Neutrinos from Stored Muons nuSTORM

Overview & Status

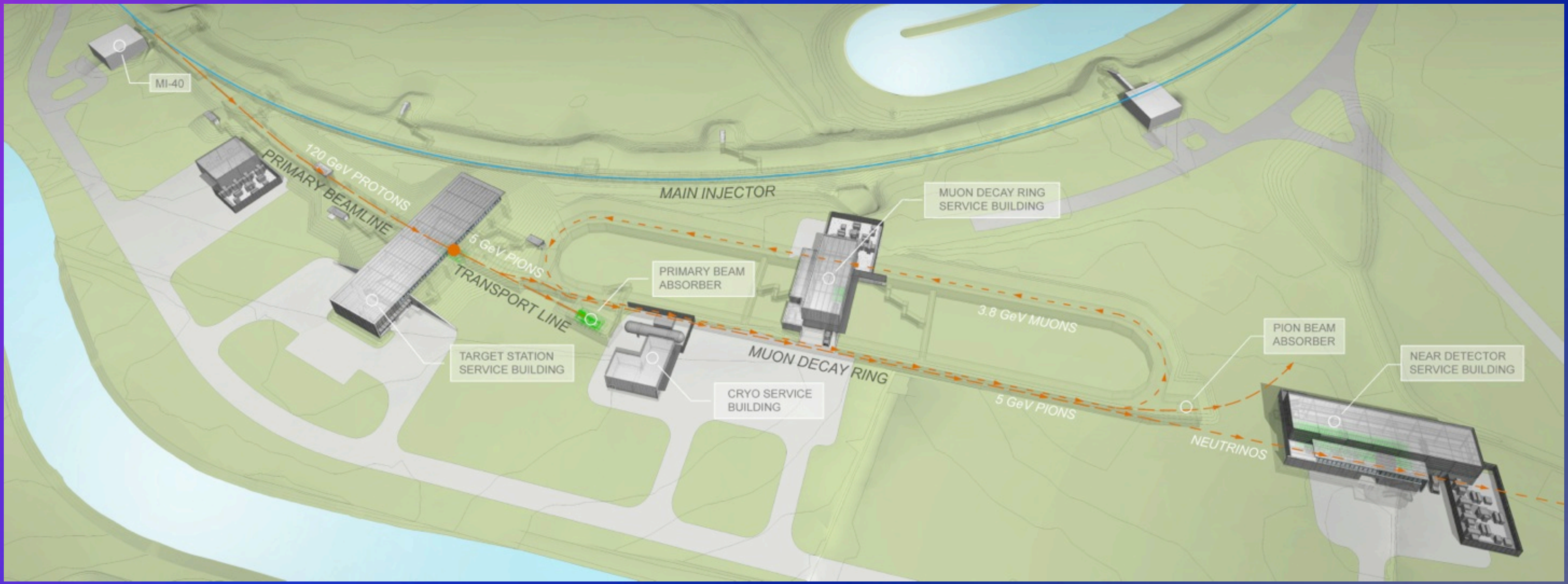
Intro….*

Y' know, every now and then
I think you might like to hear something from me
Nice and easy
But there's just one thing
You see I never ever do nothing
Nice and easy
I always do it nice and rough
So I'm gonna take the beginning of this talk
And do it easy
Then I'm gonna do the finish rough
This is the way I do ……

*With apologies to T.T.

