Physics impact of the SBND cryostat in ND-LAr

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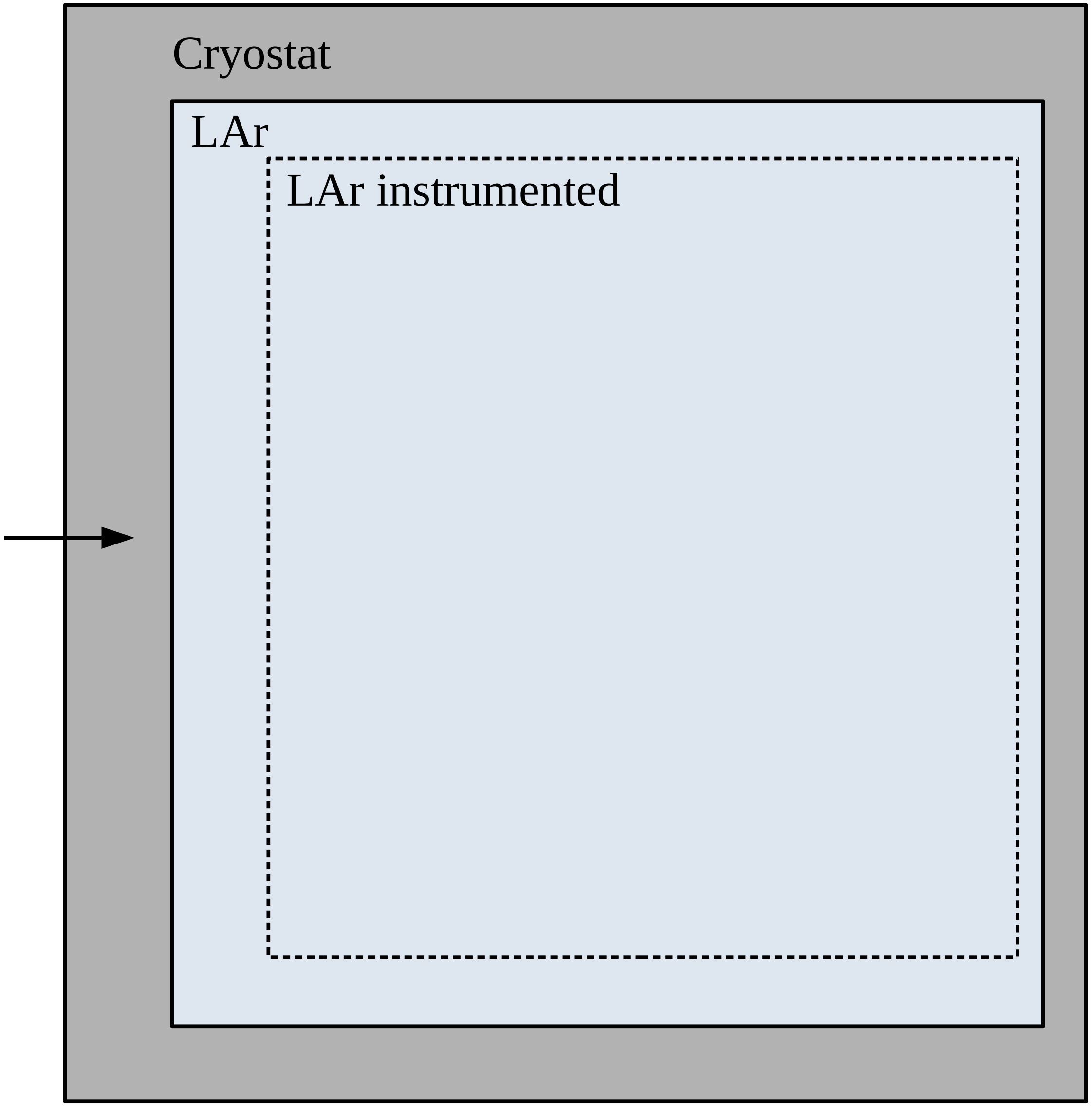
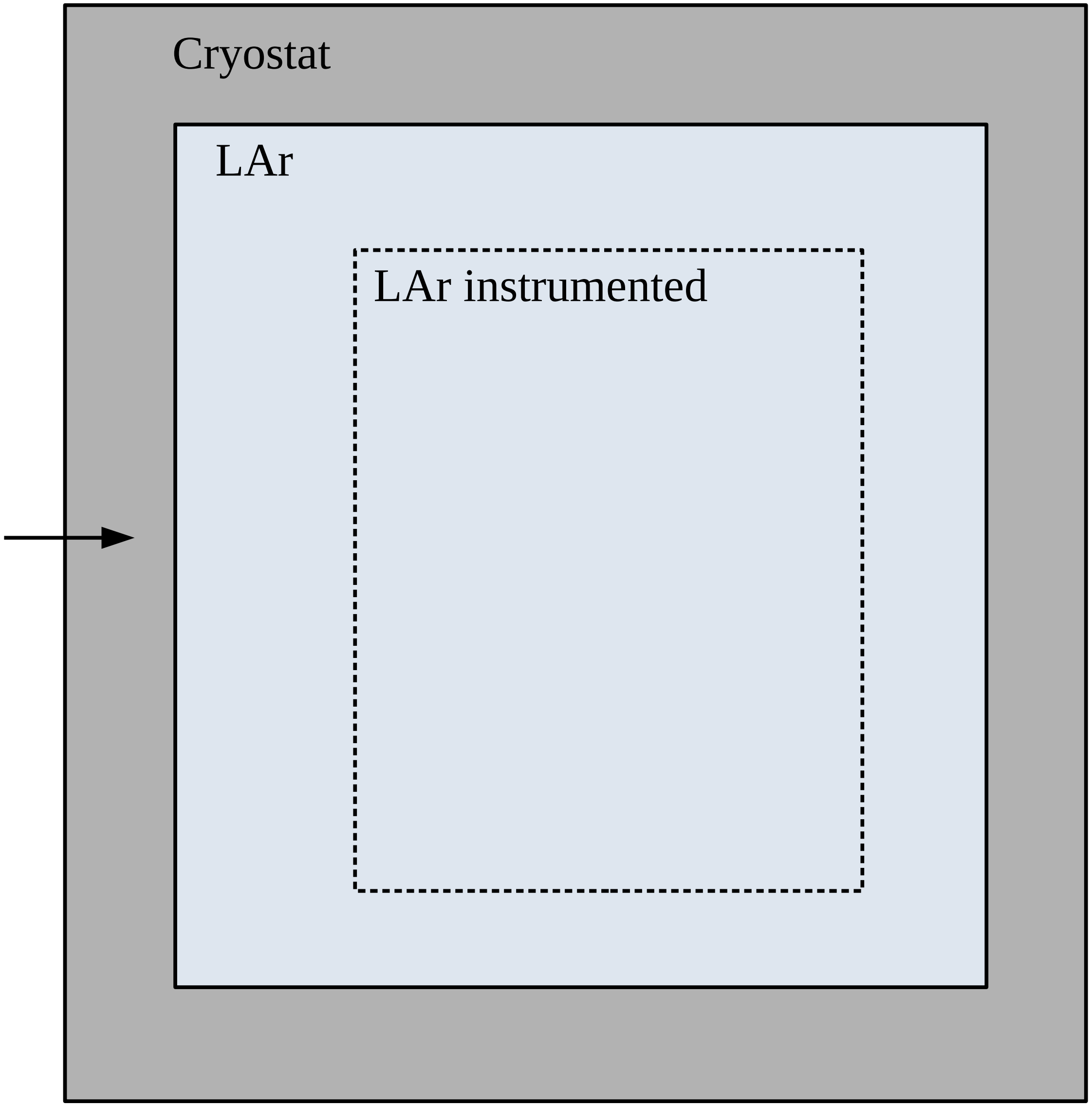
Key physics features: Ref. cryostat



