Preliminary results from gamma-ray observations with the CALorimeteric Electron Telescope (CALET)

Y.Asaoka for the CALET Collaboration

RISE, Waseda University

2016/12/15 CTA-Japan Workshop

“The extreme Universe viewed in very-high-energy gamma rays 2016”

CALET Collaboration

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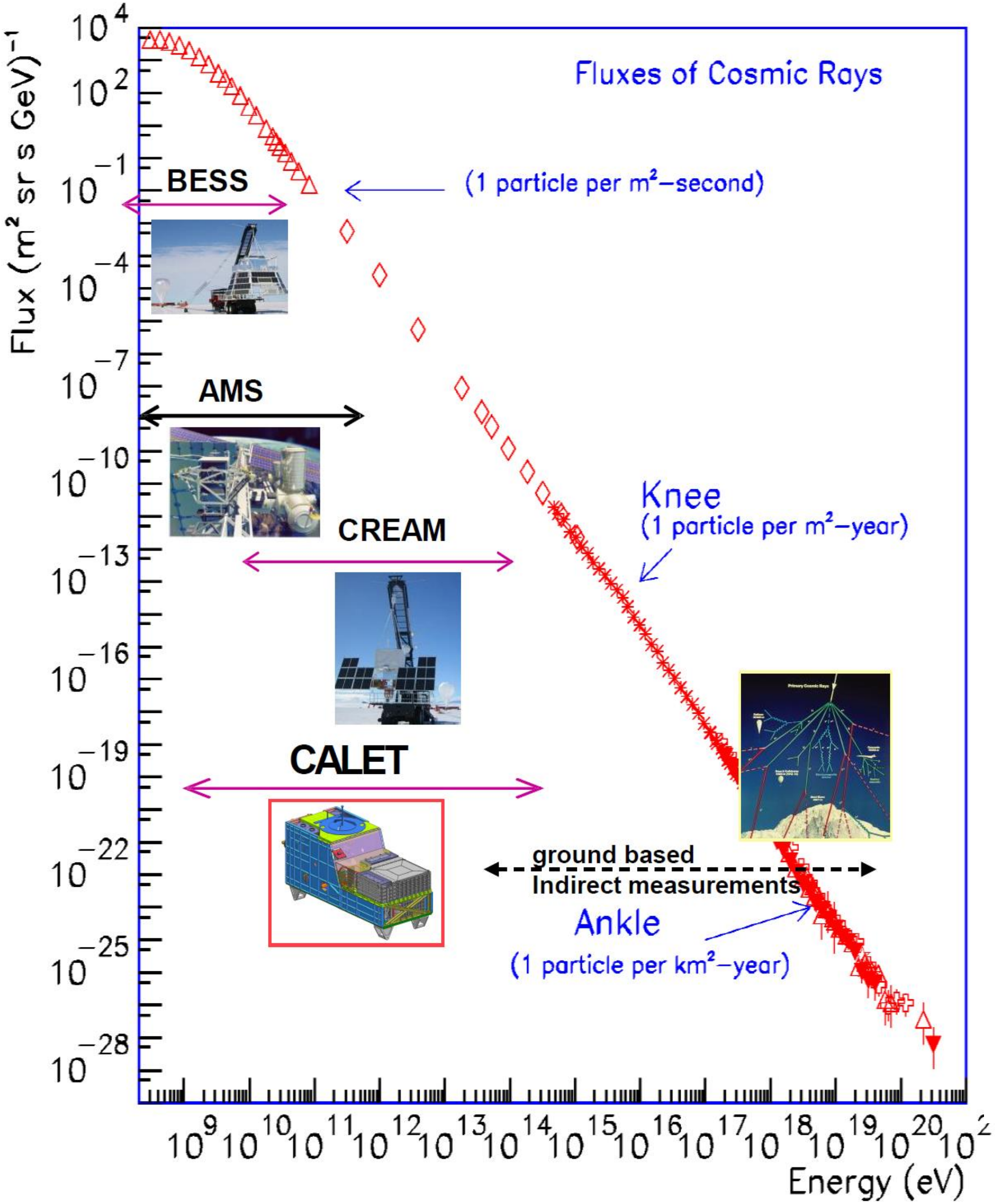
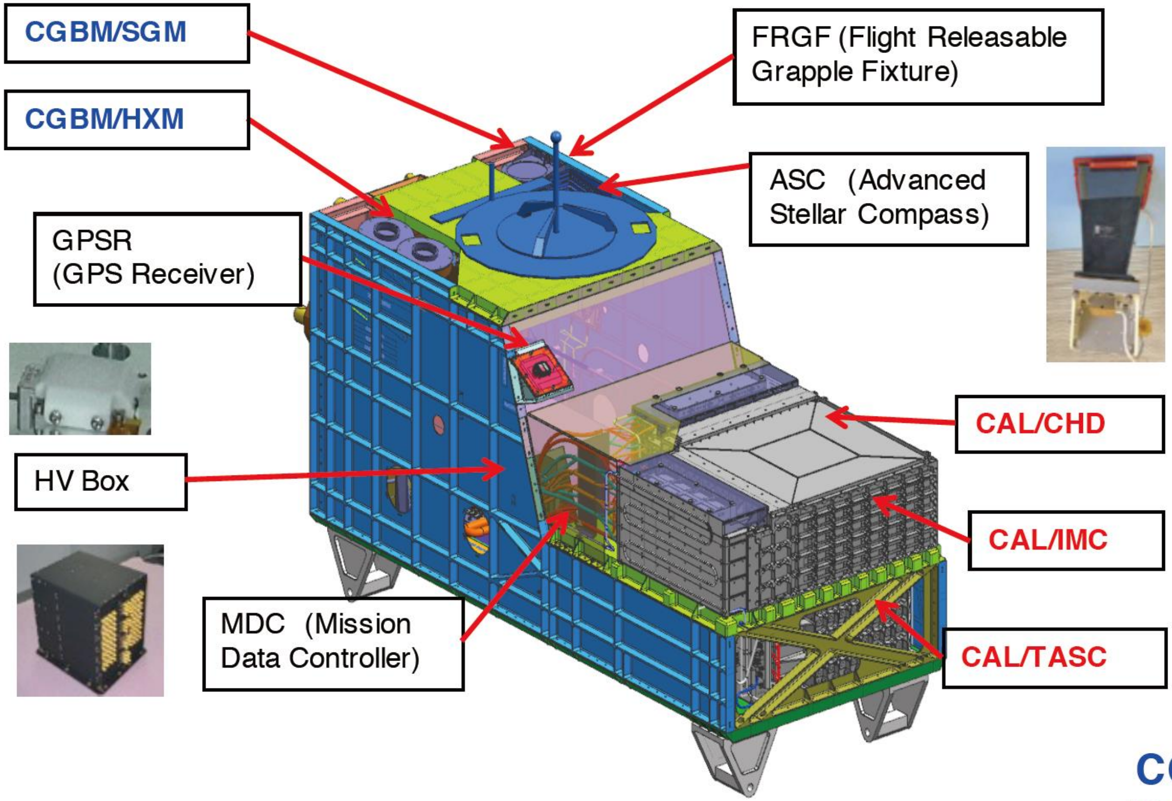
What's CALET

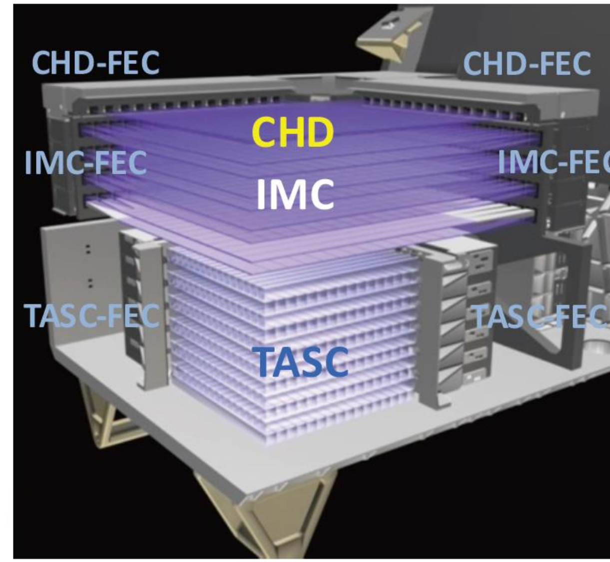


- highest energy region accessible from space
  - long duration observation onboard the international space station (ISS)
  - instrument featuring the thick calorimeter of 30 radiation length
  - specialized to electron measurements
  - continuous observation since October 2015
- Direct and indirect measurements of cosmic rays are complementary to each other.

CALET System Overview



CALORIMETER (CAL)



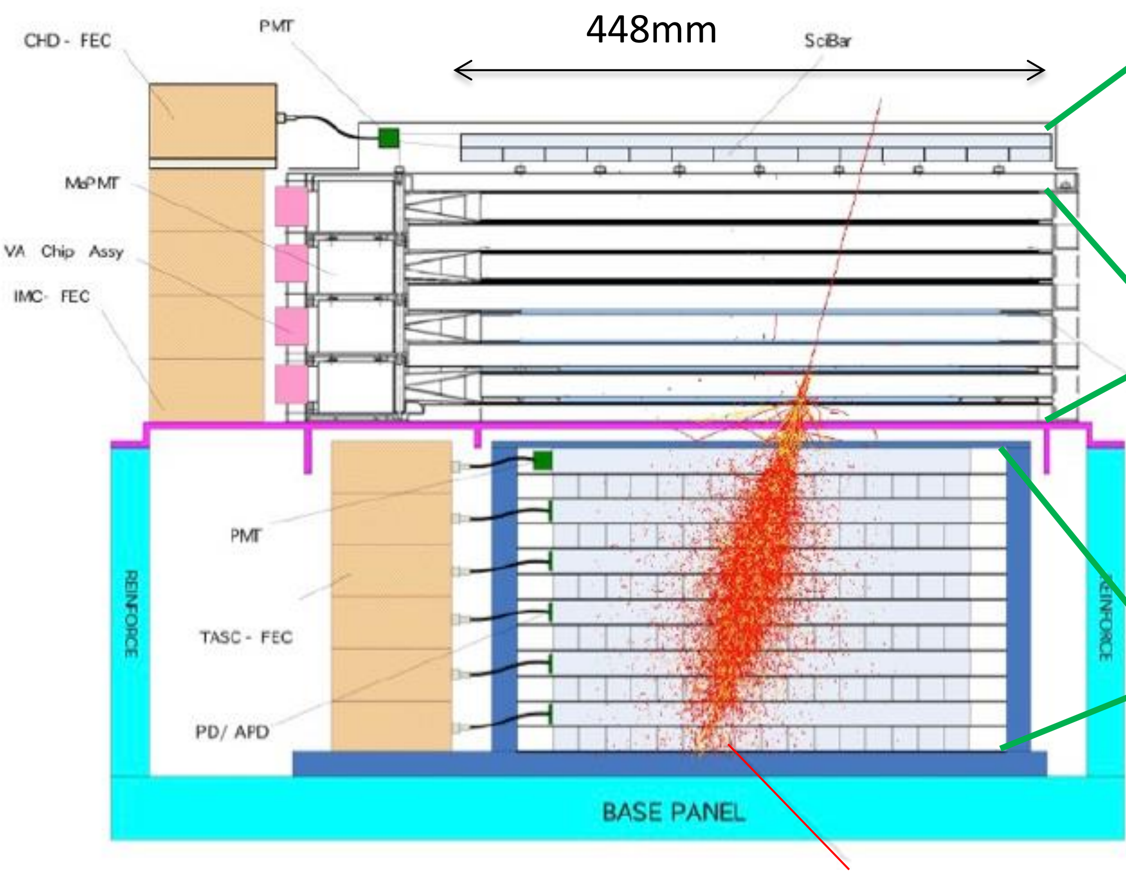
- **Mass:** 612.8 kg
- JEM Standard Payload Size
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption:** 507 W (max)
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CGBM (CALET Gamma-ray Burst Monitor)

