AMS02 results after 5 years of data taking on the International Space Station

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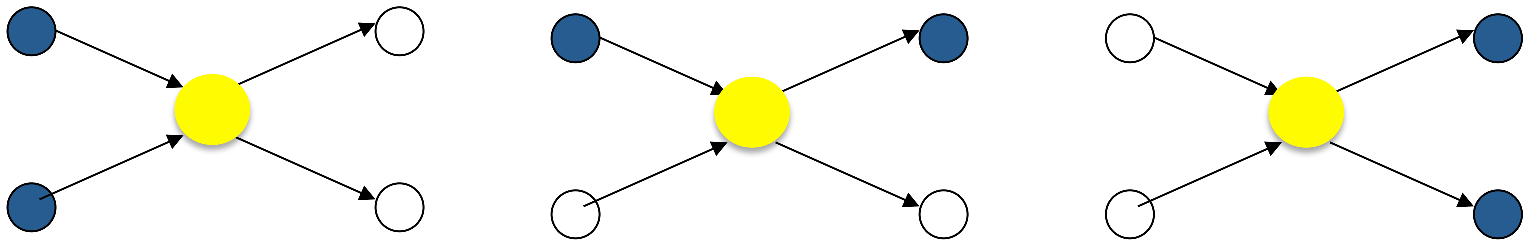
XII international Workshop Dark Side of the Universe

Bergen - 25 July 2016

Dark Matter Indirect Detection

Annihilation (indirect search) | Interaction (direct search) | Production (Colliders)

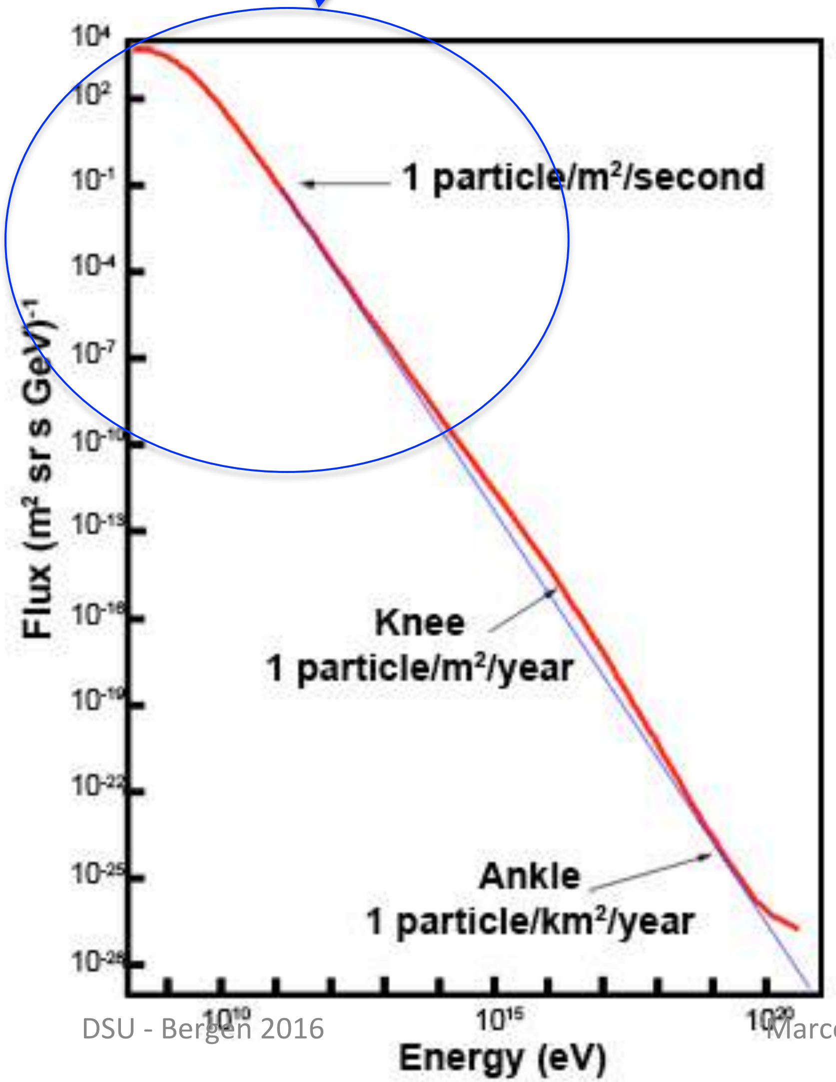


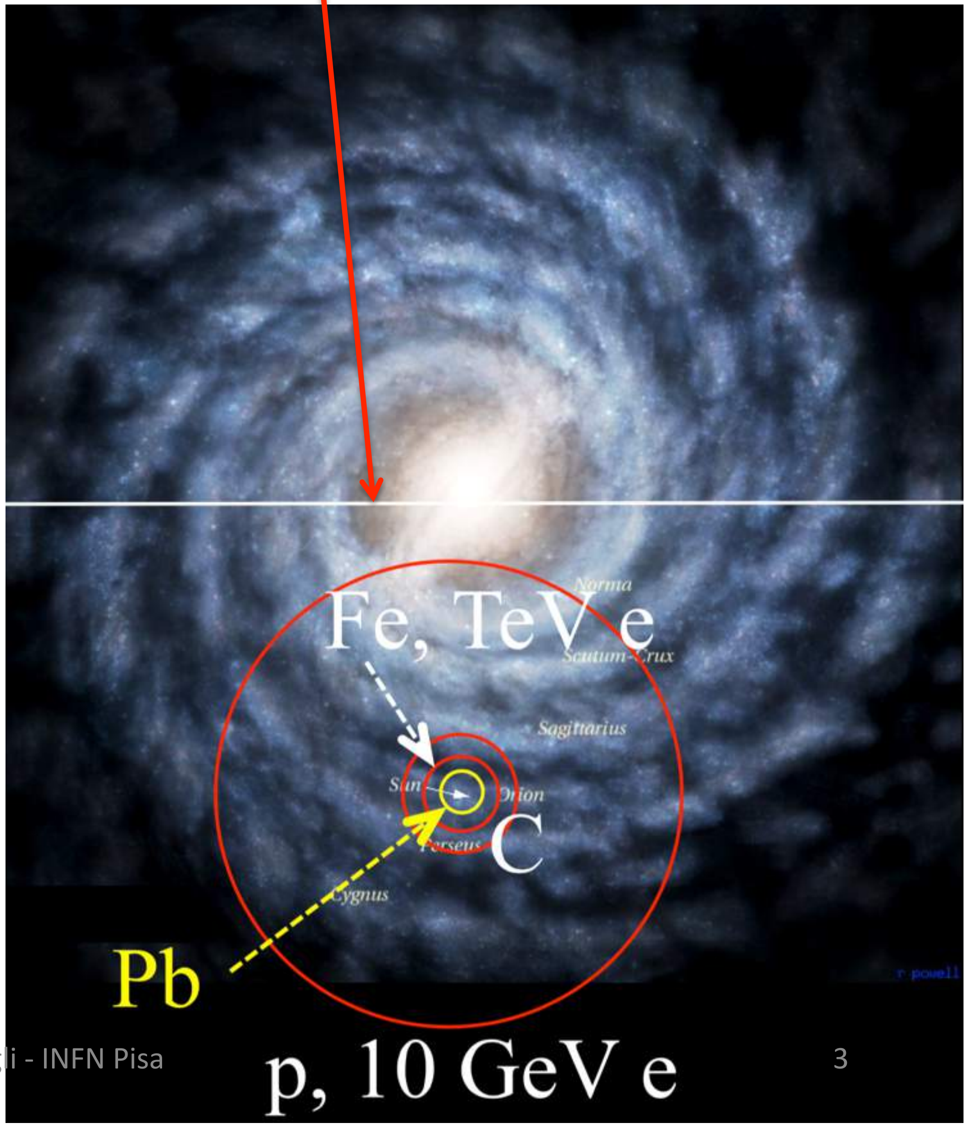
= DM (Dark Matter)   = SM (Standard Model)

- Many possibilities, but the WIMPs (=Weakly Interacting Massive Particles) are special: singular coincidence between the parameters of the Standard Model and of the Cosmological Model to provide valid DM candidates at the electroweak scale (~TeV) with a cross section $\langle\sigma v\rangle \sim 3*10^{-26} cm^3 s^{-1}$

Space Experiments Charged Cosmic Rays with

- Probe lower (GeV-TeV) energy range Probe the local galaxy





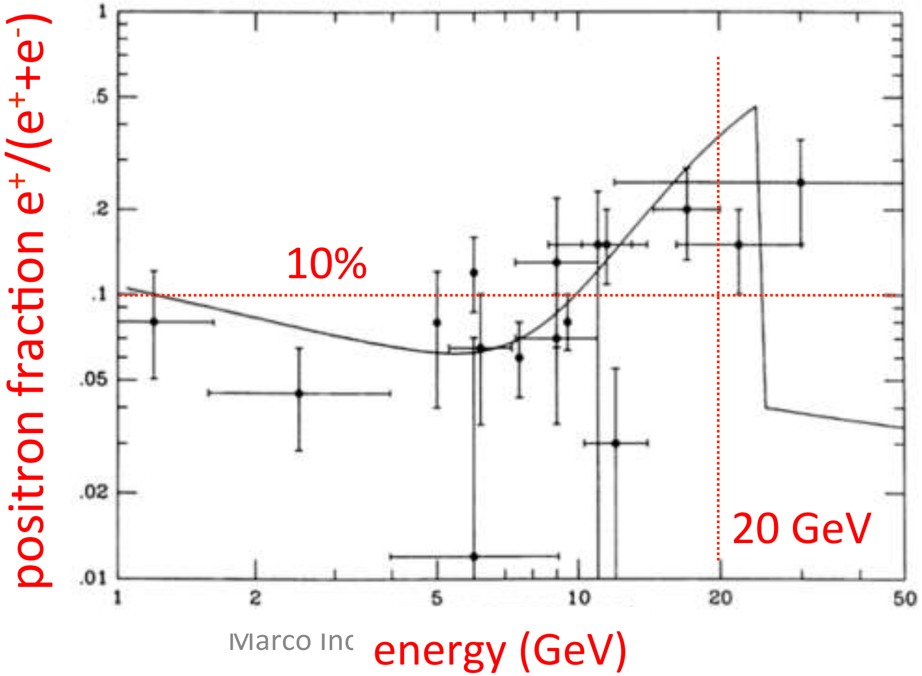
Why GeV-TeV range? Why charged cosmic rays?

