νSTORM in Venice

C.D Tunnell (JAI/Oxford)
on behalf of the collaboration

Today's talk

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- *Bonus credit: "Future accelerator R&D"*

John Adams Institute for Accelerator Science

History of neutrino beams

History of neutrino beams

- 1960s π decay beam (and horns)

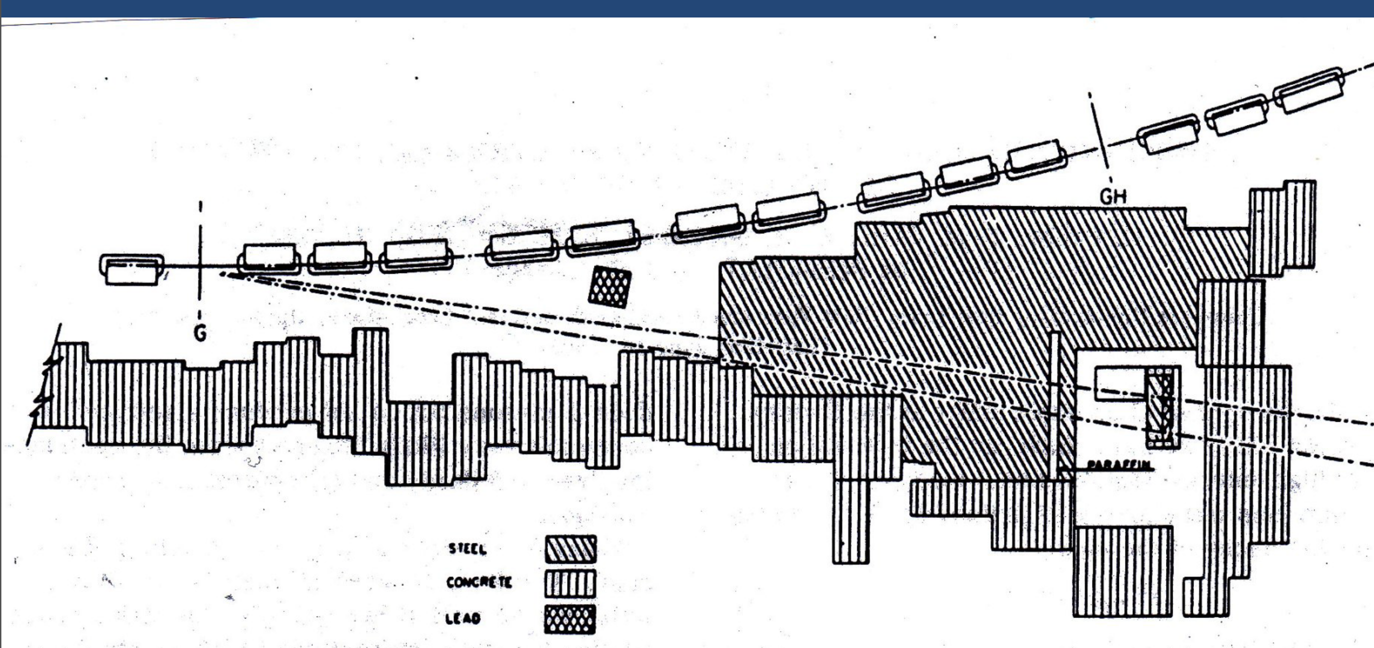
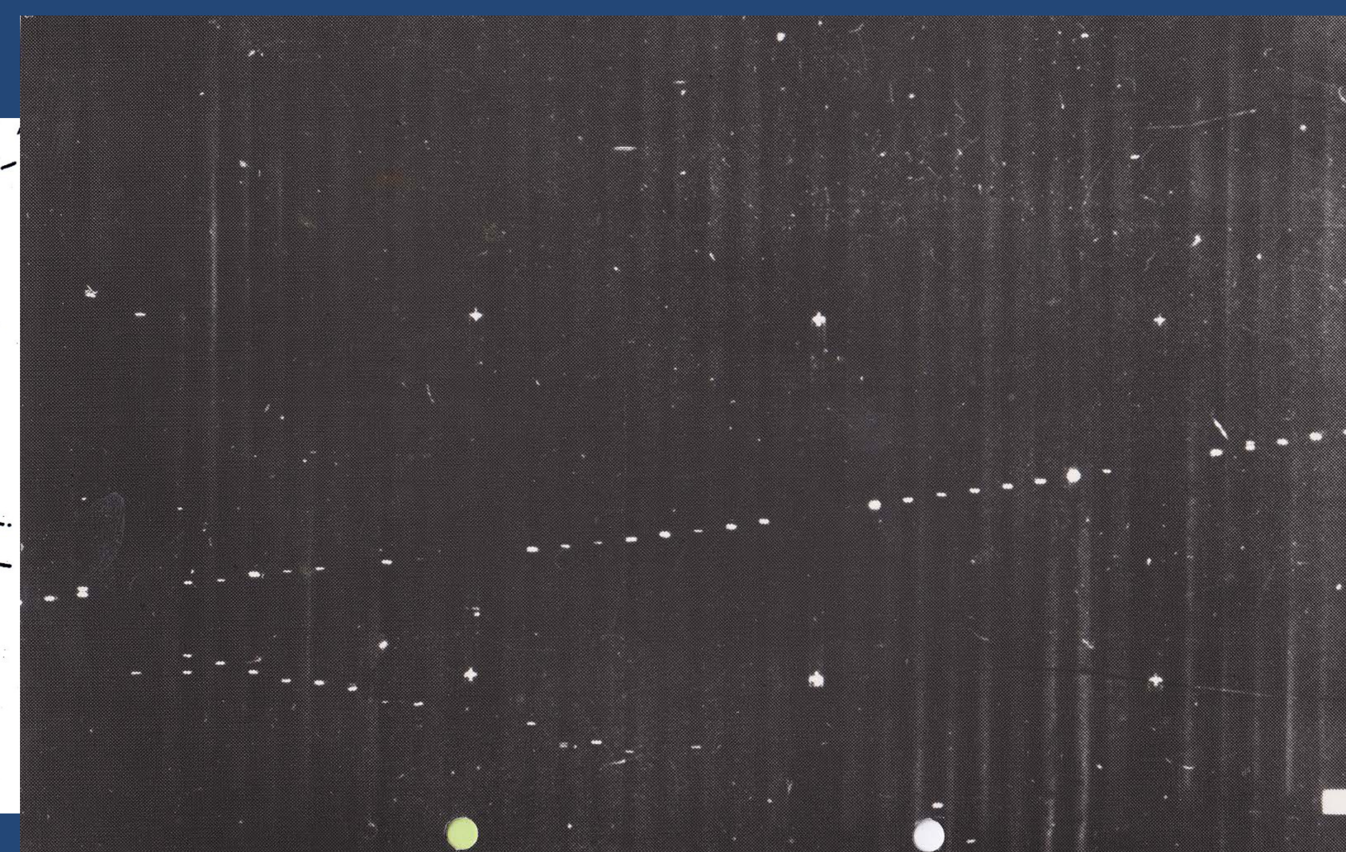


FIG. 1. Plan view of AGS neutrino experiment.



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DESIGN CONSIDERATIONS FOR A MUON STORAGE RING

David Neuffer
Fermi National Accelerator Laboratory*, Batavia, ILL 60510

ABSTRACT

It was noted earlier[1] that a muon (μ) storage ring can provide neutrino (ν) beams of precisely knowable flux and therefore suitable for ν oscillation experiments. In that paper it was suggested that parasitic use of the Fermilab $\bar{p}$ precooler could provide a useful μ storage ring. In this paper design possibilities for μ storage rings are explored. It is found that a low energy (~1 GeV) ring matched to a high intensity proton source (8 GeV Booster) is most practical and can provide ν beams suitable for accurate tests of ν oscillations.

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- Summer 2011: nuSTORM (then VLENF) born

What is the difference from NF? #1

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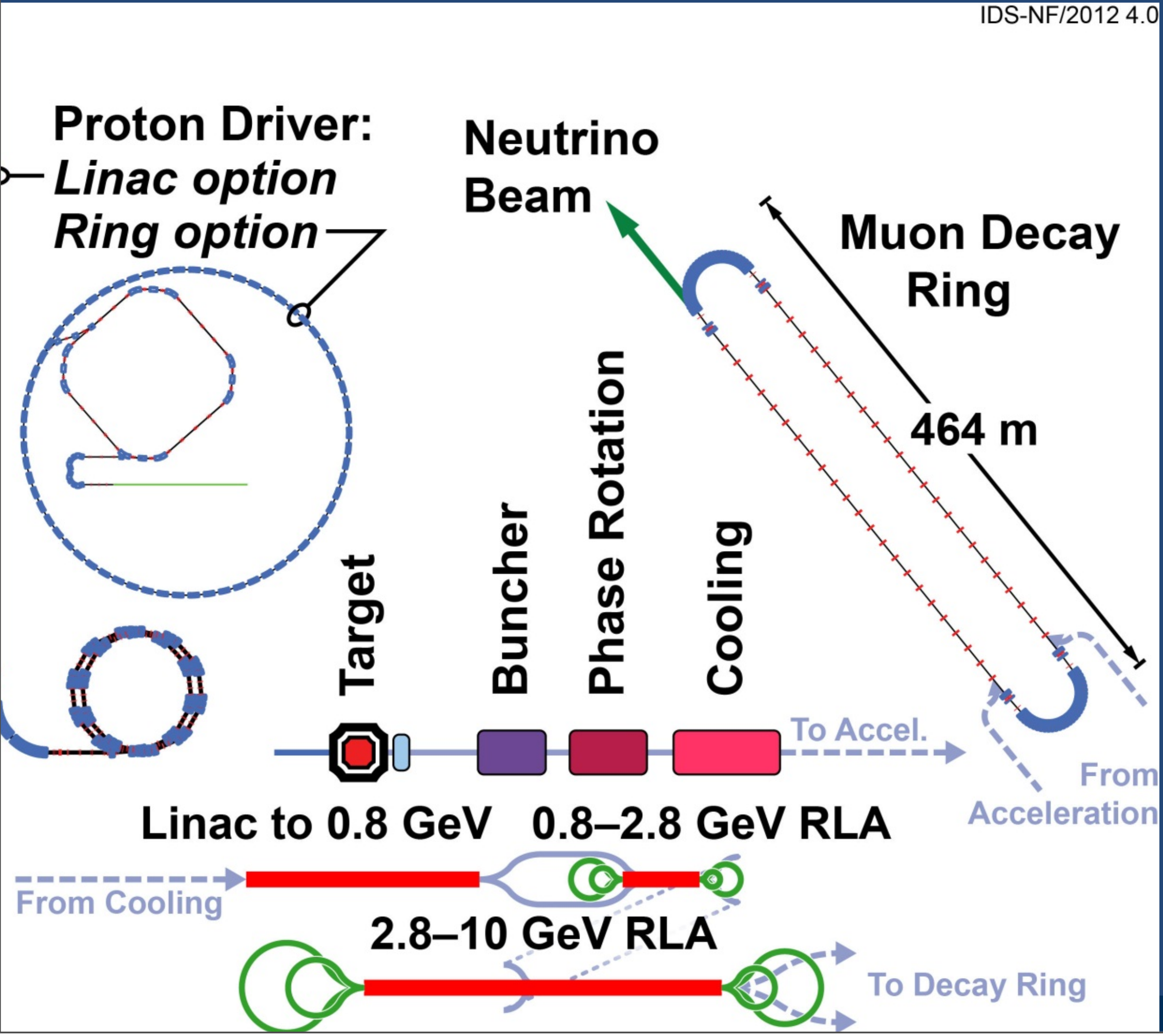
NF for CPV



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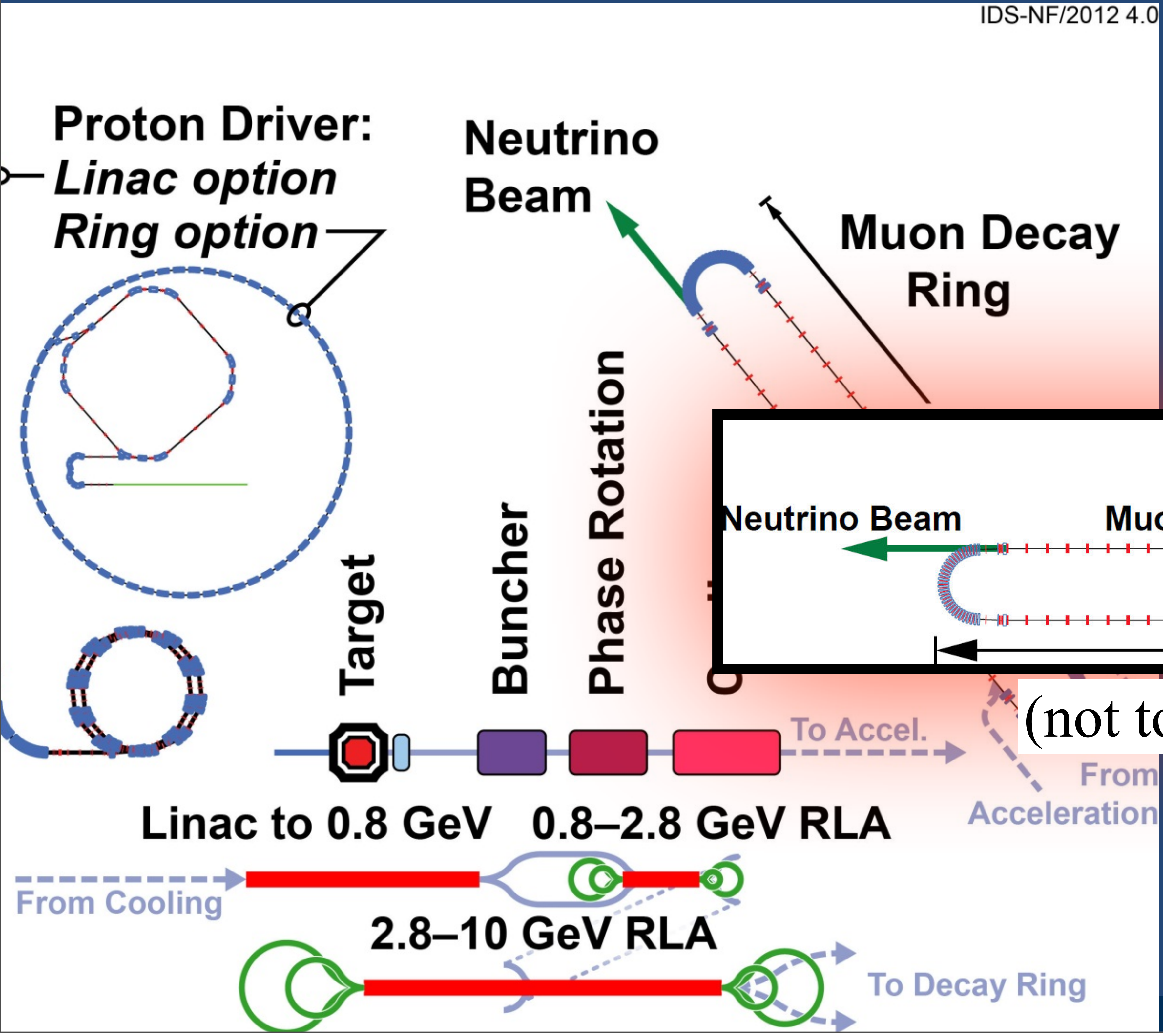
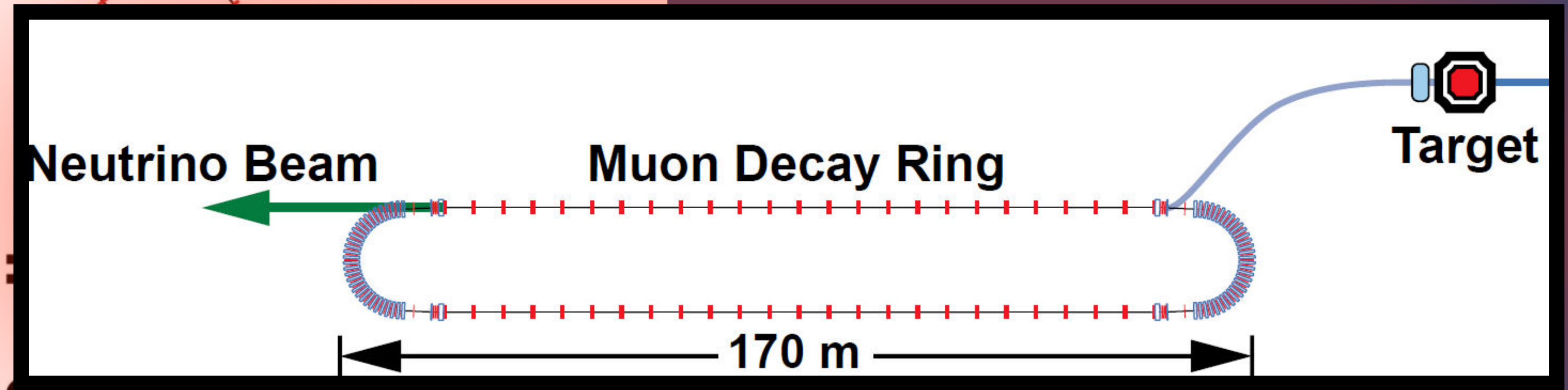
NF for CPV

