Beam monitor with SAND detector

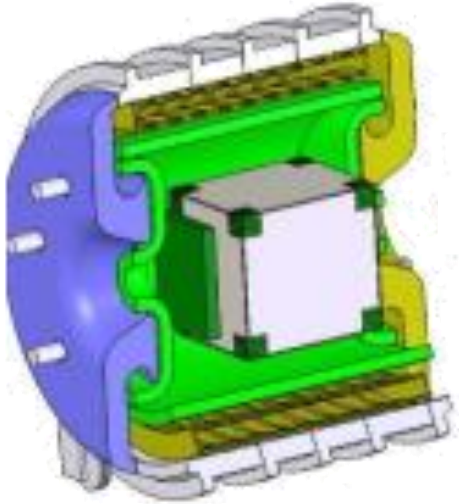
Lea Di Noto
University of Genova and INFN Genova

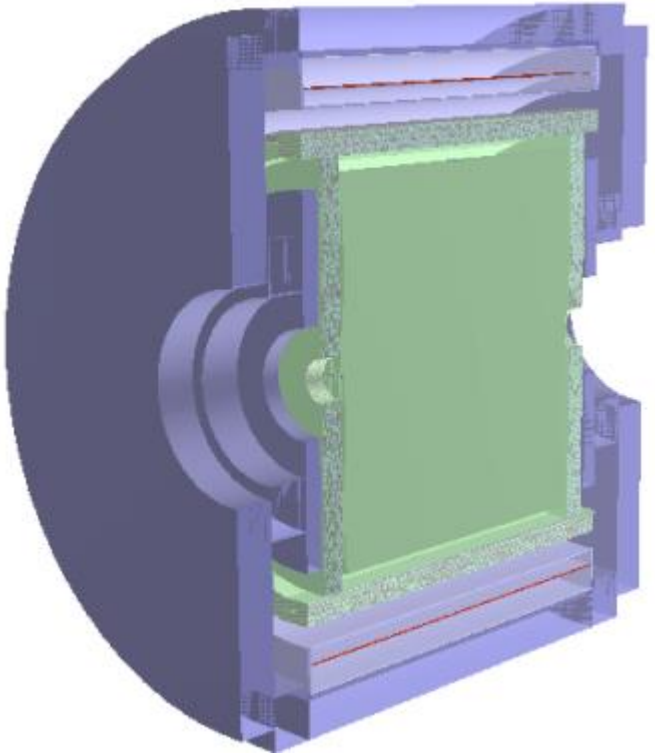
on behalf of SAND detector group

Near Detector call, 15th April 2020

Overview

- We are designing SAND, considering different geometries:
  - ECAL + 3DST+ STT
  - ECAL + 3DST + TPC
  - ECAL + STT





also for beam monitoring we need a magnet

because spectral monitoring is necessary

In this talk

- Beam monitoring with → 3DST only (update)
  → ECAL + STT

A summary of many analysis

→3DST only 2 analysis

- Guang Yang, Davide Sgalaberna
- Artem Chukanov, Bing Guo, Roberto Petti

→ ECAL + STT 2 analysis

-Artem Chukanov, Bing Guo, Roberto Petti, Svetlana Vasina,
-Federico Battisti and Matteo Tenti

Beam monitoring

Study if SAND is sensitive to the flux variations listed by beam monitor group

Beam parameter	Variation
Horn current	+3 kA
Water layer thickness	+0.5 mm
Decay pipe radius	+0.1 m
Proton target density	+2%
Proton beam radius	+0.1 mm
Proton beam offset X	+0.45 mm
Proton beam θ, ϕ	0.07 mrad θ, 1.57 ϕ
Proton beam θ	0.070 mrad
Horn 1 X shift	+0.5 mm
Horn 1 Y shift	+0.5 mm
Horn 2 X shift	+0.5 mm
Horn 2 Y shift	+0.5 mm

These are quoted by the beam group as 1 sigma variation

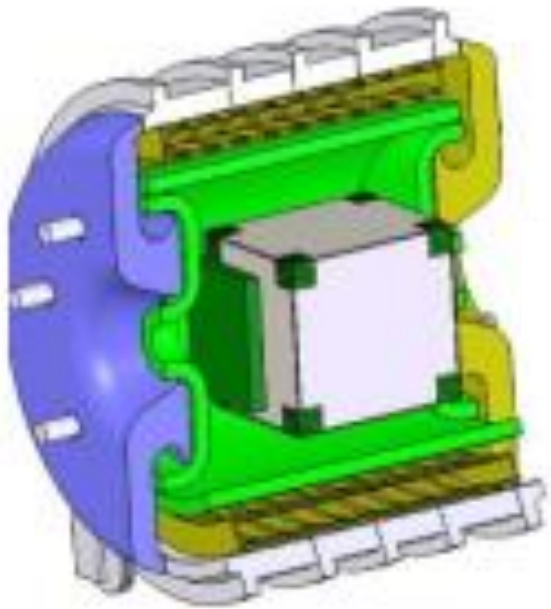
How much is our detector sensitive?

How many days we need to discover the different beam respect to the nominal one?

What is our sensitivity in one week?

In both the studies the nominal and the variated flux were generated.
The nominal flux was simulated in the detector geometry and the events for the variated flux were reweighted accordingly to the variated flux distribution (in different ways in the two analysis)

Beam monitoring with 3DST only



INTERACTIONS in 3DST

cube of dimensions: 2.4 m x 2.4 m x 2 m

FV 10 cm from the edge → 8.7 ton

SIMULATIONS PROCEDURE

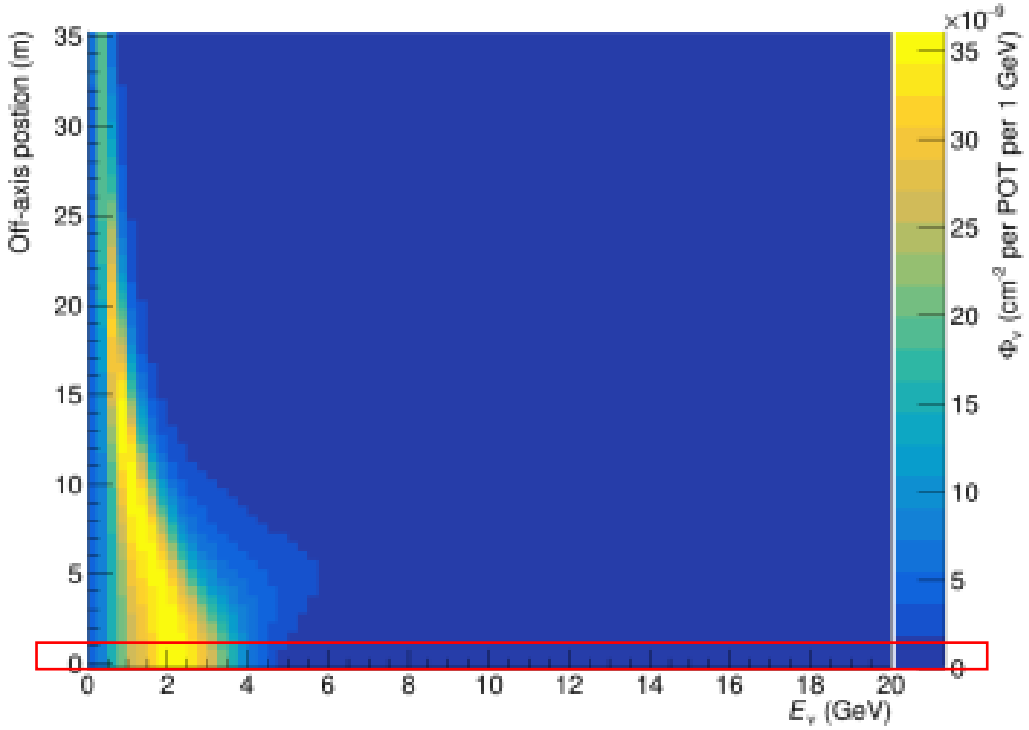
dk2nu + GENIE + smearing with expected resolution

Reweighting technique for events

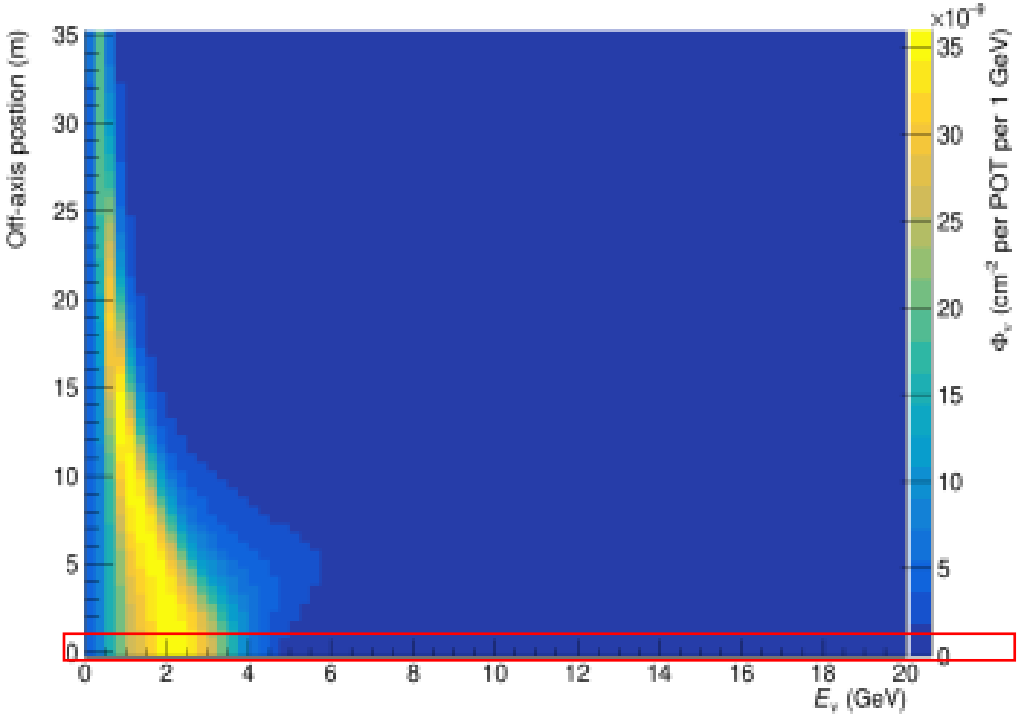
The nominal flux was simulated in the detector geometry
the events for the variated fluxes were reweighted accordingly to the variated flux distribution

