AMS02 results after 4 years of data taking on the International Space Station

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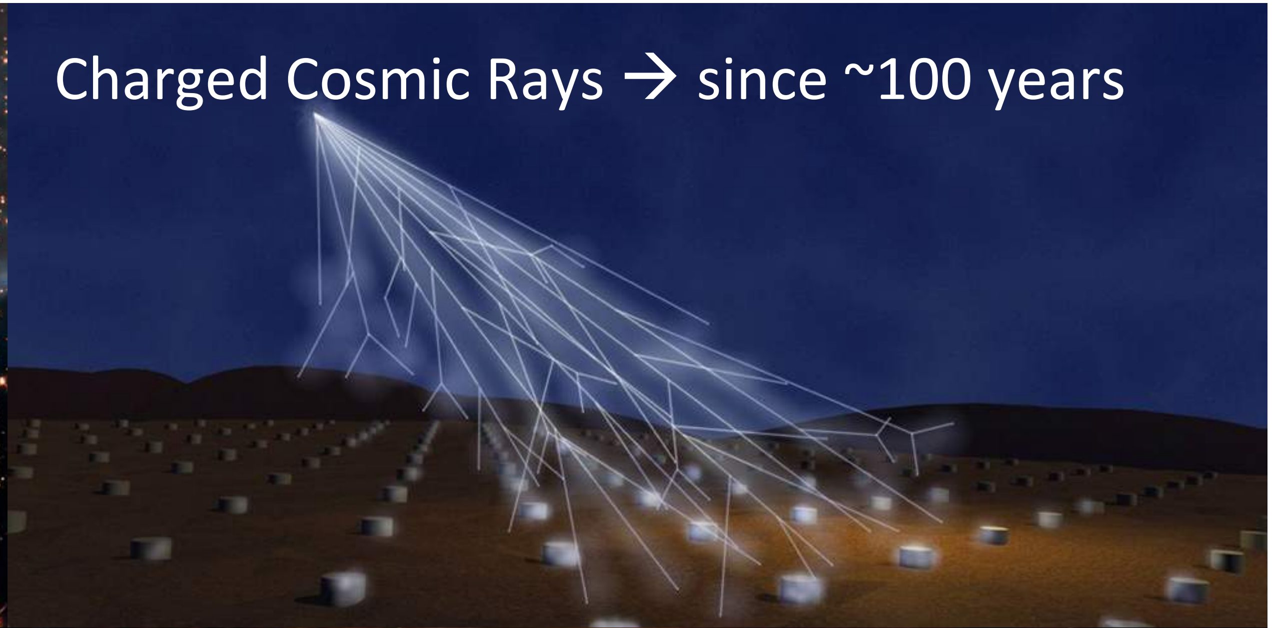
Les Rencontres de Physique de la Vallée d'Aoste

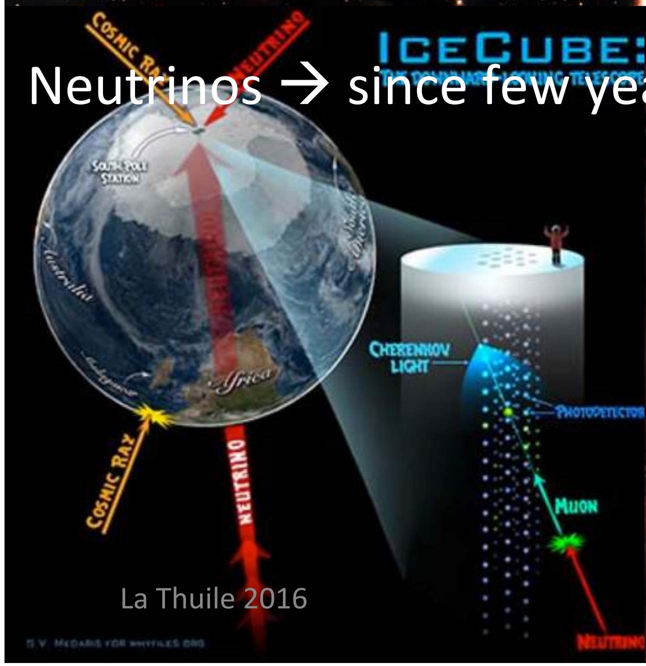
La Thuile, March 6-12, 2016

Multi messenger astronomy

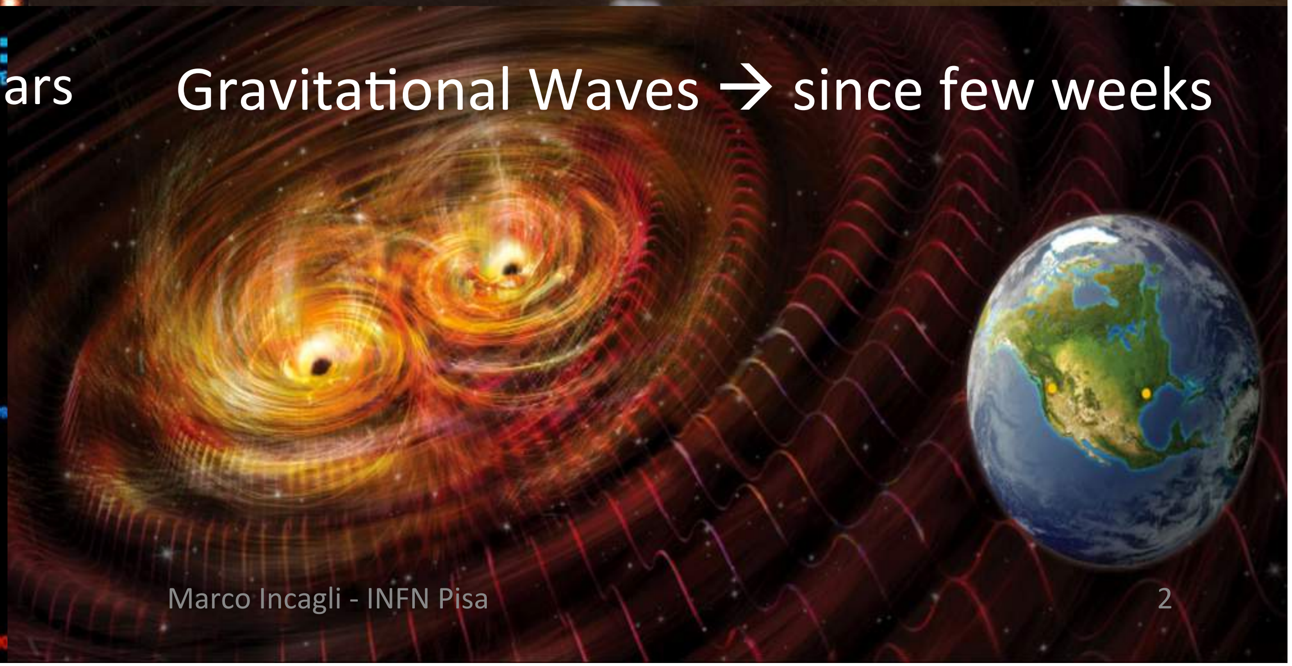
Photons → since ever



Charged Cosmic Rays → since ~100 years



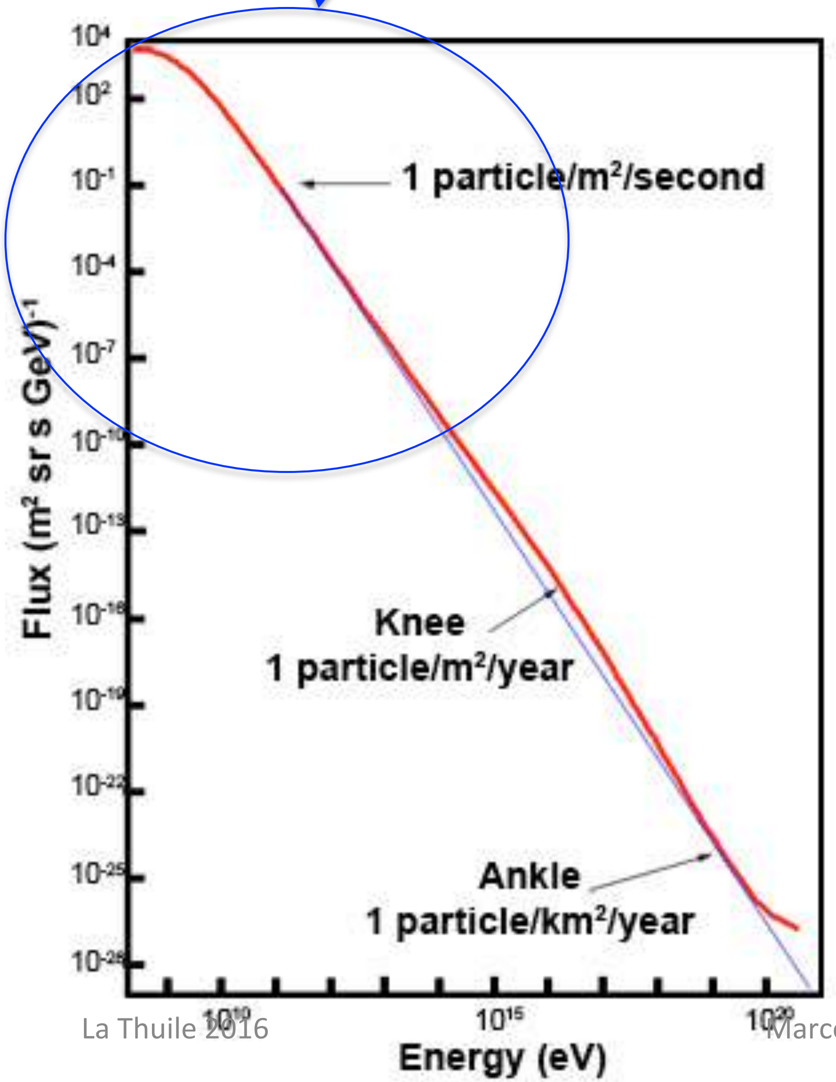
Neutrinos → since few years

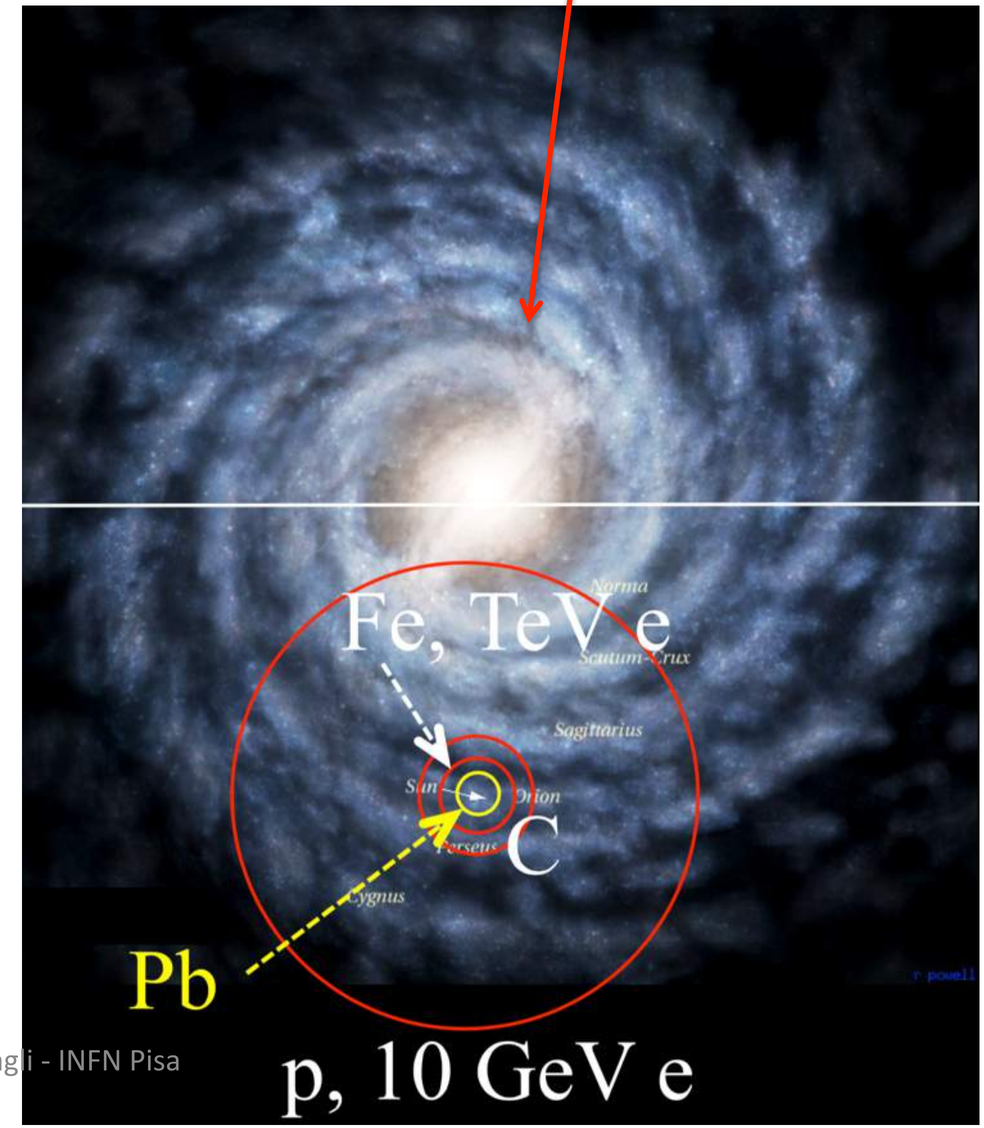


Gravitational Waves → since few weeks

Charged Cosmic Rays with Space Experiments

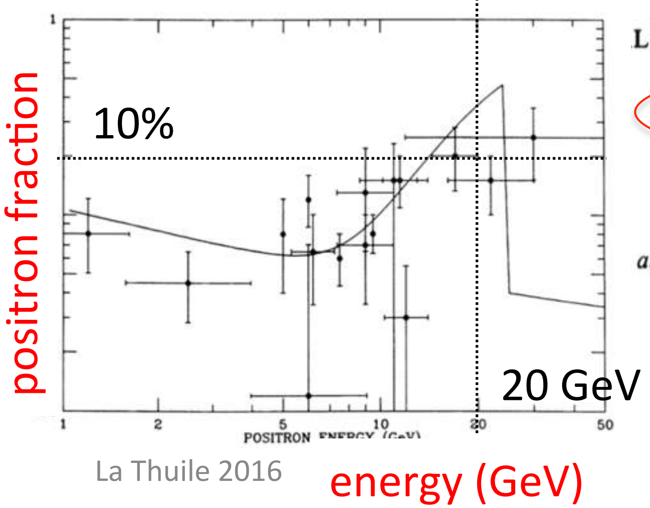
- Cosmic Rays with space experiments probe the local galaxy





