Beam Monitoring in 3DST and ECAL+STT

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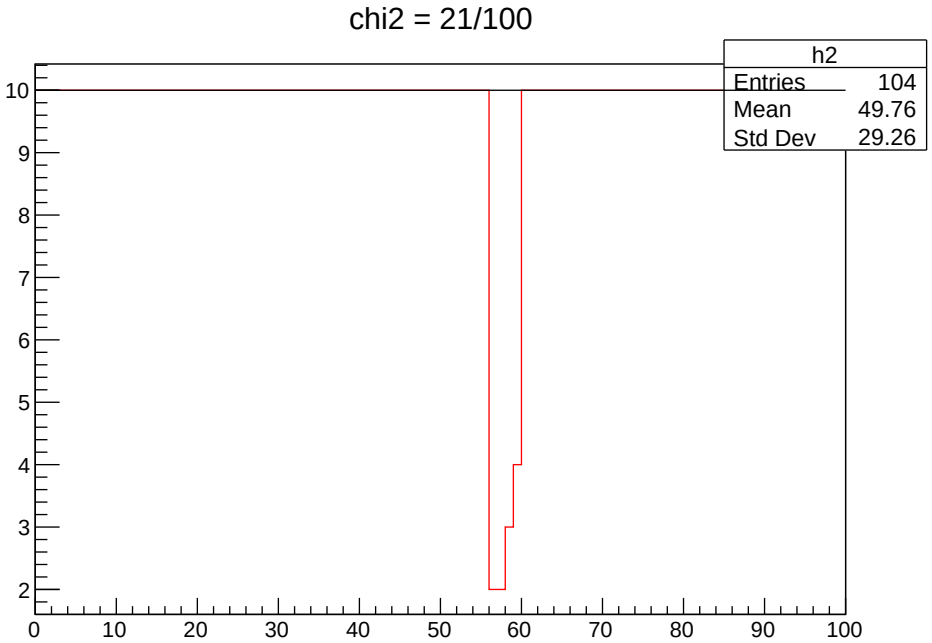
SAND meeting 3^{rd} of March 2020

Part I: interpretation of χ^2

Histogram with spike



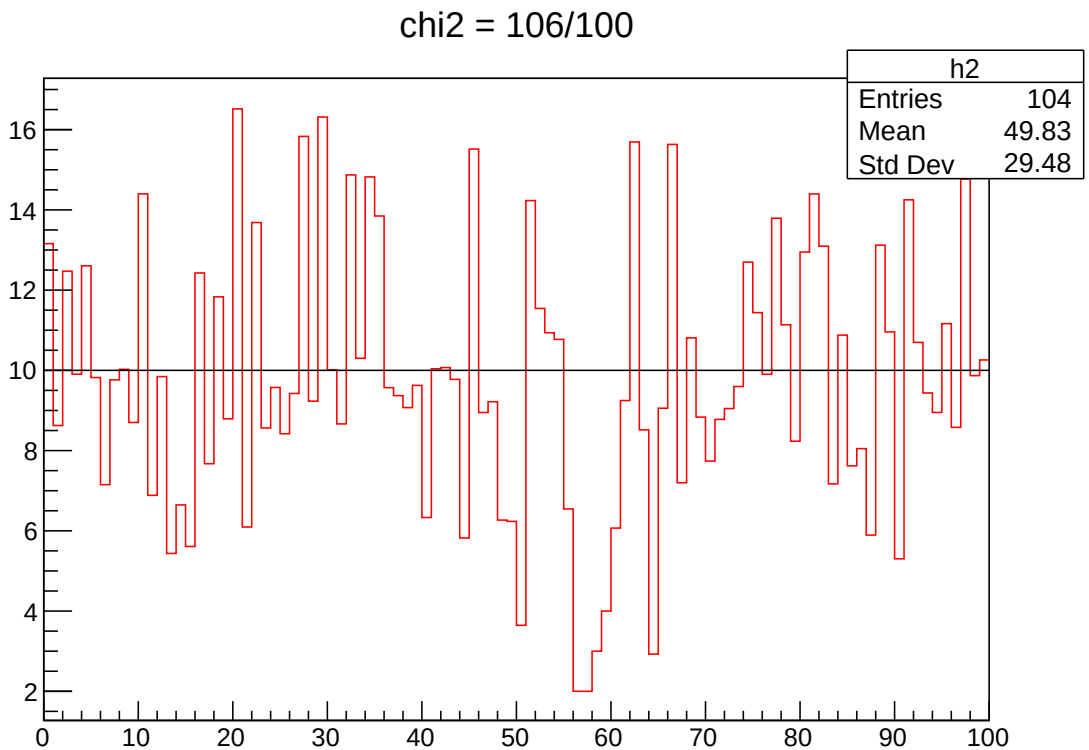
χ^2 calculation:

$$\chi^2 = \frac{(obs - exp)^2}{exp}, \text{ (only stat)}$$

From the first point of view - there is no χ^2 sensitivity, but by eyes we can easily distinguish spike

