Beam Monitoring with SAND

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Outline

In this presentation:

- Presentation of proof of concept beam monitoring analisys with SAND STT
- Based on thesis work by Francesco Barilari, supervised by me, Matteo Tenti and Gabriele Sirri (https://amslaurea.unibo.it/id/eprint/35319/)
- Thesis work concluded in March 2025, only presented to the collaboration during group meeting

Beam monitoring procedure with SAND

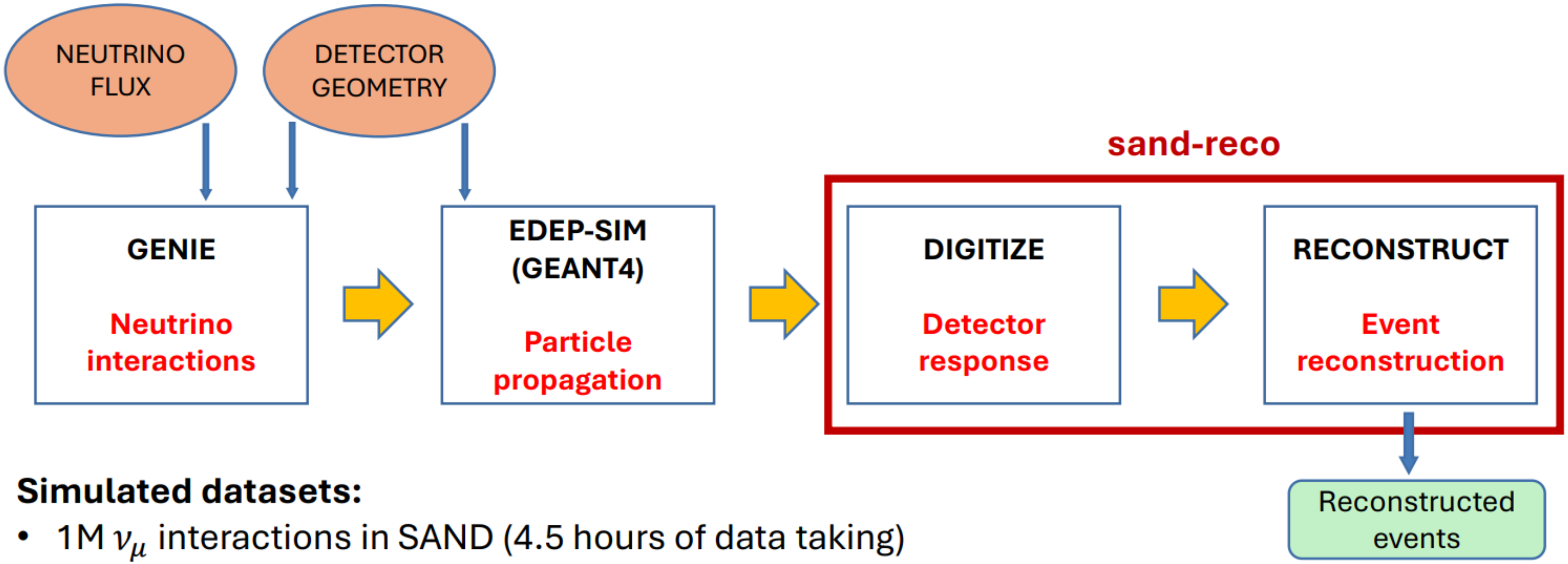
The prompt **detection of beam variations** is crucial to **validate** measurements at Far Detector

How? Periodic **comparison** of beam **spectra** at the near site with SAND detector

Observable used for comparison in this work: **reconstructed muon momentum**

Analysis procedure:
- Full simulation of neutrino interactions in SAND
- Selection and characterization of muon neutrino CC interactions
- Generation of altered spectra
- Comparison and results

Simulation Chain



Simulated datasets:

- 1M ν_μ interactions in SAND (4.5 hours of data taking)
- $\sim$ 500k ν_μ interactions in the calorimeter only (15.5 h)