nuSTORM: Siting

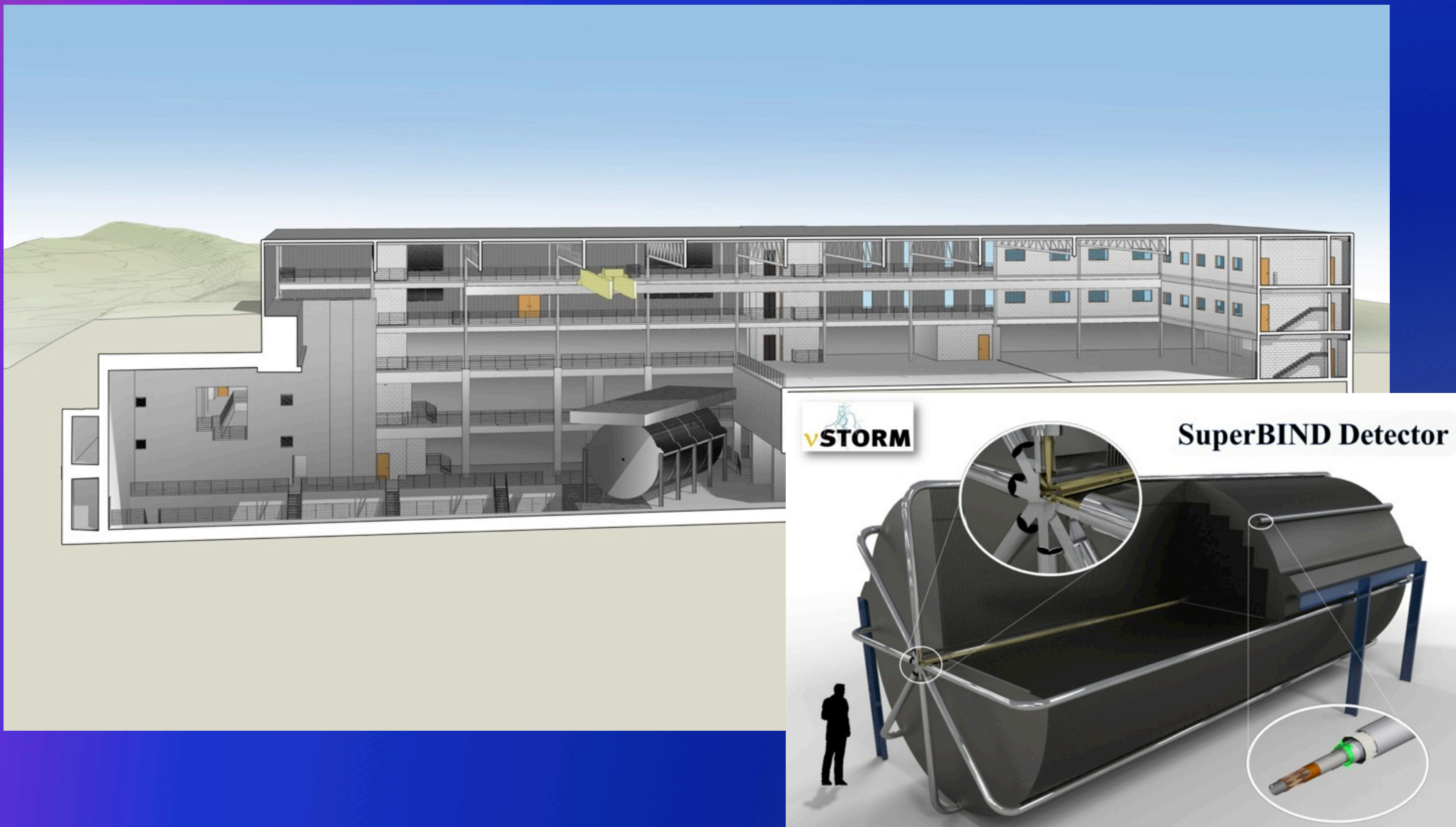
Scope: nuSTORM Facility near site



μ decay ring: P = 3.8 GeV/c ± 10%

vSTORM

Scope: Far site – D0 Assembly Building



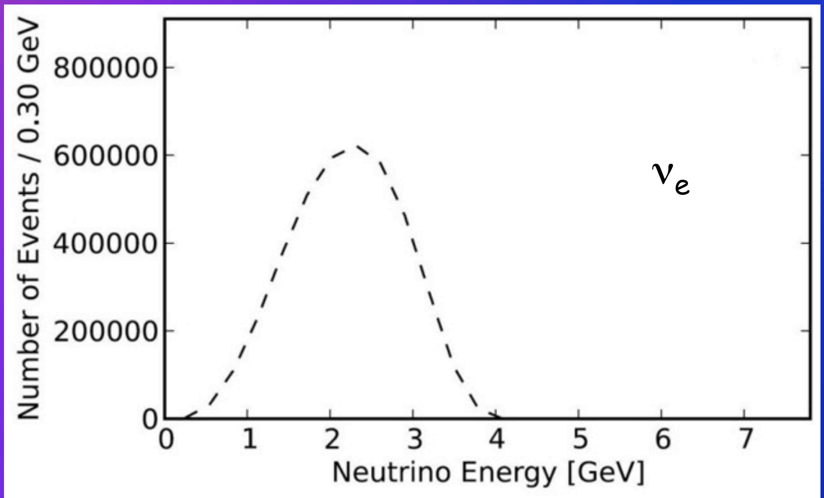
nuSTORM Physics program

- Addresses the SBL, large δm^2 ν-oscillation regime
- Provides a beam for precision ν interaction physics (GeV-scale high-statistics ν_e & anti-ν_e data for the First Time)
  - Approach 0.1% uncertainty on flux & spectrum
- Accelerator & Detector technology test bed
  - Potential for intense low energy muon beam
  - Provides for μ decay ring R&D (instrumentation) & technology demonstration platform
  - Provides a ν Detector Test Facility

ν flux

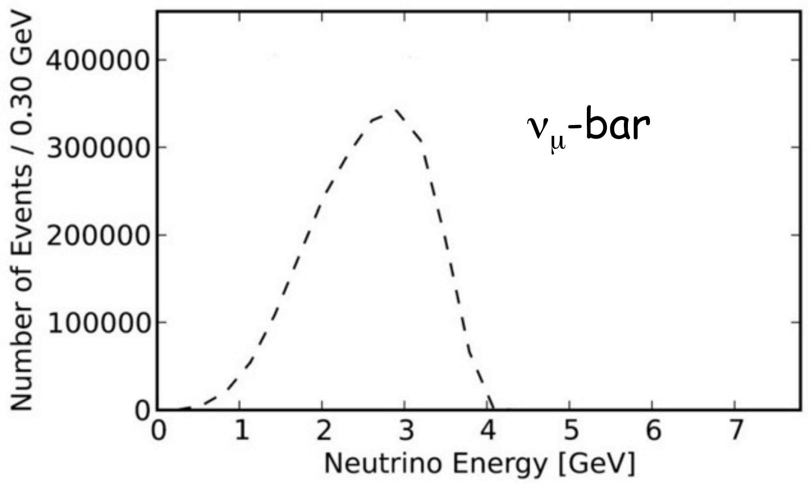
- Based on 10^{21} 120 GeV POT, we obtain ≈ 1.9×10^{18} useful μ decays
  - In PIP era, extract one Booster batch/ cycle (10^{20} POT/yr → 10 year run)
  - Baseline FODO ring, C target, NUMI style 1 horn
- Inconel target + horn optimization + RFFAG → X5 (2 year run)

E_ν spectra (3.8 GeV/c μ^+ stored)



Event rates/100T
at ND hall 50m
from straight with
μ^+ stored
for
10^{21} POT exposure

