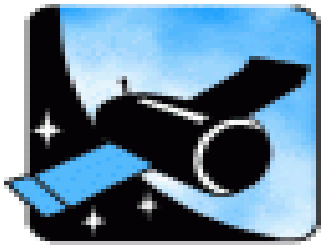


Search for signatures of hypothetical dark matter particles in space from PAMELA to GAMMA-400

Professor Arkady Galper

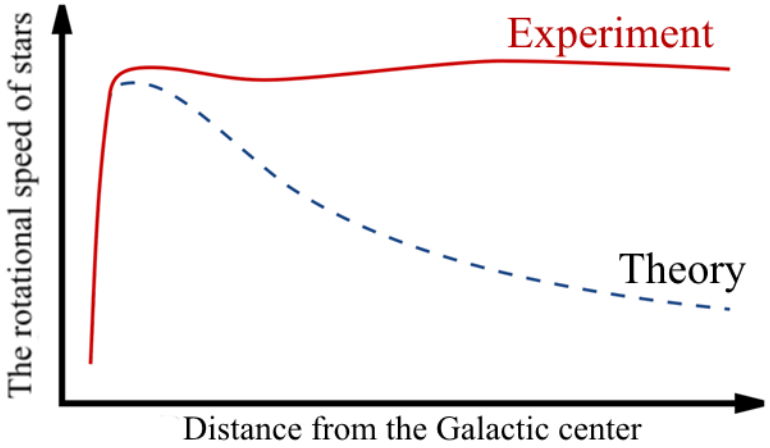
National Research Nuclear University MEPhI
Lebedev Physical Institute

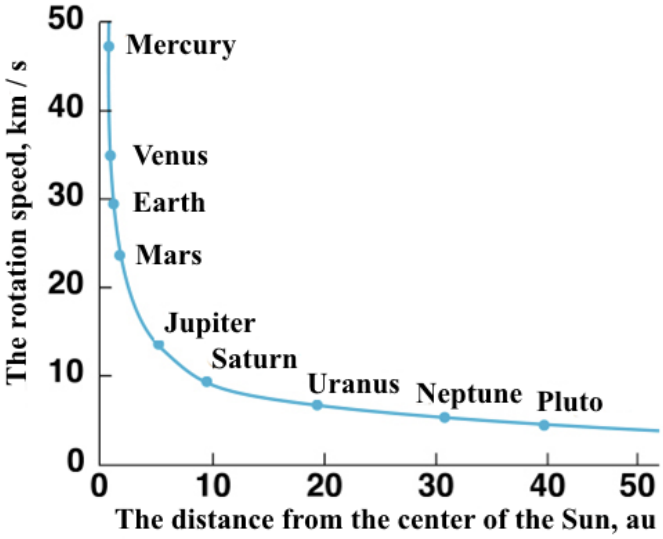
Charm and Beauty in Physics, November 10-11, 2016

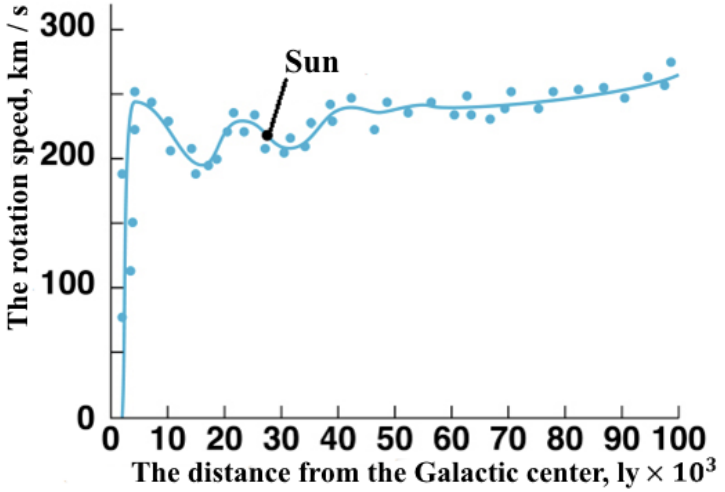
Signatures of Dark matter

Fritz Zwicky
1898 — 1974 years

$$E_{kin} = -\frac{U}{2}; \quad \frac{mv^2}{r} = \frac{GMm}{r^2} \quad \Rightarrow \quad v = \sqrt{\frac{GM}{r}}$$

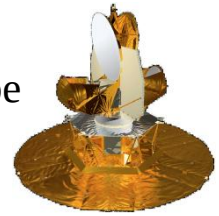




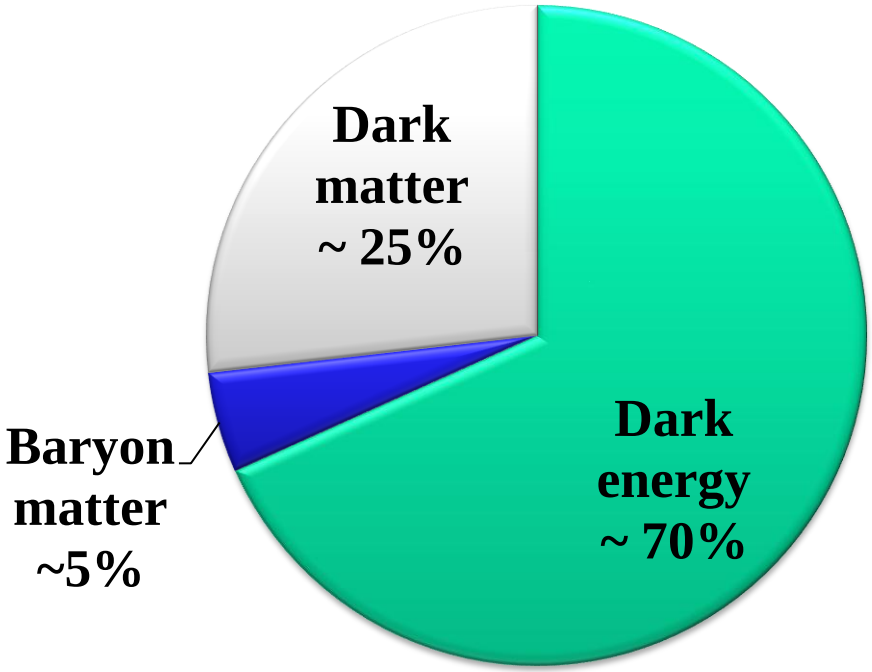


Cosmic observatories

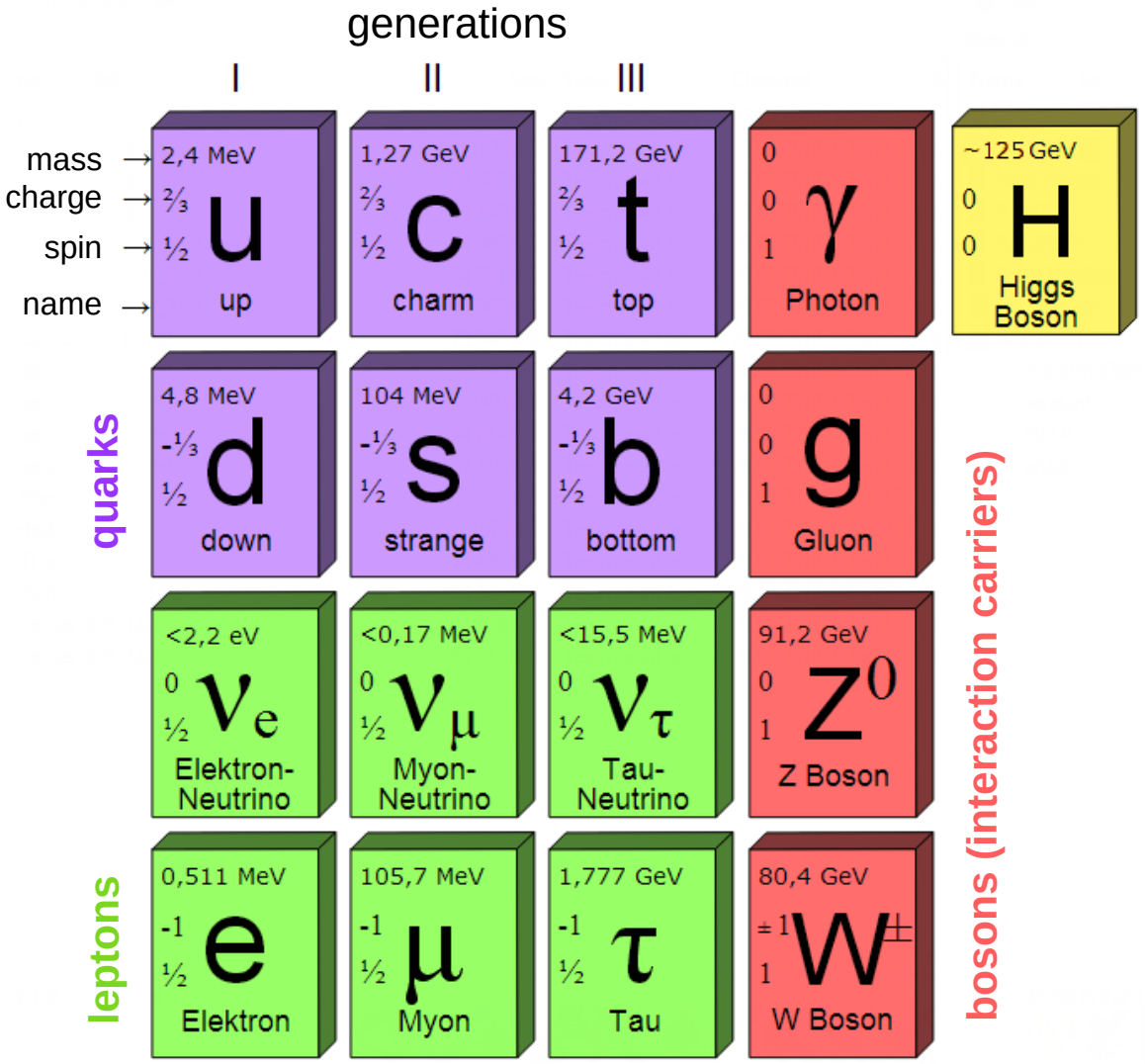
WMAP
Wilkinson Microwave Anisotropy Probe
(2001 - 2009)



Planck
(2009 - Now)



