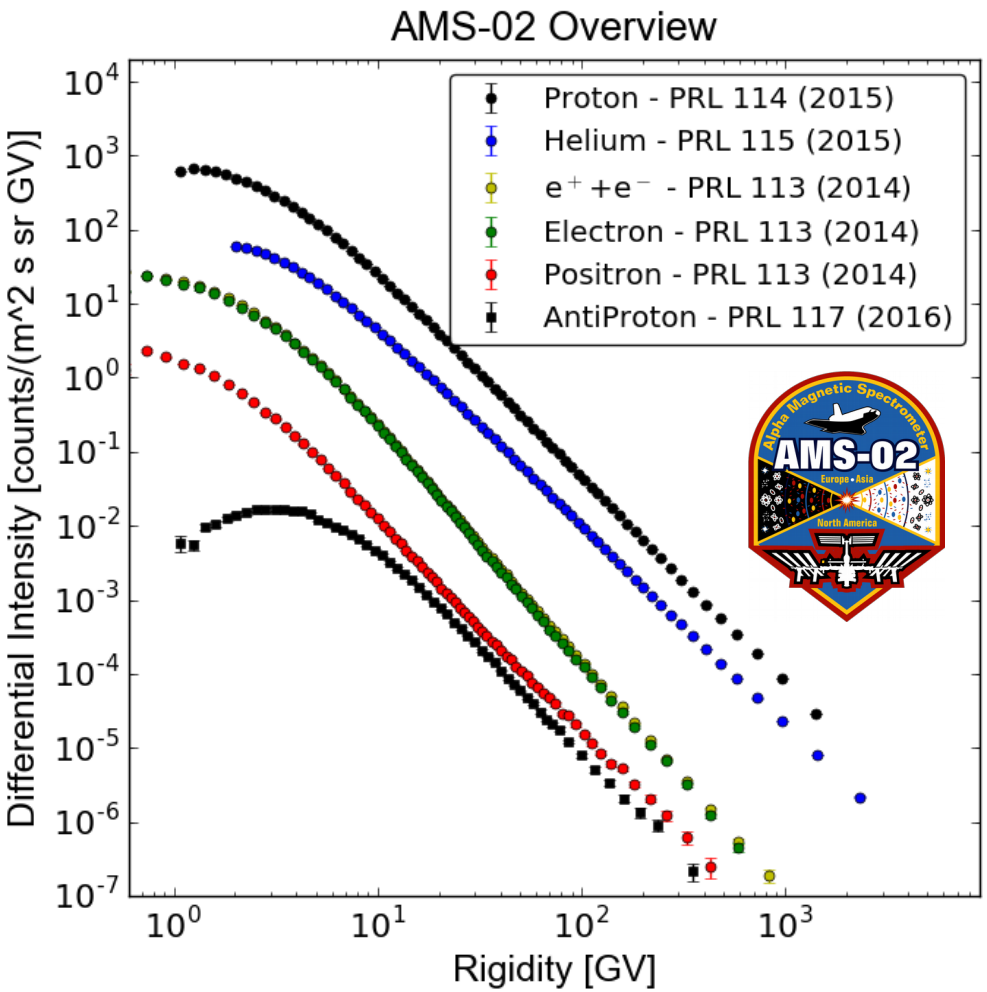
Measurement of leptonic cosmic rays with AMS-02, interpretation in terms of dark matter

Sami Caroff

Galactic cosmic rays



Protons ~ 90 %
Nucleus ~ 10 %
Electrons ~ 1 %
Positrons ~ 0.1 %

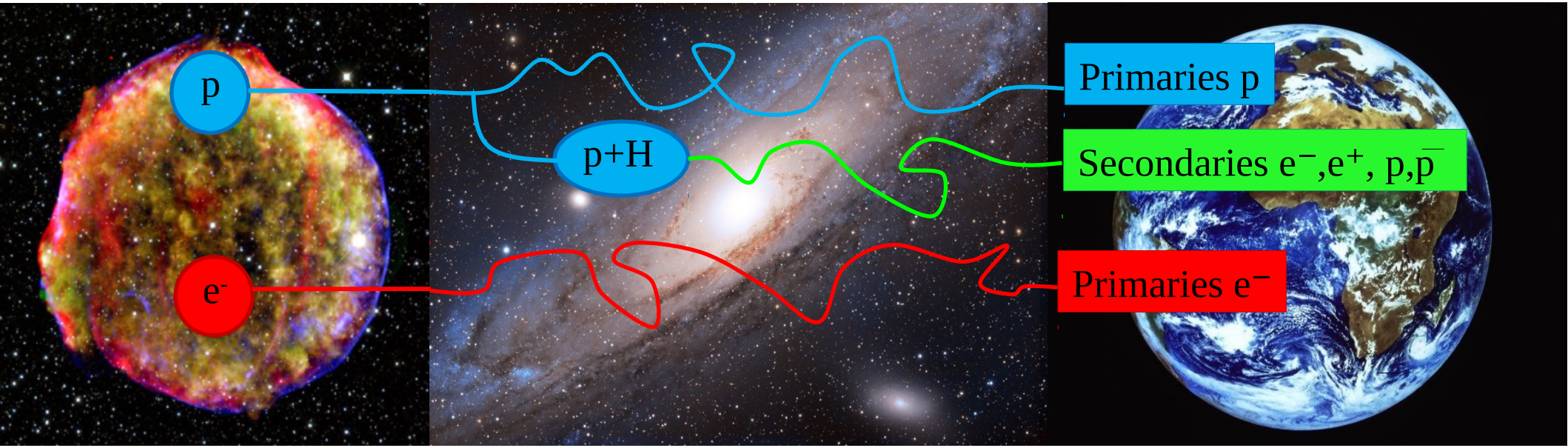
- Matter is the principal component of cosmic rays, antimatter is rare.

The standard scope

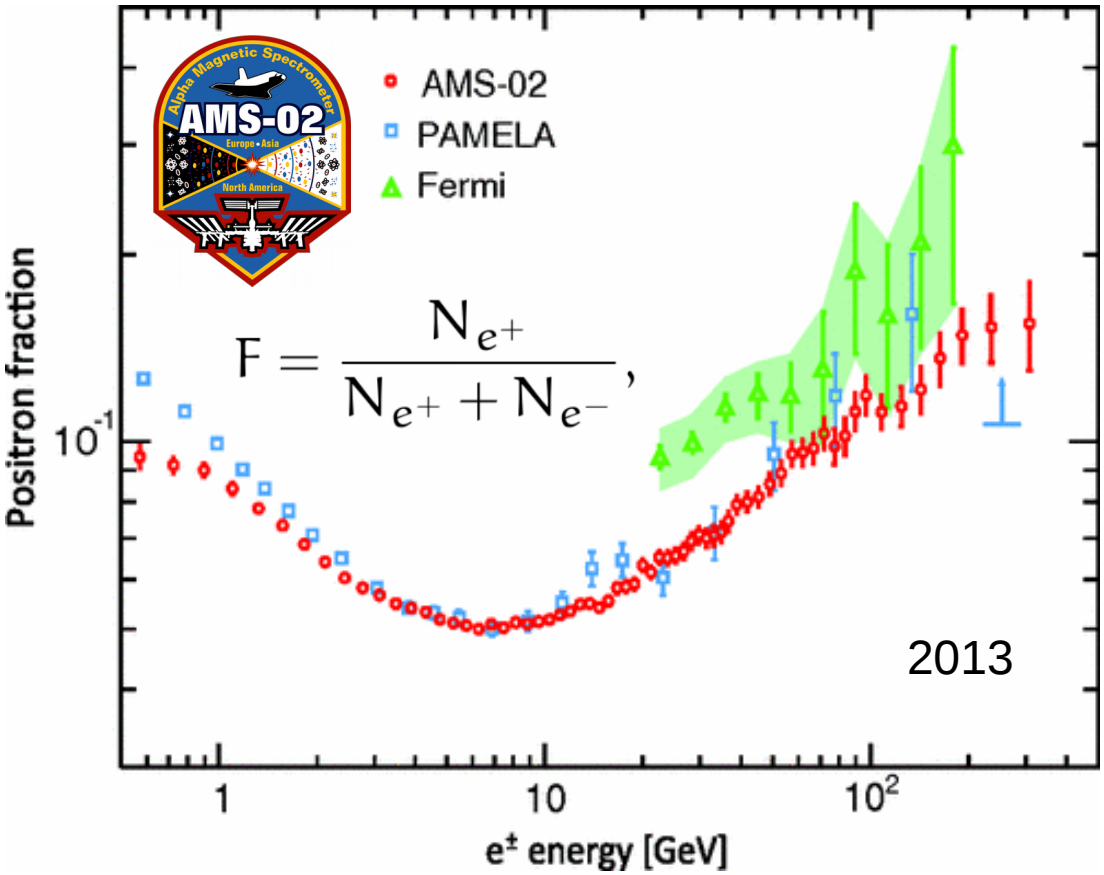
Production and acceleration

Propagation (diffusion) in our galaxy

Observation



The positron excess

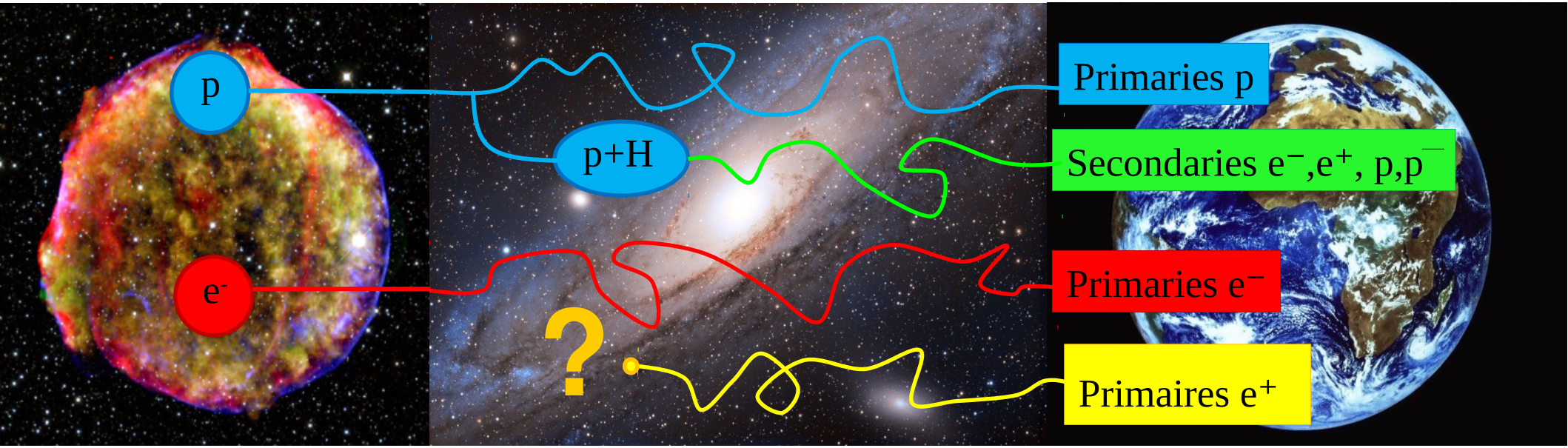


Physical Review Letters, 110(14) : 141102

- **The positron fraction exhibits an increase from 8 up to 350 GeV**
- **This positron excess is not compatible with a pure secondary origin**
- **It exists a source of primary cosmic positrons in our galaxy**

