Search for dark matter lines in the energy spectra of Galactic gamma rays with 13.75 years of *Fermi*-LAT data

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On behalf of the *Fermi*-LAT collaboration

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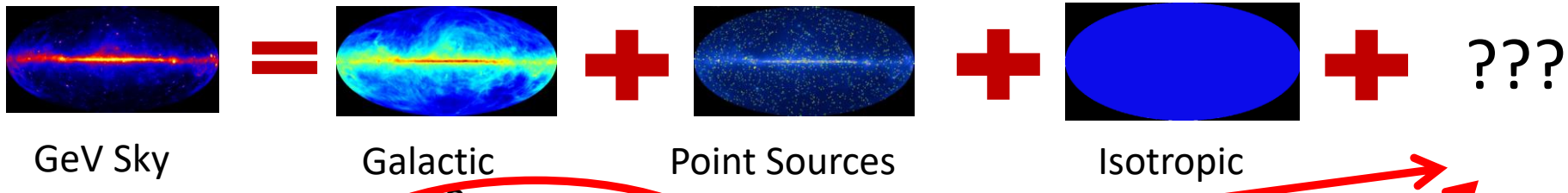
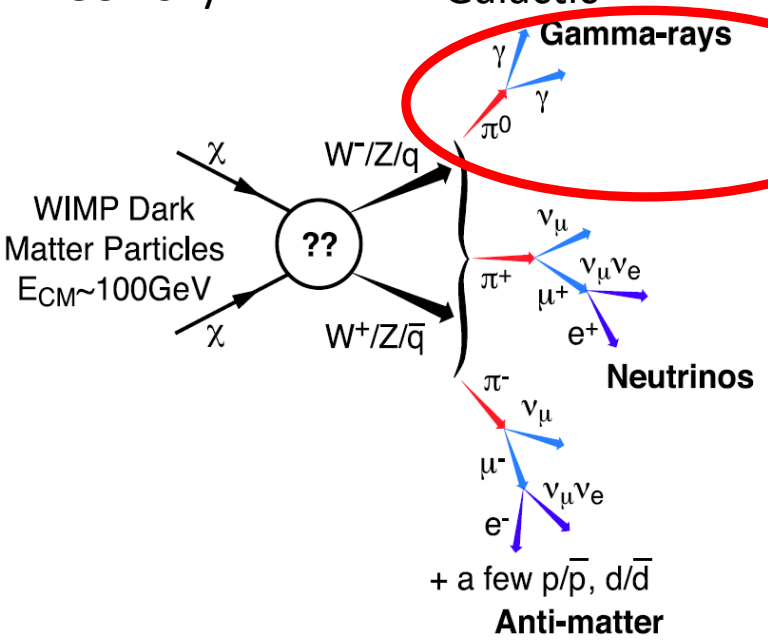
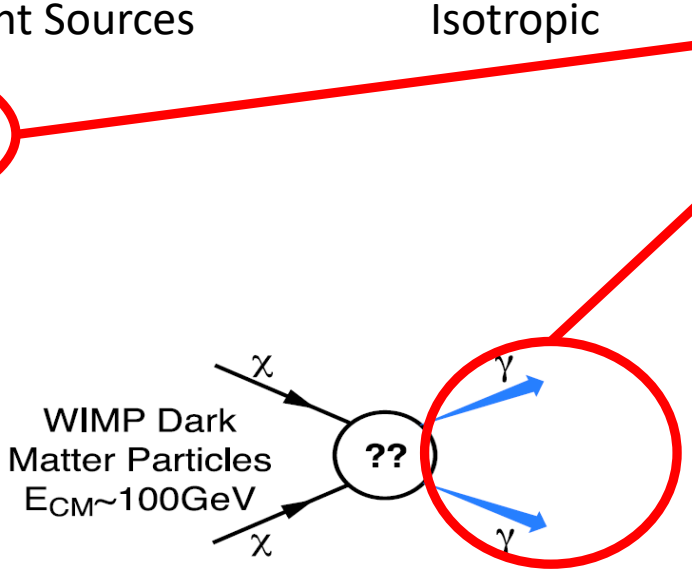
DM searches with gamma rays

- Indirect detection (i.e. astrophysical) searches for DM in the astrophysical targets where it is known to exist





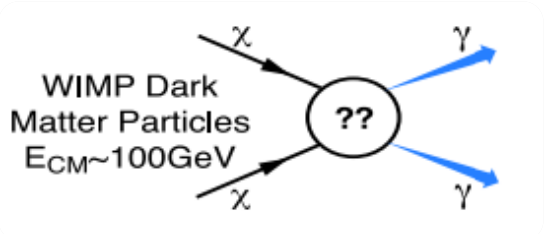


Possible probes for indirect search of dark matter
Credits: *E.A. Baltz et al., 2008*

Indirect DM Searches with gamma rays in the WIMP scenario

2 explored channels:

