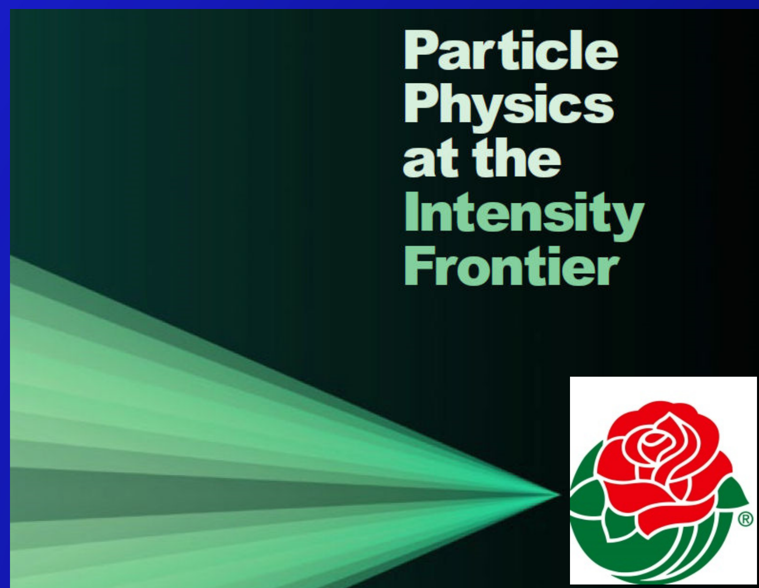
νSTORM

Neutrinos from Stored Muons
nuSTORM



A new paradigm for neutrino physics & a path to the future?

Fermilab

Introduction

- For over 30 years physicists have been talking about doing ν experiments with νs from μ decay

Well-understood neutrino source:

μ Decay Ring:

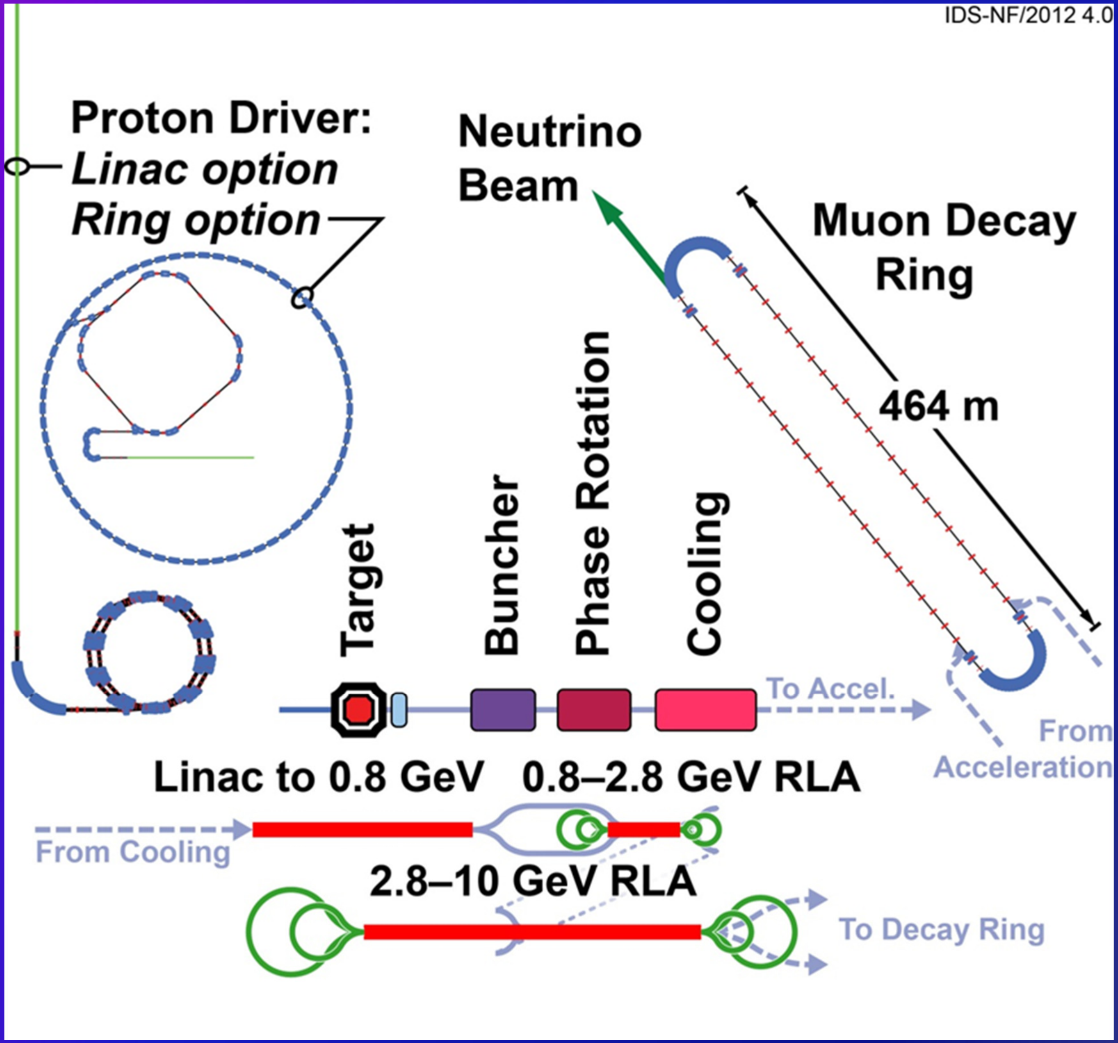
$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$

$$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$$

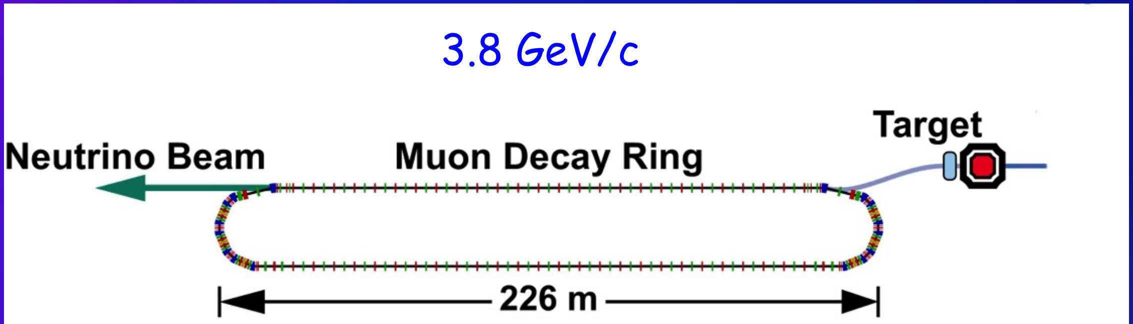
- Flavor content fully known
  - On the order of rare decay modes (10^{-4})
- "*Near Absolute*" Flux Determination is possible in a storage ring
  - Beam current, polarization, beam divergence monitor, μ_p spectrometer
- Overall, there is tremendous control of systematic uncertainties with a well designed system
- Initially the motivation was high-energy ν interaction physics.