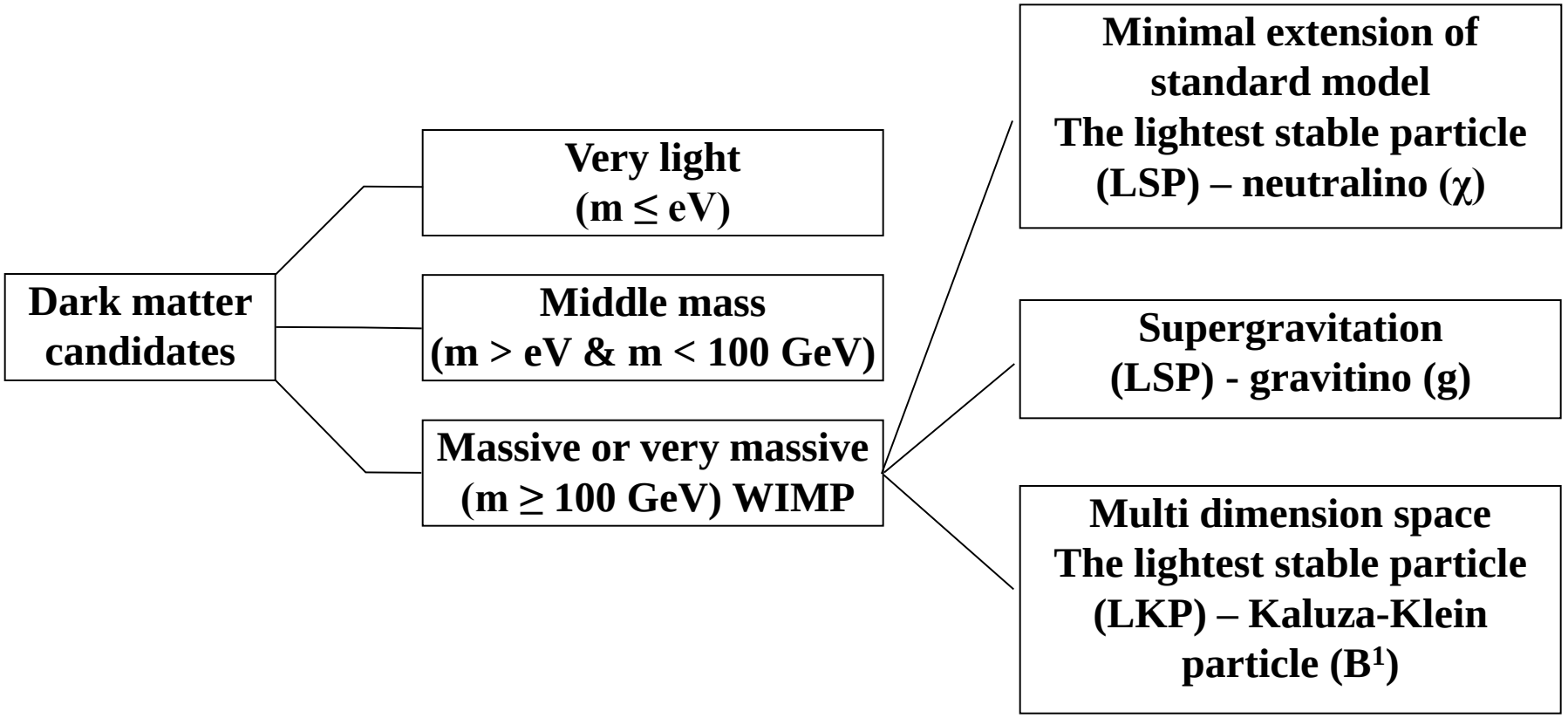
Standard model today



Dark matter candidates

- Neutralino
- Kaluza-Klein Boson
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes
- Dark Photons
- ...

Dark matter candidates: simply classification

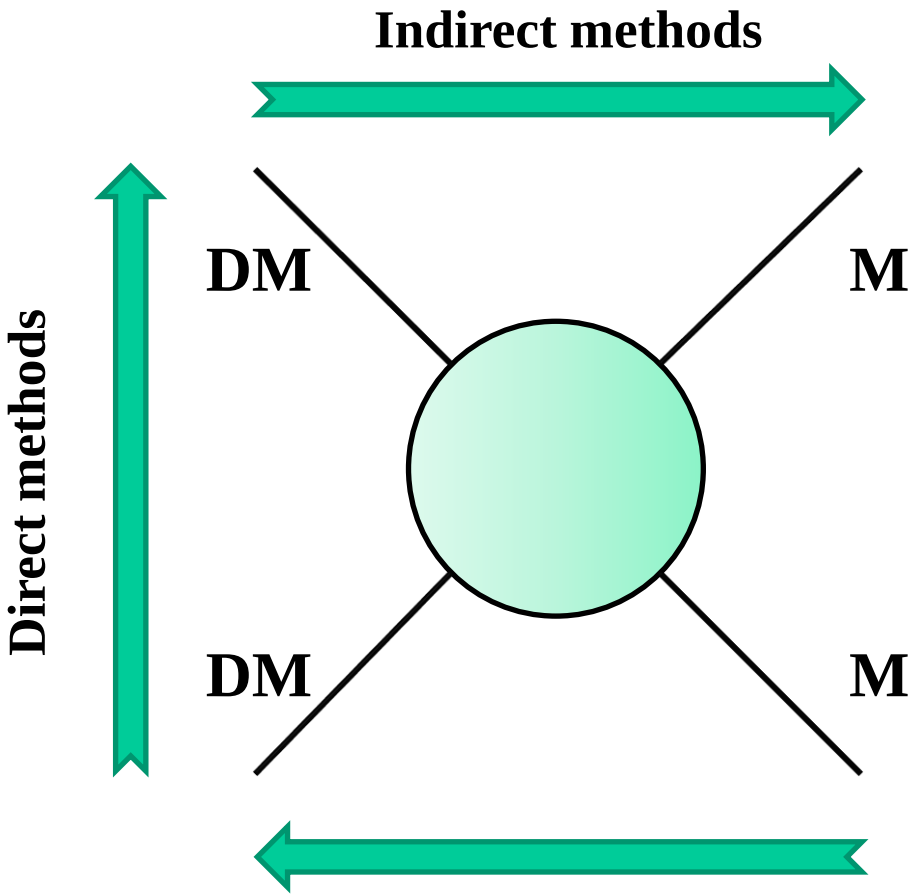


WIMPs: Weakly Interacting Massive Particles

1. Possess only gravitational interaction
2. Interaction intensity not more than weak interaction
3. Neutral
4. Stable or with large time of decay
5. Have a large mass

