Fermi LAT Instrument Response Functions

Fermi Summer School

June 2011

Outline

- Context of IRFs
  - Likelihood formarlism
- Effective Area
- Point Spread Function
- Energy Dispersion
- Validation & Correction of IRFs

CONTEXT OF IRFs

IRFs defined in Instrument Frame

Recall that IRFs are designed in context of Likelihood fitting, for example:

$$A_{eff}(\mathbf{p},E,t)$$

where **p** is the celestial direction and the time dependence is there for 2 reasons:

1. Changing instrument (configuration, degradation, etc.)
2. Instrument pointing

In practice we work in the instrument frame, so we have, for example:

$$A_{eff}(\mathbf{v},E,t)$$

where **v** is the direction in the instrument frame and the time dependence only reflects changes in the instrument

In fact, this is why we build “livetime cubes” which give us the viewing profile for each direction in the sky:

$$t_{live}(\mathbf{v};\mathbf{p})$$

Which we can use to derive the exposure for each direction and energy band

$$\mathcal{E}(E,\mathbf{p}) = \int Aeff(\mathbf{v},E)\, t_{live}(\mathbf{v};\mathbf{p})\, d\Omega$$

$\int$ = Integral symbol in Microsoft Power Point

PSF and E_{disp} also done in instrument frame

We also define the PSF and E_{disp} in instrument coordinates, for example:

$$P(\mathbf{v}';\mathbf{v},E,t)$$

$$D(E';\mathbf{v},E,t)$$

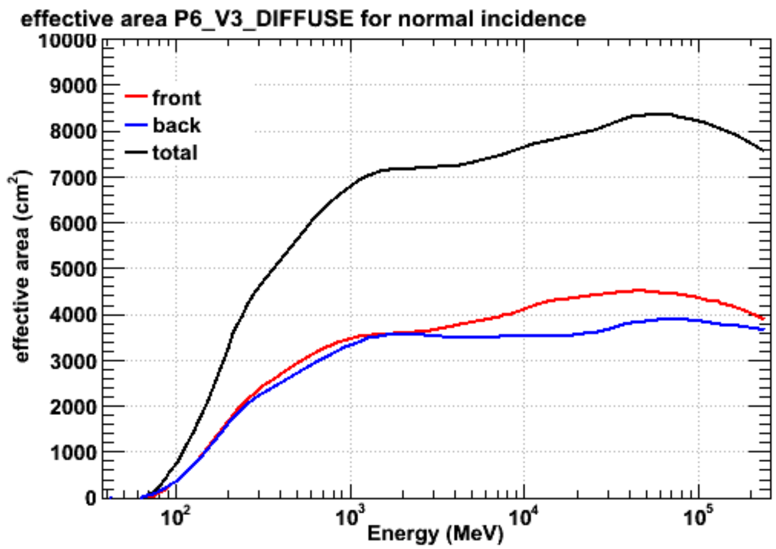
Where **v**' and E' and observed direction and energies (as opposed to true ones)

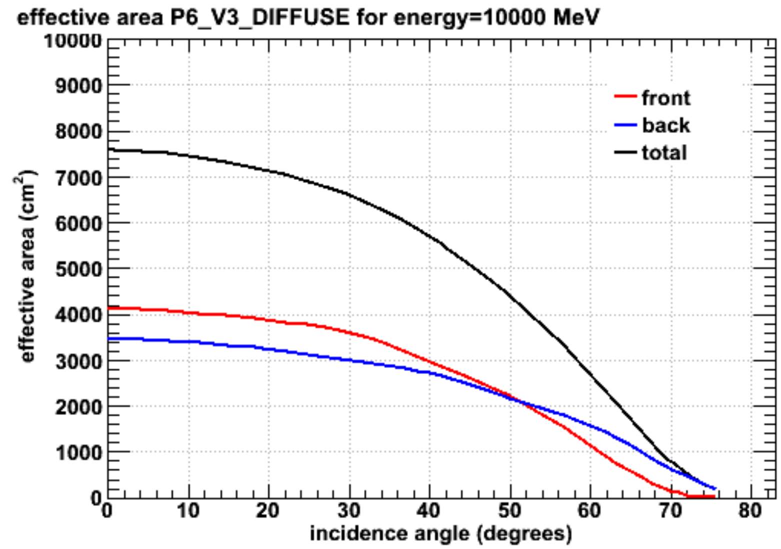
Then with the "livetime cubes" we can do the current convolution integrals to get the expected counts distribution $M(E',\mathbf{p}')$ from a flux model $F(\mathbf{p};E)$ which is what we need for the likelihood fit

$$M(E',\mathbf{p}') = \int t_{live}(\mathbf{v};\mathbf{p})\, A_{eff}(\mathbf{v},E)\, P(v';\mathbf{v},E)\, D(E';\mathbf{v},E)\, F(\mathbf{p},E)\, d\Omega_{\mathbf{v}}$$

EFFECTIVE AREA: A_{EFF}

Effective Area (A_{eff})





