



Analysis of High-energy Gamma-rays observed with CALET for five years

CALETの5年間の観測に基づく 高エネルギーガンマ線の解析

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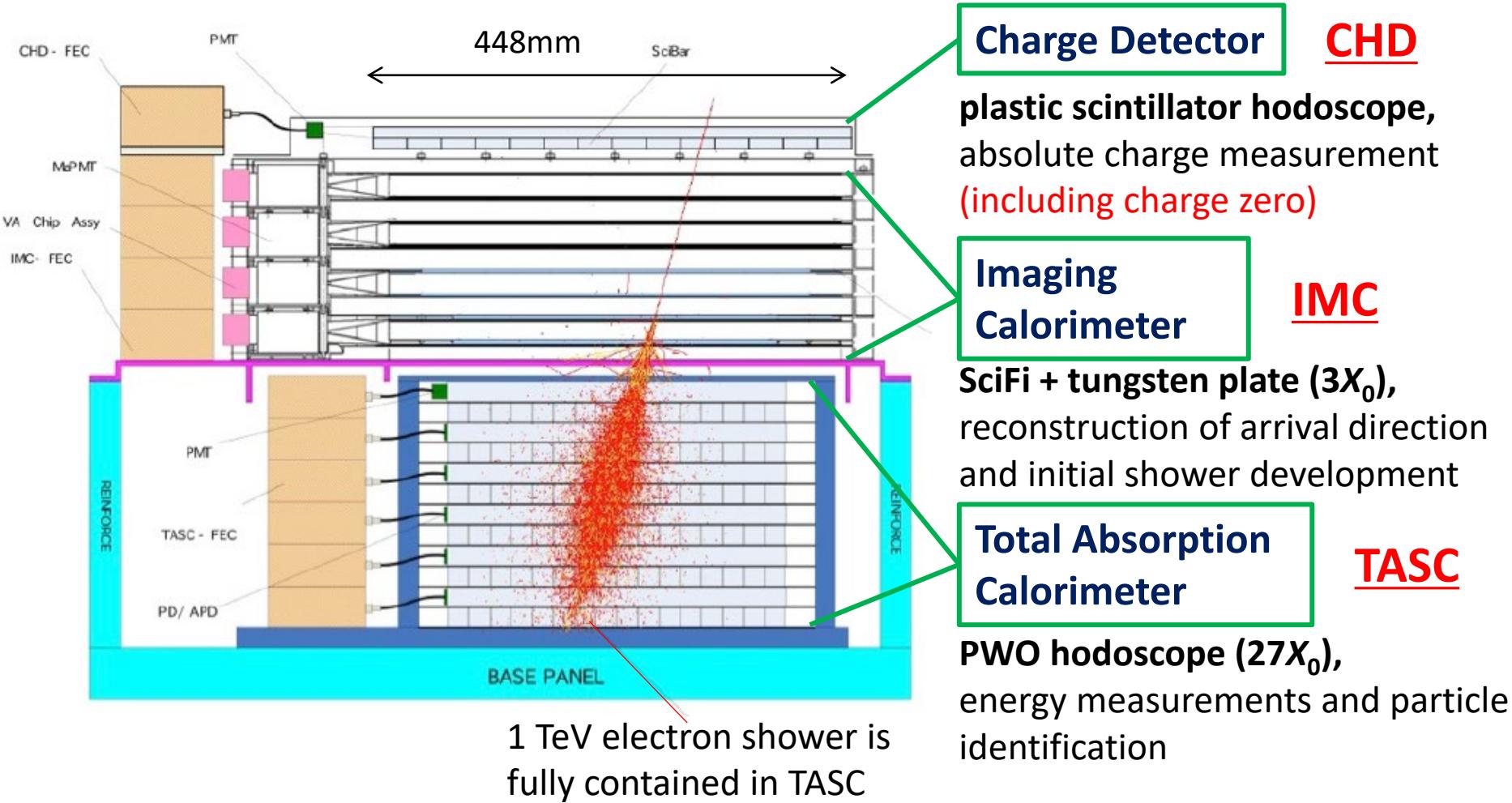
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CALET/CAL Detector

Fully active thick calorimeter (30 radiation lengths [X_0]) optimized for electron spectrum measurements well into TeV region