- **Self annihilation**: $\chi\chi \rightarrow \gamma\gamma$

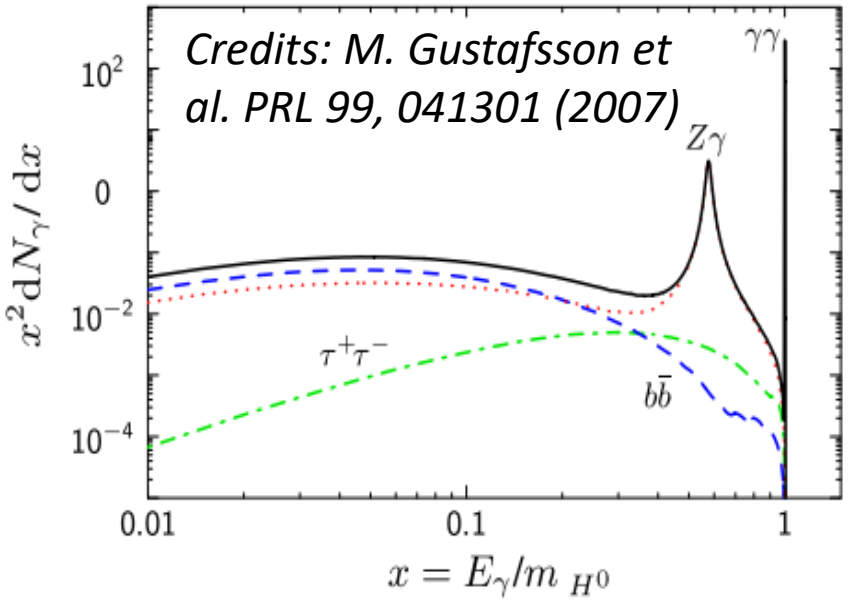


$$\left(\frac{d\Phi}{dE}\right)_{ann} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\chi}^2}\left(\frac{dN_{\gamma}}{dE}\right)_{ann} J_{ann}(\Delta\Omega)$$

- **Decay**: $\chi \rightarrow \gamma\gamma$

$$\left(\frac{d\Phi}{dE}\right)_{decay} = \frac{1}{4\pi}\frac{1}{m_{\chi}\tau}\left(\frac{dN_{\gamma}}{dE}\right)_{decay} J_{decay}(\Delta\Omega)$$

Differential flux = **Particle Physics Factor** ✗ **Astrophysics factor (J-factor)**



Possible signal features: the line feature is a «smoking gun»

➢ The *Fermi*-LAT collaboration published **five previous DM line searches** in the gamma-rays from the Milky Way, the last one in 2015. *(Ackermann et al., 2015)*

DM line search in the multimessenger context

Monochromatic lines are not associated to gamma ray-only final states.

$\chi\chi \rightarrow \gamma X$, where X is another neutral state (ν, γ)

$$E_\gamma = m_\chi \left(1 - \frac{m_X^2}{4m_\chi^2}\right)$$

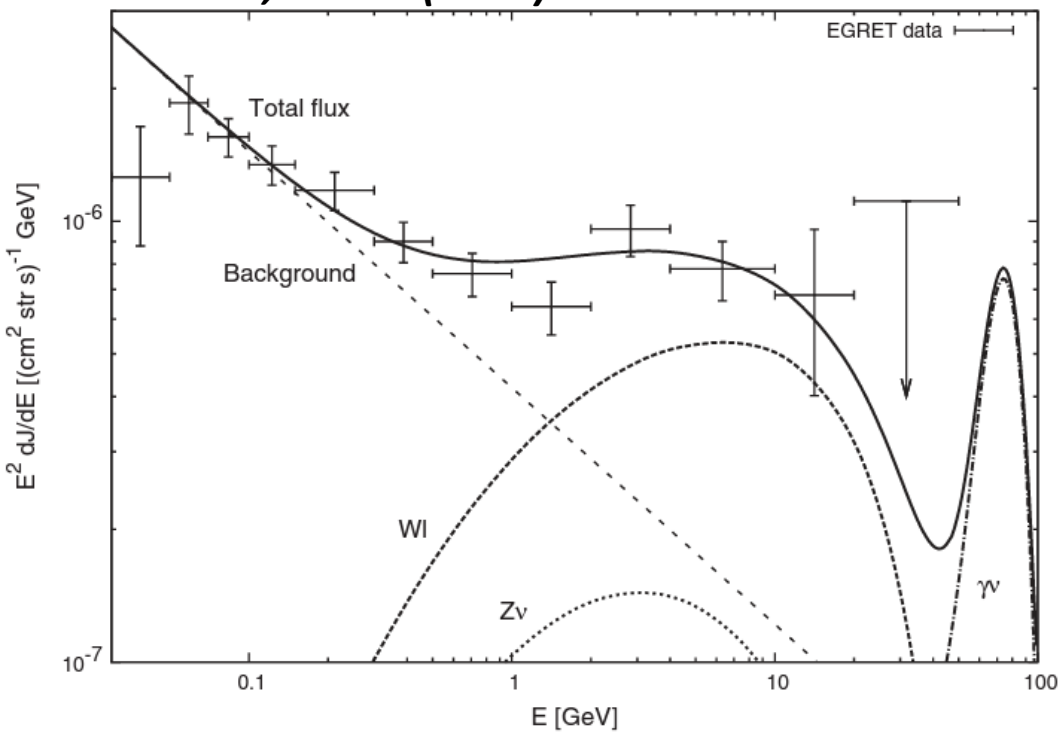
$\gamma\nu$ can be associated not only to WIMP decay $\chi \rightarrow \gamma\nu$ but also to **gravitino decay** $\psi_{3/2} \rightarrow \gamma\nu$ **.**

