The Search for Dark Photons at the Short-Baseline Near Detector

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on behalf of the SBND Collaboration

In collaboration with
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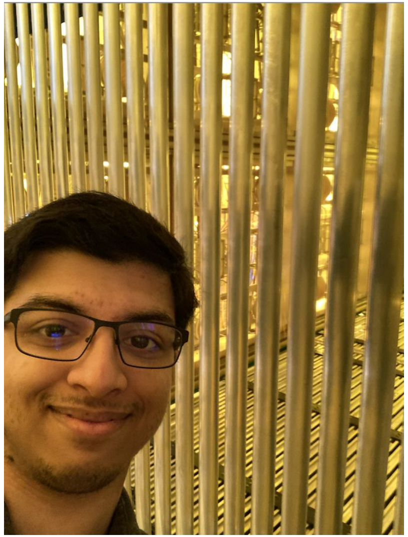
Overview

- Introduction of DP Model
  - Theoretical Motivations/Foundations
  - Expected Sensitivity at SBND
- Event Selection Development
  - Truth Based Studies
  - Initial Efficiency Estimates
- Timing Studies
  - Motivation for Timing selection cut
  - Expected Bunch Structure
- Next Steps & Conclusions

Short Baseline Neutrino Detector

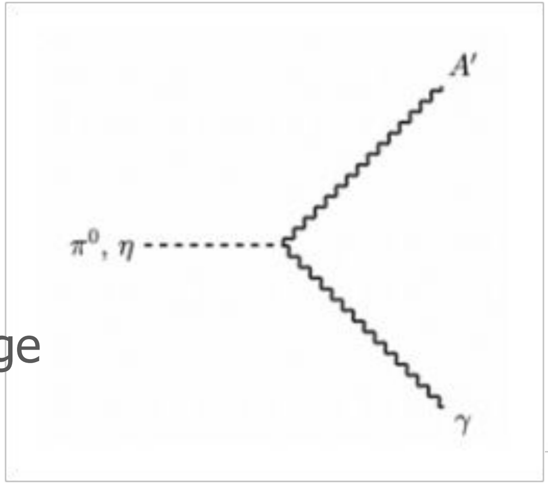
- 112 ton Liquid Argon TPC (LArTPC) sitting at 110 meters from target[1]
- SBND is performing physics analyses in 3 general categories:
  - Neutrino Oscillations
  - Cross section Measurements
  - **BSM Searches**
- Proximity to the target provides sensitivity to a plethora of BSM models
  - Explanations for low energy excess observed at MiniBooNE

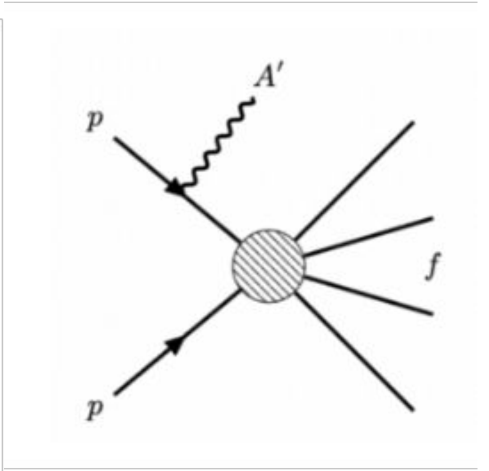


[1] https://indico.fnal.gov/event/64625/contributions/295391/

Dark Photon Model

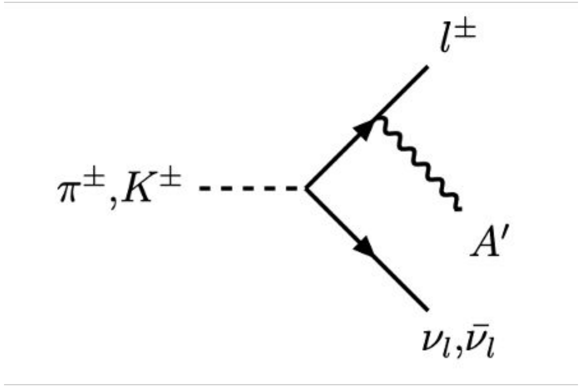
- Dark Photons (DP) are hypothetical gauge bosons proposed to be force carriers for the dark sector, coupling to SM photons[1].
- Our DP Model will cover a mass range consistent with the BNB energy/flux expected at SBND





Sources:

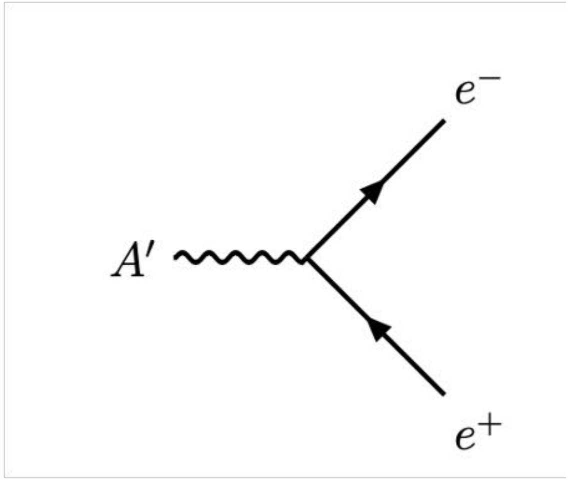
- *Charged mesons - 3 body decay* [2][3][4]
- Neutral mesons - 2 body decay[5]
- Protons - Bremsstrahlung
  - Fermi-Weizsacker Williams[6]
  - Quasi-real Initial state radiation[7]

