DC2 Instrument Response Functions

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IRF Definitions and Use

- It is conventional to factor the instrument response into effective area, energy dispersion, and point spread function components:

$$R(E', \hat{p}'; E, \hat{p}) = A(E, \hat{p}) D(E'; E, \hat{p}) P(\hat{p}'; E, \hat{p}) \quad (1)$$

$$= \frac{d\sigma}{dE' d\hat{p}'}(E, \hat{p}) \quad (2)$$

  where E is energy, $\hat{p}$ is photon direction, and primed variables indicate measured values and unprimed variables, true values.

- In `gtobssim`, these IRF components are used as follows:
  1. A candidate event, with energy E and direction $\hat{p}$, is obtained from the `flux` package, using a cross sectional area A_0 ($= 6\,\mathrm{m}^2$ in `Gleam`, $= \max(A(E, \hat{p})) \gtrsim 1\,\mathrm{m}^2$ for ST).
  2. This event is accepted if $\xi < A(E, \hat{p})/A_0$, where $\xi \overset{d}{\sim} [0, 1)$.
  3. Apparent energy and direction are then drawn according to the energy dispersion and PSF:

$$E' \overset{d}{\sim} D(E'; E, \hat{p}) \quad (3)$$

$$\hat{p}' \overset{d}{\sim} P(\hat{p}'; E, \hat{p}) \quad (4)$$

- In the likelihood calculation, M, describes the expected distribution of photons,

$$M(E', \hat{p}') = \int dE\, d\hat{p}\, R(E', \hat{p}'; E, \hat{p}) S(E, \hat{p}). \quad (5)$$

The source model consists of point sources and diffuse emission,

$$S(E, \hat{p}) = \sum_i s_i(E) \delta(\hat{p} - \hat{p}_i) + S_G(E, \hat{p}) + S_{\rm eg}(E, \hat{p}). \quad (6)$$

The index i labels the individual point sources; $s_i(E)$ is the true energy spectrum of source i; and $\hat{p}_i$ is its location on the sky. S_G is the Galactic diffuse component, and $S_{\rm eg}$ is the extragalactic diffuse component. Note that the $s_i(E)$ have dimensions of $dN/dEdtdA$ while S_G and $S_{\rm eg}$ have dimensions of $dN/dEdtdAd\Omega$.

Labeling individual photon events with the index j, the logarithm of the Poisson likelihood is

$$\log Ł = \sum_j \log M({E'}_j, \hat{p}'_j, t_j) - N_{\rm pred}, \quad (7)$$

where the predicted number of photons is

$$N_{\rm pred} = \int dE'\, d\hat{p}'\, dt\, M(E', \hat{p}', t). \quad (8)$$

DC2 IRF Development Group

Participants: Jean Ballet, Toby Burnett, Julie McEnery, Riccardo Rando, JC

- Use the AllGamma data, $dN/dE \propto E^{-1}$ incident spectrum, sampled uniformly on the upper hemisphere enclosing the LAT.
- Divide the data into bins in $\log E$ and $\cos i$ space (neglect azimuthal dependence about instrument z-axis).
- Also, divide the work:
  - Final background filters and event class definitions – Julie
  - Effective area – Jean
  - Energy dispersion – Riccardo
  - Point spread function – Toby
  - ST implementation – JC

See `https://confluence.slac.stanford.edu/display/DC2/IRF+Development` for the gory details.

Event Class Definitions

- Recall Bill's GoodEvent definitions

```
GoodEvent1 = CTBCORE > 0.10 && CTBBestEnergyProb > 0.30 && CTBGAM > 0.35
GoodEvent3 = CTBCORE > 0.35 && CTBBestEnergyProb > 0.35 && CTBGAM > 0.50
```

- For IRF development and for use by the ScienceTools, it is convenient to partition the data into distinct classes

```
Class A = GoodEvent3
```

  These satisfy SRD.

```
Class B = GoodEvent1 && !GoodEvent3
```

  Include these to maximize effective area while still maintaining reasonably good PSF and energy resolution.