In total: 4.4×10^{18} POT

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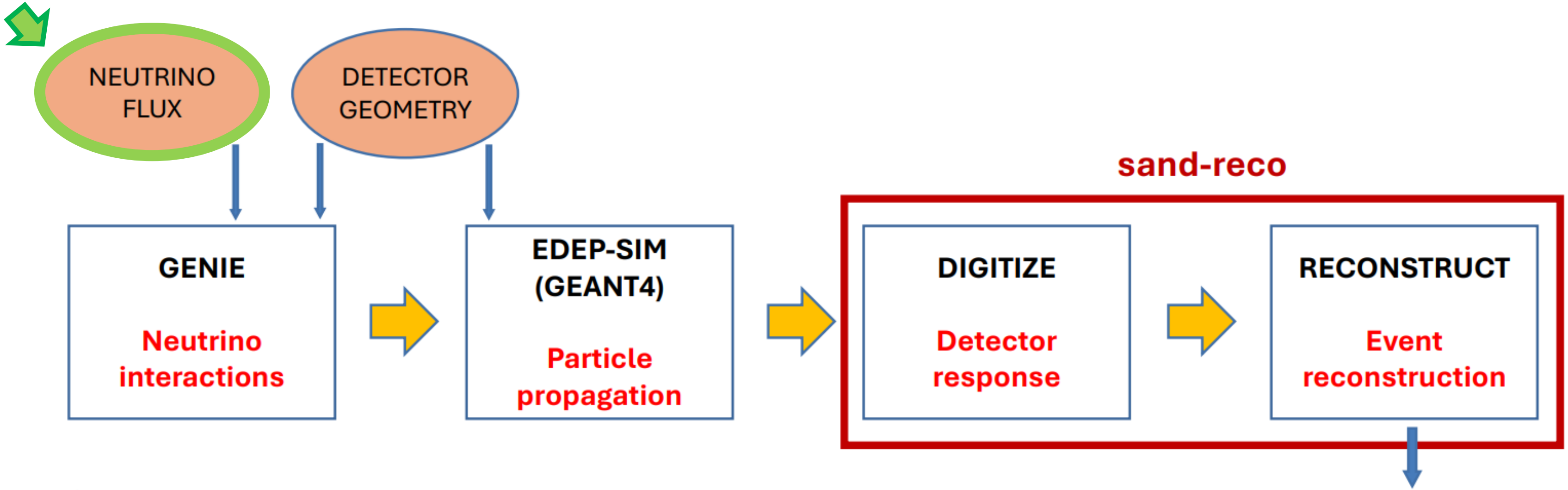

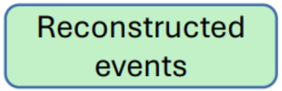

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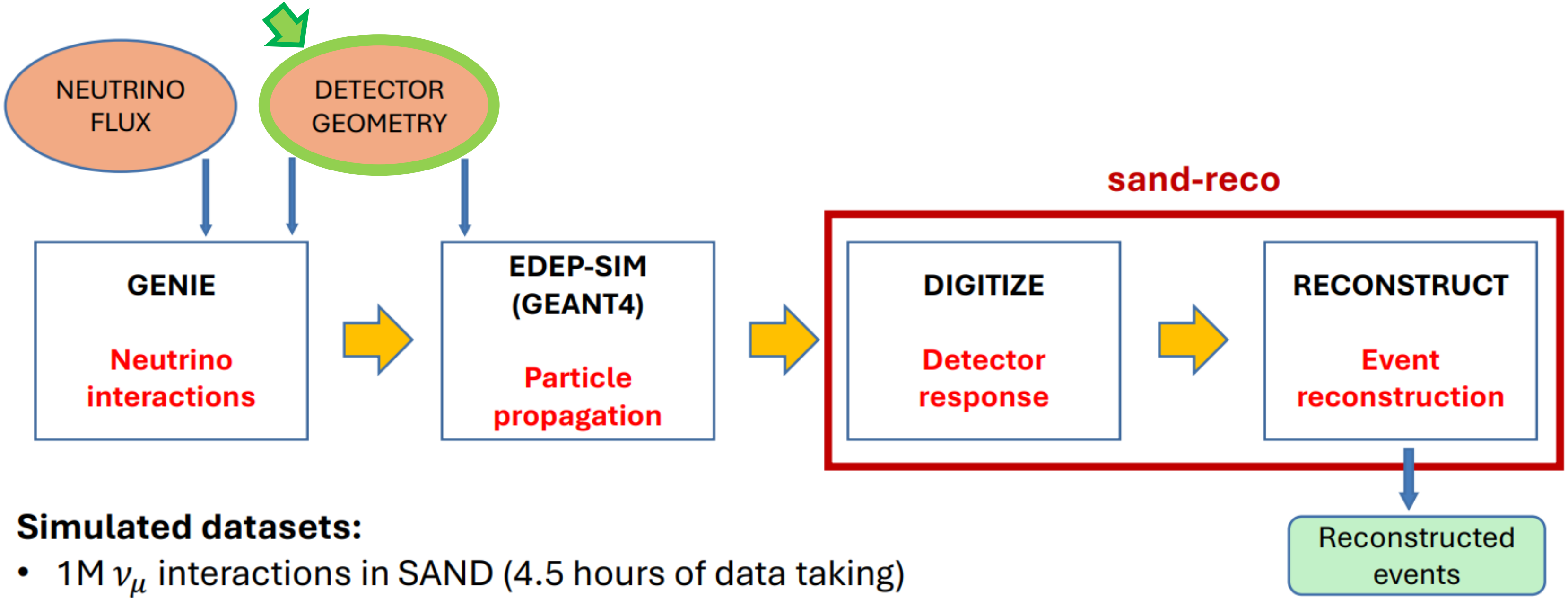
Neutrino flux and variations

