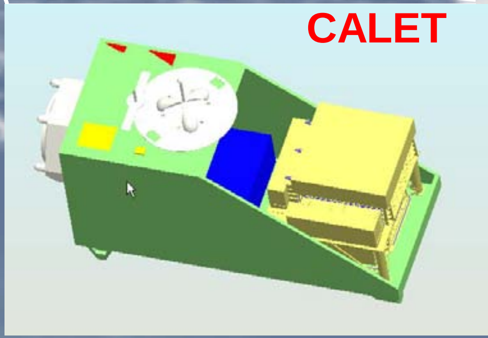
CALETプロジェクト：
国際宇宙ステーション日本実験棟（きぼう）における宇宙科学観測ミッション

CALET Project: Astrophysics Mission for Japanese Experiment Module (Kibo) at the ISS



Shoji Torii
on behalf of the CALET Collaboration
Waseda University
& JAXA/Space Environment Utilization Center

2011.08.31

宇宙線研究所セミナー

CALET International Collaboration Team

JAPAN
Waseda University
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
Kanagawa University,
Aoyama Gakuin University
Shibaura Institute of Technology
Institute for Cosmic Ray Research , University of Tokyo
Yokohama National University
Hirosaki University
Tokyo Technology Inst.
National Inst. of Radiological Sciences
High Energy Accelerator Research Organization (KEK)
Kanagawa University of Human Services
Saitama University
Shinshu University
Nihon University
Ritsumeikan University

USA
NASA/GSFC
Louisiana State University
Washington University in St Louis
University of Denver

ITALY
University of Siena
University of Florence & IFAC (CNR)
University of Pisa
University of Roma Tor Vergata

Funding Agencies

JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

JAXA/SEUC

Waseda University
supported also by
JSPS, MEXT

NASA

ASI

CALET Collaboration Member

O. Adriani[19], K.Asano[17], M.G. Bagliesi[22], G. Bigongiari[22], W.R. Binns[24], S. Bottai[19], J.Buckley[24], G. Castellini[19], M.L. Cherry[9], G. Collazuol[20], K. Ebisawa[5], V. Di Felice[21], H. Fuke[5], T.G. Guzik[9], T. Hams[10], N. Hasebe[23], M. Hareyama[5], K. Hibino[7], M. Ichimura[2], K. Ioka[8], J. B. Isbert[9], M. H. Israel[24], E. Kamioka[15], K. Kasahara[23], Y. Katayose[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. Krawzczynski[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], K. Mizutani[14], A.A. Moiseev[10], K.Mori[23], M. Mori[13], F. Morsani[20], K. Munakata[16], H. Murakami[23], Y.E.Nakagawa[23], J. Nishimura[5], S. Okuno[7], J.F. Ormes[18], S. Ozawa[23], P. Papini[19], B.Rauch[24], S.Ricciarini[19], Y. Saito[5], 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[7], N. Tateyama[7], T. Terasawa[3], H. Tomida[5], S. Torii[23], Y. Tunesada[17], Y. Uchihori[11], S. Ueno[5], E. Vannuccini[19], J.P. Wefel[9], K.Yamaoka[1], A. Yoshida[1], K. Yoshida[15], 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 Inst., Japan
18) University of Denver, USA
19) University of Florence and IFAC(CNR), Italy
20) University of Pisa, Italy
21) University of Rome Tor Vergata , Italy
22) University of Siena, Italy
23) Waseda University, Japan
24) Washington University - St Louis, USA
25) Yokohama National University, Japan

CALETの経緯

（1）平成19年5月、ISSきぼう利用推進委員会の審議を経て、CALETを含むポート占有ミッション候補3件が選定され、その後CALETの概念設計を開始。

（2）平成21年11月、システム要求審査会（SRR)を実施。

（3）平成22年2月、 システム定義審査（SDR)を実施。

（4）平成22年3月、開発移行審査を実施。

（5）平成22年4月、開発移行審査の理事会報告時に、CALETをプロジェクト化する方針が決定。

（6）平成22年7月、CALETプロジェクト移行審査（経営審査）を実施。設定された課題への対応を整理することとして、プロジェクト移行デルタ審査の実施を決定。

（7）平成22年10月、CALETプロジェクト移行デルタ審査を実施。

（8）平成22年12月、宇宙環境利用センターにCALETプロジェクトチームが発足。

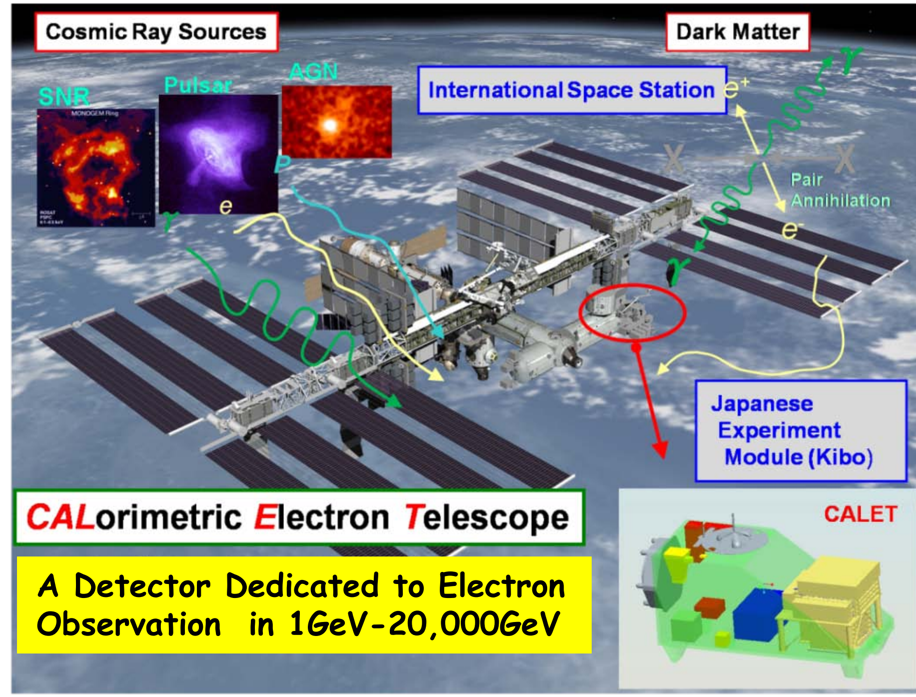
CALET Observation

Calorimeter (CALET/CAL)

- Electrons: 1 GeV – 20,000 GeV
- Gamma-rays: 10 GeV – 10,000 GeV
  (Gamma-ray Bursts: > 1 GeV)
- Protons and Heavy Ions:
  several tens of GeV – 1,000 TeV
- Ultra Heavy Ions:
  over the rigidity cut-off

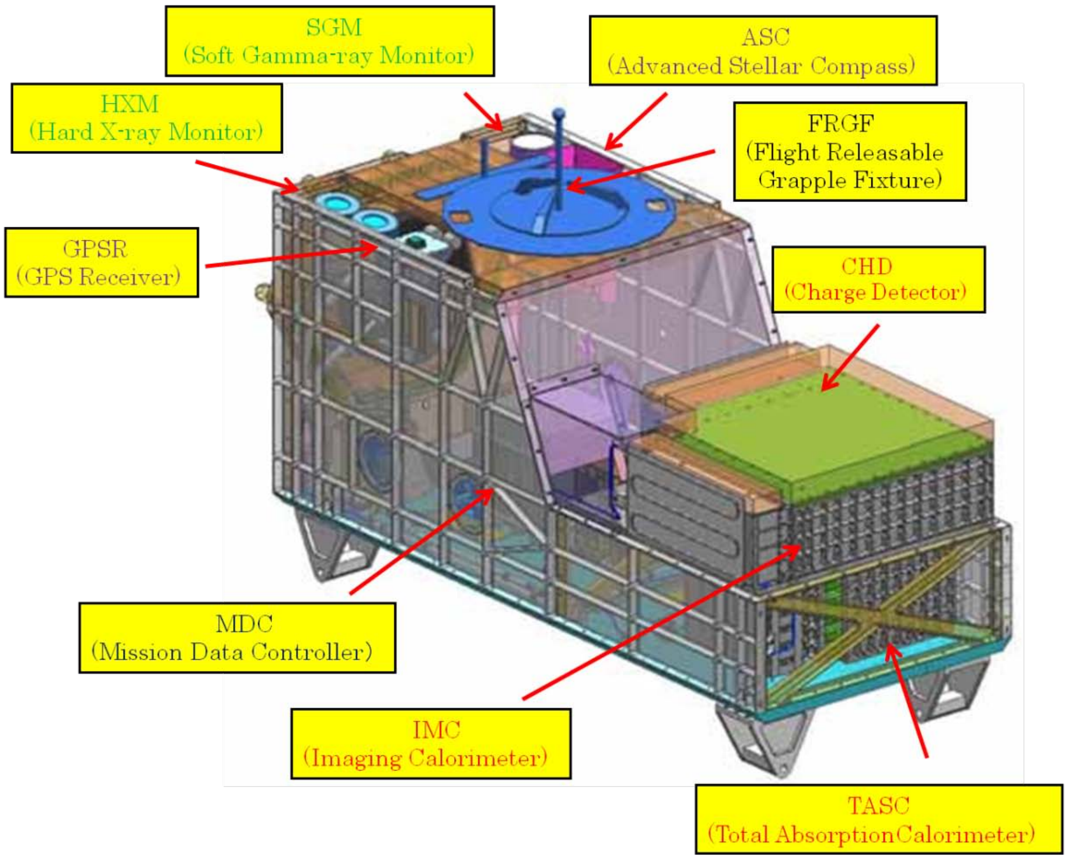
Gamma-ray Burst Monitor (CGBM)

- Soft Gamma-rays : 30 keV – 30 MeV
- Hard X-rays: 3keV – 3 MeV



Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum in trans-TeV region
Dark Matter	Signatures in electron/gamma energy spectra in 10 GeV – 10 TeV region
Origin and Acceleration of Cosmic Rays	p-Fe over several tens of GeV, Ultra Heavy Ions
Cosmic –ray Propagation in the Galaxy	B/C ratio up to several TeV /n
Solar Physics	Electron flux below 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays in 3 keV – 30 MeV

CALET Payload



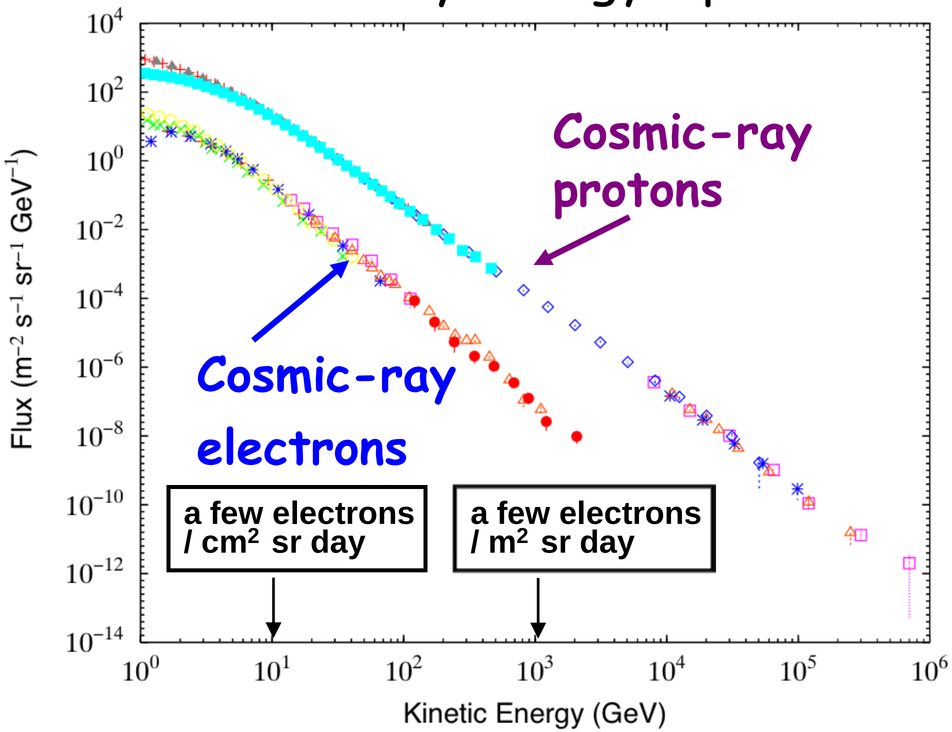
3

Items	Specification
Mission Equipment	CAL: Calorimeter CGBM: Gamma-ray Burst Monitor
Launch Carrier	HTV-5
Launch Target Date	JFY 2013 (TBD)
Mission Period	More than 2 years (5 years target)
Mass	586 kg (Nominal) — 620kg (Max)
Envelope	Standard Payload Size
Power	Less than 500 W
Data Rate	Medium Data Rate : 300 kbps Low Data Rate : 20 kbps

CALET Detector System	Support Sensor	JEM/EF Equipment
Calorimeter: CHD,IMC, TASC+MDC GBM : HXM, SGM	GPSR ASC	FRGF

Electron and Positron Observation

Cosmic-ray Energy Spectra



- Flux of electrons and positrons:
  - ~1 % of protons @10GeV
  - ~0.1 % @ 1000GeV
  - ~0.1 % @ 10 GeV
- Spectrum of electrons:
  - softer than protons
  - power-law index:
    e:~-3.0, p:-2.7

=> As higher energies,

✓ Lower electron flux

✓ Lager proton backgrounds

Large amount of exposures
with a detector of high proton rejection power (+ charge separation)

➡ Long duration balloon flight in 10~1000 GeV (~10 m^2srday)
Observation in space for years over 1000 GeV (> 100 m^2srday)

$e^{\pm}$ Propagation

$$\frac{\partial}{\partial t} f\left(t, \varepsilon_e, \vec{x}\right) = D\left(\varepsilon_e\right)\nabla^2 f + \frac{\partial}{\partial \varepsilon_e}\left[b\varepsilon_e^2 f\right] + q\left(t, \varepsilon_e, \vec{x}\right)$$

Diffusion

Energy loss by IC & synchro.

Injection

$$b \sim 10^{-16}\,\mathrm{GeV}^{-1}\mathrm{s}^{-1}$$

$$D\left(\varepsilon_e\right) \sim 5.8\times10^{28}\,\mathrm{cm}^2\mathrm{s}^{-1}\left(1+\frac{\varepsilon_e}{4\mathrm{GeV}}\right)^{1/3}$$

← B/C ratio

For a single burst with $q \propto \varepsilon_e^{-\alpha}$ Power law spectrum

$$f = \frac{q_0 \varepsilon_e^{-\alpha}}{\pi^{3/2} d_{diff}^3}\left(1 - bt\varepsilon_e\right)^{\alpha-2} e^{-\left(d/d_{diff}\right)^2}$$

$$d_{diff}\left(t, \varepsilon_e\right) \sim 2\left[D\left(\varepsilon_e\right)t\right]^{1/2}$$

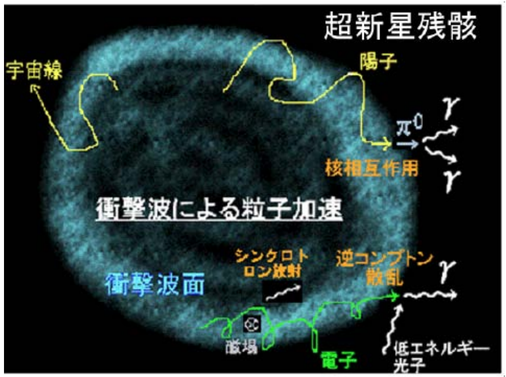
Atoyan 95, Shen 70
Kobayashi 03

$$\varepsilon_{\mathrm{cut}} \sim \frac{1}{bt}$$

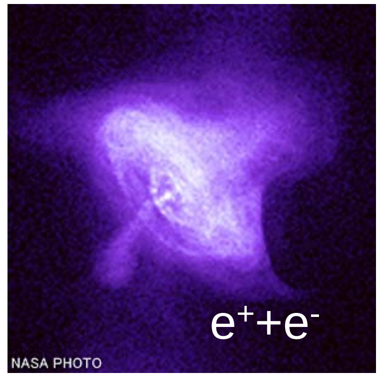
Electron & Positron Observation

Astrophysical Origin

Shock Wave Acceleration in SNR

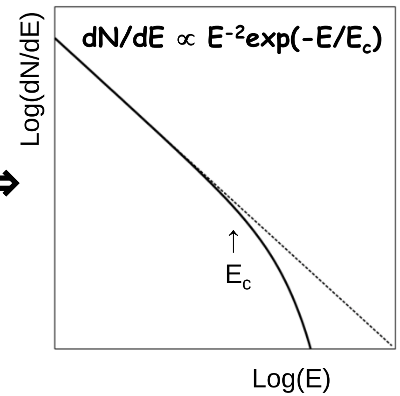


Acceleration in PWN



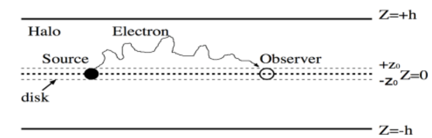
⇒

Production Spectrum
（**Power Law Distribution ＋Cutoff**）



⇒

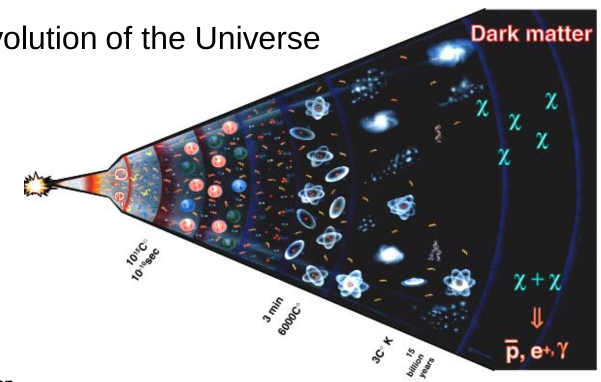
Propagation in the Galaxy
- **Diffusion Process**
- **Energy Loss**
  $dE/dt = -bE^2$
  （**Syncrotron＋Inverse Compton**）
- **π+/- or K+/- → μ+/- → e+/-**



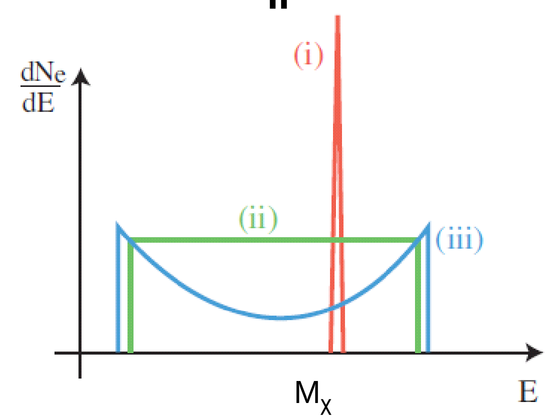
⇑

Dark Matter Origin

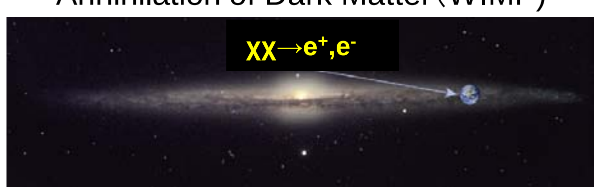
Evolution of the Universe



⇒



Annihilation of Dark Matter（WIMP)



Production Spectrum

（ i ） Monoenergetic: Direct Production of e+e- pair
（ ii ） Uniform：Production via Intermediate Particles
（iii） Double Peak： Production by Dipole Distribution via Intermediate Particles

A Naïve Result from Propagation

$T\,(age) = 2.5 \times 10^5 \times (1\ TeV/E)\ yr$

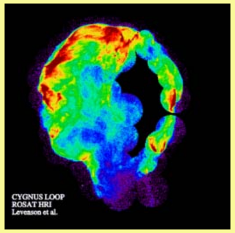
$R\,(distance) = 600 \times (1\ TeV/E)^{1/2}\ pc$

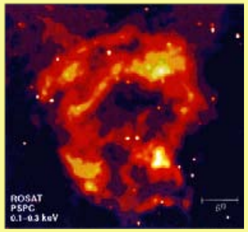
1 TeV Electron Source:

- **Age < a few10^5 years**
  very young comparing to ~10^7 year at low energies
- **Distance < 1 kpc**
  nearby source

Source (SNR) Candidates :

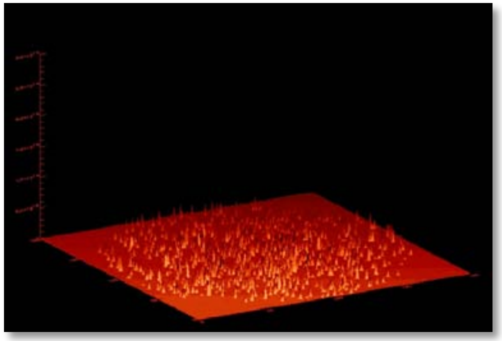
Vela Cygnus Loop Monogem

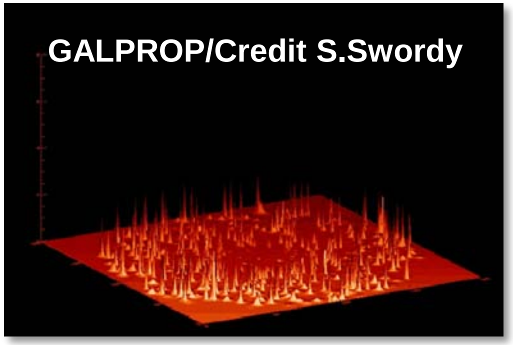


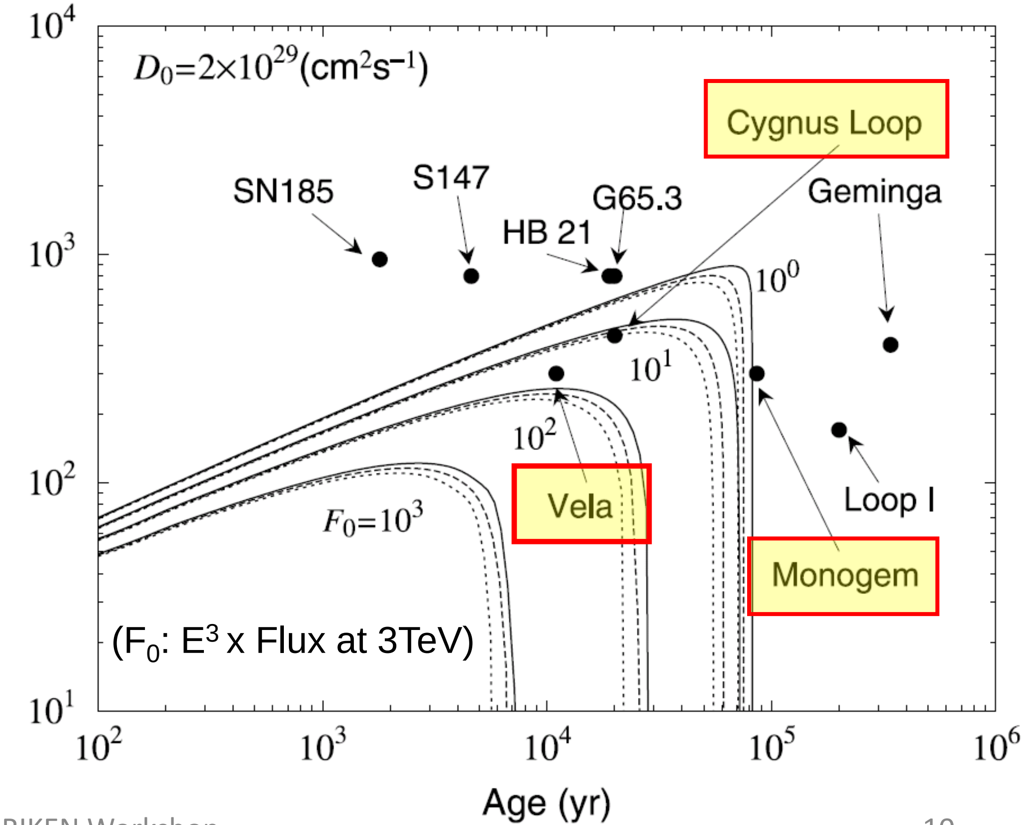
Unobserved Sources?