- Active volume is very close to membrane
- Downstream composite wall is thin, uniform
- Very little material traversed by forward muons exiting system, <60 g/cm^2 total areal density from active volume to warm side

Key physics features: SBND cryostat



- Active volume is ~70 cm from membrane
- Downstream wall has thick steel support beams, highly non-uniform
- Minimum areal density is ~118 g/cm^2, roughly twice the muon energy loss
- Muons lose up to 100s MeV if they happen to cross support beams
- It's too small to support the optimized ND-LAr volume, restricted to 5x4 active

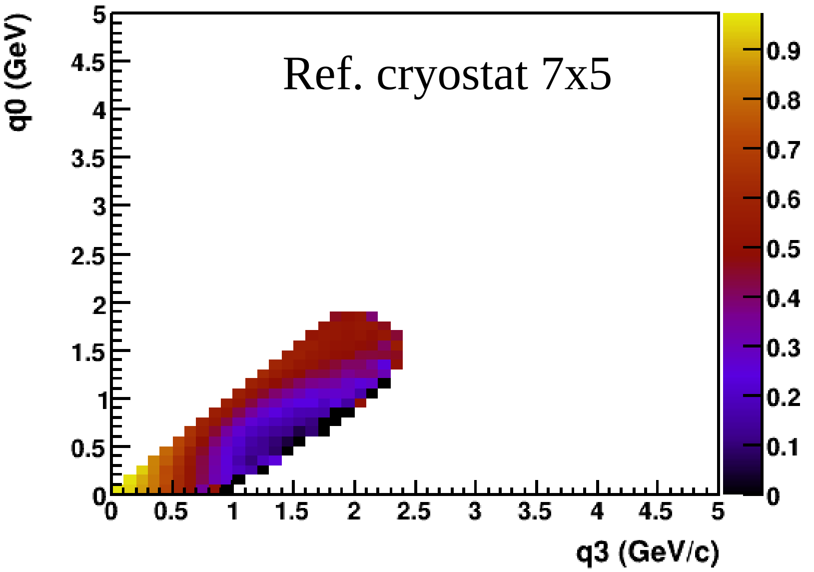
What this means for physics

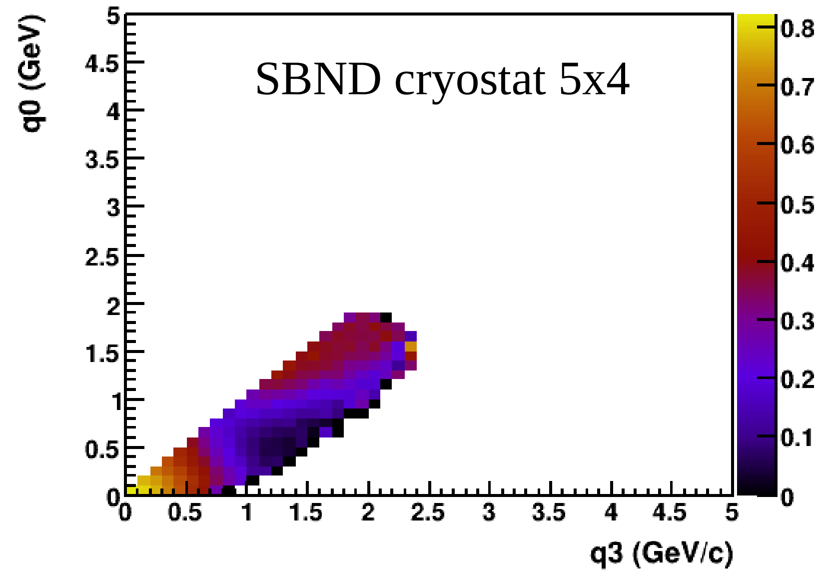
- Smaller active volume
  - Smaller fiducial volume (or worse hadronic containment)
  - Worse coverage for high-angle muons
- More passive material between LAr and TMS
  - More muons will stop in passive material and be excluded from analysis, or have poor resolution
- Less uniformity in passive material
  - For muons that reach TMS, passive material correction has large spread due to nonuniformity → worse muon energy resolution

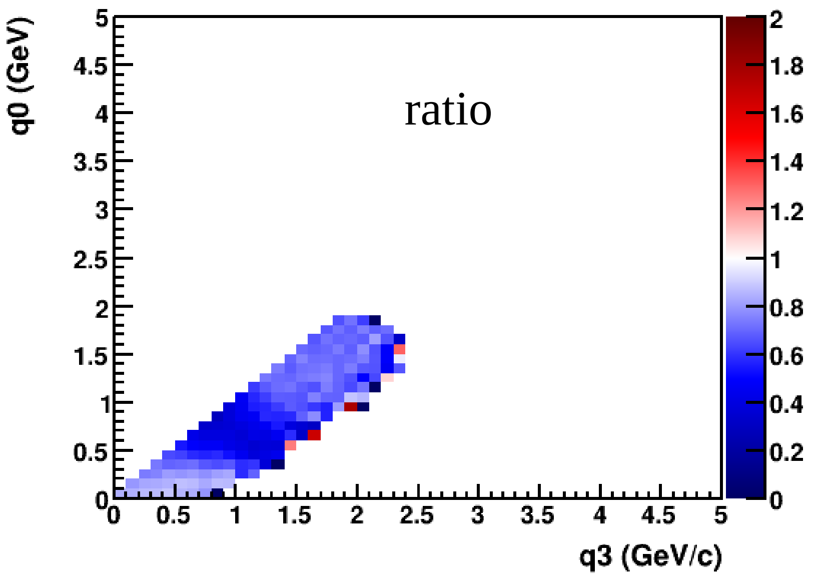
Assumptions in this study

- The SBND TPC is replaced with a pixelated, modular TPC – only the dimensions, and cryostat passive elements are considered
- TMS is used as a muon spectrometer and sits immediately downstream of ND-LAr
- Muons that exit through the sides are excluded from analysis
- Muons that exit the downstream end of the LAr active region but do not make it to the TMS are excluded
- (Alternatively, one could analyze those events with poor resolution, but this would lead to a similar level of model dependence entering the analysis)