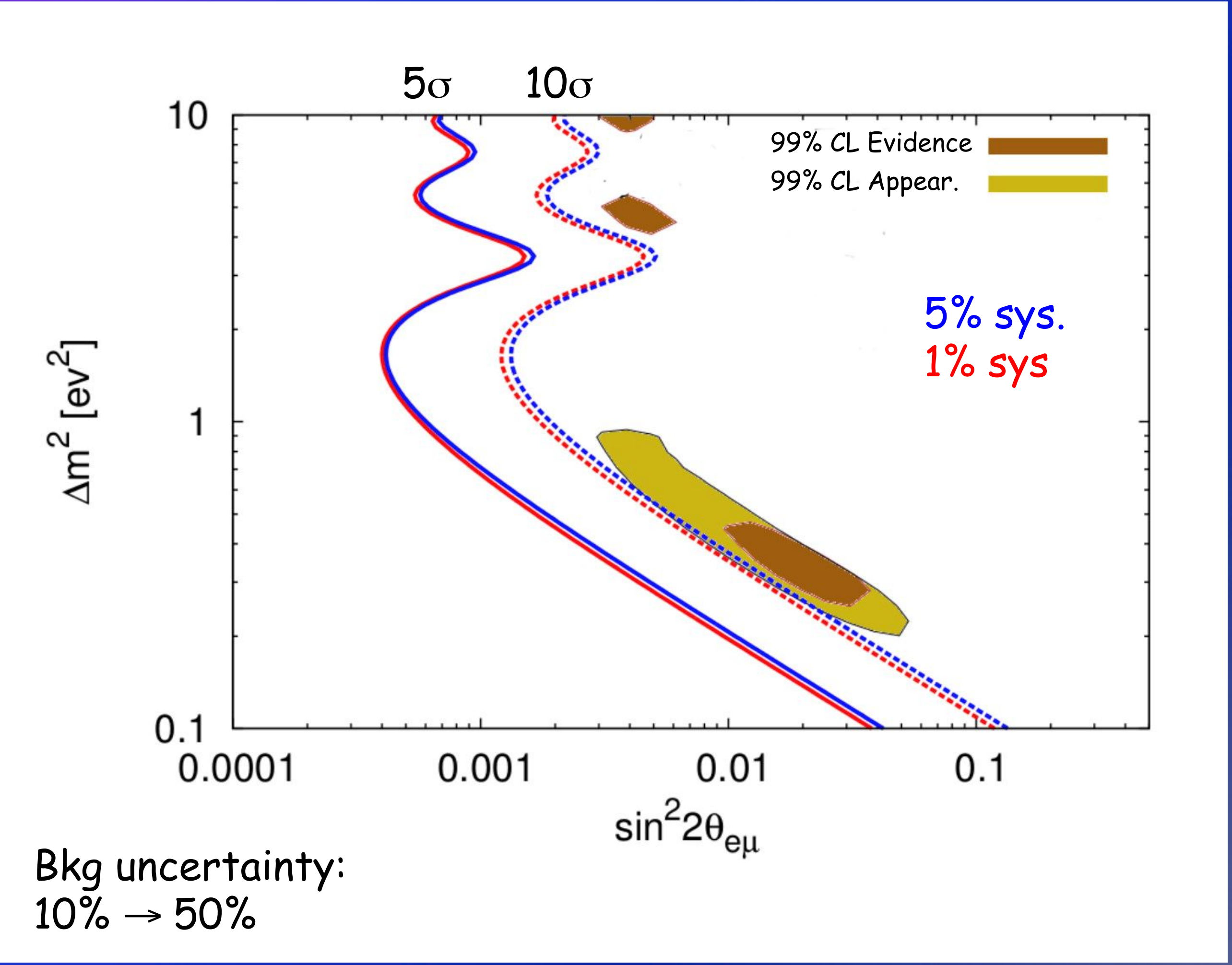
Channel	N_{evts}
$\bar{\nu}_\mu$ NC	844,793
ν_e NC	1,387,698
$\bar{\nu}_\mu$ CC	2,145,632
ν_e CC	3,960,421



Event rates at Far detector

Channel	$N_{osc.}$	N_{null}	Diff.	$(N_{osc.} - N_{null})/\sqrt{N_{null}}$
$\nu_e \to \nu_\mu$ CC	332	0	∞	∞
$\bar{\nu}_\mu \to \bar{\nu}_\mu$ NC	47679	50073	-4.8%	-10.7
$\nu_e \to \nu_e$ NC	73941	78805	-6.2%	-17.3
$\bar{\nu}_\mu \to \bar{\nu}_\mu$ CC	122322	128433	-4.8%	-17.1
$\nu_e \to \nu_e$ CC	216657	230766	-6.1%	-29.4

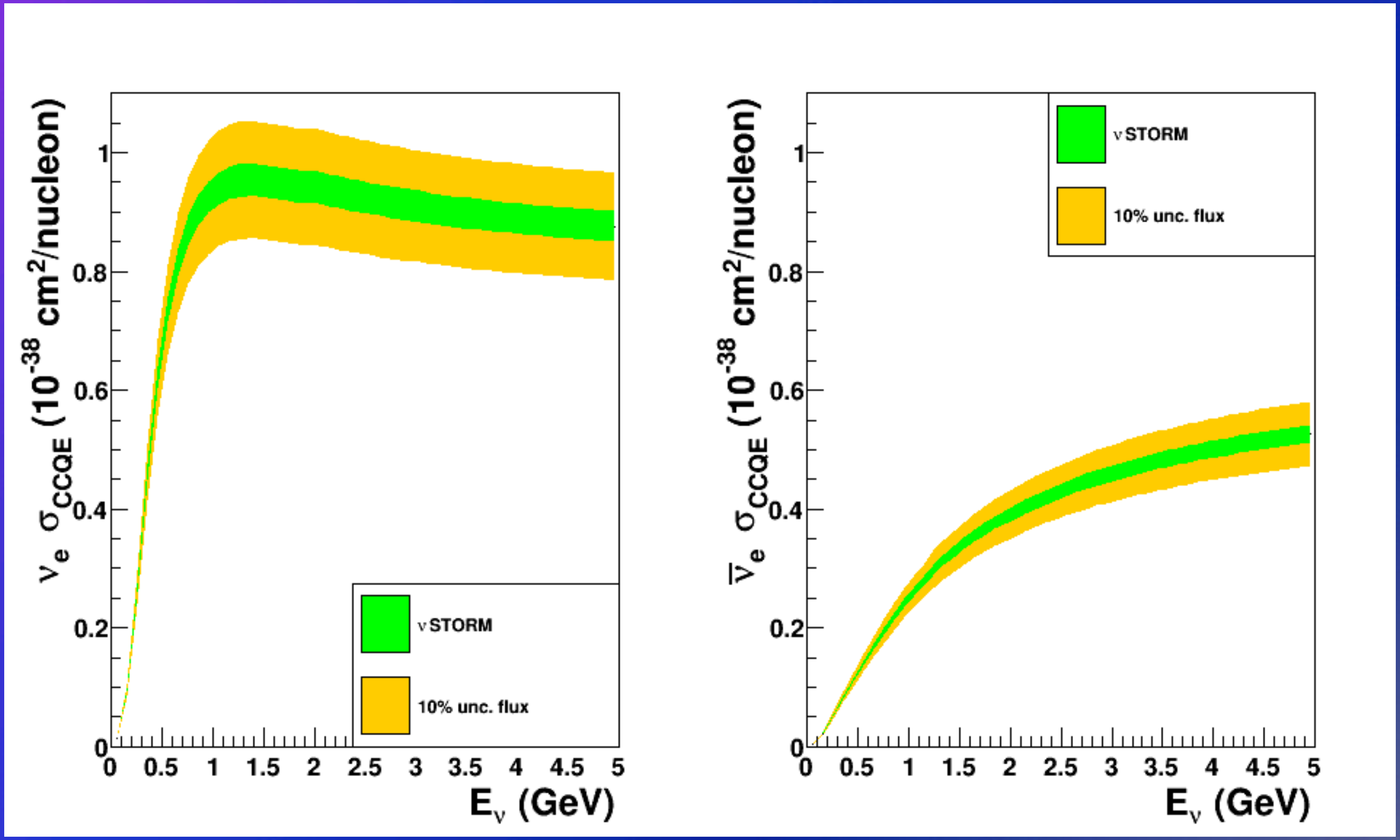
Appearance: Exclusion contours $\nu_e \rightarrow \nu_\mu$ (CPT invariant mode of LSND)



