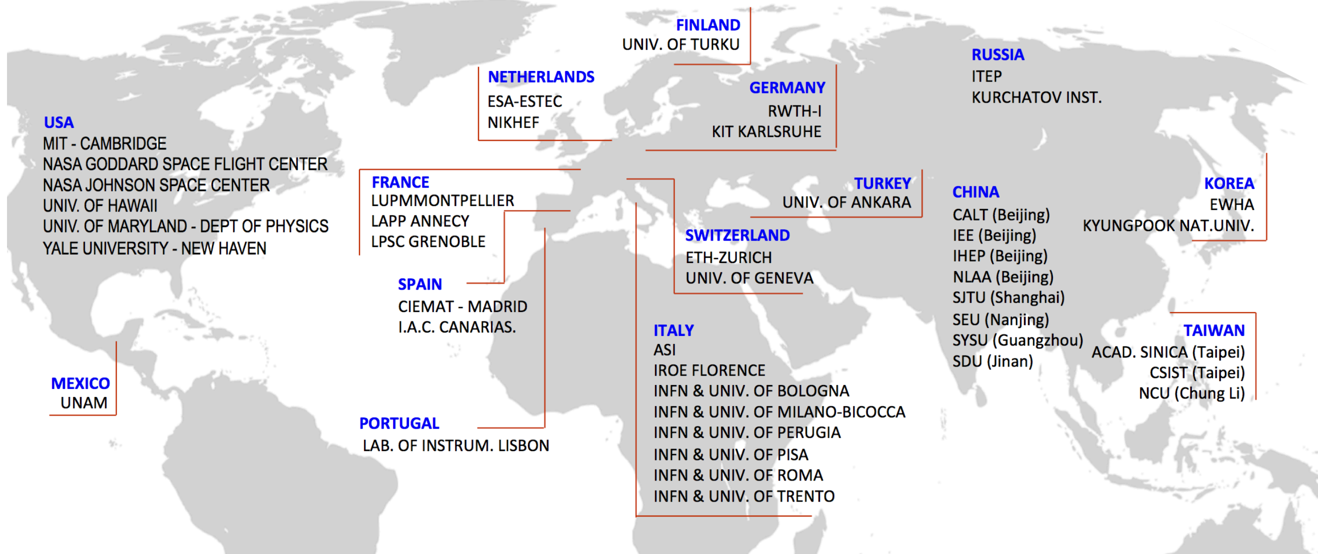
*MAGNETIC HALO*

- *Turbulent B-field. Zero matter.*
- *Energy dependent CR diffusion*

# The AMS Project

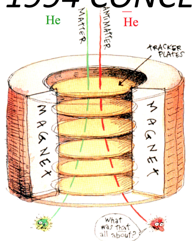
## AMS Collaboration

- *16 countries*
- *60 institutes*
- *500+ physicists*
- *20 years*




## Project timeline

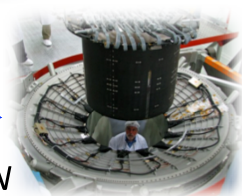
*1994 CONCEPT*



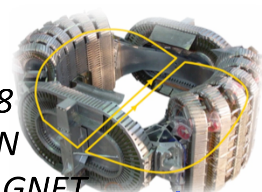
*1997 AMS-01 PROTOTYPE*

*1998: STS-91*

*2000 @CERN AMS-02 CONSTRUCTION*



*2008 @CERN SC MAGNET BEAM TEST*



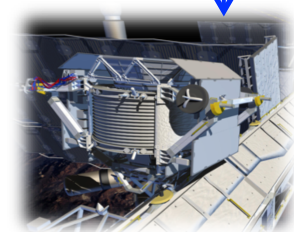
*2010 TVT @ ESA (NL)*

*2010 @CERN SC -> PM NEW BEAM TEST*

*2011 @KSC INTEGRATION & CR-μ RUN*


*MAY 2011 STS-134 FLIGHT*

*ON THE ISS*



**→ Steadily taking data on the ISS since May 19th 2011**

# May 16th 1011: launch!

# May 19th 2011: activation!

# Full time monitored

## The Payload Operation Control Center (POCC)

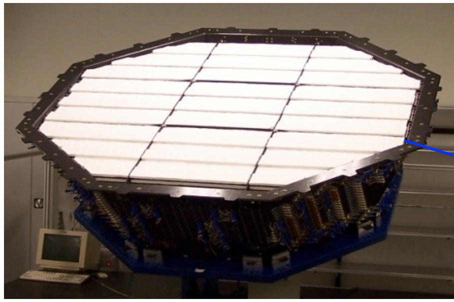
*Since the 27th June, 2011, 5:00 am GMT, AMS-02 is controlled 24/7 from the new POCC building at CERN, Prevessin site.*

*Shifts are organized to monitor the AMS-02 conditions, operations, and the continuous flow of data to ground.*

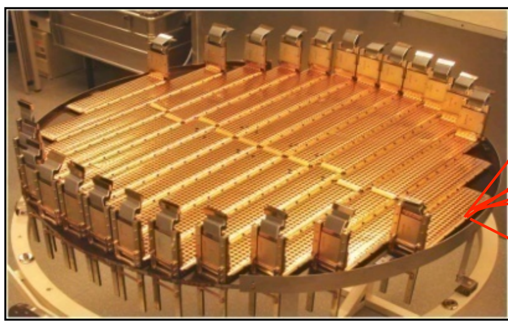
*Since July 2012, a second control room (the asia POCC) is running at the CSIST facility in Taiwan.*

