

# AMS实验结果：宇宙线电子的起源

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on behalf of AMS Collaboration

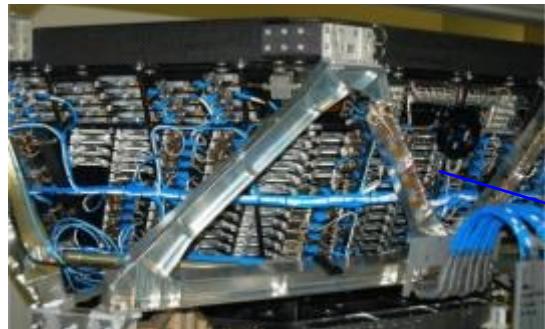
2021年8月

AMS



# 阿尔法磁谱仪AMS

TRD: 识别  $e^+$ ,  $e^-$ , 测量Z

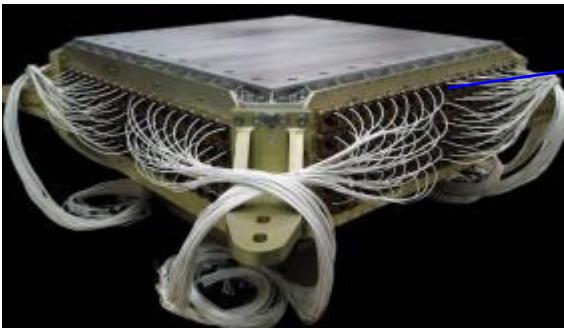


电荷Z、能量E（或动量P）  
是粒子和原子核的基本物理量

Tracker: 测量 Z, P



ECAL: 识别  $e^+$ ,  $e^-$ , 测量E



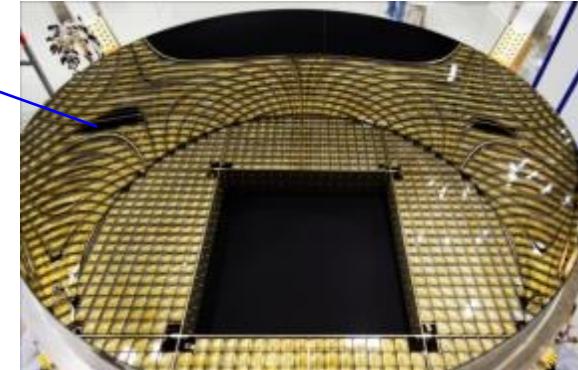
TOF: Z, E



Magnet:  $\pm Z$

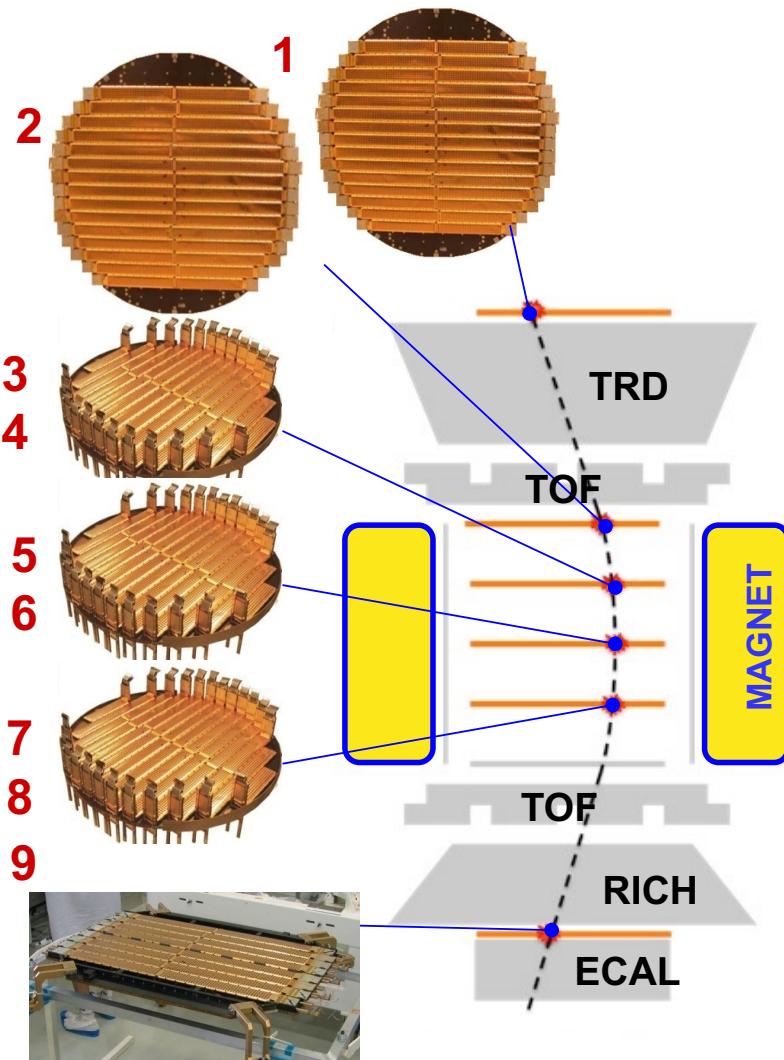


RICH: Z, E

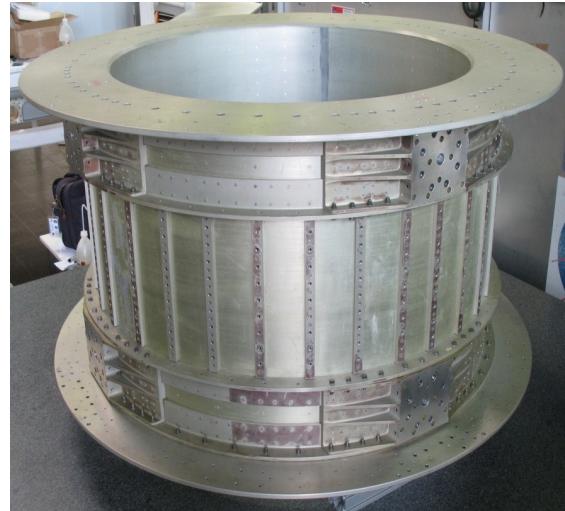


Tracker, RICH, TOF 和 ECAL  
对Z和P(E) 进行多次精确测量

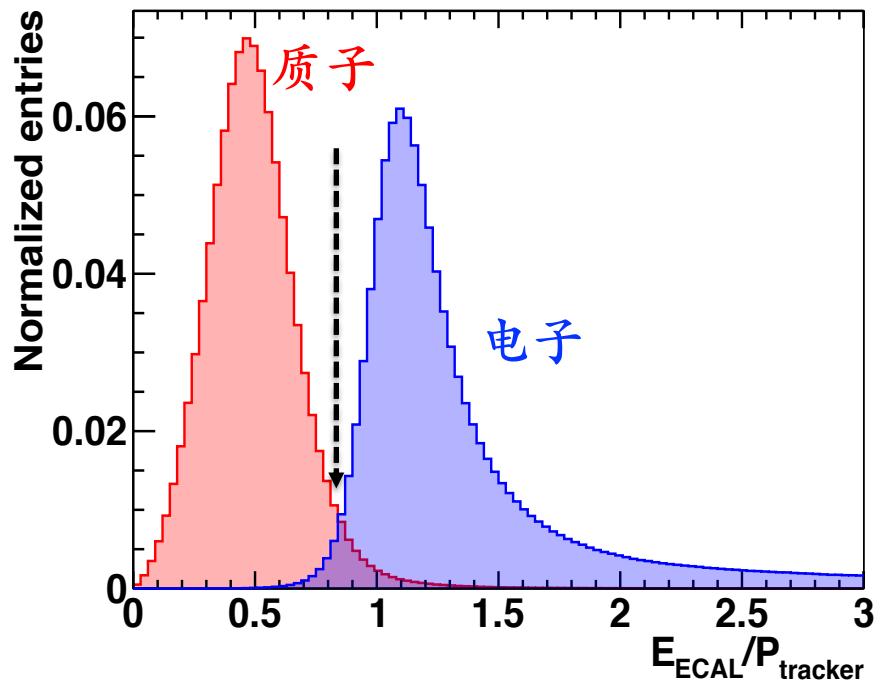
# 硅微条径迹探测器和磁铁



第一层L1至第九层L9: 3 m lever arm;  
单层位置测量精度:  $10 \mu\text{m}$  for  $Z=1$ ;  
最大可测量刚度(MDR):  $2.0 \text{ TV}$  for  $Z=1$ .



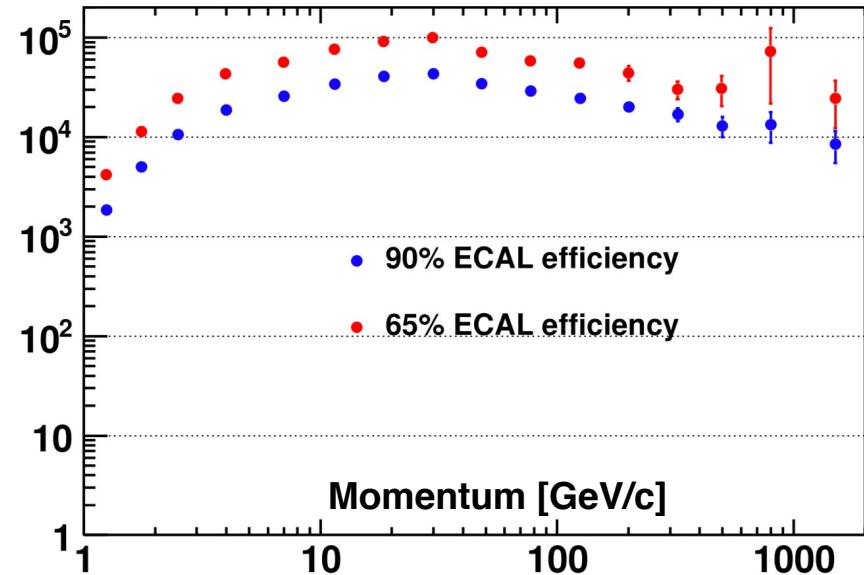
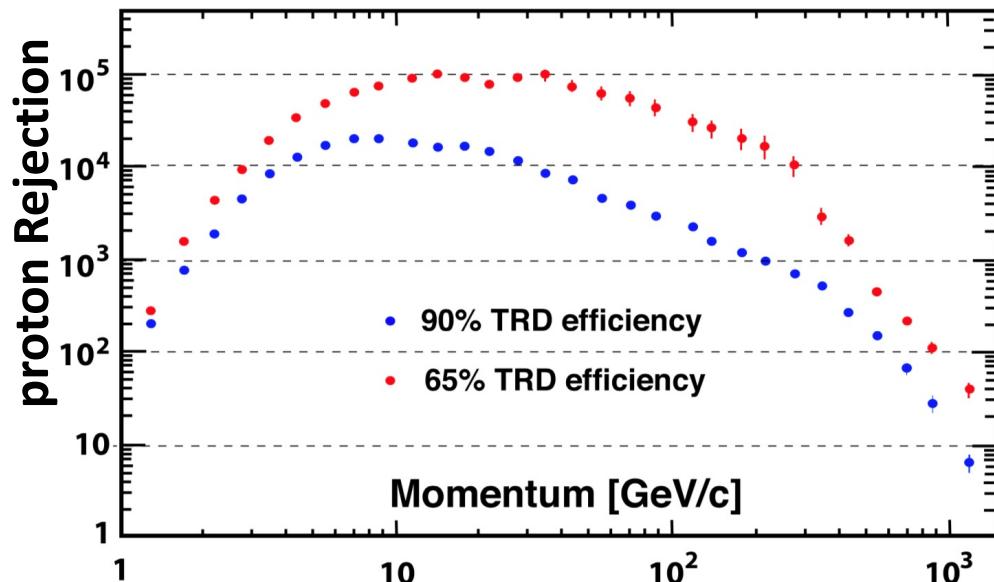
AMS的独特优势



