The CALET Project on ISS/JEM

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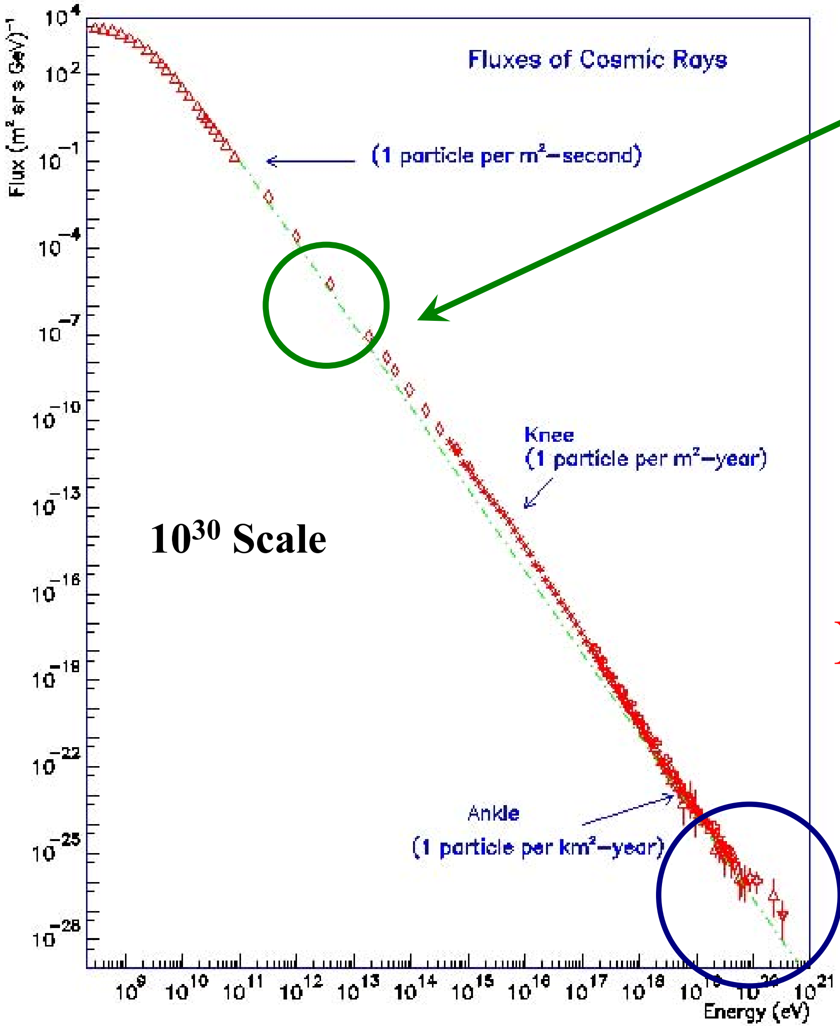
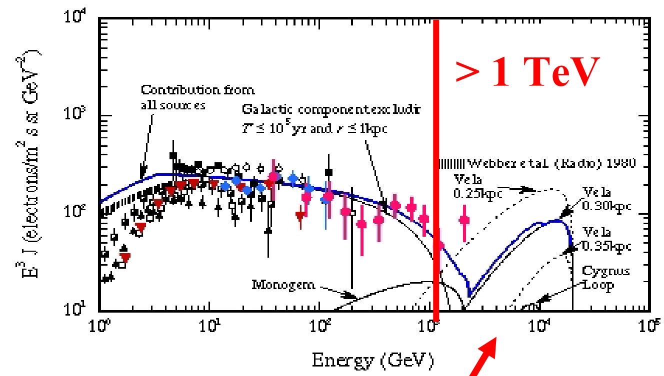
BUAA April 19th-21th 2006

Cosmic Ray Energy Spectrum at the Highest Energy for Electrons and Protons



Electron

IC, Synchrotron Cut-off



Nearby (or Unknown) Sources

Distance < 1 kpc

Age < 10^5 year

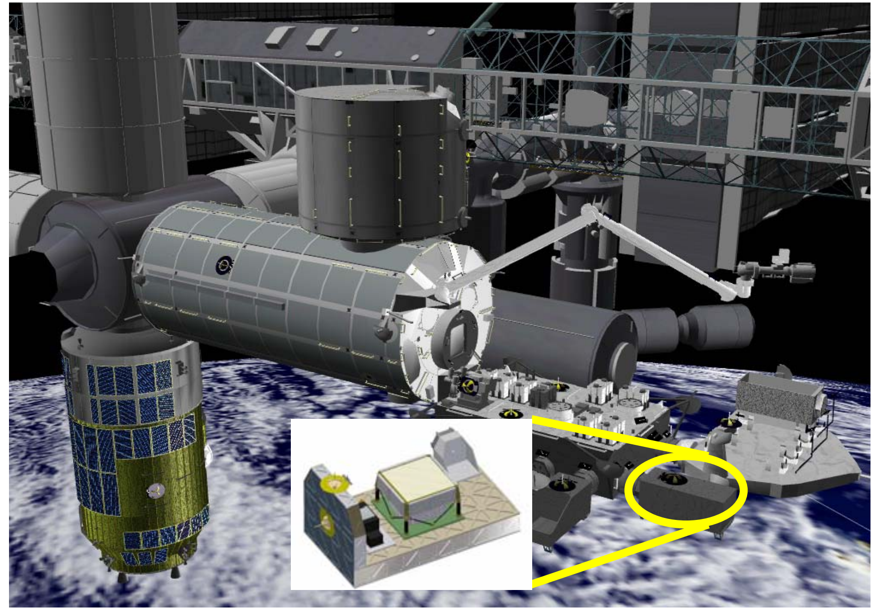
Hadron

GZK Cut -off

CALET: CALorimetric Electron Telescope

CALET Mission Concept

- **Instrument:**
  High Energy Electron and Gamma-Ray Telescope Consisted of
  - Imaging Calorimeter (IMC)
  - Total Absorption Calorimeter (TASC)
- **Launch:**
  HTV: H-IIA Transfer Vehicle
- **Attach Point on the ISS:**
  Exposed Facility of Japanese Experiment Module (JEM-EF)
- **Nominal Orbit:**
  407 km, 51.6° inclination
- **Life Time:**
  3 years (minimum)
- **Mission Status**
  Mission Concept Study
  Launch around 2012 in Plan

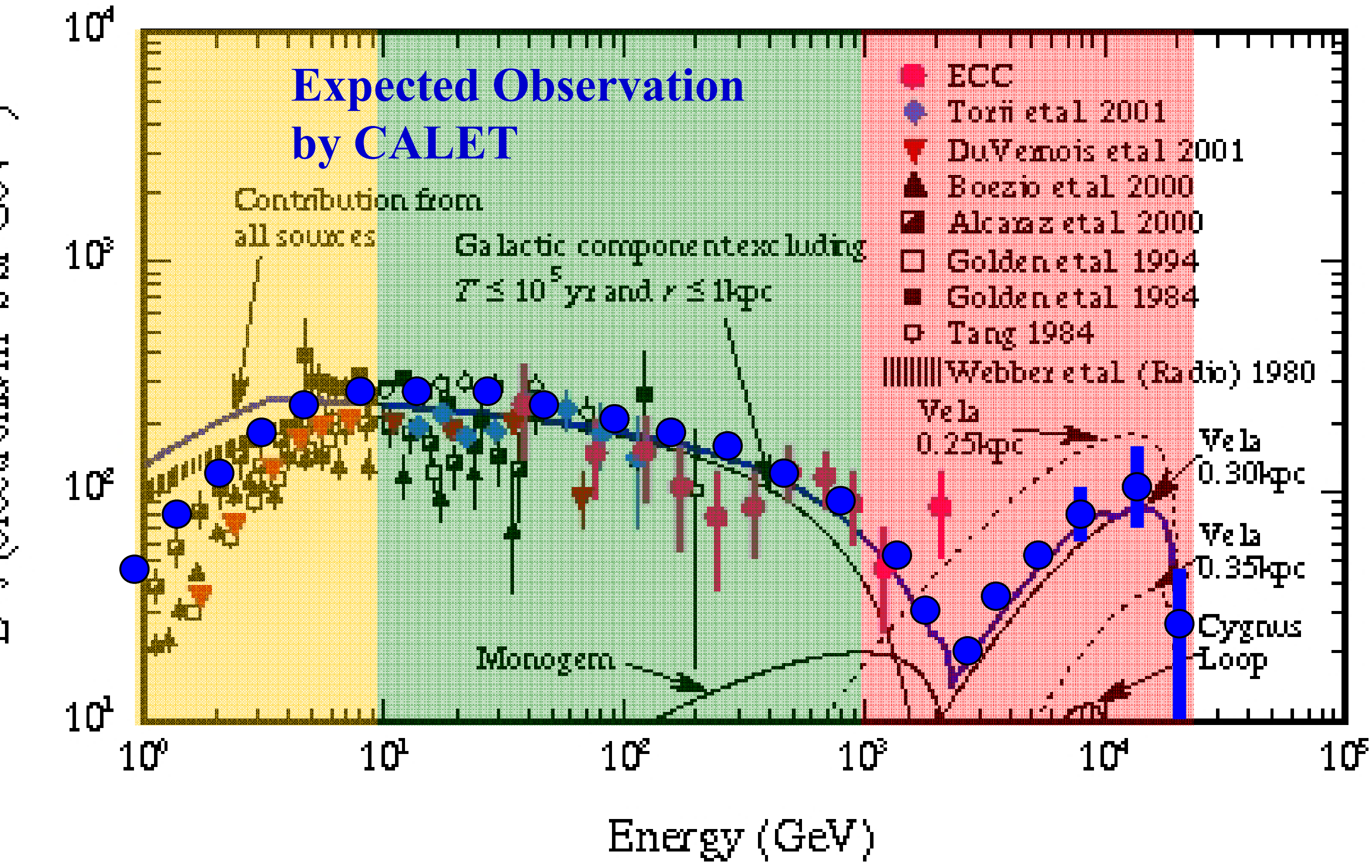


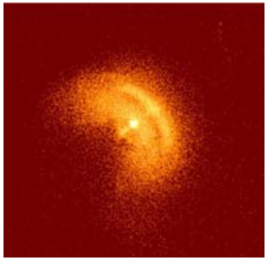
CALET Payload:

- 1GeV ~ 10 TeV for electrons
- 20 MeV ~ TeV for gamma-rays
- several 10 GeV ~ 1000 TeV for nuclei
- Weight: 2500 kg
- Geometrical Factor: 1 $m^2 sr$
- Power Consumption: 600 W
- Data Rate: 600 kbps

Origin and Propagation of Electrons

- *Detection of Nearby Sources*
- *Electron Propagation in Our Galaxy*
- *Acceleration by Supernova Shock Wave*
- *Solar Modulation*

