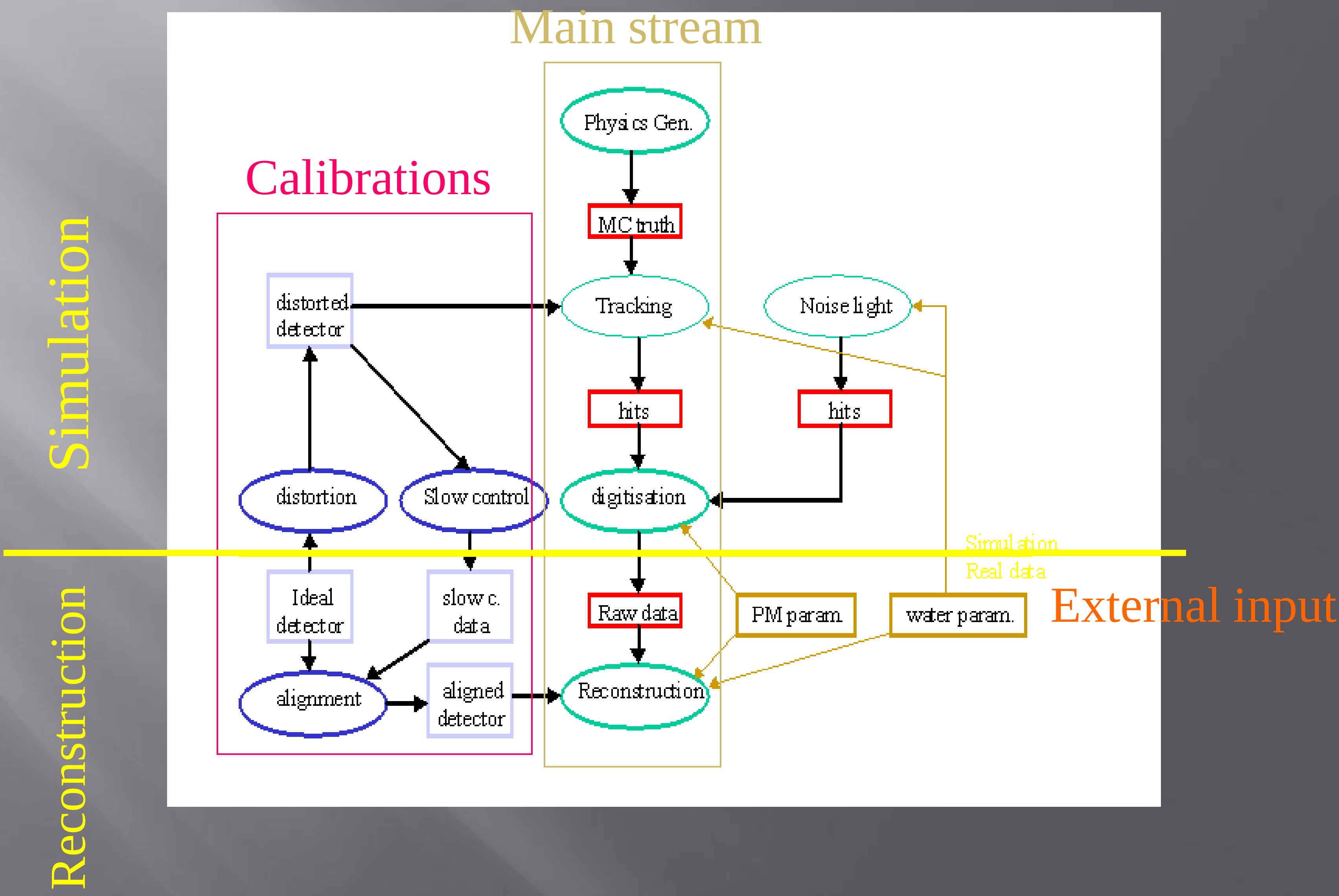
SIMULATION & RECONSTRUCTION TOOLS OF ANTARES

Linked to ORCA/PINGU

J. Brunner

Software scheme



Physics Generators
Cosmic Ray Muons

CORSIKA

- 5 primary nuclei
- Several hadronic models
- Muon bundles at sea level stored
- Muons with E>500 GeV propagated through water to detector

Physics Generators
Cosmic Ray Muons

MUPAGE

- No primary CR interactions
- Muon bundles generated at detector level
- Parametrisation tuned on MACRO data
- Advantage
  - Faster than CORSIKA
- Disadvantage
  - Modify complex parametrisation

Physics Generators
Cosmic Ray Muons

MUPAGE & CORSIKA

- Both can be used for ORCA straight away
- No modifications / adjustments needed
- PINGU : difficult to adjust MUPAGE

- First mass productions for ORCA already being performed with MUPAGE

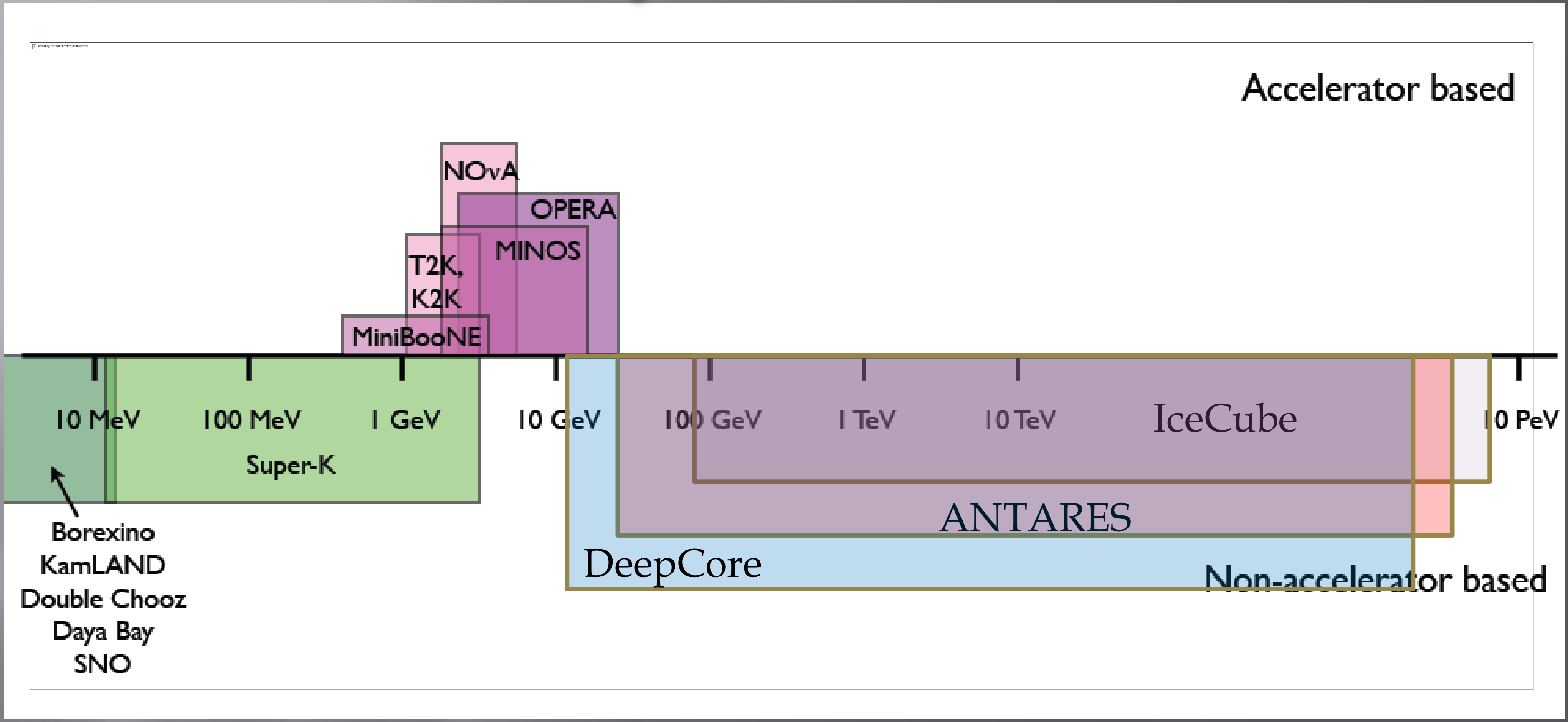
Physics Generators
Neutrino Interactions

