# Polarization prospects for Blazars observation with COSI

## Estimation of the MDP

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# Different "types" of Blazars

## Low Synchrotron Peak Blazars ($\nu_{syn} < 10^{14}$ Hz)

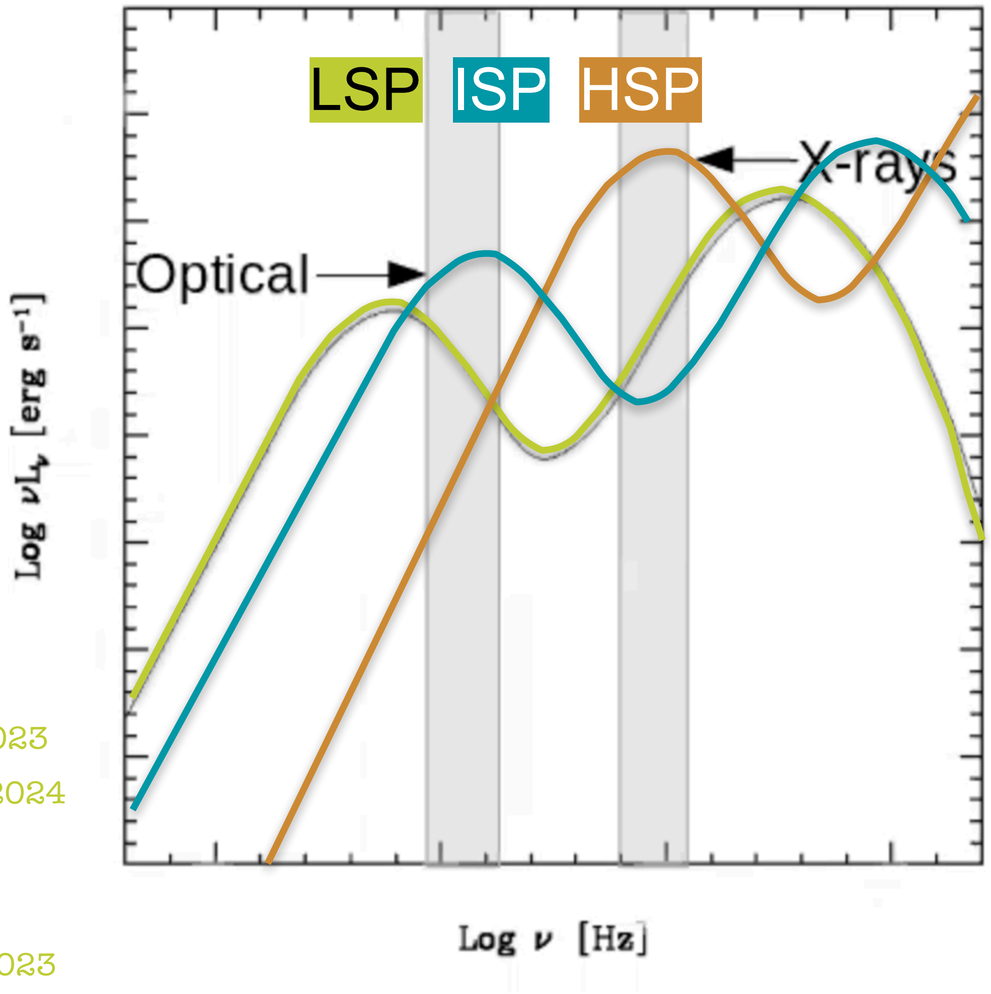
| | | |
|---|---|---|
| BL Lacertae | <12.6 % | Middei et al 2022 |
| 3C 273 | < 9.0 % | Marshall et al 2023 |
| 3C 279 | < 12.7 % | Marshall et al 2023 |
| 3C 454.3 | < 28 % | Marshall et al 2023 |
| S4 0954+65 | < 14 % | **xpqlt**: IXPE quick look tool |

## Intermediate Synchrotron Peak Blazars

| | | |
|---|---|---|
| S5 0716+714 | < 26 % | Marshall et al 2023 |
| BL Lacertae (outburst) | ~10% (2-4 keV) | Pierson et al. 2023 |

## High Synchrotron Peak Blazars ($\nu_{syn} > 10^{15}$ Hz)

| | | |
|---|---|---|
| Mrk 421 | ~10–15% | Di Gesù et al 2022, 2023 Kim et al 2023 |
| Mrk 501 | ~10–15% | Liodakis et al. 2021 Xin-ke Hu et al. 2024 |
| 1ES 0229+200 (estreme HSP) | ~18% | Ehlert et al. 2023 |
| PKS 2155-304 | ~20% | Xin-Ke Hu et al 2024 |
| 1ES 1959+650 | ~ 8–12% | Bharathan et al 2023 Errando et al 2023 |
| PG 1553+113 | ~10% | Middei et al 2023 |



# The Ingredients

MDP in residence of a non negligible background:

$$MDP_{99\%} = \frac{4.29}{\mu N_S}\sqrt{N_S + N_B}$$

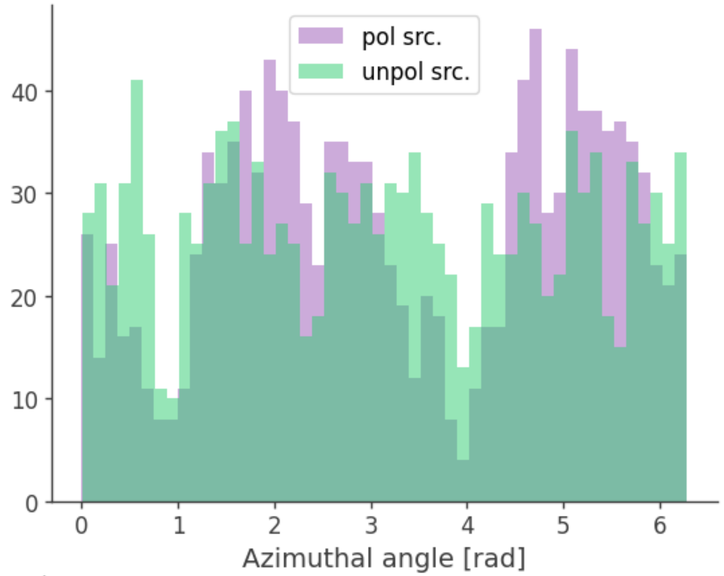
Average modulation factor over the energy range considered given a spectrum (sqrt(mu_i^2))

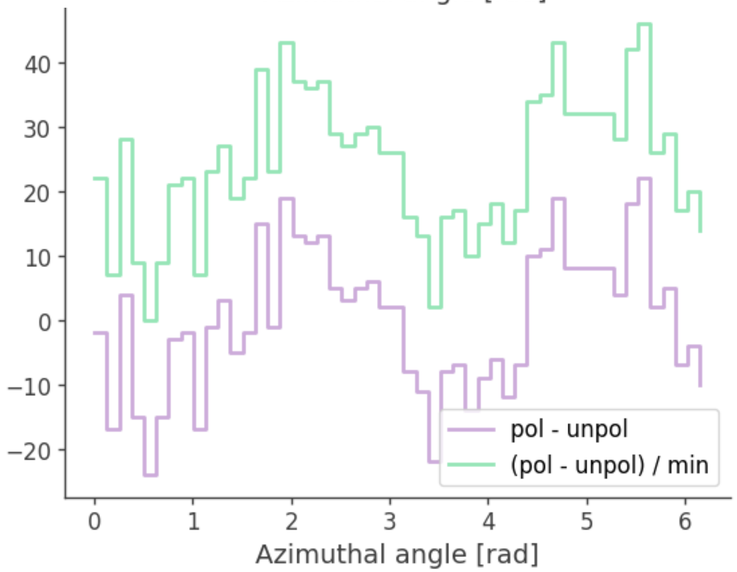
Total number of counts estimated int eh energy range of interest (0.2 — 5 MeV)

