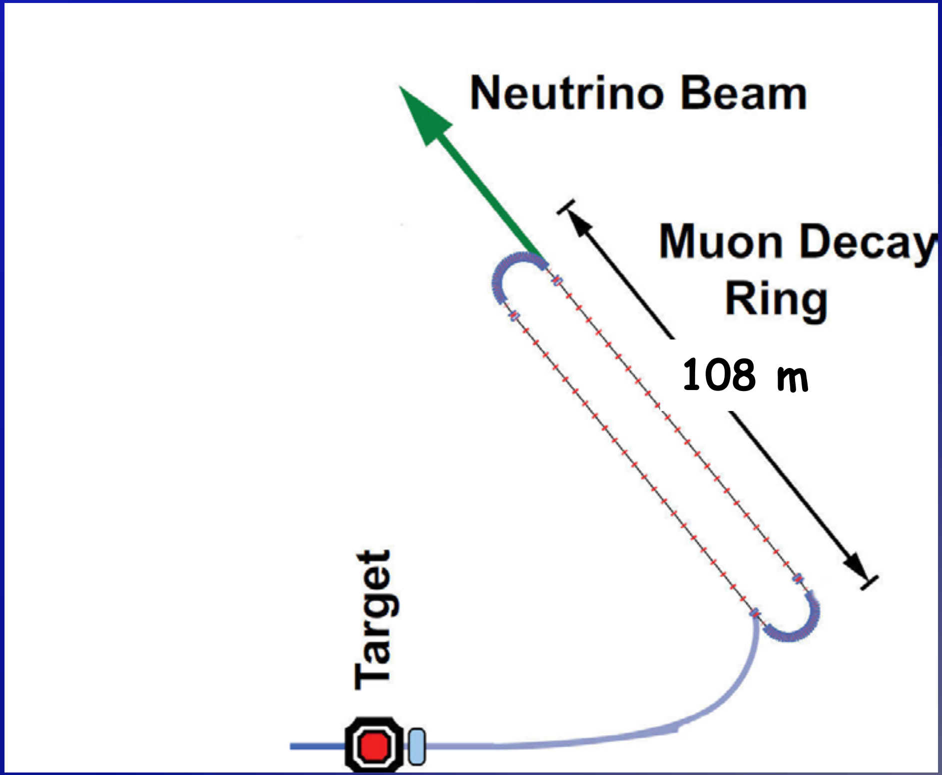
The Very-Low Energy Neutrino Factory (VLENF)

Overview

Fermilab

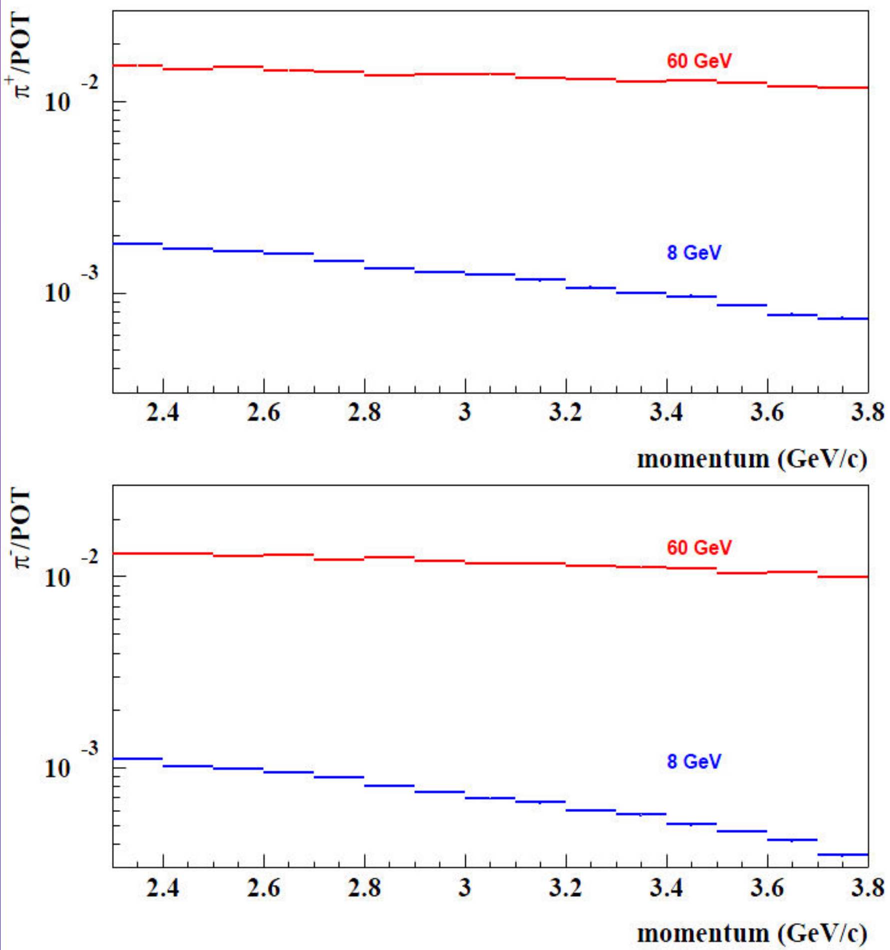
Baseline(s)

- 100 kW Target Station
  - Assume 60 GeV proton
    - Fermilab PIP era
  - Be target
    - Optimization on-going
  - Li Lens or horn collection after target
- Collection/transport channel
  - Two options
    - Stochastic injection of π
    - Kicker with $\pi \rightarrow \mu$ decay channel
    - At present NOT considering simultaneous collection of both signs
- Decay ring
  - Large aperture FODO
  - Racetrack FFAG
  - Instrumentation
    - BCTs, mag-Spec in arc, polarimeter



Sergei Striganov
Fermilab

π production



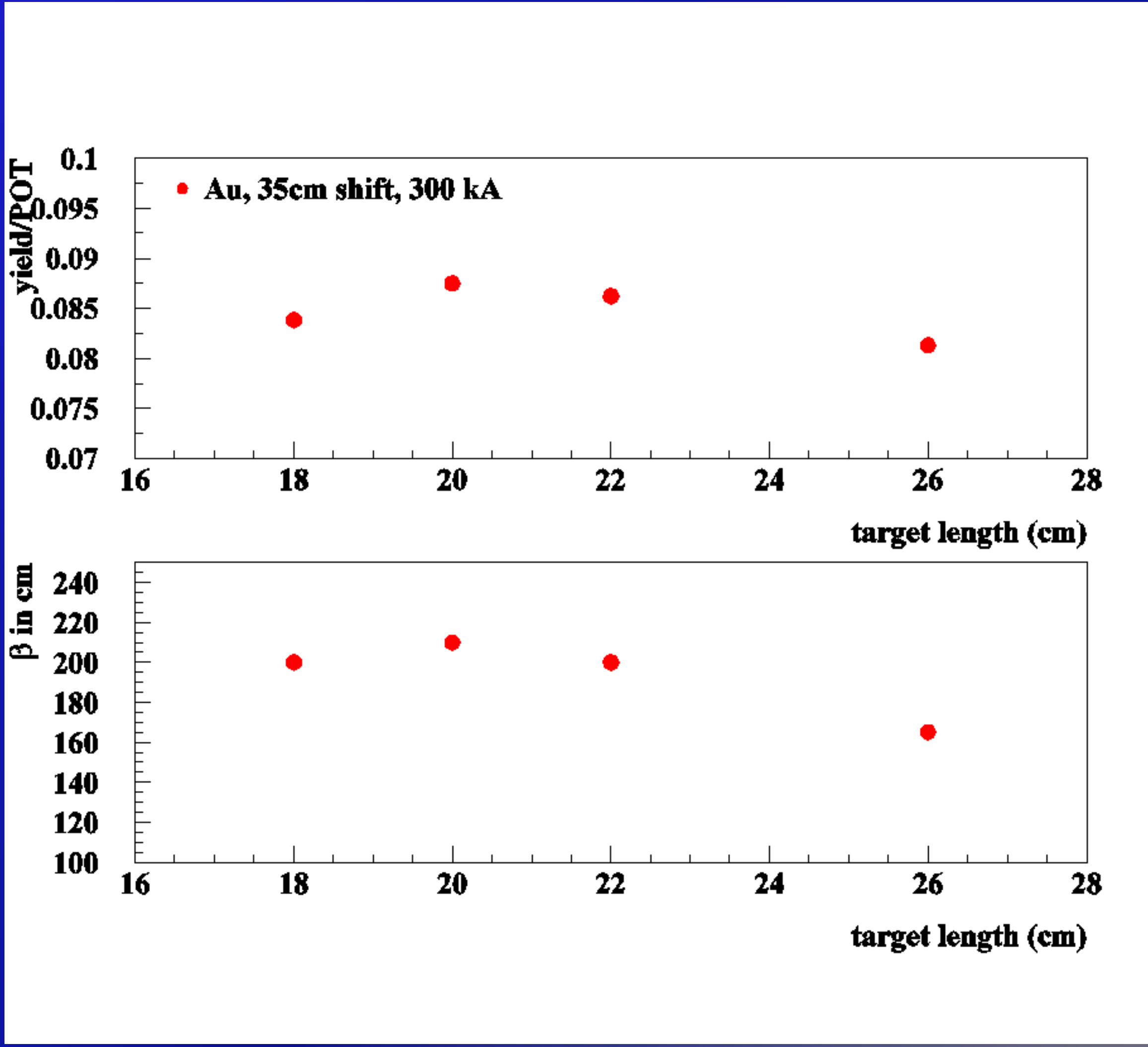
Pion production from 70 cm beryllium target ($\theta < 120$ mrad)

