



Measurement of Diffuse Galactic gamma-ray Emission based on source-deduction method at Galactic plane by LHAASO

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The First LHAASO Collaboration Conference in 2026,
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at Nanjing University, Suzhou Campus in the city of Suzhou, Jiangsu Province, China

Outline

LHAASO DGE previous results

LHAASO data use

Resolved Sources (RS) and DGE at Galactic plane

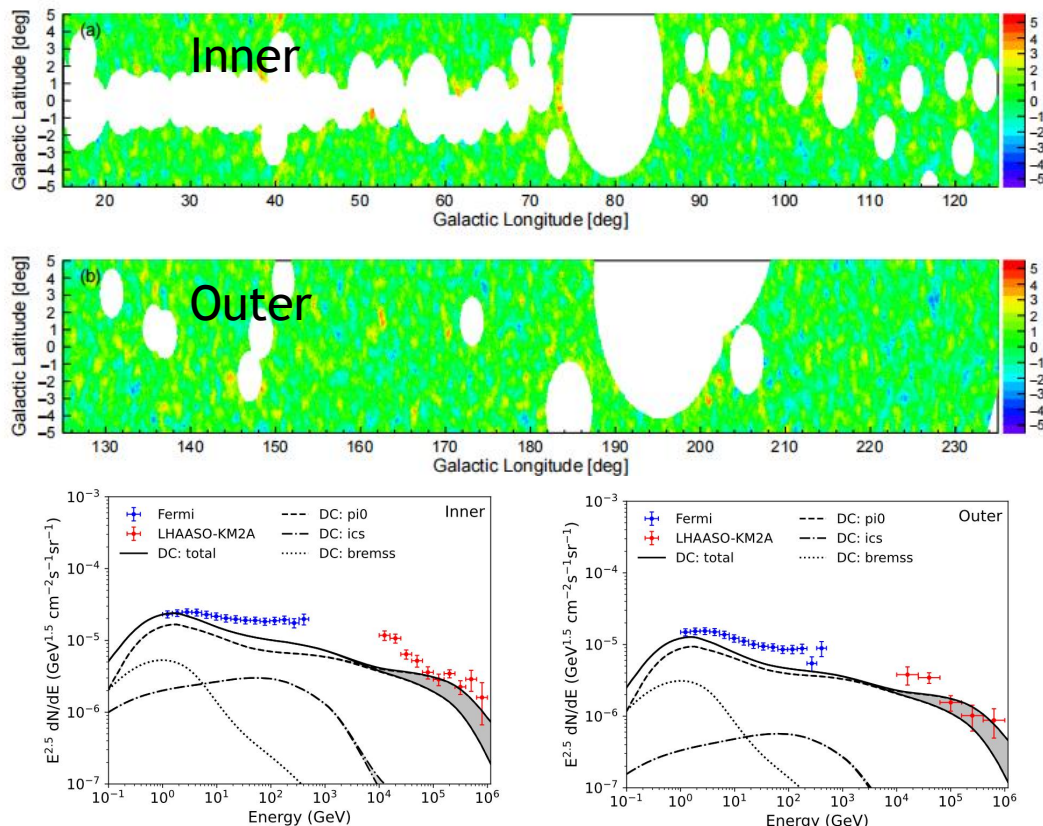
Analysis & Results

Crosscheck

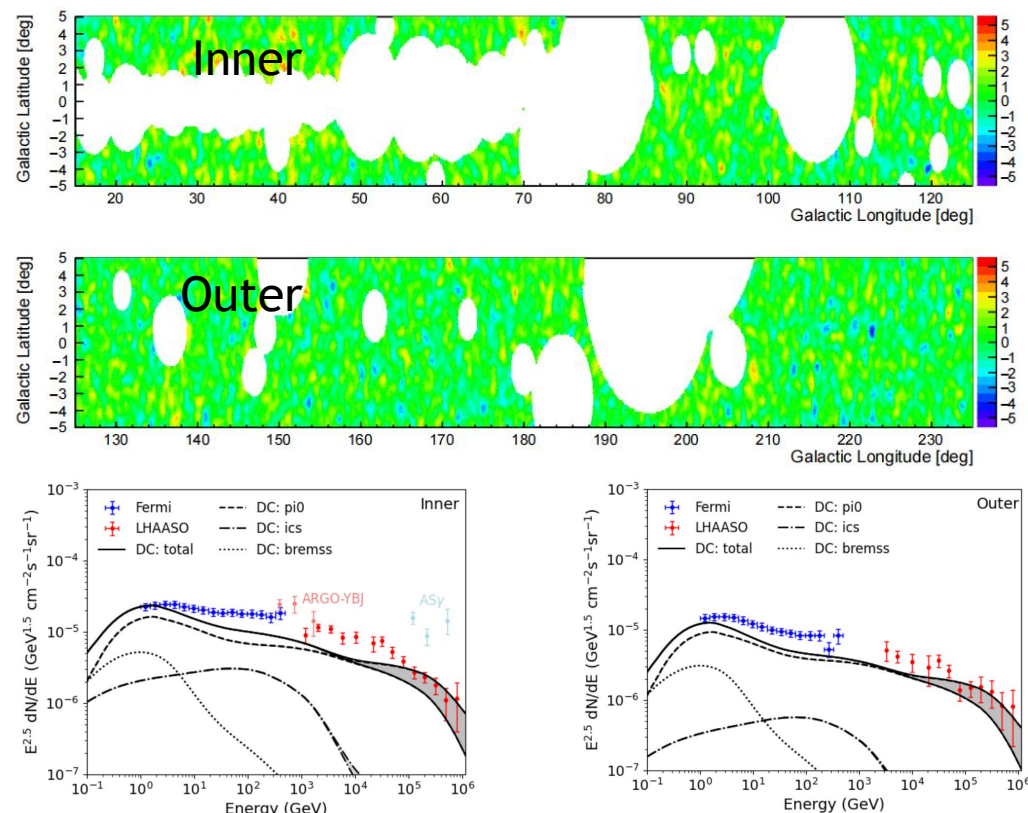
Conclusion

LHAASO DGE previous results

LHAASO-KM2A, mask1



LHAASO-WCDA, mask2



PRL, 131, 151001 (2023)
R. Zhang et al. (ApJ, 2023)

➤ few GeV ~ 60 TeV: obvious excess over model expectations

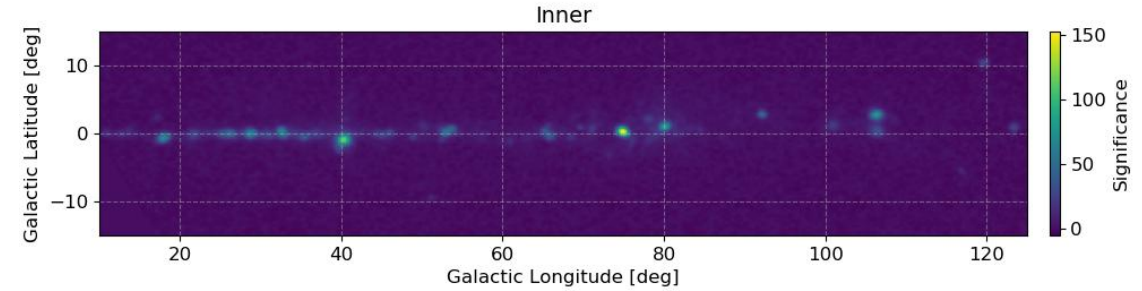
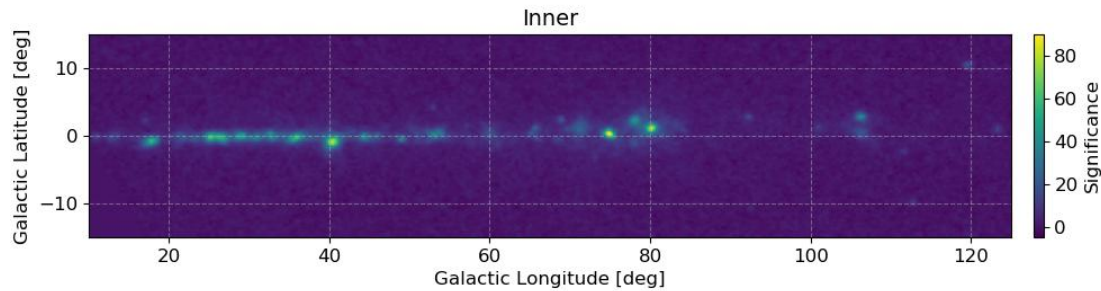
PRL, 134, 081002 (2025)

Gamma-Ray Emission at Galactic plane

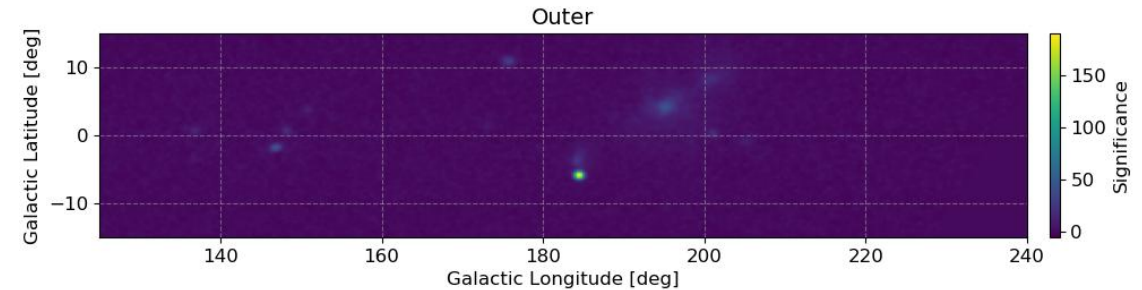
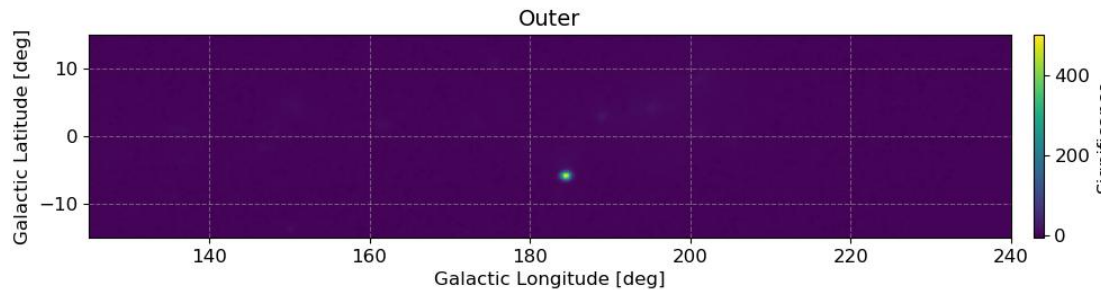
WCDA

KM2A

INNER



OUTER

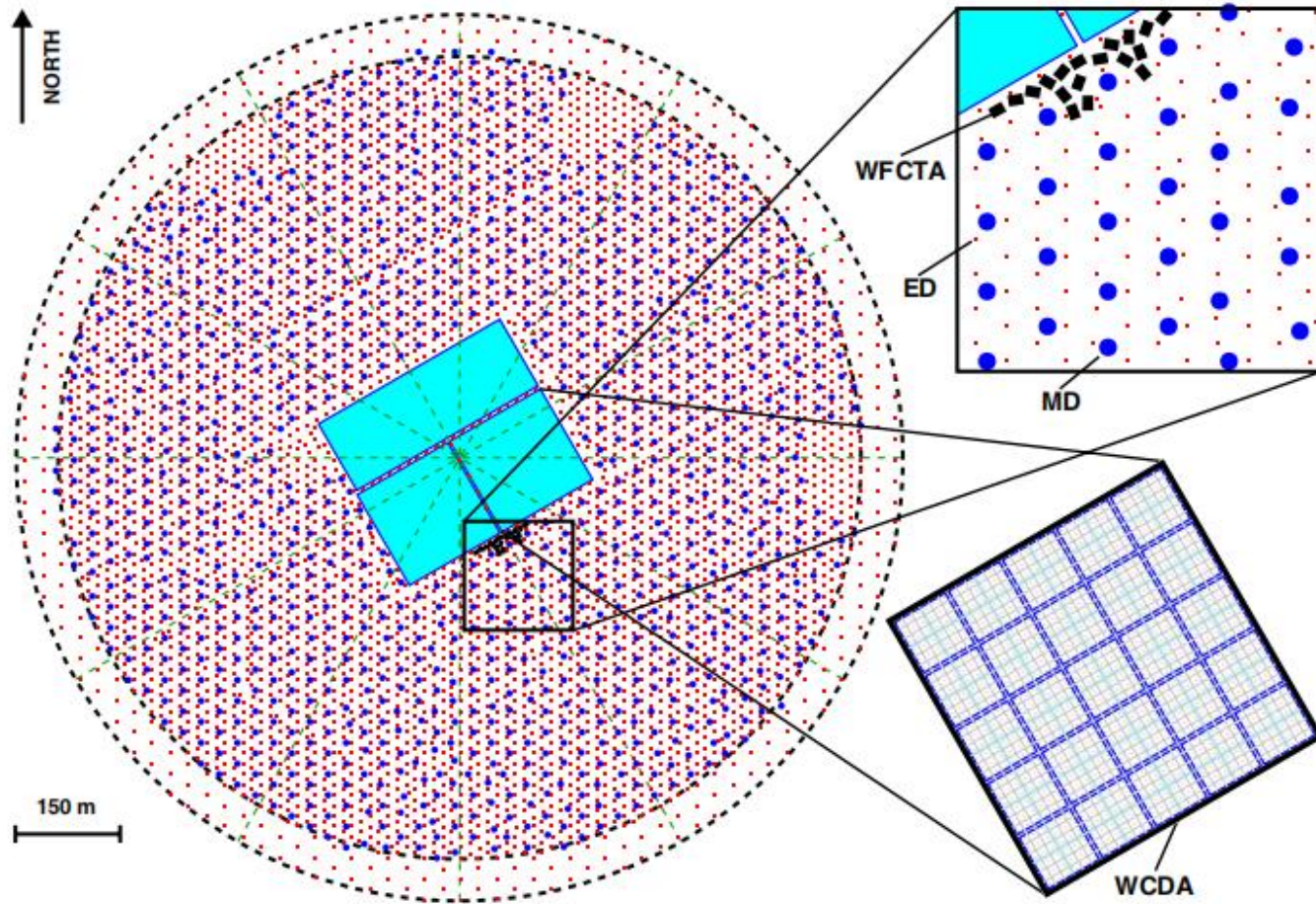


Motivation:

- Preserve ROI of DGE in the Galactic plane.
- Detailed investigation into the spatial/spectral characteristics of DGE.
- Enhance the understanding of resolved sources in the Galactic plane.