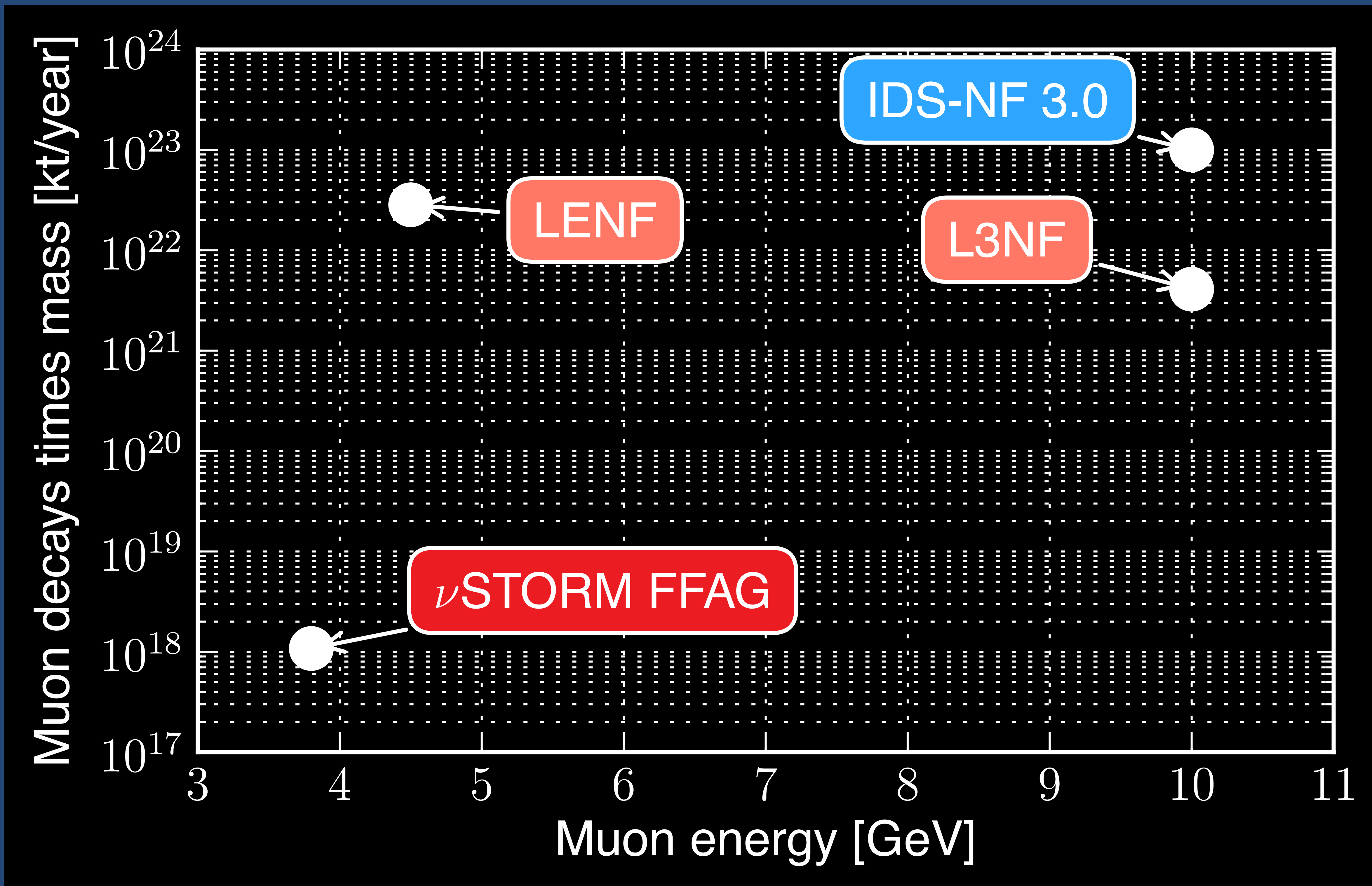
nuSTORM





(not to scale; nuSTORM tiny!)

What is the difference from NF? #2



νSTORM

No New Technology

νSTORM

No New Technology

60 GeV/c
protons

νSTORM

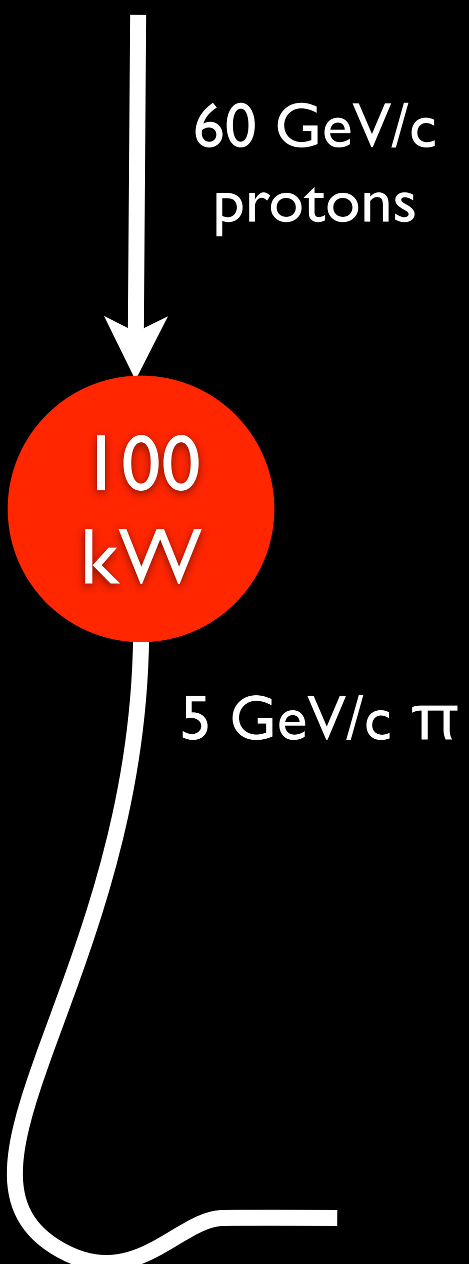
No New Technology

60 GeV/c
protons

100
kW

νSTORM

No New Technology



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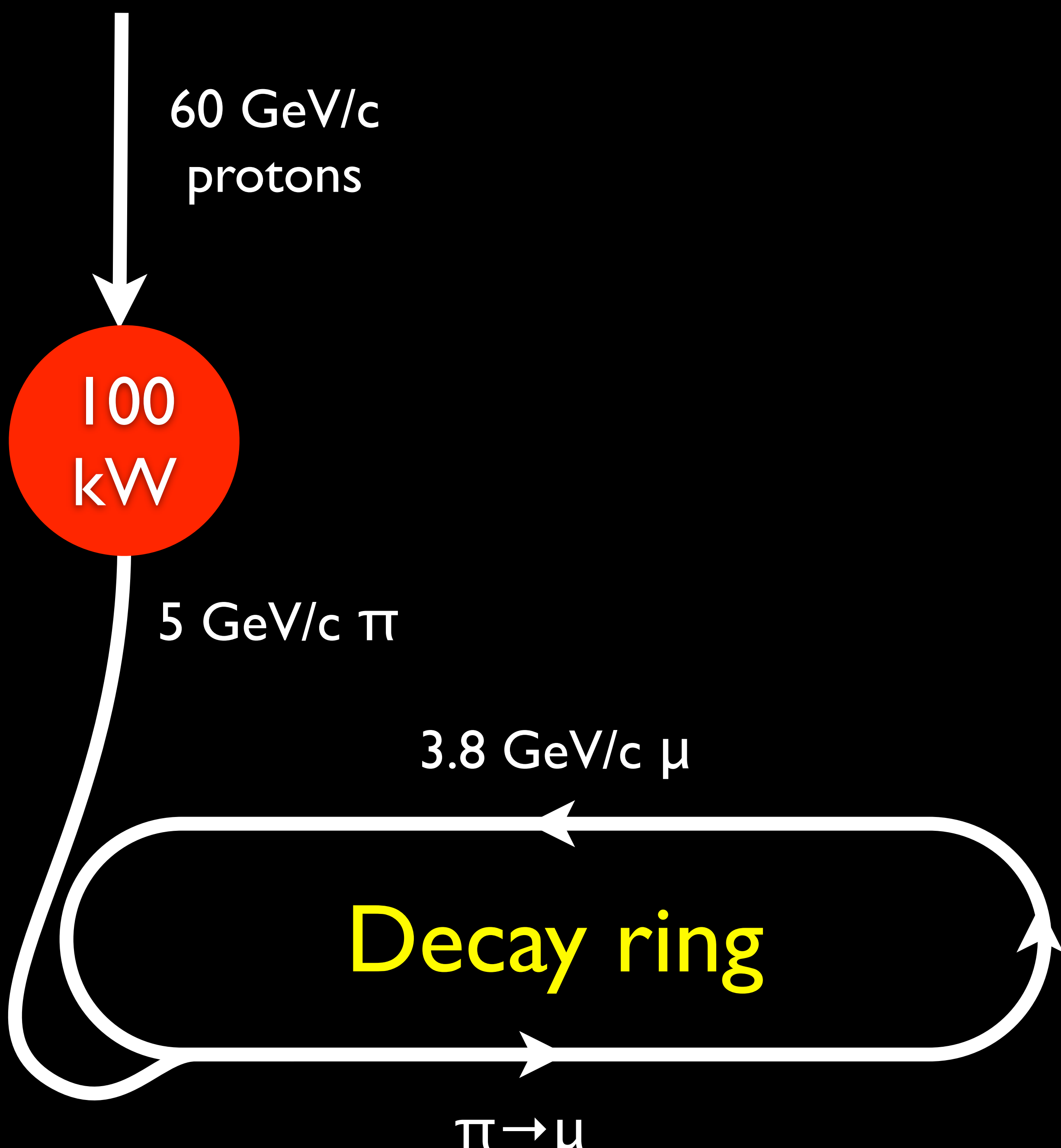

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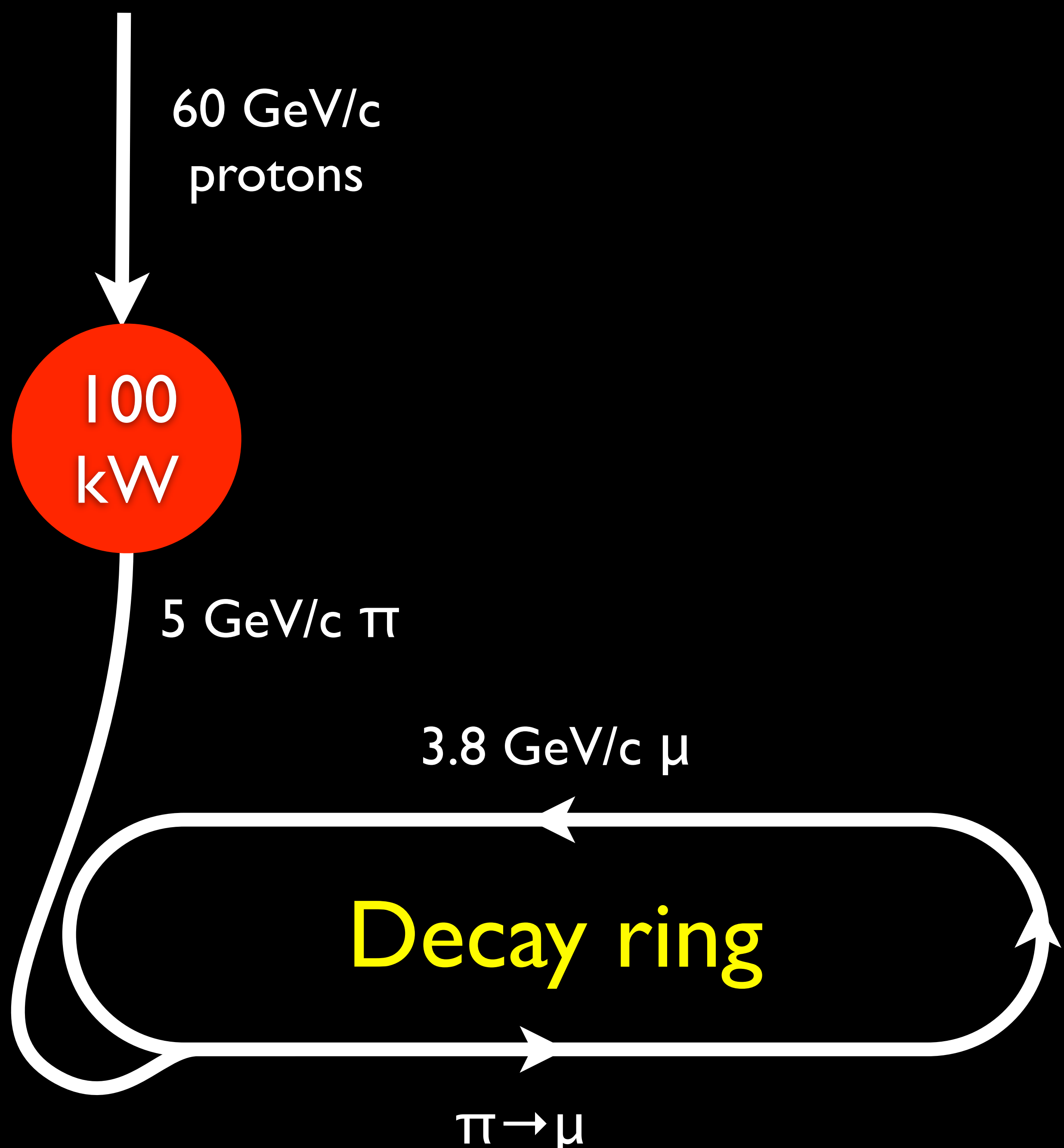
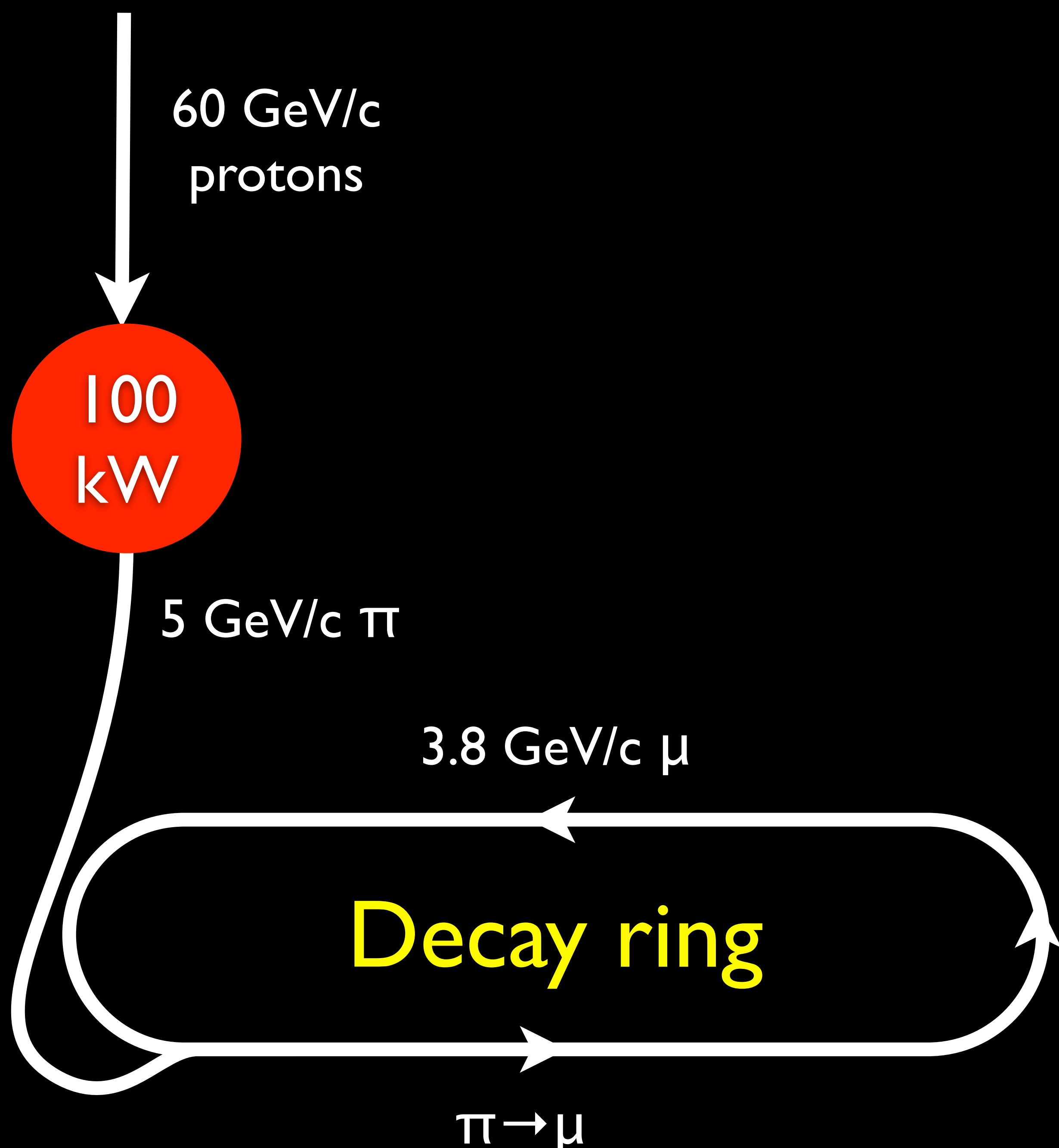