< 100 MeV limited by 3-in a row requirement

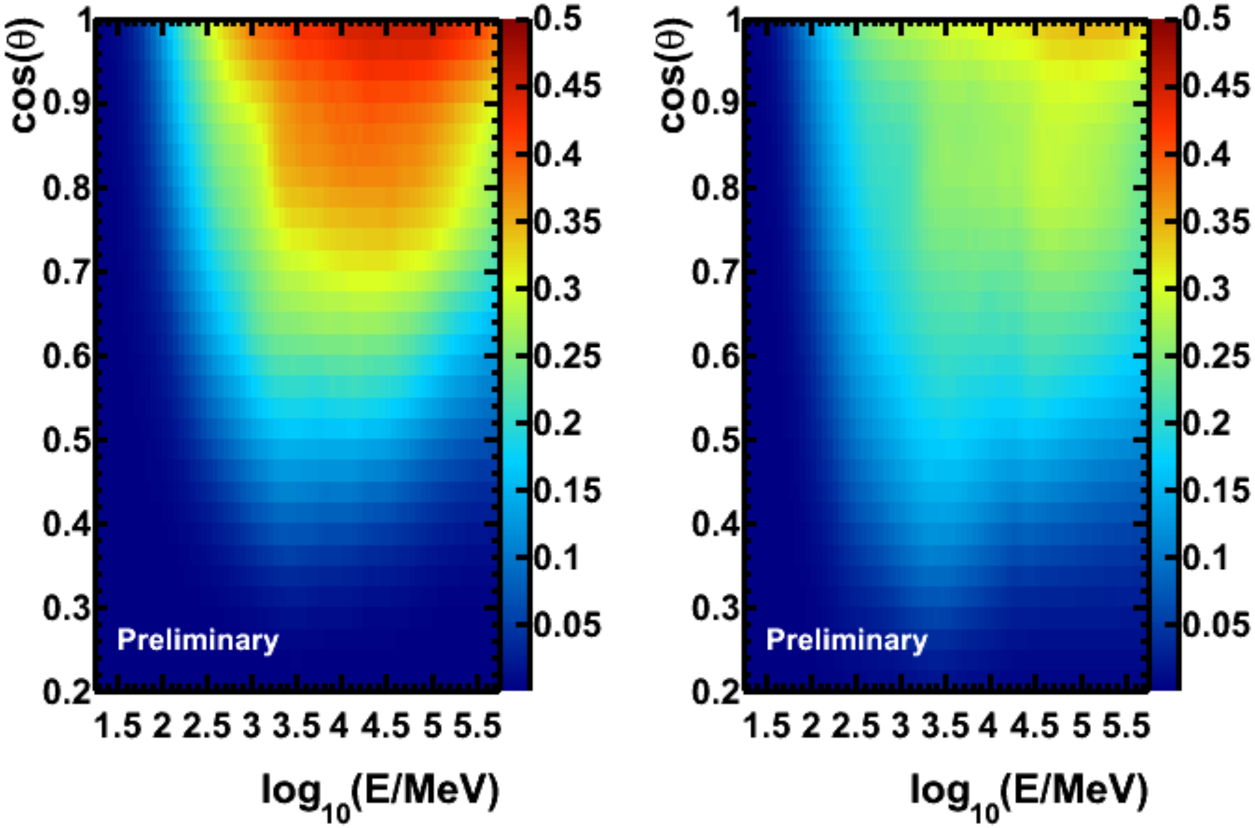
< 1 GeV limited discriminating information

> 100 GeV self-veto from backsplash

Off-axis: more material, less cross section

Shift from front/back events as we go off-axis

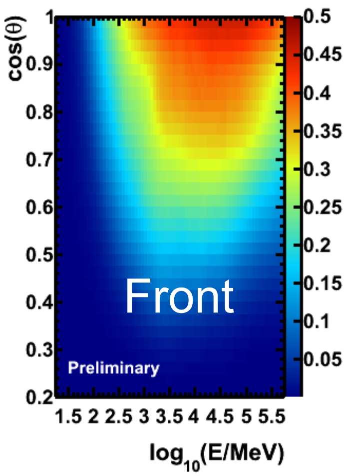
Building the A_{eff} tables

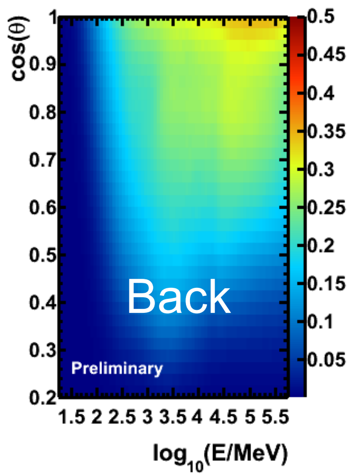


Generate known "isotropic" incoming flux: (200M events, 1/E spectrum)
Count how many events pass cuts in each bin
Normalize to input flux

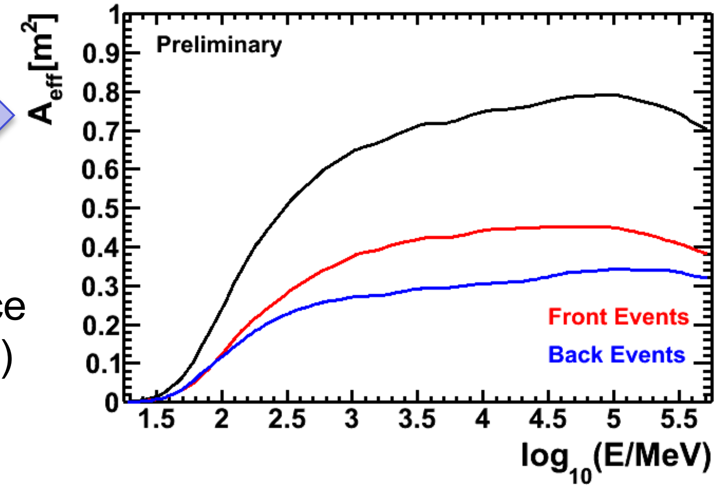
Understanding A_{eff} Behavior

A_{eff} (logE,cosθ) tables: generate uniform event set and count how many pass cuts

