INFN
Istituto Nazionale
di Fisica Nucleare

Università
degli Studi
di Perugia

International school of subnuclear physics

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electrons flux measurement with AMS-02

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Outline

1. The AMS-02 experiment

2. electrons and positrons analysis

   2.1 $e^+ + e^-$ flux

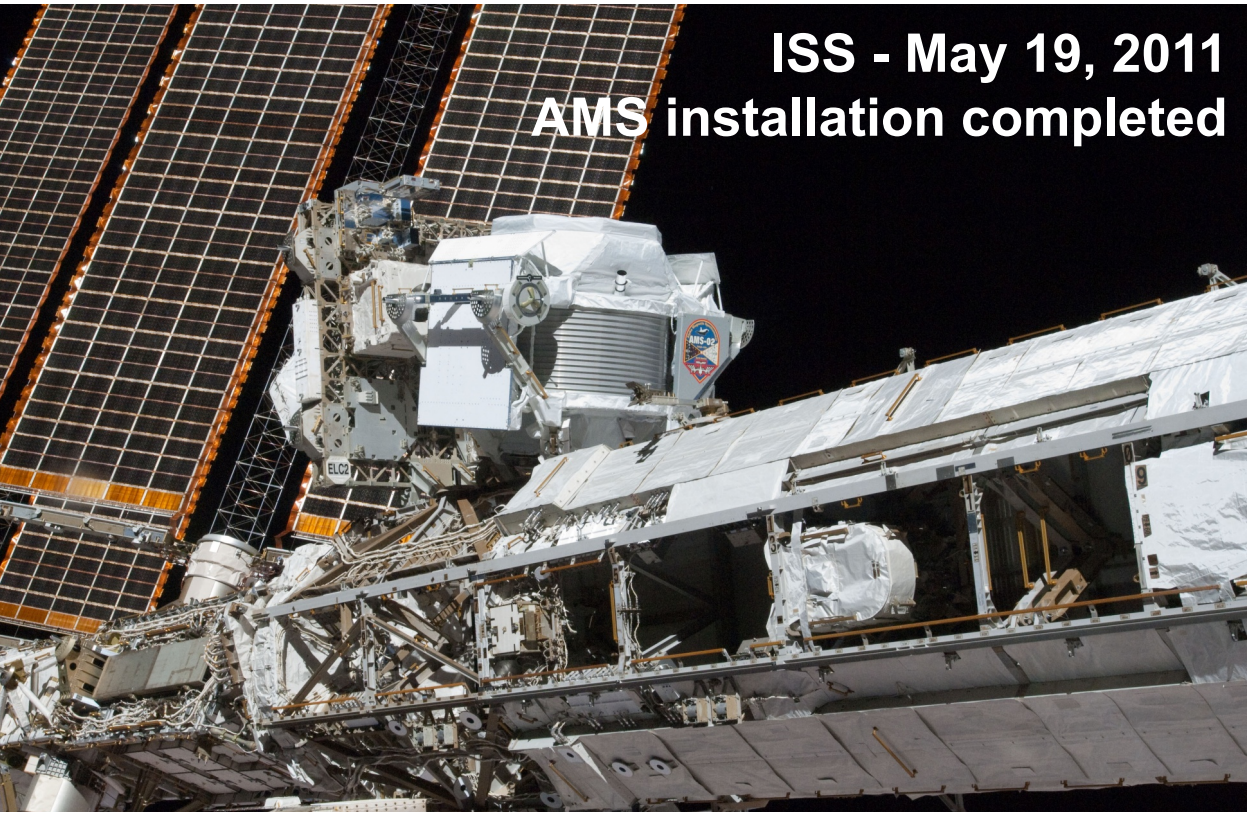
   2.2 e^+, e^- fluxes in time

3. Conclusion

AMS-02: Alpha Magnetic Spectrometer

PHYSICS GOALS

- Measurement of the *composition of charged cosmic rays up to TeV*
- *Direct search for primordial antimatter* (anti-nuclei)
- *Indirect search for dark matter* (matter/antimatter spectra)
- Gamma ray astrophysics
- Exotic physics (strangelets...)



measurements of ***cosmic rays*** (O(GeV) – O(TeV))

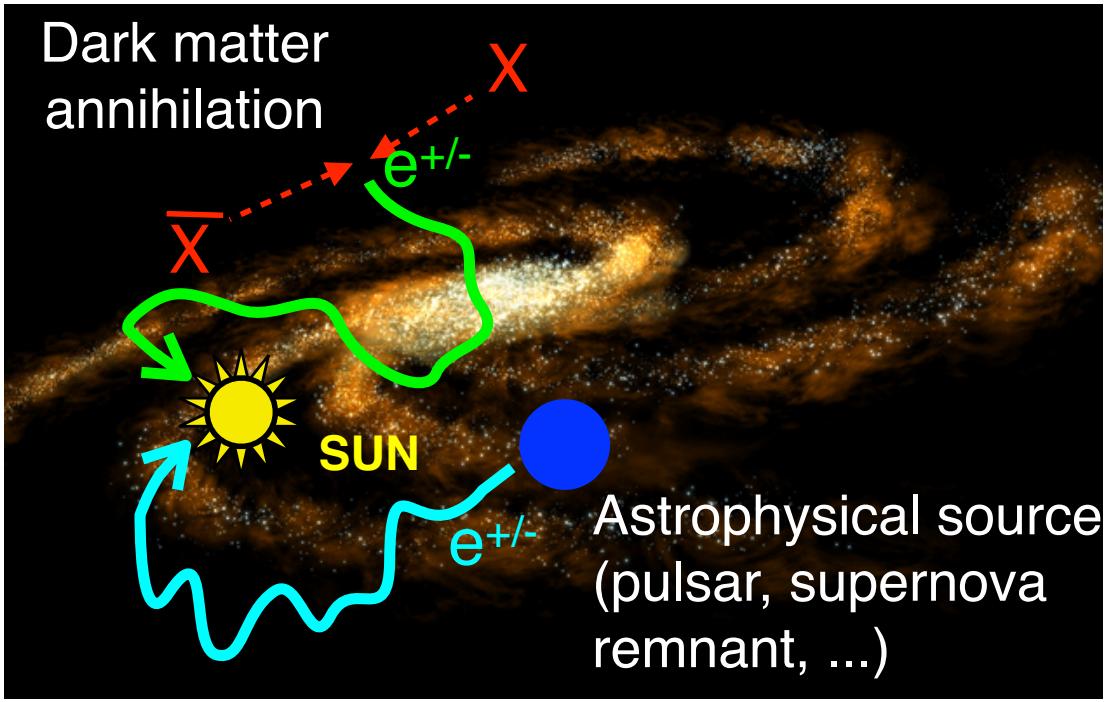
p (~90%)

e^- (~1%)
e+ (~0.1%)

He (~8%)

Be, C, Fe, … (~1%)

Why electrons?



1. **Information** about the **origin** and the **propagation of cosmic rays** complementary to the hadronic component ($m_e << m_p$ → very different energy losses in the interaction with ISM);
2. possible **indirect detection of dark matter**.

Very challenging measurement:

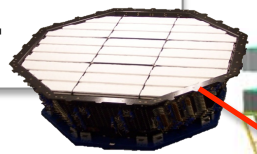
$e^-/p \sim 10^{-2} - 10^{-3}$
$e^+/p \sim 10^{-3} - 10^{-4}$

→ **high e/p rejection power is needed**

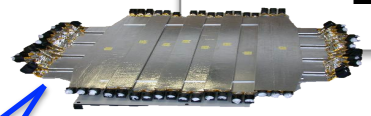
AMS: A TeV precision, multipurpose spectrometer

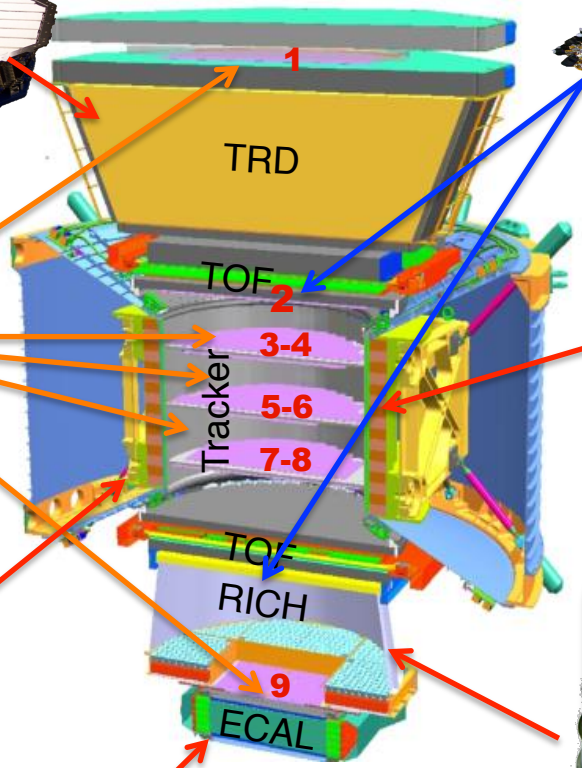
Z, P are measured independently by the Tracker, RICH, TOF and ECAL

TRD, *Transition Radiation Detector*
Identify e+, **e-**

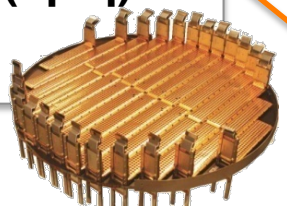


TOF
"Time of Flight"
Z, E

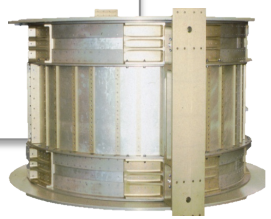




Silicon Tracker
Z, R(=p/q)

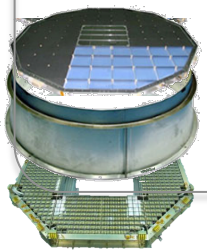


Permanent Magnet
±Z



Anti-Coincidence Counters (ACC)

RICH, *Ring Imaging Cherenkov*
Z, E
($\sigma_\beta/\beta \sim 0.1\%$)



ECAL, *Electromagnetic Calorimeter*
E of e⁺, e⁻, γ

see S.Schael talk "Highlights from AMS" for more details

$e^{\pm}$ selection with AMS-02

Minimum requirements on the event

TRD:
- Minimum 8 hits used for e/p identification
- |Z| = 1

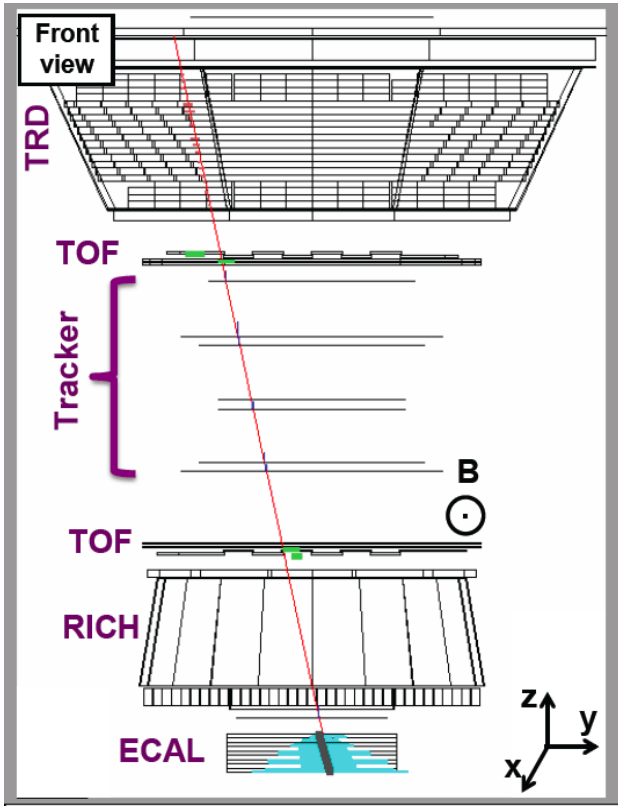
TOF:
- relativistic down-going particle (β>0.83)

TRACKER:
- |Z| = 1
- track/ECAL matching to define fiducial volume

ECAL:
- Shower axis within the fiducial volume
- Not MIP in the first $5X_0$

Signals released by e and p have different distributions in the TRD and ECAL:

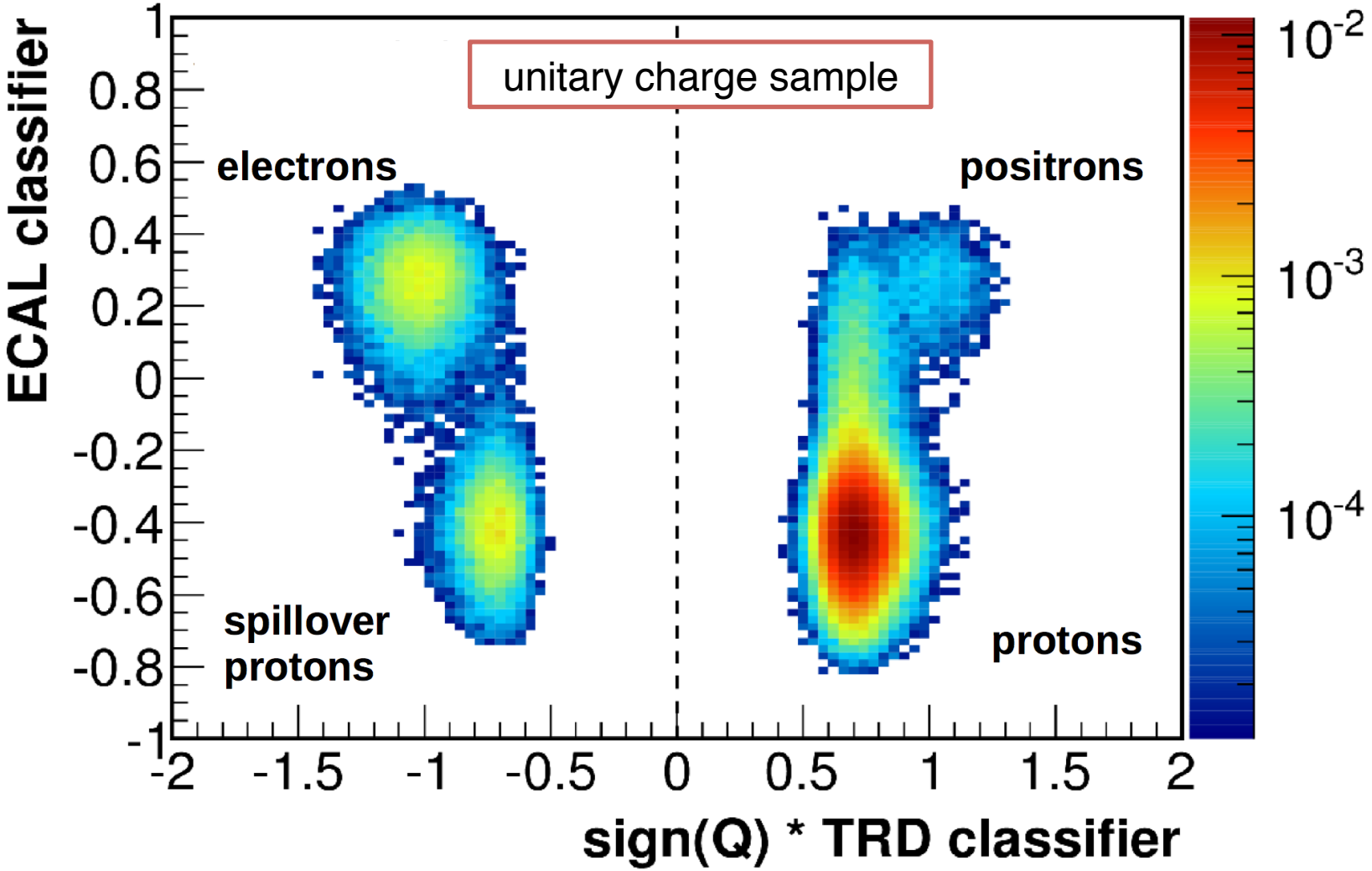
600 GeV electron



→signals from the different TRD layers are combined with a likelihood method to define the **TRD classifier**

→ Signals in the ECAL are combined in with a Boost Decision Tree technique to define the **ECAL classifier**

TRD and **ECAL** are the key instruments for e/p separation:



