18aW1-4

RITSUMEIKAN

Observation of Galactic diffuse gamma-rays with CALET

CALETによる 銀河拡散ガンマ線の観測

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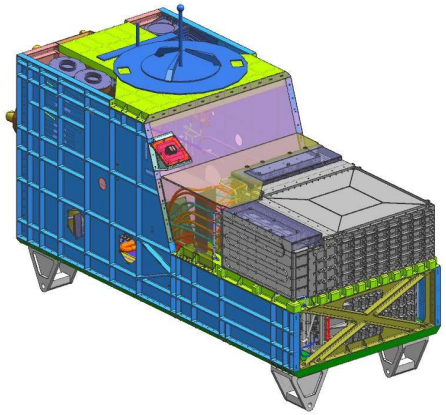
Masaki Mori, for the CALET collaboration

日本物理学会2025年春季大会（オンライン開催）2025年3月18～21日

CALET (CALorimetric Electron Telescope)



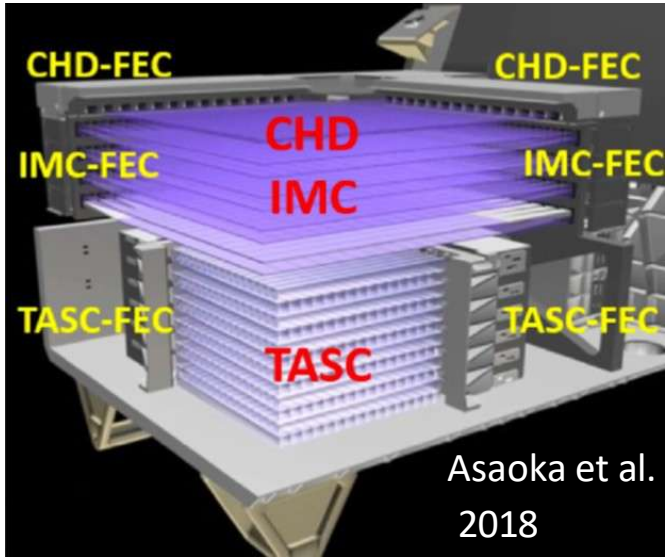
- In operation on the Japanese Experiment Module (JEM) `Kibo'-Exposed Facility of the International Space Station since 2015
- Japan-USA-Italy collaboration

Calorimeter (CAL)

Electrons: 1 GeV - 20 TeV

Gamma rays: 1 GeV – 10 TeV

Protons and nuclei: 10 GeV – 1 PeV



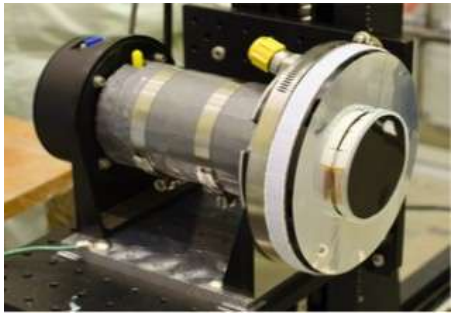
CHD
- charge

IMC
- tracking
- particle ID

TASC
- energy
- particle ID

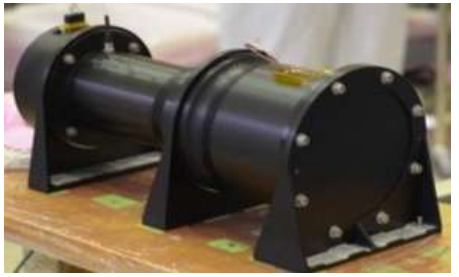
CALET Gamma Ray Burst Monitor (CGBM)

- **Hard X-ray Monitor (HXM)**



7 - 1000 keV
$LaBr_3(Ce)$ + PMT
(2 sets)

- **Soft Gamma-ray Monitor (SGM)**



0.04 – 20 MeV
BGO + PMT
(1 set)

Cannady et al., ApJS 238:5 (2018)

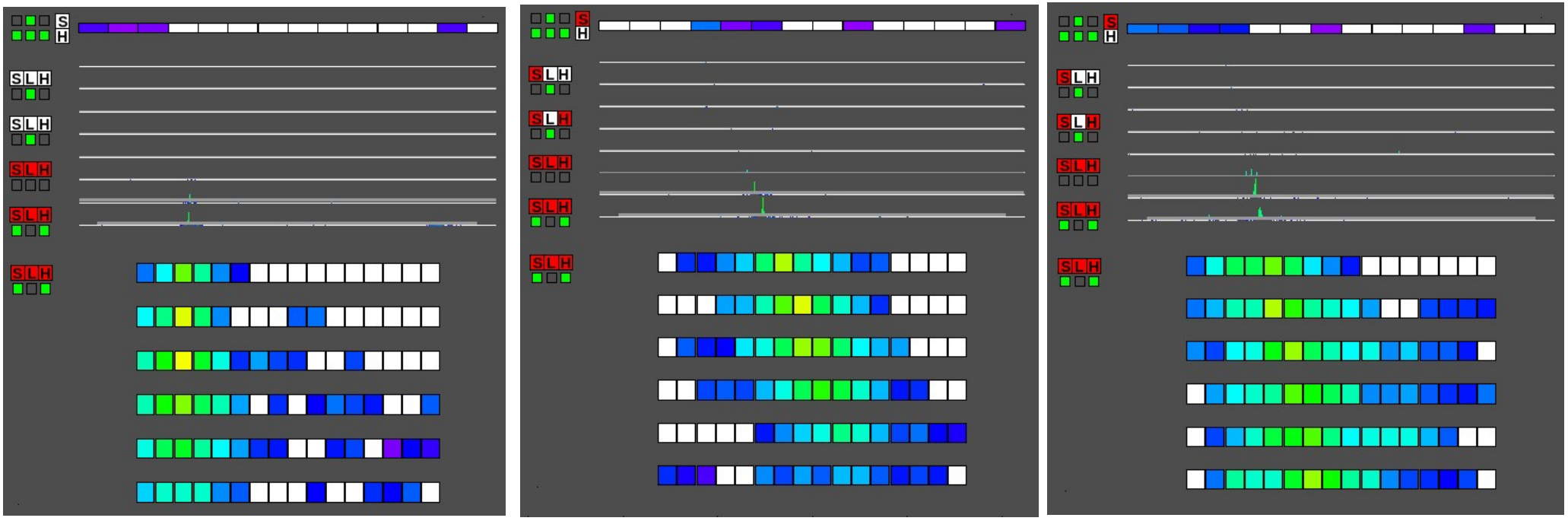
Gamma Ray Event Selection (CAL)

