

Assessing SWGO Sensitivity to Lorentz Invariance Violation through Transparency Studies

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Outline

1. Anomalous transparency to very-high-energy gamma rays
2. The Southern Wide-field Gamma-ray Observatory (**SWGO**)
3. Source - **PKS 2155-304**
4. Workflow
5. Results

Photon-photon interaction

Very-high energy (VHE) gamma rays ($10^{-1} - 10^2$ TeV) interact with the Extragalactic Background Light (EBL) through the interaction:

$$\gamma_{\text{VHE}}(k) + \gamma_{\text{EBL}}(q) \rightarrow e^- + e^+, \quad k \equiv (E, \vec{k}), q \equiv (\omega, \vec{q})$$

General *modified dispersion relation*:

$$E^2 - \vec{k}^2 = E^2 \sum_{n=1}^{\infty} S_n \left(\frac{E}{E_{\text{LIV},n}} \right)^n$$

where $S_n = \pm 1$.

Our study concerned the case $n = 2$, with $S_2 = -1$:

$$E^2 - \vec{k}^2 = -E^4 / \Lambda^2 \quad (\Lambda \equiv E_{\text{LIV},2})$$

Threshold energy

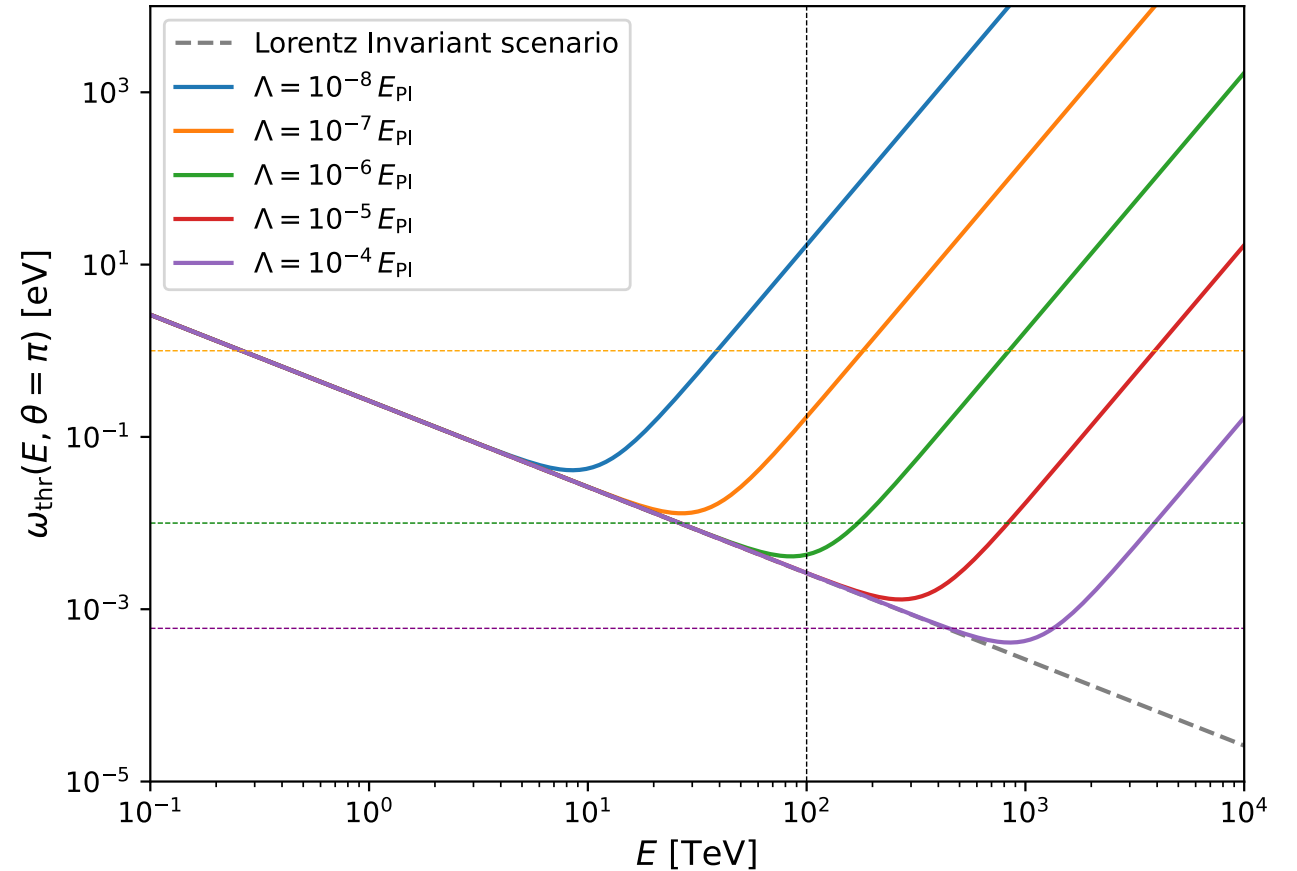
$$(k + q)^2 = 4m_e^2 \Rightarrow \frac{2E\omega(1 - \cos \theta)}{4m_e^2} \geq 1$$