$1.5 < E_\nu < 2.0$ GeV

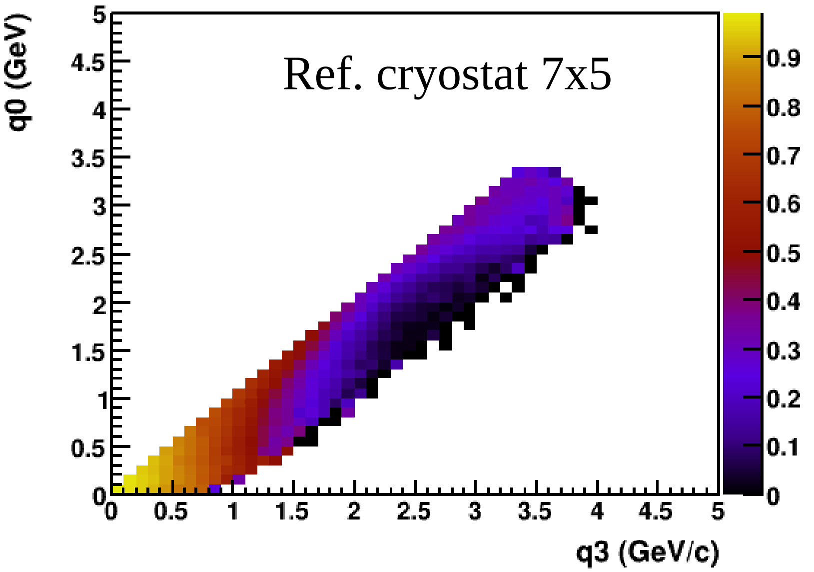


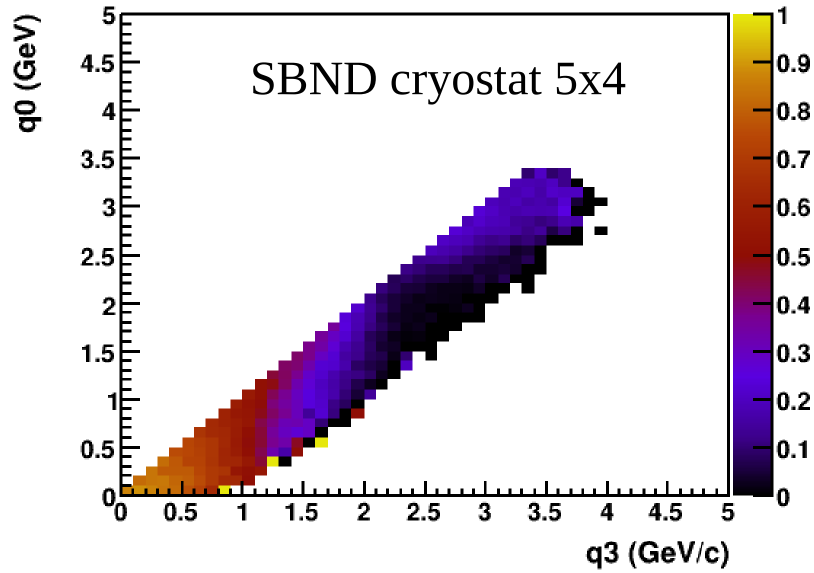


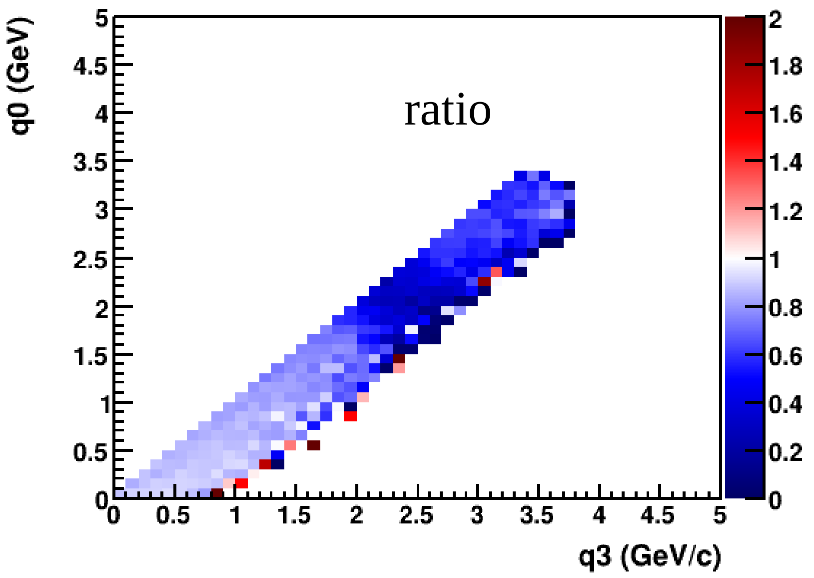


- In a slice of neutrino energy, what is the acceptance vs. kinematics (energy & 3-momentum transfer), for the nominal ND-LAr (top-left), a 5x4 ND-LAr in the SBND cryostat (top-right)
- Ratio of SBND / nominal (bottom)

