



# Constraints on Dark Matter Interpretations of the Galactic Center GeV Excess

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Collaboration**

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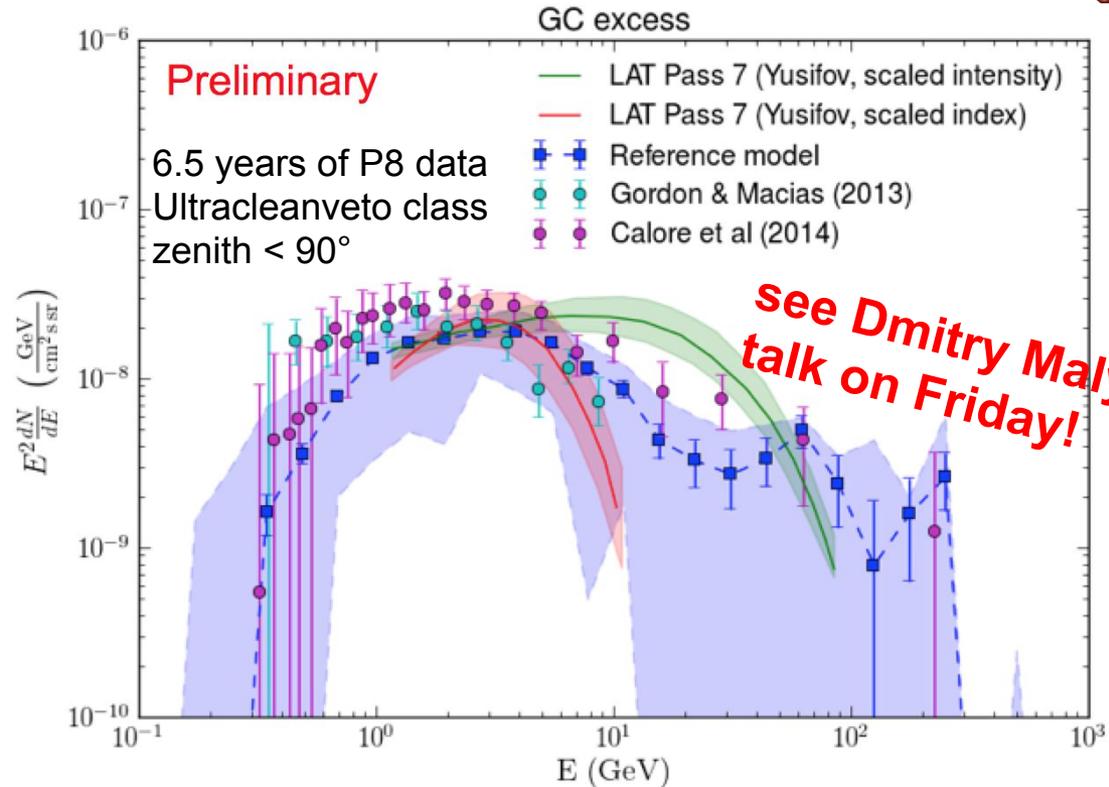


## Reference Model Components

- Inverse Compton
- Gas (pi0 decay)
  - five GALPROP rings
- Loop I
- Isotropic
- Fermi Bubbles (  $|b| > 10^\circ$  )
- Point Sources
- Sun / Moon

## Excess Template

- contracted NFW (NFWc,  $\gamma = 1.25$ )



- **We find an excess persists that peaks around a few GeV**
  - Similar to many previous results e.g. LAT-Collaboration P7 Inner Galaxy work, Abazajian et al (2015), Calore et al (2014), Daylan et al (2014)
- This analysis differs from previous LAT-team work (now submitted for publication)
  - differences in approach to Galactic diffuse emission modeling, evaluating systematic uncertainties, and in accounting for point sources

