Monash Centre for Astrophysics

ARC Centre of Excellence for Particle Physics at the Terascale

On the cosmic $e^{\pm}$ anomaly

Auchettl, Balázs Ap. J. 749 (2012) 184 (arXiv:1106.4138)

See also

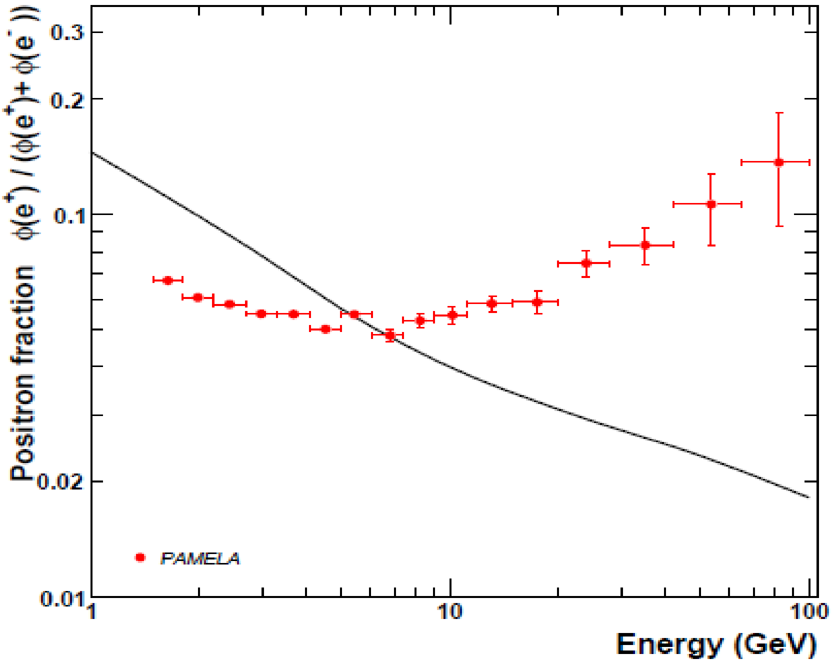
Liu et al. Phys.Rev.D81 (2010) 023516

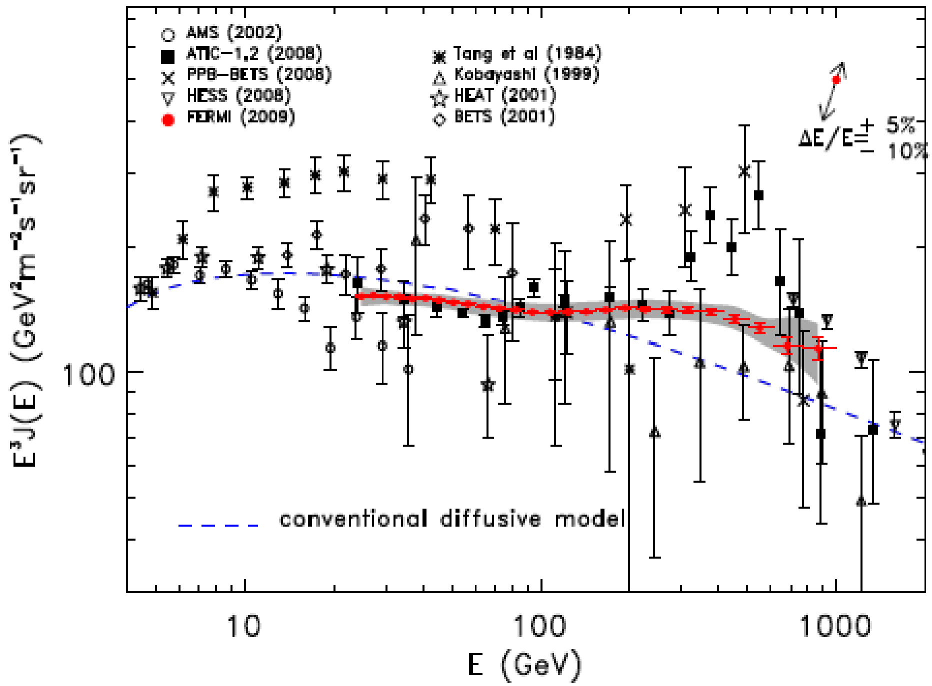
Trotta et al. Astrophys.J.729 (2011) 106

Liu et al. arXiv:1106.3882

PAMELA & Fermi-LAT

Anomalous $e^{\pm}$ flux measurements





PAMELA: Observation of an *anomalous* positron abundance in the cosmic radiation

arXiv:0810.4995

Fermi: Measurement of the Cosmic Ray e^++e^- spectrum from 20 GeV to 1 TeV with the Fermi LAT

arXiv:0905.0025

PAMELA & Fermi-LAT

Anomalous $e^{\pm}$ flux measurements

Is this 'real'?

Is this new physics?

Is this dark matter?

