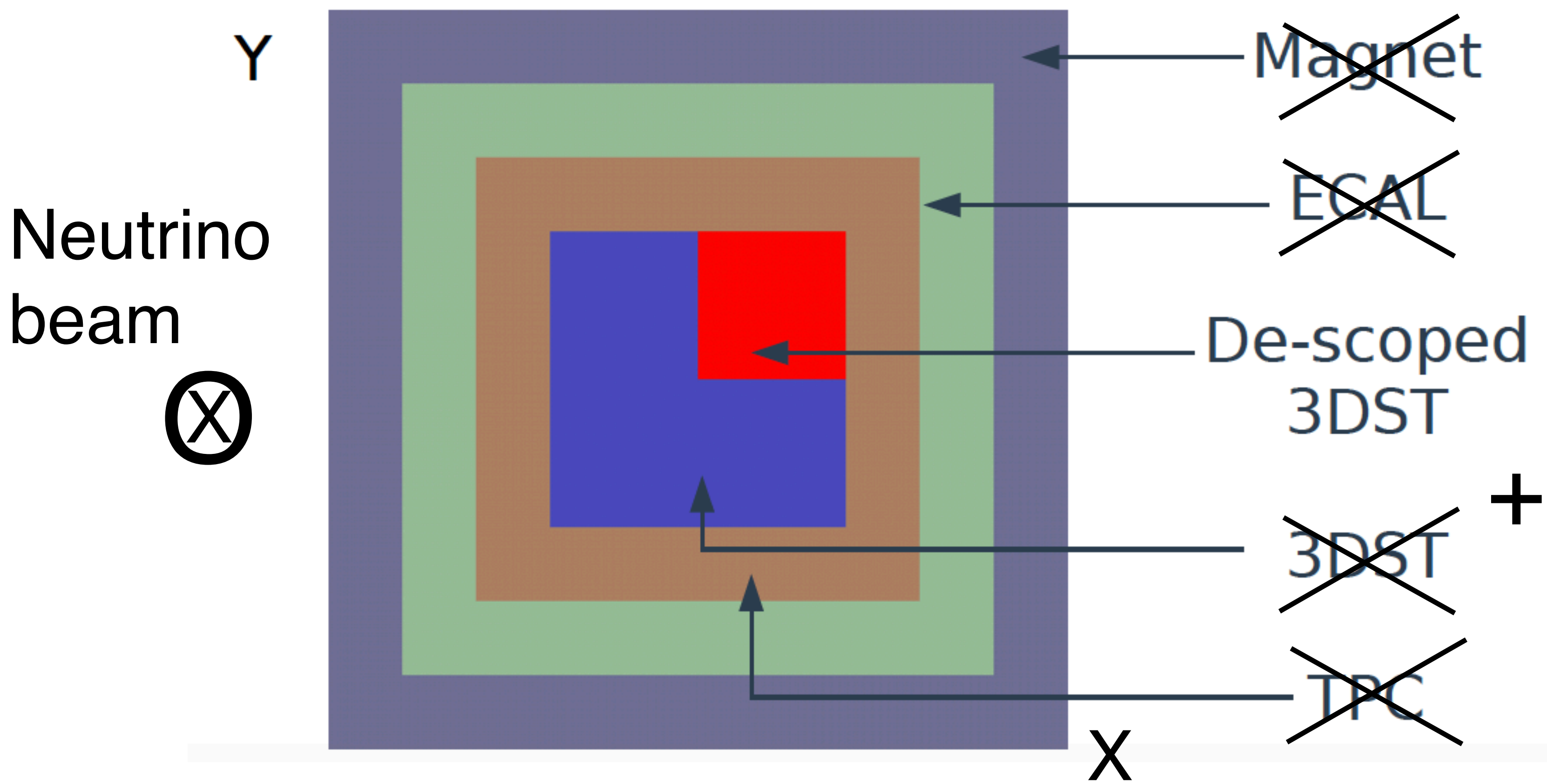
Descoping / Staging

De-scoped configuration

- Fiducial Volume: 1x1x1 m^3
- Without TPCs, ECAL and magnet
- Forward spectrometer only downstream of 3DST

The de-scoped 3DST-S

- The fixed parameter is the Fiducial Volume: 1 x 1 x 1 m^3
- Applied the same out-FV cuts, i.e. 10 cm outer-shell:
  - ✦ Total Volume = 1.2 x 1.2 x 1.2 m^3
  - ✦ Fiducial Mass = 1 ton



✦ The de-scoped configuration has 8.7 times less events than baseline configuration

+ forward spectrometer

- Implemented the de-scoped configuration "by symmetry", i.e. consider only bkg produced on the X, Y, Z side as 3DST de-scoped volume and multiply it by a factor x2. Now Running the full simulation

The 3DST event rate

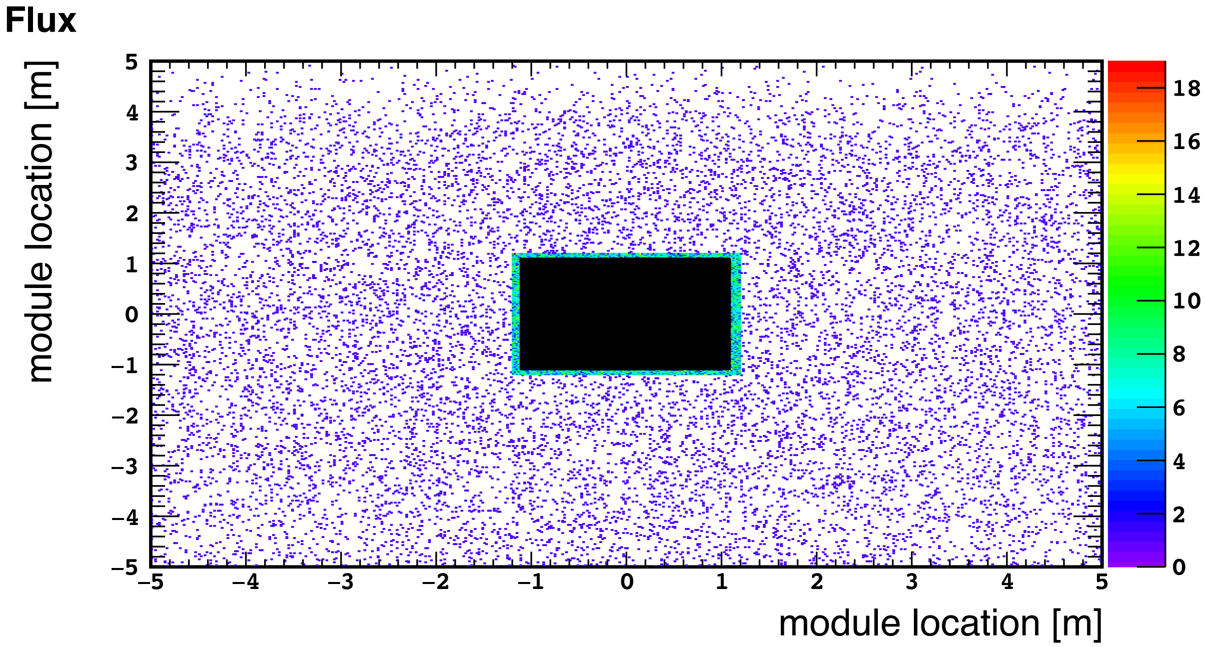
- Event rate for 1.46×10^{21} POT / year (80 GeV beam, three horns, optimized)
- Applied a 10 cm out-of-FV cut:
  - ✦ Fiducial Volume = 2.2 x 2.2 x 1.8 m^3
  - ✦ Fiducial Mass = 8.7 tons (only 3DST)

Channel	ν mode	$\bar{\nu}$ mode
ν_μ CC inclusive	13.6×10^6	5.1×10^6
CCQE	2.9×10^6	1.6×10^6
CC π° inclusive	3.8×10^6	0.97×10^6
NC total	4.9×10^6	2.1×10^6
ν_μ-e^- scattering	1067	1008
ν_μ CC coherent	1.26×10^5	8.6×10^4
ν_μ CC low-ν (ν <250 MeV)	1.48×10^6	8.8×10^5
ν_e CC coherent	2.1×10^3	719
ν_e CC low-ν (ν <250 MeV)	2.1×10^4	4.7×10^3
ν_e CC inclusive	2.5×10^5	0.56×10^5

- The FV will have different definitions depending on the physics measurement
- Depending on the ECAL design, additional mass could be achieved for some physics channels

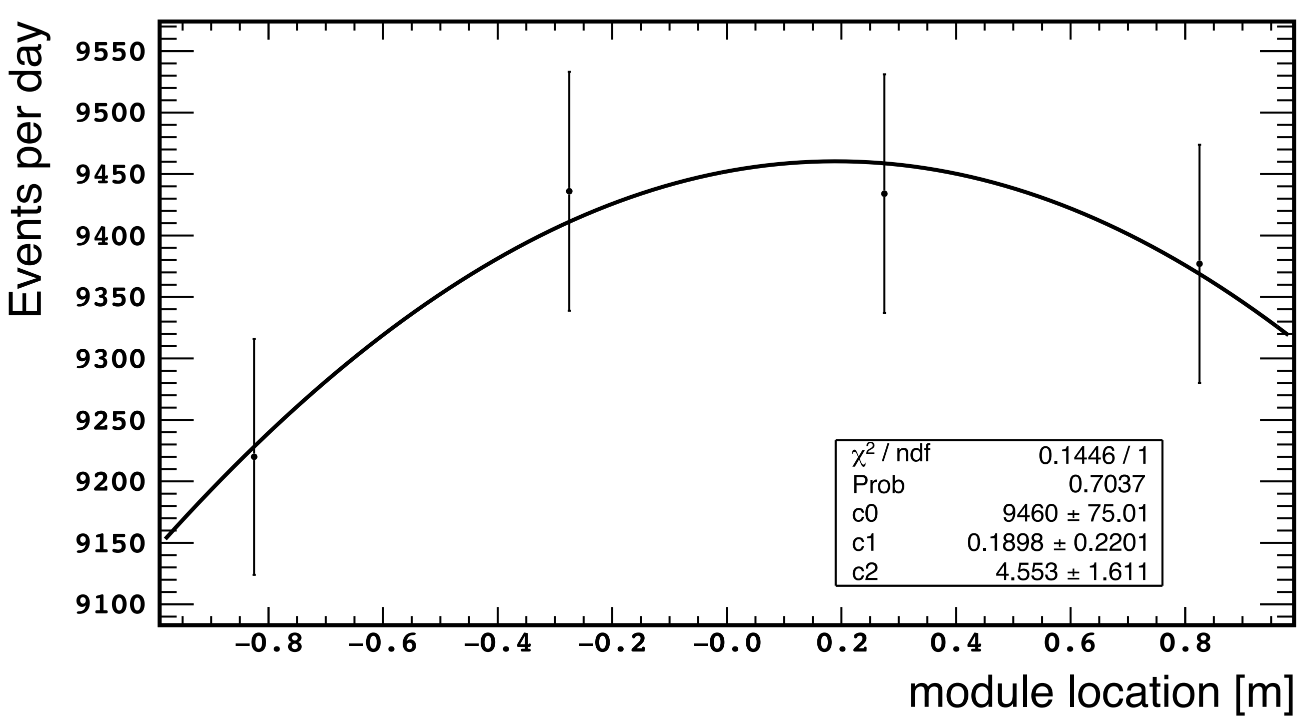
Beam monitor with single 3DST module

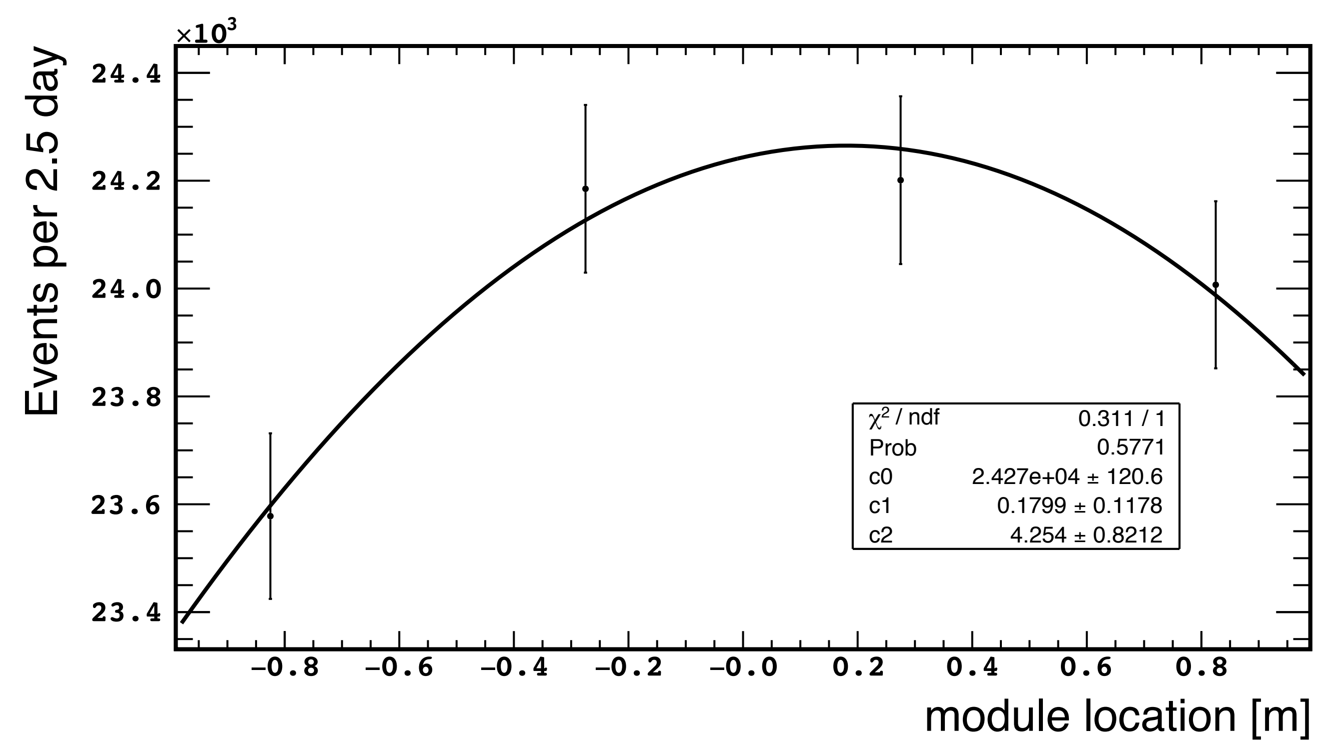
- Study uses single 3DST module (2.4x2.4x2 m³ volume, FM 8.7 tons)



- Using single 3DST module, ~11 cm uncertainty on the beam center can be achieved with 2.5 days data taking
- If ECAL is designed to have capability to detect the event vertex, it can be used as part of the beam monitor system. In such case it would increase the statistics by nearly a factor of 3 (by mass)