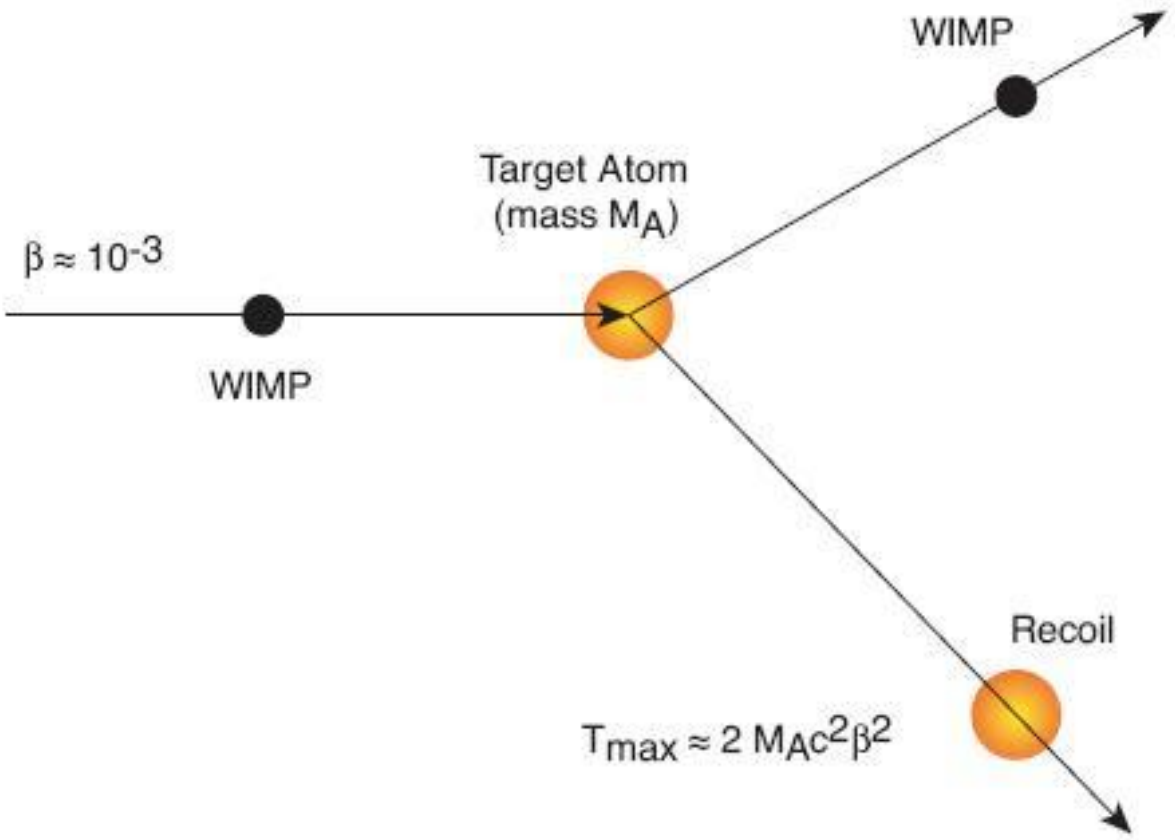
Dark matter searches

LUX
DARKSIDE
XENON
DAMA
CDMS
…



M – baryonic matter
DM – dark matter

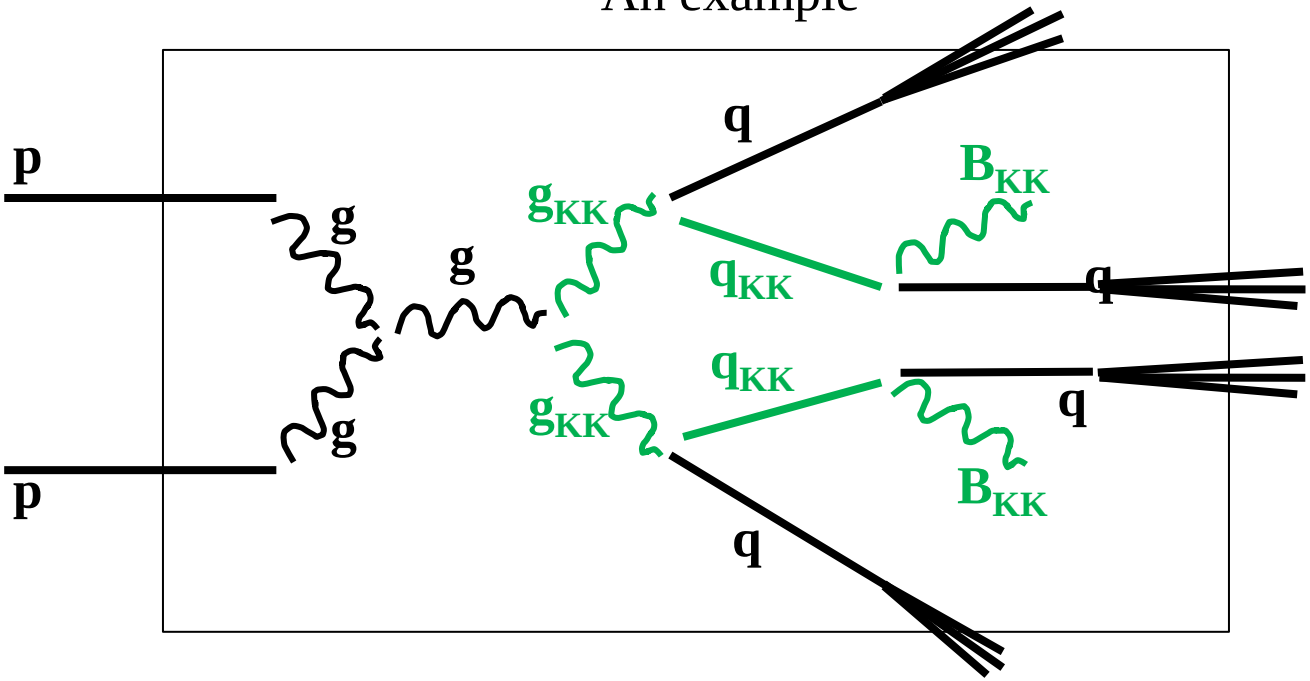
Dark matter searches: direct method



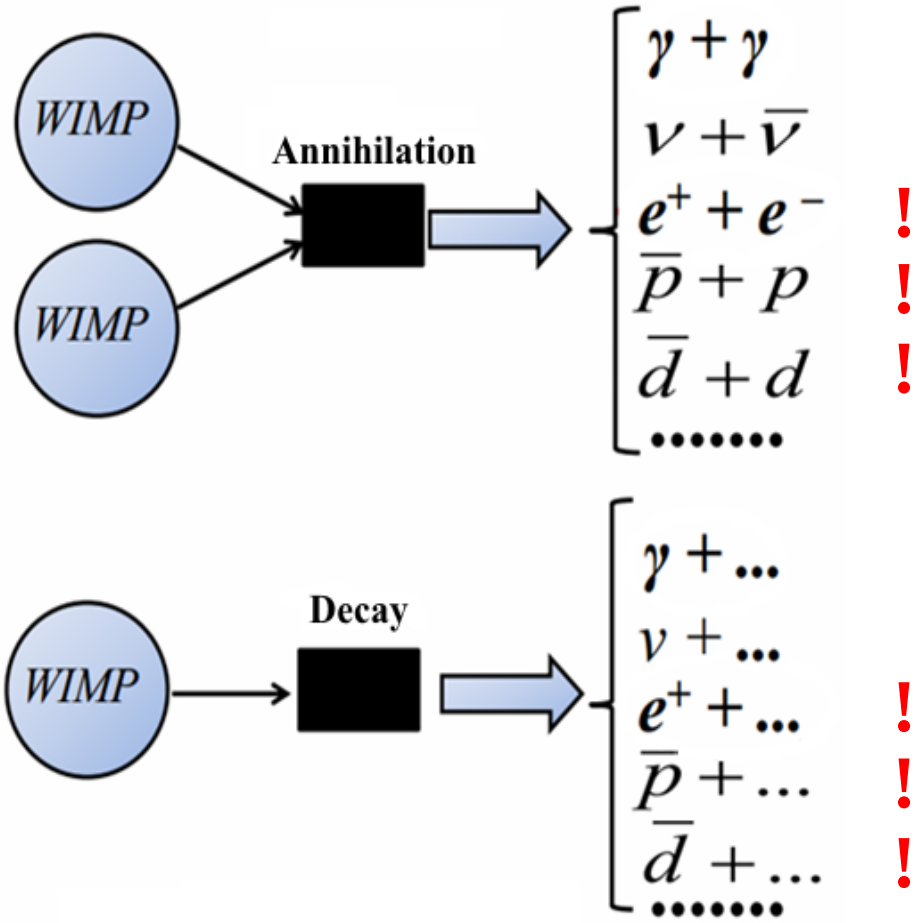
Search for Kaluza-Klein boson with simplest process

pp → g_{KK}+g_{KK} → … B_{KK}+ B_{KK}

An example

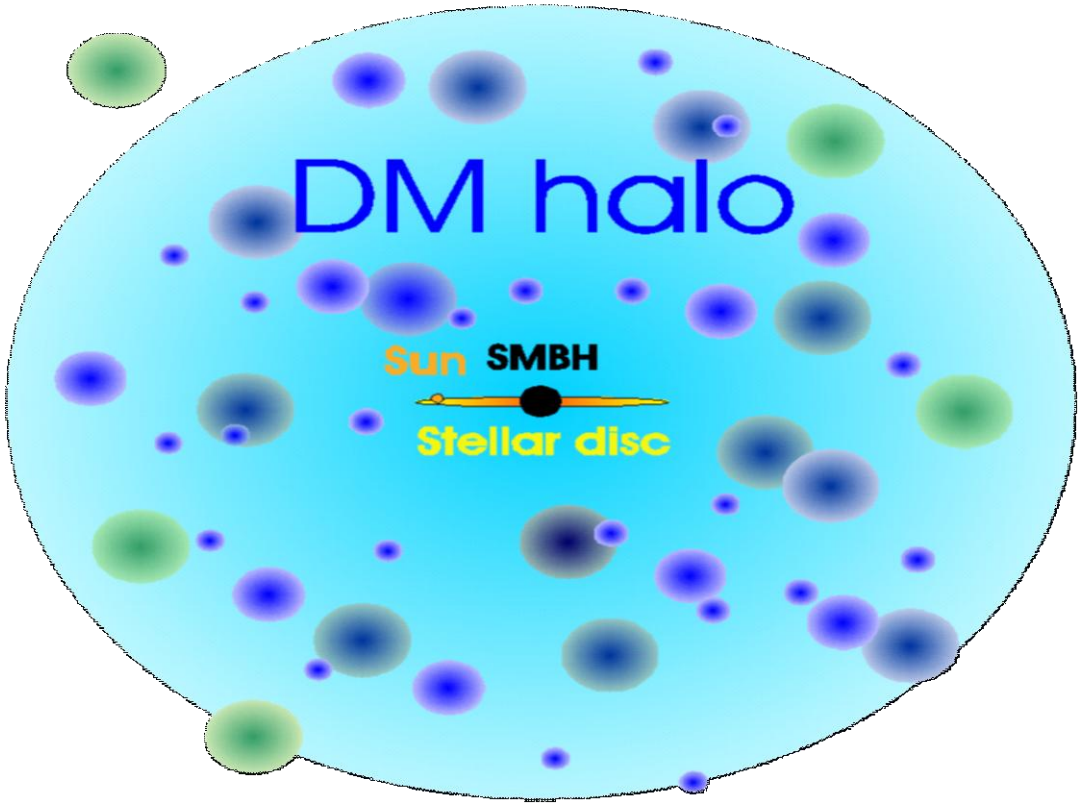


4 jets and E_{missed}



Black box : $b\bar{b}, t\bar{t}, \tau^+\tau^-, \mu^+\mu^-, e^+e^-, Z^0Z^0, Z^0\gamma, W^+W^-, HH, \ldots$

Small-scale clumps of dark matter in the Galactic halo



Distribution of dark matter in Galaxy

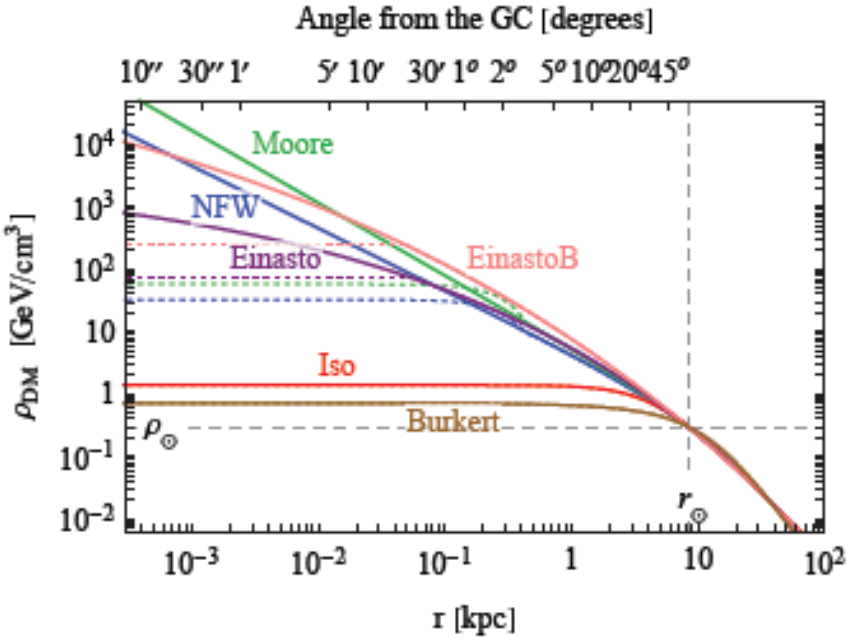
$$\text{NFW}: \quad \rho_{\rm NFW}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$\text{Einasto}: \quad \rho_{\rm Ein}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

$$\text{Isothermal}: \quad \rho_{\rm Iso}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

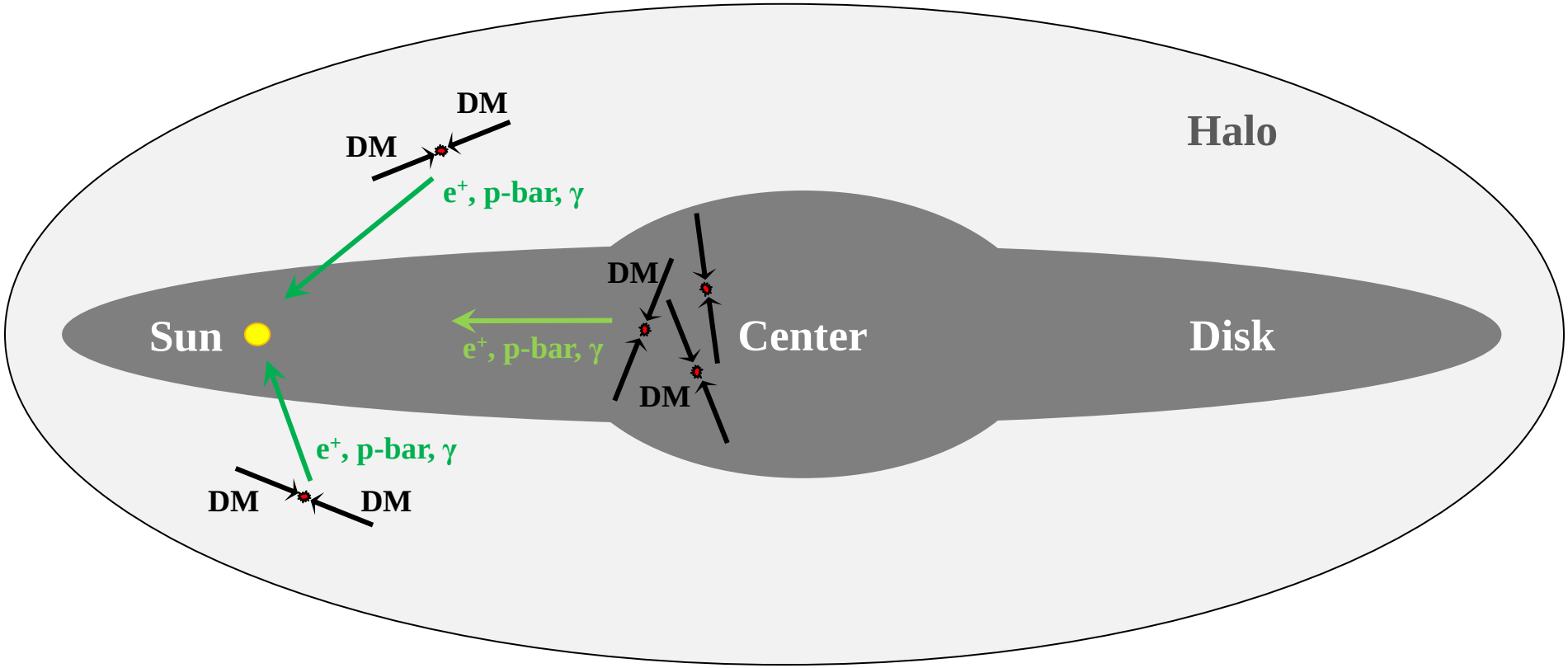
$$\text{Burkert}: \quad \rho_{\rm Bur}(r) = \frac{\rho_s}{(1+r/r_s)(1+(r/r_s)^2)}$$

$$\text{Moore}: \quad \rho_{\rm Moo}(r) = \rho_s \left(\frac{r_s}{r}\right)^{1.16}\left(1+\frac{r}{r_s}\right)^{-1.84}$$