Global fit from: J. Kopp, P. A. N. Machado, M. Maltoni, and T. Schwetz, 392 JHEP 1305, 050 (2013)

Cross section measurements - ν_e

μ^-

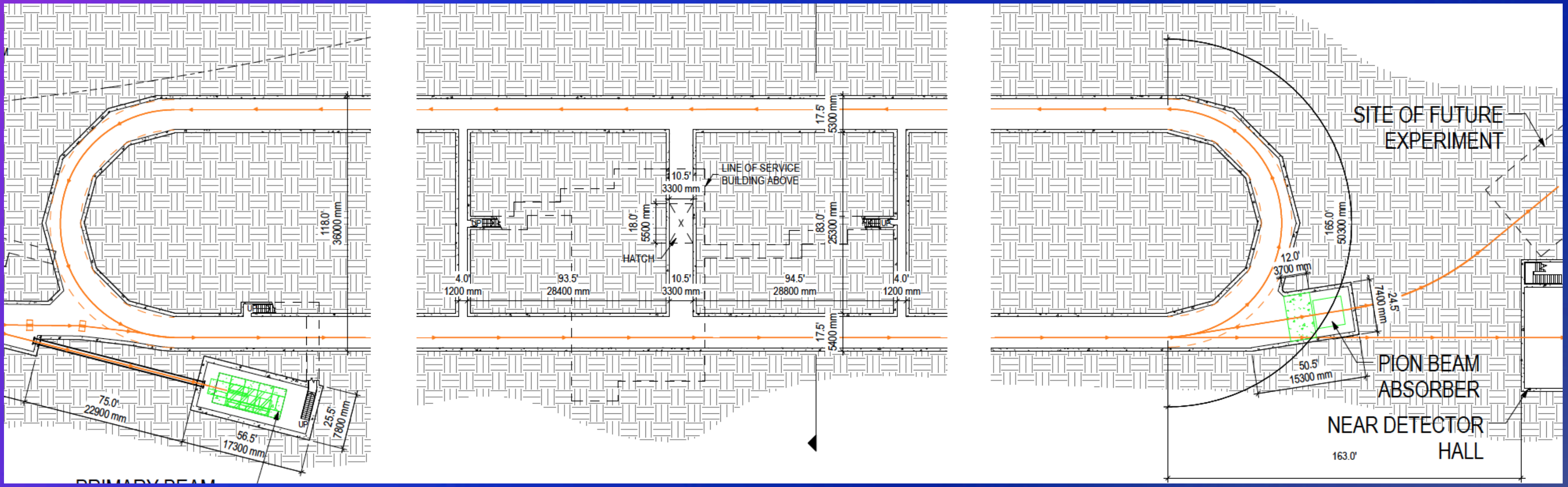


μ^+

The search for CP in LBL expts. counts ν_e and anti-ν_e events (flux X xsection)

Note: not shown here ν_e (200 evts) and ν_e-bar (60 evts) inclusive xsection data (1978)

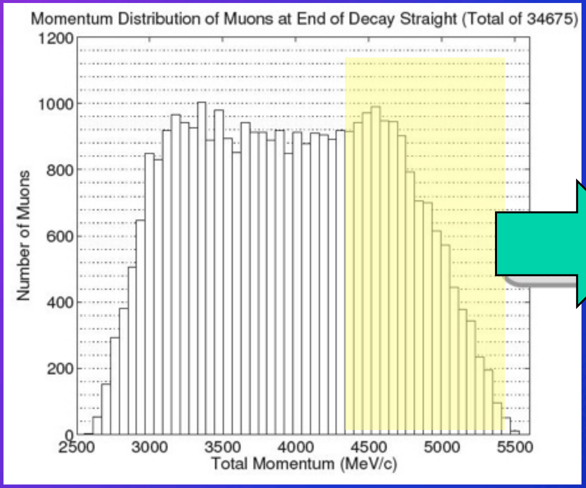
nuSTORM
Setting the stage for the next step

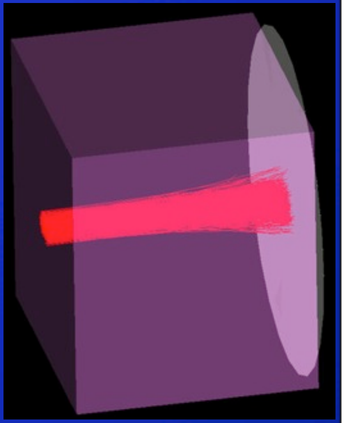


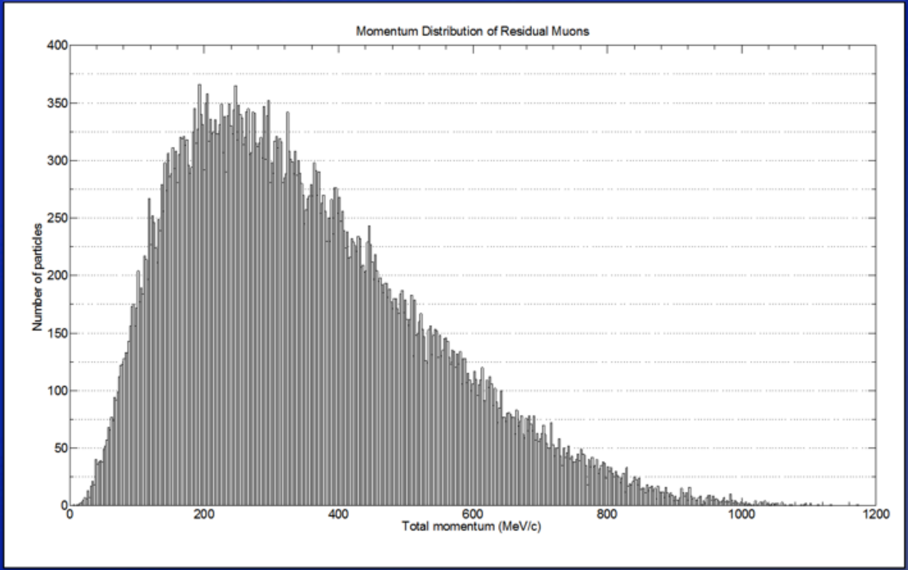
Capture and inject πs with P=5 GeV/c ± 10%
Only ~50% of πs decay in straight
Need π absorber

