Sub-GeV Dark Matter Searches at E-LBNF

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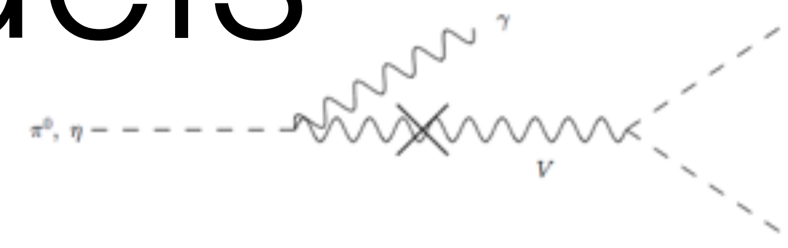
Sub-GeV Dark Matter

- Relic Density points to WIMPs: DM with weak scale mass/interaction
- Observed Relic Density also possible with sub-GeV DM belonging to a hidden sector
  - Requires non-SM annihilation
    - e.g. DM couples to mediator which mixes with photon and/or couples to baryonic current.
  - DM light → small recoil → inaccessible to direct detection
    - Boosted DM can be produced in fix target experiments.
    - Neutrino beam experiments have larger detector volume than typical fix target experiments.
    - LBNF beam power of course also helps…
- DM searches add to physics motivations: neutrino, supernova, and proton decay.

Sub-GeV DM Models

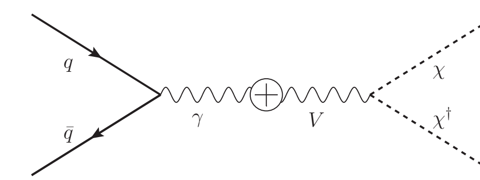


- Light mediator is the only requirement for relic density.

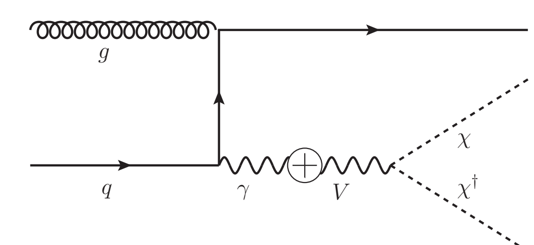
- Some simple model independent possibilities/choices:

$$p + p(n) \to \phi + \cdots$$
$$\searrow X + \cdots$$
$$\searrow \chi\chi$$

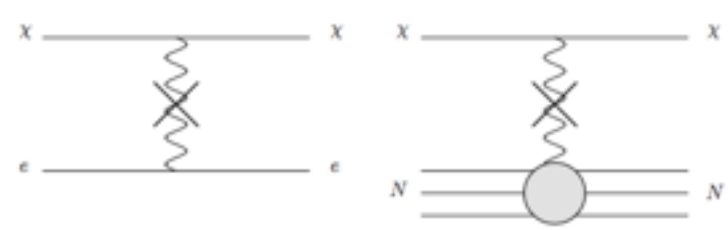
  - *Mediator:* Scalar or vector (aka Higgs/Vector portal)
    - On-shell/off-shell: usually assume $m_V > 2m_\chi$

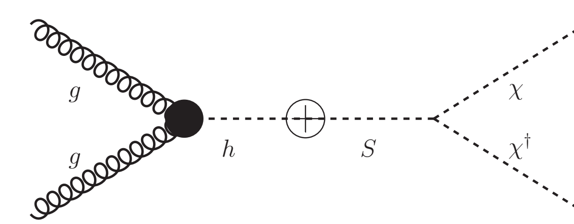


  - *Production:*
    - Indirect: dominant at low energy, e.g. miniBooNE
    - Direct: dominant at high energy, e.g. E-LBNF