In momentum range
2.7 < 3.0 < 3.3
Obtain
0.11 π^+/pot
0.10 π^-/pot
with 60 GeV p

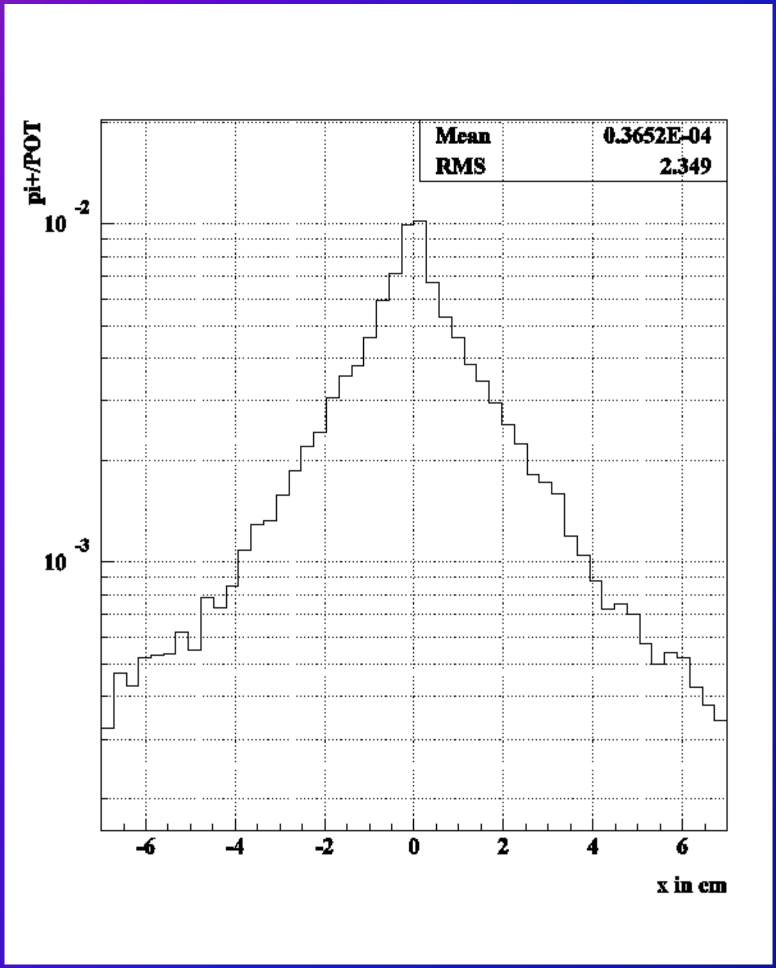
What Fraction of this can we actually accept and transport?

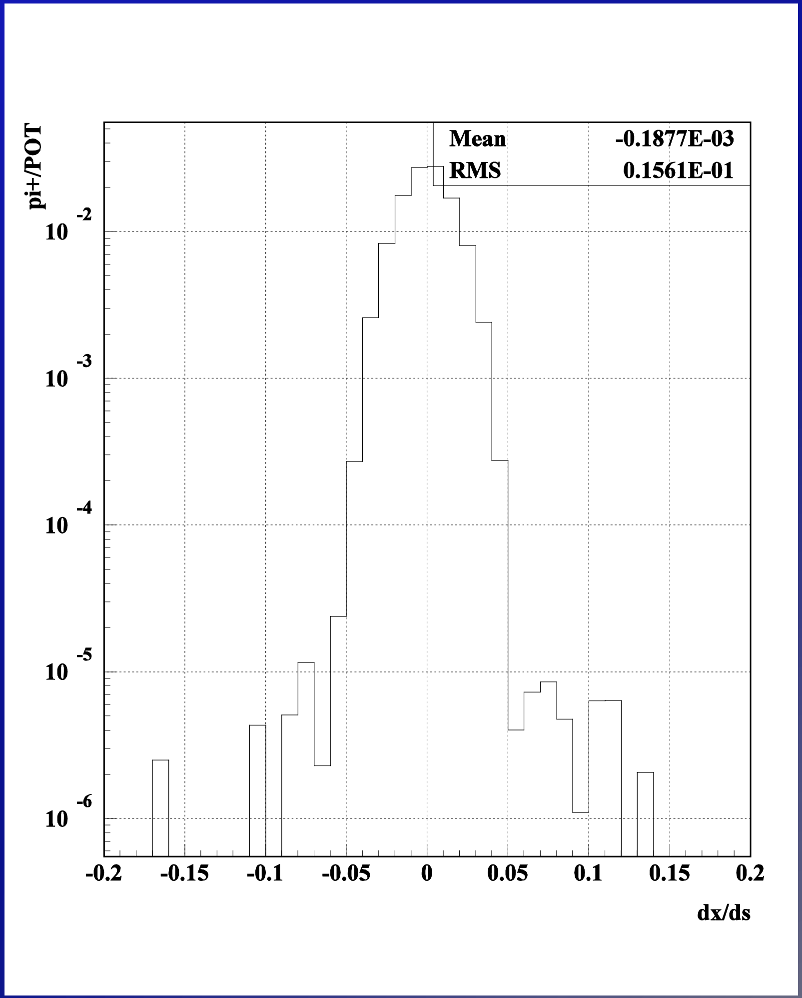
π^+ Yield, $\delta p/p = \pm 0.1$, NuMI horn, 60 GeV

Pion beam size = sqrt(Ɛβ), Ɛ=0.2 cm and β=500 cm => 10 cm radius!



