THE INTERNATIONAL DESIGN STUDY FOR THE NEUTRINO FACTORY

Near Detector - Scintillating Fibre simulations

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On behalf of UniSofia group

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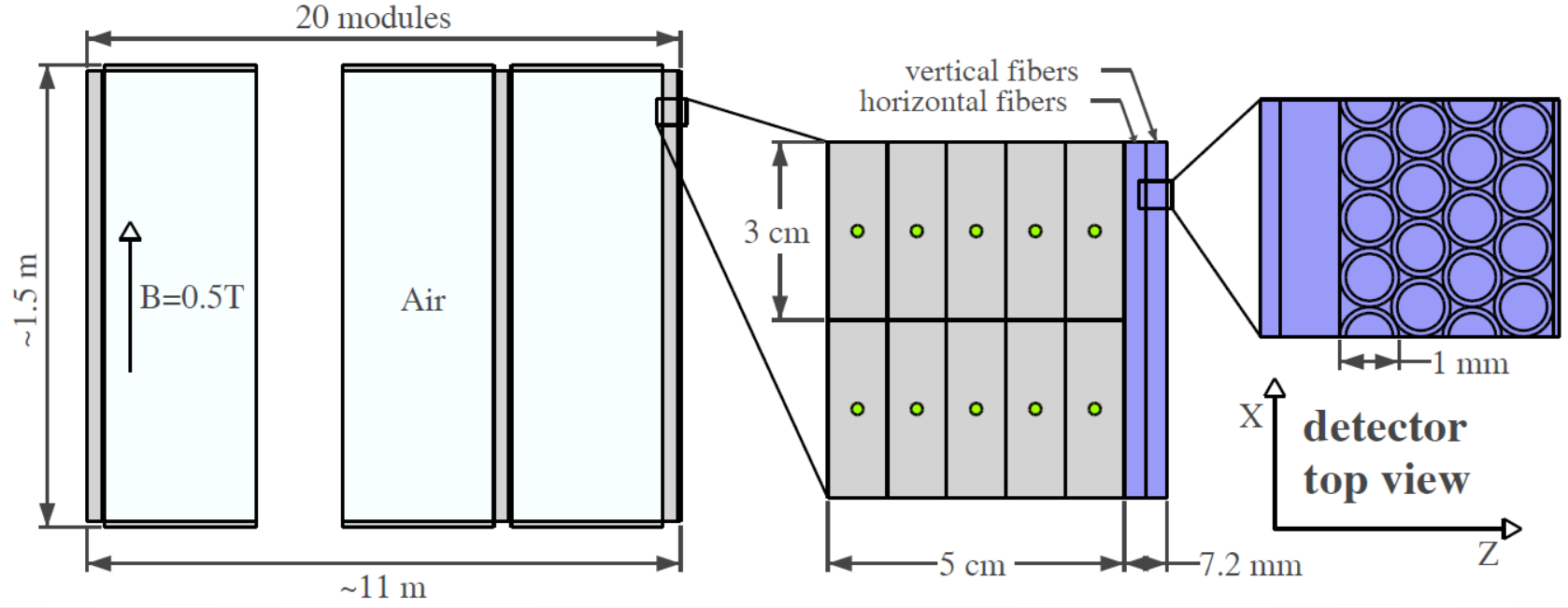
SciFi tracker baseline

- **20 tracker stations, each consists of 4 X and 4 Y layers of 1 mm diameter scintillating fibres shifted with respect to each other; 12 000 fibres per station (240k in total);**
- **5 cm thick active absorber (target), divided into 5 slabs to allow for more precise measurement of recoil energy near the event vertex;**
- **Air gaps are closed by a layer of scintillating bars;**
- **Overall detector dimensions: 1.5 x 1.5 x 11 m^3 (2.7 tons);**