See next talk (16aW2-6: Kawakubo et al.) for CALET/CGBM results

Gamma Ray Event Selection

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

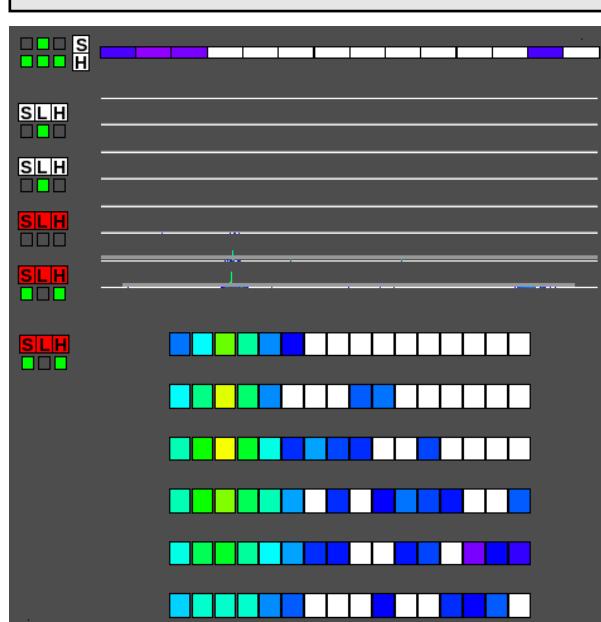
100 GeV Event Examples

gamma-ray

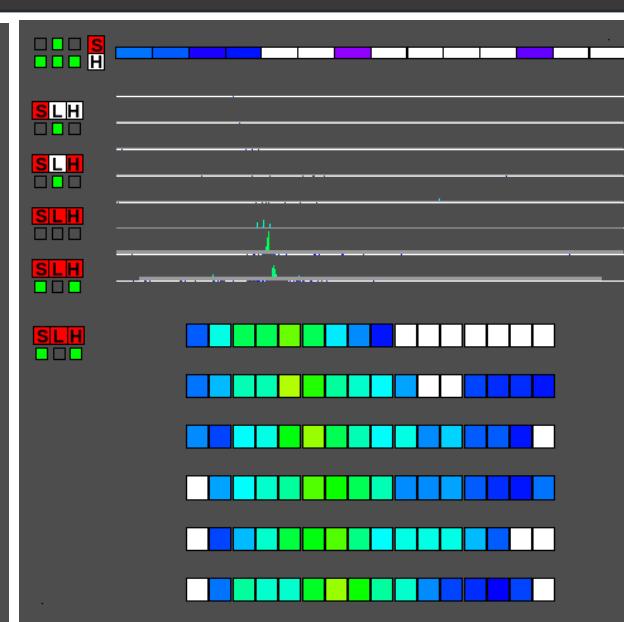
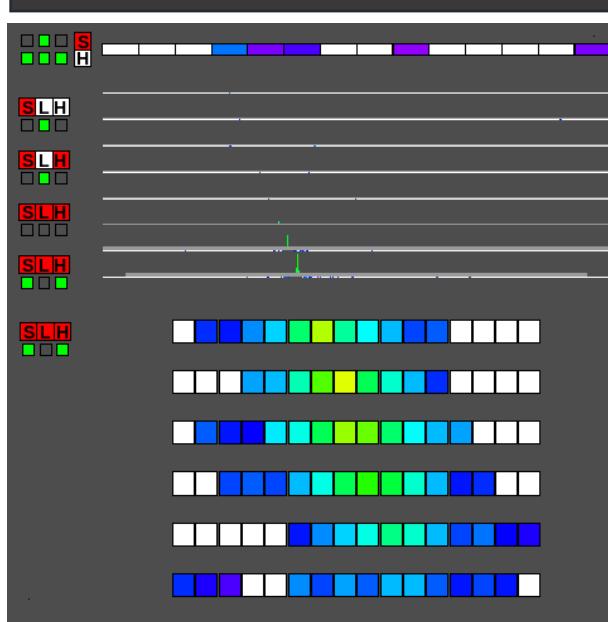
electron

proton

Charge Z=0



Charge Z=1



Electromagnetic Shower

well contained, regular shower development

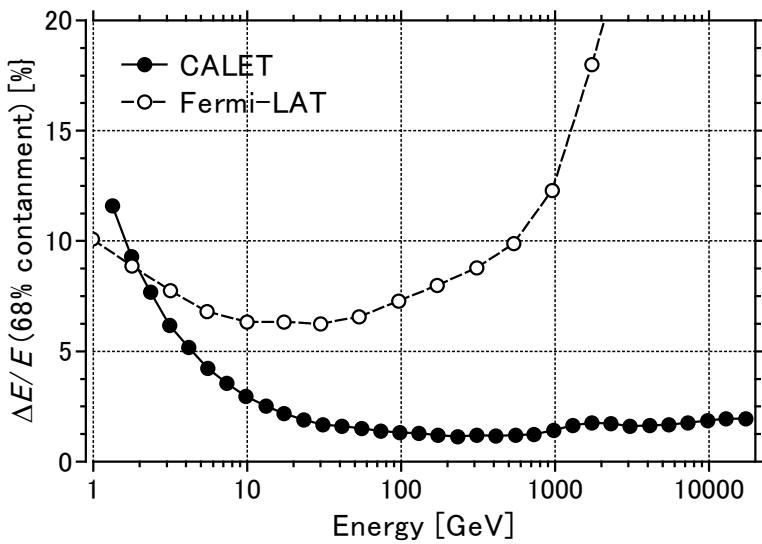
Hadron Shower

larger spread 4

CALET performance for HE trigger

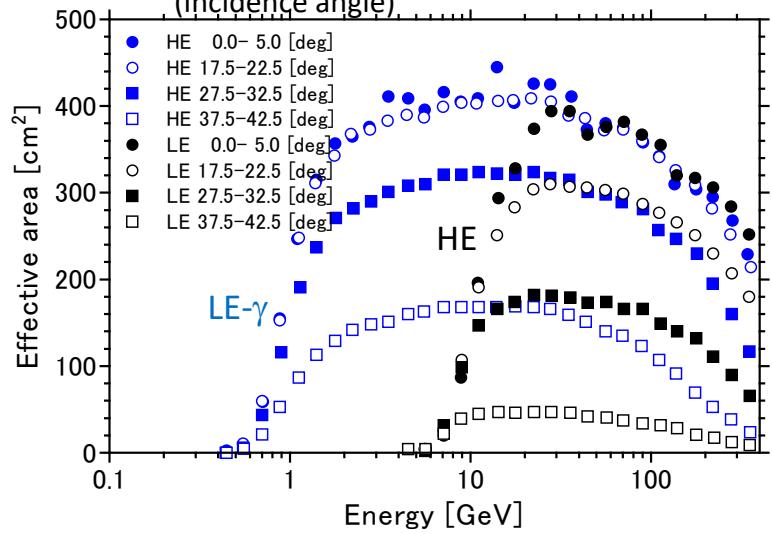
- HE trigger (>10 GeV) is always active in normal observations
- LE- γ trigger (>1 GeV) mode is activated when the geomagnetic latitude is below 20° or following a CALET Gamma-ray Burst Monitor (CGBM) burst trigger