1 GeV Electrons



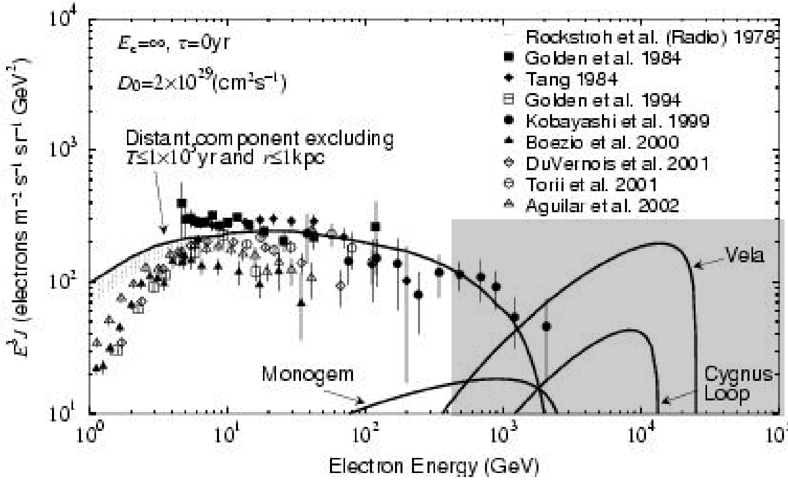
100 TeV Electrons



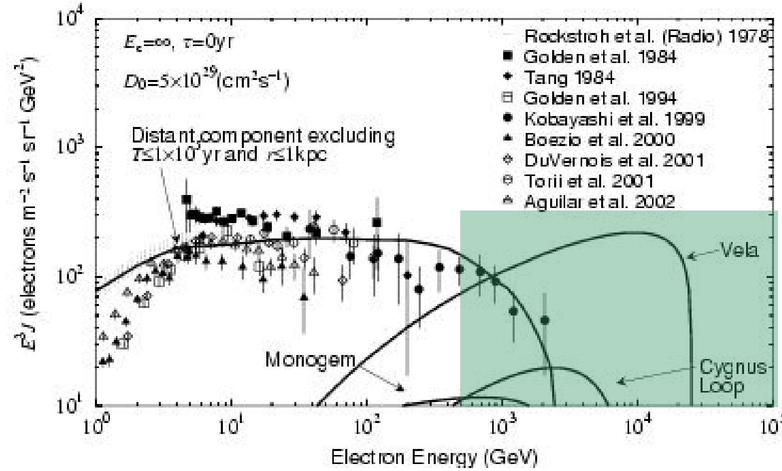


Model Dependence of Energy Spectrum and Nearby Source Effect

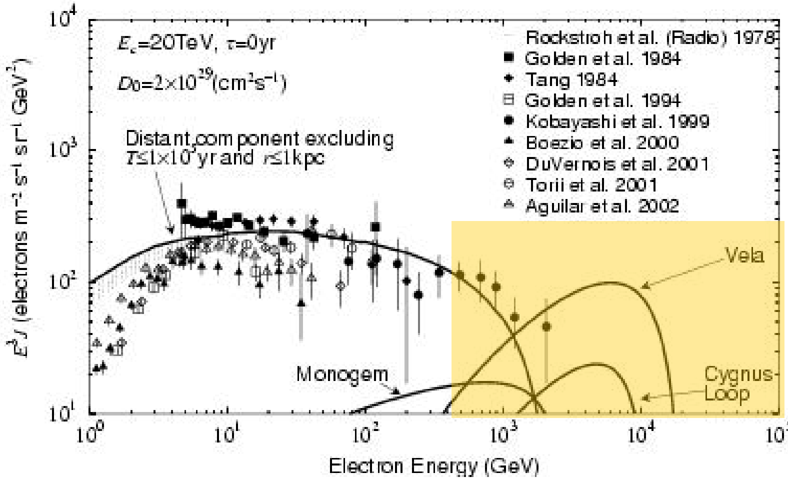
Ec=∞、ΔT=0 yr, Do=2x10^{29} cm^2/s



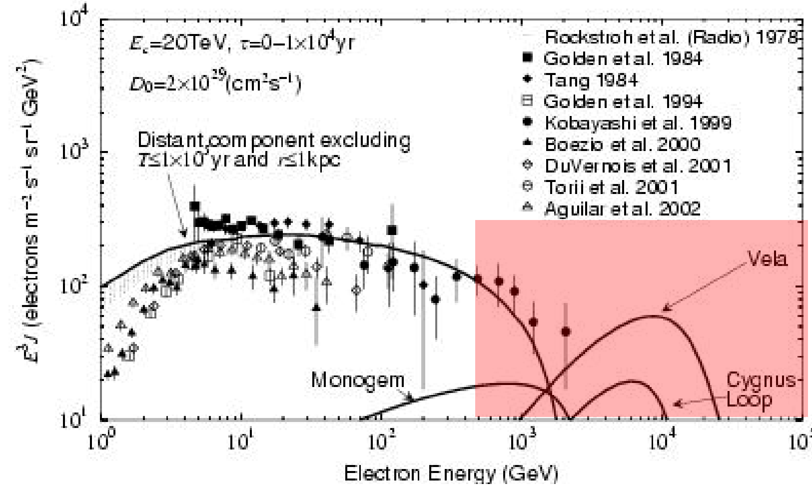
Do=5 x 10^{29} cm^2/s



Ec= 20 TeV



Ec=20 TeV、ΔT=1-10^4 yr



Kobayashi et al. ApJ (2004)

New Calculation for SNR Origin

S.Profumo arXiv:0812.4457v2 28 Apr. 2009

Name	Distance [kpc]	Age [yr]	$\dot{E}$ [ergs/s]	E_{out} [ST]	E_{out} [CCY]	E_{out} [HR]	E_{out} [ZC]	$f_{e^\pm}$	g
Geminga [J0633+1746]	0.16	3.42×10^5	3.2×10^{34}	0.360	0.344	0.013	0.053	0.005	0.70
Monogem [B0656+14]	0.29	1.11×10^5	3.8×10^{34}	0.044	0.133	0.006	0.020	0.020	0.70
Vela [B0833-45]	0.29	1.13×10^4	6.9×10^{36}	0.084	0.456	0.006	0.372	0.0015	0.14
B0355+54	1.10	5.64×10^5	4.5×10^{34}	1.366	0.677	0.022	0.121	0.2	0.61
Loop I [SNR]	0.17	2×10^5		*0.3*				0.006	
Cygnus Loop [SNR]	0.44	2×10^4		*0.03*				0.01	

Source Candidates

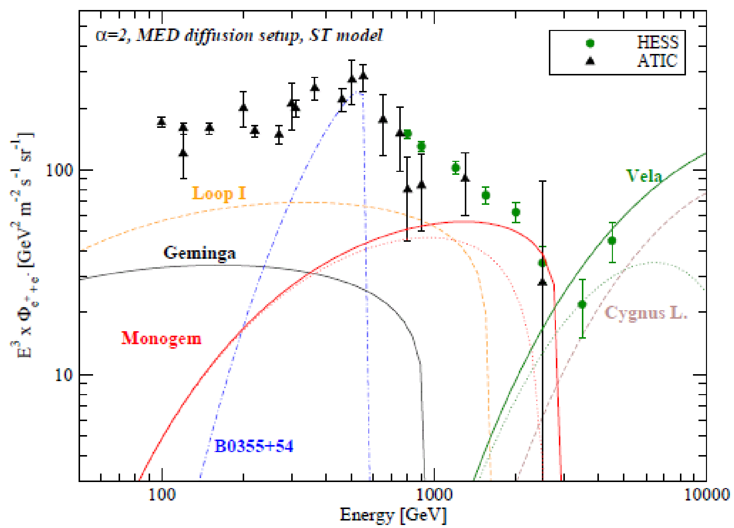


FIG. 4: The spectrum of selected nearby pulsars and SNR's (for the parameters employed to calculate the fluxes see tab. II). We assume an $e^\pm$ injection spectral index $\alpha = 2$, and a median diffusion setup (MED). The dotted lines correspond to injection spectra featuring an exponential cutoff at $E_{e^\pm} = 10$ TeV.

Electron + Positron

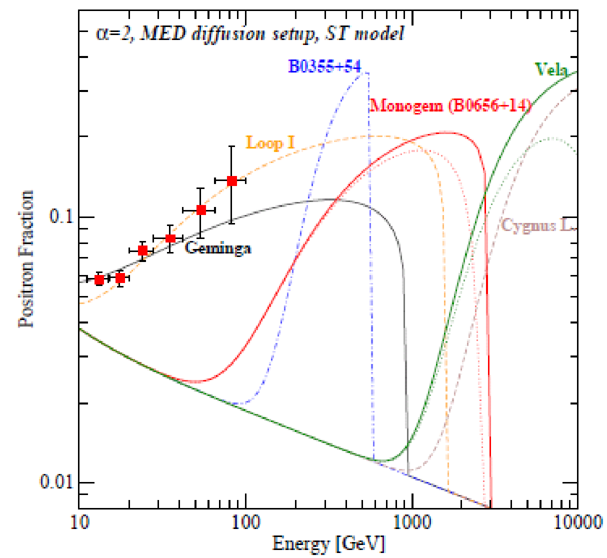
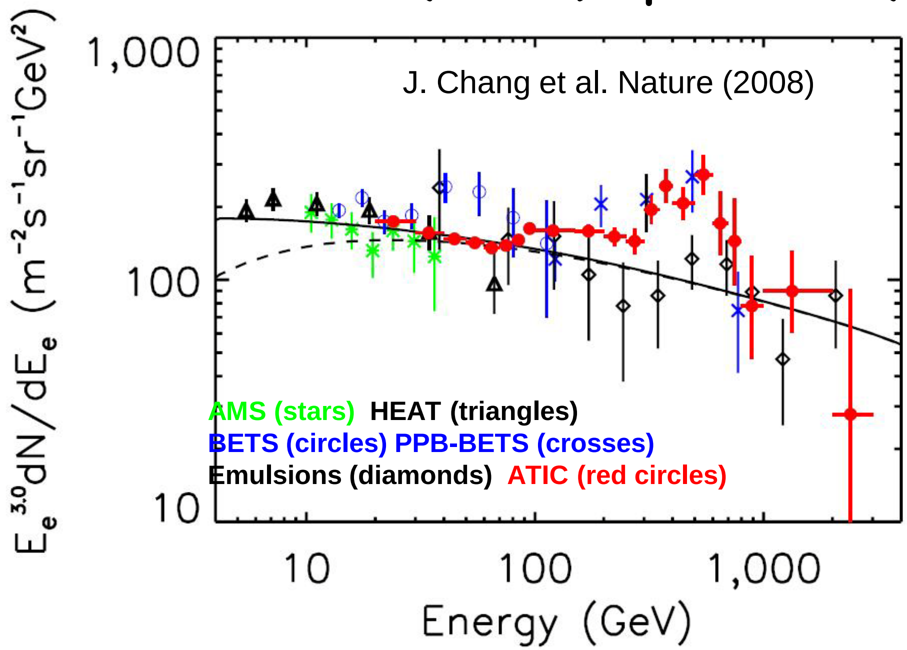
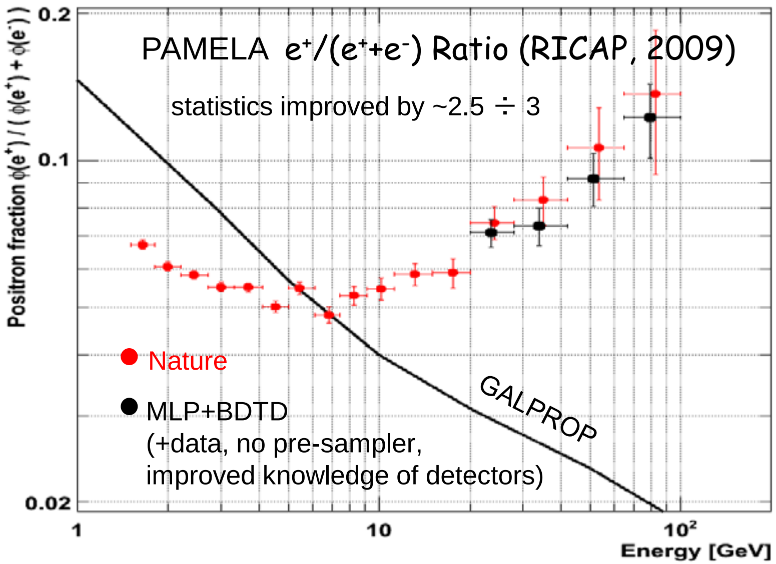


FIG. 5: The positron fraction for the same sources as in fig. 4 and tab. II.

Positron Ratio

Observed $(e^+ + e^-)$ Spectra (as of 2008) & $e^+/(e^+ + e^-)$ Ratio





- If we assume the power law spectrum (with γ=-3.3) calculated by GALPROP, an excess of $(e^+ + e^-)$ is seen in 300-800 GeV.
- The excess might be contributed from exotic sources: Nearby Pulsars or WIMPs.

- The positron ratio observed by PAMELA presents unexpected increase over 10 GeV.
- This increase can be understood if the positrons are created by Nearby Pulsars or WIMPs in addition to secondary process.

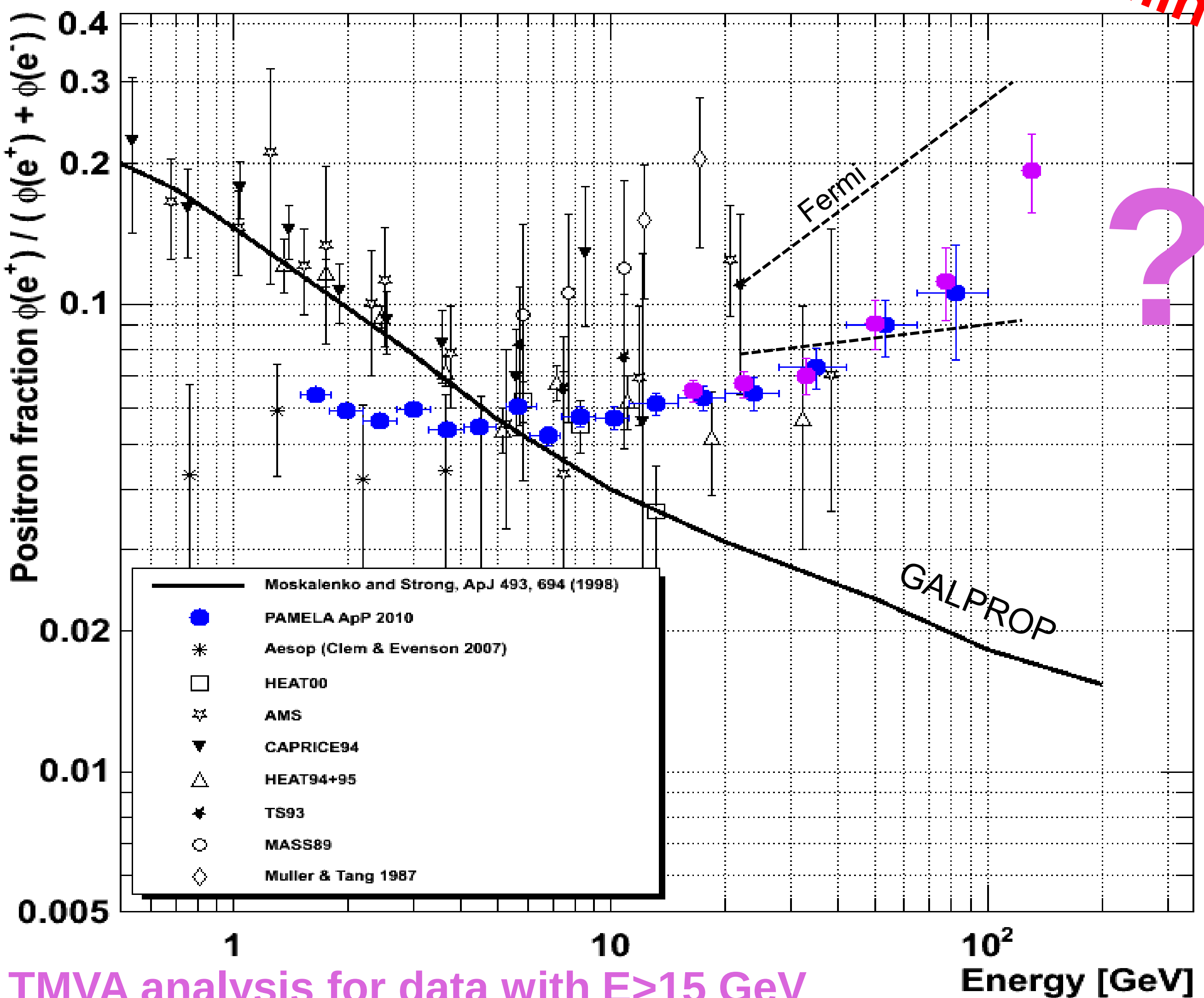
Both anomalies from same reason ?

To identify the reason, Anisotropy in $(e^+ + e^-)$ and $e^+/(e^+ + e^-)$ over 100 GeV are indispensable.