Estimating the decay time sets constraints also in the gravitino scenario

Analogous searches in neutrino spectra could be decisive

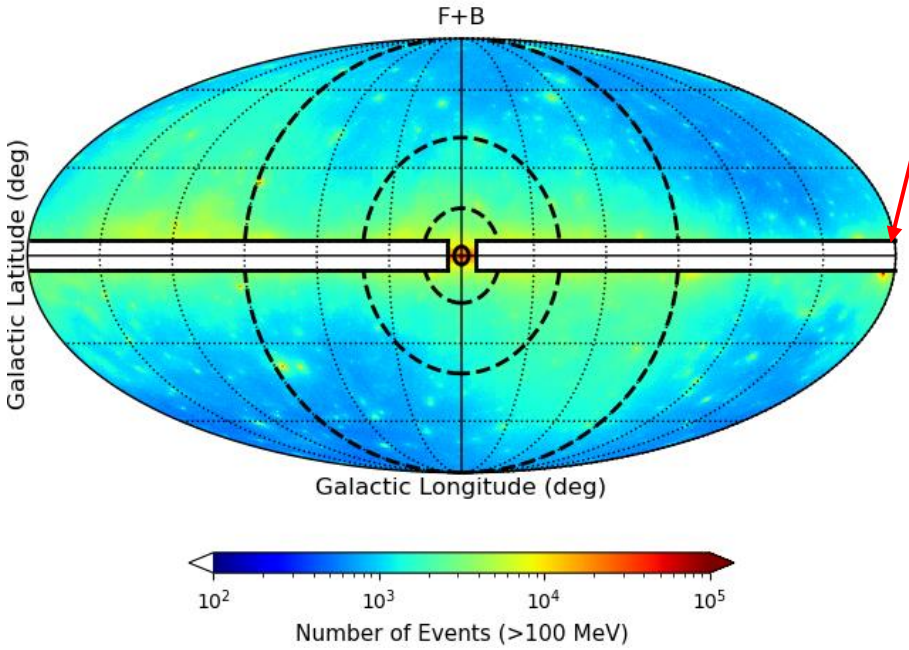
(*see arXiv:2303.13663 [astro-ph.HE] from IceCube collaboration)*

PRL100,061301(2008)



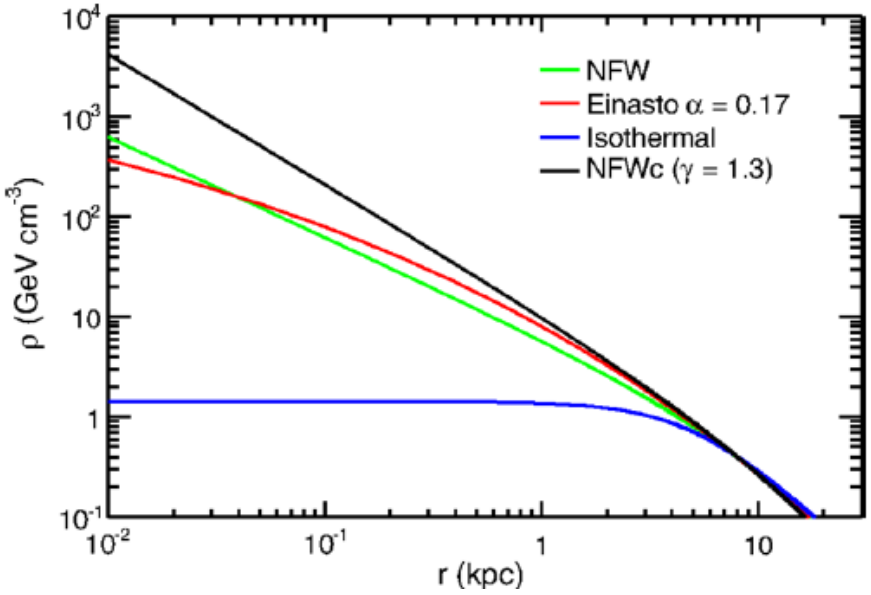
Contributions to the total gamma-ray flux for several gravitino-decay channels compared to the EGRET data.

Choice of the Regions Of Interest (ROIs) and data selection



Observation time	August 2008 – April 2022
Energy Range	[100 MeV – 2 TeV]
Maximum zenith angle θ_z	100°
Event class	256 (CLEAN)
Event Type	All event types
Data Quality	DATA_QUAL==1 LAT_CONFIG==1 IN_SAA!=T

- **Galactic Plane used as a control region**
- **Each ROI is optimized for a specific DM density profile like in previous line searches *(Ackermann et al., 2013)***
- **Data sample selection and cuts**
- **Different analyses for each EDISP sample (EDISP0, EDISP1, EDISP2, EDISP3)**