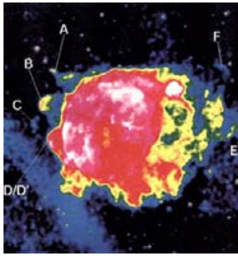


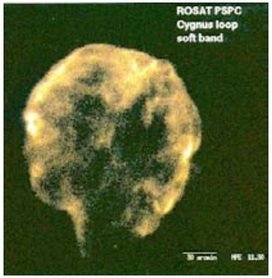


Vela
10,000 yea
820 ly

Chandra

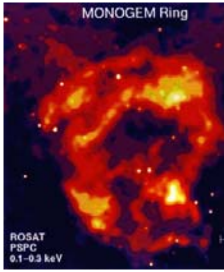
ROSAT





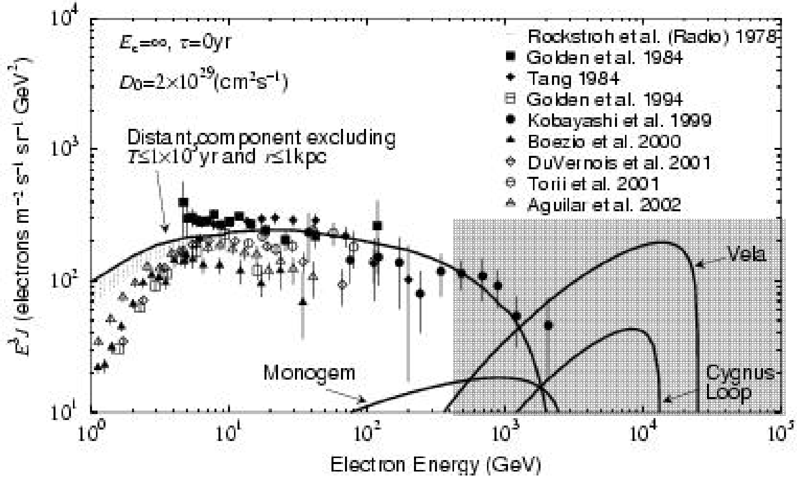
Cygnus Lo
20,000 yea
2,500 ly

Monogem
86,000 years
1,000 ly

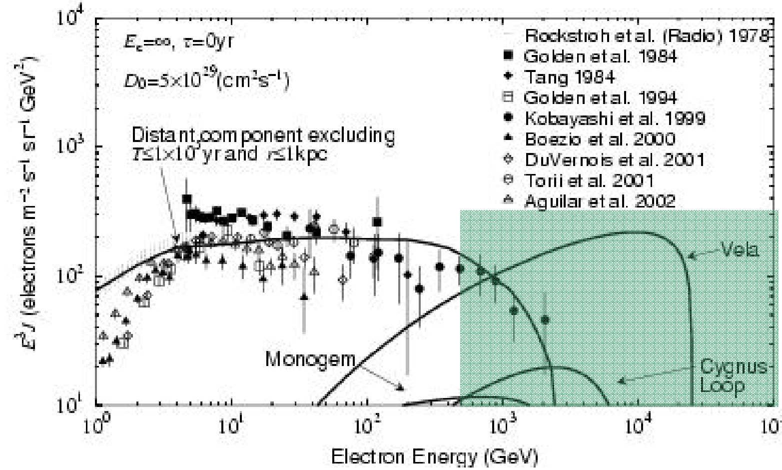


Model Dependence of Nearby Source Effect

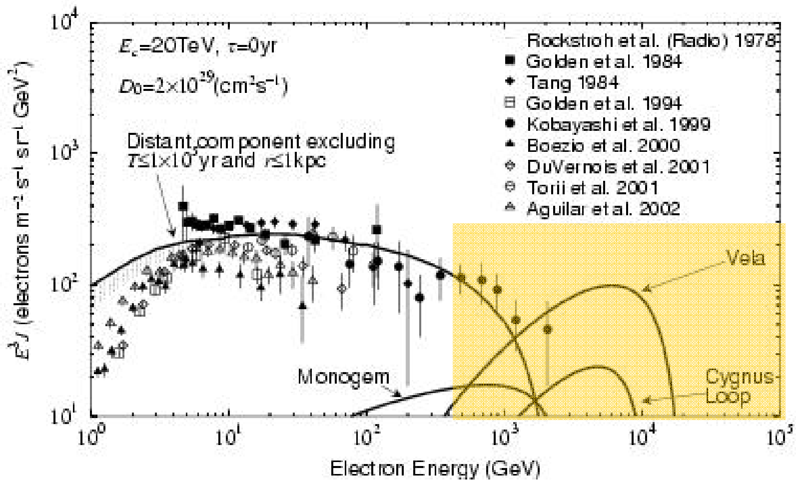
Ec=∞、 ΔT=0 yr, Do=2x10^{29} cm^2/s



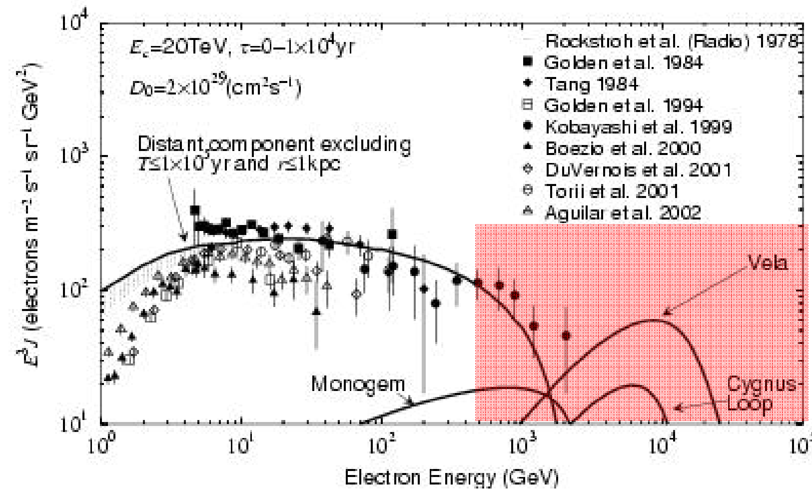
Do=5 x 10^{29} cm^2/s



Ec= 20 TeV



Ec=20 TeV、 ΔT=1-10^4 yr



Gamma-Ray Observation in 20 MeV~10 TeV

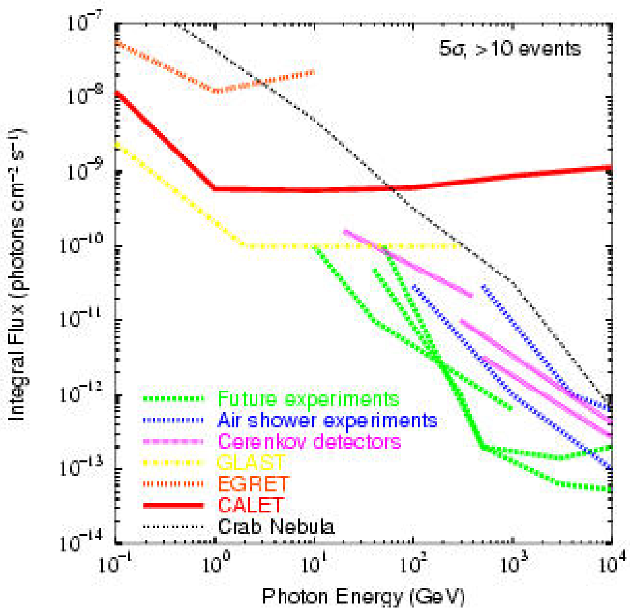
CALET on the ISS orbit without attitude control of the instrument:

Wide FOV (~45°) and Large Effective Area (~0.5 m^2) in 20 MeV- 10 GeV

⇒
- Sky coverage of 70 % for one day
- All sky coverage in 20 days
- Typical exposure factor of ~50 days for point source

Good Energy Resolution (< a few %) over 100 GeV

⇒
- Measurement of change of power-law spectral index
- Possible detection of line gamma-rays from Neutralino annihilation

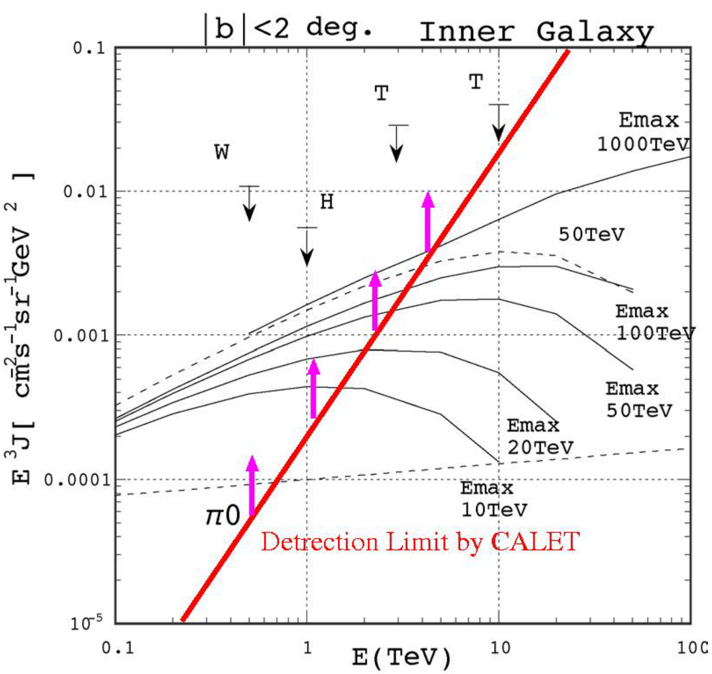


Point Source Sensitivity in One-Year Observation

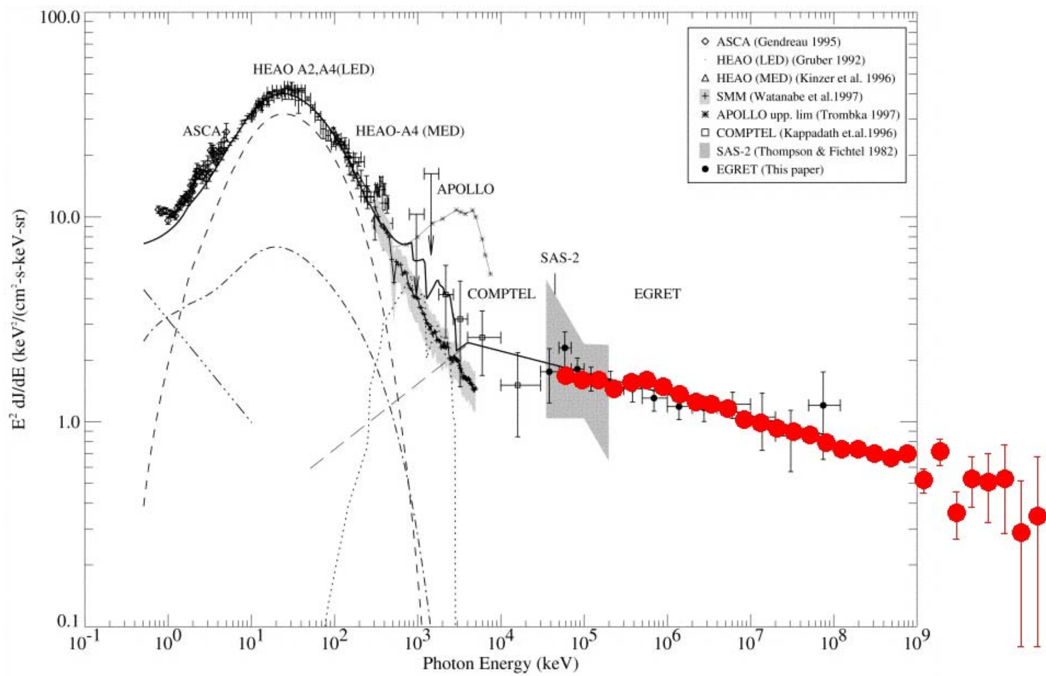
Nature of Cosmic Gamma-Ray Sources

- Diffuse Components in Our Galaxy
Electron or Proton Origin ?

Galactic Diffuse Component



Extra-Galactic Diffuse Component

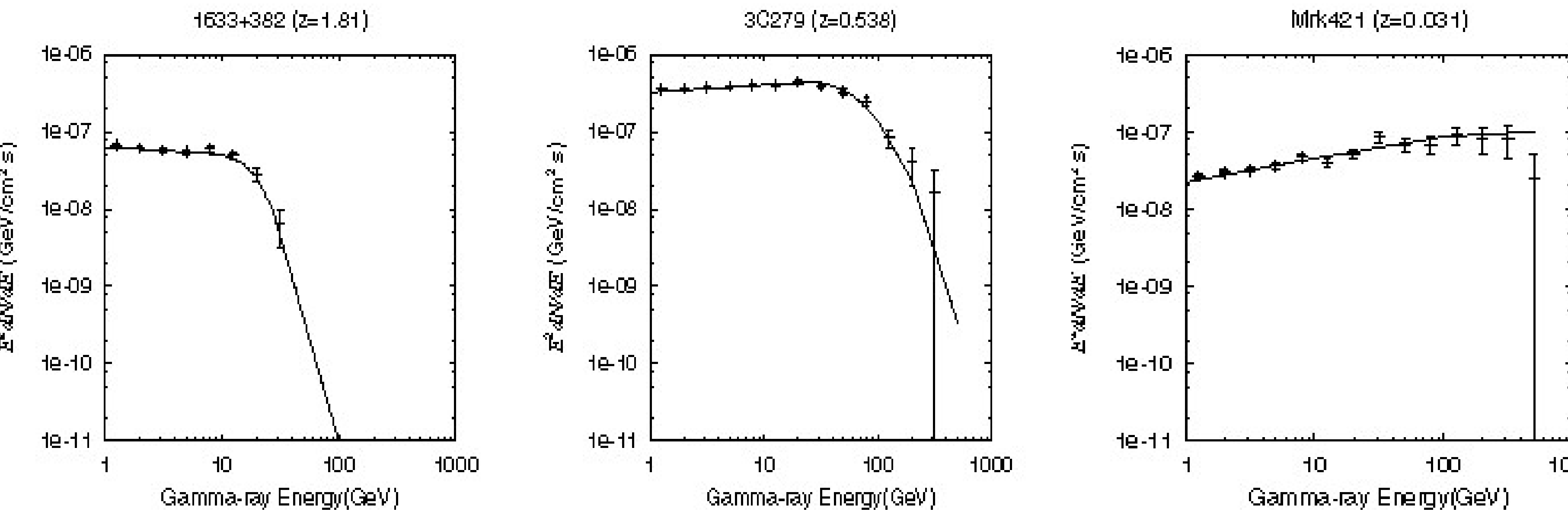


Nature of Cosmic Gamma-Ray Sources

- Diffuse Components in Our Galaxy
Electron or Proton Origin ?

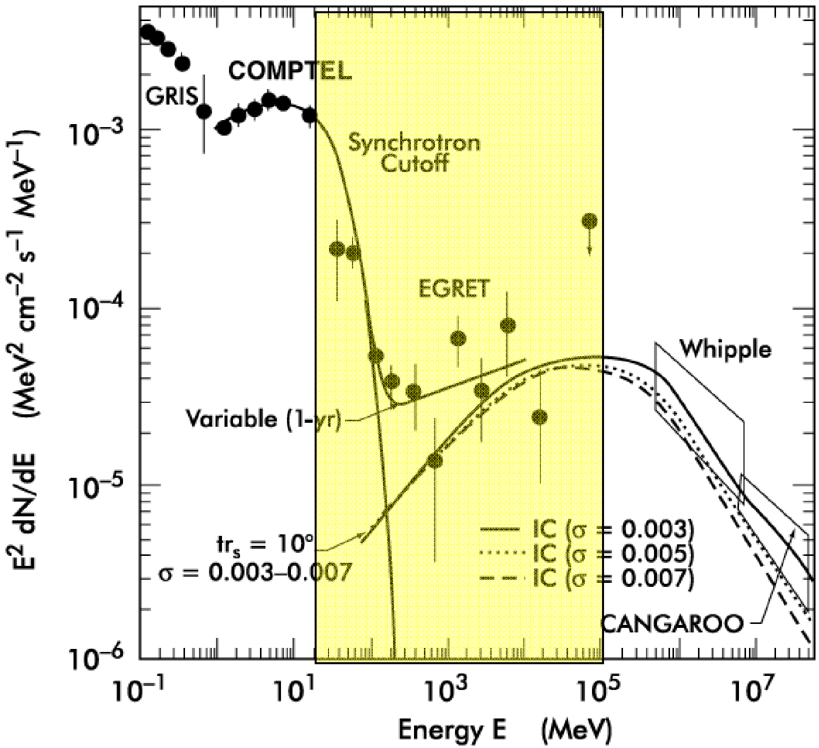
- AGN sources and absorption by IR background

Observed AGN Spectra after Absorption by IR background



Nature of Cosmic Gamma-Ray Sources

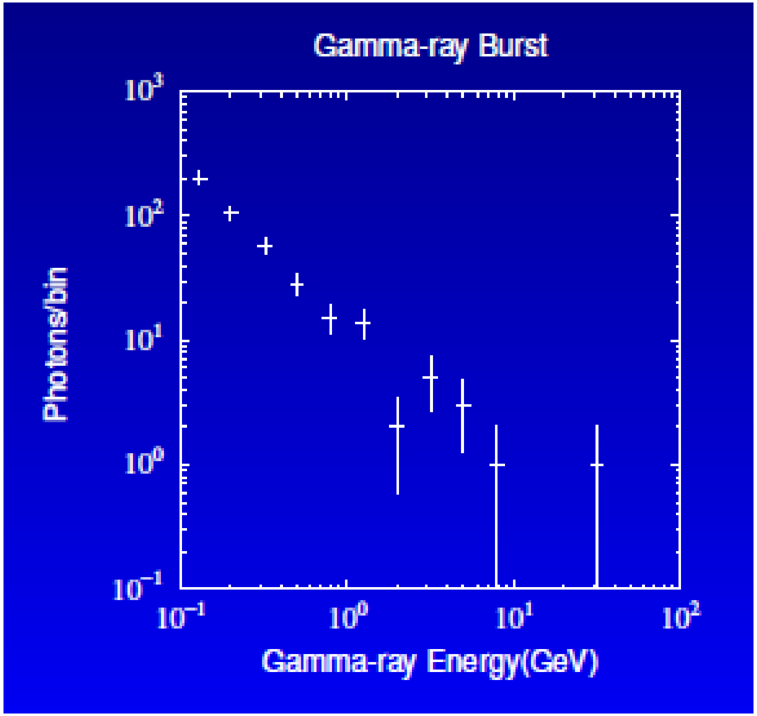
- *Diffuse Components in Our Galaxy*
  Electron or Proton Origin ?
- *AGN sources and absorption by IR background*
- *Supernova Remnants and Pulsar*



Predicted CALET measurement region of Crab unpulsed spectrum in the overlap region with ground-based Cherenkov telescopes.