Energy resolution



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

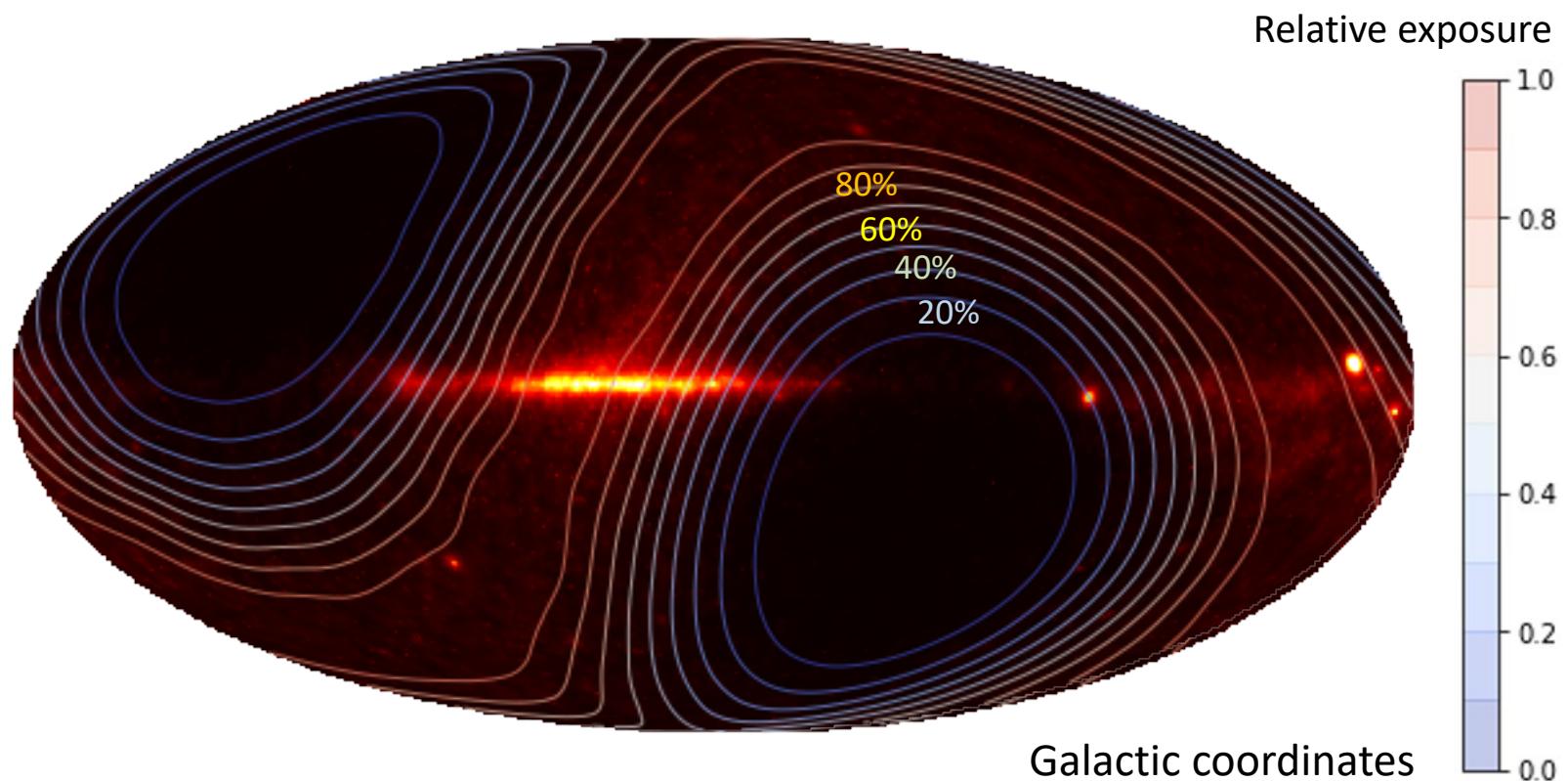
Effective area (for gamma rays)



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

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

Skymap (LE- γ trigger, >1 GeV)



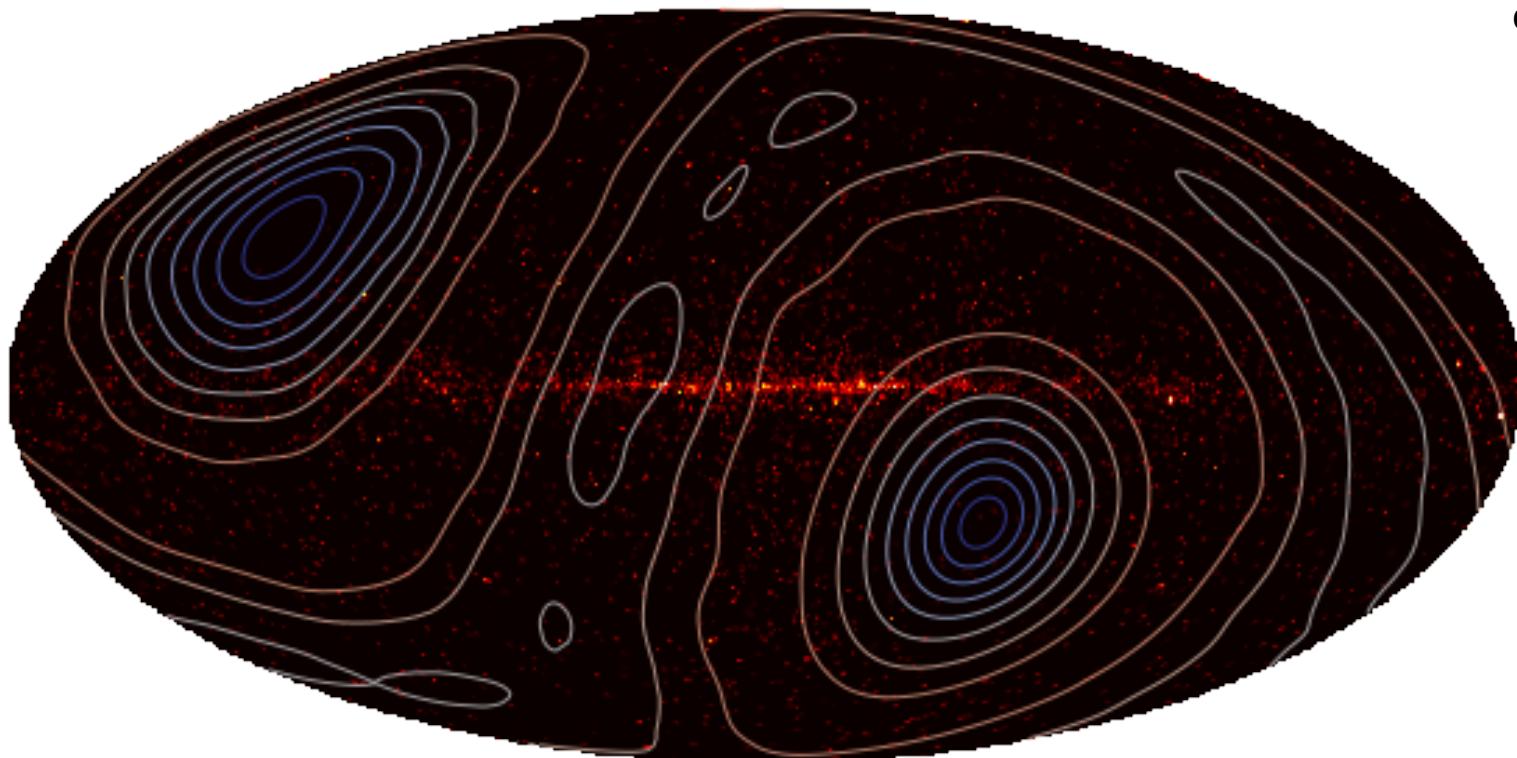
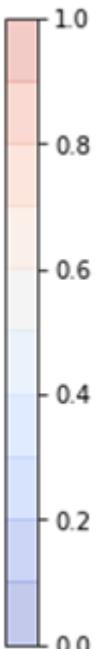
Skymap (HE trigger, >10 GeV)