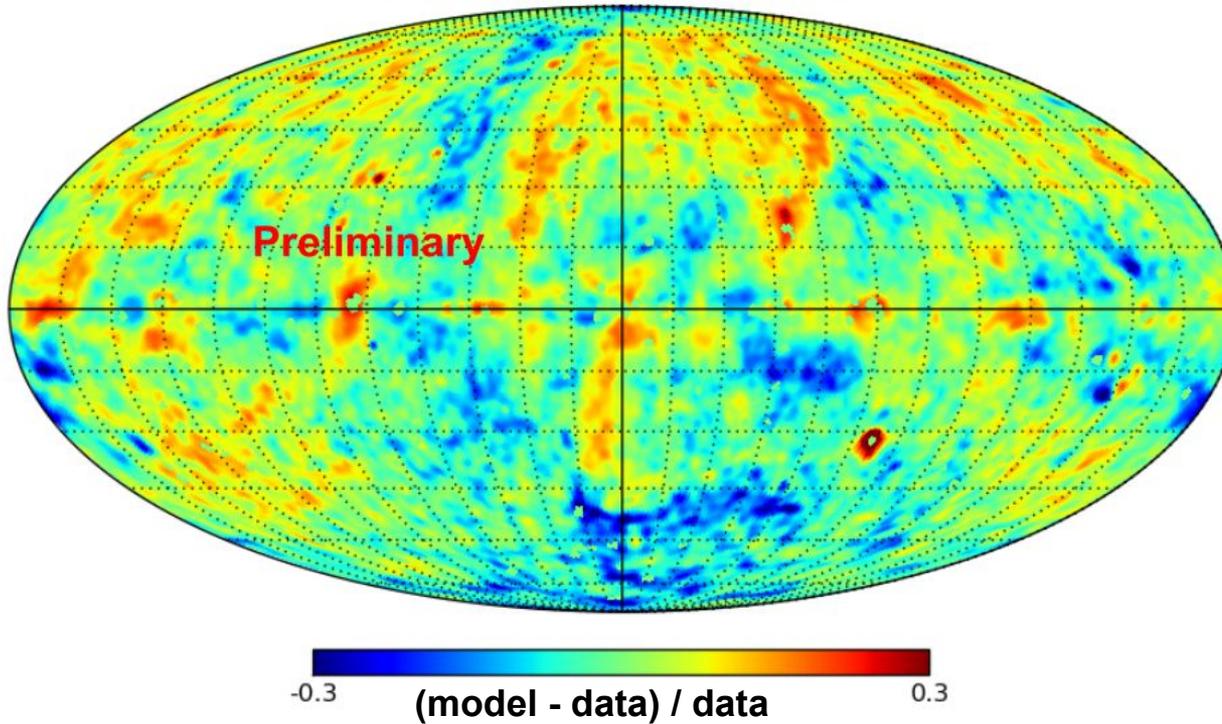


- Many have shown the Galactic Center GeV excess can be well-fit with various dark matter annihilation models
  - e.g. LAT-Collaboration P7 Inner Galaxy work, Abazajian et al (2014), Calore et al (2014), Daylan et al (2014)
  - But can the excess *only* be explained with dark matter models?
  
- We have studied two other possible explanations -- Diffuse Emission Modeling Uncertainties and Millisecond Pulsars
  - Residuals exist when you fit standard diffuse emission models to the LAT all-sky data
    - Potentially troublesome if pieces of these residuals can mask or mimic dark-matter signals
  - Excess may be due to a population of unresolved MSP
    - e.g. Yuan and Zhang (2014), Petrovic et. al. (2015), Brandt and Kocsis (2015), Bartels et al (2015), Lee et al (2015)

# Diffuse Model Residuals



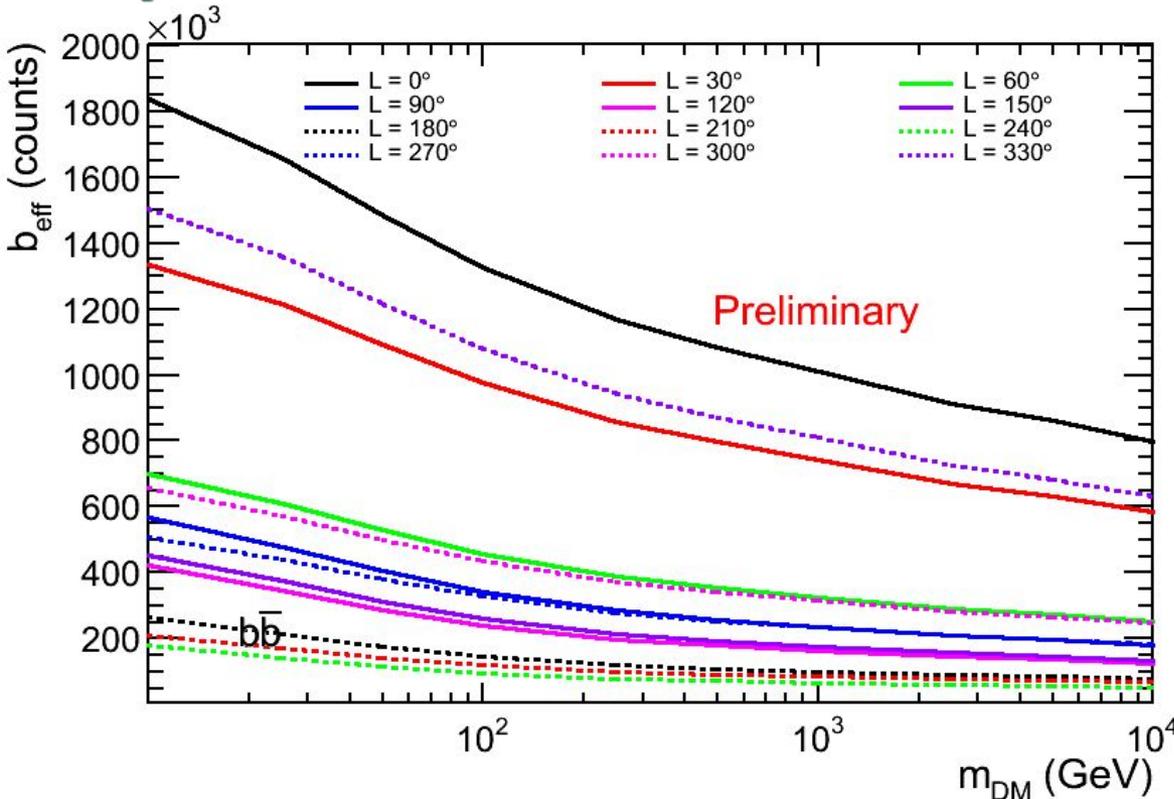
Fractional residual, 1.1 - 6.5 GeV



**Fractional residual maps for adopted Reference Model w/out NFWc template (see Dmitry Malyshev's talk for more details)**

- There are unmodeled residuals similar in size to those in the Galactic Center across the entire  $\gamma$ -ray sky
- If the residuals are similar to dark matter models, they could potentially mask or mimic a true signal
- We use the Galactic Plane ( $30^\circ < L < 330^\circ$ ) as a control region to quantify the amount of dark-matter-like residuals