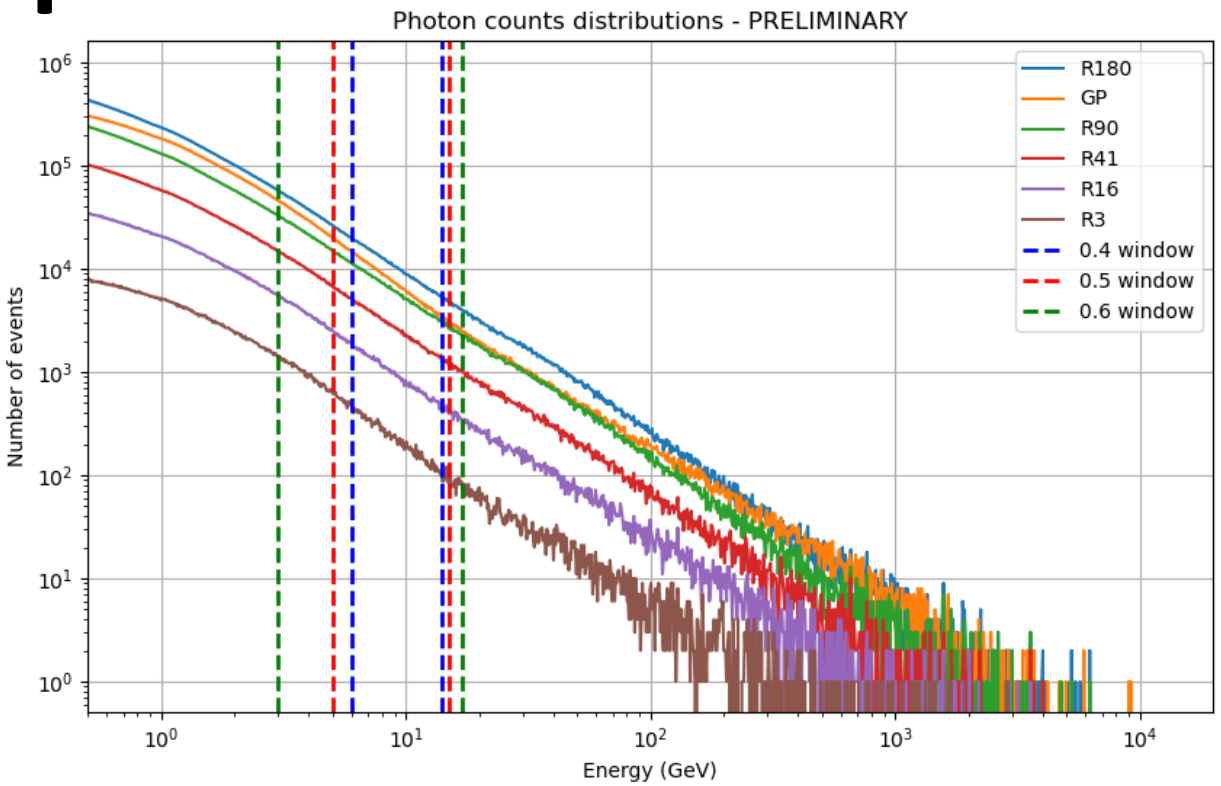


DM density profiles different only in GC region

Credits: *Ackermann et al., 2015*

Hypothesis test and fit procedure

- Photon flux from any ROI:
  - **H1**: $\boldsymbol{\Phi_{RoI}(E_t) = \Phi_{bkg}(E_t) + \Phi_{sig}(E_t)}$
  - **H0**: $\boldsymbol{\Phi_{RoI}(E_t) = \Phi_{bkg}(E_t)}$
- Signal flux :
  - $\boldsymbol{\Phi_{sig}(E_t) = s\delta(E_t - E_{line})}$
    - the parameter $s \geq 0$ represents the line intensity
- The background flux is the sum of a "smooth" contribution from known astrophysical processes, and a possible line-like contribution which could mimic a DM feature:
  - $\boldsymbol{\Phi_{bkg}(E_t) = \Phi_{smooth}(E_t) + \Phi_{bkg,line}(E_t)}$
    - $\boldsymbol{\Phi_{smooth}(E_t)}$ modeled with a log-parabola for E<10GeV or a power law for E>10GeV
    - $\boldsymbol{\Phi_{bkg,line}(E_t|b) = b\delta(E_t - E_{line})}$
    - The parameter b can be either positive or negative



- Expected counts in each observed energy bin:
- $\boldsymbol{\mu_j = \int dE_t \varepsilon_{RoI}(E_j|E_t)\,\Phi(E_t)}$
  - $\Phi(E_t)$ is the gamma-ray flux
  - $\boldsymbol{\varepsilon_{RoI}}$ is the exposure in each RoI
- **Maximum likelihood fit procedure implemented in sliding energy windows**

Combined likelihood analysis

- **Combined likelihood:**

$$\mathcal{L}_{\mathbf{combined}}(\mathbf{s}) = \prod_{\mathbf{i}} \mathcal{L}_{\mathbf{i}}(\mathbf{s})$$