= 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

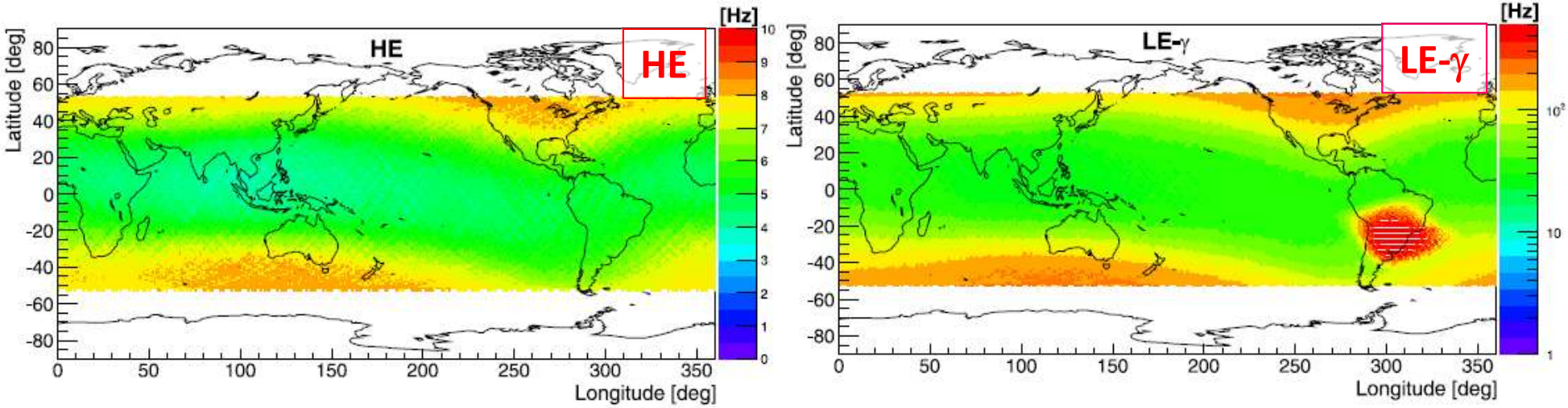


Electromagnetic Shower | Hadron Shower

well contained, constant shower development | larger spread

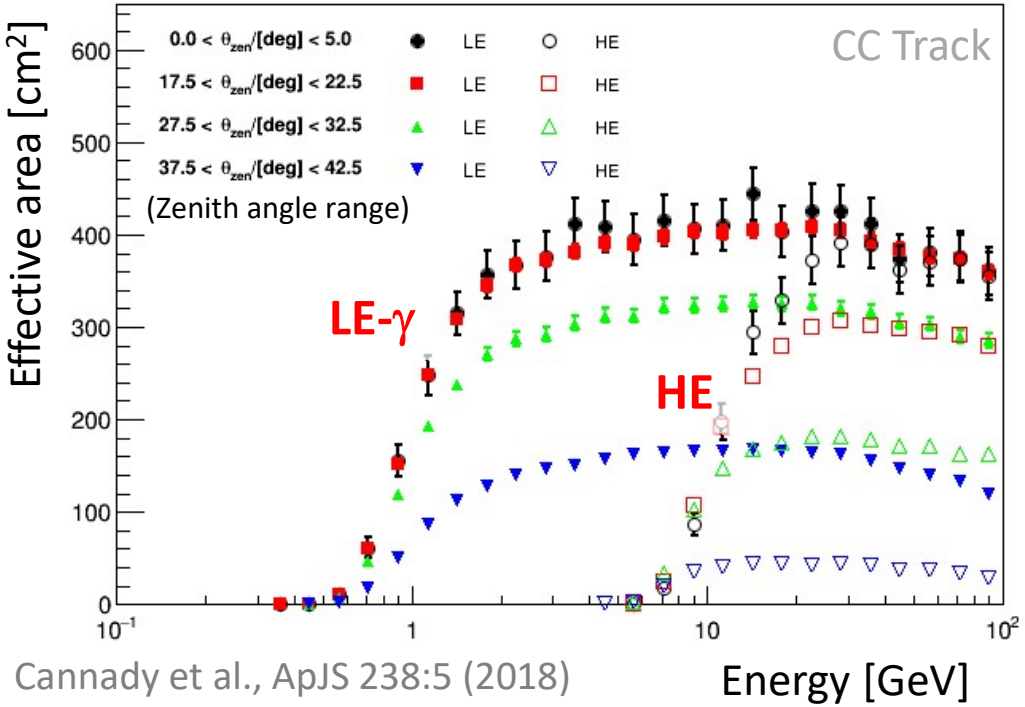
CALET triggers and gamma-ray observation

Trigger rate vs ISS location



Asaoka et al., Astropart.Phys. 100, 29 (2018)

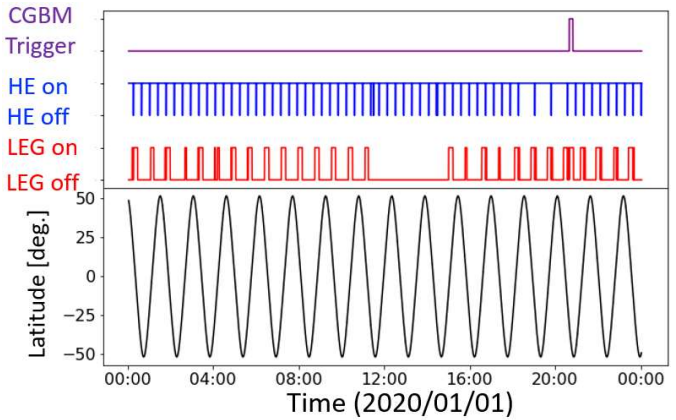
Effective area for gamma rays



Cannady et al., ApJS 238:5 (2018)

HE trigger: E_γ > 10 GeV
LE-γ trigger: E_γ > 1 GeV

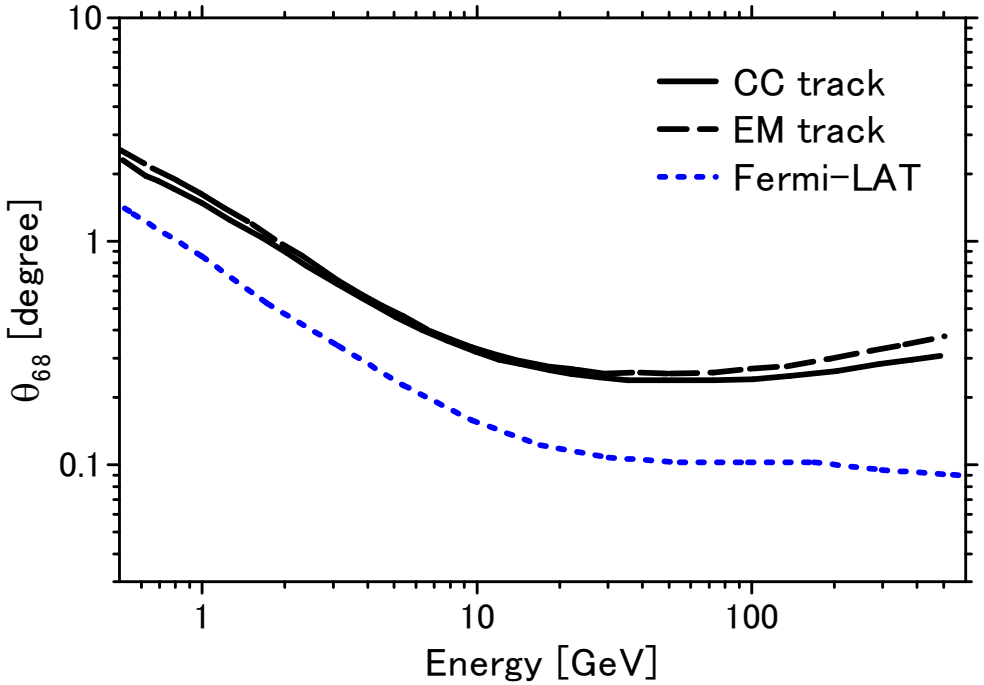
- HE trigger mode: always ON
- LE-γ mode: ON if geomag. Lat. < 20° or CALET Gamma-ray Burst Monitor (CGBM) is triggered