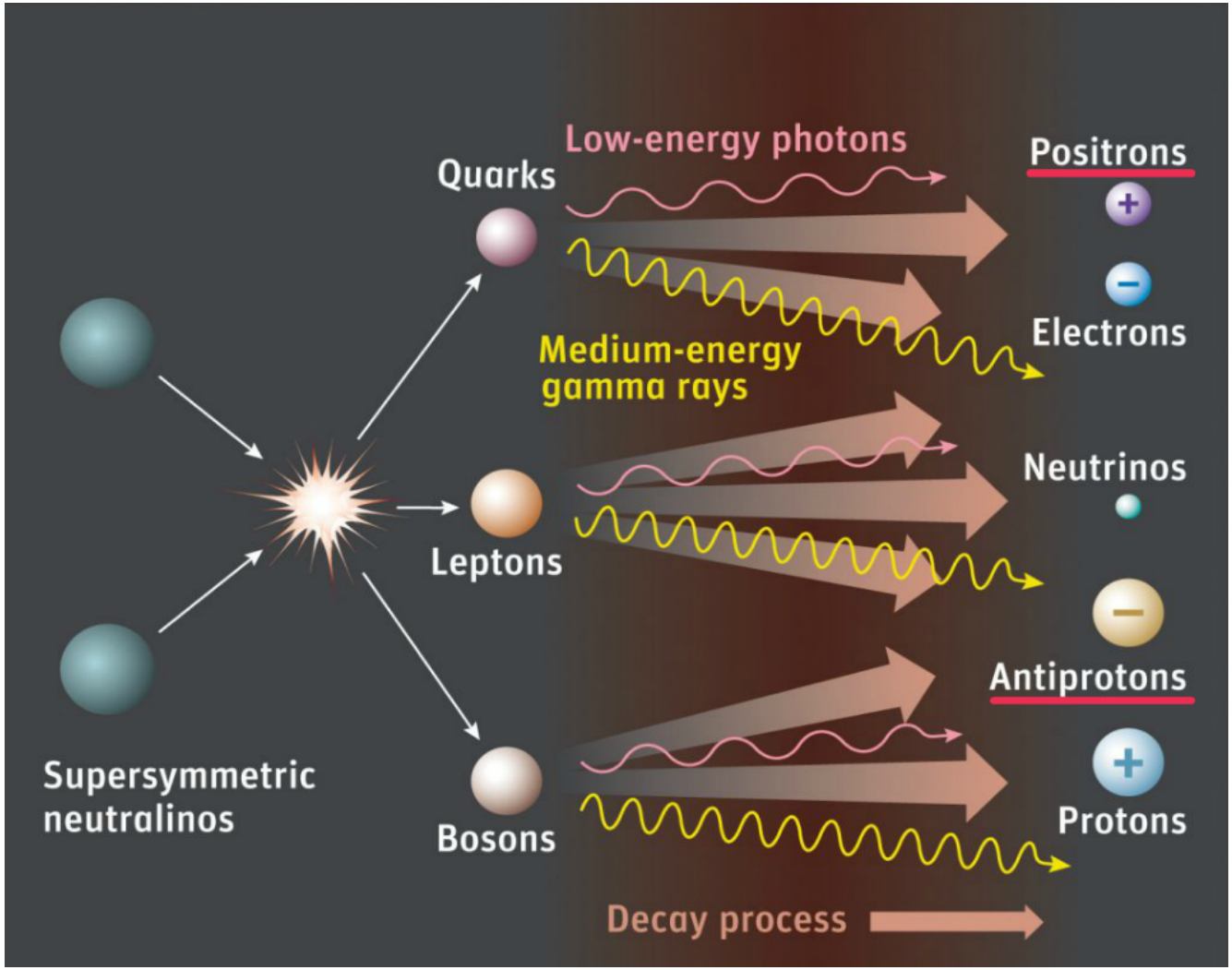
Beyond the standard scope

Production and acceleration | **Propagation (diffusion) in our galaxy** | **Observation**



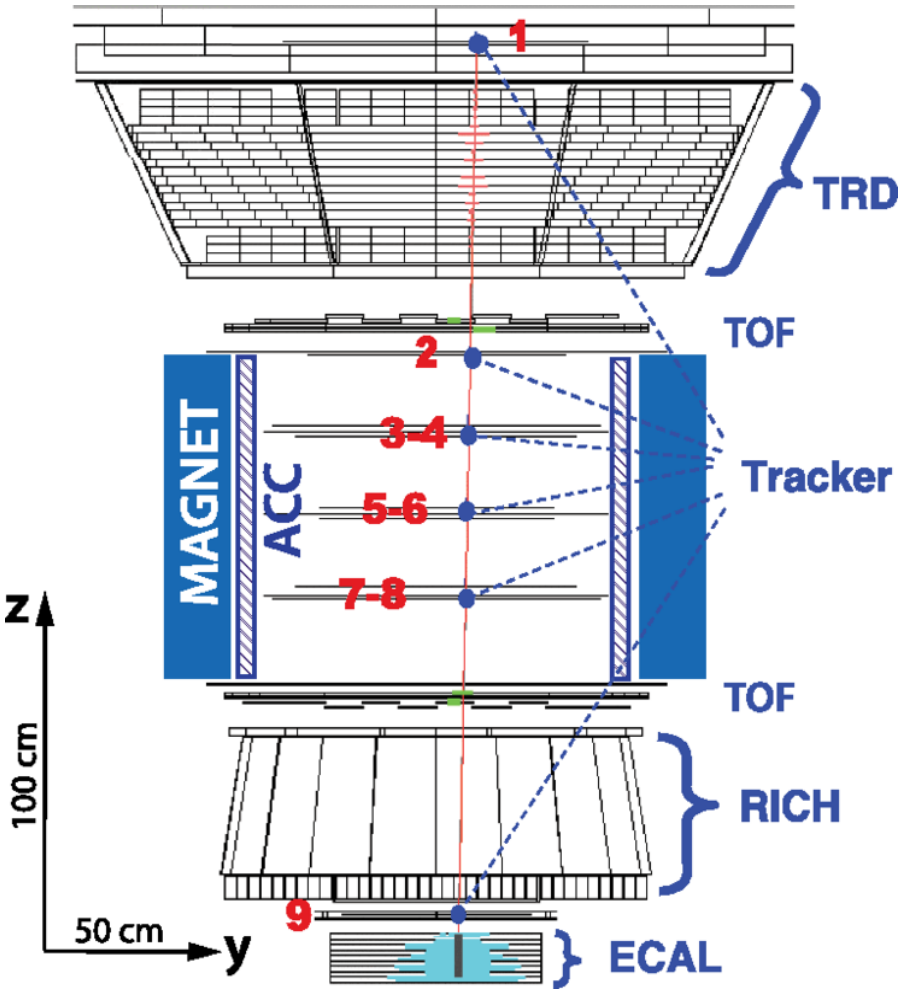
The identification of this primary positron component needs a precise measurement of the positrons and electrons trend

Motivation



Dark matter can produce an additional antimatter in cosmic rays that can be observed by experiment such AMS-02