- The GeV-TeV range is favored by the WIMP miracle
- DM annihilation in charged (anti)particles of energy 1-1000 GeV can be observed as excess in particle spectrum

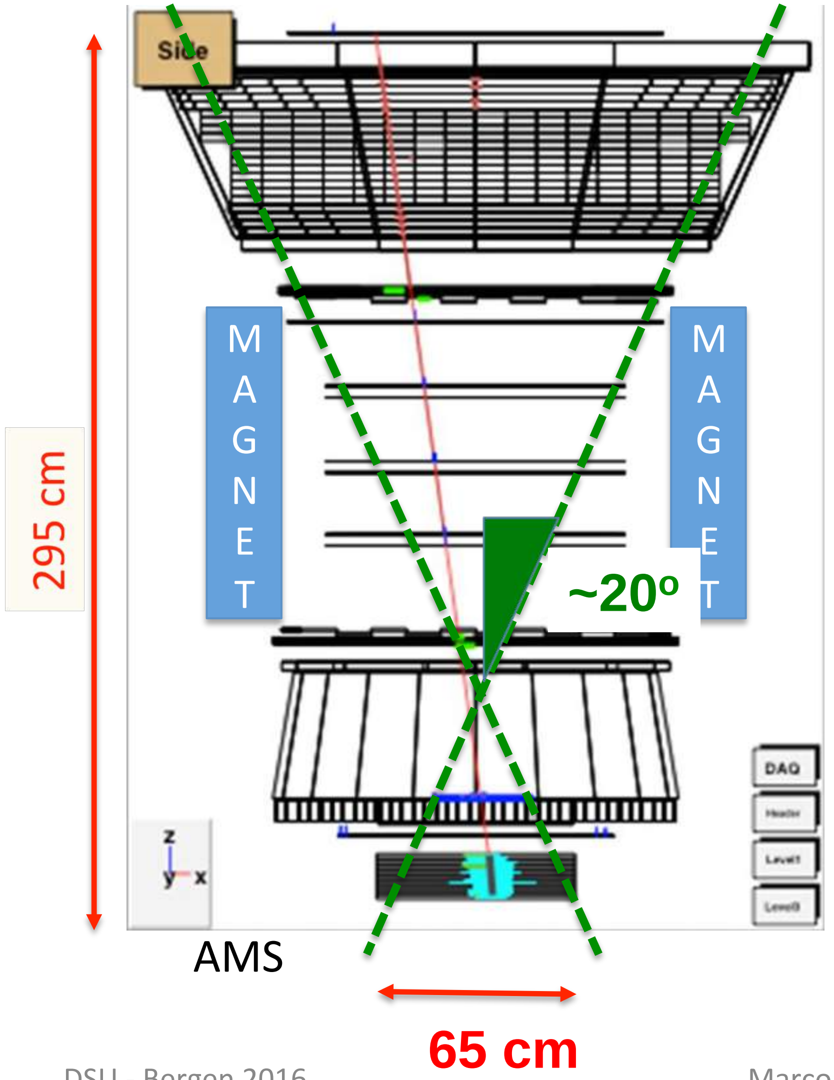
PHYSICAL REVIEW D VOLUME 42, NUMBER 4 15 AUGUST 1990

Positron line radiation as a signature of particle dark matter in the halo

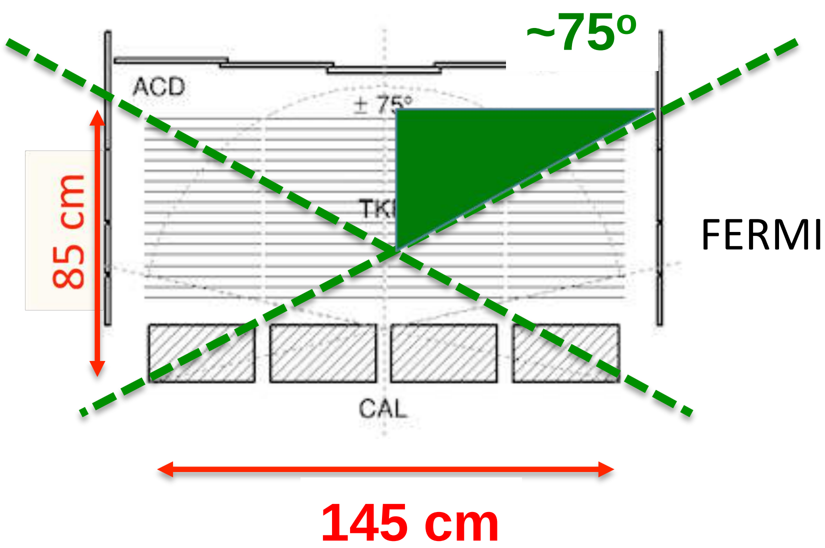
M. Turner, F. Wilczek



Magnetic Spectrometers vs Calorimeters

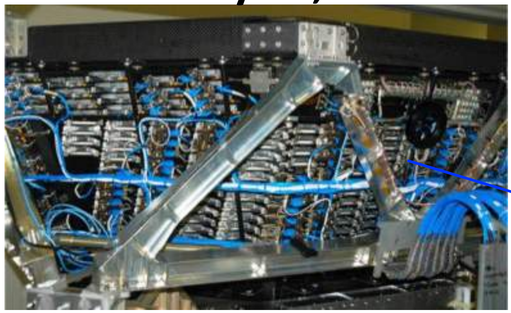


- magnetic spectrometers: access to anti-particles (relevant for DM and AM searches)
- calorimeters: maximize acceptance (important because of steeply falling CR spectrum)

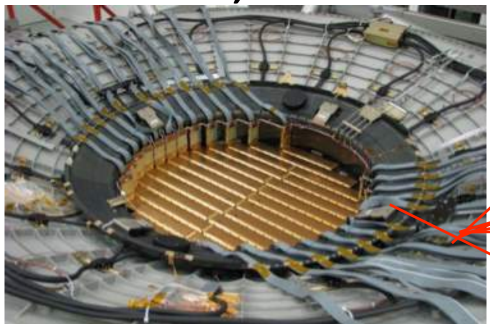


AMS02 magnetic spectrometer: a particle detector in Space

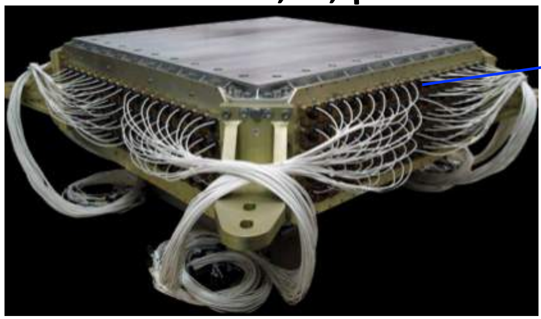
TRD
Identify e+, e-

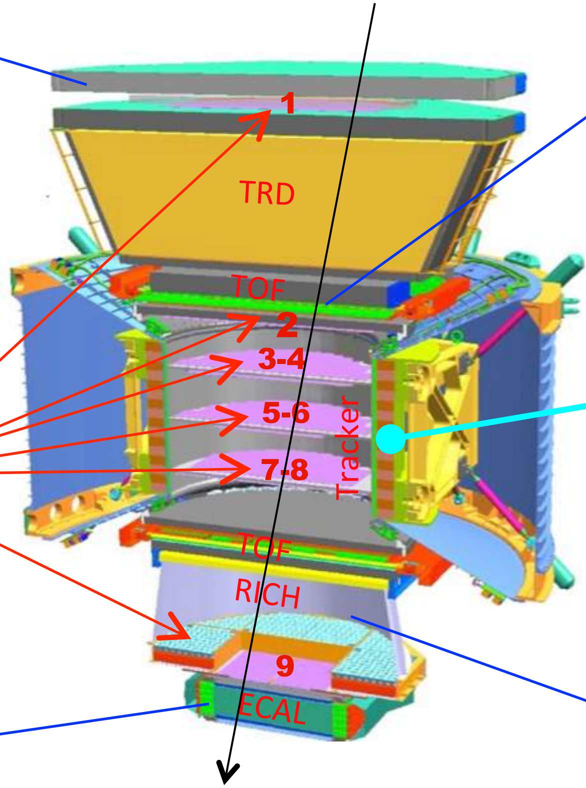


Silicon Tracker
Z, P



ECAL
E of e+, e-, γ

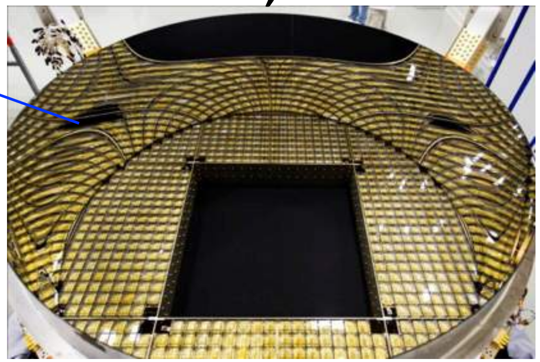




TOF
Z, E

Magnet
±Z

RICH
Z, E



AMS02 characteristic: redundancy

AMS02 has access to many channels

- positron fraction and anisotropy
- positron and electron flux
- total electron+positron flux
- proton and helium flux
- anti-proton to proton ratio
- anti-proton flux
- B/C ratio
- B, C fluxes
- Li and O fluxes
- other elements (Be, Be/B,...) and isotopes ($^3He/^4He$)
- deuterons
- anti-deuterons and anti-helium (^3He and ^4He)
- Heavier ions, ...