Challenge

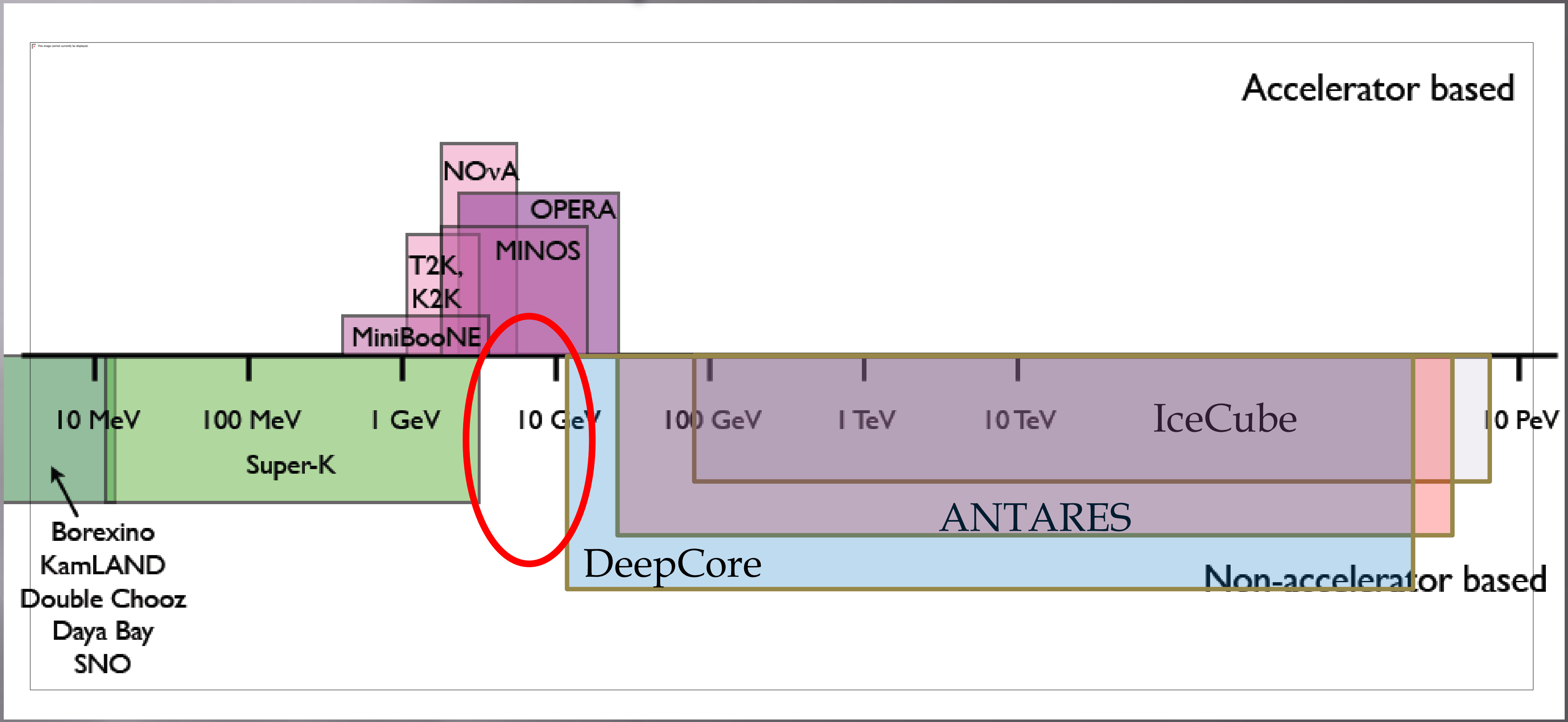
Shifted energy region of interest

ANTARES : 50 GeV – 1 PeV
ORCA : 1 GeV – 50 GeV

Energy range of neutrino experiments



Energy range of neutrino experiments

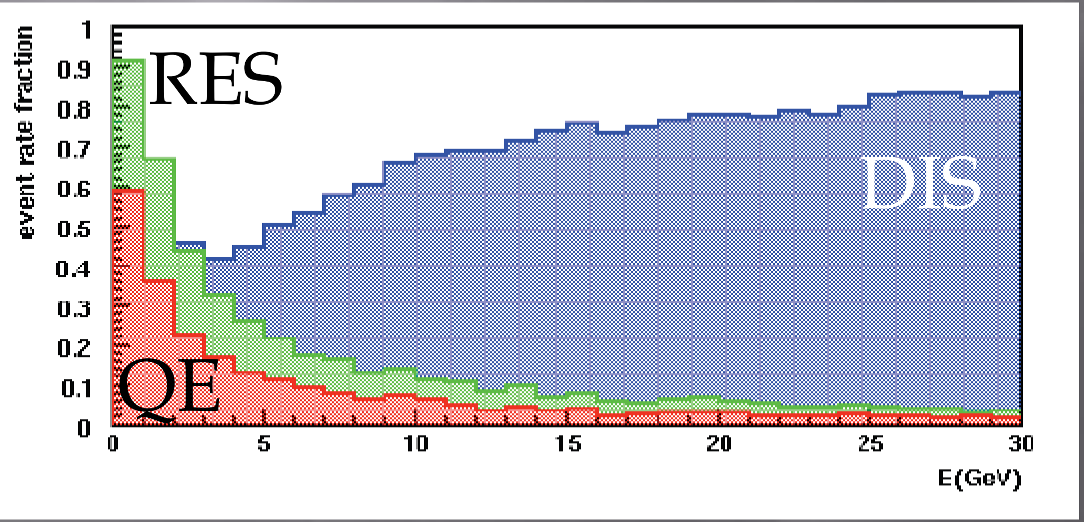


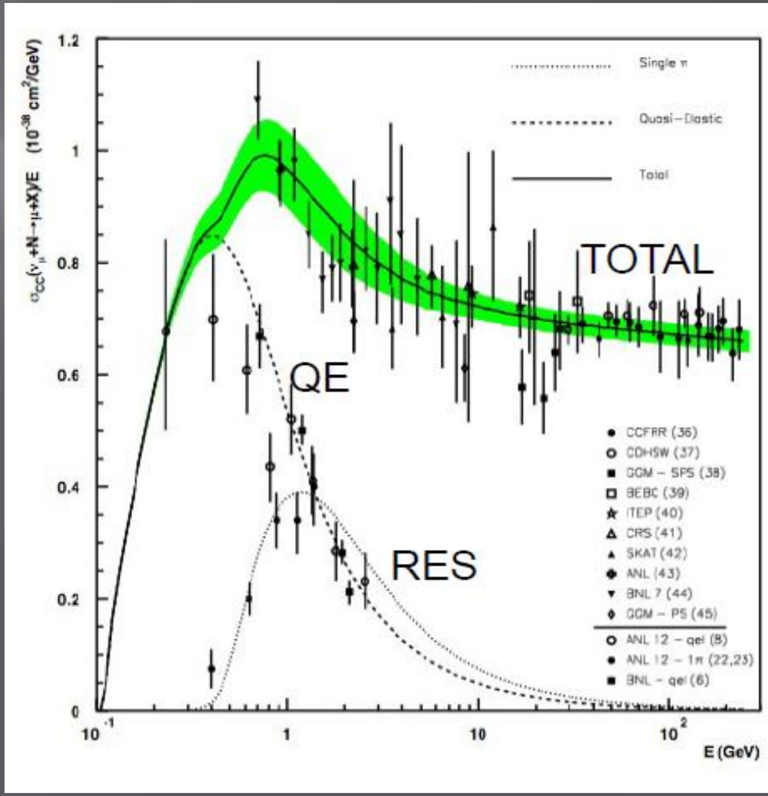
Unexplored region in atmospheric neutrinos

Contribution of different channels to total cross section

- Three main contribution
  - Quasi-elastic
  - Resonant
  - Deep inelastic
- All three important in energy range 1-50 GeV

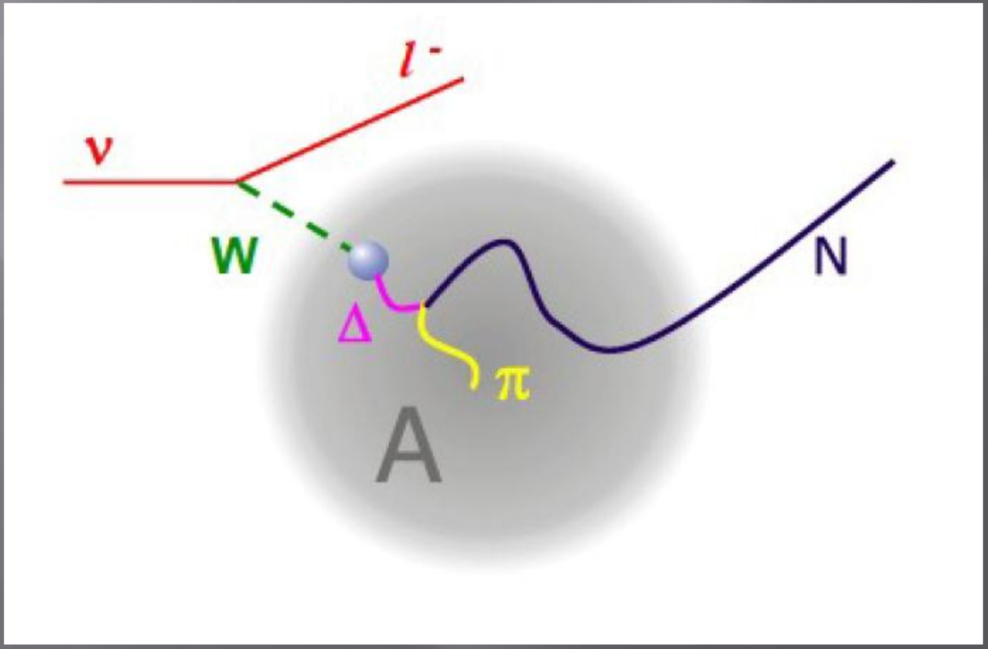
ANTARES tool
GenNeu/GenHen
has all three incorporated





