DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Future Dark Matter Searches with LBNF/DUNE

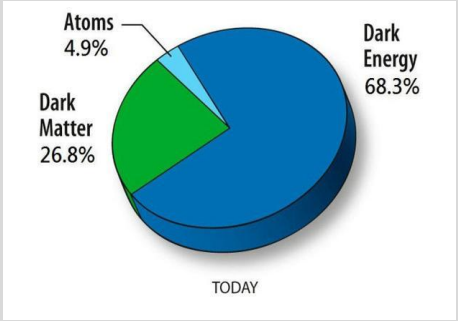
Animesh Chatterjee
Dark Sectors Workshop 2016
April 28-30, 2016

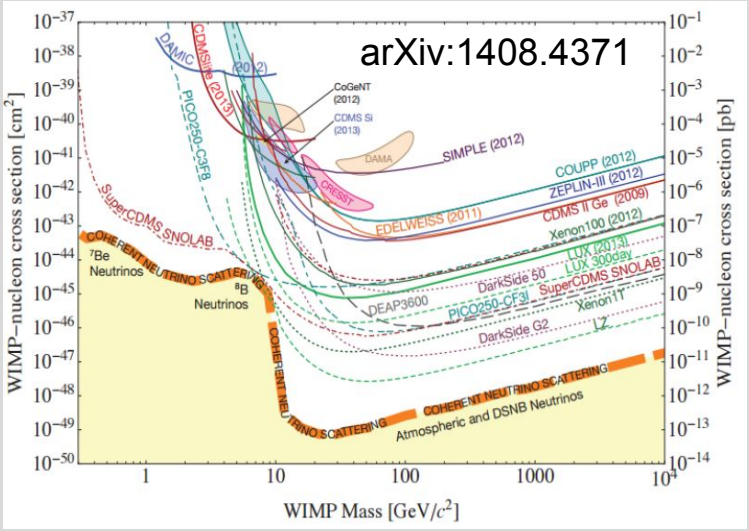
Outline

- Introduction and Motivation
- Benchmark model
- Dark Matter search at Neutrino Experiment
- Dark Matter search at DUNE
- Outlook

We know that dark matter exists … but we don't know much about it.

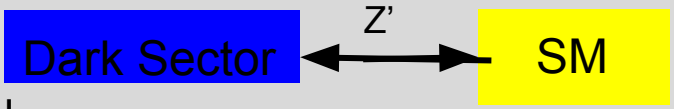
- Dark matter has manifested its presence so far only via gravitational interactions with surrounding baryonic matter.
- Weakly Interacting Massive Particles(WIMPs) are the leading particle physics candidate for the dark matter.
- Several Direct and Indirect Dark matter detection experiment put limits on Dark matter mass and cross-section.
- Not seen yet any direct search for the dark matter mass > few GeV.
- Hence, accelerator produced sub-GeV dark matter search will also be good probe.





Benchmark model

- Vector portal model: For lighter dark matter masses to give significant contribution to the relic density, a lighter mediator is needed.

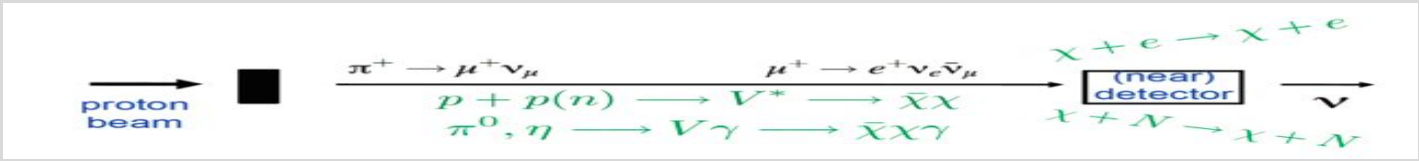


- Models of sub-GeV dark matter typically involve scalar or fermionic DM and vector or scalar mediator.
- The simplest model may be the Dark Photon model. The mediator mixes with SM with the kinetic mixing κ.
- 4 free parameters, Dark mediator(V), dark matter particle(χ), kinetic mixing(κ), coupling constant α.