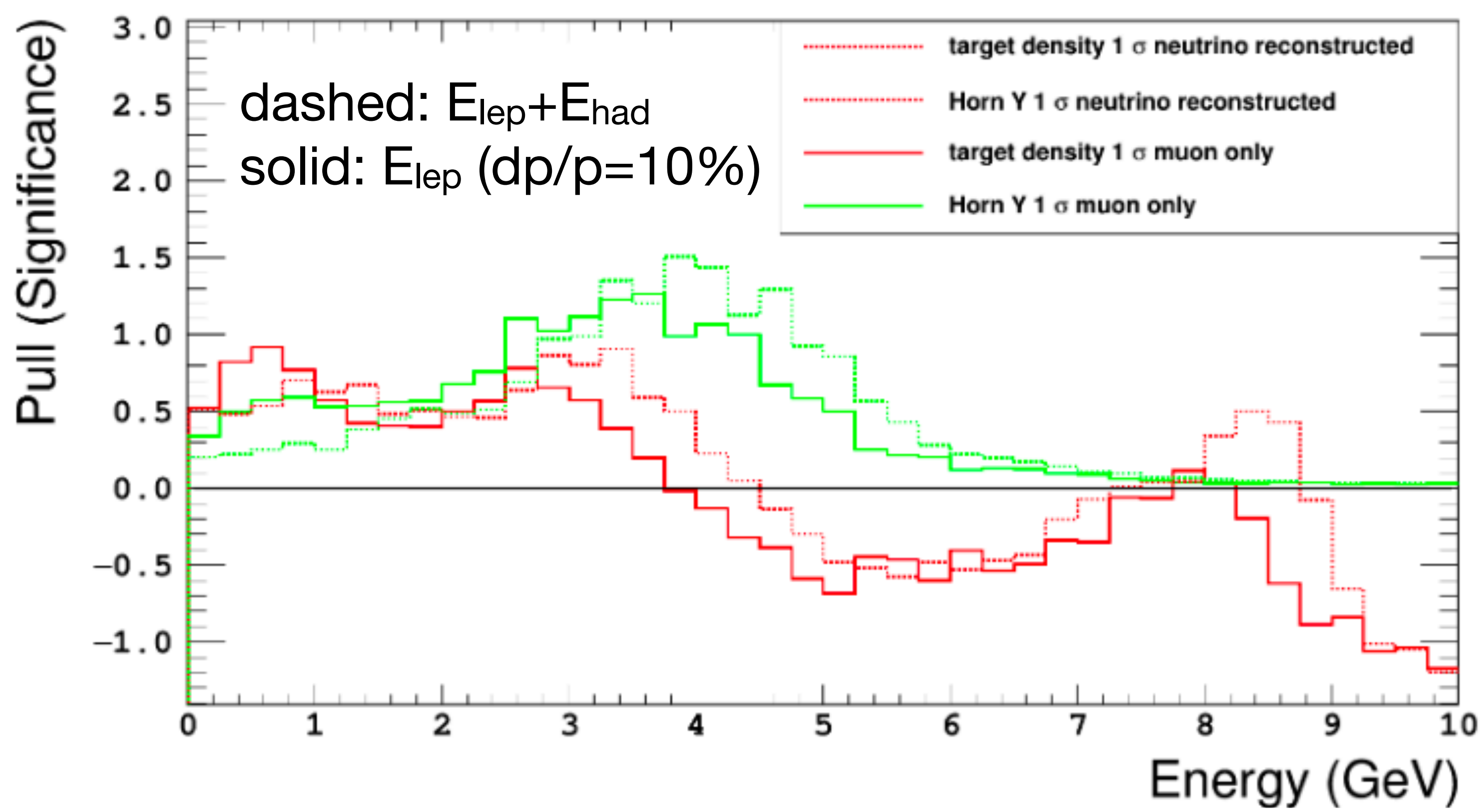
Statistics reduced by a factor 8.7 for the de-scoped configuration (1m³)



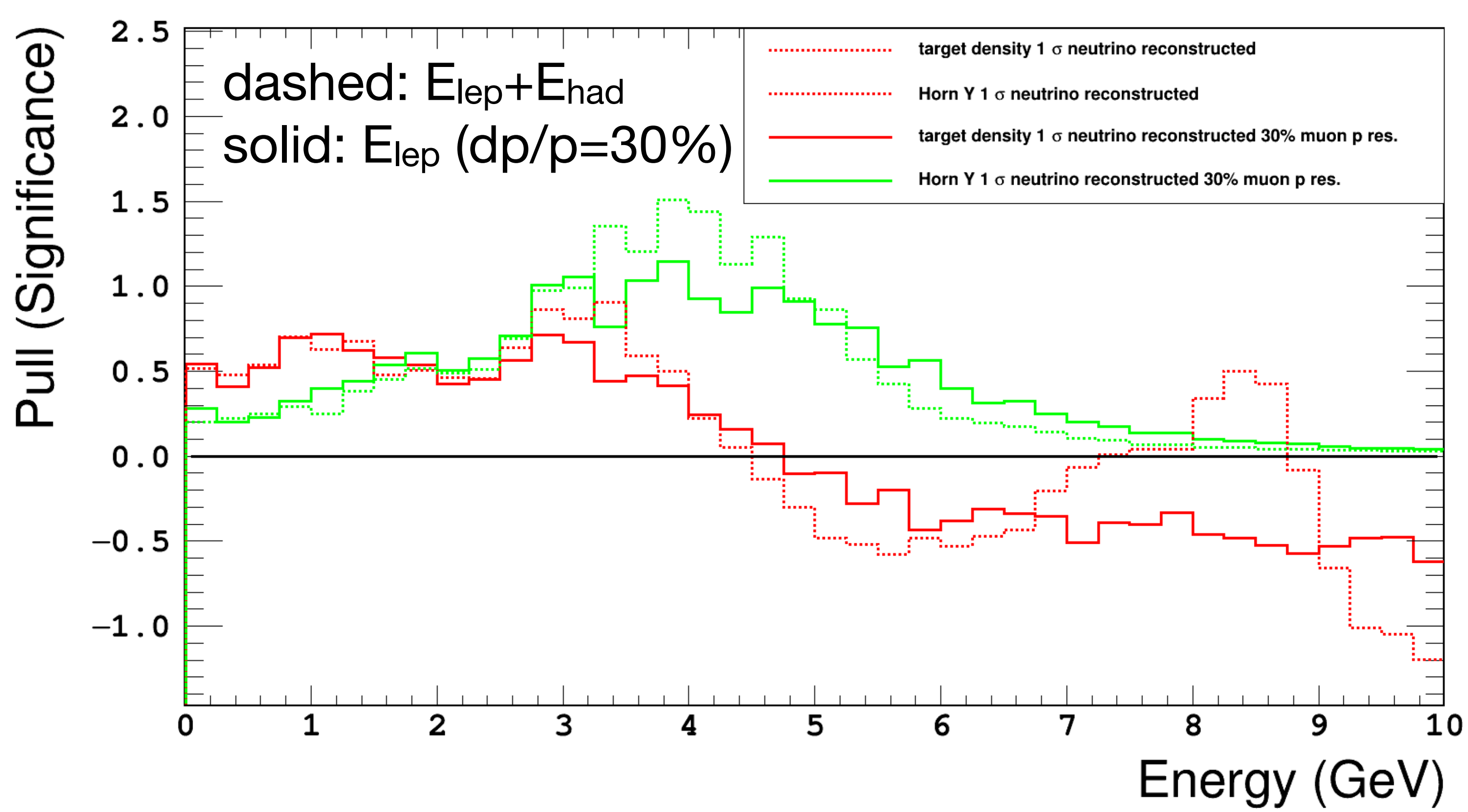


Beam monitor with single 3DST module

Stat. Error and detector effect (smearing + efficiency applied)



Stat. Error and detector effect (smearing + efficiency applied)

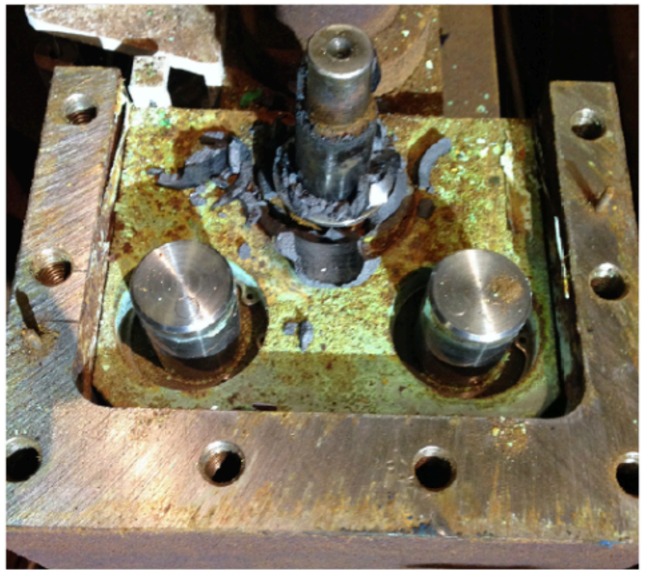


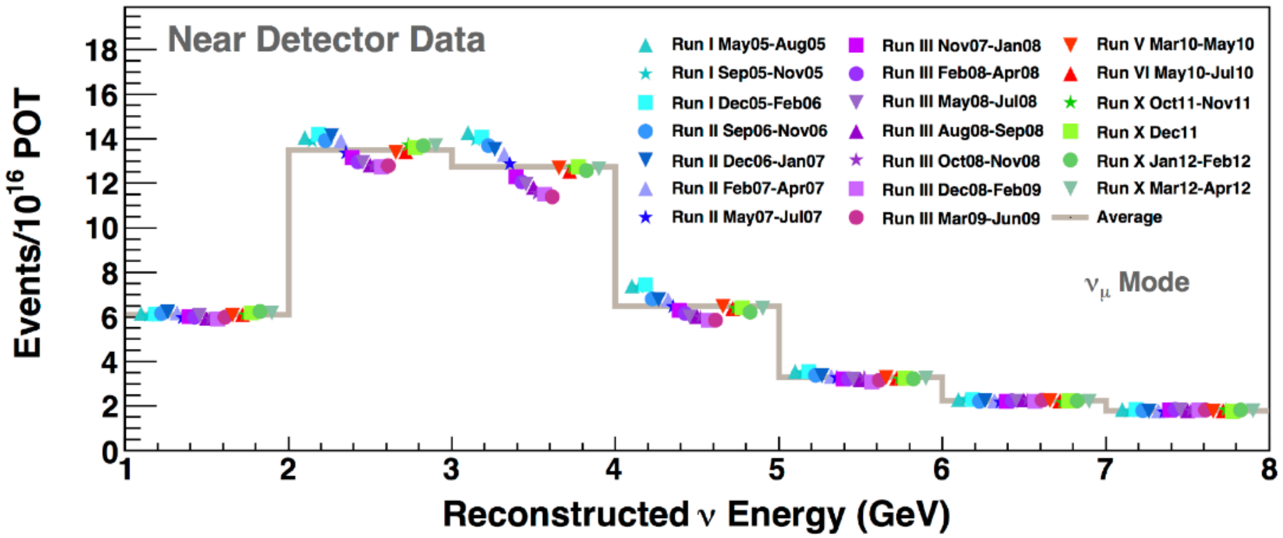
- We need mass to monitor in a short time period
- We can't do it without a spectrometer
- The better is the efficiency/resolution on produced particles the better is the shape resolution

Beam monitor with single 3DST module

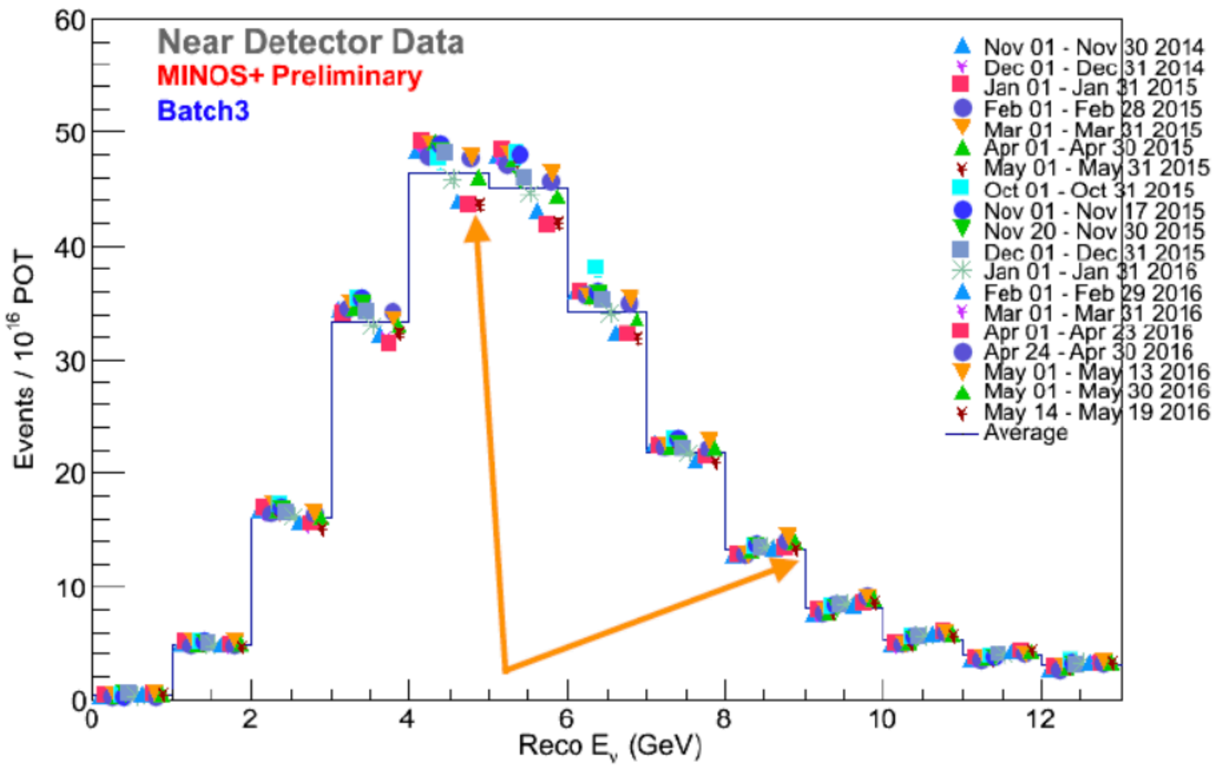
- Talk @CENF-ND meeting

  https://indico.cern.ch/event/674901/contributions/2799260/attachments/1565380/2466505/beam_27Nov2017CERN-CENF-NDmeeting.pdf