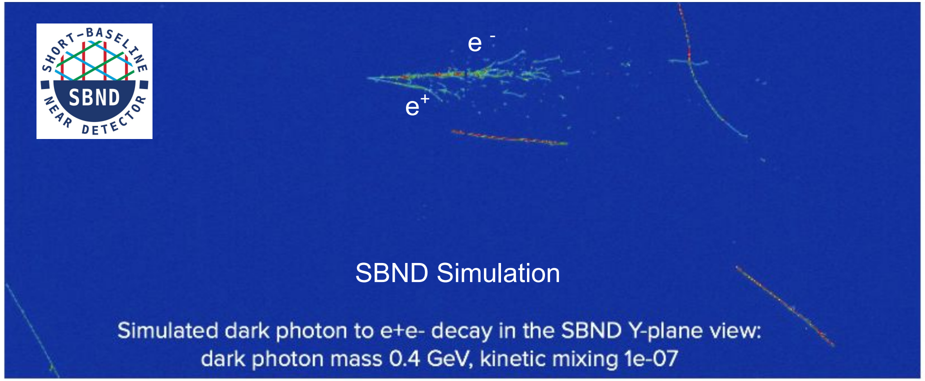


[1] arxiv.org/abs/2005.01515
[2] arxiv.org/abs/2110.11944
[3] arxiv.org/abs/1206.3587
[4] arxiv.org/abs/2308.01491
[5] arxiv.org/abs/1801.04847
[6] arxiv.org/abs/1311.3870
[7] arxiv.org/abs/2108.05900

Dark Photon Signal Topology

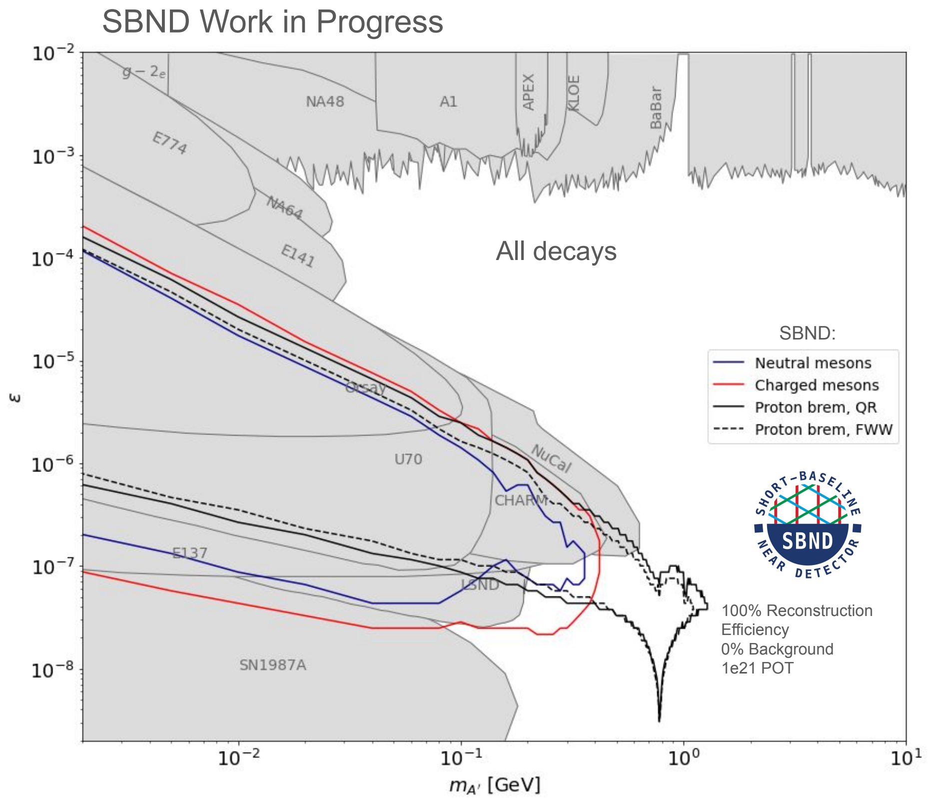
- We expect Dark Photons to kinetically mix with Standard Model Photons (ε) and then promptly decay
- More channels shall be investigated as this analysis develops.
  - For now, we are focussing on the e^+e^- channel.
- The high performance of LArTPC technology when reconstructing electron signals (and differentiating from photons) is another attraction to performing this analysis on SBND[1]