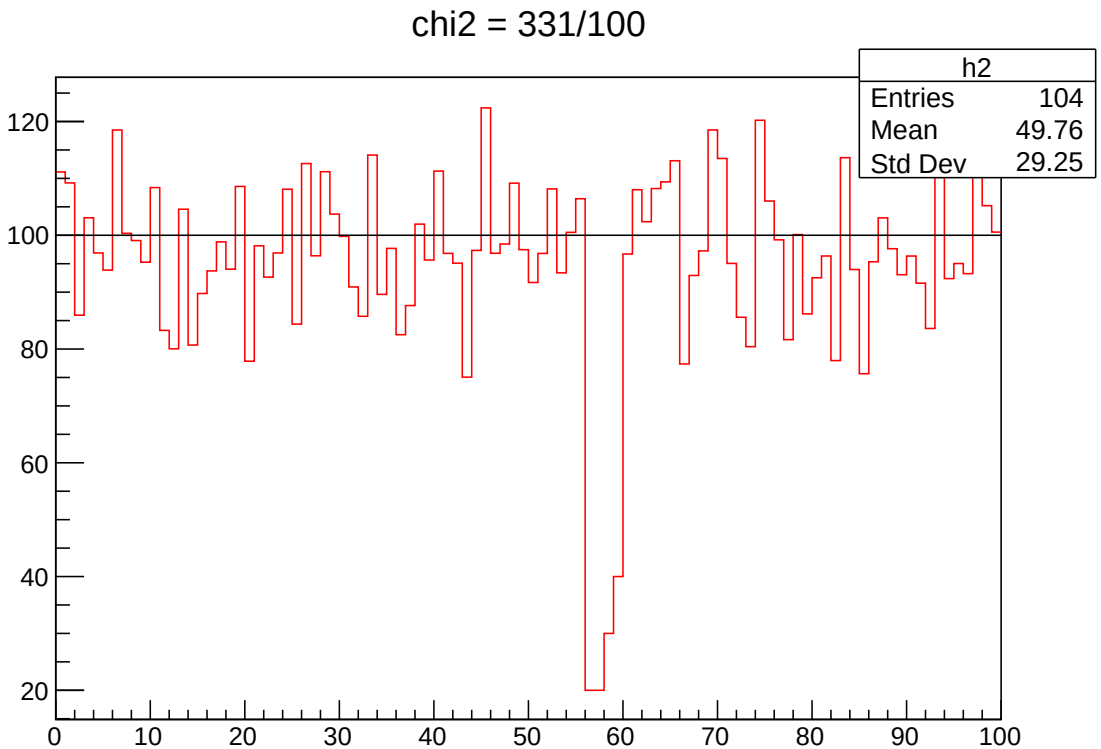
Histogram with spike with statistical fluctuations

Let's include statistical fluctuations for the experimental data (Gaussian distribution around mean value). Mean value - 10.



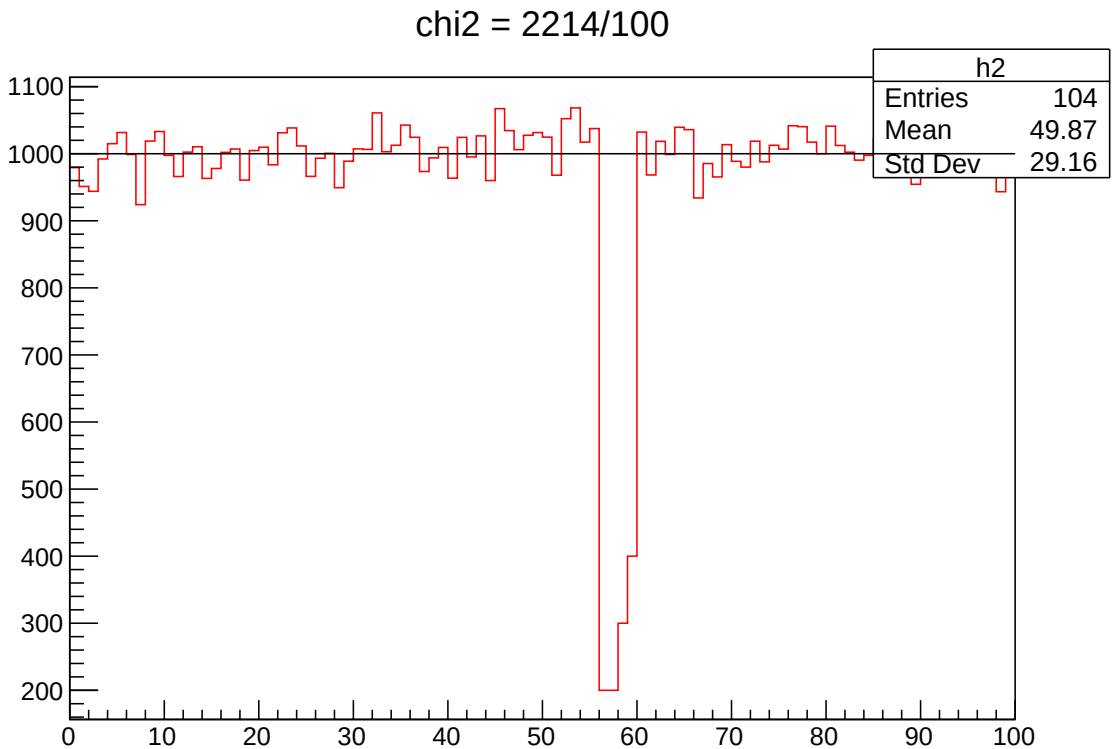
Histogram with spike with statistical fluctuations

Let's include statistical fluctuations for the experimental data (Gaussian distribution around mean value). Mean value - 100.



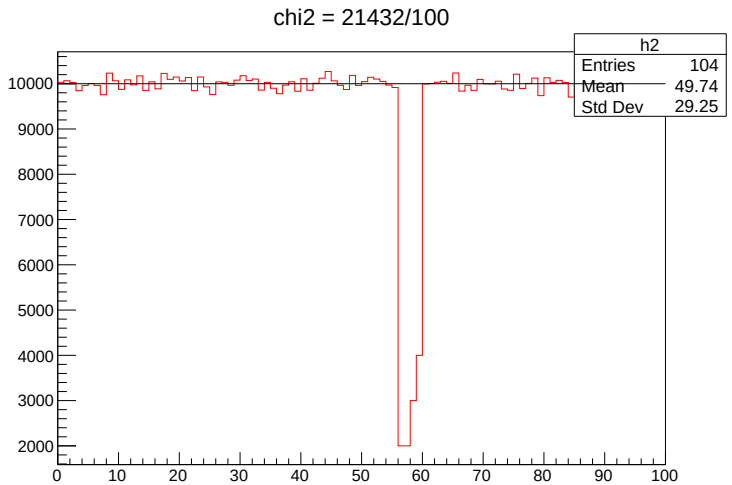
Histogram with spike with statistical fluctuations

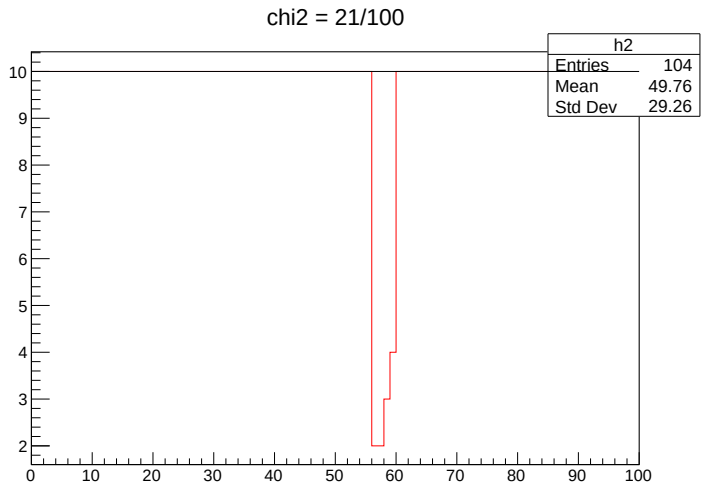
Let's include statistical fluctuations for the experimental data (Gaussian distribution around mean value). Mean value - 1000.



