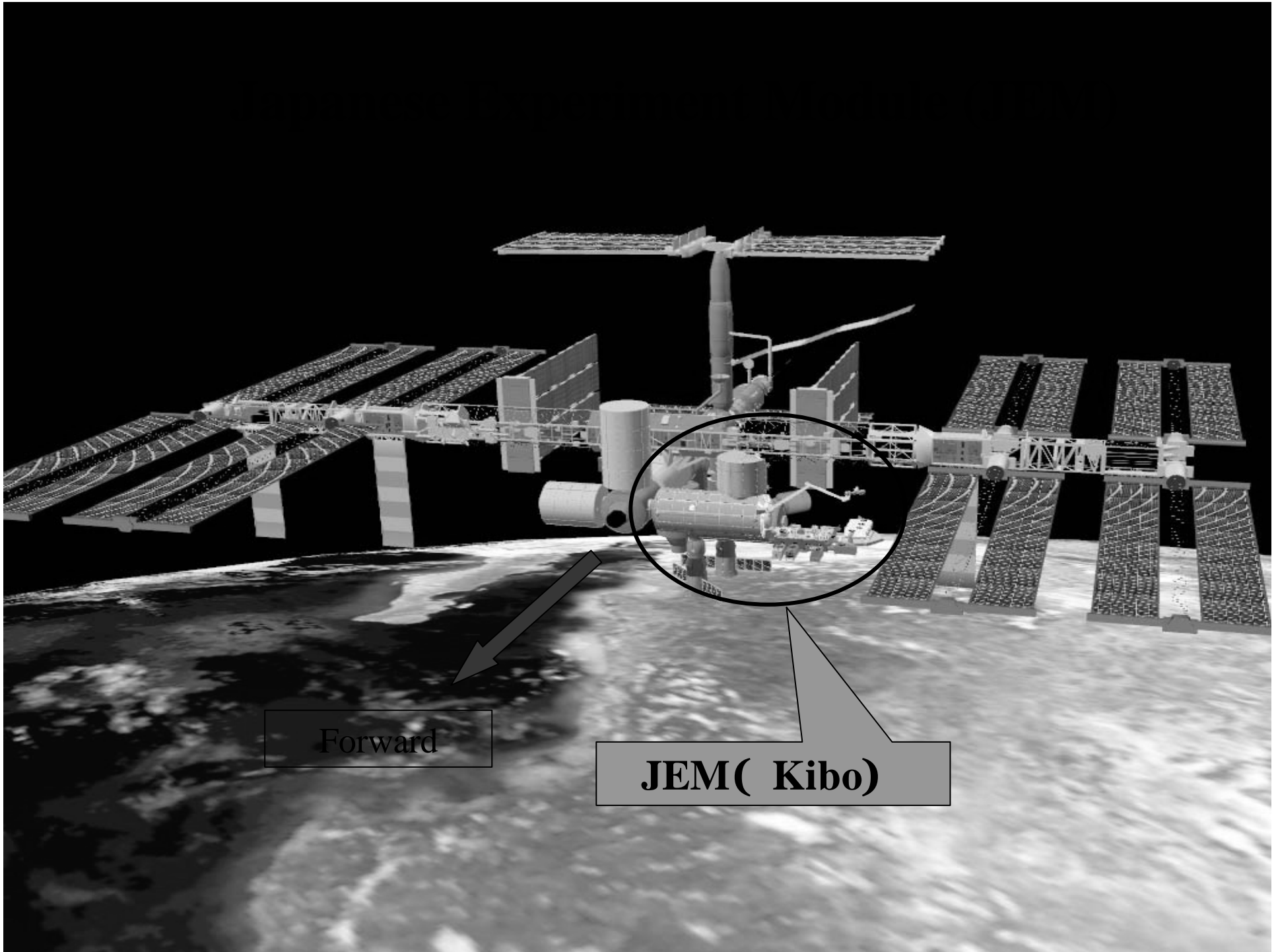


**CALET**  
**for High Energy Electron and Gamma-Ray**  
**Measurements on ISS-JEM**

**Shoji Torii**  
**Kanagawa University**  
**for the CALET Collaboration**  
**[http:// calet.n.kanagawa-u.ac.jp](http://calet.n.kanagawa-u.ac.jp)**



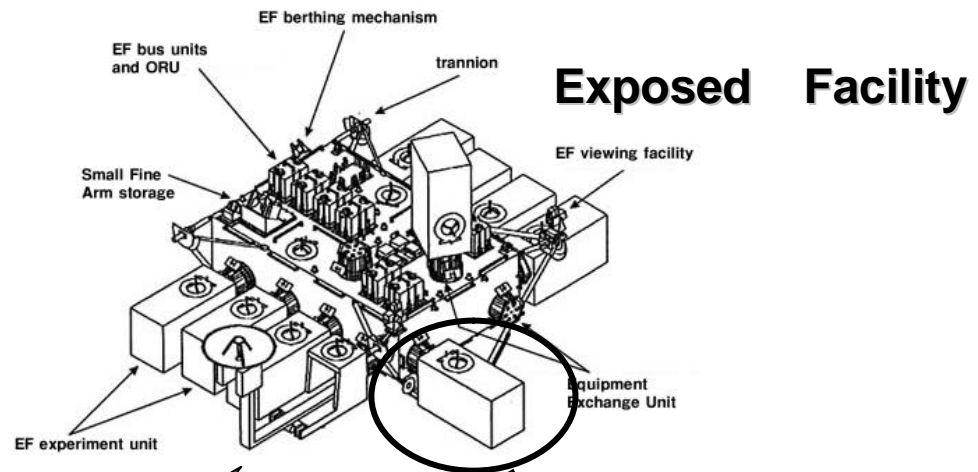
Forward

JEM( Kibo)

# CALET on JEM/KIBO Expose Facility



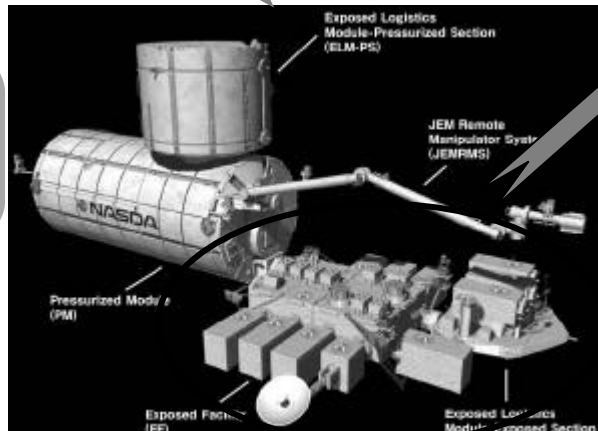
International Space Station



Exposed Facility

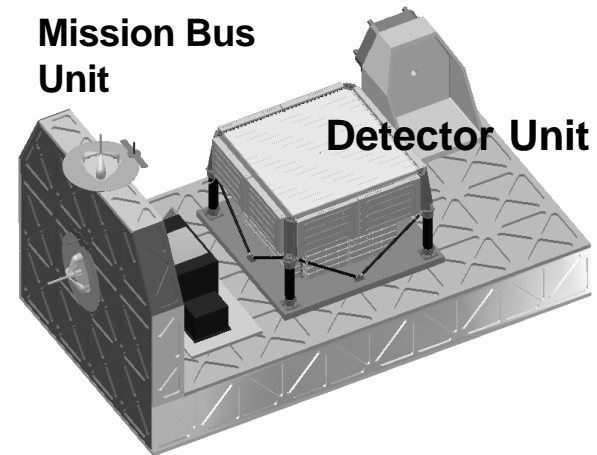


きぼう



JEM: Japanese Experiment Module

CALET System



Mission Bus Unit

Detector Unit

# 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:

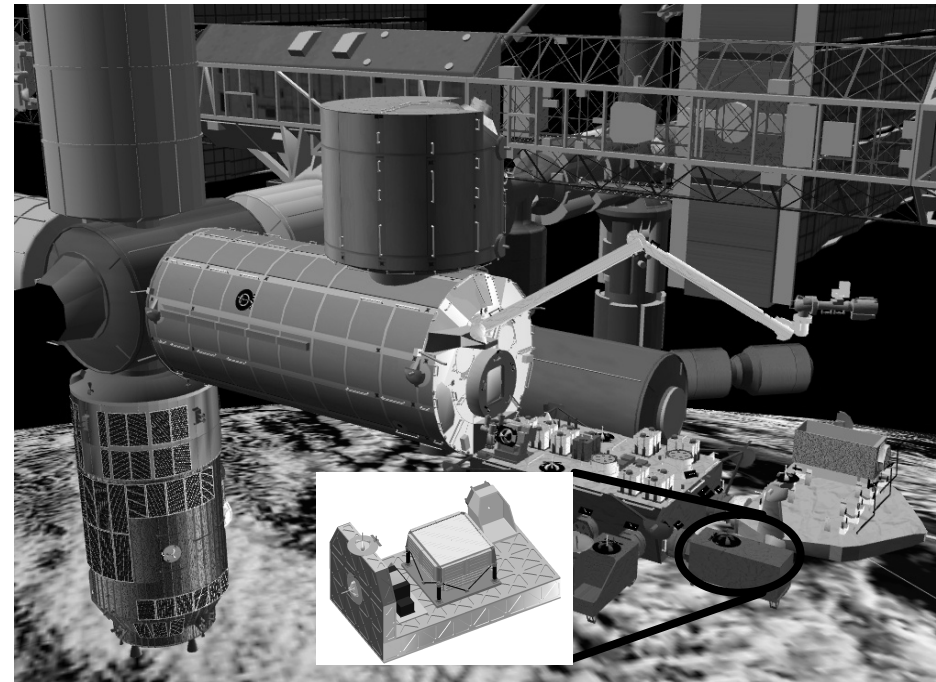
407 km, 51.6° inclination

### Life Time:

3 years (minimum)

### Mission Status

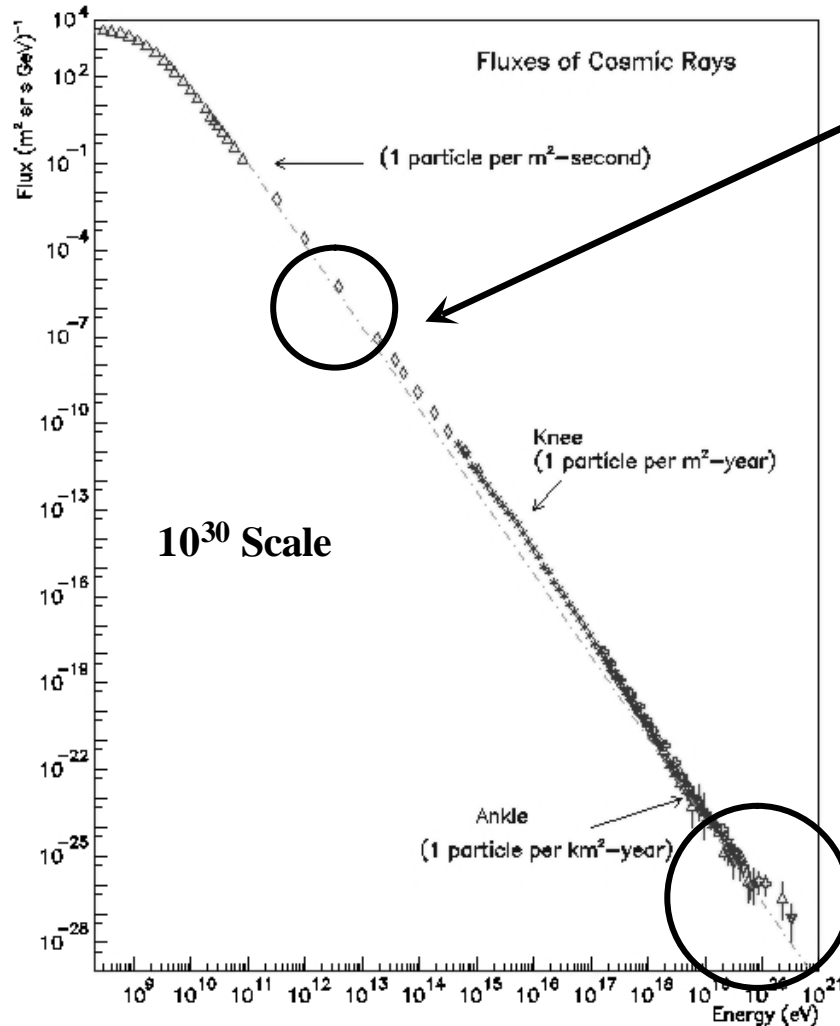
Mission Concept Study  
Launch around 2010 in Plan



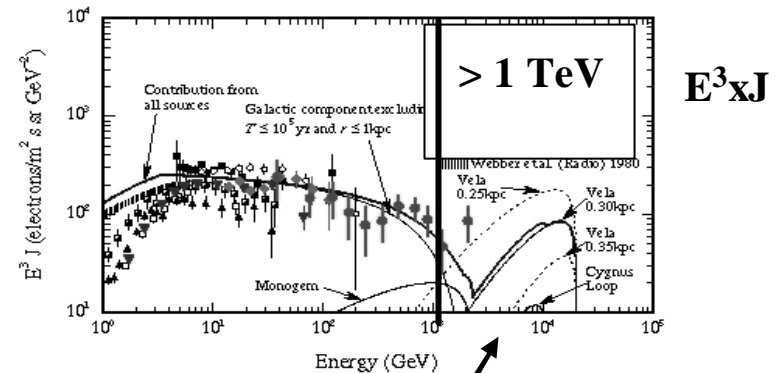
### CALET Payload:

- 1GeV ~ 10 TeV for electrons
- 20 MeV ~ TeV for gamma-rays
- Weight: 2500 kg
- Geometrical Factor: 1 m<sup>2</sup>sr
- Power Consumption: 600 W
- Data Rate: 600 kbps

# Cosmic Ray Energy Spectrum



**Electron  
IC, Synchrotron Cut-off**



**Nearby or Unknown Sources !!!**

Distance < 1 kpc  
Age < 10<sup>5</sup> year

**Hadron  
GZK Cut-off**

# Scientific Objectives



## ■ Detection of Nearby Electron Sources

- *Electron Propagation in Our Galaxy*
- *Supernova Explosion*
- *Solar Modulation*
- *Signature of Dark Matter*

## ■ Exploration of Cosmic Gamma-Ray Sources

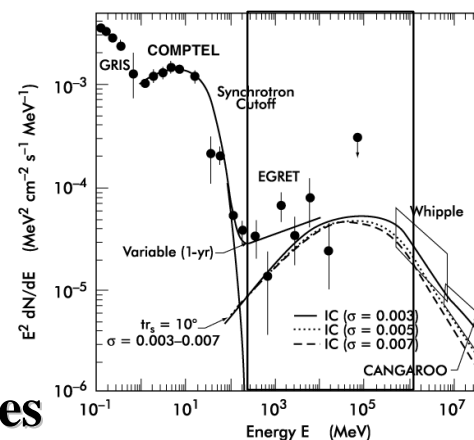
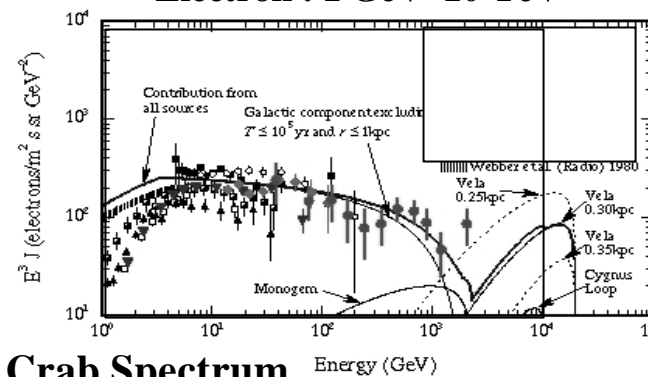
- *Diffuse Components in Our Galaxy*
- *Electron and Proton Origin*
- *Supernova Remnants and Pulsar*
- *Active Galactic Nuclei*
- *Isotropic Extragalactic Diffuse Components*
- *Gamma Ray Burst*
- *Dark Matter*
- *Solar Physics*