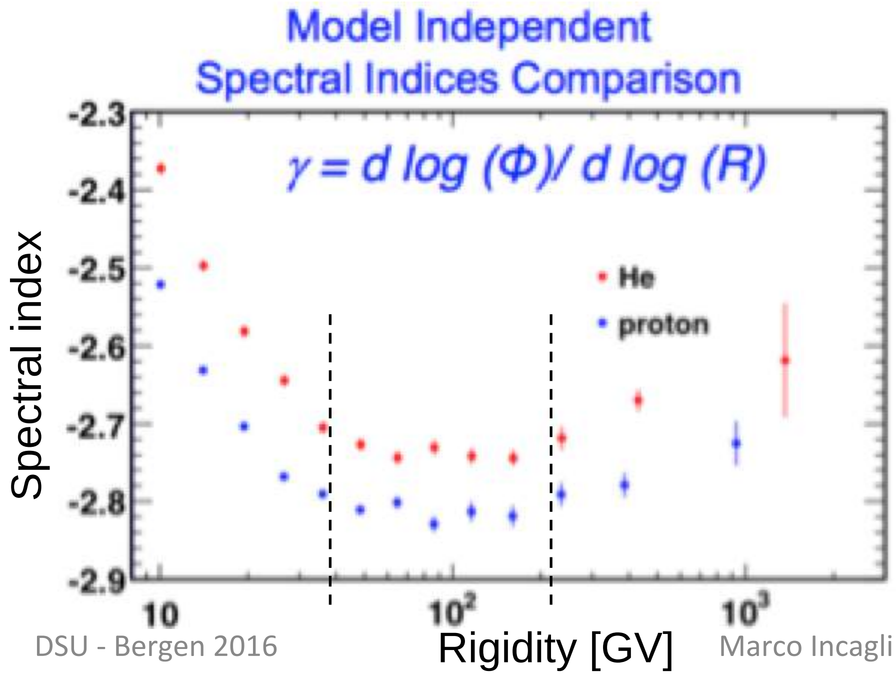
PUBLISHED

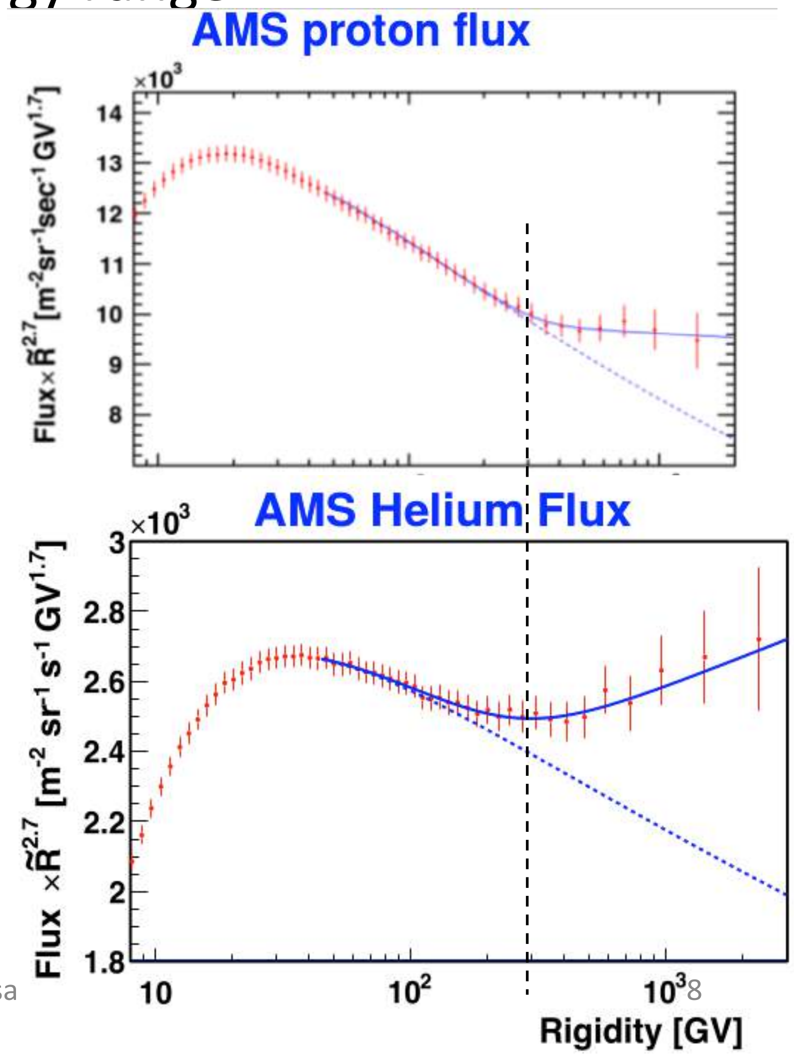
IN PREPARATION
(expected this year)

FUTURE ANALYSES

p and He fluxes

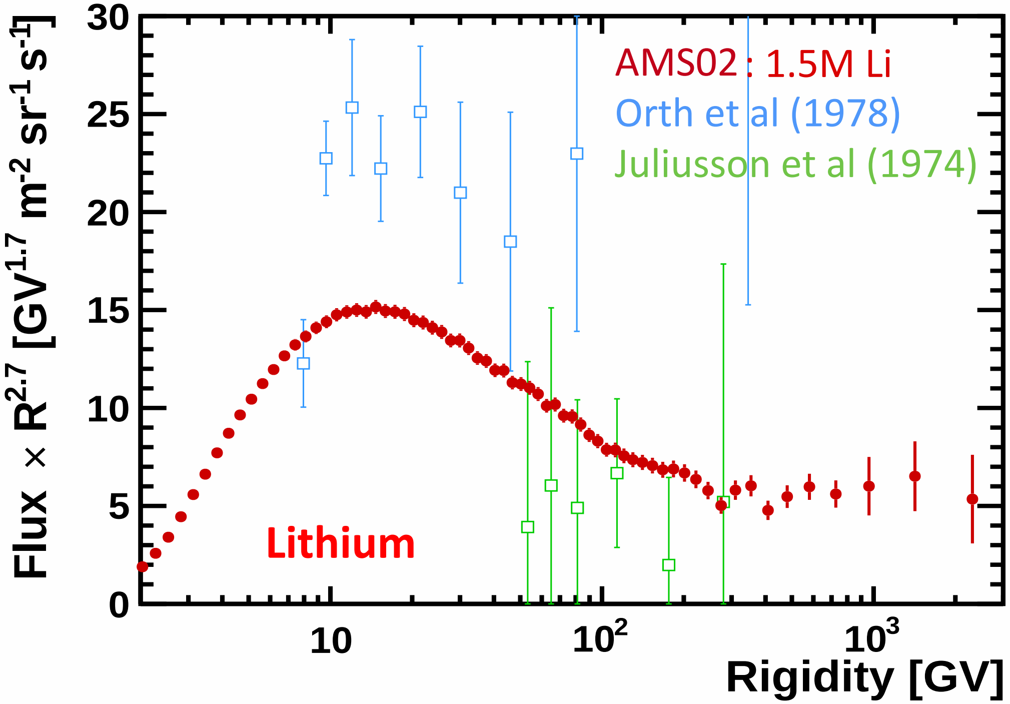
- proton and Helium fluxes show 2 puzzling features: a (soft) break at similar rigidities (~200-300 GeV) and a spectral index which differs by ~0.1 in a large energy range
- Some possible reasons:
  - acceleration in SNR
  - propagation in ISM
  - local or distance sources

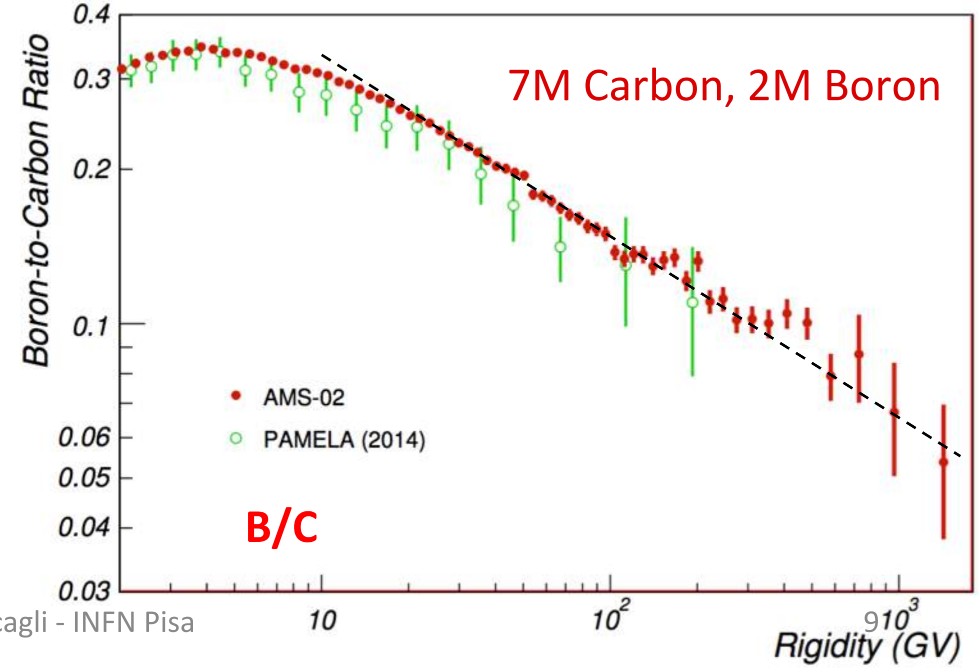




Lithium and B/C

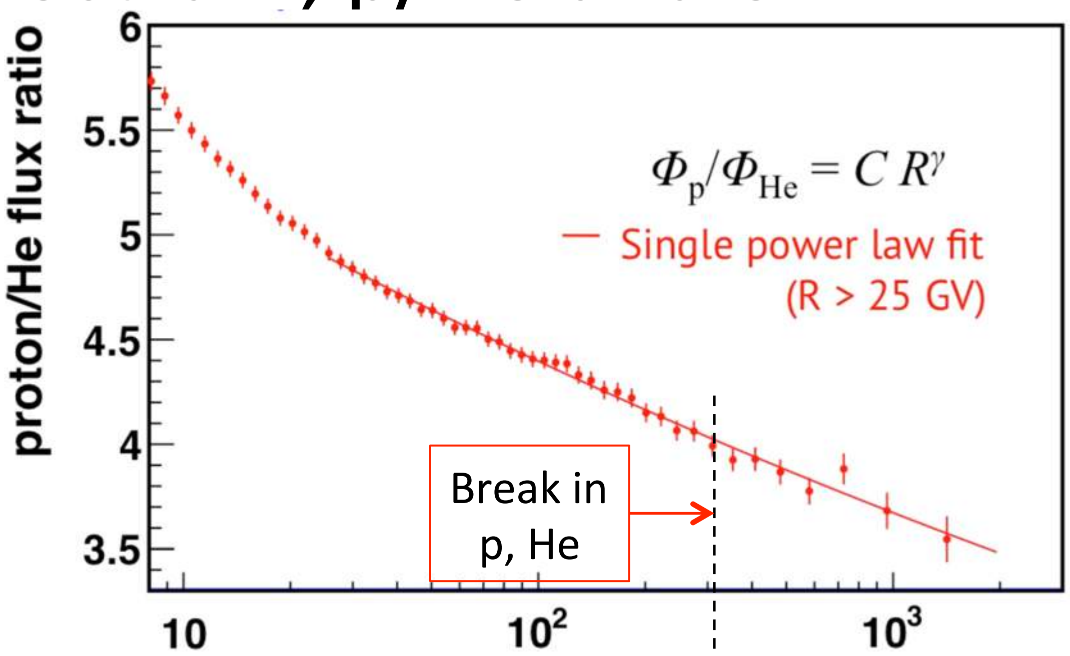
- However a similar break *at a similiar Rigidity* is observed also in Li, a secondary species
- Maybe a component of secondaries and primaries are accelerated together inside SNR shocks?
- A similar break is expected also in Carbon, but not necessarely at the same Rigidity
- B/C ratio smooth → need to look at single fluxes

