On the PeV knee of cosmic-ray spectrum and TeV cutoff of electron spectrum

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C. Jin, W. Liu, H. B. Hu, and Y. Q. Guo, On the PeV knee of cosmic rays spectrum and TeV cutoff of electron spectrum, arXiv:1611.08384

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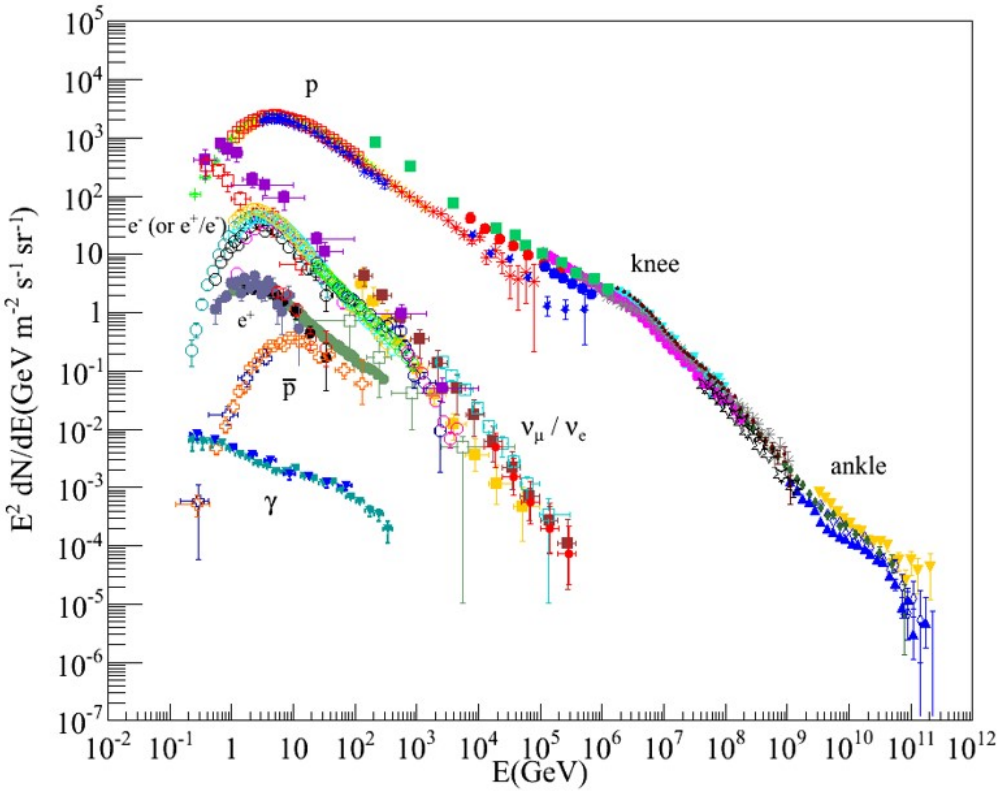
Introduction

- Cosmic rays knee

cosmic rays knee $\sim 4\ PeV$, assume the dominant component is He$(\sim 4\ GeV) \longrightarrow$ $\gamma_A \sim 10^6$