(*) JEM stands for Japan Experiment Module

CALET-CAL Detector

Fully active thick calorimeter ($30X_0$) optimized for electron spectrum measurements well into TeV region



1TeV electron shower is fully contained in TASC

Charge Detector CHD

plastic scintillator hodoscope, absolute charge measurement (including charge zero)

Imaging Calorimeter IMC

SciFi + tungsten plate (3X0), reconstruction of arrival direction and initial shower development

Total Absorption Calorimeter TASC

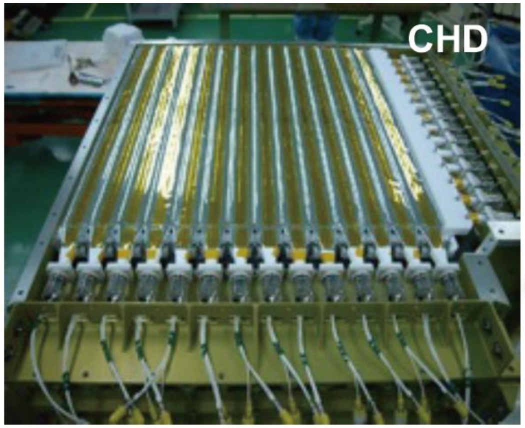
PWO hodoscope (27X0), energy measurements and particle identification

CALET-CAL Flight Model

CHD

14 × 1 layer (x,y) = 28

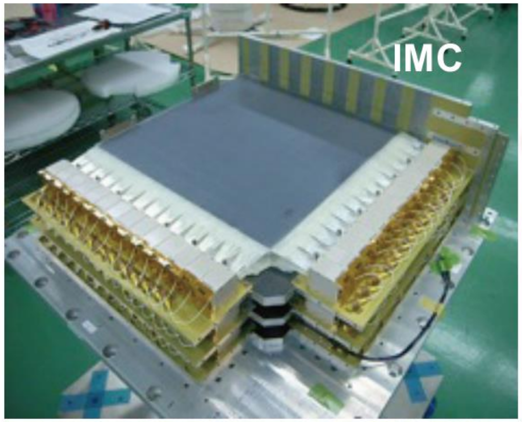
32mm x 10mm x 450mm



IMC

448 x 8 layers (x,y) = 7168

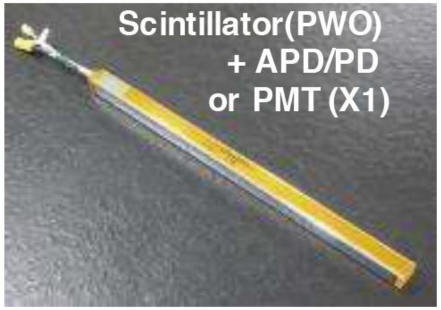
1mm^2 x 448 mm

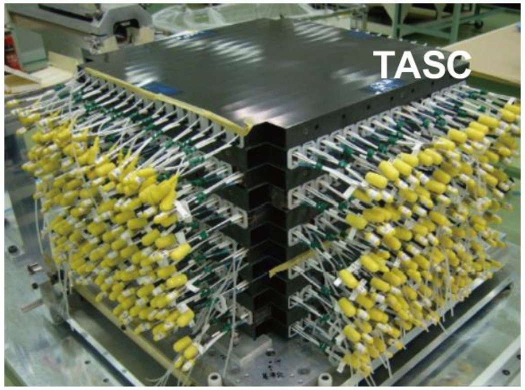


TASC

16 x 6 layers (x,y)= 192

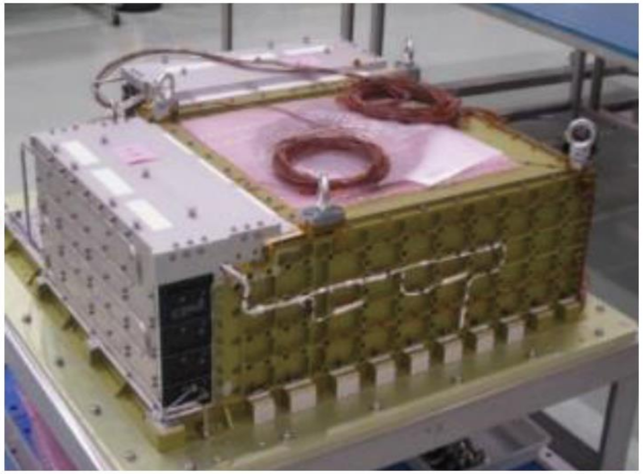
19mm x 20mm x 326mm



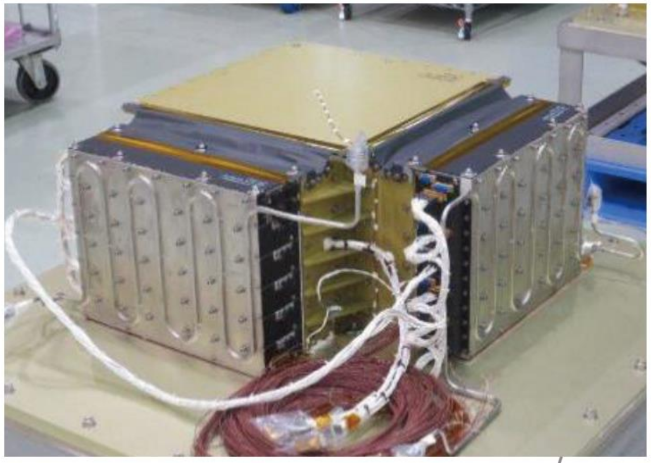


Completed Component with Front End Circuit

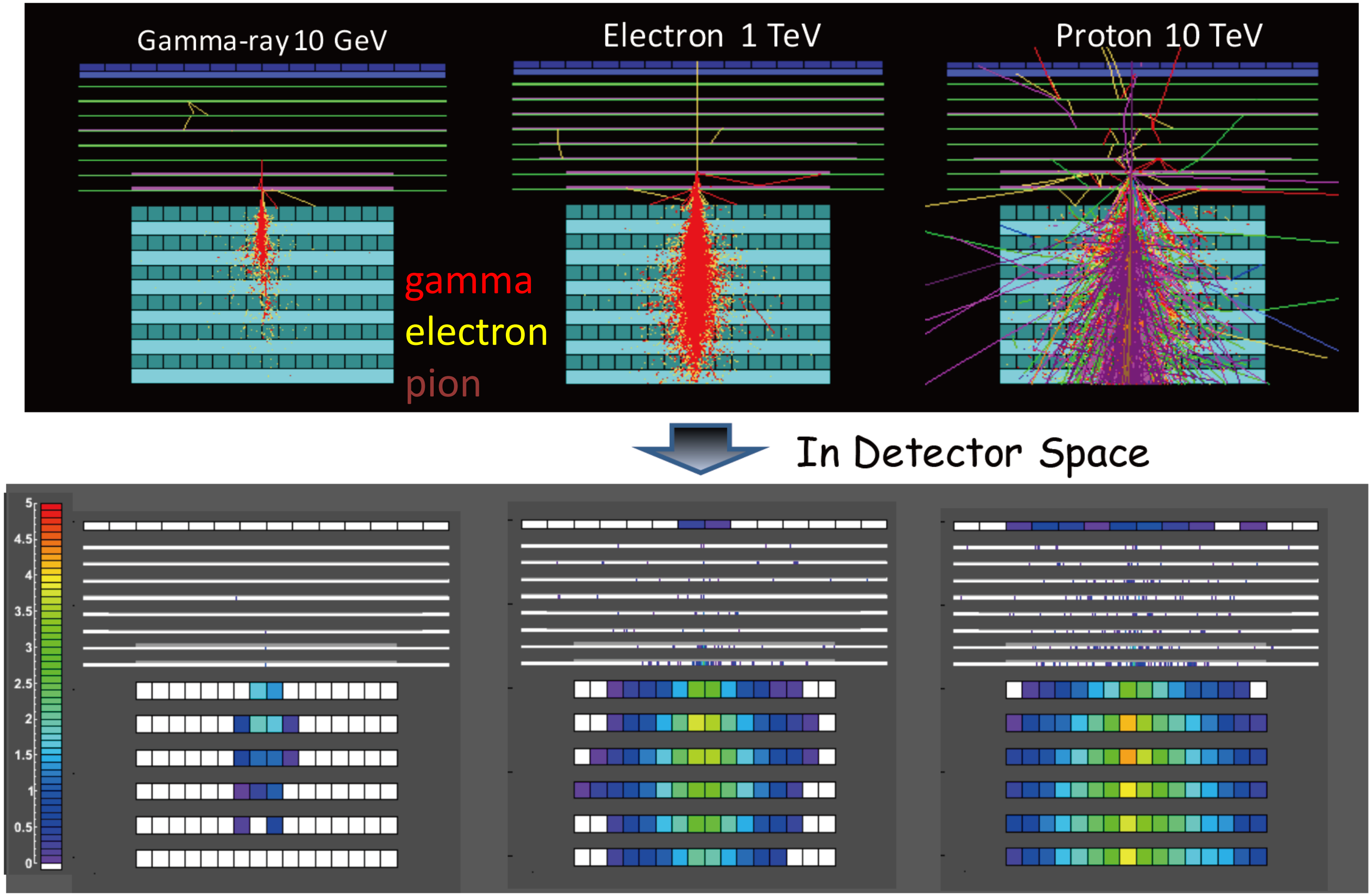
CHD/IMC



TASC



CALET-CAL Shower Imaging Capability (MC)