# Effective Background



$$b_{\text{eff}} = \frac{N}{\left( \sum_k \frac{P_{\text{sig},k}^2(\mu)}{P_{\text{bkg},k}(\theta)} \right) - 1}$$

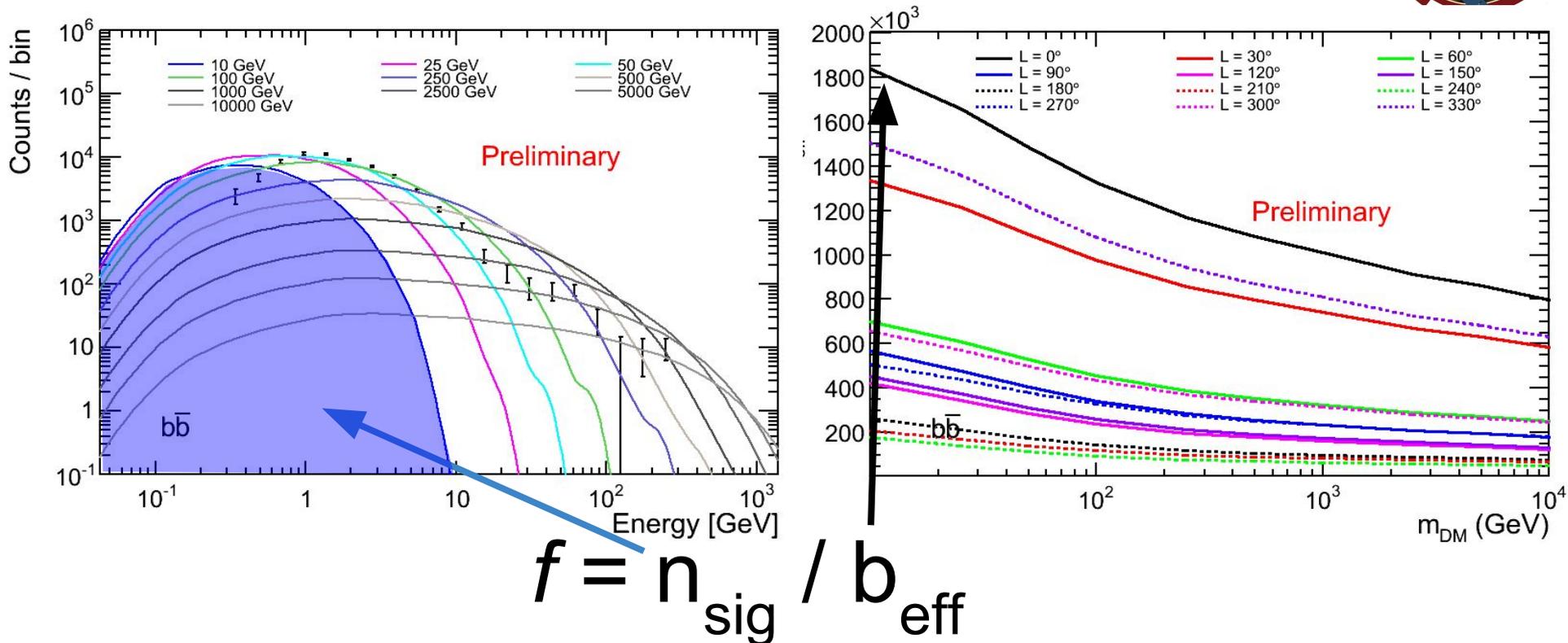
sum over spatial  
and energy bins  
N = total counts

$$f = \frac{n_{\text{sig}}}{b_{\text{eff}}}$$

$$\text{signif} \approx \frac{n_{\text{sig}}}{\sqrt{b_{\text{eff}}}}$$

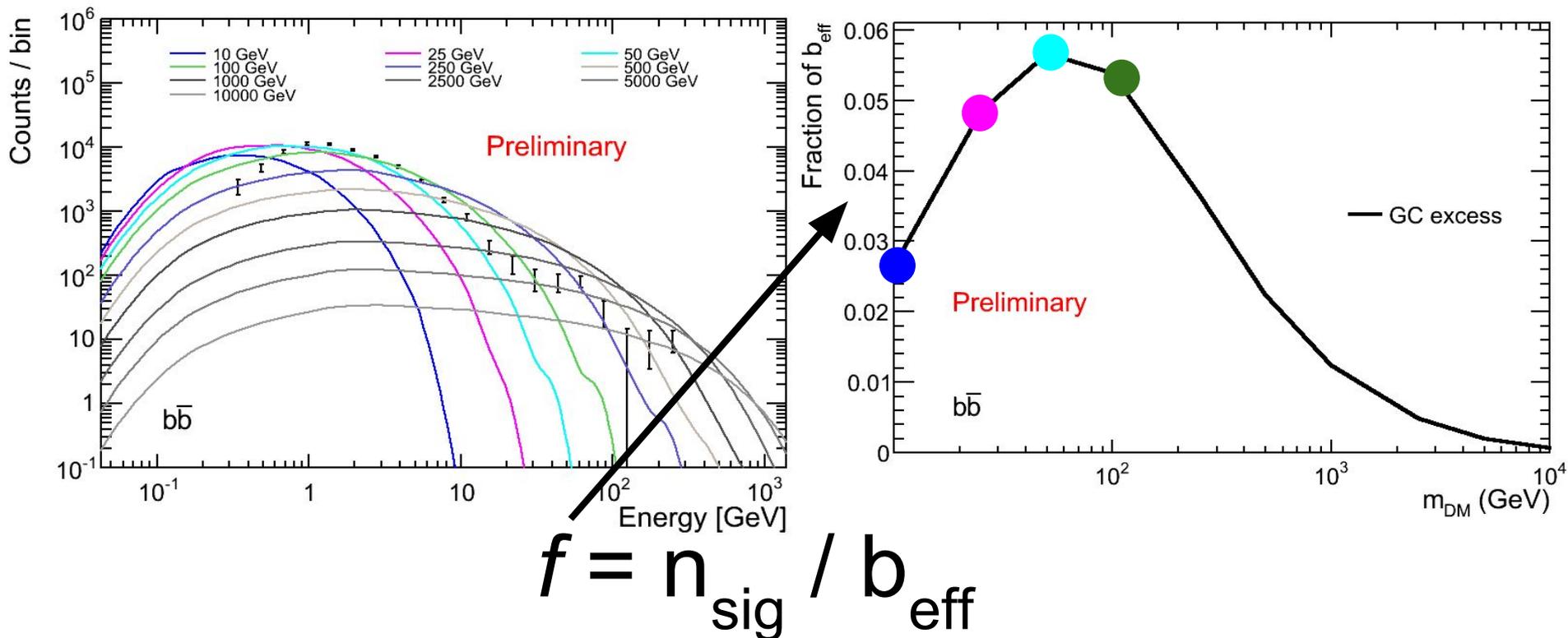
- $b_{\text{eff}}$  is the weighted “number of counts under the signal”
  - Background Model ( $P_{\text{bkg}}$ ) = adopted Reference Model
  - Signal Model ( $P_{\text{sig}}$ ) = NFWc ( $\gamma = 1.25$ ) centered on  $B = 0^\circ$
- If signal model and background model overlap more, the effective background is higher

