AMS-02结果介绍

毕效军
中国科学院高能物理研究所

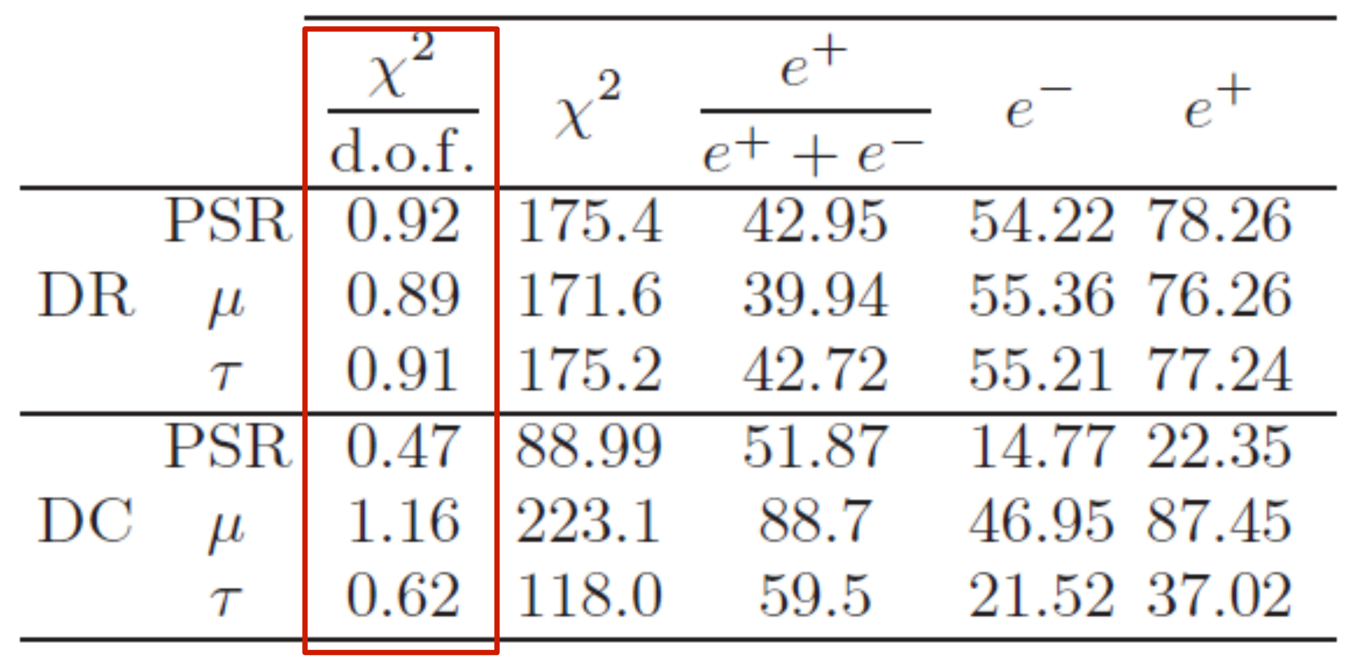
13th LHC mini-workshop, 浙江大学物理学院，
2014/11/11

Outline

- 结论
- AMS-02数据和研究过程概述
- 更多细节

结论：

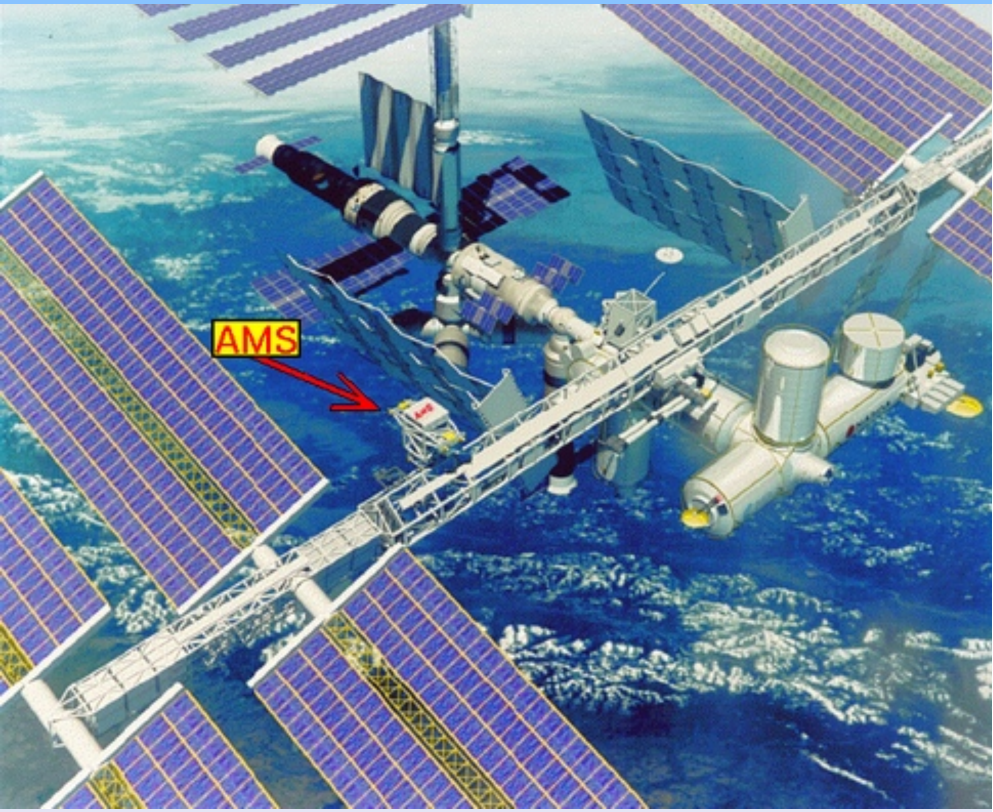
Both pulsar and DM give good fit to the AMS-02 data



		$\frac{\chi^2}{\text{d.o.f.}}$	χ^2	$\frac{e^+}{e^+ + e^-}$	e^-	e^+
DR	PSR	0.92	175.4	42.95	54.22	78.26
	μ	0.89	171.6	39.94	55.36	76.26
	τ	0.91	175.2	42.72	55.21	77.24
DC	PSR	0.47	88.99	51.87	14.77	22.35
	μ	1.16	223.1	88.7	46.95	87.45
	τ	0.62	118.0	59.5	21.52	37.02

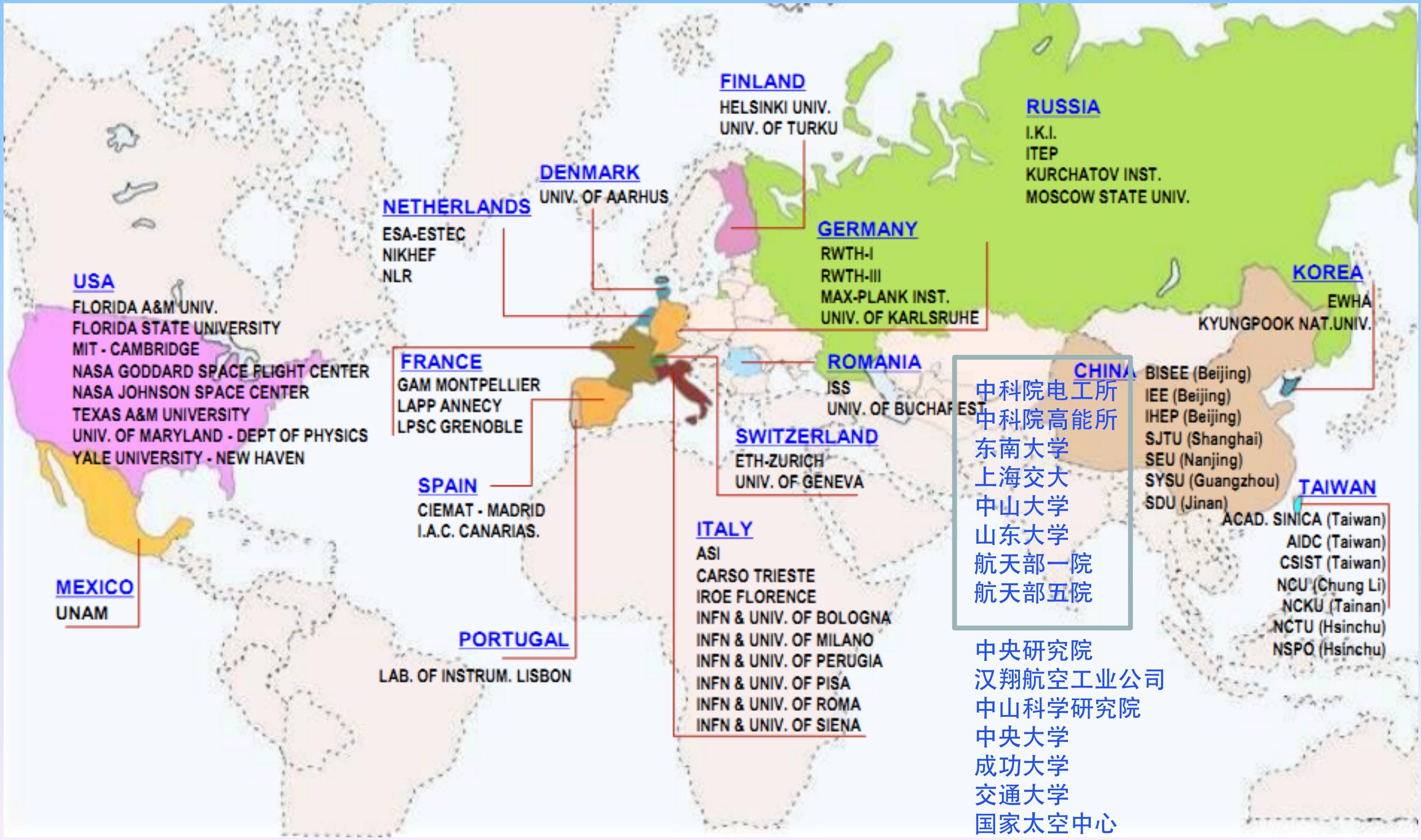
概述AMS-02数据和研究

AMS02



AMS-02（阿尔法磁谱仪）

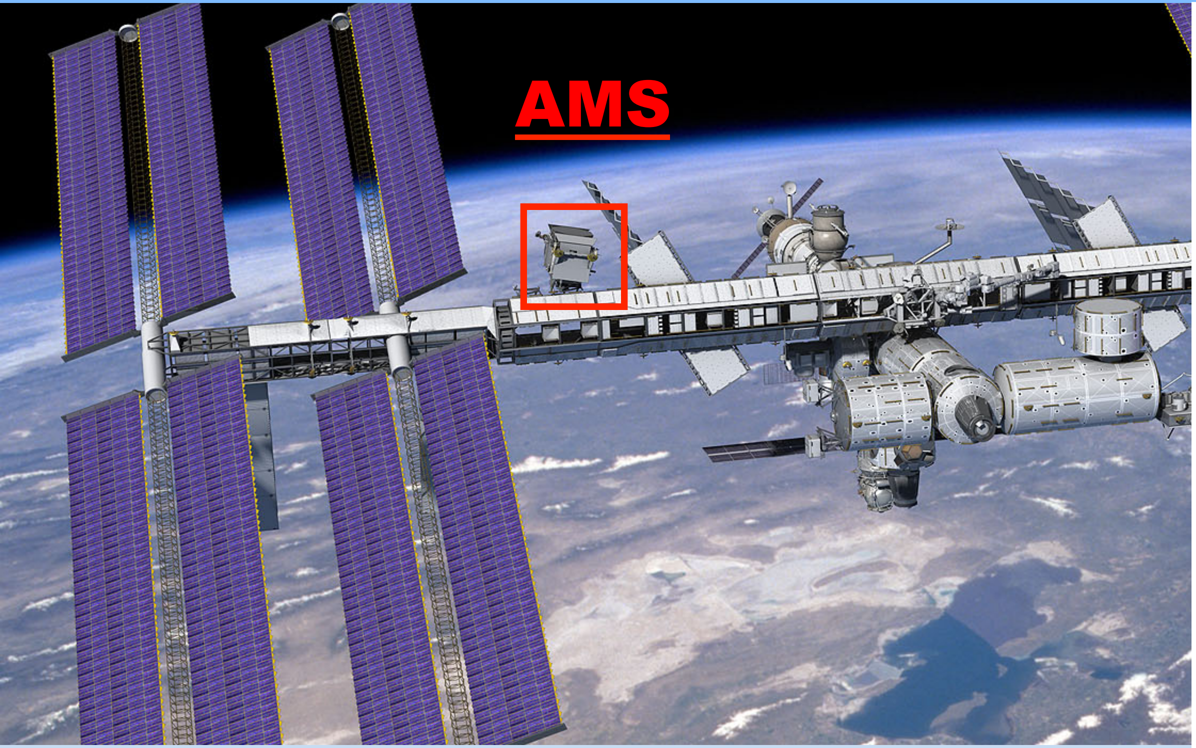
AMS02由丁肇中教授领导，历时近20年，参加实验的科学工作者来自美洲，欧洲和亚洲的16个国家（地区），共有60个大学或研究机构，600多人，目前投资约20亿美元。