# 电子和正电子的鉴别

TRD的质子排除能力为 $10^3$  to  $10^4$

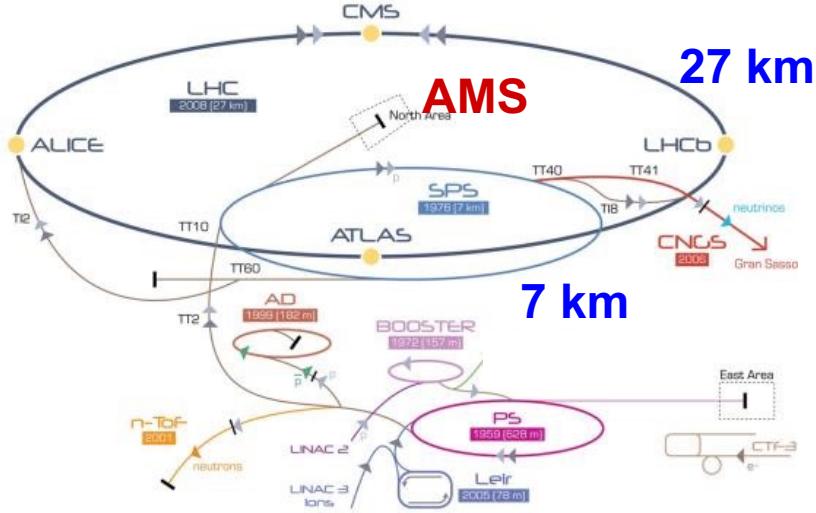
ECAL和tracker的质子排除能力为 $10^4$



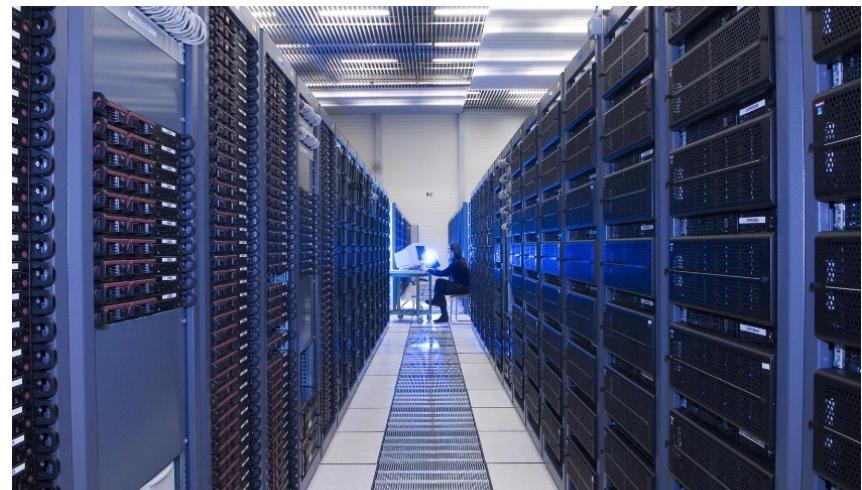
TRD 和 ECAL 被磁铁分开，可以排除掉次级电子，  
因此二者的质子排除能力是相互独立的。

# AMS探测器束流测试

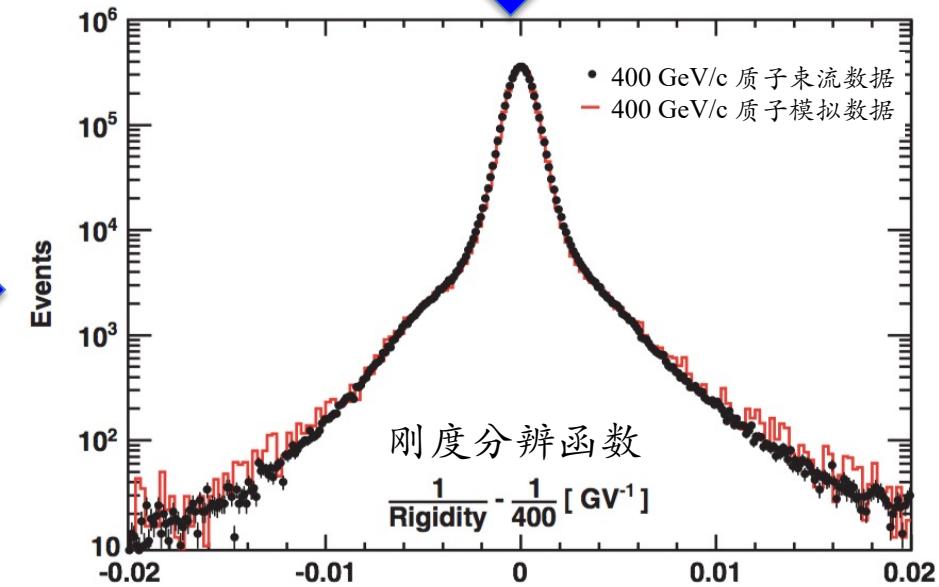
CERN SPS 测试束流:  
 $p, e^\pm, \pi^\pm$ , 10–400 GeV



2000个束流位置和方向



蒙特卡罗模拟:  
粒子相互作用, 探测器材料与结构, 电子学特征



# AMS测量电子和正电子

原初宇宙线:

- $E > 1.2 \cdot \text{max cutoff}$  (地球截止磁场)

TOF

- 自上向下的相对论性粒子  $\beta > 0.8$
- 电荷为  $|Z|=1$

TRD:

- 排出质子

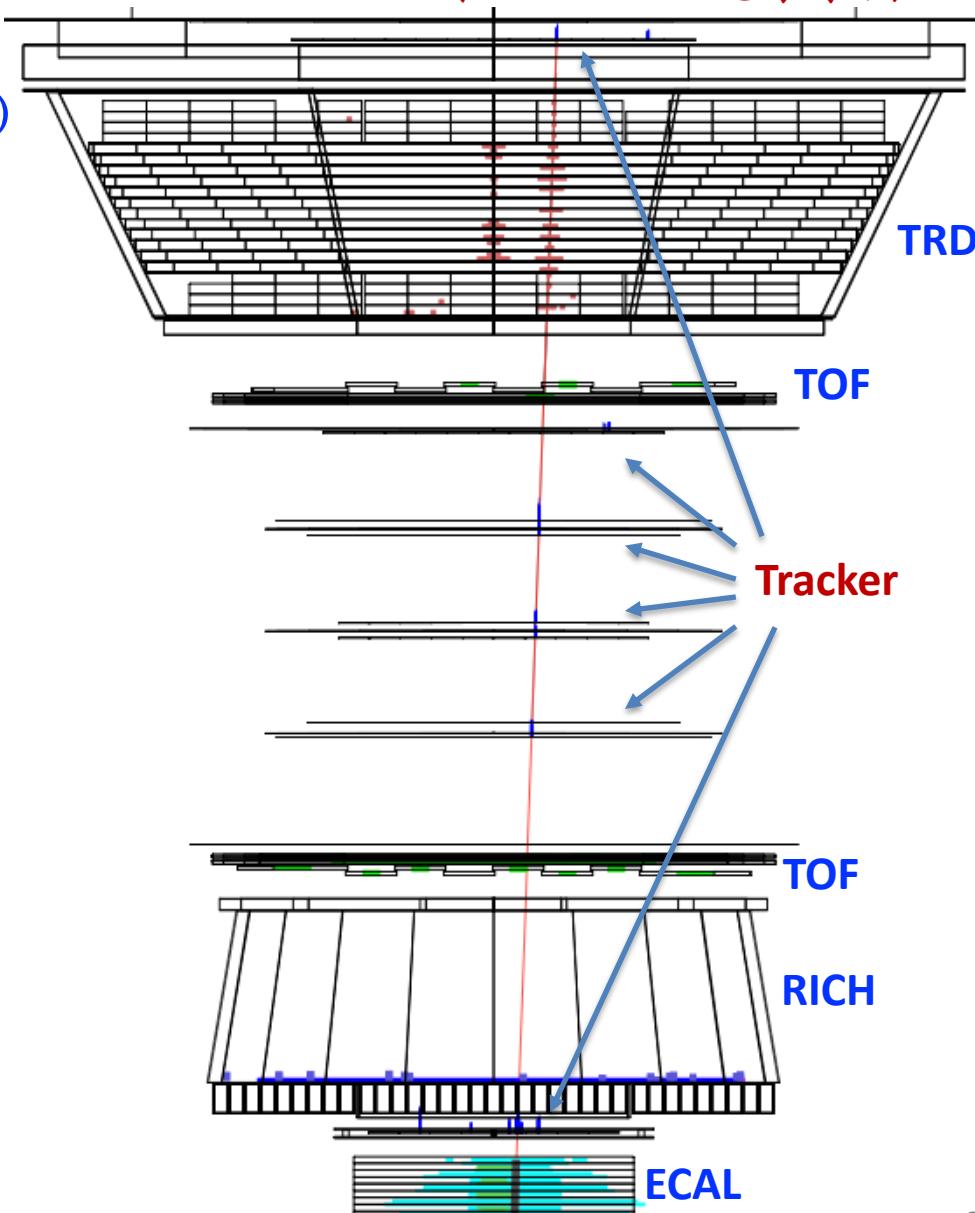
tracker and magnet

- 精确测量粒子动量  $P$  和电荷符号
- 电荷为  $|Z|=1$

ECAL

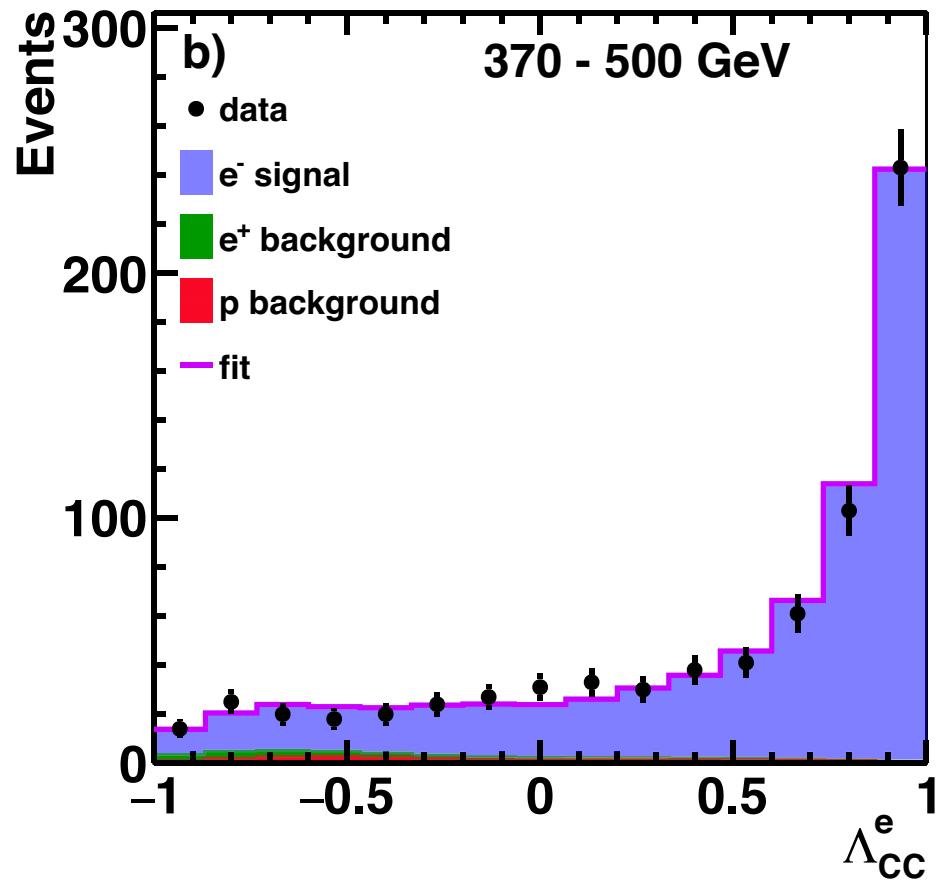
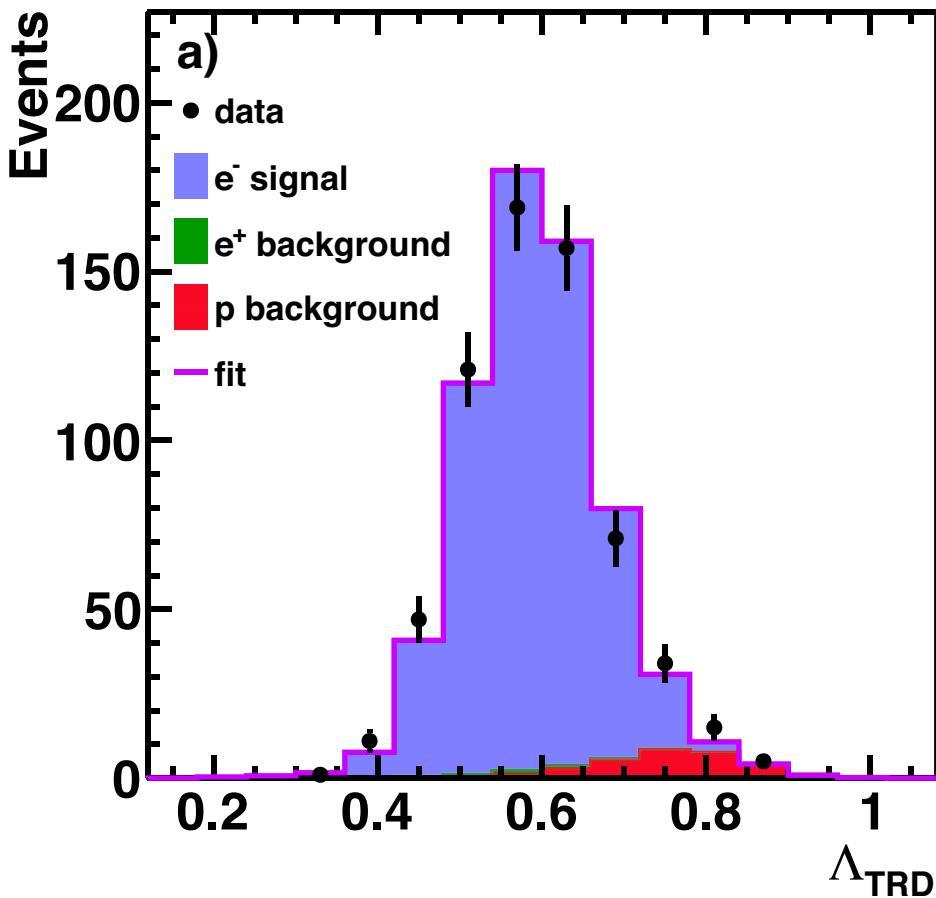
- 精确测量粒子能量  $E$ .
- 通过三维簇射形状排除质子