SR

$$\omega_{\text{thr}}(E, \theta) = \frac{2m_e^2}{E(1 - \cos \theta)}$$

LIV

$$\omega_{\text{thr}}(E, \theta; \Lambda) = \frac{2m_e^2}{E(1 - \cos \theta)} + \frac{E^3}{2\Lambda^2(1 - \cos \theta)}$$



Constraints on Λ

H.E.S.S. Collaboration; 2019:

- $\Lambda \gtrsim 7.8 \cdot 10^{20} \text{ eV}$
- Source: Mrk 501, $z = 0.034$
- Observations of $\sim 20 \text{ TeV}$ gamma rays.

Back-of-the-envelope argument:

$$\frac{d\omega_{\text{thr}}}{dE} = 0 \Rightarrow E_{\text{obs}} = 8.5 \cdot 10^{14} \text{ eV} \left(\frac{\Lambda}{10^{-4} E_{\text{Pl}}} \right)^{1/2}$$

Intrinsic and observed flux

$$\Phi_{\text{obs}}(E) = P_{\gamma\gamma}(E, z_s) \times \Phi_{\text{int}}(E(1 + z_s))$$

Survival probability:

$$P_{\gamma\gamma}(E, z_s) = \exp(-\tau(E, z_s))$$

Opacity:

$$\tau(E, z_s) = \int_0^{z_s} \frac{dl}{dz} dz \int_{-1}^1 d \cos \theta \left(\frac{1 - \cos \theta}{2} \right) \int_{\omega_{\text{thr}}(E, \theta)}^{\infty} d\omega n(\omega, z) \sigma(E(1 + z), \omega, \theta)$$

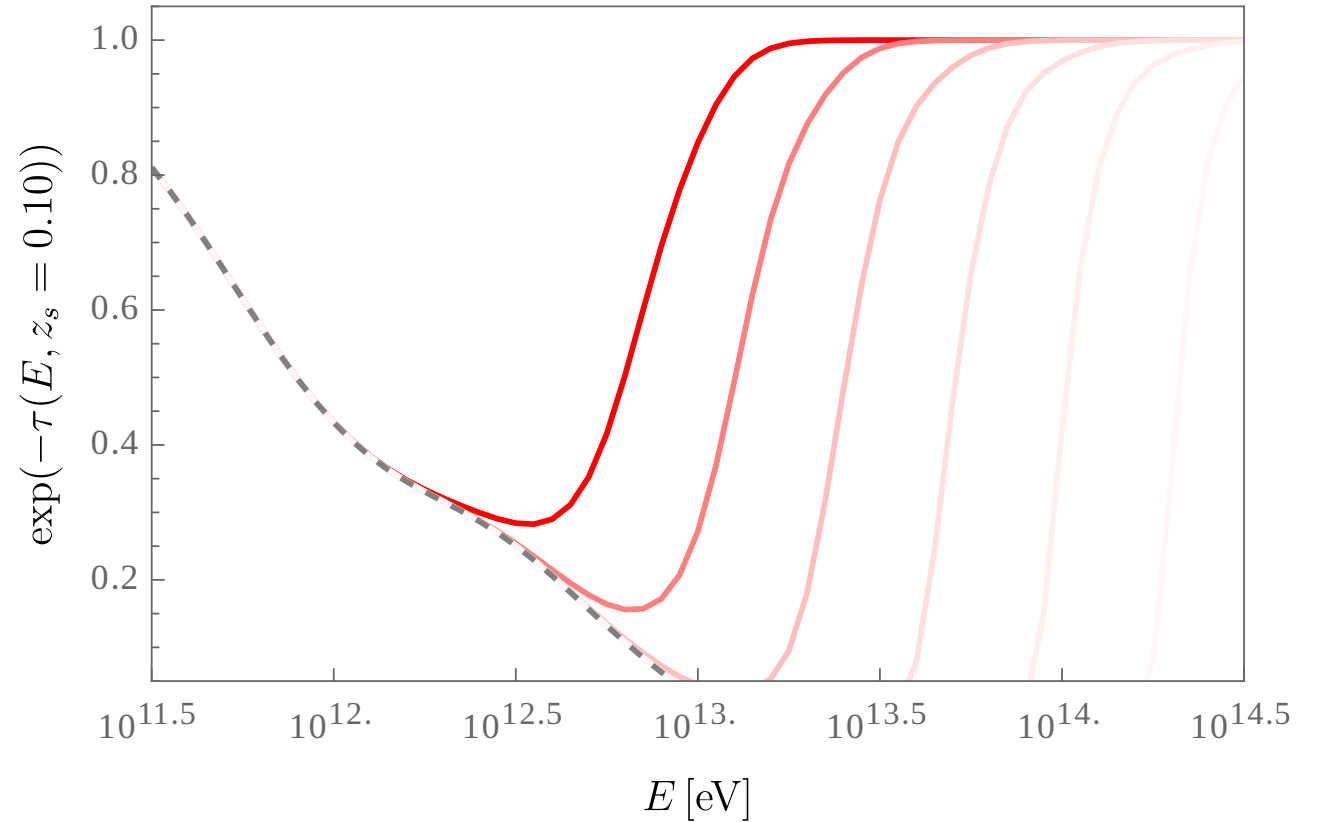
LIV cross section: [Carmona et al.; 2024](#)