LHAASO data use

Detecting air showers produced by cosmic rays (and gamma rays)



LHAASO:

- composition: **WCDA**, **KM2A**, WFCTA
- WCDA (1-25 TeV): 210305-250731
- KM2A (>25 TeV): 1/2+3/4+full (191226-250731)

Data Selection:

WCDA-

- Reconstructed zenith angle $< 50^\circ$
- 6 Nhit bins: [60,100], [100,200], [200,300], [300,500], [500,800], [800,2000]
- Pincness thresholds (per bin): 1.02, 0.90, 0.88, 0.88, 0.84, 0.84

KM2A-

- EDs & particles used in reconstruction > 10
- Reconstructed zenith angle $< 50^\circ$
- Particles ($r < 40$ m) $>$ Particles (40–100 m)
- Shower age: 0.6–2.4
- Distance to KM2A edge > 20 m

Background Estimation

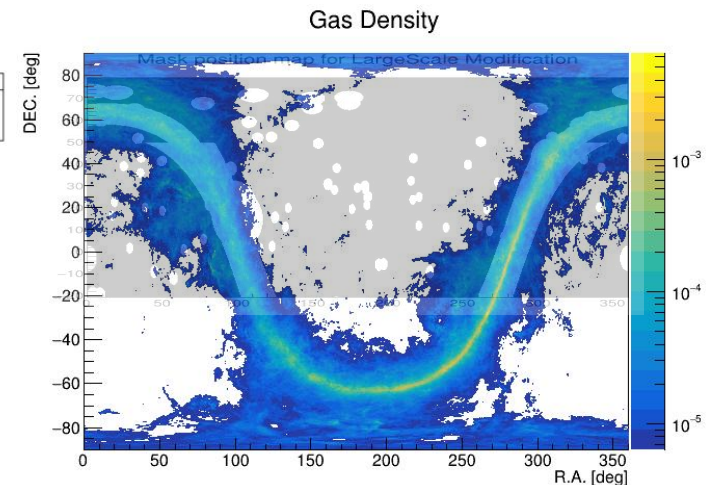
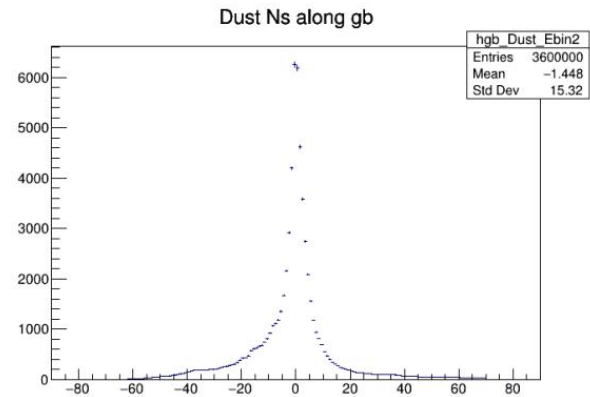
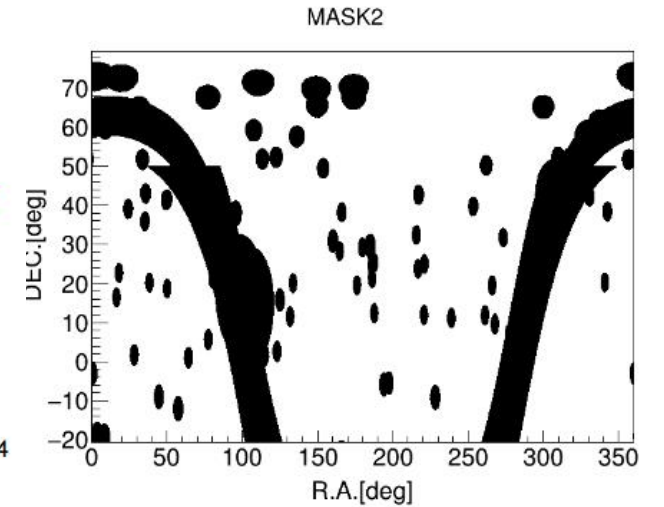
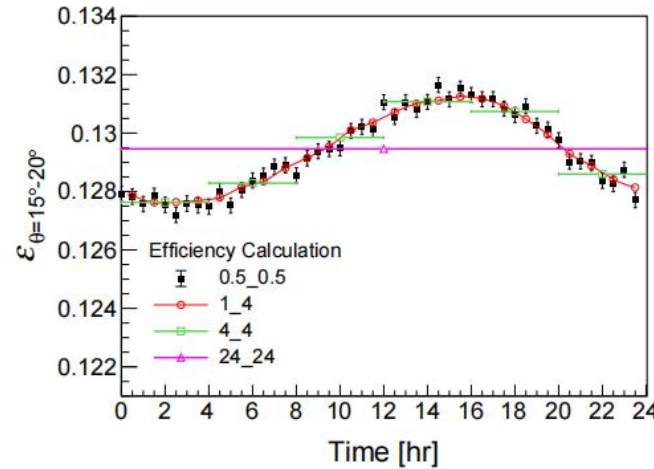
“Direct Integral” method

- Efficiency at same direction (zen, azi) changes over time
- “MASK”: TeVcat source + Galactic Plane
($|b| < 10$ deg, $dec < 50$ deg, $|b| < 5$ deg, $dec > 50$ deg)
-> Timewindow = 10h, step=1h
-> Fake LargeScale Structure
- 20% DGE signal outside $|b| > 15$ deg
-> DGE leakage into BKG

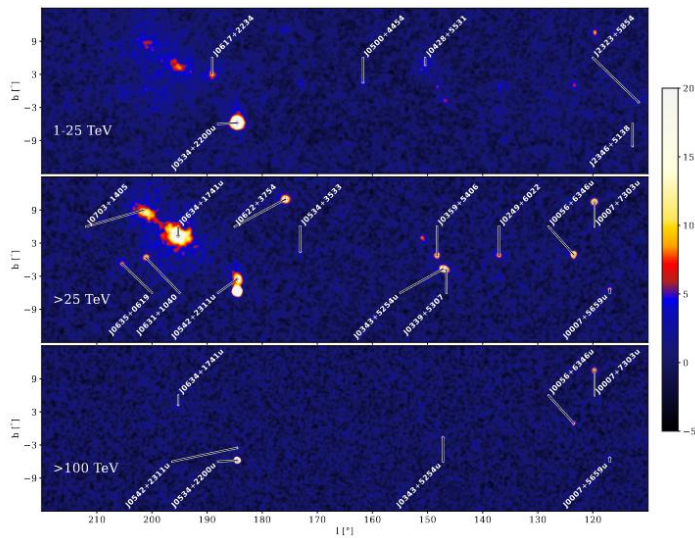
➤ DGE leakage correction:

Fake CR + Fake DGE (PLANCK Dust map)
vs Fake CR -> correction factor

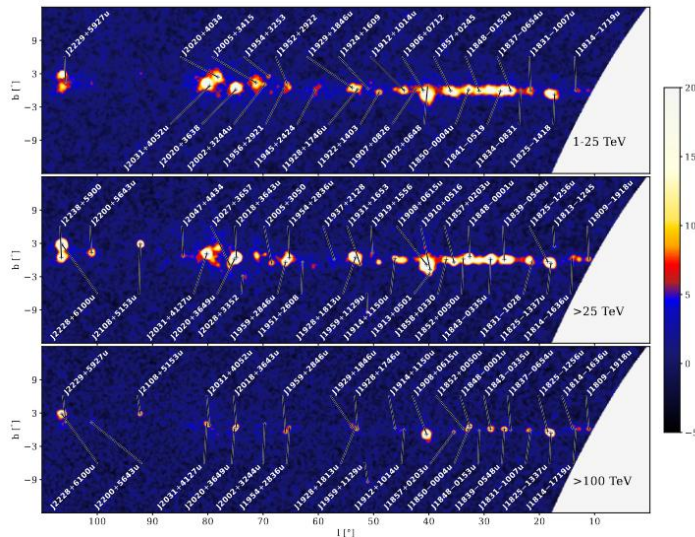
➤ Fake LargeScale Structure correction: top-hat Smoothed intensity correction



Resolved Sources (RS) Measurement & Extraction from DGE



1. **RS:** Morphology - Gaussian & Spectrum - Log-Parabola
2. **DGE:** Morphology - Planck Dust Map & Spectrum - Log-Parabola
3. **Iteration loop**
 - Fit RS + DGE
 - Check residual significance map
 - Add new RS if needed
 - Repeat with updated catalog



1st LHAASO Cat:
 69 1-25 TeV ($> 5\sigma$)
 75 > 25 TeV ($> 5\sigma$)
 90 ALL



Galactic Plane ($|b| < 15$ degree):
 171 resolved sources, WCDA
 154 resolved sources, KM2A
 189 resolved sources, JOINT-fit

- Subtract RS emission from whole gamma-ray skymap -> Expect a **Pure DGE Galactic Plane!**

Properties of RS

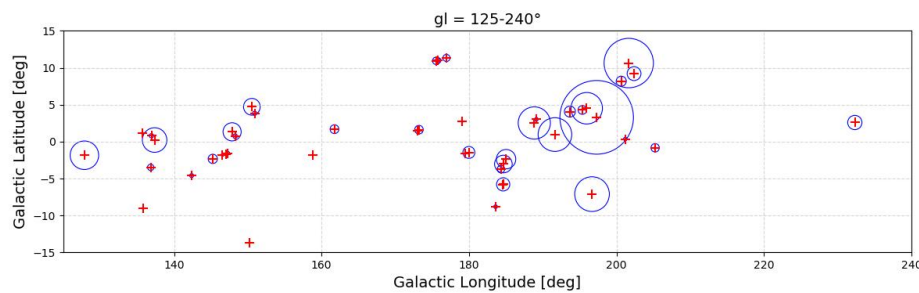
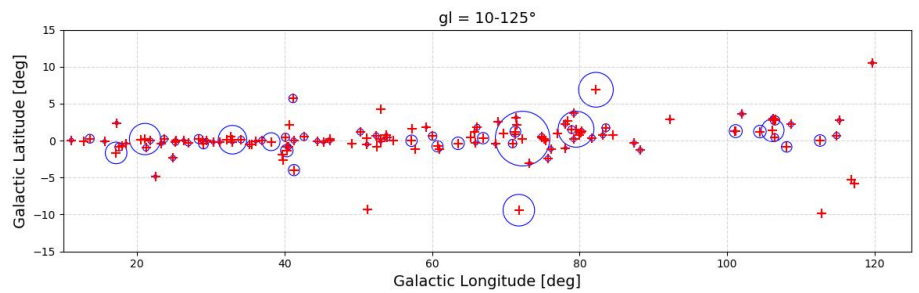
Galactic Plane ($|b| < 15$ deg):

171 resolved sources, WCDA

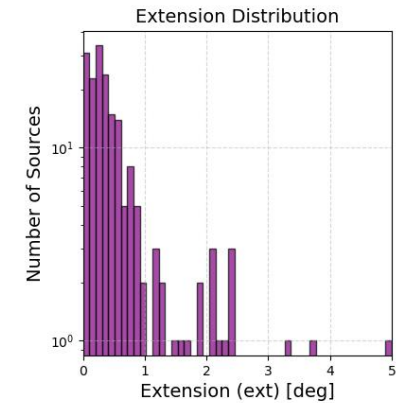
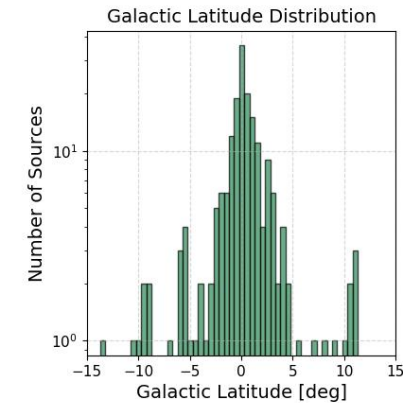
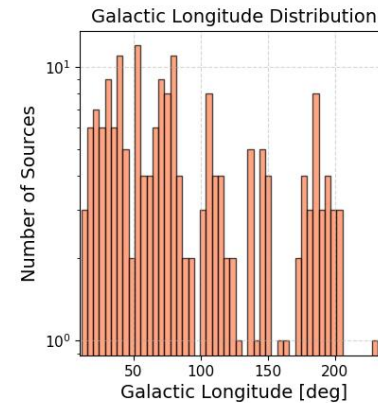
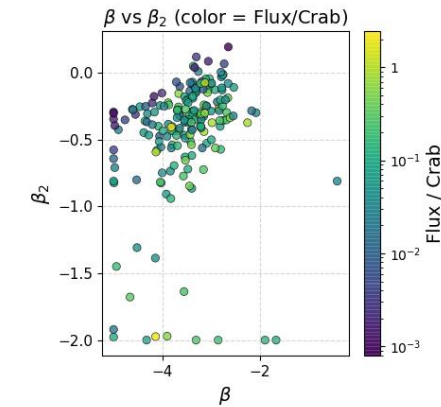
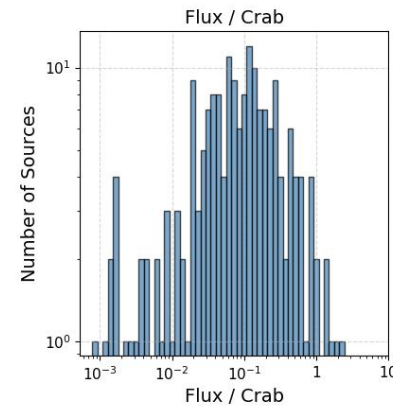
154 resolved sources, KM2A

189 resolved sources, JOINT-fit

Source Positions in Galactic Coordinates (with Extent)



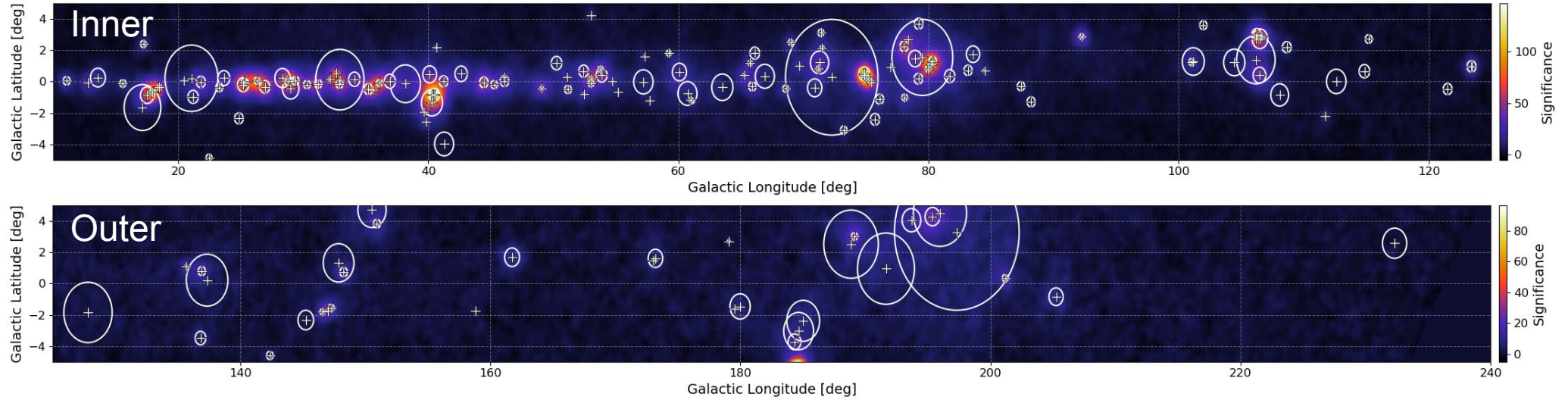
Source Properties from JOINT LP Catalog



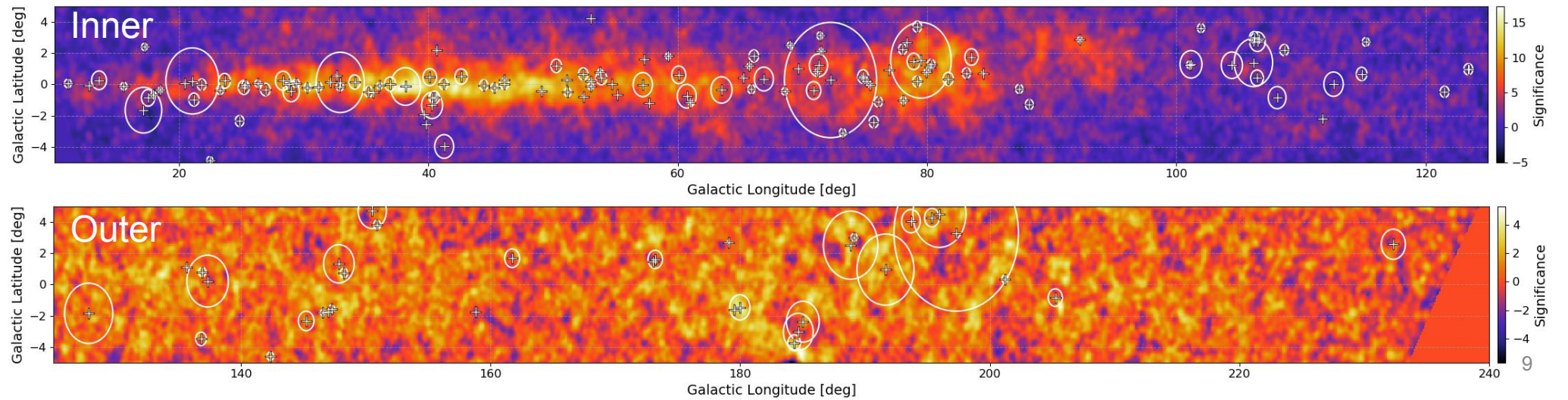
➤ Subtract RS emission from whole gamma-ray skymap -> Expect a **Pure DGE Galactic Plane!**

