# TMS – like detector: First preliminary studies with PRISM

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*on behalf of DUNE – PRISM working group*

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# Overview

→ Look at the **impact** a **TMS**-like **detector** would have **on PRISM** Analysis

- Currently have only the old (ND-GAr like) parametrized reco → try re-parametrizing for TMS
- TMS-like features:
  - charge reconstruction
  - momentum resolution
  - TMS energy cutoff

  ⟶ Effect on PRISM analysis
- Note: re-parameterizing the existent reconstruction is a big approximation (would need correct values and maybe detailed dedicated reconstruction eventually)

  - we can **start building** some **intuition about the capabilities and requirements of TMS** before full TMS-like ND sim production

  - **first studies** of the effect the 2 main TMS-like features would have on the PRISM oscillation sensitivities when flux systematics are applied

# Main Plan

- **TMS not magnetized: no charge selection in TMS (charge selection in ND-LAr)**
  - framework in place: – oscillation sensitivity with no systematics results (done)
    – oscillation sensitivity with systematics: – flux systs (in progress)
    – xsec systs (TO DO)
    – detectors systs (TO DO)
- **TMS energy resolution and energy cutoff (less scintillator bars and shorter TMS)**
  - framework in place: **5% energy resolution and 6 GeV energy cutoff**
    – oscillation sensitivity with no systematics results (done)
    – oscillation sensitivity with systematics: – flux systs (in progress)
    – xsec systs (TO DO)
    – detectors systs (TO DO)

– different energy resolutions (3%, 10%..) and 5 GeV energy cutoff → study how a shorter TMS would influence oscillation sensitivities (TO DO)

– repeat same study with a constant smearing of ~20 MeV rather than % energy resolution (TO DO)

# TMS-like studies with PRISM: no ND muon charge selection – RHC mode

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ND_FHC: reco_q = – 1
**ND_RHC: reco_q = + 1**

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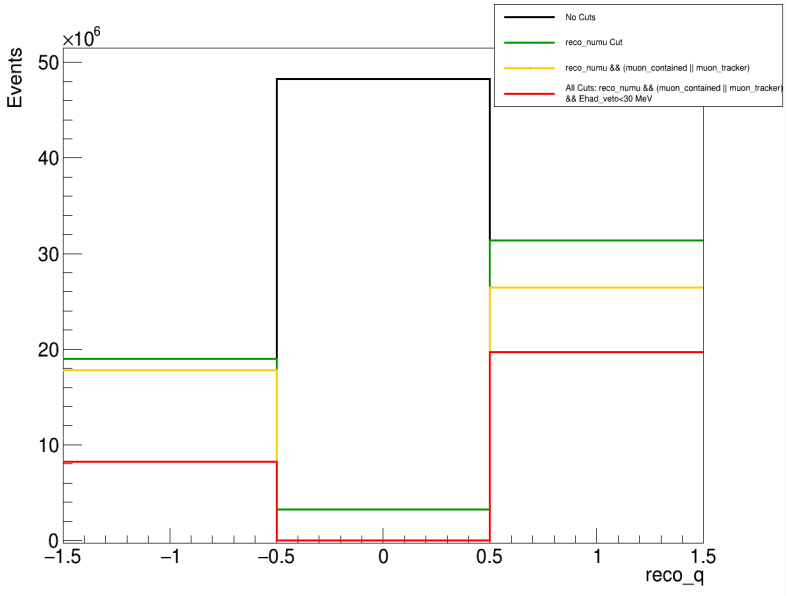
→ applied to ND data (I.e before background subtraction)



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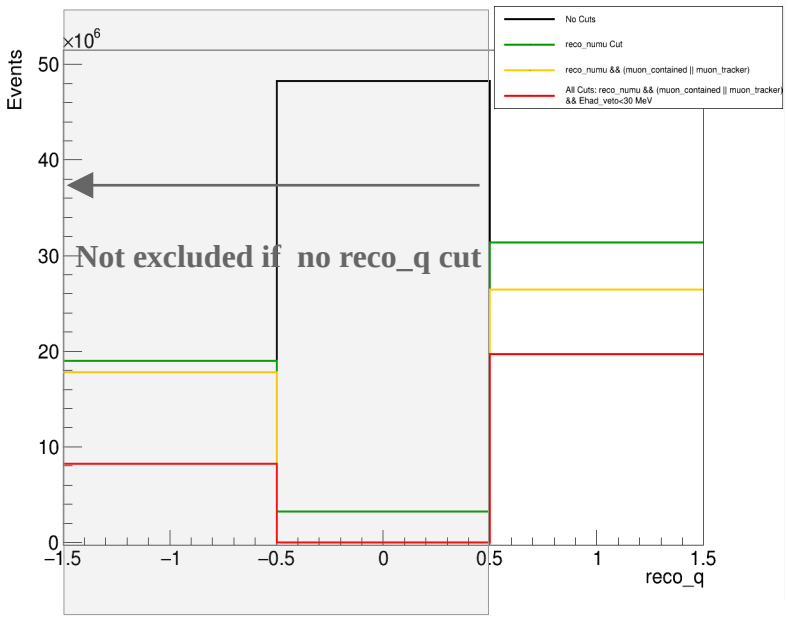
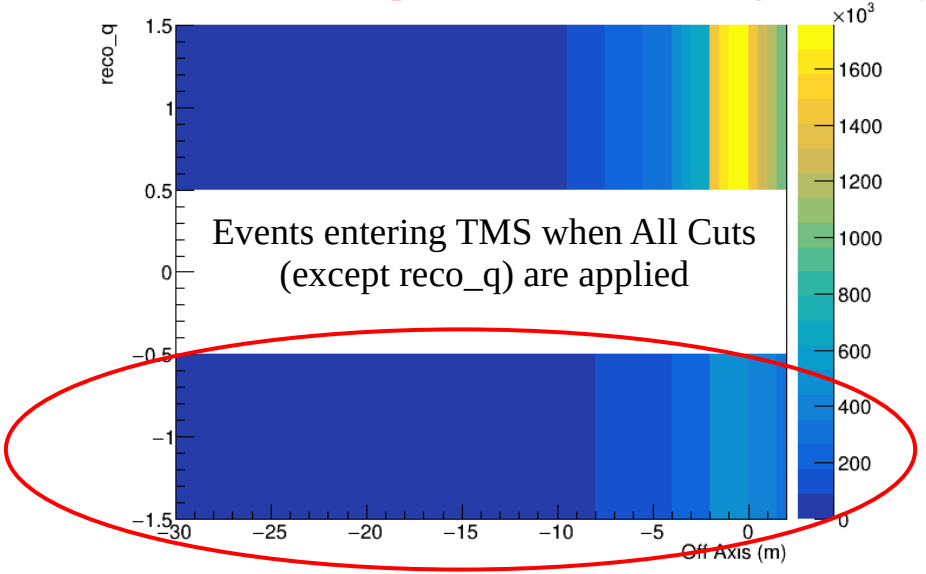



If no charge selection ~ 9 × $10^6$ extra events in RHC mode

~ **6.4 × $10^6$ events** are entering TMS (muon_tracker)