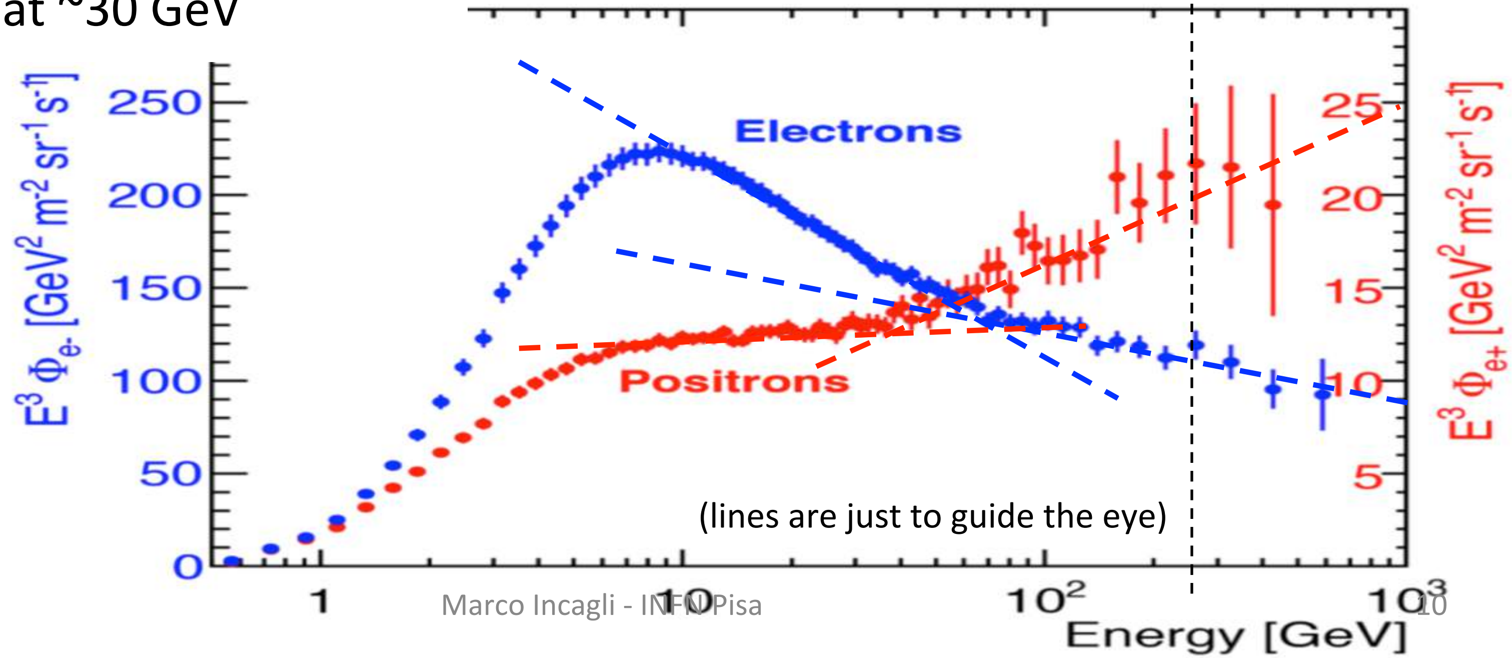




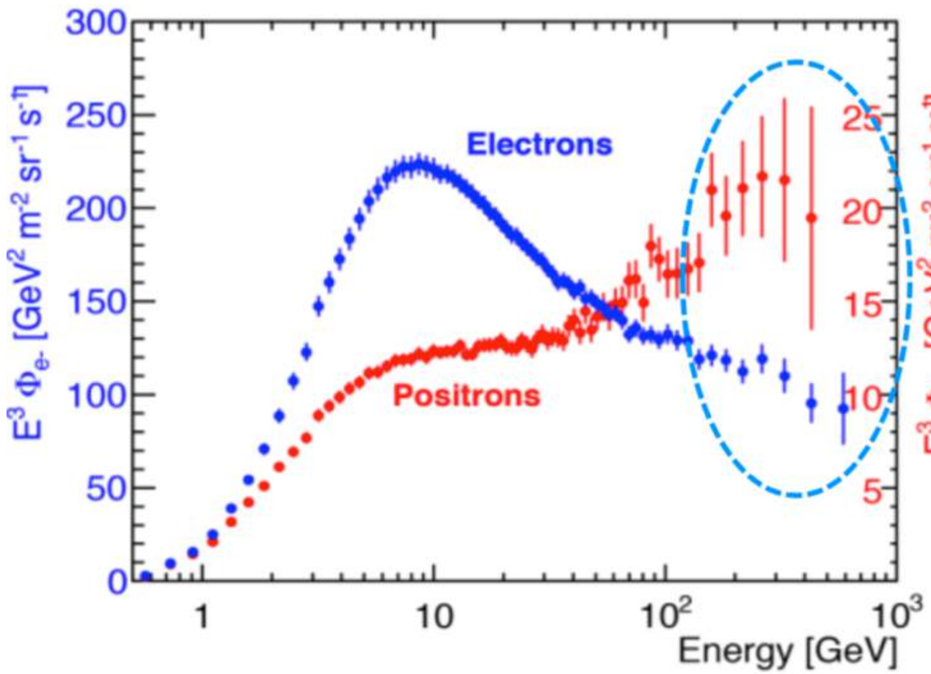
Break in the spectrum, p/He and e$^{\pm}$

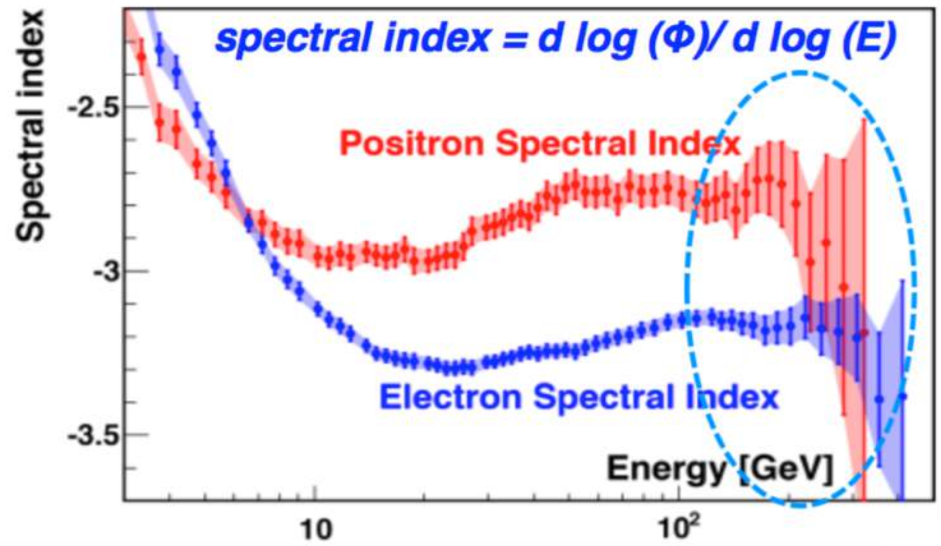
- The p/He spetrum is featureless
- Indicate the same (unknown) mechanism works for p, He and possibly higher charges
- What about e?
- Break not evident in e^{-}
- Not enough statistics in e+
- Concave spectra with additional component at ~30 GeV