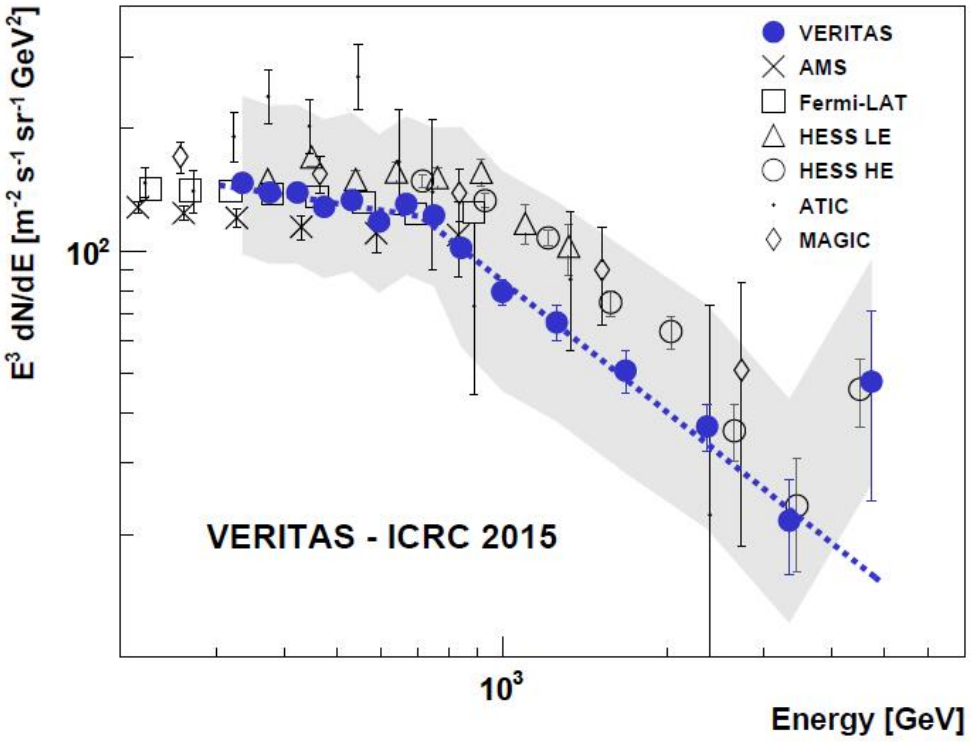
Introduction

- Spectral cutoff of the electrons

Experiments measure a spectral cutoff of the electron at

$\sim 1\ TeV \longrightarrow$

$\gamma_e \sim 10^6$



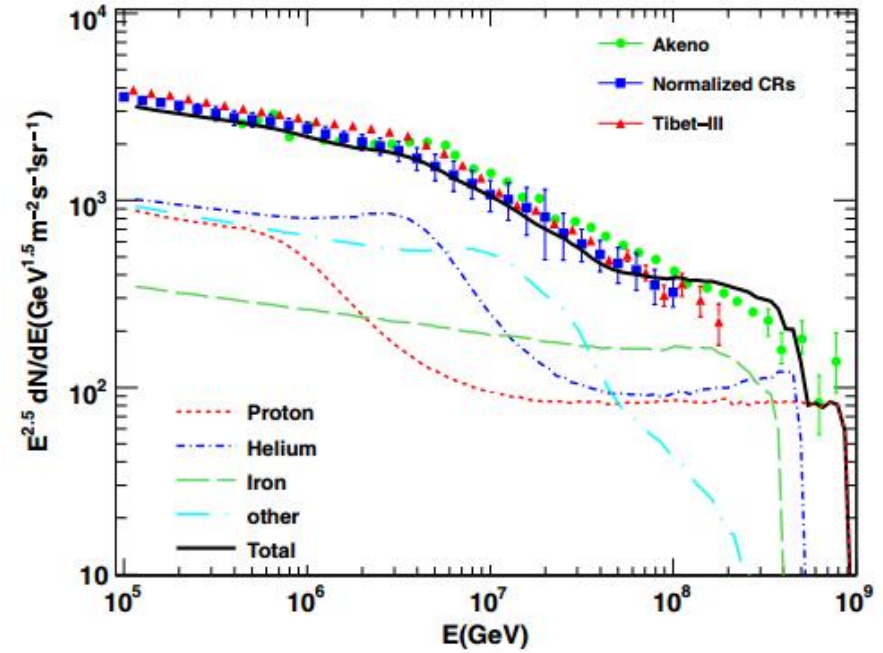
D. Staszak, and for the VERITAS Collaboration,

arXiv:1508.06597

Introduction

- The 4 PeV knee of CRs and 1 TeV electron cutoff have a similar Lorentz factor $\gamma \sim 10^6$
- Assuming they have a common origin, we can associate them with a threshold interaction, like pair production by photons

- CRs can interact with 1 eV photons at the SNR sources and lead to the spectral breaks



Introduction

- But the total number of photons in the Galaxy is insufficient

  We need at least 10000 cm^{-3} photons to explain those spectral breaks, while only 1 cm^{-3} is obtained. Substituting the photon by a new particle X, the invisible property indicates a much less cross section σ_{CR}, thus $n_X \gg 10000\ cm^{-3}$

- the X particles are abundant in the Galaxy

  CRs interact with Xs above their thresholds and produce X', $m_{X'} = 10^6 m_X$

$$CR + X \longrightarrow CR + X'$$

- X' is not necessary to be a particle, maybe a resonance or a collection of particles