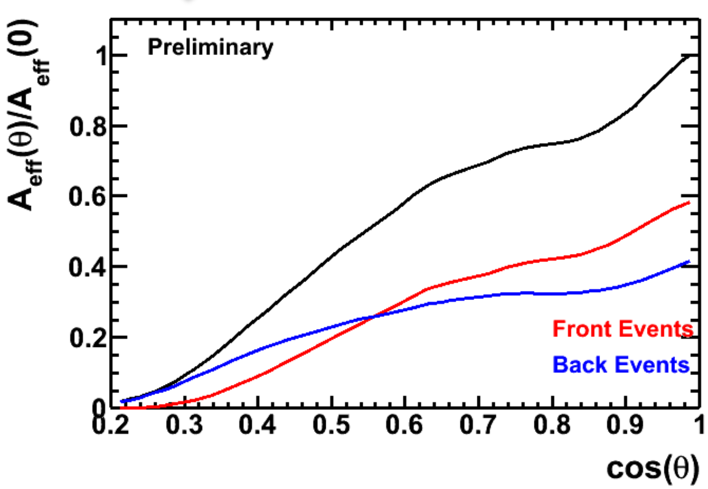




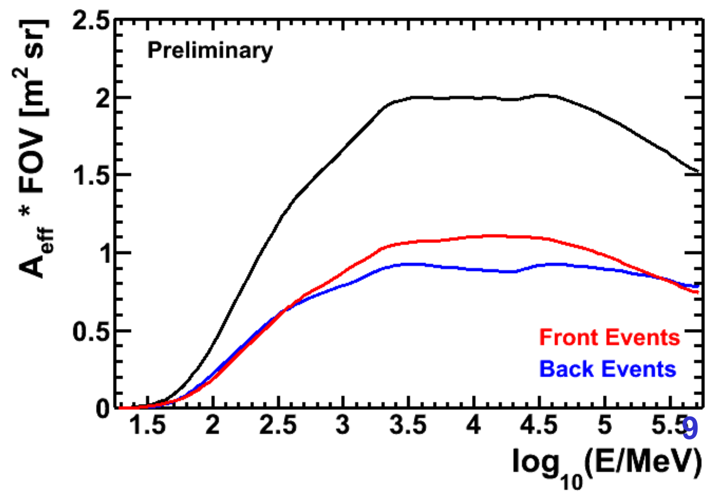
Slice in cosθ
E dependence
$A_{eff}(E;\cos\theta=1)$



Slice in Energy
cosθ dependence
$A_{eff}(\cos\theta;E=1\text{GeV})$



Integrate over cosθ
Acceptance A(E)



Using the A_{eff} tables

Recall that the likelihood interface expects:

$$A_{eff}(\mathbf{v},E,t)$$

What we have produced is a table of values:

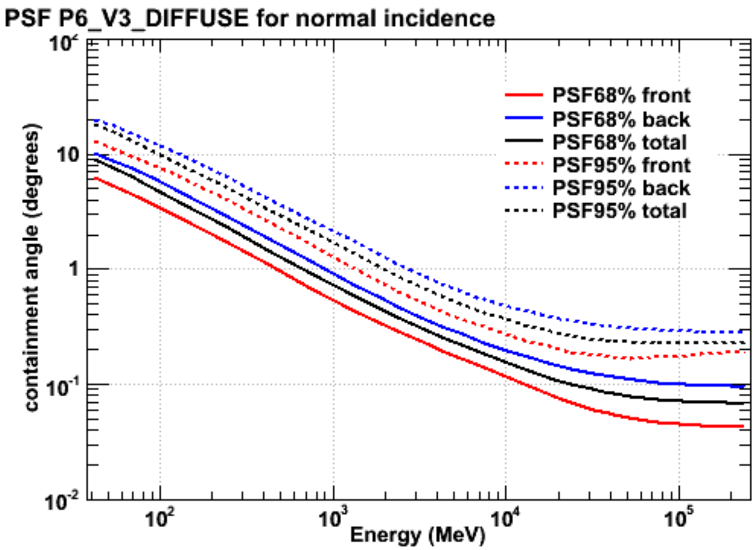
$$A_{eff}(\cos\theta,\log E)$$

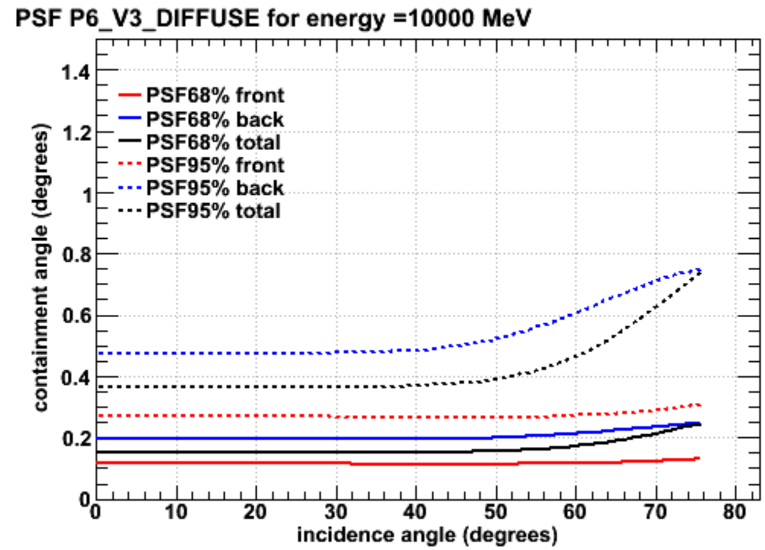
Clearly a bit of work is required to do interpolations, verify that errors for interpolations are not significant

