暗物质和宇宙线观测

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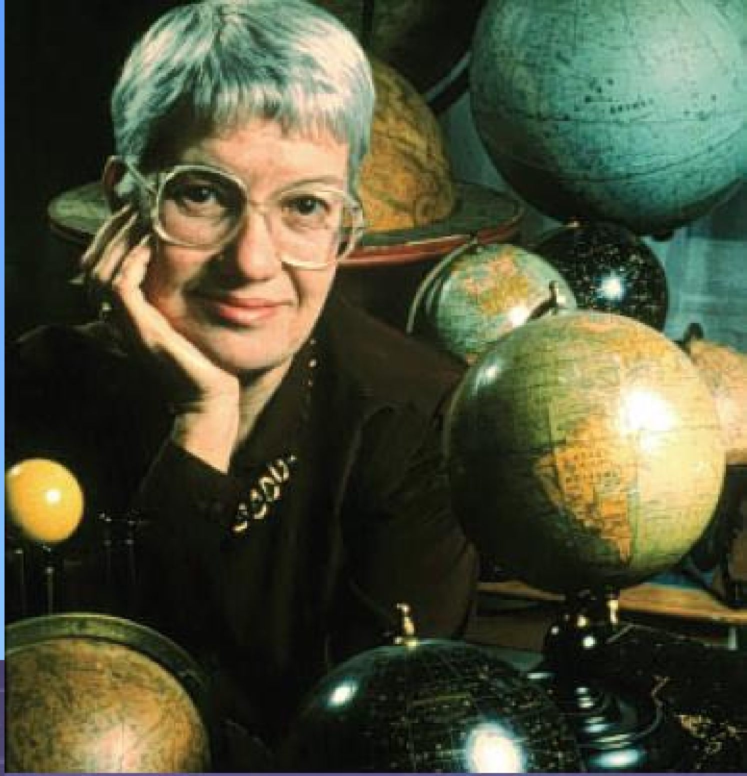
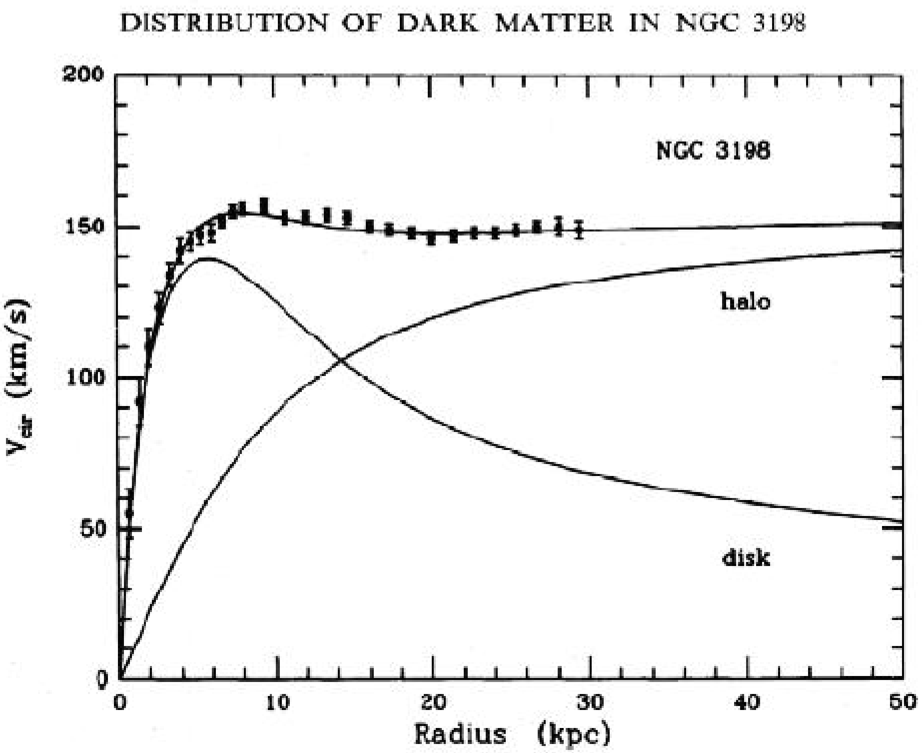
中国科学院高能物理研究所

首届LHAASO合作组会，
天津，南开大学
2016/8/19

Vera Rubin

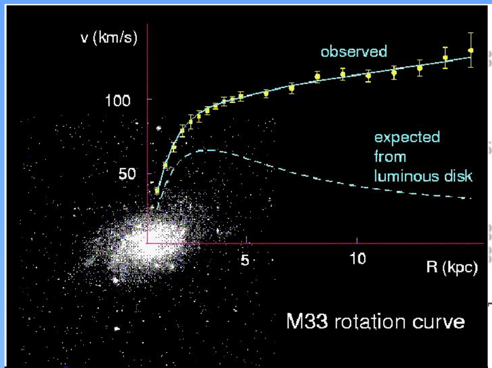


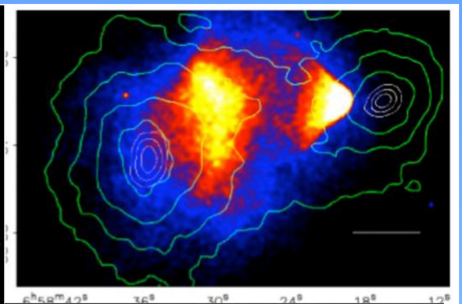


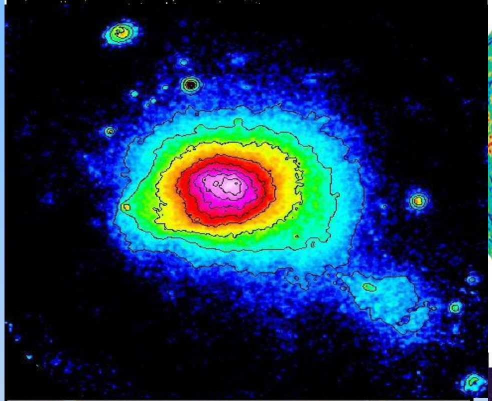
OBSERVED:
FLAT ROTATION
CURVE

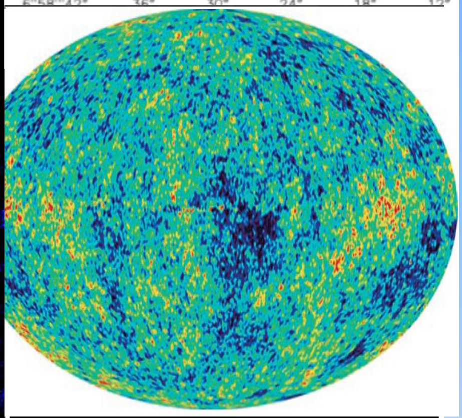
EXPECTED
FROM STARS

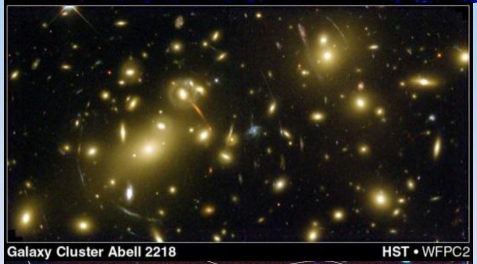
Standard cosmology

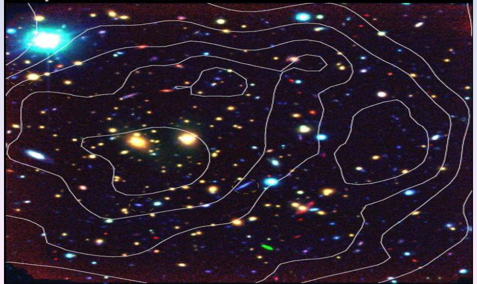


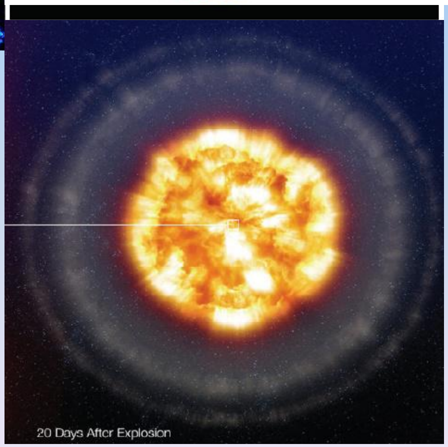


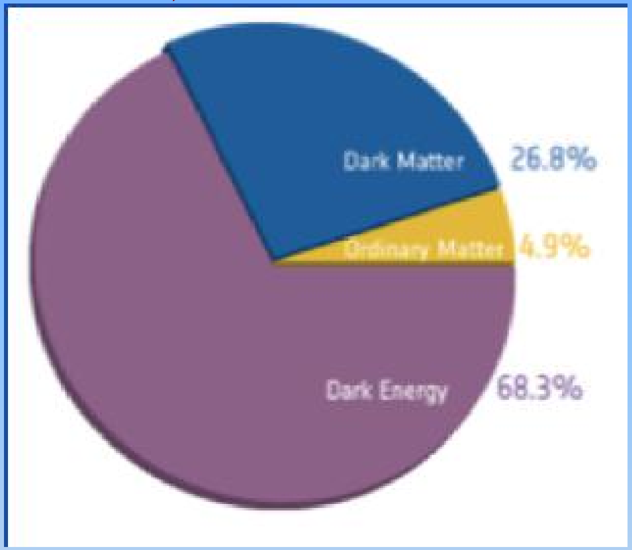










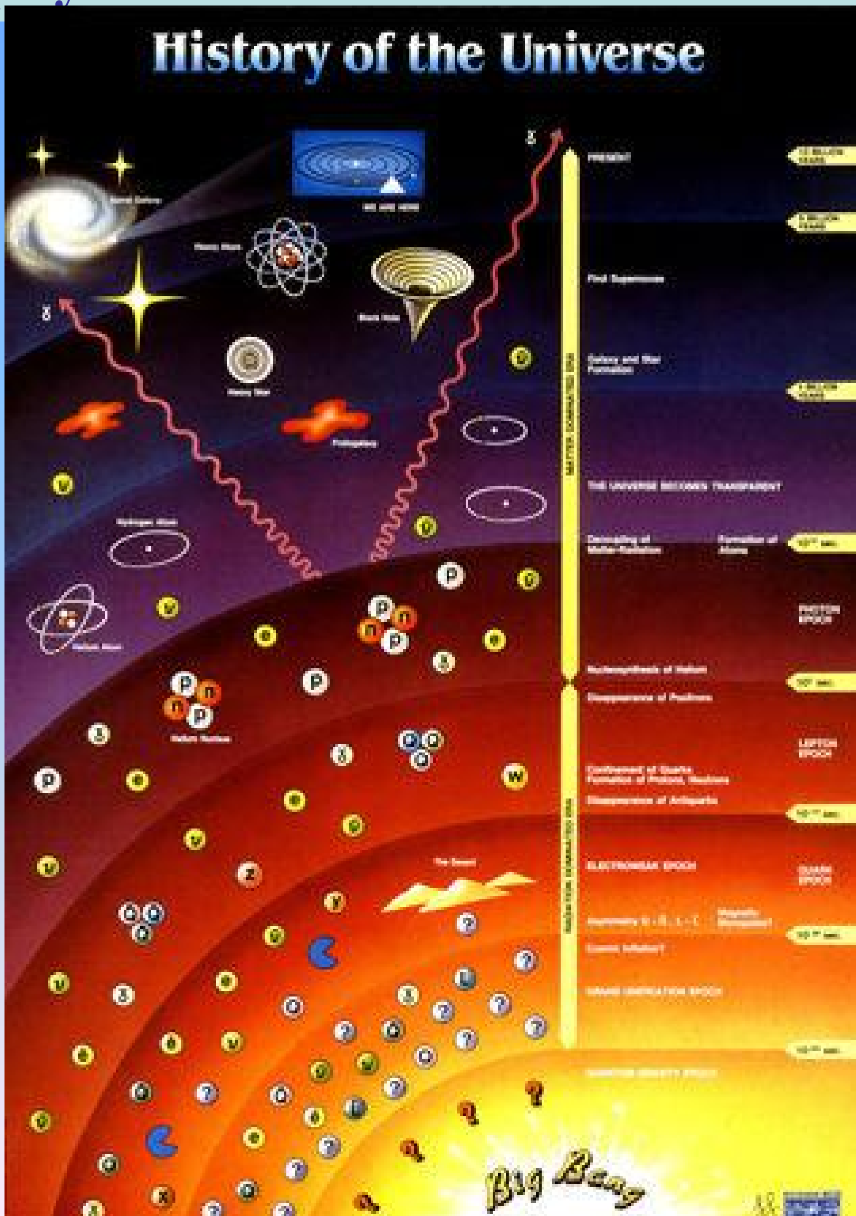


Dark matter (dark energy) exists in the universe. However, we have to figure out its property.

Properties of dark matter

- stable
- neutral;
- non-baryonic
- cold, non-relativistic to behave like gravitational seed of the structure formation (not neutrinos)
- Abundence ~27%, production process MAY require weakly interaction with the SM particles (WIMPs).

