ECAL events in 3DST

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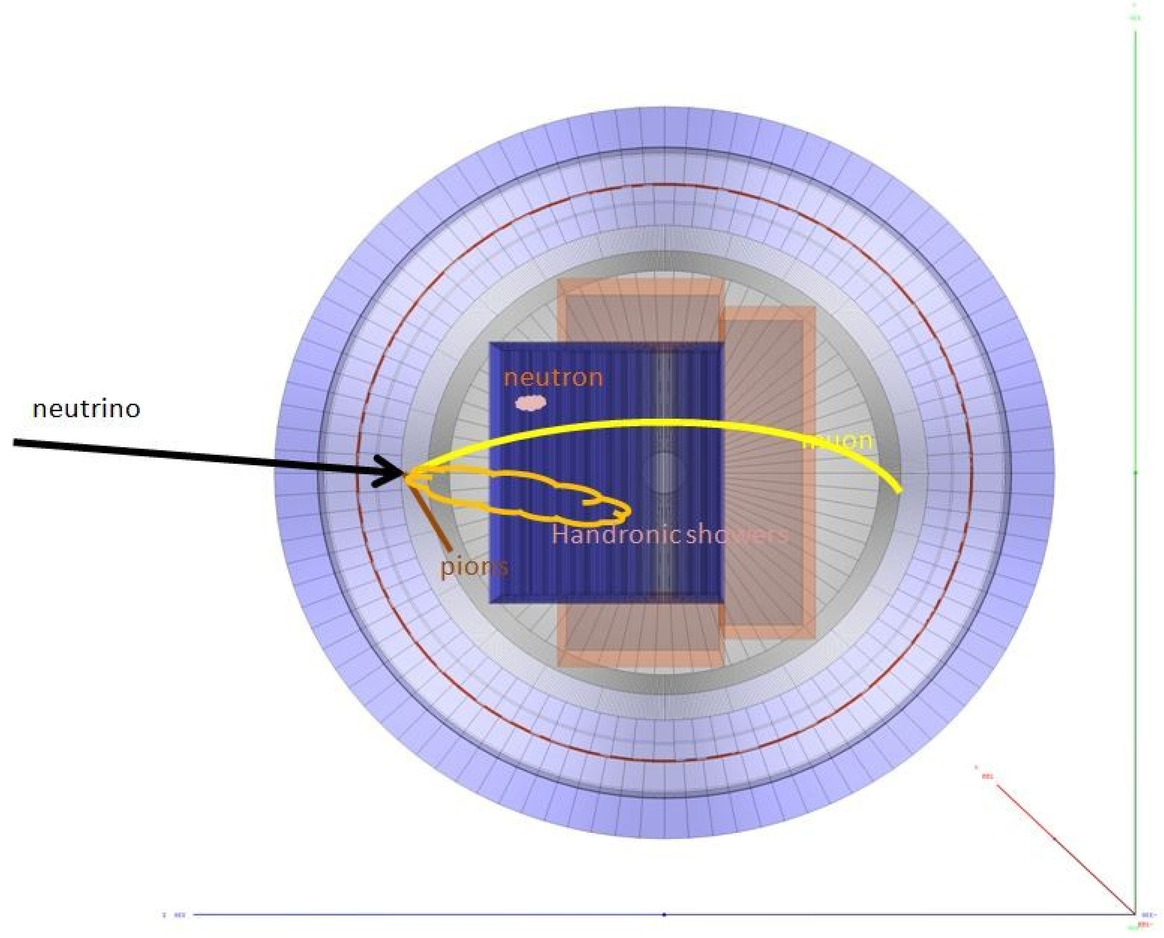
Introduction

- Interactions in ECAL and tracked by 3DST+TPC.
- Mainly used for beam monitoring at this point. Due to the high mass of ECAL, we expect at least a factor of 1.414 in sqrt(dchi2) sensitivity to beam variations.
- There could be other valuable usage such as neutron detection.
- Caveat: 3DST and downstream TPC have been extended to 3 m along X.

Geometry

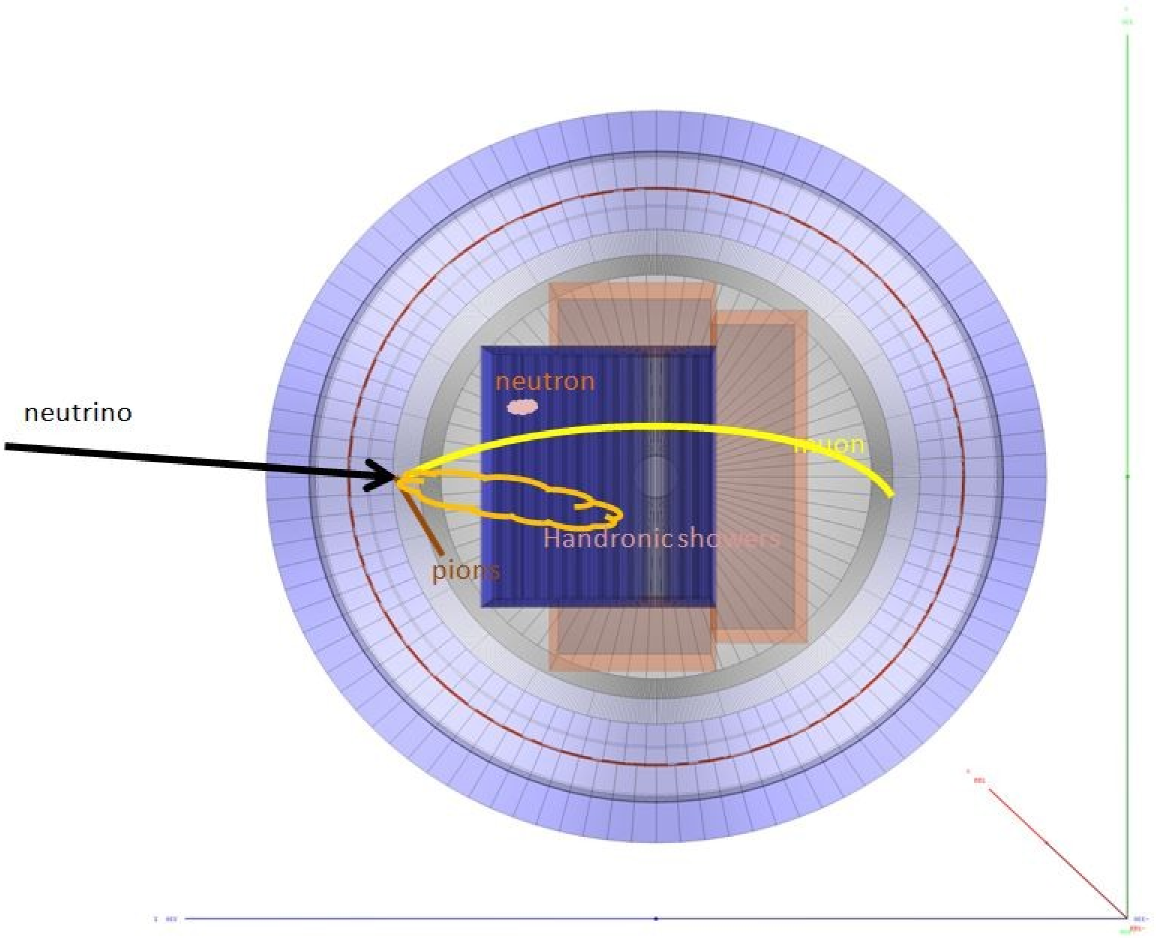


3DST 3 x 2.4 x 2 m^3

TPC covering downstream, top and bottom

Sensitive volumes are all ECAL region and 3DST.