# GC Excess -- Fractional Signal



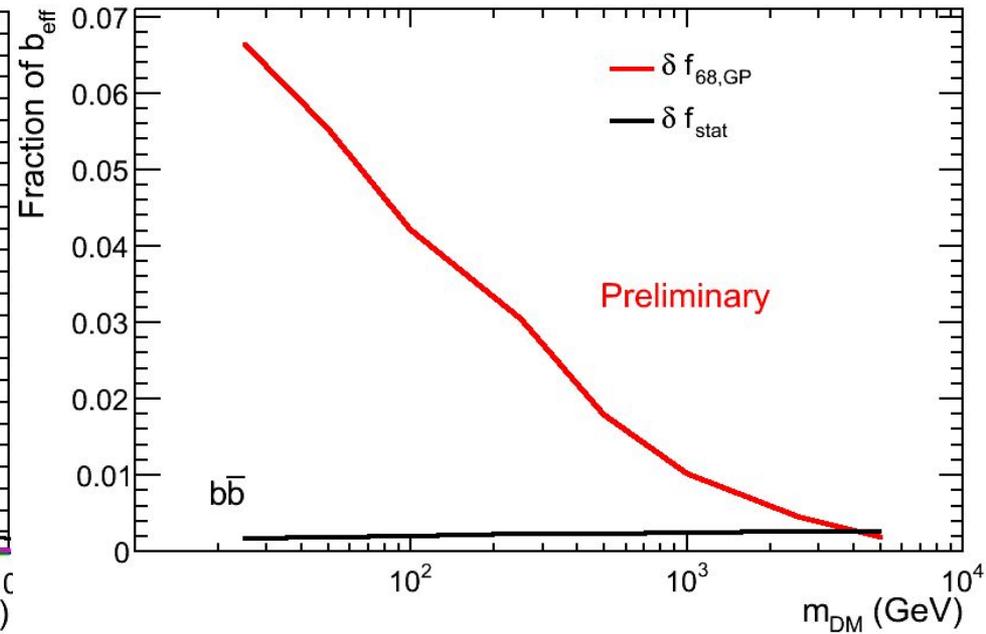
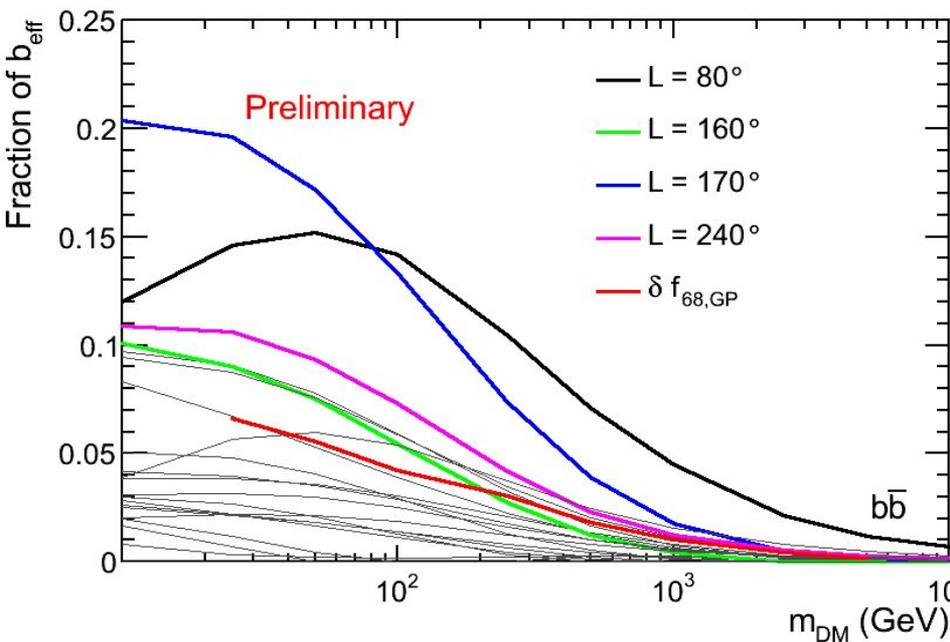
- Fit NFWc template in each energy bin independently
  - DM models do not provide a good fit to entire excess
- For a specific annihilation channel (e.g.  $\chi\chi \rightarrow b\bar{b}$ ) and DM mass, we find the best fit to the NFWc template spectrum
  - Integrate over energy to get total  $n_{\text{sig}}$
- Galactic Center excess is only a small fraction of  $b_{\text{eff}}$