## ■ Observation of Proton & Nucleus Sources (Optional)

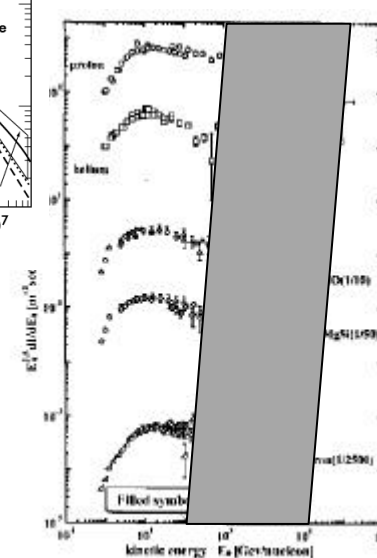
- *Supernova Shock Acceleration*
- *Propagation in Our Galaxy : Structure of the Galaxy*
- *Ion Sources: FIP source or Dust grain*

## ■ Discovery in Un-observed Region !!

Electron : 1 GeV~10 TeV



Gamma-Ray:  
20 MeV ~ TeV



p-Fe:  
1 ~ 1000 TeV

# Electron Energy Spectrum in 1 GeV ~ 10 TeV



Background: p/e

100 ~ a few  $10^3$

$10^3 \sim 10^5$

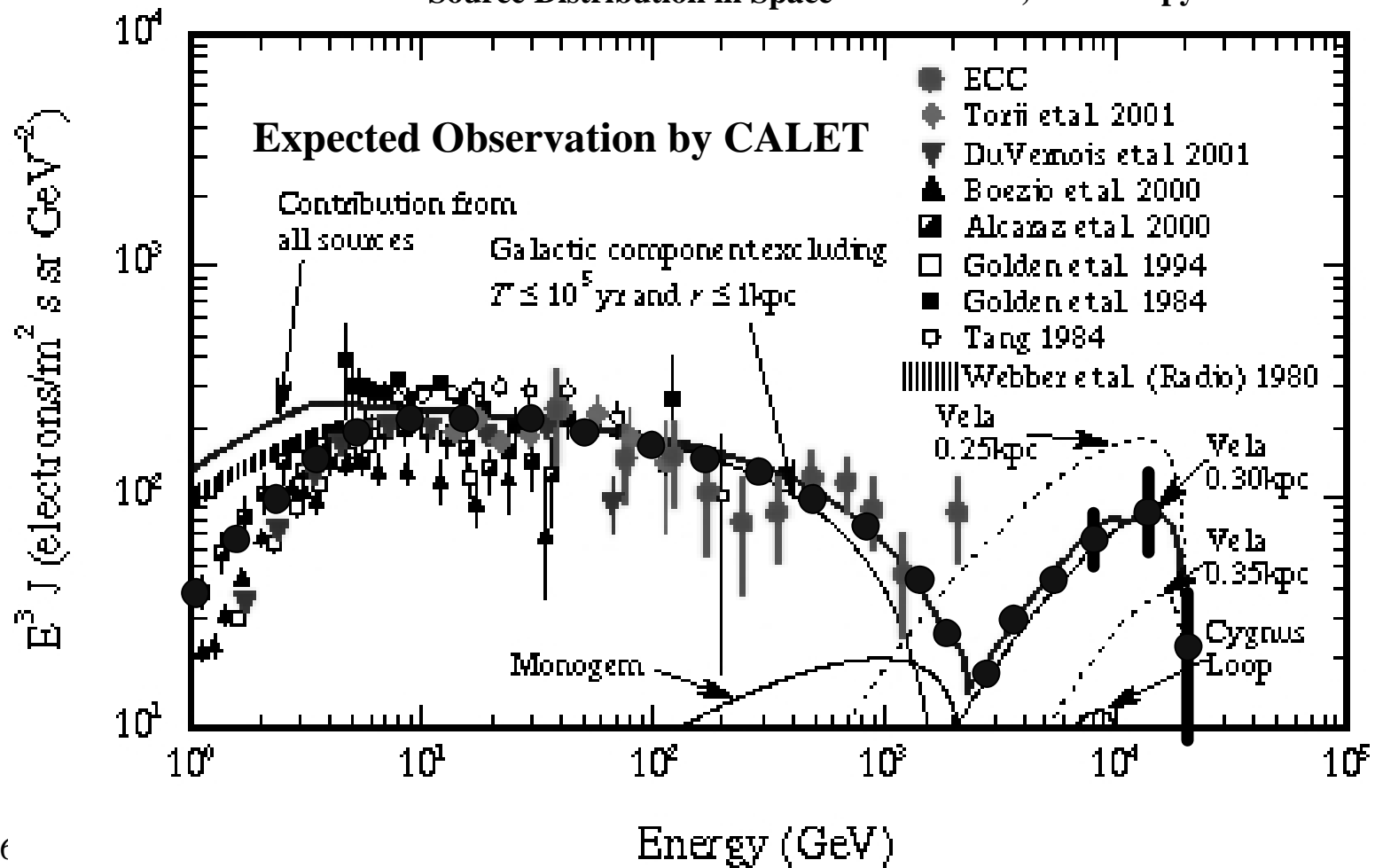


Rejection Power  
of  $10^6$  !!!

Solar  
Modulation

Poor Statistics & Inconsistency:  
- Acceleration and Propagation  
- Source Distribution in Space

No Observation:  
Direct Evidence of  
Sources, Anisotropy



# Gamma-Ray Observation in 20 MeV~10 TeV



**CALET on the ISS orbit without attitude control of the instrument:  
Wide FOV (  $\sim 45^\circ$  ) and Large Effective Area ( $\sim 0.5 \text{ m}^2$  ) in 20 MeV- 10 GeV**

?

- ⌚ Sky coverage of 70 % for one day
- ⌚ All sky coverage in 20 days
- ⌚ Typical exposure factor of  $\sim 50$  days for point source

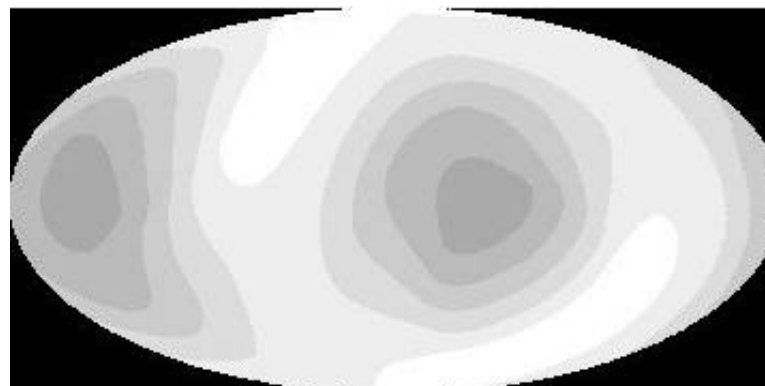
**Good Energy Resolution (  $< \text{a few } \%$  ) over 100 GeV**

?

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

CALET all-sky exposure map ( $>100 \text{ MeV}$ )  
in the Galactic coordinate for one year.

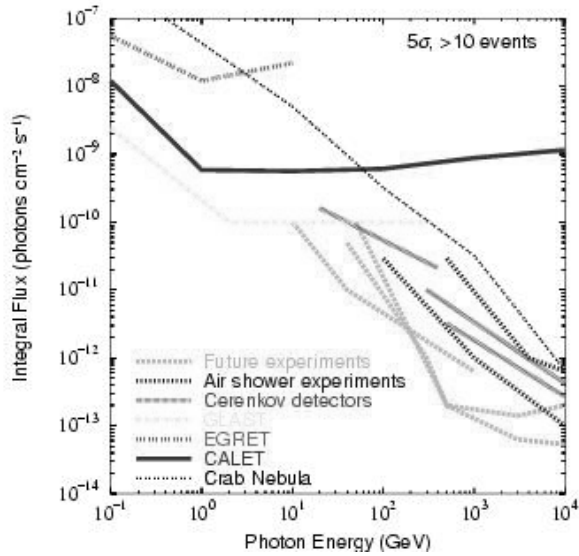
Brightness indicate the amount of exposure  
from 43 days, the shortest, to 52 days, the  
longest.



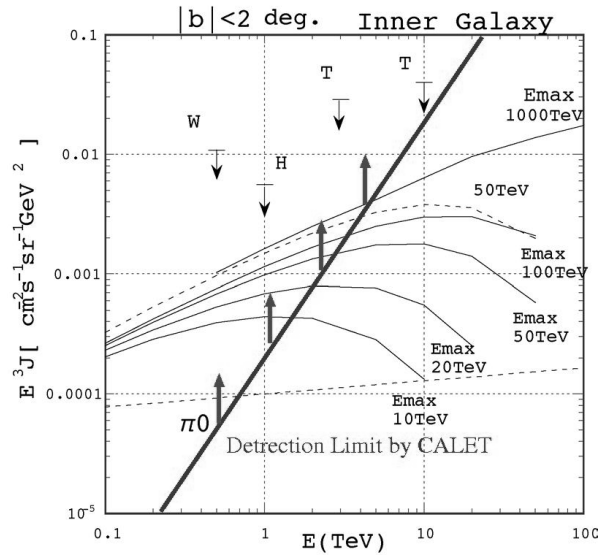
# CALET Capability of Gamma-Ray Observation



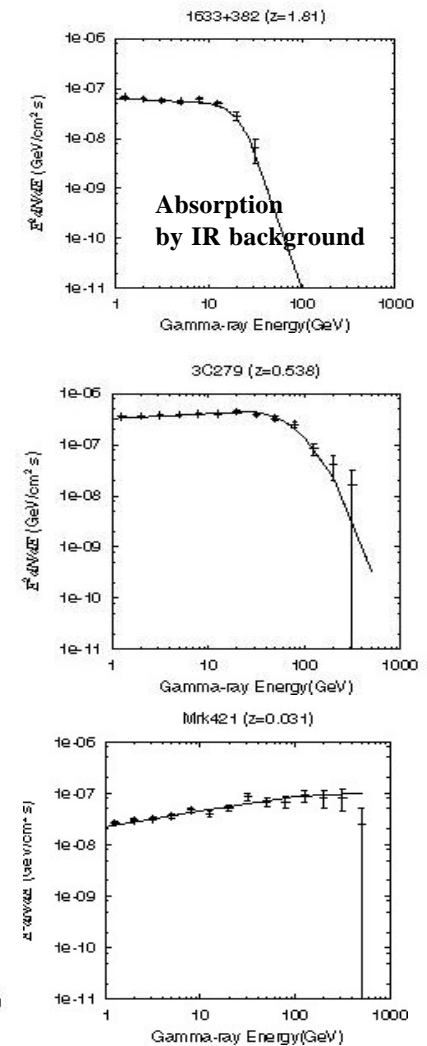
## Point Source Sensitivity in One-Year Observation



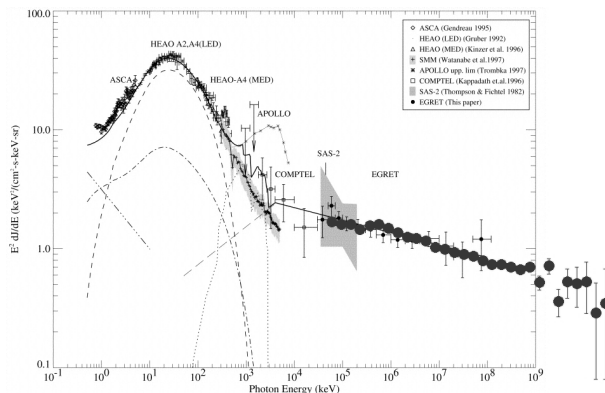
## Galactic Diffuse Component



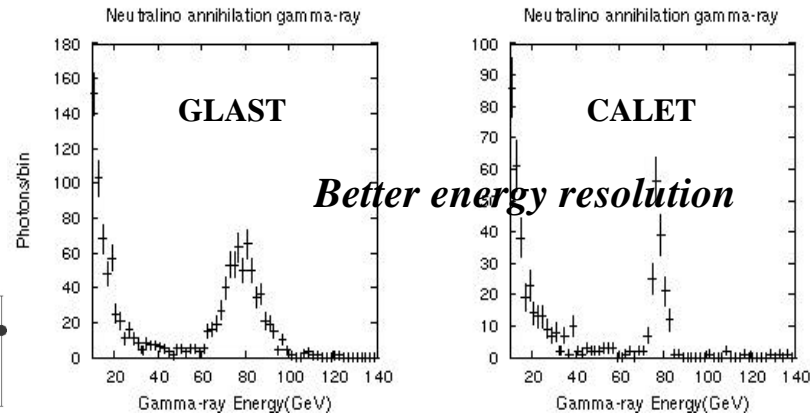
## AGN Spectra



## Extra-Galactic Diffuse Component



## Line Gamma-Ray from Neutralino



# Conceptual Structure of CALET



## Requirements:

- ✍ Large Acceptance:  $1 \text{ m}^2 \text{ sr}$
- ✍ Imaging Capability:  $< 1 \text{ mm}$
- ✍ Hadron Rejection Power:  $\sim 10^6$
- ✍ Energy Measurement:
  - 20 MeV~10 TeV for  $e, \mu$
  - 1 ~ 1000 TeV for hadrons (Optional)

## SciFi/Lead Imaging Calorimeter (IMC):

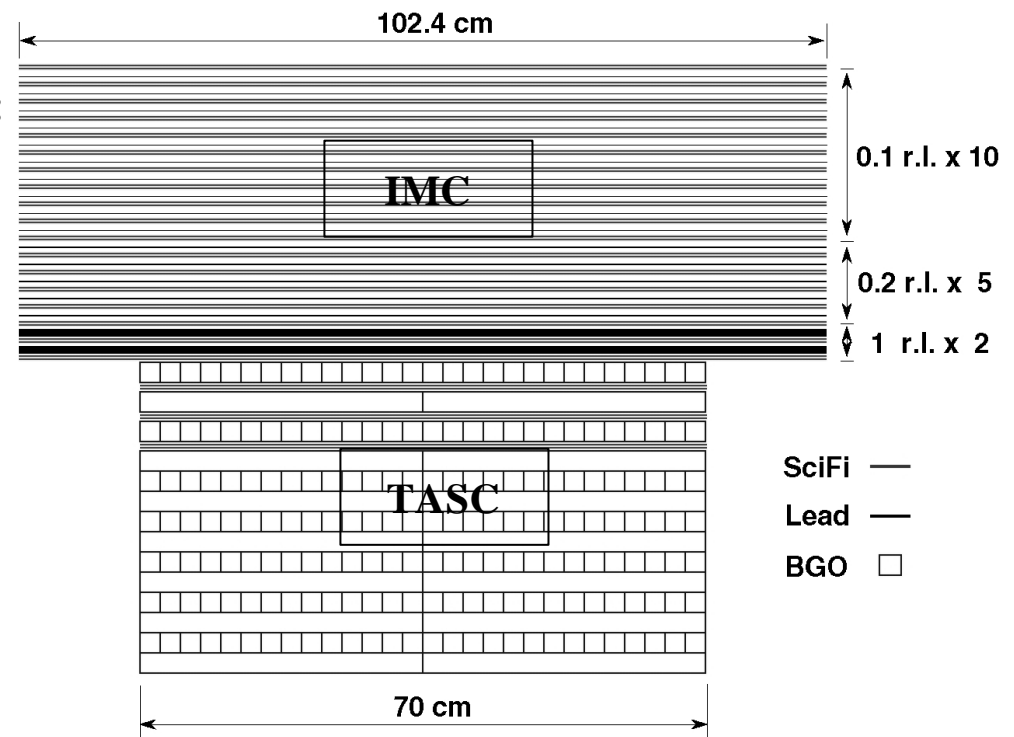
- ✍ Area:  $\sim 1 \text{ m}^2$
- ✍ SciFi Belt: 1mm square x  $\sim 1 \text{ m}$  length  
17 layers(x &y)
- ✍ Lead Thickness: 4 r.l, 0.13 m.f.p