- Neutrino flux histograms are disseminated by the DUNE collaboration at this link: https://glaucus.crc.nd.edu/DUNEFluxes/
- For the most up-to-date «**Optimized 3-horn Design with 1.5 m target and fully engineered Horns (Sept 2021)**» configurations, neutrino energy dependent fluxes are available, including spectra for 93 possible flux modifications
- What is not readily available are the input files needed by Genie (gsimple/dk2nu) to produce a full simulation in a detector geometry (had to use workaround, see later slides)
- These files are being made available by the FNAL computing team, but it's still a work in progress

Variations
BaffletScrapingInX_pos_1_sigma
BaffletScrapingInX_neg_1_sigma
BaffletScrapingInY_pos_1_sigma
BaffletScrapingInY_neg_1_sigma
HornCurrent_pos_1_sigma
HornCurrent_neg_1_sigma
HornWaterLayerThickness_pos_1_sigma
HornWaterLayerThickness_neg_1_sigma
ProtonBeamRadius_pos_1_sigma
ProtonBeamRadius_neg_1_sigma
DecayPipe3SegmentBowingX(Y)_pos(neg)_1_sigma
DecayPipeDisplaceTransverseX(Y)_pos(neg)_1_sigma
DecayPipeEllipticalCrossSectionXA(YB)_pos(neg)_1_sigma
DecayPipeGeoBField_pos(neg)_1_sigma
DecayPipeRadius_pos(neg)_1_sigma
DecayPipeTiltX(Y)_DSOA_pos(neg)_1_sigma
HornADisplaceLongitudinalZ_pos(neg)_1_sigma
HornADisplaceTransverseX(Y)_pos(neg)_1_sigma
HornAEccentricityXInducedBField_pos(neg)_1_sigma
HornAEllipticityXInducedBField_pos(neg)_1_sigma
HornATiltTransverseX(Y)_pos(neg)_1_sigma
HornBDisplaceLongitudinalZ_pos(neg)_1_sigma
HornBDisplaceTransverseX(Y)_pos(neg)_1_sigma
HornBEllipticityXInducedBField_pos(neg)_1_sigma
HornBTiltTransverseX(Y)_pos(neg)_1_sigma
HornCDisplaceLongitudinalZ_pos(neg)_1_sigma
HornCDisplaceTransverseX(Y)_pos(neg)_1_sigma
HornCEccentricityXInducedBField_pos(neg)_1_sigma
HornCEllipticityXInducedBField_pos(neg)_1_sigma
HornCTiltTransverseX(Y)_pos(neg)_1_sigma
ProtonBeamAngleX(Y)_pos(neg)_1_sigma
ProtonBeamTransverseX(Y)_pos(neg)_1_sigma
TargetDensity_pos(neg)_1_sigma
TargetDisplaceTransverseX(Y)_pos(neg)_1_sigma
TargetLength_pos(neg)_1_sigma
TargetTiltTransverseX(Y)_pos(neg)_1_sigma
DecayPipeLength_pos(neg)_1_sigma

Simulation Chain



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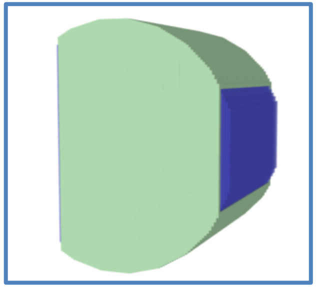
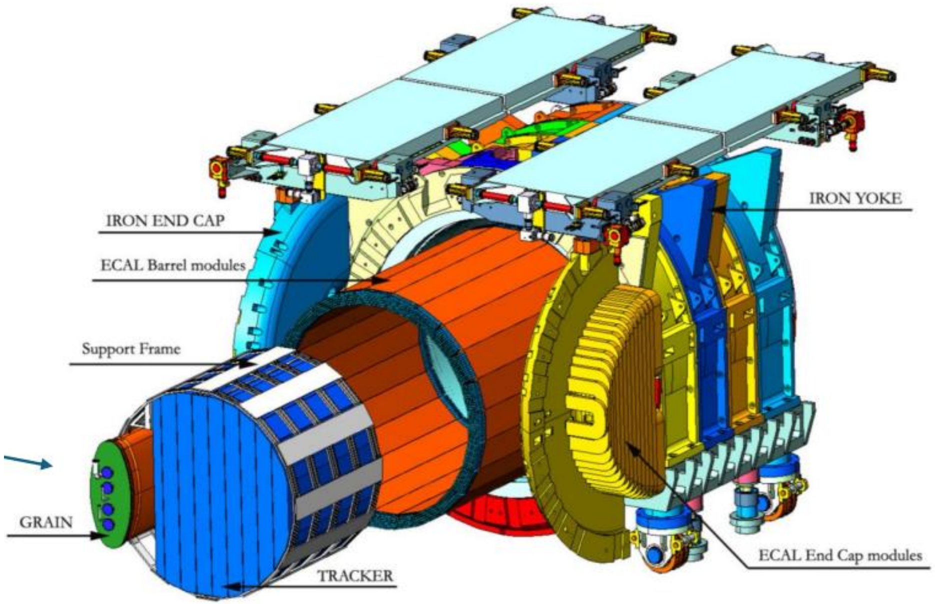
SAND geometry