Also, we have ignored ϕ-dependence. Need to quantify how much of a problem this might be for particular studies

POINT SPREAD FUNCTION

Point Spread Function





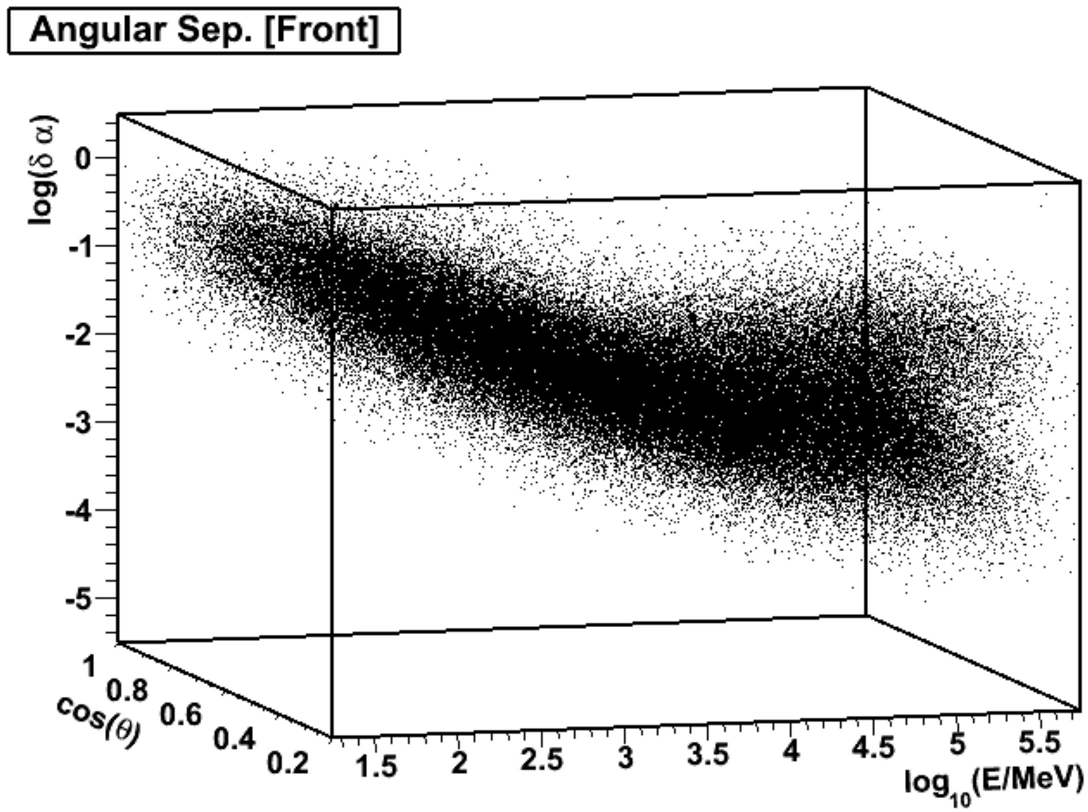
Low energy: dominated by MS

High energy: dominated by strip pitch

Off-axis: more material, more MS at low energy

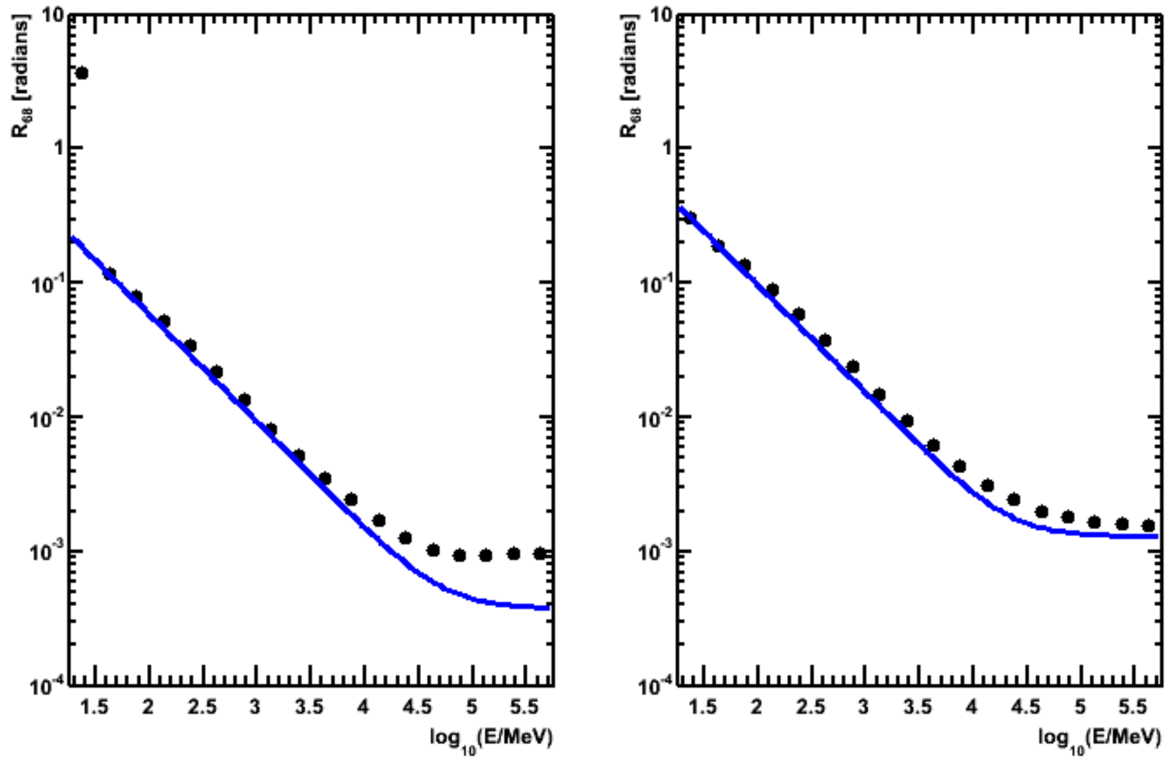
More pattern recognition confusion off-axis at high energy

