THE MODULATION OF POSITIVELY AND NEGATIVELY CHARGED PARTICLES AT 1 GV RIGIDITY DURING 23-24 SOLAR CYCLES

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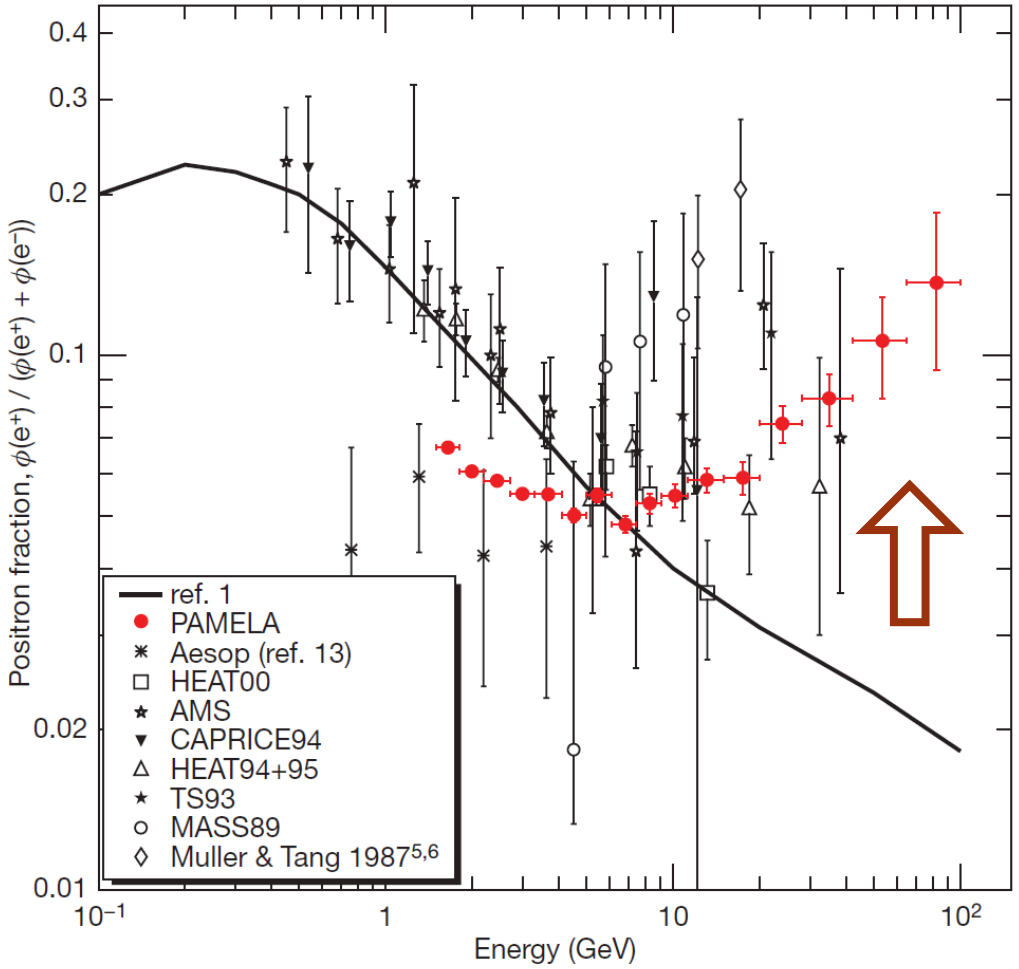
NRNU MEPhI + the PAMELA collaboration

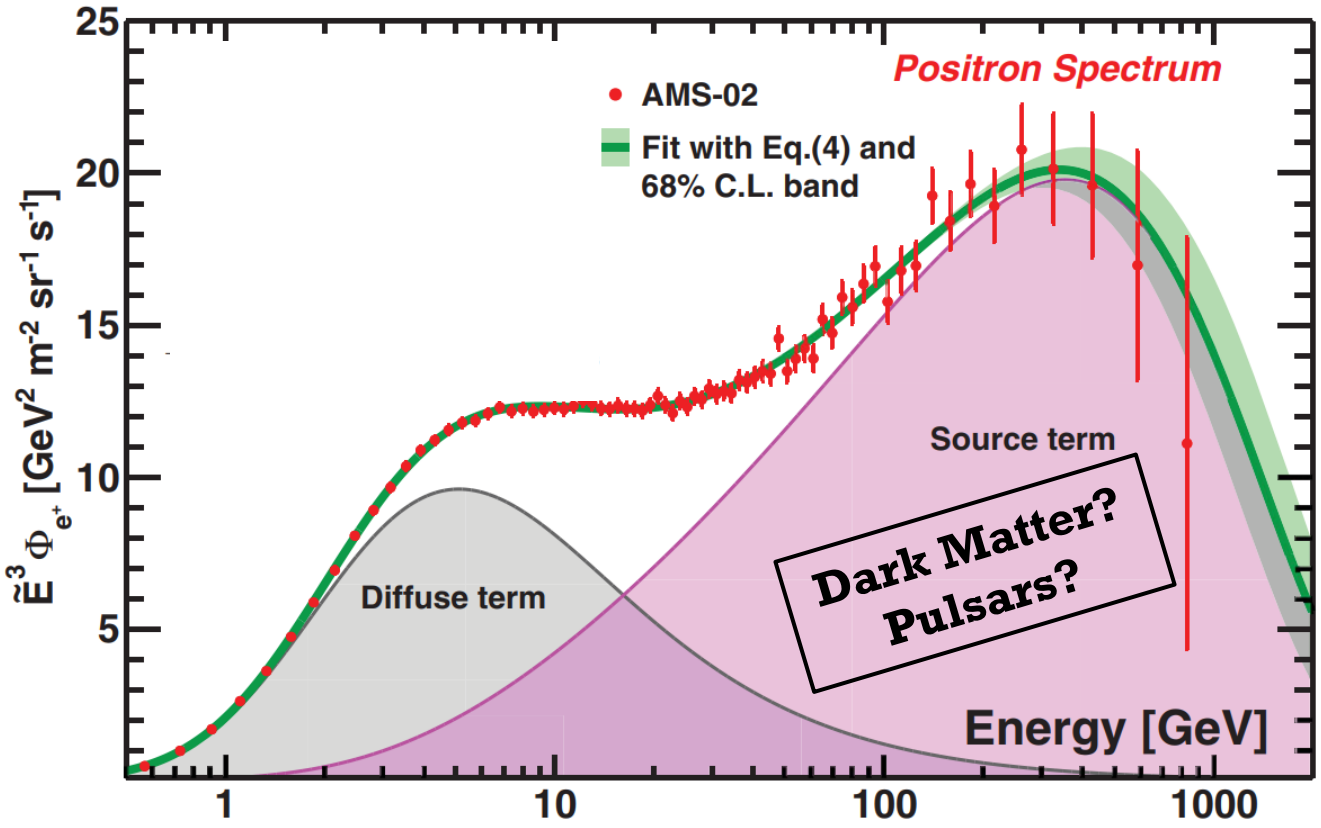
ICPPA 2022

ELECTRONS & POSITRONS: HIGH ENERGIES

Positron fraction



Nature 458, 607–609 (2009)



Phys. Rev. Lett. 122, 041102 (2019)

POTENTIAL SOURCES

- Supernovae → Secondary production in interstellar medium

Phys. Rev. Lett. 122, 041102 (2019)

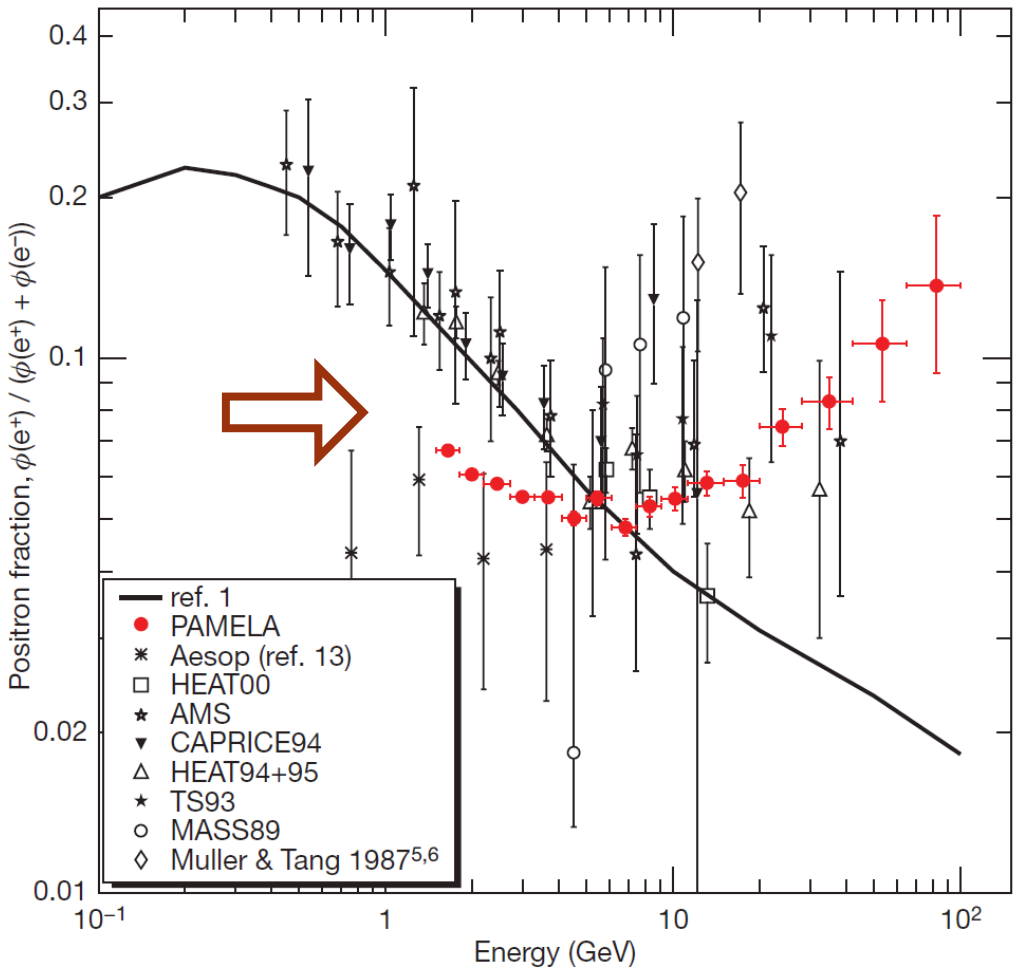
- **Dark Matter**
  - Primordial Black Holes

