Searching for the Dark Sector at Neutrino Experiments

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JB, Y. Cui, Y. Zhao: JCAP1502 (2015) no.02,005
JB: 1812.05616
JB, Convery, Cui, Graham, Necib, Petrillo,
Stocks, Tsai, Zhao: In Progress (DUNE TDR)
Batell, JB, Ismail: 1905.xxxxx

May 22, 2019

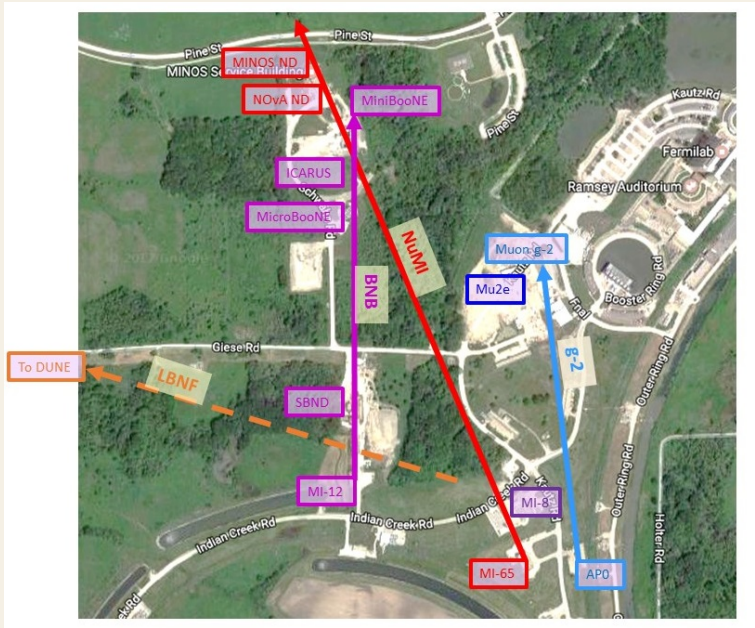
SUSY 2019

Beyond the Minimal WIMP

- Spin-dependent interactions dominate
- Velocity suppression at low v
- Non-SM annihilation modes
- Non-minimal stabilization symmetry
- Multi-component DM sector: Portal Mediators
- High(er) velocity flux: Boosted Dark Matter

Where can we look?

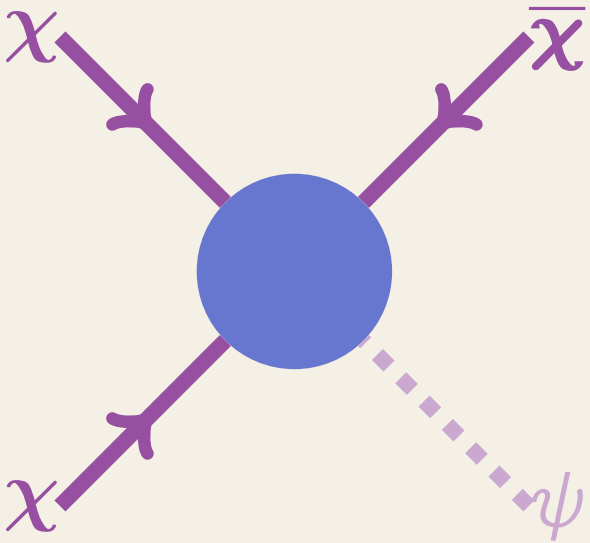
- Boosted dark matter:
  - Higher threshold OK
  - Need large size
- Dark sector mediators:
  - Need high intensity



