Concept:
A Neutral Rich Sign Selected 3D Horn Focusing System

NF03 Kick-off Meeting
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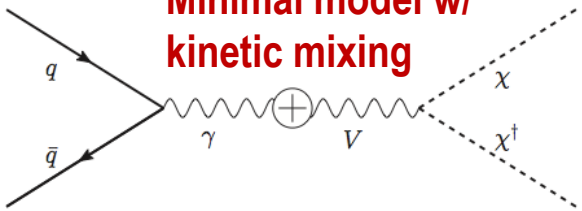
Introduction

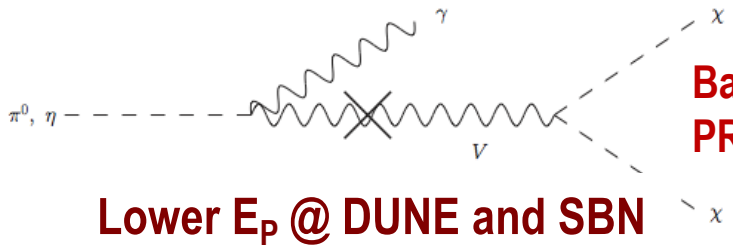
- Precision neutrino property measurements, like DUNE or Hyper – K, require
  - High proton beams to generate large number of neutrinos
  - Large mass far detectors assisted with powerful near detector system
- Provides excellent opportunities for beyond the SM physics
  - Many BSM topics can be explored
  - Of these, searches for BSM particles produced from high flux proton beams, such as Low Mass Dark Matter, HNL, ALP, etc, could bring new insights & discovery opportunities
  - Neutrinos would be the significant background to these

Light DM Production at High Intensity Accelerator

- LDM can be produced through coupling between dark photon and the SM photon through processes like



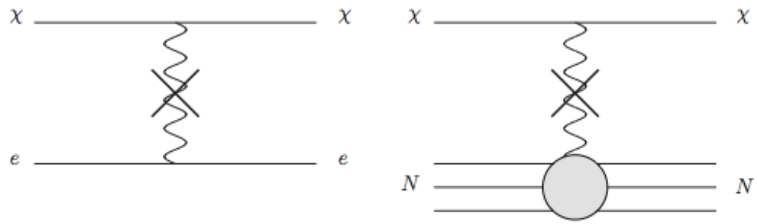
Higher E_P @ DUNE



Battell *et al.*, PRD80, 095024

Lower E_P @ DUNE and SBN

- Detection of DM (elastic):



- How does a DM event look in an experiment?:

High Intensity Proton Beam

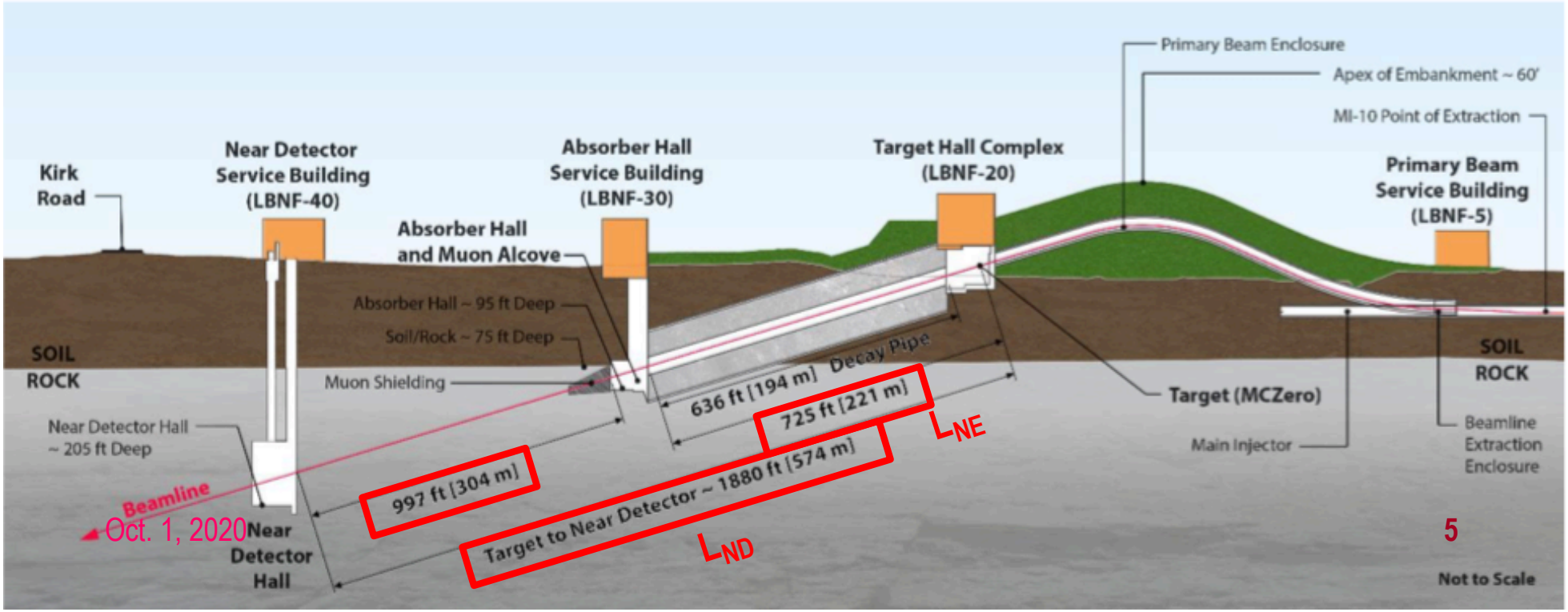
- Signatures look virtually identical to that of neutrinos