  - *Detection:* Nuclear/Electron Recoil…





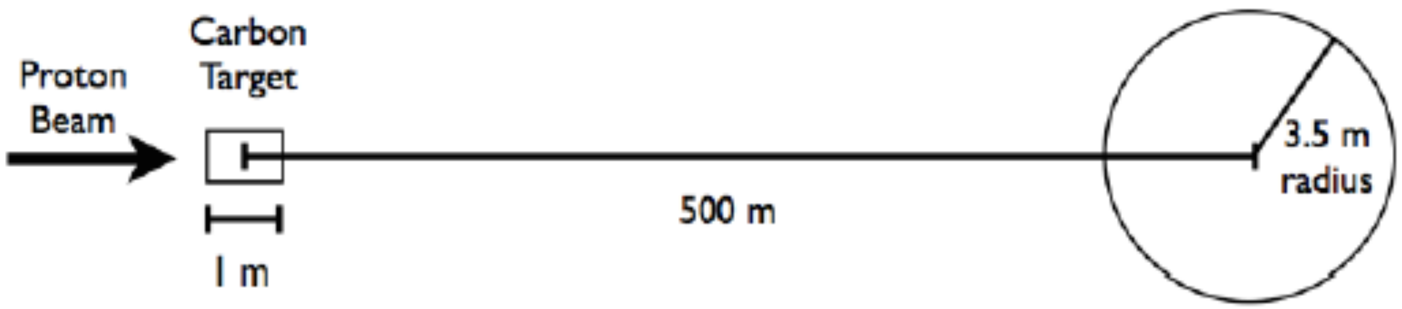
  - *Dark Matter:* Scalar/Dirac

$$pp(n) \to X^* \to \bar{\chi}\chi \text{ (or } \chi^\dagger\chi)$$

  - Model Parameters: m_χ, m_V, κ (mixing parameter), …

- Lots of other possibilities: much richer hidden sector with multiple mediator DM components, leptophobic DM, …

Preliminary study



$N_{POT} = 3 \times 10^{21}$ (number of protons on target)

$n_T = 10^{23}$ (number density of carbon atoms in the target)

$L_T = 100$ cm (length of target)

$\text{Theta}_{det} = 3.5\text{m}/500\text{m} = 0.007 = 0.4$ degrees (angular acceptance)

$n_D = 5 \times 10^{23}$ (number density of electrons in detector)

