

# **VERITAS and ctools Status**

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# Where we're going

- VERITAS->ctools data converters and progress
  - 2 different analysis chains
- Dark Matter Halo Model

# VERITAS Software Pipelines

Event  
Reconstruction

Astrophysical  
Analysis

EventDisplay

C++/ROOT

VEGAS

C++/ROOT

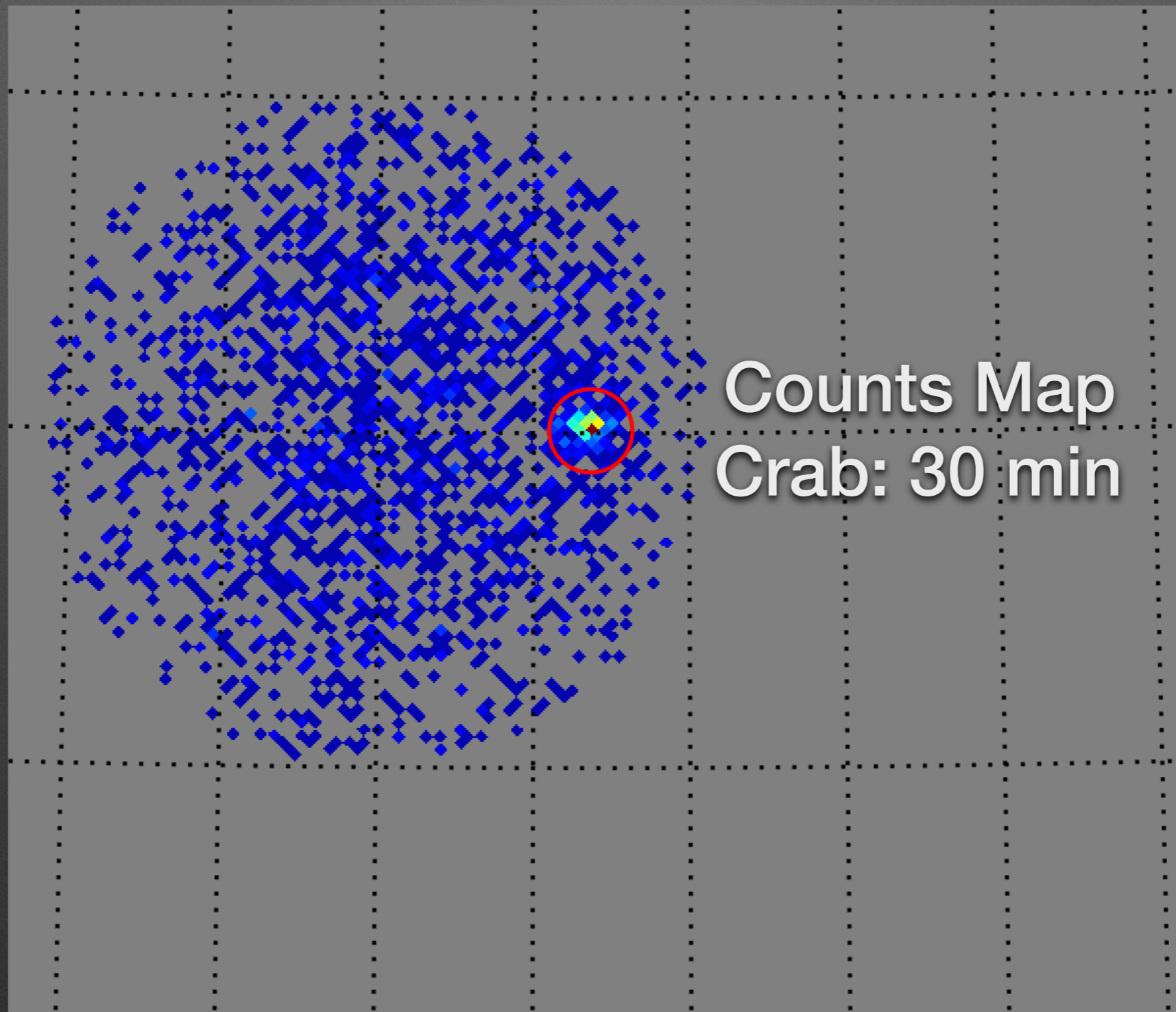
Data/Sims

CTOOLS!

# Status: EventDisplay FITS Converter

- Integrated into Event Display code
- One Veritas Run split into multiple fits files
  - one file ~ 5min observation
- Converter packs IRFs into Events List fits file