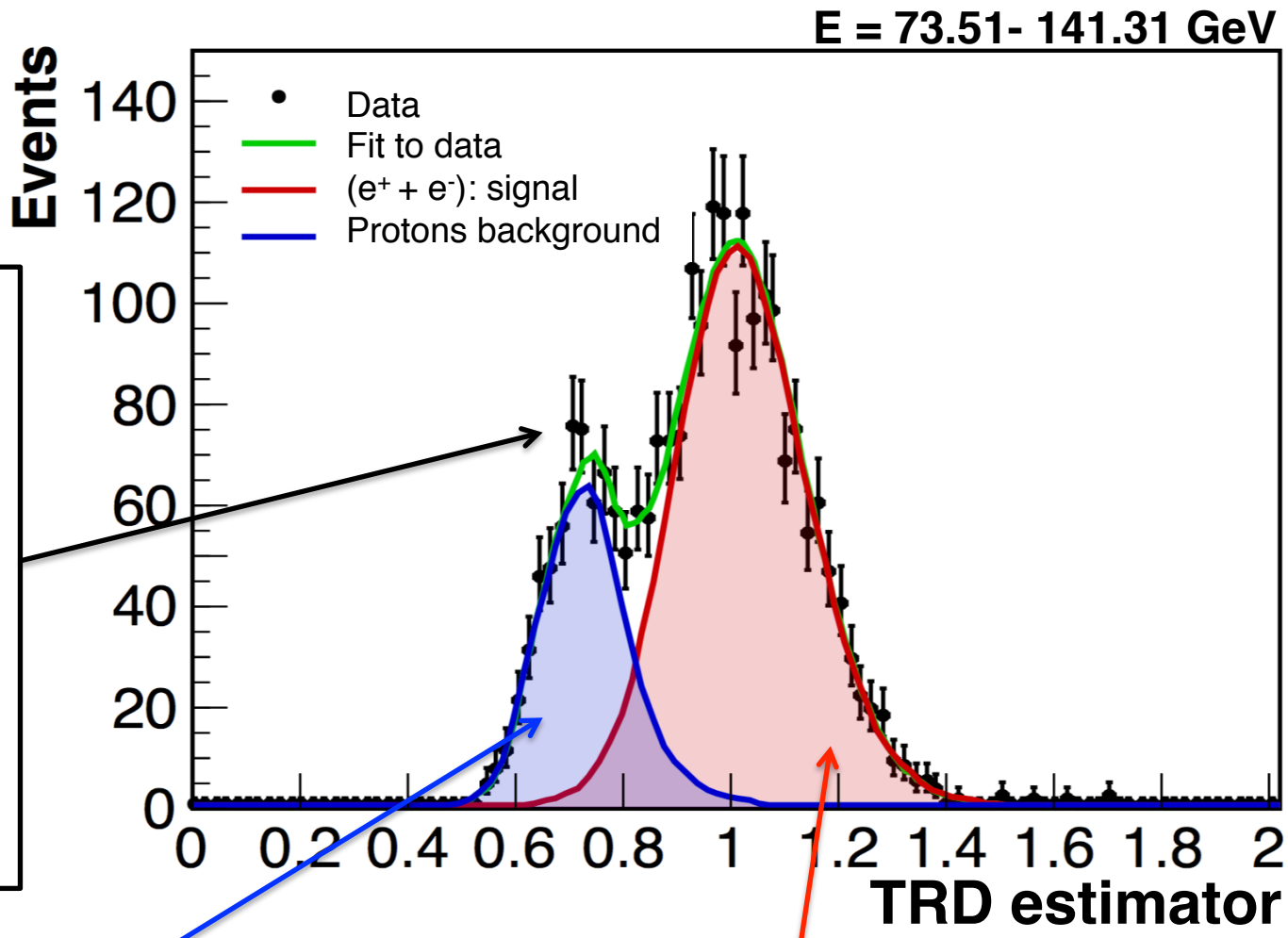
The flux ingredients

Flux definition in energy interval ΔE

$$\Phi(\Delta E) = \frac{N(\Delta E)}{\epsilon_{trigg}(\Delta E) \cdot T_{exp}(\Delta E) \cdot \Delta E \cdot A_{MC}(\Delta E) \cdot (1 + \delta(\Delta E))}$$

1. **N(ΔE)** = number of events *in ΔE*
2. **ε_{trigg}(ΔE)** = trigger efficiency *in ΔE*
3. **ΔT_{exp}(ΔE)** = exposure time (*s*) *in ΔE*
4. **A_{MC}(ΔE)** = Detector acceptances *in ΔE (on MC data)*
5. **(1+δ(ΔE))** = data/MC correction

1. N(ΔE): number of events *in ΔE*



Sample to fit:

clean **unitary charge** sample of **downgoing relativistic particle** selected from data. Protons background suppressed by mean of ECAL estimator

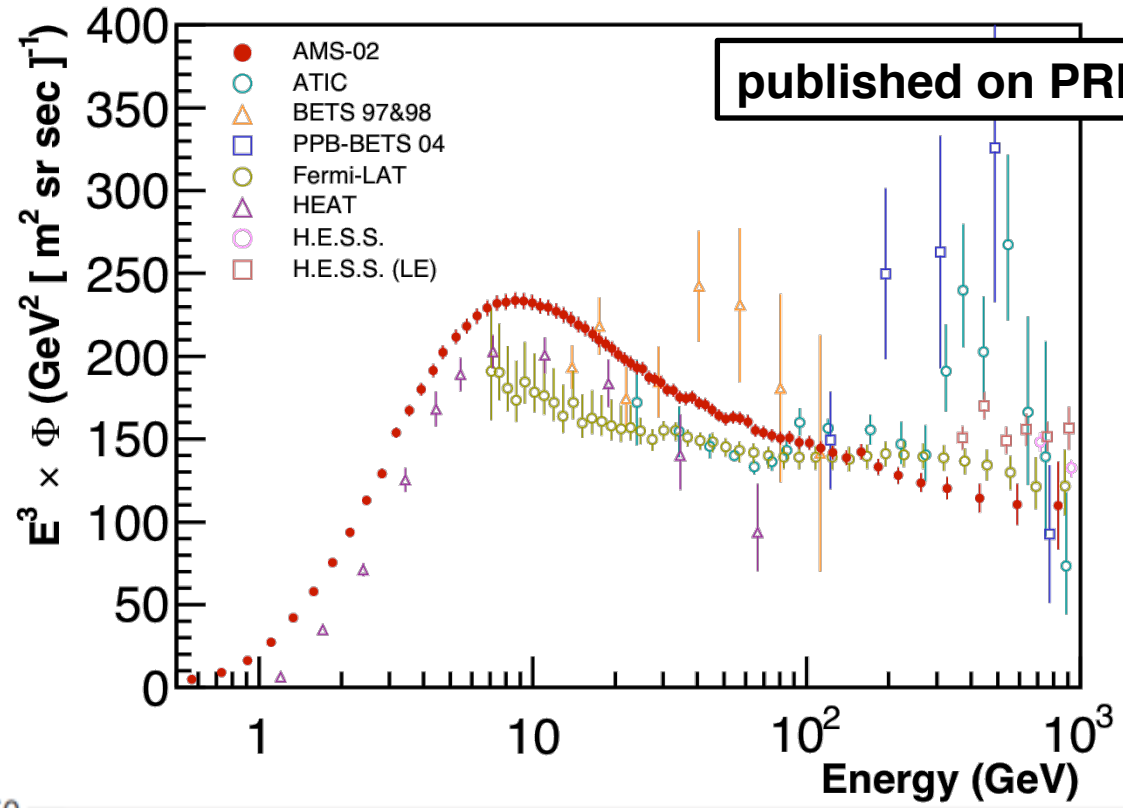
reference distribution for background:

protons sample obtained from data using *ECAL+TRD+charge sign*

reference distribution for signal:

electrons sample obtained from data using *ECAL+TRD+charge sign*

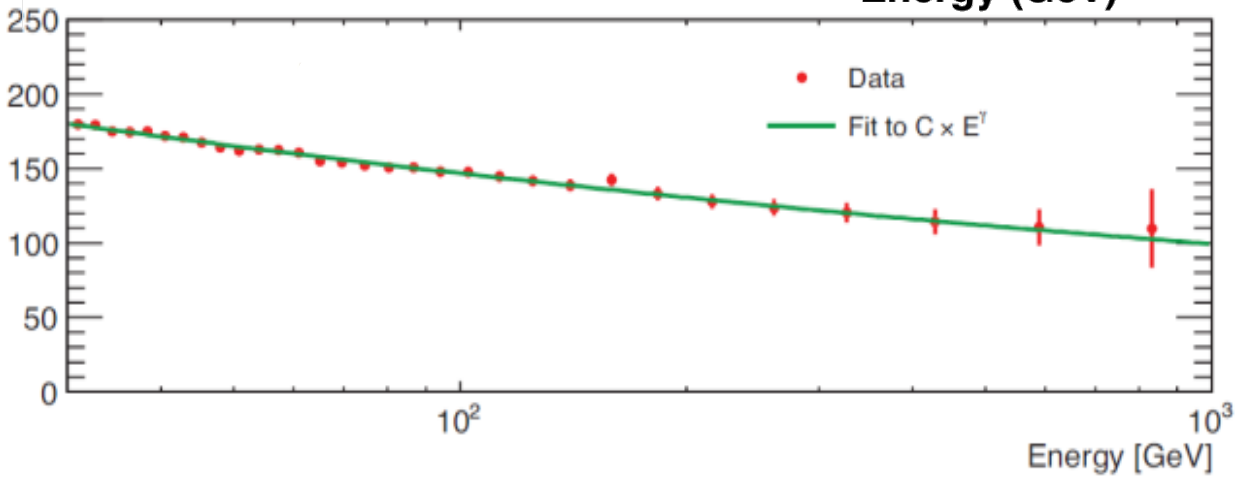
All-electrons (e^++e^-) flux results



published on PRL 113, 121102 (2014)

The flux is smooth and reveals new and distinct information.

No structures were observed.



It is consistent with a single power law above 30 GeV.

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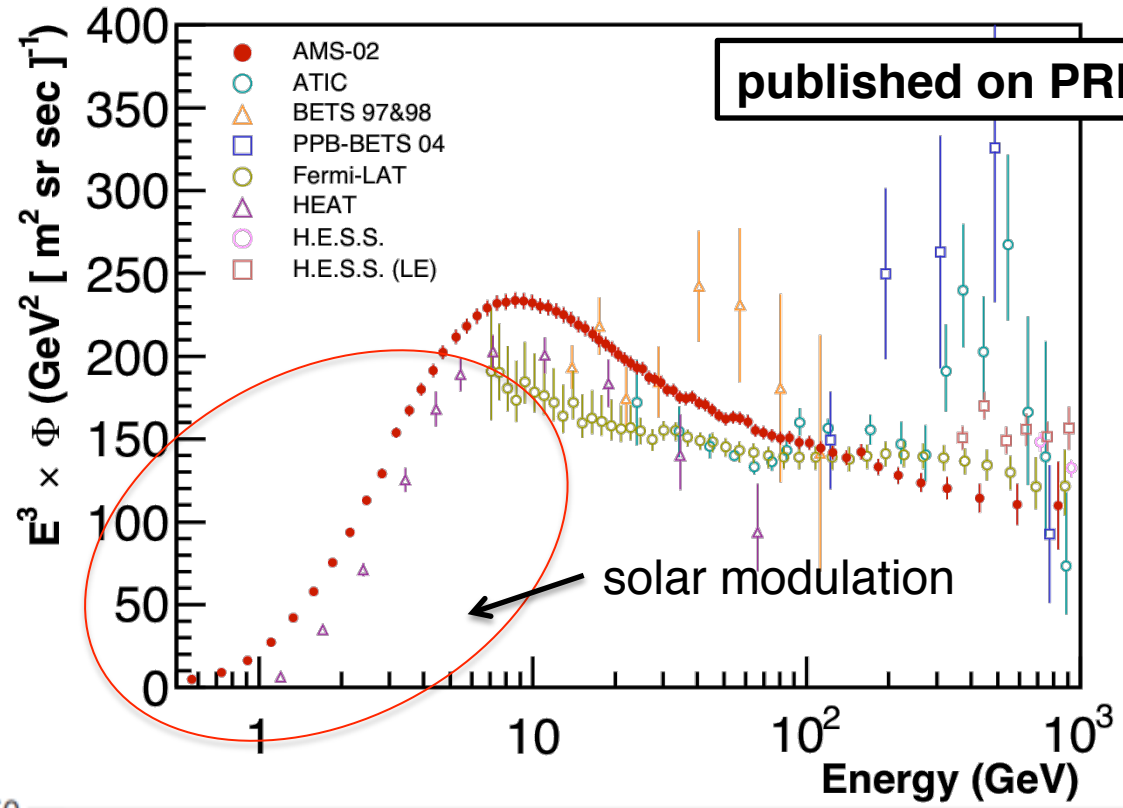

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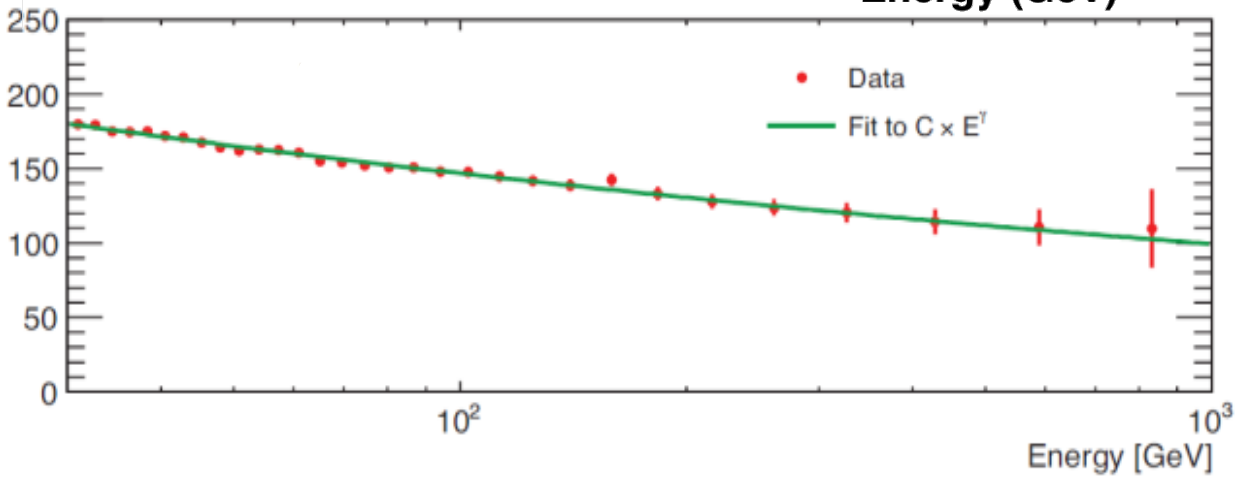

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e+, e- fluxes in time

Motivations

- The **energy spectra of galactic cosmic rays** carry fundamental information regarding their origin and propagation.

- These spectra, when measured near Earth, are significantly **affected by the solar magnetic field**. A comprehensive description of the cosmic radiation must therefore include the *transport and modulation of cosmic rays inside the heliosphere.*

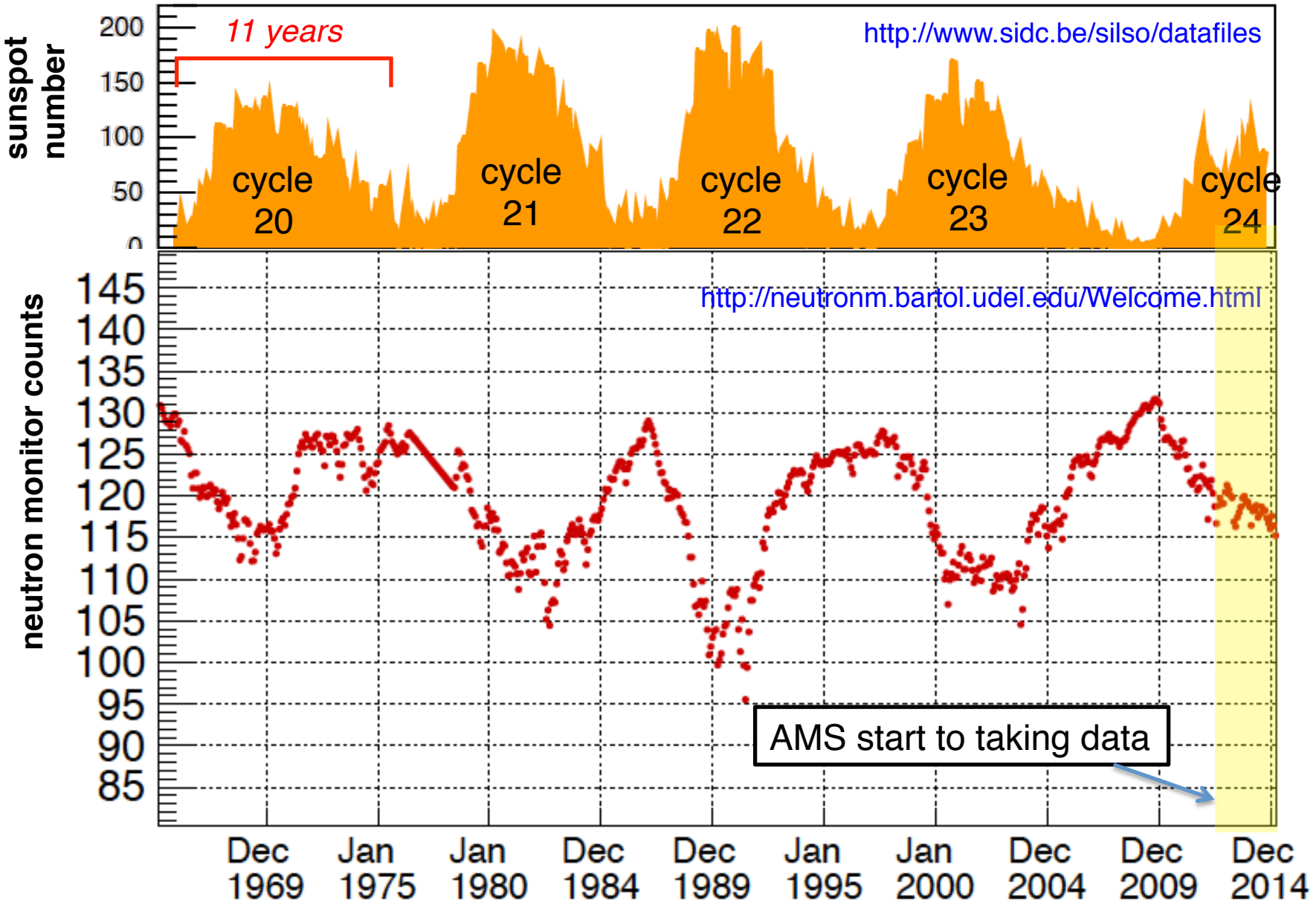
- **AMS** can provide the **most accurate measurements** of the time dependence of electron and positron fluxes since 2011 thanks to its high acceptance and the excellent performances of the detector.