Fermilab

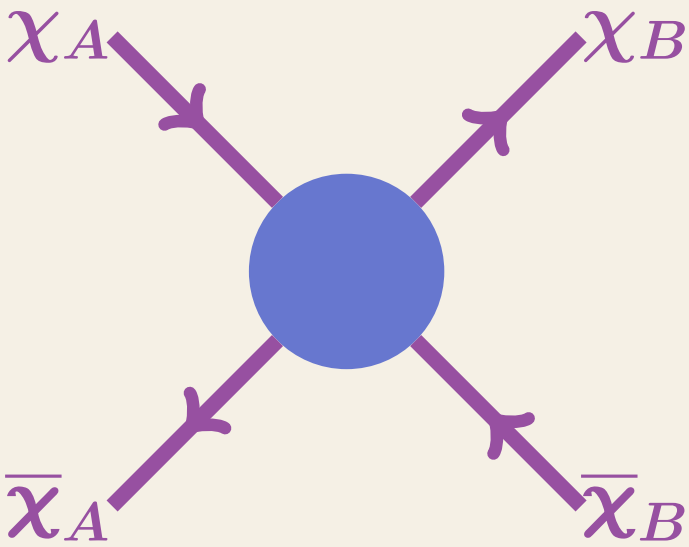
Simple BDM models exist

Z_3 Dark Matter with semi-annihilation



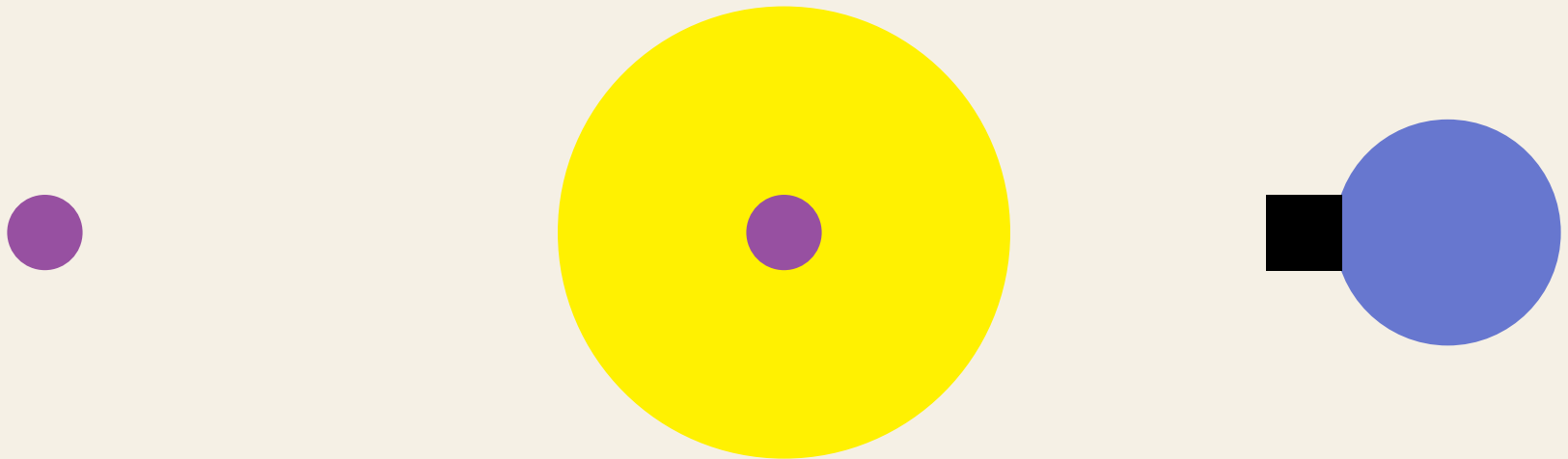
$v \approx 0.6$

Two component Dark Matter



$v = \sqrt{1 - m_B^2/m_A^2}$

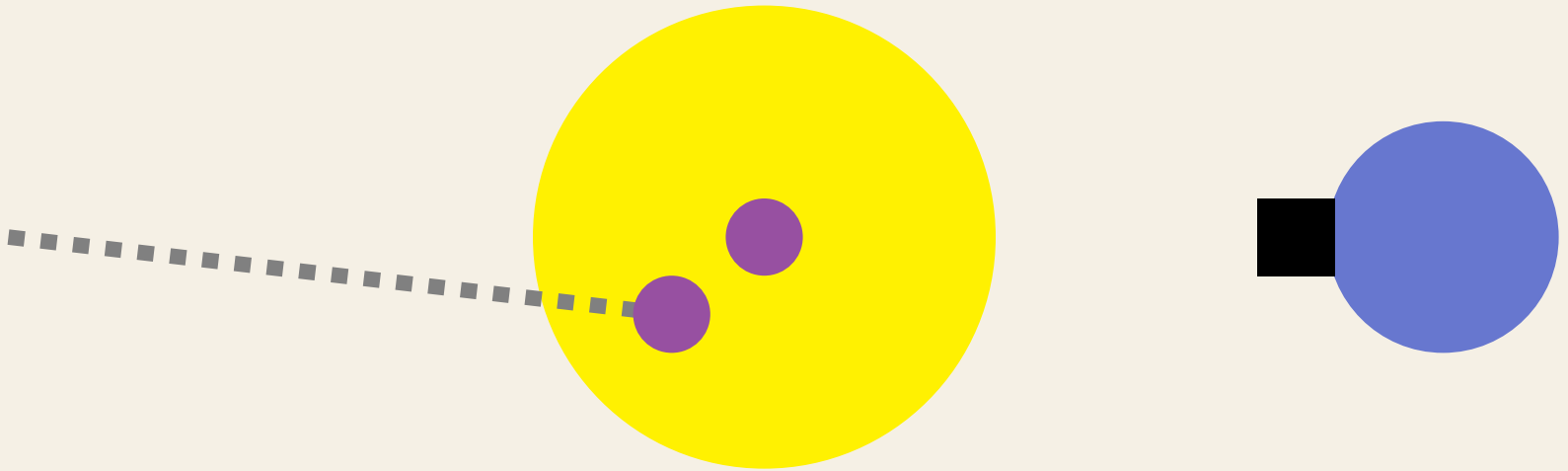
Solar capture & detection



JB, Cui, Zhao, JCAP 1502 (2015) 005
Kong, Mohlabeng, Park: PLB743 (2015) 256

Solar capture & detection

Capture: $C = \int dV\, du\, \sigma_{\chi p}(v < v_{\rm esc})\, \frac{w^2}{u}\, n_\chi\, n_H\, f(u)$



DM Sun Earth

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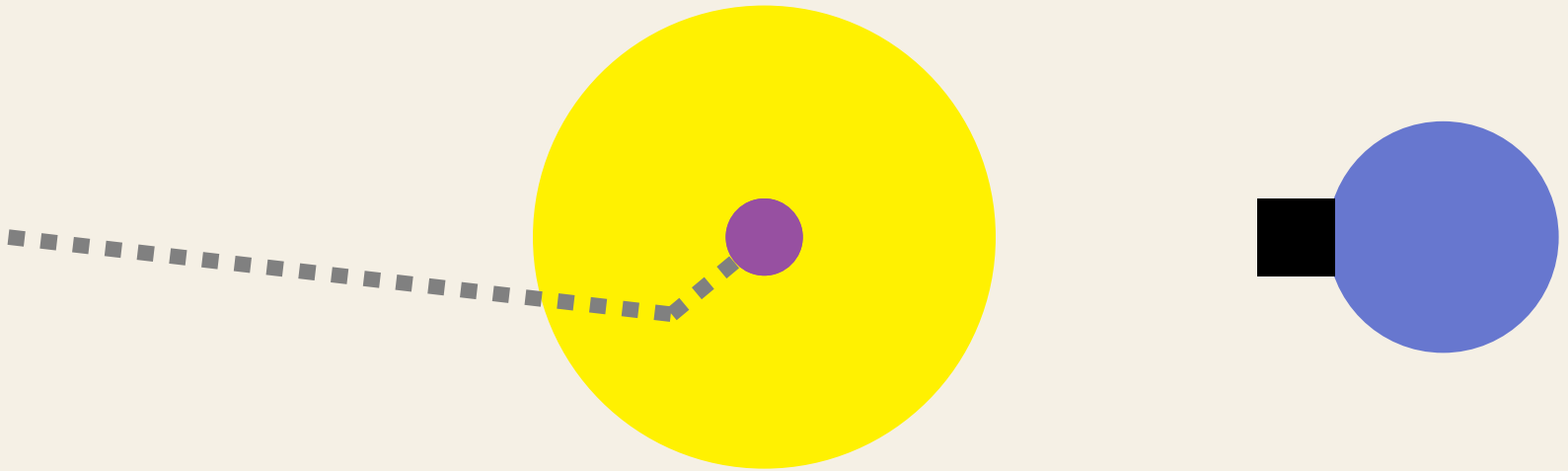