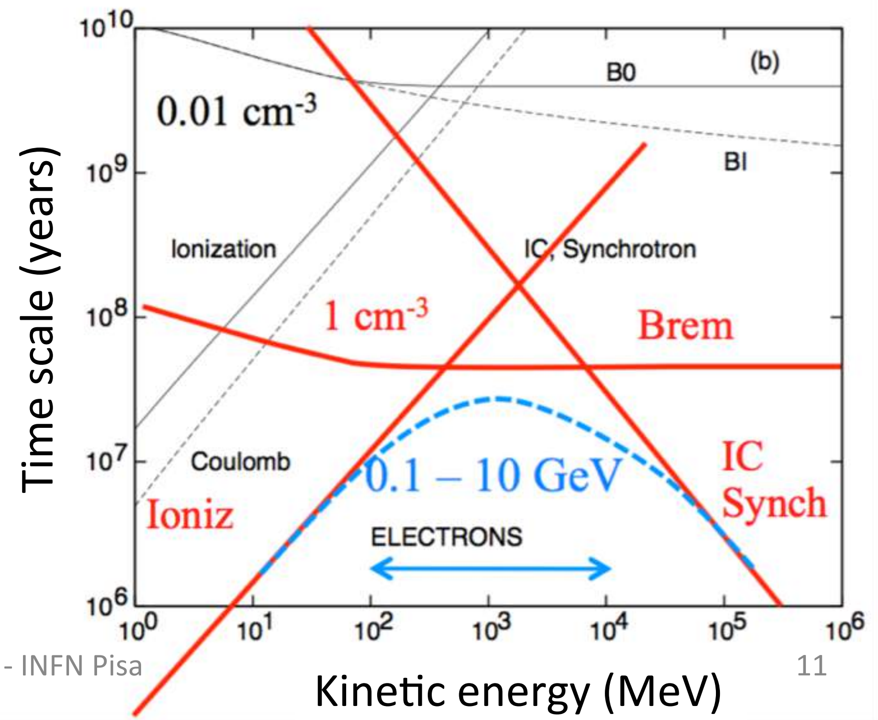
The Electron Flux and the Positron Flux





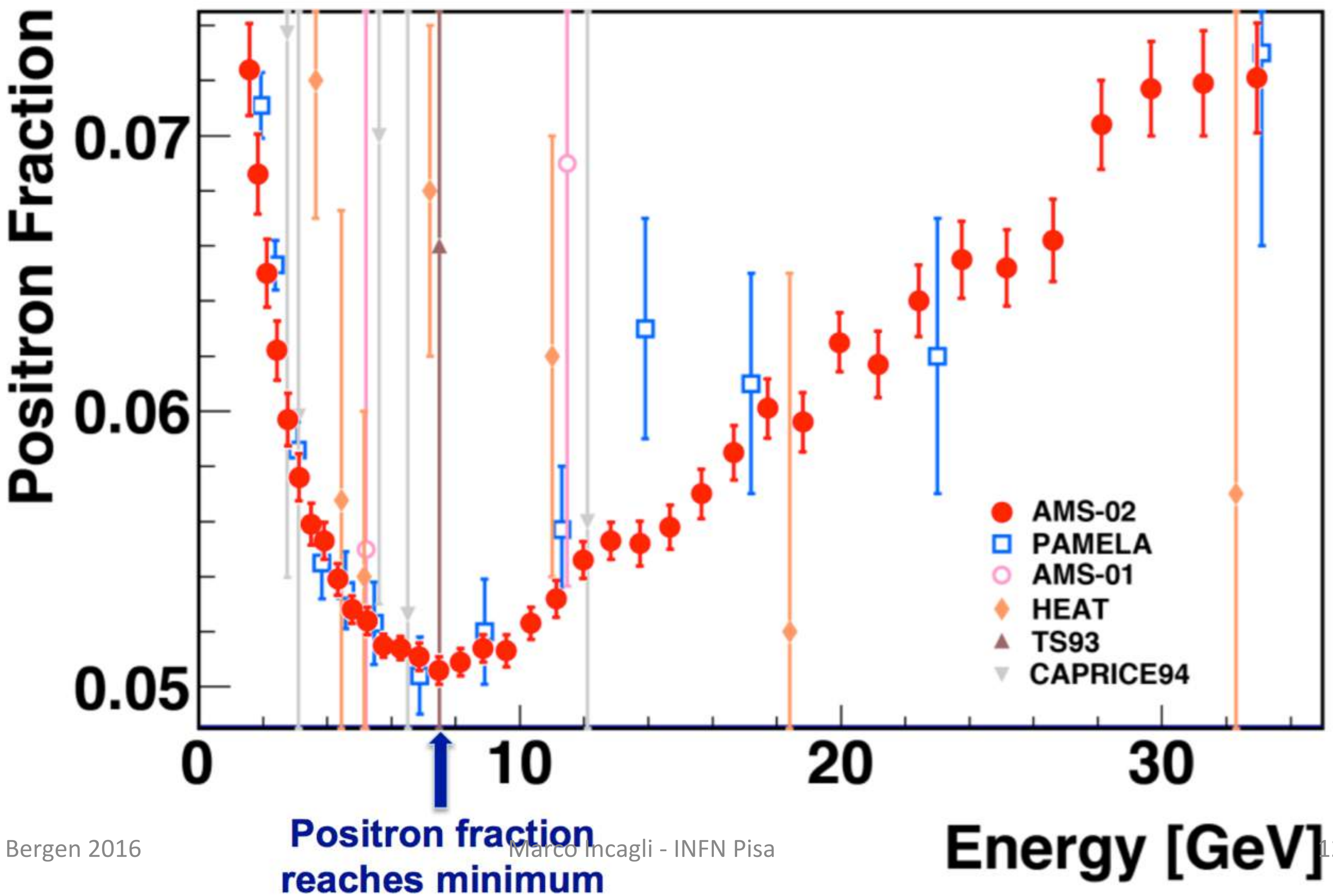
Energy losses of electrons:

- a cutoff is expected in $e^{\pm}$ spectra due to losses in propagation
- the cutoff shape at High Energies will tell about the distance to the sources



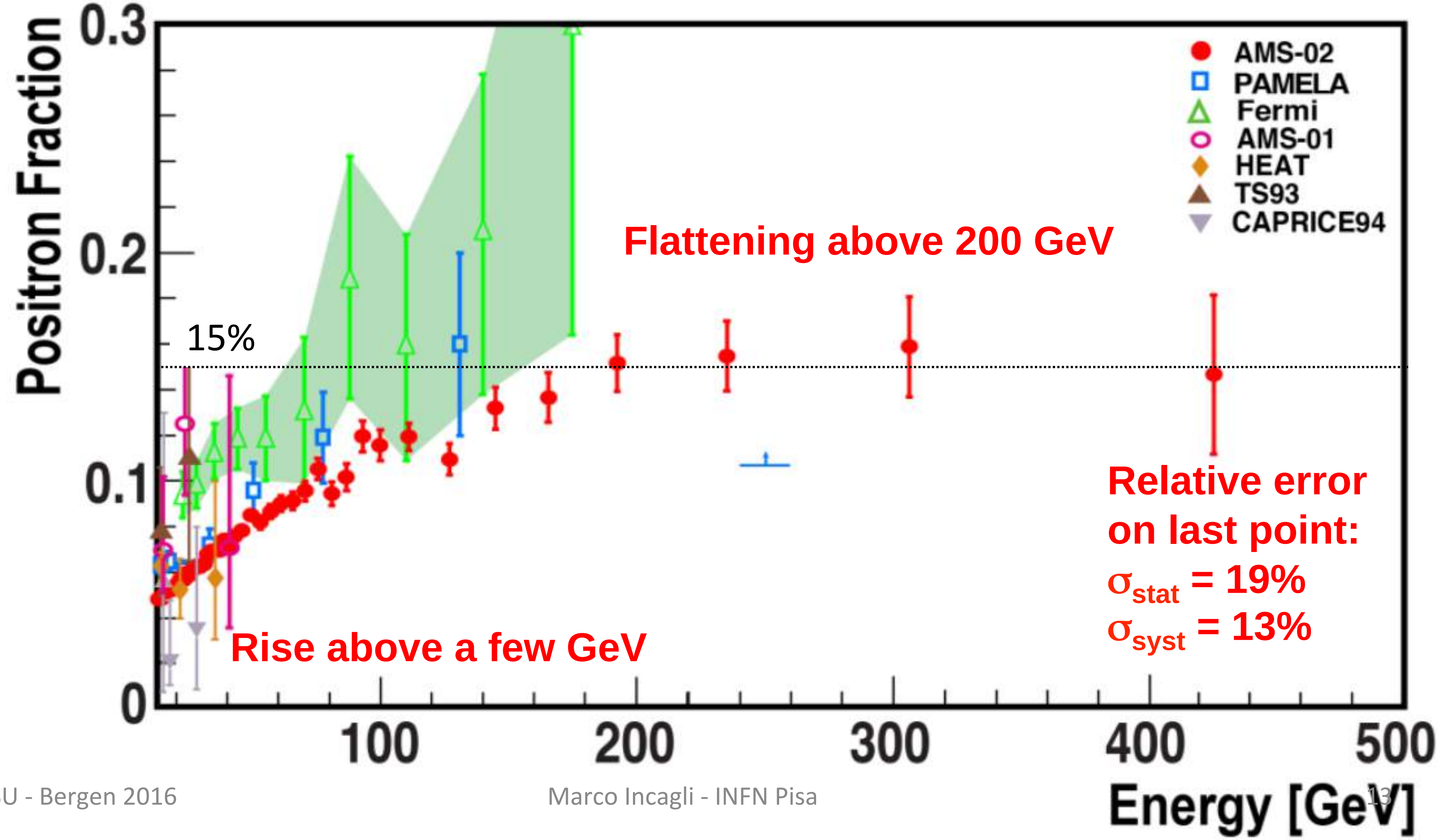
What about the positron fraction?

- As observed by previous experiments, mostly by Pamela, the fraction of positrons starts to increase above ~8GeV



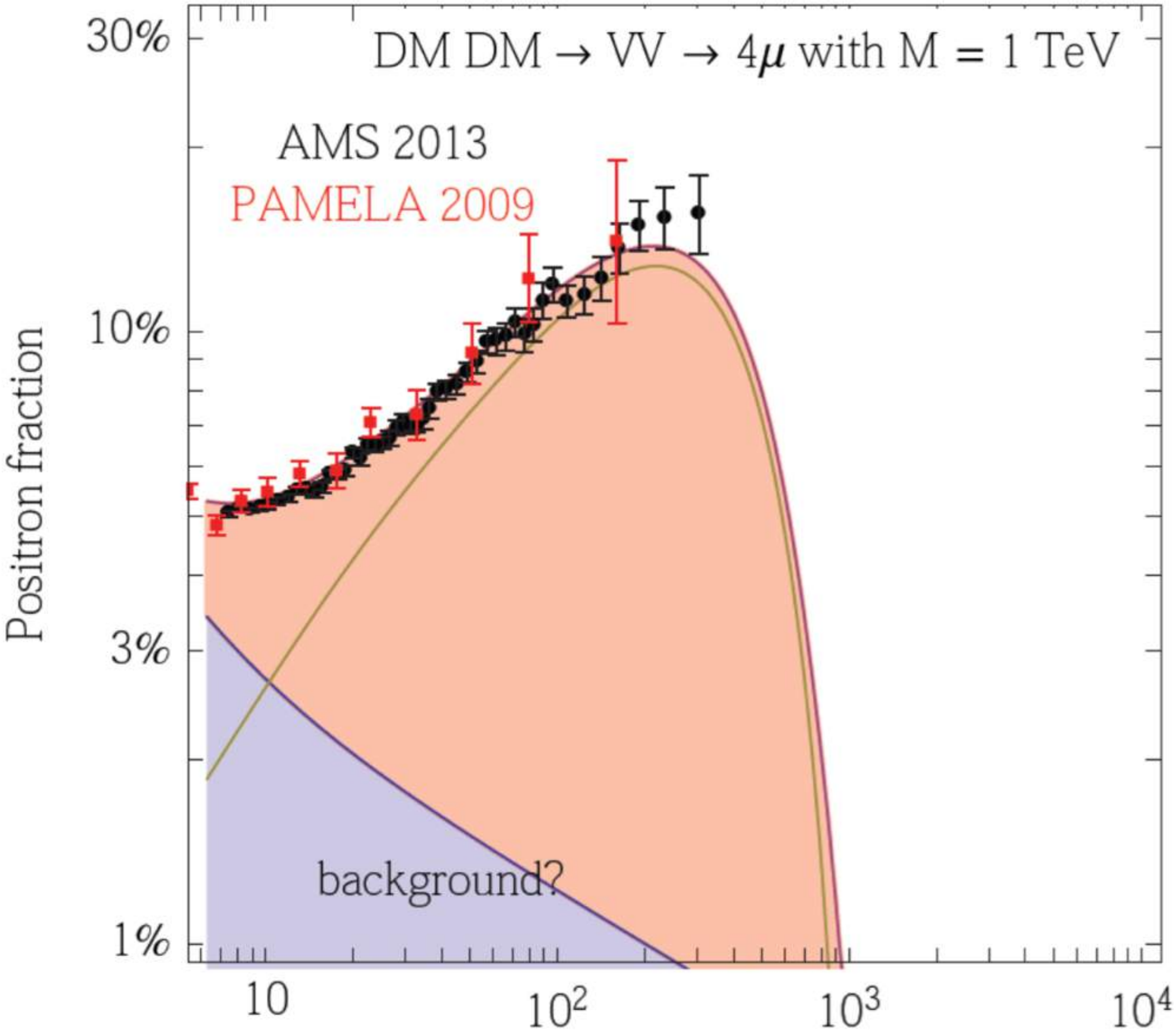
Is the rise of the positron fraction a hint of DM?