The universe is the ultimate laboratory to study fundamental physics…….

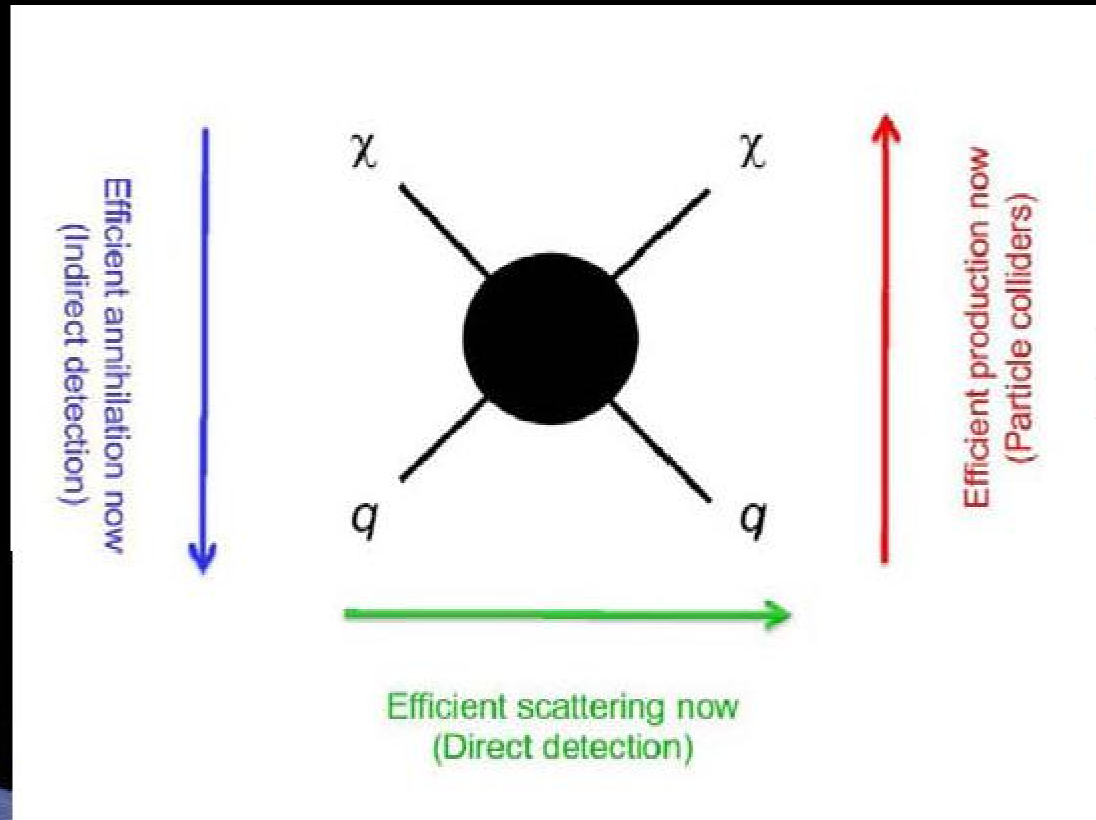


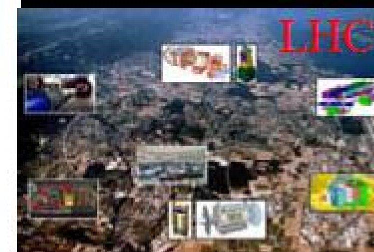
- 能标>>LHC能标
- 发现了新物理

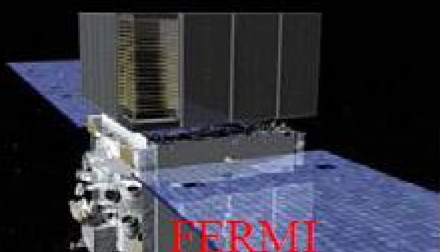
- Big bang has large enough energy. But we are very far from the reaction at the Big Bang. Only the relics (stable missing energy) of the reaction can be observed today.

- We are lucky if the relics of the early Universe is just the LHC missing energy

Different approaches to search for Dark Matter





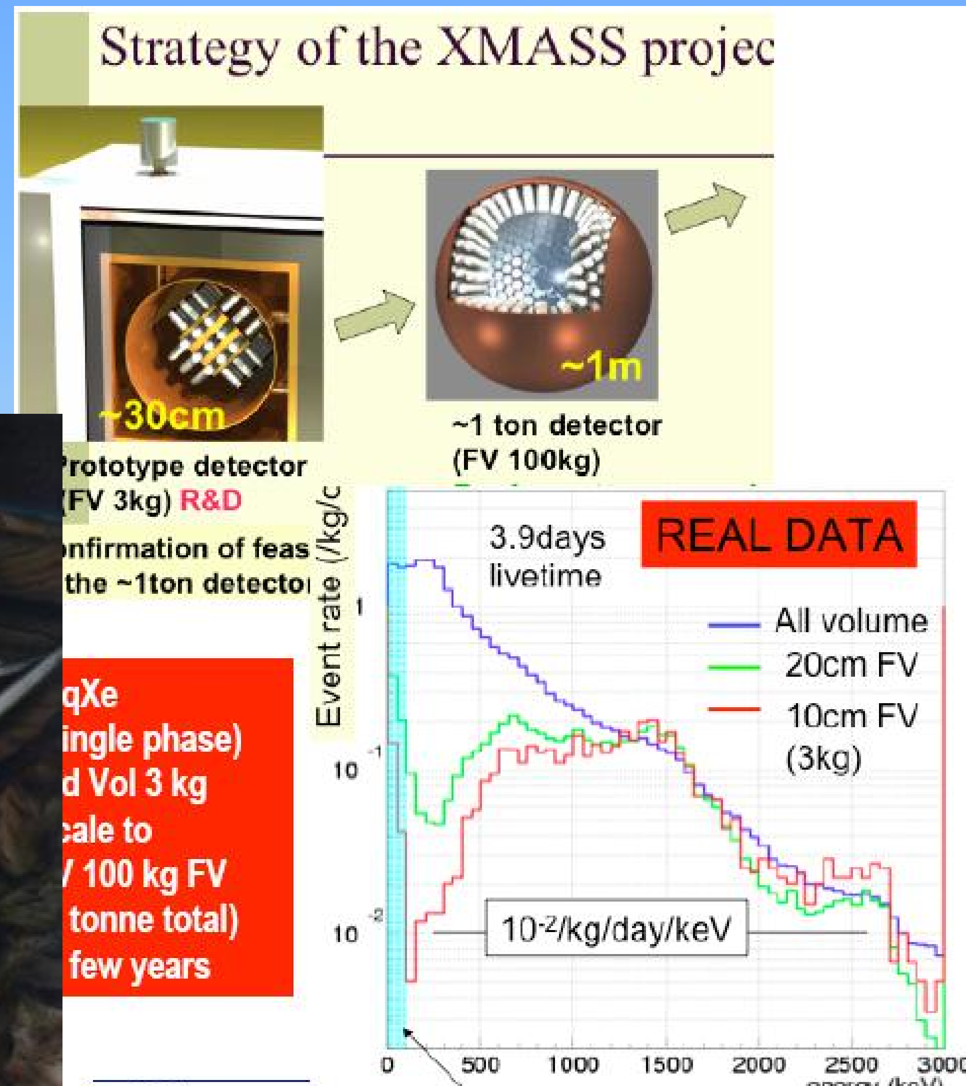


Adapted from P. Lipari

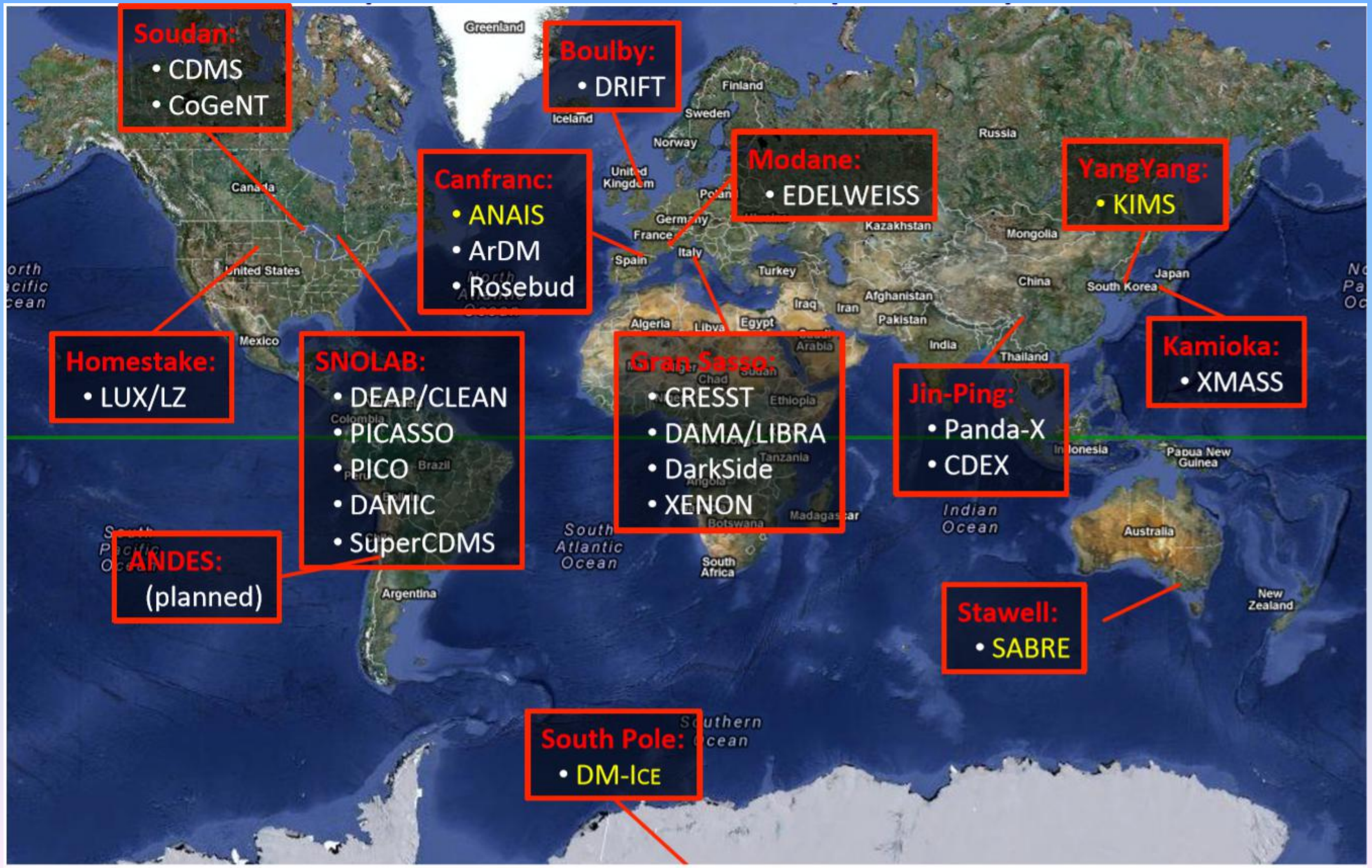
直接探测

(暗物质像空气一样充满整个银河系)