– **remove reco_q cut for events entering TMS only**



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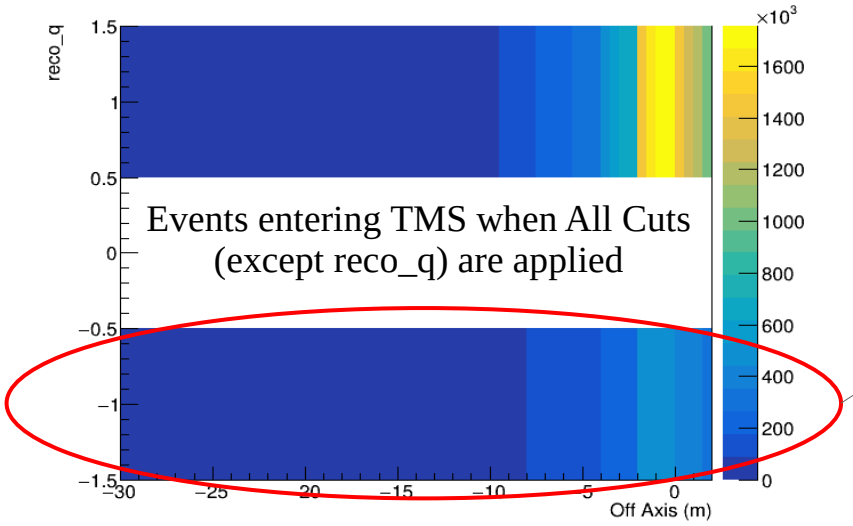
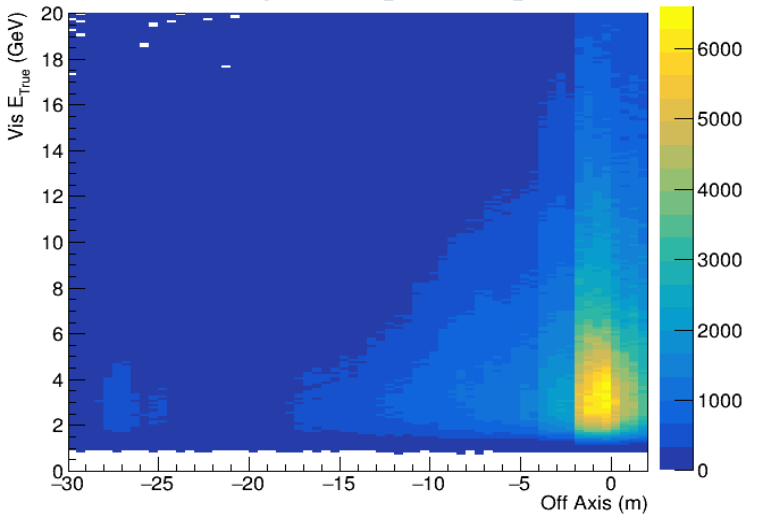



**Energy vs OA distribution of TMS Events with wrong reco_q (reco_q != +1)**



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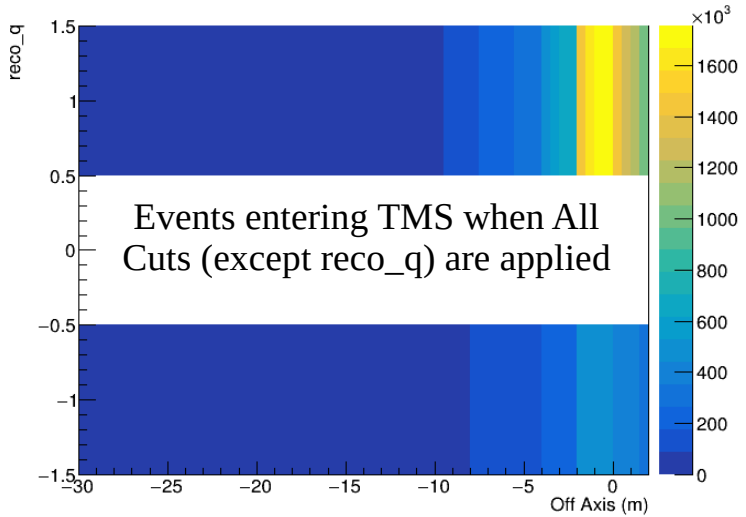
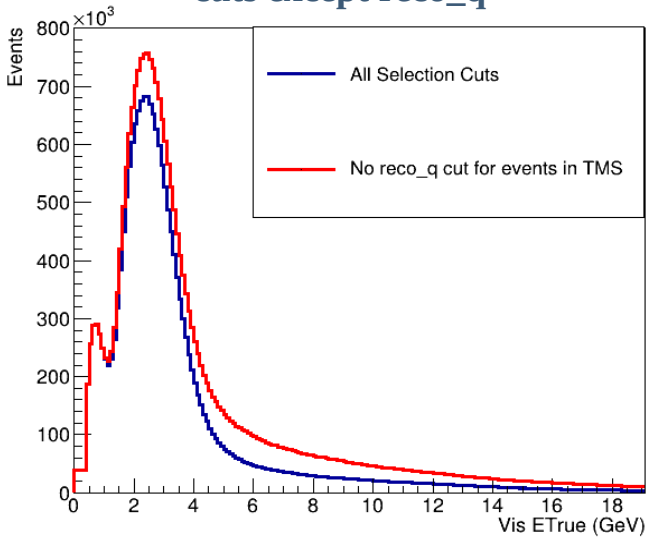