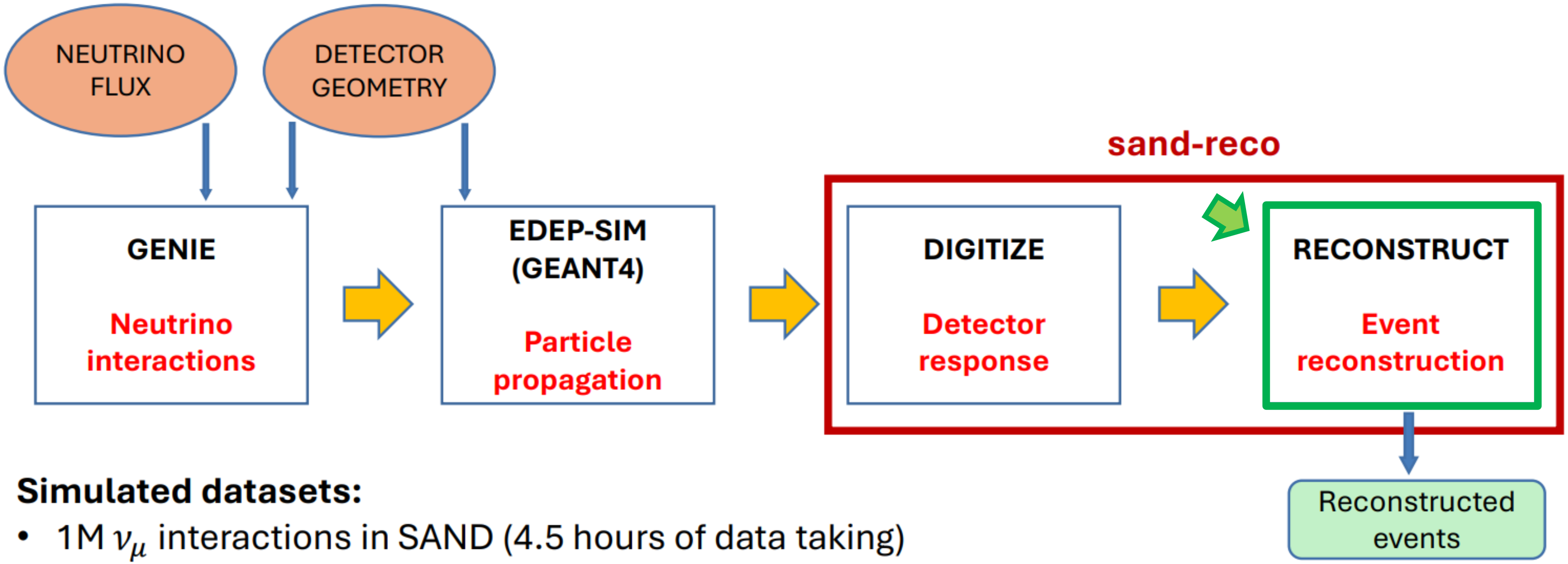
- SAND geometry used for this work is standard STT configuration
- Identified as SAND_opt3_STT1.gdml
- A copy of the gdml file can be found in neutrino-01 (CNAF server) at: /storage/gpfs_data/neutrino/SAND/GDML-GEO/SAND_opt3_STT1.gdml

Straw Tube Tracker





Simulation Chain



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Notes on tracker reconstruction

sandreco / src / reconstruction.cpp

```
case STT_Mode::fast:
  TrackFind(ev, vec_digi, vec_tr, trackerType);
  TrackFit(vec_tr);
  break;
```

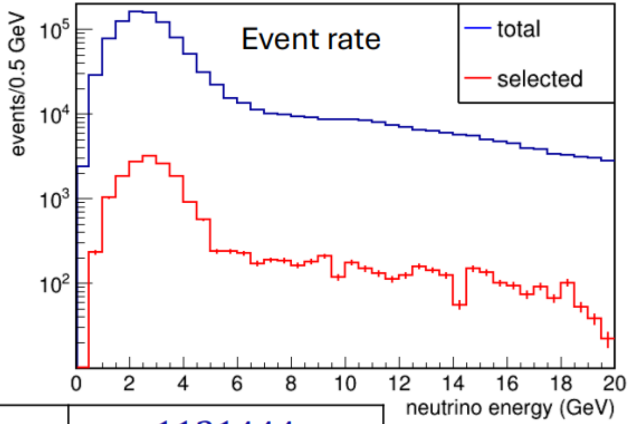
https://github.com/DUNE/sandreco/blob/241ba4c9126d4d23ee9214b50569b7c1154eaf9a/src/reconstruction.cpp#L1900

