CALET: Direct Cosmic Ray Measurements on the International Space Station

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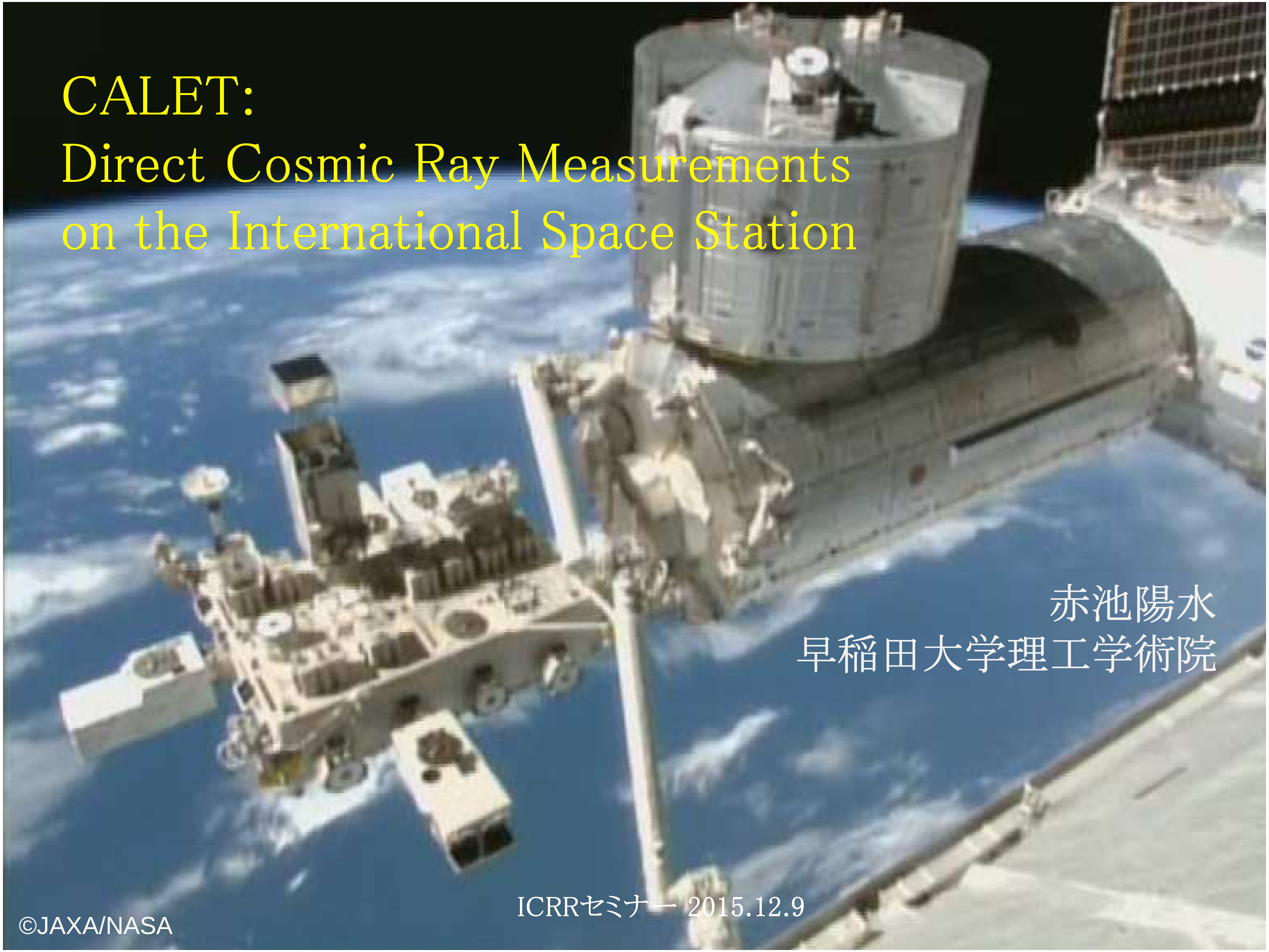


ICRRセミナー 2015.12.9

CALET International Collaboration

JAPAN — 22 institutions

Aoyama Gakuin University
Hirosaki University
Ibaraki University
Institute for Cosmic Ray Research, University of Tokyo
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
St. Marianna University, School of Medicine
Kanagawa University
High Energy Accelerator Research Organization (KEK)
Nagoya University
National Institute of Radiological Sciences
National Institute of Polar Research
Nihon University
Ritsumeikan University
Saitama University
Shibaura Institute of Technology
Shinshu University
Tokiwa University
Tokyo Institute of Technology
University of Tokyo
Waseda University (PI Institute)
Yokohama National University

ITALY — 5 institutions

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

USA — 6 institutions

NASA/GSFC
CRESST/NASA/GSFC and University of Maryland
CRESST/NASA/GSFC and Universities Space Research Association
Louisiana State University
Washington University - St Louis
University of Denver

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

Waseda University
supported also by
JSPS,MEXT

CALET is a Recognized Experiment

CERN

ASI

NASA

CALET on ISS !!

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

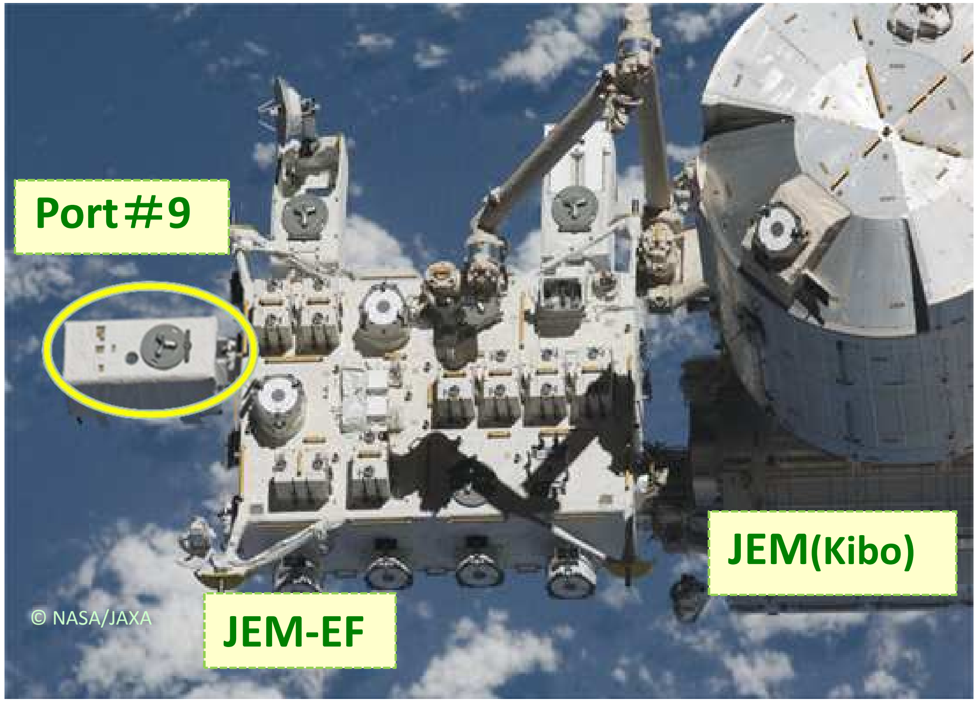
② **August 24th:**
The HTV-5 Transfer Vehicle（HTV-5) is grabbed by the ISS robotic arm.

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

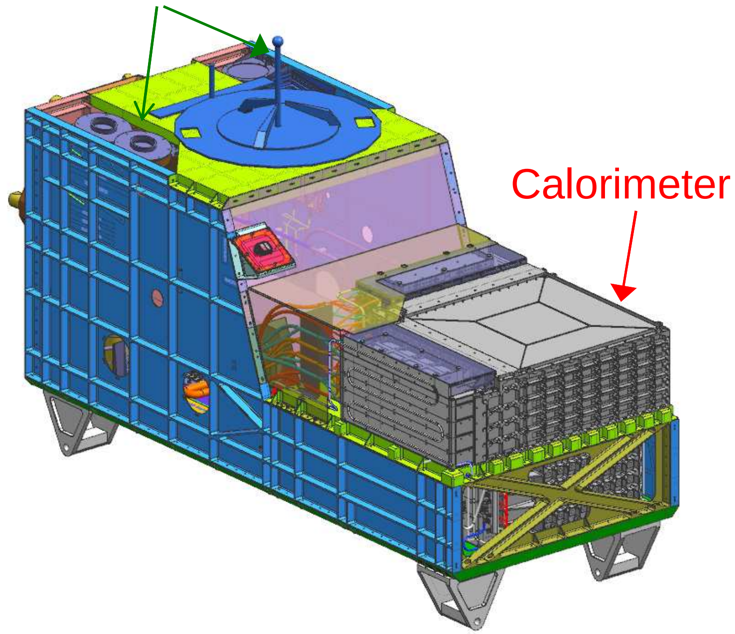
④ **August 25th:**
CALET is emplaced on port #9 of the JEM-EF and data communication with the payload is established.

CALorimetric Electron Telescope Payload

The CALorimetric Electron Telescope, CALET, project is a Japan-led international mission for the International Space Station, ISS, in collaboration with Italy and the United States.

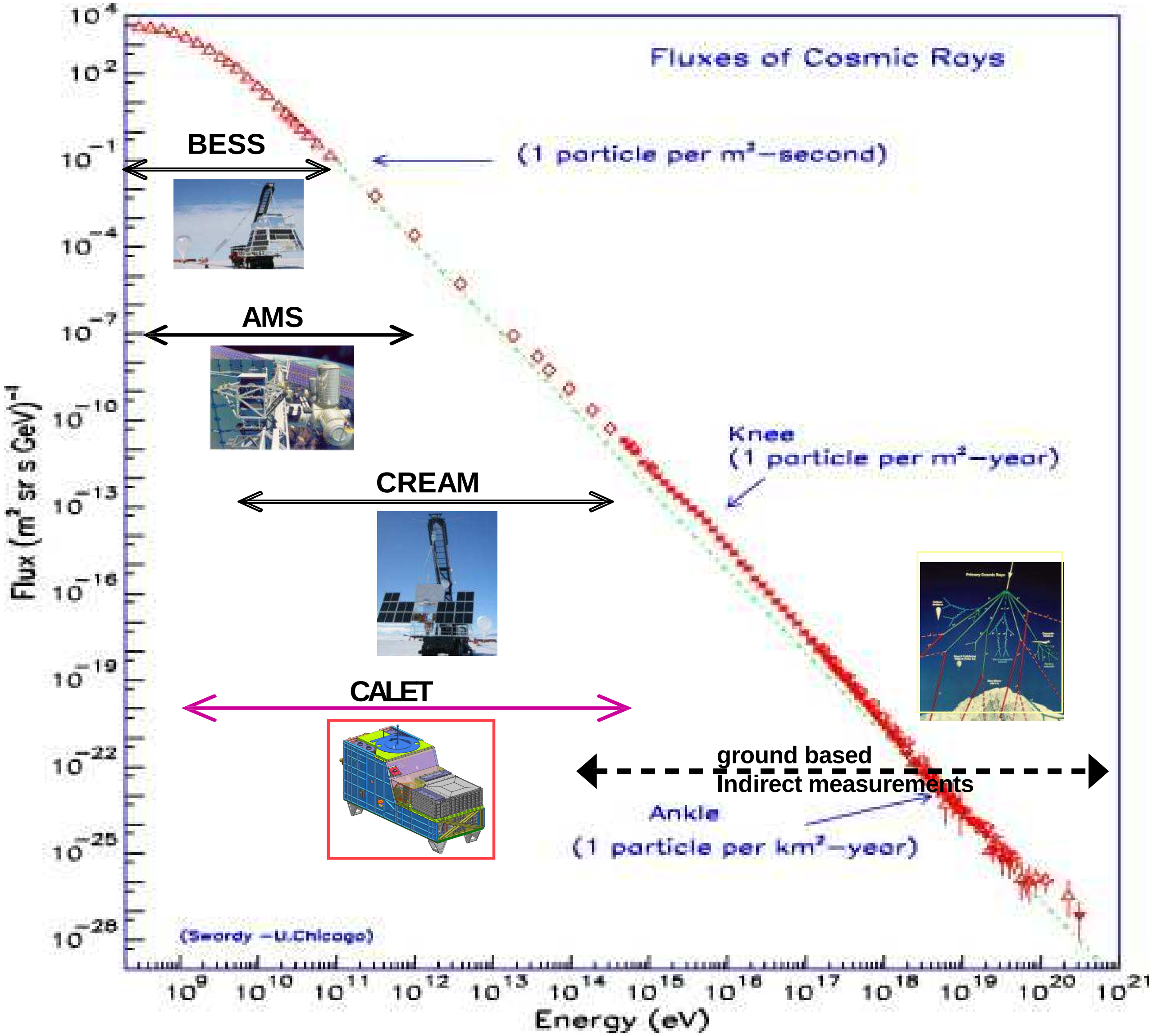


Mission Life (Target) : 5 years
Launch Date: Aug.19,2015



The CALET payload is launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV5) and robotically attached to the port #9 of the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station.

Cosmic ray Observation



Ref: J. Cronin, T. Gaisser, S. Swordy, Sci. Amer., 276 (1997), p. 44

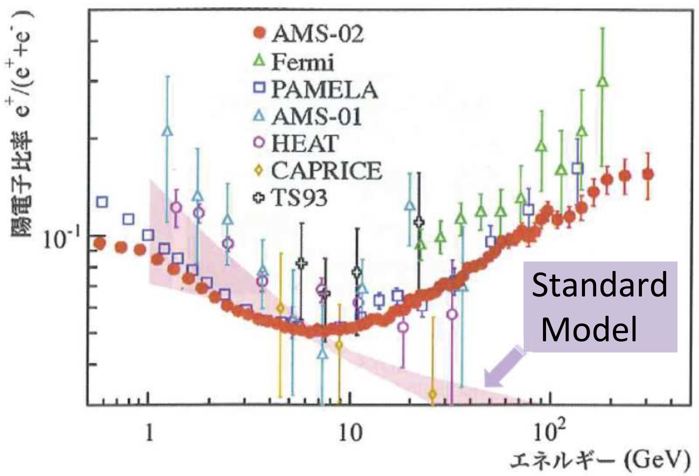
Interesting happening with the energy spectra

Standard Model of acceleration and propagation of GCR

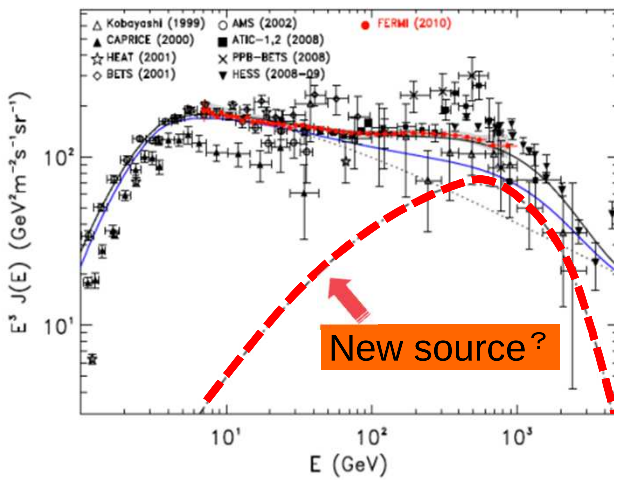
- ☐ Shock wave acceleration in SNR
  - Power spectrum ($dN/dE \propto E^{-\gamma}$)
  - Acceleration limit depending on the rigidity (E_c ～100 Z TeV)
- ☐ Diffusion process due to galactic magnetic field
  - Steeping of energy spectra of nuclei (~$E^{-\gamma-\alpha}$) by leakage from Galaxy (Leaky Box Model)
  - Energy loss by synchrotron radiation and inverse Compton scattering of electrons ($dE/dt = -bE^2$)
  - Energy dependence of secondary /primary ratio（e^+/e^-, B/C etc)（$\propto E^{-\delta}$）

Recent observations found results at high energies contradicting "Standard Model"

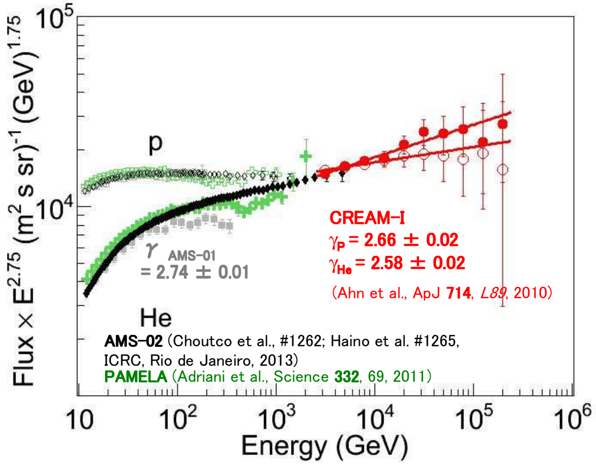
Increase of positron/electron ratio



Excess of electron+positron flux



Hardening of p, He spectra



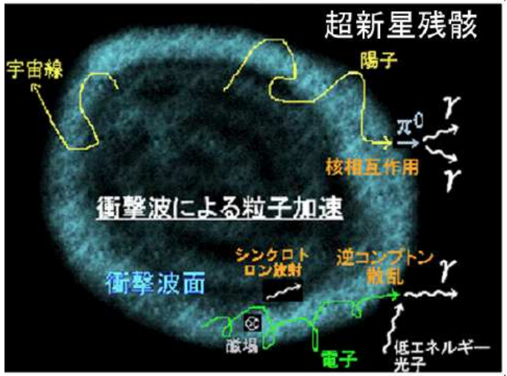
New source of electrons and positrons at several 100 GeV ?

Unknown process in acceleration and/or propagation?

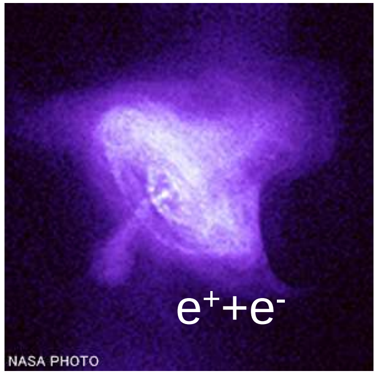
Electron & Positron Origins and Production Spectrum

Astrophysical Origin

Shock Wave Acceleration in SNR

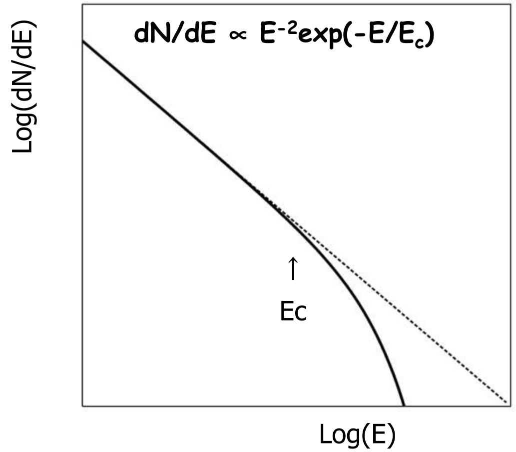


Acceleration in PWN

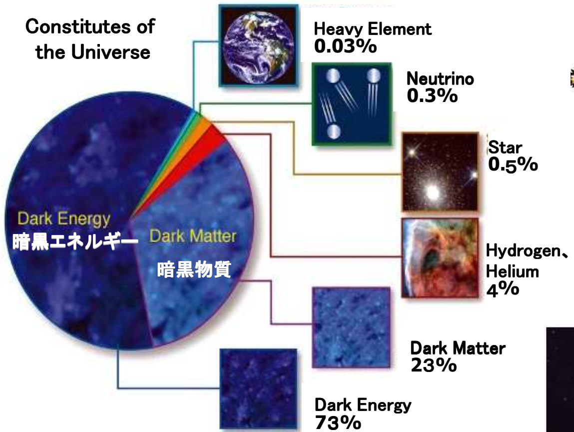


etc.