Analysis method:

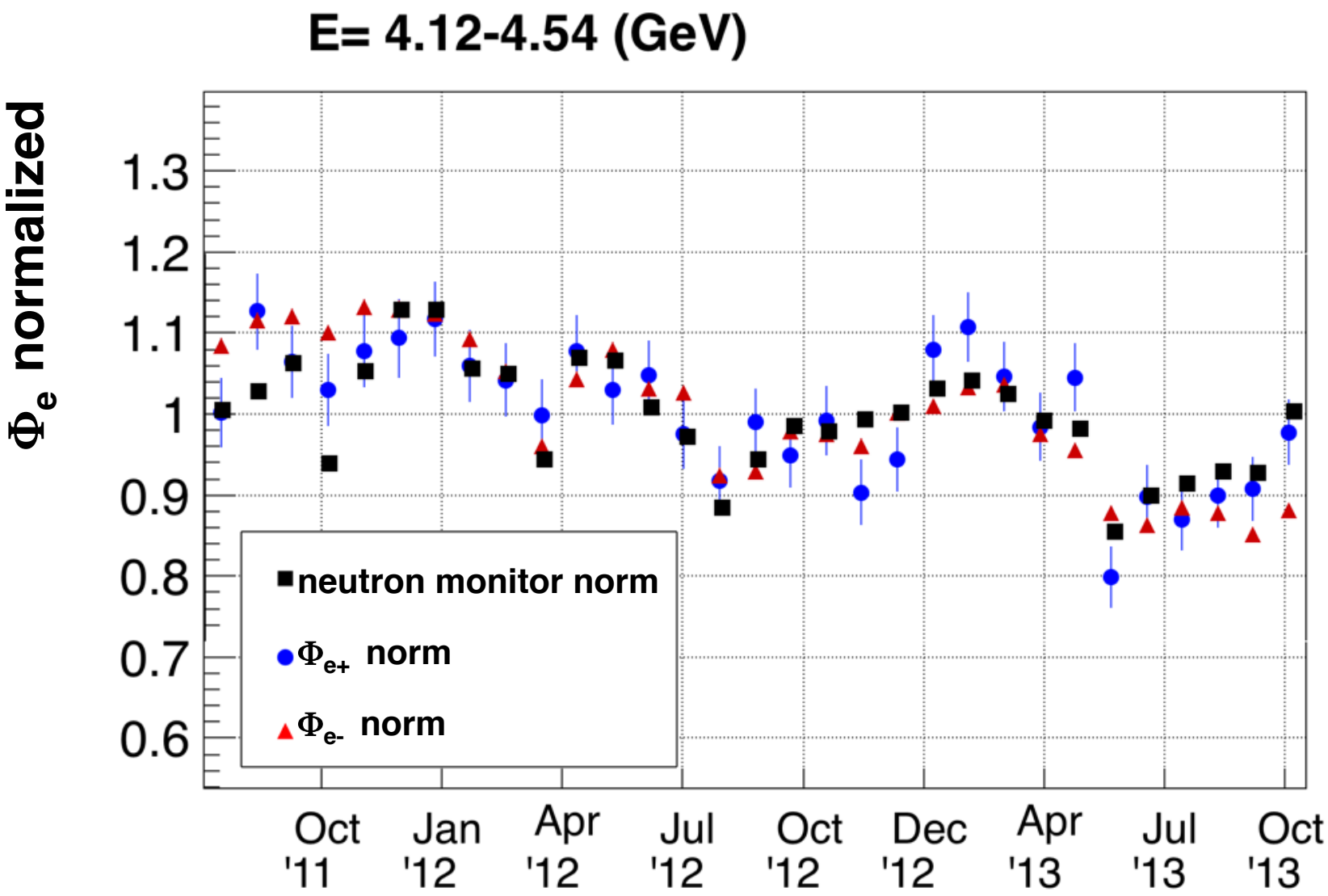
- same approach for $(e^+ + e^-)$ fluxes + Tracker for charge sign

- time binning: 27 days

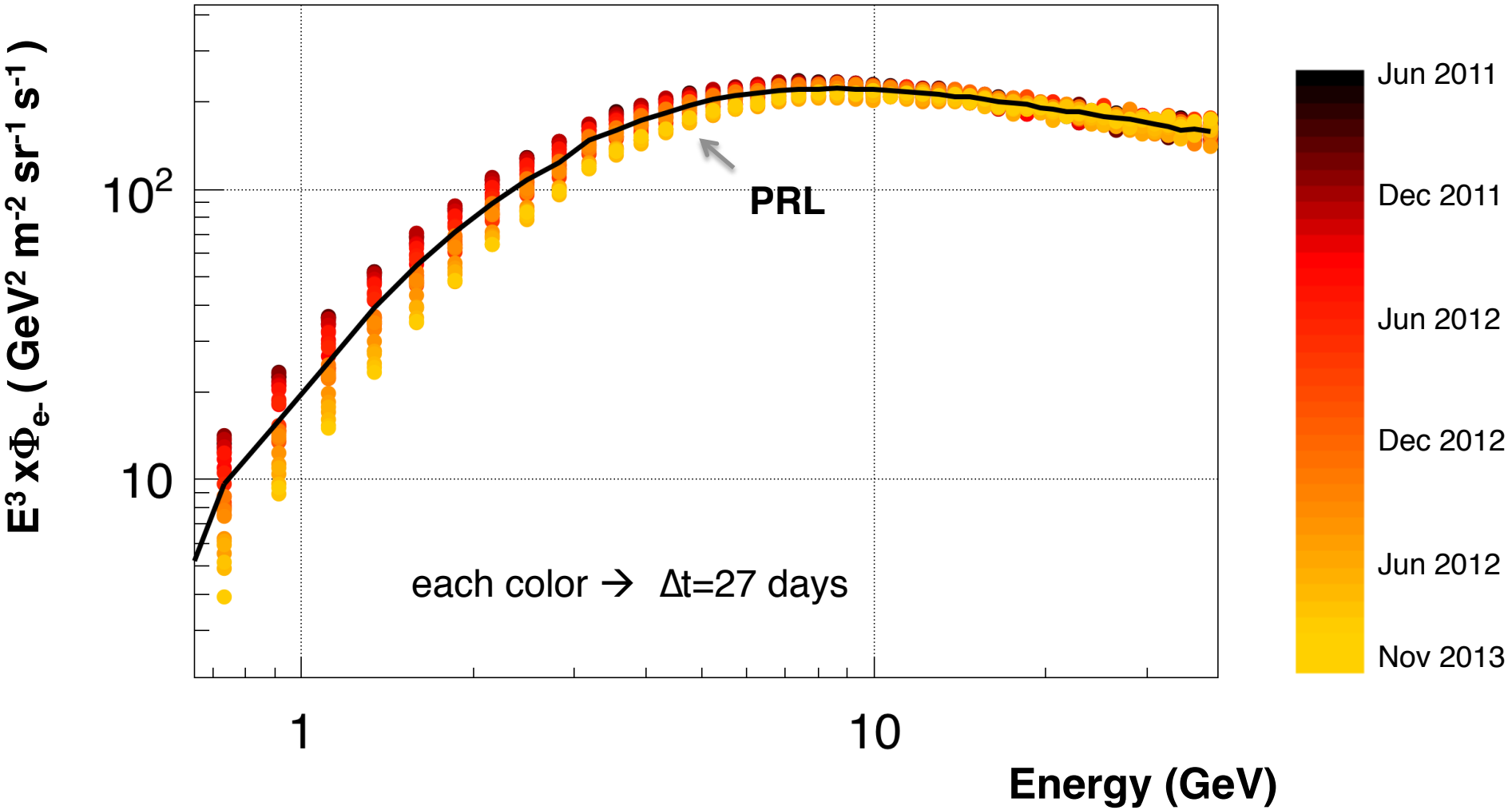
Solar modulation of CR



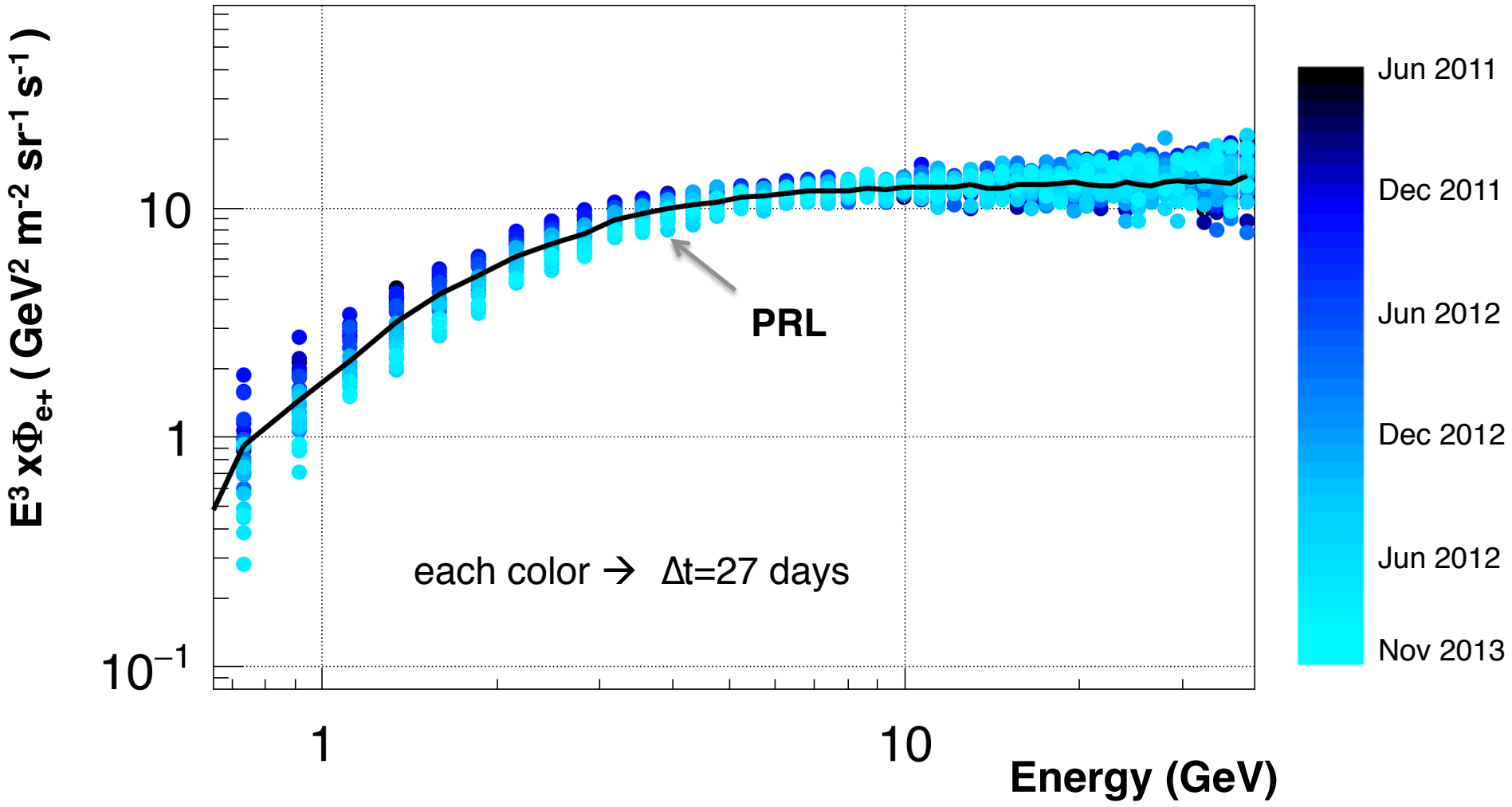
Solar modulation, comparison with neutron monitor



Solar modulation of CR – e^- flux result



Solar modulation of CR – e^+ flux result



Conclusions

1. $(e^+ + e^-)$ flux

10.5 million electrons and positrons collected by AMS-02 have been analyzed to measure the $e^+ + e^-$ spectrum up to 1 TeV

- Electron plus positron spectrum measured with unprecedented precision up to 1 TeV.
- Measurement systematics within few percent in a wide energy range.
- No evidence of prominent features observed.

2. e^+, e^- fluxes in time

- same approach for $(e^+ + e^-)$ flux
- preliminary results → to be finalized
- this work will be useful in the understanding of solar modulation

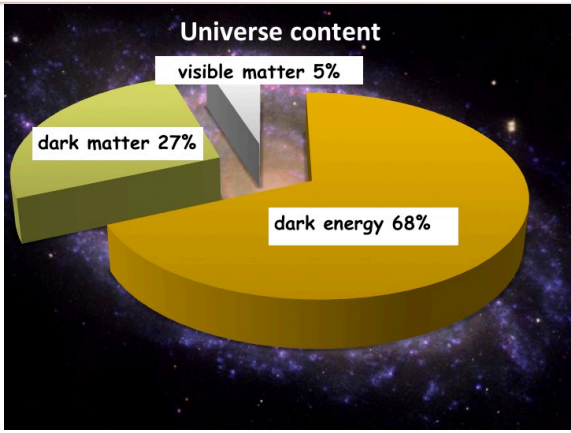
THANKS FOR YOUR ATTENTION

- Fundamental physics & Antimatter :
  - Primordial origin (Signal: anti-nuclei)

Dirac's Nobel speech

"We must regard it rather as an accident that the Earth [...] contains a preponderance of negative electrons and positive protons. It is quite possible that for some stars it is the other way about."