PAMELA & Fermi-LAT

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Anomalous $e^{\pm}$ fluxes

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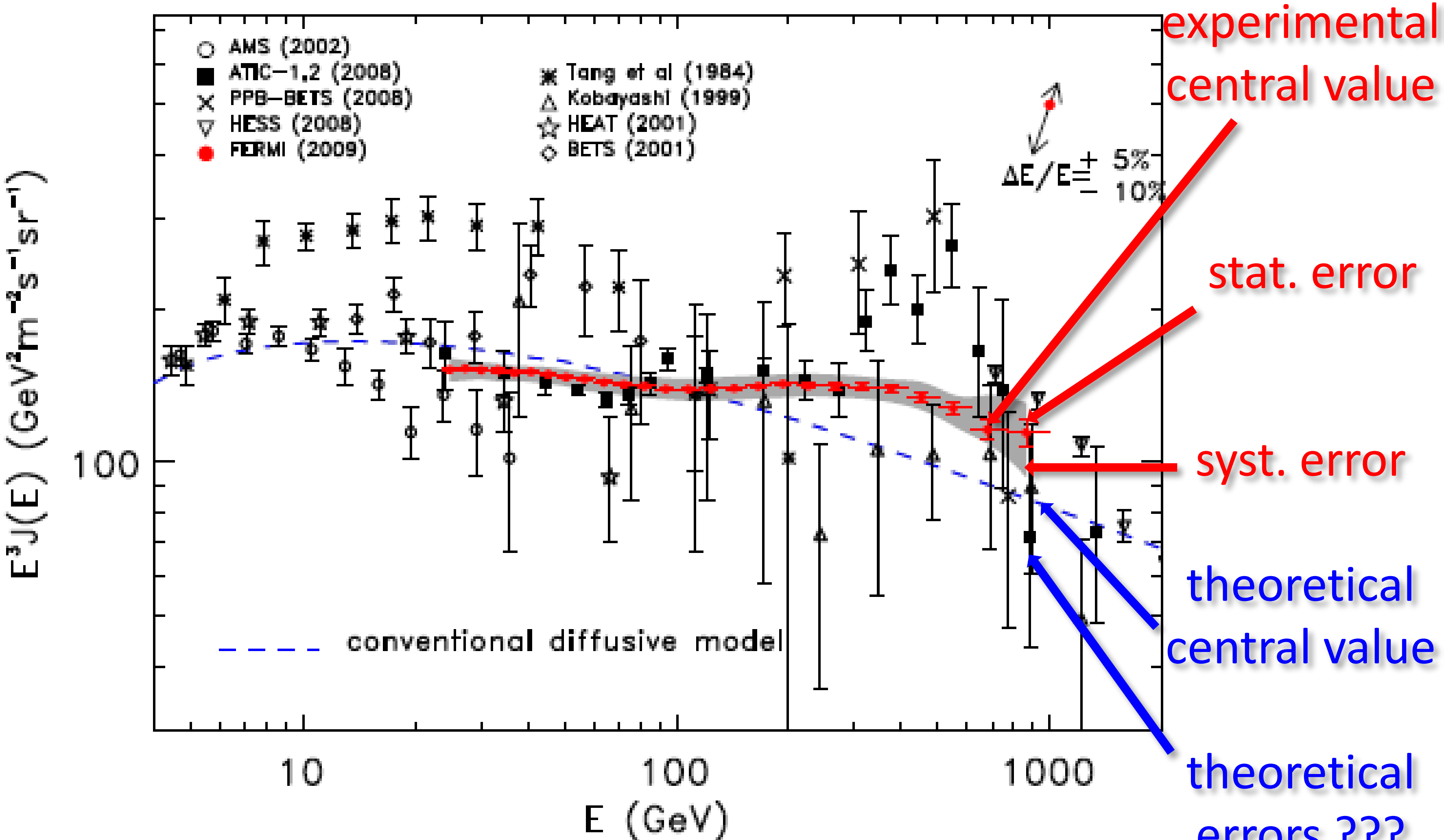
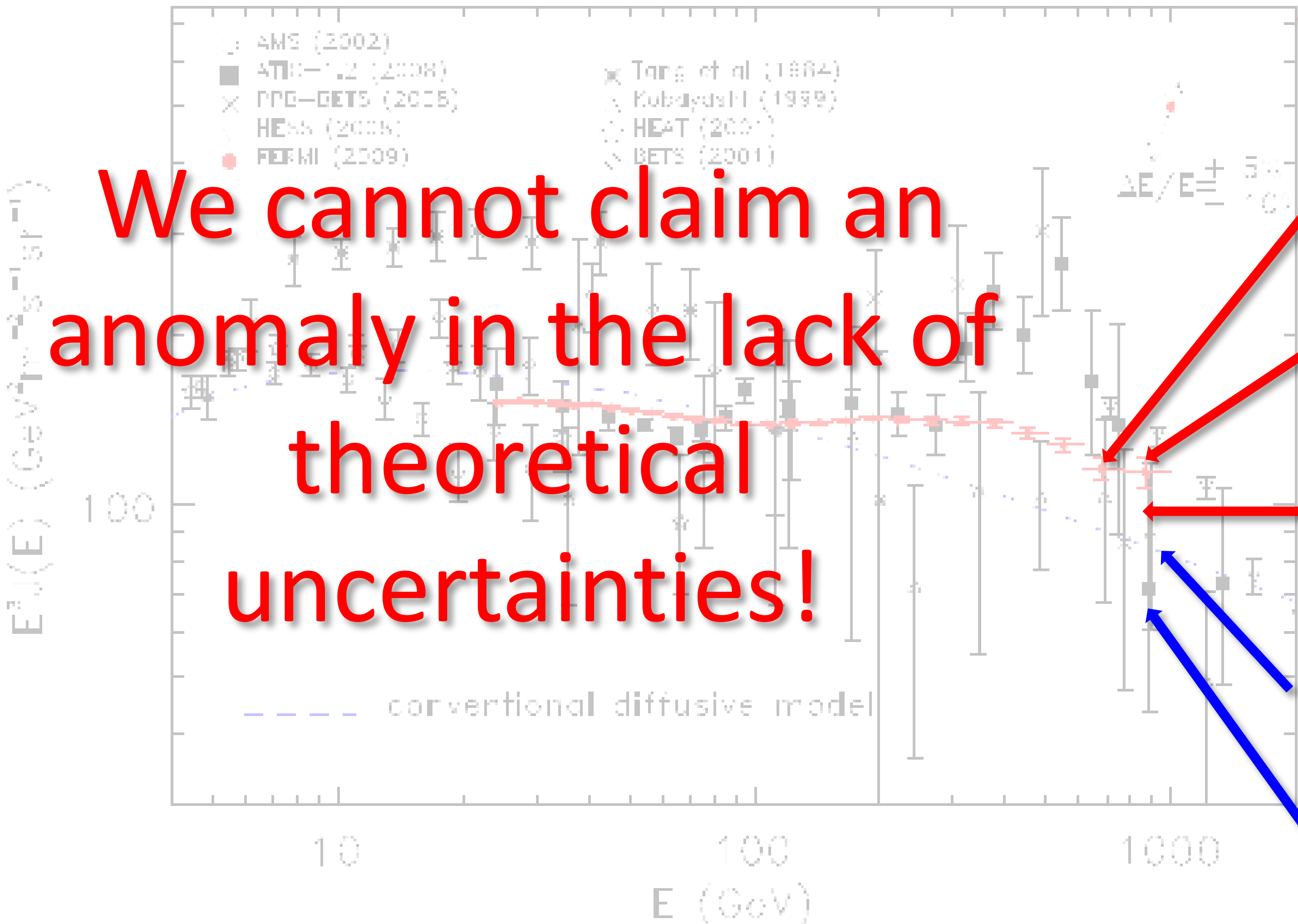


Anomalous $e^{\pm}$ fluxes

Is there an anomaly?



We cannot claim an anomaly in the lack of theoretical uncertainties!

experimental central value

stat. error

syst. error

theoretical central value

theoretical errors ???

Cosmic ray propagation

$$\frac{\partial \psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi - \vec{V}\psi) + \frac{\partial}{\partial p}\left(p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi\right) - \frac{\partial}{\partial p}\left(\dot{p}\psi - \frac{p}{3}(\vec{\nabla}\cdot\vec{V})\psi\right) - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

$$D_{xx} = D_{0xx}\beta\left(\frac{R}{\mathrm{GeV}}\right)^{\delta} \qquad D_{0xx} = \frac{2c(1-\delta)L^{1-\delta}}{3\pi w\delta(\delta+2)}$$

$$D_{pp}D_{xx} = \frac{4p^2 {v_A}^2}{3\delta(4-\delta^2)(4-\delta)w}$$

Cosmic ray propagation

$$\frac{\partial\psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi - \vec{V}\psi) + \frac{\partial}{\partial p}\left(p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi\right) - \frac{\partial}{\partial p}\left(\dot{p}\psi - \frac{p}{3}(\vec{\nabla}\cdot\vec{V})\psi\right) - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

O(100) ***propagation parameters***

Their values have to be fixed to predict the $e^{\pm}$ flux; ***uncertainties unknown***

$$D_{xx} = D_{0xx}\beta\left(\frac{R}{\mathrm{GeV}}\right)^{\delta} \qquad D_{0xx} = \frac{[illegible](1-\delta)L^{1-\delta}}{3\pi w\delta(\delta+2)}$$

Bayesian parameter inference using cosmic ray data → most preferred values of parameters & uncertainties

$$D_{pp}D_{xx} = \frac{4p^2 v_A^2}{3\delta(4-\delta^2)(4-\delta)w}$$

Theoretical parameter inference

The $e^{\pm}$ flux is mostly sensitive to the following propagation parameters:

$$P = \{\gamma^e, \gamma^n, \delta_1, \delta_2, D_{0xx}\}$$

γ^e, γ^n electron and nucleus injection indices

δ_1, δ_2 spatial diffusion coefficients below and above ref. rigidity

D_{0xx} normalization of spatial diffusion coefficient

Using 219 cosmic ray spectral data points, we infer the posterior probability distributions of these parameters

Theoretical parameter inference

Cosmic ray data used:

Measured flux	Experiment	Energy (GeV)	Number of data points
$e^+ + e^-$	Fermi-LAT (Ackermann et al. 2010)	7.05 - 886	47
$e^+/(e^+ + e^-)$	PAMELA (Adriani et al. 2010a)	1.65 - 82.40	16
	AMS (Aguilar et al. 2002)	0.60 - 0.91	3
e^-	PAMELA (Adriani et al. 2011)	1.11 - 491.4	39
	HESS (Aharonian et al. 2008, 2009)	918 - 3480	9
antiproton/proton	PAMELA (Adriani et al. 2010b)	0.28 - 129	23
	IMP8 (Moskalenko et al. 2002)	0.03 - 0.11	7
	ISEE3 (Krombel & Wiedenbeck 1988)	0.12 - 0.18	6
Boron/Carbon	Lezniak & Webber (1978)	0.30 - 0.50	2
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	PAMELA (et al. 2008)	1.24 - 72.36	8
	CREAM (Ahn et al. 2008)	91 - 1433	3
(Sc+Ti+V)/Fe	ACE (Davis et al. 2000)	0.14 - 35	20
	SANRIKU (Hareyama 1999)	46 - 460	6
	Wiedenbeck & Greiner (1980)	0.003 - 0.029	3
	Garcia-Munoz et al. (1981)	0.034 - 0.034	1
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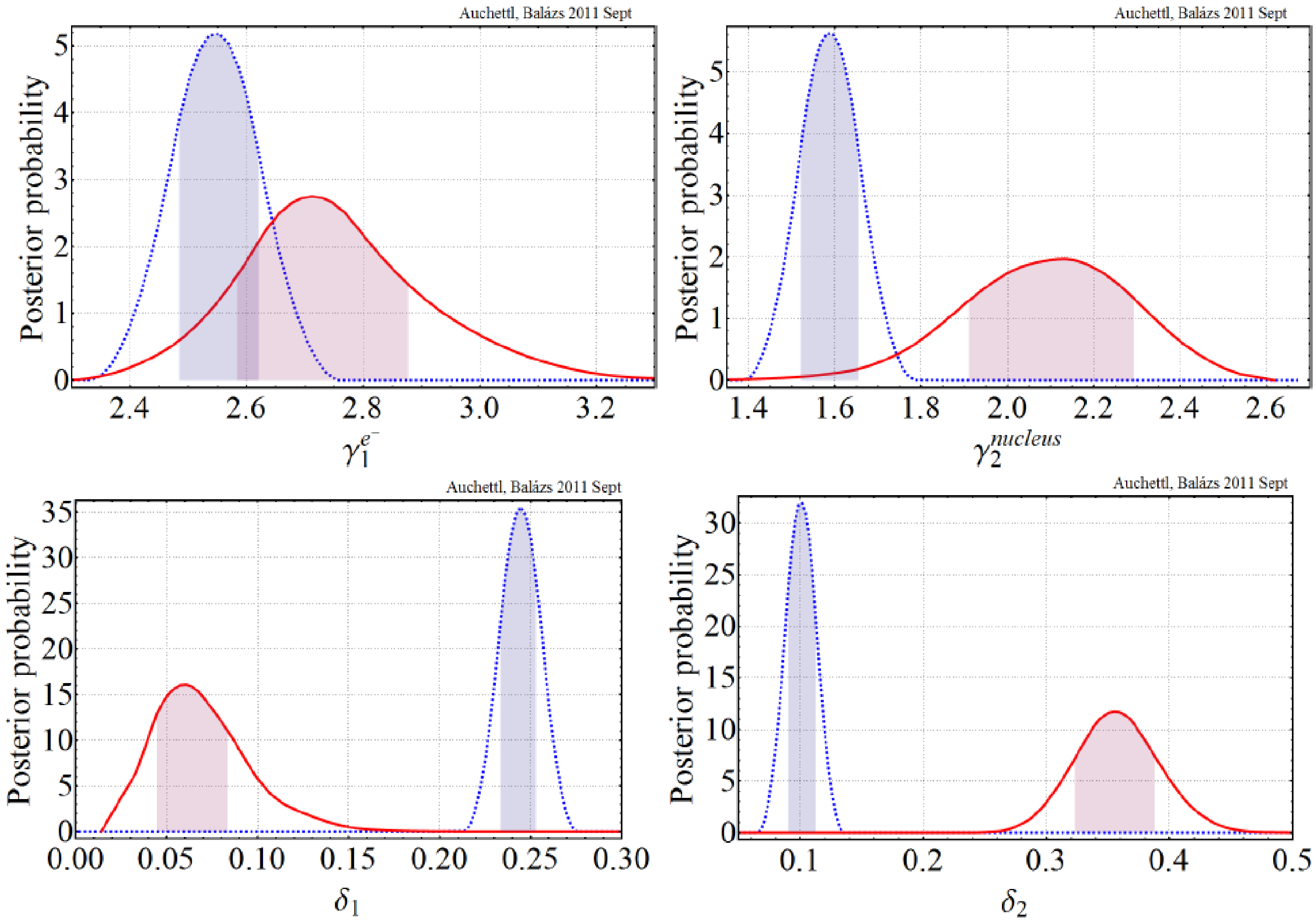
	AMS-02 (Burger 2004)	0.15 - 9.03	15

Theoretical parameter inference

Posterior distributions of parameters:



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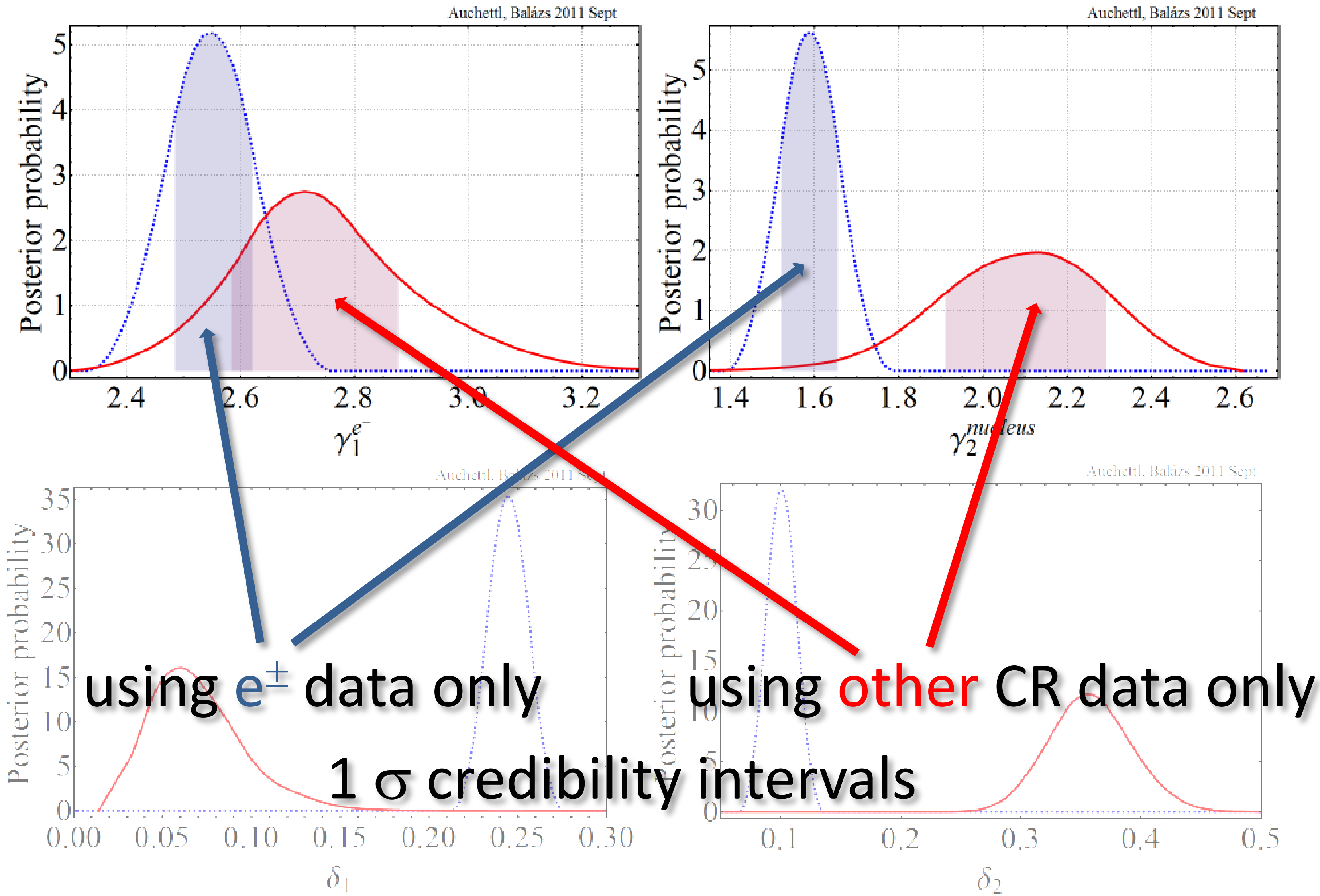