- We partition further by conversion layer,

```
Front = Tkr1FirstLayer > 5.5
Back  = Tkr1FirstLayer < 5.5
```

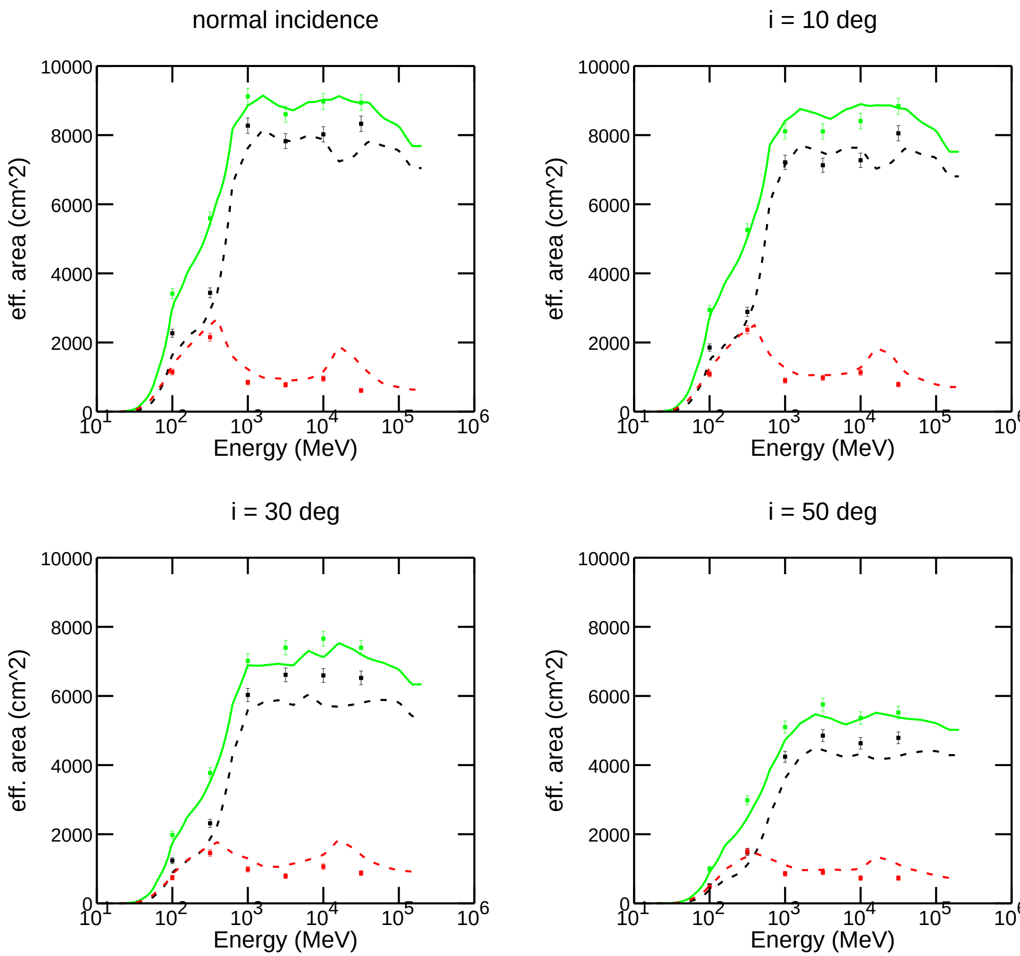
  for a total of four event classes:

```
0 FrontA     1 BackA
2 FrontB     3 BackB
```

  These numbers are used in `gtselect` to identify subsets of data based on these classes.