Nature of Cosmic Gamma-Ray Sources

- *Diffuse Components in Our Galaxy*
  Electron or Proton Origin ?
- *AGN sources and absorption by IR background*
- *Supernova Remnants and Pulsar*
- ***Gamma-Ray Bursts***



- $> 10^{-5}$ erg/cm^2 Gamma-ray burst $\Rightarrow$ $\sim$10/yr
- $> 10^{-5}$ erg/cm^2 Gamma-ray burst $\Rightarrow$ up to $\sim$10GeV

An expected gamma-ray burst spectrum, assuming a power-law

Origin and Propagation of Proton and Nucleus

- *Supernova Shock Acceleration*

Change of power spectrum index depending on Z ?

Measurements of proton and heavy ion flux in the energy region exceeding 1 TeV, in which magnet spectrometer is not capable.

For proton measurement:

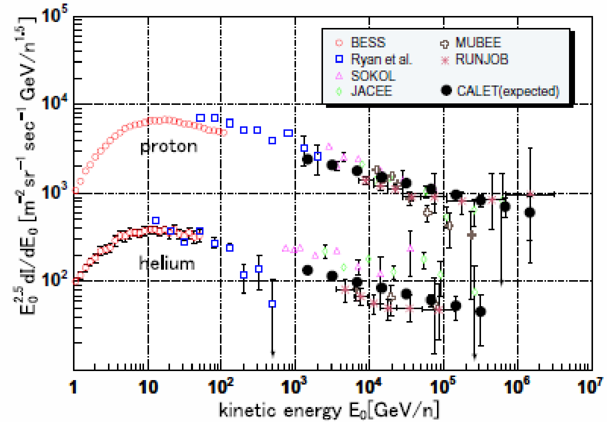
$S_{eff} \sim 0.5\ m^2 \times\ 1/3\ (\text{for p}) \sim 0.17\ m^2$

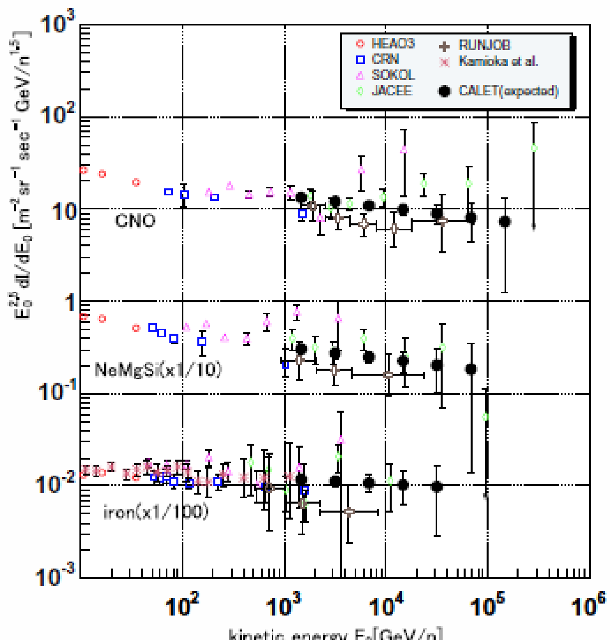
Exposure factor for 1000 days:

$170\ m^2\ sr\ day \sim 1.5 \times 10^7\ m^2\ s\ sr$

Expected numbers of protons:

Energy (TeV)	Number
1	$\sim 10^6$
10	1.8×10^4
100	3.2×10^2
1000	6

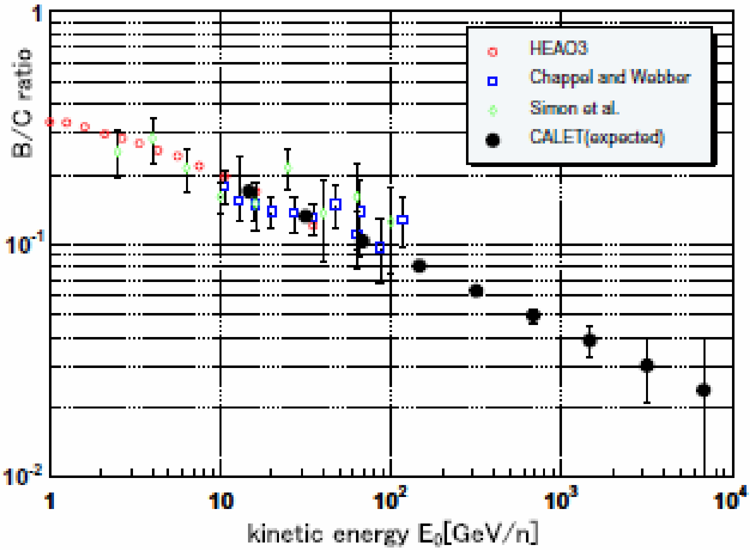




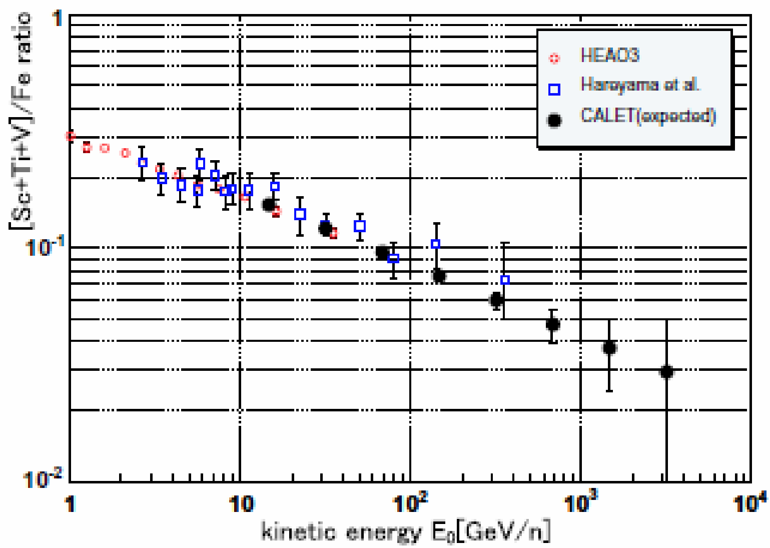
Origin and Propagation of Proton and Nucleus

- *Supernova Shock Acceleration*
  Change of power spectrum index depending on Z ?
- *Propagation in Our Galaxy : Structure of the Galaxy*
  Leaky box model is still valid in the Knee region ?

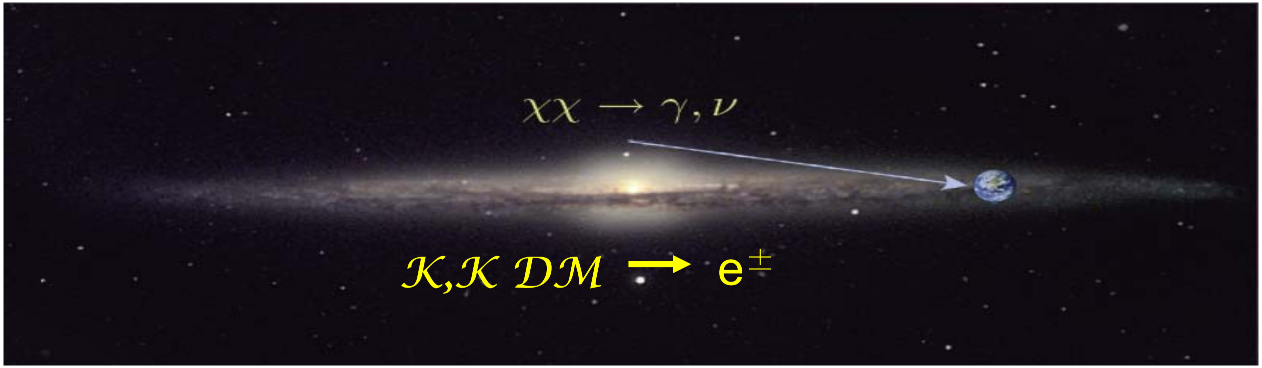
B / C Ratio



Sub Fe / Fe



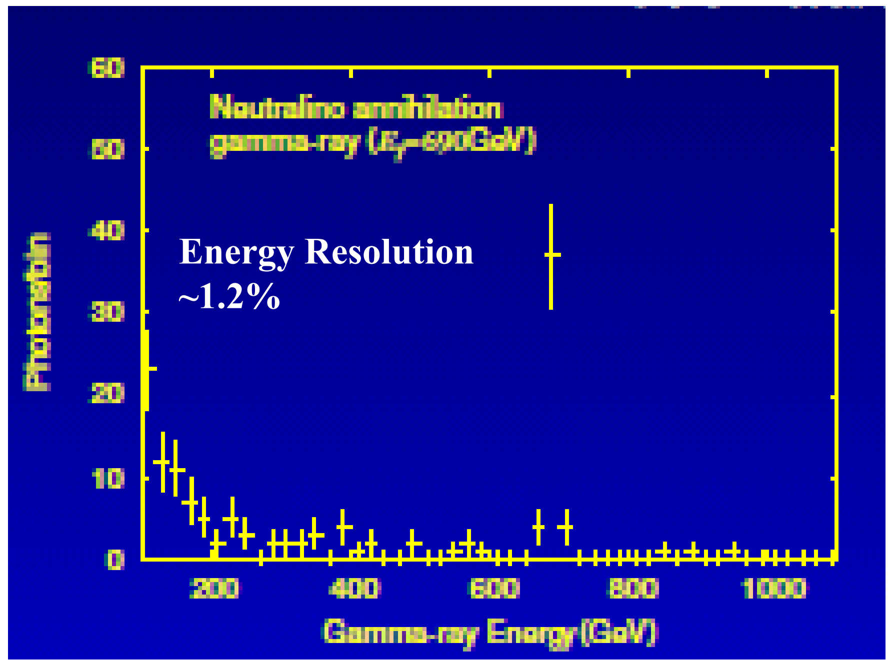
SUSY Dark Matter Search by Gamma Line



- 690 GeV neutralino annihilating to $\gamma\ \gamma$
- Clumpy halo as realized in N-body simulation of Moore et al. (ApJL 1999)
- Simulated Signal in CALET for 3 years

$$\Phi_\gamma = \frac{N_\gamma \sigma v}{m_\chi^2} \frac{1}{4\pi} \int\int_{line\ of\ sight} \rho^2(\ell) d\ell d\Omega$$

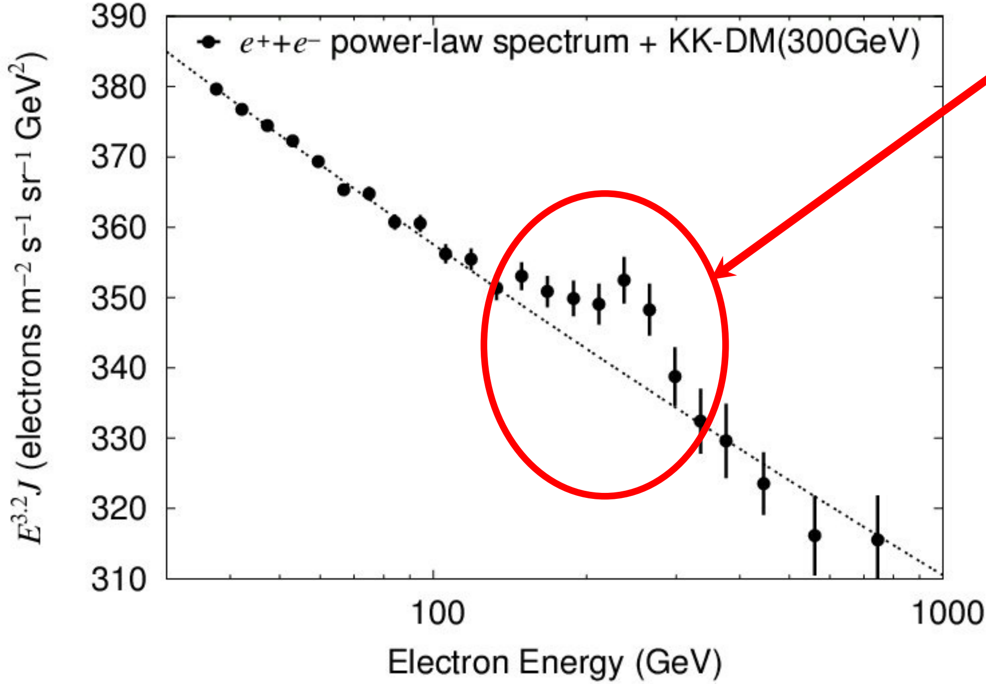
- $m_\chi = 690\text{GeV}$
- $N_\gamma \sigma v = 1.5 \times 10^{-28} \text{cm}^3 \text{s}^{-1}$

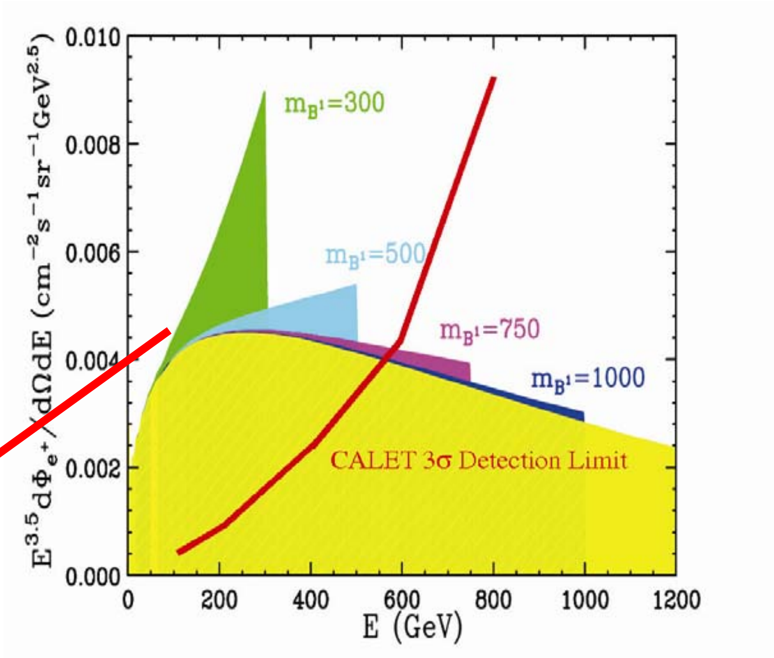


Dark Matter Search by Positrons (& Electrons)

Positron will be measured by
- **PAMELA flying soon**
- **AMS to be launched in 2008 on ISS**
- **CALET on ISS (can not separate e+ and e-)**

Simulation for 300 GeV KK DM





H.C. Cheng et al., PRL 2002.