Building the Point Spread Function



Use same simulated event sample as for A_{eff}
Calculate delta between generated (true) and reconstructed directions $\delta\mathbf{v} = \mathbf{v}' - \mathbf{v}$
Describe distribution as a function as of Energy, incident angle

Energy Scaling of PSF

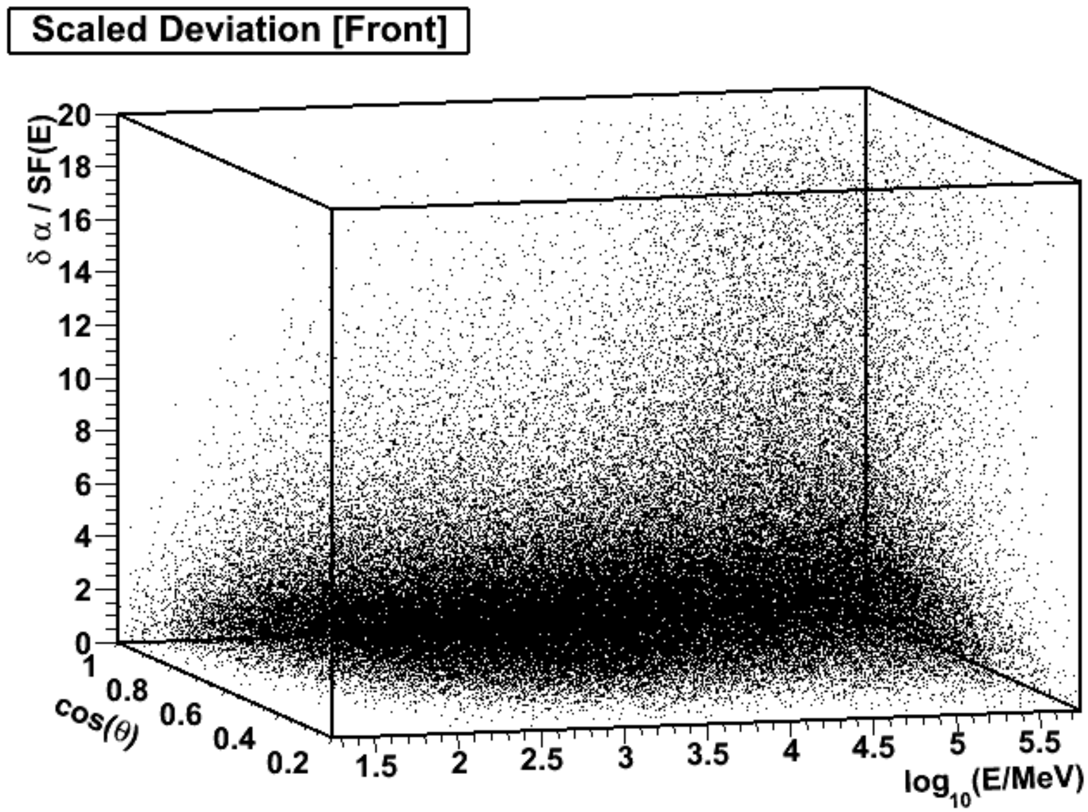


Describe (on-axis) angular resolution scale as a function of energy

$$SP(E) = \left(c_0^2 + c_1^2 \, (E/100\mathrm{MeV})^{2*\gamma} \right)^{½}$$

Note that A_{eff} weighted containment (points) can be somewhat larger

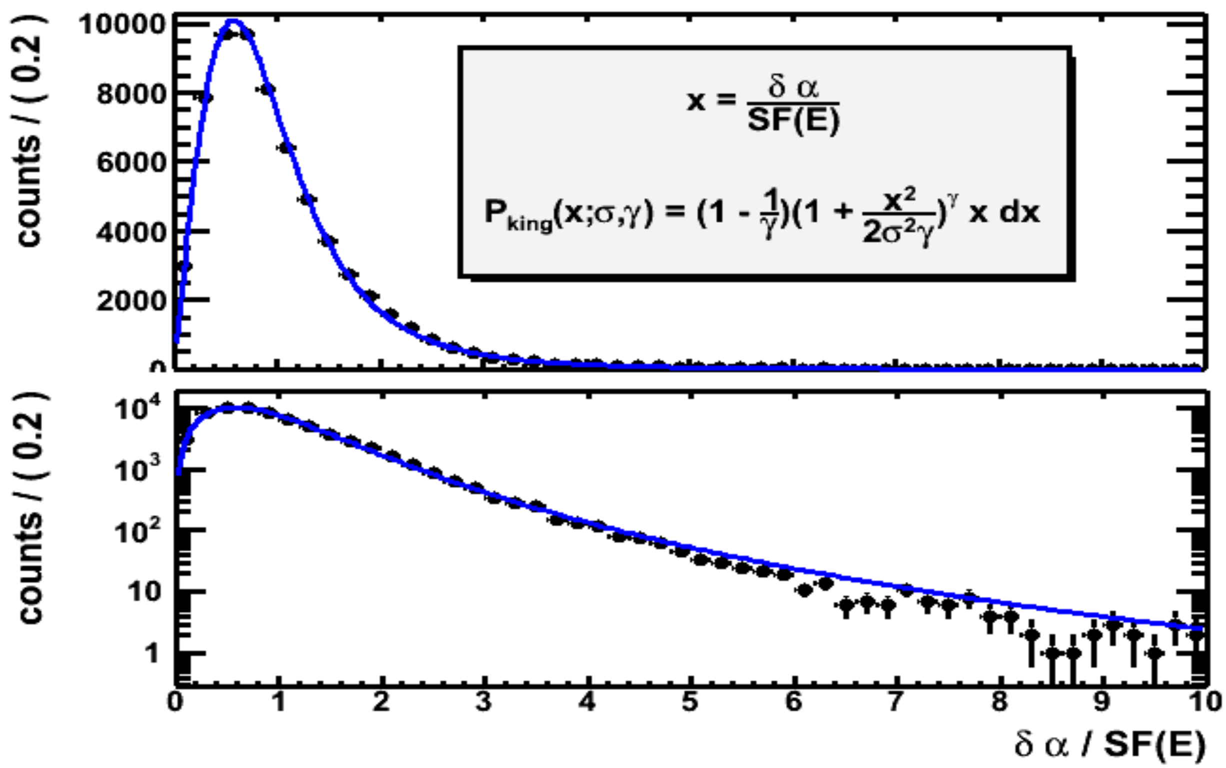
Scaled Angular Deviation



Scaling takes away much of energy dependence