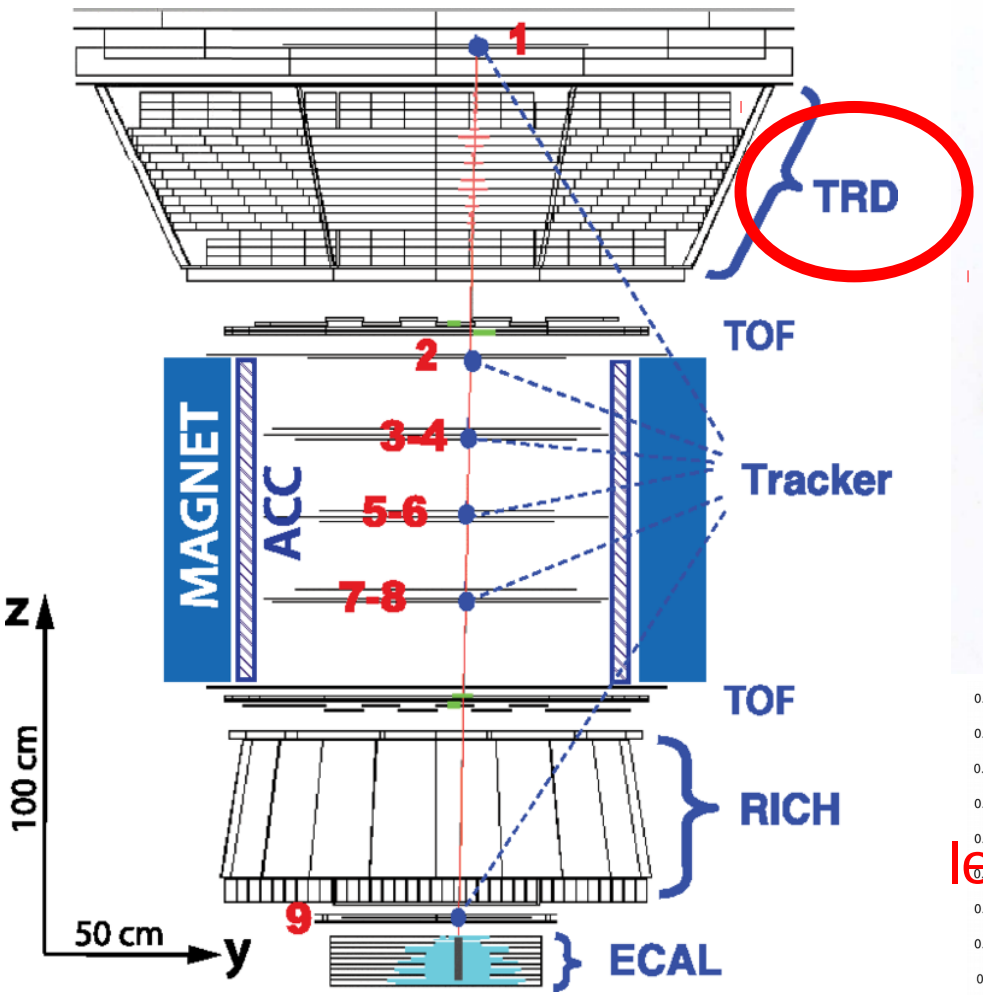
AMS-02 experiment

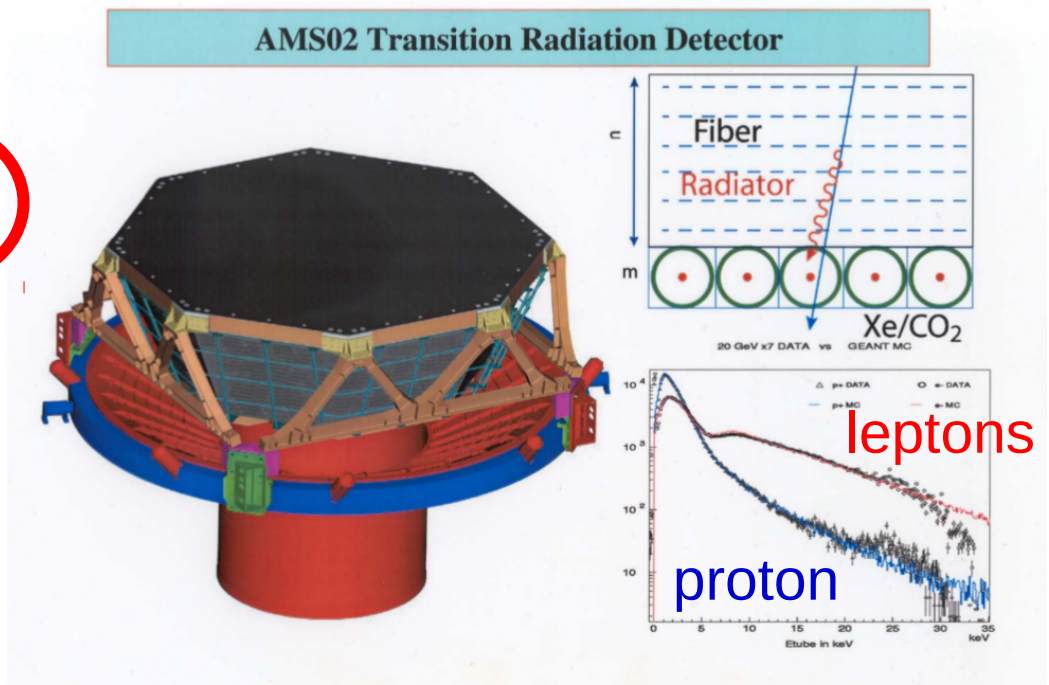


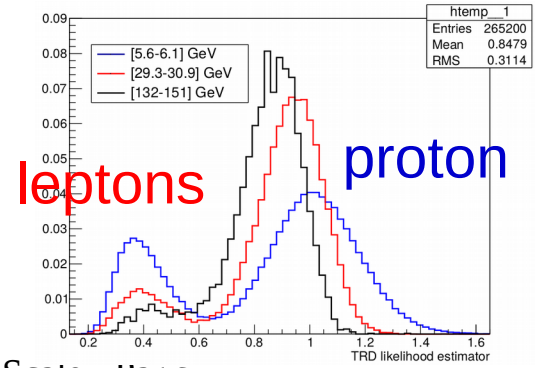
AMS-02 : particle detector in space

- Charged particles and gamma rays up to TeV
- Taking data since May 2011 (5 years of data available)
- Installed on International Space Station at an altitude of 400 km
- Operational up to 2024

Transition radiation detector

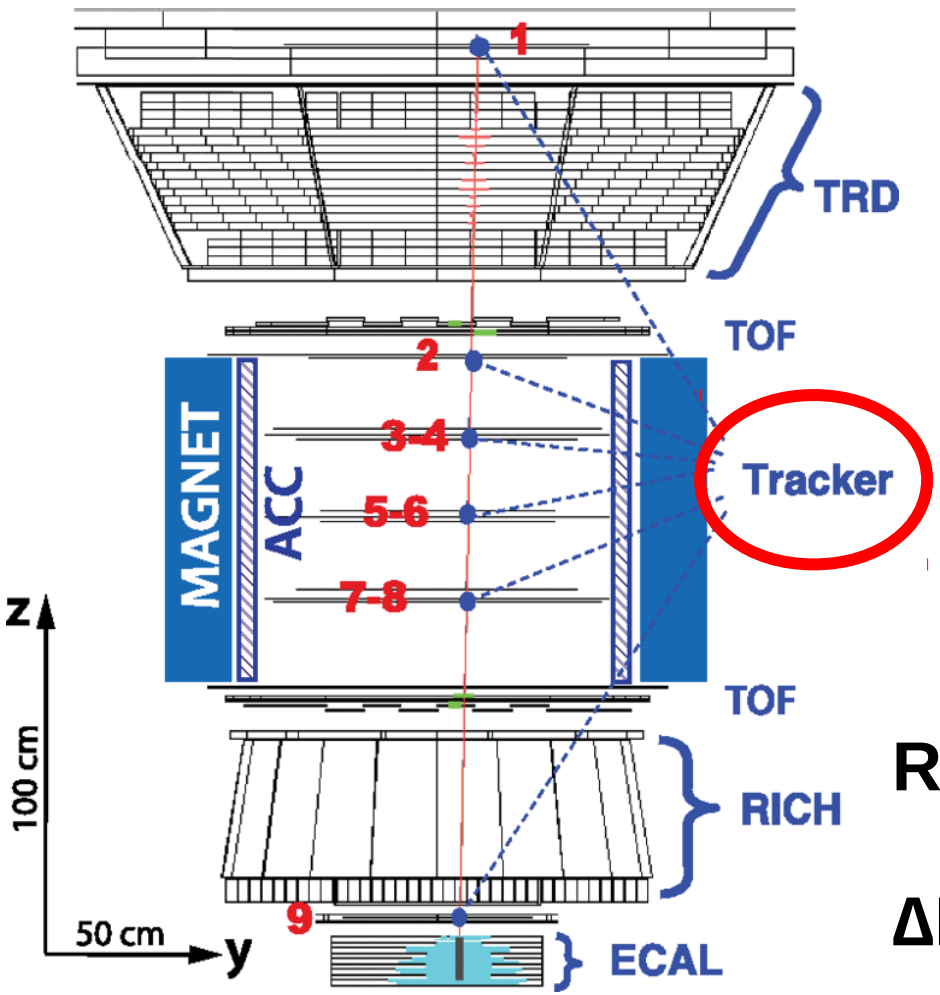


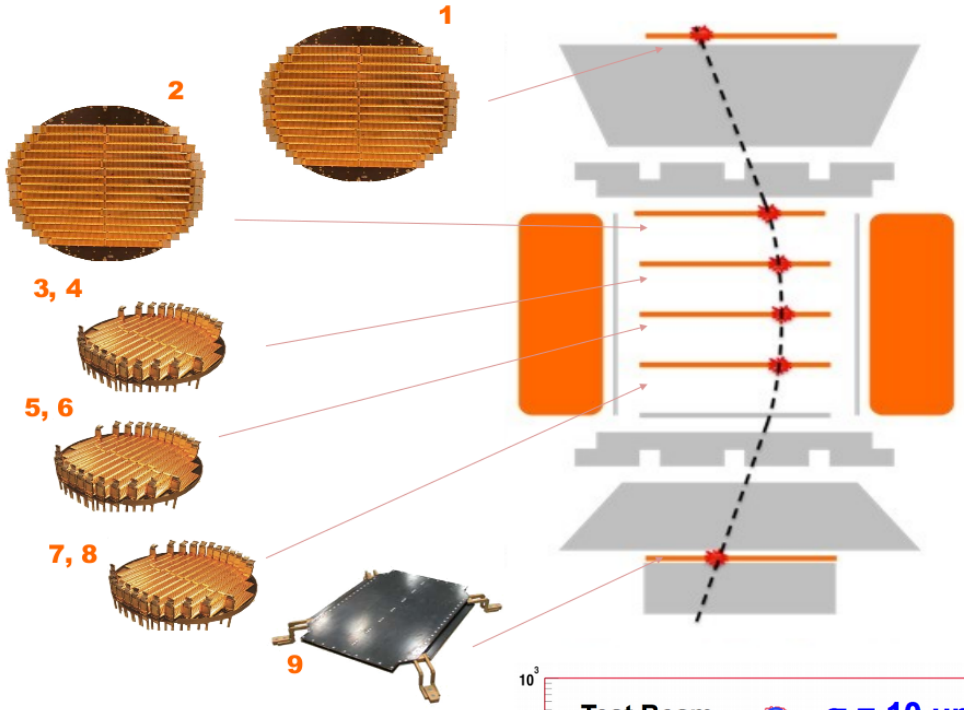




TRD estimator

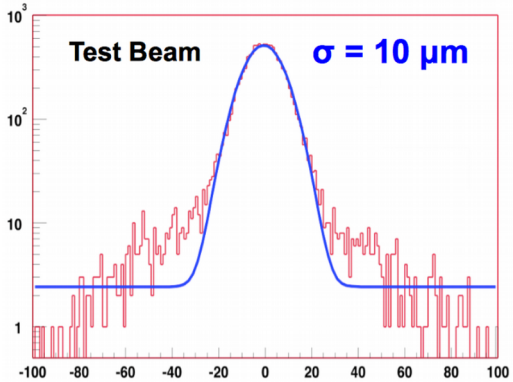
Spectrometer





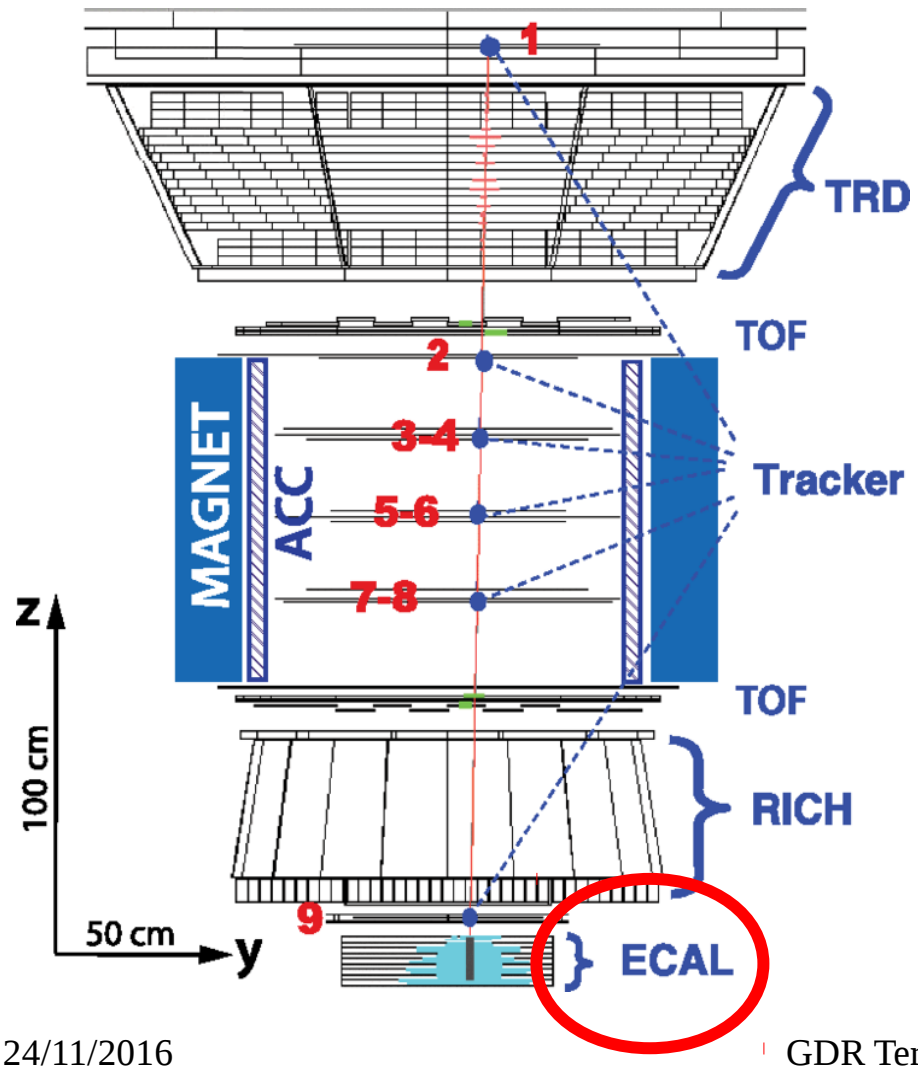
Rigidity (p/Z)