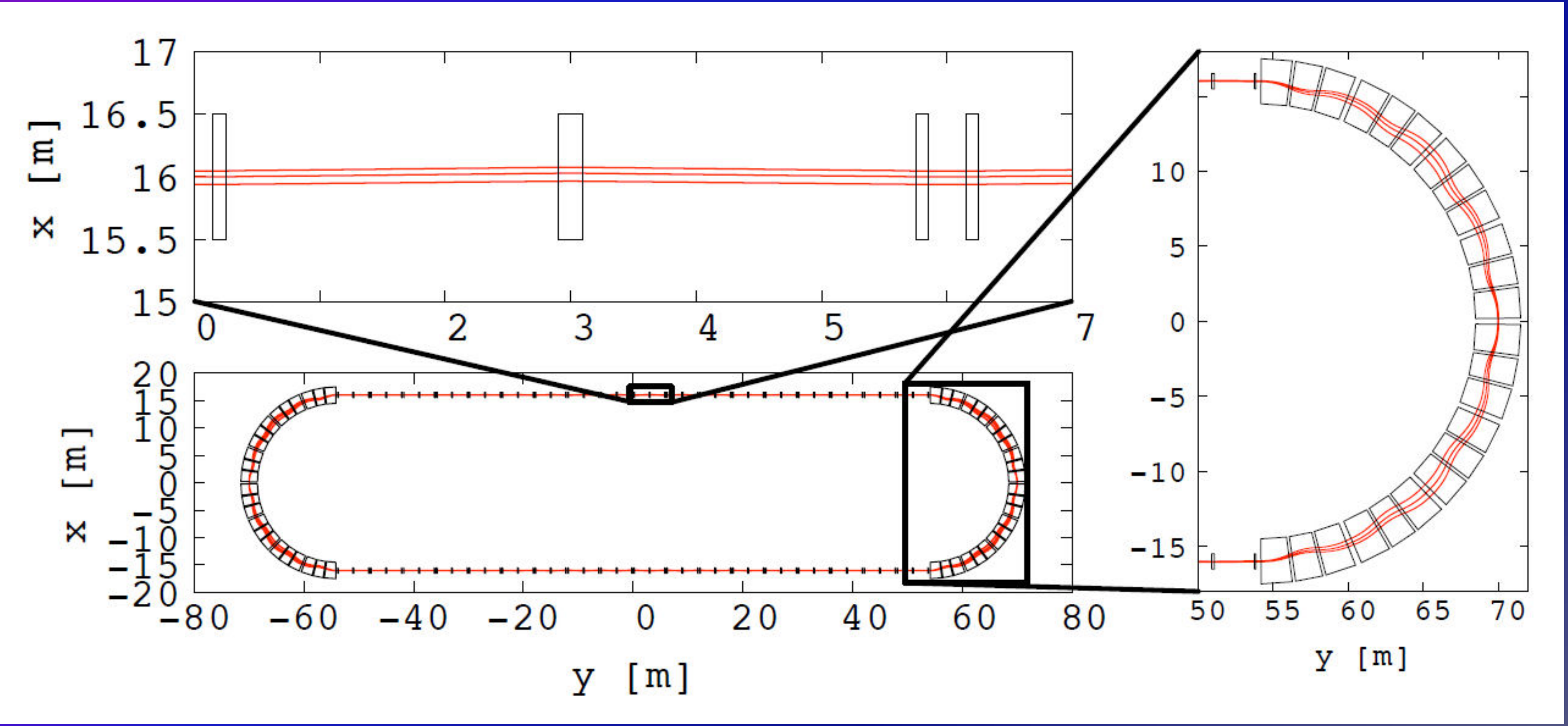
19cm gold target, NuMI horn, 400 kA: 0.087 π^+ $\delta p/p=\pm 0.1$ in 2mm rad acceptance after horn