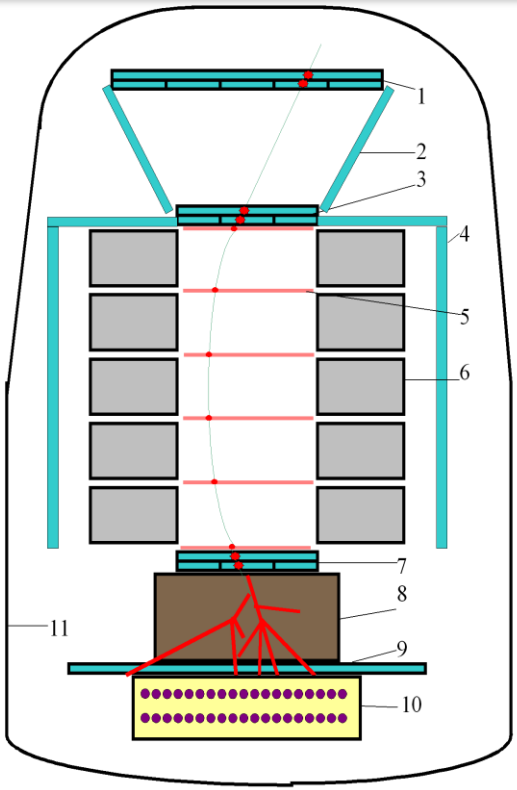


DM halo	α	r_s [kpc]	ρ_s [GeV/cm^3]
NFW	–	24.42	0.184
Einasto	0.17	28.44	0.033
EinastoB	0.11	35.24	0.021
Isothermal	–	4.38	1.387
Burkert	–	12.67	0.712
Moore	–	30.28	0.105

DM annihilation (or decay) in the Galaxy



PAMELA scheme



Measurements:

- **Velocity (β)**
- **Deflection & Rigidity**
- **Energy losses**
- **Cascades**
- **Number of neutrons**

Determine:

- **Lepton/hadron**
- **Charge and sign of charge (±Z)**
- **Mass (A, M)**
- **Momentum and energy**
- **Particle's direction**

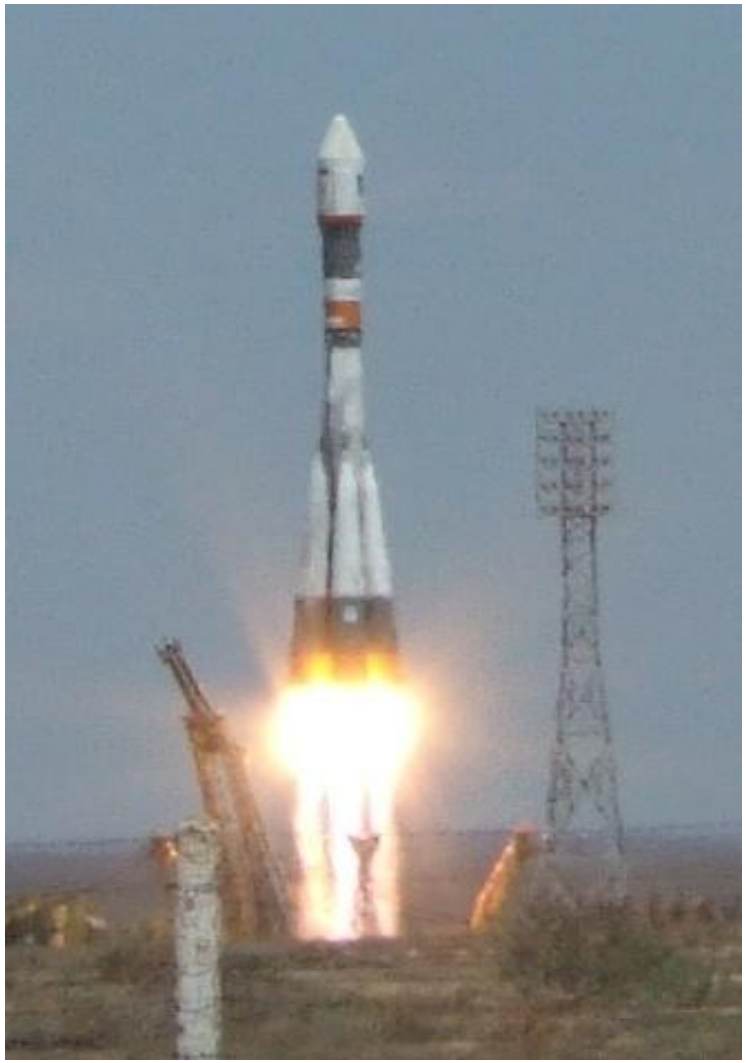
Magnetic spectrometer PAMELA

1, 3, 7	***Time-of-Flight;***
2, 4	***Anticoincidence;***
5	***Coordinate tracking system (6 double-side orthogonal planes);***
6	***Magnet (5 modules);***
8	***Silicon strip coordinate-sensitive detector;***
9	***Cascade tail detector C4;***
10	***Neutron detector;***
11	***Herm container.***

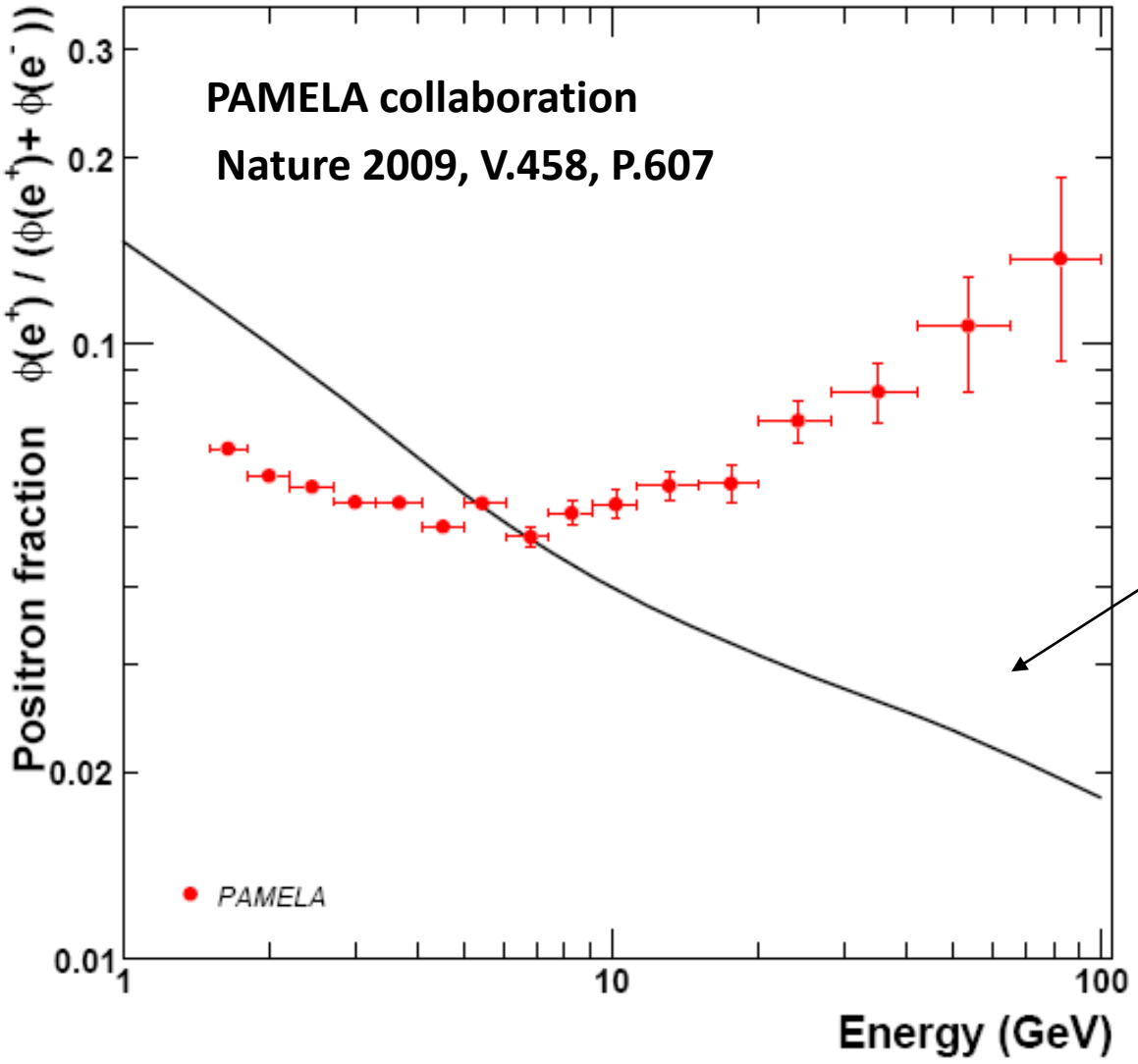
PAMELA

Energies:	
protons	0.08 – 1200 GeV
antiprotons	0.08 – 350 GeV
electrons	0.08 – 700 GeV
positrons	0.08 – 300 GeV
nuclei	0.05 – 100 GeV/nuc.
Mass	450 kg
Dimensions	1 m × 1 m ×1.25 m
Magnetic field	0.48 T
Power	350 W