一个960 GeV正电子事例



# 基于数据的电子分析方法

- 通过ECAL排除掉大多数质子本底
- 选择负电荷 ( $\text{Rigidity} < 0$ ) 样本，通过  $(\Lambda_{\text{TRD}} - \Lambda_{\text{CC}}^e)$  二维模板拟合得到电子计数



相对于电子的信号事例数，质子本底的贡献很小

在6.5年的数据中，在0.5 GeV 至 1.4 TeV的能量范围内共识别出2810万电子

# 电子流强测量的系统误差

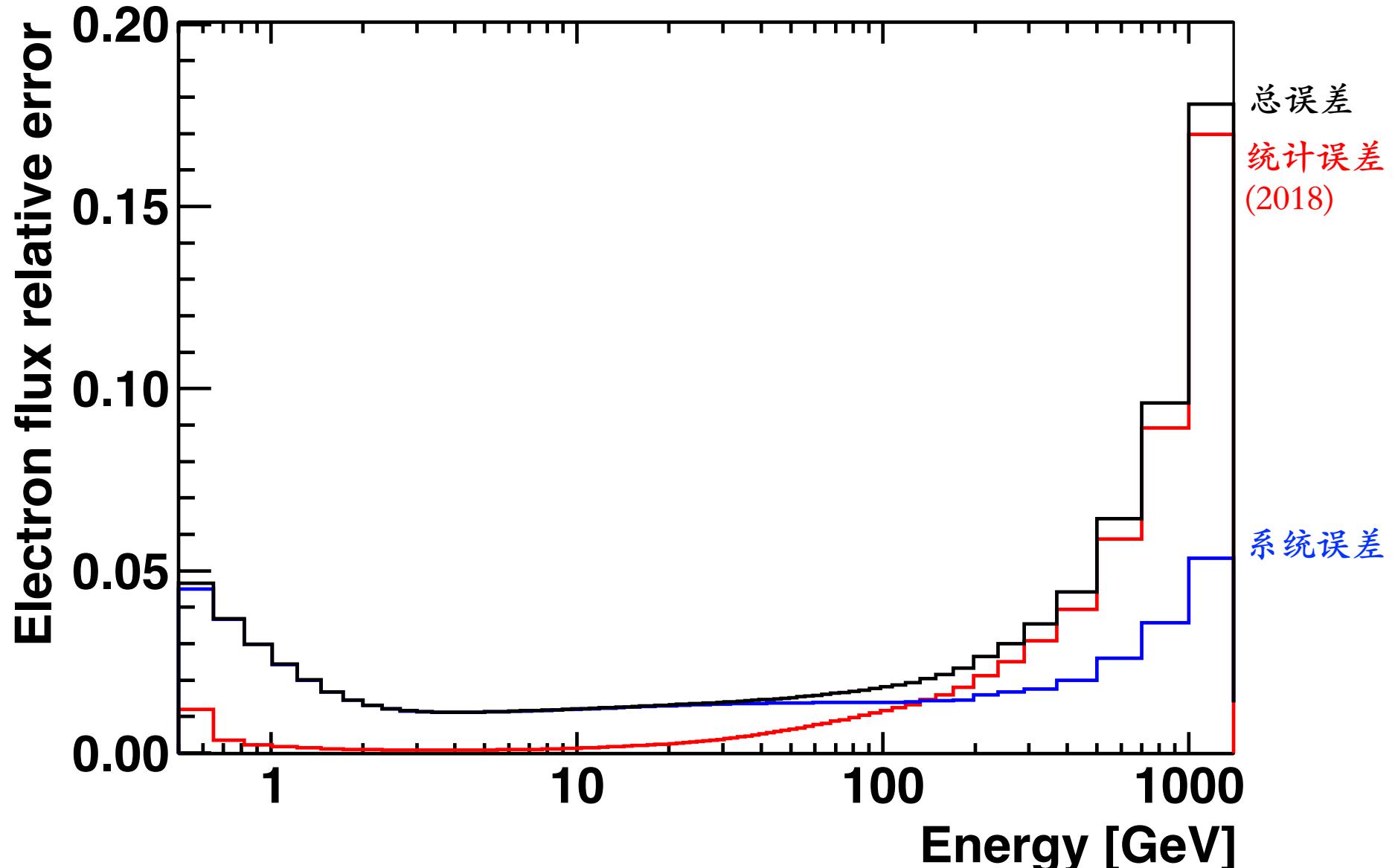
五类系统误差来源:

- 1) 效率修正的误差
- 2) 拟合模板的不确定性
- 3) 电荷误判估计
- 4) 电子能量测量的反卷积

分析表明，由于电子纯度高， 2), 3), 和4)对系统误差的贡献  
可以忽略

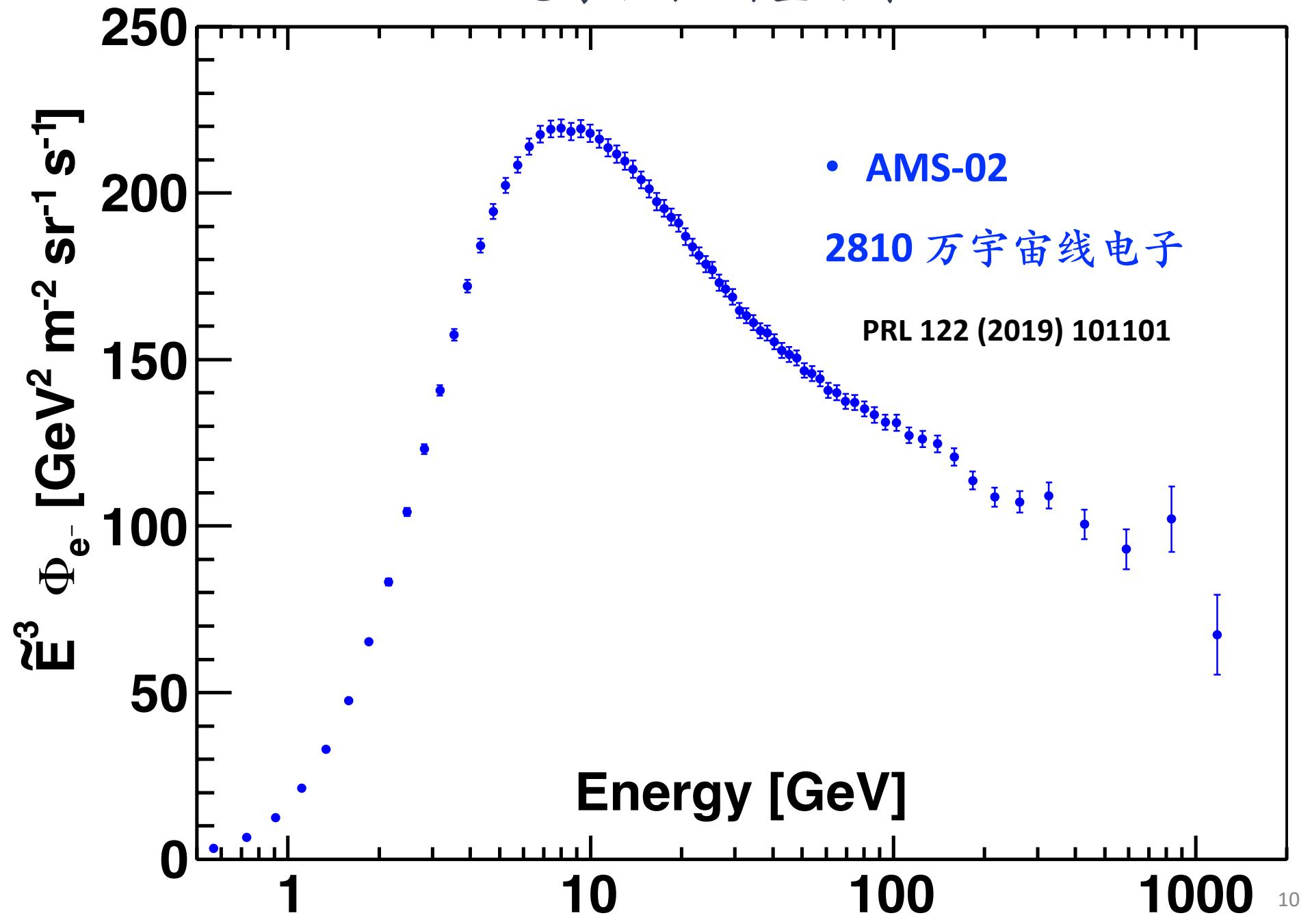
- 5) 能量定标的不确定性，作为能量bin的误差.