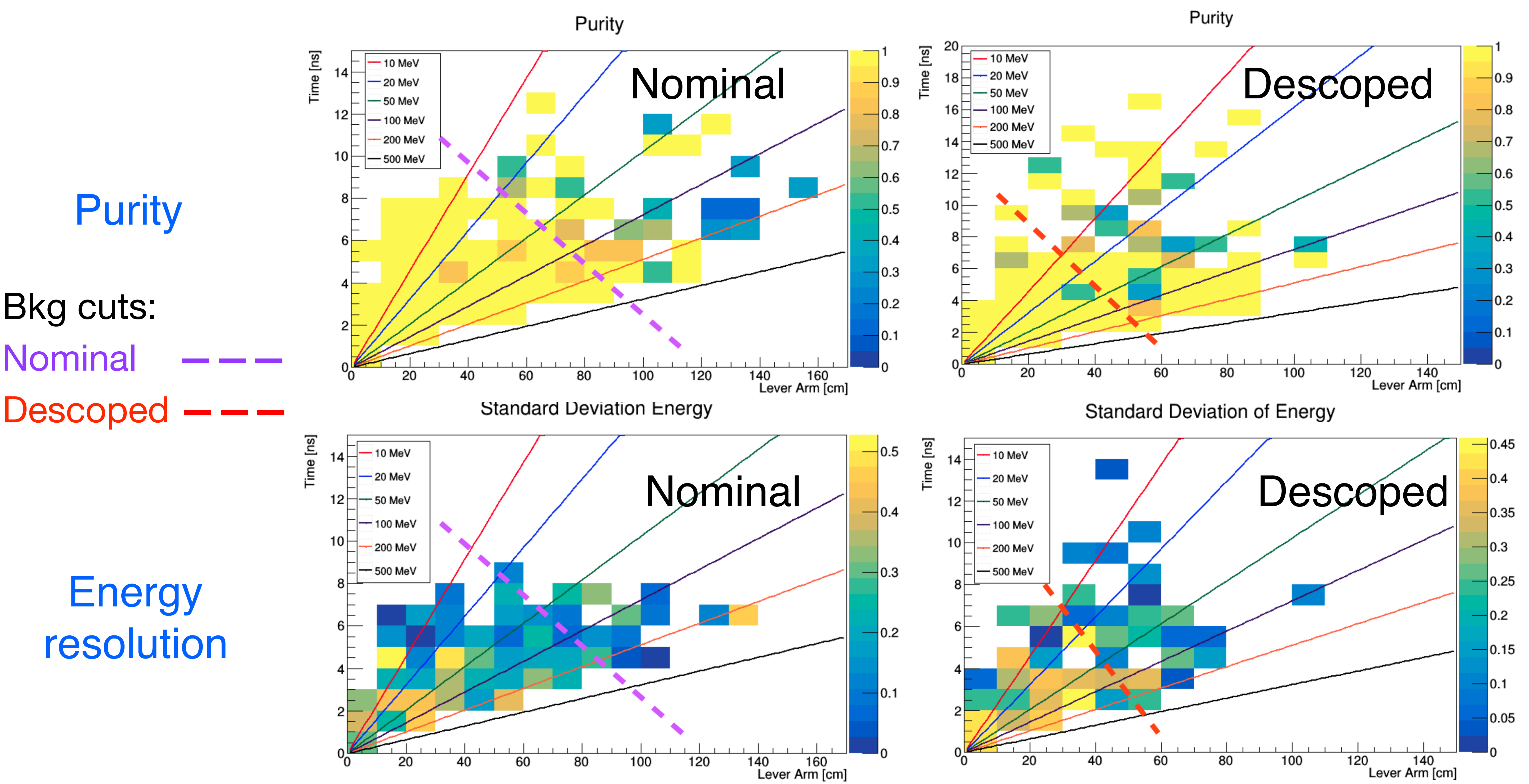
Neutrino Selected Batch Energy Spectrum Stability (PQ and NQ)



- MINOS ND found these problems by looking at the time-dependent variation of the neutrino reconstructed energy spectrum
- MINOS ND ~100tons, 3DST ~ 12 tons (FV~8.7 tons)

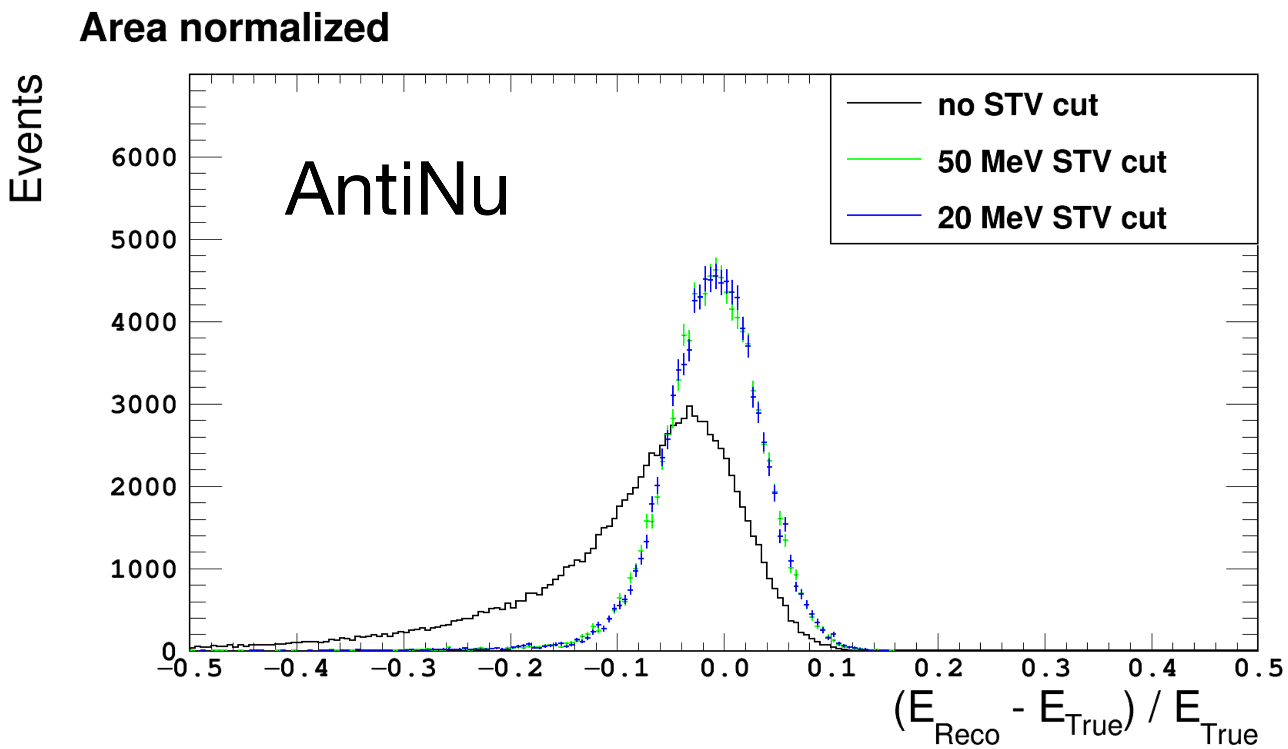
Neutron detection

- Compare neutron study with descoped configuration:
  - ✦ 1x1x1 m^3 FV, 1.2x1.2x1.2 m^3 Total Volume, Out-of-FV cuts same as nominal

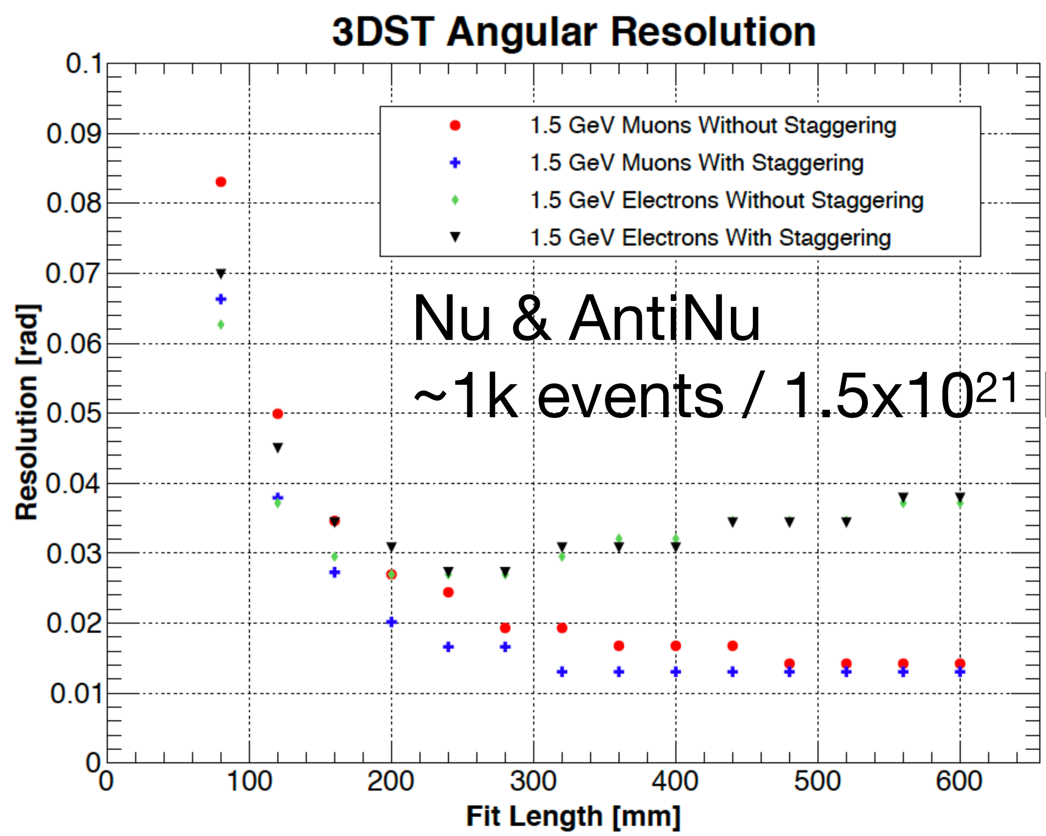


- Nominal configuration shows ~20% or better energy resolution for a large fraction of the lever arm - time. Above 30% for de-scoped configuration

Neutrino Flux measurement



+



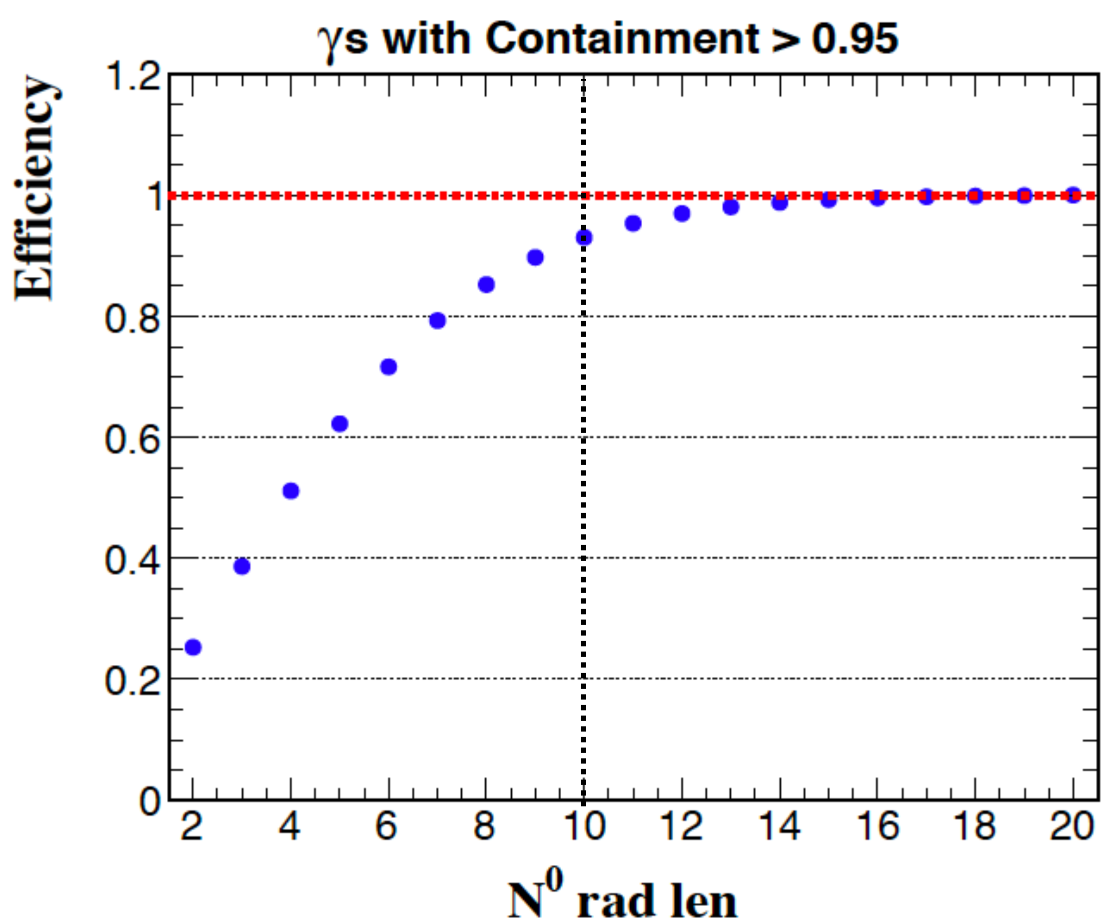
Nu & AntiNu
~1k events / 1.5x10^{21} POT