Histogram with spike with statistical fluctuations

Let's include statistical fluctuations for the experimental data (Gaussian distribution around mean value). Mean value - 10000.





Summary for part I

- χ^2 functional is sensitive to any spikes that can be easily distinguished by eyes
- during statistical analysis it is necessary to take into account statistics and statistical errors (distribution), otherwise results can be interpreted in a wrong way

Part II: Beam Monitoring in 3DST with re-weighting

Beam re-weighting for 3DST

Initial data: Nominal beam spectra, Difference between nominal beam and variated beam - W (same W used by 3DST analysis provided by Guang)

Procedure:

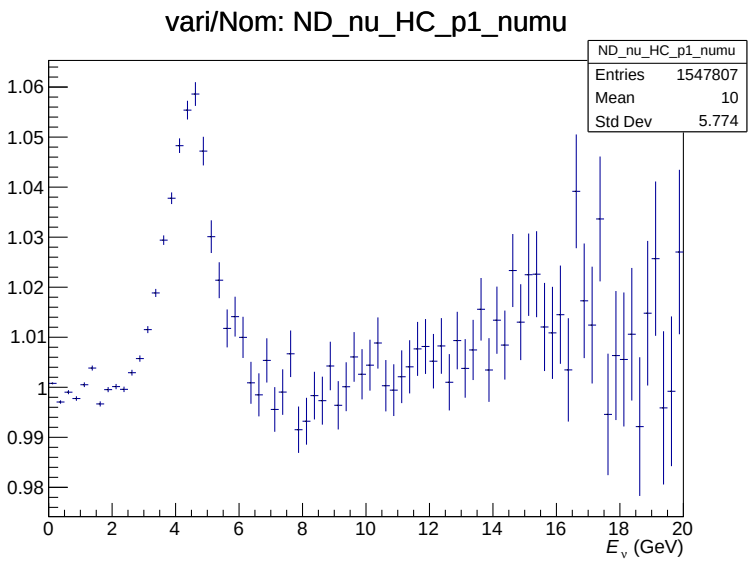
- generate events for nominal beam - H_{nom} (exact statistics expected in one week)
- making correction of H_{nom} by the weights W
- get re-weighted histogram for beam variation H_{var}
- get re-weighted histogram for muon distribution with smearing - M_{var}
- calculate χ^2 between H_{nom} and H_{var}, M_{nom} and M_{var}

Histograms H_{nom} and H_{var} are self normalized

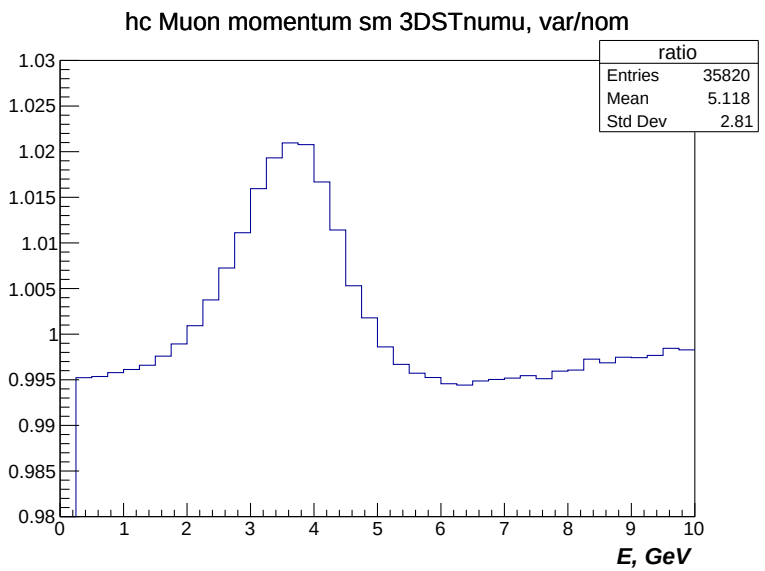
$$\text{Used } \chi^2 = \frac{(\mathrm{H_{nom}} - \mathrm{H_{var}})^2}{\mathrm{H_{nom}}}$$

Beam re-weighting for variation of Horn Current

Beam energy weights (initial data)

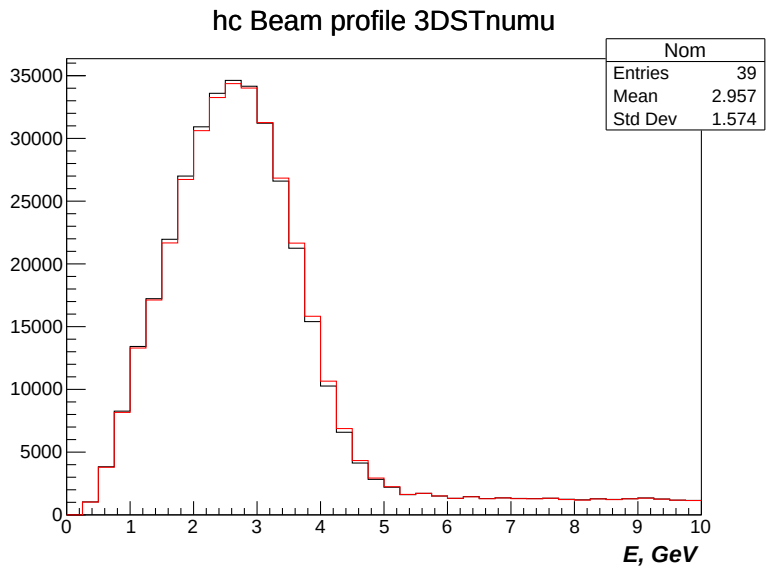


Muon spectra weights (obtained)