Conceptual Structure of CALET

Requirements:

- Large Acceptance: 1 m^2 sr
- Imaging Capability: < 1mm
- Hadron Rejection Power: ~10^6
- Energy Measurement:
  - 20 MeV~10 TeV for e, γ
  - 1 ~ 1000 TeV for hadrons (Optional)

SciFi/Lead Imaging Calorimeter (IMC)

- Area: ~1 m^2
- SciFi Belt: 1mm square x ~1 m length
  - 17 layers(x &y)
- Lead Thickness : 4 r.l , 0.13 m.f.p

Total Absorption Calorimeter (TASC):

- Area: ~0.5 m^2
- BGO Log: 25 x 25 x 350 mm
  - 7 layers (x &y)
  - SciFi Belt for 3 layers (x &y)
- Thickness: 32 r.l , 1.6 m.f.p

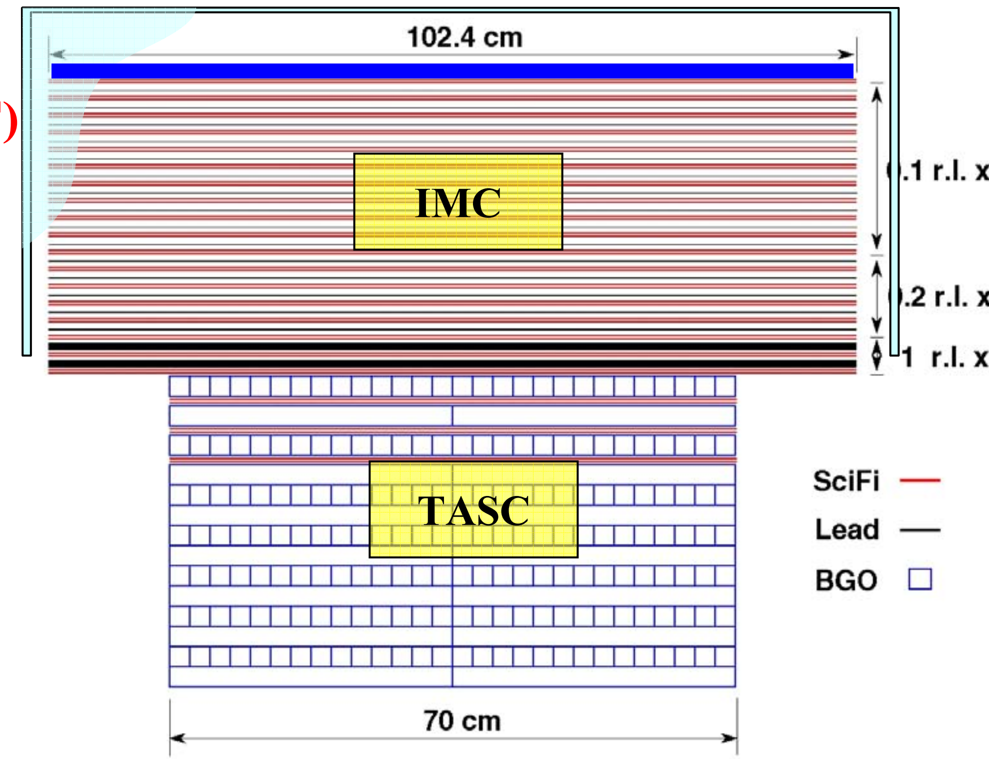
Schematic Side View of CALET

・Anti-Coincidence System for Low E. γ

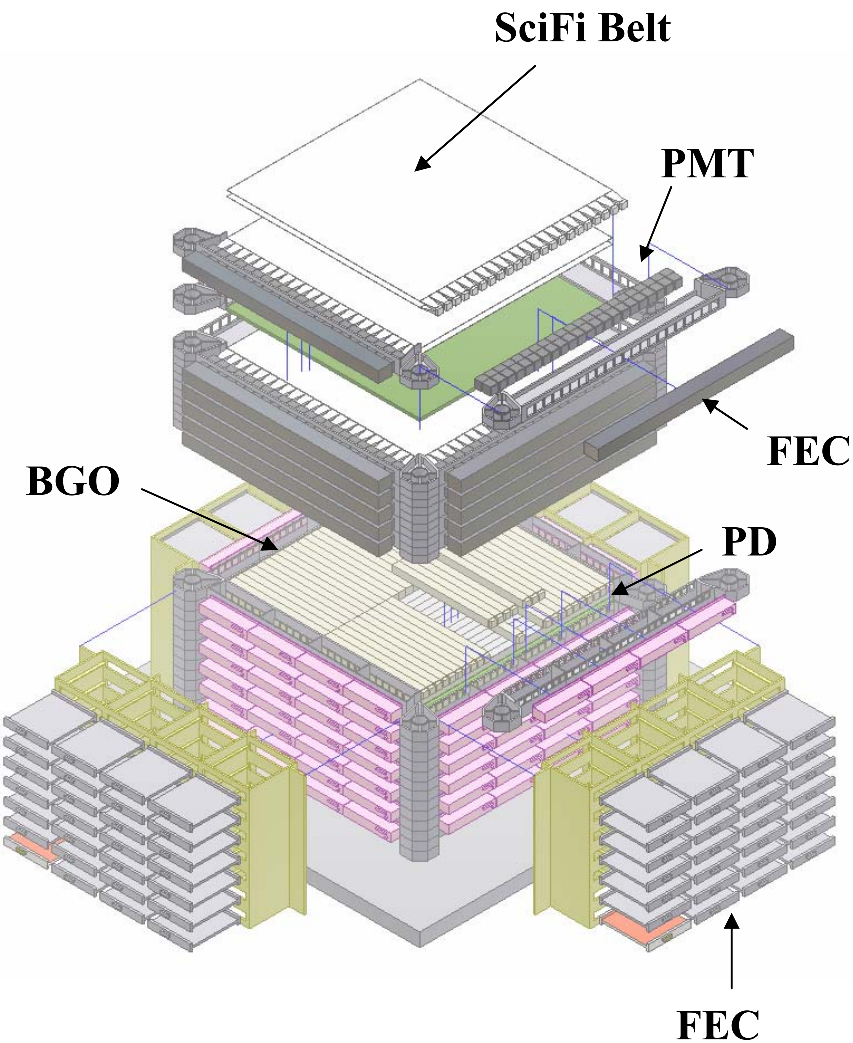
・Silicon Detector for High Z and Particle ID

Detector Weight: 1760 kg

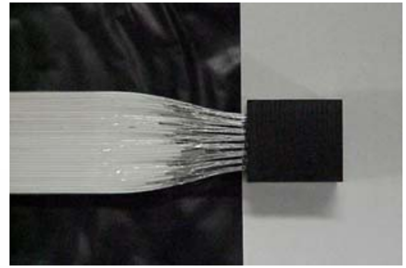
Total Absorber Thickness: 36 r.l, ~1.7m.f.p



Detector Components



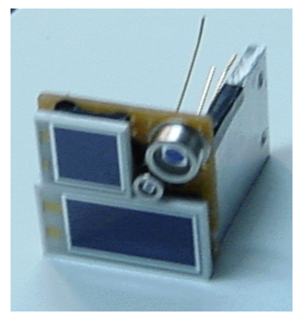
SciFi Belt (32 x 2 layers)



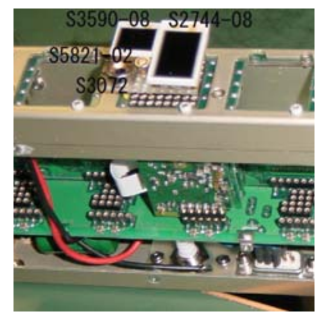
64-anode PMT

FEC (VA32, TA, 16bits ADC, FPGA)