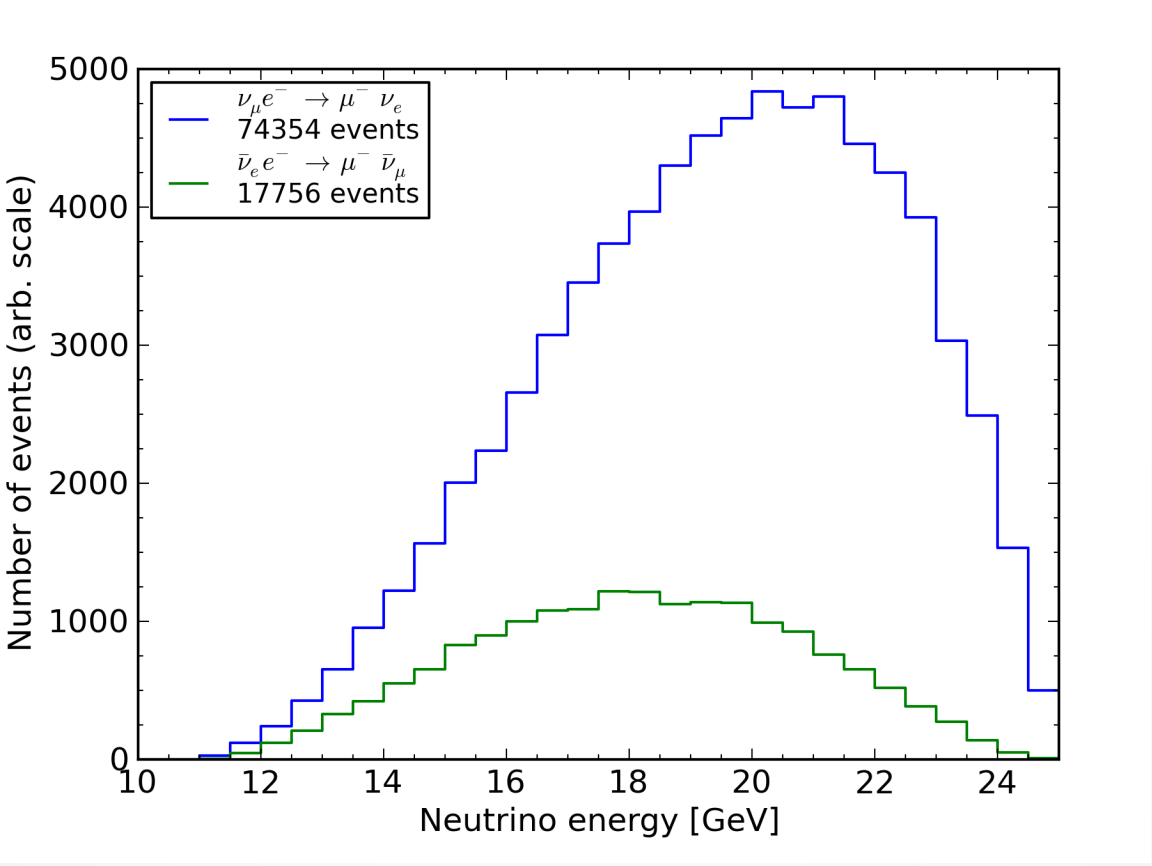


Simulation chain

- Neutrino flux
- Genie generator – added IMD annihilation channel
- Geant4 transport
- Digitization
- Reconstruction – improved lepton momentum resolution
- Signal extraction
- Reconstruction of neutrino energy - new

IMD annihilation channel in Genie

- Implemented $\overline{\nu}$e IMD (annihilation) channel in Genie. Code to be released in version 2.8.0
- 25% increase of IMD signal



EM calorimeter

- Measuring electron momenta with the tracker is hard, (low efficiency, poor resolution)
- We need to add an ECAL surrounding the tracker to measure (at least) electron enegy in pure lepton NC interactions
- No G4 simulations have been done
- We adopt EM energy resolution from HiResMuNu – $6\%/\sqrt{(E/GeV)}$

Muon track reconstruction

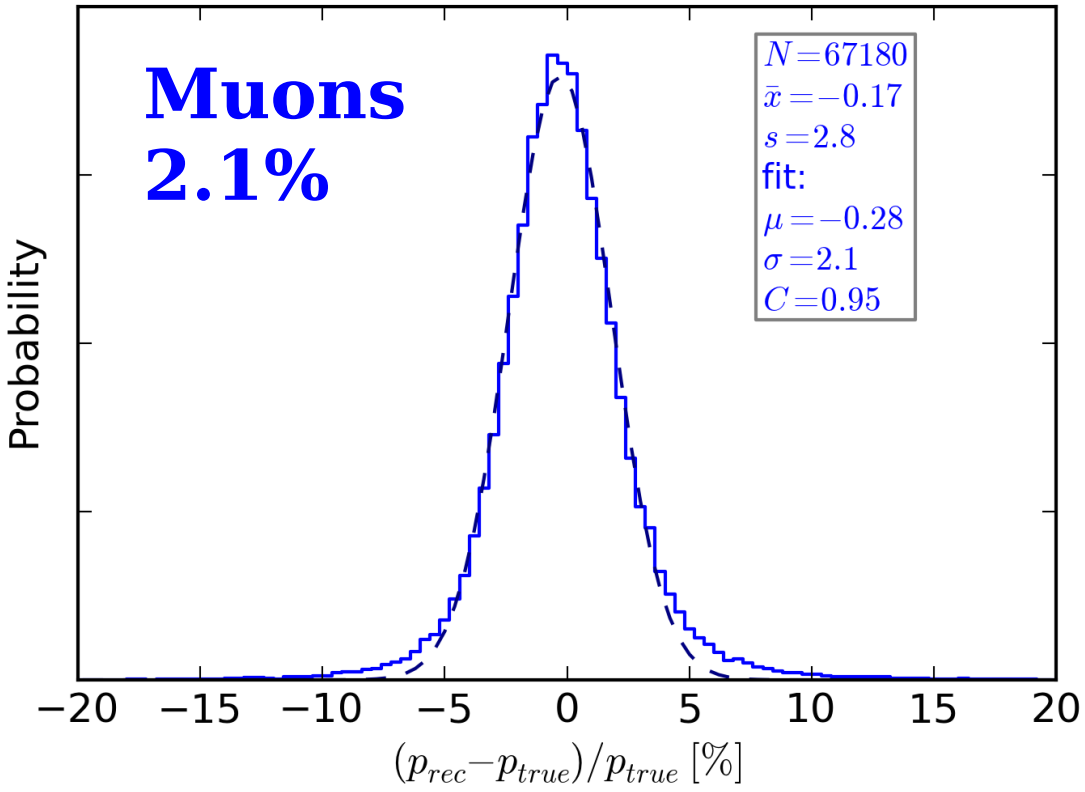
- Effort made ot introduce **RecPack** (trunk)
- Seed is calculated by **least squares fit** of a parabola to **all lone clusters**
- Already significant improvement on muon momentum resolution – **from 8% to 2%**
- Tried several fitting procedures combining forward and/or backward fits, with or without association of more clusters
- **Unfortunately**, no procedure improved on seed's momentum, and all worsened seed's initial angle
- Multipe scattering and energy loss are small, probably RecPack cannot improve (at least not significanly)