Nuclear re-interations

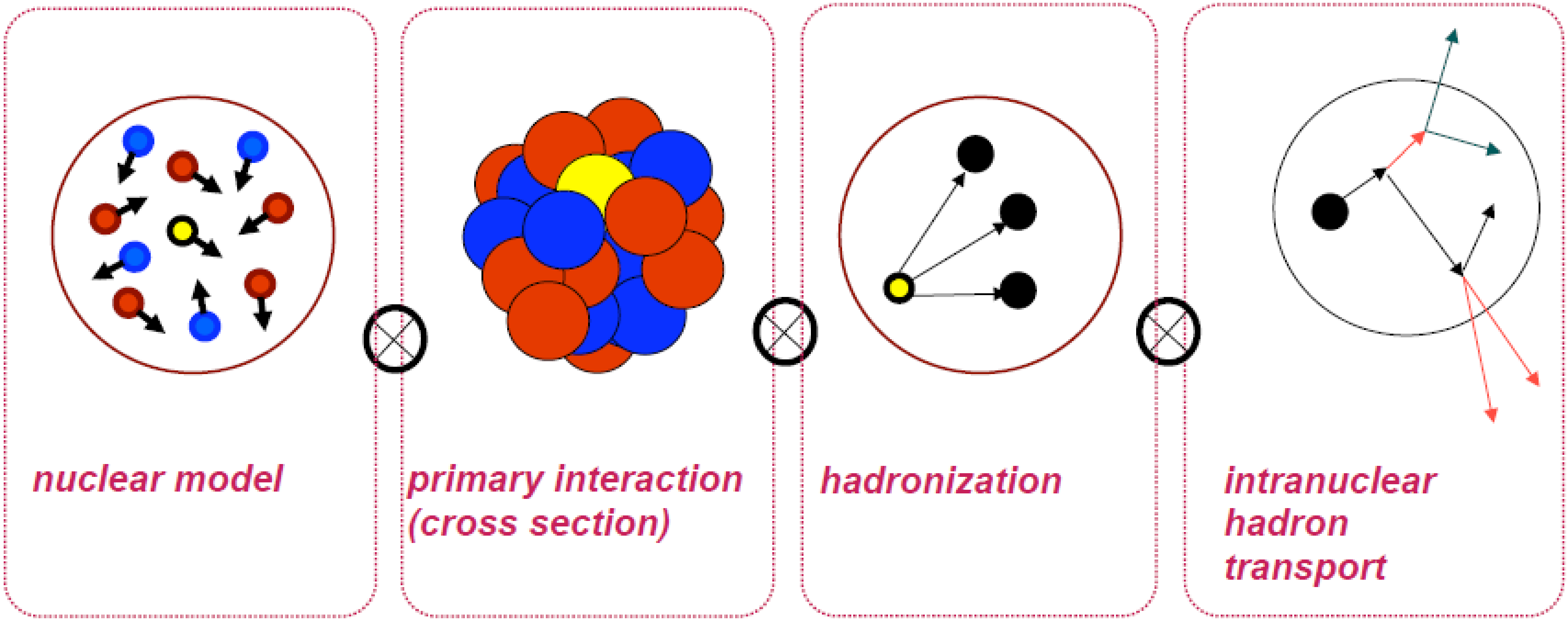
- 89% of ANTARES neutrino interactions not at free nucleons but at Oxygen nuclei
- Nuclear re-interactions important at low energies
- Implemented in **GENIE**
- Currently being tested for ORCA/PINGU



GENIE simulation steps

1) Choose E_ν, flavor, and target nucleus from (σ_{tot}, ϕ, ρ, L)
2) Choose interaction type j from $\sigma_{tot} = \sum \sigma_j$
3) Choose kinematics (x,y) from cross section model for σ_j (with nuclear mods)
4) Determine particles in hadronic system (inside the nucleus)
5) Propagate particles in hadronic system through the nucleus, decay

C. Andreopoulos



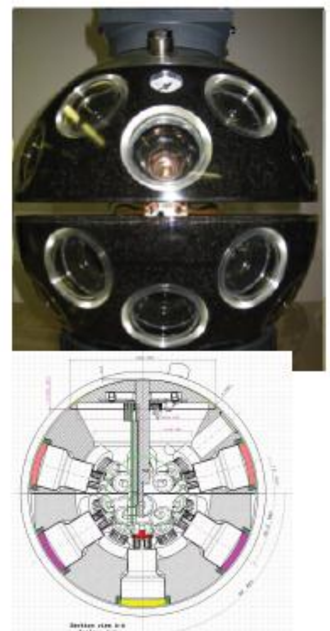
Interface: Geometry

- Significant increase in number of channels
- More than one PMT per optical module
- Modification of interfaces needed (mostly done)

ANTARES like

1 large PMT (10" or 8")
inside a benthos sphere

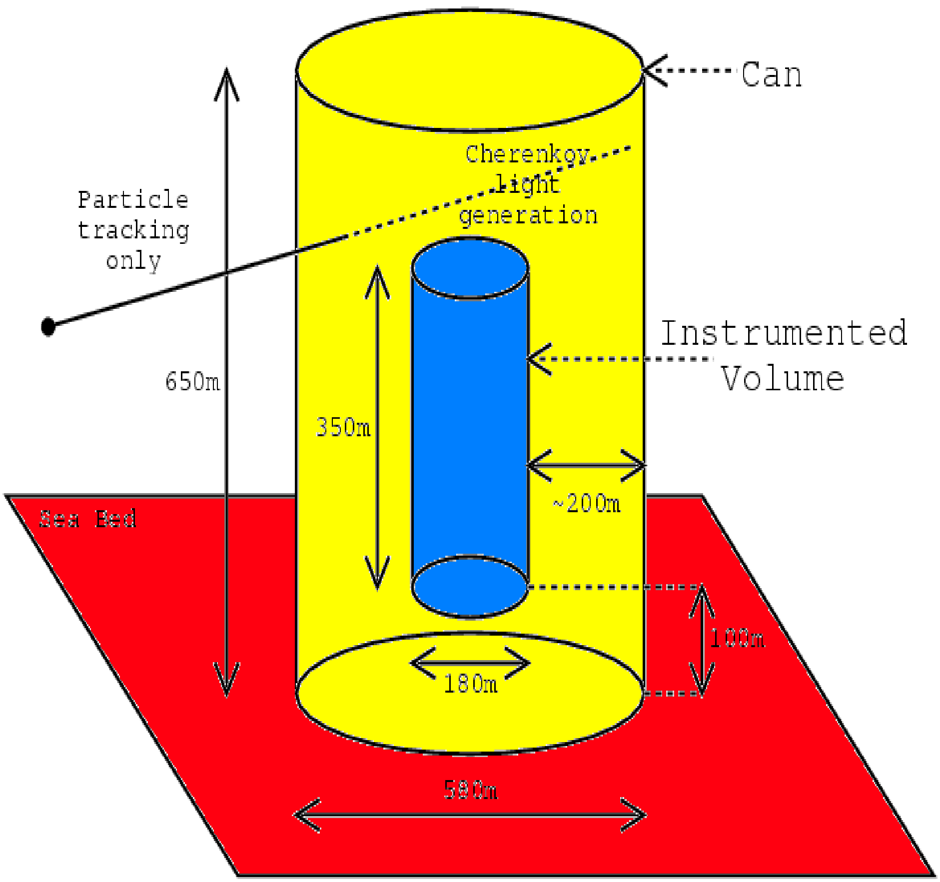
DOM

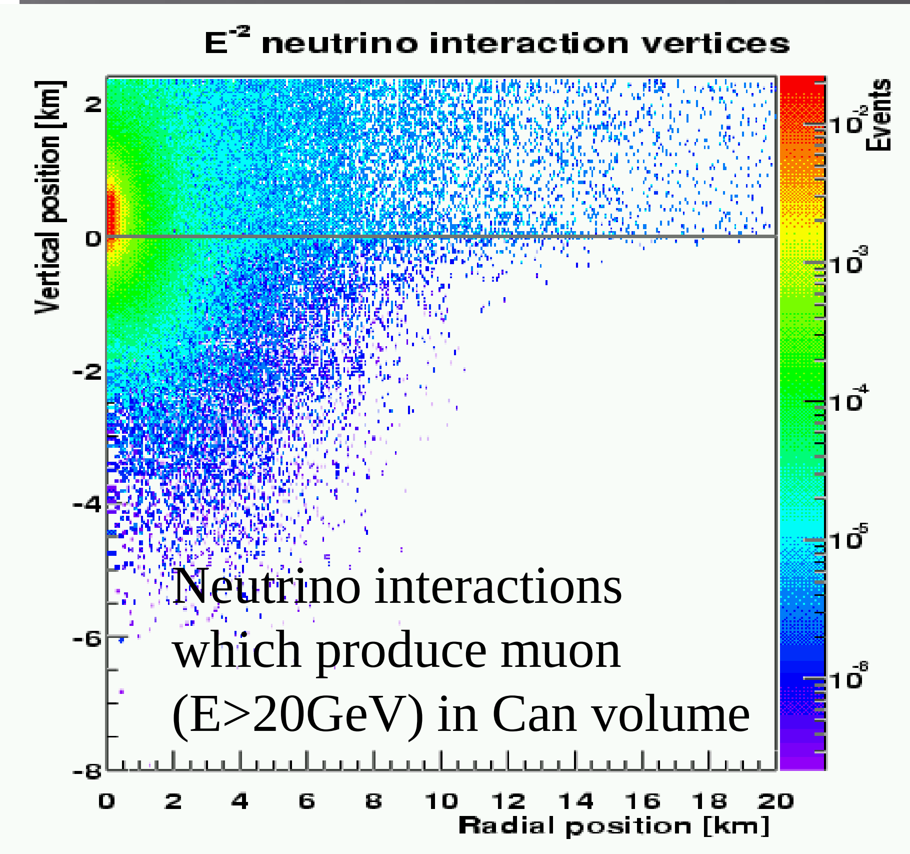


31 little PMT (3") inside a
large benthos sphere (17")