3.0 < E_ν < 3.5 GeV

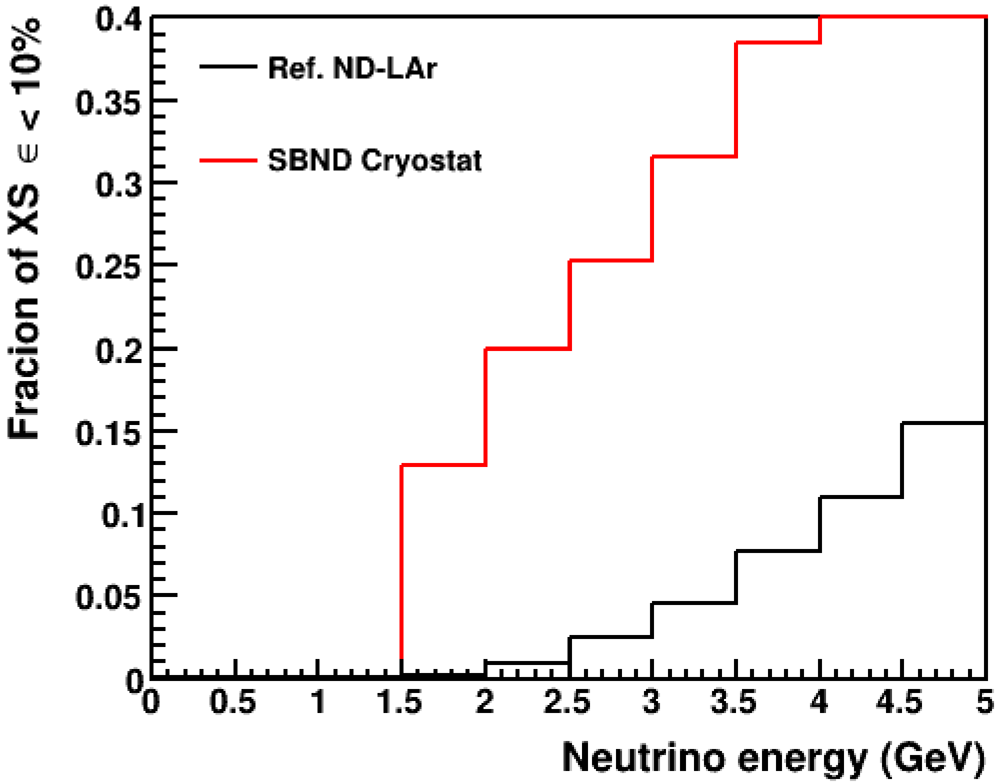






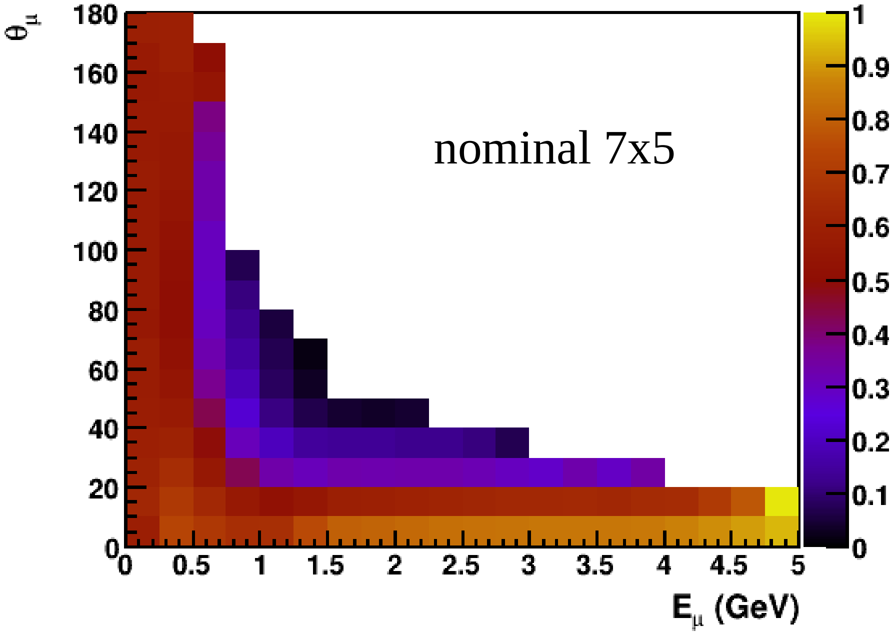
- Repeat this in each neutrino energy slice
- Metric for good detector: for what fraction of the total XS is the acceptance < 10%