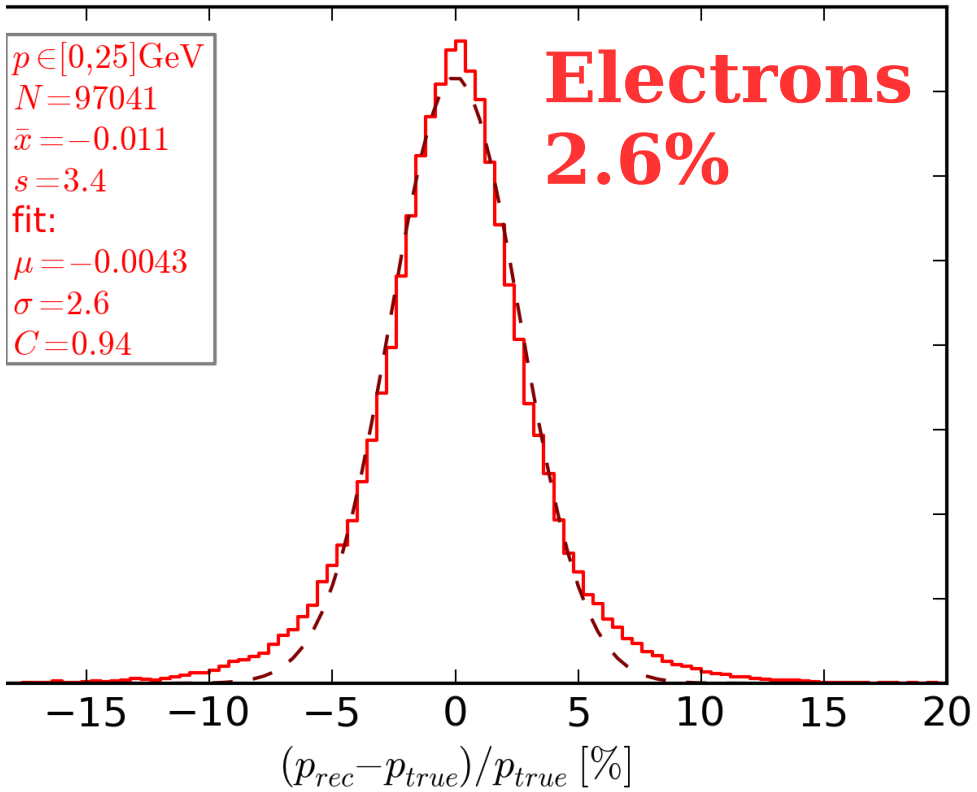
Side effect: RecPack timing

- Geometry should have the smallest possible number of volumes and surfaces
- **Kalman filter fitting takes more time than G4 simulation of IMD events!**
- Profiling the code revealed two issues:
  - bad implementation of class *dictionary<T>*,
  - use of the generic HepVector as opposed to Hep3Vector (where possible) costs a lot.
- **Improvement on these points made fitting nearly 3 times faster!**

Momentum resolution

- Left - Muons (from lsq fit of lone clusters)
- Right - Electrons (from ECAL)





Impact on nu-electron scattering

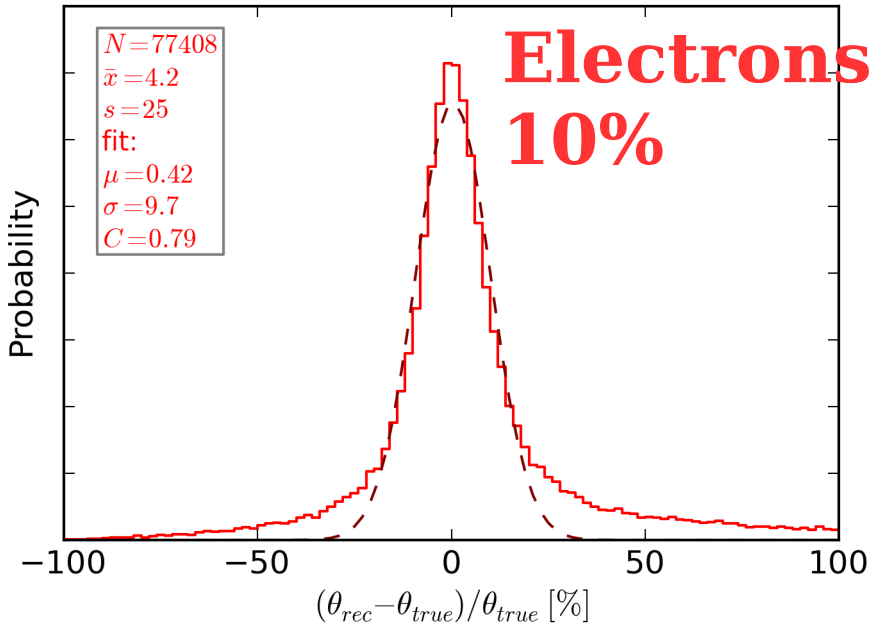
- Unfortunately, better momentum resolution has negligible impact on measurements of neutrino electron scattering

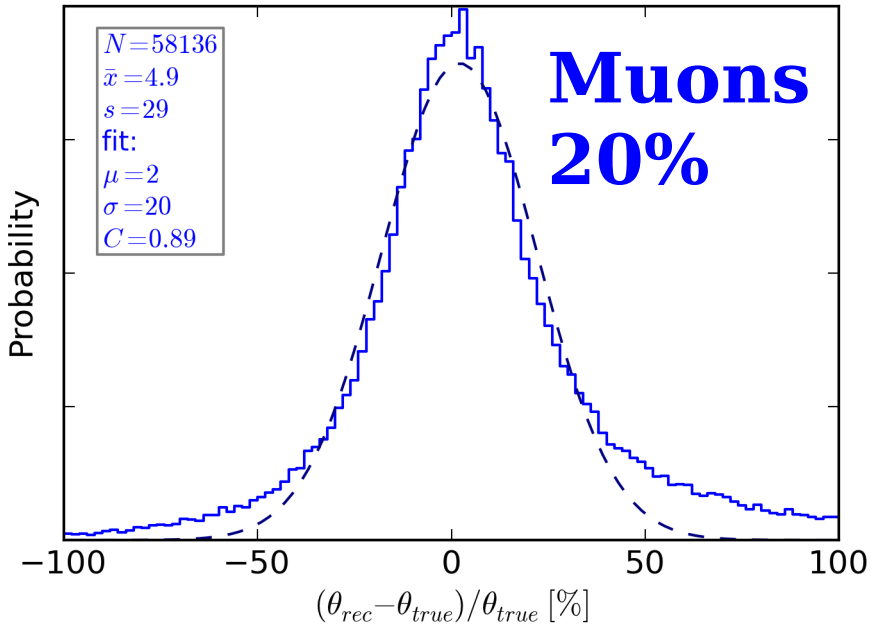
$$\frac{\sigma E \theta^2}{E\theta^2} \approx \sqrt{\left(\frac{\sigma E}{E}\right)^2 + 4\left(\frac{\sigma\theta}{\theta}\right)^2} \approx 2\frac{\sigma\theta}{\theta}$$