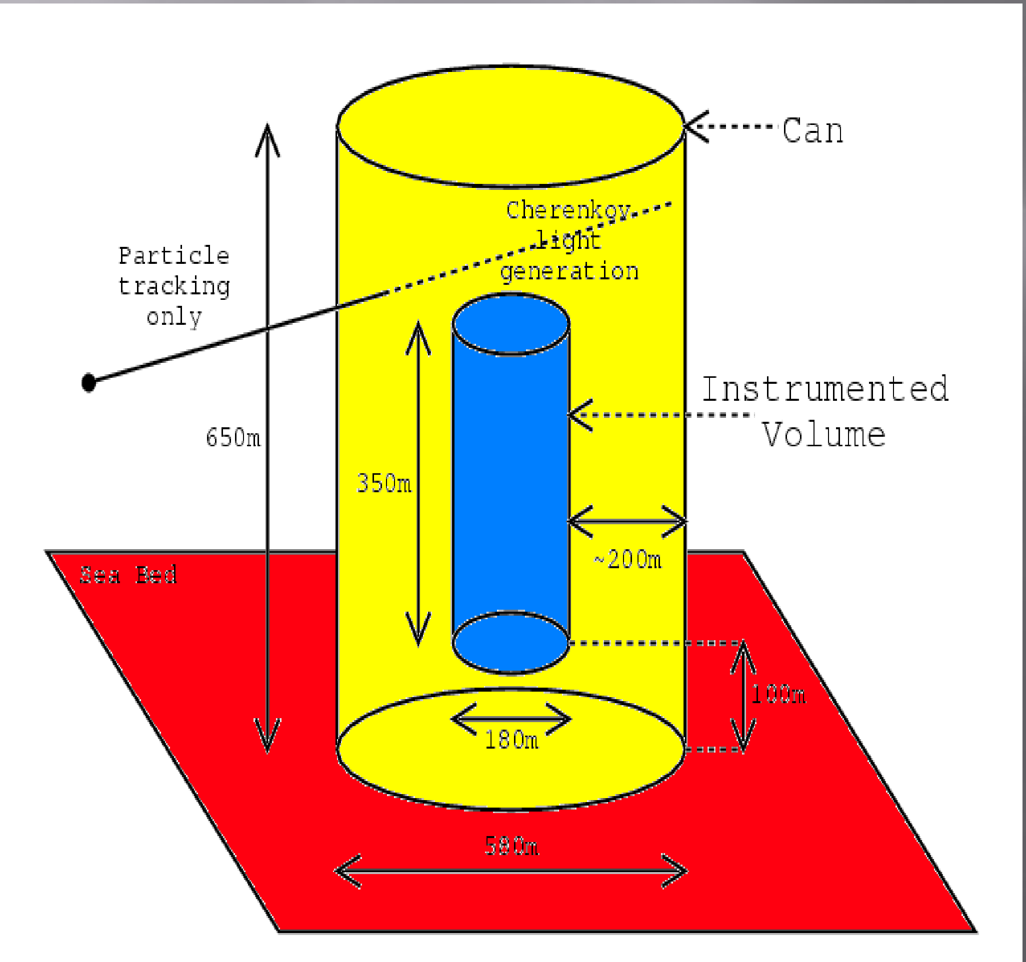
Interface: Can definition

Cherenkov light generation only inside Can which surrounds the Instrumented volume (about 3 absorption lengths)





Interface: Can definition



Modifications for ORCA

Instrumented volume is smaller and denser
Events are more compact

Reduce can size accordingly
150-200m is too much
Waste of computing time

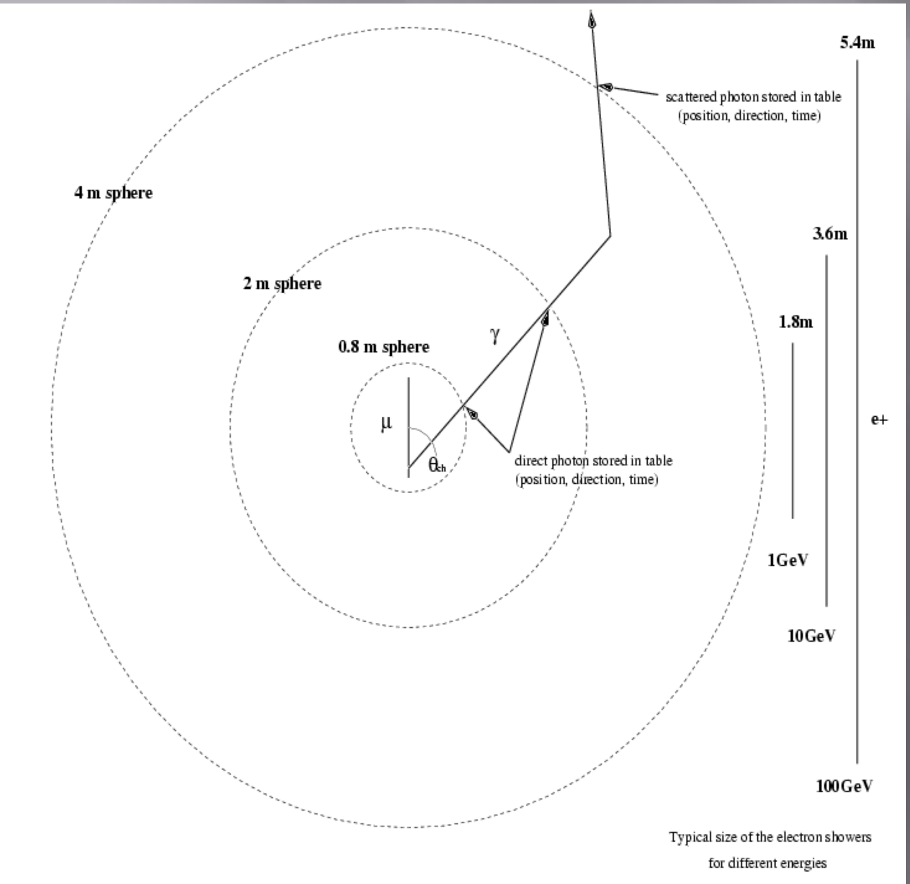
Optimisation ongoing

Tracking & Cherenkov Light

- ANTARES concept
  - Focused on ν_μ and CR-muons
- Muons are handled by **KM3**
  - **Light diffusion included**
- **All other particles : GEANT 3**
  - **Cherenkov light cone calculated analytically for each tracking step**
  - **No light diffusion**

Tracking & Cherenkov light

First step: scattering tables are created
Tracking of e/m showers (1-100 GeV) &1m muon track pieces
Tracking of individual Cherenkov photons with Geant 3



Use of light scattering & absorption storage of photon parameters when passing spherical shells (2m-160m) $(r,\theta,\theta_\gamma,\phi_\gamma,t,\lambda)$