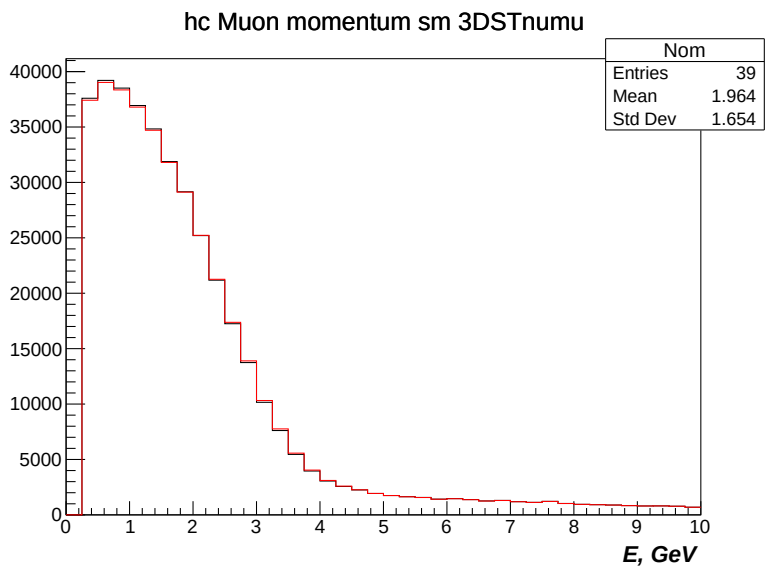


Beam re-weighting for variation of Horn Current

Beam spectra



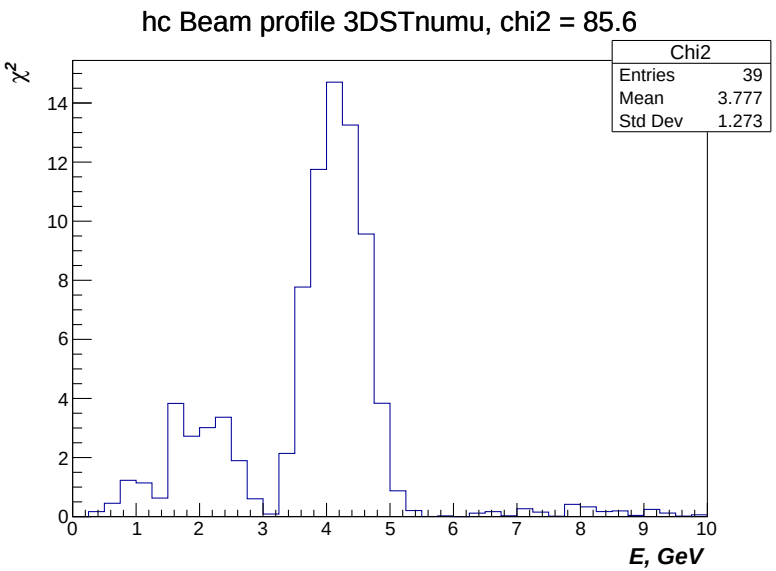
Muon momentum



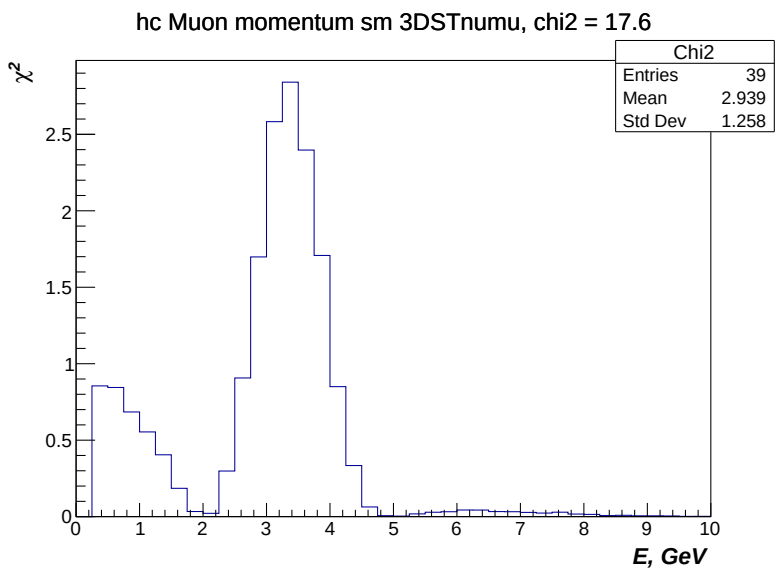
black - nominal, red - re-weighted

Chi-square for variation of Horn Current

Beam spectra

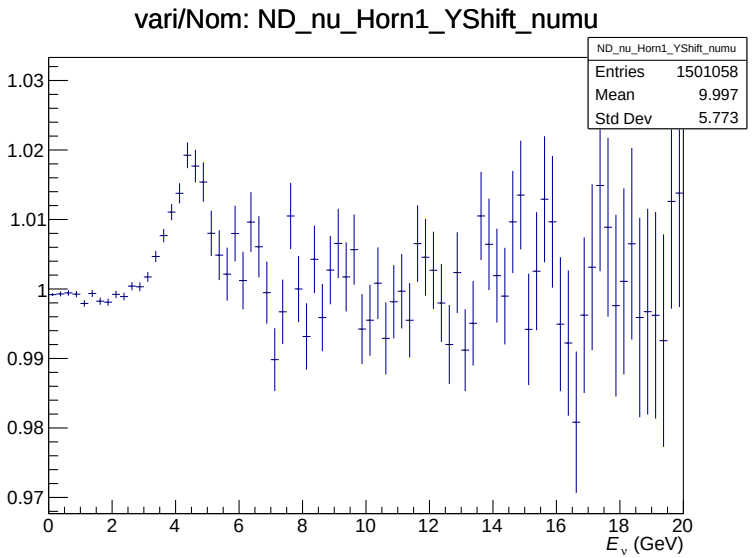


Muon momentum

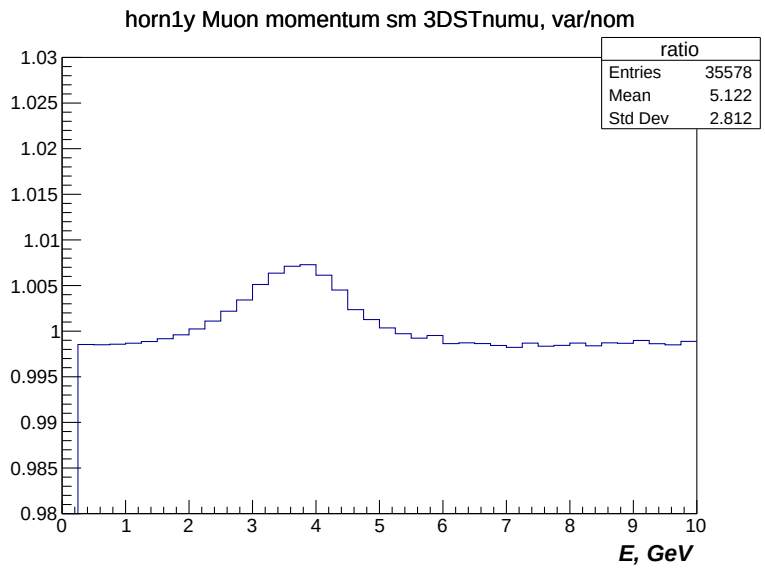


Beam re-weighting for variation of Horn1 Y Shift

Beam energy weights (initial data)

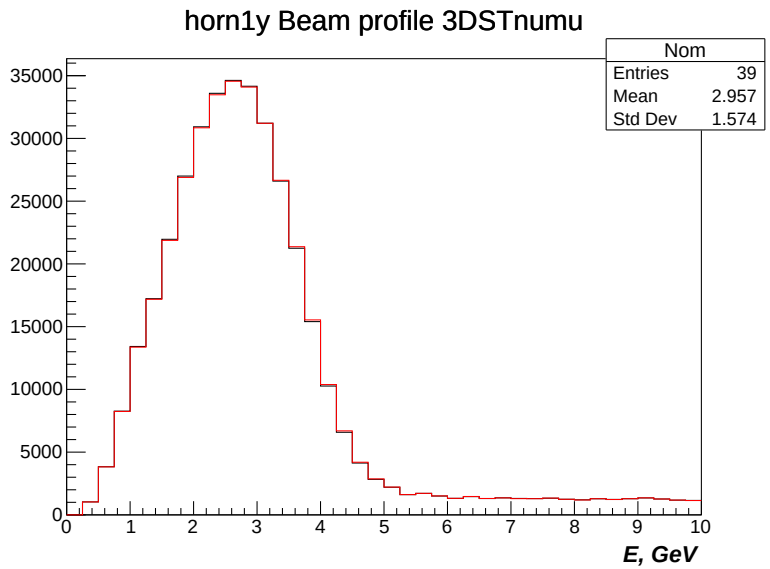


Muon spectra weights (obtained)