Phys. Rev. Lett. 119, 021103 (2017)
Phys. Rev. Lett. 122, 041102 (2019)

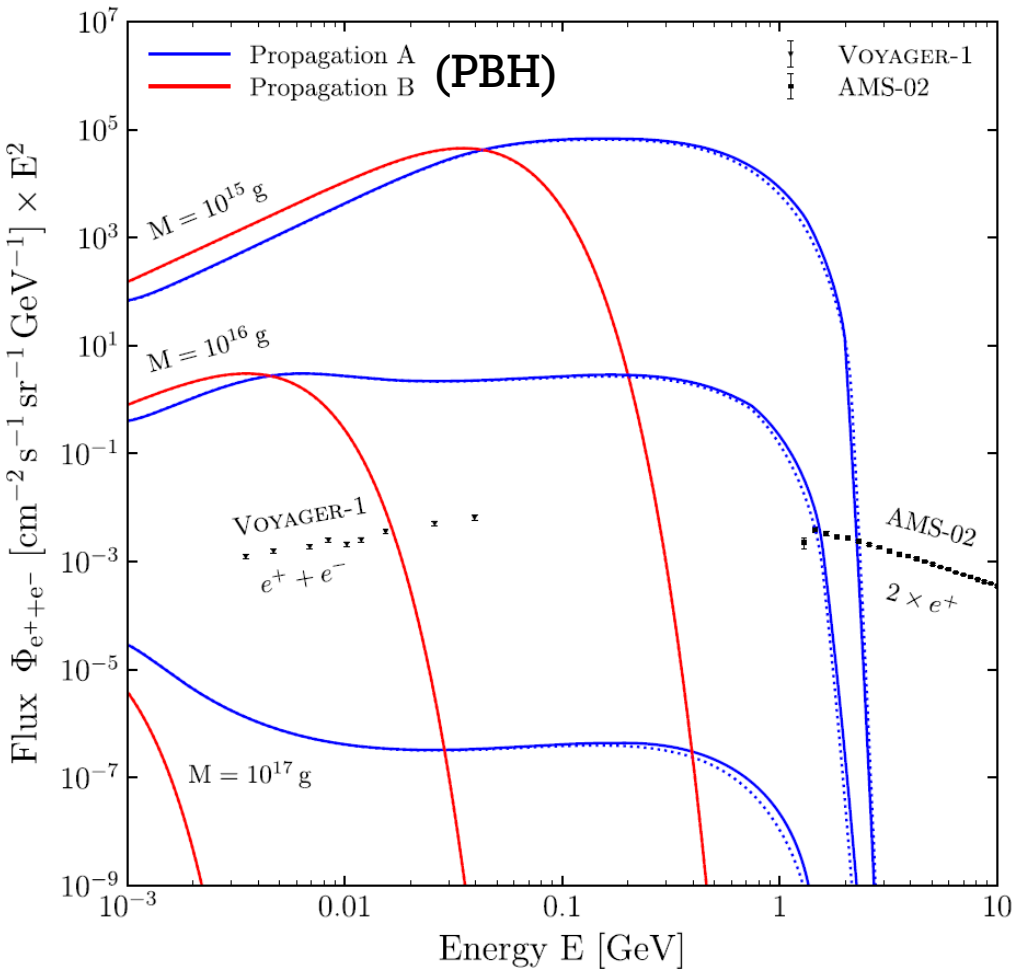
Phys. Rev. Lett. 122, 041104 (2019)
Nature Astr. 3, 485–486 (2019)
a.k.a. «The light side of dark matter»

…

ELECTRONS & POSITRONS: LOW ENERGIES

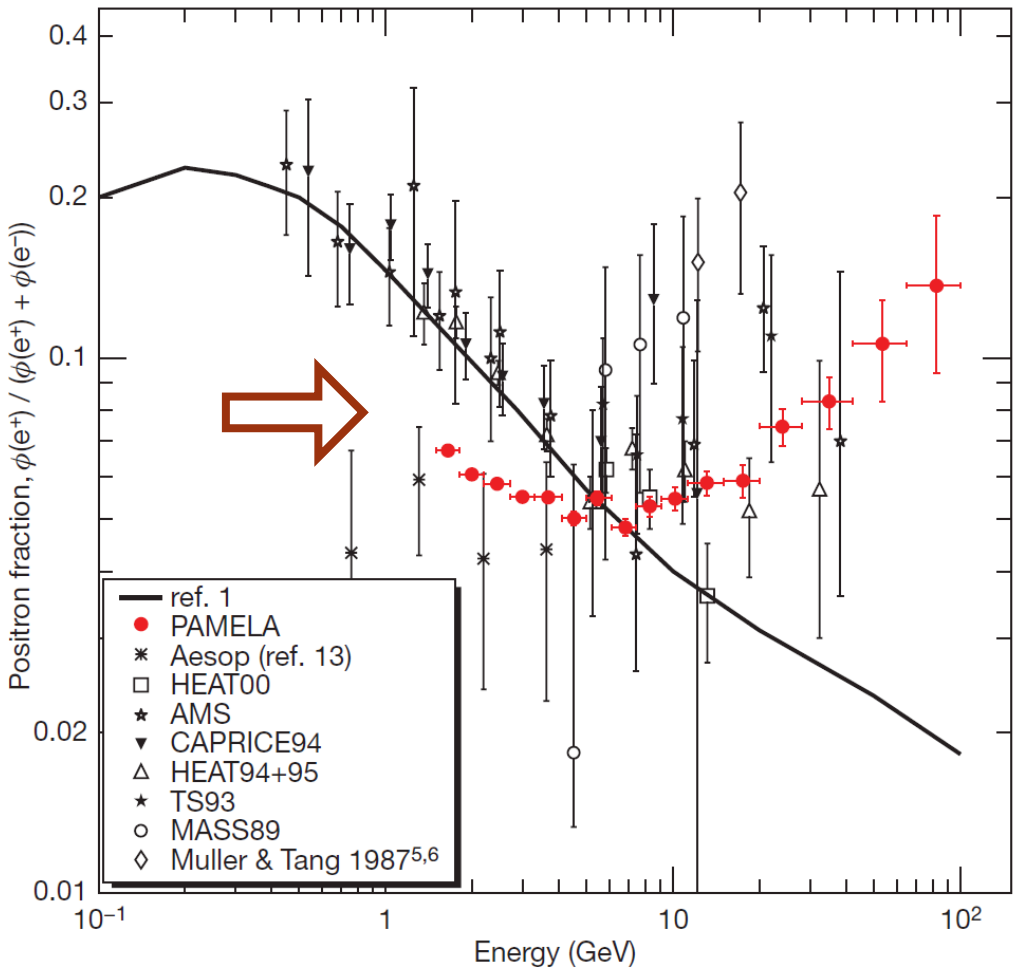


Nature 458, 607–609 (2009)

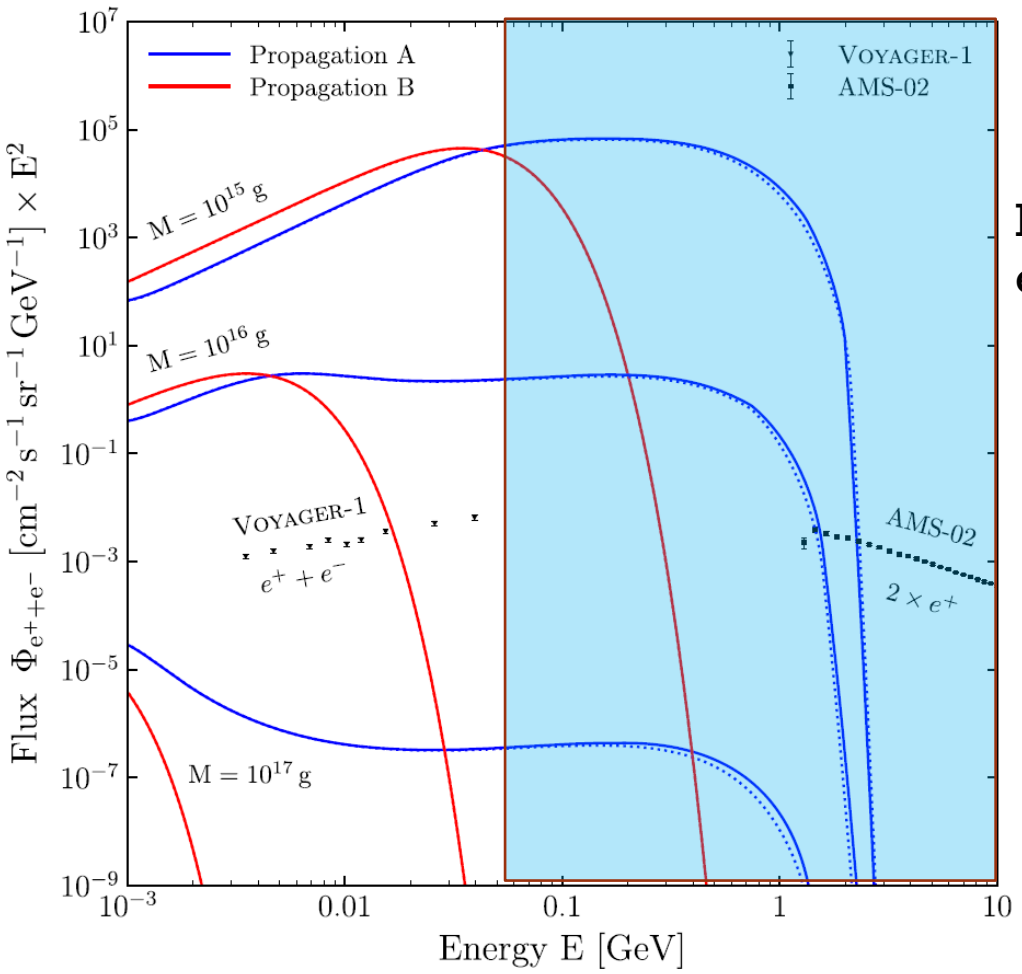


Phys. Rev. Lett. 122, 041104 (2019)