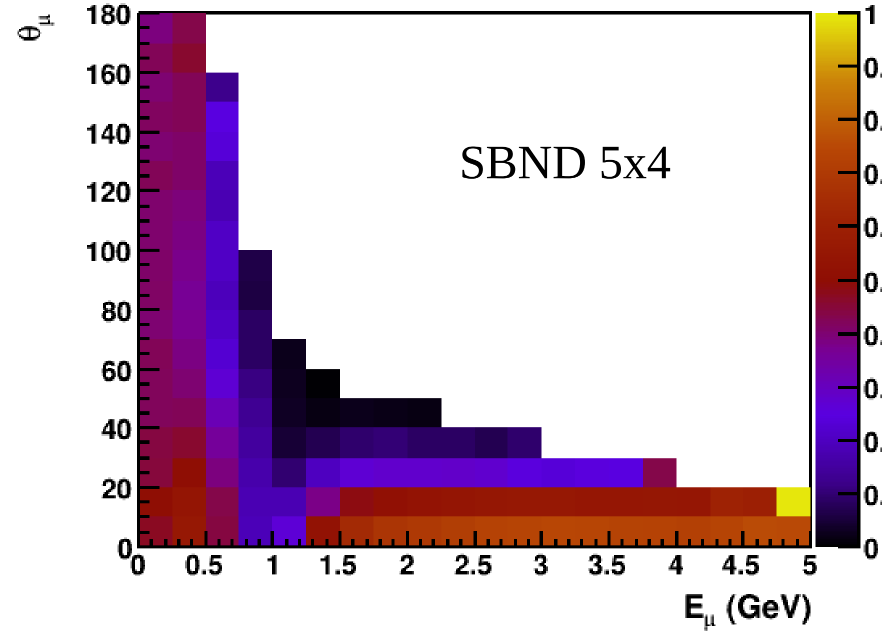
Fraction of XS with poor acceptance



- Standard metric for good kinematic coverage is requiring that acceptance is reasonable (>10%) over entire phase space
- Still using symmetry to sample events → OK to have low acceptance, but kinematic holes mean we are blind to certain types of events
- Ref. design is <2% of total XS in the oscillation peak by design
- SBND cryostat is ~25% of events in poorly-covered kinematic region