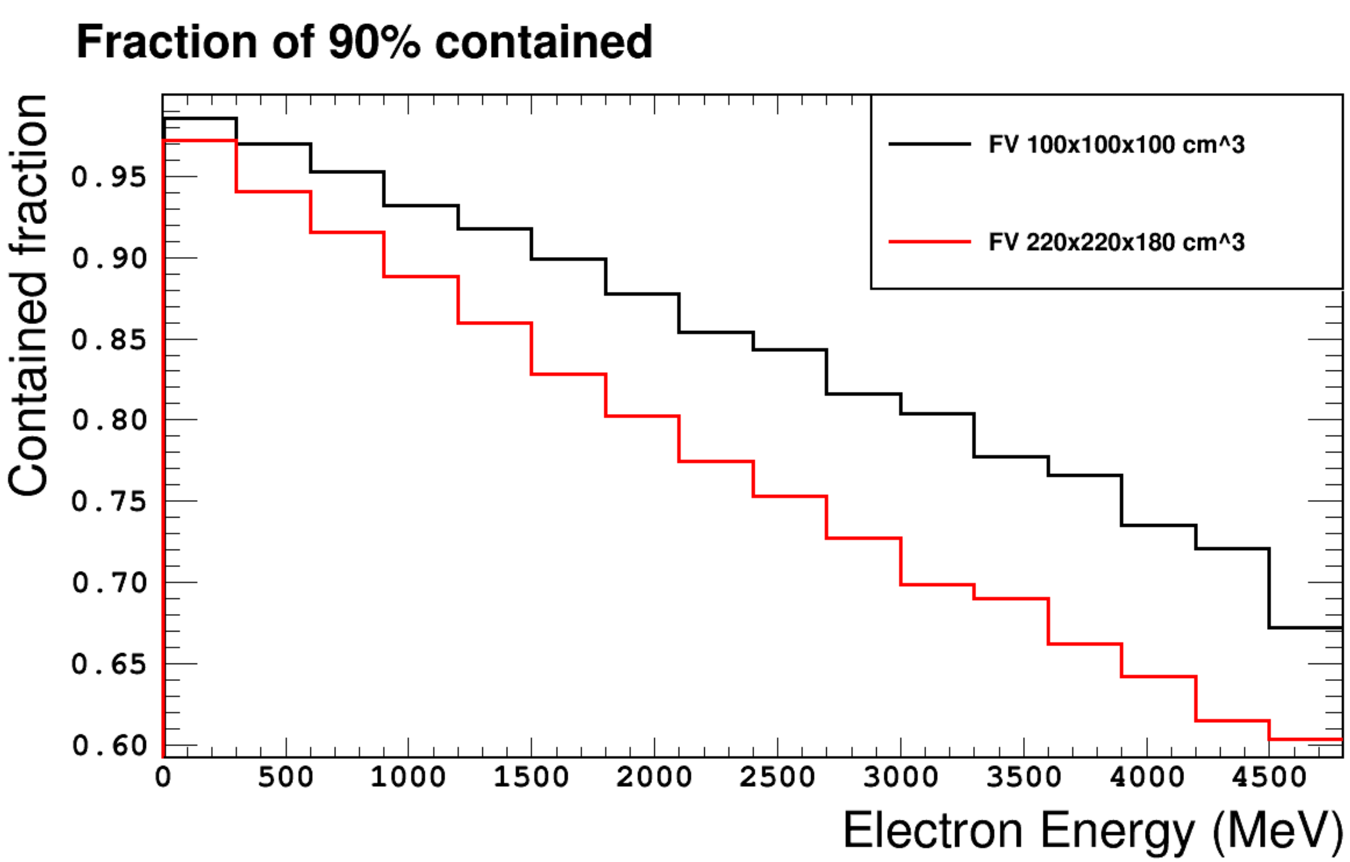
+ **LOW-ν METHOD (tricky and model dependent)**

- Three different methods for flux measurement but in the same detector and at different energy ranges (nu+e xsec higher at high energy)
- Partial cancellation of the detector systematic uncertainties, in a well know detector (plastic scintillator)
- Only detector with the potential of measuring the flux in AntiNu mode

ECAL e.m. containment

- ECAL thickness = 0.5 m (~10 radiation lengths)
- Look at containment in 3DST+ECAL
  - ✦ Photons from DUNE neutrino interactions
  - ✦ Electrons from Nu+e scattering
- About ~90% containment for both photons and Nu+e electrons



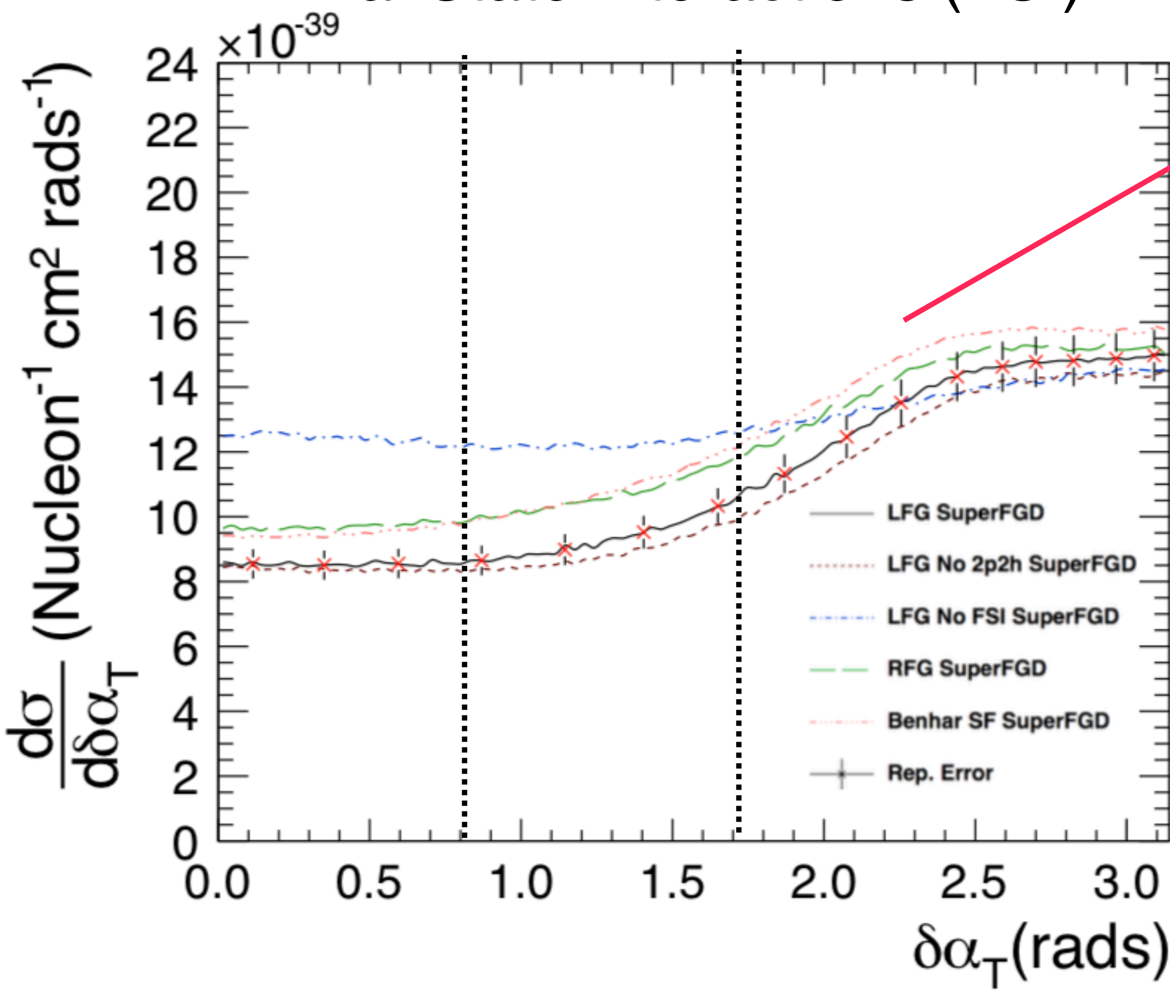


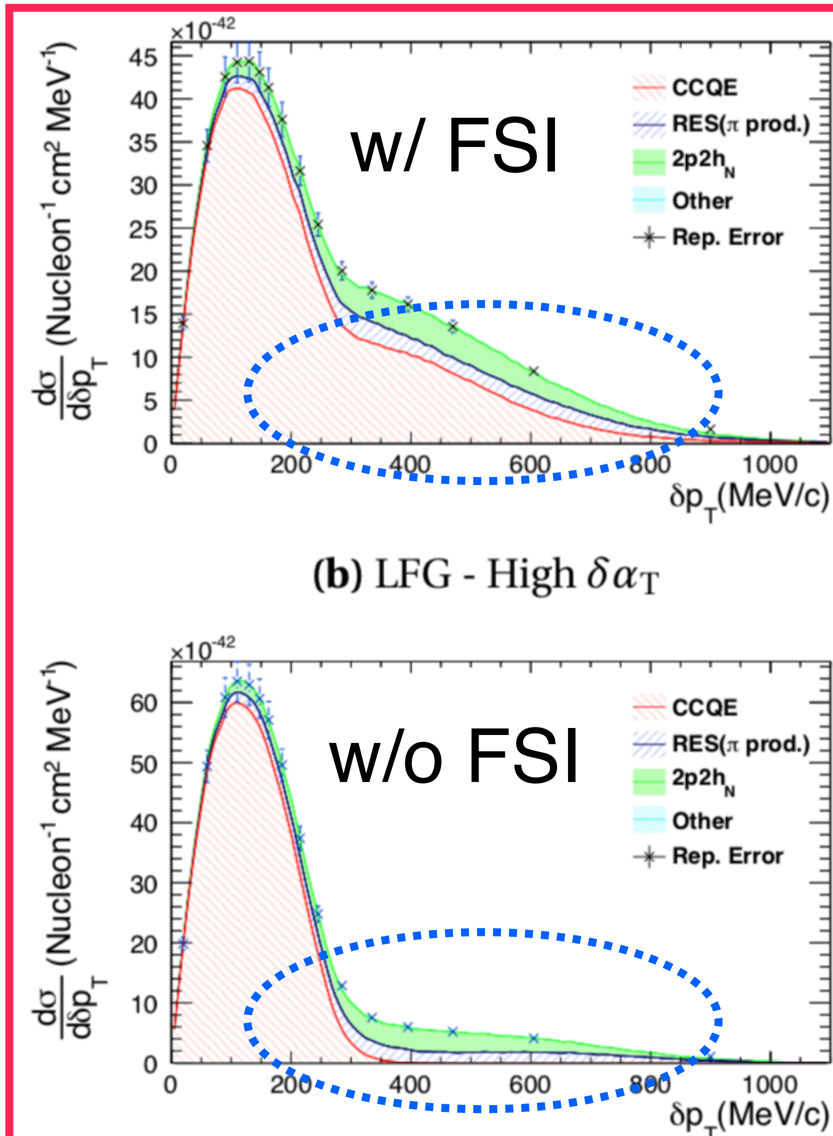
- We can't contain e.m. showers without ECAL

Single Transverse Variables at ND280 upgrade

- Look at the transverse plane to probe nuclear effects (PRC 94,015503 2016)
  - ✦ δp_T —> sensitive to “invisible” processes
  - ✦ $\delta\alpha_T$ —> Acceleration of the system
- The full solid angle coverage needed to provide a good sensitivity
- High statistics to combine δp_T and $\delta\alpha_T$: improved sensitivity to FSI, 2ph2

$\delta\alpha_T$ provide information on Final State Interactions (FSI)





(b) LFG - High $\delta\alpha_T$

(d) LFG -no FSI - High $\delta\alpha_T$

Very large difference in the tail if FSI is enabled

Comments on the de-scoped configuration

- De-scoped configuration was also considered:
  - ✦ Fiducial Volume: 1x1x1 m^3
  - ✦ Without TPCs, ECAL and magnet
  - ✦ Forward spectrometer only downstream of 3DST
- Neutron bkg would increase, depending on the distance between rock and 3DST FV and alcove size to be optimized. Worse time resolution
- Expected event rate will decrease because
  - ✦ Fiducial Mass is smaller by a factor 8.7 ($1m^3$)
  - ✦ Only mostly forward particles would be measured. Only a region of the phase space would be measured with an impact on the robustness of the neutrino interaction model

Comments on the de-scoped configuration

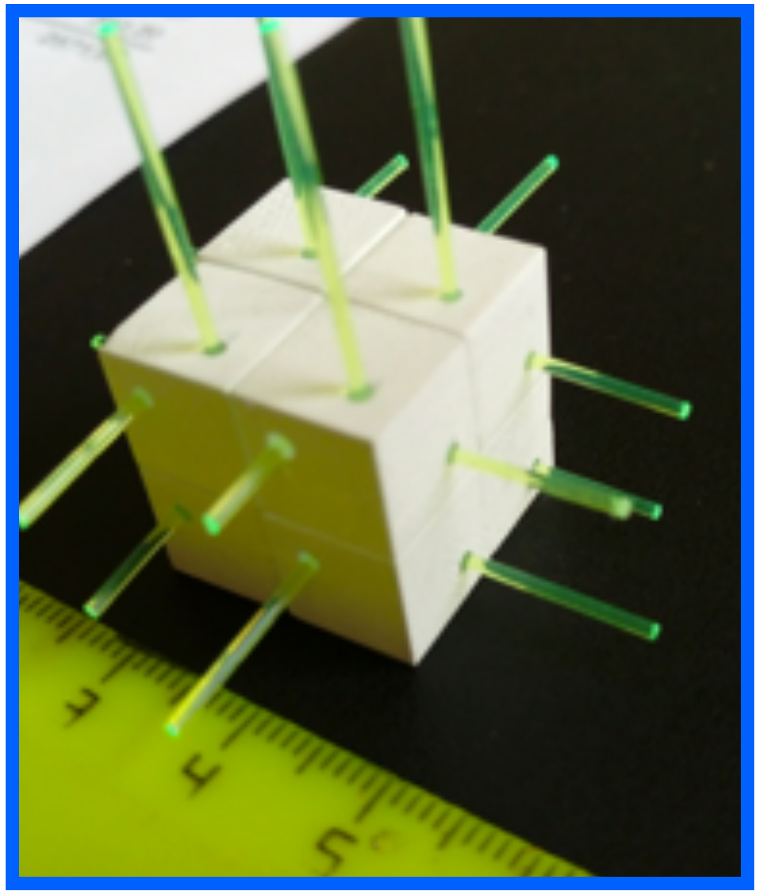
- Containment of particles (hadron and e.m. showers) would be compromised
- Hard to obtain a reconstruction on event-by-event basis. This will greatly diminish the usefulness of precisely measure the neutrons
- Also not possible to measure the momentum balance for each single event preventing from inferring the NuBar energy reconstruction. Drastically reduced # of nu+e scattering events
- Beam / spectrum monitor would be affected by all the reasons explained above
    - ✦ Harder to monitor the beam spectrum on a short time period
- Not possible to perform all the neutrino interaction studies with the precision we need
- In summary the de-scoped configurations would not allow to perform all the precise measurements foreseen with the nominal configuration

Comments on staging

- The beam should be monitored since the first stage and possibly always with the same system during the whole data taking
- Better if stage ha 3DST-S to cross-calibrate the other detectors before they move off-axis
- Cross-check between different detector technologies at the beginning of the data taking is worth

BACKUP

The 3DST Spectrometer (3DST-S)