EBL model: [Domínguez et al.; 2011](#)

Survival probability: SR & LIV

Probability of survival for:

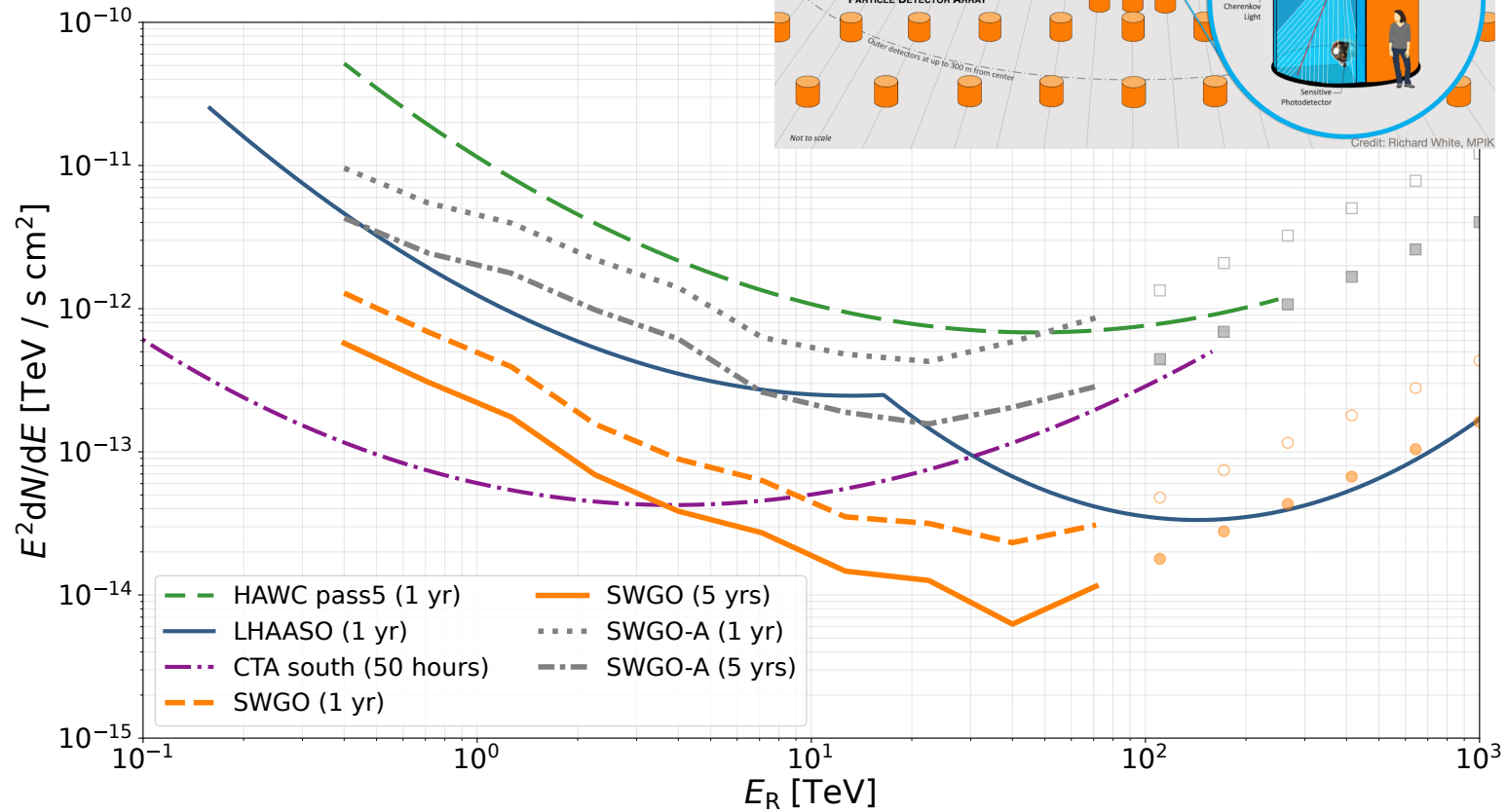
- $\Lambda/E_{\text{Pl}} \in [10^{-8.5}, 10^{-6}]$
(with steps of 0.5)
- $z = 0.1$
- Curves:
 - dashed $\rightarrow$ **SR**
 - red $\rightarrow$ **LIV**