ICRC2011

PAMELA NEW RESULTS

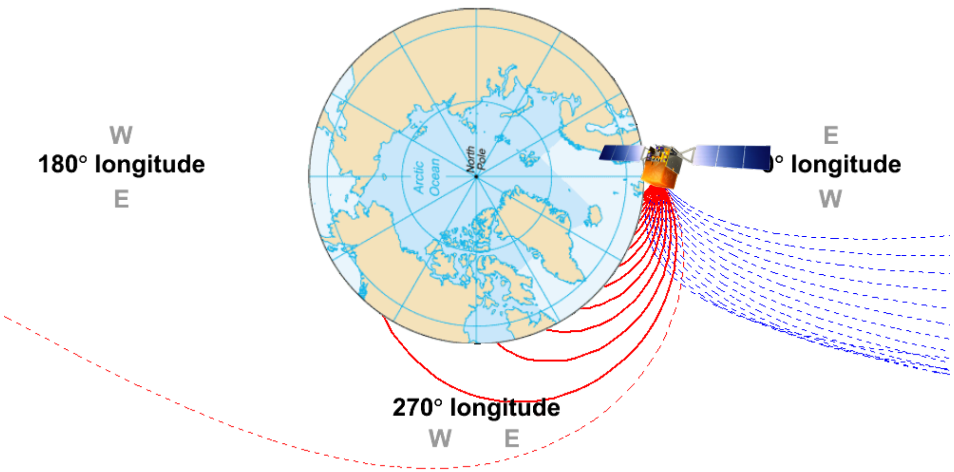
Preliminary

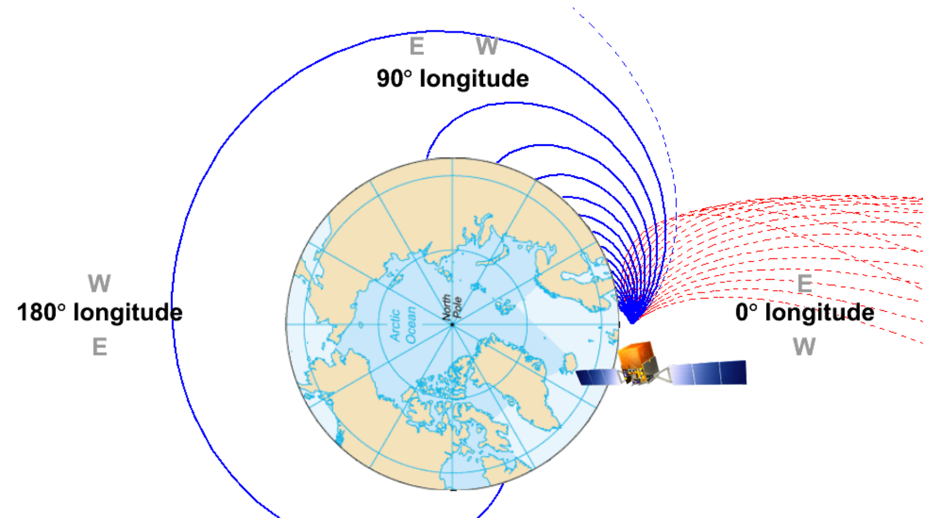


TMVA analysis for data with E>15 GeV

Geomagnetic field + Earth shadow = directions from which only electrons or only positrons are allowed

events arriving from West:
e^+ allowed, e^- blocked

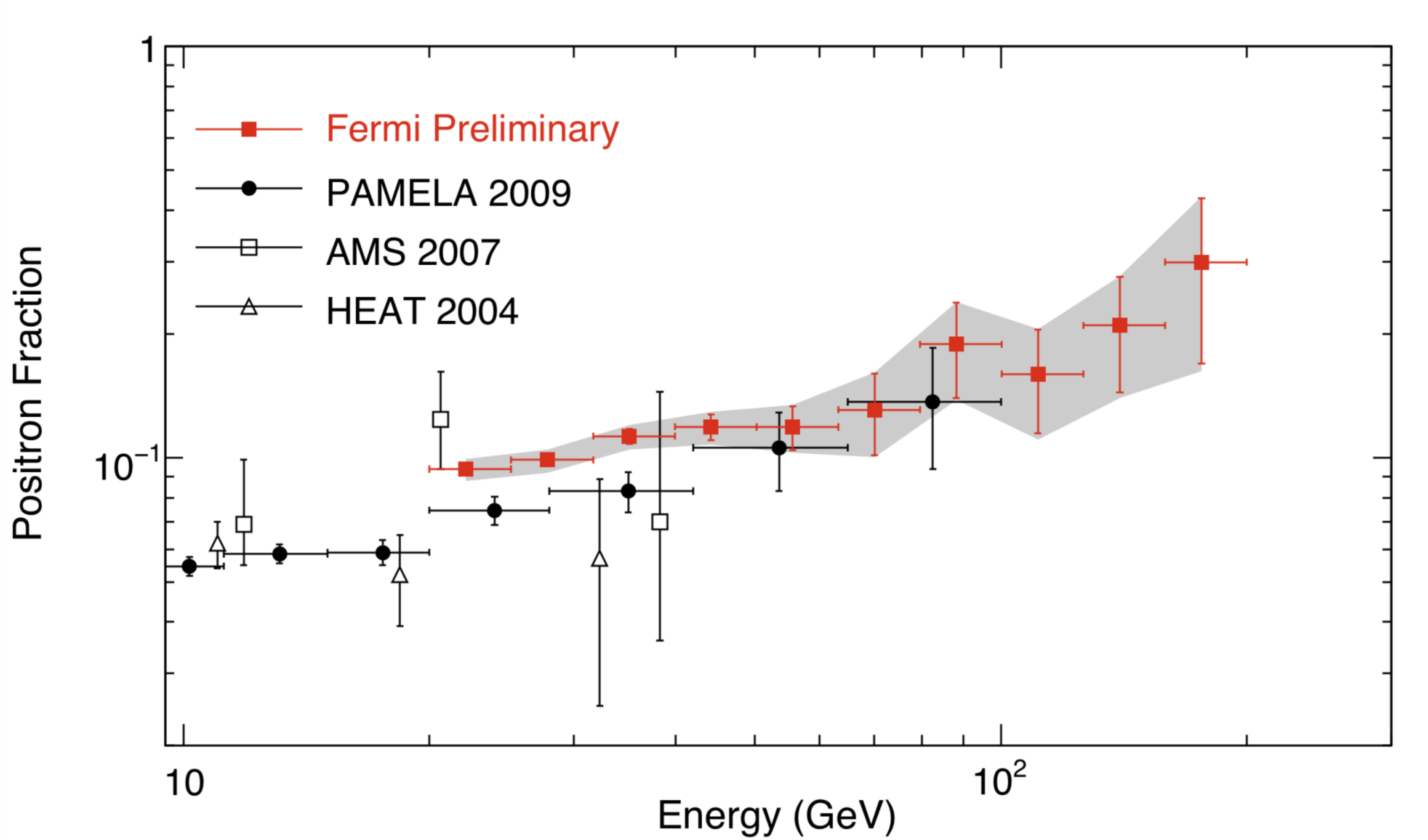




events arriving from East:
e^- allowed, e^+ blocked

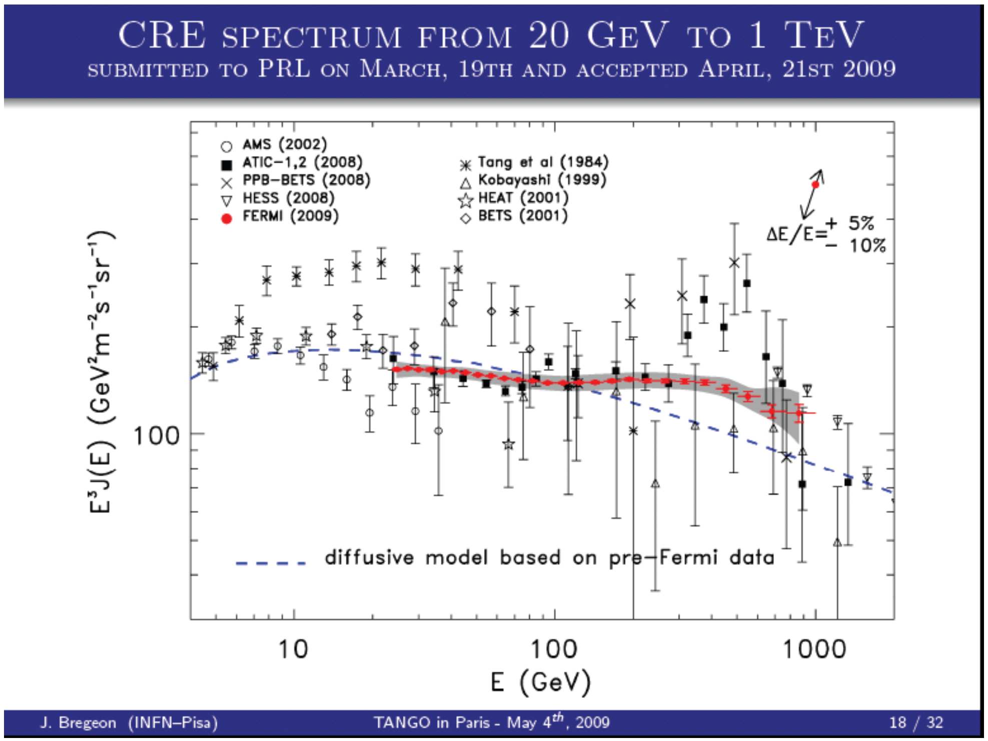
- For some directions, e^- or e^+ forbidden
- Pure e^+ region looking West and pure e^- region looking East
- Regions vary with particle energy and spacecraft position
- To determine regions, use code by Don Smart and Peggy Shea (numerically traces trajectory in geomagnetic field)
- Using International Geomagnetic Reference Field for the 2010 epoch

Final results: positron fraction

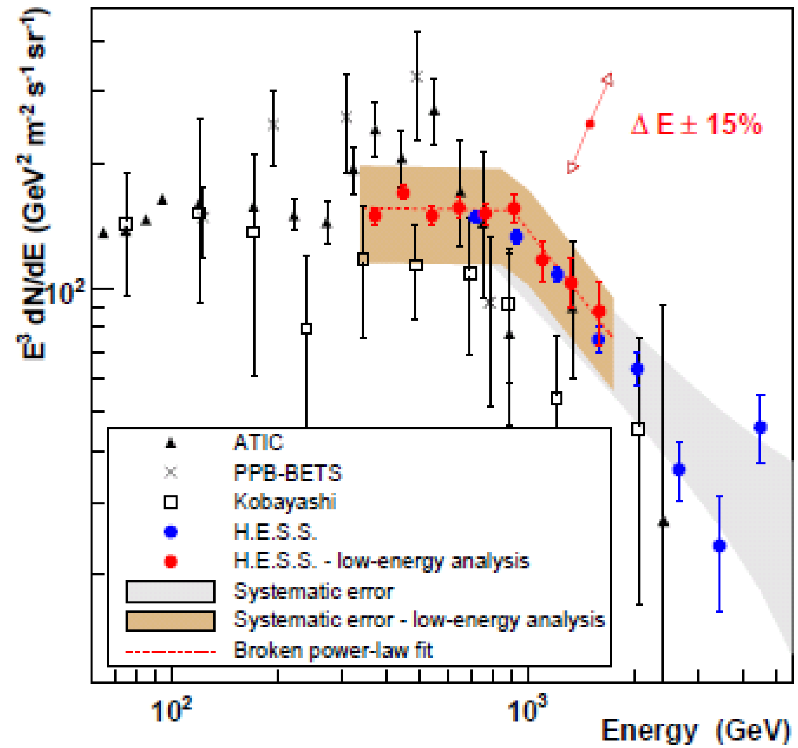


- Fraction = $\varphi(e^+) / [\varphi(e^+) + \varphi(e^-)]$
- We don't use the both-allowed region except as a cross check
- **Positron fraction increases with energy from 20 to 200 GeV**

Then, excellent observations of (e^{+}+e^{-}) in statistics are carried out by FERMI-LAT and HESS, and a new era of electron observation is opened probably by indicating a flattening of energy spectrum and a sharp cut-off over 1 TeV, respectively.

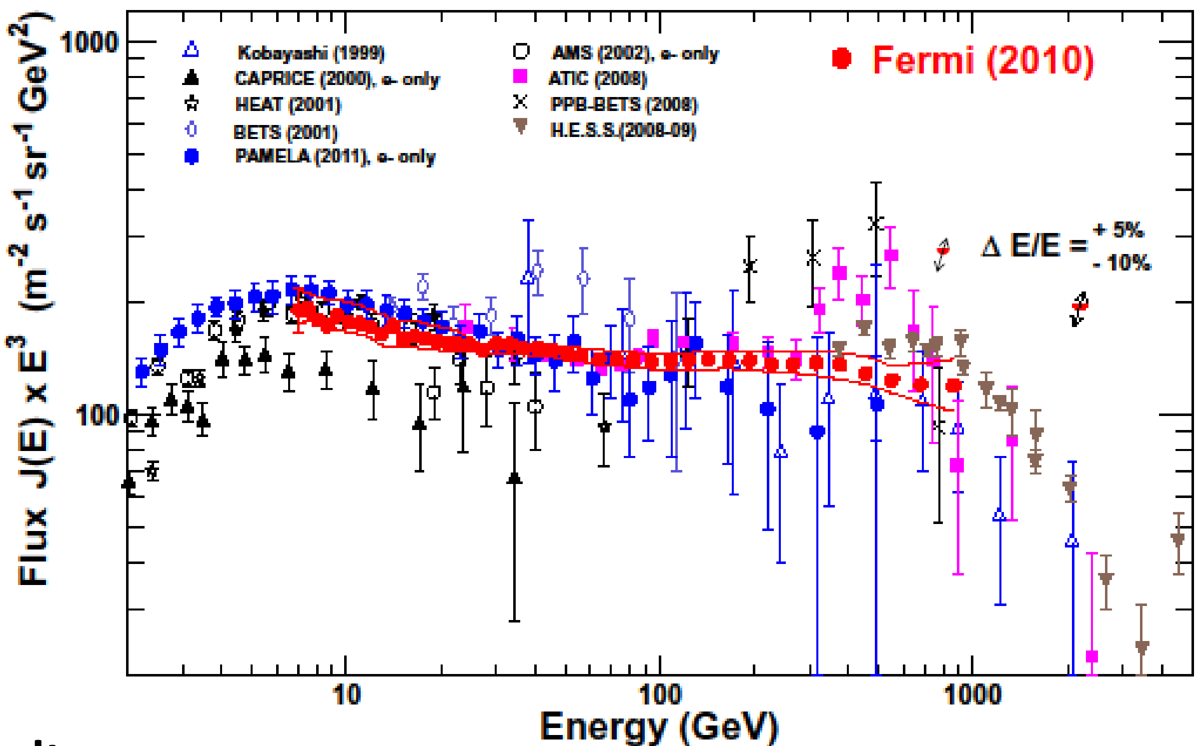


F.Aharanian et al. arXiv:0905:0105



I really appreciate their efforts to derive the electron spectrum in unexploded region.

Currently available results on high energy CRE

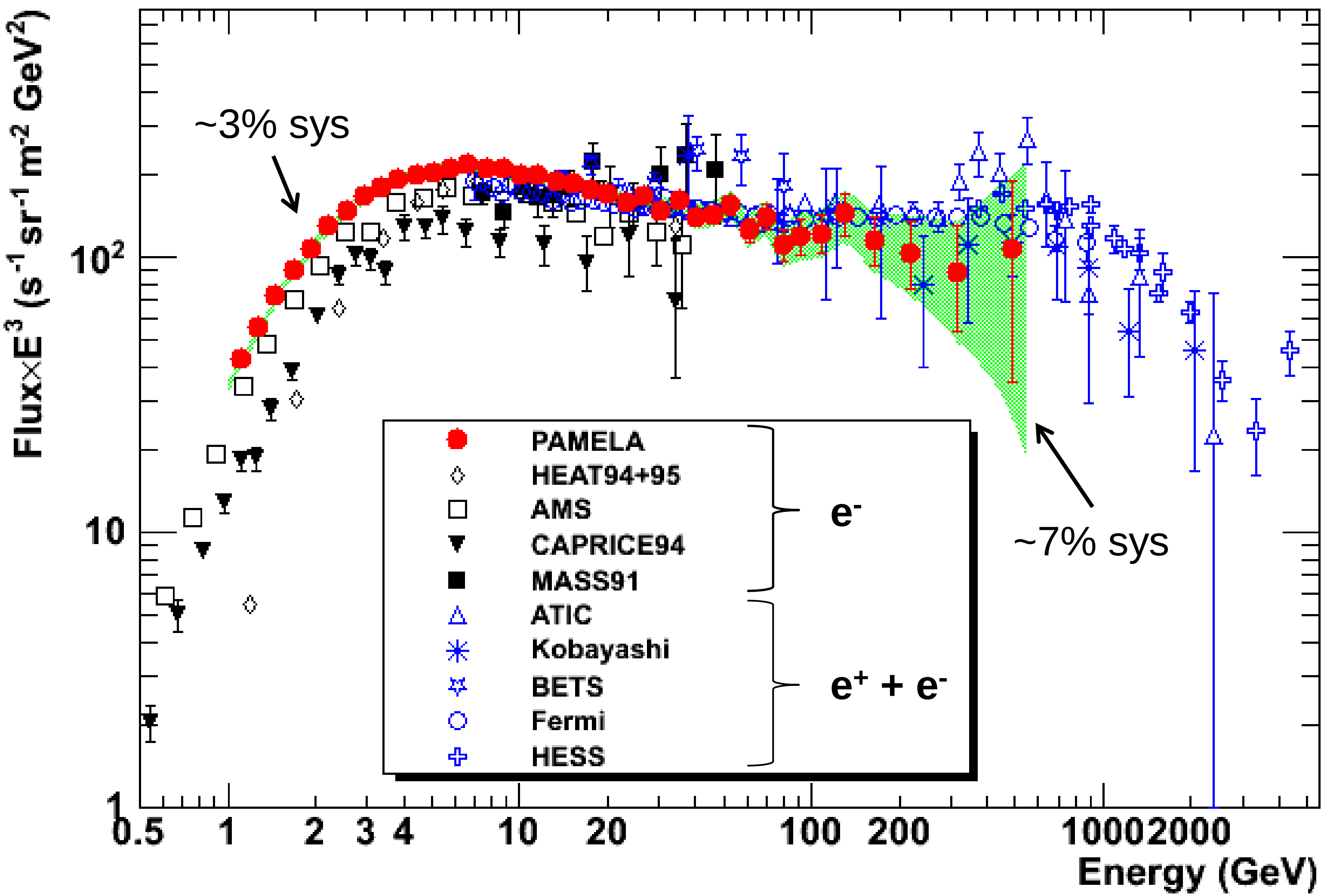


Fermi LAT results:

- **PRL 102, 181101, 2009 reported the spectrum from 20 GeV to 1 TeV, taken in the first 6 months of operation. Total statistics 4.7M events. Most cited Fermi LAT paper so far (over 450 times)**
- **PRD 82, 092004, 2010: spectrum from 7 GeV to 1 TeV, collected in the 1st year. Total statistics 7.95 M events. More than 1000 events in highest energy bin (772 – 1000 GeV)**

ICRC2011

Adriani et al., Phys. Rev. Lett. 106, 201101 (2011), arXiv: 1103.2880



Electron Observation for 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:

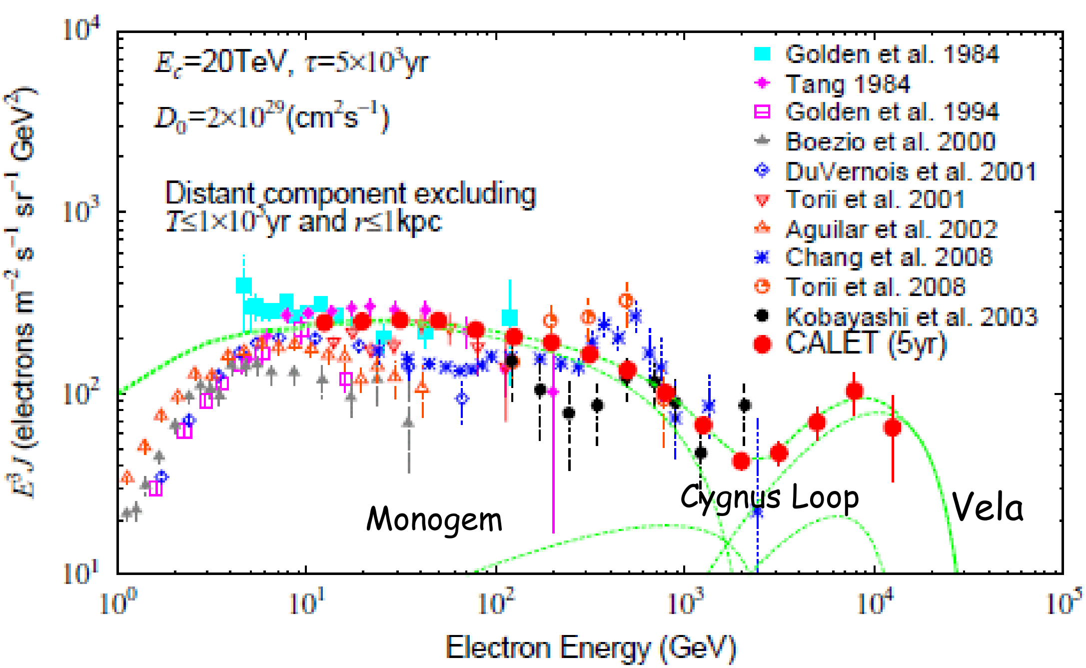
Electron efficiency = 70%
Proton rejection factor = 10^5
Geometrical factor = 0.12 m^2sr
Exposure time = 5 years

Primary electron spectrum from Fermi data with Hess cutoff:

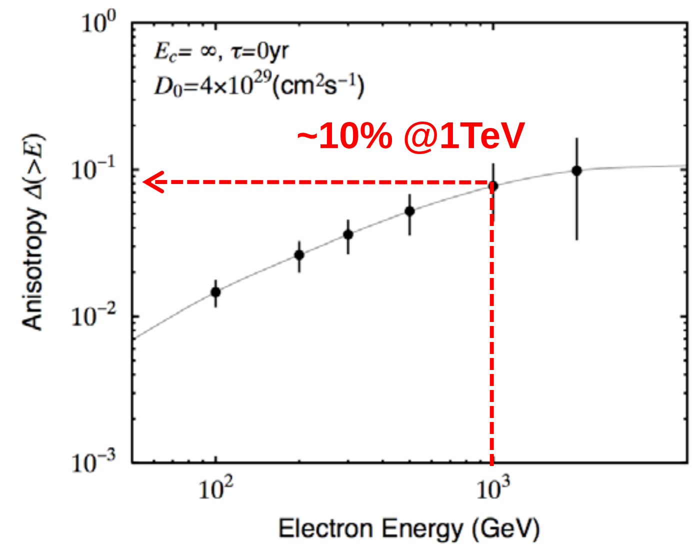
$J(E) = 185 * (E/1\ GeV)^{-3.045}\ e^{-E/3.4\ TeV}\ GeV^{-1}\ m^{-2}\ s^{-1}\ sr^{-2}$

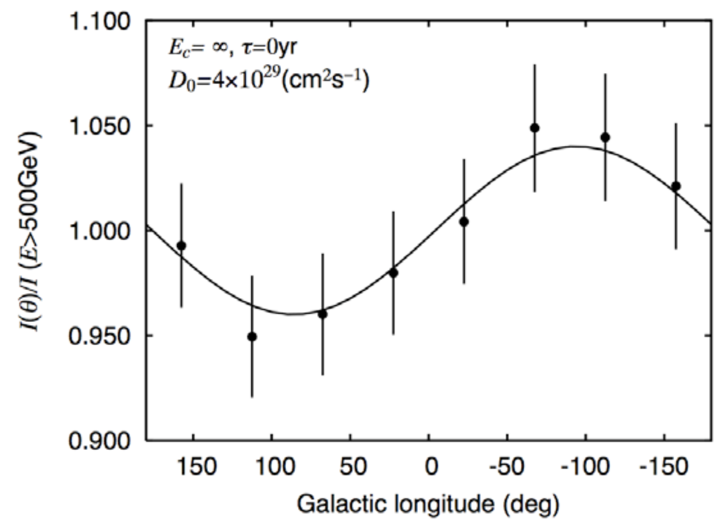
Vela spectrum from Astro-ph/0308470v1, Kobayashi et al., Figure 4 Top