Main Goals to Achieve

1. Maximally enhance the signal flux
2. Minimize neutrino background
3. Coexist with precision neutrino experiments

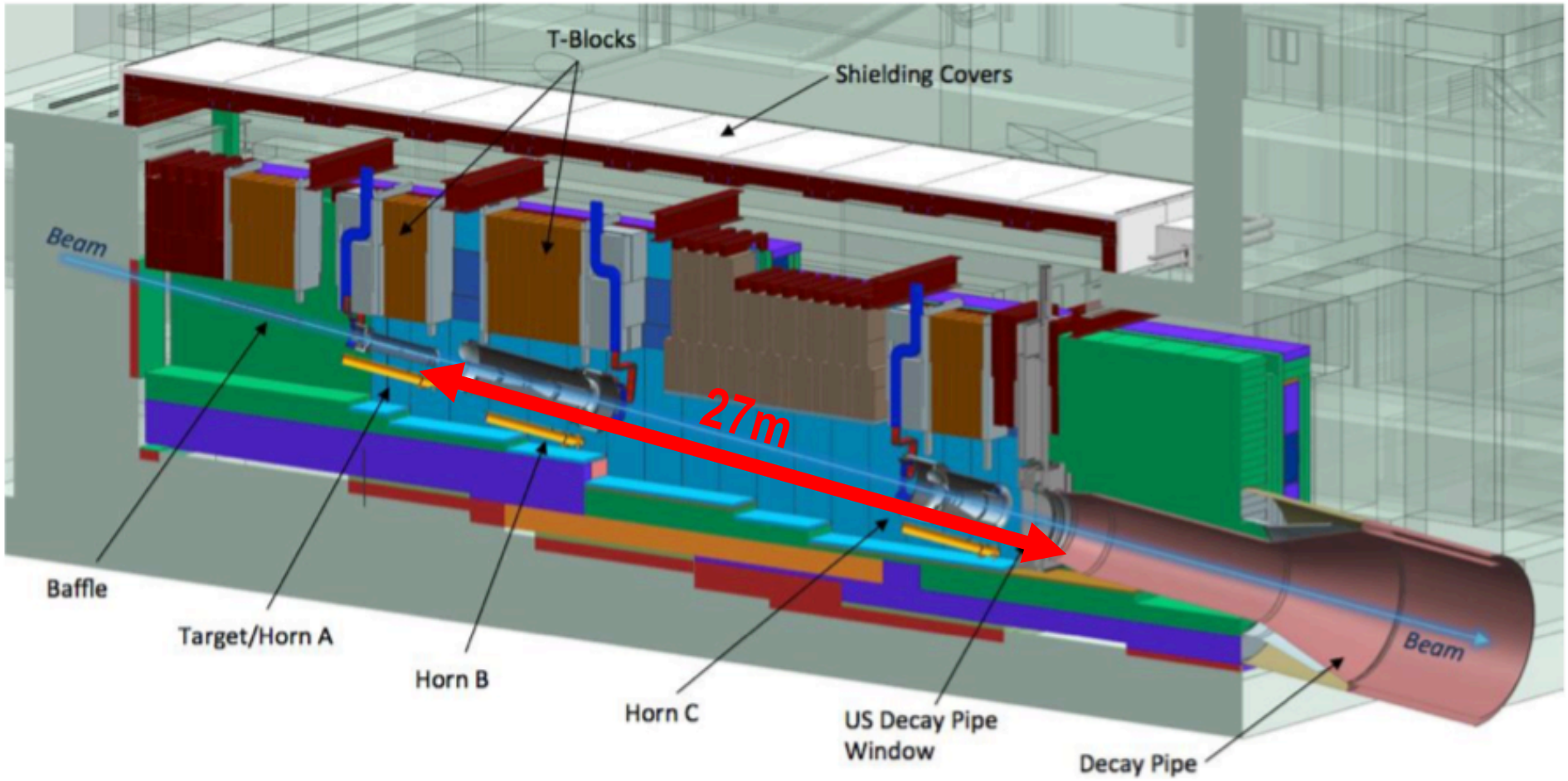
DUNE ND Complex

- Signal flux inversely proportional to the square of the distance from the neutrino target to the detector
- Fermilab's main injector shoots 1.2MW (upgradable to 2.4MW in late 2020's) of proton beams at energies 60 – 120GeV, depending on optimized neutrino beam energies onto a 2m long graphite target embedded inside horn A
- Some crucial distances
  - Target to ND : **574m (L_{ND})**
  - Charged meson decay pipe length: **194m** starting at **27m** downstream of the target **(L_{NE}~220m)**
  - From the start of the beam dump (hadron absorber) to ND: **304m**



