Basics & applications of effective areas

Martin Tluczykont, Zeuthen, November 21, 2006

- **effective areas**
  - basic definition: most simple experiment
  - application to IceSim (ANIS)
  - application to nusim
  - effective volumes
- **other applications**

Disclaimer

“The problem with Hegel is that he liked to explain.
That's why nobody understands him.”

Jean-Paul Sorg (private communication)

Encouragement

“Actually it's easy.”

Martin Tluczykont (helpful comments)

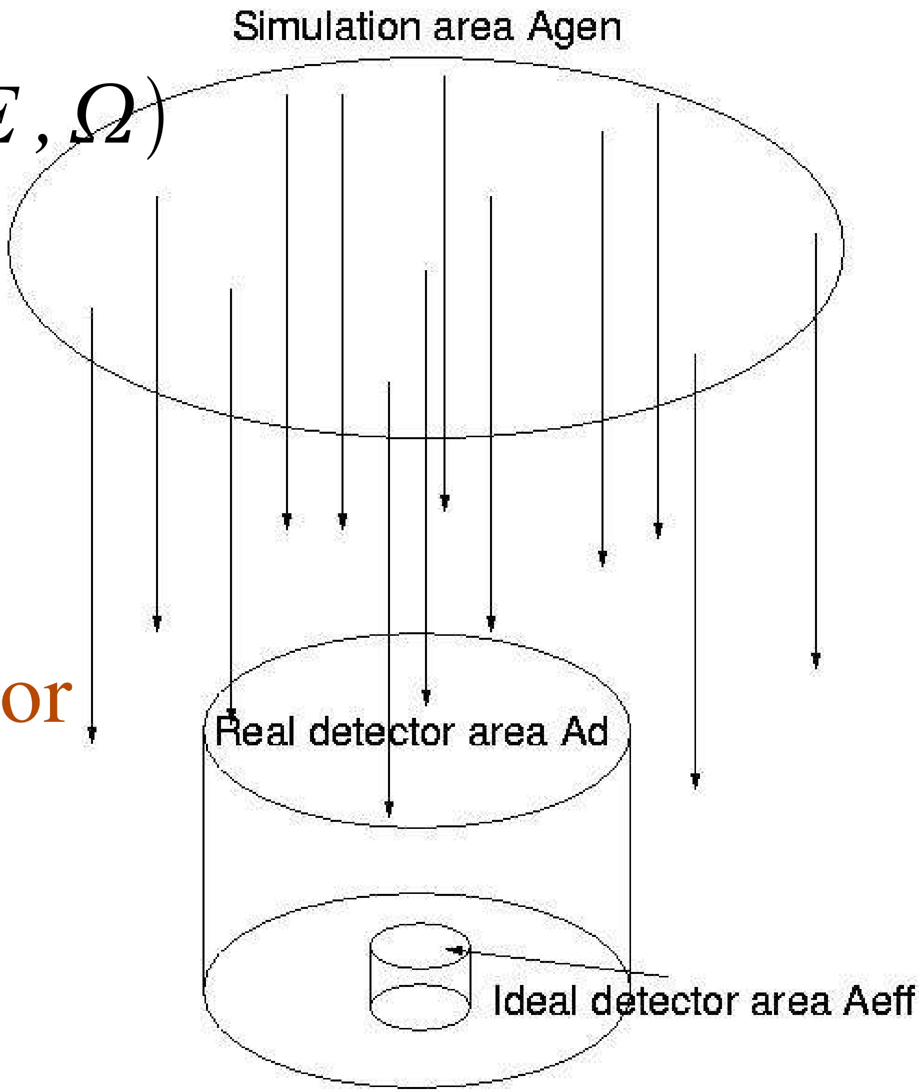
BASICS

Definition of effective area

Number of detected events: N_d

$$N_d = T \iint dE\, d\Omega\, \phi(E,\Omega)\, A_{eff}(E,\Omega)$$

$$\Omega = \Omega(\theta)$$



or: area of an **ideal** detector

i.e. area of 100% efficient detector

Trivial formula

N_{gen} : number of genearated Monte Carlo events
A_{gen} : generation area
N_d : number of detected events
A_d : detector area
ϕ_{gen} : simulated flux