Temporary tables, very big, rough binning

Tracking & Cherenkov light

Second step: Folding with PMT parameters
Wave length integration

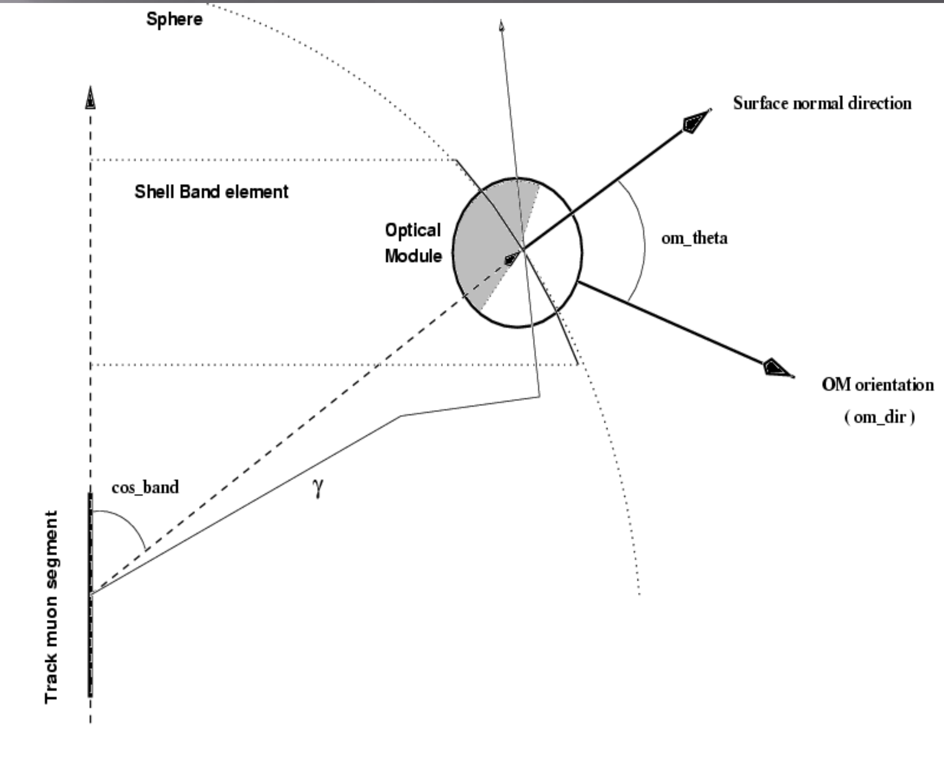
One set of tables per
PMT & water model

$(r,\theta,\theta_{pm},\phi_{pm},t,Prob)$

Independent of detector geometry
and Physics input

Third step:

Tracking of muons (MUSIC)
Through water volume
(including bremsstrahlung etc)
Hits in free detector geometry

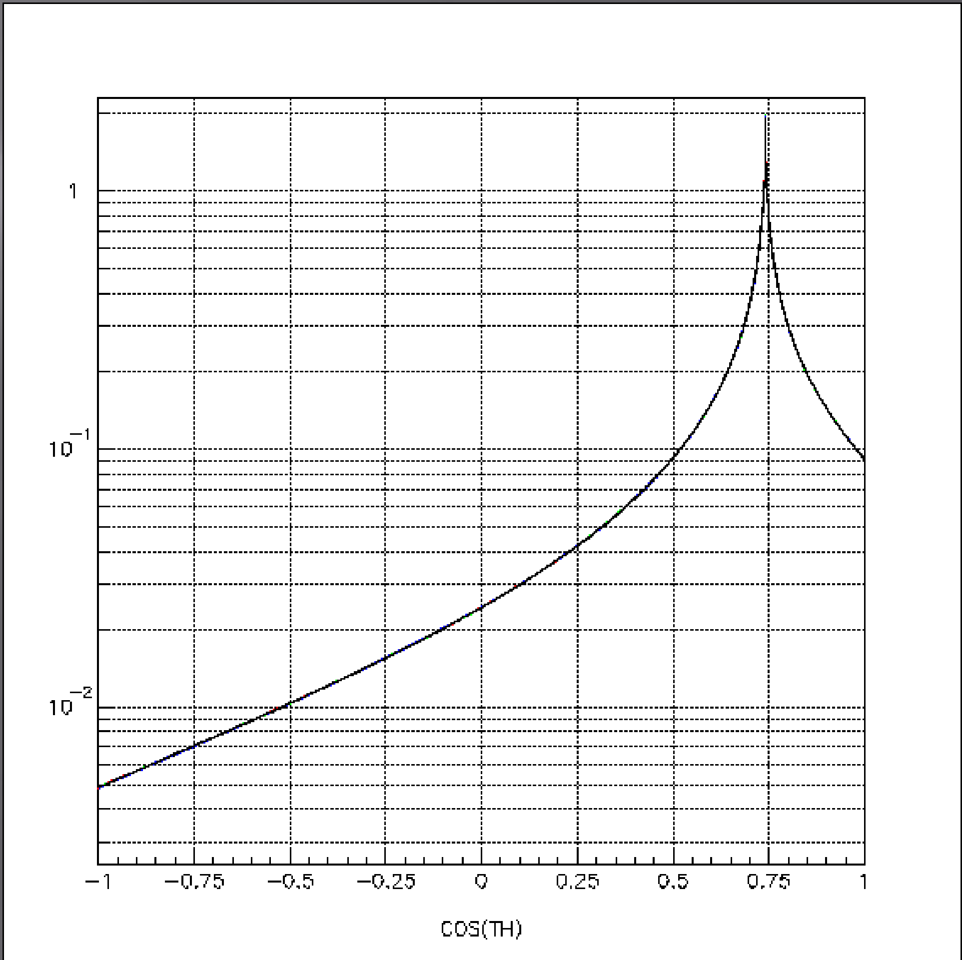


Tracking & Cherenkov light

What about hadronic showers at neutrino vertex ?
Problem of hadronic models in TeV/PeV range
What about ν_e , ν_τ interactions ?

Angular distribution of Cherenkov photons and Time residuals more 'fuzzy' than for muons

Light Scattering less important



Treatment with Geant
No scattering, but attenuation
E/m showers parametrized to
Save CPU time

τ tracking ? Modification of muon propagation code work just started

Challenges ORCA/PINGU

- Both muon and shower at neutrino vertex important for ν_μ
- All neutrino flavours needs to be treated equally well
- Distance between detector elements smaller than typical binning in km3 tables

Possible Remedy

- Do nothing, use ANTARES scheme
  - Used in current “early” ORCA simulations
  - Ok for first steps of feasibility studies
- Ignore light diffusion
  - All particles treated in Geant
  - Analytical Cherenkov Light Cones per step
- Modify **km3**
  - Adapt to be used with all particles
  - Binning adjusted to ORCA geometry

Possible Remedy

- Do nothing, use ANTARES
  - Used in … ORCA simulations
  - … first steps of feasibility studies
- Ignore light diffusion
  - All … in Geant
  - …nalytical Cherenkov Light Cones per step
- Modify **km3**
  - Adapt to be used with …s
  - Bi… to ORCA geometry