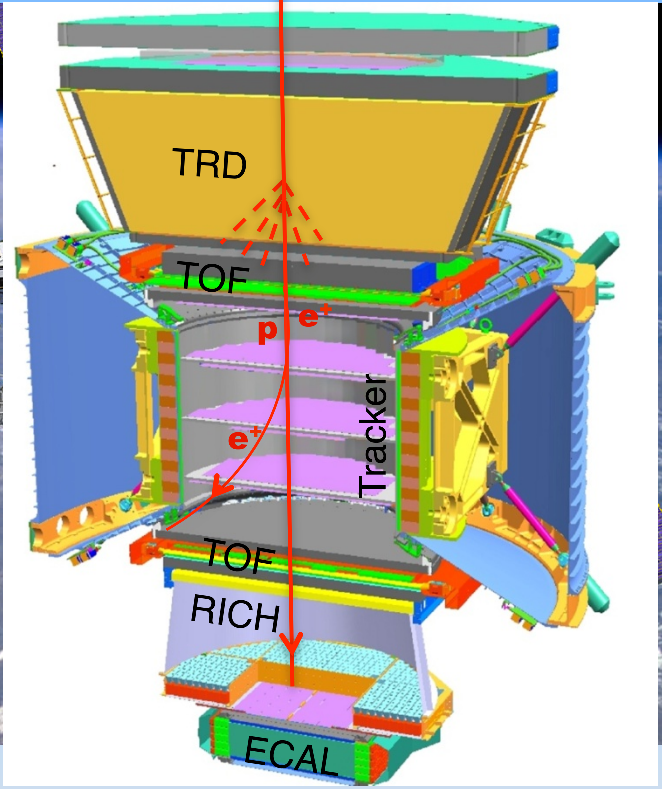


AMS02于2011年5月16日发射升空，5月19日安装到空间站上开始物理取数。

STS-134 launch   May 16, 2011 @ 08:56 AM

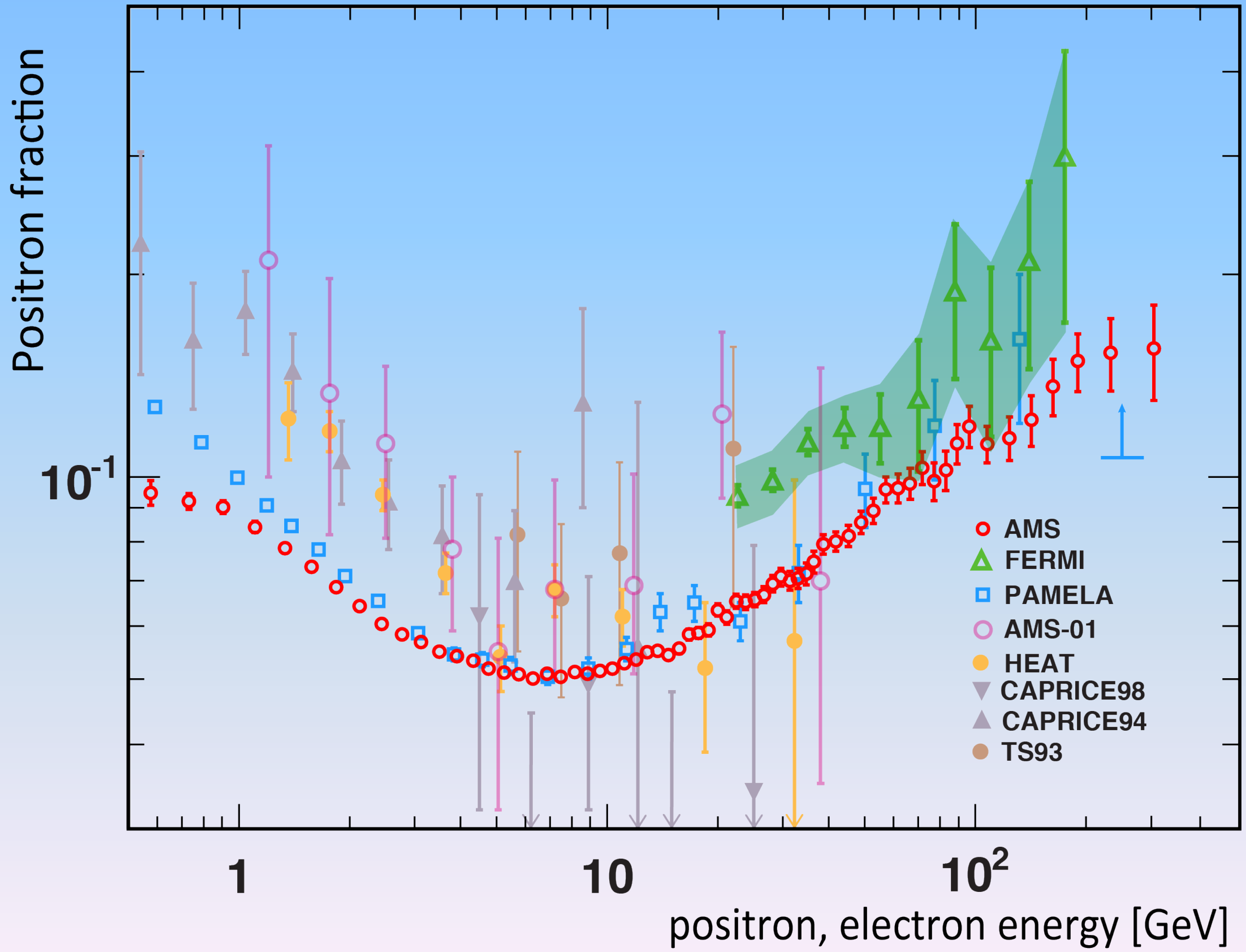
AMS02是国际空间站上唯一大型科学实验，将长期在轨运

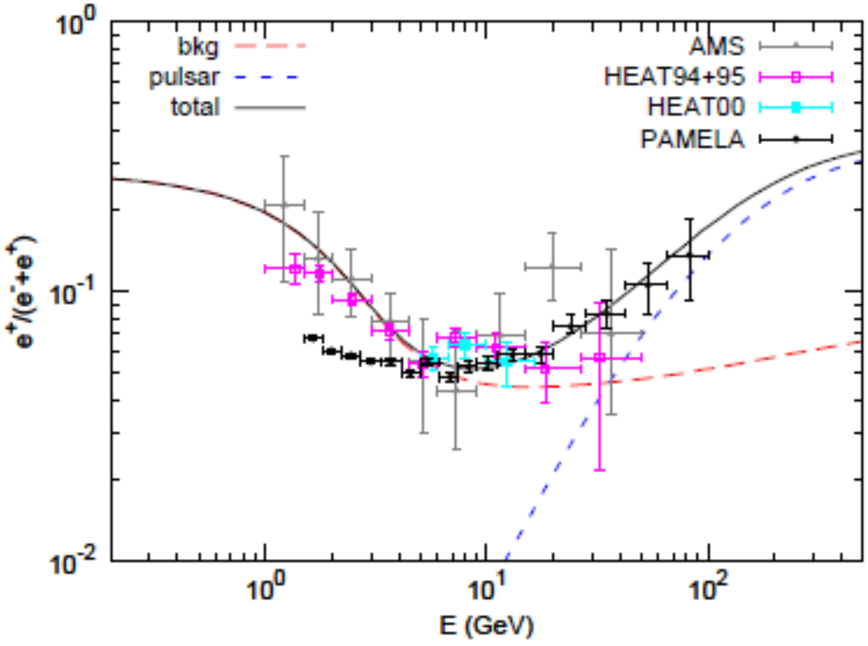


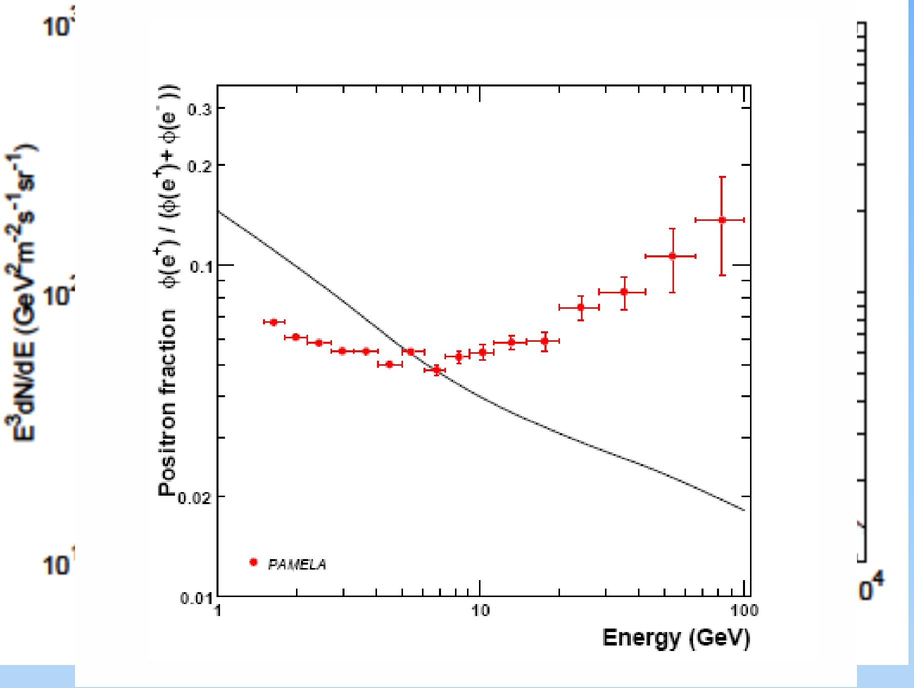


AMS物理目标：暗物质寻找
AMS物理目标：寻找反物质
AMS物理目标：带电宇宙线的精确测量

2013年4月发布第一个物理结果，既正电子比例的测量结果







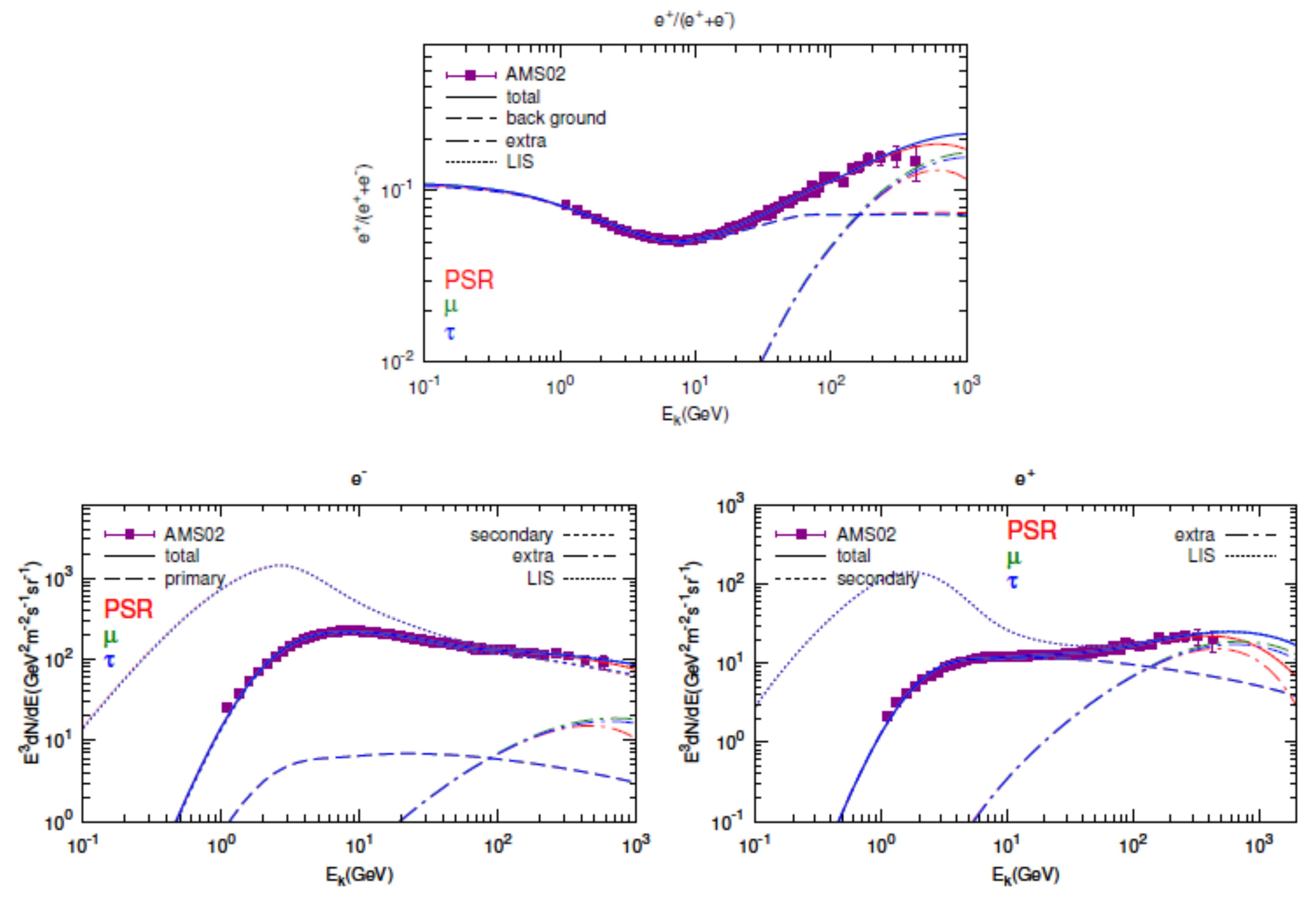
J.Liu, Q. Yuan, X-J Bi, H. Li, and X. Zhang, PRD85, 043507, 2012

DM can explain both the positron excesses and total spectrum; but it is not better than astrophysical explanation. To clarify the situation more precise data are necessary.