# 电子流强测量的系统误差

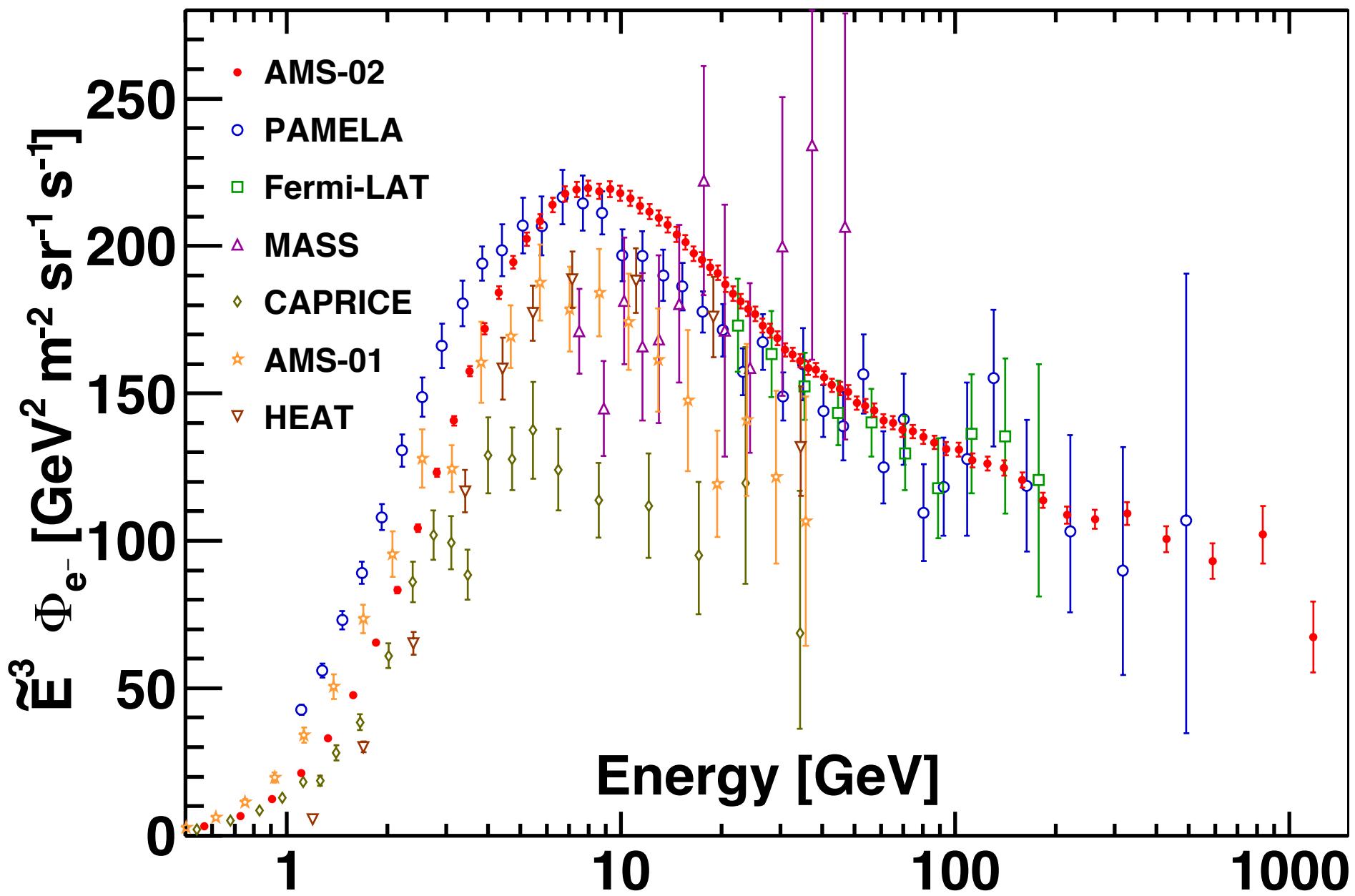


统计误差在200GeV以上占主导

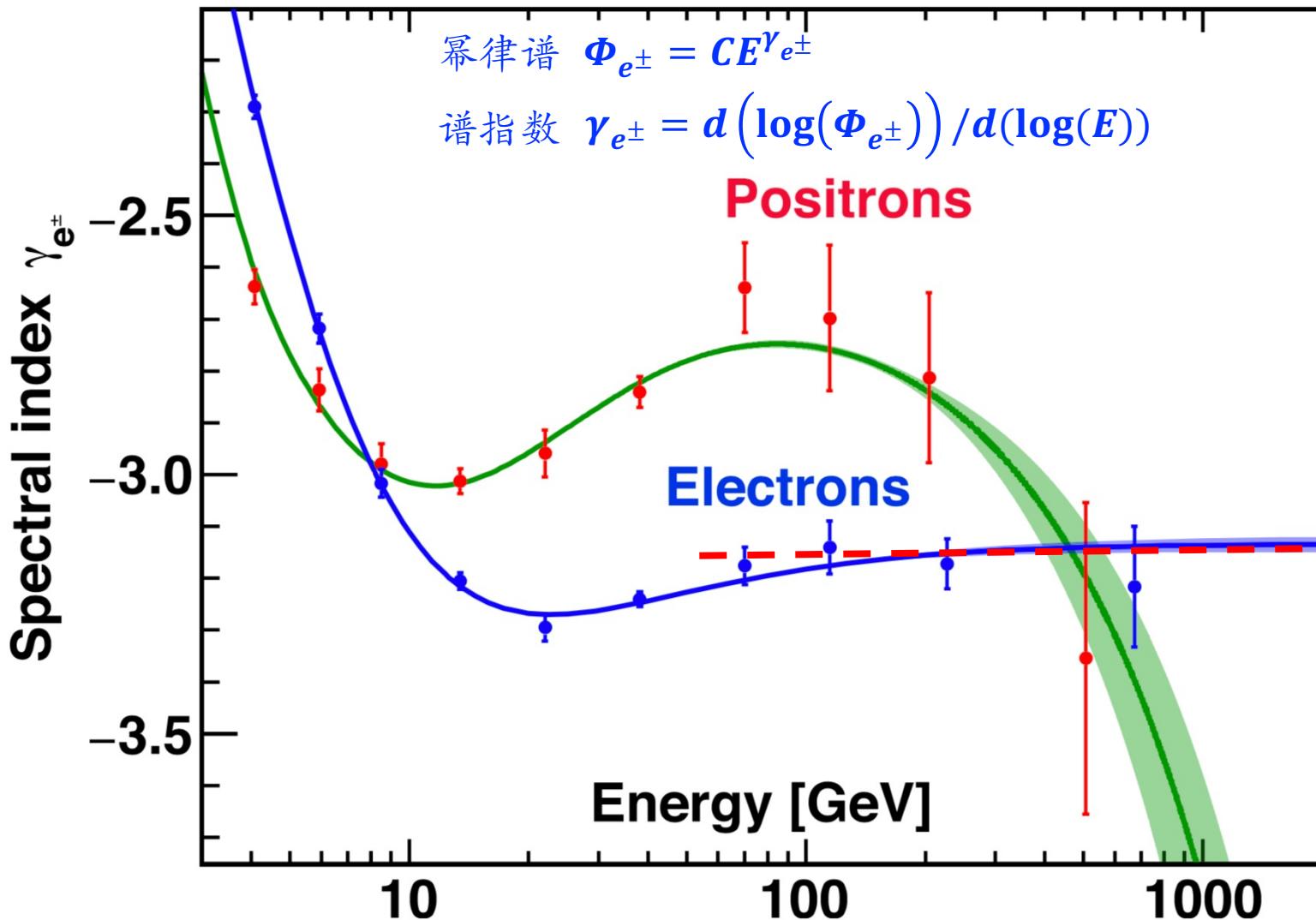
# AMS电子流强测量结果



# AMS电子流强与以往实验的比较



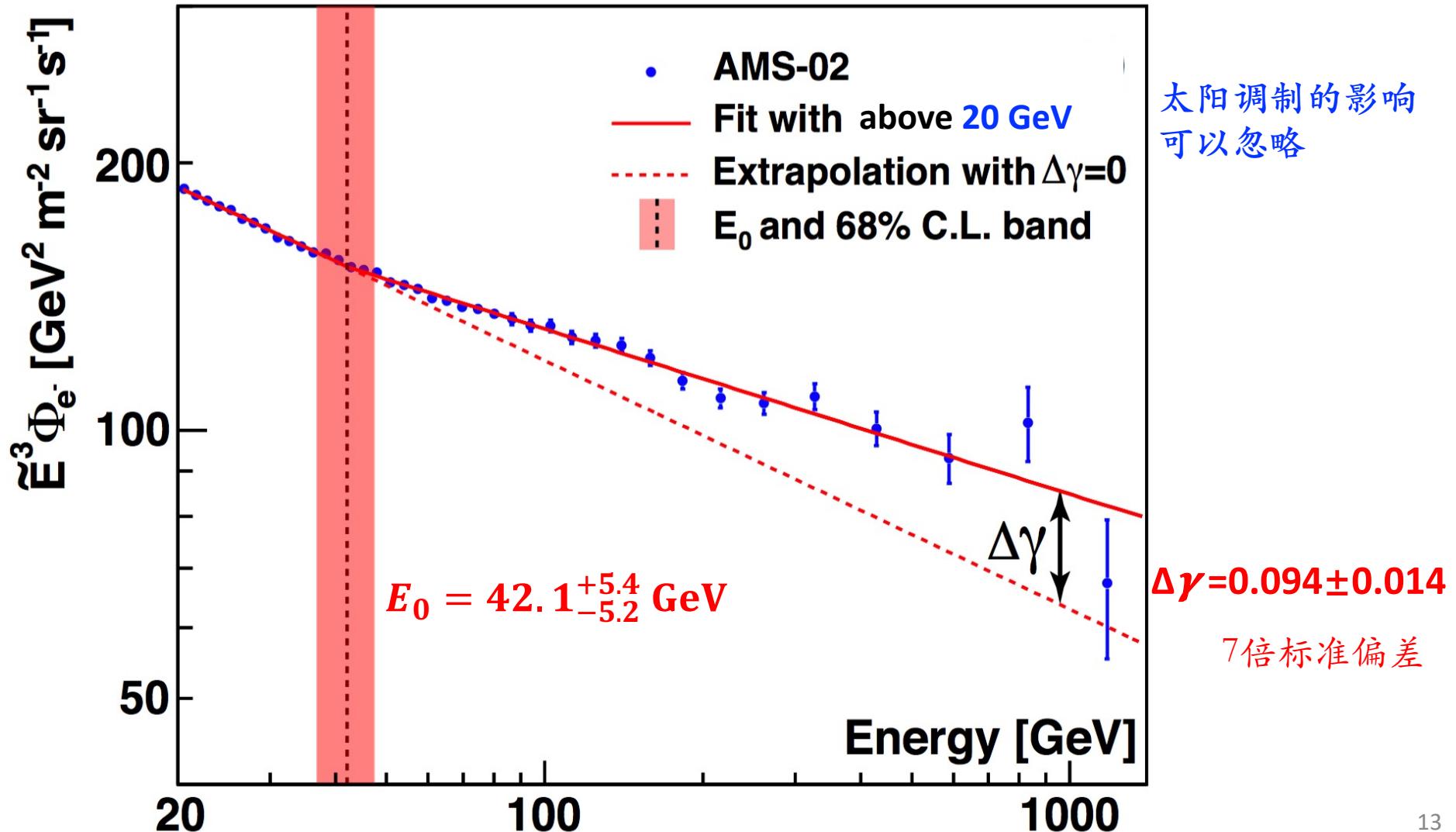
# 电子能谱指数



- 电子能谱指数自~20 GeV开始变硬.
- 电子能谱指数在56 GeV接近常数，即不随能量变化

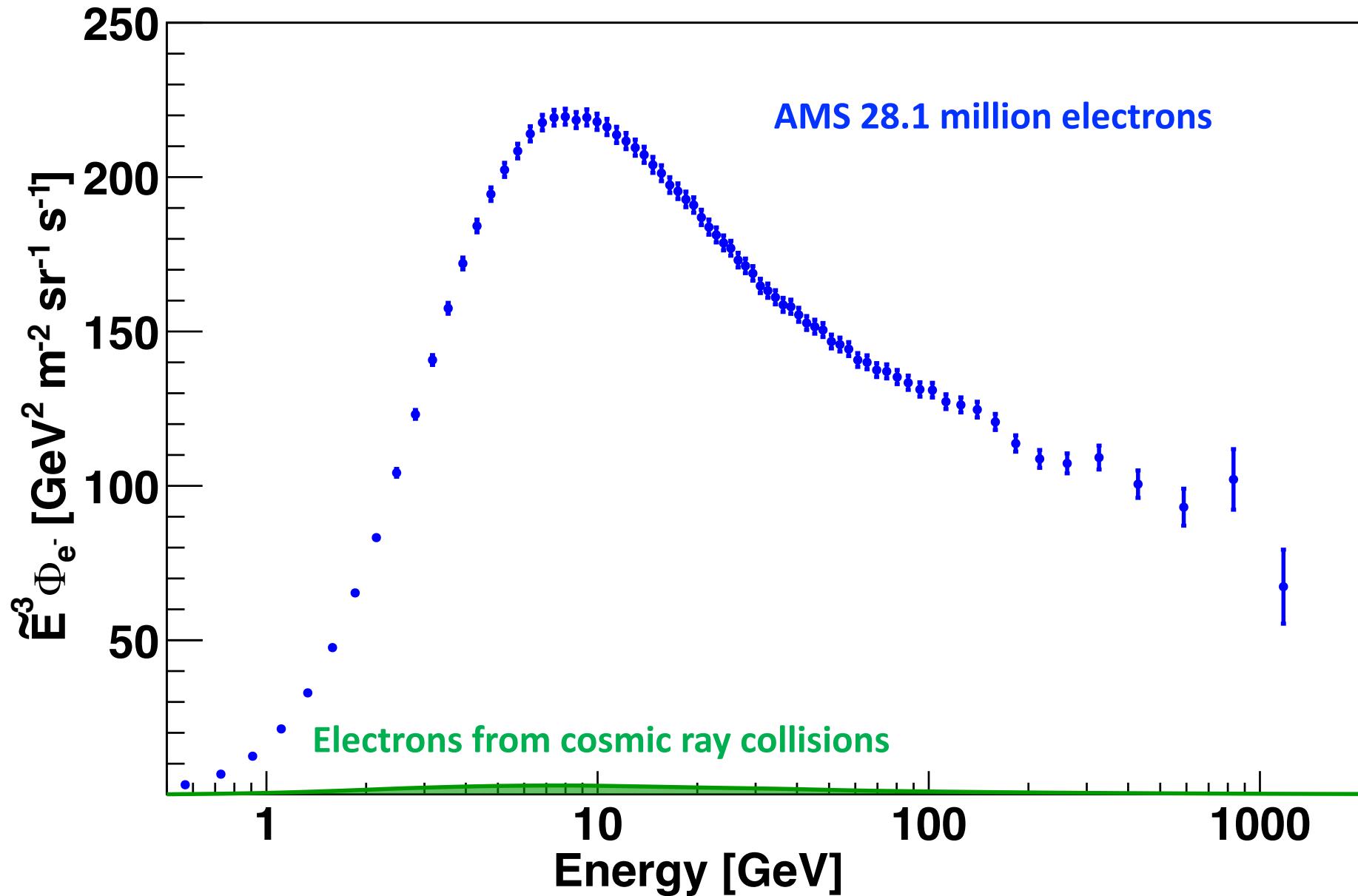
# 能谱转变能量 $E_0$

$$\Phi_{e^+}(E) = \begin{cases} CE^\gamma, & E \leq E_0; \\ CE^\gamma(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$$