2-3%

10-20%

- Angular resolution is much more important!





Neutrino energy reconstruction

- Naively assume

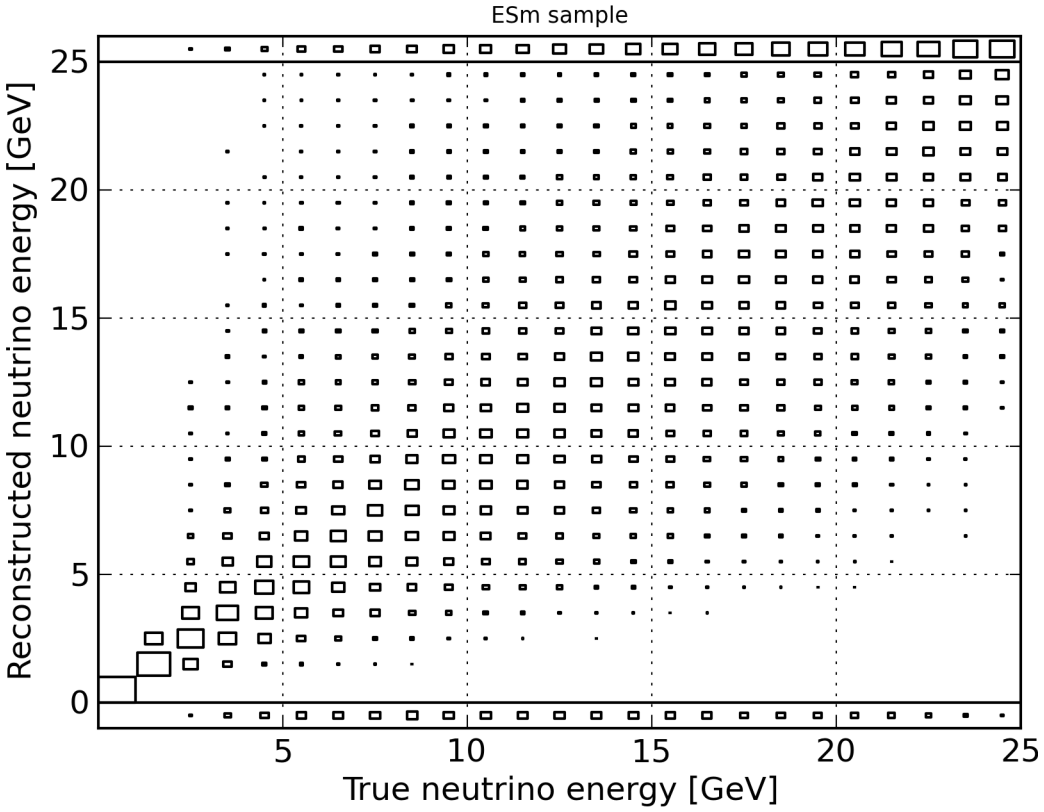
$$\theta'_l = \theta_l$$

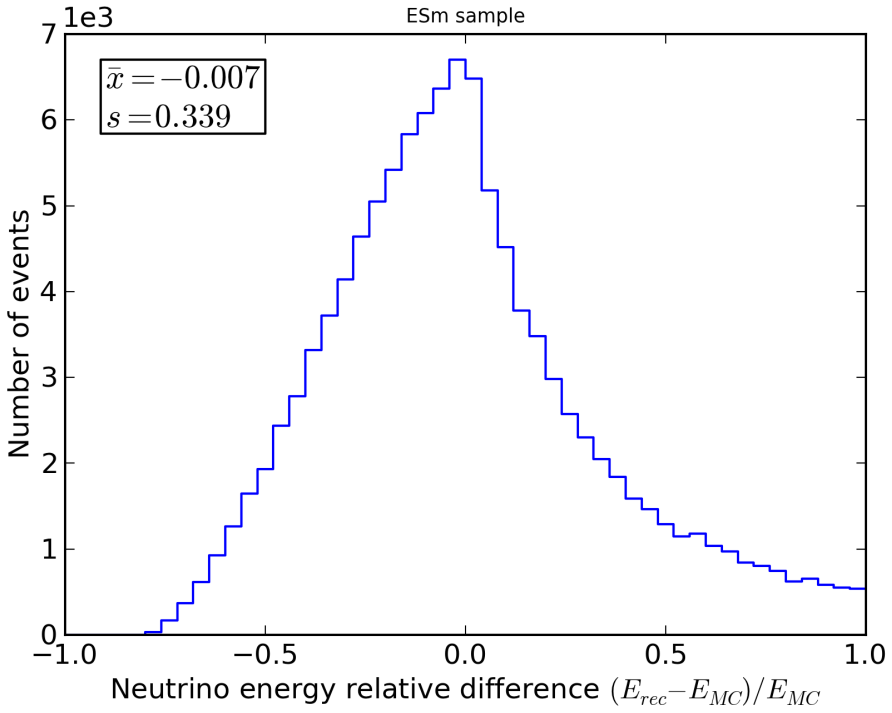
scattering angle

measured lepton angle

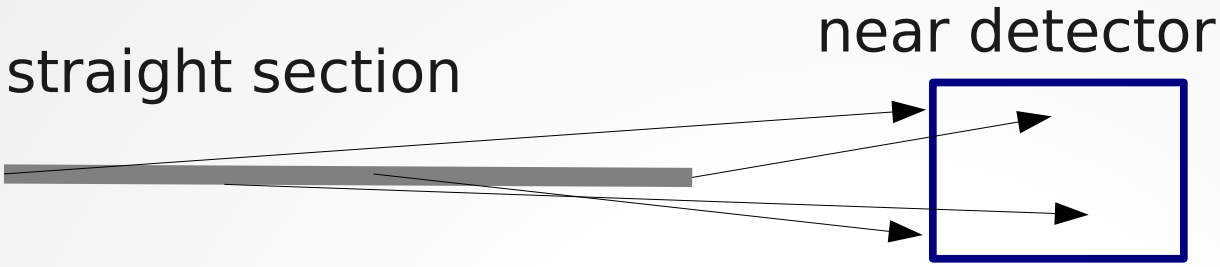
$$E_\nu = \frac{2E_l m_e - m_l^2 - m_e^2}{2(m_e - E_l + p_l \cos\theta'_l)}$$

E and θ from MC truth, no detector response involved !

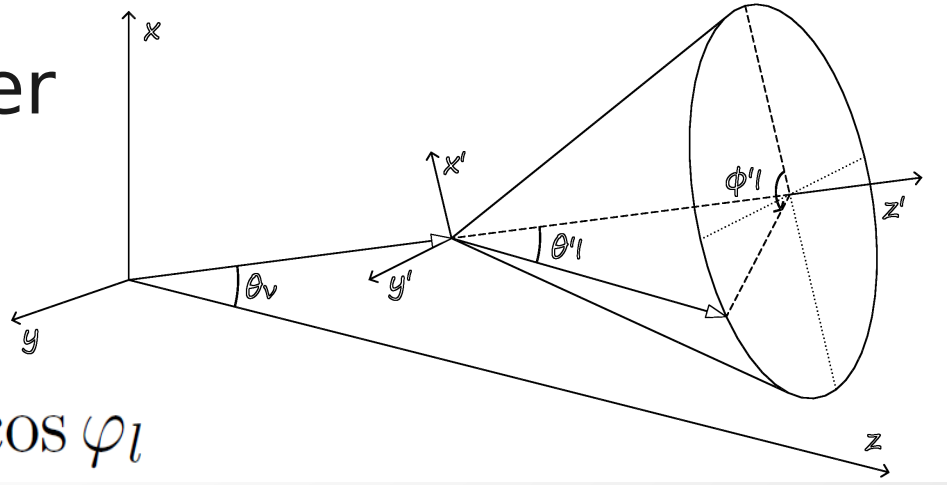




NF neutrino flux



- $z_{decay}(\theta_{\nu})$ not known on event by event basis
- This prevents us to reconstruct straightforwardly neutrino energy from neutrino electron interactions
- However, we can do better



$$\cos\theta_l' = \cos\theta_\nu \cos\theta_l + \sin\theta_\nu \sin\theta_l \cos\varphi_l$$