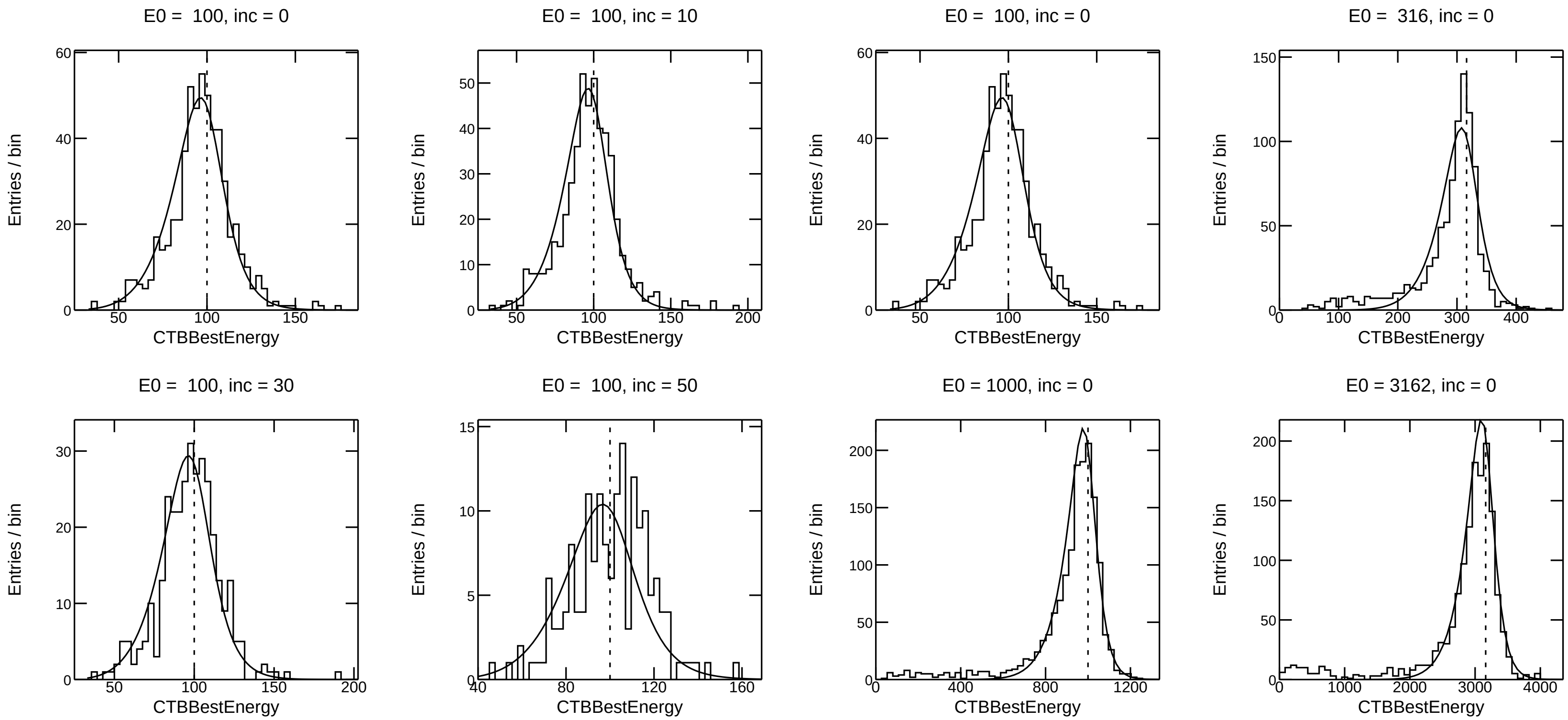
- In addition to Bill's filters, we impose `CTBBestZDir < 0.4` to reduce Albedo gammas.

Effective Area



Self-veto effects, etc., prevent a simple parametrization; instead we interpolate in $\log E$-$\cos i$. black = A, red = B, green = A+B; points are from single-energy/single inclination Gleam runs.

Energy Dispersion



- Use non-Gaussian functional form:

$$\frac{dN}{dx} = \frac{(1+x)^{p_1}}{1+\exp(x/p_2)} \qquad \text{where} \qquad x = (E' - E)/E \tag{9}$$

- If we require `CTBBestEnergyProb > 0.3`, then we can combine all classes in fitting.

Point Spread Function

- Remove the bulk of the energy-dependence via the scaling function,

$$\tilde{\theta}(E) = [(p_1(E/100)^{-0.8})^2 + p_2^2]^{1/2} \quad (10)$$

where $(p_1, p_2) = (5.4 \times 10^{-2}, 5.5 \times 10^{-4})$ for front-converting events, and $(p_1, p_2) = (9.6 \times 10^{-3}, 1.3 \times 10^{-3})$ for back-converting events.