# The AMS-02 instrument

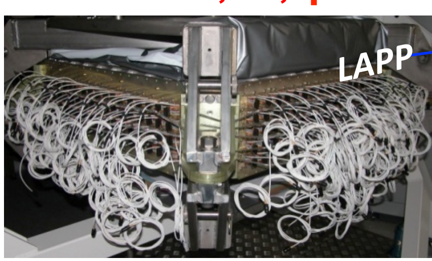
**TRD**
**Identify e+, e-**



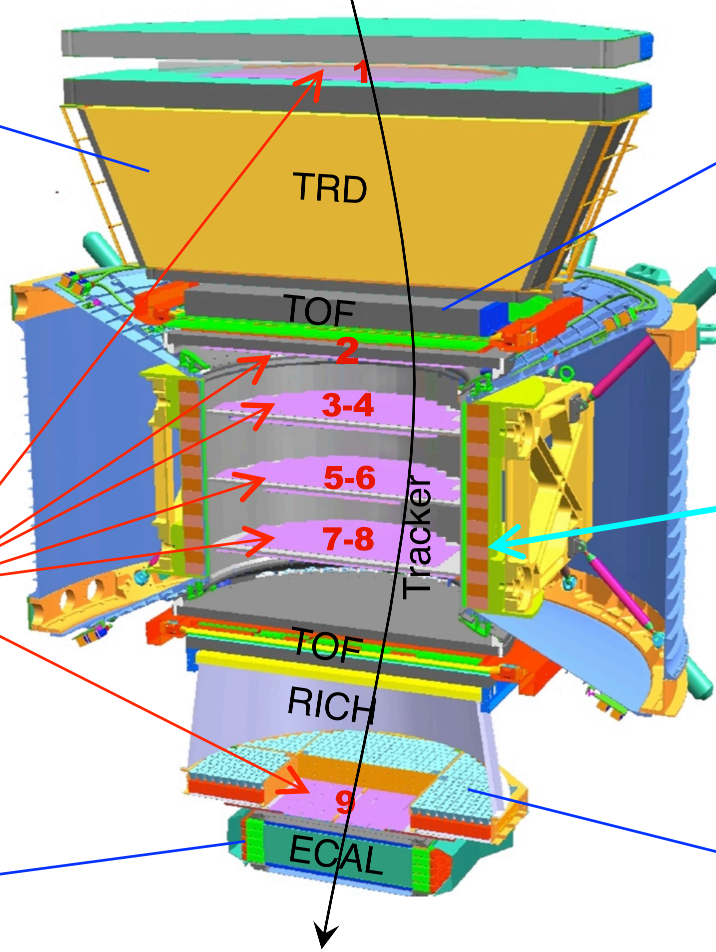
**Silicon Tracker**
**Z, P**



**ECAL**
**E of e+, e-, γ**

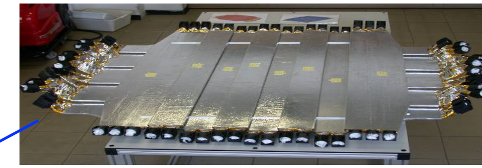



**Particles and nuclei are defined by their charge (Z) and energy (E ~ P)**

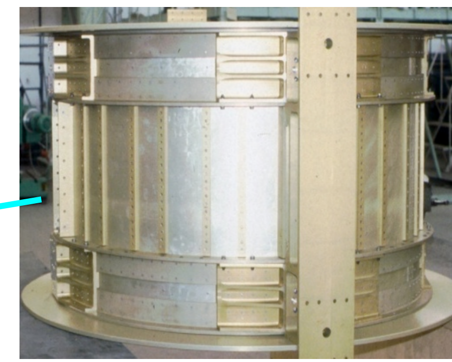



***Z, P* are measured independently from Tracker, RICH, TOF and ECAL**

**TOF**
**Z, E**

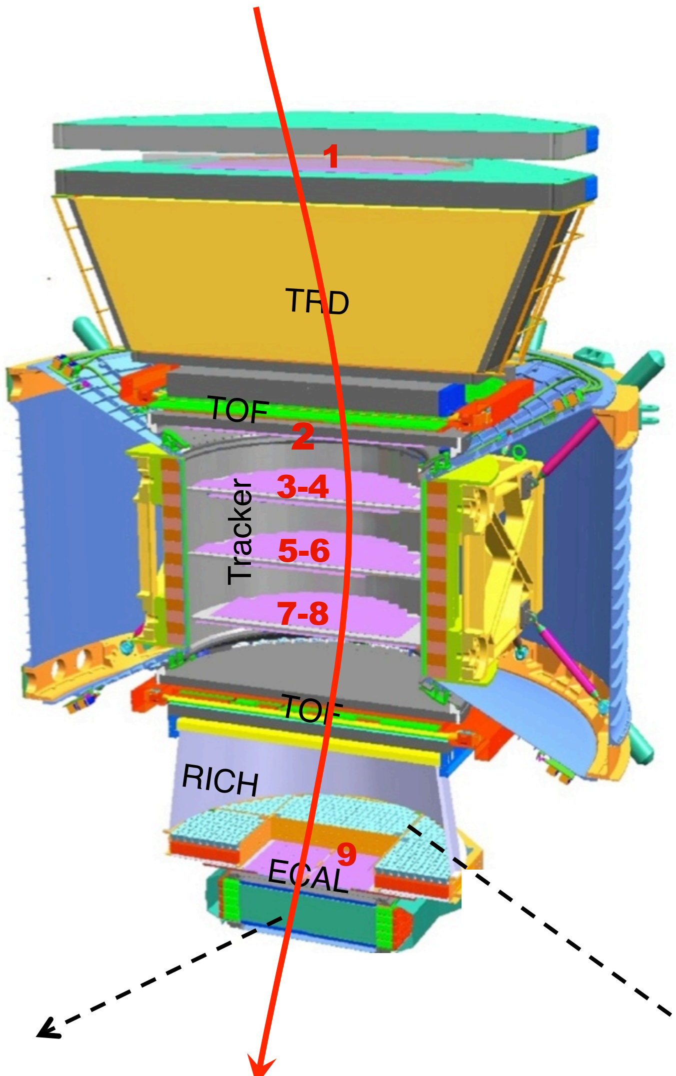


**Magnet**
**±Z**



**RICH**
**Z, E**

# Multiple measurements of energy




***Tracker, R = p/Z***
*MDR ≈ 2TV*

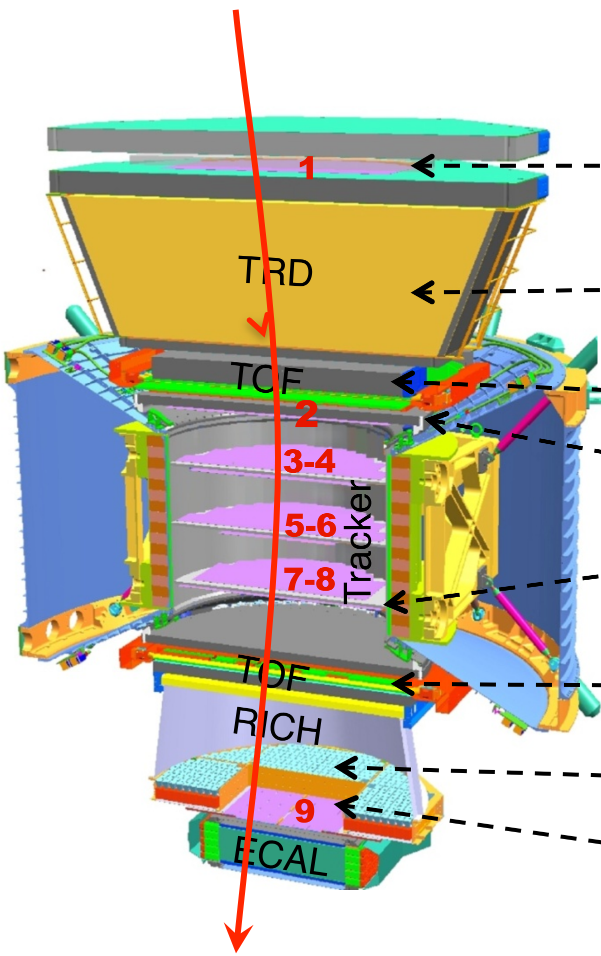
***TOF**, β*
*Δβ/β ≈ 1%*