Note: injection produces a ν_μ "flash" from $\pi \rightarrow \mu\nu_\mu$ decay
= integrated flux of the neutrinos from μ decay

Low Energy μ beam







At end of straight we have a lot of πs, but also a lot of μs with 4.5 < P(GeV/c) < 5.5

After 3.48m Fe, we have ≈ 10^{10} μ/pulse in 100 < P(MeV/c) < 300

P5 Question 1

- *What makes nuSTORM unique, and how does fit in the overall picture of this area?*

νSTORM

What makes nuSTORM unique

The Physics:

- Can confirm/exclude at 10σ (CPT invariant channel) the LSND/ MiniBooNE result
  - Only experiment that has access to appearance & disappearance for both ν_μ and ν_e, neutrino and anti-neutrino
- ν interaction physics studies with near detector(s) offer a unique opportunity & can be extended to cover $0.2 < E_\nu(\text{GeV}) < 4$
  - Could be "*transformational*" w/r to ν interaction physics
    - Unique opportunities for ν_e interaction studies
  - For this physics, nuSTORM should really be thought of as a facility: A ν "*light-source*" is a good analogy
    - nuSTORM provides the beam & users will bring their detector to the near hall

What makes nuSTORM unique II

The Facility:

- Although it only needs very manageable extrapolations from existing technology
  - It can explore new ideas regarding beam optics and instrumentation
- Offers opportunities for extensions
  - Add RF for bunching/acceleration/phase space manipulation
  - Provide μ source for 6D cooling experiment with intense pulsed beam

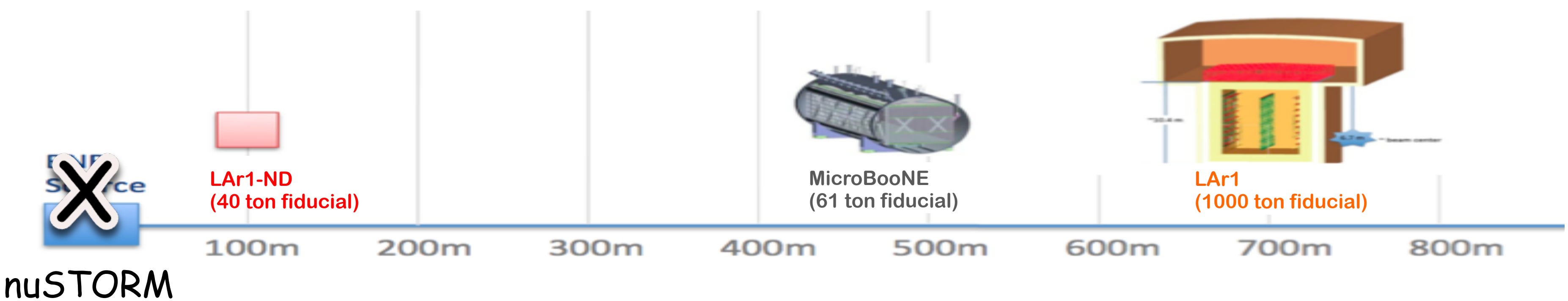
Three Pillars of nuSTORM

- Delivers on the physics for the study of sterile ν
  - *"Prepare for discovery, have a plan for machines that can exploit it."* nuSTORM is preeminent in this regard w/r to sterile neutrinos
  - Offers a new approach to the production of ν beams setting a 10σ benchmark to make definitive statement w/r LSND/ MiniBooNE
    - Only facility that can do appearance & disappearance for ν and anti-ν
- Can add significantly to our knowledge of ν interactions, particularly for ν_e
  - ν *"Light Source"*
- Provides an accelerator science test facility

BUT, we have new hurdles to overcome

- New Administration
  - "Need relevant SBL program"
    - Also, ν interaction physics will be done @ LBNE
  - "Frontier" muon facilities in the far distant future
  - *"Costing not believable"*