# Status: EventDisplay FITS Converter



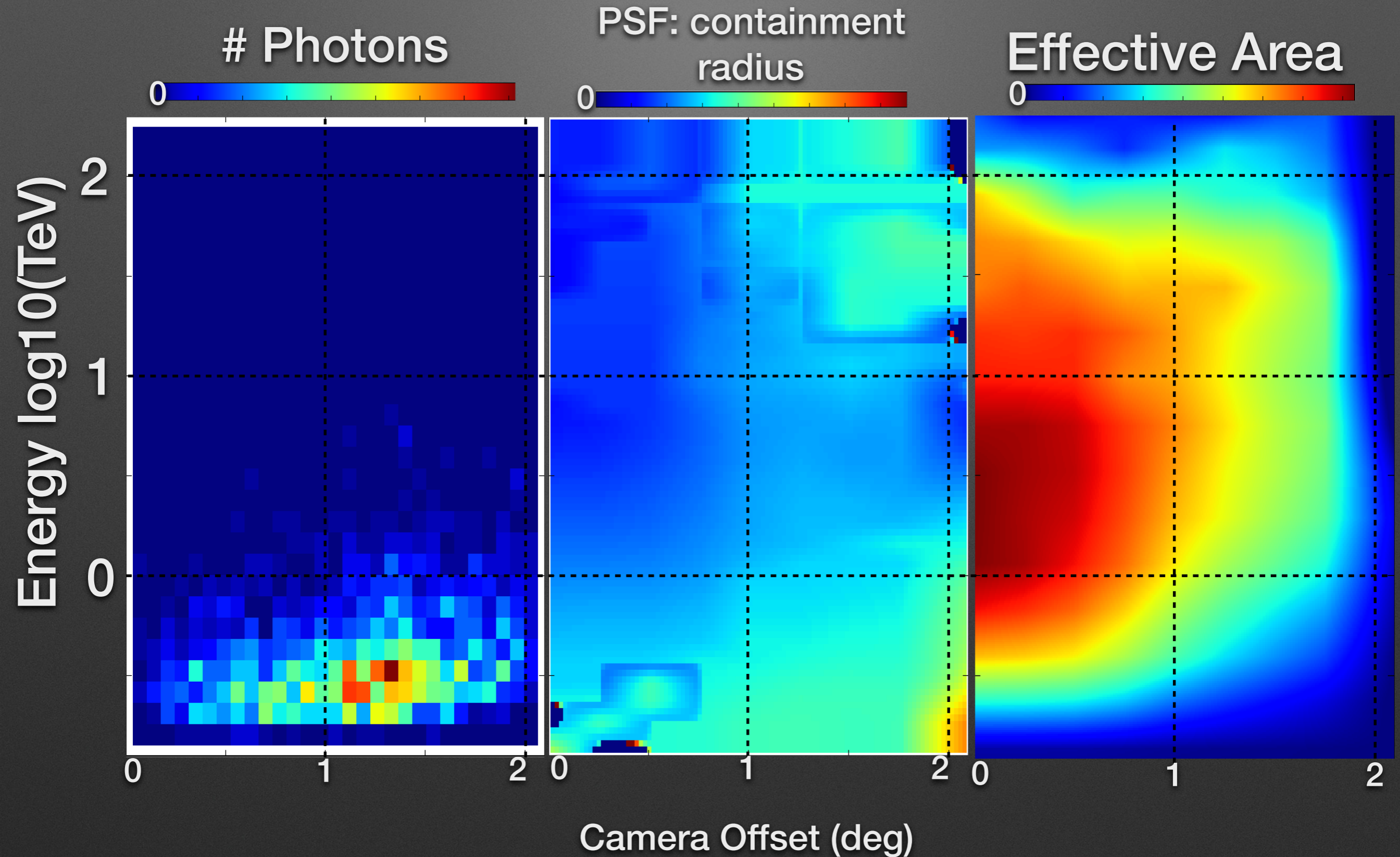
0

# photons

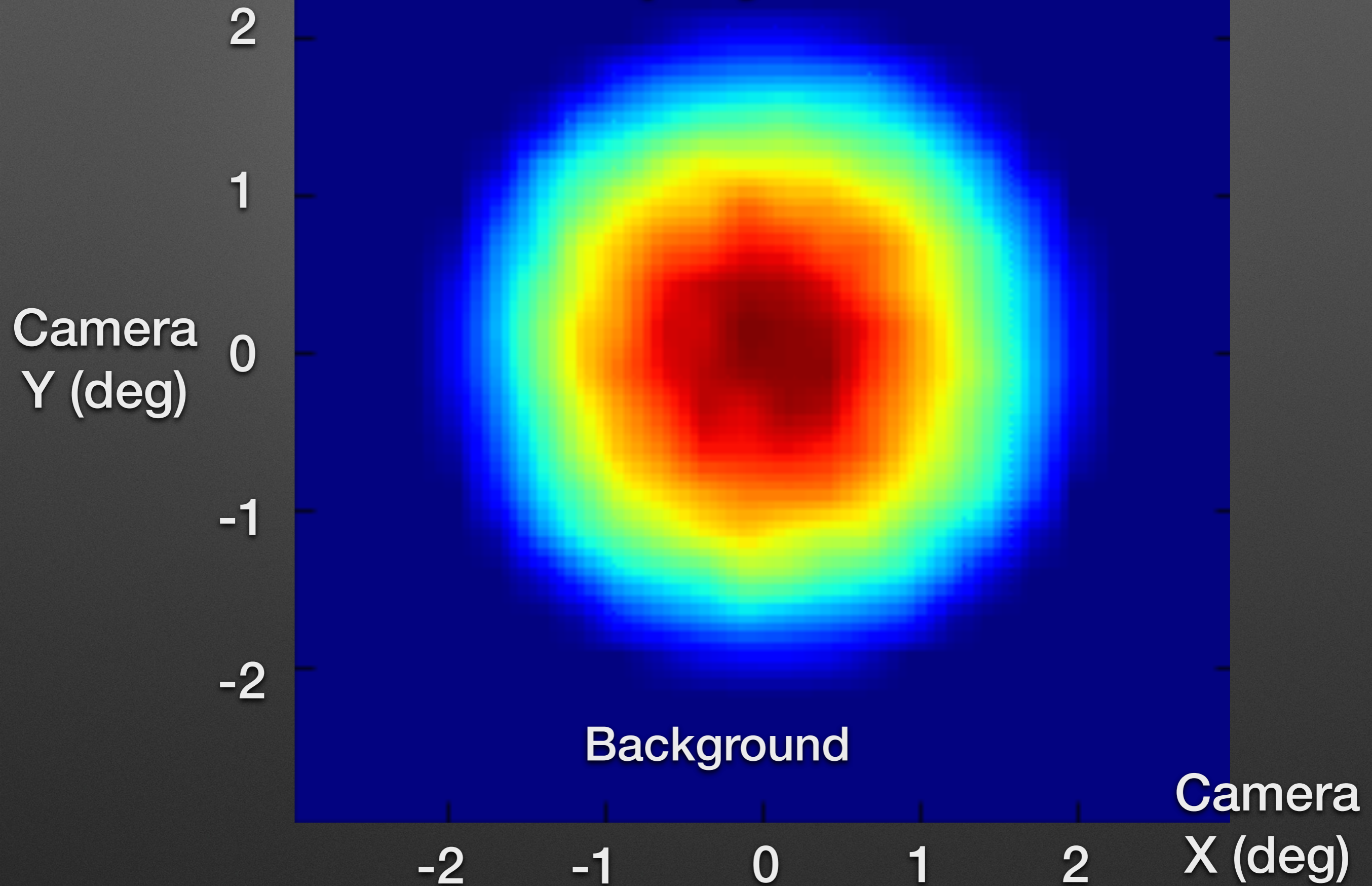
Many



# Status: EventDisplay FITS Converter



# Status: EventDisplay FITS Converter



# Status: EventDisplay FITS Converter

- **Done:**
  - All Veritas data to ctools FITS format
  - Effective area
- **Almost Done:**
  - PSF (minor issues)
  - Background (from data)



# VEGAS Converter

Hugh Dickinson

- Current progress:
  - IRFs and Event lists converted