The Physics: The quest for Dark Matter

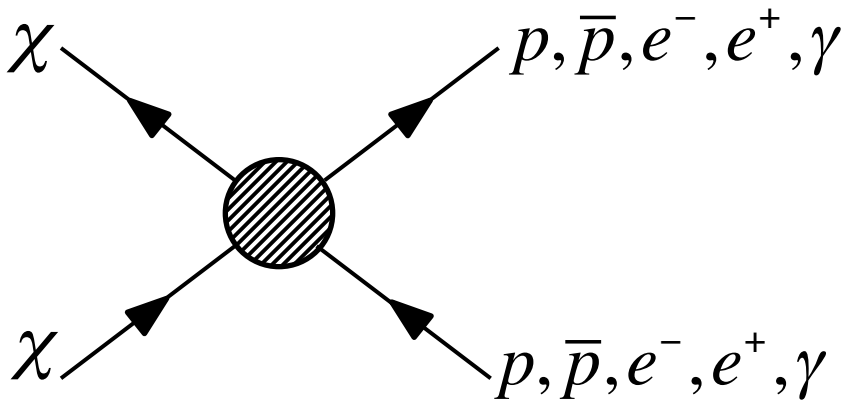


Annihilation

$$\chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma$$

Scattering

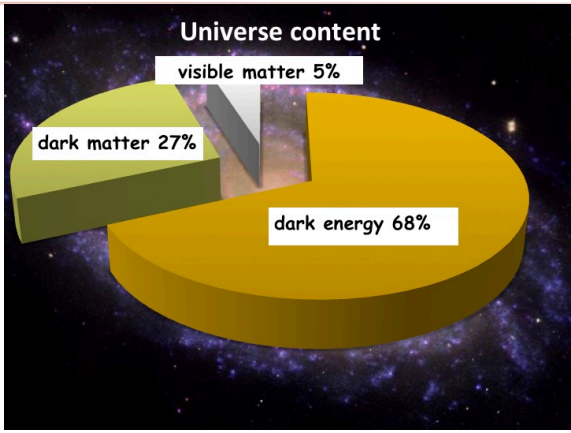
$$\chi + p \rightarrow \chi + p$$



$$\chi + \chi \leftarrow p + p$$

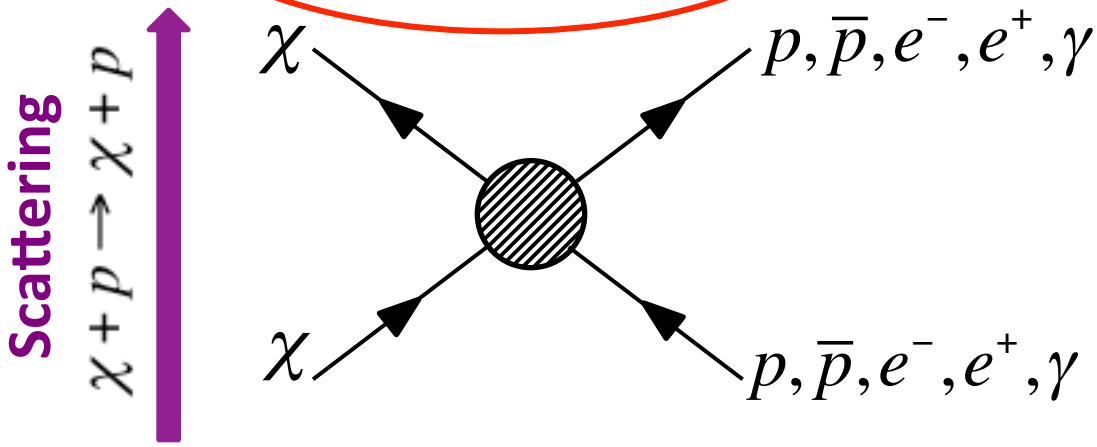
Production

The Physics: The quest for Dark Matter



Annihilation

$$\chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma$$



$$\chi + \chi \leftarrow p + p$$

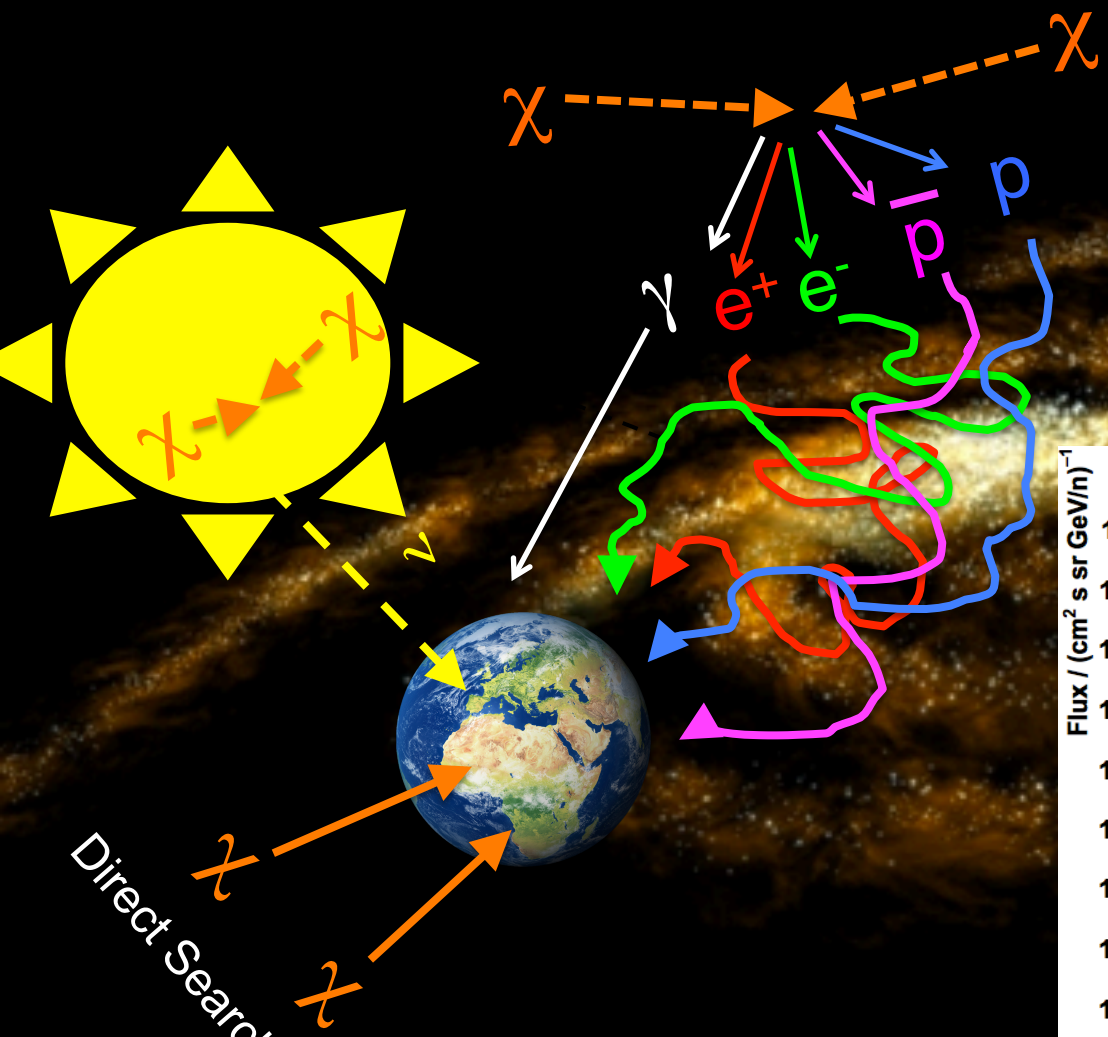
Production

The Physics: Anti-Matter & Dark Matter

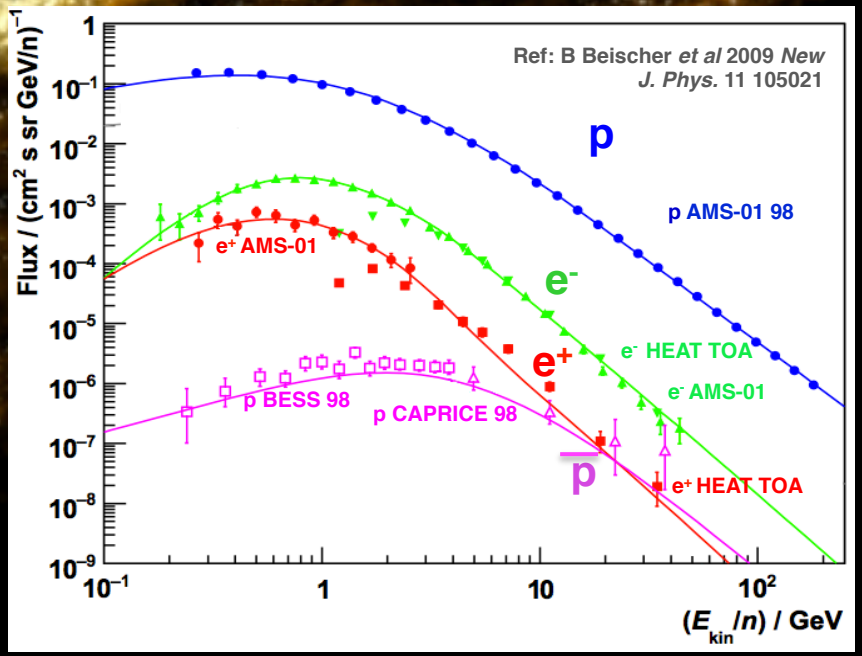
WIMP as the responsible of Dark Matter (?)

Direct Searches

Indirect DM search → search for (RARE IN CR) products from their annhilation….

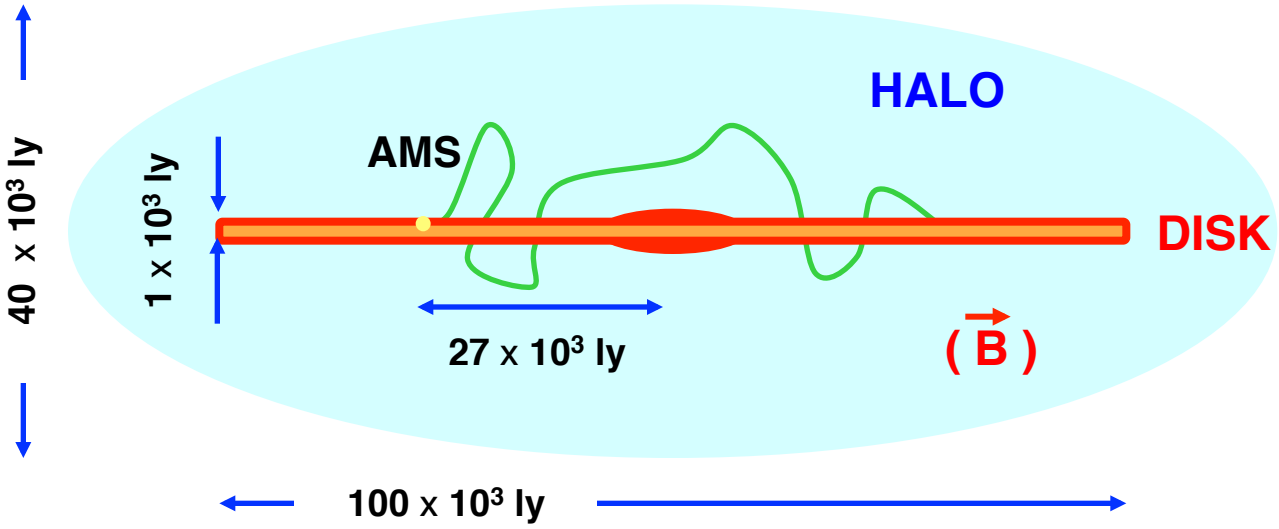


But you should know what you expect in the ISM !!



Precise measurement of the energy spectra of B, C …
provides information on Cosmic Ray Interactions and Propagation

Interactions with the Interstellar Medium:
C + (p,He) → B + ...

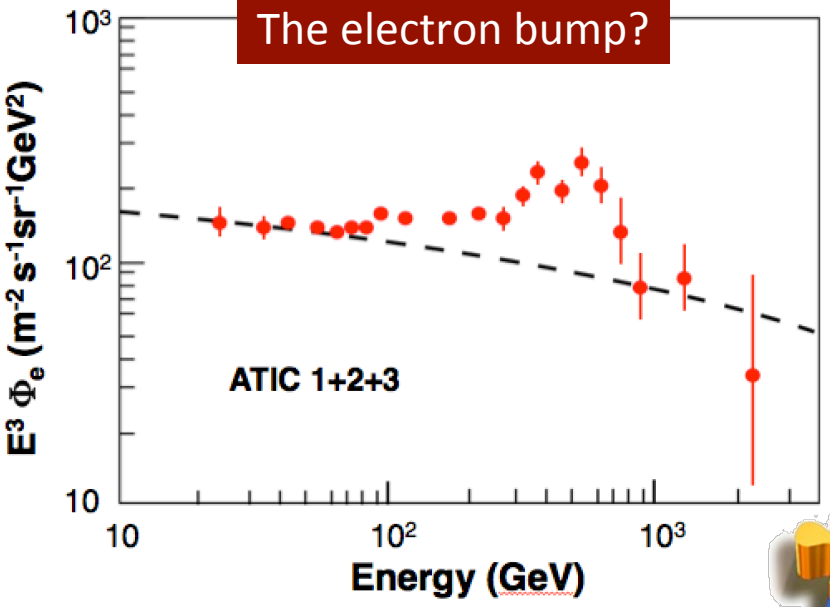


Diffusion
Convection
Reacceleration

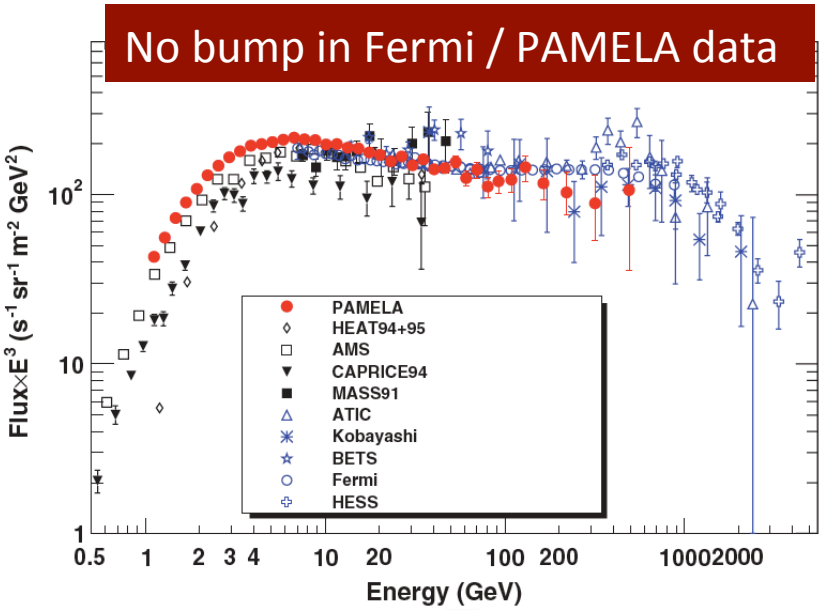
Interactions with the Interstellar Medium (ISM):
- Fragmentation
- Secondaries
- Energy loss

The Physics: DM/exotic sources

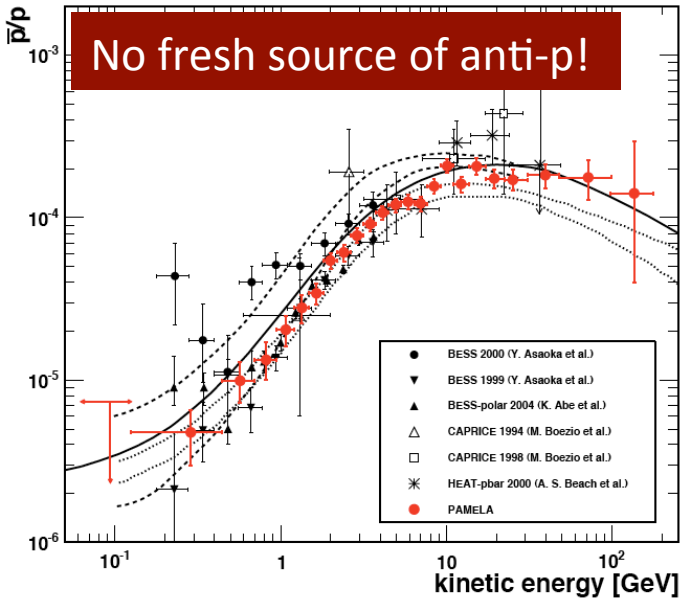
The electron bump?



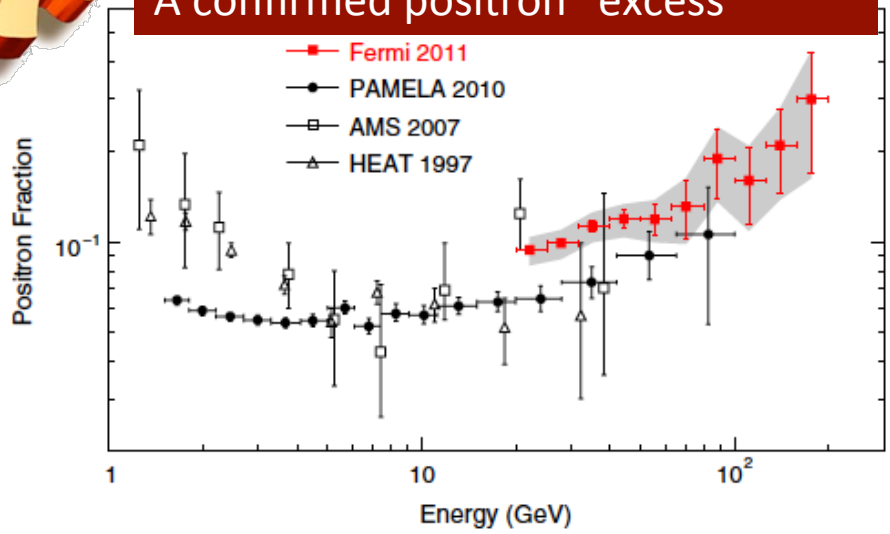
No bump in Fermi / PAMELA data



No fresh source of anti-p!