LAr1-ND:
Testing Neutrino Anomalies with Multiple LArTPC Detectors at Fermilab

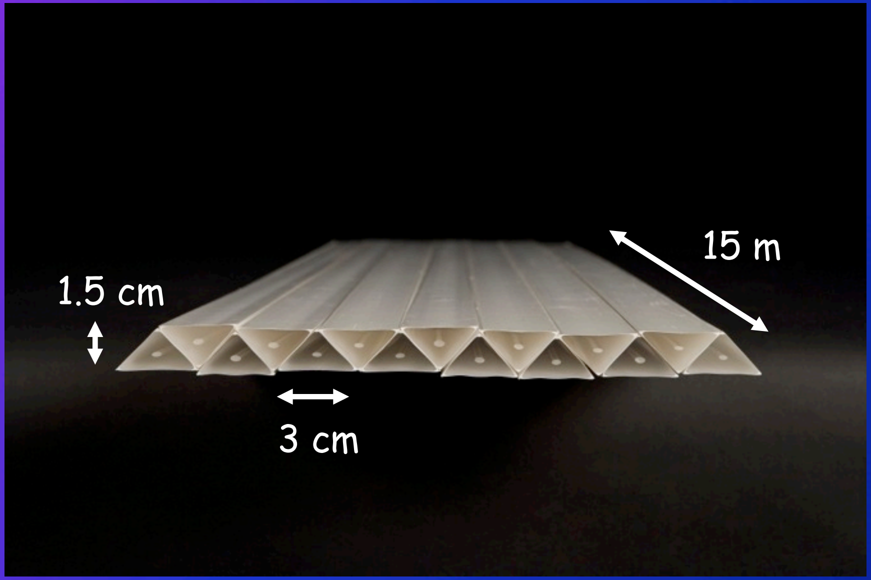


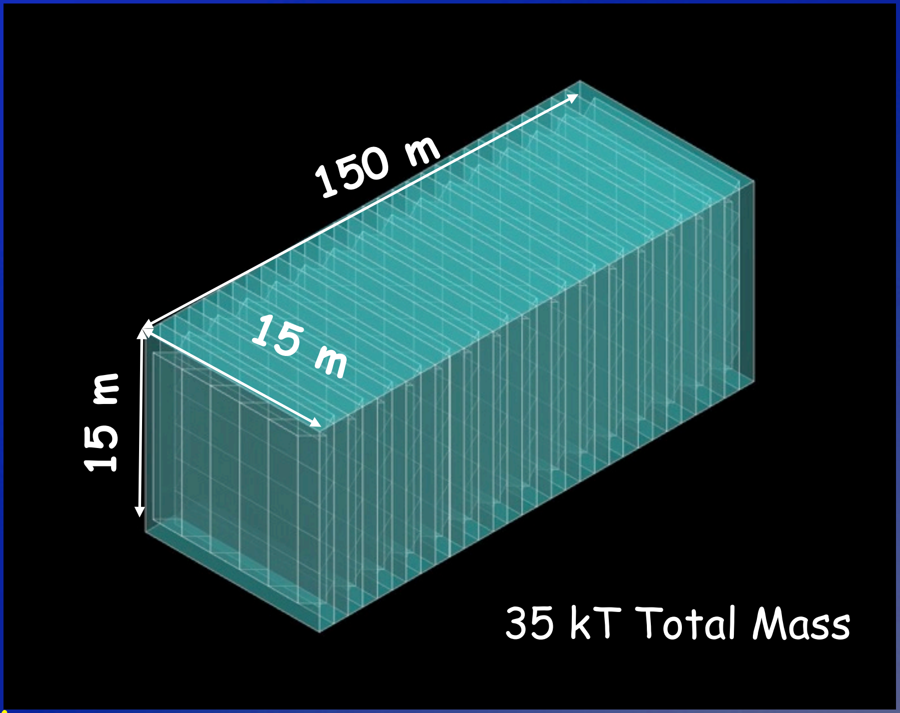
Contact: *B. Fleming, Yale University*
O. Palamara, Yale University
D. Schmitz, University of Chicago

Fine-Resolution Totally Active Segmented Detector (IDS-NF)

Simulation of a Totally Active Scintillating Detector (TASD) using Nova and Minerva concepts with Geant4

- 3333 Modules (X and Y plane)
- Each plane contains 1000 slabs
- Total: 6.7M channels



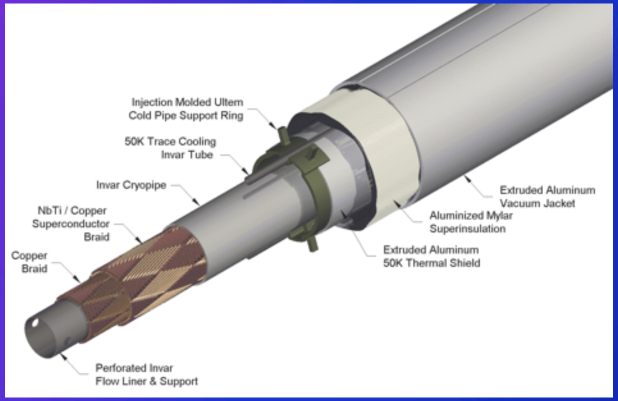


- **Momenta between 100 MeV/c to 15 GeV/c**
- **Magnetic field considered: 0.5 T**
- **Reconstructed position resolution ~ 4.5 mm**