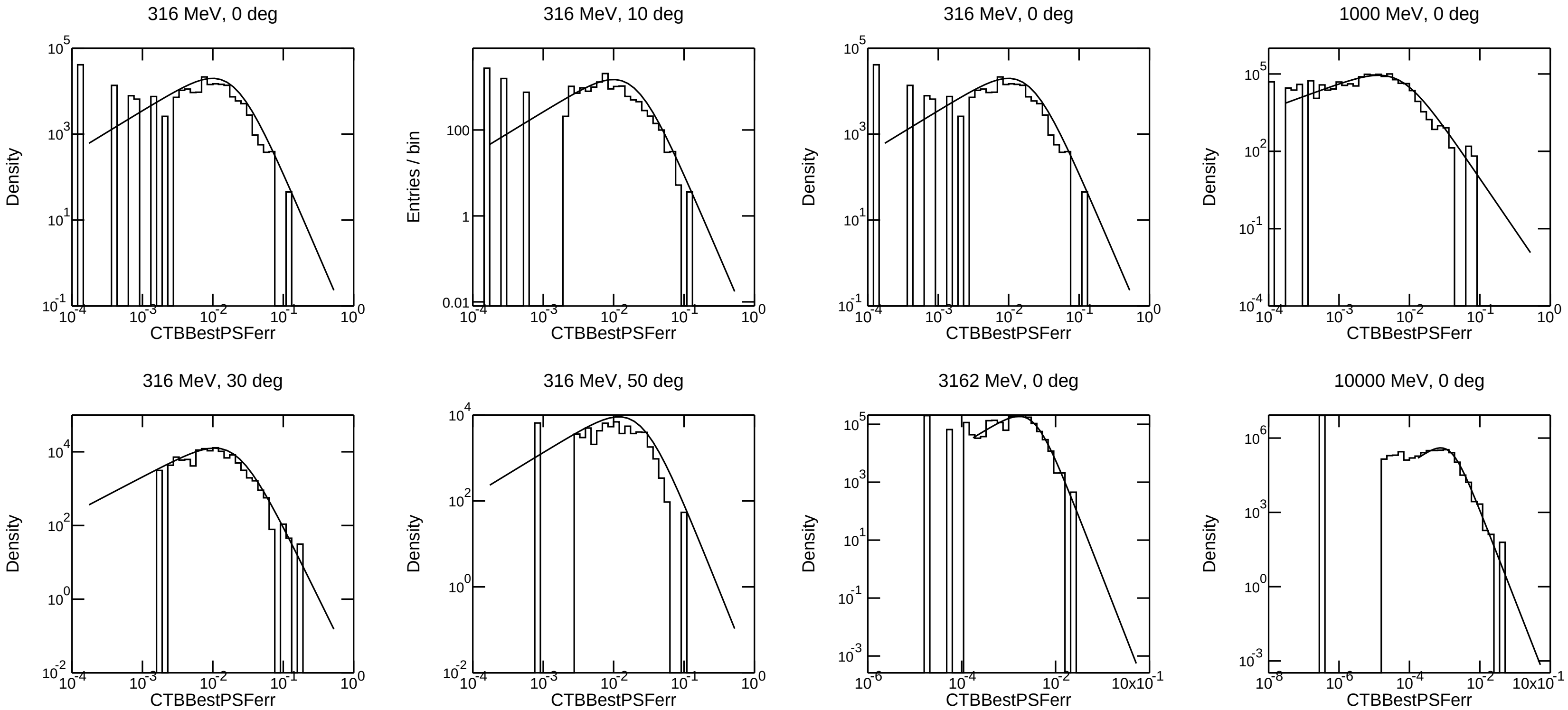
- In each $\log E$-$\cos i$ bin, fit the scaled deviation, $\delta \equiv \theta/\tilde{\theta}$, using

$$\frac{1}{N}\frac{dN}{d\delta} = 2\frac{\delta}{\sigma}\left(1 - \frac{1}{\gamma}\right)\left[1 + \frac{1}{2\gamma}\left(\frac{\delta}{\sigma}\right)^2\right]^{-\gamma} \quad (11)$$