# 宇宙线电子的起源 (I): 次级宇宙线

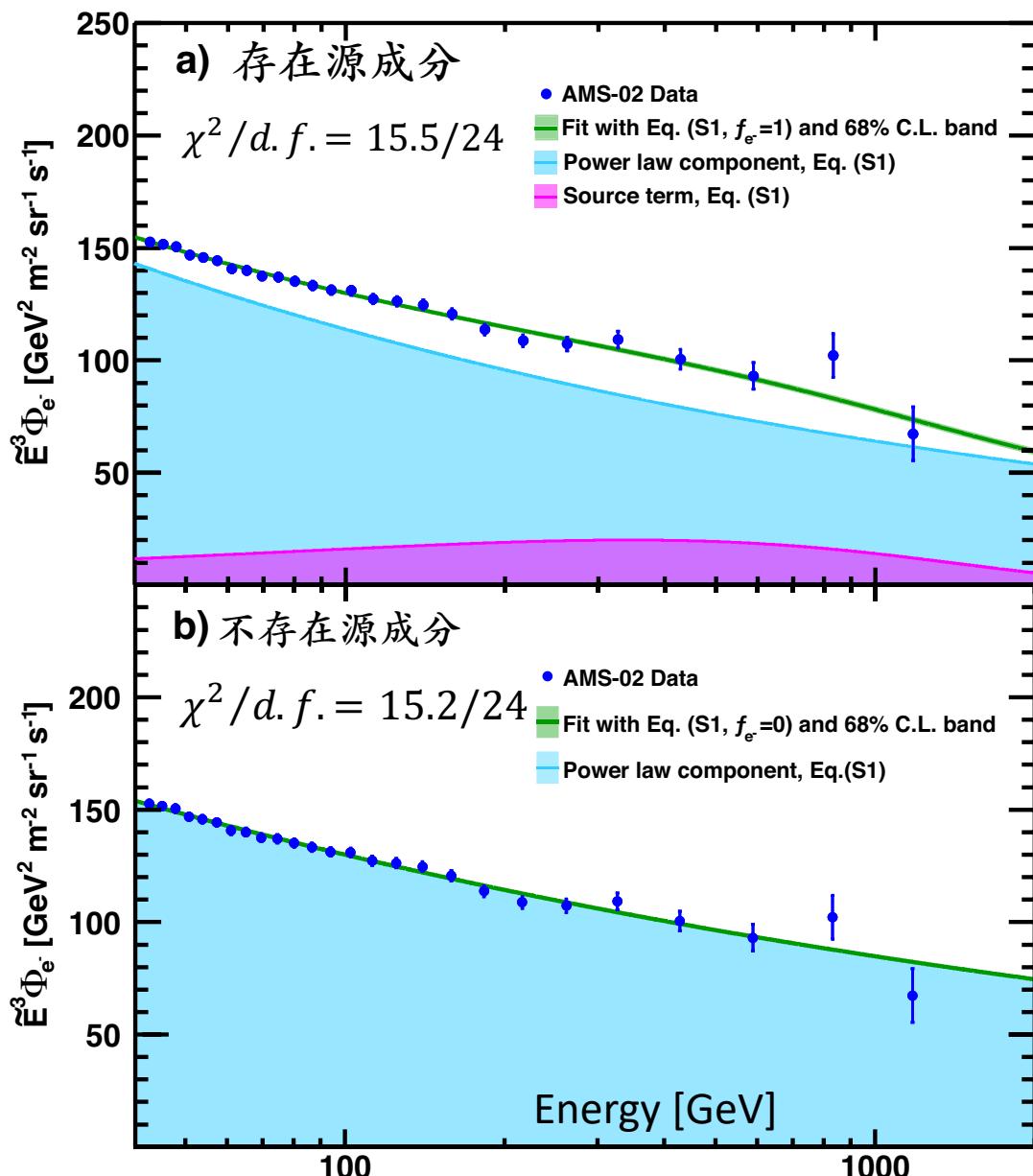
来自宇宙线与星际物质碰撞产生的次级电子可以忽略



# 宇宙线电子的起源 (II): 电荷对称的电子-正电子源

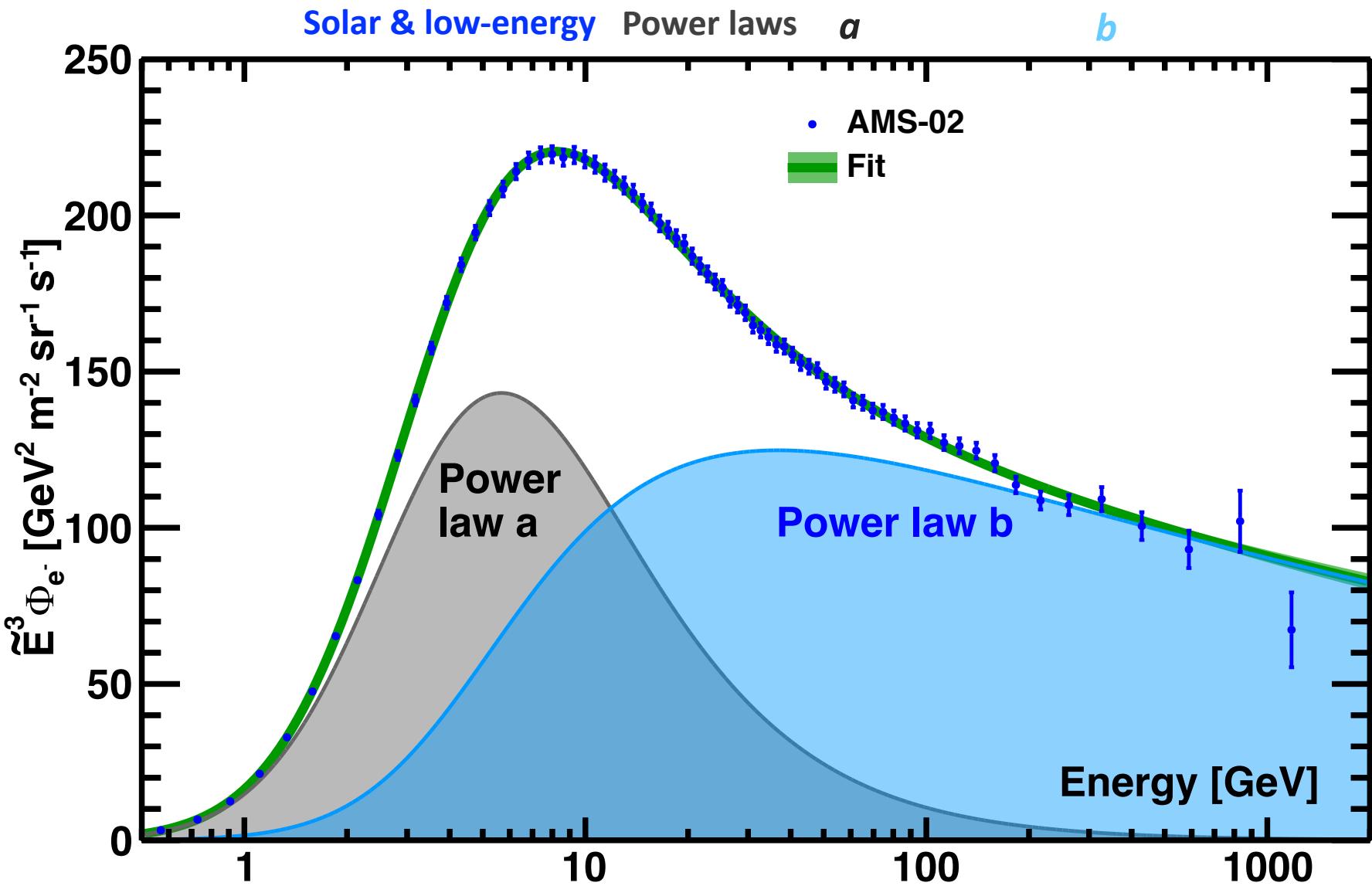
$$\Phi_{e^-}(E) = C_{e^-} (E/E_1)^{\gamma_{e^-}} + f_{e^-} C_s^{e^+} (E/E_2)^{\gamma_s^{e^+}} \exp(-E/E_s^{e^+})$$

- AMS现有的电子流强结果不能区分是否存在电荷对称的电子-正电子源
- 对电荷对称的电子-正电子源的显著性主要来自AMS正电子



# 宇宙线电子的起源 (III): 双幂律谱模型

$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2} \left[ 1 + (\hat{E}/E_t)^{\Delta\gamma_t} \right]^{-1} \left[ C_a (\hat{E}/E_a)^{\gamma_a} + C_b (\hat{E}/E_b)^{\gamma_b} \right]$$

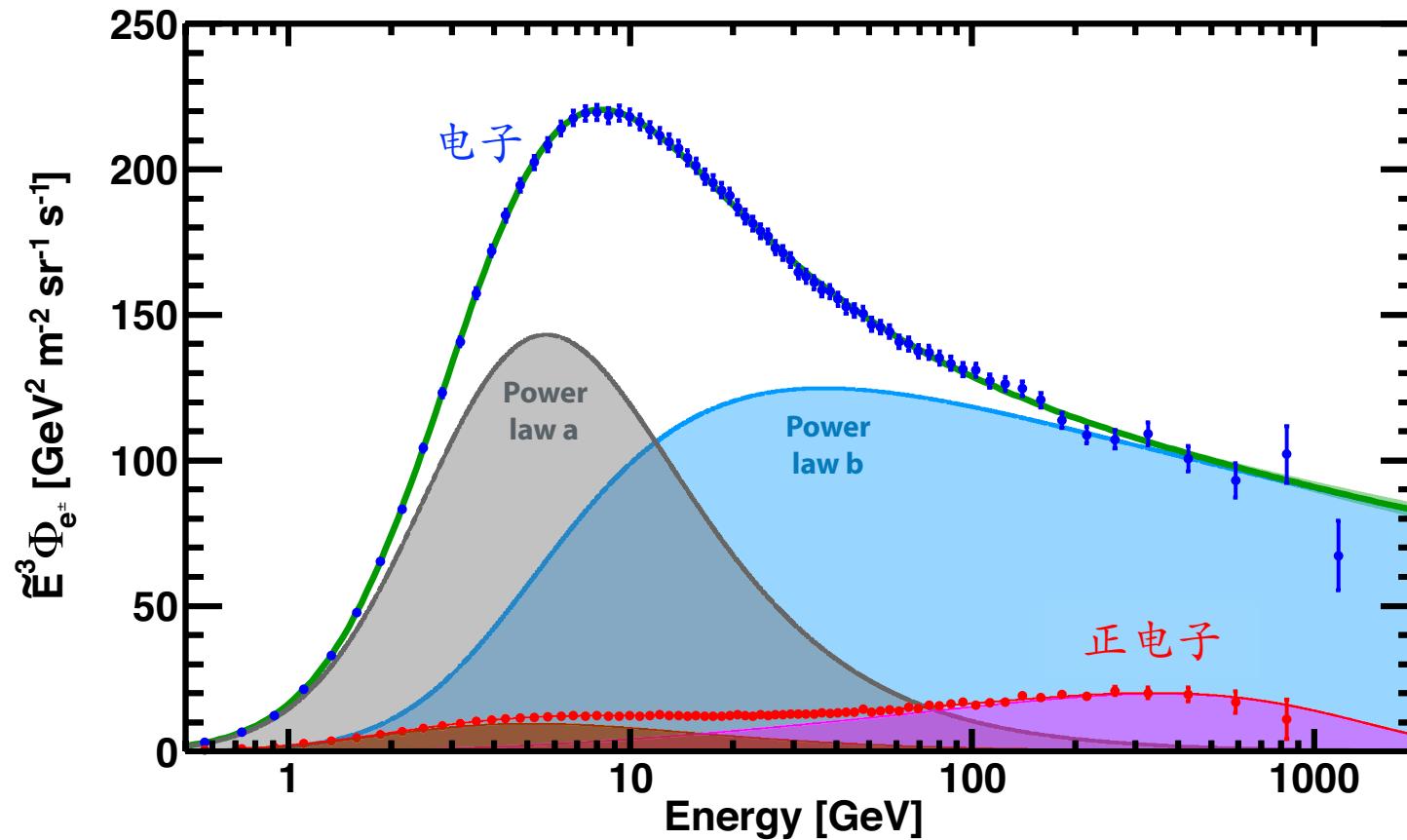


## 结论

AMS基于2810万电子事例测量了0.5 GeV至1.4 TeV的宇宙线电子流强，结果表明：

- 1) 宇宙线电子流强在  $42.1^{+5.4}_{-5.2}$  GeV显著变硬，但是电子流强的超出与正电子流强的超出具有本质的不同。
- 2) 在0.5 GeV至1.4 TeV的能量范围内，电子能谱可以用双幂律谱来解释。