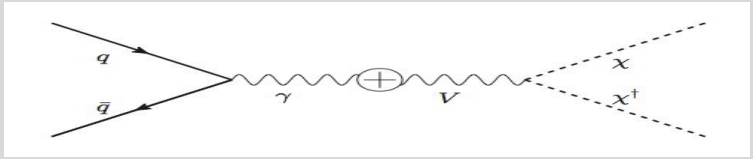
C. Boehm & P. Fayet, Nucl. Phys. B683 (2004) 219. arXiv:hep-ph/0305261 [hep-ph]
C. Boehm et al., Phys. Rev. Lett. 92 (2004) 101301. arXiv:astro-ph/0309686 [astro-ph]

Dark matter at neutrino experiment

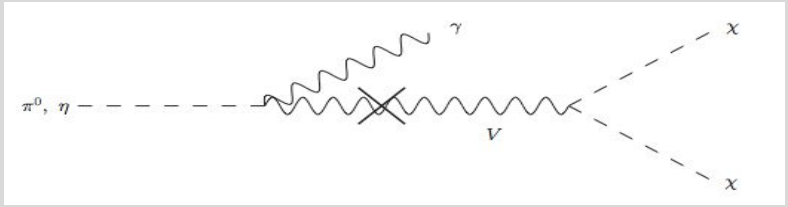
- DM searches at neutrino experiments were first proposed by Batell, Pospelov and Ritz 0906.5614 [hep-ph]
- Dark Matter production at fixed target experiment



DM production :



Higher Ep LBNF/DUNE

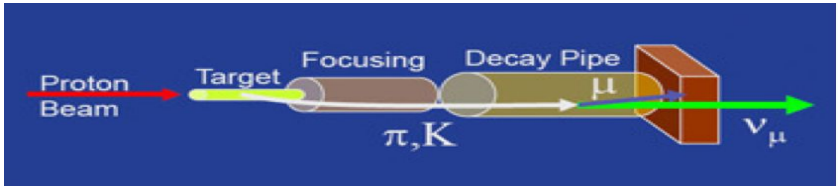


Low Ep MiniBooNE

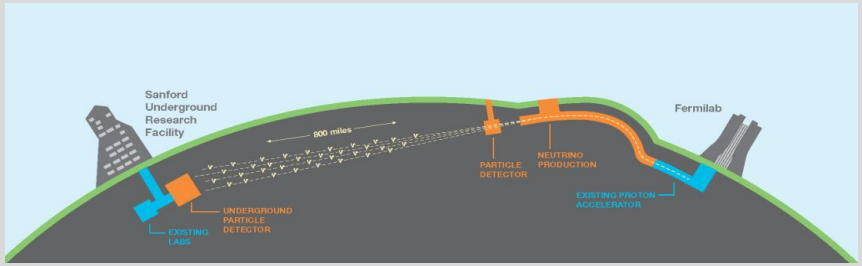
Detection :

Why LBNF/DUNE will be a future facility for LDM Search

- MiniBooNE experiment using beam produced by protons accelerated in the Booster at Fermilab.
- Signal at MiniBooNE decreases fast for a mediator above 1 GeV,because the Booster proton energy is only 8 GeV.
- Searching dark matter with higher mediator mass (1-10 GeV), we need higher proton energy.
- Using Fermilab's Main Injector accelerator as a proton source of energy 120 GeV, Long Baseline Neutrino Facility (LBNF) is expected to make highest energy neutrino beam for DUNE experiment.
- 120 GeV proton in the main injector scattering with a fixed target may produce a mediator of higher mass.