Lagrange & Mori
Kyoto

FFAG Racetrack



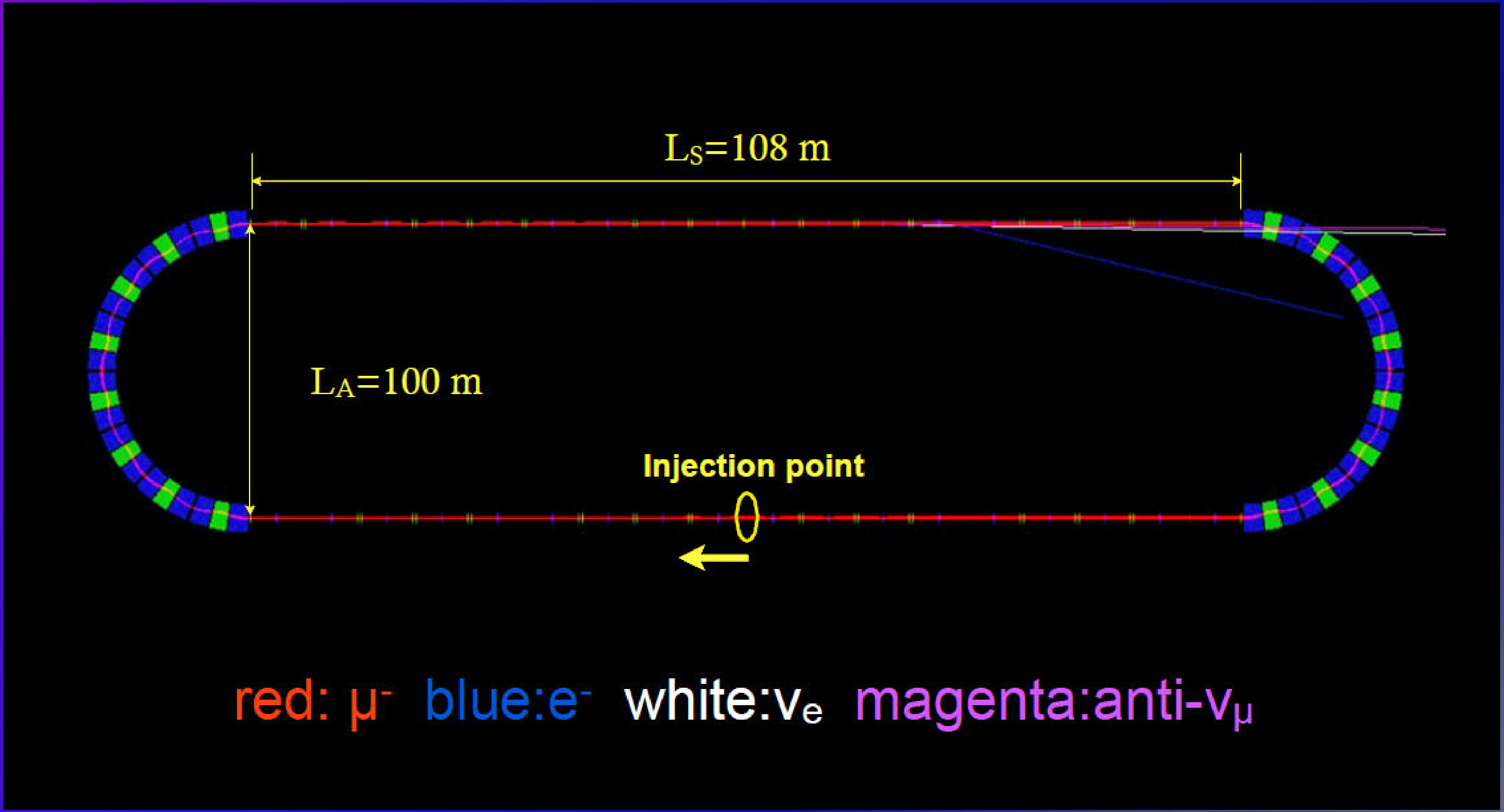
$\delta p/p \approx 15\%$

acc-kurri – 1119-01-2011

Low dispersion in straight

2 GeV/c

RFFAG Tracking Studies



Akira Sato
Osaka University

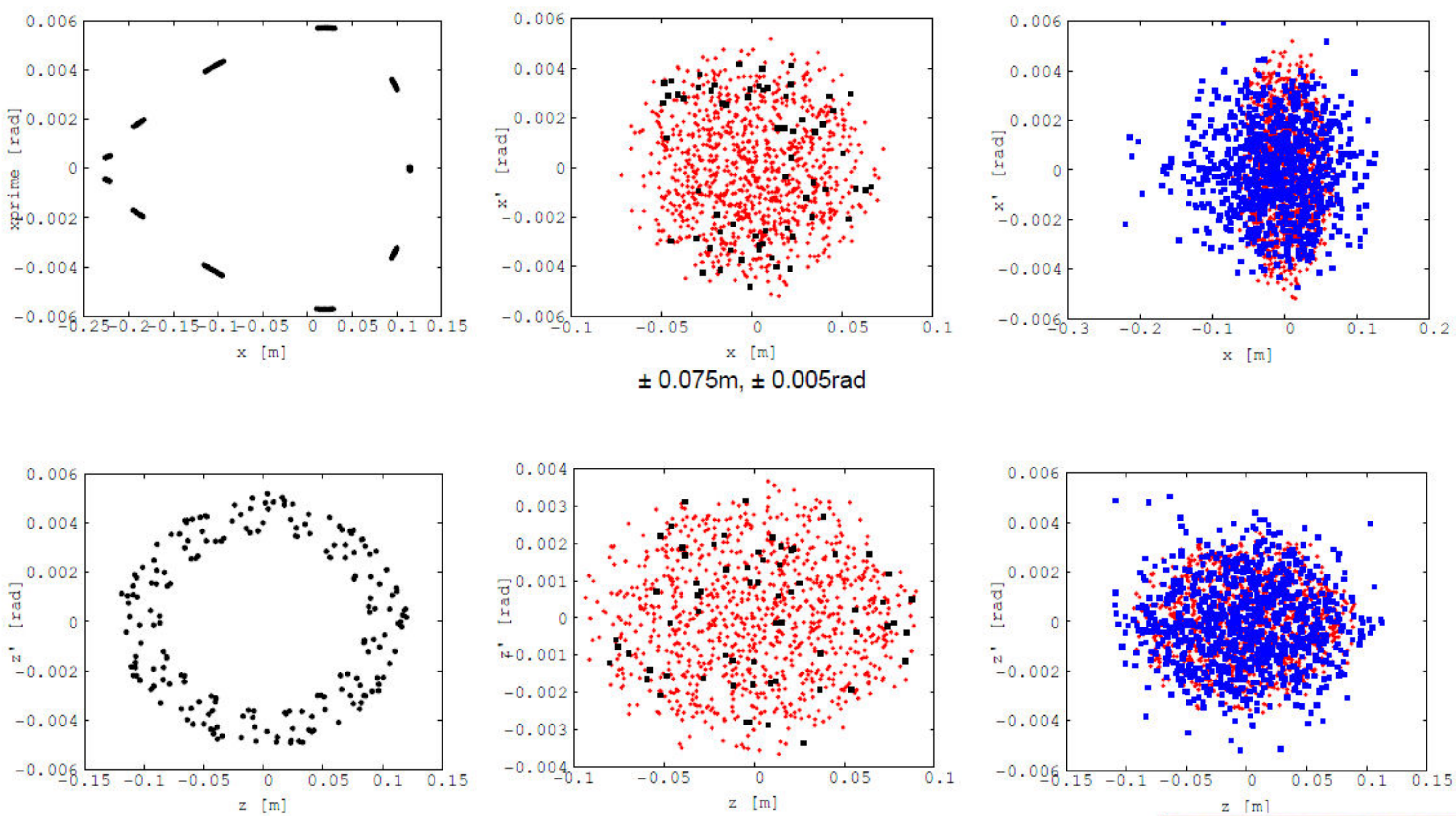
FFAG Tracking

Muon Accelerator Program

Max amplitude 100 turns for p_0

Initial phase: Red
($\varepsilon_{unnormalized}$ ~ 400π mm mrad)