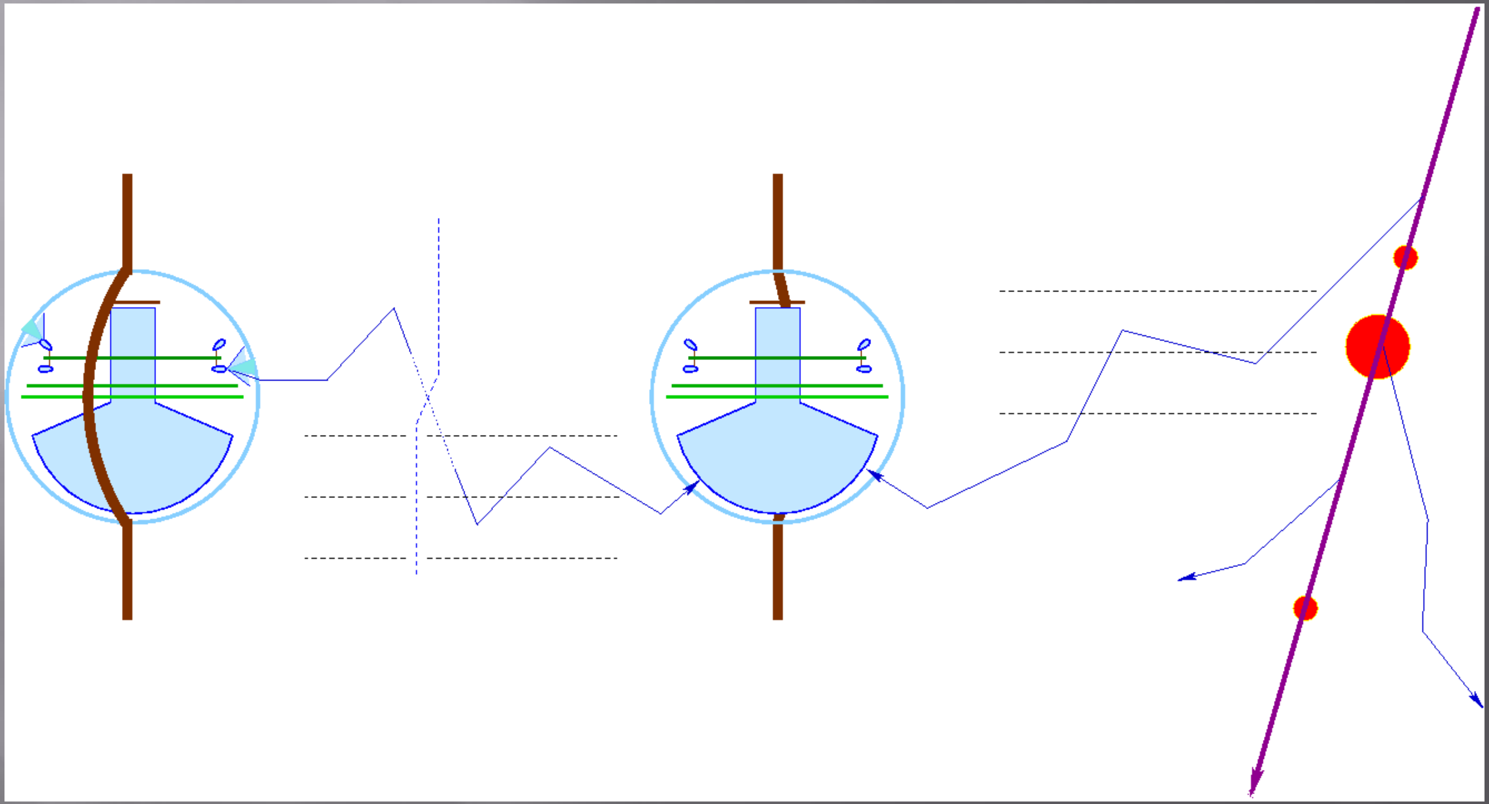
Effect of approximation to be evaluated

Effect of approximation to be evaluated

Significant software work

IceCube simulation with PPC on GPUs

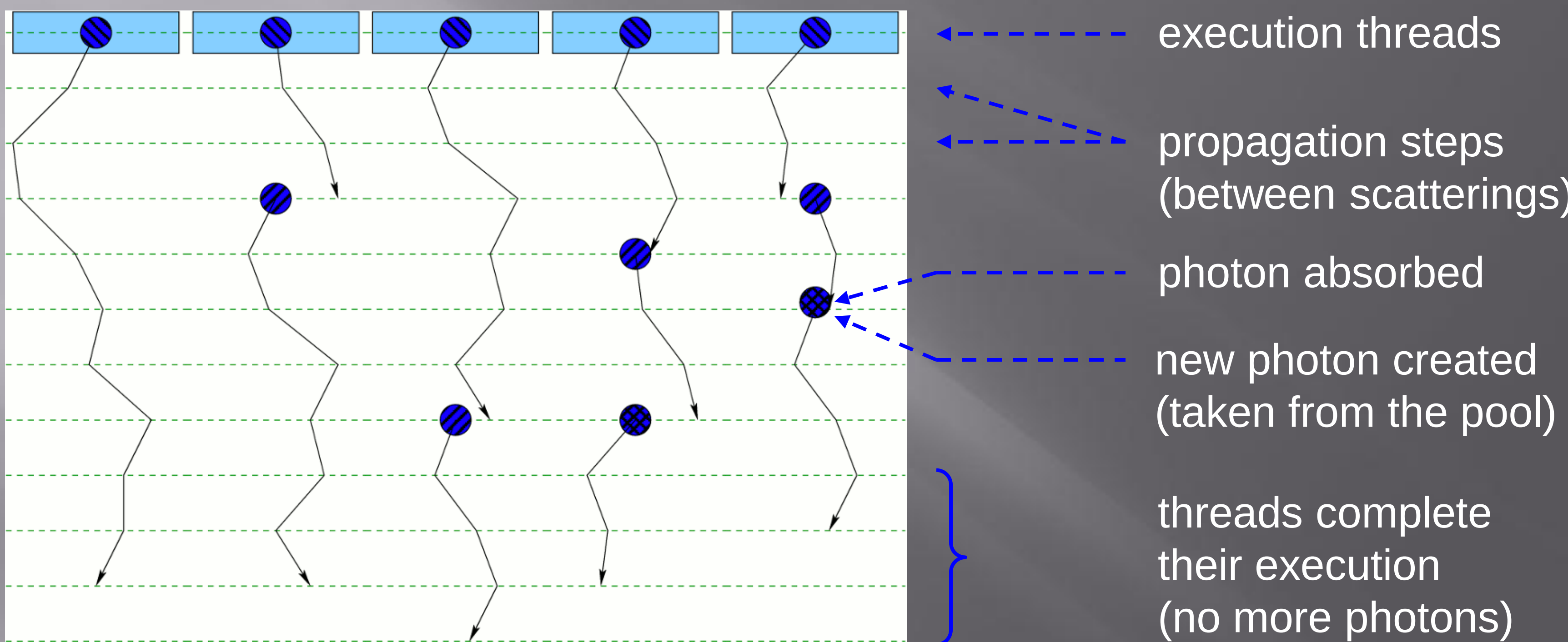
photon propagation code
graphics processing unit



Dmitry Chirkin, UW Madison

PPC simulation on GPU

graphics processing unit



Running on an NVidia GTX 295 CUDA-capable card, ppc is configured with:

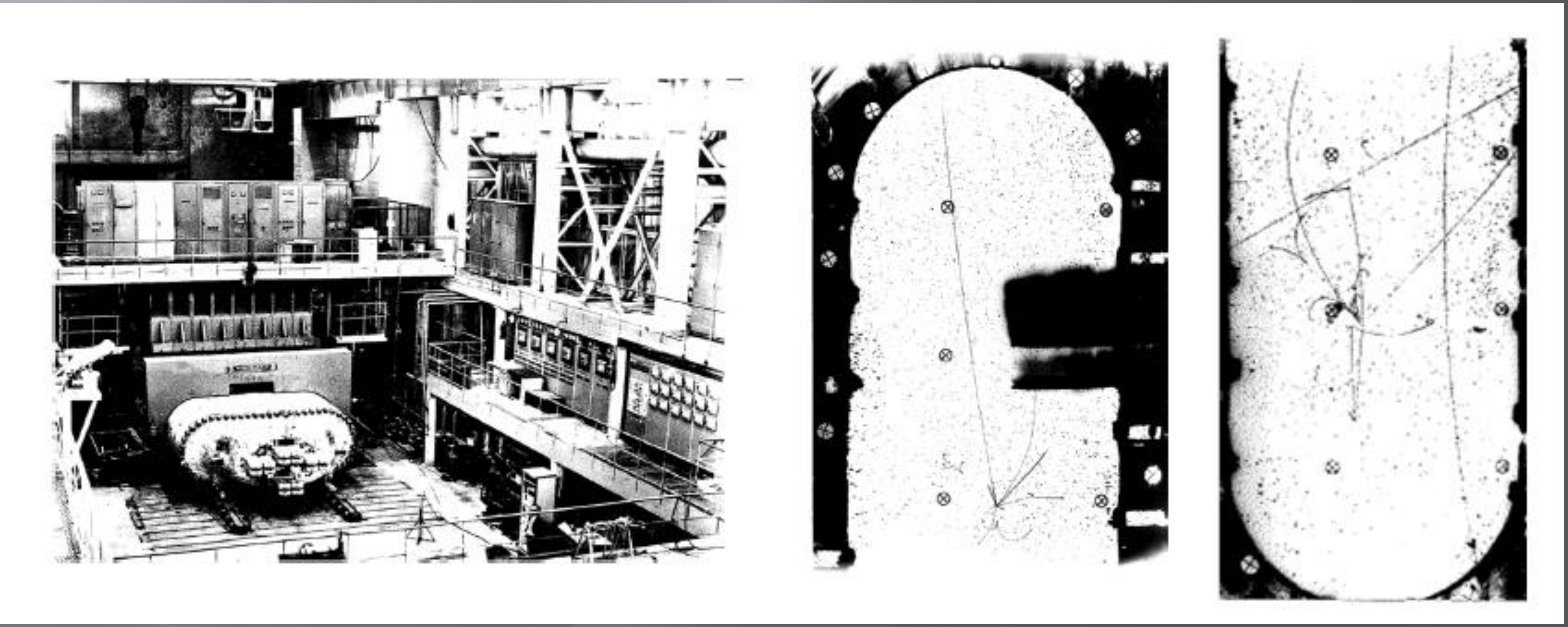
448 threads in 30 blocks (total of 13440 threads)

average of ~ 1024 photons per thread (total of $1.38 \cdot 10^7$ photons per call)