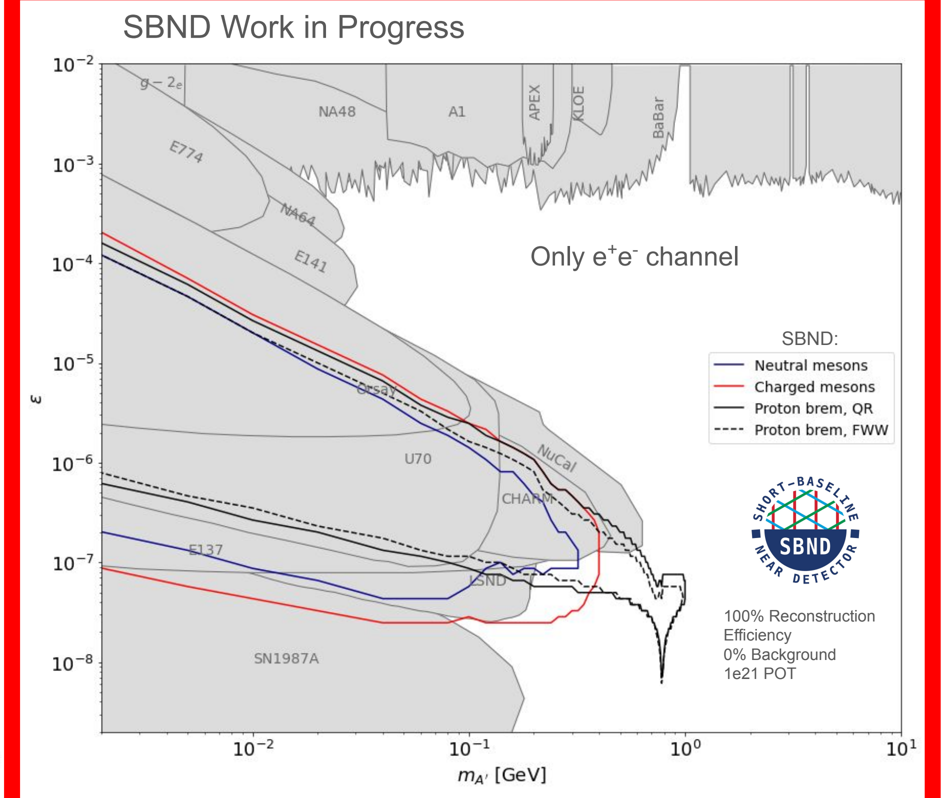




[1] https://indico.fnal.gov/event/49432/contributions/221022/

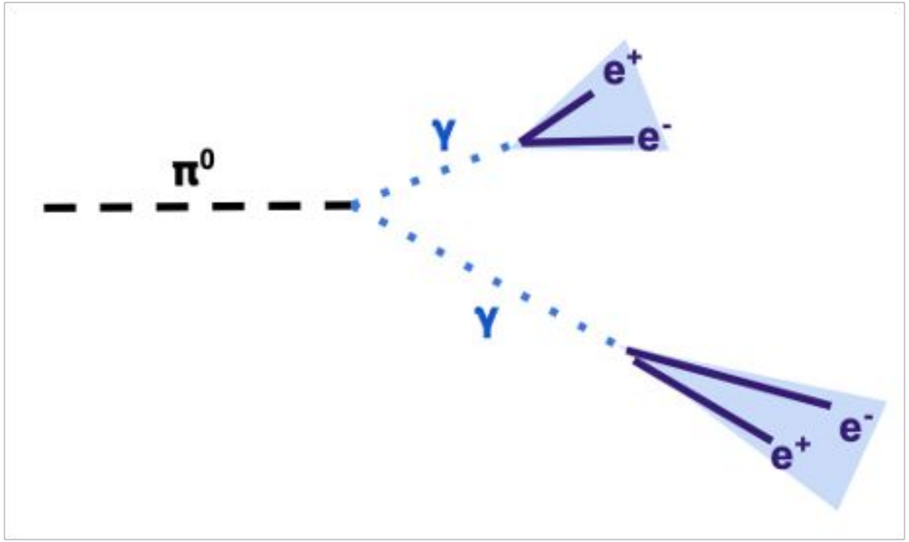
SBND Dark Photon Sensitivity





Neutrino-Induced NC π_0 Backgrounds

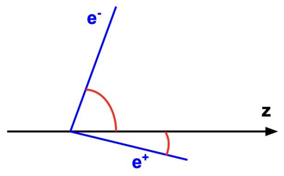
- **We expect the first order largest background to arise from Neutral Current (NC) π^0 events**
- For 1e21 POT, we expect ~280k background events
- Can characterize NC π^0 events by particles produced at their primary vertex
- Can further observe particles produced in the neutrino interaction for NC π^0 events