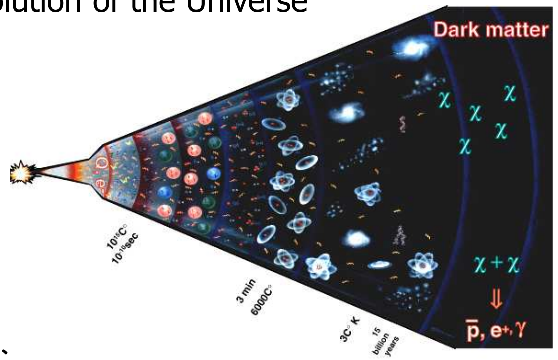
Power Law Distribution with a Cutoff



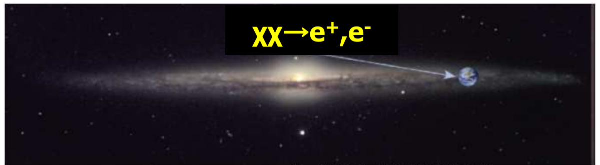
Dark Matter Origin



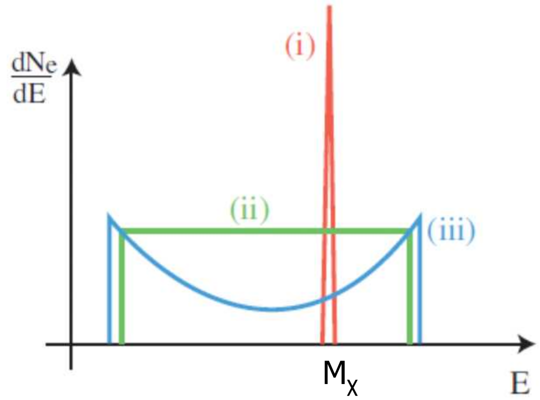
Evolution of the Universe



Annihilation of Dark Matter（WIMP）



Typical Distribution Depending on the Mass and Type of DM



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

Nearby Sources of Electrons at TeV Region

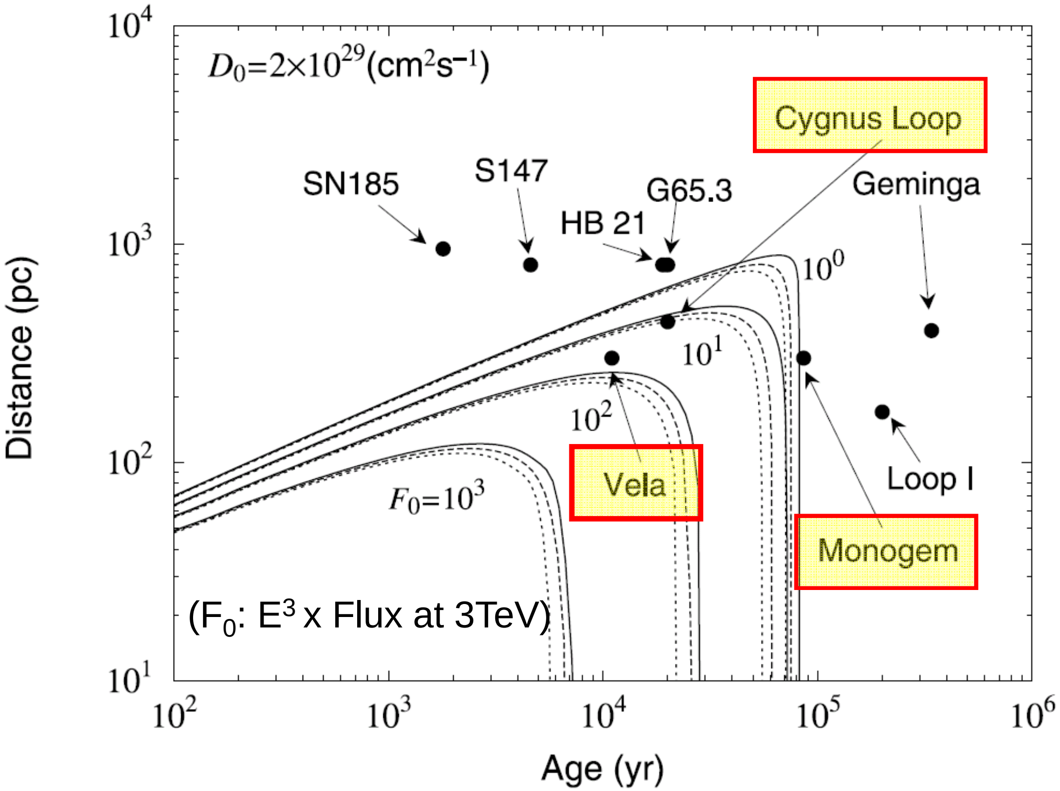
$$\frac{\partial}{\partial t} f(t,\varepsilon,r) = D(\varepsilon)\nabla^2 f + \frac{\partial}{\partial \varepsilon}[b\varepsilon^2 f] + Q(t,\varepsilon,r)$$

Diffusion — Energy loss by IC & synchoro — Injection

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

$D(\varepsilon) \sim 5.8 \times 10^{28}\ \mathrm{cm}^2\mathrm{s}^{-1}\left(1+\frac{\varepsilon}{4\mathrm{GeV}}\right)^{1/3}$ ←B/C ratio

Contribution to 3 TeV Electrons from Nearby Source Candidates

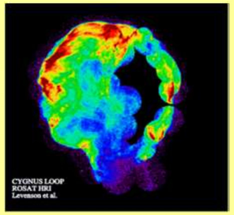


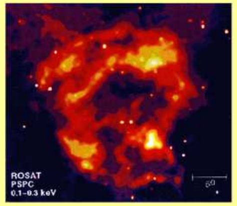
> 1 TeV Electron Source:

- **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





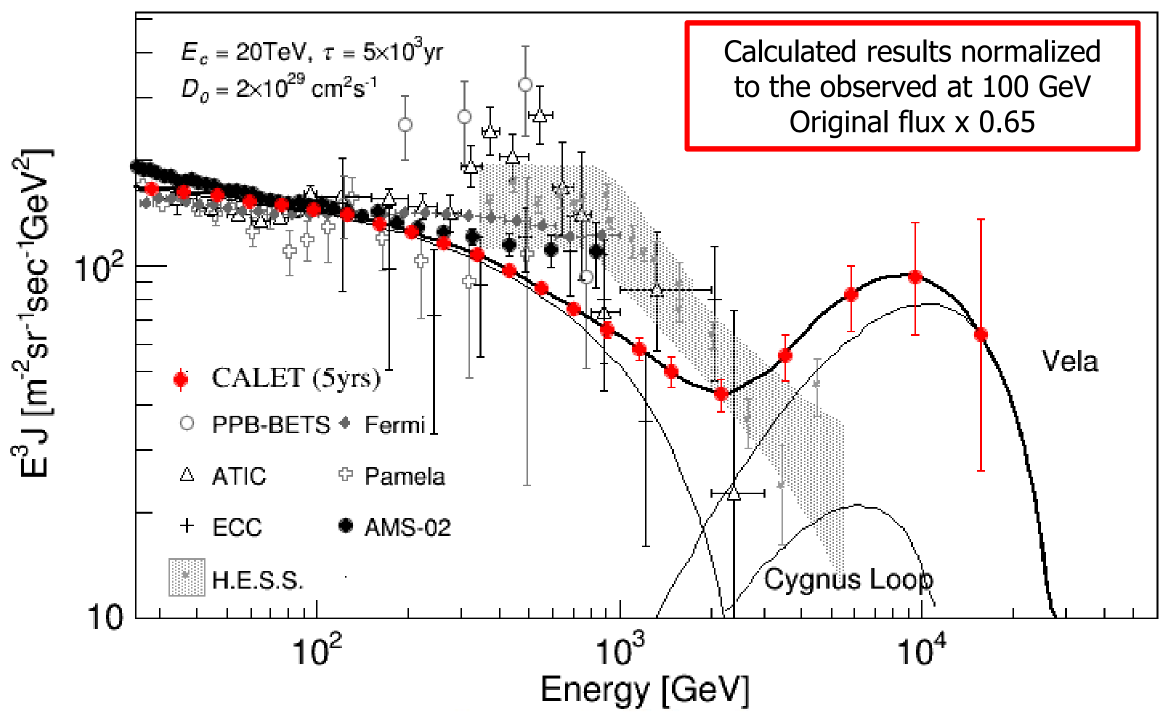
Unobserved Sources?

Identification Electron Sources

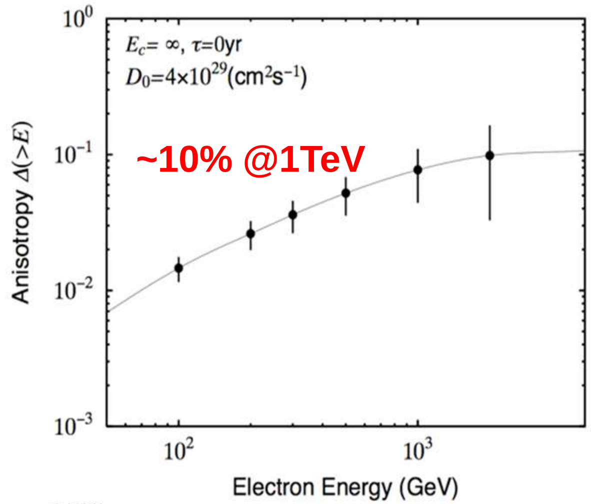
Some nearby sources, e.g. Vela SNR, might have unique signatures
in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

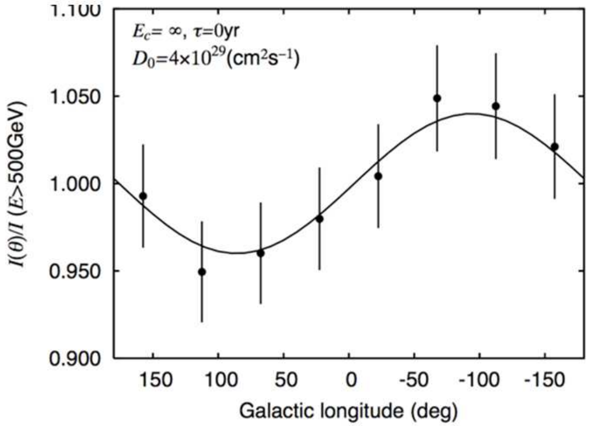
Expected flux
for 5 year mission

> 10 GeV	~ 2.7 x 10^7
>100 GeV	~ 2.0 x 10^5
>1000 GeV	~ 1.0 x 10^3



Expected Anisotropy
from Vela SNR





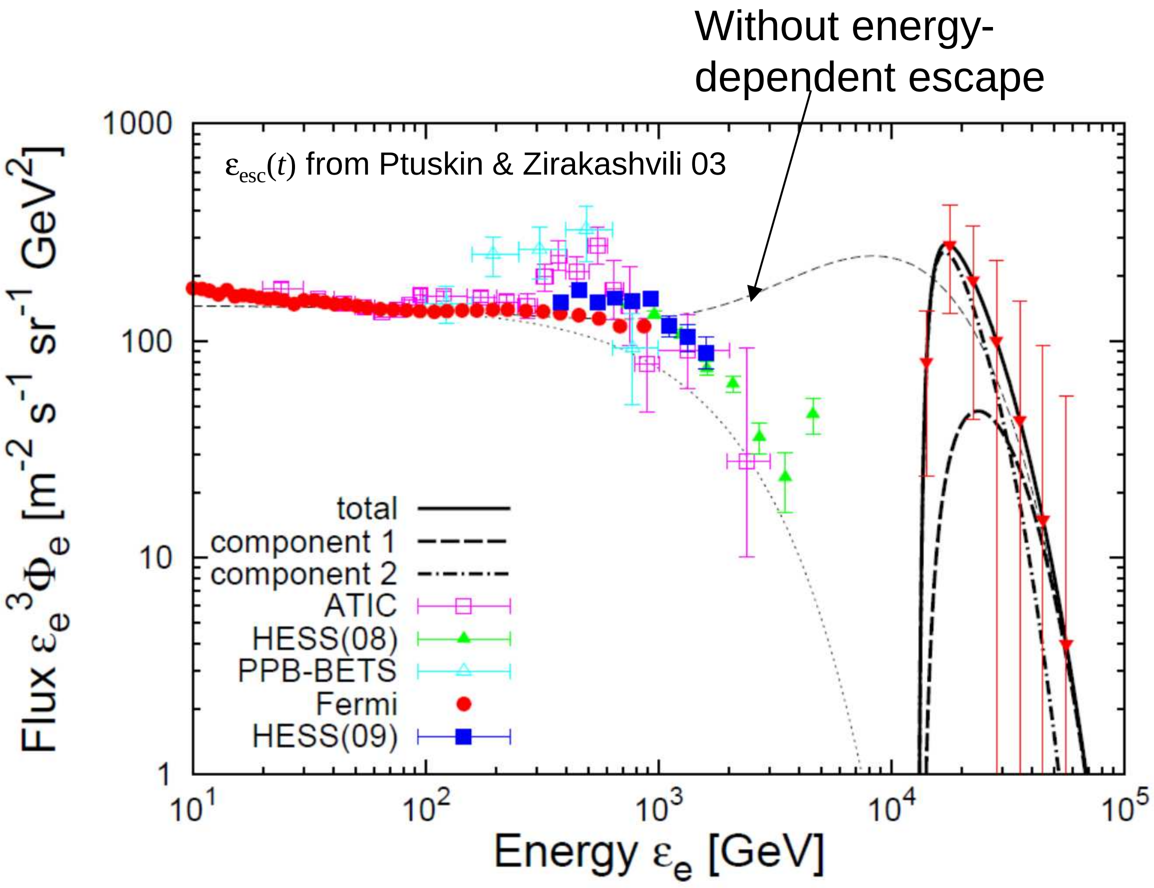
Identification of the unique signature from nearby SRNs,
such as Vela in the electron spectrum by CALET

TeV electron spectrum with the CR escape model

- Electron spectrum from Vela SNR/PSR (d=290pc, t_{age}~10^4yr, E_{tot}=10^{48}erg)
- Only $e^{\pm}$ with $\varepsilon_e > \varepsilon_{esc}(t_{age})$ can run away from the SNR.

→ **Low Energy Cutoff**

- 5yr obs. by CALET ($S\Omega T$=220m^{2}sr days) may detect it.



Kawanaka, Ioka et al. ApJ 2011

Direct Evidence of Escape-Limited Model for CR accelerators (=SNR)!

Requirements for high energy electron observation

電子観測の現状:

- 各観測結果に統計誤差だけでは説明できない差異
- **TeV領域はほぼ未観測**

電子観測の困難:

- **Flux自体が希少**

  ~ 5 イベント / m^{2}sr day (> 1TeV)
- **膨大な陽子バックグラウンド**

  電子:陽子 = 1: 100 @10GeV

  電子:陽子 = 1:1000 @1TeV

電子観測のための必須事項:

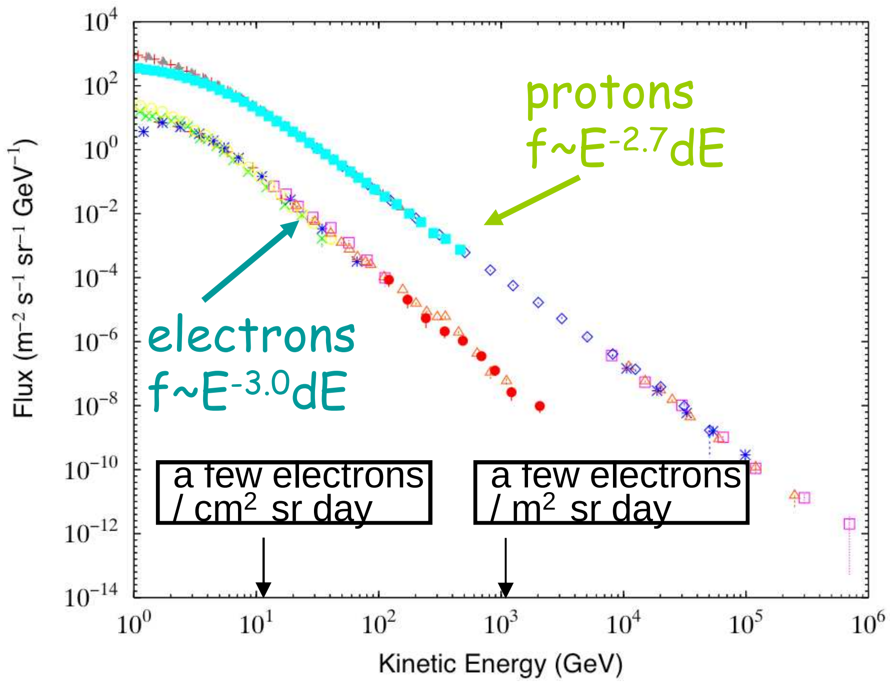
- **大きな検出器による長期間観測**

  ~220 m^{2}sr day ⇒ 約1000例 (>1TeV)
- **強力な陽子除去性能**

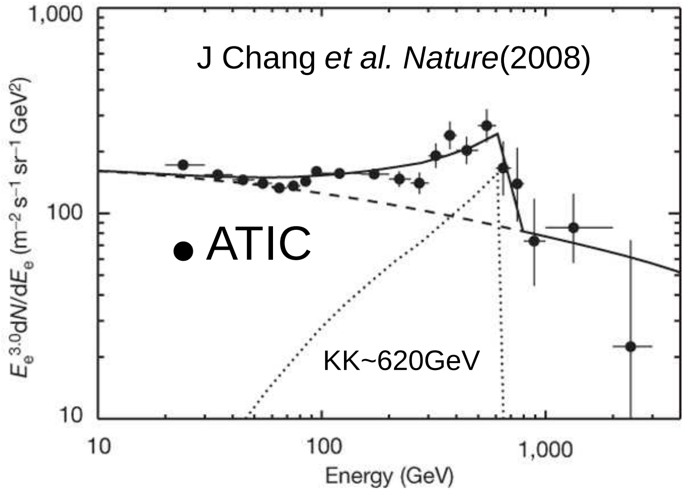
  10^5 @ TeV
- **優れたエネルギー分解能**

  数% (数100GeV領域)

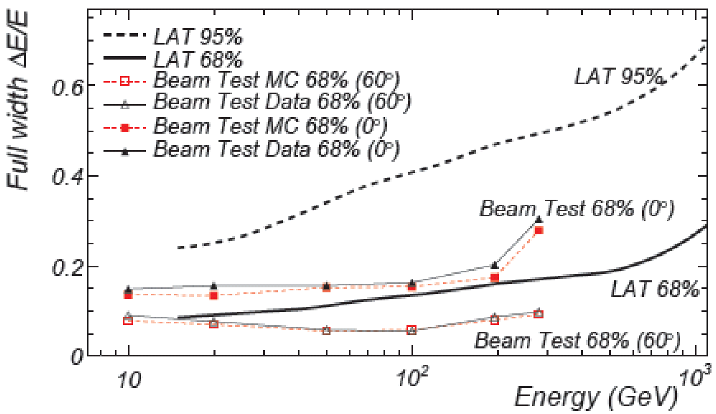
Cosmic-ray Energy Spectra



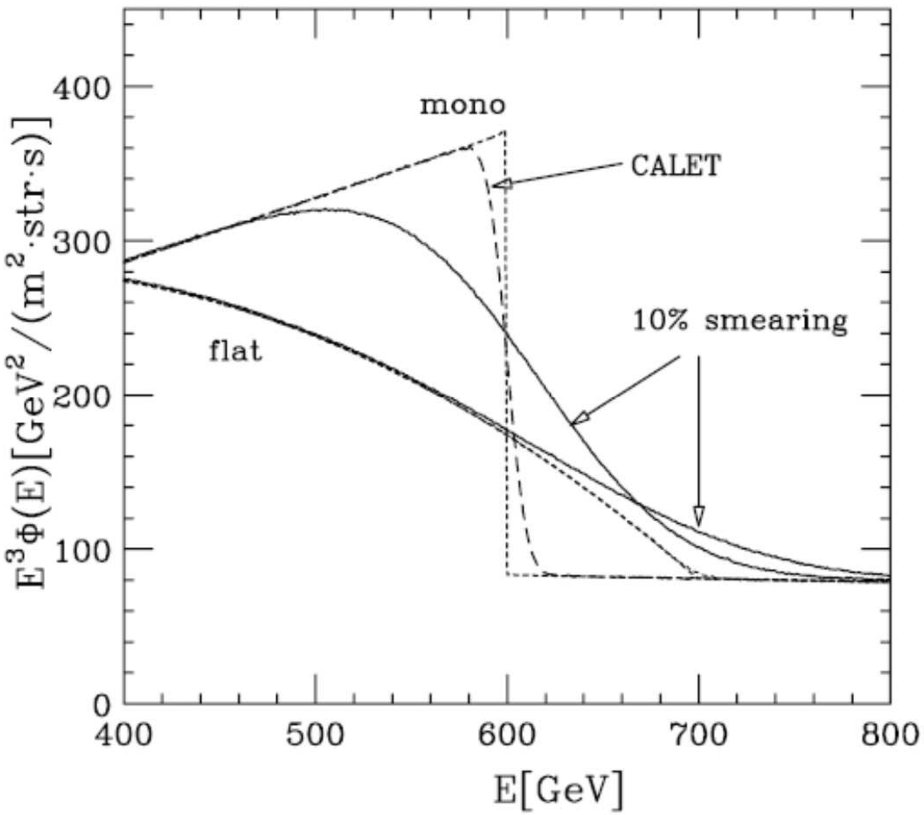
Energy resolution



Energy resolution of Fermi-LAT



Energy Resolution vs. DM Sensitivity



arXiv: 0812.4200[astro-ph] C.R.Chen et al.

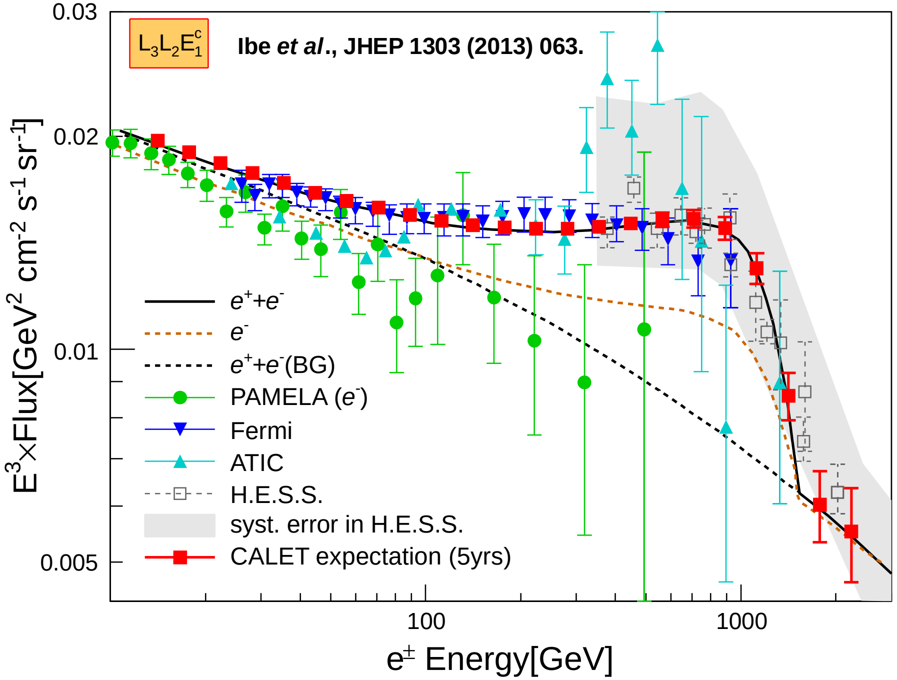
CALET Science Goals

The CALET mission will address many of the outstanding questions of High Energy Astrophysics, such as the origin of cosmic rays, the mechanism of CR acceleration and galactic propagation, the existence of dark matter and nearby CR sources.

Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum into trans-TeV region
Dark Matter	Signatures in electron/gamma energy spectra in the several GeV – 10 TeV range
Cosmic-ray Origin and Acceleration	p-Fe energy spectra up to 10^{15} eV and trans-iron elements (Z=26-40) at a few GeV
Cosmic–ray Propagation in the Galaxy	B/C ratio above TeV /nucleon
Solar Physics	Electron flux below 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays in the 7 keV - 20 MeV range

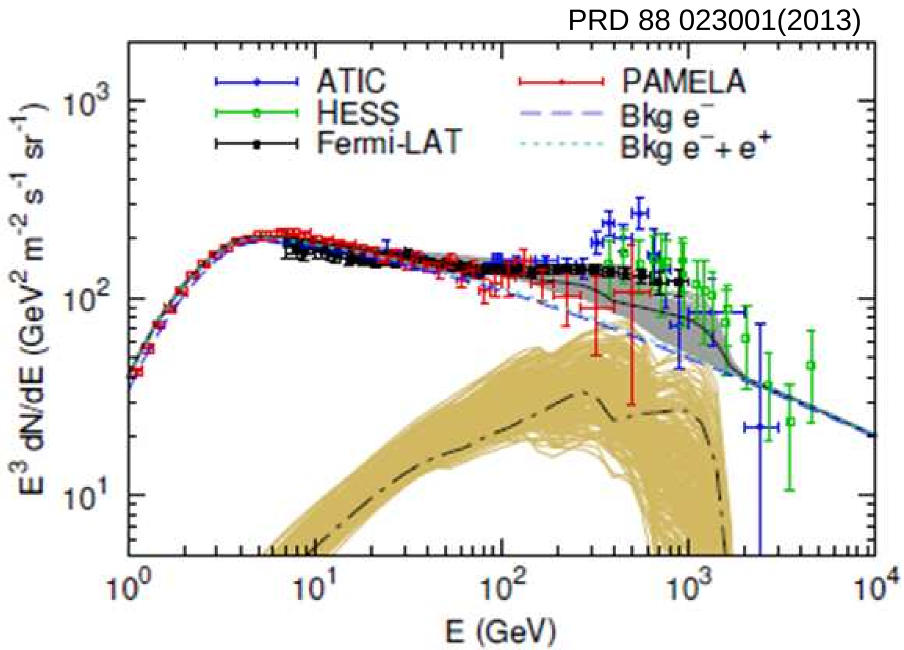
Dark Matter / Pulsar

Decay of Dark Matter (LSP)



Expected $e^+ + e^-$ spectrum by **Lightest Super Symmetry Particle (LSP) (black line)** after 5-year CALET measurement (red dots)

Multiple Pulsar



The fine structure is observable by CALET thanks to the high energy resolution

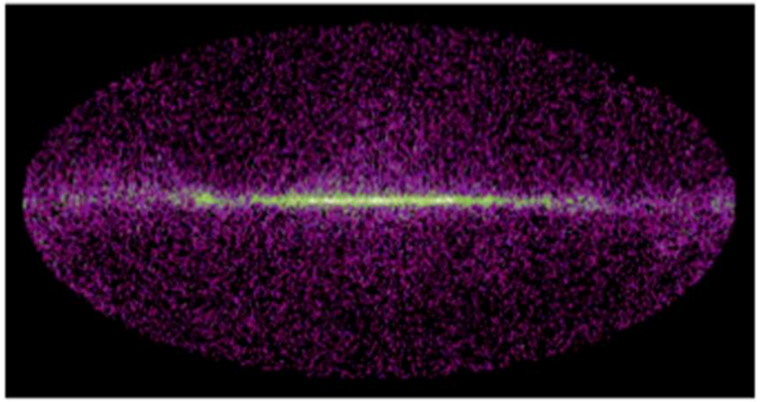
Detection of high energy gamma-rays

Performance for Gamma-ray Detection

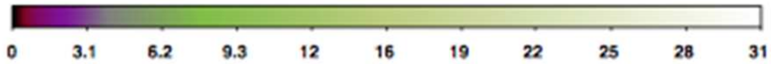
Energy Range	4 GeV-10 TeV
Effective Area	600 cm^2 (10GeV)
Field-of-View	2 sr
Geometrical Factor	1100 cm^{2}sr
Energy Resolution	3% (10 GeV)
Angular Resolution	0.35° (10GeV)
Pointing Accuracy	6′
Point Source Sensitivity	8 x 10^{-9} cm^{-2}s^{-1}
Observation Period (planned)	2015-2020 (5 years)

*) Trigger efficiency included below 10 GeV
**) 100 % efficiency over 5 GeV

Simulation of Galactic Diffuse Radiation

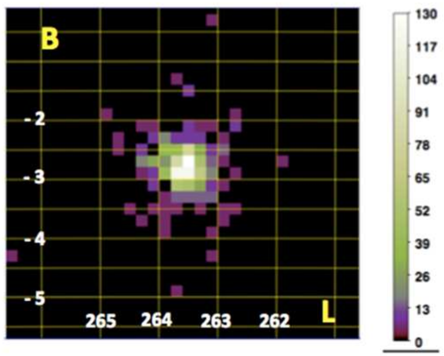


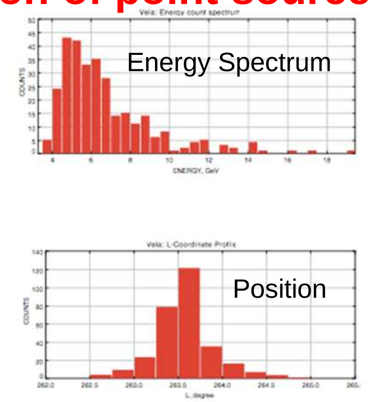
~5,700 photon* are expected per one year



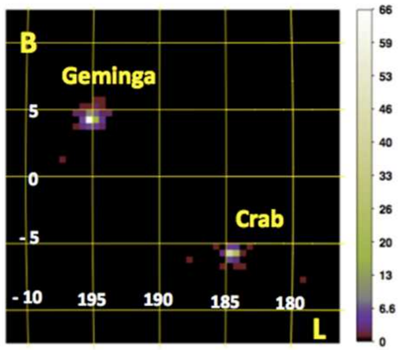
~1,700 photon* from extragalactic γ-background (EGB) each year

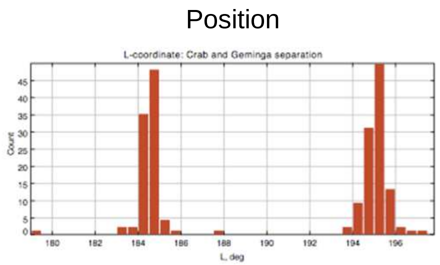
Simulation of point source observations in one year





Vela: ~ 300 photons above 5 GeV**



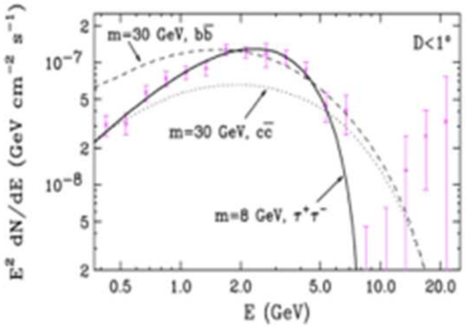


Geminga: ~150 photons above 5 GeV**
Crab: ~ 100 photons above 5 GeV**

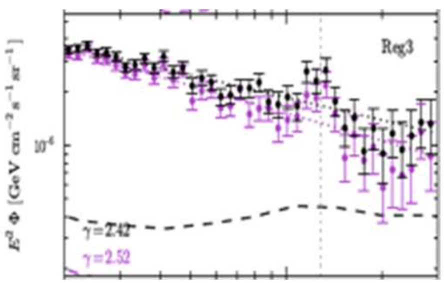
Detection Capability of Gamma-ray Lines from DM

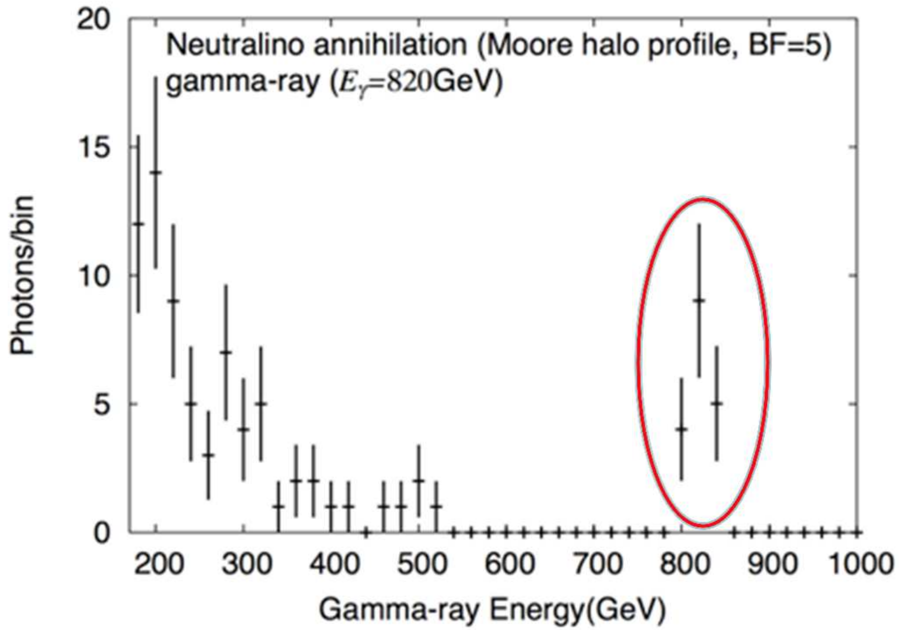
Monochromatic gamma-ray signals from WIMP dark matter annihilation would provide a distinctive signature of dark matter, if detected. Since gamma-ray line signatures are expected in the sub-TeV to TeV region, due to annihilation or decay of dark matter particles, CALET, with an excellent energy resolution of 2 - 3 % above 100 GeV, is a suitable instrument to detect these signatures .

Gamma-ray excess in the Galactic Center?



A 130 GeV line?



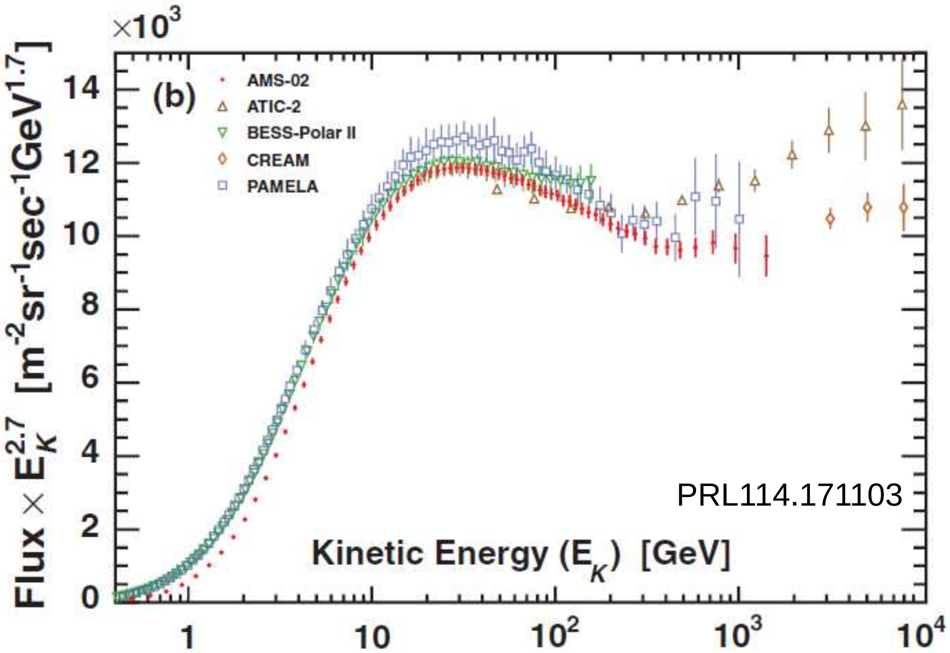


Simulated gamma-ray line spectrum for 2yr from neutralino annihilation toward the Galactic center with m=820GeV, a Moore halo profile, and BF=5

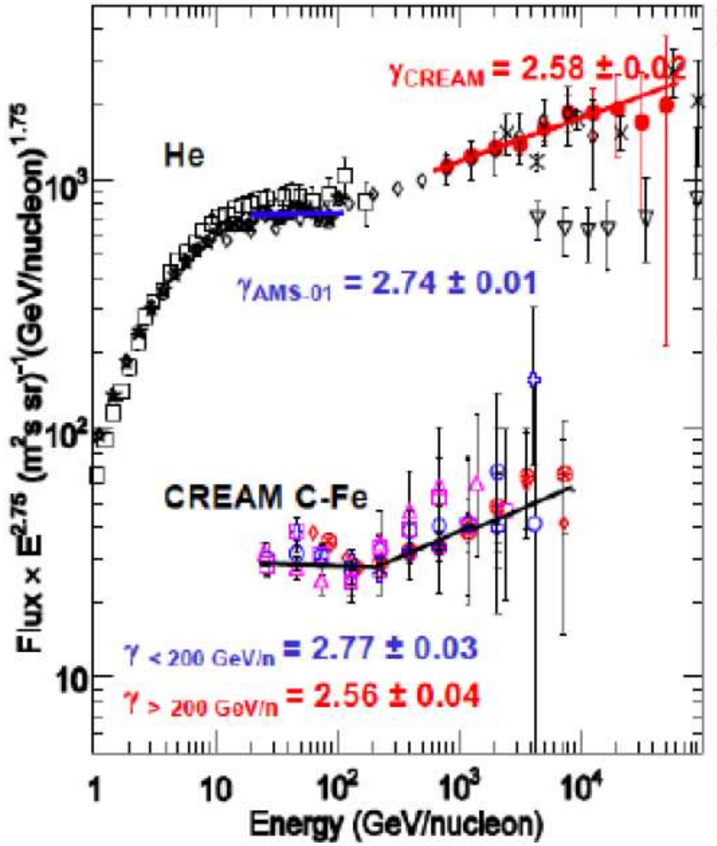
Measurements of Cosmic Nuclei Spectra

<u>A single power-law seems inadequate to fit the spectra of nuclei</u>

- **PAMELA/AMS-02 detected a spectral break**
  - **PAMELA : 240GeV**
  - **AMS-02 : 336GeV**



- **The break also appears in the nuclei spectra measured up to several TeV/n**

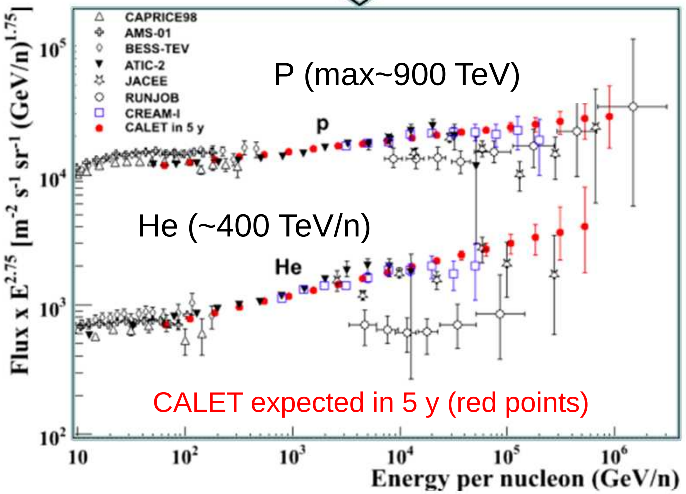


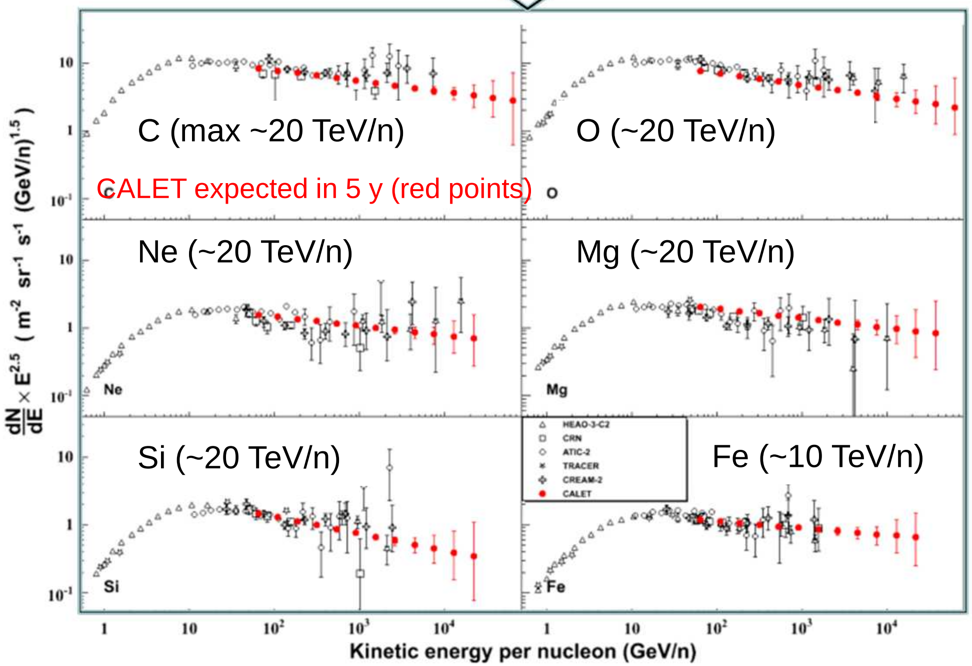
CALET will be able to perform an **accurate scan** of the energy region around the spectral break with an energy resolution ~30 % and larger GF ~ 0.1 m^2 sr

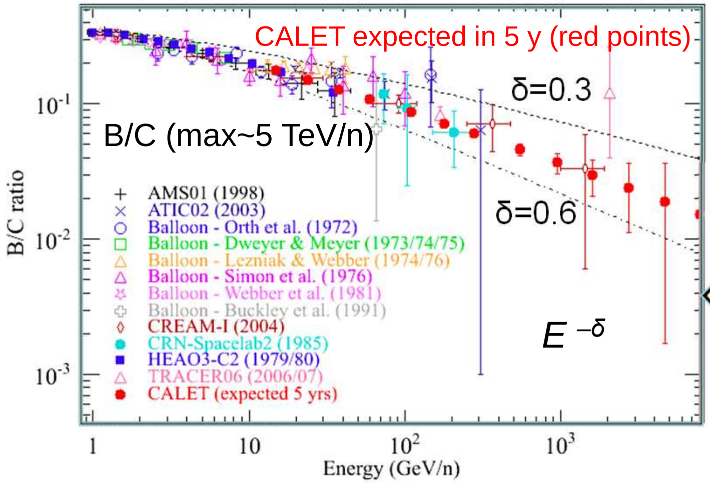
Expectation of CALET observation

- Hardening in the p and He at a few 100s GV
- p and He spectra have different slopes in the multi TeV region (CREAM)
- Acceleration limit by SNR shock wave around 100 TeV/Z ?