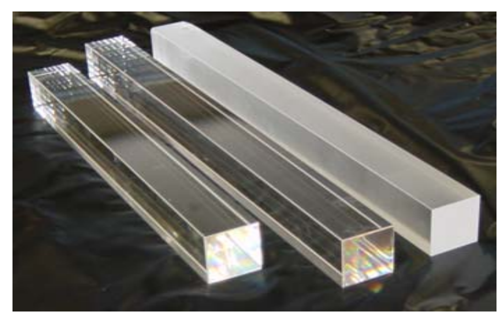
Si PIN Photodiodes



FEC with PD

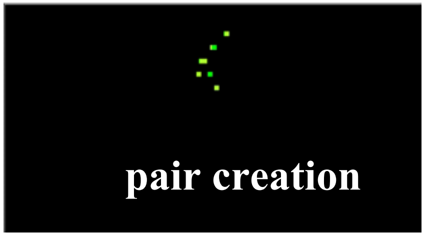


BGO or $PbWO_4$



Examples of Shower Profile by Simulation

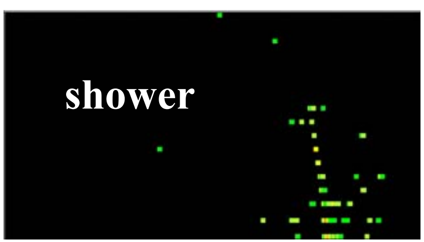
Gamma-ray 20 MeV



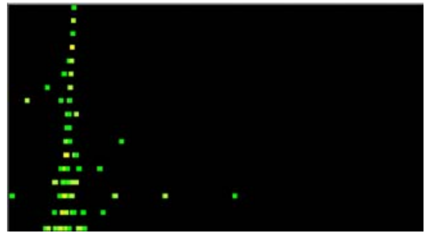
Gamma-ray 100MeV

Gamma-ray 1GeV

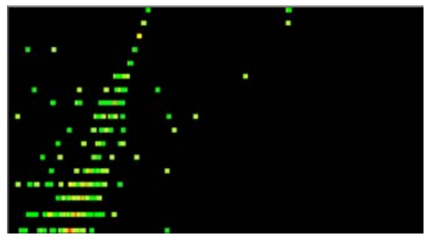
Gamma-ray 10GeV



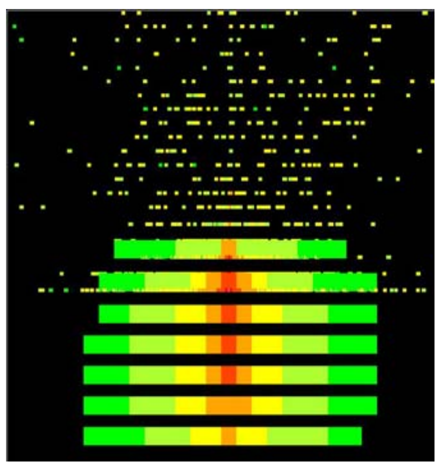
Electron 10 GeV



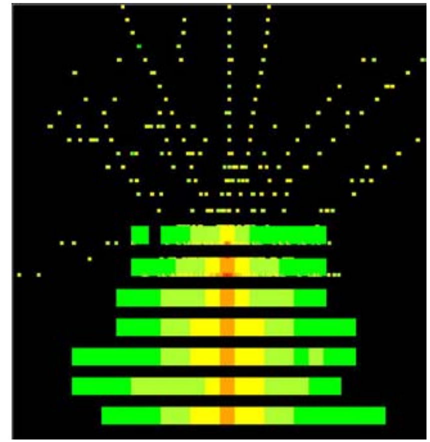
Electron 100 GeV



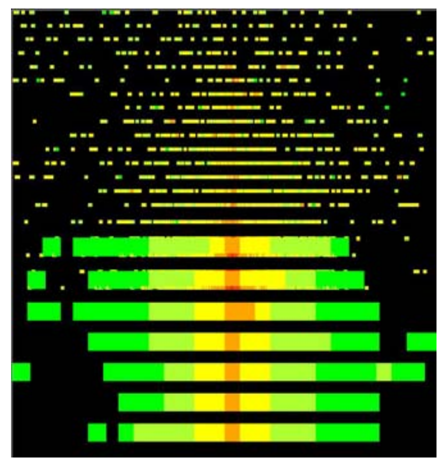
Electron 10 TeV



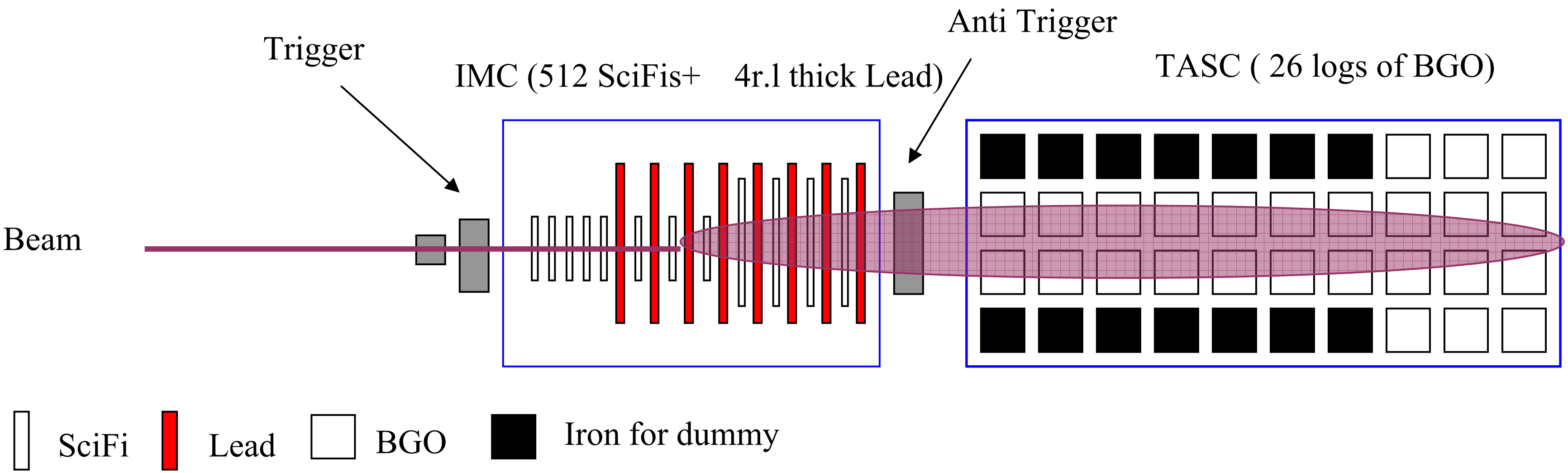
Proton 3 TeV



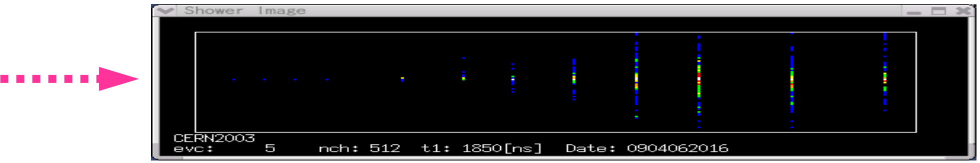
Proton 3 TeV

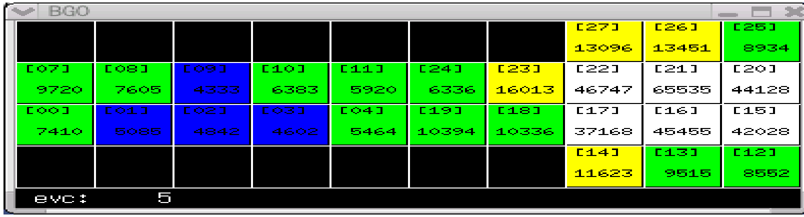


Examples of Observed Showers in Beam Test at CERN



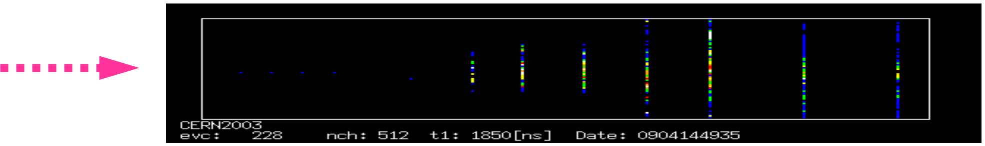
e 100 GeV/c

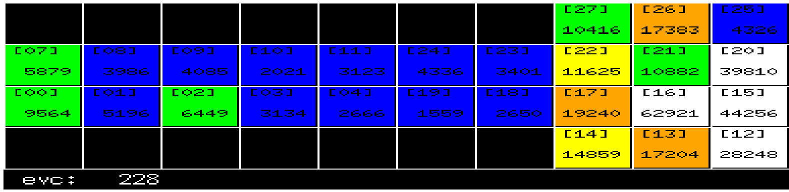




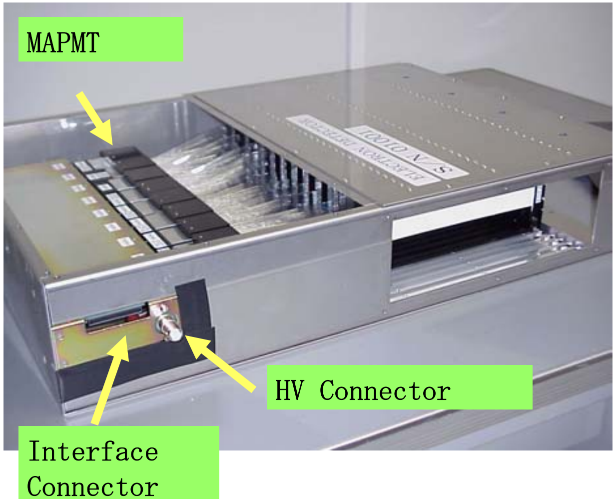
p 150 GeV/c

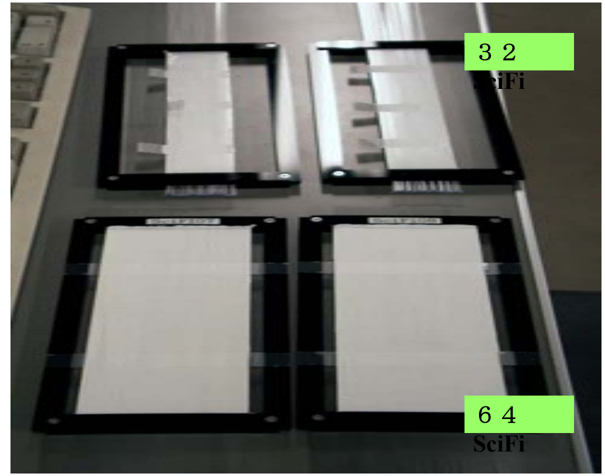
interaction



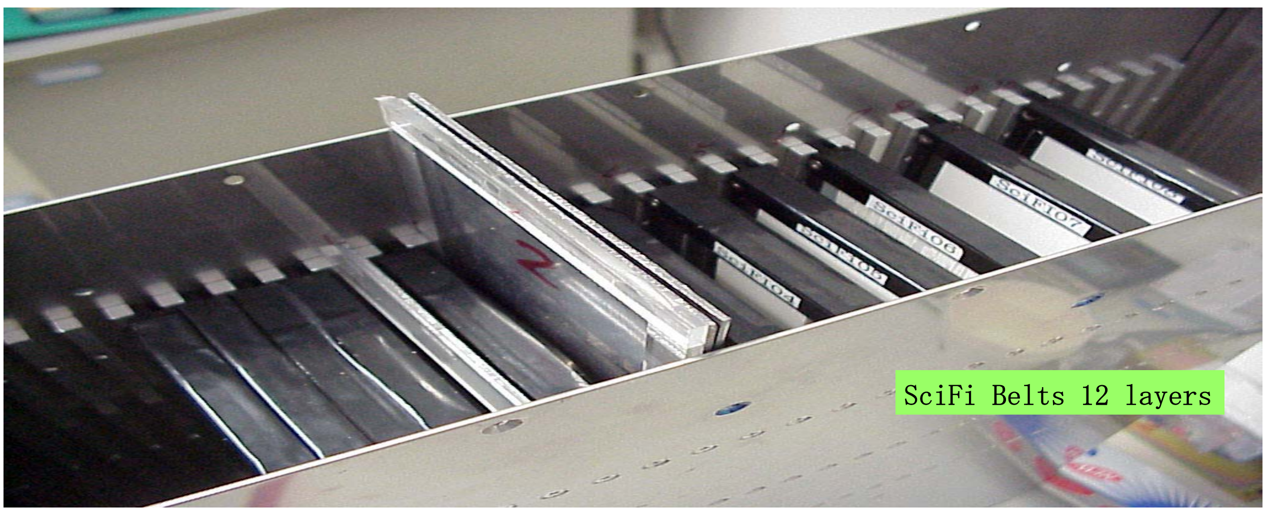


Imaging Calorimeter

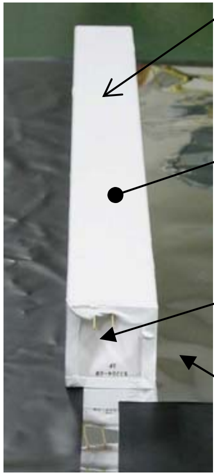




SciFi Belts



Total Absorption Calorimeter



BGO Crystal

25mm×25mm×300mm

Teflon Sheet

0.1mm thick×3

Photodiode

S3204-08

Area 18mm×18mm

Aluminized Sheet

12μthick on both side

BGO Logs and PD

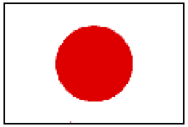
Pre-amplifier

Beam

Shaping Amplifier

Shaping time ~2μs

Member List



Japan：

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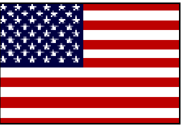
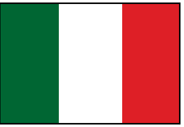
(1) RISE, Waseda University (2) Kanagawa University (3) JAXA (4) Yokohama National University (5)Hirosaki University (6) National Institute of Radiological Sciences (7) Shibaura Institute of Technology (8) Rikkyo University (9) Aoyama Gakuin University (10) Kanagawa University of Human Services (11) Saitama Universit (12) University of Tokyo



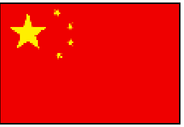
USA:

NASA/GSFC: R.E.Streitmatter, J.W.Mitchell, L.M.Babier *USRA:* A. A.Moissev, J.F.Krizmanic
Louisiana State University: G.Case, M. L. Cherry, T. G. Guzik, J. B. Isbert, J. P. Wefel
Washington University in St Louis: W. R. Binns, M. H. Israel, H. S. Krawzczynski
University of Denver : J. F. Ormes



Italy：

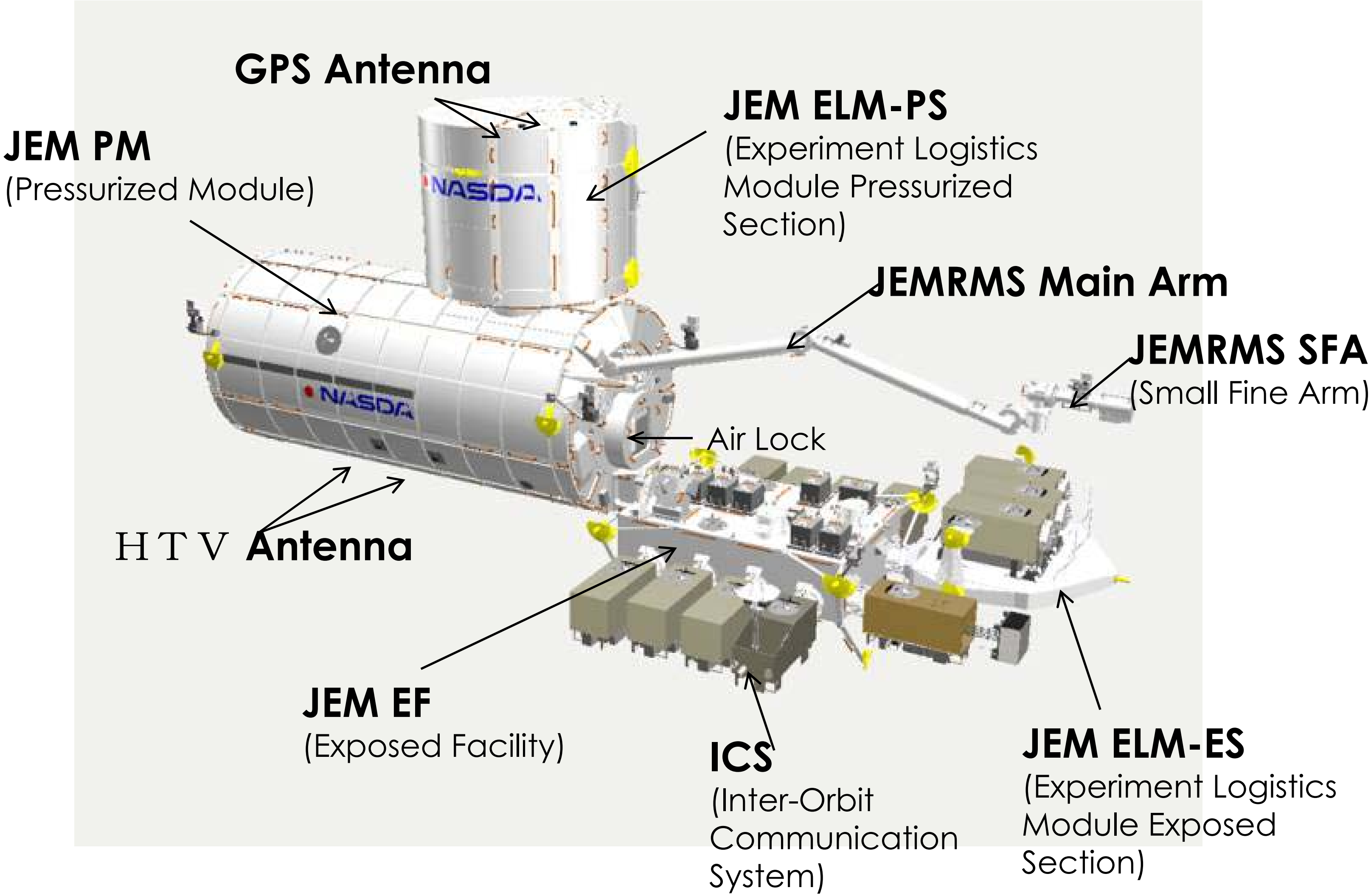
University of Siena and INFN:
P.S.Marrocchesi , P.Maestro, M.G.Bagliesi, V.Millucci , M.Meucci , G.Bigongiari , R.Zei
University of Florence: O. Adriani, P. Papini, P. Spillantini, L. Bonechi, L.E. Vannuccini
Scuola Normale Superiore & INFN Pisa : F.Morsani ,F.Ligabue