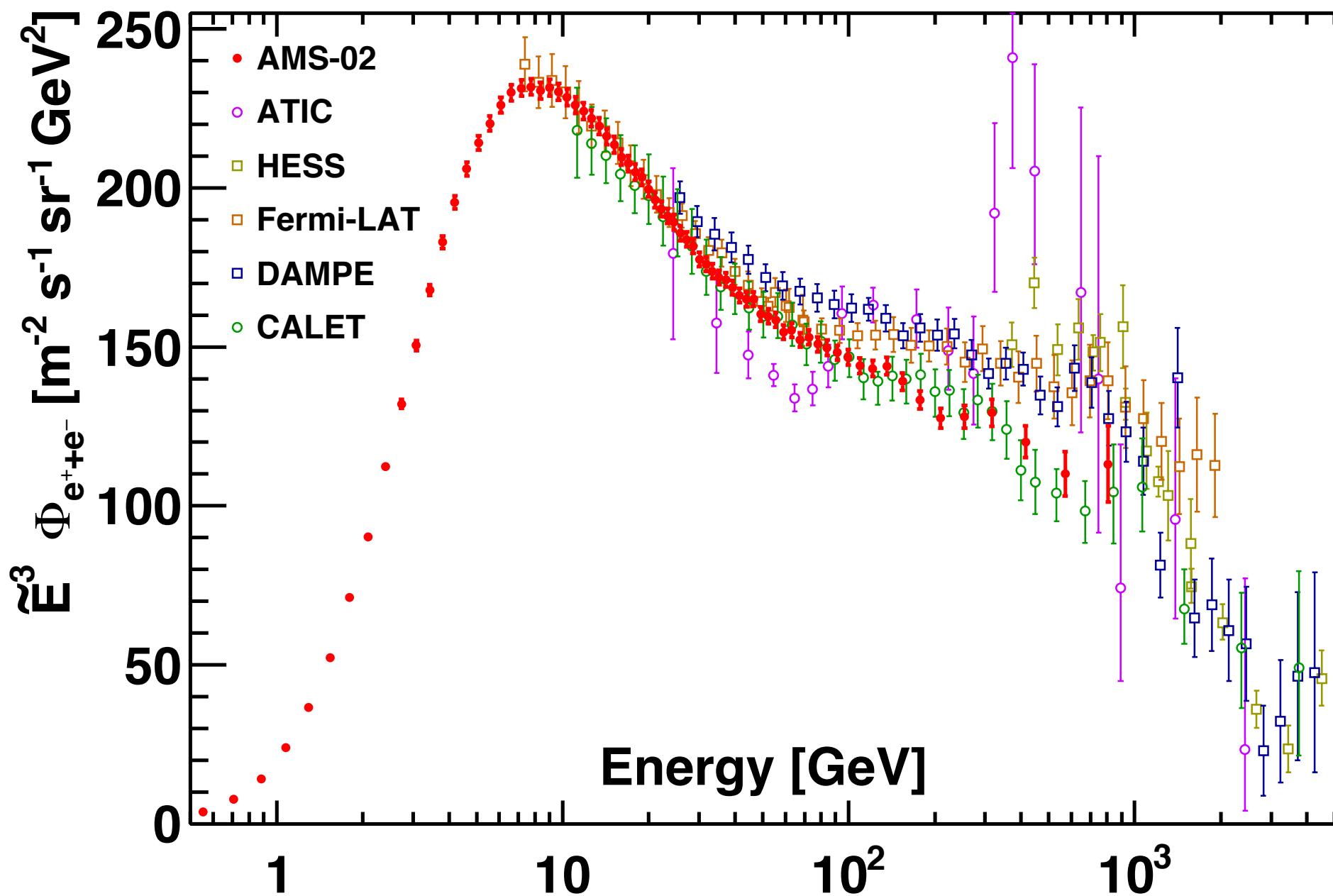
高能电子与高能正电子存在不同的来源



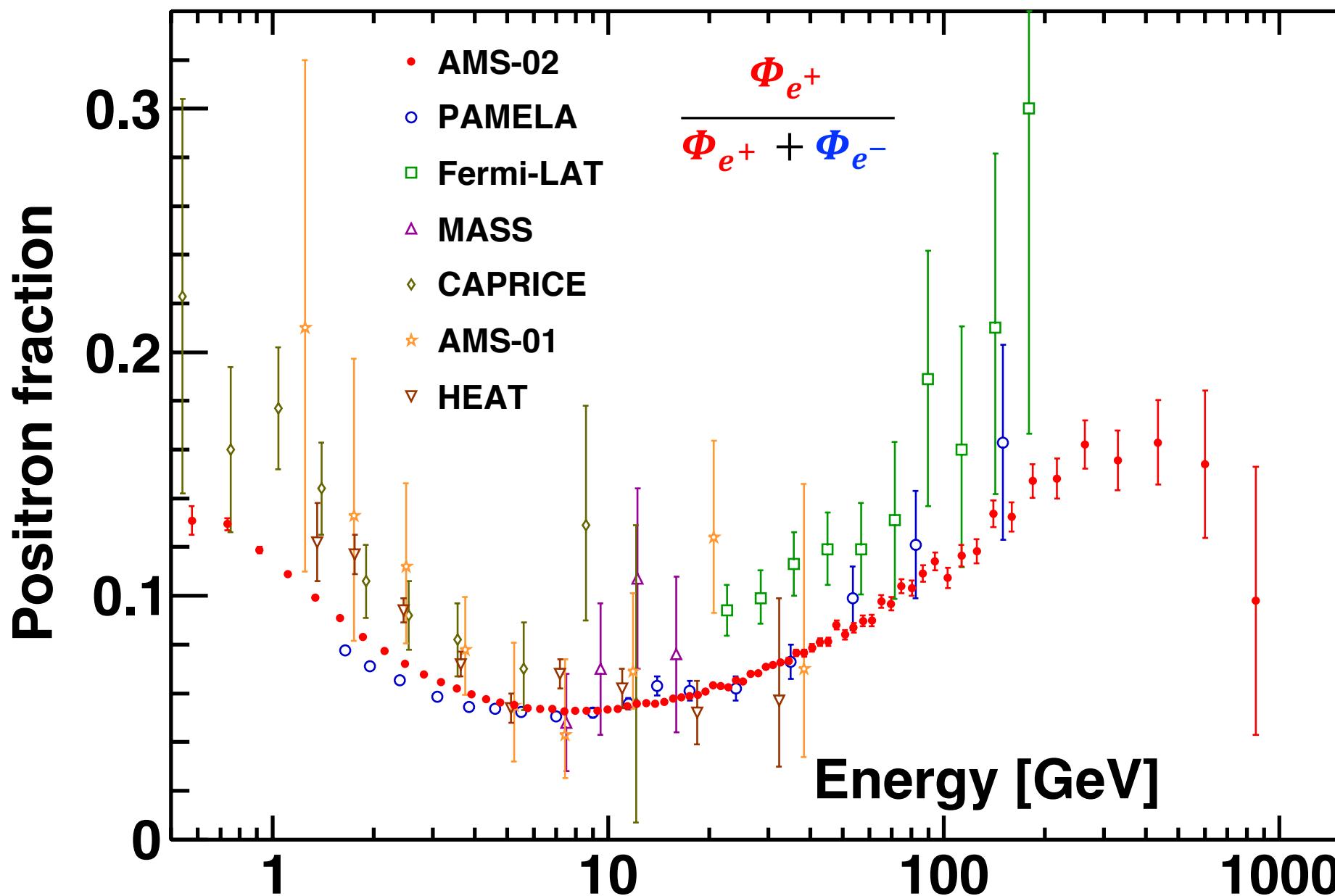
谢谢



# AMS (electron + positron) spectrum with earlier measurements

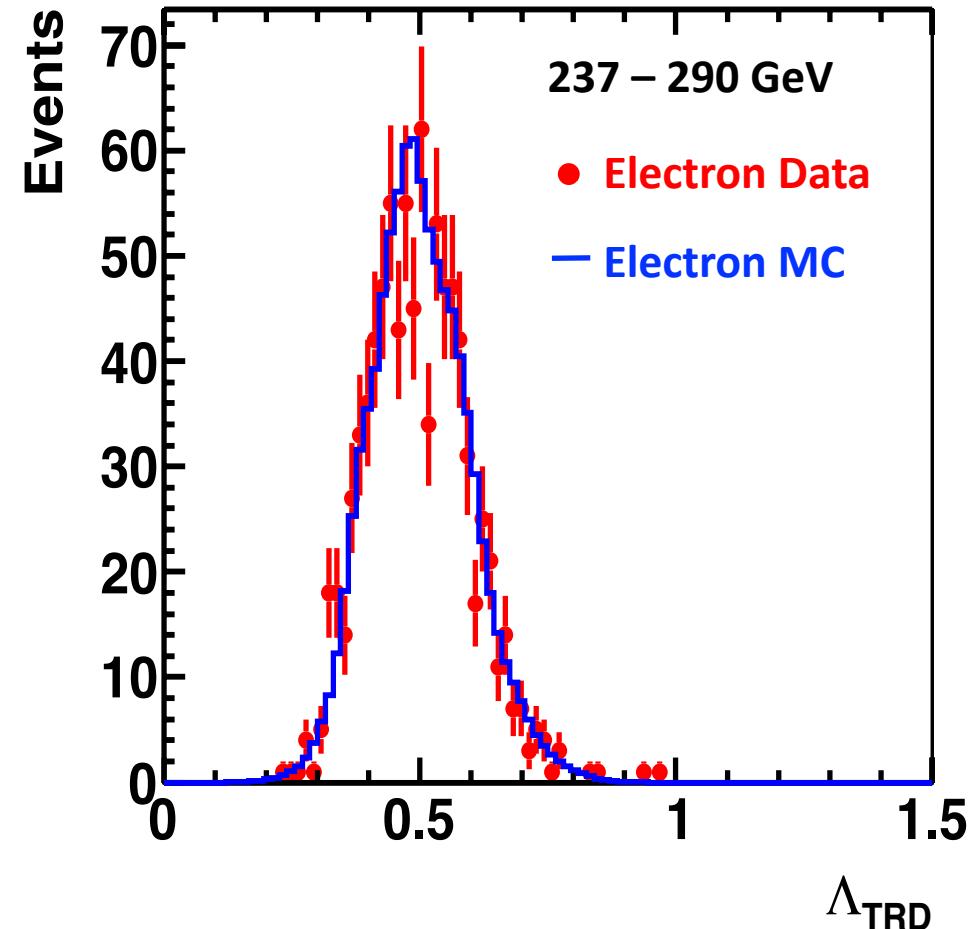


# AMS positron fraction together with earlier measurements

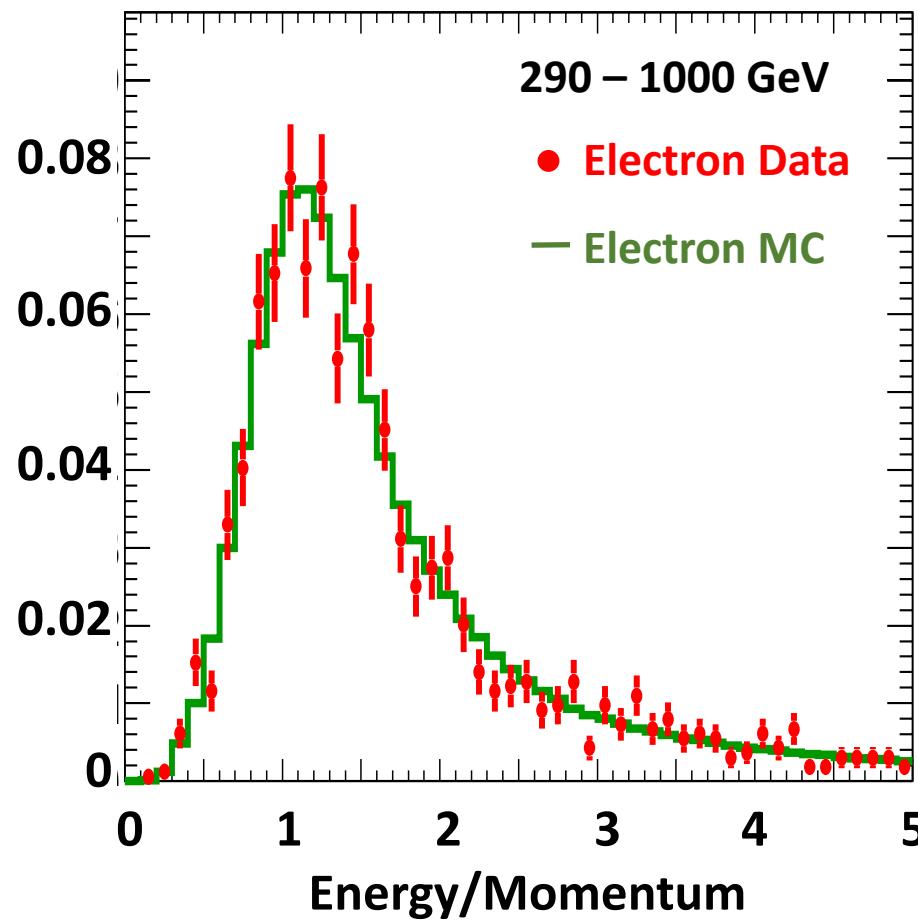


# Accurate understanding of the detector response to $e^\pm$

TRD Estimator



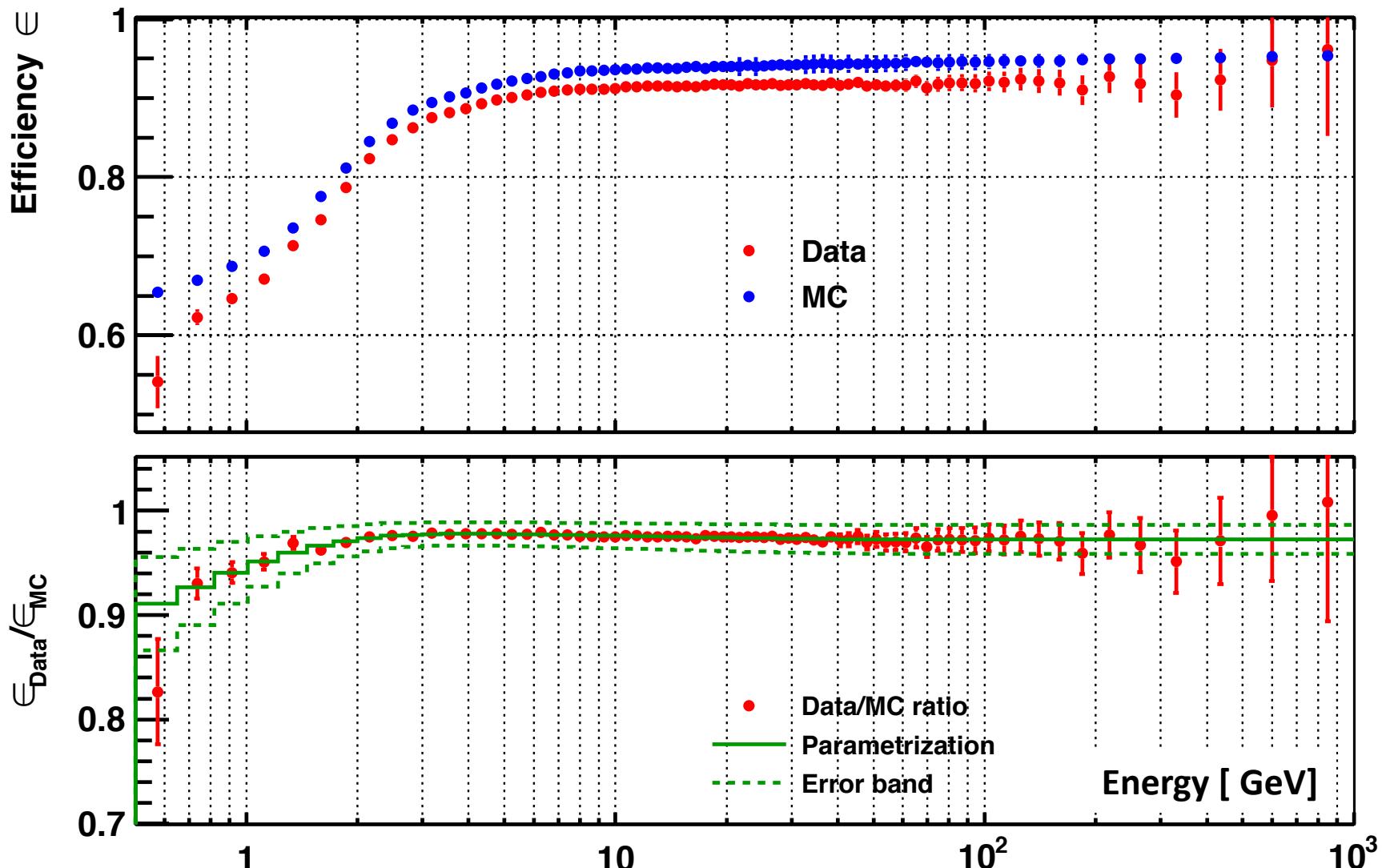
Momentum from tracker  
Energy from EACL