Expected Flux



Expected Anisotropy from Vela SNR

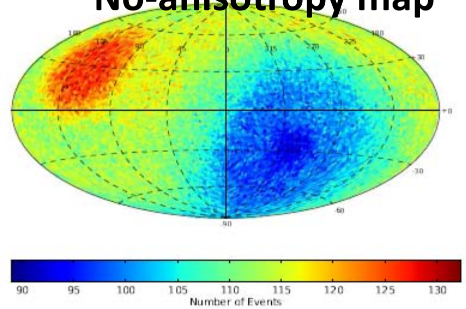




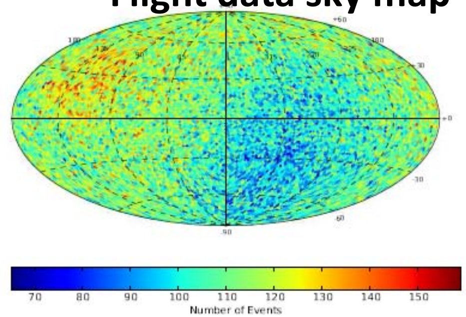
CR Electrons Anisotropy

Ackermann et al., Fermi LAT Collaboration, Phys Rev D82, 092003, 2009

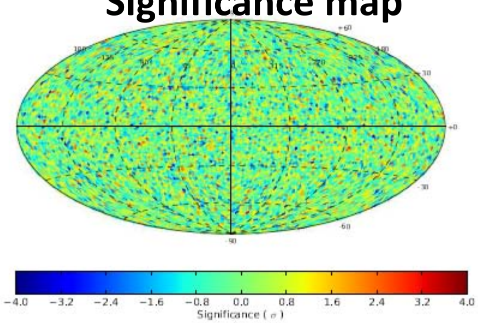
No-anisotropy map



Flight data sky map



Significance map

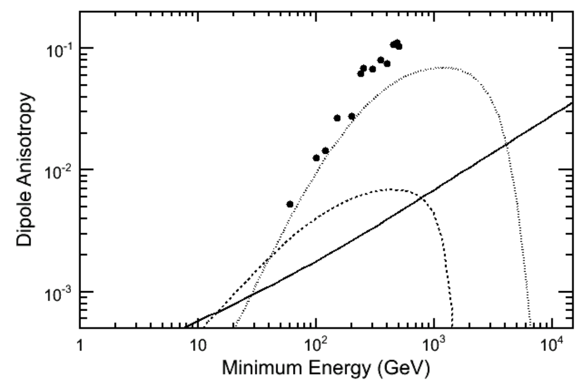


✓ **Search for CR electrons anisotropy provides an information on:**

- **Local CR sources and their distribution in space**
- **propagation environment**
- **heliospheric effects**
- **presence of dark matter clumps producing $e^+ e^-$**

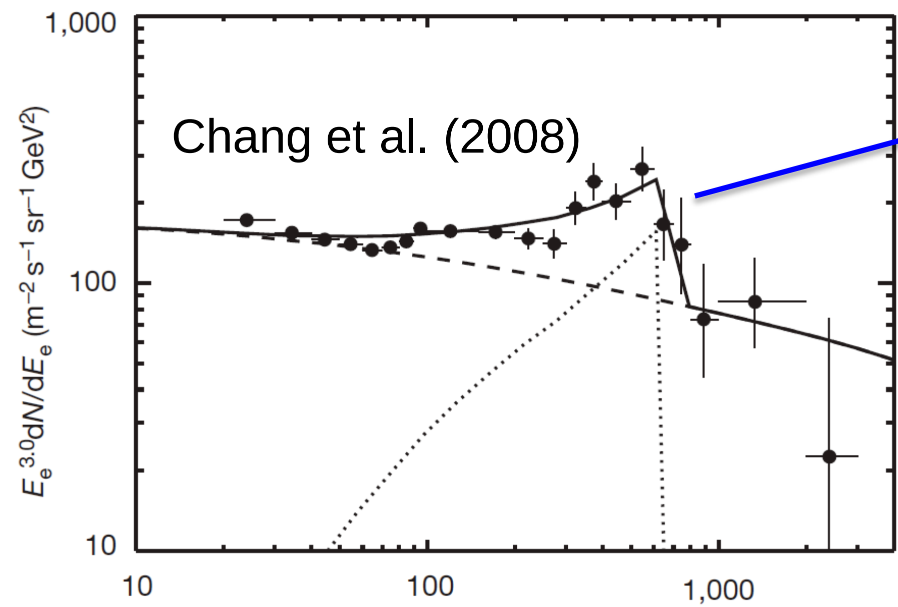
✓ **Result:**

- **More than 1.6 million electron events with energy above 60 GeV have been analyzed on anisotropy**
- **Upper limit for the dipole anisotropy has been set to 0.5 – 5% (depending on the energy)**
- **Upper limit on fractional anisotropic excess ranges from a fraction to about one percent (depending on the minimum energy and the anisotropy's angular scale)**
- **Our upper limits lie roughly on or above the predicted anisotropies**

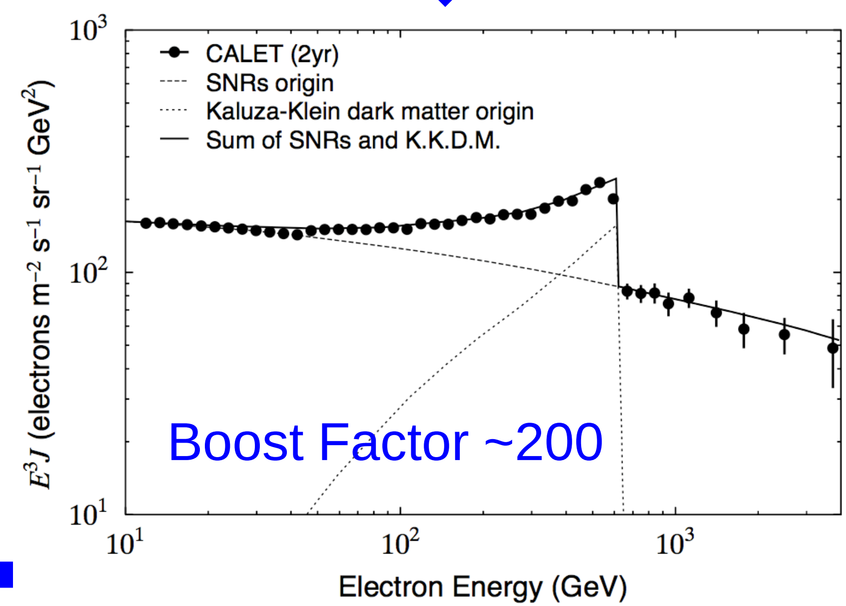


Dipole anisotropy vs. minimum energy. Solid line: Galprop spectrum, dashed line – Monogem, dotted line – Vela Circles: Fermi LAT 95 % CL data

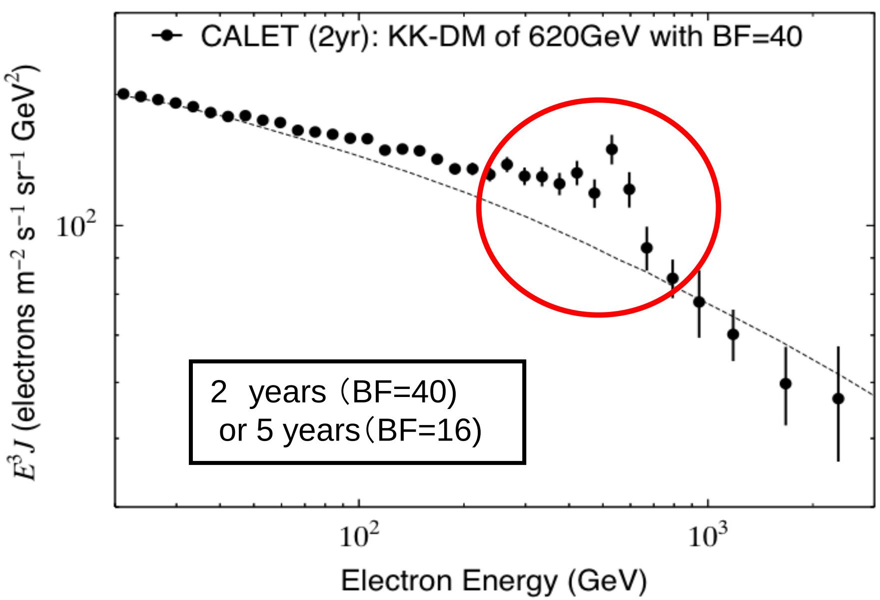
Electron (+ Positron) from Dark Matter Annihilation



Expected energy spectrum from Kaluza-Klein Dark Matter (m=620GeV)



Expected e^-+e^+ energy spectrum by CALET in case of the ATIC observation

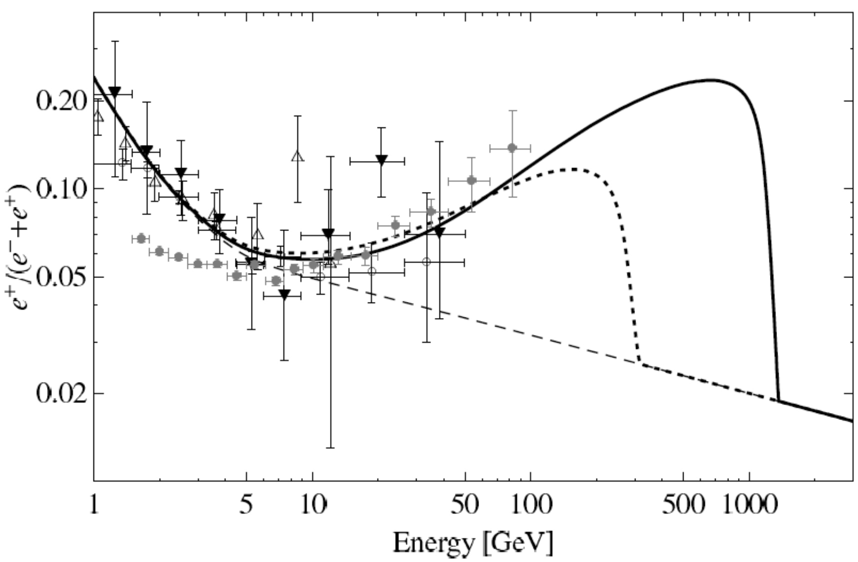


Dark Matter detection capability by CALET

Electron and Positron from Dark Matter Decay

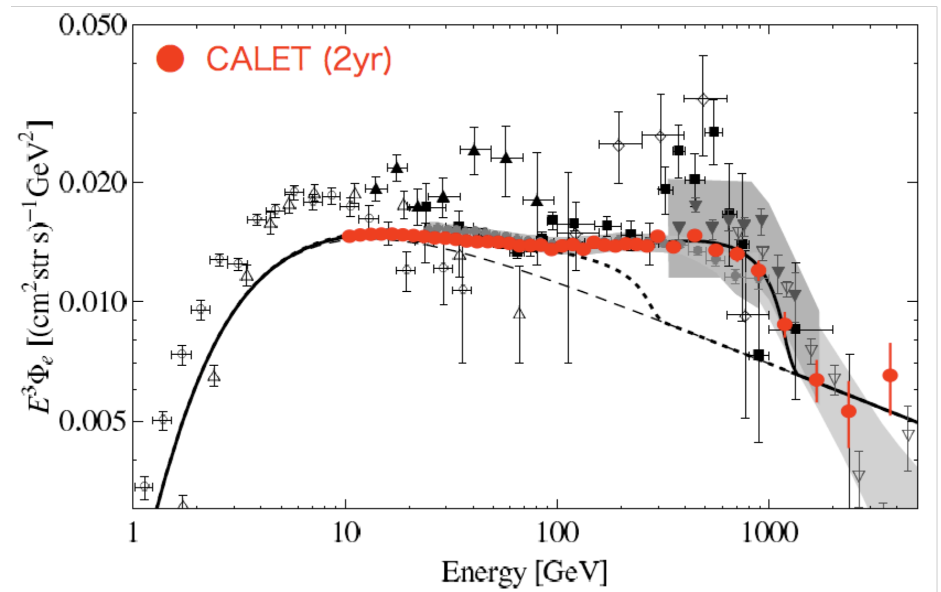
Decay Mode: D.M. -> $l^+l^-\nu$
Mass: $M_{D.M.}$=2.5TeV
Decay Time: $\tau_{D.M.}$ = 2.1×10^{26} s

Expected $e^+/(e^-+e^+)$ ratio by a theory and the observed data



Ibarra et al. (2010)

Expected e^-+e^+ energy spectrum by CALET observation

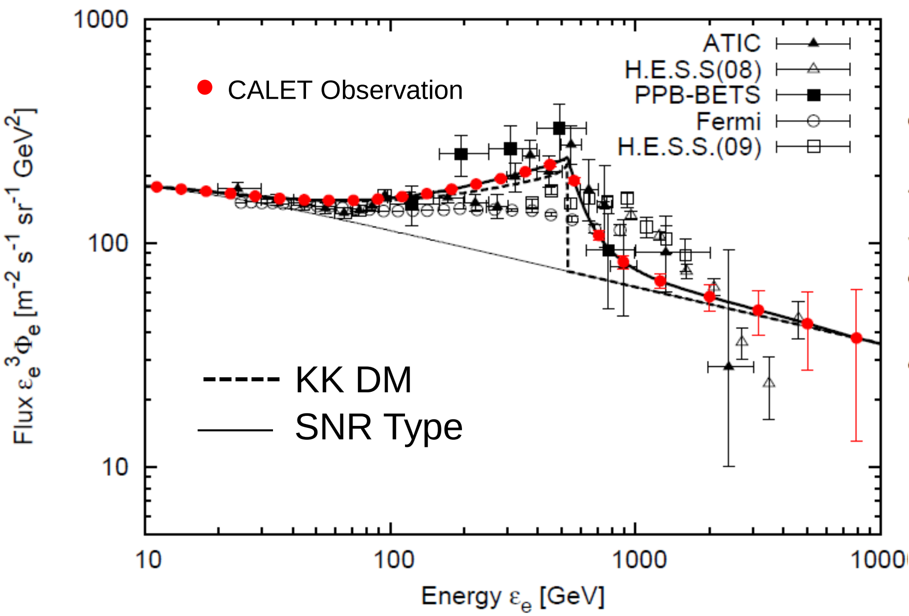


Observation in the trans-TeV region

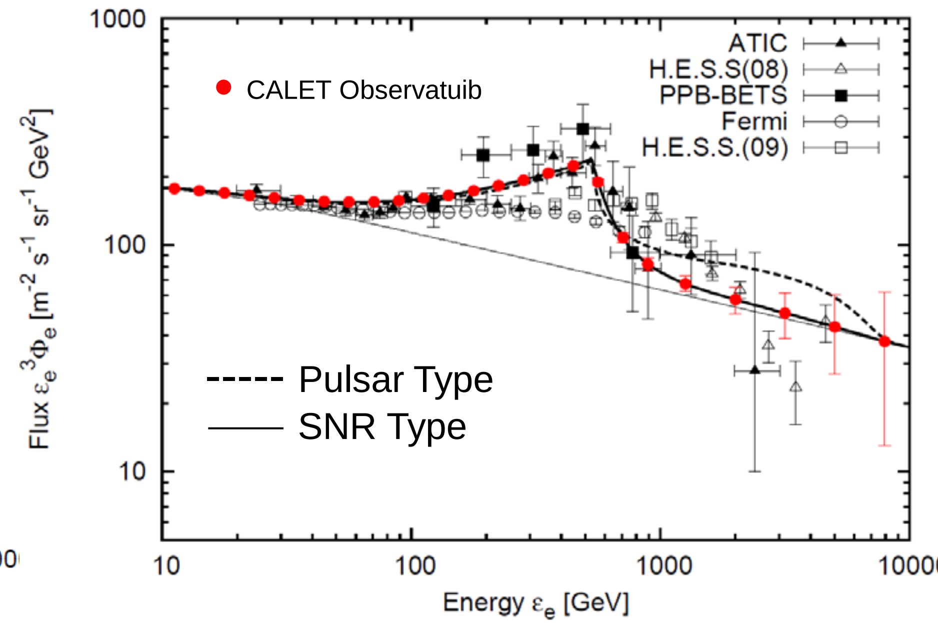
Dark Matter signal

Electron Observation (5 years) - Astrophysical Model-

KK DM(Δt=0) vs SNR type (Δt=10^5 year)



SNR Type vs Pulsar (Δt=3 × 10^5 year)

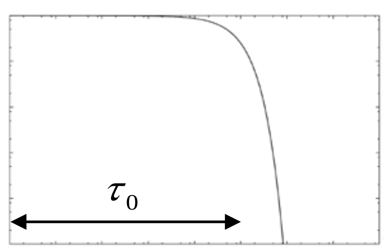


Source

age=5.6x10^5 yr,
E_e=1.7x10^{50} erg,
spectral index=1.7

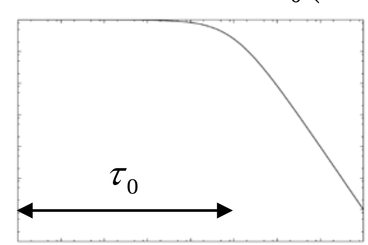
SNR Type (exp(-t))

$$Q_0(t) \propto \frac{E_{tot} \ln 4}{\tau_0} \exp\left(-\frac{t \ln 4}{\tau_0}\right)$$

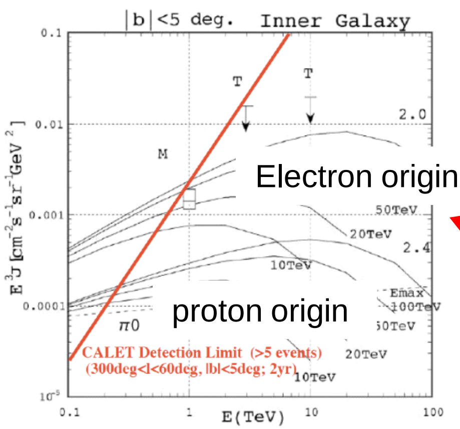


Pulsar Type (t^{-2})

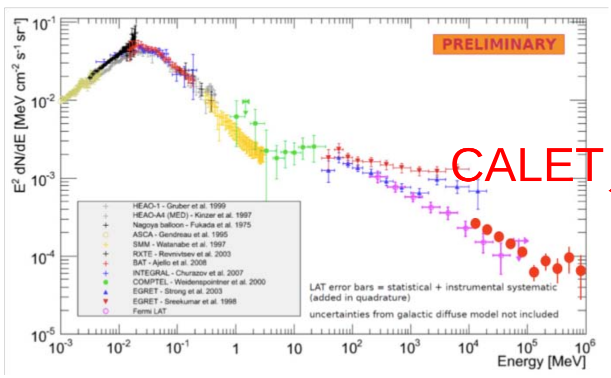
$$Q_0(t) \propto L_{spindown} = \frac{E_{tot}}{\tau_0 (1 + t/\tau_0)^2}$$



Diffuse Gamma-Ray Observation

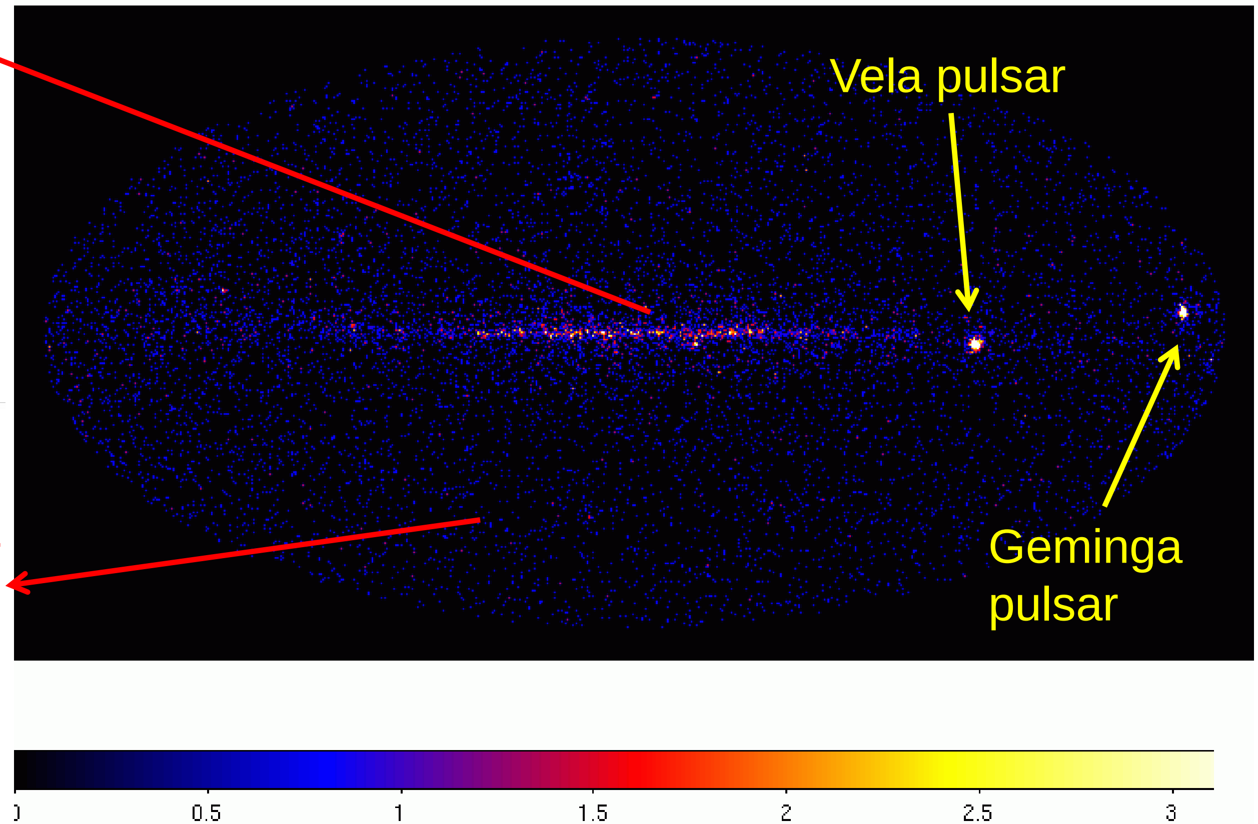


Detection limit of Galactic diffuse gamma rays



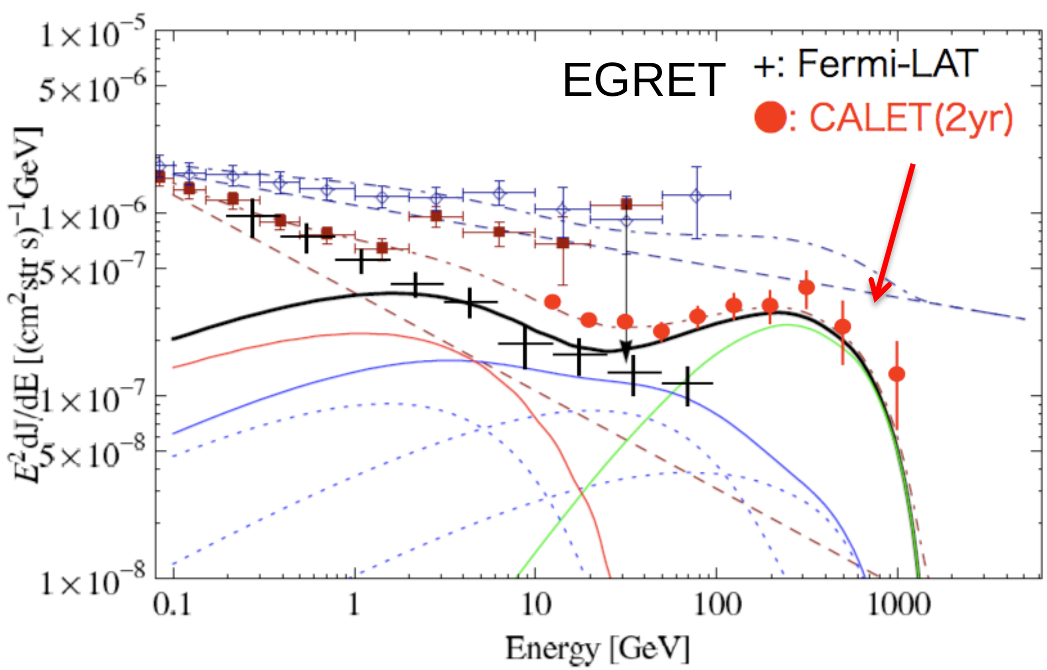
Extra-galactic diffuse gamma-ray spectra