A confirmed positron "excess"



The Physics: DM/exotic sources

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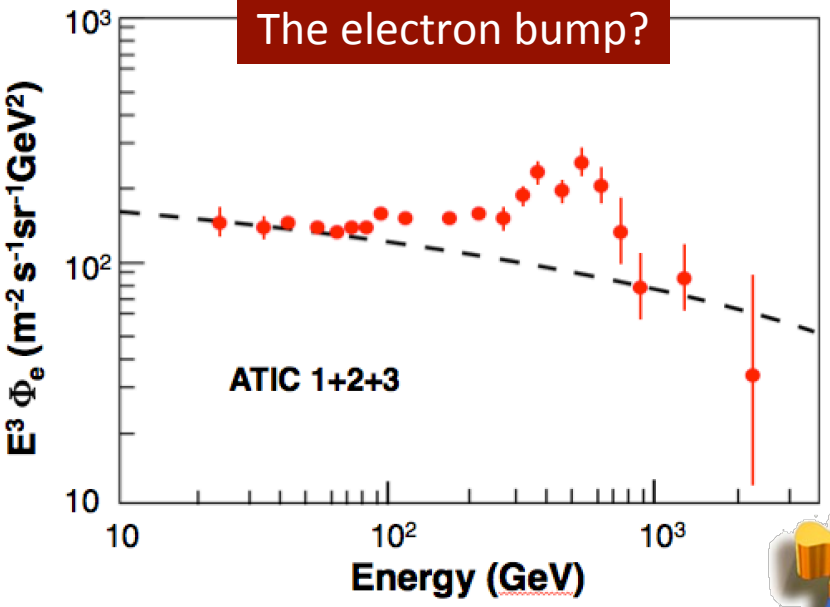

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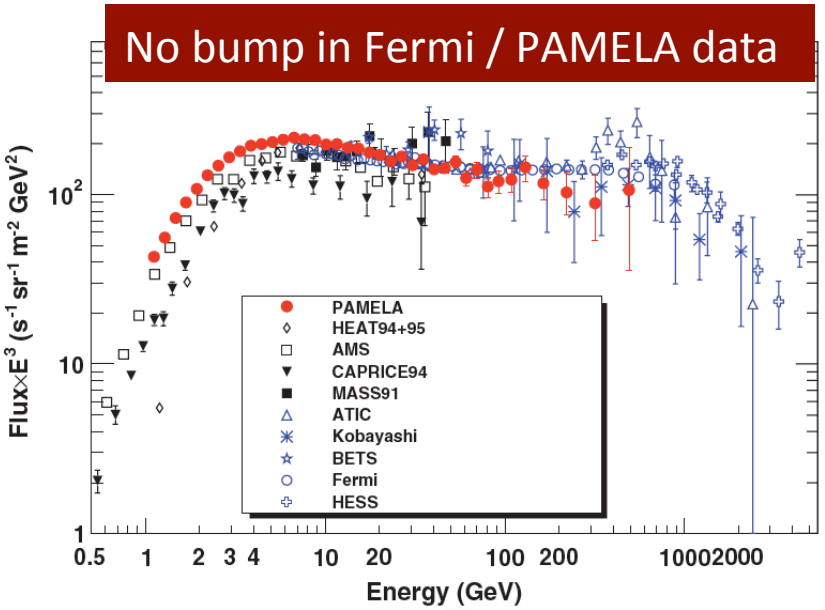

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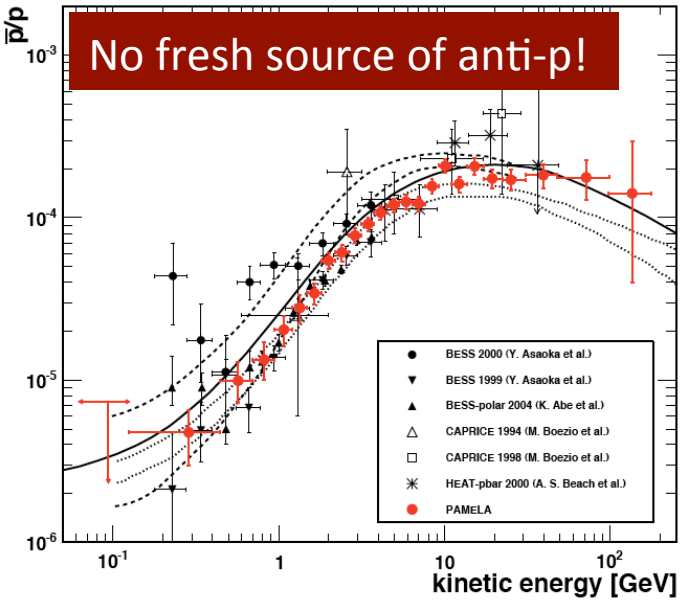

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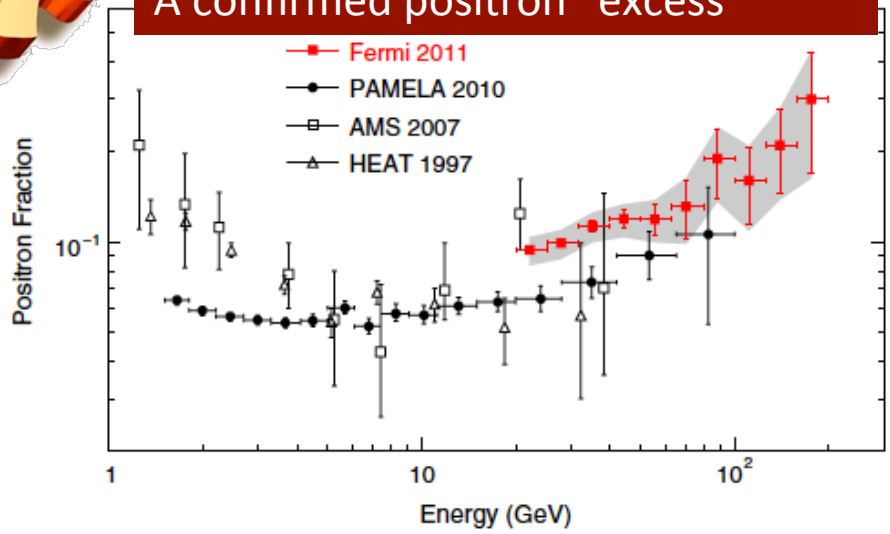
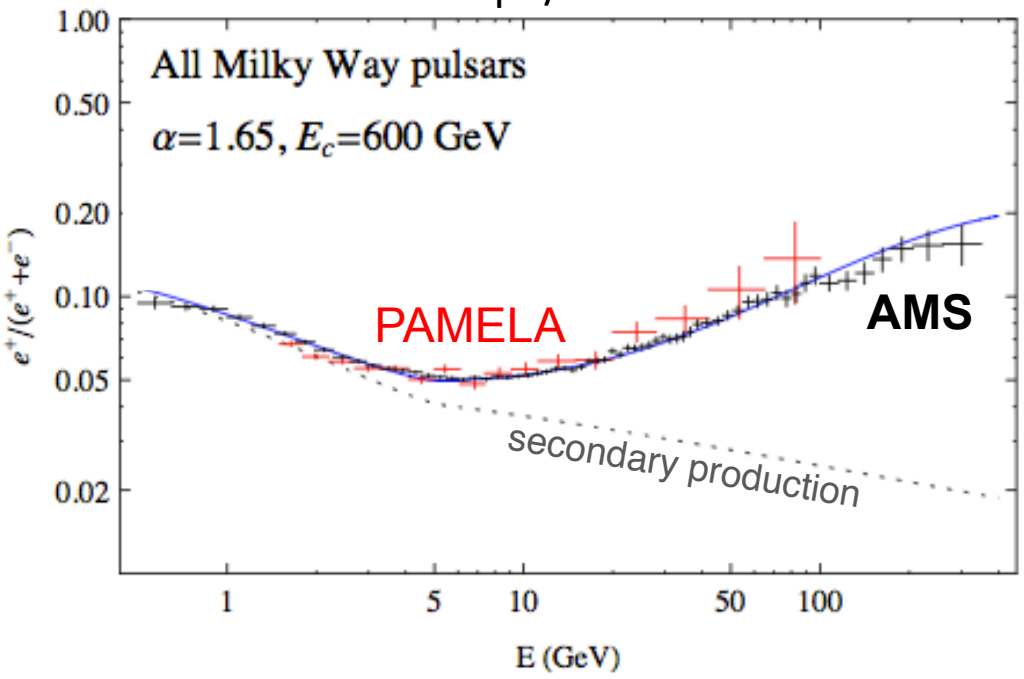


Origin of the excess

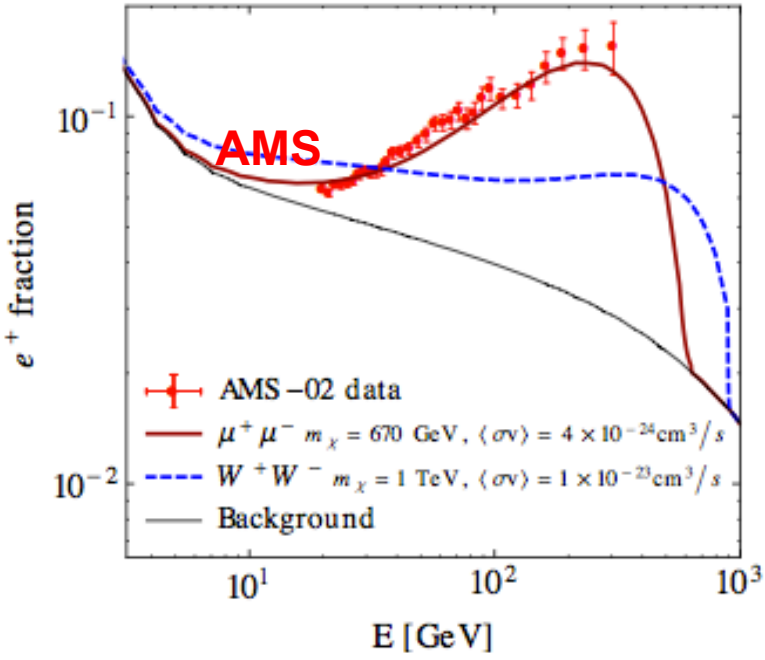
Astrophysical objects

Cholis arXiv: astro-ph/1304.1840



Dark Matter

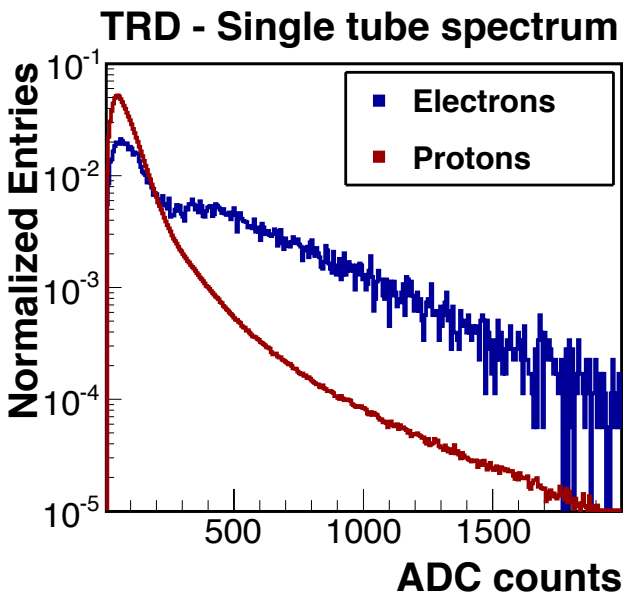
Kopp hep-ph/1304.1184

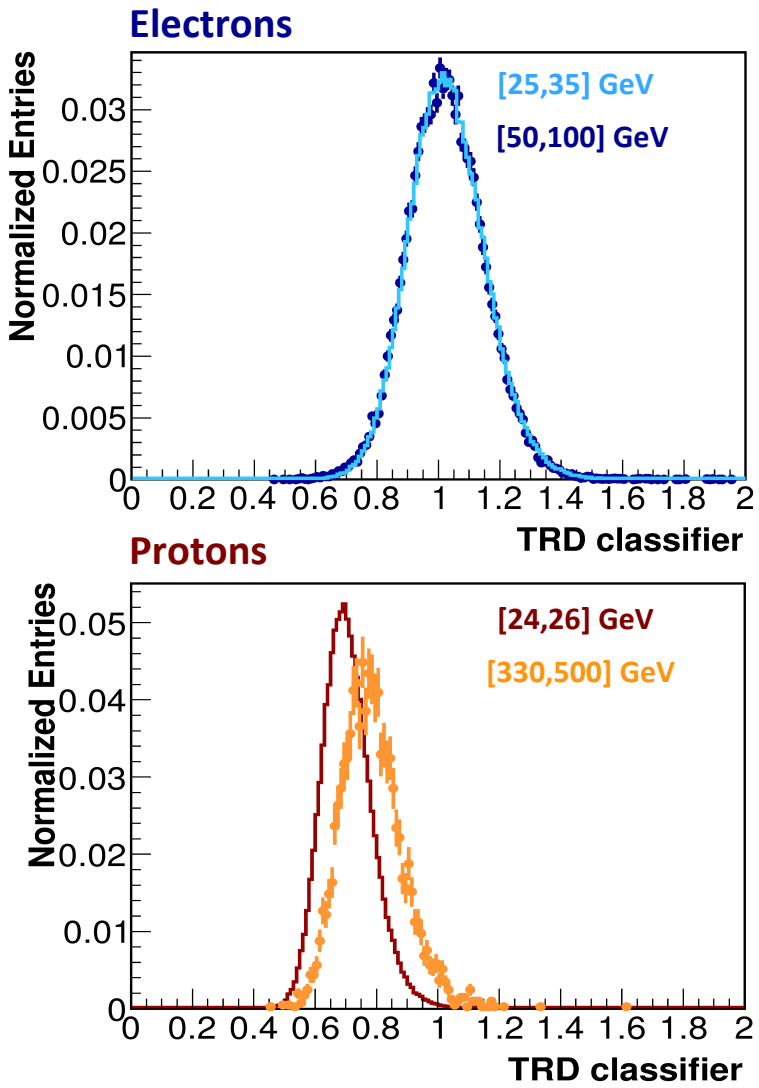


Different energy behavior of the positron fraction:

- **Pulsars predictions:**
  - **slow fall at high energies**
  - **anisotropic positron flux**
- **Dark Matter prediction:**
  - **steeper fall at high energies**
  - **isotropic positron flux**

e/p separation with TRD





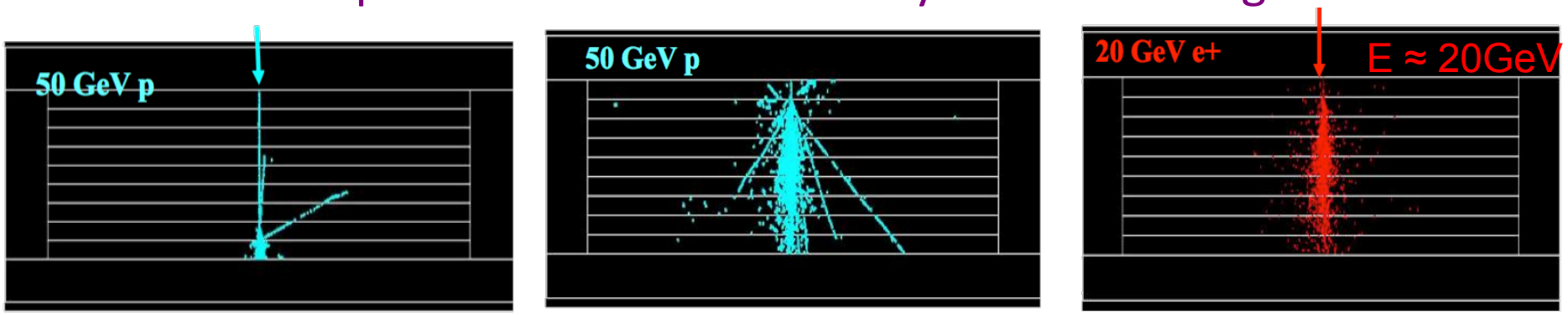
Combined Probability to be electron :

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

TRD-Classifier = $-\mathrm{Log}_{10}(P_e)-2$

e/p separation with ECAL

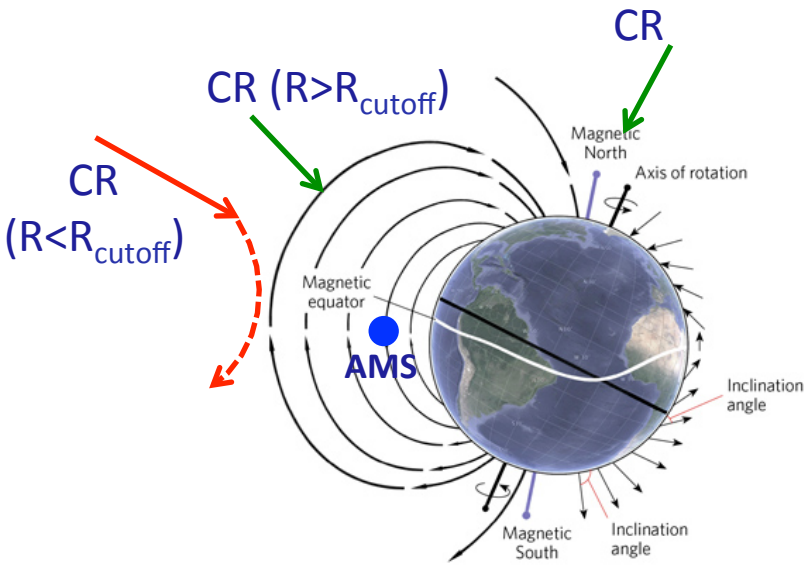
electrons and protons behave differently when entering the ECAL

