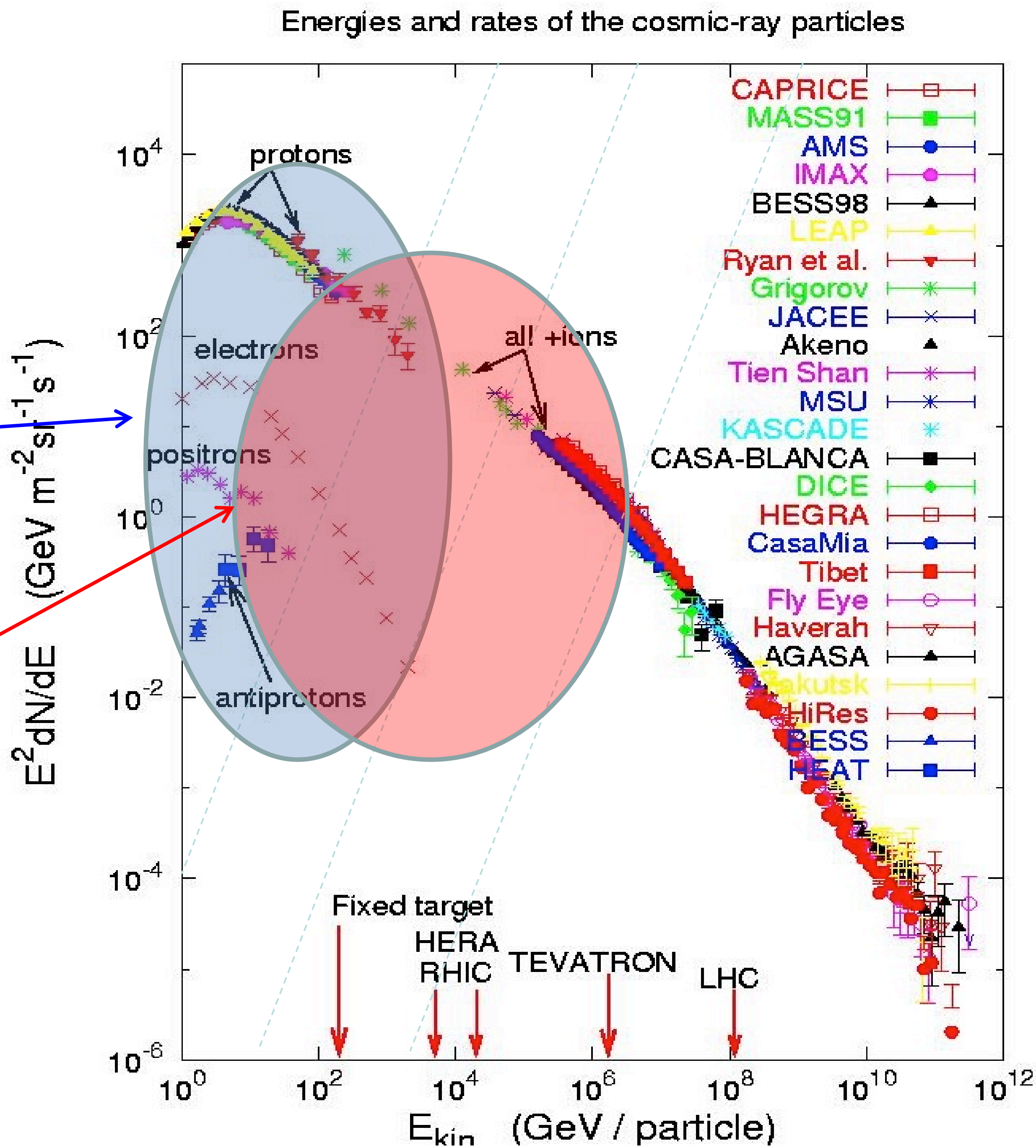
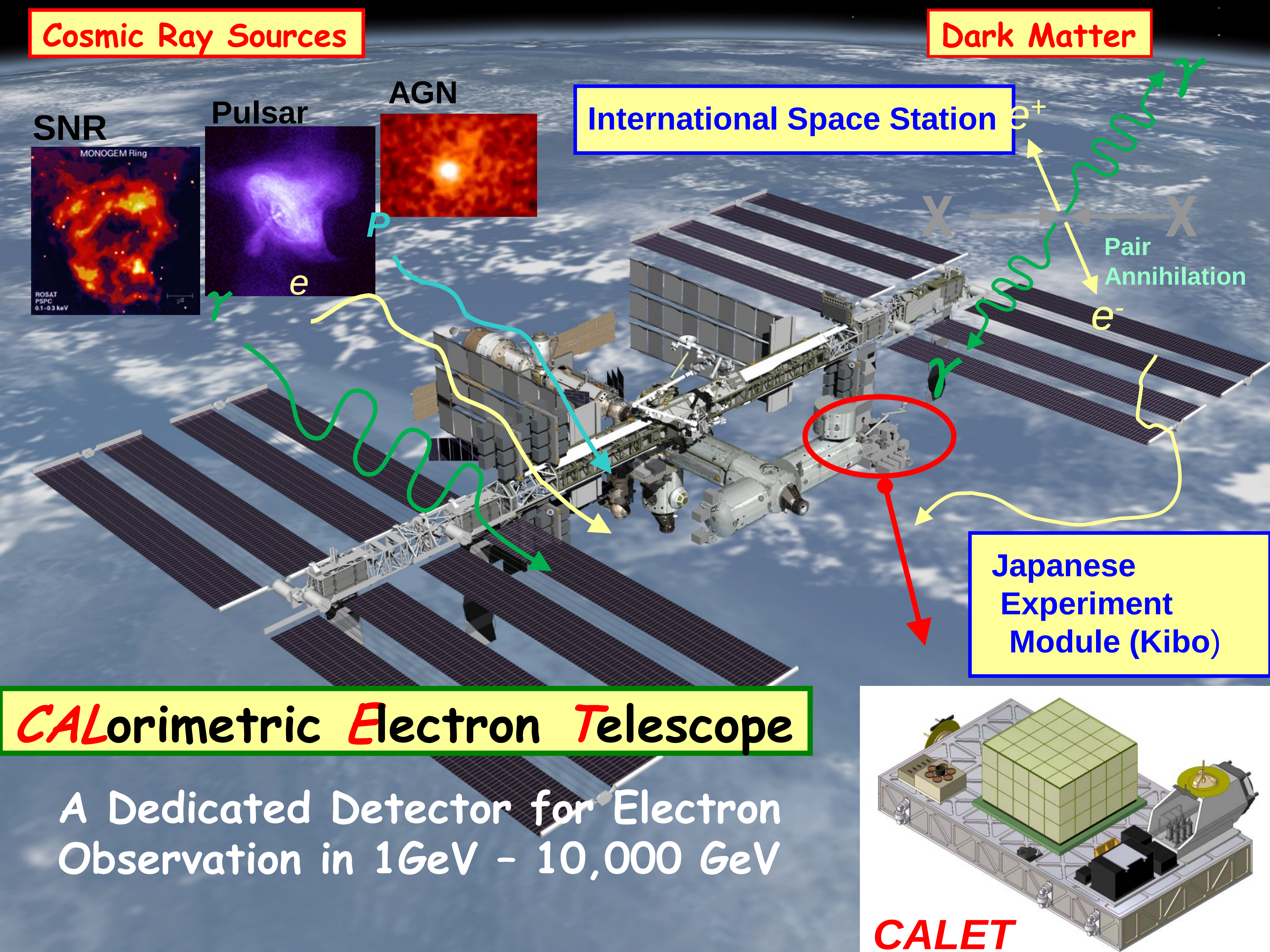
The beam !

(charged particles)

PAMELA
CREAM
ATIC
FERMI
AMS-02

CALET
DAMPE
ISS-CREAM
GAMMA-400
HERD





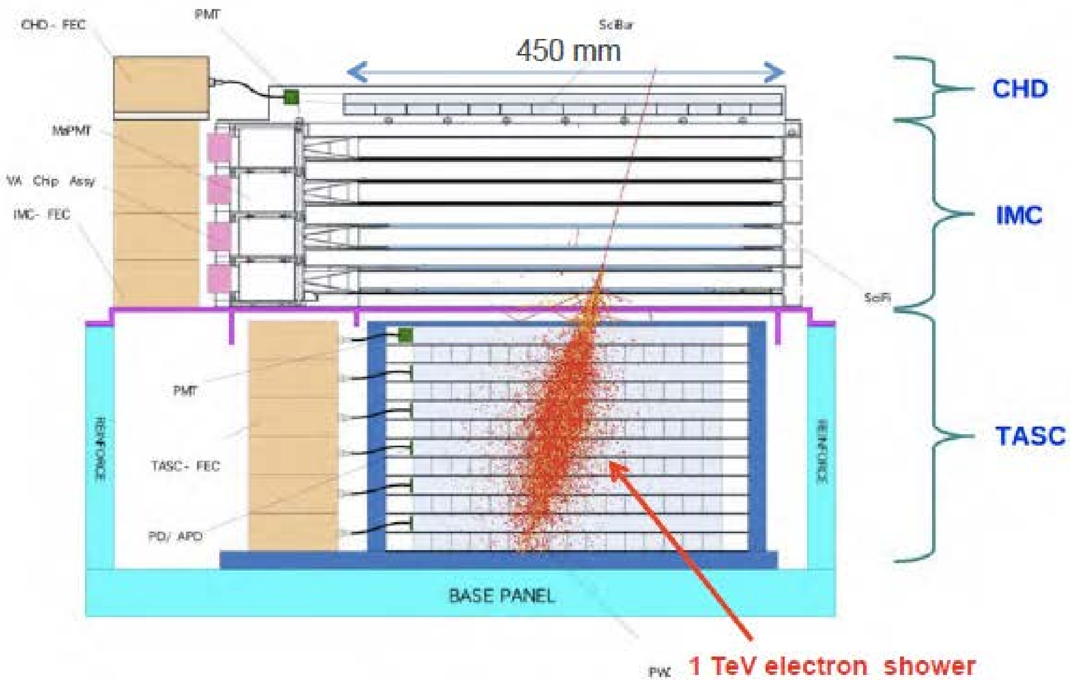
Cosmic Ray Sources
Dark Matter
SNR
MONOGEM Ring
ROSAT PSPC 0.1-0.3 keV
Pulsar
AGN
International Space Station
P
e
γ
e+
e-
γ
X
X
Pair Annihilation
γ
Japanese Experiment Module (Kibo)
CALorimetric Electron Telescope
A Dedicated Detector for Electron Observation in 1GeV - 10,000 GeV
CALET

CALET Collaboration Team

O. Adriani[19], Y. Akaike[3], K. Asano[17], M.G. Bagliesi[22], G. Bigongiari[22], W.R. Binns[24], M. Bongi[19], J.H. Buckley[24], G. Castellini[19], M.L. Cherry[9], G. Collazuol[26], K. Ebisawa[5], V. Di Felice[21], H. Fuke[5], A. Gherardi[19], T.G. Guzik[9], T. Hams[10], N. Hasebe[23], M. Hareyama[5], K. Hibino[7], M. Ichimura[2], K. Ioka[8], M.H. Israel[24], A. Javaid[9], E. Kamioka[15], K. Kasahara[23], Y. Katayose[4,25], J. Kataoka[23], R. Kataoka[17], N. Kawanaka[8], M.Y. Kim[22], H. Kitamura[11], Y. Komori[6], T. Kotani[23], H.S. Krawczynski[24], J.F. Krizmanic[10], A. Kubota[15], S. Kuramata[2], T. Lomtadze[20], P. Maestro[22], L. Marcelli[21], P.S. Marrocchesi[22], V. Millucci[22], J.W. Mitchell[10], S. Miyake[28], K. Mizutani[14], A.A. Moiseev[10], K. Mori[5,23], M. Mori[13], N. Mori[19], K. Munakata[16], H. Murakami[23], Y.E. Nakagawa[23], S. Nakahira[5], J. Nishimura[5], S. Okuno[7], J.F. Ormes[18], S. Ozawa[23], P. Papini[19], B.F. Rauch[24], S. Ricciarini[19], Y. Saito[5], T. Sakamoto[1], M. Sasaki[10], M. Shibata[25], Y. Shimizu[4], A. Shiomi[12], R. Sparvoli[21], P. Spillantini[19], M. Takayanagi[5], M. Takita[3], T. Tamura[4,7], N. Tateyama[7], T. Terasawa[3], H. Tomida[5], S. Torii[4,23], Y. Tunesada[17], Y. Uchihori[11], S. Ueno[5], E. Vannuccini[19], J.P. Wefel[9], K. Yamaoka[4,23], S. Yanagita[27], A. Yoshida[1], K. Yoshida[15], and T. Yuda[3]