Simulated CALET gamma-ray all sky map for 3yr (>10GeV)



Extragalactic Diffuse Gamma-rays from Dark Matter Decay

Decay Mode: D.M. -> $l^+l^-\nu$
Mass: $M_{D.M.}$=2.5TeV
Decay Time: $\tau_{D.M.}$ = 2.1x10^{26} s



Ibarra et al. (2010)

Extra-galactic diffuse gamma-rays

Extragalactic background
+
Gamma-rays from inverse Compton scattering of the electrons and positrons from DM decay with the inter-stellar and extragalactic photons
+
Gamma-rays from DM

Observation in the sub-TeV region

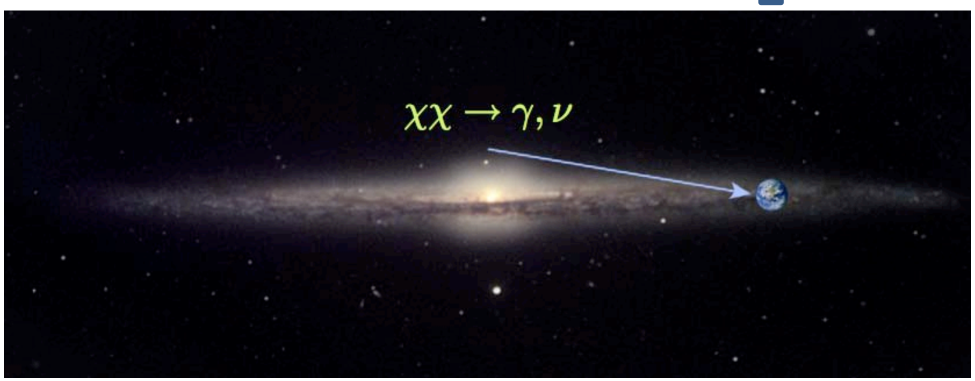
→ Dark Matter signal

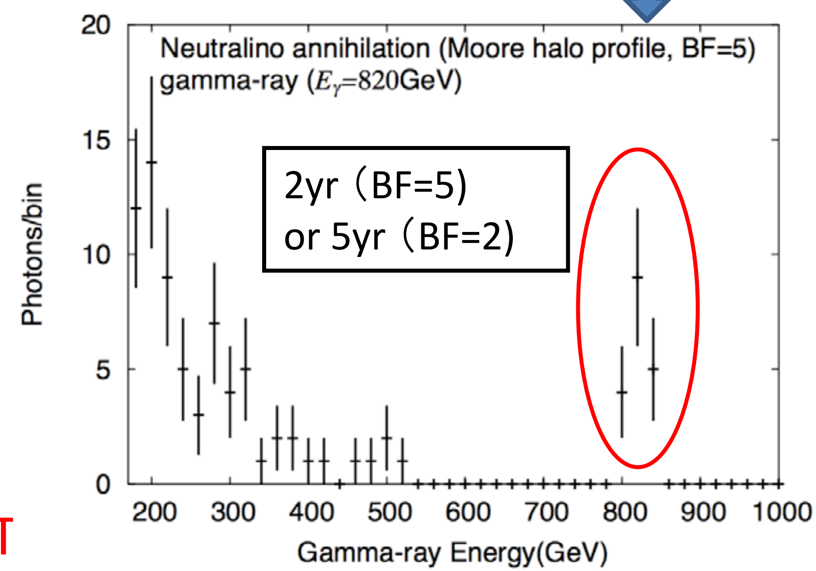
Gamma-ray line from Dark Matter

WIMP Dark Matter（Neutralino, Kaluza-Klein D.M.）

→ Annihilation or Decay

→ Gamma-ray Line





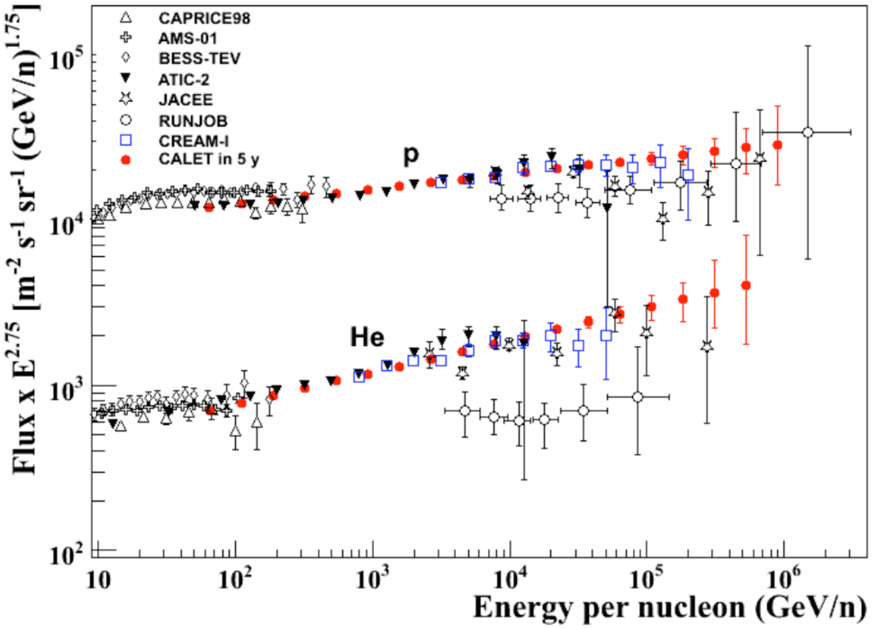
Excellent energy resolution with CALET
（2%：10GeV～10TeV）

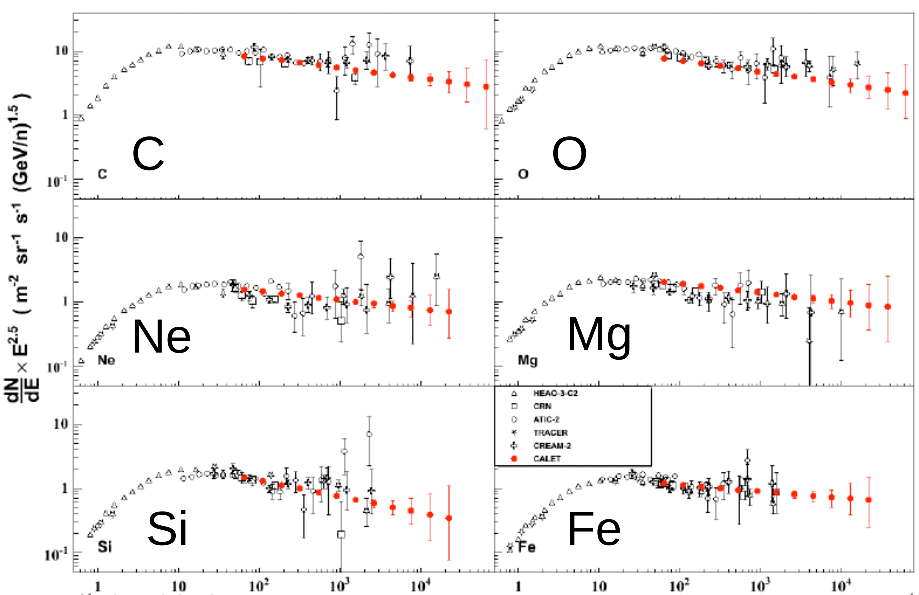
→ Detection for gamma-ray line due to DM annihilation or decay

Expected gamma-ray line for DM (m=830 GeV) annihilation by CALET observation

(ref. Bergstrom et al. 2001)

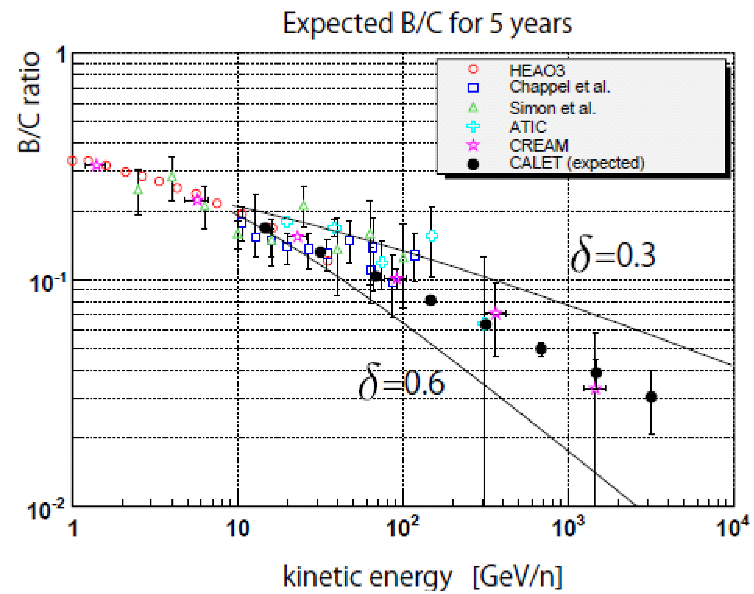
Proton and Nucleus Observation（5years）

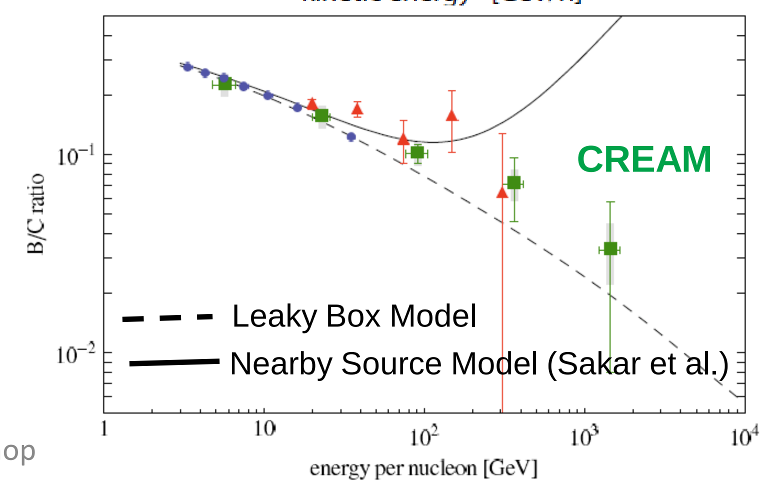




2ry/ 1ry ratio (B/C)

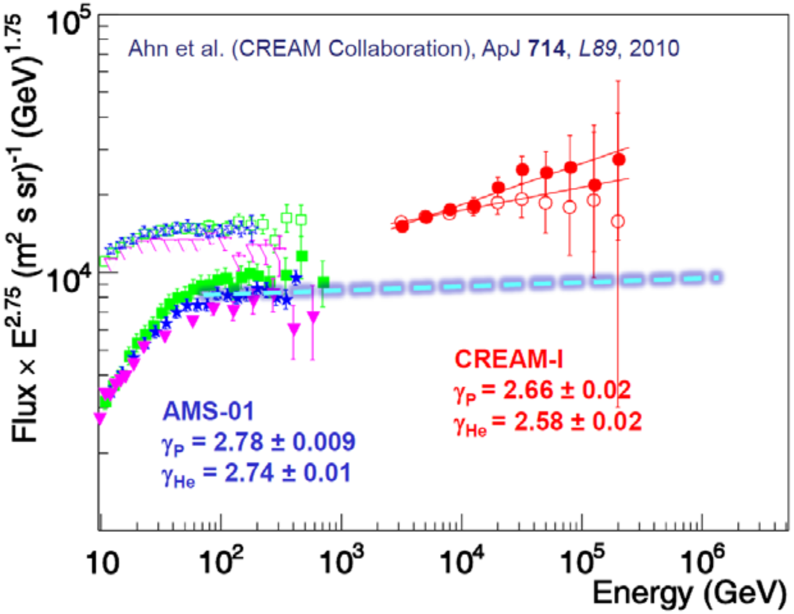
- Energy dependence of diffusion constant: $D \sim E^{\delta}$
- Observation free from the atmospheric effect up to several TeV/n



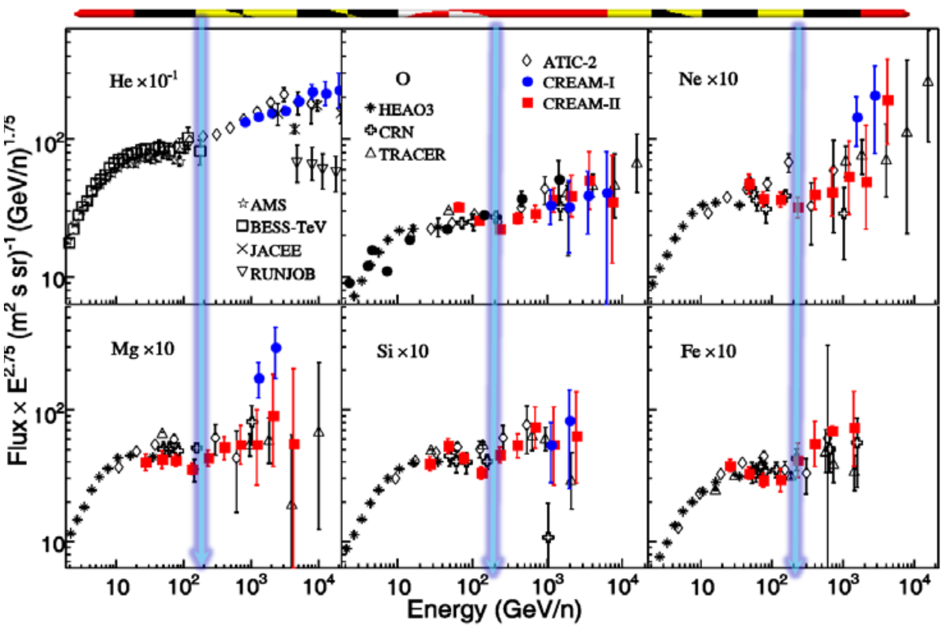


CREAM Results showing hardening of spectra around 200 GeV/n

TeV spectra are harder than spectra < 200 GeV/n



Discrepant hardening

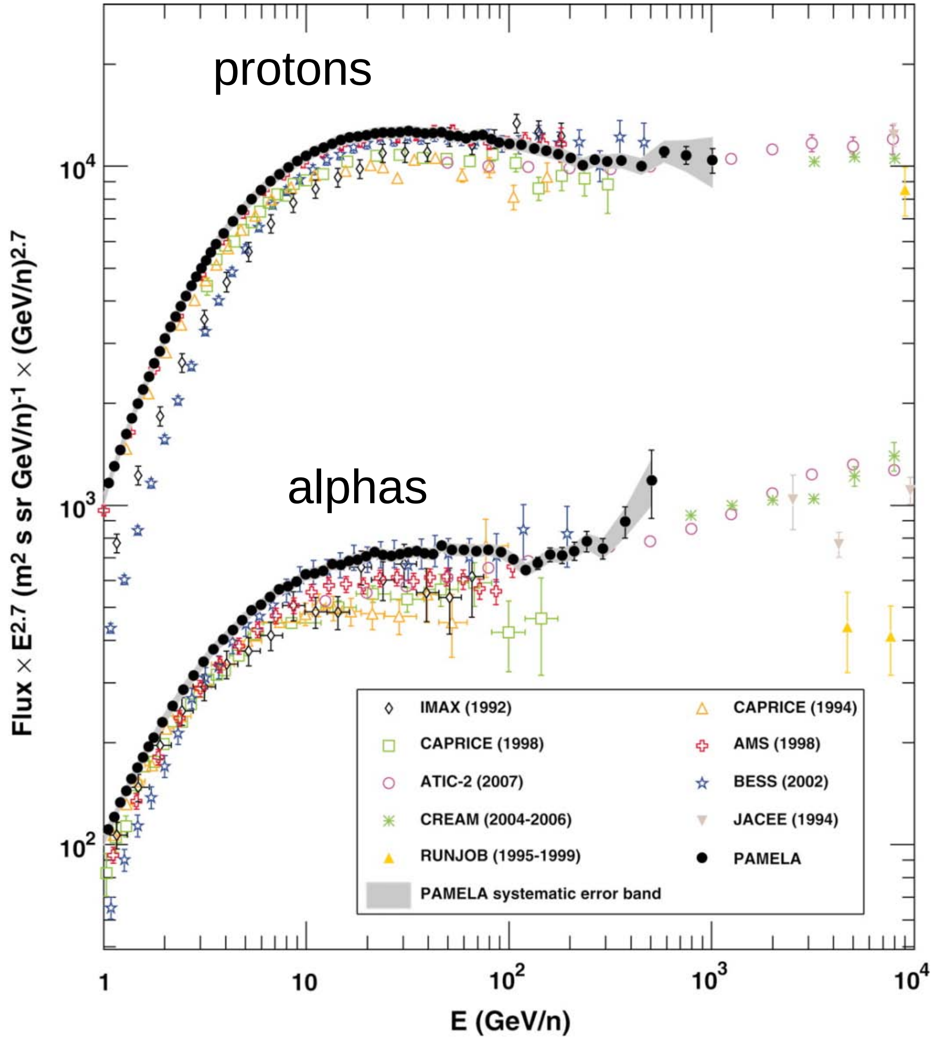


The hard spectra do not continue > ~20 TeV

ICRC2011

PAMELA proton and alpha spectra

Science 332 (6025): 69-72 (2011)



- ~$E^{-2.7}$ power law
- Proton flux an order of magnitude larger than alpha flux

ICRC2011

New Measurements: Boron to Carbon Ratio

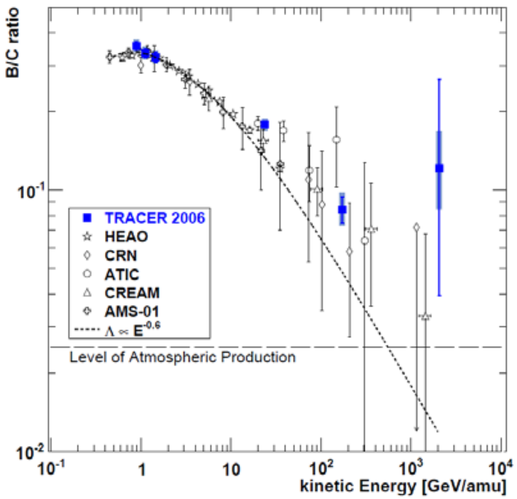
All data.

TRACER

- **Dotted Line**

  Extrapolation of $E^{-0.6}$ from fit to data below 100 GeV / amu.

  Next talk by Obermeier.



B/C ration up to 1TeV/n

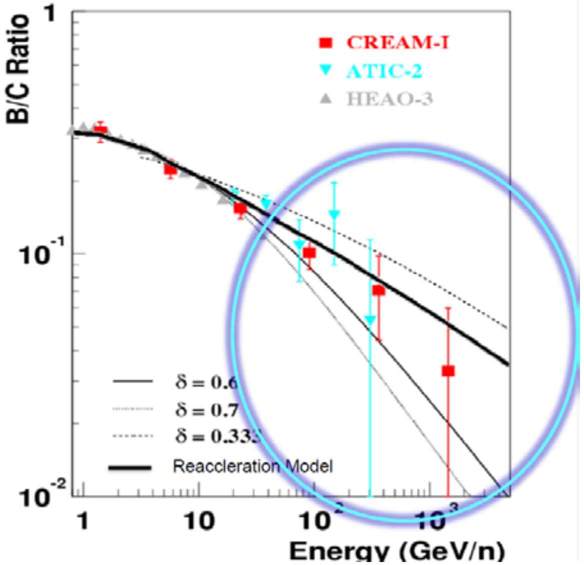
CREAM

What is the history of cosmic rays in the Galaxy?