Current Event Selection

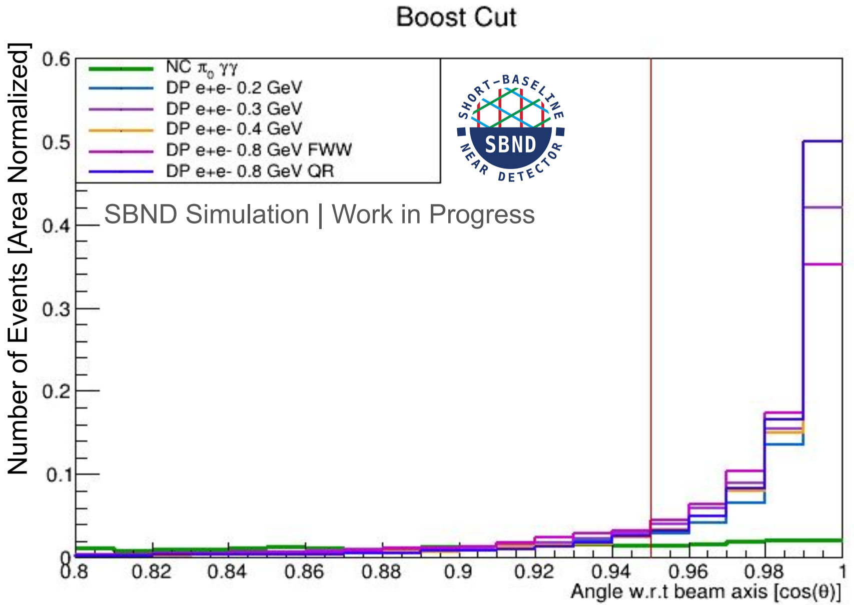
- Based on truth level studies, we have developed a preliminary event selection
- Main assumption taken:
  - We have 100% cosmic rejection efficiency
- Our next step will be to move into reconstruction and expand our selection
- ***Efficiency*** : Signal events remaining after all cuts / Generated Signal events before all cuts
- ***Purity*** : # Signal events / (# Selected Signal events + # Selected Background events)
- **Signal/Background:** Event vertices within the FV, no detection thresholds

Event Selection Chain

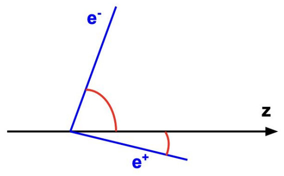


- **Proton Cut**: We require that no protons > 15 MeV KE to be at the primary vertex
- **Charged Pion Cut**: We require that no charged pions > 10 MeV KE to be at the primary vertex
- **Boost Cut**: We require the angle with respect to the beam axis [cos(**θ**)] ≥ 0.95
  - Based on theoretical predictions, the e^-/e^+ pair should be more forward going than NC π^0 photons.

	NC π^0 Background Rejection Efficiency
Proton Cut	*73.3%*
$\pi^\pm$ Cut	*79.1%*
Boost Cut	***97.5%***



Event Selection Chain



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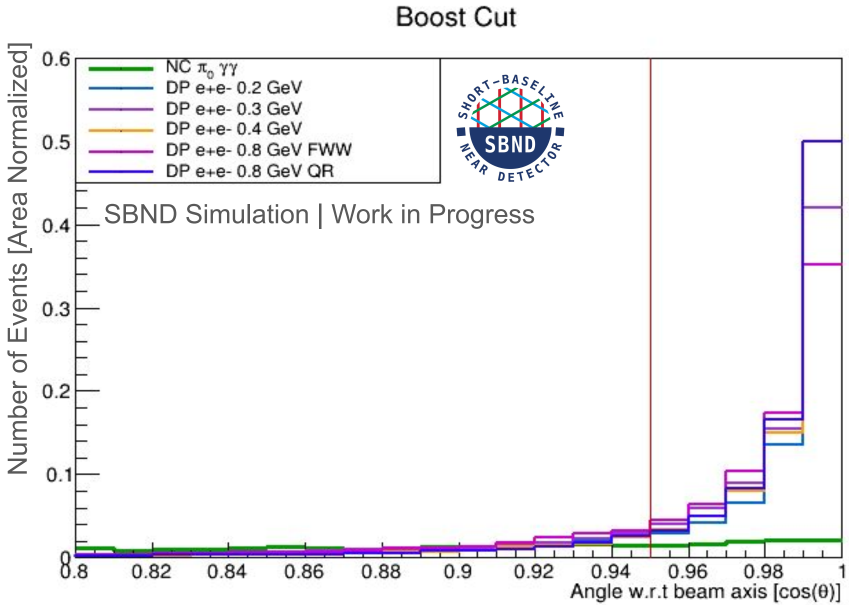
- Our initial efficiency results have yielded a background rejection efficiency of **~97.5%**
- Our signal selection efficiencies remain circa **70-80%**
- Signal purities remain low circa **~4%**
  - As we fold in other selection cuts (e^-/γ separation, timing, etc) we expect this to improve significantly



