Search for GeV Gamma-Ray Counterparts of Gravitational Wave Events with CALET

Yoichi Asaoka for the CALET Collaboration

WISE, Waseda University

2018/03/06 Gravitational wave physics and astronomy: Genesis

CALET Collaboration

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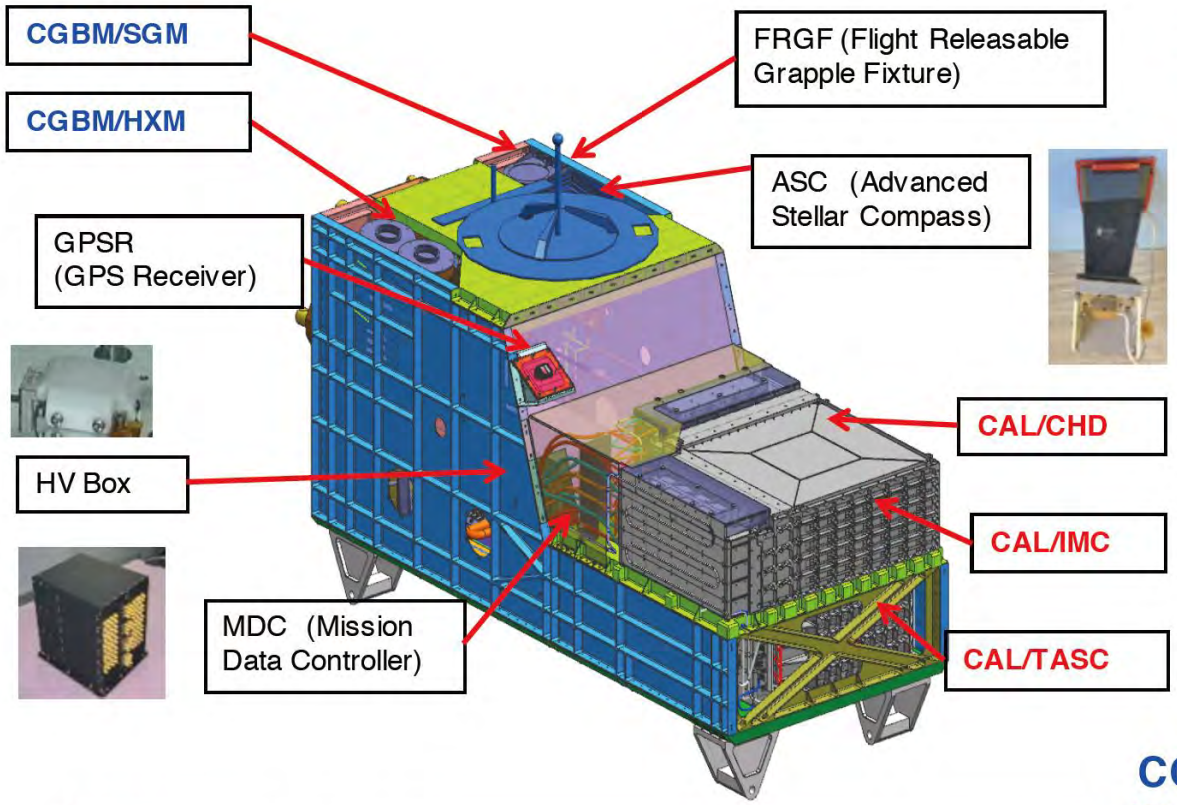
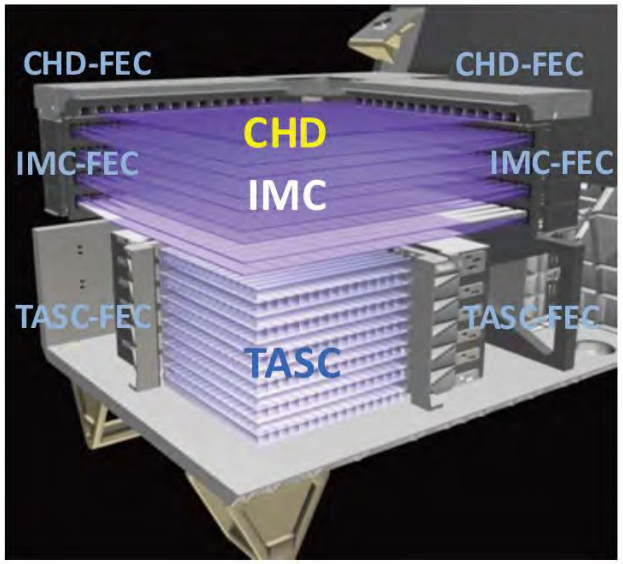
CALET System Overview



CALORIMETER (CAL)



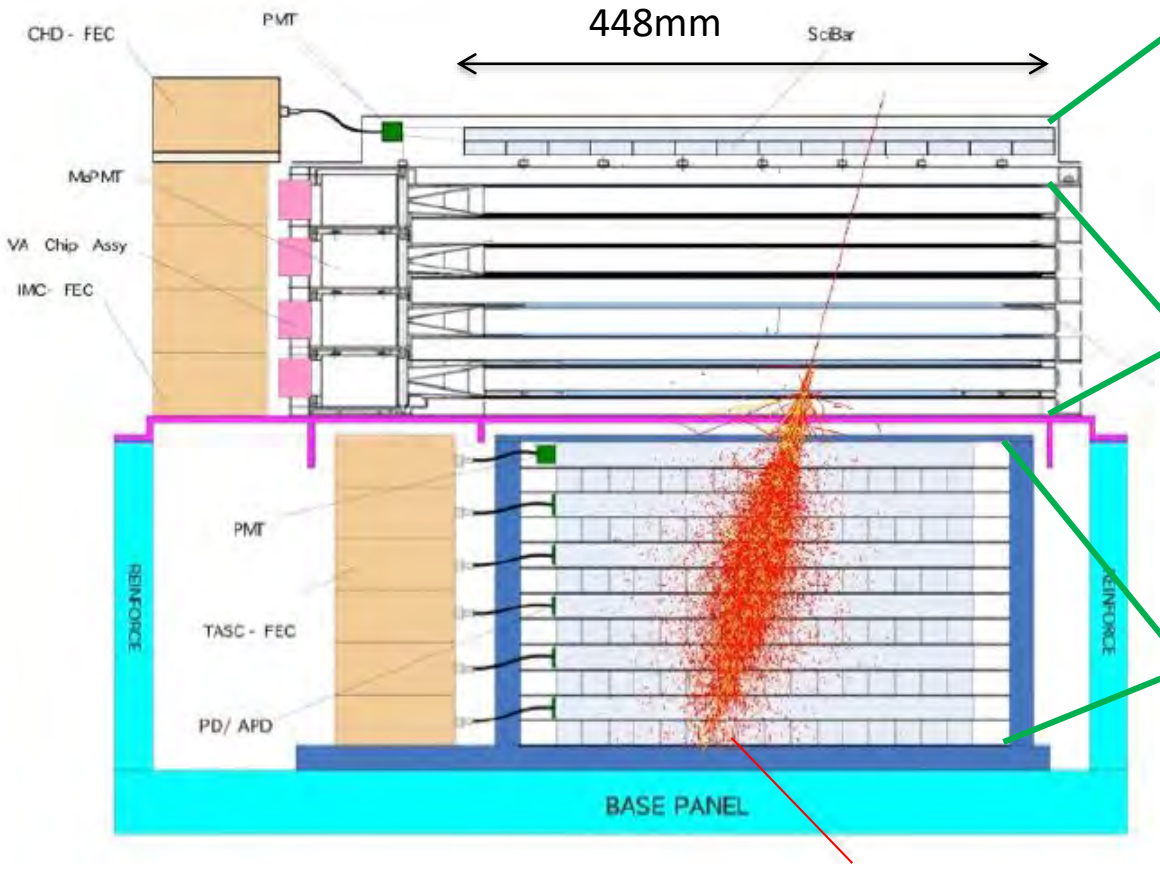
- Mass: 612.8 kg
- JEM Standard Payload Size
  1850mm(L) × 800mm(W) × 1000mm(H)
- Power Consumption: 507 W(max)
- Telemetry:
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