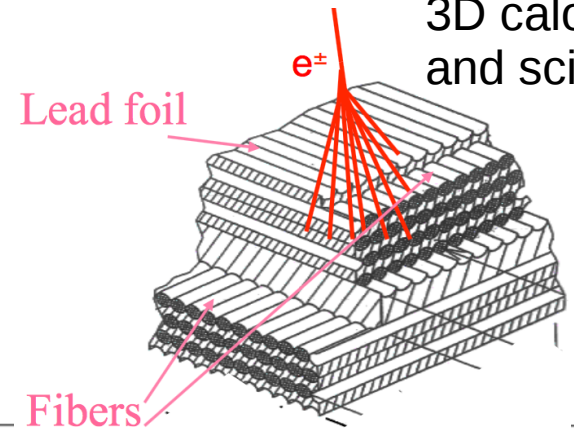
ΔR/R > 1 @ 2 TeV

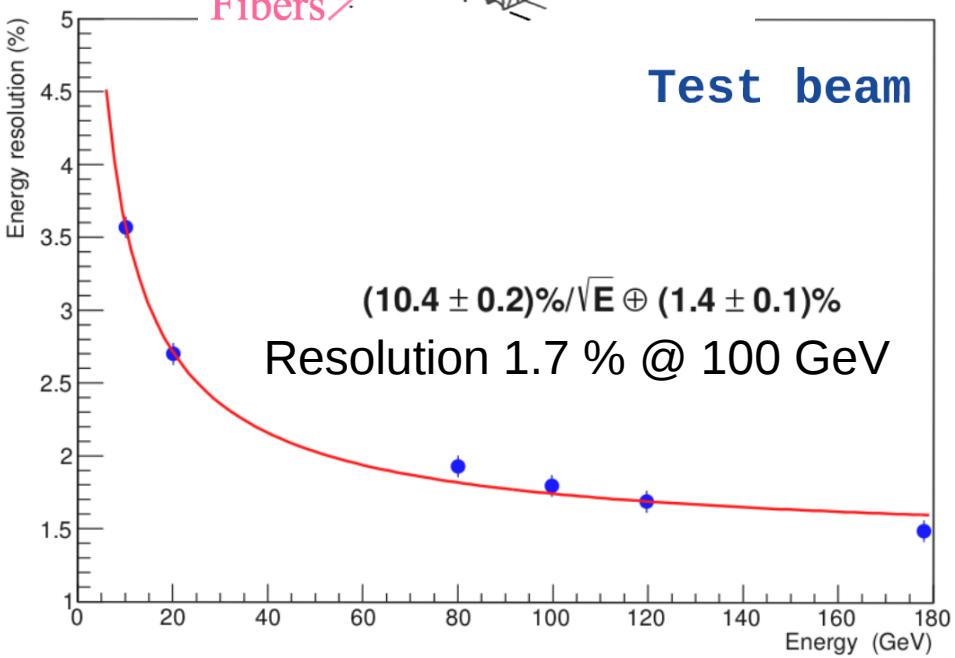


Electromagnetic calorimeter

3D calorimeter, lead and scintillating fibers

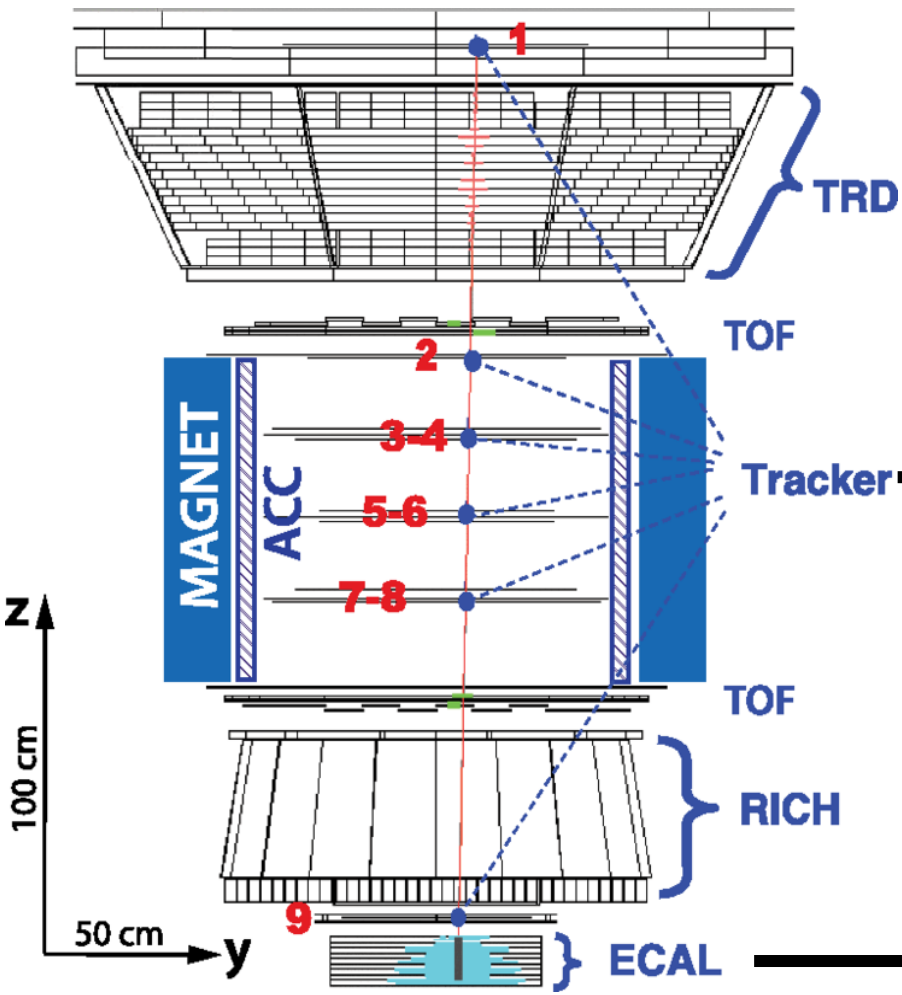


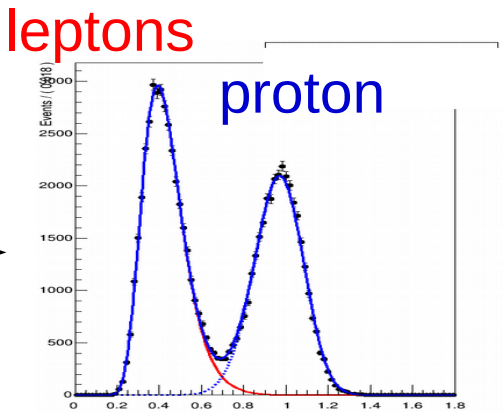


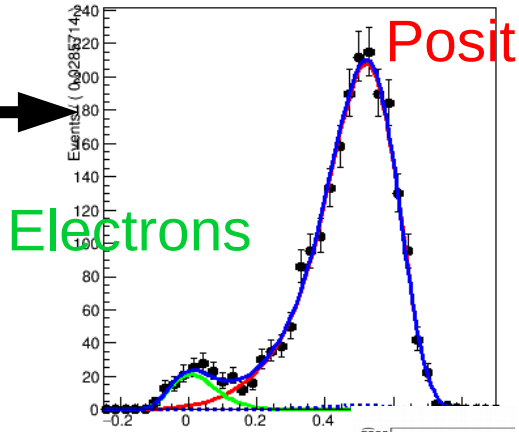


Resolution 1.7 % @ 100 GeV

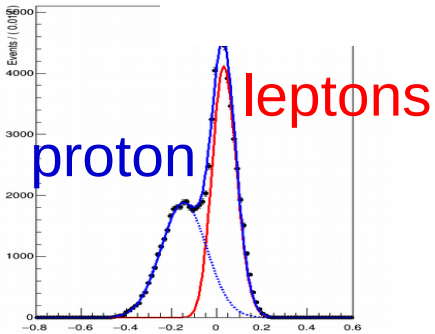
Analysis principle







- **TRD estimator**
- **Charge sign estimator**
- **Ecal estimator**

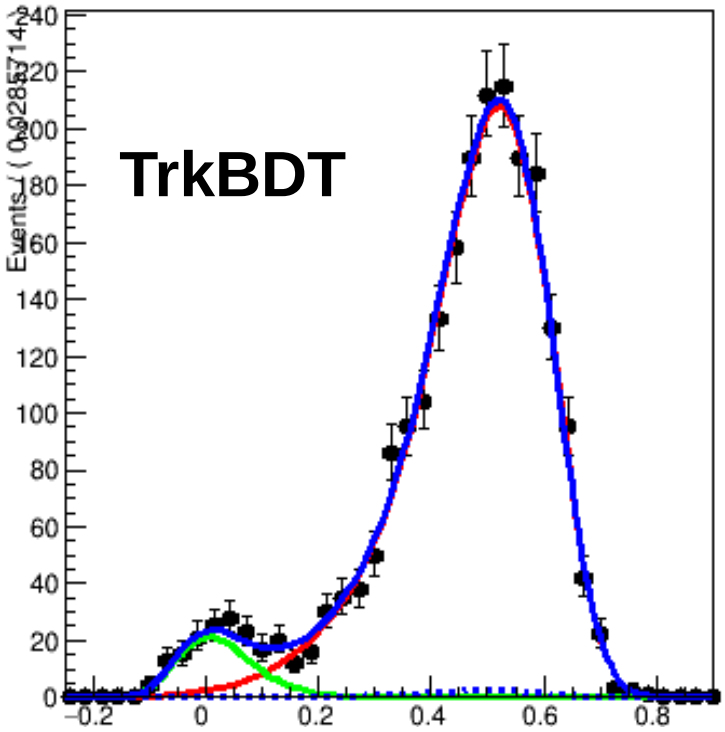


Charge confusion

Causes of charge confusion :