## Total Absorption Calorimeter (TASC):

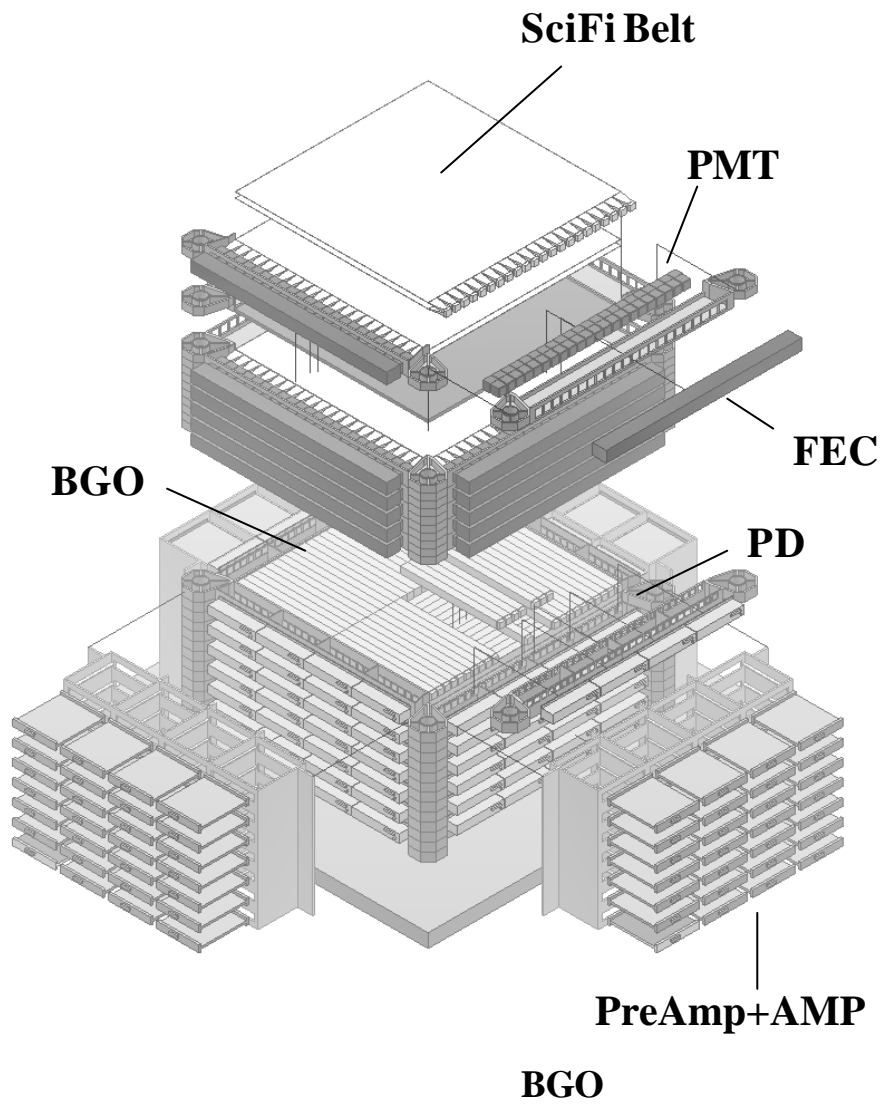
- ✍ Area:  $\sim 0.5 \text{ m}^2$
- ✍ BGO Log: 25 x 25 x 350 mm  
7 layers (x &y)
- ✍ SciFi Belt for 3 layers ( x &y)
- ✍ Thickness: 32 r.l, 1.6 m.f.p

## Schematic Side View of CALET ( without Anti-Coincidence System)

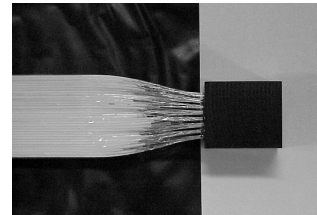
Detector Weight: 1760 kg  
Total Absorber Thickness: 36 r.l,  $\sim 1.7 \text{ m.f.p}$



# Detector Components



SciFi Belt (32 x 2 layers)



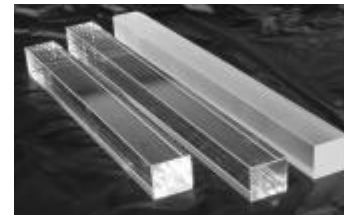
64-anode PMT



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



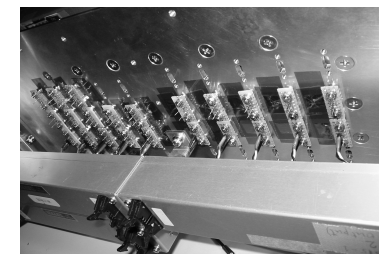
BGO or PbWO<sub>4</sub>



BGO+PD



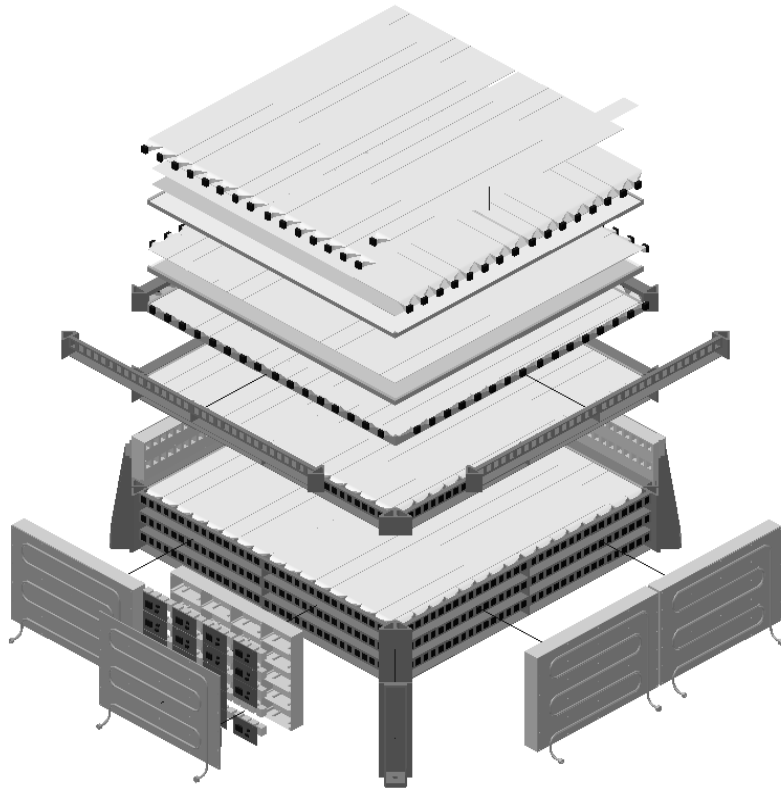
Connectors to Pre-Amplifier



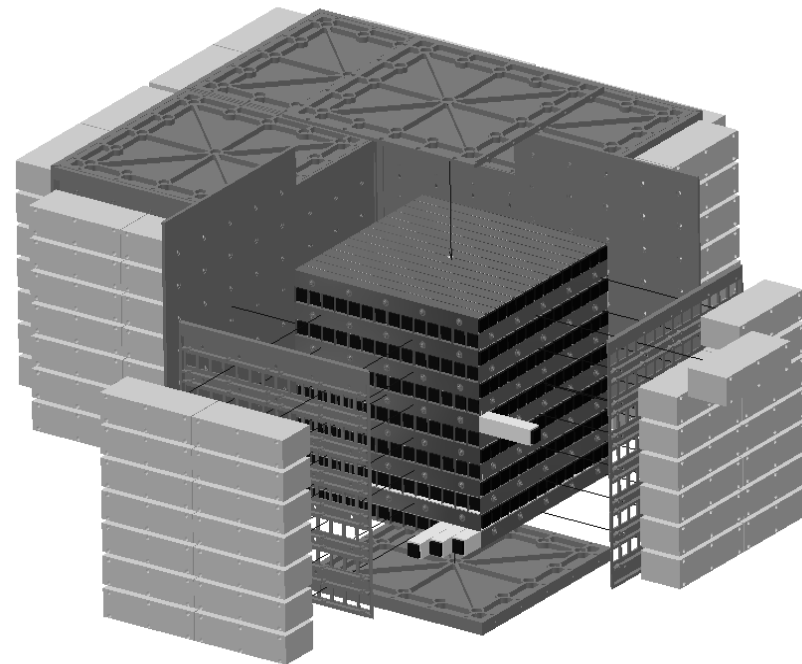
# Structural Design



## Imaging Calorimeter



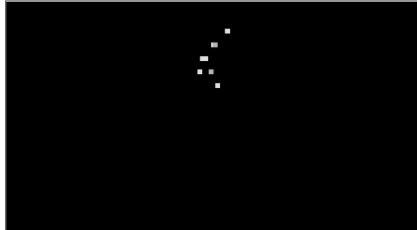
## Total Absorption Calorimeter



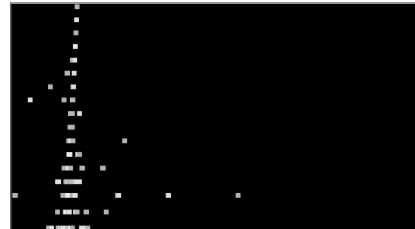
# Examples of Shower Profile by Simulation