Significance Map before/after subtracting RS

allsource



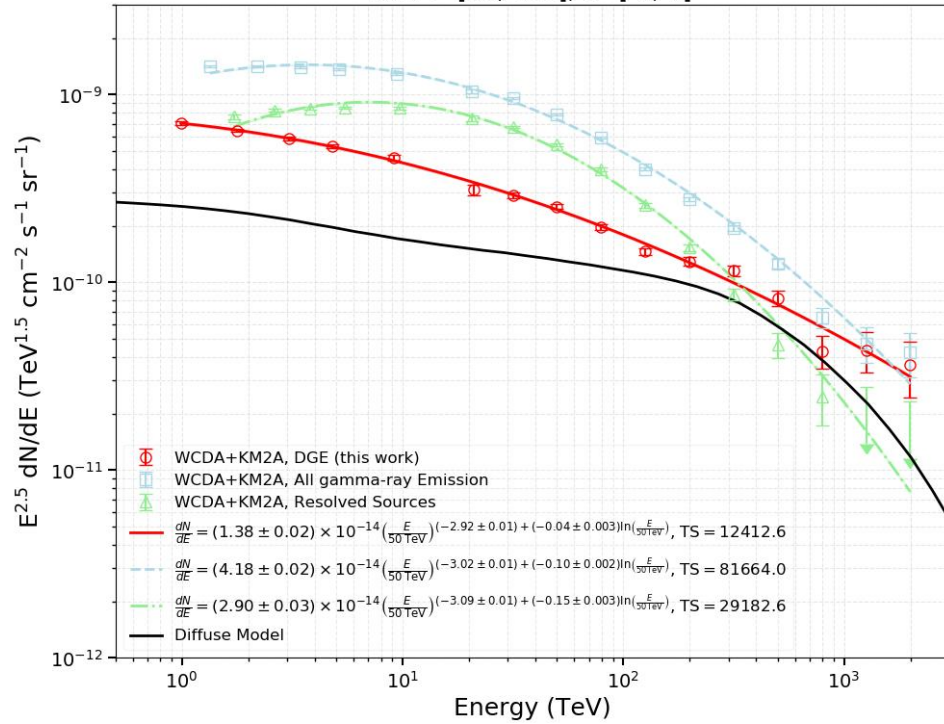
DGE:
allsource-RS



SED of DGE

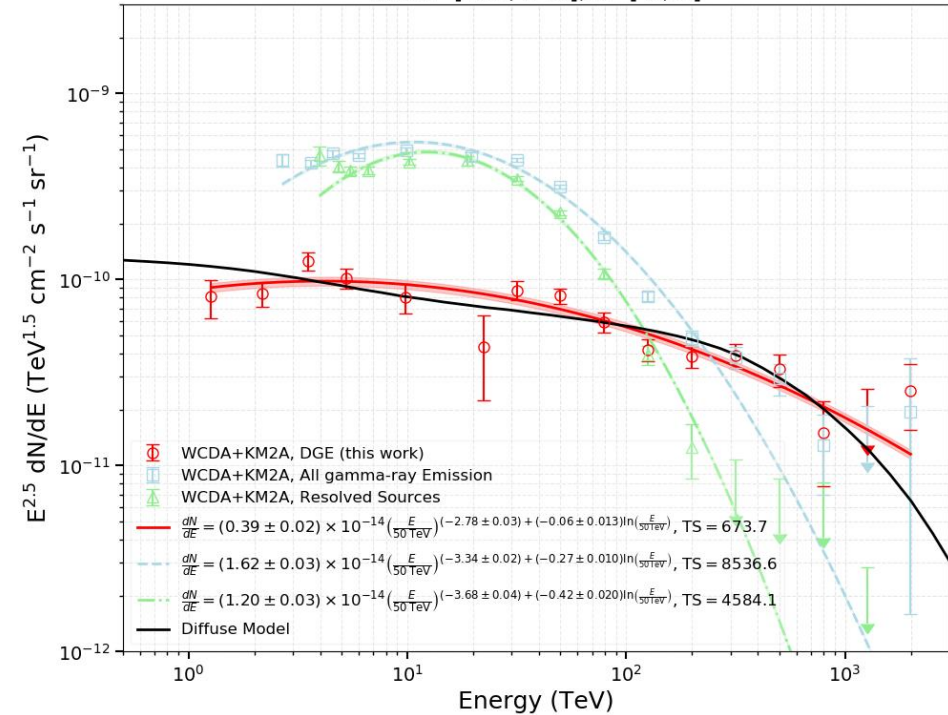
INNER

ROI: $l=[10, 125], b=[-5, 5]$



OUTER

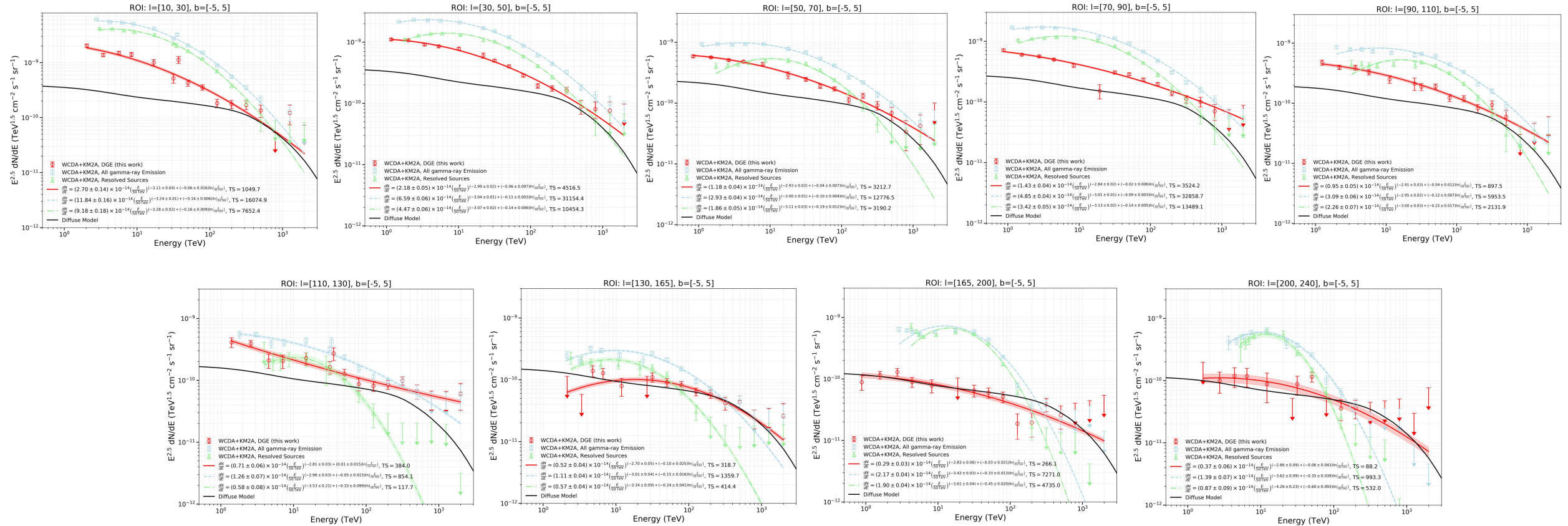
ROI: $l=[125, 240], b=[-5, 5]$



- Diffuse Model: LHAASO CR (proton) spectrum + ISM, no CR distribution
- $E > 100$ TeV: similar spectral shape (index) as that of measurements
- $E < 100$ TeV: extra component with E_{cut} around tens of TeV for Inner Galaxy region

SED of DGE (small ROIs)

- Separate Galactic Plane into 9 parts:

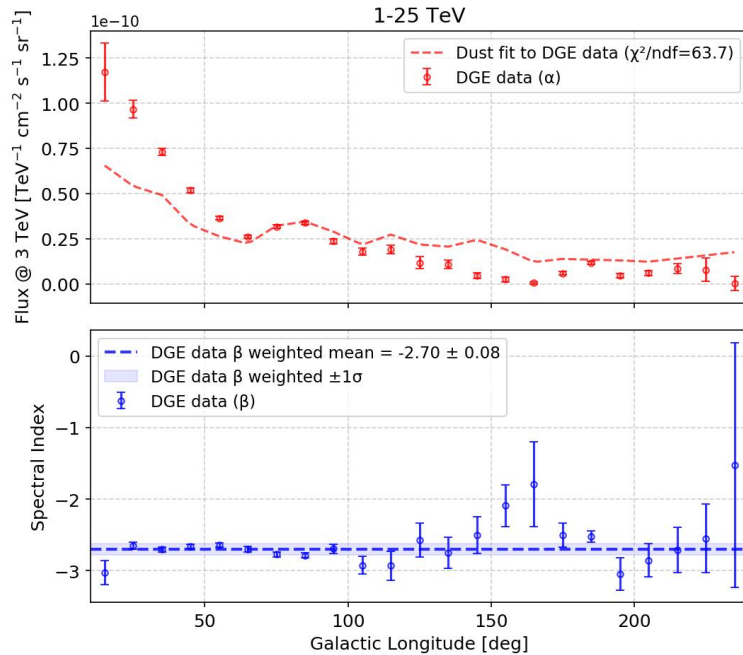


Profile of Galactic Longitude

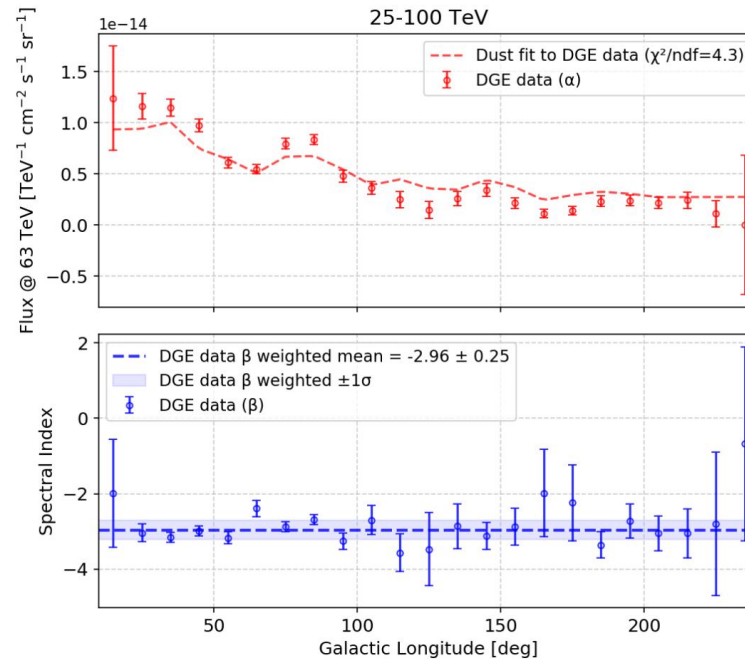
- Separate Measurements into (1-25 TeV), (25-100 TeV), (100-2500 TeV), use PowerLaw give distribution of Flux and Index.

b: $[-5^\circ, 5^\circ]$

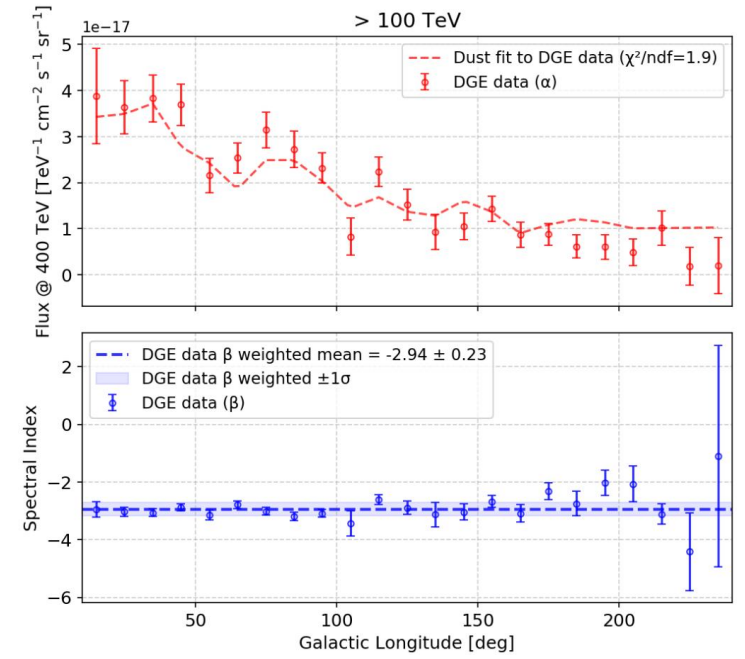
1-25 TeV



25-100 TeV



>100 TeV



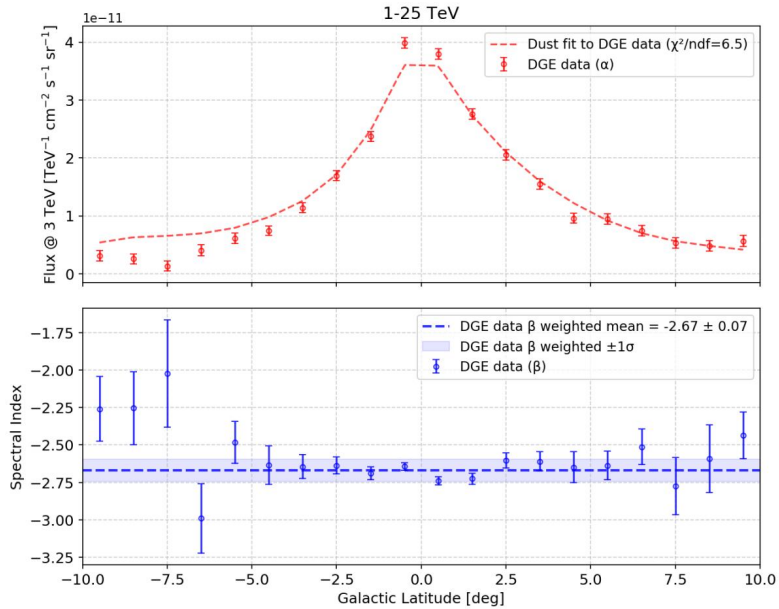
- Discrepancy between data and Gas distribution (PLANCK Dust Map), especially for 1-25 TeV, $l < 50^\circ$.
- Spectral Index remains nearly constant along Galactic longitude.

Profile of Galactic Latitude

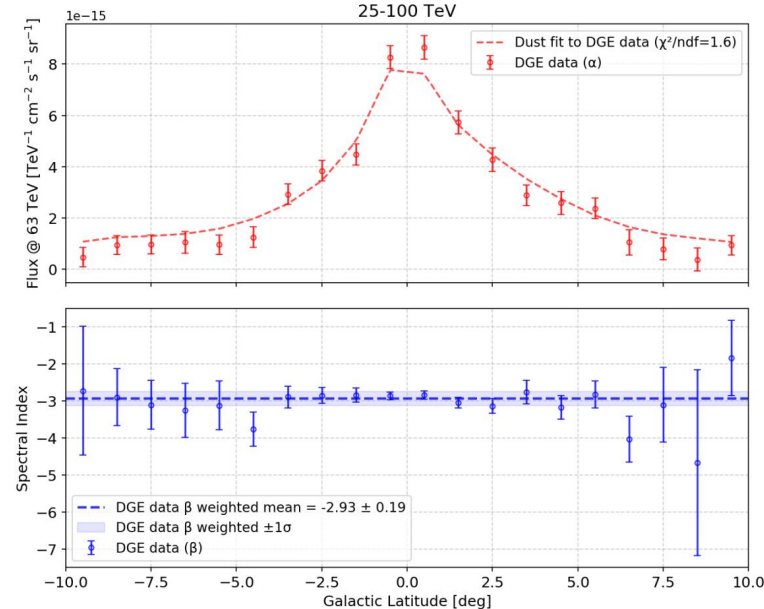
- Separate Measurements into (1-25 TeV), (25-100 TeV), (100-2500 TeV), use PowerLaw give distribution of Flux and Index.