Model Construction

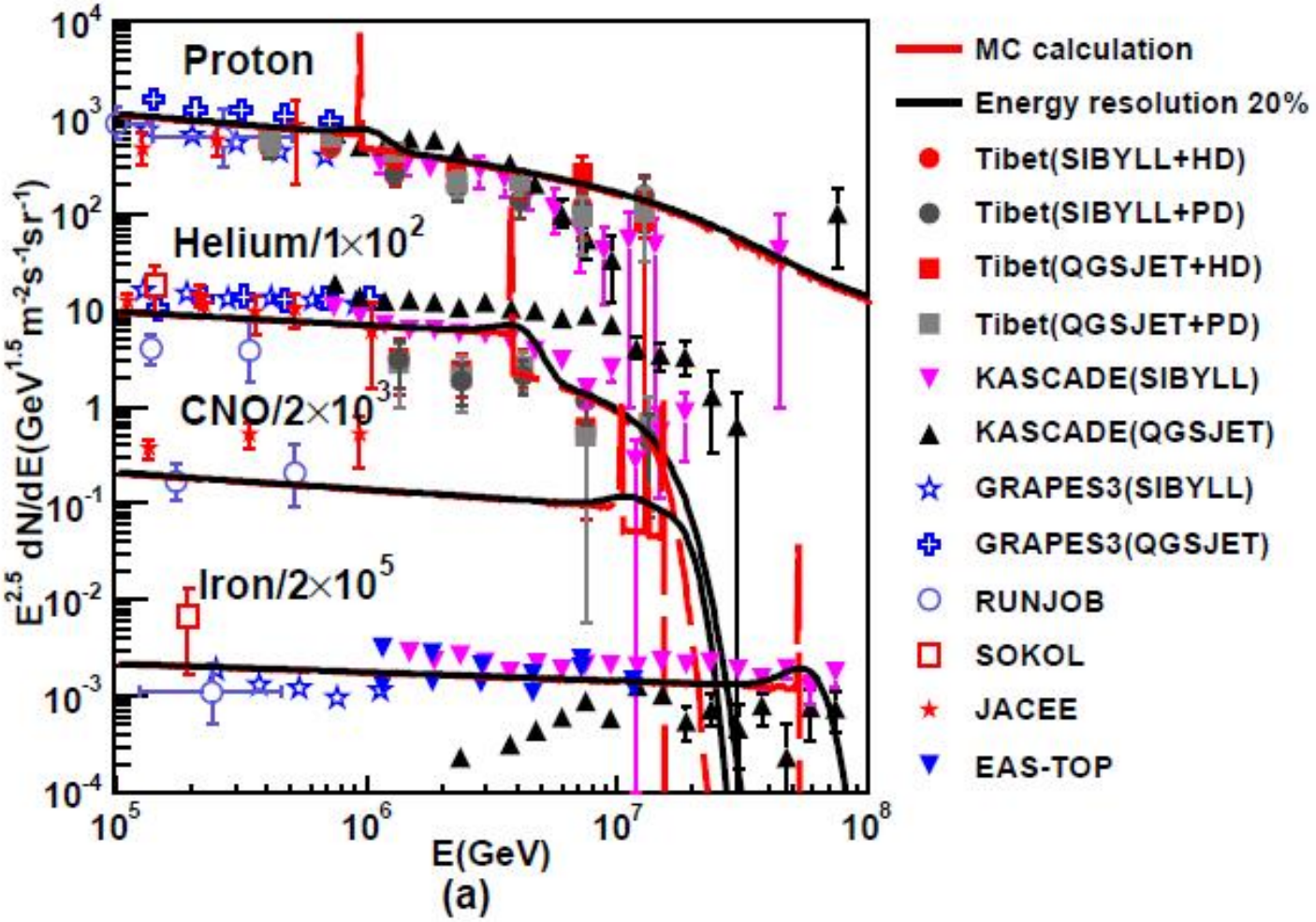
- Non-relativistic of the X, $v_x = 0$
- The constant cross section σ above the threshold
- Possible coherent state of the X with amplified σ by η
- Uniform distribution of final particles in CM
- Separate the propagation and the interaction