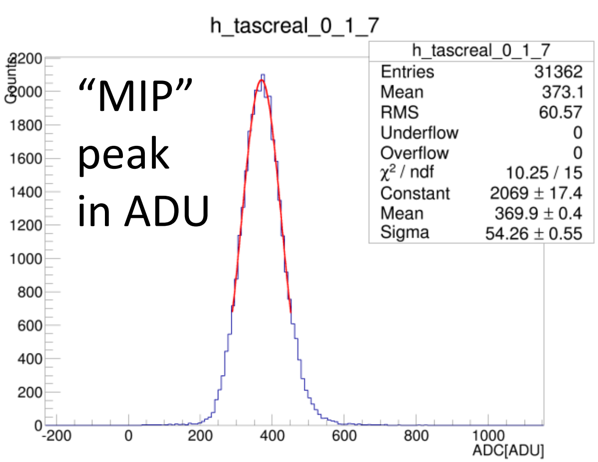


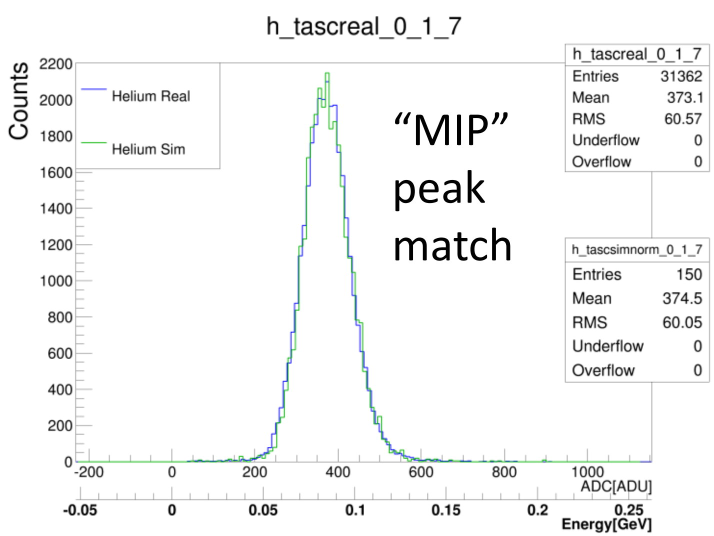
- Proton rejection power of 10^5 can be achieved by taking advantage of shower imaging capability of IMC and TASC
- Angular resolution of ~0.2^o for 10GeV gamma rays

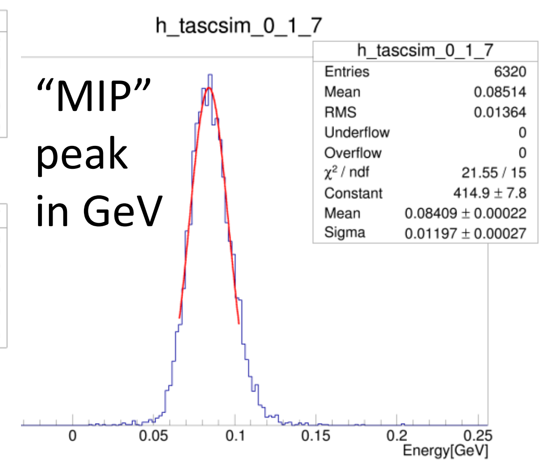
Intrinsic Advantage of CALET Instrument

EM Shower Energy Measurement =
TASC Energy Sum × "small" Correction

- Active and thick calorimeter absorbs most of the electromagnetic energy (~95%) up to the TeV region
- In principle, energy measurement with very small systematic error is possible.
- We can use penetrating particles to do absolute calibration of the instrument (so called "MIP" calibration).
  - NO worries about quantum efficiency or collection efficiency







Flight Data

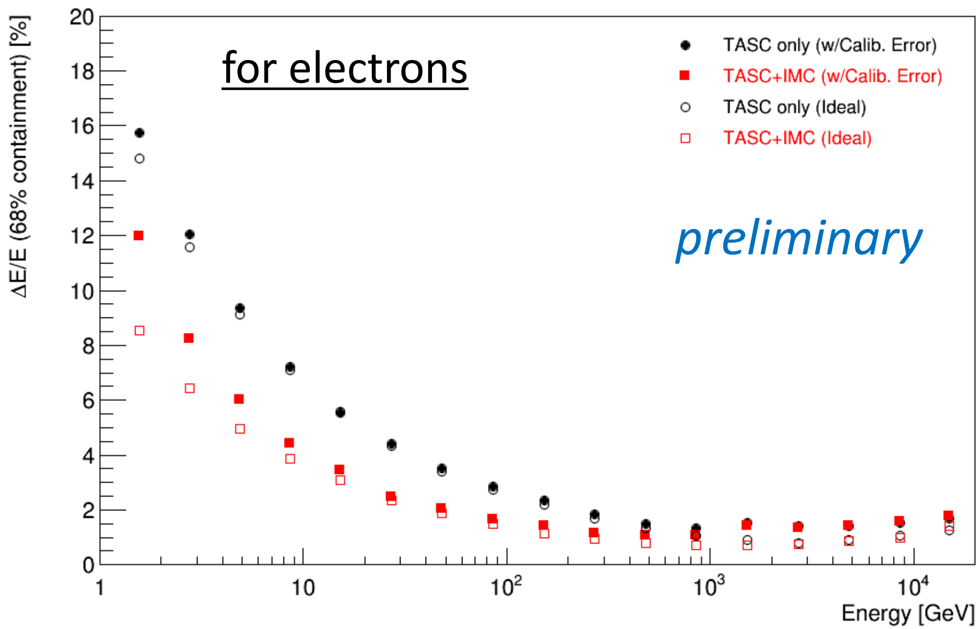
Penetrating helium

Equivalent histograms in ADC unit and in Energy

MC Data

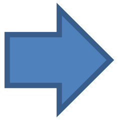
Penetrating helium

Resultant Energy Resolution



- All the calibration including position/temperature dependence, dynamic range calibration are applied and accuracy of each calibration is estimated.
- Considering the calibration errors and instrument noise, energy resolution is estimated as a function of energy

- Space based direct detection with CALET
  - event-by-event particle identification
  - excellent energy resolution
  - limited effective area
- Ground based indirect detection method
  - very large effective area
  - decent energy resolution



Complementary to each other

CALET Scientific Objectives

While CALET is optimized for observation of TeV electrons, the instrument is sensitive to gamma-rays, protons and nuclei.

Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	**Electron spectrum in trans-TeV region**
Dark Matter	**Signatures in electron/gamma energy spectra**
Origin and Acceleration of Cosmic Rays	**p-Fe over several tens of GeV, Ultra-heavy ions**
Cosmic-ray Propagation in the Galaxy	**B/C ratio up to several TeV/nucleon, Diffuse gamma-ray observation up to TeV**
Solar Physics	**Electron flux below 10 GeV**
Gamma-ray Transients	**X-rays/Gamma-rays in 7 keV－20MeV in CGBM and GeV gamma-rays in CAL**

Objectives of CALET Gamma-Ray Observation

- Diffuse Component => High energy region
  - Galactic
  - Extragalactic
- Point Source
  - Calibration of pointing accuracy
  - Confirmation of angular resolution
  - Cross check of energy measurements/efficiency
- Transient Object
  - GRB
  - Gravitational wave
  - Other transients

Objectives of CALET Gamma-Ray Observation

- Diffuse Component => High energy region
  - Galactic
  - Extragalactic

Statistics is the KEY

- Point Source
  - Calibration of pointing accuracy
  - Confirmation of angular resolution
  - Cross check of energy measurements/efficiency
- Transient Object
  - GRB
  - Gravitational wave
  - Other transients

GW Counterpart Search with CALET

THE ASTROPHYSICAL JOURNAL LETTERS, 829:L20 (5pp), 2016 September 20 doi:10.3847/2041-8205/829/1/L20

CALET UPPER LIMITS ON X-RAY AND GAMMA-RAY COUNTERPARTS OF GW151226

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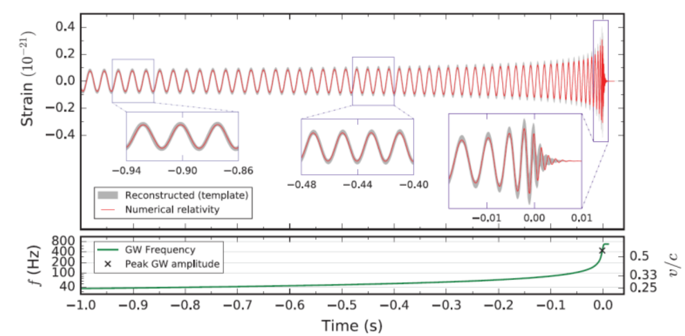
Published in ApJ Letters

GW 151226 [B. P. Abbott *et al.*, PRL 116 (2016) 241103]

- GW trigger Time: 2015/12/26 3:38:53.647 UT
  - **gravitational-wave signal** produced by the coalescence of two stellar-mass black holes at a luminosity distance of ~440Mpc.



CALET Observation

- CGBM HV-on (3:20 – 3:40 UT)
  - No on-board trigger
- CAL: low-energy gamma-ray mode (> 1GeV) 3:30-3:43UT

Overview of CALET Trigger System

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 ～)
- Ultra heavy nuclei (combined with heavy mode)

Single Trigger (Single)

- For detector calibration : penetrating particles (mainly non-interacting 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.

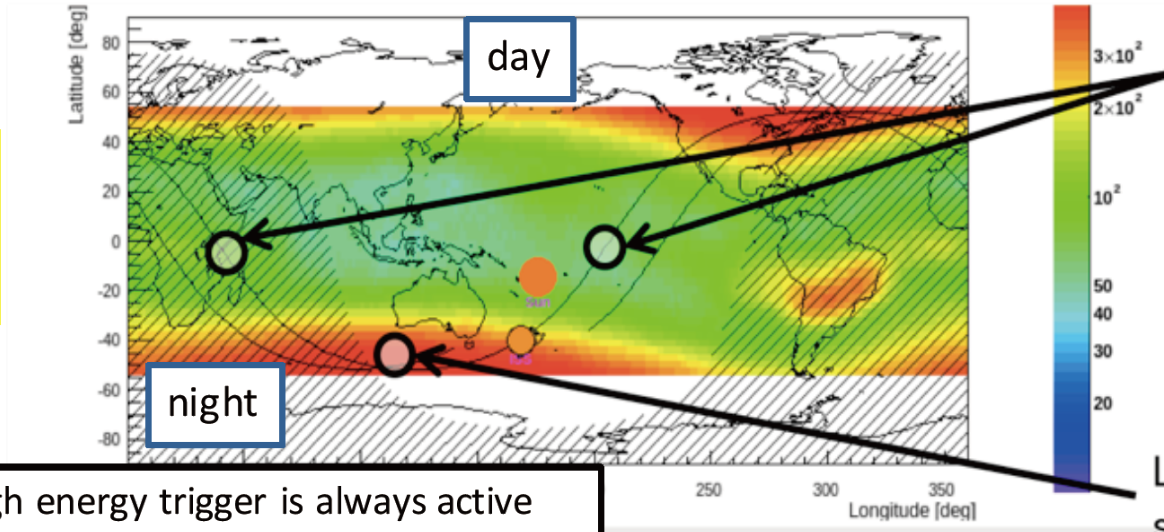
Auto Trigger (Pedestal/Test Pulse)

- For calibration:
  - ADC offset measurement (Pedestal)
  - FEC's response measurement (Test pulse)