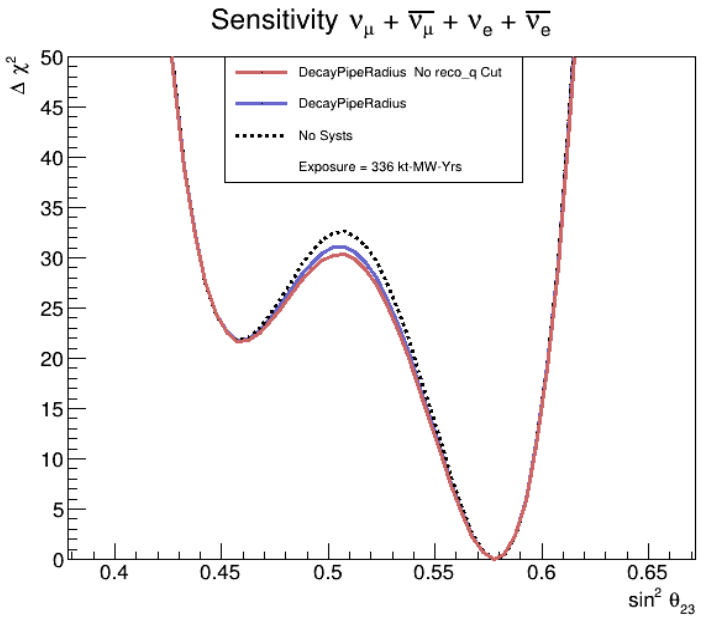

**Energy distribution of Events with all cuts Vs all cuts except reco_q**

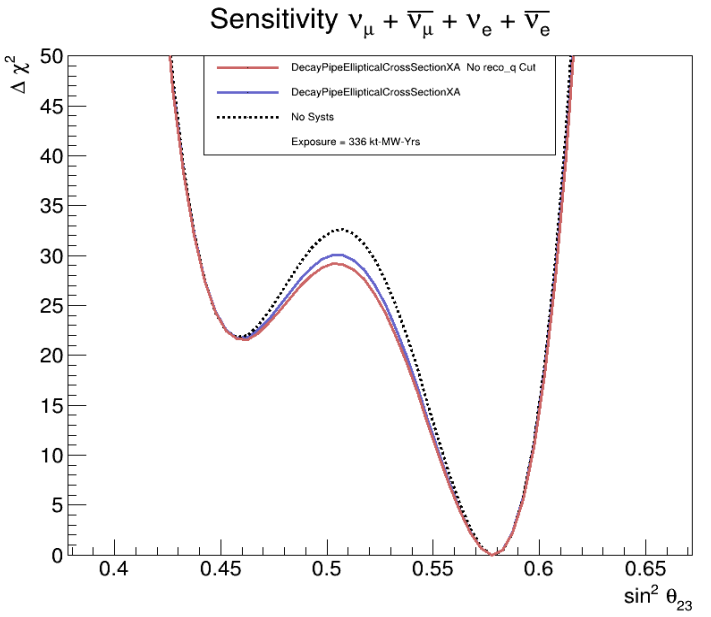


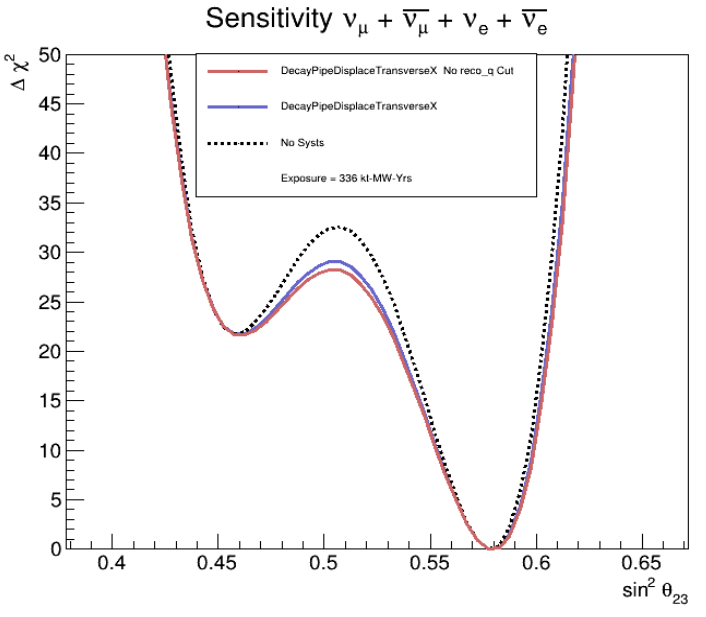

**→ Remove the reco_q cut for events in TMS only (NDLAr will have charge selection) and study the effects this has on PRISM oscillation sensitivities**

# Oscillation fits with flux systematics - $\sin^2\theta_{23}$

- Nominal (stats-only) fit does not change when no reconstructed charge
- **Old plots (from CM – May2024) – reco_q cut removed everywhere: both in NDLAr and TMS → to be updated with reco_q cut removed for TMS only**
  - PRISM sensitivity changes for 4 flux parameters for $\sin^2\theta_{23}$ if TMS + NDLAr have no charge reconstruction (9 flux parameters reducing PRISM sensitivity in $\sin^2\theta_{23}$)



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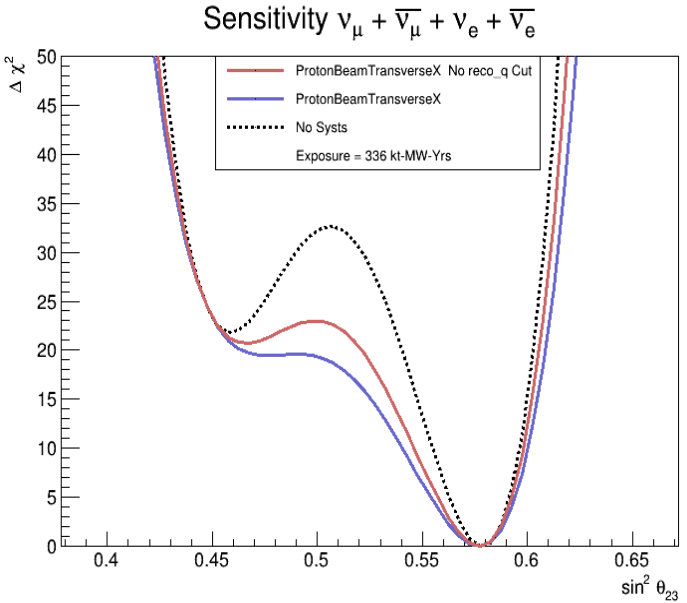


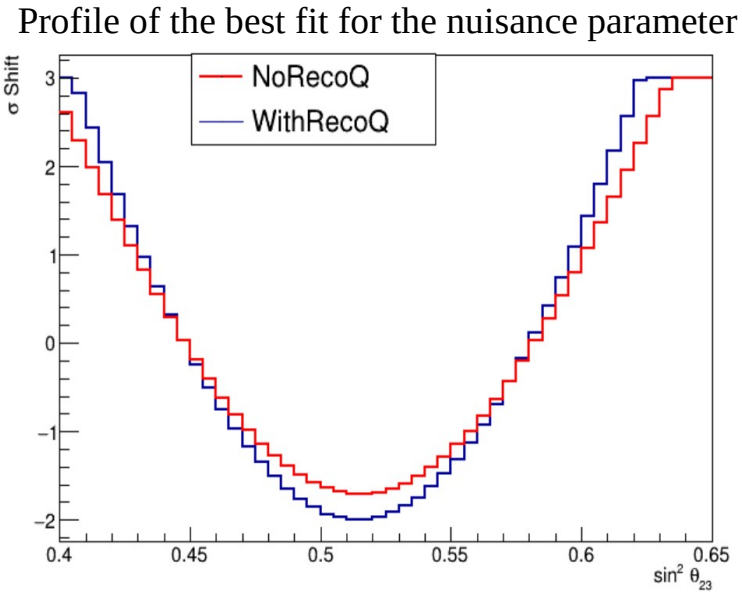


– for this particular flux parameter – Proton Beam Transverse X (interaction position) – the sensitivity is improved for the no reconstructed charge case → lower parameter shift values chosen for the best fit

# No Charge Reconstruction in TMS: main remarks so far

– based on the previous (CM May 24) study: q_reco cut removed from both ND-LAr and TMS –> to be updated for the current study: no q_reco cut in TMS only

- PRISM sensitivity for the nominal (no systs) case is unchanged in a no charge separation scenario
- PRISM for $\sin^2\theta_{23}$ sensitivity changes when flux systematics are applied
  - 3 (decay pipe related flux parameters) out of 4 cases sensitivity is reduced, while sensitivity increases when the proton beam transverse X (interaction position) flux systematic is applied
- PRISM sensitivity for $\Delta m_{32}^2$ is almost not changed at all when flux systematics are applied
- PRISM sensitivity for $\Delta$CP is not changed at all when flux systematics are applied
  - flux parameters have a minimal effect on $\Delta$CP

**Results should change with no q_reco in TMS but q_reco NDLAr: significantly less WSB events at E <~1.3 GeV**

Note: very preliminary study → however most important results would be obtained once all systematics (flux, flux + xsec, flux + xsec + detector) are applied

Next: look how the energy resolution (TMS resolution) and E cutoff affects the oscillation sensitivity

# TMS-like studies with PRISM: TMS like lepton energy

***What if TMS momentum resolution is worse than ND-GAr (thicker iron or less scintillation bars) ?***

1) Estimate what the TMS would measure

– split true lepton energy Elep into Energy deposited in ND-LAr and remaining energy to be deposited in TMS:

$$Elep = Edep\_NDLAr + E\_TMS\ , \quad Edep\_NDLAr = 0.002 \cdot (600 - vtxz)$$

– lepton energy left for TMS: $E\_TMS = Elep - 0.002 \cdot (600 - vtx\_z) \rightarrow$ true lepton energy deposited in TMS

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5) Extract oscillation parameters using PRISM Analysis