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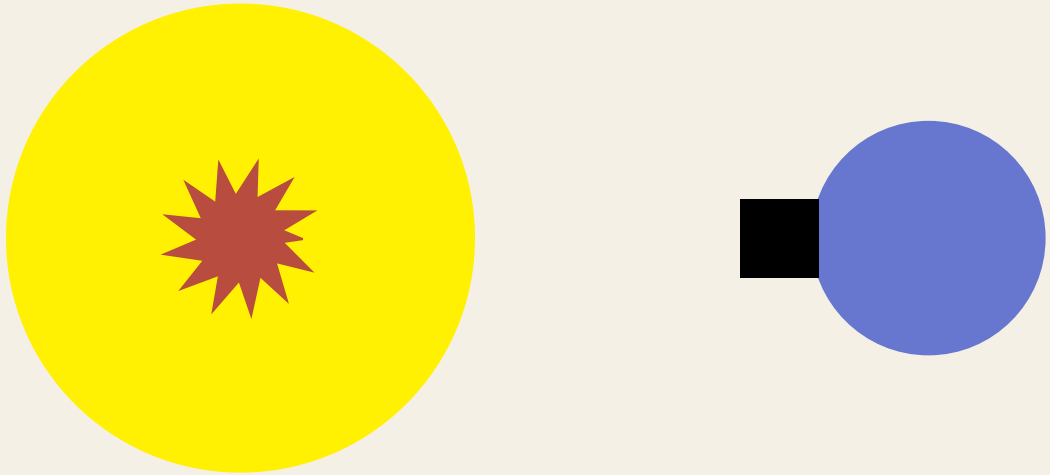
Solar capture & detection

Annihilation: $A\,N^2 = C - E\,N$



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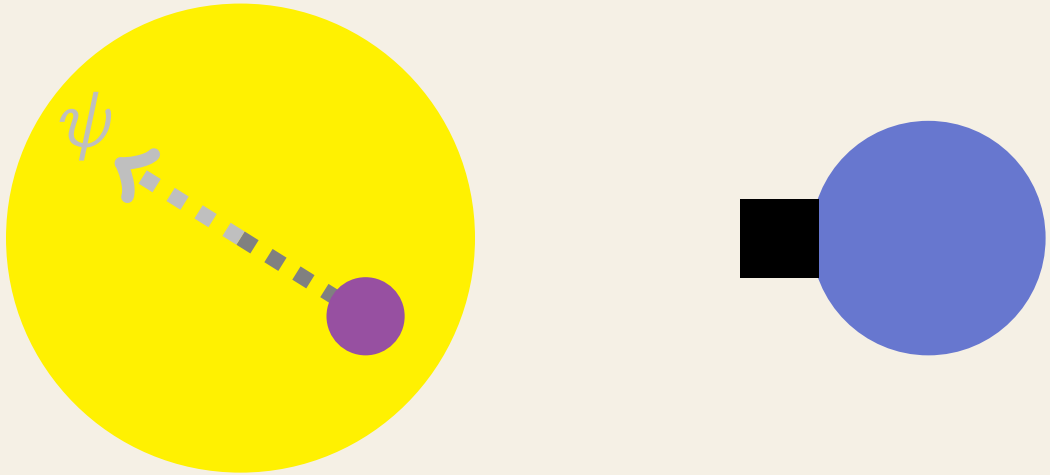

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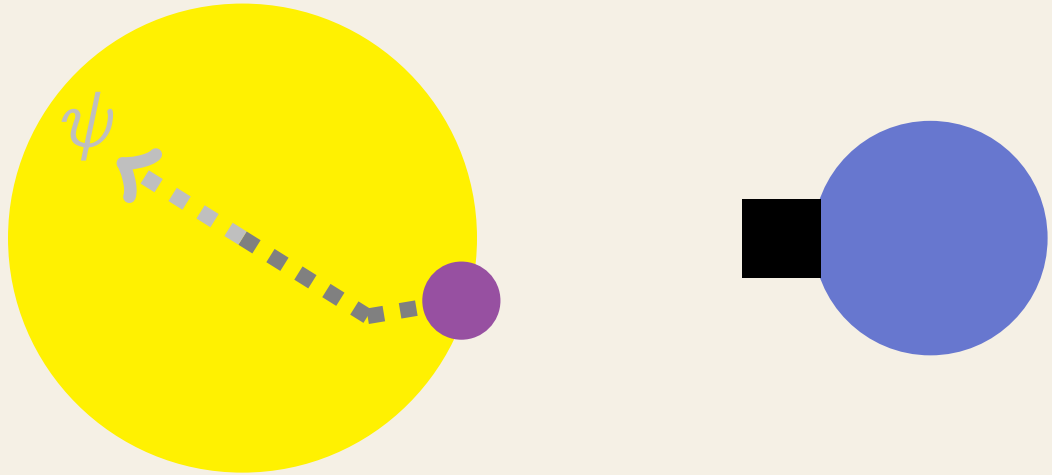
Solar capture & detection

Rescattering: Generally negligible



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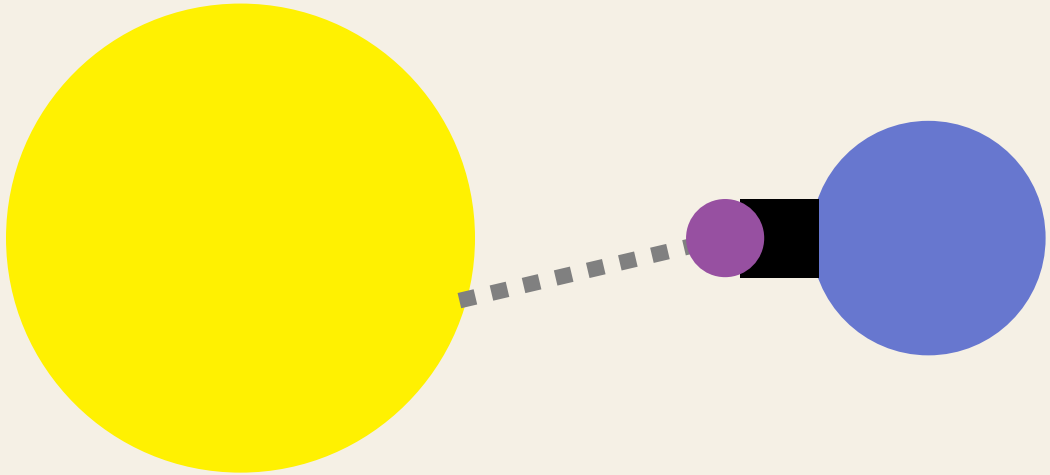
Solar capture & detection