ISS Orbit and CALET Operations

ISS orbit: inclination 51.6 degree, ~400 km

Concept of on-orbit operations



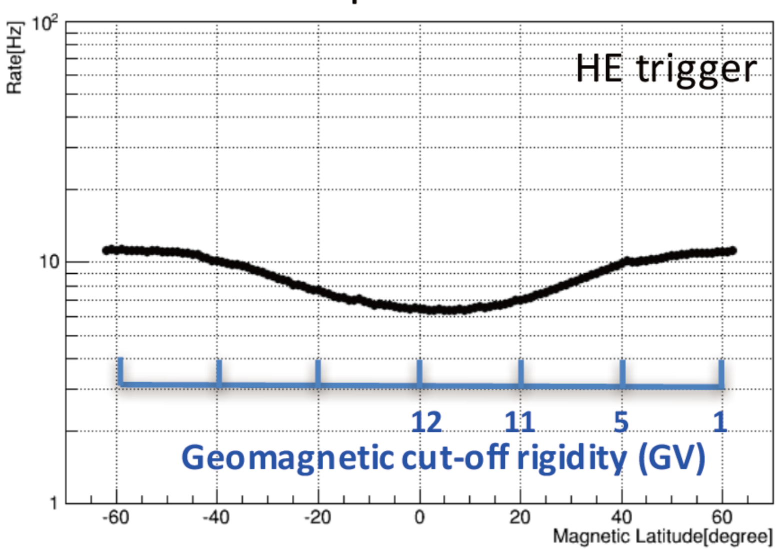
Pedestal data acquisition

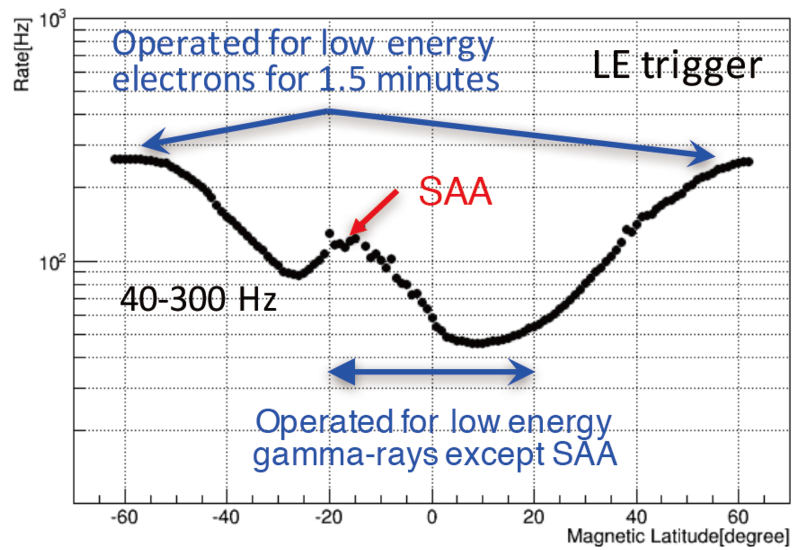
Schedule file: sequence of time and command

Low energy electron shower data acquisition

High energy trigger is always active

Dependence of the count rate on geomagnetic latitude





CAL Limit Calculation Procedure

Gamma-ray Event Selection

Lower energy is important

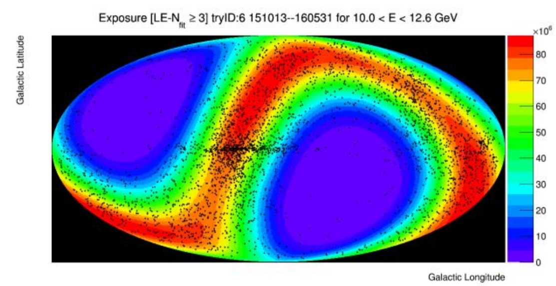
Effective Area and Sensitivity Calculation

S_{eff} as a function of zenith and azimuth

Validation of Sensitivity with Observation of Diffuse Component

Exposure Calculation

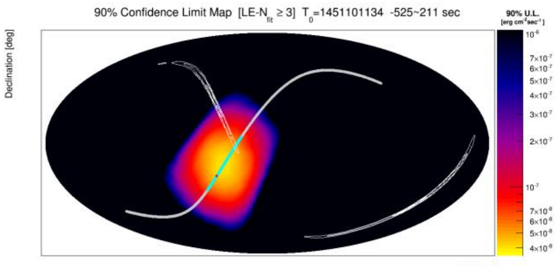
$S_{eff}(zen,azi)\ T_{live}$ projected to sky event by event along CALET trajectory



Upper Limit Calculation

If no gamma-rays are observed

Check Overlap with LIGO Localization Map

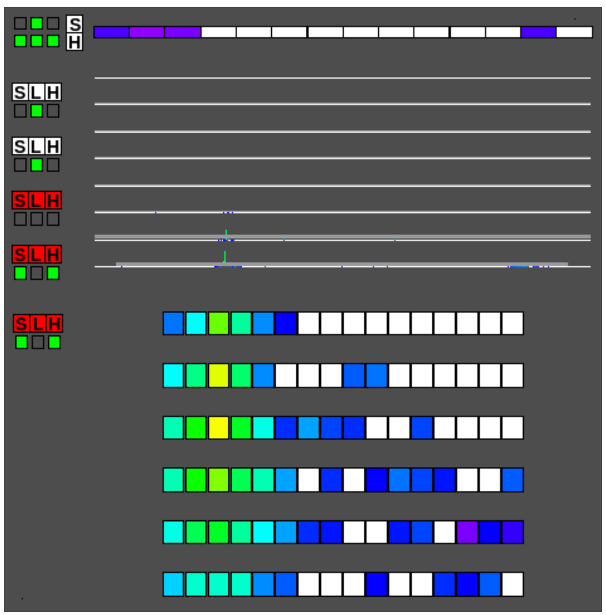


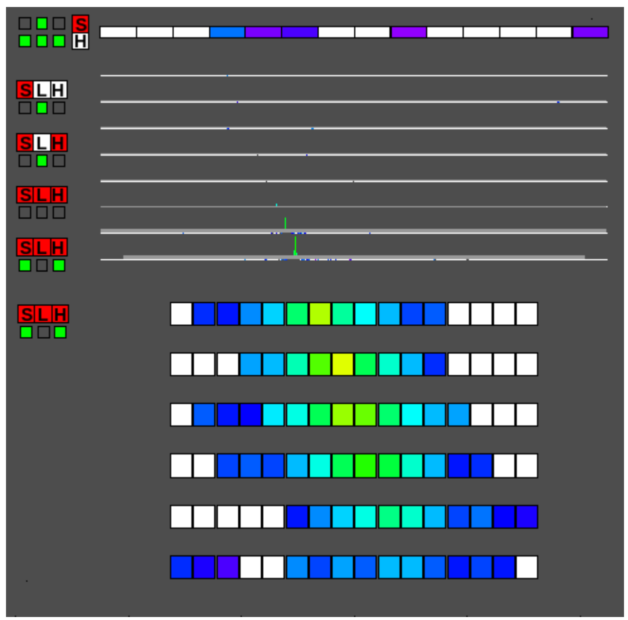
Gamma Ray Event Selection

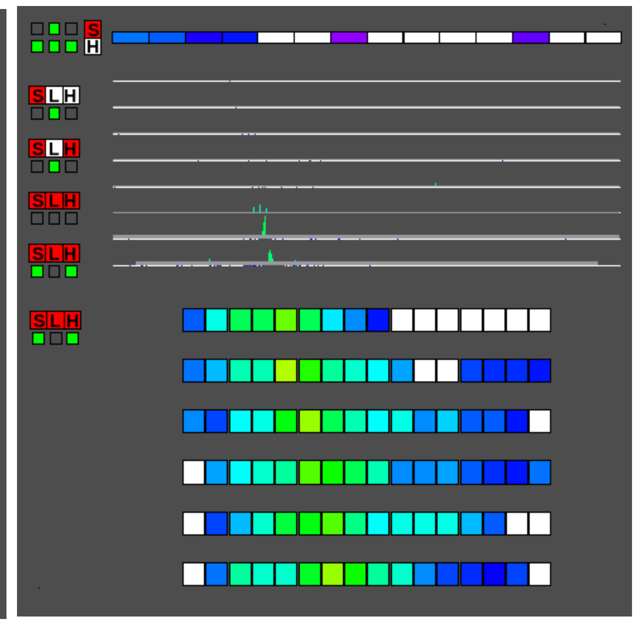
= Electron Selection Cut + Gamma-ray ID Cut w/ Lower Energy Extension

100 GeV Event Examples

gamma-ray	electron	proton
Charge Z=0	Charge Z=1	



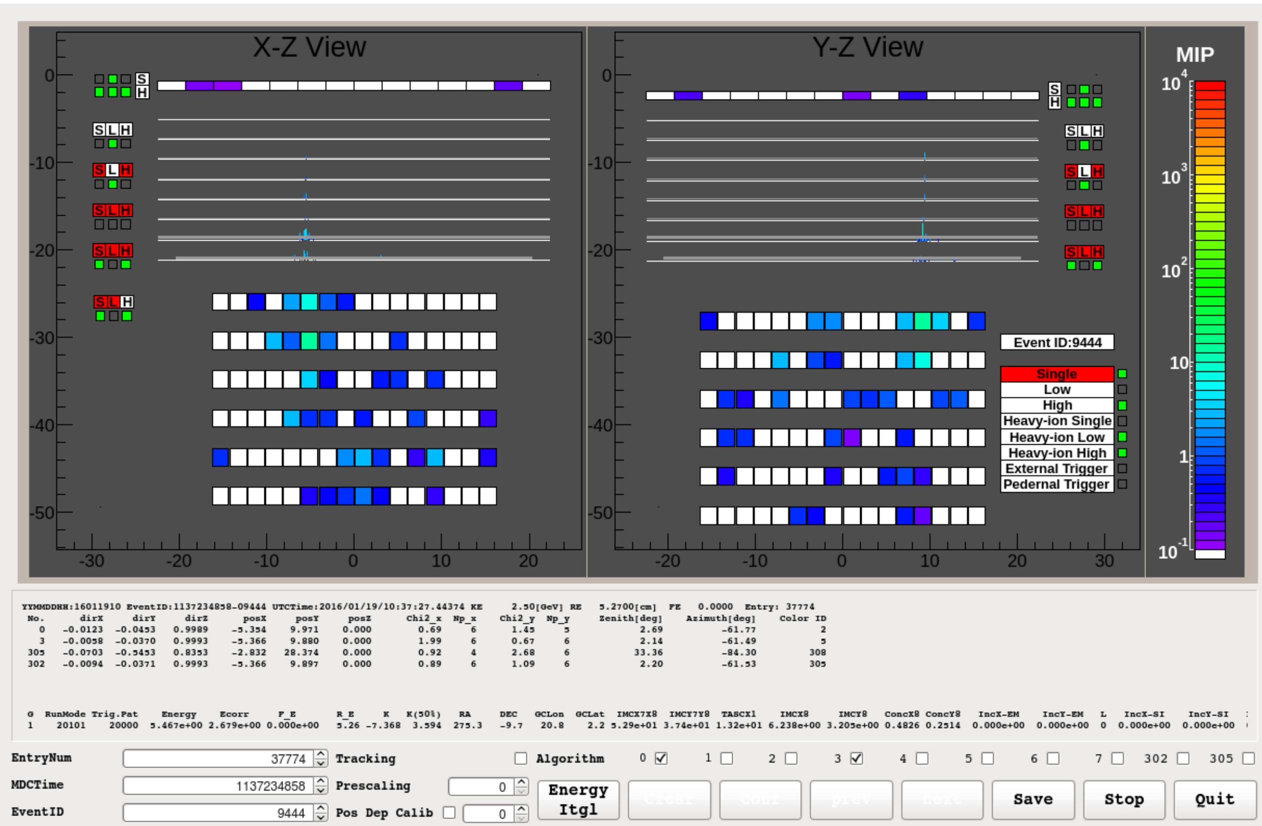




Electromagnetic Shower		Hadron Shower
well contained, constant shower development		larger spread