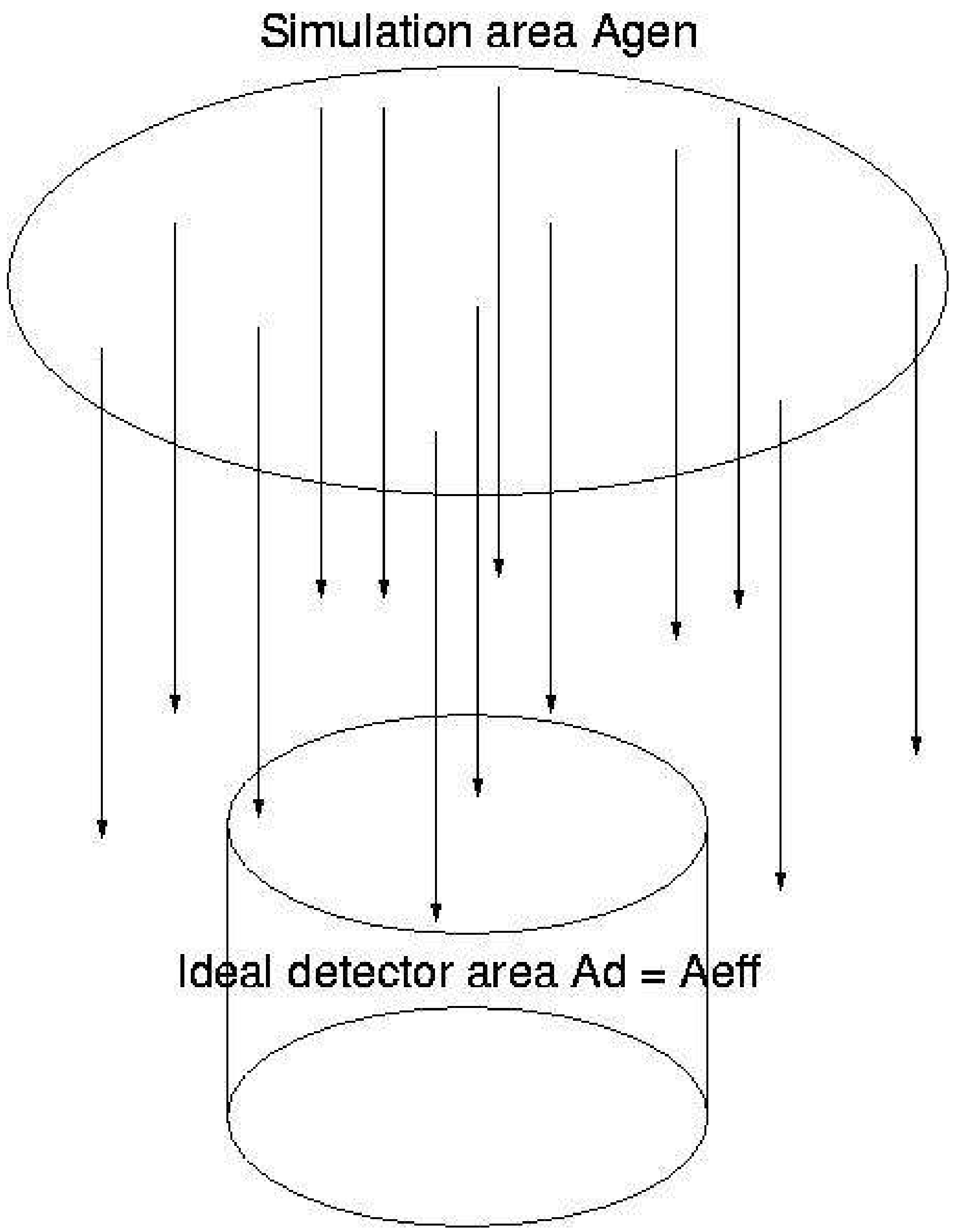
$$\phi_{gen} = \frac{N_{gen}}{A_{gen} T} \quad \& \quad \phi_{gen} = \frac{N_d}{A_{eff} T}$$

$$\rightarrow A_{eff} = \frac{N_d}{N_{gen}} A_{gen}$$

EXAMPLE:
WATER DROP EXPERIMENT

Most simple case: water drops fall in cup

- Simulate N_{gen} drops on area A_{gen}
- Detect N_d drops on area A_d
- No dependencies (energy, ...)
- all drops on A_d are detected



This is an ideal detector:

$$N_d = \rho_{gen} A_d = \frac{N_{gen}}{A_{gen}} A_d$$

$$A_{eff} = \frac{N_d}{N_{gen}} A_{gen} = A_d$$

More complex case: water drops but...