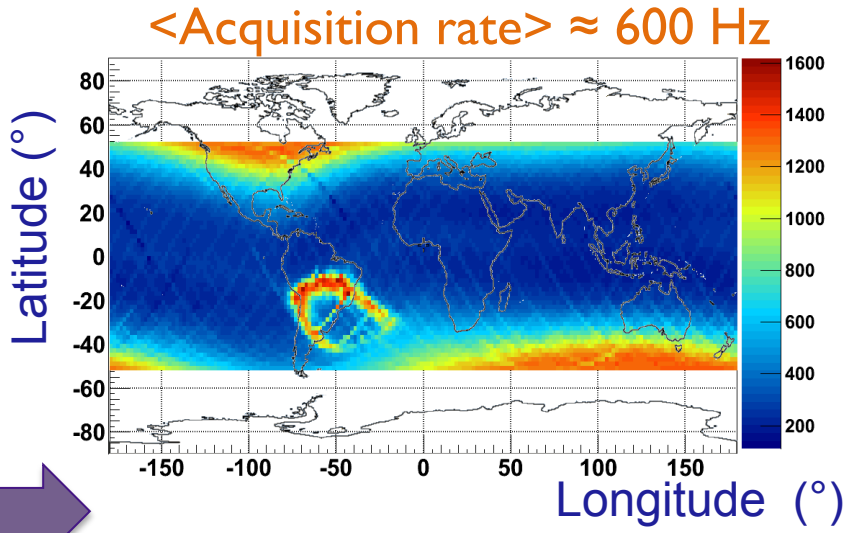


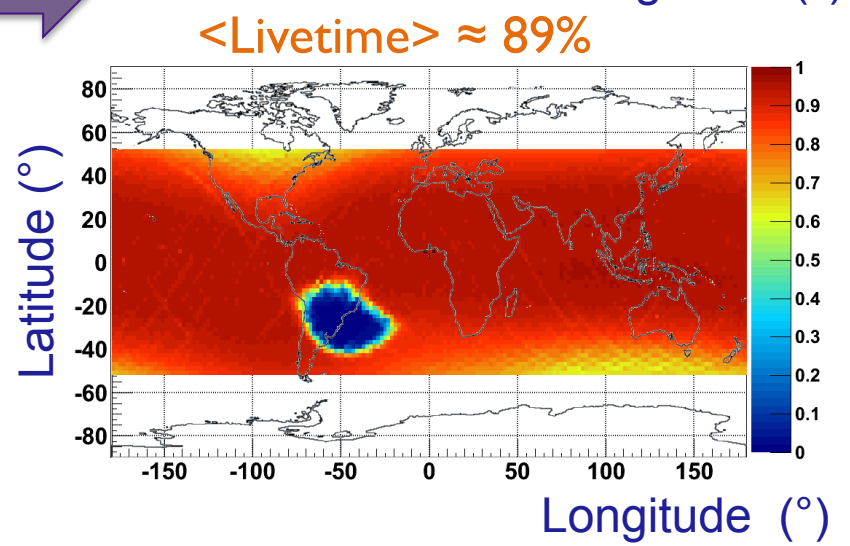
Two complementary techniques can exploit electron/proton differences in ECAL

1) Matching measured momentum in tracker with the deposited energy in ECAL [not used for event selection, but to select control samples]
2) 3D imaging of the energy shower allows to discriminate electron or proton initiated showers [ECAL classifier, used to preselect events for further analysis]

Exposure time : geomagnetic effects





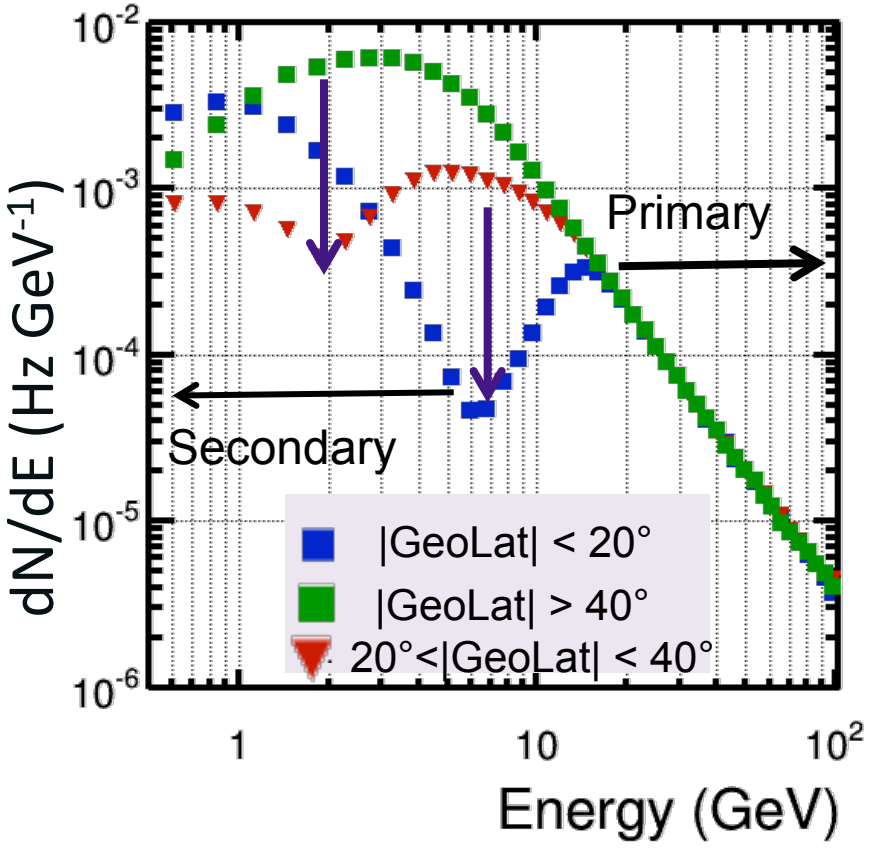


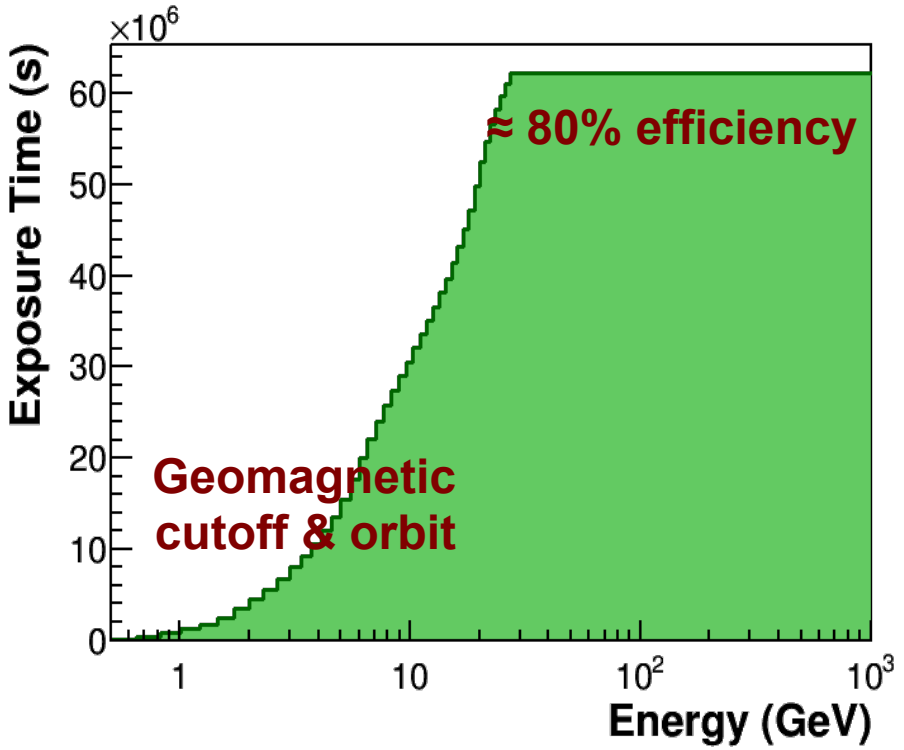
Effect on data taking:

- **Reduced livetime**: in South Atlantic Anomaly region and close to geomagnetic poles.

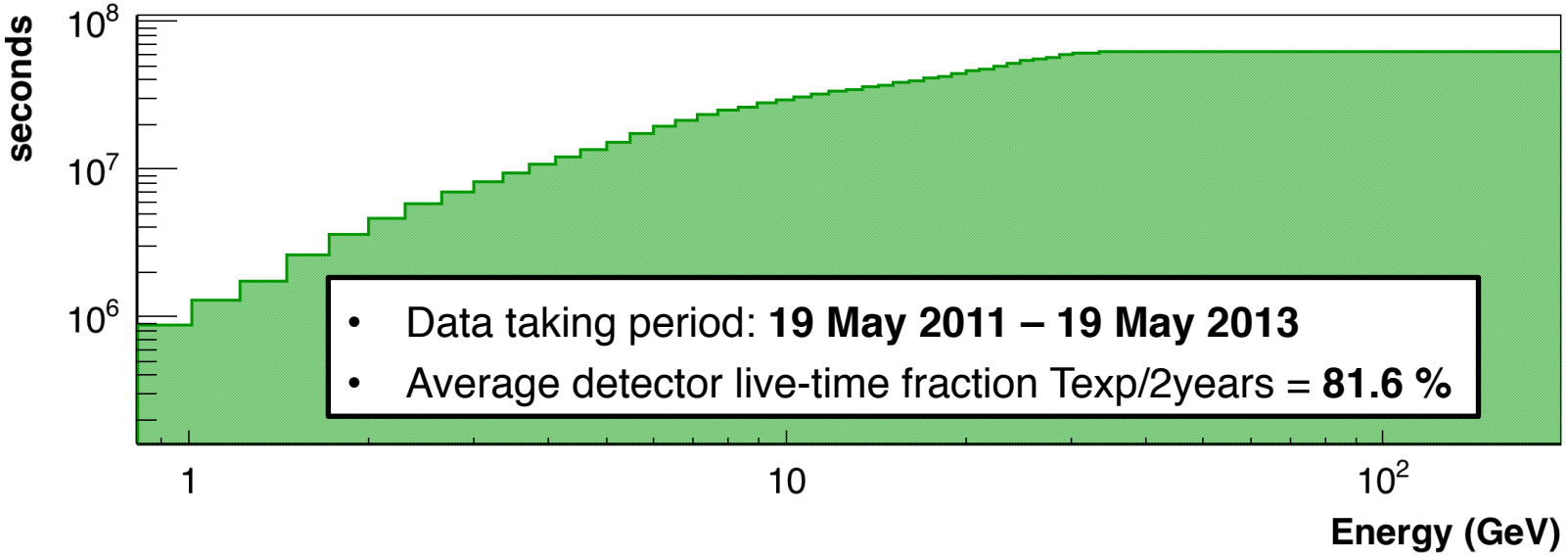
Exposure time : geomagnetic effects

The exposure time to a given energy along the orbit is performed only considering the time spent in the regions where the rigidity cutoff used in the event selection is lower than the energy.

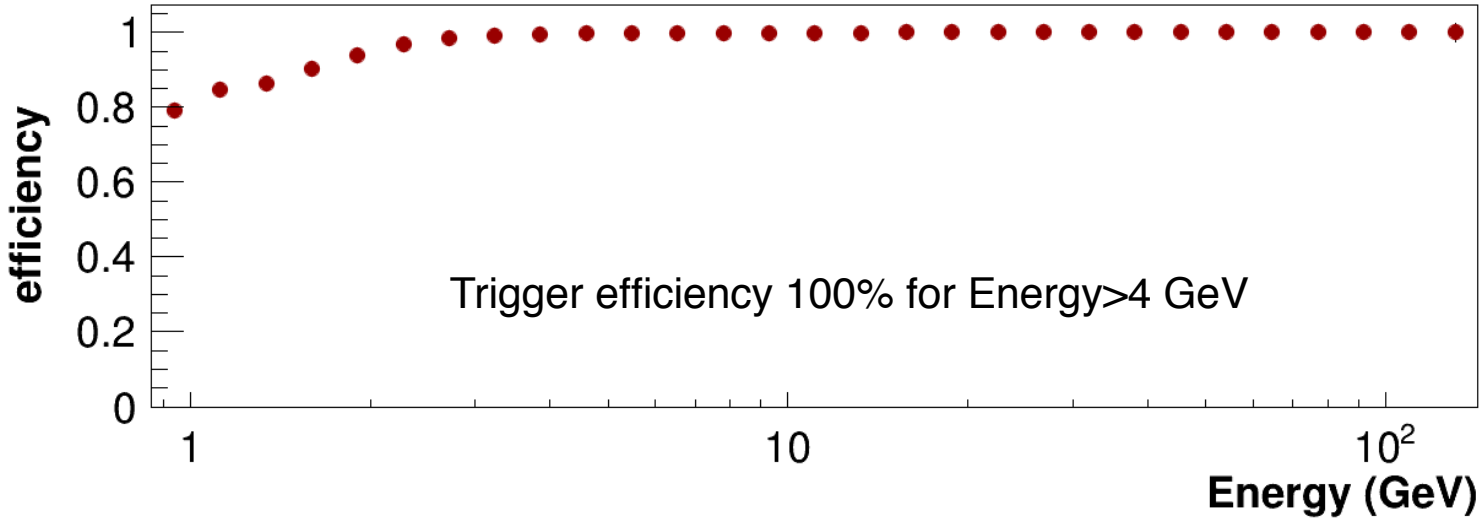




2. Exposure Time



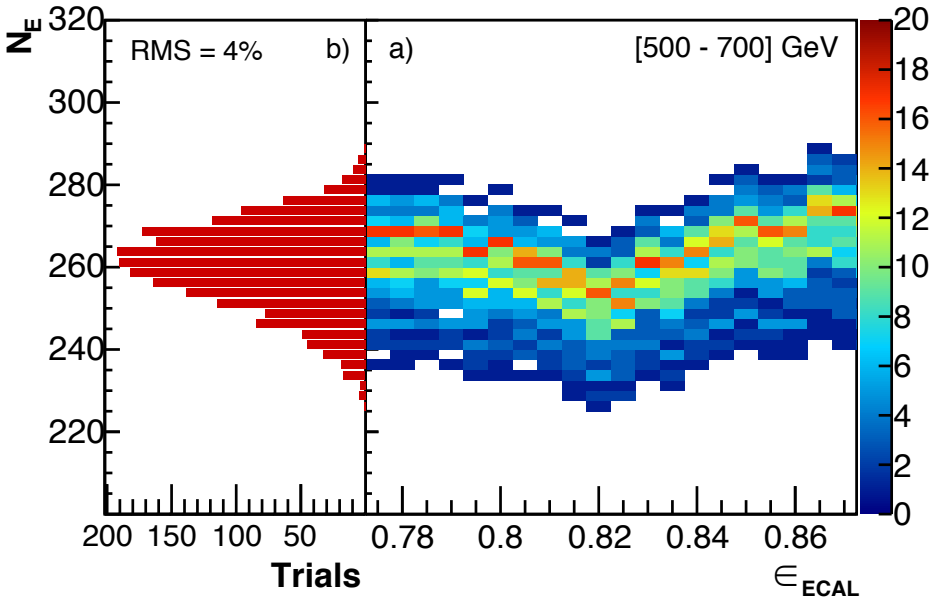
3. Trigger Efficiency



Systematic errors: stability of the signal

Dominating systematic uncertainties on $N_{e^+ + e^-}$

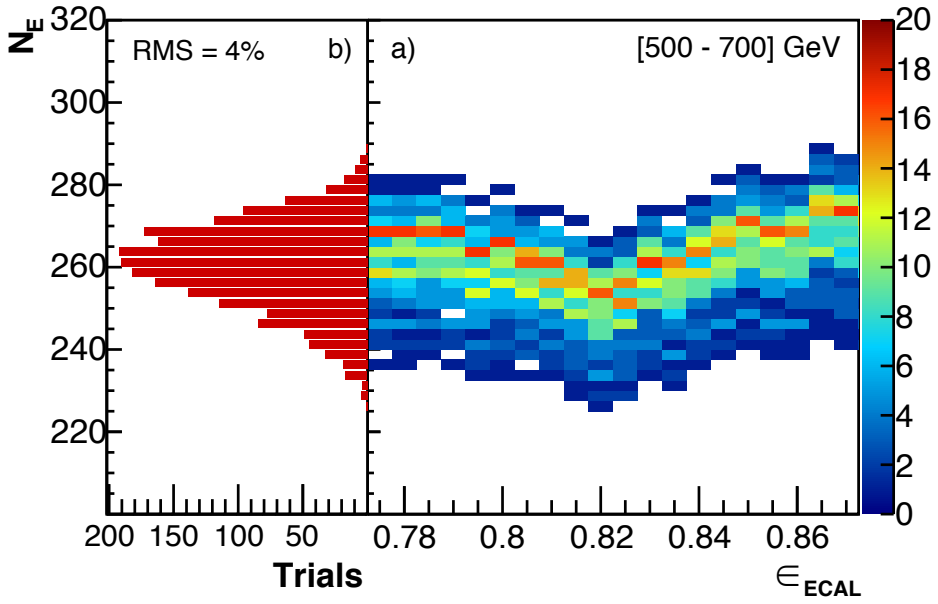
- **Knowledge of the TRD reference distributions**
- **Stability of the fit result for different background levels, e.g. ECAL classifier cuts**



The analysis was repeated 2000 times in each energy bin varying the ECAL classifier cut and different values of selection cuts used to construct the templates and the stability of the results verified within a 5% window in ECAL classifier cut efficiency

Systematic errors: stability of the signal

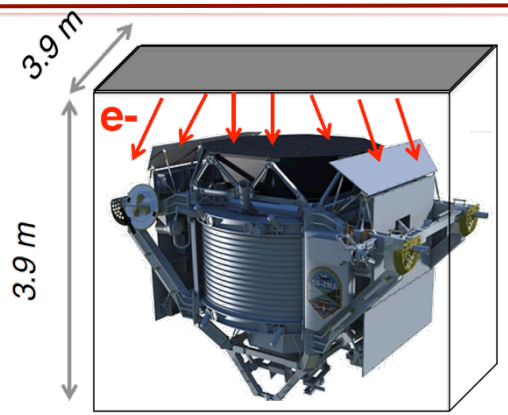
The RMS of the N_e as been used as systematics uncertainty, the effect of purely statistical contributions were taken into account and subtracted estimated from a dedicated simulation.