怎么理解实验观察到的正电子超出呢？（since PAMELA 2008)

Astrophysical sources	Exotic sources
Nearby pulsars，SNRs, Propagation effects Early SN stage interaction of CRs …….	Dark matter annihilation Dark matter decay

$$e+/(e-+e+) = (e+_{bkg}+e+_{extra})/(e-_{bkg}+e-_{extra} +e+_{bkg}+e+_{extra})$$



Updated positron fraction and electron/positron spectra are published in Sep. 2014.

→ **We have precise CR data** → **Quantitatively study of physics behind**

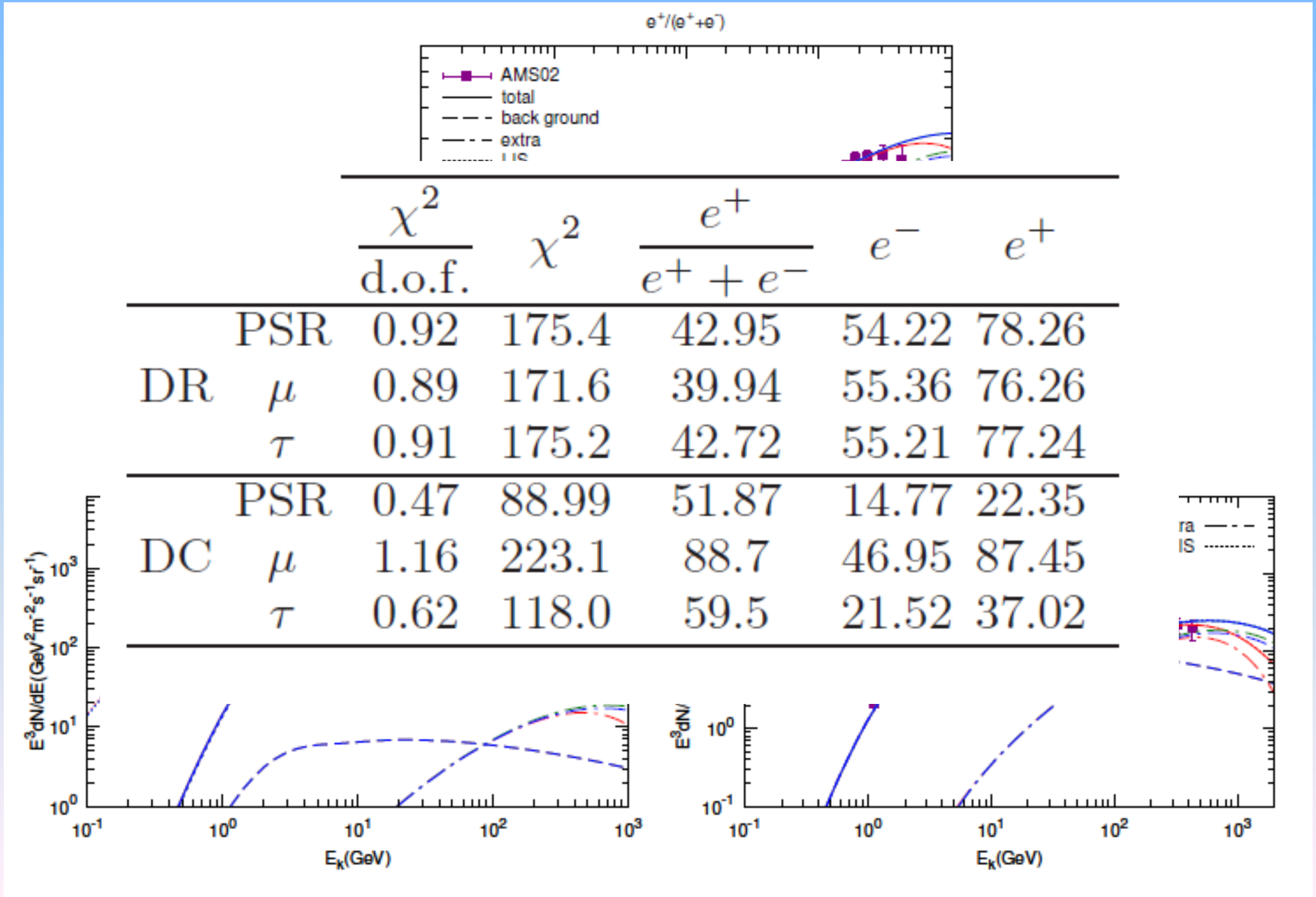
Bkg+pulsar (or DM) to fit the data

$$\mathcal{P} = \begin{cases} \{A_p, \nu_1, \nu_2, p^p_{\rm br}\}, & \text{bkg protons,} \\ \{A_e, \gamma_1, \gamma_2, p^e_{\rm br}\}, & \text{bkg electrons,} \\ \underline{\{A_{\rm psr}, \alpha, E_c\} \text{ or } \{m_\chi, \langle\sigma v\rangle\},} & \text{exotic sources,} \\ \{c_{e^+}, \phi\}, & \text{others.} \end{cases}$$

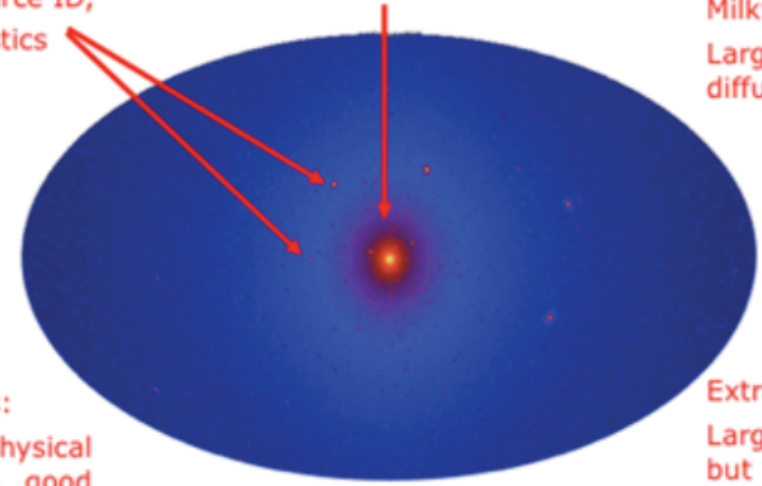
We fit the parameters to data by MCMC to determine the natures of bkg and extra sources.

Both pulsar and DM give good fit

Lin, Yuan, Bi, 1409.6248



		$\frac{\chi^2}{\text{d.o.f.}}$	χ^2	$\frac{e^+}{e^+ + e^-}$	e^-	e^+
DR	PSR	0.92	175.4	42.95	54.22	78.26
	μ	0.89	171.6	39.94	55.36	76.26
	τ	0.91	175.2	42.72	55.21	77.24
DC	PSR	0.47	88.99	51.87	14.77	22.35
	μ	1.16	223.1	88.7	46.95	87.45
	τ	0.62	118.0	59.5	21.52	37.02



Satellites:
Low background and good source ID, but low statistics

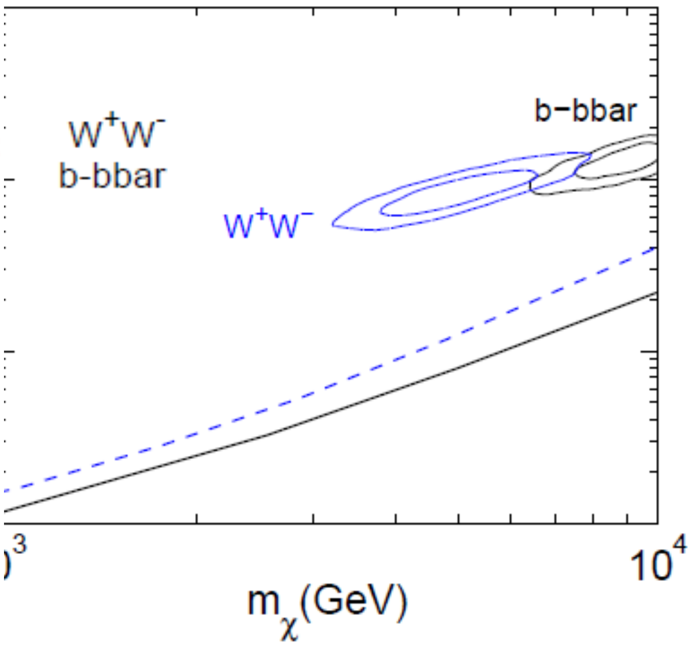
Galactic center:
Good statistics but source confusion/diffuse background

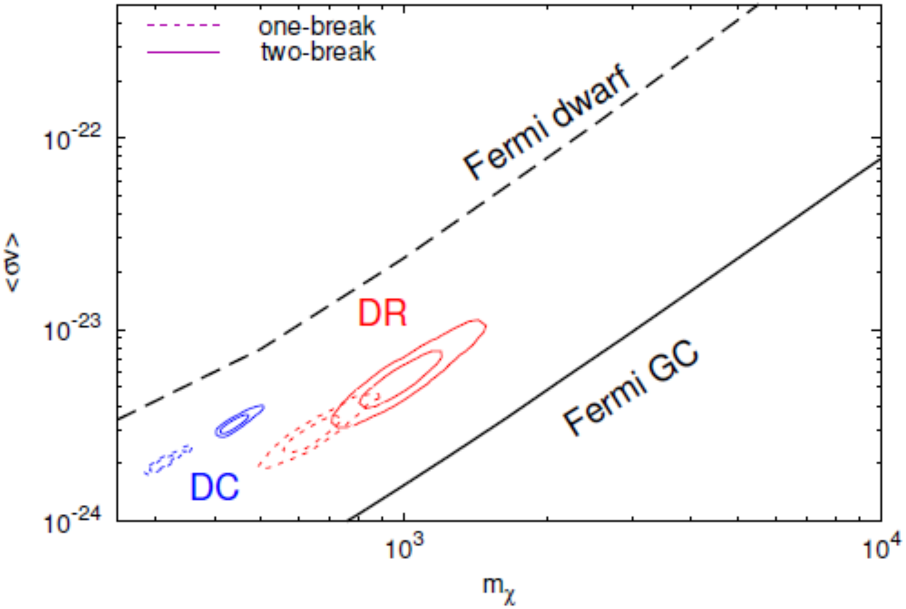
Milky Way halo:
Large statistics but diffuse background

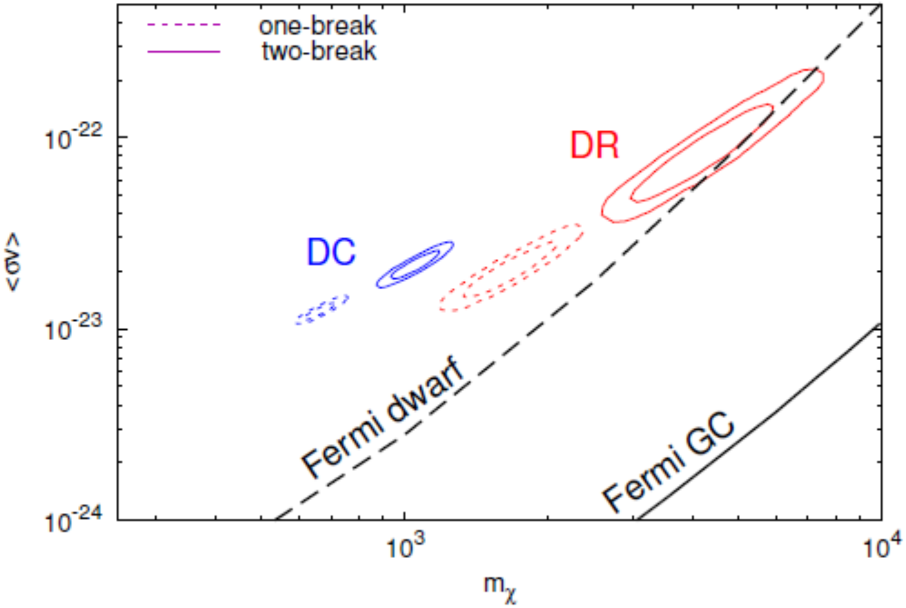
Spectral lines:
No astrophysical uncertainties, good source ID, but low statistics