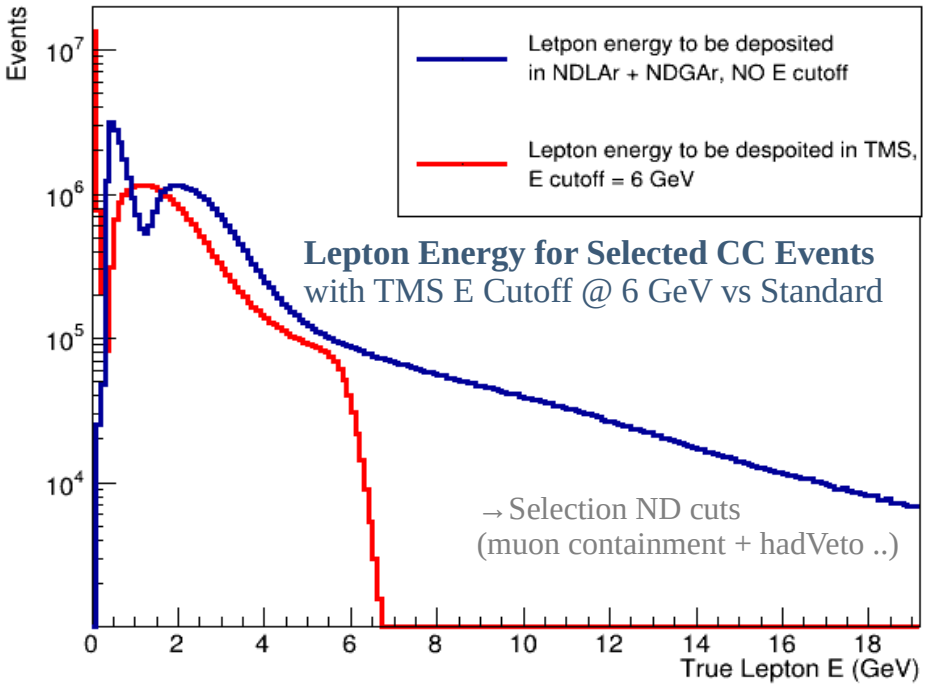
→ **see how this scenario affects PRISM sensitivities (nominal and systs applied)**

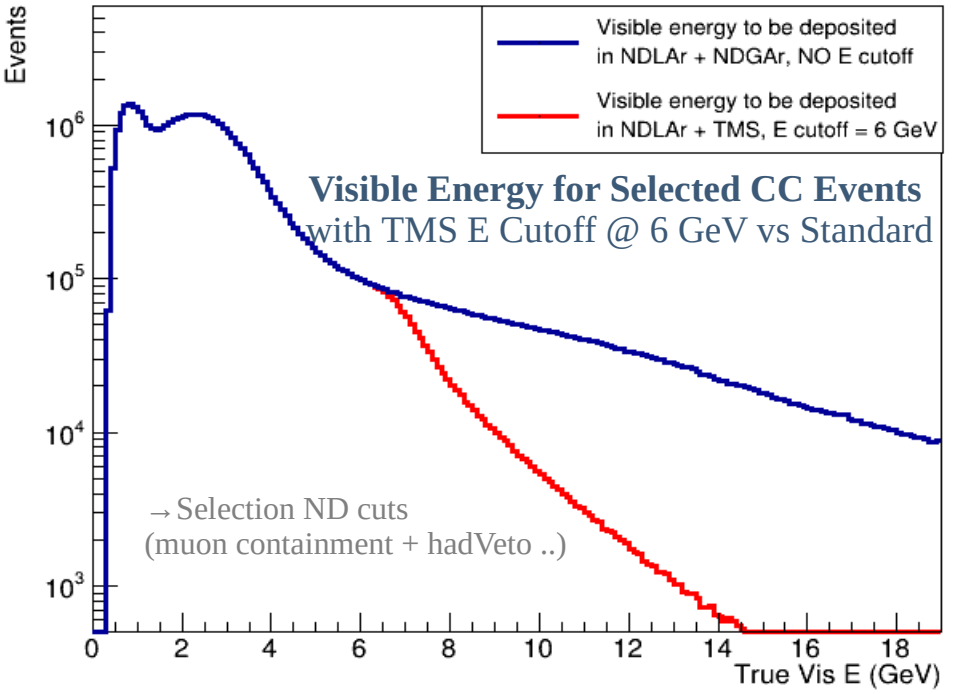
# TMS-like studies with PRISM: TMS like lepton energy

1) Estimate what the TMS would measure, i.e. subtract energy deposited in ND LAr

true lepton energy in TMS: LepETMS = LepE – 0.002*(600-vtx_z);
true visible energy stays the same: VisEtrueTMS = LepE + HadE

– include **TMS energy cutoff: Elep_recoTMSOnly < 6.0** → additional selection

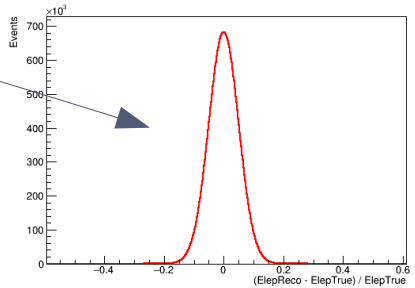


# TMS-like studies with PRISM: TMS like lepton energy

2) Smear the energy by some additional amount for TMS-matched. Maybe 3%, **5%**, 10% to start

2.1 Extract ELep_recoTMSOnly from a Gaussian with mean = LepETMS (true E in TMS) and sigma = 5%Etrue




2.2 Apply **TMS energy cutoff** @ 6 GeV → additional events selection

Elep_recoTMSOnly < 6 GeV

2.3 Add back the energy deposited in NDLAr:

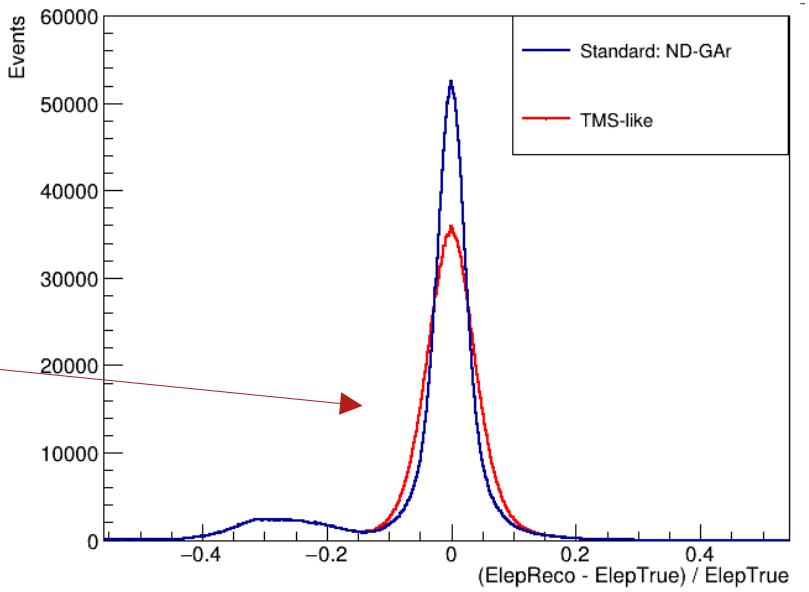
Elep_recoTMS = Elep_recoTMSOnly + 0.002*(600-vtx_z)

→ **reconstructed lepton energy in the ND with TMS**

2.4 Calculate the visible reconstructed energy:

VisERecoNDTMS = Elep_recoTMS + HadEvisReco_ND

(VisERecoND standard = Elep_reco + HadEvisReco_ND)