- Above 200GeV there is a flattening in the spectrum
- Is it a hint of Dark Matter?What happens above 500 GeV?
  (results based on 30 months of data taking from 19/05/11 to 26/11/13)



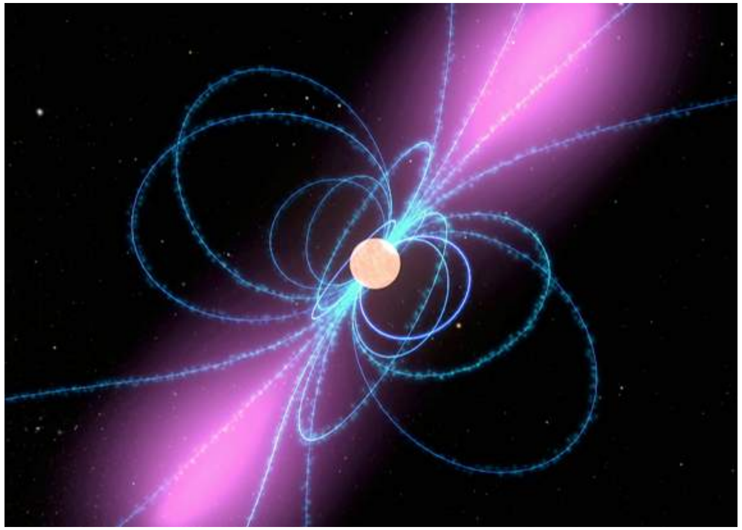
Dark Matter model with intermediate state

M.Cirelli, M.Kadastik, M.Raidal and A.Strumia, Nucl.Phys. B873 (2013) 530



Positron Energy

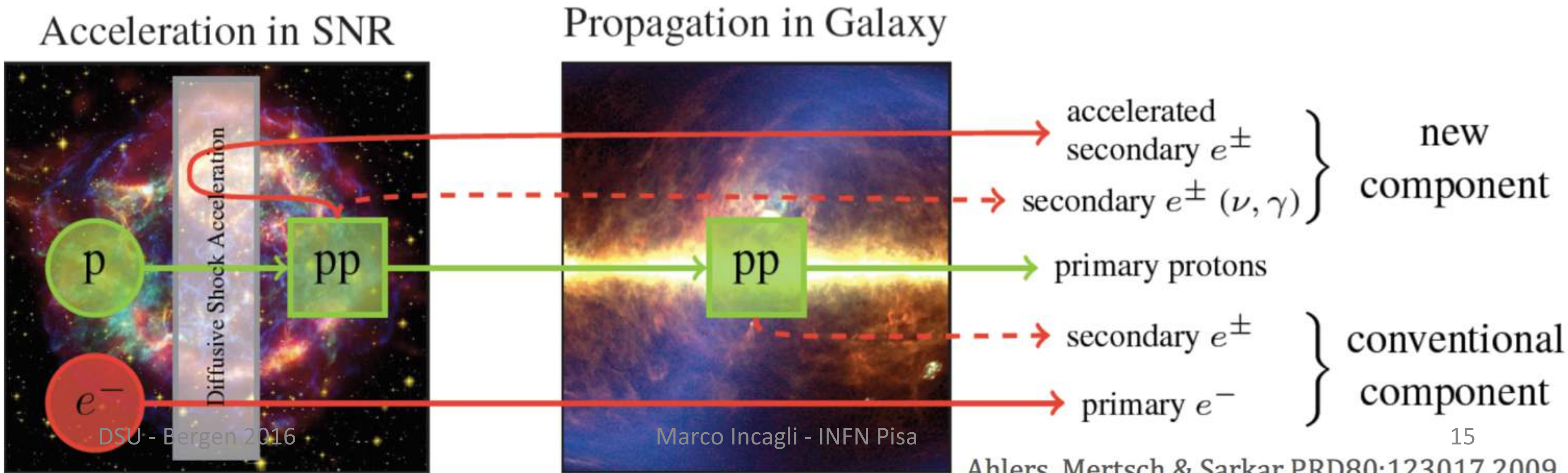
But the excess can be due to standard astrophysics



Possible explanations:

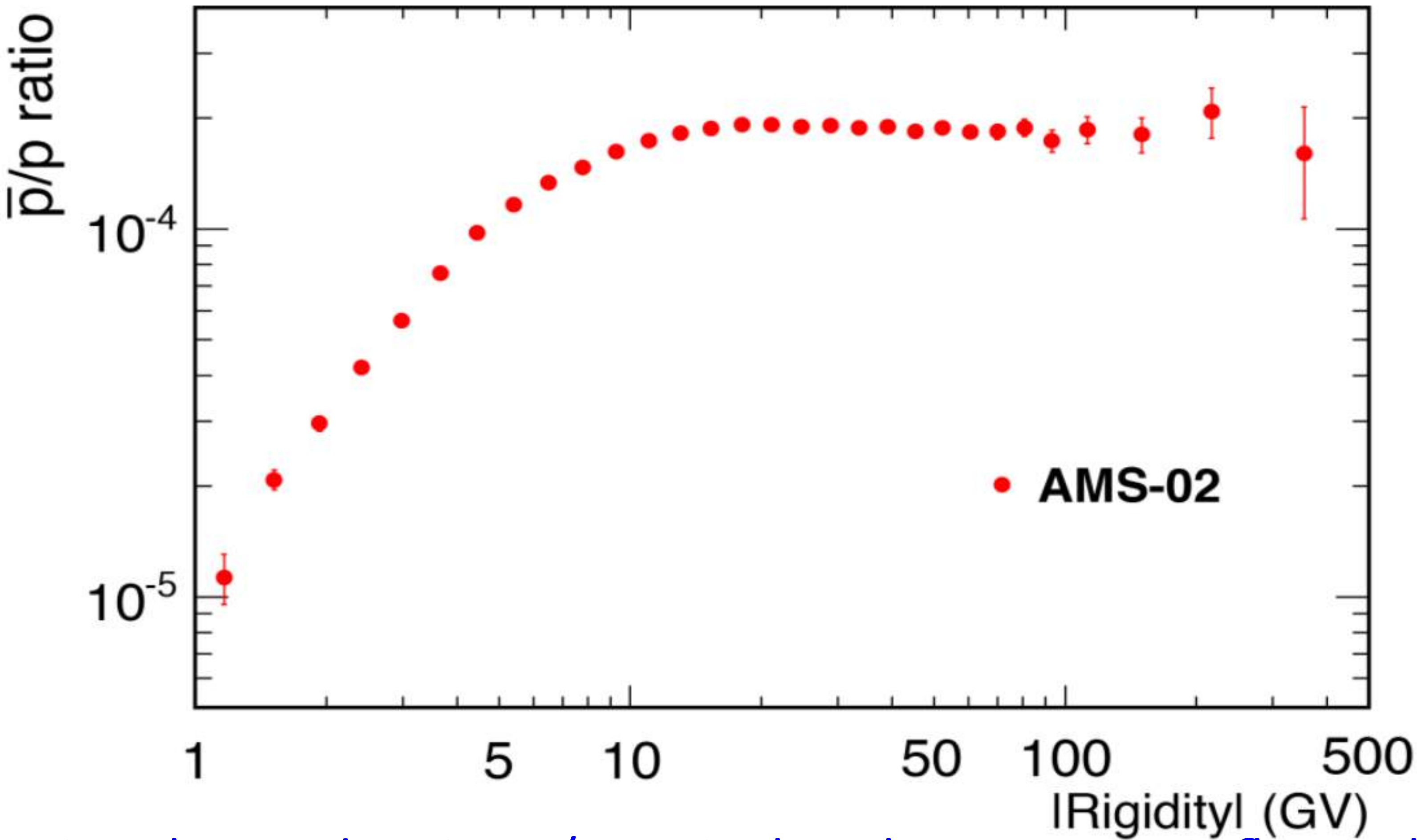
1. PULSARS: $e^{\pm}$ pairs are produced by the interaction of energetic photons with the strong magnetic field of the neutron star. No $p\bar{p}$ pairs!

2. RE-ACCELERATION of SECONDARIES: secondaries are produced inside the shock-wave of a SNR and boosted to higher energies. All particles (e, p, ...).