- BUT, so far no experiment has ever been done!

Status of the Neutrino Factory design: IDS-NF



This is what we want to do near-term: Neutrinos from STORed Muons, νSTORM



This
is the simplest
implementation
of the NF

And
DOES NOT
Require the
Development of
ANY
New Technology

nuSTORM is an affordable μ-based ν beam *"First Step"*

- It is a NEAR-TERM FACILITY
  - Because, technically, we can do it now

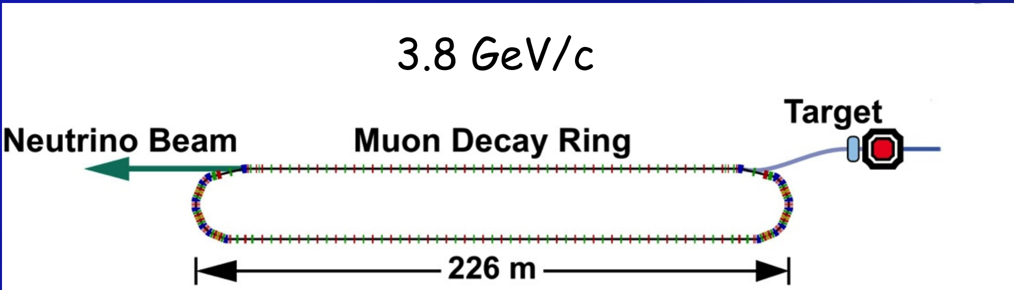
Three Scientific Pillars or themes

- Addresses the SBL, large δm^2 ν-oscillation regime
- Provides a beam for precision ν interaction physics
- 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

The Facility

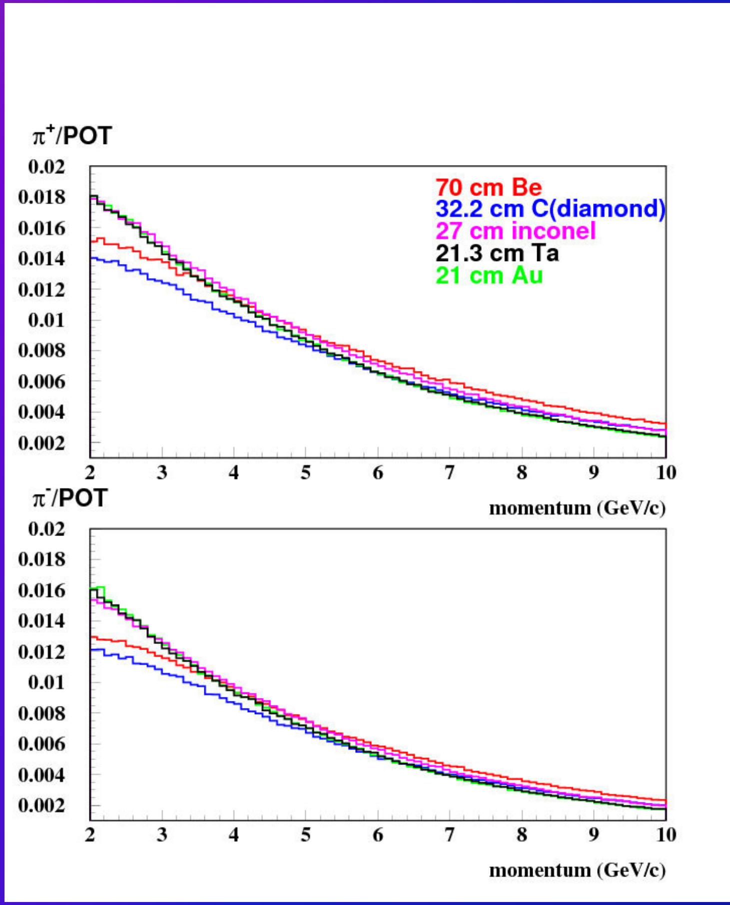
Baseline

- ~ 100 kW Target Station (designed for 400kW)
  - Assume 60-120 GeV proton
  - Carbon target
    - Inconel
  - Horn collection after target
- Collection/transport channel
  - Stochastic injection of π
- Decay ring
  - Large aperture FODO
    - Also considering RFFAG
  - Instrumentation
    - BCTs, mag-Spec in arc, polarimeter

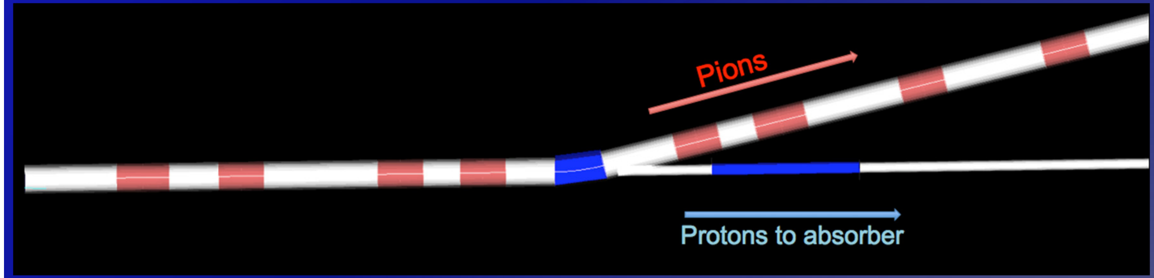


π Production, Capture & Transport

Sergei Striganov
Ao Liu
Fermilab

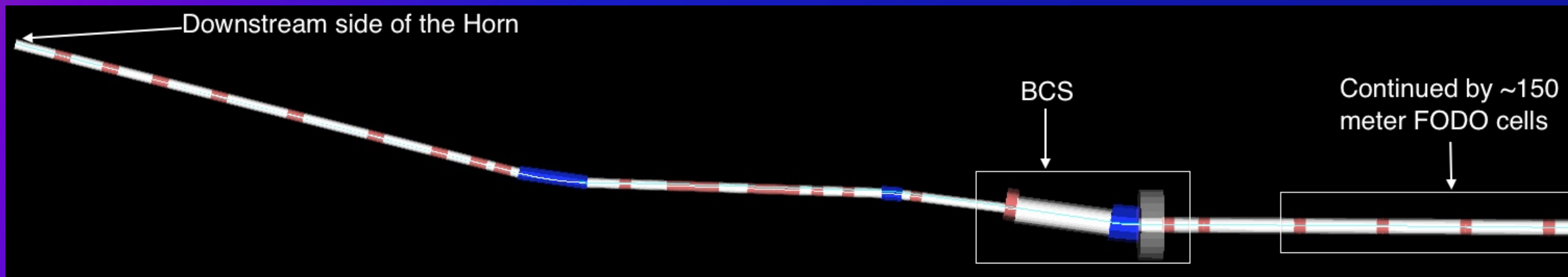


In momentum range
4.5 < 5.0 < 5.5
obtain ≈ 0.09 $\pi^{\pm}$/POT
within decay ring acceptance.
With 120 GeV p & NuMI-style horn 1
Carbon target



