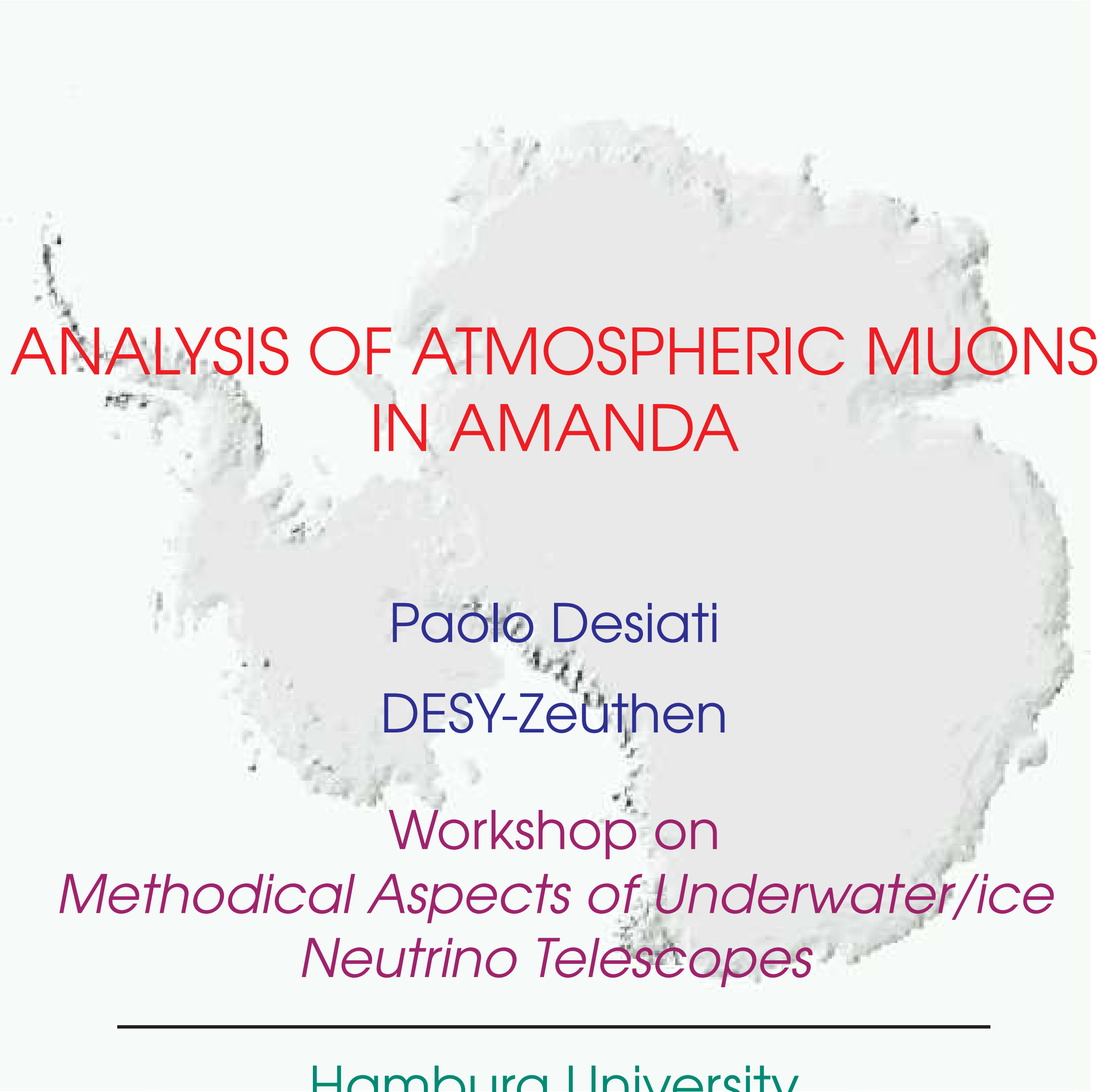

ANALYSIS OF ATMOSPHERIC MUONS IN AMANDA

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