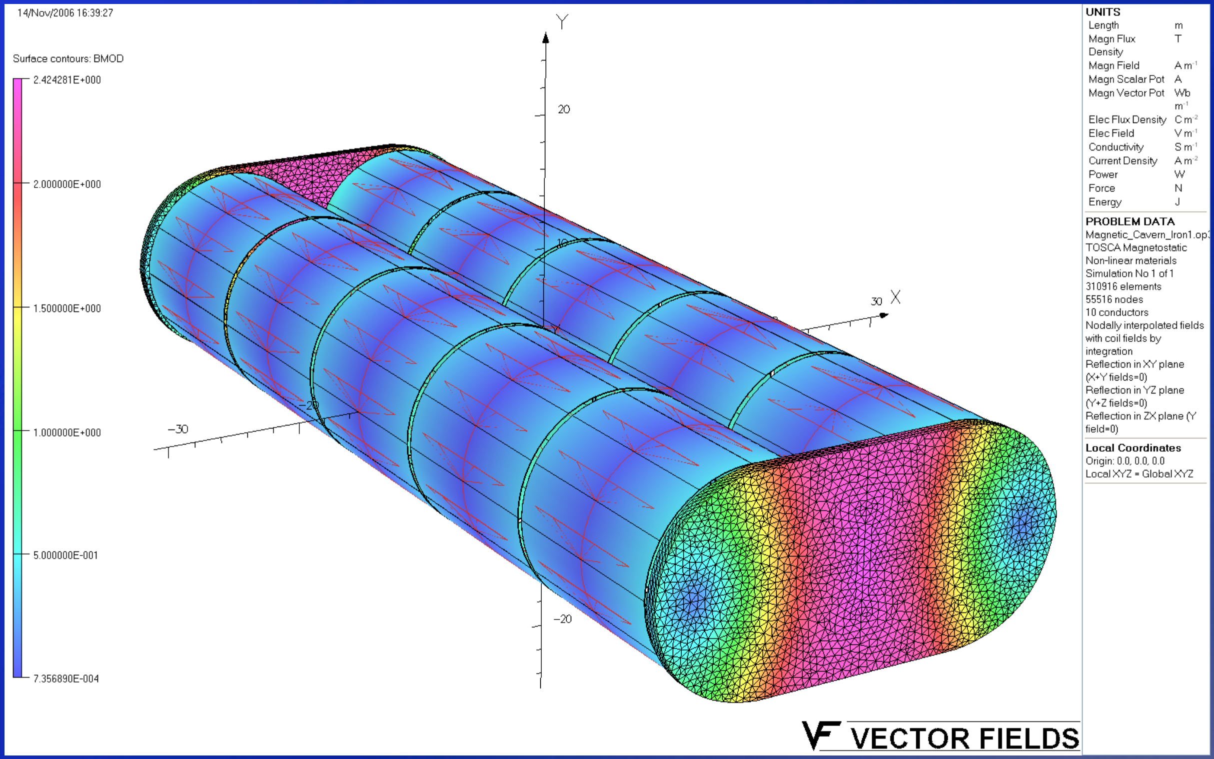
B = 0.5T

Magnet- Concept for IDS-NF

- VLHC SC Transmission Line
  - Technically proven
  - Affordable



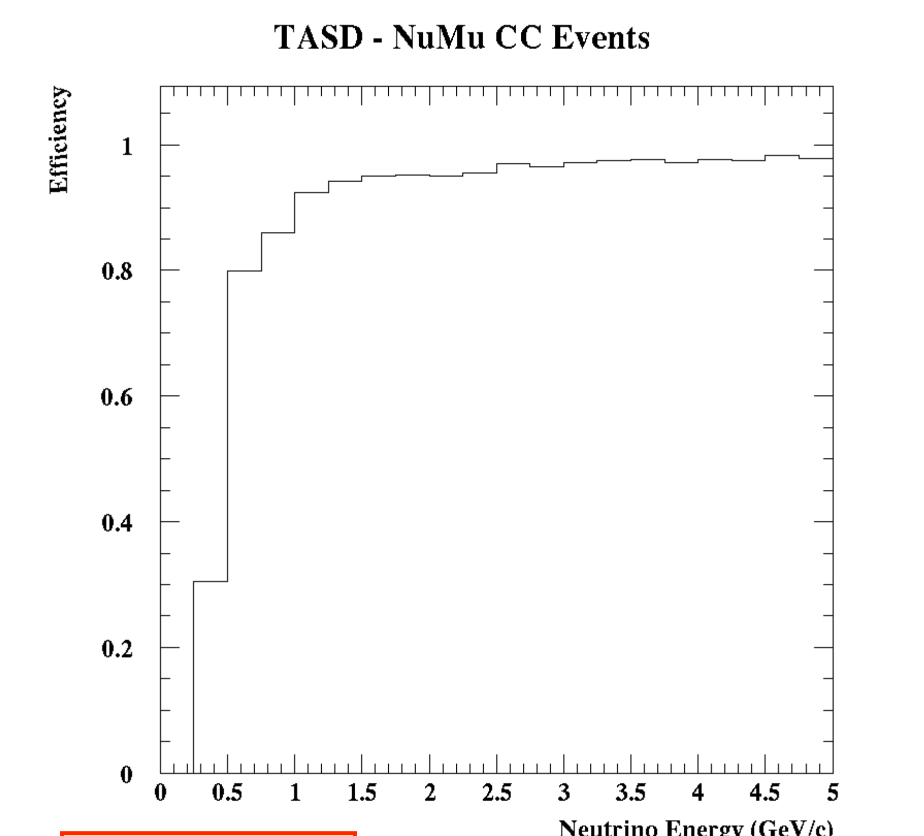
R&D to support concept
Has not been funded