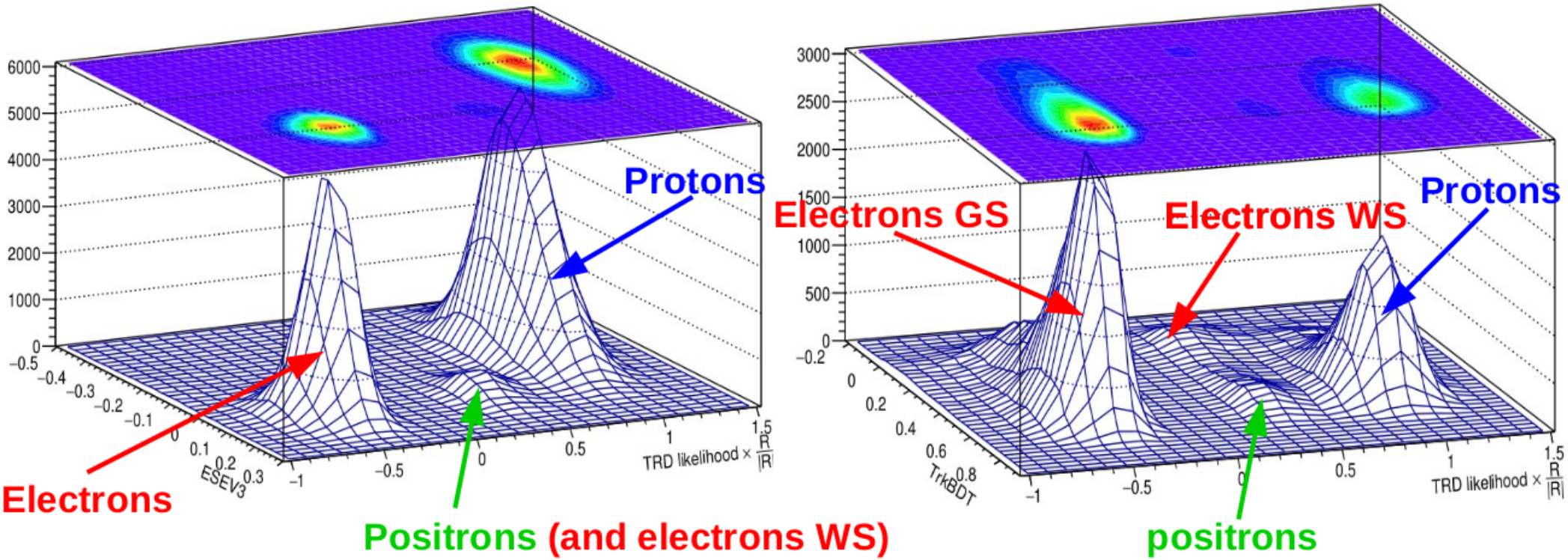
- Resolution of curvature measurement
- Multiple scattering
- Secondary production of particles in the detector material

~1 % @ 50 GeV
~10 % @ 400 GeV



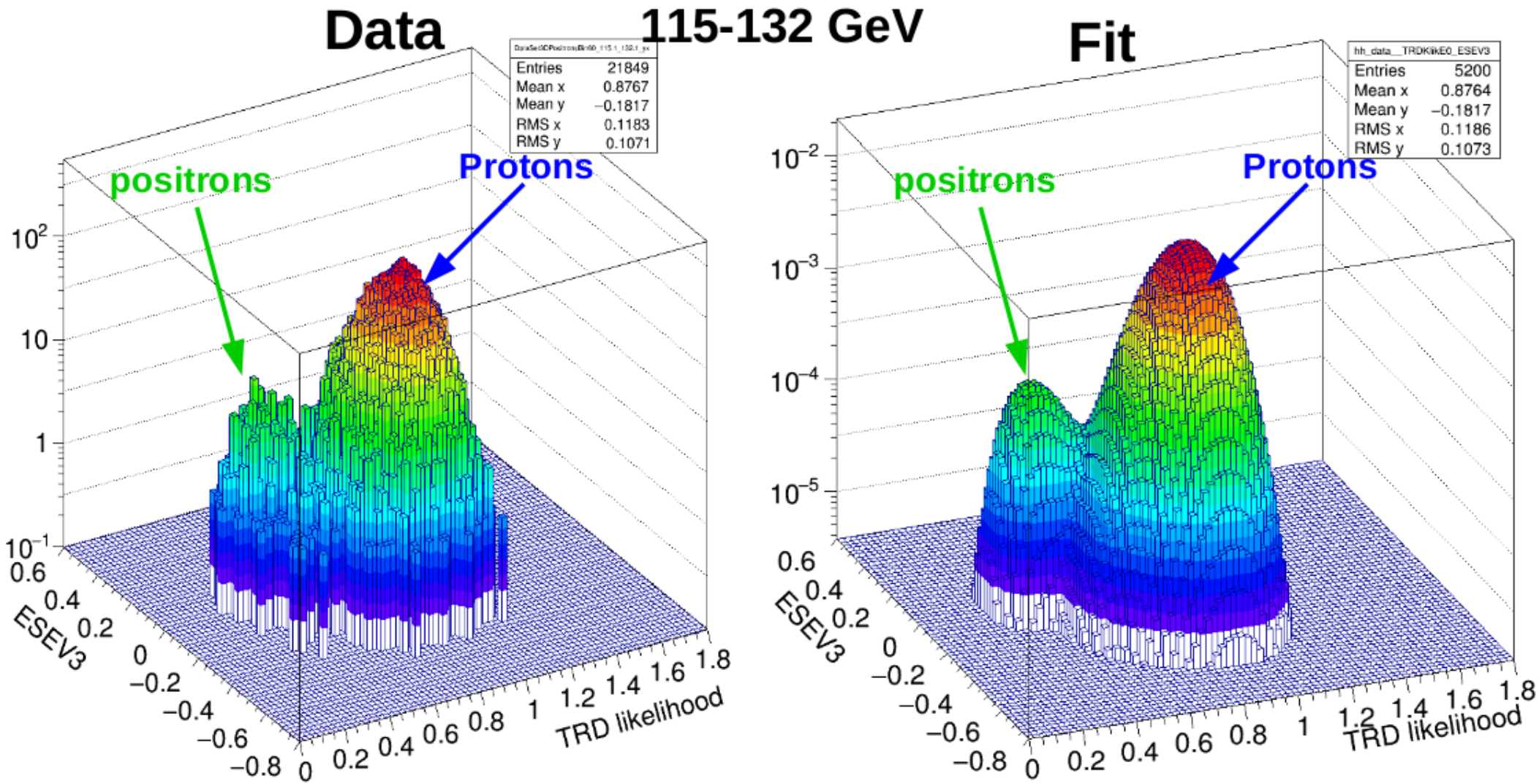
BDT estimator based on tracker variables developed in order to discriminate wrong sign and true sign events.

Multidimensional analysis

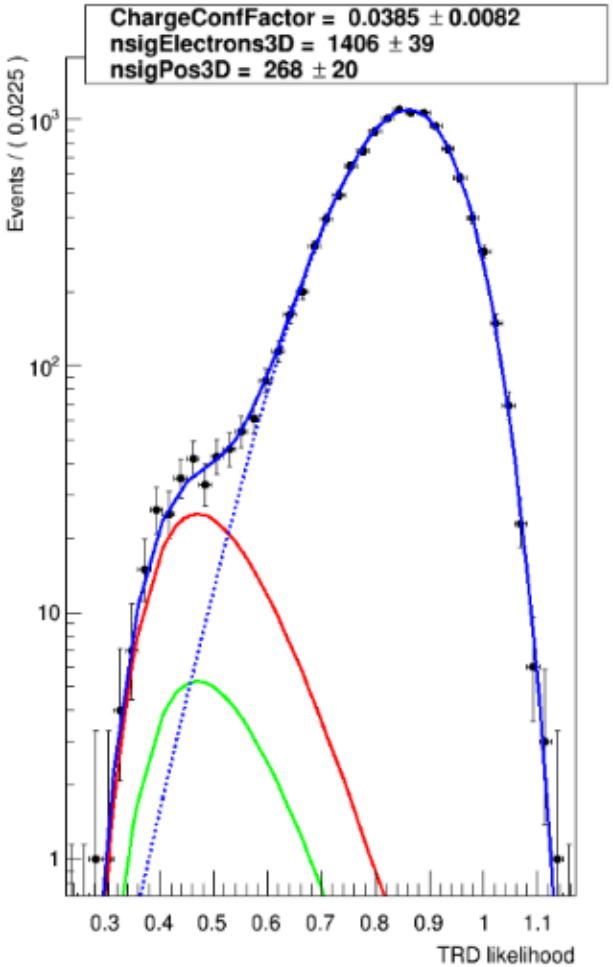


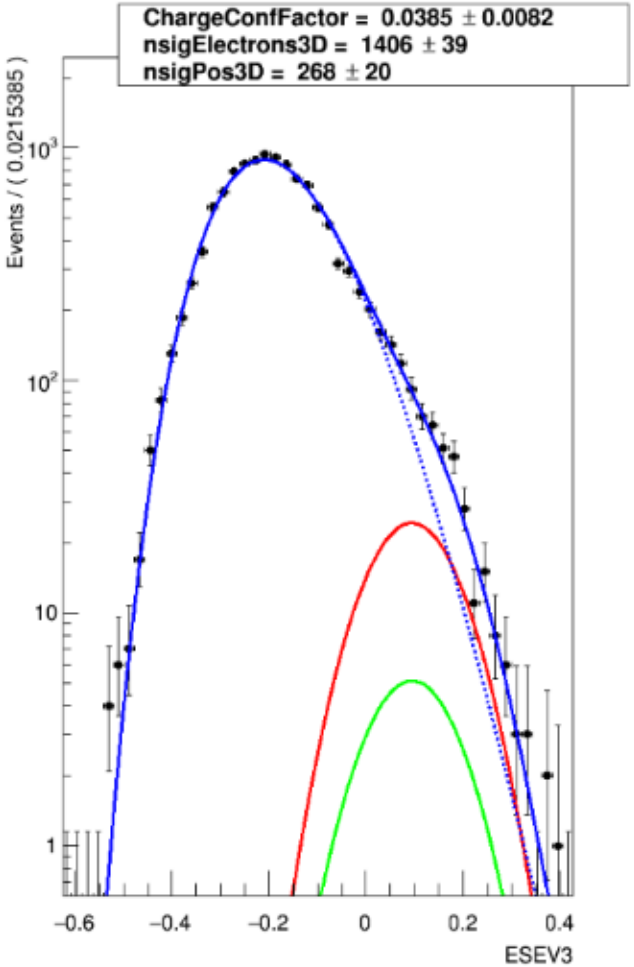
- The position of an event on the cube [TRD likelihood, ESEV3, TrkBDT] is sufficient to know if the event is an electron, a positron or a proton.
- To count the number of electrons and positrons, we construct the PDF of this species on this cube.