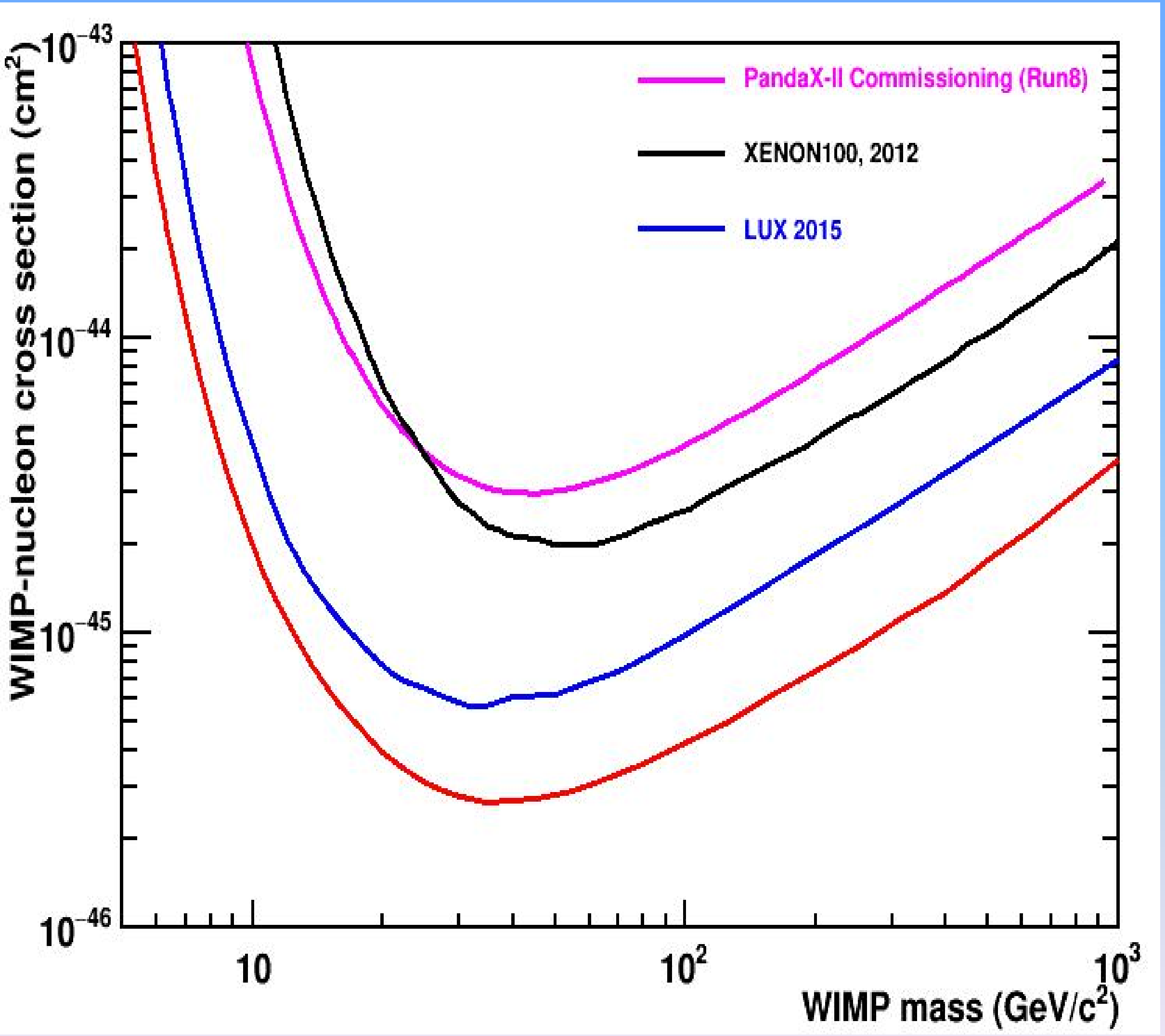
探测暗物质粒子与探测器碰撞所产生的信号



Underground labs and experiments

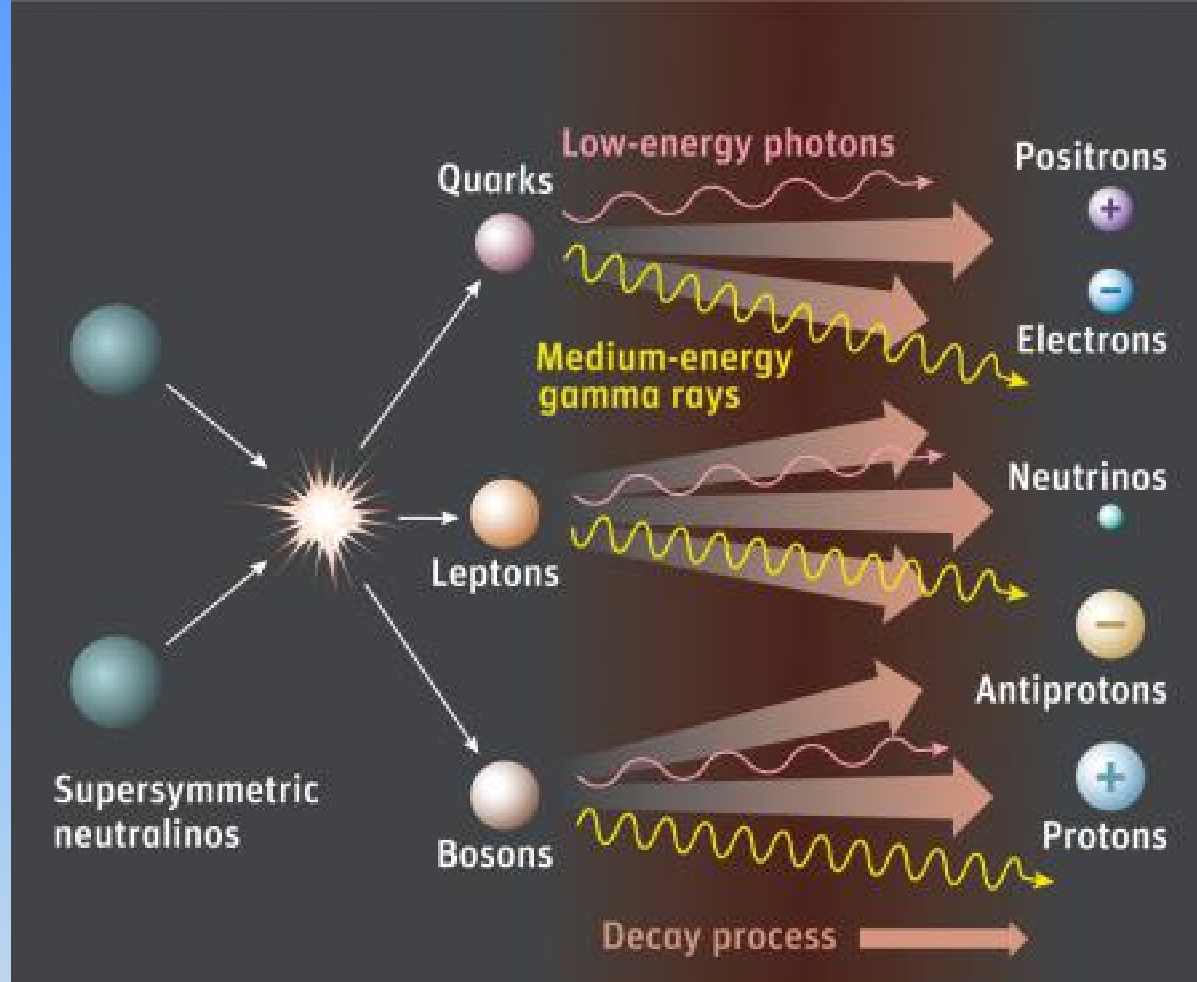


Preliminary results



Minimum upper limit for isoscalar SI elastic cross section at $2.7 \times 10^{-46}\ cm^2$, more than a factor of 2 improvement compared to the LUX 2015 results

间接探测

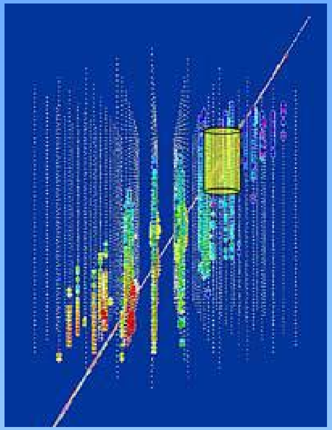


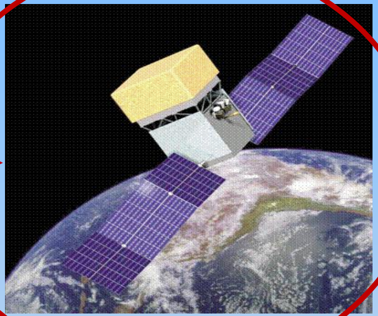
- 暗物质并不暗：它们湮灭后发出光，中微子，和带电粒子的宇宙线。

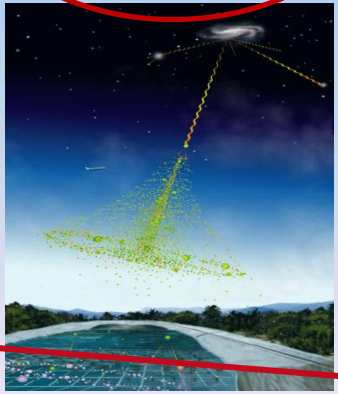
$$\chi^0\chi^0 \rightarrow l\bar{l}, q\bar{q}, 2W^{\pm}, 2Z^0, 2H^0, Z^0H^0, W^+H^-, gg$$

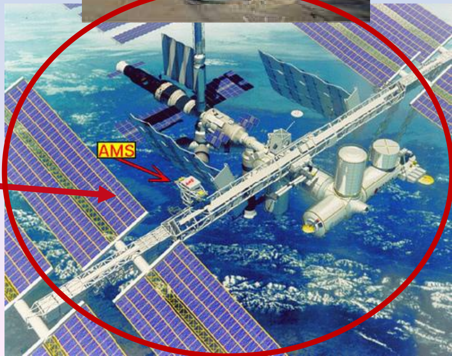
What Tools Do We Use?

- **Auger** and **HiRes** measure the highest energy cosmic ray flux, spectrum, and anisotropy
- **ICECube** searches for TeV neutrino sources – the most direct signature of hadronic accelerators
- **Fermi** detects thousands of new GeV sources
- **VERITAS, HESS, MAGIC**, and CANGAROO image and measure spectra and variability of TeV sources
- **Milagro/HAWC, Asγ/ARGO** image large-scale structures and searches for new and transient TeV sources
- **AMS-02** (space-based antimatter search), **PAMELA** measure ANTIPROTON, POSITRON
- *PLANCK/SNAP*