averaged on the X, Y coordinates

Nominal flux

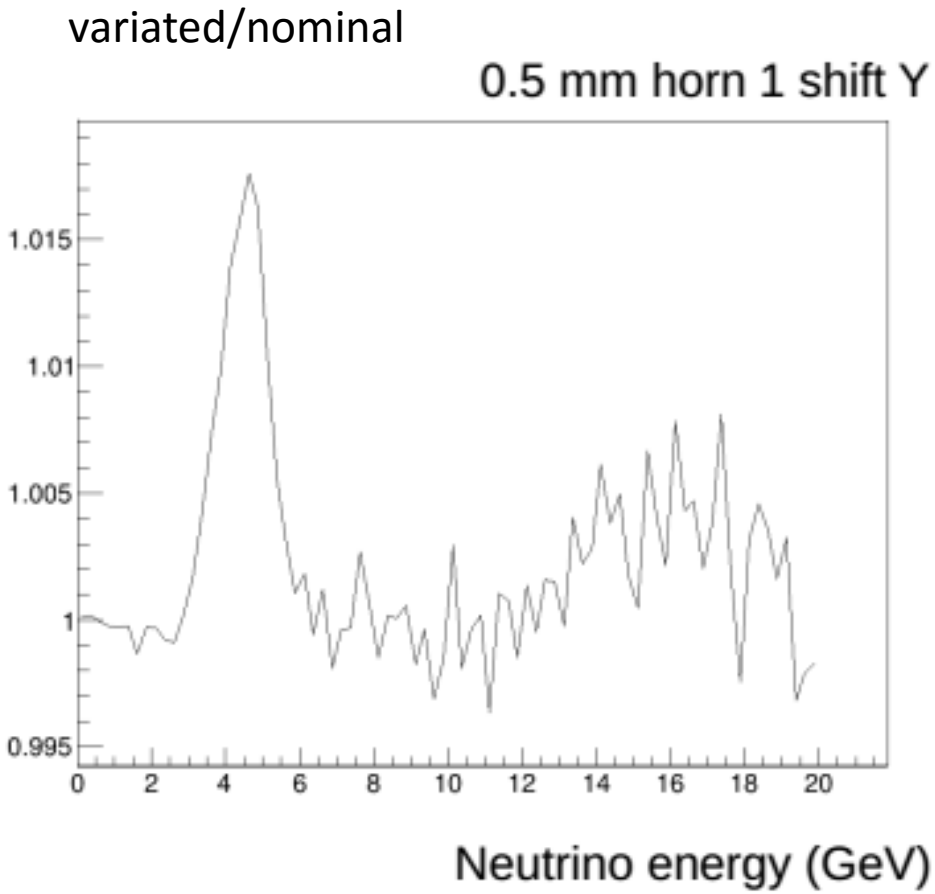


0.5 mm horn 1 shift Y



So the reweights are calculated as a function of the neutrino energy

Reweigthing technique for events



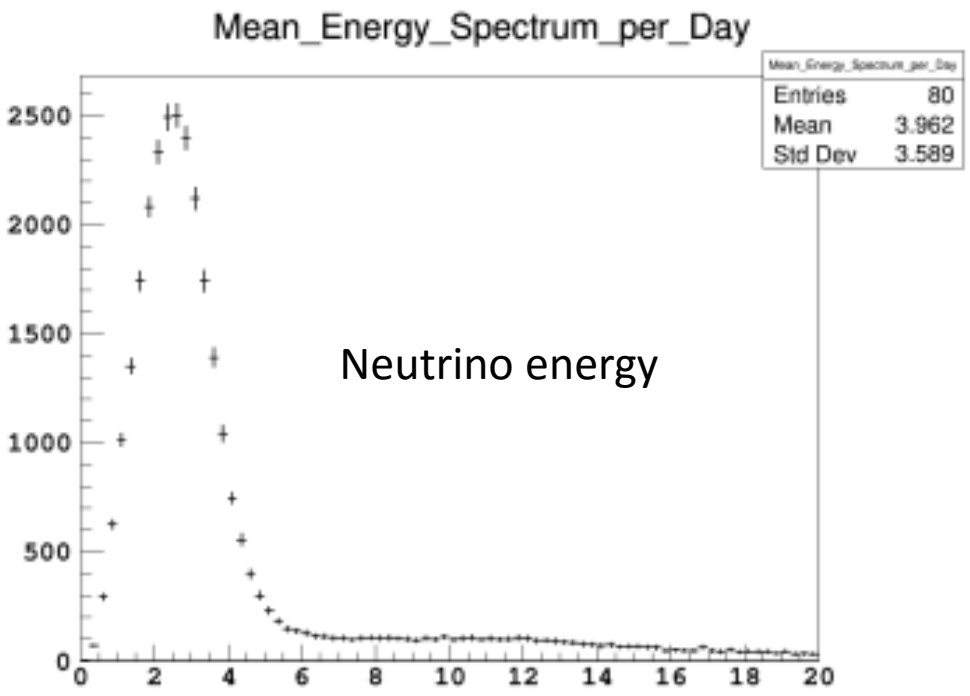
With respect to the CDR data 20 times more statistic was considered

In this analysis
the flux was integrated between -1 m to 1 m in X and Y directions
Bin energy≈ 3 GeV

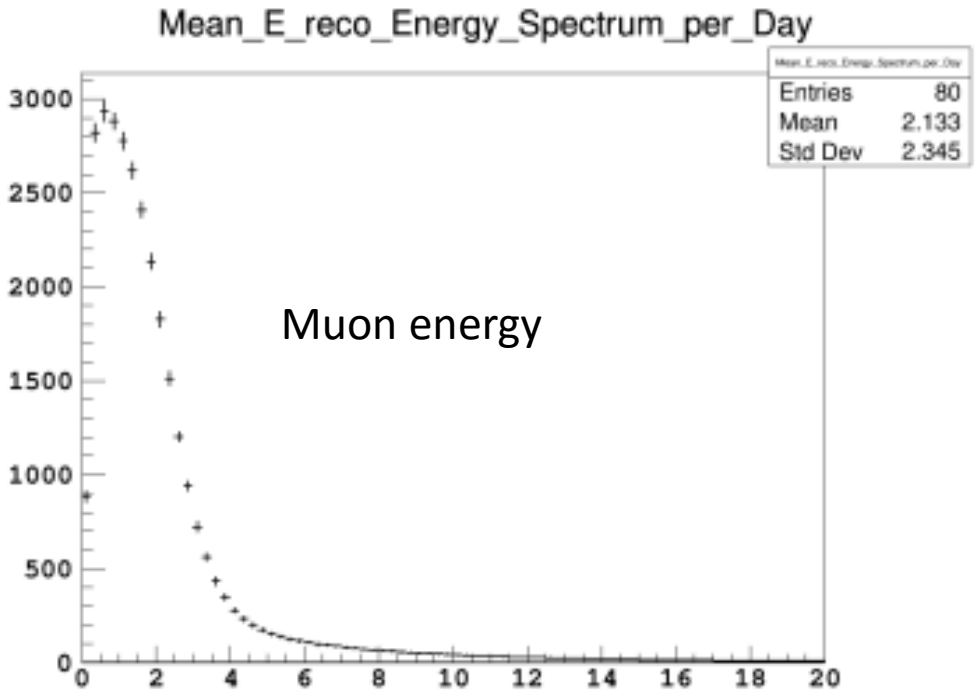
POT/week considered= POT year/52=1.1E21/52=2.12E19 POT