- **The physics of water drops**
  - created in clouds, falling through atmosphere: interaction
  - can evaporate: **only a fraction** P_{ev} **drops reach the cup**
  - drop reflection: **not all drops detected** (energy dependent effect)

- **The simulation of water drops**
  - N'_{gen} drops close to the detector, *interaction enforced* (CPU power)

    true drop number: $N_{gen} = N'_{gen} / P_{ev}$

  - energy dependent drop simulation: $N_{gen}(\Delta E) = N_{gen} f_{\Delta E}$

More complex case: water drops but...

$$N_{gen}(\Delta E) = \frac{N'_{gen}}{P_{ev}} f_{\Delta E}$$

- **Effective area calculation**

$$A_{eff}(\Delta E) = \frac{N_d(\Delta E)}{N_{gen}(\Delta E)} A_{gen}$$

$$A_{eff}(\Delta E) = \frac{N_d(\Delta E)}{N'_{gen} f_{\Delta E}} A_{gen} P_{ev}$$

APPLICATIONS

Event MC in non-thermal astrophysics

- here: nusim & IceSim = ANIS
- $\frac{dN}{dE} = N_0 E^{-\Gamma}, E_1 < E < E_2$
- typically $\Gamma = 1$
- large # simulated events & $A_{gen} > A_d$

Effective areas in astrophysics

- **Reconstruction & analysis dependent**
  - Algorithm (First guess, likelihood...)
  - Trigger / Filtering level
  - Analysis cuts
- **Zenith angle (declination) dependent**
- **Energy dependent**

Energy & Declination bins

- **Energy bin i:** boundaries $[e_1, e_2]_i$

  fraction of events simulated in energy bin i:

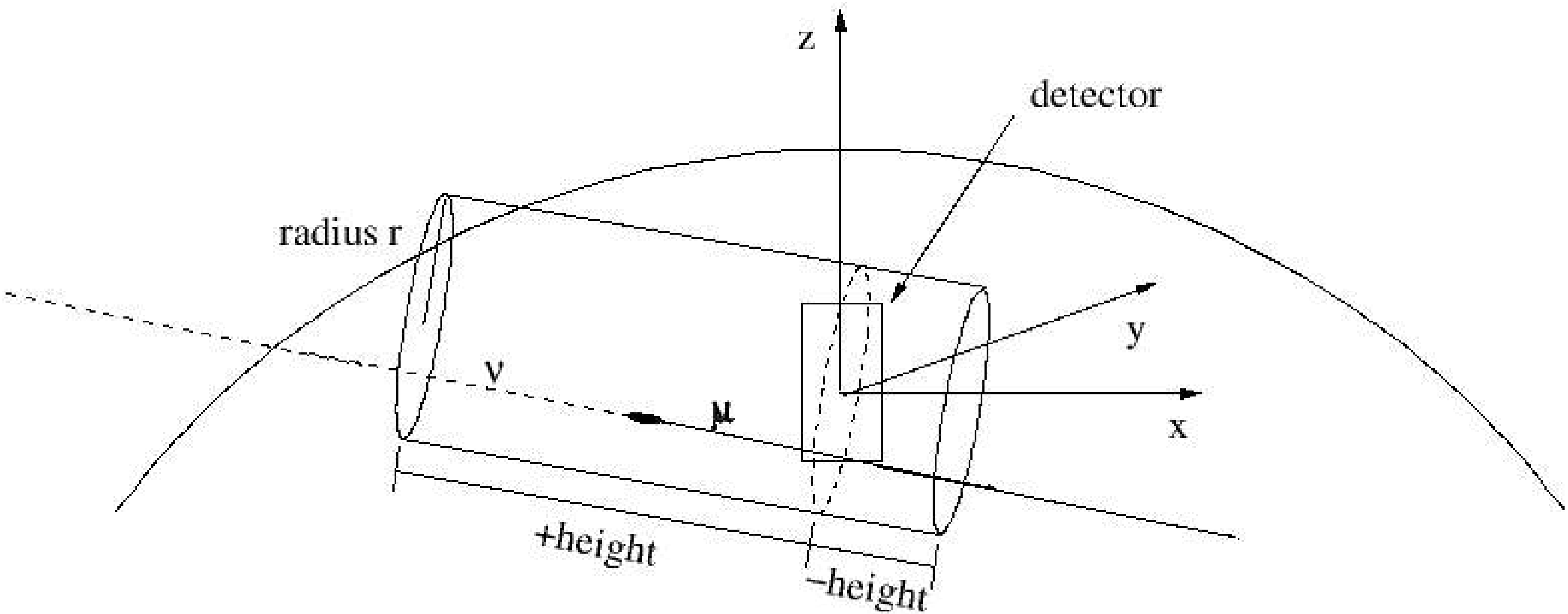
$$(f_E)_i = \frac{\int_{e1}^{e2} dE\, E^{-\Gamma}}{\int_{E1}^{E2} dE\, E^{-\Gamma}} = \frac{\ln(e_2/e_1)_i}{\ln(E_2/E_1)}$$