1) Aoyama Gakuin University, Japan
2) Hirosaki University, Japan
3) ICRR, University of Tokyo, Japan
4) JAXA/SEUC, Japan
5) JAXA/ISAS, Japan
6) Kanagawa University of Human Services, Japan
7) Kanagawa University, Japan
8) KEK, Japan
9) Louisiana State University, USA
10) NASA/GSFC, USA
11) National Inst. of Radiological Sciences, Japan
12) Nihon University, Japan
13) Ritsumeikan University, Japan
14) Saitama University, Japan
15) Shibaura Institute of Technology, Japan
16) Shinshu University, Japan
17) Tokyo Technology Institute, Japan
18) University of Denver, USA
19) University of Florence, IFAC (CNR) and INFN, Italy
20) University of Pisa and INFN, Italy
21) University of Rome Tor Vergata and INFN, Italy
22) University of Siena and INFN, Italy
23) Waseda University, Japan
24) Washington University-St. Louis, USA
25) Yokohama National University, Japan
26) University of Padova and INFN, Italy
27) Ibaraki University, Japan
28)Tokiwa University, Japan

Main Telescope: CAL (Calorimeter)

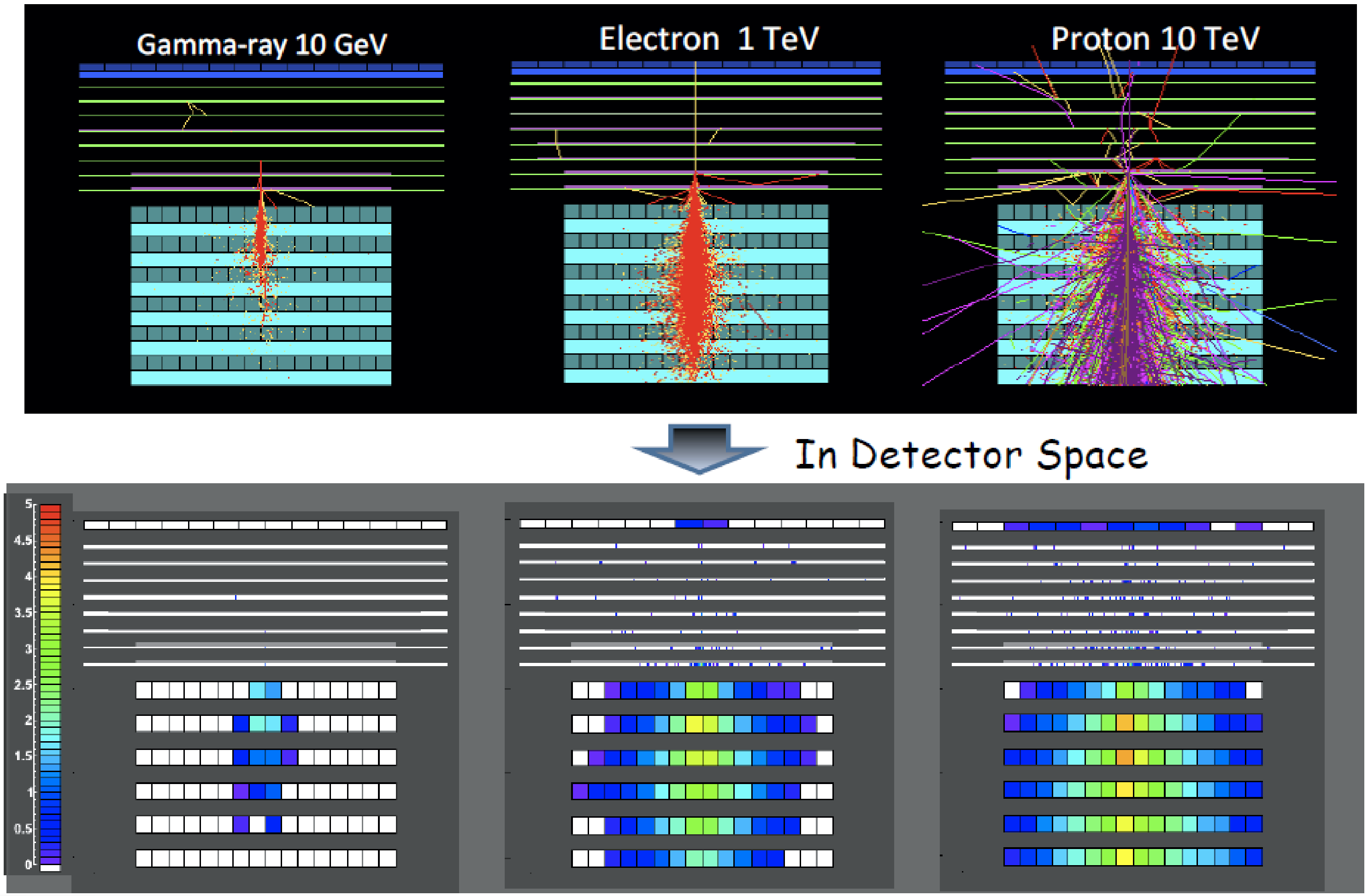


Expected Performance
(from Simulations and/or Beam Tests)

- SΩ :
  1200 cm^{2}sr for electrons, light nuclei
  1000 cm^{2}sr for gamma-rays
  4000 cm^{2}sr for ultra-heavy nuclei*
  * for E > 600 MeV/nucleon
- ΔE/E :
  ~2% (>10 GeV) for e's, γ's
  ~30 % for protons
- e/p separation: 10^{-5}
- Charge resolution: 0.15-0.3 e
- Angular resolution: ~0.1° e's, γ's

	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-46)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	Plastic Scintillator : 14 × 1 layer (x,y) Unit Size: 32mm x 10mm x 450mm	SciFi : 448 x 8 layers (x,y) = 7168 Unit size: 1mm^2 x 448 mm **Total thickness of Tungsten: 3 X_0**	PWO log: 16 x 6 layers (x,y)= 192 Unit size: 19mm x 20mm x 326mm **Total Thickness of PWO: 27 X_0**
Readout	PMT+CSA	64 -anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)

CALET/CAL Shower Imaging Capability (Simulation)



- Proton rejection power of 10^5 can be achieved with IMC and TASC shower imaging capability.
- Charge of incident particle is determined to σ_Z=0.15-0.3 with the CHD.

S. Torii, TeVPA 2013, Irvine, USA

CALET is now on the ISS !

① **August 19th**: After a successful launch of the Japanese H2-B rocket by the Japan Aerospace Exploration Agency (JAXA) at 20:50:49 (local time), CALET started its journey from Tanegashima Space Center to the ISS.

② **August 24th:** The HTV-5 Transfer Vehicle（HTV-5) is grabbed by the ISS robotic arm.

③ **August 24th:** The HTV-5 docks to the ISS at 19:28 (JSTT).

④ **August 25th:** CALET is emplaced on port #9 of the JEM-EF and data communication with the payload is established.

CALET Capability for Electron (+ Positron) Observation : Nearby Sources

Energy (GeV)	Primary e⁻	e⁻ from Vela
500-600	1168	154
600-800	1235	239
800-1000	501	168
1000-1500	546	270
1500-2000	146	134
2000-3000	99	134
3000-4000	23	51
4000-5000	7	23
5000-7000	5	22
7000-9000	1	7
>9000	0	3
> 1000	827	644

Conditions applied:

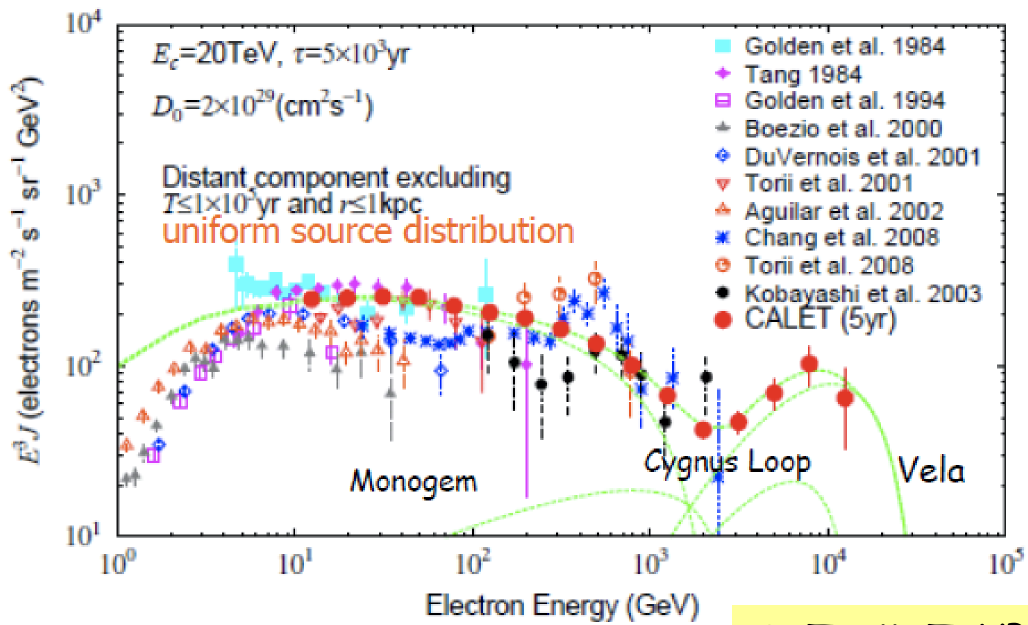
Electron efficiency = 70%
Proton rejection factor = 10^5
Geometrical factor = 0.12 $m^2 sr$
Exposure time = 5 years

Primary electron spectrum from Fermi data with Hess cutoff:

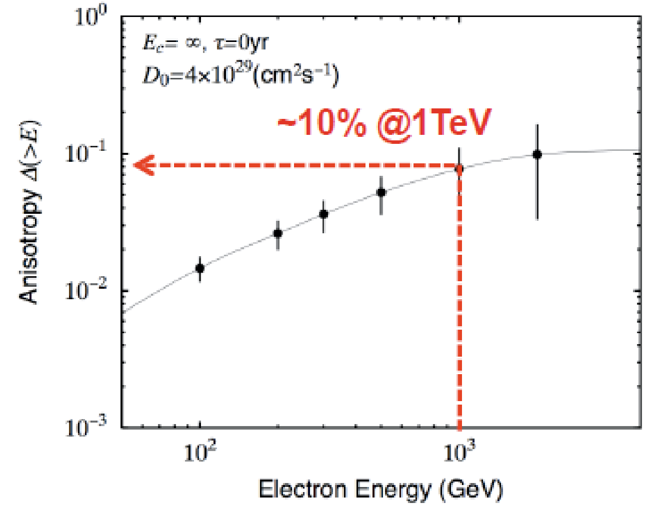
$J(E) = 185 * (E/1\ GeV)^{-3.045}\ e^{-E/3.4\ TeV}\ GeV^{-1}\ m^{-2}\ s^{-1}\ sr^{-2}$

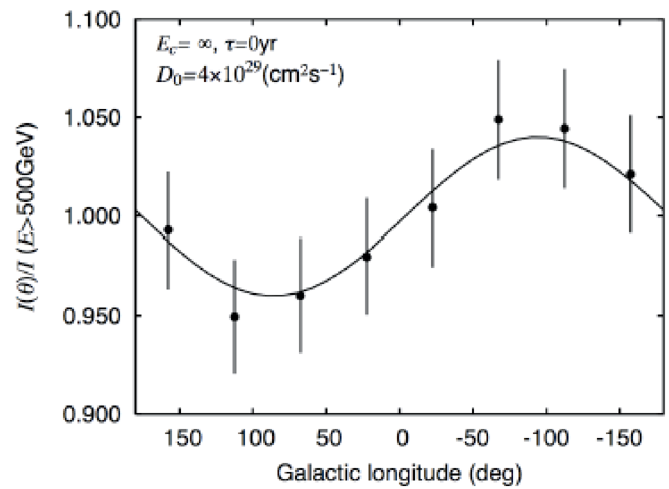
Vela spectrum from Astro-ph/0308470v1, Kobayashi et al., Figure 4 Top