Speed gain ~ 100 w.r.t. CPU

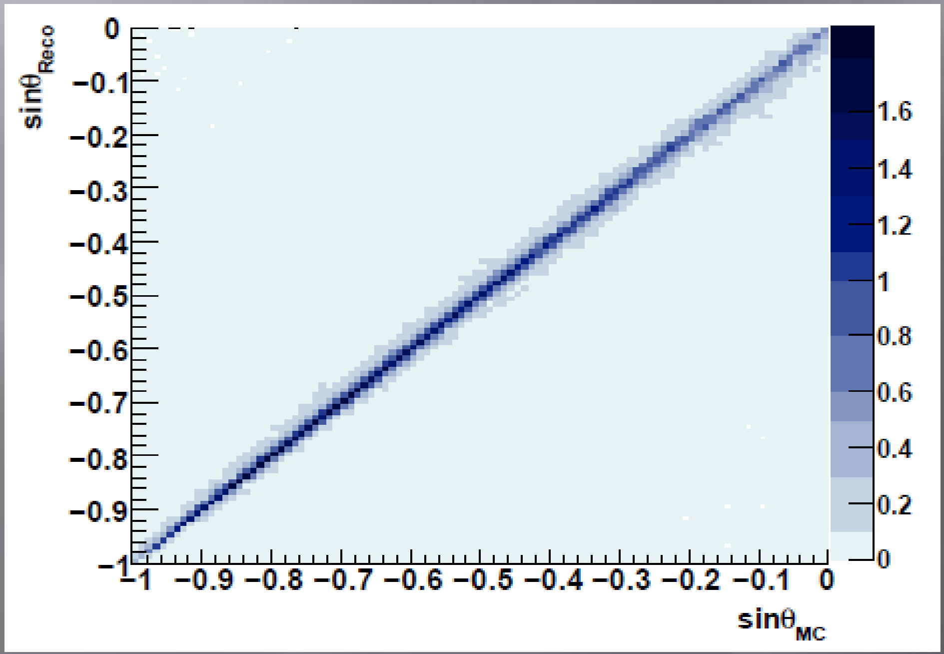
Reconstruction
The REAL challenge

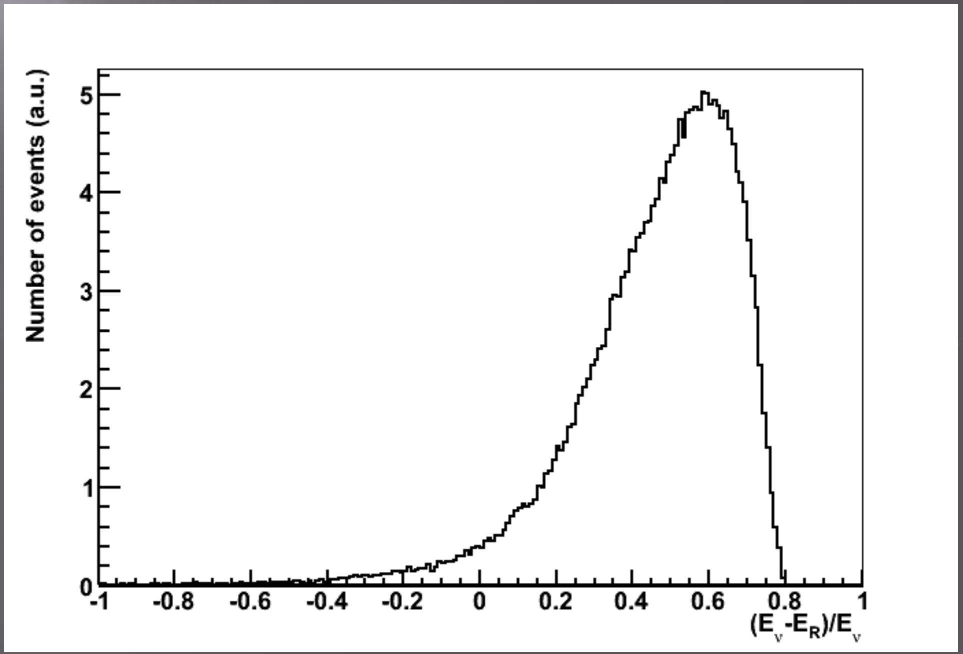
- What do we want to measure ?



Reconstruction
What do we have ?

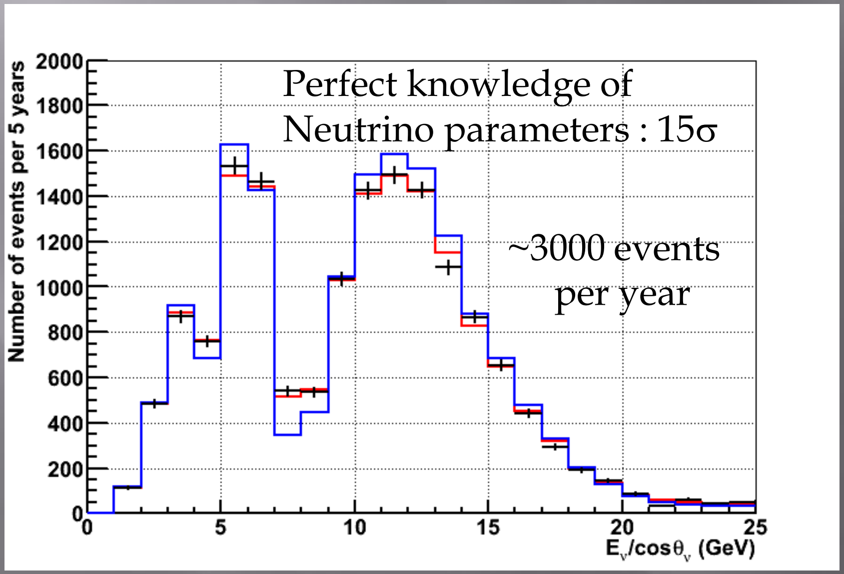
- Zenith Angle resolution of MUON 0.8˚
- MUON Energy resolution from range ~50%

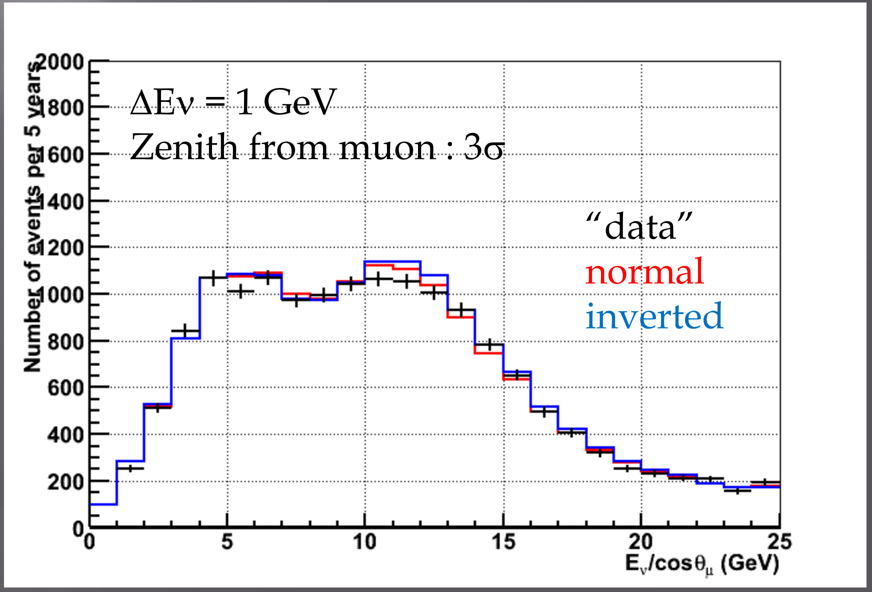




Reconstruction
What do we need ?

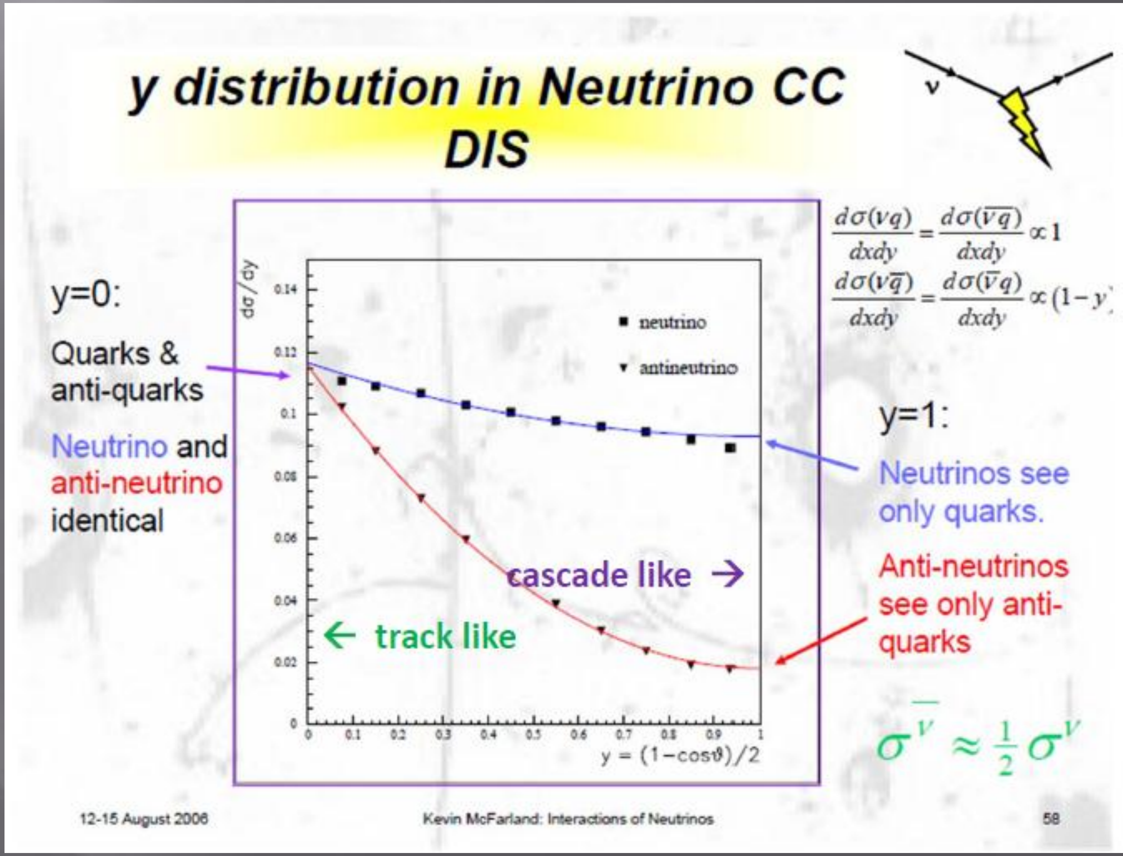
- Challenges
  - Resolution in neutrino energy and zenith angle
  - Background rejection (veto ?)
  - Flavour tagging
- Systematic effects
  - Energy dependent detector acceptance
  - Knowledge of resolution
  - Earth model
  - Oscillation parameter uncertainties