(*) JEM stands for Japan Experiment Module

CGBM (CALET Gamma-ray Burst Monitor)

CALET-CAL Detector

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

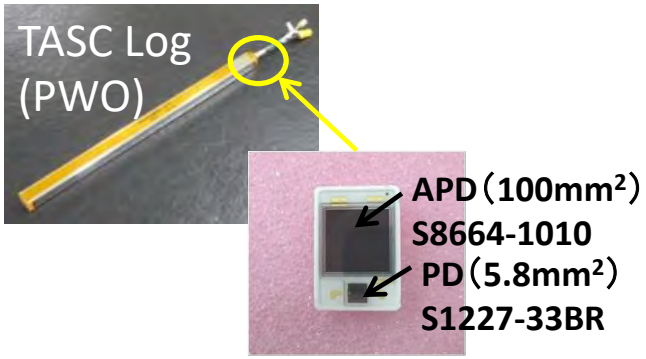
SciFi + tungsten plate (3X0), reconstruction of arrival direction and initial shower development

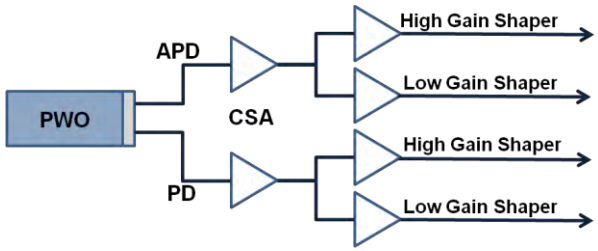
Total Absorption Calorimeter **TASC**

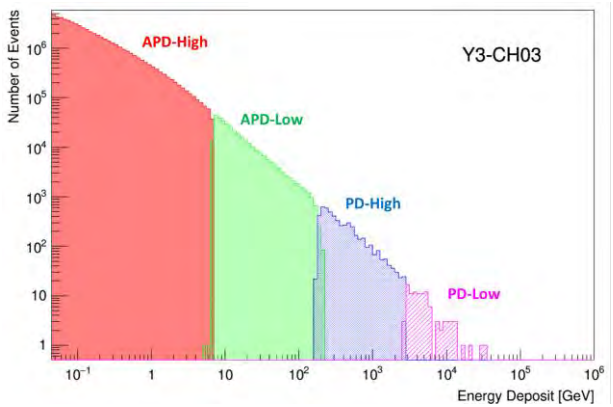
PWO hodoscope (27X0), energy measurements and particle identification

Energy Measurements with TASC

Y.Asaoka, Y.Akaike, Y.Komiya, R.Miyata, S.Torii et al., Astropart. Phys. 91 (2017) 1.

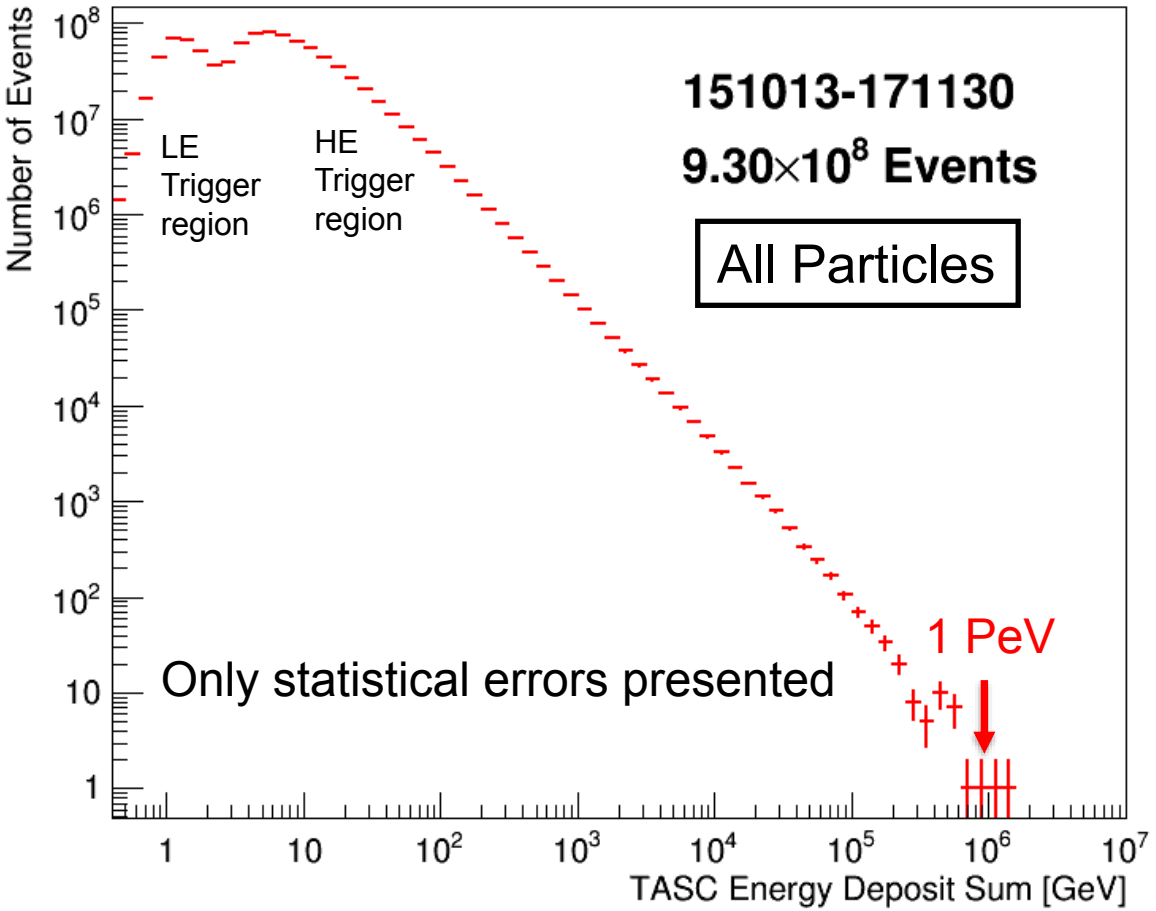






Seamless transition between adjacent gain ranges

Distribution of deposit energies (ΔE) in TASC



The TASC energy measurements have successfully been carried out in the dynamic range of 1 GeV – 1 PeV.