Selected events

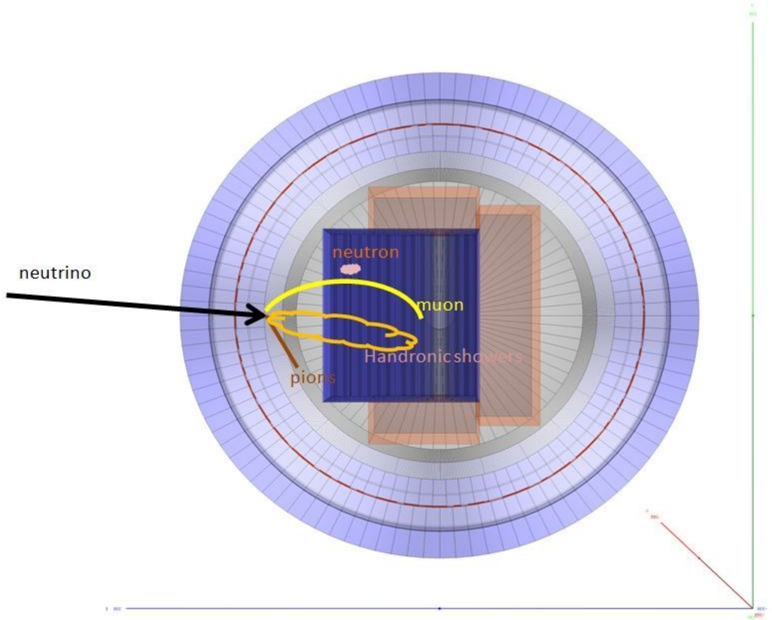


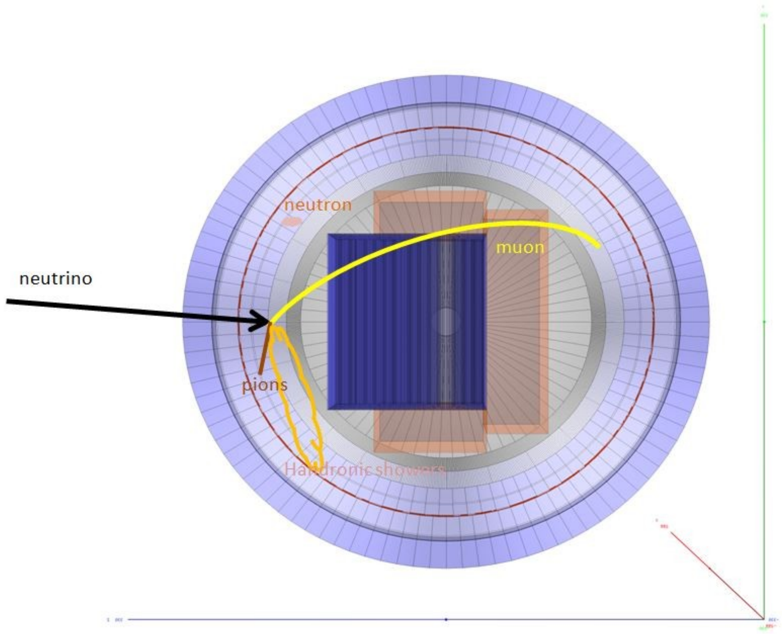
- Energy resolution in ECAL, calorimetrically

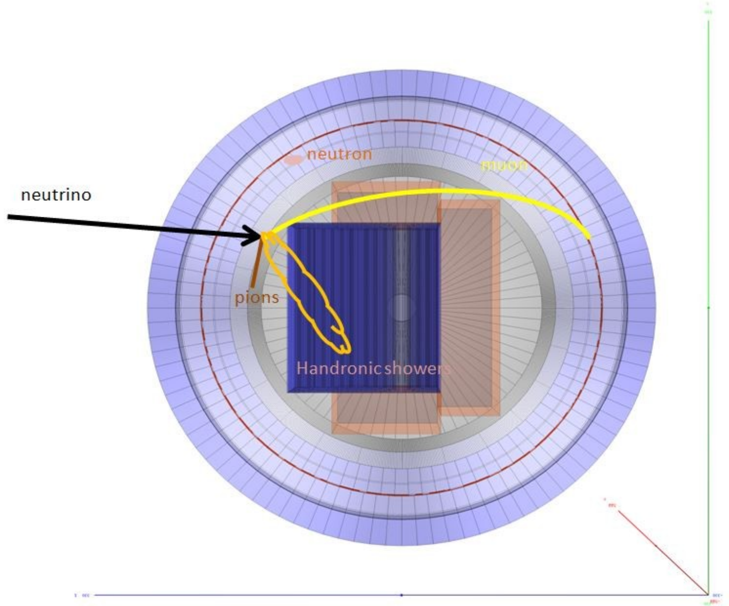
$$\sigma_E = 5.7\,\% \;/\; \sqrt{E_{dep}(GeV)}$$

- Muon in 3DST, calorimetrically 1% and curvature fitting 15%
- Muon in TPC, mom. Res. 4% at 1GeV
- Hadron in 3DST: calorimetrically all 10% energy res.