- All primary heavy nuclei spectra well fitted to single power-laws with similar spectral index (CREAM, TRACER)
- However hint of a hardening from a combined fit to all nuclei spectra (CREAM, AMS-02)



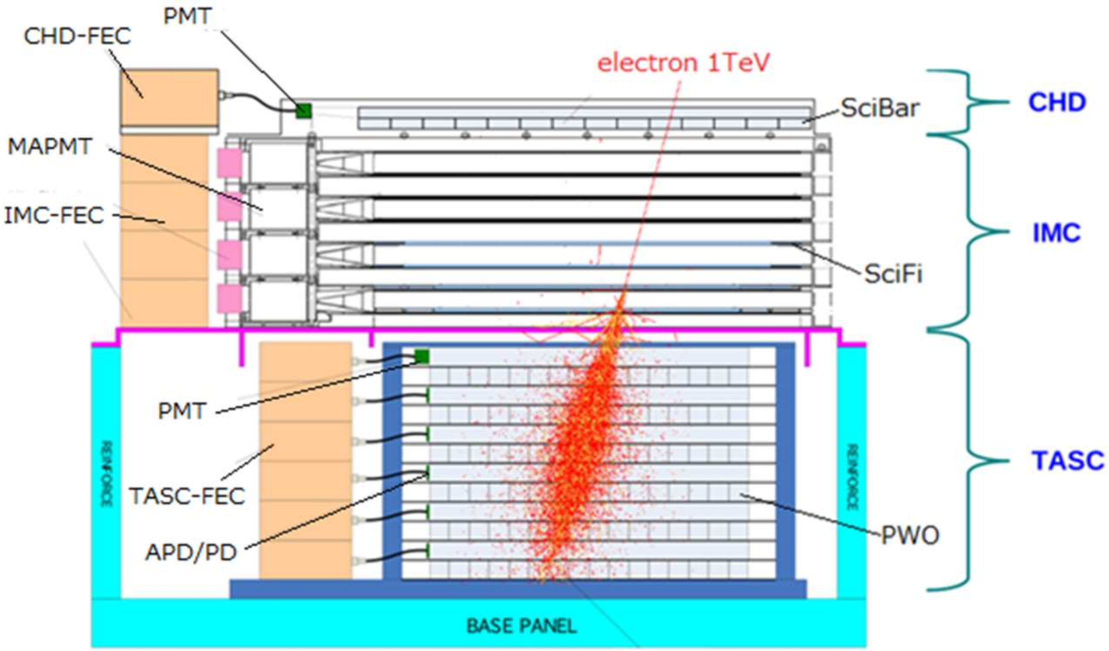




- At high energy (> 10 GeV/n) the B/C ratio measures the energy dependence of the escape path-length, $\sim E^{-\delta}$, of CRs from the Galaxy
- Data below 100 GeV/n indicate δ~0.6. At high energy the ratio is expected to flatten out (otherwise CR anisotropy should be larger than that observed)

CALET Calorimeter

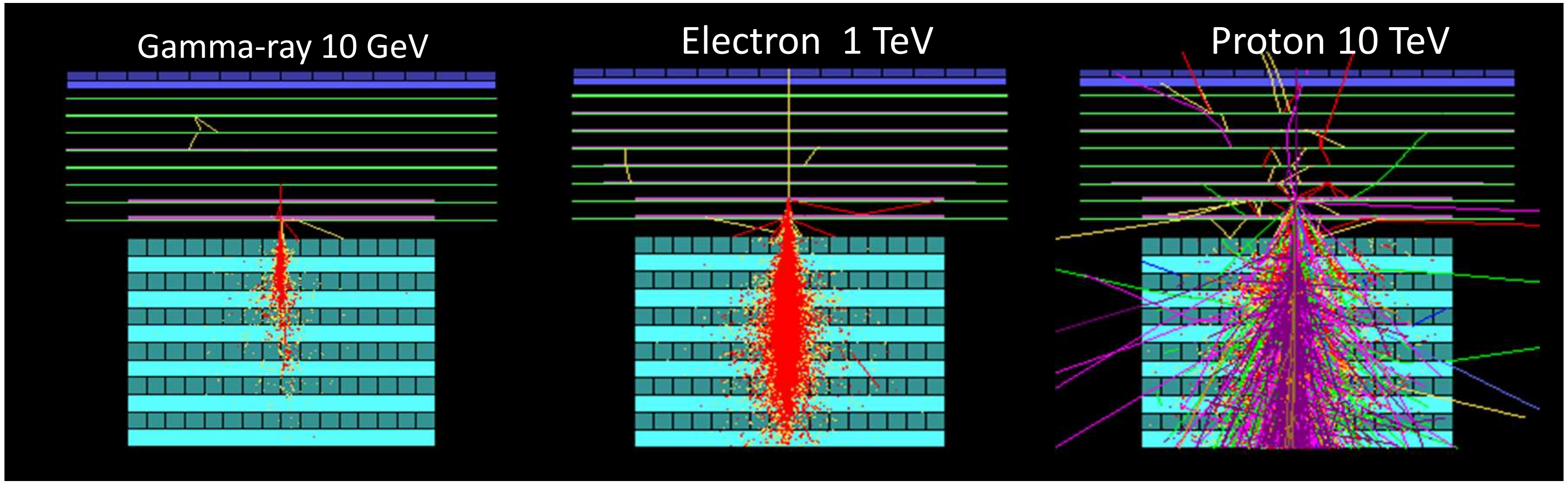
Field of view: ~ 45 degrees (from the zenith)
Geometrical Factor: 0.12 m^2sr (for electrons)



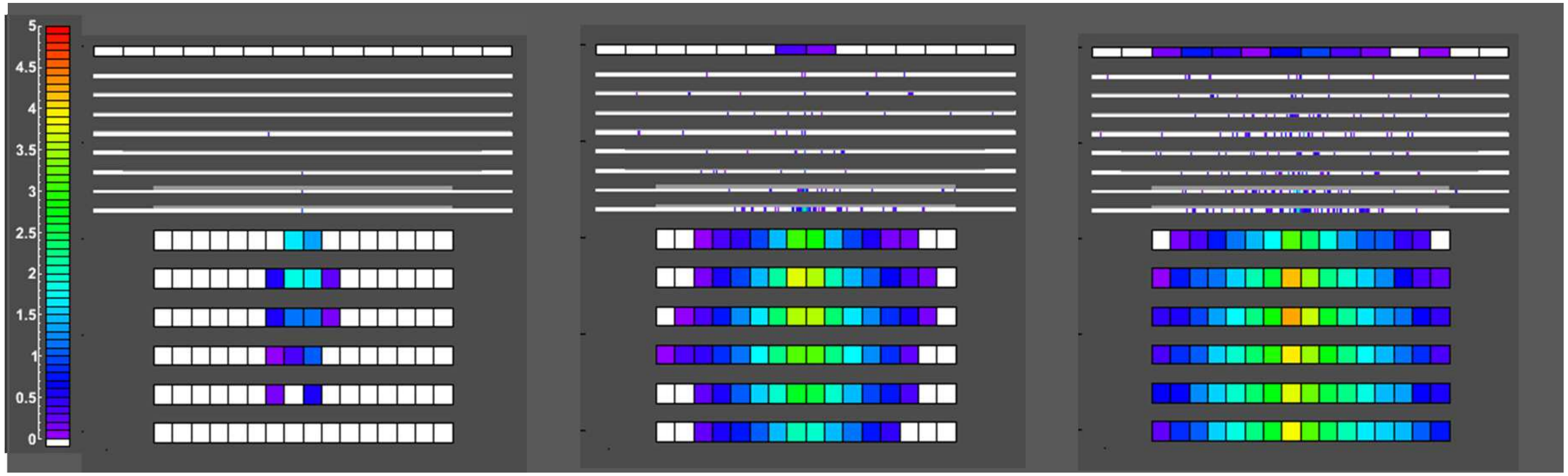
- The unique feature of CALET is its thick(~30 X_0), homogeneous calorimeter that allows to extend electron measurements into the TeV energy region with excellent energy resolution(~2-3%), coupled with a high granularity imaging pre-shower calorimeter to accurately identify the arrival direction of incident particles (~0.1°) the starting point of electro-magnetic showers. Combined, they powerfully separate electrons from the abundant protons: rejection power (~10^5).
- A dedicated charge detector + multiple dE/dx track sampling in the IMC allow to identify individual nuclear species (Δz~0.15-0.3).

	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 x 10mm x 450mm	**SciFi : 448 x 8 layers (x,y) = 7168** Unit size: $1mm^2$ x 448 mm **Total thickness of Tungsten: 3 X_0**	**PWO log: 16 x 6 layers (x,y)= 192** Unit size: 19mm x 20mm x 326mm **Total Thickness of PWO: 27 X_0**
Readout	**PMT+CSA**	**64 -anode PMT(HPK) + ASIC**	**APD/PD+CSA** PMT+CSA (for Trigger)@top layer

CALET Shower Imaging (Simulation)



In Detector Space



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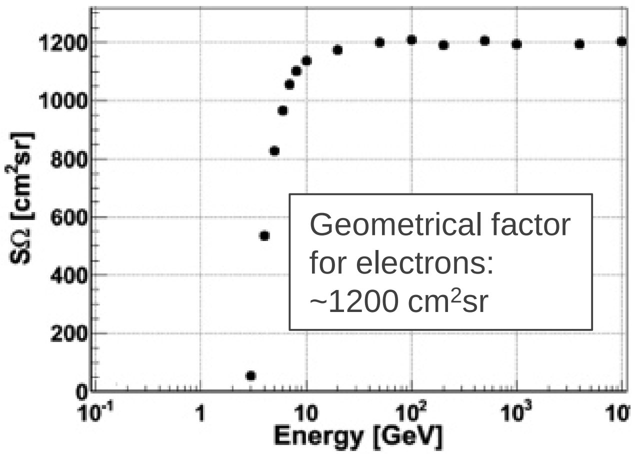
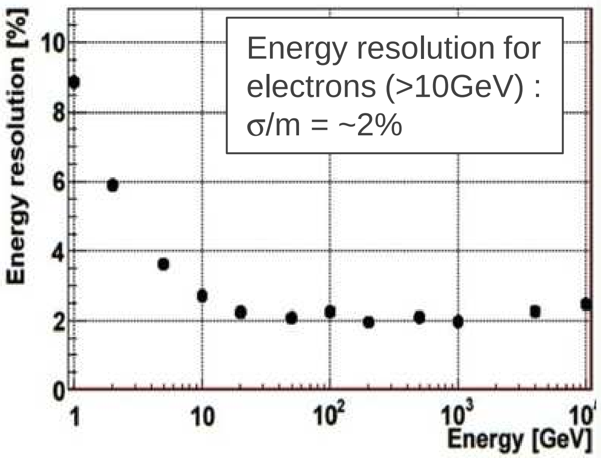
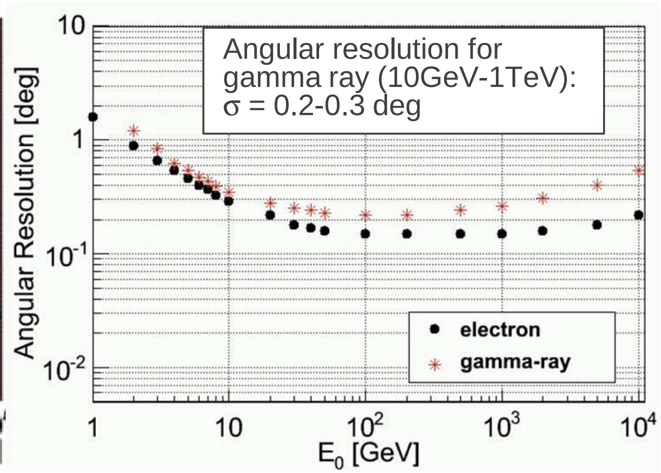
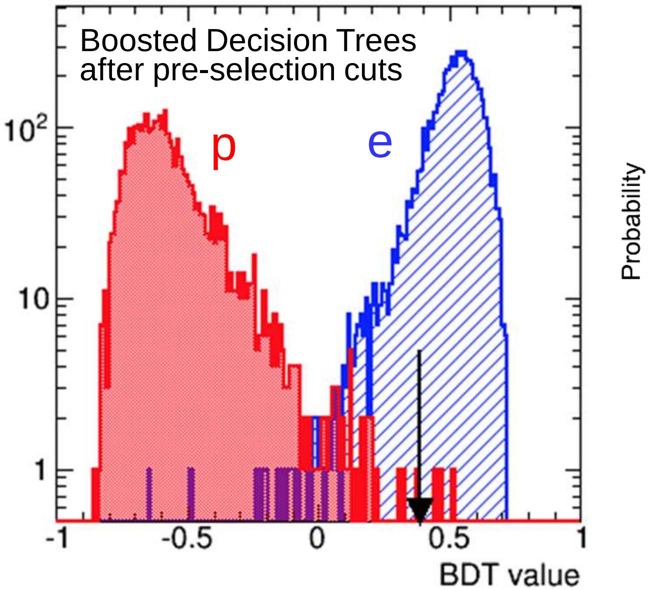
CALET Expected Performance by Simulations

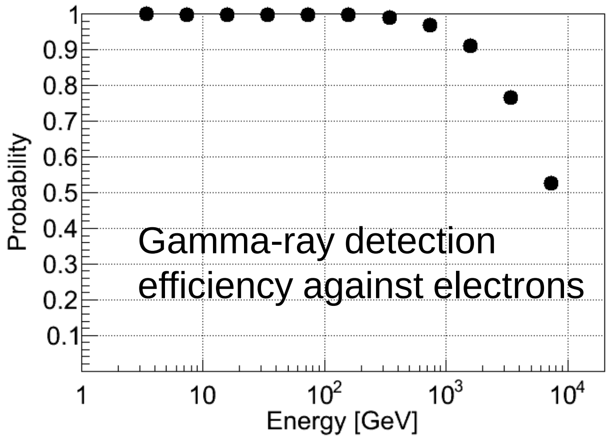


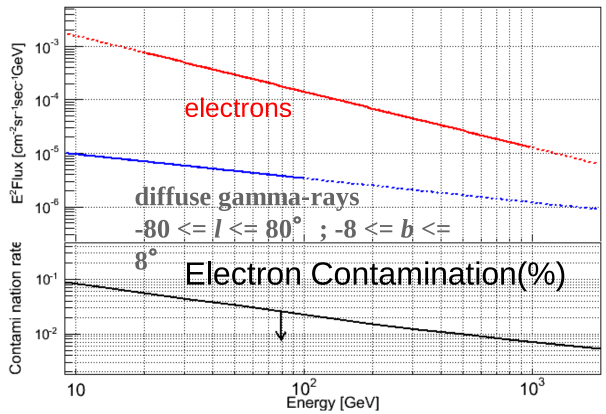






Proton rejection power at 1TeV :
≈1.3x10^5 with 88% efficiency for electrons





Left: detection efficiency of gamma-rays with electron discrimination power 3.54 x 10^{-4} (90% CL): >95% in 10-900 GeV
Right: electron contamination in galactic diffuse gamma-rays : 10% @10GeV – 1%@TeV

Development/Evaluation by Prototype Detectors

気球実験・加速器実験を通して、開発要素の技術実証、性能評価を実施

2006 **気球実験（bCALET-1 @三陸）**
¼プロトタイプ検出器

2008 **加速器実験（東北大核理研）**
GeV領域ガンマ線の観測性能

2009 **気球実験（bCALET-2 @大樹町）**
½プロトタイプ検出器

2010 **加速器実験（CERN-SPS）**
μ粒子、電子の観測性能

2011 **加速器実験（HIMAC）**
CHD, SciFiの電荷分解能

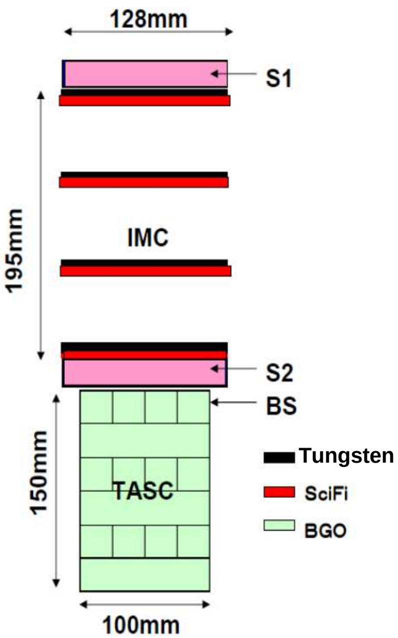
2012 **加速器実験（CERN-SPS）**
μ粒子、電子、陽子の観測性能

2012 **加速器実験（CERN-SPS）**
μ粒子、電子の観測性能
熱構造モデルによる性能検証

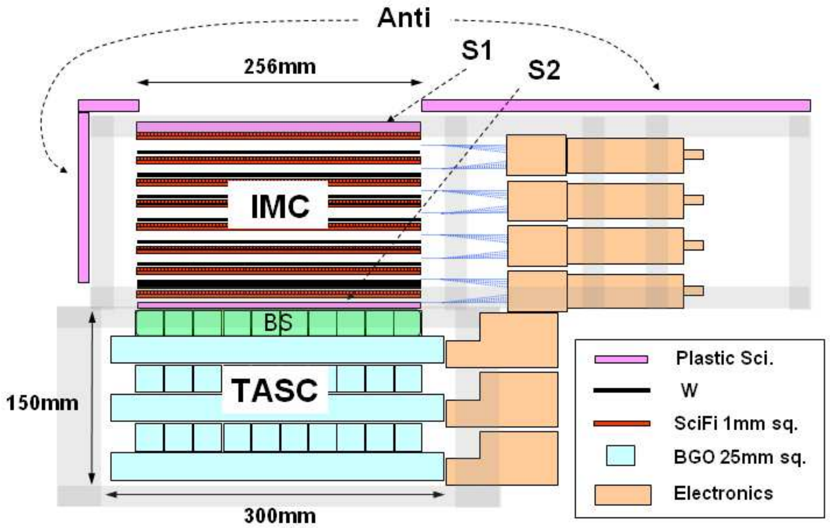
2013/2015 **加速器実験（CERN-SPS）**
原子核の観測性能

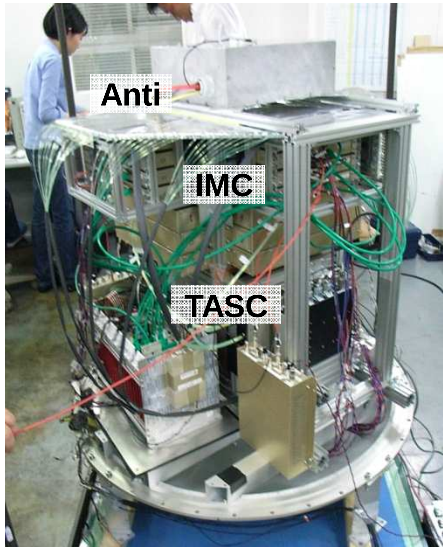
Balloon-borne CALET

bCALET-1



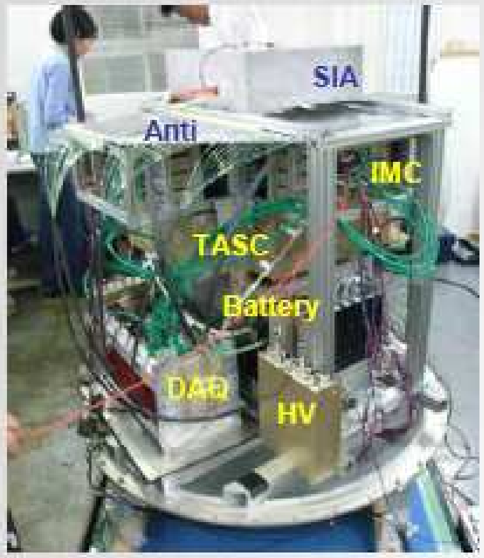
bCALET-2

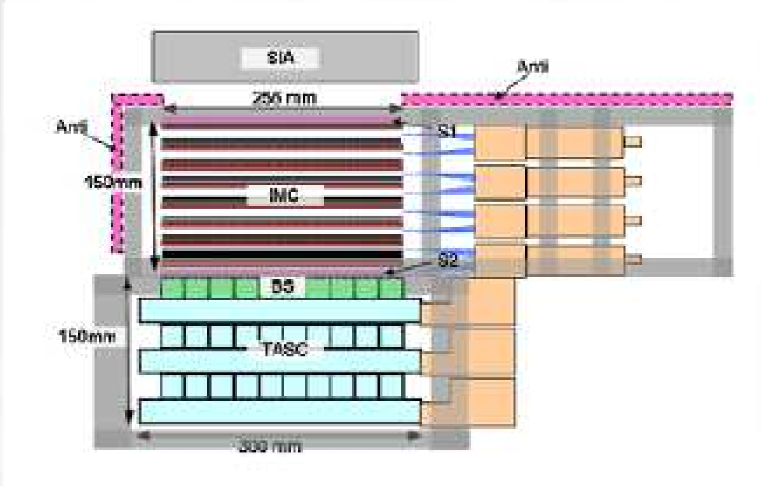




	bCALET-1	bCALET-2	CALET
IMC	1.3 r.l. (W 4 layers) SciFi 128mm x 4XY layers	3.5 r.l. (W 7 layers) SciFi 256mm x 8XY layers	3.0 r.l. (W 7 layers) SciFi 448mm x 8XY layers
TASC	13.4 r.l. (BGO 4 logs x 6 layers)	13.4 r.l. (BGO 10 logs x 6 layers)	27.2 r.l. (PWO 16 logs x 12 layers)
Trigger	Plastic scintillator (S1, S2) & TASC top layer (BS)	Plastic scintillator (S1,S2,Anti) & TASC top layer (BS)	IMC dynode & TASC top layer
SΩ	21 cm^2sr	320 cm^2sr	1200 cm^2sr