but remind that the number quoted as POT/year corresponds to about 206 days

Reconstructed spectra



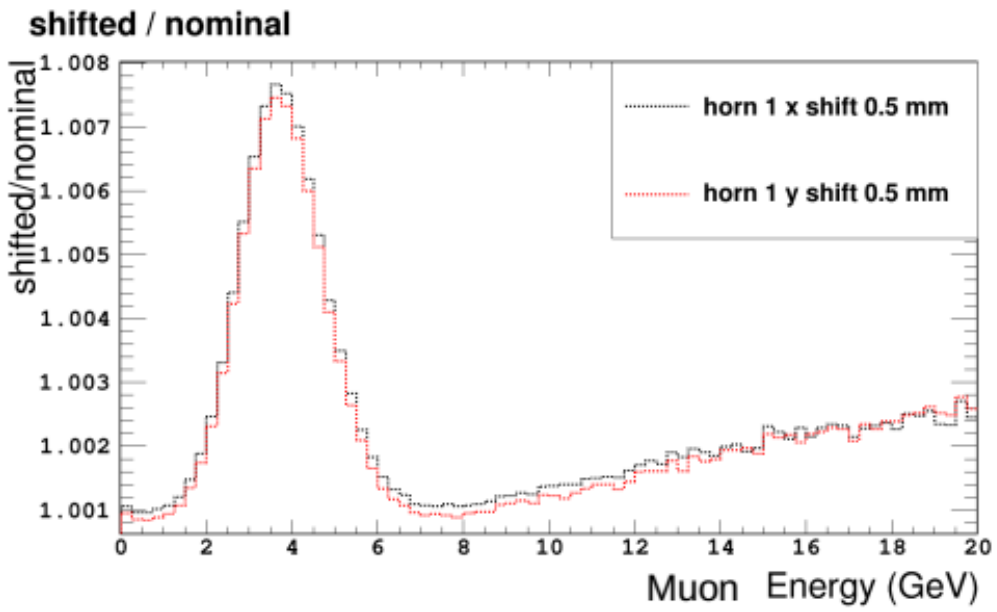
One day neutrino energy w/ smearing



One day muon energy w/ smearing

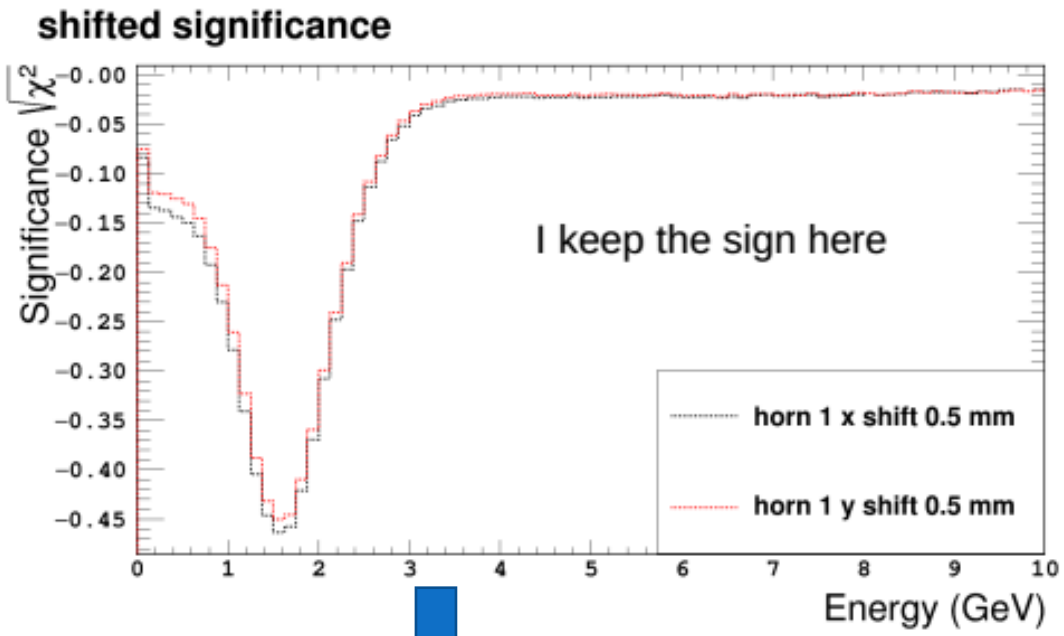
Reconstruction done by:
Muon in 3DST, calorimetrically 1%
Muon in TPC, mom. Res. 4% at 1GeV
smearing applied on true momentum

Analysis



Nbin =80

$$\frac{nominal-shifted}{\sqrt{nominal}}$$



$$Sqrt(dchi2) = \sqrt{\sum \frac{(nominal - shifted)^2}{\sigma_{nominal}}}$$

Spectral results (with 2% rate uncertainties included)

Muon reconstruction

sqrt(dchi2)	Horn 1X	Horn 1Y	Horn 2X	Horn 2Y
7 days	0.9 / (AC) 1.3	0.9 /(AC) 1.2	0.1/ (AC) 0.1	0.03 / (AC) 0.04
30 days	1.9	1.9 /	0.2 /	0.1 /

sqrt(dchi2)	Target density	P Beam width	P Beam offset	P Beam theta
7 days	2.2 / (AC) 2.8	1.2 / (AC) 1.6	0.1 / (AC) 0.1	0.1 / (AC) 0.1
30 days	4.5	2.5	0.2 /	0.2 /

sqrt(dchi2)	P Beam tilt	Horn current	Water layer	Decay pipe radius
7 days	0.03 / (AC) 0.1	2.9 / (AC) 4.2	1.3 / (AC) 1.9	1.9 / (AC) 2.6
30 days	0.1	6.1	2.6	3.9

AC is the validation by Artem (who did not include 2% rate uncertainty and used 3.8E19 pot instead of 2.1E19 pot

In first approximation

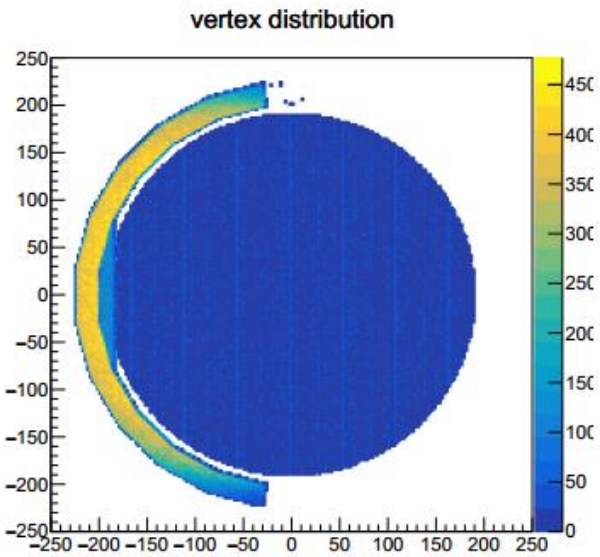
$$Sqrt(dchi2) = \sqrt{\sum \frac{(nominal - shifted)^2}{\sigma_{nominal}}} \approx \sigma_{confid}$$

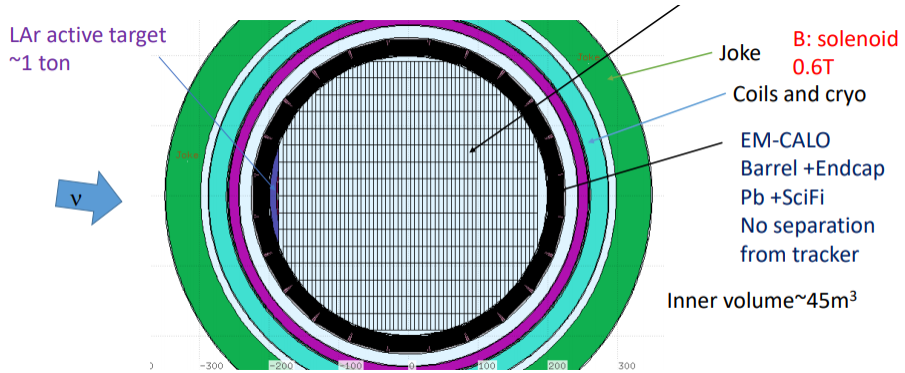
or more precisely the p value can be obtained by $\chi^2 = Sqrt(dchi2) + n$ with nof=nbins-1

Further studies

- 3DST FV cut to be changed from 10cm outer edge to 2cm → increase of 4(?) tons mass
- 3DST volume can be extended along X (there is lot of empty space left inside KLOE)
- ECAL events have been added to 3DST and currently under validation → expect to have a # of events comparable to 3DST.
- Now looking only to the muon spectrum, but also neutrino spectrum will be used

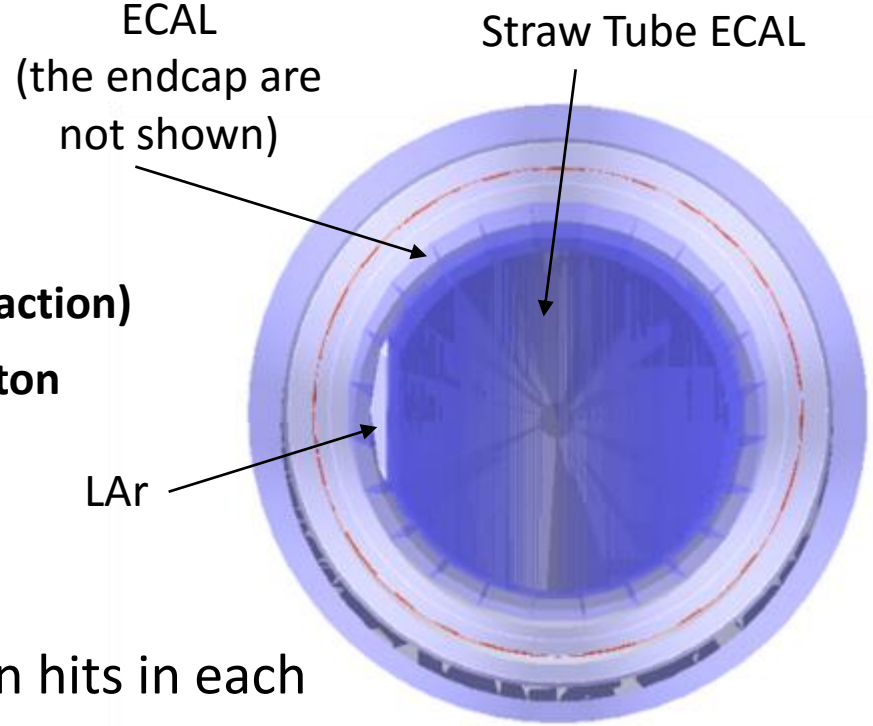
ECAL + STT





INTERACTIONS in

- STT fiducial volume: $R < 190$, $|X| < 159$ cm **7.4 ton**
- LAr meniscus fiducial volume: $R < 200$, $Z < -184$ cm **1 ton (small fraction)**
- ECAL fiducial volume: $200 < R < 225$, $|X| < 169$, $Z < 0$ cm **22.7 ton**



SIMULATIONS PROCEDURE:

dk2nu + GENIE + EDEPSIM (GEANT4) + fast reconstruction based on hits in each subdetector