$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$

νSTORM

No New Technology



$$\frac{L}{E} \sim 1$$

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

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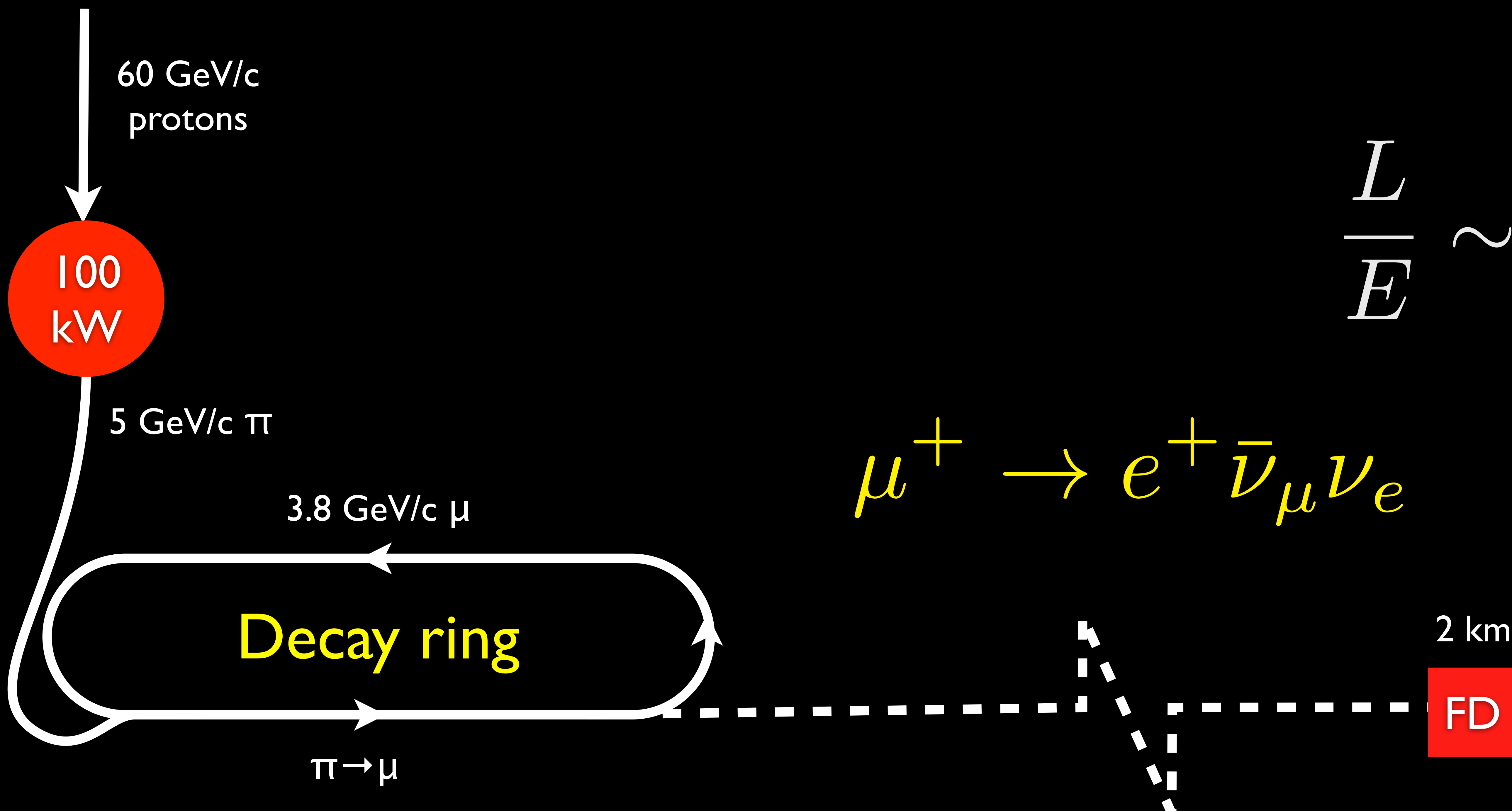

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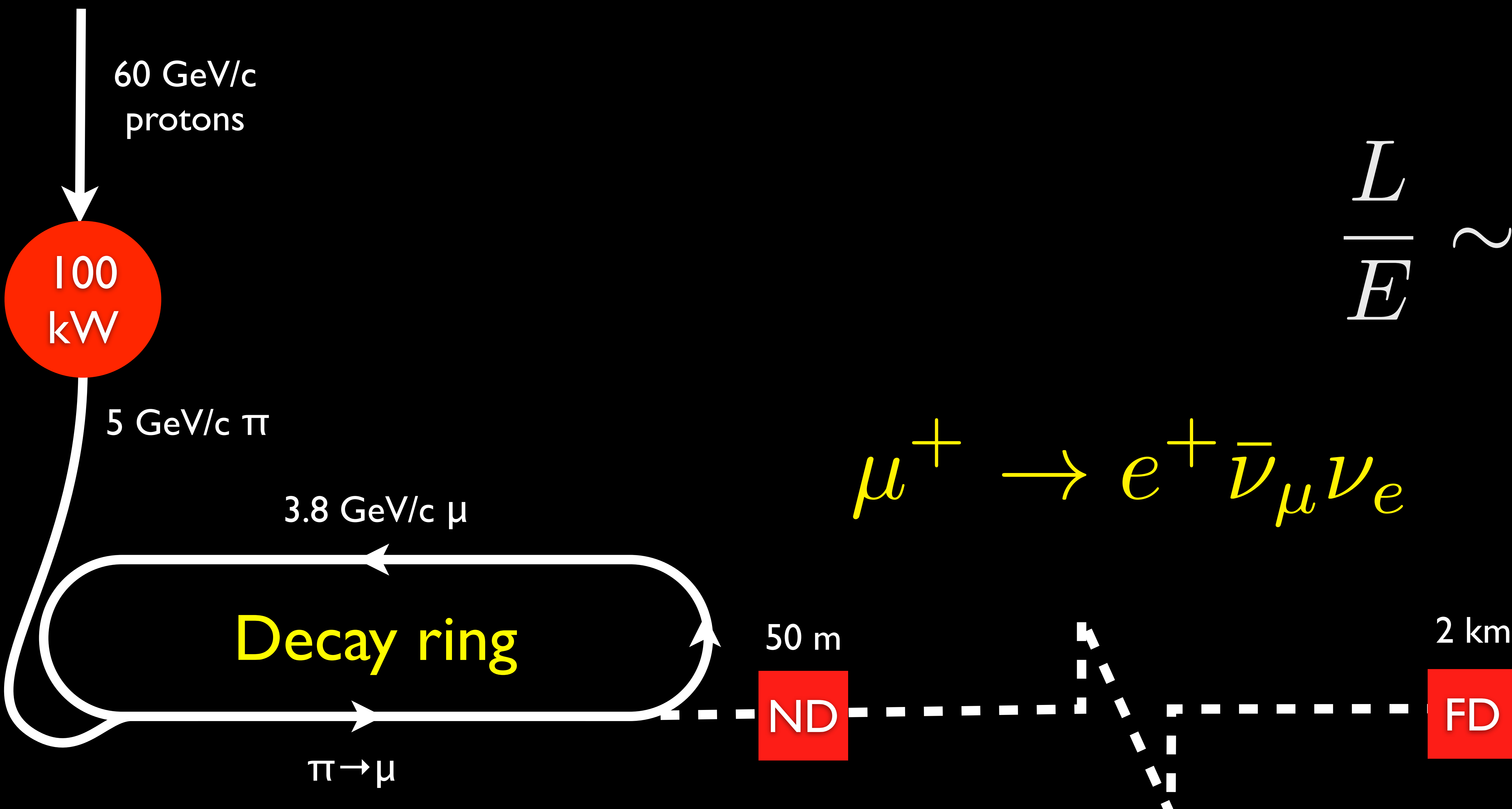

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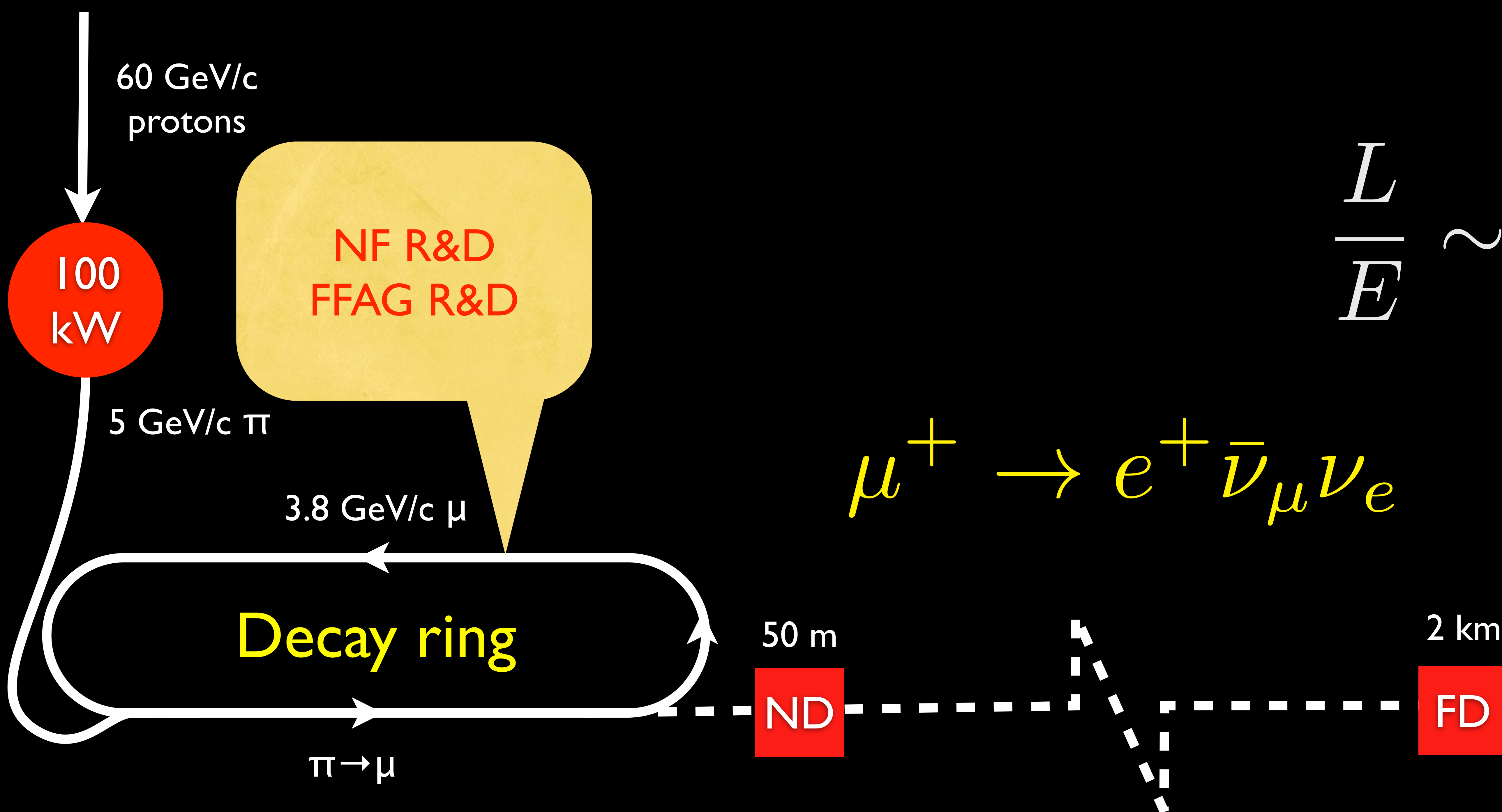

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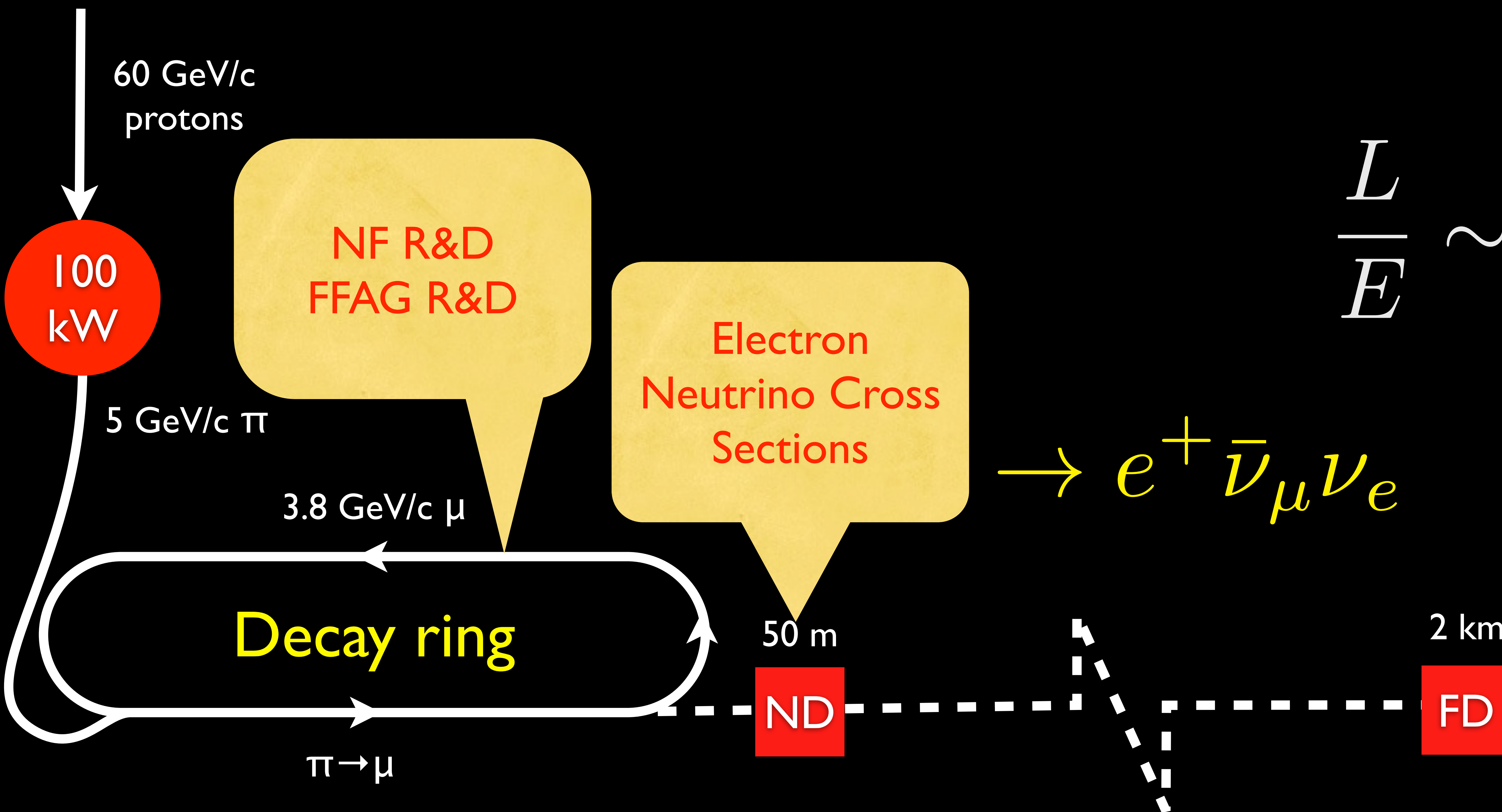
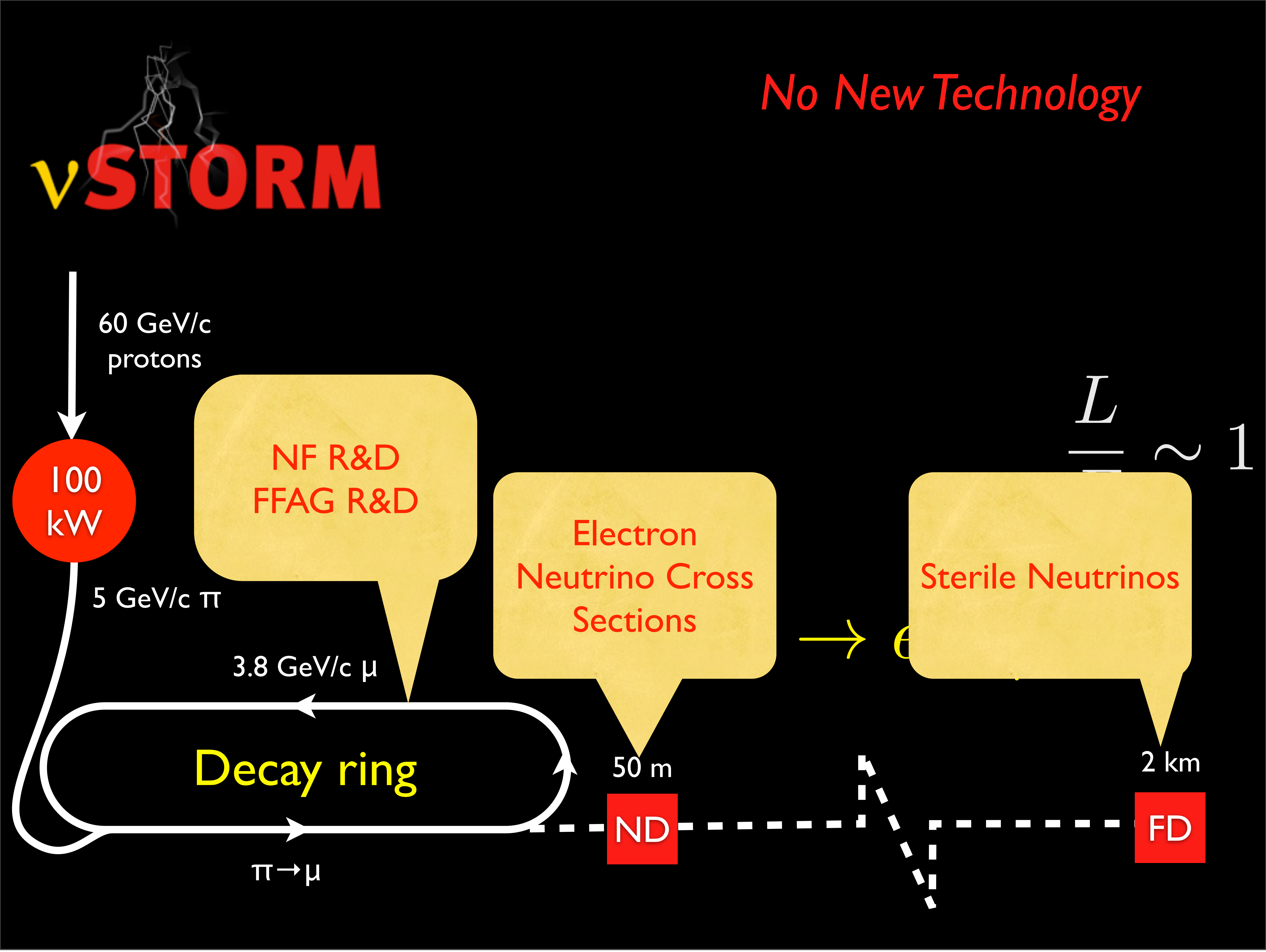