Detection: $\Phi \approx \frac{C}{4\,\pi\,\mathrm{AU}^2}$



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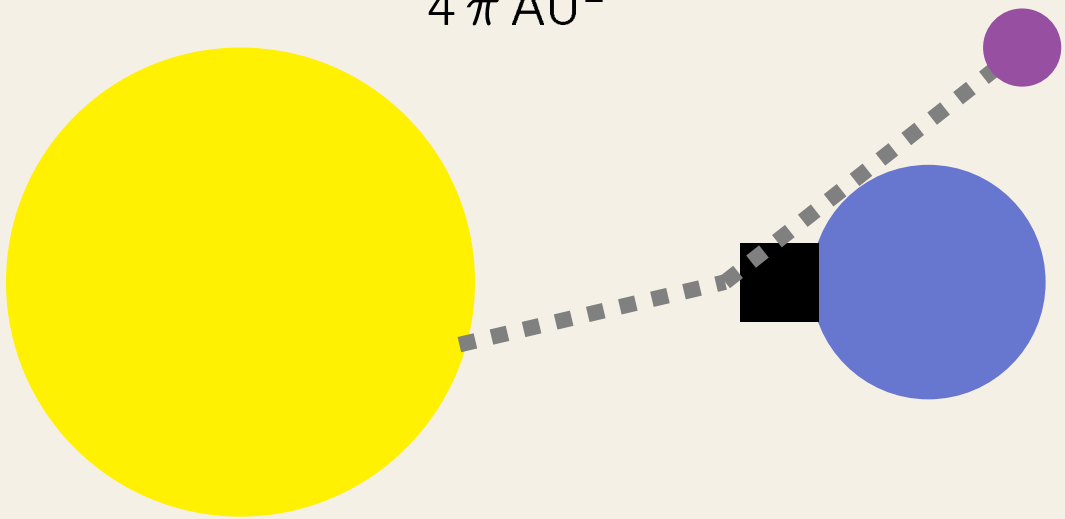

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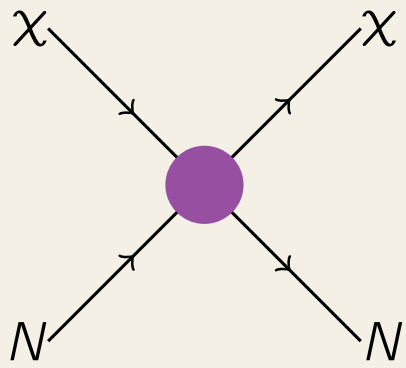
Detector Interactions: A New Tool

- Elastic scattering off free nucleons analytically calculable
- Nuclear physics at scale 250 MeV
- DIS above scale 2 GeV
- New Monte Carlo tool as part of GENIE

JB: 1812.05616

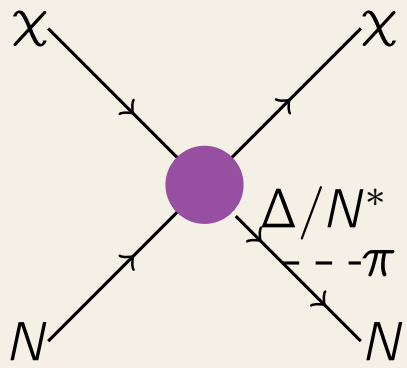
Three different processes



Elastic

Relatively easy

Needs form factor

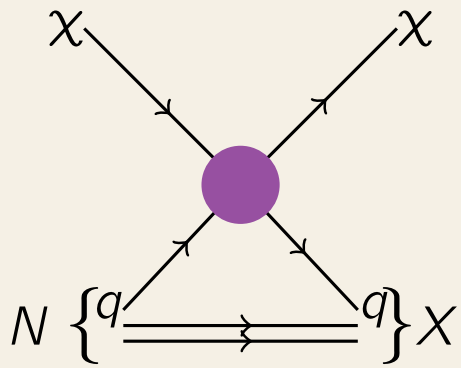


Resonant

Dominated by Δ, N^*

$M_{\text{had}} \in [1, 2]$ GeV

Needs a model



Deep Inelastic

Use standard parton model

DM beam?

Rein & Sehgal: Ann.Phys.133, 79 (1981)

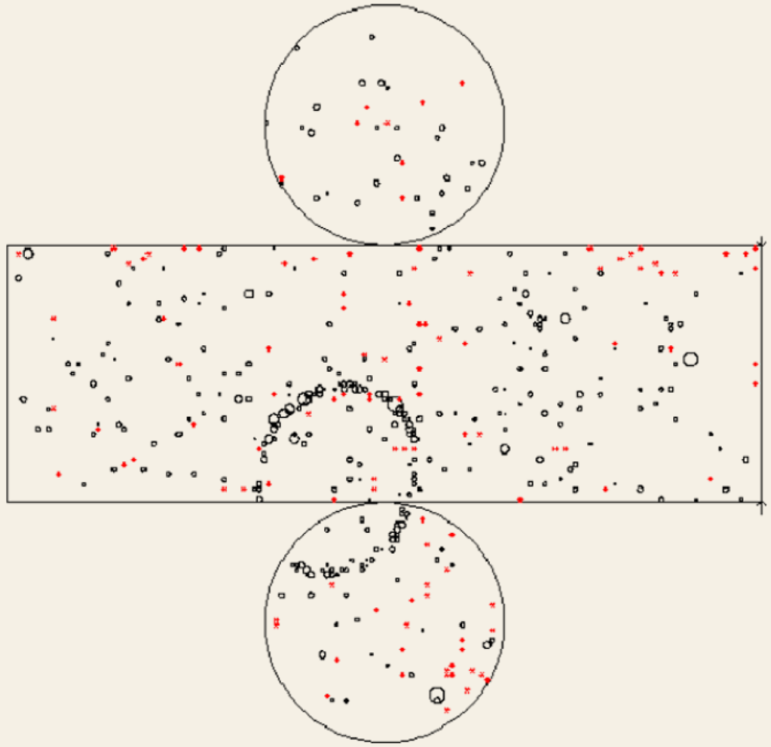
Current Status of BDM in GENIE

- ✓ Fermion or scalar DM, arbitrary Z' coupling
- ✓ Elastic, DIS and electron scattering implemented
- ✓ Framework mostly set for further models
- ✓ Integrated into GENIE v3

Looking with water Čerenkov

Physical energy threshold:

$$E_{K,recoil} = 480 \text{ MeV}$$



Hard to reconstruct inelastic

Experiments:

- Super-Kamiokande
- Hyper-Kamiokande

Super-Kamiokande: PRD79 (2009) 112010

A future in liquid argon TPCs

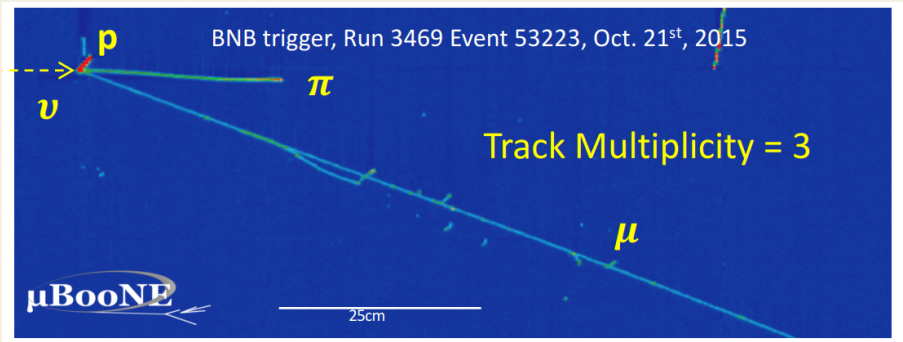
Threshold:

$E_{K,recoil} \lesssim$ 50 MeV

Inelastic reconstruction possible

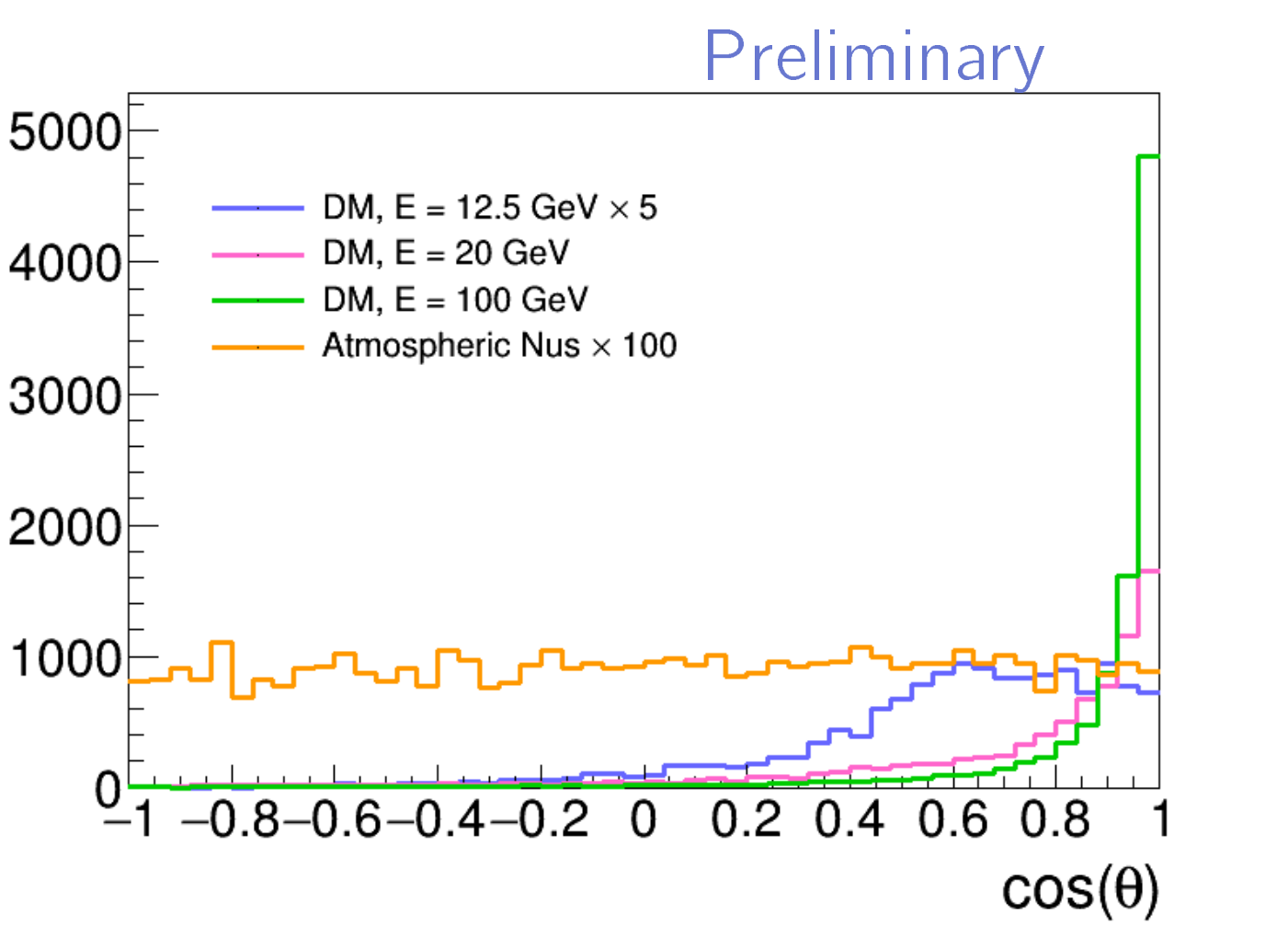
Experiments

- LArIAT, MicroBooNE
- ArgoNeuT, ProtoDUNE
- SBND, ICARUS
- DUNE



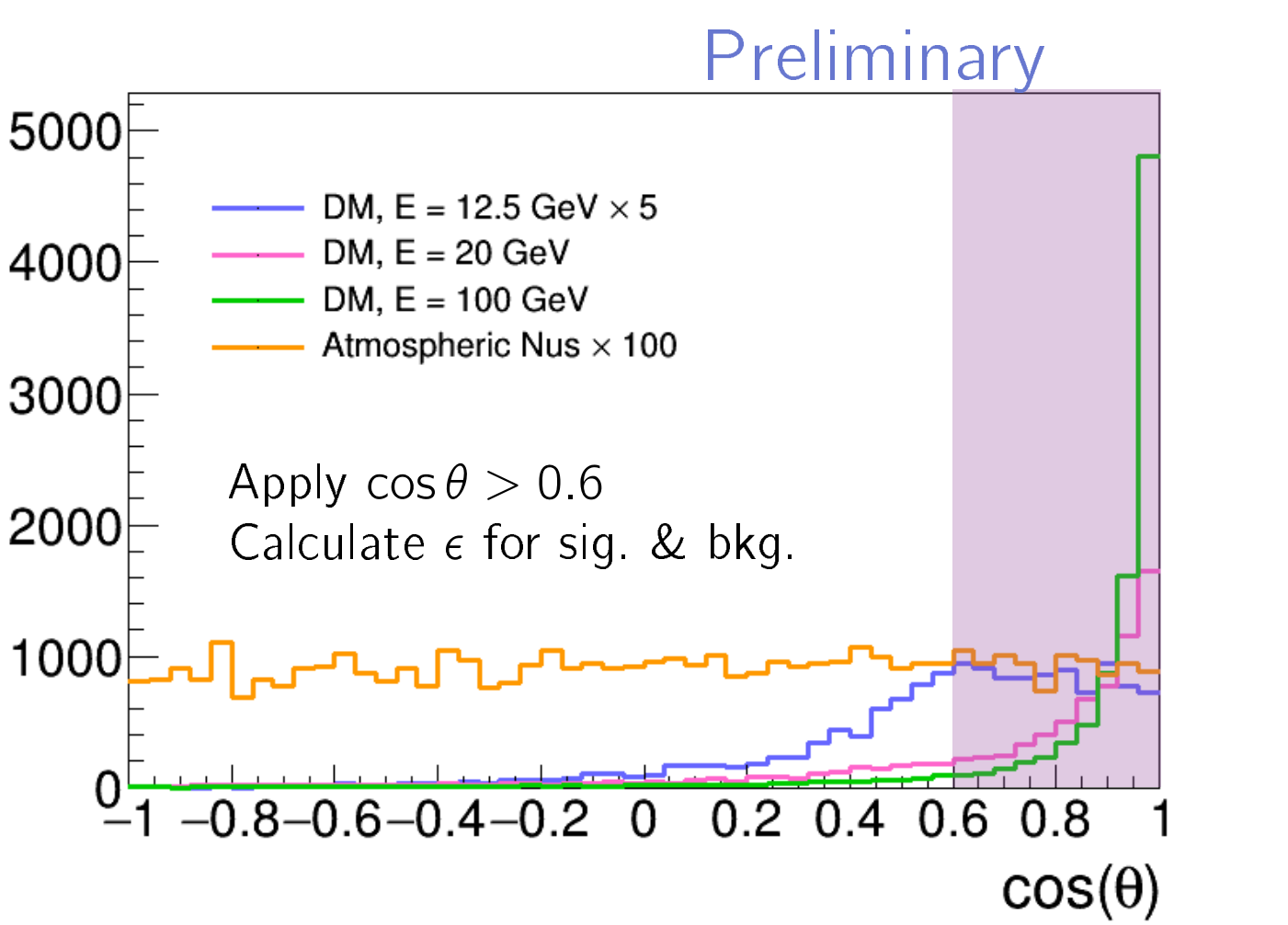
Yellow captions from talk by Luo