Ahn et al. (CREAM collaboration) Astropart. Phys., 30/3, 133-141, 2008

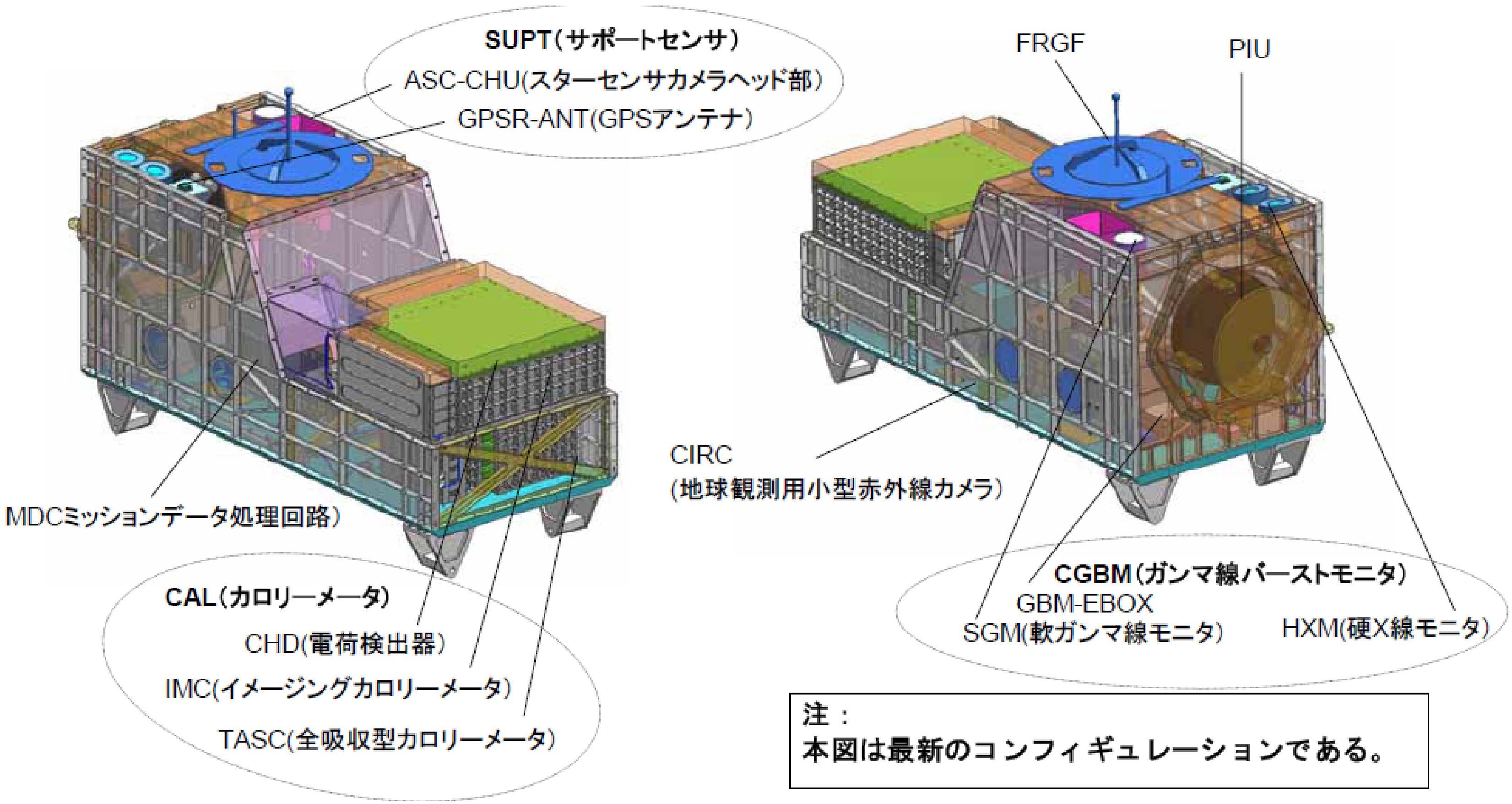
- Measurements of the relative abundances of secondary cosmic rays (e.g., B/C) in addition to the energy spectra of primary nuclei will allow determination of cosmic-ray source spectra at energies where measurements are not currently available
- First B/C ratio at these high energies to distinguish among the propagation models

$$X_e \propto R^{-\delta}$$



CALET System Configuration

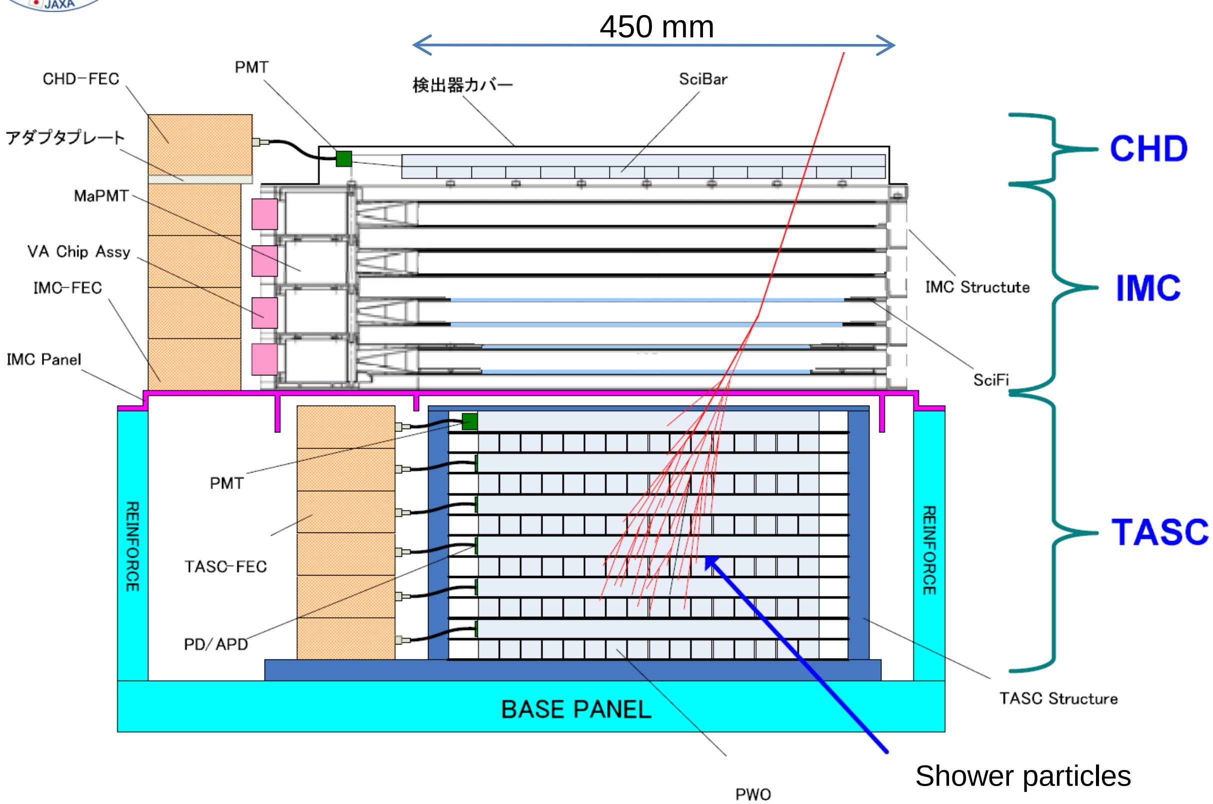
(IA)



Total Mass of Payload： 586 kg (Nominal) — 620kg (Max)

- ☐ Detector: Calorimeter, Gamma-ray Burst Monitor (HXM, SGM) + MDC
- ☐ Support Sensor: Advanced Sky Camera, GPS
- ☐ Additional Sensor: Compact Infrared Camera for Earth Observation (CIRC)

CALET/CAL Instrument

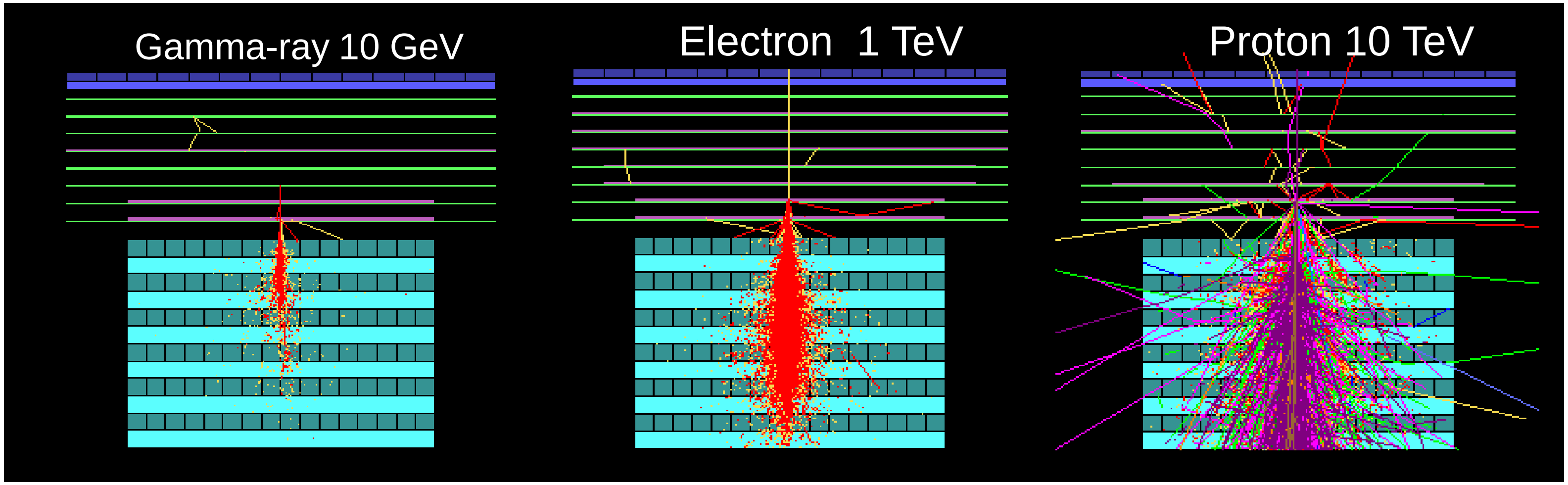


Expected Performance
(from Simulations and/or Beam Tests)

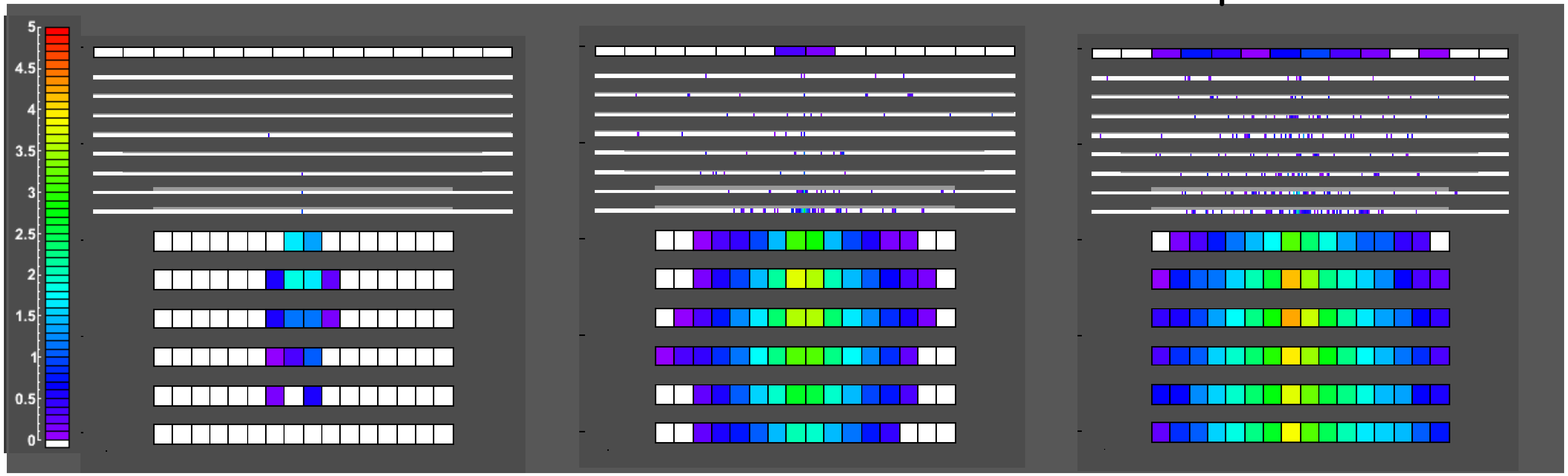
- SΩ :
  1200 $cm^2 sr$ for electrons
  1000 $cm^2 sr$ for gamma-rays
- ΔE/E :
  a few % (>10 GeV) for e,γ's
  ~30 % for protons
- e/p separation : 10^{-5}
- Charge resolution : 0.15-0.3 e
- Angular resolution : Preliminary
  0.24-0.76 deg. for gamma-rays

	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	Plastic Scintillator : 14 × 1 layer (x,y) Unit Size: 32mm x10mmx450mm	SciFi : 448 x 8 layers (x,y) = 7168 Unit size: 1mmsq x 448 mm Total thickness of Tungsten: 3 r.l.	PWO log: 16 x 6 layers (x,y)= 192 Unit size: 19mm x 20mm x 326mm Total Thickness of PWO: 27 r. l.
Readout	PMT+CSA	64 -anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)

CALET Shower Imaging Capability (Simulation)



In Detector Space



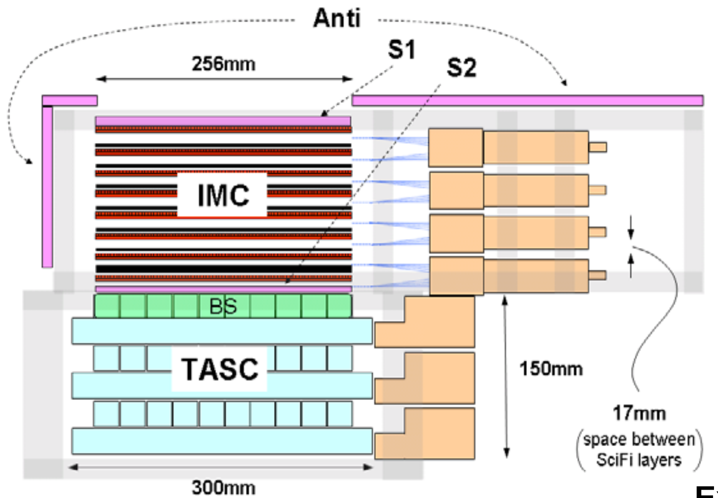
- Proton rejection power of 10^5 can be achieved with the IMC and TASC shower imaging capability.
- Charge of incident particle is determined to ΔZ=0.15-0.3 with the CHD.

CALET Prototype Test

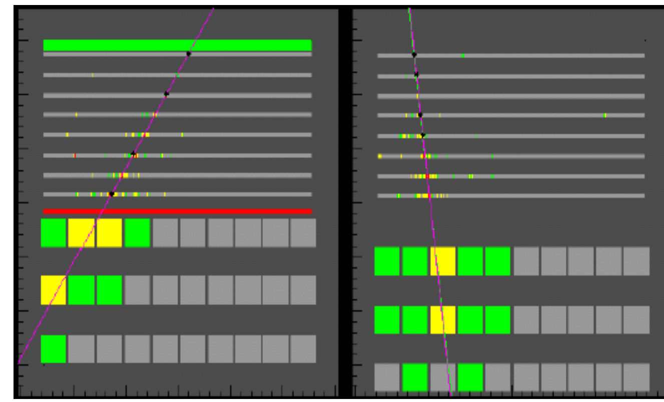
Balloon Experiment of the CALET Prototype (1/4 - Scale of CALET) in 2009 , bCALET2

bCALET2 Detector

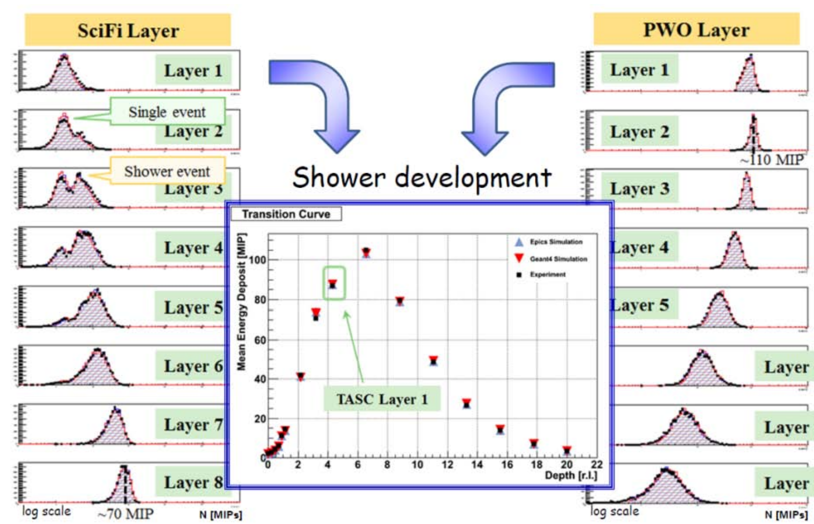
Schematic Side View



Example of Observed Electron Candidate

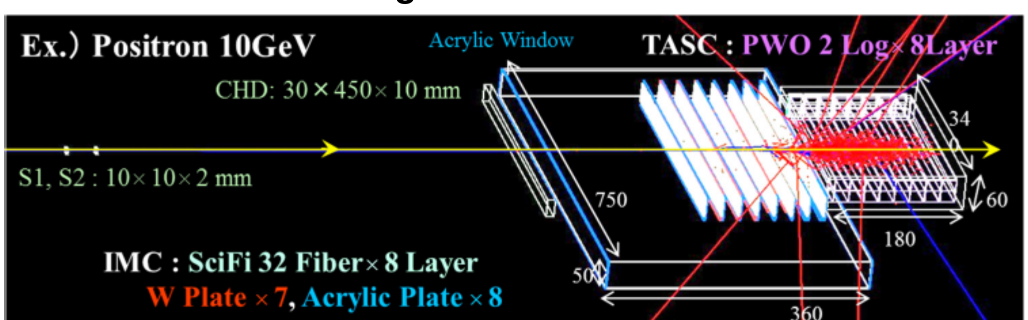


Experimental results of energy deposit by 10 GeV e, compared with GEANT4 and EPICS



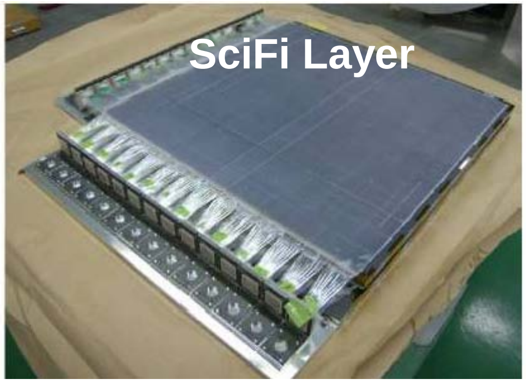
CERN-SPS Beam Test of the Scale-model of CALET in 2009, 2010 (2011)

Configuration of Detector



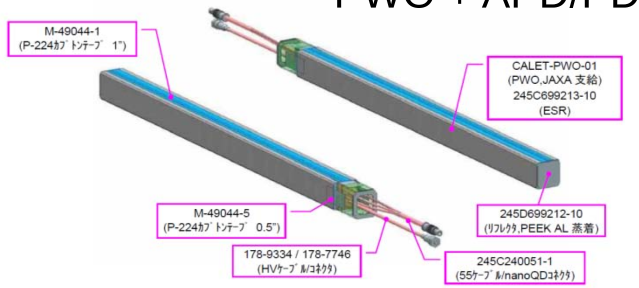
Development of Bread Board Model

IMC

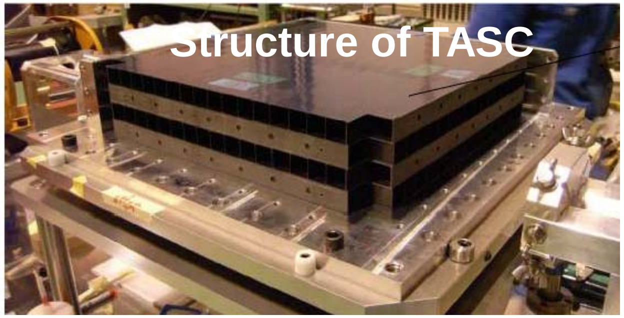


TASC

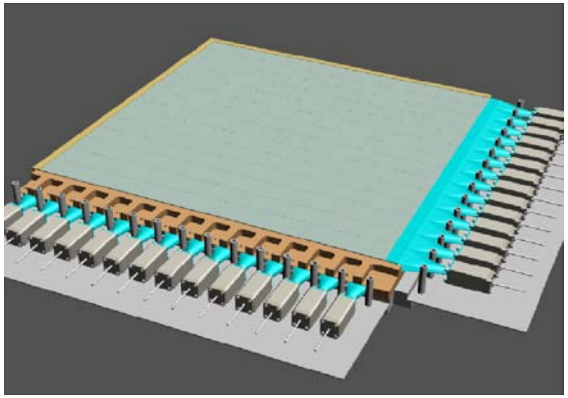
PWO + APD/PD



CHD



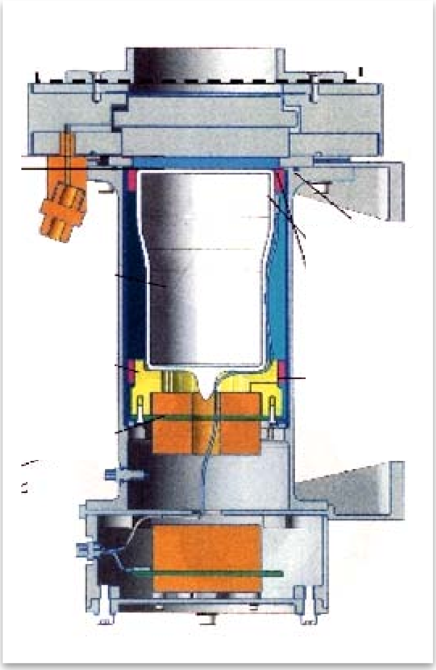
Design Study of Structure



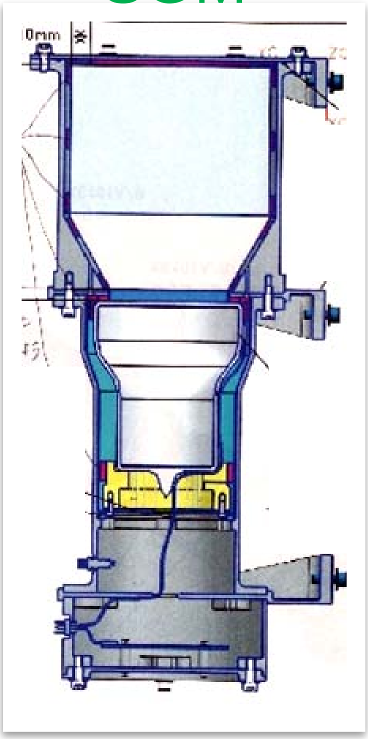
3.1 CGBM instrumentation – Sensors –

- 2 Hard X-ray Monitors (HXMs)
  - $LaBr_3(Ce)$ (ϕ66 mm x 0.5 inch) with a 410um thick beryllium window by Saint Gobain Crystals. This crystal is used in GRB observations for the first time.
  - Hamamatsu 2.2-inch PMT R6232-05
  - High voltage divider and charge-sensitive amplifier

