Beam Monitoring in ECAL+STT

Artem Chukanov, Bing Guo, Roberto Petti, Svetlana Vasina

SAND meeting 17^{th} of March 2020

Main goal

Study the possibility of beam monitoring with the SAND detector in ECAL+STT configuration

Idea: get the neutrino beam spectrum and muon energy spectrum for nominal conditions and compare them with the beam with all the various systematic changes (including horns, protons, etc.) recommended by the beam working group and find the sensitivity to these changes

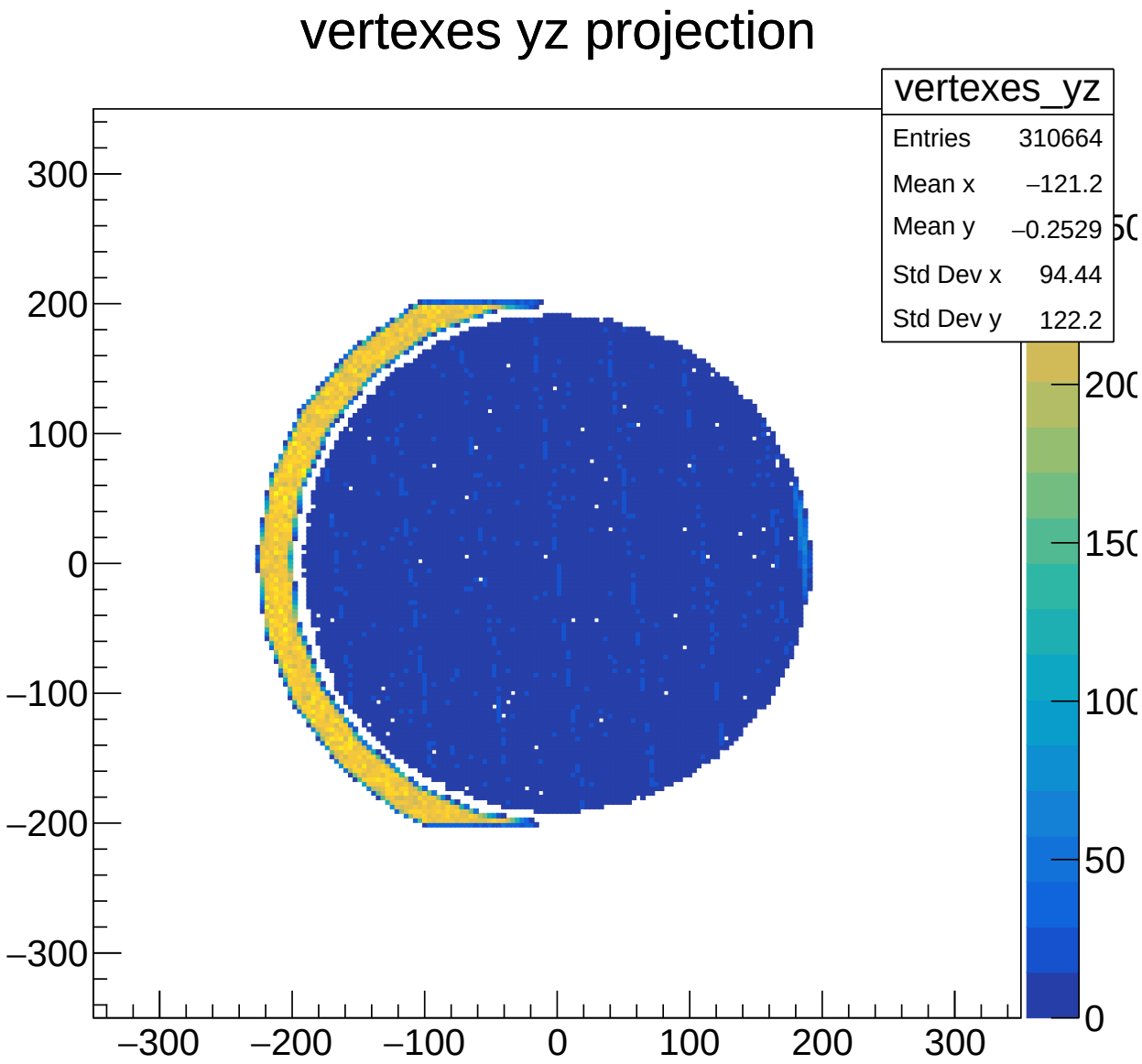
- fiducial volume STT: R < 190, $|X| < 159$ cm
- fiducial volume ECAL: $200 < R < 225$, $|X| < 169$, $|Y| < 200$, $Z < 0$ cm