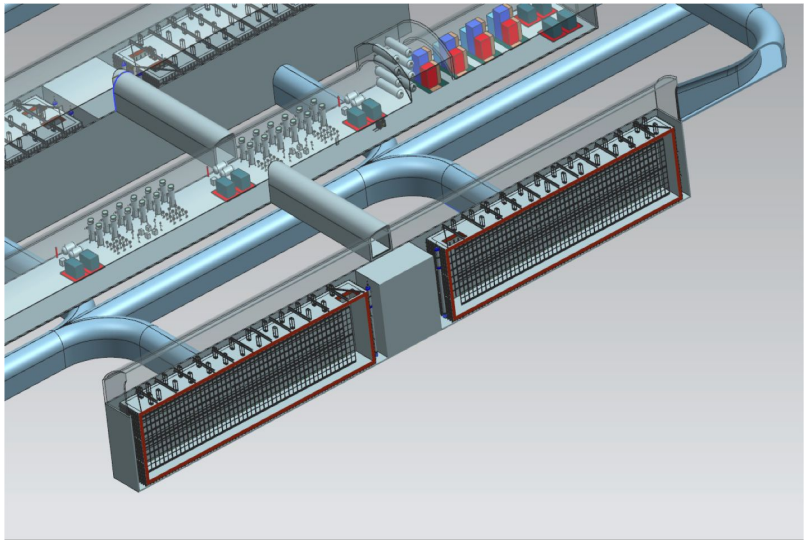
Dark matter search at DUNE



- The Deep Underground Neutrino Experiment (DUNE) is the next generation long baseline neutrino experiment to provide a broad program of ν oscillation physics, ν interaction physics, underground science, and physics beyond the standard model.
- DUNE Far detector will be installed at the sanford underground laboratory. The detector will consist of four 10 kt LArTPC.
- Near Detector will be placed at a distance of 574 m from the beam line.
- DUNE having an excellent LArTPC far detector and a Near detector will be good probe to study Physics beyond SM, as sterile neutrino, non standard interaction, **low mass dark matter**.

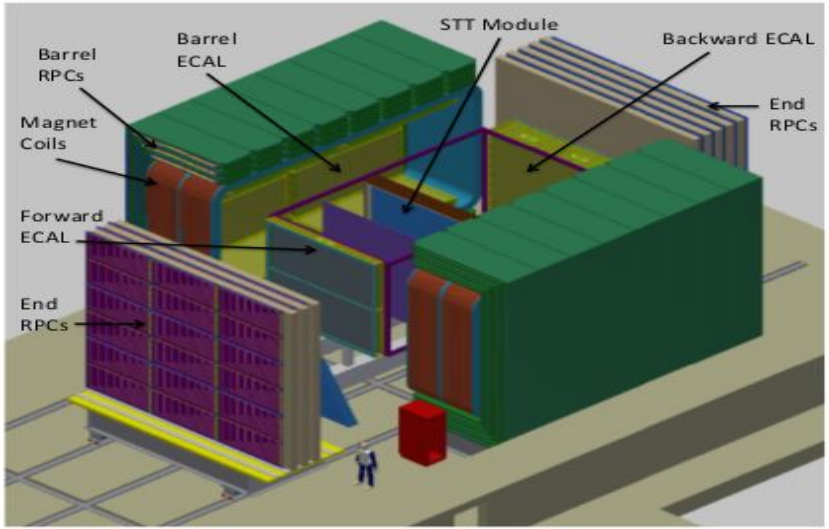
DUNE proposed detector

Far Detector



3D models of two 10-kt detectors using the single-phase reference design(12m,14.5m,58m)

Near Detector



Schematic drawing of fine-grained tracker(3.5m,3.5 m,6.4m)

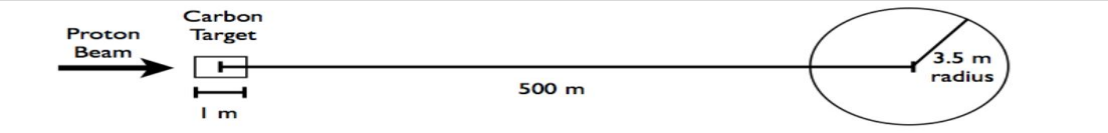
Detail : http://docs.dunescience.org/

DM Simulation at DUNE

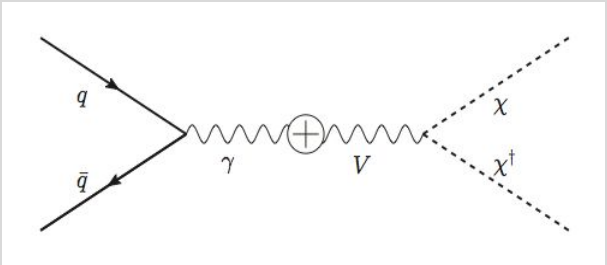
Preliminary Analysis

DM @DUNE Simulation(We are at the early stage!)