China：

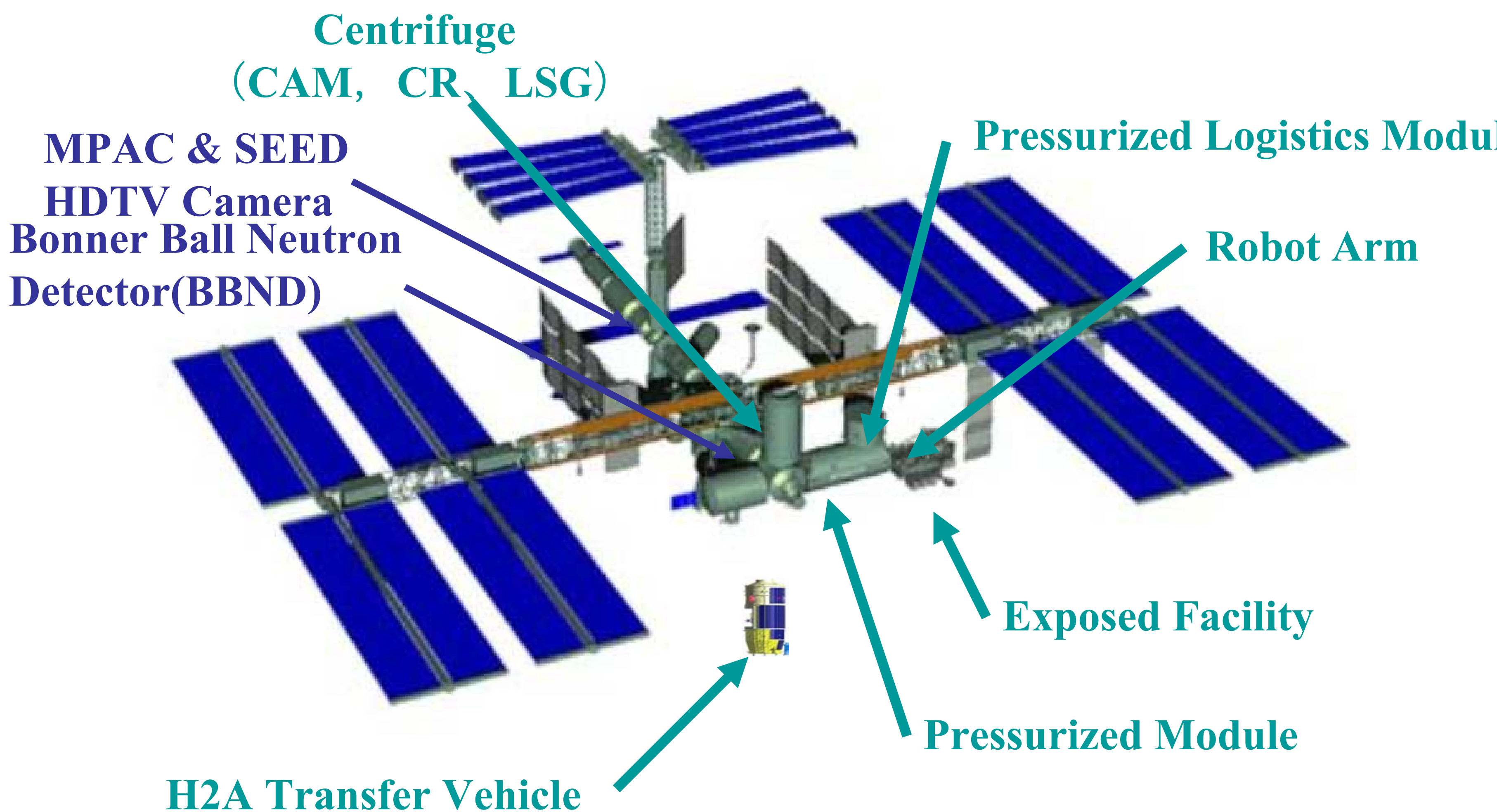
Purple Mountain Observatory, Chinese Academy of Science: J. Chang, W. Gan, T. Lu

JEM (KIBO) Survived !!

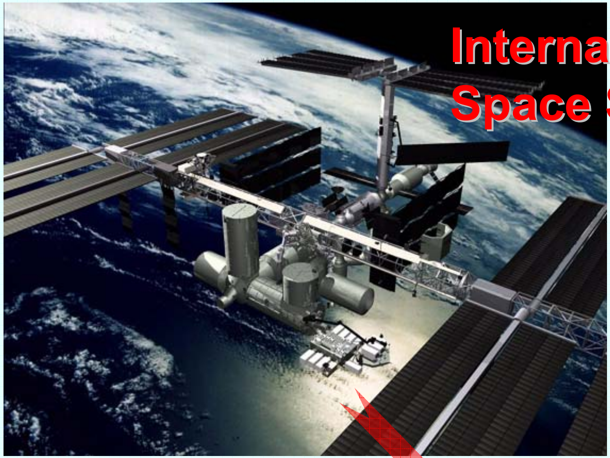


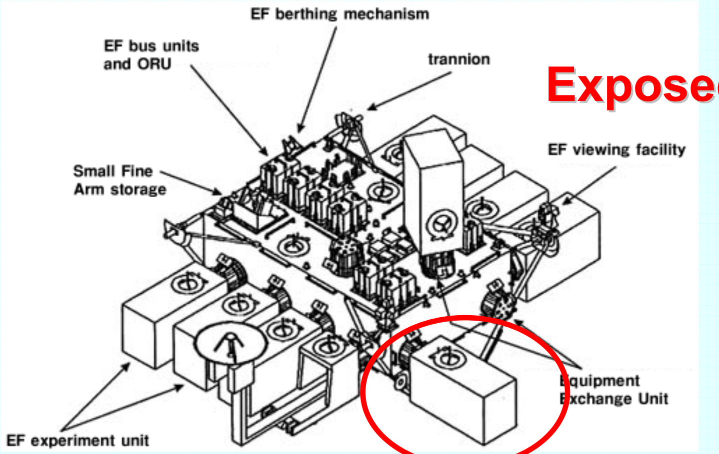
Japanese Participation

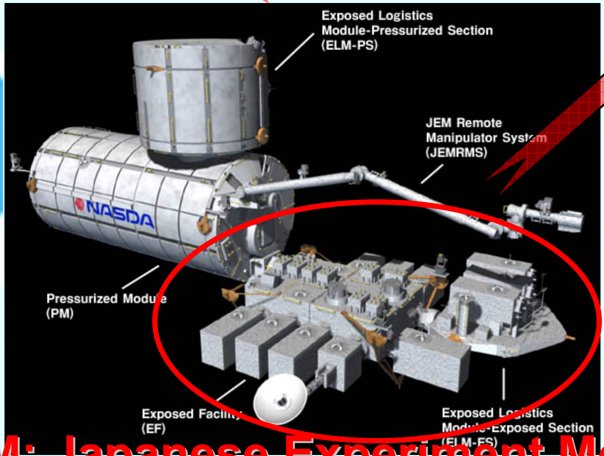
Japanese facilities except CAM will be launched by Space Shuttles, and
Most of the instruments onboard JEM will be launched by H2A Transfer Vehicles.

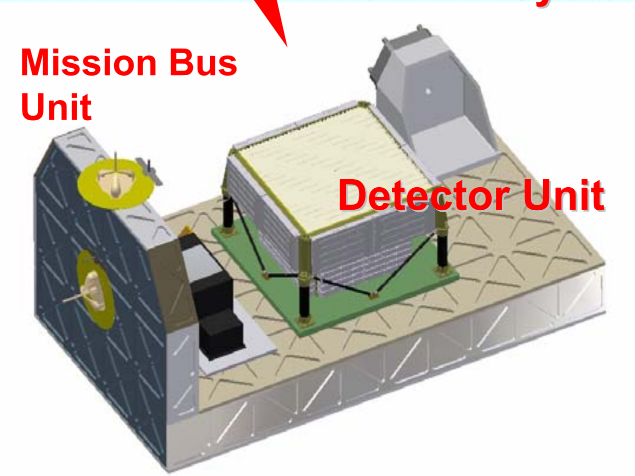


CALET on JEM/EF Facility

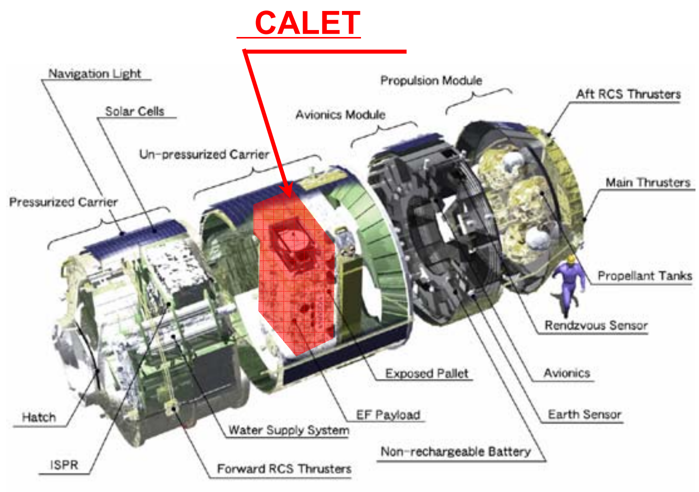








Launching Procedure of CALET

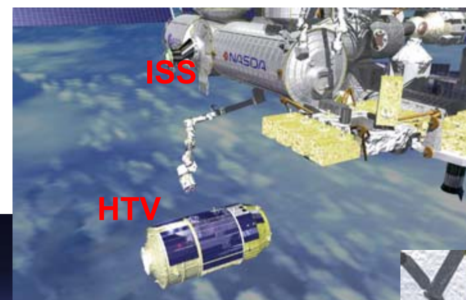


H-IIA Transfer Vehicle (HTV)

CALET launched by HTV

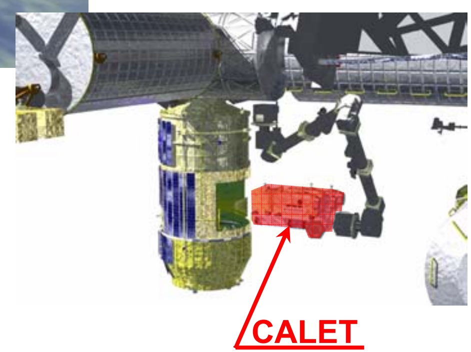
Launching of H-II Rocket

Separation from H-II



Approach to ISS

Pickup of CALET



HTV Operation & Supporting System

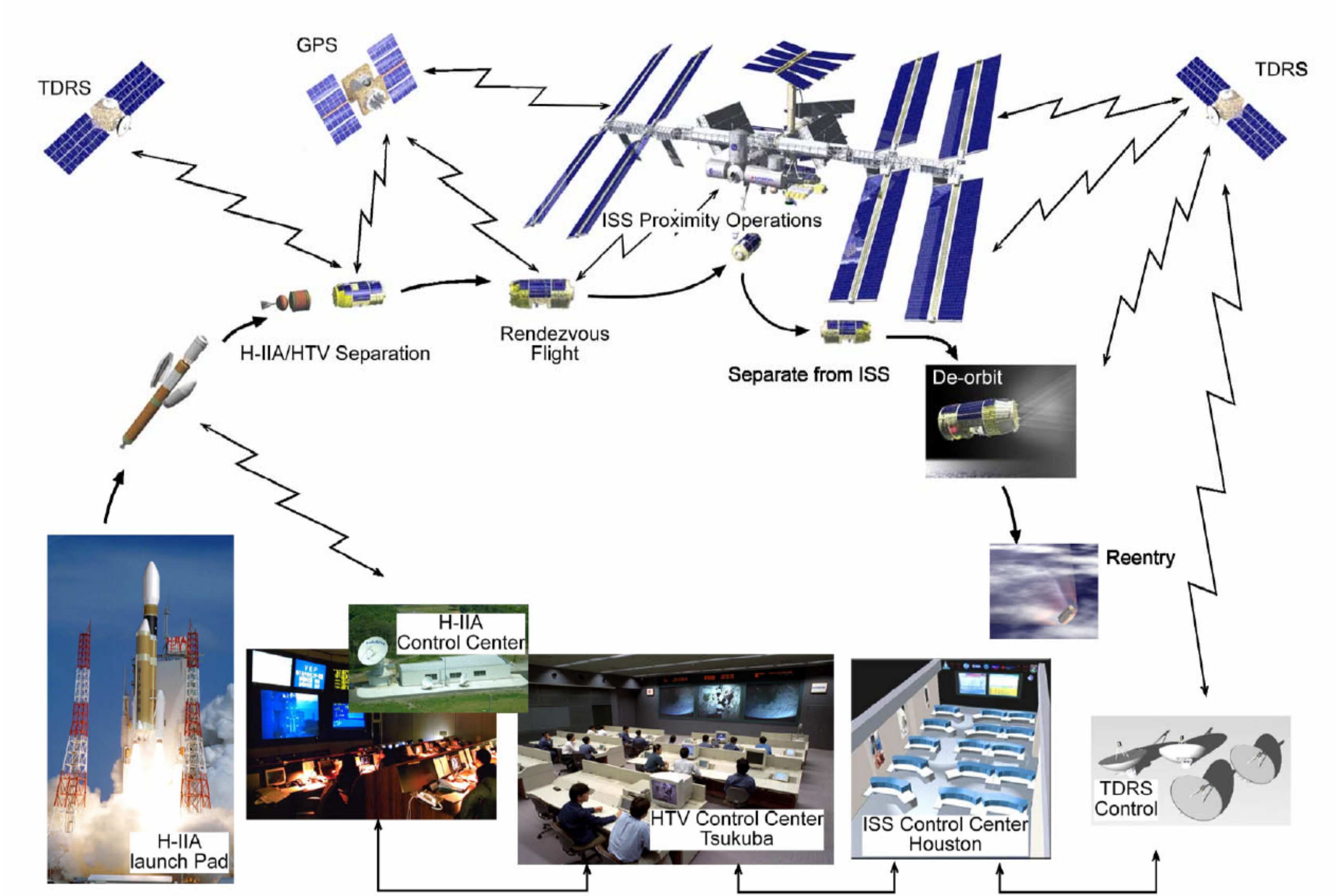


Figure-1 HTV Operations & Supporting Systems

Summary and Future Prospects

- ✓ The JEM/EF facility of ISS is very suitable to cosmic ray observation at very high energies with a heavy payload.
- ✓ We have successfully been developing the CALET instrument for JEM/EF facility from the experience of balloon experiments.
- ✓ The CALET has capabilities to observe the electrons up to 10 TeV , gamma-rays in 20 MeV- a few TeV , proton and heavy ions in several 10 GeV - 1000 TeV, for investigation of high energy phenomena in Universe.
- ✓ We have already completed a pre-phase A study within last 6 years, and expect a phase A study in 2006 to start operations on the ISS/JEM around 2012.