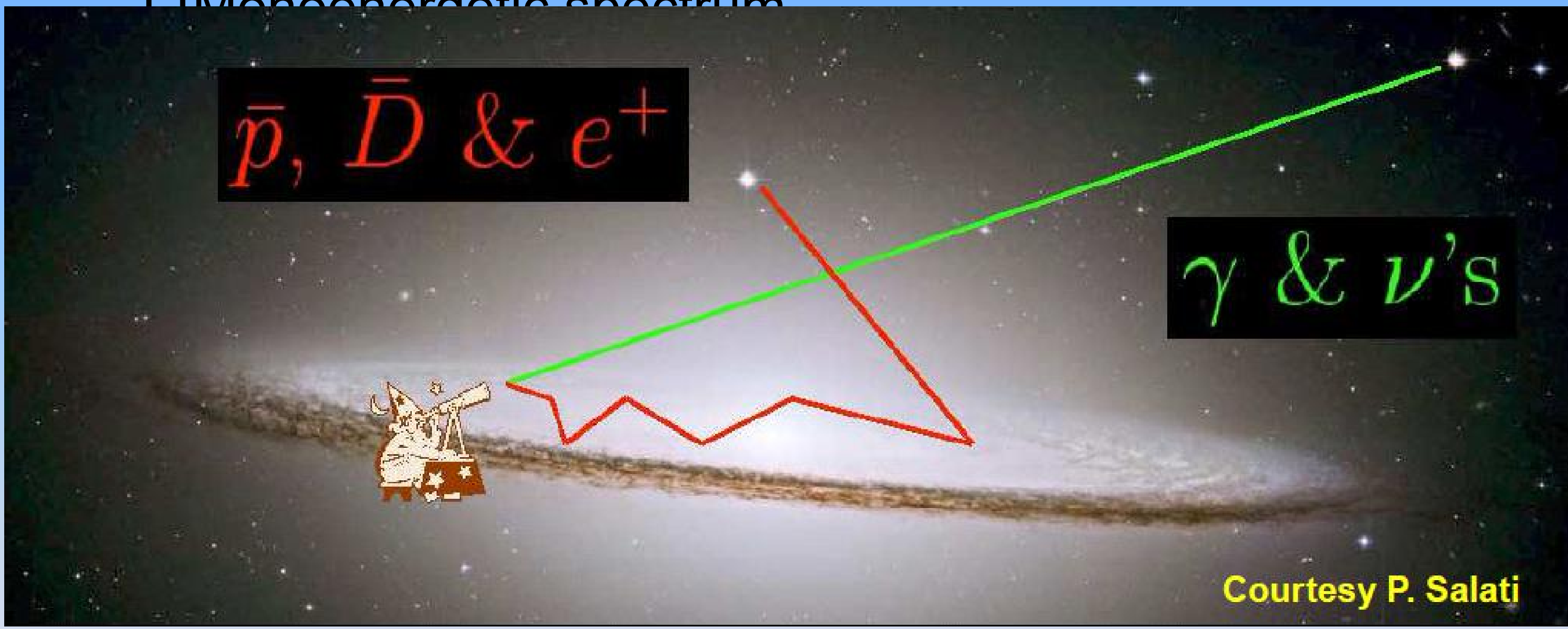






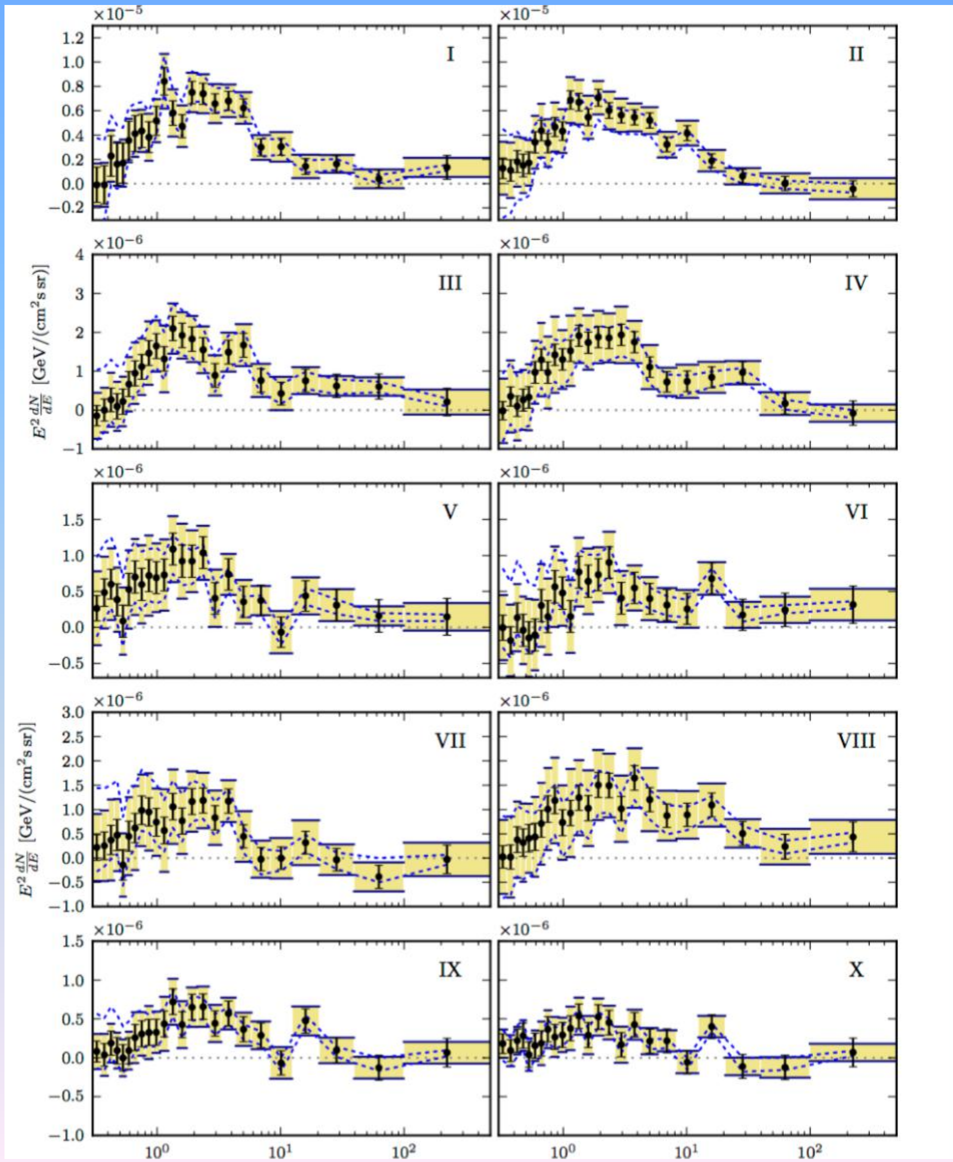
Indirect detection of dark matter -- signals