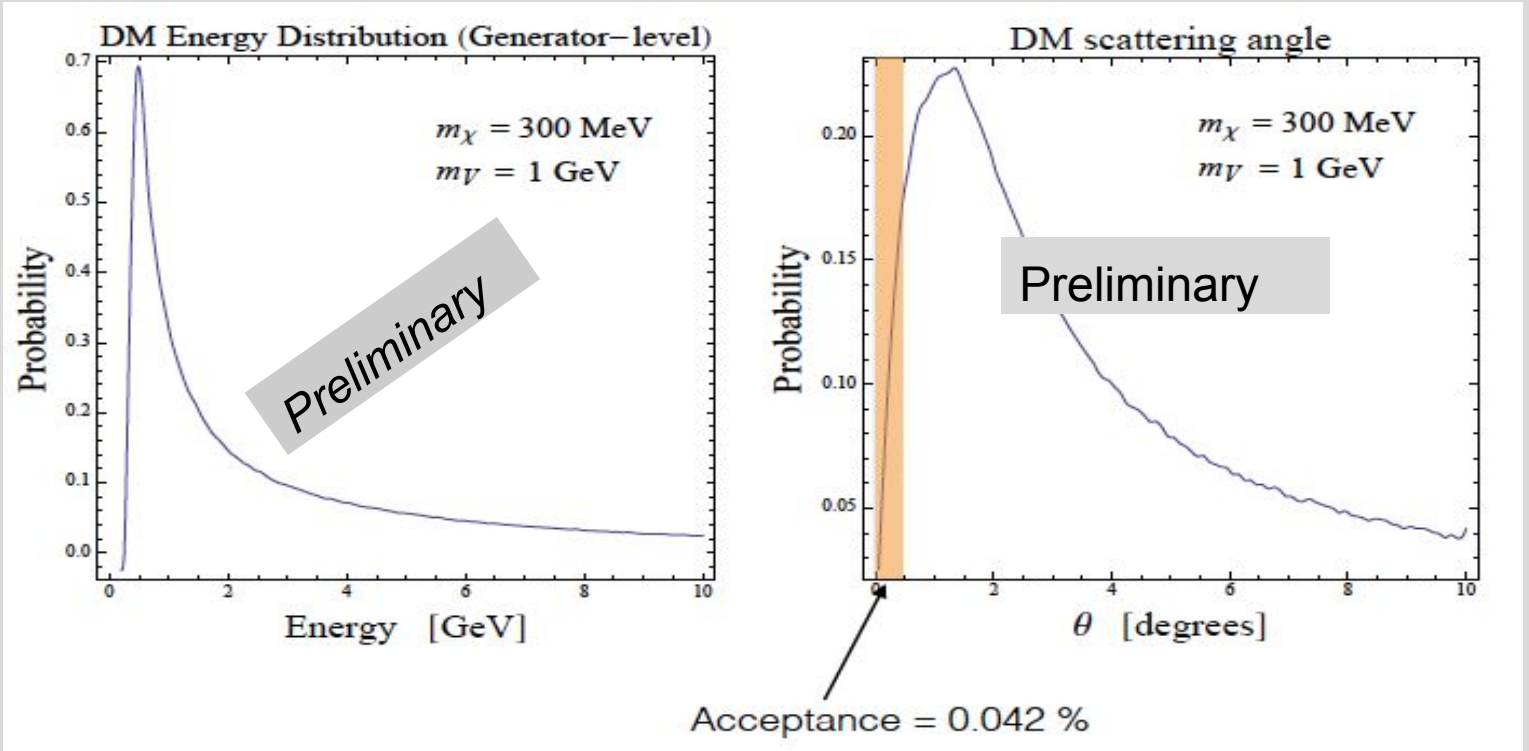
- We have started to study sub-GeV DM production at DUNE with the following setup (**First Attempt**)



- We generate 1 million DM events using MadGraph5 in FT mode.
- Spherical detector (radius 3.5 m) located at a distance of 500m from the target.
- 120 GeV of proton energy with 3x 10^21 POT.
- The model parameters: α = 1, κ = 0.01.
- Acceptance of the detector = 0.042 deg.