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

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- Diffuse Component => High energy region
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- Point Source
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  - Confirmation of angular resolution
  - Cross check of energy measurements/efficiency

Statistics is the KEY

- 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

O. Adriani[1,2,3], Y. Akaike[4,5], K. Asano[6], Y. Asaoka[7,8], M. G. Bagliesi[2,9], G. Bigongiari[2,9], W. R. Binns[10], S. Bonechi[2,9], M. Bongi[1,2,3], P. Brogi[2,9], J. H. Buckley[10], N. Cannady[11], G. Castellini[1,2,3], C. Checchia[12], M. L. Cherry[11], G. Collazuol[12], V. Di Felice[2,13], K. Ebisawa[14], H. Fuke[14], T. G. Guzik[11], T. Hams[5,15], M. Hareyama[16], N. Hasebe[8], K. Hibino[17], M. Ichimura[18], K. Ioka[19], W. Ishizaki[6], M. H. Israel[10], A. Javaid[11], K. Kasahara[8], J. Kataoka[8], R. Kataoka[20], Y. Katayose[21], C. Kato[22], N. Kawanaka[23], Y. Kawakubo[24], H. Kitamura[25], H. S. Krawczynski[10], J. F. Krizmanic[4,5], S. Kuramata[18], T. Lomtadze[26], P. Maestro[2,9], P. S. Marrocchesi[2,9], A. M. Messineo[26], J. W. Mitchell[27], S. Miyake[28], K. Mizutani[29], A. A. Moiseev[5,30], K. Mori[8,14], M. Mori[31], N. Mori[1,2,3], H. M. Motz[32], K. Munakata[22], H. Murakami[8], Y. E. Nakagawa[14], S. Nakahira[7], J. Nishimura[14], S. Okuno[17], J. F. Ormes[33], S. Ozawa[8], L. Pacini[1,2,3], F. Palma[2,13], P. Papini[1,2,3], A. V. Penacchioni[9,34], B. F. Rauch[10], S. Ricciarini[1,2,3], K. Sakai[5,15], T. Sakamoto[24], M. Sasaki[5,30], Y. Shimizu[17], A. Shiomi[35], R. Sparvoli[2,13], P. Spillantini[1,2,3], F. Stolzi[2,9], I. Takahashi[36], M. Takayanagi[14], M. Takita[6], T. Tamura[17], N. Tateyama[17], T. Terasawa[37], H. Tomida[14], S. Torii[7,8], Y. Tsunesada[38], Y. Uchihori[25], S. Ueno[14],

Published in ApJ Letters

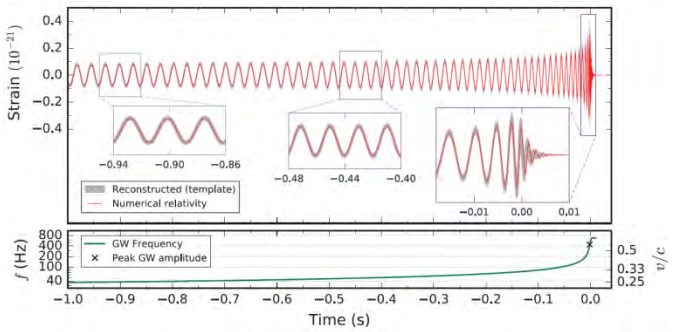
updated analysis will be presented

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



CAL Limit Calculation Procedure

Gamma-ray Event Selection

Effective Area Calculation

Exposure Calculation

Upper Limit Calculation

Check Overlap with LIGO Localization Map

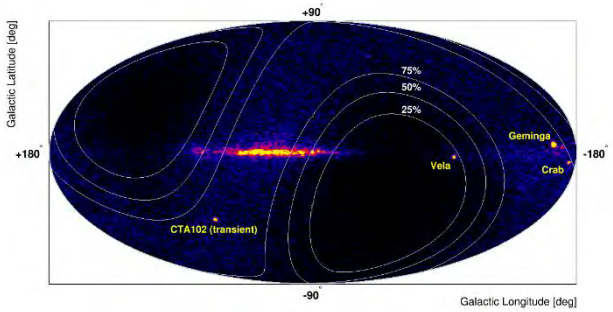
Lower energy is important

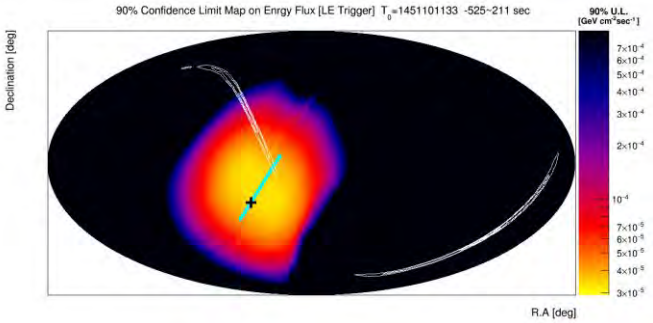
S_{eff} as a function of zenith and azimuth

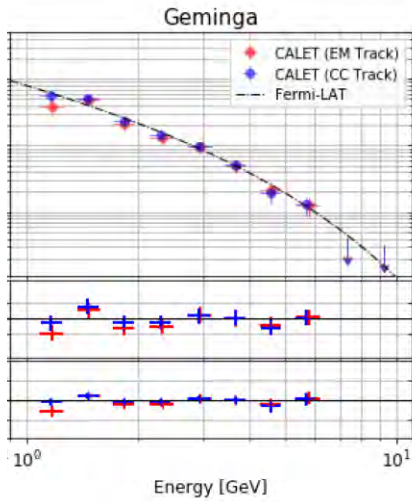
$S_{eff}(zen,azi)\ T_{live}$ projected to sky event by event along the ISS (CALET) orbit