***ECAL, E***
*ΔE/E (TeV e±) ~ 2 %*
*ΔE/E (TeV p) ~ 50 %*

***RICH**, β*
*Δβ/β ≈ 0.05%*

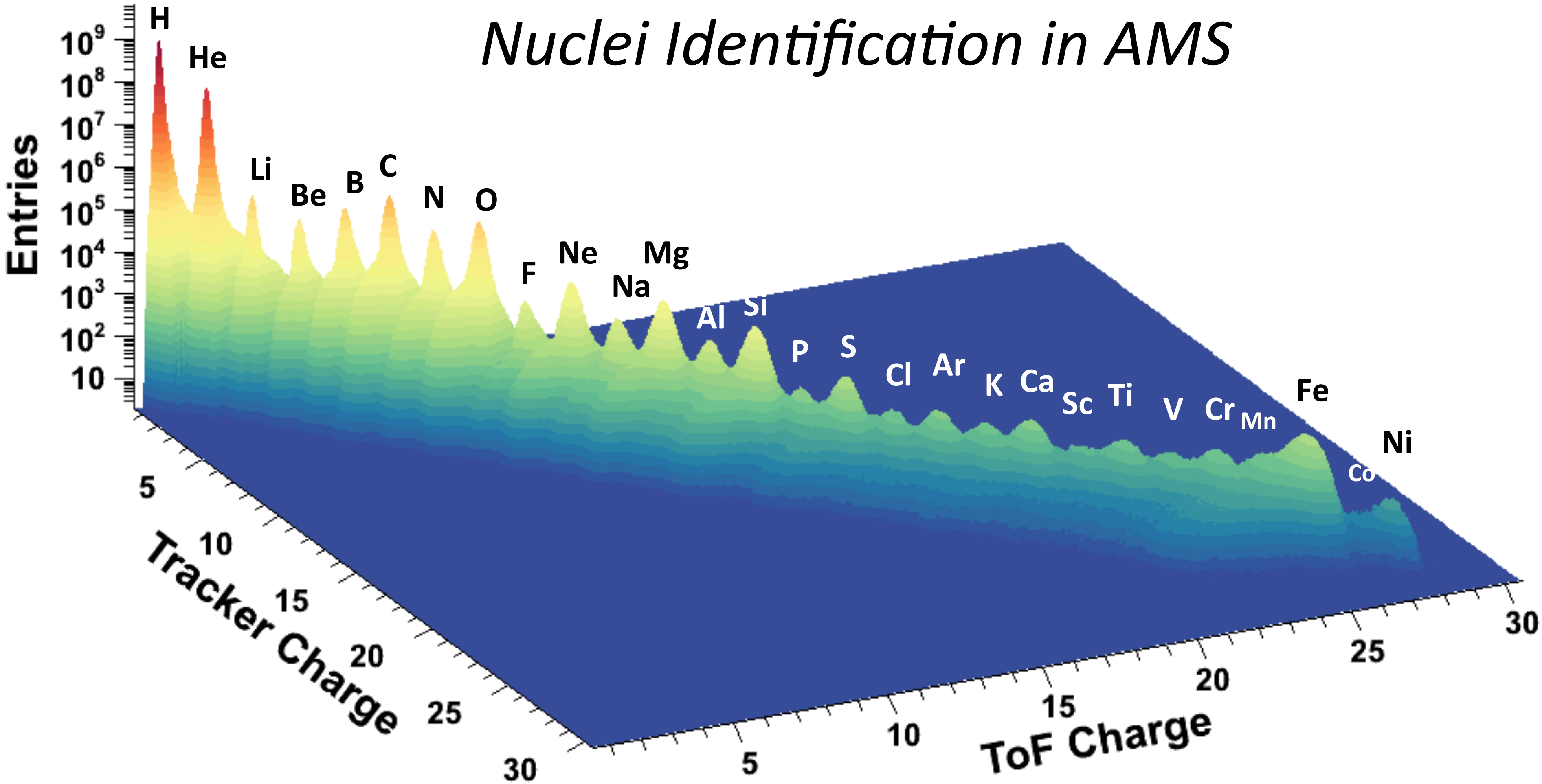
***Geomagnetic cutoff***
*ΔR/R ≈ 10% up ~25 GV*

# Multiple measurements of charge




| | ΔZ (carbon) |
|---|---|
| *Tracker Plane 1 (L1)* | *0.30* |
| *TRD* | *0.33* |
| *Upper TOF (1 counter)* | *0.16* |
| *Inner Tracker (L2-L8)* | *0.12* |
| *Lower TOF (1 counter)* | *0.16* |
| *RICH* | *0.32* |
| *Tracker Plane 9 (L9)* | *0.30* |

# Multiple measurements of charge

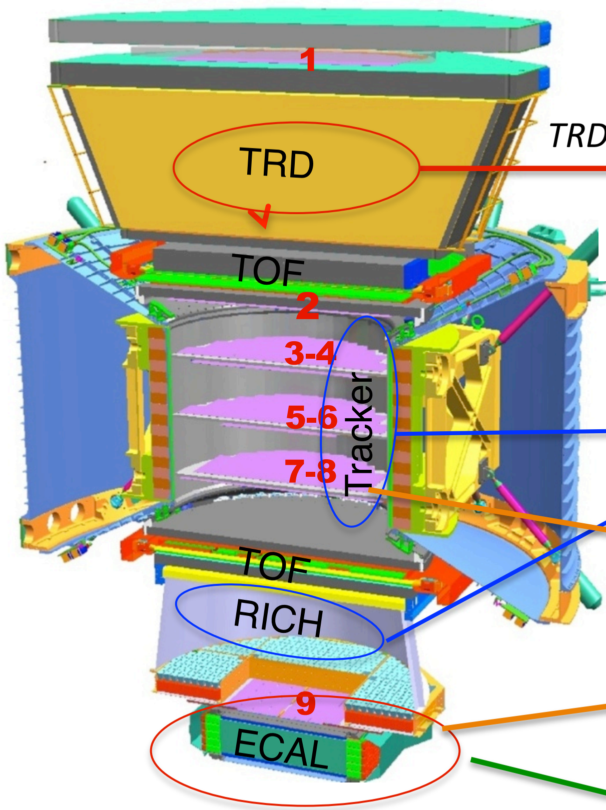


# Multiple lepton/hadron separation

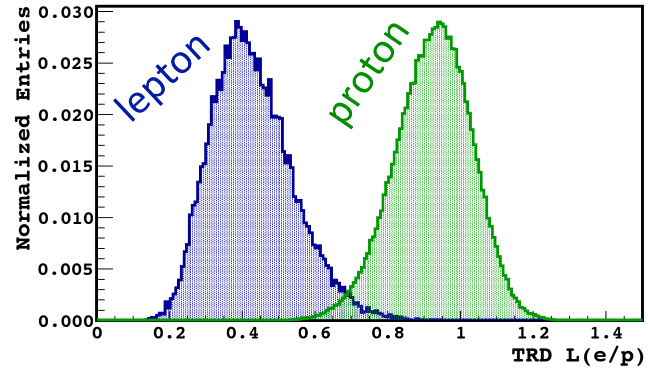
$$P_e = \sqrt[n]{\prod_{i}^{n} P_e^{(i)}(A)}$$