The physics of charged cosmic rays

- Understand the mechanisms of production and propagation of CR in the galaxy: interesting per se and to understand astrophysical background to exotic sources
- Dark Matter (DM) in the WIMP regime: DM annihilation in charged (anti)particles of energy 1-1000 GeV → DM masses of tens of GeV to few TeV (depending on abudance, decay channel, couplings, ...).
- Anti Matter (AM) direct search through anti-Helium-4



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

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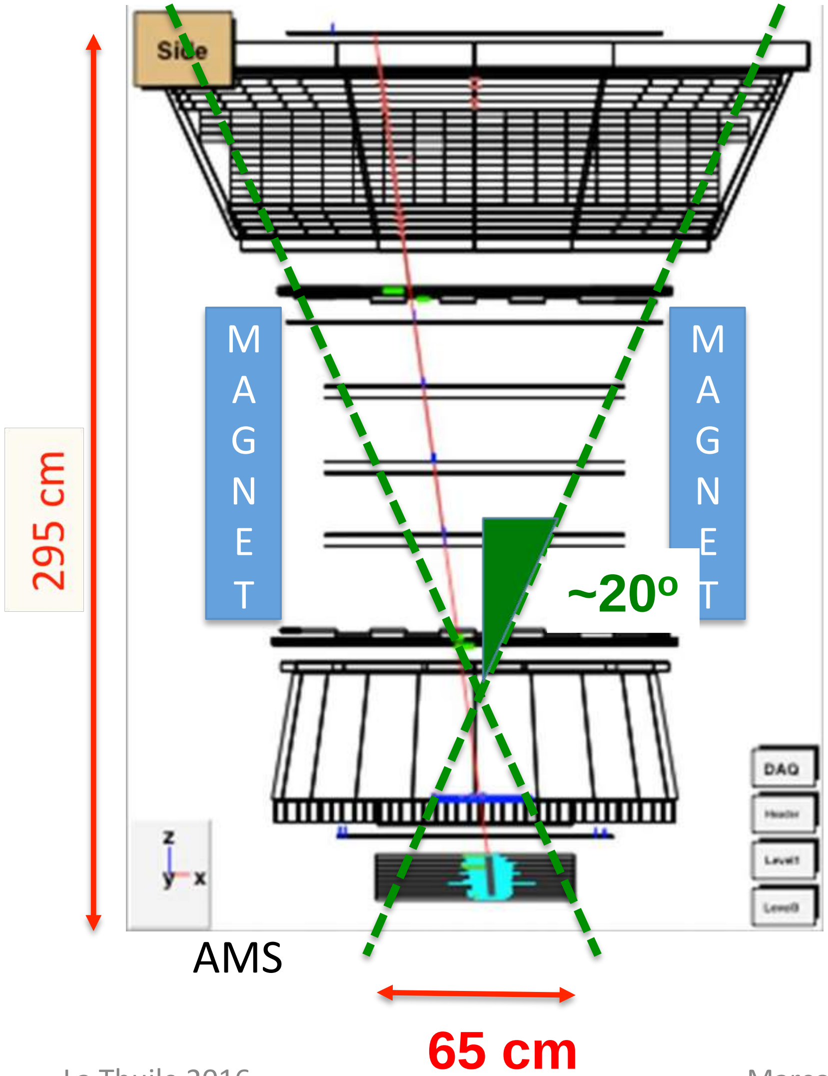
(Received 23 February 1989; revised manuscript received 21 February 1990)

Why Cosmic Rays in Space Experiments

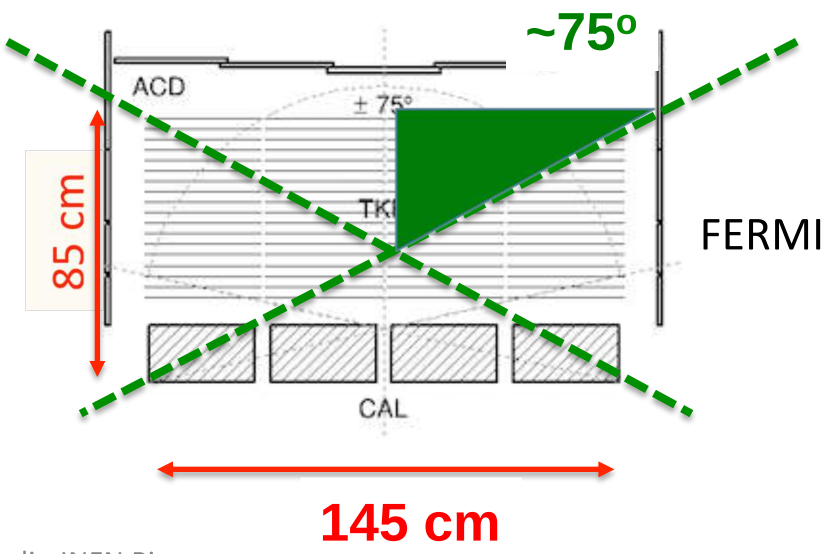
- ✦ *Sensitive to "primary" CR component* (i.e. before interacting with earth atmosphere)
- ✦ A *higher precision on energy and on chemical composition* can be reached, wrt ground exp.
- ✦ With magnet → *sensitivity to anti-particles*
- ✦ Compared to balloons: long period of continuos data taking → increased statistics, but also a better control of systematics

- Limited mass
- Limited geometrical acceptance
- Large cost

Magnetic Spectrometers vs Calorimeters

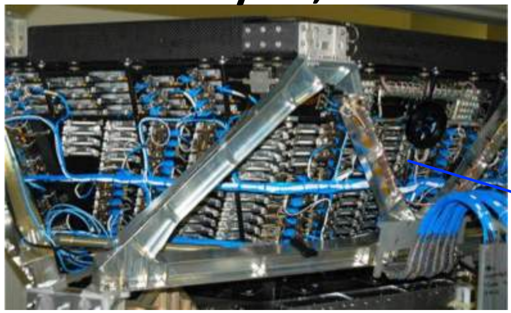


- magnetic spectrometers: access to anti-particles (relevant for DM and AM searches)
- calorimeters: maximize acceptance (important because of steeply falling CR spectrum)

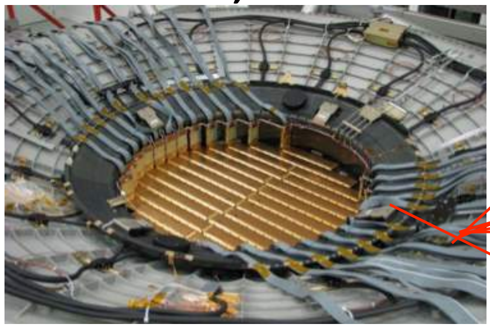


AMS02 magnetic spectrometer: a particle detector in Space

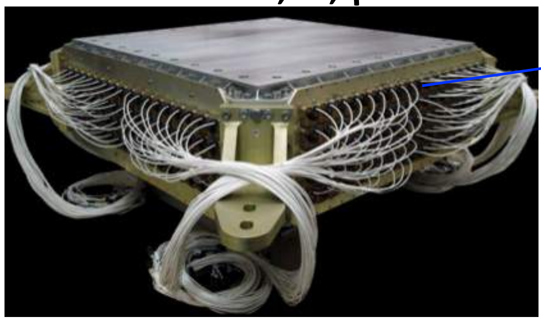
TRD
Identify e+, e-

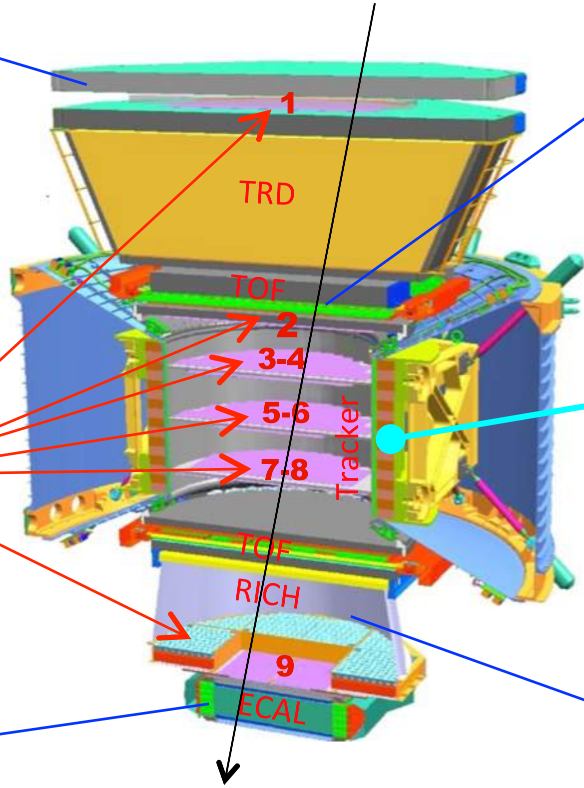


Silicon Tracker
Z, P



ECAL
E of e+, e-, γ



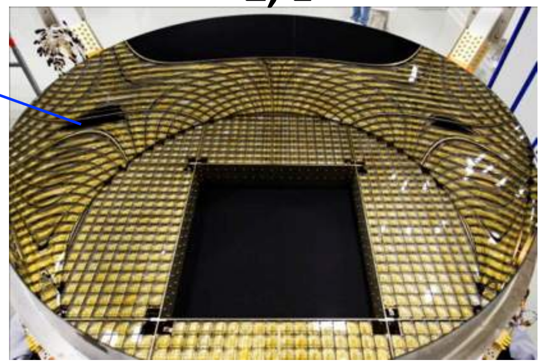


AMS02 characteristic: redundancy

TOF
Z, E

Magnet
±Z

RICH
Z, E



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

Main sources of systematics

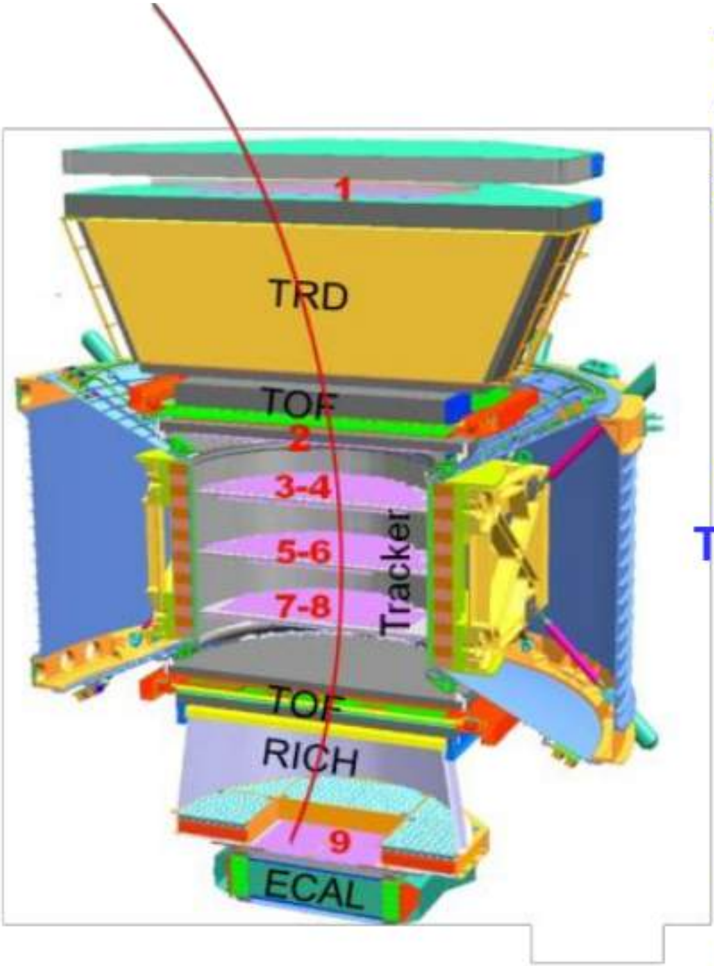
- No time to discuss analyses → 3 relevant issues:

1. **electrons, positrons**. ep-separation = discrimination between em particles and the much more abundant hadronic (mostly proton) component
2. **anti-particles**. Charge Confusion = probability of measuring the wrong sign of the charge ("negative protons", "positive electrons", ...)
3. **nuclei**. Z identification and fragmentation inside the detector (Z→Z-1, Z-2, ...) whose probability increases with Z:
    - He = 14%
    - C = 40%
    - Fe = 70%

    (N.B.: ECAL not included in fragmentation probability)

ep-separation

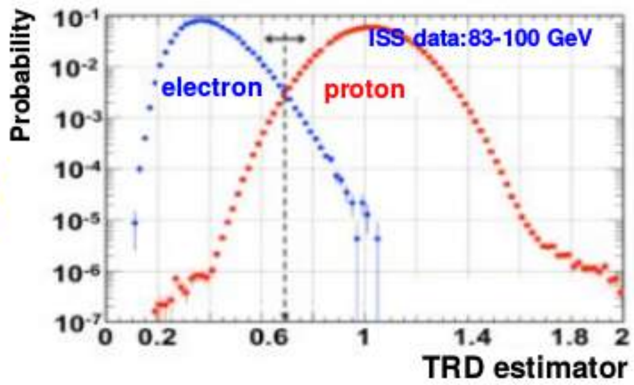
Three detectors to separate e± from hadrons

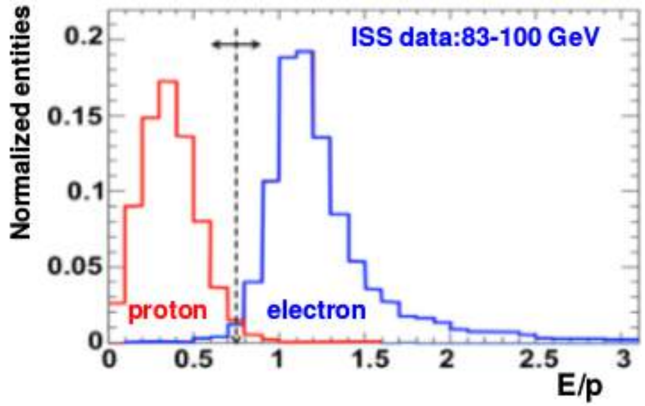


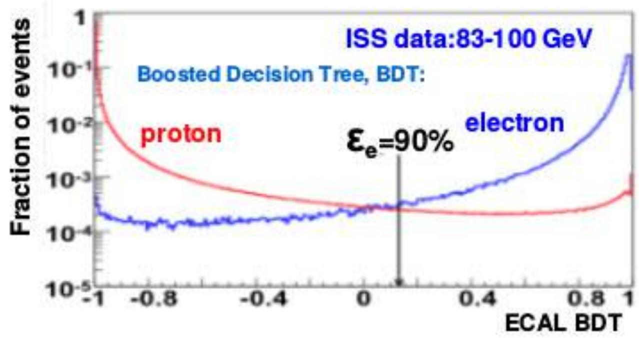
TRD
(transition radiation)
to identify e±

ECAL measures E
Tracker measures p
e±: E=p
proton: E<p

ECAL
(shower shape)
to separate e±
from protons





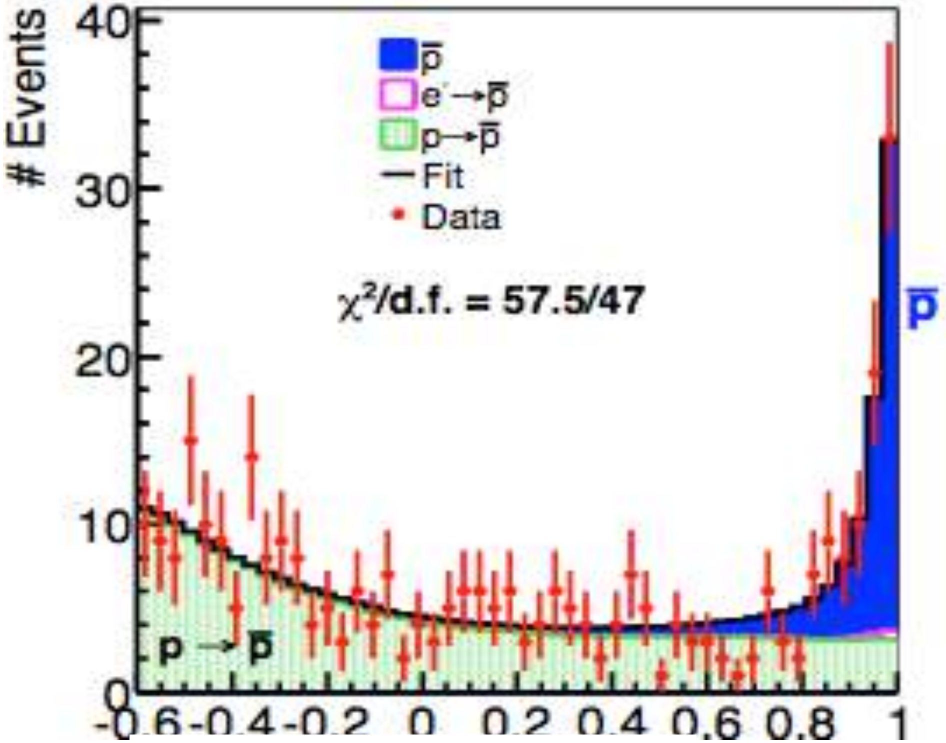


Charge confusion

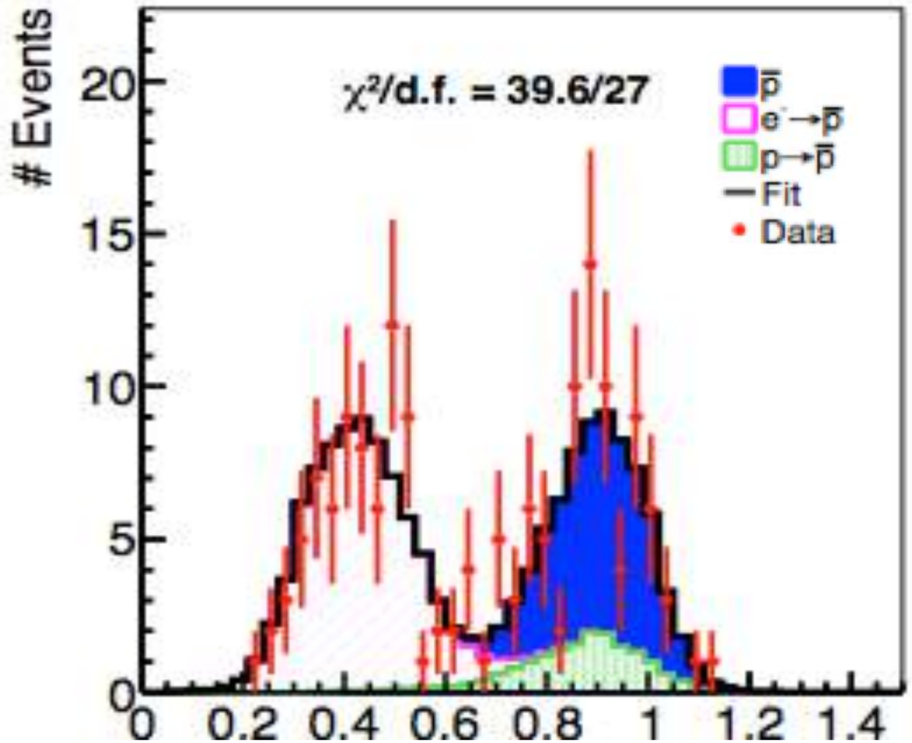
- 2 sources of Charge Confusion (CC):
  - Rigidity resolution: MDR (Maximum Detectable Rigidity) = Rigidity at which the error on Curvature (*k=1/R*) is 100% (p=1.8 TeV for protons, p=3.3 TeV for Helium).
    - This is a "hard wall", but its effect on CC decreases rapidly as you move down in Rigidity (gaussian distribution in *k*)
  - Multiple Scattering: much more important at all rigidities
    - normally it has *additional features*: extra secondary hits in Tracker, higher activity in TOF counters due to emitted radiation, ...
    - possible to build a *classifier* which separates *anti-protons* from *negative protons*, or *positrons* from *positive electrons*

Separating pbar from p and e^- background

- *CC-separation* and *ep-separation estimators* (based on BDT) are built; a 2D plane is formed on which cuts are applied
- Below is an example of each estimator after cutting on the other
- Good separation, but residual proton background is non negligible