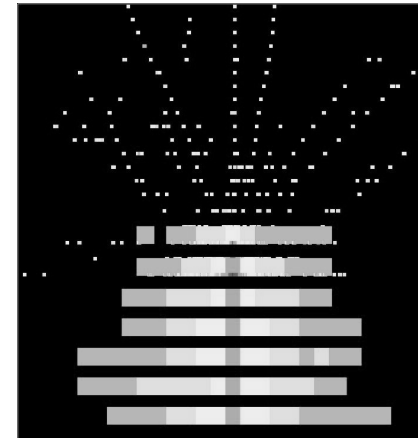
**Gamma-ray 20 MeV**



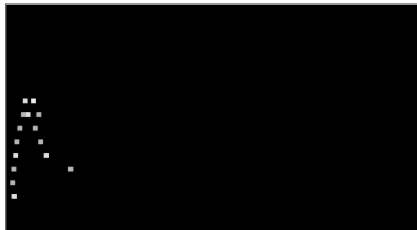
**Electron 10 GeV**



**Proton 3 TeV**



**Gamma-ray 100MeV**



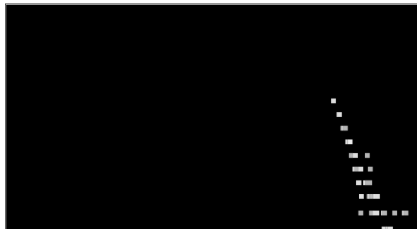
**Electron 100 GeV**



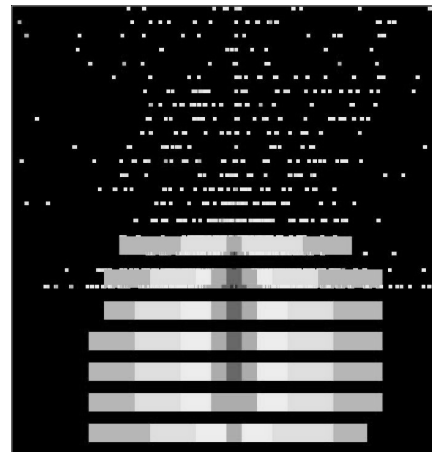
**Proton 3 TeV**



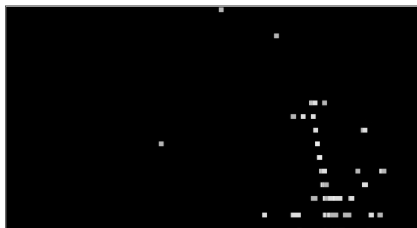
**Gamma-ray 1GeV**



**Electron 10 TeV**



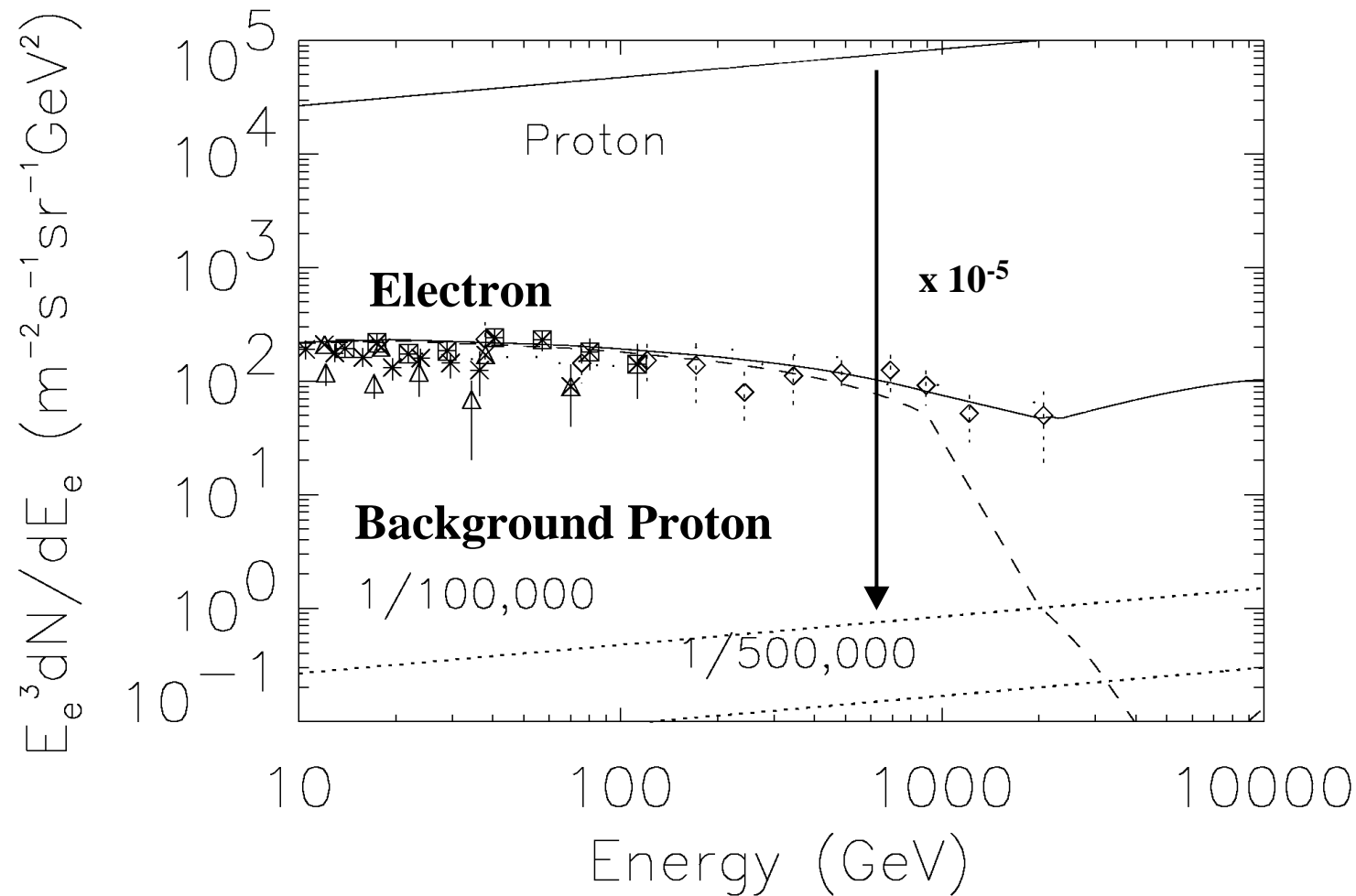
**Gamma-ray 10GeV**



# Electron Detection in CALET



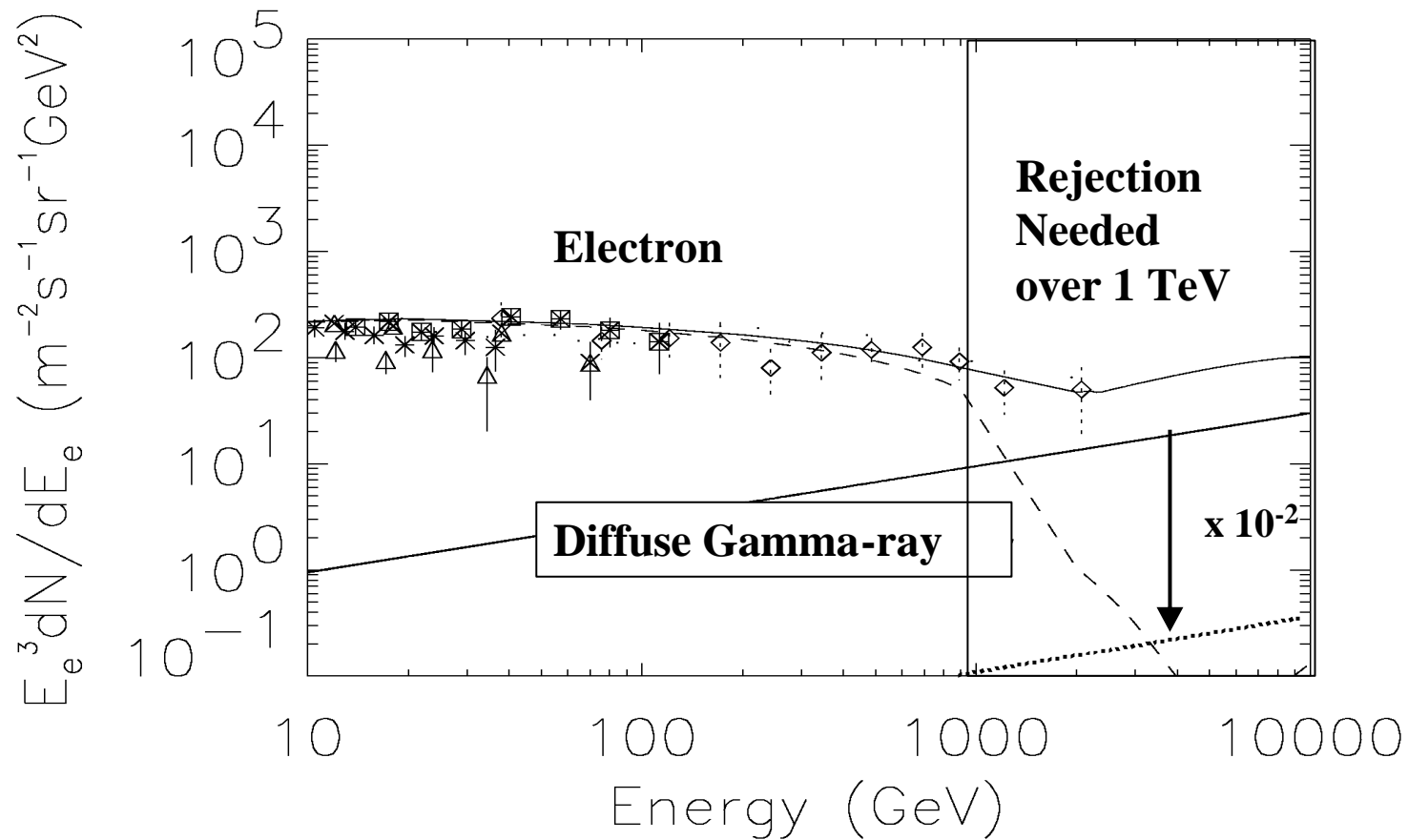
## Proton Rejection Power $\sim 10^6$



# Electron and Gamma-ray Separation



## Gamma-ray selection from electron $\sim 10^2$



# Simulation Study on Proton Rejection Power

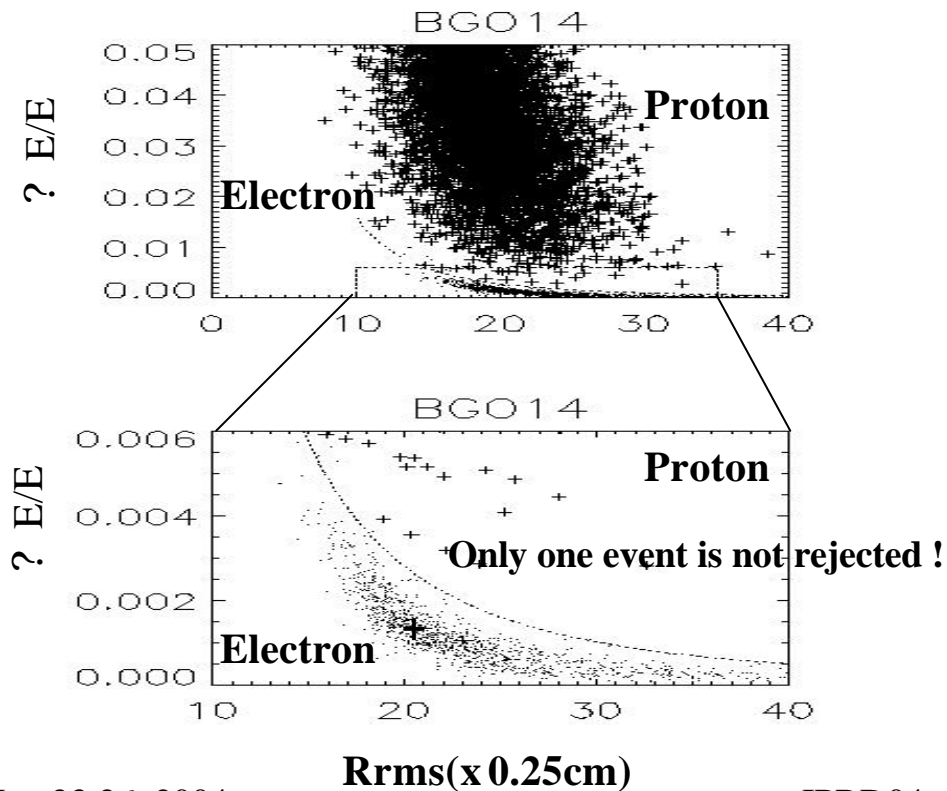


Simulation Events: Isotropic Incident and Uniform Distribution on the Top  
**Proton Events  $\sim 10^6$  at 10 TeV (Spectrum) : Electron Events 1000 at 4 TeV**

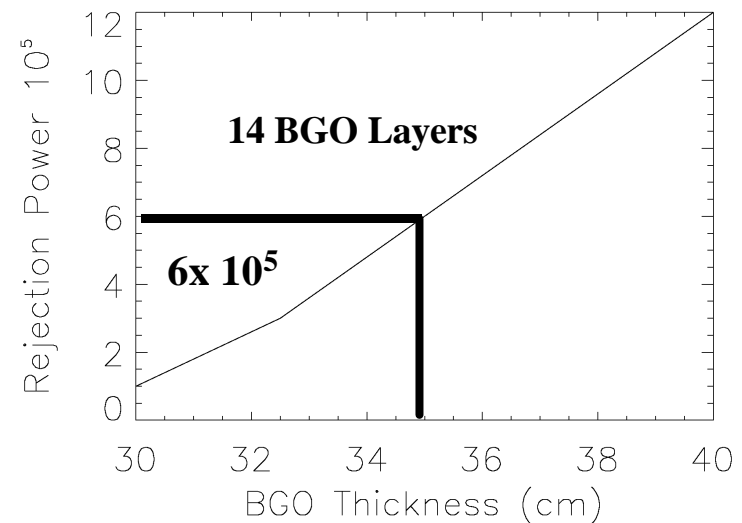
## Fraction of Energy Deposit vs Energy Weighted Lateral Spread

? E/E: Fraction of Energy Deposit at Each Layer  
 Rrms: Root Mean Square Lateral Spread of Shower (Energy Weighted)

**Rejection Power  $\sim 10^6$  !!!**



## Rejection Power vs BGO Thickness

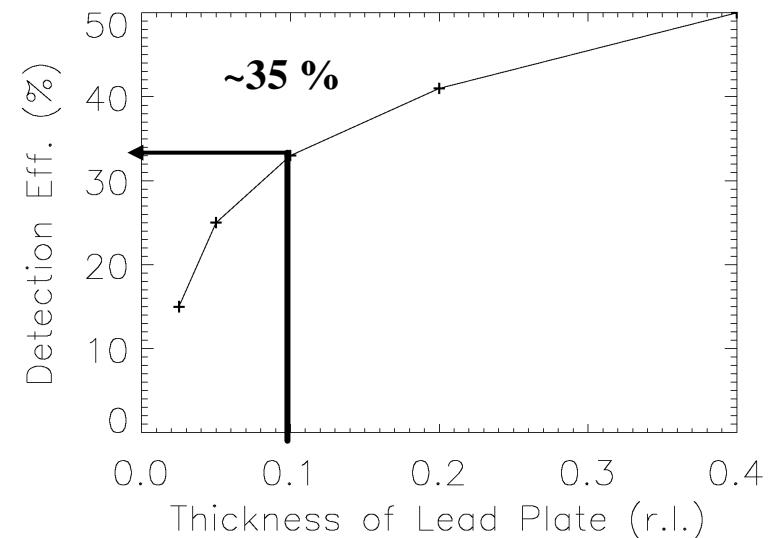
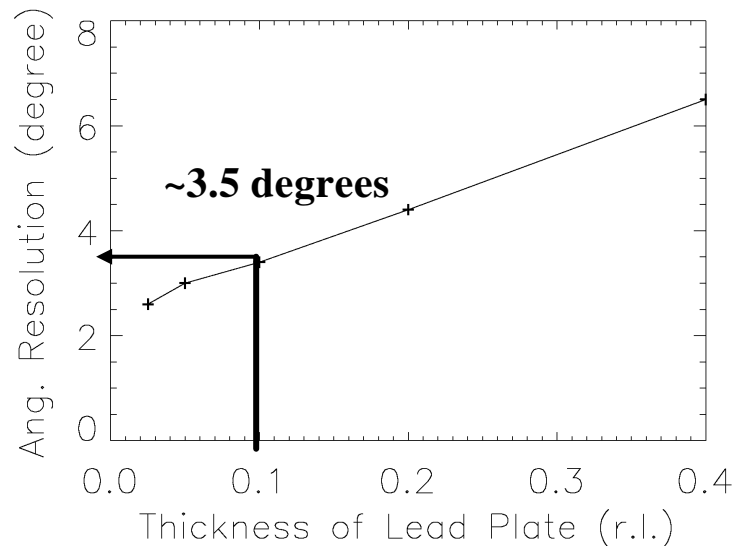


# Gamma-Ray Detection vs. Lead Thickness



For Gamma-ray observation, the angle resolution and detection efficiency depends on the thickness of lead plate

100 MeV gamma-ray for 0.1 r.l. thickness of lead



Angle Resolution vs Lead Thickness

Detection Efficiency vs Lead Thickness

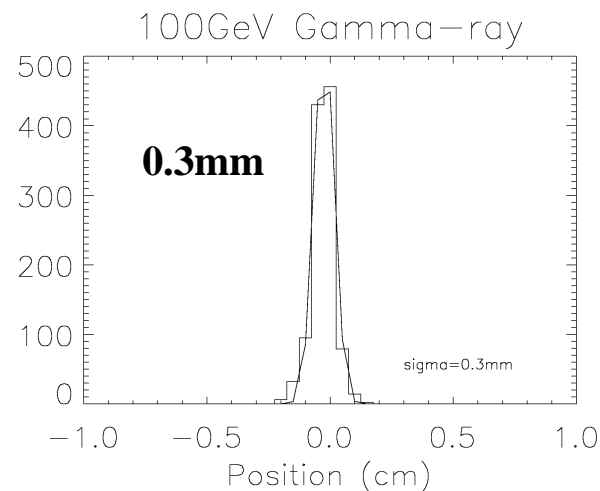
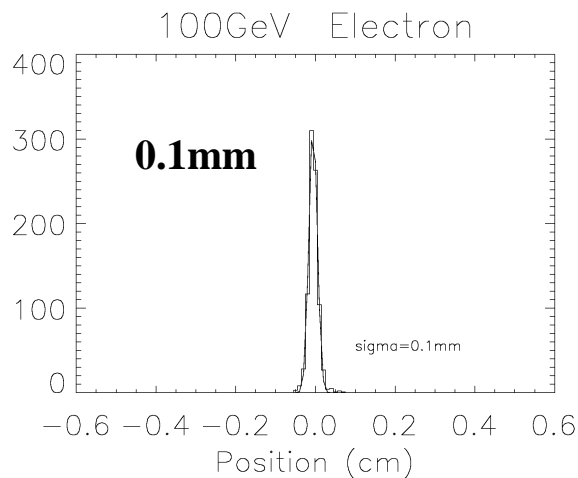
# Gamma-ray Selection from Electron



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

**→ Gamma-ray can be selected after proton rejection ( $\sim 10^6$ ) by segmented anti-coincidence using the top layer of SciFi.**

## Simulation of Positional Errors of the Incident Point



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

**→ ? /e>500!!**

# Imaging Calorimeter of CALET



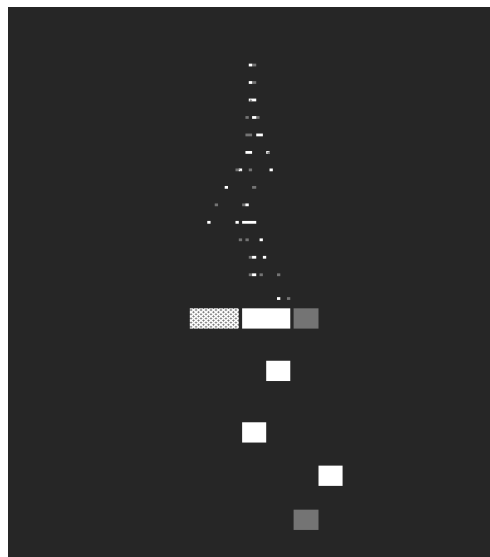
## ✍ Purpose :