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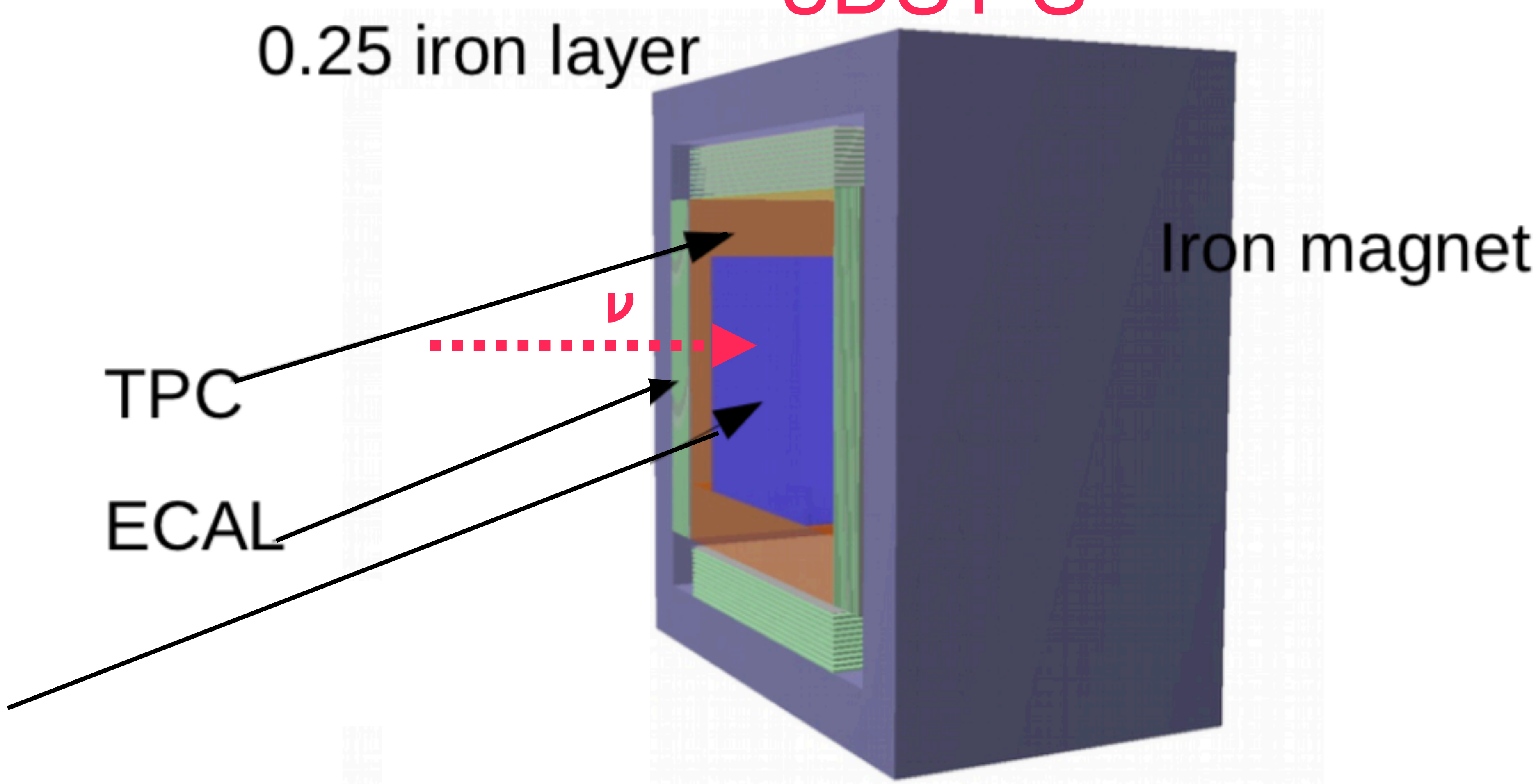


- Muon detection efficiency >90% at 4π
- Muon p resolution by range ~2-3%
- Detect protons above ~300 MeV/c
- Very good neutron detection capability

- B-field = 0.6 T
- 0.5 m depth for both TPC and ECAL
- TPC:
  - space-point resolution <0.5 mm
  - 5% p resolution @3 GeV/c

T2K Near Detector will be upgraded with 2 tons 3DST-like detector and TPC

The request of the Spokespersons

To help us respond to the LBNC, we are asking all ND sub-groups to address these recommendations, and in particular, to assess the impact of descoping their detector component. As we understand it, the current 3DST concept envisages a 2 x 2 x 4 m^3 scintillator volume surrounded by calorimetry, and a magnetic spectrometer to perform muon momentum measurements.

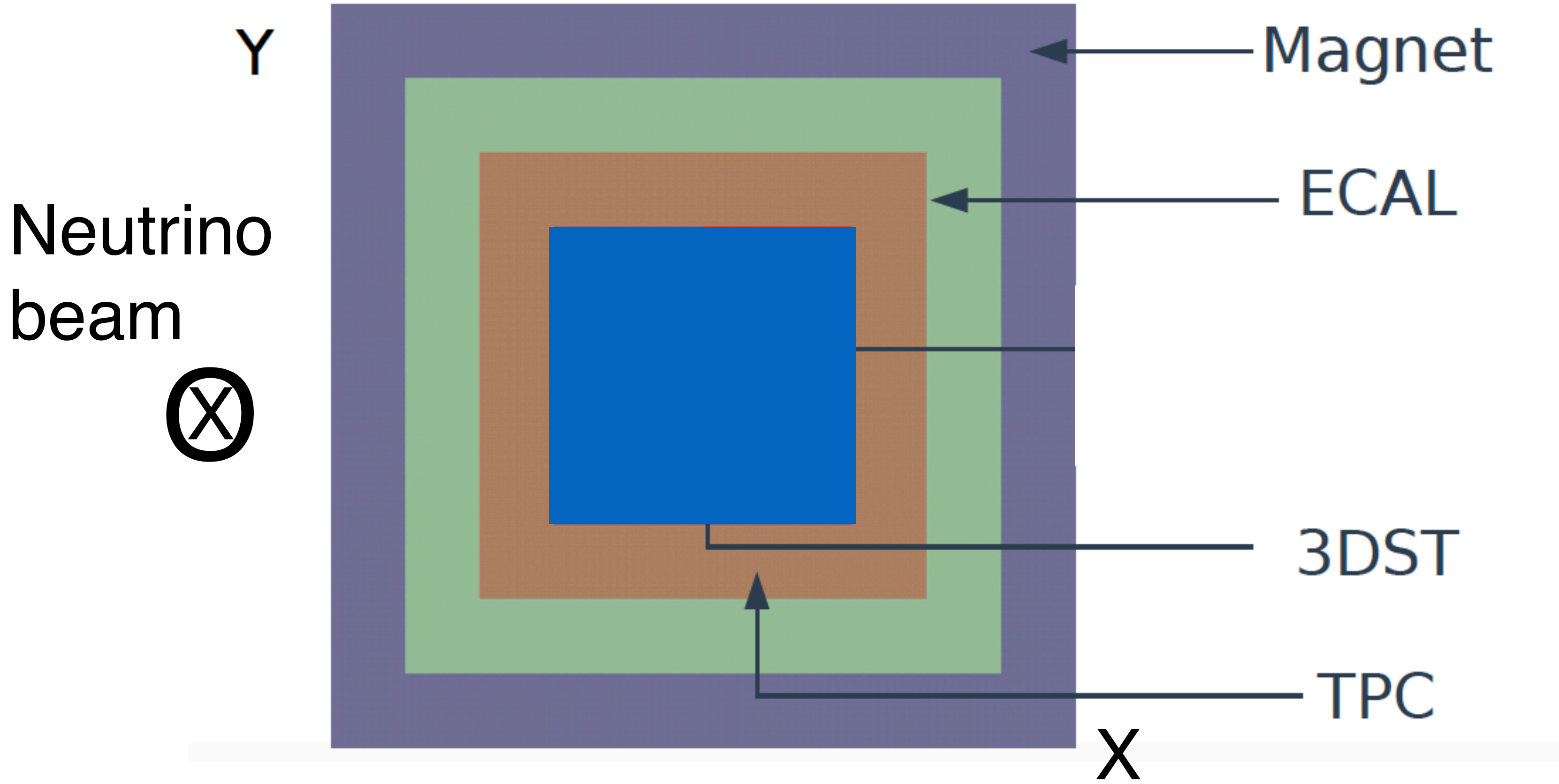
Specifically, could you please address the following points?

1. Articulate (concisely) the goals of the 3DST system with regard to measurements that will be performed to impact the neutrino oscillation measurements at DUNE.

2. Investigate a descoped 3DST system, with an approximately 1 m^3 scintillator fiducial volume and a forward tracking spectrometer focused on on-axis beam monitoring, as suggested by the LBNC. Describe the tradeoffs/compromises between this descoped system and the current concept with regards to the impact on DUNE oscillation measurements.

The nominal 3DST-S

- The fixed parameter is the Fiducial Volume: 1 x 1 x 1 m^3
- Applied the same out-FV cuts, i.e. 10 cm outer-shell:
  - ✦ Total Volume = 1.2 x 1.2 x 1.2 m^3
  - ✦ Fiducial Mass = 1 ton



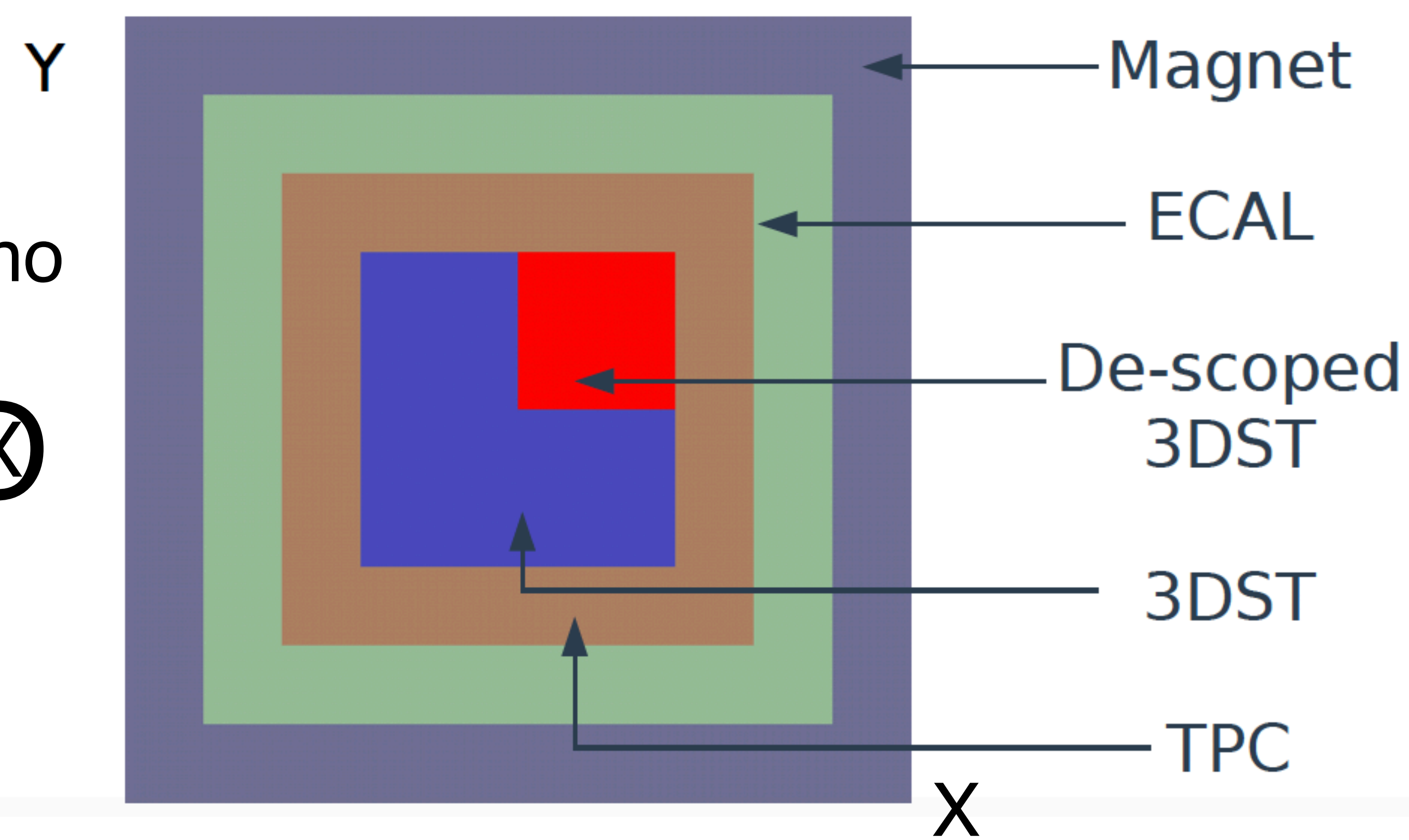
✦ The de-scoped configuration has 8.7 times less events than baseline configuration

- Implemented the de-scoped configuration “by symmetry”, i.e. consider only bkg produced on the X, Y, Z side as 3DST de-scoped volume and multiply it by a factor x2. Now Running the full simulation

The de-scoped 3DST-S

- The fixed parameter is the Fiducial Volume: 1 x 1 x 1 m^3
- Applied the same out-FV cuts, i.e. 10 cm outer-shell:
  - ✦ Total Volume = 1.2 x 1.2 x 1.2 m^3
  - ✦ Fiducial Mass = 1 ton

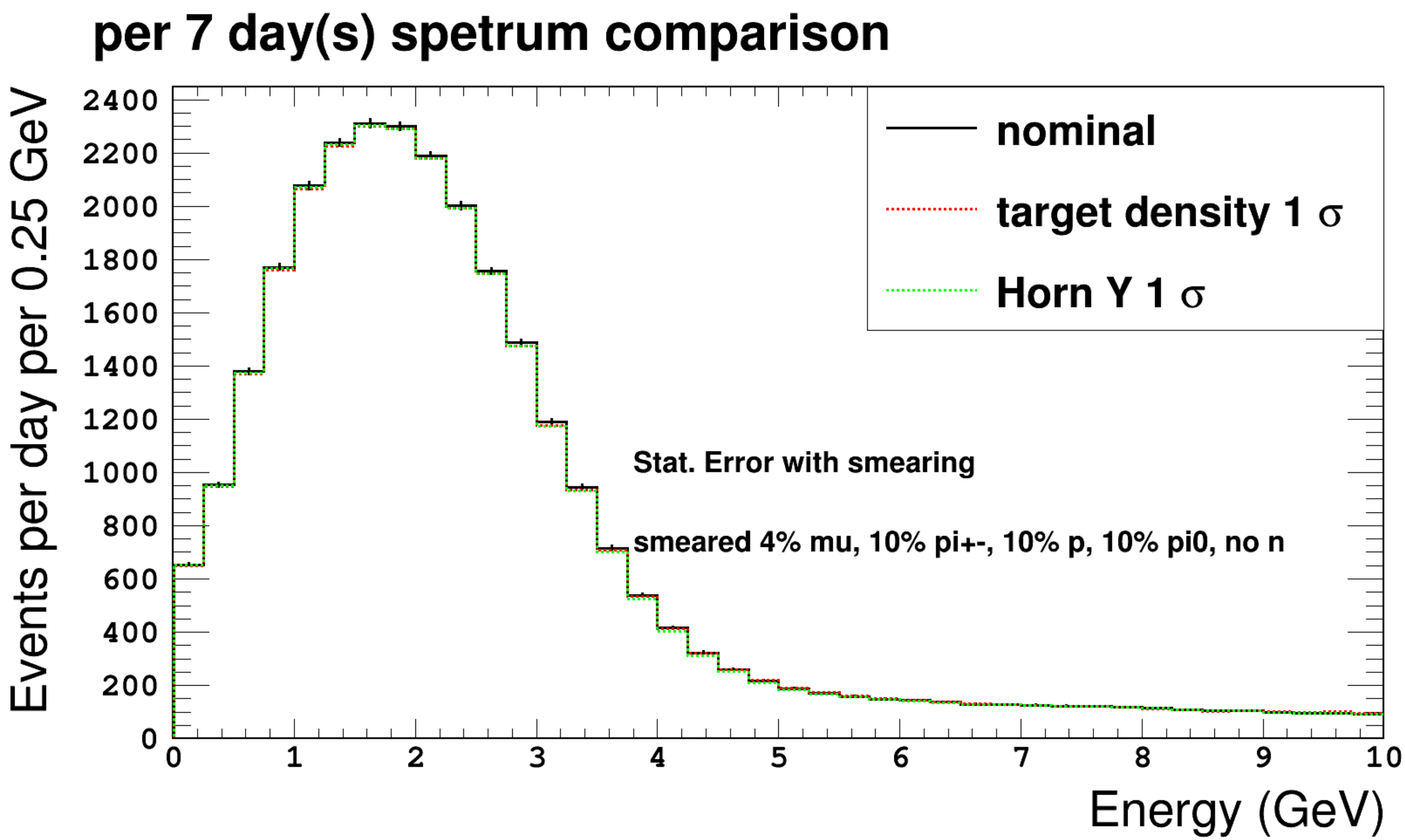
Neutrino beam ⊗



✦ The de-scoped configuration has 8.7 times less events than baseline configuration