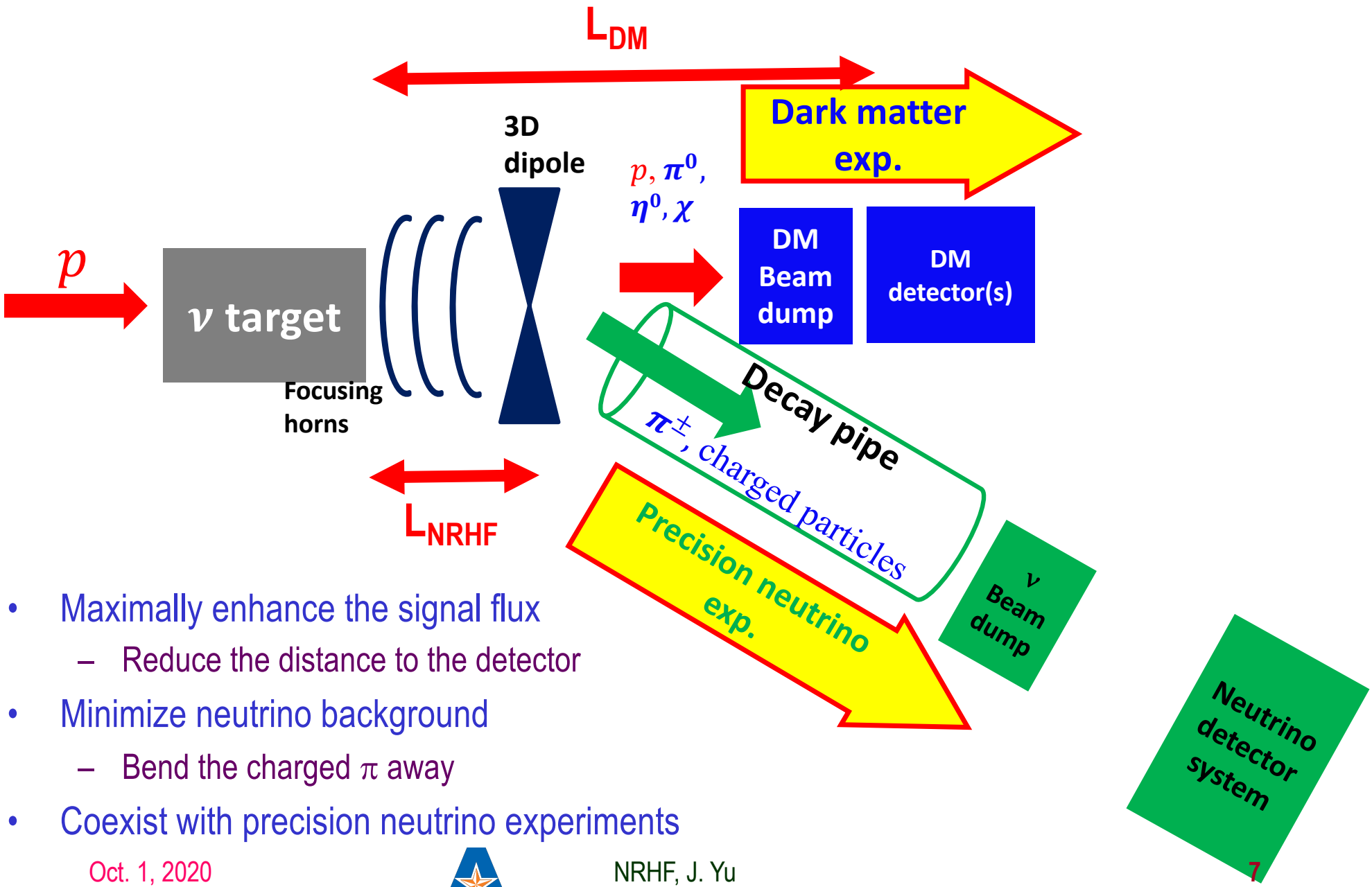
Ex: DUNE ND Target and Horn Complex

Consists of the baffle, 16mm diameter, 2m long cylindrical graphite target, three focusing horns, 194m long