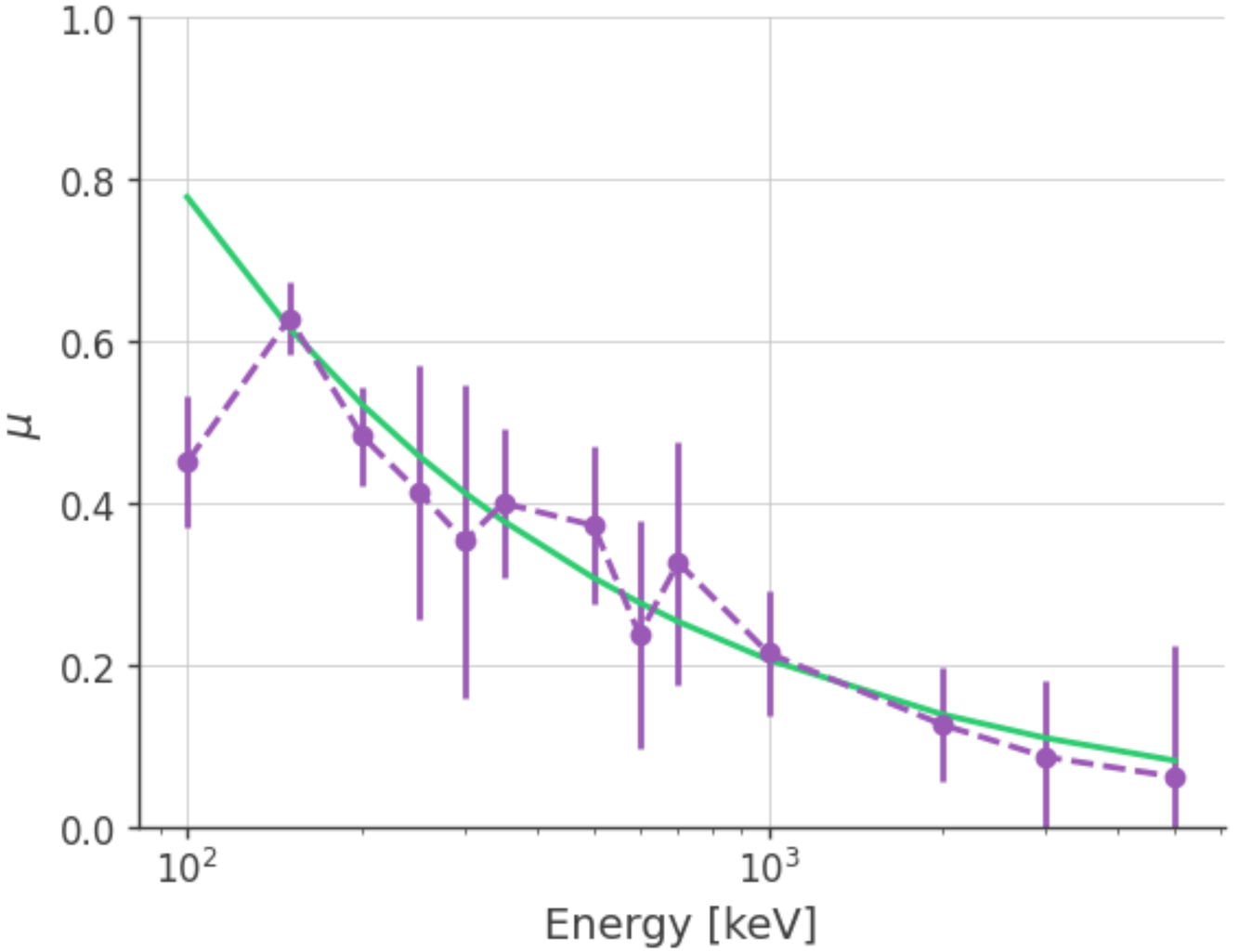
Ingredients:

- modulation factor
- sources spectra
- expected background rate

# Modulation factor



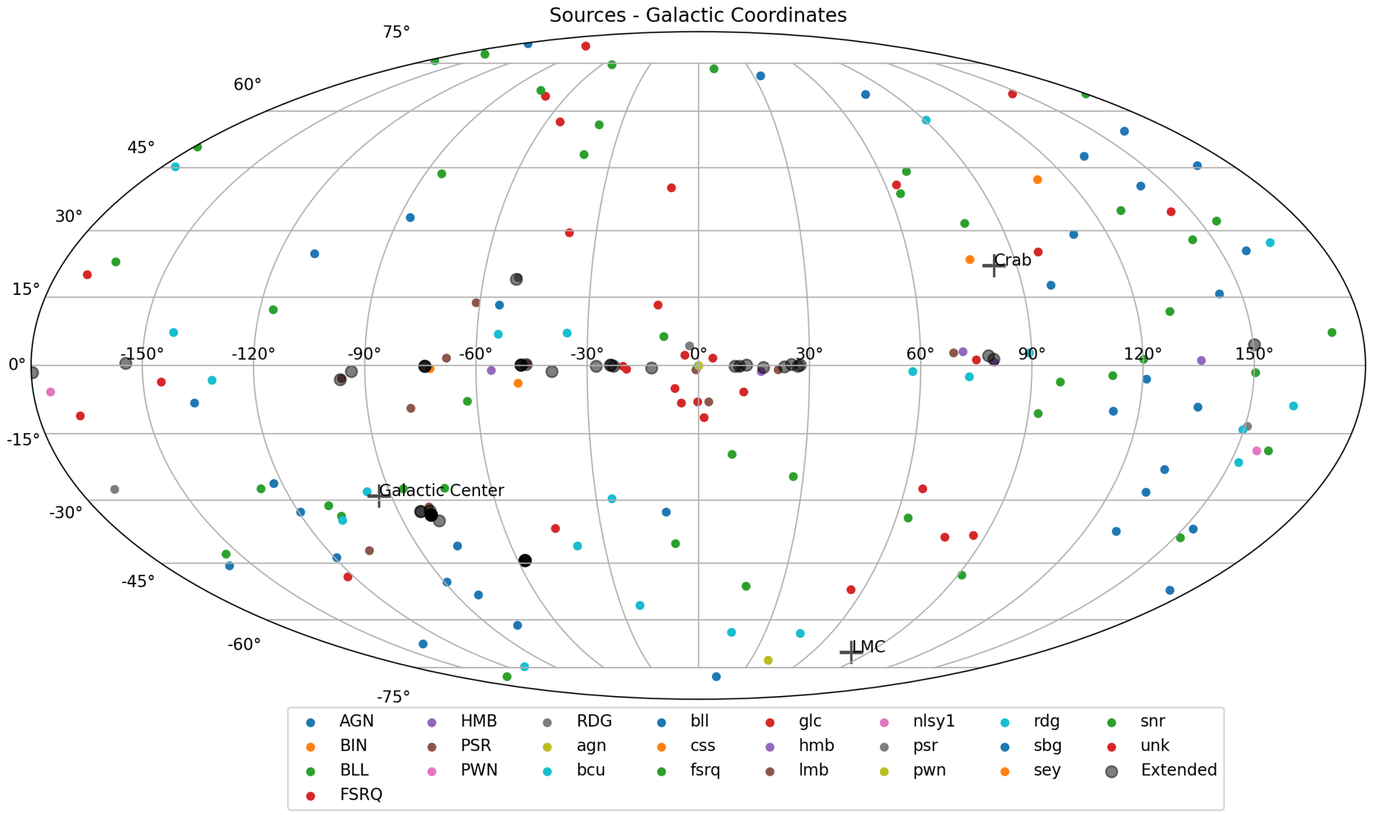



# The sample

## The matched Swift/BAT - Fermi-LAT catalog

Selected all the **beamed AGN** in the Tsuji 2021 catalog (106 sources; 88 at |b|>10 degrees.