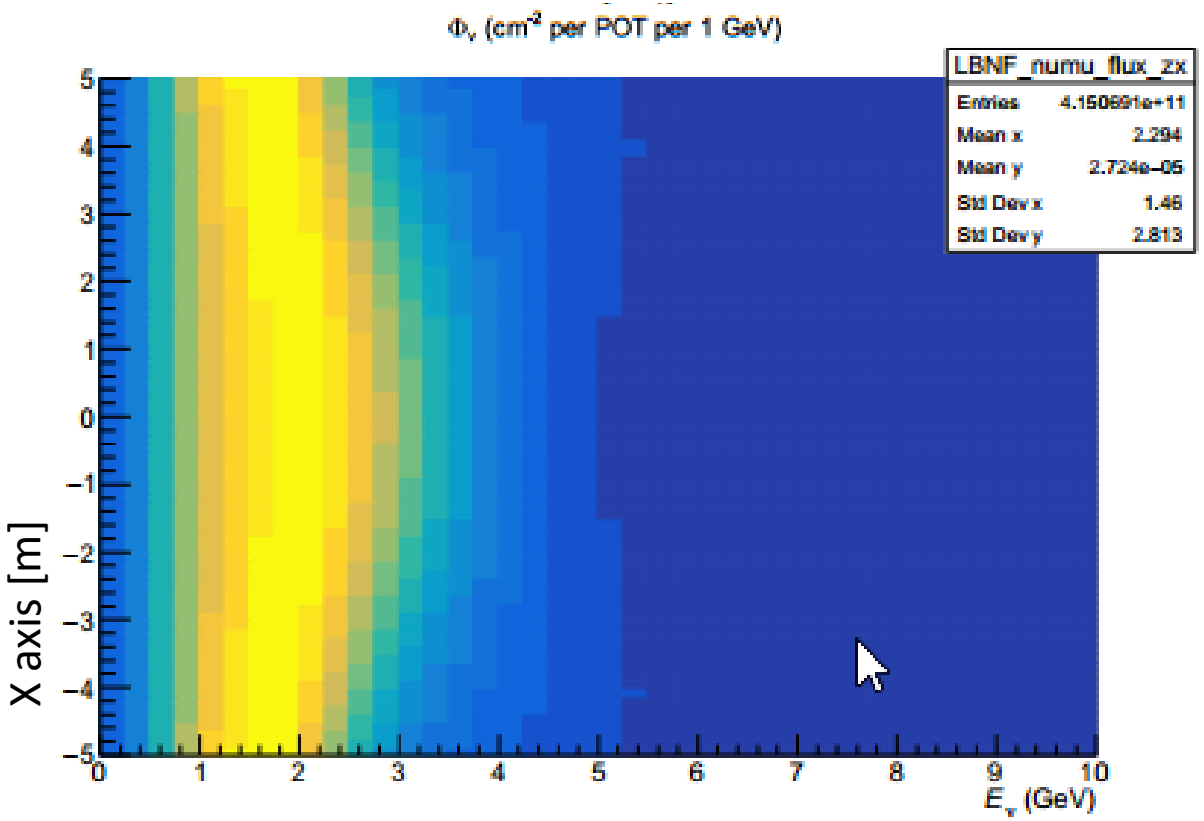
Reweighting

Simulating with dk2nu files allows us to have beam information up to the interaction point in the detector (neutrino direction and energy)

In this case the detector dimensions are bigger +-2m along X axis and +-2.5 m along Y axis

The variations depends on distance from z axis, on x coordinate, on y coordinates

Reweighting for X and Y distribution bins: 12.5 cm x 12.5 cm x 250 MeV



expected weekly exposure 3.78×10^{19} p.o.t.

Fast reconstruction based on hits

- Require a reconstructed muon track in STT: at least 6 hits in the vertical tubes (bending plane)

- Reconstructed energy =

  + calibrated energy deposited in ecal

  + deposited energy in liquid argon meniscus

  + kinetic energy for particles entering STT

- Kinetic energy for charged particle in STT :

smearing on momentum of particle at the entering point

(by using equation Gluckstern formula + multiscattering term based on number of detected hits and consistent with reconstruction of circular fit) **validated by full reconstruction**

- Neutral particles : from charged particles in STT or from photons from pi0 in ecal

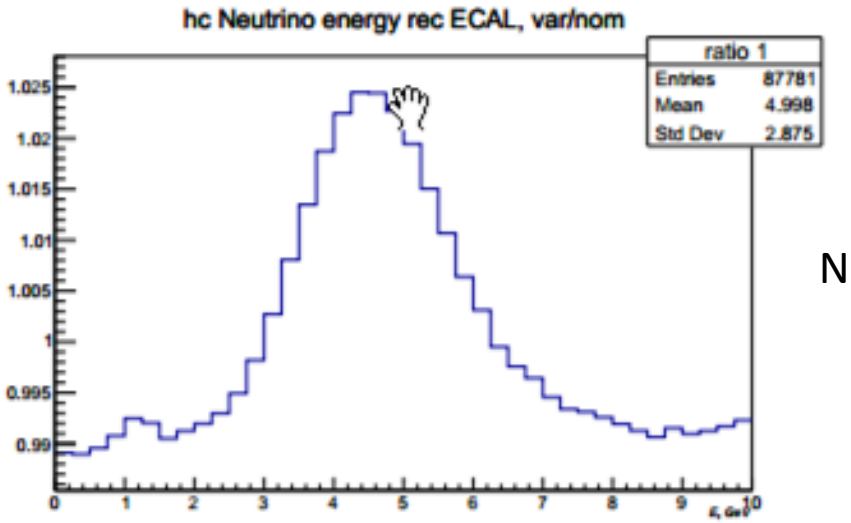
accordingly to results from full simulation

Muon energy resolution	sigma=3%	rms= 5%
Neutrino energy resolution	sigma= 7	rms=15%

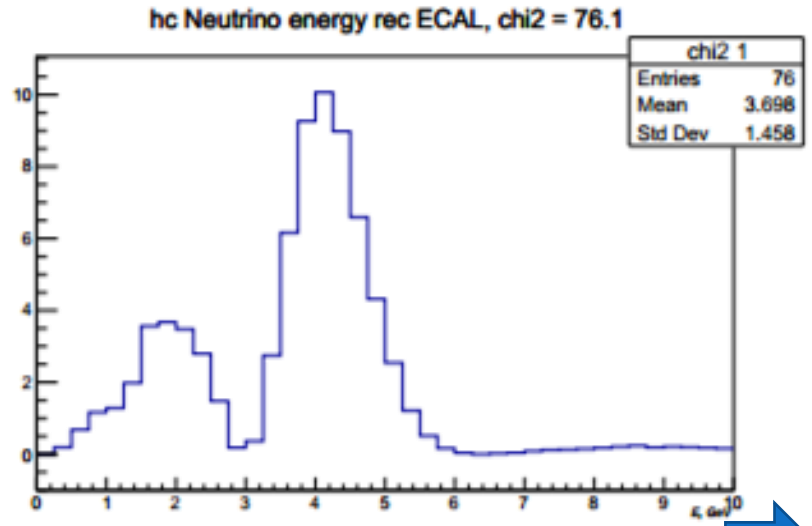
Analysis

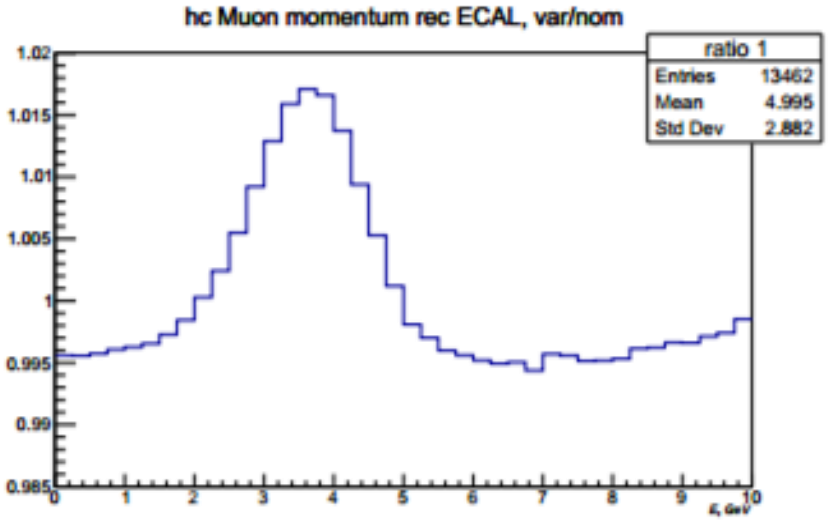
Shifted/nominal

$$\frac{(N_i^{\text{nom}} - N_i^{\text{var}})^2}{N_i^{\text{nom}}}$$

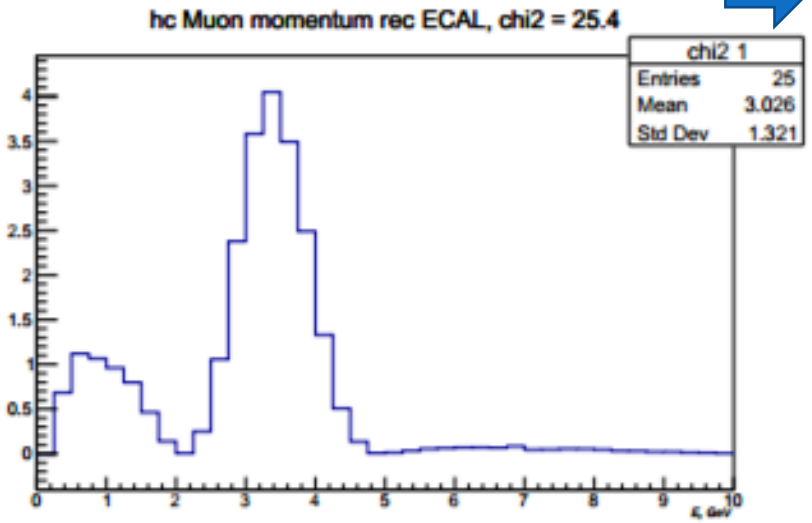


Neutrino energy





Muon momentum



$$\Delta\chi^2 = \sum_{i=1}^{N} \frac{(N_i^{\text{nom}} - N_i^{\text{var}})^2}{N_i^{\text{nom}}}$$