After 100 turns: Blue



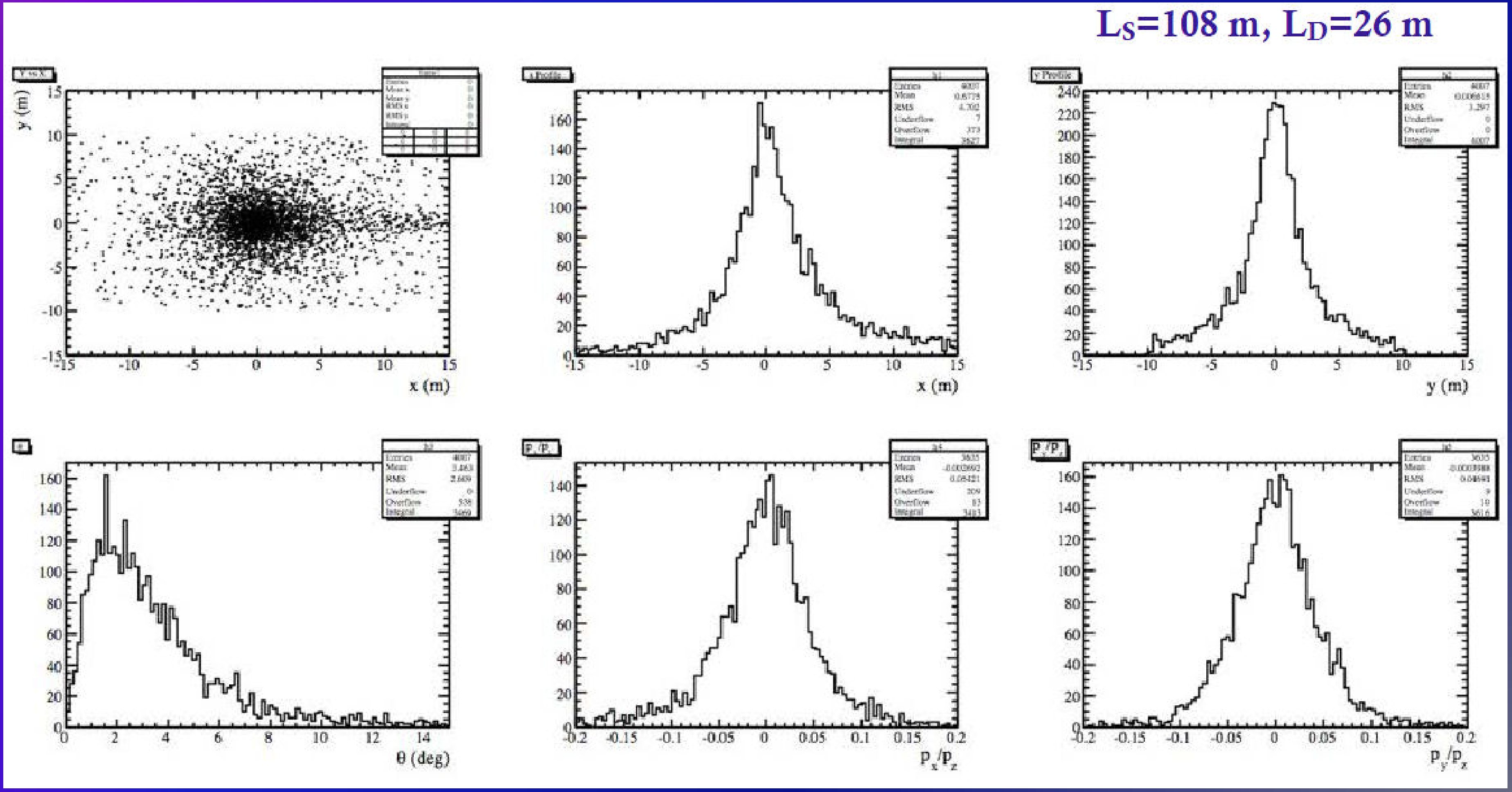
± 0.075m, ± 0.005rad

± 0.090m, ± 0.035rad

from JB. Lagrange, acc-kurri-1119-01-2011

>90% dynamic aperture

G4Beamline Simulation Output
ν beam at monitor detector at L_D=26m



Flux

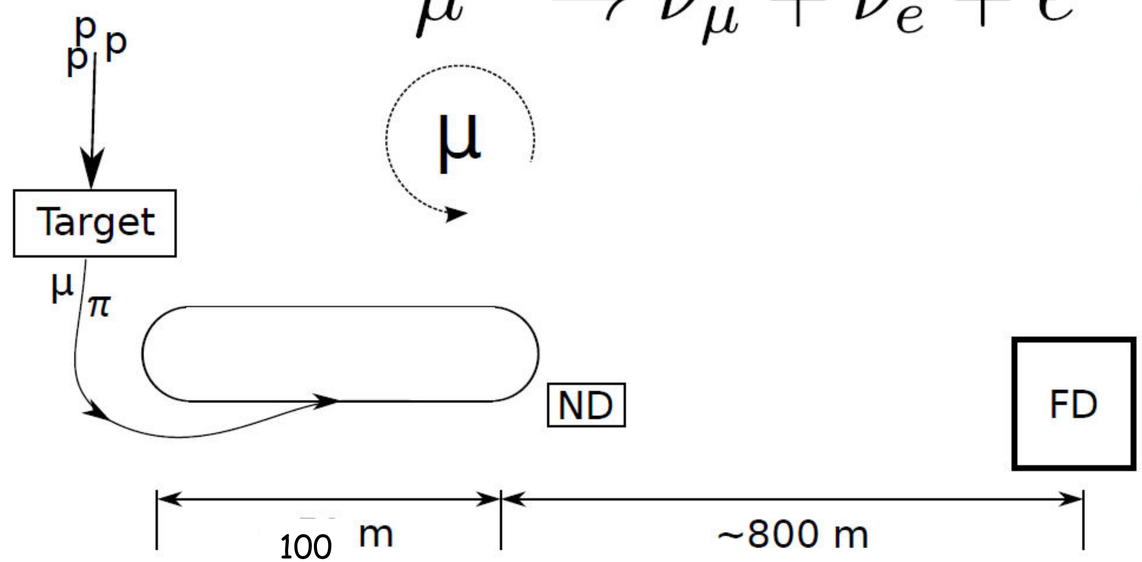
Muons, more Muons & more Muons

Assumptions

- N_μ = (POT) X (π/POT) X $\varepsilon_{collection}$ X ε_{inj} X (μ/π) X $A_{dynamic}$ X Ω
  - 10^{21} POT in 5 years of running @ 60 GeV in Fermilab PIP era
  - 0.1 π/POT
  - $\varepsilon_{collection} = 0.9$
  - $\varepsilon_{inj} = 0.9$
  - $\mu/\pi = 0.08$ (γct X μ capture in $\pi \rightarrow \mu$ decay) [π decay in straight]
    - Might do better with a $\pi \rightarrow \mu$ decay channel
  - $A_{dynamic} = 0.9$ (from G4Beamline simulation)
  - Ω = Straight/circumference ratio (0.34)
- This yield 2 X 10^{18} useful μ decays

Experimental Layout

$$\mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + e^+$$



Appearance-only (though disappearance good too!)

$$Pr[e \rightarrow \mu] = 4|U_{e4}|^2|U_{\mu 4}|^2 \sin^2(\frac{\Delta m^2_{41} L}{4E})$$

Appearance Channel:

$\nu_e \rightarrow \nu_\mu$

Golden Channel

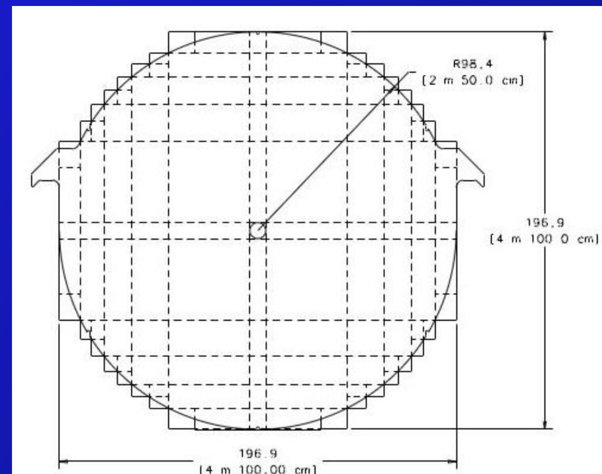
Must reject the "wrong" sign μ with great efficiency

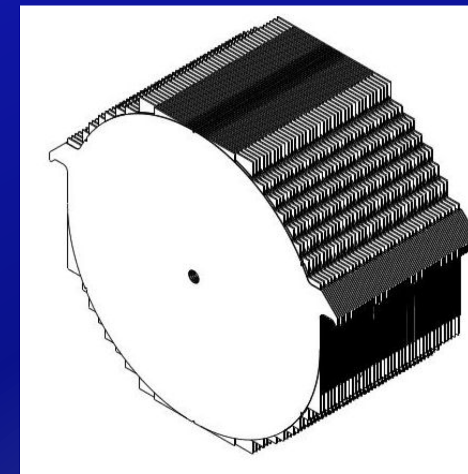
Why $\nu_\mu \rightarrow \nu_e$ Appearance Ch. not possible

Baseline Detector

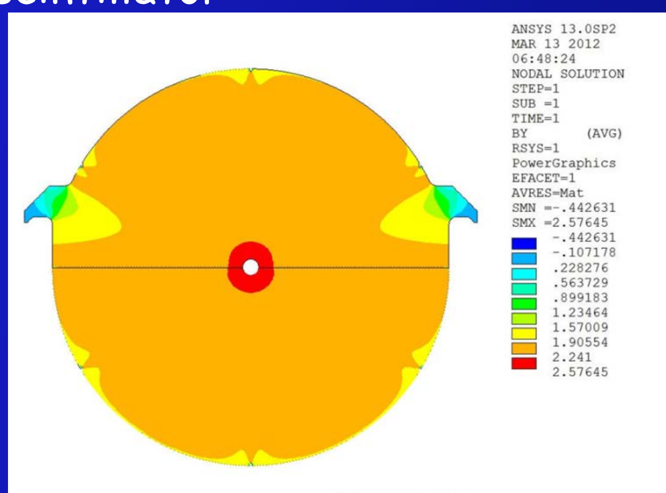
Super B Iron Neutrino Detector: SuperBIND

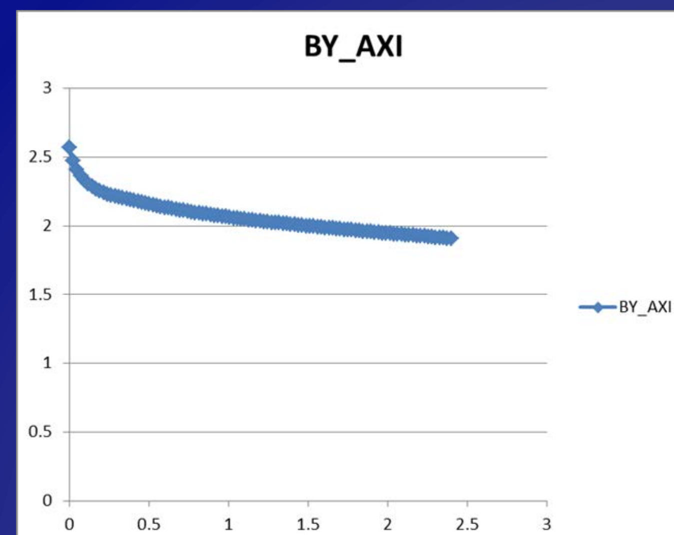
- Magnetized Iron
  - 1 kT fiducial volume
    - Following MINOS ND ME design
    - 1 cm Fe plate
    - 5 m diameter
  - Utilize superconducting transmission line for excitation
    - Developed 10 years ago for VLHC
  - Extruded scintillator +SiPM