CALET/CAL performance

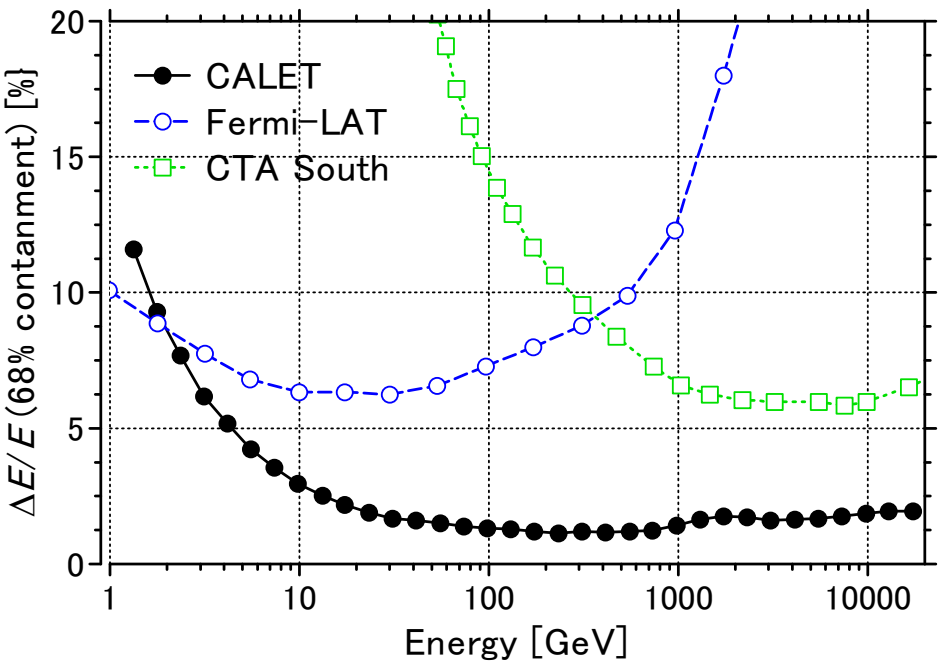
- **HE** trigger (>10 GeV) is always active in normal observations
- **LE-γ** trigger (>1 GeV) mode is activated when the geomagnetic latitude is below 20° or following a CALET Gamma-ray Burst Monitor (CGBM) burst trigger

Angular resolution



Cannady et al., ApJS 238, 5 (2018)

Energy resolution



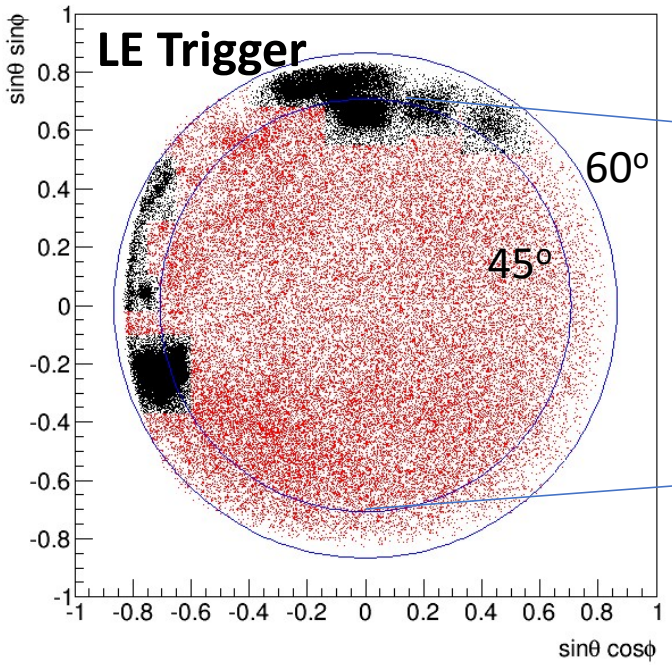
Asaoka et al, Astropart. Phys. 91, 1 (2017)

- Good energy resolution at high energies thanks to the thick calorimeter!

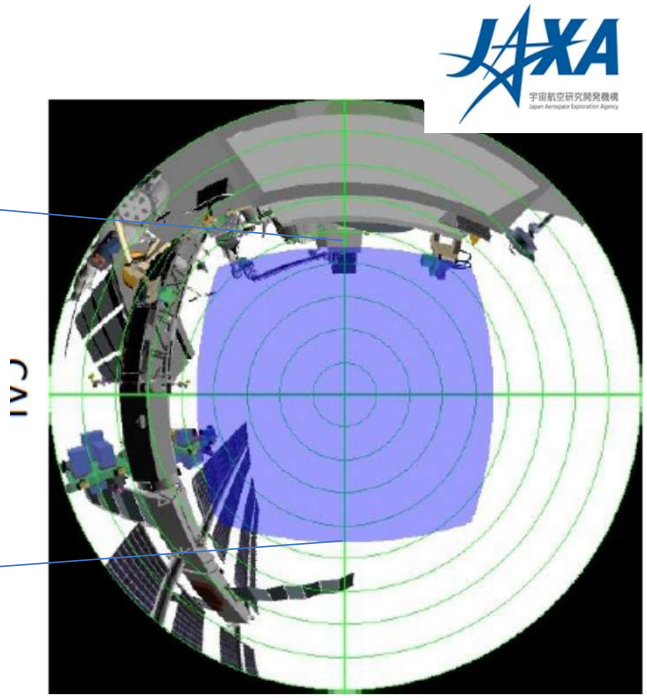
Gamma Ray Event Selection in CAL

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

It was found that secondary gamma rays produced in ISS structures are dominant source of background.