ELECTRONS & POSITRONS: LOW ENERGIES



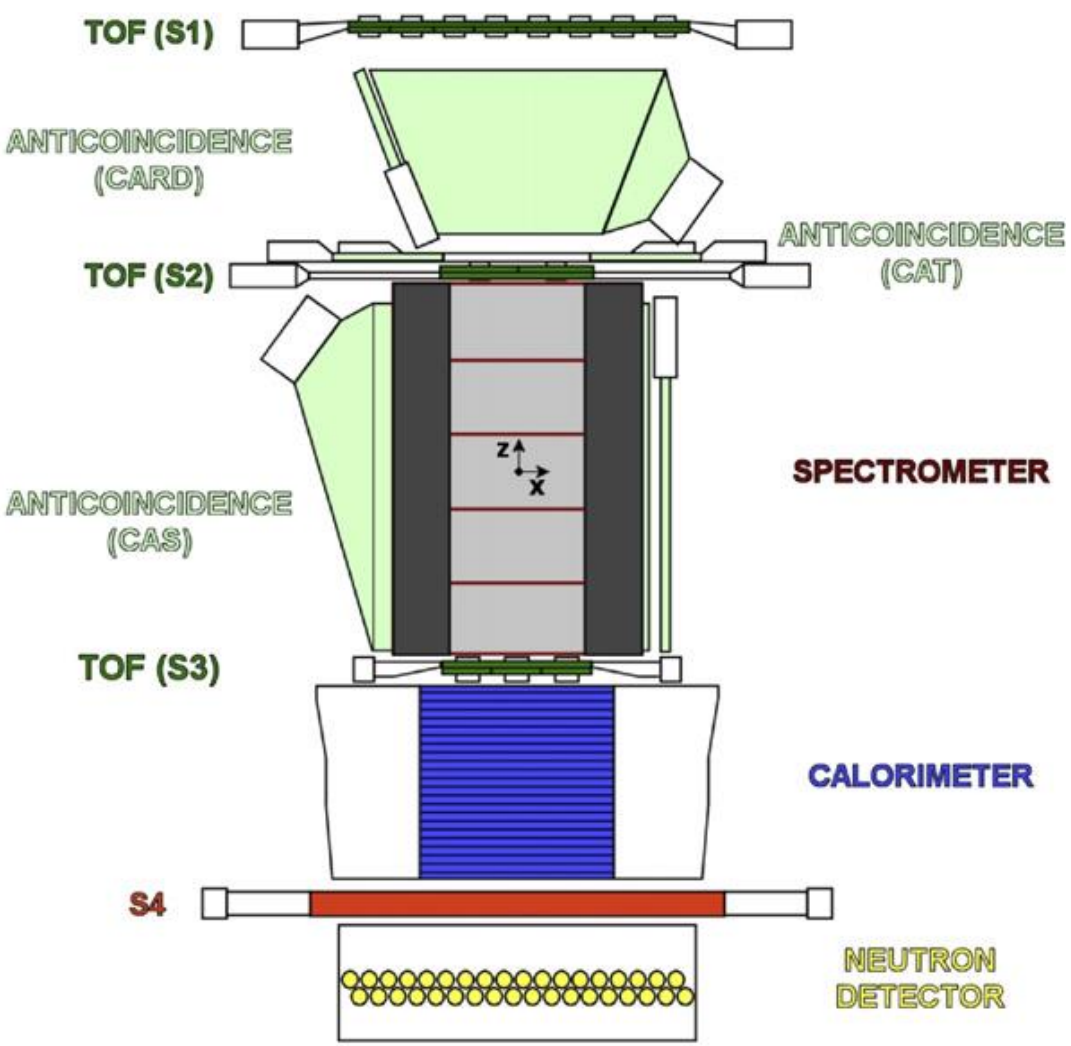
Nature 458, 607–609 (2009)



PAMELA energy range

Phys. Rev. Lett. 122, 041104 (2019)

PAMELA



- Detects:
  - **e^-, e^+:** **50 MeV** – hundreds of GeVs
  - p: 80 MeV – TeVs
  - Nuclei (He, etc.): ...
- The satellite orbit:
  - 350-600 km
  - Inclination 70°
- Work Time: 2006 – 2016
  (Solar cycle 23 – cycle 24)

COSMIC-RAY PROPAGATION IN HELIOSPHERE

intensity

solar modulation

of low energy particles

sources

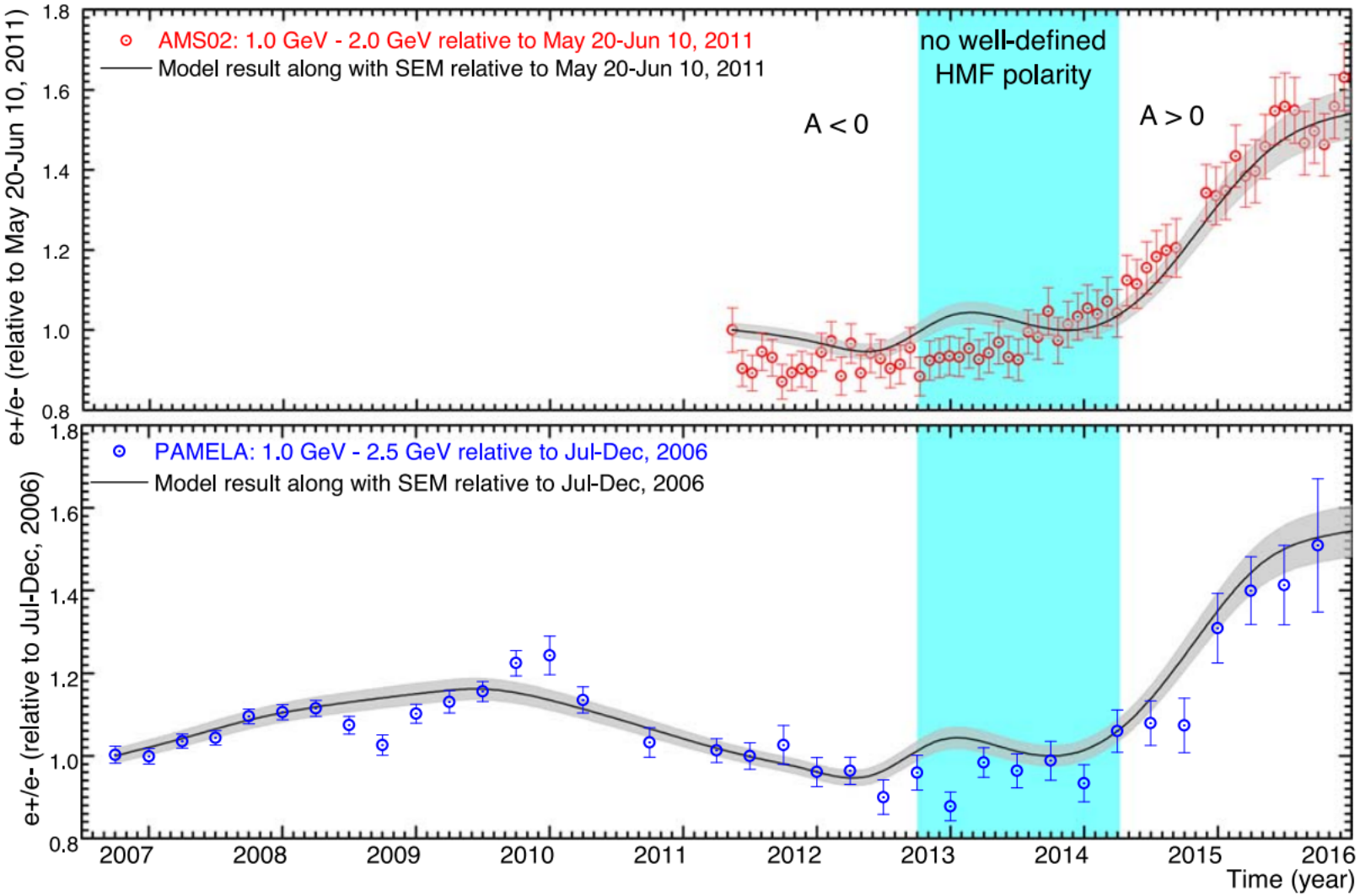
$$\frac{\partial f}{\partial t} = -\vec{V}_{\mathrm{sw}} \cdot \nabla f - \langle \vec{v}_{\mathrm{d}} \rangle \cdot \nabla f + \nabla \cdot (\mathbf{K}_{\mathrm{s}} \cdot \nabla f) + \frac{1}{3} \left(\nabla \cdot \vec{V}_{\mathrm{sw}} \right) \frac{\partial f}{\partial \ln P} + Q$$