HXM



SGM



- Soft Gamma-ray Monitor (SGM)
  - BGO (ϕ4 inch x 3 inch) + Light guide by OKEN Co Ltd.
  - Hamamatsu 3-inch PMT R6233-20

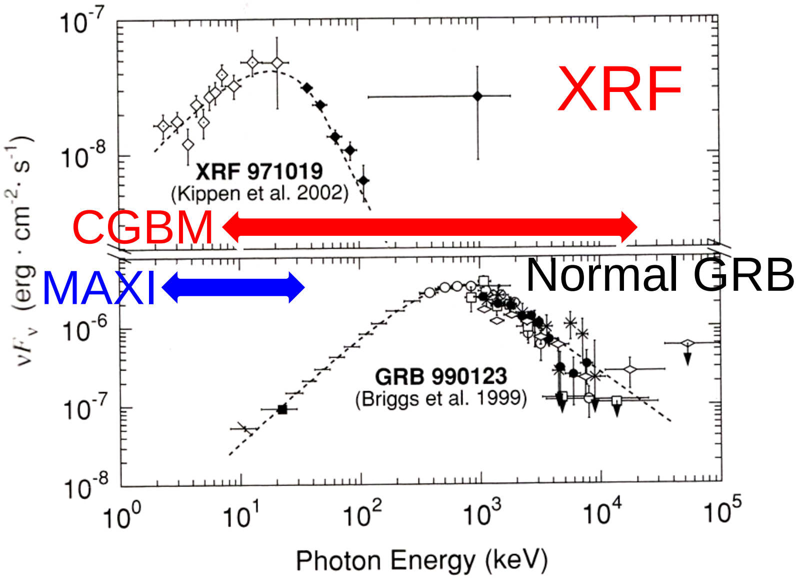
2. GRB observations with CALET (I)

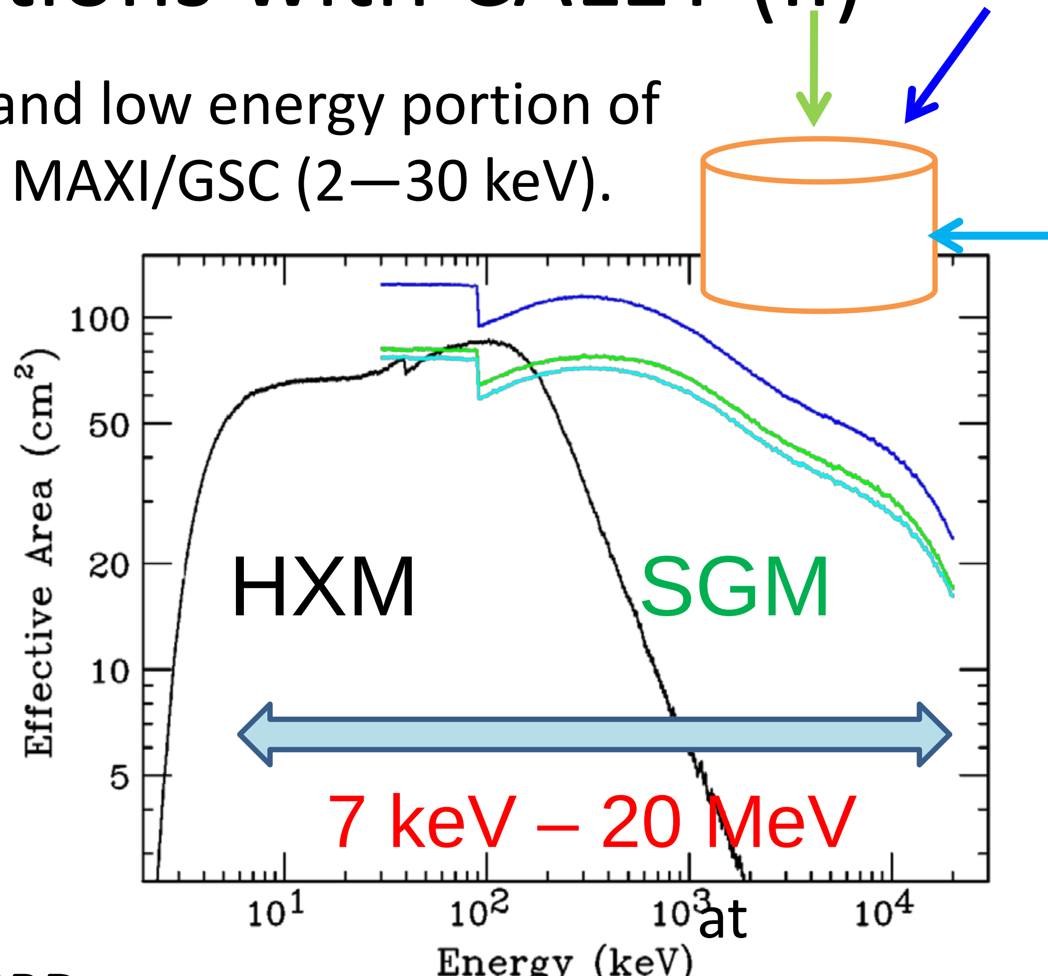
- Simultaneous broadband coverage with CAL(GeV-TeV), CGBM(keV-MeV), and possibly ASC (Advanced Star Camera: optical)
- The CAL would be comparable to the CGRO/EGRET sensitivity.

Parameters	CAL	CGBM
Energy	1 GeV- 10 TeV (GRB trigger)	HXM: 7keV– 1MeV (Goal 3 keV--3 MeV) SGM: 100keV– 20MeV (Goal 30keV-30MeV)
Effective area	~1000 cm^2	68 cm^2 (2HXMs), 82 cm^2 (SGM)
Angular resolution	2.5 deg@1 GeV, 0.4 deg@10 GeV	No localization capabilities by CGBM itself, but IPN localization is possible
Field of view	~45 deg.(~2 str.)	~π str. (HXM), ~4π str. (SGM)
Dead time	~1.8 ms	~20 us
Time resolution	1 ms	GRB trigger：62.5 us (Event-by-event data) Normal mode:1/8 s with 4 channels and 4 s with 256 channels (Histogram data)

2. GRB observations with CALET (II)

- Study of X-ray flashes (XRFs) and low energy portion of normal GRBs with CGBM and MAXI/GSC (2—30 keV).

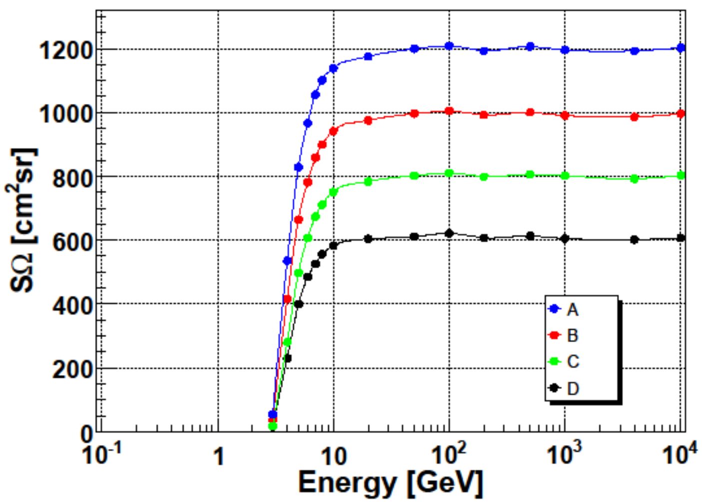




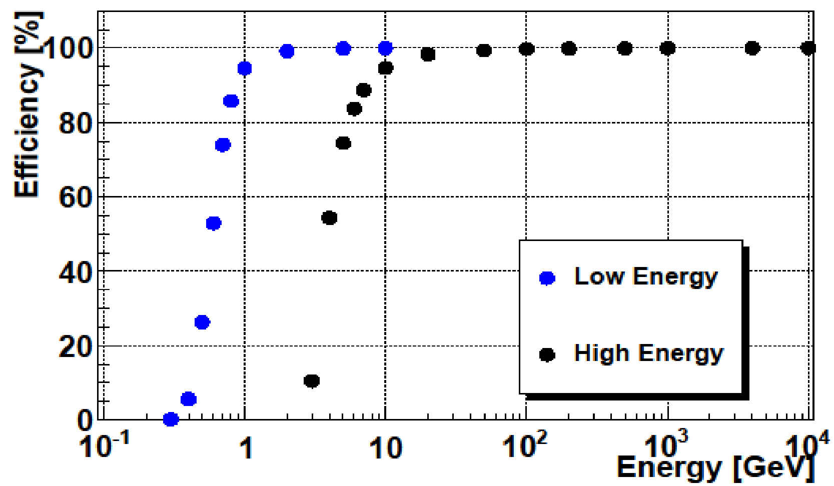
- Study of absorption features at 20-30 keV seen by Ginga/GBD.
- The CGBM effective area is comparable to that of Ginga/GBD (~60 cm^2). We will expect to detect -40 GRBs/year by HXM and -80 GRBs/year by SGM.

CALET Performance for Electron Observation

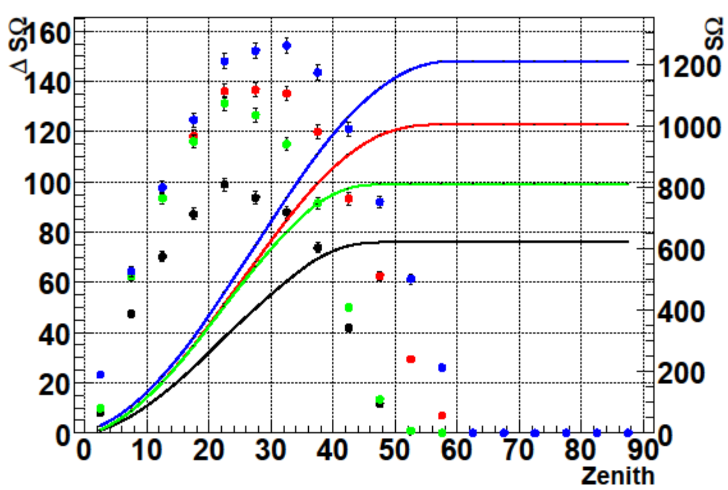
Geometrical Factor (Blue Mark)



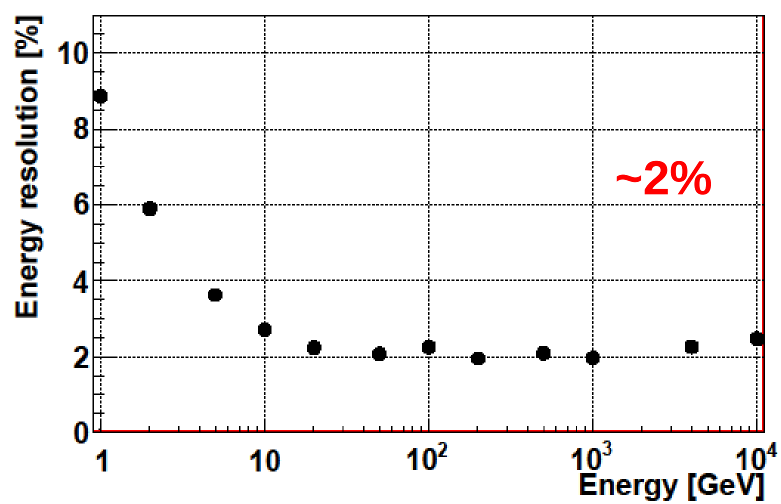
Detection Efficiency



SΩ (for electrons) vs Incident Angle



Energy Resolution

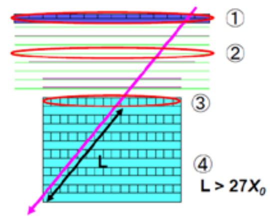


CALET Performance by Simulation

Expected Performance

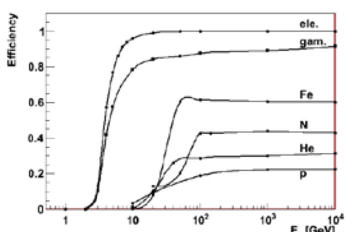
Event Selection

We select the events of which shower axis pass through;
① CHD (for nuclei)
② 4th layer of IMC
③ top layer of TASC
④ length in TASC (>27X_0 : thickness of TASC)
(protons and nuclei) To avoid energy leakage effects, we select the events with the first collision above the second TASC layer.



Trigger Efficiency

In the high energy region over threshold, the efficiency for electrons is almost 100% while that for protons is about 20%: The HES selects showering electron events and rejects non-showering proton events very efficiently.



Trigger efficiency by HES

Geometric Factor

(Electrons) 1200 cm² sr
(Gamma Rays) 1000 cm² sr

Assuming the simple extrapolation of the electron spectrum by Fermi, CALET can observe about 1000 electrons over TeV region with a 5 year exposure.

Angular Resolution

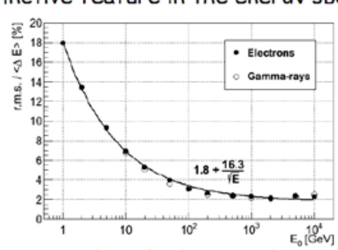
(Electrons) θ_{68} : 0.26 ~ 2.0 deg (1~10GeV)
θ_{68} : 0.13 ~ 0.26 deg (>10GeV)
(Gamma Rays) θ_{68} : 0.24 ~ 0.76 deg

The incident direction is estimated by fitting shower axis in IMC. Besides incident directio the precise track reconstruction is important for particle identification of electrons and gamma-rays.

Energy Resolution

□ Electrons and Gamma-rays

CALET, with its thick calorimeter (~30X_0), provides excellent energy resolution, ~2% (>100GeV) It enables us to detect a distinctive feature in the energy spectrum.



Energy resolution for electrons and gamma-rays

□ Protons and Nuclei

The energy resolution for protons and nuclei does not depend on incident energy. For heavy nuclei like Fe, the energy deposit in the calorimeter is dispersive because the number of π^0's produced depends on the collision targets. If we select events of which the first interaction occur at the top layer in TASC the energy resolution becomes better.

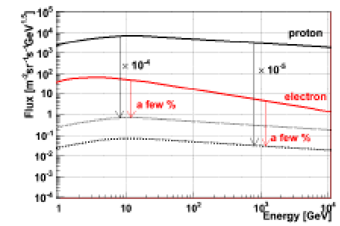
Energy resolution for nuclei [%]

H	Ne	N	Fe	Fe (collision at 1st TASC layer)
30	20	17	25	17

Electron / Proton Separation

Ratio of Flux

e : p = 1 : 100 @10GeV
e : p = 1 : 1000 @1TeV
⇒ Requirement for proton contamination: ~1% at 1TeV (rejection power: ~10^5)



Flux of Electron and Proton (x$E^{2.5}$)

The Method of Identification

We distinguish electrons and protons from the difference in shower development in TASC.

- **Energy Weighted Spread R_E**
The lateral distribution of the electromagnetic shower is narrower than that of hadronic shower due to the spread of the secondary hadrons.
- **Energy Fraction F_E**
The electromagnetic shower develops earlier than the hadronic cascade shower.

$$R_E = \sqrt{\frac{\sum_i(\sum_j \Delta E_{i,j} \times R_i^2)}{\sum_i \sum_j \Delta E_{i,j}}}$$

$$F_E = \frac{\sum_j \Delta E_{12,j}}{\sum_i \sum_j \Delta E_{i,j}} \qquad R_i = \sqrt{\frac{\sum_j \left(\Delta E_{i,j} \times (x_{i,j} - x_{i,c})^2\right)}{\sum_j \Delta E_{i,j}}}$$

$\Delta E_{i,j}$: the energy deposited in the ith layer and jth PWO
$x_{i,j}$: the coordinate of the center of ith layer and jth PWO
$x_{i,c}$: the coordinate of the shower axis in the ith layer

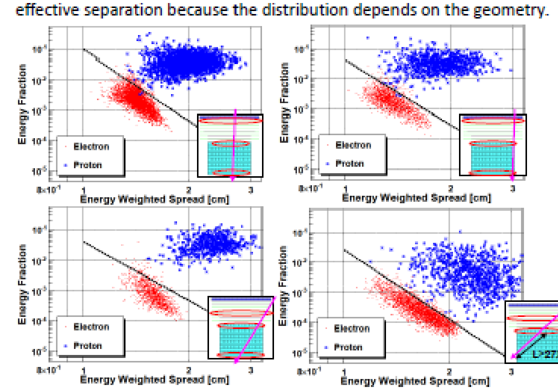
Estimation

Electrons : 1TeV
Protons : 1~1000TeV ($E^{-2.7}dE$)
Generated event number: 1.6×10^6

Electrons : 95% eff.
Protons : 4 events
⇒ 2.0×10^5 (90% C.L.)

Scatter plots of R_E vs. F_E

The classification by the geometry of the shower axis provides effective separation because the distribution depends on the geometry.



Efforts by the new experiments for deriving the positron and electron spectra are really appreciated to open a door to new era in astroparticle physics.

We are waiting for much more study by ATIC, PAMELA, Fermi-LAT, HESS and a forthcoming experiment in space, AMS-02.

Moreover,
We need an accurate and very-high-statistics observation for searching Dark Matter and/or Nearby Pulsars in the sub-TeV to the trans-TeV region with a detector which has following performance:

- The systematic errors including GF is less than a few %.
- The absolute energy resolution is as small as a few % (~ATIC).
- The exposure factor is as large as more than 100 m^2srday (~ FERMI-LAT).
- The proton rejection power is comparable to 10^5 , and does not depend largely on energies .

It should be a dedicated detector for electron observation in space.

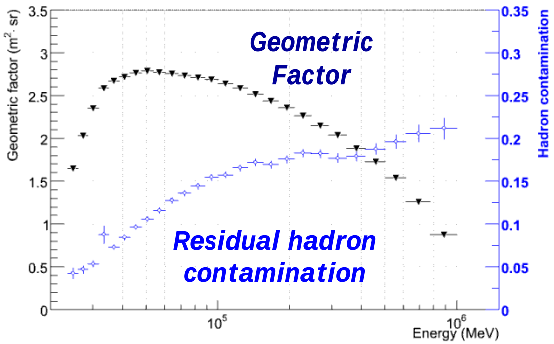
→ **Calorimetric Electron Telescope (CALET) is proposed.**

Why we need CALET ?

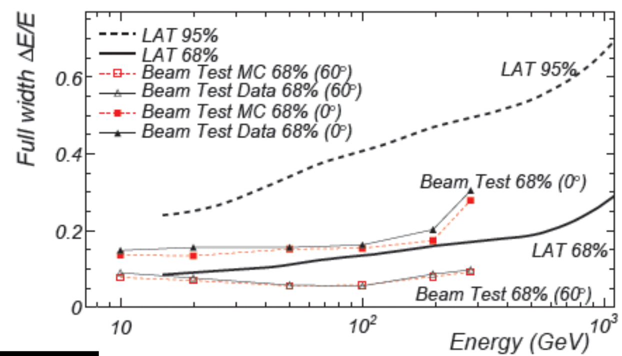
CALET is a dedicated detector for electrons and has a superior performance in the trans-TeV region as well as at the lower energies by using IMC and TASC

FERMI Electron Analysis

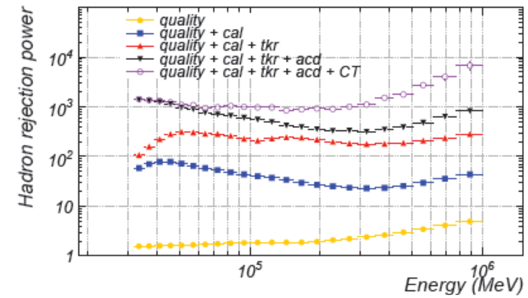
Geometric Factor depends strongly on energy

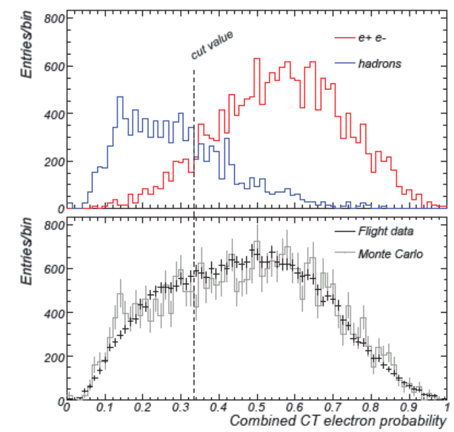


Energy resolution becomes worse at high energies(~30 %@ 1 TeV)



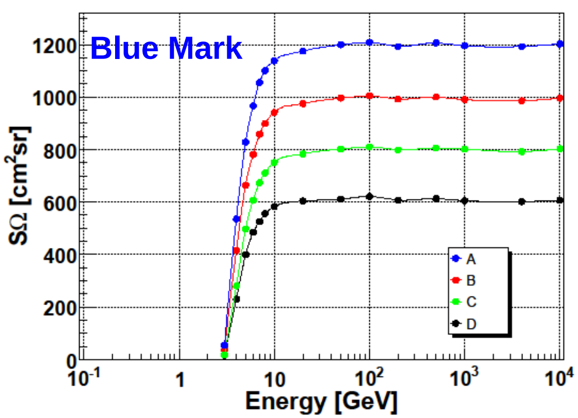
Proton rejection power depends fully on simulation by using different parameters



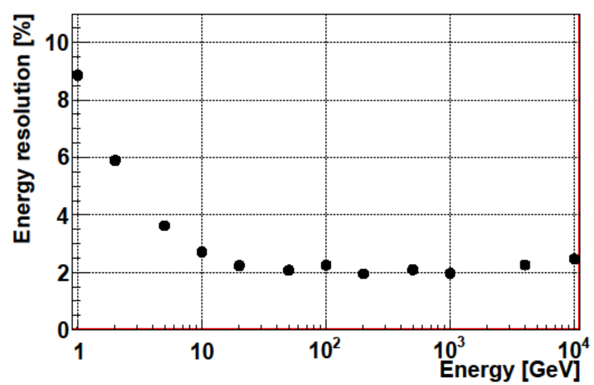


Expected CALET Performance

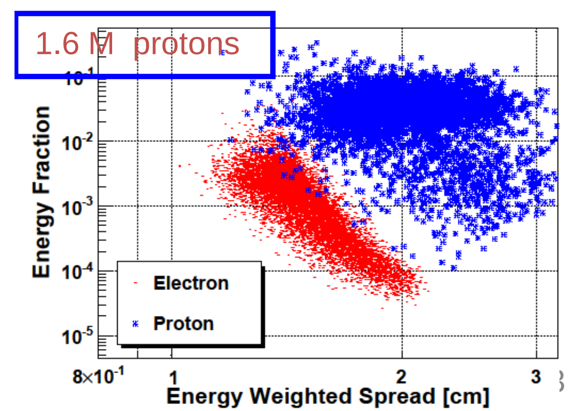
Geometric Factor is constant up to 10 TeV