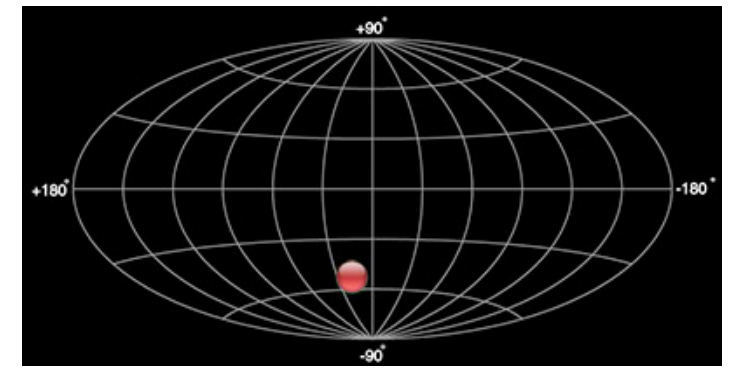


SWGO

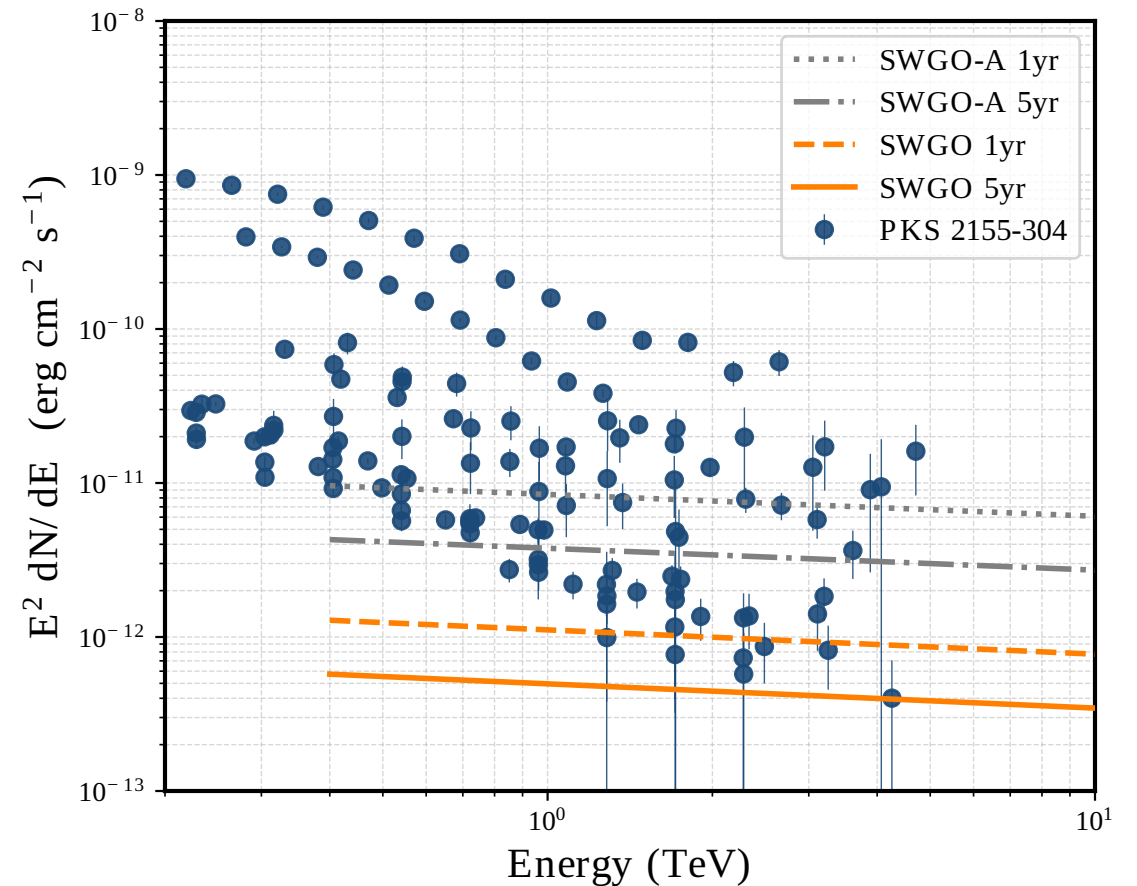
- Water Cherenkov Detector units
- Location: Atacama Astronomical Park, Chile
- Altitude: 4770 m
- Energy range: 100s of GeV up to 10s of PeV
- SWGO-A:
 - 385 WCD units
 - 65% fill factor