solar wind | particle drift | diffusion | adiabatic solar wind expansion

~ causes charge-sign dependence of modulation

Parker, 1965; Potgieter et al., 2017 +

FLUX RATIO > 1 GEV

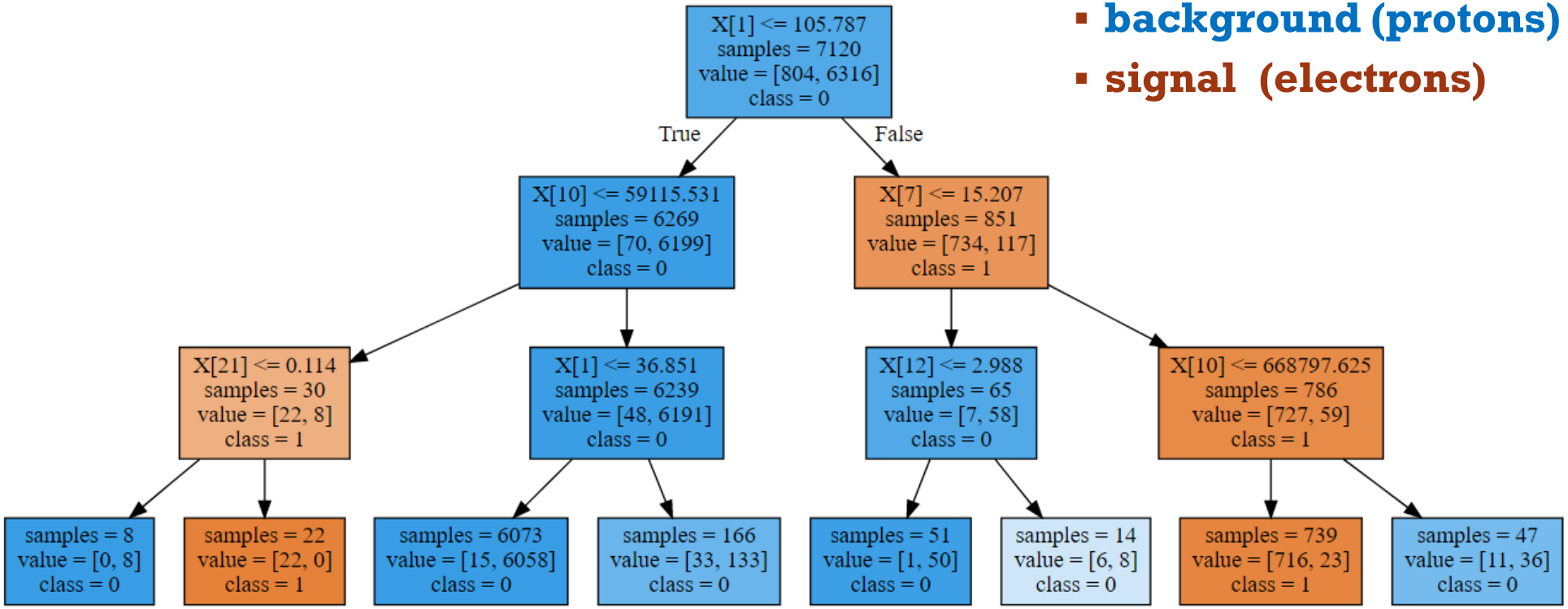


- ApJ 909:215 (2021)
- to provide new data for lower energies **(< 1 GeV)** to observe features