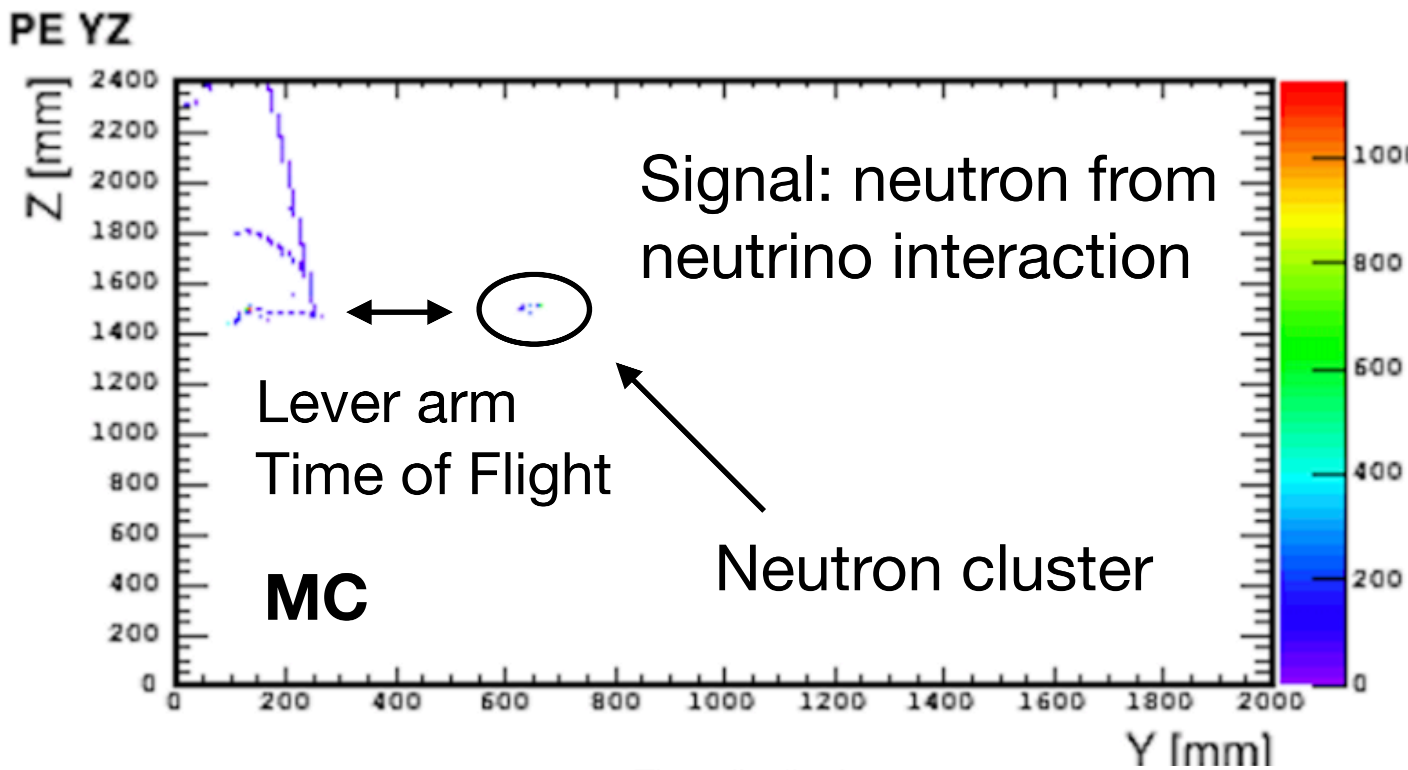
- The Fermilab queue was very busy with other jobs for more than a week
- Implemented the de-scoped configuration "by symmetry", i.e. consider only bkg produced on the X, Y, Z side as 3DST de-scoped volume and multiply it by a factor x2. Now Running the full simulation

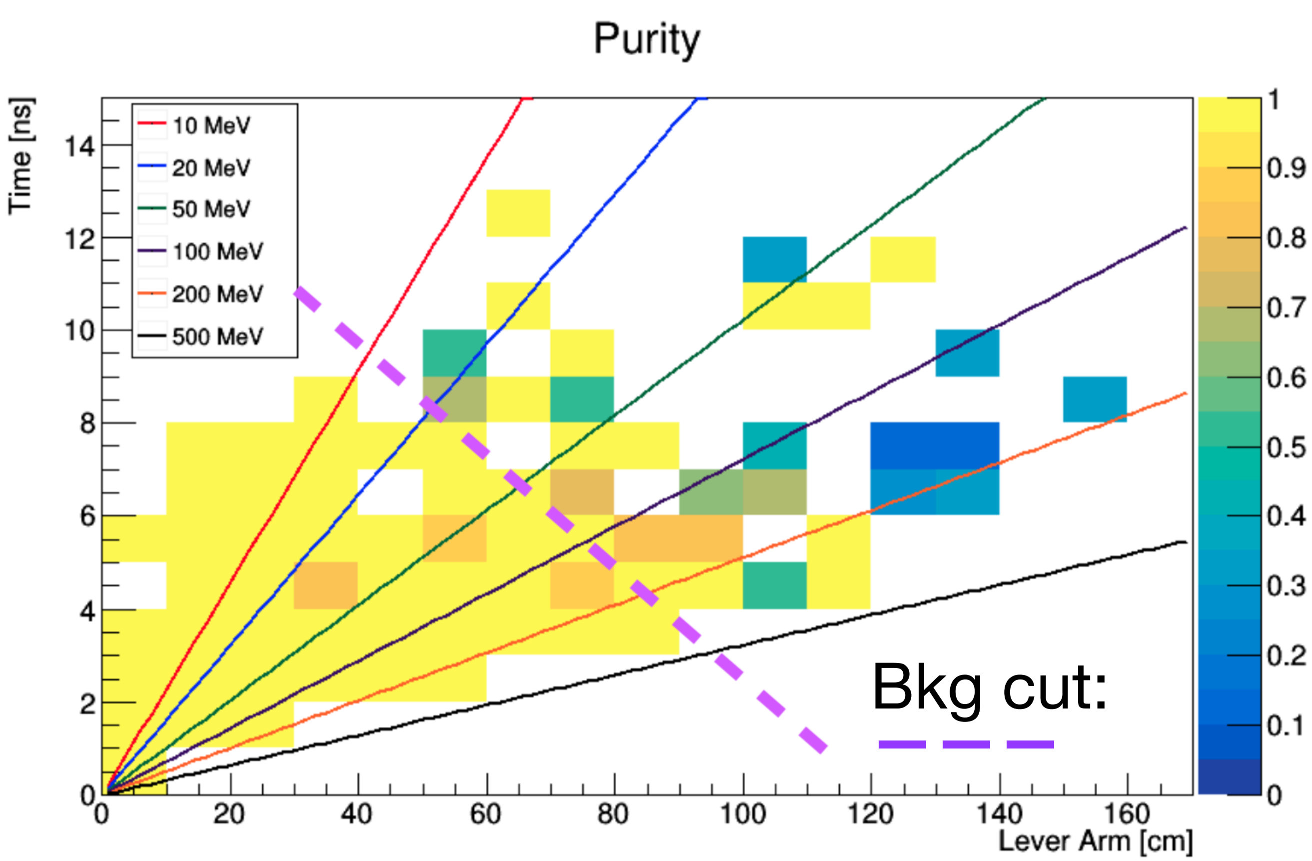
Beam monitor with single 3DST module

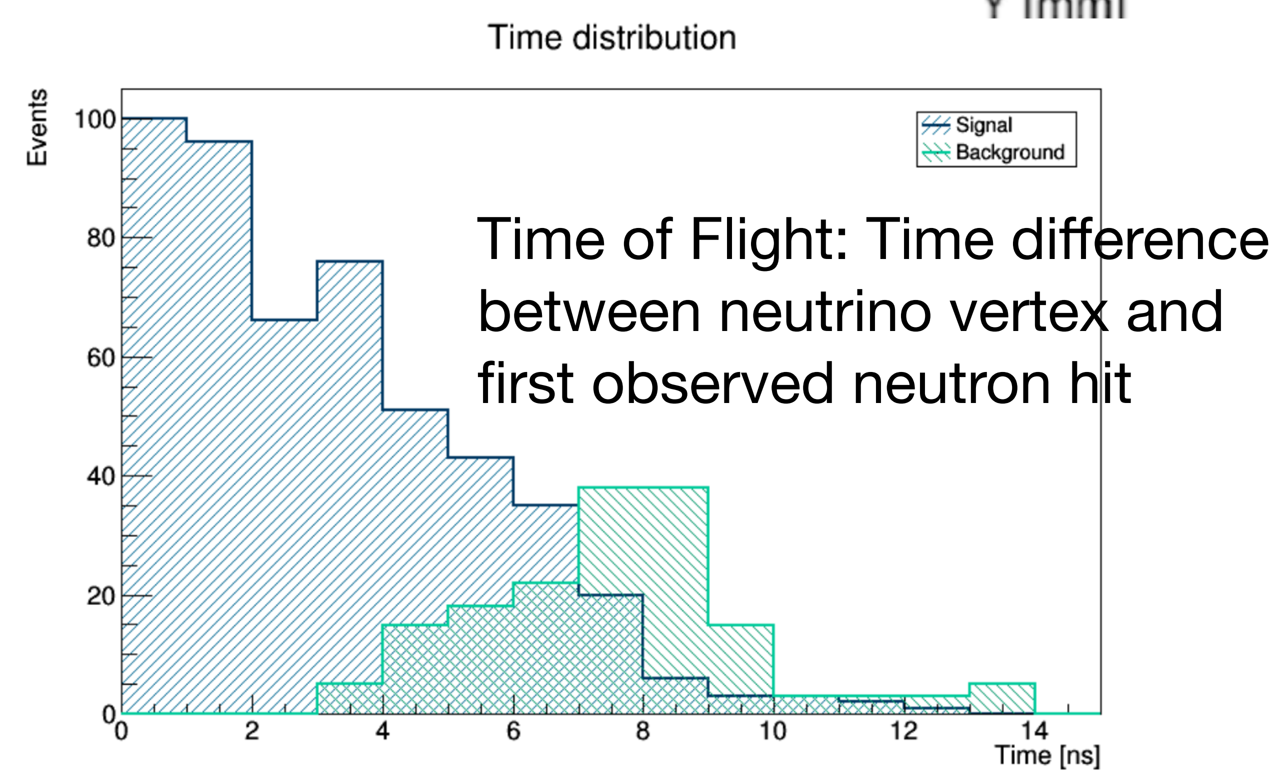


Neutron detection performance

- Simulated 10k spills (time structure recommended by Beam WG)
- Simulated neutrons produced by neutrino interactions in rock, magnet, ECAL, 0.25m thick iron upstream of 3DST
- FV cut —> inner core of 1x1x1 m^3
- Conservatively require deposited energy > 0.5 MeV per cube





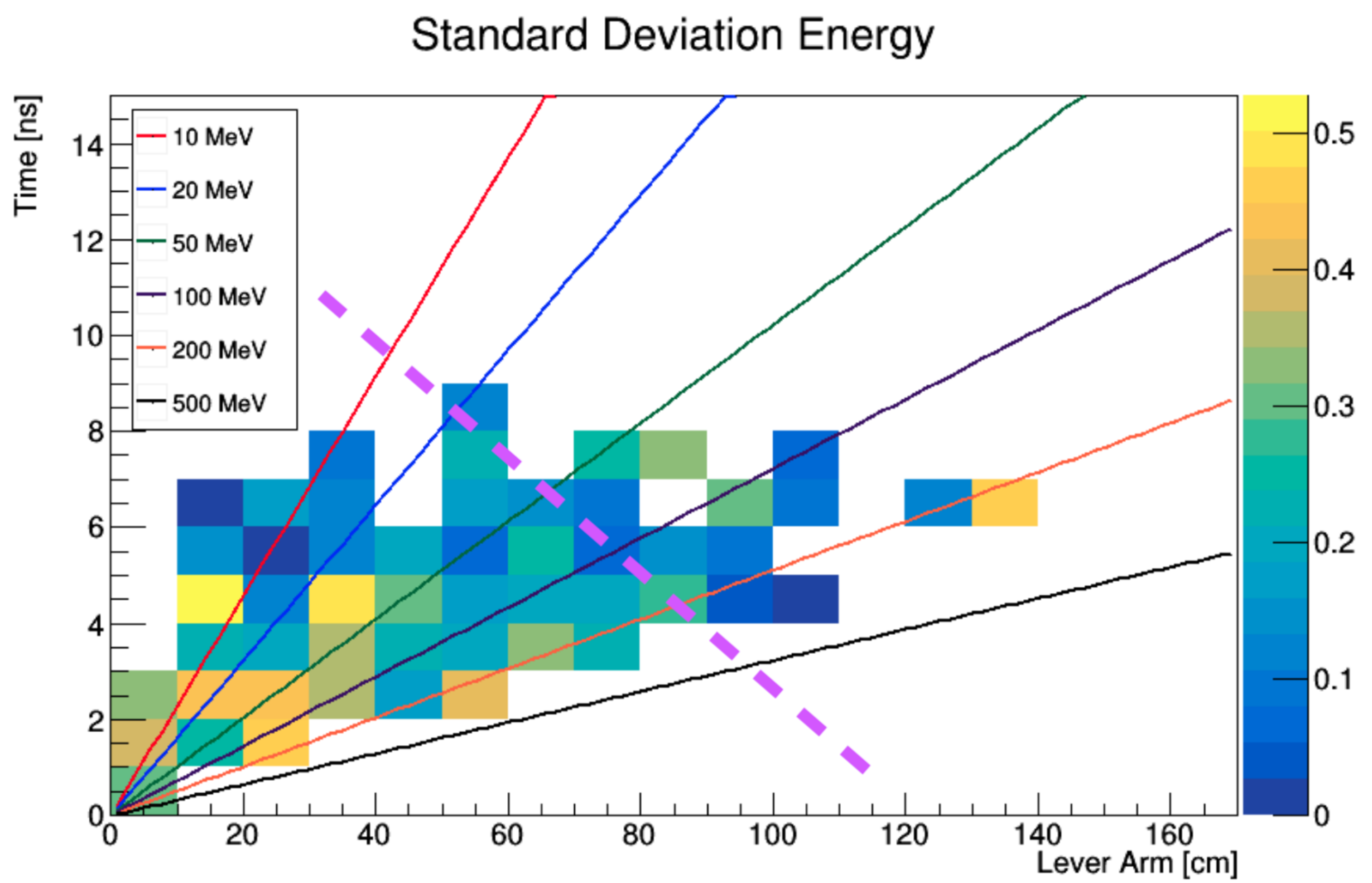


Selection of events by lever arm and the time difference allows to obtain a very pure neutron signal sample