Salvador Dali, Galatea of the Spheres, 1952

Calculation & Results

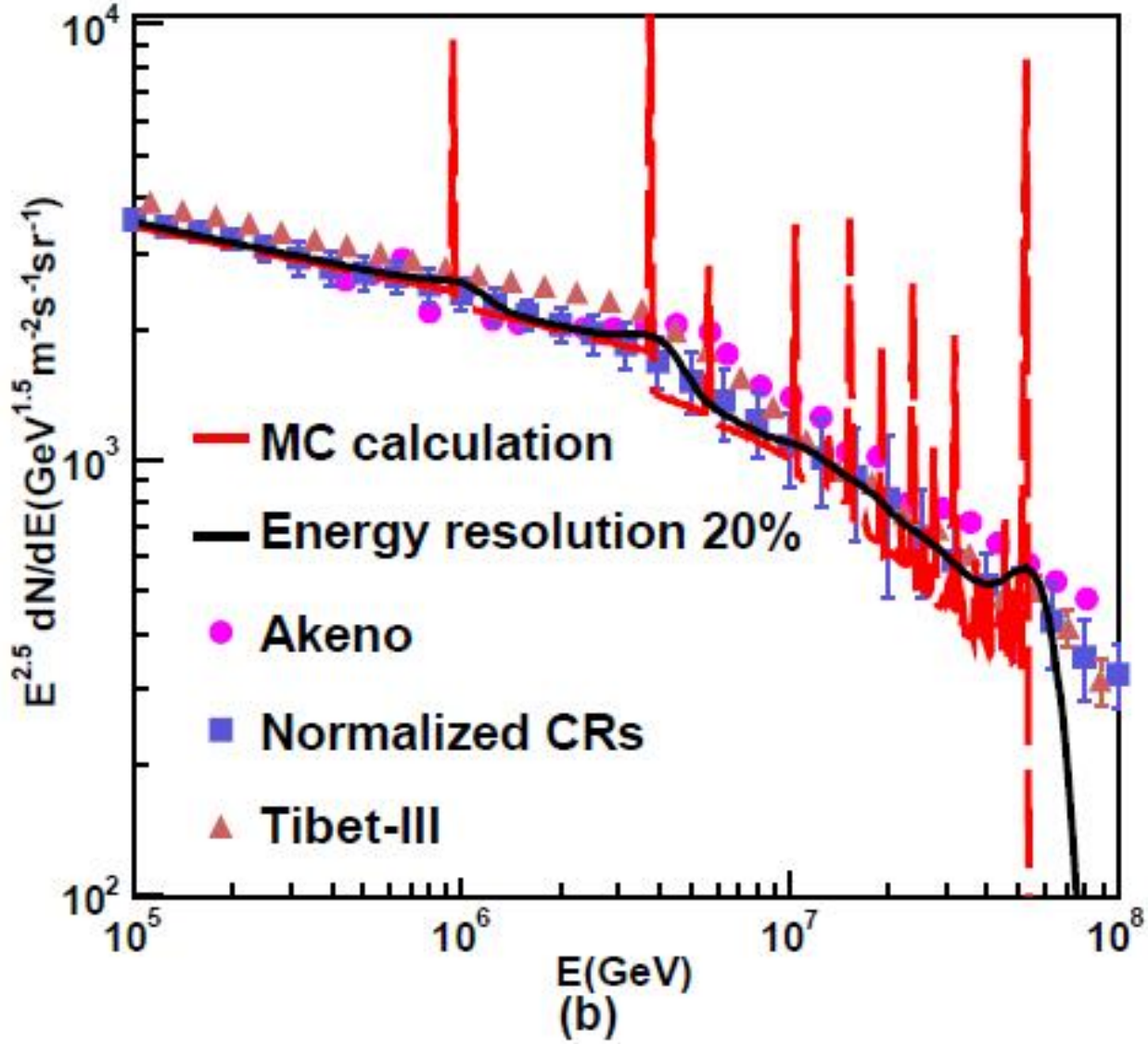
Spectra of the CR nuclei

$m_x = 1\ eV$, $\eta n_x \sigma_A = 4A^2 \times 10^{-21}\ cm^{-1}$, the simple σ can well explain the data