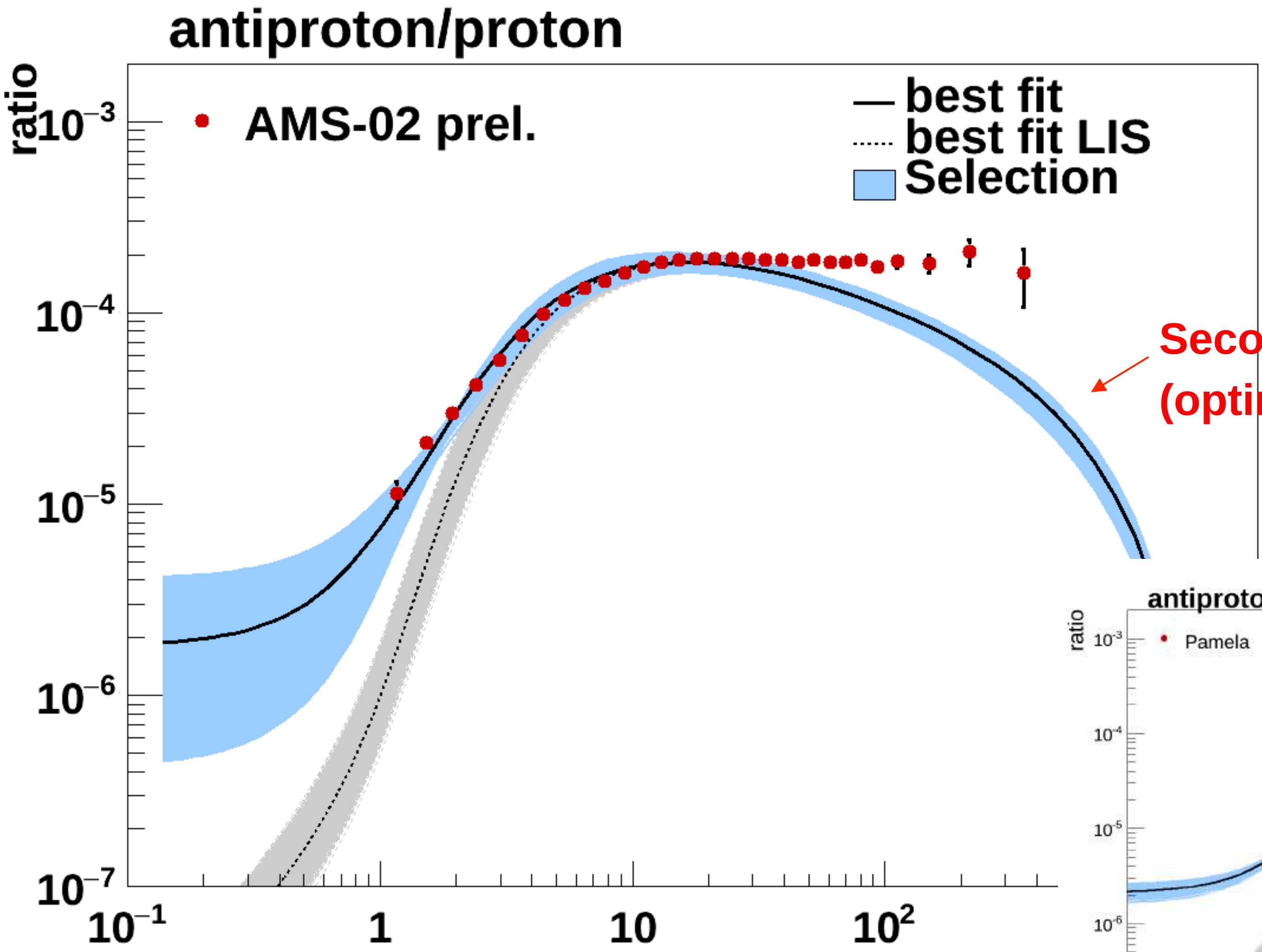
Ahlers, Mertsch & Sarkar,PRD80:123017,2009

What about anti-protons?

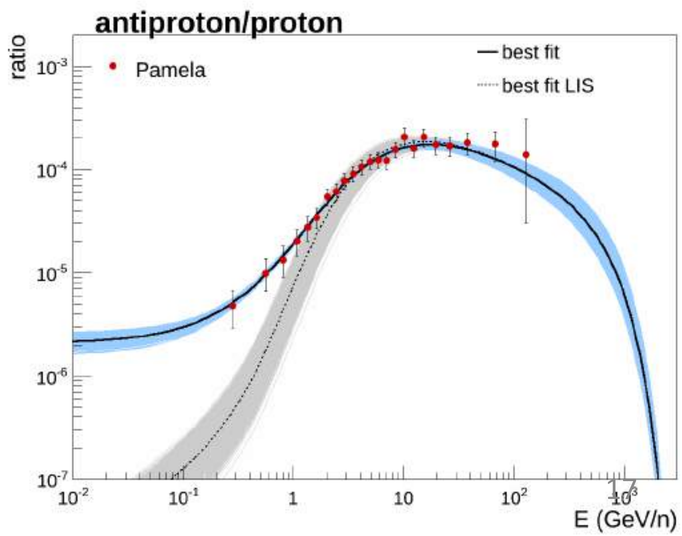


- no rise observed, as in e+/e- ratio, but the spectrum is flatter than expected
- precise measurement up to R=450 GeV; hard to go above in AMS02

Example of a fit with a model optimized on Pamela data

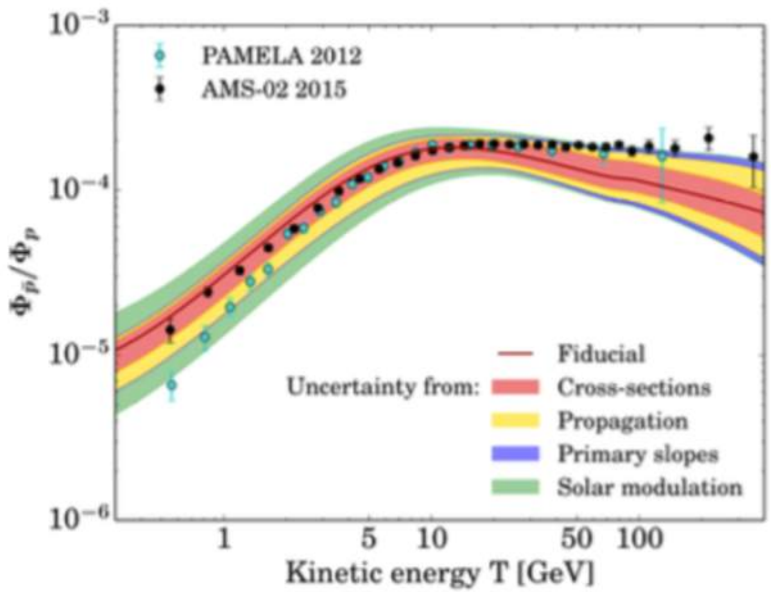


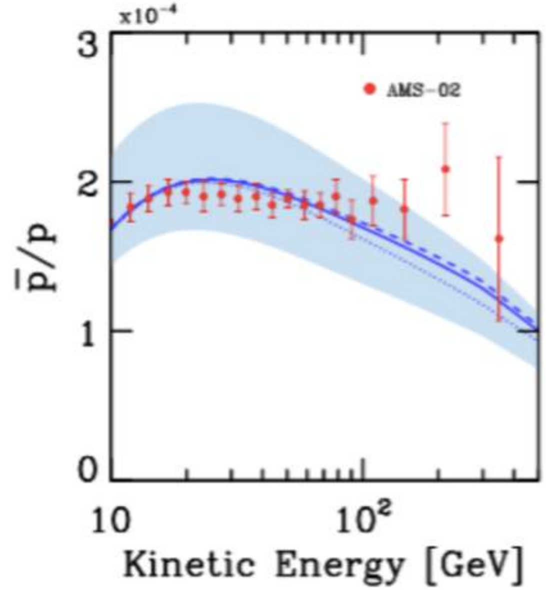
Secondary production (optimized for PAMELA)



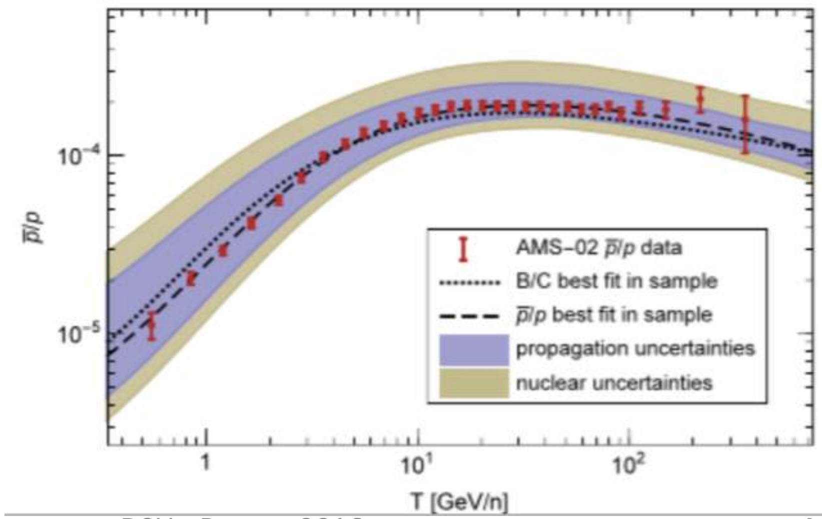
Dissertation / PhD Thesis IEKP-KA/2014-20
Simon Kunz (2014)
http://ekp-invenio.physik.uni-karlsruhe.de/record/48605

but if models are tuned on AMS ...