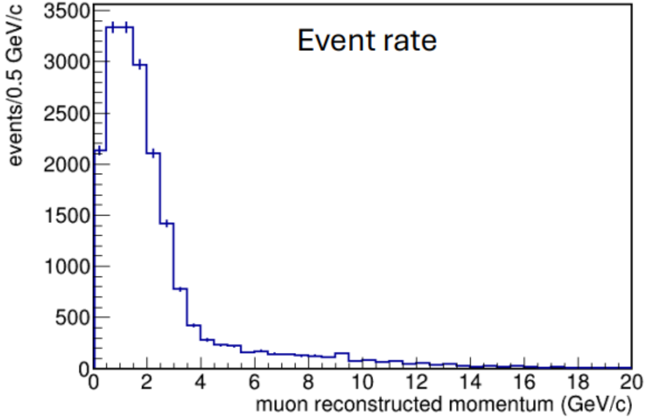
- For this study charged particle tracks in STT were reconstructed using a **simple helix fit applied to smeared trajectory points** (fastreco option in sandreco)
- Track formation from MC truth info;
- Disregarded digitization, done simply with truth smearing;
- No Kalman Filter (no handling of enrgy loss/multiple scattering);

N.B. Predates most up-to-date reconstruction presented by G.Lupi

Event Selection

Several cuts to select events interacting in the front calorimeter with a muon-like particle





N_{tot}	1121444
N_1	845195
N_2	25693
N_3	23945
N_4	18881
R	0.0168 ± 0.0001

1. Charge current interactions
2. Vertex in the front calorimeter
3. Neutrino energy less than 20 GeV
4. Muon *well* reconstructed in the tracker

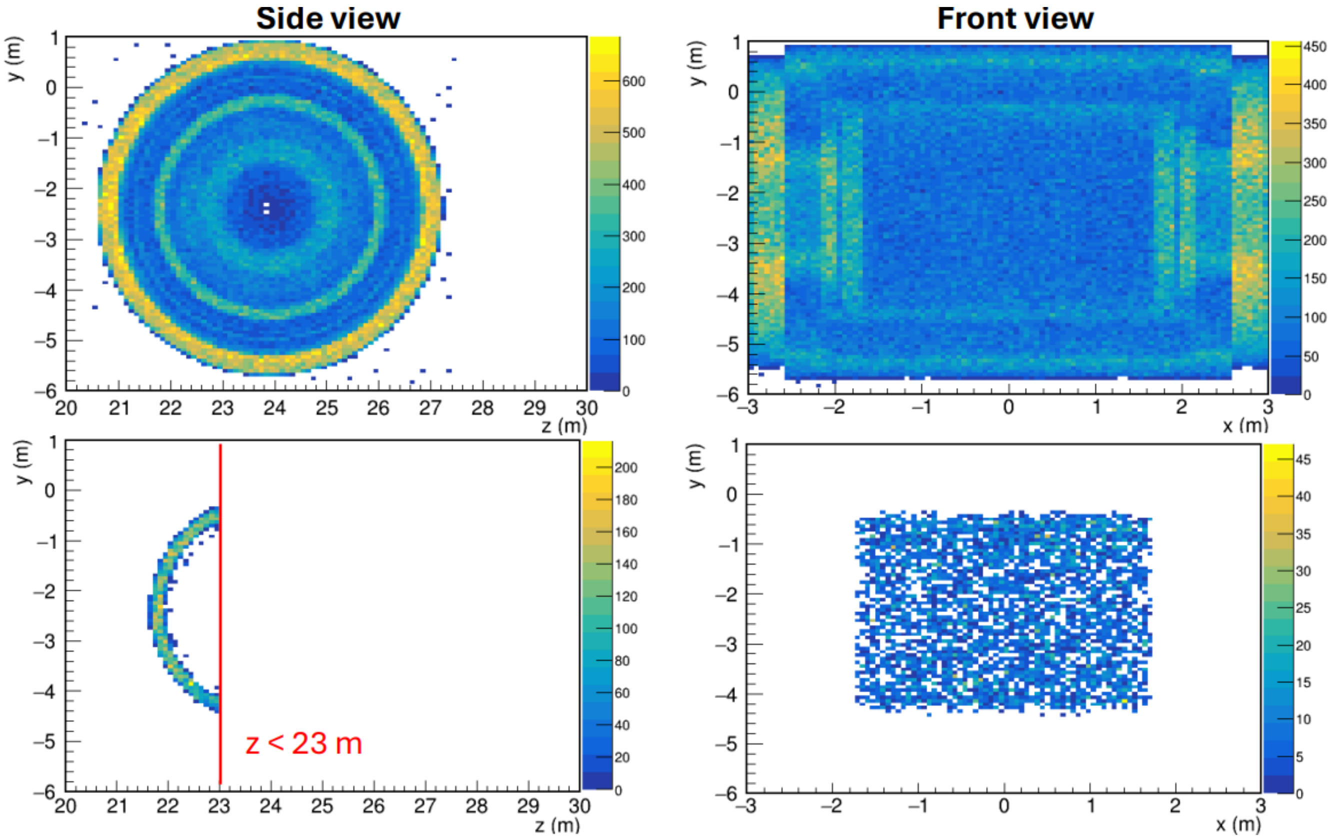
   (Reconstruction produced non zero result)