If no gamma-rays are observed

Validation of Sensitivity with Observation of Diffuse/Point Sources







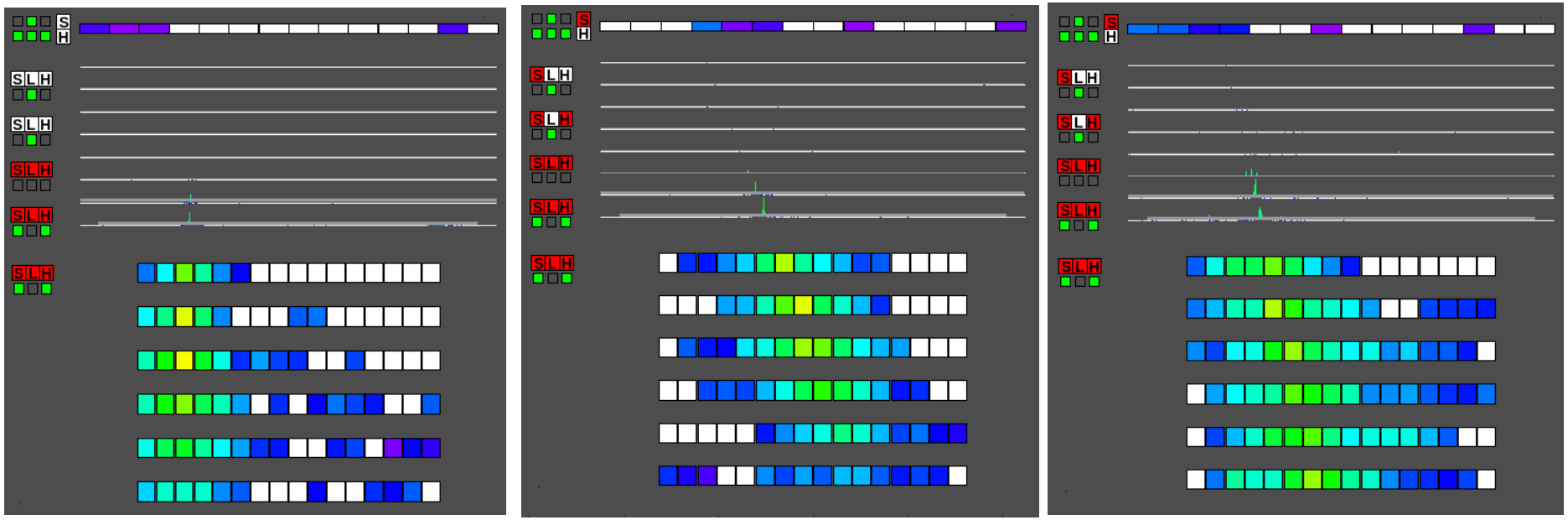
Gamma Ray Event Selection

= 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

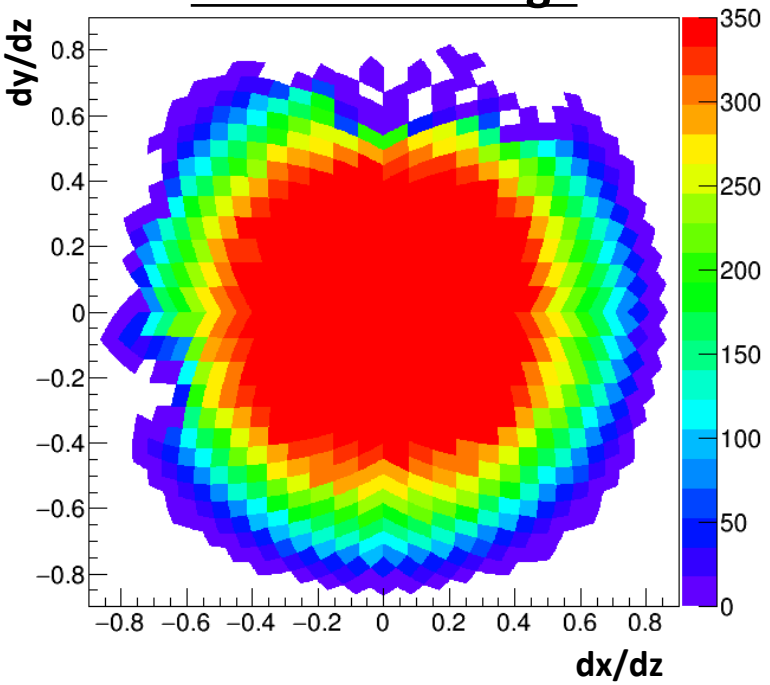
well contained, constant shower development

larger spread

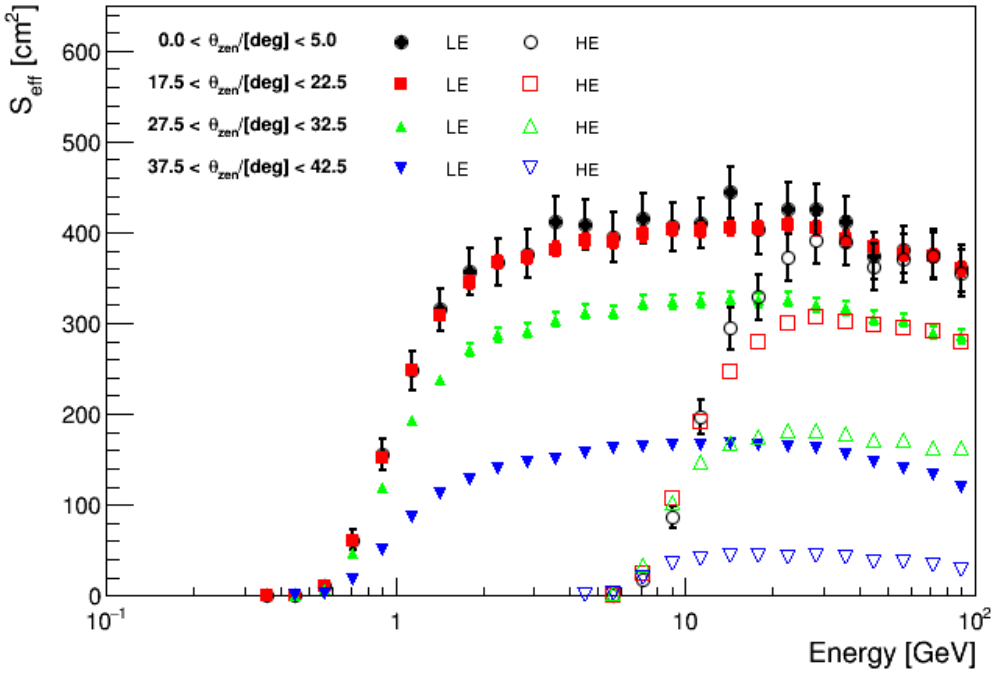
Effective Area and Sensitivity

Effective area is estimated as a function of incident angle (dx/dz, dy/dz) and energy. Maximum effective area is achieved at around 5 GeV, but lower energy is more important for steep spectrum like E^{-2}.