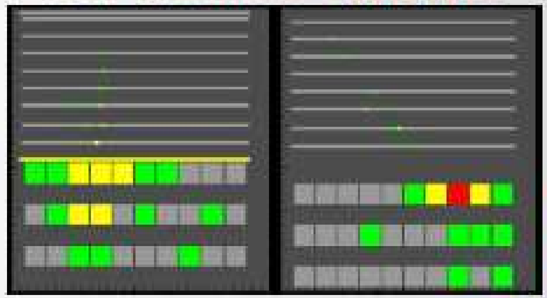
bCALET-2 observation





10GeV程度の電子候補例

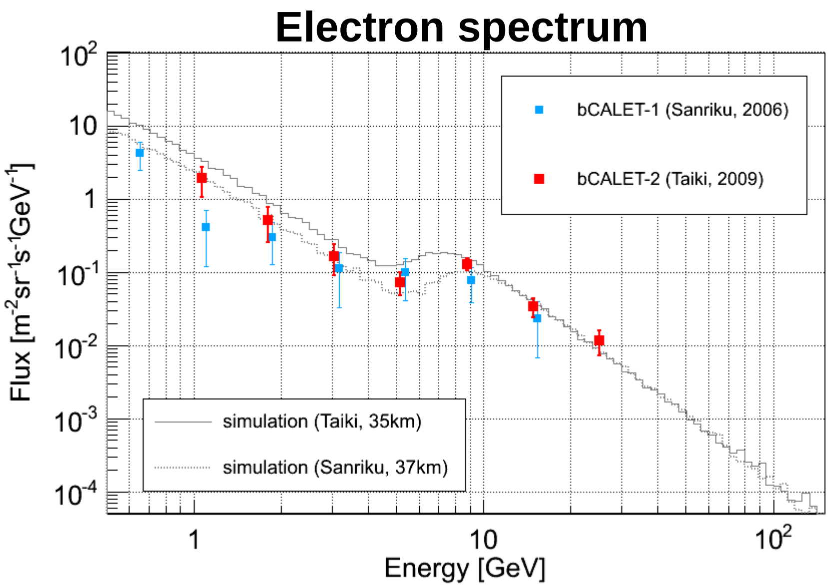
1GeV 以上のガンマ線候補例

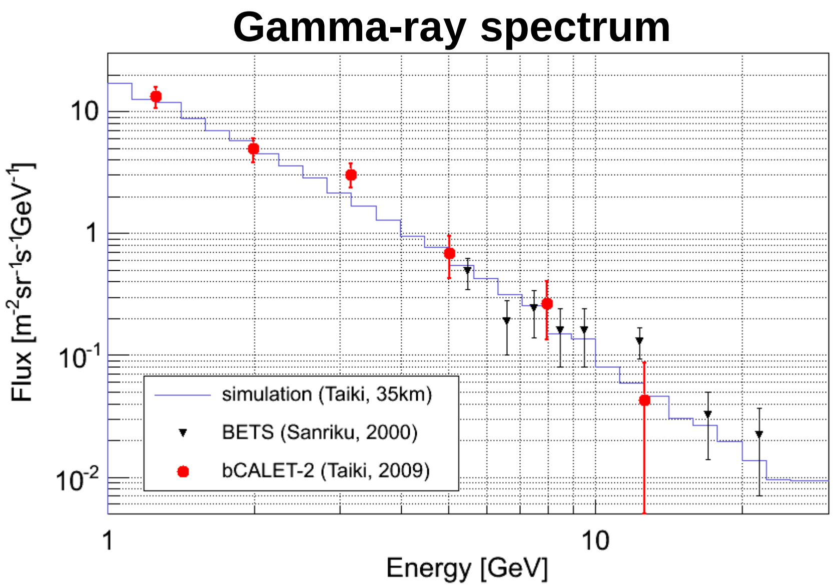


陽子候補例

bCALET observations

	bCALET-1	bCALET-2
Date	**31, May, 2006**	**27, Aug, 2009**
Place	**Sanriku**	**Hokkaido**
Level flight altitude	**37km**	**35km**
Duration	**6 hours** **(37km level fright: 3.5hours)**	**4.5 hours** **(35km level flight: 2.5hours)**
Triggered event number	**~3000@37km**	**~12000@35km**



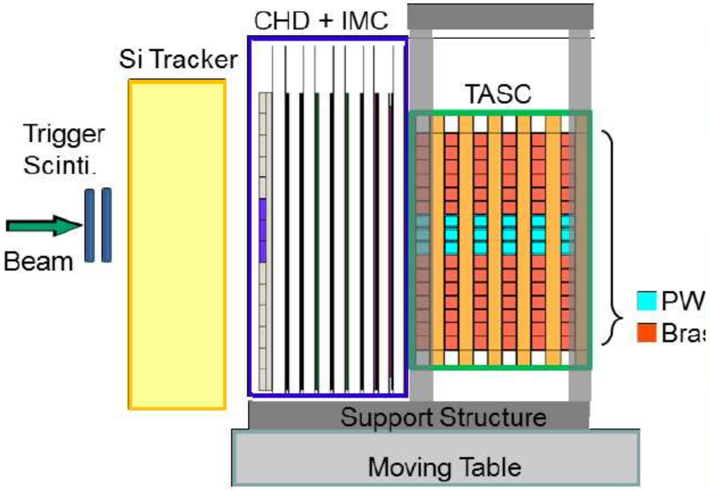


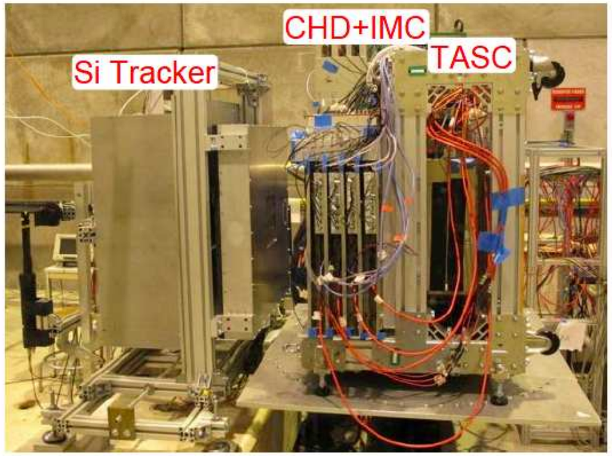
Beam Test at CERN-SPS

場所:CERN-SPS
日時:2012.9.24 – 10.15
粒子: 電子 10 – 290 GeV
　　　陽子 30 – 400 GeV
　　　ミューオン: 150, 180GeV
検出器: 熱構造モデル(フライトモデルと同じ構造)
　　　　回路系の一部はBBMを使用

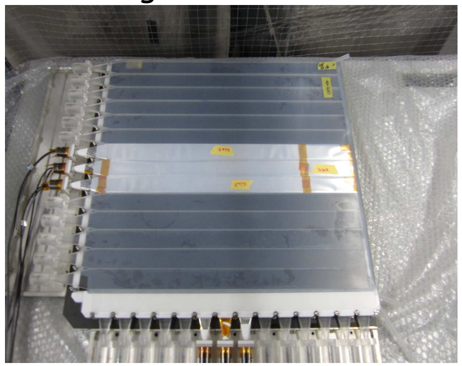
フライトモデルとの違い

	CALET	ビーム試験(2012)
CHD	14枚 x (X,Y)	3枚 x (X,Y)
IMC (SciFi)	448本 x (X,Y) x 8層	256本 x (X,Y) x 8層
(W)	7層 ($3X_0$)	7層 ($3X_0$)
TASC	16本 x (X,Y) x 6層	3本 x (X,Y) x 6層

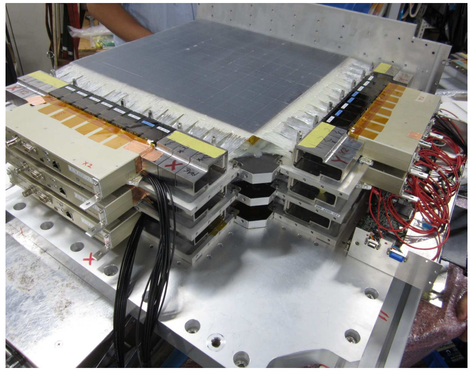




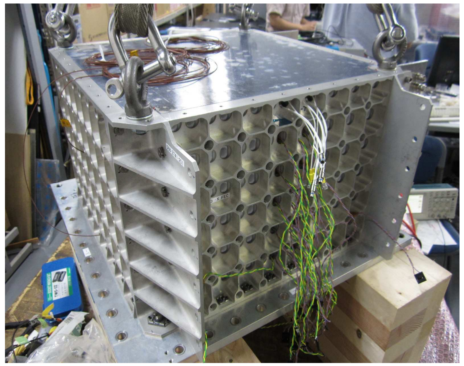
Charge Detector: CHD



Imaging Calorimeter: IMC



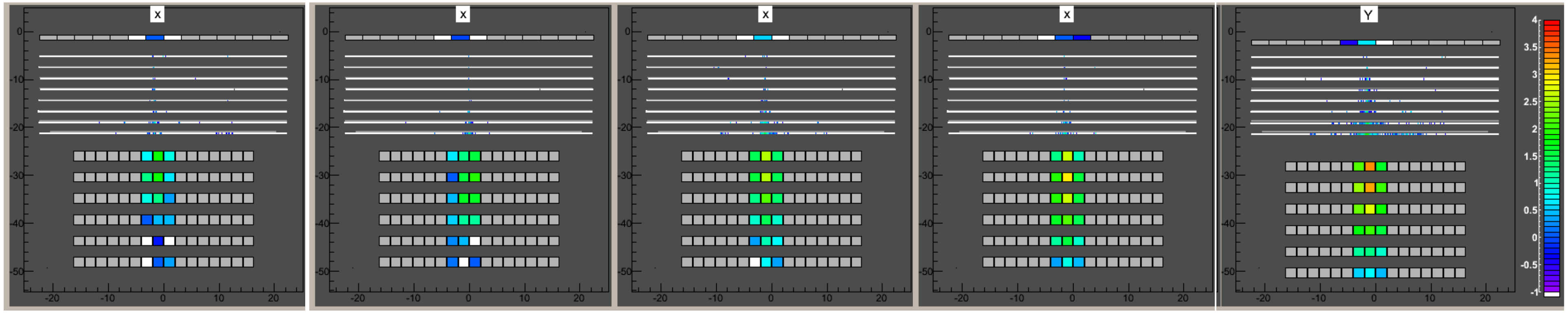
Total Absorption Calorimeter: TASC



Examples of Shower Events Observed at CERN-SPS

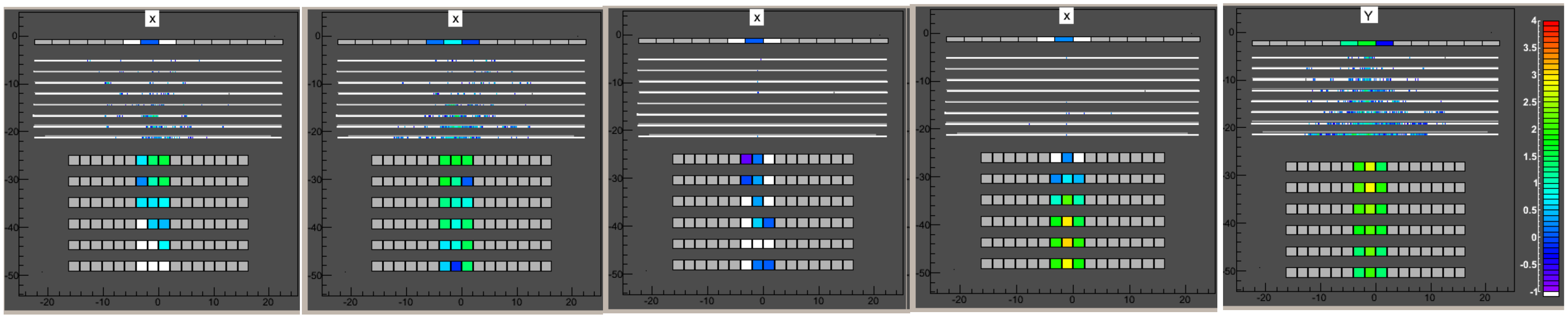
Electron Showers

10 GeV | 20 GeV | 50 GeV | 100GeV | 200GeV

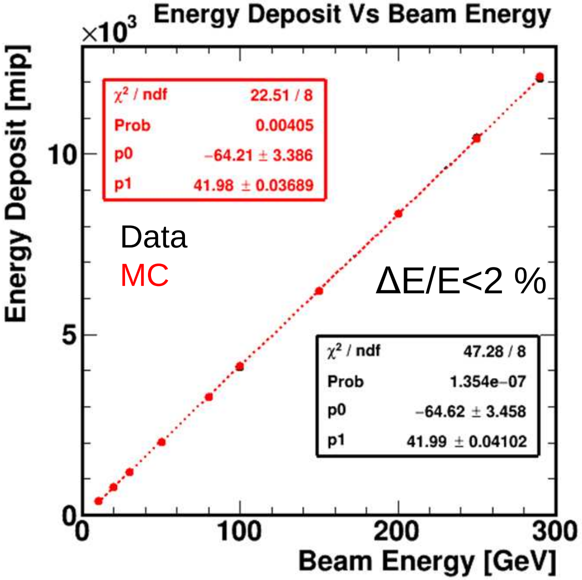


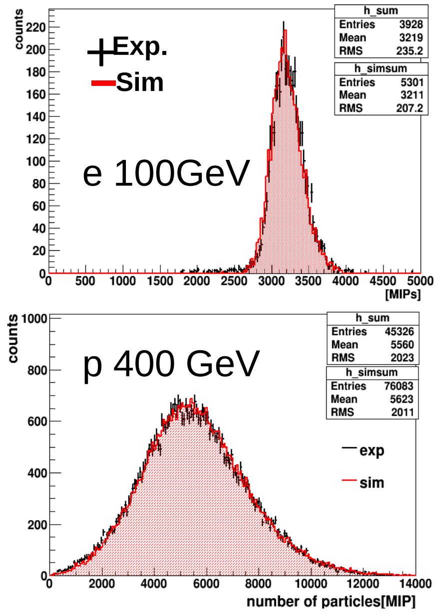
Proton Showers

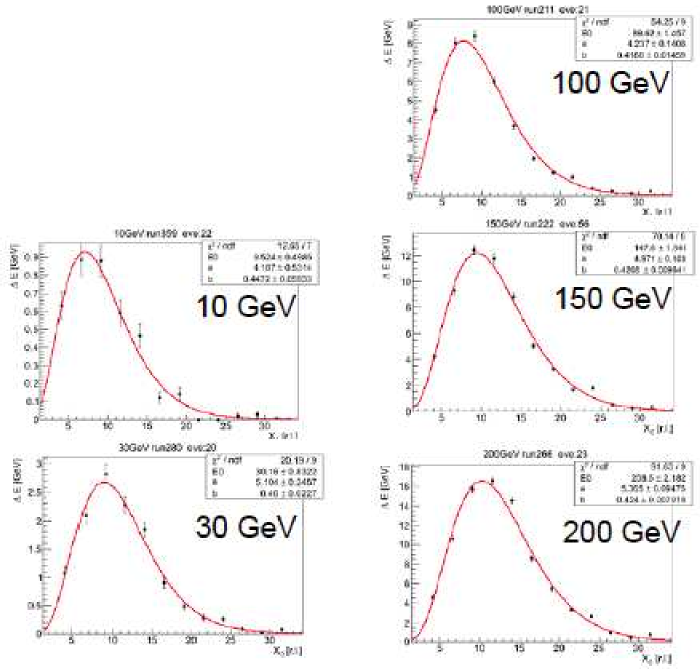
30 GeV Interacted in IMC | 100 GeV Interacted in IMC | w/o Interaction | 400 GeV Interacted in TASC | interacted in IMC

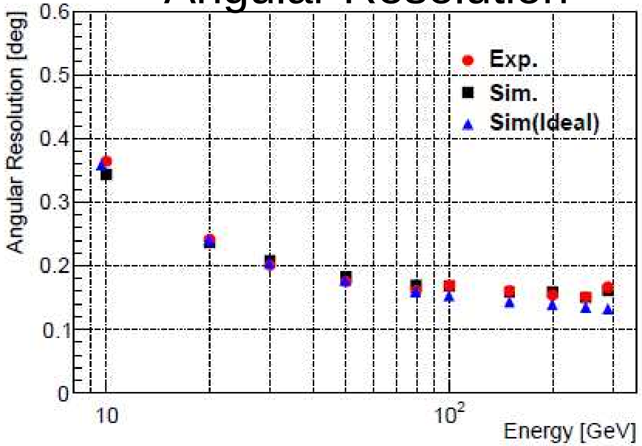


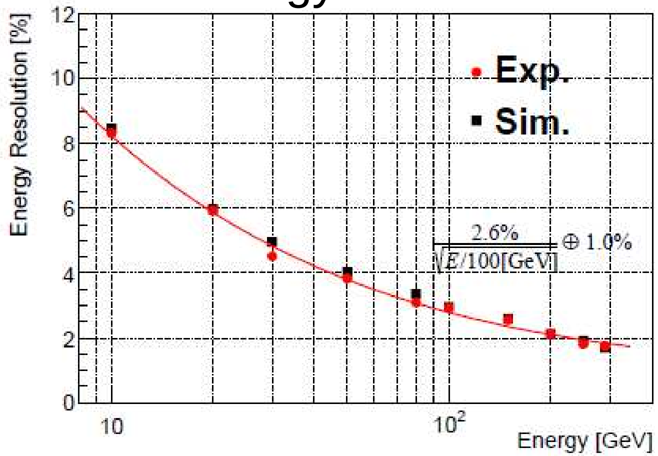
CERN-SPS Beam Test Results



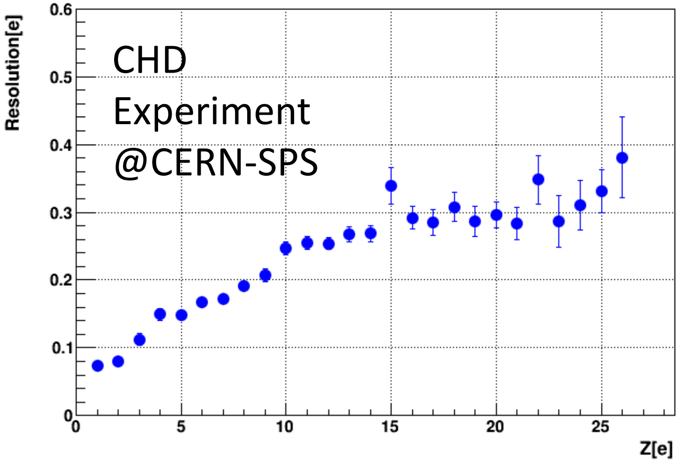




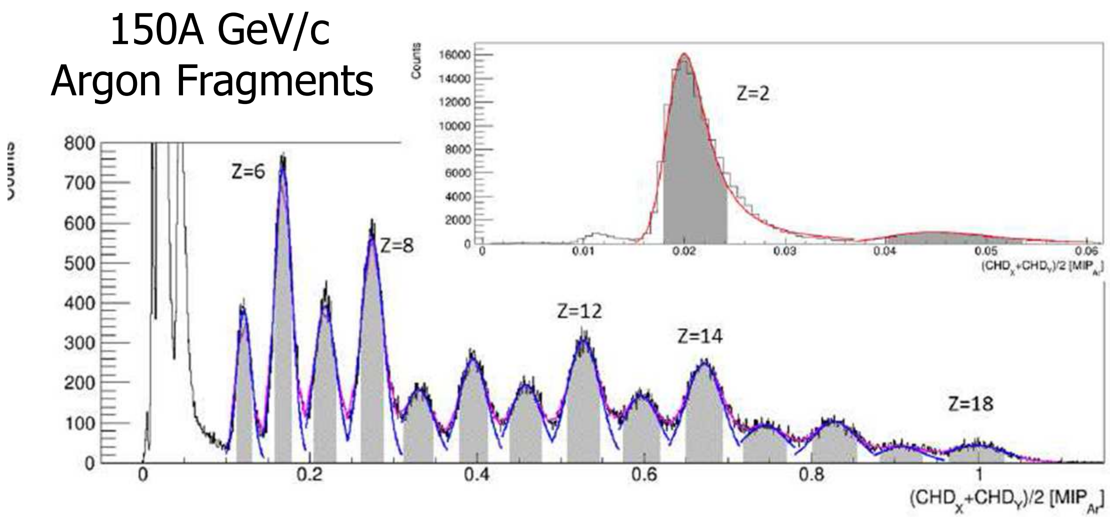


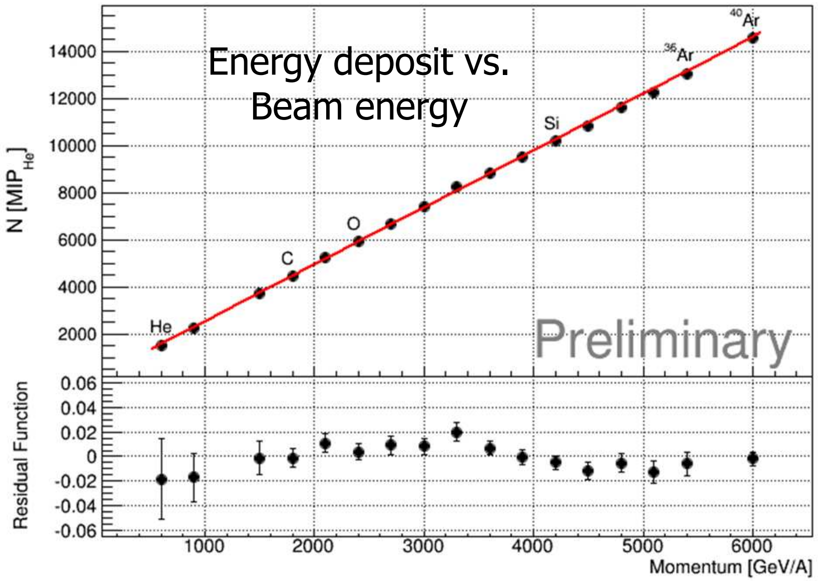


Heavy Ion Beam Tests at CERN-SPS

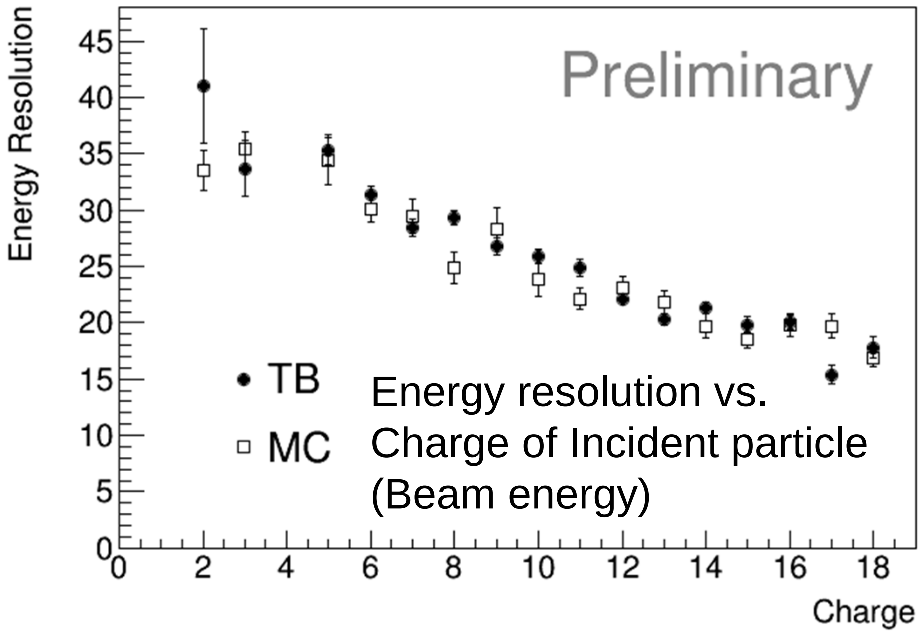


Charge resolution:
σ_Z = 0.15e(@B) – 0.30e(@Fe)