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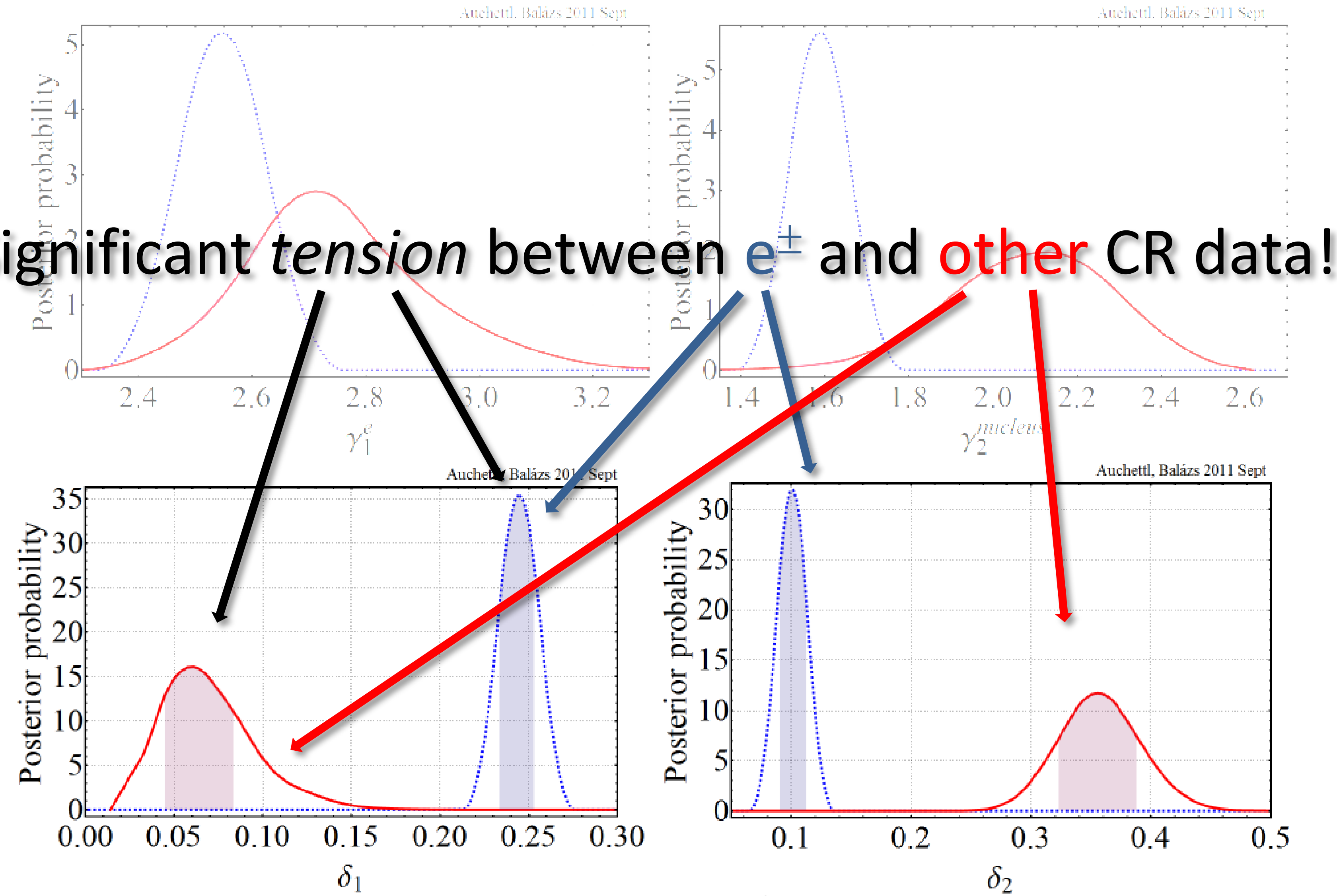

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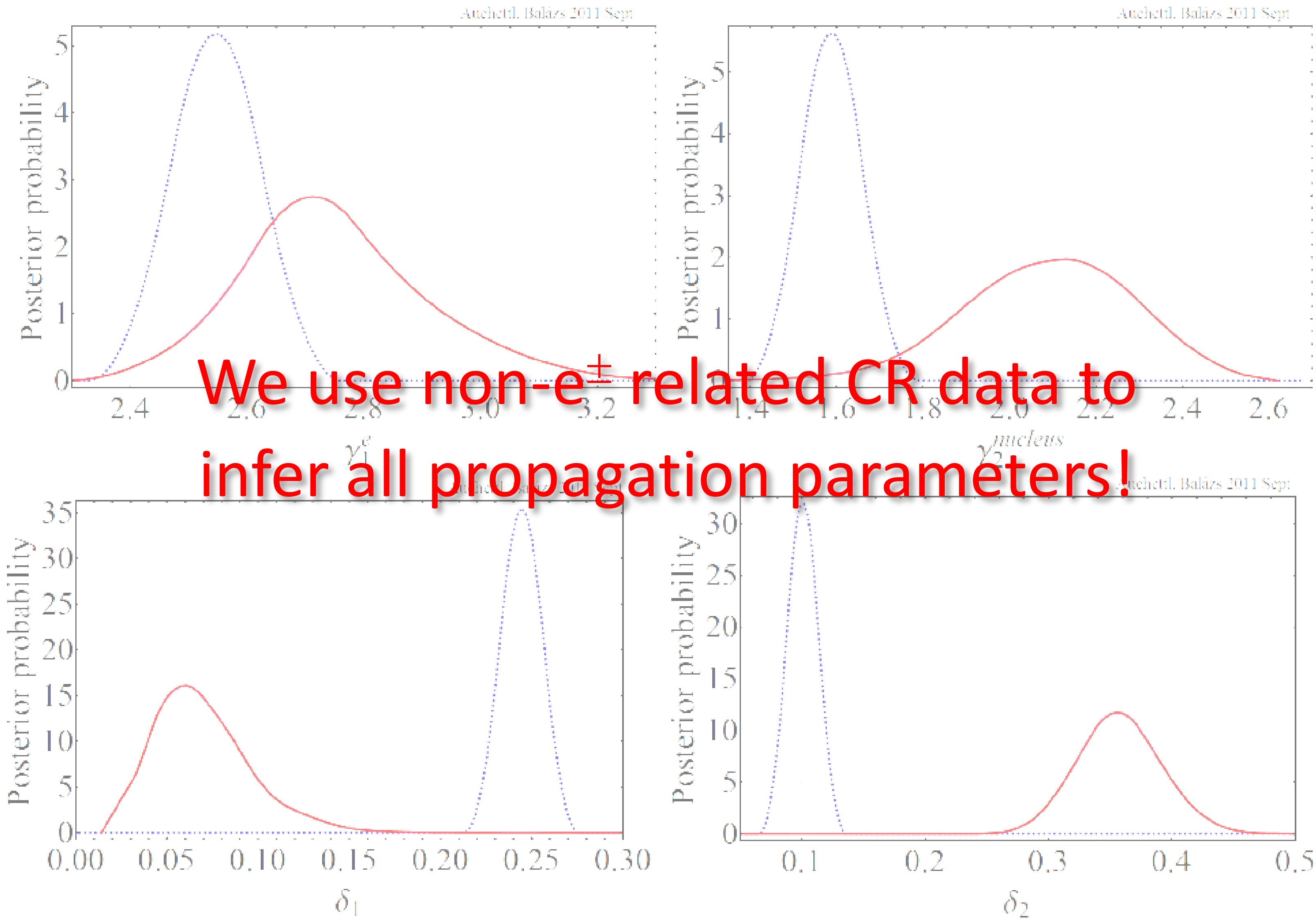
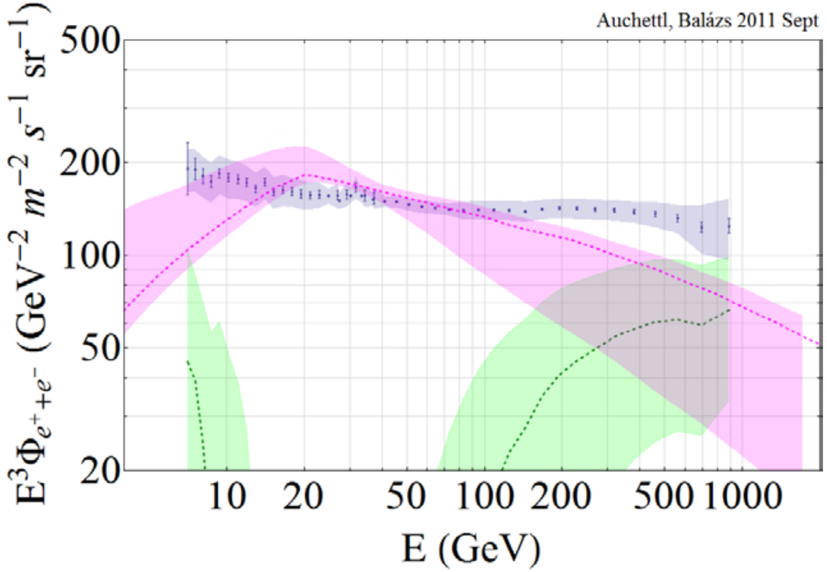
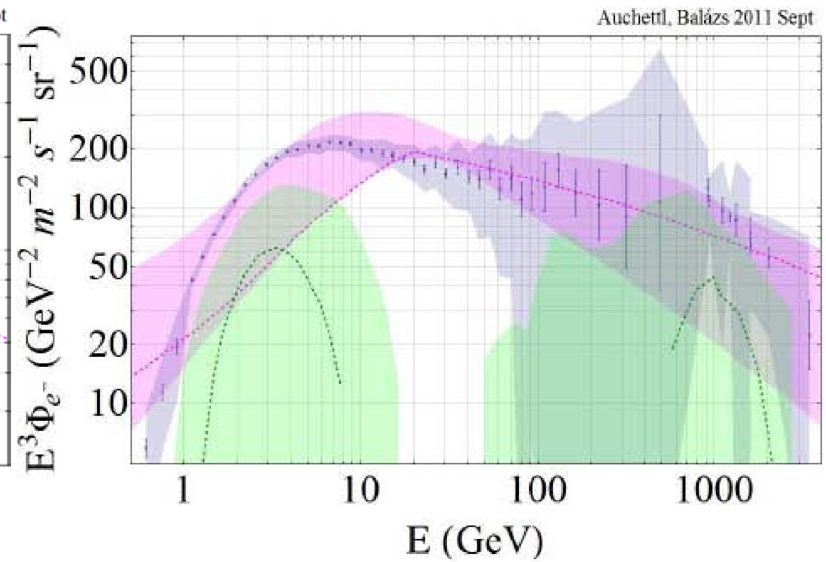