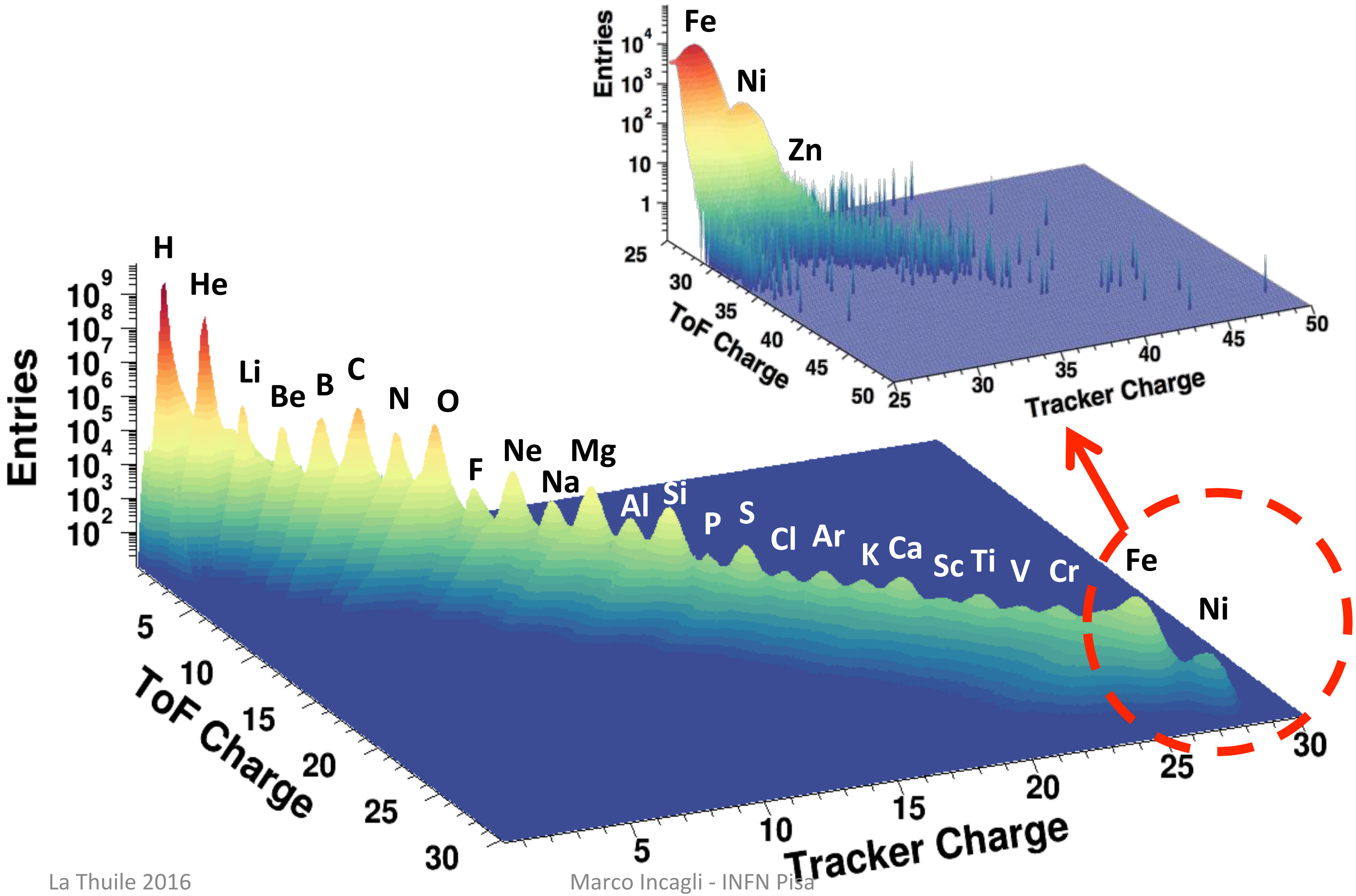
CC separation estimator



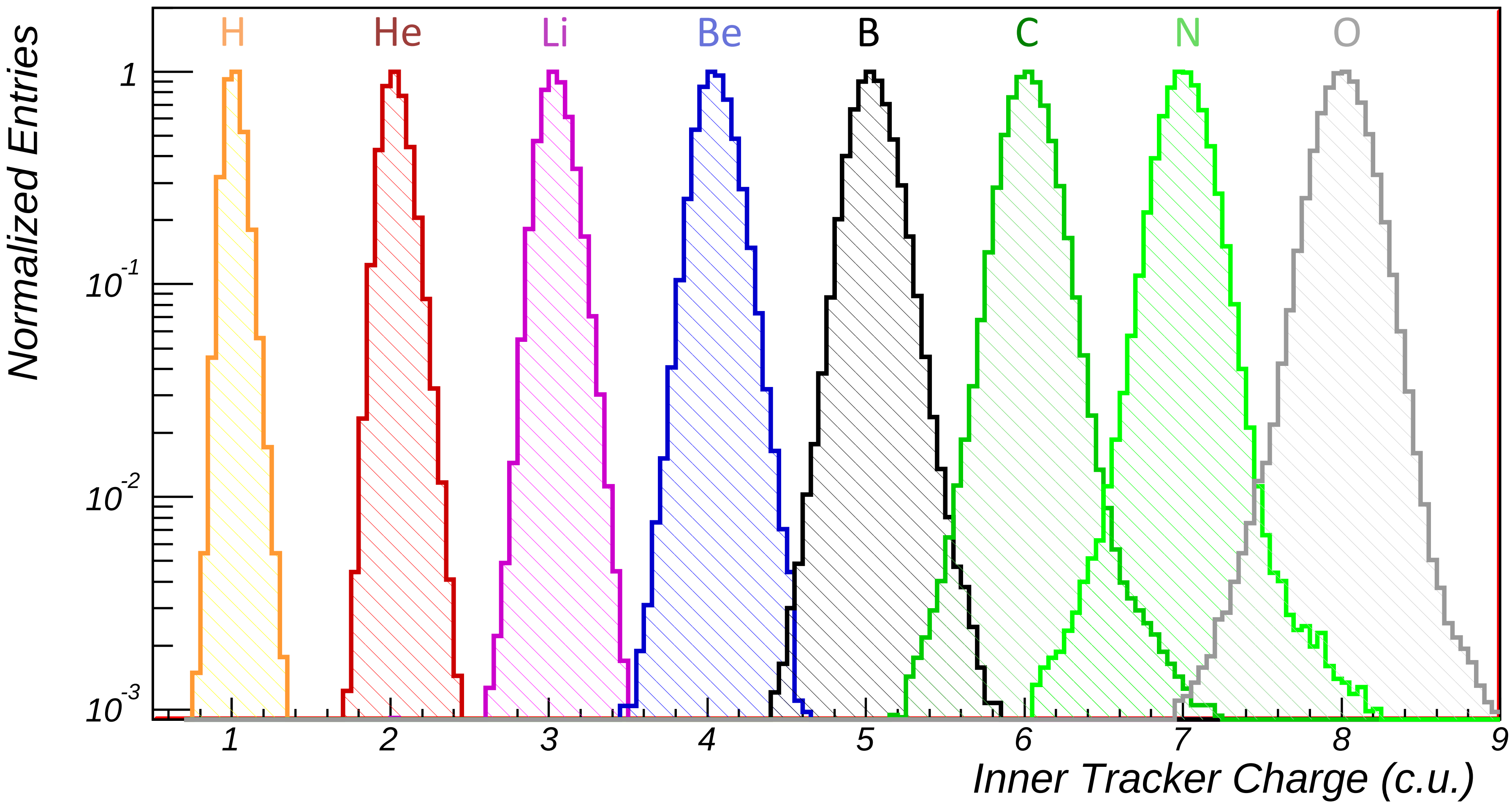
ep separation estimator

E = [177, 211] GeV

Cosmic-Rays Composition with AMS

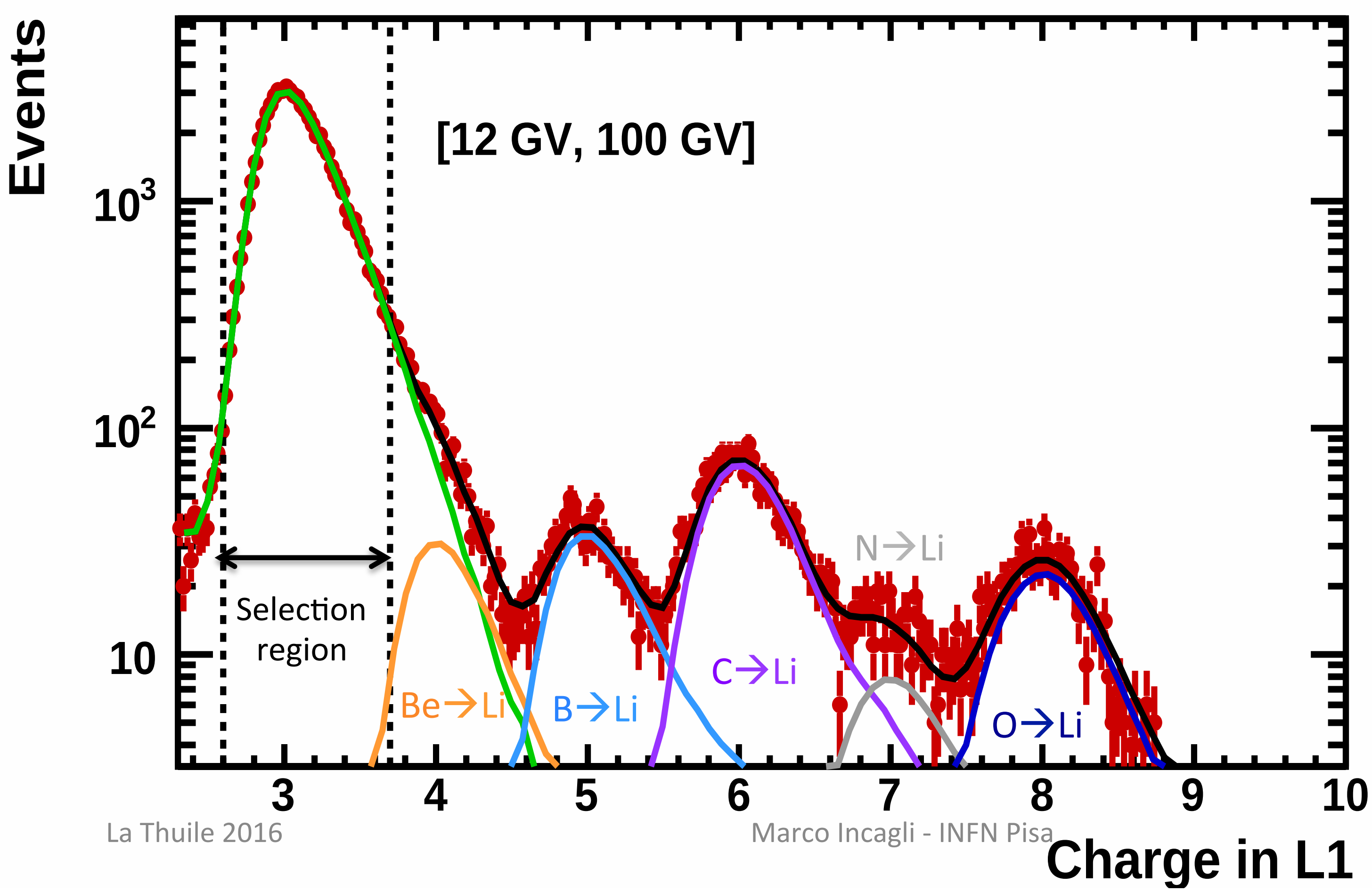


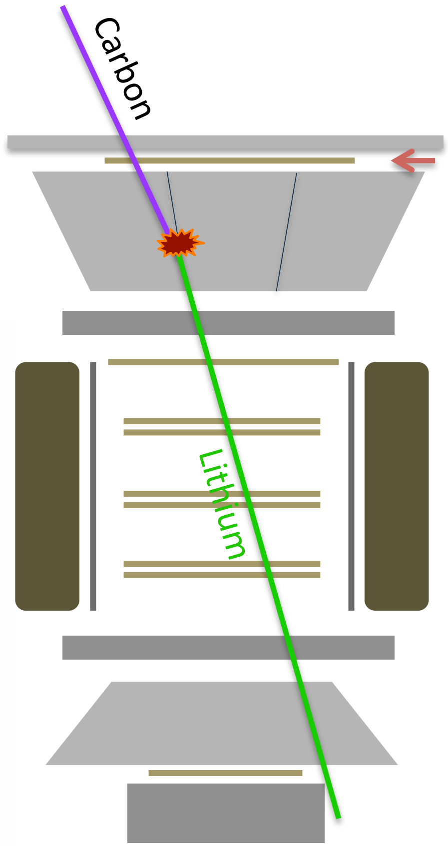
Nuclei identification for light elements



Fragmentation: example with Lithium

- Use Layer 1 to determine original charge
- Exploit redundancy to observe fragmentation
- (similar effects in Boron analysis)