Study with a well known detector option (DocDB # 13262) in line with SAND presentation at LBNC (6.12.2019)

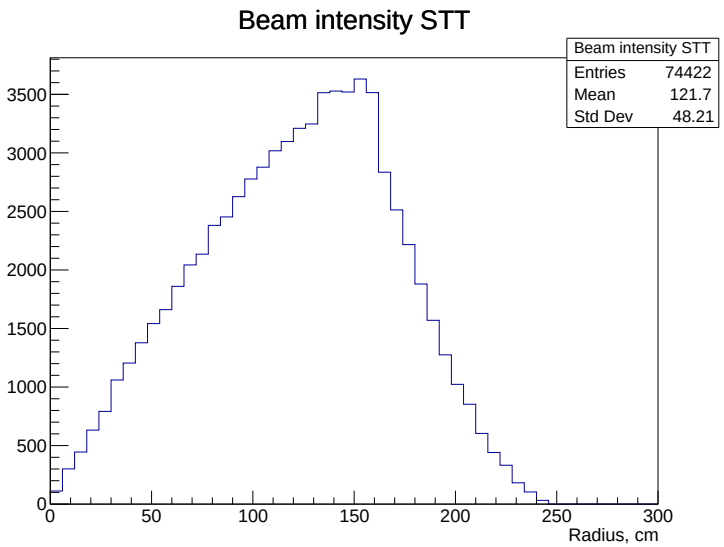
Procedure

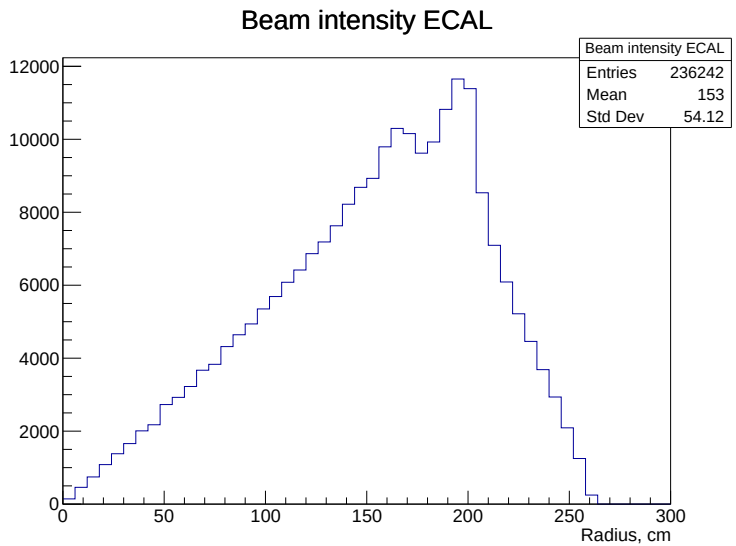
- making primary vertex distribution map
- rotate all events to the beam direction (-0.101 rad)
- expected weekly exposure 3.78×10^{19} p.o.t.
- simulate one week statistics with nominal beam setting and the complete chain dk2nu+GENIE+GEANT4+edep-sim
- reconstruction smearing applied using detector hits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