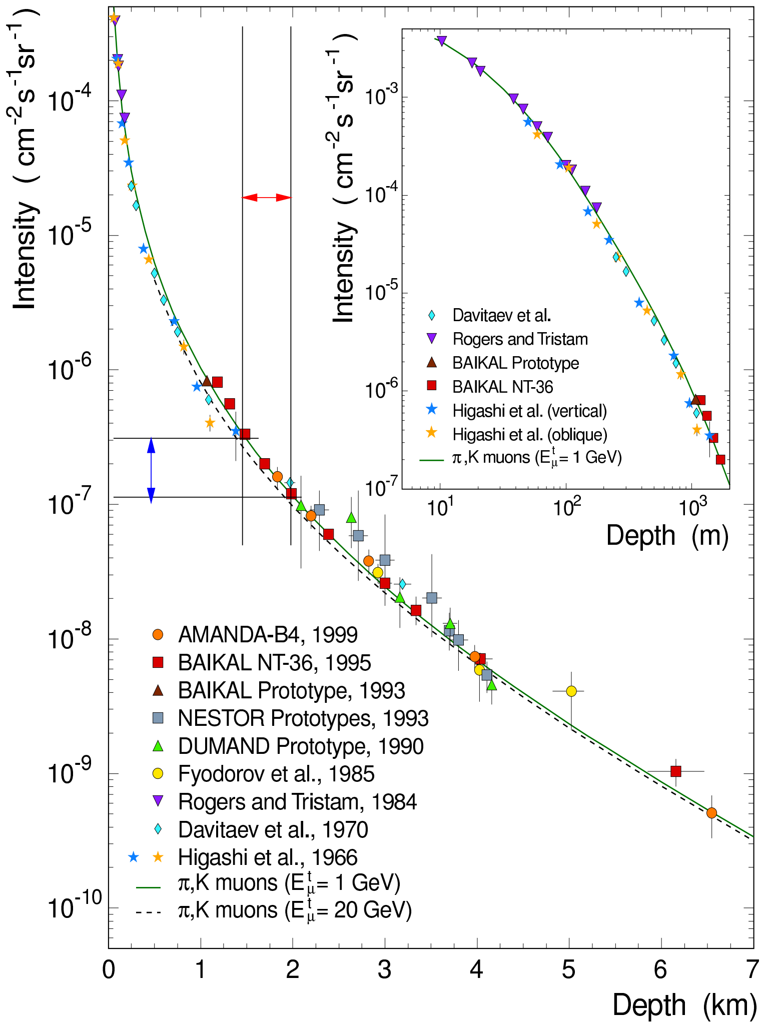
Workshop on
Methodical Aspects of Underwater/ice Neutrino Telescopes