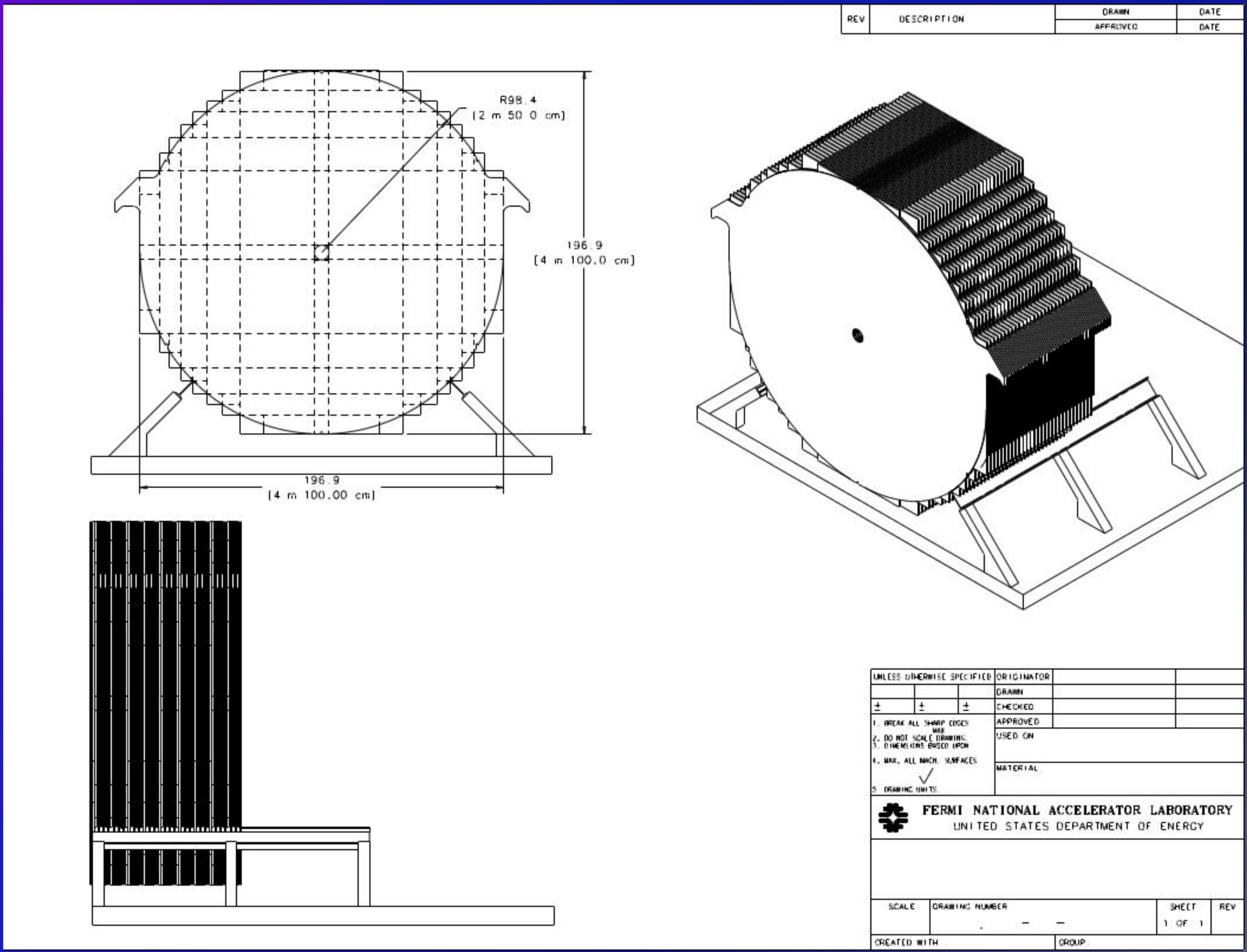




20 cm hole
For 3 turns
of STL






REV
DESCRIPTION
DRAWN
APPROVED
DATE
DATE
R98.4
[2 m 50.0 cm]
196.9
[4 m 100.0 cm]
196.9
[4 m 100.00 cm]
UNLESS OTHERWISE SPECIFIED
ORIGINATOR
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USED ON
MATERIAL
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
SCALE
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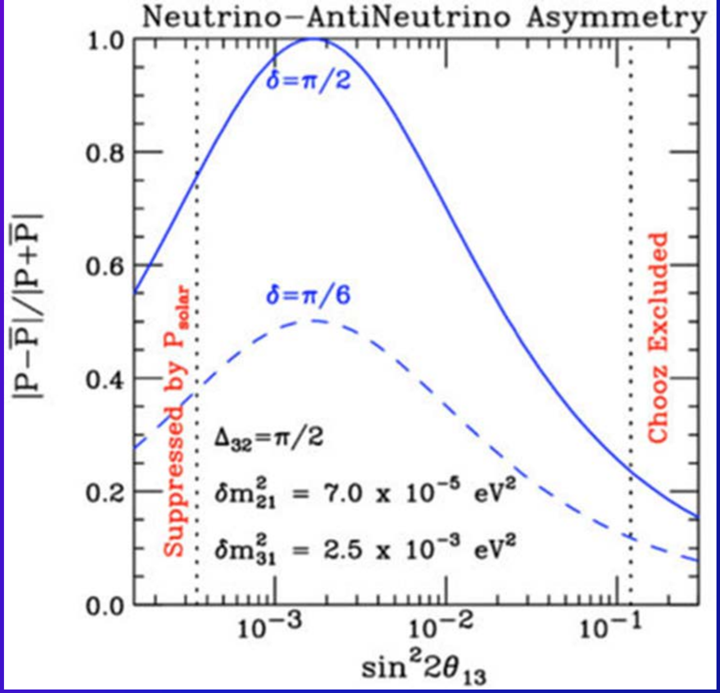
1 OF 1
CREATED WITH
GROUP

Cross-Section Measurements & Disappearance Searches

ν Cross-section measurements

- Cross-section measurements
  - μ storage ring presents only way to measure ν_μ & ν_e & (ν and $\bar{\nu}$) x-sections in same experiment
    - Supports future long-baseline experiments



$$\frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}$$

- Important to note that with θ_{13} large, the asymmetry you're trying to measure is small, so:
  - Need to know underlying ν/νbar flux & σ more precisely
  - Bkg content & uncertainties start to become more important

ν_e, ν_μ Disappearance Searches *Rates*

- Detector mass – Near & Far
  - 100T Near
  - 1kT Far
- 10^{21} POT exposure (μ^+)
  - Number of ν_e events (CC):
    - $N_{evts\text{-}near} \approx 1.8M$
    - $N_{evts\text{-}far} \approx 200k$
  - Number of $\bar{\nu}_\mu$ events (CC):
    - $N_{evts\text{-}near} \approx 0.9M$
    - $N_{evts\text{-}far} \approx 100k$
- < 1% Measurements certainly possible from # events available
  - ν_e disappearance might require re-optimization *(global)* of detectors
- In addition, NC disappearance would provide very strong case for new physics
  - $\approx$ 140k $\nu\,[\bar{\nu}_\mu + \nu_e]$ NC interactions
    - Look for $\nu + p \rightarrow \nu + p$

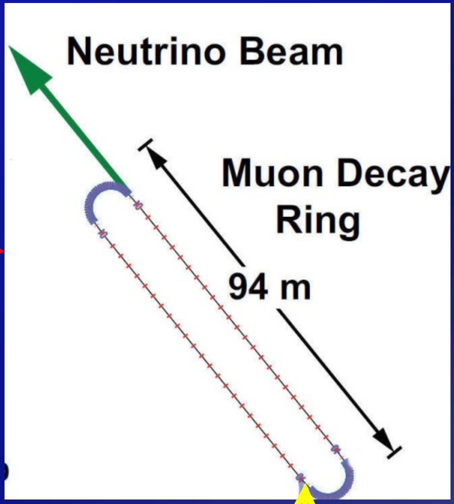
A Hypothetical

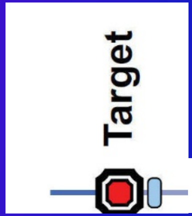
The Existence of sterile ν_s is confirmed

Precision studies?
100X in μ flux?

8X – 100kW @ 8GeV
3X – Peak of π production
3X – Collection cone

Add RF to RFFAG
.6 $\rightarrow$ 2 GeV?





NF front-end: Cap Solenoid (200 MeV), DC, B&PR

FFAG:
2-600
MeV

Preparing a LOI

- I met with Stephen Parke on March 26th and he encouraged us to submit a LOI for consideration at the June PAC
  - Must submit to PAC by May 18th
  - http://www.fnal.gov/directorate/program_planning/phys_adv_com/PACdates.html
- Need not be a "detailed" proposal, but should
  - Be detailed enough to judge scientific merit, ie, "*is there is enough for the PAC to give serious consideration to what is in the document*"
    - Large δm^2 oscillation physics
    - ν cross-section measurements
    - Technology development/demo
    - SP said – "Do what you can"
  - Stephen said not to include costing
    - But we should assemble as much information as possible for our internal discussions

LOI

- Outline:
  - Overview
  - Theoretical & experimental motivation
  - Facility
    - Targeting/capture
    - Transport/injection
    - Decay ring
  - Far Detector
  - Near Detectors
    - For oscillation physics
    - For cross-section measurements
  - Performance
    - Event rates
    - MC
    - Sensitivities
    - x-section
  - Conclusions

"What's in a name? That which we call a rose
By any other name would smell as sweet."