Angular Distribution (Total P)



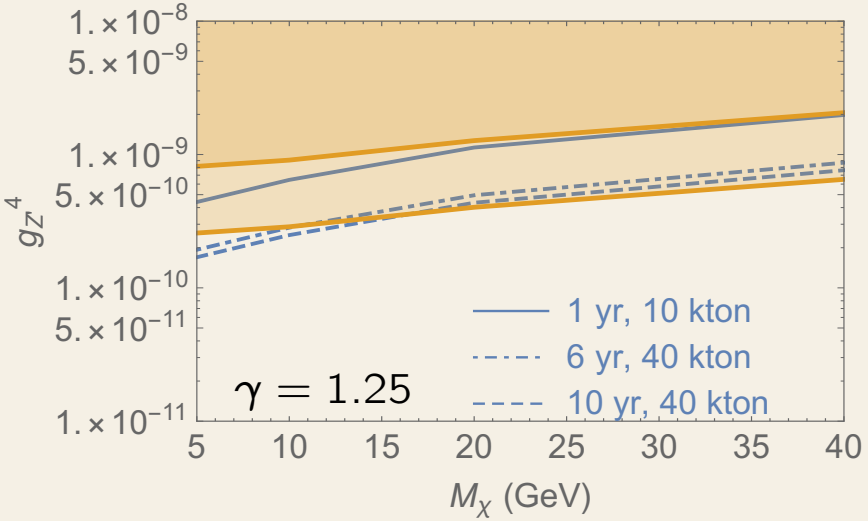
Courtesy of Yun-Tse Tsai

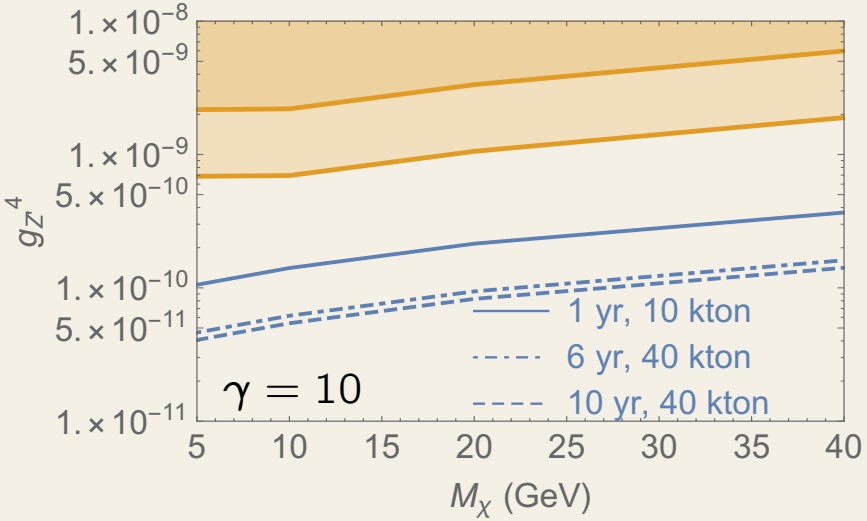
Angular Distribution (Total P)



Courtesy of Yun-Tse Tsai

Preliminary Results

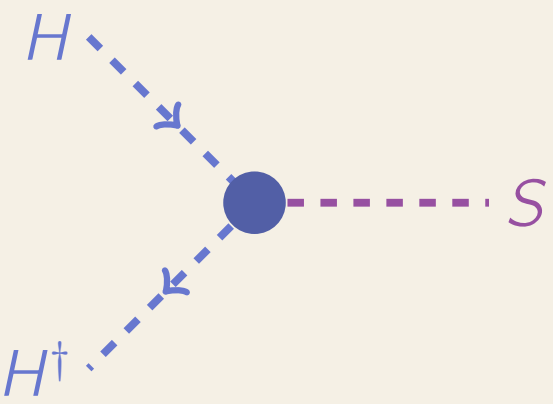




- Super-Kamiokande: 22.5kt fiducial volume, 6 yrs
- No angular cut to reduce atmo bkg for Super-K
- Efficiency (resolution, other FS particles)?