3-10GeV average



Mostly axially symmetric except for FOV cut



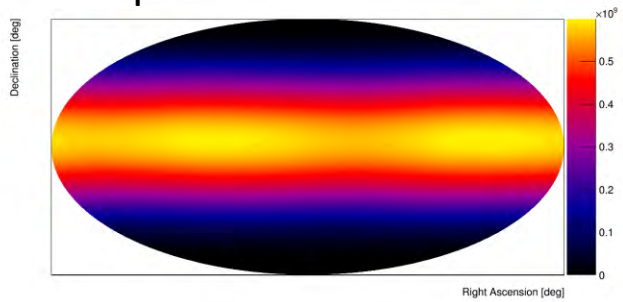
Effective area as a function of energy. Four representative zenith angle ranges are shown.

Rejects events coming from the direction of ISS structures
$\Rightarrow$ remove majority of secondary gamma-rays

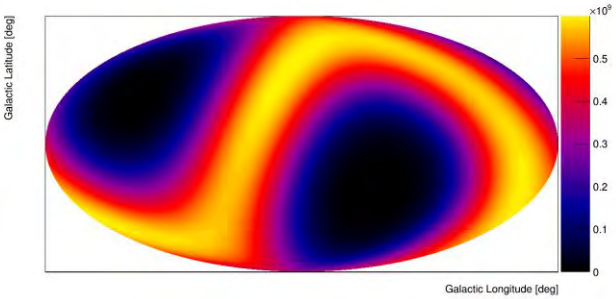
CALET Sky Map w/ LE-γ Trigger (E>1GeV)

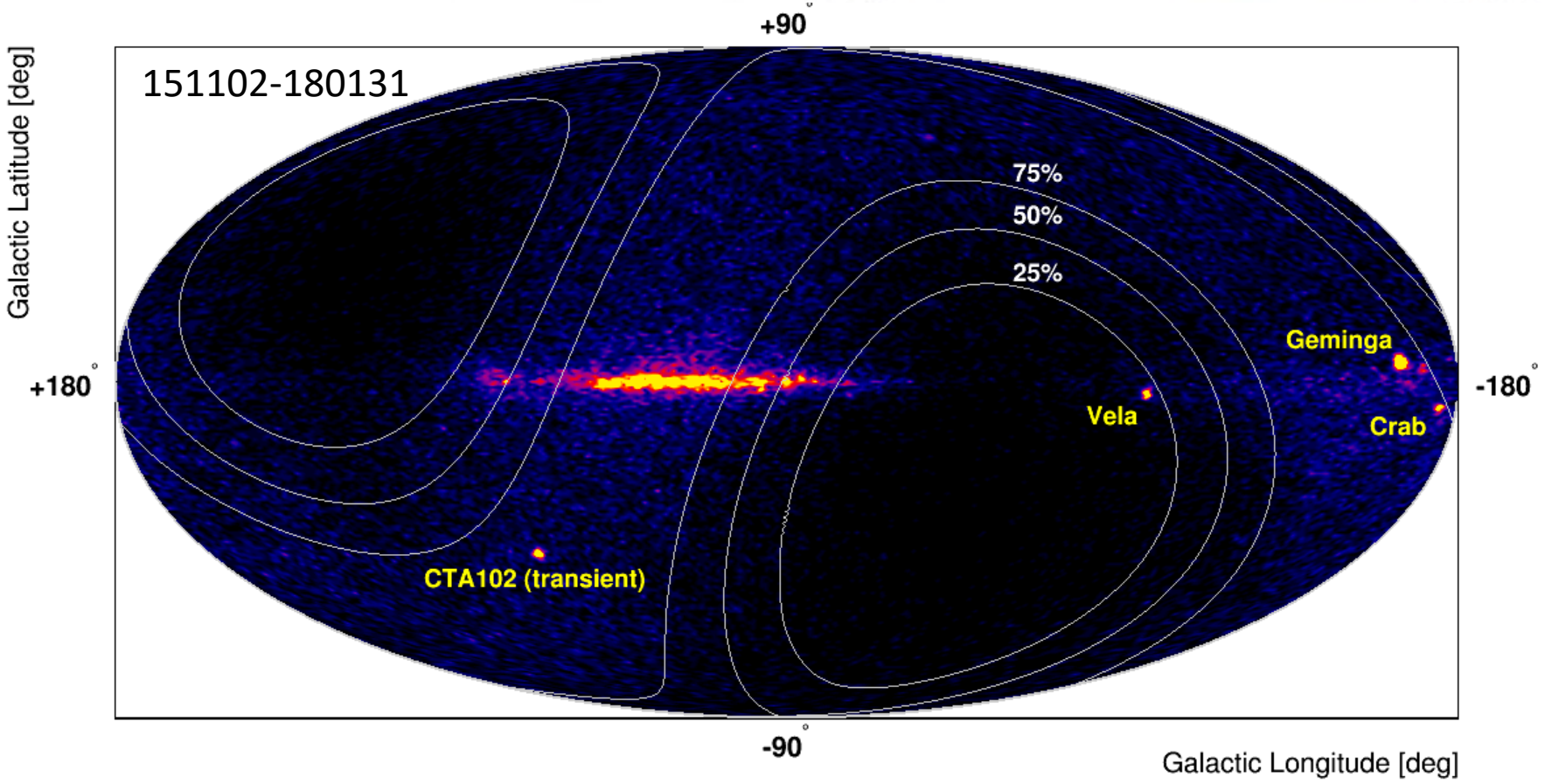
While exposure is not uniform, we have clearly identified the galactic plane and bright GeV sources.