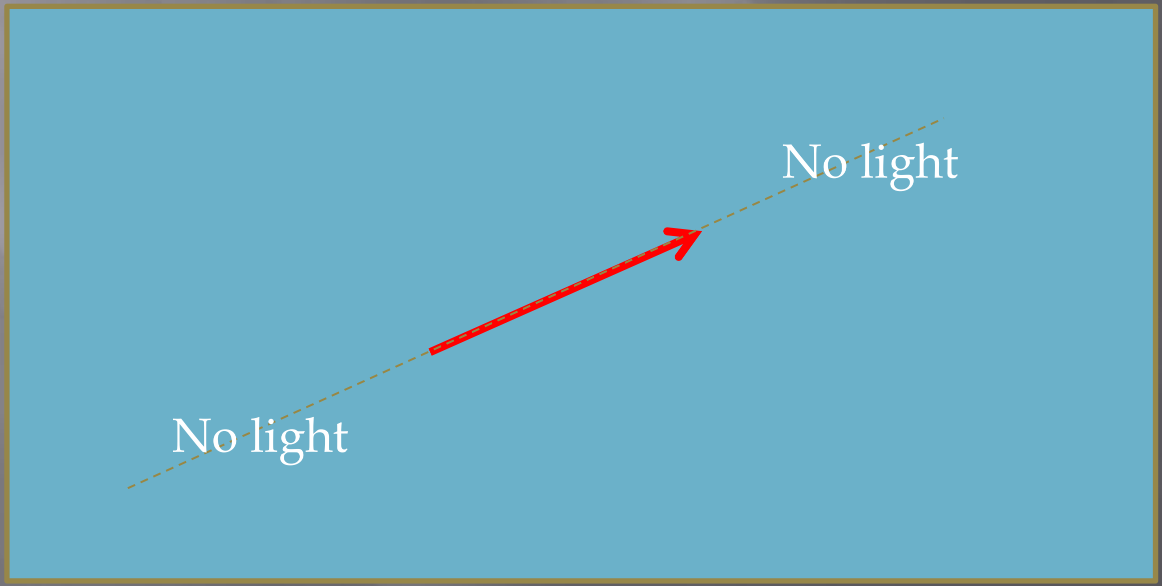
Reconstruction Some Ideas

- Select events with little hadronic activity
  - Enhances Antineutrino sample
  - Enhances QE and RES contributions
  - Muon close to Neutrino kinematics



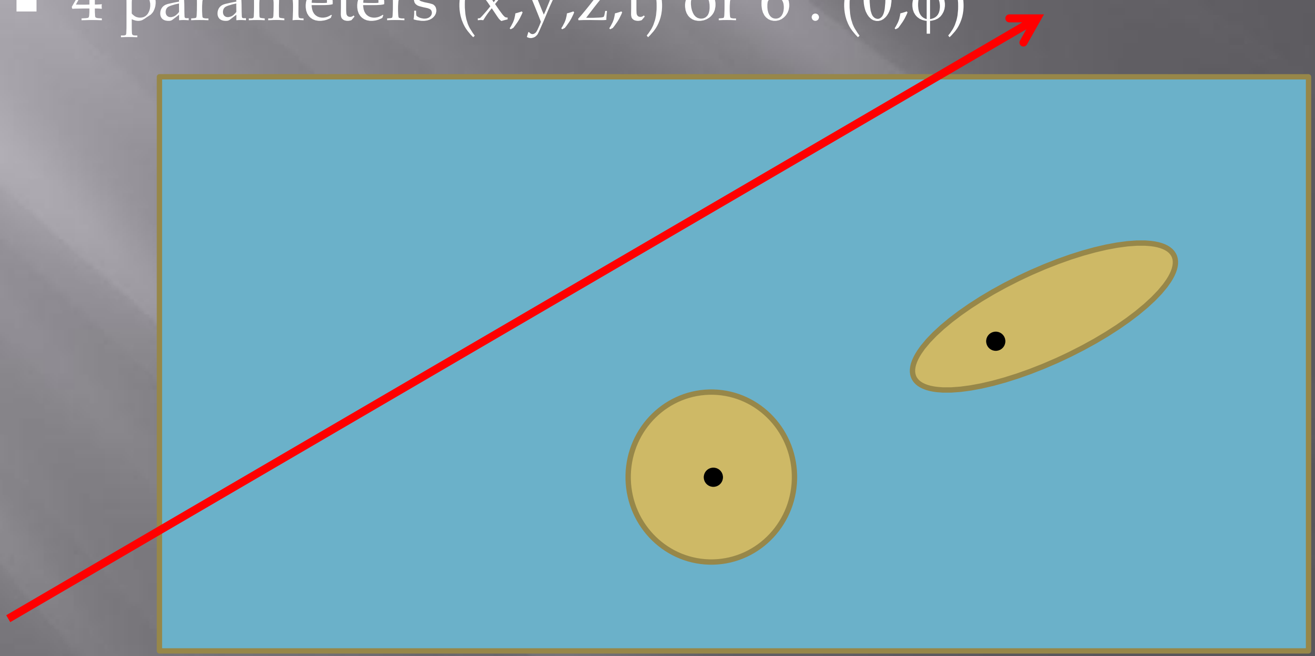
Reconstruction
Some Ideas

- Use Veto to improve muon range determination → tradeoff between efficiency and resolution



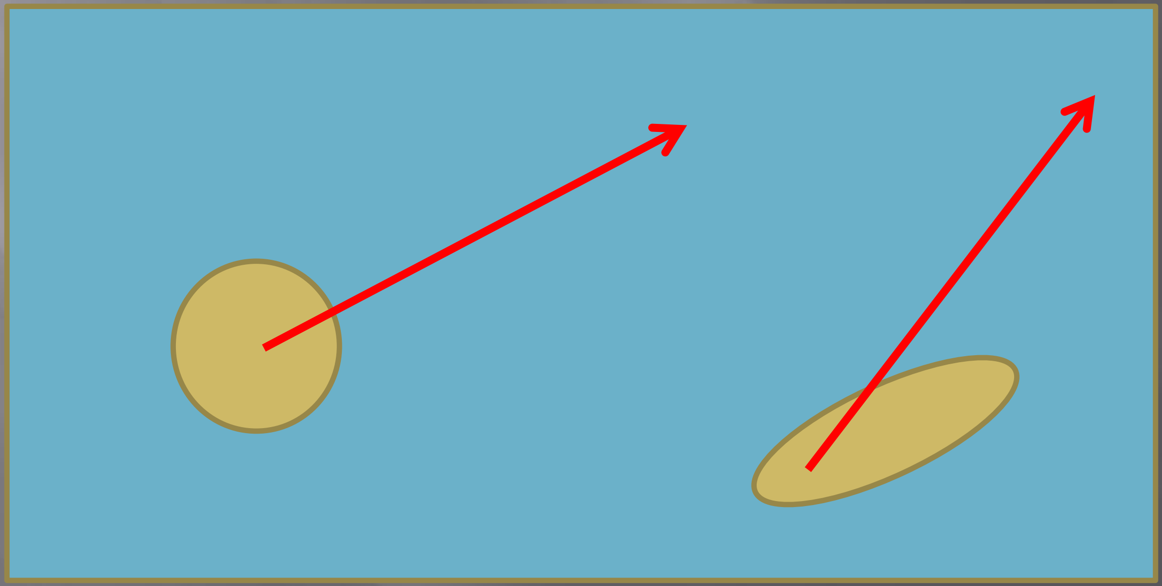
Reconstruction Traditional

- (Infinite) Track
  - 5 parameters (x,y,z) at t_0 and (θ,φ)
- Point-like shower
  - 4 parameters (x,y,z,t) or 6 : (θ,φ)



Reconstruction Hybrid (PINGU)

- Track + Shower
  - 8 parameters (x,y,z,t) with length l and (θ,φ) and E_{sh}
- Track + directed shower
  - 10 all above + shower direction E(θ,φ)



Conclusion

- Full simulation & reconstruction chain of Antares available for ORCA (PINGU)
- Modifications in simulations planned
- Challenges in Event Reconstruction

- Large effort to prove feasibility of mass hierarchy measurement with neutrino telescopes just started