*TRD emission In 22 layers*

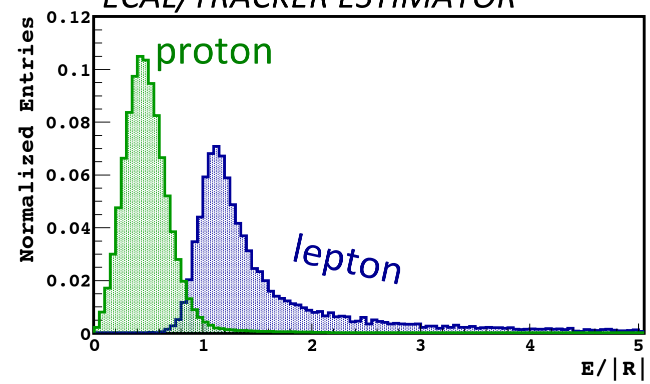
*Rigidity + β + Z = particle's mass*



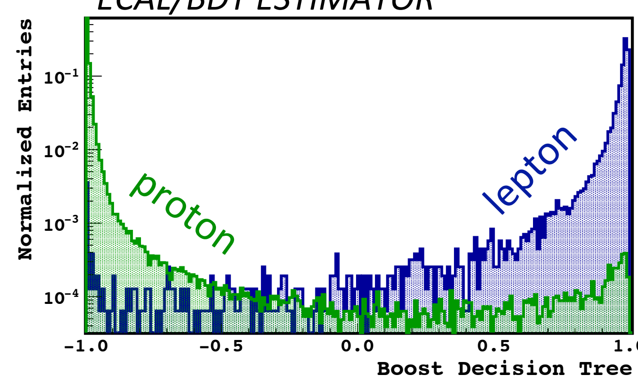

*TRD ESTIMATOR*



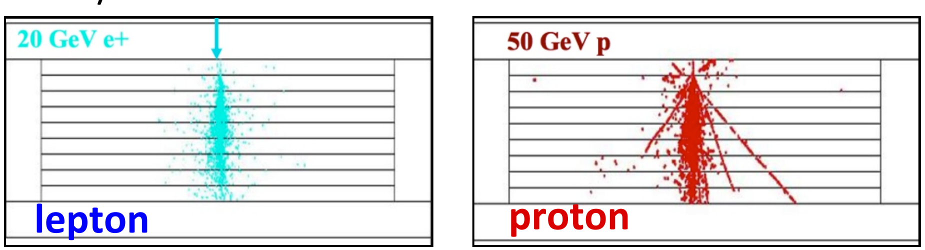

*ECAL/TRACKER ESTIMATOR*




*ECAL/BDT ESTIMATOR*



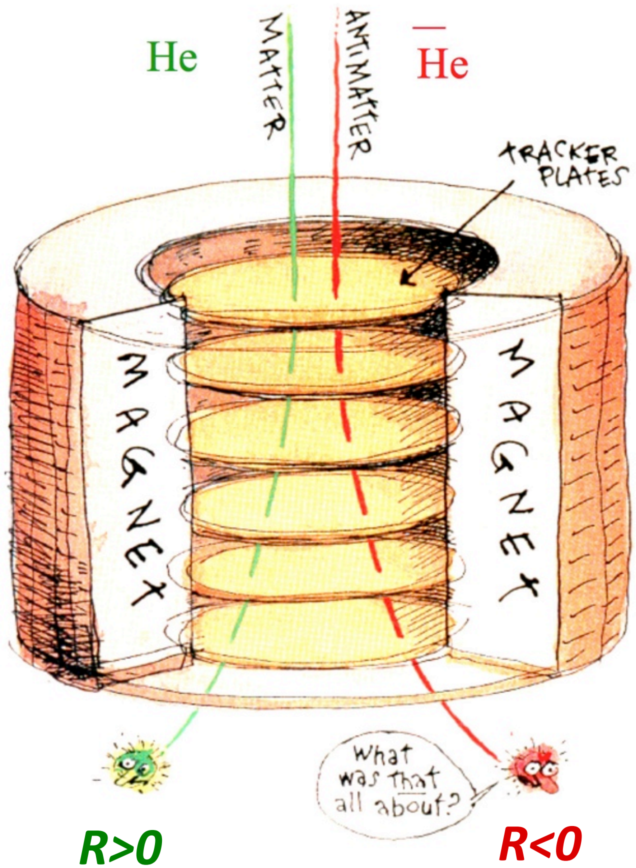

ECAL/BDT DISCRIMINATION ON SHOWER TOPOLOGY



# No redundancy for particle sign

**Matter-antimatter distinction: only from the track curvature**

***Charge confusion*: probabilty to get the wrong particle sign**




*Sources of charge confusion:*

- Interactions & sec production
- Track mis-reconstruction
- Finite momentum resolution

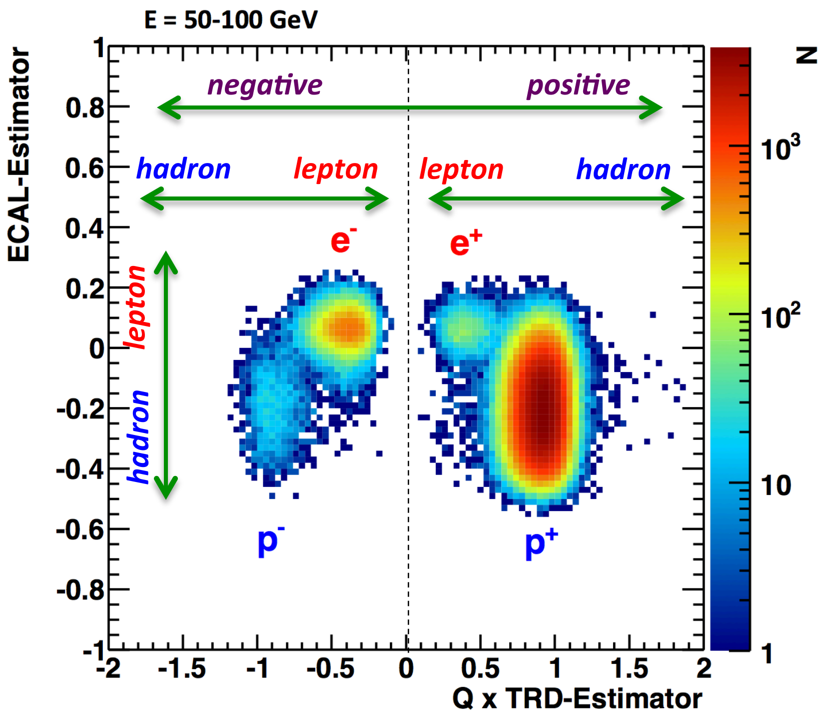
*Charge confusion probability estimators have been developed for leptons and hadrons, with the help of beam test data and MC simulation*