In this work the authors cross-matched the
- Swift-BAT 105-months catalog with the
- Fermi-LAT 4FGL-DR2 (10-years) catalog.



# FSRQ like sources

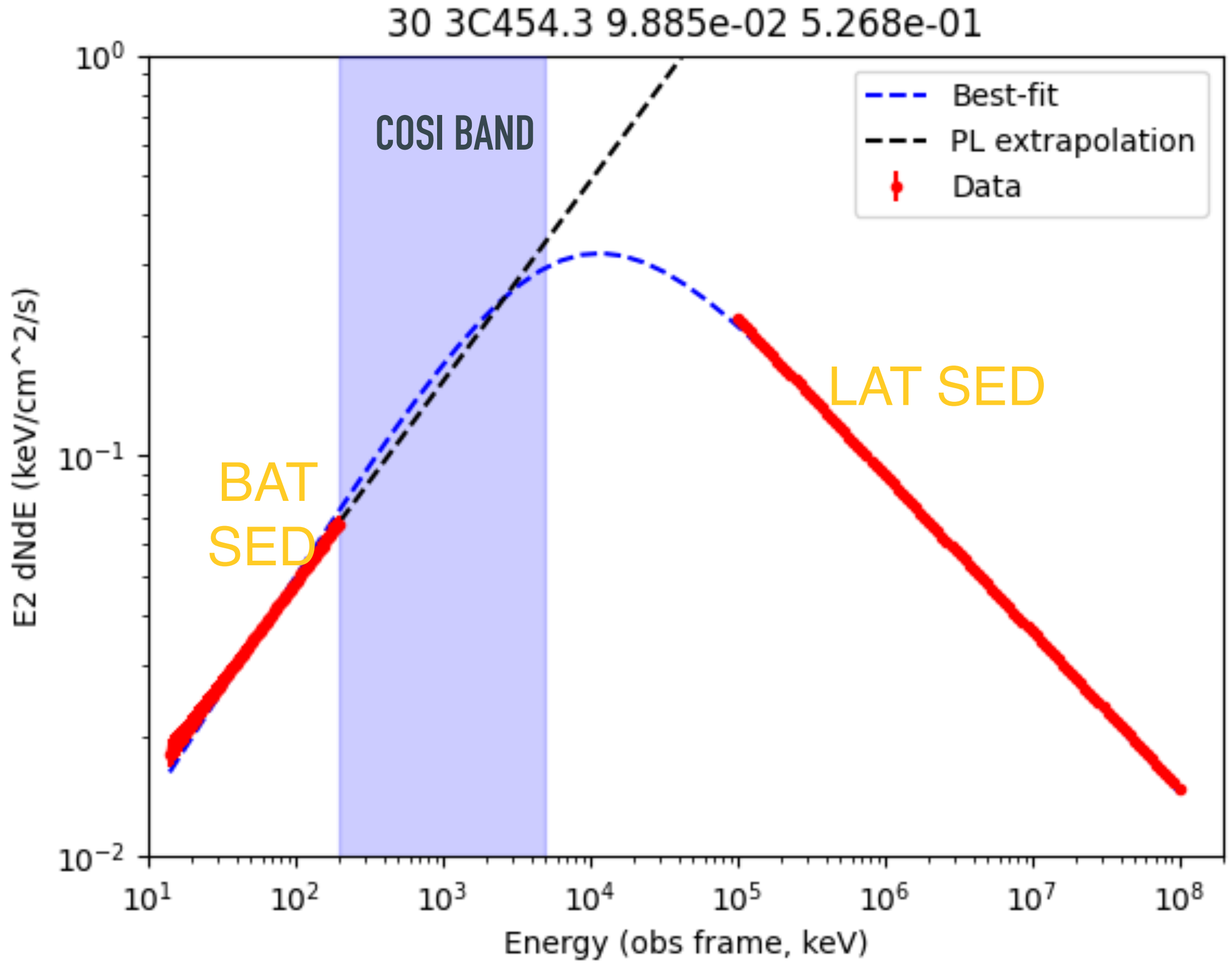
## (i.e. BAT index softer than LAT index)

Fitting function

$$y = N \frac{E^2}{\left(\frac{E}{E_b}\right)^{\gamma_1} + \left(\frac{E}{E_b}\right)^{\gamma_2}}$$

$E^2dN/dE$

Units of
[ph/cm^2/s/keV]




Thank you Lea!

# BL Lacs like sources

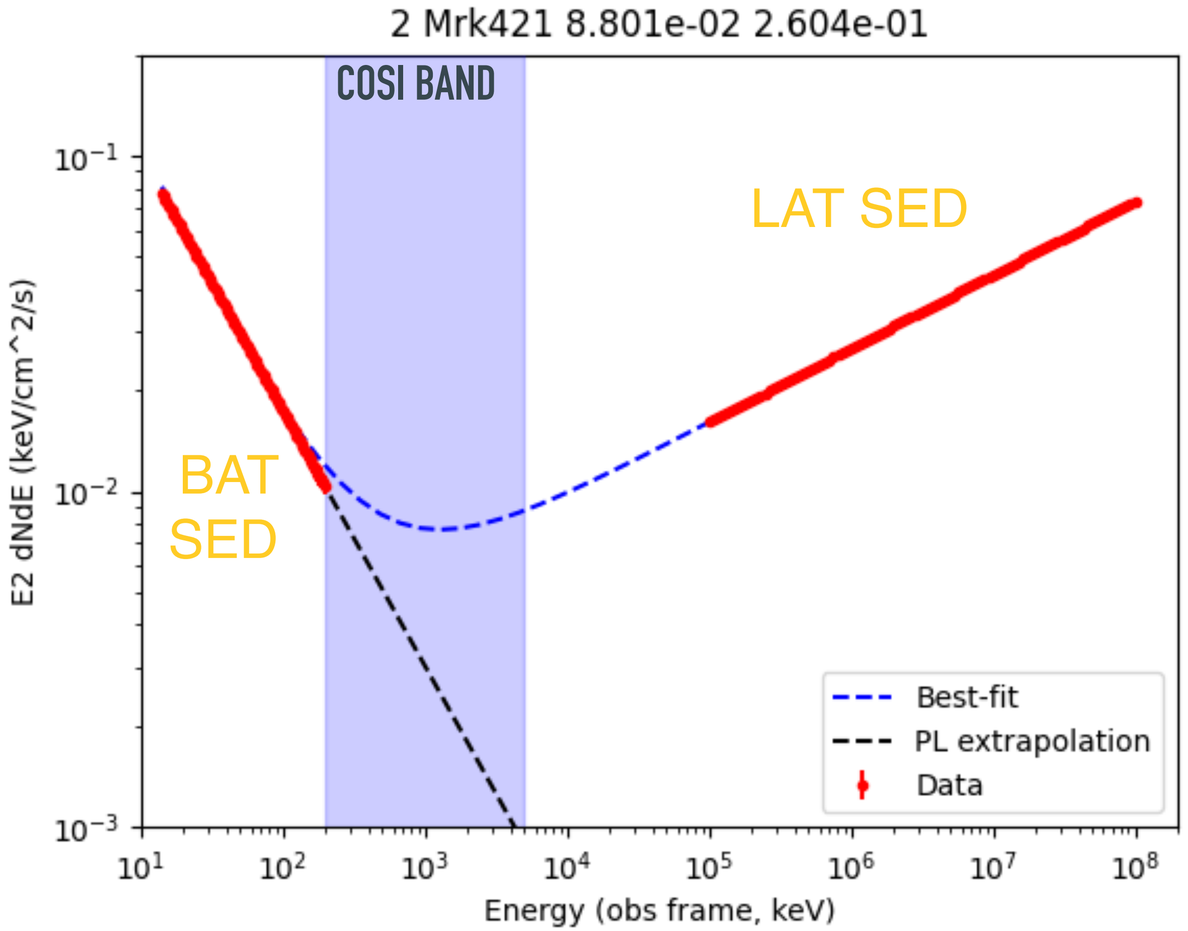
## (i.e. BAT index softer than LAT index)