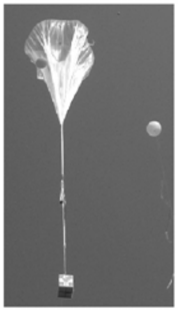
This work is supported by a part of "Ground-based Research Announcement for Space Utilization" promoted by Japan Space Forum

Backup Charts

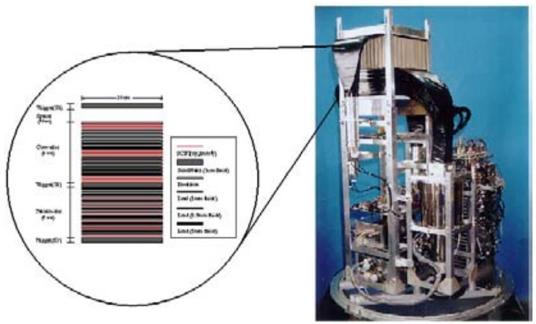
Scientific Heritage

1993-1998 :

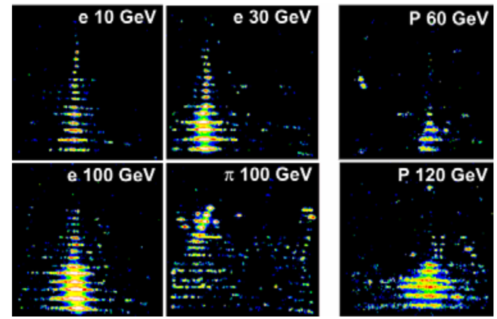
- Development of SciFi/Lead Calorimeter for Electron Observation (BETS) NIM 457, 499-508 (2001)
- Successful observation of electrons in 10-100 GeV ApJ 559, 973-984 (2001)
- Observation of atmospheric gamma-ray flux with improved BETS Phys Rev D.66 052004(1-9) (2002)



Balloon Flight



BET Instrument

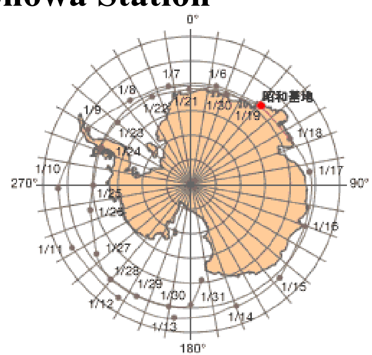


Shower Image at CERN

1999-2003:

- Development of new detector of Antarctic Flight (PPB-BETS) for observation in 100-1000 GeV
- Observation expected in 2003 at Showa Station

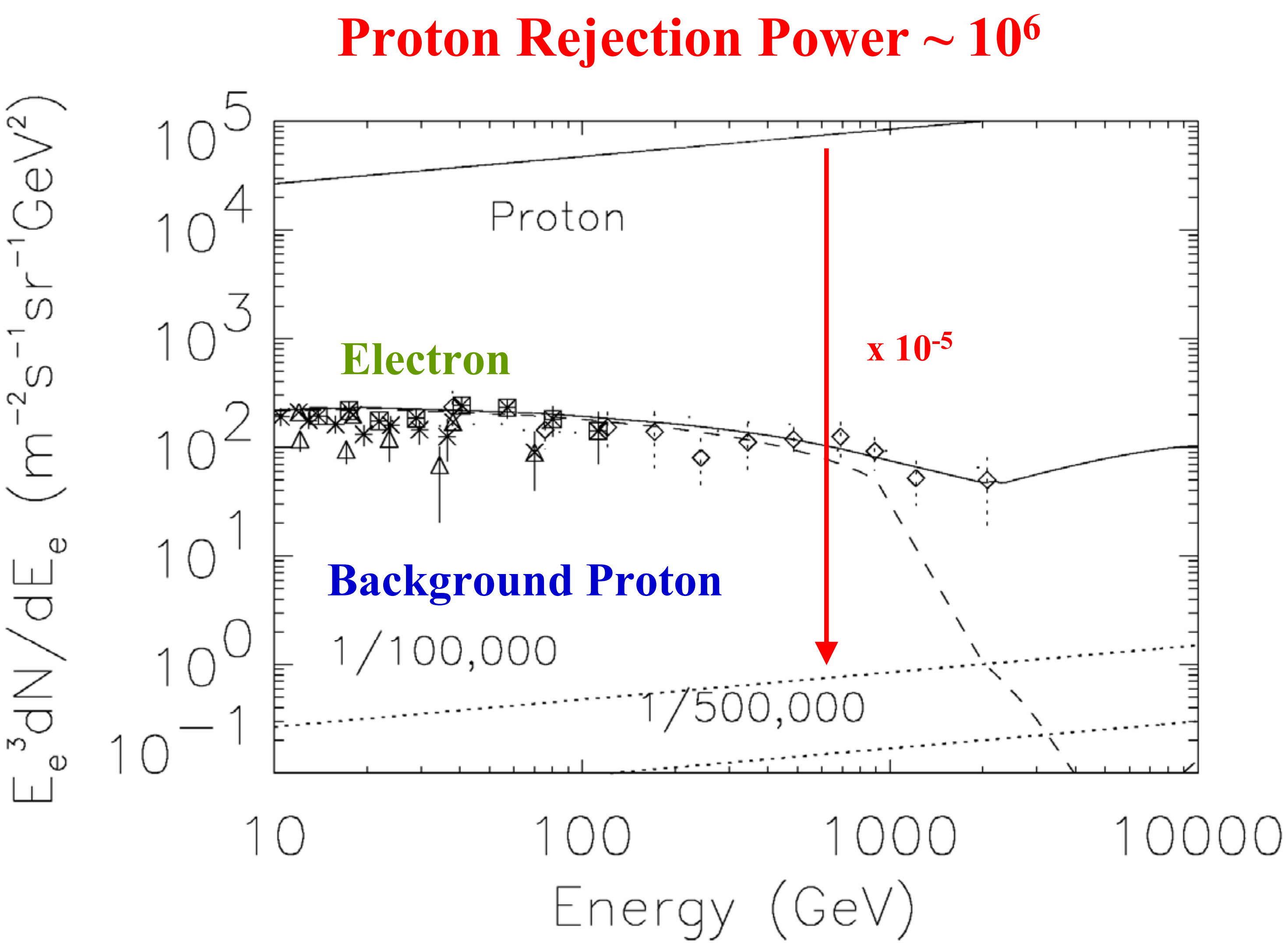
Balloon Flight at Antarctica



Expected Trajectory

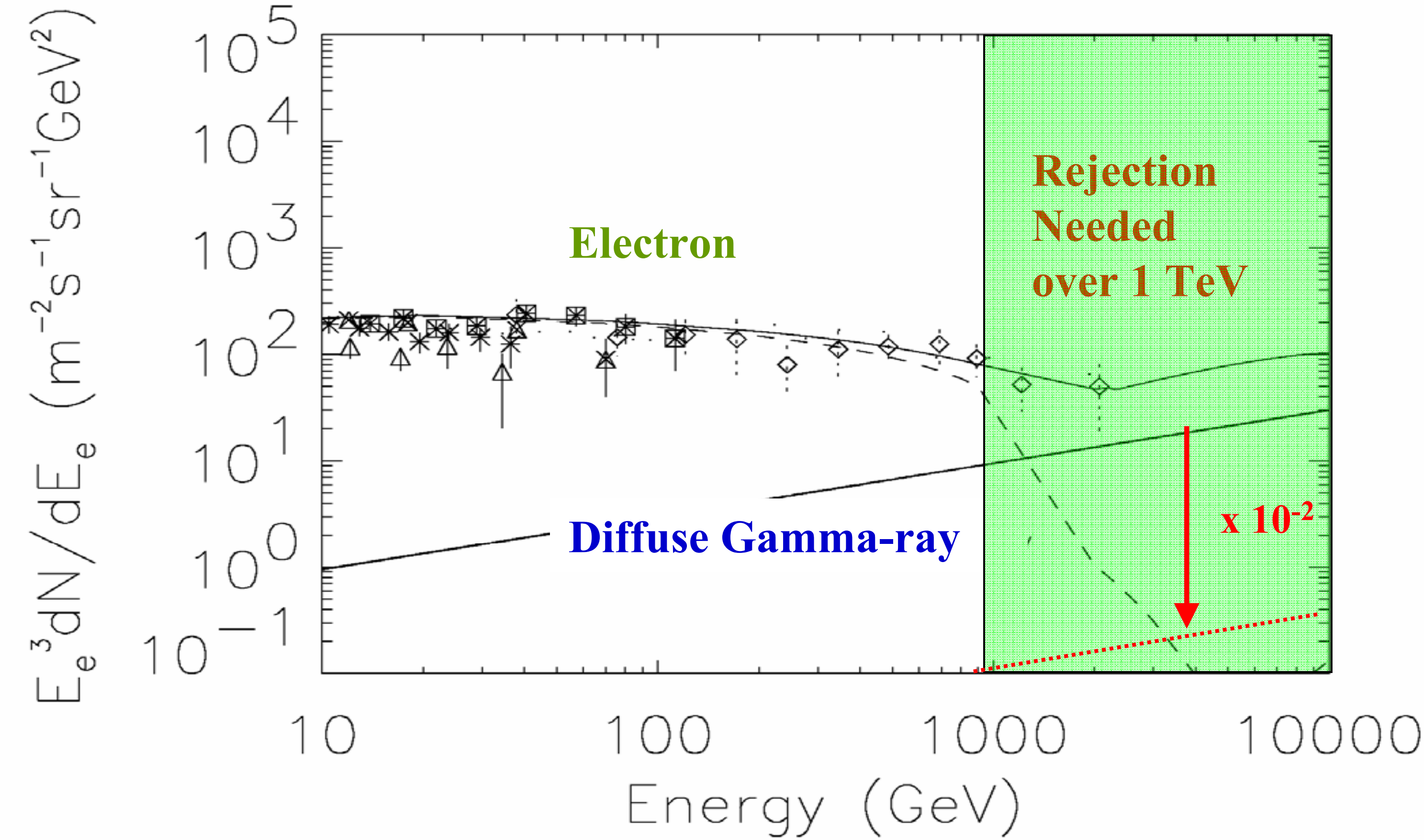
PPB-BETS with solar panels

Electron Detection by CALET

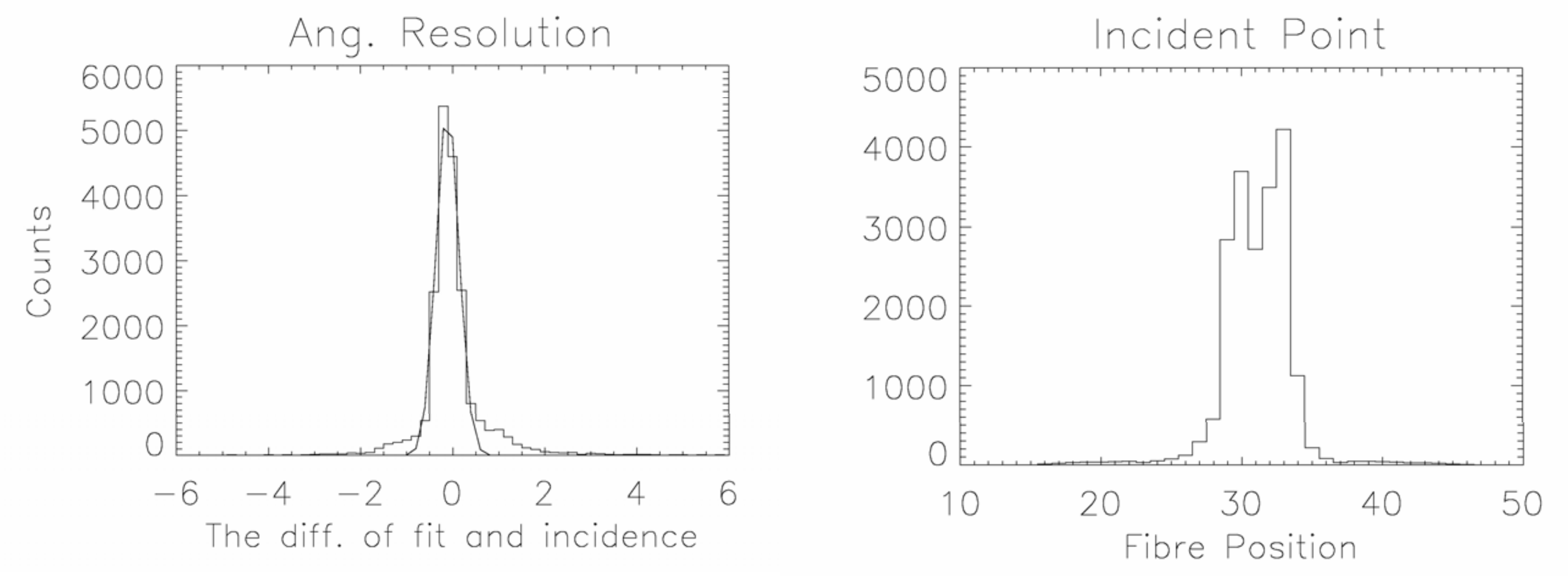


Electron and Gamma-ray Separation

Gamma-ray selection from electron ~10^2



Data Analysis (1) –Angle and Position Resolution -



Incident Beam 1cm x 1cm

Expected after correction

Without gain correction :