Equatorial coordinate



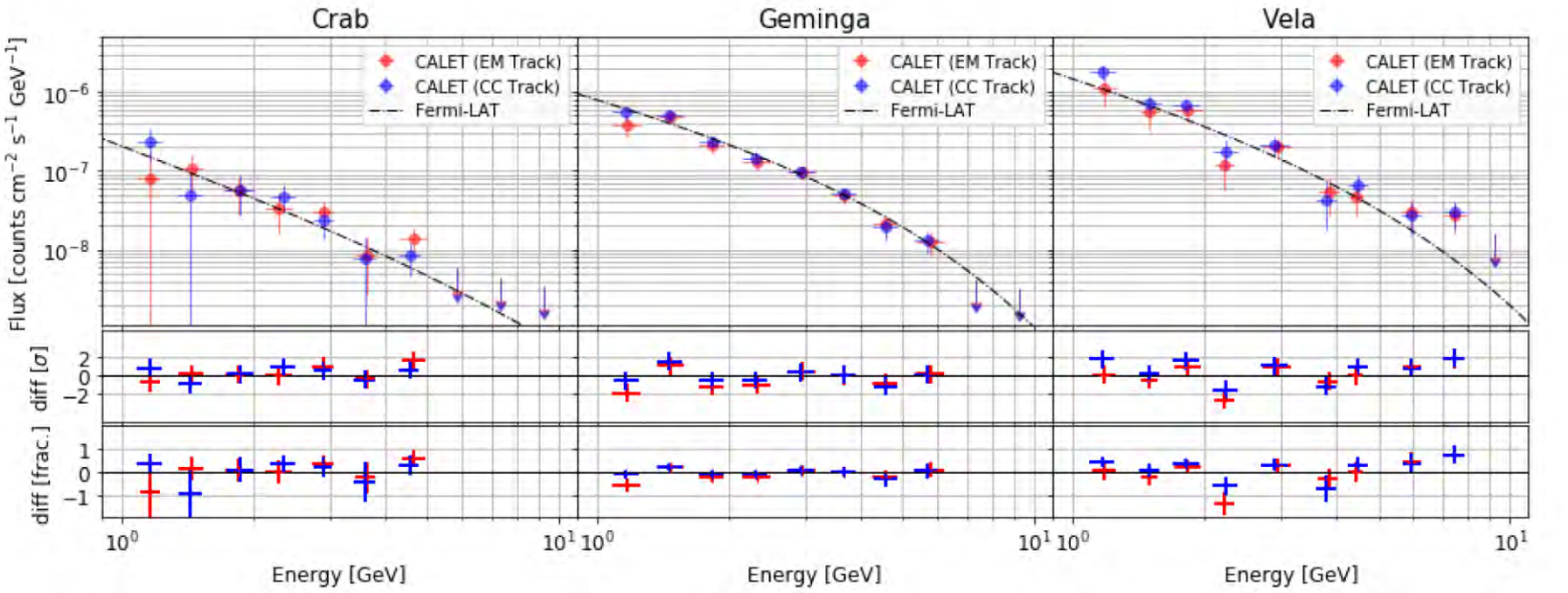
Galactic coordinate





Point Source Spectra: Sensitivity Validation

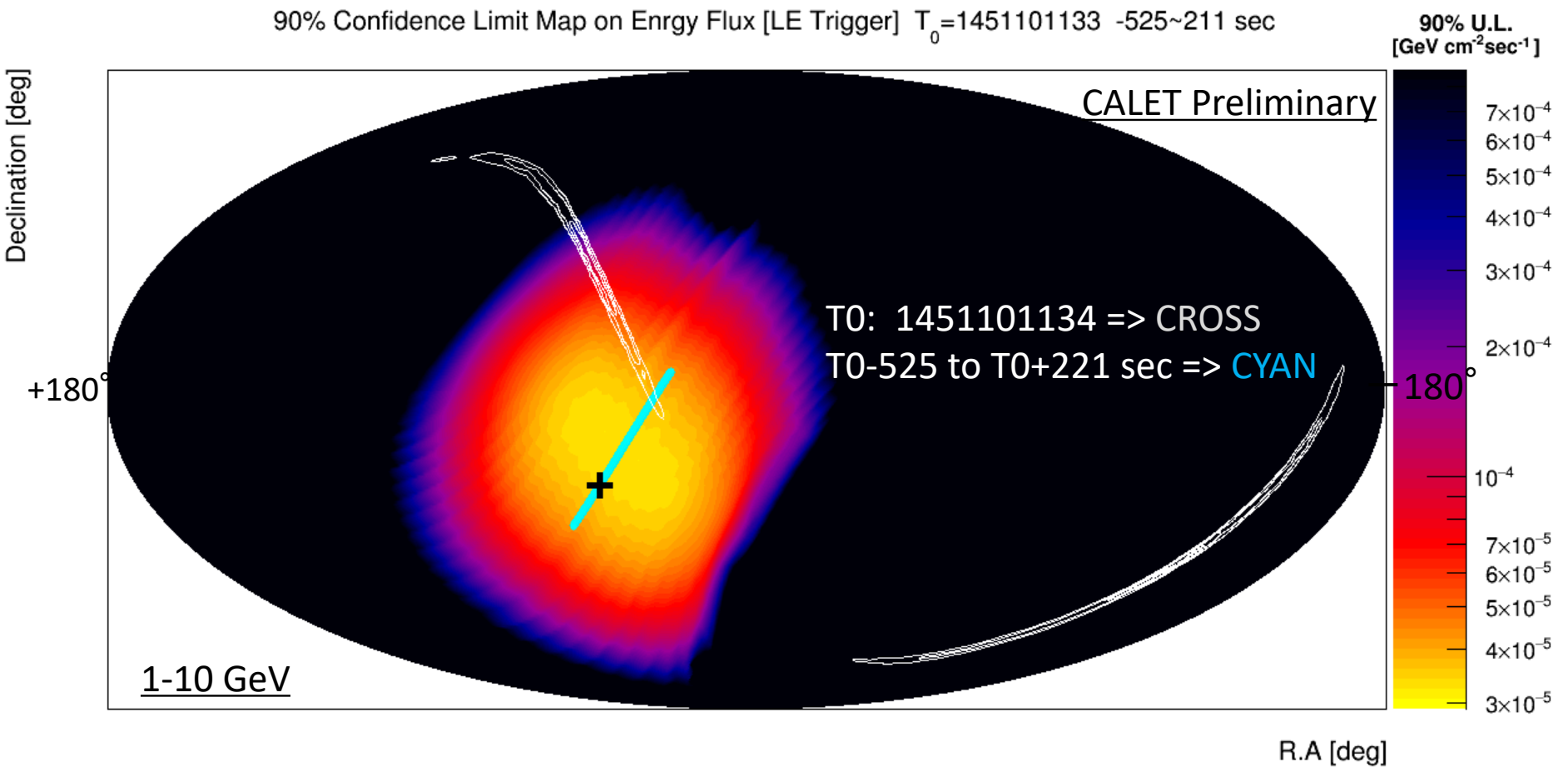
CALET Preliminary



The observed point source spectra are well consistent with Fermi-LAT's parameterizations. Therefore, it was found that current selection criteria has a validated sensitivity and can be used to set limit on GW counterpart flux.