Tracking and shower information are used for determining the axis of cascade shower and for identifying the particle species

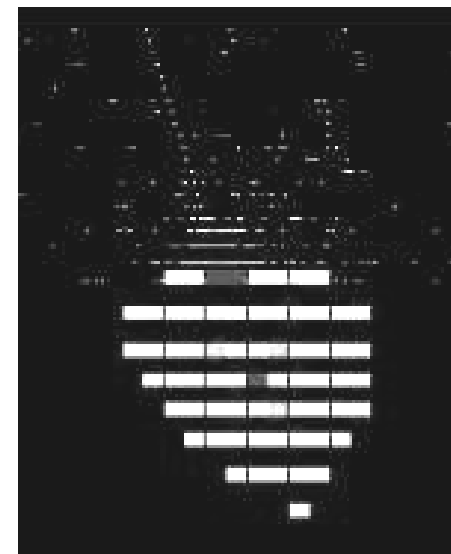
## ✍ Requirements

- ✍ Dynamic range from 1 MIP to 2~3000 MIP
- ✍ Trigger  $\sim 100$  Hz ✍ 1 kHz DAQ capability
- ✍ Readout power low as possible (FEC  $< \sim 300$  W in total)

500 MeV ?



4 TeV electron



# How to Read SciFi? – MA-PMT and ASIC

See Poster



MA-PMT and ASIC(Viking chip, IDEAS) are developed for the SciFi readout need matching of the dynamic range of MA-PMT and ASIC

## 64-multi-anode PMT(MA-PMT): HAMAMATSU R5900

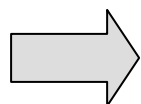
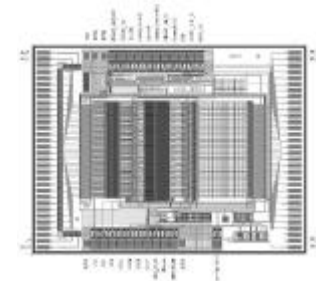
Standard : 12 dynode stages, designed for high gain  $> 10^6$   
 MA-PMT with 8 dynode stages is developed

Dynamic range up-to 11pC(2500 MIP) at 550V(gain 5000)  
 20pC(1300 MIP) at 650V(gain 15000)



## ASIC(Viking Chip) one for 32 channel readout

	VA32HDR2(Conventional)	HDR14(new chip)
gain	370 $\mu$ A / pC	73 $\mu$ A / pC
noise	0.2 fC	0.85 fC
input	< 0.8 pC	< 18 pC
power	1.5 mW / channel	3.7 mW / channel -> 150W(total)
Peaking time	1 ~ 3 $\mu$ sec	1.85 $\mu$ sec

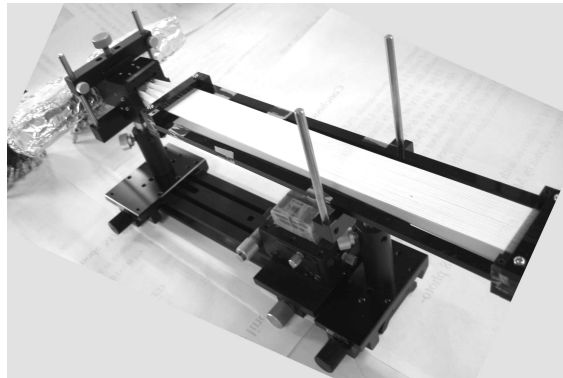


Dynamic range reaches 2000 ~ 3000 MIP,  
 if the output charge of MA-PMT at 1 MIP is set at ~6 fC (gain 7000)

# Measurements of Dynamic Range of PMT and FEC

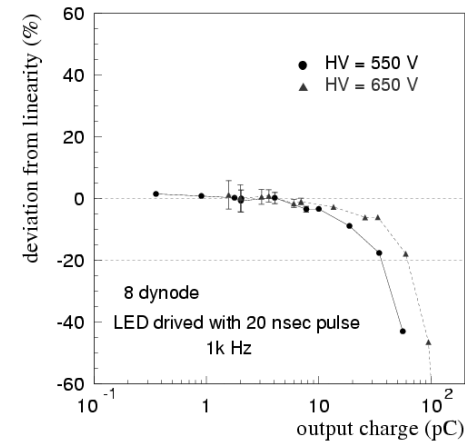


## Measurement of 1MIP Peak of SciFi



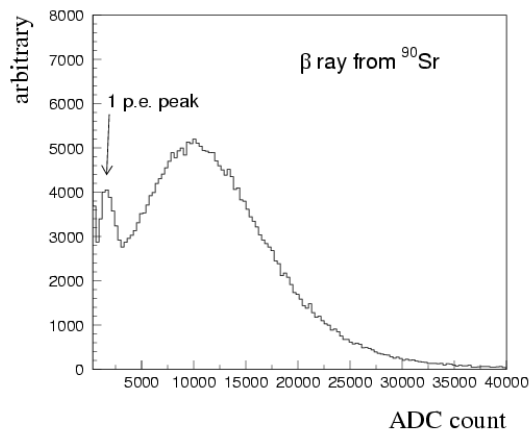
## PMT Dynamic Range Depending on Gain

\*) Measured value of 20 ns width is corrected by 6/20 for 6ns pulse width of SciFi

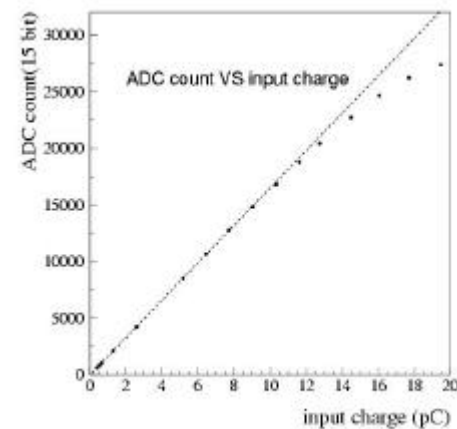


Peak – 6.5 p.e for the  $\beta$  - ray source

→ 5.7 p.e for 1 MIP



## FEC Dynamic Range up to 18pc (~10%)



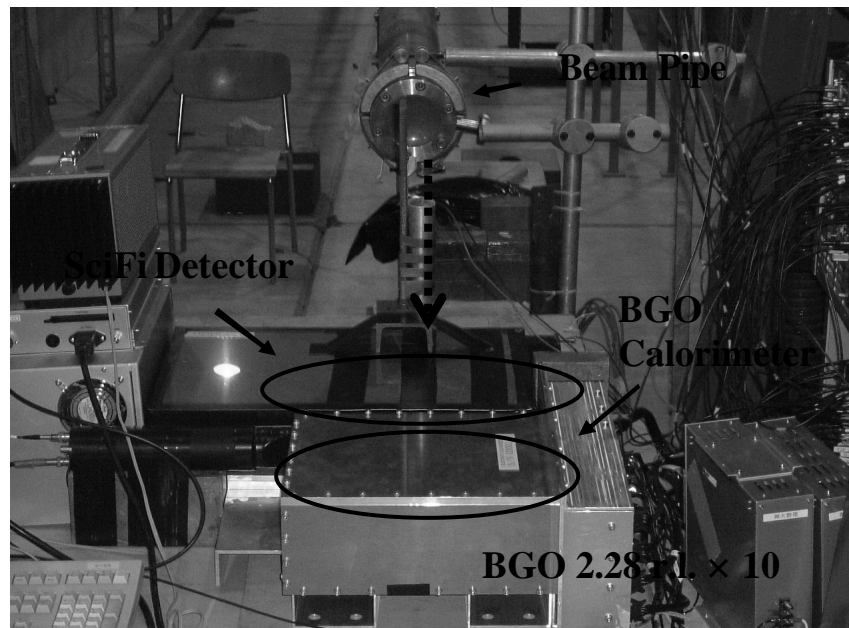
# Beam Test at CERN & HIMAC in 2003



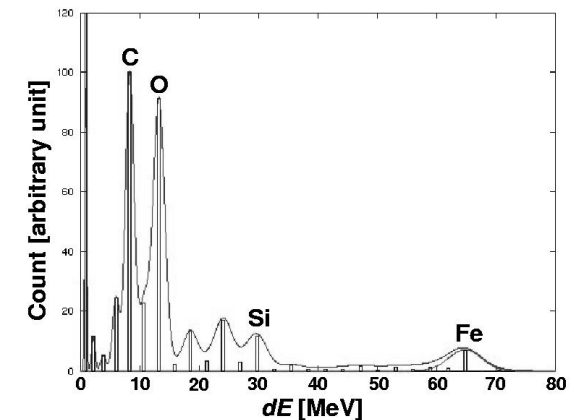
- ✍ CERN Beam Test at H6 Beam Line
- ✍ General purpose Front End Card developed in ISAS
- ✍ CAEN VME modules for controlling VA readout and ADC
- ✍ ADC separated from FEC
- ✍ 512 ch multiplexed in one ADC

- ✍ HIMAC Beam Test
- Heavy Ions:  
He 1.7MeV, C 10.1MeV,  
Si 29.9MeV, Fe 71.6 MeV

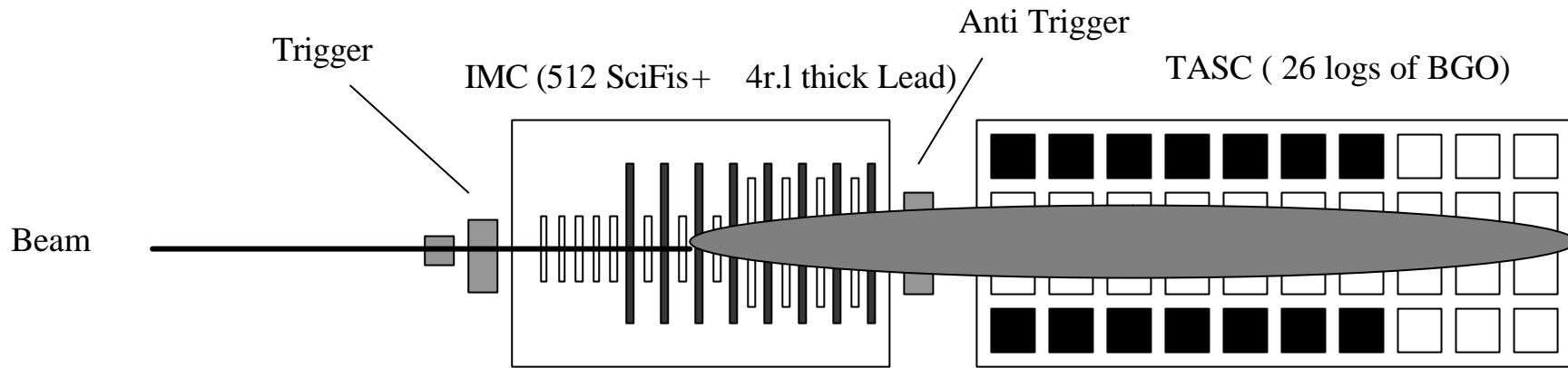
Electron: 50 GeV/c, 100GeV/c Proton: 150 GeV/c



## Charge Resolution



# Scale Model (~ 1/50) and Examples of Observed Showers



SciFi
  Lead
  BGO
  Iron for dummy

**e 100 GeV/c**



								[27]	[26]	[25]
								13096	13451	8934
[07]	[08]			[10]	[11]	[24]	[23]	[22]	[21]	[20]
9720	7605			6383	5920	6336	16013	46747	65535	44128
[00]					[04]	[19]	[18]	[17]	[16]	[15]
7410					5464	10394	10336	37168	45455	42028
								[14]	[13]	[12]
								11623	9515	8552
								evc: 5		

**p 150 GeV/c**      ↓ interaction

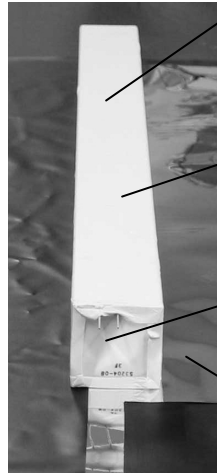


								[27]	[26]	[25]
								10416	17383	8335
[07]								[22]	[21]	[20]
5879								11625	10882	39810
[00]	[01]	[02]						[17]	[16]	[15]
9564	8106	6449						19240	62921	44256
								[14]	[13]	[12]
								14859	17204	28248
								evc: 228		

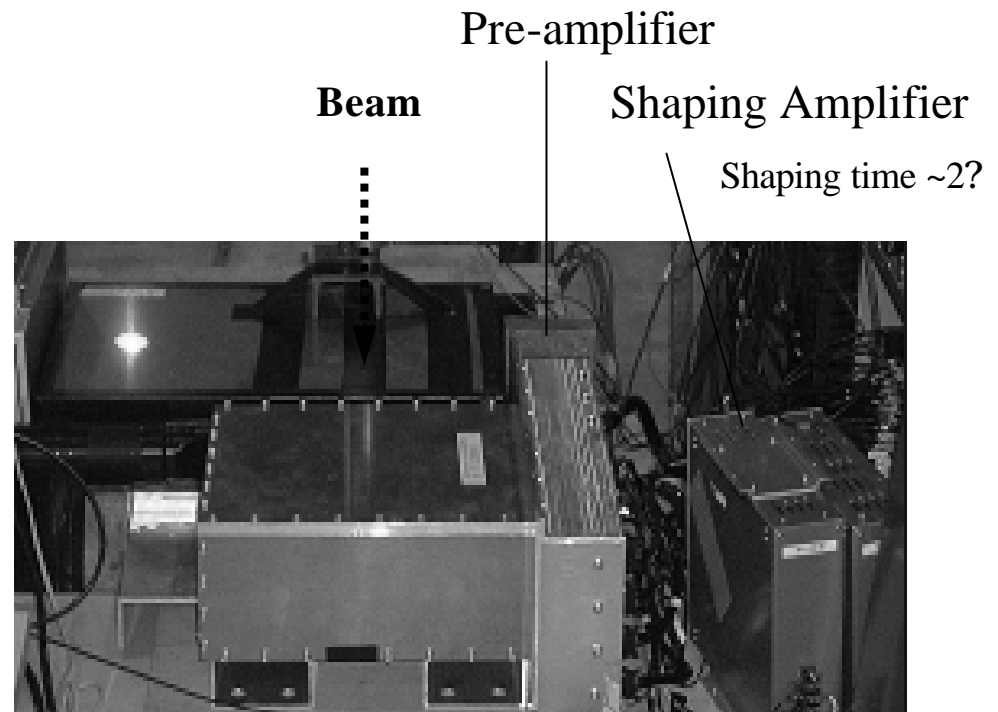
# TASC Setup



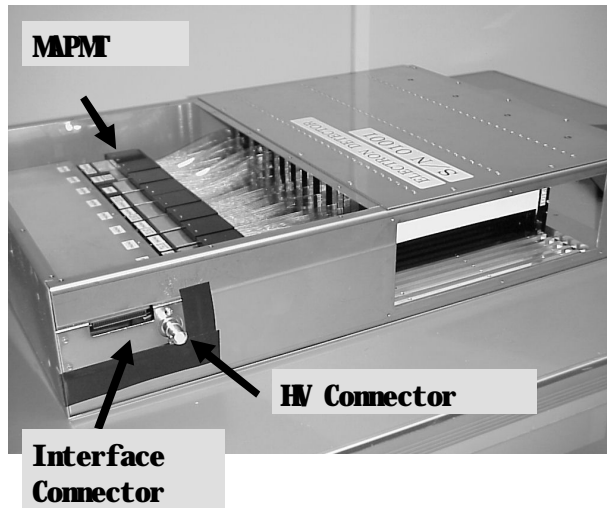
- BGO Crystal  
25mm× 25mm× 300mm
- Teflon Sheet  
0.1mm thick× 3
- Photodiode  
S3204-08  
Area 18mm× 18mm
- Aluminized Sheet  
12μthick on both side