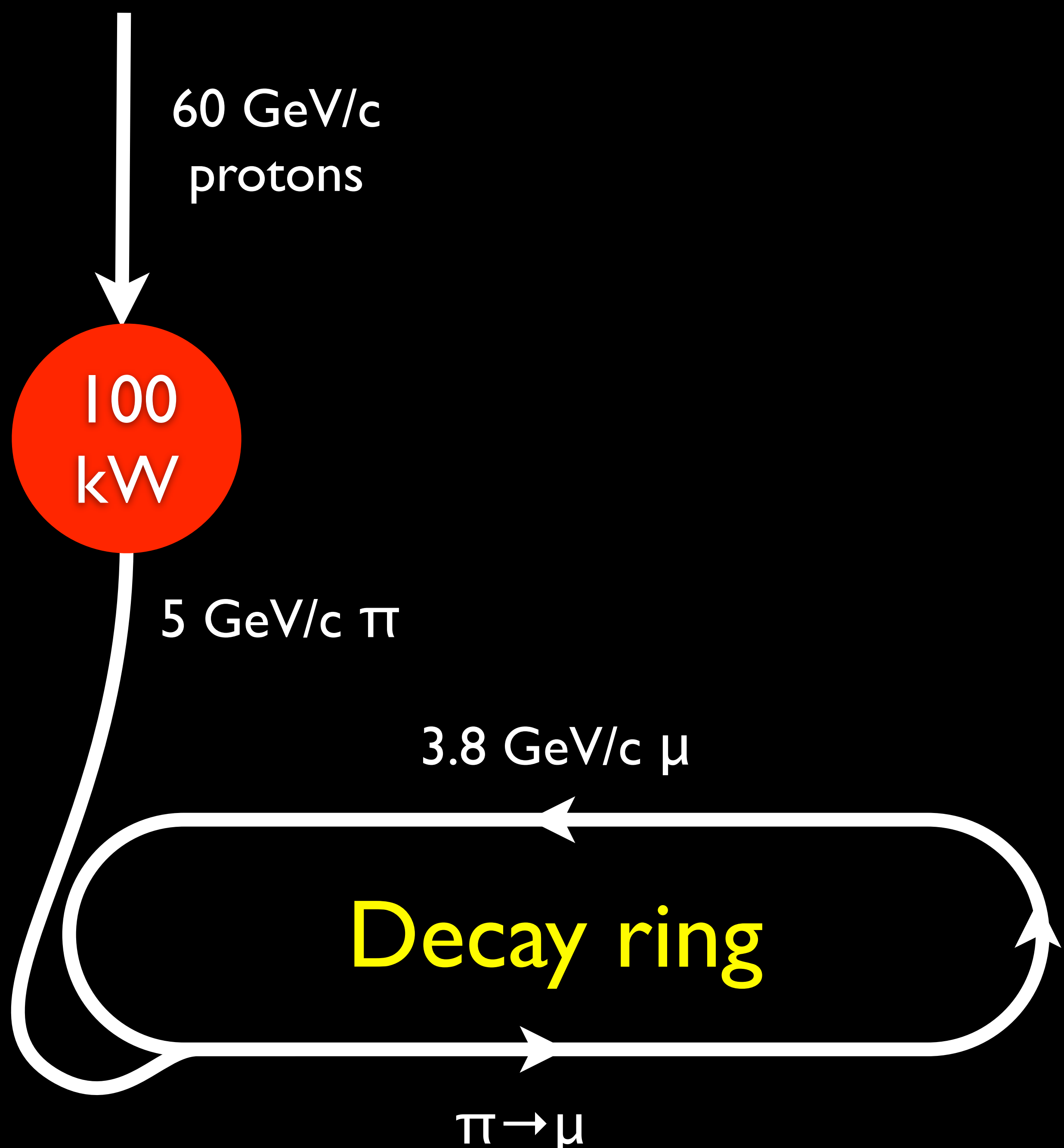
$$\frac{L}{E} \sim 1$$

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


No New Technology
νSTORM
60 GeV/c protons
100 kW
5 GeV/c π
NF R&D
FFAG R&D
Electron Neutrino Cross Sections
Sterile Neutrinos
3.8 GeV/c μ
Decay ring
π→μ
50 m
ND
2 km
FD

νSTORM

Accelerator



1. Target Station

- 60 GeV/c protons (e.g., FNAL MI/CERN SPS)
- 100 kW
- High-Z Ta target (considering C too)
- Horn pion collection; Li lens not ideal

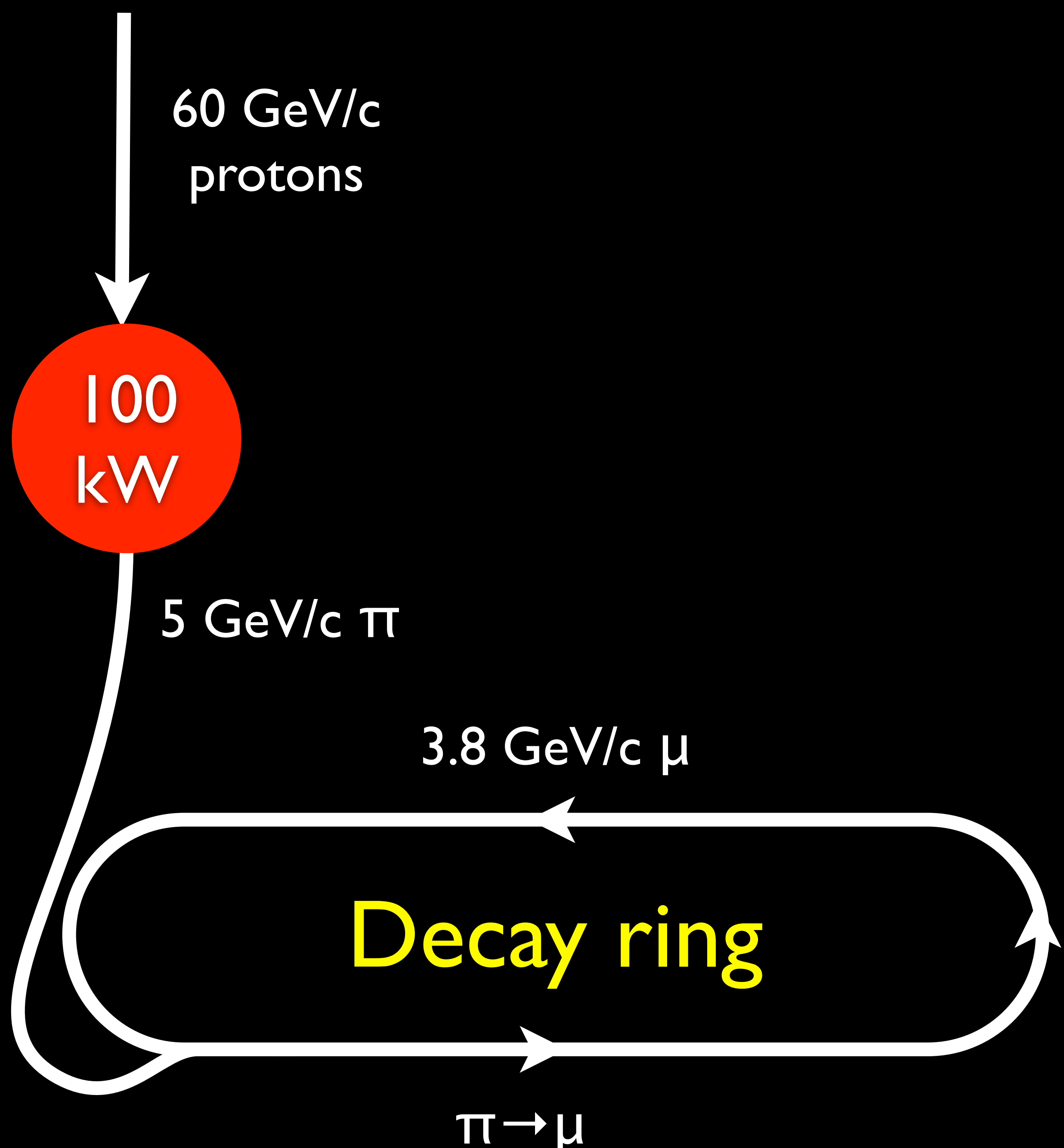
2. Collection/transport channel

- Quadrupole triplets for transport
- Two options:
  1. Stochastic injection of π
  2. Kicker with π → μ decay channel

3. Decay ring

- Two options with ~150 m straights:
  1. Large aperture FODO
  2. Racetrack FFAG
- Neutrino Factory beam instrumentation; anticipate few % flux uncertainty
  - BCTs
  - Magnetic spectrometer
  - Polarimeter

νSTORM



Accelerator

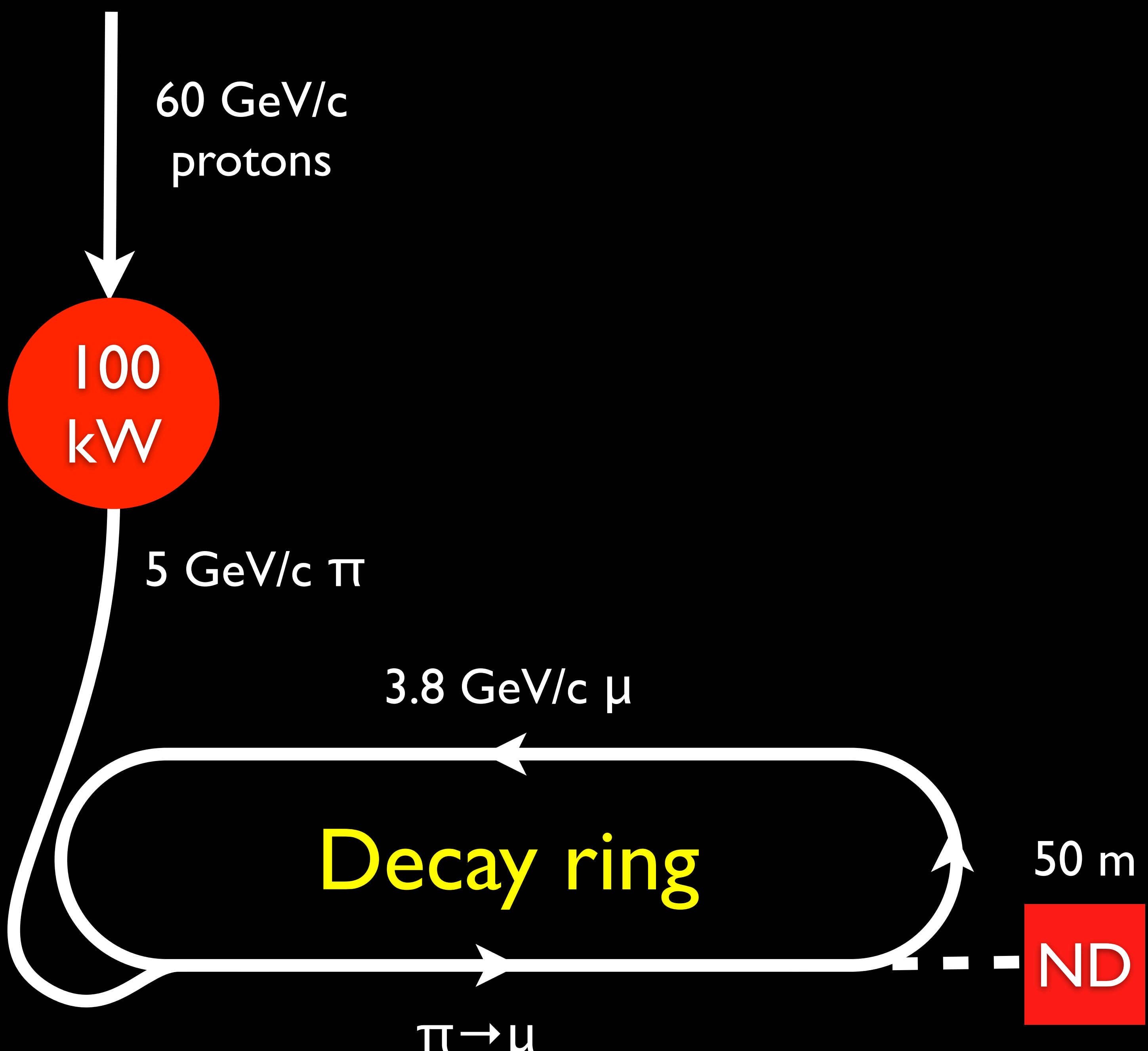
N_{μ} = (POT) X (π/POT) X $\varepsilon_{collection}$ X ε_{inj} X (μ/π) X $A_{dynamic}$ X Ω

- 10^{21} POT in 5 years of running @ 60 GeV in Fermilab PIP era
- 0.1 π/POT (FODO)
- $\varepsilon_{collection}$ = 0.8
- ε_{inj} = 0.8
- μ/π = 0.08 (γcτ X μ capture in π → μ decay) [π decay in straight]
  - Might do better with a π → μ decay channel
- $A_{dynamic}$ = 0.75 (FODO)
- Ω = Straight/circumference ratio (0.43) (FODO)