Preliminary

October 13, 2015 – September 30, 2020

110,855 gamma-ray candidates

Relative
exposure



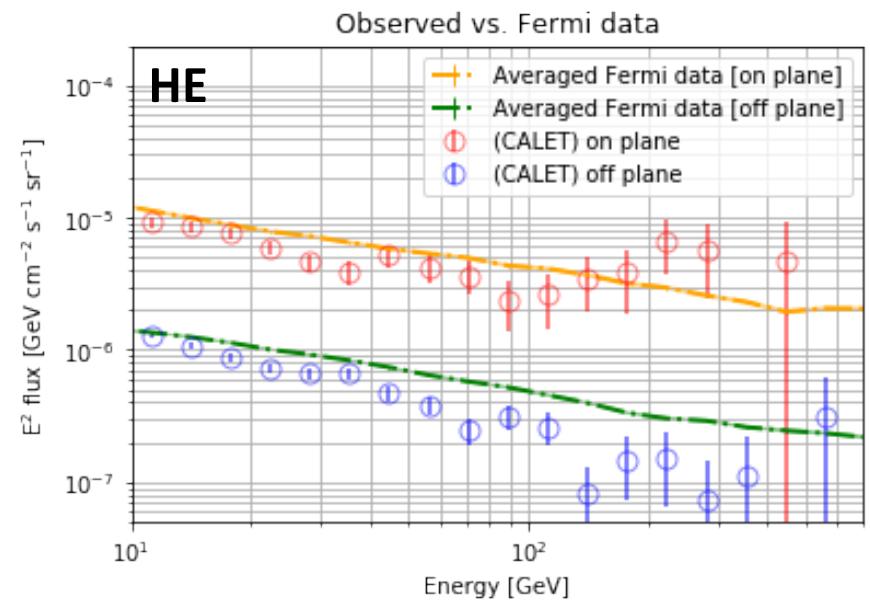
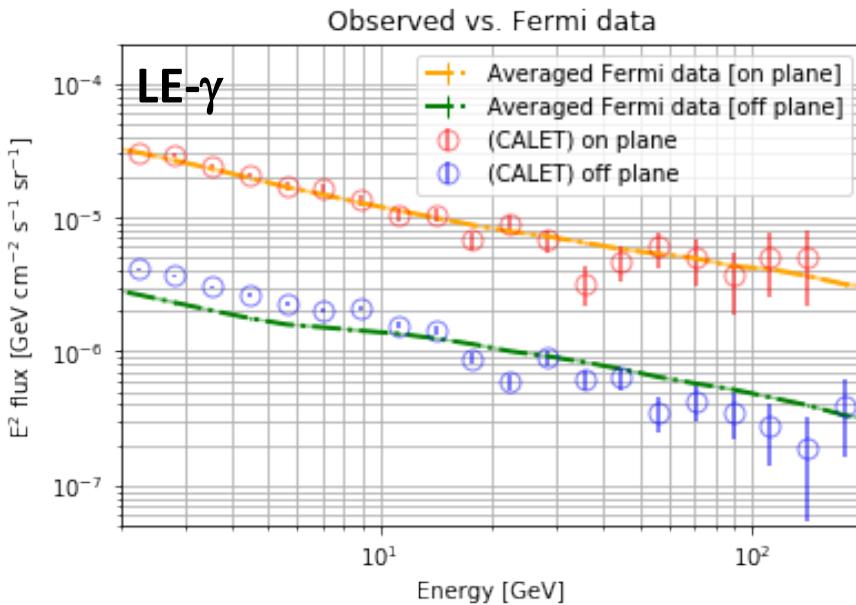
Galactic coordinates

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

Gamma-ray spectra (LE- γ & HE)

Preliminary

October 13, 2015 – September 30, 2020

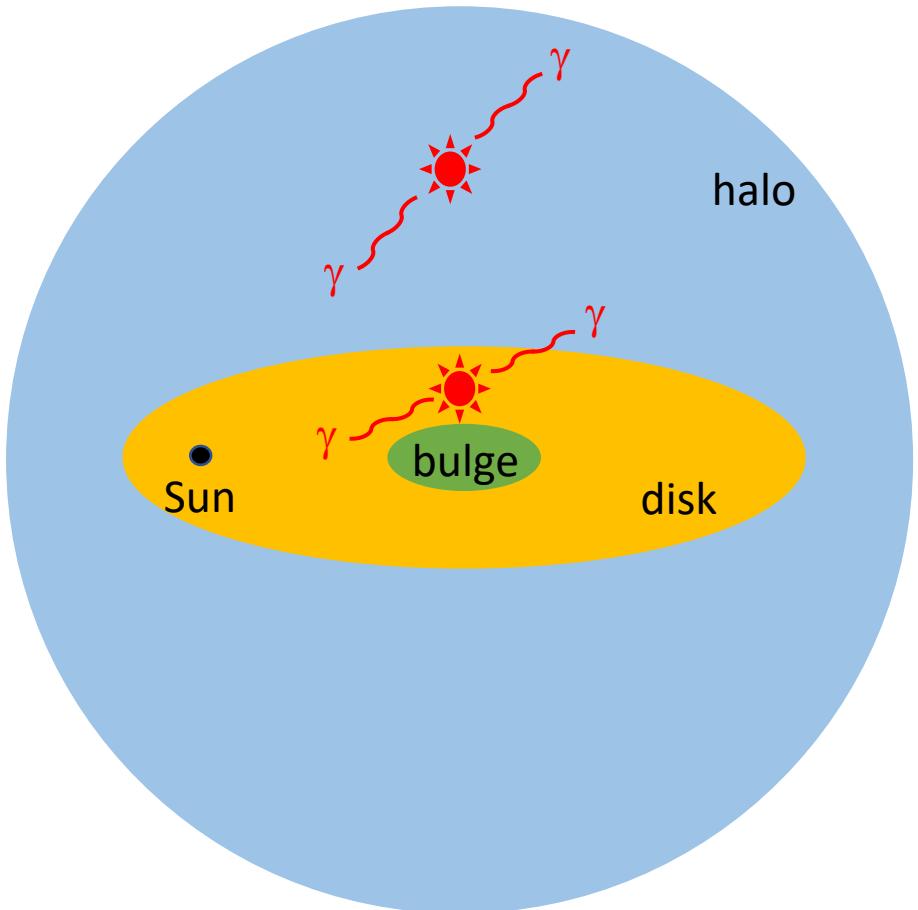
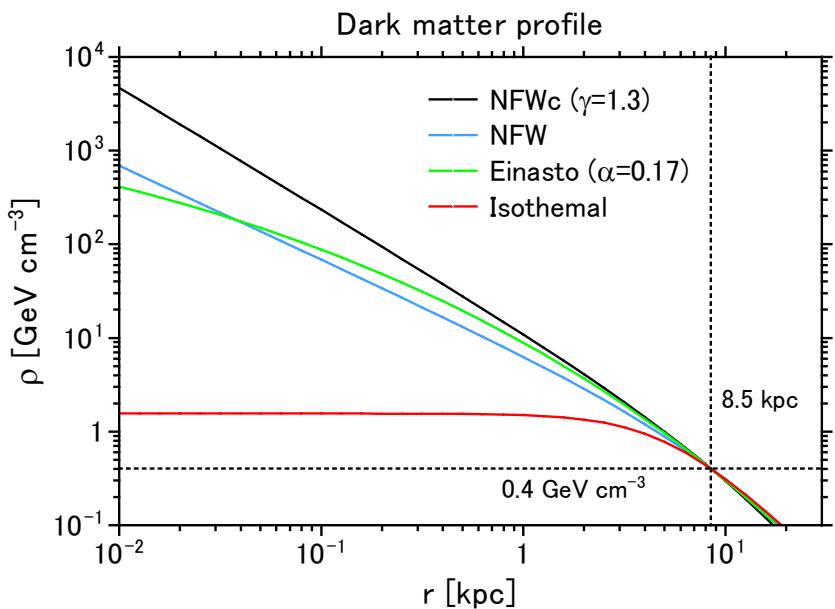