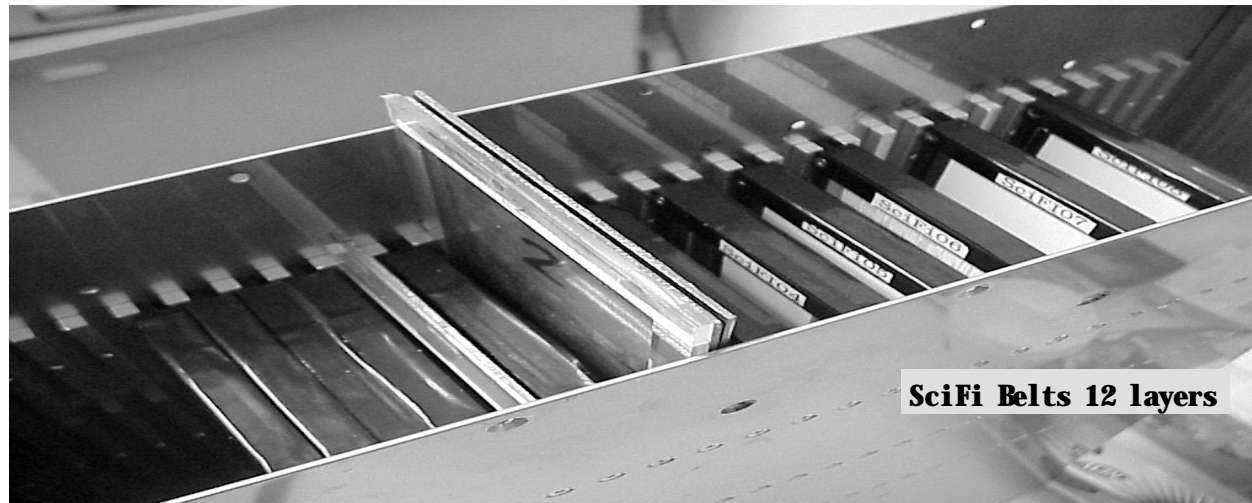
**BGO Logs and PD**



# Setup of Imaging Calorimeter



SciFi Belts



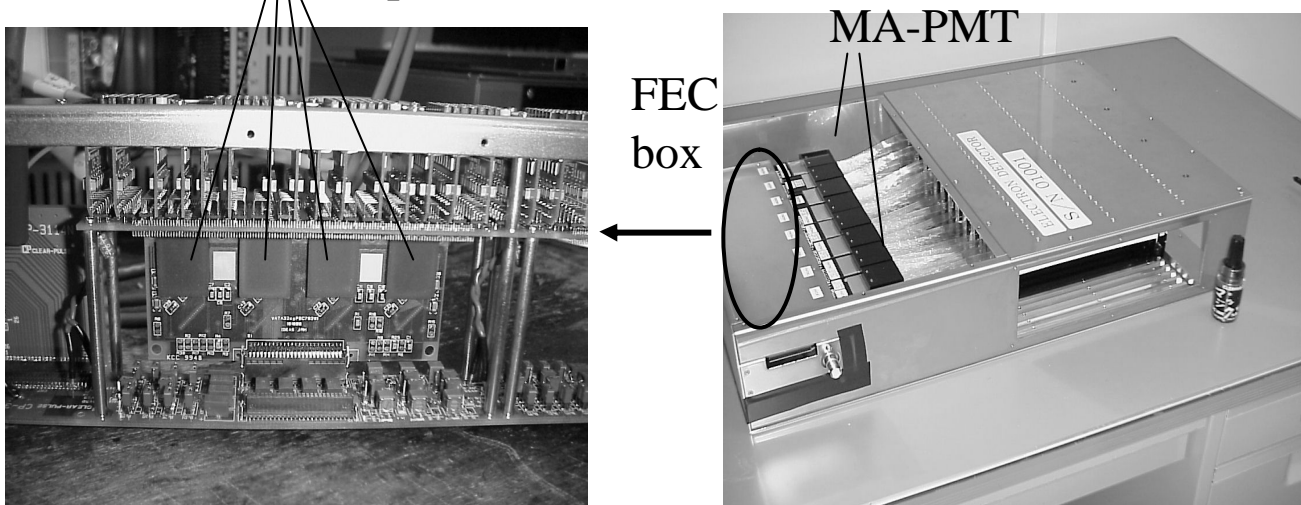
SciFi Belts 12 layers

# Readout System of IMC



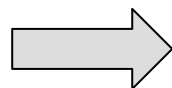
Use CAEN VME module for controlling VA and ADC

Bond new chip (HDR14)



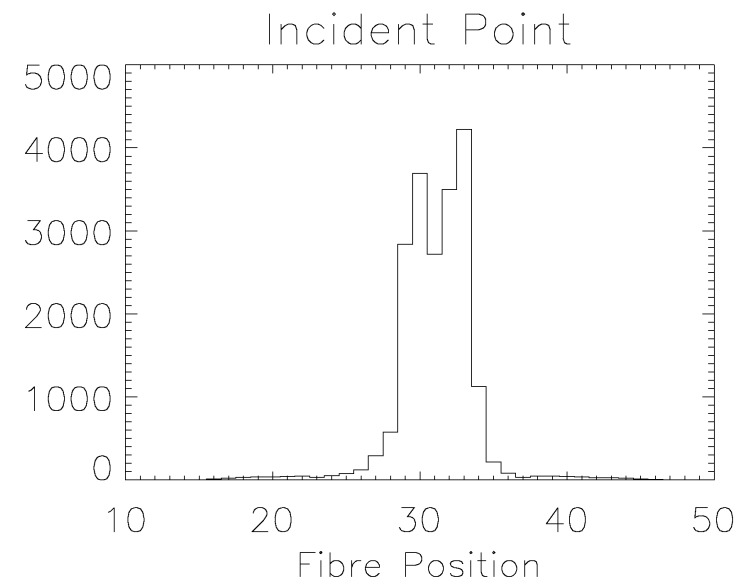
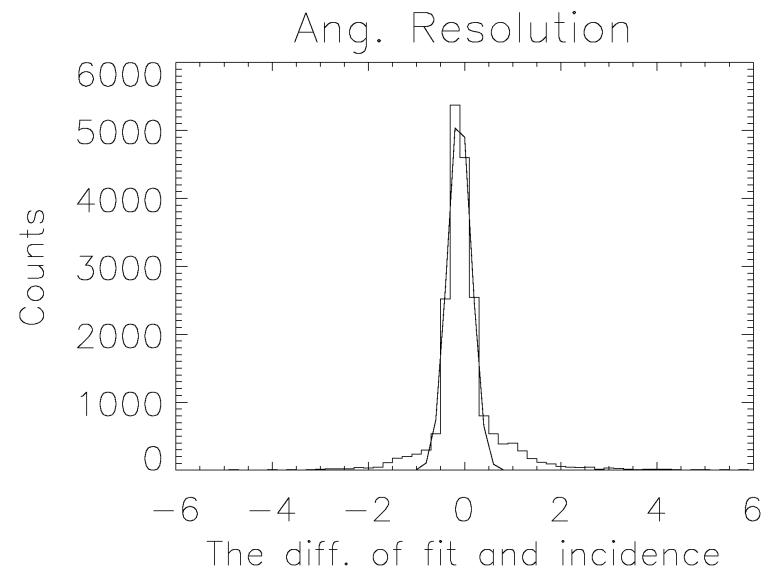
The system with the new chip was successfully used in the data taking in the beam test at CERN (2003/09)

**But,** ADC(VME module) is separated from FEC  $\Rightarrow$  large noise:  $\sim 12$  fC  
512 channels are read in one ADC  $\Rightarrow$  not fast enough



Need new readout system ( See Poster)

# Data Analysis (1) –Angle and Position Resolution -



## Incident Beam 1cm x 1cm

**Without gain correction :**

**Angle Resolution ~0.25 degree**

**Position Resolution ~ 0.5mm**

**Expected**

**after correction**

**— 0.1 degree**

**— 0.2 mm**

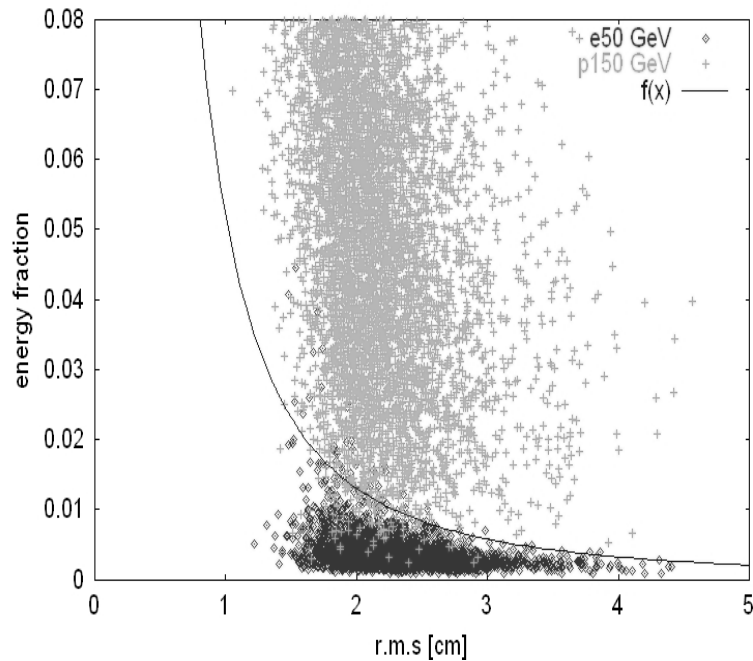
# Data Analysis (2) -Proton Rejection Power -



at the bottom ( 25cm thick BGO) layer

**Simulation**

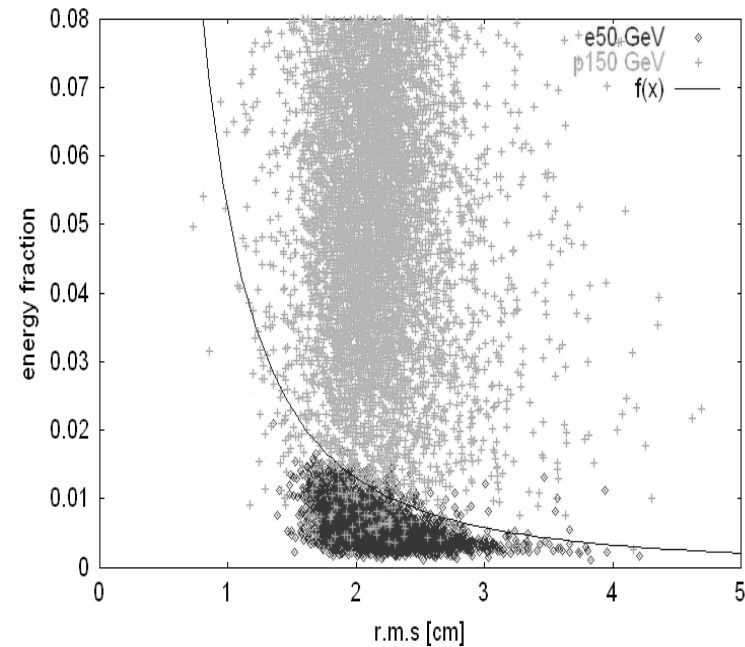
Proton 14,000 events  
Electron 3,000 events