However, behavior of tails varies with energy and incidence angle

Fitting the Scaled Angular Deviation



Fit a reasonable functional form to scaled angular deviation distribution in each bin of logE,cosθ

Using the PSF tables

Recall that the likelihood interface expects:

$$P(\mathbf{v}';\mathbf{v}',E,t)$$

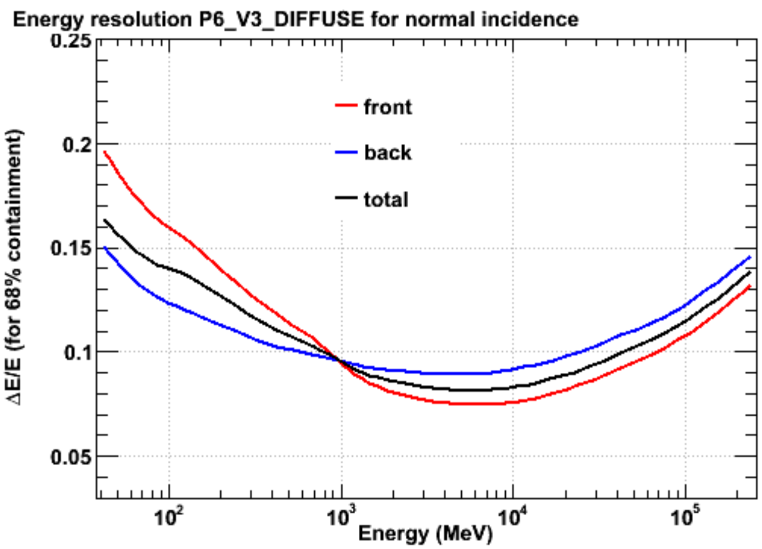
What we have produced is tables of parameters for

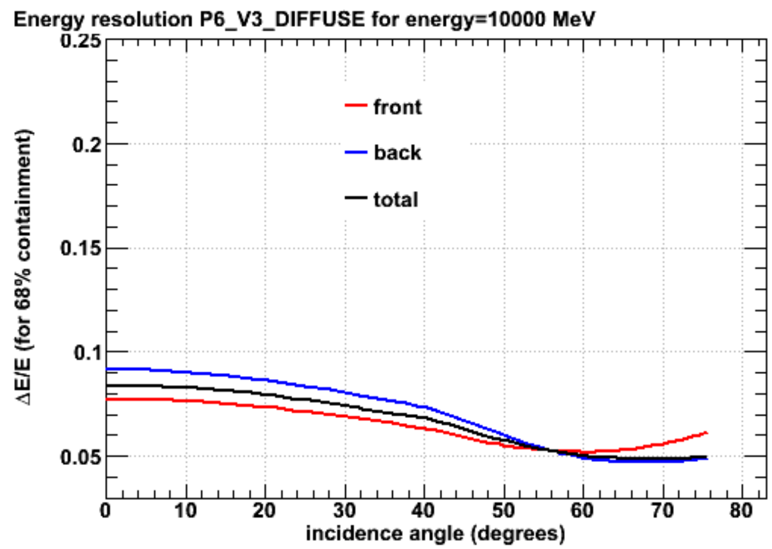
$$K((\mathbf{v}'-\mathbf{v})/S_P(E),\sigma_c,\gamma_c,\sigma_t,\gamma_t,f_c;\cos\theta,\log E)$$

Clearly a fair amount of work is required to do interpolations, verify that errors for interpolations are not significant

ENERGY DISPERSION

Energy Dispersion (D)