meson decay pipe and the beam dump/hadron absorber



I am not proposing to make any changes to DUNE!!

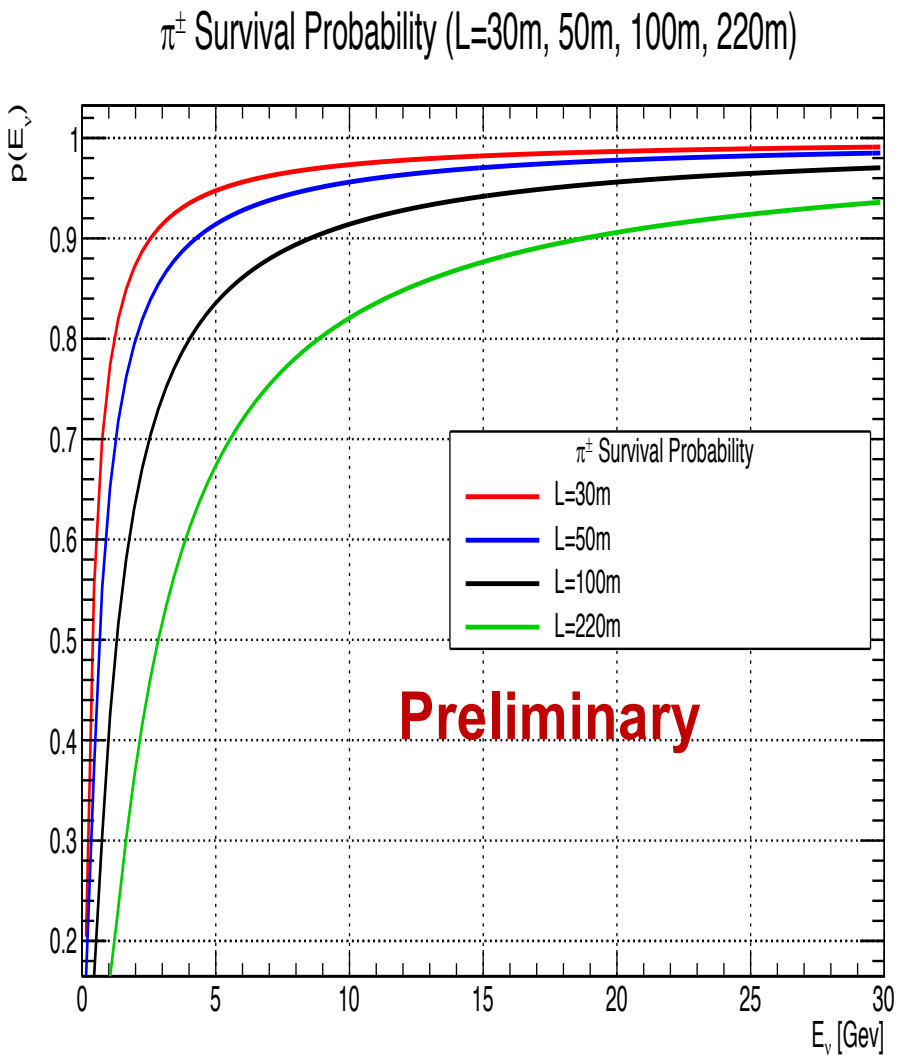
Neutral-Rich 3D Horn Focusing (NRHF) System