Galaxy clusters:
Low background but low statistics

Extragalactic:
Large statistics, but astrophysics, Galactic diffuse background







More details

宇宙线的产生和传播

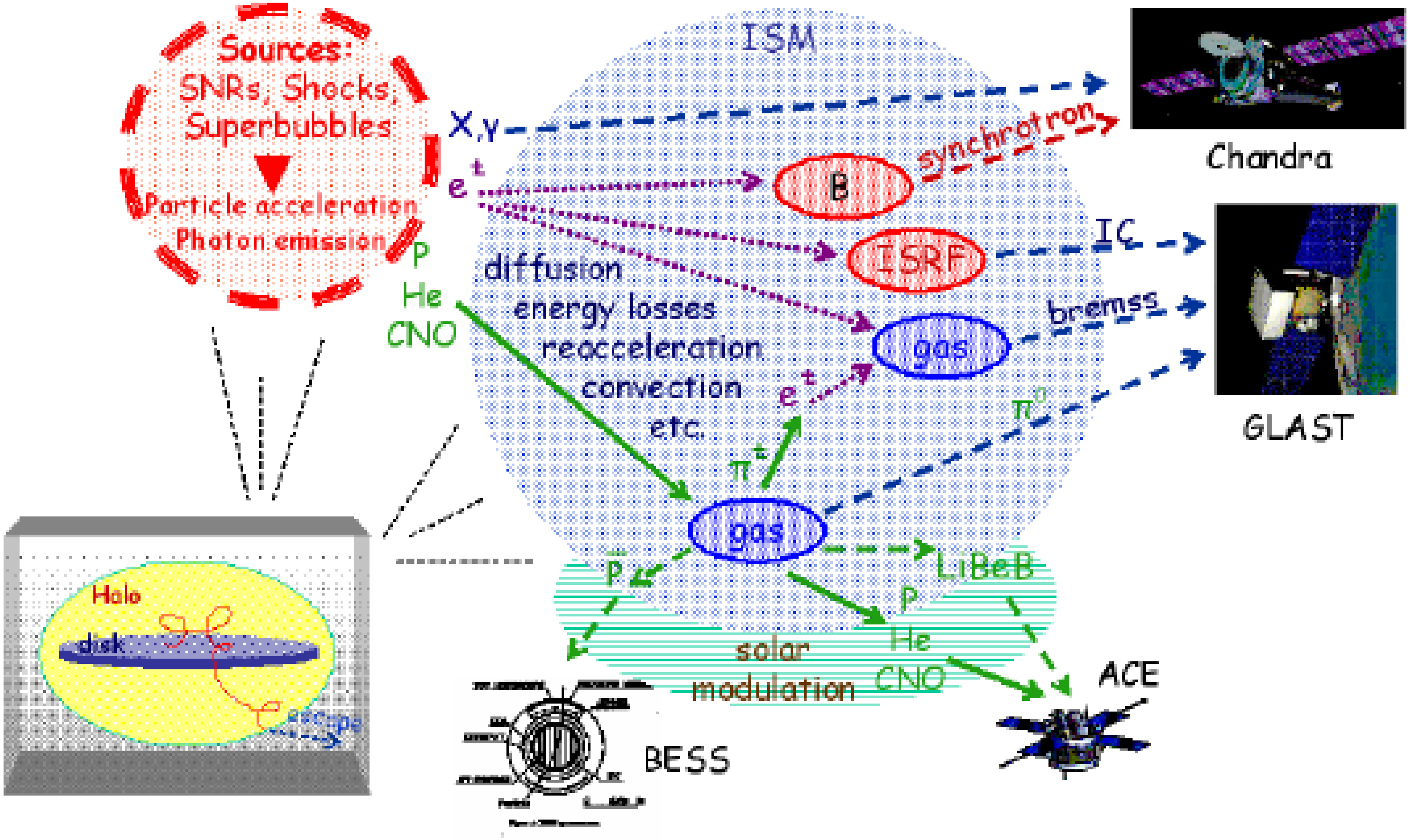


Figure 3. A schematic view of cosmic ray propagation in the interstellar medium (ISM), production of secondary nuclei, particles and γ-rays.

Bkg+pulsar (or DM) to fit the data

$$\mathcal{P} = \begin{cases} \{A_p, \nu_1, \nu_2, p_{\rm br}^p\}, & \text{bkg protons,} \\ \{A_e, \gamma_1, \gamma_2, p_{\rm br}^e\}, & \text{bkg electrons,} \\ \underline{\{A_{\rm psr}, \alpha, E_c\} \text{ or } \{m_\chi, \langle\sigma v\rangle\},} & \text{exotic sources,} \\ \{c_{e^+}, \phi\}, & \text{others.} \end{cases}$$

$$q(p) = A_{p,e}\left(\frac{p}{p_{\rm br}^{p,e}}\right)^{-\nu_1/\nu_2}$$

$$q(p) = A_{\rm psr} p^{-\alpha} \exp(-p/p_c)$$

1， propagation of charged particles is treated by Galprop. We fit the parameters to data by MCMC

2, Note: propagation parameters are the best value to fit B/C, 10Be/9Be (later we discuss the uncertainties from astrophysics)

源的空间分布

- 脉冲星

$$q(p) = A_{\rm psr} p^{-\alpha} \exp(-p/p_c)$$

$$f(R, z) \propto \left(\frac{R}{R_\odot}\right)^a \exp\left[-\frac{b(R - R_\odot)}{R_\odot}\right] \exp\left(-\frac{|z|}{z_s}\right)$$

- 暗物质湮灭

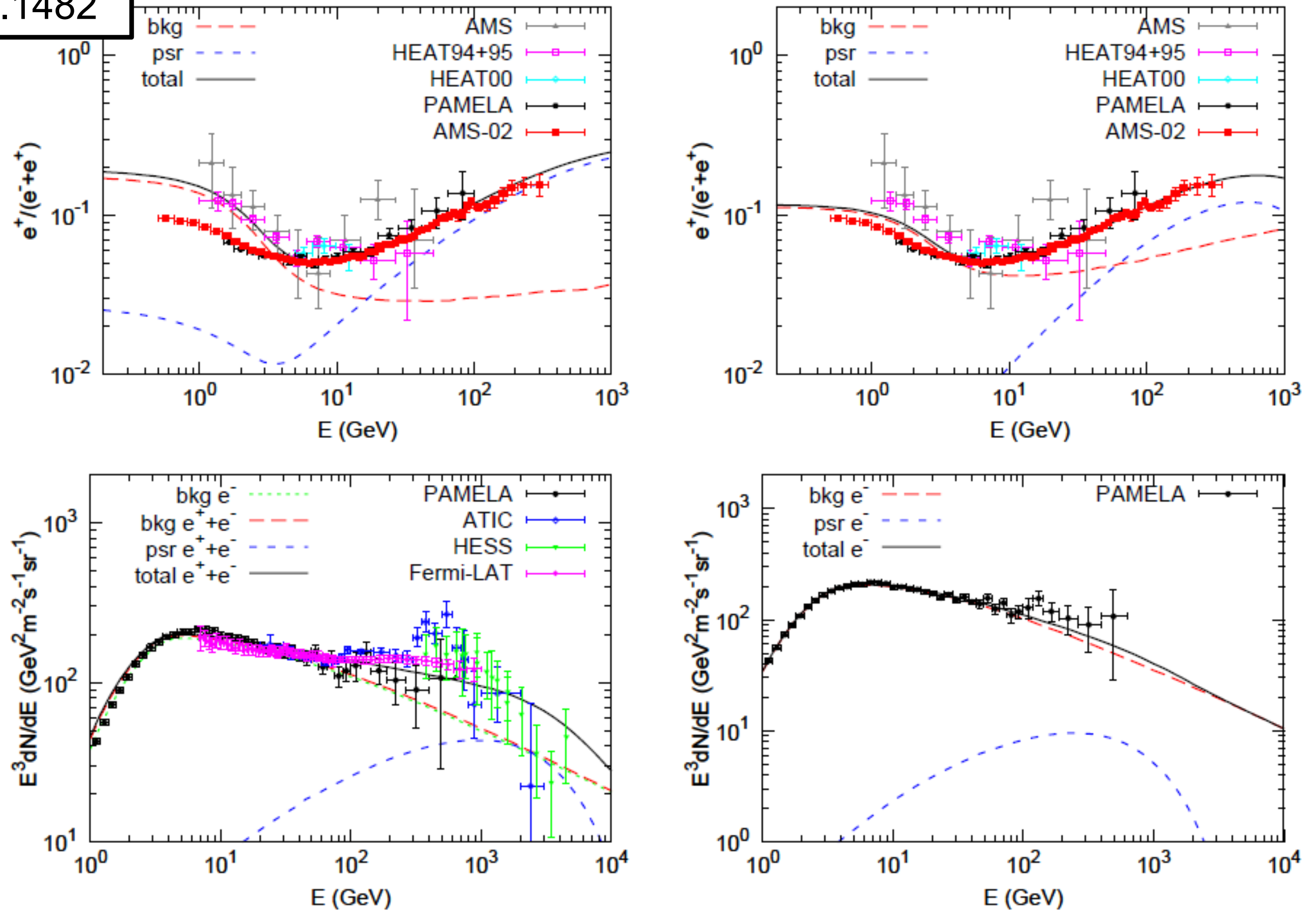
$$q(E, r) = \frac{\langle \sigma v \rangle}{2m_\chi^2} \sum_f B_f \left.\frac{\mathrm{d}N}{\mathrm{d}E}\right|_f \times \rho^2(r),$$

$$\rho(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2}$$

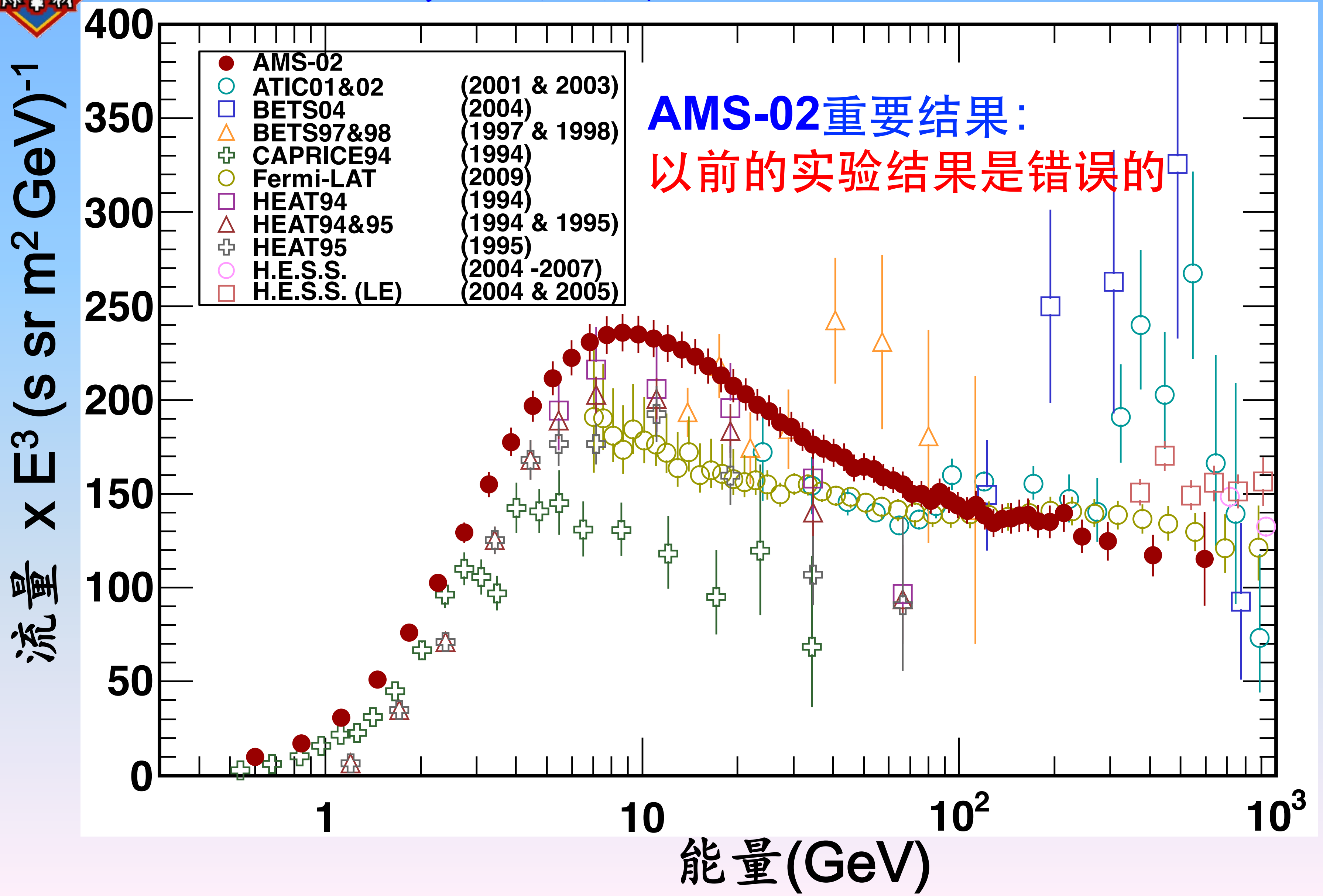
It seems pulsar can fit data roughly. However, the χ^2/dof=1.8; 6σ deviates from expectaion. ***Fermi data is not consistent with the AMS02 data***. We fit without including the Fermi data. χ^2/dof=52/80; perfect fit to data!