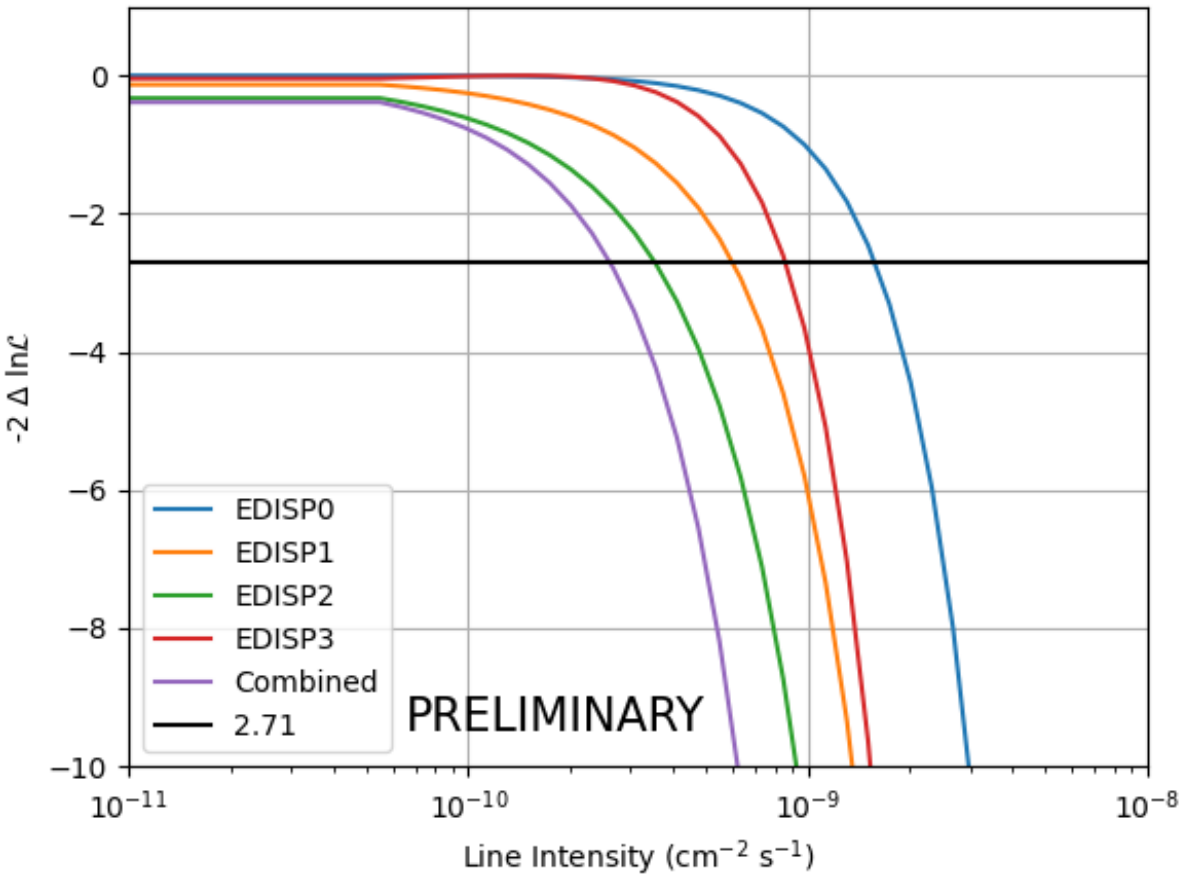
  - The index i runs over the different **EDISP types**
- We define the **Test Statistic *TS*:**

$$\boldsymbol{TS} = \mathbf{2}\left[\boldsymbol{ln}\mathcal{L}_{\mathbf{1},\boldsymbol{max}} - \boldsymbol{ln}\mathcal{L}_{\mathbf{0},\boldsymbol{max}}\right]$$

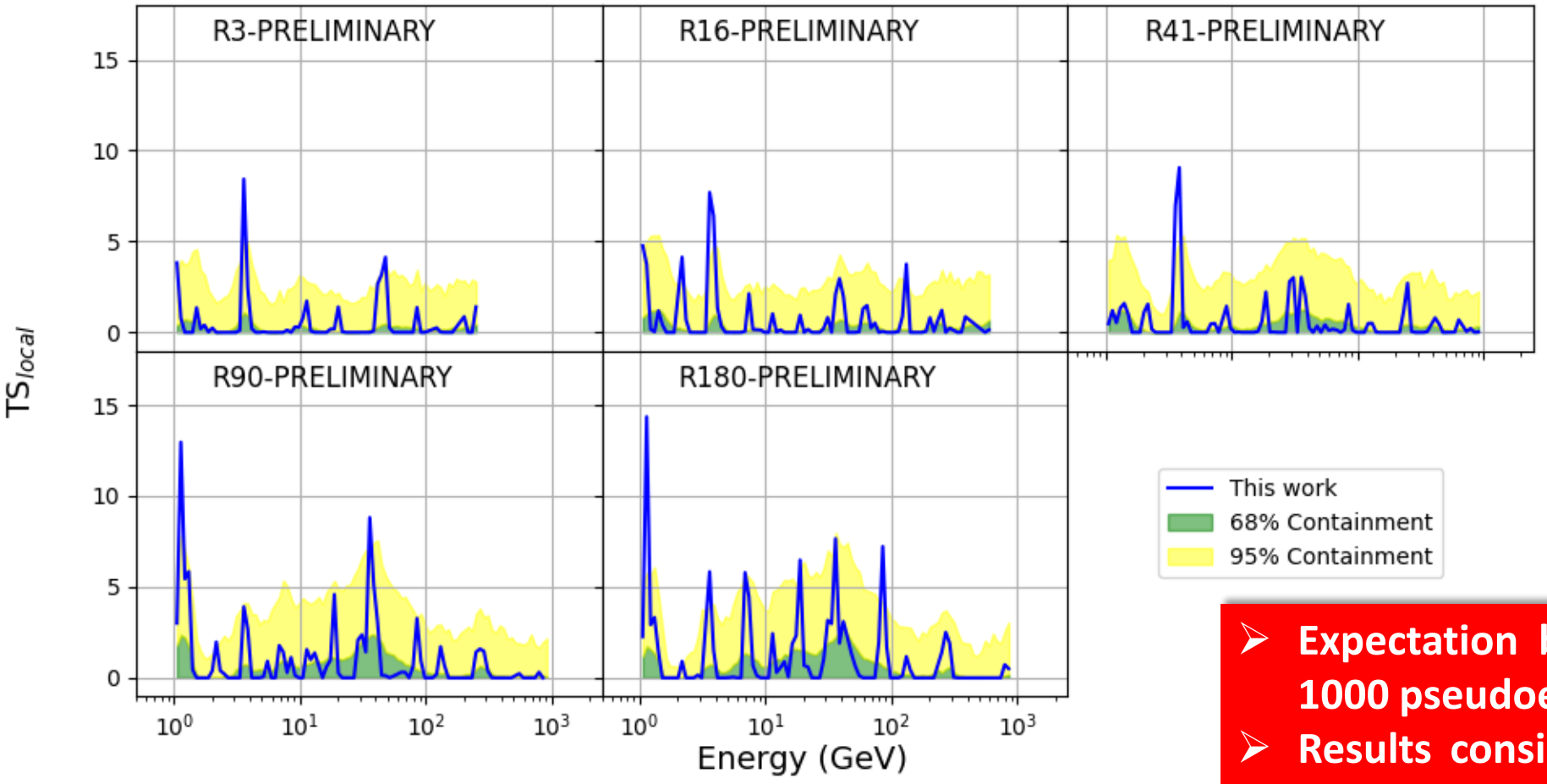
- A feature is significantly detected if $\boldsymbol{TS} > \mathbf{25}$
- If a signal is not significant, the UL on the line intensity is evaluated from the log$\mathcal{L}$ function:
  - UL at 95%CL:

$$\boldsymbol{log\mathcal{L}} = \boldsymbol{log\mathcal{L}}_{\text{max}} - (\mathbf{2.71})/\mathbf{2}$$

Mazziotta et al., PoS (ICRC2023)



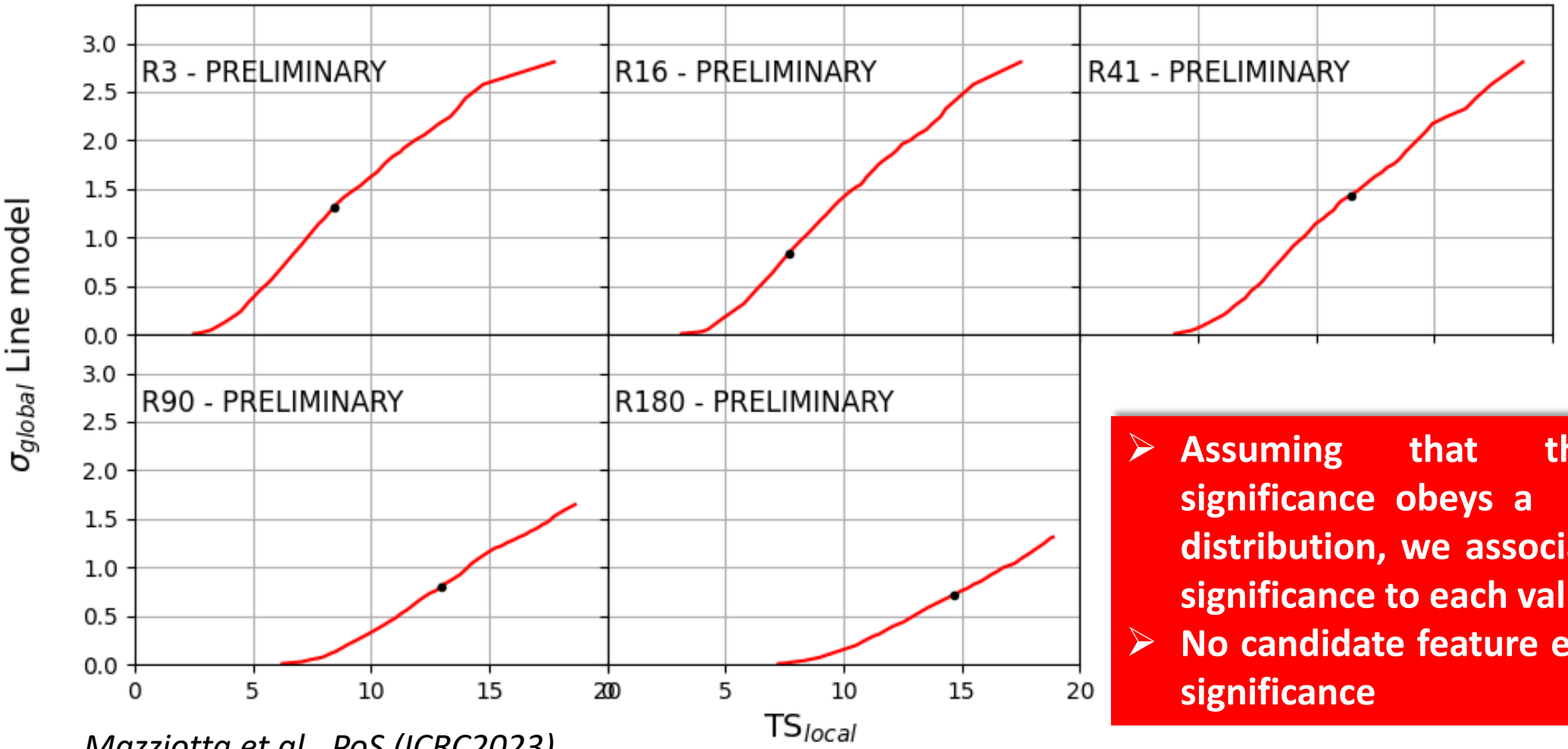
Preliminary results: no significant features detected



Mazziotta et al., PoS (ICRC2023)

- **Expectation bands obtained by means of 1000 pseudoexperiments**
- **Results consistent with expectations from the null hypothesis, with few outliers**