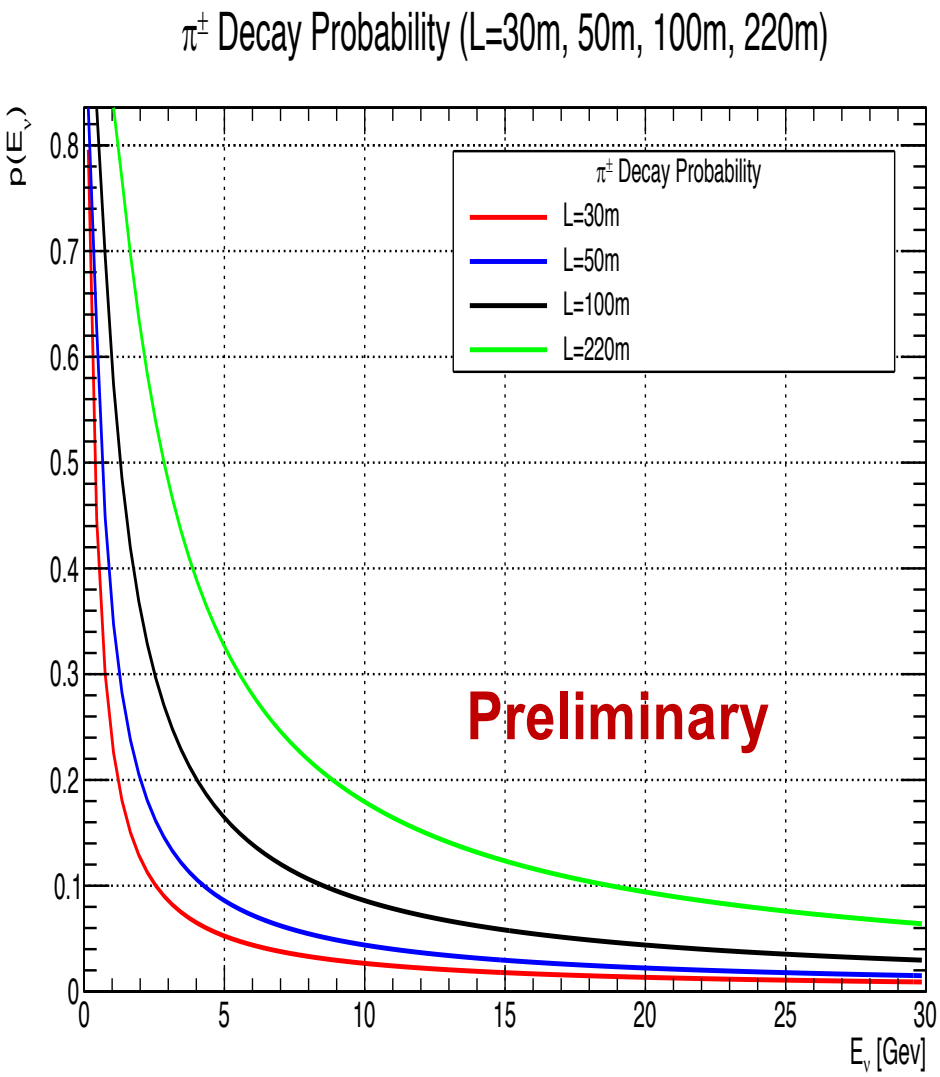


- Maximally enhance the signal flux
  - Reduce the distance to the detector
- Minimize neutrino background
  - Bend the charged π away
- Coexist with precision neutrino experiments