➡This yields ≈ 1.7 X 10^{18} useful μ decays

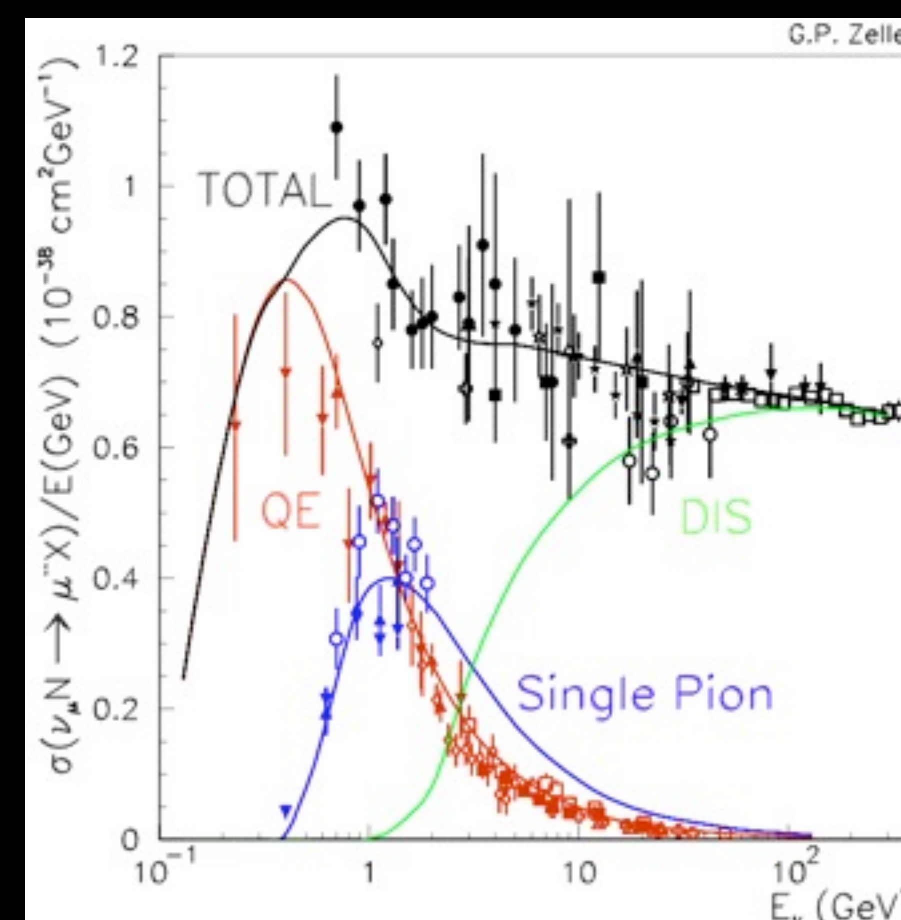
Near detector hall

νSTORM



Test beam facility

- Near detector for oscillation physics
- First electron neutrino test beam
- Precision cross section physics
    - Specifically, electron ν for future long-baseline expts
- *...whatever else you want*



Near detector hall

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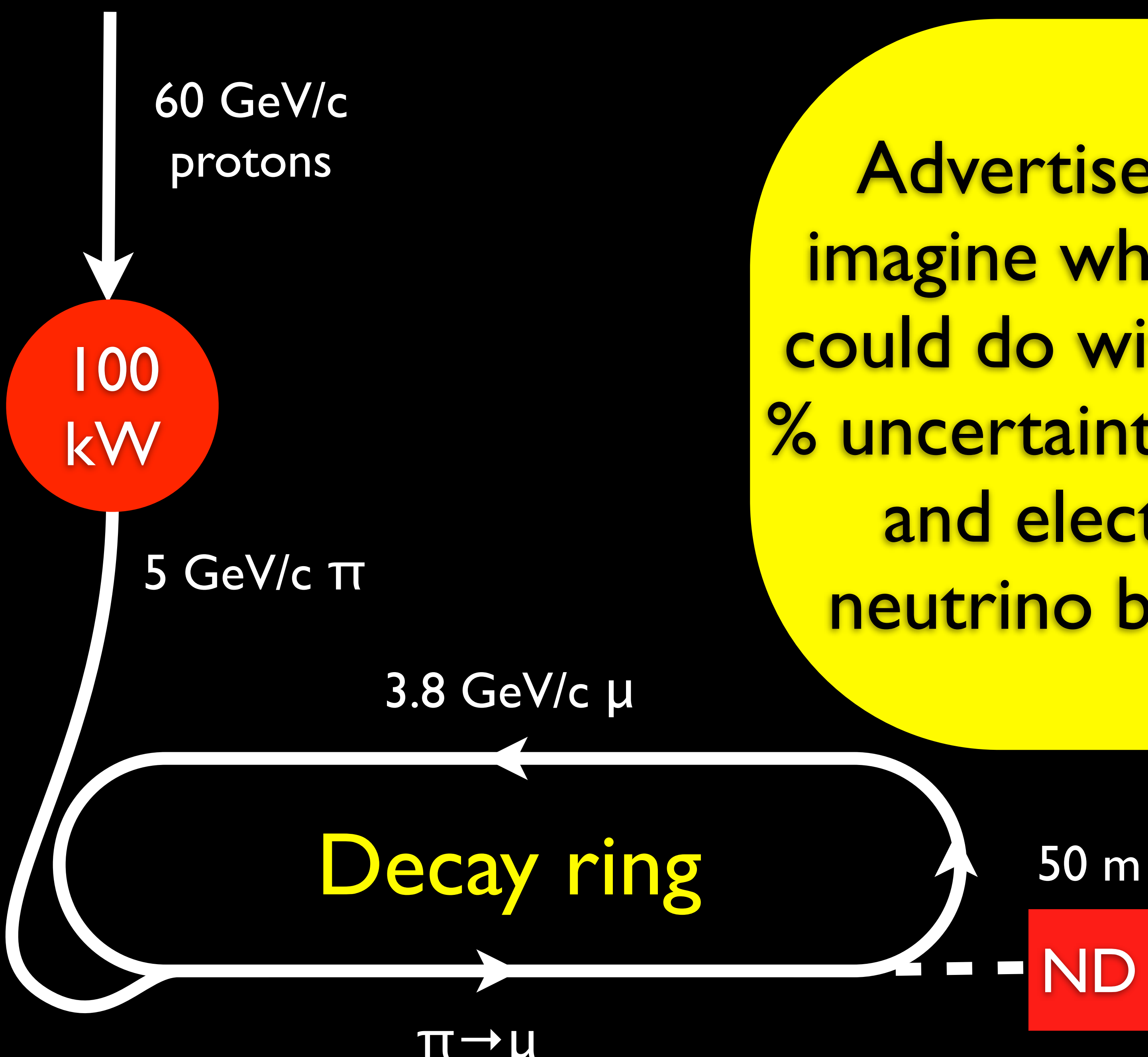

Test beam facility

- Near detector for oscillation physics
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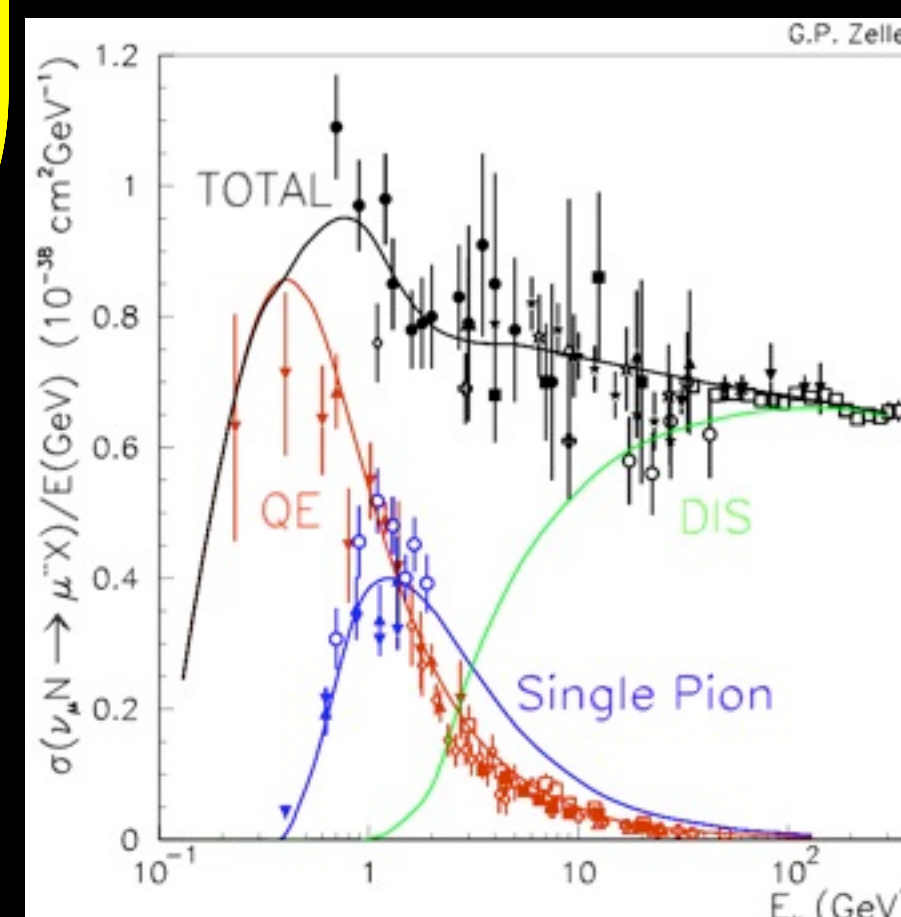
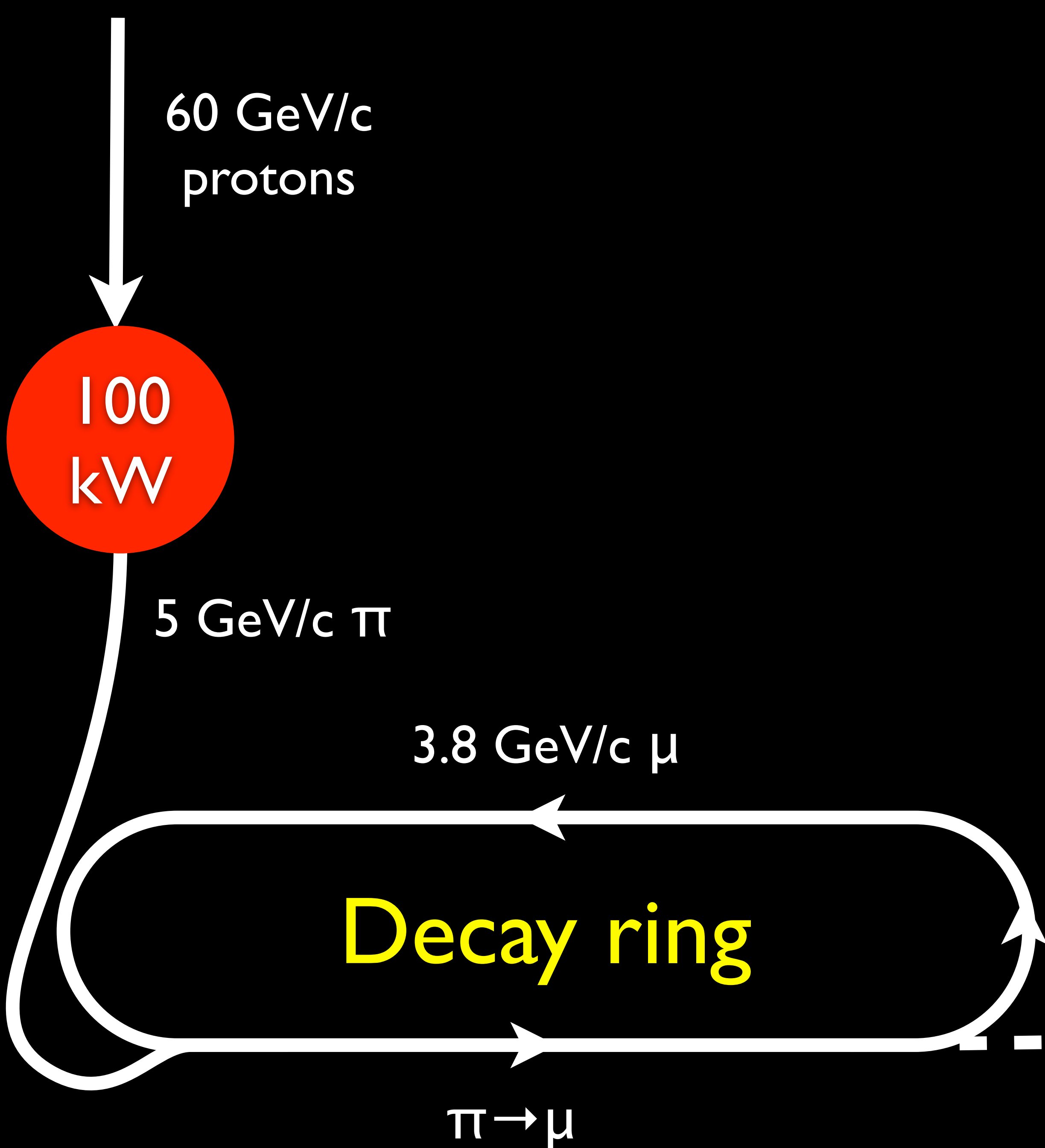
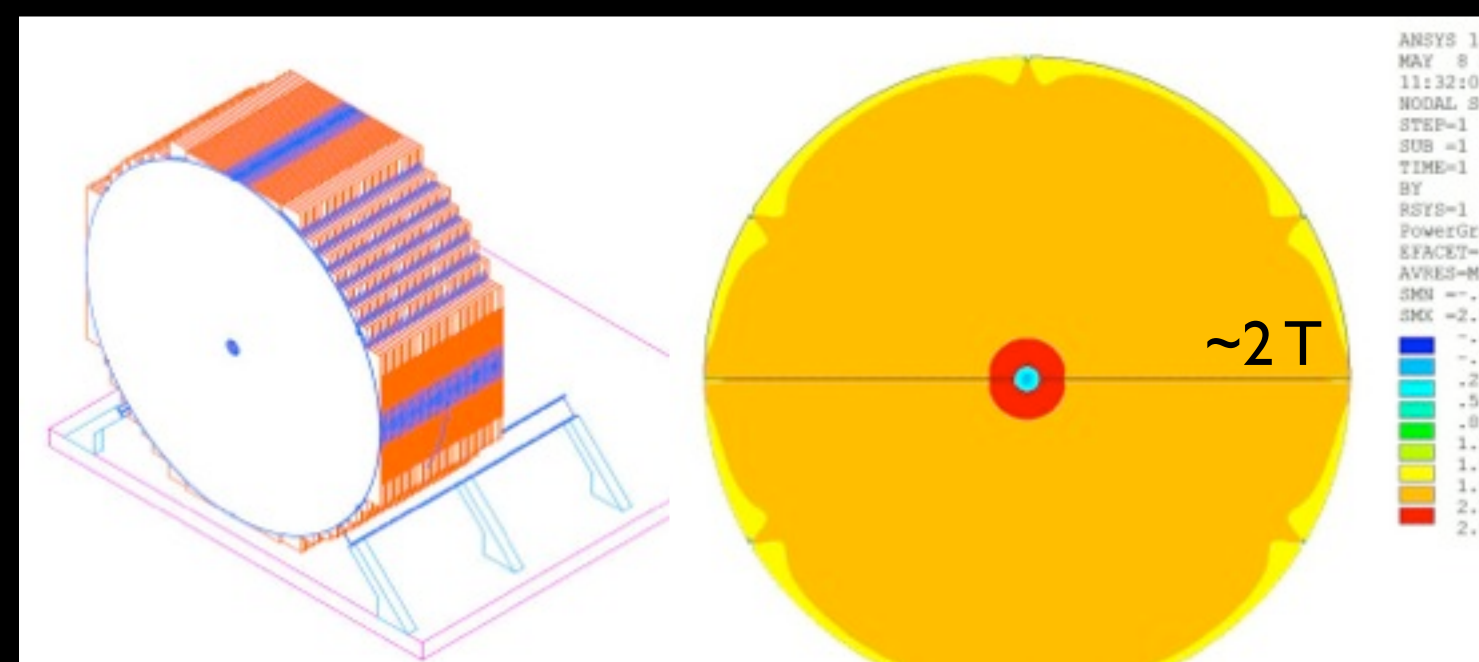
Advertisement: imagine what **you** could do with a few % uncertainty muon- and electron-neutrino beam!...