- 3 possible models: always some tension with data but no evident effect



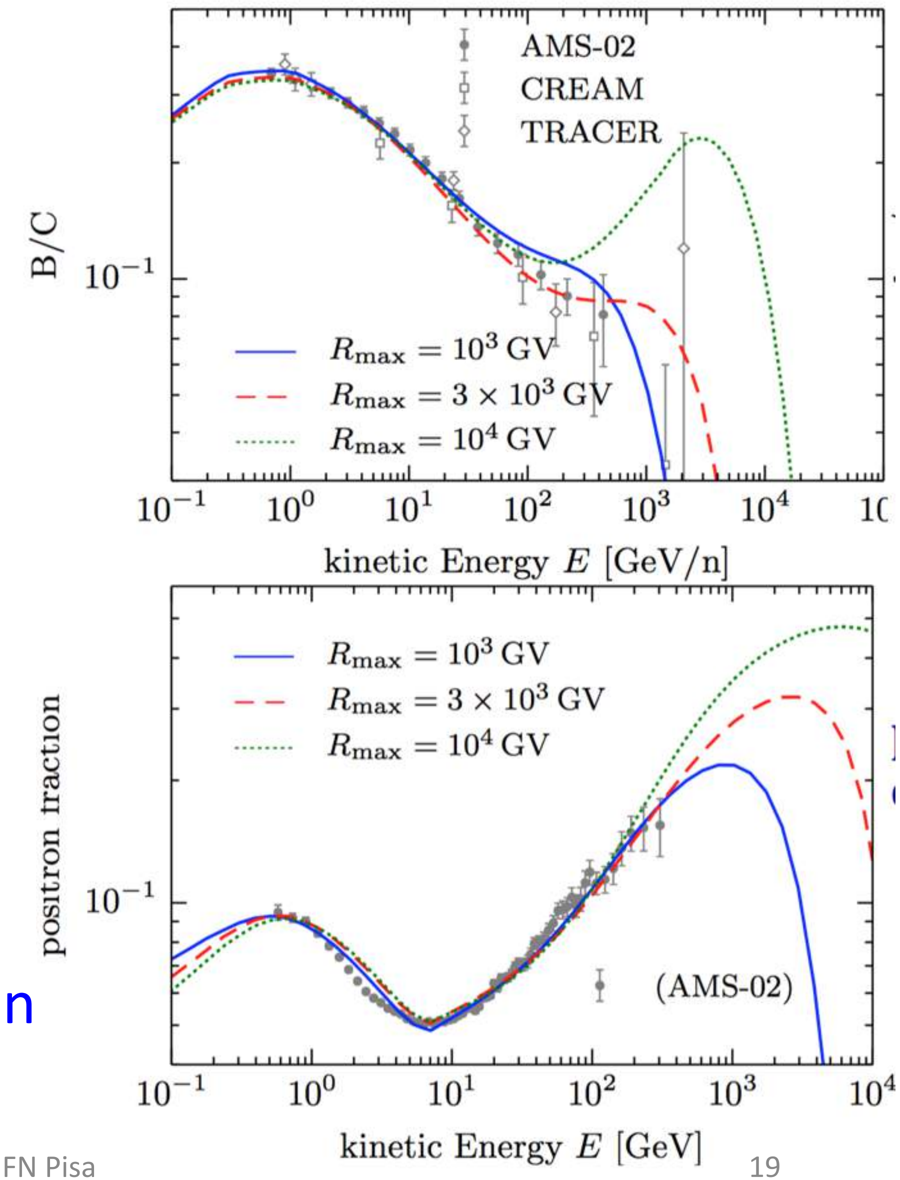
(a) G.Giesen, M.Boudaud, Y.Gènolini, V.Poulin, M.Cirelli, P.Salatiand, and P.D.Serpico, JCAP1509 (2015) 09, 023 [arXiv:1504.04276 [astro-ph.HE]].

(b) C.Evoli, D.Gaggero and D.Grasso, arXiv:1504.05175 [astro-ph.HE].

(c) R.Kappl, A.Reinertand, and M.W.Winkler, arXiv:1506.04145 [astro-ph.HE].

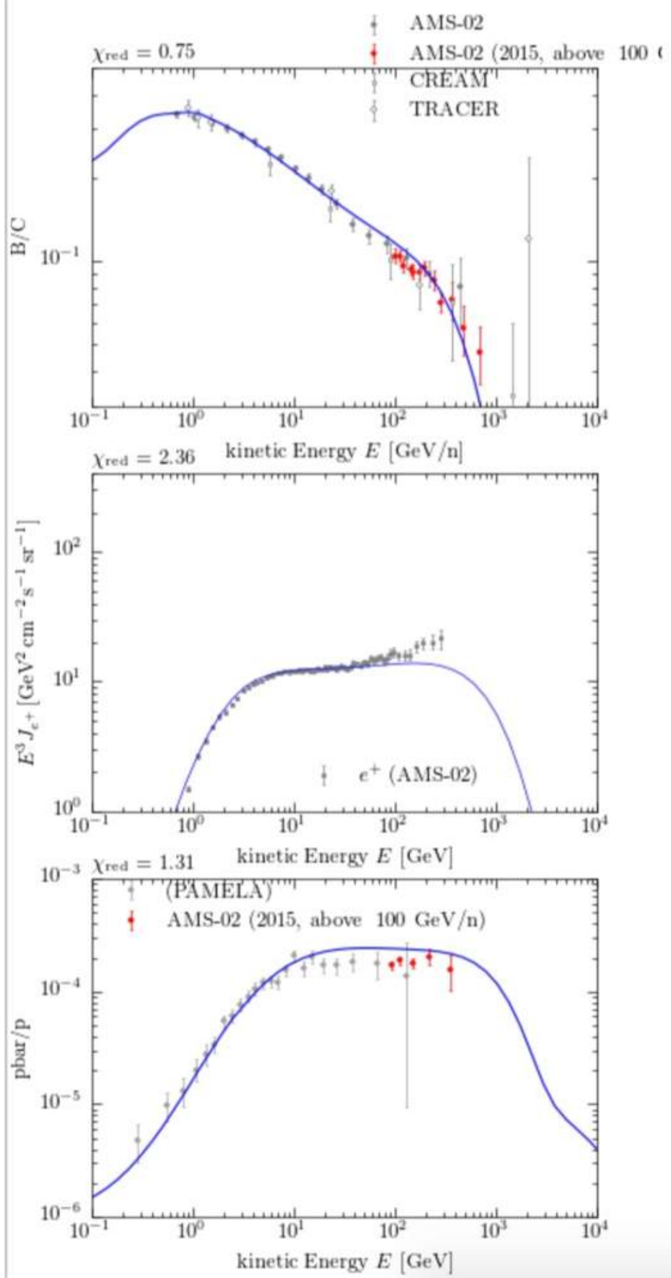
How can we distinguish among many models?

- Only one way: make precision measurements in many channels!
- Models will have to explain:
  - rise and flattening of positron fraction
  - break at ~300 GeV in H, He, Li
  - break at ~30 GeV in e±
  - flatness of pbar/p
  - constant slope in p/He and B/C
  - absolute fluxes of many nuclei
  - ...
- Example: comparison of B/C and positron fraction data with one model which includes re-acceleration (Mertsch et al, PR D90 (2014))



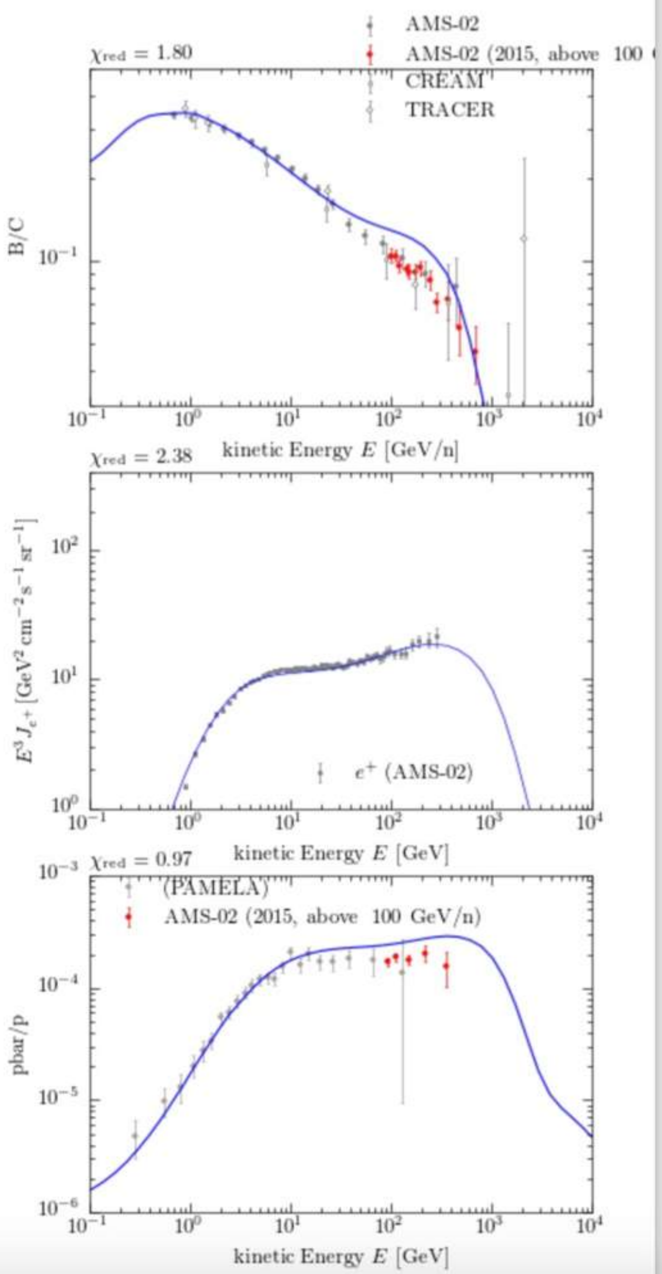
Additional example: slide from S. Sarkar talk @ Cern - April, 2015

N.B.: new results from same group exist, this slide is just to show the concept of "precision data"



We have been trying (late last night!) to get better fits to the new data but it is not easy ... perhaps our model is *too* simple and some further refinements are necessary.

This is justified now that we have *precision* data from AMS!



Is there still room for Wimp Dark Matter?

- Definitely yes; we have the duty of digging well into our data to look for DM signatures as a magnetic spectrometer will not be soon launched in Space!
- Calorimetric experiments (CALET, DAMPE and, in a short time frame, ISSCREAM) will provide additional information on the generation/propagation of standard Cosmic Rays

Future for Wimp Dark Matter in Space

- medium term: HERD (Chinese Space Station) → calorimetric experiment, R&D in progress, 202N with N<5 (?)
- long term: ALADINO → magnetic + calorimetric experiment, ESA call for "Science ideas for which missing (immature) enabling technologies are clearly identified", LOI submitted 6 June 2016, proposal due 20 October 2016

Conclusions

- With AMS02 (partly also with Pamela) a precision era of Charged Cosmic Ray measurements has started
- WIMP dark matter is not ruled out, but to find it many subtle effects of CR generation and propagation must be kept under control
- Additional information on CR from calorimetric experiments (CALET, DAMPE, ISSCREAM)
- AMS will operate for few more years and it will be the only space experiment with a magnet for long time → let's get the most out of it!