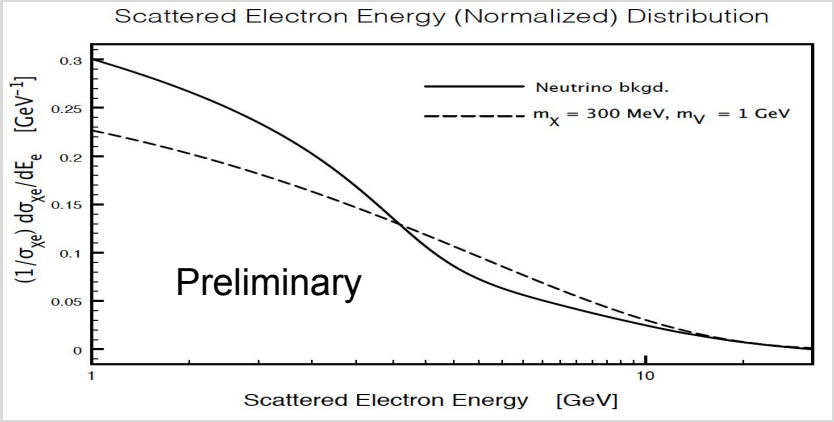


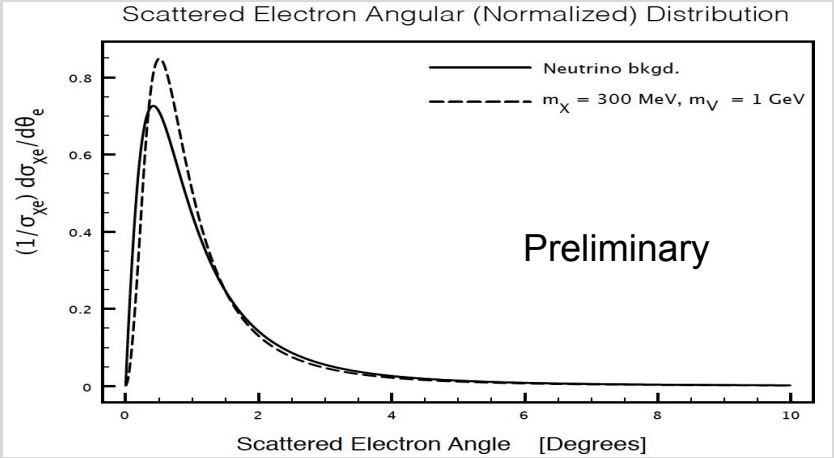
DM Energy and Angular spectrum



Scattered electron

- At the first attempt, we calculate Dark matter-electron and neutrino-electron scattering cross-section .
- Clearly the energies of scattered electron from DM and neutrinos are very similar.
- The angular distribution of the scattered electron also looks very similar.
- We are mainly focusing on nucleon events.





More precise (preliminary)events

- The number of nucleon events considering our configuration ..

- Mediator mass = 3 GeV , alpha = 1, k =0.01

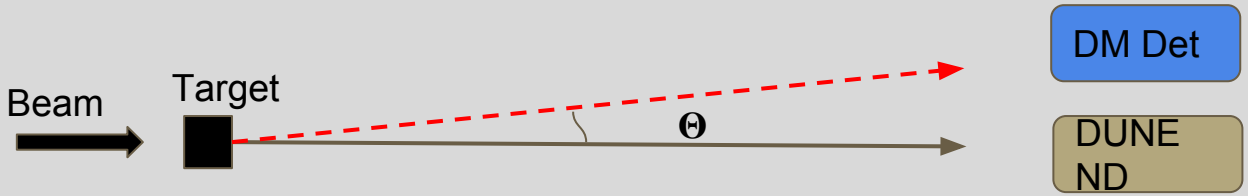
DM Mass(GeV)	Nucleon Events
0.01	4562
0.1	4143

Preliminary

What about neutrino background ?

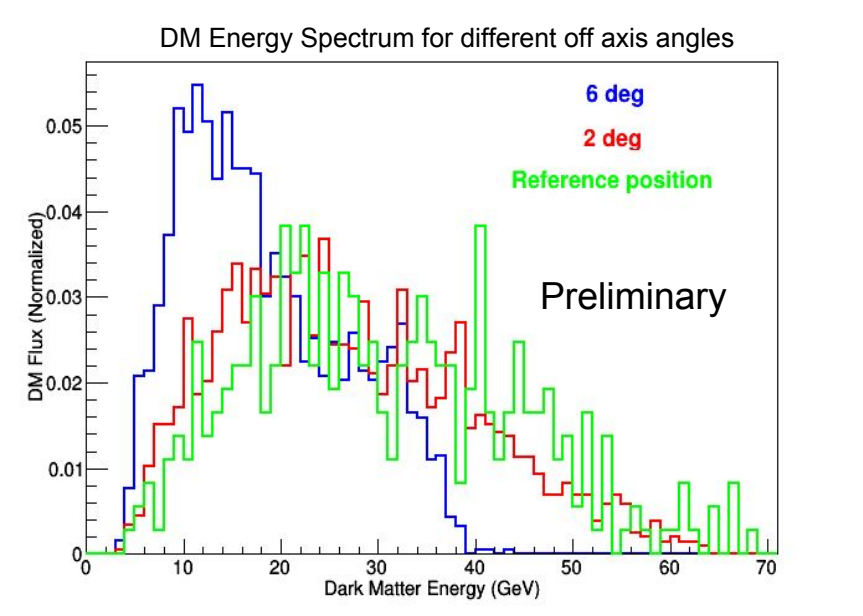
- Main Background for the DM signal is the neutrino neutral current events.
- Possible Dark Matter Detector configuration :