Some Silliness

A NF by any other name is still a NF

- I have felt strongly that whatever we call this effort, NF should be in the name
- However, recent events have changed my mind
- What is unique?
  - A new way to produce high-energy νs

νSTORM

Neutrinos from STORed Muons

Thanks to Joachim

Proto-Collaboration

Chuck Ankenbrandt[5], Ryan Bayes[2], Alex Bogacz[8], Herman Cease[1], John Cobb[7], Malcolm Ellis[9], Jim Kilmer[1], Joachim Kopp[1], Jean-Baptist Lagrange[4], Ken Long[3], Nikolai Mokhov[1], Yoshi Mori[4], David Neuffer[1], Jaroslaw Pasternak[3], Milorad Popovic[1], Tom Roberts[5], Akira Sato[6], Edward Santos[3], Paul Soler[2], Sergei Striganov[1], Chris Tunnell[7], Bob Wands[1], Walter Winter[10]

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[5]Muons Inc

[6]Osaka University

[7]Oxford University

[8]TJNL

[9]Westpac-HEPh

[10]Universität Würzburg

Outlook

Future Work:

- Facility
  - Targeting, capture/transport & Injection
    - Need detailed design and simulation
  - Decay Ring optimization
    - Continued study of both RFFAG & FODO decay rings
  - Decay Ring Instrumentation
    - Define and simulate performance of BCT, polarimeter, Magnetic-spectrometer, etc.
  - Produce full G4Beamline simulation of all of the above to define ν flux
    - And verify the precision to which it can be determined.

Outlook II

Future Work:

- Detector simulation
  - For oscillation studies, continue MC study of backgrounds & systematics
    - Also investigate disappearance channels
  - In particular the event classification in the reconstruction needs optimization.
  - For cross-section measurements need detector baseline design
    - Learn much from detector work for LBNE & IDS-NF
      - Increased emphasis on ν_e interactions, however
    - Near Detector hall could be envisioned as ν detector test facility

Conclusions

νSTORM:

- Delivers on the physics for the study of sterile ν
  - Offering a new approach to the production of ν beams and will allow us to confirm/exclude LSND/MiniBooNE ν-bar data
- Can add significantly to our knowledge of ν cross-sections, particularly for ν_e interactions
- Provides an accelerator technology test bed
  - But can also utilize existing accelerator infrastructure
- Provides a powerful ν detector test facility