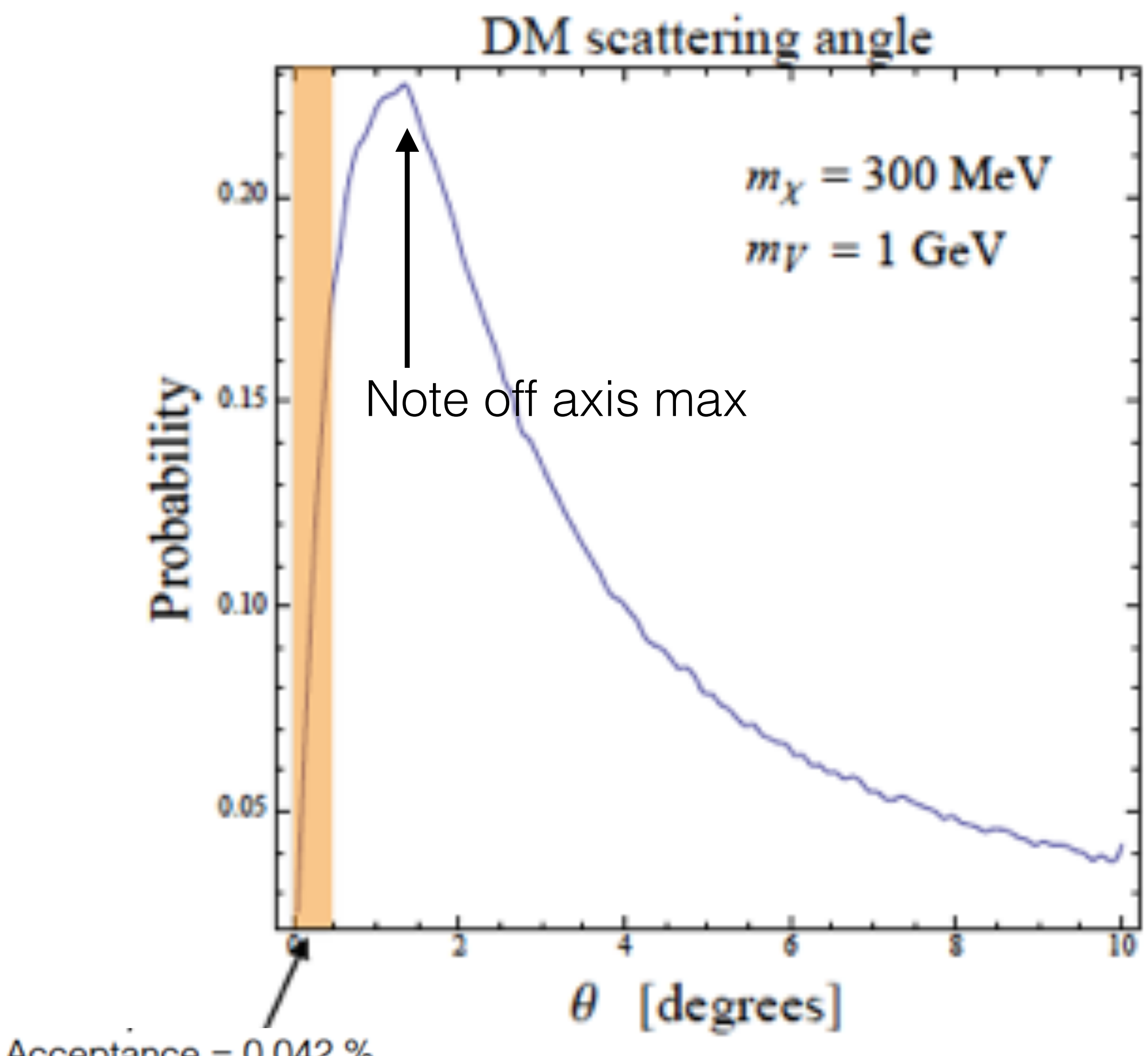
$R_D = 350$ cm (radius of detector)

