Dark Sector Studies With Neutrino Beams

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Based in part on LOI of same title!

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Model Landscape

Can be broadly classified by

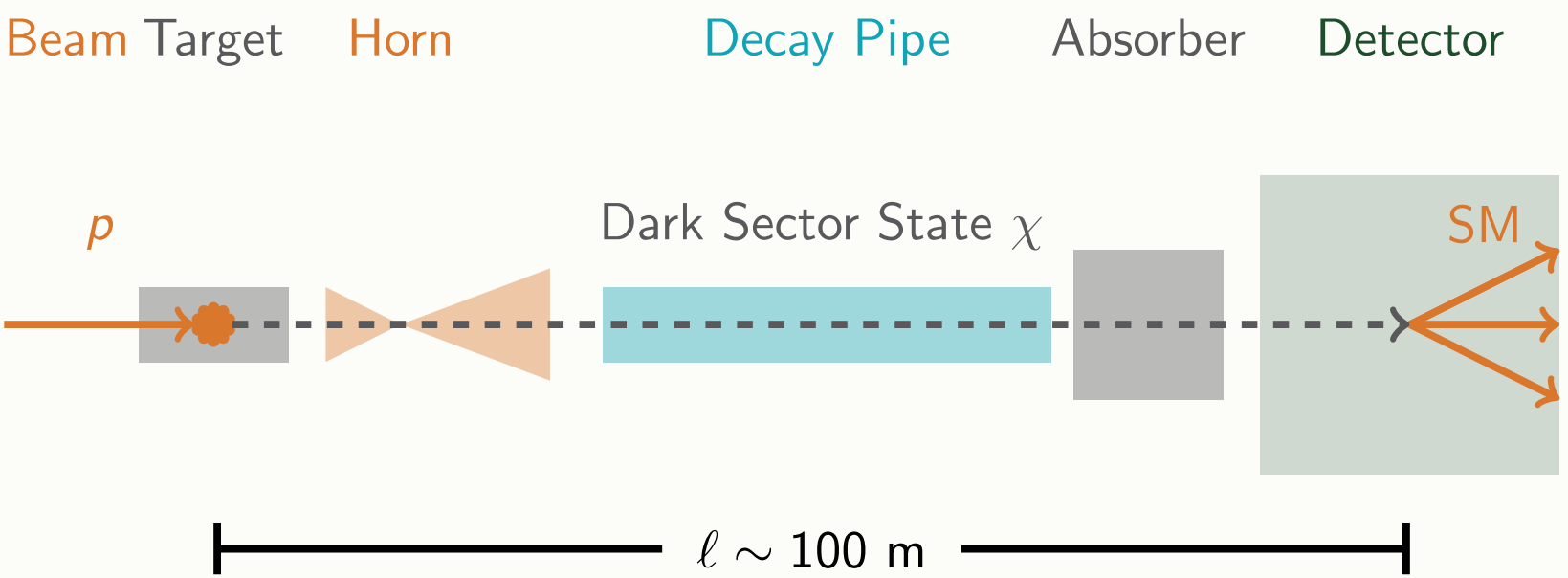
production and detection channels

Model	Production	Detection
Higgs Portal	K, B decay	Decay ($\ell^+\ell^-$)
Vector Portal	π^0, η Decay Proton Bremmstrahlung Drell-Yan	Scattering (χe^-, χX, Dark Tridents) Decay ($\ell^+\ell^-$, $\pi^+\pi^-$) Inelastic Decay ($\chi \to \chi' \ell^+\ell^-$)
Neutrino Portal	π, K, $D_{(s)}$, B decay	Decay (many final states)
ALP Portal (γ-coupling dominant)	Meson Decay Photon Fusion Primakoff Process	Decay ($\gamma\gamma$) Inverse Primakoff process
Dark Neutrinos Dipole Portal	SM Neutrino Dalitz Decay	Upscattering + Decay Decay ($\nu_D \to \nu\gamma$)
νphilic Mediators	SM Neutrino	Scattering (Missing $p\!\!\!/_T$, SM Tridents)

Why Accelerator Neutrino Experiments?