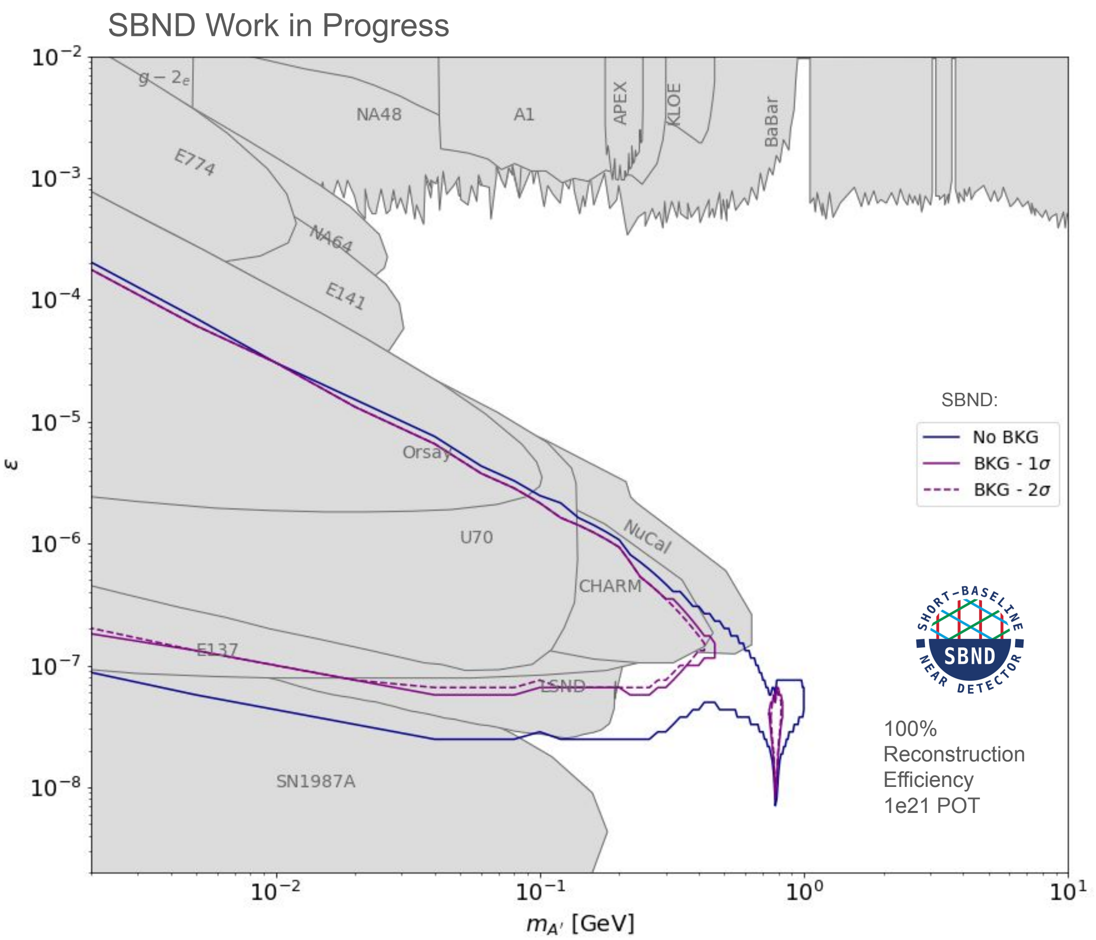
Sensitivity after cuts

Exclusion limits:

- Most conservative estimate - only electrons.
- Looking for sensitivity with timing cuts would give better estimates as background rejection = 100%

$$\Delta\chi^2 = \sum_i \frac{\text{signal}_i^2}{\text{bkg}_i}$$

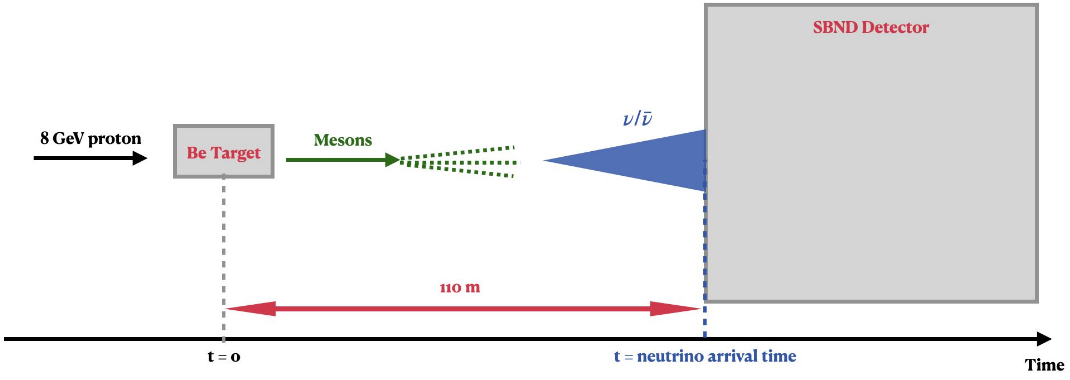
$$\Delta\chi^2 > 2.3(4.61) \text{ for } 1\sigma(2\sigma) \text{ C.L}$$