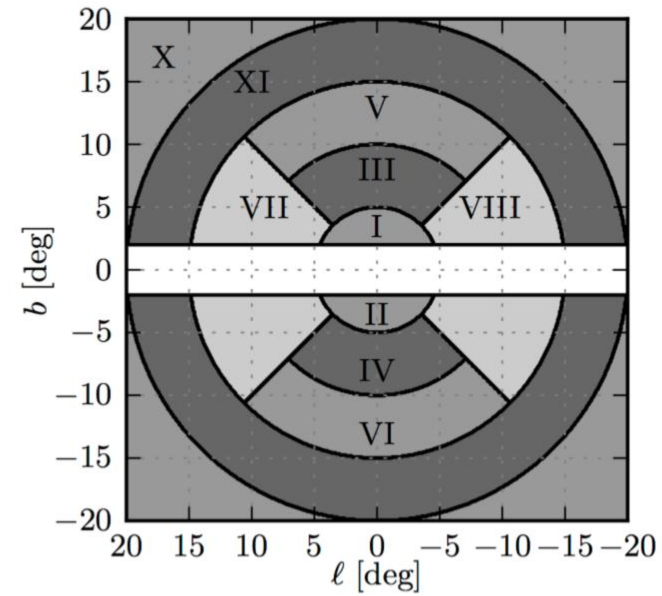
- Monoenergetic spectrum

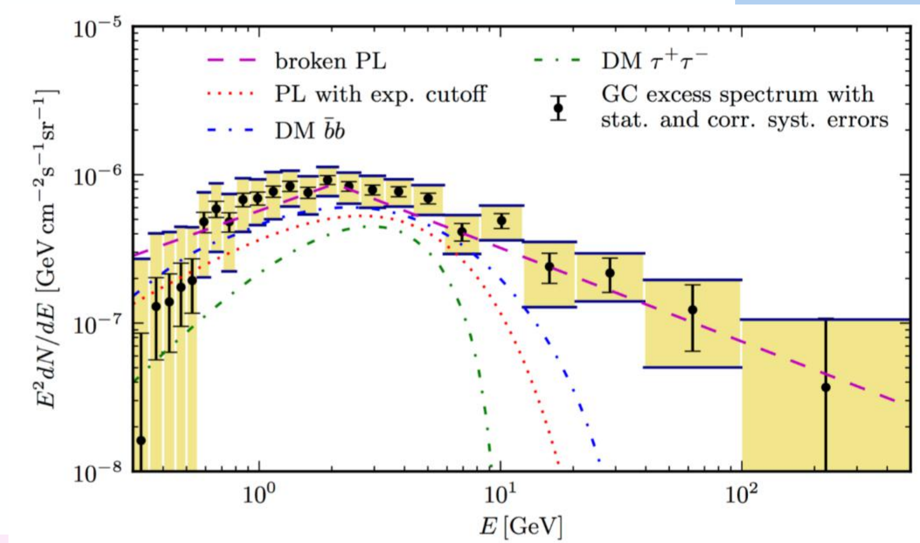


definitive signal

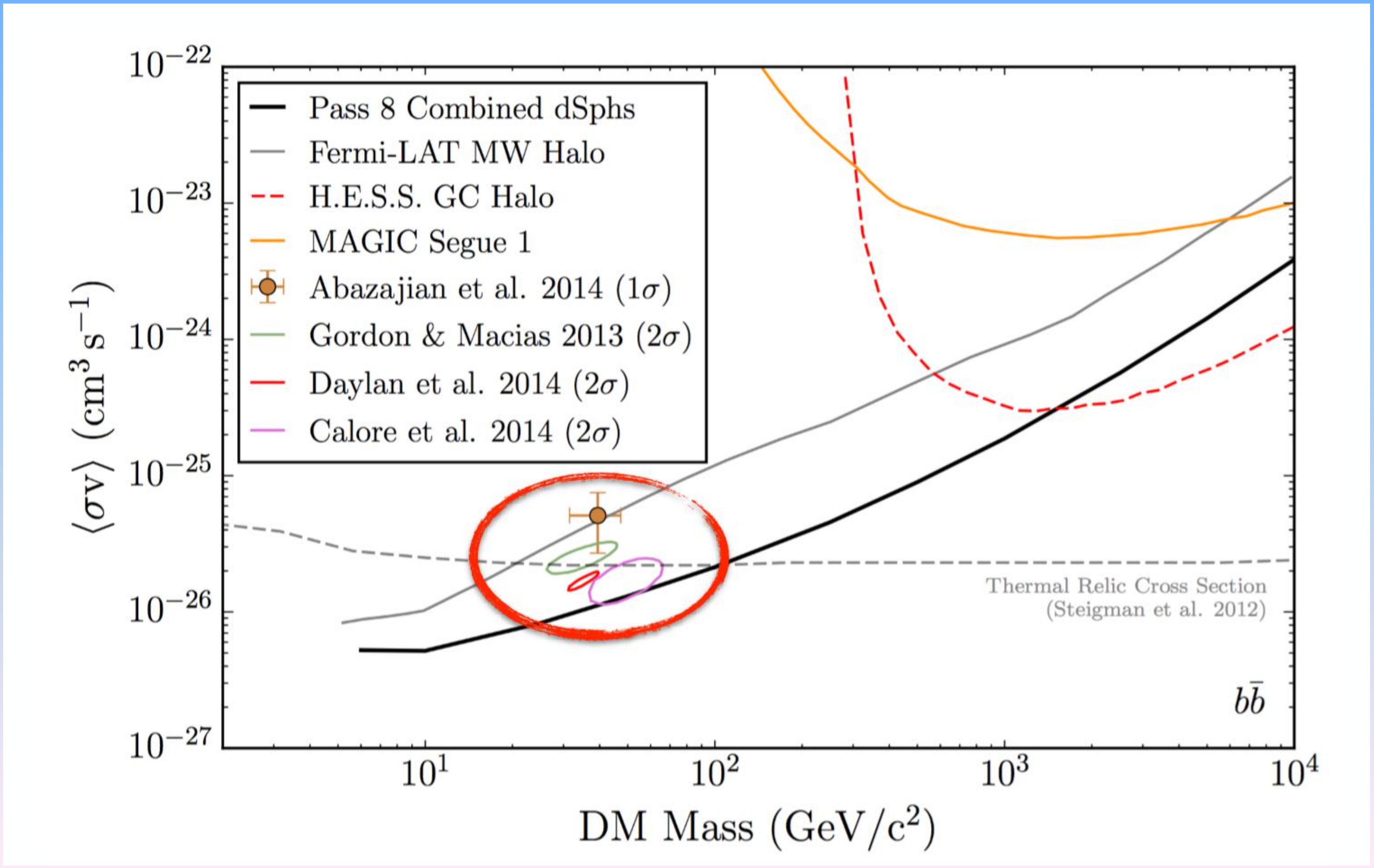
Gamma ray excess from the GC



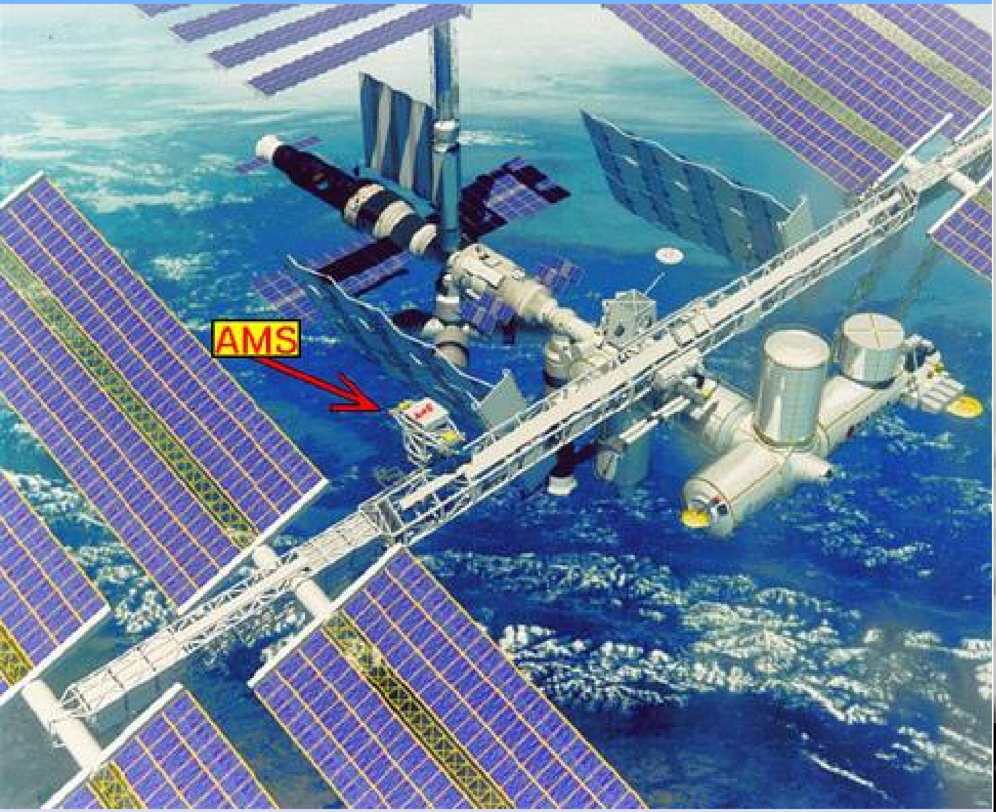




The GC excess due to DM annihilation seems be disfavored



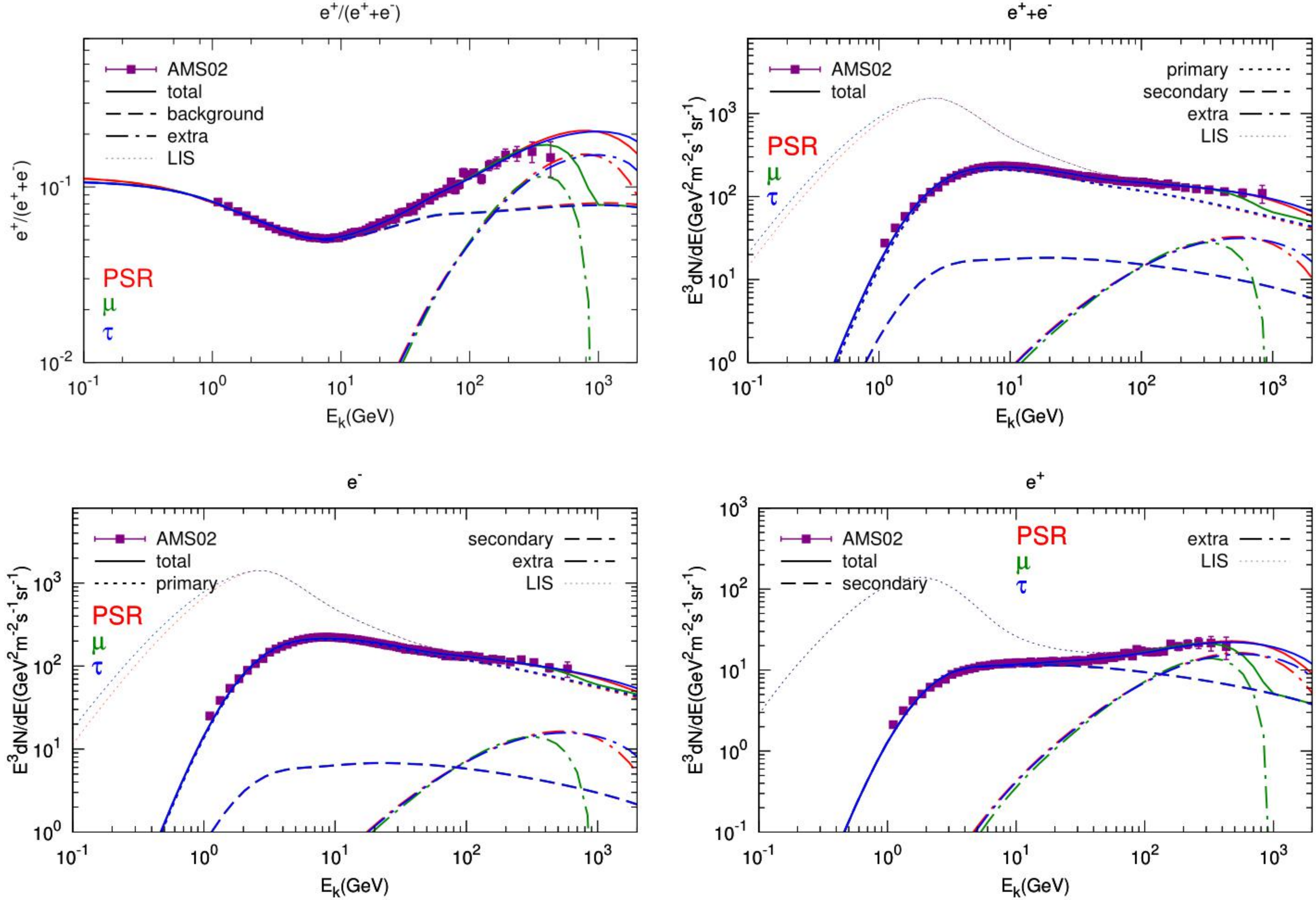
AMS02



1409.6248

Quantitative study of the AMS-02 electron/positron spectra: implications for the pulsar and dark matter properties

Su-Jie Lin, Qiang Yuan, and Xiao-Jun Bi
Key Laboratory of Particle Astrophysics, Institute of High Energy Physics,



Conclusions of the quantitative study

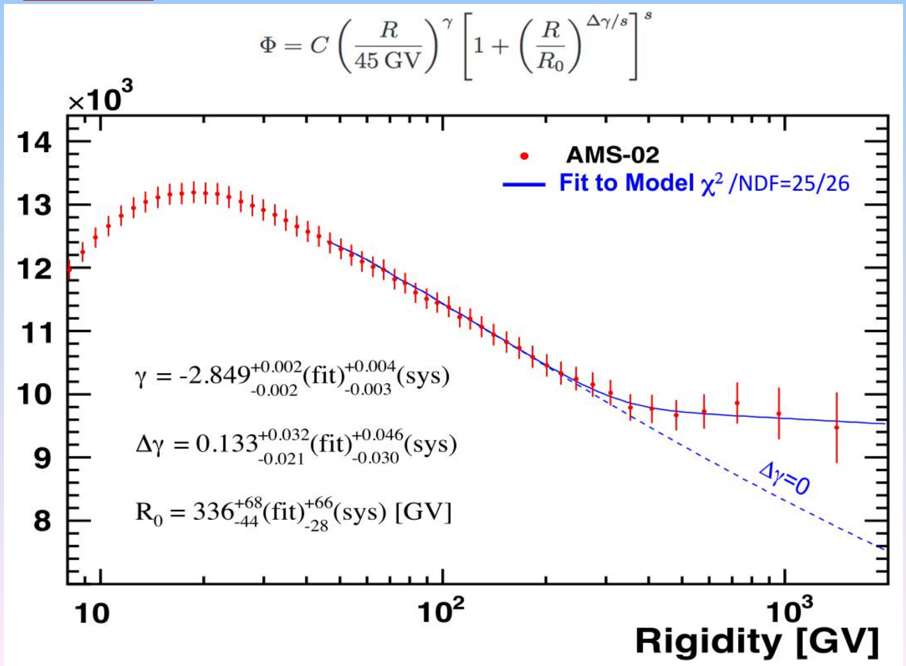
- There is a new break at the primary electron spectrum

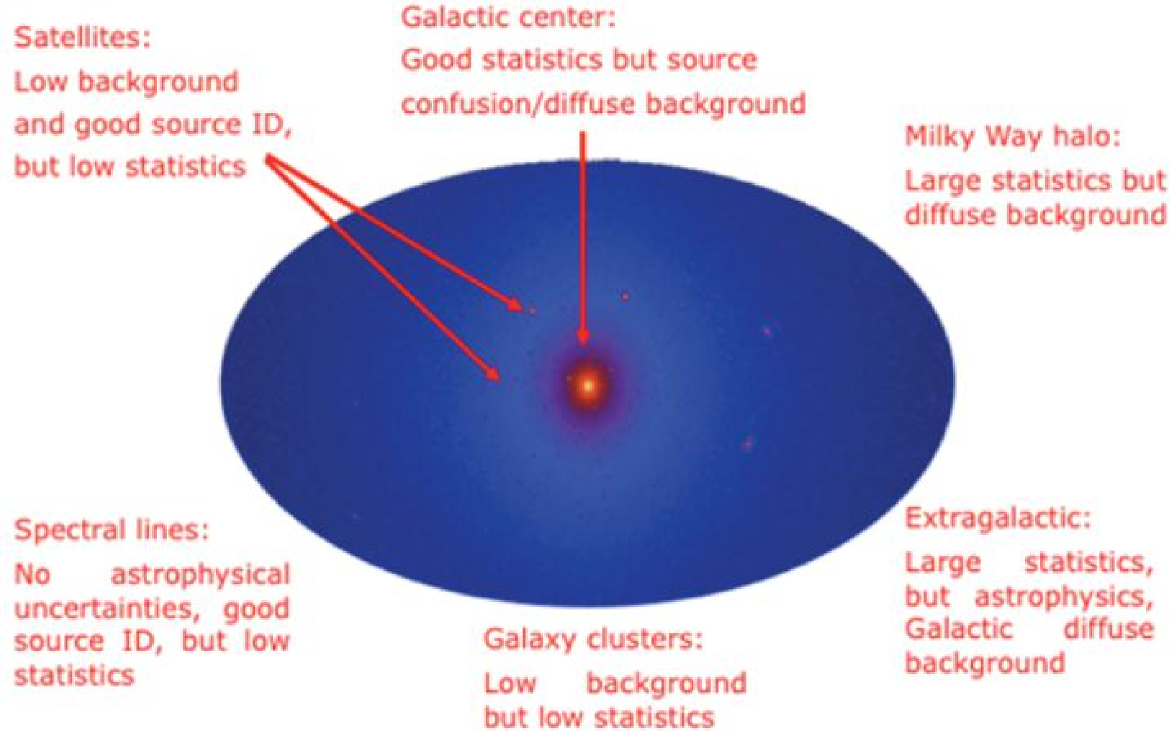
		two breaks					one break				
		$\frac{\chi^2}{\text{d.o.f.}}$	χ^2	$\frac{e^+}{e^+ + e^-}$	e^-	e^+	$\frac{\chi^2}{\text{d.o.f.}}$	χ^2	$\frac{e^+}{e^+ + e^-}$	e^-	e^+
	PSR	0.92	175.4	42.95	54.22	78.26	2.11	407.5	60.44	239.8	107.3
DR	μ	0.89	171.6	39.94	55.36	76.26	2.48	481.2	121.9	275.9	83.38
	τ	0.91	175.2	42.72	55.21	77.24	2.35	456.5	91.29	265.7	99.55
	PSR	0.47	88.99	51.87	14.77	22.35	1.26	242.7	74.95	130.4	37.35
DC	μ	1.16	223.1	88.7	46.95	87.45	3.45	669.1	278.2	271.7	119.2
	τ	0.62	118.0	59.5	21.52	37.02	1.90	368.9	95.22	200.9	72.75

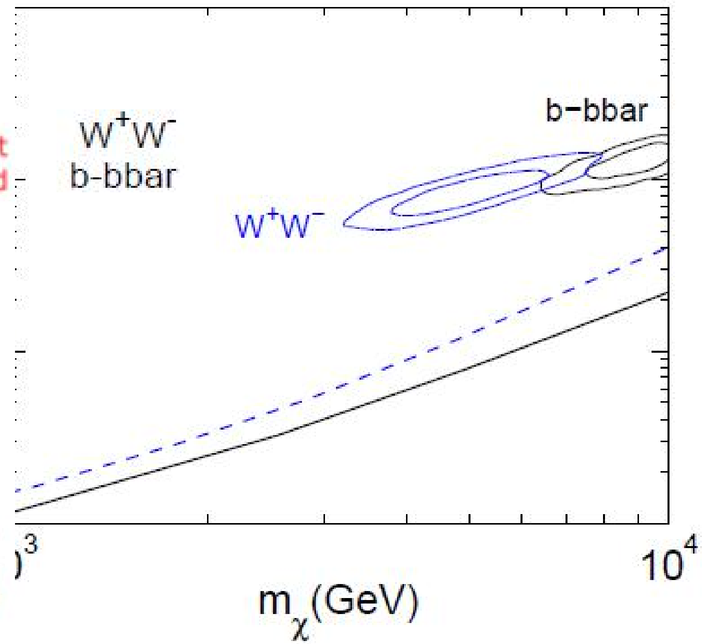
Comments: 1， This is exactly similar to the case of proton spectrum measured by AMS2. The electron break is at ~60GeV with Δγ ≈ 0.3.

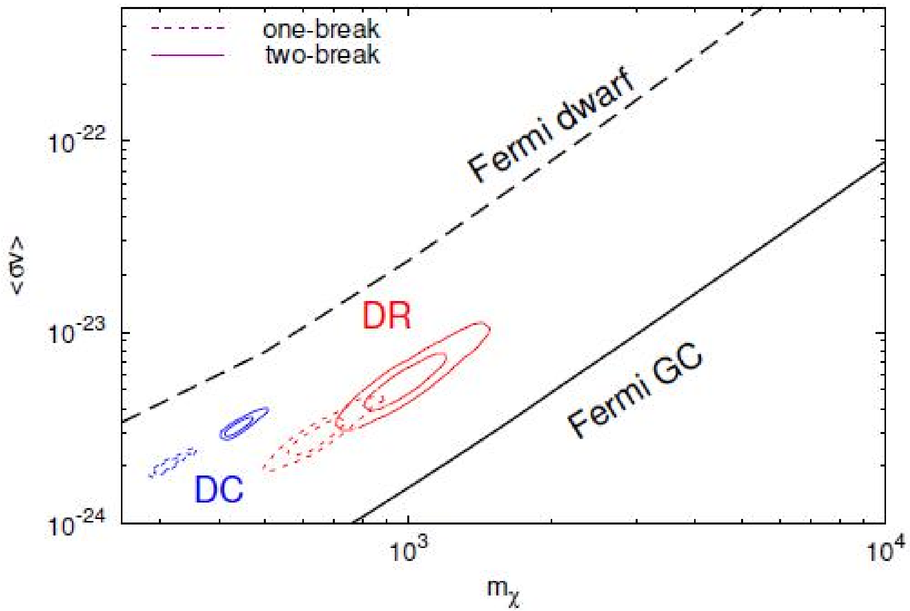
2, again precise fit! without second break a wrong background is adopted! （Without a sufficient understanding of background, we can never understand the signal correctly.）

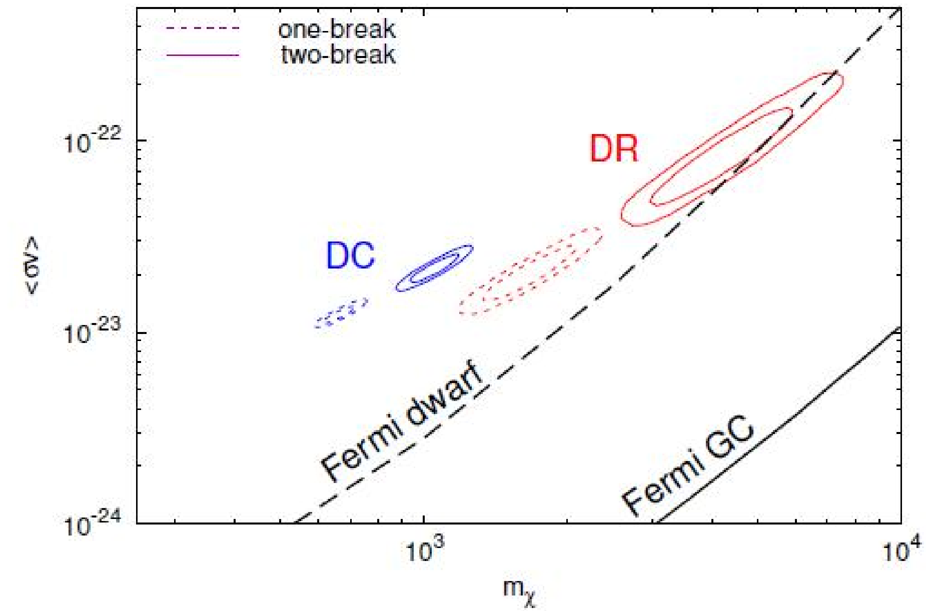
3, subtle effect is hid behind the precise data, only by quantitative study can it be revealed.