1 m iron wall thickness.
~2.4 T peak field in the iron.
Good field uniformity

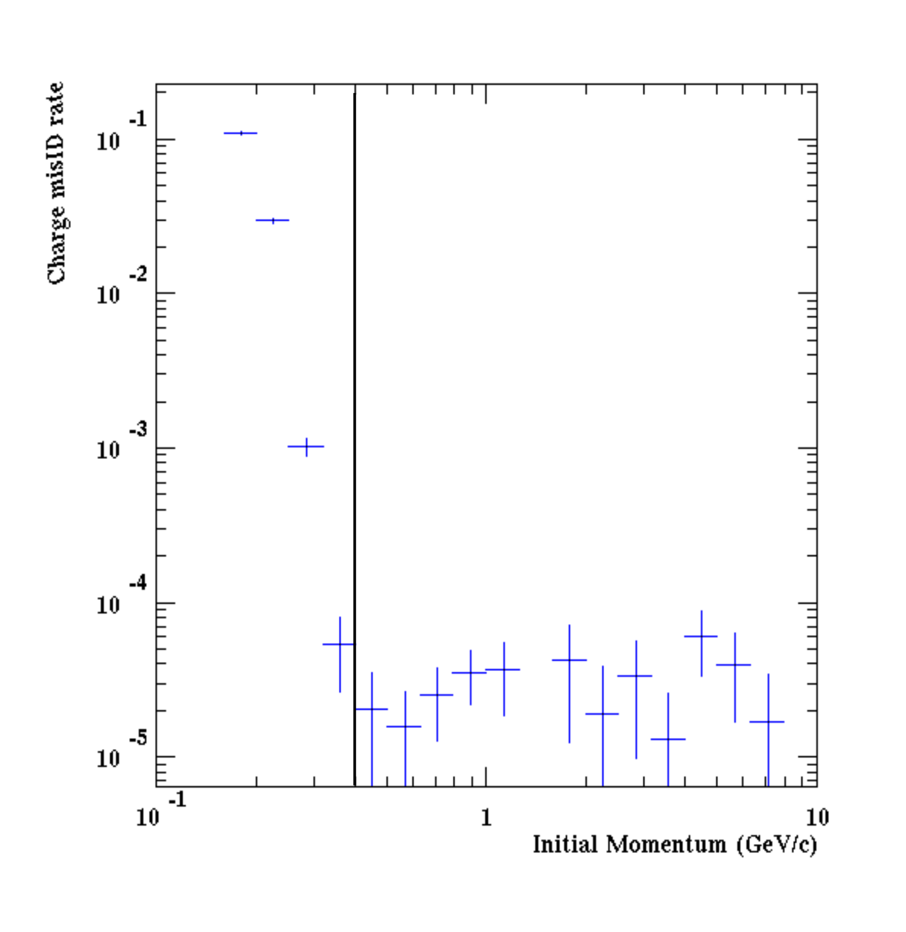
TASD Performance

ν Event Reconstruction ε



Excellent σ_E

Muon charge mis-ID rate



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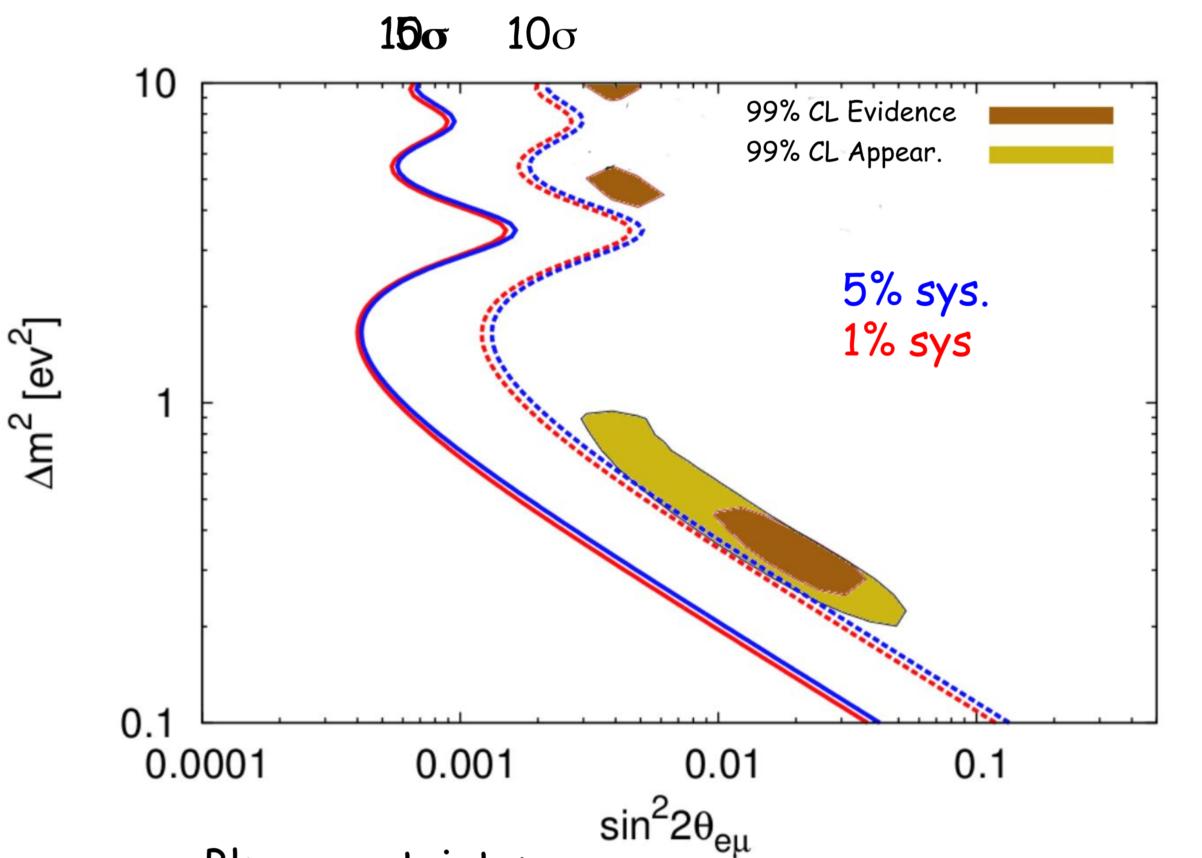

Bkg uncertainty:
10% → 50%

Integrated recon. Eff:
17% -> 80+%
SuperBIND -> MLAr

Global fit from: J. Kopp, P. A. N. Machado, M. Maltoni, and T. Schwetz, 392 JHEP 1305, 050 (2013)

νSTORM

Detector Options

Technology check List

	Fid Volume	B	Recon	Costing Model
SuperBIND	☑ (blue)	☑ (blue)	☑ (blue)	☑ (blue)
Mag-TASD	☑ (blue)	☑ (black)	☑ (blue)	☑ (black)
Mag-LAr	☑ (blue)	☑ (black) -> ☑ (blue)	☑ (black) -> ☑ (blue)	☑ (red) -> ☑ (black)

☑ (blue)	Yes - OK
☑ (black)	Maybe
☑ (red)	Not Yet

Costing

nuSTORM: Total Project Cost

Subsystem	Base cost	Contingency	Cost
Proton beam line	21,143,940	7,356,253	28,500,193
Target Station	26,674,694	11,225,150	37,899,844
Capture/transport	10,811,010	5,681,943	16,492,953
Decay ring	89,248,924	45,956,474	135,205,398
Near detector hall	16,778,572	6,711,429	23,490,001
Far detector hall	1,182,581	650,420	1,833,001
SuperBIND	21,057,070	4,190,528	25,247,598
Site work	17,429,678	9,586,323	27,526,000
CF other	1,804,286	721,714	2,526,000
TOTAL	**206,130,755**	**92,080,233**	**298,210,988**
Management			37,080,186
TPC		**45% contingency**	**335,291,175**

Total contingency – 45%

[1]Near Hall sized for multiple experiments & ND for SBL oscillation physics
[2]1.3kT Far + .2kT Near & include DAB work
[3]Assumes LBNE estimates: Proj. Office (10%), L2 (9.4%), L3 (4%)

νSTORM

Conventional Facilities

			EDIA	Contingency			
WBS	Functional Area	Base Cost	30%	%	$	Indirects	Totals
1.0	Primary Beamline Enclosure	$7,013,000	$2,104,000	40%	$3,647,000	$1,266,000	$14,030,000
2.0	Target Station	$8,993,000	$2,698,000	55%	$6,430,000	$1,662,000	$19,783,000
3.0	Transport Line Enclosure	$1,883,000	$565,000	60%	$1,469,000	$504,000	$4,421,000
4.0	Muon Decay Ring Enclosure	$26,002,000	$7,801,000	60%	$20,282,000	$4,215,000	$58,300,000
5.0	Near Detector	$11,750,000	$3,525,000	40%	$6,110,000	$1,882,000	$23,267,000
6.0	Far Detector	$720,000	$216,000	55%	$515,000	$333,000	$1,784,000
8.0	Site Work	$12,233,000	$3,670,000	55%	$8,747,000	$2,115,000	$26,765,000
	TOTALS	**$68,594,000**	**$20,579,000**		**$47,200,000**	**$11,977,000**	**$148,350,000**

Overall contingency on Base Cost + EDIA – 53%

If you don't believe this, then you should not believe the costs for μ2e or LBNE

LBNE started with approximately 40% contingency on CF -> 25% once drawings done

If 53% is unbelievable, then our "Flagship" is likely to become the Titanic

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Association for the Advancement of Costing Engineering (AACE)

Bob O'Sullivan

Developing the Cost Range

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

LBNE CD-1 Director's Review - 25-27 September 2012 16

Magnets present largest uncertainty. Even if we let contingency go to to 100%, this only adds ~ $25M to the TPC

Moving Forward

- Continue work to generate TDR
- Facility
  - Decay Ring
    - Pursue in parallel FODO and RFFAG
    - But, try to reach "a" solution ASAP in order to accurately determine nuSTORM's ability to determine ν flux (intensity & spectrum)
      - Biggest impact on ν interaction physics program
- Detector (SBL osc physics)
  - Time to move to MLAr?

Too Hard?