“On-plane”: $|l| < 80^\circ$ & $|b| < 8^\circ$, “Off-plane”: $|b| > 8^\circ$

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

Dark matter distribution

- Dark matter halo is associated with our Galaxy and distributes spherically.
- Typical velocity:
 $v \sim O(10^{-3})c$



Profile is highly model dependent...
→ 4 models are assumed here.

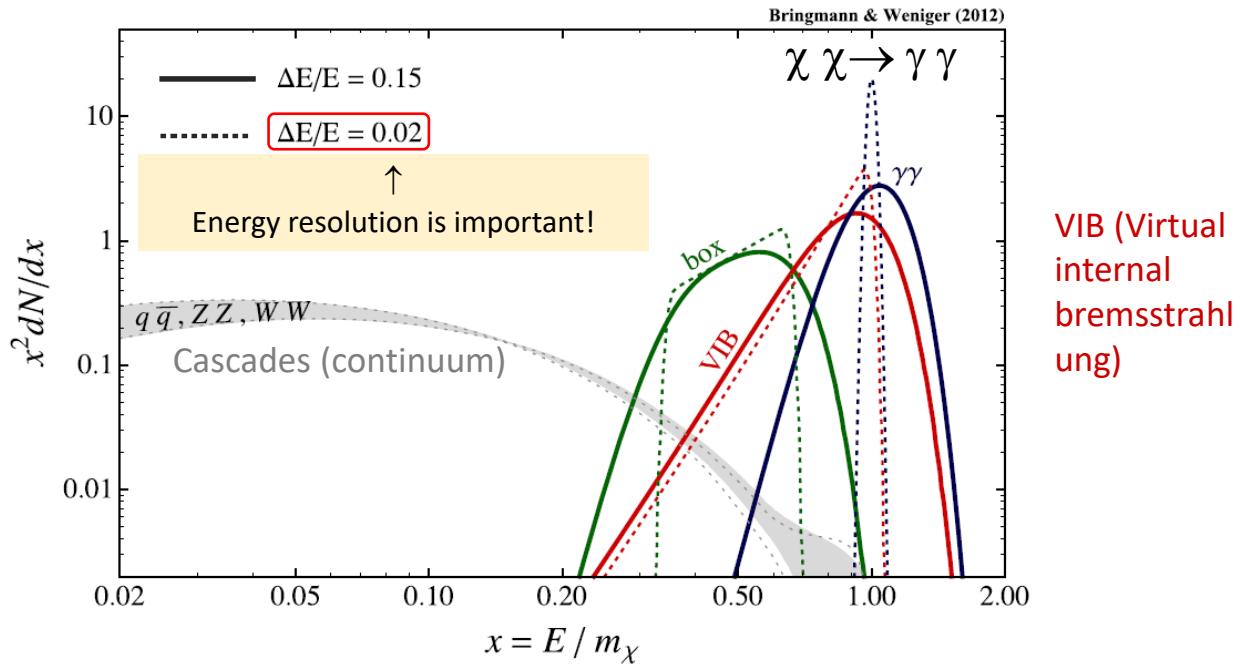
Ref. Ackermann+, PR D91, 122002 (2015)

Line signals from dark matter interaction

Annihilation: $\chi \chi \rightarrow \gamma \gamma$ etc., $E_\gamma = m_\chi$

T. Bringmann, C. Weniger / Dark Universe 1 (2012) 194–217

Note that generally the branching ratio into $\gamma\gamma$ suffers suppression ($< 10^{-3}$).



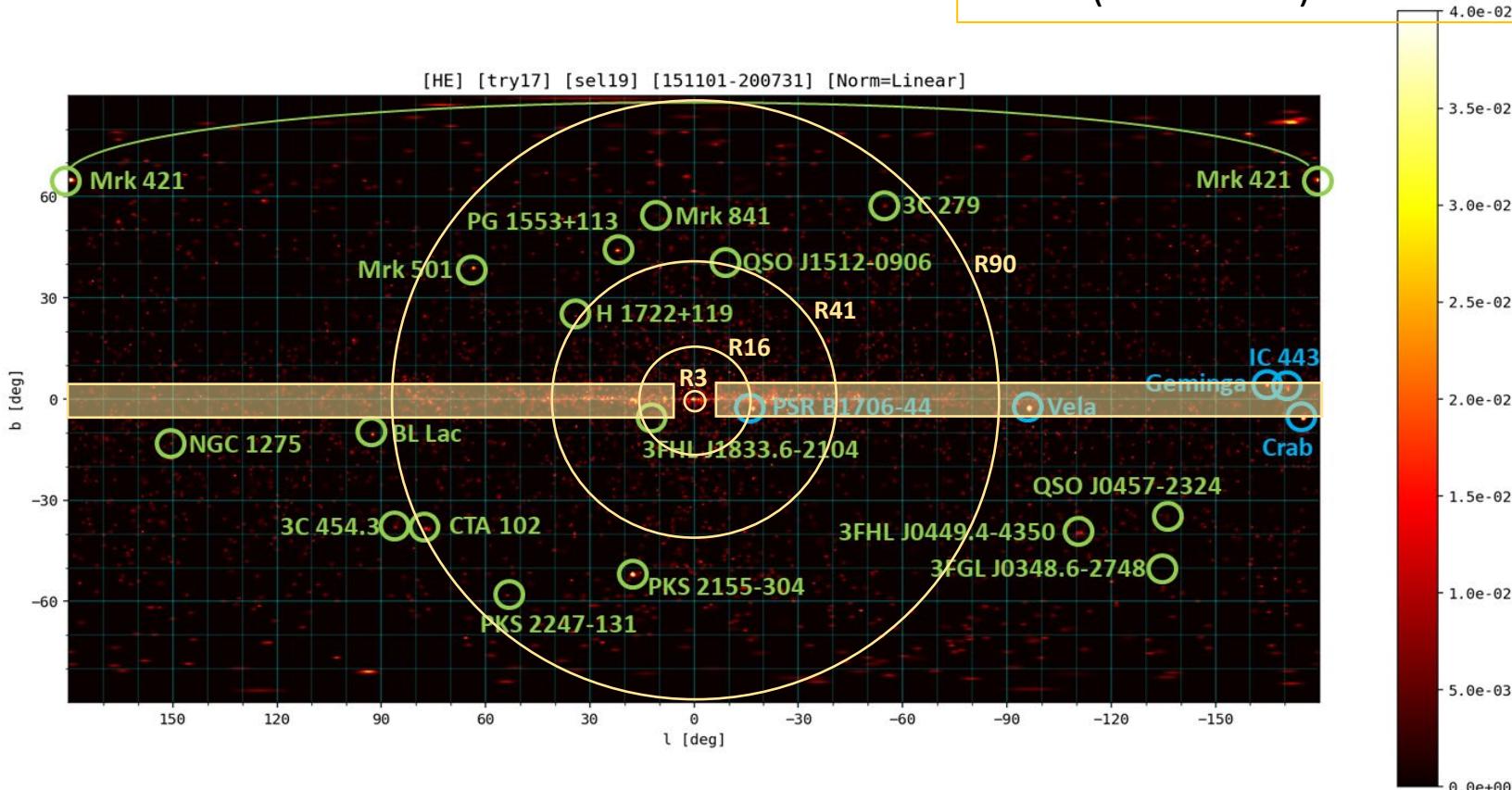
Decay: $\chi \rightarrow \gamma \nu$ etc., $E_\gamma = m_\chi/2$