Neutron detection performance

- The neutron kinetic energy obtained by ToF measurement
- Study performed with signal only
- The selection cut ensures an almost 100% pure sample, fundamental to obtain an unbiased and precise measurement of the neutron energy by ToF

Bkg cut: – – –



- A neutron energy resolution between 10-20% is provided for a large region of the lever arm - time space

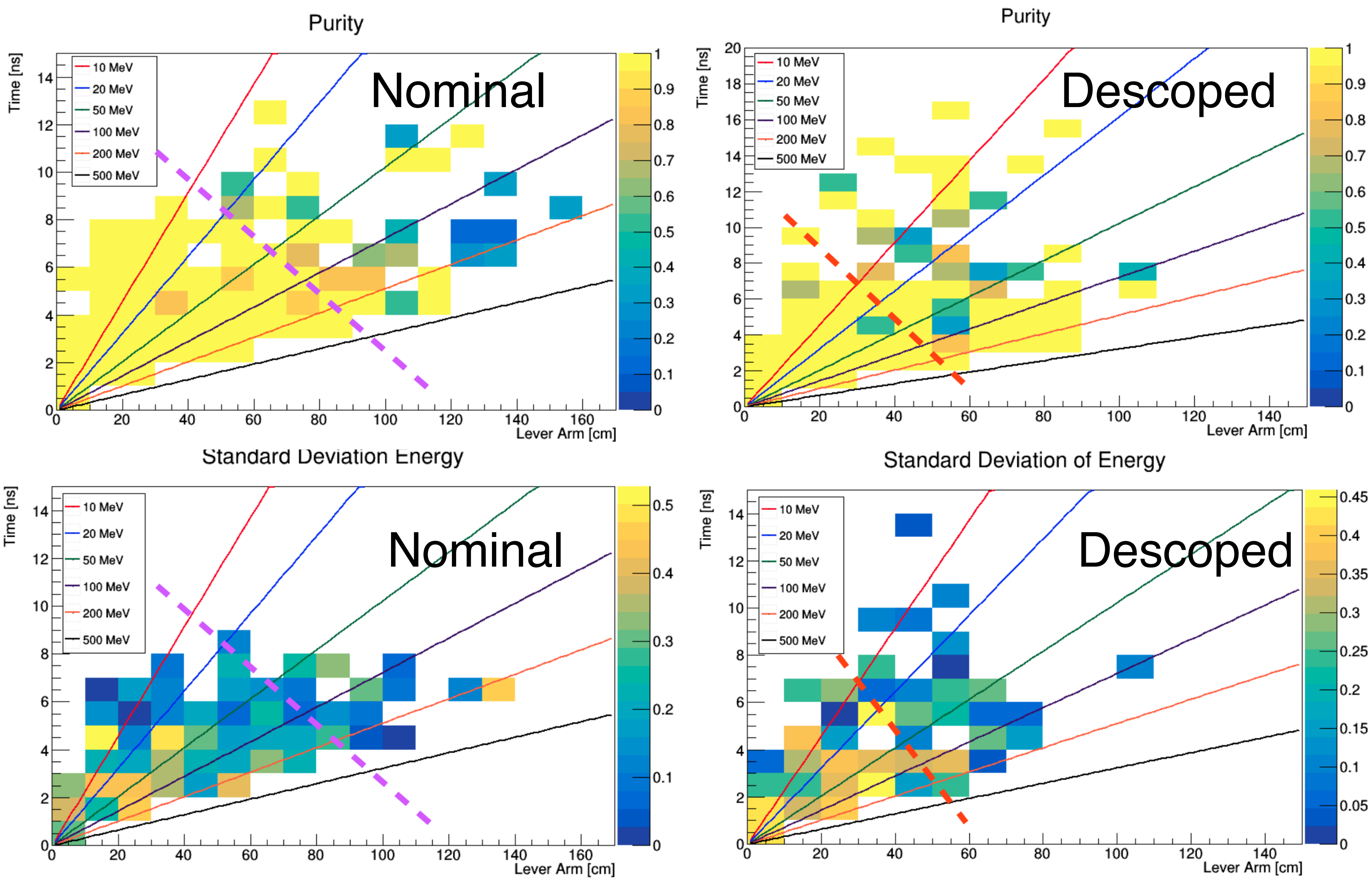
Comparison with descoped option

- Compare neutron study with descoped configuration:
  - ✦ 1x1x1 m³ FV, 1.2x1.2x1.2 m³ Total Volume, Out-of-FV cuts same as nominal

Purity

Bkg cuts:
Nominal
Descoped

Energy resolution

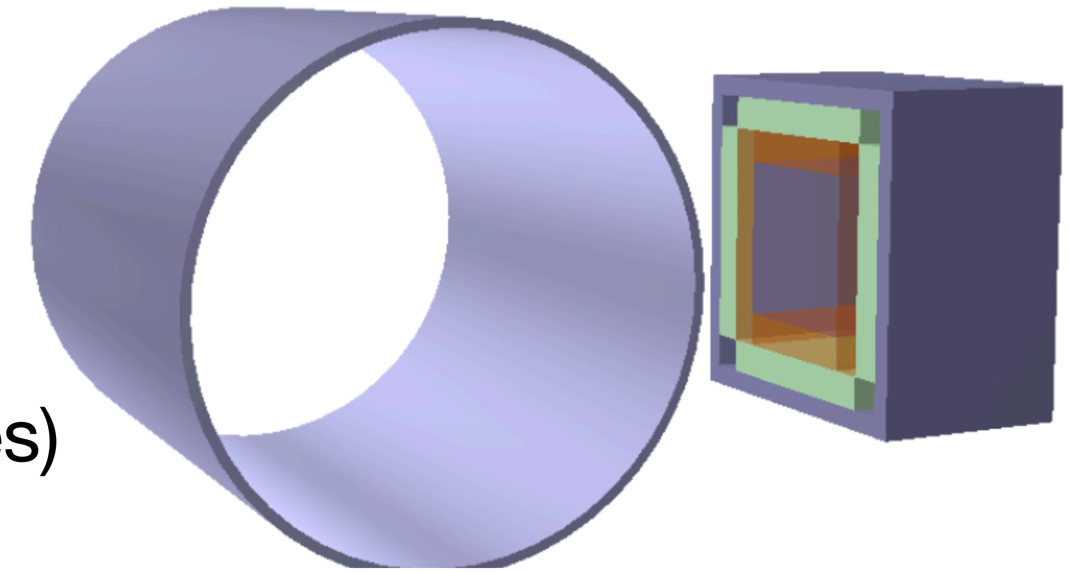


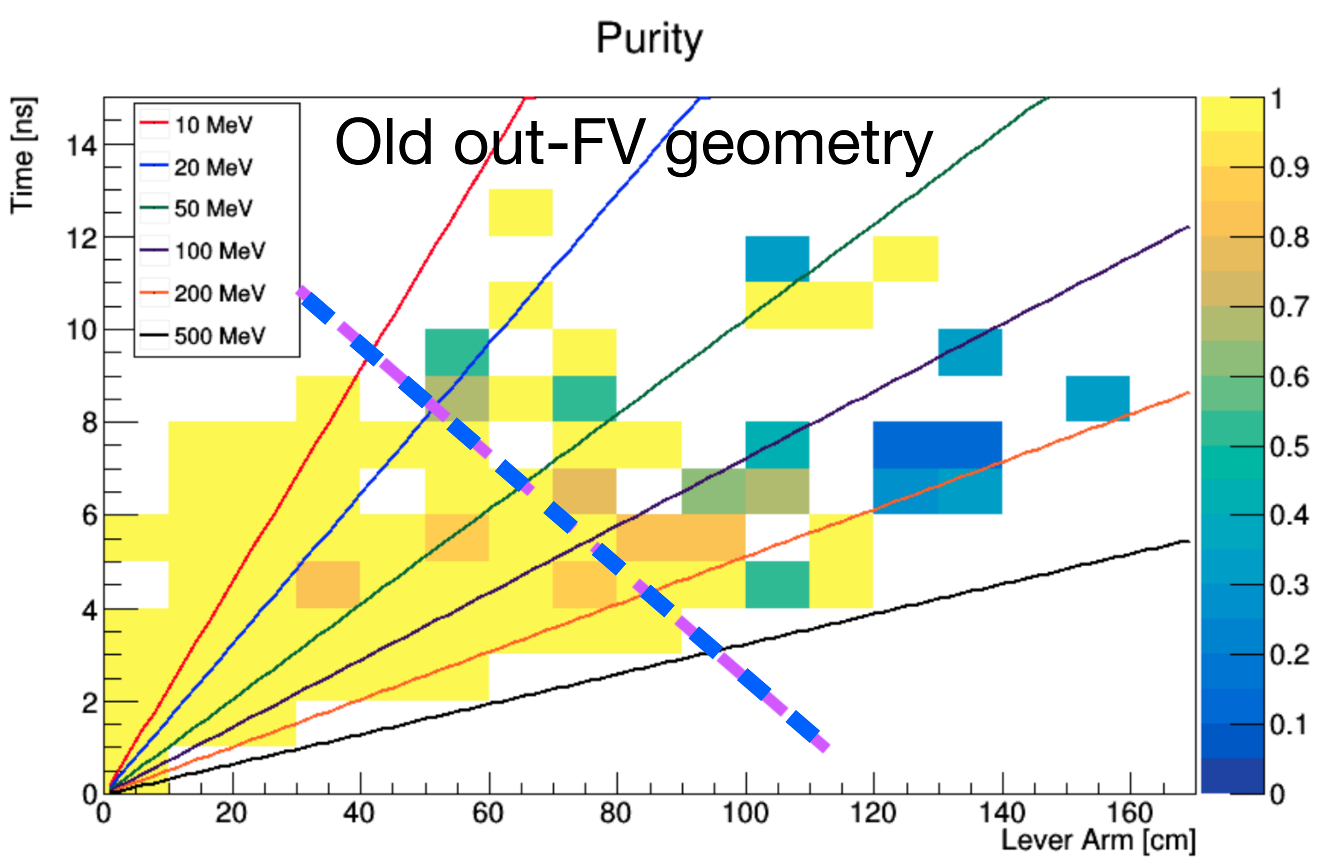
- Nominal configuration shows ~20% or better energy resolution for a large fraction of the lever arm - time. Above 30% for de-scoped configuration