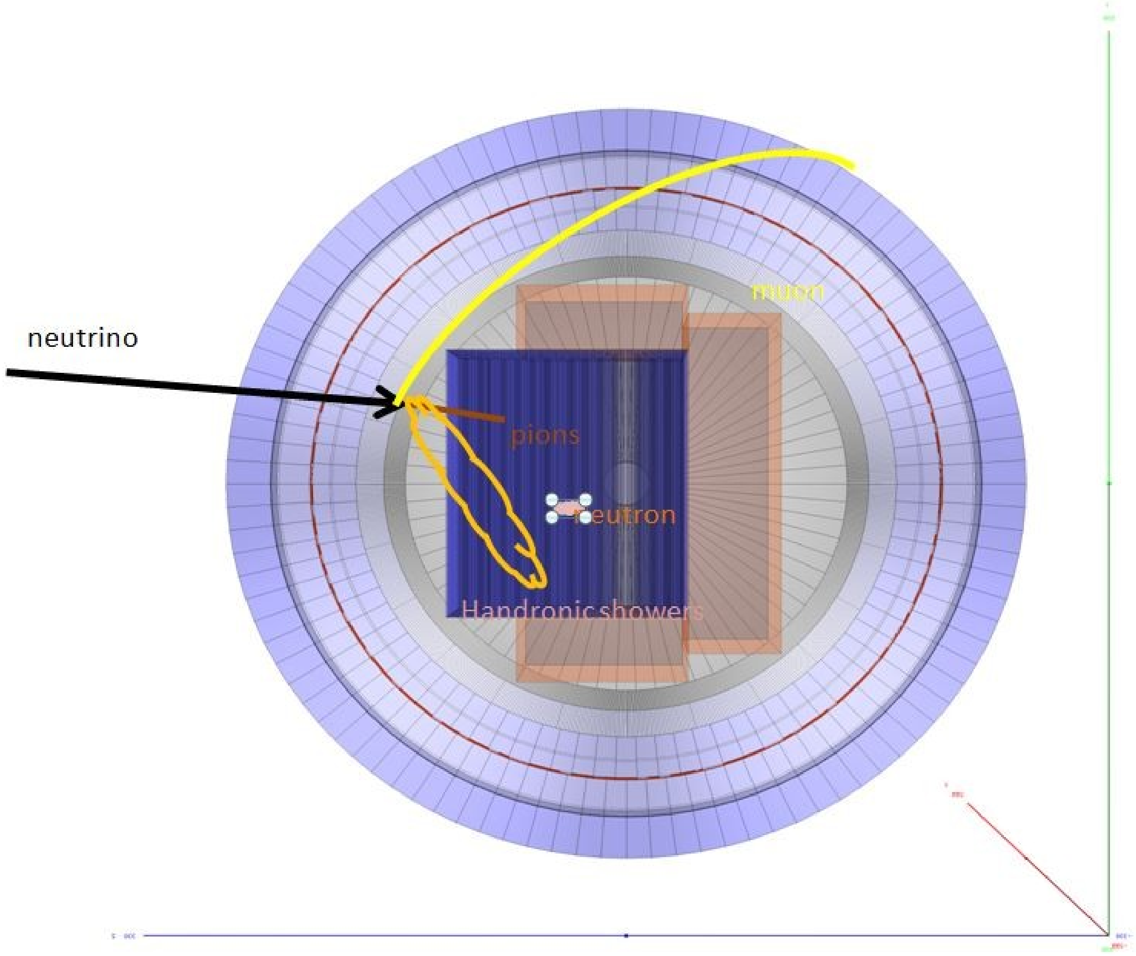
Selected events







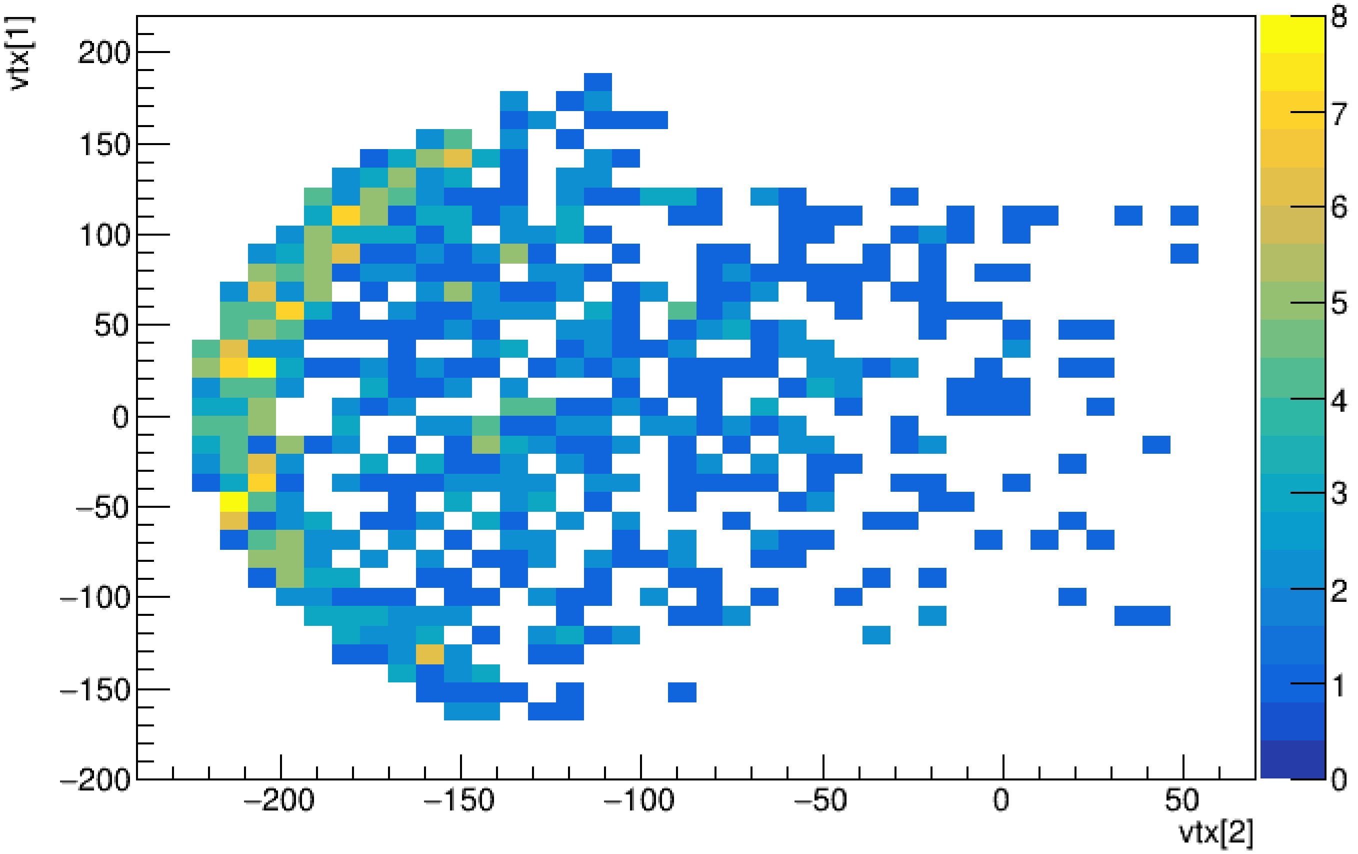
Rejected events



- If muon was not going through either 3DST or TPC, regardless hadron, it is rejected.