Ibarra and Tran, PRL 100, 061301 (2008)

Regions of interest (ROI)

R (angular distance from GC)

- <3° (NFWc profile)
- <16° (Einasto profile)
- <41° (NFW profile)
- <90° (isothermal)

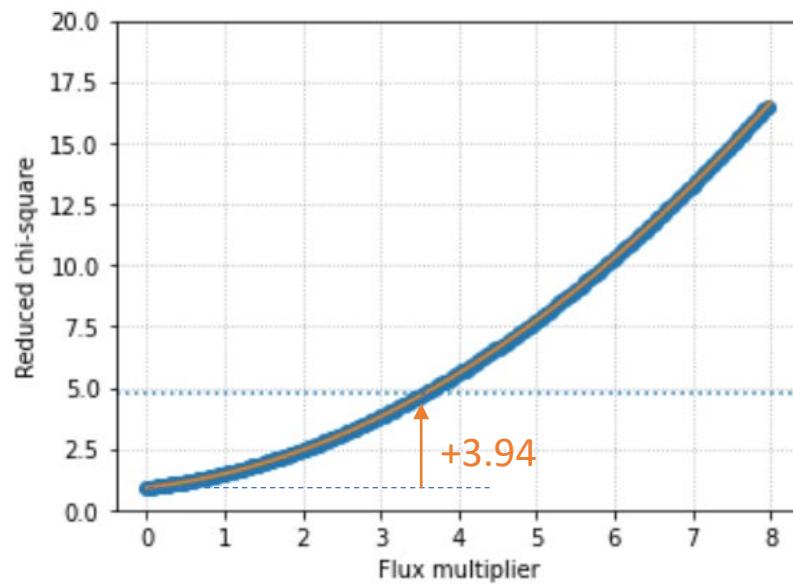


- Radius of ROI are optimized for each Galactic halo density profile model
- The disk regions ($|l| > 6^\circ$ and $|b| < 5^\circ$) are removed from analysis.

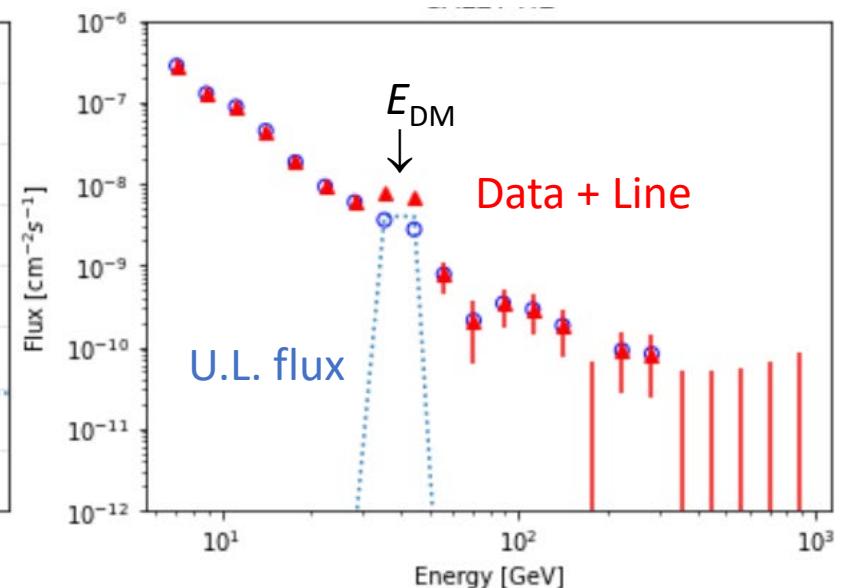
Calculation of upper limits

- Monoenergetic lines are assumed.
- Adding the assumed line signals (broadened by a Gaussian distribution with CALET energy resolution) to the observed spectra which raise the reduced χ^2 for the power-law fit by 3.94 (corresponding to 95% C.L.).