Gamma Ray Event Selection

= Electron Selection Cut + Gamma-ray ID Cut w/ Lower Energy Extension

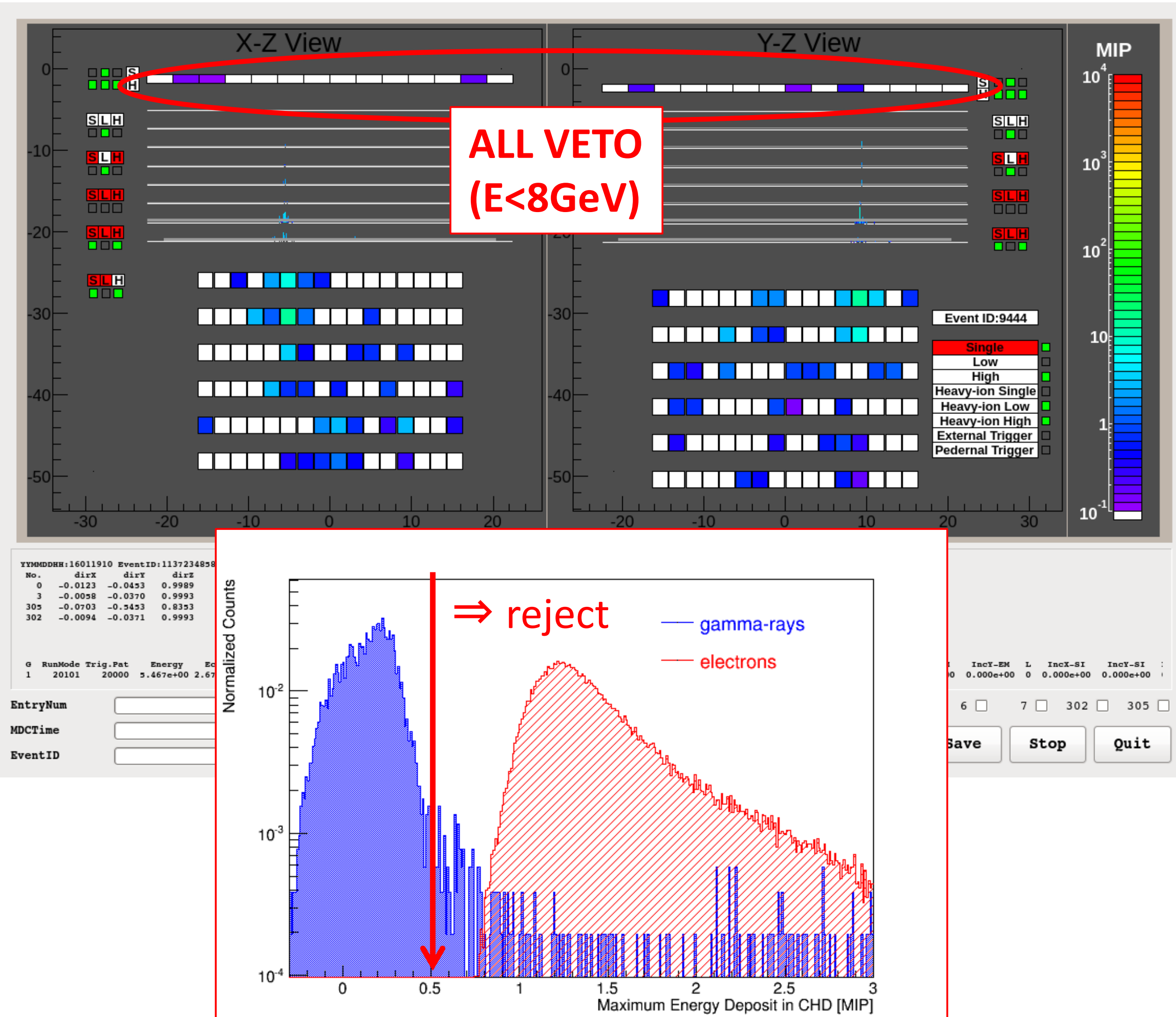


1. Geometry Condition
   - CHD-Top to TASC Bottom ($415 cm^2$)
2. Pre selection
   - Offline trigger
   - Shower concentration
   - Shower starting point
3. Track quality cut
   - Track hits >2
   - matching w/ TASC
4. Electromagnetic shower selection
   - shower shape
5. Gamma-ray ID
   - CHD-veto

For quick result, not fully optimized, yet.

Gamma Ray Event Selection

= Electron Selection Cut + Gamma-ray ID Cut w/ Lower Energy Extension

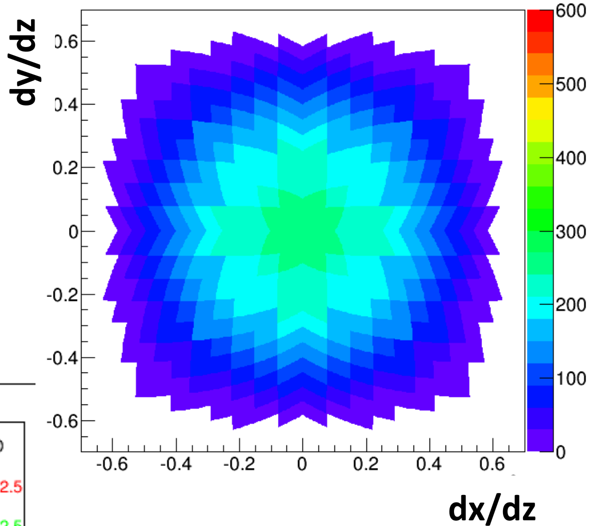


1. Geometry Condition
   - CHD-Top to TASC Bottom ($415 cm^2$)
2. Pre selection
   - Offline trigger
   - Shower concentration
   - Shower starting point
3. Track quality cut
   - Track hits >2
   - matching w/ TASC
4. Electromagnetic shower selection
   - shower shape
5. **Gamma-ray ID**
   - **CHD-veto**

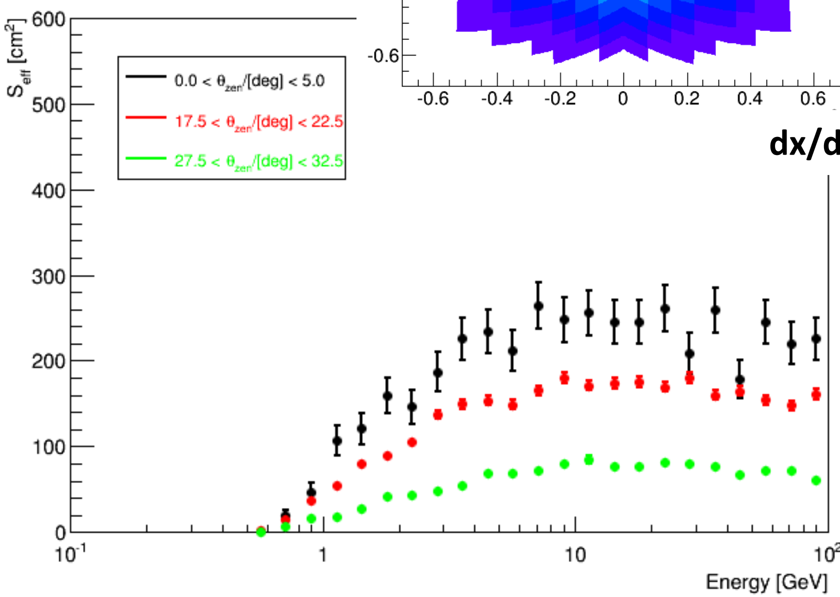
Effective Area and Sensitivity

3-30 GeV average

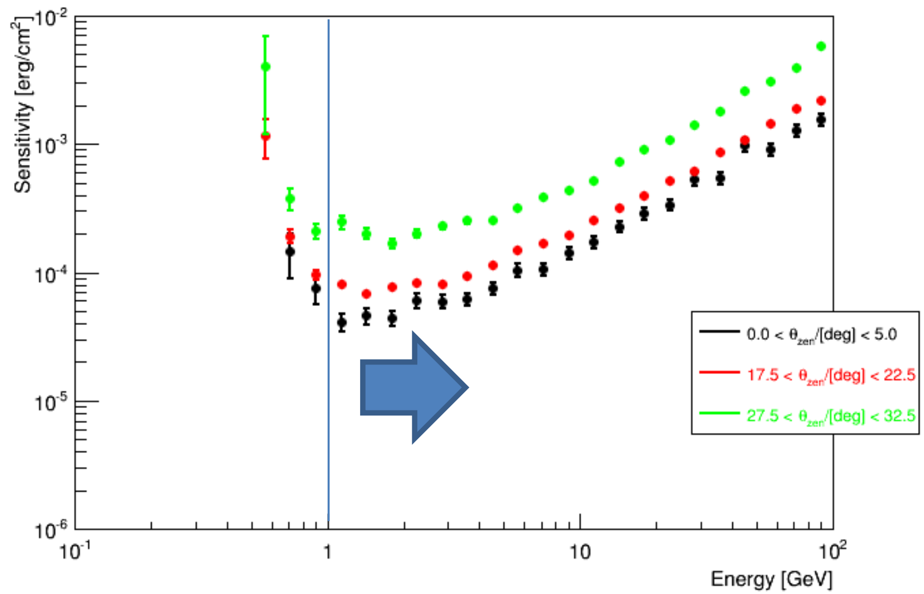
mostly axially symmetric



Effective area is estimated as a function of incident angle (dx/dz, dy/dz) and energy. Maximum effective area is achieved at around 10 GeV, but lower energy is more important for steep spectrum like E^{-2}.