$l: [10^\circ, 240^\circ]$

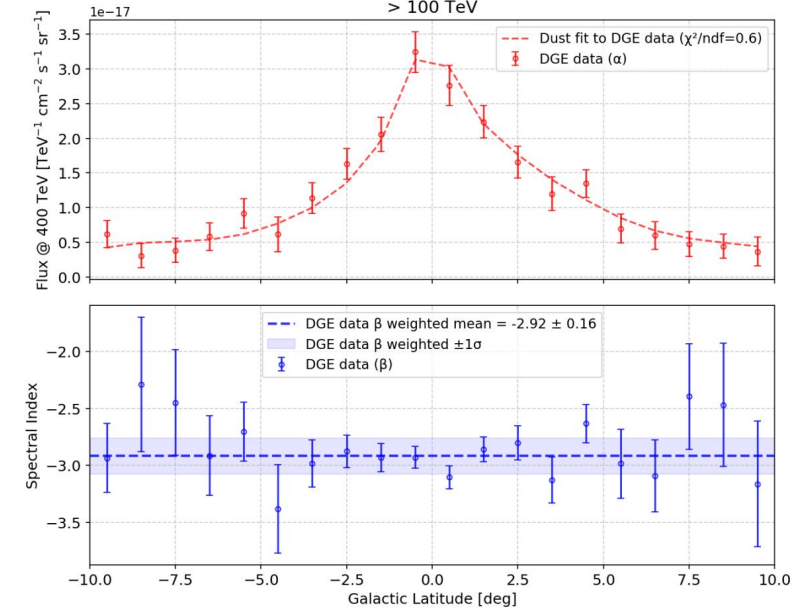
1-25 TeV



25-100 TeV



>100 TeV



- Discrepancy between data and Gas distribution (PLANCK Dust Map), especially for 1-25 TeV, $b < -5^\circ$.
- Spectral Index remains nearly constant along Galactic Latitude.

Systematic Uncertainty

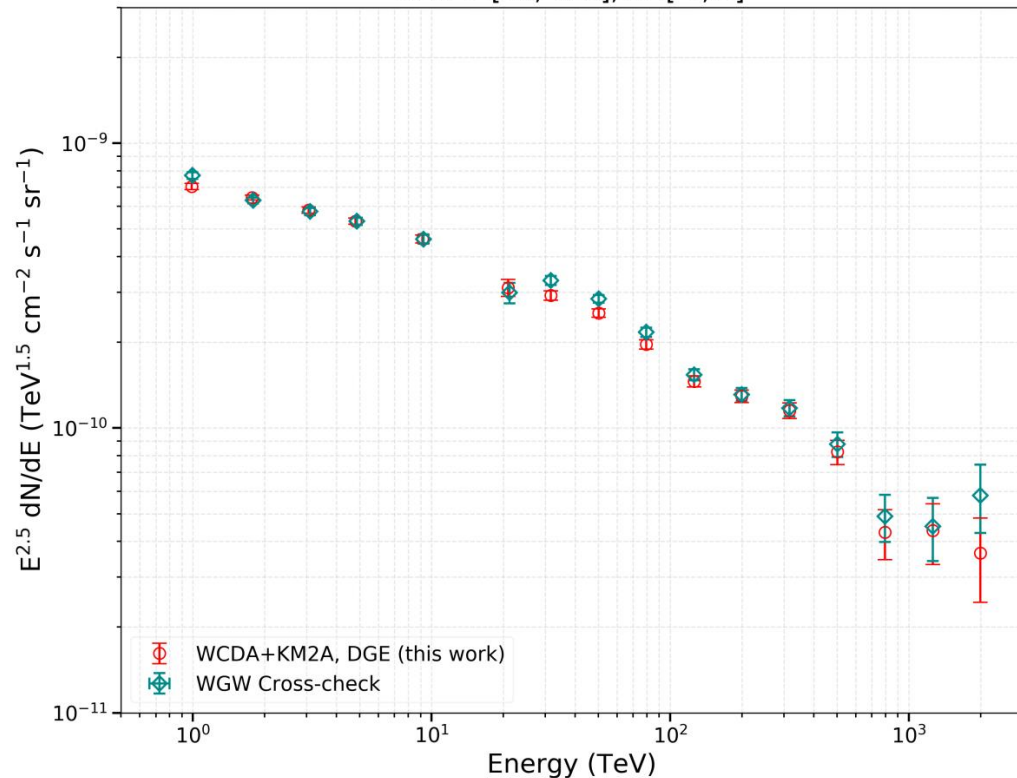
- **Background Estimation**
 - DGE leakage + LargeScale Structure Correction
 - ~ 3% (Inner) and 15% (Outer) for flux
 - ~ 0.01 (Inner) and 0.02 (Outer) for index
- **DGE morphology template**
 - for RS & DGE separation -> RS Catalog -> DGE measurement
 - PLANCK Dust map or measured DGE map after Gaussian smooth
 - ~ 1% (Inner) and 3% (Outer) for flux
 - ~ 0.04 (Inner) and 0.05 (Outer) for index
- **Individual (WCDA/KM2A) vs. Combined (WCDA+KM2A)**
 - ~ 6% (Inner) and 13% (Outer) for flux for WCDA energy
 - ~ 7% (Inner) and 8% (Outer) for flux for KM2A energy
- **Temp.-Atmos. effect (detection efficiency)**
 - ~7% for flux, 0.02 for index
- **Declination-dependent efficiency corr. (large ZA)**
 - ~Negligible

Overall Uncertainty		
	Norm Flux	Spectral Index
Inner	9.7%	0.05
Outer	21.3%	0.06

Cross-Check with USTC group

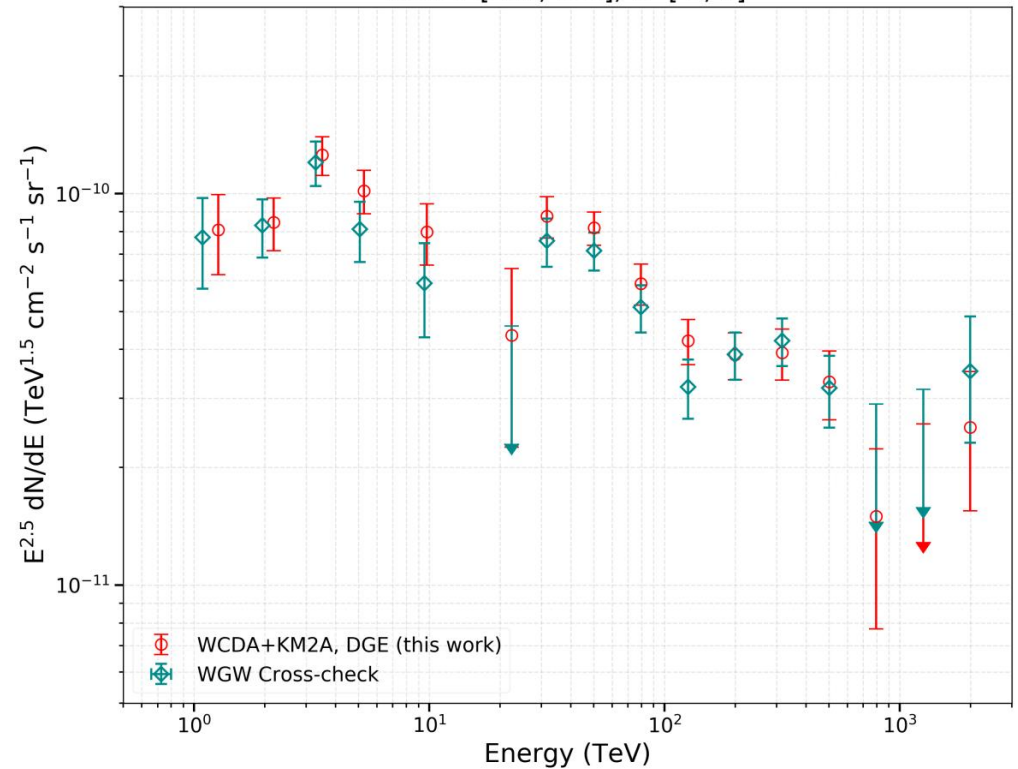
INNER

ROI: $l=[10, 125], b=[-5, 5]$



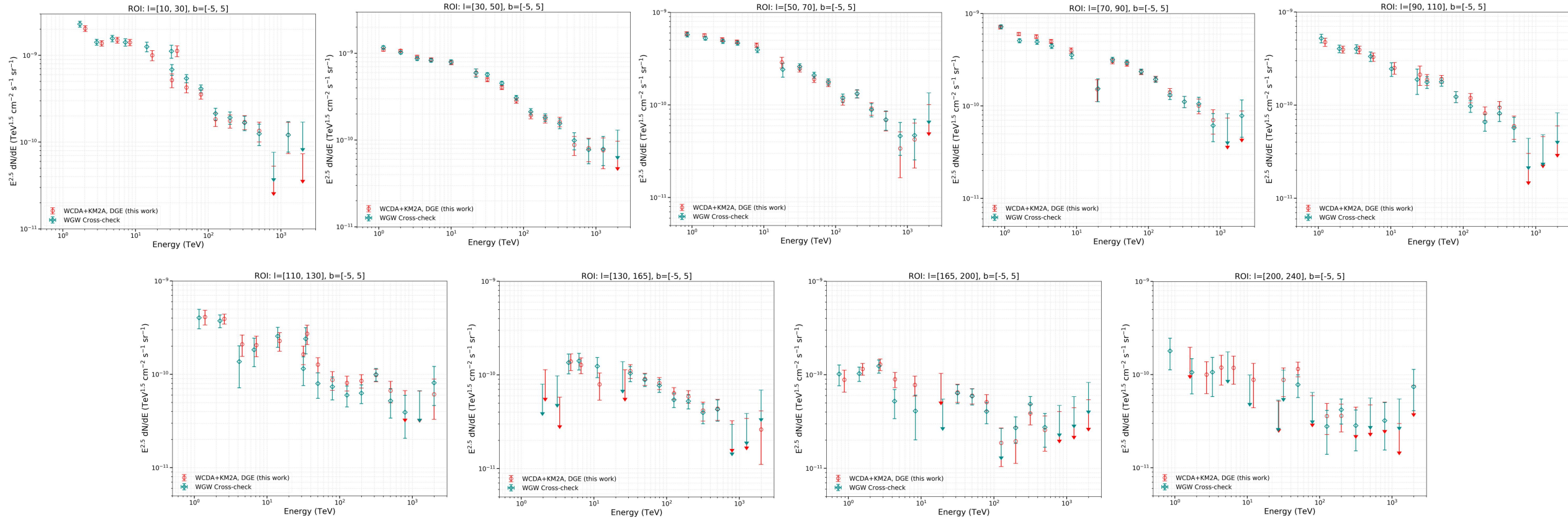
OUTER

ROI: $l=[125, 240], b=[-5, 5]$



- Wang Guangwei independently performed the DGE measurement
- Results show good agreement with this work

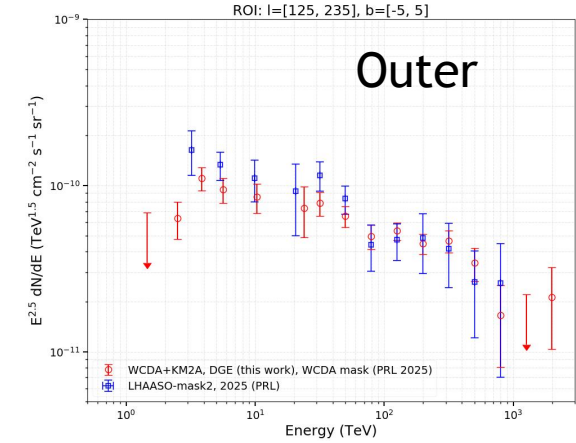
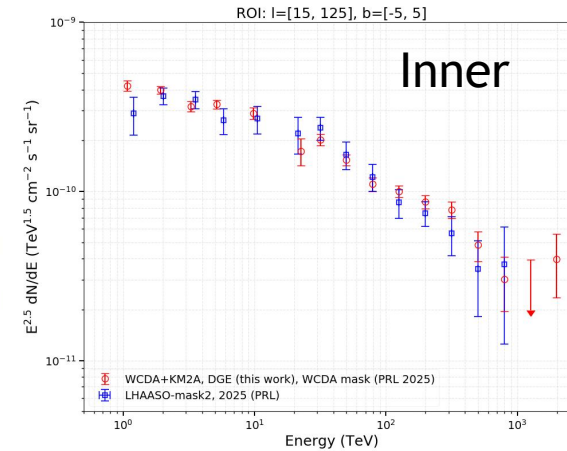
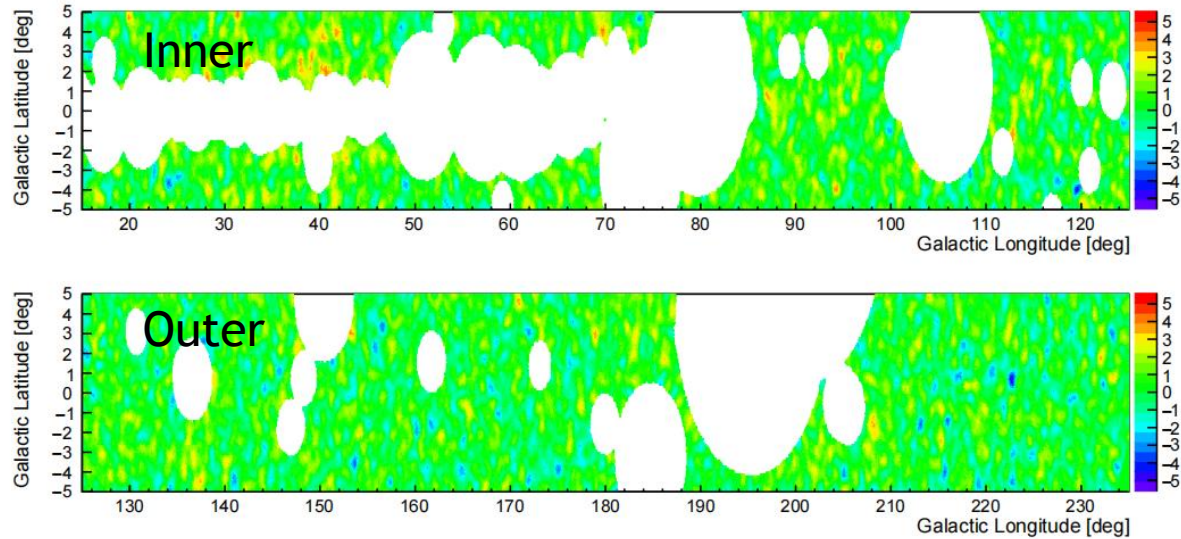
Cross-Check with USTC group



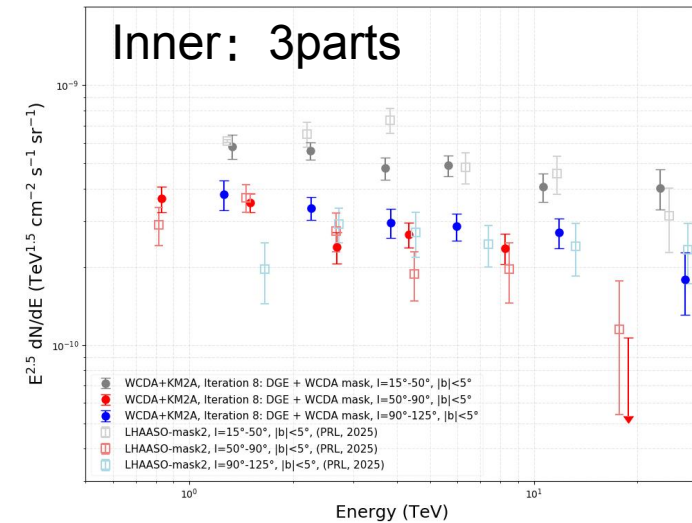
- Wang Guangwei independently performed the DGE measurement
- Results show good agreement with our measurements

Cross-Check (mask ROI)

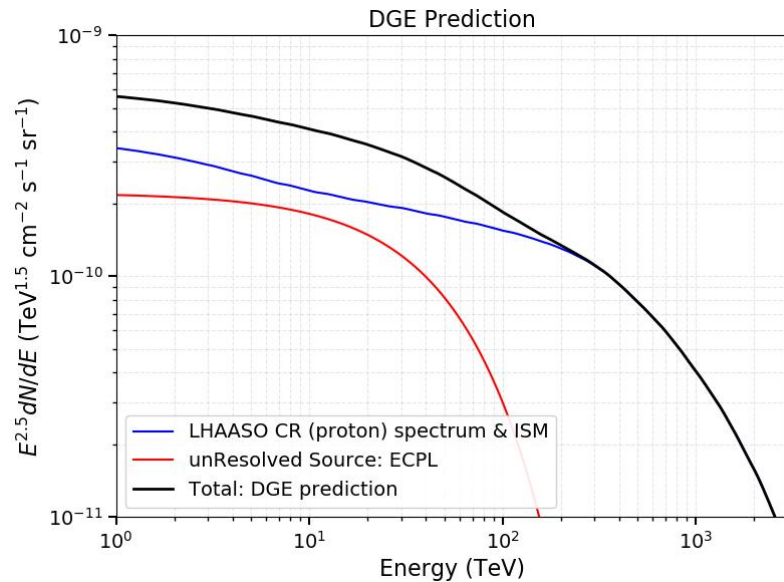
LHAASO-WCDA, mask2 (PRL, 2025)



- Consistent with the previous LHAASO result by mask2 for the inner region
- Slightly lower in WCD+KM2A energy range for the outer region, possibly due to the Geminga region and newly found weak sources



DGE component Separation: CR-ISM & uRS



Multi small ROIs for DGE separation:

- CR-ISM component:** CR-ISM prediction model, free normalization for each ROI.
- uRS component:** represented by ECPL, free all parameters, sharing same index and E_{cut} , for each ROI.