R16: $E_{\text{DM}} = 39.8 \text{ GeV}$ case

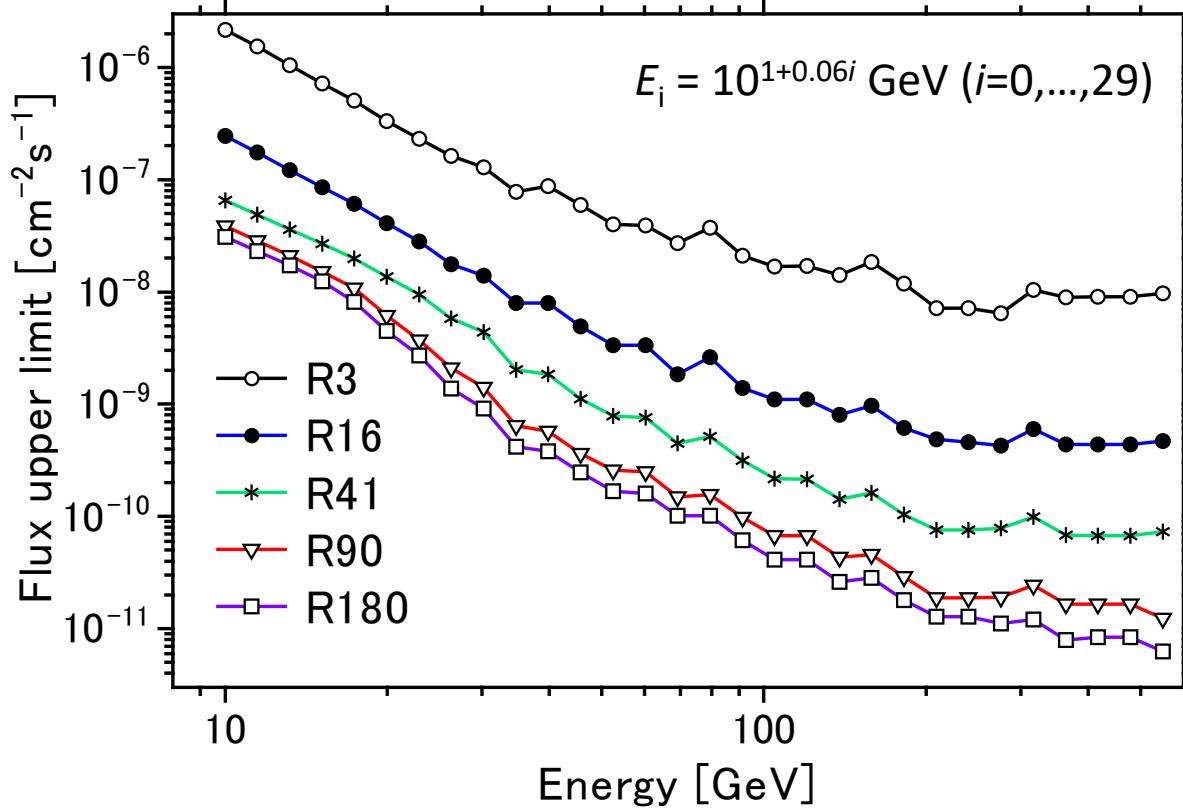


Assumed flux (unit: Power-law-fit)



Upper limits as a function of energy

Preliminary



- Upper limits are mostly determined by event statistics.
- Systematic errors are not taken into account (under study).

Gamma-ray line signal from dark matter

- **Annihilation**

$$\left(\frac{d\Phi}{dE}\right)_{\text{ann}} = \frac{\langle\sigma v\rangle}{8\pi m_{\text{DM}}^2} \left(\frac{dN}{dE}\right)_{\text{ann}} \underbrace{\left[\int_{\text{ROI}} d\Omega \int_{\text{l.o.s.}} ds \rho(r)^2 \right]}_{<\!\!\sigma v\!>}$$

$\langle\sigma v\rangle$: velocity-averaged cross section

$$dN/dE = 2\delta(E_\gamma - E), E_\gamma = m_{\text{DM}}$$

- **Decay**

$$\left(\frac{d\Phi}{dE}\right)_{\text{dec}} = \frac{1}{4\pi\tau_{\text{DM}}m_{\text{DM}}} \left(\frac{dN}{dE}\right)_{\text{dec}} \underbrace{\left[\int_{\text{ROI}} d\Omega \int_{\text{l.o.s.}} ds \rho(r) \right]}_{\tau_{\text{DM}}}$$

τ_{DM} : lifetime

$$dN/dE = \delta(E_\gamma - E), E_\gamma = m_{\text{DM}}/2$$

J-factors: $\left[\int_{\text{ROI}} d\Omega \int_{\text{l.o.s.}} ds \rho(r)^2 \right], \left[\int_{\text{ROI}} d\Omega \int_{\text{l.o.s.}} ds \rho(r) \right]$ halo-model dependent!

Integral of (halo density)² $\rho(r)^2$ [halo density $\rho(r)$] along line-of-sight
(l.o.s.) over Region-of-Interest (ROI)