Calculation & Results

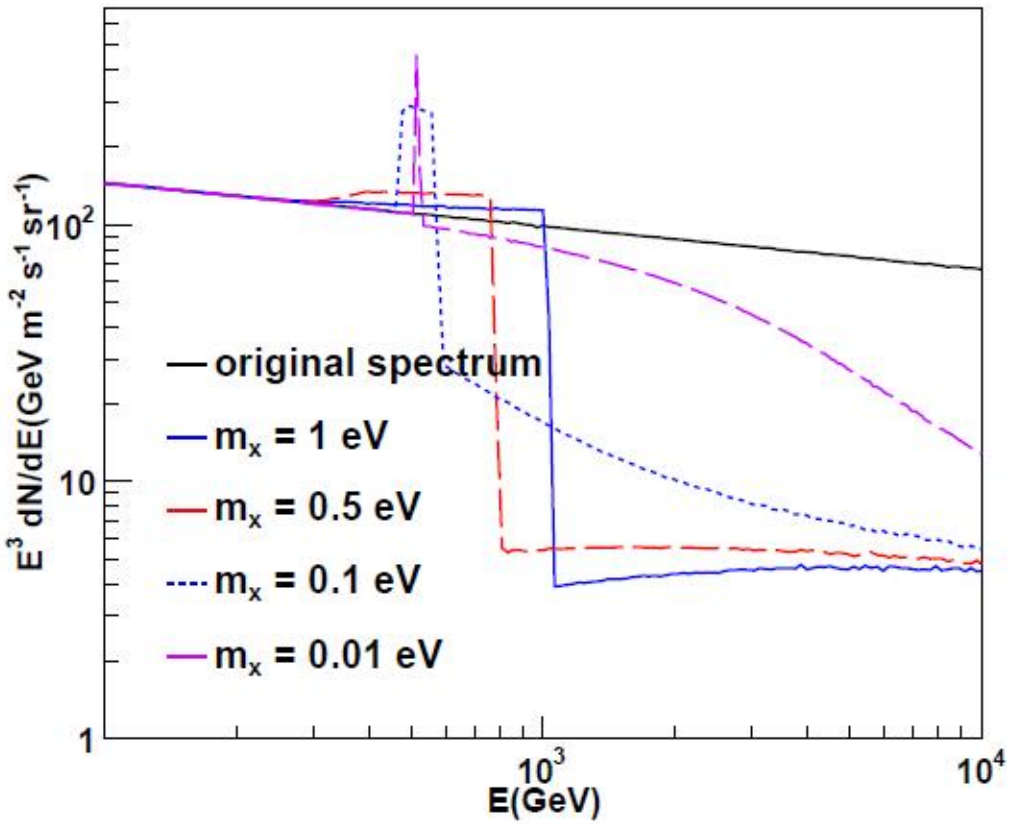
Spectra of the CR nuclei



Calculation & Results

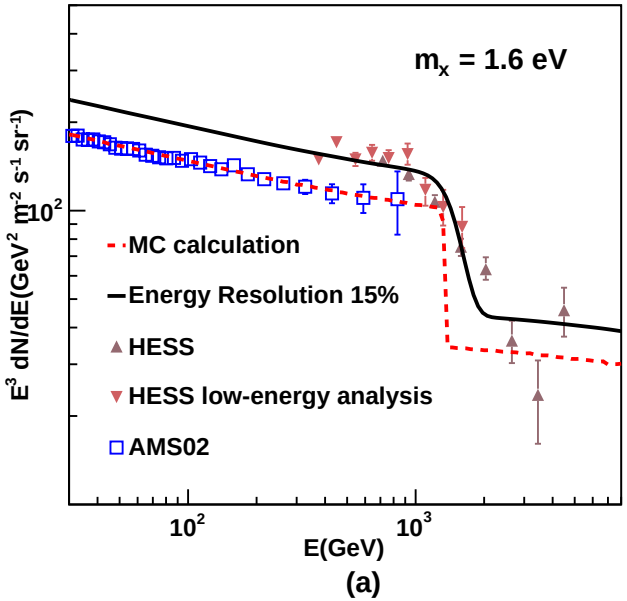
Spectrum of the electron varying with X's mass

- the electron spectrum is sensitive to the X's mass
- the spectral pile-up peak get more prominent with decreasing X's mass
- the cutoff energy decreases as the X's mass decreases