  - VERITAS-specific VTOOLS applications (Branch of CTOOLS)
- Ongoing efforts:
  - Multi-observation VERITAS-only likelihood fitting.
  - Multi-instrument, independent and joint-likelihood fitting.

# Galactic Center Dark Matter Halo

- Analyse Galactic Center VERITAS data
- Model its Dark Matter Halo
- Likelihood analysis
- Derive upper limits on mass/cross section
- But:
  - Halo has unique shape
  - No Dark Matter Halo templates in ctools...yet

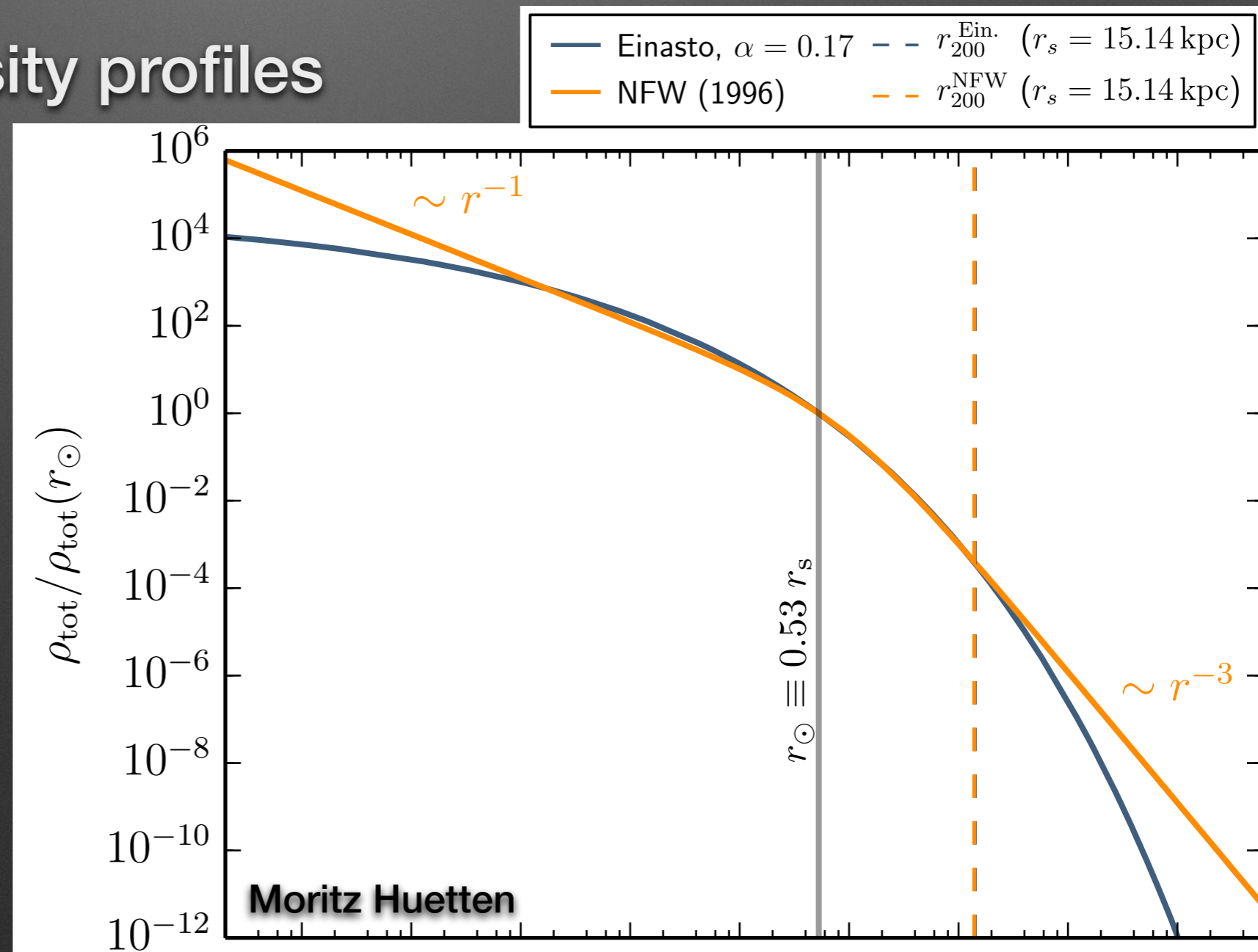
# GModel Spatial Radial Dark Matter Halo