Target/capture optimization ongoing

π Transport & Decay ring

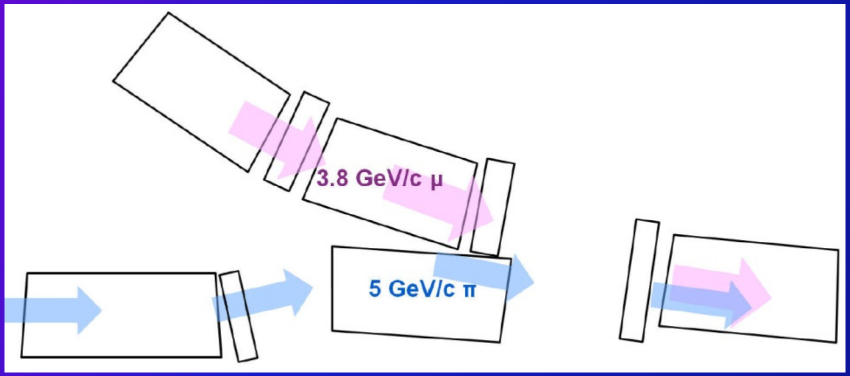


Parameter	Specification	Unit
Central momentum P_μ	3.8	GeV/c
Momentum acceptance	± 10%	
Circumference	480	m
Straight length	185	m
Arc length	50	m
Arc cell	DBA	
Ring Tunes (ν_x, ν_y)	9.72, 7.87	
Number of dipoles	16	
Number of quadrupoles	128	
Number of sextupoles	12	

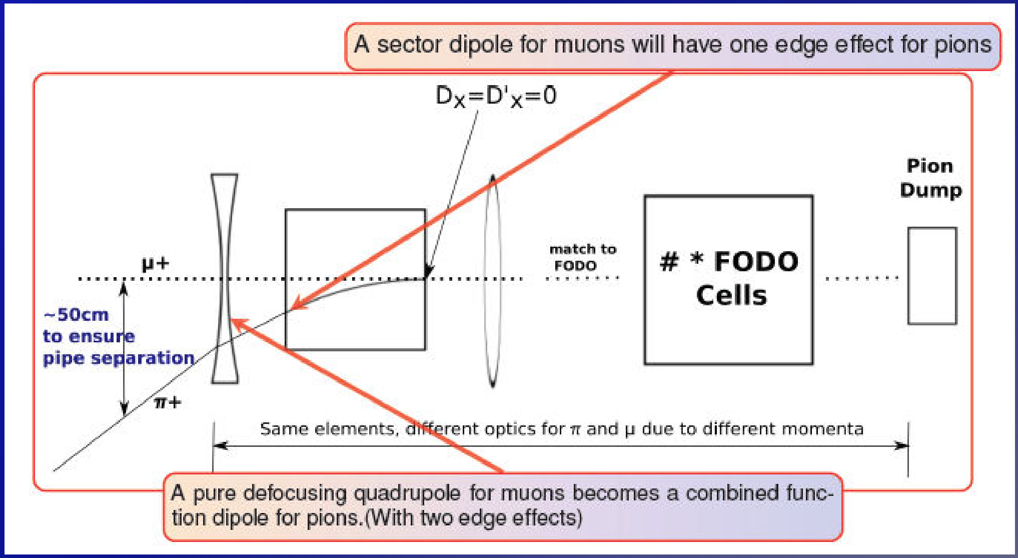
νSTORM

Injection scheme

- π's are on an injection orbit
  - separated by chicane
- μ's are in ring circulating orbit
  - lower p ~3.8 GeV/c
- ~30cm separation between
- Concept works for FODO lattice
  - Now detailed by Ao Liu
- Beam Combination Section (BCS)



David Neuffer's original concept from 1980

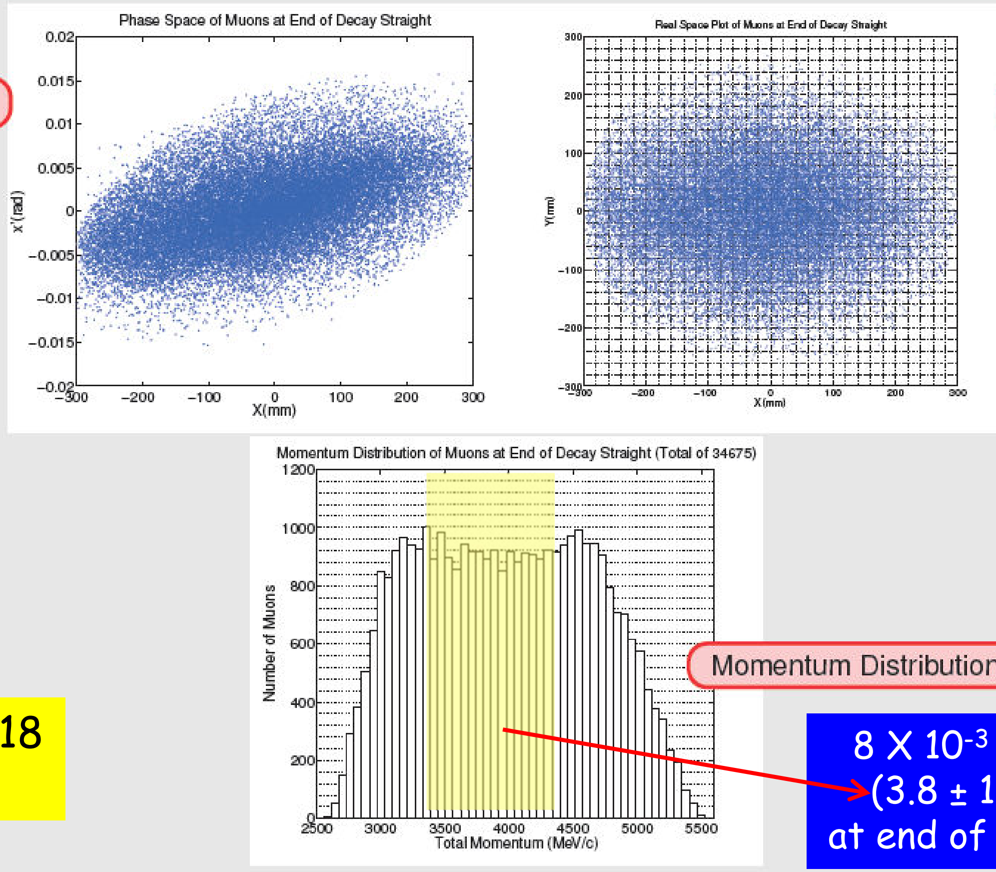


μs at end of first straight

Ao Liu
Fermilab

Phase space plot

Real space plot



Momentum Distribution

See Poster TUPBA18
Ao Liu

8×10^{-3} muons/POT
(3.8 ± 10%) GeV/c
at end of first straight

Muons at the end of decay straight.(Total of 34675 muons. ~ 18% of initial pions.)