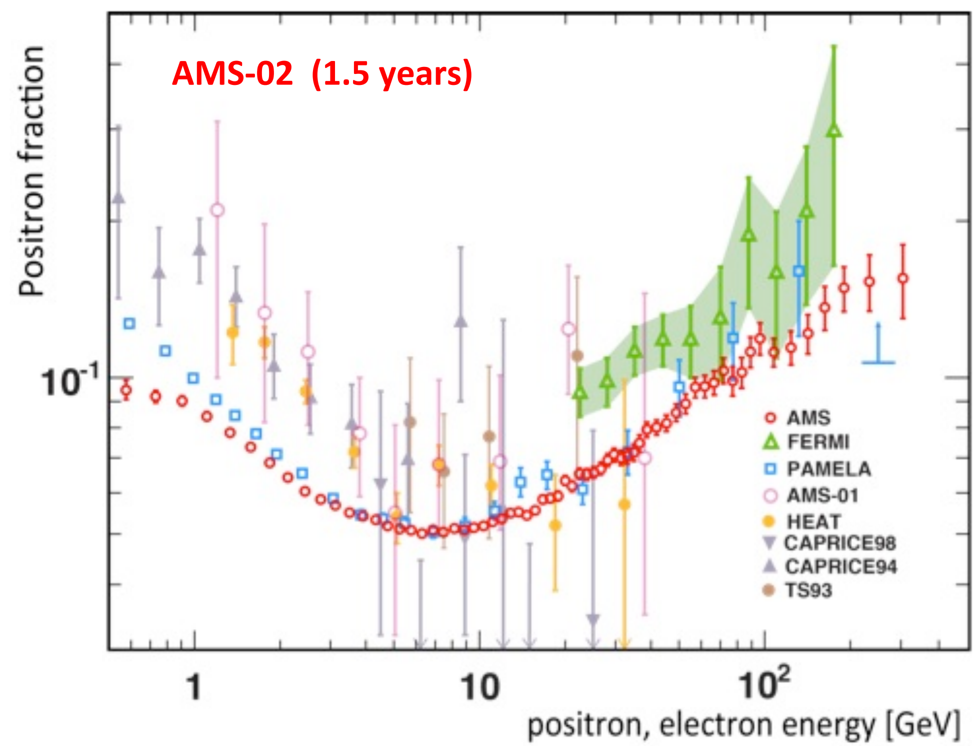
# Positron fraction results

Positron fraction measured between 0.5 to 350 GeV of energy

- ✓ *1.5 years of data. 74,000 events.*
- ✓ *72 events in the last energy bin*
- ✓ *No fine structure in the spectra.*
- ✓ *Persistent rise up ~ 200 GeV*

***The e+ secondary production is expected to decrease monotonically, while results indicate a persistent rise. The positron fraction increases steadily from 10 to 250 GeV.***



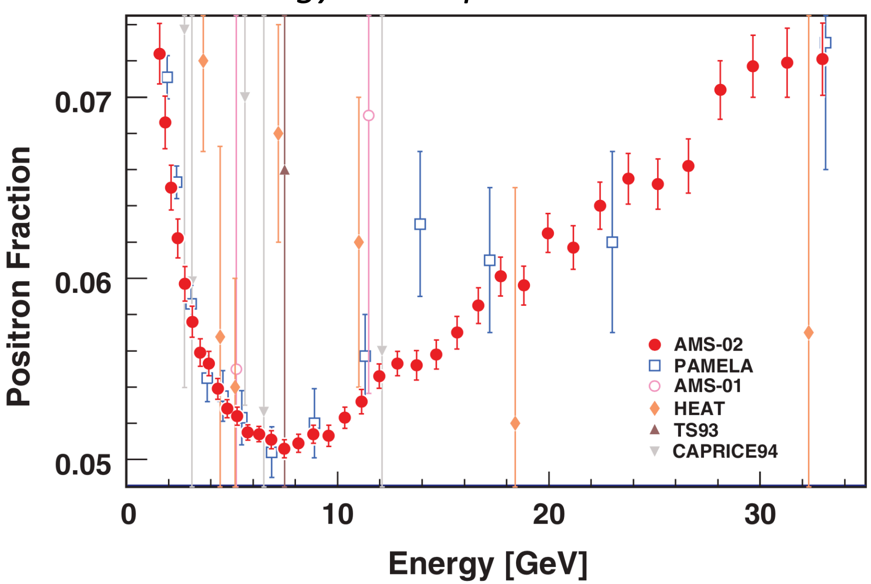



# Positron fraction at high energy

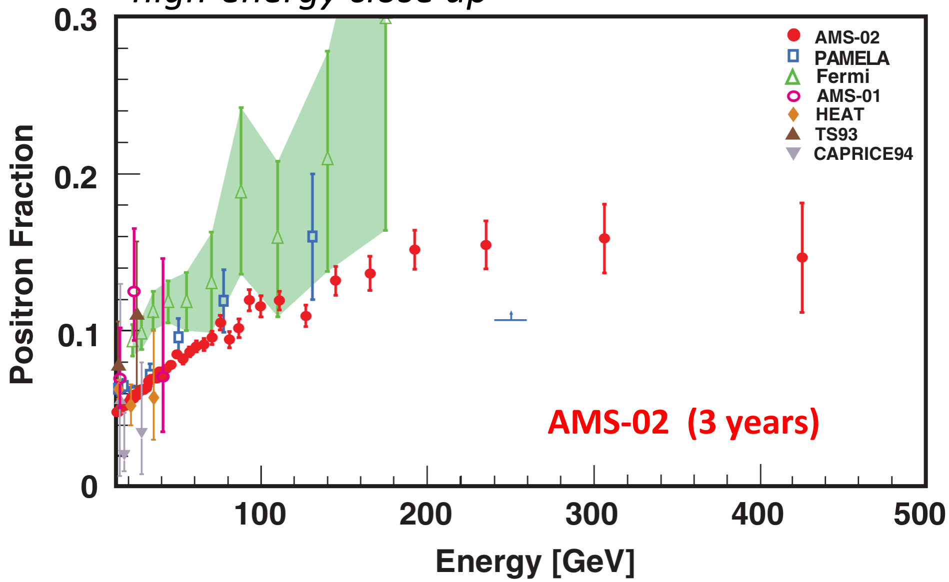
***October 2014 – New publication: positron fraction up ~500 GeV w/ 3yrs data***