Launch of Resurs-DK1

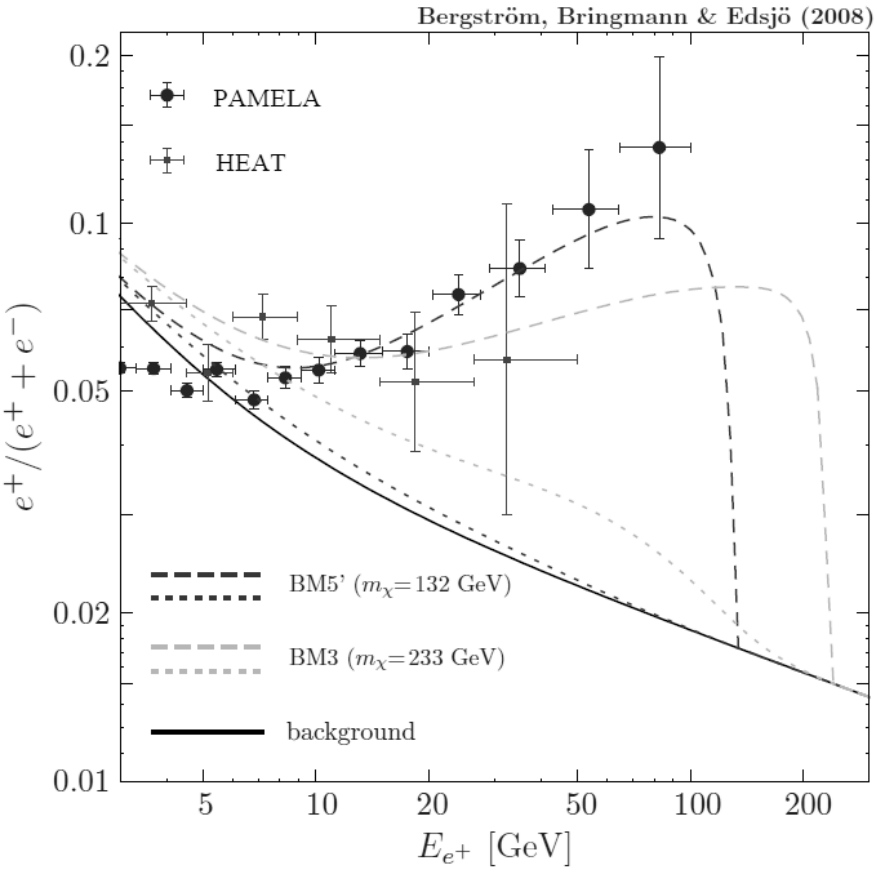


Positron to electron + positron ratio



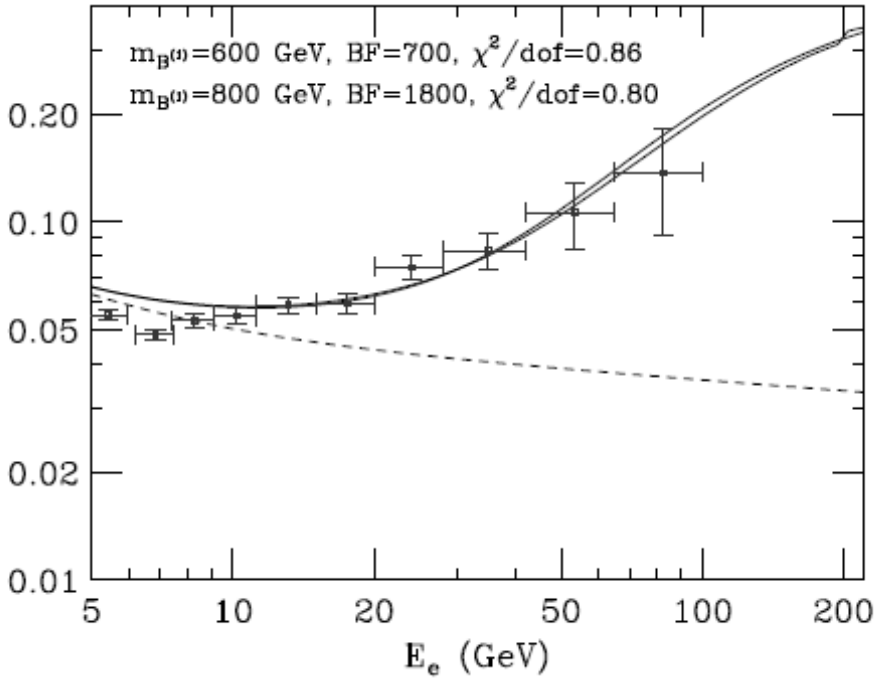
Secondary production Moskalenko-Strong (1998)

Positron to electron + positron ratio: nature of dark matter



Neutralino annihilation, boost-factor $3 \cdot 10^4$

D. Hooper, K.M. Zurek, arXiv:0902.0593v1



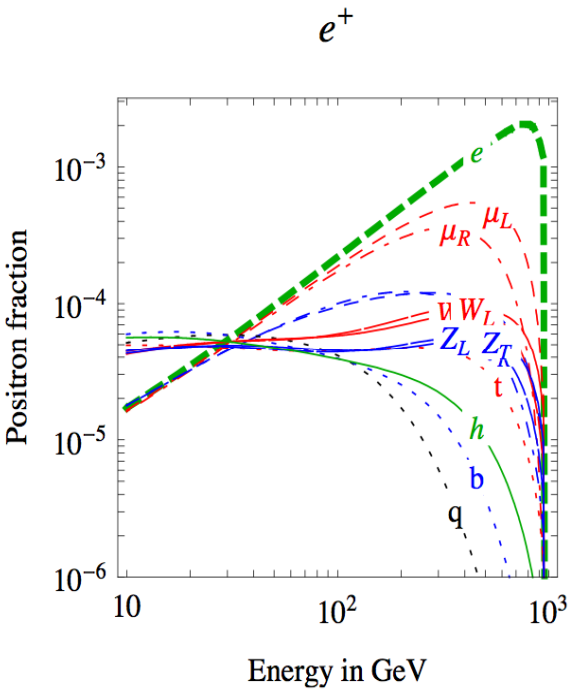
KK annihilation, boost-factors 700 & 1800

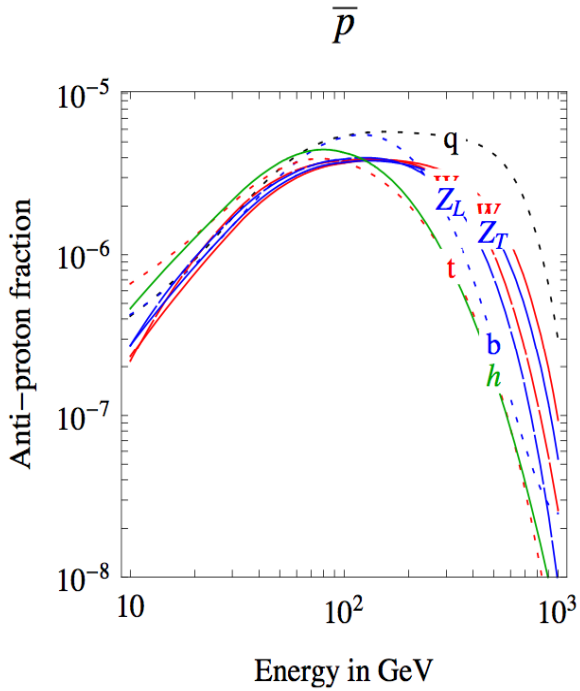
Positrons and antiprotons from WIMP's annihilation

M_{WIMP}= 1 TeV

The shape of spectrum is depends on

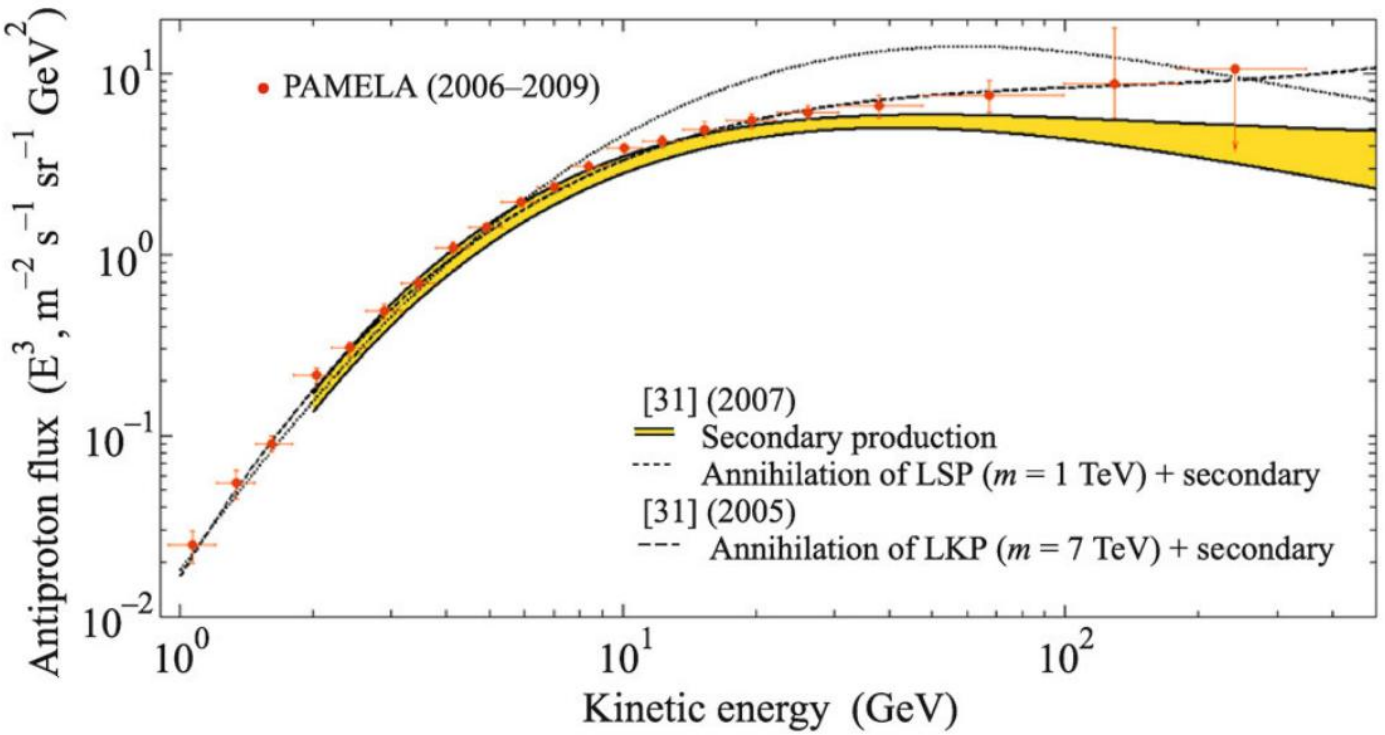
1) Mass of WIMP
2) Channels of annihilation