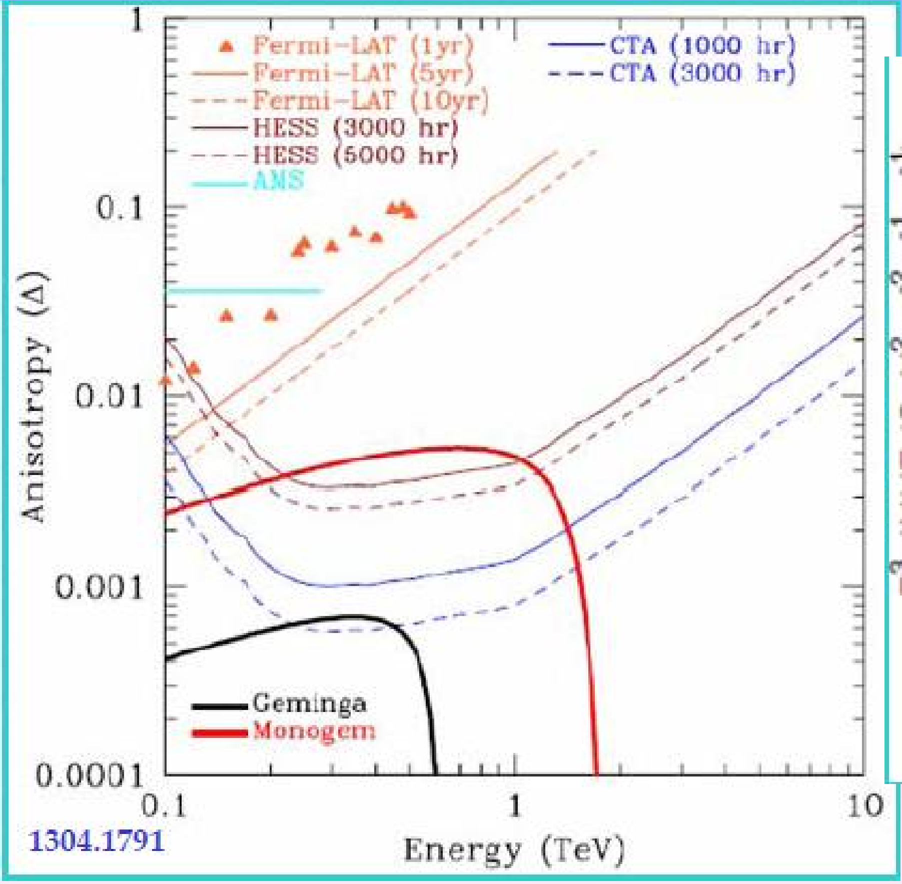

Satellites:
Low background and good source ID, but low statistics
Galactic center:
Good statistics but source confusion/diffuse background
Milky Way halo:
Large statistics but diffuse background
Spectral lines:
No astrophysical uncertainties, good source ID, but low statistics
Galaxy clusters:
Low background but low statistics
Extragalactic:
Large statistics, but astrophysics, Galactic diffuse background

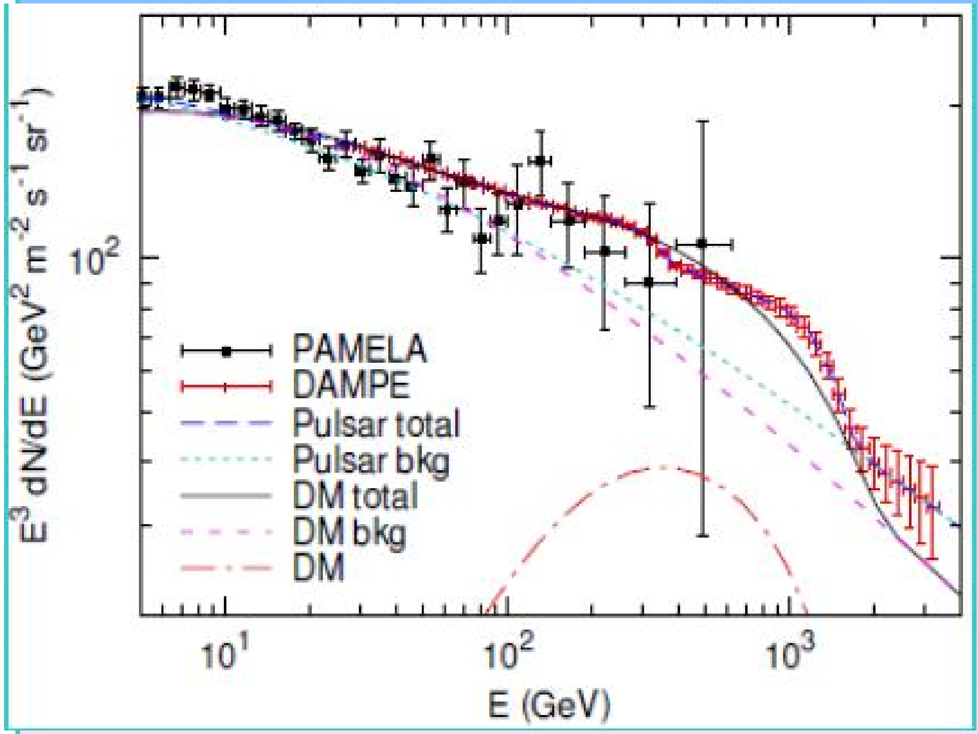

W+W-
b-bbar
b−bbar
W+W-
10^4
mχ(GeV)


one-break
two-break
Fermi dwarf
DR
DC
Fermi GC
10^-22
10^-23
10^-24
<σv>
10^3
10^4
mχ

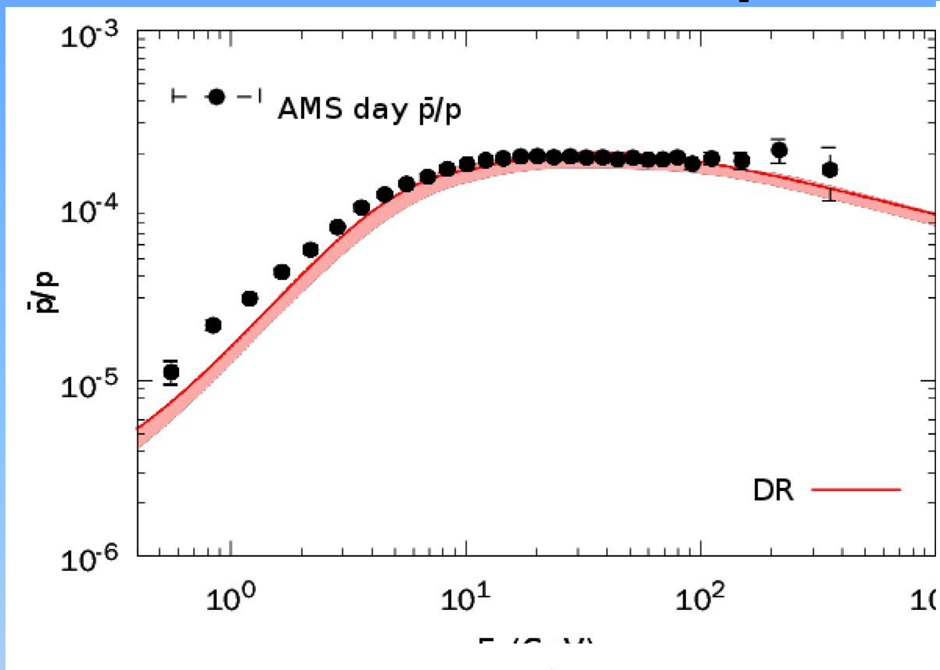

one-break
two-break
DR
DC
Fermi dwarf
Fermi GC
10^-22
10^-23
10^-24
<σv>
10^3
10^4
mχ

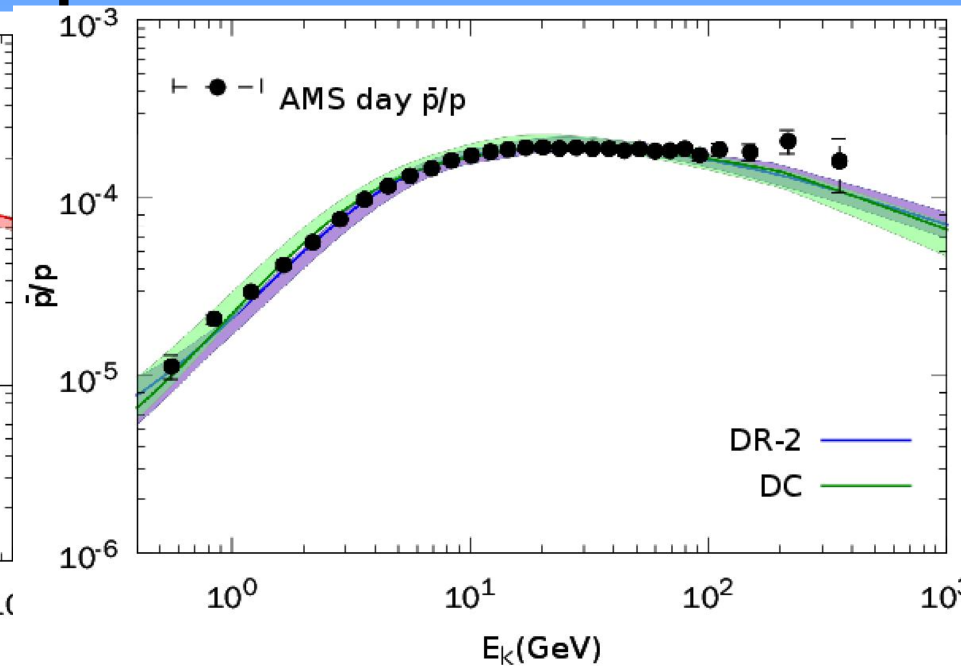
DM vs pulsar: flux anisotropy vs spectrum wiggles

