Magnetic Field Requirements

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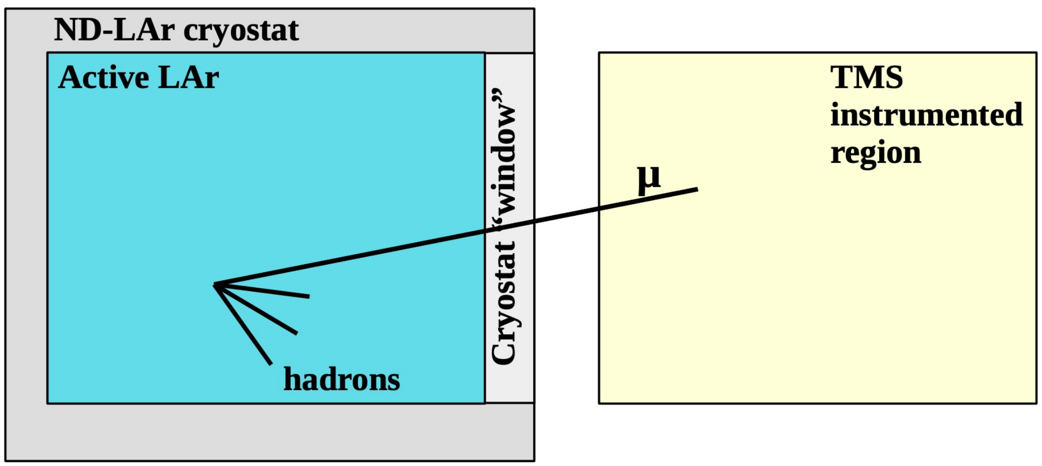
Reminder: what is "accepted"



- Hadrons contained in ND-LAr
- Muon stops in ND-LAr active volume or TMS instrumented region

I'll call these events the **ND Physics Sample**.

C. Marshall / KiYoung Jung
September 2024 Collab Meeting
"TMS Physics Requirements: Width"
(talk here)

Defined a metric based on the ND acceptance in relevant phase space, required this to be greater than 10%.

Will require a large acceptance correction, which is largely geometric.

Key points:

1. ND-LAr + TMS measurements will be systematics limited.
2. We will not measure anything perfectly.
3. How large are the corrections we need to make?
4. How well do we know them?

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Follow the same systematics approach used for previous ND-LAr physics / systematics studies. (ND measurements are systematics limited)

N: Total number of events in our ND Physics sample.

f: Fraction that are selected as wrong-sign by TMS.

$$N_{RS} = (1-f)*N$$
$$N_{WS} = f*N$$

Important to note that these two samples are completely anti-correlated.

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Let’s now consider the systematic uncertainty on the expected event rate in the RHC FD ν_e sample due to the systematic uncertainty on f.

$$n = P(\bar{\nu}_\mu \to \bar{\nu}_e) * (1 - f) * N * X^{RS}_{N\to F} + P(\nu_\mu \to \nu_e) * f * N * X^{WS}_{N\to F}$$

$$\delta n = \delta f * N * (-P(\bar{\nu}_\mu \to \bar{\nu}_e\ ) * X^{RS}_{N\to F} + P(\nu_\mu \to \nu_e) * X^{WS}_{N\to F})$$

”X” here extrapolate from ND to FD. Defining:

$$P(\bar{\nu}_\mu \to \bar{\nu}_e) = P(\nu_\mu \to \nu_e) * (1 + \Delta P)$$

$$X^{RS}_{N\to F} = X^{WS}_{N\to F} * (1 + \Delta X)$$

Note that the Δ terms here are NOT uncertainties, but differences.

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$$\delta n = -\delta f * N * P(\nu_\mu \rightarrow \nu_e) * X^{WS}_{N \rightarrow F} * (\Delta P + \Delta X - \Delta X * \Delta P)$$

Which behaves as we expect:

- Is zero when the wrong-sign fraction is measured perfectly
- Scales with exposure
- Since the wrong-sign and right-sign fractions are completely anti-correlated, the only way to introduce a difference in the FD rates is through an effect that is different for neutrinos and anti-neutrinos.

Criteria proposed by C. Marshall at the May 2024 collab mtg for Phase 1:

$\delta n \leq$ 0.05 n

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Using this criteria to solve for δf (keeping leading order terms only):

$$\delta f \leq \frac{\alpha}{(\Delta P + \Delta X)}$$

If ΔX=0, ΔP=0.13 gives δf=0.39.   (Independent of f)

Takeaways for Phase 1 physics:

- What matters is not how well we do the sign selection, but how well we understand it.
- Our requirements on this are not very strict.