Hamburg University
15-16 August 2001

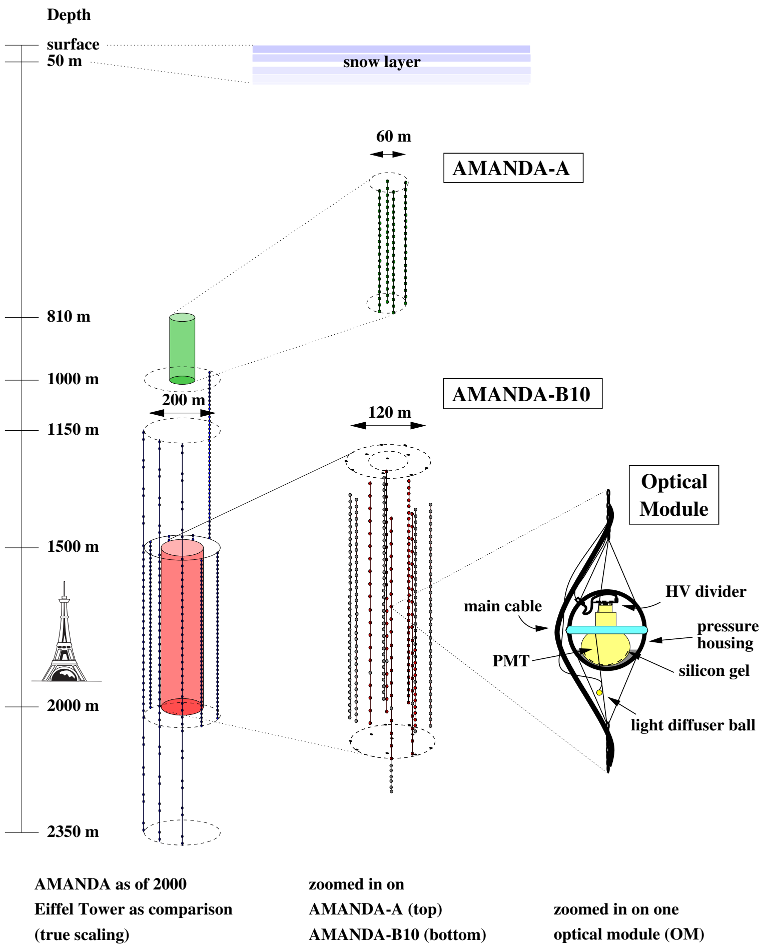
Summary

- Atmospheric muons
- AMANDA-B10 detector
- The analysis
  - Monte Carlo and Data Events
  - Reconstruction
  - Quality cuts
  - Data Unfolding
- Propagation codes
- Results
- Comments & Conclusions

Muon Depth-Intensity

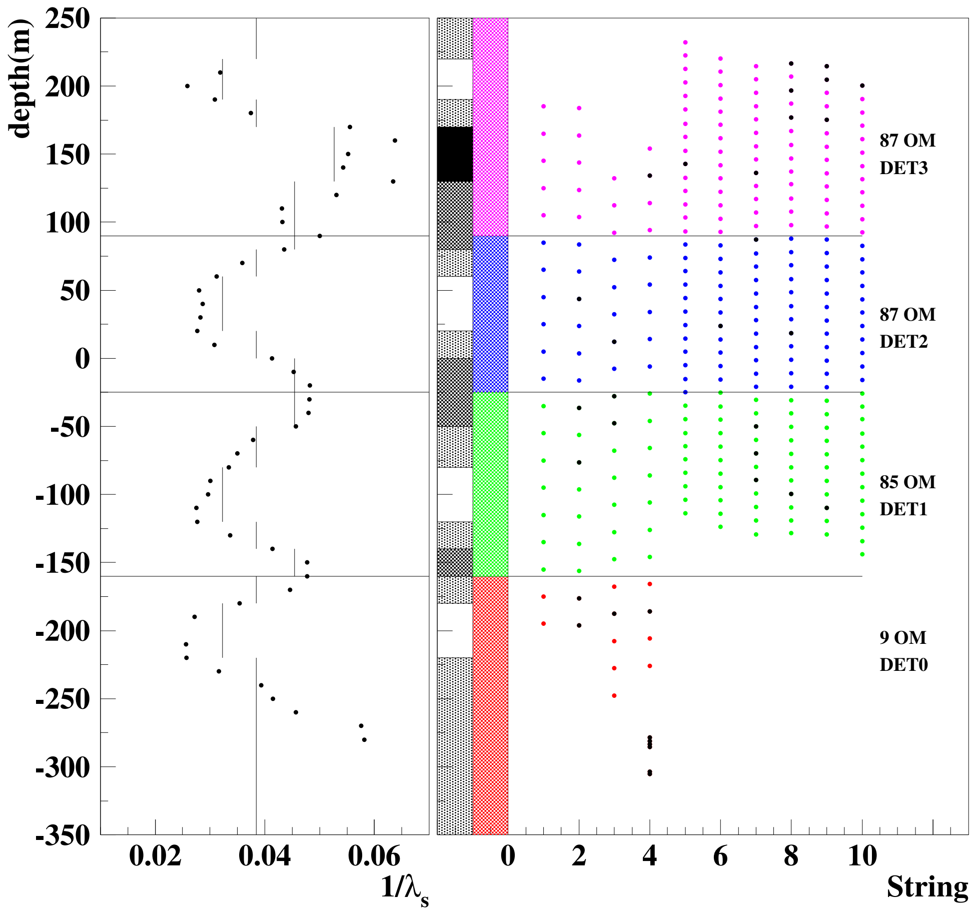


The AMANDA detector



- 677 Optical Modules (OM) in 19 strings
- Most @ depths 1500-2000 meters
- AMANDA-B10: first 10 strings, 302 OM