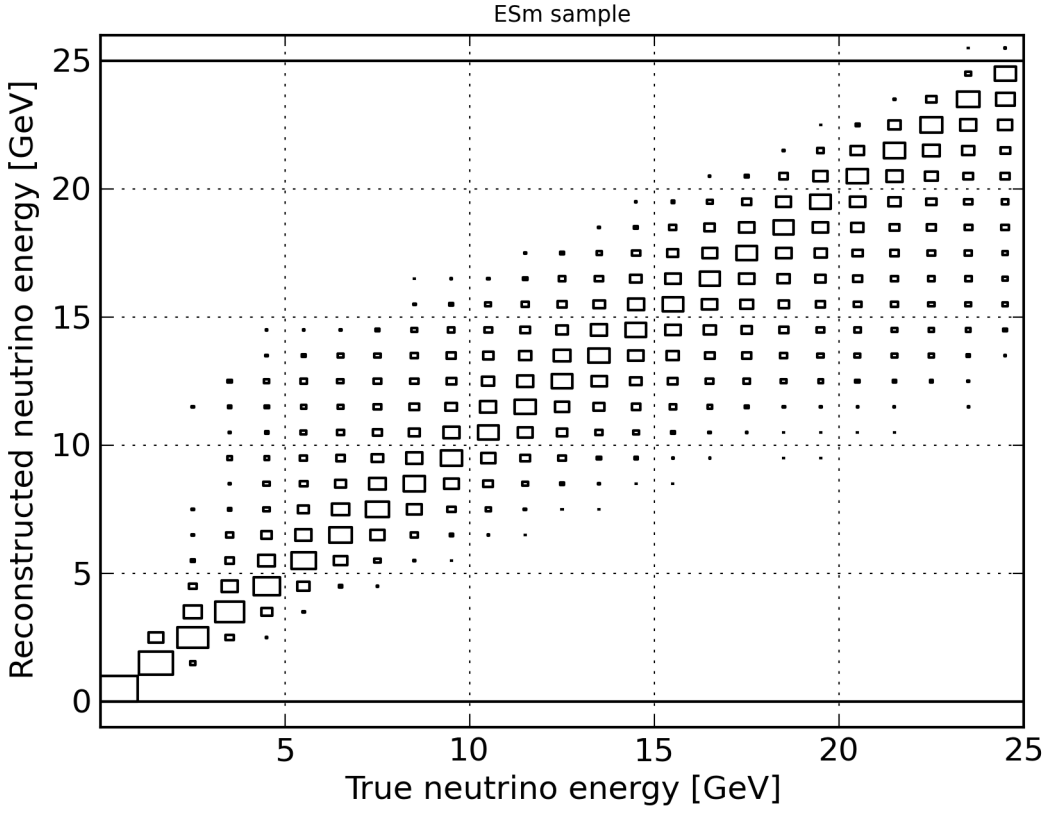
Improved method

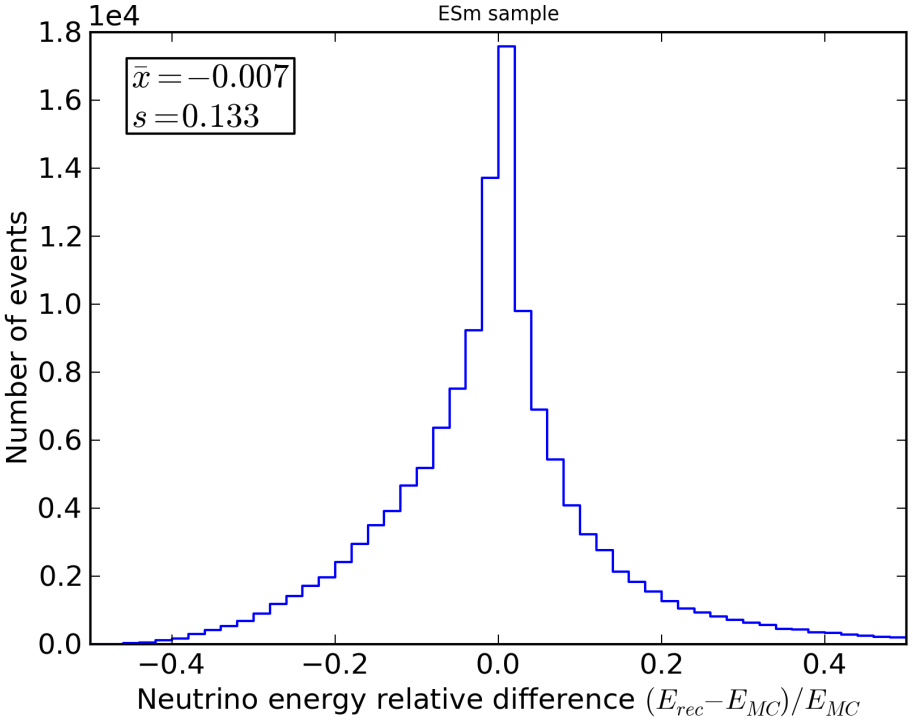
- Measure $E_l,\ \theta_l,\ \varphi_l$, and (x,y) position
- Constrain possible values of θ_ν and take an average
- Even better, for each event construct a likelihood function $f(\vec{\eta})$, which takes into account all you know: *cross sections, flux, detector resolutions.*
- *Then, obtain neutrino energy from*

$$\int E_\nu(\vec{\eta})\, f(\vec{\eta}) d\vec{\eta}$$

Improved method

- Improvement: stdandart deviation down from 34% to 13%

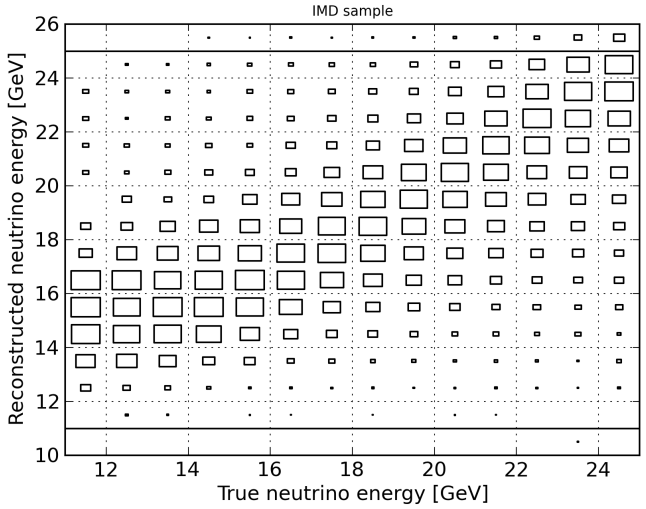


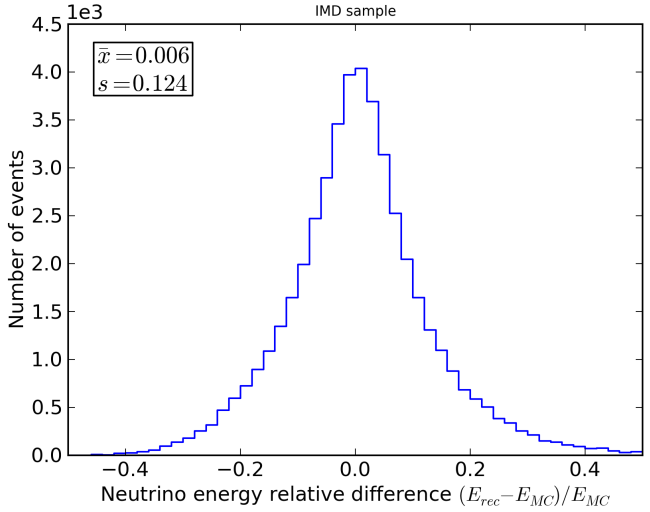


E and θ from MC truth, no detector response involved !