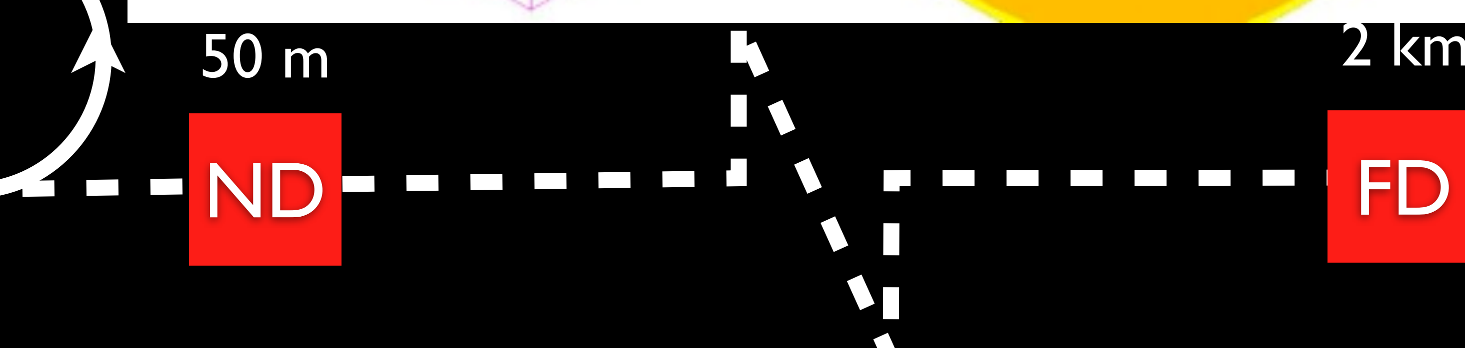


Far detector

- Magnetized Iron
  - 1.3 kT fiducial
    - Following MINOS ND ME design
    - 1-2 cm Fe plate
    - 5-6 m diameter
  - Utilize superconducting transmission line for excitation
    - Developed 10 years ago for VLHC
  - Extruded scintillator +SiPM







$$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

LSND:

$$\bar{\nu}_\mu \to \bar{\nu}_e$$

LSND:

$$\mathrm{CPT}(\bar{\nu}_\mu \to \bar{\nu}_e)$$

LSND:

$$\mathrm{CPT}(\bar{\nu}_\mu \to \bar{\nu}_e) = \nu_e \to \nu_\mu$$

LSND:

νSTORM:

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LSND:

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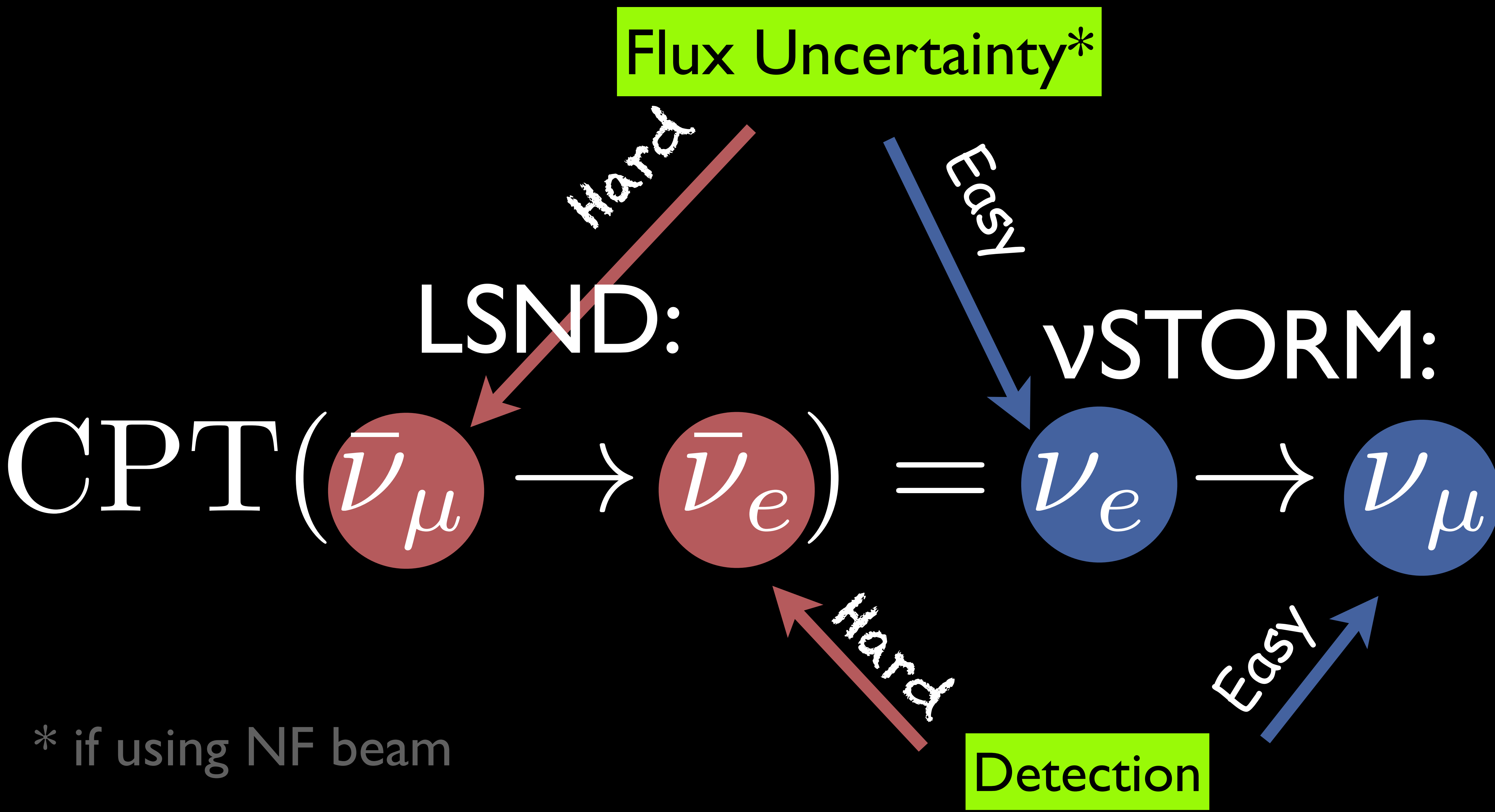
Hard

Easy

Detection


Flux Uncertainty*
Hard
Easy
LSND:
νSTORM:
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Hard
Easy
Detection
* if using NF beam

Flux Uncertainty*

Hard — Easy

LSND: $\qquad$ νSTORM:

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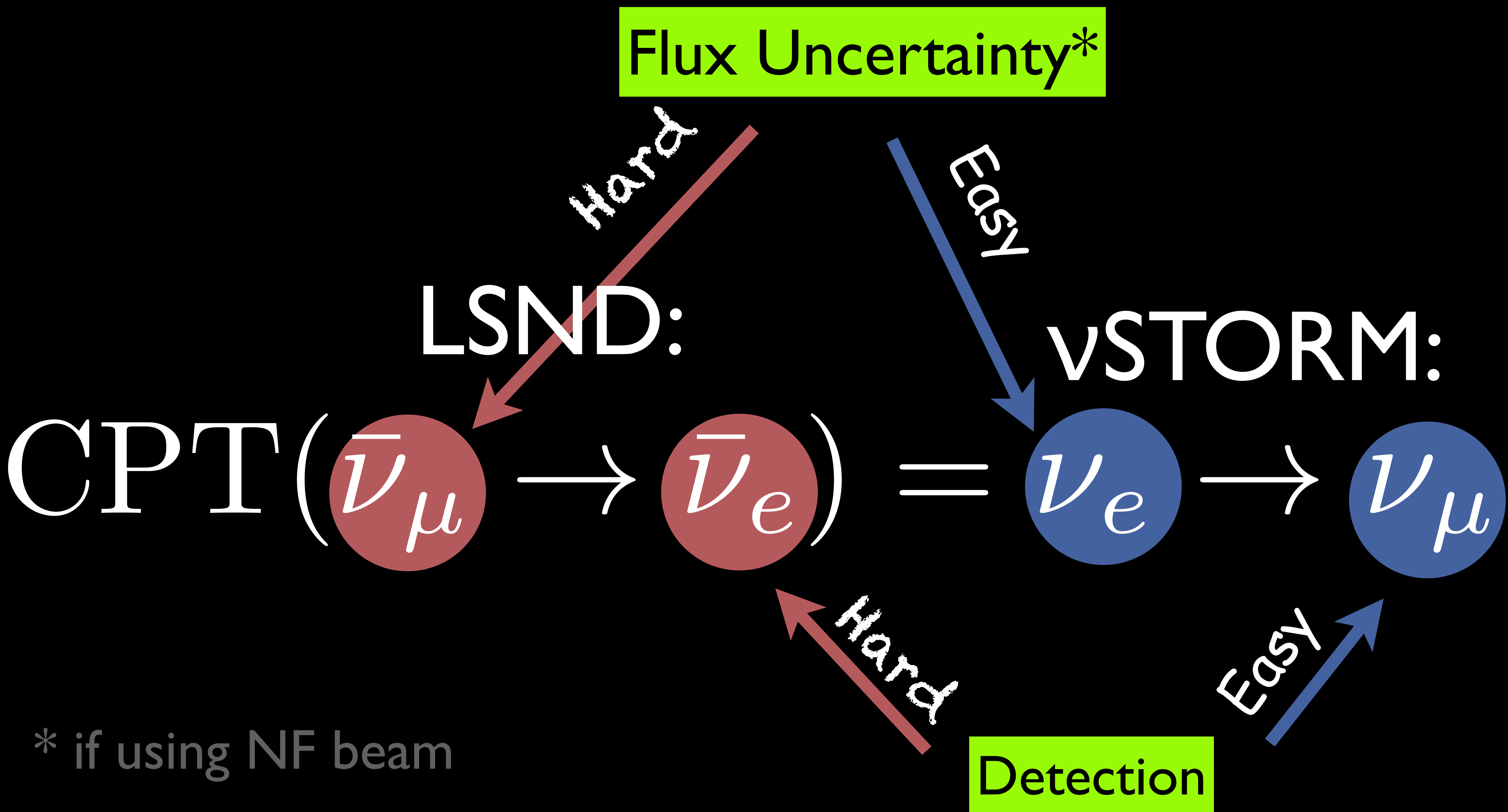
Hard — Easy

Detection

* if using NF beam

However, there is a anti-nu background:

$$\bar{\nu}_\mu \longrightarrow \bar{\nu}_\mu$$



$$\mathrm{CPT}(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \nu_e \rightarrow \nu_\mu$$

* if using NF beam

However, there is a anti-nu background:

$$\bar{\nu}_\mu \longrightarrow \bar{\nu}_\mu$$

hence magnetization

Physical motivation of cuts

Decaying particle	Channel	Interaction	Cut
μ^+	$\nu_e \to \nu_\mu$	CC	*(Signal; do not cut)*
	$\bar{\nu}_\mu \to \bar{\nu}_\mu$	CC	Curvature
	$\bar{\nu}_\mu \to \bar{\nu}_\mu$	NC	Range
	$\nu_e \to \nu_e$	CC/NC	
	$\bar{\nu}_\mu \to \bar{\nu}_e$	CC/NC	Range and double suppressed
	$\nu_e \to \nu_\mu$	NC	
π^+	$\nu_\mu \to (\nu_\mu \text{ or } \nu_e)$	CC/NC	Dipoles and timing with π's $c\tau$

Interactions

C. Tunnell (me)
Oxford

5 years, 2 km, 1.3 kt

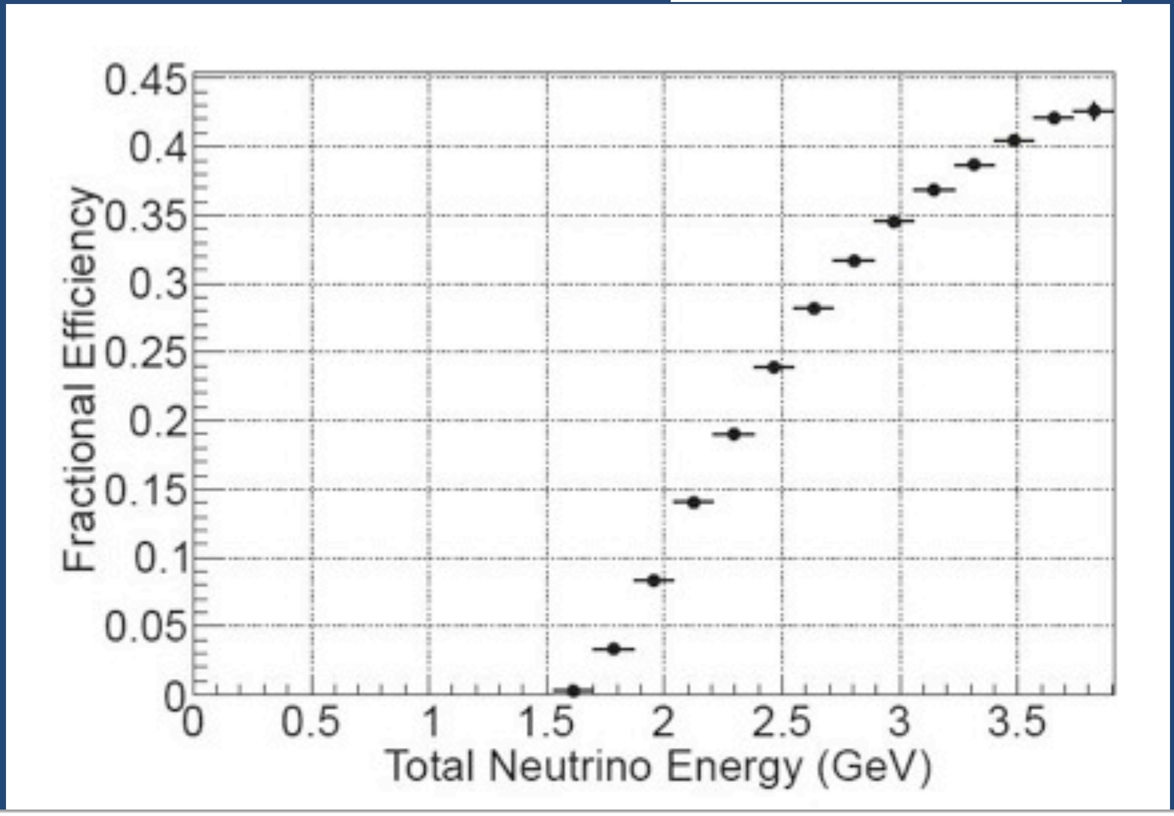
Decaying Particle		Channel	$N_{\text{osc.}}$	N_{null}	Diff.	$(N_{\text{osc.}} - N_{\text{null}})/\sqrt{N_{\text{null}}}$
	Signal	$\nu_e \to \nu_\mu$ CC	332	0	∞	∞
μ^+		$\bar{\nu}_\mu \to \bar{\nu}_\mu$ NC	47679	50073	-4.8%	-10.7
		$\nu_e \to \nu_e$ NC	73941	78805	-6.2%	-17.3
		$\bar{\nu}_\mu \to \bar{\nu}_\mu$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