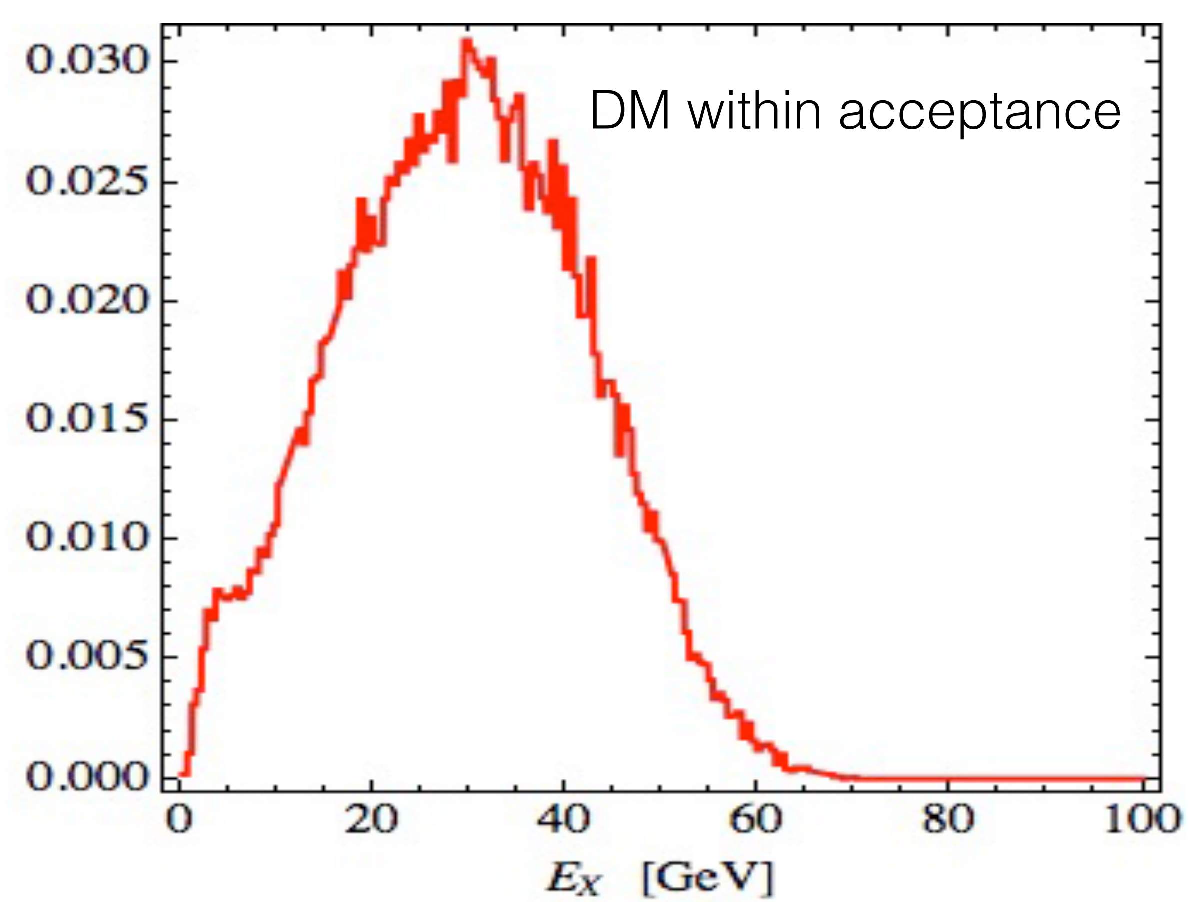
d = 500 m (distance from target to detector)

$$N_{event} = N_{POT} n_T L_T \left(12\, \sigma_{pp\to\chi\bar{\chi}}\right) n_D R_D \sigma_{\chi e} \times \eta_{det}$$

$$\sigma_{pp\to\chi\bar{\chi}} \simeq 10^7 \text{ pb} = 10^{-29} \text{ cm}^2 \quad \text{(madgraph)}$$

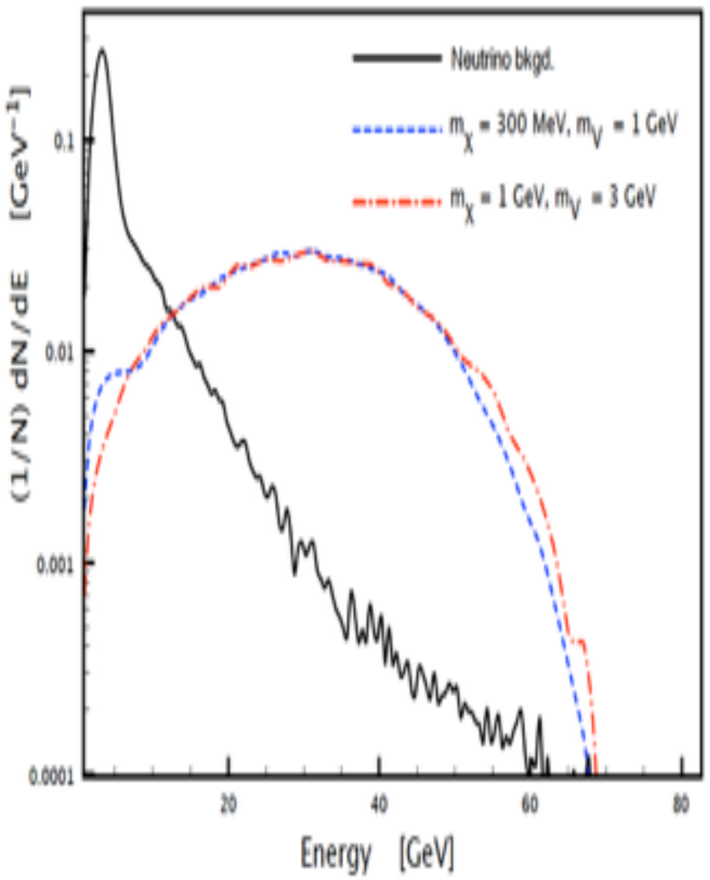
$$\sigma_{\chi e} \simeq 10^{-32} \text{ cm}^2 \quad \text{(analytic)}$$