AMANDA-B10



$$\boxed{\Phi^{\mu}_{top} \approx 2 \cdot \Phi^{\mu}_{bottom}}$$

& Photon scattering length depth-dependent

⇒ Detector divided into 3 parts

So far analysis in DET1 and DET2

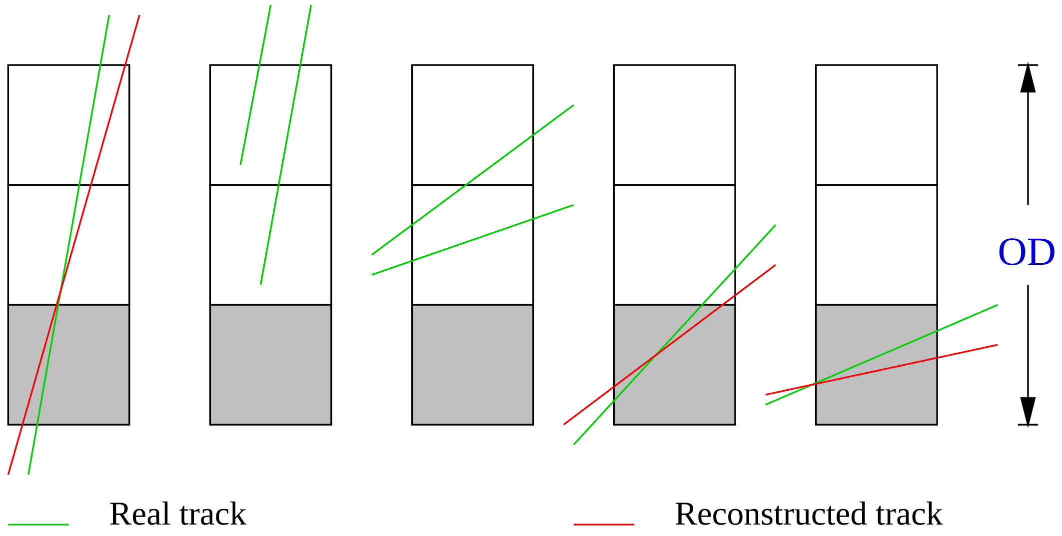
Analysis: Reconstruction

- Data *Cleaning*
- Reco of events with hits in specific part
  - **Line Fit as a first guess**
  - **First Likelihood for the** *Over-Detector* **(OD)**
  - **Second Likelihood for selected part (DET1,DET2,DET3)**

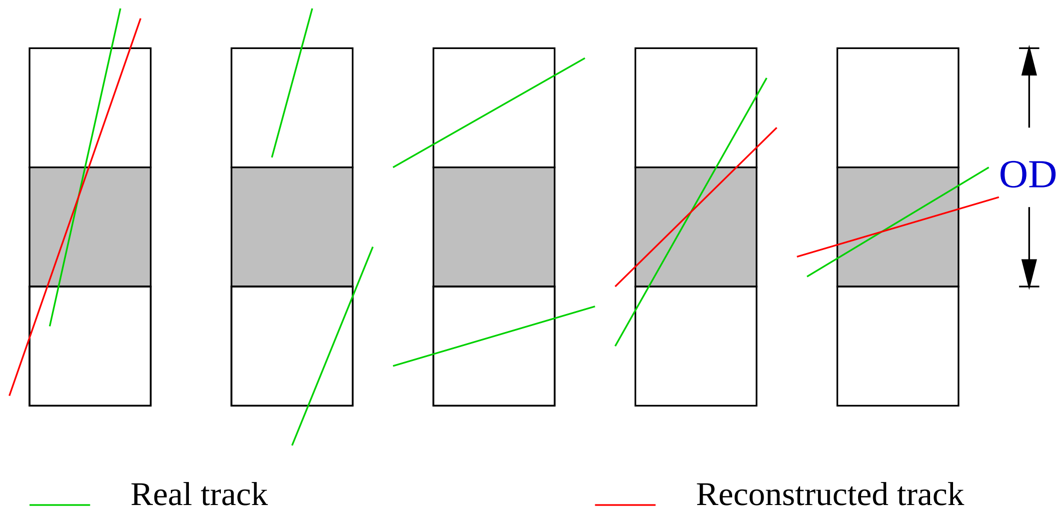
Trying to avoid tracks not passing through selected part