Multi small ROIs	ECPL-index	ECPL-Ecut [TeV]	dof	TS
l: [10, 125, 240] deg	-2.62 ± 0.04	41 ± 7	6	13255.0
l: [10, 70, 125, 180, 240] deg	-2.57 ± 0.04	37 ± 6	10	13655.6
l binwidth=20 deg	-2.53 ± 0.04	31 ± 3	24	14527.2
l binwidth=10 deg	-2.52 ± 0.03	30 ± 3	48	14814.6

uRS previous prediction:

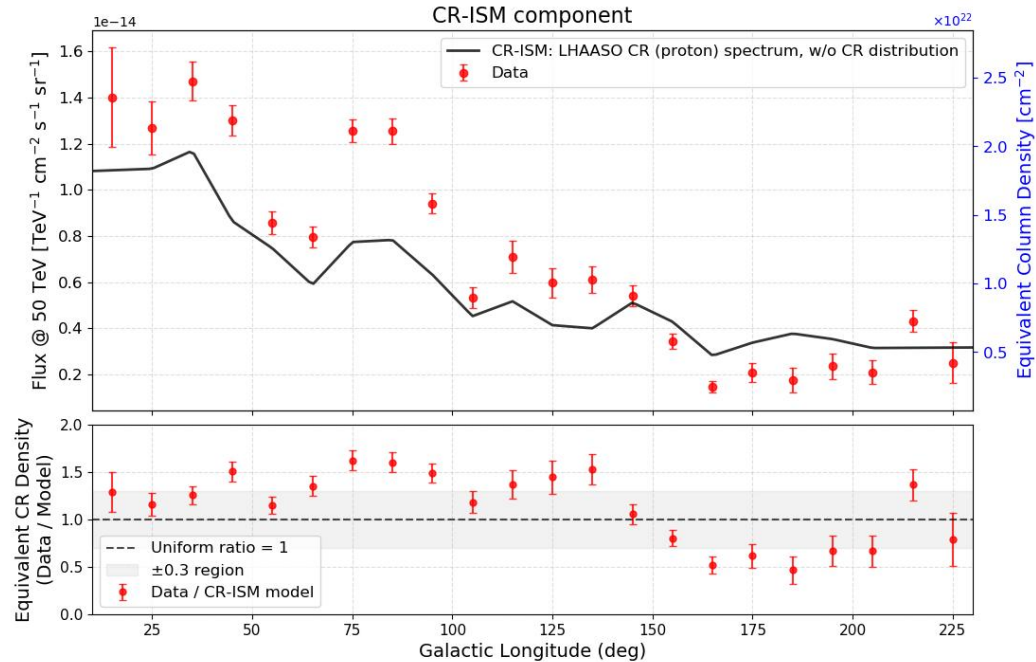
LHAASO-WCDA, mask2 (PRL, 2025)
ApJ, 957, 43 (2023)

$$\propto E^{-2.45} \exp(-E/20 \text{ TeV})$$

spectral index of -2.40 with cutoff energy of 30 TeV

DGE component Separation: CR-ISM & uRS

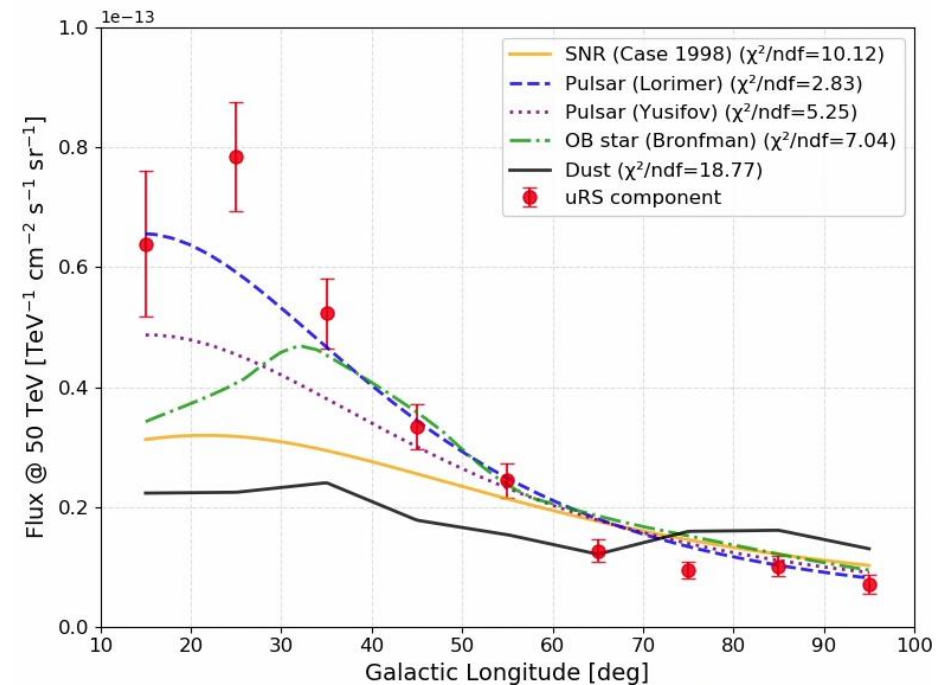
CR-ISM



CR-ISM component:

- $l < 150$ deg, higher than CR-ISM prediction, implying higher cosmic density, especially Cygnus region
- $l > 150$ deg, lower than CR-ISM prediction, implying lower cosmic density compared with average level

uRS



uRS component:

- good consistency with distribution of pulsar

Constraint on DGE knee (direct)

Fix uRS spectral parameters :

- Index ~ -2.52 , $E_{\text{cut}} \sim 30$ TeV

Test:

- PL+uRS (H_0) vs. Broken PL+uRS (H_1)
- considering Absorption of UHE photons by background radiation field
->Fit to Galactic disk diffuse emission

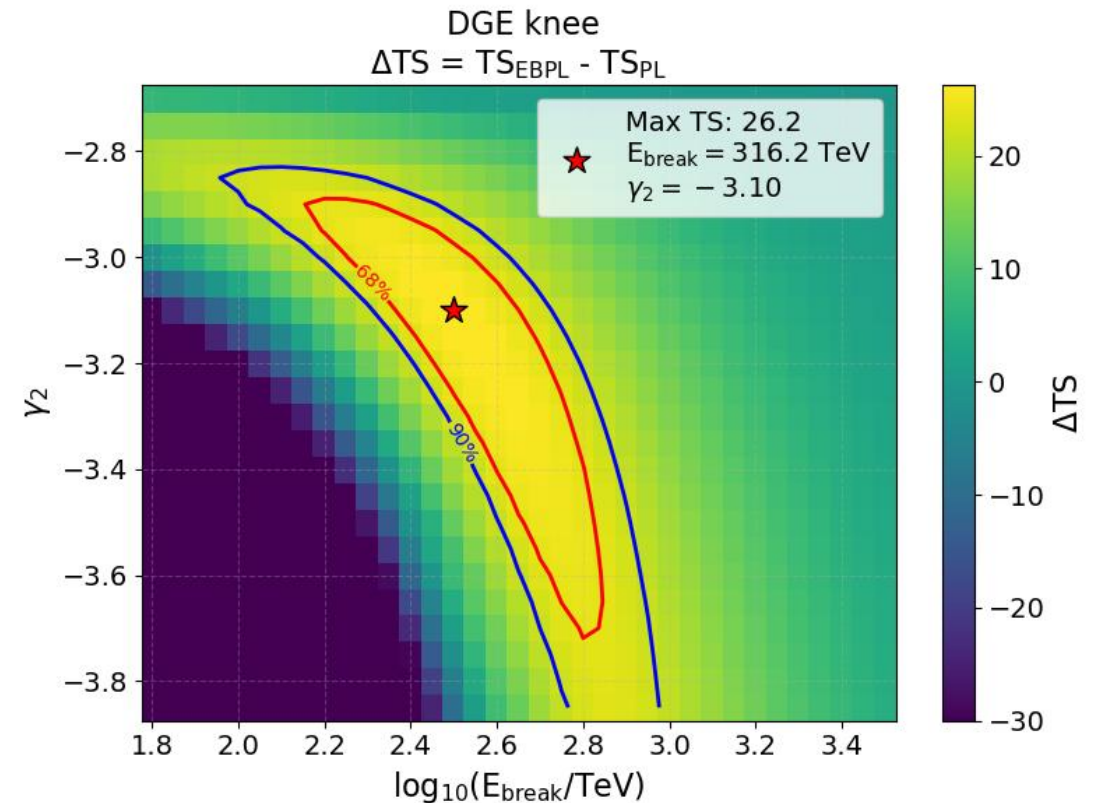
Result:

PL:

- Index: -2.69 ± 0.01

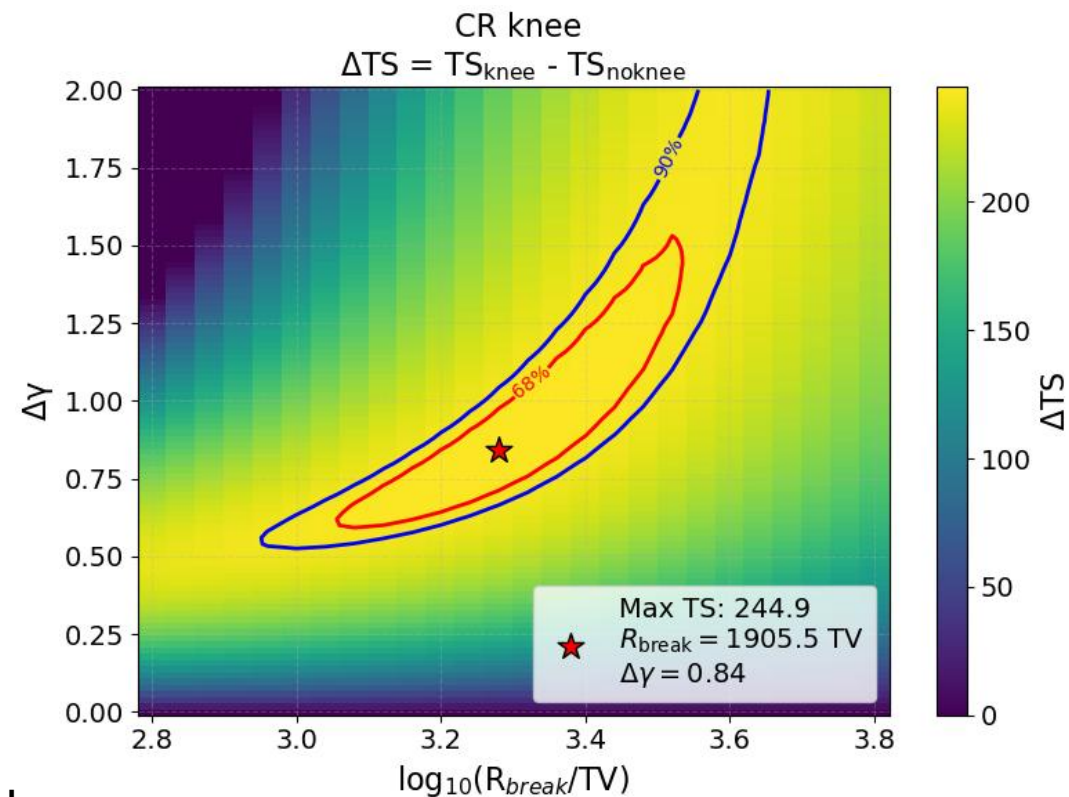
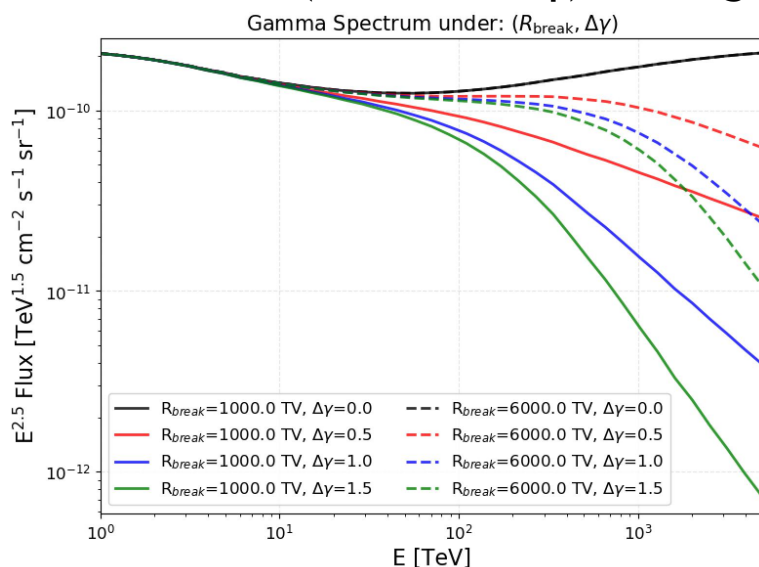
Broken PL:

- $E_{\text{break}} \sim 316$ TeV
- Index: -2.65 ± 0.03 (pre-knee)
→ -3.10 (post-knee)



Constraint on CR knee (indirect)

- use **AAfrag** package to predict secondary γ -ray production from inelastic hadronic interactions
 - using latest CR (Proton + Helium) spectrum before knee
 - CR knee with (R_{break} , $\Delta\gamma$) setting