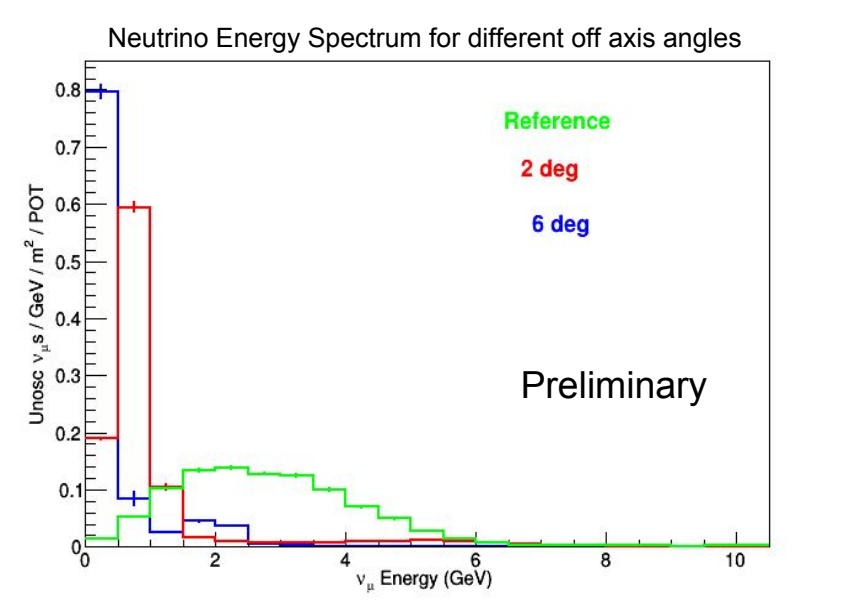
1. Dedicated DM Detector (same as Near Detector) slightly off-axis to Beam.



- In the case of pions, neutrinos emitted with a sizable angle have very low energies regardless of the parent pion energy because of the low pion mass.
- Main background is going to come from the neutrinos produced from kaon decay.