Gamma-ray candidates in CALET FOV



Fish-eye view of CALET FOV

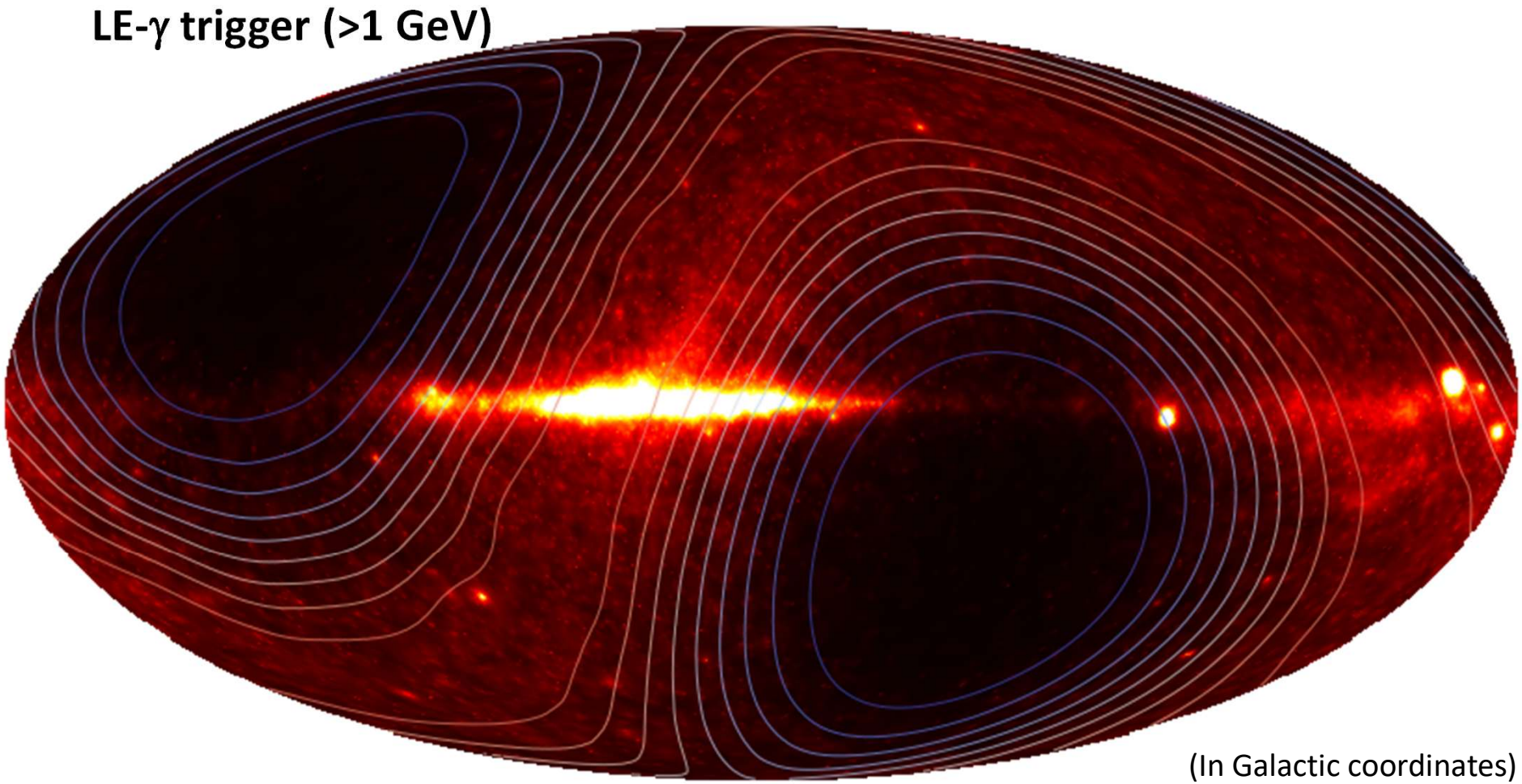
1. Geometry Condition
   - CHD-Top to TASC 1st layer (2cm margin)
2. Preselection
   - Offline trigger
   - Shower concentration
   - Shower starting point
3. Track quality cut
   - Track hits >2
   - matching w/ TASC
4. Electromagnetic shower selection
   - shower shape
5. Gamma-ray ID
   - CHD-veto
6. FOV cut

By removing Black parts, it is possible to reject majority of such background. More sophisticated rejection method is under development.

Gamma-ray skymaps

Preliminary

November 2015 – December 2022



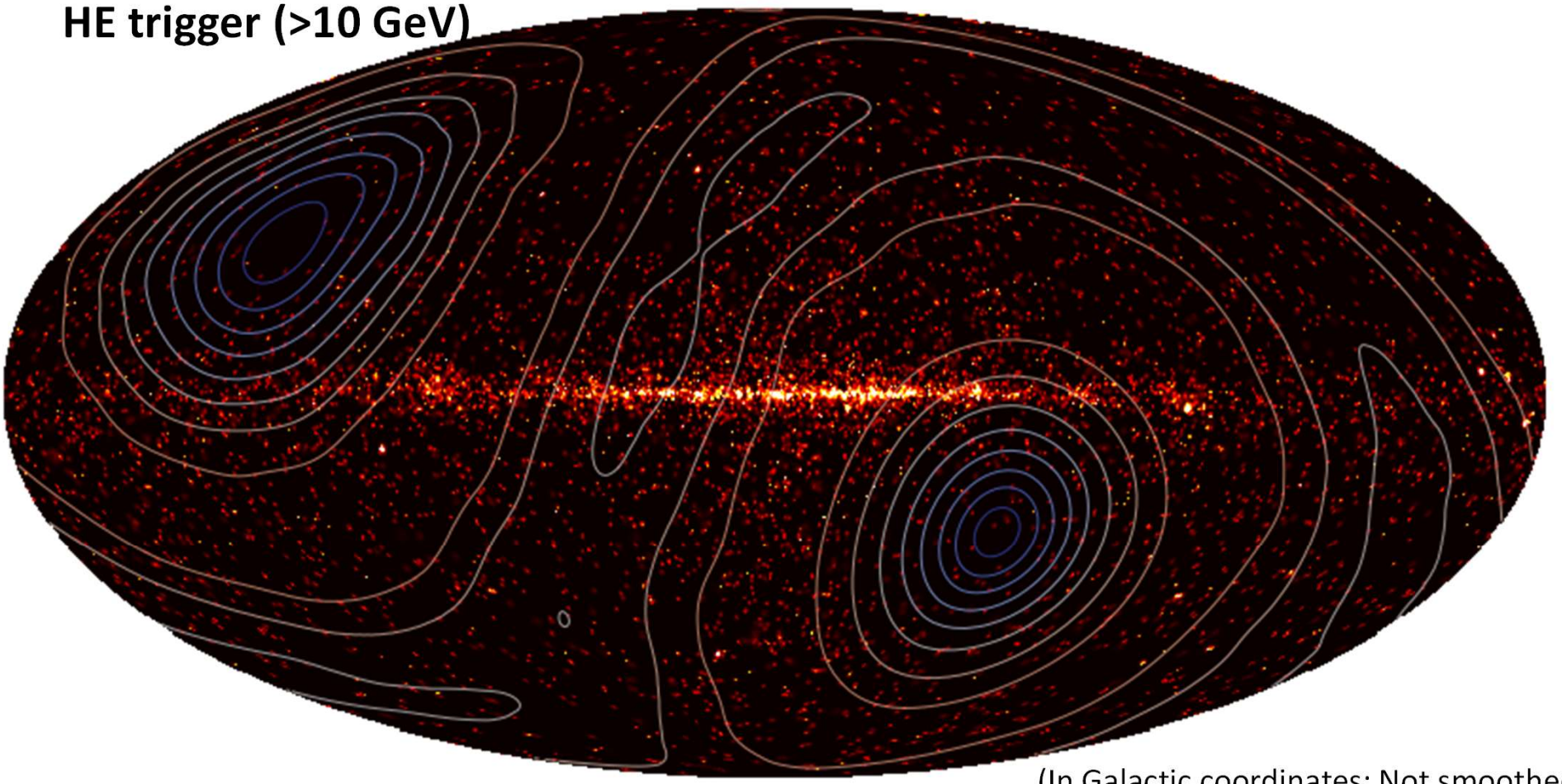
(In Galactic coordinates)