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# Galactic Plane Scan



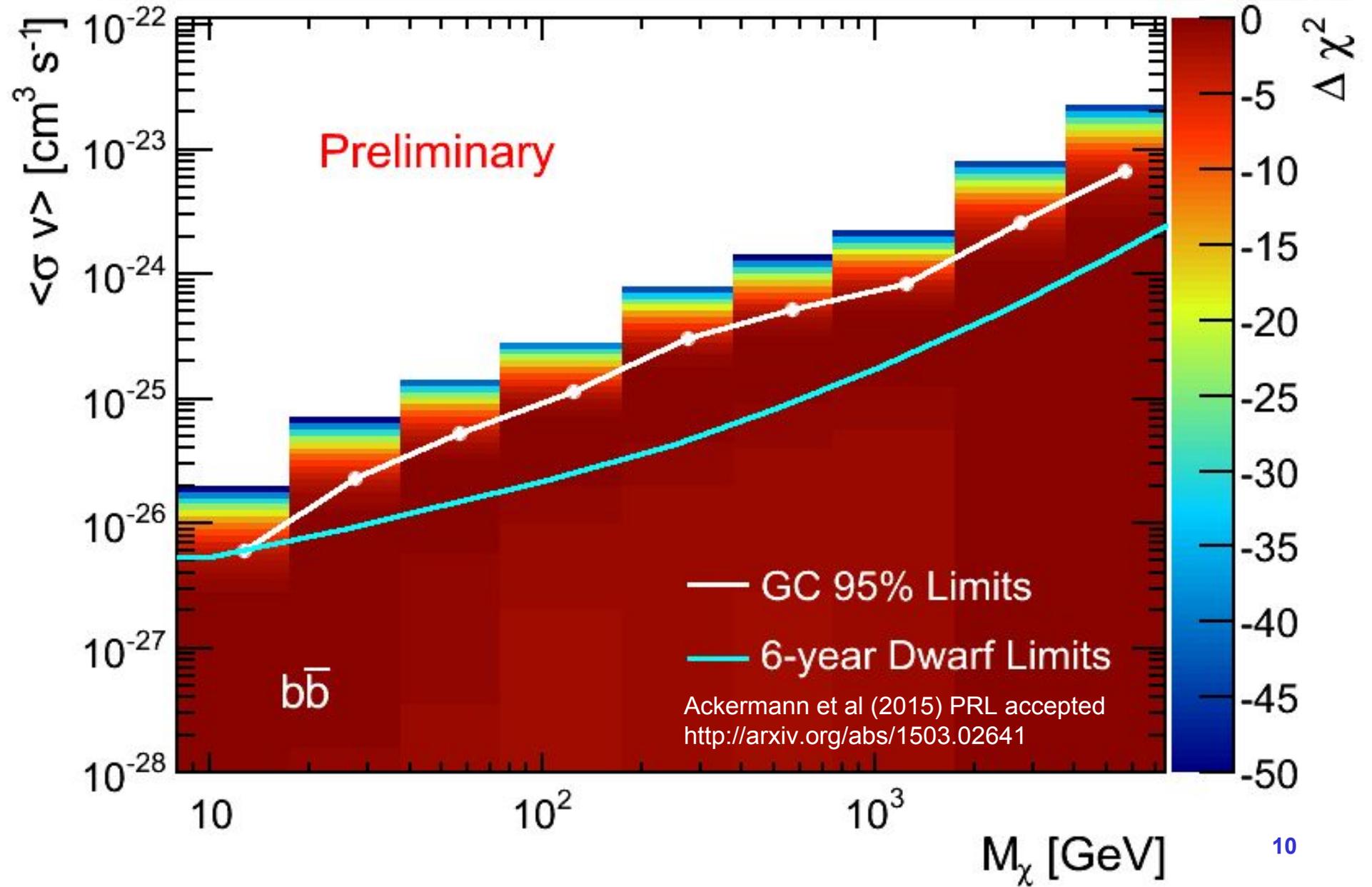
- Perform same fitting with the NFWc template centered along the Galactic Plane
  - Fit NFWc template in each energy bin independently
- Many dark-matter like residuals also found along GP
- Use 68% containment of fractional signals found along GP as estimate of systematic uncertainty from modeling uncertainties
  - Note the size of  $\delta f_{68,GP}$  is comparable to the frac. signal in the Galactic Center