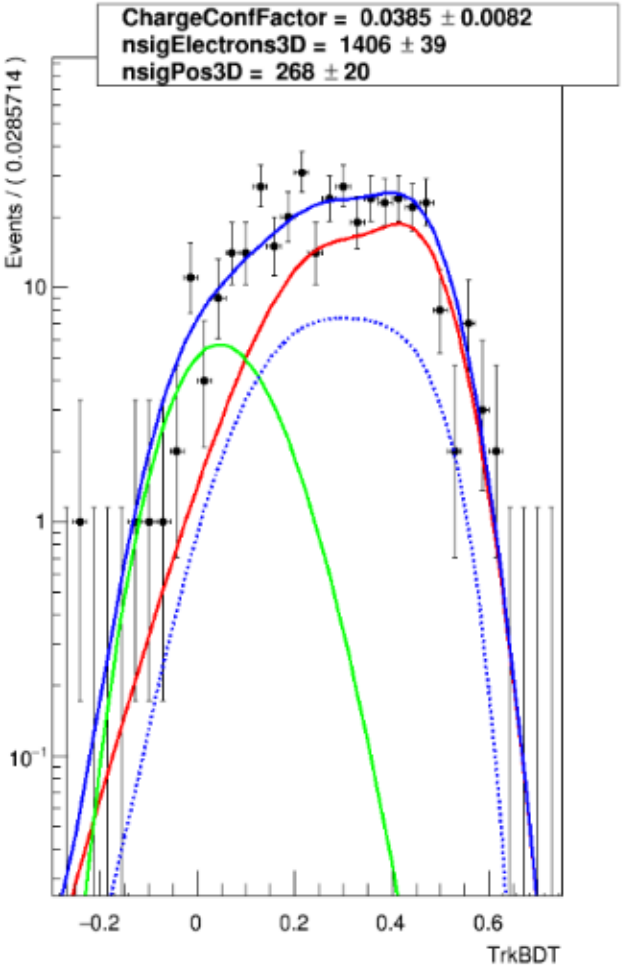
Example : 2D fit



3D fit method

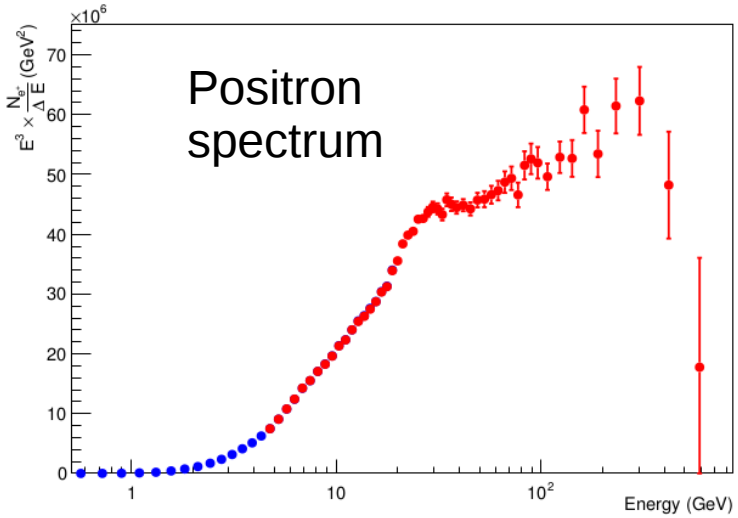




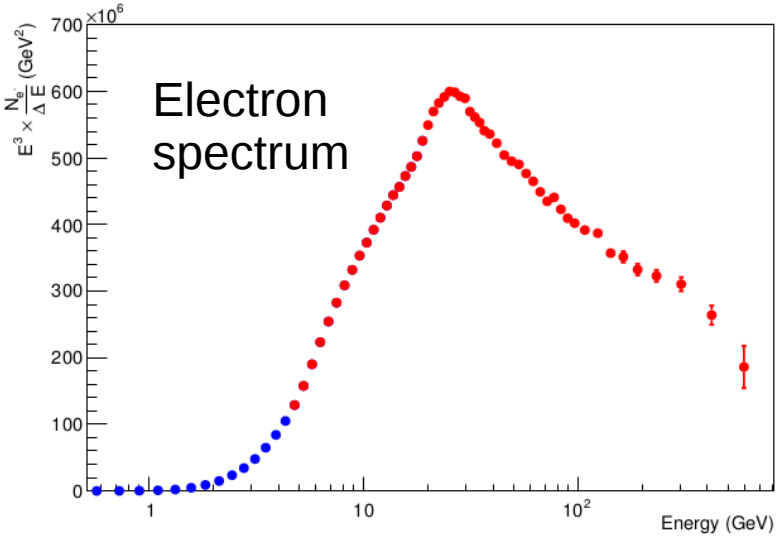


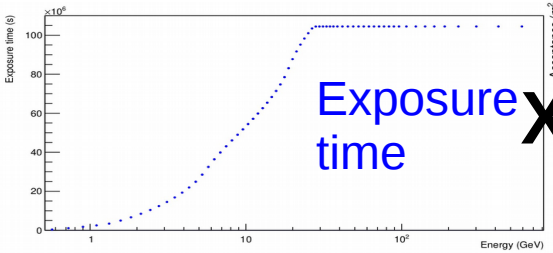
Positrons Electrons WS Protons

Flux measurement

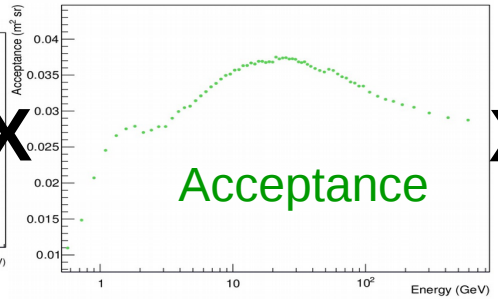


OR





X



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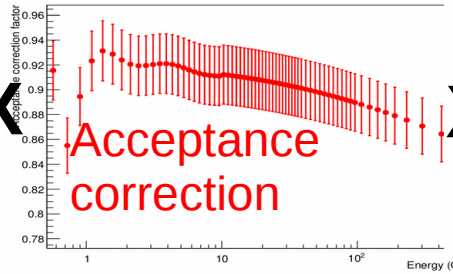

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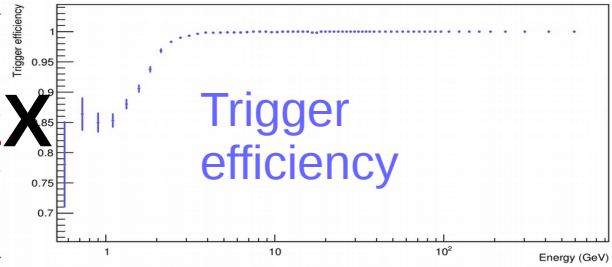
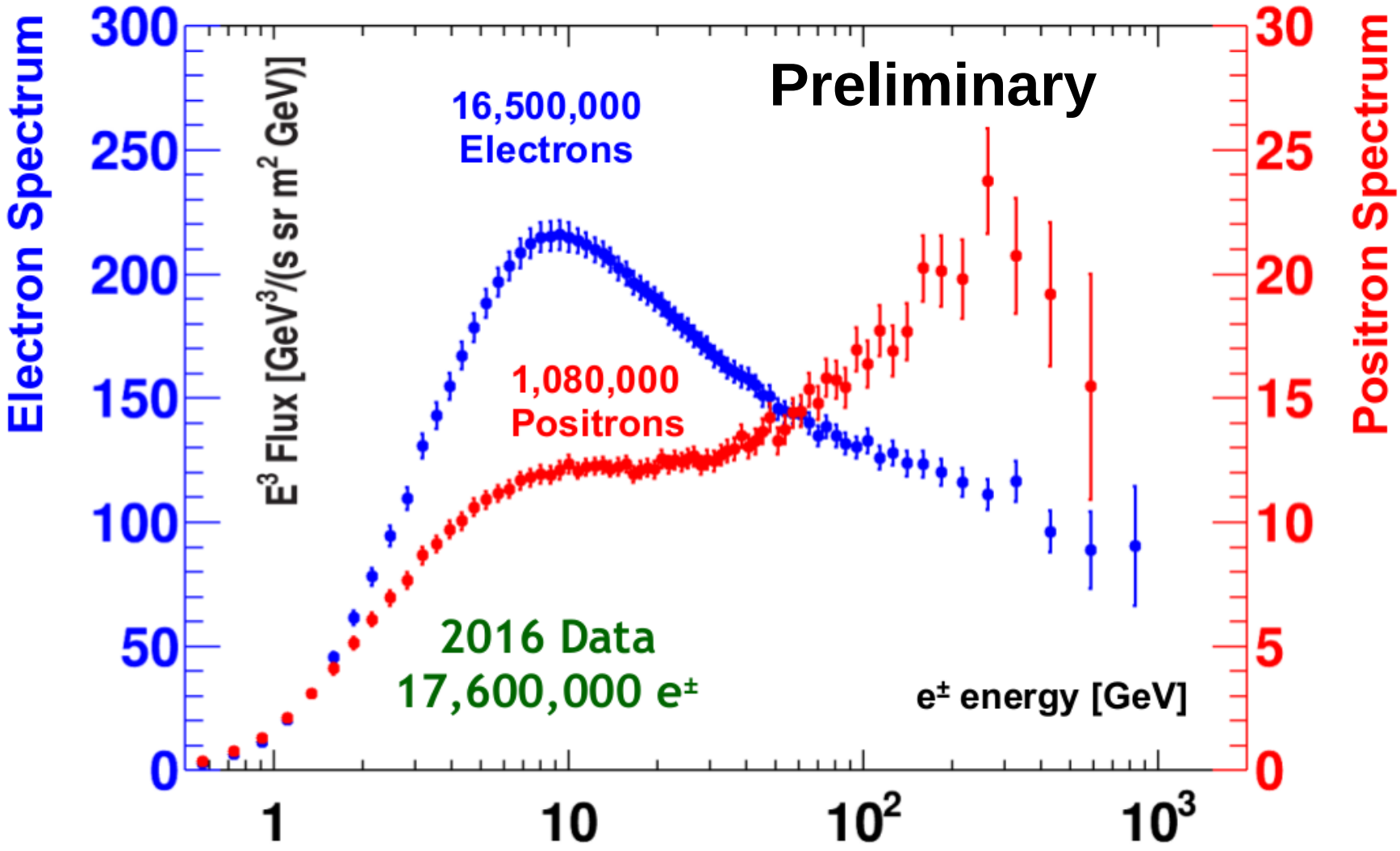
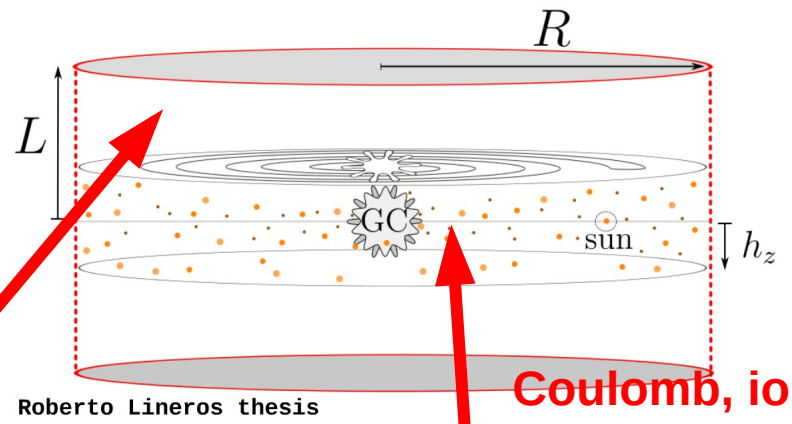