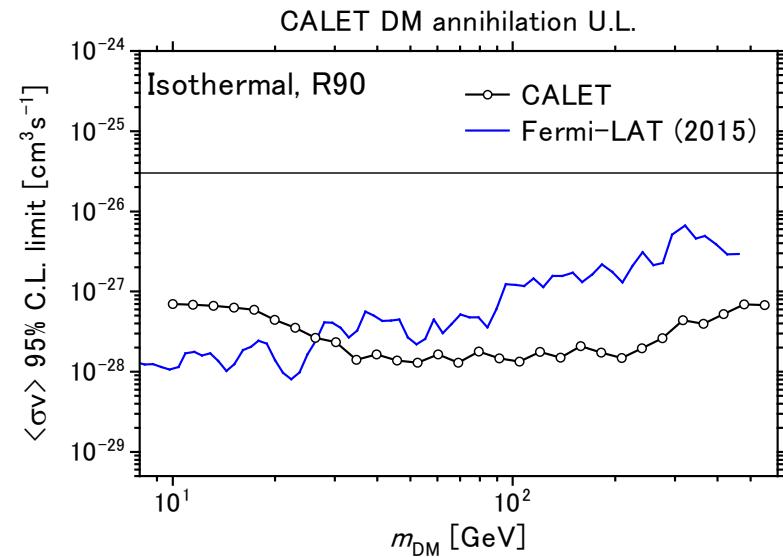
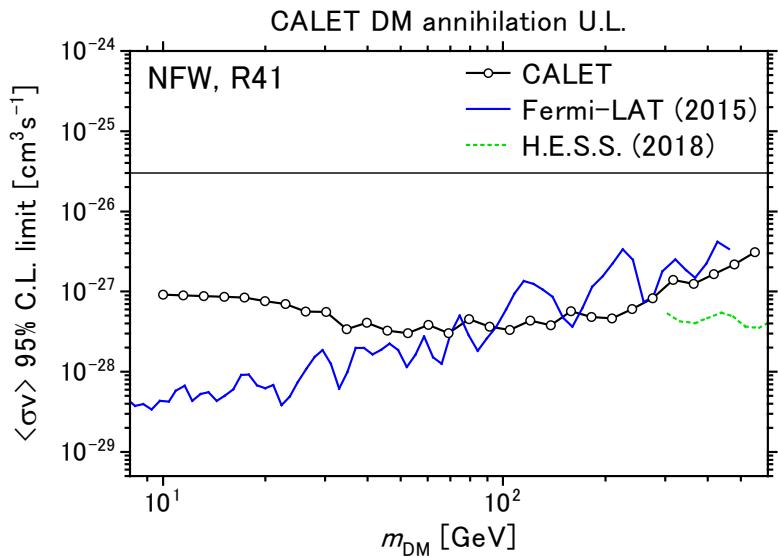
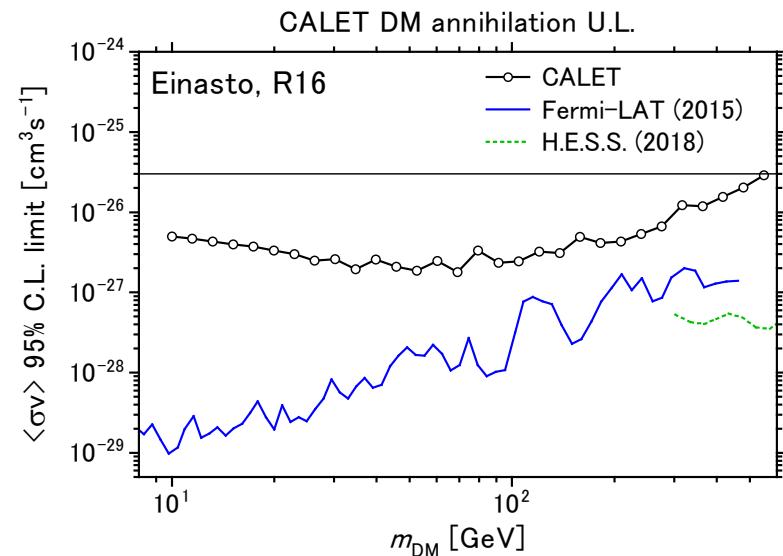
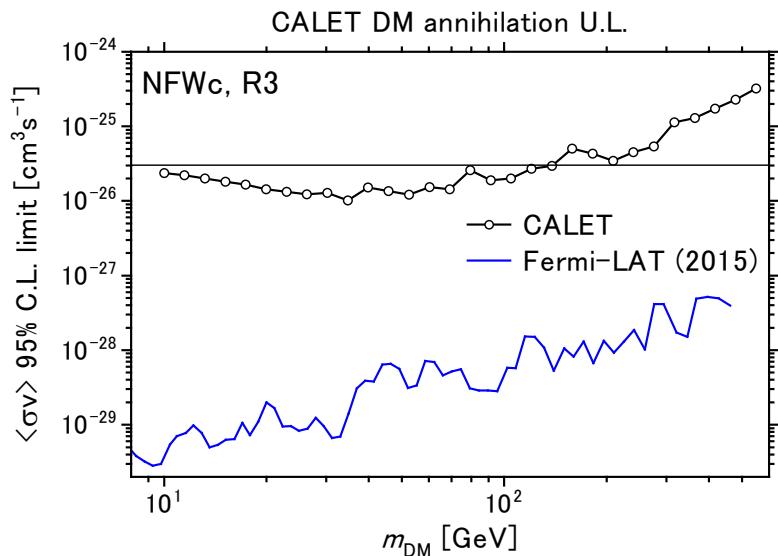
Upper limits on $\langle\sigma v\rangle$

Fermi-LAT: Ackermann+, PR D91, 122002 (2015)

H.E.S.S.: Abdallah+, PRL 120, 201101 (2018)

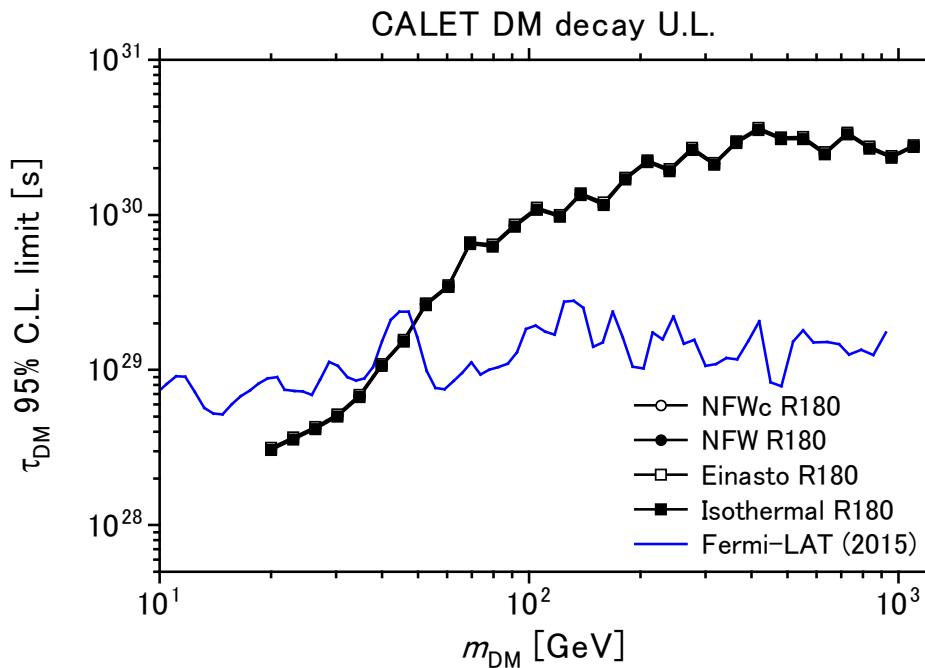
Thin line: thermal relic ($3 \times 10^{-26} \text{ cm}^3 \text{s}^{-1}$)

Preliminary: statistical error only



Upper limits on lifetime

Preliminary: statistical error only



For R180, limits are almost independent of the profile models.

- Good energy resolution of CALET enables sensitive search at high energies, but limited by the statistics of observed gamma rays.
- Thus for larger ROI, we may set better upper limits.



Summary

- Gamma-ray events above 10 GeV observed during five years of operation of the CALET detector have been analyzed to search for possible line signals.
- Good energy resolution of CALET enables sensitive search in the high energy region.
- We found no hint of line signals and gave upper limits on parameters of the DM annihilation and decay models for $m_{\text{DM}} = 10 \sim 500 \text{ GeV}$.
- For annihilation, $\langle\sigma v\rangle_{\gamma\gamma} < 10^{-28}\text{-}10^{-25} \text{ cm}^{-3}\text{s}^{-1}$ depending on m_{DM} and the Galactic halo density models.
- For decay, lifetime limits reach $\tau_{\text{DM}} > 10^{30} \text{ s}$ ($m_{\text{DM}} > 100 \text{ GeV}$) and almost model-independent.
- We are now studying possible systematic errors in our limits.

See also PoS (ICRC2021) 619