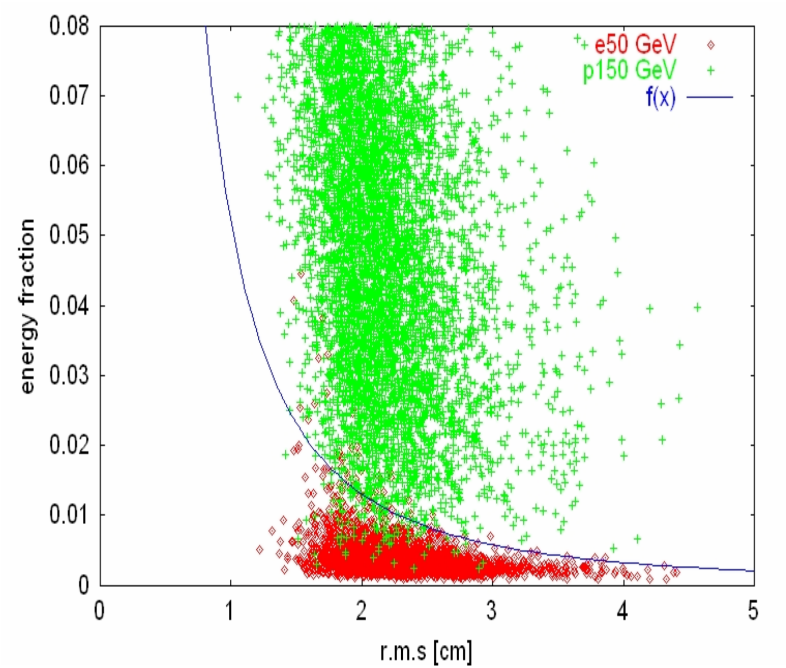
Angle Resolution ~0.25 degree → **0.1 degree**

Position Resolution ~ 0.5mm → **0.2 mm**

Data Analysis (2) -Proton Rejection Power -

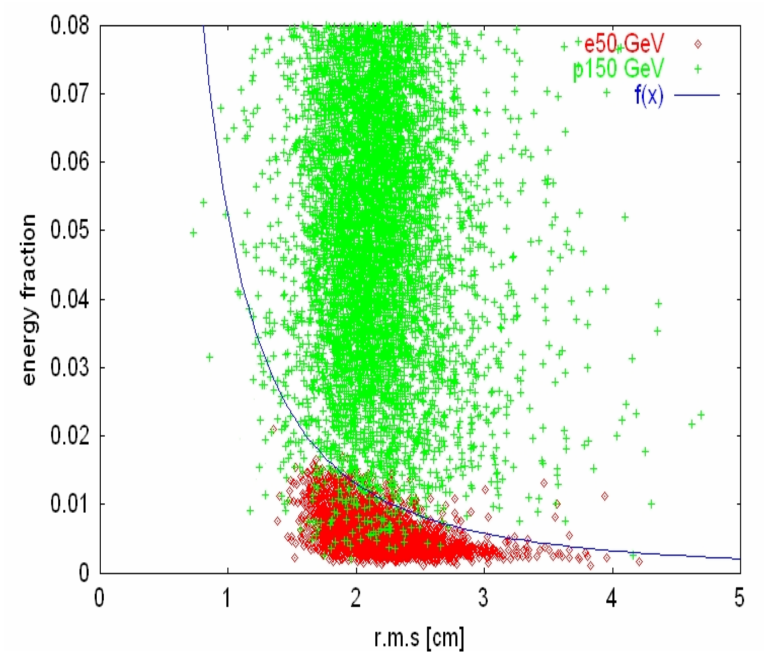
at the bottom (25cm thick BGO) layer

Simulation Proton 14,000 events
Electron 3,000 events



e50 GeV : 98.0%, p150 GeV : 0.63%

Experiment Proton ~14,000events
Electron ~3000events



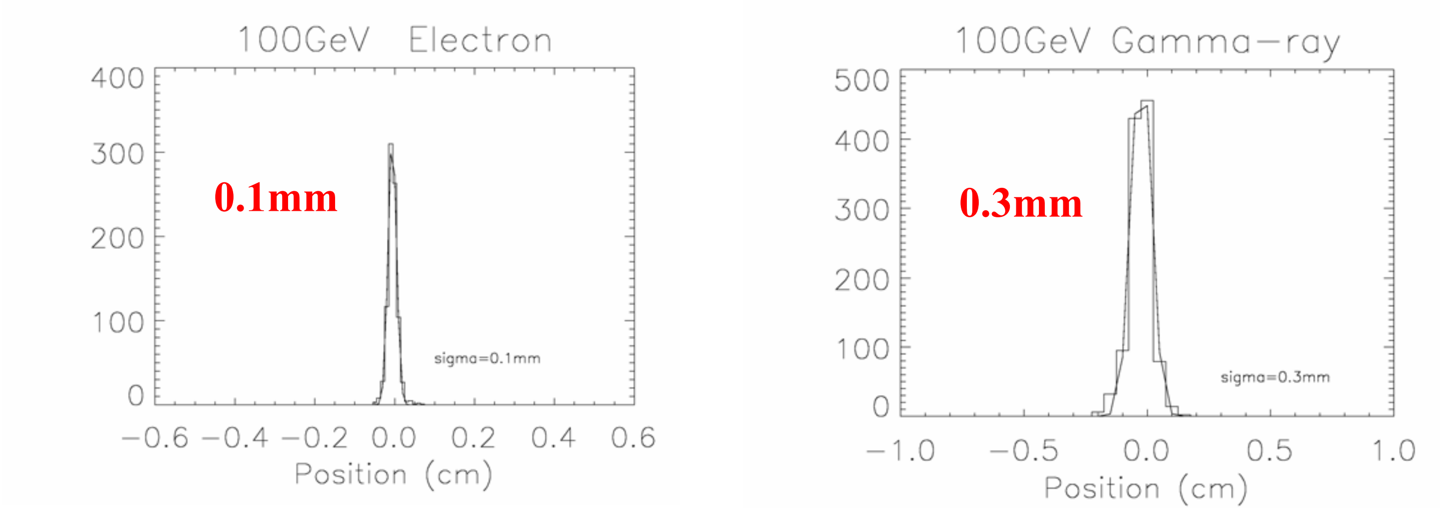
e50 GeV : 96.91%, p150 GeV : 1.27%
p150 GeV : 0.38% (after shower cut)

Gamma-ray Selection from Electron

Over 10 GeV, γ -rays can not be rejected by the anti-coincidence counter due to the back-scattered particles.

→ **γ -ray can be selected after proton rejection (~10^6) by segmented anti-coincidence and silicons using the top layer of IMC.**

Simulation for Positional Errors of the Incident Point of Particle

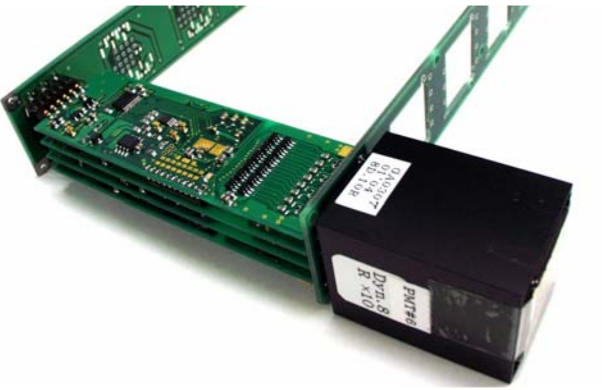


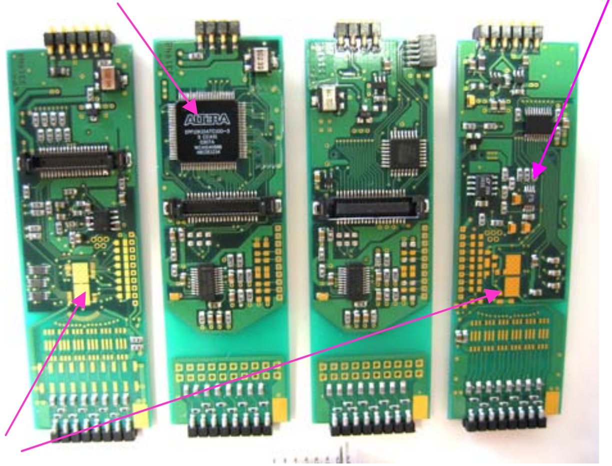
The possibility that gamma-ray has hits within 5 fibers around the incident point is less than 2×10^{-3}

→ **γ /e>500!!**

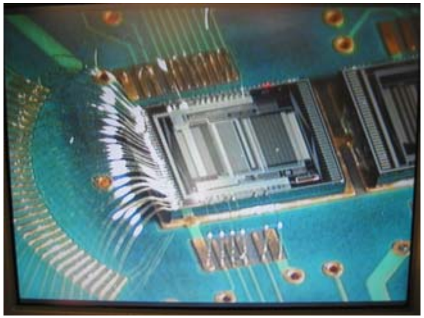
New FEC (1) – Power Consumption-

This new FEC system was already tested in CERN last year.





VA Bonding



Design and parts(ADC, Op Amp etc) of FEC are optimized for small size, low power consumption, low noise.

Power consumption of FEC for 64 channels (VA + ADC + FPGA)

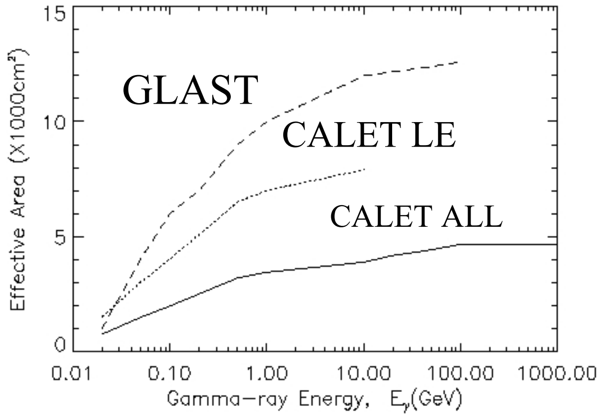
~ 420 mW (350 mW, other than the efficiency of the regulator)

→ total ~260 W (220 W) ← acceptable

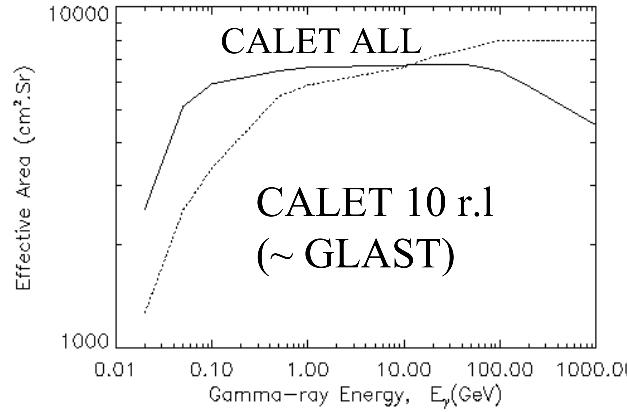
Simulation of Gamma-ray Performance

(Preliminary)

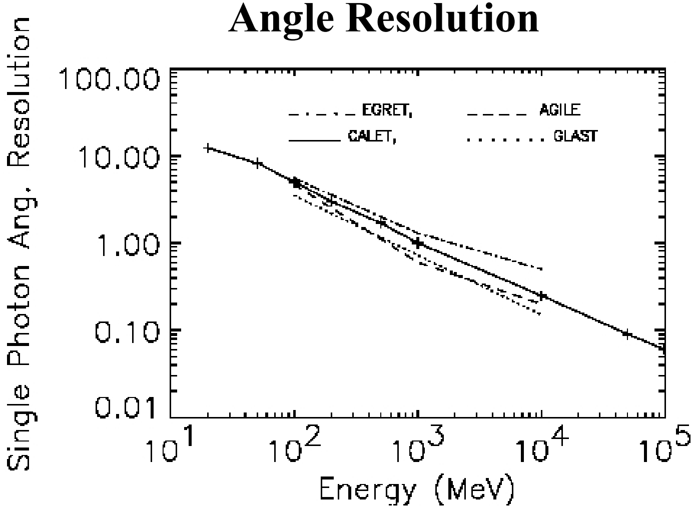
Effective Area



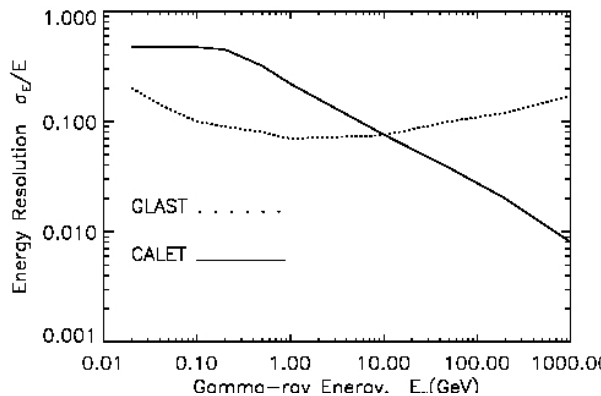
Geometical Factor



Angle Resolution

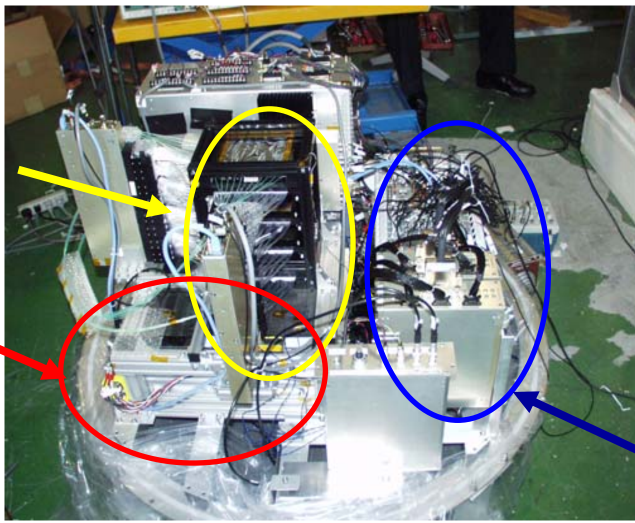


Energy Resolution



CALET ~1/64 Scale Model for Balloon Experiment

- *Effective Area : 128 mm ×128 mm*
- *IMC : 1024ch SciFi (1mm square) + 64-Anode PMT*
- *TASC : 24ch BGO Logs (2.5 cm ×2.5cm ×30cm) + Si PIN PD*



Basic Performance Obtained by Simulation

Attachment Payload (Max. Total Weight)	JEM/EF Heavy (2500 kg)
Energy Range of Electrons	1~ 10,000 GeV
Geometrical Factor	0.5~1.0 m^2sr
Proton Rejection Power	$10^5 \sim 10^6$ #)
Energy Resolution	9.2 / sqrt(E(10 GeV)) %
Angular Resolution [deg.]	0.03 ~0.1 deg.
Instrumental Weight	2,200 kg

#) Total Rejection Power by Scifi .Cal. and BGO Cal. for the protons
at same energy with electrons