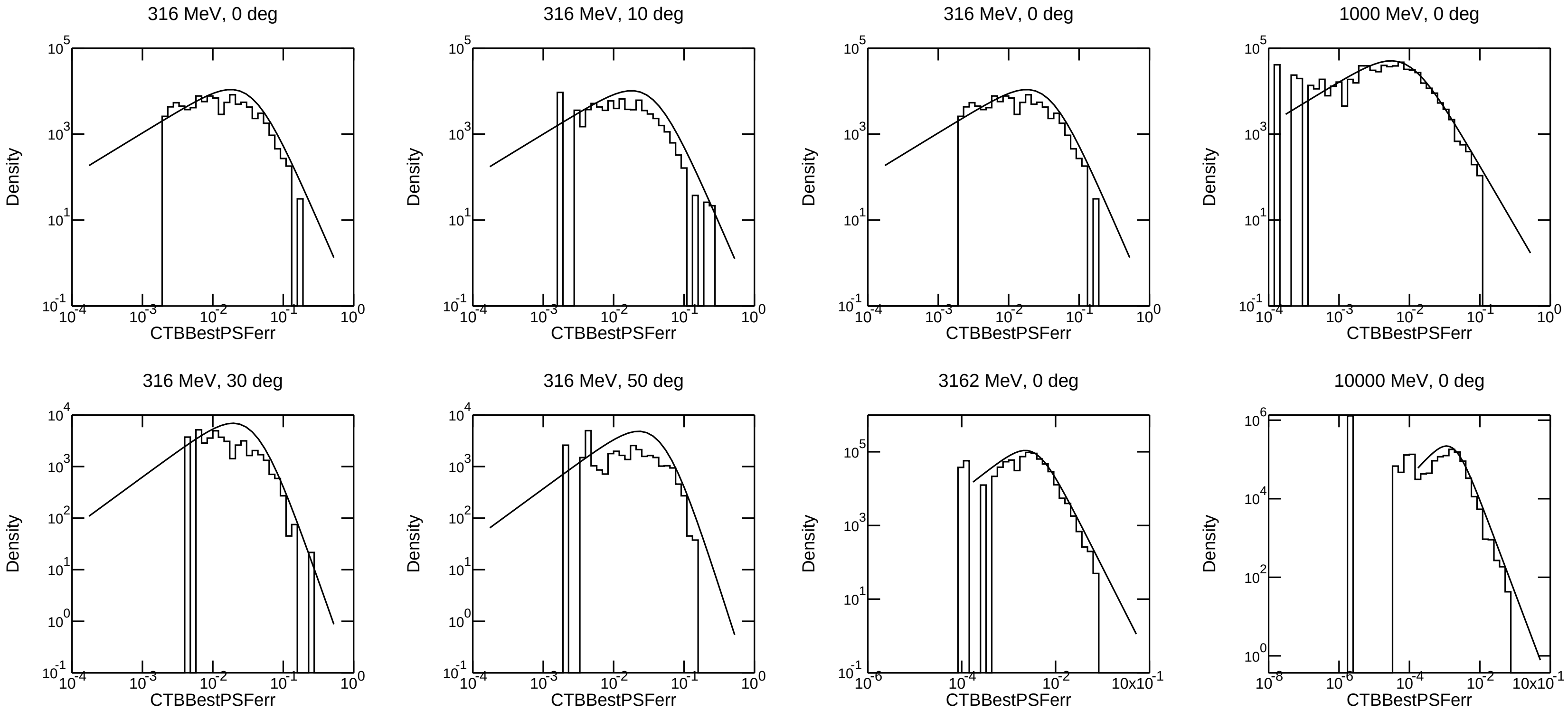
The index γ characterizes the PSF tail at large angular separations. For $\gamma = 2$, we have $\theta_{95}/\theta_{68} = 3$. For $\gamma \to \infty$, this function approaches a Gaussian.

- Smooth behavior across bin boundaries is essential.