MC truth

Vertex position

Full dataset

Selected sample: vertices in the **front calorimeter**

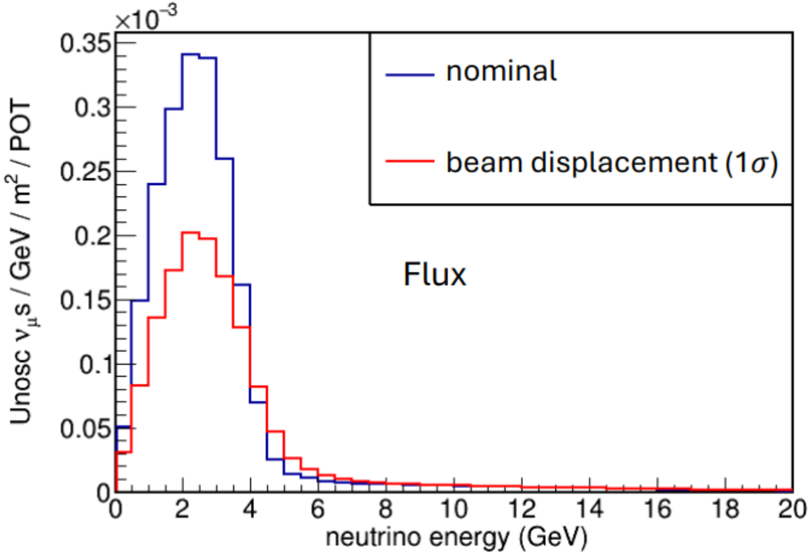


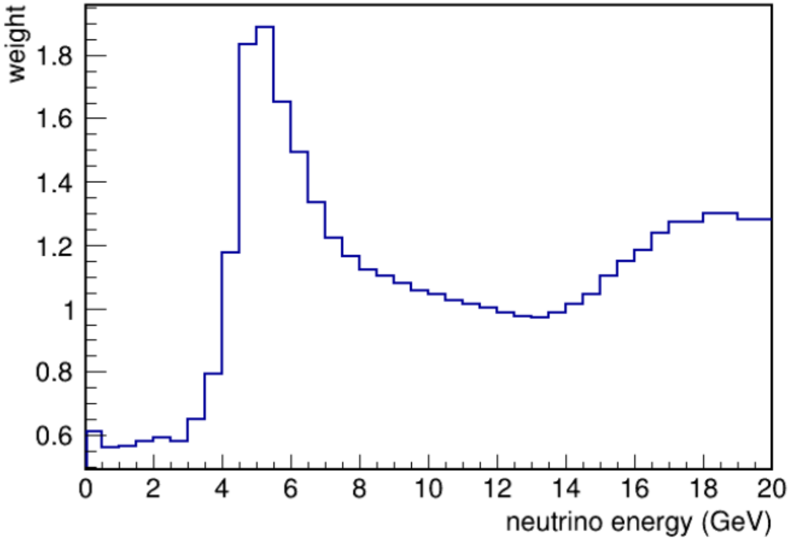
Altered flux re-weighting (work-around)