- Because they have some of the highest intensity proton beams
- Because they have excellent detectors
- Because beam-produced DM/DSP tend to be very energetic
- Because there are a lot of facilities right now or in the next few year

Short-Baseline/Near Detector Setup



$$N = \sigma_{\text{prod}} \cdot N_{\text{POT}} \cdot n_T \cdot L_T \cdot f_{\chi \to \text{det}} \cdot P_{\chi \text{ dec./int.}}$$

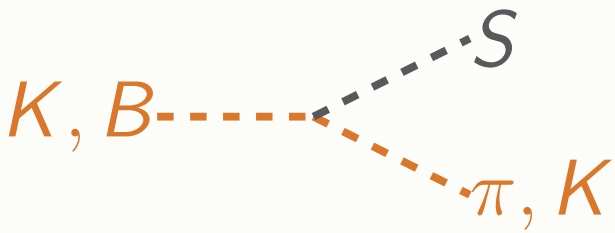
Proton Beam Facilities

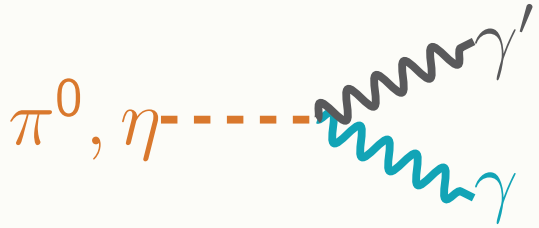
Location	Beam	Kin. E (GeV)	Power (kW)
Fermilab	BNB	8	20
	NuMI	120	600
	LBNF	60 – 120	1200
RA	ISIS	0.8	160
J-PARC	RCS	3	530
	MR	30	500 / 55
Los Alamos	LAMPF	0.8	800
CERN	SPS	400	100

Production Mechanisms

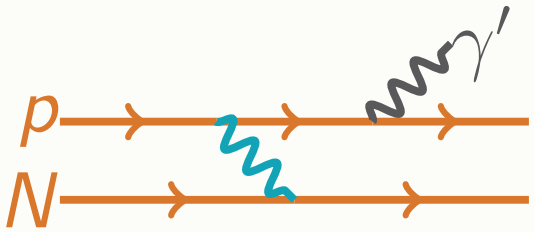
Broad falls into three categories:

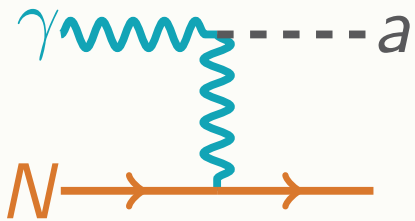
- Production in meson decays



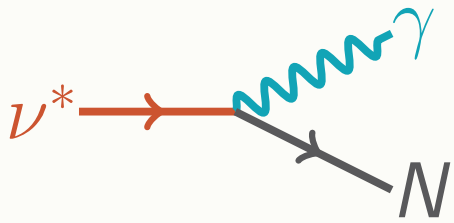


- Production via photons





- Production via neutrinos

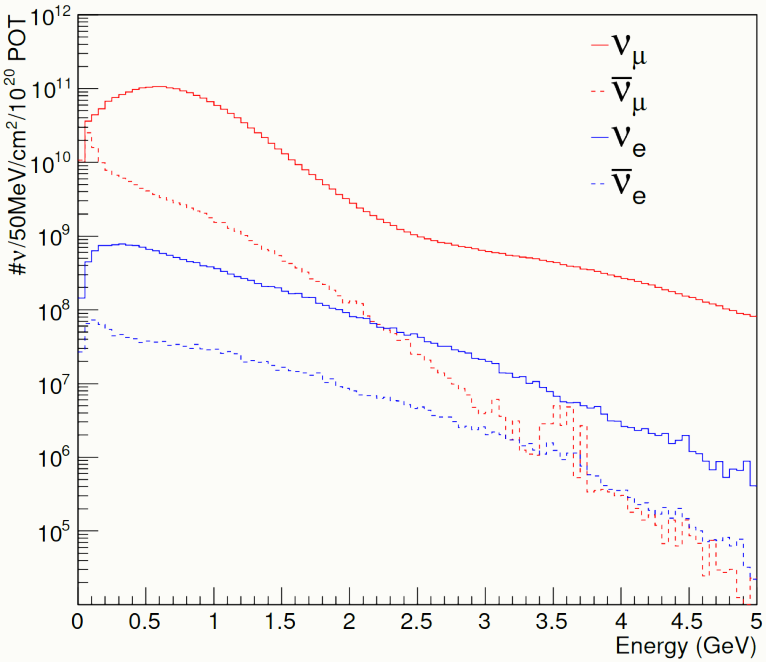


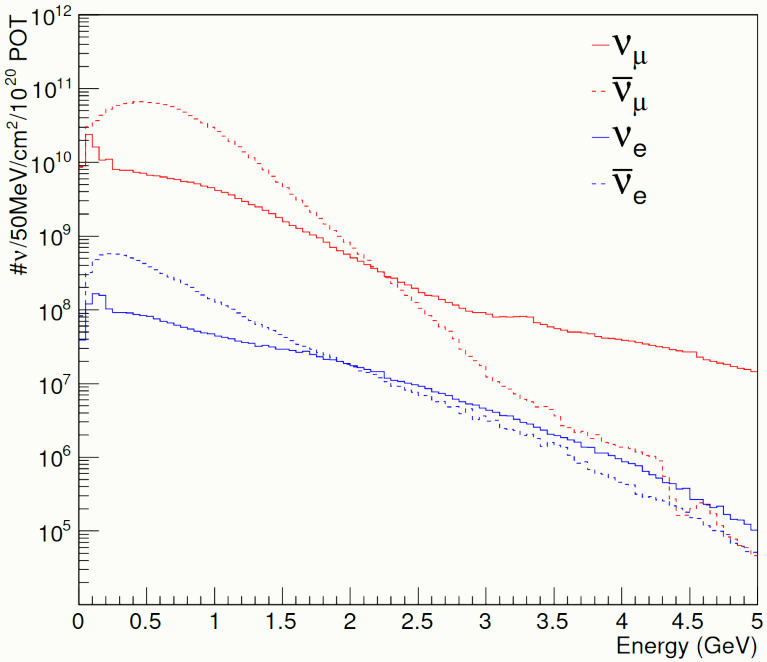
Focusing Horns

B field to focus one Q of mesons toward detectors

Can affect the flux of signals from meson decay

BNB at fluxes at SBND





Adams et. al.: LAr1-ND Proposal

Absorber

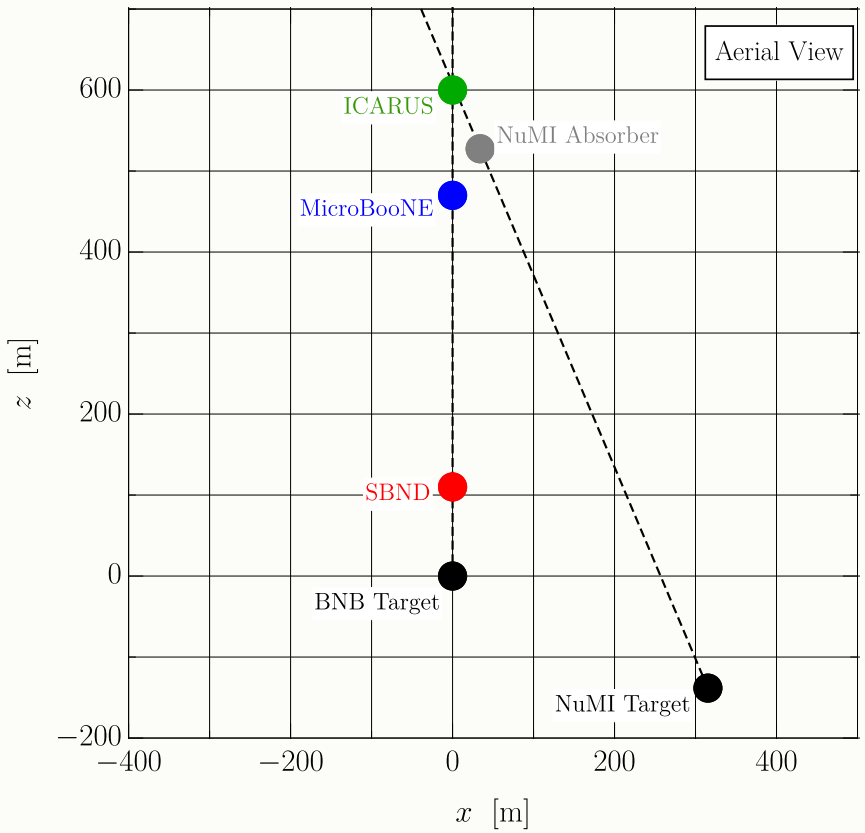
Mesons can travel into absorber & stop

Leads to decay at rest

Unique kinematics:

Easier to select

But also lower energy



Batell, JB, Ismail: PRD 100 (2019) 11, 115039

Experimental Landscape

FNAL

ArgoNeuT SBND

MicroBooNE ICARUS

DUNE MINERνA

NOνA MiniBooNE

J-PARC

ND280

INGRID

JSNS^2

LANL CCM

CERN

CHARM

Tools: Production

- BdNMC deNiverville et. al.: PRD 95 (2017) 3, 035006
  - Simulates dark photon/gauged B-mediated DM
  - Includes prompt and meson decay production
  - Assumes thick target (beam dump)
- MadDump Buonocore et. al.: JHEP 05 (2019) 028
  - MadGraph-based, so UFO model implementation
  - Includes prompt and meson decay production
  - Assumes thick target (beam dump)
- Beam-specific Batell, JB, Ismail: PRD 100,115039 (2019)
  - Needs to be done "by hand"
  - Prompt is tricky (but maybe not necessary)
  - Includes full geometry for thin targets