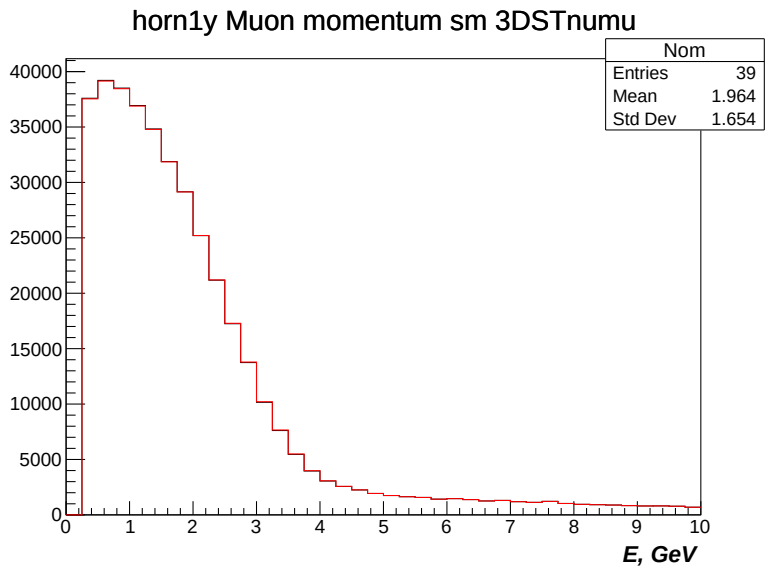


Beam re-weighting for variation of Horn1 Y Shift

Beam spectra



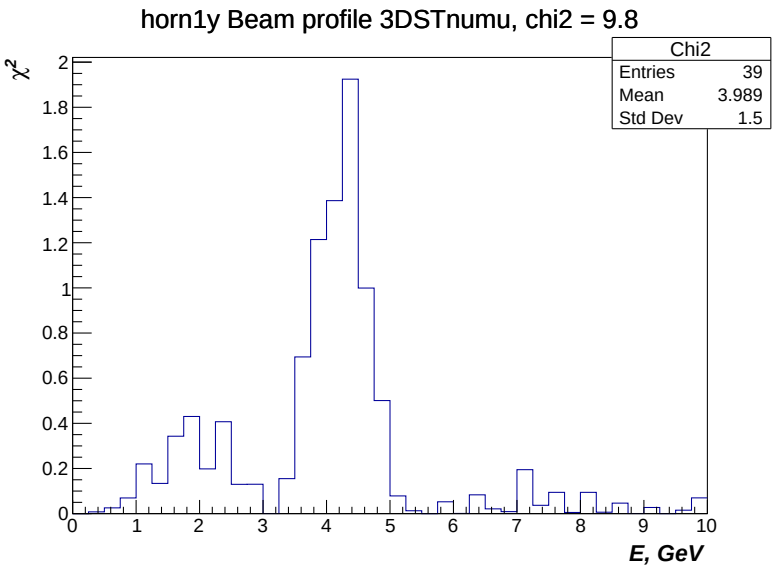
Muon momentum



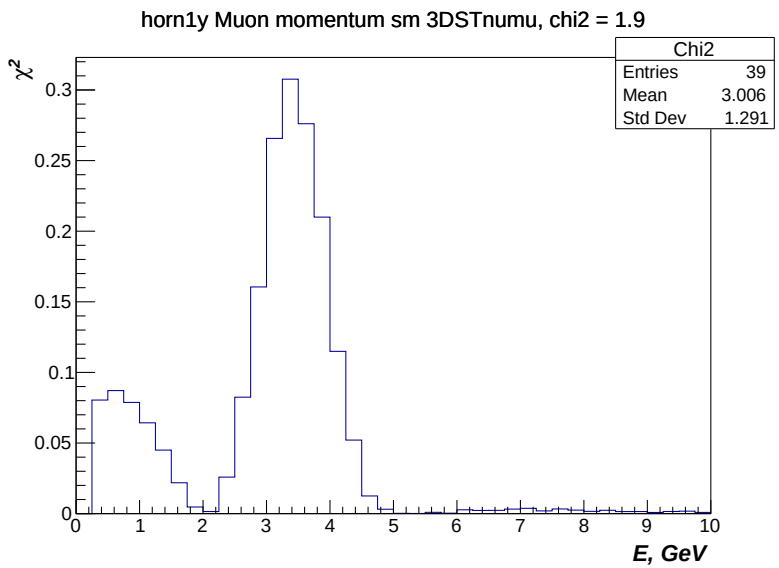
black - nominal, red - re-weighted

Chi-square for variation of Horn1 Y Shift

Beam spectra

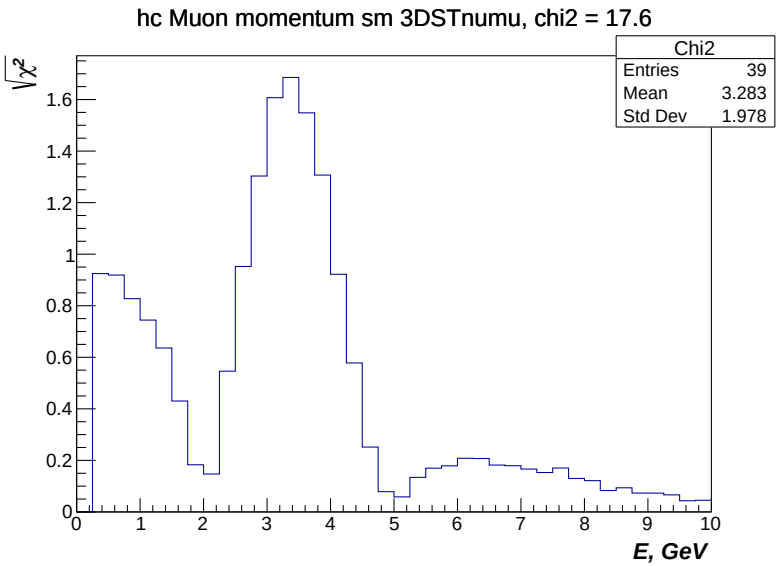


Muon momentum