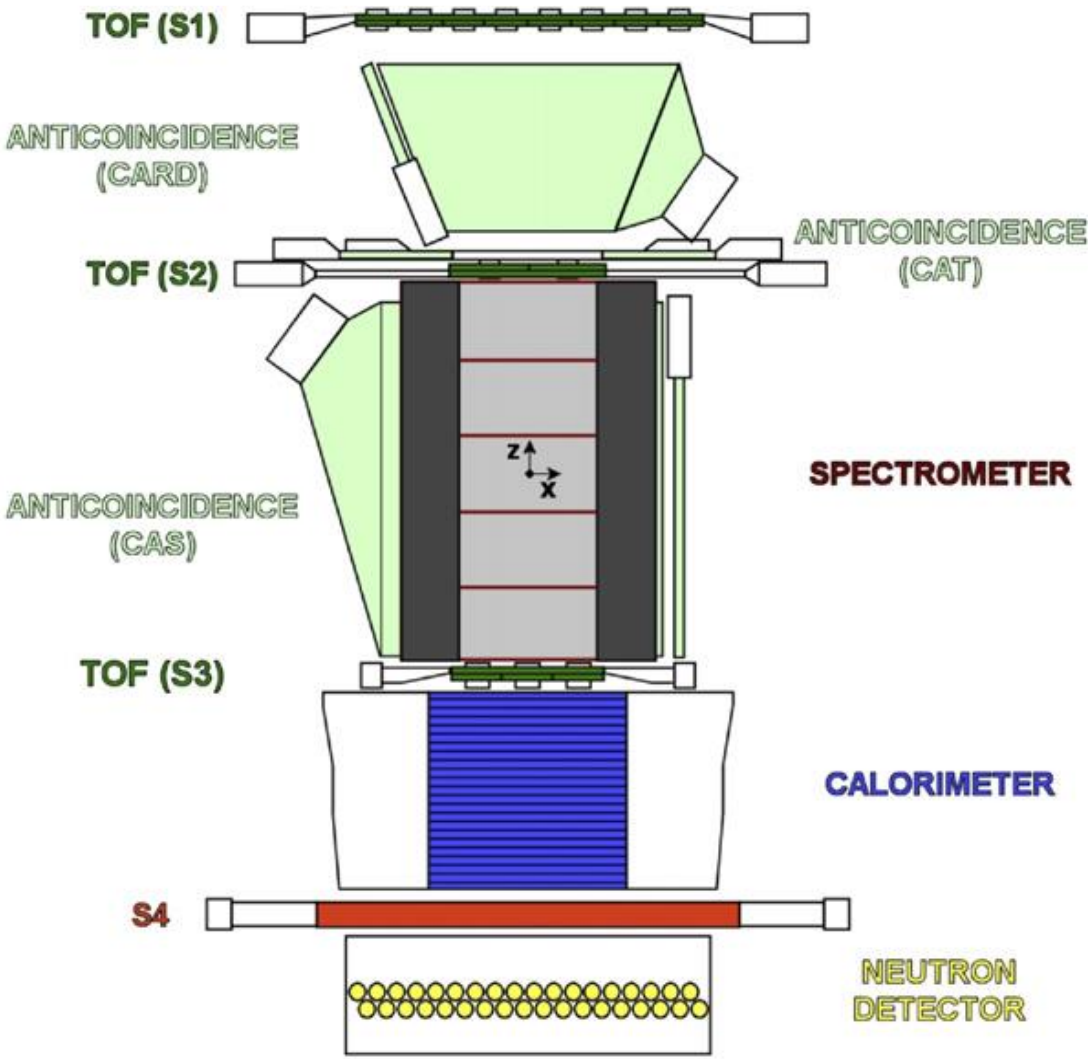
MULTIVARIATE ANALYSIS: DECISION TREE

Method: Boosted Decision Tree (BDT) — to divide events into 2 classes

- **background (protons)**
- **signal (electrons)**



MULTIVARIATE ANALYSIS: EVENT SELECTION



20+ relevant parameters to be analyzed

→ anticoincidence

→ velocity, dE/dx

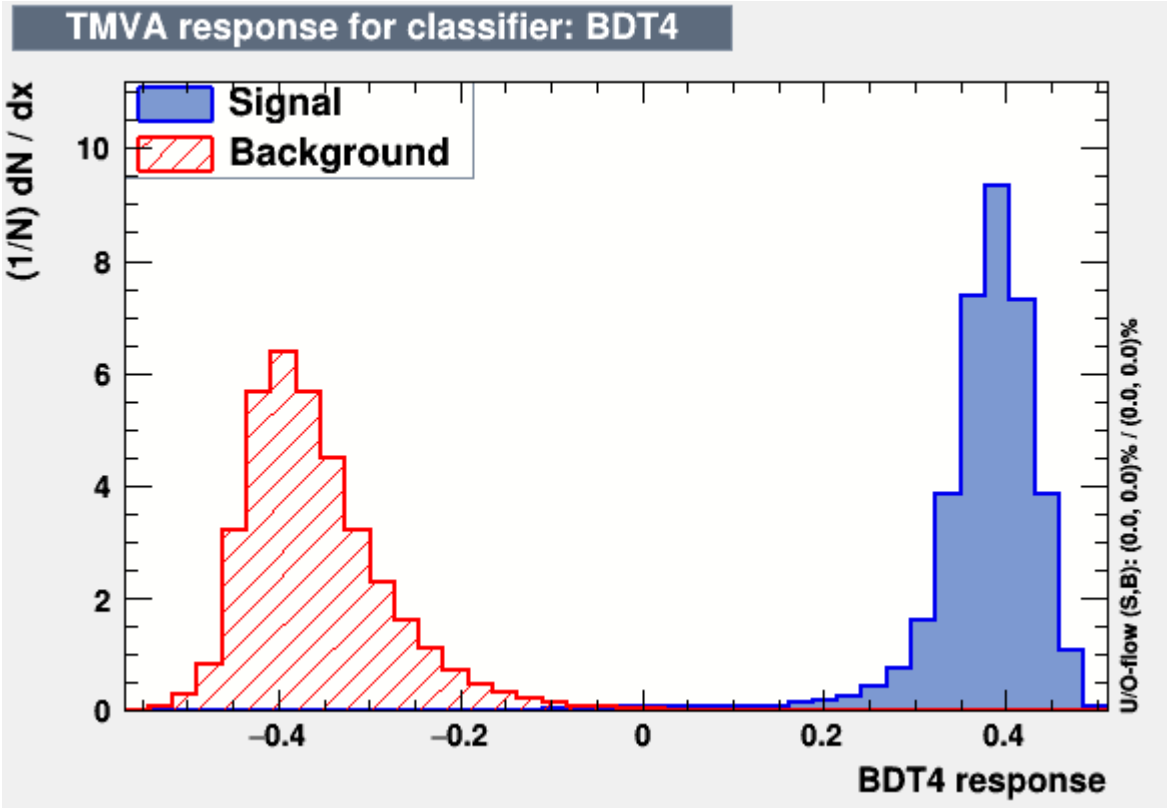
→ rigidity, dE/dx

→ energy deposit in showers

→ energy deposit

→ neutron detector trigger

MULTIVARIATE ANALYSIS



An example of the BDT parameter response

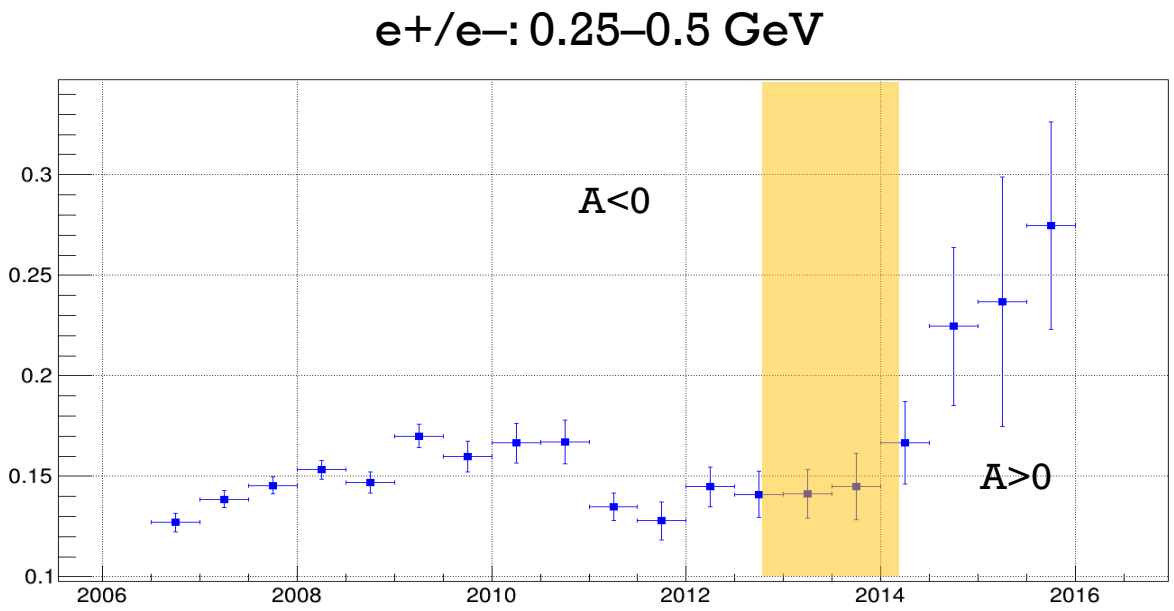
- Training: modeling in GEANT4
  - **signal:** **electrons**
  - **background:** **protons**
- Testing: the PAMELA database
- **~ 1.5 times increase of statistics of selected e+, e–**

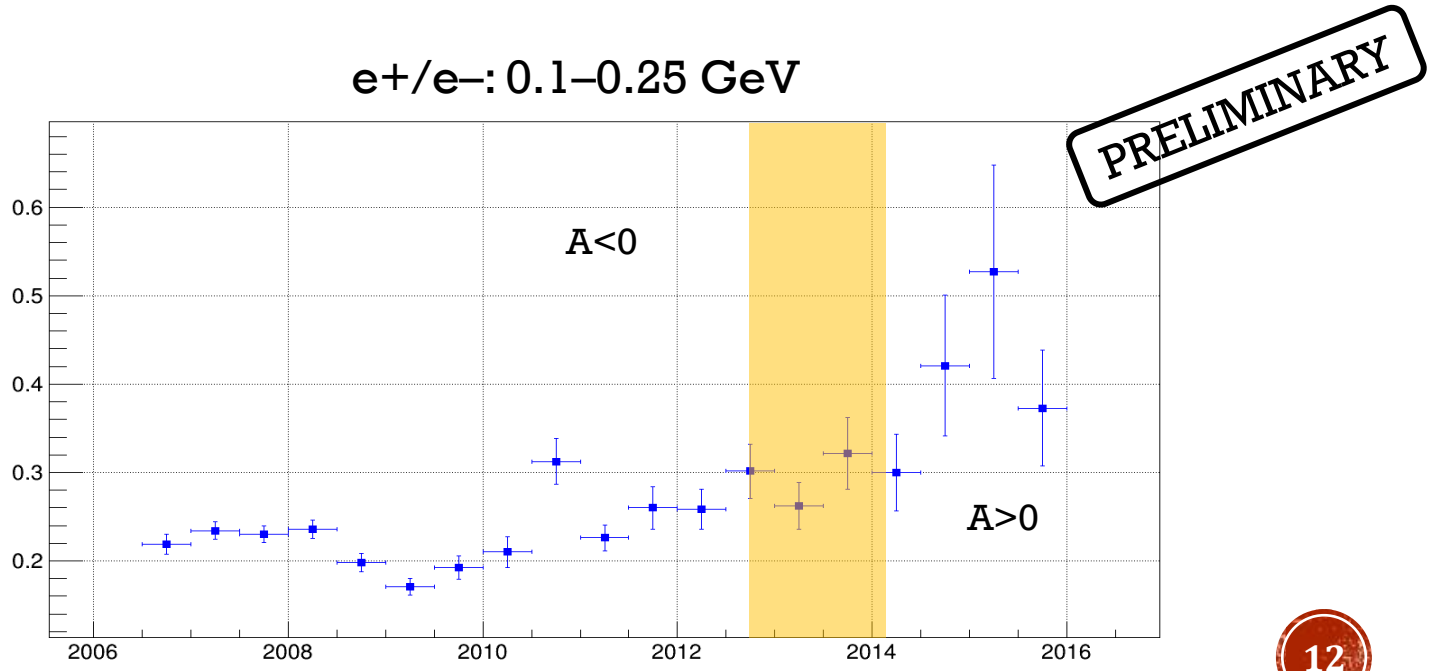
RESULTS

A feature is observed in 2008

A rise in 2014-2015…

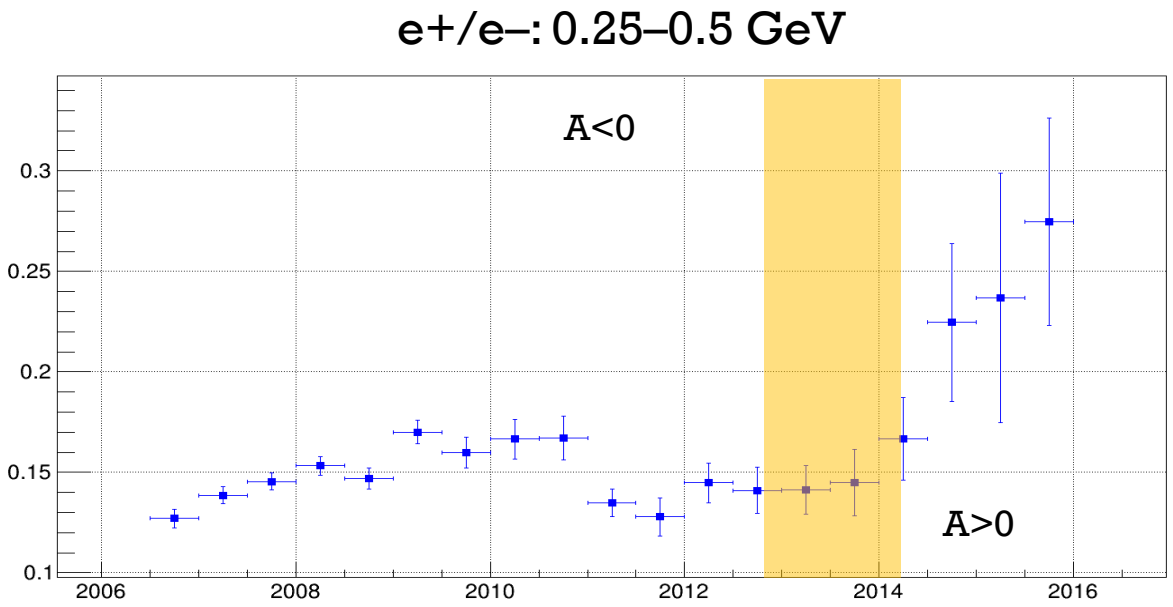
(expected)

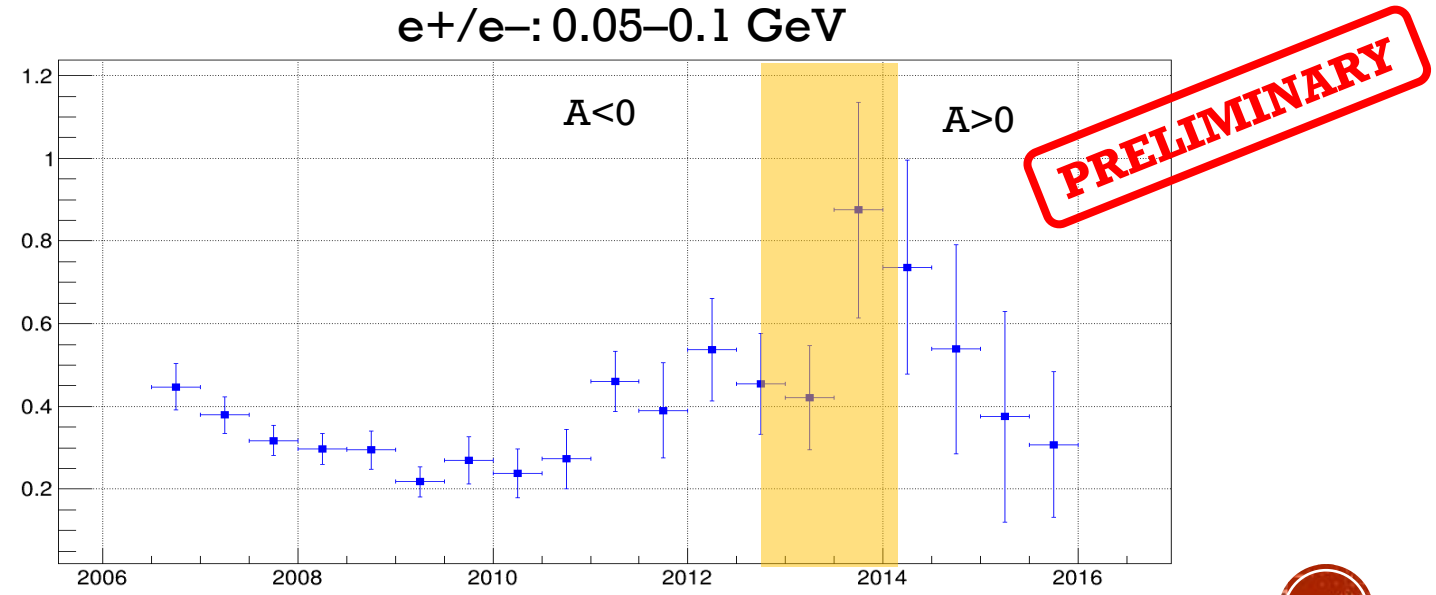




RESULTS

Different charge-sign modulation dependence? (2006-2008)