Expected Flux



Expected Anisotropy from Vela SNR





S. Torii, TeVPA 2013, Irvine, USA

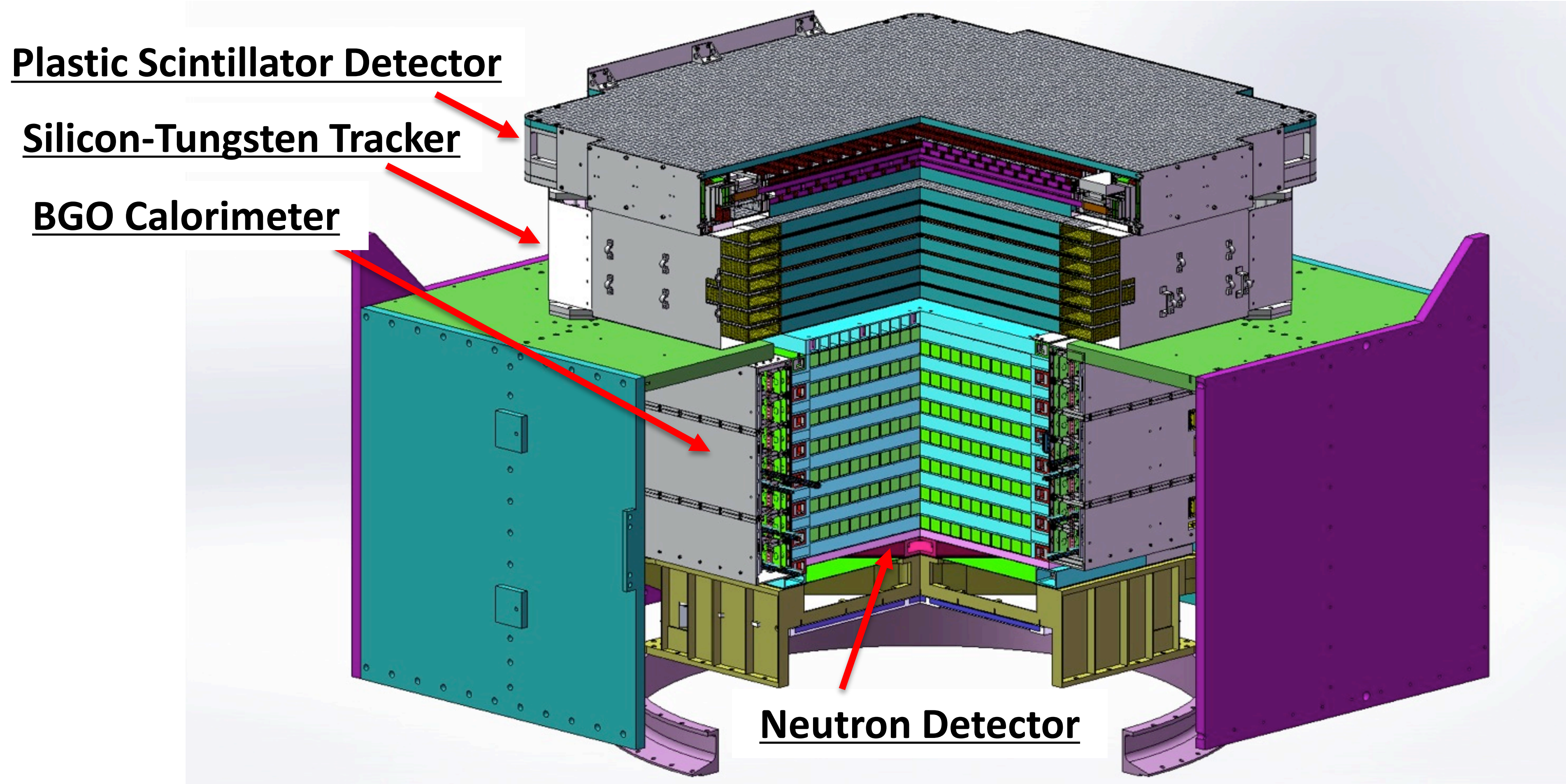
The DAMPE Collaboration

- China
  - Purple Mountain Observatory, CAS, Nanjing
    - Chief Scientist: Prof. Jin Chang
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou

- Switzerland
  - University of Geneva

- Italy
  - INFN and University of Perugia
  - INFN and University of Bari
  - INFN and University of Lecce

The DAMPE Detector

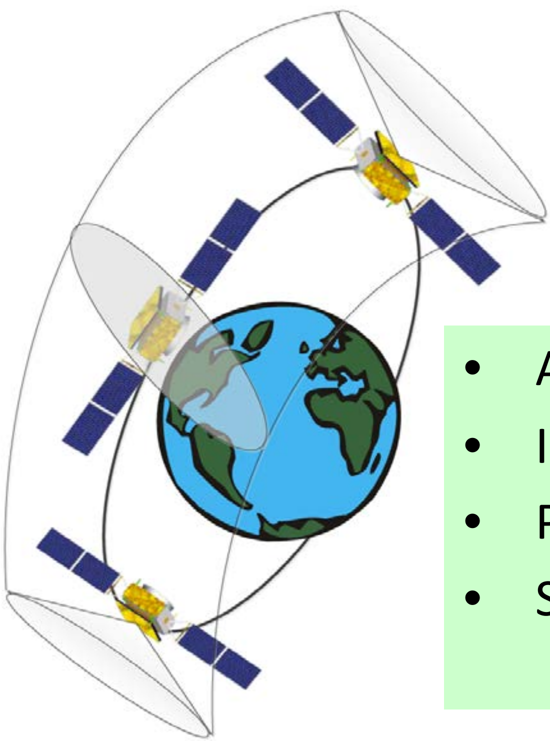


W converter + thick calorimeter (total 33 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

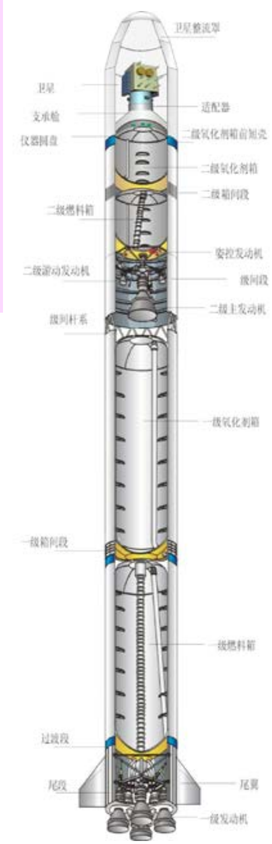
Dark Matter Particle Explorer Satellite

- One of the 5 satellite missions of the Chinese Strategic Priority Research Program in Space Science of CAS
  - Approved for construction (phase C/D) in Dec. 2011
  - Launched on 17 December 2015 from Jiuquan Satellite Launch Center

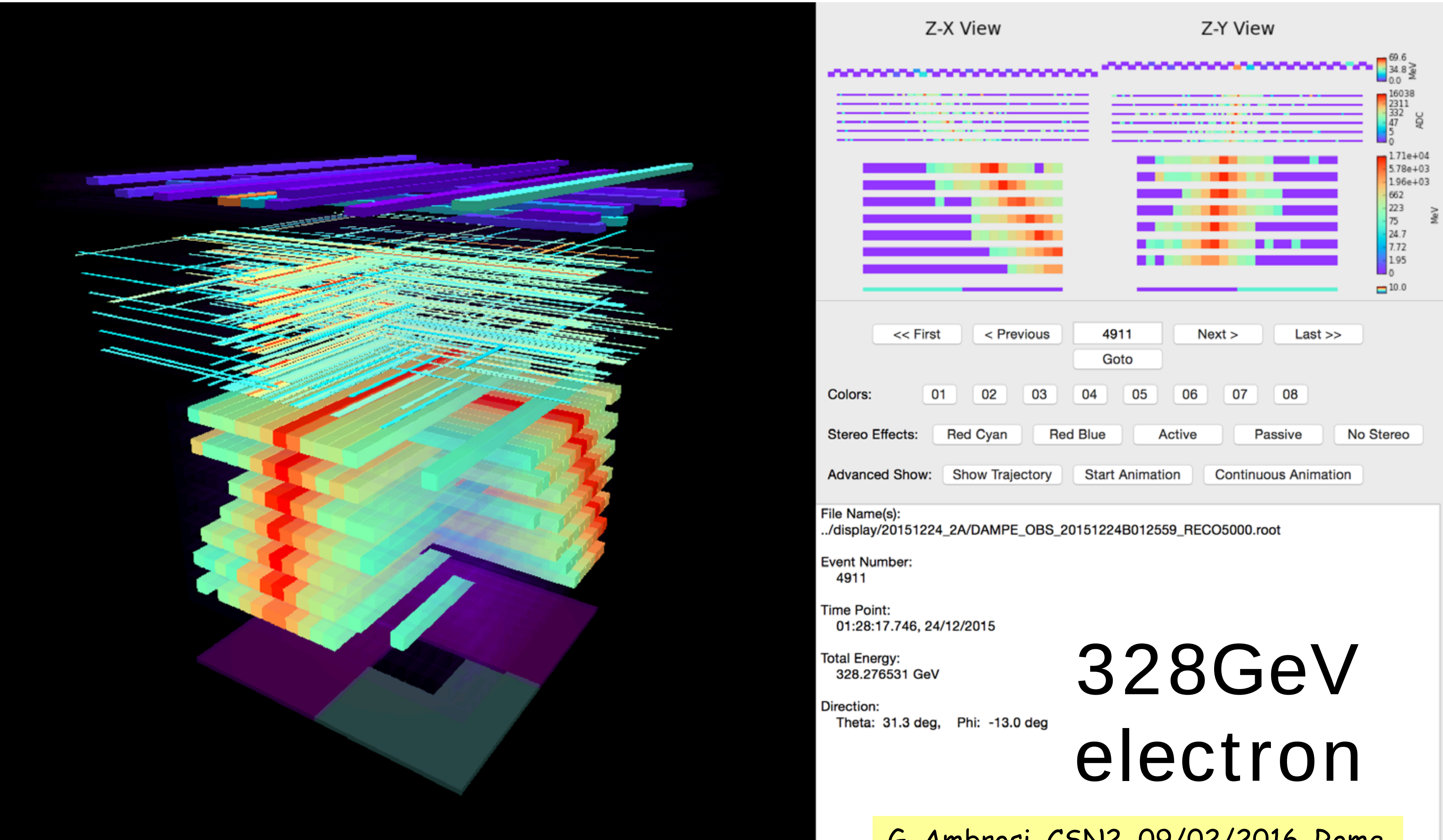
- Satellite ≈ 1900 kg, payload ≈1300kg
- Power consumption ≈640W
- Lifetime > 3 years
- Launched by CZ-2D rockets



- Altitude 500 km
- Inclination 97.4°
- Period 95 minutes
- Sun-synchronous orbit