- Detector parts are compact
- Lower angular sensitivity

$\Rightarrow$ Data unfolding required



(a) **Reco in DET1**



(b) **Reco in DET2**

Analysis: Quality Cuts

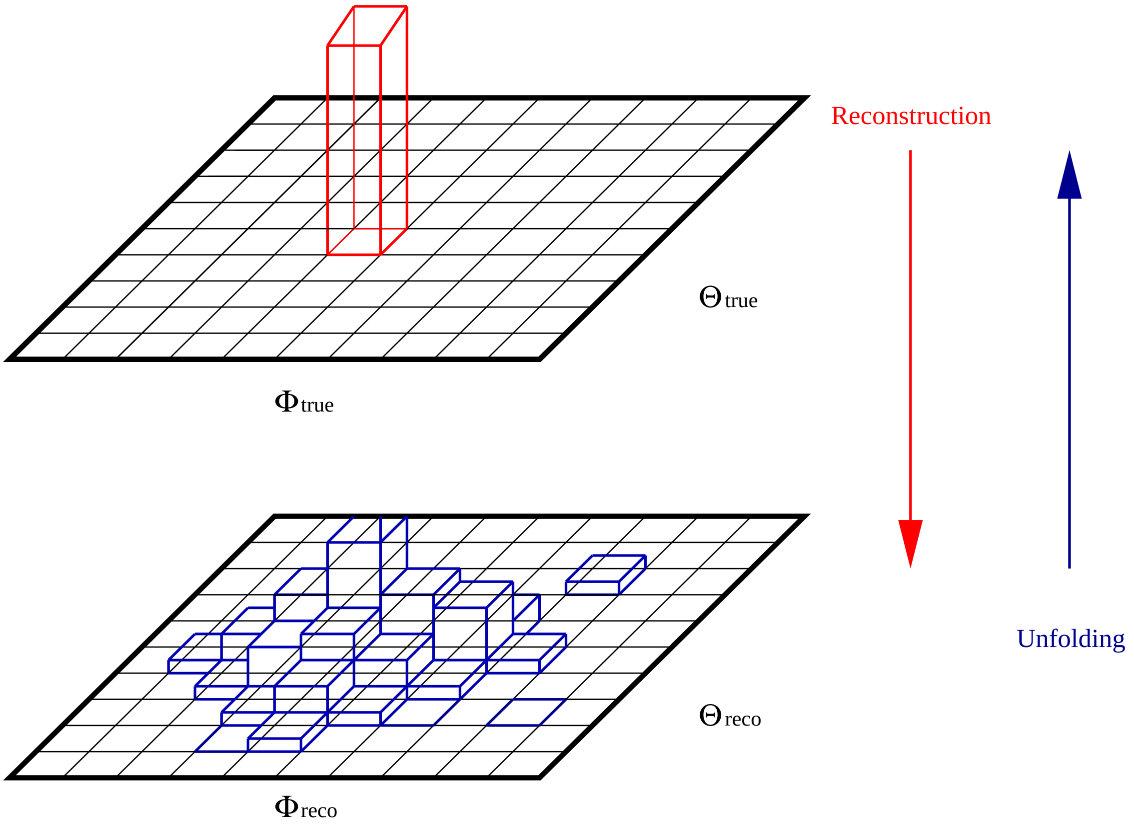
1. $\left(\frac{\chi^2}{ndf}\right)_{OD} < 10$ & $\left(\frac{\chi^2}{ndf}\right)_{DET} < 15$
   - Cuts on reconstruction quality
2. dist(μ_{reco},DET) $<$ 60 m
   - Reconstructed track inside DET volume
3. $|\Theta_{reco} - \Theta_{DET}| \; < \; 30^o$
   - Geometrical considerations

- Up-ward reconstructed μ: $11\% \Rightarrow 0.3\%$
- Poor angular resolution

What remains ?