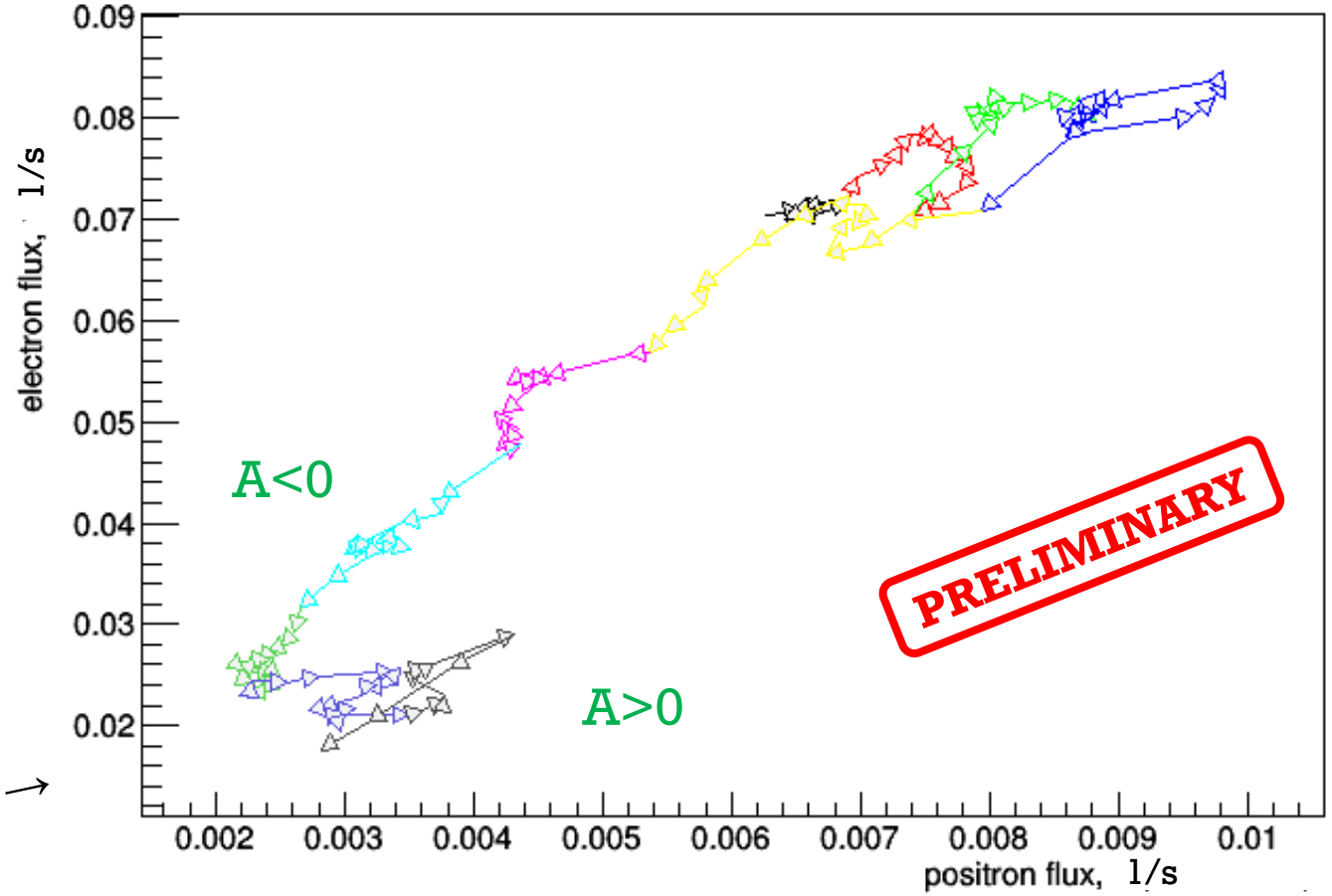
ELECTRON VS POSITRON COUNT RATE REGRESSION

Stat. errors are not shown

Data is smoothened

R = 0.5 – 2.5 GV

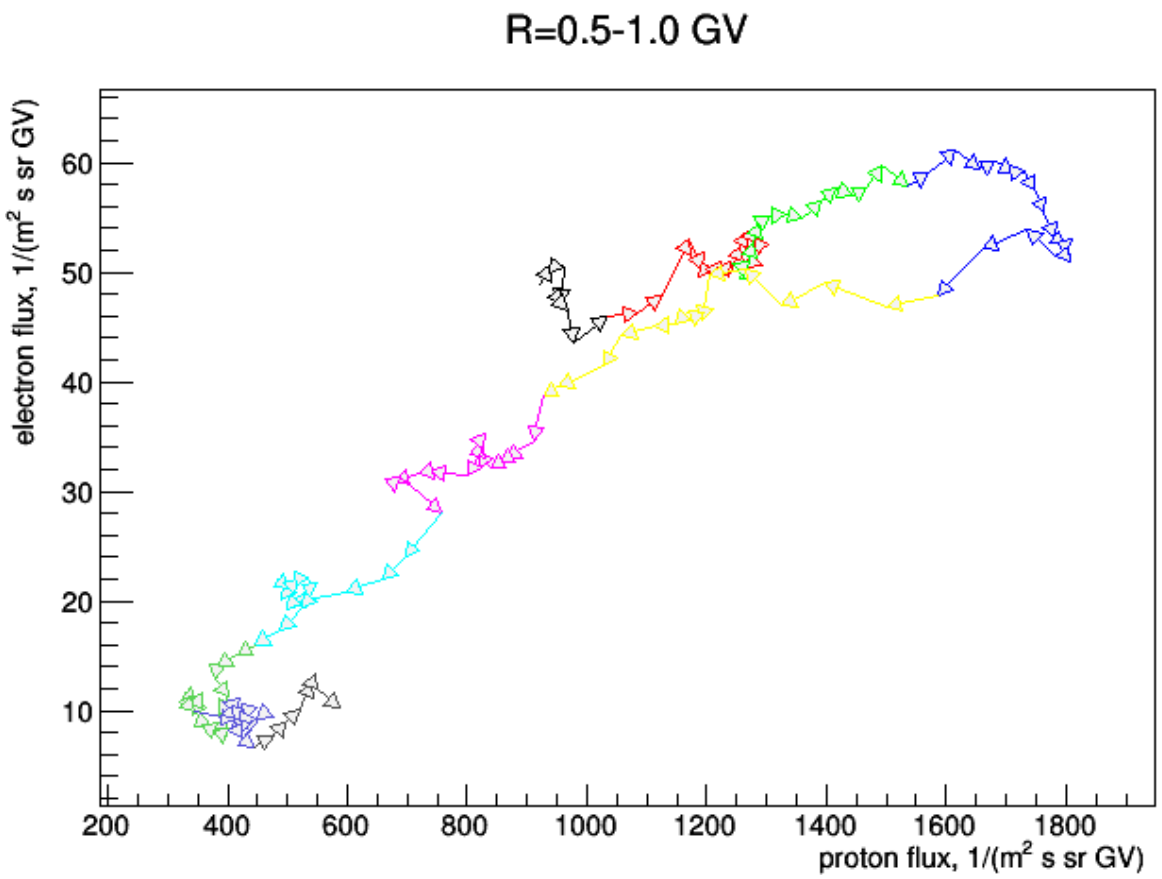
← Solar min (2009)



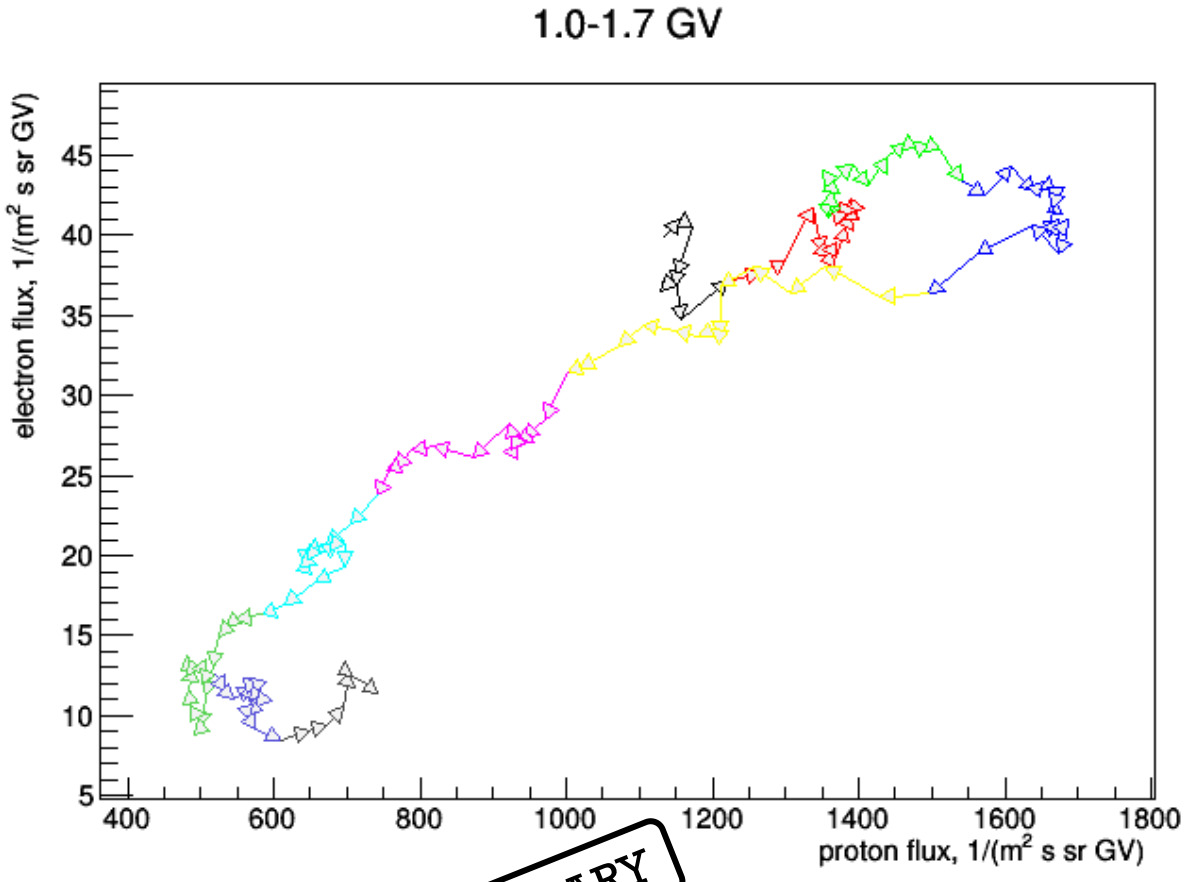
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