**e50 GeV : 98.0%, p150 GeV : 0.63%**

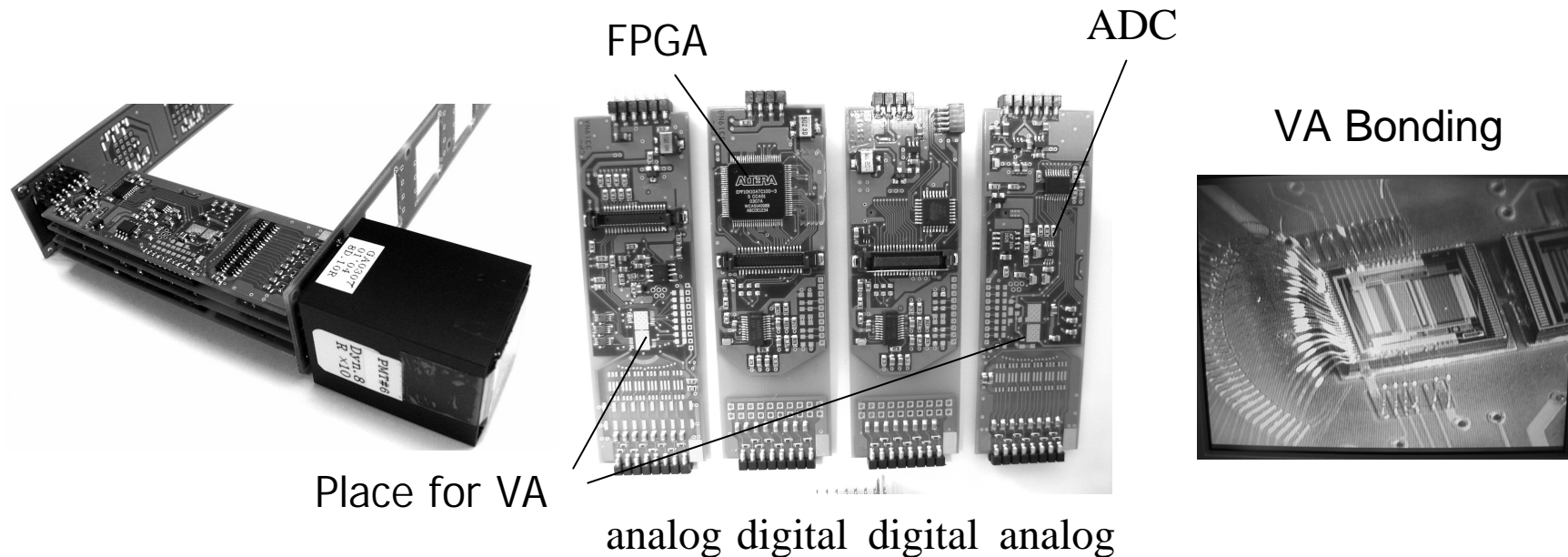
**Experiment**

Proton ~14,000events  
Electron ~3000events



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

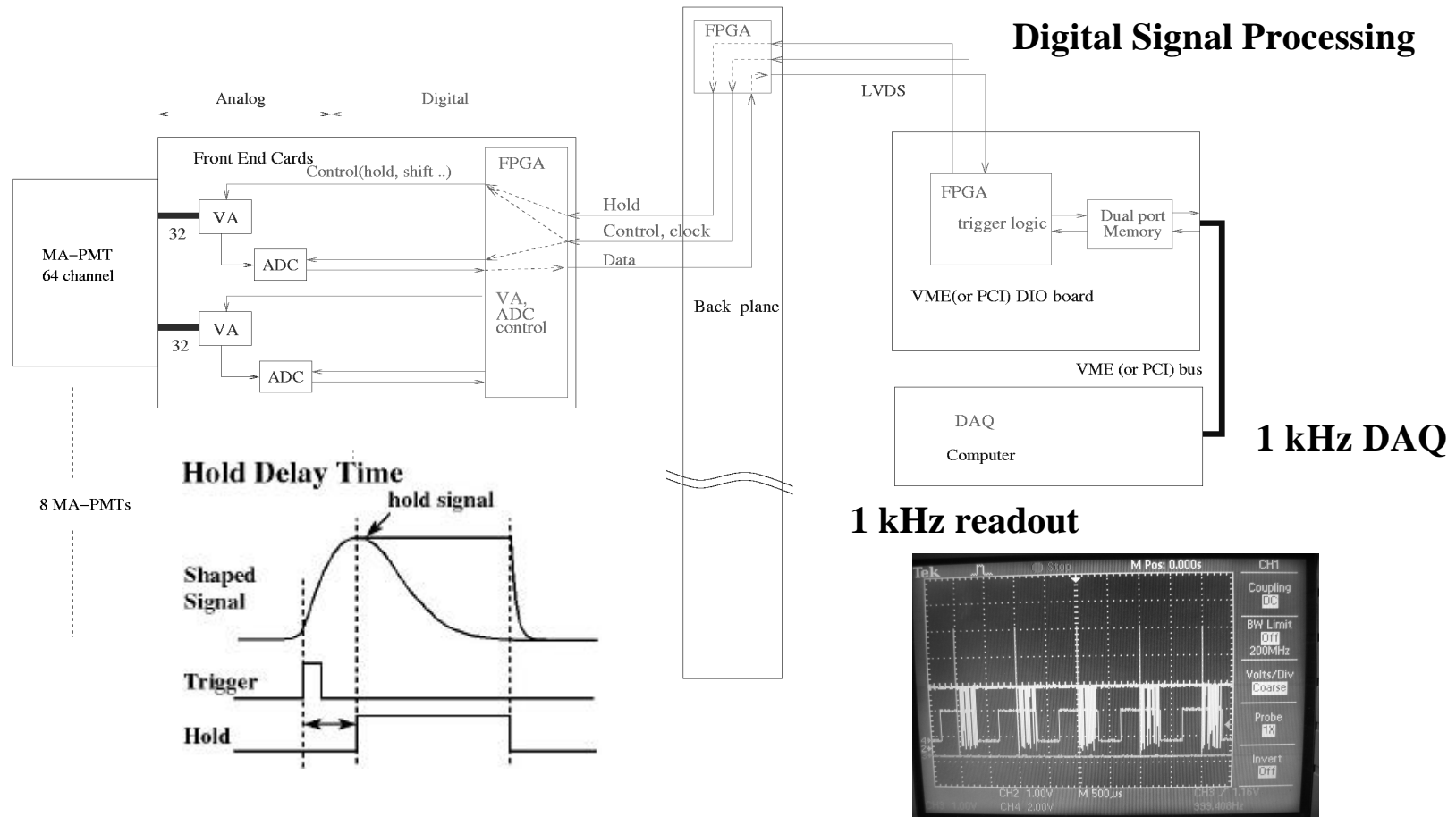
# New FEC (1) – Power Consumption-



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

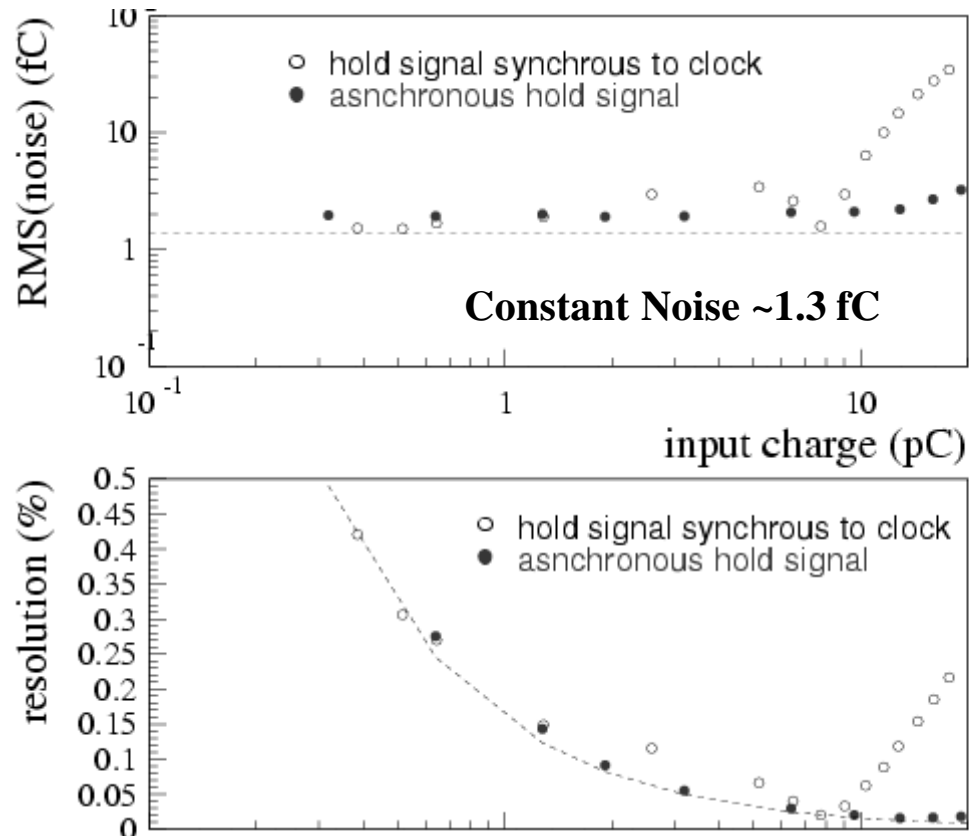
Power consumption of FEC for 64 channels (VA + ADC + FPGA)  
~ 420 mW (350 mW, other than the efficiency of the regulator)  
✂ total ~260 W (220 W) ✂ acceptable

# New FEC (2) -Readout Speed-



**1 ADC for 1 VA chip(A/D conversion is performed in FEC)**  
**16 bit ADC(max 250 kHz) operated with 10  $\mu$  sec / channel (100 kHz)**  
~~160~~ **320  $\mu$  sec / event (3 kHz)** ~~160~~ **enough for CALET application**

# New FEC(3) – Noise and Resolution



✍ Noise at large input charge ( $> 10\text{pC}$ ) in case of the synchronous hold signal comes from the time jitter

✍ Flatter (better) noise performance in case of the asynchronous (trigger) hold signal    ✍ use asynchronous hold signal

# Event Trigger and Event Rate



## Gamma-Rays at Lower Energies: 20 MeV ~ 10 GeV

- **Anti-Coincidence** ( $< 0.5$  MIPs) & **On-board Tracking in IMC** ( $> 3$  layers )  
Trigger Rate of Gamma Rays:  $\sim 14$  Hz (mostly from the Galactic Plane)  
Background: Albedo.  $\sim 37$  Hz ( $> 10$  MeV); Hadron, negligibly small
- **Identification of gamma-ray by image analysis in IMC**

## Electrons and Gamma Rays\* at Higher Energies: 10 GeV~ 10 TeV

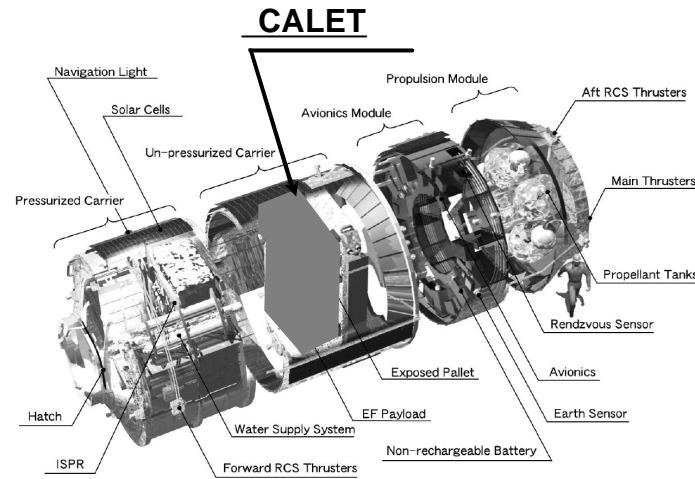
\*) The anti-coincidence is not valid due to backscattered particles

- **On-Board Shower Trigger in IMC** to reduce the backgrounds less than 1 %  
Trigger Rate:  $\sim 40$  Hz
- **Analysis of the Shower Development in TASC and the Shower Image in BGO**  
Proton backgrounds to electrons and gamma-rays:  $< \text{less than } 10^{-5}$   
Electron background to gamma-rays :  $< 2 \times 10^{-3}$

## Proton and Heavy Ions: 1 TeV ~ 1000 TeV

- **On-Board Shower Trigger in TASC**  
Trigger Rate:  $\sim 0.1$  Hz
- **Charge Identification by Incident Track in IMC**

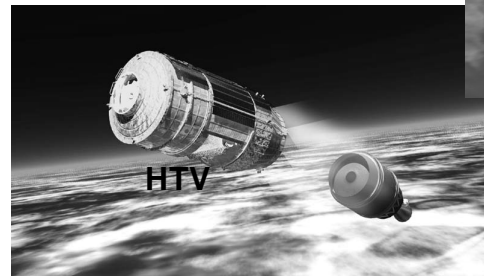
# Launching Procedure of CALET



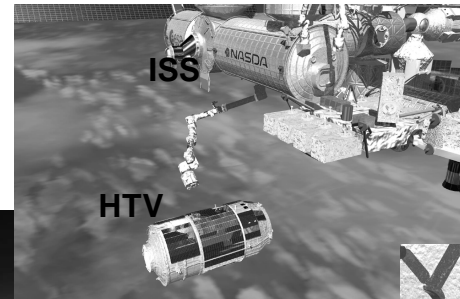
## H-IIA Transfer Vehicle( HTV)



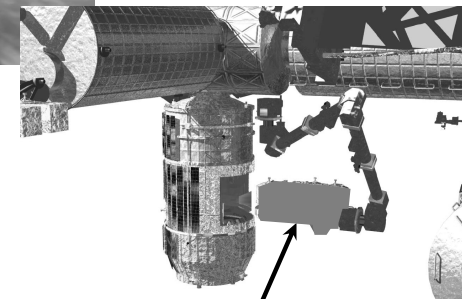
**CALET launched by HTV**



**Launching of H-II Rocket** **Separation from H-II**



**Approach to ISS**



**Pickup of CALET**

**CALET**

# Summary and Conclusion

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- ✍ 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- 10 TeV , proton and heavy ions in 1 TeV- 1000 TeV, for investigation of high energy phenomena in Universe.
- ✍ CALET is now under Mission Concept Study and might be launched by HTV around 2009 for 3 years if the mission will be approved in AO expected in near future.

**We welcome very much the international collaborators !!!**

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



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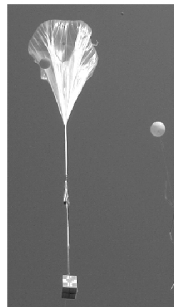
# Backup Charts

# Scientific Heritage

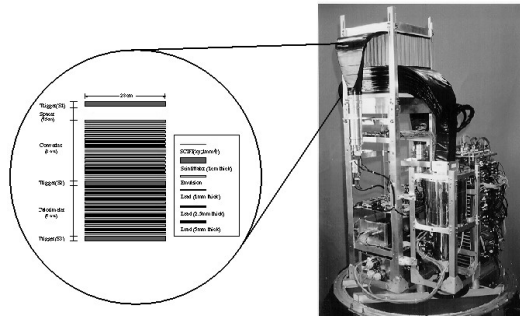


## 1993-1998:

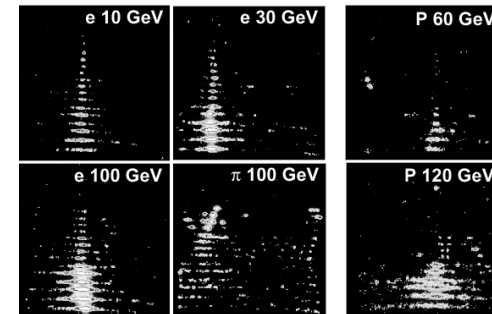
- ✍ Development of SciFi/Lead Calorimeter for Electron Observation (BETS) NIM 457, 499-508 (2001)
- ✍ Successful observation of electrons in 10-100 GeV ApJ 559, 973-984 (2001)
- ✍ Observation of atmospheric gamma-ray flux with improved BETS Phys Rev D.66 052004(1-9) (2002)



Balloon Flight



BET Instrument



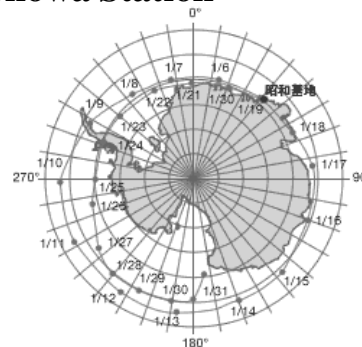
Shower Image at CERN

## 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

# Observation of Proton and Heavy Ions (Optional)



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

For proton measurement:

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

Exposure factor for 1000 days:

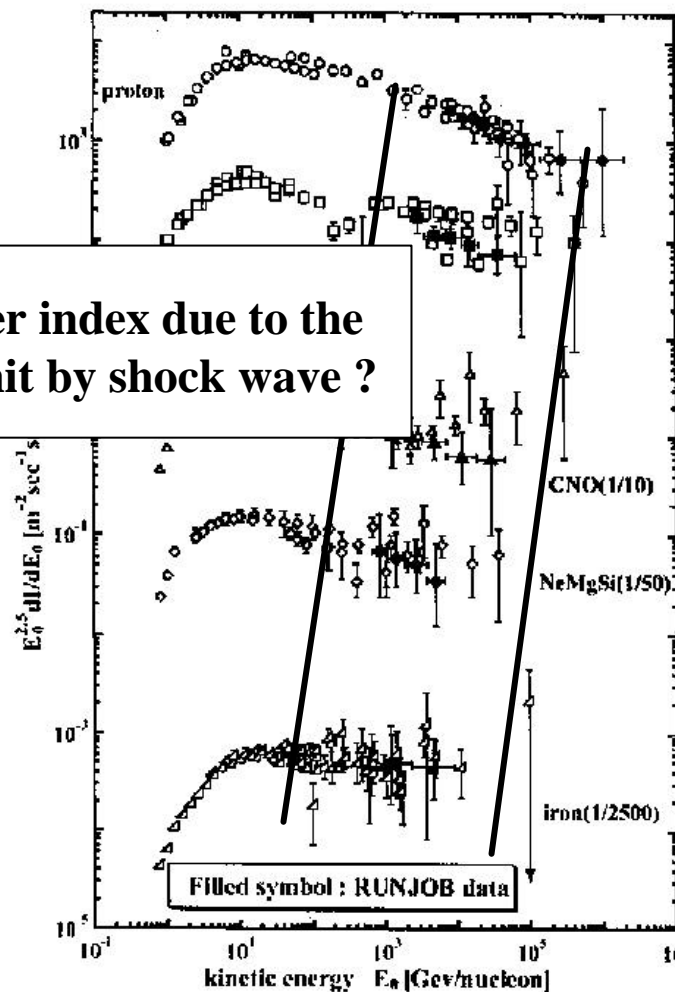
$170 \text{ m}^2 \text{ sr day} \sim 1.5 \times 10^7 \text{ m}^2 \text{ s sr}$

Expected numbers of protons:

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

Change of power index due to the acceleration limit by shock wave ?