- CORSIKA Monte Carlo
  - $\sim 28\%$ of reconstructed events
- Experimental Data
  - $\sim 32\%$ of reconstructed events

Analysis: Data Unfolding



Use of Bayesian Unfolding

Giulio D'Agostini, *A multidimensional unfolding method based on Bayes' theorem*, **NIM A 362**

Bayes Unfolding

Bayes' Theorem

$$\boxed{P(C_i|E_j) = \frac{P(E_j|C_i) \cdot P_0(C_i)}{\Sigma_{k=1}^{nc} P(E_j|C_k) \cdot P_0(C_k)}}$$

- C_i $(i = 1, ..., n_c)$: indipendent causes (Θ_{true},Φ_{true})
- E_j $(j = 1, ..., n_e)$: produced effects (Θ_{reco},Φ_{reco})

- $P(C_i|E_j)$: probability that observation $E_j \Leftarrow C_i$
- $P(E_j|C_i)$: conditional probability $C_i \Rightarrow E_j$
  - from Monte Carlo events
- $P_0(C_i)$: initial probability of the causes C_i
  - from Physics hypotheses
  - Increase of knowledge of $P_0(C_i)$

Unfolded distribution

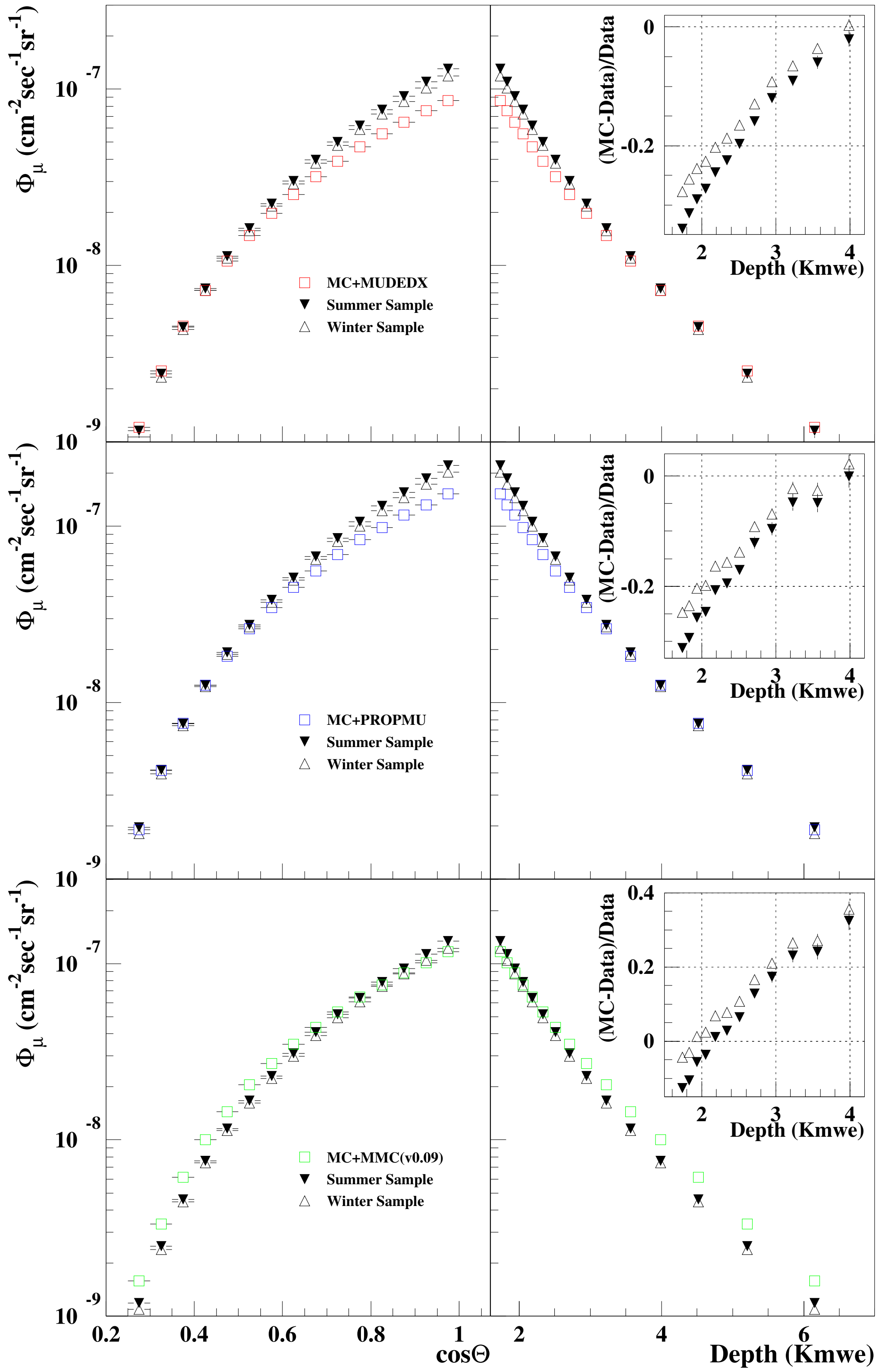
$$\boxed{n_{unf}(C_i) = \Sigma_{k=1}^{n_e} n_{obs}(E_k) \cdot P(C_i|E_k)}$$