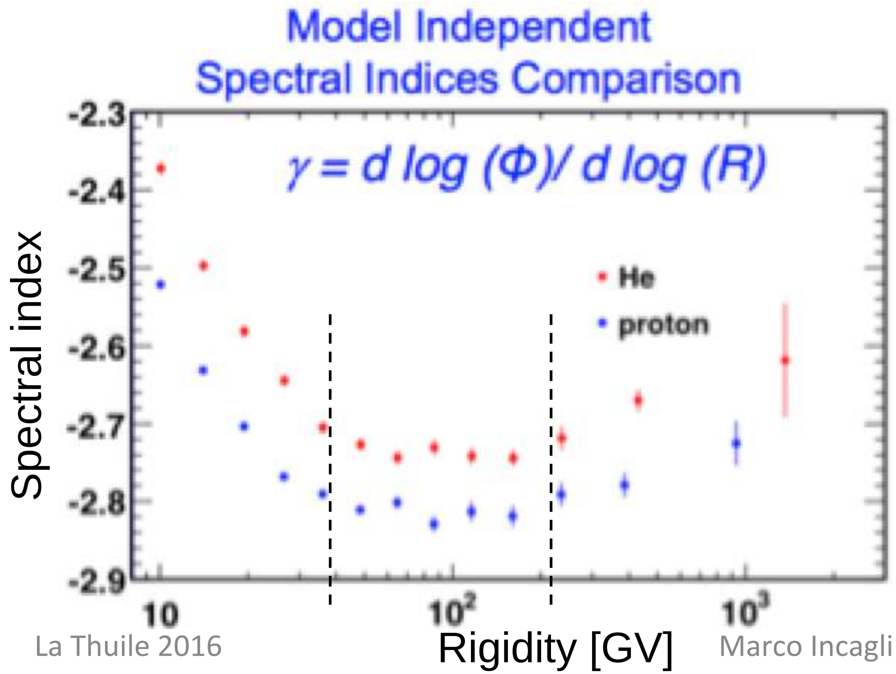


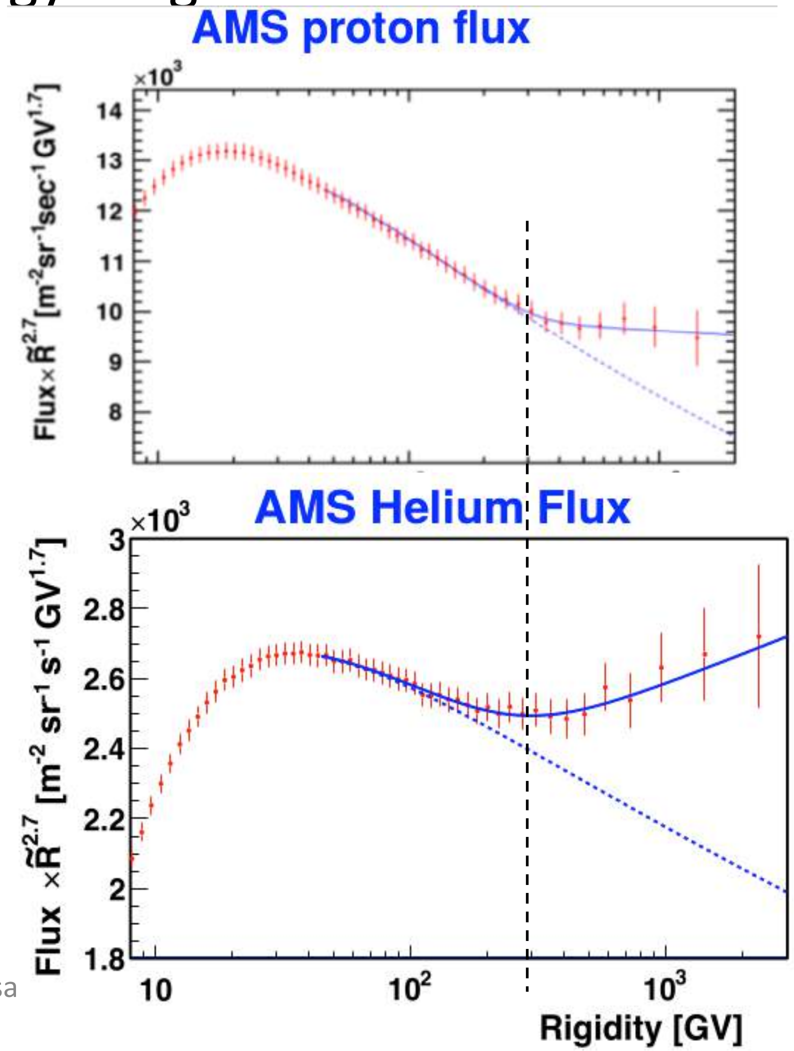


Results

p and He fluxes

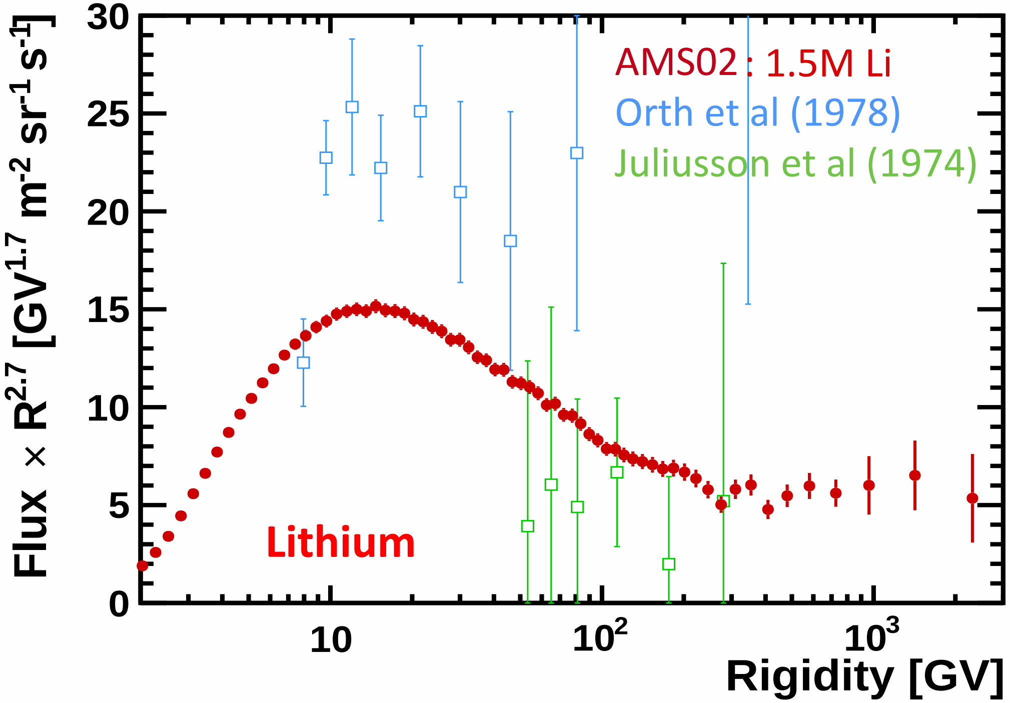
- proton and Helium fluxes show 2 puzzling features: a (soft) break at similar rigidities (~200-300 GeV) and a spectral index which differs by ~0.1 in a large energy range
- Some possible reasons:
  - acceleration in SNR
  - propagation in ISM
  - local or distance sources

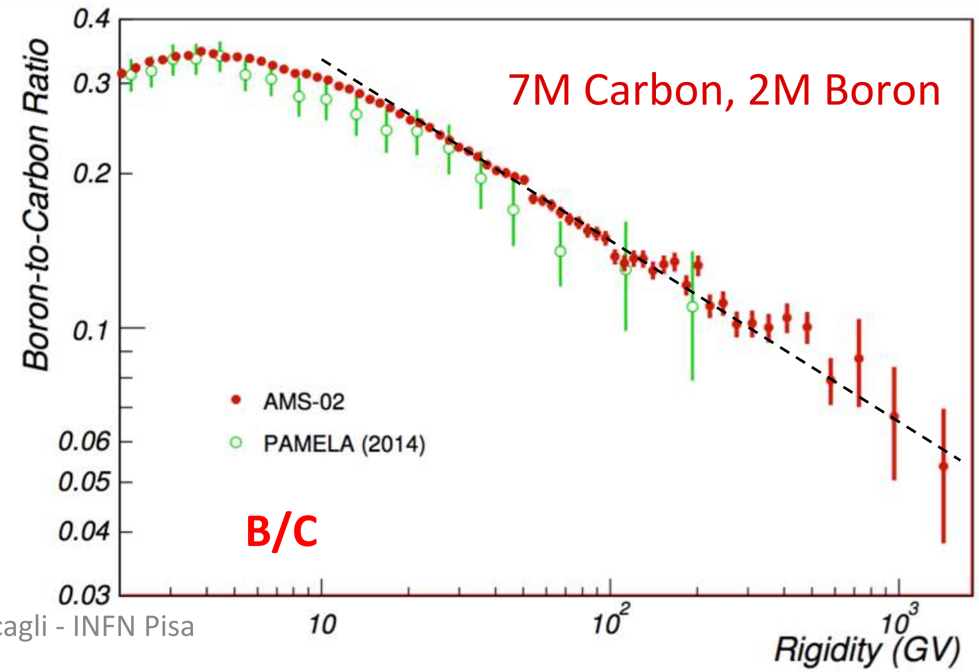




Lithium and B/C

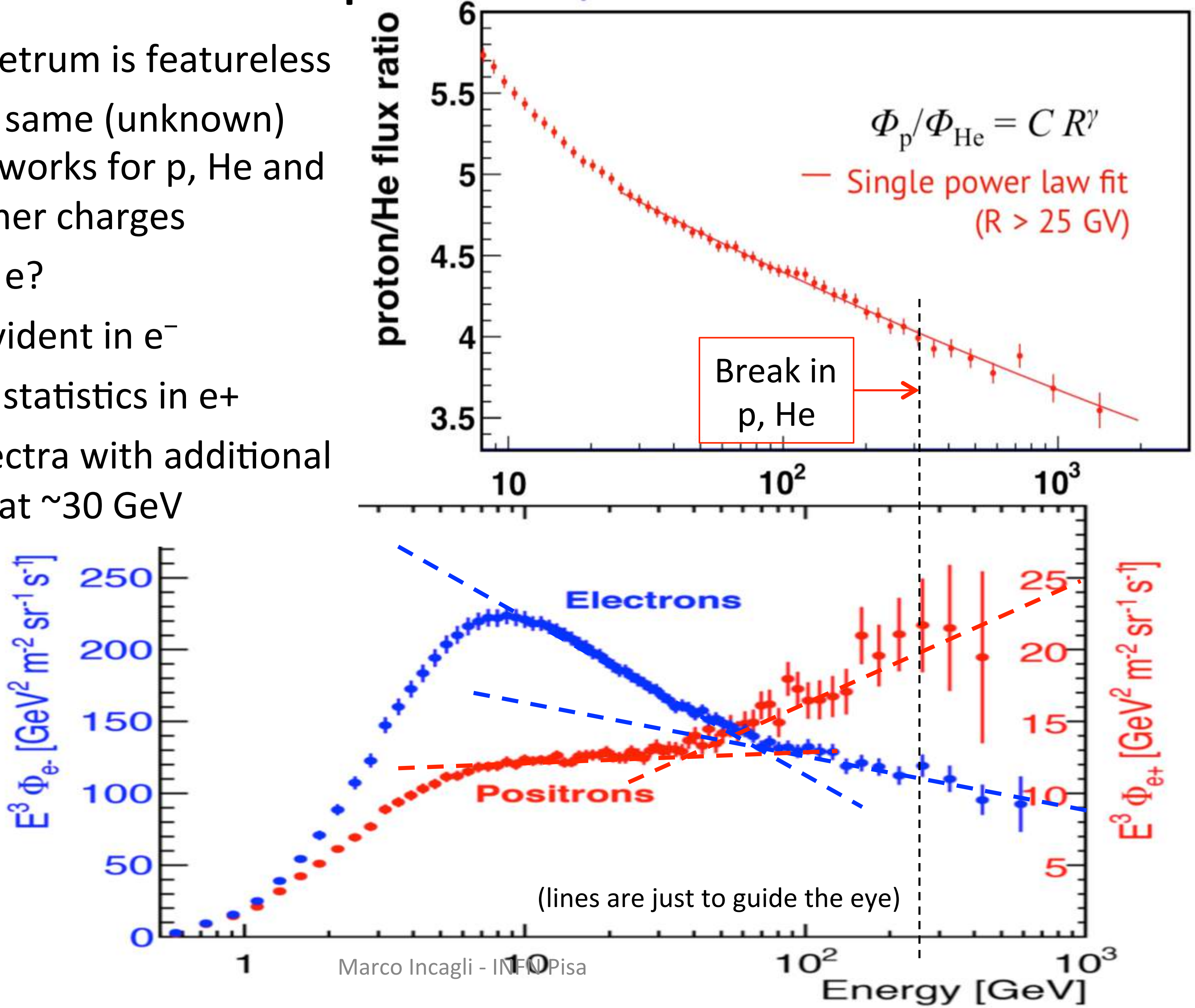
- However a similar break *at a similiar Rigidity* is observed also in Li, a secondary species
- Maybe a component of secondaries and primaries are accelerated together inside SNR shocks?
- A similar break is expected also in Carbon, but not necessarily at the same Rigidity
- B/C ratio smooth → need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



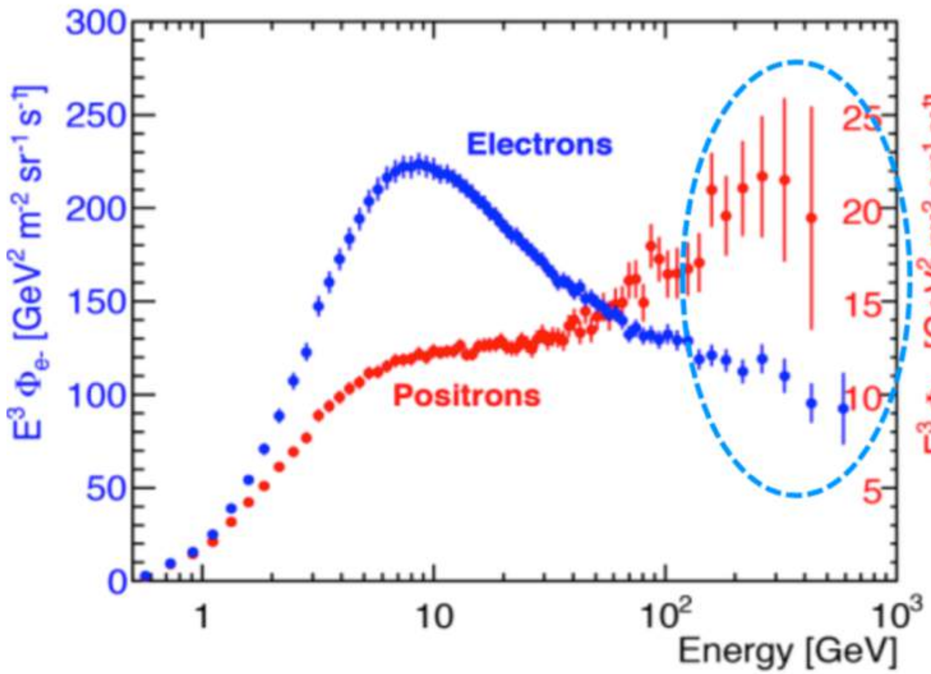


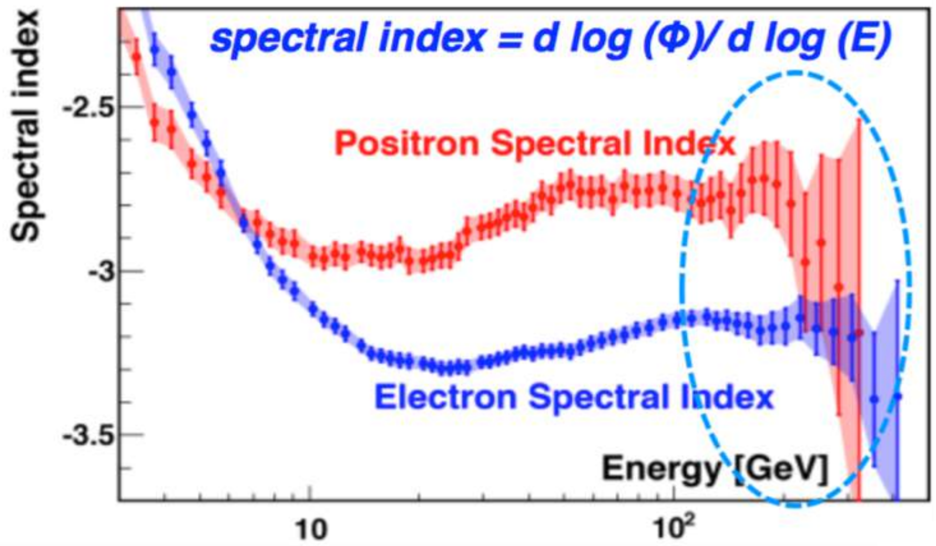
Break in the spectrum, p/He and e$^{\pm}$