- Density profiles extensively studied via galaxy rotation curves and N-body simulations ([arXiv:0509417](https://arxiv.org/abs/0509417))
- Einasto & NFW density profiles

$$\rho_{\text{einasto}}(r) = \rho_s e^{-\frac{2}{\alpha} \left( \left( \frac{r}{r_s} \right)^\alpha - 1 \right)}$$

$$\rho_{\text{zhao}}(r) = \rho_s \left( \frac{r}{r_s} \right)^{-\gamma} \left( 1 + \left( \frac{r}{r_s} \right)^\alpha \right)^{\frac{\gamma-\beta}{\alpha}}$$

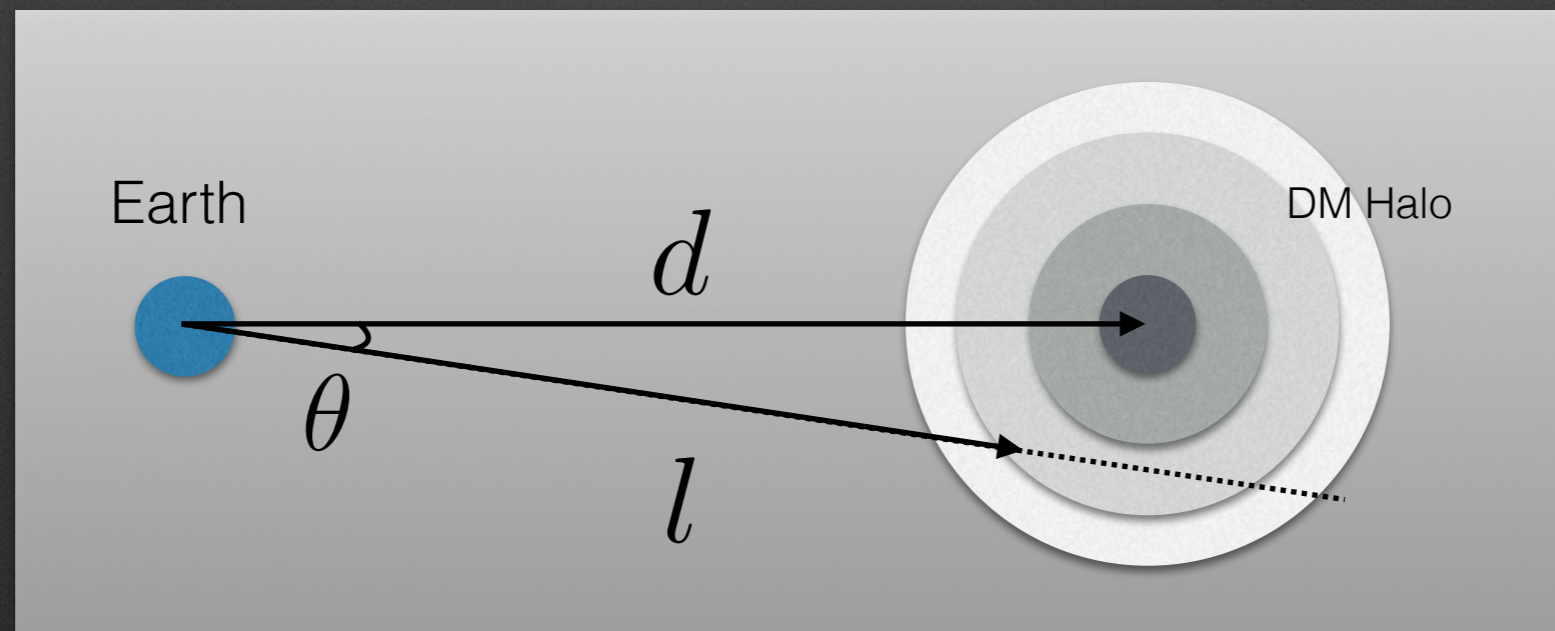
$$\text{NFW} = \text{zhao} (\alpha = 1, \beta = 3, \gamma = 1)$$



# GModelSpatialRadialDarkMatterHalo

Gamma Ray Flux from  
Annihilating Dark Matter Halo:

$$\frac{d\Phi}{dE d\Omega} = \frac{\langle\sigma v\rangle}{8\pi m_{\chi}^2} * \frac{dN}{dE} * \int_{l=0}^{\infty} \rho^2(\theta, l) dl$$