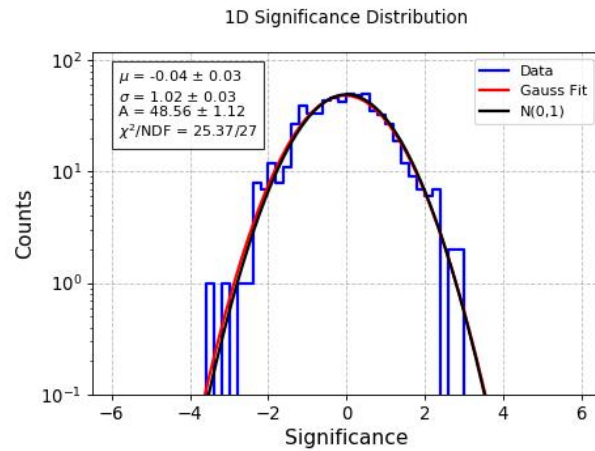
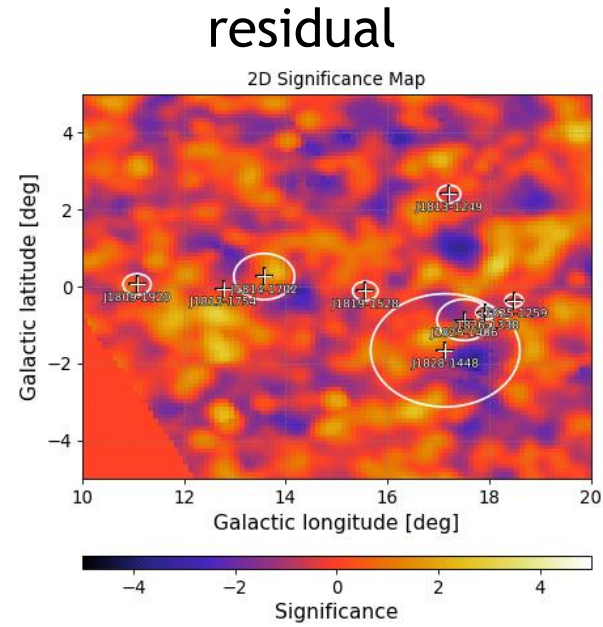
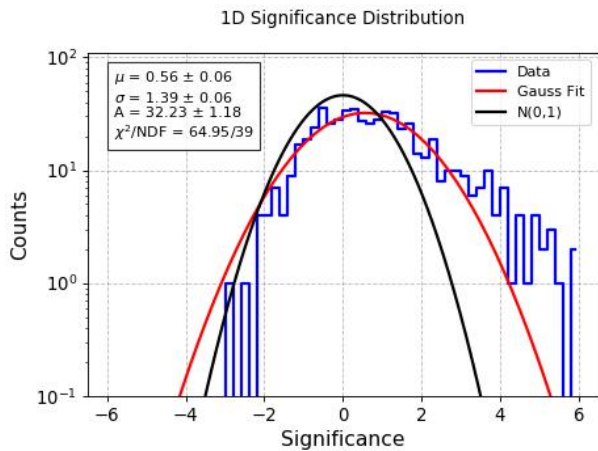
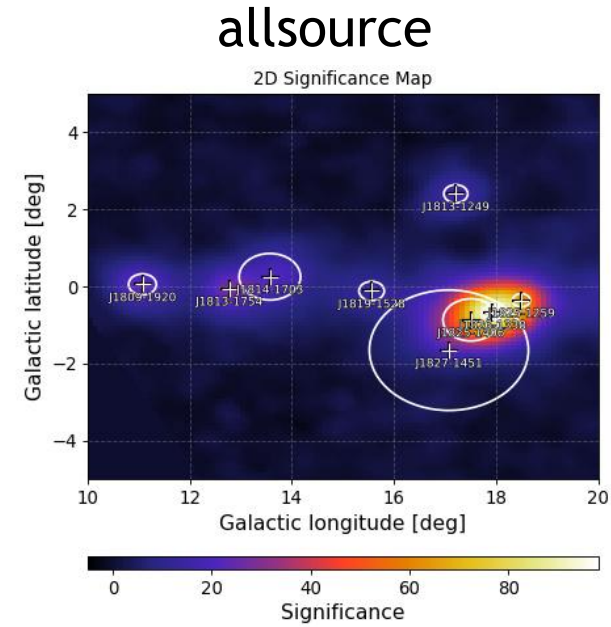
- considering Absorption of UHE photons by background radiation field
 - > Fit to Galactic disk diffuse emission

Discussion & Conclusion

1. We have achieved the measurement of the DGE using the source-subtraction method.
2. 189 sources have been resolved by Joint fit using WCDA and KM2A data.
3. SED of DGE, >100 TeV similar spectral shape as diffuse model, <100 TeV extra component with Ecut: **a soft component (unresolved sources) with Ecut over a hard component (CR-ISM).**
4. Profile of DGE along galactic longitude and latitude deviates from the distribution of the Planck Dust map at 1-25 TeV; Spectral index of DGE is almost constant.
5. We have analyzed Systematic Uncertainty for DGE measurements.
6. We separate DGE measurements into **CR-ISM** and **uRS** component.
7. DGE knee test: Ebreak ~ 316 TeV, index -2.65 ± 0.03 (pre) \rightarrow -3.10 (post).
8. CR knee test: Rbreak ~ 1905 TV, $\Delta\gamma \sim 0.85$.

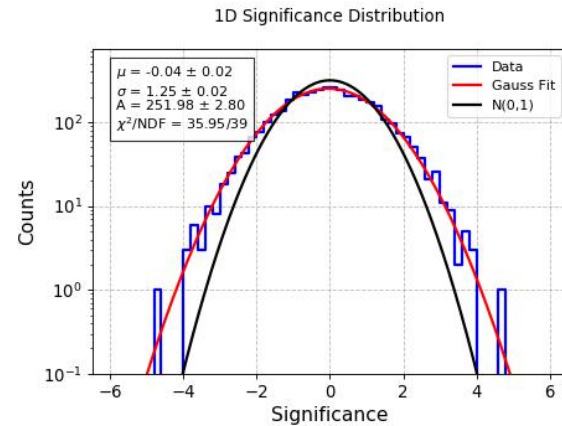
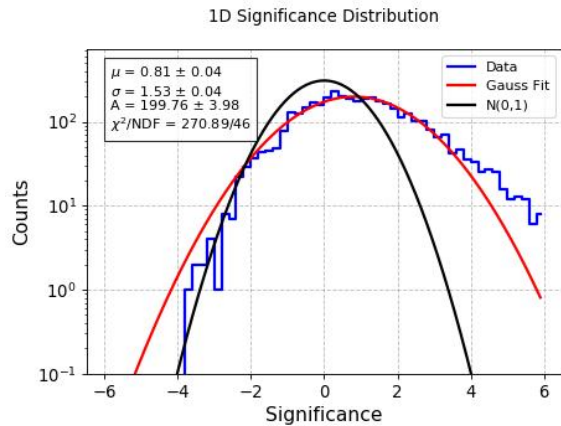
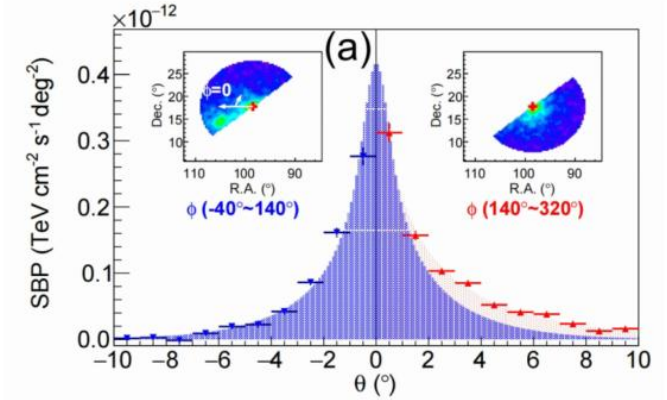
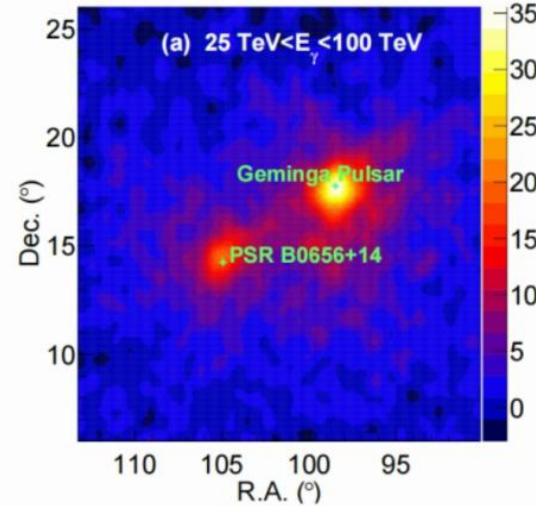
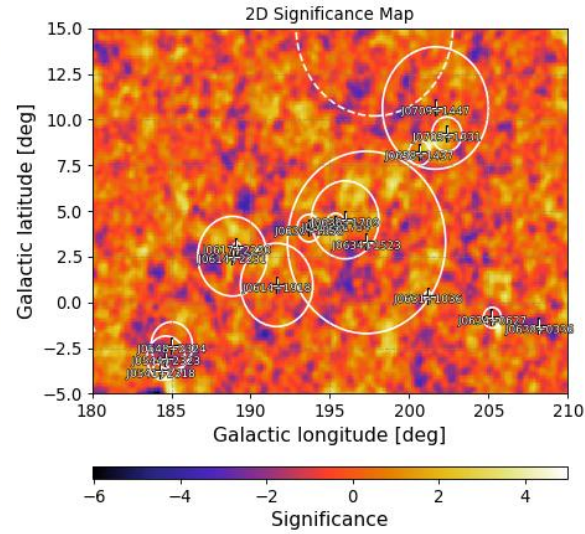
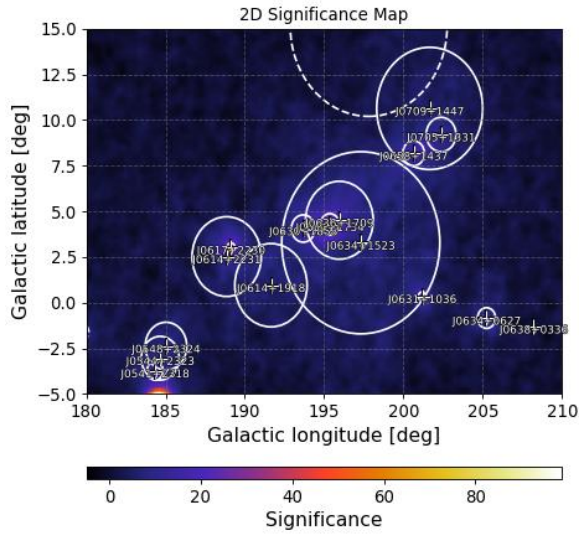
backup

Special ROI: Close to Galactic Center



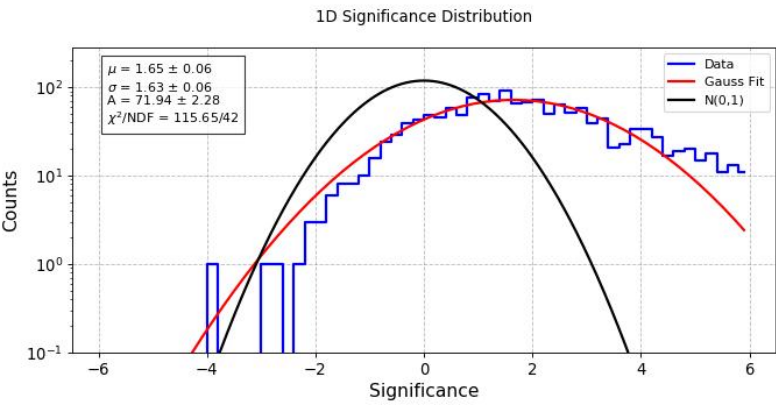
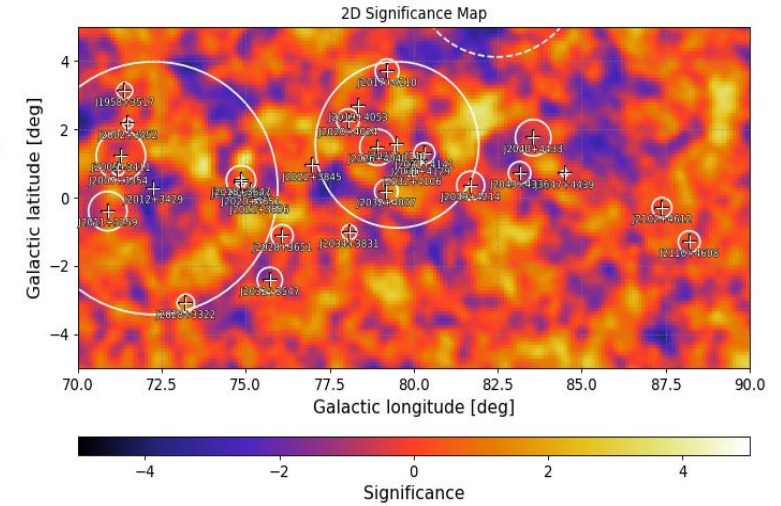
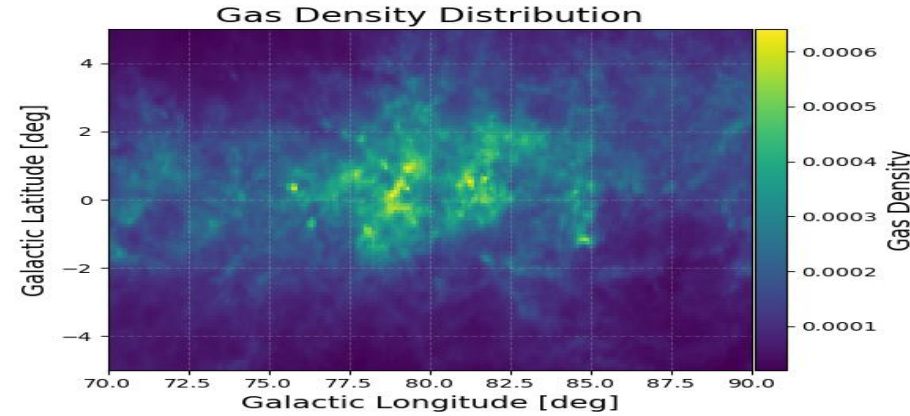
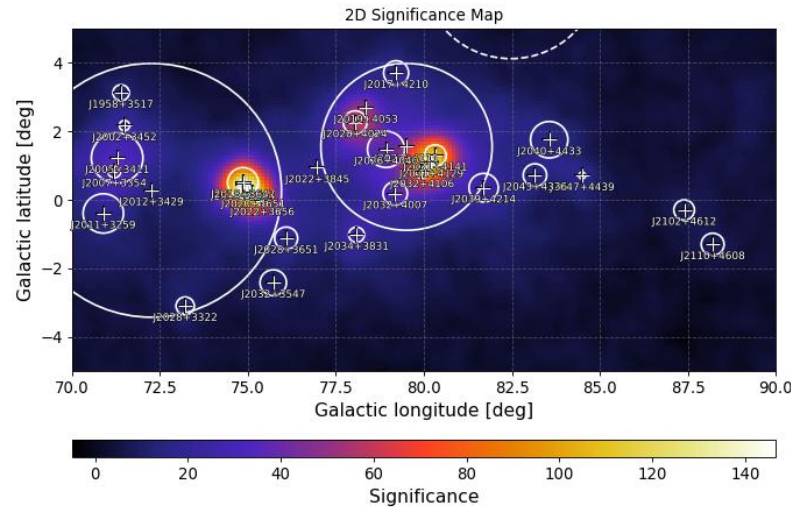
- Low efficiency (zenith: ~50 deg) & Complicated region;
- Residual Significance Map after subtracting RS and DGE: well-fit by the current model given the existing observations.

Special ROI: Geminga & Monogem

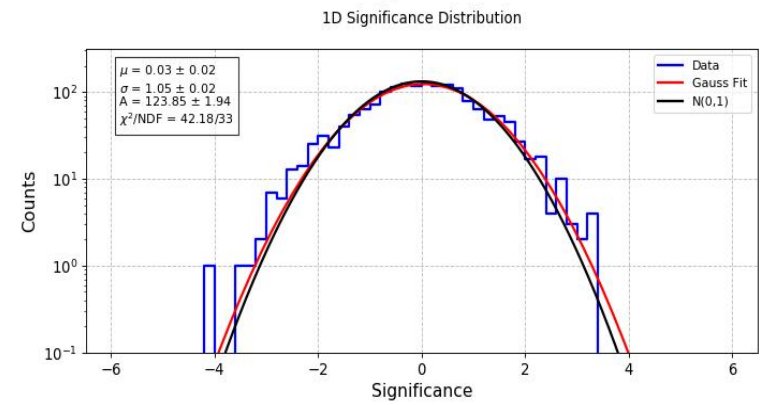


- Asymmetric halo morphologies are observed for Geminga and Monogem, which suggest that the diffusion of electrons and positrons is non-uniform or anisotropic.
- This work: Multi 2D gaussian shape sources for Geminga and Monogem.
- 1D independent significance distribution: inaccurate model for RS or DGE.