Yuan, Bi, Chen, Guo, Lin, Zhang, 1304.1482

定量研究宇宙线的重要性。



宇宙线中的电子加正电子能谱
与以往实验的比较



AMS-02重要结果:

以前的实验结果是错误的

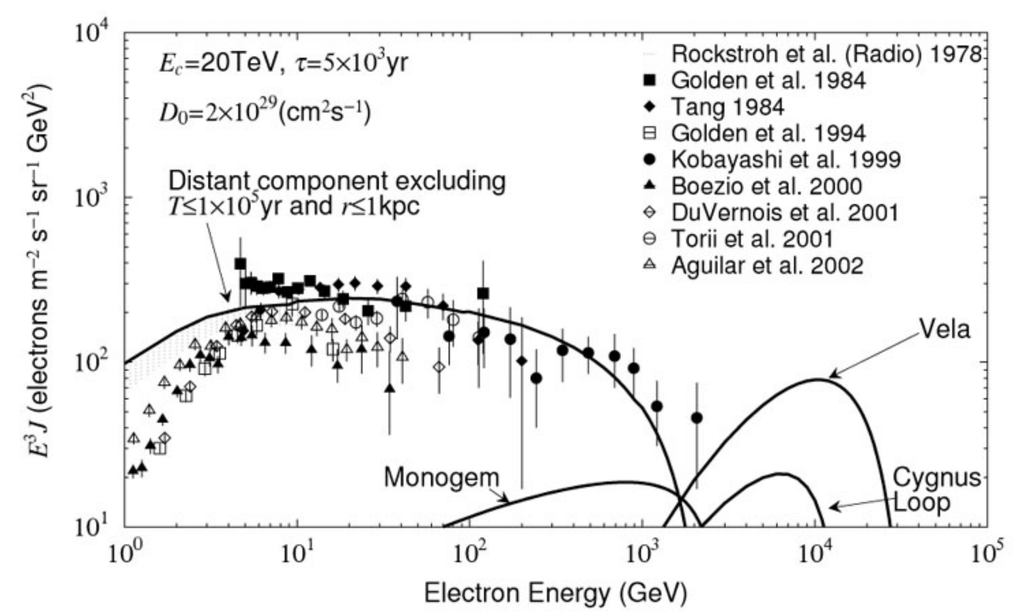
其他一些有意义的结果

- 电子谱本底有“结构”
- 宇宙线的传播模型不倾向于“重加速”模型

Electrons can provide additional information about the GCR source

- High energy electrons have a high energy loss rate ∝ E^2
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away

- Electrons <u>are</u> accelerated in SNR
- Only a handful of SNR meet the lifetime & distance criteria
- Kobayashi et al (2004) calculations show structure in electron spectrum at high energy



"Advances in Cosmic Ray Science" Waseda University

NEWS & ANALYSIS

Science, 20 May 2011

SPACE SCIENCE

Chinese Academy Takes Space Under Its Wing

DAMPE (June 2015)

LOFTY AMBITIONS

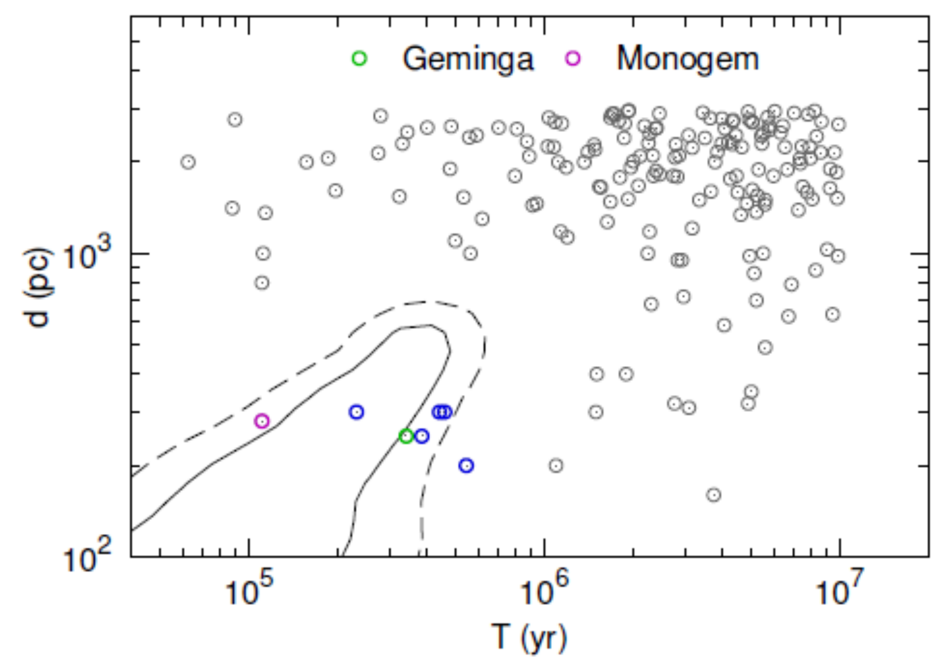
Mission	Chief scientist	Goals	Estimated launch
HXMT	Li Tipei, CAS Institute of High Energy Physics and Tsinghua University	Survey of x-ray sources; detailed observations of known objects	2014
Shijian-10	Hu Wenrui, CAS Institute of Mechanics	Study physical and biological systems in microgravity and strong radiation environment	Early 2015
Kuafu Project	William Liu, Canadian Space Agency and CAS Center for Space Science and Applied Research	Study solar influence on space weather	Mid-2015
Dark Matter Satellite	Chang Jin, CAS Purple Mountain Observatory	Search for dark matter; study cosmic ray acceleration	Late 2015
Quantum Science Satellite	Pan Jianwei, University of Science and Technology of China	Quantum key distribution for secure communication; long-distance quantum entanglement	2016

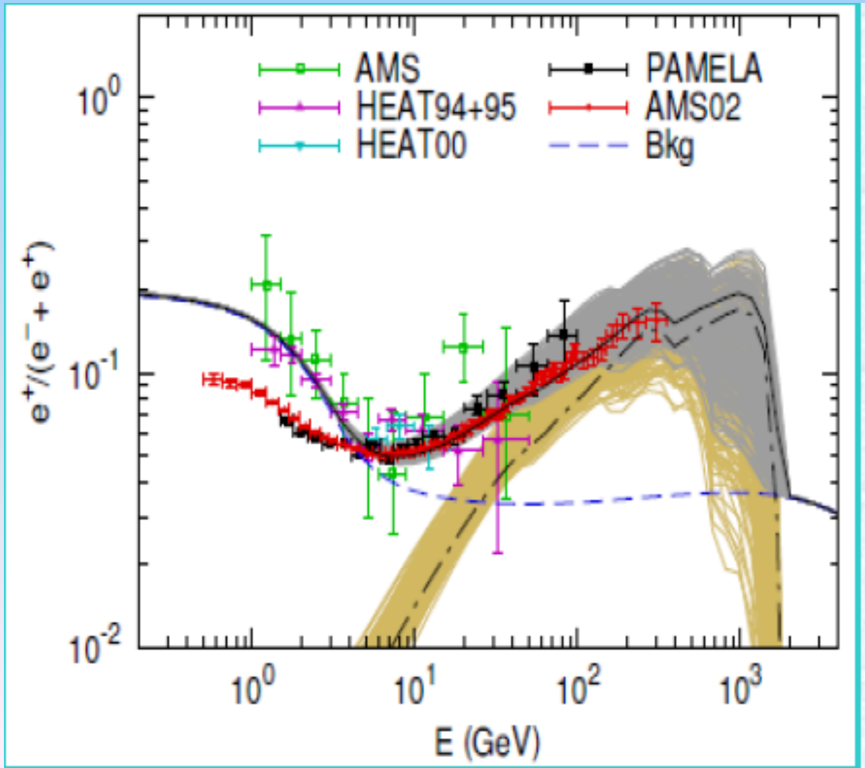
Strategic Priority Research Program in Space Science

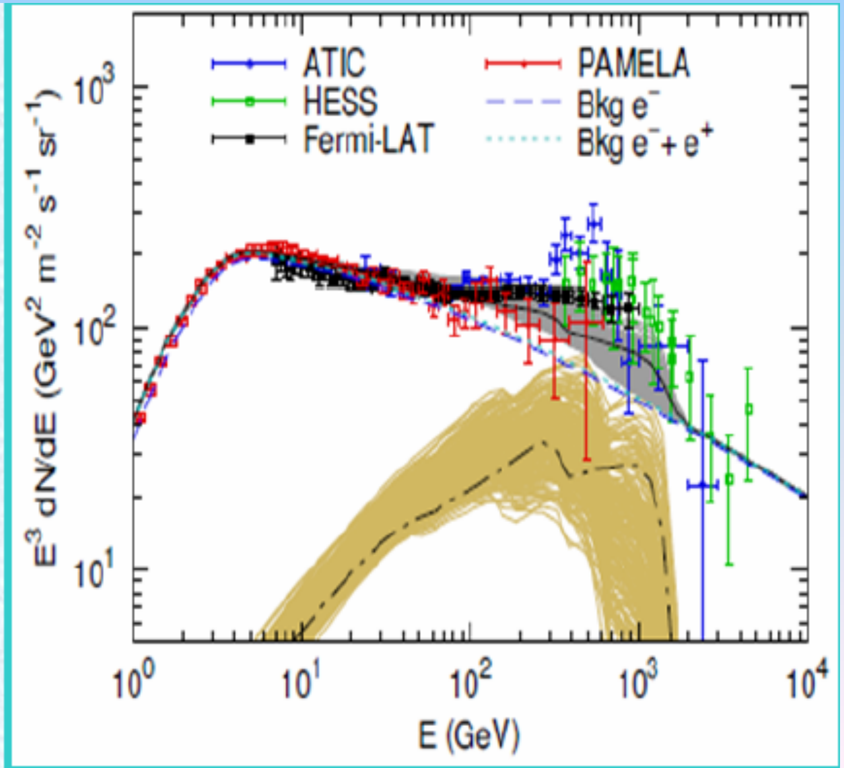
Dark Matter Particle Explorer Satellite

We consider contributions from nearby pulsars and add contributions from all pulsars.