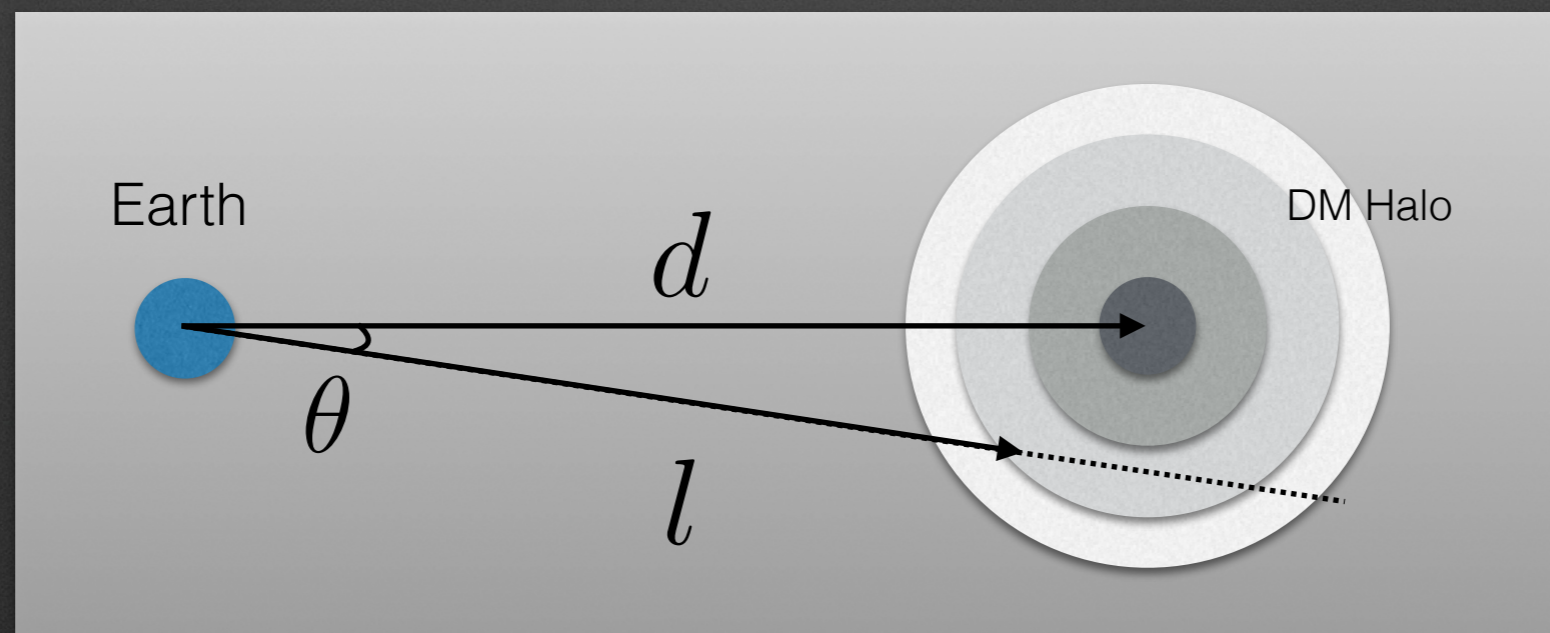


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Particle  
Physics



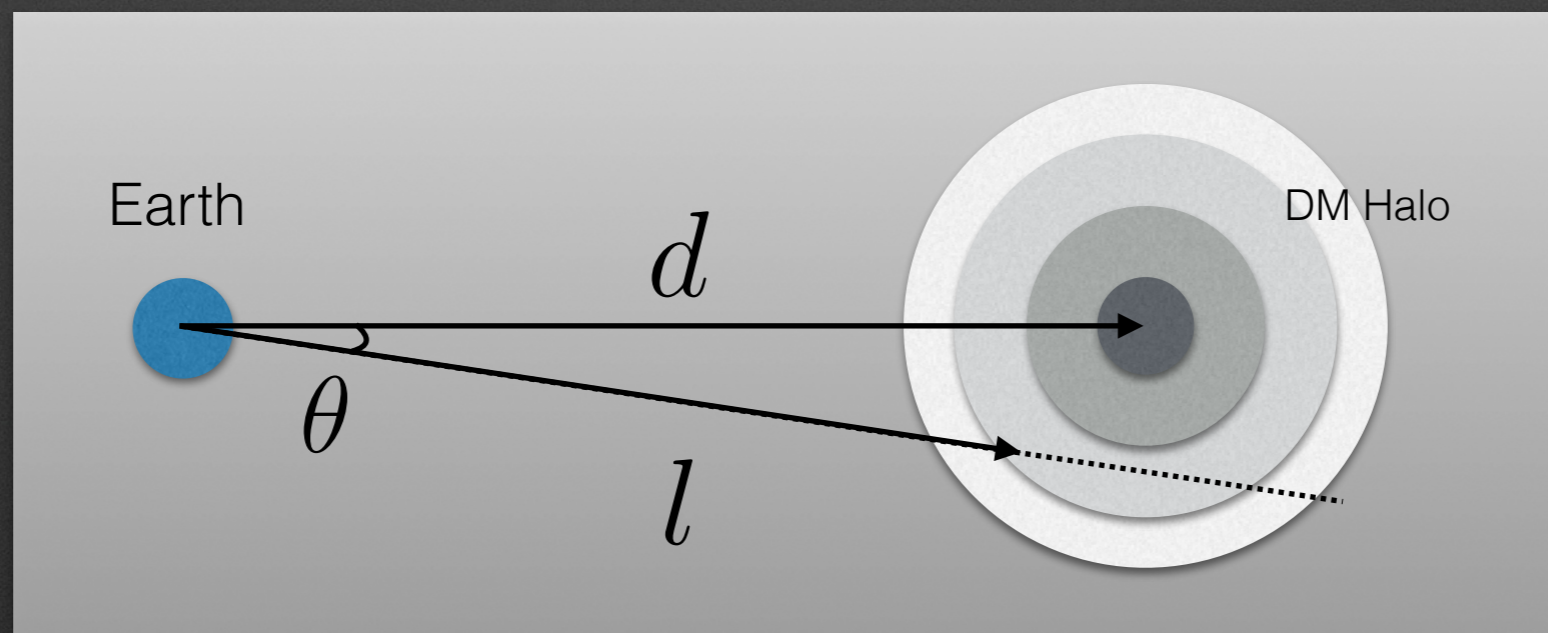
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Particle  
Physics