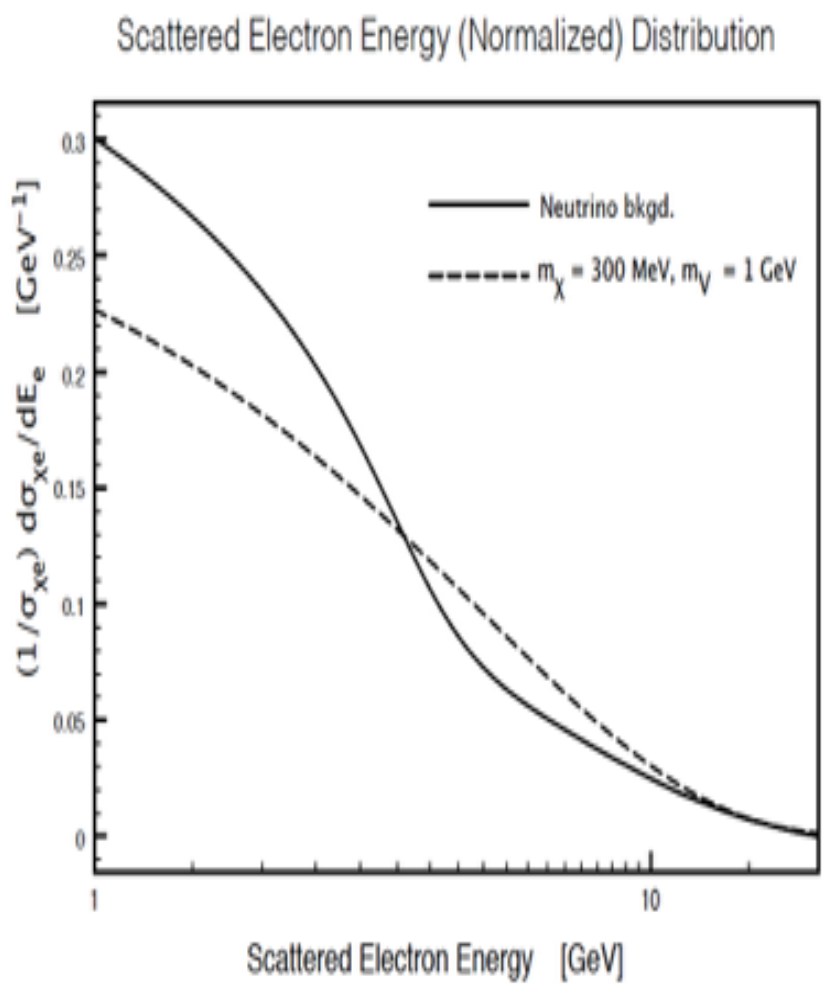


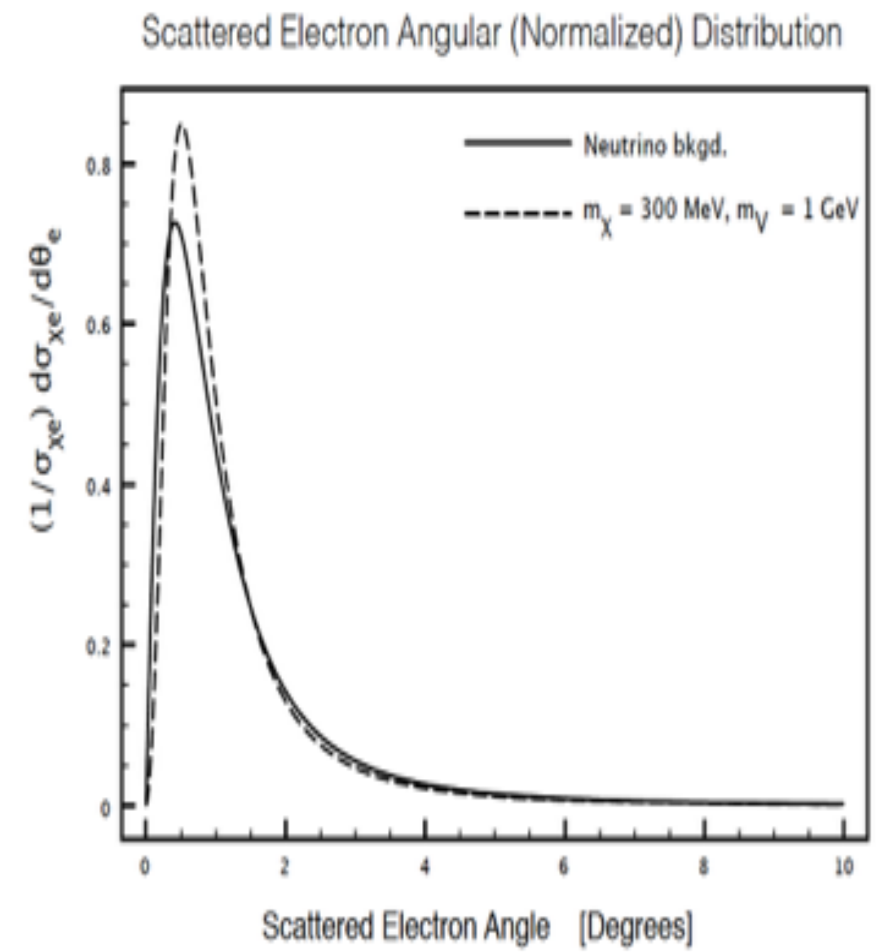


Background

- Signal looks like a neutrino, so neutrinos are the primary background…



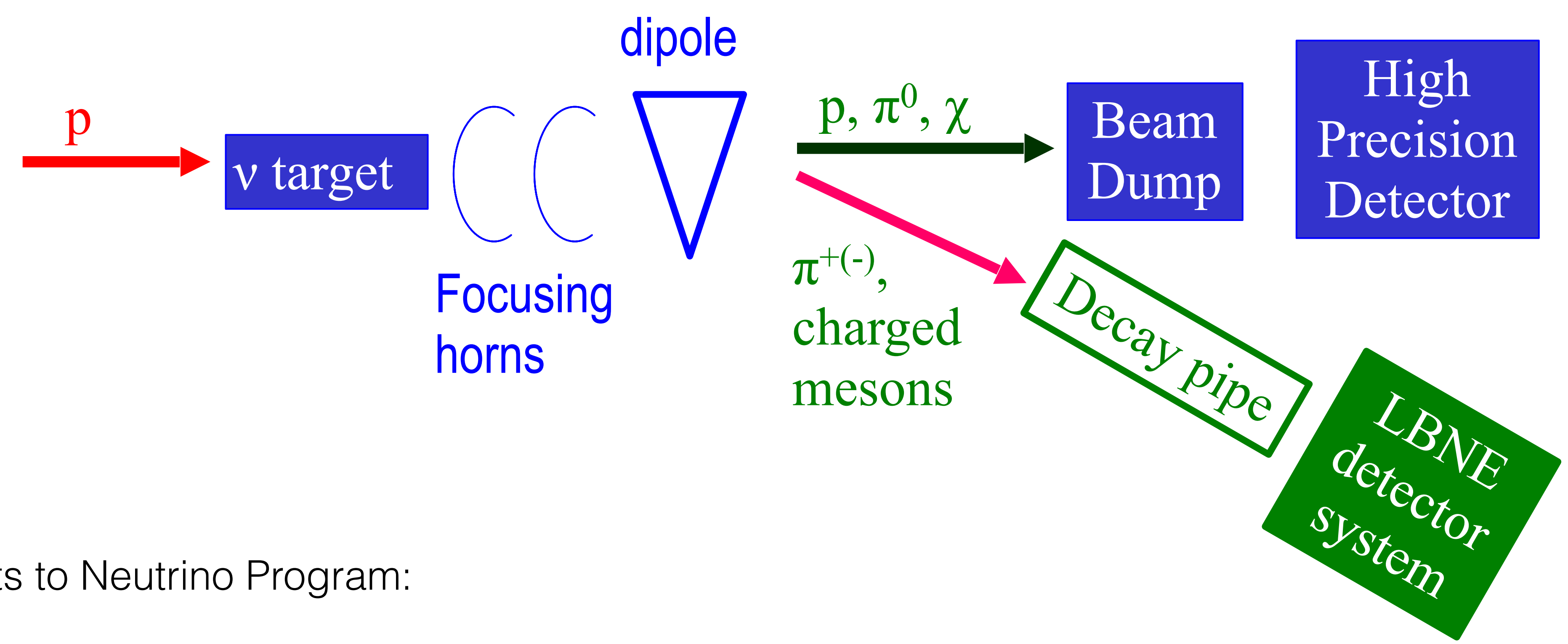




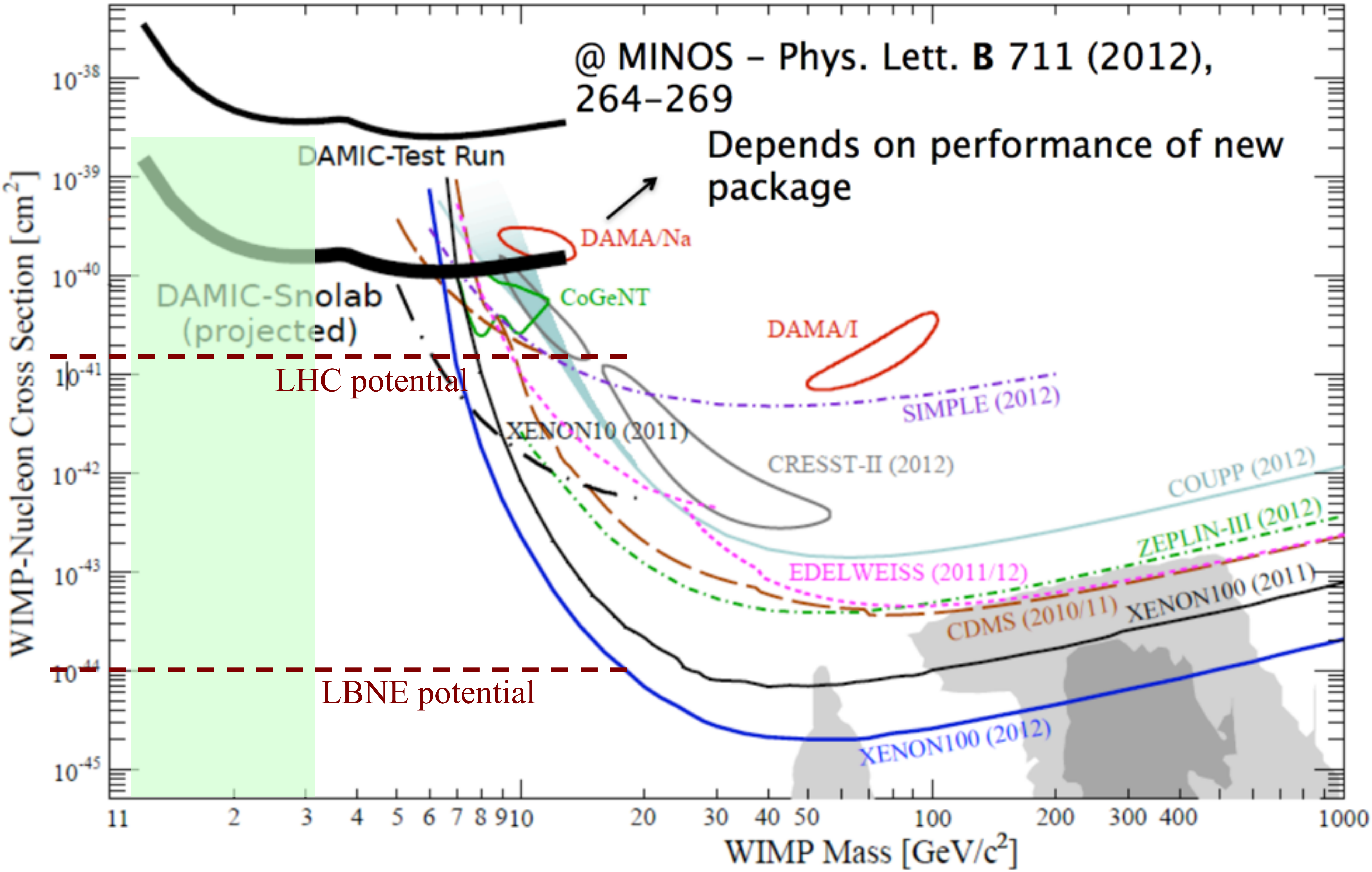
- Fighting backgrounds:
  - DM arrives later that Neutrinos…. use timing. Higher energy → better separation.
  - DM are heavier… use scattering angle.
  - MiniBooNE ran off axis, forcing pions to interact before decay.
  - Ideas to separate neutrino and DM beams…

Beam ideas

- Add a dipole: Double-sign Selected Horn System (DSHS)