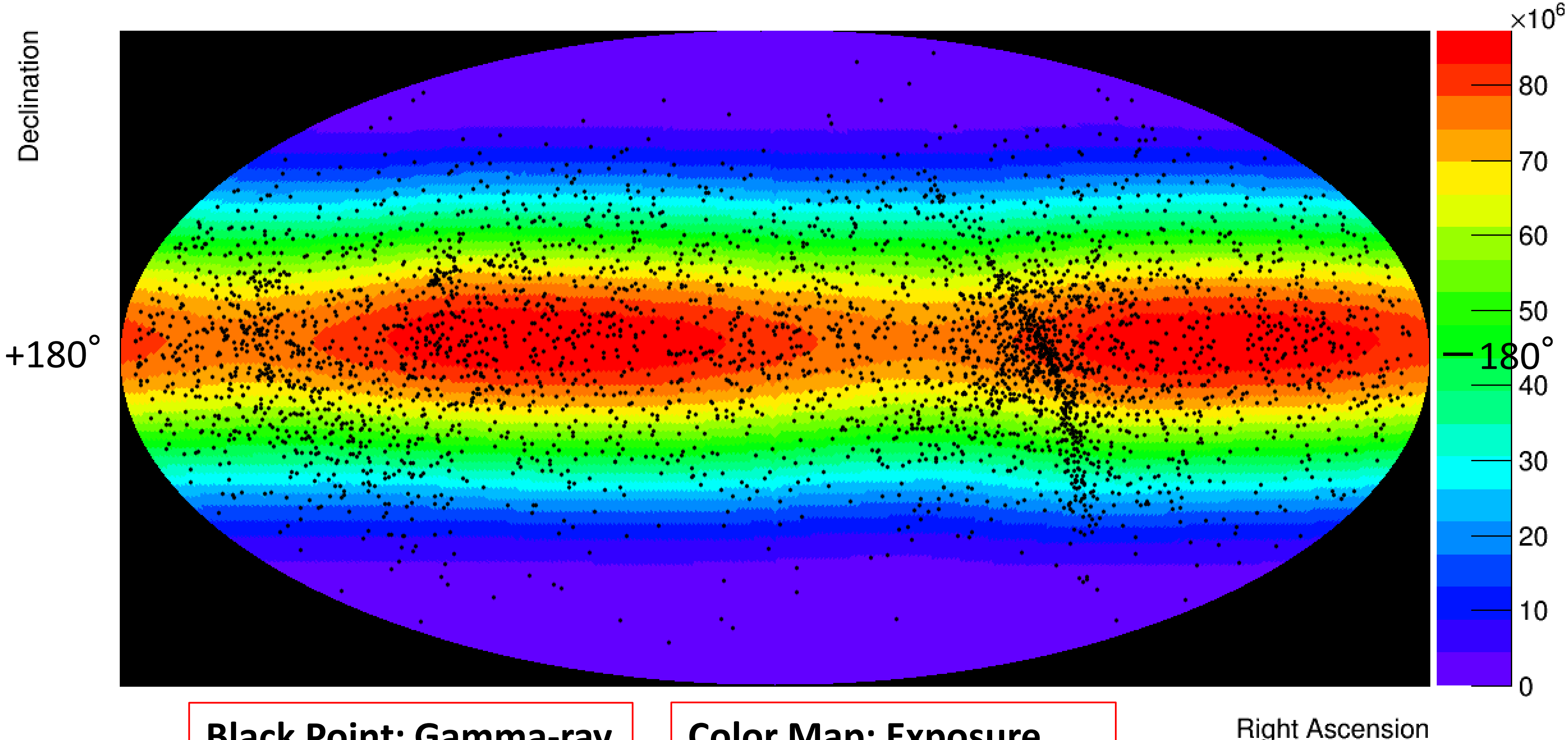
Effective area as a function of energy. Three representing zenith angle ranges are shown



Maximum sensitivity of 4×10^{-5} erg/cm^2 per $\Delta(\ln E)$ was achieved at around 1 GeV for E^{-2} spectrum

Diffuse Gamma-Ray Observation

- Purpose: Sensitivity validation & BG estimation
- Data set: from 151013 to 160531 (232 days)
- Observation Mode: Low Energy Gamma-Ray Trigger



Black Point: Gamma-ray event candidates

Color Map: Exposure in 10-12.6GeV in cm^2sec

Diffuse Gamma-Ray Observation

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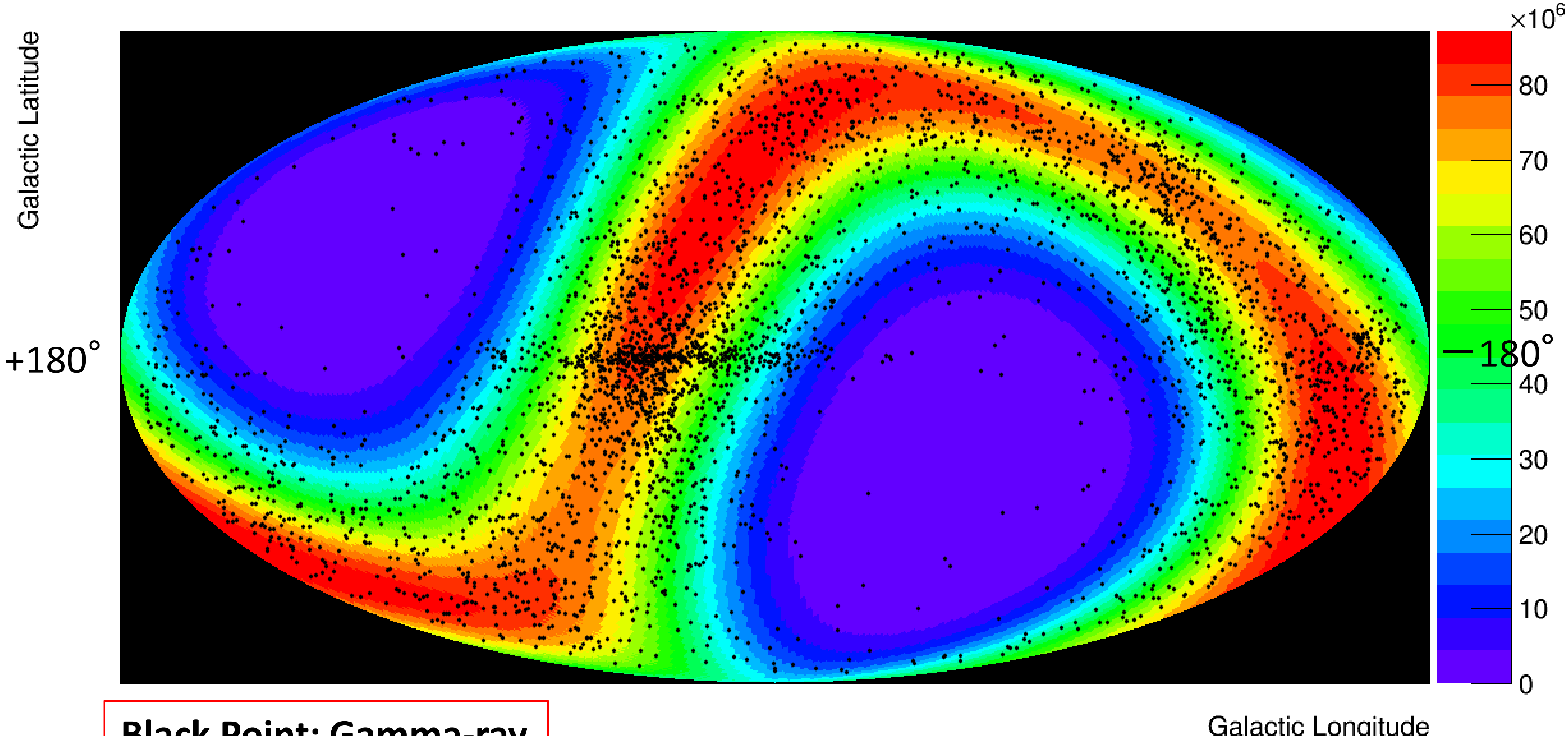

Black Point: Gamma-ray event candidates

exposure is limited in low latitude region, it covers a half of galactic plane including Geminga+Crab region

Diffuse Gamma-Ray Observation

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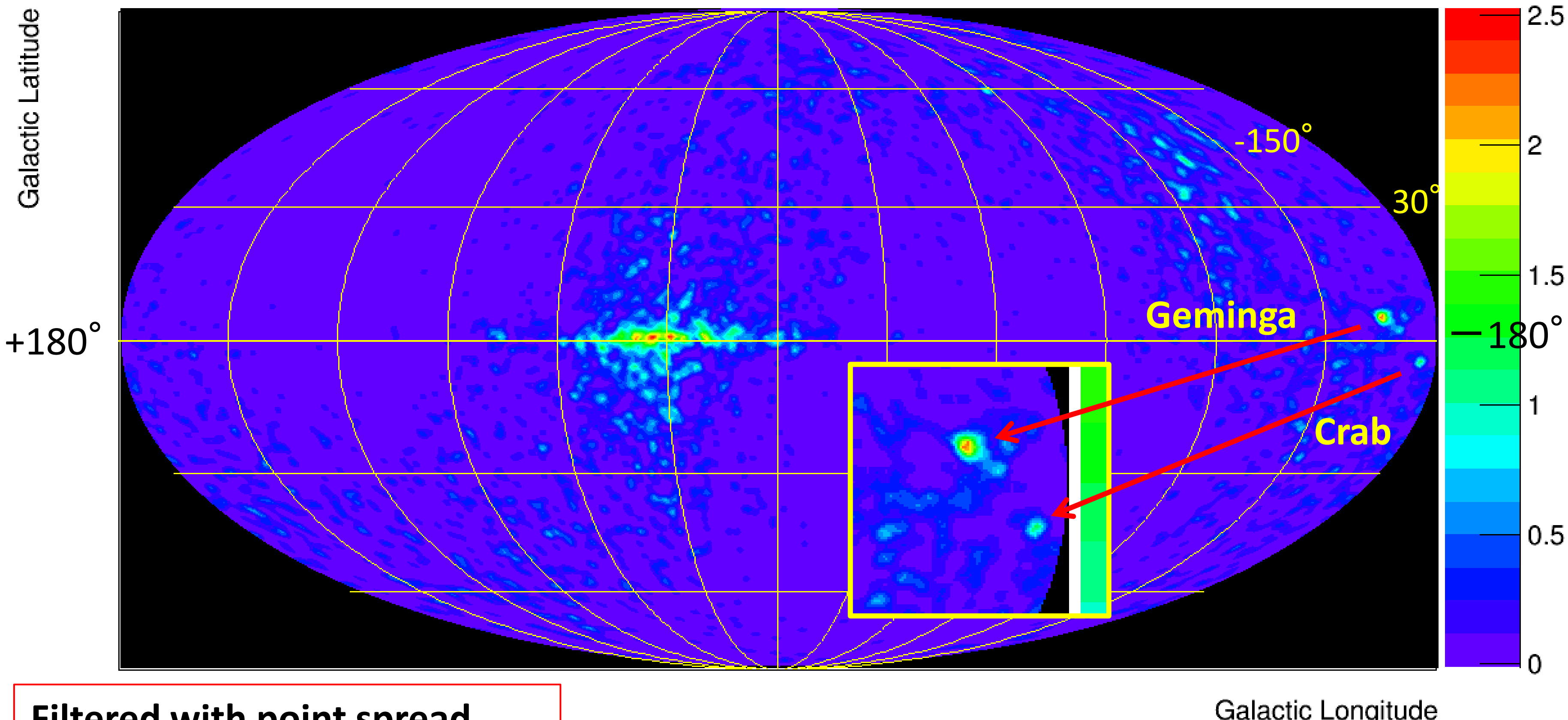
- Data set: from 151013 to 160531 (232 days)
- Observation Mode: Low Energy Gamma-Ray Trigger