ICR



CALET Instruments

CAL

- Charge Detector (CHD)
- Imaging Calorimeter (IMC)
- Total Absorption Calorimeter (TASC)

CGBM

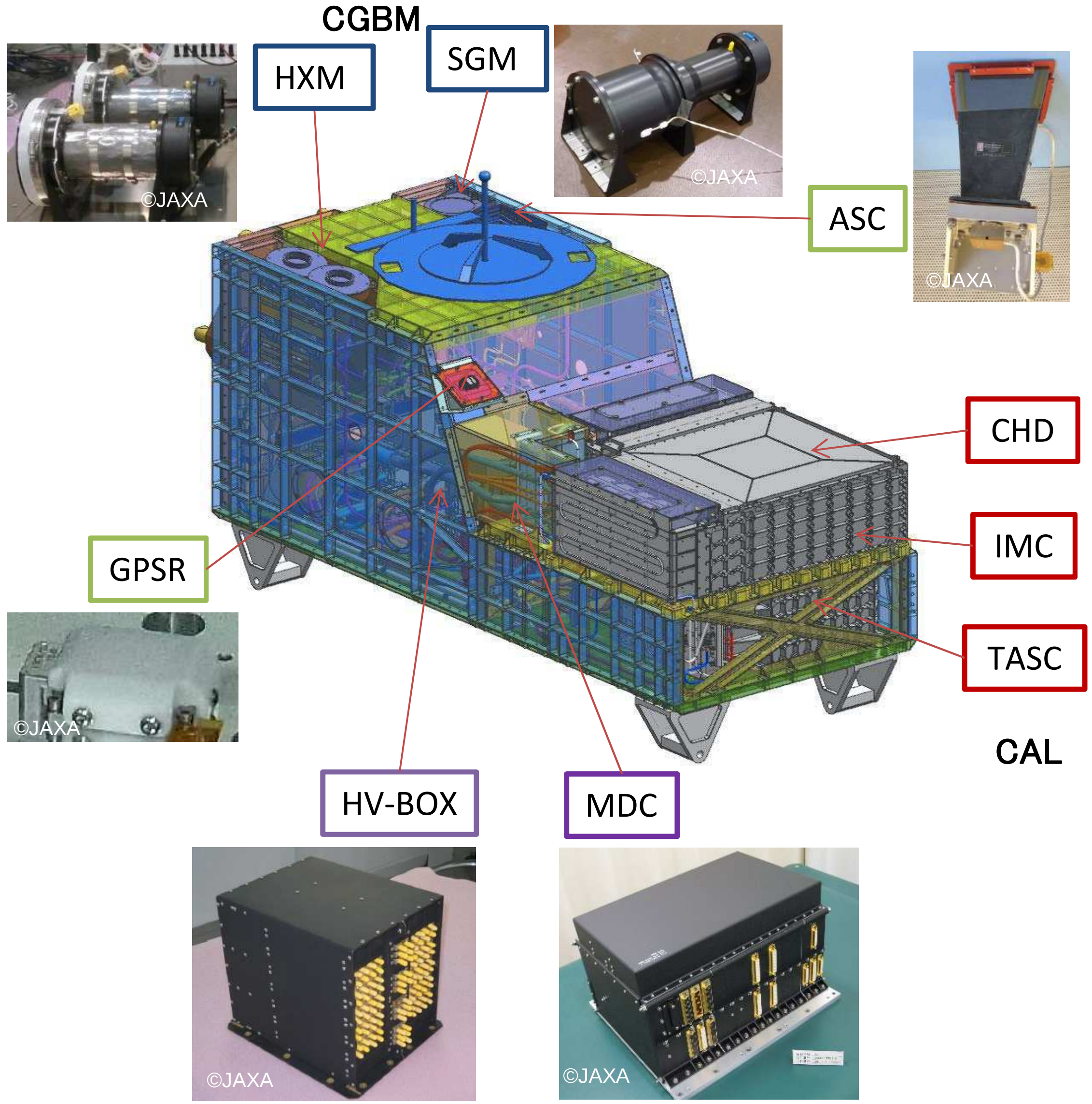
- Hard X-ray Monitor (HXM)
  $LaBr_3$: 7keV～1MeV
- Soft γ-ray Monitor (SGM)
  BGO : 100keV～20MeV

データ処理・電源

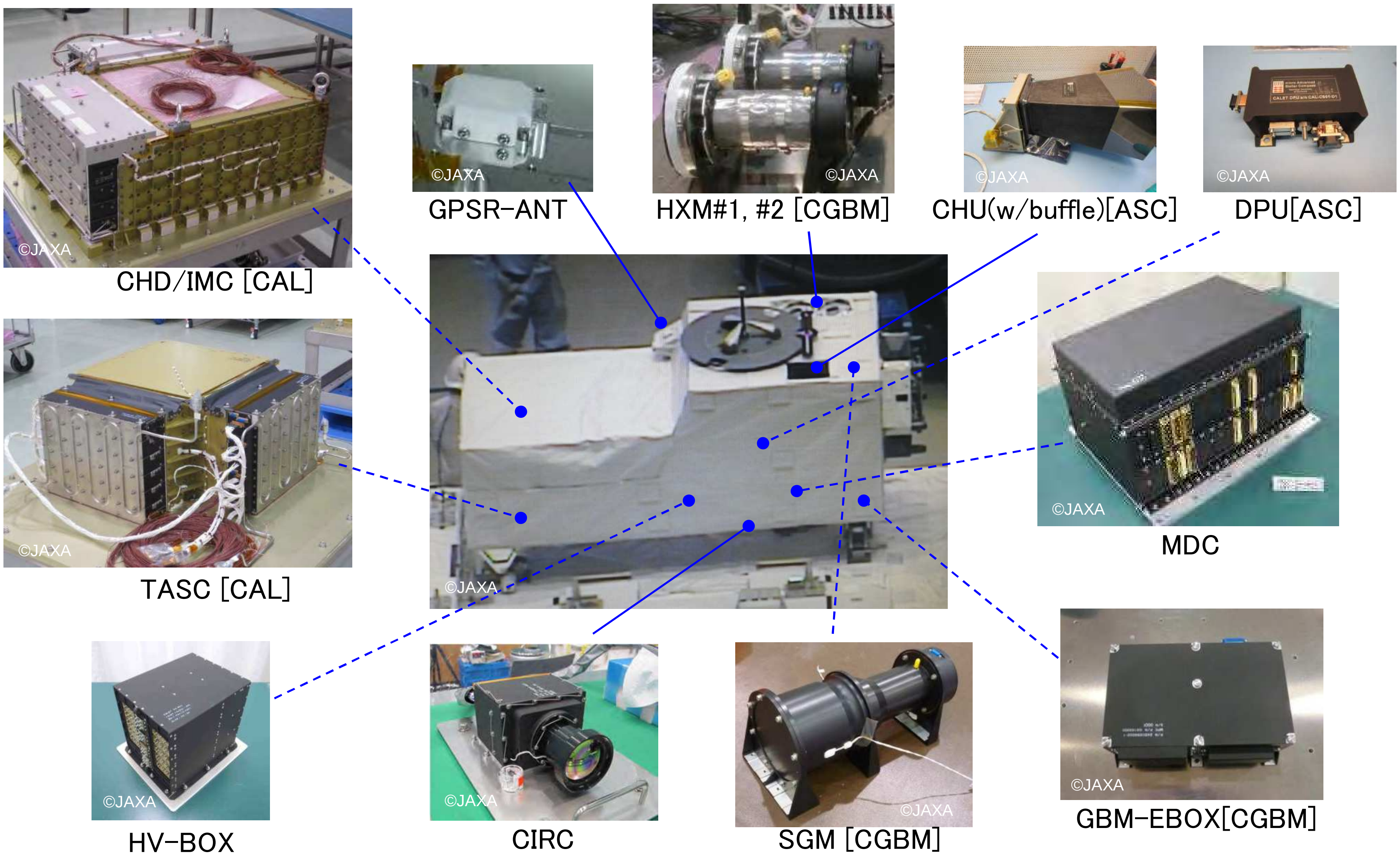
- Mission Data Controller (MDC)
  制御、データ送受信、トリガ、電源
- HV-BOX
  高電圧電源(PMT:68ch, APD:22ch)

サポートセンサ

- Advanced Stellar Compass (ASC)
  観測装置の方向測定
- GPS Receiver (GPSR)
  イベントへの時刻付け(<1ms)



CALET Instruments



Calorimeter

CAL構成機器

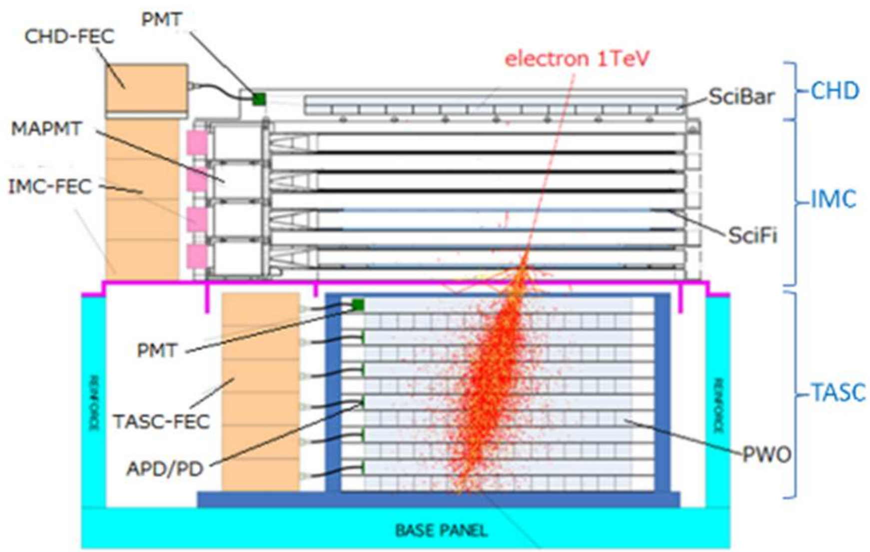
カロリメータのコンポーネント

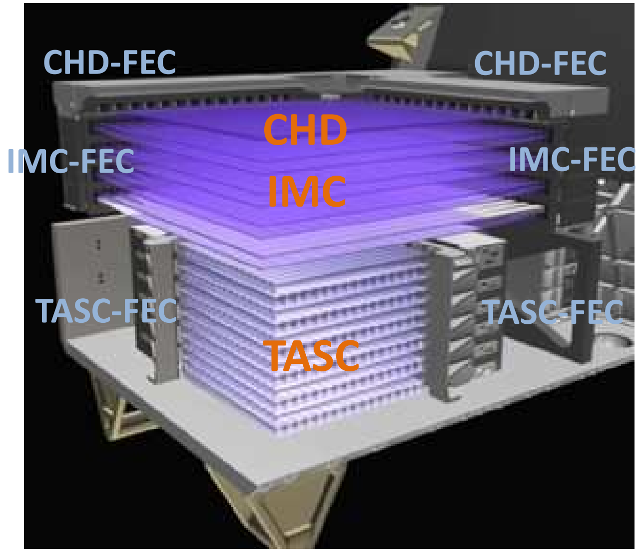
- **<u>検出器アセンブリ</u>**
  - ➢ CHD: プラスチックシンチレータ(EJ200)
    PMT(R7400-06相当品)
  - ➢ IMC:シンチレーティングファイバー(SCSF-78)
    64ch MaPMT(R7600相当品)
  - ➢ TASC: PWOシンチレータ(SICCAS製)
    PMT(R-7400-06相当品)
    PD/APD(S1227-33/S8664-10相当品)

- **<u>検出器構体</u>**
  - ➢ IMC/CHD構体:タングステン板、アルミハニカム
  - ➢ TASC構体:CFRPセル

- **<u>フロントエンド回路(FEC)</u>**
  - ➢ CHD-FEC: CHIC + 整形アンプ + ADC(16bit)
  - ➢ IMC-FEC: VA32-HDR14.3 + ADC(16bit)
  - ➢ TASC-FEC: CHIC + 整形アンプ(H/L)
    +ADC(16bit)

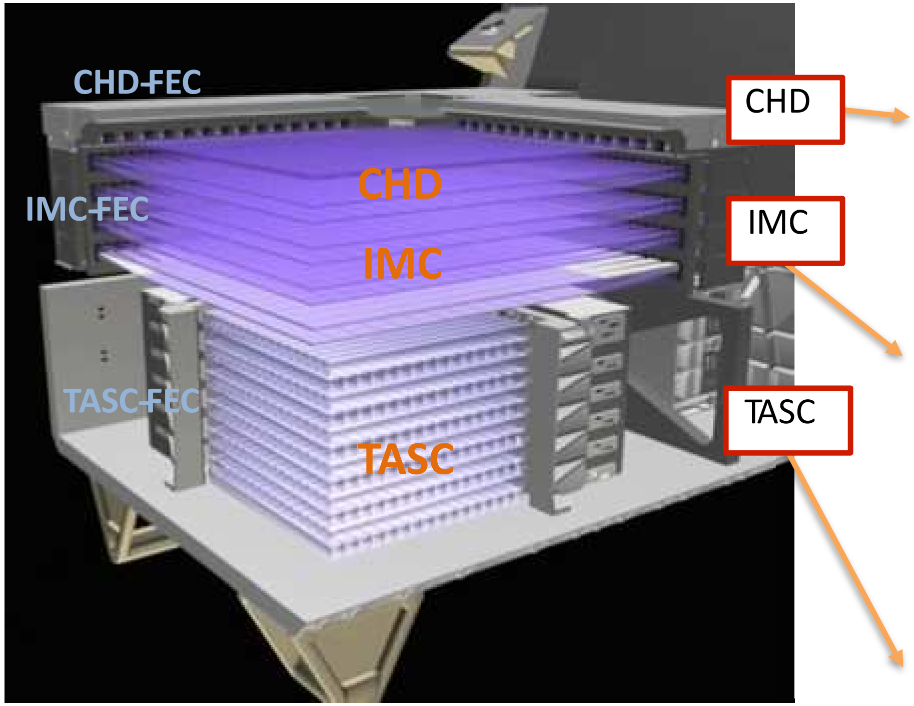
※CHIC(CALET Hybrid IC)

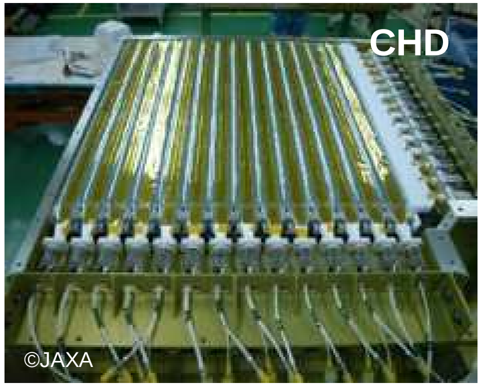


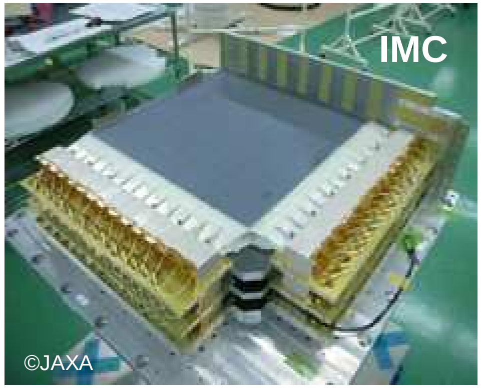


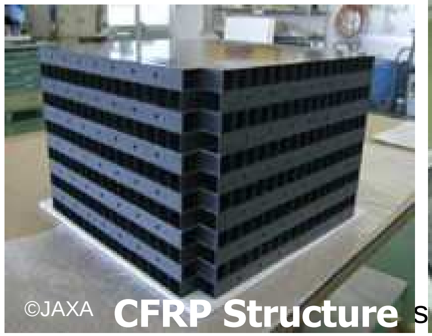
Calorimeter

CAL構成機器









16 x 6 layers (x,y)= 192
19mm x 20mm x 326mm

Ground Tests of Flight Model

IHIエアロスペース社

製造・システム組立

↓

初期機能試験

↓

筑波宇宙センター

環境試験
- 音響試験
- 熱真空試験
- EMC試験

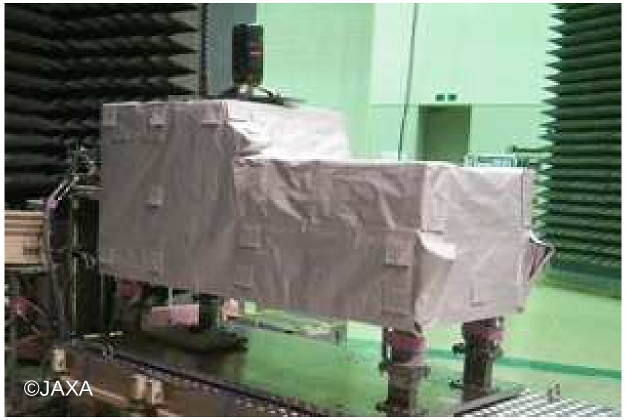
↓

end-to-end通信試験
最終機能試験
連続運転試験

↓

射場へ輸送

CALETフライトモデル(MLIなし)



CALETフライトモデル（MLI有り）

Ground Muon Tests

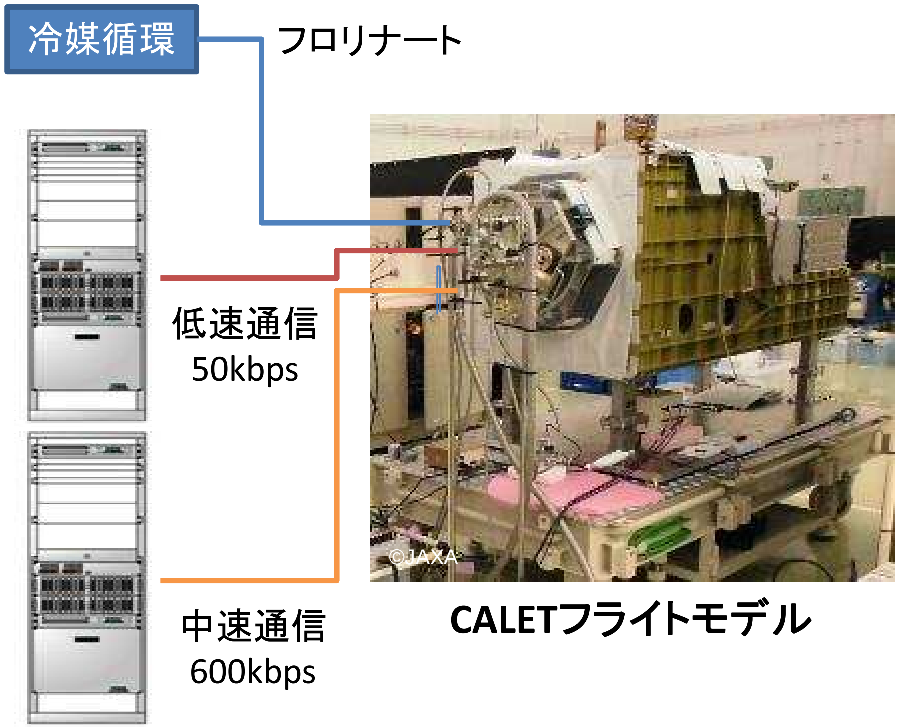
地上連続運転試験概要

- CALETの全ての検出器を動作させて測定を実施
- 軌道上観測時と同様の冷媒による温度制御、通信方式(600/50kbps)を使用
- コマンドを記述したスケジュールファイルを利用して測定を実施