Global significance does not exceed ~1.5σ

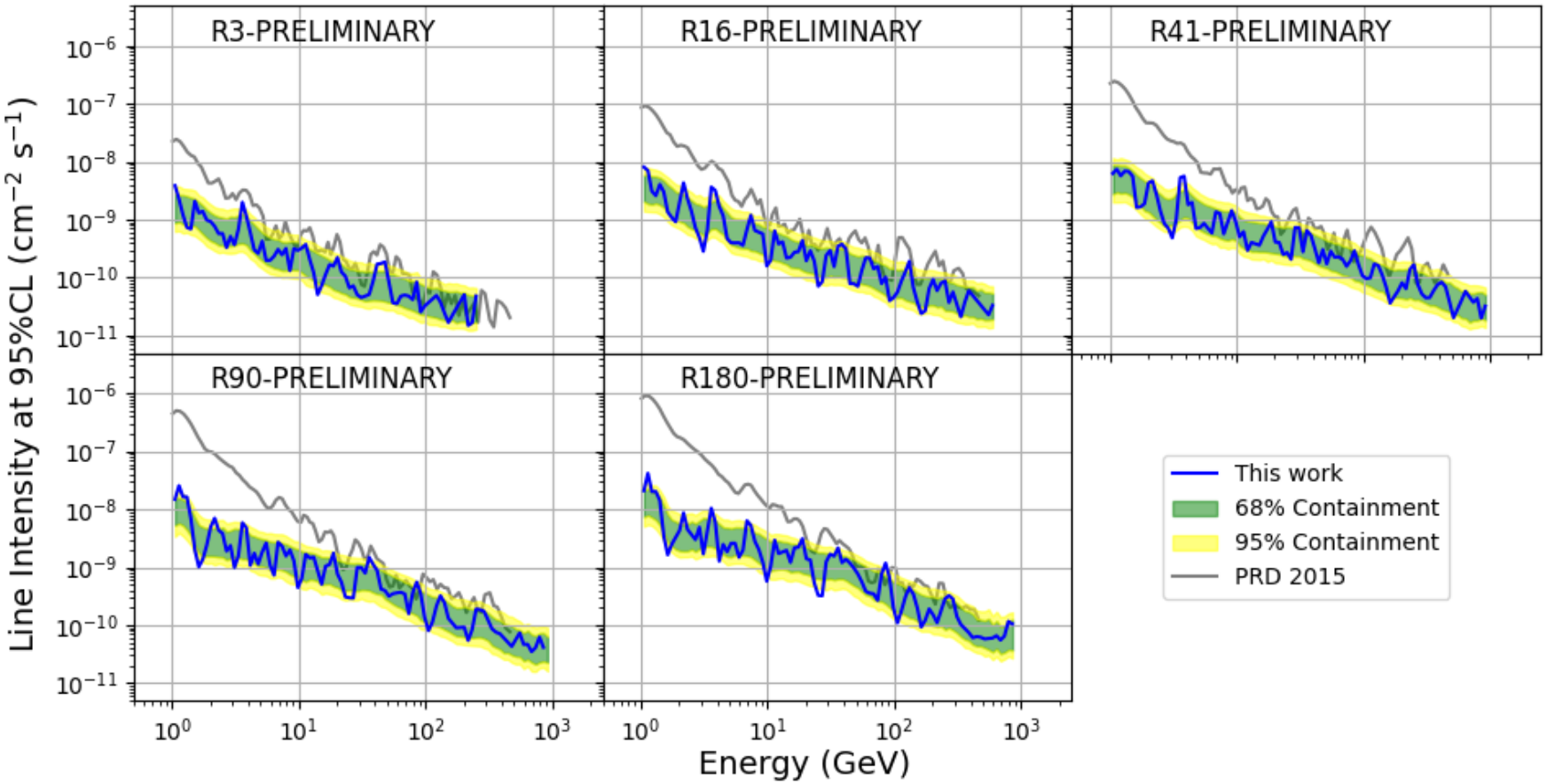


Mazziotta et al., PoS (ICRC2023)

- Assuming that the global significance obeys a half-normal distribution, we associate a global significance to each value of TS
- No candidate feature exceeds 1.5σ significance