Note: Exposure (shown by contours) is not uniform due to the ISS orbit (inclination 51.6°)

Gamma-ray skymaps

Preliminary

November 2015 – December 2022



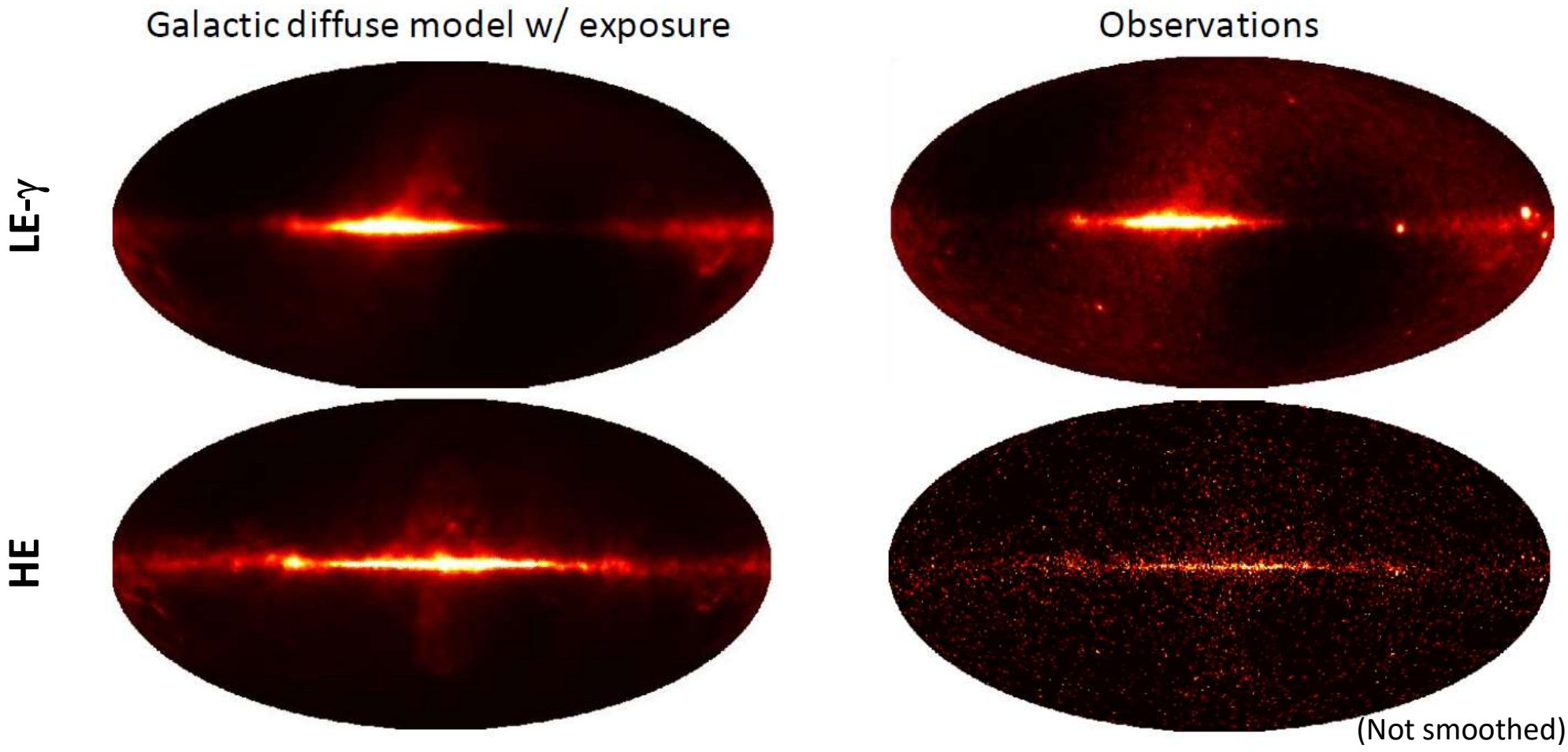
(In Galactic coordinates; Not smoothed)

Note: Exposure (shown by contours) is not uniform due to the ISS orbit (inclination 51.6°)

Gamma-ray skymaps

November 2015 – February 2022

Preliminary

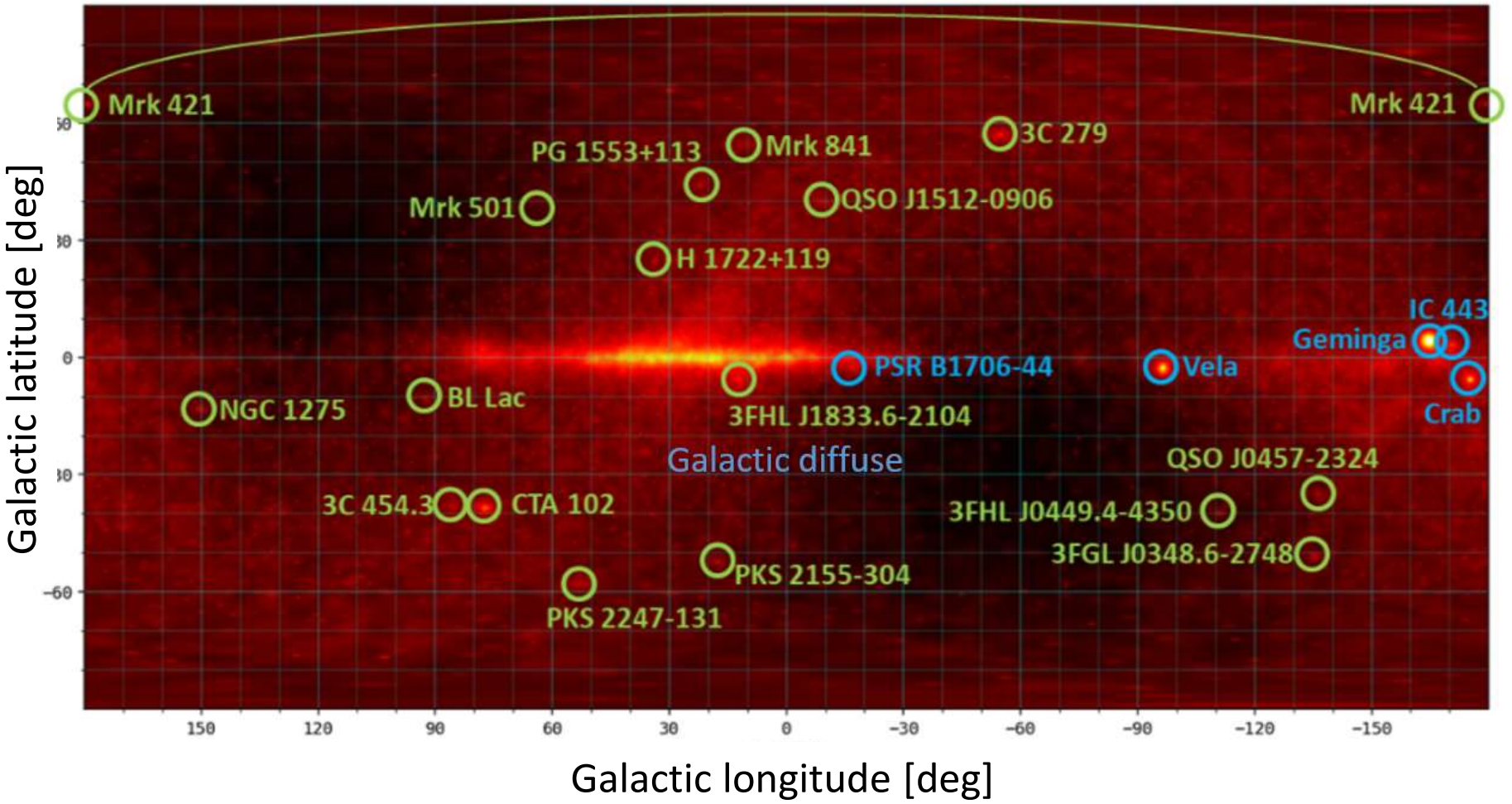


Note: Exposure is not uniform due to the ISS orbit (inclination 51.6°)