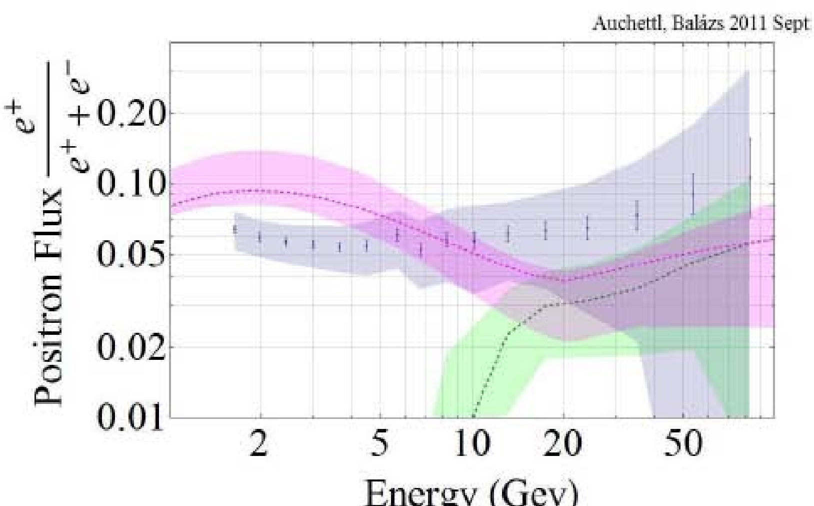
We use non-$e^{\pm}$ related CR data to infer all propagation parameters!

Uncertainty of the e$^{\pm}$ flux prediction

inferred from the 1 σ credibility ranges







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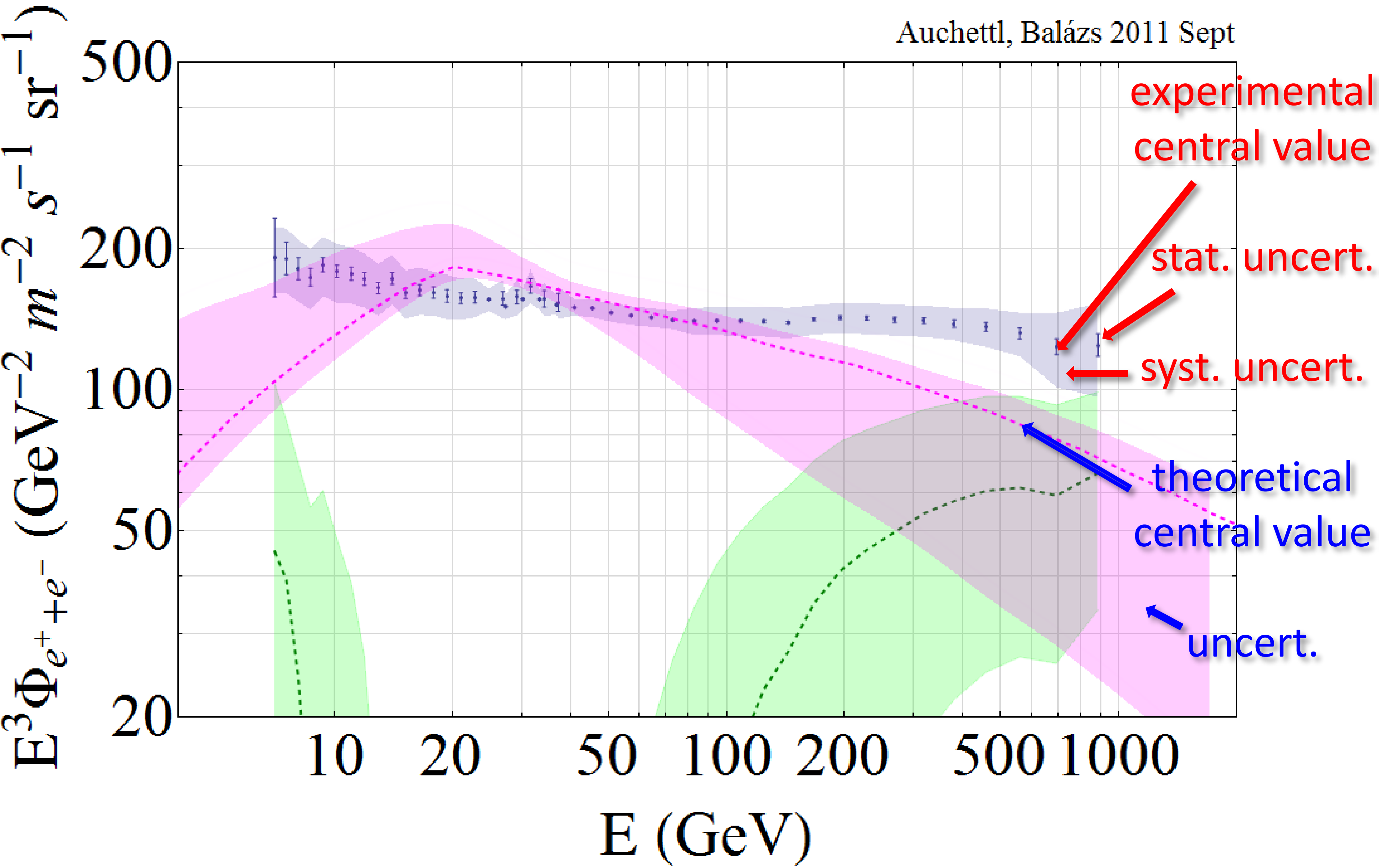