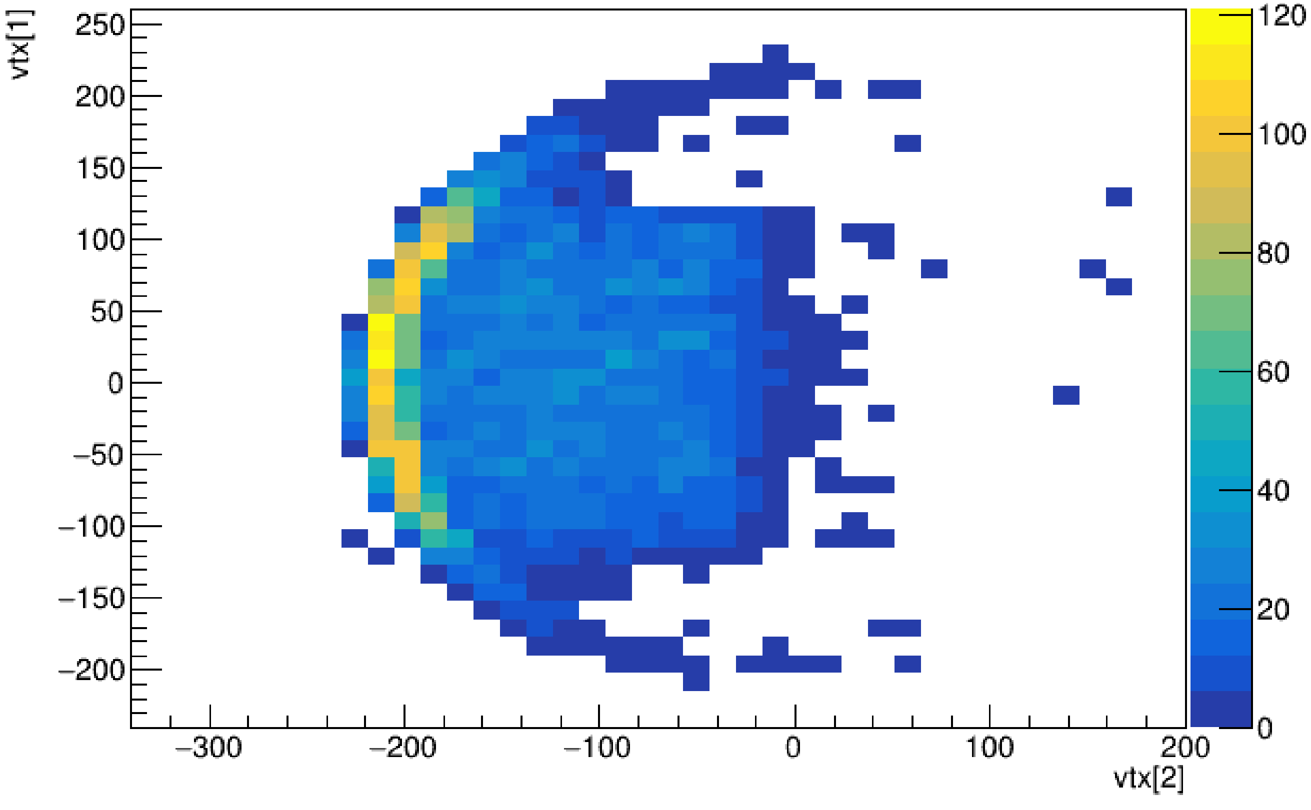
Selected events

- Vertices that muons contained in 3DST



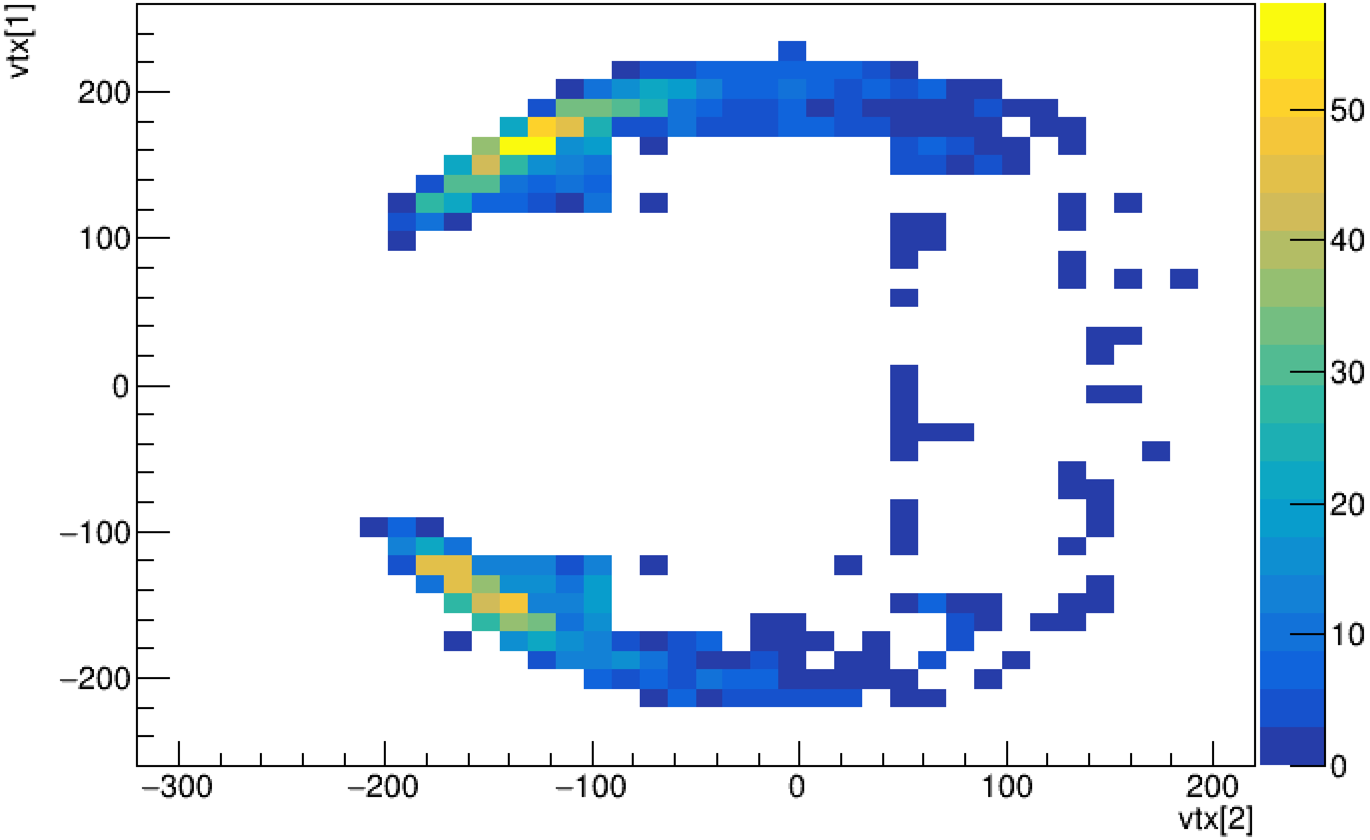
Selected events

- Vertices that muons going through at least 100 cm 3DST (may not be contained)



Selected events

- Vertices that muons going through only TPC with a cut on x direction



Event rate

- 1.6e6 per year per ton with 100 ton ECAL
- A 0.8 efficieincy due to outer layer as veto
- Selection efficiency ~ 23%
- It turns out ~ 550k events per week

- Beam sensitivity calculation is the same way as before using flux reweighting.

POT systematics

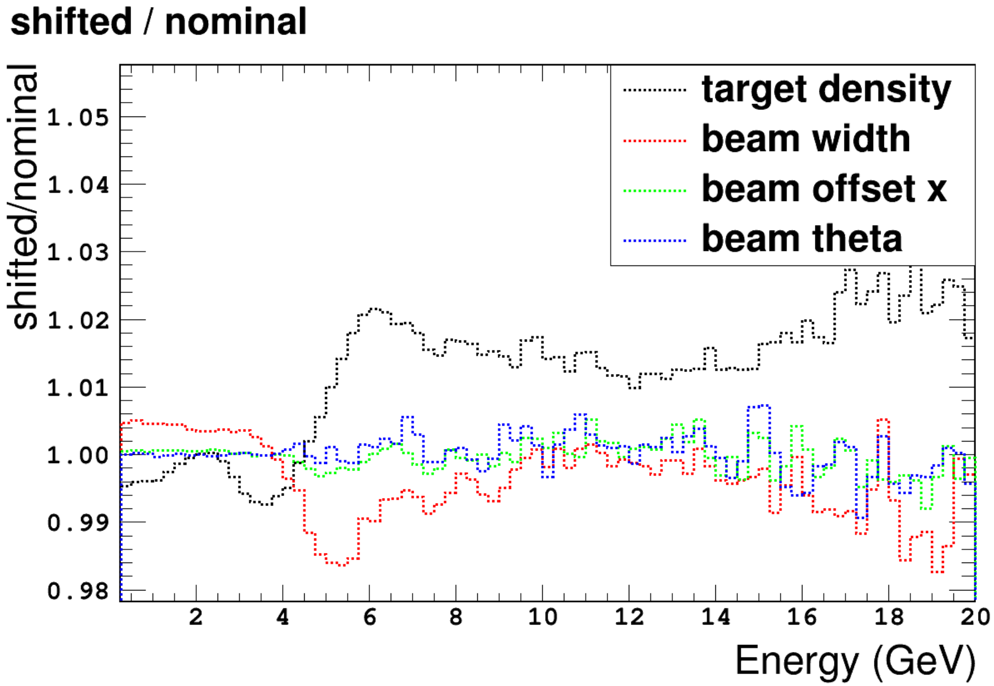
- Zarko: “ The systematic that you care about here is how precise can we measure the POT. We typically assign 2% to this number. It includes several effects, like toroid precision but also if there is some beam in the tail that doesn't go through whole target or if the beam wanders a bit and again some protons at the edge don't go through the whole target. The power of monitoring with on-axis spectrum is coming from the shape, but I don't think you should drop the normalization. I'd include it and have a 2% uncertainty to begin with.”
- Reference talk: https://indico.fnal.gov/event/20144/session/5/contribution/149/material/slides/1.pdf

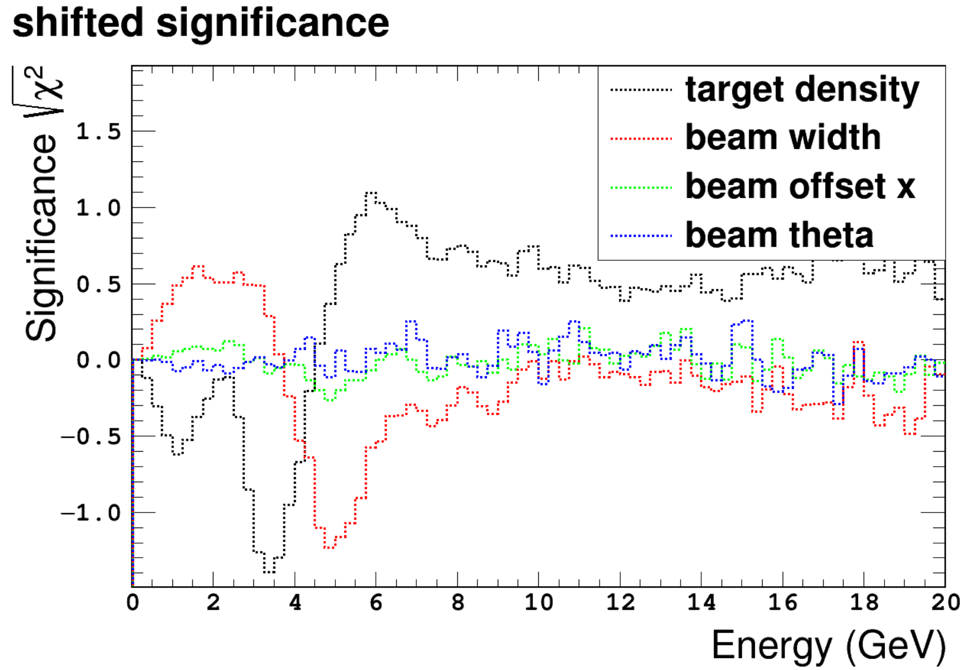
Designed tolerance of the target parameter at LBNF

Parameter	Tolerance
Target Position (each end)	0.5 mm
Horn A Position (each end)	0.5 mm
Horn B Position (each end)	0.5 mm
Horn C Position (each end)	0.5 mm
Decay Pipe Radius	0.1 m
Horn Current	3 kA
Horn water layer thickness	0.5 mm
Beam radius at target	0.1 mm
Baffle Scraping	0.25%
Beam position at target	0.45 mm
Beam angle at target	70 microradians
Target Density	2%
Protons on Target	2%

Sensitivity calculation

- There will be a POT 2% uncertainty as systematics
- Significance (sqrt(chi2)) in each bin defined as (nominal – shift)/error for each bin
- Total sqrt(dchi2) is the square root of squared sum of all bins





Spectral Results (with 2% rate uncertainty)