Vertex distribution



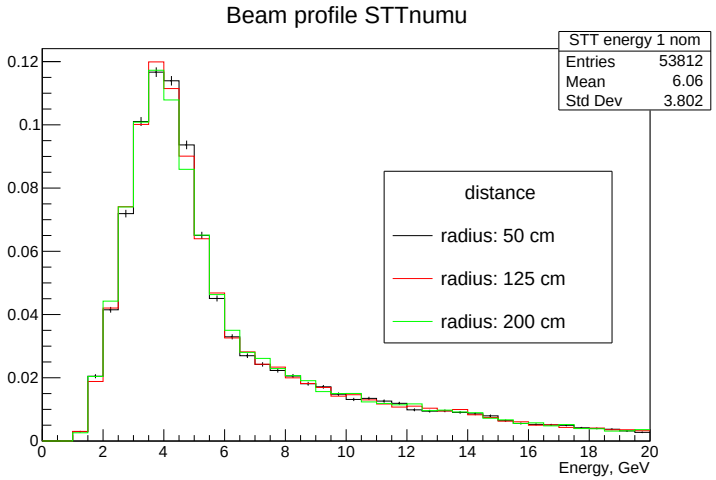
Distance to the beam axis - FHC

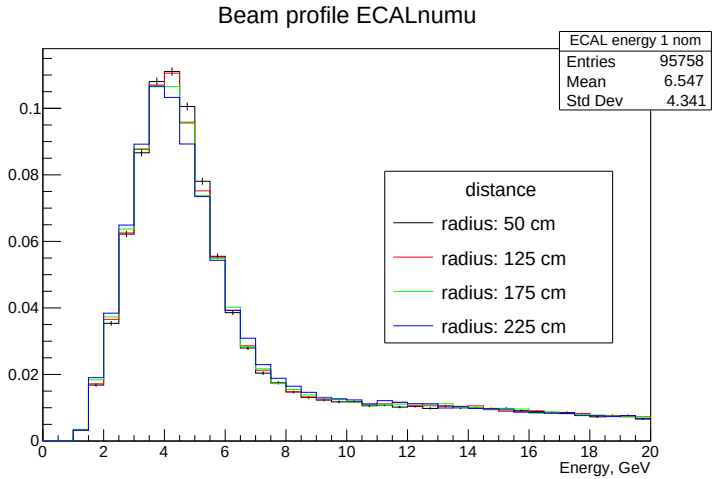


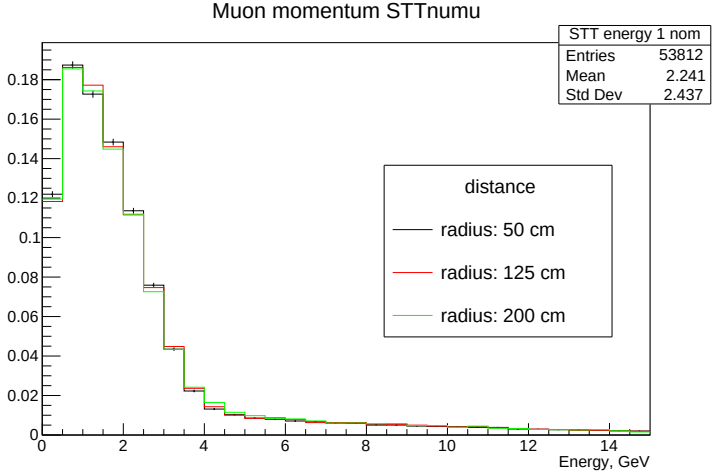


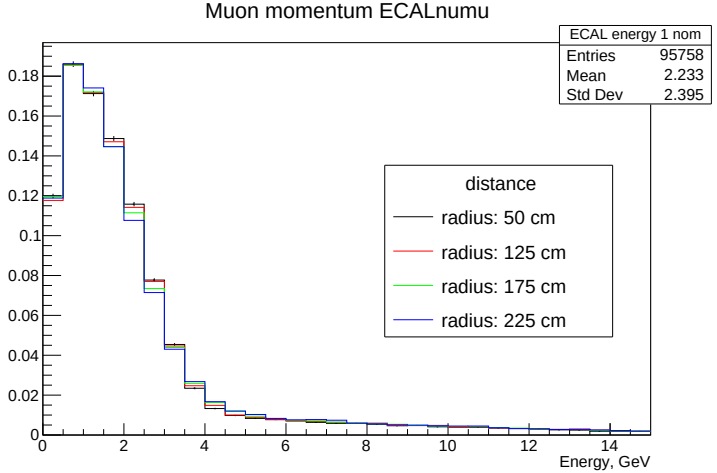
Both ECAL and STT extend to large radial distances up to 2.5 m