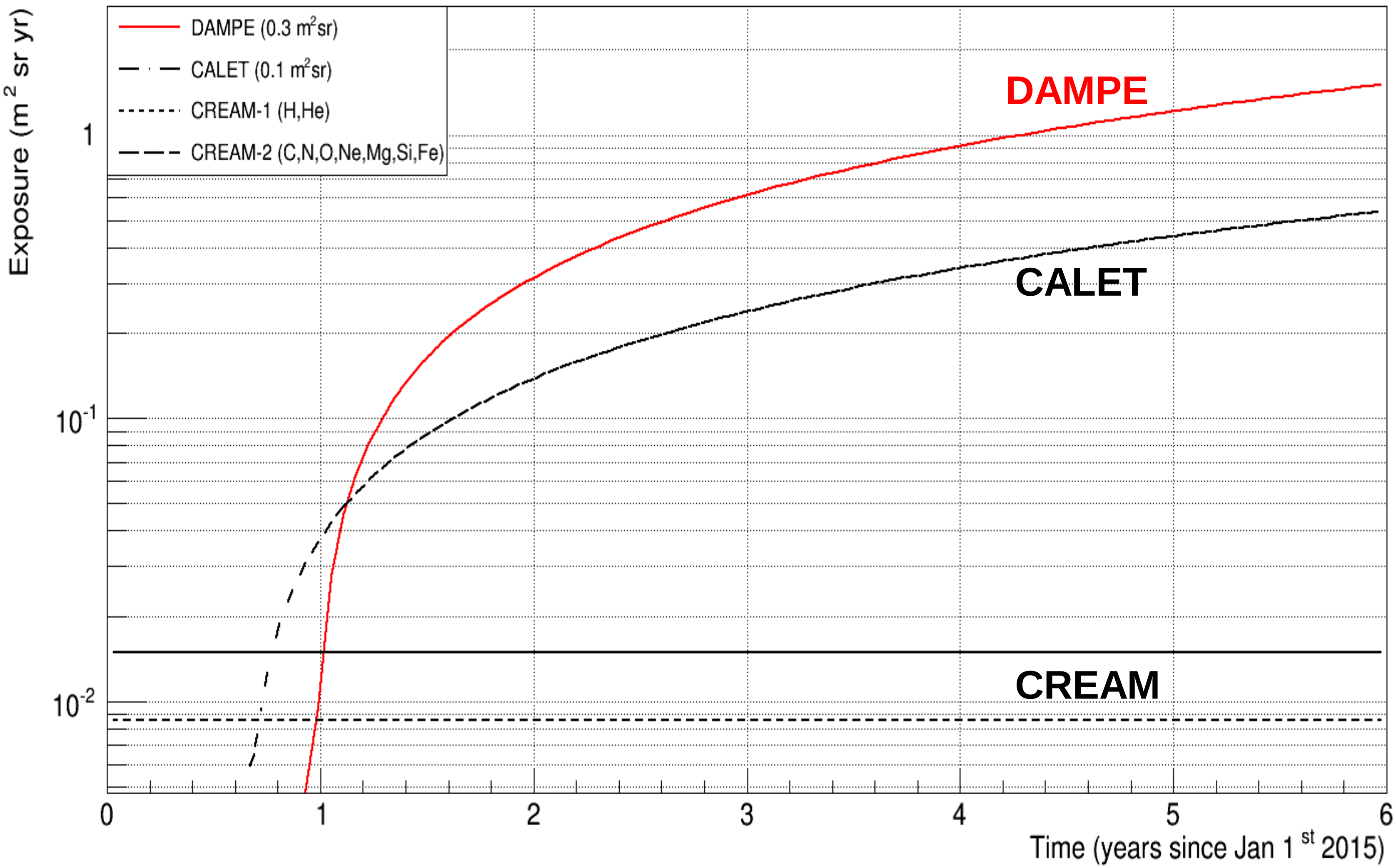


Dec. 24 2015 First Light of DAMPE



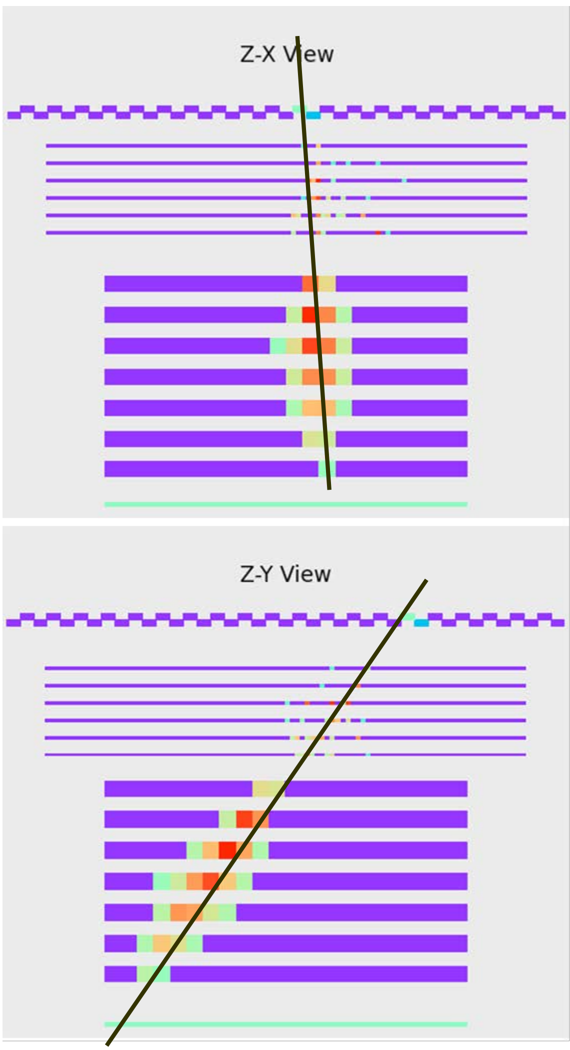
G. Ambrosi, CSN2, 09/02/2016, Rome

Exposure

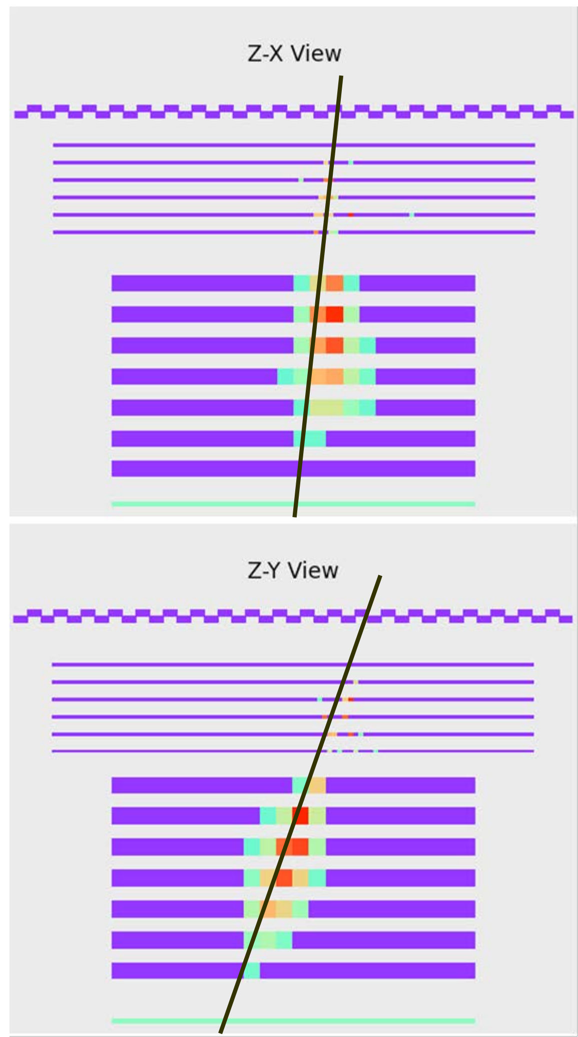


DAMPE (0.3 m²sr)
CALET (0.1 m²sr)
CREAM-1 (H,He)
CREAM-2 (C,N,O,Ne,Mg,Si,Fe)
DAMPE
CALET
CREAM
Exposure (m 2 sr yr)
1
10-1
10-2
0
1
2
3
4
5
6
Time (years since Jan 1 st 2015)

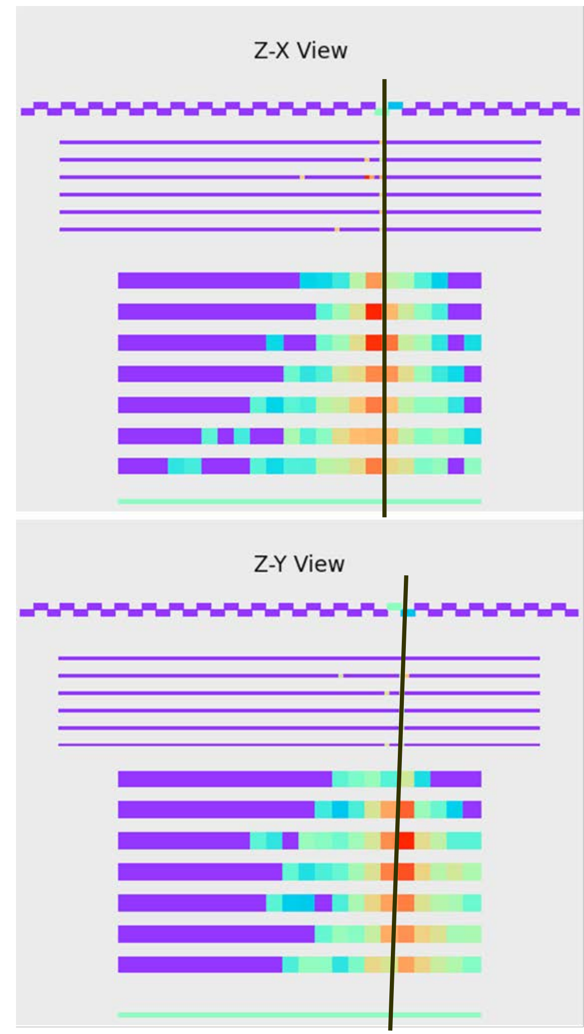
electron



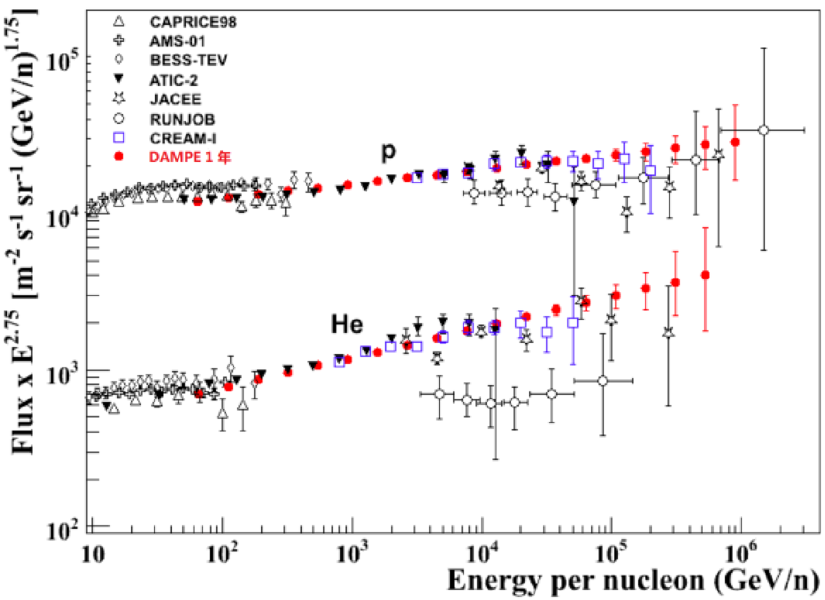
gamma-ray

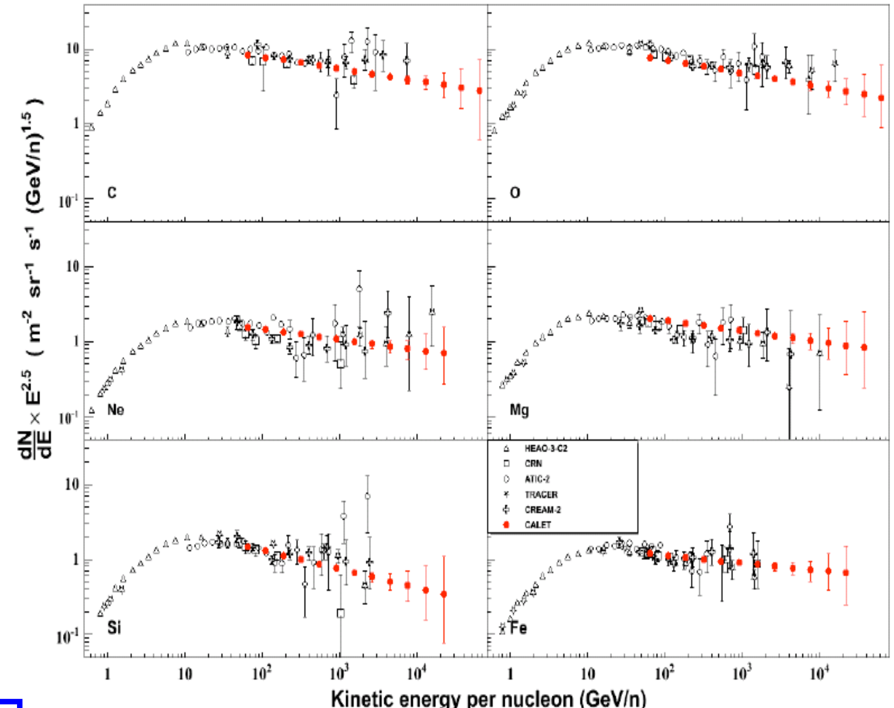


Proton

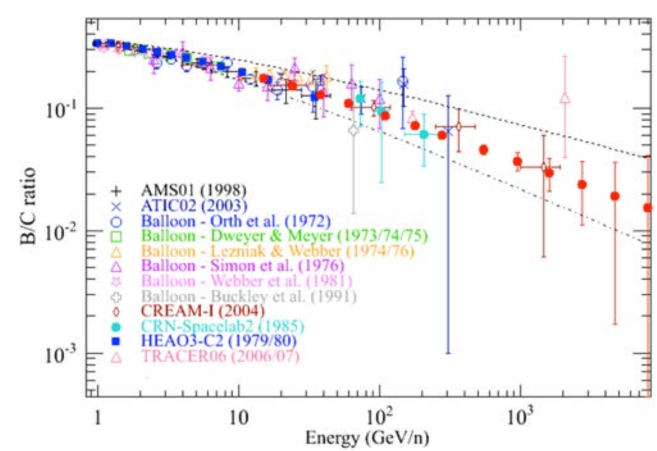


Nuclei: CR Spectra & Composition toward the knee(s)





Proton spectrum to	≈ 900 TeV
He spectrum to	≈ 400 TeV/n
Spectra of C, O, Ne, Mg, Si to	≈ 20 TeV/n
B/C ratio to	≈ 4-6 TeV/n
Fe spectrum to	≈ 10 TeV/n