Point sources (LE-γ, >1 GeV)

Preliminary

November 2015 – July 2020



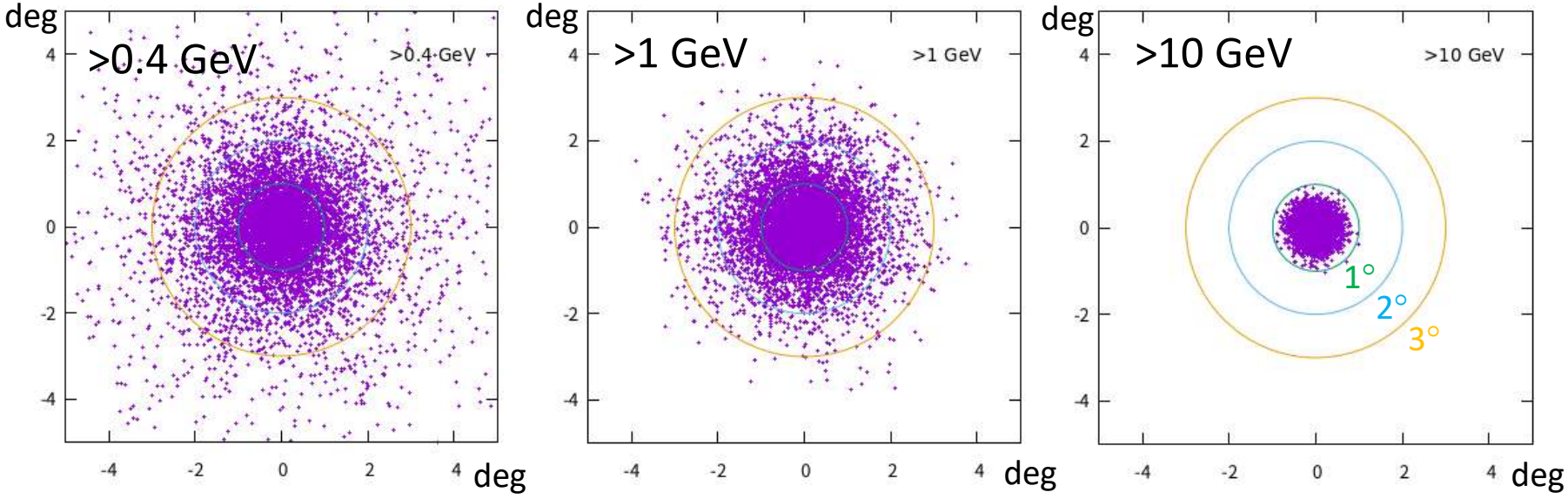
- >20 point sources (Crab, Geminga, Vela, CTA102,…) have been detected.

Point source detection – simple method

- ON region : $\Delta\theta \leq 1°$
- OFF region : $2° \leq \Delta\theta \leq 3°$
- Li-Ma (1983) significance

$$S = \frac{N_S}{\hat{\sigma}(N_S)} = \frac{N_{on} - \alpha N_{off}}{\sqrt{\alpha(N_{on} + N_{off})}}$$

($\alpha = A_{ON}/A_{OFF}$)



(<1°, <2°, <3°) ↔ (56% / 81% / 91%)

(67% / 92% / 99%)

(99.9% / ~100% / 100%)

(Toy M.C. simulation assuming observed energy spectra)

Preliminary

Sources ($S \geq 5$) from LE triggers

≥ 1 GeV, 2015 Oct - 2020 Sep, 4.3×10^5 events, 3FHL catalog (M. Ajello et al 2017 ApJS 232 18)

	Name	RA(°)	Dec(°)	S
1	Crab	83.6	22	5.0
2	IC 443	94.3	22.6	6.4
3	3FGL_J0619.4+2242	94.9	22.7	7.6
4	Geminga	98.5	17.8	9.4
5	Vela Pulsar	128.8	-45.2	13.0
6	Mkn 421	166.1	38.2	5.4
7	1ES 1215+303	184.5	30.1	7.2
8	PSR J1410-6132	212.4	-61.5	10.8
9	Kookaburra (Rabbit)	214.7	-61	13.8
10	PG 1553+113	238.9	11.2	5.0
11	HESS J1632-478	248.2	-47.8	17.4
12	3FGL_J1636.2-4709c	249.1	-47.2	18.6

	Name	RA(°)	Dec(°)	S
13	PSR J1709-4429	257.4	-44.5	19.8
14	Galactic Center	266.4	-29	22.4
15	3FGL_J1748.3-2815c	267.1	-28.3	23.4
16	3FGL_J1814.0-1757c	273.5	-18	20.2
17	LAT PSR J1826-1256	276.5	-12.9	23.0
18	HESS J1837-069	279.1	-6.9	17.8
19	HESS J1848-018	282.1	-1.7	16.2
20	3C 391	282.4	-1	21.4
21	3FGL_J1857.8+0129c	284.5	1.5	18.2
22	PKS 2155-304	329.7	-30.2	8.2
23	CTA 102	338.1	11.7	5.2

(Possibly confused sources are unified.)

Preliminary

Sources ($S \geq 5$) from HE triggers

No E cut, 2015 Oct - 2020 Sep, 9.8×10^4 events, 3FHL catalog (M. Ajello et al 2017 ApJS 232 18)

	Name	RA(°)	Dec(°)	S
1	Crab	83.6	22	15.0
2	IC 443	94.3	22.6	6.0
3	Geminga	98.5	17.8	44.1
4	Vela Pulsar	128.8	-45.2	25.6
5	3C 279	194	-5.8	5.7
6	3FGL_J1726.6-3530c	261.7	-35.5	5.4
7	Galactic Center	266.4	-29	8.9
8	W28	270.3	-23.4	6.7
9	LAT PSR J1803-2149	270.8	-21.8	5.3
10	3FGL_J1814.1-1734c	273.5	-17.6	6.6
11	LAT PSR J1826-1256	276.5	-12.9	8.9

	Name	RA(°)	Dec(°)	S
12	3FGL_J1828.4-1121	277.1	-11.4	6.9
13	3FGL_J1833.9-0711	278.5	-7.2	5.5
14	W41	278.6	-8.7	6.4
15	HESS J1837-069	279.1	-6.9	9.2
16	LAT PSR J1838-0537	279.7	-5.6	8.2
17	3C 391	282.4	-1	5.1
18	W44	284	1.4	9.0
19	W49B	287.7	9.1	6.2
20	W51C	290.8	14.1	6.3
21	CTA 102	338.1	11.7	11.8