- New high-energy data (3 yrs statistics) have been released
- The Positron fraction above ~200 GeV does not increase anymore

*low-energy close up*




*high-energy close up*



# Lepton fluxes: $e^+$, $e^-$, and "*all electron*"

***October 2014 – New publication: electron and positron fluxes up to 700 GeV***

***November 2014 – New publication: electron + positron total flux up to 1 TeV***

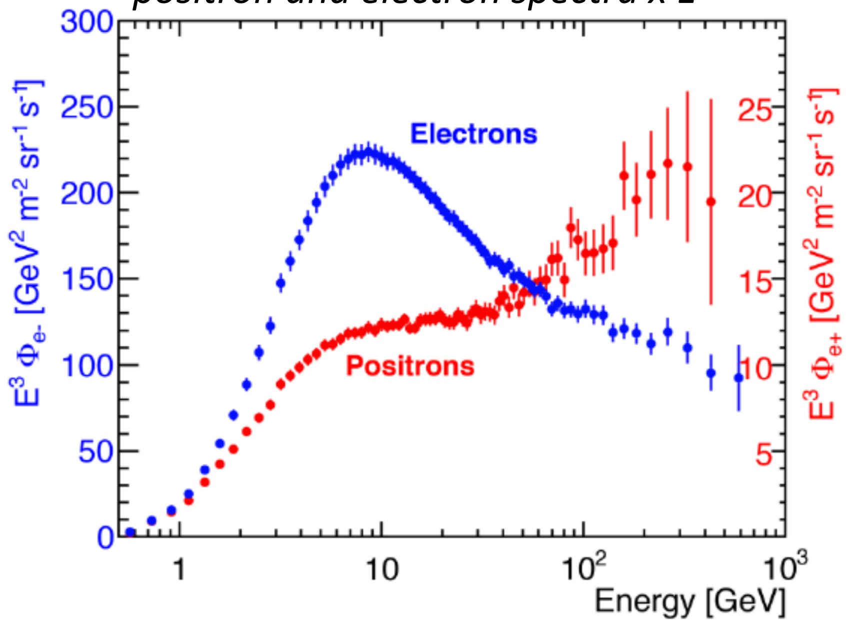
**Electron spectrum x $E^3$**

Above 10 GeV: smooth, slowly falling curve. Fairly good agreement with the PAMELA data. Different solar modulation at low energies.

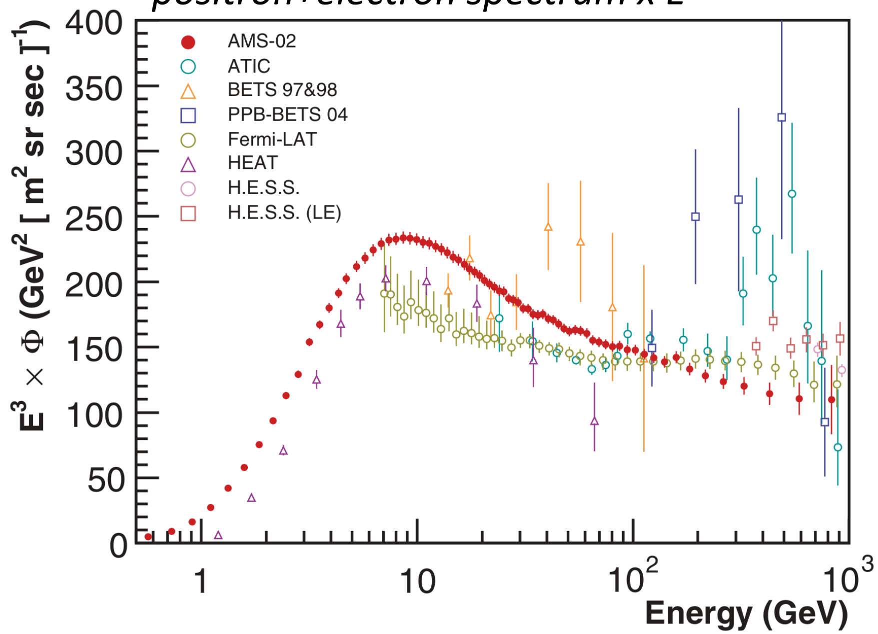
**Positron spectrum x $E^3$**

Flat spectrum from ~10 to 30 GeV. Change of slope above 30 GeV, harder than E-3, completely different from the e- spectrum.

*positron and electron spectra x $E^3$*



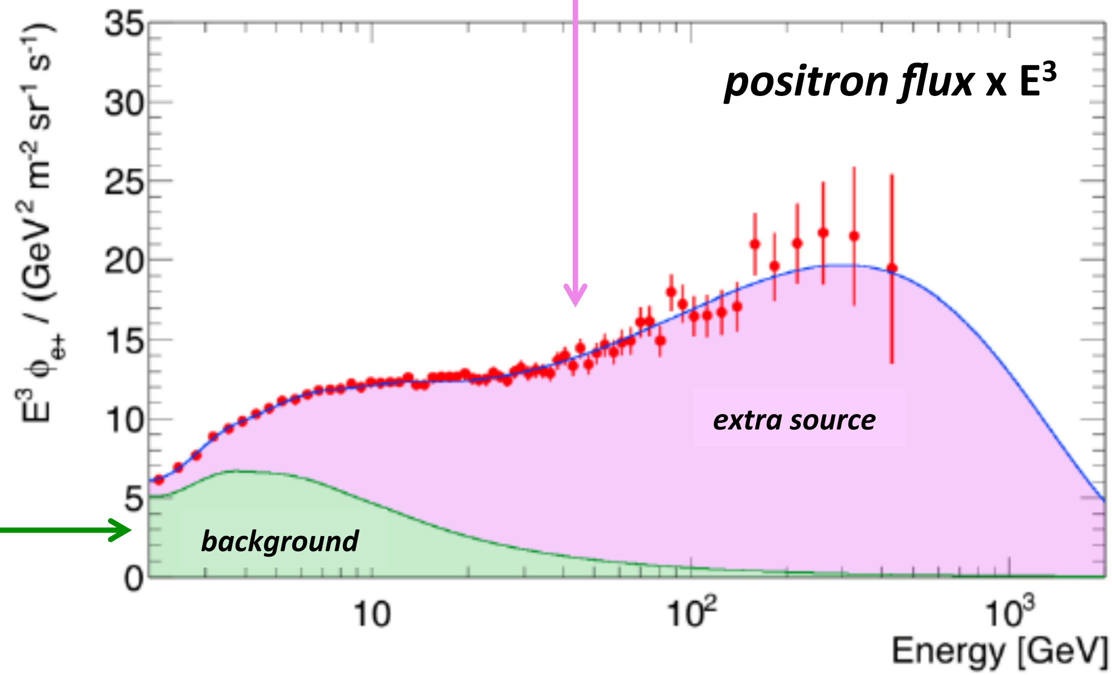

*positron+electron spectrum x $E^3$*



# Positron excess: sources of HE positrons

*Standard prediction: of e+ from p+ISM collisions*
*→Cannot account for the observed positron data*
*→Background for new physics/astrophysicssignals*

