

Beam Monitoring in **ECAL+STT**

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Motivations

Study on-axis beam monitoring with a well known detector configuration (DocDB #13262) including **ECAL+STT** (see LBNC presentation 6.12.2019)

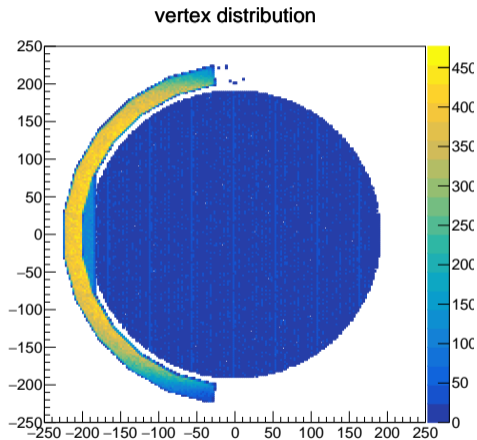
Idea: compare the reconstructed neutrino and muon spectra obtained with the nominal beam settings with the ones including the various systematic changes (e.g. horn current and positions, etc.) recommended by the beam working group and evaluate the corresponding sensitivity

- **STT** fiducial volume: $R < 190, |X| < 159$ cm
- **LAr meniscus** fiducial volume: $R < 200, Z < -184$ cm
- **ECAL** fiducial volume: $200 < R < 225, |X| < 169, Z < 0$ cm (22.8t FV)

Procedure

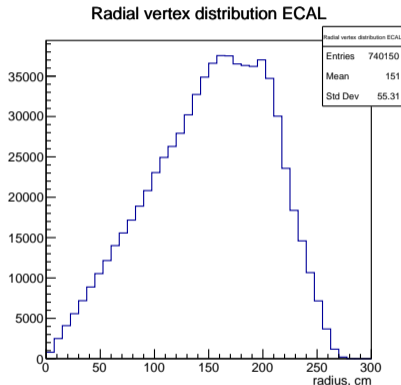
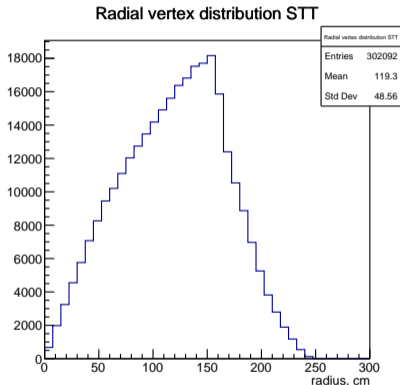
- making primary vertex distribution map
- rotate all events to the beam direction (-0.101 rad)
- expected weekly exposure 3.78×10^{19} p.o.t.
- simulate one week statistics with nominal beam setting and the complete chain `dk2nu+GENIE+edep-sim` (GEANT4)
- reconstruction smearing applied using detector hits for all detectable particles

Vertex distribution



Detector configuration DocDB # 13262

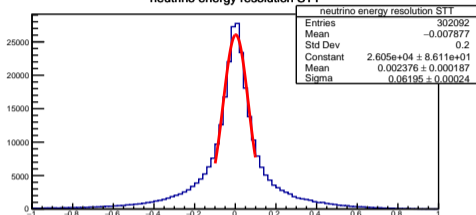
Distance to the beam axis - FHC



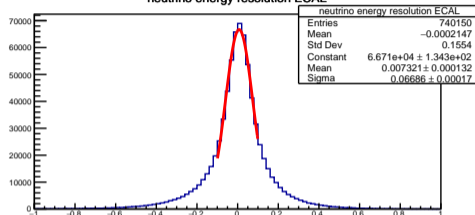
Both ECAL and STT extend to large radial distances up to 2.5 m

Energy resolution

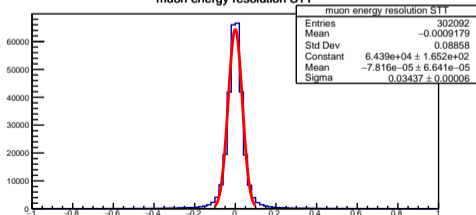
neutrino energy resolution STT



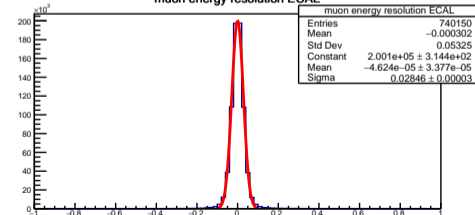
neutrino energy resolution ECAL



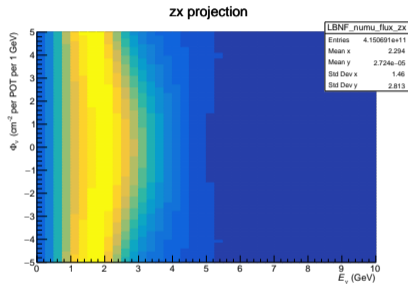
muon energy resolution STT



muon energy resolution ECAL



Beam profile distributions



We have different beam variations:

- beam variations with cylindrical symmetry (e.g. horn current)
- beam changes along **x-axis** (e.g. horn 1 x)
- beam changes along **y-axis** (e.g. horn 1 y)

Using 3 dimensional beam re-weighting: **XY-beam distribution**

Statistical analysis

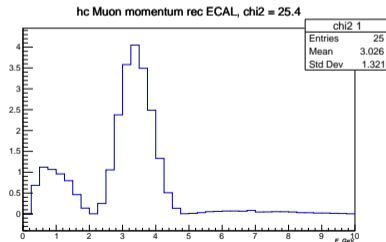
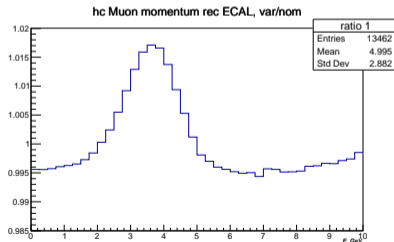
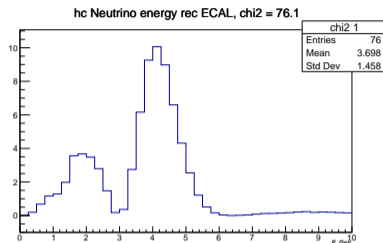
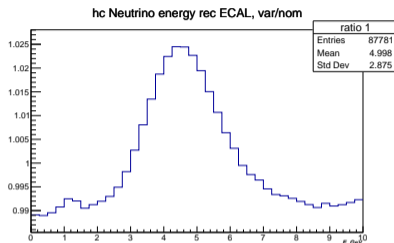
- **Nominal sample:** complete simulation of one week statistics with reconstruction smearing N^{nom}
- **Variation sample:** re-weight nominal sample using ratios between nominal and beam variations using XY beam energy distribution N^{var}
- Use the following test statistics:

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

where N is the total number of bins used in the histograms ($N=80$, $E_\nu \in (0, 20)$ GeV)

- Using energy, X, Y, and radial information we may identify specific beam variations

Example: horn current variation

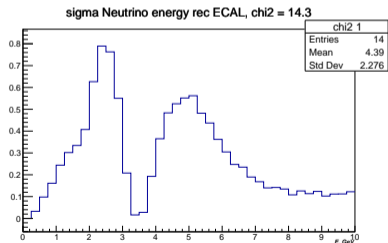
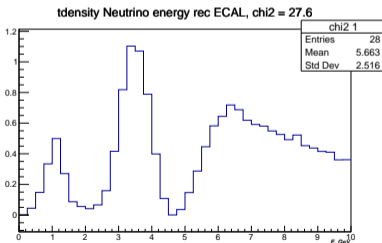
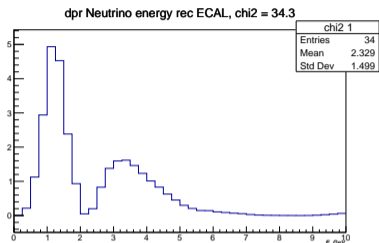
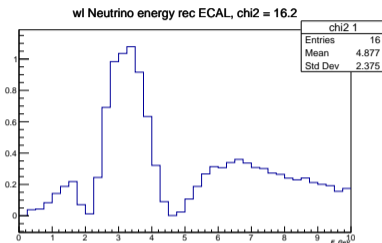


Results - 1 week

Beam parameter	Variation	ECAL				STT			
		$\Delta\chi^2(E_\nu)$		$\Delta\chi^2(E_\mu)$		$\Delta\chi^2(E_\nu)$		$\Delta\chi^2(E_\mu)$	
		true	rec	true	rec	true	rec	true	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

Radial corrections, X corrections, Y corrections

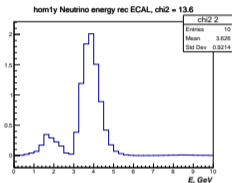
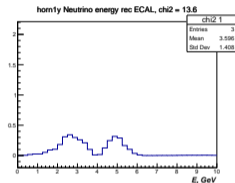
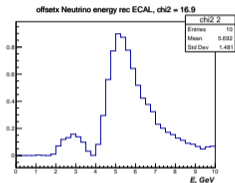
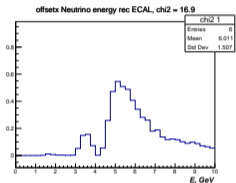
Energy dependence with cylindrical symmetry