Negligible contribution to the measurement error below ≈ 200 GeV
Dominant source of systematic error at higher energies (> 500 GeV)

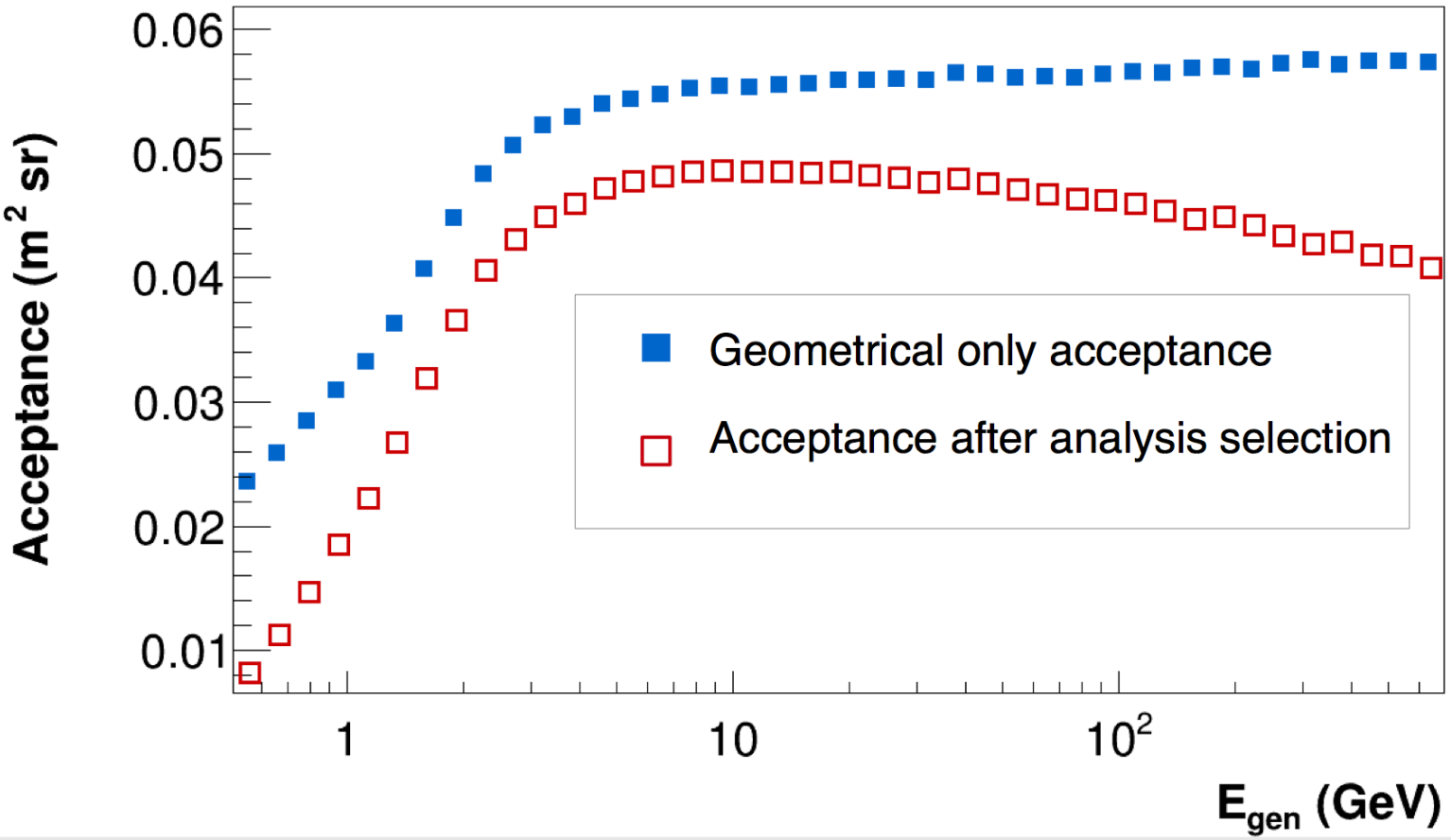
4. Acceptance

$A_{eff}(\Delta E, \Delta t) = A_{geom} \cdot \epsilon_{sel} \cdot (1 + \delta)$



evaluated from MC:

$$A_{MC}(\Delta E) = \frac{N_{sel}(\Delta E)}{N_{gen}(\Delta E)} \pi l^2$$

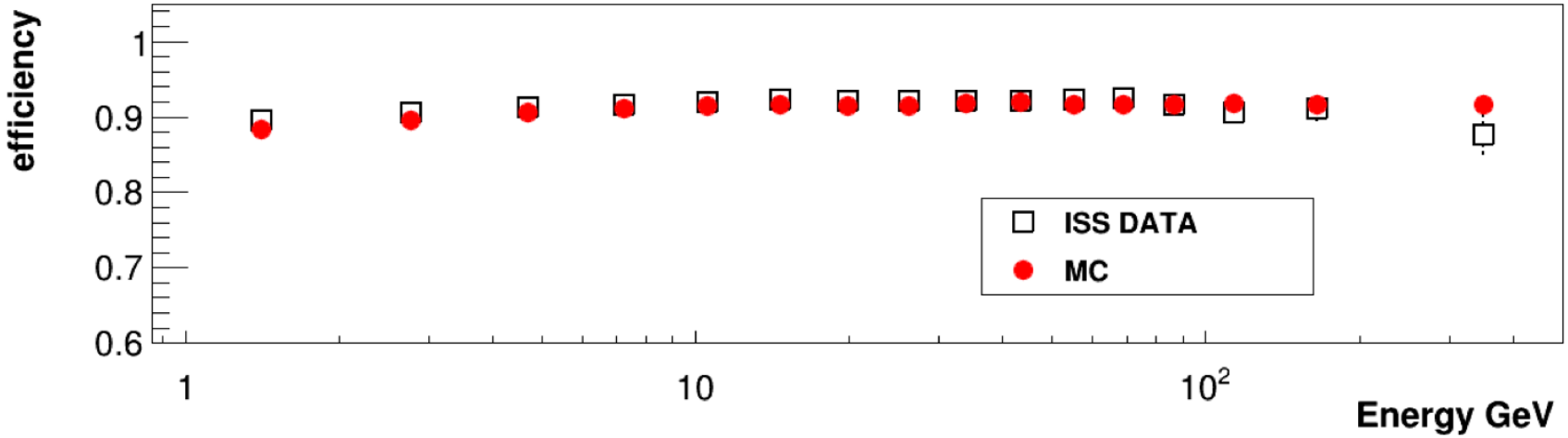


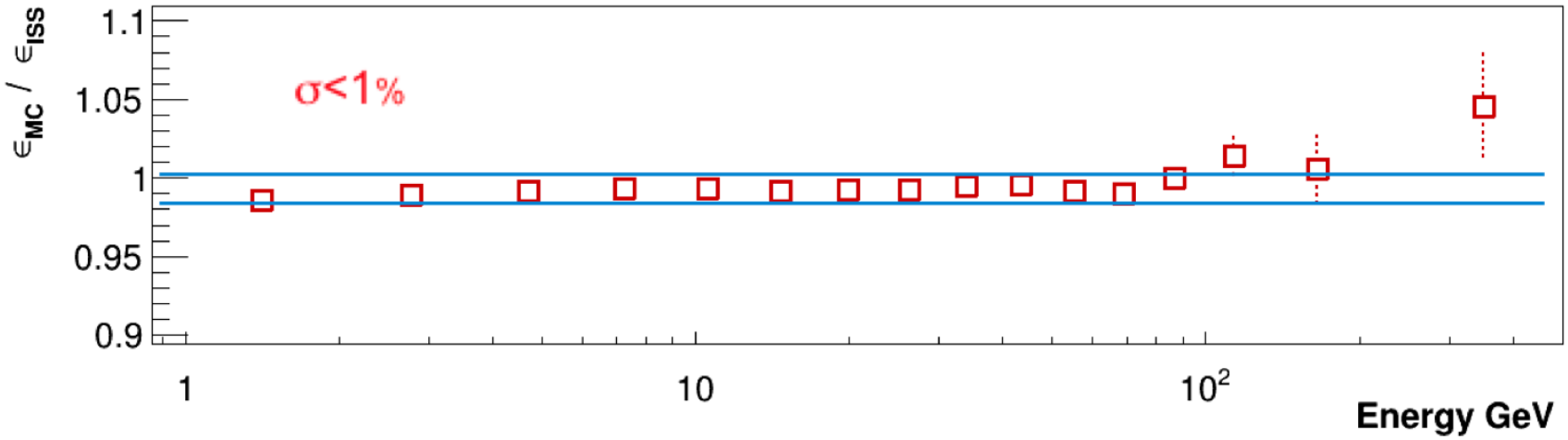
4. Acceptance correction 1+δ

$A_{eff}(\Delta E) = A_{geom} \cdot \epsilon_{sel} \cdot (1+\delta)$

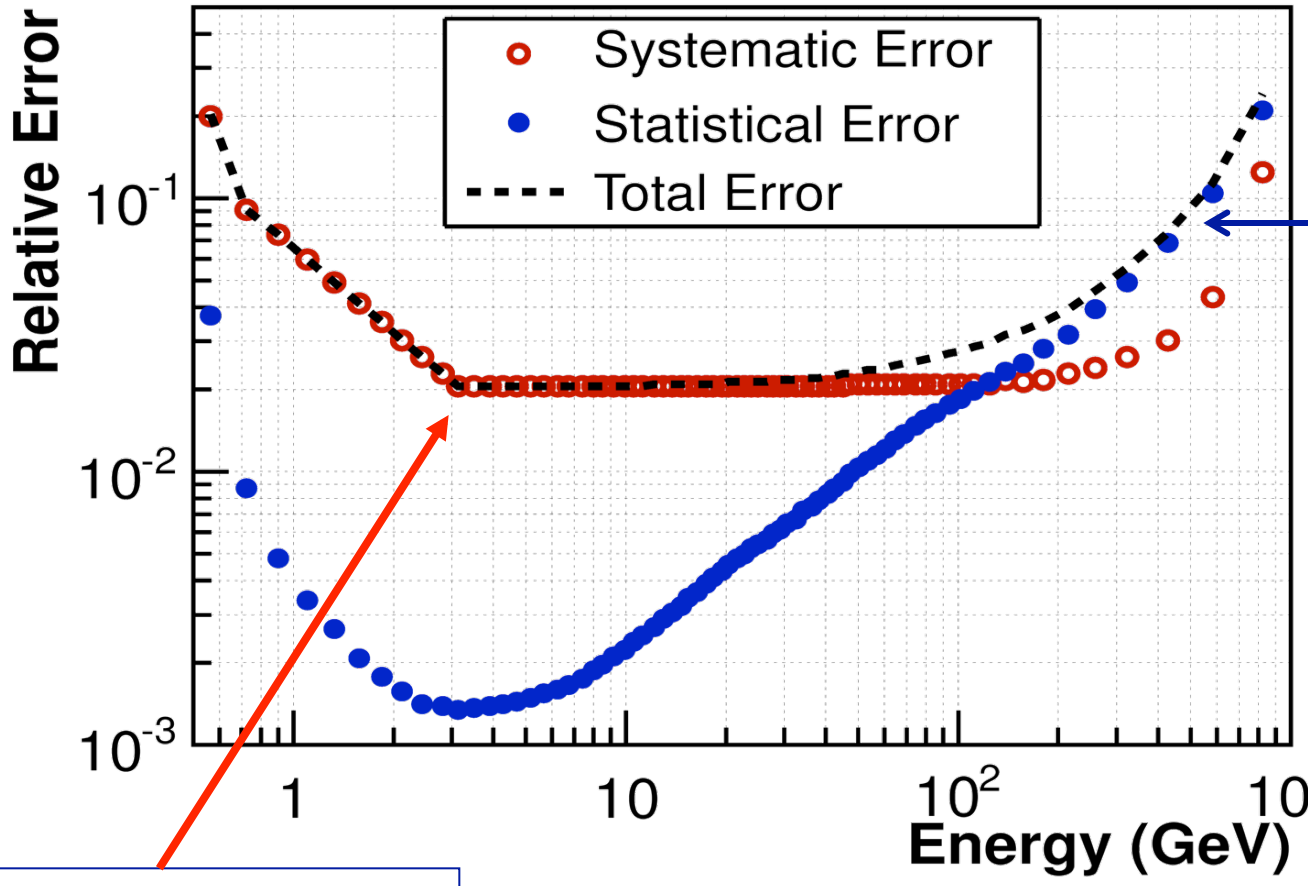
Evaluated via the disagreement in the selection efficiency between data and MC for each analysis cut