Energy resolution is nearly 2 %, and constant over 10 GeV



Proton rejection power at 4 TeV is better than 10^5 with 95 % electron retained



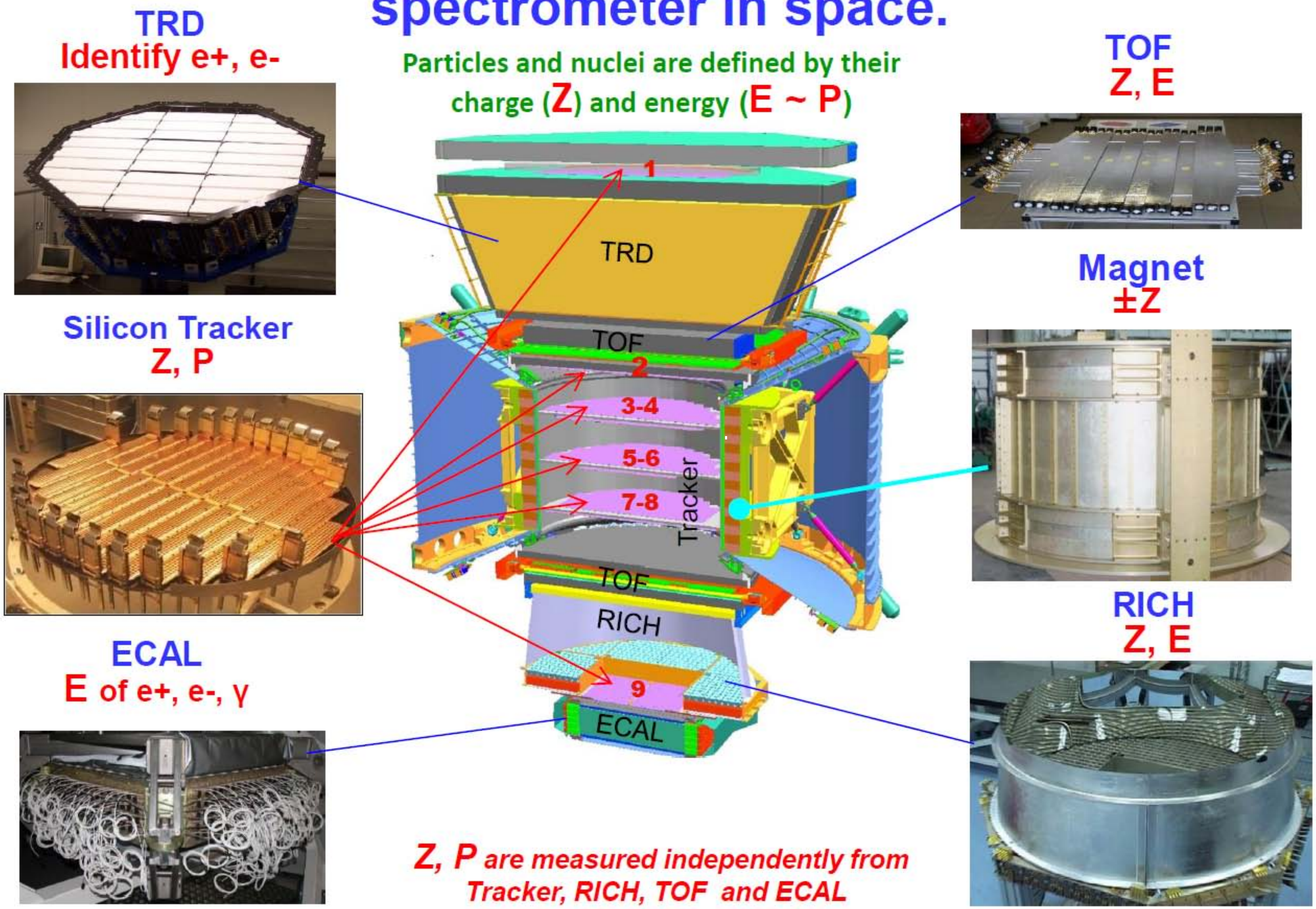
Comparison of Detector Performance for Electrons

CALET 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)
PPB-BETS (+BETS)	10 -1000	13% @100 GeV	4000 (> 10 GeV)	IMC (Lead: 9 X_0)	~0.42
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)	300@TeV (1 year)
AMS **(less capability in PM model)**	1-1,000 (Due to Magnet)	~2.5% @100 GeV	10^4 (x 10^2 by TRD)	Magnet+IMC +TRD+RICH (Lead: 17X_0)	~200(?) (5year)
CALET	**1-20,000**	**~2% (>100 GeV)**	**~10^5**	**IMC+Thick Seg. CAL (W: 3 X_0+ PWO : 27 X_0)**	**220 (5 years)**

ICRC2011

AMS: A TeV precision, multipurpose particle physics spectrometer in space.

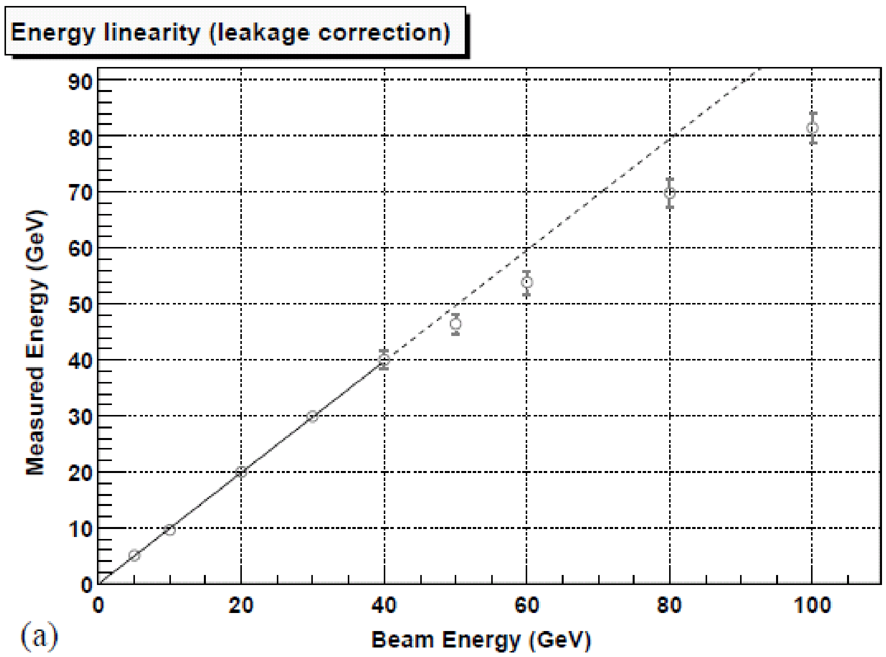


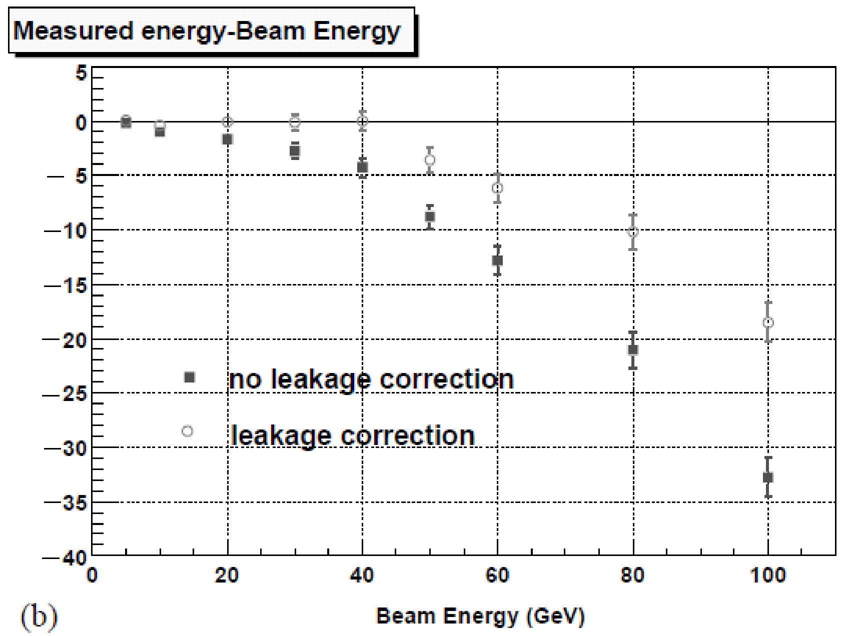
TRD+ECAL: 0.09m^2 sr

TRACKER: 0.4m^2 sr => 0.09m^2 sr (for current magnet)

Calorimeter Thickness: 17 X_0

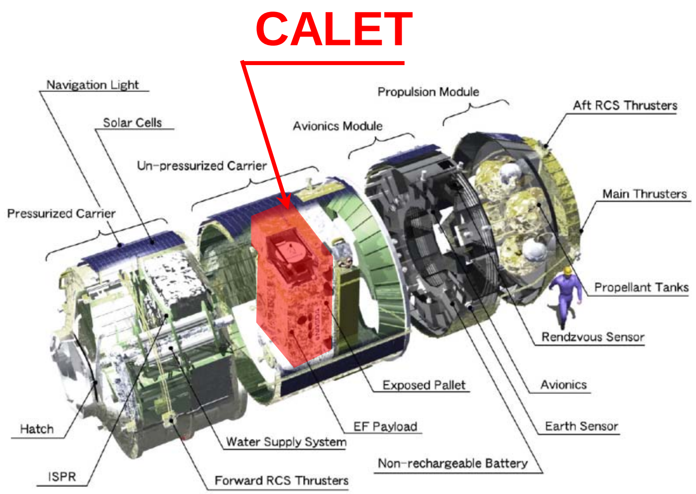
=> Energy Leakage over 50 GeV





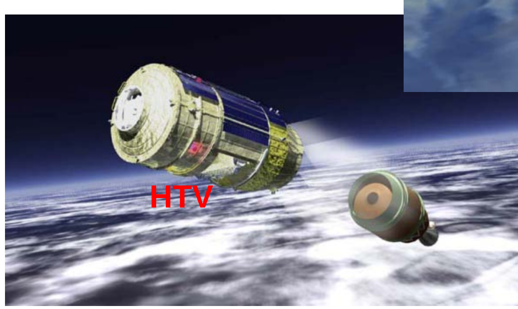
NIM 490 (2002) 132

Launching Procedure of CALET

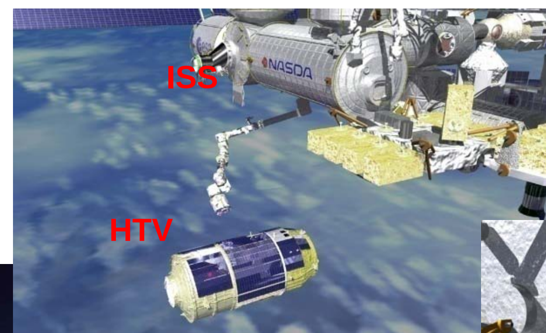


H2B Transfer Vehicle(HTV)

Launching by H2B Rocket

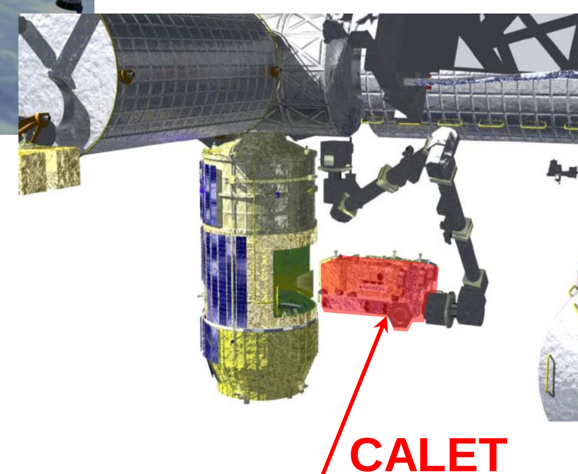


Separation from H2B



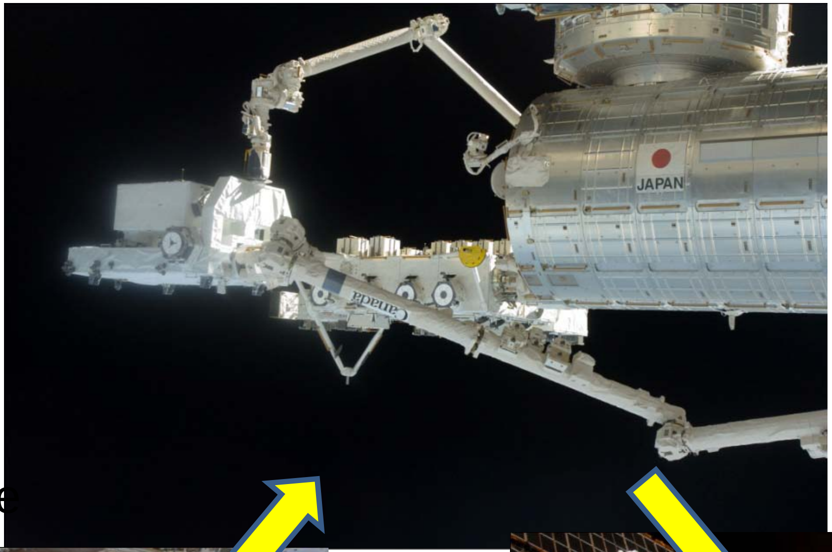
Approach to ISS

Pickup of CALET



Procedure of Payload Placement on JEM/EF Attach Point

Hand-off of HTV Palette

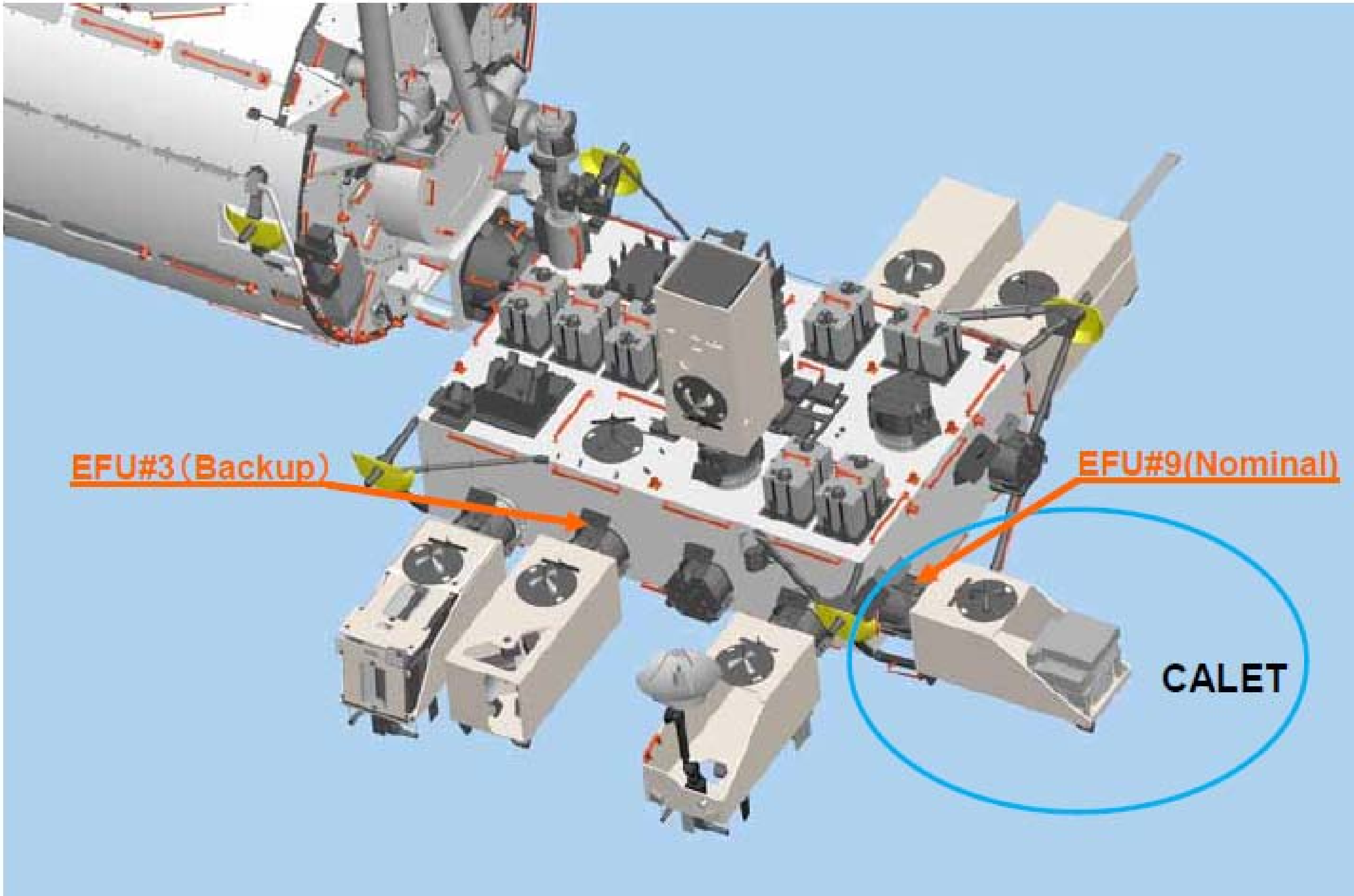


Real Pictures !!

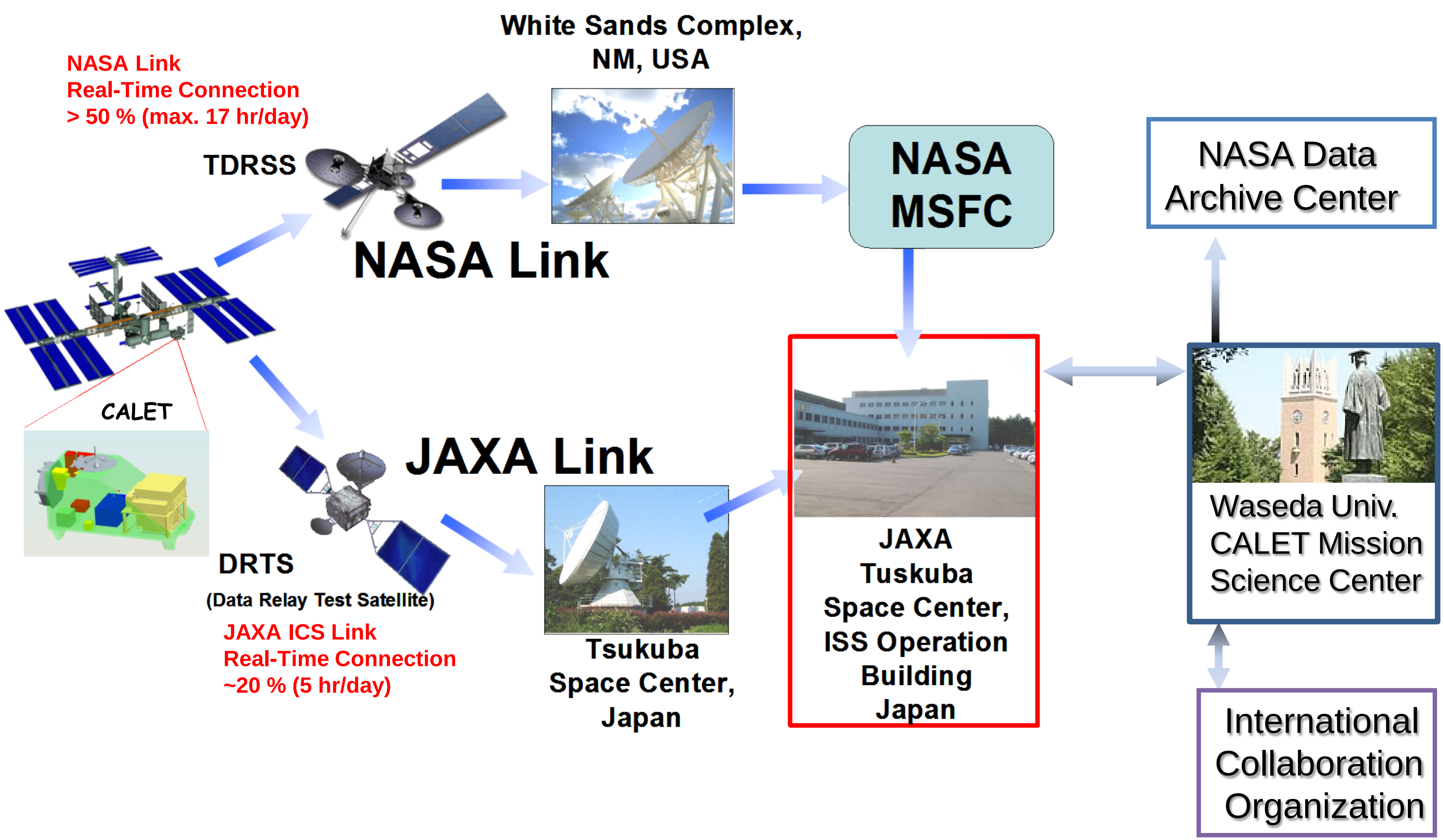
Pick up HTV Palette

Place JEM/EF Payload

CALET Attach Point in Japanese Experiment Module (Launching Schedule in 2013 by HTV5)



Concept of Data Downlink Stream



Summary

- CALET is a dedicated detector to electron observations in the trans-TeV region, that will provide crucial information on nearby sources and dark matter .
- We have successfully developed the CALET instrument based on out experience of balloon-borne instruments (BETS, bCALET) and beam tests of CALET proto-type detectors.
- CALET has the capability to observe electrons up to 20 TeV , gamma-rays from 10 GeV to 10TeV , protons and heavy ions from several tens of GeV to ~1000 TeV, and ultra heavy ions to an accuracy better than present balloon payloads.
- The CALET project has been approved for launch with a schedule in 2013 (or 2014) JFY by HTV-5 to the Japanese Experiment Module (Kibo). The project is currently in the final phase of "Preliminary Design Study" .