Fitting function

$$y = NE^2 \times \left( \frac{E}{E_b}^{\gamma_1} + \frac{E}{E_b}^{\gamma_2} \right)$$

Units of [ph/cm^2/s/keV]

$E^2dN/dE$

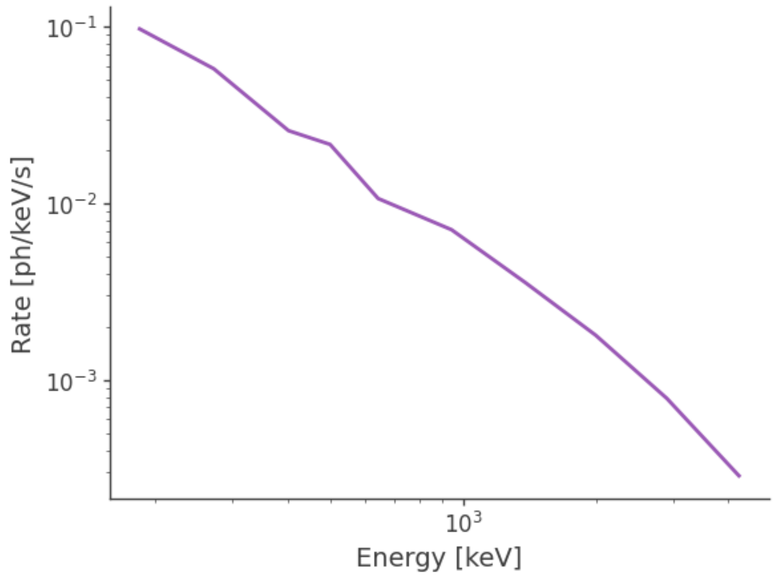


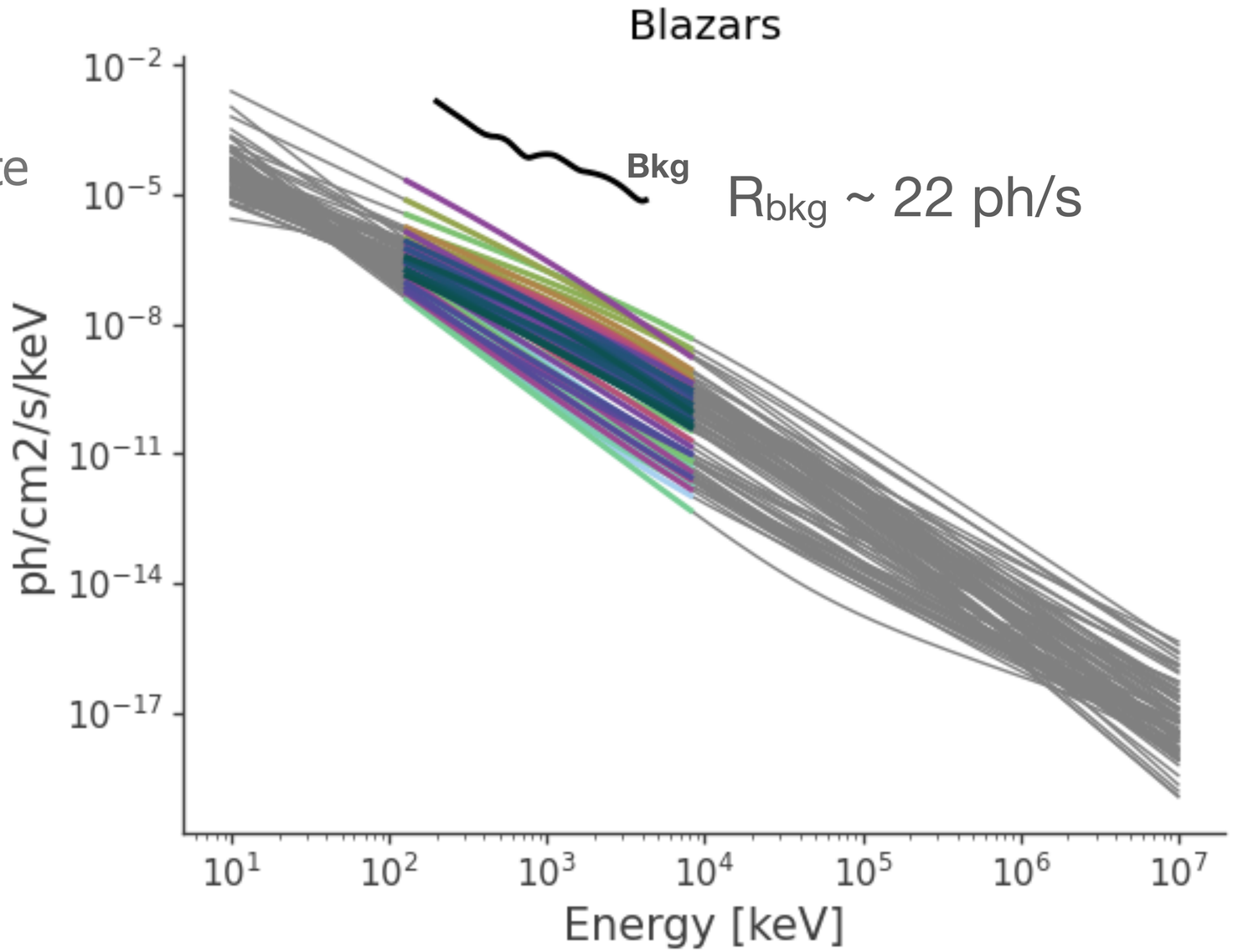

Thank you Lea!

# Just a quick look

## Sources vs bkg

Full COSI SMEX background rate
Thank you Chris!