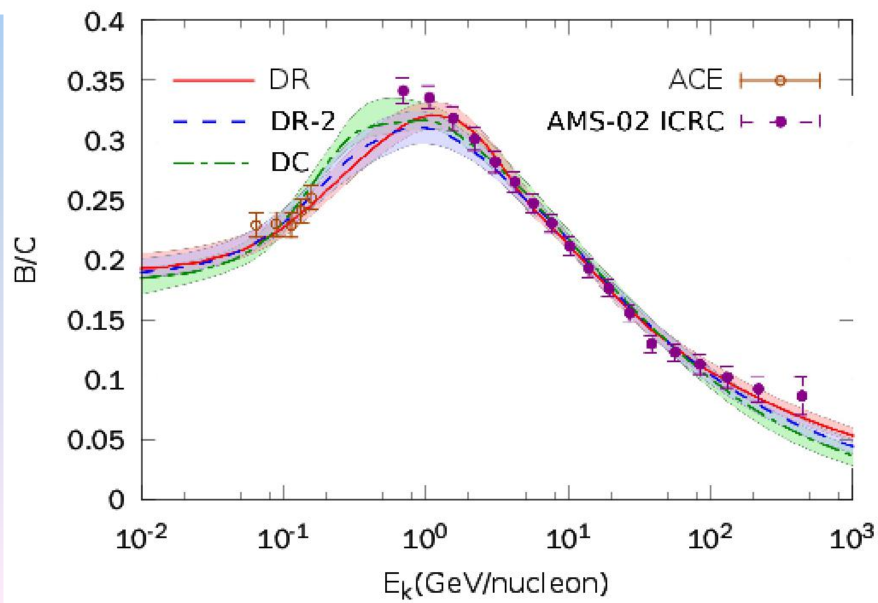




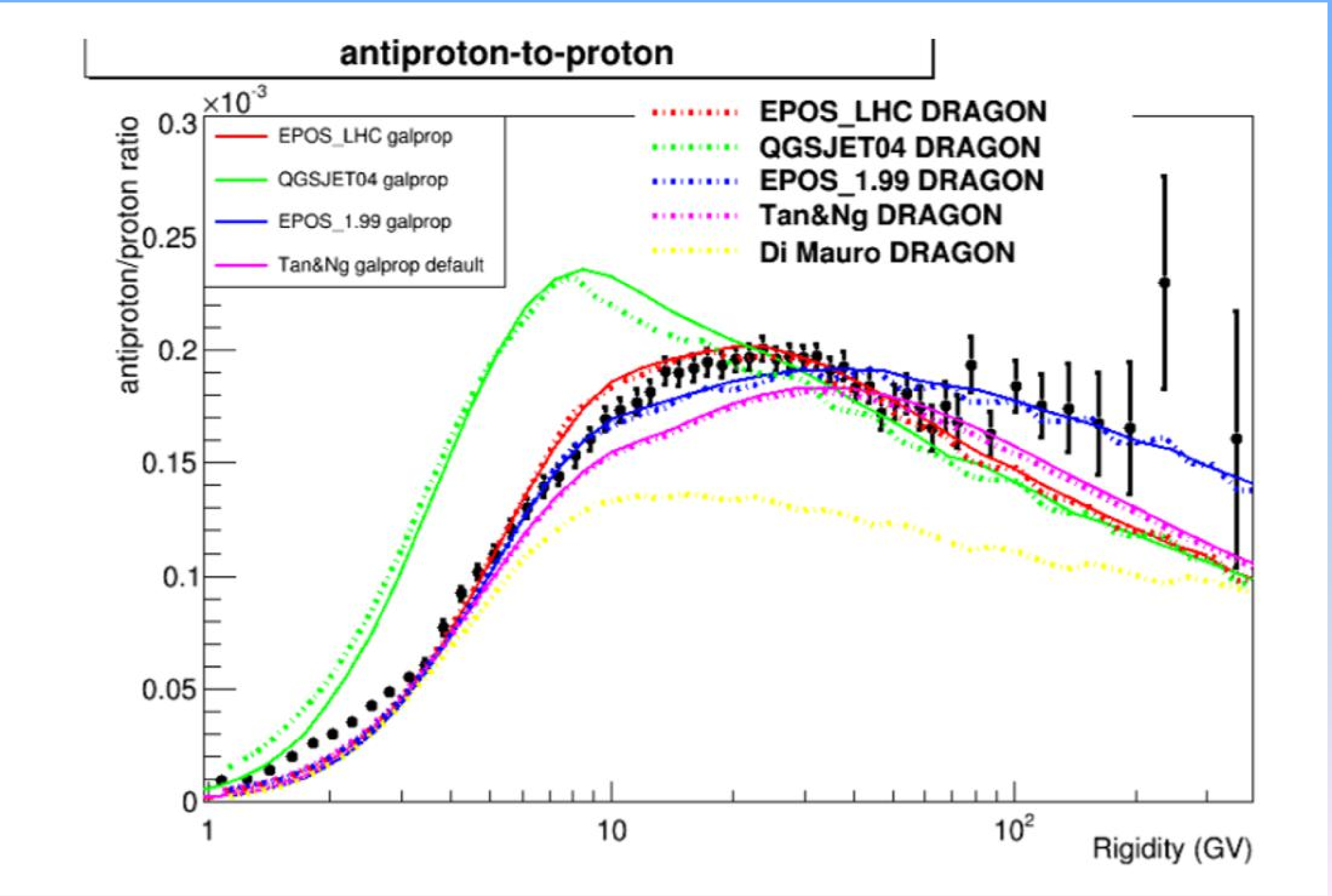
有关AMS-02 pbar/p初步结果的研究

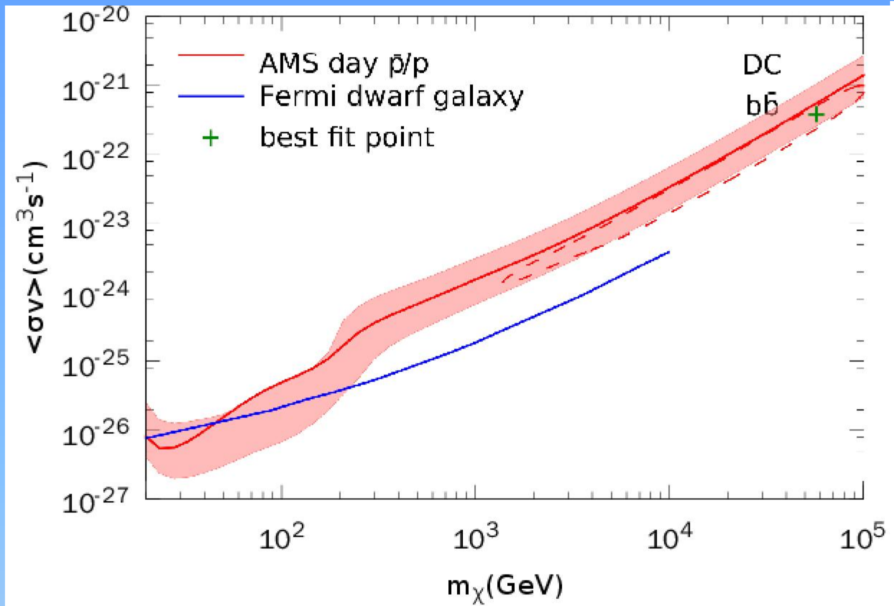


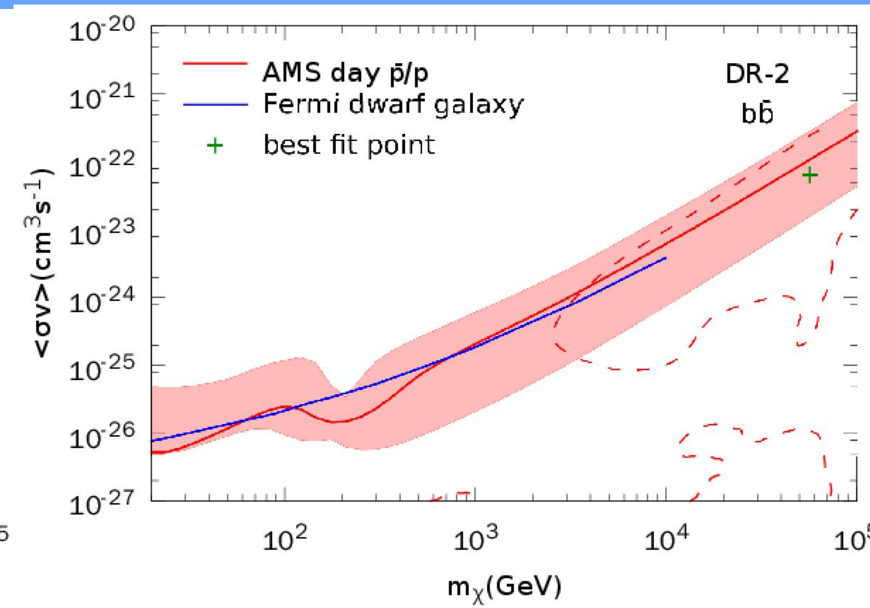


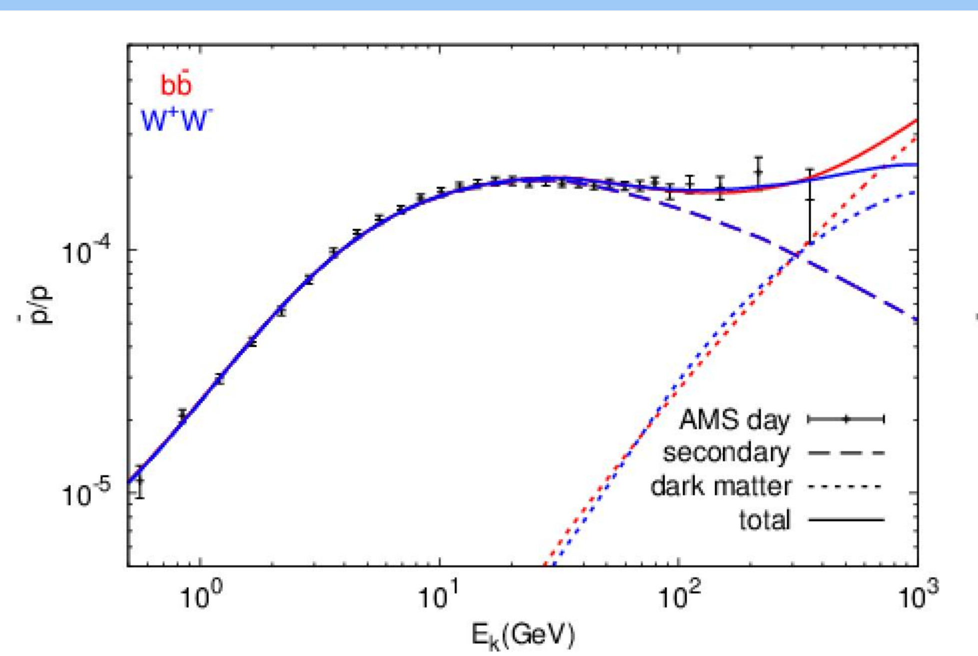


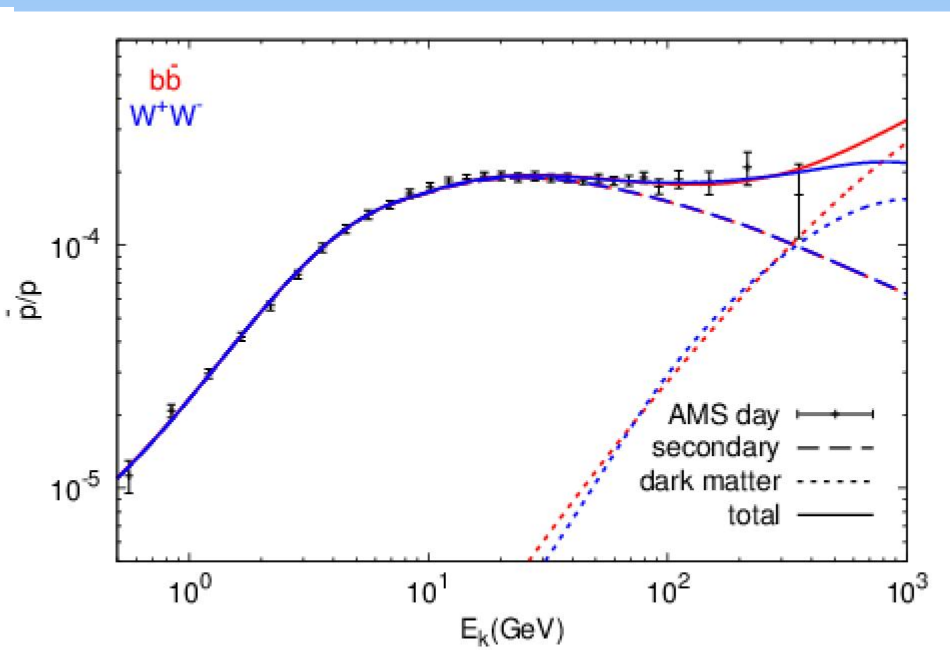
Pbar/p adopting different interaction model