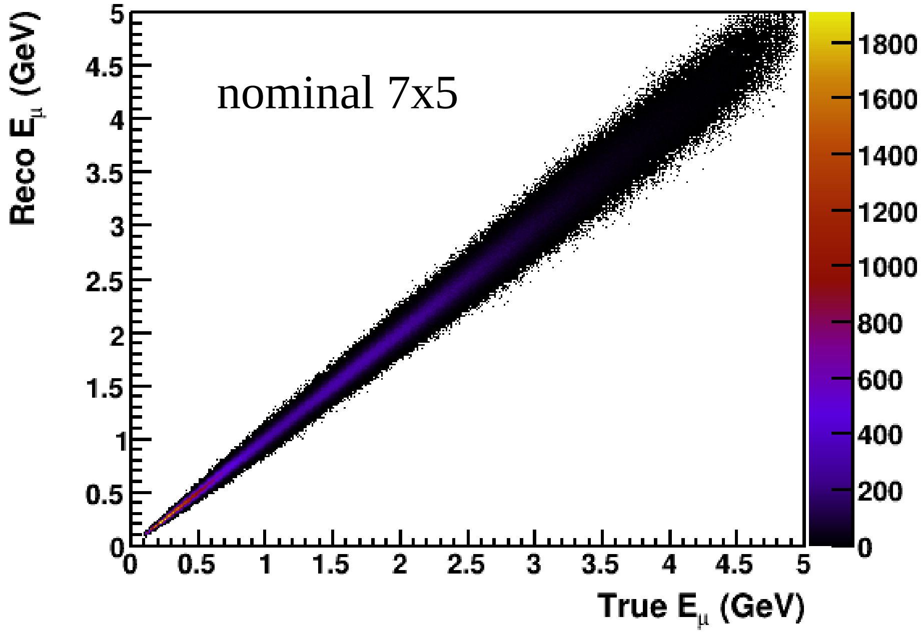
Acceptance in E_μ, θ_μ

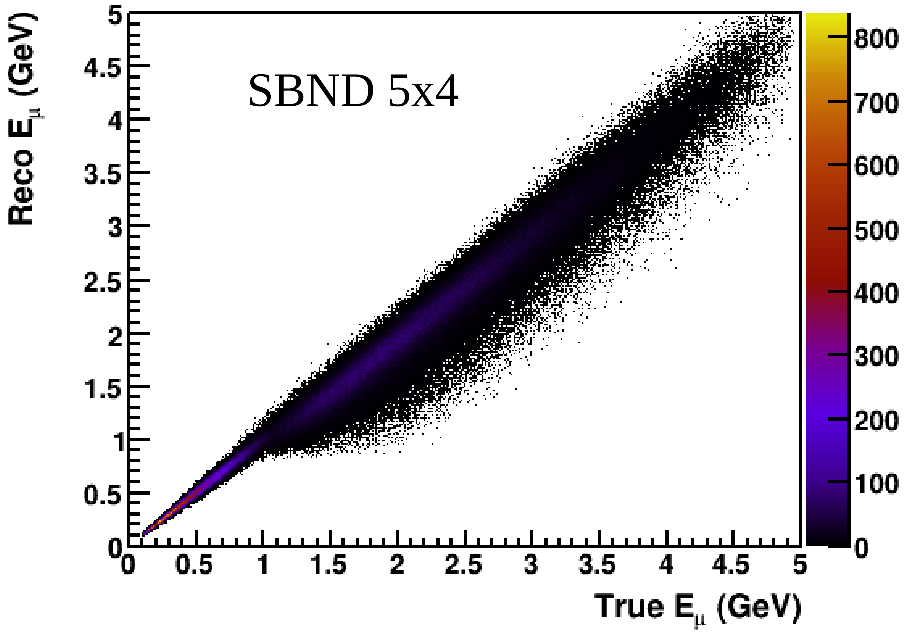




- Key region is forward muons around 1 GeV, where cryostat thickness is critical
- Large dip with SBND cryotat would be challenging to model