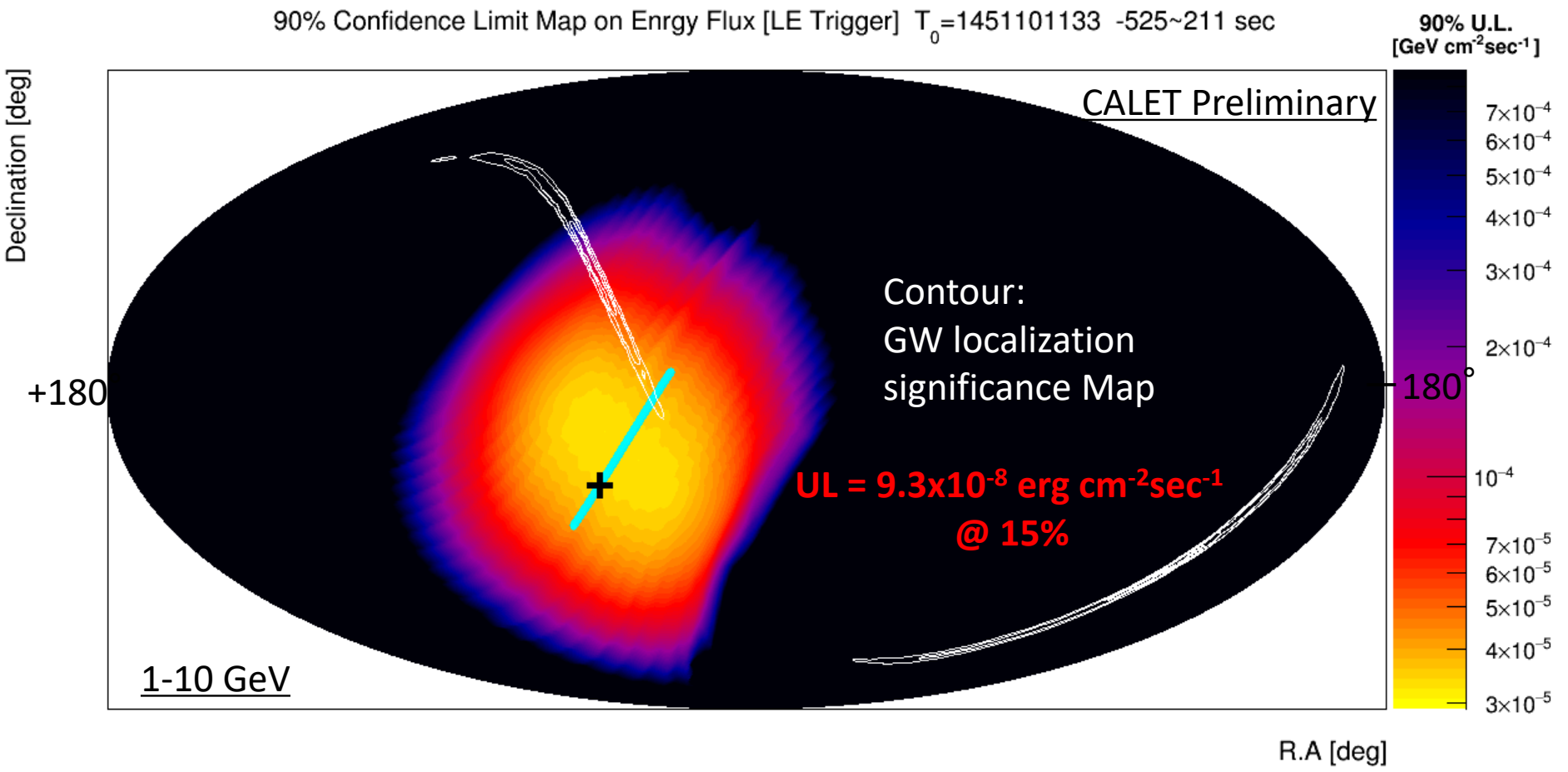
90% CL Upper limit for GW151226 Counterpart Search

NO event remained after applying all the selection criteria.



Background contamination is negligible in such a short time period.

90% CL Upper limit for GW151226 counterpart search

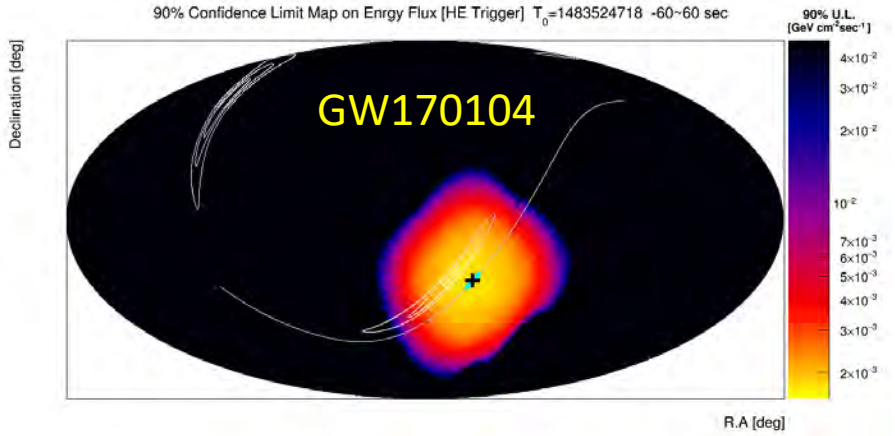


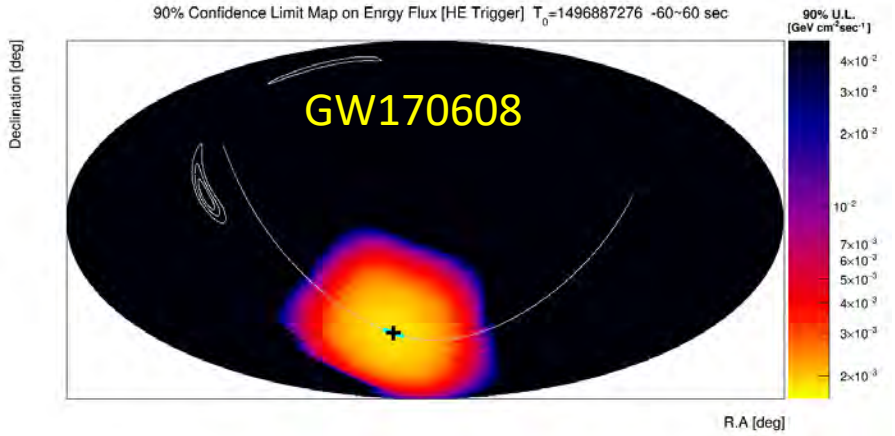
CALET observation constrains at least some portion of LIGO probability.

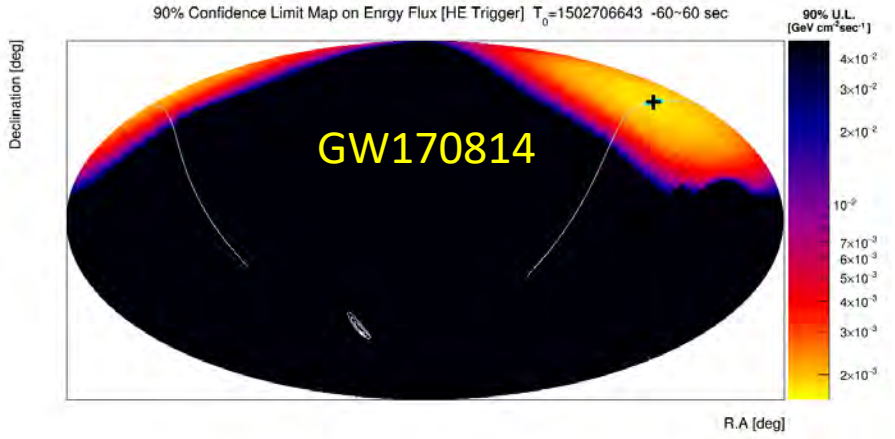
Complete Search Results for GW Events during O2