PKS 2155-304

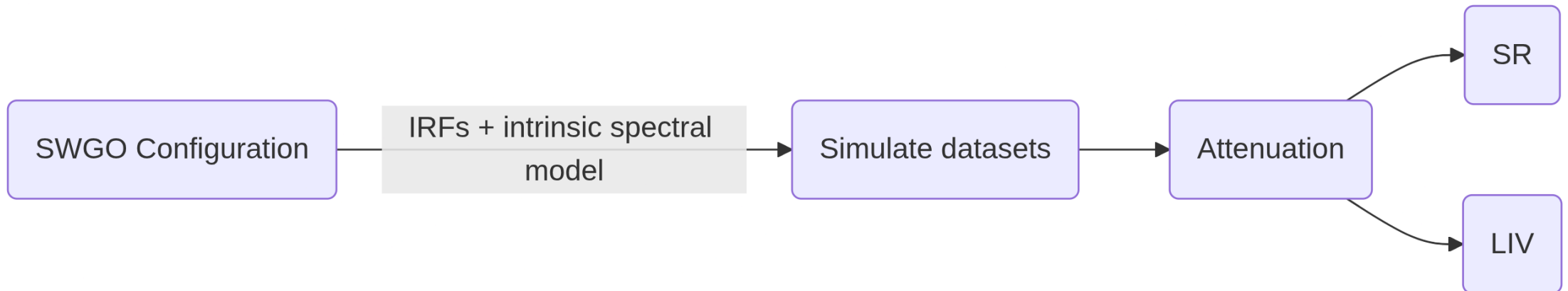
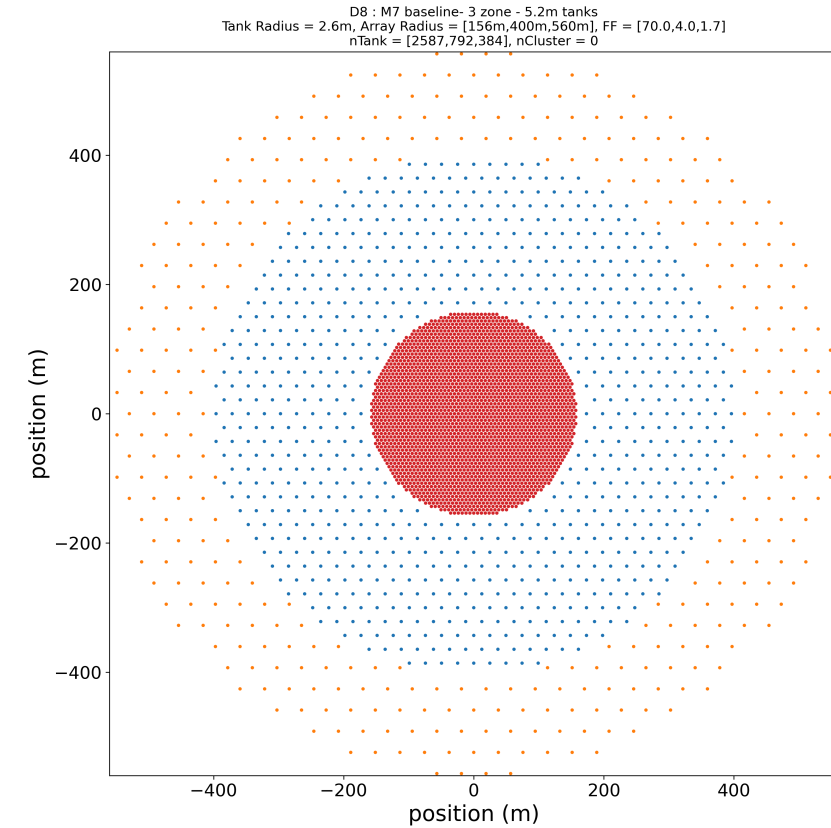


- Both baseline and flaring states (H.E.S.S. Collaboration; 2010, 2012, 2013)
- $z = 0.116$
- One of the brightest sources in the Southern sky
- [SWGO White Paper](#)