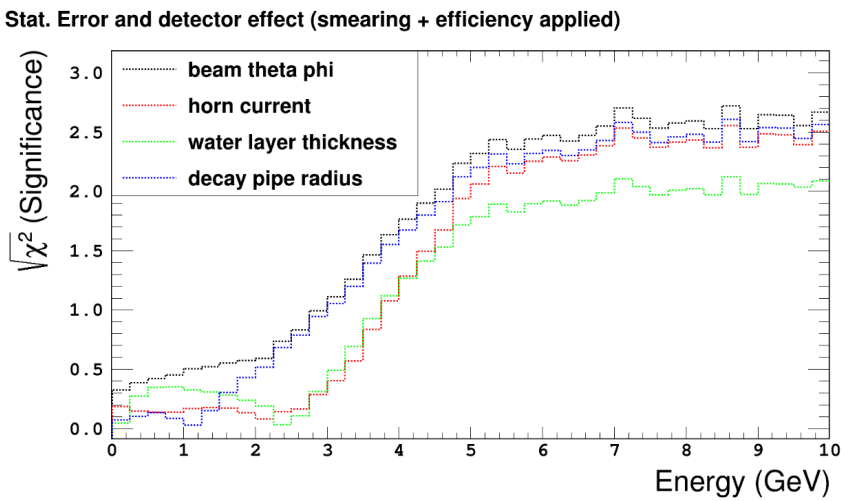


Comparison of $\sqrt{\chi^2}$ distributions for Horn Current variations

$\sqrt{\chi^2}$ obtained in our analysis



$\sqrt{\chi^2}$ obtained by 3DST group



Comparison of $\sqrt{\chi^2}$ distributions for Horn1 Y Shift variations

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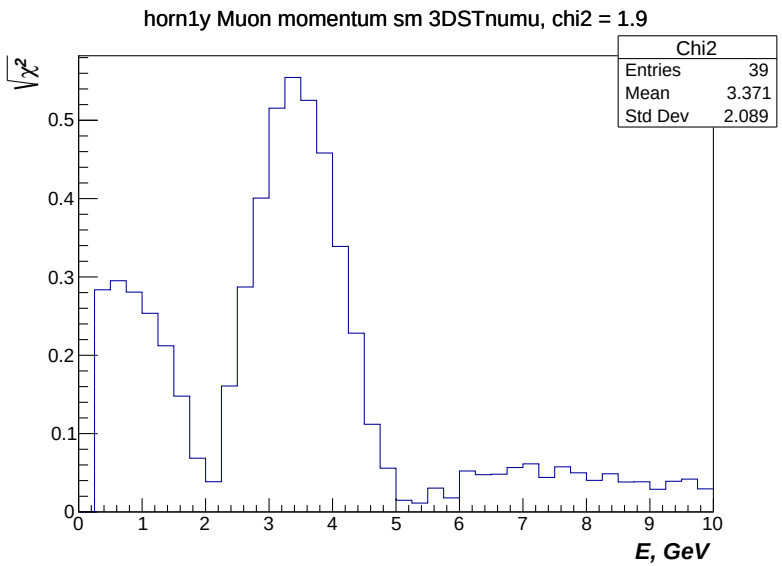