Positron and electron flux



Propagation modelisation



Convection (convective wind)

Synchrotron, inverse Compton

Energy losses

Coulomb, ionisation, bremsstrahlung, adiabatic

$$-K(E)\Delta\Psi + \frac{\partial}{\partial z}\left(\Psi V_c(z)\right) + \frac{\partial}{\partial E}\left(b_{halo}(E)\Psi\right) + 2h\delta(z)\frac{\partial}{\partial E}\left(b_{disk}(E)\Psi - C(E)\frac{\partial\Psi}{\partial E}\right) = q(E,\vec{x}),$$

Reacceleration

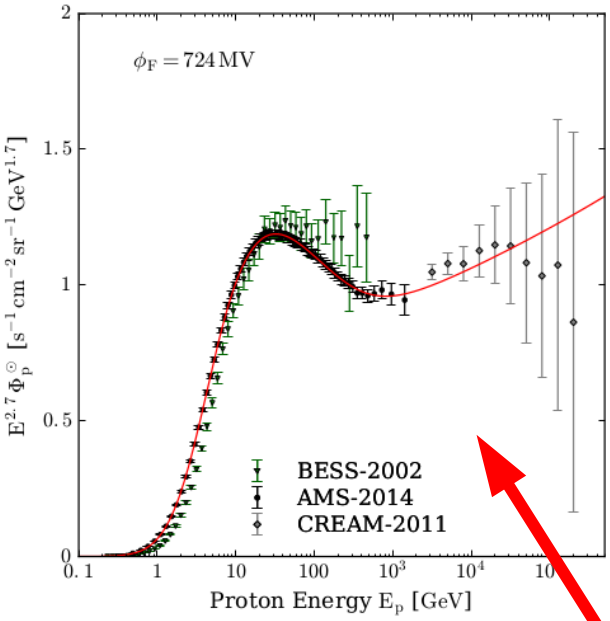
Diffusion (turbulent galactic magnetic field)

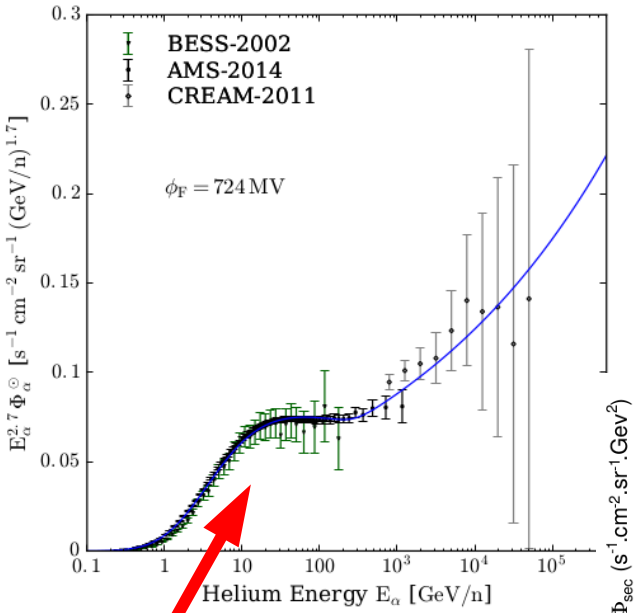
Maurin et al. 2001

Modèle	δ	K_0 (kpc^2.Myr^{-1})	L (kpc)	V_c (km.s^{-1})	V_a (km.s^{-1})
min	0.85	0.0016	1	13.5	22.4
med	0.70	0.0112	4	12	52.9
max	0.46	0.0765	15	5	117.6

This equation can be solved with a semi-analytical method (cf Mathieu Boudaud thesis)

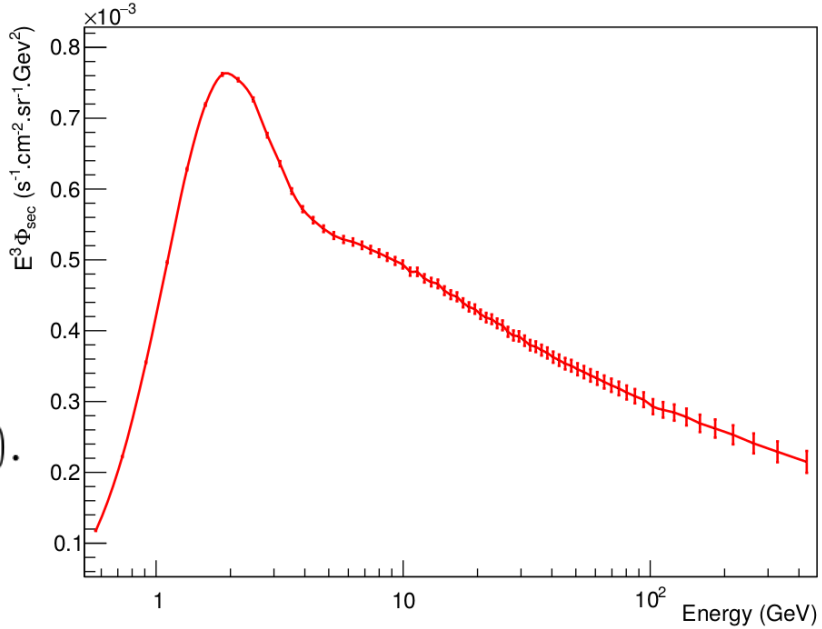
Secondary production



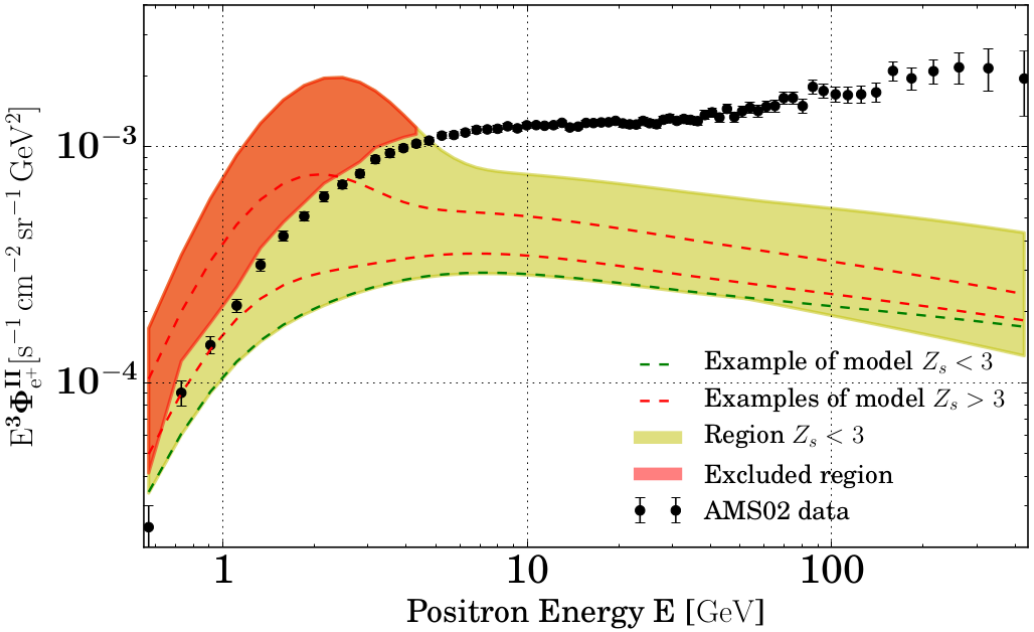


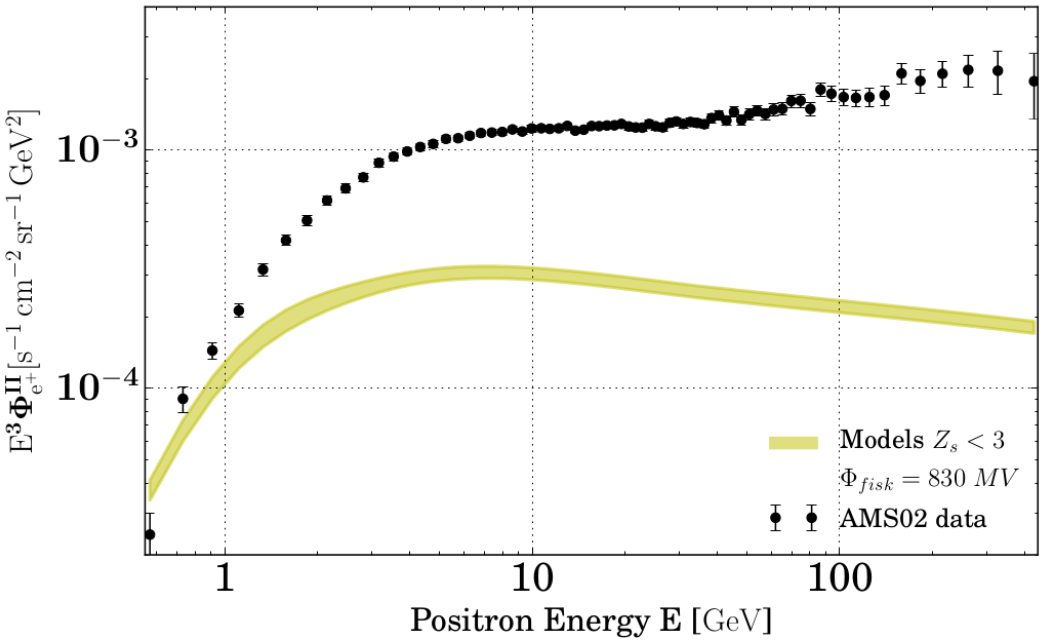
$$q(\vec{x},E) = 4\pi \sum_{i=H,He} \sum_{j=H,He} n_i \int \phi_j(\vec{x},E_j)\,dE_j \frac{d\sigma_{ji}}{dE}(E_j \to E).$$