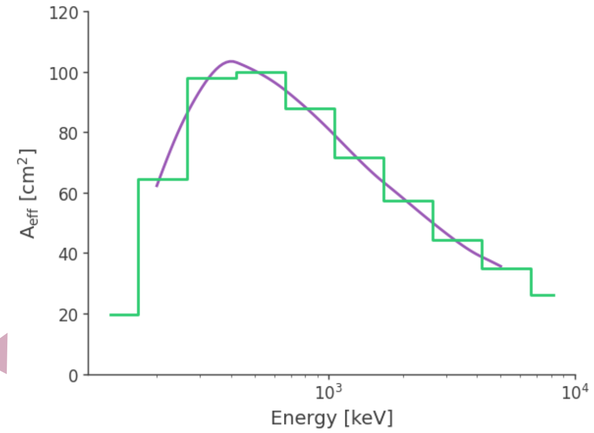


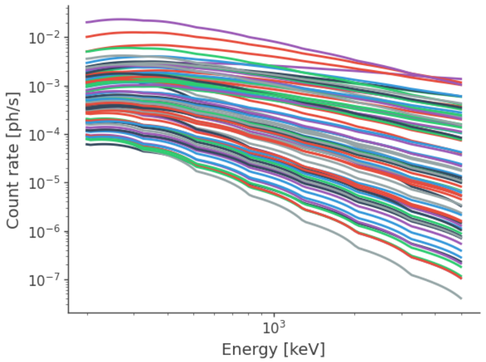



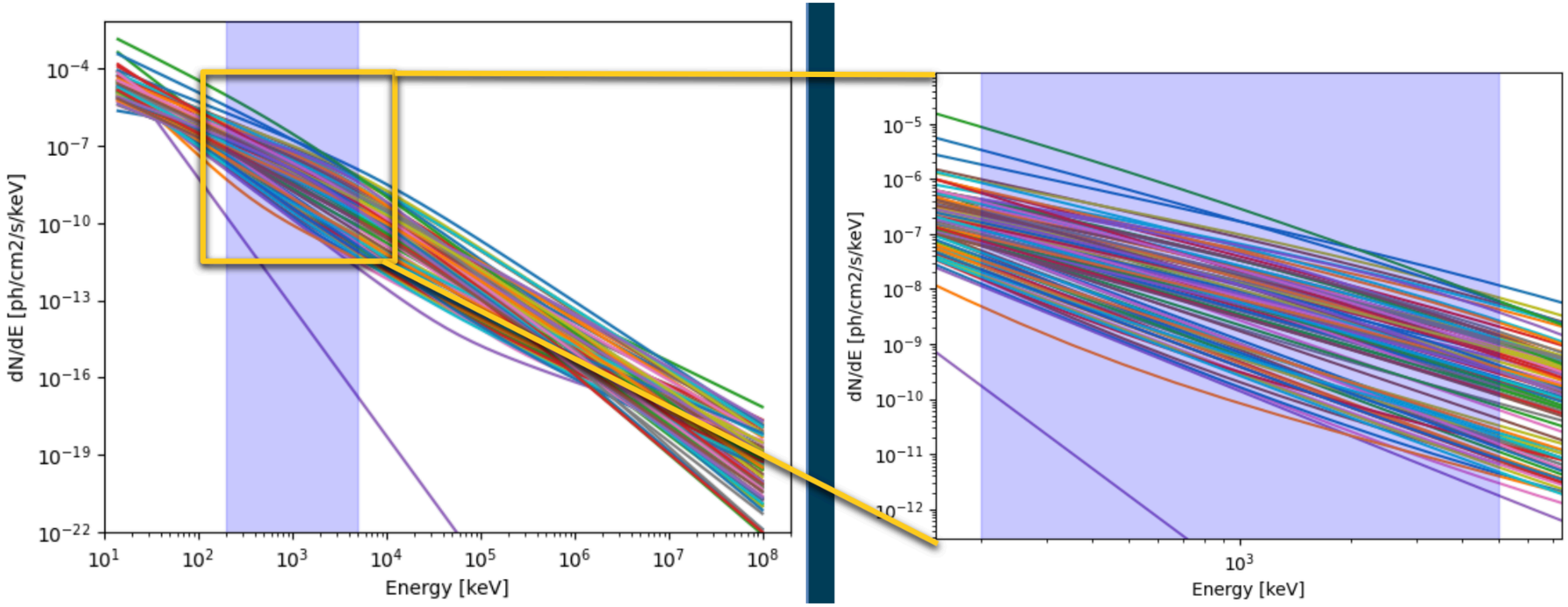
# The spectra

## Using COSI/**SMEX** response with 10 Energy bins

SMEXv12.Continuum.HEALPixO3_10bins_log_flat.binnedimaging.imagingresponse.nonsparse_nside8.area.h5