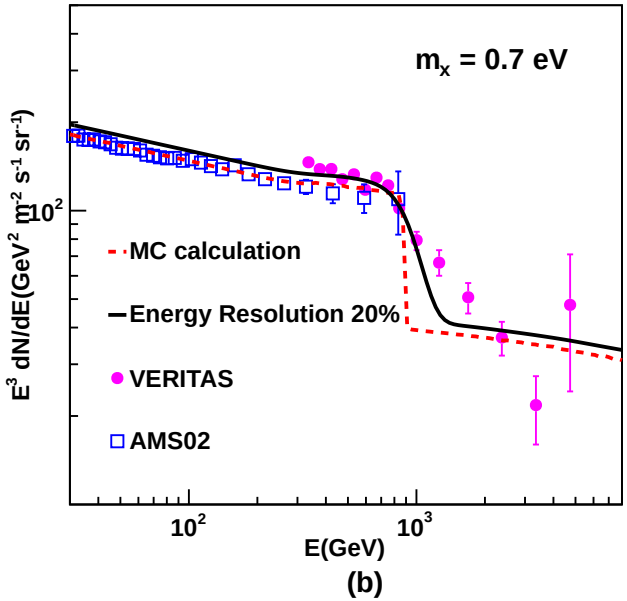


Calculation & Results

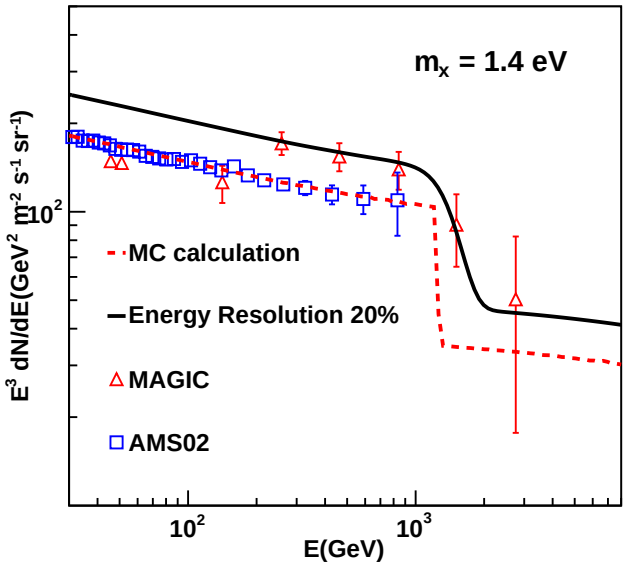
The electron calculations comparing with experiments

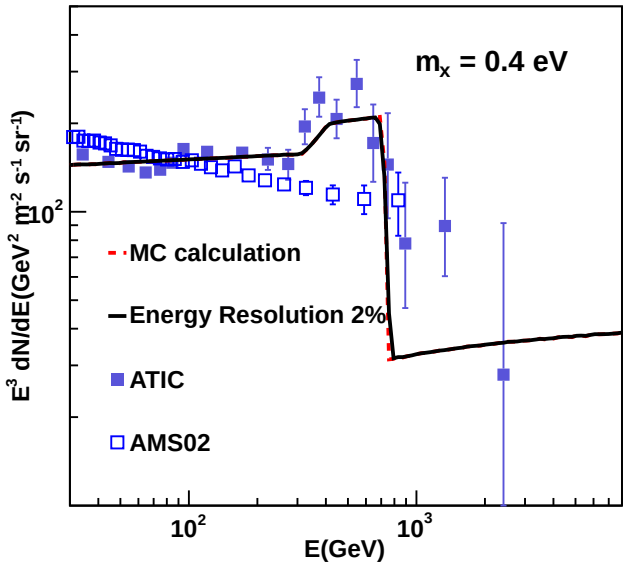


(a)



(b)





Calculation & Results

The electron calculations comparing with experiments

The calculations for the electron are compared with the HESS, VERITAS, MAGIC, and ATIC measurements

parameters	HESS	VERITAS	MAGIC	ATIC
m_x (eV)	1.6	0.7	1.4	0.4
$\eta n_x \sigma_e$ ($\times 10^{-23}\ cm^{-1}$)	1.2	1.2	1.2	2.4
ξ	1.08	1.01	1.09	1

Given that the energy density of the dark matter is 0.4 $GeV\ cm^{-3}$, we can derive the cross section

parameters	HESS	VERITAS	MAGIC	ATIC
n_x ($\times 10^{8}\ cm^{-3}$)	2.5	5.7	2.9	10
$\eta \sigma_e$ ($\times 10^{-5}\ mb$)	4.8	2.1	4.1	2.4