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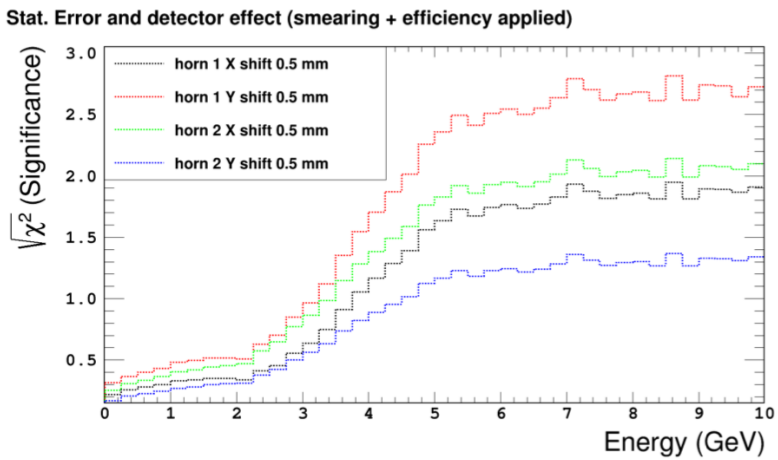


Significance comparison - 3DST

Significance $= \sqrt{\chi^2}$

Beam parameter	Variation	E_ν	E_μ	E_μ (3DST group)
Horn current	+3 kA	9.2	4.2	~ 10
Horn 1 along y	0.5 mm	3	1.4	12.8

Beam monitoring is more sensitive to neutrino energy spectra than to the muon energy because of smearing according to the y_{Bj} distribution

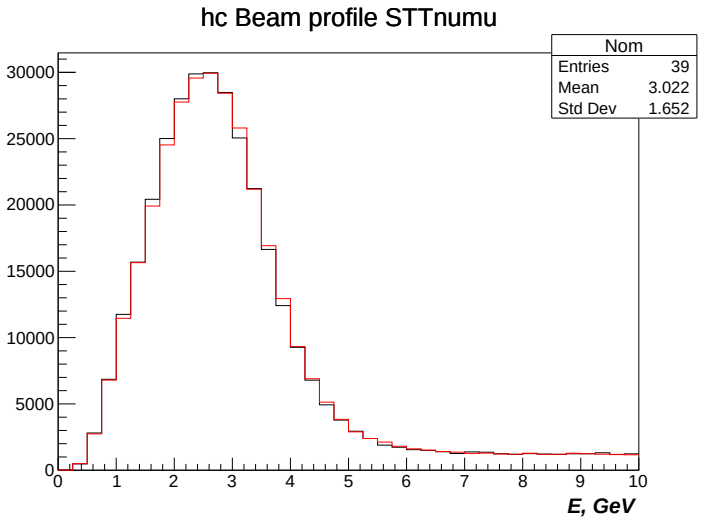
Part III: Beam Monitoring in ECAL+STT

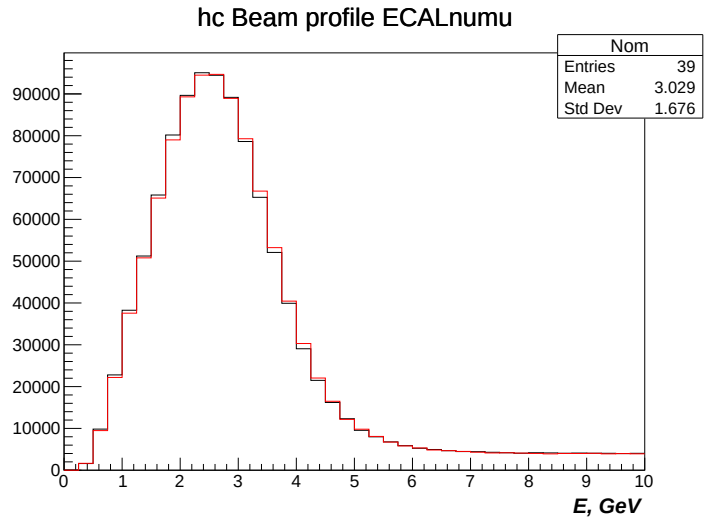
Events generation for ECAL+STT

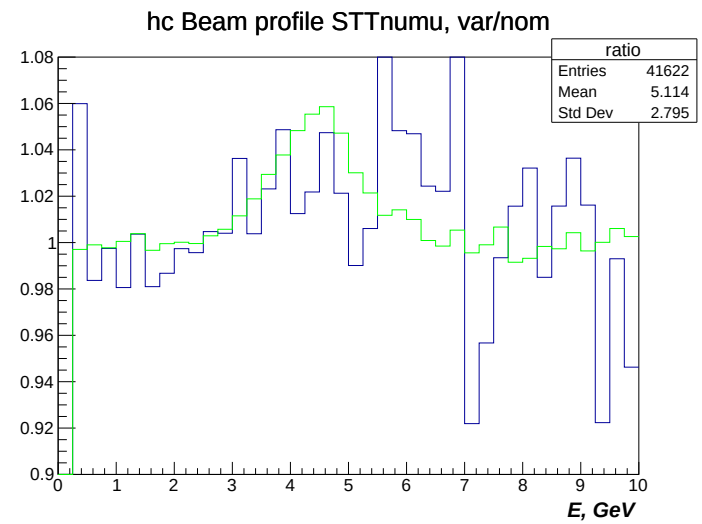
- generated exactly one week of statistics for each sample: nominal, horn current, horn 1 shift Y
- used χ^2:

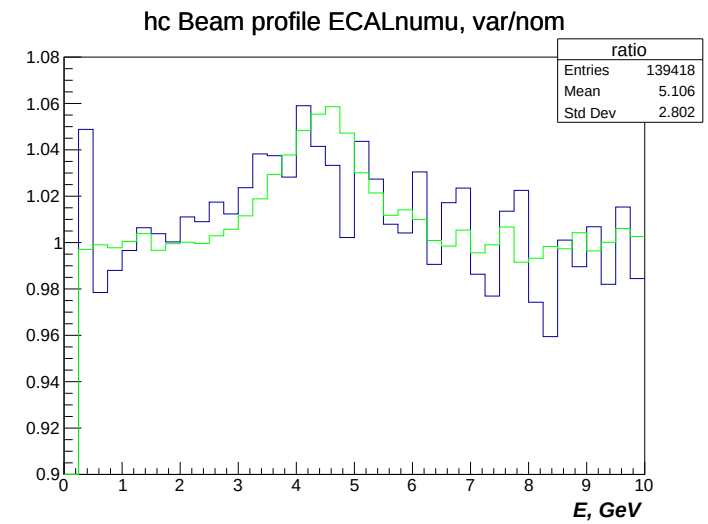
$$\chi^2 = \frac{1}{N^{nom} \cdot N^{var}} \sum_{i=1}^{k} \frac{(N^{var} \cdot n_i^{nom} - N^{nom} \cdot n_i^{var})^2}{n_i^{nom} + n_i^{var}}$$