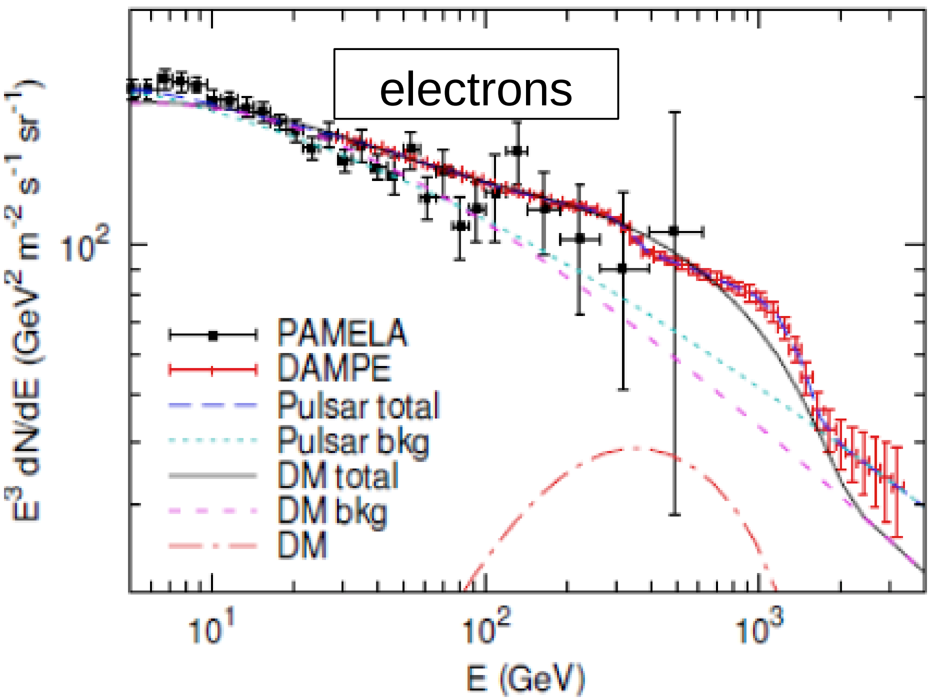
(Depending on the assumed single primary spectra)

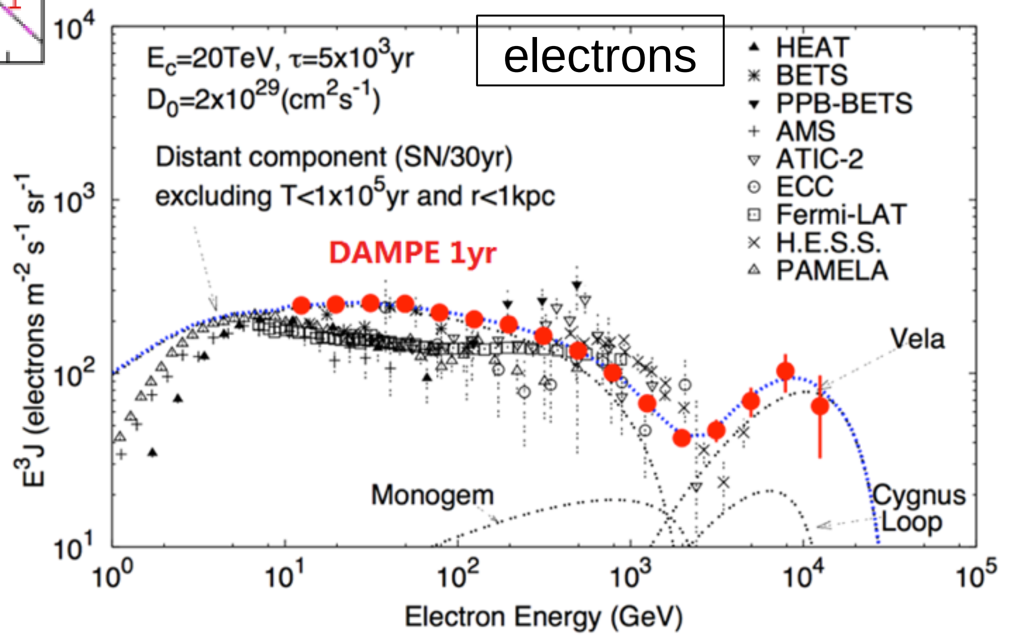
Comparison of Detector Performance for Electrons

DAMPE is optimized for the electron observation in the tran-TeV region, and the performance is best also in 10-1000 GeV.

Detector	Energy Range (GeV)	Energy Resolution	e/p Selection Power	Key Instrument (Thickness of CAL)	SΩT (m^2srday)
ATIC1+2 (+ ATIC4)	10 - a few 1000	<3% (>100 GeV)	~10,000	Thick Seg. CAL (BGO: 22 X_0) + C Targets	3.08
PAMELA	1-700	5% @200 GeV	10^5	Magnet+IMC (W:16 X_0)	~1.4 (2 years)
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)	～2-4% @100 GeV	10^4 (x 10^2 by TRD)	Magnet+IMC +TRD+RICH (Lead: 17X_0)	~50(?) (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)

Electrons: Dark Matter vs Nearby Sources

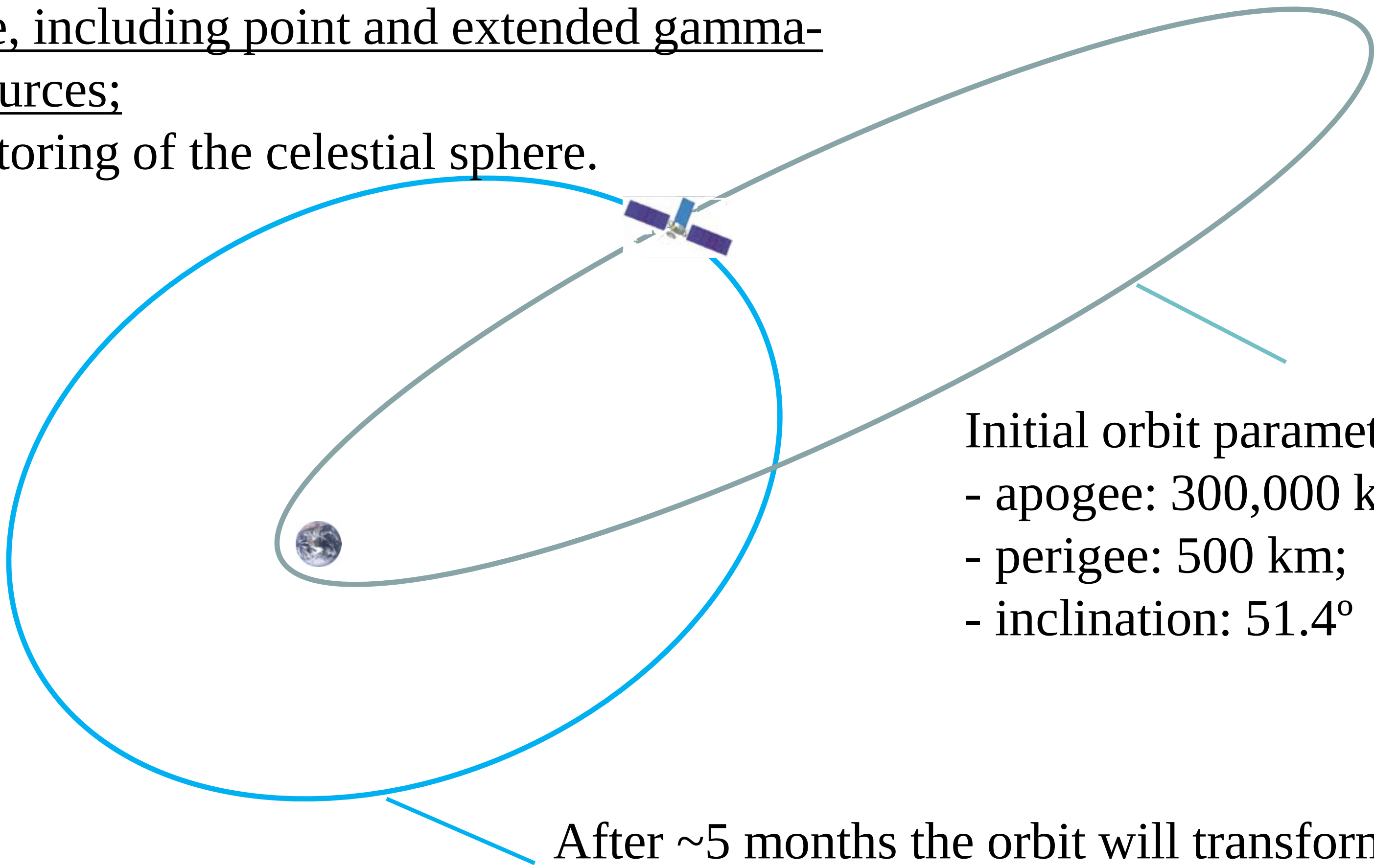




OBSERVATION MODES AND THE GAMMA-400 ORBIT EVOLUTION

Observation modes:

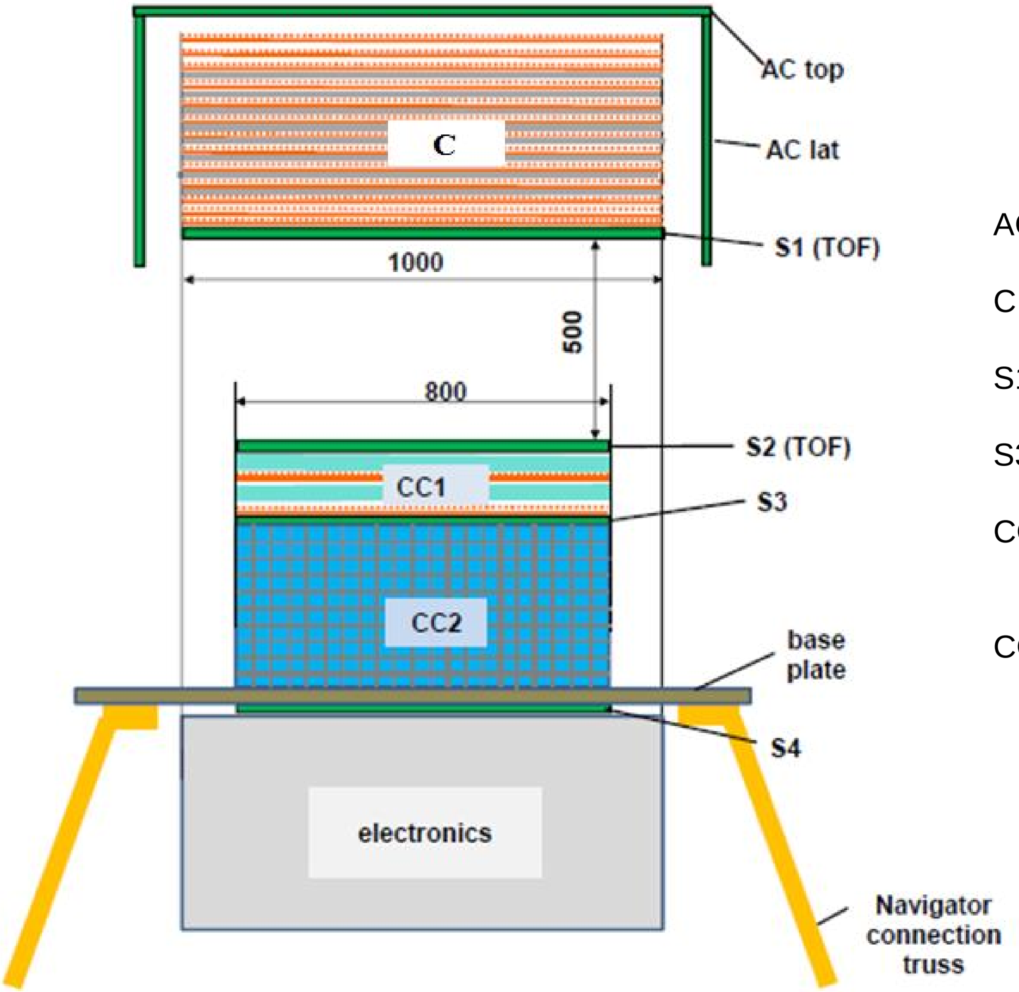
- continuous long-duration (~100 days) observation of some regions of celestial sphere, including point and extended gamma-ray sources;
-monitoring of the celestial sphere.



Initial orbit parameters:
- apogee: 300,000 km:
- perigee: 500 km;
- inclination: 51.4º

After ~5 months the orbit will transform to nearly circular with a radius of ~150,000 km.