- **Declination bin j:** $[\theta_1, \theta_2]_j$

  fraction of events simulation in decl.-bin j:

$$(f_{dec})_j = \frac{2\pi[\cos(\theta_1) - \cos(\theta_2)]_j}{\Omega}$$

Application to IceSim (ANIS)



- N'_{gen} neutrinos parallel to axis of cylindrical volume
- neutrino interaction inside Volume is enforced: P_{inter}
- $N_{gen}^{(i,j)} = \frac{N'_{gen}}{P_{inter}} (f_E)_i (f_{dec})_j$

.

Application to IceSim (ANIS)

- Simulation of: $\frac{dN}{dE} = N_0 E^{-\Gamma}, E_1 < E < E_2$
- constant simulation area: $A_{gen} = \pi r^2 = \frac{N_{gen}}{T \phi_{gen}}$
- interaction probability: $P_{inter}^{(i,j)}$
- simulated solid angle: Ω
- **effective area in energy bin i, declination bin j:**

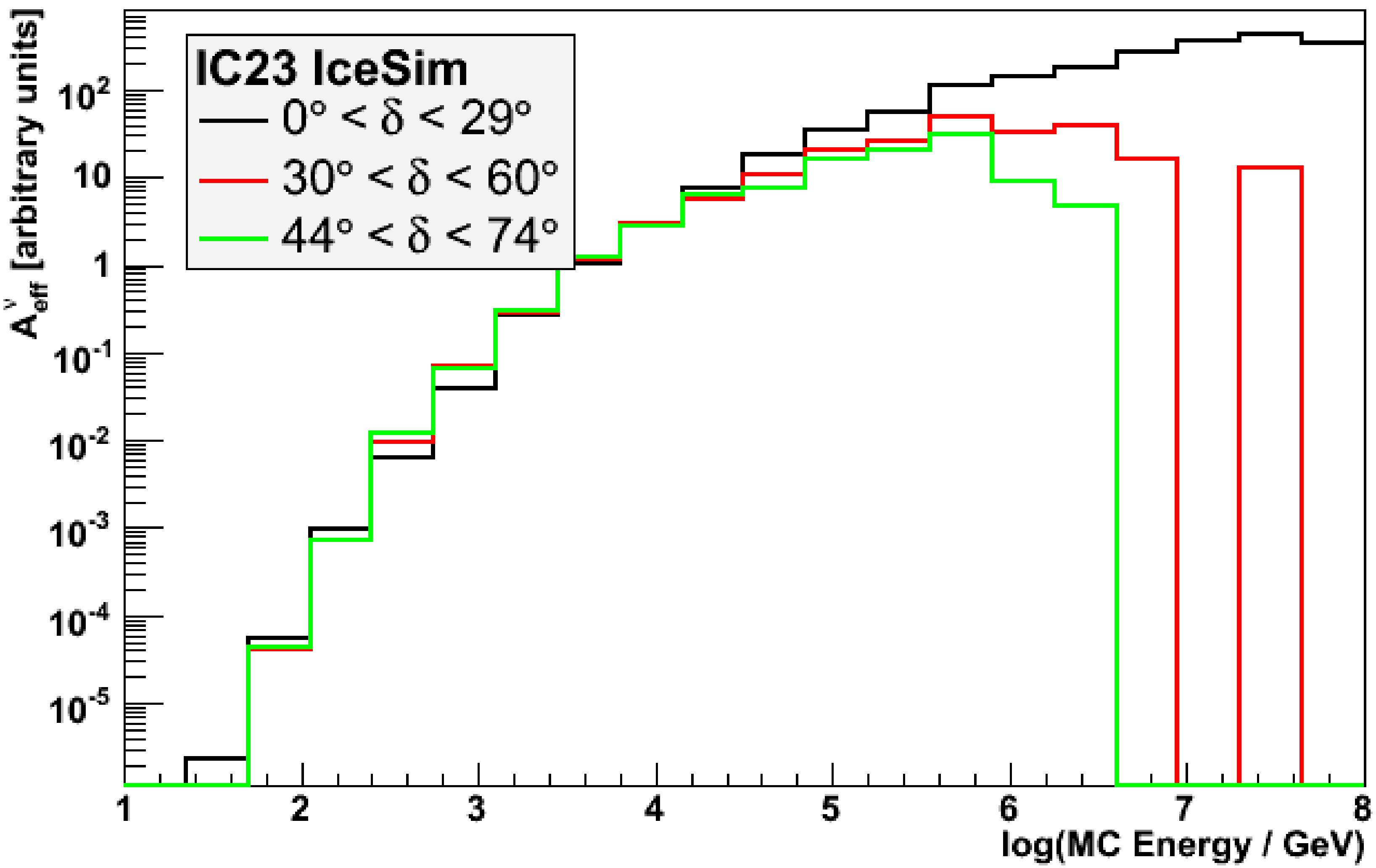
$$A_{eff}^{(i,j)} = \sum_{events} \frac{N_d^{(i,j)}}{N_{gen}^{(i,j)}} A_{gen} P_{inter}^{(i,j)}$$