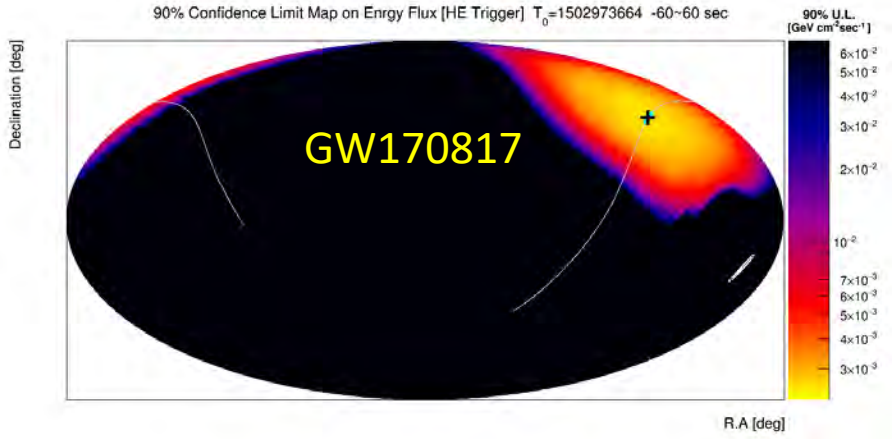
- For GW170104, we set 90% C.L. limit of 8.3 x 10^{-6} erg cm^{-2} s^{-1} (10-100GeV) covering 30% of the summed LIGO probabilities in the time window [T0-60sec,T0+60sec] (observation mode was HE trigger).
- Unfortunately, other GW events (GW170608, GW170814, GW170817) occurred during O2 are all out of the CALET-CAL FOV.

CALET Preliminary



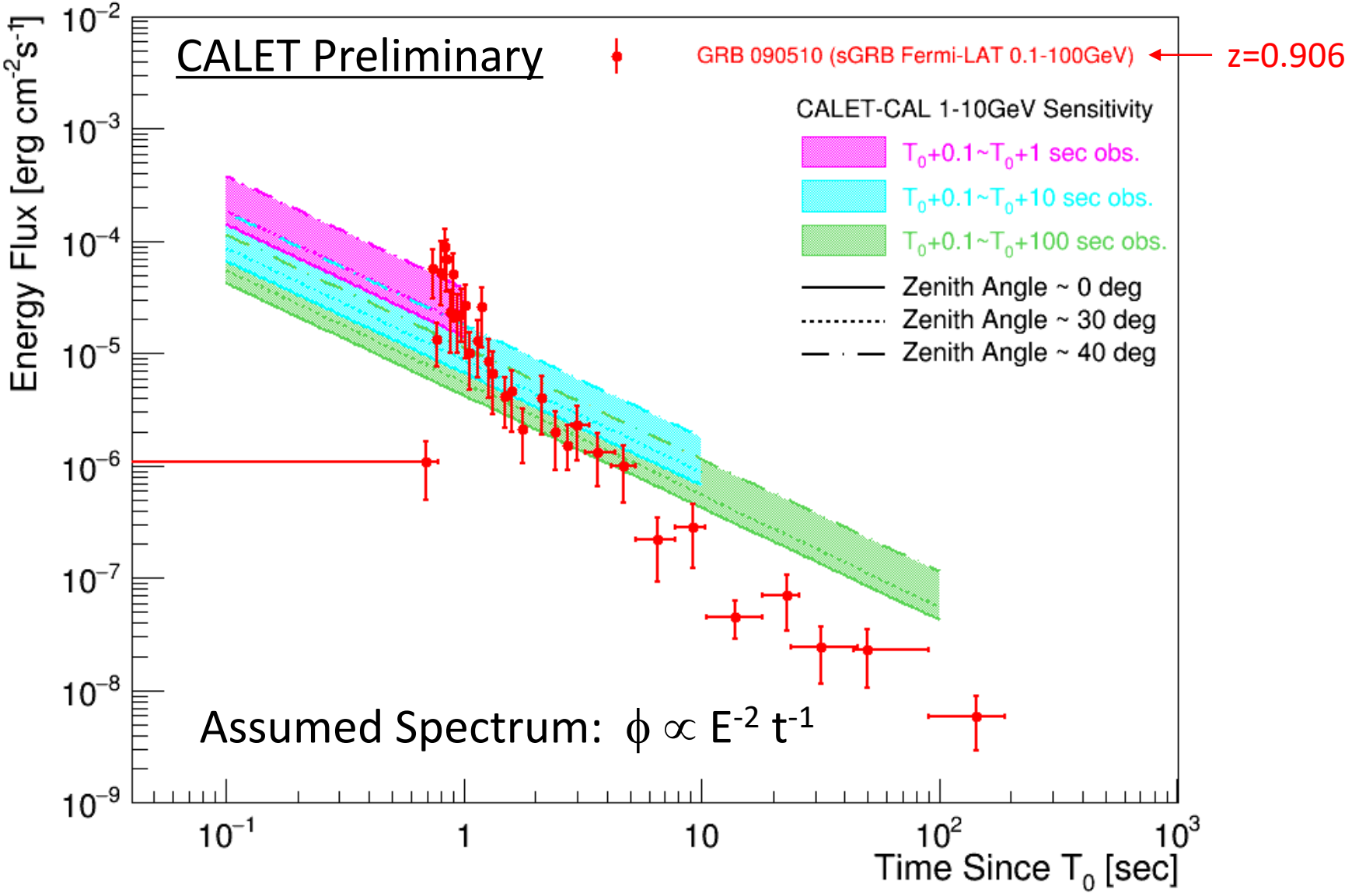






CALET Sensitivity to GeV Gamma-Rays

GeV gamma-ray emissions from short GRB coincident with GW signal could be detected by CALET-CAL given the closeness of GW candidates.



Summary & Prospects

1. **CALET was successfully launched on Aug. 19, 2015, and the detector is being very stable for observation since Oct. 13, 2015.**
2. **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 9.3×10^{-8} erg $cm^{-2} sec^{-1}$ (1-10GeV).**
3. **GeV gamma-ray counterpart seraches of other GW events during O1&O2 have been performed and limits are set if there are overlap between our FOV and LIGO/Virgo localization map.**
4. **Its sensitivity was validated with diffuse and point-source observations.**
5. **Due to closeness of GW candidates, FOV coverage is more important than deepness of counterpart search assuming on-axis short GRBs as candidates.**
6. **Automated pipeline to search for gamma-ray transient was also developed and is being implemented.**

$\Rightarrow$ **Transient objects such as GW counterparts and GRBs, as well as flaring point sources will be monitored.**

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