GAMMA-400



AC – anticoincidence detectors

C – Conveter-Tracker

S1, S2 – ToF detectors

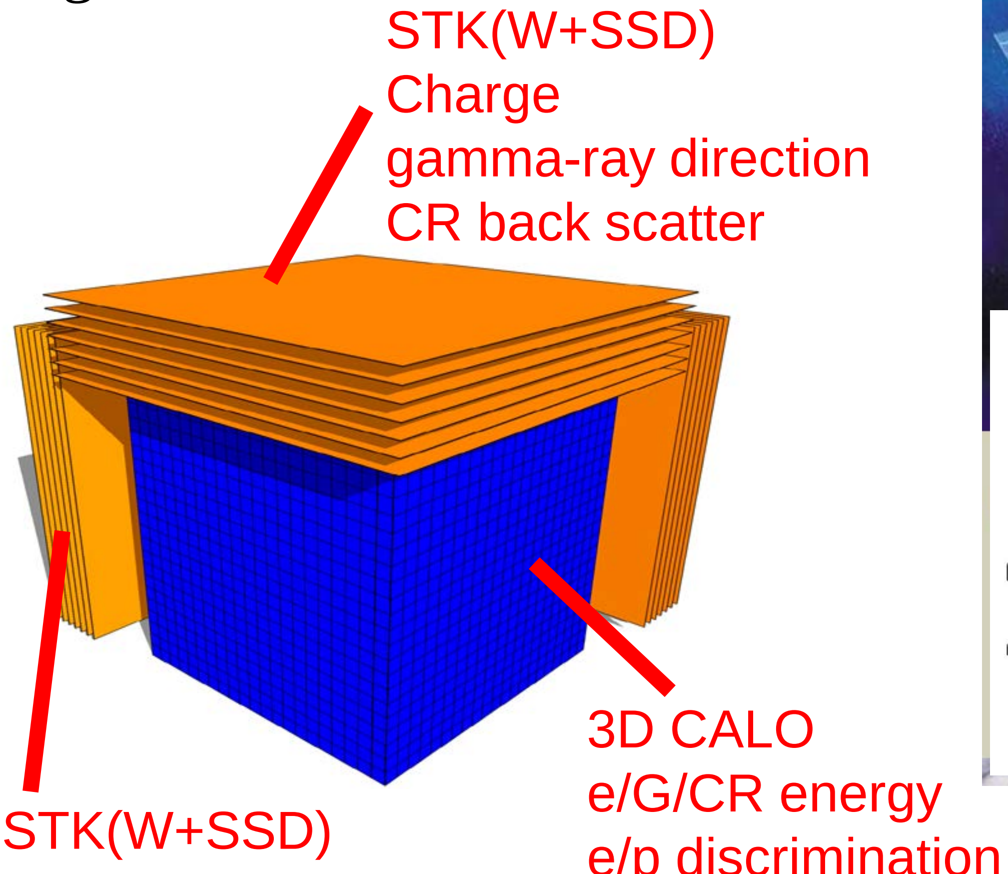
S3, S4 calorimeter scintillator detectors

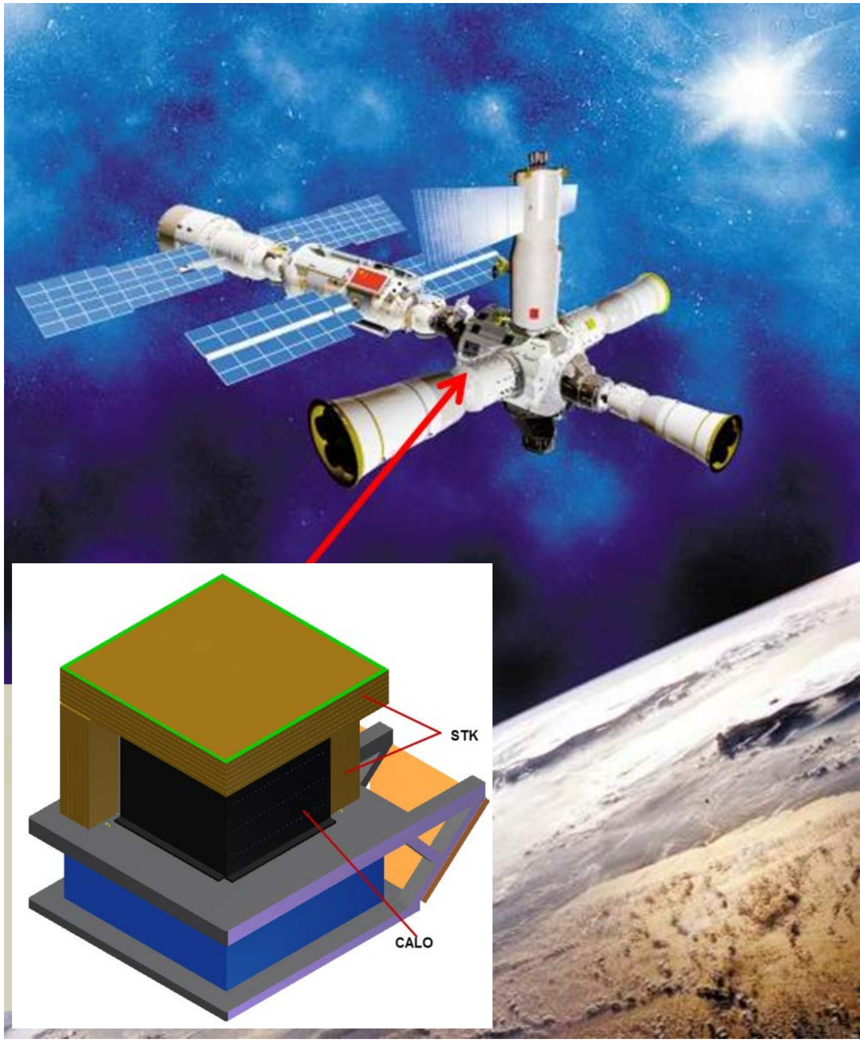
CC1 – imaging calorimeter (2 X_0)
2 layers: CsI(Ti) 1 X_0 + Si(x,y) (pitch 0.1 mm)

CC2 - electromagnetic calorimeter
CsI(TI) 20 X_0 3.6x3.6x3.6 cm^3 – 22x22x10 = 4840

HERD Design : 3D Calo & 5-Side Sensitive

About a factor 10 increase in statistics respect to existing experiments with a weight 2.3 T ~1/3 AMS

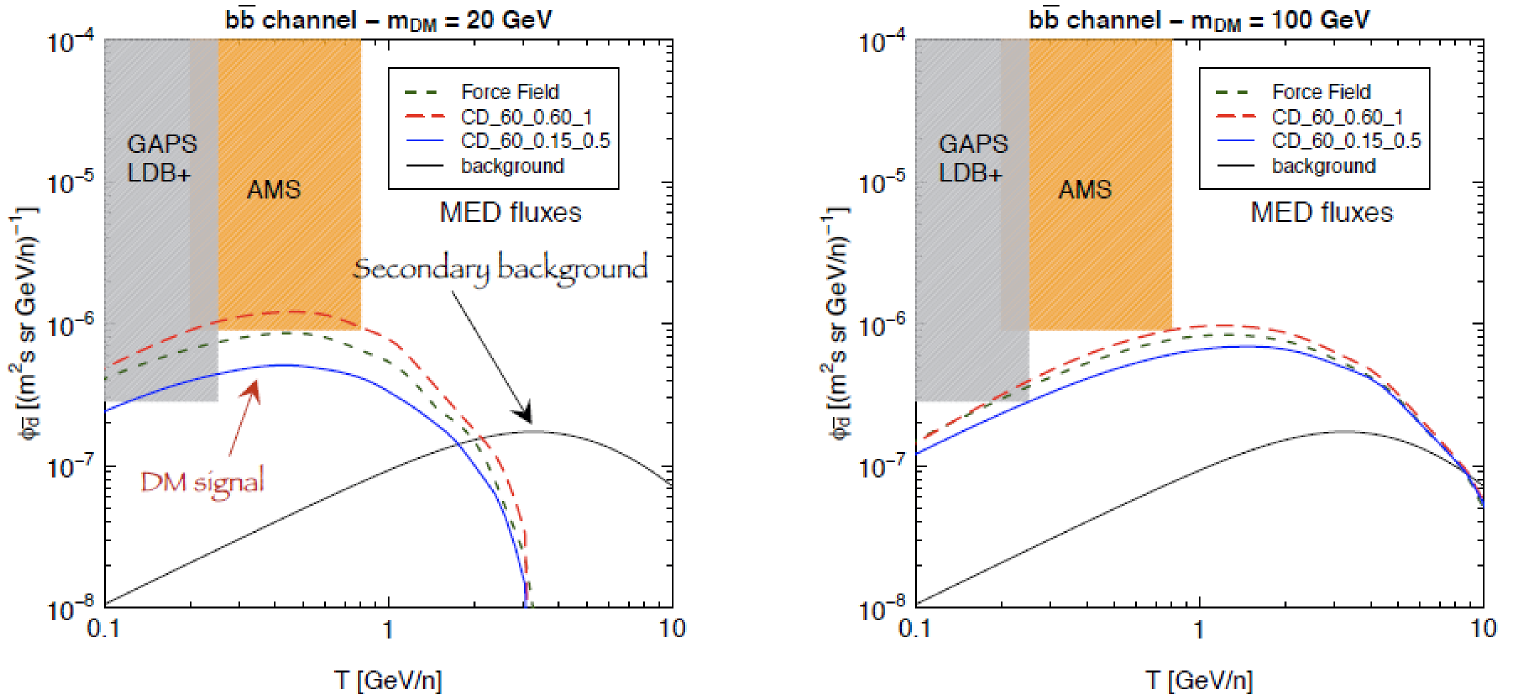




HERD detectors

	type	size	X0,λ	unit	main functions
tracker (top)	Si strips	70 cm × 70 cm	2 X0	7 x-y (W foils)	Charge Early shower Tracks
tracker 4 sides	Si strips	65 cm × 50 cm	2 X0	7 x-y (W foils)	Charge Early shower Tracks
CALO	~10K LYSO cubes	63 cm × 63 cm × 63 cm	55 X0 3 λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation

Detection prospects



DM configurations allowed by antiproton bounds

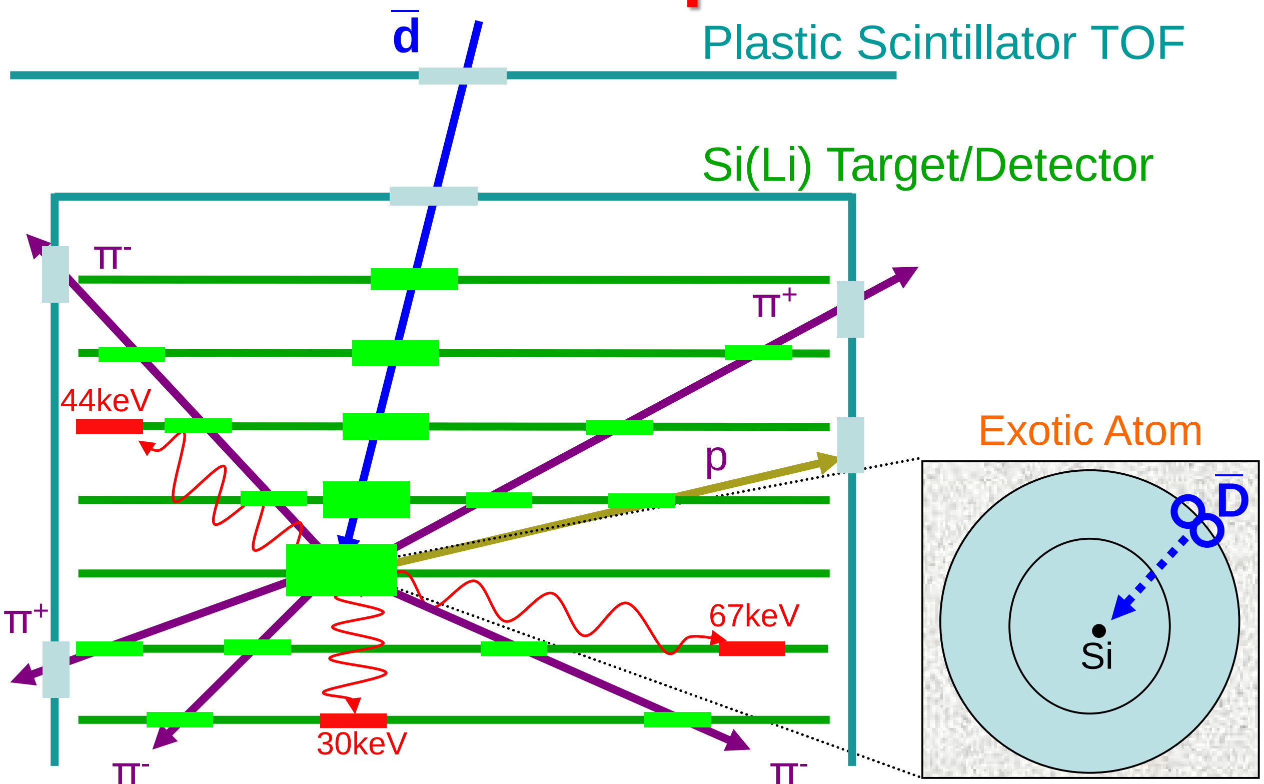
Relevant detection prospects for Dbar energies below few Gev/n, where dependence on solar modulation modeling can have an impact on the DM signal up to a factor of 2

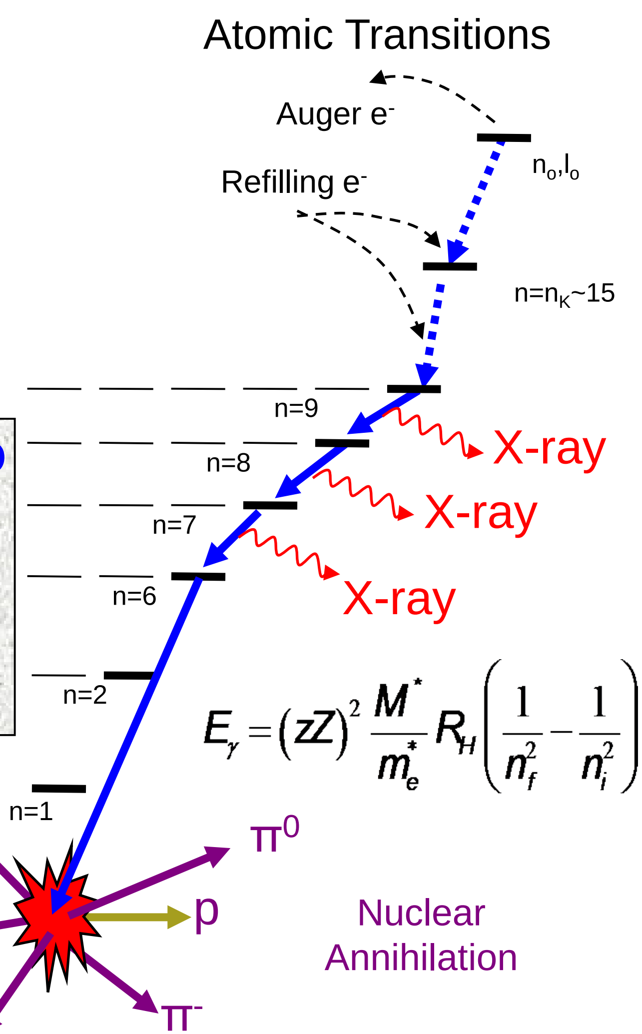
Experimental expected sensitivities : 3σ C.L.