日時:2015年3月20日 – 22日
取得時間:約40時間
取得イベント数:　約2 x 10^6
トリガー: 30分毎に以下を変更

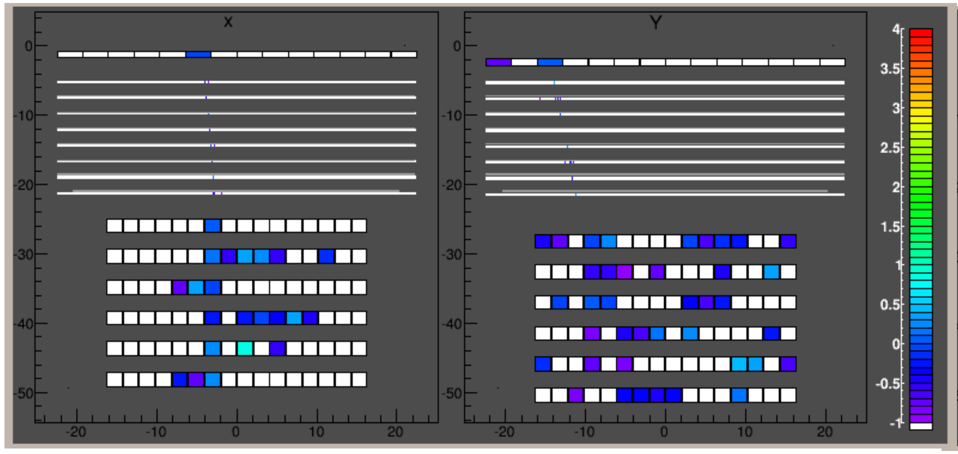
-(X1+2) & (Y3+4) & (X5+6) & (Y7+8)
-(Y1+2) & (X3+4) & (Y5+6) & (X7+8)

ペデスタルは30分毎に2秒間(50Hz)取得

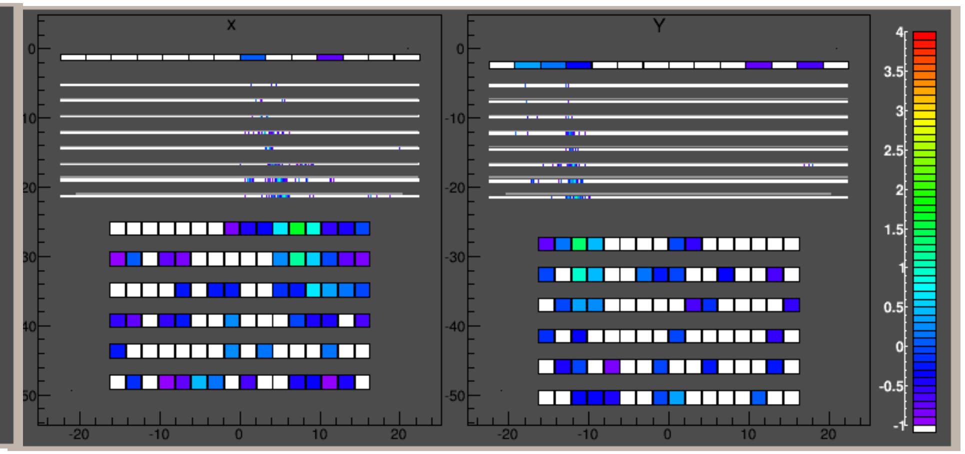


Events observed by ground muon tests

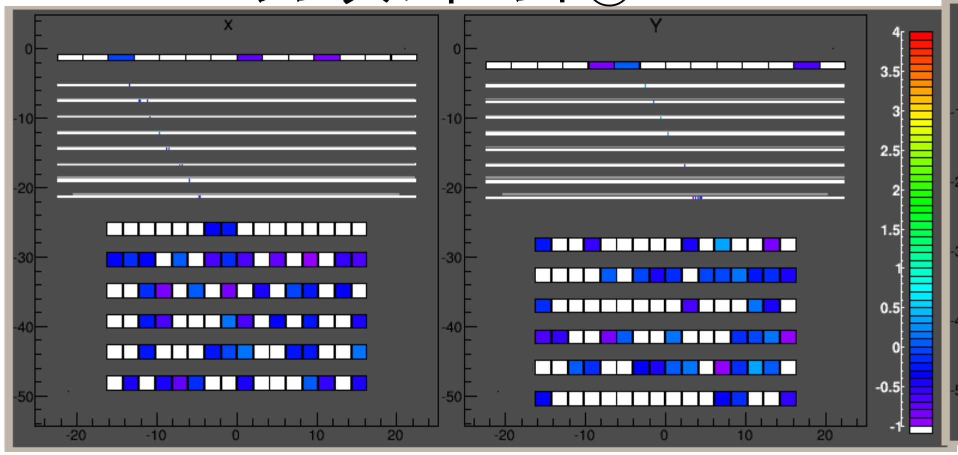
シングルイベント①



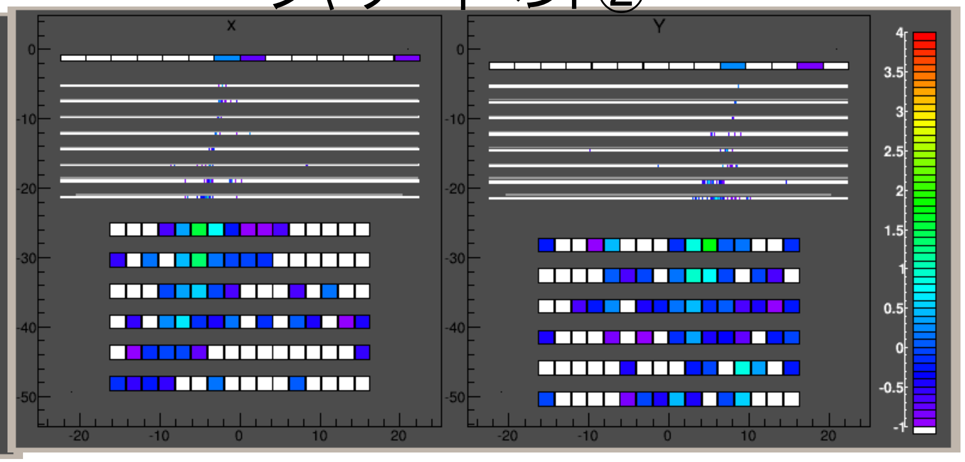
シャワーイベント①



シングルイベント②



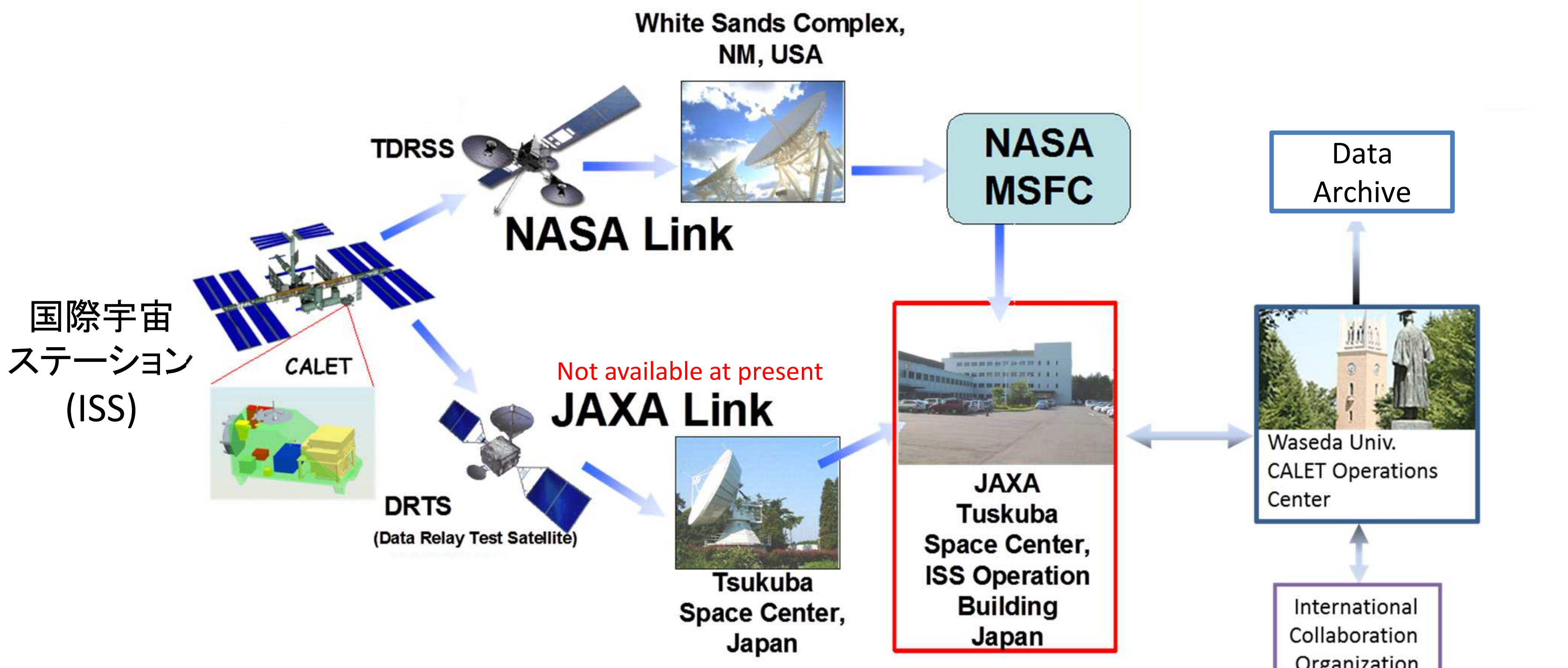
シャワーイベント②



CALET Flight Instruments at Tanegashima

種子島宇宙センターでHTV パレットに設置されたCALET

CALET dataflow from ISS to ground



WCOCでは2種類のデータを受信

<u>リアルタイムデータ</u>

- ISSから送出後数秒以内に受信

<u>解析用生データ（Level0データ）</u>

- 1時間に1回受信
- 時系列補正, 欠損補完済

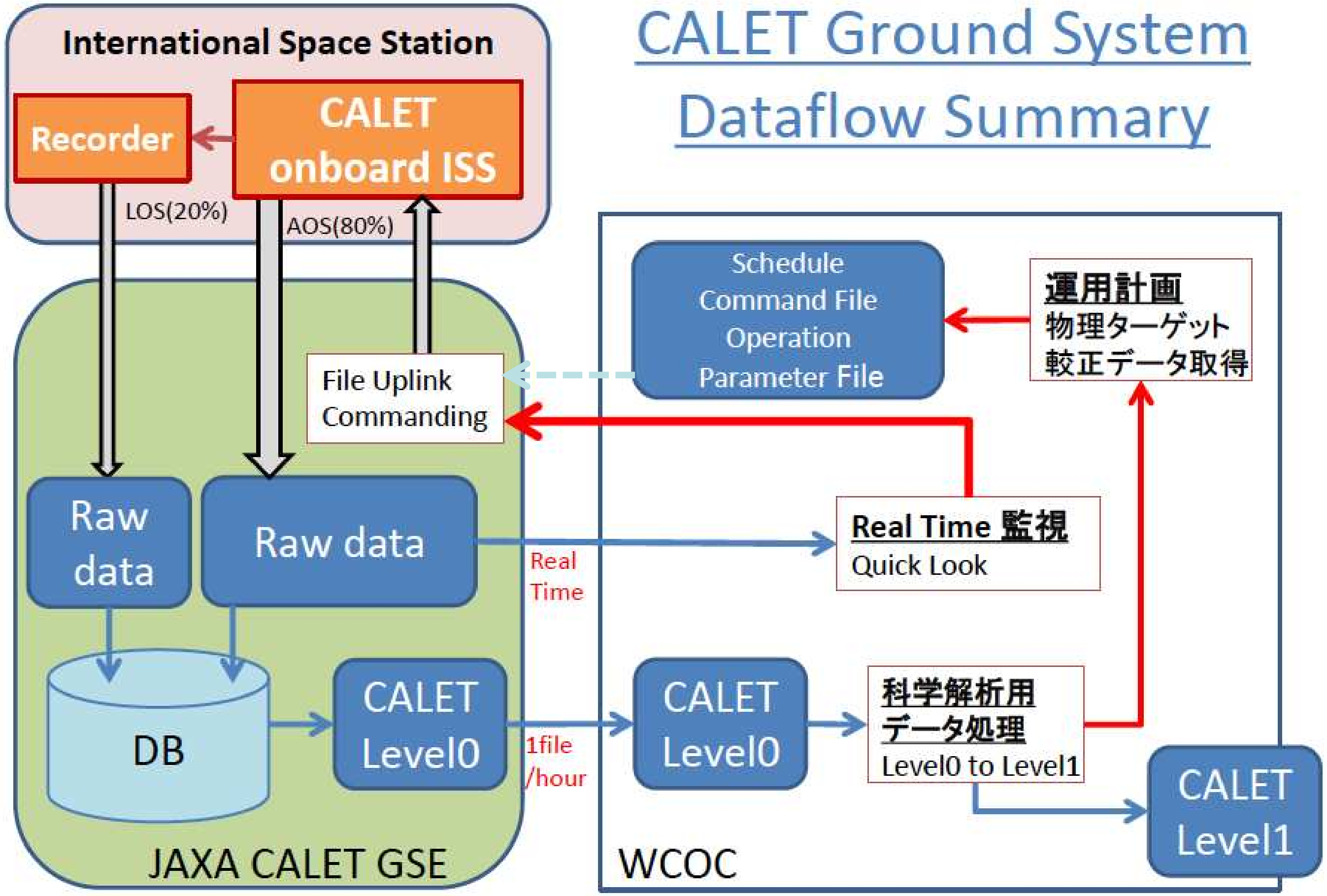
筑波宇宙センターにおいて
CALET地上運用設備を構築し、主に装置の安全性の監視を行う
軌道上CALETとの直接のインタフェースを有し、データ受信・コマンド送信を行う.

早稲田大学にWaseda CALET Operations Center (WCOC)を構築し
ミッション運用として科学観測状況の監視とオペレーションを行う

CALETの統一的運用を担っている

Dataflow and Operation System

- WCOCにおける24時間体制のリアルタイム監視を行い、つくば宇宙センターのオペレーションチームとの共同運用体制を構築した。
- 科学解析用データ処理、国内外研究機関へのL1データ配信、運用計画に基づくスジュールコマンドの作成による数日間の観測運用の自動化を実現した。



GSE: Ground Support Equipment（地上支援装置）

3

Trigger Mode

Trigger	Purpose
High Energy Shower Trigger (HE)	– High energy electrons (10GeV ~20TeV) – High energy gamma rays (10GeV ~10TeV) – Nuclei (a few10GeV~1000TeV)
Low Energy Shower Trigger (LE)	– Low energy electron at high latitude(1GeV ~10GeV) – GeV gamma-rays originated from GRB (1GeV ~) – GeV gamma-rays at low latitude (1GeV ~) – Ultra heavy nuclei (combined with heavy mode)
Single Trigger (Single)	– For detector calibration : penetrating particle (mainly protons and heliums)

(*) In addition to above 3 trigger modes, heavy modes are defined for each of the above trigger mode. They are omitted here for simple explanation.

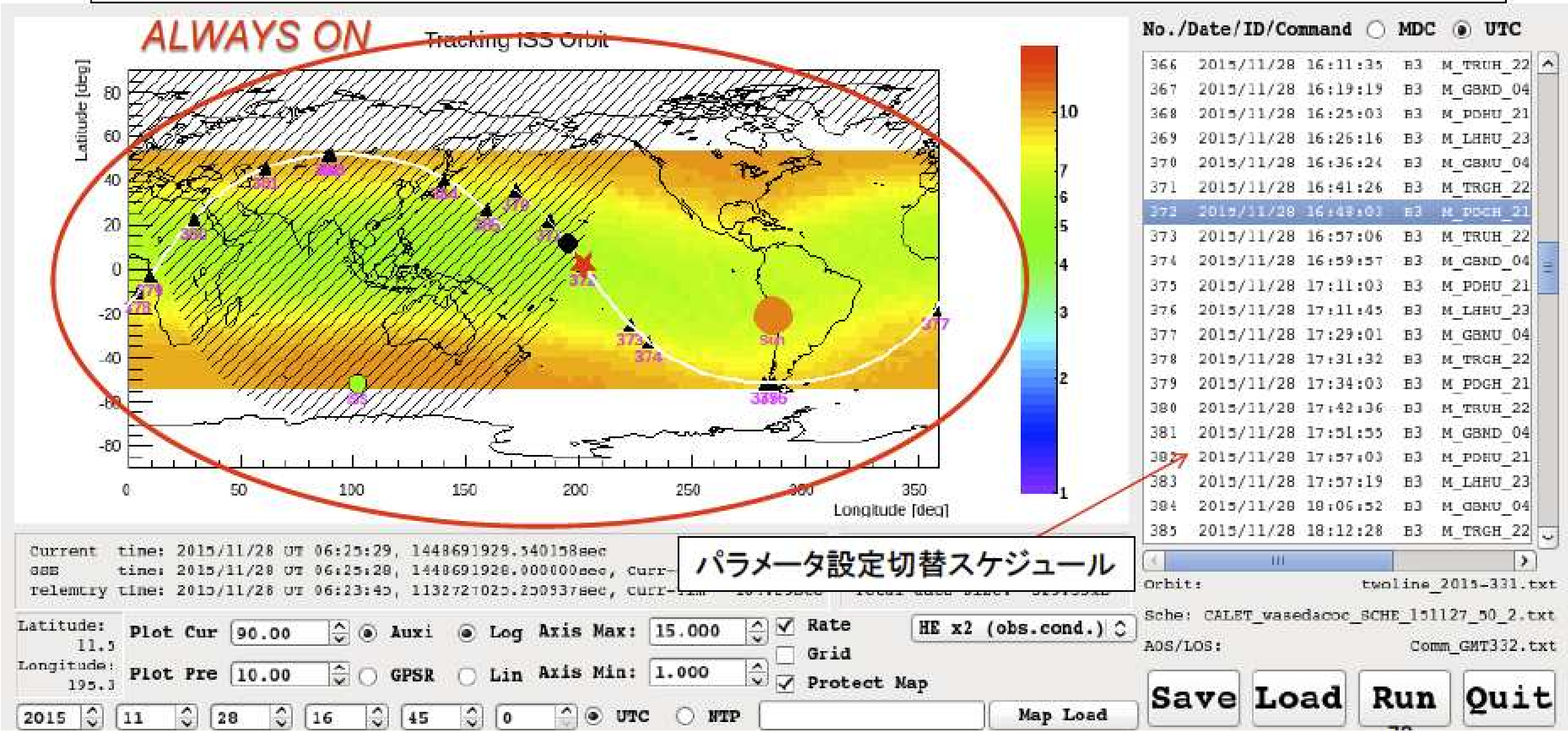
Trigger	Purpose
Auto Trigger (Pedestal/Test Pulse)	– For calibration: ADC offset measurement (Pedestal), FEC's response measurement (Test pulse)

On-orbit Operation

スケジュールコマンドを用いた軌道上運用を実施

高エネルギー電子観測(High Energy Electoron Observation)

高エネルギー領域の観測時間を最大限確保するため、常時実施している。
SAA, 高緯度地方にかかわらず、また、他のトリガーモードを併用している場合でも
HE Trigger は常時ONとなっている。Trigger Rate の低い Ultra Heavy Triggerも常時ON

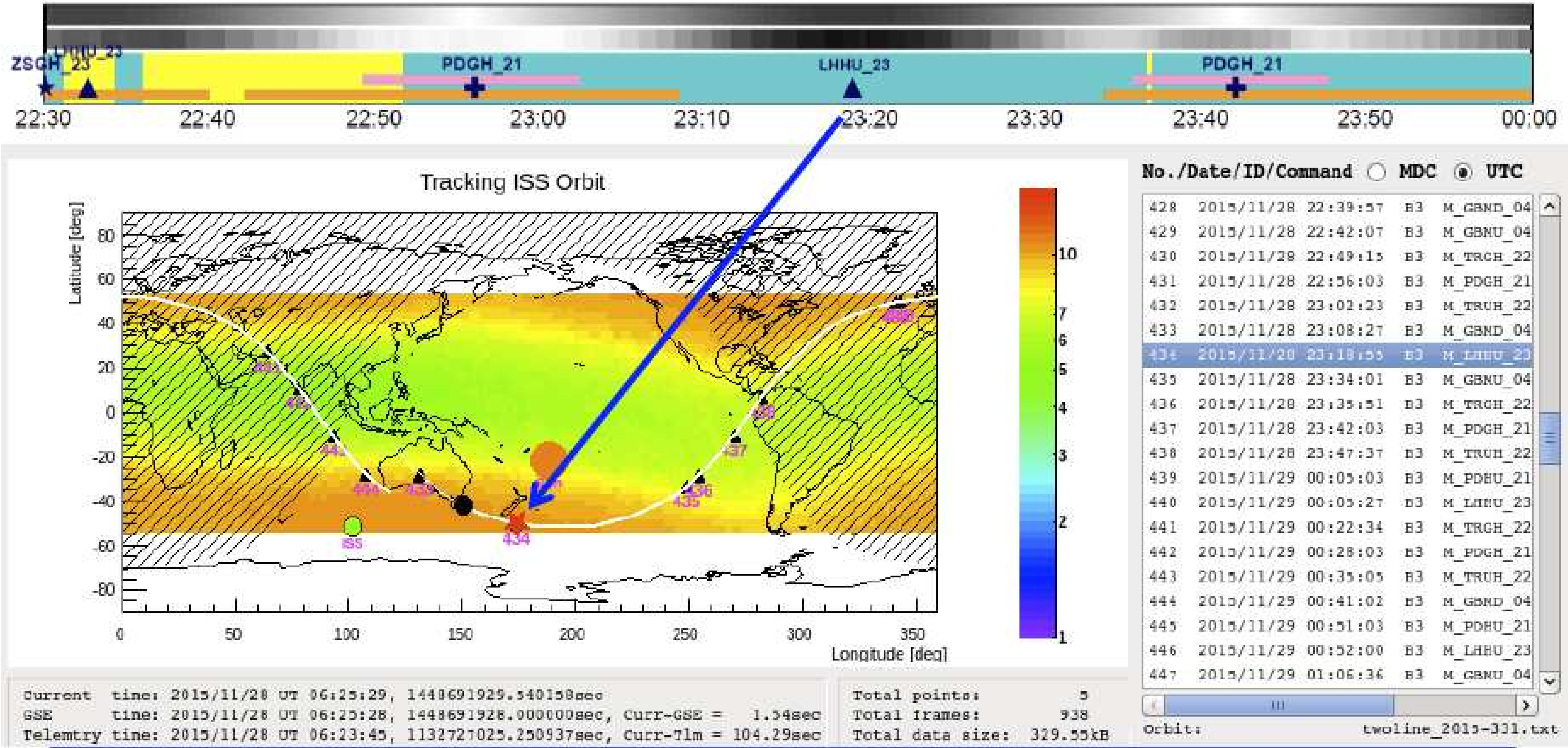


On-orbit Operation

スケジュールコマンドを用いた軌道上運用を実施

低エネルギー電子観測(Low Energy Electoron Run)