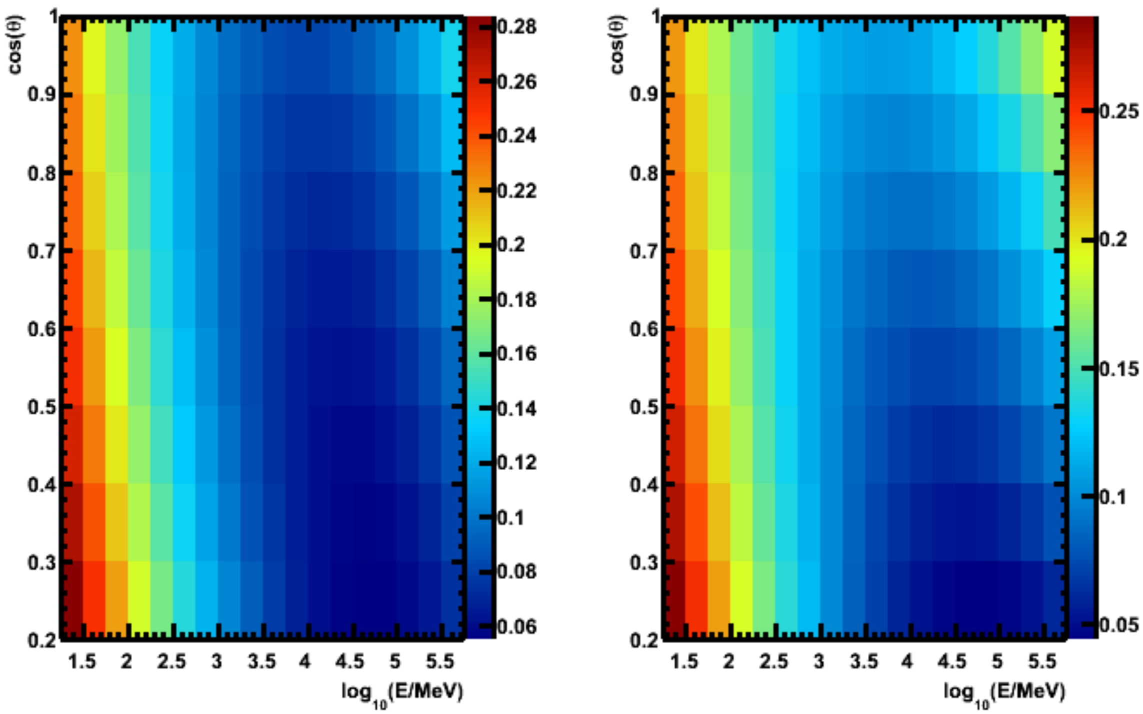
Low energy: energy lost in TKR

High energy: energy lost out back of CAL

Off-axis: more material, more MS at low energy

More pattern recognition confusion off-axis at high energy

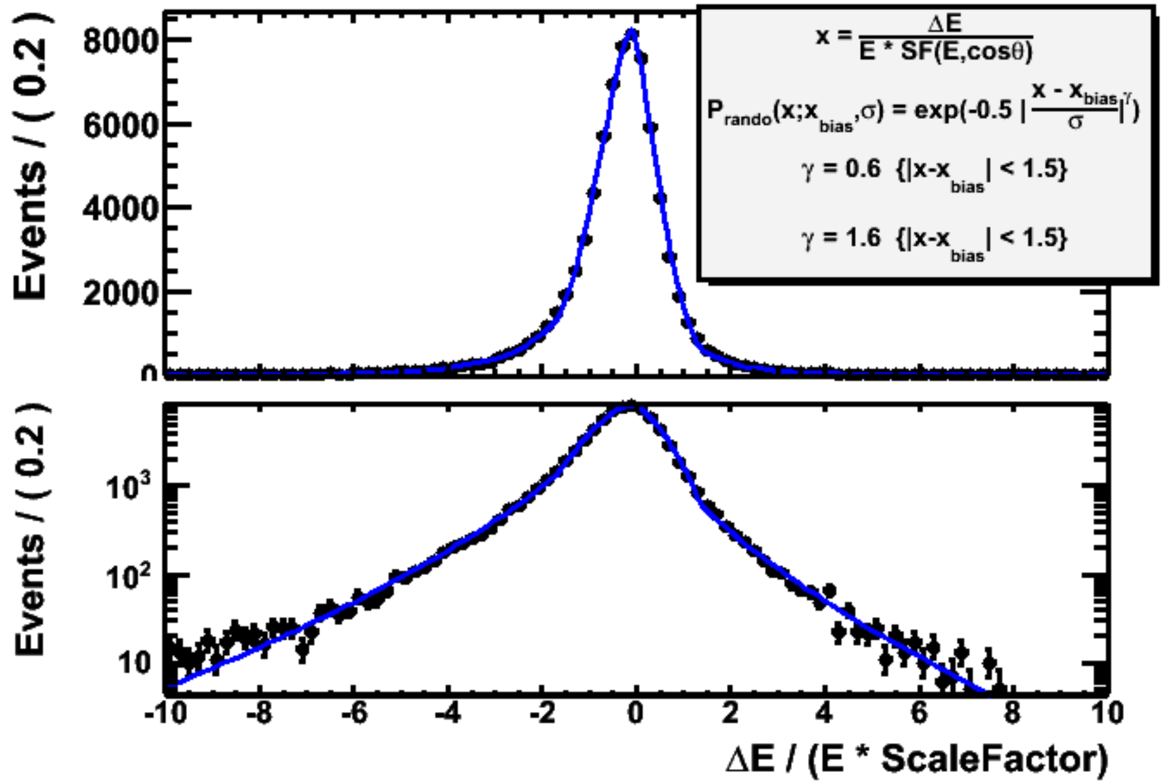
Scaled Energy Resolution



Scaling (with paraboloid) takes away much of energy and angular dependence

However, as with PSF, behavior of tails varies with energy and incidence angle

Fitting the Scaled Energy Resolution



Fit a reasonable (?) functional form to scaled energy dispersion distribution in each bin of logE,cosθ