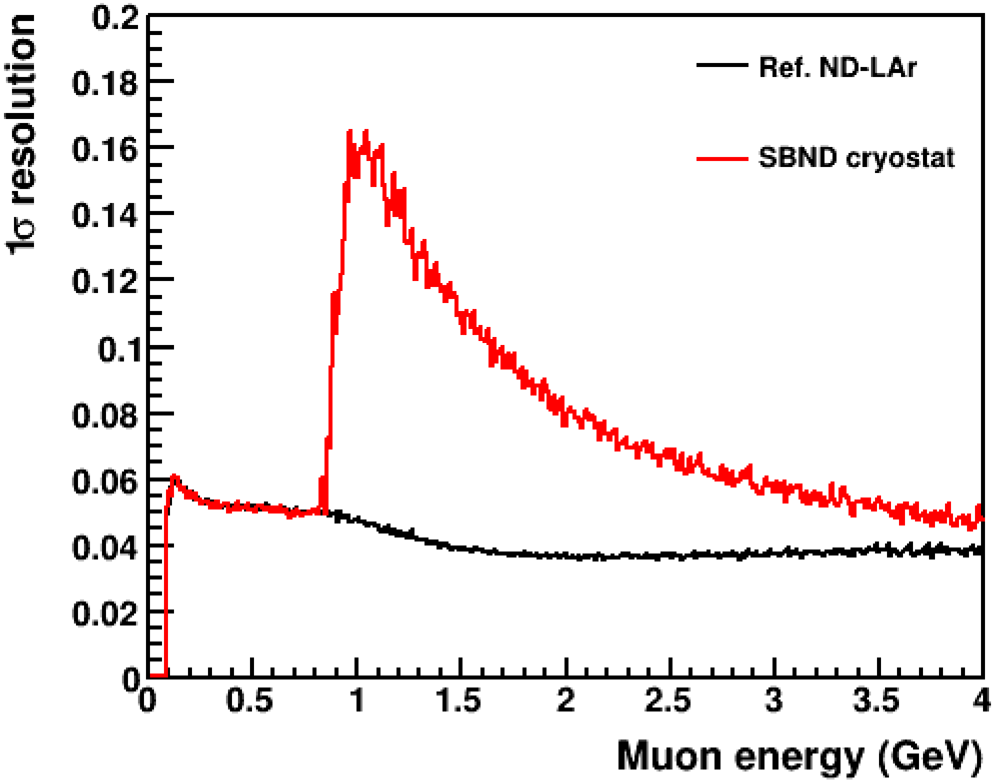
Muon energy resolution





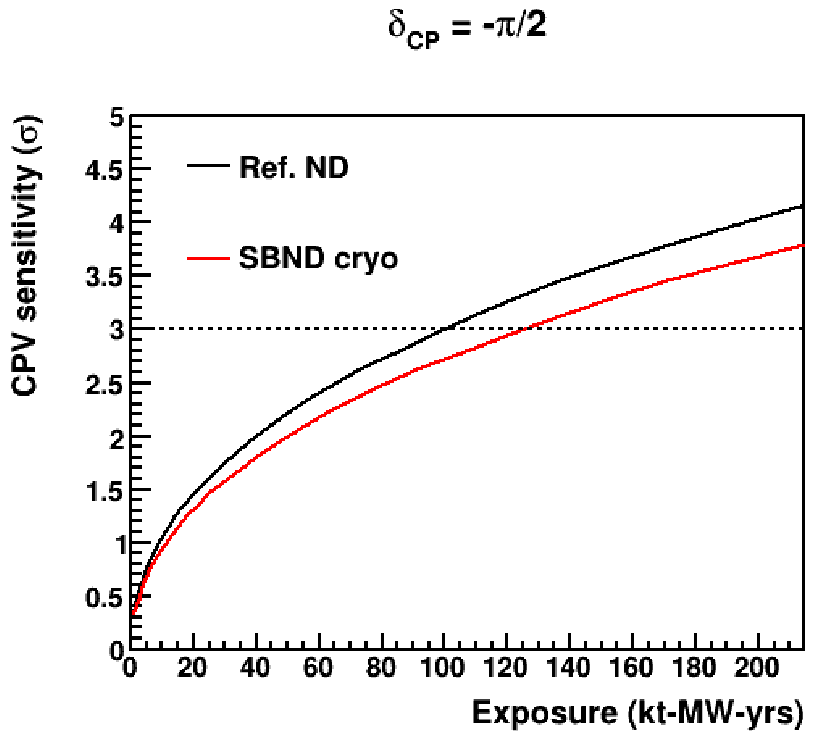
- TMS reco begins around 1 GeV
- With composite wall cryostat, impact of muon energy loss in passive material is small because of good uniformity
- With SBND, significant smearing due to muons that traverse steel support beams and lose additional energy

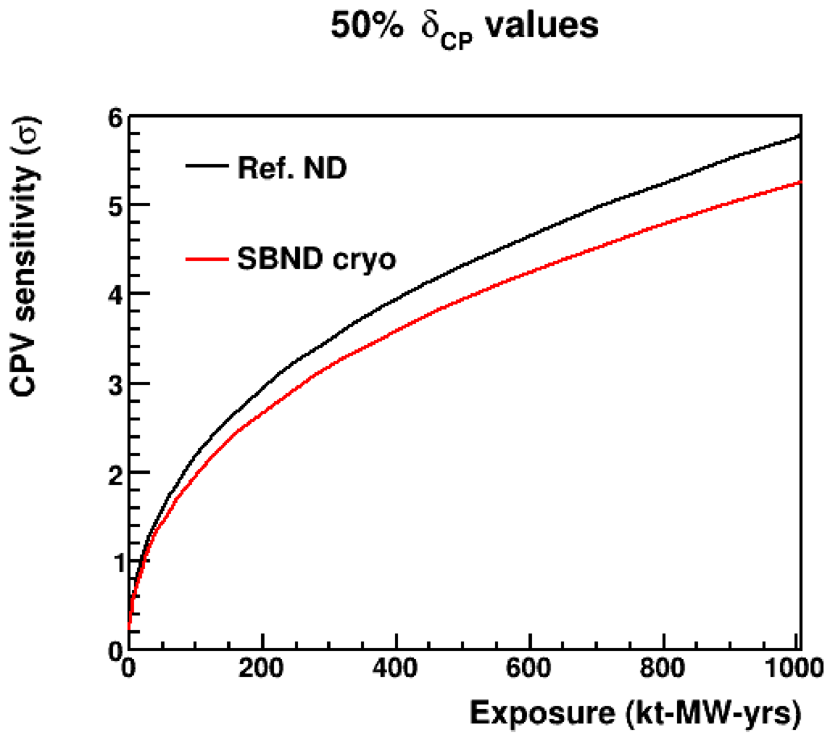
Muon energy resolution



- FD measures muons with ~4% resolution in oscillation region
- Similar resolution where muons are contained
- Passive material in SBND cryostat worsens resolution for muons that barely reach TMS
- At high momentum, passive material corrections become less significant and resolution is recovered by 4 GeV
- But 1-2 GeV is the peak of lepton energy in the FD, this is the most critical region

Impact on oscillation sensitivity of acceptance effect only





- Reject the FD events in the kinematic region where the ND acceptance is poor, since these events are not constrained by the ND
- 25% increase in time required for every milestone, equivalent to using reference ND-LAr design and removing 1 FD module
- SBND sensitivity would be worse than this due to degraded muon resolution

Conclusions

- Two key parameters get substantially worse:
  - Kinematic acceptance/coverage ~20-40% "blind spot" in oscillation region could be mitigated by excluding ~20-40% of FD events
  - Muon energy resolution worsens from 5% → 15% around 1 GeV, which is the peak of the event spectrum
- The physics impact of this is comparable to reducing the FD mass from 20 kt to 15 kt
  - Delays 3σ maximal CPV by 1 year (Phase I, 24 kt-MW-yrs per year), delays 5σ CPV for 50% δ values by >2 years (Phase II, 96 kt-MW-yrs per year)