- Benefits to Neutrino Program:
    - Eliminates nu-e's coming from neutral kaon decays ➔ reduce oscillation systematics
    - Further sign select neutrino beams ➔ reduce CPV systematics
    - Further reduce muons resulting from un-interacted protons dumped into absorber
- Preliminary Beam Study of Impact on Neutrinos: loose 9% (13%) of neutrinos if dipole placed after first (second) horn.
- Studying pion transverse momentum gradient in order to tune magnetic field to minimize losses.
- Alternatively, we may be able to introduce a beam tilt, and use remaining protons for a beam dump experiment.



Back of the envelope estimate… studies underway.

Final Remarks

- Sub-GeV Dark Matter searches provide an additional physics motivation beyond neutrino, supernova, and proton decay program.
    - Potentially we can probe 2-3 orders of magnitude smaller cross-sections and much lower masses than LHC.
- UTA group has coded direct/indirect production and nuclear/electron recoil into private Monte Carlo.
    - Goal is to provide simulated samples for ELBNF within the full software framework.
        - Basis for studies to ensure ELBNF meets sub-GeV DM requirements.
        - Sub-GeV DM requirements may influence the Near Detector choice/design.
    - Also joining miniBooNE search going on now.
- Neutrino backgrounds may be challenging. Alternative Beam-lines and dedicated detectors may be an better alternative.
    - The reduction of systematics must be carefully evaluated against loss in neutrino flux.
    - UTA also heavily involved in beam simulations… hoping for a viable design.
        - Probably require bigger target hall.
- Just getting started… many, many studies to come.