- Smearing included

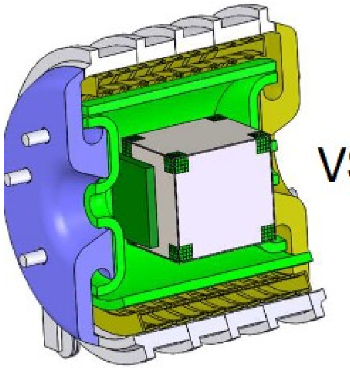
sqrt(dchi2)	Horn 1X	Horn 1Y	Horn 2X	Horn 2Y
ECAL	3.0	3.0	0.2	0.4
3DST	2.6	2.6	0.2	0.3

sqrt(dchi2)	Target density	P Beam width	P Beam offset	P Beam theta
ECAL	5.5	3.4	0.6	0.6
3DST	4.5	2.8	0.5	0.5

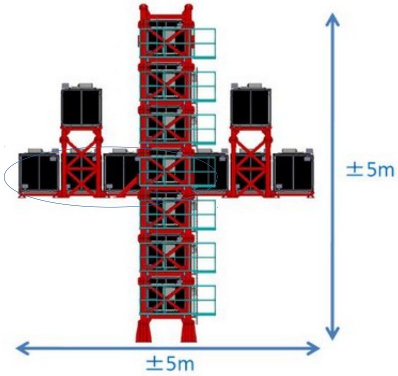
sqrt(dchi2)	P Beam tilt	Horn current	Water layer	Decay pipe radius
ECAL	0.5	10.1	3.8	5.9
3DST	0.4	8.7	3.2	5.0

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

- Spectral monitoring is needed obviously



VS



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

Summary

- Had a first look at ECAL events.
- Detail can be smoothed out further.
- As always, spectral monitoring is need.

Backups

Spectral Results (with 2% rate uncertainty)

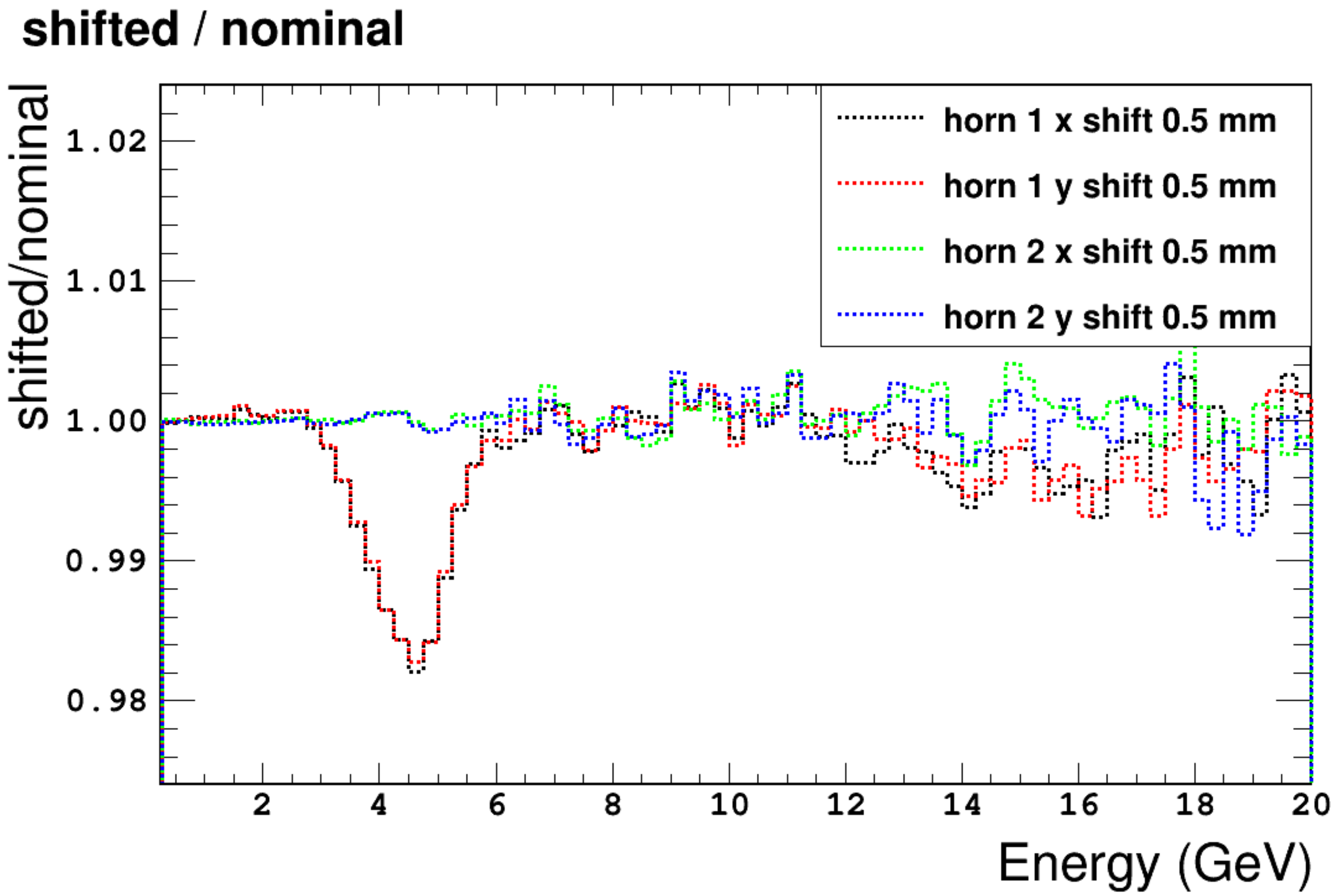
- Without smearing

sqrt(dchi2)	Horn 1X	Horn 1Y	Horn 2X	Horn 2Y
ECAL	3.4	3.4	0.5	0.6
3DST	2.8	2.8	0.4	0.5

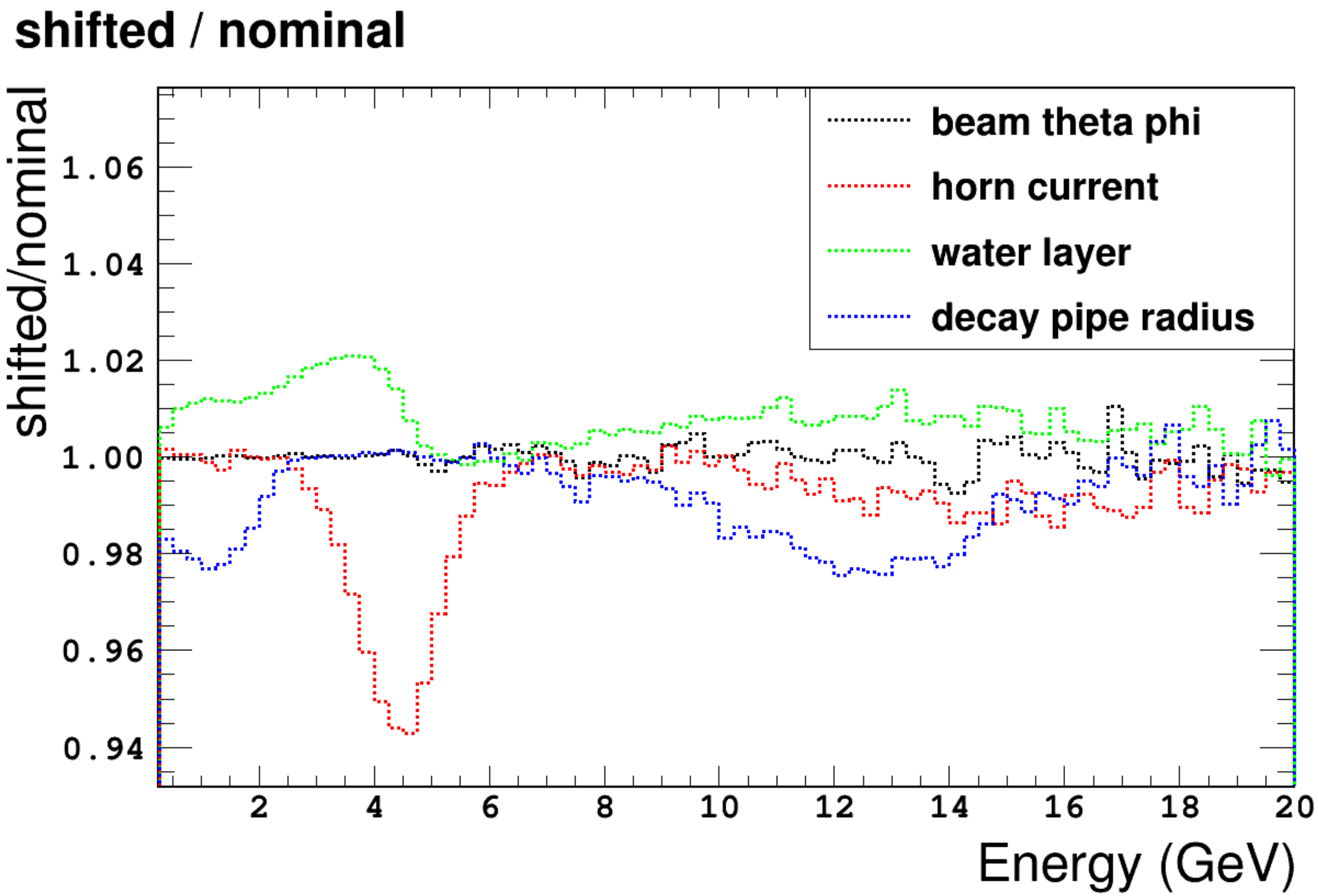
sqrt(dchi2)	Target density	P Beam width	P Beam offset	P Beam theta
ECAL	5.8	3.7	0.9	1.0
3DST	4.6	2.9	0.7	0.8