Energy distributions - FHC

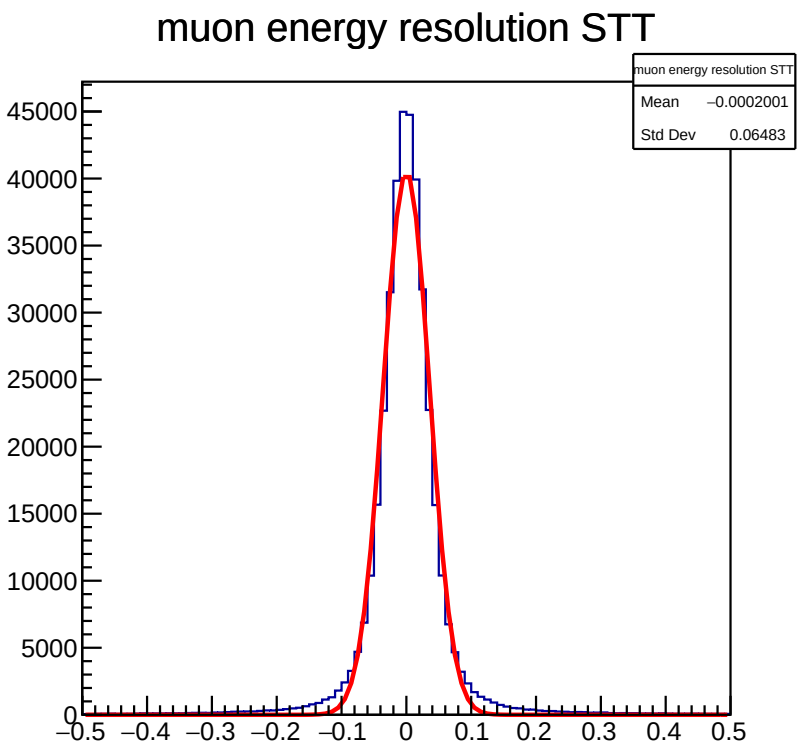


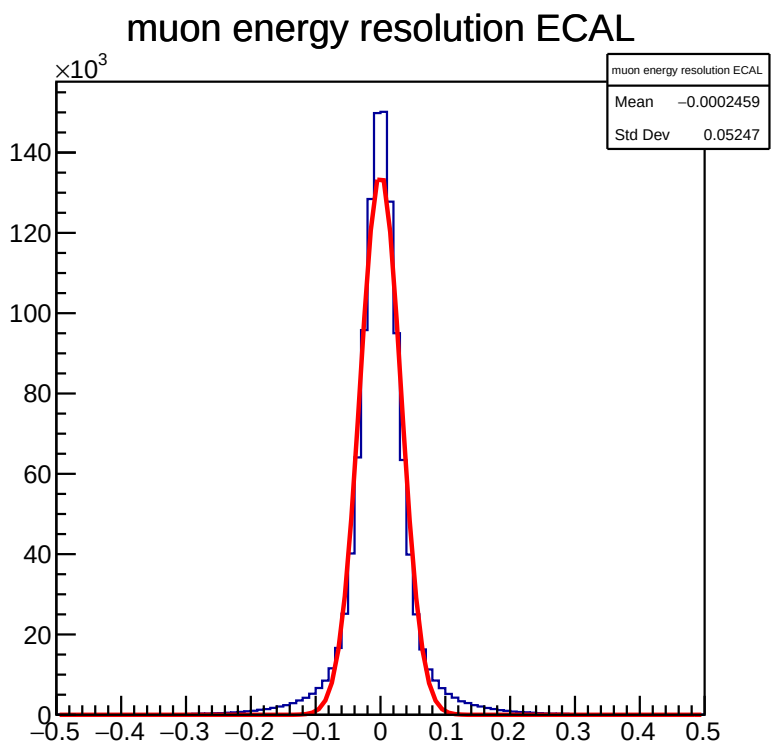






Energy resolution





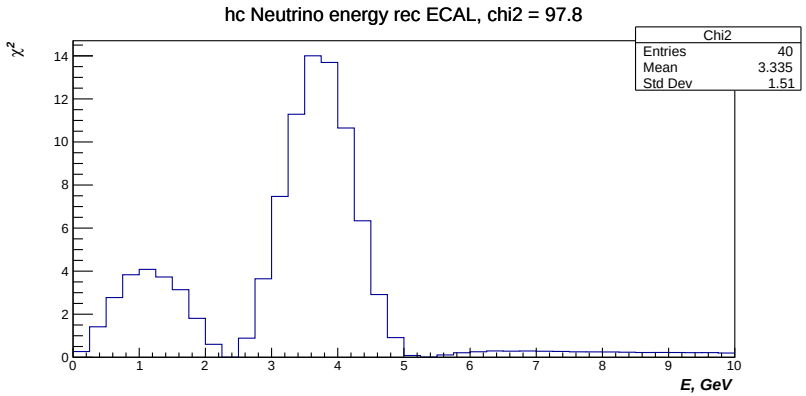
Statistical analysis

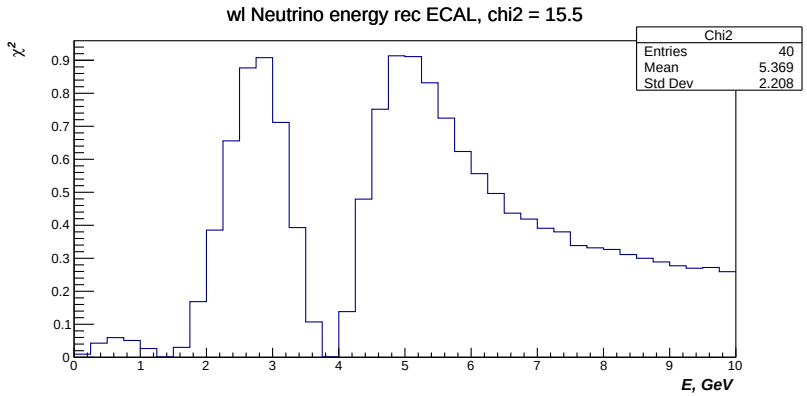
- **Nominal sample**: complete simulation of one week statistics with reconstruction smearing N^{nom}