The altered **flux** data cannot be used as input for a full simulation

solution

Re-weight events according to their neutrino energy

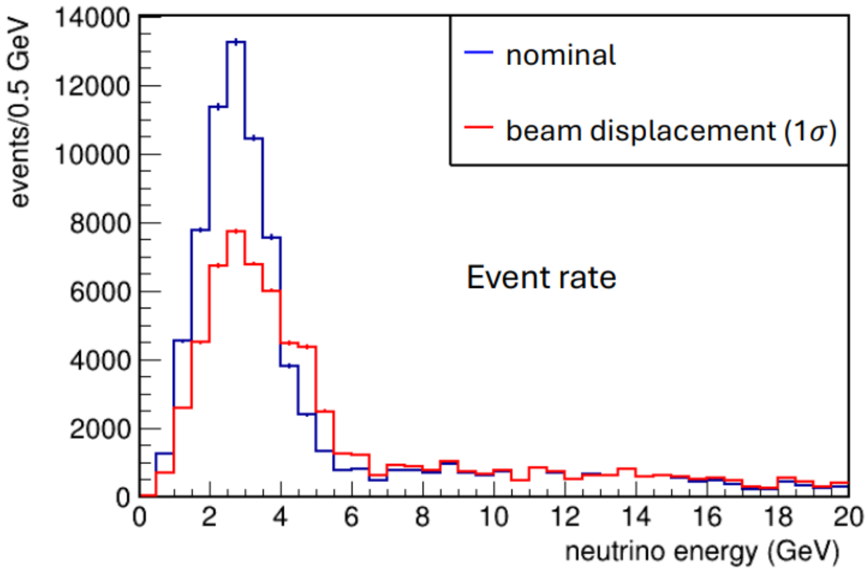


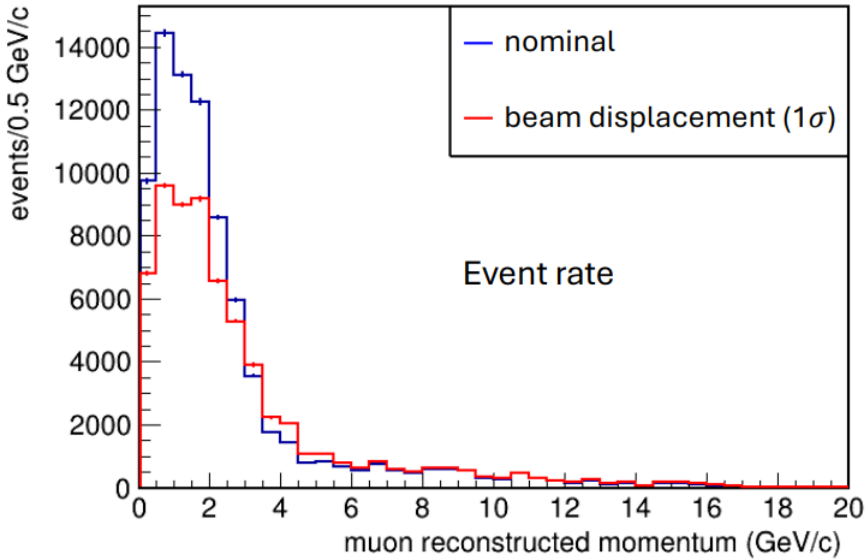


Weights are evaluated as the **ratio bin-by-bin** between the two fluxes (altered / nominal)

Muon momentum spectra

Histograms filled with muon momentum weighted by the flux ratio



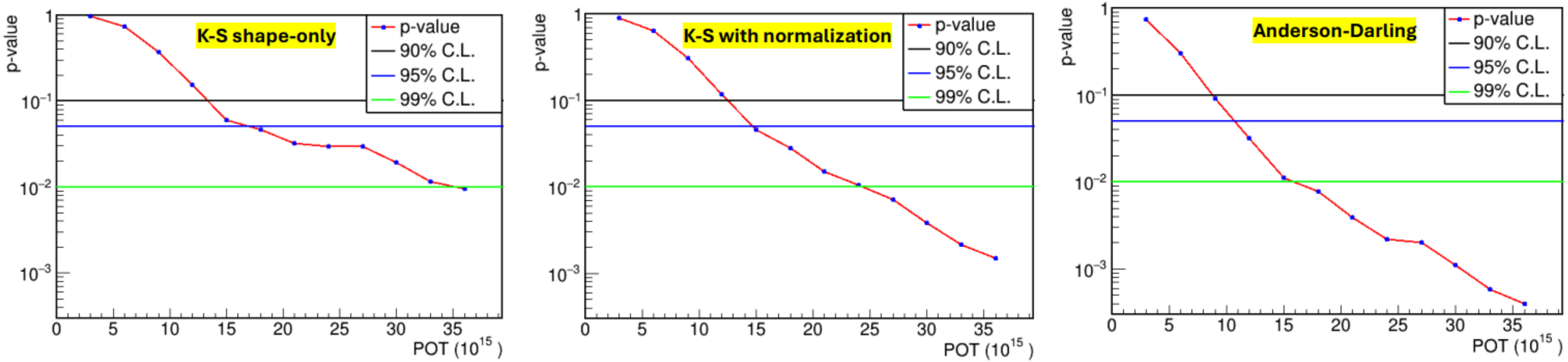


Muon reconstructed momentum spectra compared using **two-sample test statistics:**

- **Kolmogorov-Smirnov** (both shape-only, and considering the normalization)
- **Anderson-Darling**

Critical value to consider the test successfull: p-value < 0.01 (99% C.L.)