Energy dependence without cylindrical symmetry

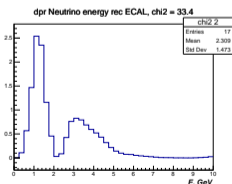
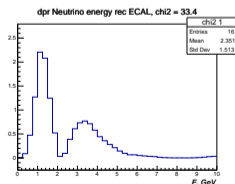
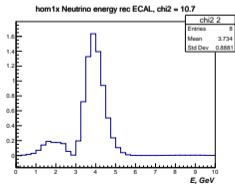
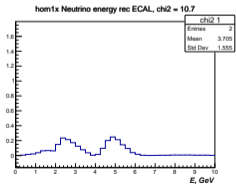
X dependence
Off set X

Y dependence
Horn 1 Y



Horn 1 X

Decay pipe radius

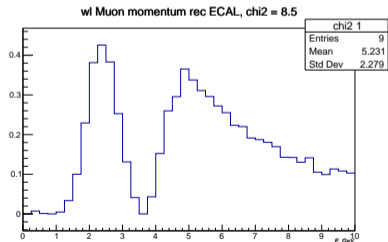
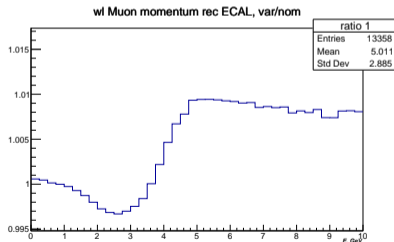
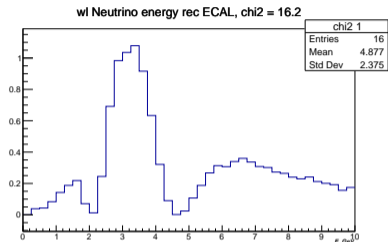
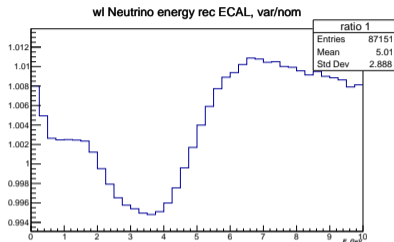


Summary

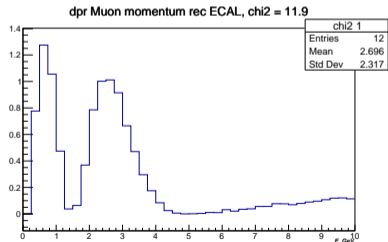
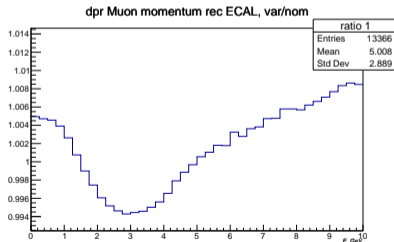
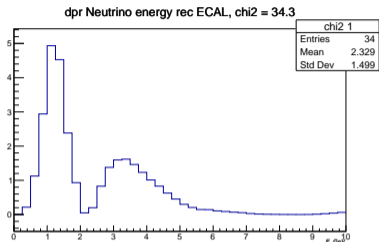
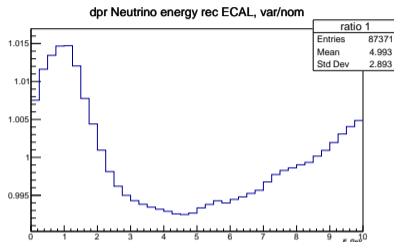
- Beam monitoring study using the ECAL+STT detector option in docdb #13262 with chain GENIE+GEANT4+edep-sim+reconstruction smearing from hits
- Use complete simulation of one week statistics with the nominal FHC beam settings and event re-weighting to account for the variations of the beam parameters
- The large ECAL mass (22.8 t) combined with its wide radial coverage (up to 2.5 m) make the front ECAL an excellent tool for beam monitoring
- Results indicate a sensitivity exceeding 3σ in one week for the following 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
- The reconstructed neutrino energy is more sensitive to beam variations than the reconstructed muon energy (y_{Bj} smearing)