- **Variation sample**: re-weight nominal sample using ratios between nominal and beam variations from file provided by Guang (many thanks) N^{var}
- Use the following test statistics:

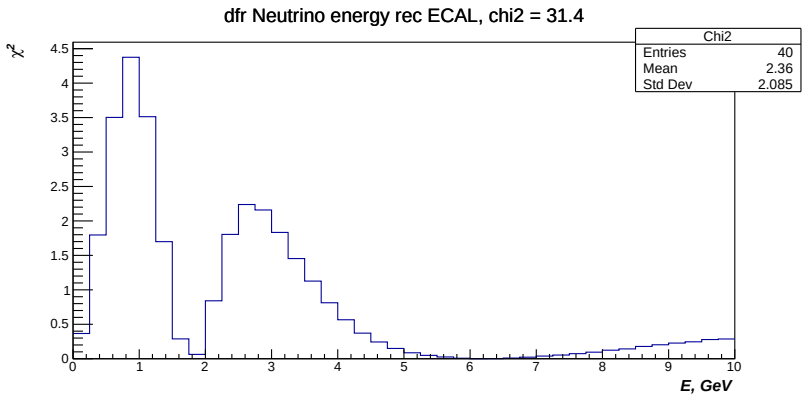
$$T = \sum_{i=1}^{N} \frac{(N^{\mathrm{nom}} - N^{\mathrm{var}})^2}{N^{\mathrm{nom}}},$$

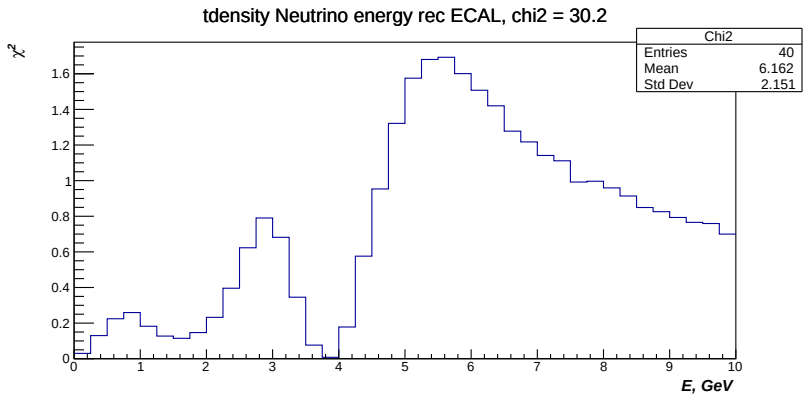
where N is the total number of bins used in the histograms (N=40)