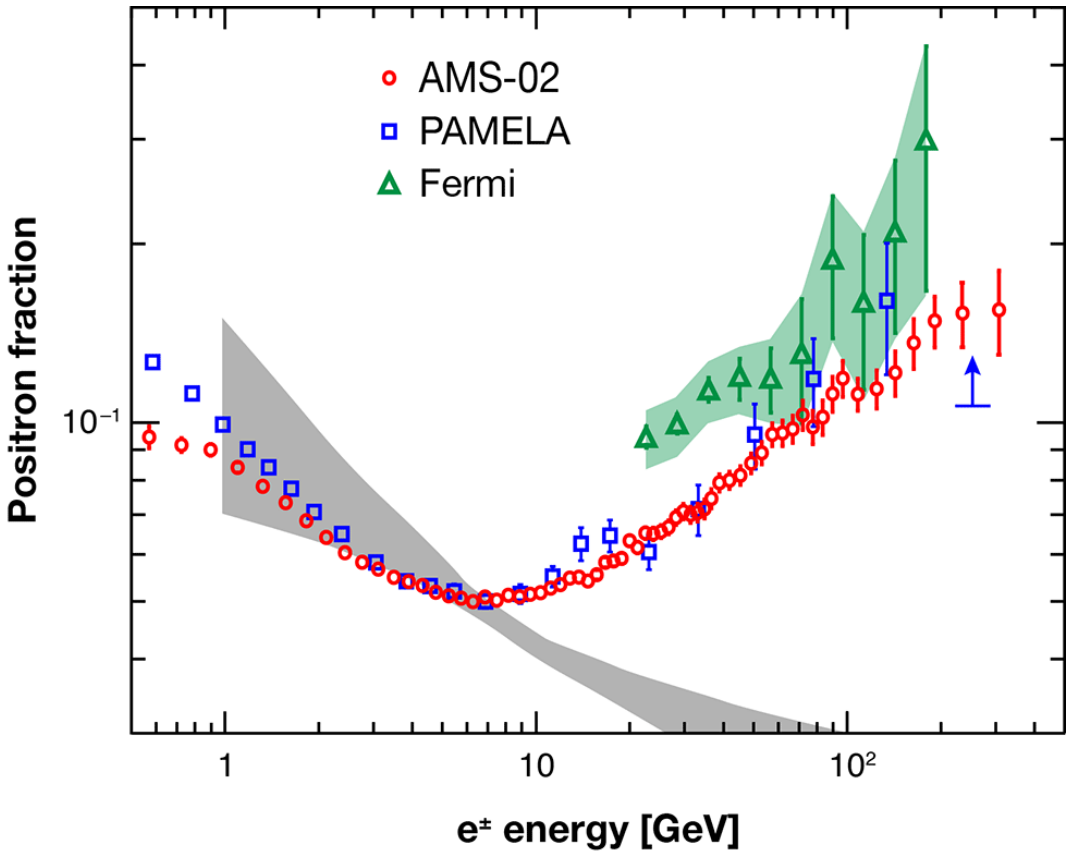


Antiproton to proton ratio

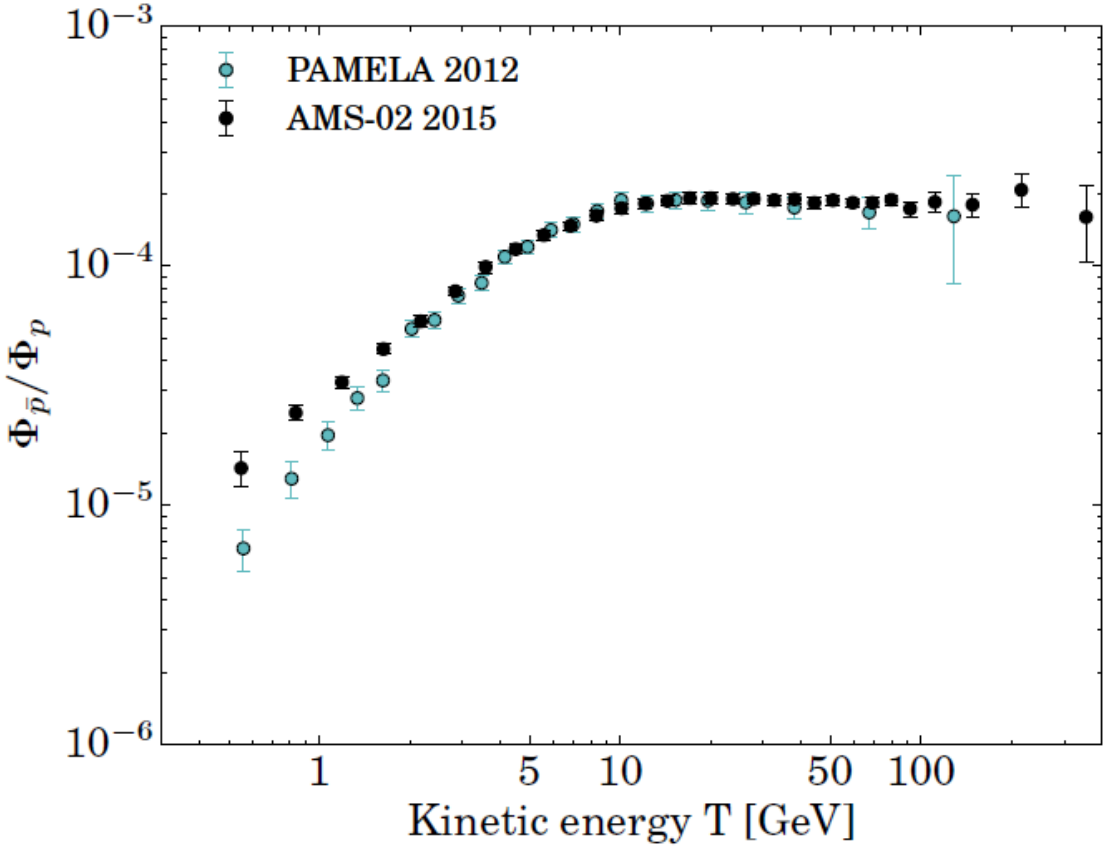
Adriani O., et al. JETP Lett. 96 (2013) 621-627



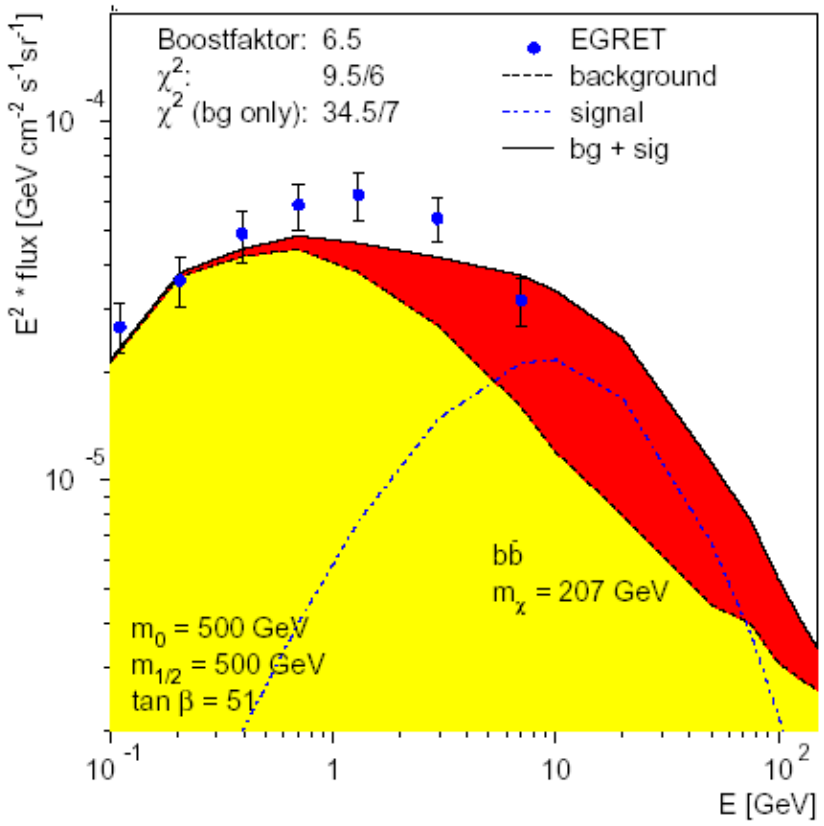
PAMELA vs AMS-02: electron to positron ration

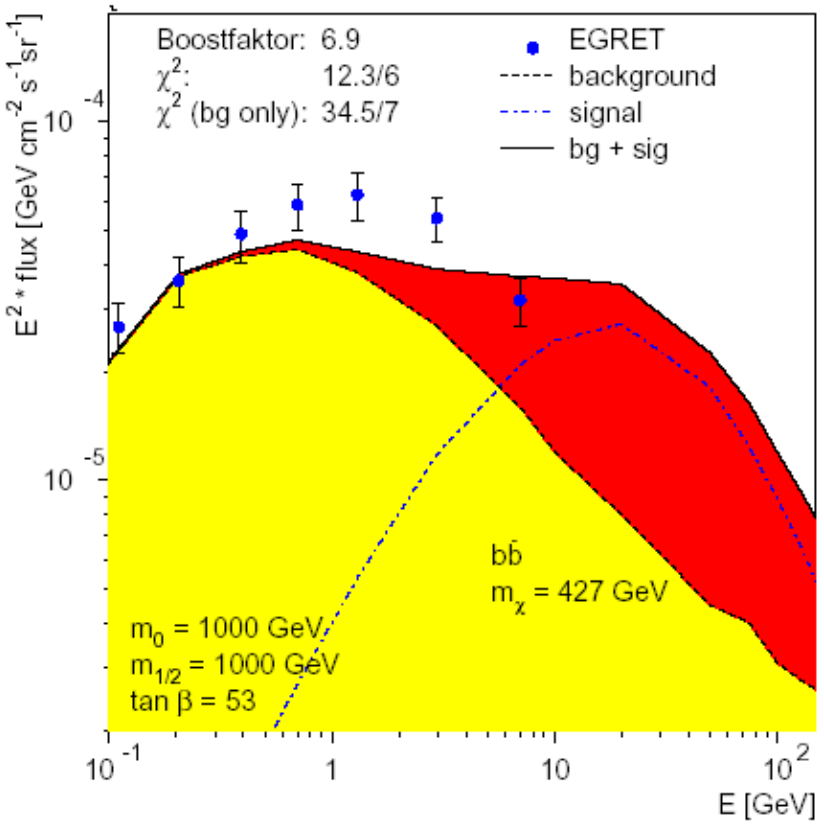


PAMELA vs AMS-02: antiproton to proton ration



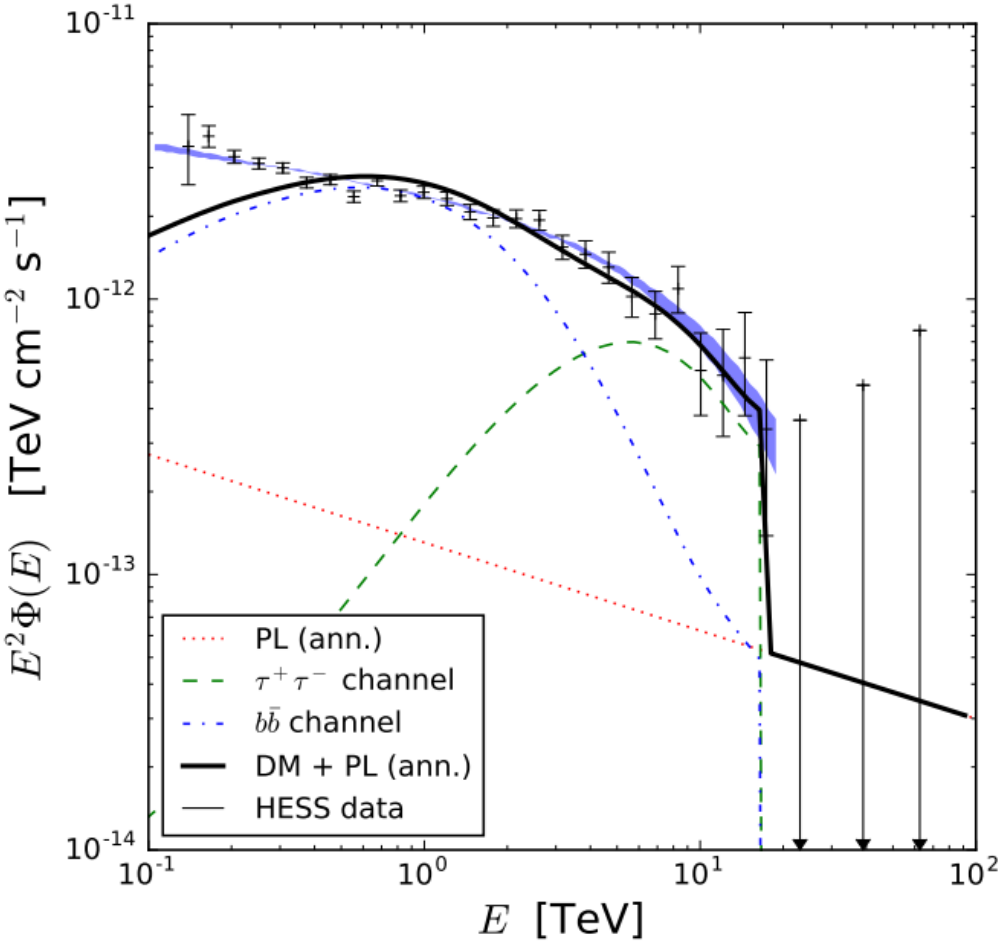
EGRET measurements of diffusion gamma emission





Yellow: flux gamma emission, calculated in standard model of cosmic rays.
Red: possible gamma-ray flux from neutralino annihilation.