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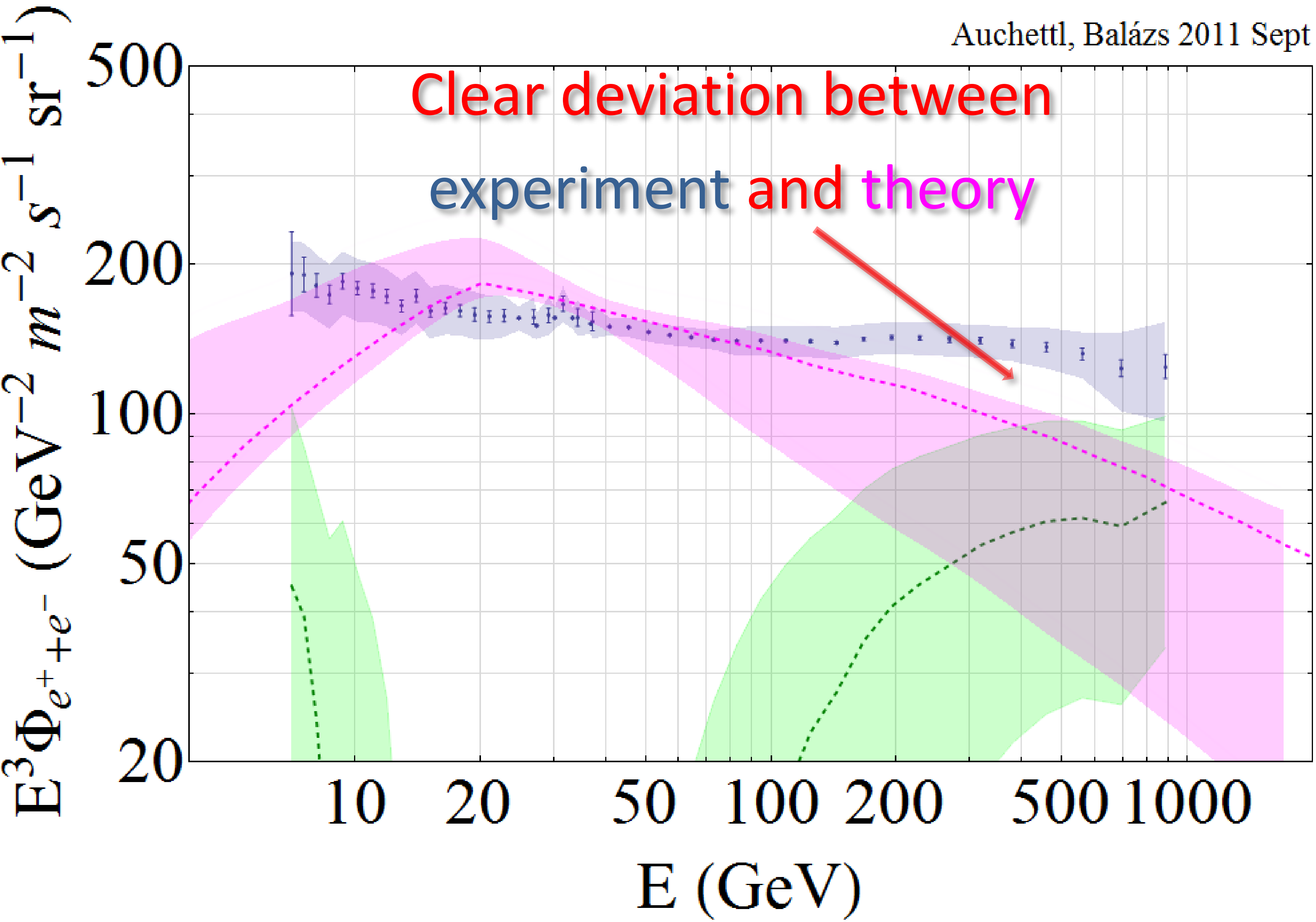
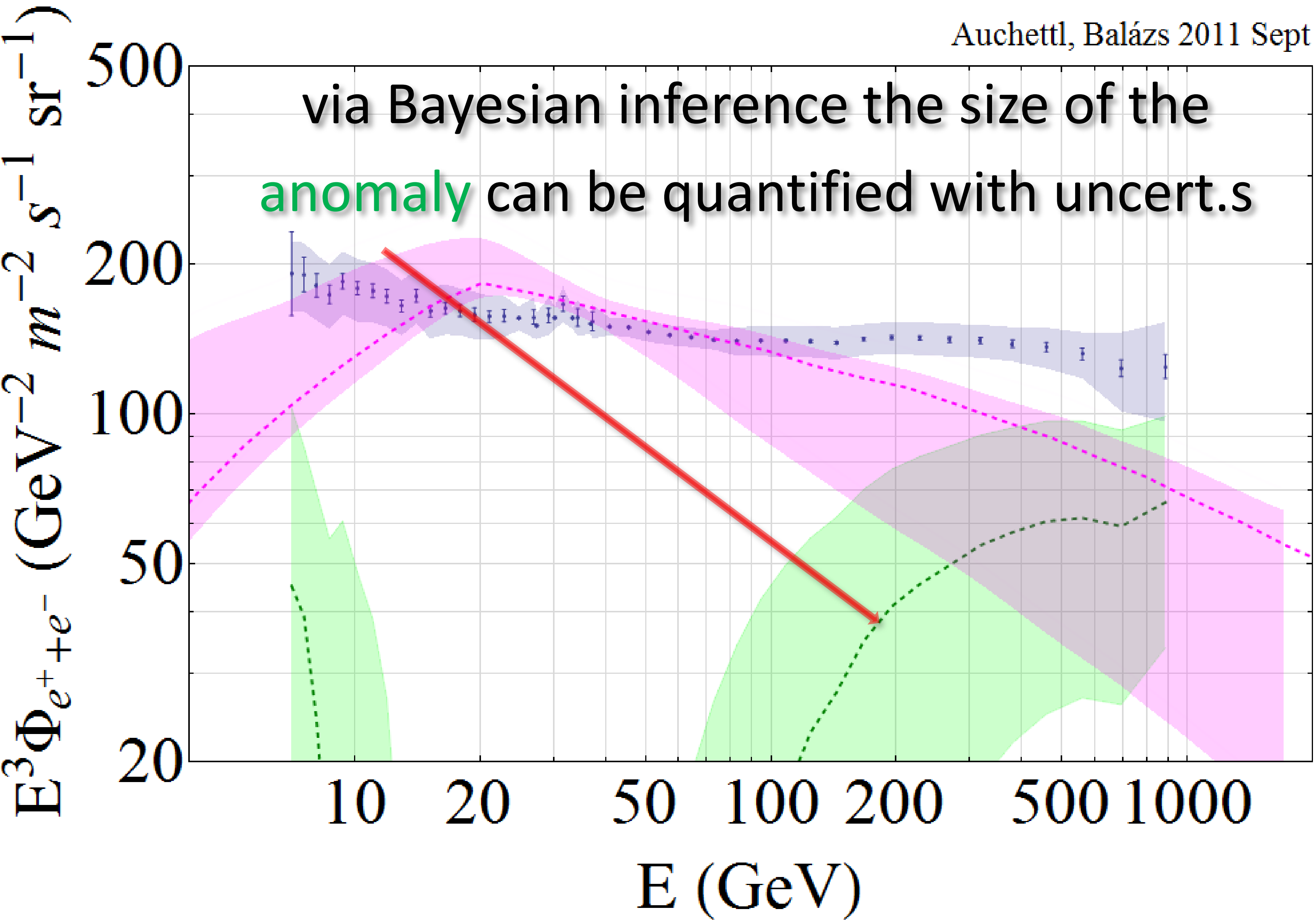


Uncertainty of the $e^{\pm}$ flux prediction



PAMELA & Fermi-LAT

Anomalous $e^{\pm}$ flux measurements

Is this 'real'?

Is this new physics?