Accurate understanding of the detector response allows for utilizing MC simulation in the analysis

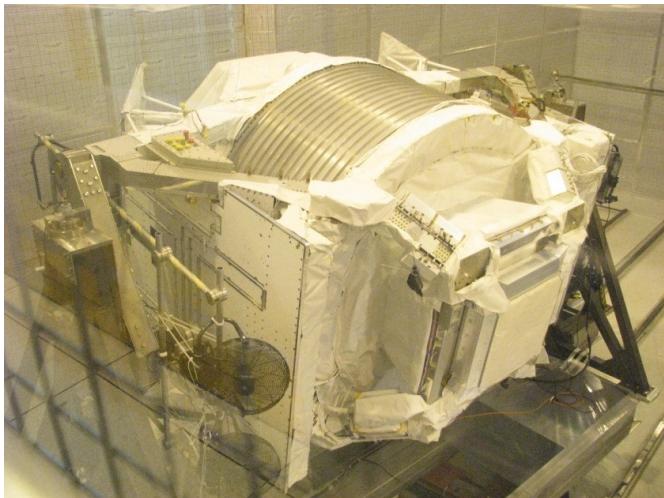
# Data / MC Efficiency correction

The redundancy and precision of AMS allows for measuring efficiency from data

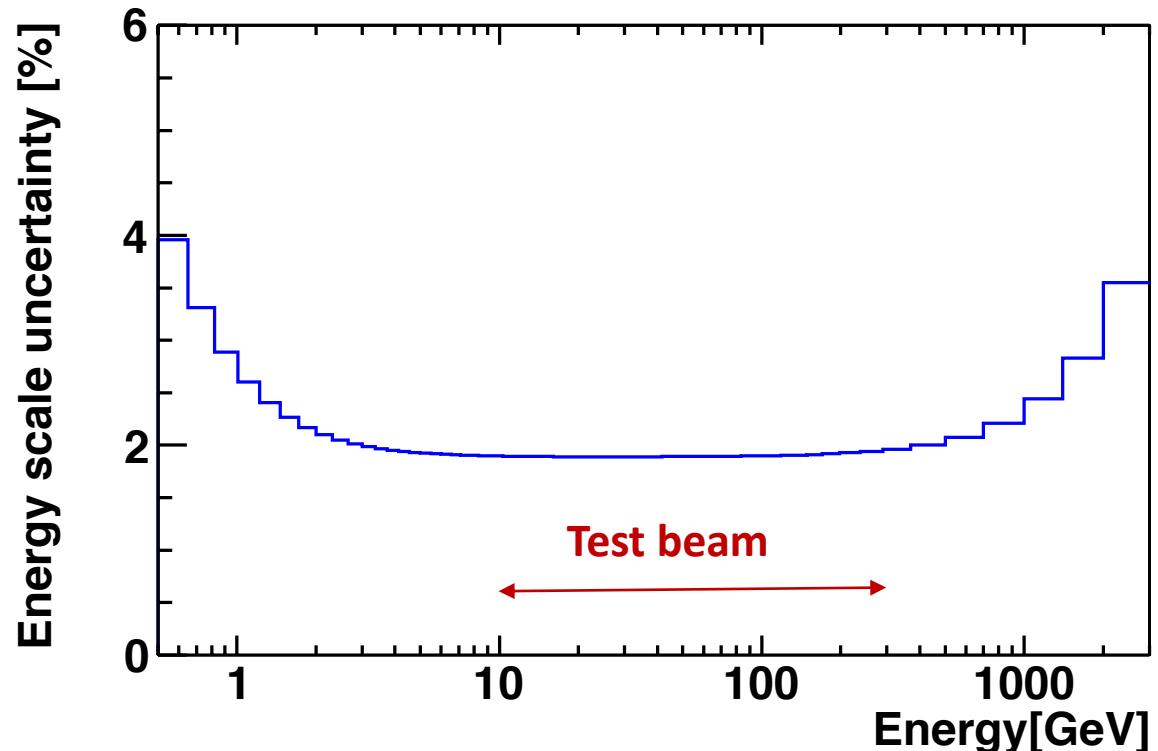


The uncertainty on electron flux due to efficiency correction is  
4% at 0.5 GeV, 1.1% at 3 GeV and 2.5% at 1.0 – 1.4 TeV

# ECAL energy scale uncertainty



$e^+$  and  $e^-$  test beam data  
from 10 GeV to 290 GeV

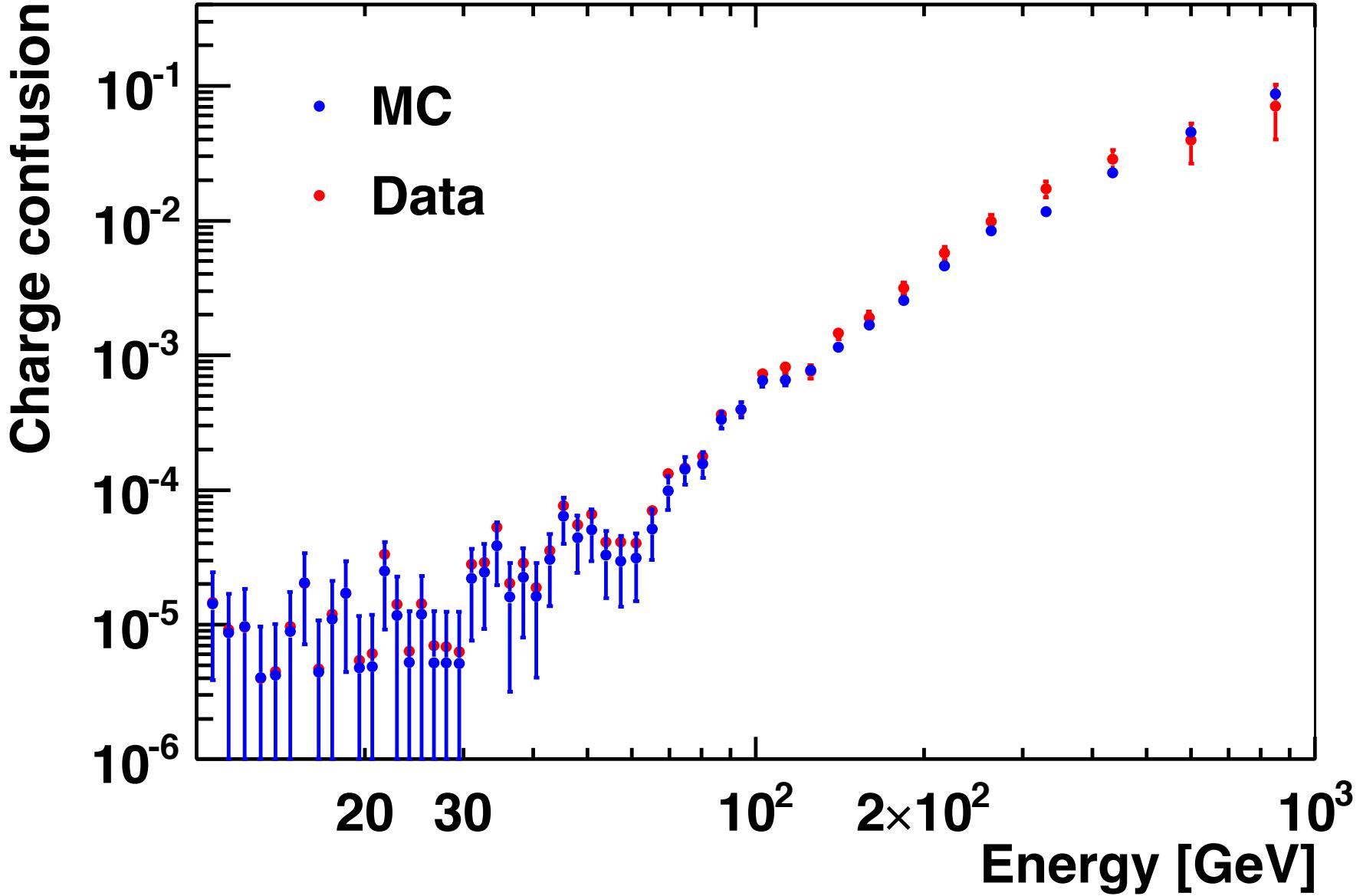


The energy scale uncertainty is verified to be  
2% from 10 to 290 GeV with test beam data.

Based on the test beam data and MC simulation, the uncertainty is estimated to be 4% at 0.5 GeV and 2.6% at 1.4 TeV.

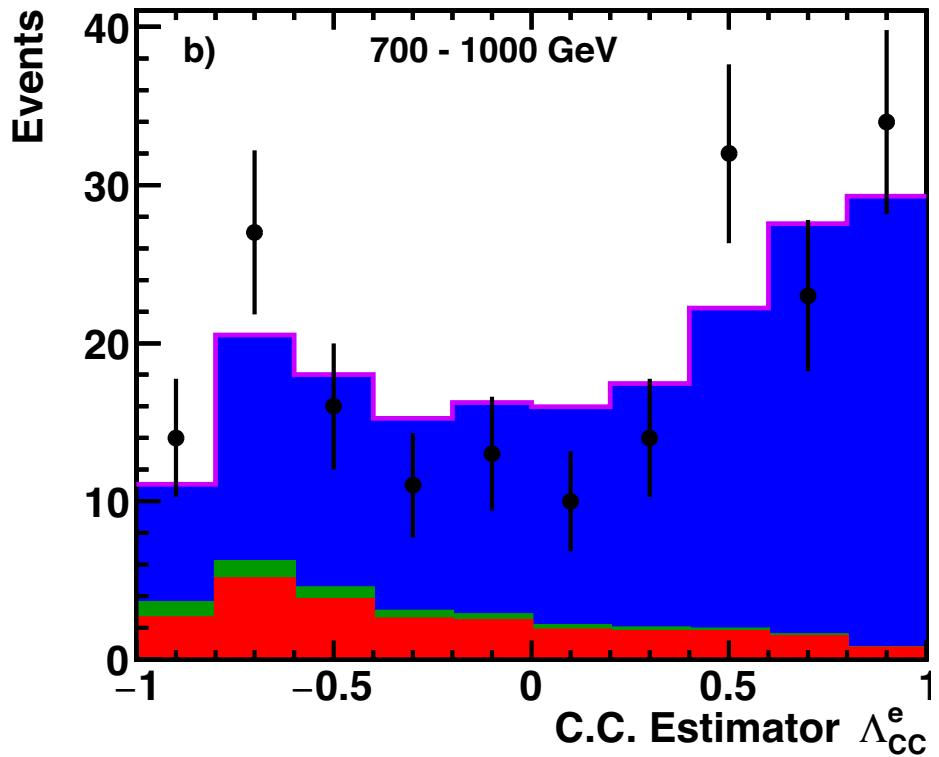
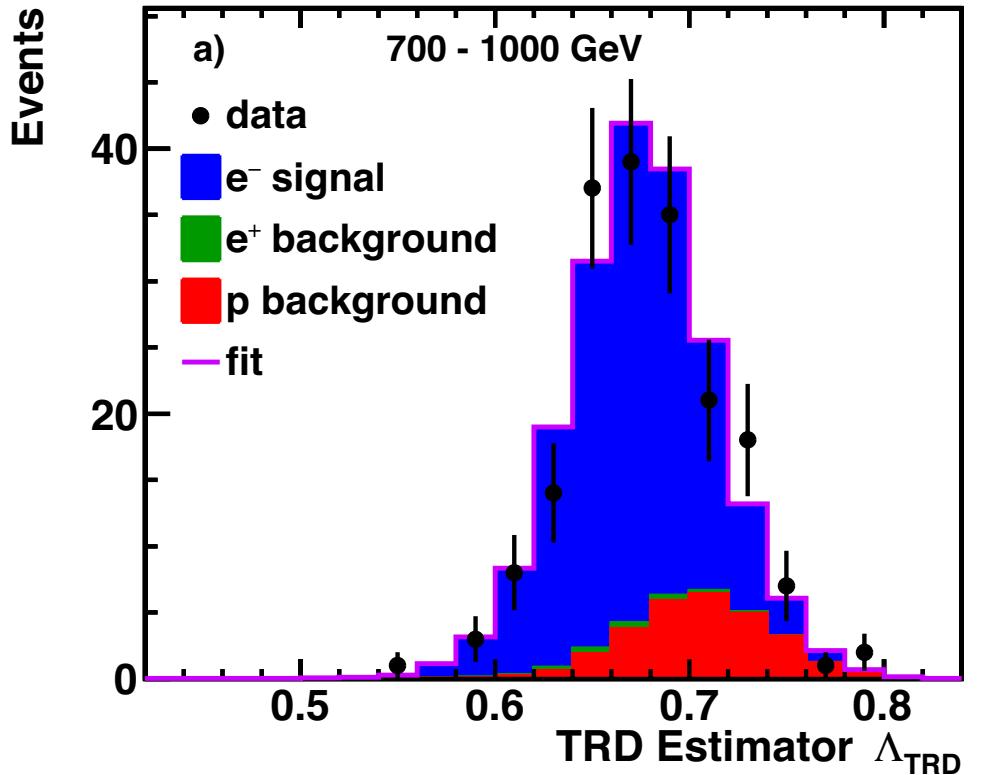
Treated as uncertainty on the energy bin boundaries