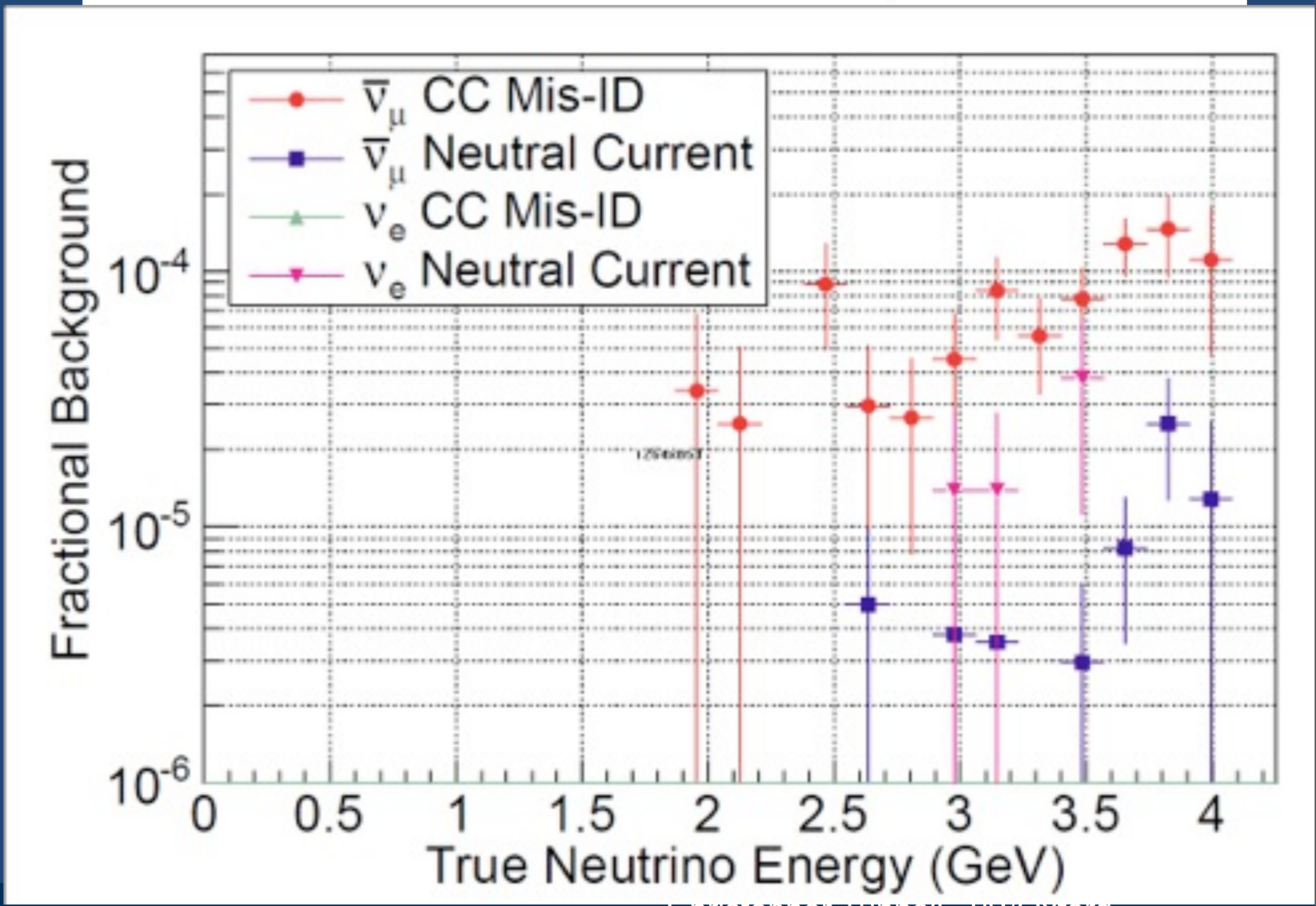
Simulation – ν_μ appearance

Ryan Bayes
Glasgow

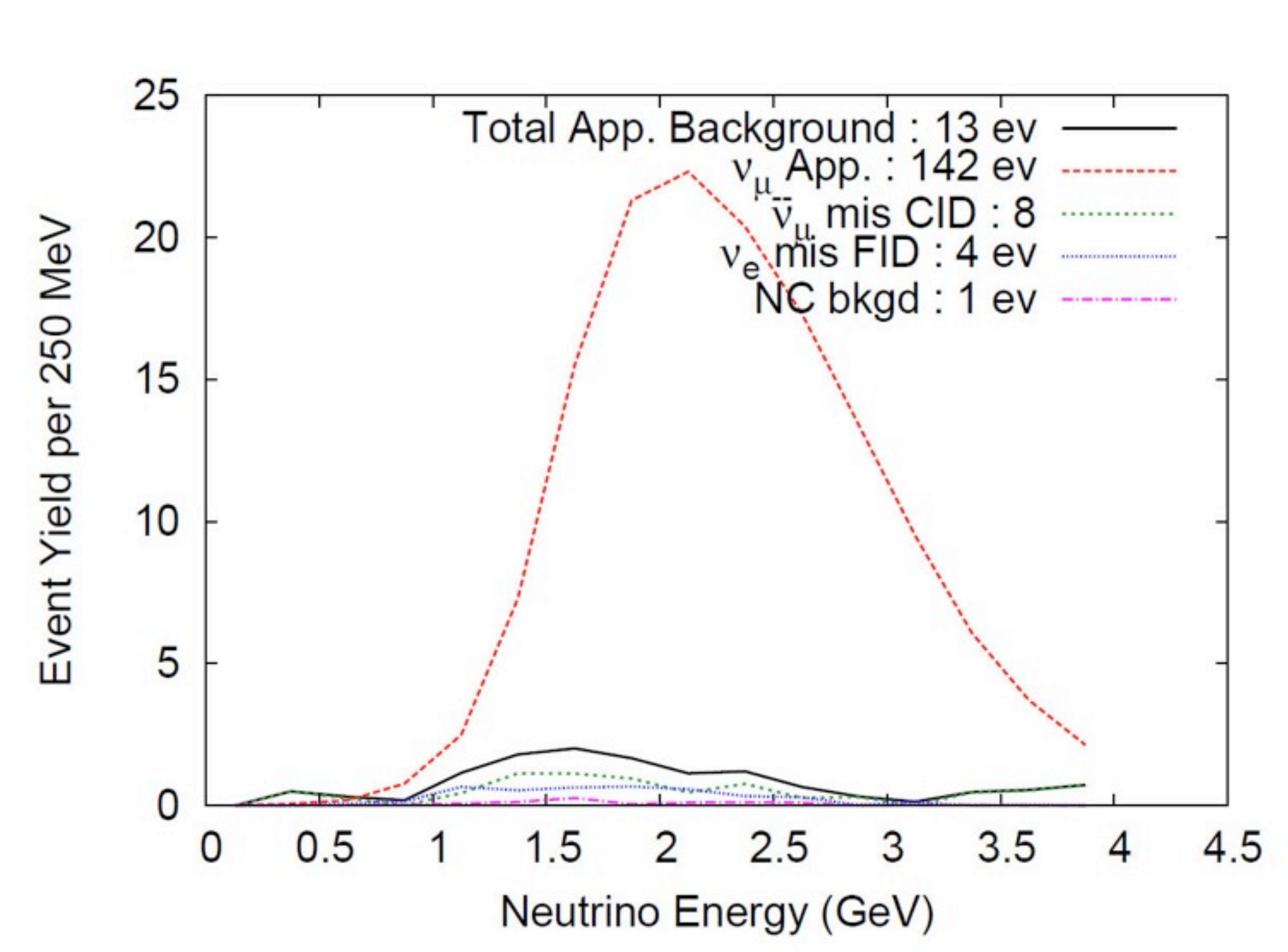
Full GEANT4 Simulation

- Extrapolation from ISS and IDS-NF studies for the MIND detector
- Uses GENIE to generate the neutrino interactions.
- Involves a flexible geometry that allows the dimensions of the detector to be altered easily (for optimization purposes, for example).
- Does not yet have the detailed B field, but parameterized fit is very good
- Event selection/cuts
  - Cuts-based analysis
  - Multivariate in development





Simulated event spectrum



Sensitivity

Sensitivity

S. Parke told me: “don’t show me plots until it’s 10σ!”

Sensitivity

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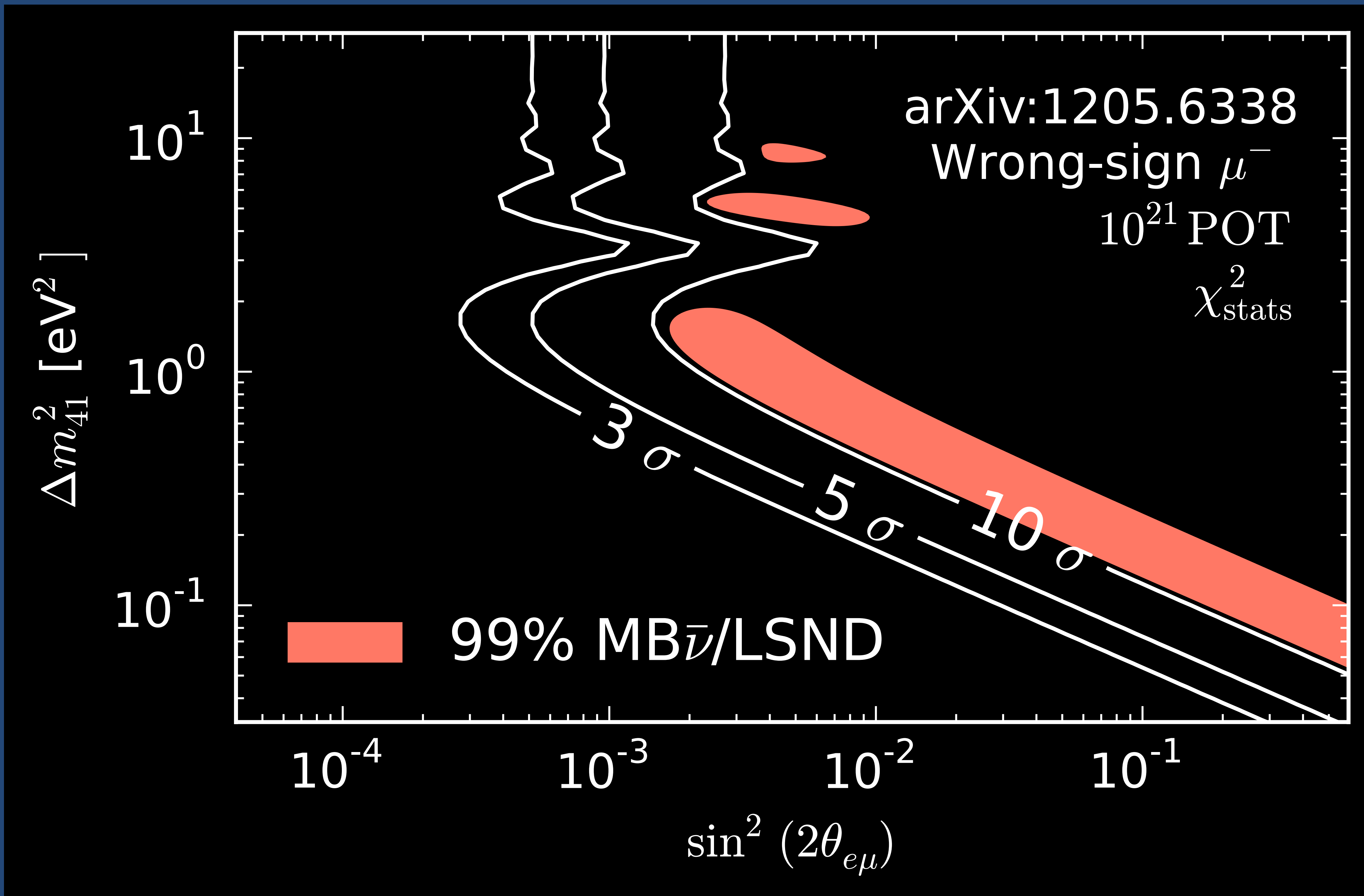
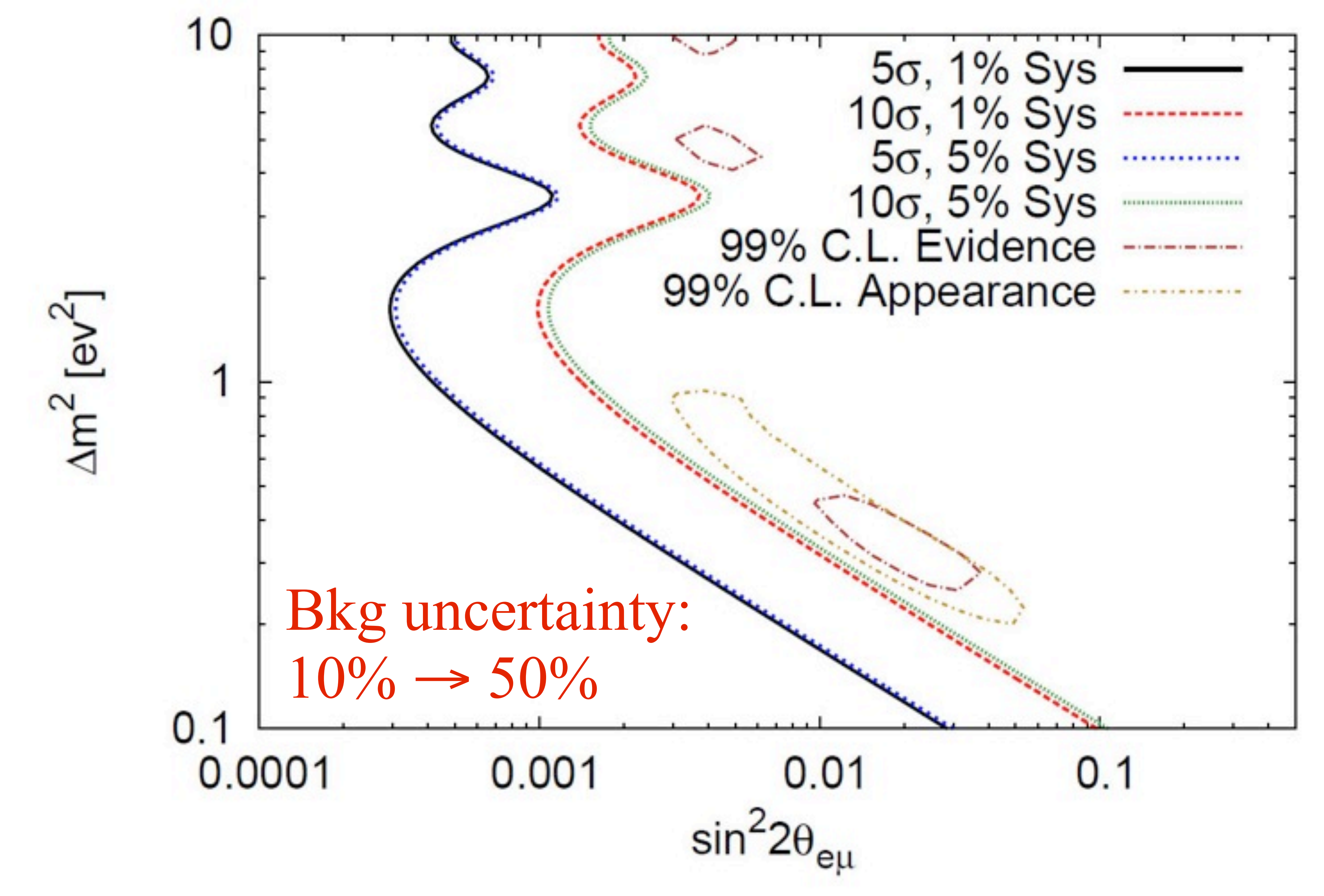
Experimentalist: “Can’t guarantee 10σ! Extinction asteroid in next decade 1/100k”

Frequentist Sensitivity



"Robustness" of appearance search
1.5 cm plate



Implementation

Implementation

- Good sterile neutrino program

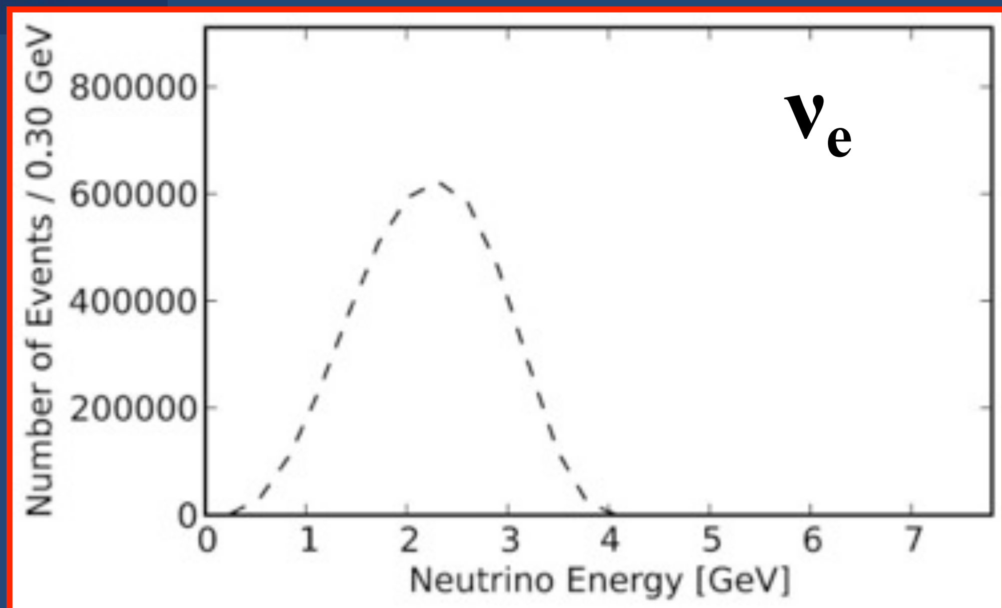
Implementation

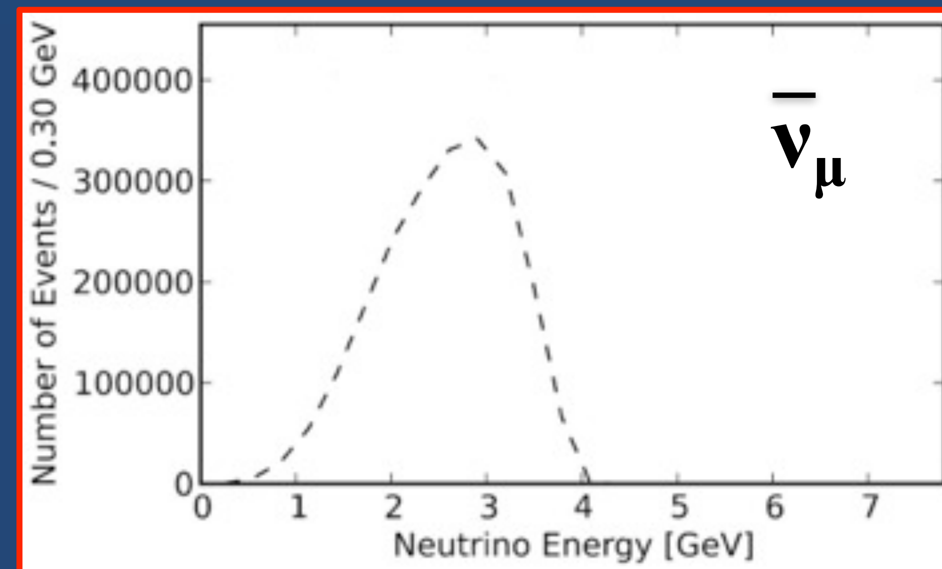
- Good sterile neutrino program
- Briefly on cross sections

Implementation

- Good sterile neutrino program
- Briefly on cross sections
- Then let’s talk *details*...