sqrt(dchi2)	P Beam tilt	Horn current	Water layer	Decay pipe radius
ECAL	0.9	11.4	4.1	6.4
3DST	0.7	9.4	3.4	5.3

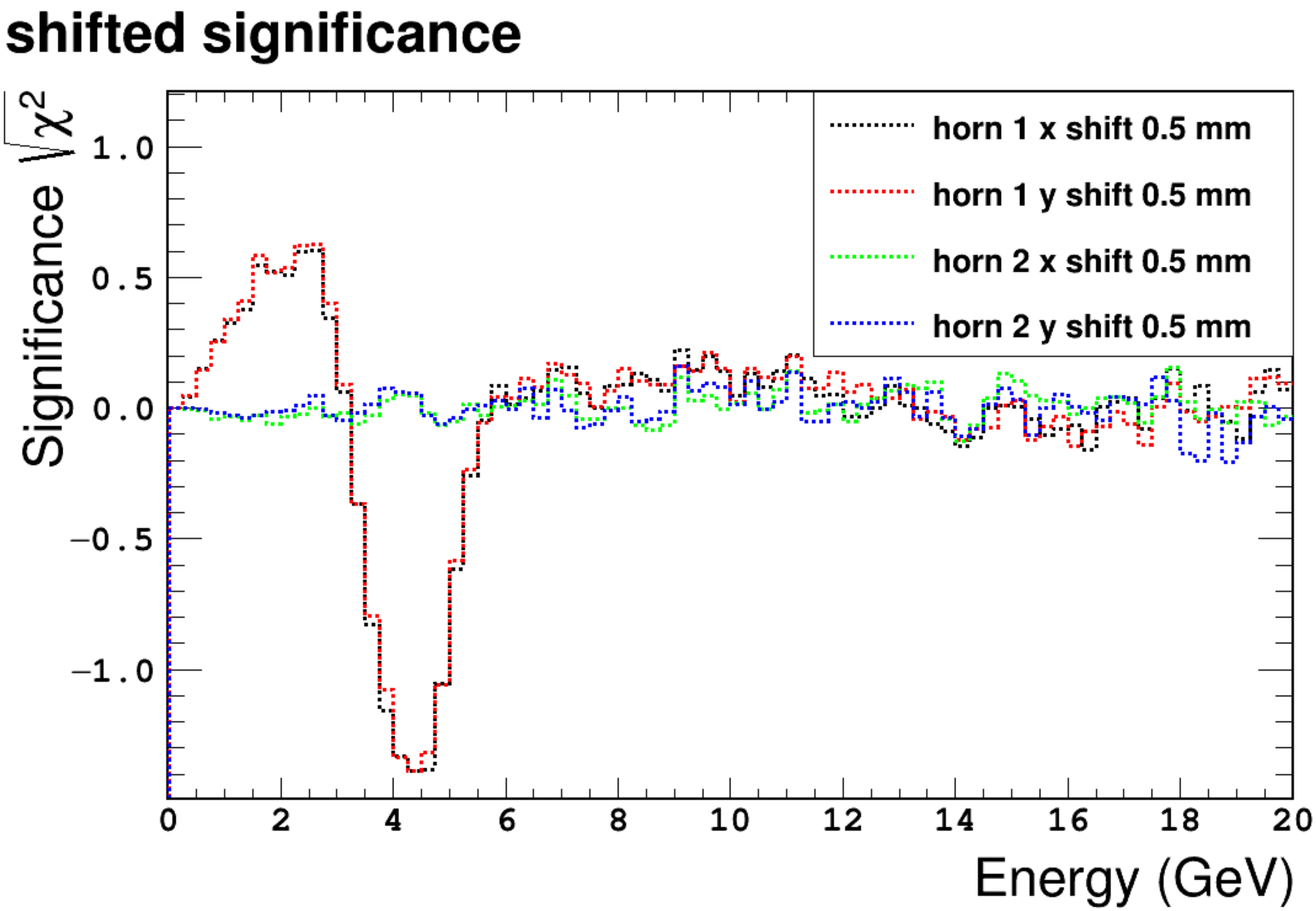
ECAL


shifted / nominal
shifted/nominal
1.02
1.01
1.00
0.99
0.98
2
4
6
8
10
12
14
16
18
20
Energy (GeV)
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