- Dark Matter particles
- Astrophysical sources (SNR/PWN)
- ✓ CR collisions with ISM



# Pure Dark-Matter scenarios

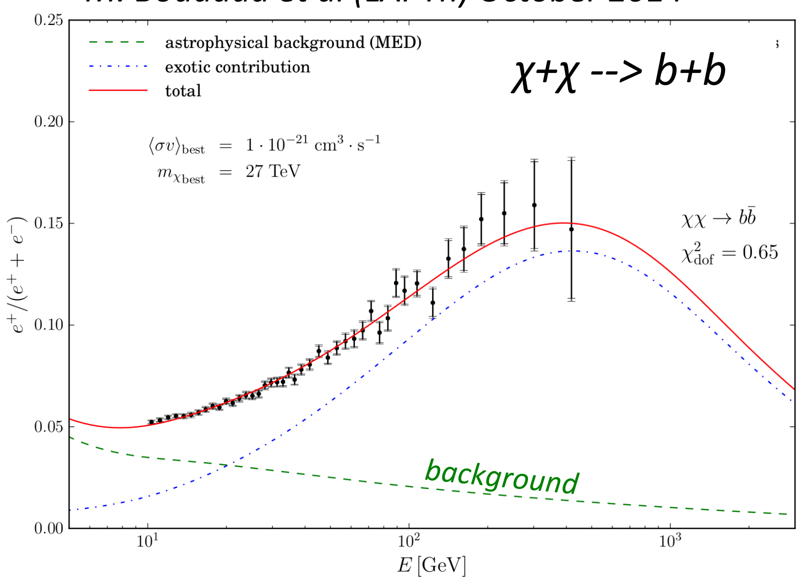
DM fits more challenging w/i precision of data. But many unknowns from DM particles

*Bosonic or hadronic channels (bb,WW): large masses (Mχ ~10 TeV). Large <σv> ~$10^{-21}$ $cm^3$/sec*
*Leptonic channels (e+e- … 2 x τ+τ-): ~ TeV mass, <σv>~ $10^{-23}$ $cm^3$/sec*

New data: hints of flattening above ~300 GeV
Pure DM scenario: TeV-scale DM, into leptonic states, with enhanced annihilation rates.

✓ **Search for signal in hadronic data: pbar/p ratio**
✓ **Uncertainty in background *and* signal propagation: CR nuclear data**

*M. Boudaud et al (LAPTh) October 2014*

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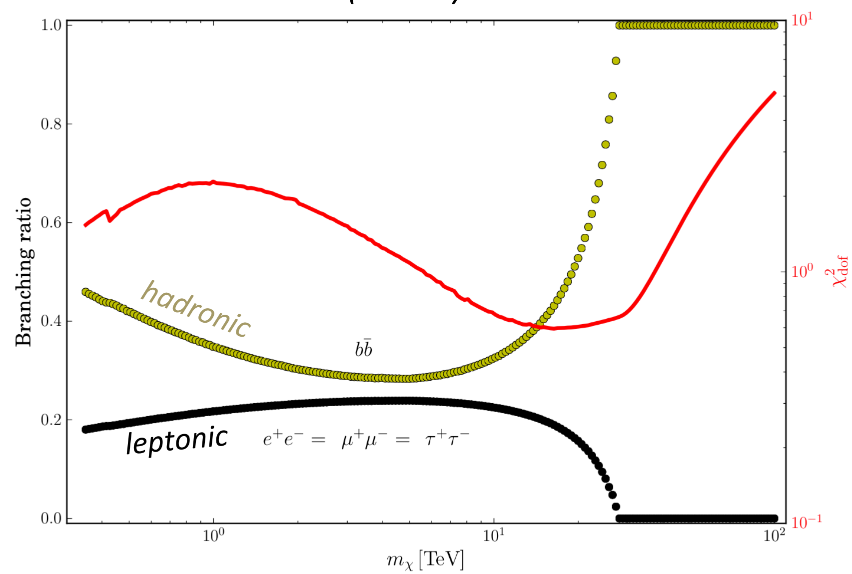


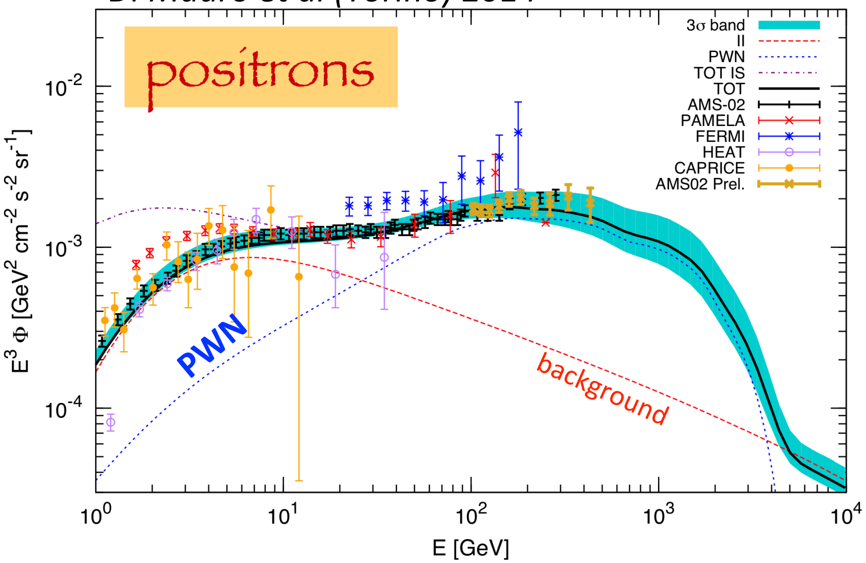
# Astrophysical Interpretation: nearby source

*Nearby Pulsar scenario*

- ✓ **SNRs: electron, hadrons**
- ✓ **hadrons+ ISM collisions: secondary e+ and e-**
- ✓ **PWN: primary e+ and e-**

- *Additional contribution to SNRs*
- *Astrophysically plausible*
- *Many parameters unknown*
- *No signal in hadronic channels*