DM and Neutrino Energy spectrum for different off axis angles

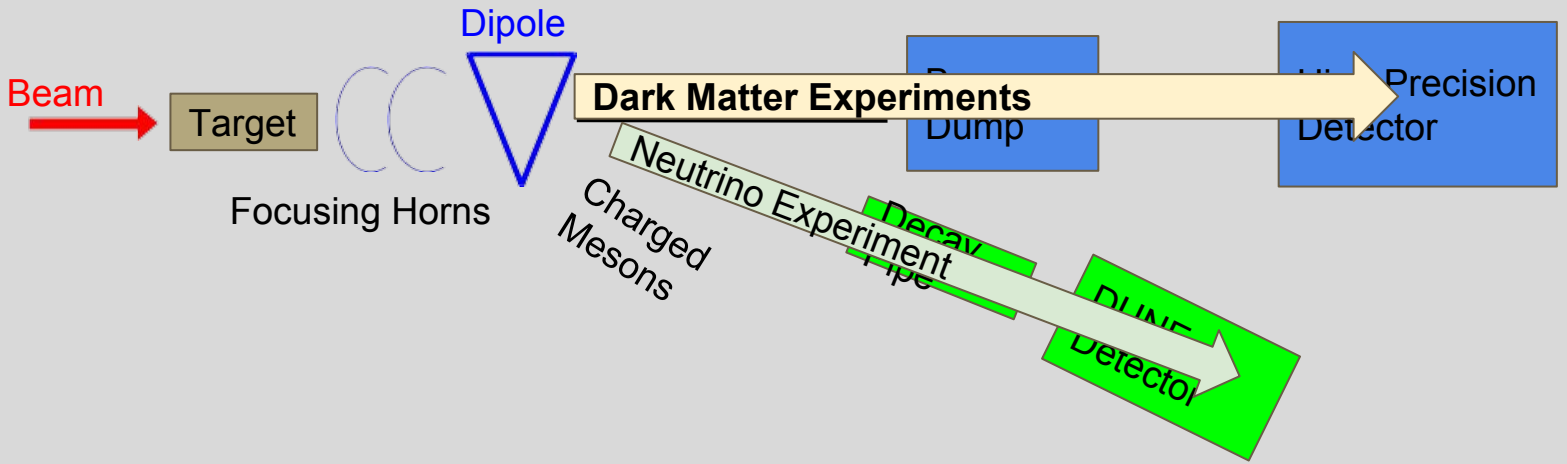




- Neutrino emitted with slightly off axis angle have very less energy compared to DM
- Optimization of energy threshold will reduce the neutrino background substantially.
- 2 deg off-axis angle looks promising

Option 2 :Doubly Sign selected Horn System (DSHS)

- Beam dump experiment would be another option, since beam dump can be made to absorb all the mesons which are the source of neutrinos.
- Separate neutrino and antineutrino from DM.



Advantage of DSHS

- Separate neutrino and antineutrino from DM.
- Eliminates nu-e's from neutral kaon decays.
- Further reduces muons resulting from un-interacted protons dumped into the absorber.
- R&D issues:
- What is the impact on the oscillation physics?
- Technical challenge to separate the beam.