Assuming the dark matter is the X, the $\eta\sigma_e$ is still very large $\longrightarrow$ $\eta \gg 1$

Conclusion & Discussion

Conclusion

- Assuming the common origin for both the CR knee and the spectral cutoff of the electron, we introduce a new particle X abundant in the Galaxy
- The new particle and its interaction with CRs can explain those breaks at the same time
- Results show the Z-type spectra
- The cross section of the nuclei is $2 \sim 3$-order of magnitudes larger than the electron

Conclusion & Discussion

Discussion

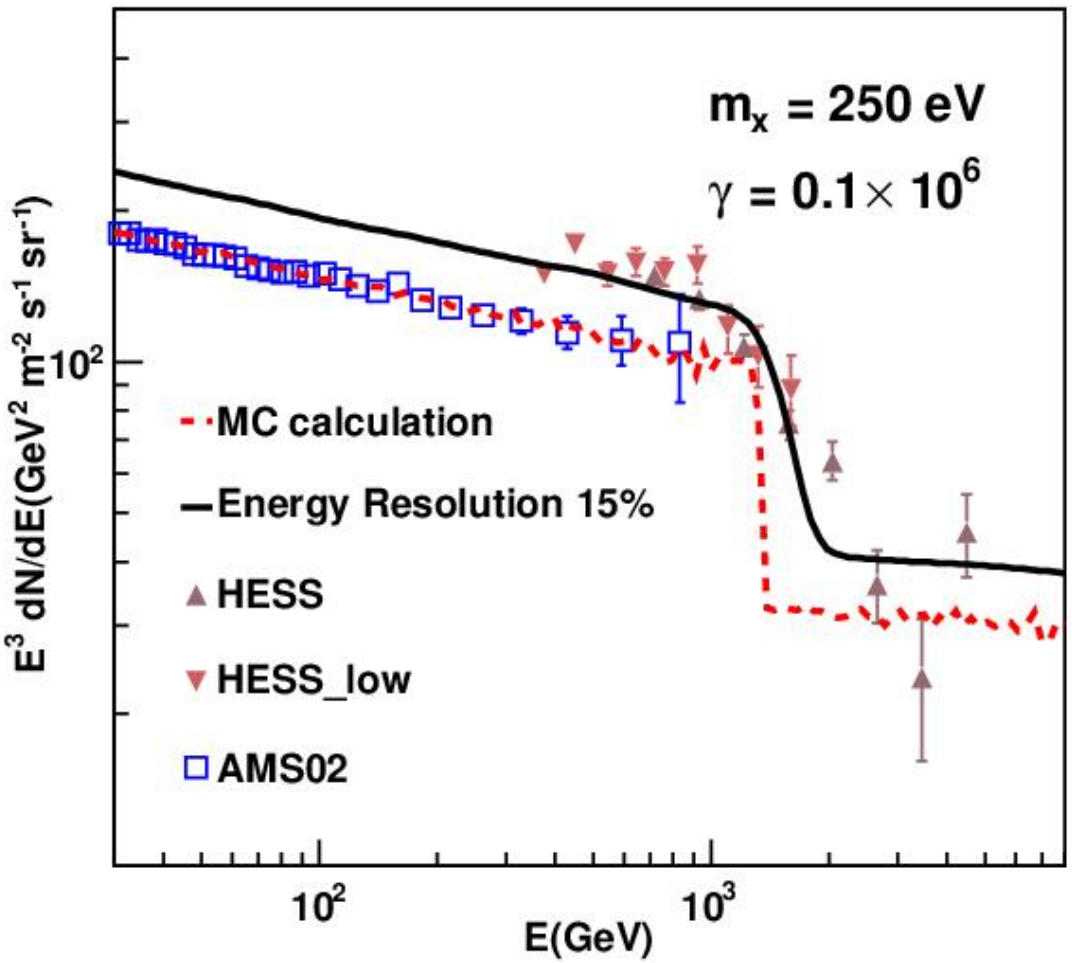
- Many peaks for the nuclei results, and totaly cutoff above the Fe's threshold $\sim 60 PeV$

  The over-simplified interaction model $\longrightarrow$ around the threshold $E_{CR} \uparrow$, $\sigma_{CR} \uparrow$; at high energies, $E_{CR} \uparrow$, $\sigma_{CR} \downarrow$