*Di Mauro et al (Torino) 2014*

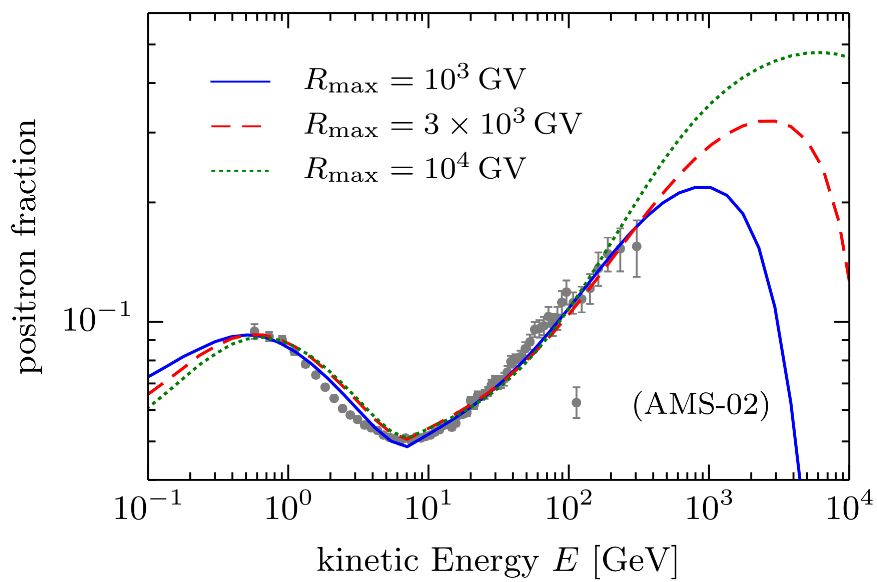



*Old Supernova Remnant scenario*

- ✓ **SNRs: electron, hadrons, e+ from p-p collisions**
- ✓ **hadrons+ ISM collisions: secondary e+ and e-**

- *No additional source required*
- *Astrophysically plausible*
- *Atypical SNR properties. Model dependent.*
- *Signals in hadronic & nuclear channels*

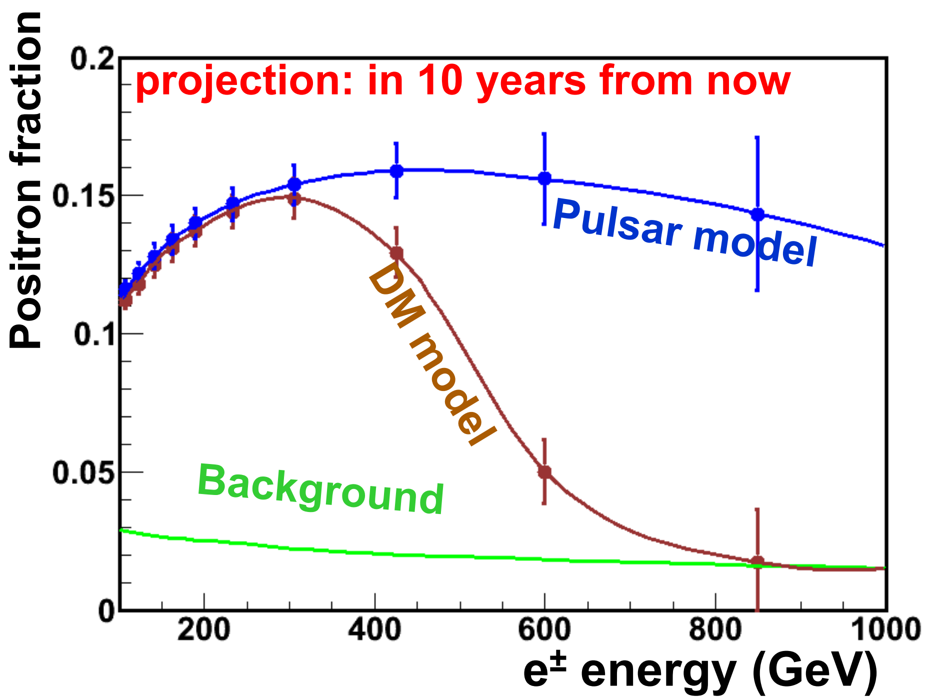
*Mertsch & Sarkar 2014*



# Perspective for the DM search

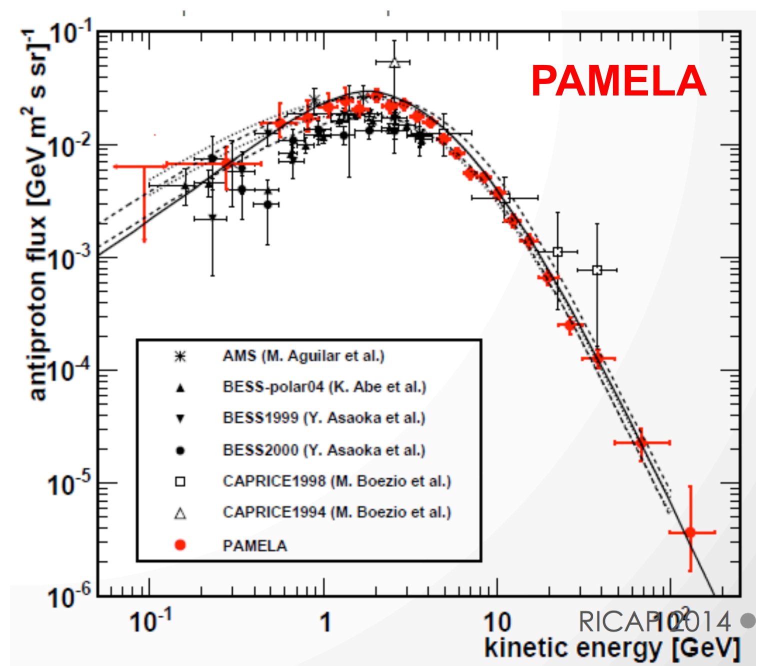
### *Lepton data at TeV energy*

- Discrimination DM/Astro scenarios
- Long observation time
- Model unknown, parameter degeneracy




### *Anti-proton/proton ratio above ~100 GeV*

- Expected signature from DM
- Present data consistent with background
- BG uncertainty (propagation &cross-sections)



# Conclusions

**AMS fundamental science experiment in the International Space Station**

**Dark Matter search is central to the AMS Physics Program**

- **Potential to shed a light on the nature of the Dark Matter**
- **Positron fraction up to 500 GeV with ~3 years of time exposure**
- **Search for anomalies in the anti-proton spectrum at high energy**
- **CR spectra measurements of proton and light nuclei**

**Data taking ongoing. Extensive data analysis ongoing.**

**~1300 days of mission. 60 Giga-particles collected**

***2014: lepton data released***

**Positron fraction at high energy**

**Electron & Positron spectra**

**All-electron energy spectrum**

***2015: hadrons and nuclei***

**Proton and Helium spectra at TeV**

**Nuclei: B/C ratio and C/O ratio**

**Antimatter: antiproton/proton ratio**