NRHF π Survival & Decay Prob. Comp

ν bck flux depends on the decay fraction before the bend





S/B ratio vs Eν

- Signal with NRHF can be written as

$$S_{NRHF} = S_{NE} \cdot \left(\frac{L_{ND}}{L_{DM}} \right)^2 \quad \text{DUNE} \quad S_{NRHF} = S_{DUNE} \cdot \left(\frac{574}{L} \right)^2$$

- The neutrino background flux at NRHF can be written as:

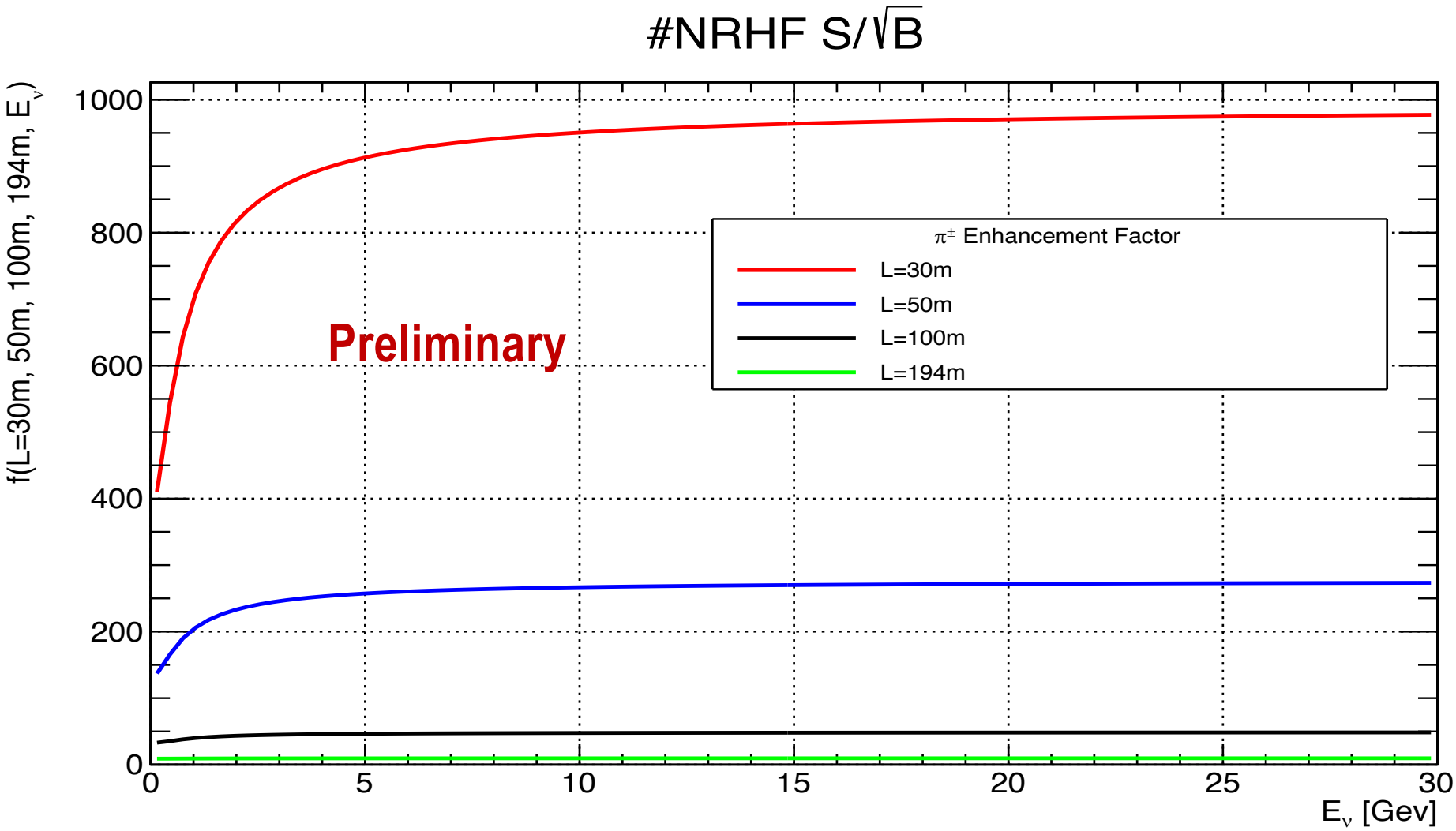
$$B_{NRHF} = N_\pi \left(E_{\pi^\pm} \right) \left[1 - p_{NRHF} \left(E_{\pi^\pm} \right) \right] = B_{NE} \frac{\left[1 - p_{NRHF} \left(E_{\pi^\pm} \right) \right]}{\left[1 - p_{NE} \left(E_{\pi^\pm} \right) \right]}$$