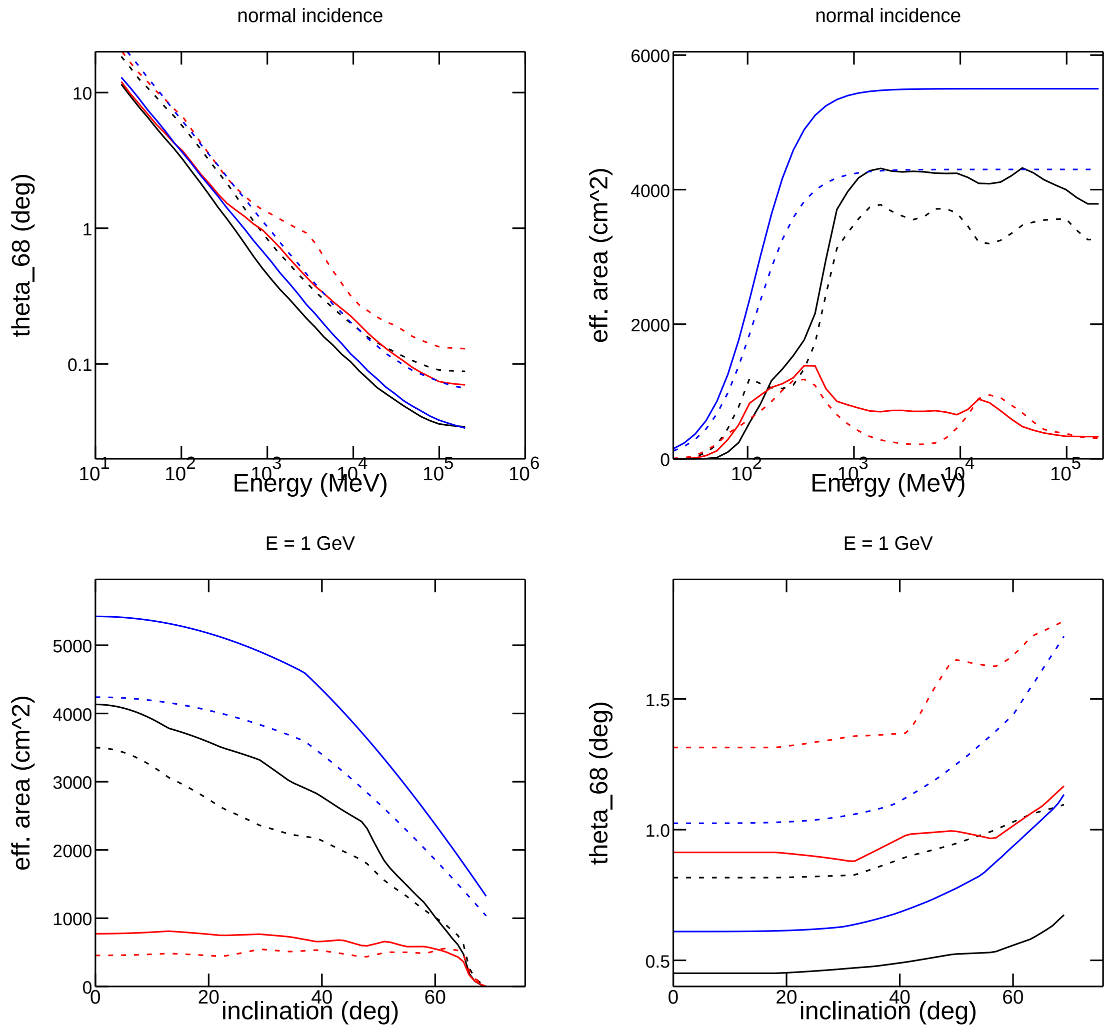
PSF comparison with Gleam runs, Class A, Front-converting



Class A, Back


316 MeV, 0 deg
316 MeV, 10 deg
316 MeV, 0 deg
1000 MeV, 0 deg
316 MeV, 30 deg
316 MeV, 50 deg
3162 MeV, 0 deg
10000 MeV, 0 deg
Density
CTBBestPSFerr