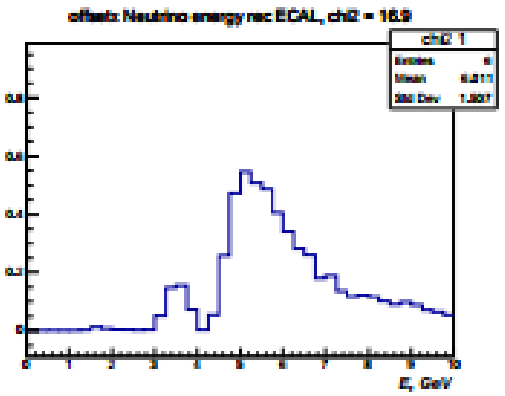
For variations depending on X or Y coordinates

the data were splitted in two histograms

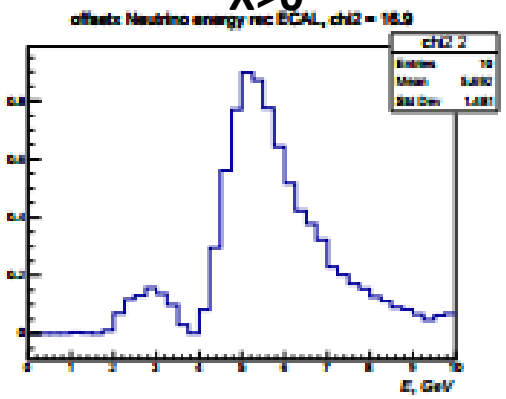
X dependence

Off set X

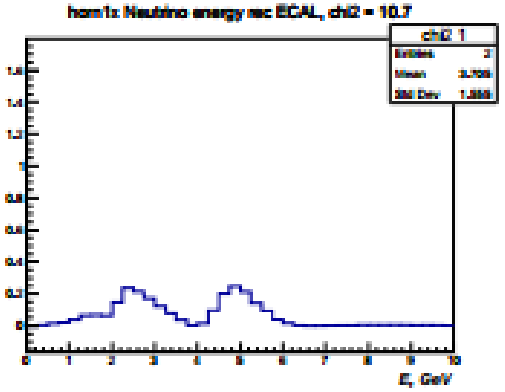
X<0

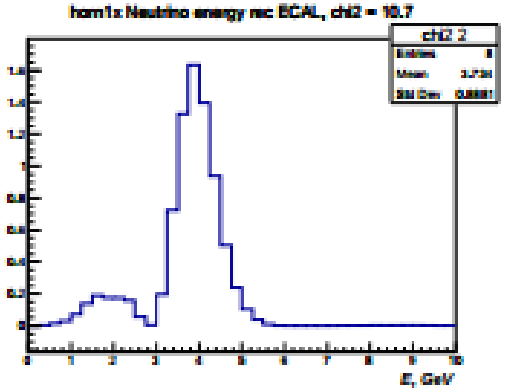


X>0



Horn 1 X

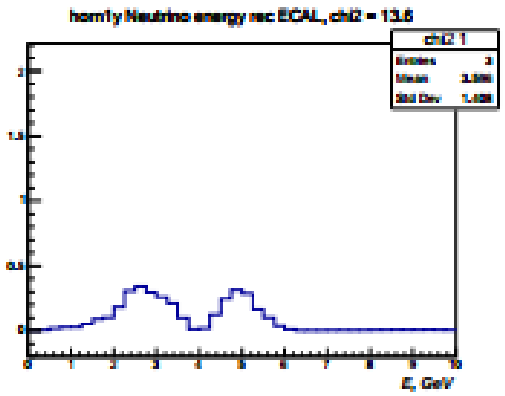




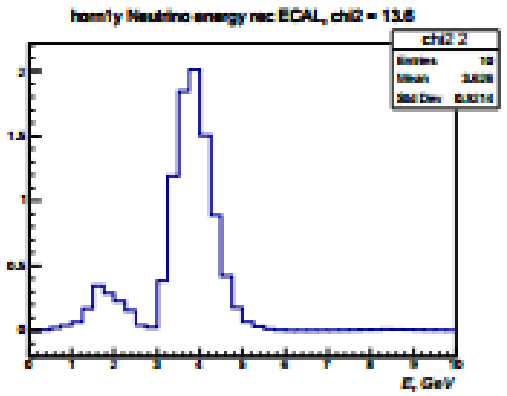
Y dependence

Horn 1 Y

Y<0

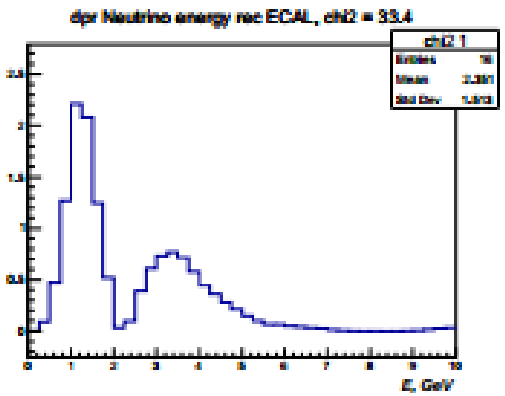


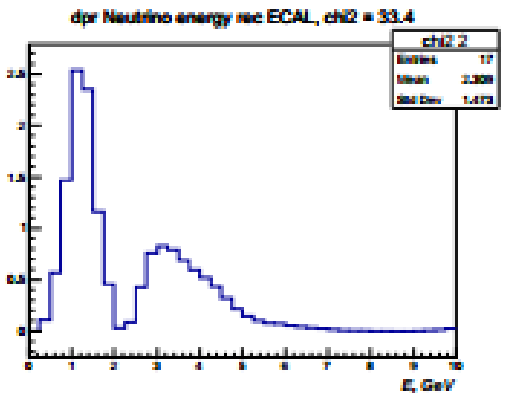
Y>0



Decay pipe radius

If the symmetry is cylindrical….no difference!





Results for 1 week

expected weekly exposure 3.78×10^{19} p.o.t.

Number of reconstructed events: **300 k in STT** **700 k in ECAL**

Beam parameter	Variation	ECAL $\Delta\chi^2(E_\nu)$ true	ECAL $\Delta\chi^2(E_\nu)$ rec	ECAL $\Delta\chi^2(E_\mu)$ true	ECAL $\Delta\chi^2(E_\mu)$ rec	STT $\Delta\chi^2(E_\nu)$ true	STT $\Delta\chi^2(E_\nu)$ rec	STT $\Delta\chi^2(E_\mu)$ true	STT $\Delta\chi^2(E_\mu)$ rec
Horn current	+3 kA	107.6	76.1	26.0	25.4	50.6	29.5	11.4	10.4
Water layer thickness	+0.5 mm	21.2	16.2	8.7	8.5	9.1	6.0	3.4	3.0
Decay pipe radius	+0.1 m	42.0	34.3	12.0	11.9	19.9	13.7	5.1	4.8
Proton target density	+2%	18.0	14.3	8.9	8.7	7.6	5.3	3.3	3.1
Proton beam radius	+0.1 mm	34.9	27.6	18.2	17.8	13.5	9.8	6.6	6.1
Proton beam offset X	+0.45 mm	24.6	16.9	9.0	8.7	9.5	5.3	3.0	2.7
Proton beam θ, ϕ	0.07 mrad θ, 1.57 ϕ	0.5	0.1	0.1	0.1	0.3	0.1	0.0	0.0
Proton beam θ	0.070 mrad	0.7	0.2	0.1	0.1	0.4	0.1	0.0	0.0
Horn 1 X shift	+0.5 mm	16.2	10.7	4.3	4.1	7.2	3.9	1.7	1.6
Horn 1 Y shift	+0.5 mm	20.6	13.6	5.7	5.5	7.3	4.1	1.8	1.7
Horn 2 X shift	+0.5 mm	0.4	0.2	0.1	0.1	0.2	0.1	0.0	0.0
Horn 2 Y shift	+0.5 mm	0.4	0.1	0.0	0.0	0.2	0.1	0.0	0.0

3 types of variations Radial corrections, X corrections, Y corrections

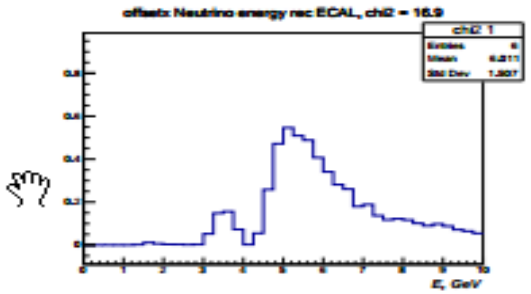
There is a significative difference between True and reconstructed → resolution is important
Neutrino energy is more sensitive with respect to muon momentum