Propagation codes I

- MUDEDX: Lohmann, Kopp, Voss, CERN 85-03
  - Old code designed for fixed target experiments with cross sections evaluated at a given energy
- PROPMU: Lipari,Stanev,Phys. Rev. D,Vol.44,3543,1991
  - Code designed for underground detectors and not optimized for secondary shower production
- MMC: Chirkin,Rhode, XXVII ICRC, HE2.02, Hamburg
  - Recent code designed for detectors in underground/water/ice locations with the most recent cross section formulæand efficient tracking techniques
- MUM: Sokalsky,Bugaev,Klimushin, XXVII ICRC, HE2.02, Hamburg
  - Another recent code designed for detectors in transparent media. Very similar to MMC on cross sections but using different tracking techniques. Results similar to MMC

Propagation codes II

- MMC/MUM produce secondaries as expected (number and energy spectrum)
- MUDEDX/PROPMU produce non-expected number and energy spectra of secondaries
- Light output (space- and time-profile) depends on number and spectrum of secondaries produced
- Similar Trigger rates but different reconstruction efficiencies
- Use of other codes for comparison, e.g.
  1. GEANT3+corrections
     - Bottai, Perrone, NIM A, 459, pp.319-325, 2001
  2. GEANT4



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Comments & Conclusions

- **$\approx$30-40% deviation observed**
  - absolute and angular/depth-dependent
  - also at trigger level
- **Similar deviation from Fréjus Experiment**

  $\Rightarrow$ see Schröder, Rhode, Meyer, XXVII ICRC, HE2.02, Hamburg
- **Reduce systematic uncertainties**
  1. Primary flux and composition
     - Systematic uncertainties $\approx$7%
     - New measurement from AMS: 30% lower proton flux for E>20 GeV

       $\Rightarrow$ AMS Collaboration, Phys. Lett. B 490, pp. 27-35, 2000
  2. Absolute OM sensitivity: new transmission measurements
     - $\approx$20% effect
  3. Photon scattering simulation close to OMs
     - $\approx$15% uncertainty - Θ-dependence
  4. Environmental properties: ice density profile, South Pole topography
     - $\approx$10% effect
  5. Multiple muons contamination evaluation
     - $<$10% effect
- **Extension to AMANDA-II**