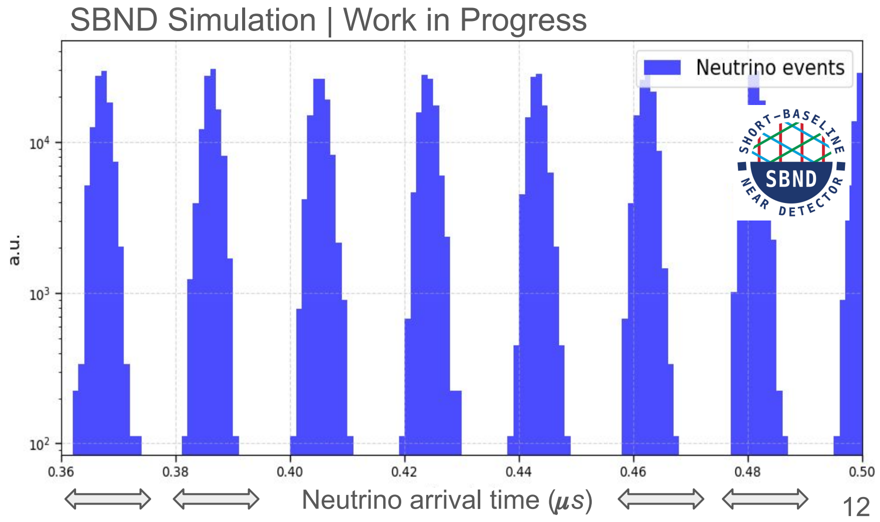


100%
Reconstruction
Efficiency
1e21 POT

Timing Studies

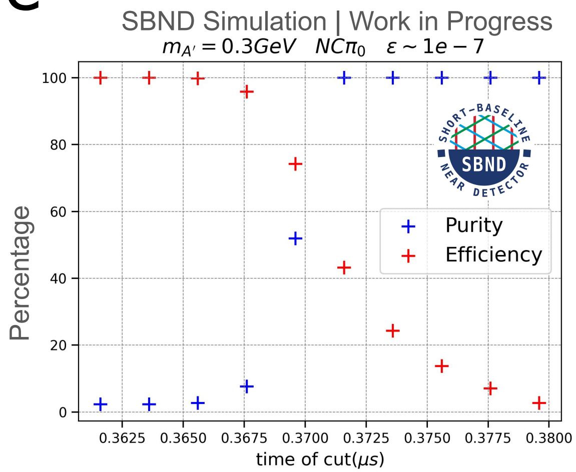
- Another important avenue for this analysis is investigating the expected decay time of Dark Photons at the detector, and how it lies within the overarching neutrino bunch structure.
- Thanks to work within the collaboration, we have made significant progress in understanding, at the truth level, how the Dark Photon behaves.