Higgs Portal Model

$$\mathcal{L} = \delta \, |H|^2 \, S$$



$$\theta_S \approx \frac{\delta \, v}{2 \, M_h^2} \ll 1$$

Simple model: Only two new parameters–M_S and θ_S

Higgs Portal Model

$$\mathcal{L} = \frac{1}{2}\,\delta\, v\, h\, S$$

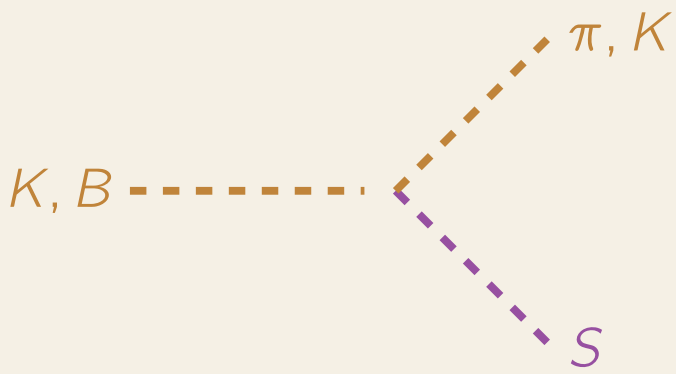
$$\theta_S \approx \frac{\delta\, v}{2\, M_h^2} \ll 1$$

Simple model: Only two new parameters–M_S and θ_S

Probing the Higgs Portal

Larger θ_S

Lab-produced meson decay



Smaller θ_S

Cosmology & Astrophysics

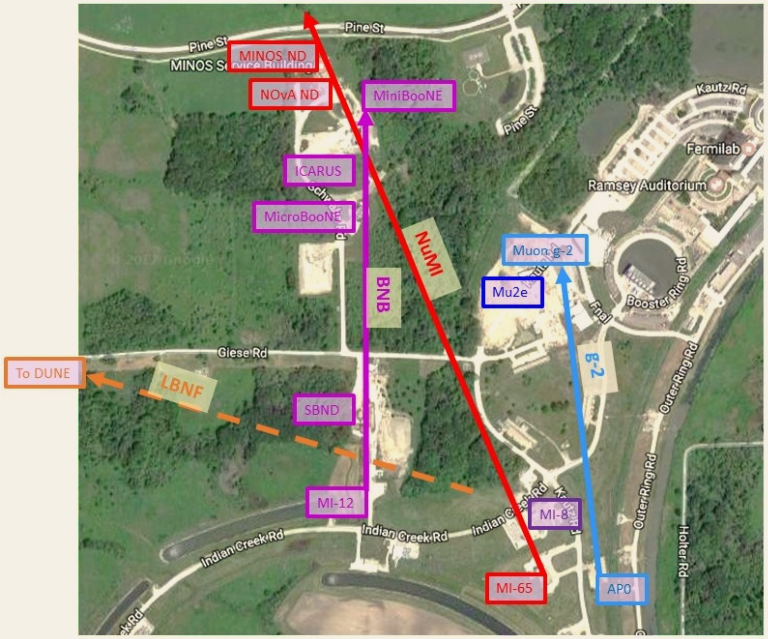
SN Cooling

Spallation/charge exchange during BBN

EM energy during recomb.

Beam Properties

Beam	BNB	NuMI
Energy	8 GeV	120 GeV
POT/year	6×10^{20}	4×10^{20}
Spill Time	1.6 μs	10 μs
Target	Beryllium	Graphite
Axis	On	Off



Detector Properties

Three LAr TPC detectors:

- SBND: Best with BNB (On axis)

  112 tons 110 m away with area 16 m^2

- MicroBooNE: Currently operating

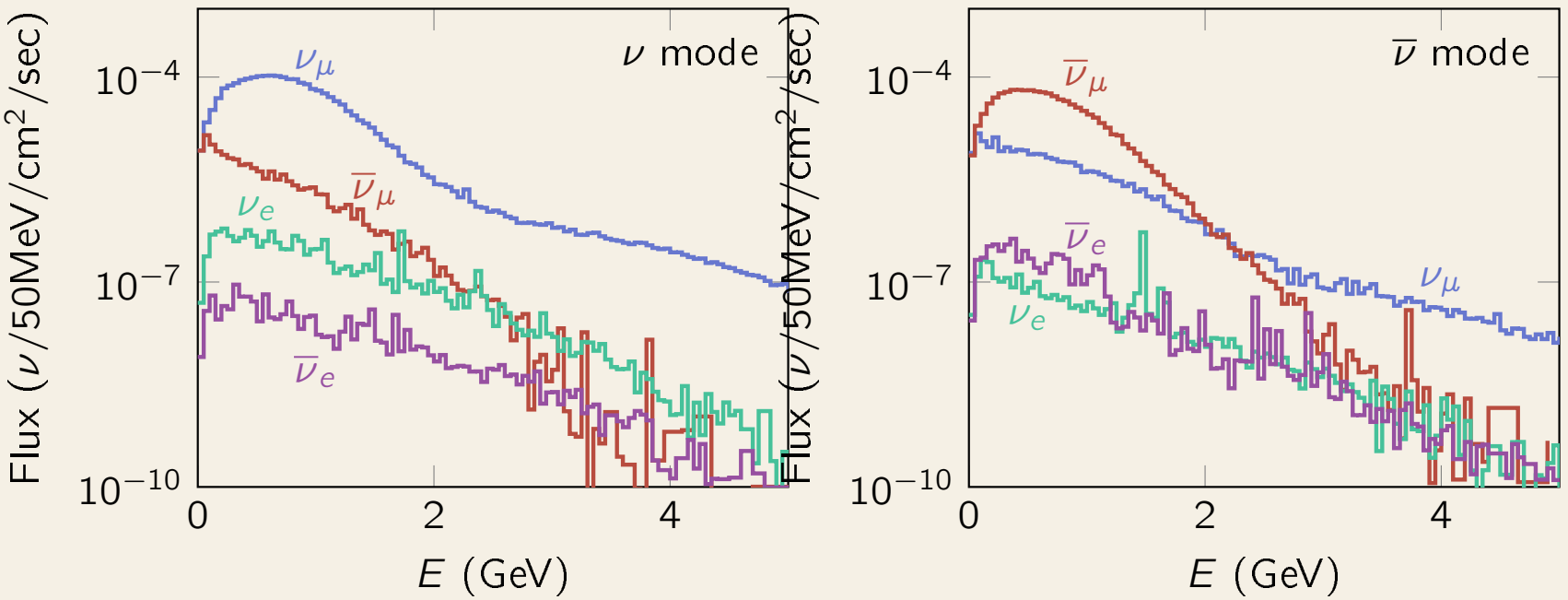
  170 tons 470 m away with area 5.96 m^2