Application to IceSim (ANIS)

effective area in energy bin i, declination bin j:

$$A_{eff}^{(i,j)} = \sum_{events} \frac{\ln(E_2/E_1)}{\ln(e_2/e_1)_i} \frac{\Omega}{2\pi[\cos(\theta_1) - \cos(\theta_2)]_j} A_{gen} P_{inter}^{(i,j)}$$

Application to IceSim (ANIS)



Application: nusim+amasim

- Simulation of: $\frac{dN}{dE} = N_0 E^{-\Gamma}, E_1 < E < E_2$
- variable simulation area: $A_{gen}^{(j)} = r_{14} 10^{10} [cm^2]$
- interaction weight: $W_{inter}^{(i,j)}$
- simulated solid angle: Ω
- **effective area - bins in energy (i) and declination (j):**

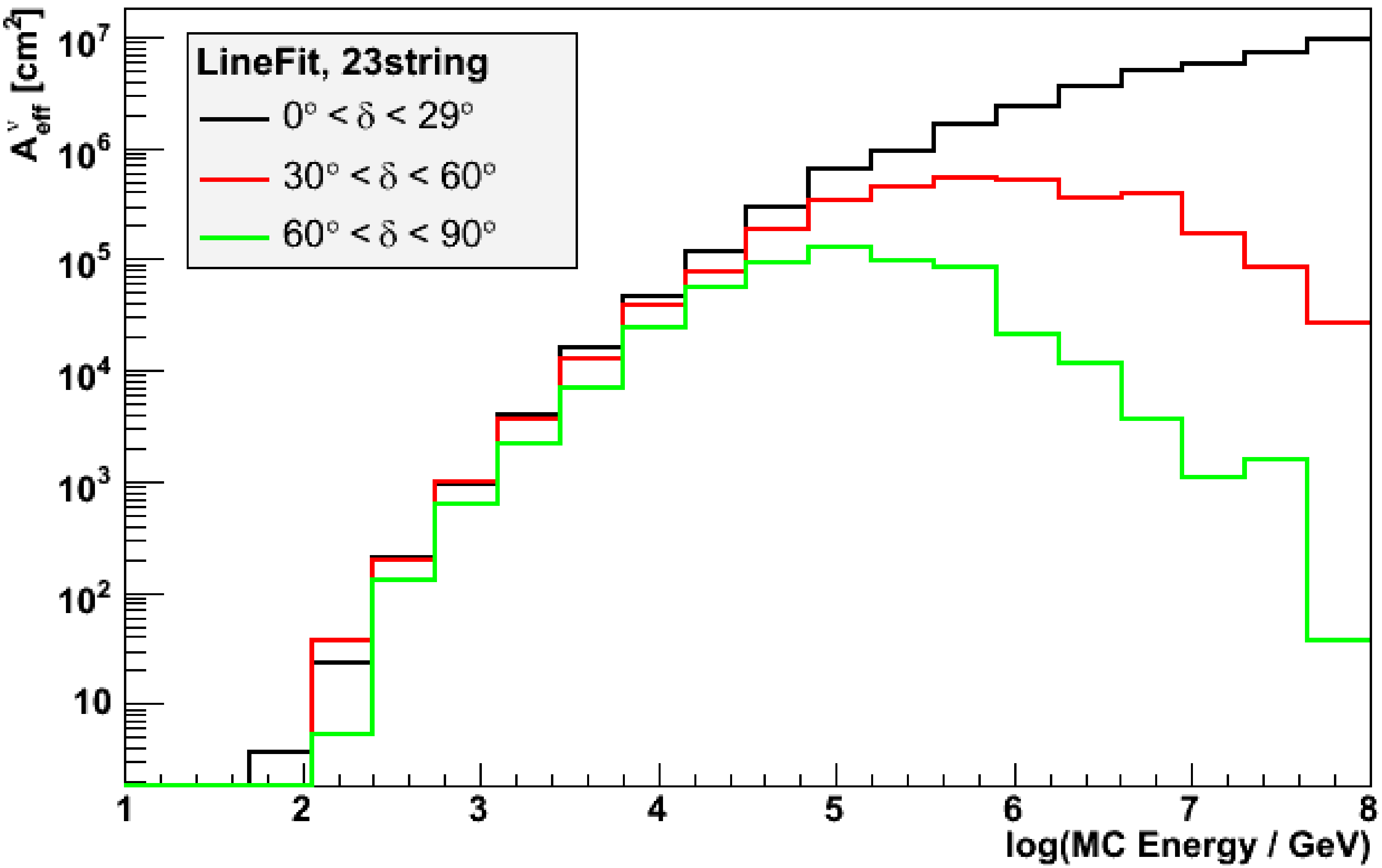
$$A_{eff}^{(i,j)} = \sum_{events} \frac{N_d^{(i,j)}}{N_{gen}^{(i,j)}} A_{gen}^{(j)} W_{inter}^{(i,j)}$$

Application: nusim+amasim

effective area - bins in energy (i) and declination (j):

$$A_{eff}^{(i,j)} = \sum_{events} \frac{\ln(E_2/E_1)}{\ln(e_2/e_1)_i} \frac{\Omega}{2\pi[\cos(\theta_1) - \cos(\theta_2)]_j} r_{14} 10^{10} W_{inter}^{(i,j)}$$

Application: nusim+amasim



Some IceRec framework details

- **nusim**

  intweight, R14 available in analysis-tree & flat-ntuple: RDMCUserlines

- **IceSim (I3NeutrinoGenerator = ANIS)**
  - Information stored in `I3Map<string, double> I3MCWeightsDict`
  - now available in flat-ntuple: MCWeights
  - not yet in analysis-tree (maybe soon)

Effective Volumes

- same principle: $$V_{eff} = \frac{N_d}{N_{gen}} V_{gen}$$

- ANIS case: P_{inter} is defined for all flavors

- effective areas for diffuse fluxes: no declination dependency

One last question about effective areas

Why to the kuckuk do I need this effective area?

- to predict the number of events detected for a given model spectrum

$$N(\theta)=\int dE\, A_{eff}(E,\theta)\,\phi_{model}(E,\theta)$$

- to impress your fellow students with color plots

Other applications of (other) Weights...

- predicted point-source event rates from a model:

$$N_{events} = \sum P_{inter} W_{norm} \frac{F_{model}(E, \theta)}{F_{gen}(E)}$$

- predicted atmospheric event rates:

$$N_{atmos} = \sum P_{inter} W_{norm} W_{atmo}$$

Summary

- Recipe for effective area calculation
- example using nusim & IceSim/ANIS
- Now possible within IceRec framework (flat-ntuple)
- First preliminary result for IC23 using I3NeutrinoGenerator