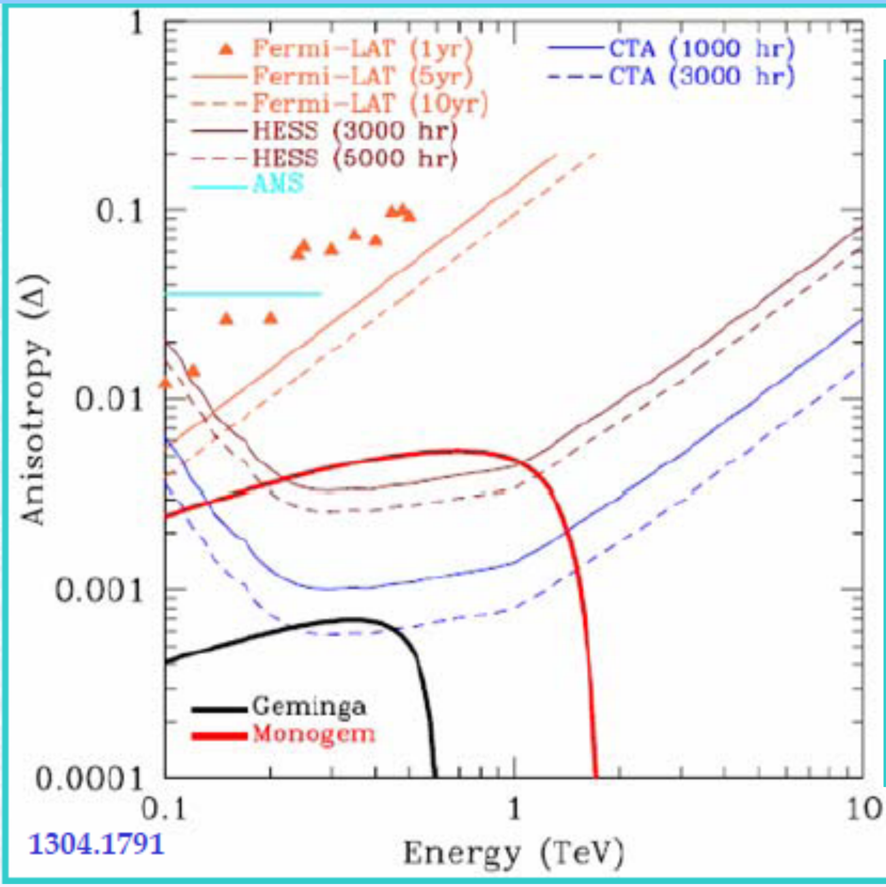
Yin et al.,1304. 4128



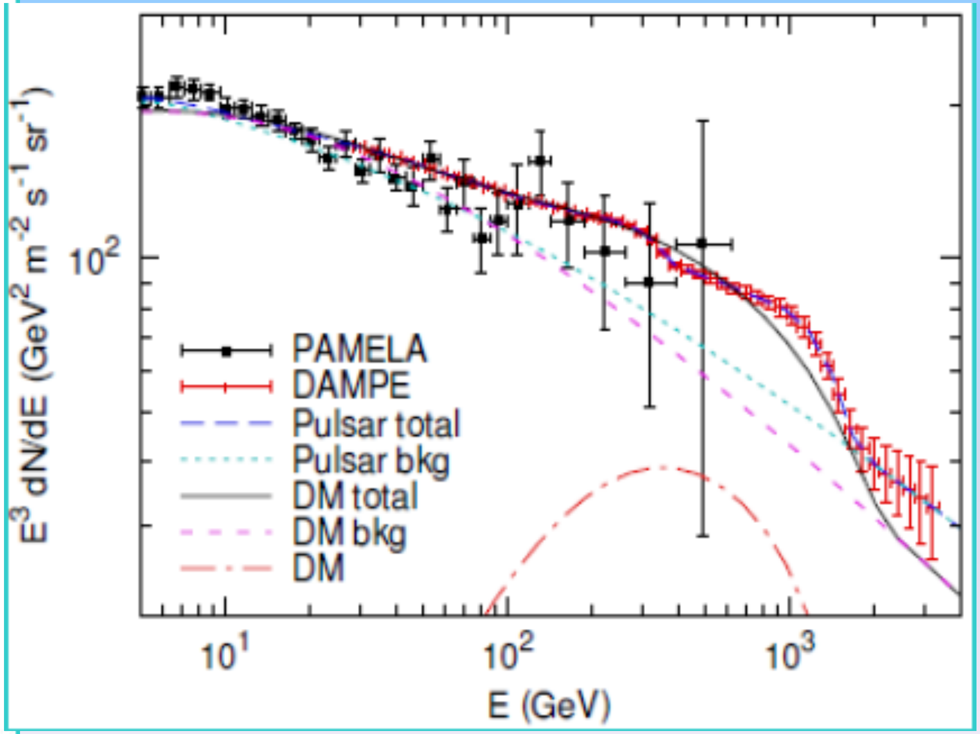




DM vs pulsar: flux anisotropy vs spectrum wiggles

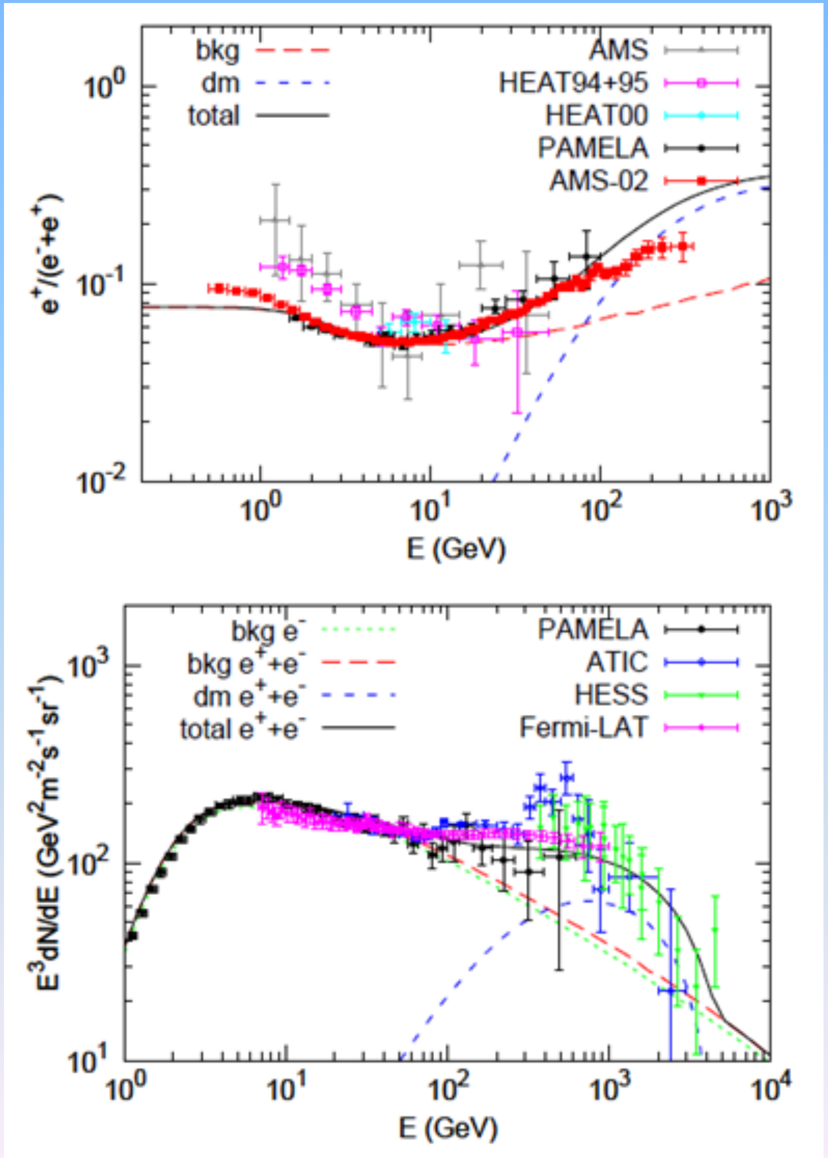


1304.1791



Systematic study of uncertainties of astrophysics

- Propagation
- Treatment of low energy data
- Models of strong interaction
- Galprop version



Propagation uncertainties

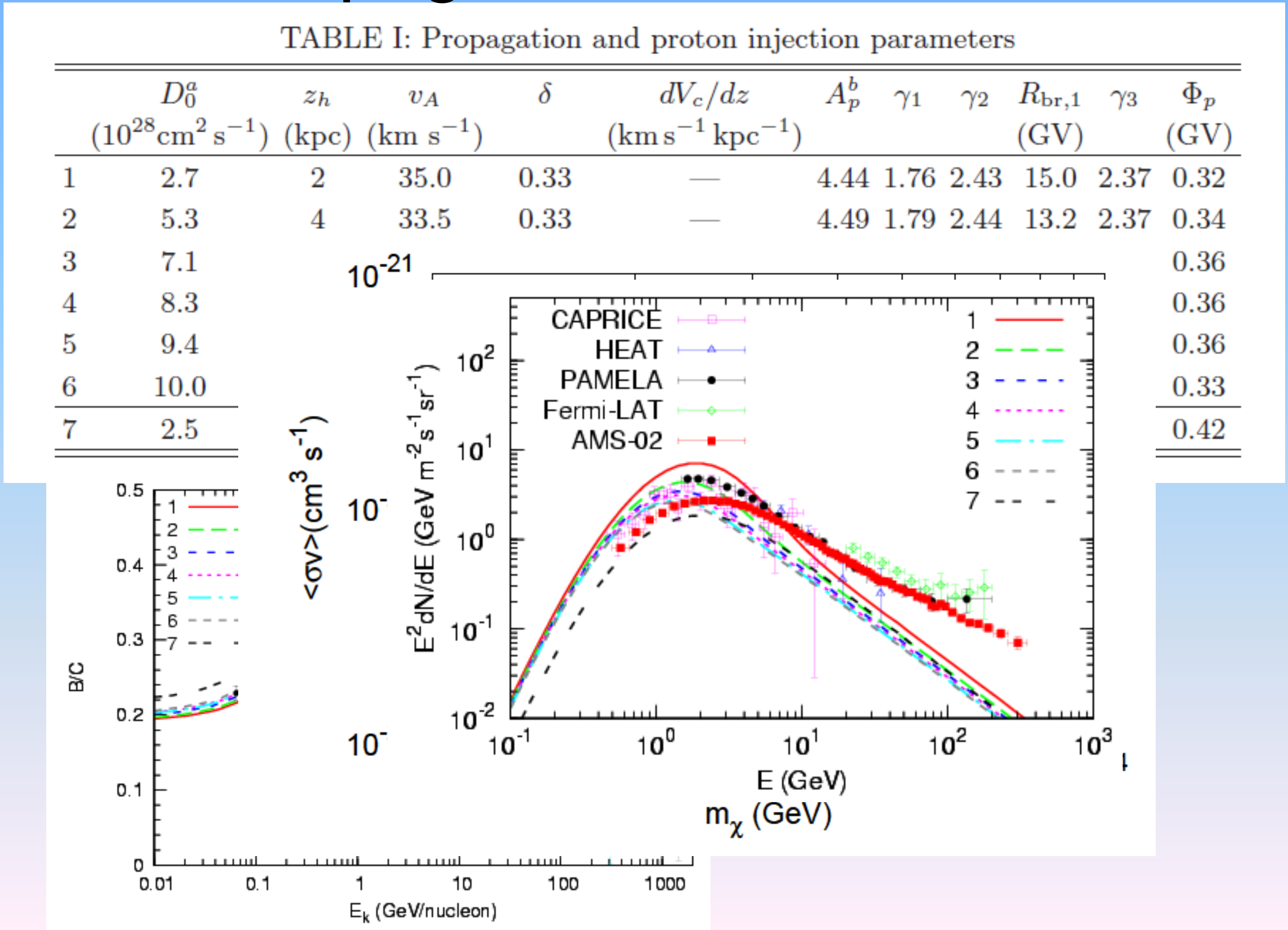
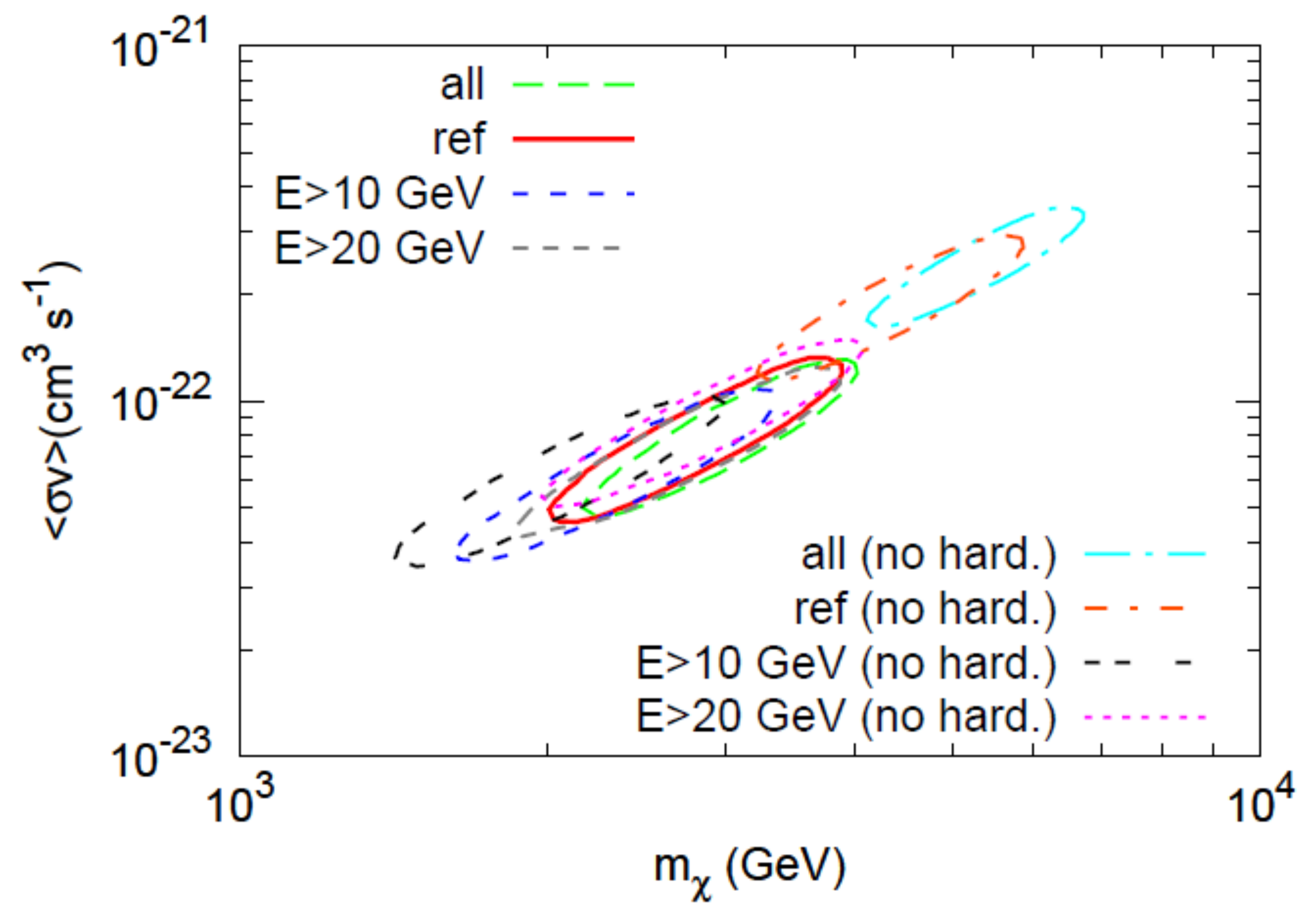