Chi-square distribution

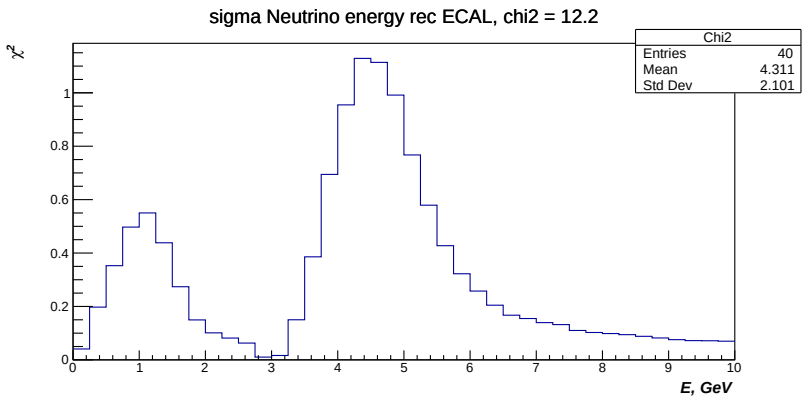


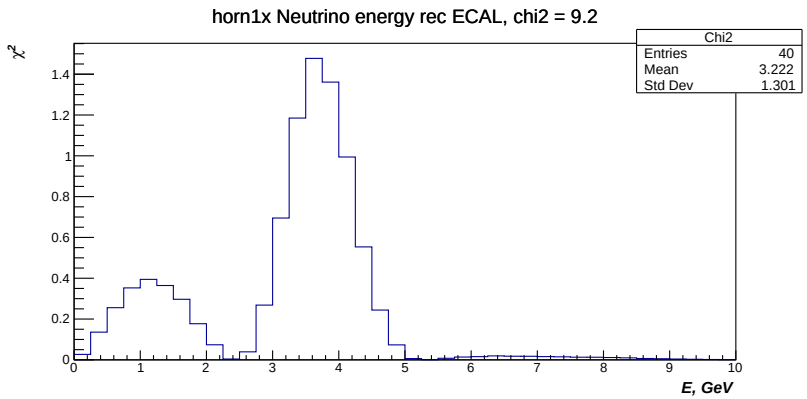






Chi-square distribution





Results - 1 week

Beam variation	ECAL				STT			
	neutrino		muon		neutrino		muon	
	sim	rec	sim	rec	sim	rec	sim	rec
Horn current	264.9	97.8	56.5	54.8	89.1	43.0	19.1	17.0
Water layer thickness	28.8	15.5	11.3	11.0	10.4	5.6	3.9	3.5
Decay pipe radius	72.9	31.4	18.4	18.1	24.1	12.6	6.3	6.0
Proton target density	43.4	30.2	23.1	22.4	13.8	9.2	7.7	7.0
Beam sigma	21.9	12.2	8.5	8.3	7.8	4.6	3.0	2.8
Beam off set X	6.9	2.8	2.0	2.0	2.5	1.2	0.8	0.7
Beam theta phi	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Beam theta	0.5	0.1	0.2	0.2	0.2	0.0	0.1	0.1
horn 1 X shift	25.4	9.2	5.5	5.4	9.2	4.4	2.0	1.8
horn 1 Y shift	22.8	7.6	4.5	4.4	7.7	3.6	1.6	1.4
horn 2 X shift	0.4	0.1	0.1	0.1	0.1	0.0	0.0	0.0
horn 2 Y shift	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0

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 ($\sim$ 20 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, horn 1 X shift
- The reconstruction neutrino energy is more sensitive to beam variations than the reconstructed muon energy
- Improve energy reconstruction and study dependence on radial bins