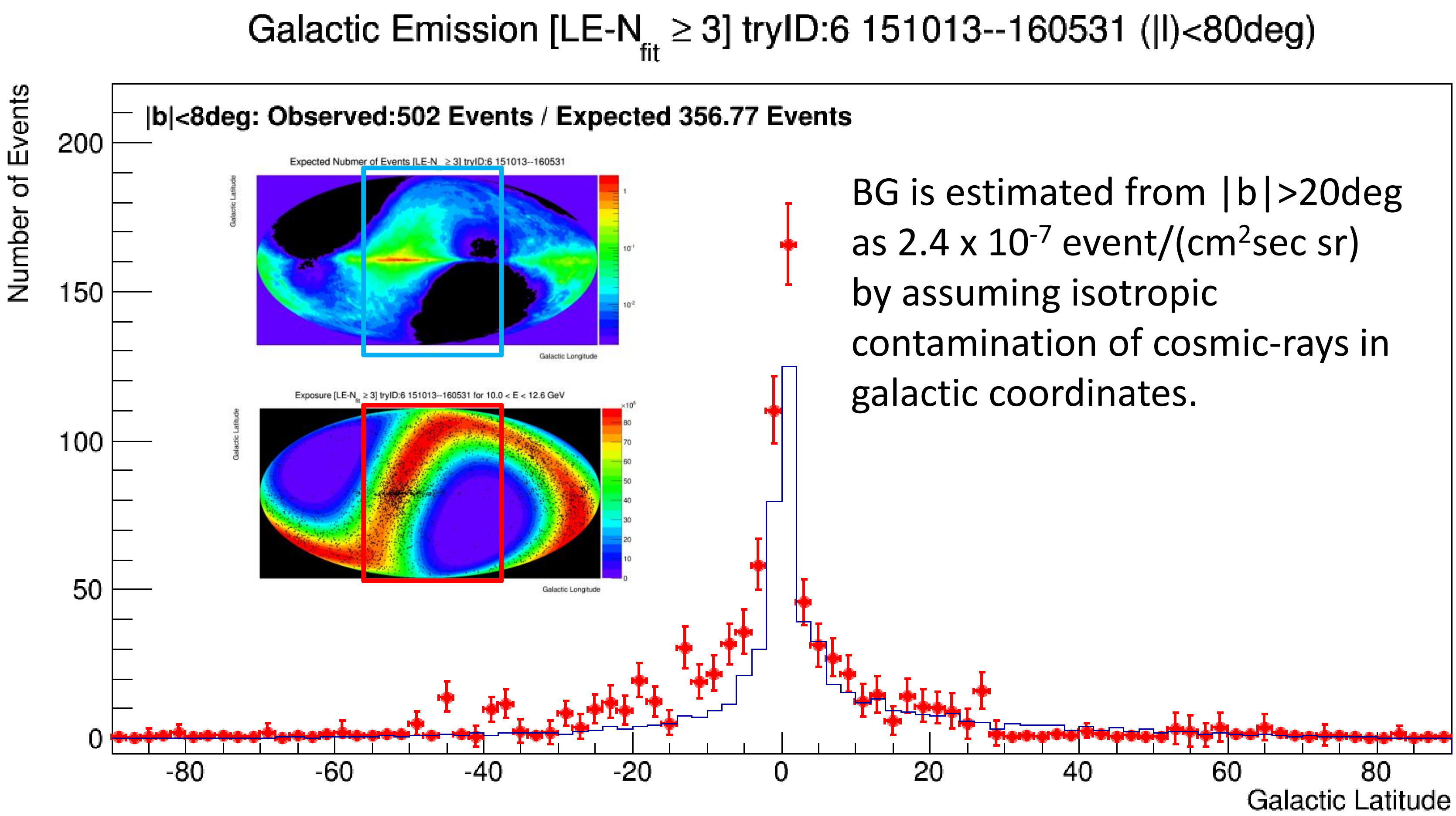


Filtered with point spread functions to see point sources

Geminga and Crab are clearly identified.

Projection to Galactic Latitude (|l|<80deg)

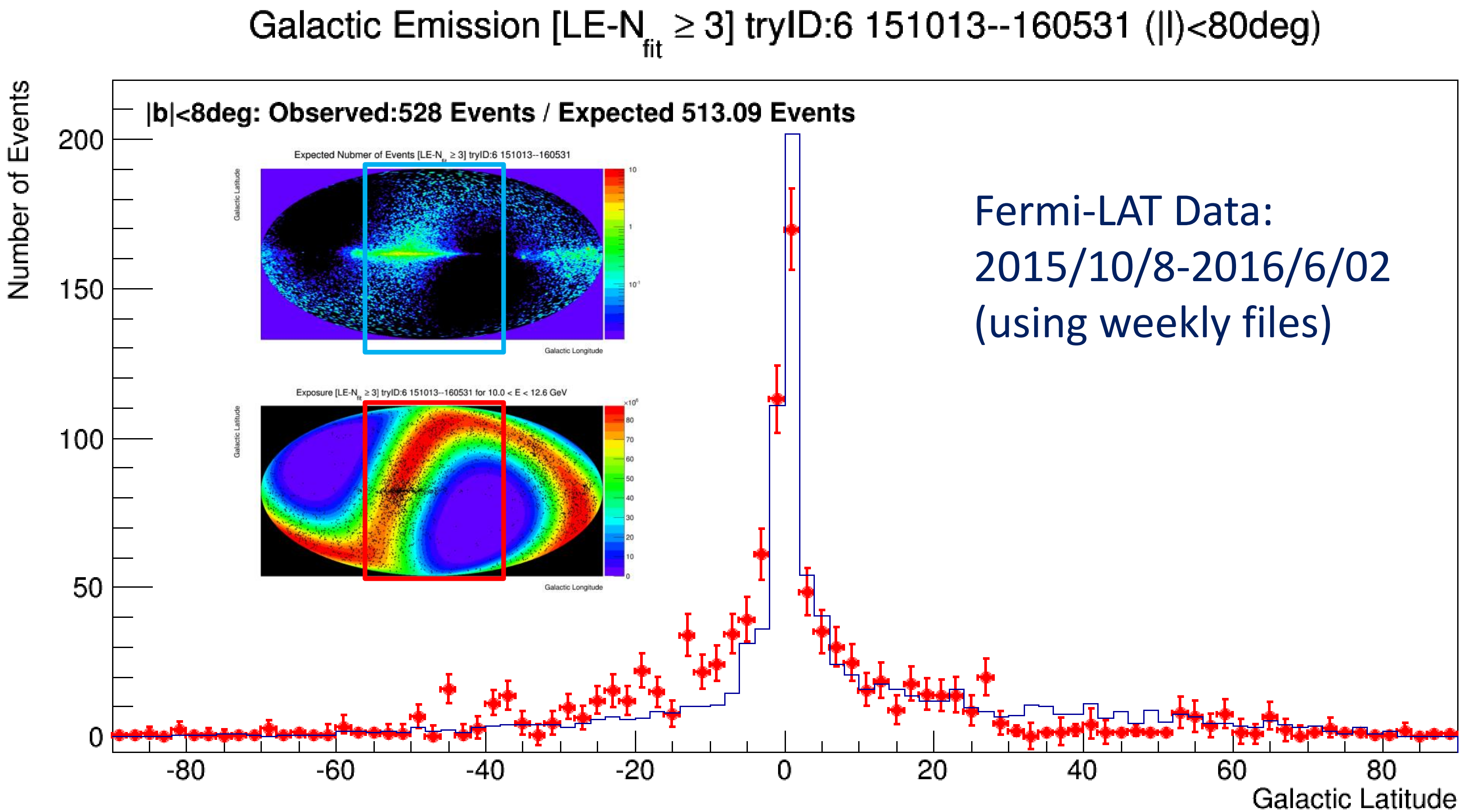
And comparison with diffuse radiation model



Considering the contribution from point sources, it will be consistent with expectation.

Projection to Galactic Latitude (|l|<80deg)

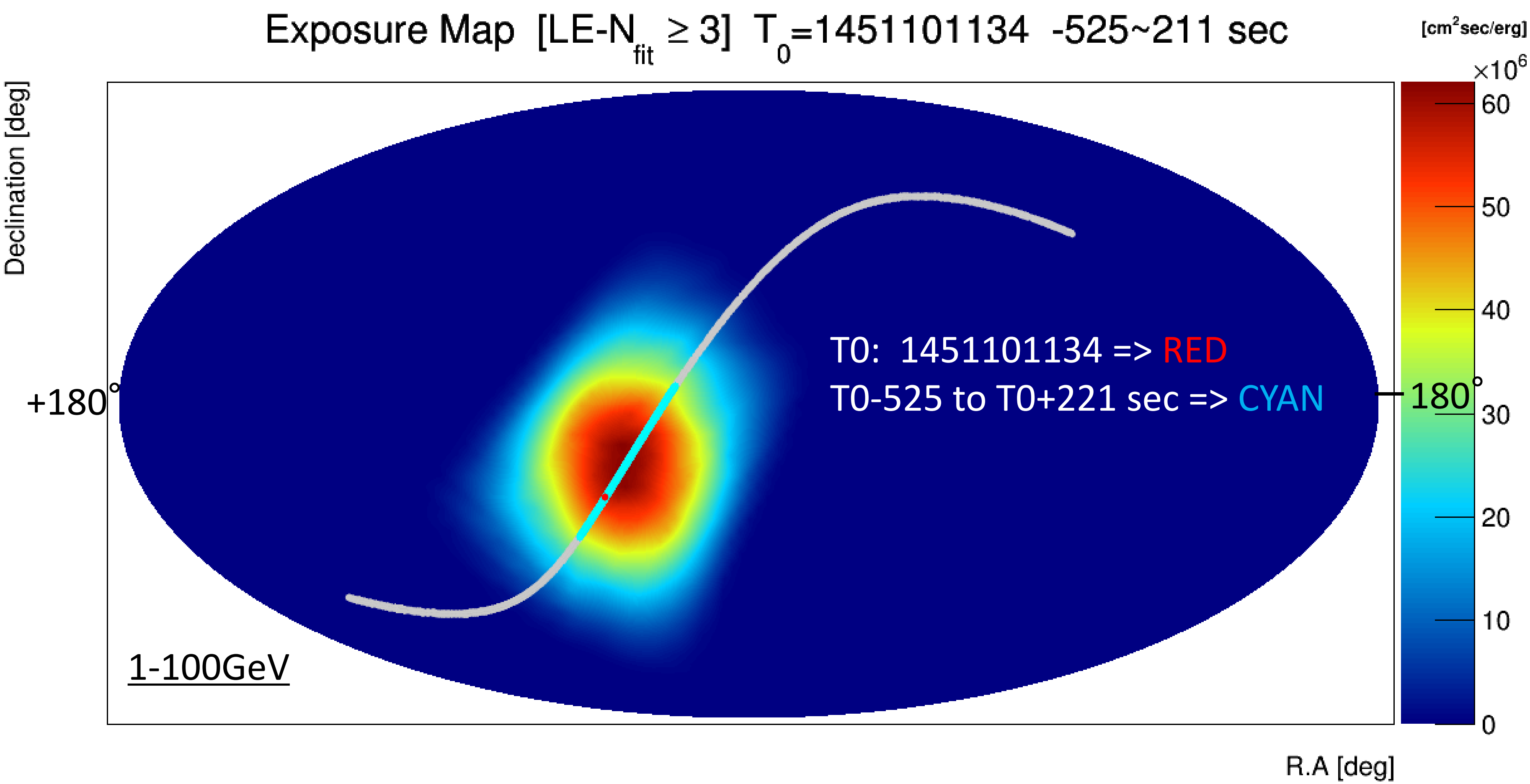
And comparison with Fermi-LAT's observation



Considering the contribution from point sources, it was actually consistent with expectation. Therefore, it was found that current selection criteria has a validated sensitivity and can be used to set limit on GW counterpart flux.