(As a comparison, if turn fringe field off –19.7%)

Looking Forward: Beyond ν physics

Conclusions (cont)

- The recent discovery of the Higgs particle of 125 GeV at CERN has brought in also the additional requirement of a remarkably small longitudinal emittance.
- The unique feature of the direct production of a H° scalar in the s-state is that the mass, total width and all partial widths of the H° can be directly measured with remarkable accuracy.
- The main innovative component could be the practical and experimental realization of a *full scale cooling demonstrator*, a relatively modest and low cost system but capable to conclusively demonstrate "ionization cooling" at the level required for a Higgs factory and eventually as premise for a subsequent multi-TeV collider and/or a long distance ν factory
- The additional but conventional facilities necessary to realize the facility with the appropriate luminosity should be constructed *only after the success of this "initial cooling experiment" has been conclusively demonstrated*.

Venice_March2013 Slide# : 38

C. Rubbia, Neutrino Telescopes 2013

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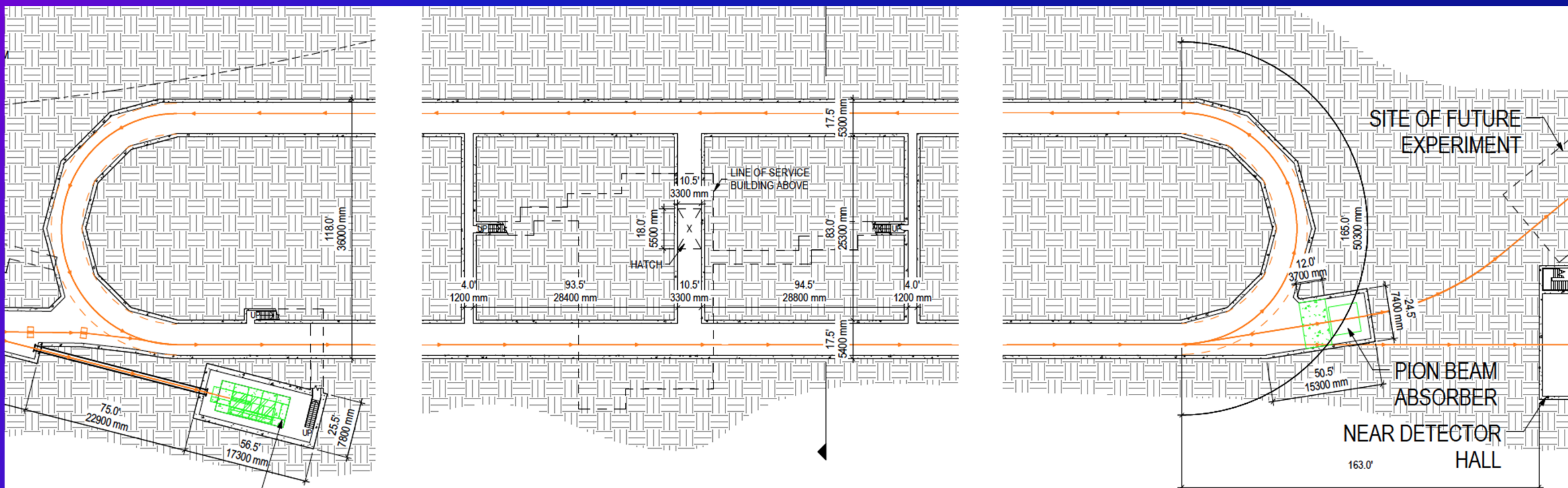
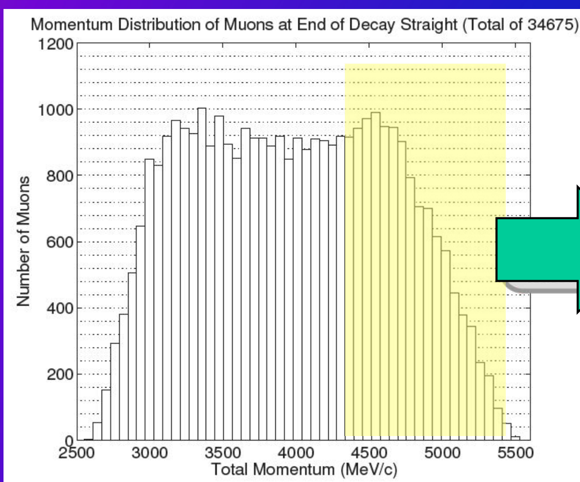
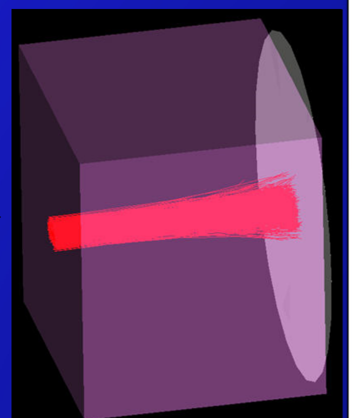
Setting the stage for the next step