Conclusion & Discussion

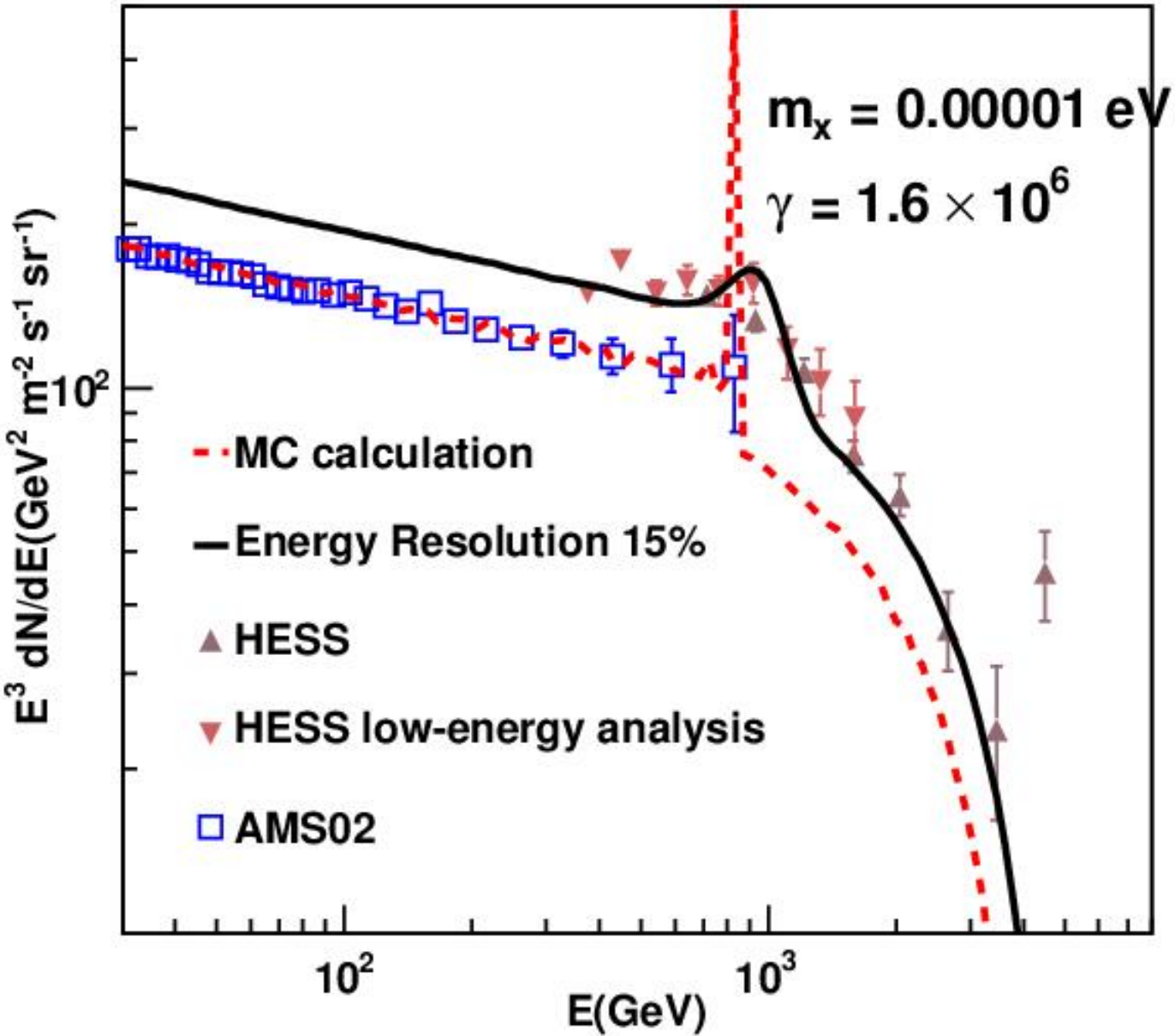
Discussion

- Due to the experimental uncertainties， γ is not sure



Conclusion & Discussion

Discussion



Conclusion & Discussion

- The precise measurements for the electron and the nuclei are necessary
- We look forward the precise measurement for the TeV electron by DAMPE
- We look forward the precise measurement for the composition of the PeV nuclei by LHAASO
- We wish the accelerator experiments can study this particle

Thanks