Special ROI: Cygnus region



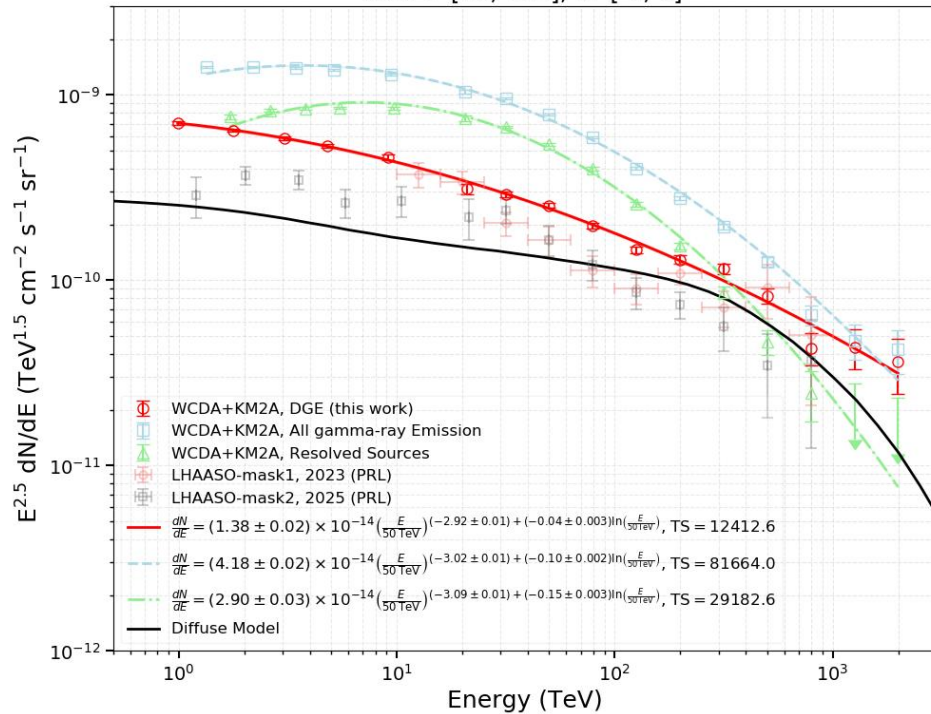
- <- Significance map of all emission (2D distribution, 1D independent $0.4 \times 0.4 \text{ deg}^2$ distribution);
- -> Residual significance map after subtracting RS and DGE ;
- The measurement is largely consistent with the analysis in LHAASO Collaboration, Sci. Bull. 69, 449 (2024).



SED of DGE

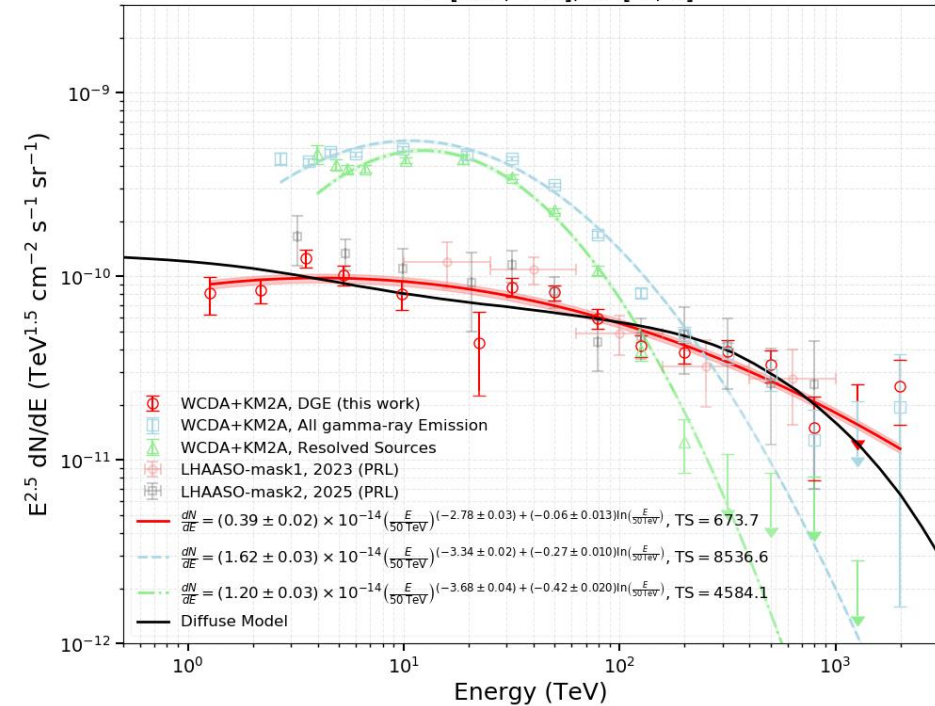
INNER

ROI: l=[10, 125], b=[-5, 5]



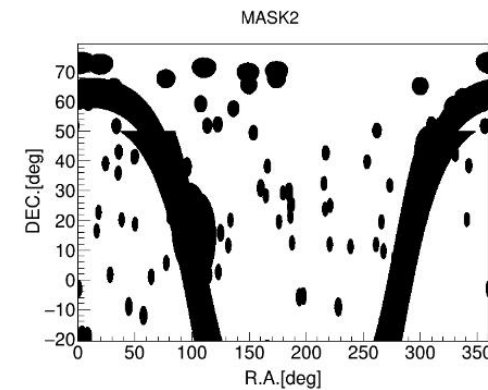
OUTER

ROI: l=[125, 240], b=[-5, 5]



- Diffuse Model: base on LHAASO CR (proton) spectrum (w/o considering Distribution of CRs)
- $E < 100$ TeV: extra component with E_{cut} around tens of TeV
- $E > 100$ TeV: similar spectral shape (index) as that of measurements

预期伽马信号分布-采用Inner和Outer $|b| < 5^\circ$ 谱组合-WCDA



Nhit:60-100

Nhit:100-200

Nhit:200-300

Nhit:300-500

Nhit:500-800

Nhit:800-2000

hon_1st on Direct_integration

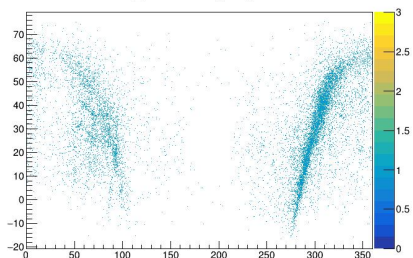
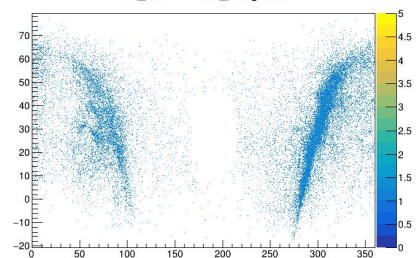
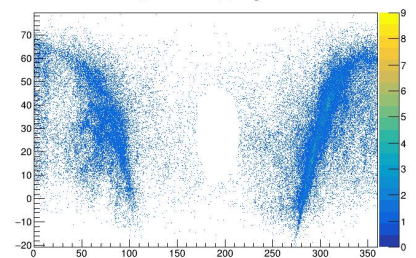
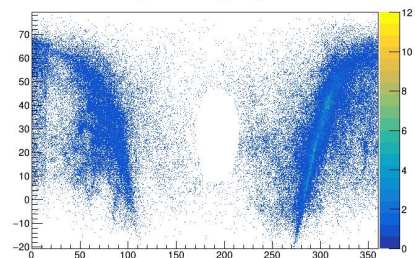
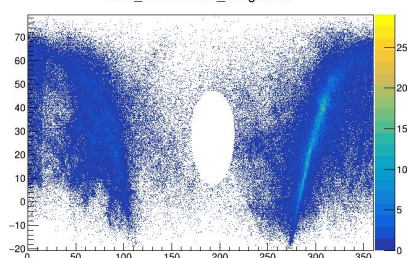
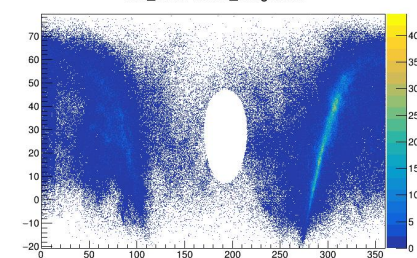
hon_1st on Direct_integration

hon_1st on Direct_integration

hon_1st on Direct_integration

hon_1st on Direct_integration

hon_1st on Direct_integration



hoff_1st on Direct_integration

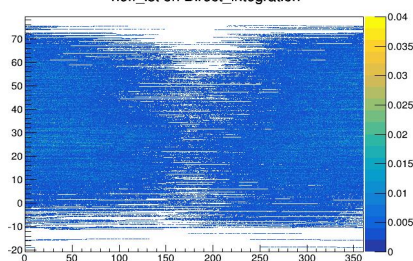
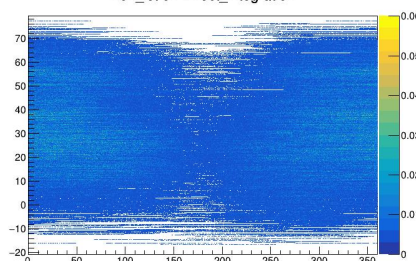
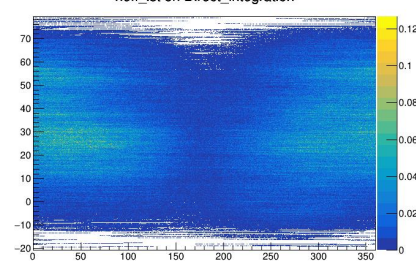
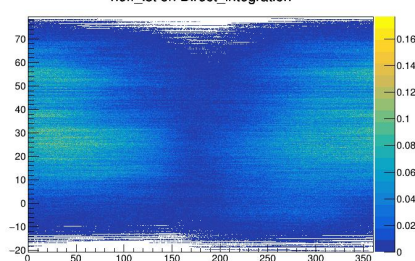
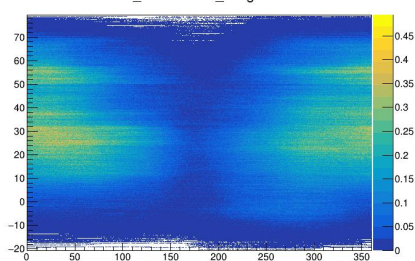
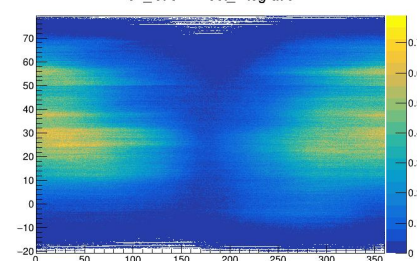
hoff_1st on Direct_integration

hoff_1st on Direct_integration

hoff_1st on Direct_integration

hoff_1st on Direct_integration

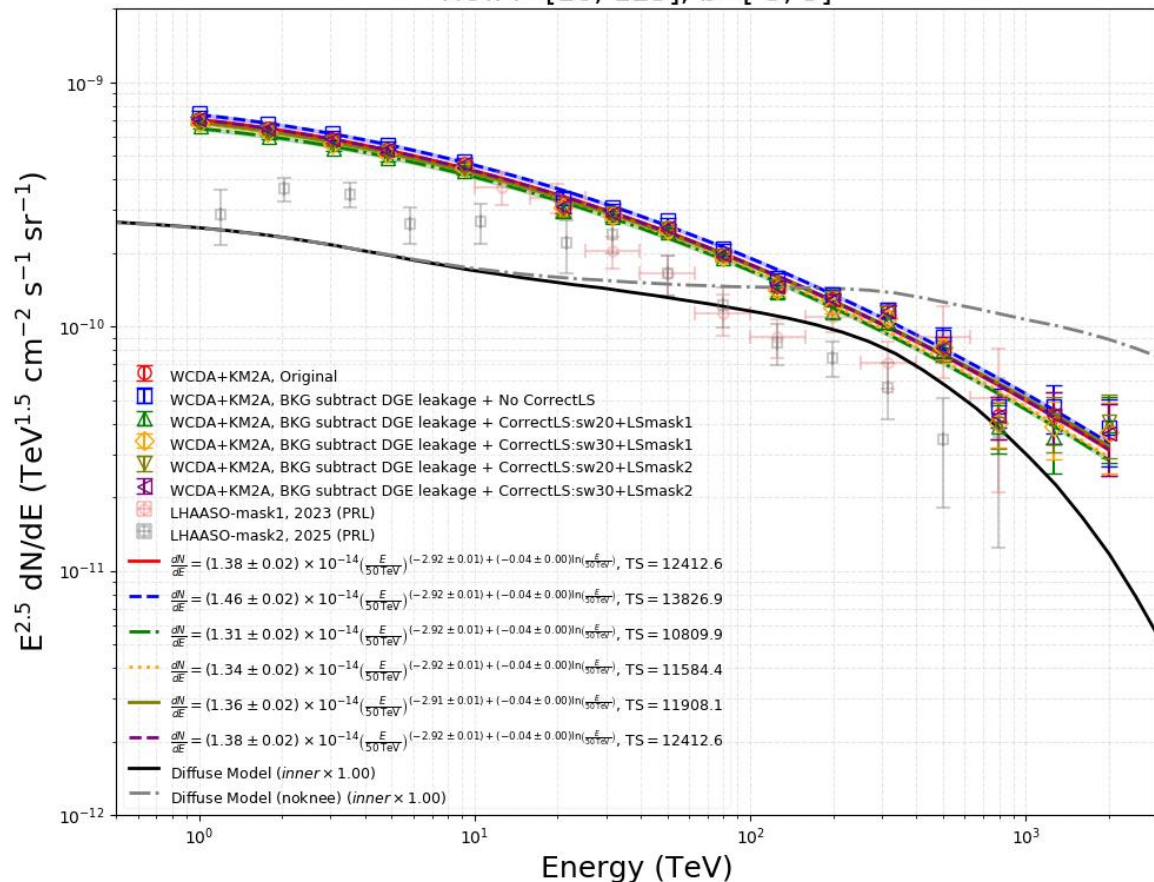
hoff_1st on Direct_integration



BKG

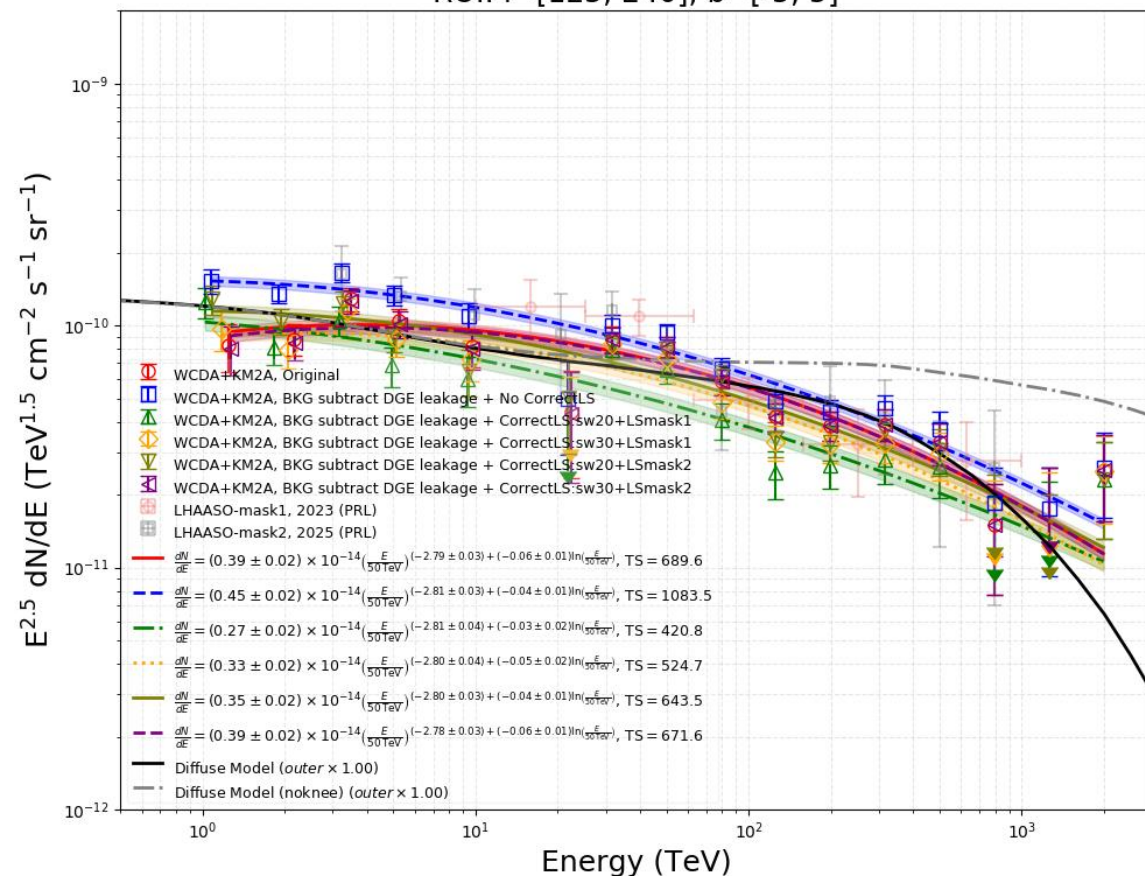
- BKG扣除DGE leakage

ROI: l=[10, 125], b=[-5, 5]