- 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



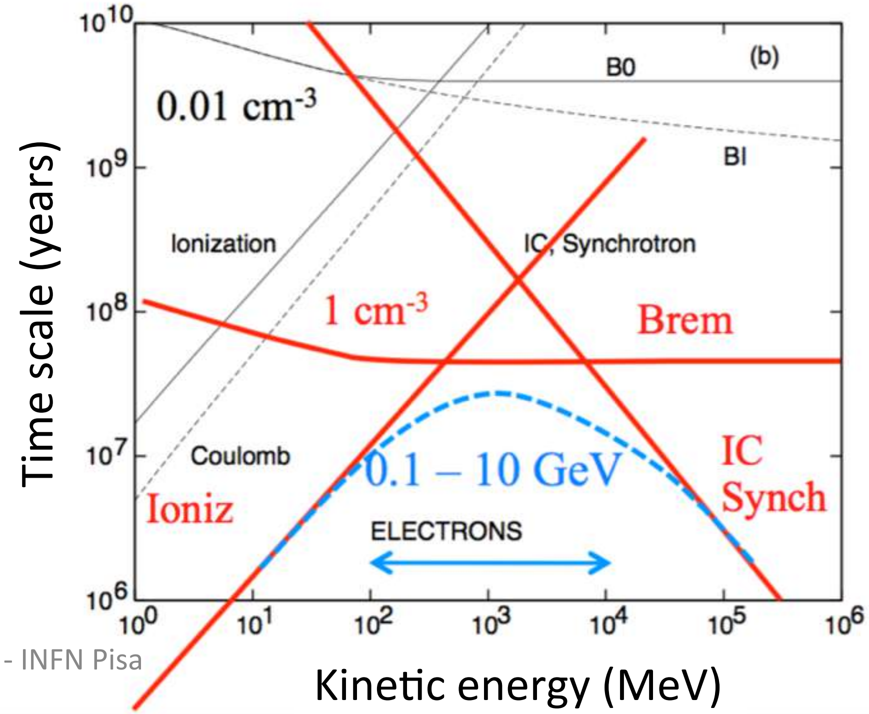
The Electron Flux and the Positron Flux





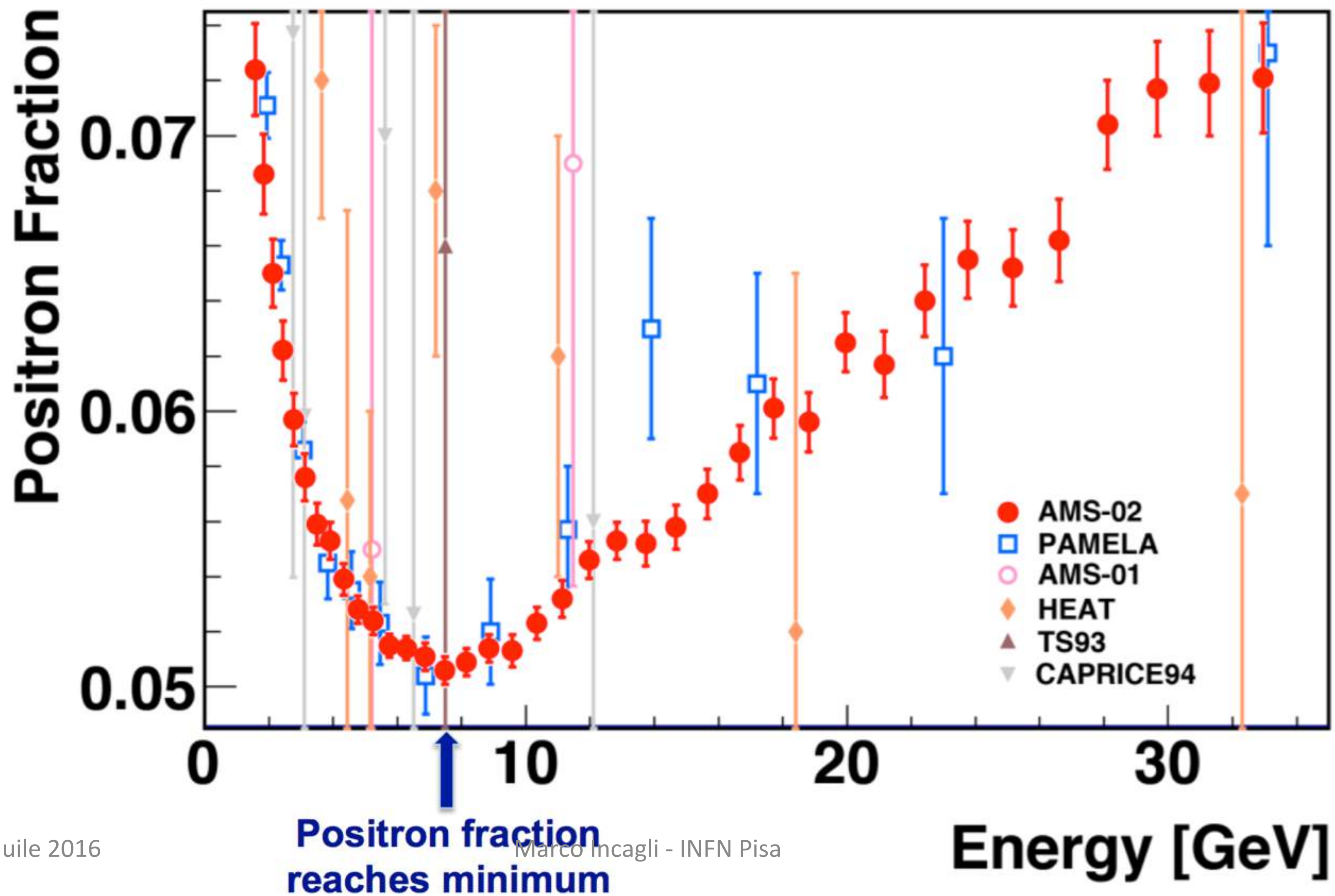
Energy losses of electrons:

- 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



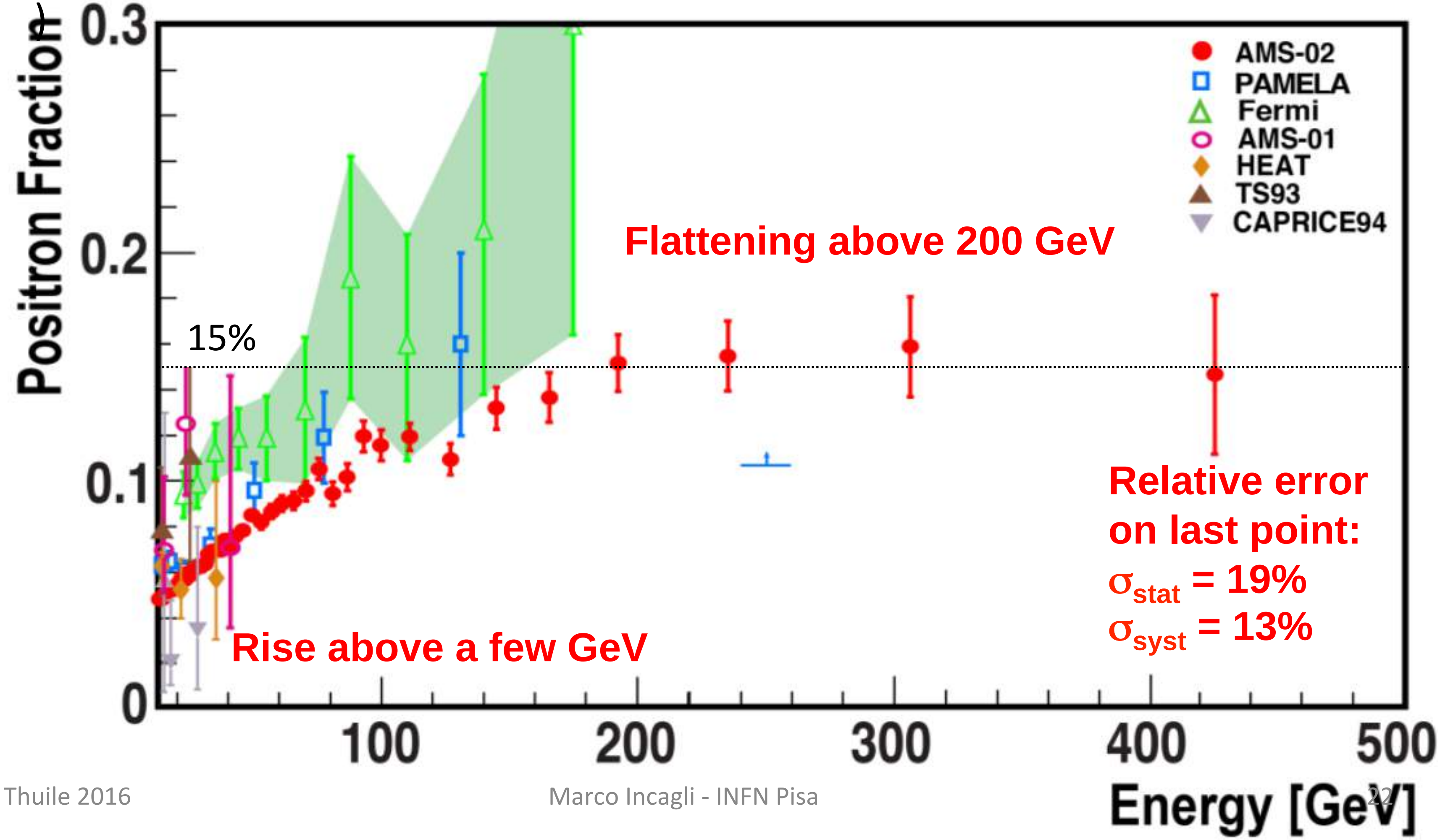
What about the positron fraction?

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



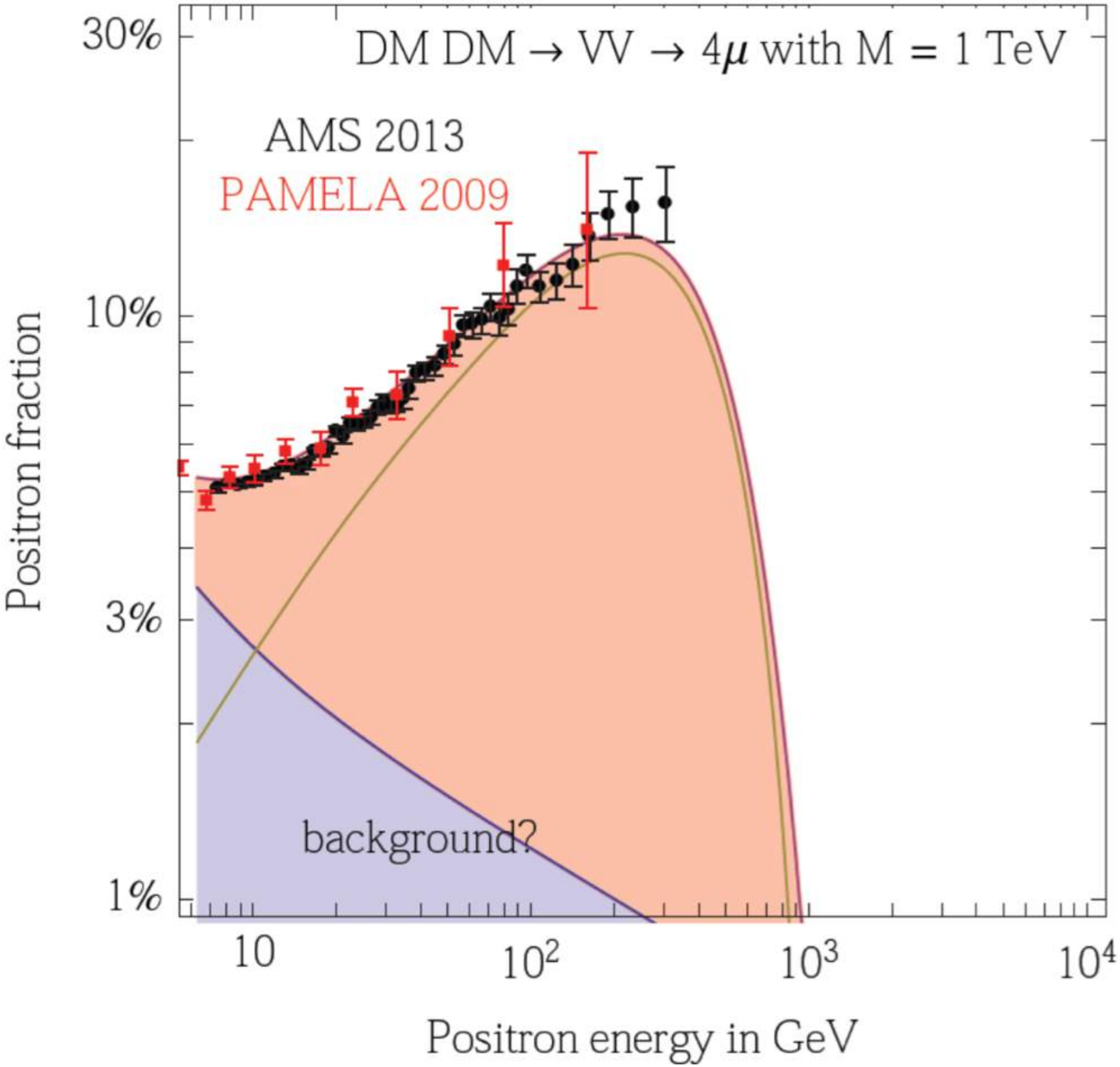
Is the rise of the positron fraction a hint of DM?