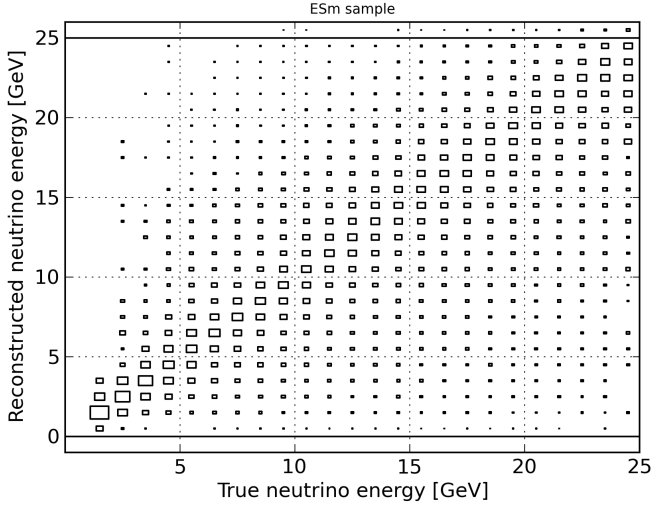
Neutrino energy reconstruction

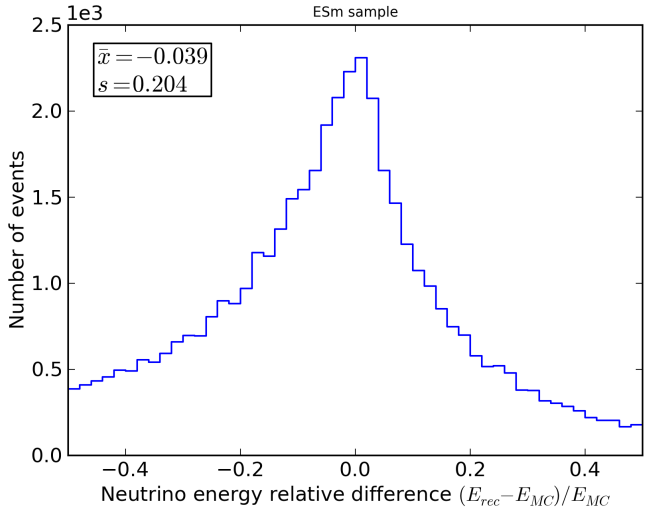
- With **reconstructed** momentum and angle. (Detector resolution not included in likelihood function)