H.E.S.S. measurements from Galactic center

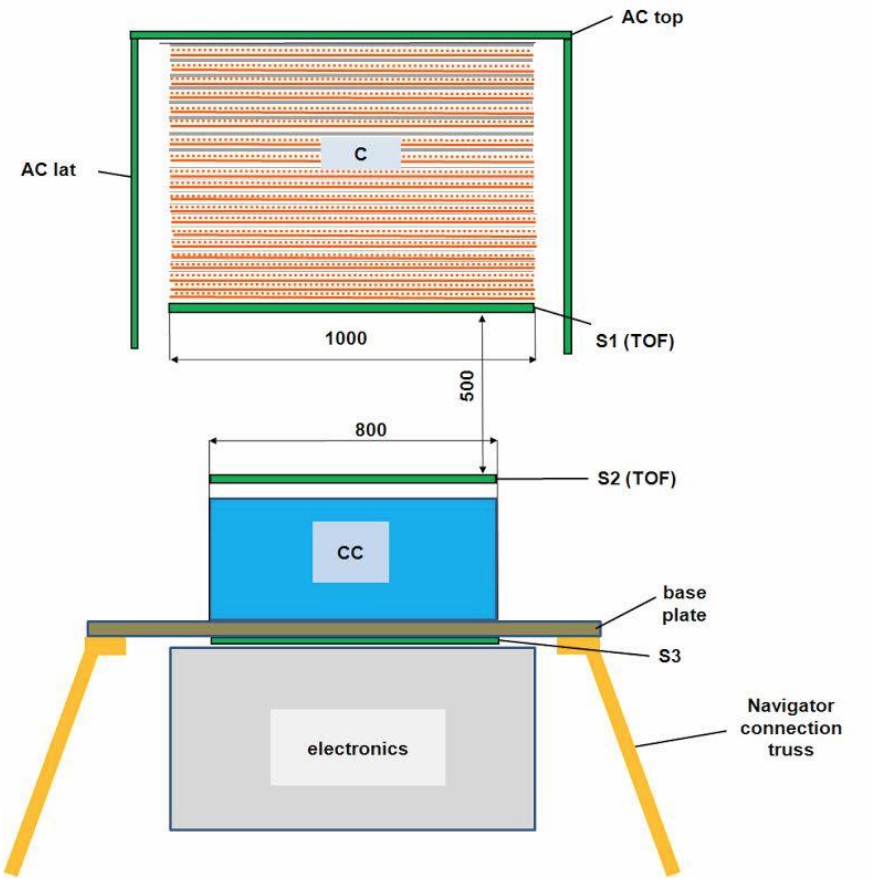


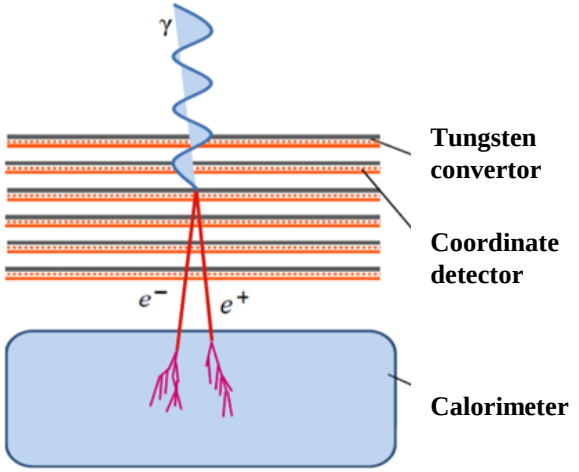
H.E.S.S. data of the Galactic Center, the annulus power-law (red, dotted line), the contribution of the τ+τ− channel (green, dashed line) of the gamma-ray spectrum of annihilation dark matter, the contribution of the b-anti-b channel (blue, dash-dotted line), and the sum (black, spline line)

Experiments which shows signatures on dark matter

Experiment	Comments
DAMA/LIBRA: yearly modulation	No confirmation from other experiments
CoGeNT: some DM scattering events	In contradiction with some other data
EGRET excess of gamma with E ~GeV	Not confirm by FERMI
INTEGRAL 511 keV line from the center of Galaxy	Not a spherical symmetry
PAMELA: anomalous positron to electron ratio Confirmed by FERMI and AMS-02	The effect may be caused by dark matter or pulsar - does not point unequivocally to the dark matter
PAMELA: antiproton to proton ratio Confirmed by AMS-02	The effect may be associated with the annihilation of dark matter or the interaction of cosmic rays
FERMI: an excess of gamma rays in the direction of the galactic center	There is no explanation; maybe it astrophysical effect
WMAP radio “haze”	Meets "FERMI bubbles" - perhaps caused by the flow emanating from the galactic center
IceCube: solar neutrino fluxes	In progress

GAMMA-400 scheme

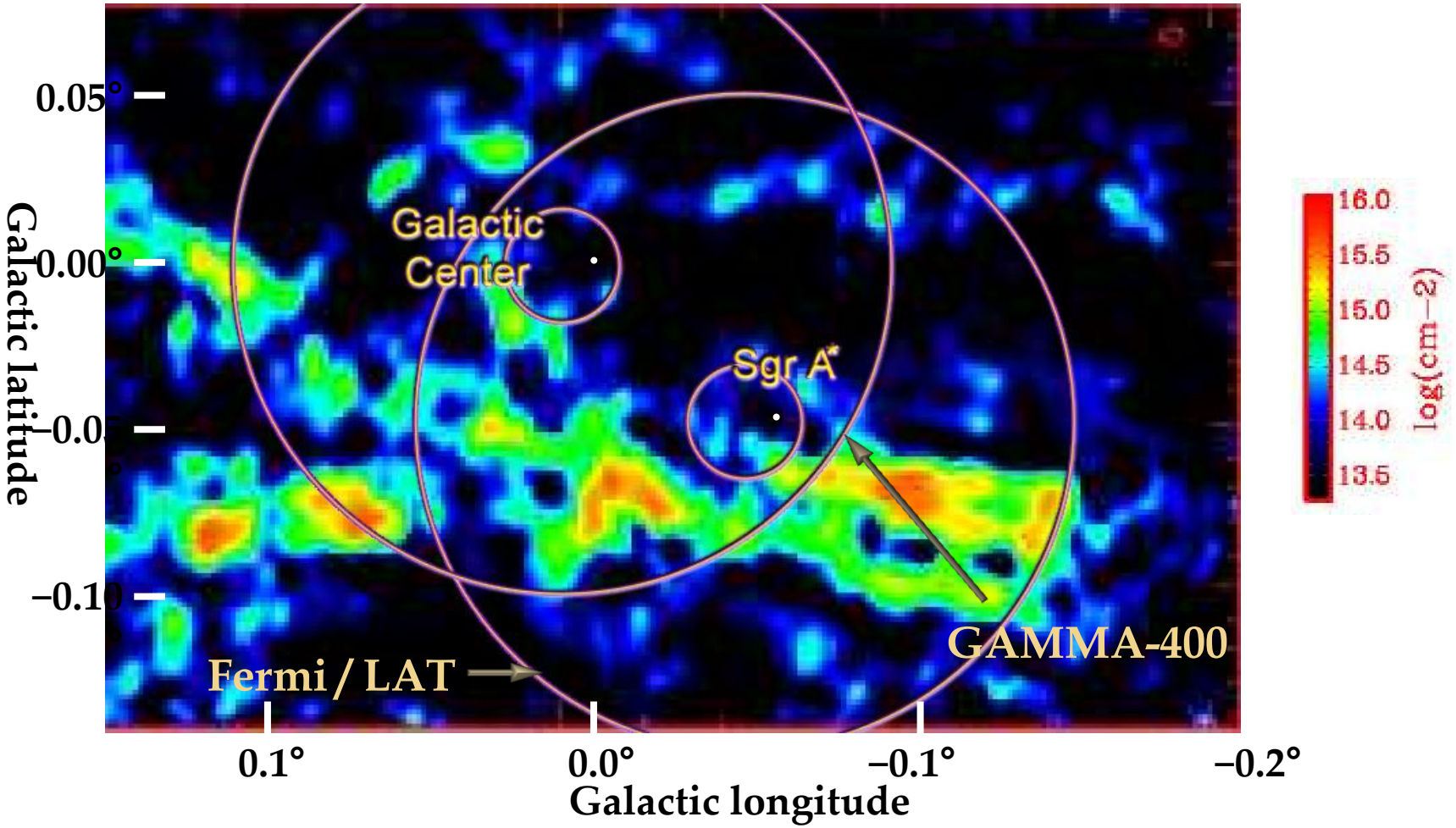




GAMMA-400 vs Other experiments

	SPACE-BASED GAMMA-RAY INSTRUMENTS				GROUND-BASED GAMMA-RAY INSTRUMENTS			
	Fermi-LAT	**DAMPE**	**CALET**	**GAMMA-400**	**H.E.S.S.**	**MAGIC**	**VERITAS**	**CTA**
Particles	γ, e	e, nuclei, γ	e, nuclei, γ	γ, e, nuclei	γ	γ	γ	γ
Operation period	2008-	2015	2015	~2023	2012-	2009-	2007-	~2020
Energy range, GeV	0.02-300	5-10000	10-10000	**0.02-10000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ > 100 GeV)	0.1°	0.1°	0.1°	**~0.01°**	0.07°	0.07° (E_γ = 300 GeV)	0.1°	0.1° (E_γ = 100 GeV) 0.03° (E_γ = 10 TeV)
Energy resolution (E_γ > 100 GeV)	10%	1.5%	2%	**~1%**	15%	20% (E_γ = 100 GeV) 15% (E_γ = 1 TeV)	15%	20% (E_γ = 100 GeV) 5% (E_γ = 10 TeV)