Workflow

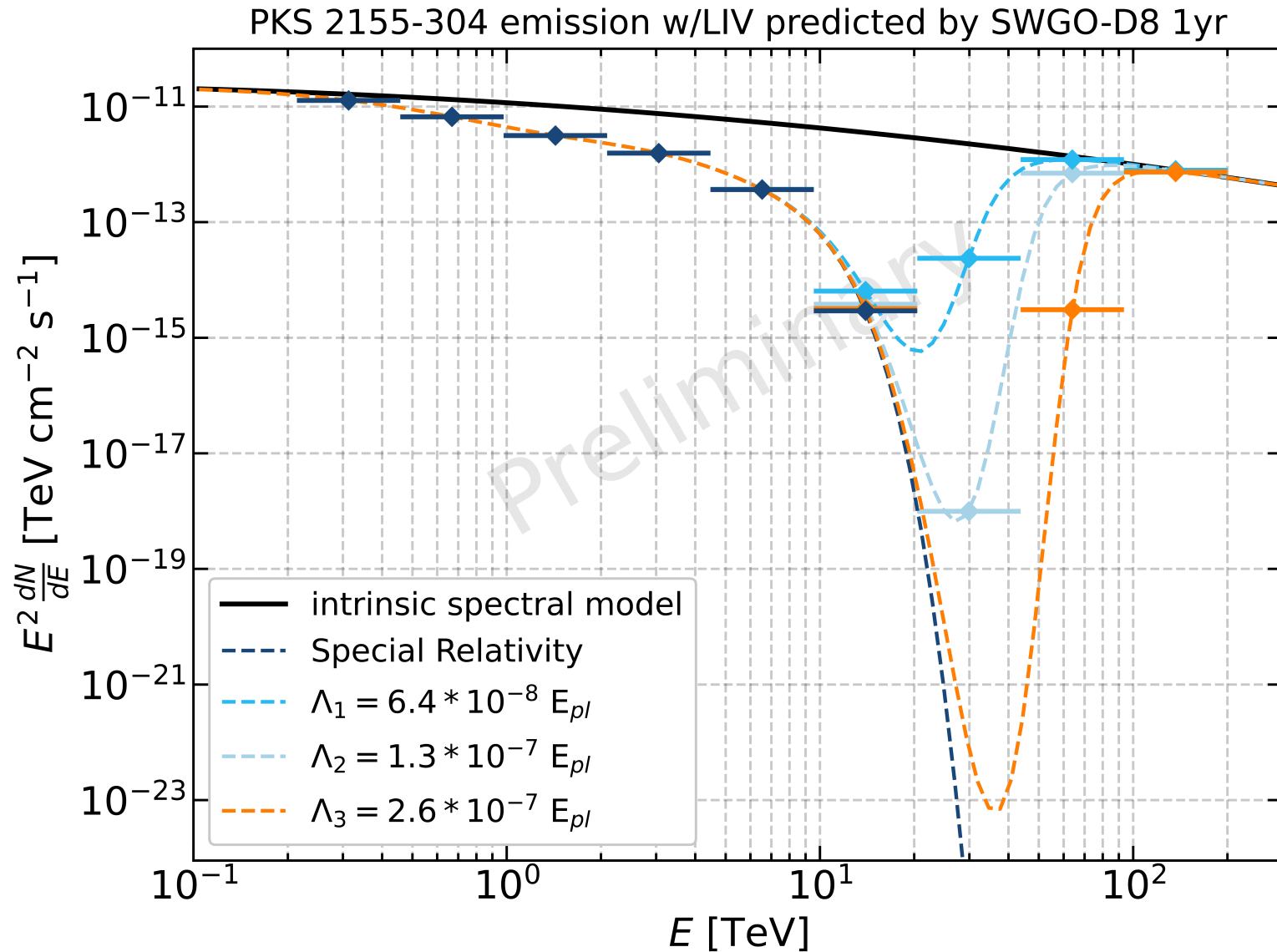
- Source model taken from [Gammapy](#)
- SWGO-D8 configuration



Results (1)

Redshift:

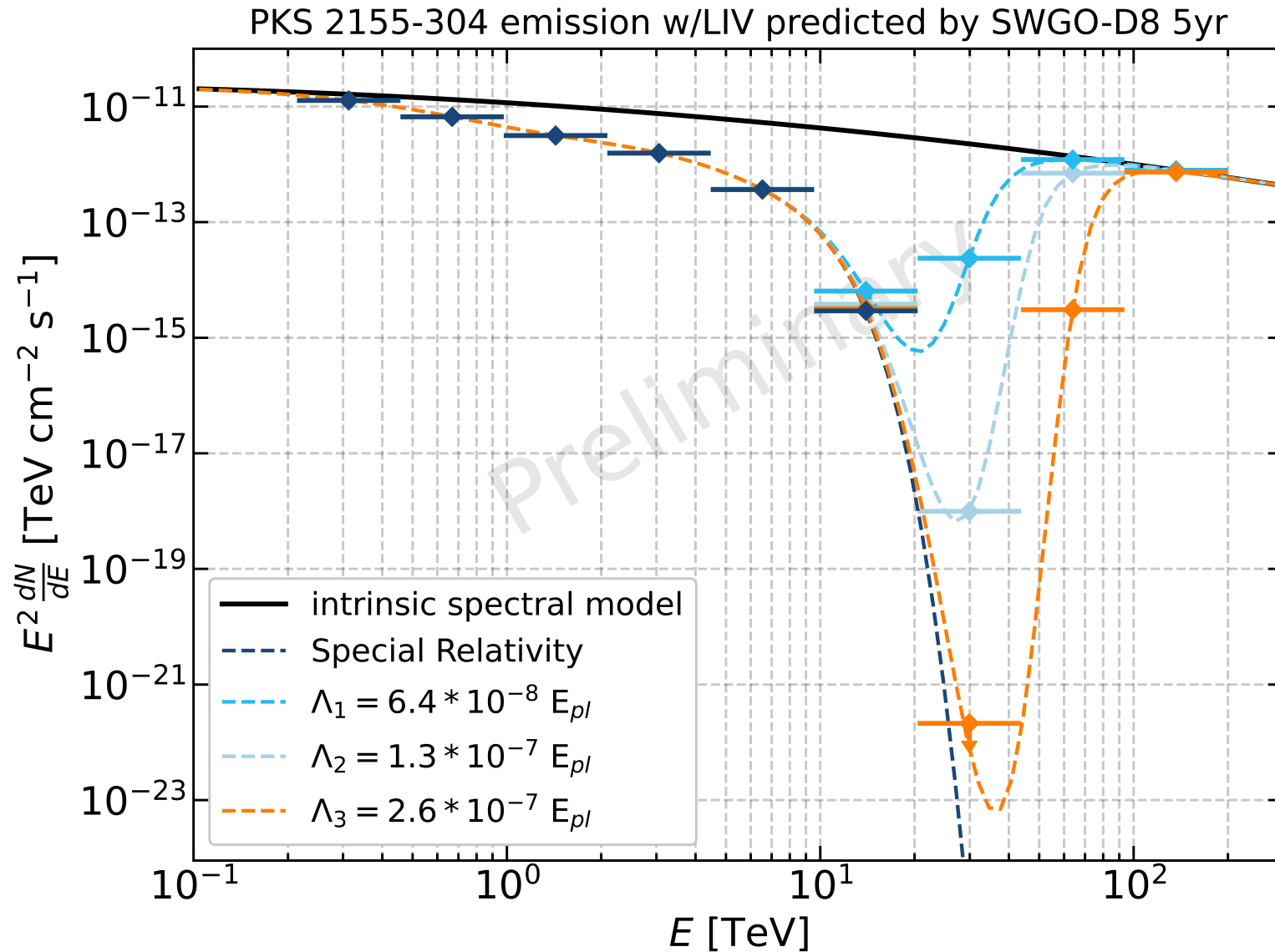
$$z = 0.116$$



Results (2)

Redshift:

$$z = 0.116$$



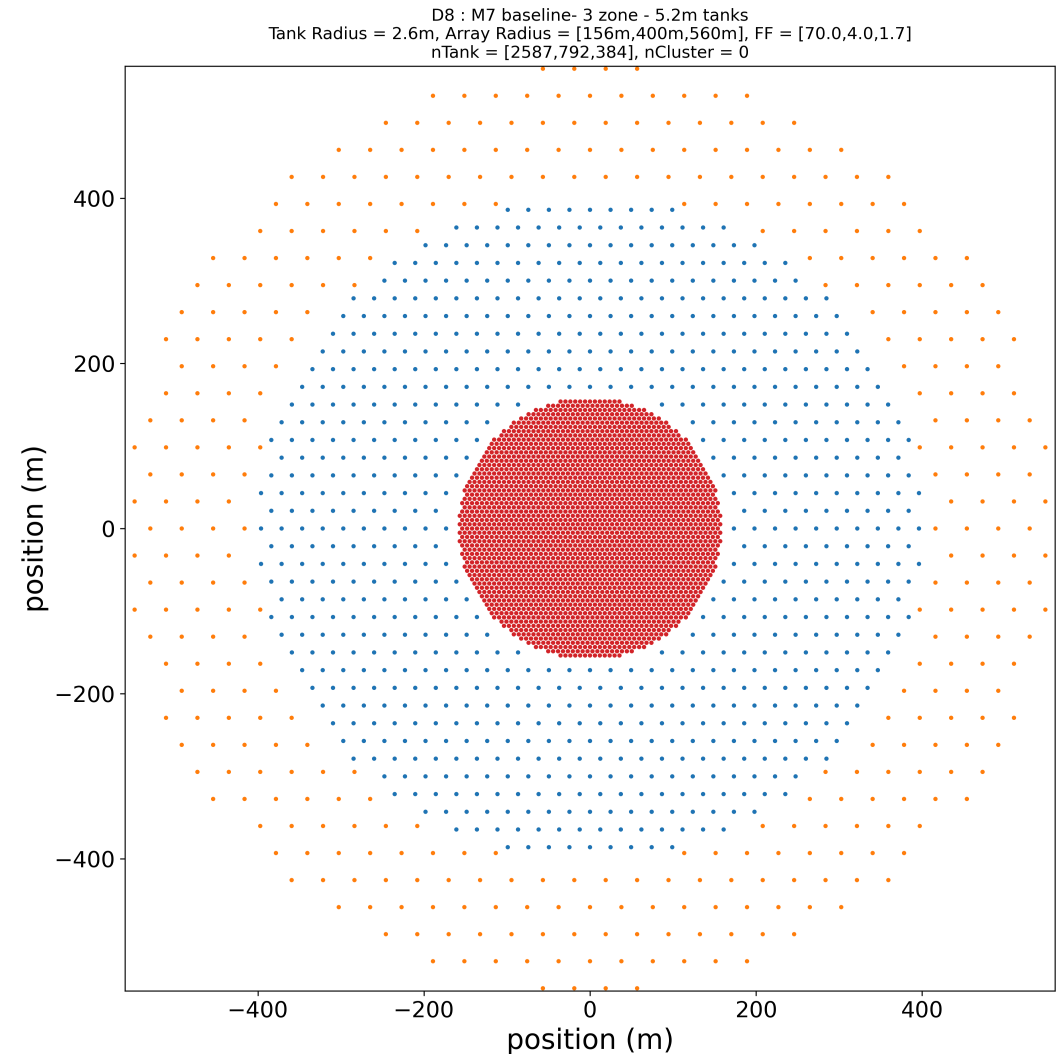
Outlook & open questions

- PKS 2155-304 proves to be a promising source
- Test additional sources
- Assess sensitivity to LIV effects depending on different detector configurations
- Apply the pipeline in a Doubly Special Relativity scenario

Back-up slides

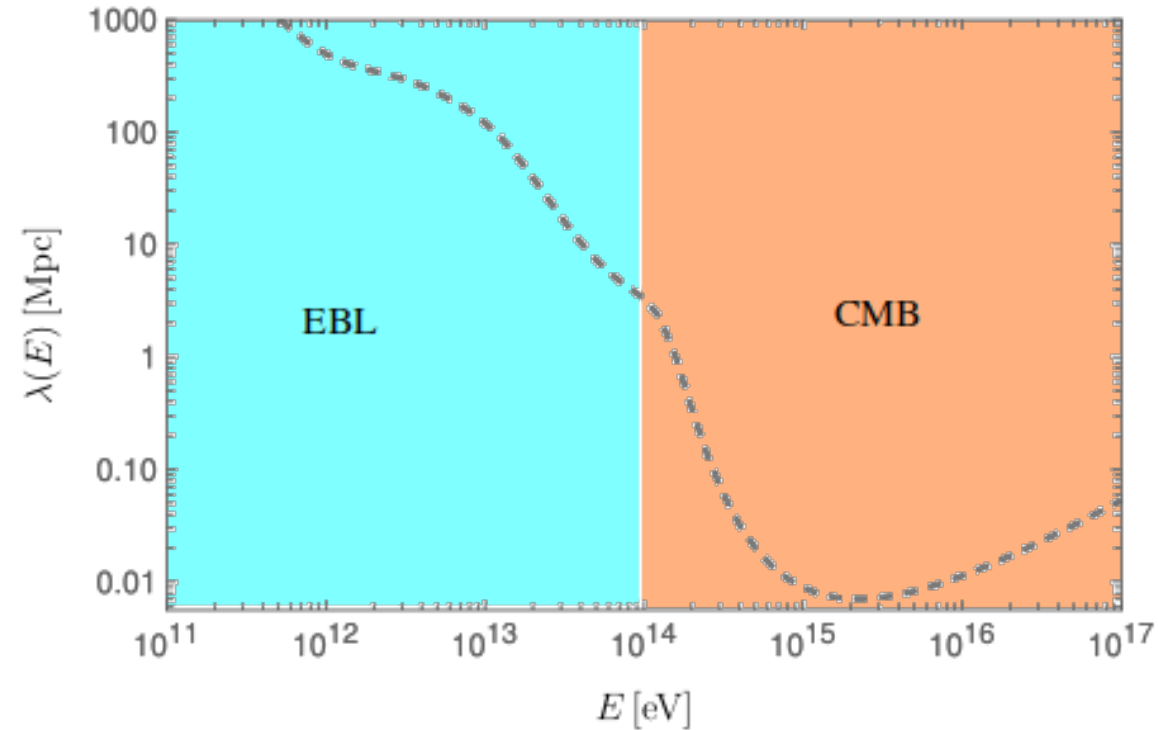
SWGO - D8 configuration

- 3 - zone configuration
 - Fill - factor: 70%, 4%, 1.7%
- Up to 600 m in radius
- Total area $\approx 1 \text{ km}^2$



Mean free path in SR

- $10 \text{ GeV} \leq E \leq 10^5 \text{ GeV}$: interaction with the EBL becomes dominant
- $10^5 \text{ GeV} \leq E \leq 10^{10} \text{ GeV}$: interaction with the CMB becomes dominant
- [De Angelis et al., 2013](#)



Cross section

For:

- $\omega_0 = 10^{-1}$ eV
- $\theta_0 = \pi$