# Fitting Including $\delta f_{\text{sys}}$

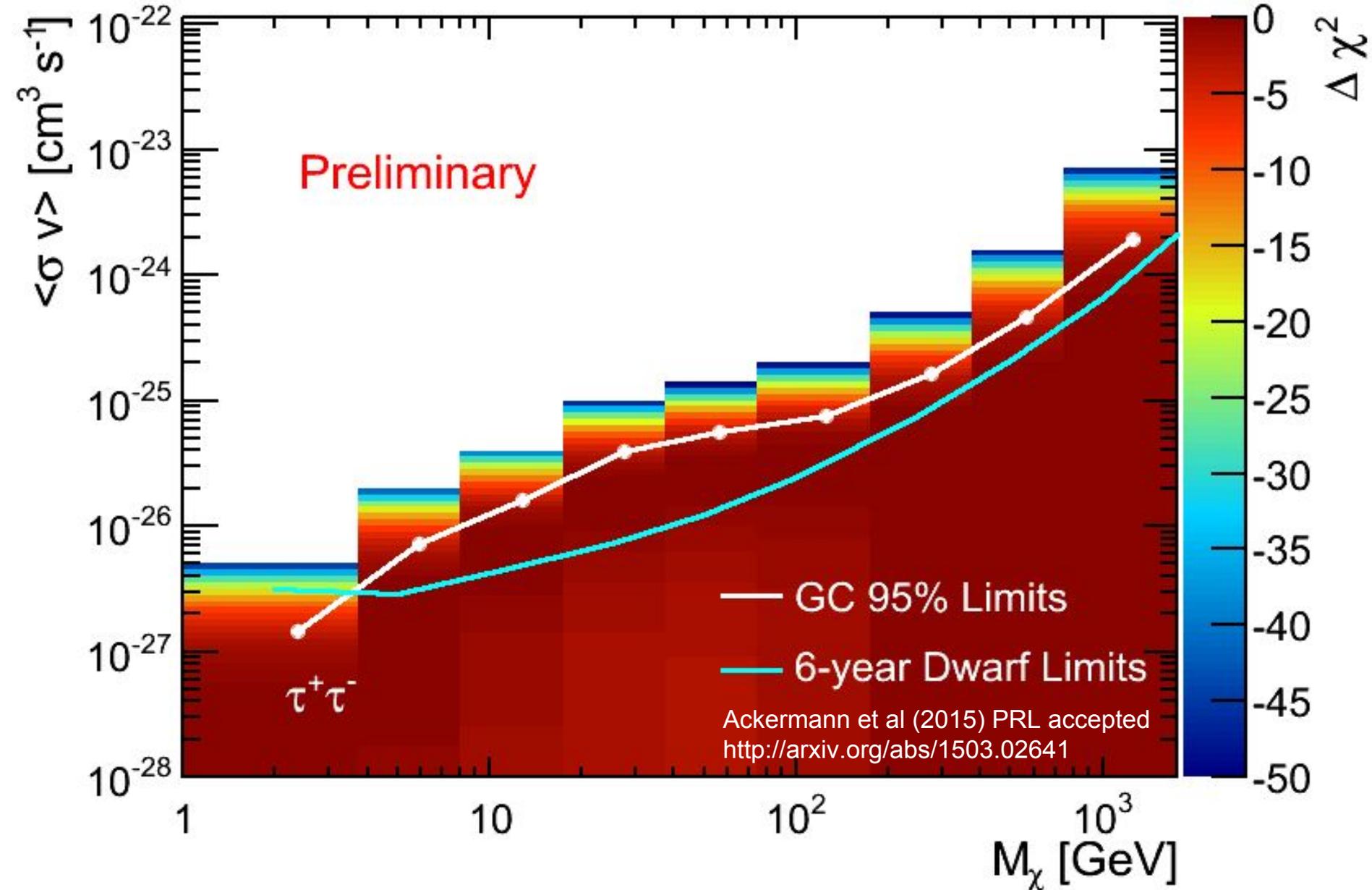


- It is useful to define  $\delta f_{\text{sys}} = \delta n_{\text{sys}} / b_{\text{eff}}$  since  $b_{\text{eff}}$  and  $n_{\text{sys}}$  both scale with the total number of counts in the fit
  - We define  $\delta f_{\text{sys}} = \max(\delta f_{68,GP}, 0.01)$
- Separate best fit “apparent signal” into  $n_{\text{sys}}$  and  $n_{\text{sig}}$  using a nuisance parameter
  - Constrain  $n_{\text{sys}}$  with a gaussian prior with width  $\delta n_{\text{sys}} = \delta f_{\text{sys}} * b_{\text{eff}}$
  - Can only observe a signal when  $n_{\text{sig}} > n_{\text{sys}}$ 
    - We are only sensitive to dark matter signals larger than the dark-matter-like signals seen in control regions
  - See Eric Charles’ talk from Wed.
- Similar to technique used in LAT-Collaboration P8 Line Search and Search for Dark Matter in the LMC
  - Ackermann, M. et al. 2015, Phys. Rev. D, D91, 122002
  - Buckley, M. R. et al. 2015, Phys. Rev. D, 91, 105004