Solar max (~2014) →

ELECTRON VS PROTON FLUX REGRESSION

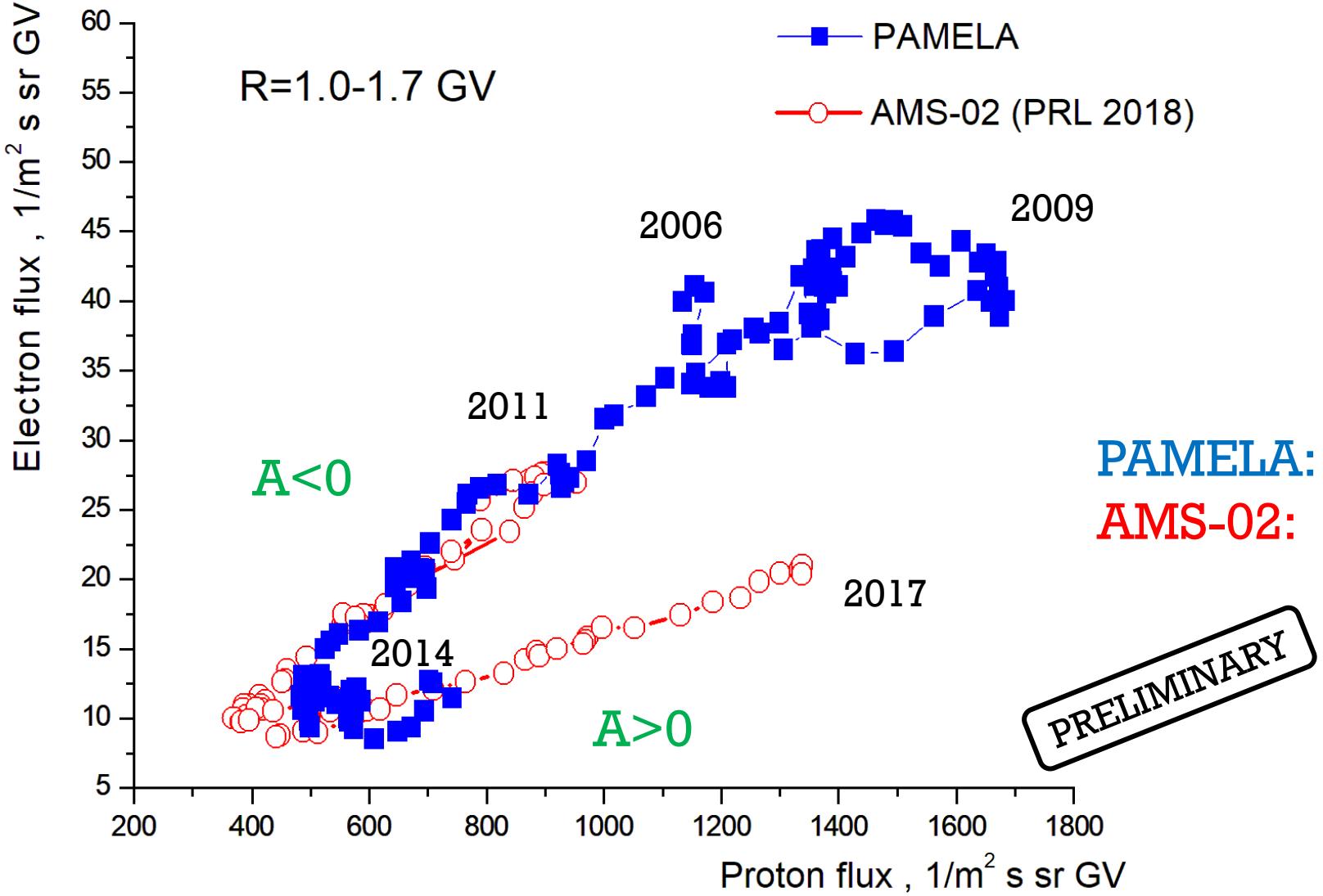


2006
2007
2008
2009
2010
2011
2012
2013
2014
2015



PRELIMINARY

HYSTERESIS



PAMELA: 2006-2015

AMS-02: 2011-2017

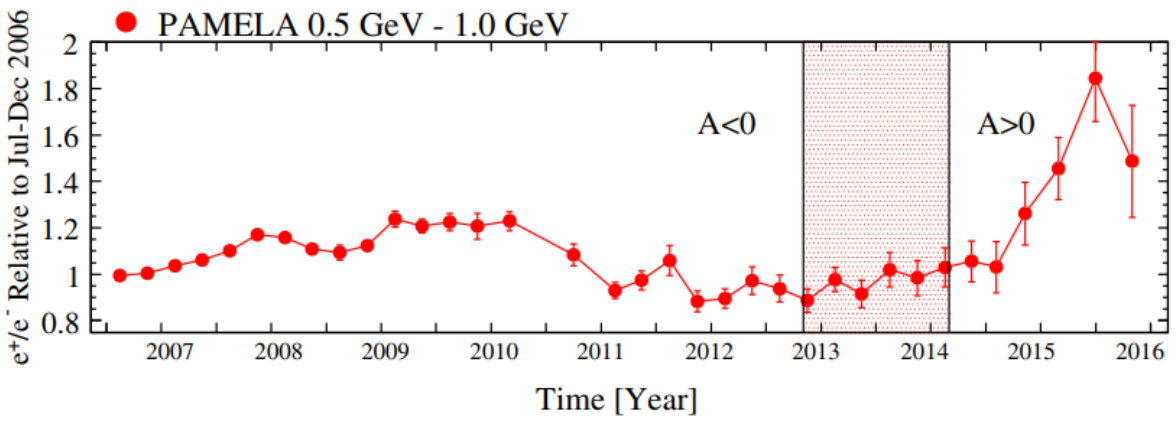
SUMMARY

- New results on e+, e– fluxes < 1 GeV obtained
- Modulation features are observed

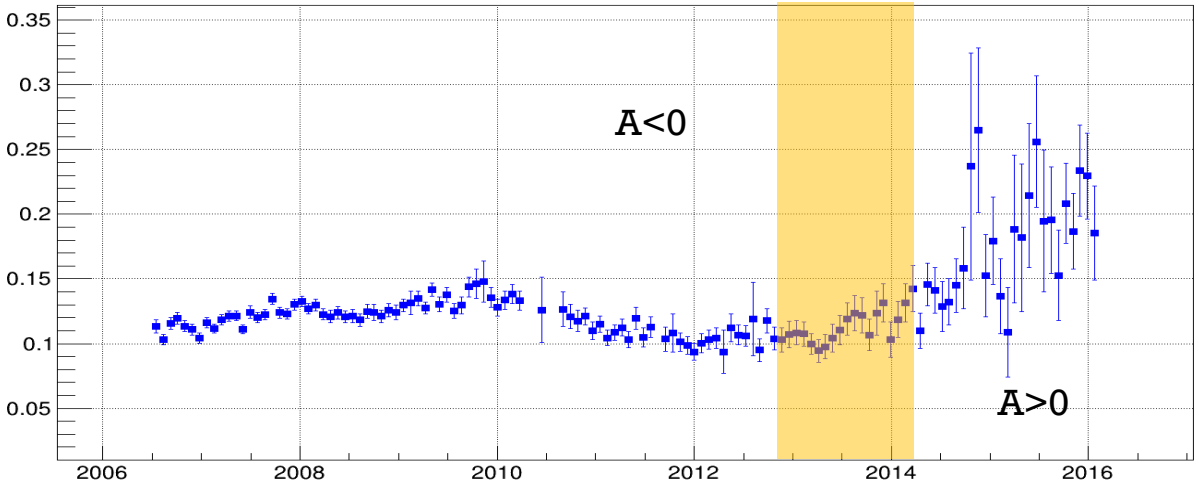
- The results can be applied for works on modeling cosmic-ray propagation in heliosphere
- It may be possible to better separate solar modulation and source components