Galactic center observations: GAMMA-400 vs Fermi-LAT



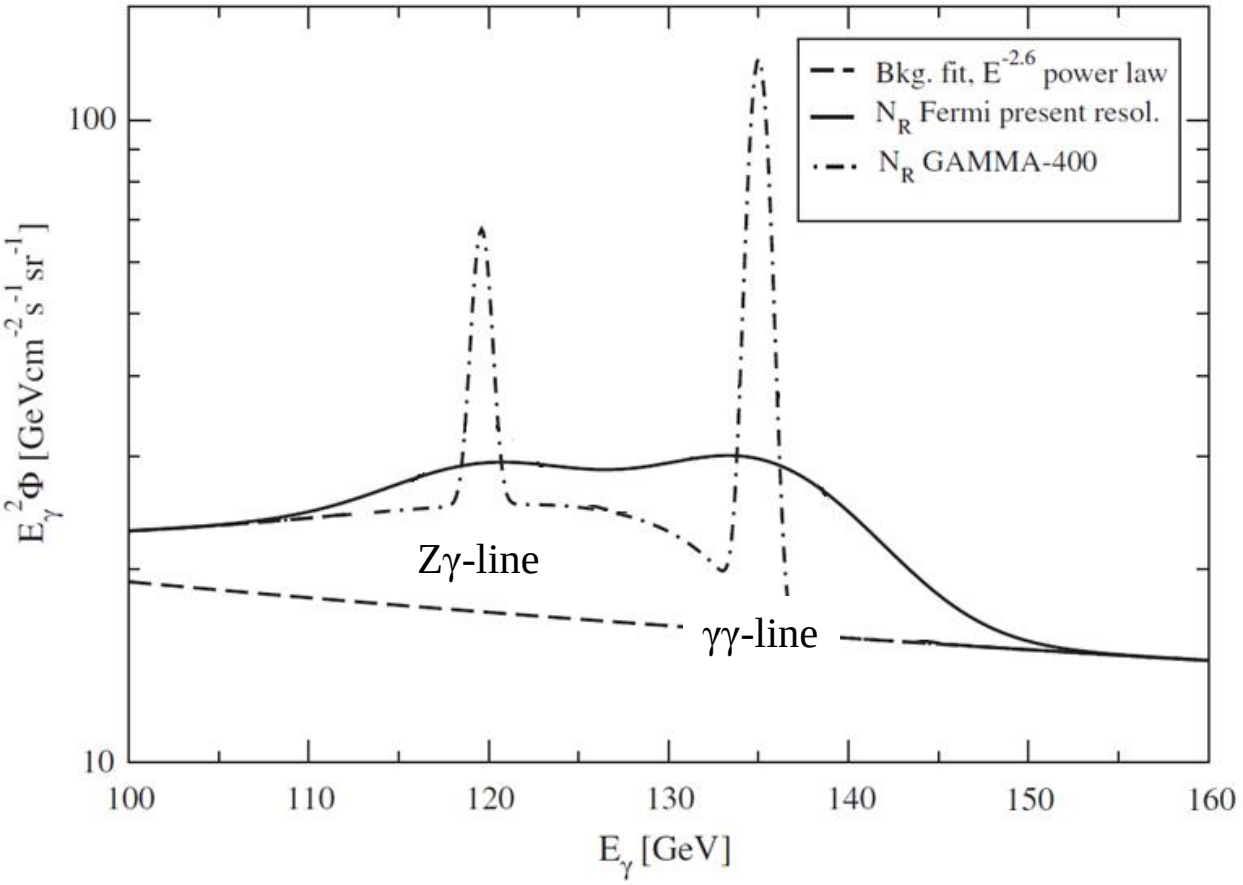
Background:

Integrated intensity map of the NH_3 (1,1) emission (1.2652 cm wavelength) from [arXiv:1402.4531].

Circles:

point spread functions for Fermi/LAT (outer: ~0.1°) and GAMMA-400 (inner: ~0.015°) at E_γ ~ 100 GeV

GAMMA-400 vs Felmi-LAT in searching for gamma-lines from DM



ΔE/E
10%
1%

FIG. 3. The γ-ray differential energy results (multiplied by E^2) for a 135 GeV right-handed neutrino dark matter candidate are shown, with the present Fermi-LAT energy resolution $\Delta E/E =$ 10% FWHM (solid line)

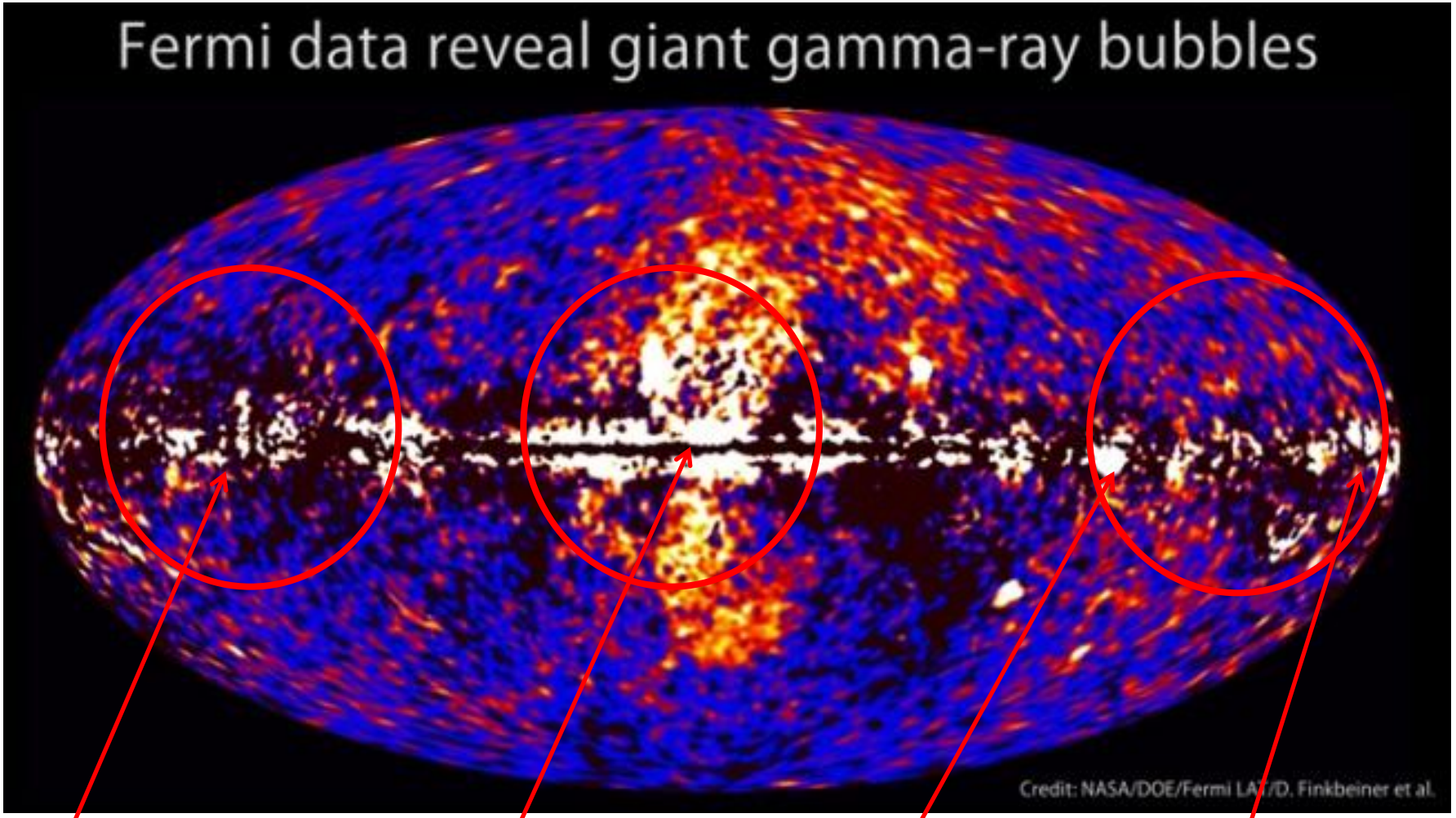
and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with resolution at the one percent level. The extrapolated power-law $\sim E^{-2.6}$ of the presently measured continuous γ-ray background is also shown.

PHYSICAL REVIEW D **86,** 103514 (2012)

130 GeV fingerprint of right-handed neutrino dark matter

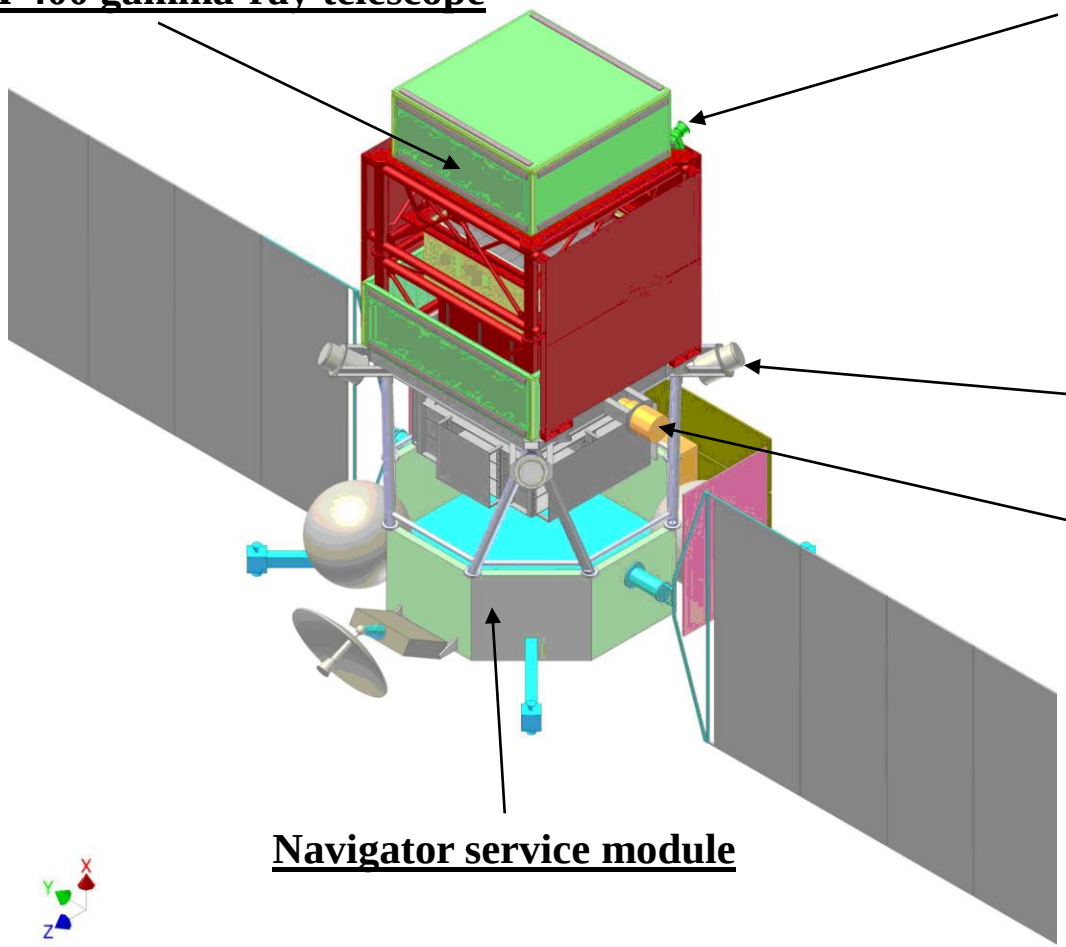
Lars Bergström*

GC, Crab, Cygnus, Vela, Geminga, and other regions will be observed with the GAMMA-400 aperture of ±45°



Cygnus **GC** **Vela** **Crab, Geminga**

GAMMA-400 scientific complex on Navigator service module



The GAMMA-400 spacecraft and Navigator service module are designed by Lavochkin Association

Congratulations!

Chief of department of NRNU MEPhI

Chief of laboratory in Lebedev Physical Institute