# TMS-like studies with PRISM: TMS like lepton energy – FHC mode

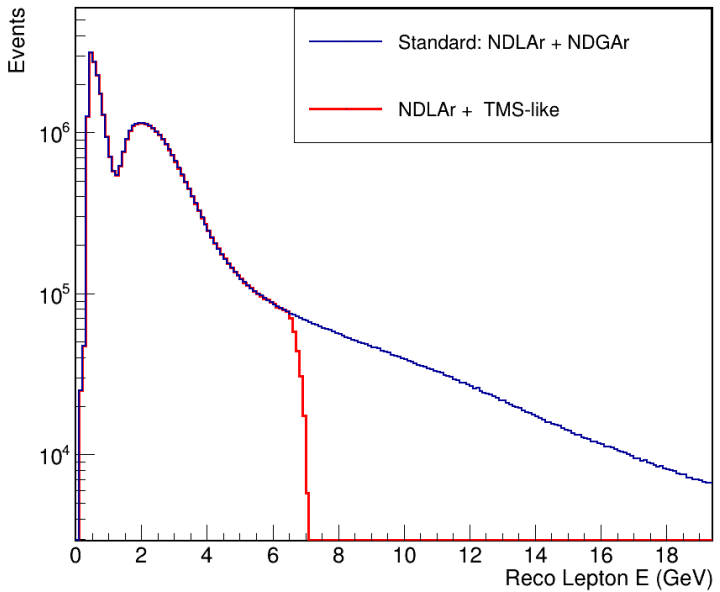
2) Smear the lepton energy by some additional amount for TMS-matched – **5% energy resolution** – and then add back the energy deposited in ND LAr + **energy cutoff at 6 GeV**

→ reconstructed lepton energy in ND with TMS: Elep_recoTMS = Elep_recoTMSOnly + 0.002*(600-vtx_z)

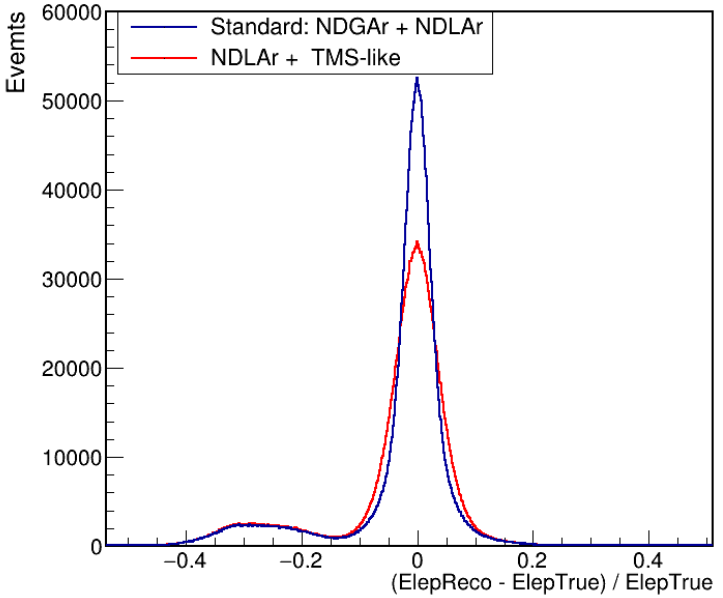
(Elep_reco ND standard = Elep_reco from CAF file)

**Reco Lepton Energy for CC Events**

(after bkg subtraction)




**Lepton energy resolution**




**Similar energy dependence of the reconstructed lepton energy deposited in ND with both TMS and ND-GAr before the energy cutoff, but slightly worse lepton energy resolution for TMS**

# TMS-like studies with PRISM: TMS like lepton energy – FHC mode

2) Smear the lepton energy by some additional amount for TMS-matched – **5% energy resolution** – and then add back the energy deposited in ND LAr

→ reconstructed visible energy in ND with TMS: VisERecoNDTMS = Elep_recoTMS + HadEvisReco_ND

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**Visible RecoEnergy for CC Events**

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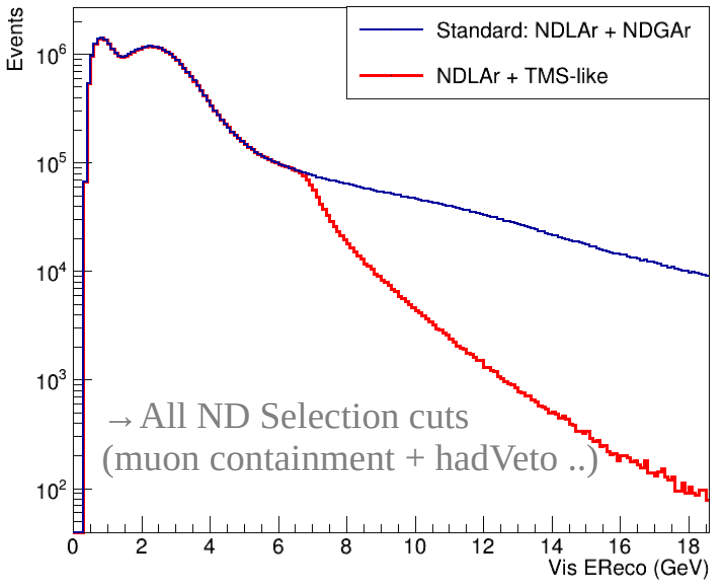


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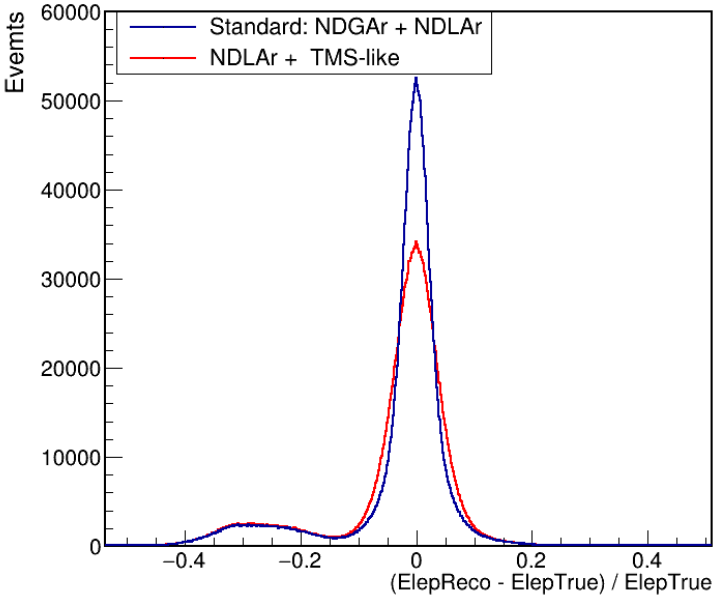
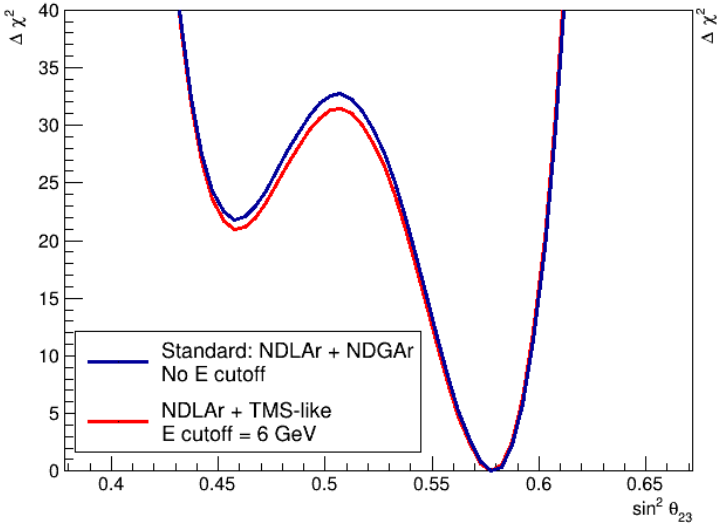
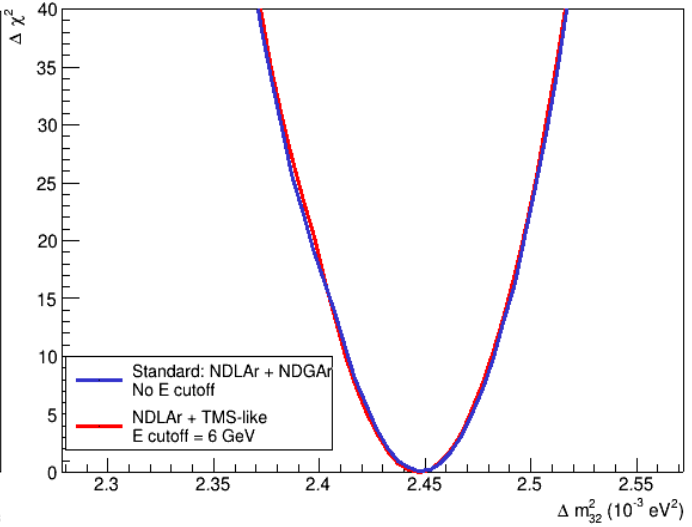