Back up slides

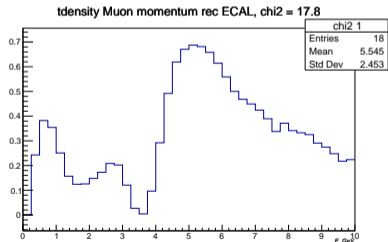
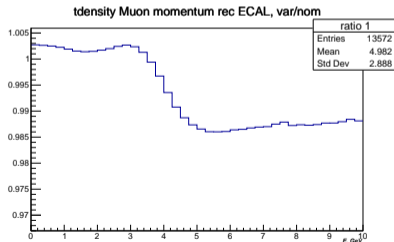
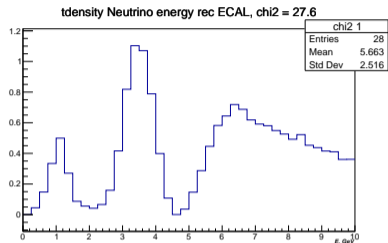
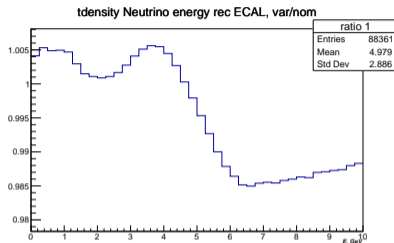
Water layer thickness variation



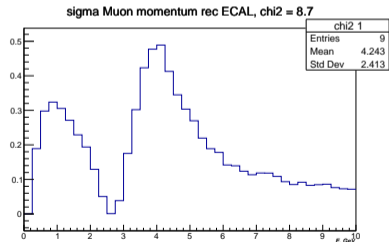
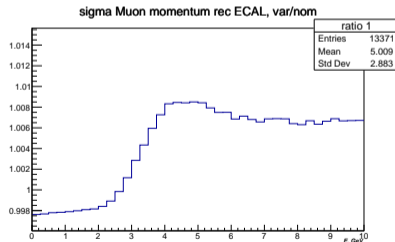
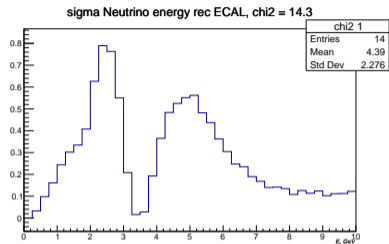
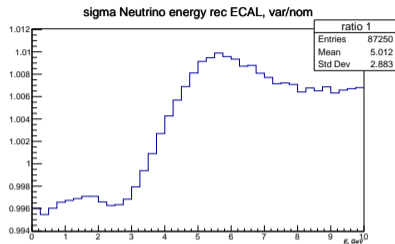
Decay pipe radius variation



Proton target density variation



Proton beam radius

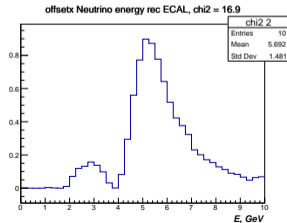
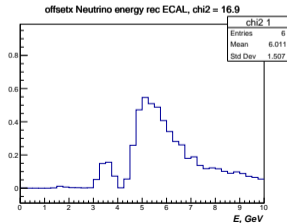
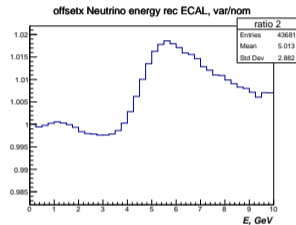
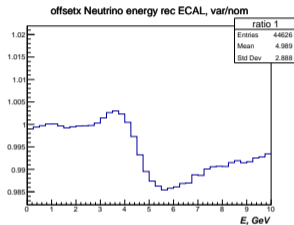


Proton beam off set X

X variation bins:

-200 .. 0 cm

0 .. 200 cm

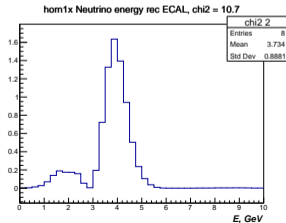
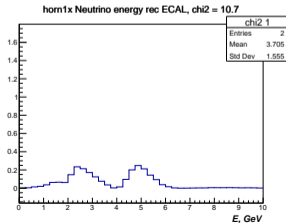
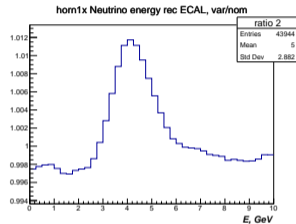
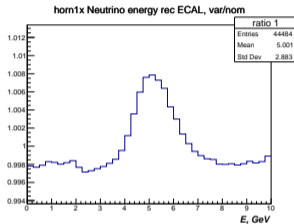


Horn 1 X

X variation bins:

-200 .. 0 cm

0 .. 200 cm



Horn 1 Y

Y variation bins:

-200 .. 0 cm

0 .. 200 cm