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In the ND we will measure the wrong-sign fraction with some amount of mis-identification (m), which we will know with some uncertainty (dm).

$$f_{rec} = (1 - f)m + f(1 - m)$$

$$f = \frac{f_{rec} - m}{1 - 2m}.$$

To see the impact of δm, we can consider the inferred wrong-sign fraction f' when $m \to m + \delta m$:

$$f' = \frac{(1 - f)m + f(1 - m) - (m + \delta m)}{1 - 2(m + \delta m)} = \frac{f(1 - 2m) - \delta m}{1 - 2m - 2\delta m}.$$

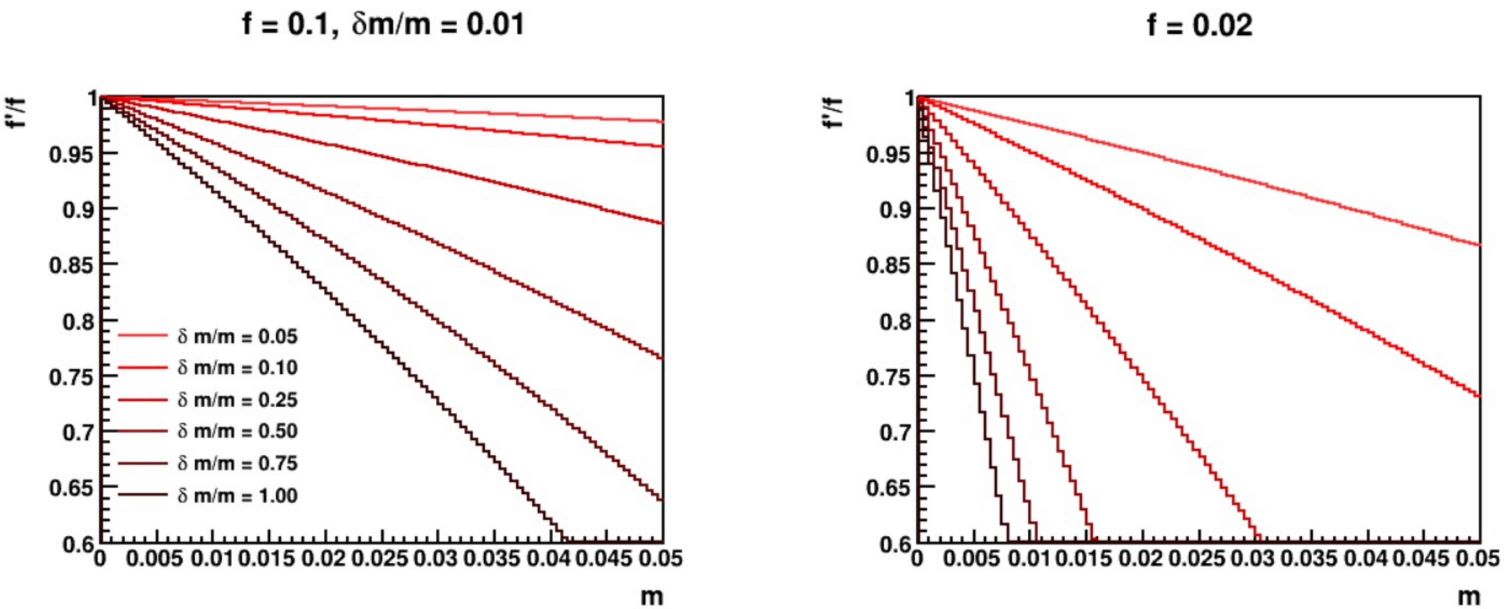

Figure 1: For a 10% wrong-sign fraction (left) and a 2% wrong-sign fraction (right), the impact on the inferred wrong-sign fraction due to a systematic uncertainty on the sign mis-ID rate, as a function of that rate.

For the 10% wrong sign fraction of RHC, this shows that a mis-ID rate of $< 4\%$ is able to tolerate a 100% systematic uncertainty ($\delta m/m = 1$), to obtain the required maximum allowed uncertainty from above.

The wrong sign fraction is a neutrino-energy dependent quantity (only).

Analysis strategies to take advantage of:

”Phase Space Symmetry”:

- Select events with the same energy / event kinematics in different regions of the ND-LAr volume.
- Could even extend this to events in TMS.

Running with different B-fields

- No field
- Field reversed

PRISM