Present Data



# Nearby Source Candidates

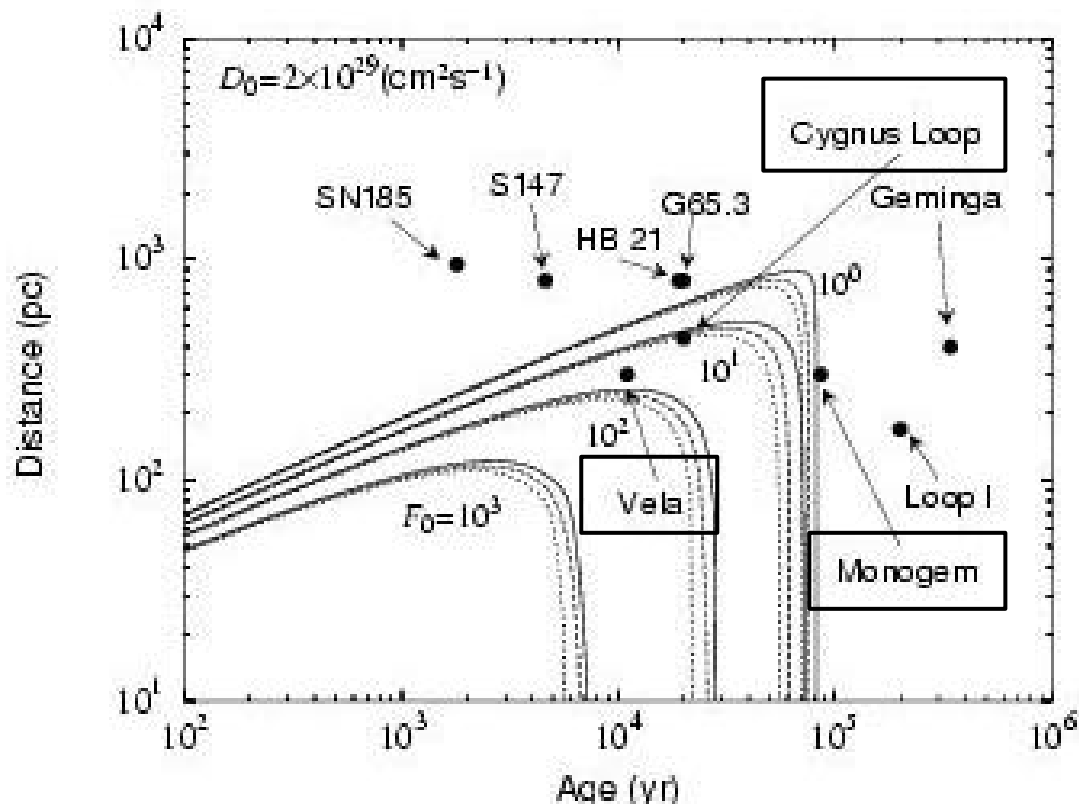


## Electron Energy Loss by

- Inverse Compton Scattering
- Synchrotron Radiation

Energy Loss Rate  
 $dE/dt \propto 1/E^2$

Age ?  $1/E$   
 Distance ?  $\text{Age}^{1/2}$



## 1 TeV Electron Source:

- ✍ Age <  $10^5$  years
- ✍ Distance < 1 kpc

Vela  
 Cygnus Loop  
 Monogem

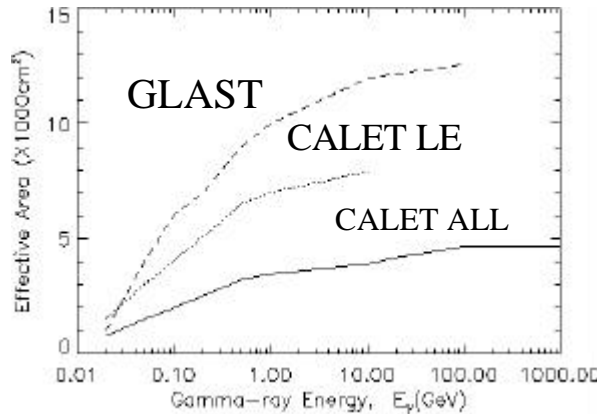
.....  
**Unobserved ?**

# Simulation of Gamma-ray Performance

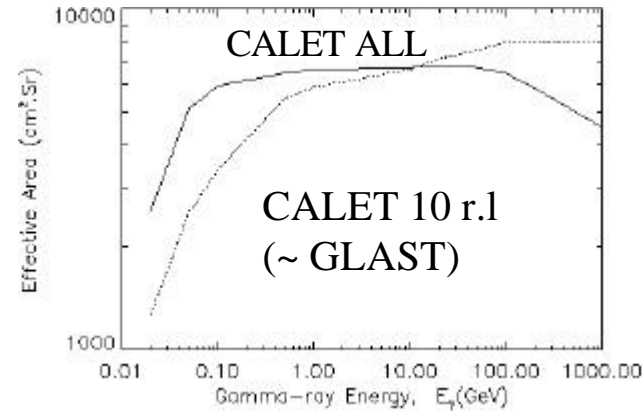


(Preliminary)

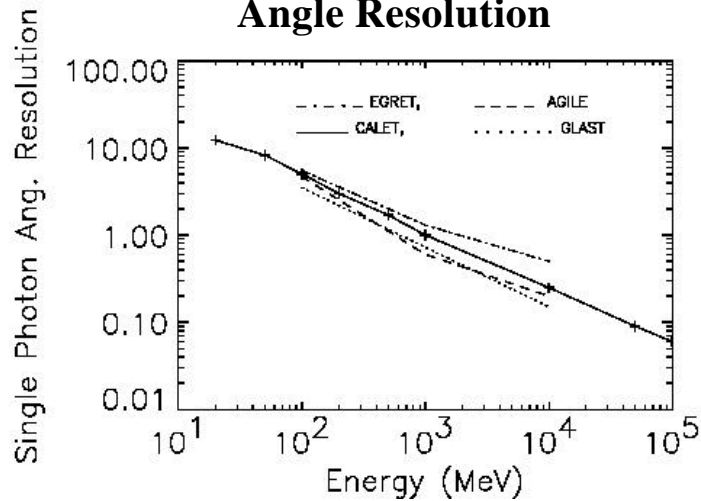
**Effective Area**



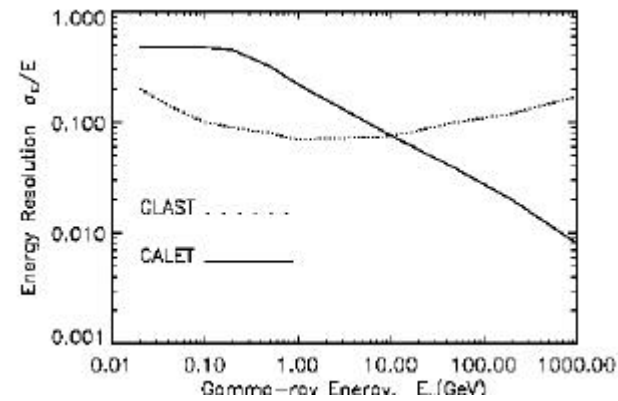
**Geometrical Factor**



**Angle Resolution**



**Energy Resolution**



# Basic Performance Obtained by Simulation



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

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

# HTV Operation Outline

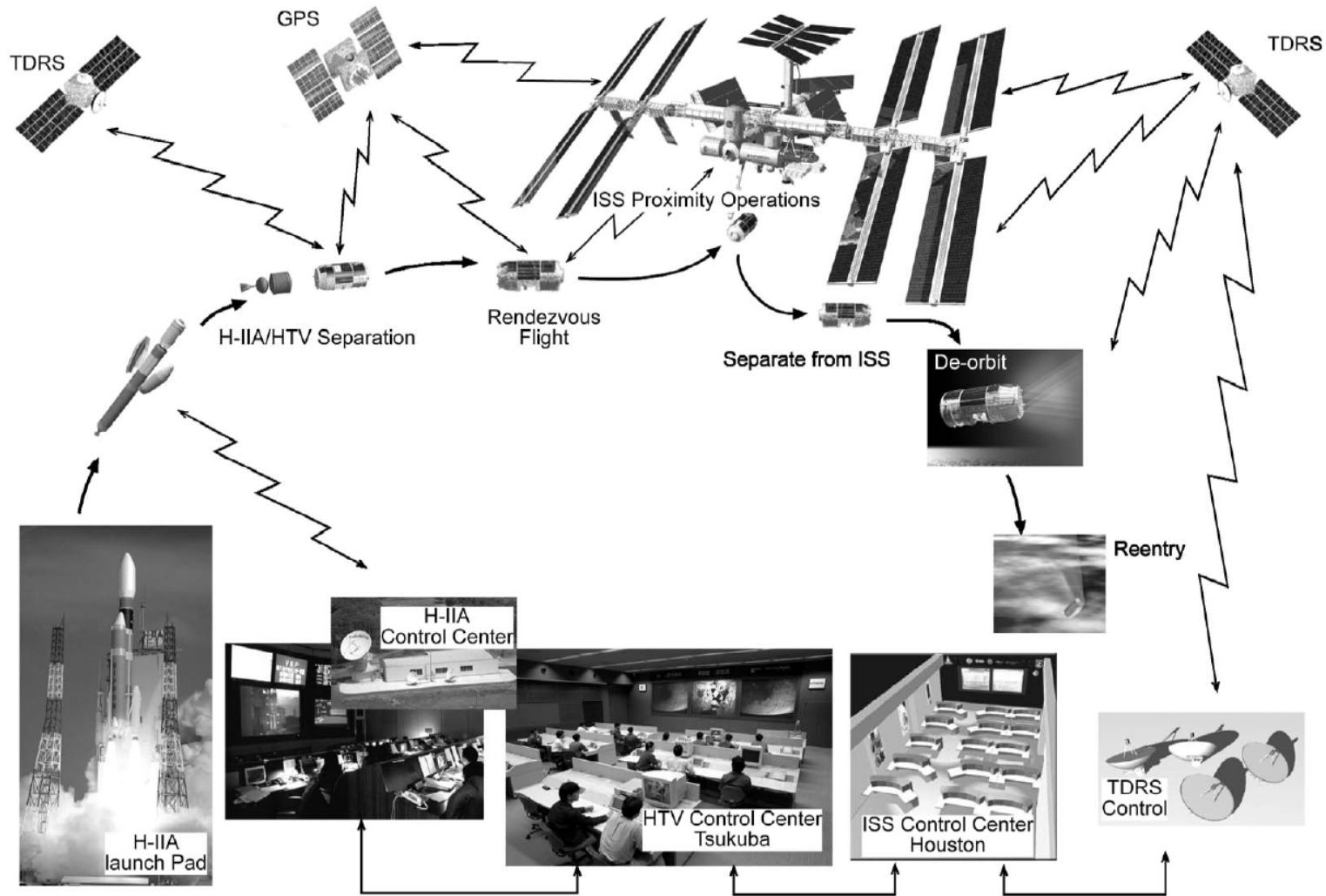
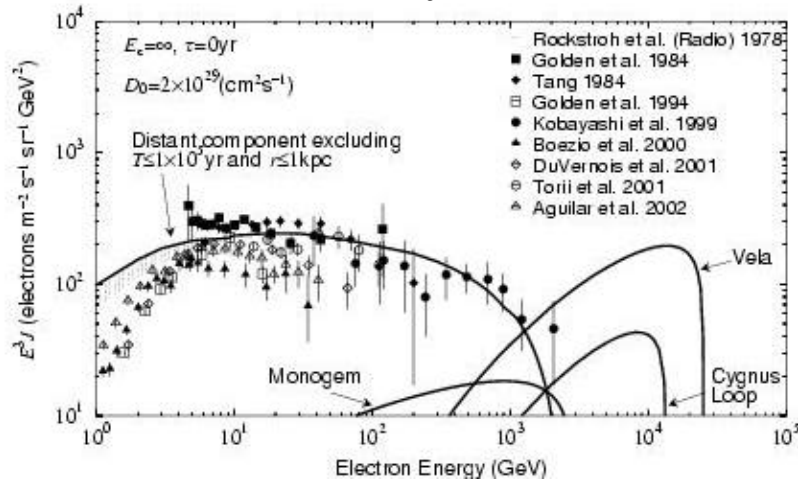


Figure-1 HTV Operations & Supporting Systems

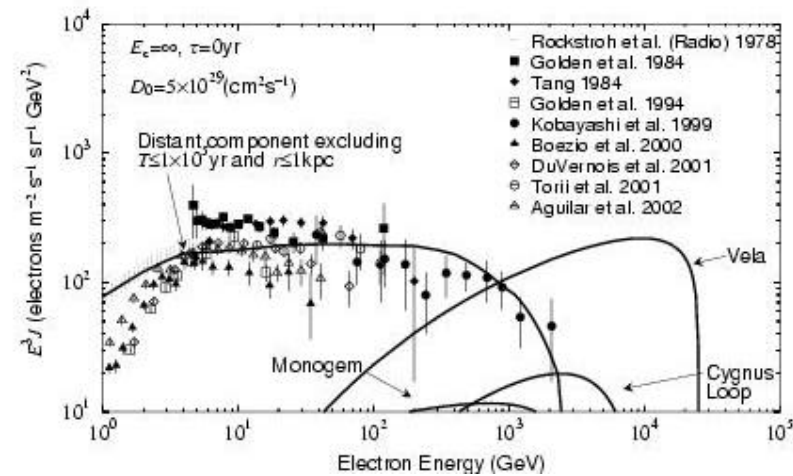
# Model Dependence of Nearby Source Effect



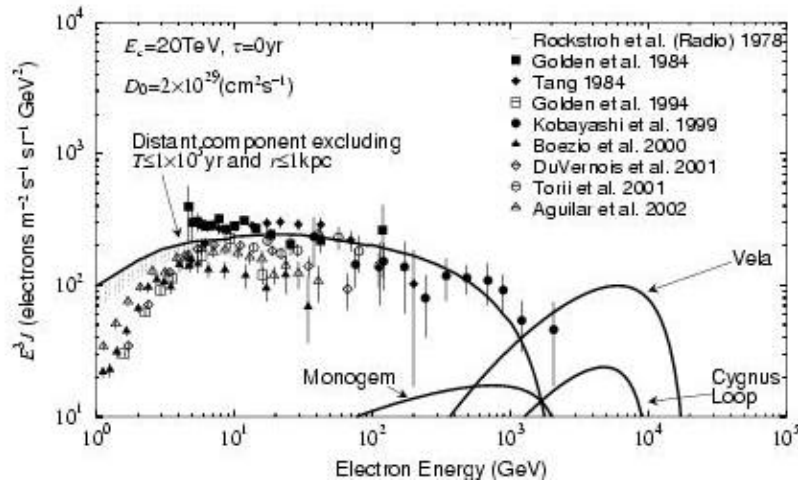
$E_c=8 ? ? T=0 \text{ yr}, D_0=2 \times 10^{29} \text{ cm}^2/\text{s}$



$D_0=5 \times 10^{29} \text{ cm}^2/\text{s}$



$E_c=20 \text{ TeV}$



$E_c=20 \text{ TeV} ? ? T=1-10^4 \text{ yr}$