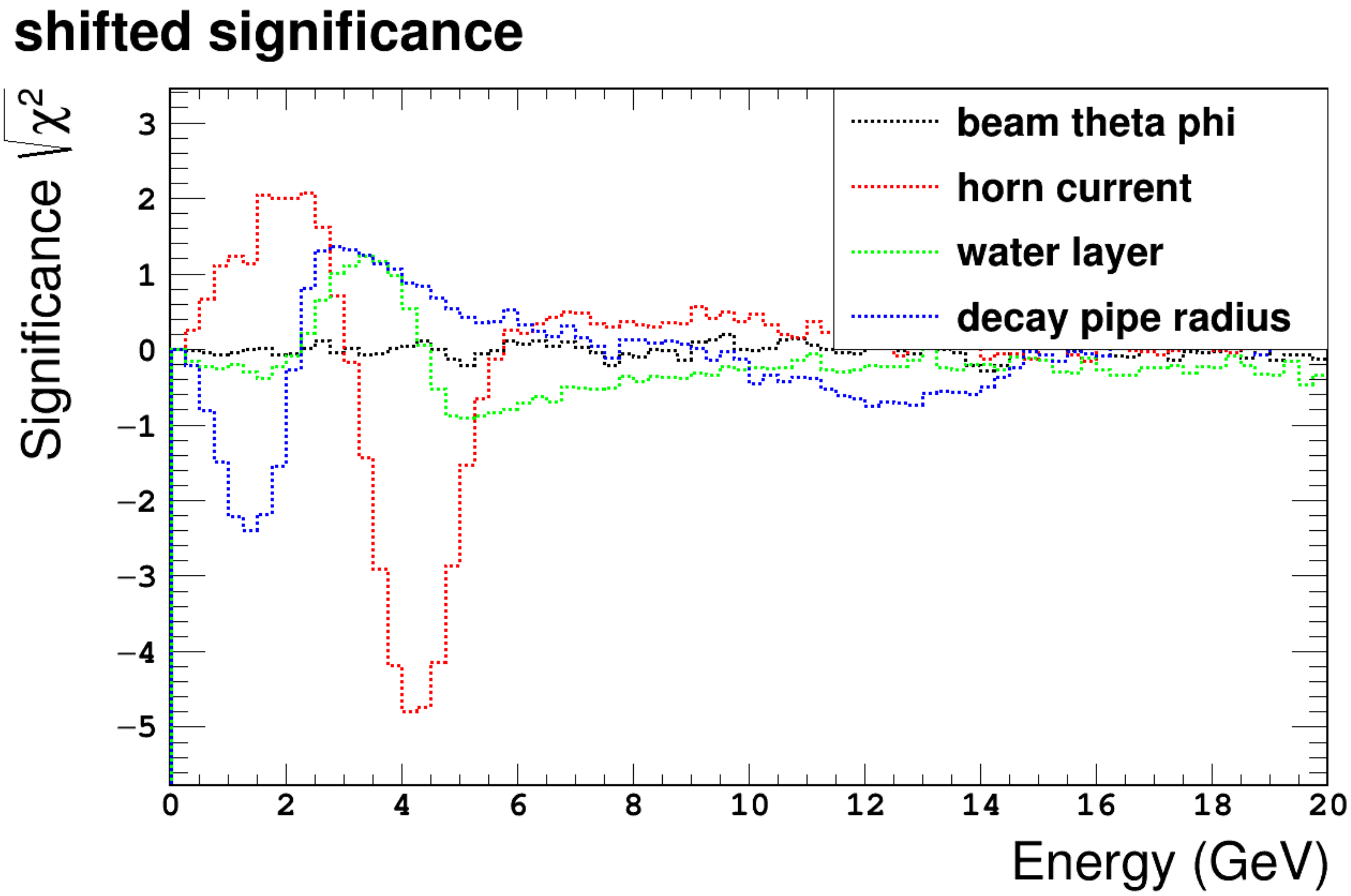
ECAL


shifted / nominal
shifted/nominal
1.06
1.04
1.02
1.00
0.98
0.96
0.94
2
4
6
8
10
12
14
16
18
20
Energy (GeV)
beam theta phi
horn current
water layer
decay pipe radius

ECAL

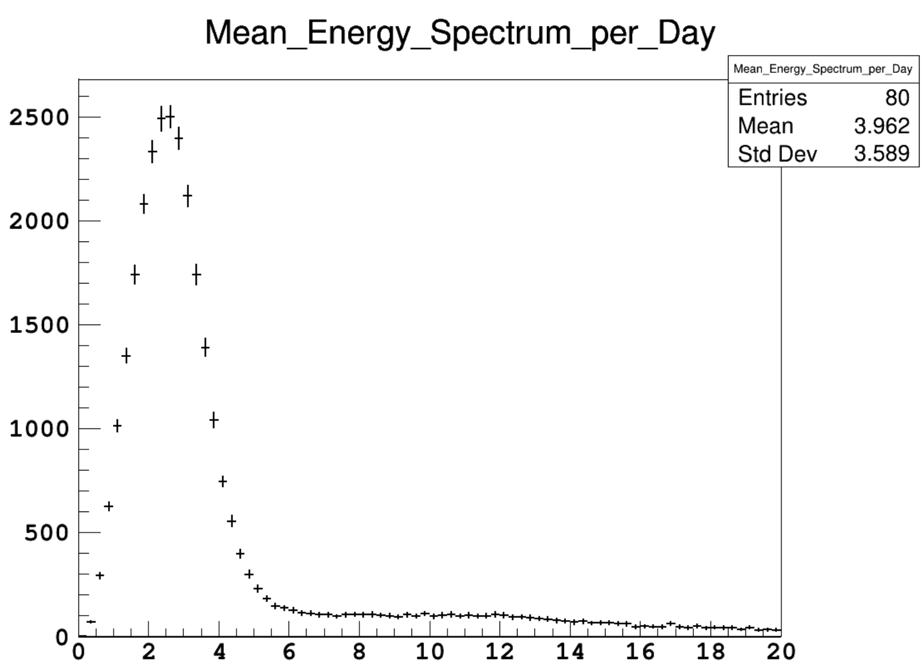

shifted significance
Significance $\sqrt{\chi^2}$
1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
12
14
16
18
20
Energy (GeV)
horn 1 x shift 0.5 mm
horn 1 y shift 0.5 mm
horn 2 x shift 0.5 mm
horn 2 y shift 0.5 mm

ECAL

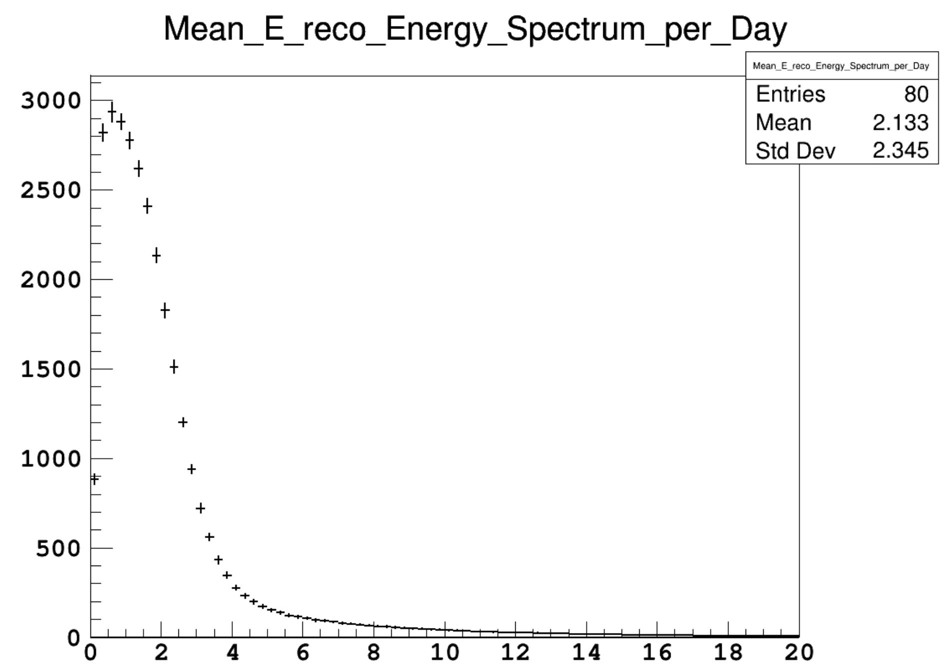

shifted significance
Significance $\sqrt{\chi^2}$
3
2
1
0
−1
−2
−3
−4
−5
0
2
4
6
8
10
12
14
16
18
20
Energy (GeV)
beam theta phi
horn current
water layer
decay pipe radius

How the work was done? - step 1

- Averaged one-day spectra are generated with nominal flux based on a year of sample. These spectra can be scaled to whatever desired stat.