END

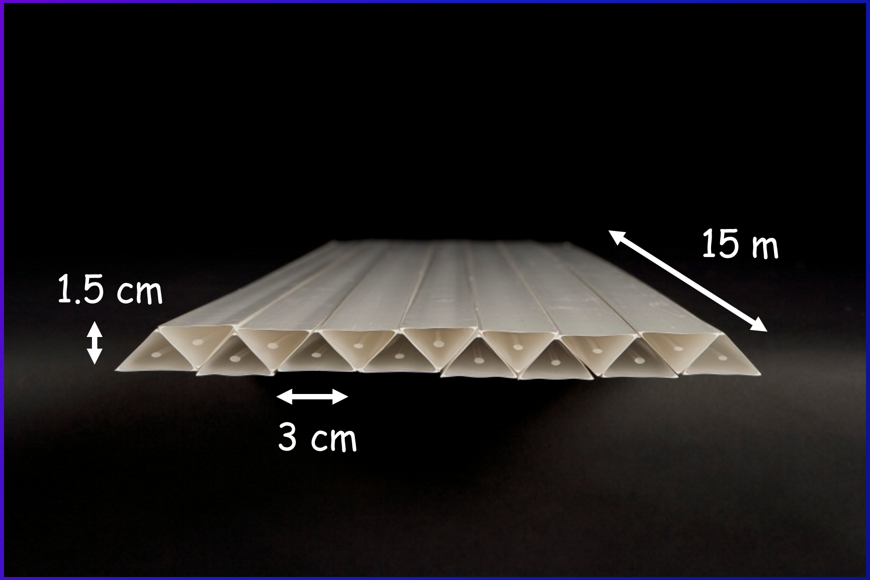
Thank You

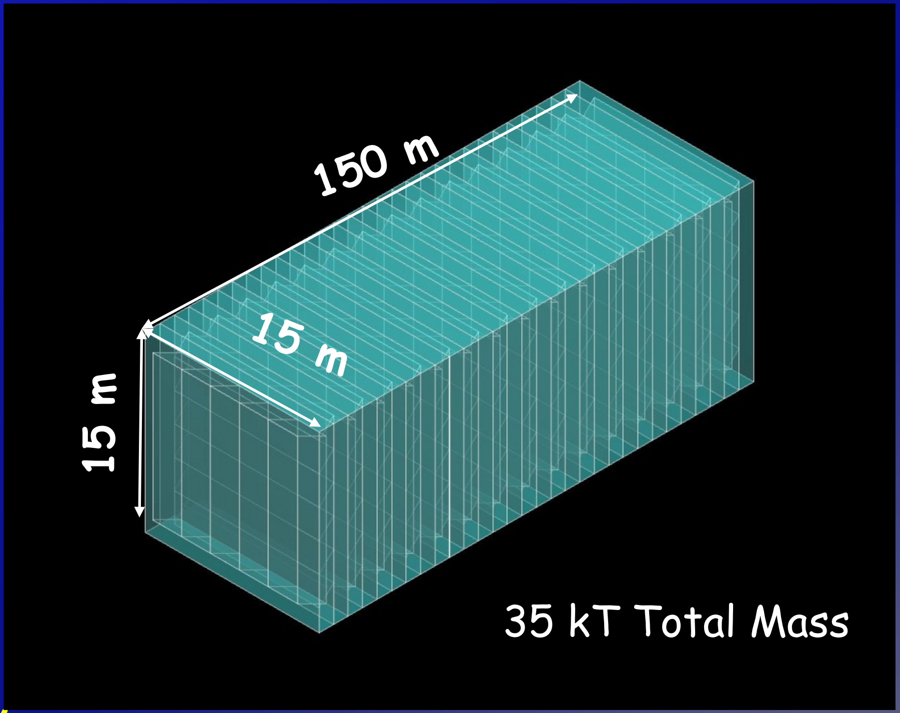
BACK UPS

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



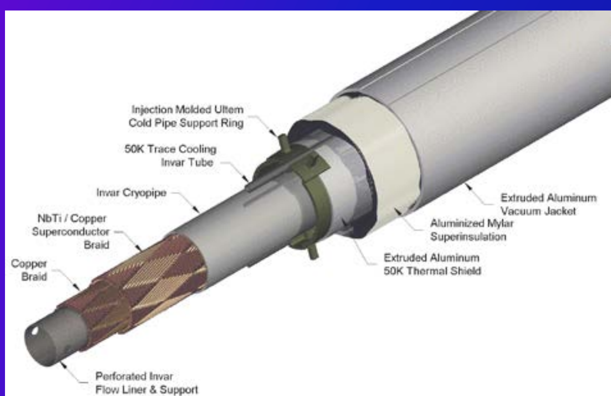


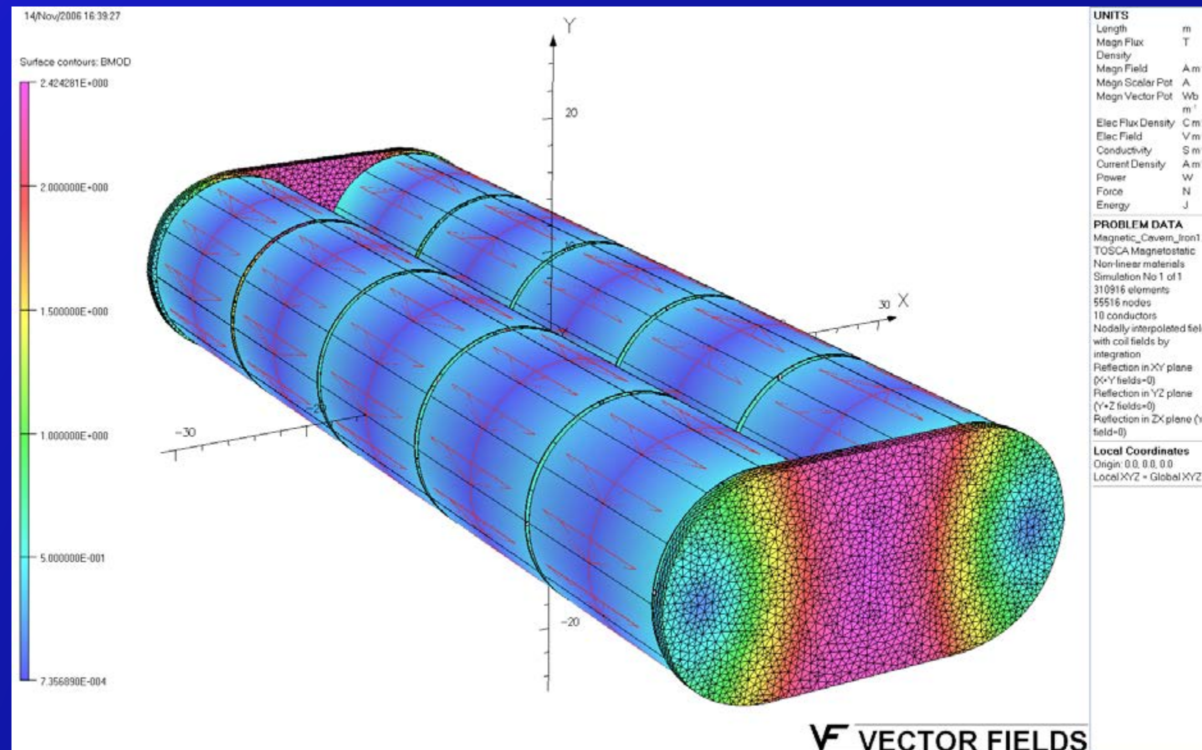
- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

B = 0.5T

Magnet- Concept for IDS-NF

- VLHC SC Transmission Line
  - Technically proven
  - Affordable



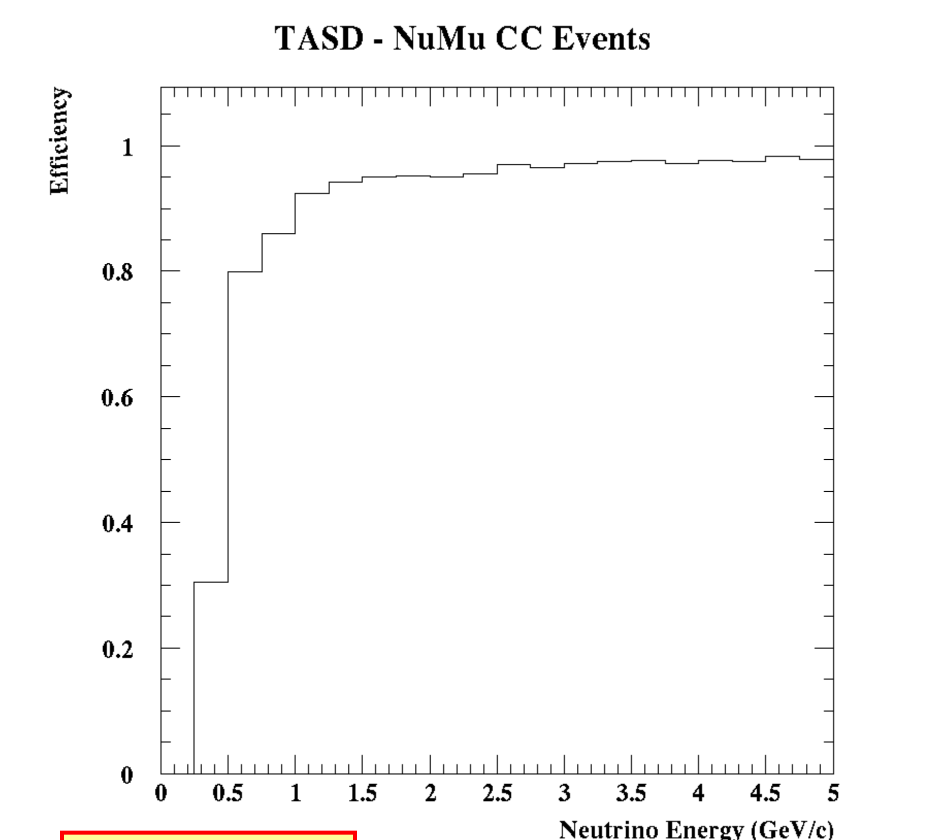


R&D to support concept
Has not been funded

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

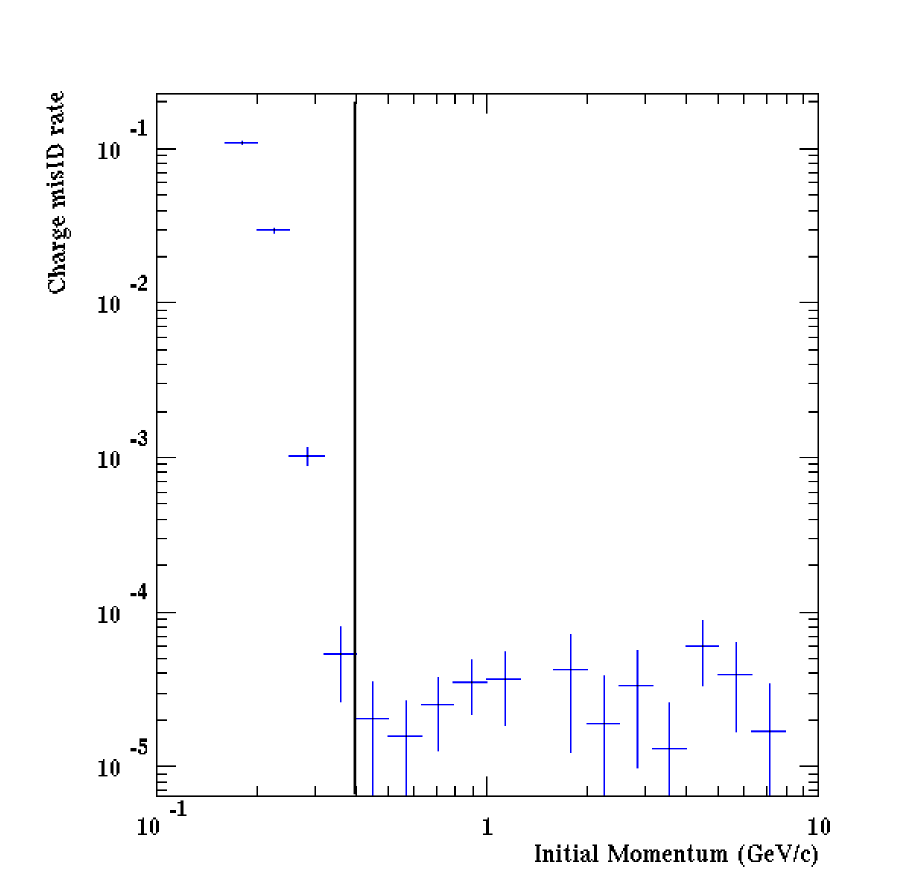
TASD Performance

ν Event Reconstruction ε



Excellent σ_E

Muon charge mis-ID rate



Detector Options

Technology check List

	Fid Volume	B	Recon	Costing Model
SuperBIND	☑	☑	☑	☑
Mag-TASD	☑	☑	☑	☑
Mag-LAr	☑	☑	☑	☑

☑	Yes - OK
☑	Maybe
☑	Not Yet