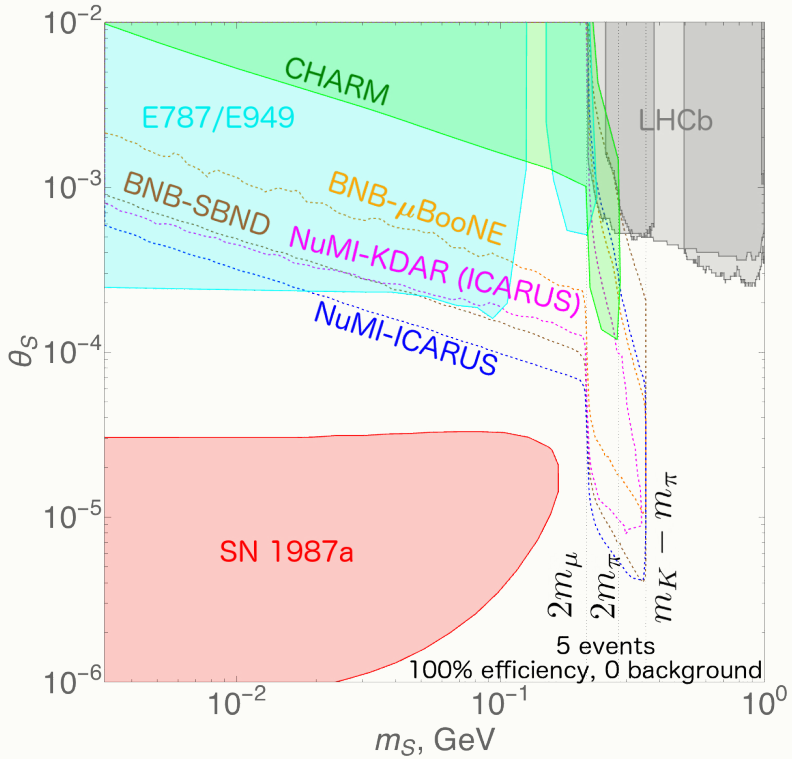
Tools: Detection

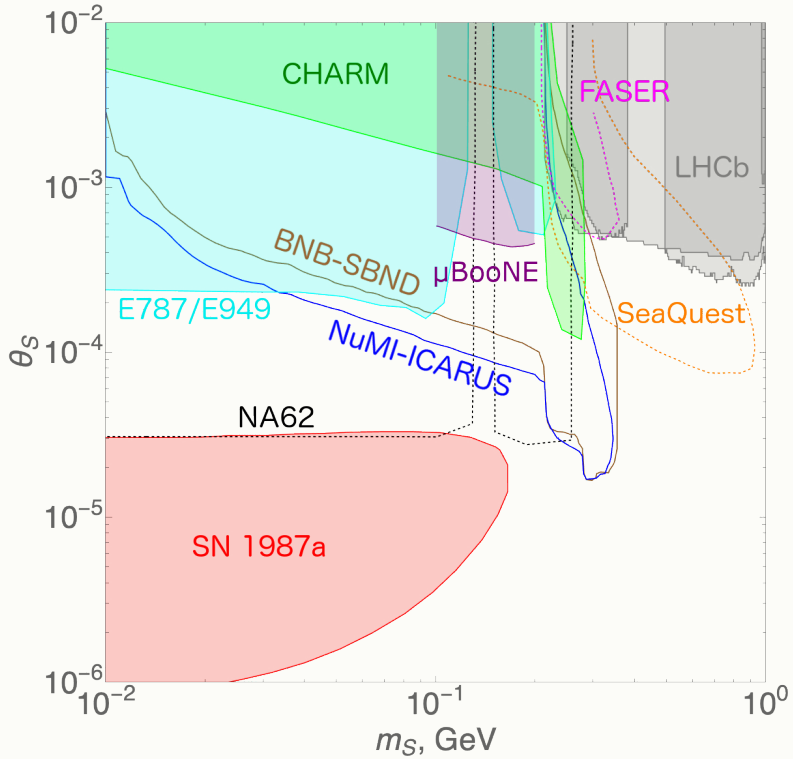
- Decay
  - Usually straightforward (up to detector effects)
- GENIE JB: 1812.05616
  - Arbitrary spin 1 mediated
  - Includes elastic and DIS (resonant forthcoming!)
- BdNMC deNiverville et. al.: PRD 95 (2017) 3, 035006
  - Dark photon/gauged B-mediated
  - Includes elastic, Δ production
- MadDump: Buonocore et. al.: JHEP 05 (2019) 028
  - MadGraph-based, so UFO model implementation
  - Includes elastic e^- and DIS

Detector response?

- Detectors need a dense medium:
  ν interactions are the main target
- Along with cosmic rays: main background
- Understanding detector response can be important when not background free
- For now: parameterized or neglected
- LArTPC case: still under study by experimentalists!
- γ conversion can fake small opening e^+e^-

Example: Higgs Portal





Batell, JB, Ismail: PRD 100,115039 (2019)

Outlook

- Neutrino experiments continue to be excellent probes of a variety of dark sector models
- Many experiments operating and on the horizon: new opportunities to be explored!
- Tools and detector response still under development and can affect understanding of sensitivity