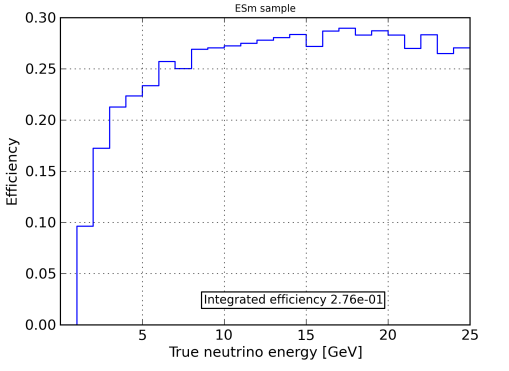


IMD sample

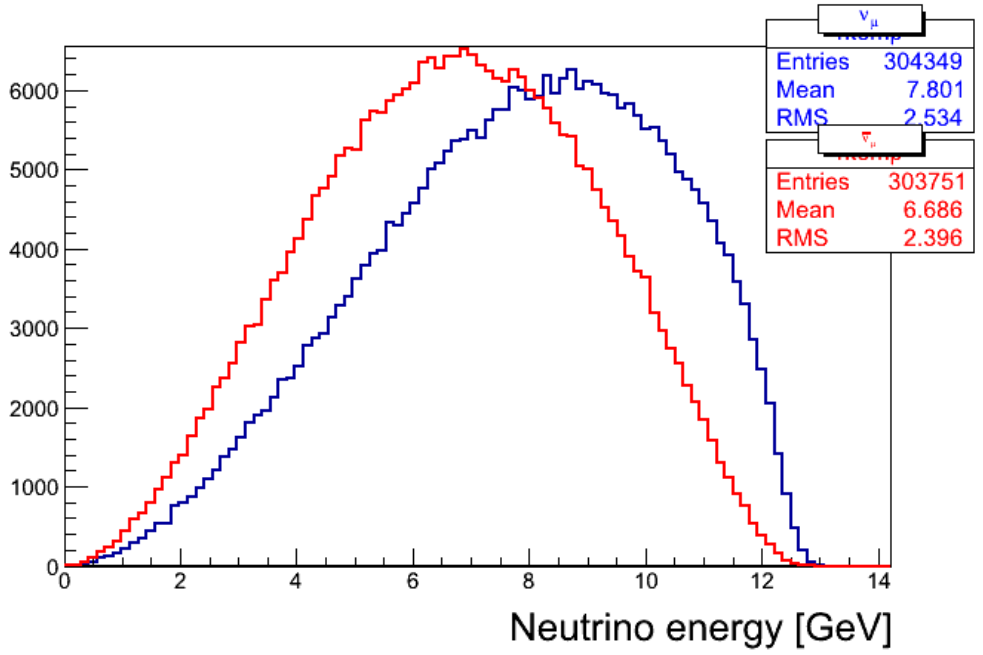


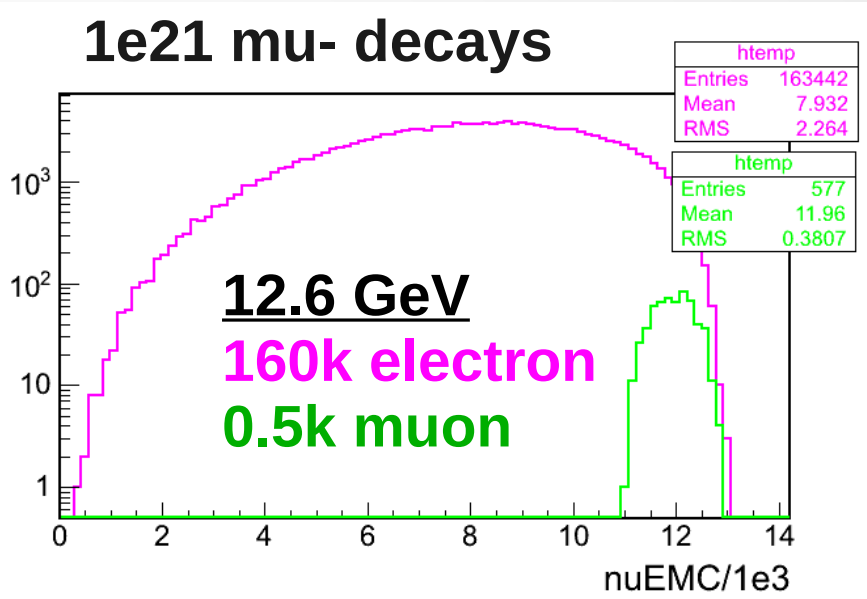


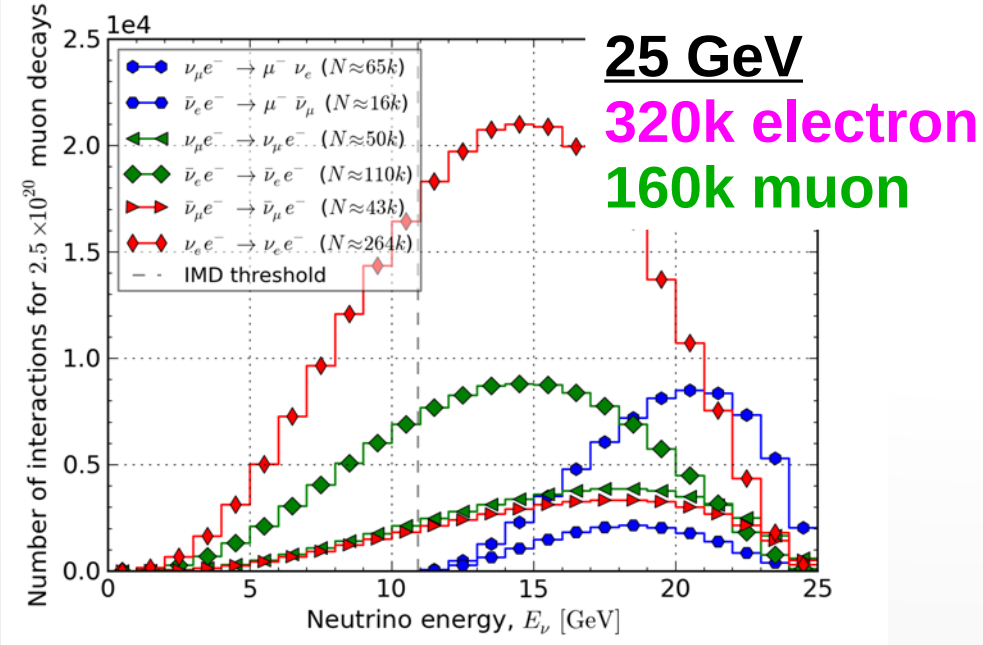
ESm sample (electrons in mu-beam)



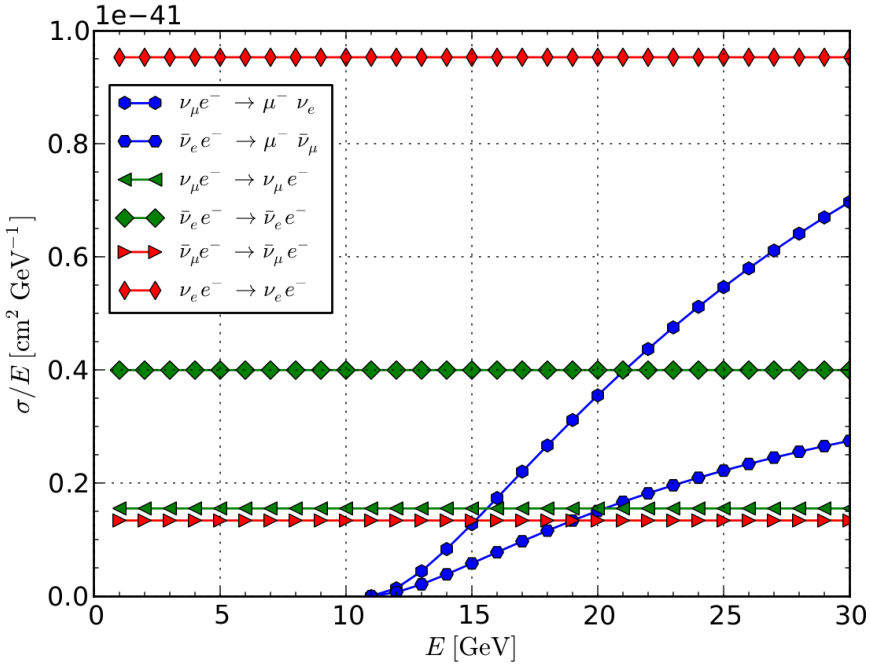
12.6 or 10 GeV (IMD or **not**)?







25 GeV
320k electron
160k muon



Summary

- Implemented IMD annihilation channel in Genie
- Introduced EM calorimeter in the design
- Muon momentum resolution improved **from 8% to 2%**
- Neutrino energy reconstruction on event by event basis can be made within **15-20%** uncertainty for NC pure leptonic events
- However, migration matrix can probably be improved
- We are still confident that we can **count neutrino electron** interactions
- An effort is needed to improve both overall efficiency and the drop below ~4 GeV for electron events
- **IMD** is not relevant when deciding on LENF energy