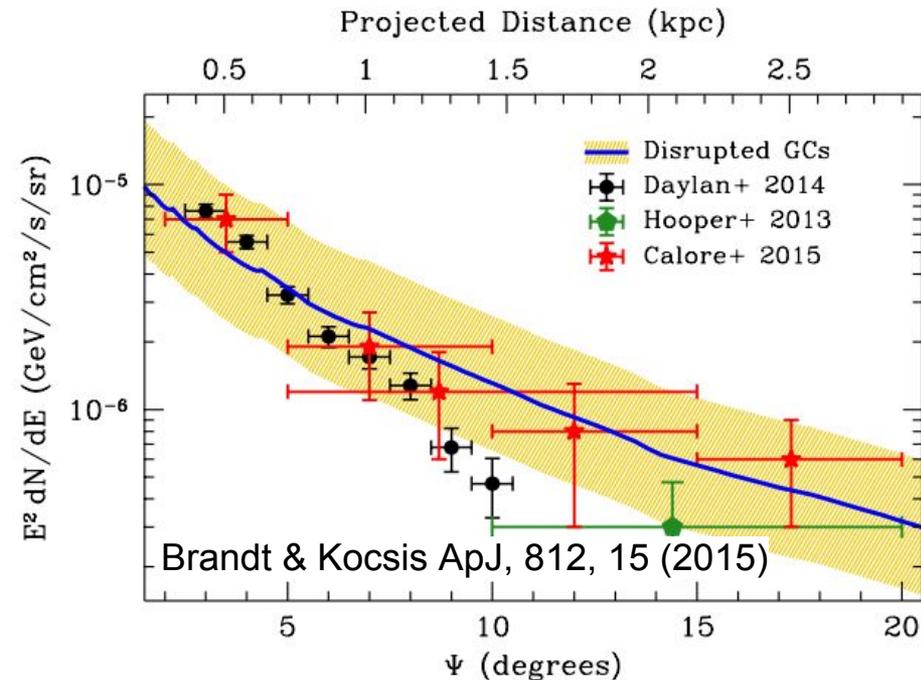
# Results -- bb



# Results -- $\tau^+\tau^-$



# Unresolved Millisecond Pulsars



- Challenging to predict the number and luminosity function of unresolved MSPs
  - need to extrapolate properties of fainter MSPs from observed MSPs
  - Soft MSP luminosity functions can account for GeV excess
    - e.g. Yuan and Zhang (2014), Petrovic et. al. (2015)
- Derived templates from unresolved point sources can account for the excess
  - Bartels et al (2015), Lee et al (2015)
- Galactic Bulge may contain MSPs from dissolved Globular Clusters
  - Brandt and Kocsis (2015)
- Even though dark-matter-like part of GC excess comparable to those seen along the Galactic Plane, an excess persists
- Many have shown a population of unresolved MSPs can account for the excess
  - currently we do not include MSP template in our fit
  - including a MSP template would likely improve our limits



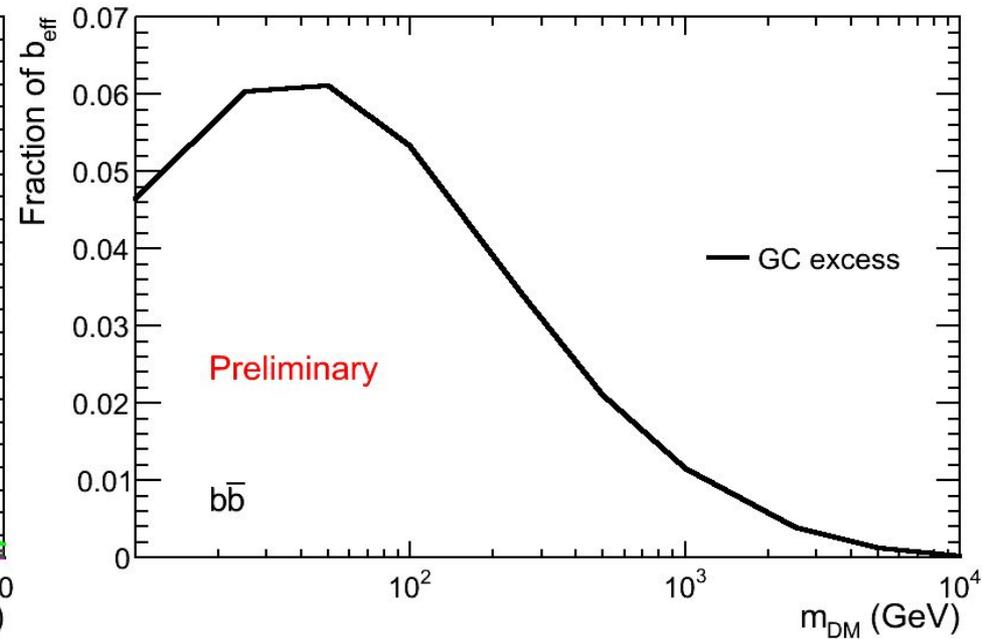
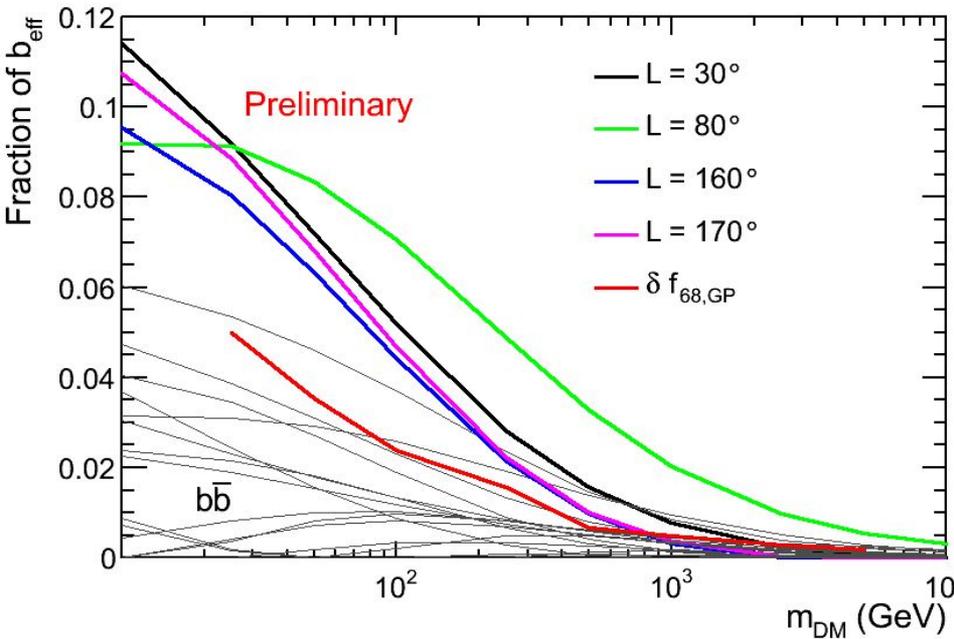
- With Pass 8 we confirm the persistence an excess towards the Galactic Center peaking around a few GeV
- The fractional signal in the Galactic Center is comparable to the fractional signals at other longitudes along the Galactic Plane
  - Do not expect a true dark matter signal to appear at off-center longitudes. Diffuse emission residuals along the GP can mimic a dark matter signal
- We derive dark matter limits incorporating systematic uncertainties
- The GC excess can be explained by plausible models of an unresolved population of Millisecond Pulsars
  - Our limits do not currently include MSP templates