Generated variations for ECAL+STT - Horn Current



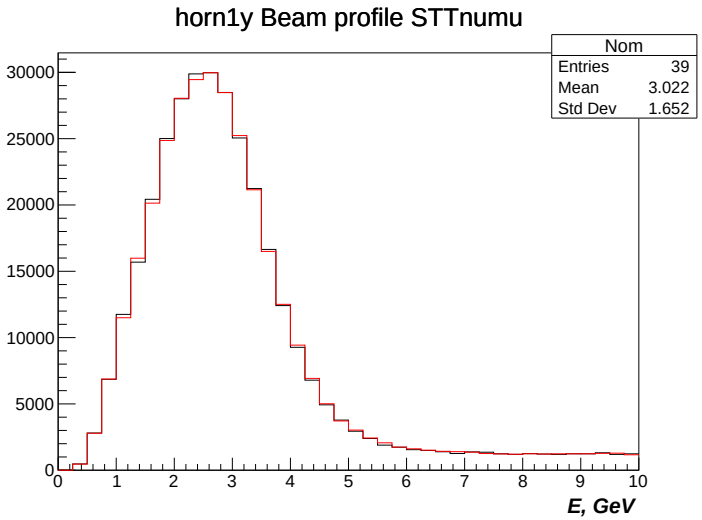


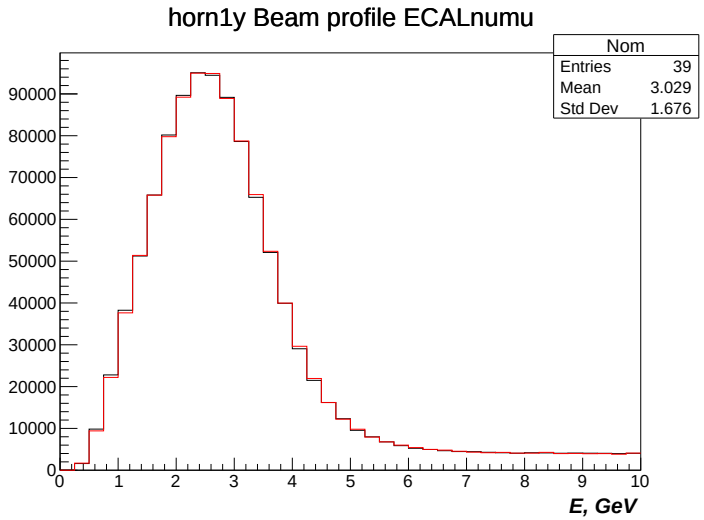


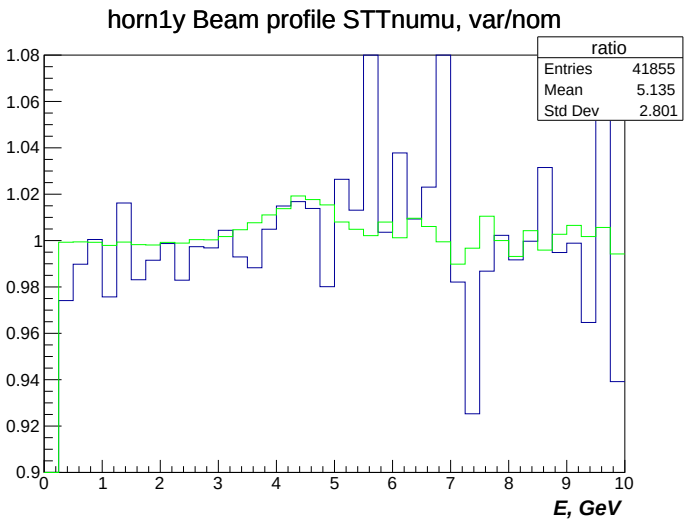


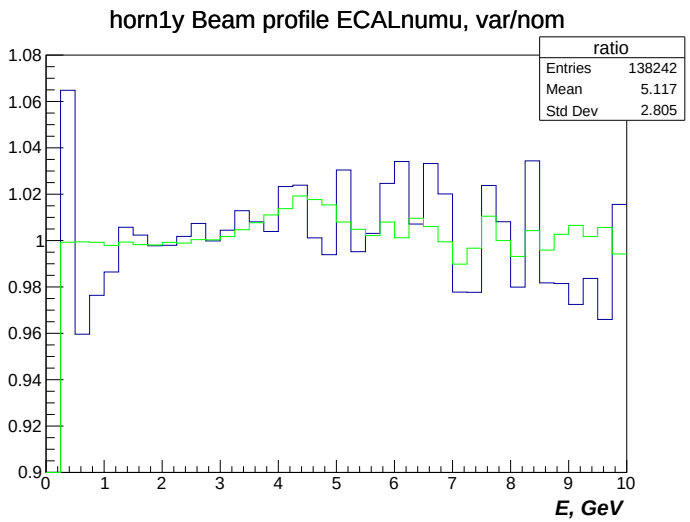
blue - ratio between generated HC and nominal, green - weights histogram W

Generated variations for ECAL+STT - Horn1 Y shift









blue - ratio between generated HC and nominal, green - weights histogram W

Results

Beam parameter	STT E_ν	ECAL E_ν	STT E_μ	ECAL E_μ
Horn current	85/39	141/39	54/39	53/39
Horn 1 along y	46/39	70/39	31/39	43/39
nominal/2	37/39	31/39	33/39	22/39

Conclusion

- χ^2 functional is sensitive to any spikes that can be easily distinguished by eyes
- during statistical analysis it is necessary to take into account statistics and statistical errors (distribution), otherwise results can be interpreted in a wrong way
- our results for significance calculation is inconsistent with the 3DST group for Beam Monitoring for re-weighted data samples
- results (χ^2 distributions) for generated samples are differ from the re-weighted one
- neutrino energy spectrum is more sensitive to Beam Monitoring compared to muon energy because of y_{Bj} distribution
- ECAL+STT provides an excellent beam monitoring due to high mass and large transverse size