Different shapes for identifying the problem

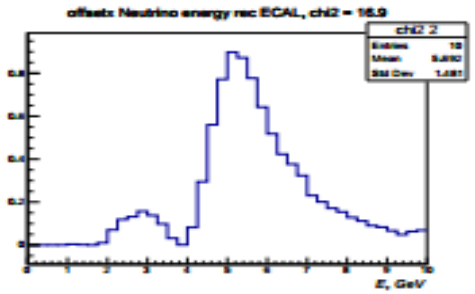
X dependence

Off set X

X<0



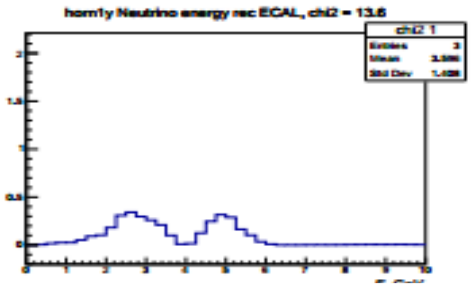
X>0



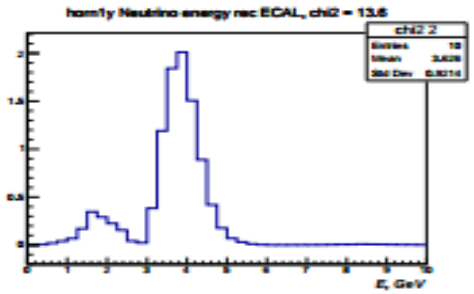
Y dependence

Horn 1 Y

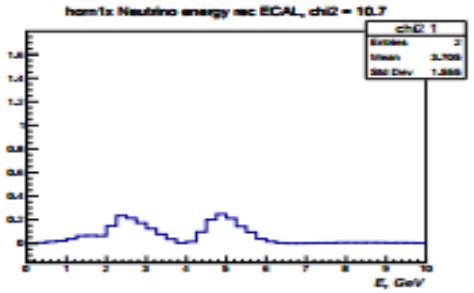
Y<0

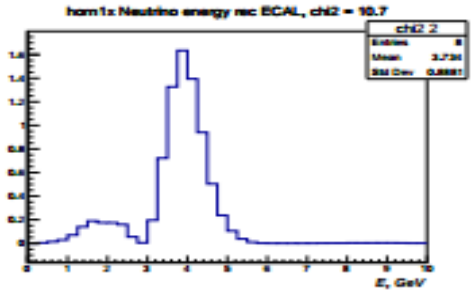


Y>0



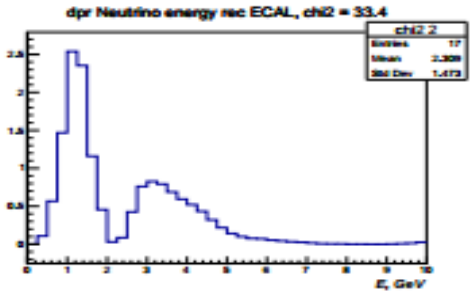
Horn 1 X

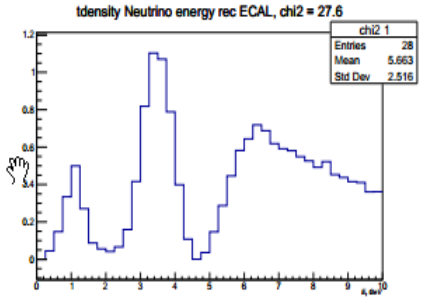


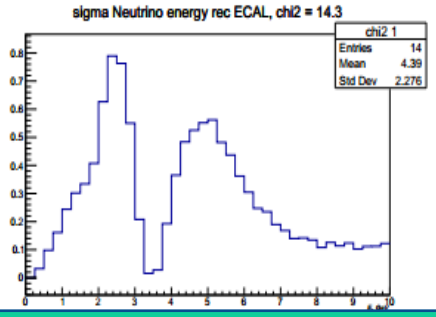


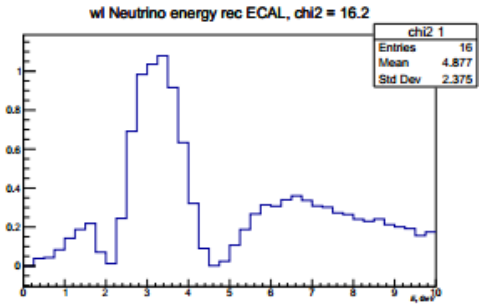
Cylindrical symmetry

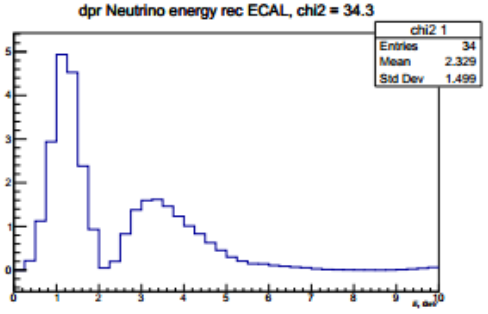
Decay pipe radius



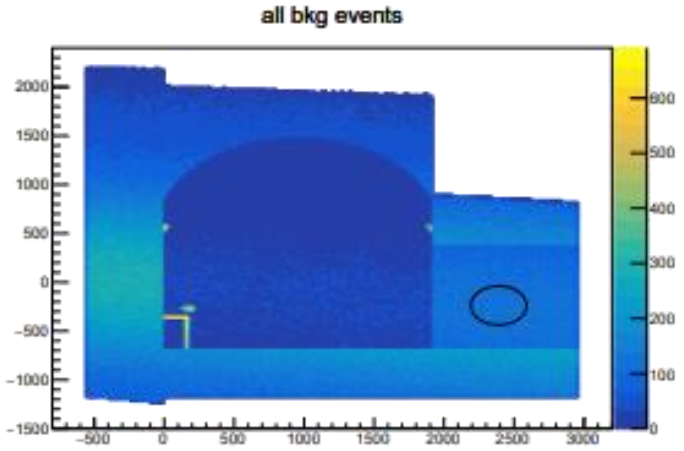








Background rejection for events in ECAL FV

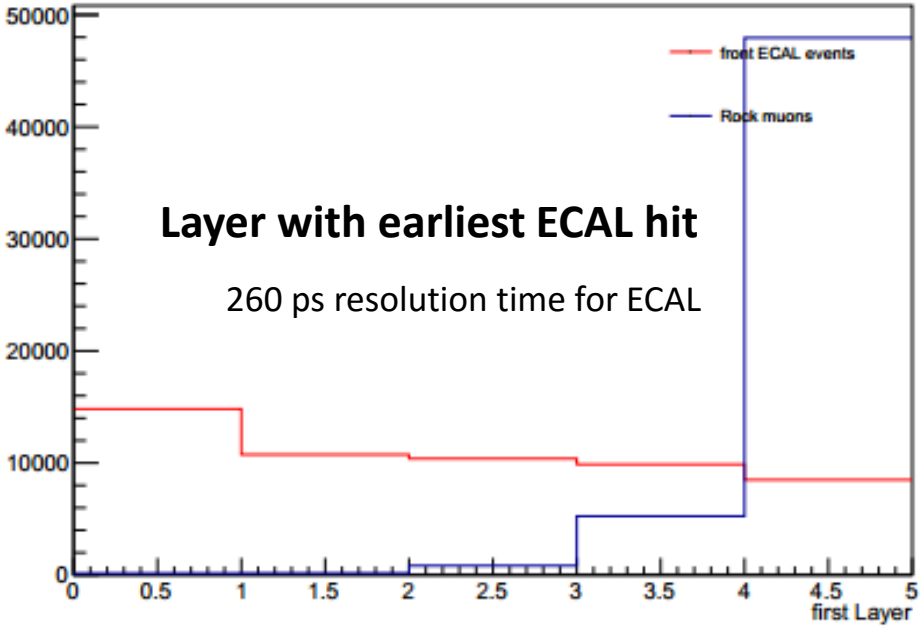


Reconstructed muon in STT with N(Y) hit >= 6 (YZ: bending plane)
Reconstructed hits in FV of front ECAL with deposited energy in (active) cell >= 100*keV*

Events from the side and downstream rocks result in negligible

Background from rock muons almost entirely from rocks & materials in front of SAND

Background reconstructed in STT and ECAL: 0.4%
Signal reconstructed in STT and ECAL : 73%



Cuts	ECAL	Ecal efficiency	Rock	Magnet
No Cut	2.234	100%	1447.26	50.82
Muon in ECAL FV	2.234	100%	12.73	18.92
$STTN(Y) > 6 \&\& ECALhits$	1.630	72.93%	6.048	3.443
NN cut	1.556	95.51%	0.100	0.069

With a Neural Network based on timing and topological information we can reject the background from rocks and from magnet with a small loss of efficiency and keeping ECAL FV

Conclusions

- **3DST only**

Beam monitoring with 3DST only and by using muon spectrum are not enough for 3 σ significance

→ Adding ECAL interactions will increase the statistic and the significance will improve

ECAL + STT

- Results indicate a sensitivity exceeding 3σ in one week for many variations:
  horn current, water layer thickness, decay pipe radius, proton target density, beam rms, beam off set X, horn 1 X shift, horn 1 Y shift
- More sensitivity for neutrino energy
- Possible identification of the type of beam variation

Further studies

→ For other geometries (ECAL + 3DST)

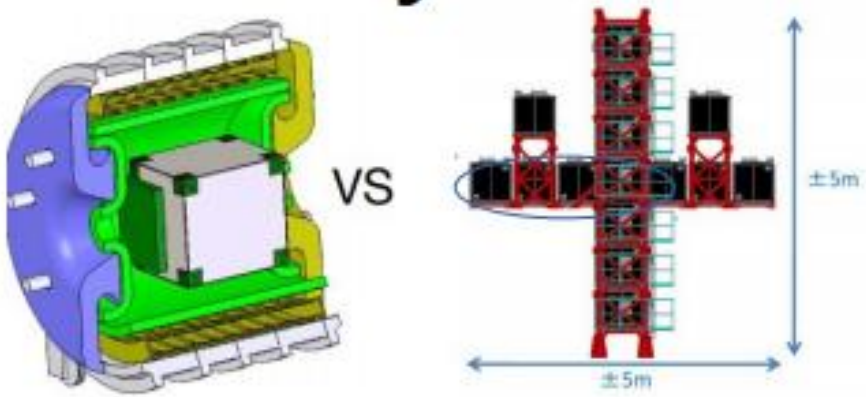
→ Use complete detector simulation and reconstruction for all detector configurations

→ Improving and checking the background rejection

BACKUP

Ingrid-like 28 ton Rate results (with 2% rate uncertainty)