# Systematic error from charge confusion

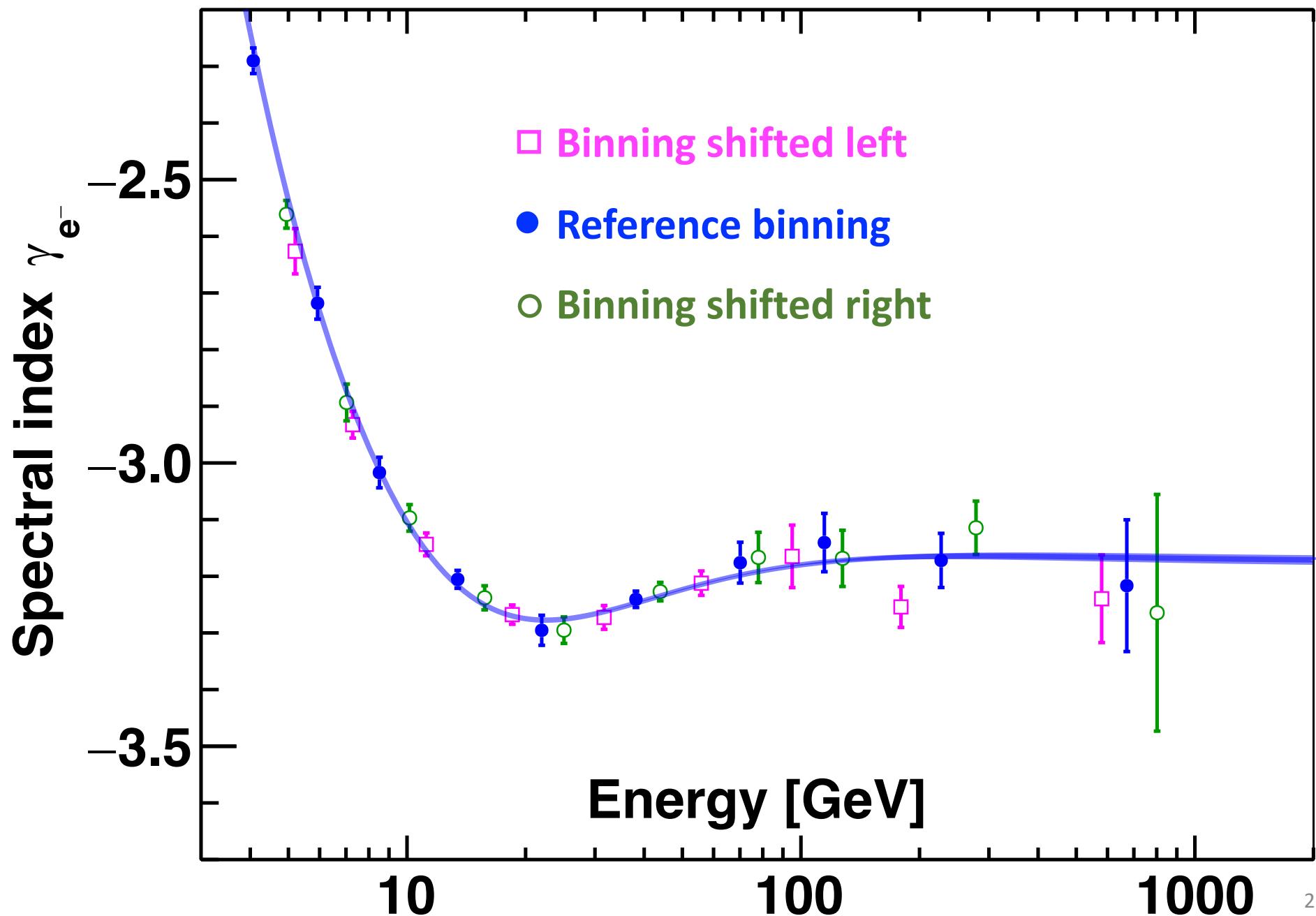


The charge confusion is well reproduced in the MC simulation

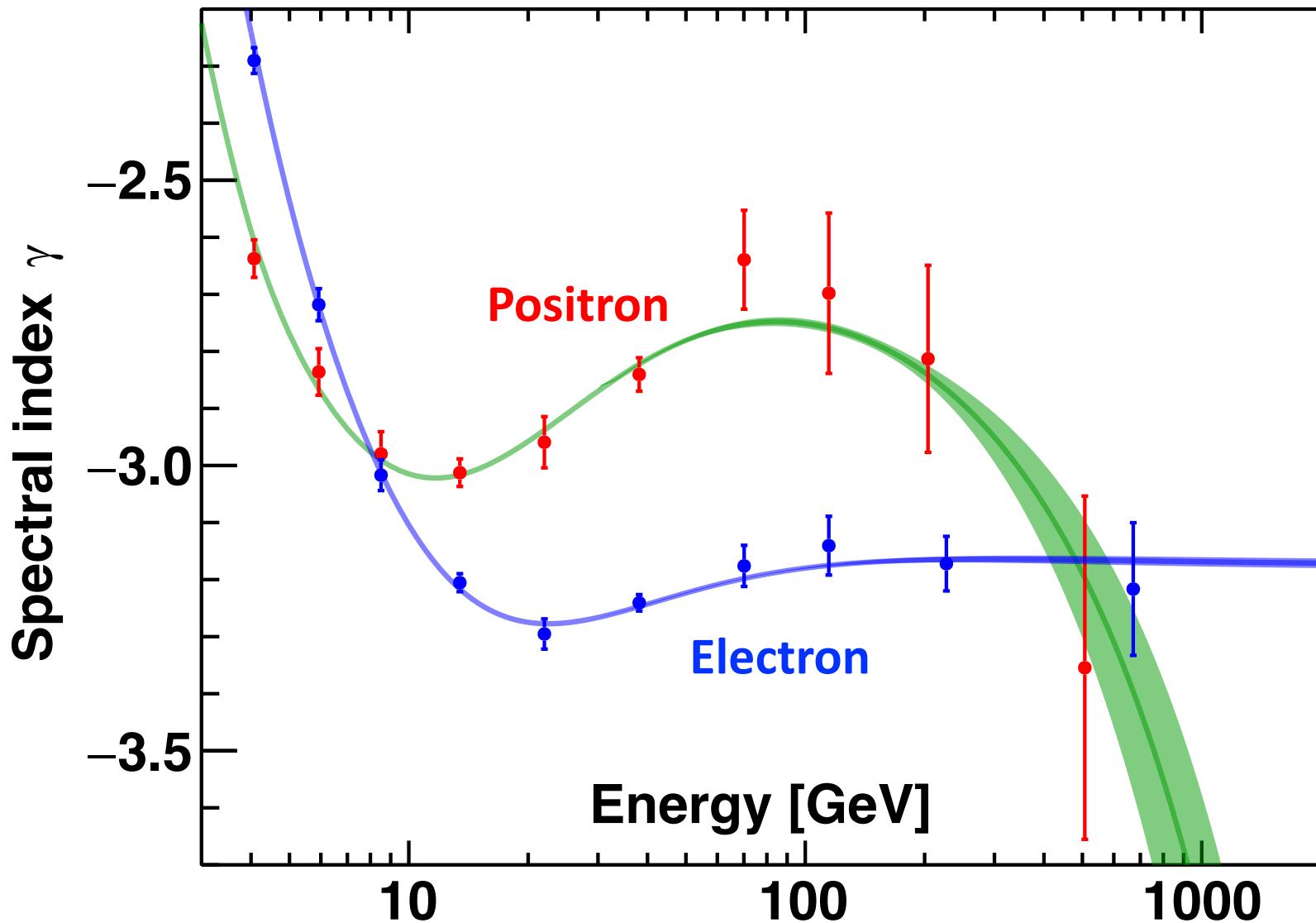
# Fit demonstration for energy 700 – 1000 GeV



# The electron spectral indices with different binning

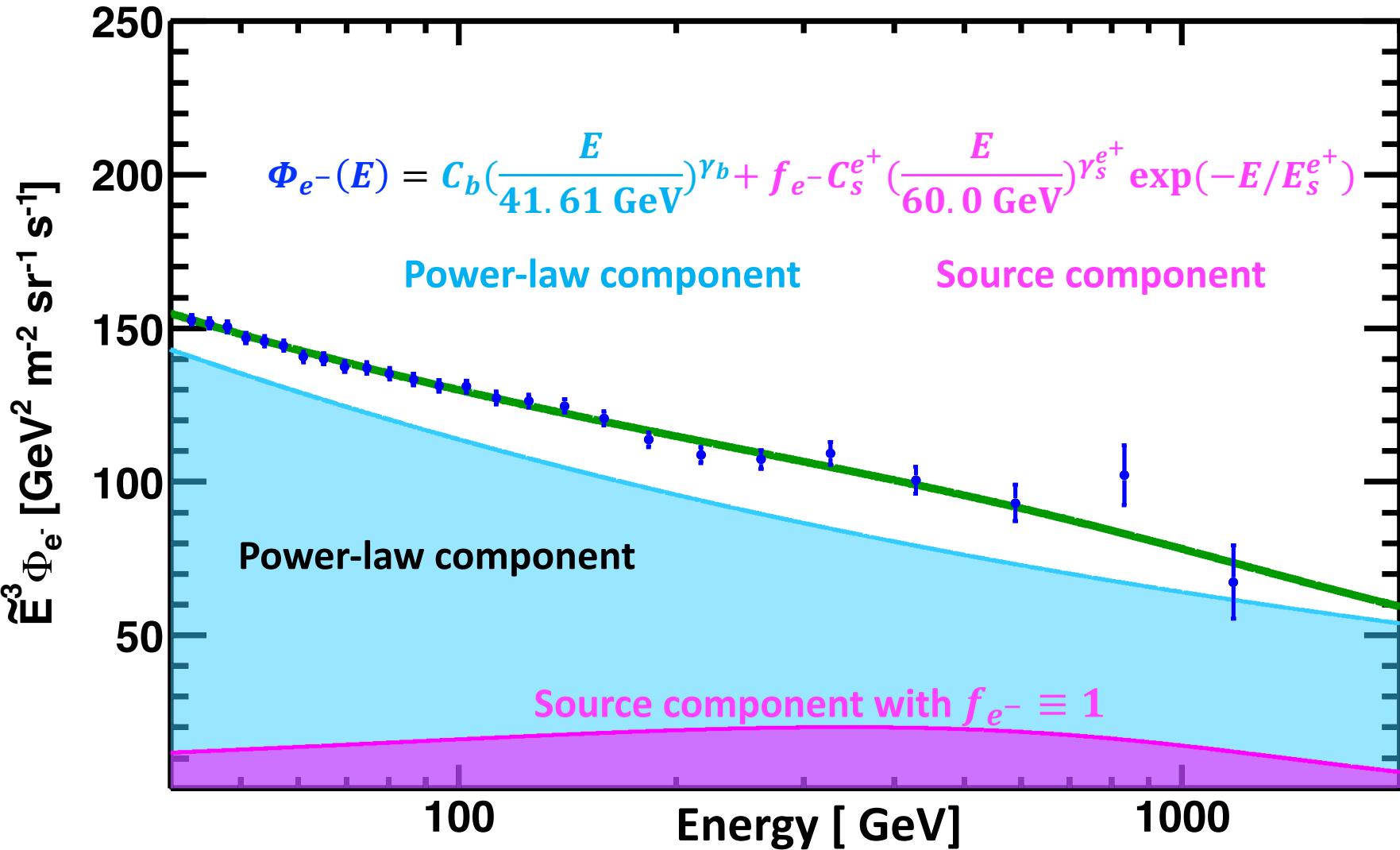


# The spectral indices of electron and positron fluxes



Both the magnitude and energy dependences of the spectral indices are distinctly different for electrons and positrons

# The origin of high energy electrons (II)



- AMS Electron flux is consistent with a charge symmetrical source which produce positrons and electrons with equal amount.
- The fit yields  $f_{e^-} = 0.5^{+1.2}_{-0.6}$  leaving  $f_{e^-}$  as a free parameter, which means the significance to the source term comes mostly from the positron data.