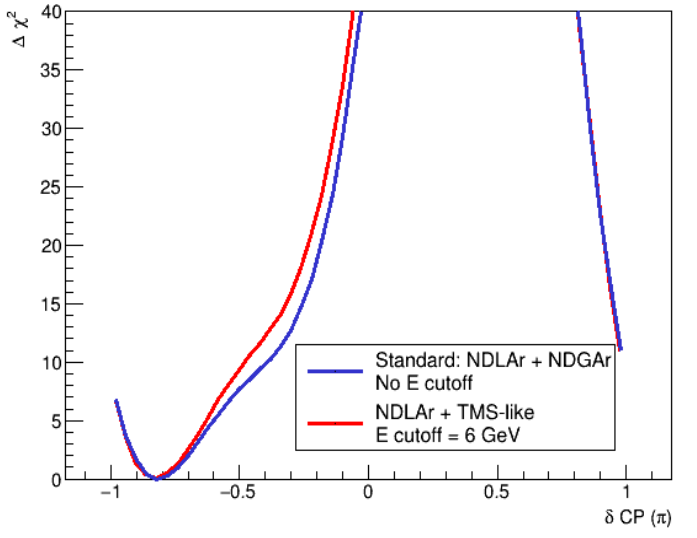

**Similar energy dependence of the visible reconstructed energy deposited in ND with both TMS and ND-GAr before energy cutoff, but slightly worse lepton energy resolution for TMS**

# TMS-like studies with PRISM: TMS energy resolution 5% + Energy Cutoff = 6 GeV

- Nominal: no systematics for all 4 channels combined and 7 yr – 336 kt-MW-yr exposure




– all of these effects are due to the energy cutoff (not present, I.e same nominal oscillation fit as “Standard” for all 3 parameters when only energy resolution 5% and no energy cutoff)

# Overview

- First dedicated study towards the impact several TMS features would have on the oscillation parameters sensitivity
- Trying to reparametrize different parameters available in the ND sim/reco CAF files and mimic the TMS energy resolution → temporary solution until we get dedicated TMS sim/reco
- Study in the **very preliminary stage** (no charge reconstruction + **5%** TMS energy resolution + Ecutoff = 6 GeV)
    - nominal oscillation results are not modified by the absence of charge
    - Nominal oscillation results for 5% TMS energy resolution and energy cutoff of 6 GeV: lower sensitivity for $\sin^2\theta_{23}$ , no sensitivity change in $\Delta m^2_{32}$ , increased sensitivity in $\delta$CP ??

# TO DO

- Apply flux + x-sec + detector systematics → study PRISM sensitivity for the 3 TMS scenarios
- Study different energy resolutions (7%, 10%, 12% etc)
- Study different (lower) energy cutoff (I.e 5 GeV)
- Study fixed impact of constant (20 MeV) smearing

**→ Framework for this dedicated study is now in place: suggestions are welcome**

# BACKUP

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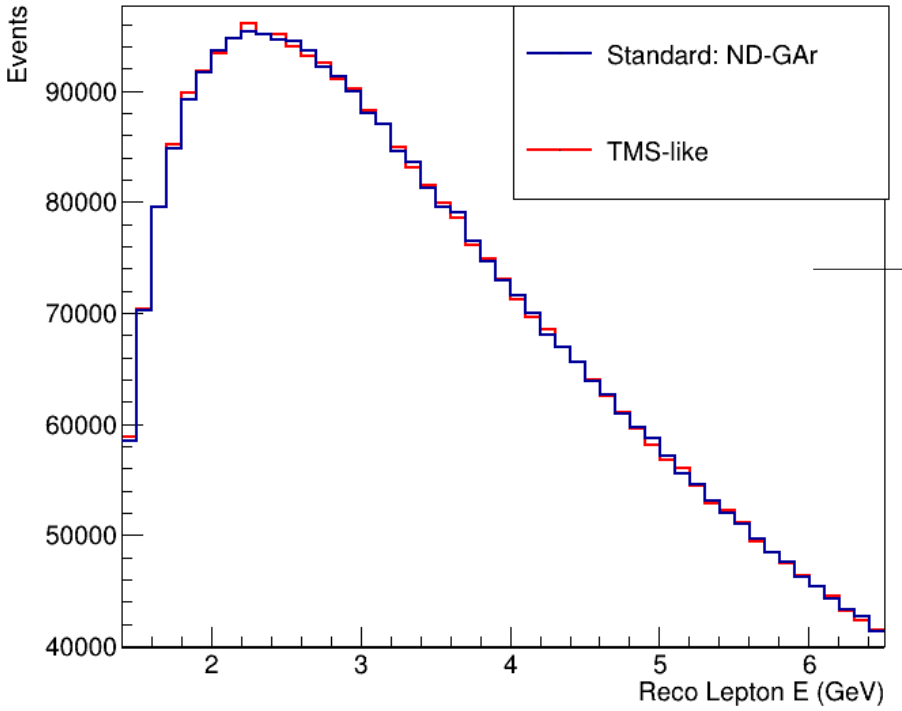
- 5% Energy resolution

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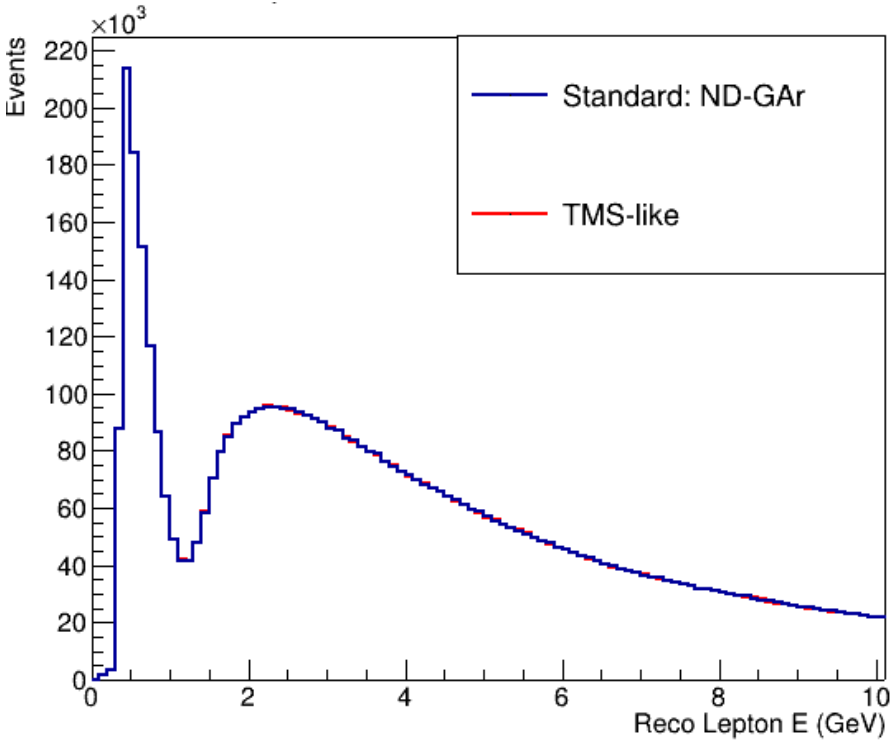