Analysis and results



p-values computed as a function of POT for «beam displacement (1σ)» variation

Results:

- Variation of the nominal flux can be found in **few minutes** ($\sim 10^{16}$ POT)
- Anderson-Darling test is the most effective

All other **93** variations considered are not resolved with this statistics, which is limited to 20 hours

Results for all variations

- With our limited simulated statistics ($\sim$ 20 hours data-taking) we are sensitive to the most substantive flux variations
- Some very limited sensitivity was found for other for additional variation sets
- No sensitivity was found for the majority of variations
- Higher statistics needed to study sensitivity to other variations

Variations	KS	shape KS	shape AD
BaffletScrapingInX_pos_1_sigma	$< 10^{-15}$	$< 10^{-15}$	$< 10^{-15}$
BaffletScrapingInX_neg_1_sigma	$< 10^{-15}$	$< 10^{-15}$	$< 10^{-15}$
BaffletScrapingInY_pos_1_sigma	$< 10^{-15}$	$< 10^{-15}$	$< 10^{-15}$
BaffletScrapingInY_neg_1_sigma	$< 10^{-15}$	$< 10^{-15}$	$< 10^{-15}$
HornCurrent_pos_1_sigma	0.999	0.994	0.867
HornCurrent_neg_1_sigma	0.999	0.999	0.937
HornWaterLayerThickness_pos_1_sigma	1	1	1
HornWaterLayerThickness_neg_1_sigma	0.999	0.998	0.951
ProtonBeamRadius_pos_1_sigma	0.995	0.922	0.469
ProtonBeamRadius_neg_1_sigma	0.999	0.998	0.846
DecayPipe3SegmentBowingX(Y)_pos(neg)_1_sigma	1	1	1
DecayPipeDisplaceTransverseX(Y)_pos(neg)_1_sigma	1	1	1
DecayPipeEllipticalCrossSectionXA(YB)_pos(neg)_1_sigma	1	1	1
DecayPipeGeoBField_pos(neg)_1_sigma	1	1	1
DecayPipeRadius_pos(neg)_1_sigma	1	1	1
DecayPipeTiltX(Y)_DSOA_pos(neg)_1_sigma	1	1	1
HornADisplaceLongitudinalZ_pos(neg)_1_sigma	1	1	1
HornADisplaceTransverseX(Y)_pos(neg)_1_sigma	1	1	1
HornAEccentricityXInducedBField_pos(neg)_1_sigma	1	1	1
HornAEllipticityXInducedBField_pos(neg)_1_sigma	1	1	1
HornATiltTransverseX(Y)_pos(neg)_1_sigma	1	1	1
HornBDisplaceLongitudinalZ_pos(neg)_1_sigma	1	1	1
HornBDisplaceTransverseX(Y)_pos(neg)_1_sigma	1	1	1
HornBEllipticityXInducedBField_pos(neg)_1_sigma	1	1	1
HornBTiltTransverseX(Y)_pos(neg)_1_sigma	1	1	1
HornCDisplaceLongitudinalZ_pos(neg)_1_sigma	1	1	1
HornCDisplaceTransverseX(Y)_pos(neg)_1_sigma	1	1	1
HornCEccentricityXInducedBField_pos(neg)_1_sigma	1	1	1
HornCEllipticityXInducedBField_pos(neg)_1_sigma	1	1	1
HornCTiltTransverseX(Y)_pos(neg)_1_sigma	1	1	1
ProtonBeamAngleX(Y)_pos(neg)_1_sigma	1	1	1
ProtonBeamTransverseX(Y)_pos(neg)_1_sigma	1	1	1
TargetDensity_pos(neg)_1_sigma	1	1	1
TargetDisplaceTransverseX(Y)_pos(neg)_1_sigma	1	1	1
TargetLength_pos(neg)_1_sigma	1	1	1
TargetTiltTransverseX(Y)_pos(neg)_1_sigma	1	1	1
DecayPipeLength_pos(neg)_1_sigma	1	1	1

Conclusions and Outlooks

Summary

- Completed **proof of concept study on beam-monitoring capabilities of SAND-STT**
- Simulated statistics equivalent to ~ 20 hours of data taking and reweighed muon spectra based on 93 flux variation provided by DUNE collaboration
- Using re-weighed reconstructed muon spectra from ν_μ CCQE: showed **sensitivity to most significant variations**

Outlook & Conclusions

- **Limitations:**

1. Cuts and reconstructions heavily reliant on MC truth (not up-to-date)
2. Flux variations not fully simulated, just re-weighed
3. Only one observable considered
4. Very limited statistics

- **Study serves as solid proof-of-concept and gives a model for future work**

Thank you !

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