- The signal to background ratio wrt DUNE is

$$\frac{S_{NRHF}}{\sqrt{B_{NRHF}}} = f_{en}\left(L, E_\nu \right) \frac{S_{DUNE}}{\sqrt{B_{DUNE}}} = \left(\frac{574}{L_{DM}} \right)^2 \sqrt{B_{NE} \frac{\left\{ 1 - \exp\left[-b\left(E_\nu \right) L_{NE} \right] \right\}}{\left\{ 1 - \exp\left[-b\left(E_\nu \right) L_{NRHF} \right] \right\}}} \frac{S_{DUNE}}{\sqrt{B_{DUNE}}}$$

$$b\left(E_\nu \right) = 4.49 \times 10^{-3} \cdot \frac{\sqrt{4E_\nu^2 - 0.14^2}}{E_\nu^2}$$

S/B ratio enhancement vs Eν (L=30m, 50m, 100m and 220m - DUNE)

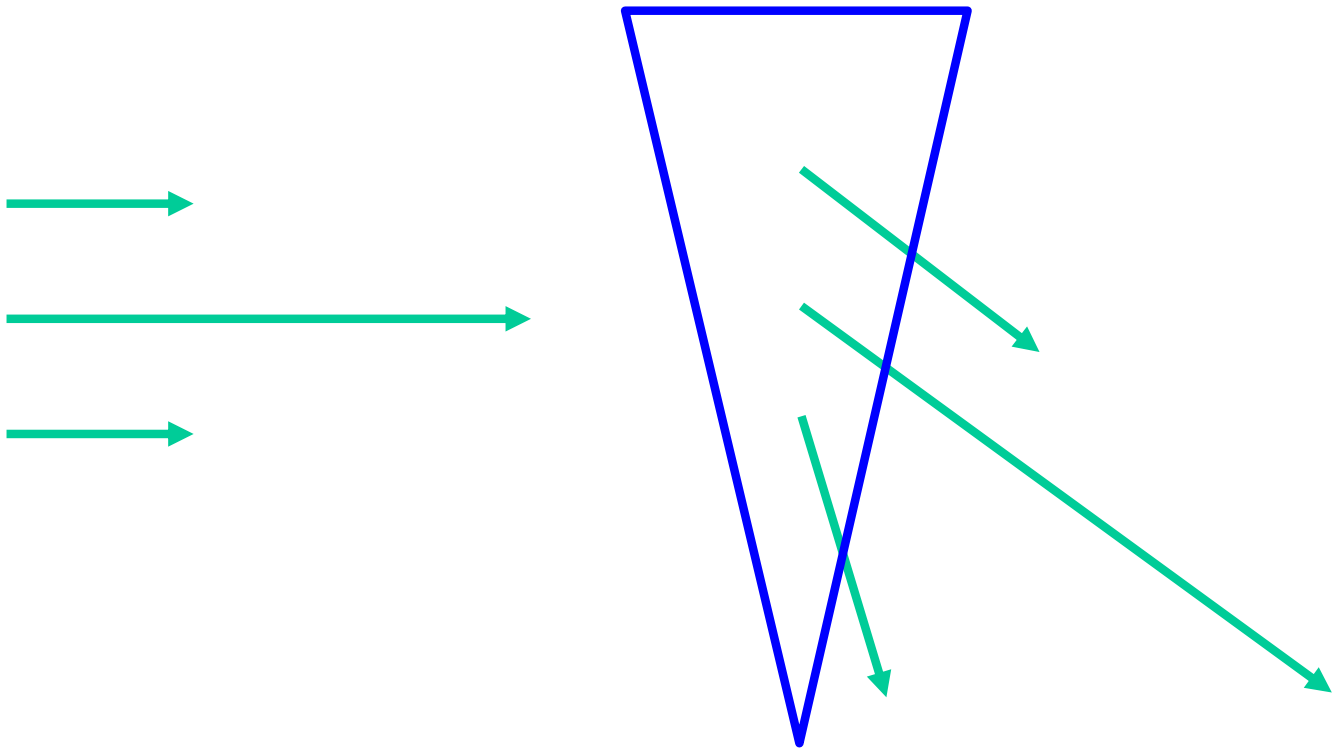


Summary

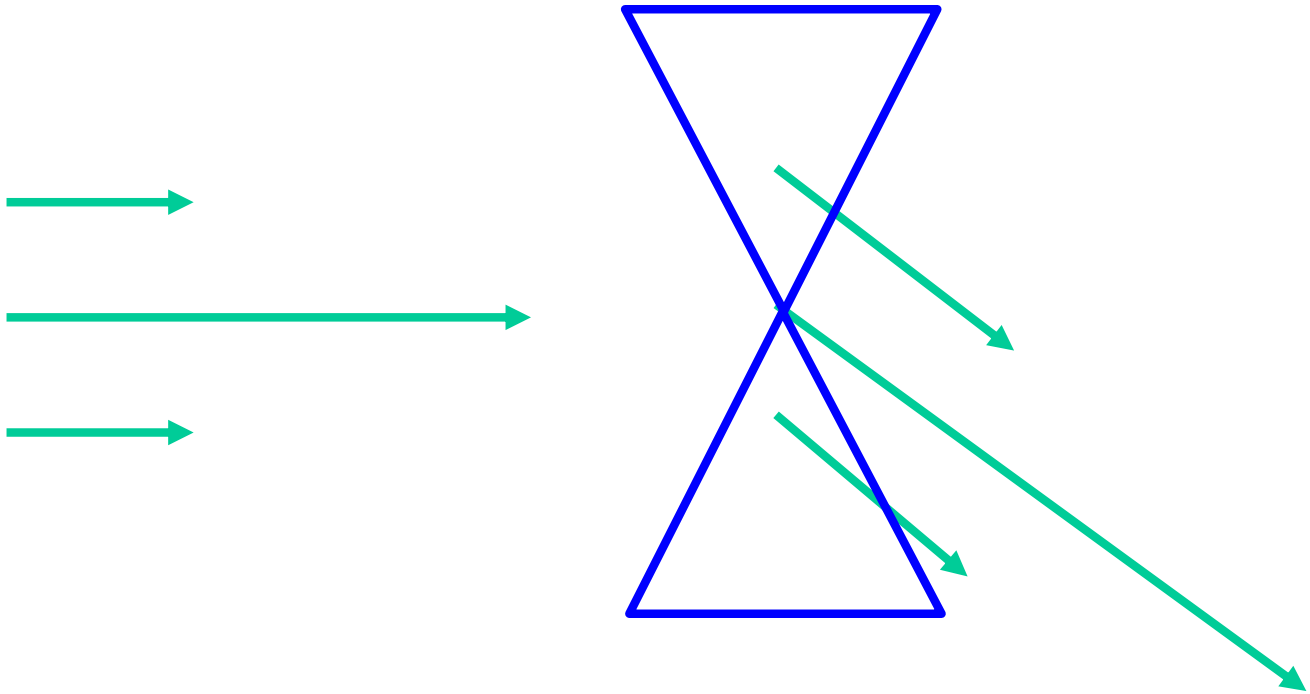
- NRHF benefits greatly from shortened distance from the beam source to the detector
  - Gain in the signal flux inversely proportional to the square of the ratio of distance to the detectors
- Neutrino flux reduction has energy dependence
  - The reduction is greater as a function of the neutrino energy ➔Different impacts to the mass of the DM
  - Shortened decay distance also contributes but slower than the gain in the signal flux
- Combined S/√B enhancement factor of 2 – 4 orders of magnitude possible ➔ worthwhile the cost
- Key element for NRHF is the 3 dimensional dipole

Back Up

Issue with the Conventional 2D Dipole



How does the 3D dipole have to work?



But this is still in 2D, just symmetric!

This shape has to be all around the azimuth!!

Do not yet know how to accomplish this field shape!