Instrument Performance (4-panel) Plots

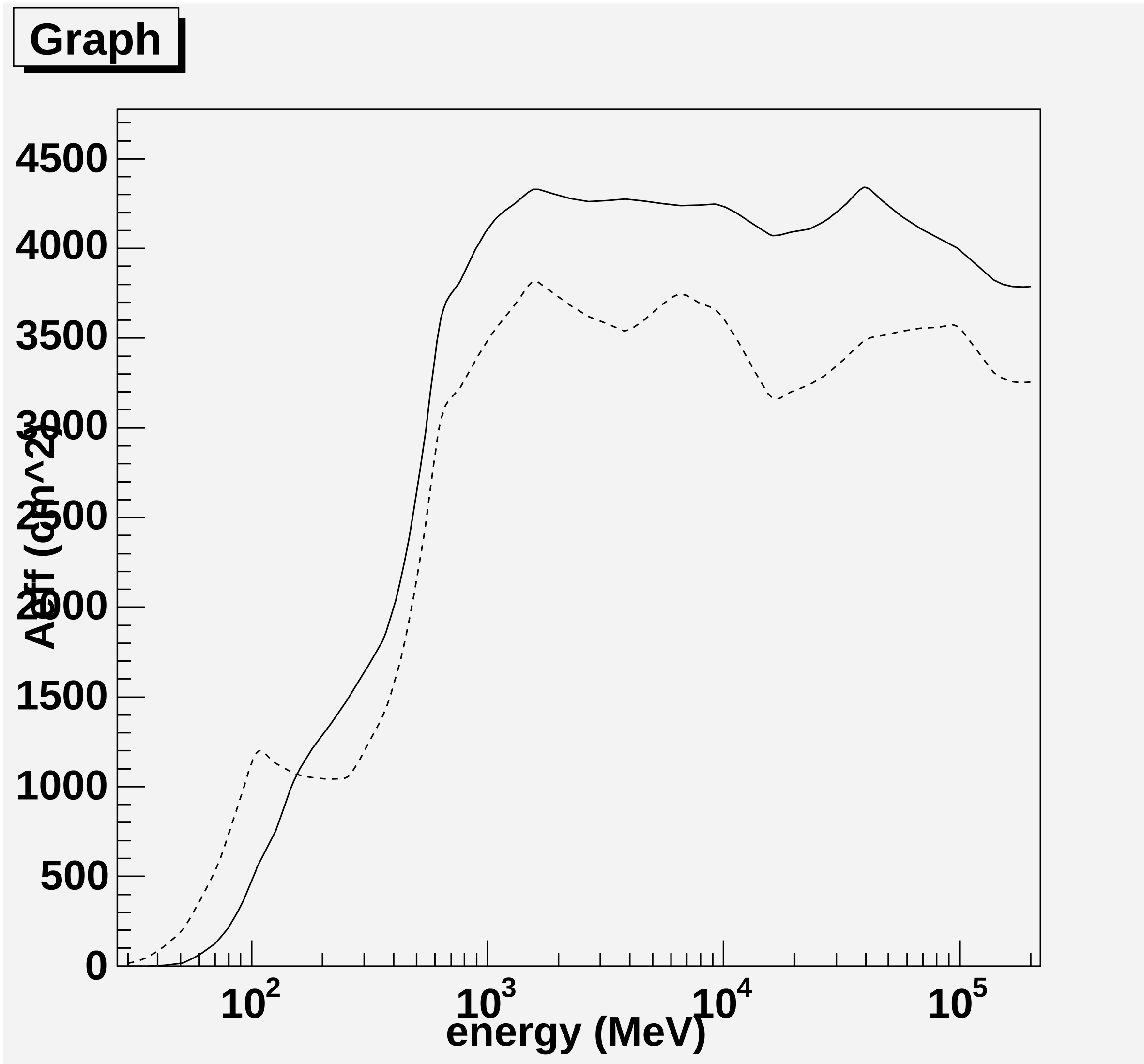


black=DC2 Class A, red=DC2 Class B, blue=DC1A; solid=Front, dashed=Back

Accessing the IRFs from ROOT

- The ScienceTools interface to the IRFs has been exposed to ROOT: `http://glast.stanford.edu/cgi-bin/viewcvs/irfs/rootIrfLoader/`
- Example from `src/irf_test.C`:

```
{
gSystem->Load("rootIrfLoader");
<...snip...>
rootIrfLoader::Aeff aeff_front("DC2::FrontA");
rootIrfLoader::Aeff aeff_back("DC2::BackA");
<...snip...>
for (Int_t i = 0; i < npts; i++) {
   energies[i] = emin*exp(de*i);
   front[i] = aeff_front(energies[i], theta, phi);
   back[i] = aeff_back(energies[i], theta, phi);
}
<...snip...>
}
```


Graph
Aeff (cm^2)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
10^2
10^3
10^4
10^5
energy (MeV)