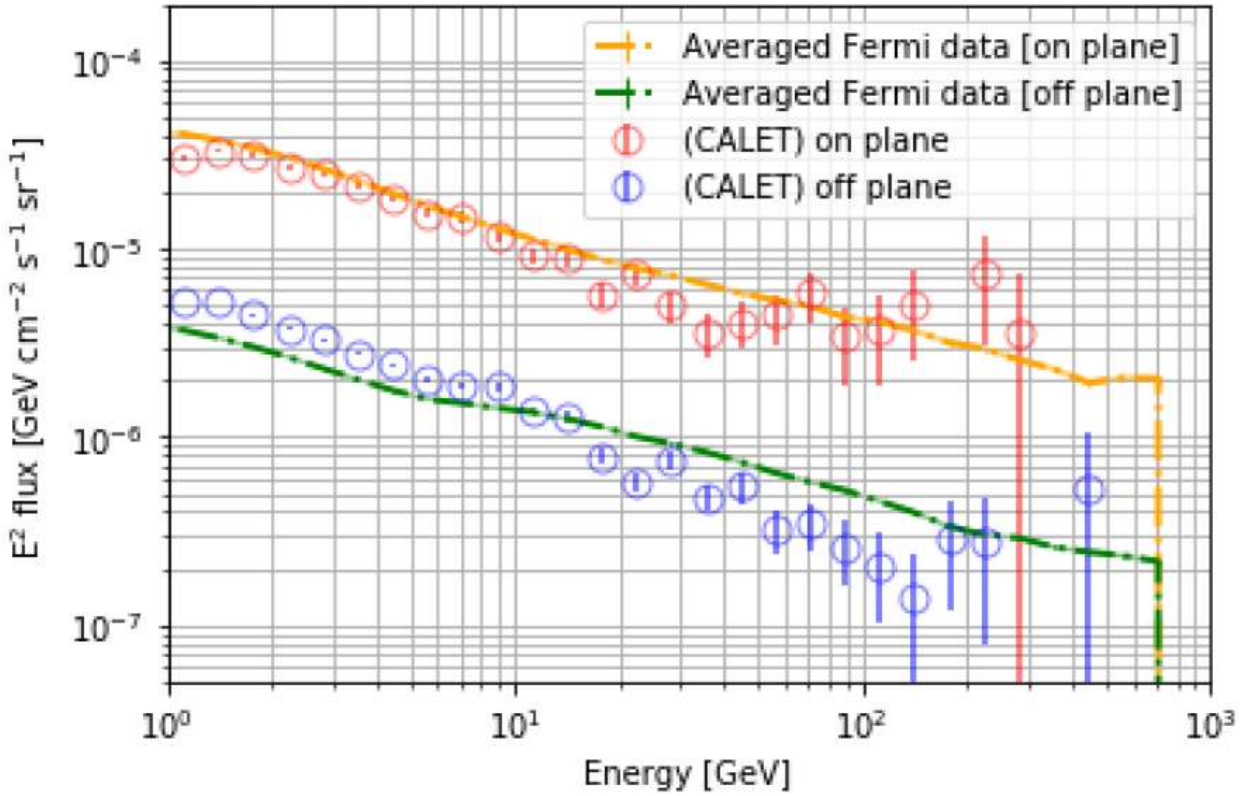
(Possibly confused sources are unified.)

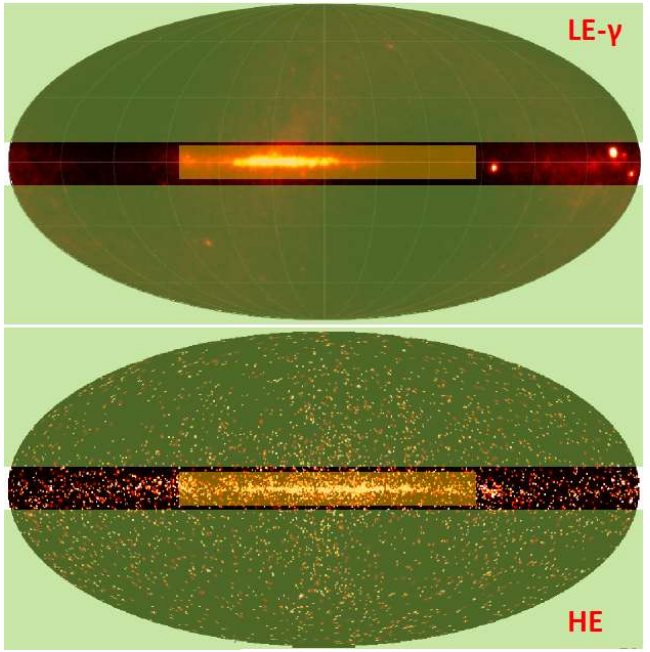
Gamma-ray spectra (LE-γ & HE)

Preliminary

LE-γ + HE November 2015 – February 2022

(Fermi data: analyzed from public data.)