- 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)
-)

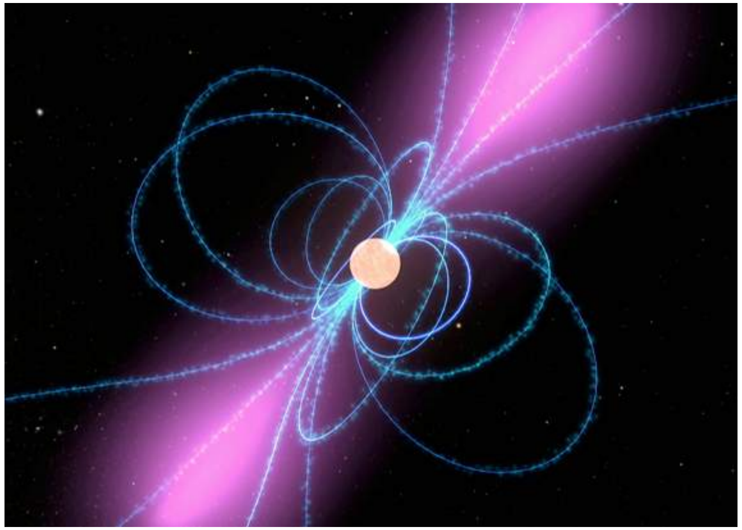


Dark Matter model with intermediate state

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



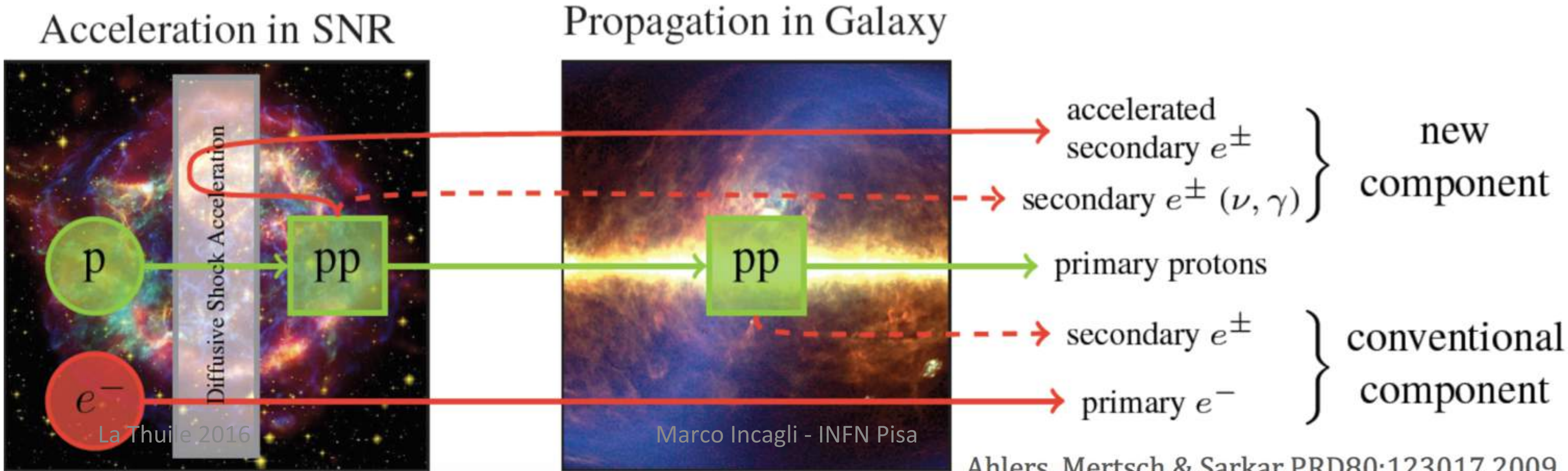
But the excess can be due to standard astrophysics



Possible explanations:

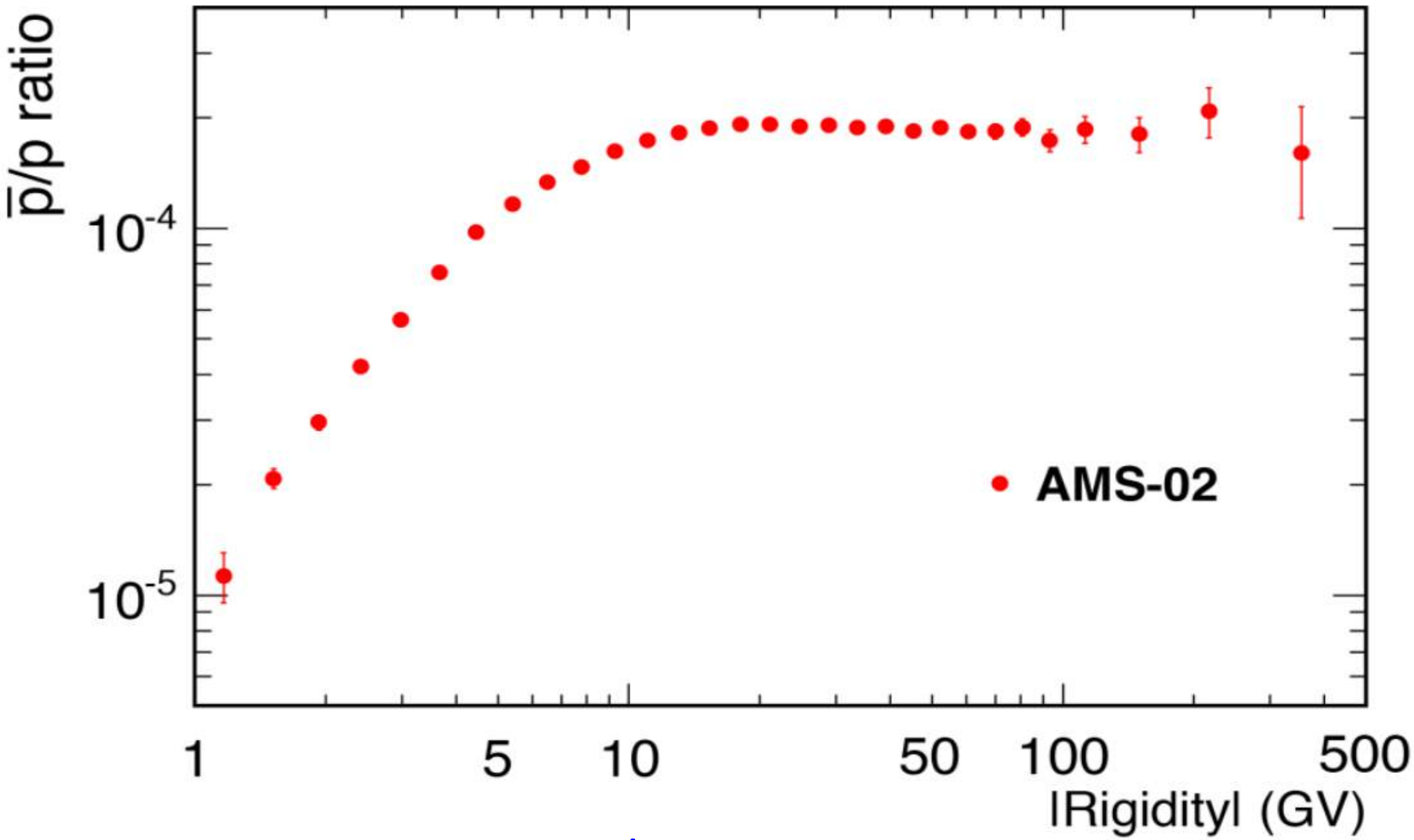
1. PULSARS: $e^{\pm}$ pairs are produced by the interaction of energetic photons with the strong magnetic field of the neutron star. No $p\bar{p}$ pairs!

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



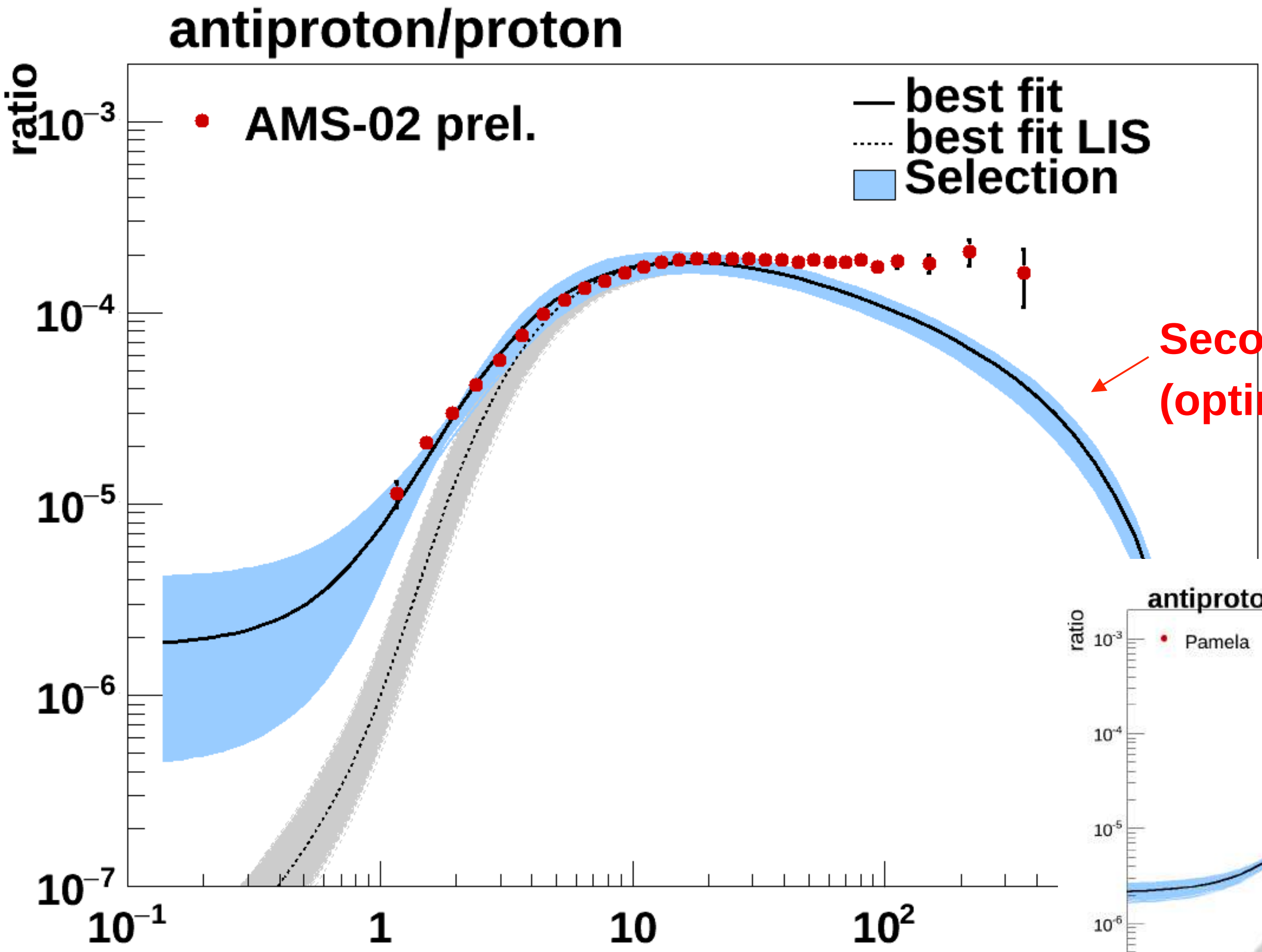
Ahlers, Mertsch & Sarkar,PRD80:123017,2009

What about anti-protons?