- Spectral monitoring is needed obviously

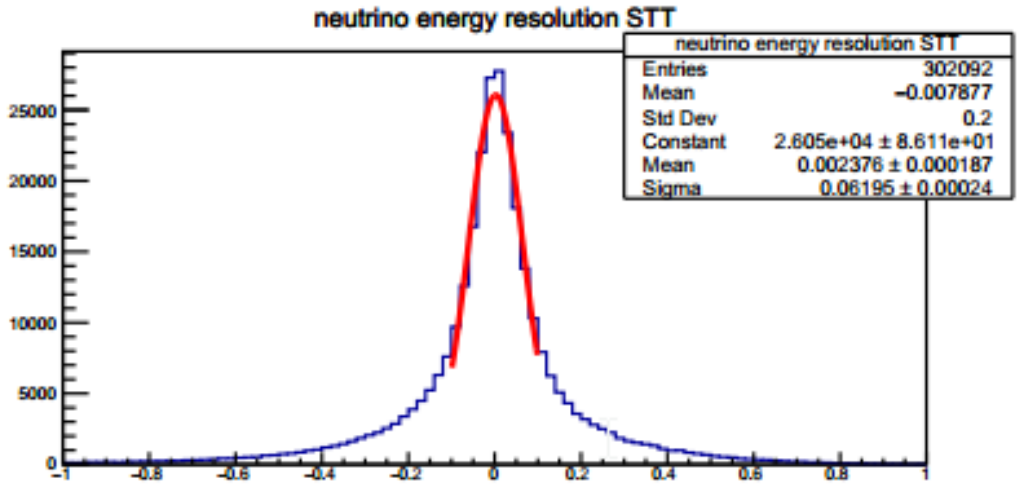


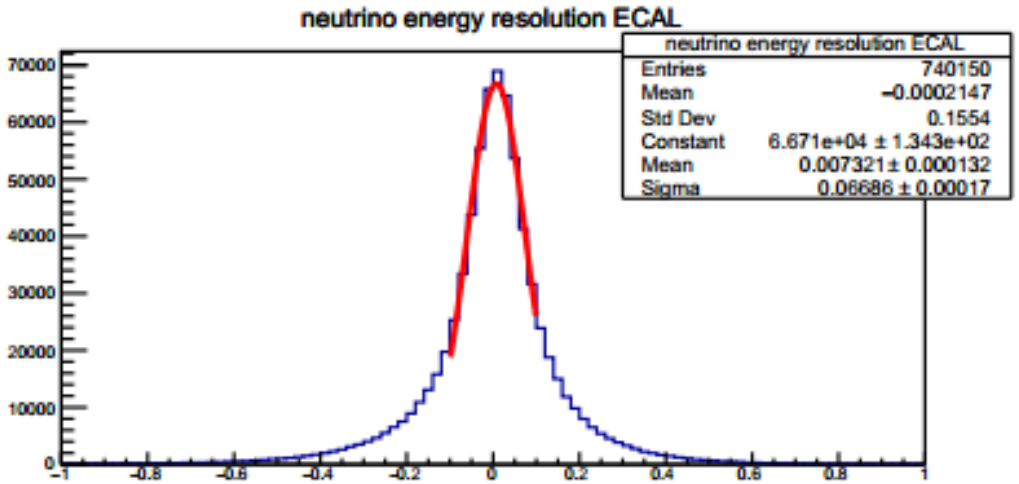
sqrt(dchi2)	Horn 1X	Horn 1Y	Horn 2X	Horn 2Y
7 days	0.5	0.1	0.02	0.00

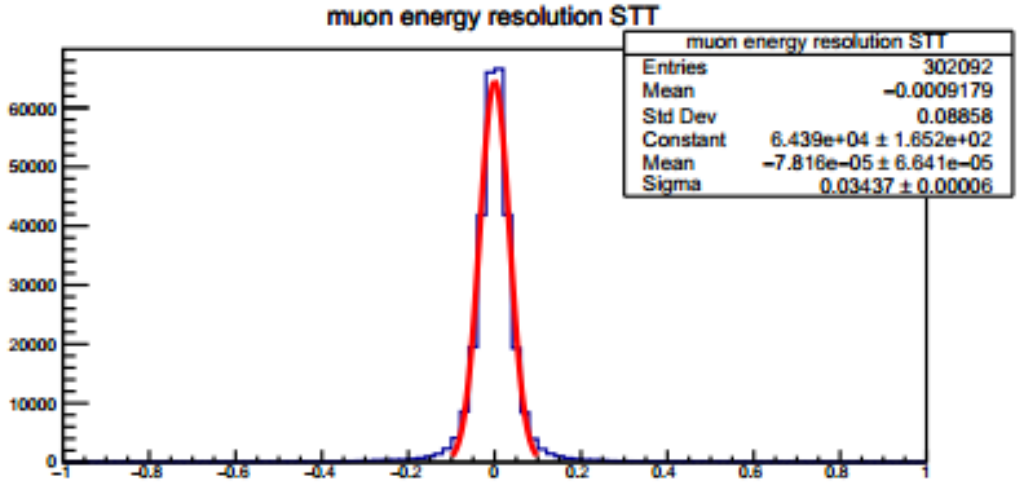
sqrt(dchi2)	Target density	P beam width	P beam offset	P beam theta
7 days	0.02	0.02	0.09	0.03

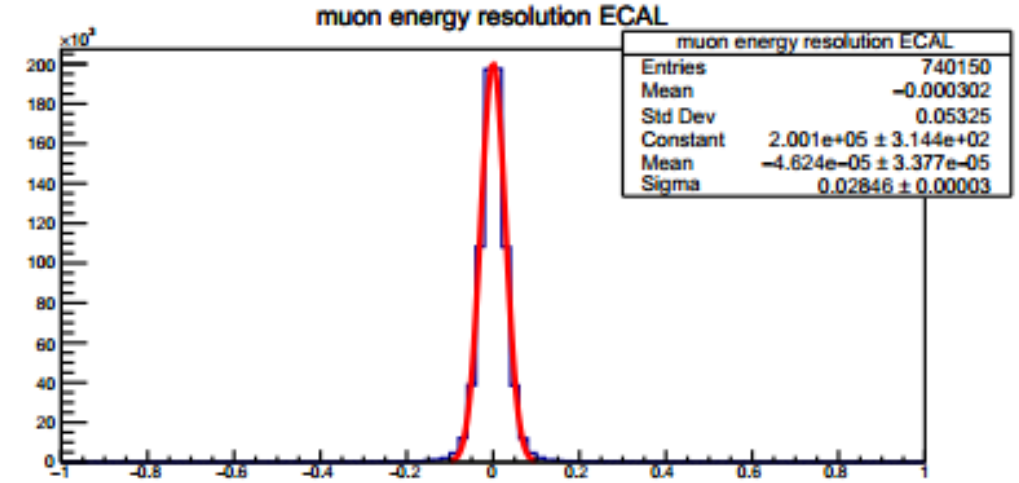
sqrt(dchi2)	P beam tilt	Horn current	Water layer	Decay pipe radius
7 days	0.00	0.2	0.5	0.5