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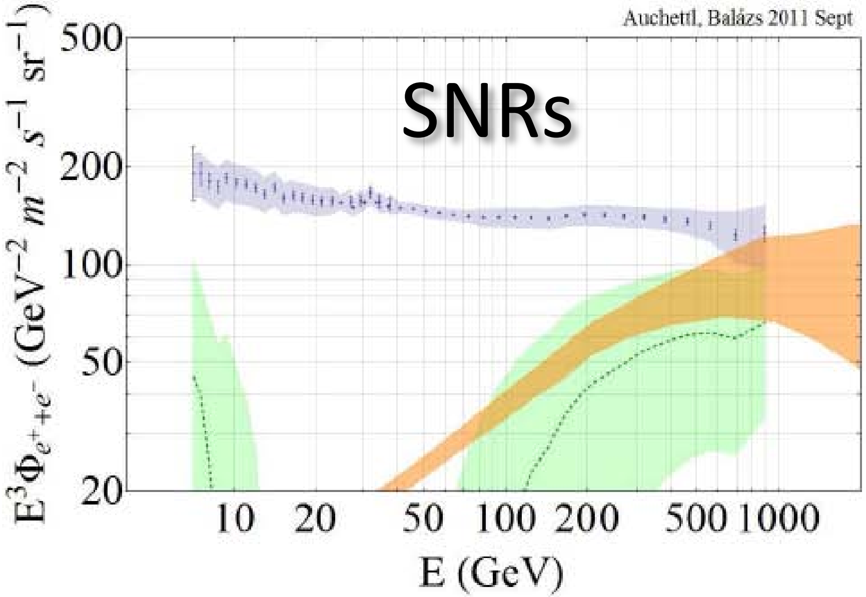
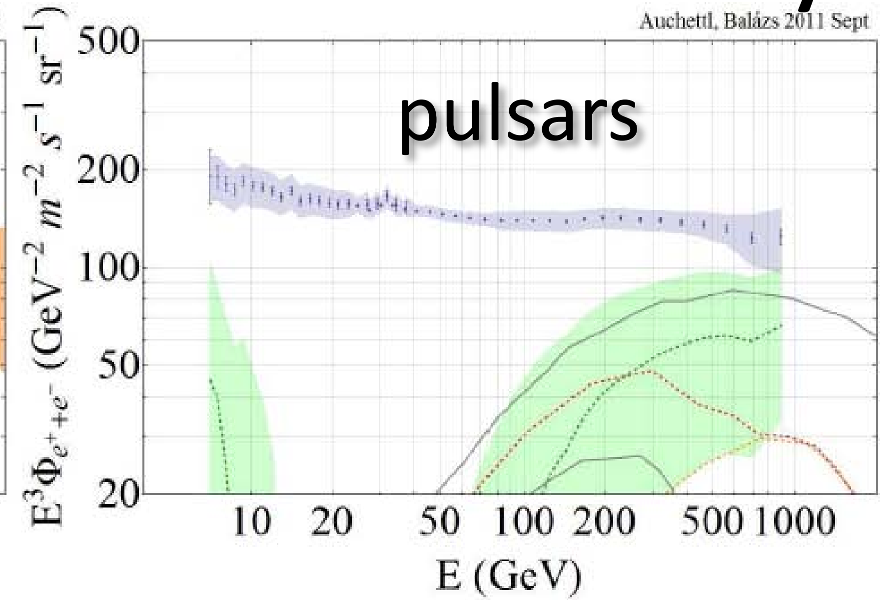
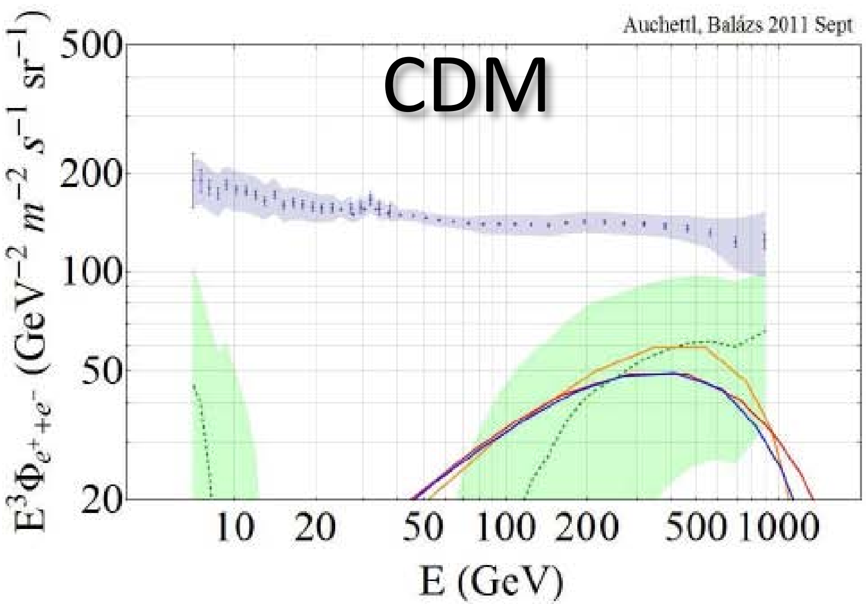
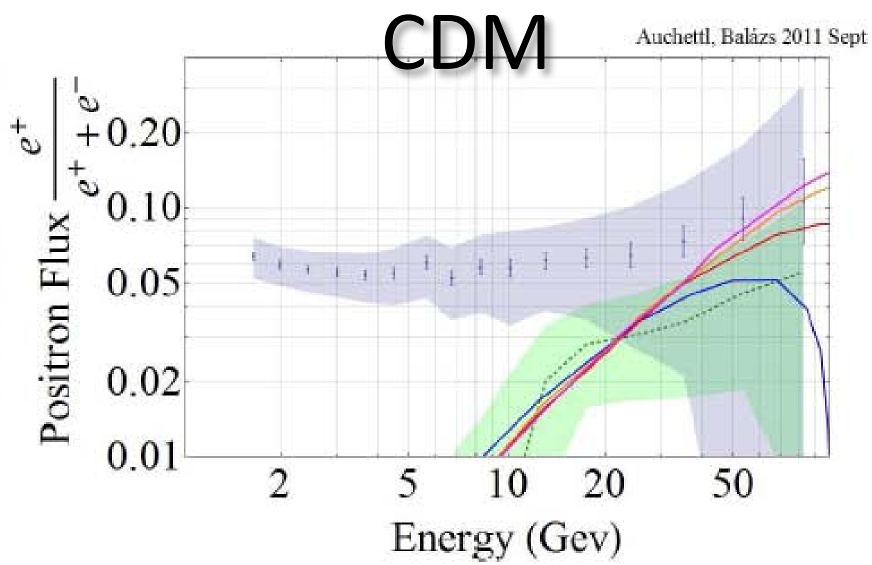
Possible sources of the anomaly









Conclusions

Newly evaluated theoretical uncertainties ***justify an anomaly*** in Fermi-LAT $e^{\pm}$ flux

Using Bayesian inference ***size of the anomaly*** is precisely quantified

Determination of the source of the anomaly calls for ***much increased experimental/theoretical precision***

Extra slides

Why do PAMELA & Fermi and GalProp differ?

The most popular answers:

- new CR source(s)
  - dark matter
  - supernova remnants
  - pulsars
- modified CR propagation model
  - non-steady sources
- local effects

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Anomalous e^--e^+ fluxes

Is there really an anomaly?

Does the present theory prediction match the data within the ***theoretical uncertainties***?

We don't know: we need theory uncertainties to decide this!

The uncertainty of the e^--e^+ flux predictions

The predicted e^--e^+ flux

- is calculated using the numerical code GalProp

- contains assumptions on various CR sources

- depends on assumptions about CR propagation

The uncertainty of the e^--e^+ flux predictions

The predicted e^--e^+ flux carries uncertainties from

- is calculated using the numerical code GalProp
- assumptions about Galactic propagation of CRs
- contains assumptions on various CR sources
- poorly understood properties of CR sources
- depends on assumptions about CR propagation
- unconstrained propgagation parameter values

The uncertainty of the e^--e^+ flux predictions

To determine the theoretical uncertainty, we

- fix assumptions about Galactic propagation

using the numerical code GalProp

- fix properties of CR sources

as encoded in GalProp

- infer uncertainty of the propagation parameters

via Bayesian inference using cosmic ray data

Theoretical parameter inference

$$\mathcal{L}(D|P) = \prod_{i=1}^{M} \frac{1}{\sqrt{2\pi}\sigma_i} \exp(-\chi_i^2(D,P)/2), \qquad \chi_i^2(D,P) = \left(\frac{d_i - t_i(P)}{\sigma_i}\right)^2$$

$$\mathcal{P}(P|D) = \mathcal{L}(D|P)\frac{\mathcal{P}(P)}{\mathcal{E}(D)}. \qquad \mathcal{P}(p_i|D) = \int \mathcal{P}(P|D) \prod_{i \neq j=1}^{N} dp_j,$$

$$x = \int_{\mathcal{R}_x} \mathcal{P}(p_i|D)\, dp_i. \qquad x = \int_{\mathcal{R}_x} \mathcal{P}(p_i, p_j|D)\, dp_i\, dp_j.$$