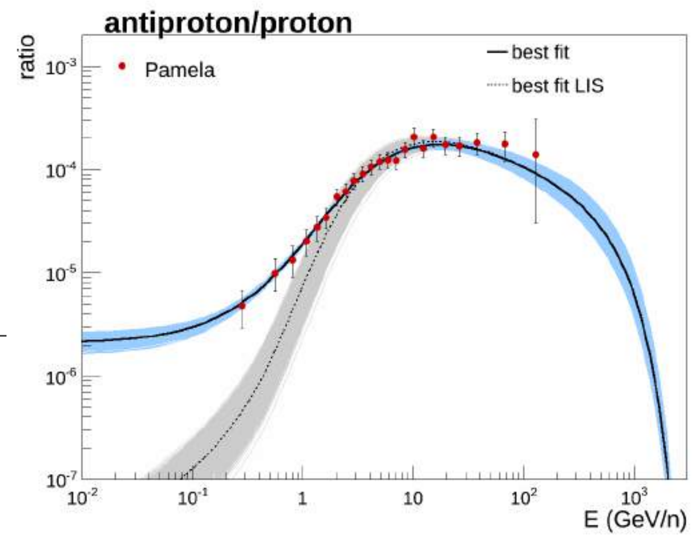


- no rise observed, as in e+/e- ratio, but the spectrum is flatter than expected
- precise measurement up to R=450 GeV; hard to go above.

Example of a fit with a model optimized on Pamela data

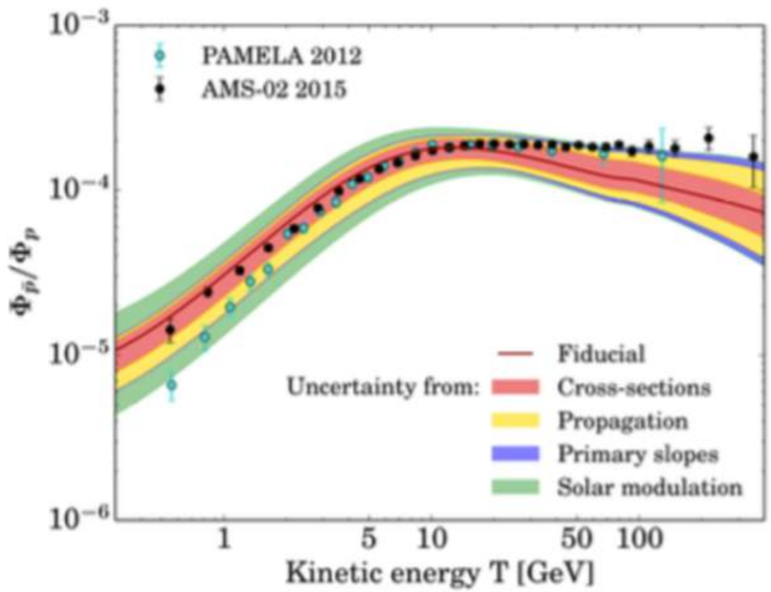


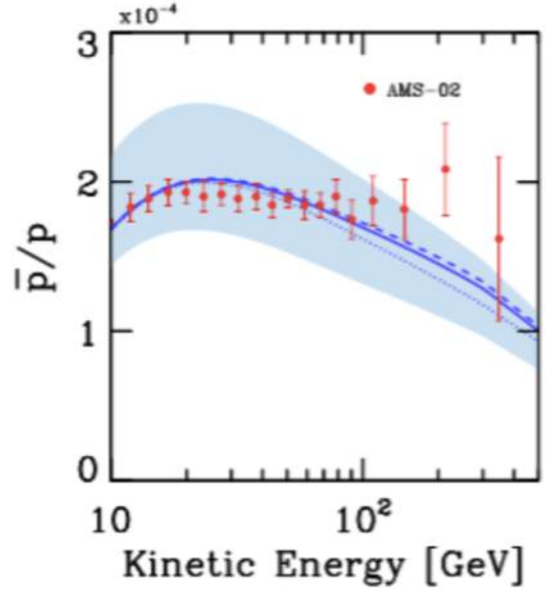
Secondary production (optimized for PAMELA)



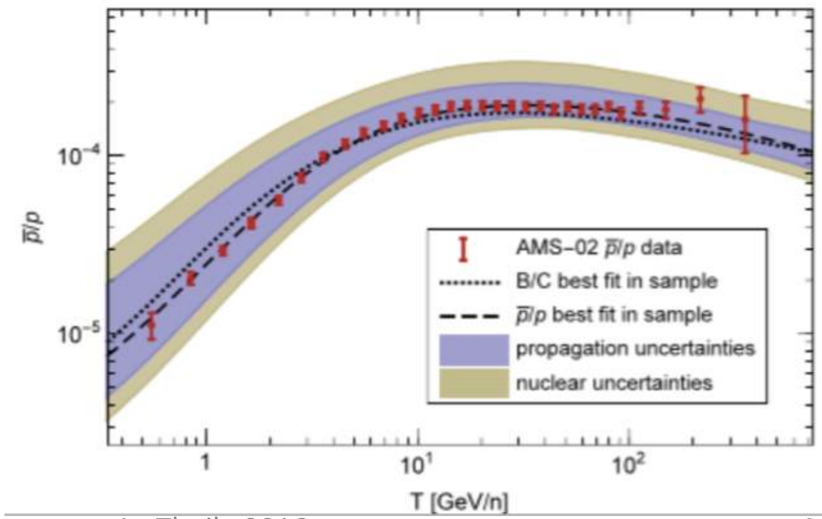
Dissertation / PhD Thesis IEKP-KA/2014-20
Simon Kunz (2014)
http://ekp-invenio.physik.uni-karlsruhe.de/record/48605

but if models are tuned on AMS ...





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



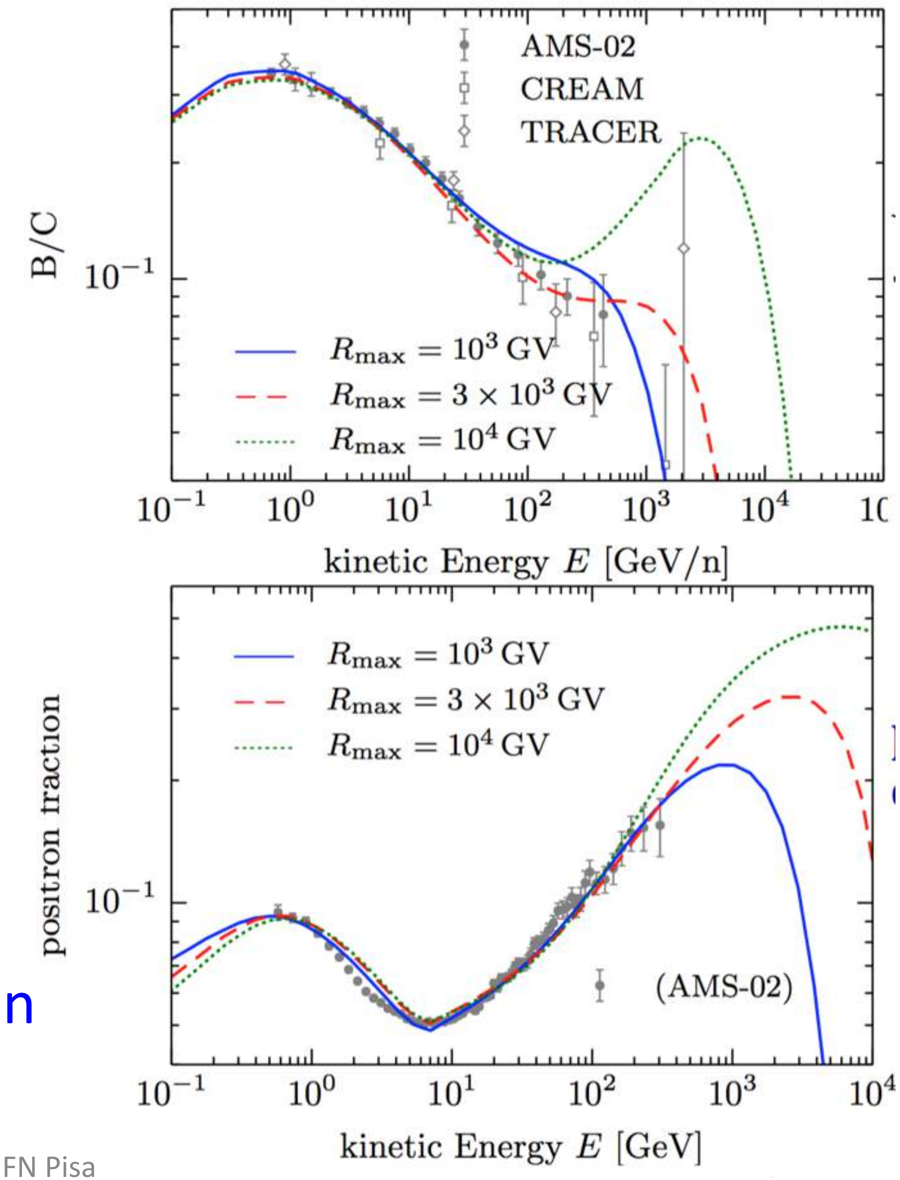
(a) G.Giesen, M.Boudaud, Y.Gènolini, V.Poulin, M.Cirelli, P.Salatiand, and P.D.Serpico, JCAP1509 (2015) 09, 023 [arXiv:1504.04276 [astro-ph.HE]].

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

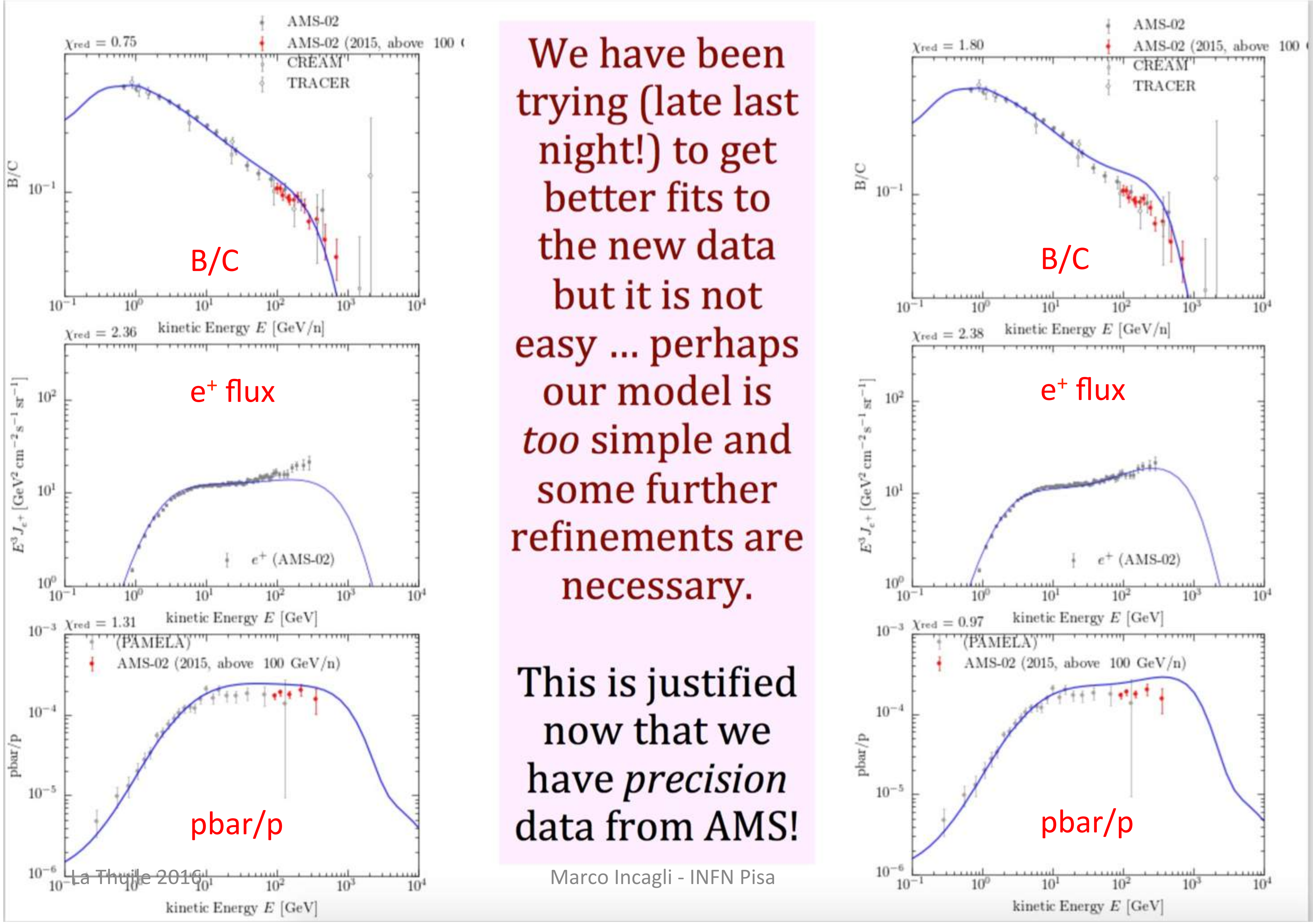
(c) R.Kappl, A.Reinertand, and M.W.Winkler, arXiv:1506.04145 [astro-ph.HE].

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



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 to constraint the generation/propagation of standard Cosmic Rays

What about Antimatter?

- The search for anti-Helium will proceed in parallel with the anti-deuteron analysis
- Both anti-Helium 3 (possible background or DM signal) and anti-Helium 4 (anti-stars) will be stuied

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!