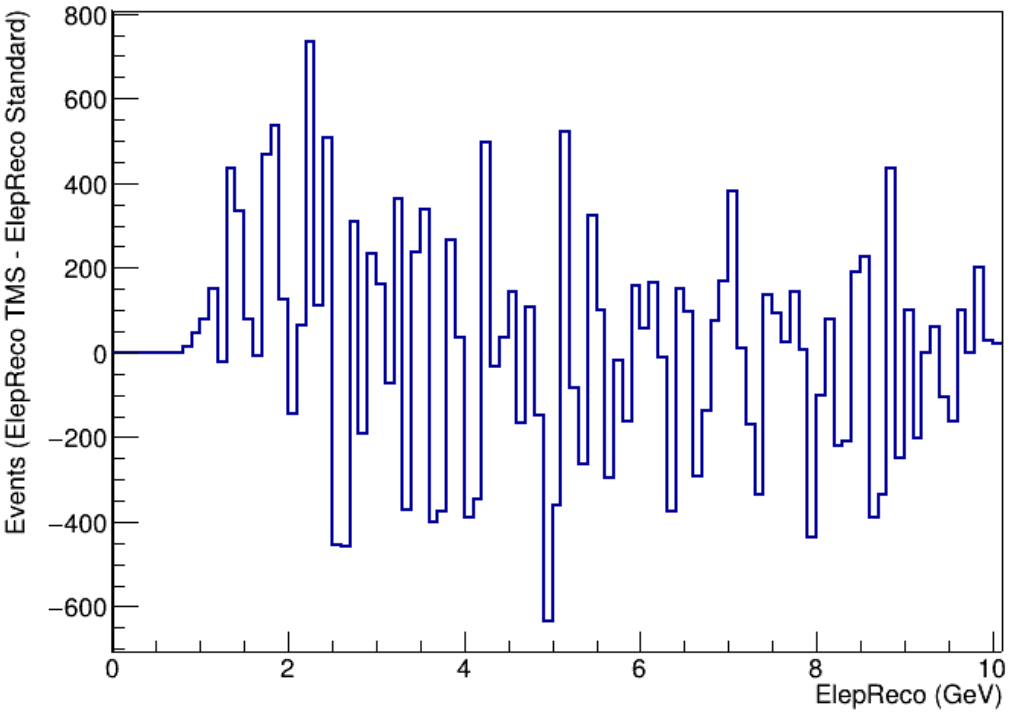


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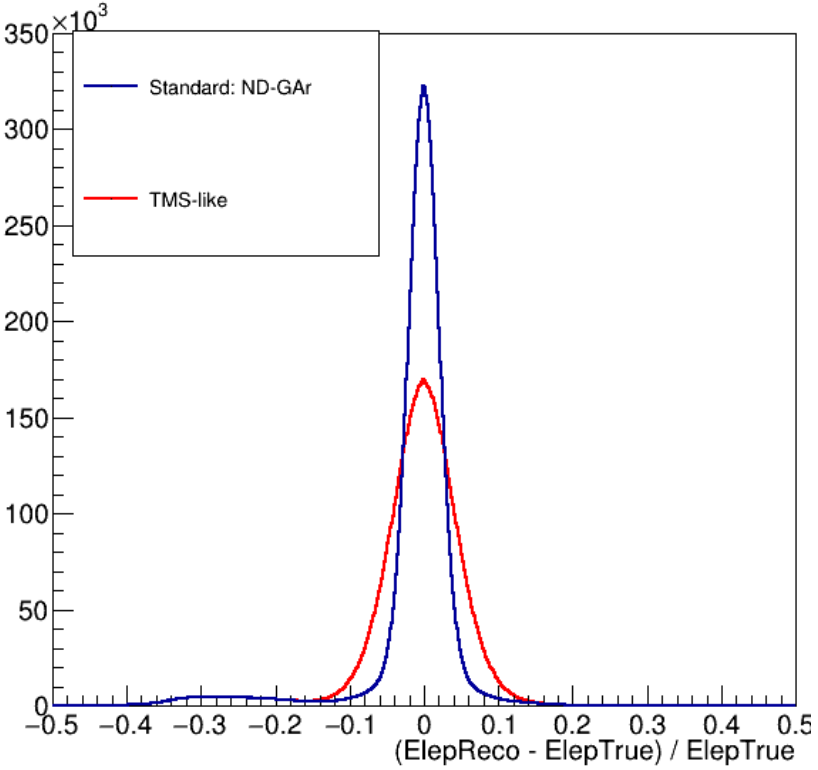
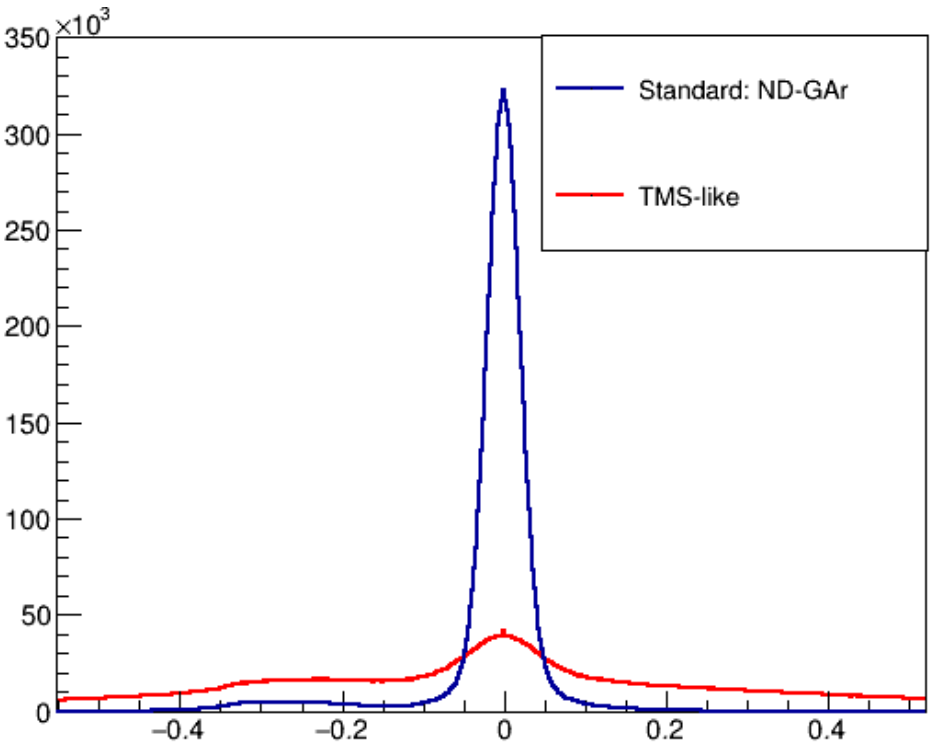
# TMS Energy Resolutions