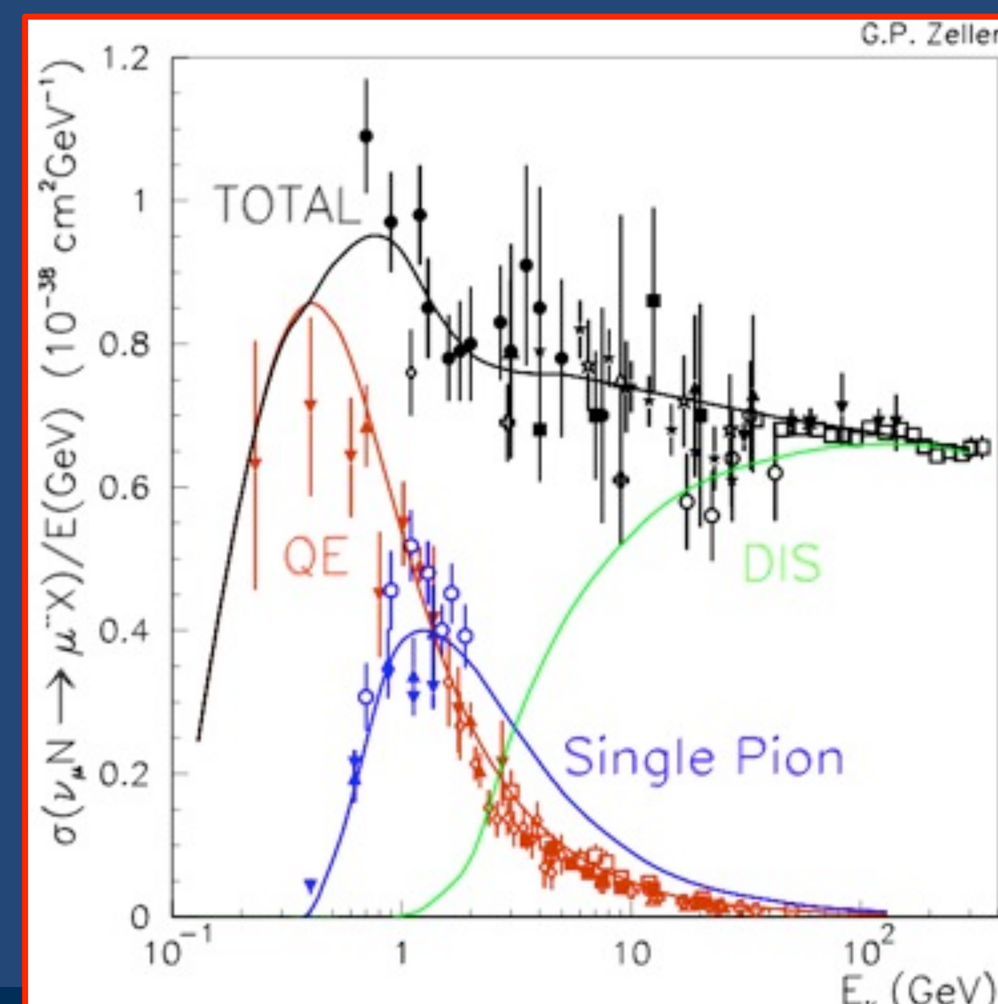
nuSTORM x-section measurement:





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

- Above (for stored μ^+):
  - nuSTORM event rates/100T at near detector 50 m from straight with μ^+ stored
- Right:
  - Almost no ν_e measurements
- Q: "How measure CP ratio w/o?"
- Detector optimization underway



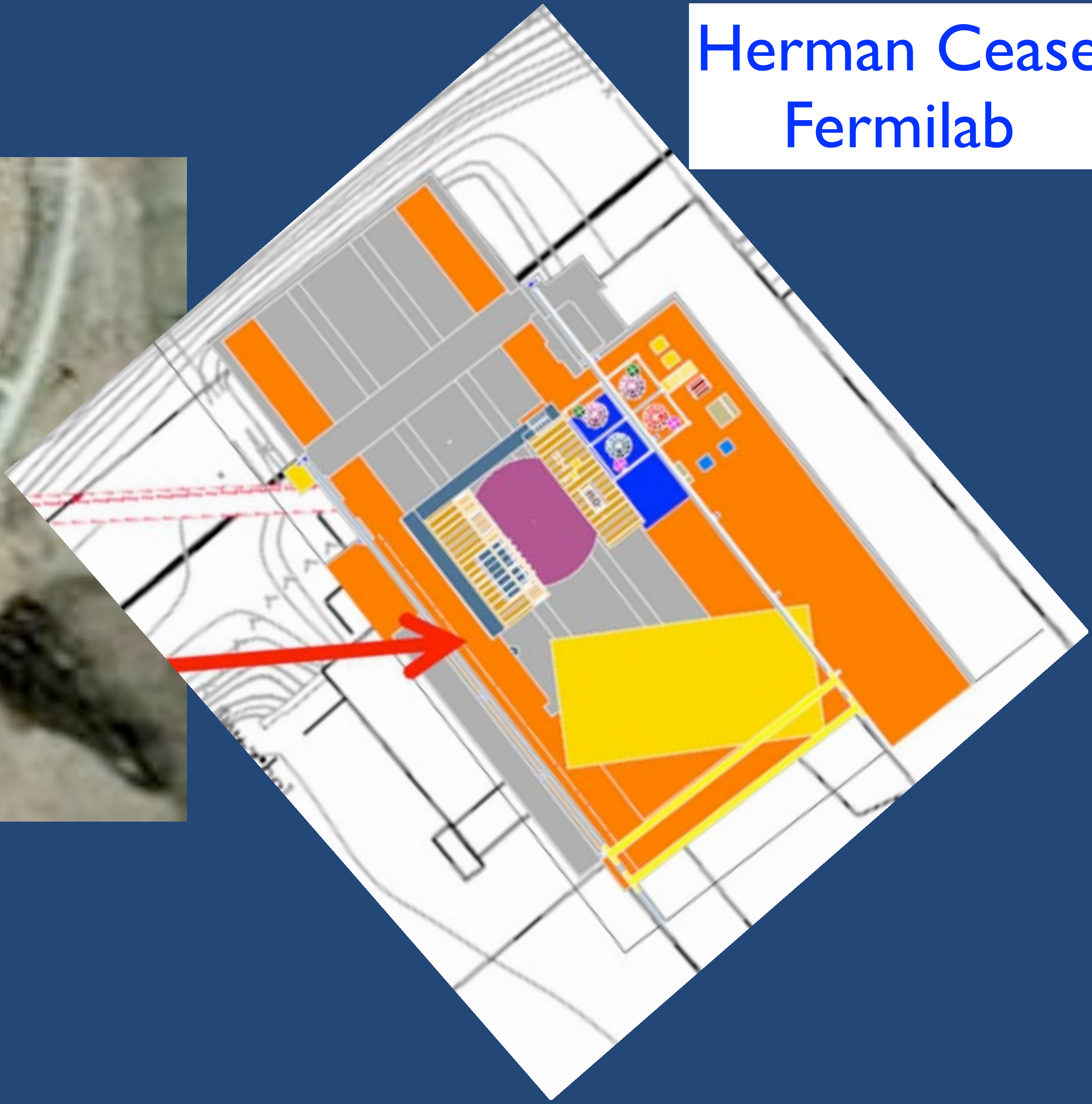
John Adams Institute for Accelerator Science

Imperial College London | Royal Holloway University of London | University of Oxford

FNAL Siting Plan

Steve Dixon
Fermilab FESS

Far Detector Hall and Detector(s)



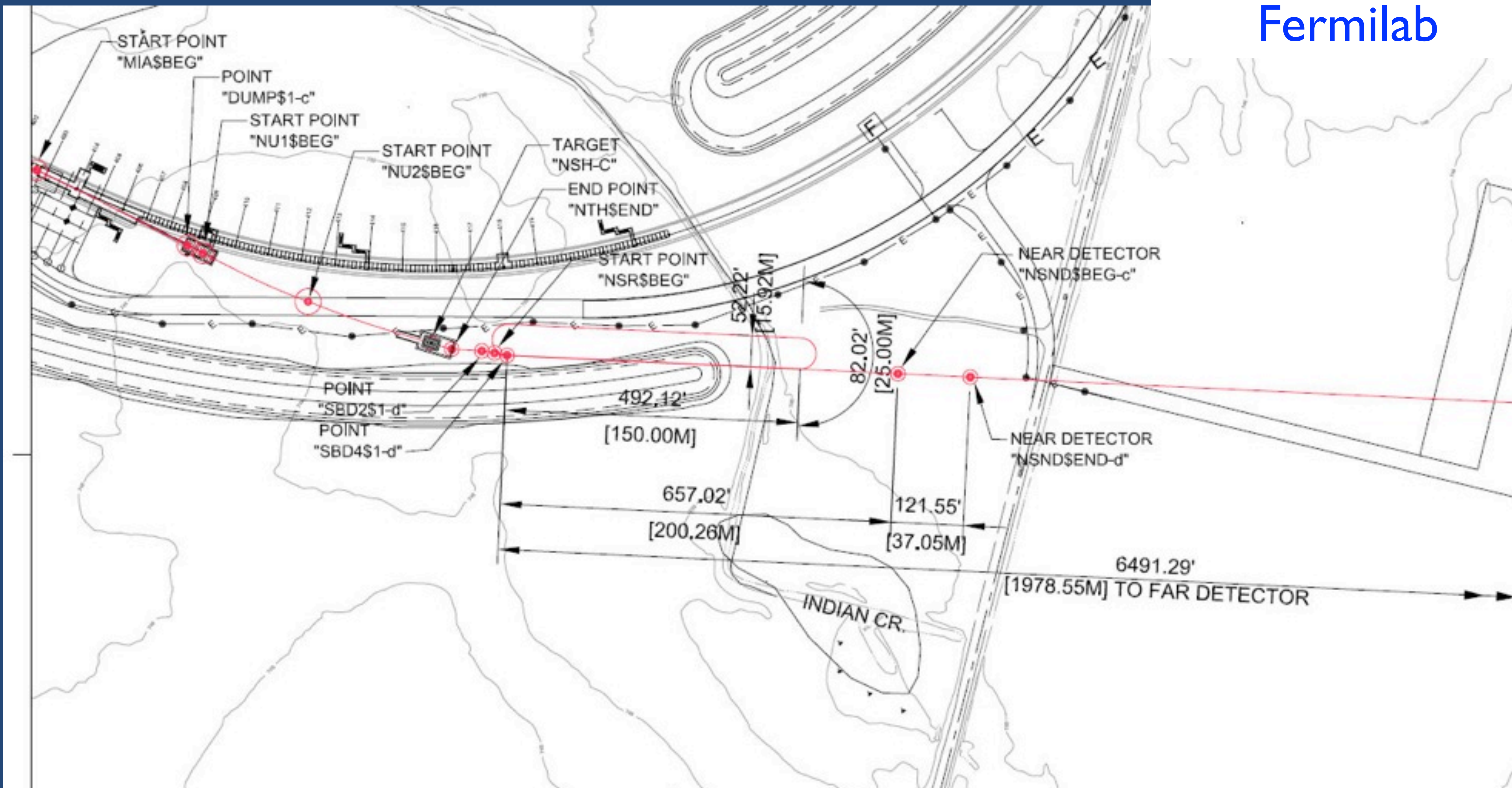
Herman Cease
Fermilab

MI-40 Beam Absorber + Proton beam line

John Adams Institute for Accelerator Science

Imperial College London | Royal Holloway University of London | University of Oxford

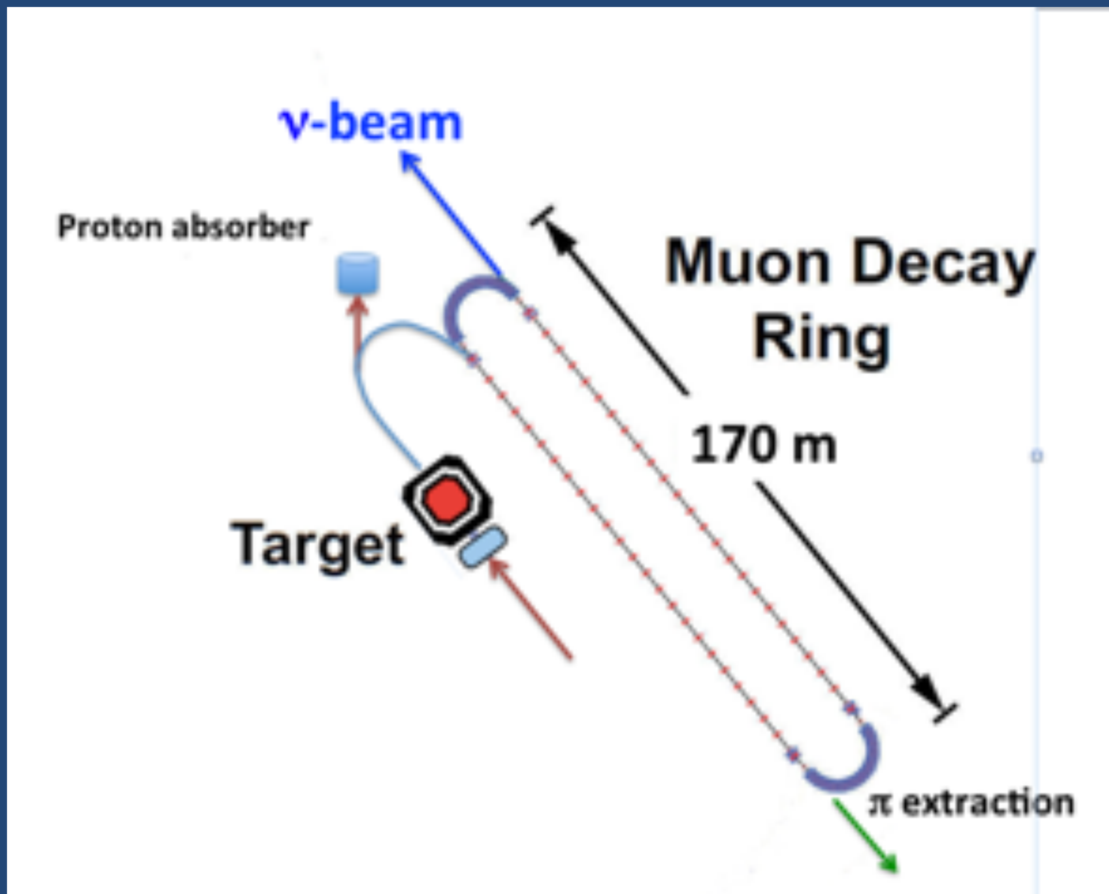
Michael Geelhoed
Fermilab



Wednesday, 13 March 13

CERN siting plan

Elena Wilder
CERN



The Collaboration

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[19]IPHC, Universit´e de Strasbourg, [20]University of Warwick

LOI submitted to Fermilab PAC, June 2012 (P=1028)

nuSTORM: input to the update of the European Strategy for Particle Physics, July 2012

JAI John Adams Institute for Accelerator Science

Imperial College London | Royal Holloway University of London | University of Oxford

Ongoing & future work

Alan Bross
FNAL

➢Facility

- Targeting, capture/transport & Injection
  - Need to complete 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.

Ongoing & future work II

Alan Bross
FNAL

➢Detector simulation

- For oscillation studies, continue MC study of backgrounds & systematics
  - Start study of disappearance channels
  - Look in detail at all sources of backgrounds: CR, atmospheric ν, etc.
  - Will lead to detector (FAR) optimization
- For cross-section (& general ν interaction physics) measurements need detector baseline design
  - Learn much from work for LBNE & IDS-NF (both detector & physics)
    - ➢Increased emphasis on ν_e interactions, however

(see Bross FNAL seminar for more)

Important steps to move forward

- nuSTORM workshop at CERN:
  - 26th and 27th March 2013
  - Goal is finalisation of EoI to CERN
  - **https://indico.cern.ch/conferenceDisplay.py?confId=219460**
- nuSTORM workshop at Virginia Tech.:
  - 14th and 15th April 2013
  - Goal is to lay foundations for preparation of proposal to FNAL
    - ➡ for June PAC and Snowmass
  - PDR through FESS
  - http://cnp.phys.vt.edu/meetings/nuSTORM2013.html
- Information:
  - NUSTORM mailing list on listserv.fnal.gov

Neutrinos from Stored Muons (νSTORM): Expression of Interest

CERN

Contents

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- The 3 legs of nuSTORM physics:

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  ➡ Developing new beams today means you have them *tomorrow*

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Note
that this is
blatantly Alan
Bross's slide!

Costing

Costing model

Basis of Estimation

- Utilized data from the LBNE CD1 (95% CL estimate on TPC ≈ $0.9B) and extrapolated to nuSTORM components
  - Primary beam line
  - Target Station
  - Beam absorber
  - Conventional Facilities
    - Civil construction
    - Used FESS estimates from μ2e CD1 review where appropriate
- The above are, of course, fully loaded and escalated
- Magnet Costs based on Strauss & Green model

Cost based on LBNE costs
Fully loaded and escalated

Sub System	Cost M$[1]
Primary Beam Line	24
Target Station	56
Transport Line	14
Decay Ring	82
Near Hall	29[2]
Far Detector	24[3]
Sub Total	**229**
Project Office	34[4]
Total	**263**

[1]No allowances made for reuse of existing equipment

[2]Near Hall sized for multiple experiments & ND for SBL oscillation physics

[3]FD cost based on MINOS as-built & EUROnu costing for MIND + full burdening + escalation & no allowance for existing FD Hall

[4]Assumes LBNE estimate of ≈ 15% (including contingency)