1軌道において、南北それぞれで最も地磁気緯度が高くなる時刻を中心に各30秒間実施

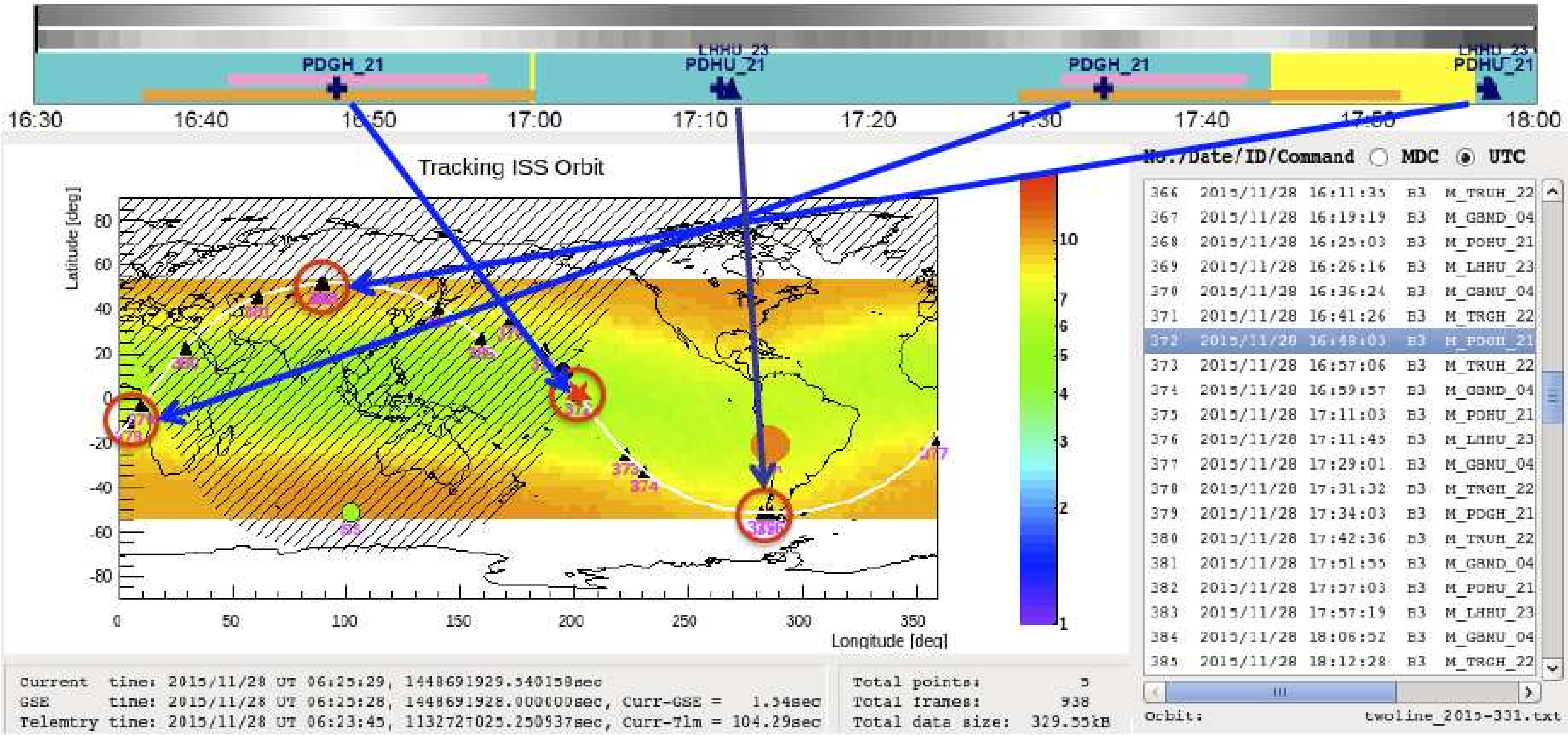


On-orbit Operation

スケジュールコマンドを用いた軌道上運用を実施

ペデスタル(ノイズオフセット)計測 (Pedestal Run)

23分毎にペデスタルマクロをセットし、2秒間(100Events)のペデスタルデータを取得

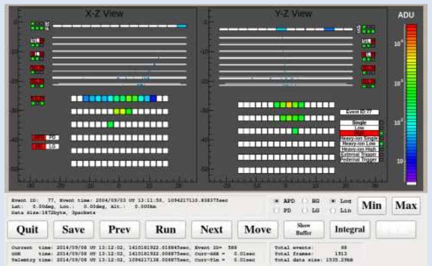


Real Time Monitoring

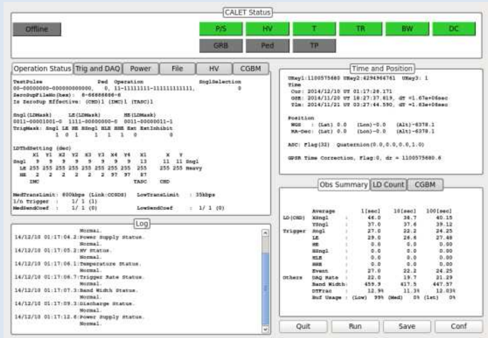
- JAXAからリアルタイムにRawデータを受信
- Quick Look(QL)を用いた24時間体制での監視

Concept of QL Monitoring System

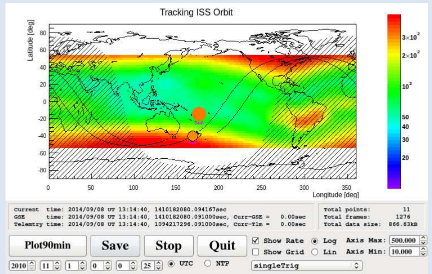
Event Display



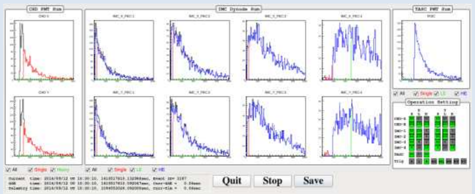
Summary Display



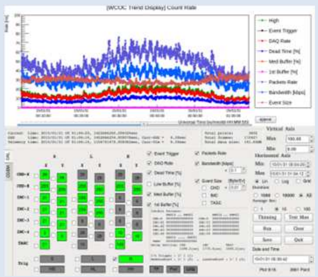
ISS Orbit Monitor



Histogram Monitor



Trend Monitor



Current Data Monitor

F

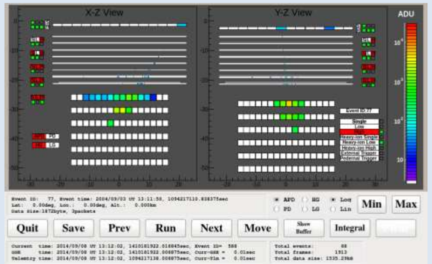
- 直感的な検出器の状態把握
- センサの健全性(生死/ノイズ)

- 運用に必要な情報を集約
- CALETの運用状況をQLプログラム自体が総合的に把握・判断し、色や音で警告

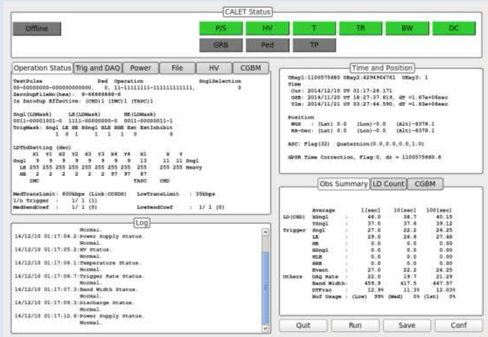
- ISS位置の確認
- 軌道予測に基づく運用計画の確認

Concept of QL Monitoring System

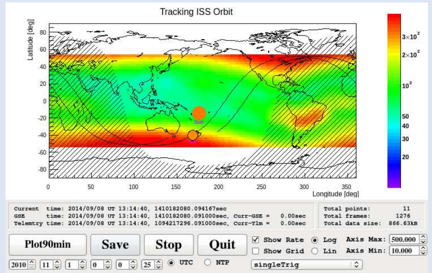
Event Display



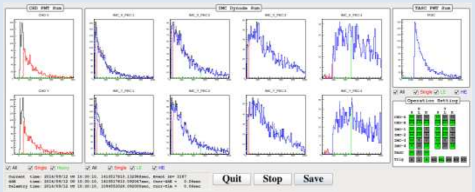
Summary Display



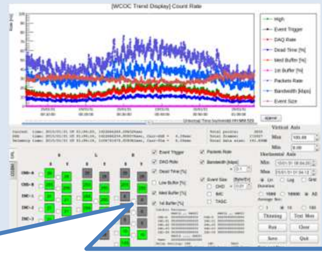
ISS Orbit Monitor



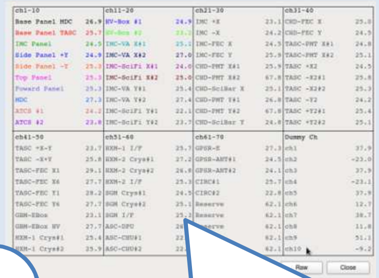
Histogram Monitor



Trend Monitor



Current Data Monitor



- データ分布の分析

- 観測データの時間変化を監視
- 異常の予測と原因の推定可能

- ある時間のデータを網羅的に表示

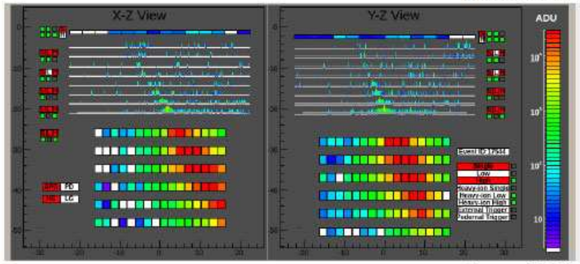
45

QL Event Viewer

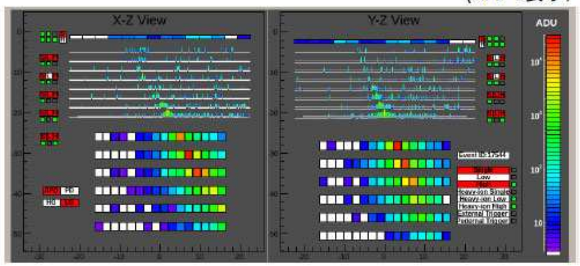
TeV電子の検出！

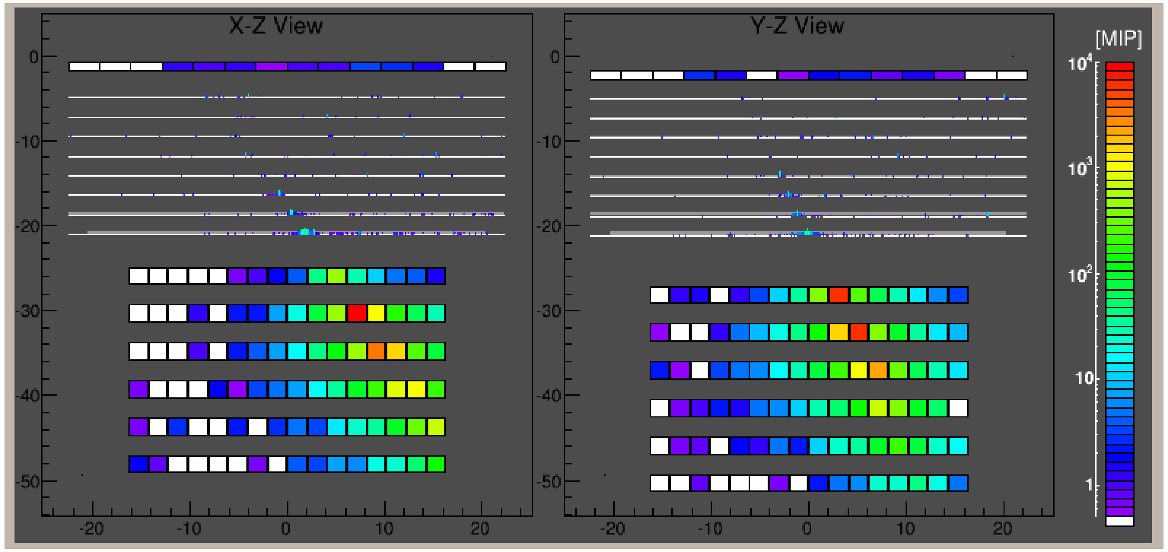
機上で検出した電子候補　約1.03TeV

(APD-H表示)

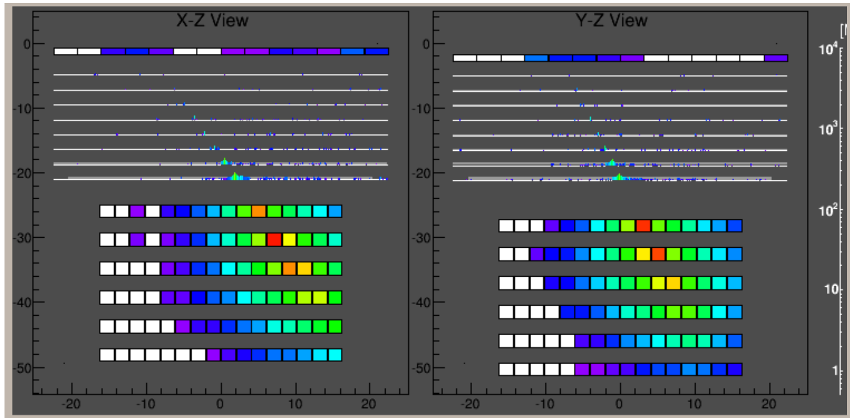


(APD-L表示)

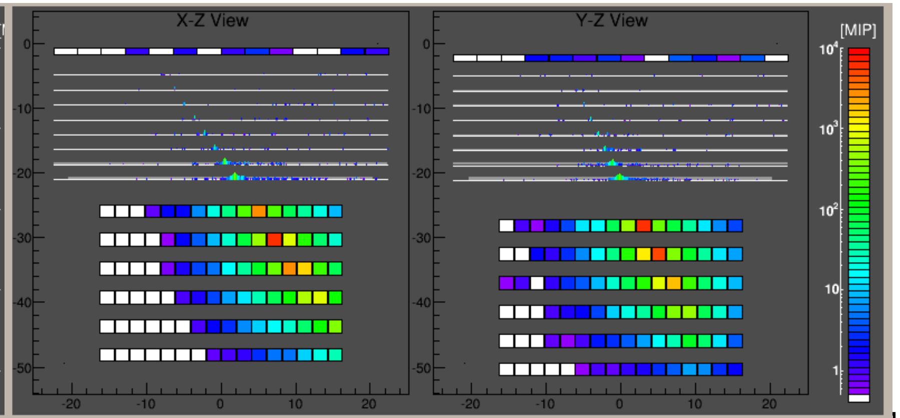




シミュレーション例1



シミュレーション例2



General Alerts of Transients by CGBM

TDRSS

DRTS

MSFC/NASA

CGBM data
- TH: Timing Histogram
- PH: Pulse height Histogram
- GRB triggered data

JAXA
Tsukuba SC

CALET Grond Sys.
in UOA

CGBM Data Processing
in
Waseda CALET
Operations Center
(WCOC)

Alerts

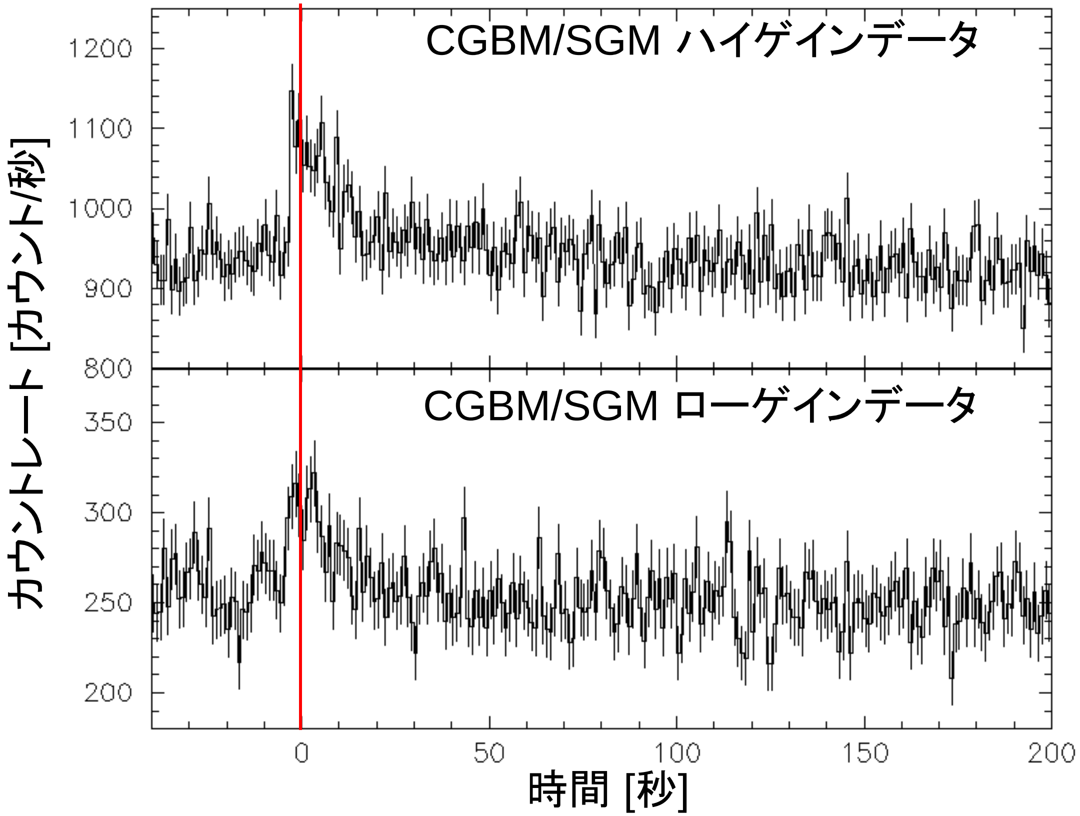
GCN, ATel,
Web

LIGO-Virgo MOU

Counterpart search
Further follow up observations in longer EM wavebands

- GCN:
  Gamma-ray Coordinates Network
- ATel:
  Astronomer's Telegram

GRB Detection!!



- 検出時刻:
  2015年10月6日 9:54:59 (世界時)
- CALET ガンマ線バーストモニター (CGBM) の 機上トリガーシステムにより、自動検出.
- CGBM の SGM 検出器で検出.
- フェルミ衛星、そしてスウィフト衛星でも同時に検出.
- 瞬間的な明るさは、かに星雲の約10倍.
- CGBM で観測されたバーストの継続時間は約20秒.

今後も1月に2-3個程度のガンマ線バーストの検出が予想され、
CALET/CAL や同じプラットフォーム上のMAXIとの連携観測が期待できる.

まとめと予定

- CALETはTeV領域に及ぶ電子・ガンマ線観測により近傍加速源と暗黒物質の探索を行うほか、陽子・原子核の観測を1000TeV領域まで実施して宇宙線の加速・伝播機構の 包括的な解明を行う。さらに、太陽変動やガンマ線バーストのモニター観測を実施する。

- CALET は、JAXAと早稲田大学の共同研究によるプロジェクトである。国際共同ミッションとして、JAXAが米国NASA,イタリアASIと協定を結んで実施している。

- CALETは、2015年8月19日に種子島宇宙センターからHTV5号機に搭載しH-IIBロケットで打ち上げられ、船外実験プラットフォーム＃9ポートに設置された。

- つくば宇宙センターユーザ運用エリア（UOA)と早稲田大学CAET Operations Center (WCOC)における90日間の初期運用（チェックアウトフェーズ）を完了し、定常運用を開始した。現在収集データの詳細な解析を進めており、今後2年間で高統計データを収集し、その成果を基に5年間の観測を実現する予定である。