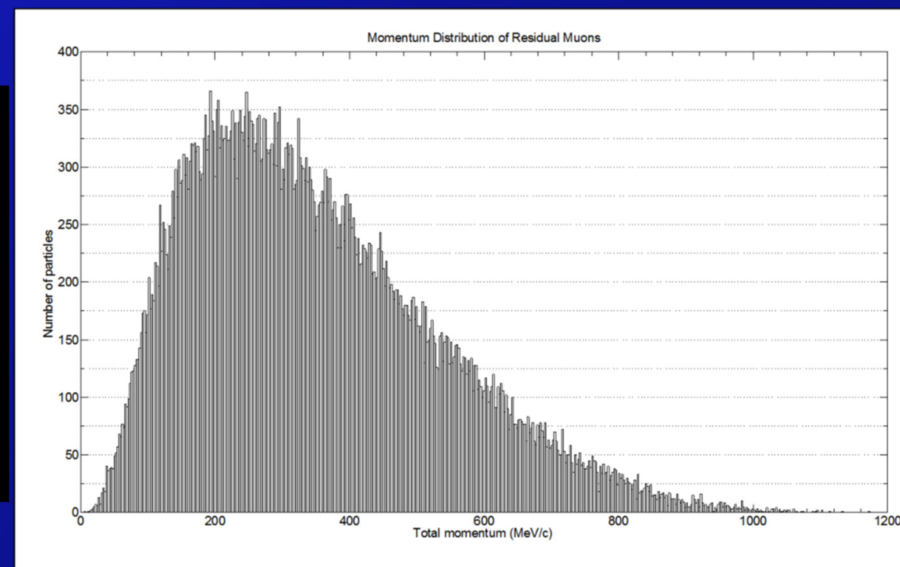


Only ~50% of πs decay in straight
Need π absorber

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

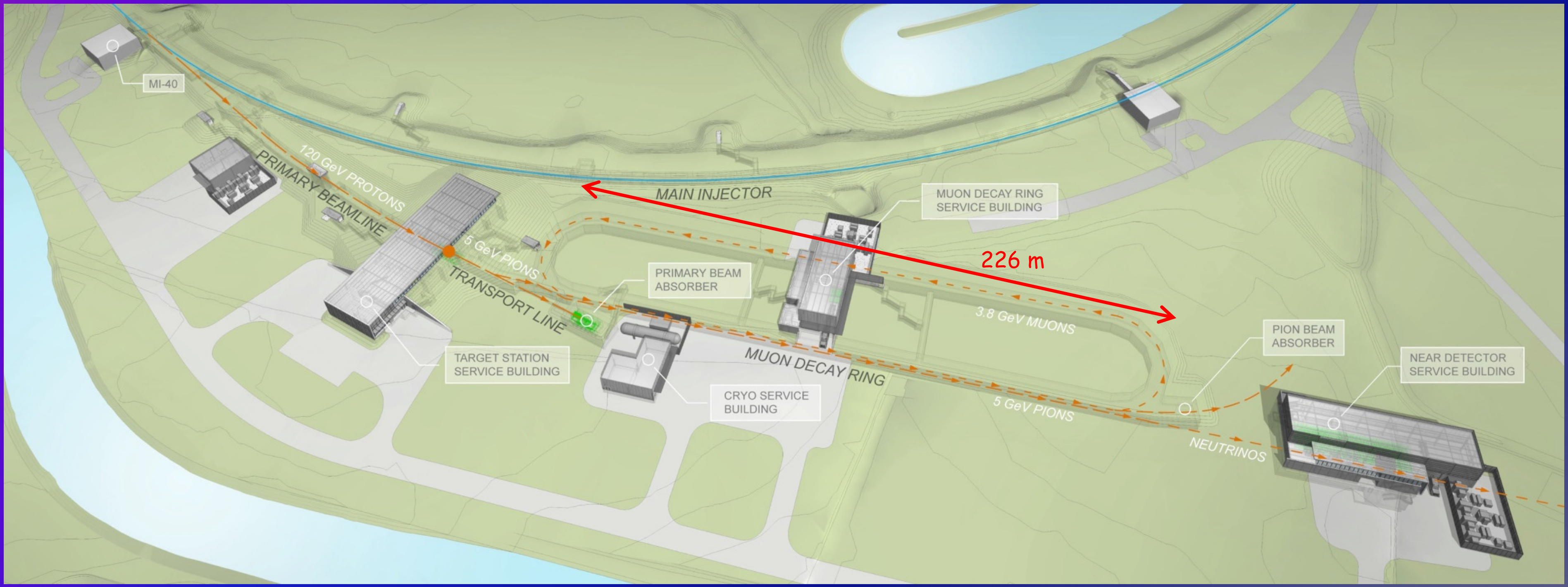
After 3.48m Fe, we have ≈ 10^{10} μ/pulse in 100 < P(MeV/c) < 300