GAPS LDB+ : 1 detected event
AMS : 2 detected events

Fornengo, Maccione, Vittino, JCAP 1309 (2013) 031

GAPS detects atomic X-rays and annihilation products from exotic atoms





$$E_\gamma = (zZ)^2 \frac{M^*}{m_e^*} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

A time of flight (TOF) system tags candidate events and records velocity

The antiparticle slows down & stops in a target material, forming an excited exotic atom

Deexcitation X-rays provide signature

Annihilation products provide added background suppression

X-ray yields were measured at KEK in 2004 and 2005

GAPS project history

2002 (original GAPS)
- Cubic detector
- 3 X-rays

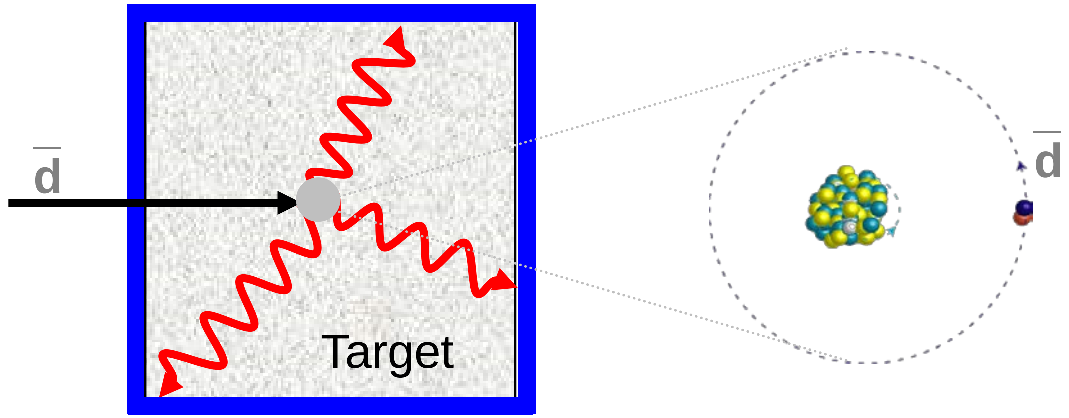
2004/2005
- KEK Beam Test

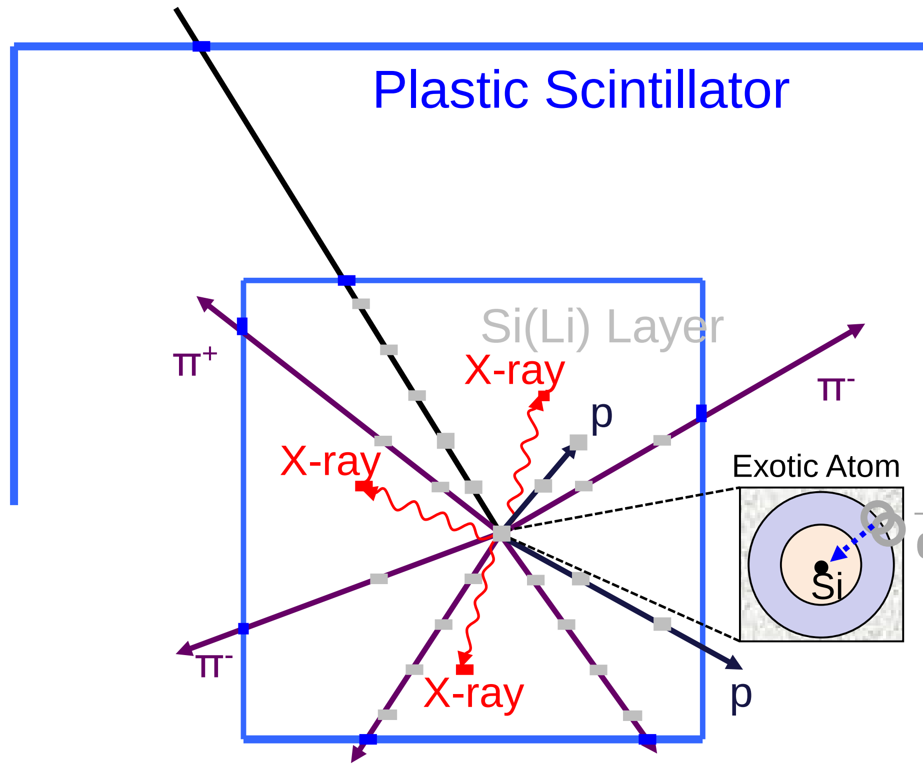
2006
- Multi-layer detector
- TOF stopping depth
- X-rays
- Pion multiplicity

2008
- Proton multiplicity

2009
- dE/dX

2012
- pGAPS flight
- Start Si(Li) fabrication





GAPS science summary

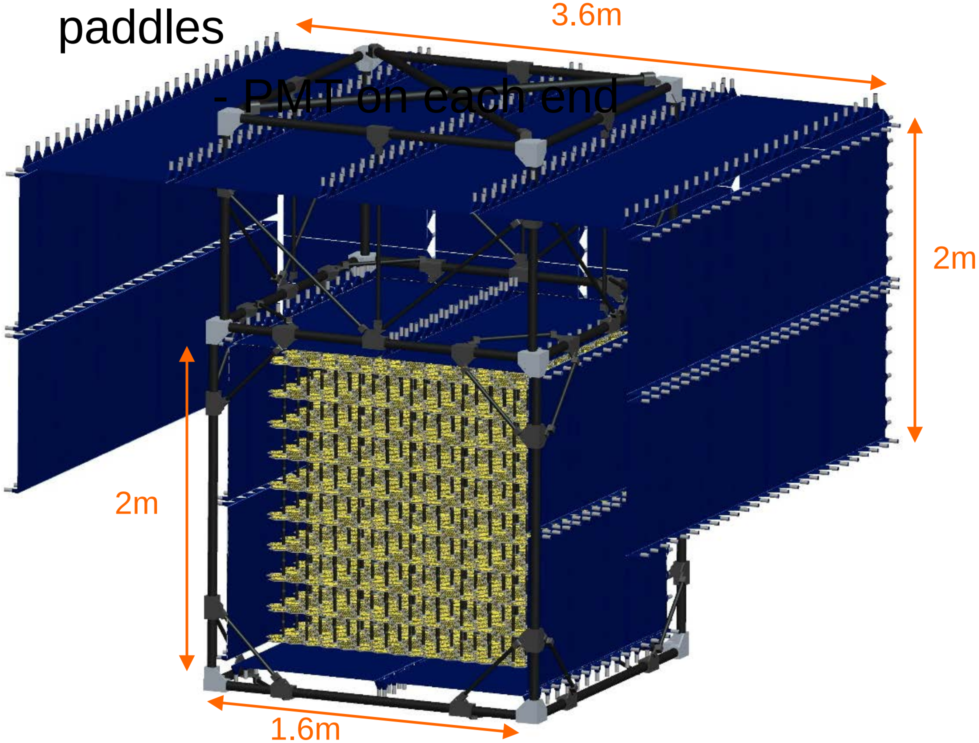
- ***Antideuterons*** as DM signatures
    - **no astrophysical background** at low energy
    - **complementary** to direct/indirect searches and collider experiments
    - search for: **light DM**, heavy DM, gravitino DM,
      LZP in extra-dimensions theories, (evaporating PBH)
- ***Antiprotons*** as DM and PBH signatures
    - precision flux measurement at ultra-low energy (E < 0.25 GeV)
    - **complimentary** to direct/indirect searches and collider experiments
    - **~ 10 times more statistics** @ 0.2 GeV, compared to BESS/PAMELA
    - search for: **light DM**, gravitino DM,
      LZP in extra-dimensions theories, evaporating PBH
- *Expected to launch from Antarctica in 2018/2019*

> ➢ **1 LDB flight** (~35 days) -> **precision antiproton flux measurement**
>
> ~1500 antiprotons in GAPS $E < 0.25$ GeV, while 30 for BESS, 7 for PAMELA at $E \sim 0.25$ GeV
>
> ➢ **2 LDB flights** (~70 days) -> **improved antideuteron statistics**
>
> Antideuteron sensitivity: ~3.0 x 10^{-6} [$m^{-2}\ s^{-1}\ sr^{-1}\ (GeV/n)^{-1}$] *at* $E < 0.25$ GeV
>
> ➢ **3 LDB flights** (~105 days) -> Antideuteron sensitivity: ~2.0 x 10^{-6} [$m^{-2}\ s^{-1}\ sr^{-1}\ (GeV/n)^{-1}$] *at* $E < 0.25$ GeV

GAPS instrument summary

TOF plastic scintillators

- outer TOF: 3.6m x 3.6m, 2m height
- inner TOF: 1.6m x 1.6m, 2m height
    - 1m b/w outer and inner TOFs
    - 500 ps timing resolution
    - 16.5 cm wide plastic paddles
    - PMT on each end



Science weight: ~1700 kg, 34H balloon

Si(Li) detectors

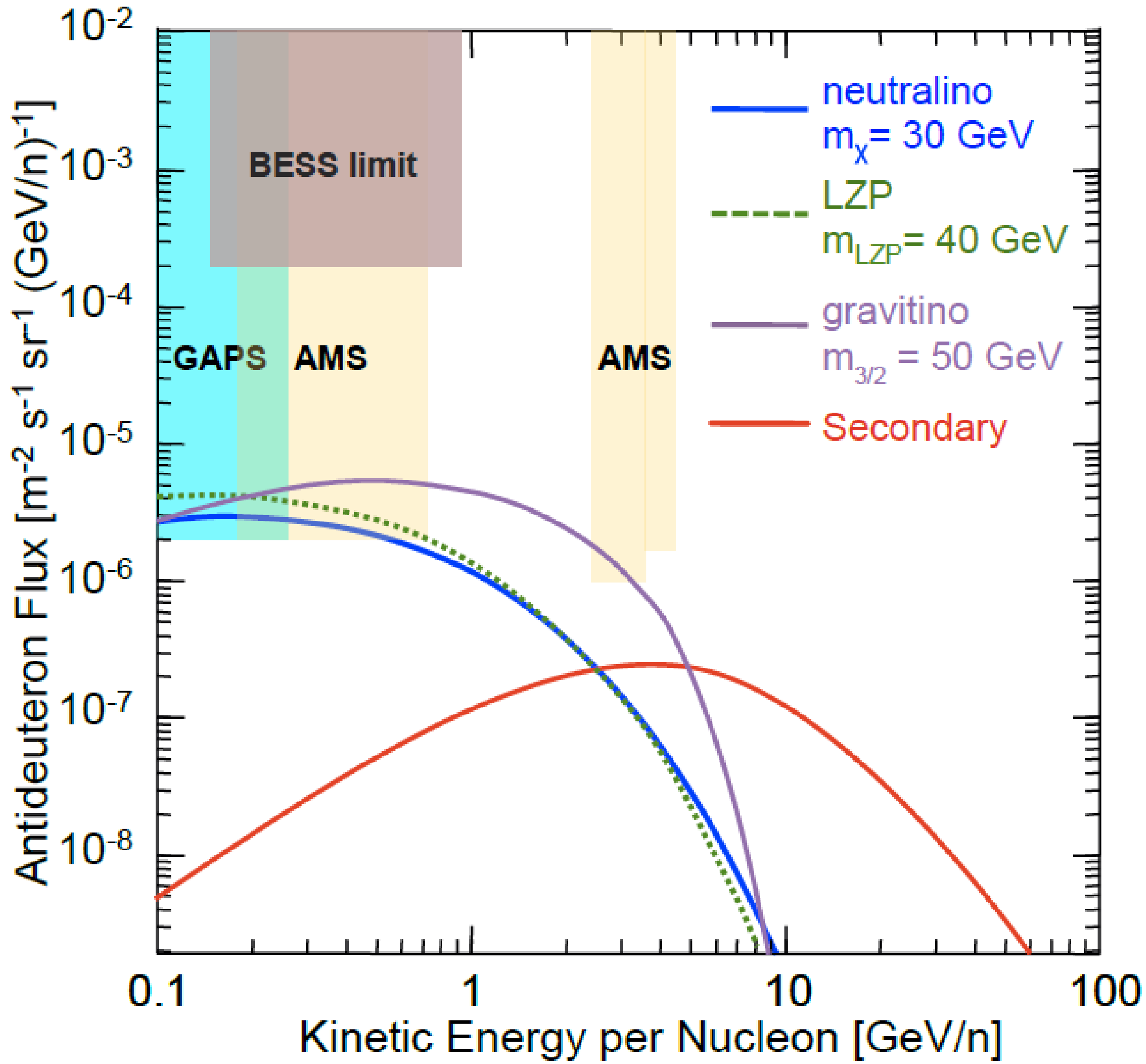
- 10 layers, 1.6m x 1.6m
- layer space: 20 cm
- Si(Li) wafer (~1500 wafers)
    - 4 inch diameter
    - 2.5mm thick wafer
    - 12 x 12 rectangular
- segmented into 4 strips
    → 3D particle tracking
- timing resolution: ~ 100 ns
- energy resolution: 3 keV
- operation temperature: -35 C
- dual channel electronics
    X-ray: 20 - 80 keV
    charged particles: 0.1 - 100 MeV