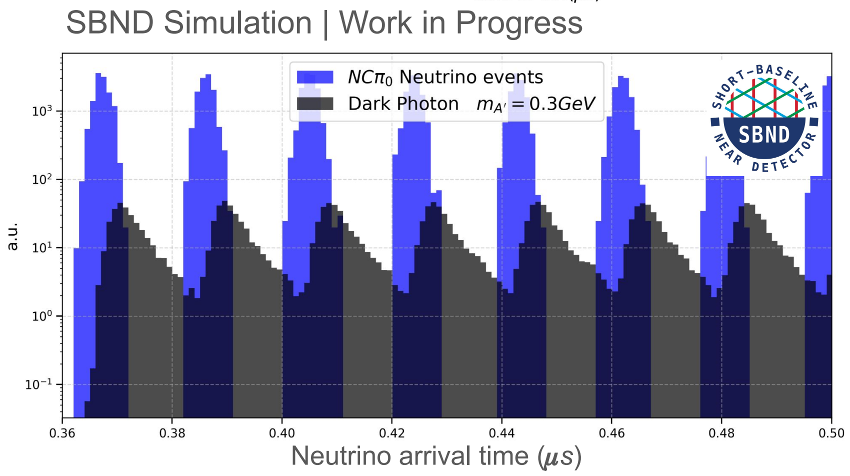




Dark Photon/Neutrino Bunch Structure

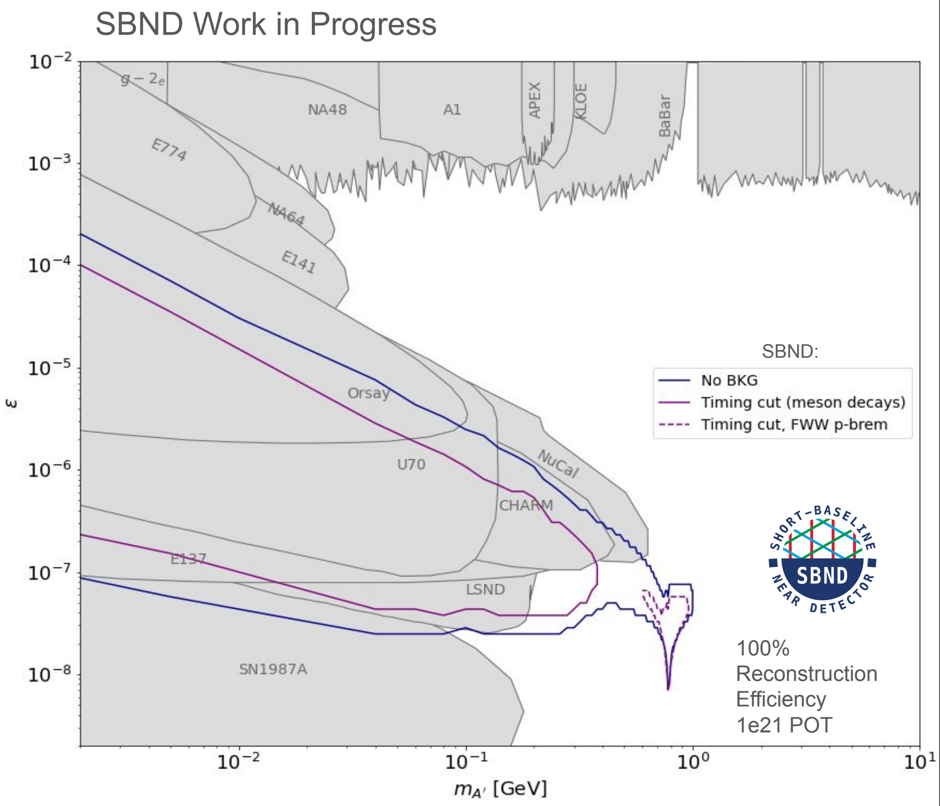
- This selection is carried out independent of the main event selection
    - To be folded into the main selection at a later date
- By taking the decay time of the Dark Photon within the detector, and overlaying this with the expected neutrino bunch structure (from collected BNB data), we can get a preliminary dark photon bunch structure