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Theoretical parameter inference

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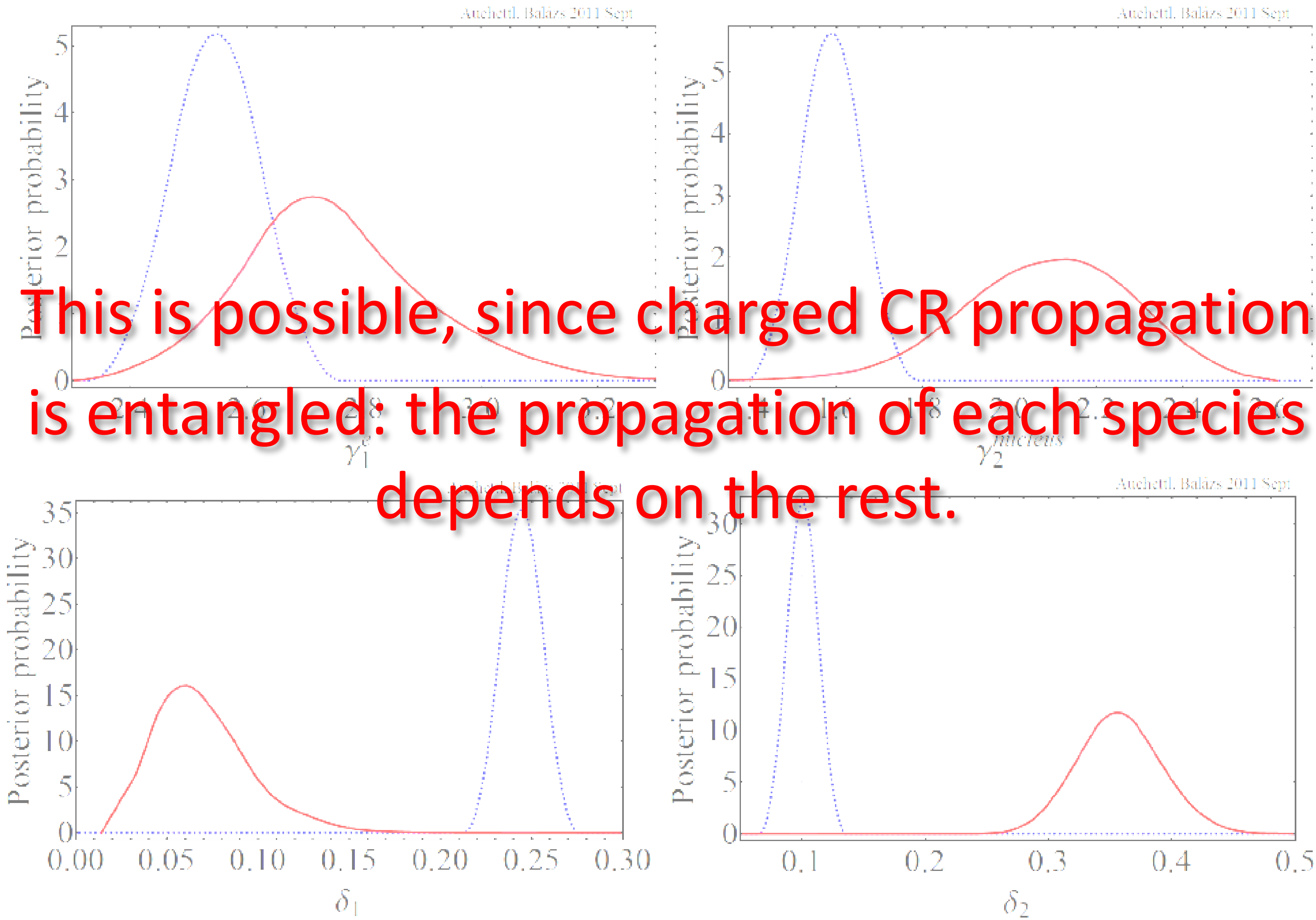
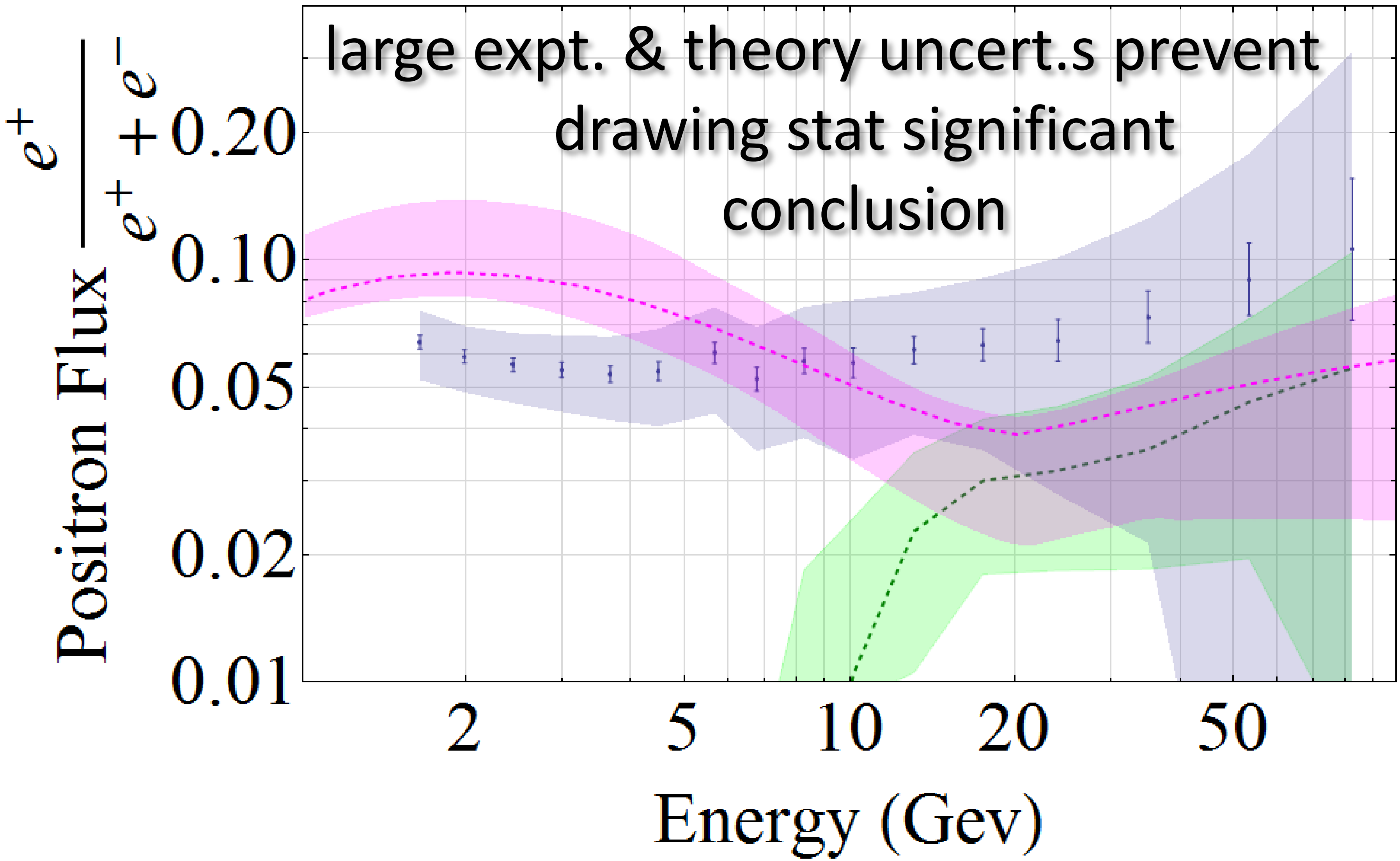


This is possible, since charged CR propagation is entangled: the propagation of each species depends on the rest.

Uncertainty - e+ fraction prediction

Auchettl, Balázs 2011 Sept



Interpretation

of the deviation between exp & theo

1. The CR propagation model is wrong
2. Missing CR ray sources

- standard astro: supernova remnants, pulsars, etc.
- exotic: dark matter

Present experimental/theoretical precision does not allow to differentiate between these possibilities