Cooling system

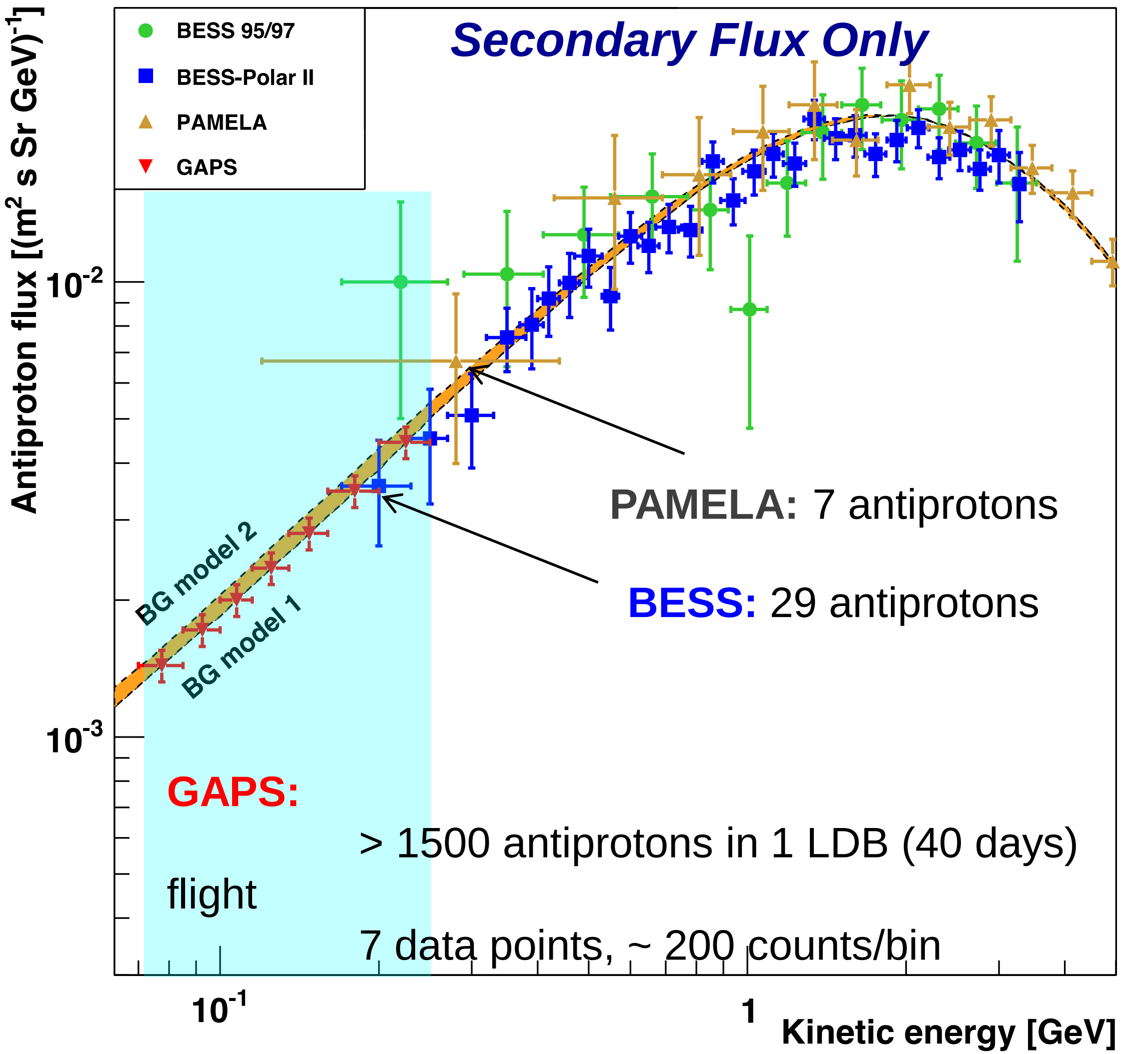
- oscillating heat pipe (OHP)
- demonstrated in pGAPS

Cosmic-ray Antideuterons

T. Aramaki et al., Astropart. Phys. 74 (2016) 6, arXiv: 1506.02513



GAPS precision antiproton flux measurement provides strong constraints on DM and PBH models



Primary flux

$$\Phi_p \propto \langle \sigma v \rangle_{\text{ann}} \left(\frac{\rho_{DM}}{M_{DM}} \right)^2 \otimes \text{propagation}$$

x 10 for Max
x 0.1 for Min
due to Halo model

Secondary flux

- constrained by B/C ratio

Complementary to direct/indirect DM searches and collider experiments for light DM

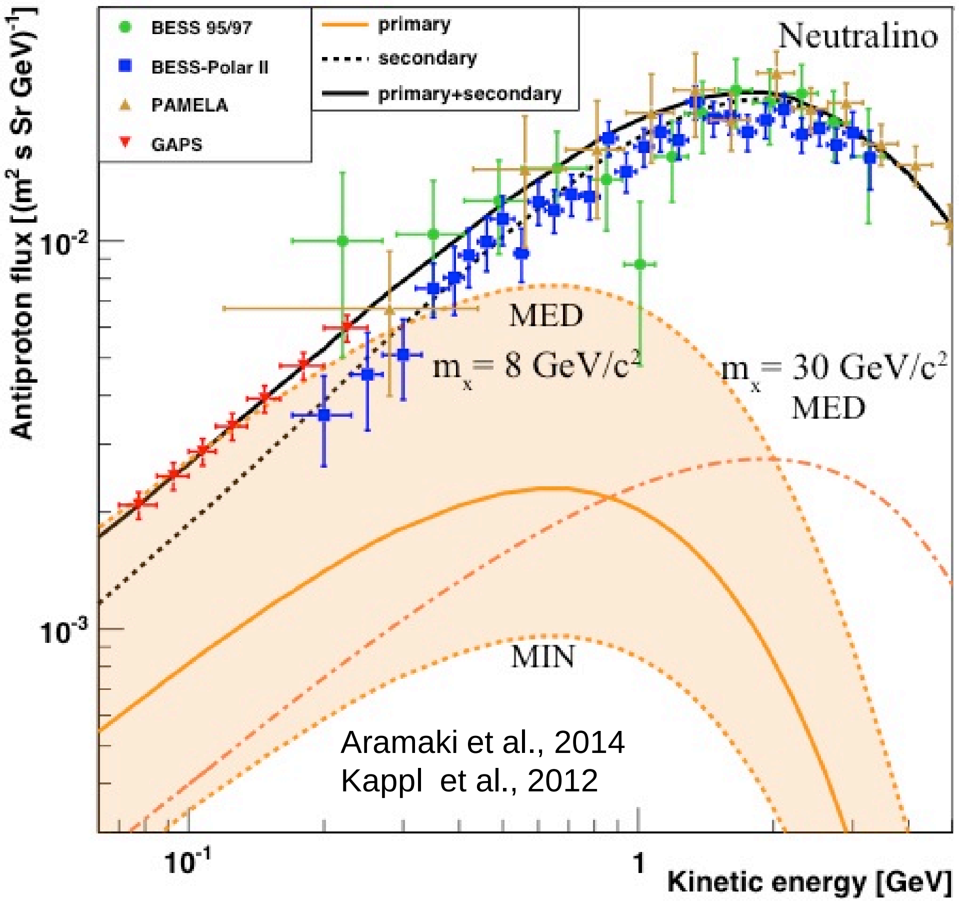
GAPS antiprotons probe light DM and gravitino DM

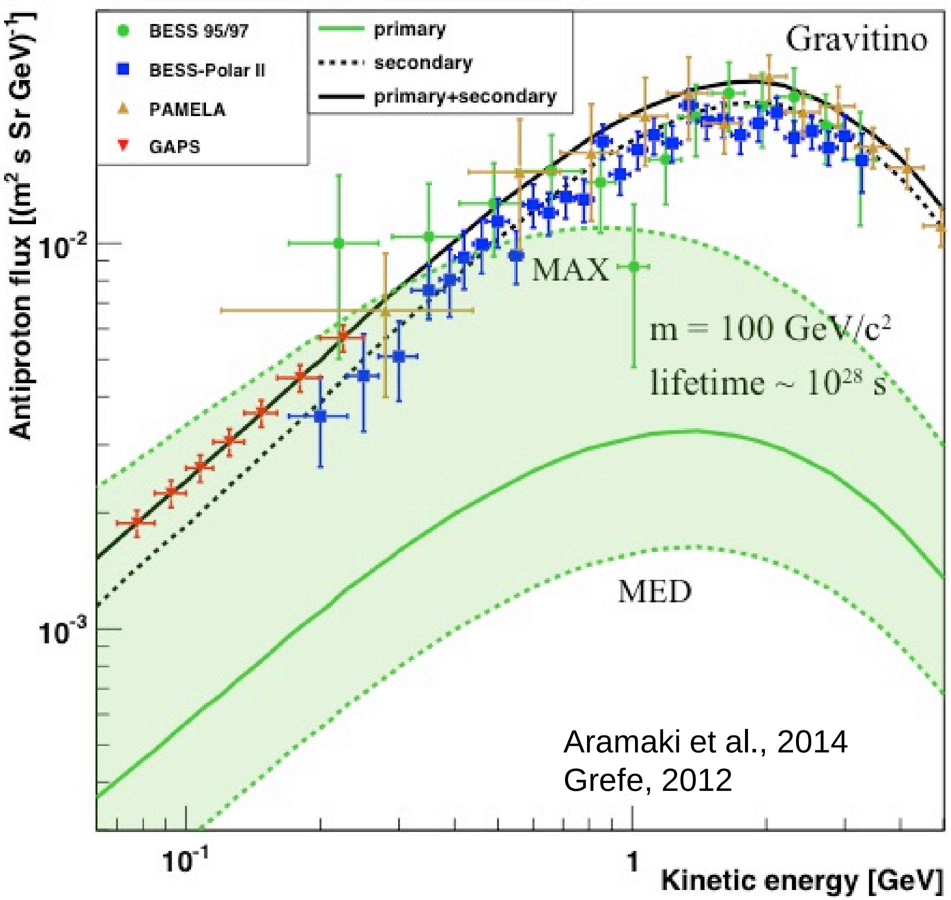
Light DM

- in non-universal gaugino model
- good agreement with experimental data
  - uncertainty on propagation model
  - uncertainty on annihilation cross-section
  - different annihilation channels

gravitino DM

- stable in galactic time scale
- small R-parity violation
  - avoid gravitino overproduction





Unique probes for DM in extra-dimensions and evaporating PBHs

LZP

- Lightest Z_3 charged particle
- stable under Z_3 symmetry
- right-handed neutrino

Primordial Black Hole Evaporation

- density fluctuations, phase transitions, collapse of cosmic strings in the early universe
- $R < 0.02$-$0.05\ pc^{-3}\ yr^{-1}$ (γ, Fermi, EGRET)
- $R < 0.0012\ pc^{-3}\ yr^{-1}$ (p, BESS-Polar II only)