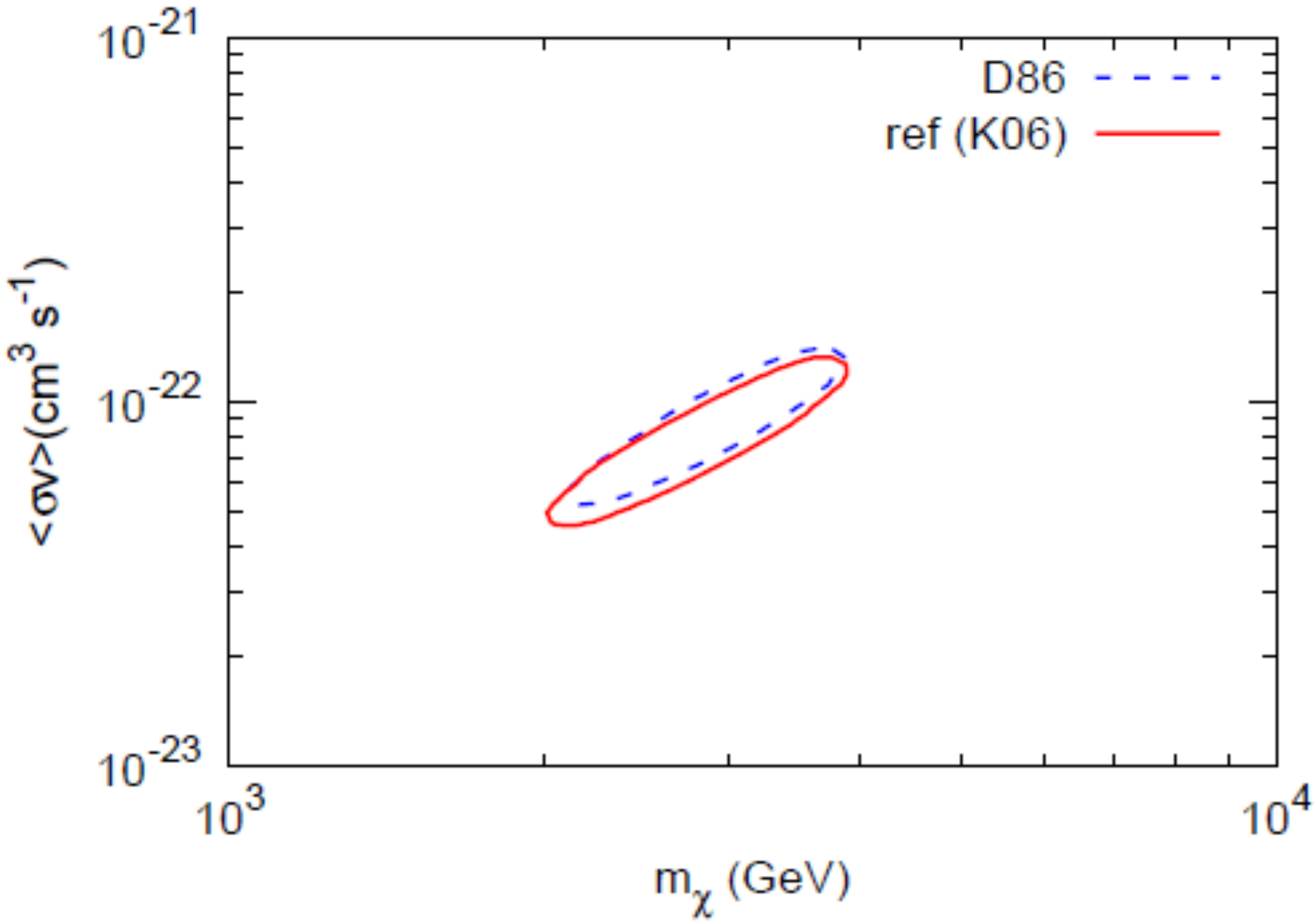
TABLE I: Propagation and proton injection parameters

	D_0^a (10^{28}cm^2 s^{-1})	z_h (kpc)	v_A (km s^{-1})	δ	dV_c/dz (km s^{-1} kpc^{-1})	A_p^b	γ_1	γ_2	$R_{\rm br,1}$ (GV)	γ_3	Φ_p (GV)
1	2.7	2	35.0	0.33	—	4.44	1.76	2.43	15.0	2.37	0.32
2	5.3	4	33.5	0.33	—	4.49	1.79	2.44	13.2	2.37	0.34
3	7.1										0.36
4	8.3										0.36
5	9.4										0.36
6	10.0										0.33
7	2.5										0.42

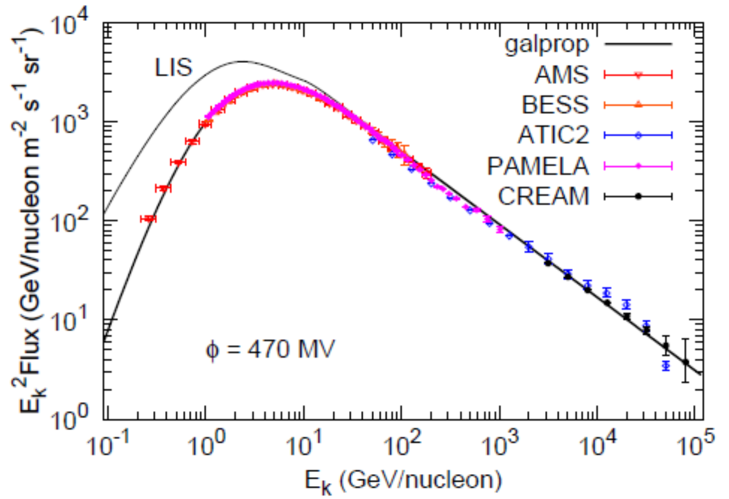
Low energy data

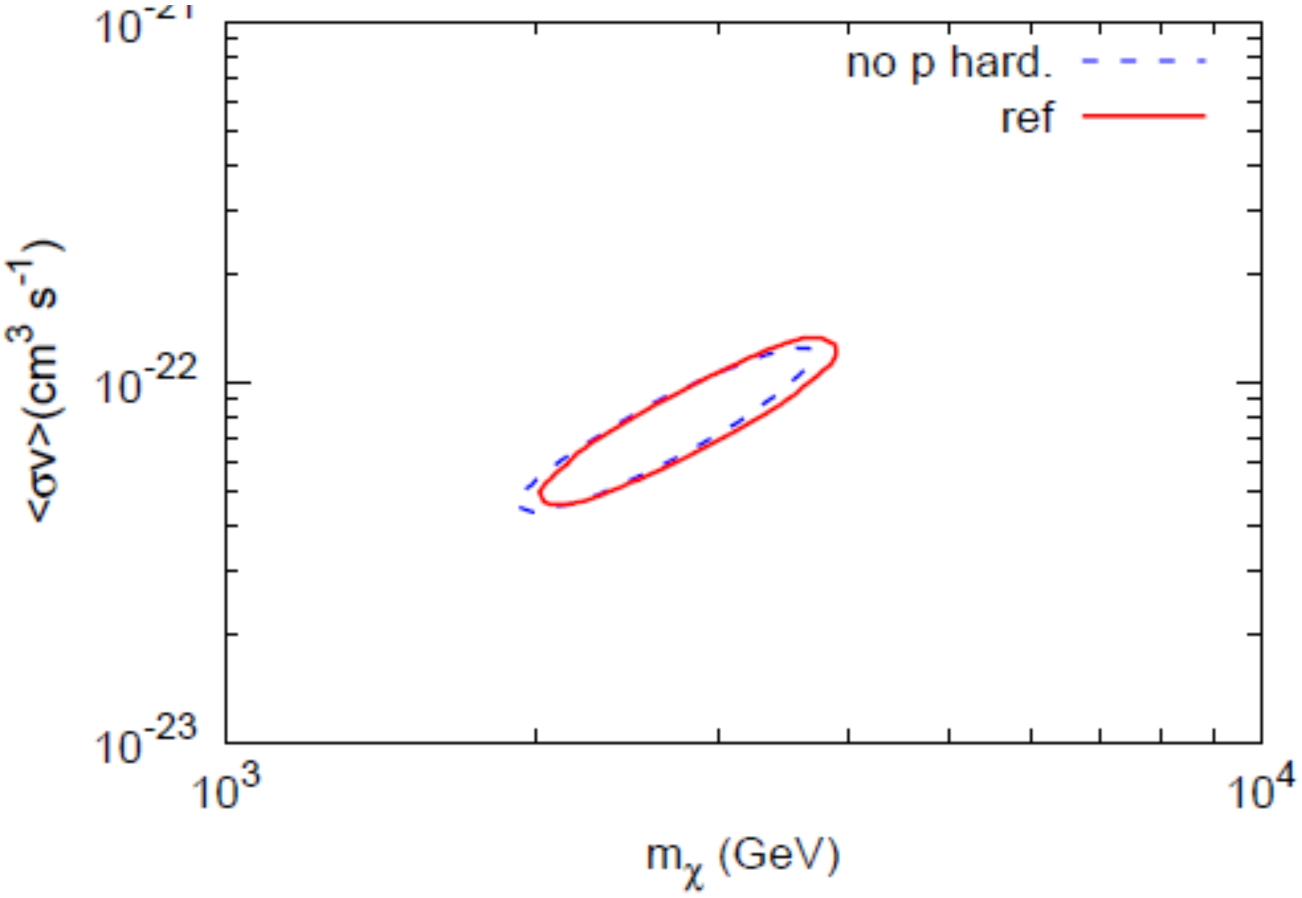


Strong interaction models

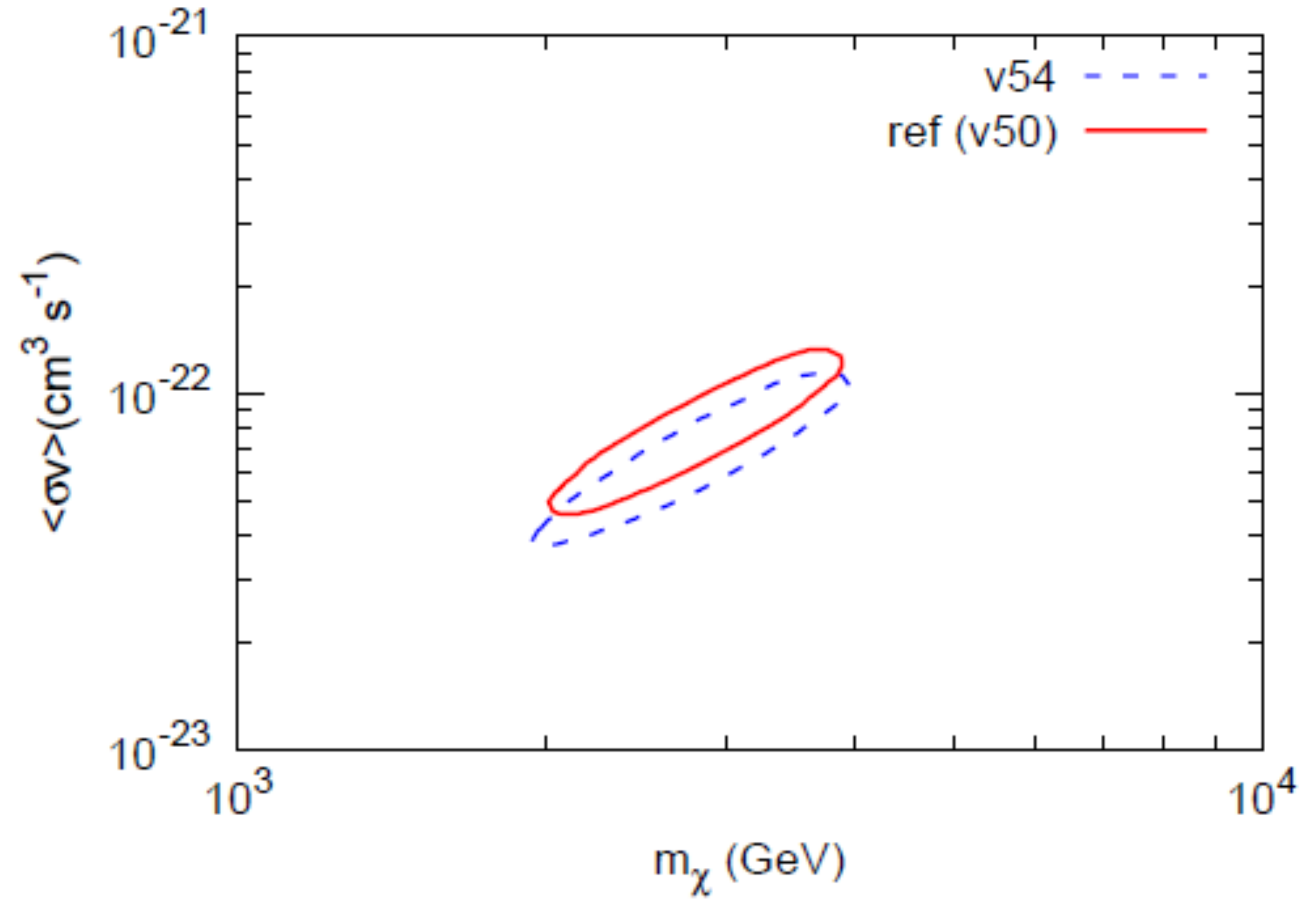


质子谱有（无）拐折


LIS
galprop
AMS
BESS
ATIC2
PAMELA
CREAM
ϕ = 470 MV
E_k^2Flux (GeV/nucleon m^{-2} s^{-1} sr^{-1})
E_k (GeV/nucleon)
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5


no p hard.
ref
<σv>(cm^3 s^{-1})
m_χ (GeV)
10^{-21}
10^{-22}
10^{-23}
10^3
10^4

Different Galprop versions



总结

- AMS-02数据使得宇宙线物理需要进行精确定量研究
- 定量研究AMS-02的数据发现了一些有趣的宇宙线物理的效应：探测到邻近的源的发射、约束传播模型
- 正电子超出仍然不能确定来源。