- No CorrectLS下, DGE leakage影响:
Flux~4% (Inner) & 21% (Outer)
- 大尺度修正会抹平DGE leakage(银纬15开外的DGE贡献一定大尺度结构)
综合系统误差: Flux~2% (Inner) & 19% (Outer)

ROI: l=[125, 240], b=[-5, 5]

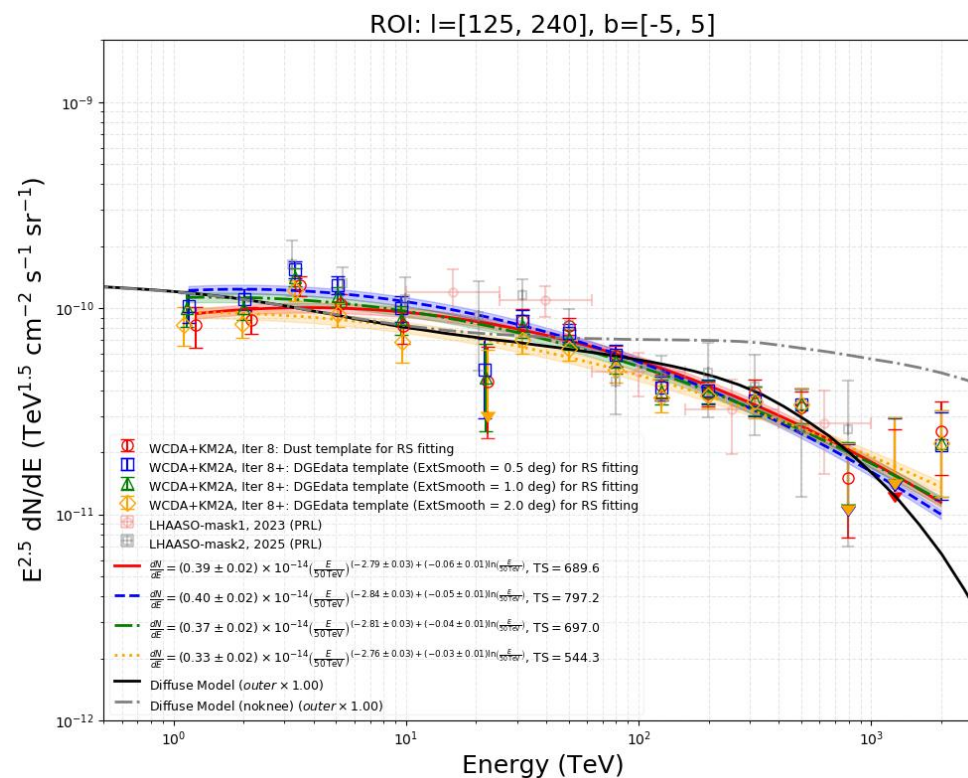
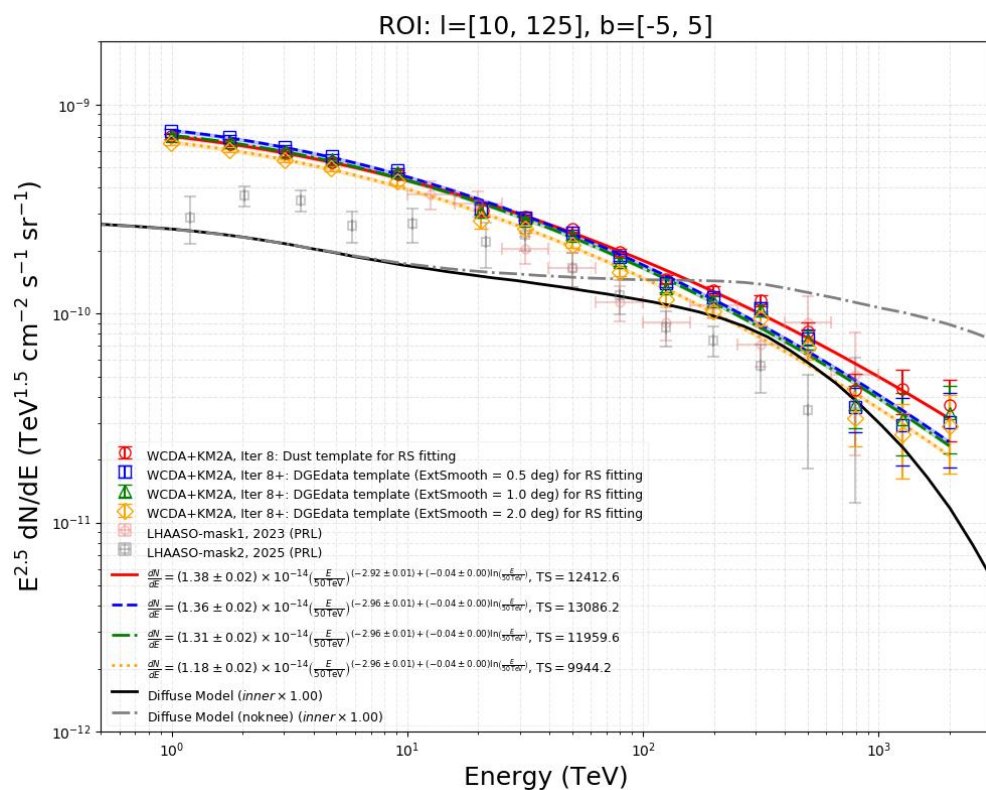


3%(15%) at flux, 0.01(0.02) at index for inner(outer)

Morphology Template for DGE

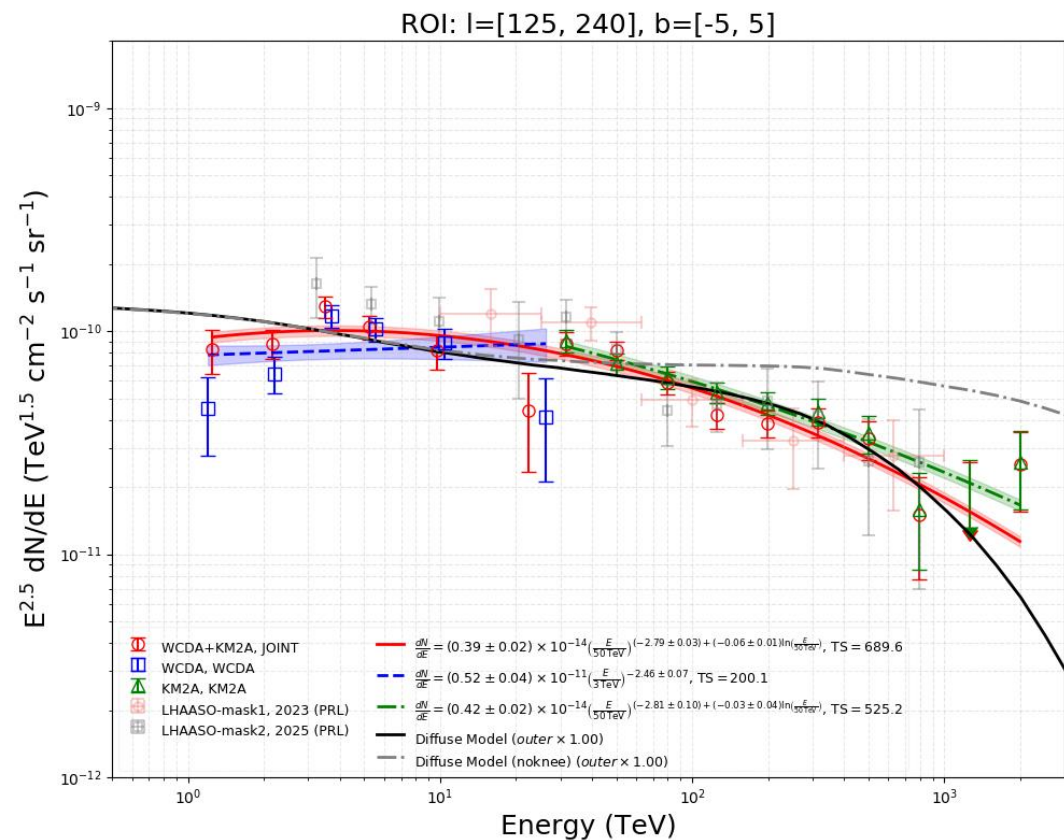
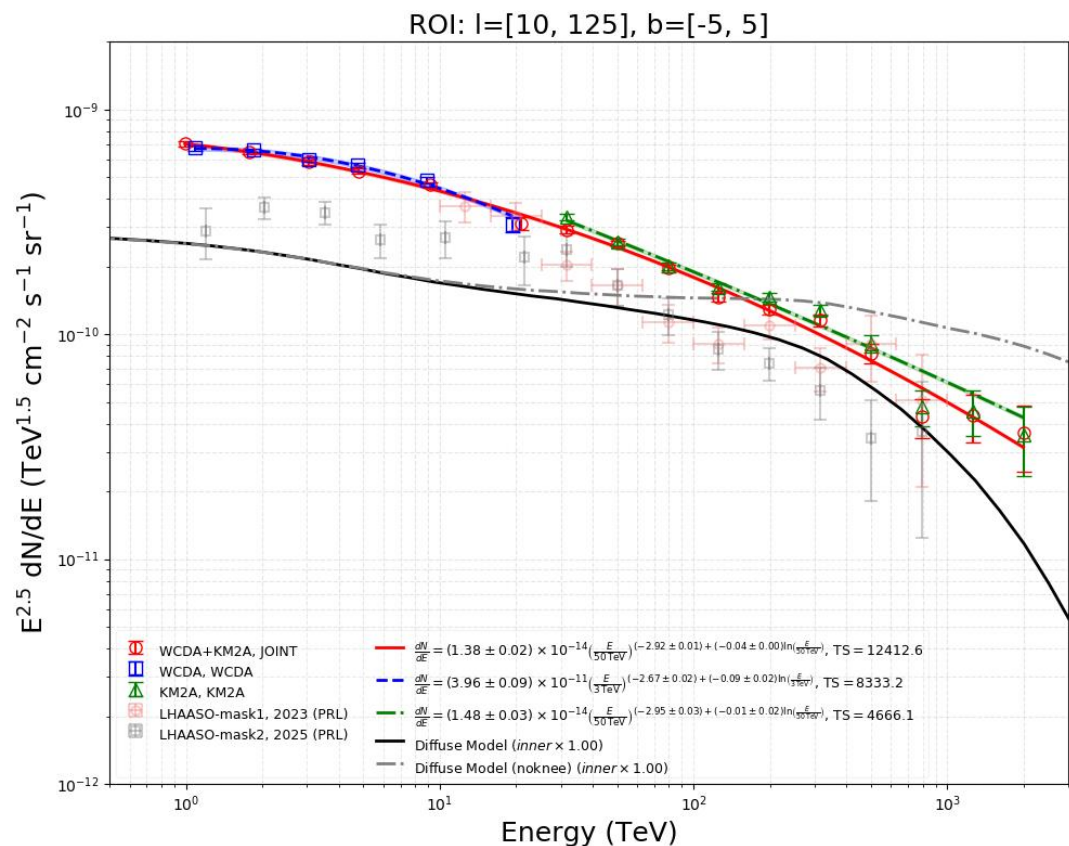


- Influence on RS measurement -> Number of RS, Spectrum/morphology of RS



1%(3%) at flux, 0.04(0.05) at index for inner(outer)

Seperate WCDA/KM2A & JOINT-fit



6%(13%) at flux for WCDA energy
 7%(8%) at flux for KM2A energy for inner(outer)

proton knee

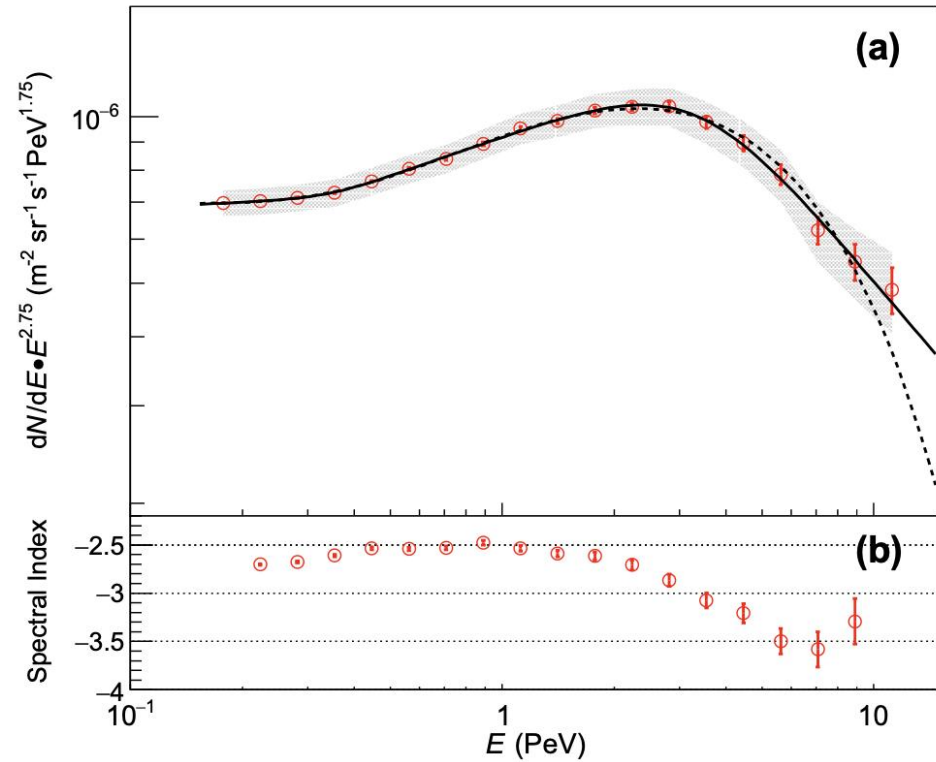


Fig. 2. CR proton energy spectrum measured by LHAASO. (a) The proton flux multiplied by $E^{2.75}$ as a function of energy. The error bars indicate the statistical uncertainties and the shaded band indicates the systematic uncertainties. EPOS-LHC is the hadronic interaction model used in the figure. The solid and dashed lines represent the best fitting results using Eq. (2) for three power-law components and for two power-law components with an exponential cut-off feature, respectively. (b) The local spectral index as a function of energy. The spectral indices are obtained using adjacent three data points fitted with a power-law function form. This indicates a slight hardening with $\Delta\gamma \sim 0.2$ and a gradual softening structure (“knee”) with $\Delta\gamma \sim -1$.