$\gamma$ -ray  
Spectrum



# GModelSpatialRadialDarkMatterHalo

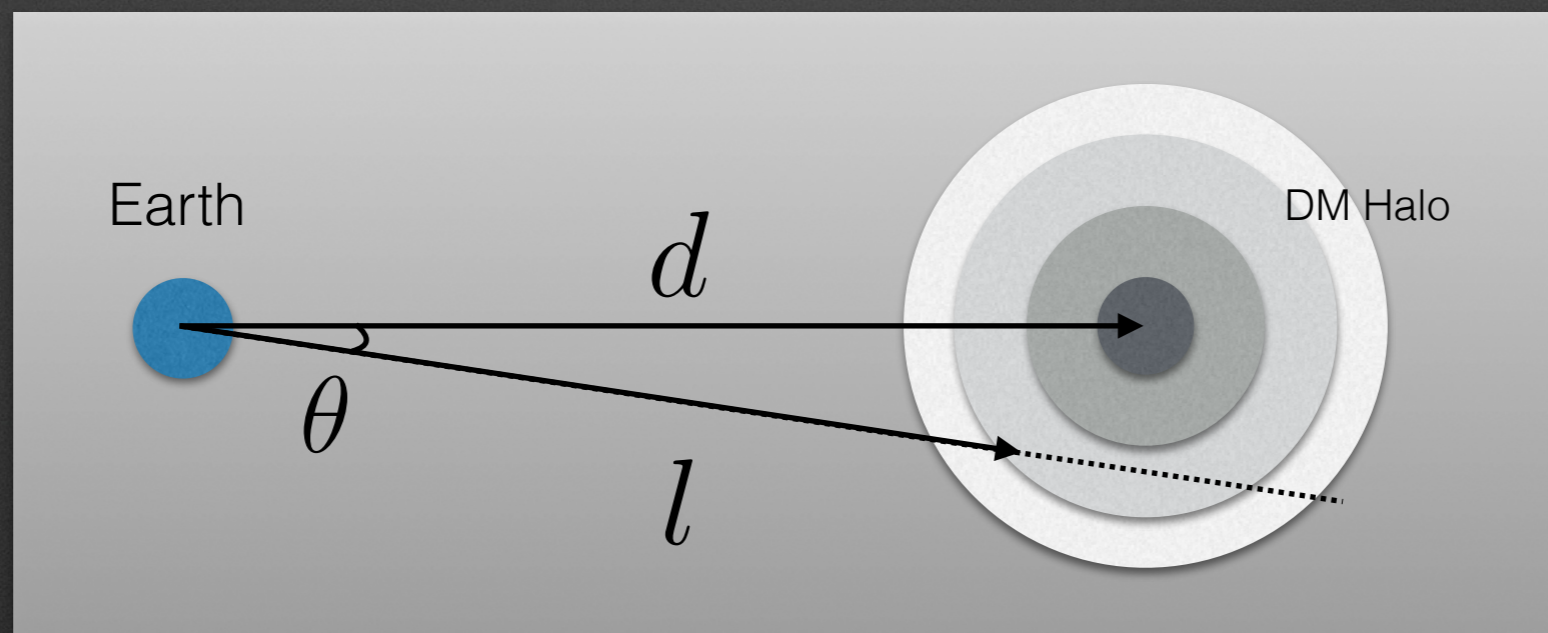
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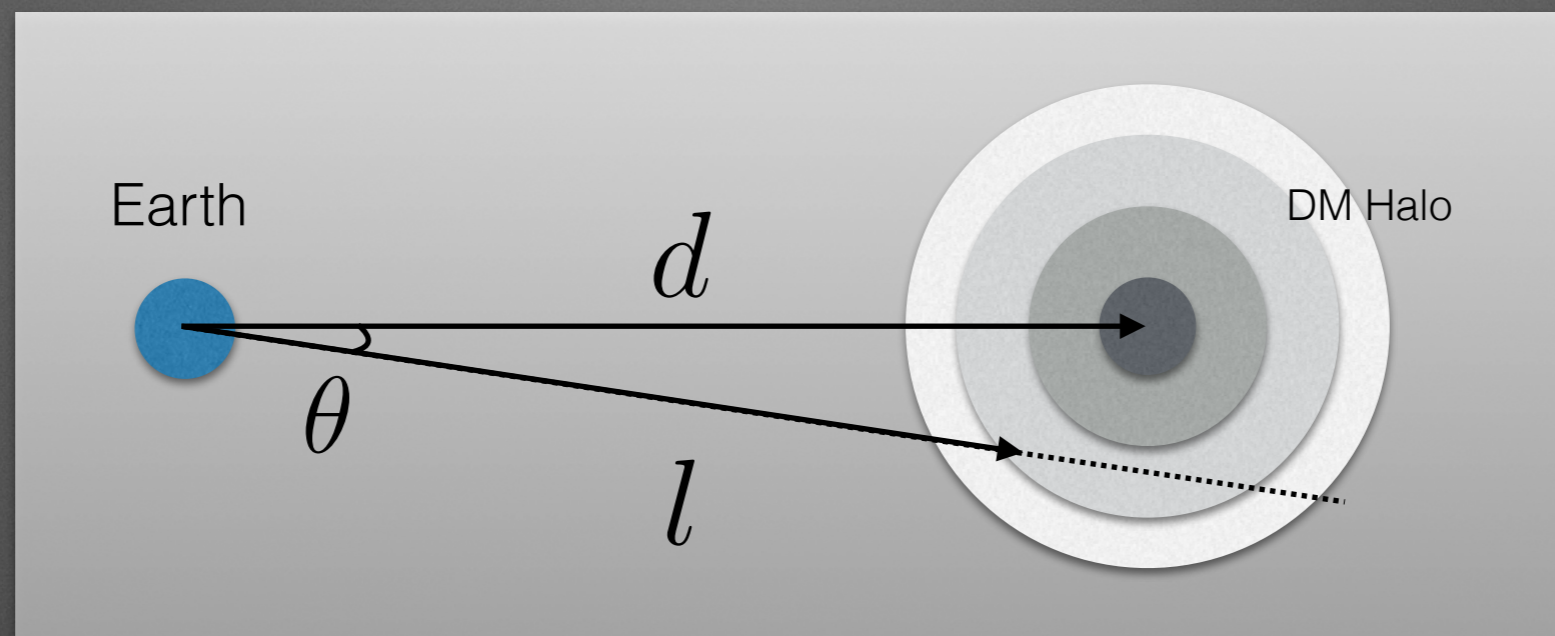
Particle  
Physics