Project Siting

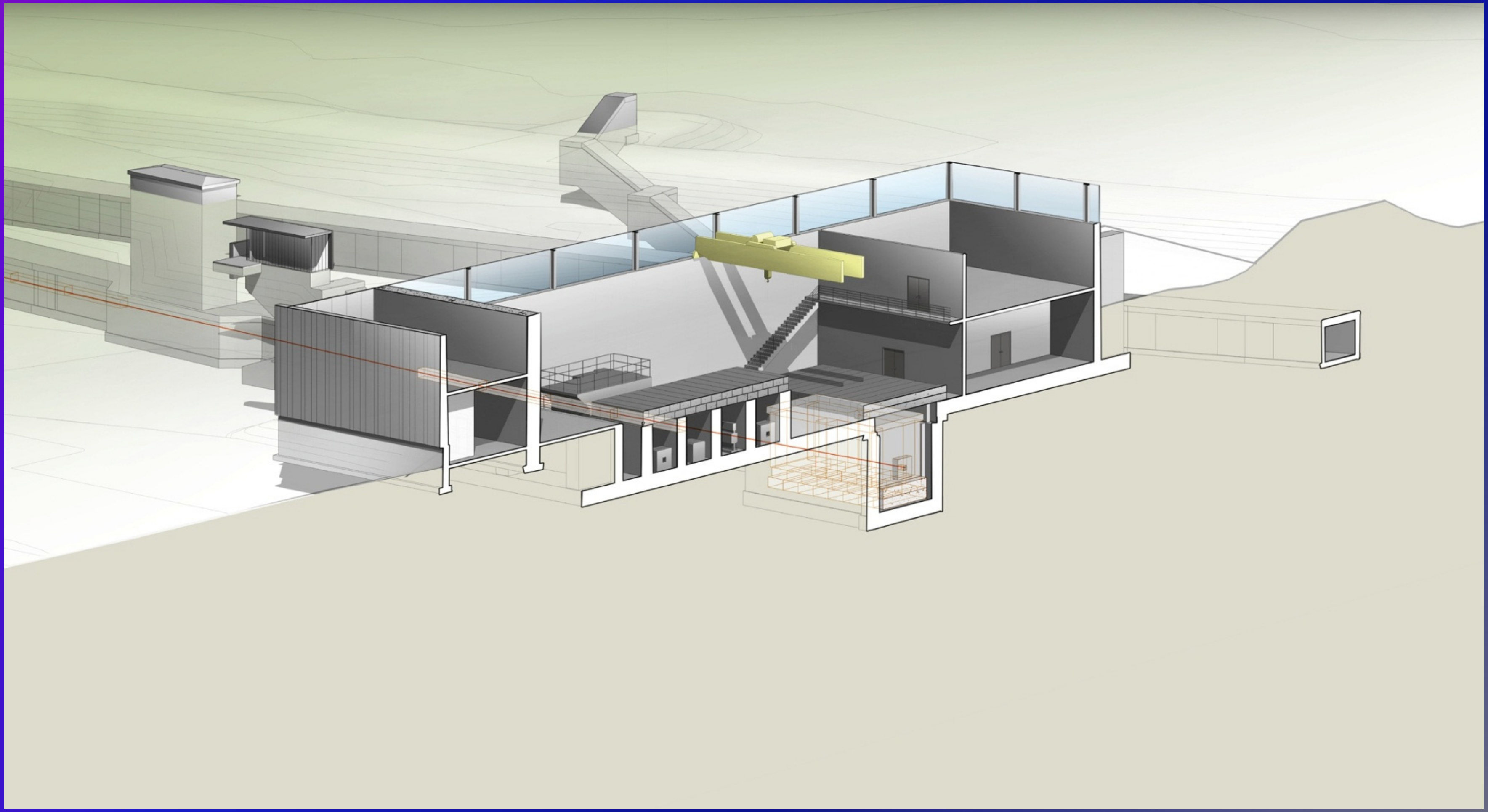
Siting Plan

Steve Dixon
Fermilab FESS

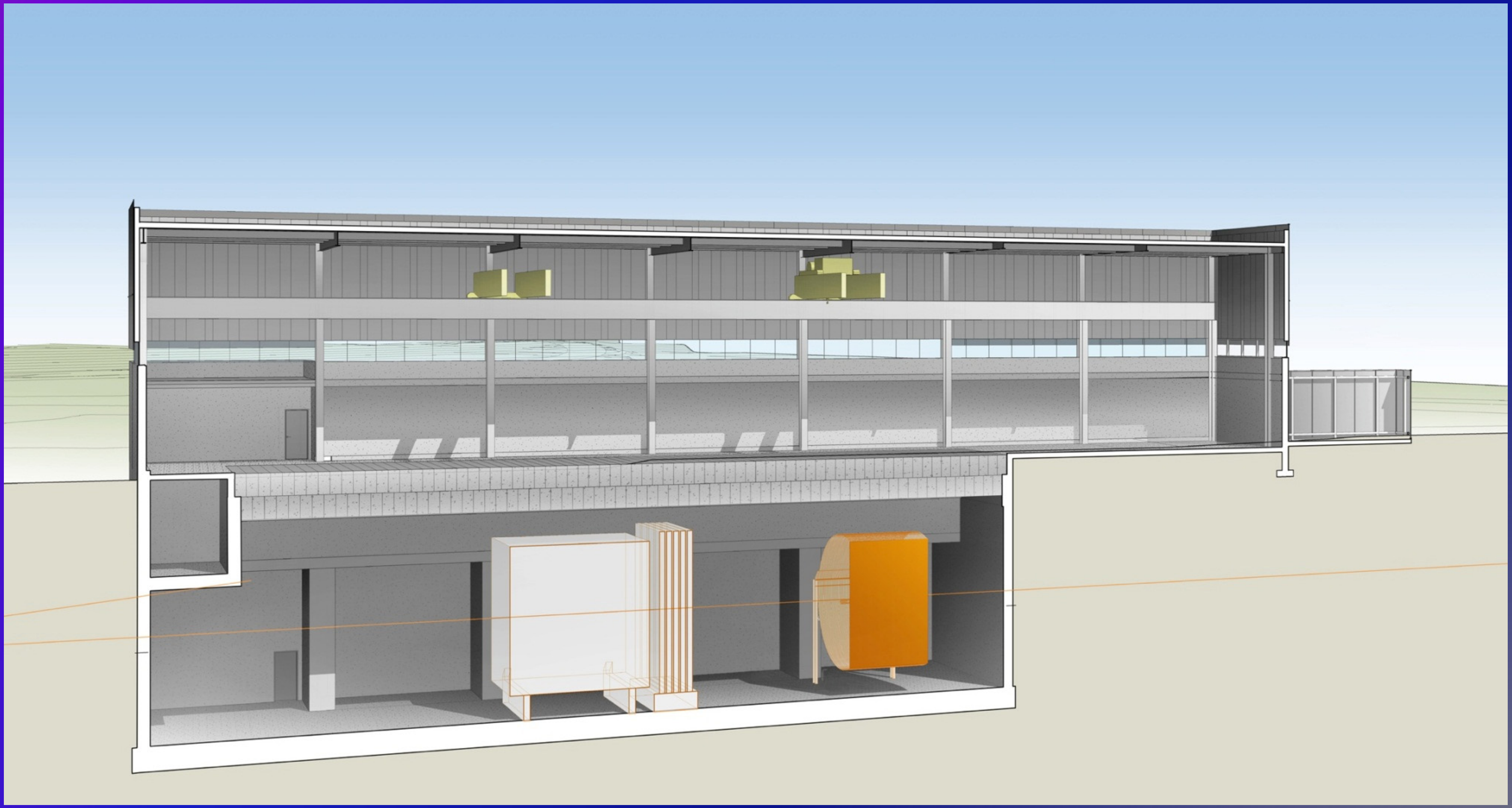
Site schematic



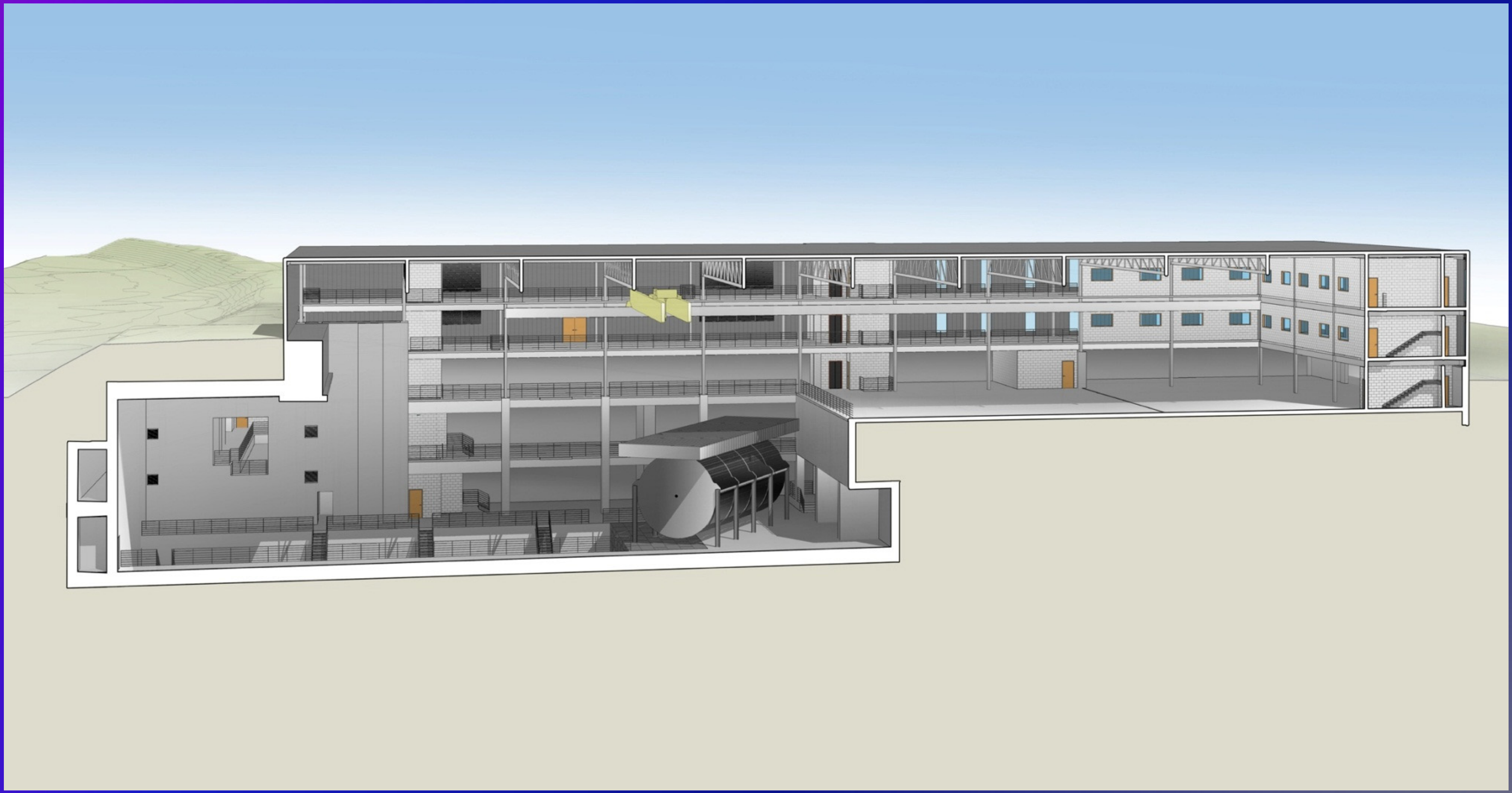
TS section



Near detector hall



Far Detector Hall
D0 Assembly Building



Physics performance
One example: SBL

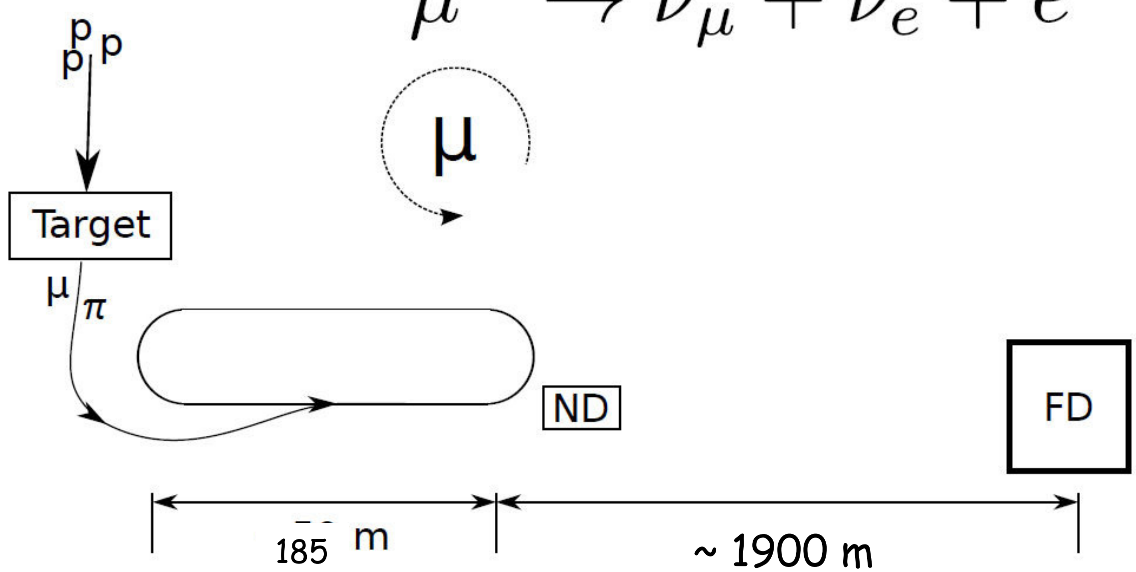
Assumptions

- N_μ = (POT) X (π/POT) X μ/π X $A_{dynamic}$ X Ω
  - 10^{21} POT @ 120 GeV integrated exposure
  - 0.1 π/POT
  - Muons/POT at end of first straight (8 X 10^{-3})
    - =(π/POT) X (μ/π) within the 3.8 ± 10% GeV/c momentum acceptance
  - $A_{dynamic}$ = 0.6 (FODO)
    - Fraction of muons surviving 100 turns
  - Ω = Straight/circumference ratio (0.39) (FODO)
- This yields ≈ 1.9 X 10^{18} useful μ decays

Experimental Layout

Chris Tunnell
Oxford*

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



Appearance-only (though disappearance good too!)

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

Appearance Channel:

$\nu_e \rightarrow \nu_\mu$

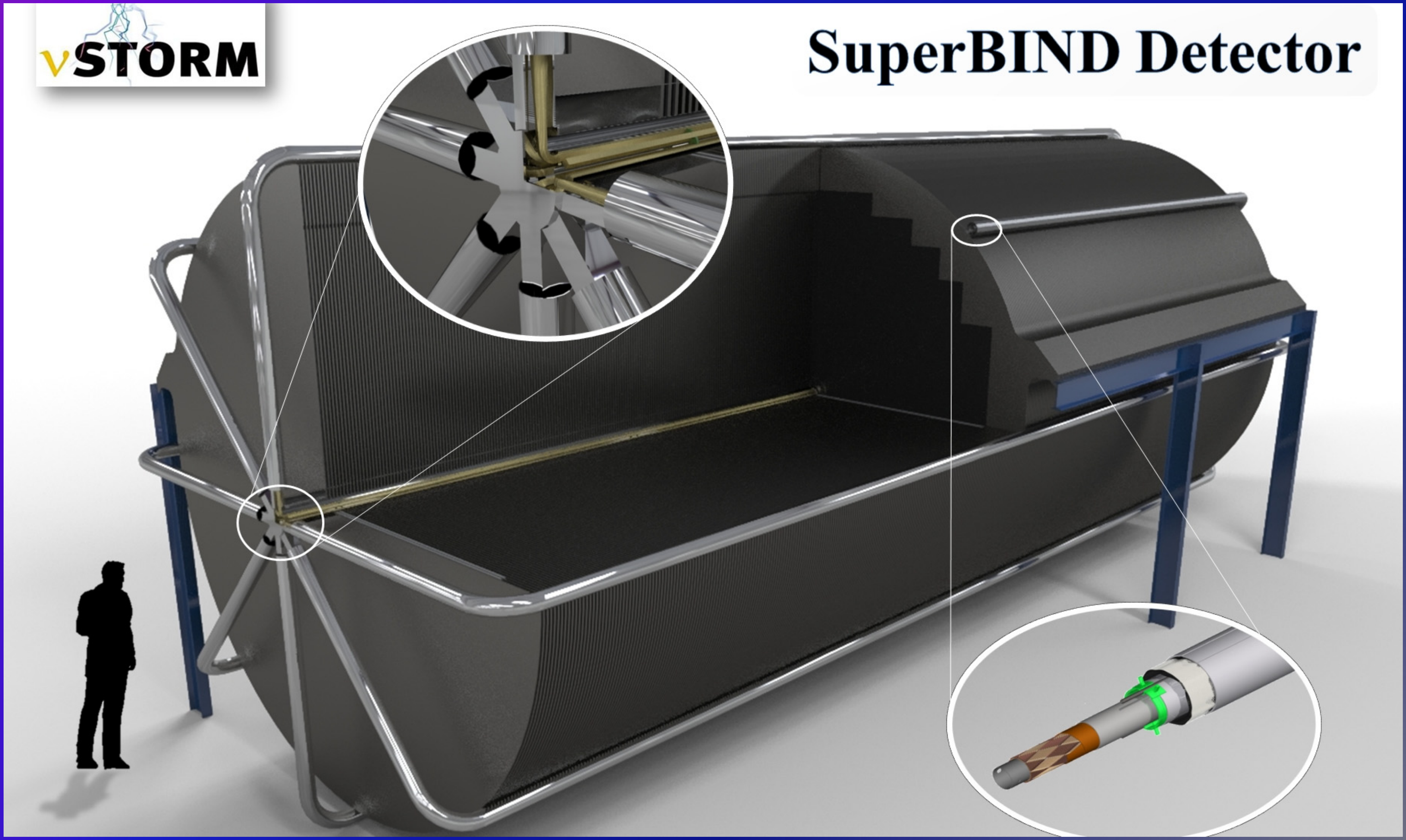
Golden Channel

Must reject the "wrong" sign μ with great efficiency

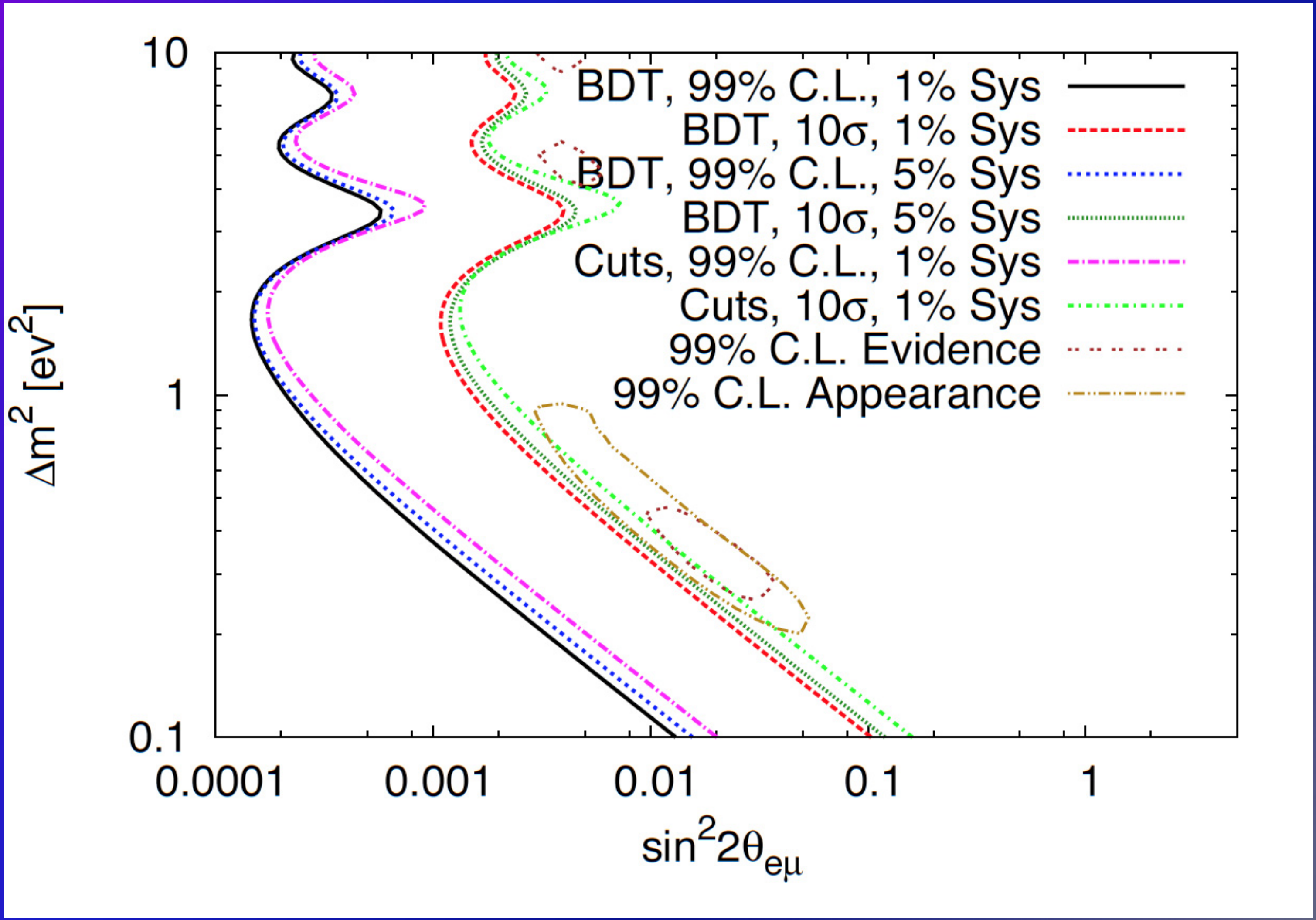
Why $\nu_\mu \rightarrow \nu_e$ Appearance Ch. not possible

* Now at NIKHEF

SuperBIND



Appearance
Exclusion contours



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Moving Forward

Fermilab

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- Twin-Track Approach
  - Develop International support at the Laboratory level for the concept
    - Already Bottom-up (grass roots), now add Top-down
  - LOI to Fermilab (June 2012), EOI to CERN (April 2013), Proposal to Fermilab (June 2013)
- Has produced significant increase in the size of the collaboration
  - From 38 at time of Fermilab LOI to 110 now (single collaboration)
- EOI to CERN presented at June SPSC meeting. Requested support to:
  - Investigate in detail how nuSTORM could be implemented at CERN; and
  - Develop options for decisive European contributions to the nuSTORM facility and experimental program wherever the facility is sited.
- Full Proposal submitted to Fermilab PAC in June
  - Requested Stage I approval
- It defines a roughly two-year program which culminates in the delivery of a Technical Design Report.

Status

- nuSTORM has received Stage I approval from Fermilab
  - Opens up opportunity for R&D funds to further development towards TDR/CDR
- Response from SPSC:
  - The SPSC recognizes the nuSTORM project as an important step in the long-term development of a neutrino factory, presently considered as the ultimate facility to study CP violation in the neutrino sector. nuSTORM would also constitute a test bed for accelerator and beam physics R&D.
  - In this context, the SPSC considers that, in line with the recently updated European Strategy, an involvement in nuSTORM could be part of the CERN contributions to the development of future neutrino programmes. A further review of the project would require a more focused proposal identifying which tasks could be performed at CERN within a more general project defined in cooperation with Fermilab and other contributing institutes.

nuSTORM: Conclusions

The Physics case:

- Simulation work indicates we can confirm/exclude at 10σ (CPT invariant channel) the LSND/MiniBooNE result
  - ν_μ and (ν_e) disappearance experiments delivering at the <1% level look to be doable
- ν interaction physics studies with near detector(s) offer a unique opportunity & can be extended to cover 0.2<GeV< E_ν< 4 GeV
  - Could be "*transformational*" w/r to ν interaction physics
  - 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

Conclusions II

The Facility:

- Presents very manageable extrapolations from existing technology
  - But can explore new ideas regarding μ beam optics, instrumentation and can provide μ beam for a definitive 6D cooling test
- Has considerable flexibility in its implementation that allows siting at either Fermilab or CERN
  - Just need the protons

Three Pillars of nuSTORM

- Delivers on the physics for the study of sterile ν
  - Offering a new approach to the production of ν beams setting a 10 σ benchmark to make definitive statement w/r LSND/MiniBooNE
- Can add significantly to our knowledge of ν interactions, particularly for ν_e
  - ν *"Light Source"*
- Provides an accelerator & detector technology test bed

Thank you