5% Energy resolution

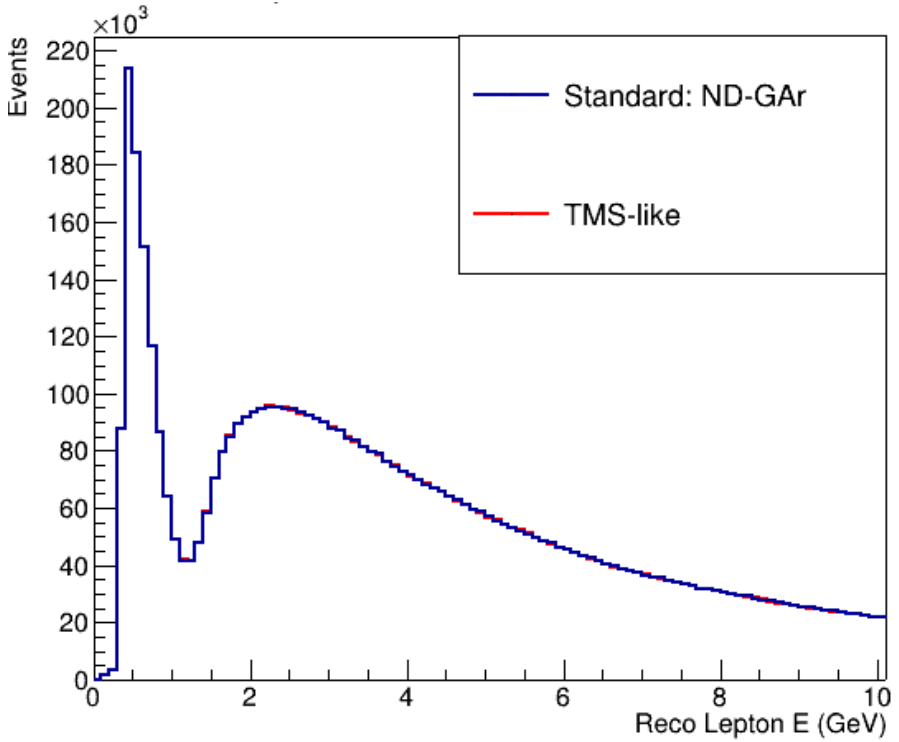



50% Energy resolution

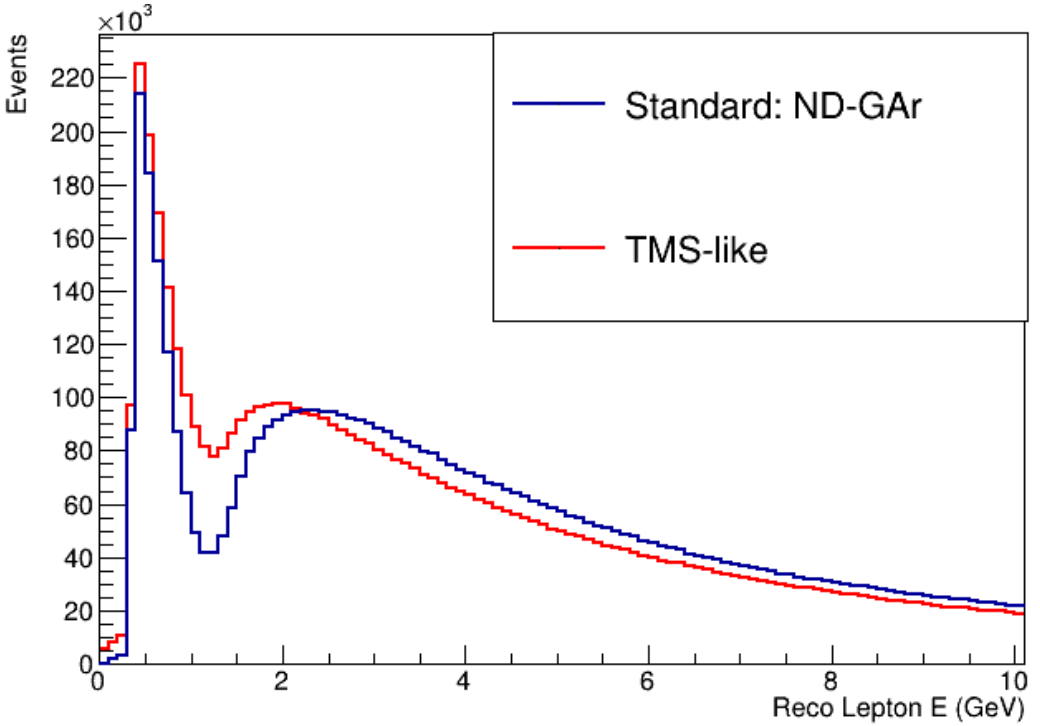


# **BACKUP:** TMS Energy Resolutions

5% Energy resolution

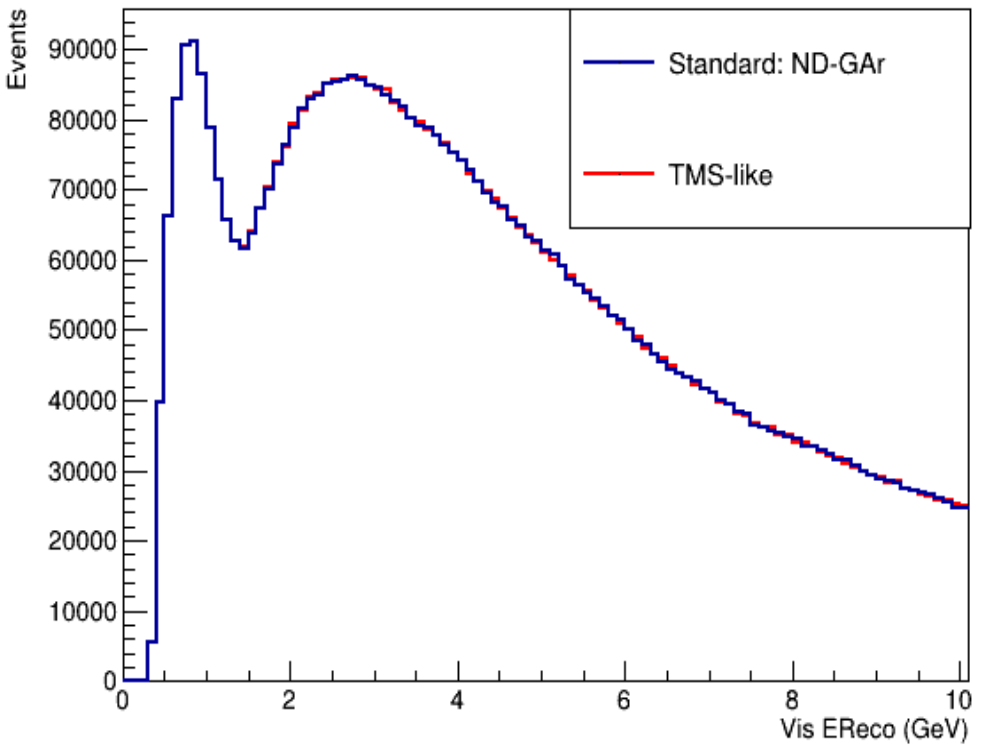



50% Energy resolution



# **BACKUP:** TMS Energy Resolutions

5% Energy resolution




50% Energy resolution