# Backup Slides

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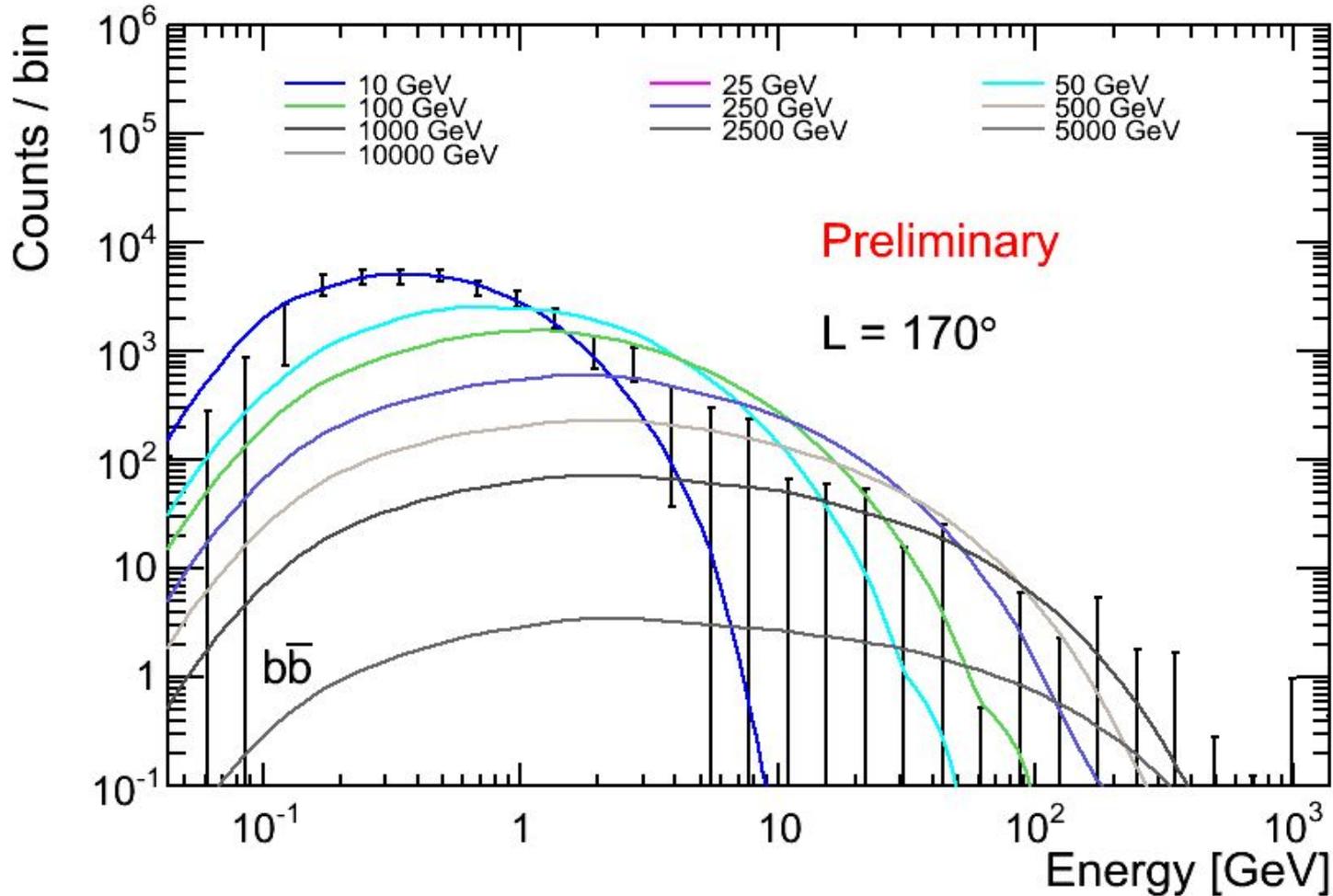


# Galactic Plane Scan -- B Mask



- Perform same fitting with the NFWc template centered along the Galactic Plane**
  - mask  $-3^\circ < B < 3^\circ$  to mitigate contribution from local gas
  - Fit NFWc template in each energy bin independently
- Still find  $\delta f_{68,GP}$  is comparable to the frac signal in the Galactic Center**

# Galactic Plane Scan -- B Mask



- Example fit for NFWc template centered at  $B=0$ ,  $L=170^\circ$ 
  - $-3^\circ < B < 3^\circ$  is masked