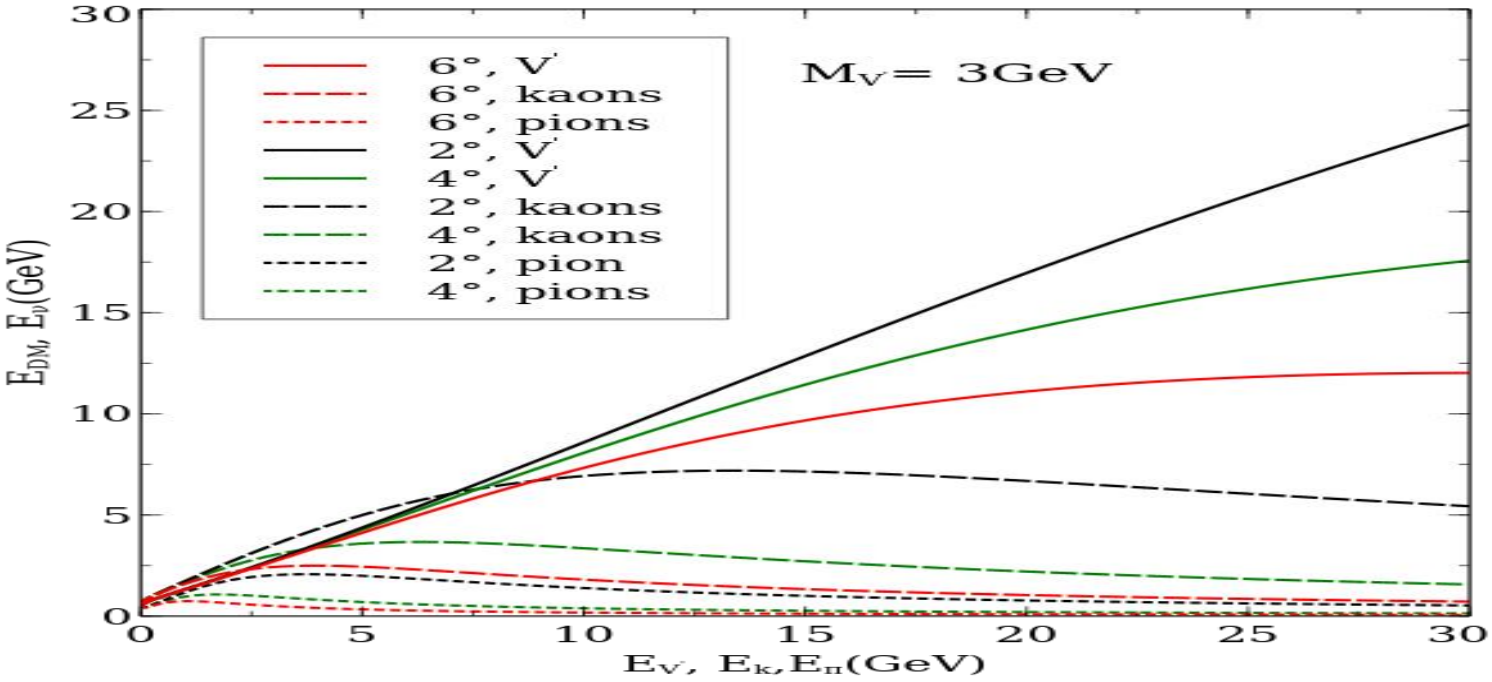
Outlook

- DUNE offers potentially exciting option for detecting and studying sub-GeV dark matter .
- We are in the early stage of the analysis, we are working to have a fully-operational MC event generator.
- In any case, neutrino background will be crucial. Working to understand Neutrino background with the two configuration
- -> DM detector slightly off axis to the beam.
  -> Running in a “beam dump” mode with DSHS configuration.
- Study about optimal location, detector design are under progress.

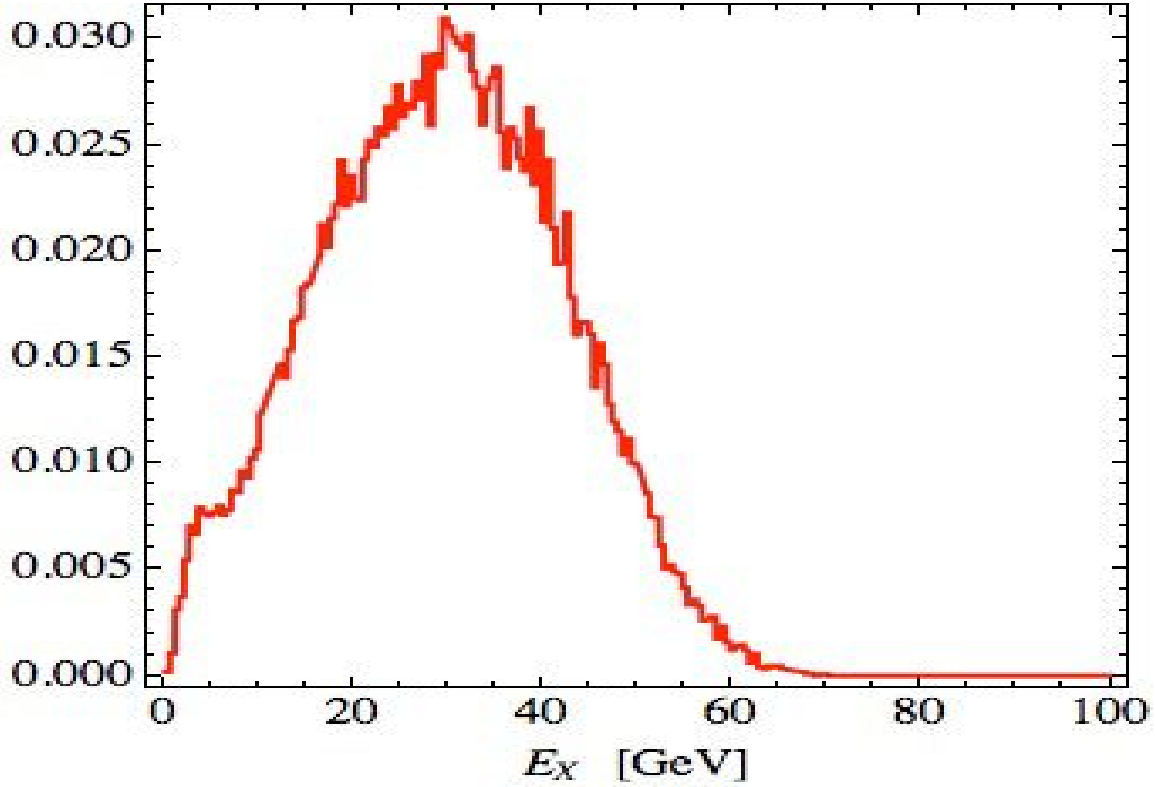
Thank you

Backup

Energy spectrum of DM and neutrino at the detector



Dark matter flux at the detector location



Preliminary result (using LBNE setup)