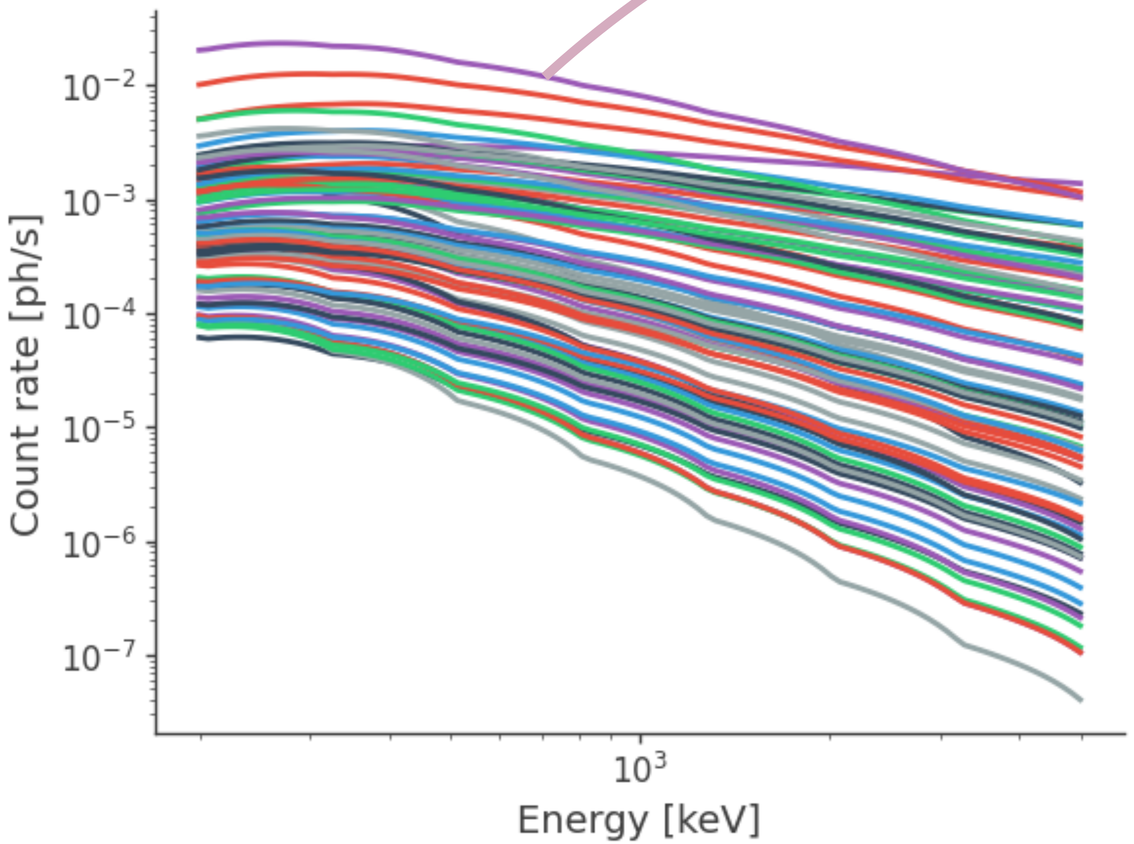


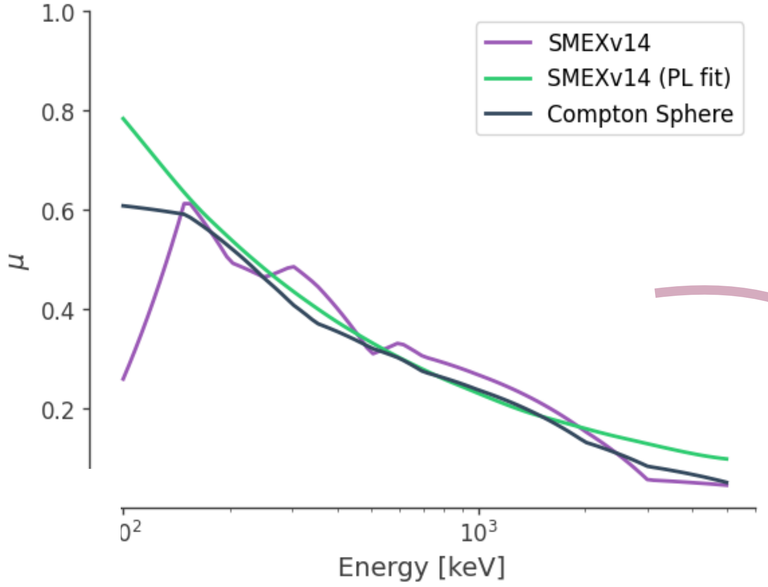



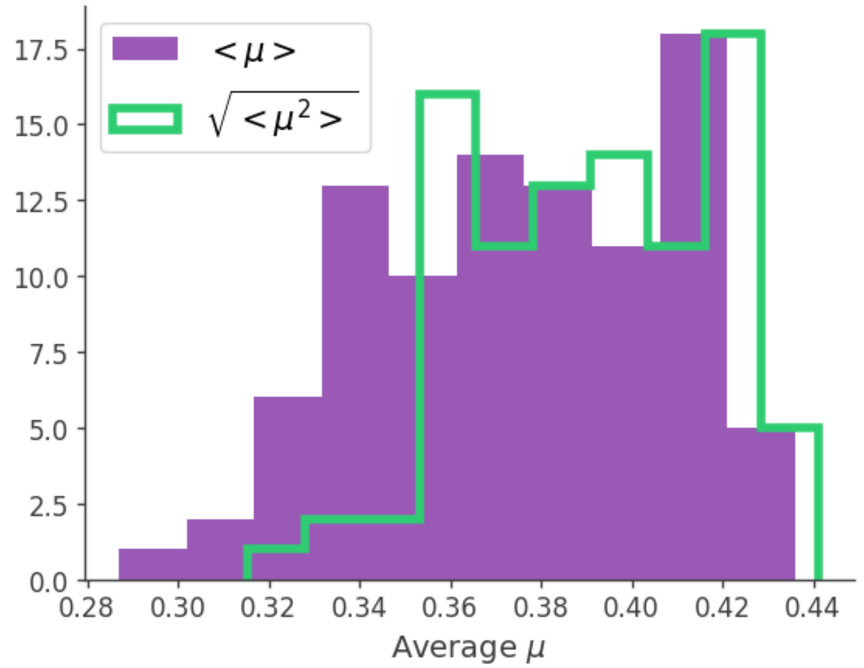



# The modulation factor

Computing the Average modulation for each source factor weighted by their observed spectrum