NEWS & ANALYSIS

Science, 20 May 2011

SPACE SCIENCE

Chinese Academy Takes Space Under Its Wing

DAMPE (June 2015)

LOFTY AMBITIONS

Mission	Chief scientist	Goals	Estimated launch
HXMT	Li Tipei, CAS Institute of High Energy Physics and Tsinghua University	Survey of x-ray sources; detailed observations of known objects	2014
Shijian-10	Hu Wenrui, CAS Institute of Mechanics	Study physical and biological systems in microgravity and strong radiation environment	Early 2015
Kuafu Project	William Liu, Canadian Space Agency and CAS Center for Space Science and Applied Research	Study solar influence on space weather	Mid-2015
Dark Matter Satellite	Chang Jin, CAS Purple Mountain Observatory	Search for dark matter; study cosmic ray acceleration	Late 2015
Quantum Science Satellite	Pan Jianwei, University of Science and Technology of China	Quantum key distribution for secure communication; long-distance quantum entanglement	2016

Strategic Priority Research Program in Space Science

Dark Matter Particle Explorer Satellite

暗物质间接探测最新重要的进展一点启示及DAMPE在国际竞争中的一些优势

启示：暗物质的空间间接探测(尤其是伽玛射线、电子)的探测的确是颇具前景的一个国际重大前沿领域，有望取得突破性的成果

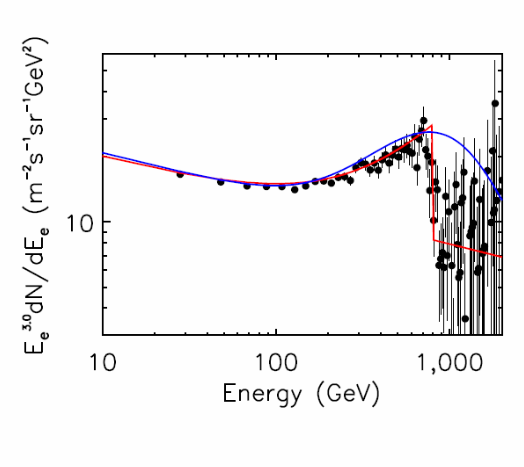
Detector	能量范围 (GeV)	能量分辨率	质子电子分辨能力	Key Instrument (Thickness of CAL)	电子/接受度（m^2srday)
FERMI-LAT	20-1,000	5-20 % (20-1000 GeV)	10^3-10^4 (20-1000GeV) Energy dep. GF	Tracker+ACD + Thin Seg. CAL (W:1.5X_0+CsI:8.6X_0)	60@TeV (1 year)
AMS	1-1,000 (Due to Magnet)	～1% @100 GeV	10^4 (x 10^2 by TRD)	Magnet+IMC +TRD+RICH (Lead: 17X_0)	~50@TeV (1year)
CALET	1-10,000	~2-3% (>100 GeV)	～10^5	IMC+CAL (W: 3 X_0+ PWO : 27 X_0)	44 (1years)
DAMPE	1-10,000	~1% (>100 GeV)	～10^6	IMC+CAL+Neutron (W: 2 X_0+ BGO: 32 X_0)	180 (1 years)

DAMPE最主要的探测对像正是伽玛射线和电子，在100GeV处的“接受度”小于Fermi但数倍于AMS-02，能量分辨显著优于Fermi，这对于探测暗物质湮灭线谱信号非常关键。DAMPE可探测能量范围为10TeV，将开辟TeV能段的空间电子能谱测量新窗口

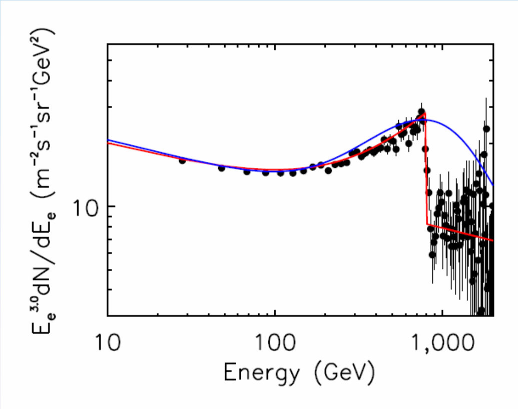
暗物质粒子卫星

- 探测器重量1200Kg（0.5m^2.sr，是ATIC的3倍）
- ATIC总共飞行48天，观测到330个电子(大于300GeV)
- 新探测器飞行60天，可以发现2000个电子(大于300GeV)
- 是世界上第一次在10GeV-10TeV能段对伽玛射线进行高分辨观测能量分辨

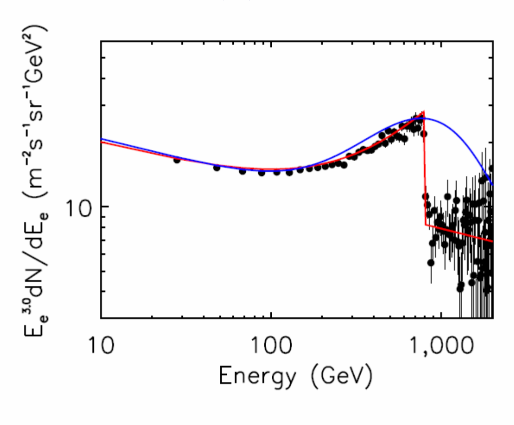
预计2个月观测结果



预计6个月观测结果



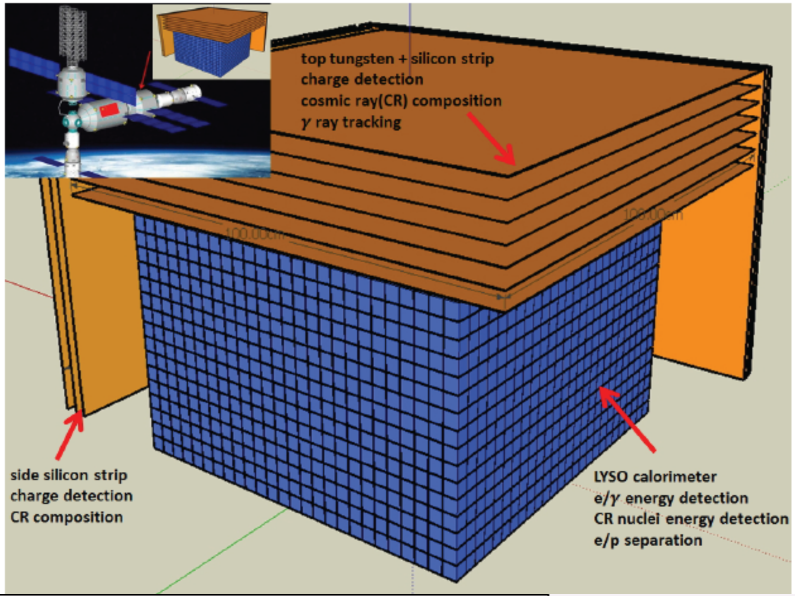
预计12个月观测结果



中国空间站

2018

Baseline design of HERD

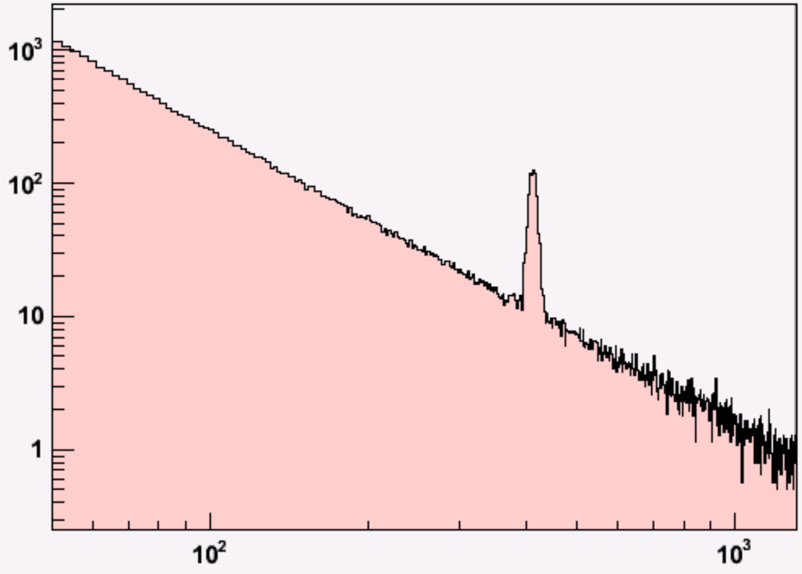


top tungsten + silicon strip
charge detection
cosmic ray(CR) composition
γ ray tracking

side silicon strip
charge detection
CR composition

LYSO calorimeter
e/γ energy detection
CR nuclei energy detection
e/p separation

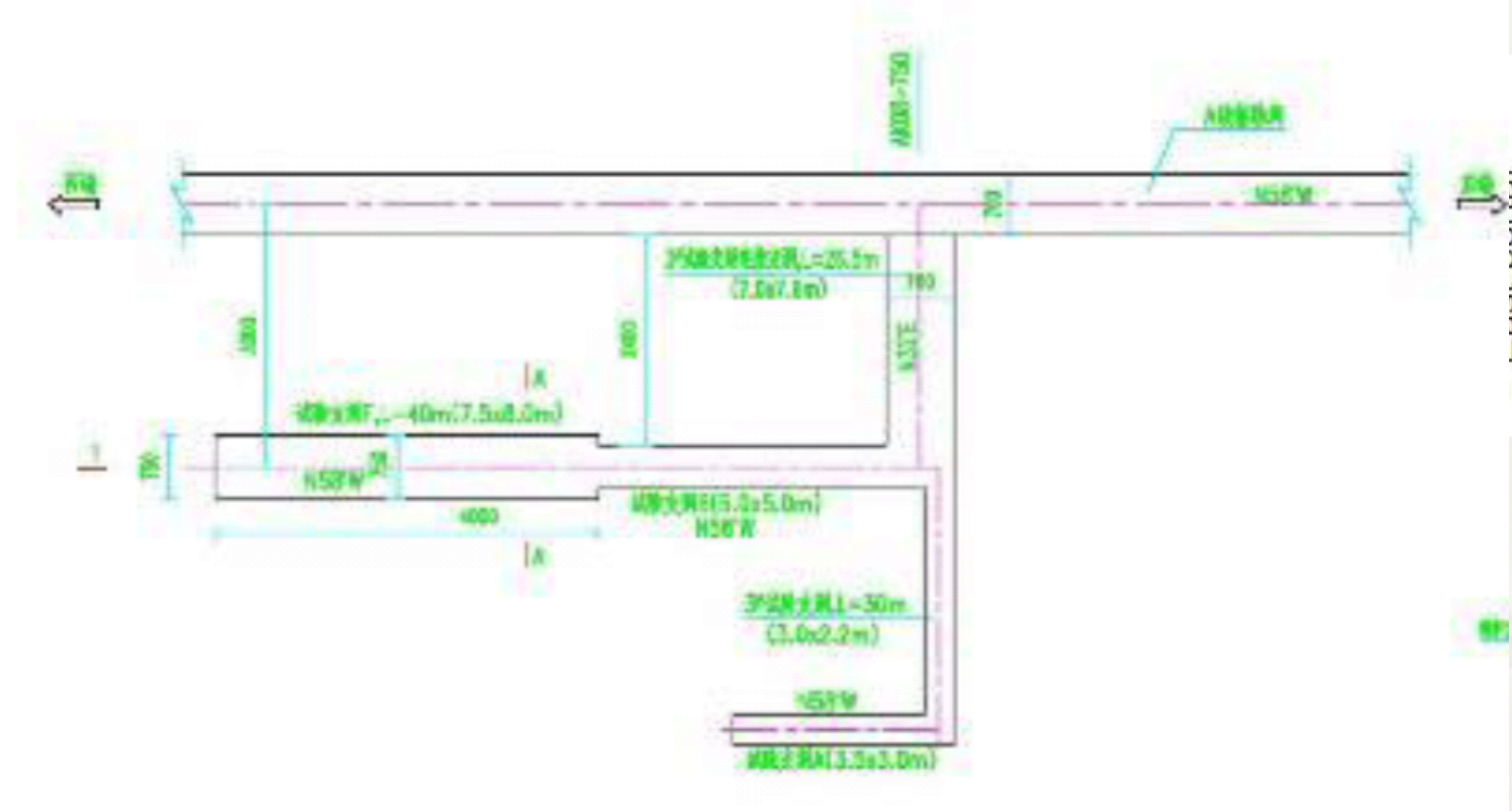
Cosmic Ray γ Energy Spectrum (Example)



Expected performance of HERD

γ/e energy range (CALO)	tens of GeV-10TeV
nucleon energy range (CALO)	up to PeV
γ/e angular resol. (top Si-strips)	0.1°
nucleon charge resol. (all Si-strips)	0.1-0.15 c.u
γ/e energy resolution (CALO)	<1%@200GeV
proton energy resolution (CALO)	20%
e/p separation power (CALO)	$<10^{-5}$
electron eff. geometrical factor (CALO)	3.1 m^2sr@200 GeV
proton eff. geometrical factor (CALO)	2.3 m^2sr@100 TeV

Geophysical conditions



- Rock burst: mainly right after excavation
- Rich underground water: 5~7m^3/s, pressure 10MPa

Comparison of main ULs in the world