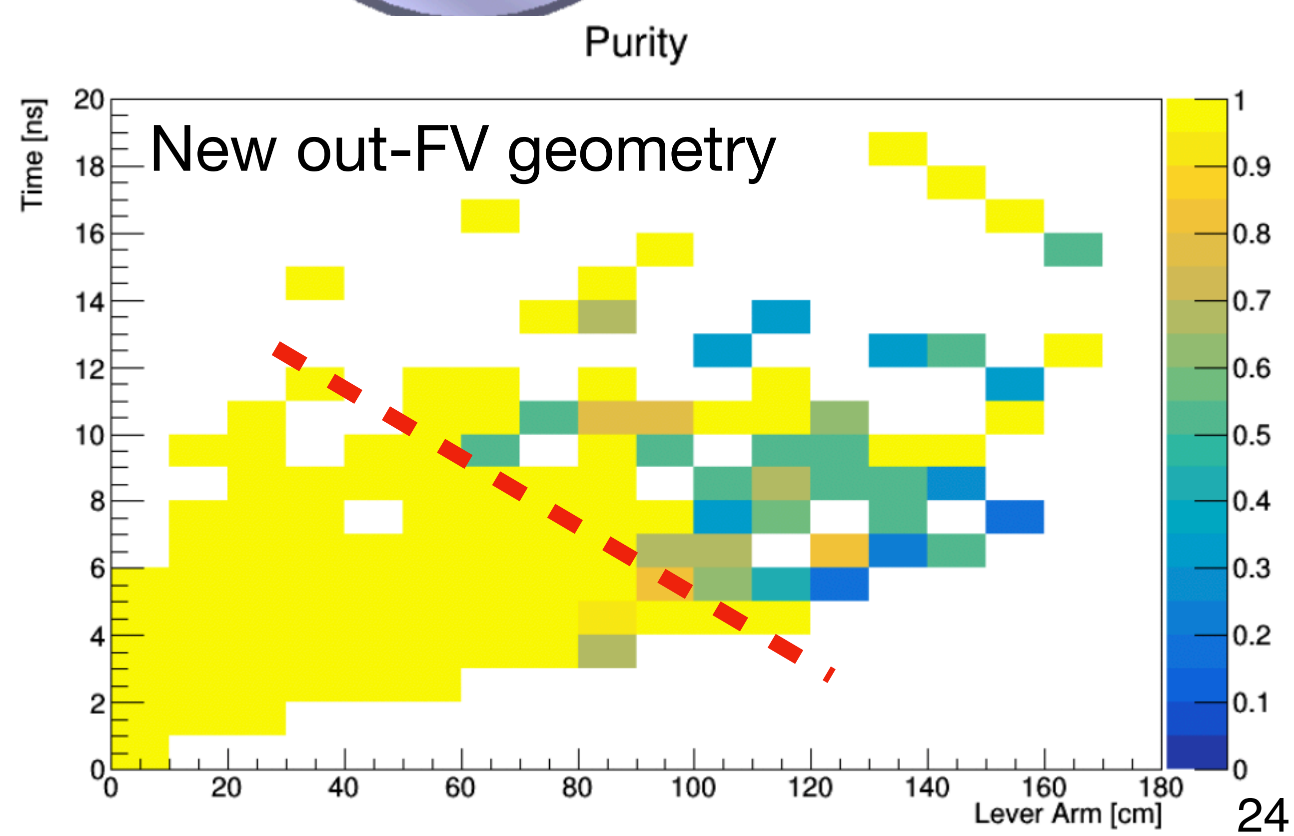
Updated out-FV geometry

NEW

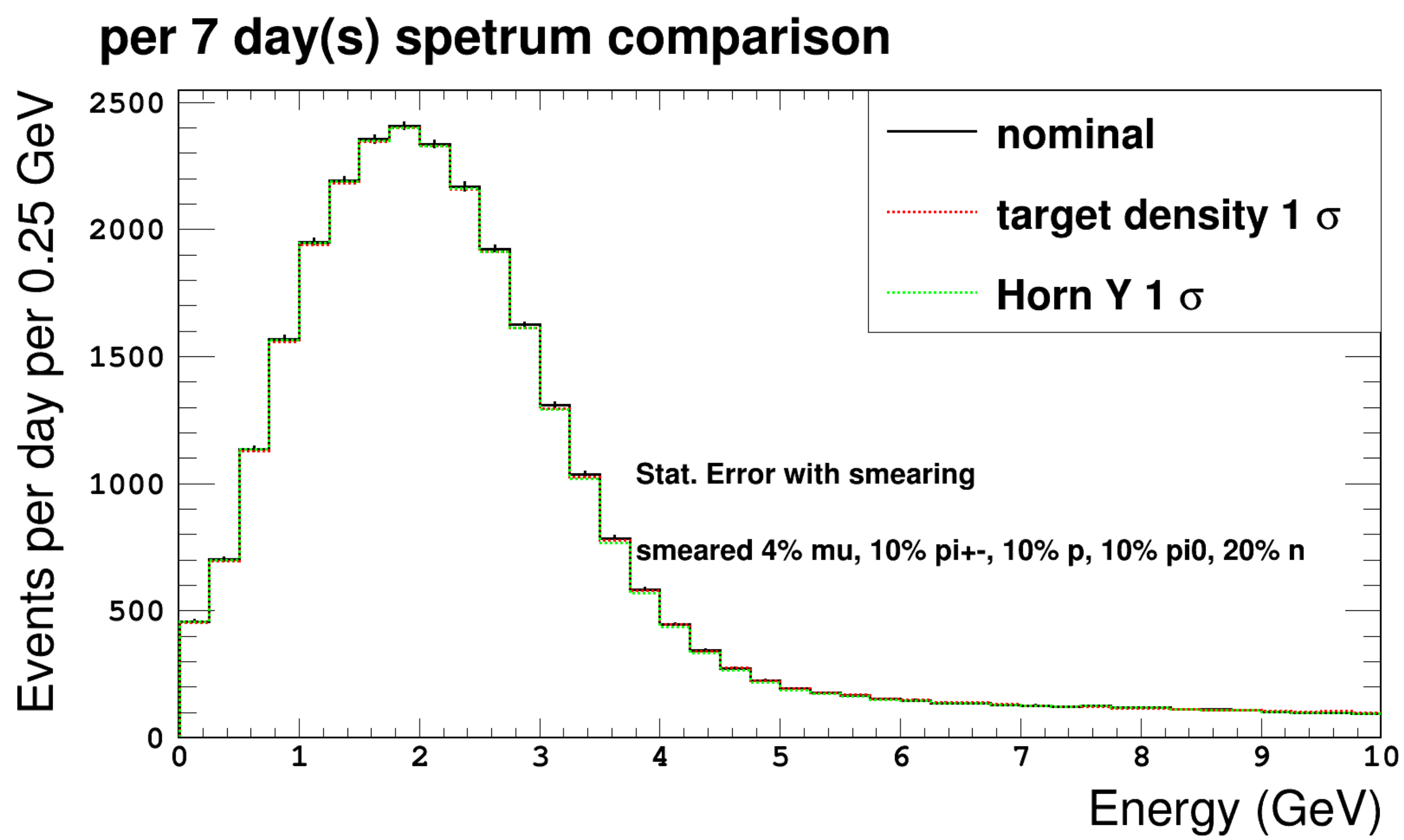
- Previously the HpGasTPC magnet not implement in the simulation but faked
  - 0.25 m thick vertical layer upstream of 3DST
- Implemented a more realistic HpGasTPC magnet simulation geometry
  - 13 cm thick aluminum cylinder
  - Diameter equal to 6.5 m
  - Total mass of 75 tons
  - HPgTPC is 4 m away from 3DST (edges)

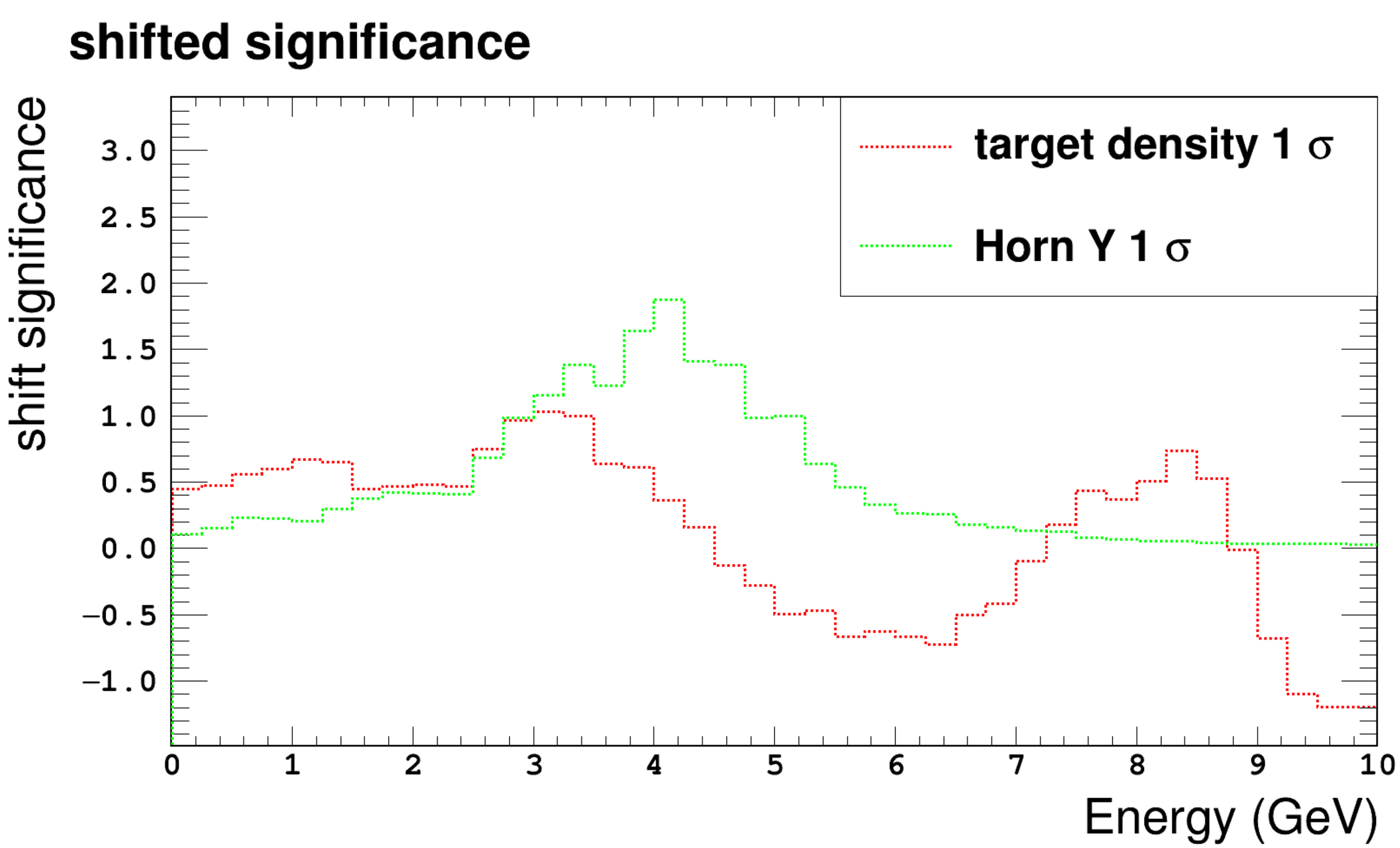






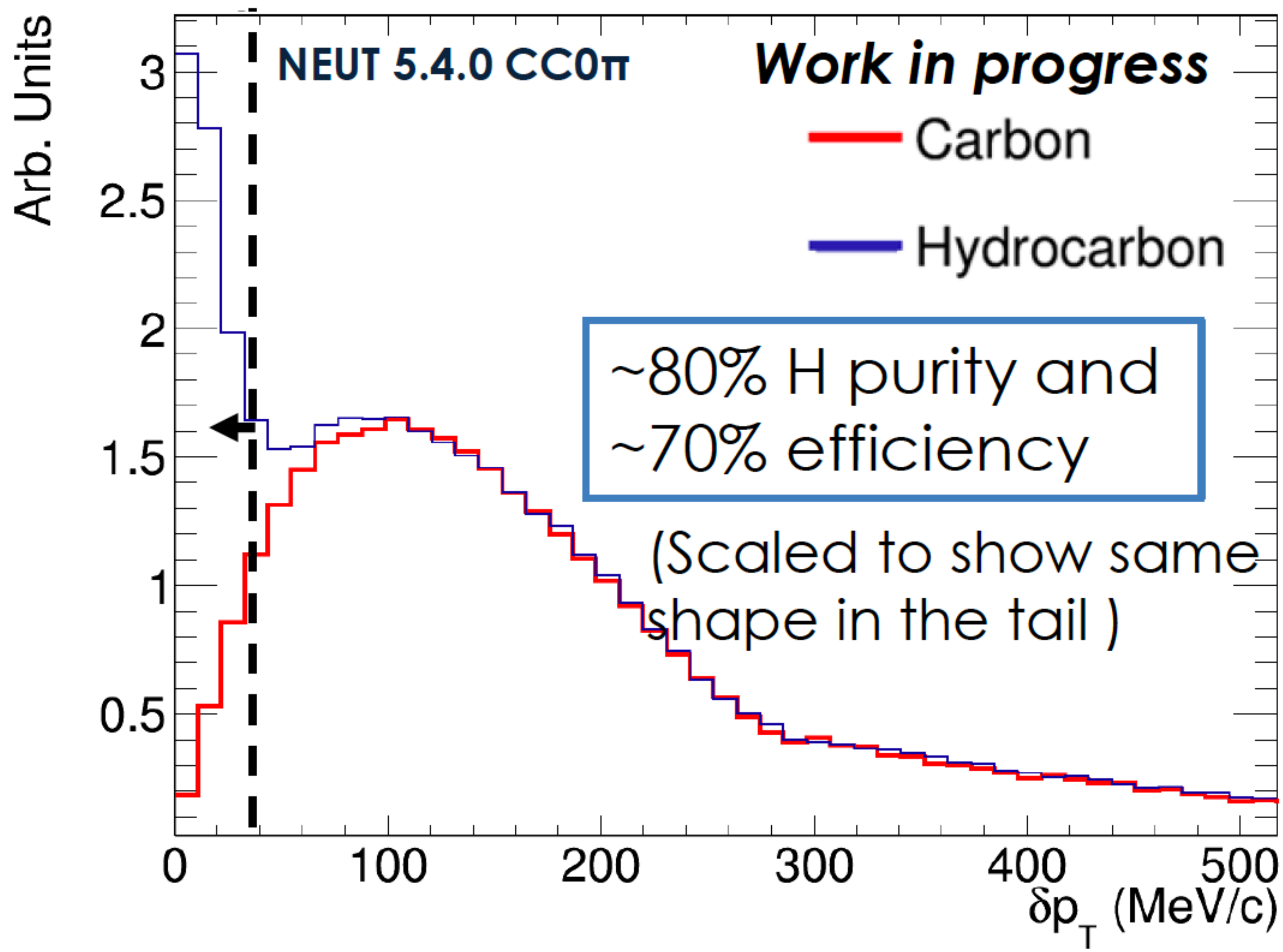
Beam monitor with single 3DST module





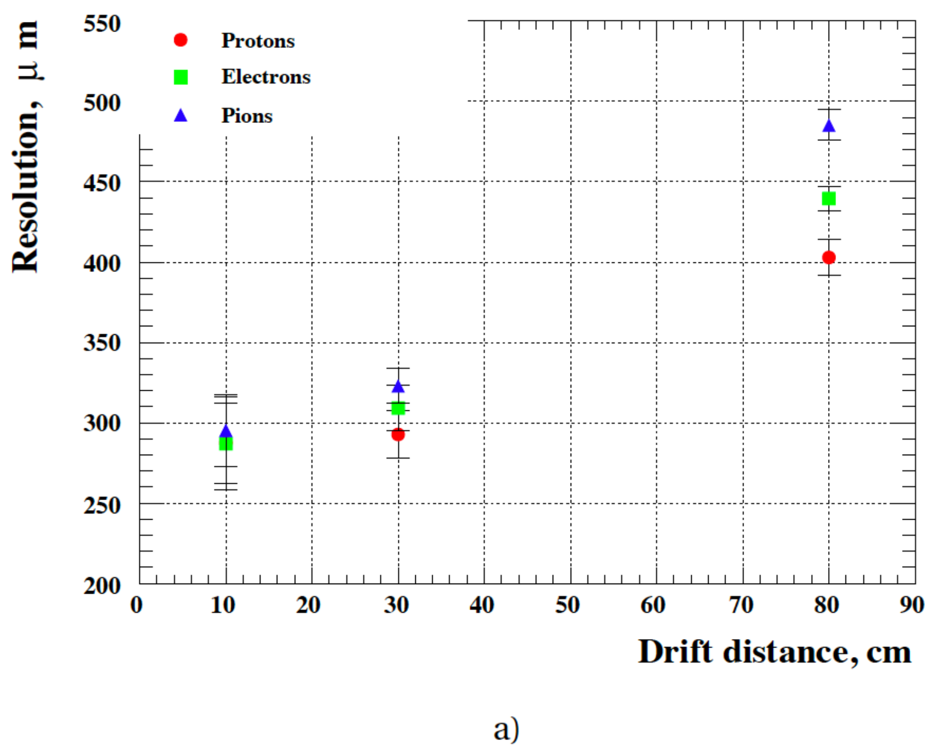
Neutron detection (20% energy smearing)

https://indico.ectstar.eu/event/19/contributions/409/attachments/313/414/sdolanTalk.pdf



TPC momentum resolution

TPC of T2K ND280 upgrade



a)

Figure 3.39: Space point resolution of MM0 as a function of the drift distance for different particle types of momentum 0.8 GeV/c.