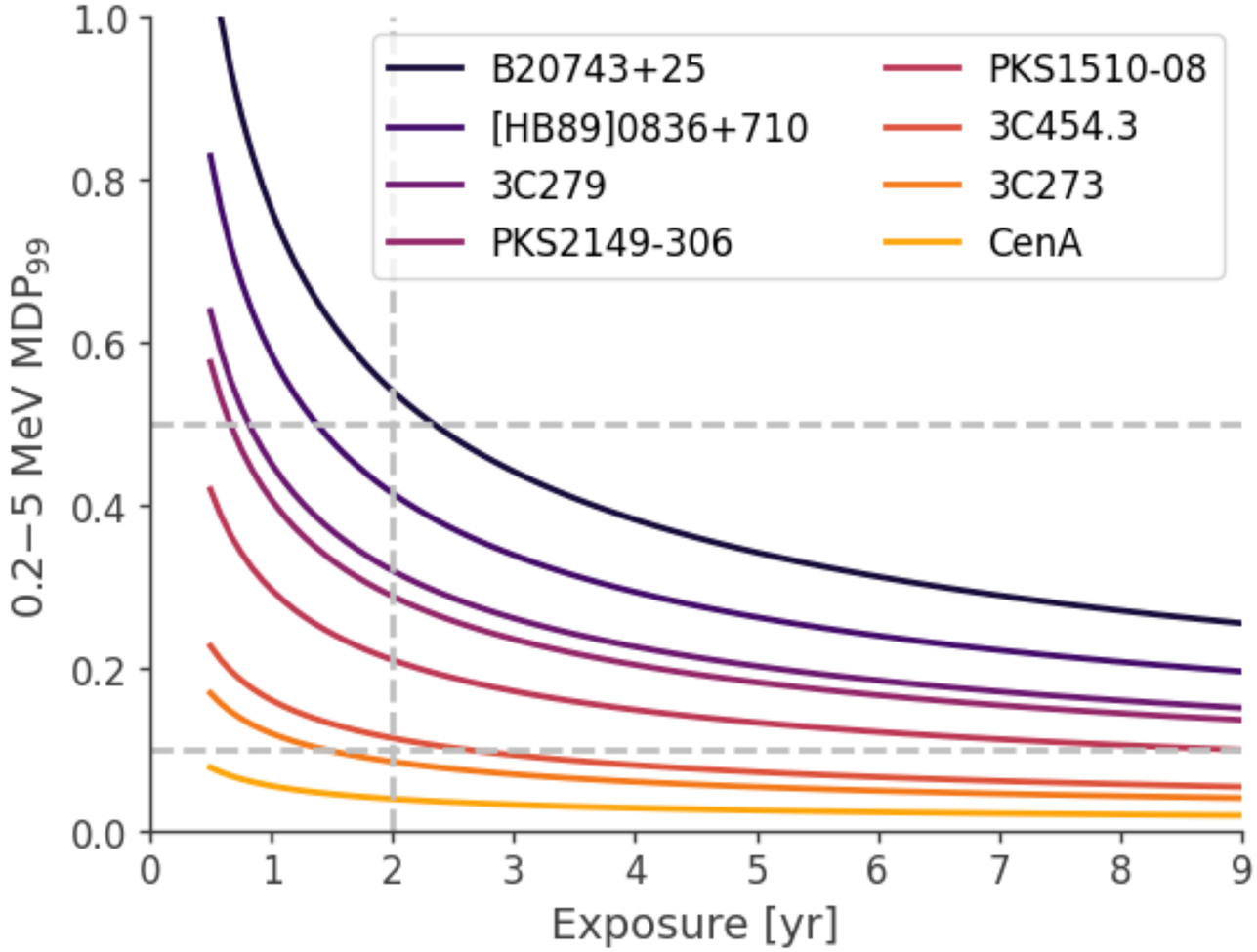


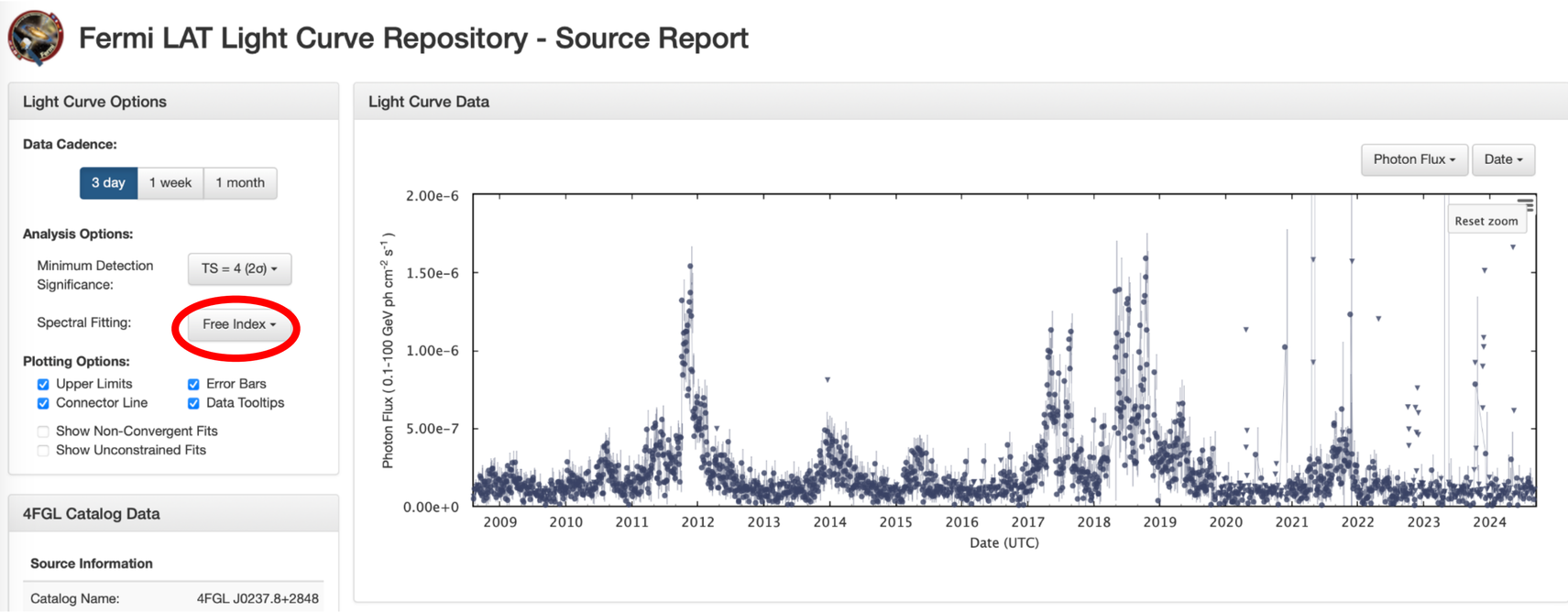
# Final Results

## MDP as a function of the exposure for the brightest sources



# Data and Data Curation

- Data analysis was performed on 15 years of Fermi LAT data with the LCR until February 2023 [1].
  - Spectral index free to vary
  - All NaN flux values for time bins were filtered out, as well as time bins where flux error was larger than the flux value itself.
  - Photon flux values not within the range $\{10^{-10}:10^{-4}\}$ ph/cm$^2$/s are not included as well (avoid spurious anomalies due to fit issues).



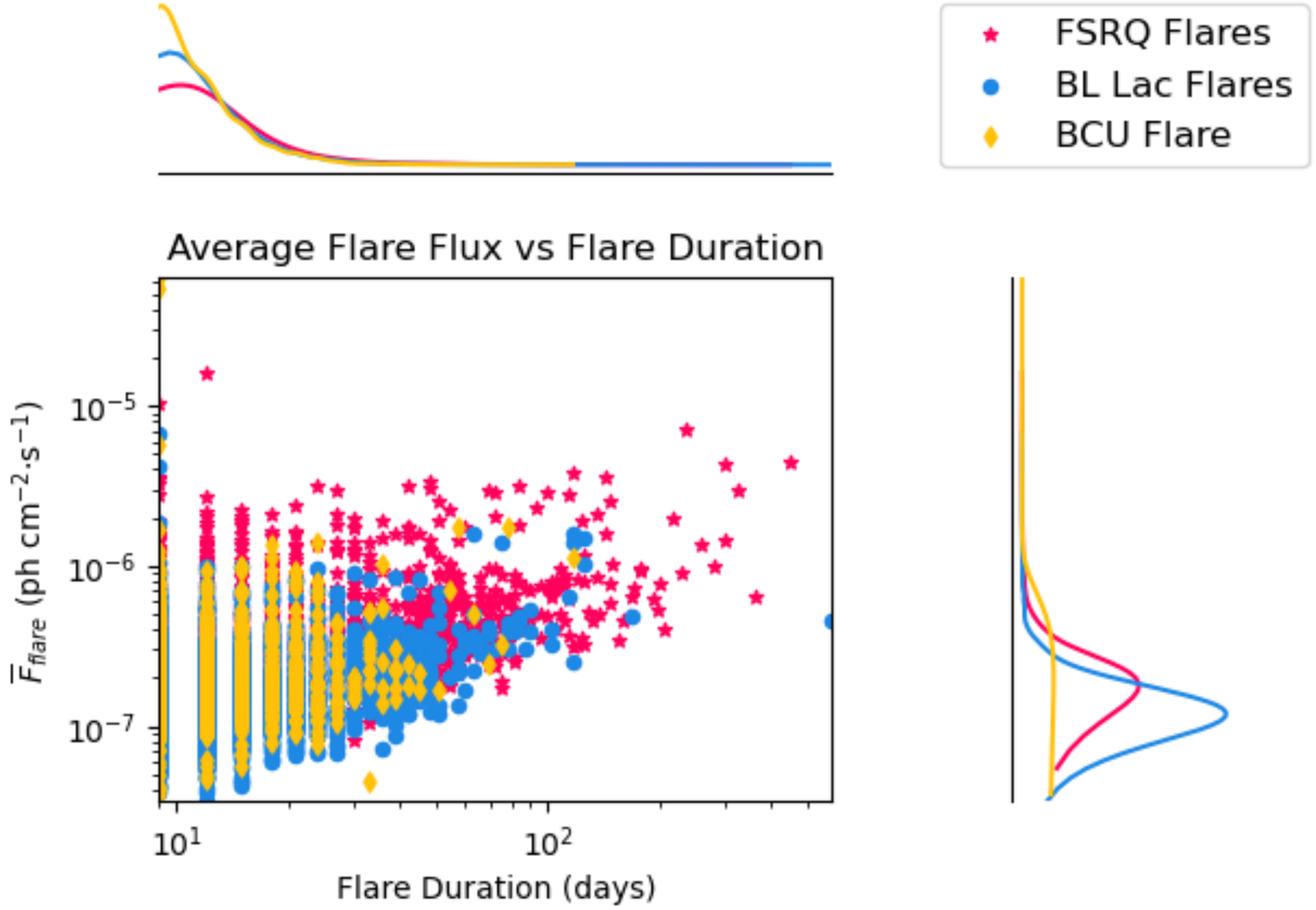

[1] - Abdollahi, S., et al. *The Fermi-LAT Light Curve Repository*. arXiv, 2023.

# Flare definition

- Any time bin where $F_{(t)} > F_{avg}$ is considered a time bin in a “flaring state”.

- For each flare we compute:
  - $F_{avgflare}$, the average flux value of the flare.
  - $\Delta t_{flare}$, the total duration of a flare.

- As expected, FSRQ flares are on average more frequent, have higher flux and longer duration.




*The average flare flux for each flare is graphed against the time duration in days. Flares that last less than 10 days (less than 3 time bins) are excluded. Red Stars are FSRQs, Blue Circles are BL Lacs, and Yellow Diamonds are BCUs.*

# Flare population

We want to determine the statistics of these flares, useful to assess what we should expect COSI to see.