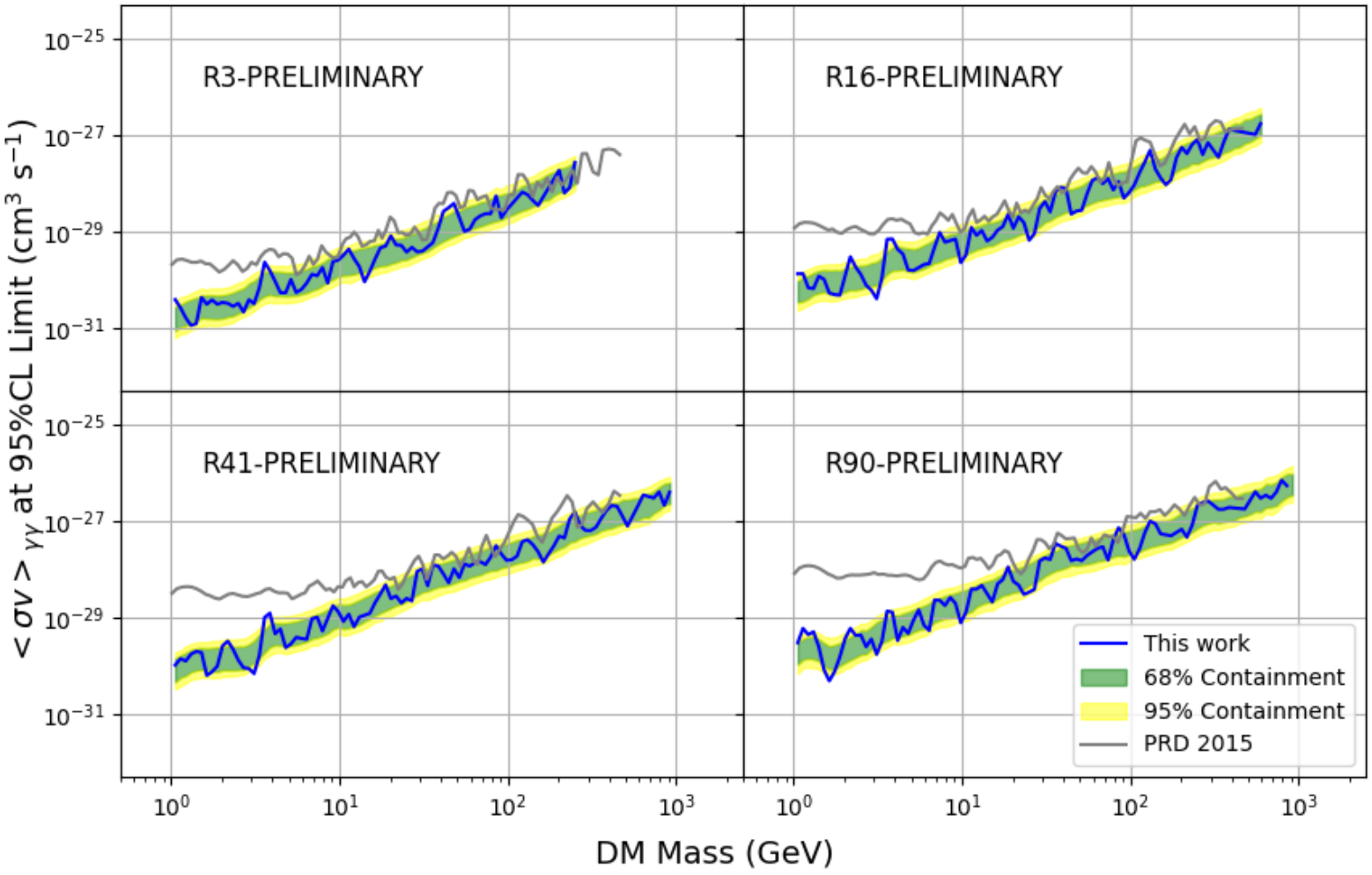
Upper limits on line signal strength

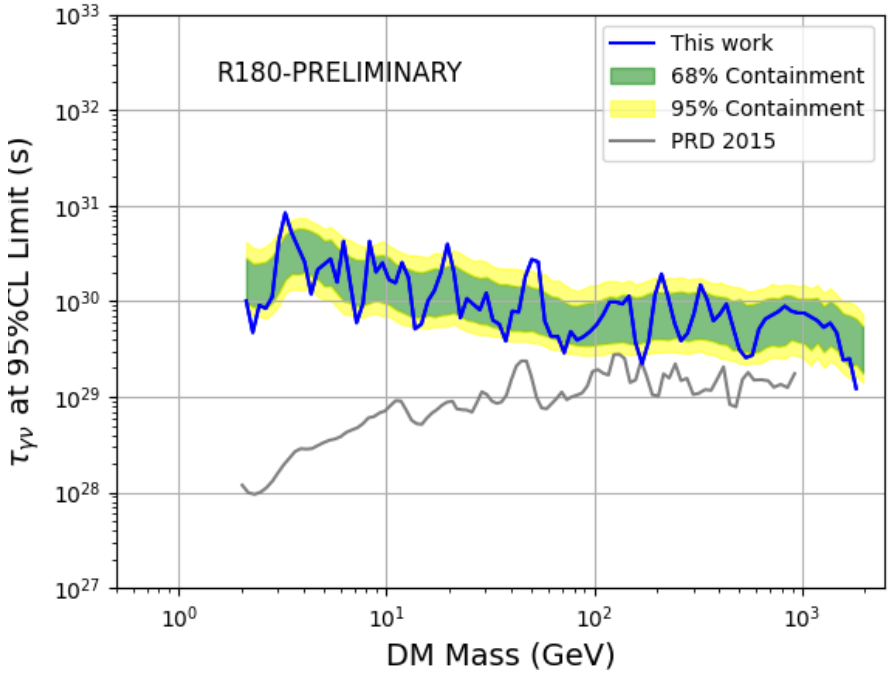
Mazziotta et al., PoS (ICRC2023)



- **Improvement of one order of magnitude at low energies with respect to the previous LAT analysis**
- **Measured limits lie within the containment bands, and are therefore consistent with the expectations for the null hypothesis**

Constraints on $\langle \sigma v \rangle$ and τ





Constraints on the line intensities are converted into constraints on $\langle \sigma v \rangle$ and τ

Mazziotta et al., PoS (ICRC2023)

Conclusions and perspectives

- **Exclusion of the existence of spectral lines**
- Stronger constraints than those in the 2015 Fermi-LAT analysis thanks to:
  - updated model for the smooth background
  - combined likelihood analysis technique
- These results were presented at the ICRC 2023
- These results can be compared to those in line searches in neutrino spectra
- **Draft in progress**

Thank you for your attention!

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