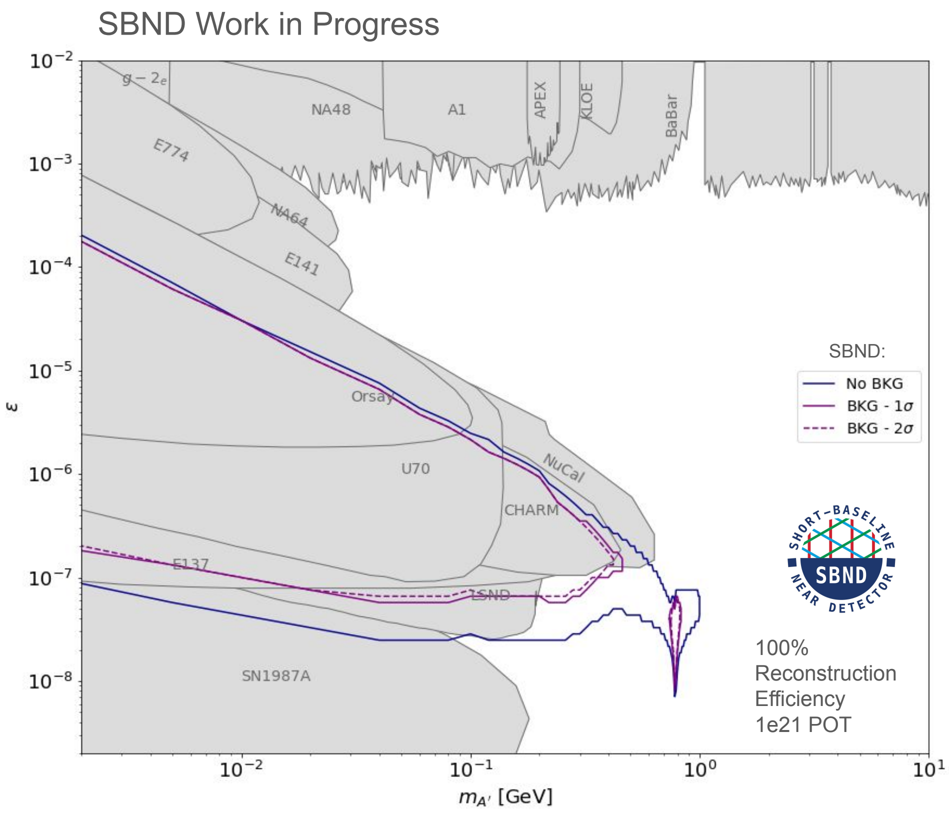


Summary of Sensitivity Estimates

Timing-Based Sensitivity



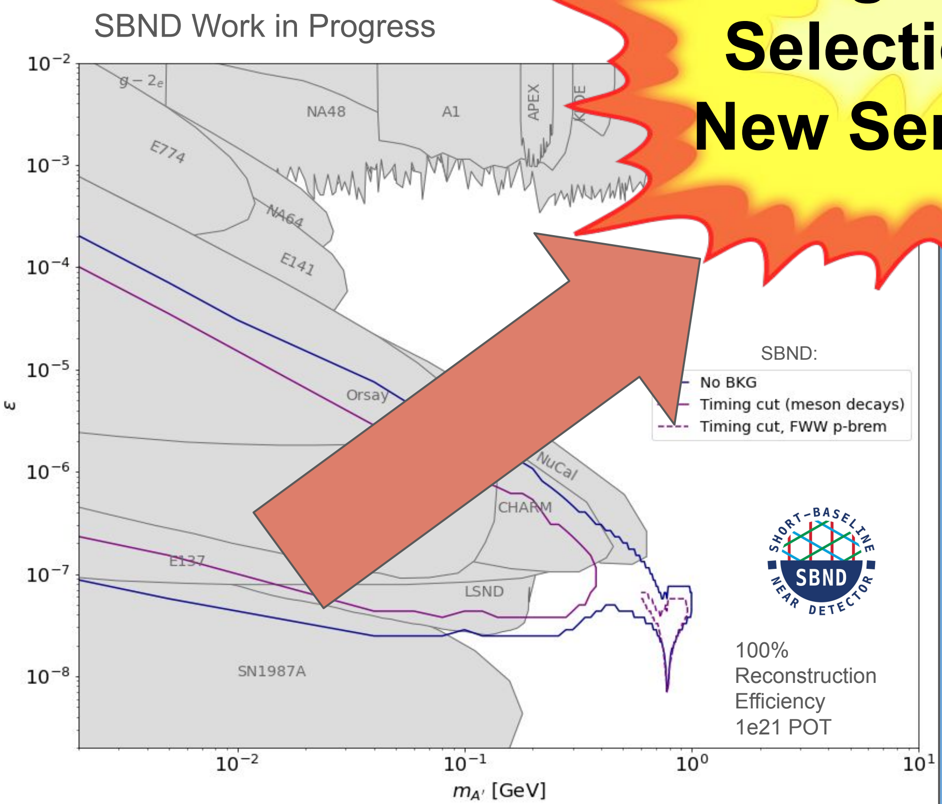
Kinematic-Based Sensitivity

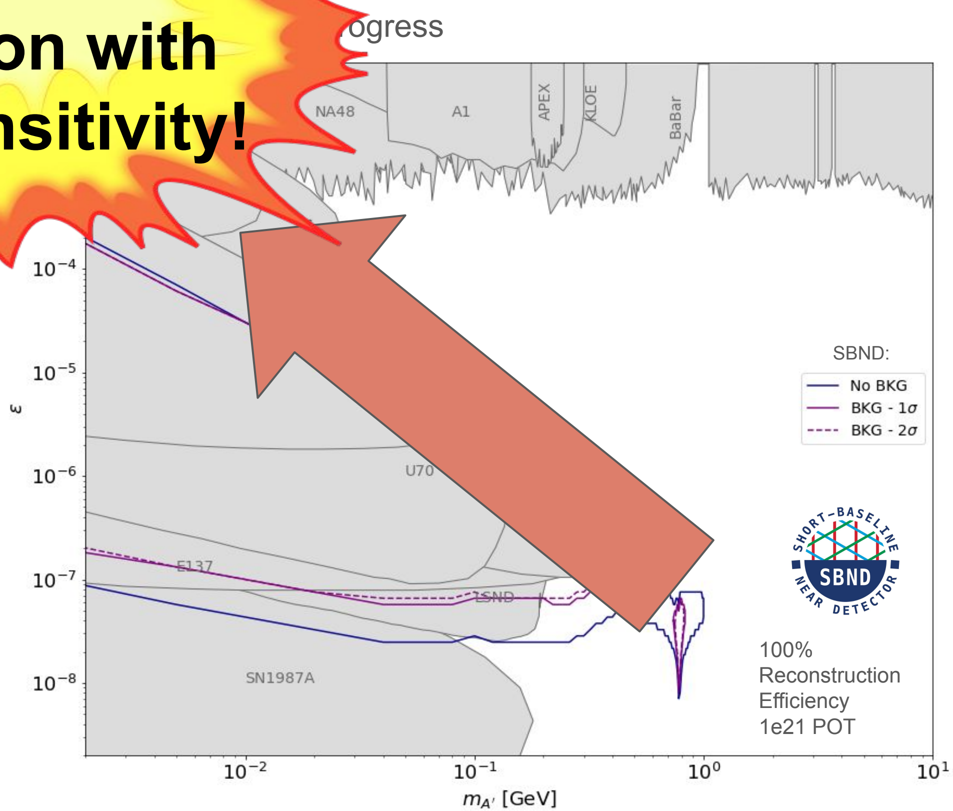


Summary of Sensitiv... Estimat...

Timing-Based Sensit... ...natic-Based Sensitivity

Merged Event Selection with New Sensitivity!





Next Steps & Conclusions

- Our team has begun to move into reconstruction
  - Using a track/shower identification schema is first on our list
- With new sensitivity estimates, and samples provided by Texas A&M, our second task will be to incorporate our timing studies into the event selection
  - Tight/loose cuts depending on location within the neutrino spill
- SBND has significant potential to set new limits for the Dark Photon mass.
- Moving into the future, with an expanded event selection, developed reconstruction, and investigation of all DP channels, we hope to cover a significant amount of parameter space.
- **Questions?**

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