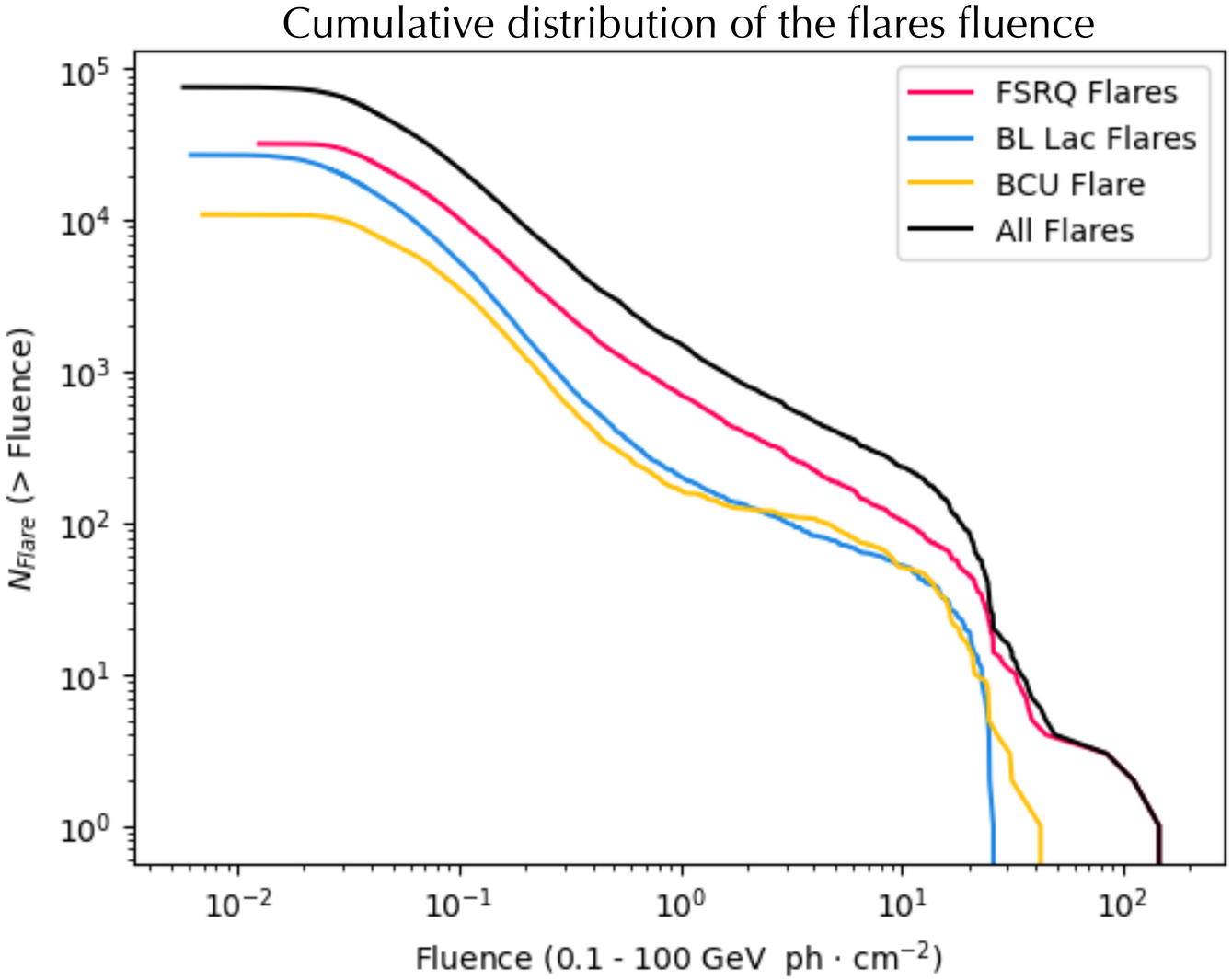
The MDP is driven by counts statistics:

**brighter-shorter flares ~ fainter-longer flares**

So we define:

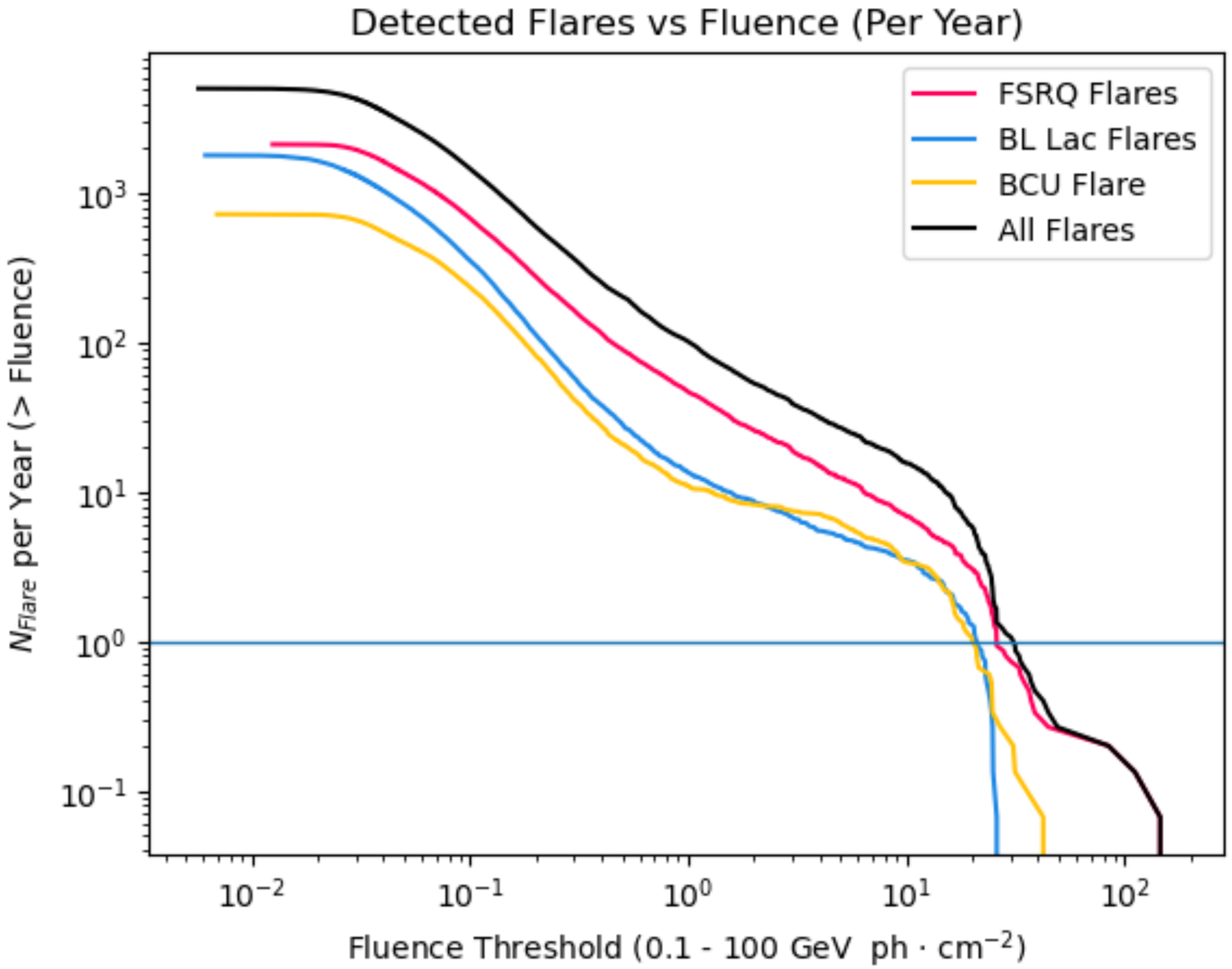
$$\text{Fluence} = F_{\text{avgflare}} * \Delta t_{\text{flare}}$$

And evaluate the cumulative distribution




*Log vs Log plot of predicted flares above a fluence threshold against the threshold itself. Red is FSRQ flares, blue is BL Lac Flares, yellow is BCU Flares, and black is all flares across the data set.*

# How many flares per year?




*Log vs Log plot of predicted flares above a fluence threshold per year against the threshold itself. Red is FSRQ flares, blue is BL Lac Flares, yellow is BCU Flares, and black is all flares across the data set.*

# Next steps

In our to-do list:

- Add ARM cut assumption: x20 less bkg
- Ask Haocheng about variability for the IC bump
- Extrapolate the fluence expected to be detected with COSI, with the spectral index obtained from interpolating the Swift and the Fermi-LAT spectra [3].
- Investigate the statistical properties of  the blazar flare population. E.g., the fluence distribution on the right can assist our understanding of the physical differences between the different blazar classes.
    - Maybe add redshift information to our blazar population sample and investigate a possible 3D blazars space for classification into different classes.

*[3] - Marcotulli et al. "BASS. XXXIII. Swift-BAT Blazars and Their Jets through Cosmic Time". The ApJ940. 1(2022): 77.*