Using the E_{disp} tables

Recall that the likelihood interface expects:

$$D(\mathbf{v}';\mathbf{v}',E,t)$$

What we have produced is tables of parameters for

$$R(\Delta E/ES_D(E),\sigma_{l1},\sigma_{l0},\sigma_{r0},\sigma_{r1},x_o;\cos\theta,\log E)$$

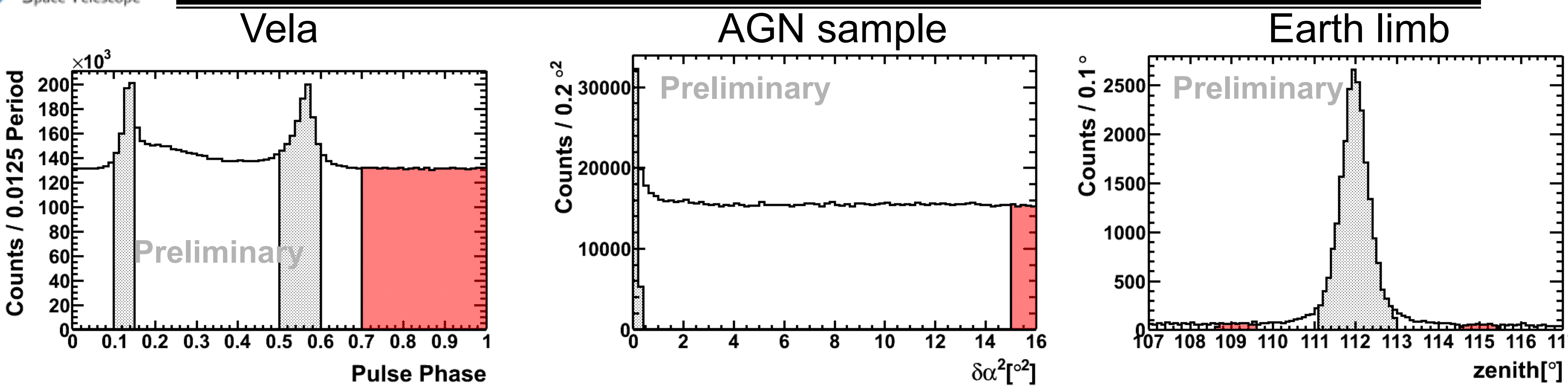
Clearly a fair amount of work is required to do interpolations, verify that errors for interpolations are not significant

VALIDATING THE IRFS WITH FLIGHT DATA

Validating the IRFs with flight data

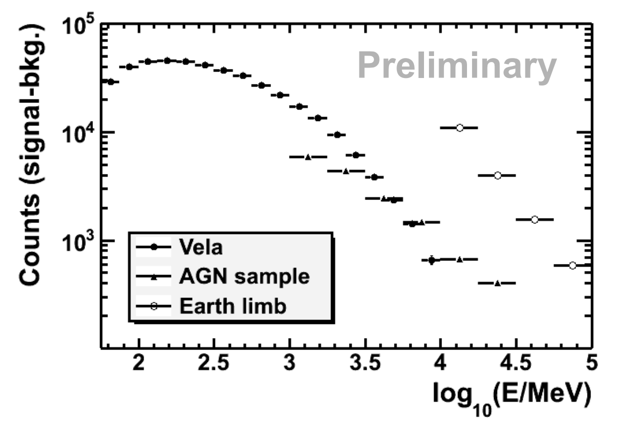
- To validate A_{eff}
  - Standard candles? No!
  - Step by step analysis of event selection efficiency
    - Need “clean” photon samples
  - Consistency checks
- To validate PSF
  - Known point sources? Sort of.
    - Pulsars.
- To validate E_{disp}
  - Known spectral features? DM lines? We wish…

Flight Data Calibration Samples



Calibration samples showing signal (grey) and background (red) regions for the **P7TRANSIENT** event class
These are used as starting point for testing **P7SOURCE** event selection criteria

Calibration Sample	Method
Vela pulsar (2 years) 15° ROI, $q_{z,vela} > 90°$ Very clean bkg. subtraction but cuts off around 3 GeV	Phase-gated
30 Bright, isolated AGN (2 years) 6° ROI, $q_z > 105°$, E > 800MeV Need small PSF for bkg. subtraction	Aperture
Earth limb (200 limb-pointed orbits) E > 8 GeV Difficult to model earth limb emission below ~ 10 GeV.	Zenith Angle cut



Statistics of the calibrations samples after background subtraction

WORK (FOR YOU) TO DO

Some (Open-Ended) Projects

- Have a go at deriving your own IRFs
  - Simulated data provided in extended FITs format
- Compare them to publically released ones
- Take a look at some data from calibration sources, design tests for IRFs
  - Pre-skimmed data with some additional variables
    - Vela Pulse Phase
    - Angular separation from nominal AGN position
    - Zenith Angle