Energy resolution

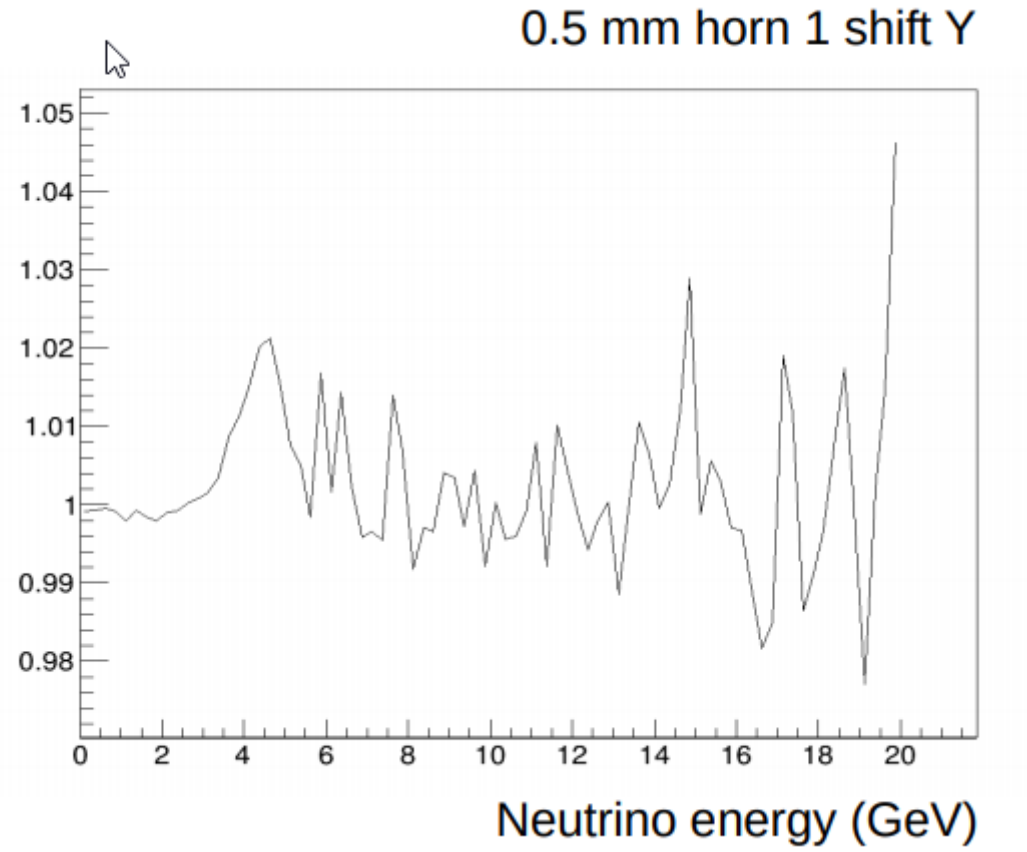


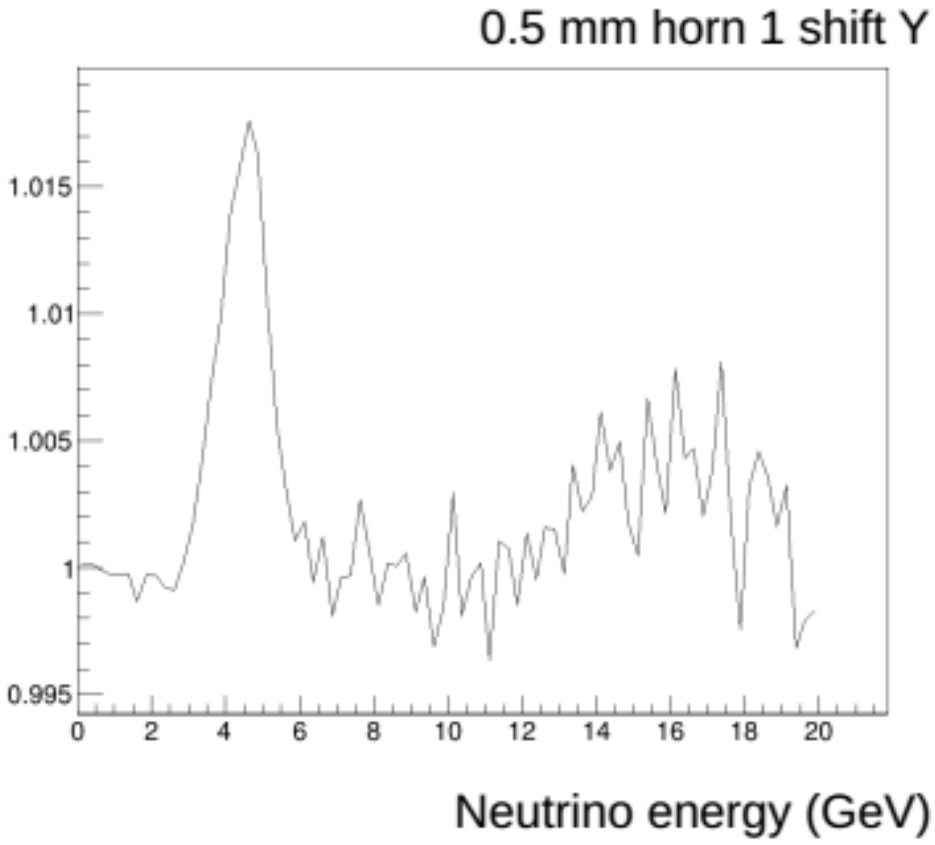


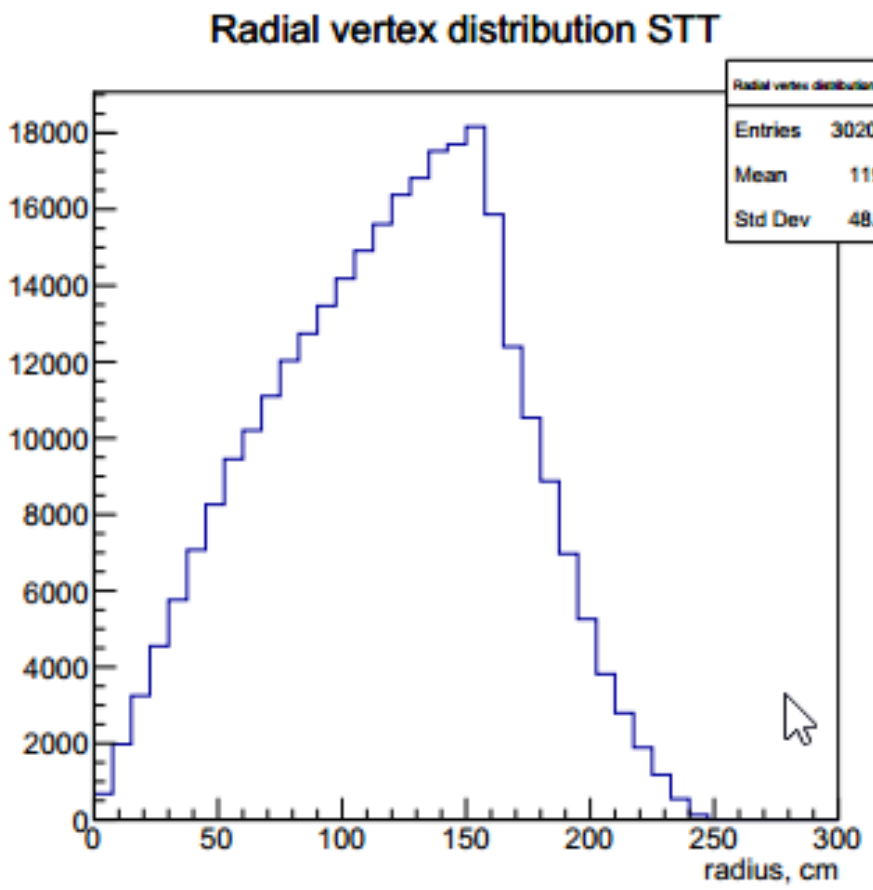


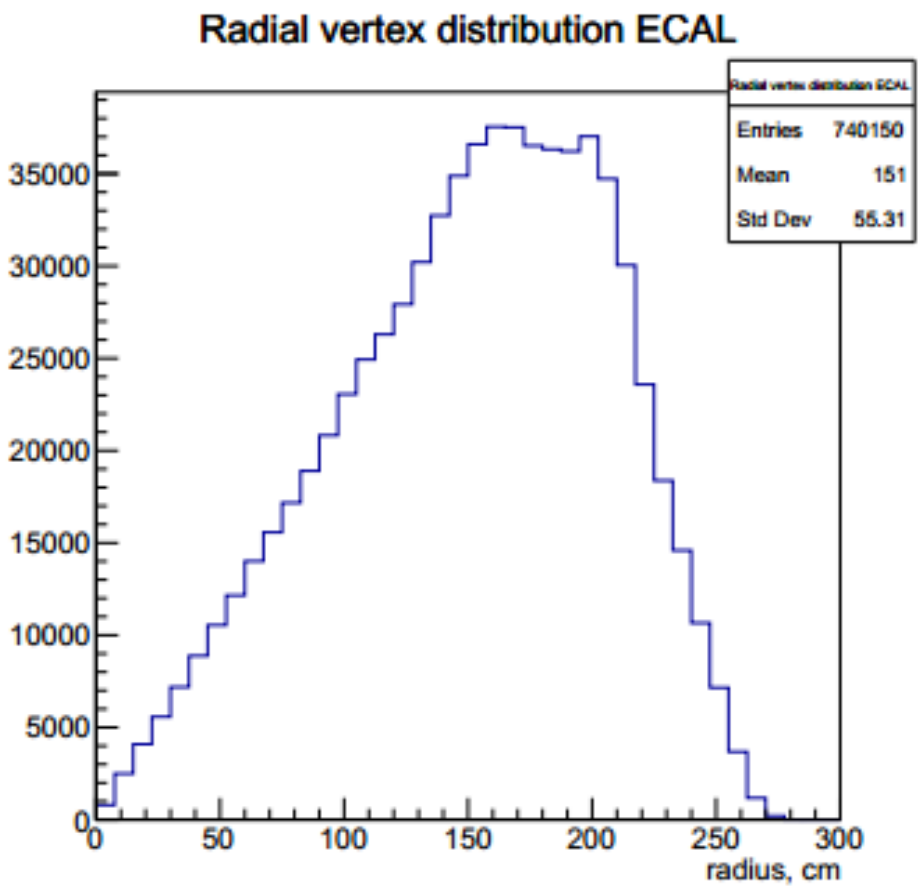


Old reweigthing
(very poor statistic for variated flux)



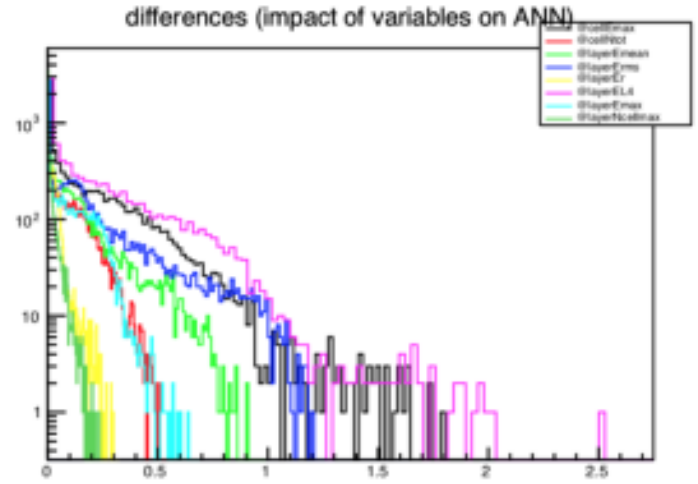


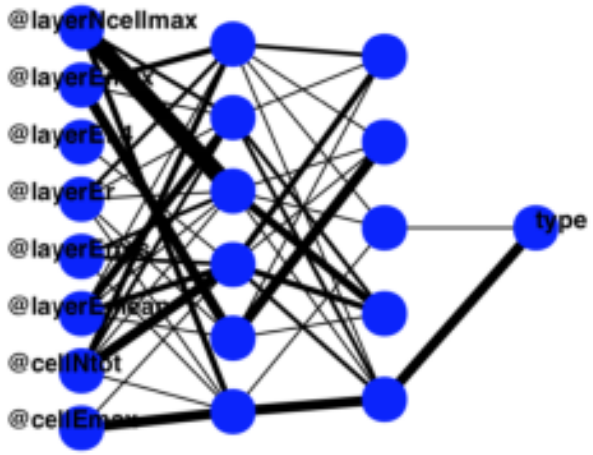


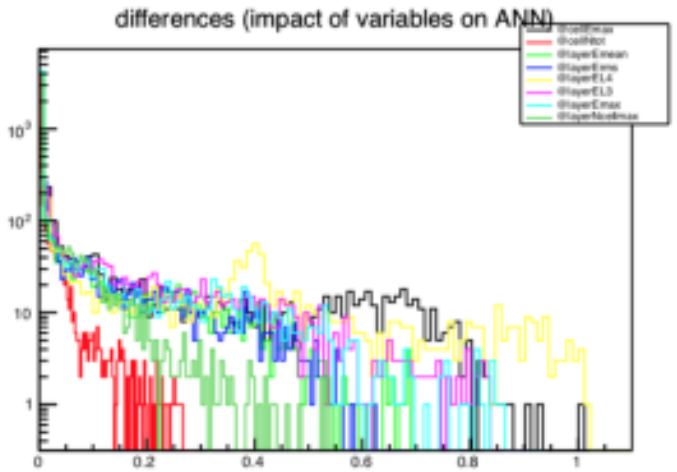


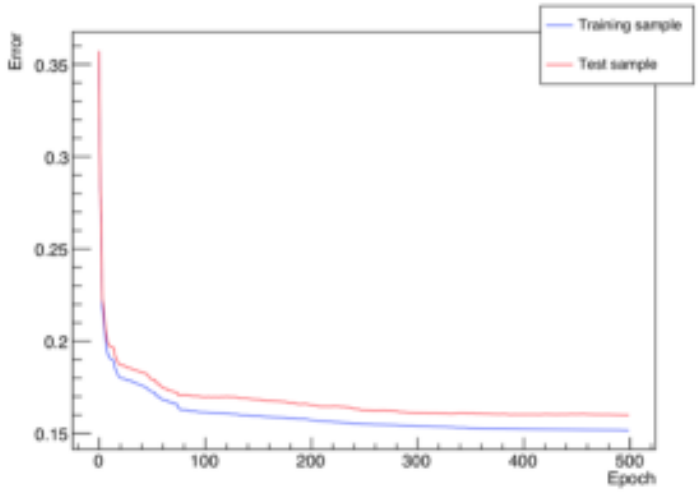
Both ECAL and STT extend to large radial distances up to 2.5 m

Neural network analysis









- 8284 train and 8285 test entries, 8063 signal and 8506 background events
- Events normalized to expected POT per spill : $7.5E13$