$\gamma$ -ray  
Spectrum

Spatial  
Template Base



# GModelSpatialRadialDarkMatterHalo



- For Spatial Radial class, need to calculate 2 integrals:

$$eval(\theta) =$$

$$\int_{l=0}^{\infty} \rho^2(\theta, l) dl$$

# Events  
at  $\theta$

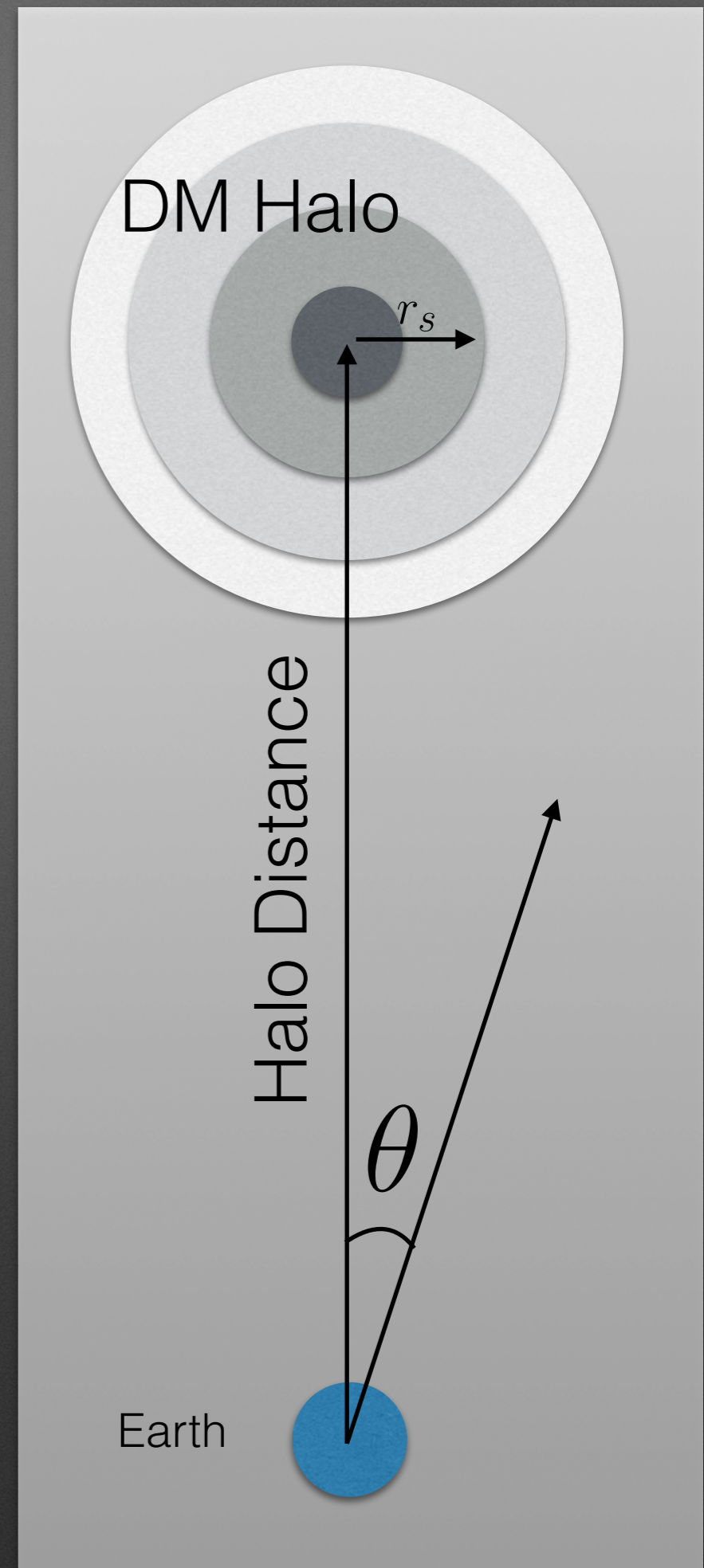
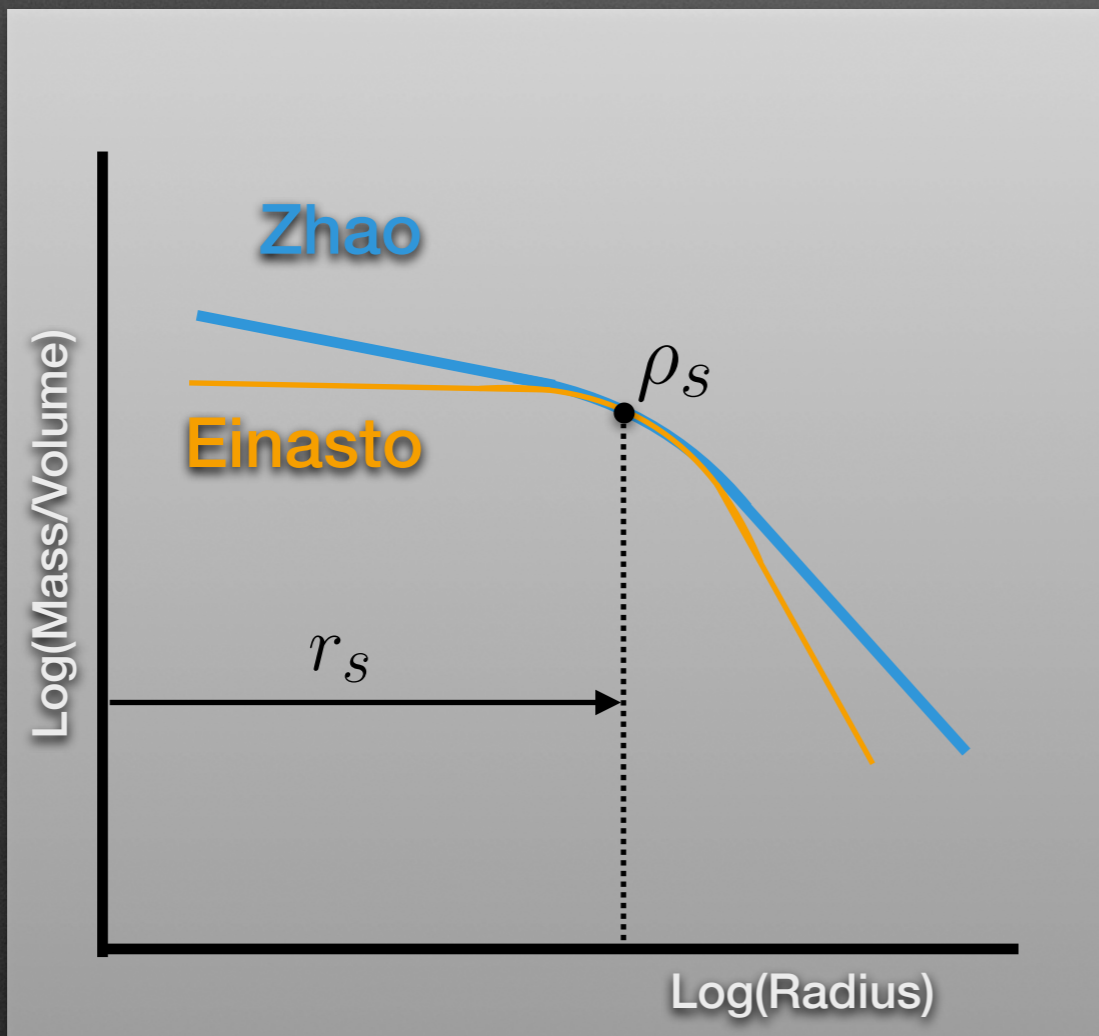
$$\int_{\phi, \varphi} \int_{l=0}^{\infty} \rho^2(\phi, l) \sin(\phi) dl d\phi d\varphi$$

# Events  
Everywhere



# Model Usage

```
$ python
>>> import gammlib
>>> h = gammlib.GModelSpatialRadialDarkMatterHalo()
>>> print(h)
=== GModelSpatialRadialDarkMatterHalo ===
Number of parameters .....: 8
RA .....: 0 deg (fixed,scale=1)
DEC .....: 0 deg (fixed,scale=1)
Halo Distance .....: 2.5e+20 m (fixed,scale=1)
Scale Radius .....: 1e+10 +/- 0 [1,infty[ m (free,scale=1,gradient)
Alpha .....: 1 +/- 0 [0.01,infty[ unitless (free,scale=1,gradient)
Beta .....: 1 +/- 0 [0.01,infty[ unitless (free,scale=1,gradient)
Gamma .....: 1 +/- 0 [0.01,infty[ unitless (free,scale=1,gradient)
Theta Max .....: 2 [0,infty[ deg (fixed,scale=1)
```



# Whats Next

- Coding Sprint: Finish Halo Template
- Background/PSF IRF
- Check whole system with one or more existing sources
- Likelihood fit halo model with VERITAS data of galactic center
  - Derive limits on dark matter mass/cross section