example: TRD reconstruction quality





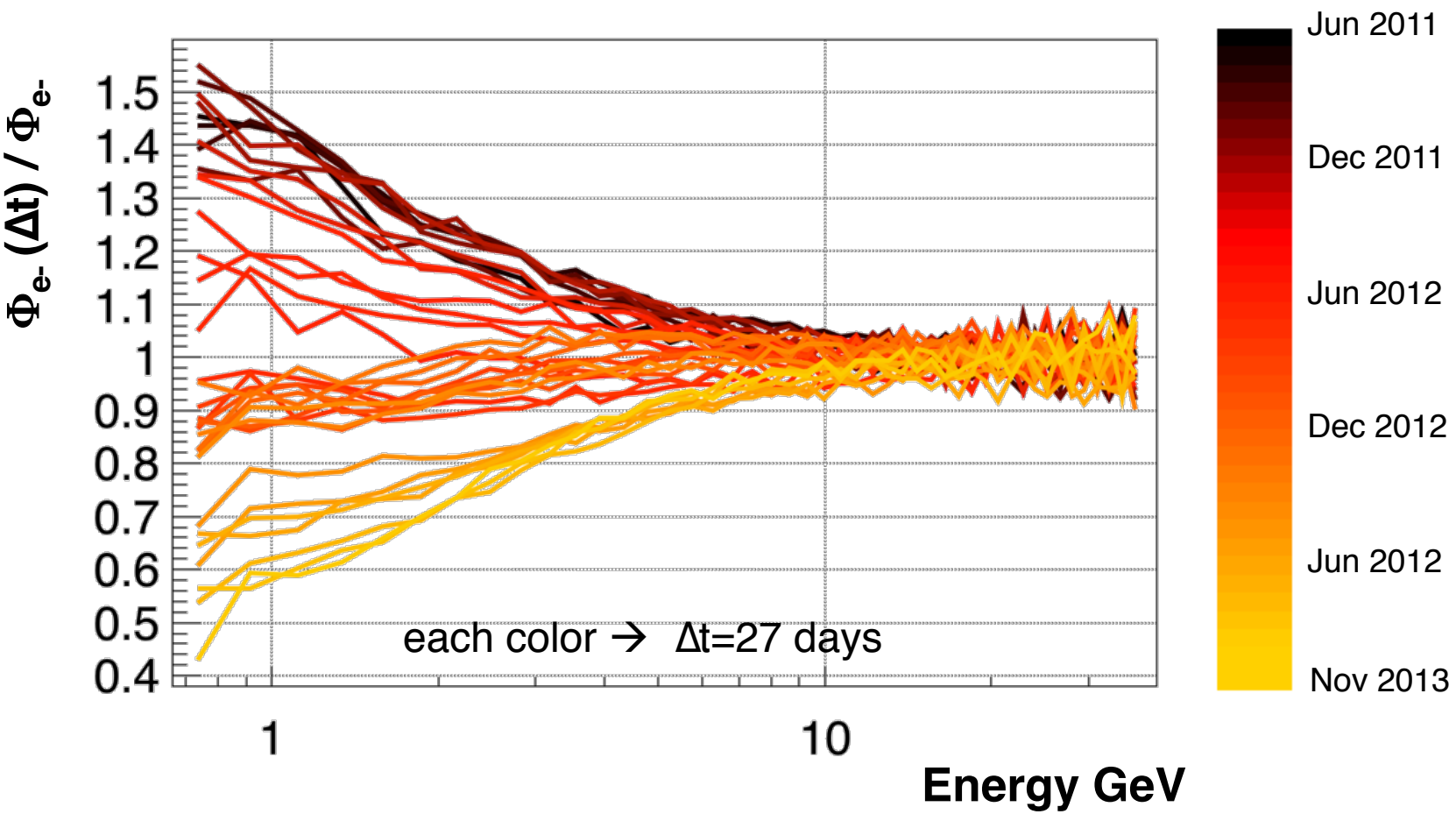
Measurement error



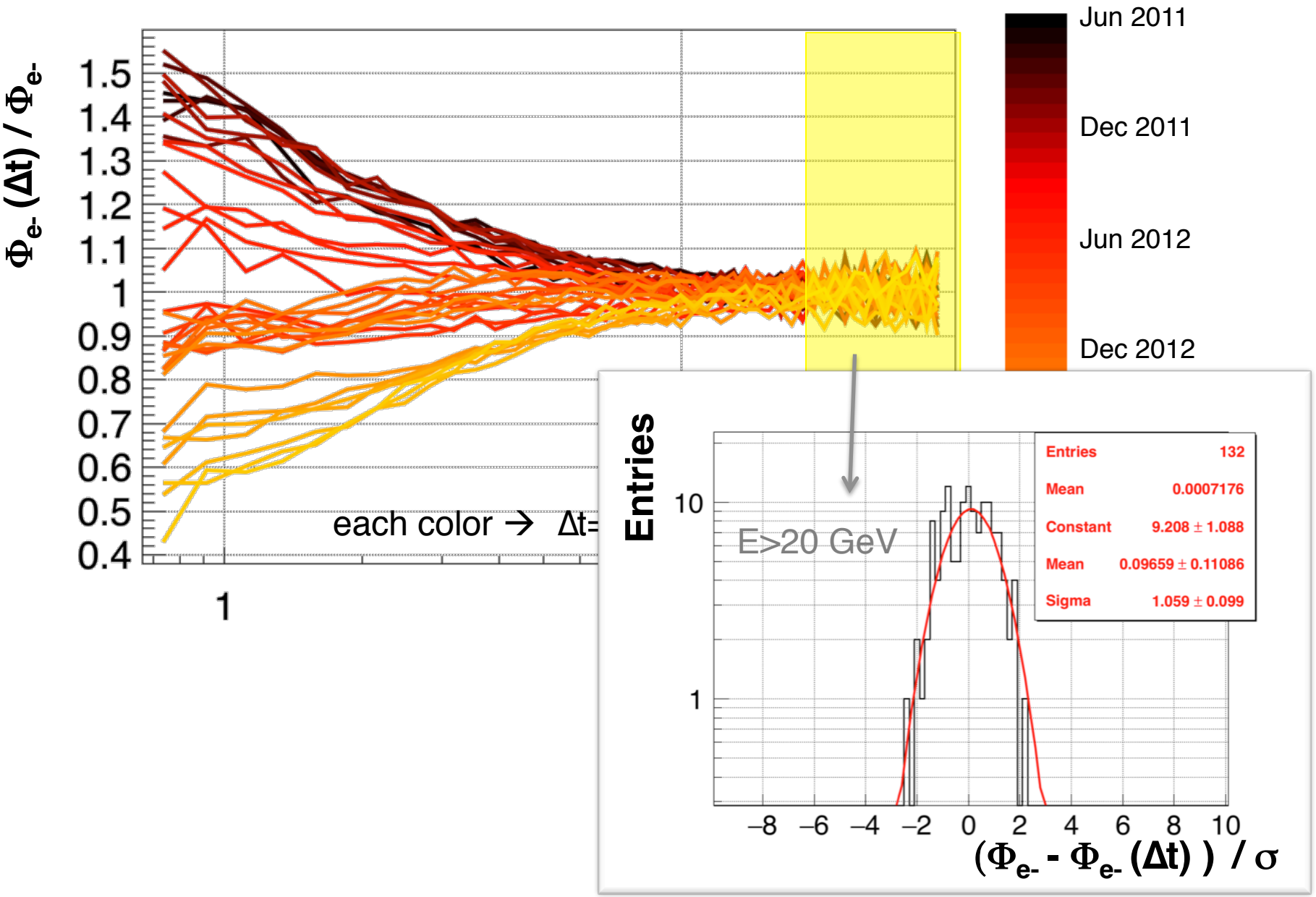
Dominated by acceptance systematics below ≈100 GeV

Dominated by statistics above 130 GeV. Finite Statistics of reference distributions in the fit are the major source of systematics. With more data both errors will decrease.

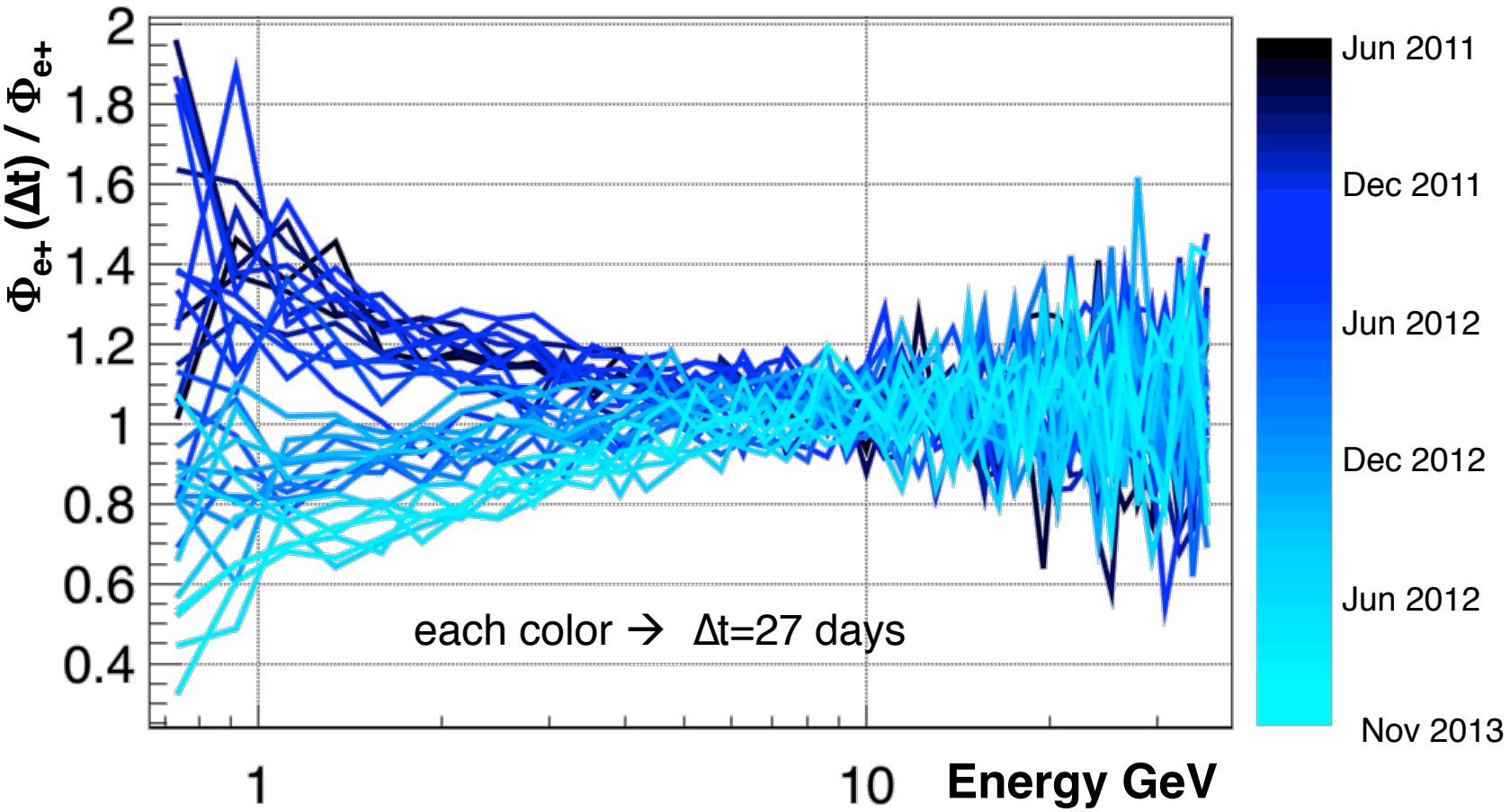
Solar modulation of CR – e^- flux result



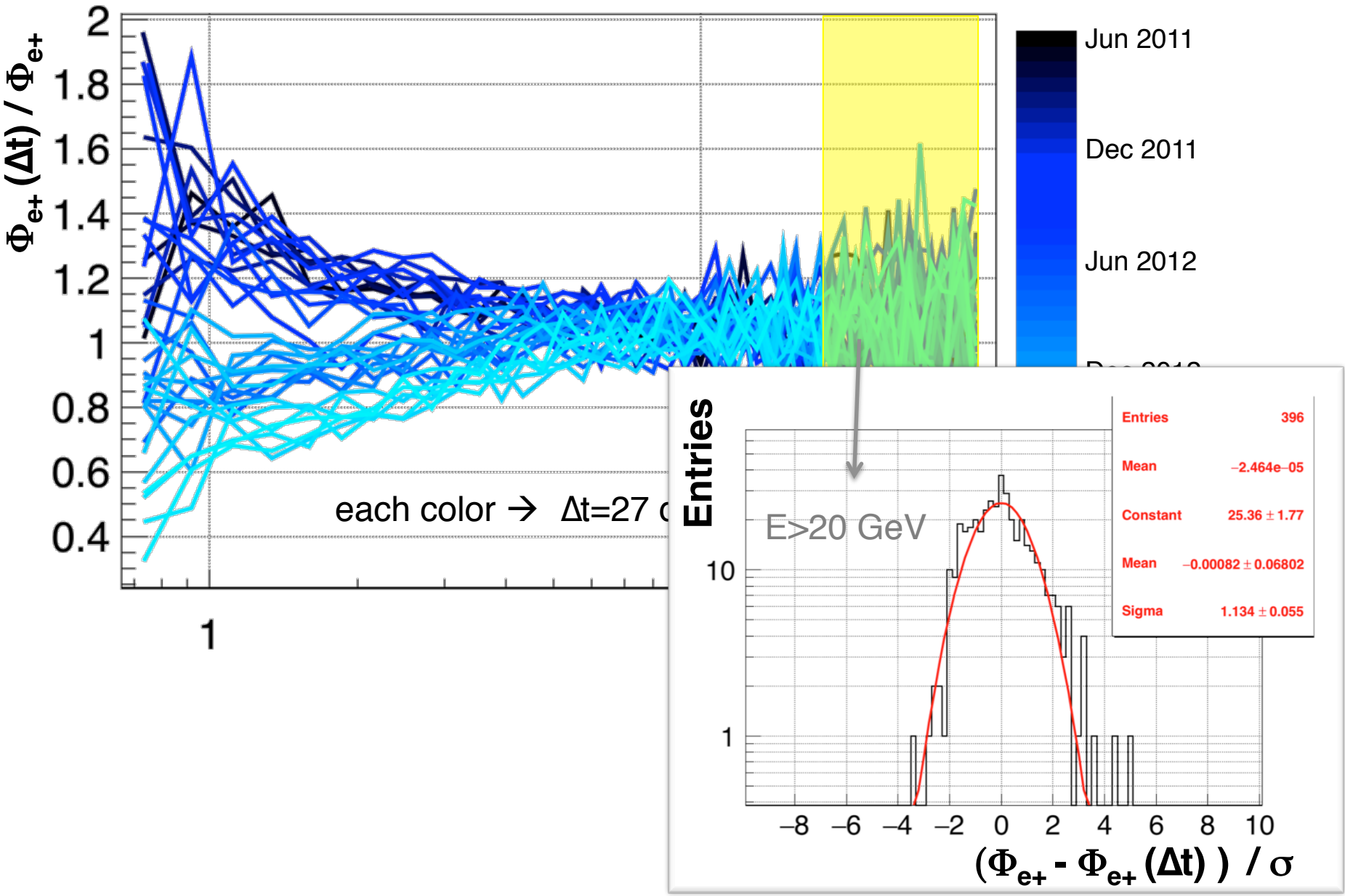
Solar modulation of CR – e^- flux result

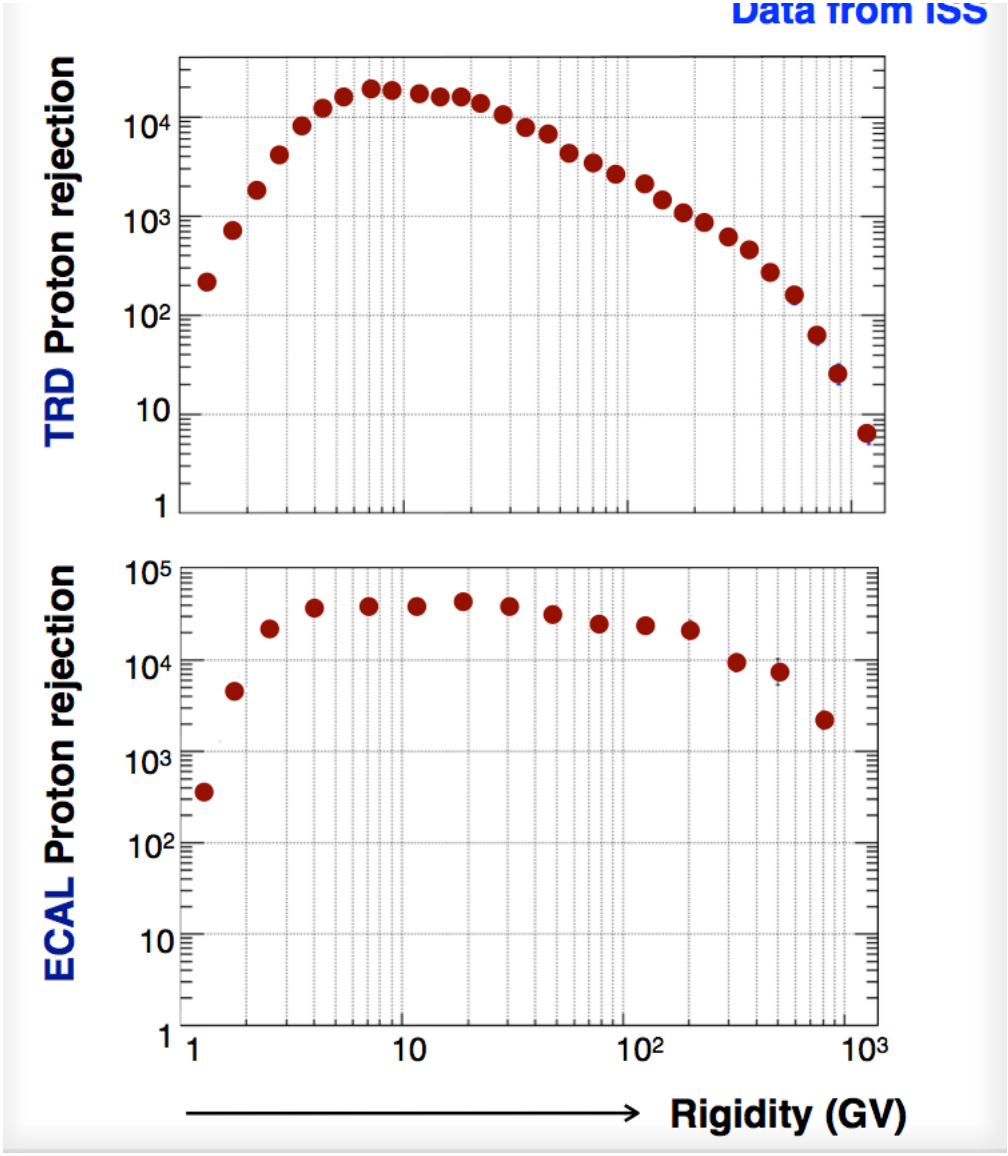


Solar modulation of CR – e^- flux result



Solar modulation of CR – e^- flux result




Data from ISS
TRD Proton rejection
10^4
10^3
10^2
10
1
ECAL Proton rejection
10^5
10^4
10^3
10^2
10
1
1
10
10^2
10^3
Rigidity (GV)