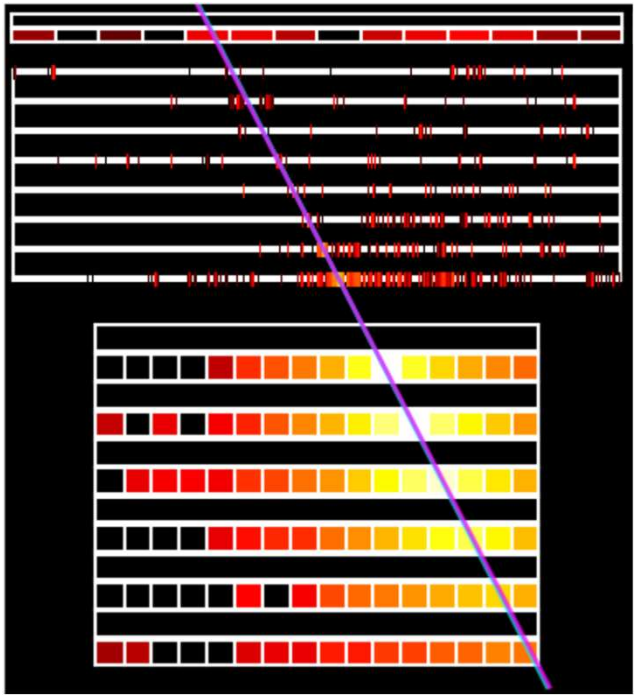


"**On-plane**": $|l| < 80°$ & $|b| < 8°$, "**Off-plane**": $|b| > 10°$

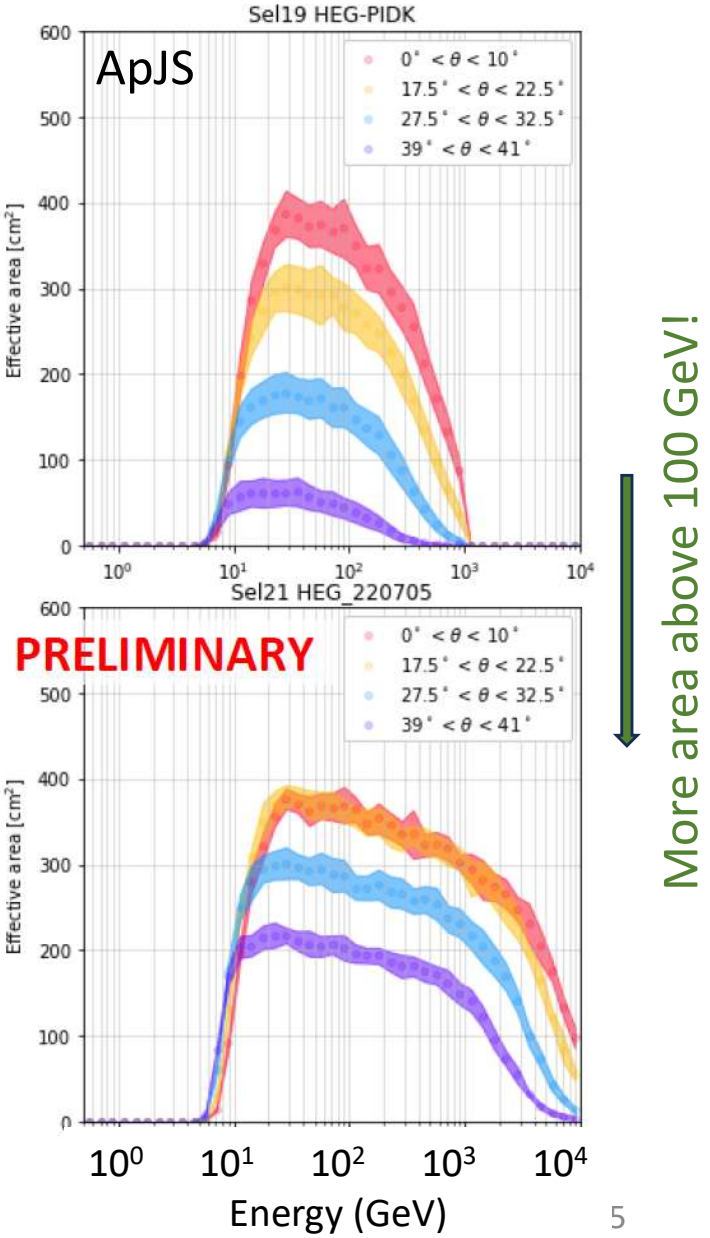
- The spectra (Galactic diffuse + point sources) look fairly consistent with those by Fermi-LAT.

Improvements to HE sensitivity

- At higher energies, charge selection with CHD becomes contaminated with backscattered secondary particles.

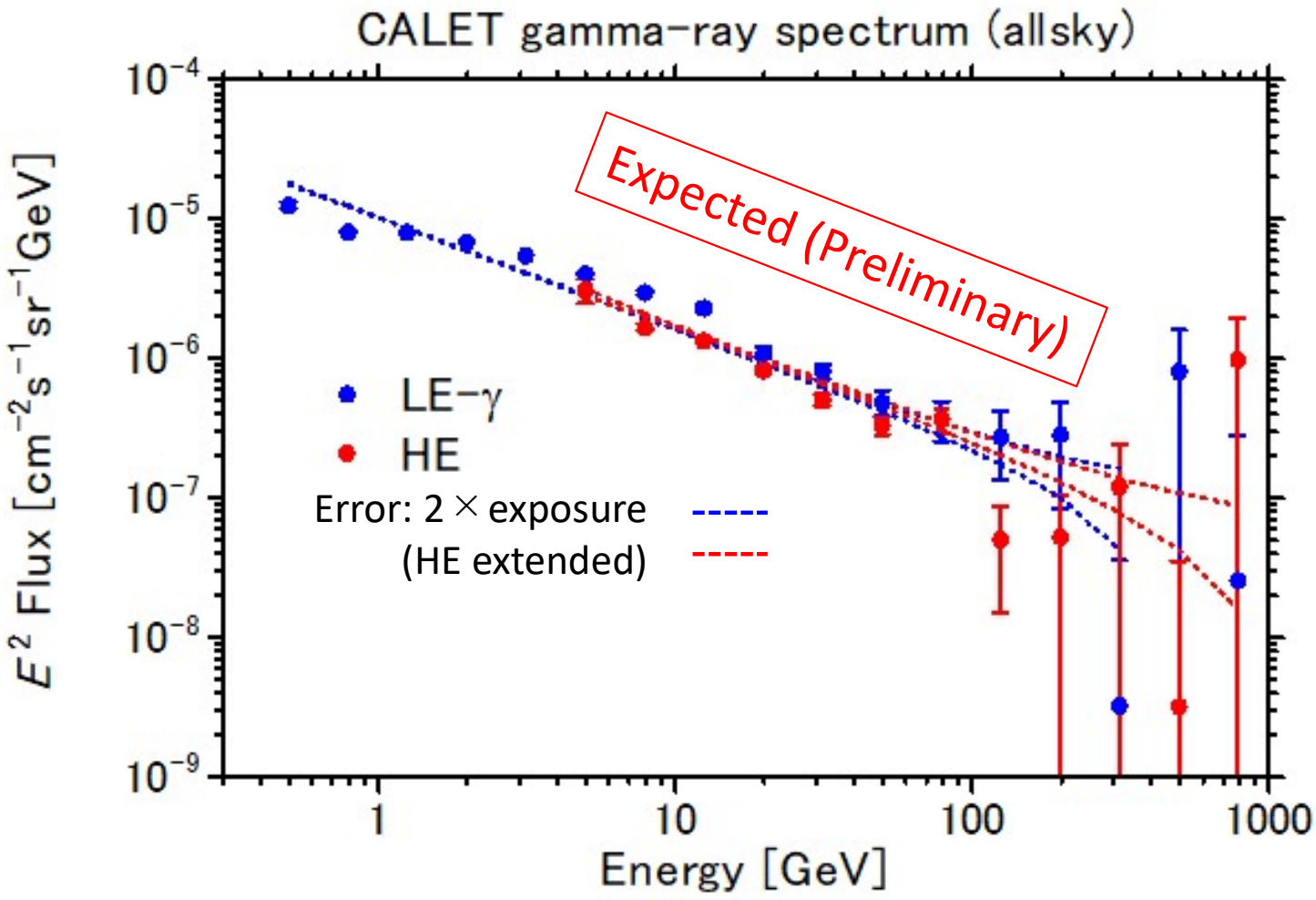


- New selection defined to use looser cuts in CHD and incorporating first two layers of IMC for charged primary rejection
- Preliminary results show significant increase in effective area $E > 100$ GeV
- Testing of selection and contamination being finalized for implementation in all analyses soon!



Gamma-ray spectra will be updated soon!

In 2025, exposure will be increased by 2 times and HE analysis update



Summary

- CALET/CAL is monitoring the gamma-ray sky continuously since 2015.
- CAL observes gamma rays above 1 GeV and tens of point sources are detected.
- Improvement to increase effective area of CAL above 100 GeV is ongoing.
- Although they are smaller than Fermi-LAT and GBM, the sky coverage is complementary.
- Updated results will be presented in ICRC2025. Stay tuned!