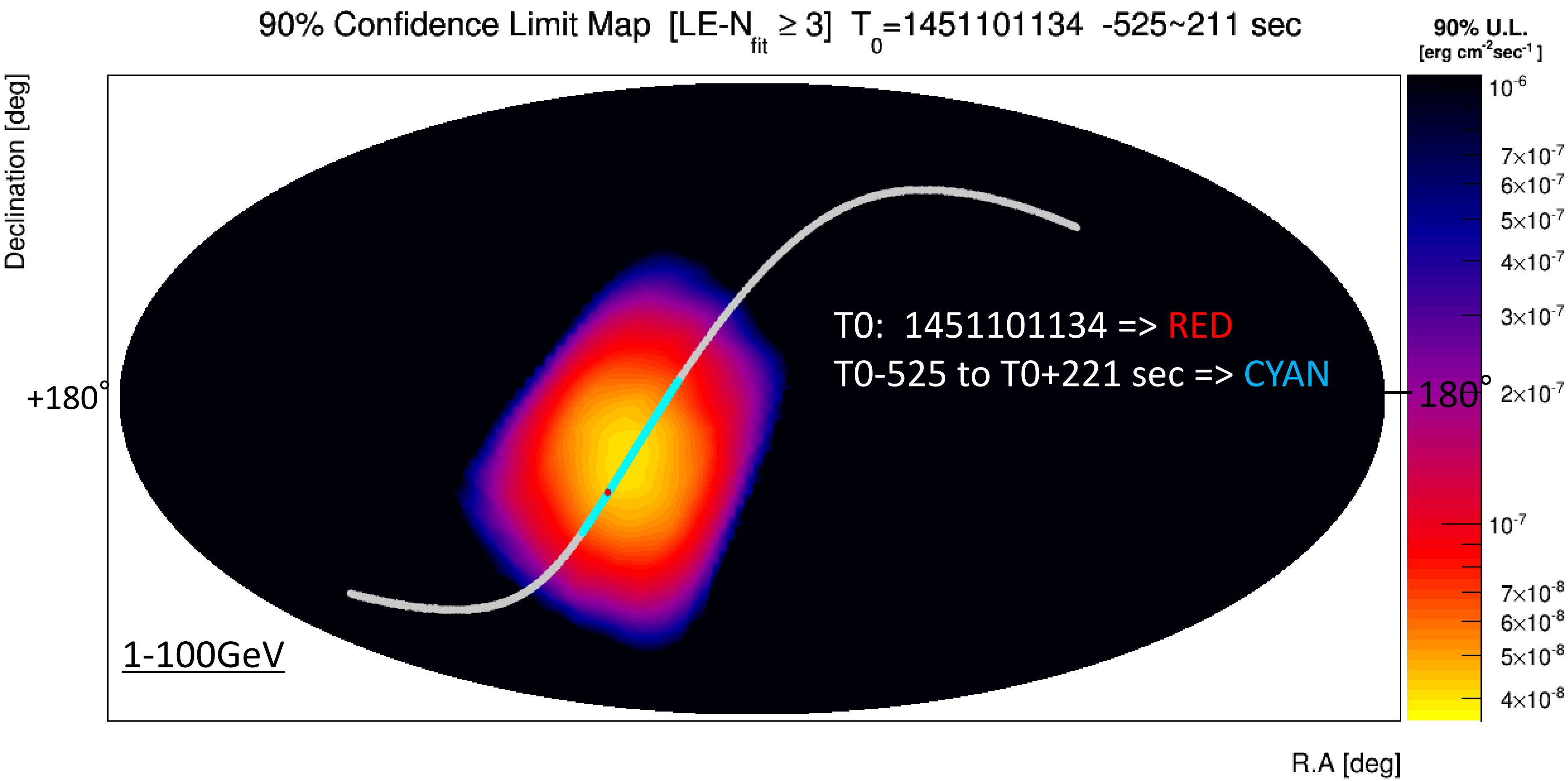
Integrated Exposure
for GW151226 counterpart search

Assuming E^{-2} spectrum, exposure was integrated over 1 to 100GeV.



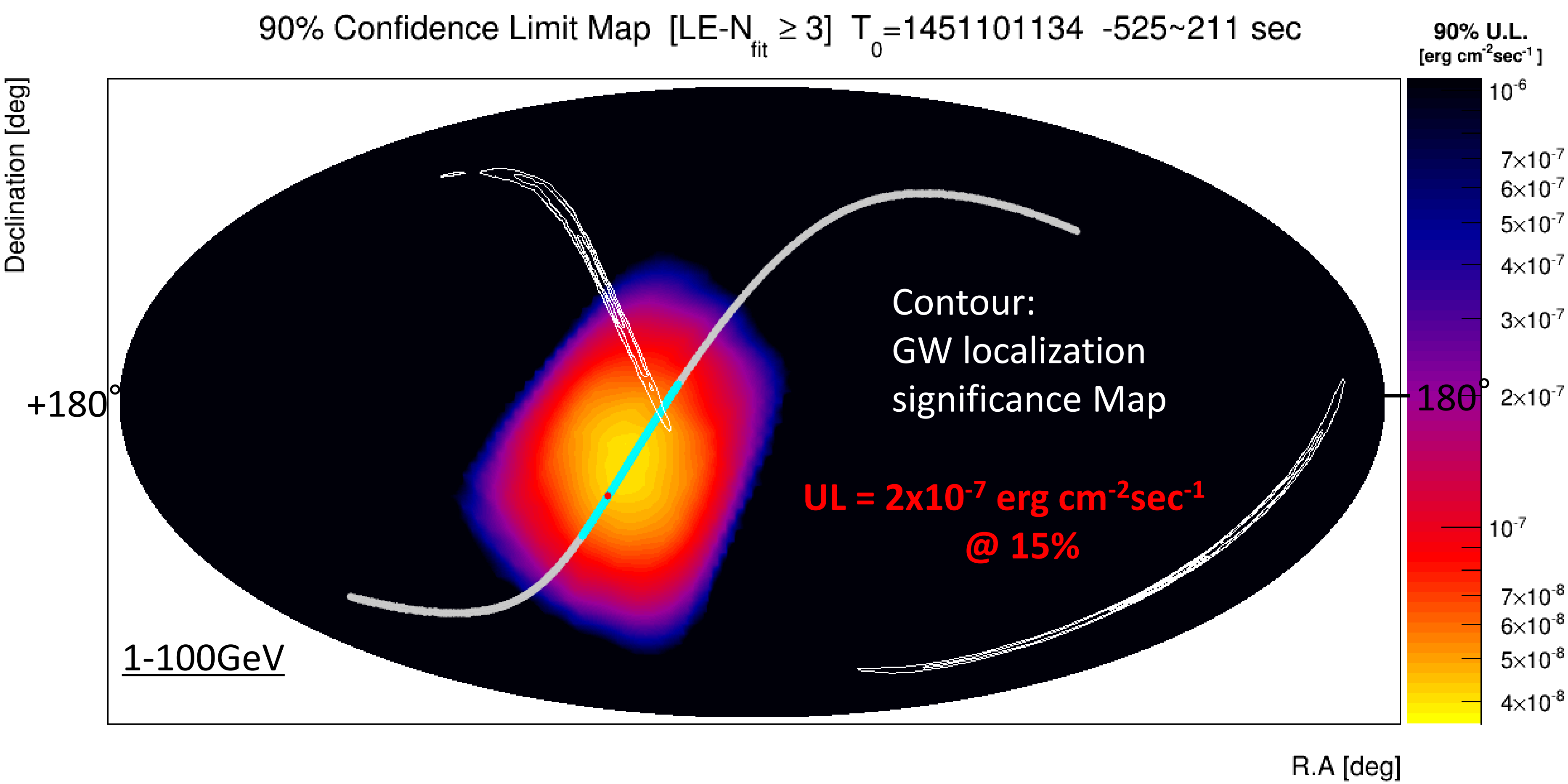
90% CL Upper limit for GW151226 counterpart search

NO event remained after applying all the selection criteria.



Background contamination is negligible: ~0.035 event

90% CL Upper limit for GW151226 counterpart search



CALET observation constrains at least some portion of LIGO probability.

Summary & Conclusion

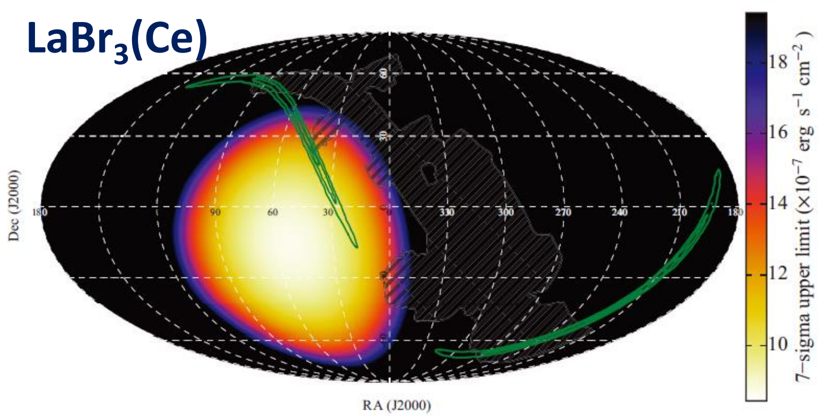
1. **As a result of GW151226 counterpart search in GeV gamma-rays, CALET-CAL observation constrains 15% of LIGO localization map by 90% upper limit flux of 2×10^{-7} erg cm^{-2}sec^{-1} .**
2. **Its sensitivity was validated with diffuse gamma-ray observation.**
3. **Due to closeness of GW candidates, FOV coverage is more important than deepness of counterpart search assuming typical short GRBs as candidates.**

CGBM Upper Limits:

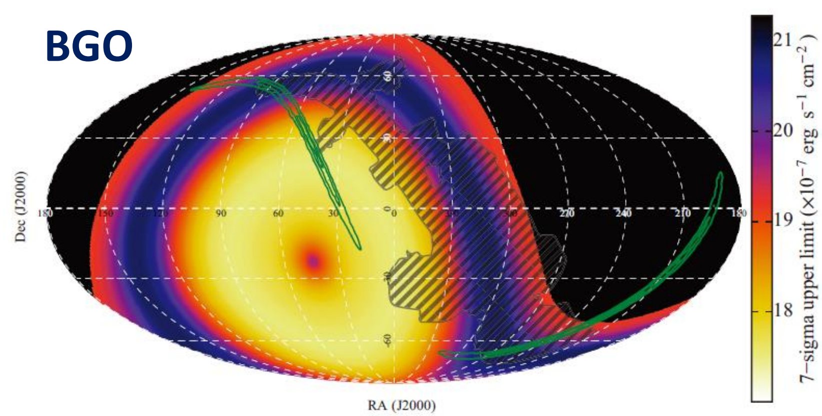
1.0×10^{-6} erg cm^{-2} s^{-1} (7-500keV) @ 33%

1.8×10^{-6} erg cm^{-2} s^{-1} (50-1000keV) @ 49%

$LaBr_3$(Ce)



BGO



Assuming the distance of 440 Mpc, the upper limit in luminosity is $3\text{-}5 \times 10^{49}$ erg s^{-1} (typical mean luminosity of s-GRB is 1.6×10^{51} erg s^{-1}).

Prospects

- Continues observation of transient objects
  - Analysis flow is established through the analysis of GW151226 counterpart.
  - We're ready for LIGO/Virgo O2 and KAGRA's alert.
- Detailed analysis of point source and diffuse components
  - optimizing analysis for each target
  - accumulating more and more statistics