THANK YOU FOR YOUR ATTENTION

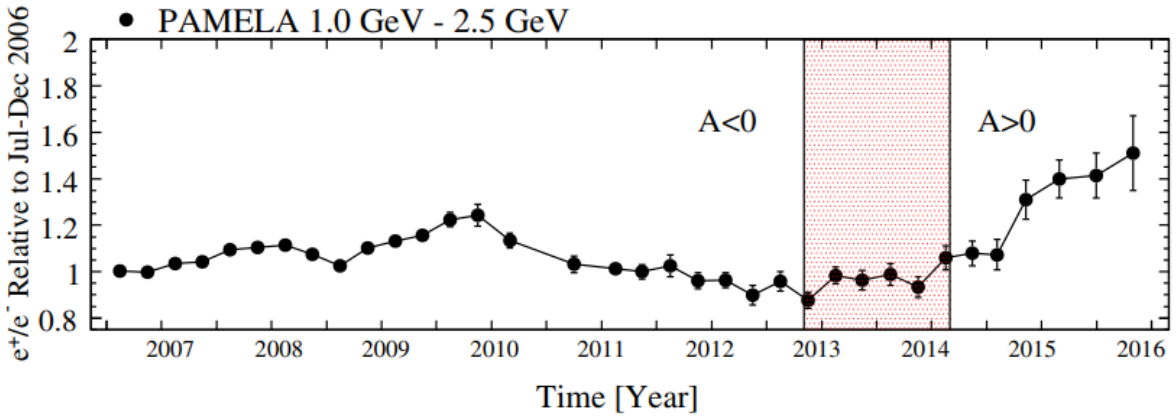
RESULTS



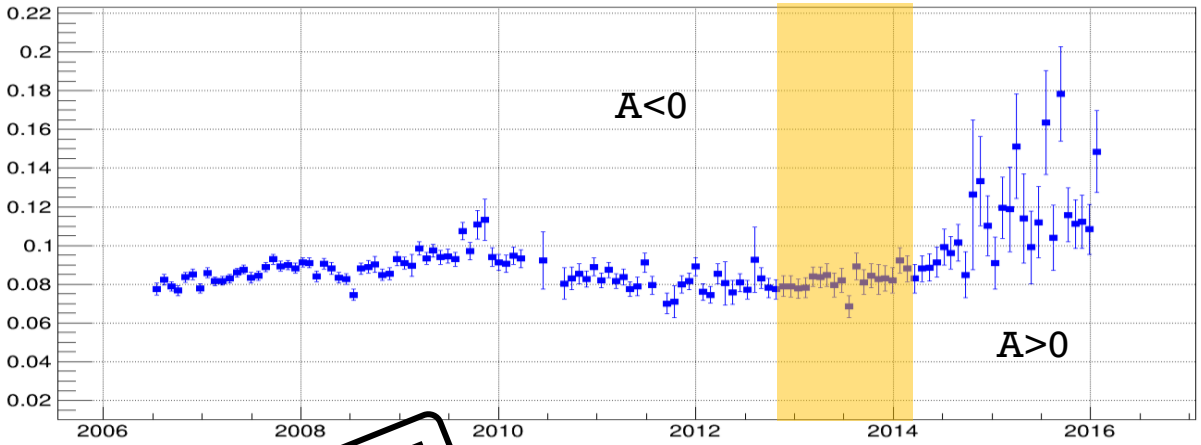
e+/e−: 0.5–1.0 GeV



AGREEMENT



e+/e−: 1.0–2.5 GeV



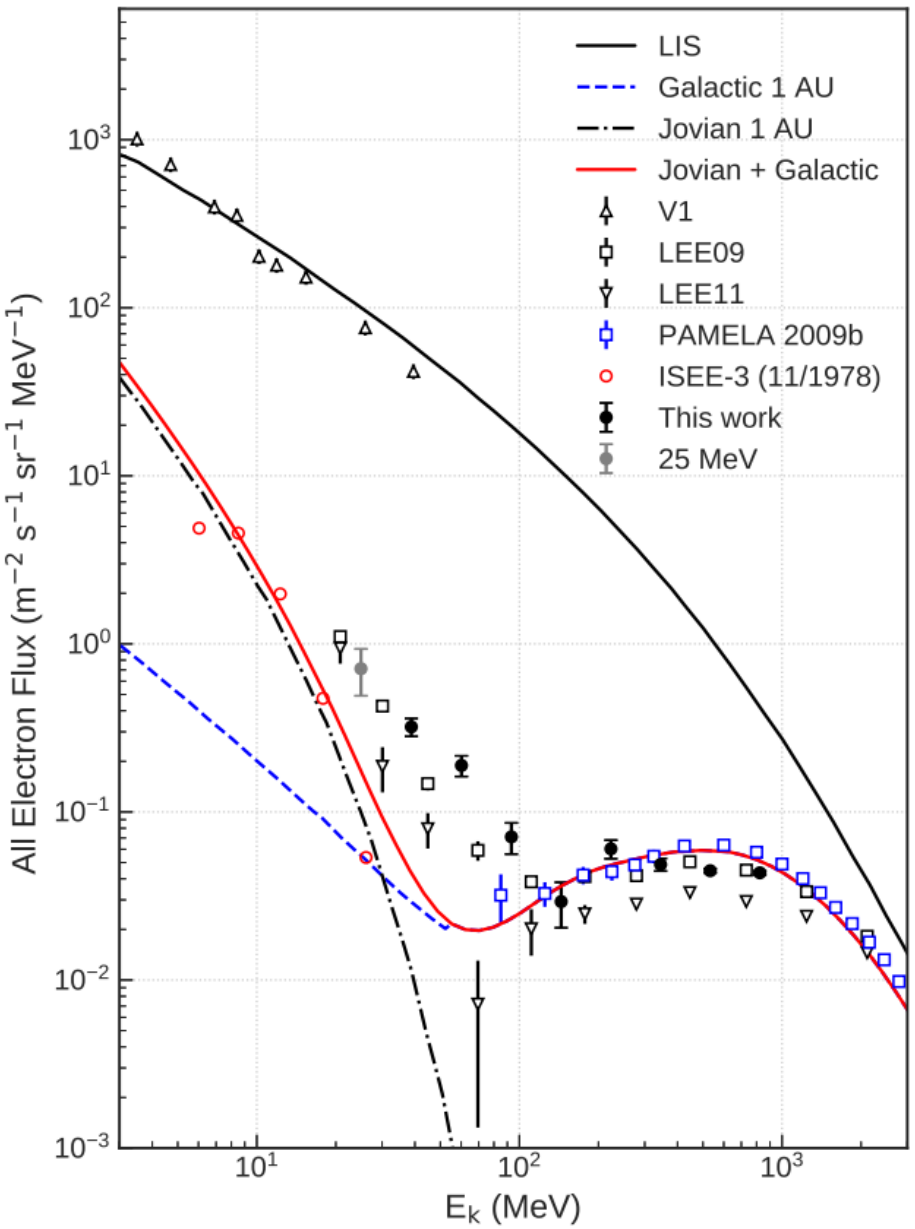
PRL 116, 241105 (2016)

PRELIMINARY

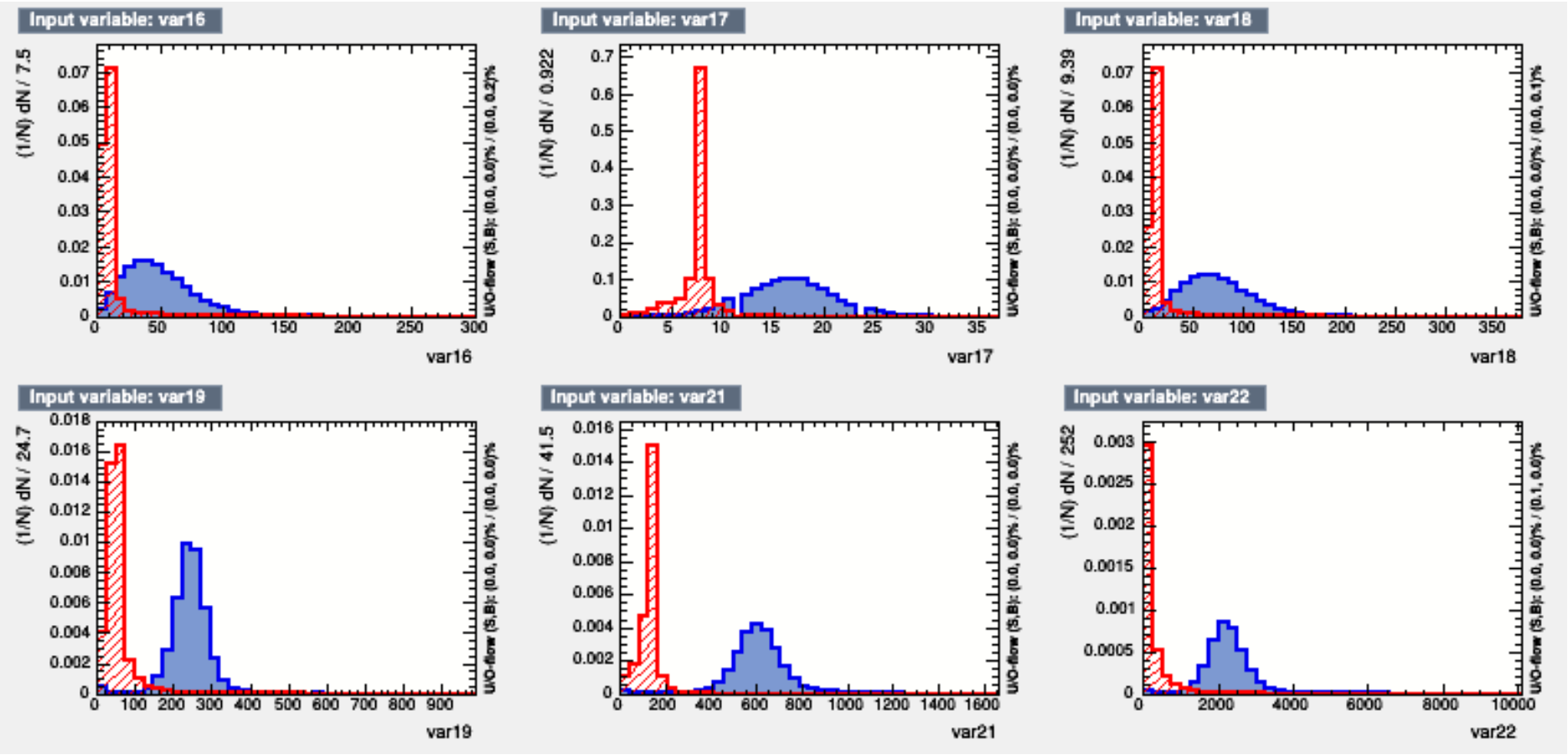
This work

ELECTRON SPECTRA

- ApJ 903:21 (2020, AESOP)



MULTIVARIATE ANALYSIS



Separating 20+ parameters for 2 event classes