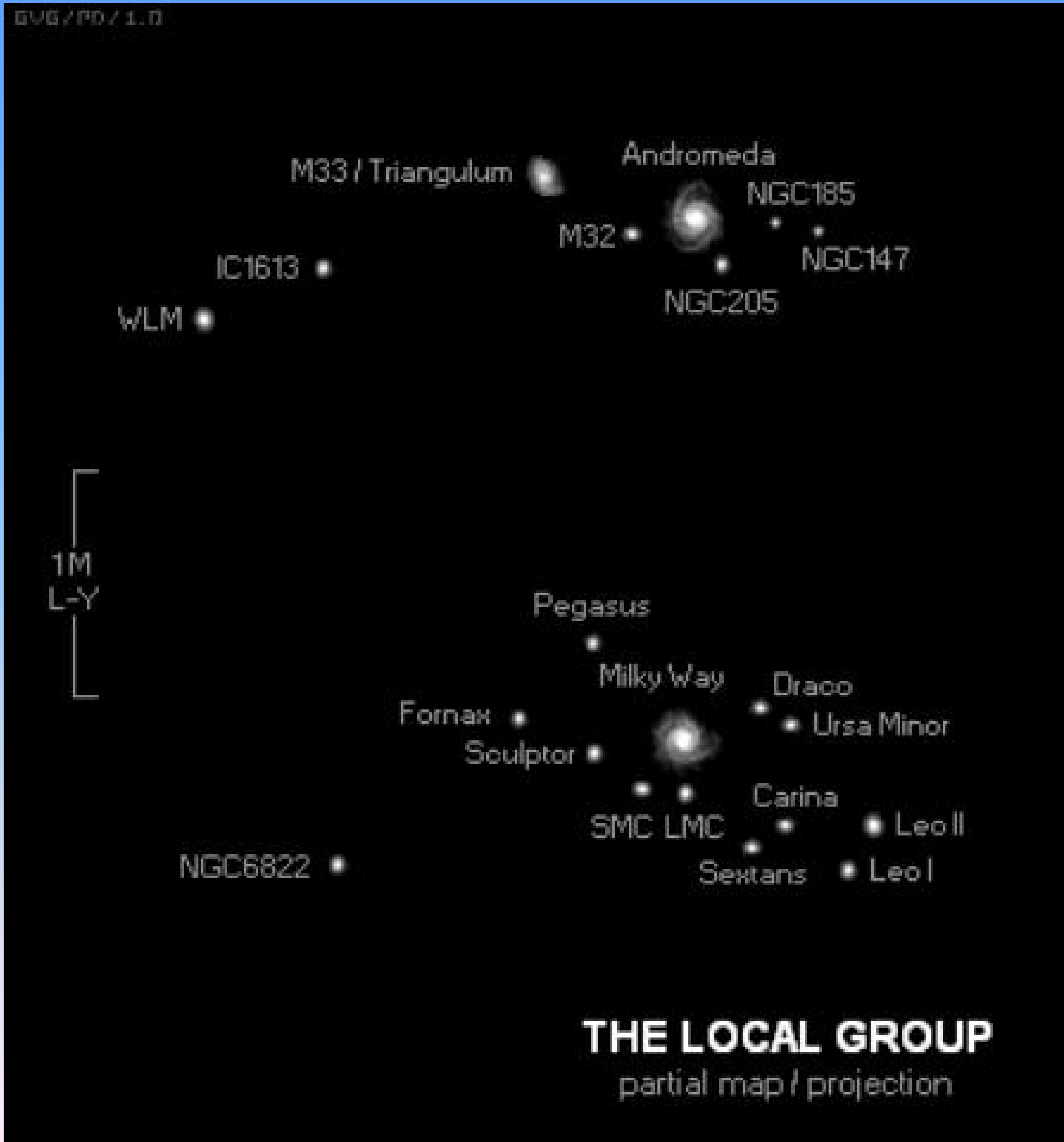

AMS day p̄/p
Fermi dwarf galaxy
best fit point
DC
$b\bar{b}$
$<\sigma v>(cm^3 s^{-1})$
m_χ(GeV)
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^2
10^3
10^4
10^5


AMS day p̄/p
Fermi dwarf galaxy
best fit point
DR-2
$b\bar{b}$
$<\sigma v>(cm^3 s^{-1})$
m_χ(GeV)
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^2
10^3
10^4
10^5


$b\bar{b}$
W^+W^-
$\bar{p}/p$
E_k(GeV)
AMS day
secondary
dark matter
total
10^{-4}
10^{-5}
10^0
10^1
10^2
10^3

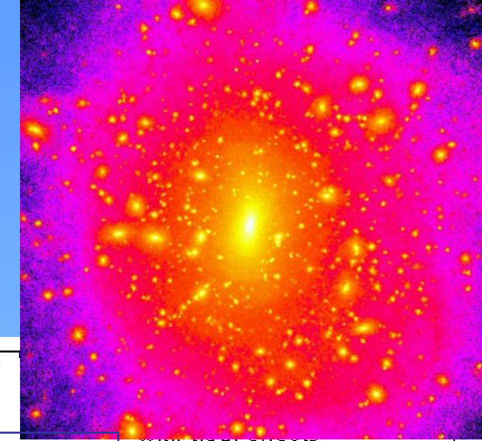

$b\bar{b}$
W^+W^-
$\bar{p}/p$
E_k(GeV)
AMS day
secondary
dark matter
total
10^{-4}
10^{-5}
10^0
10^1
10^2
10^3

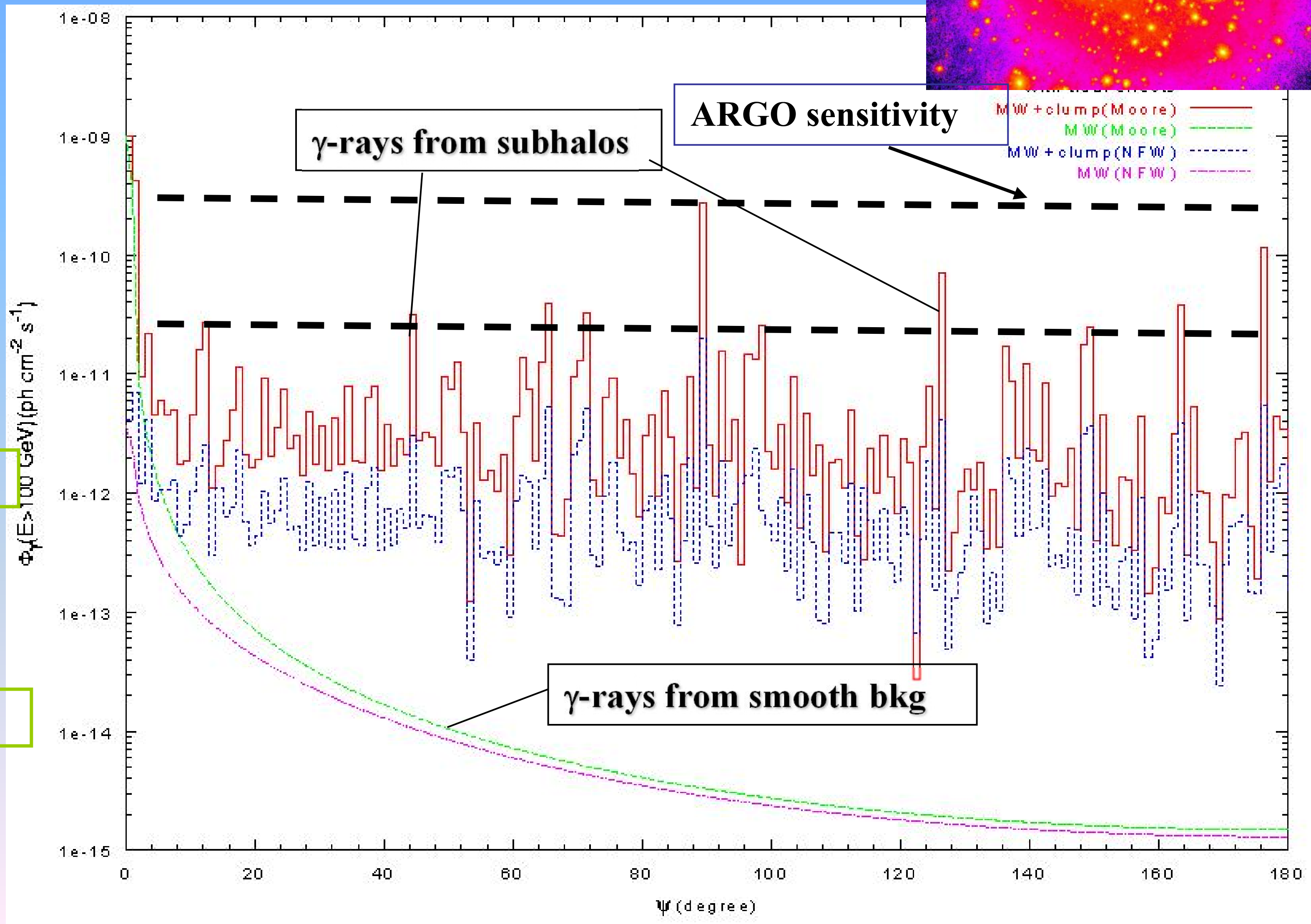
LHAASO 探测暗物质信号

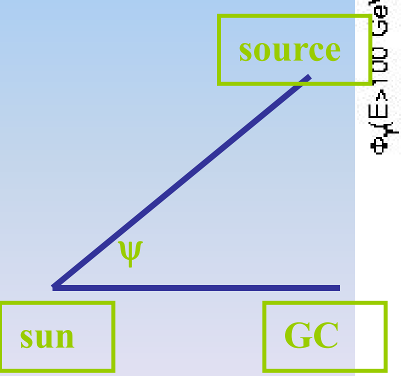


γ-rays from the subhalos– large F.O.V, high sensitivity, high duty circle (compare GLAST, HESS)

Reed et al, MNRAS357,82(2004)

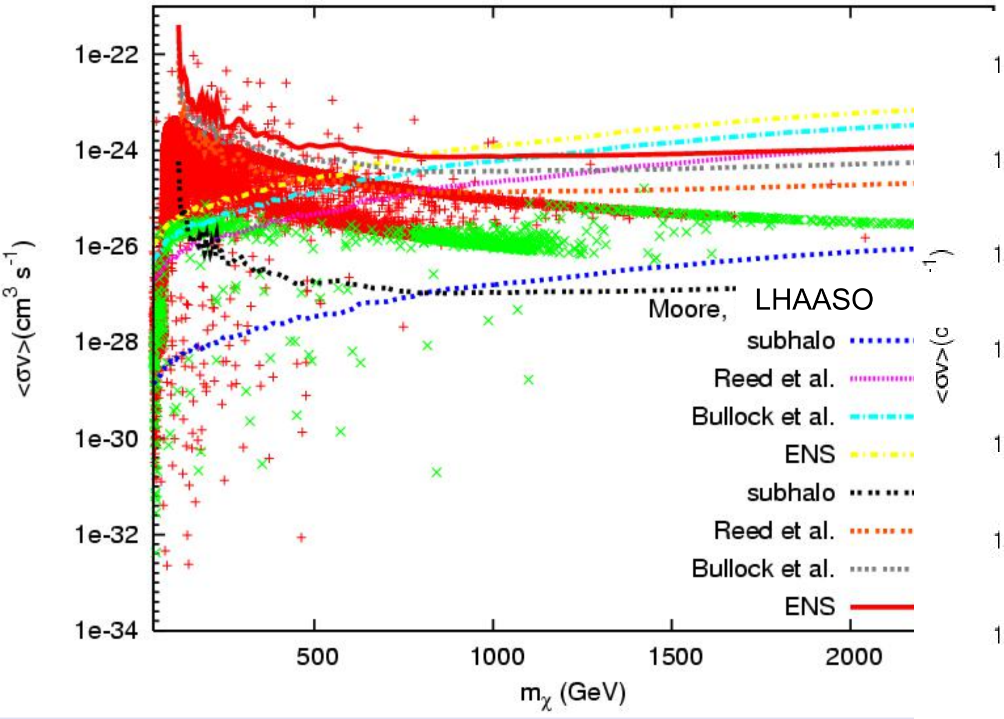


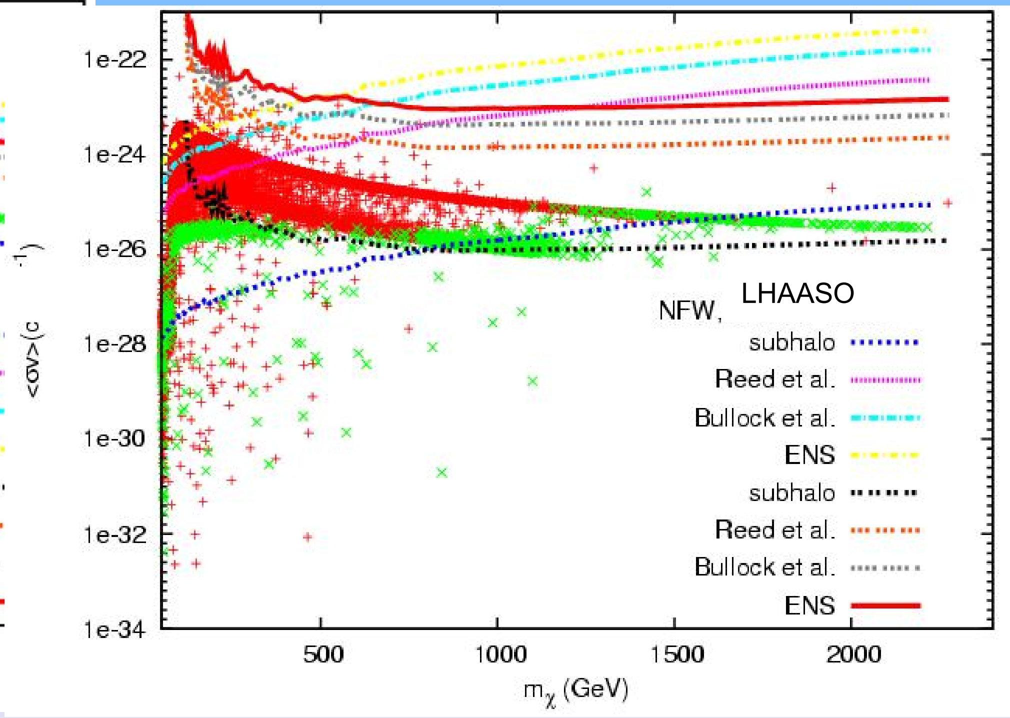




LHAASO和Fermi的灵敏度对比

- LHAASO阈能100GeV，灵敏度10％Crab





总结

- 暗物质是理解更深层的物理知识的一个重要窗口。然而，暗物质探测到现在为止仍然没有确切的实验信号。
- 宇宙线实验是寻找暗物质信号的重要手段，Fermi、AMS等实验都获得非常漂亮的实验结果。
- LHAASO可以通过伽马射线寻找暗物质信号，对于非常重的暗物质寻找有优势。