One day neutrino energy w/ smearing

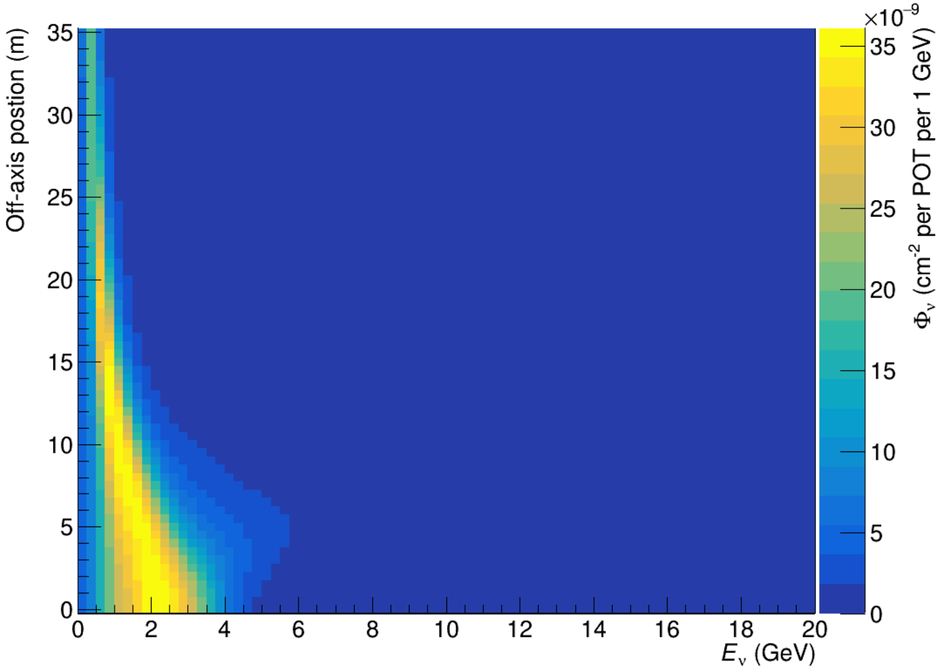


One day muon energy w/ smearing

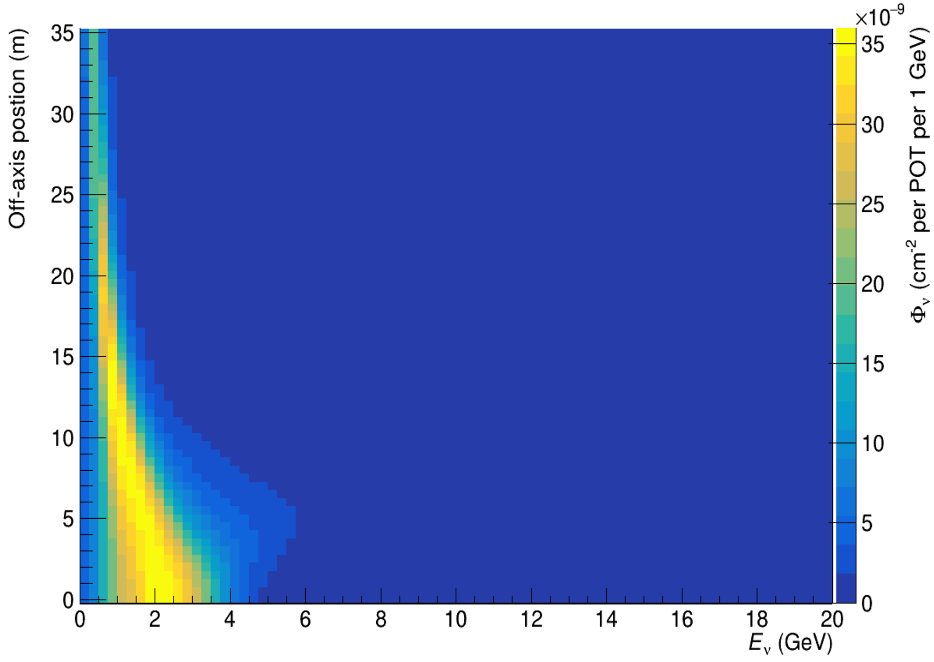
How the work was done? - step 2

- Nominal and variations have been generated (2017 engineered optimized flux)

Nominal flux

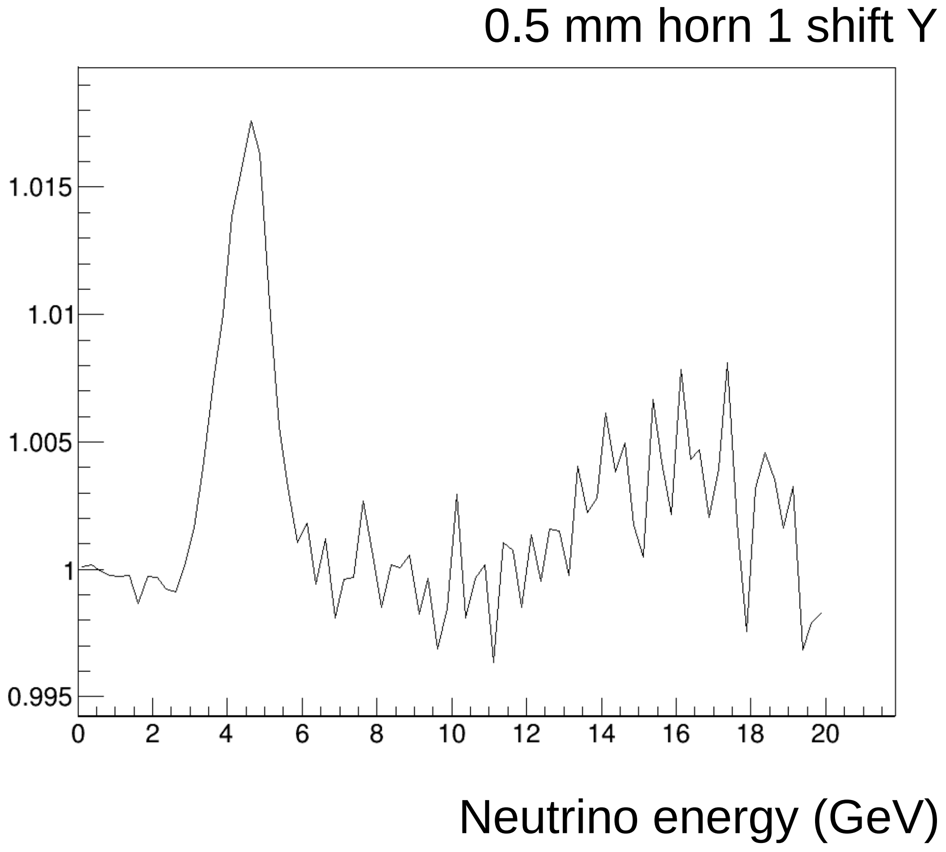


0.5 mm horn 1 shift Y



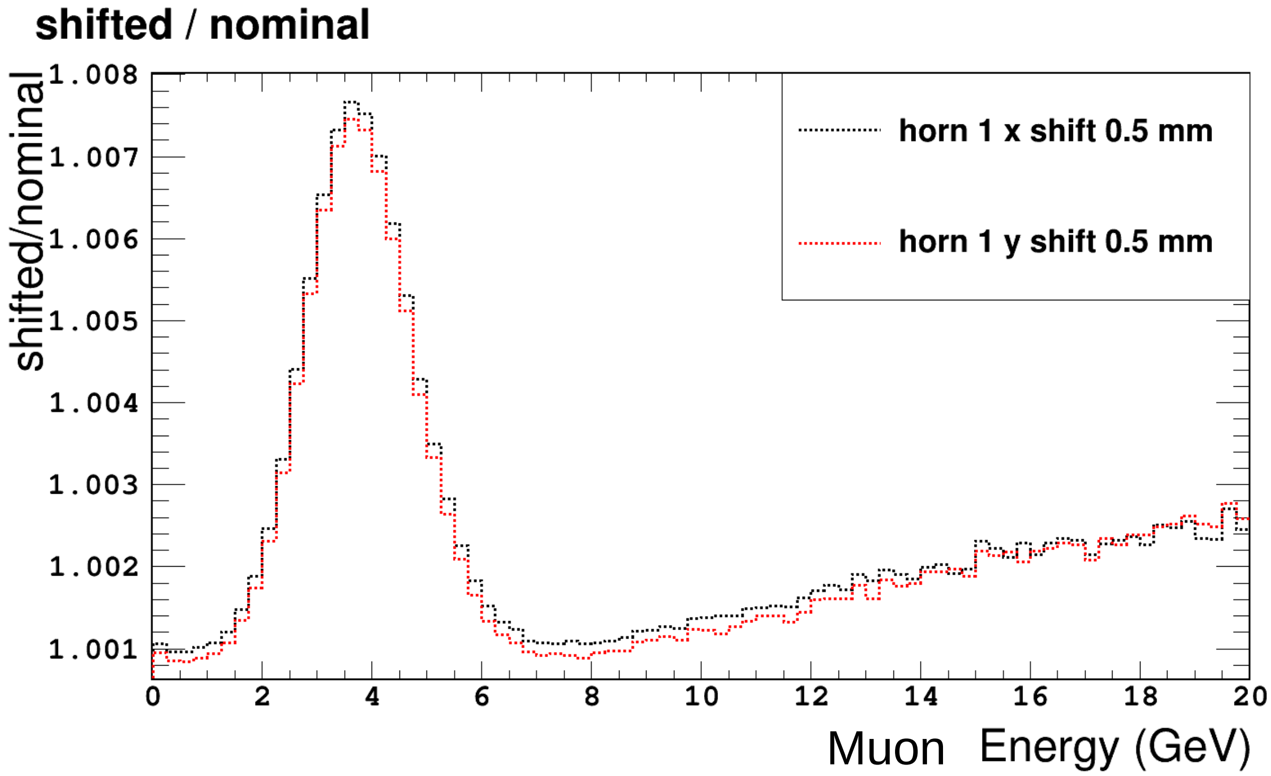
How the work was done? - step 3

- Flux reweight has been generated based on nominal flux and varied flux



How the work was done? - step 4

- Reweight has been applied to the nominal spectrum based on energy and neutrino species



Likelihood ratio

- The Pearson (standard) chi2 between A (nominal) and B (data) is our test statistics: (obs-exp)^2/exp (only stat)
- Likelihood ratio w/ Asimov :

  - chi2(A) – chi2(B) = chi2 (A/B)

  - A could be nominal while B shifted
- We are showing the sensitivity to the beam change, not the real weekly monitoring.