Secondary positron flux at Earth



Constrain propagation parameters



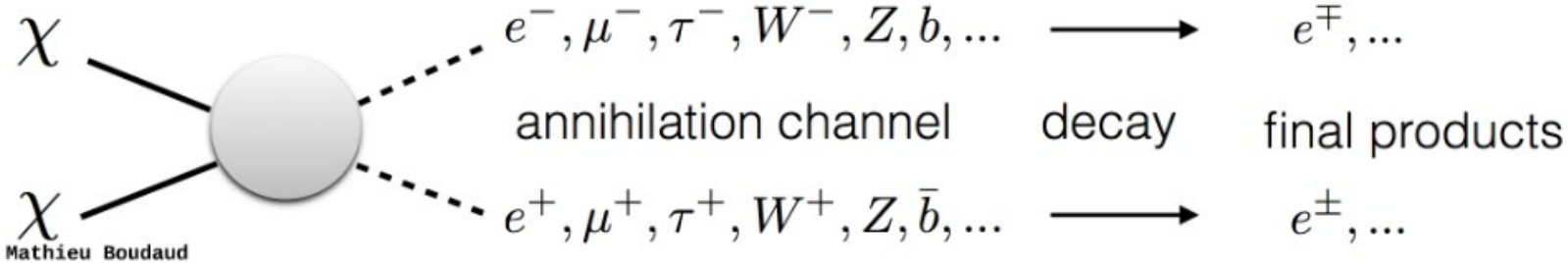


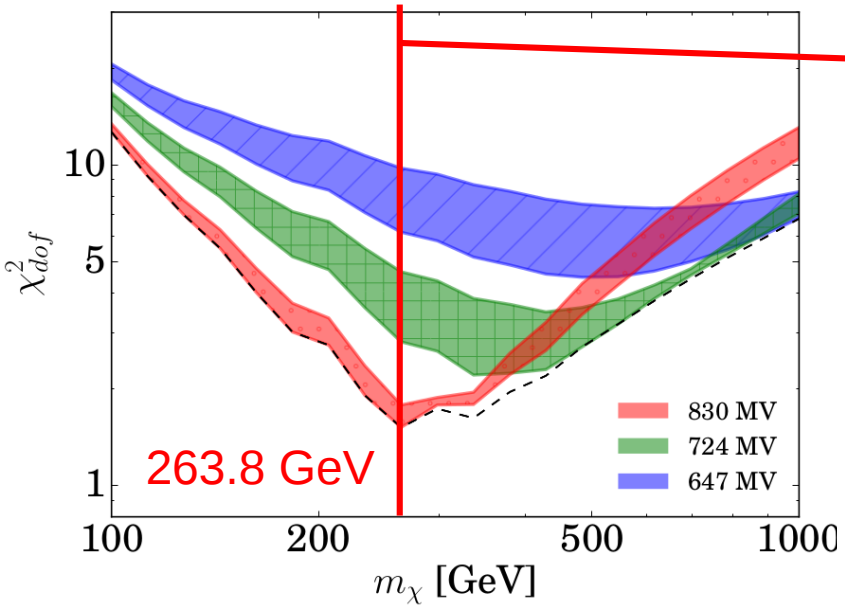
The computed secondary positron flux at low energy is more important than what is observed by AMS-02 for some propagation models → this model are excluded by data

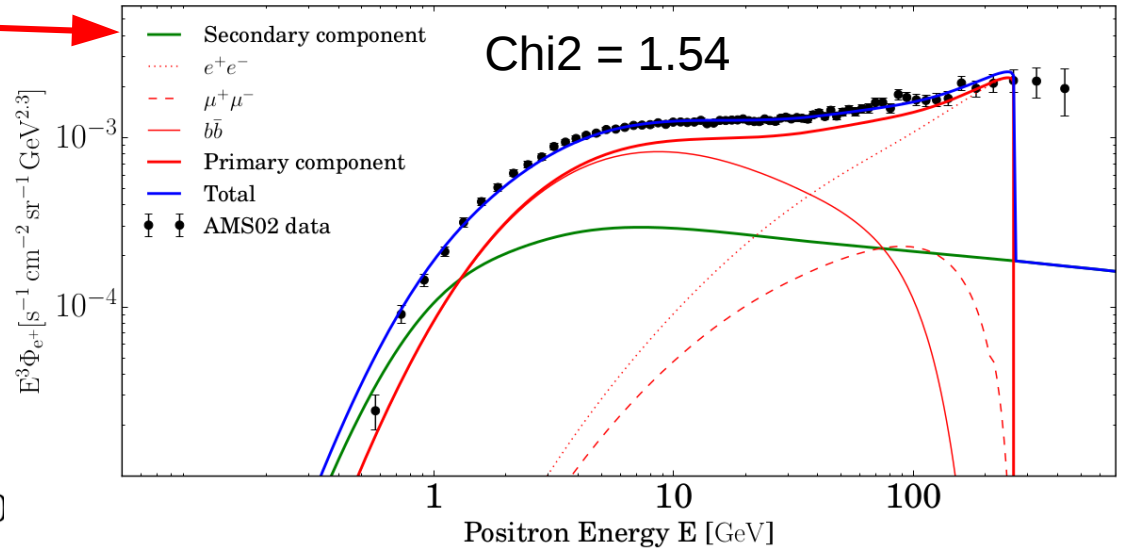
Min and med excluded !

Modèle	δ	K_0 ($kpc^2.Myr^{-1}$)	L (kpc)	V_c ($km.s^{-1}$)	V_a ($km.s^{-1}$)
min	0.85	0.0016	1	13.5	22.4
med	0.70	0.0112	4	12	52.9
max	0.46	0.0765	15	5	117.6

Dark matter interpretation

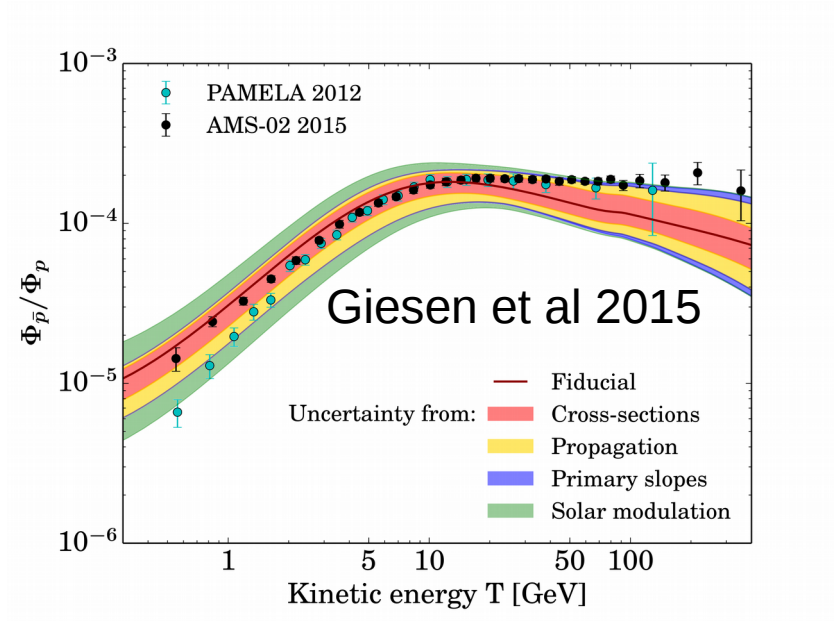




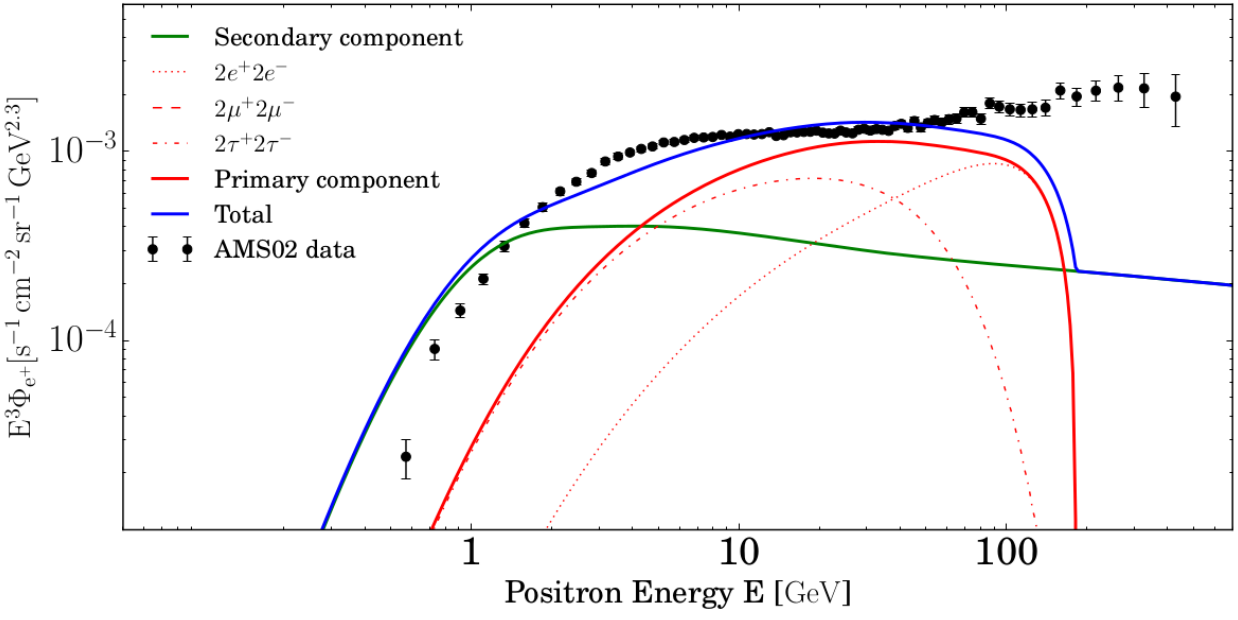


Leptophilic dark matter interpretation

Why is it interesting ?



Best fit



Leptonic production via a light scalar mediator

Conclusions

- We show measurements of AMS-02 up to 700 GeV for the positron flux and 1 TeV for the electron flux with an extended dataset of 5 years
- dark matter only failed to explain the positronic excess on the entire energy range of the measurement of AMS-02
- Astrophysical sources such pulsar can explain the positron excess (cf for example “A new look at the cosmic ray positron fraction.” Astronomy & Astrophysics, 575 :A67, feb 2015)