- ICARUS: Best with NuMI (Off axis)

  480 tons 600 m away with area 18.9 m^2

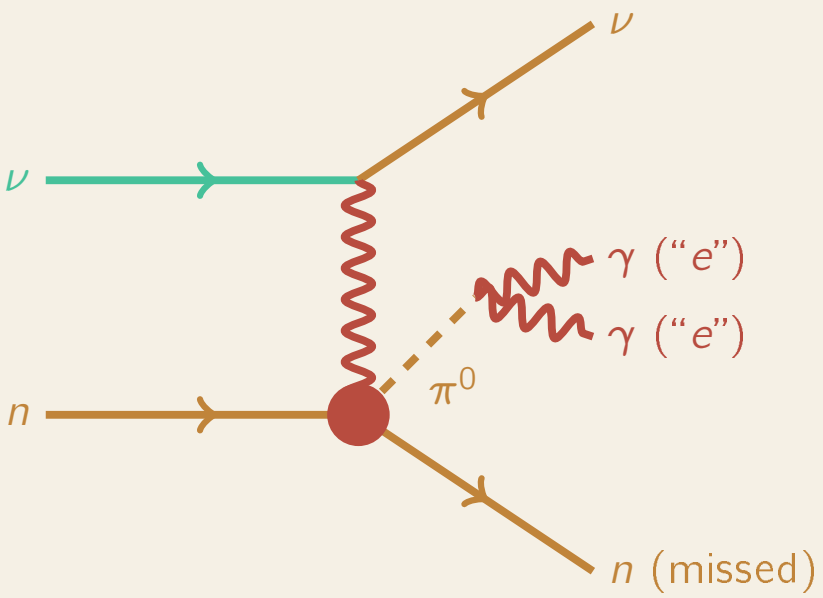
Magnetic Focusing Horn

- Focus one charge of mesons toward detectors

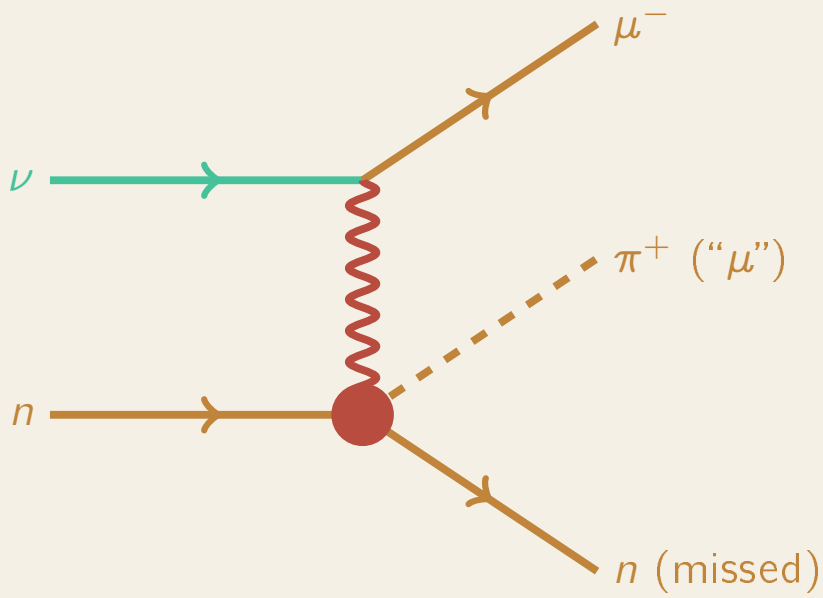


Event Generation: Backgrounds

- Irreducible backgrounds extremely suppressed
- Dominated by photon and pion fakes



$S \to e^+e^-$ background

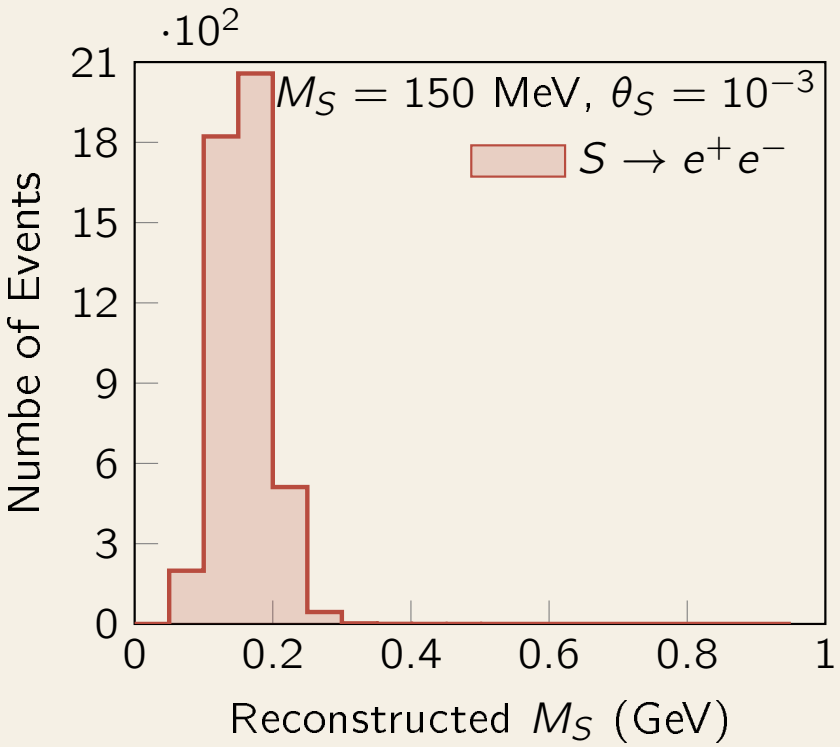


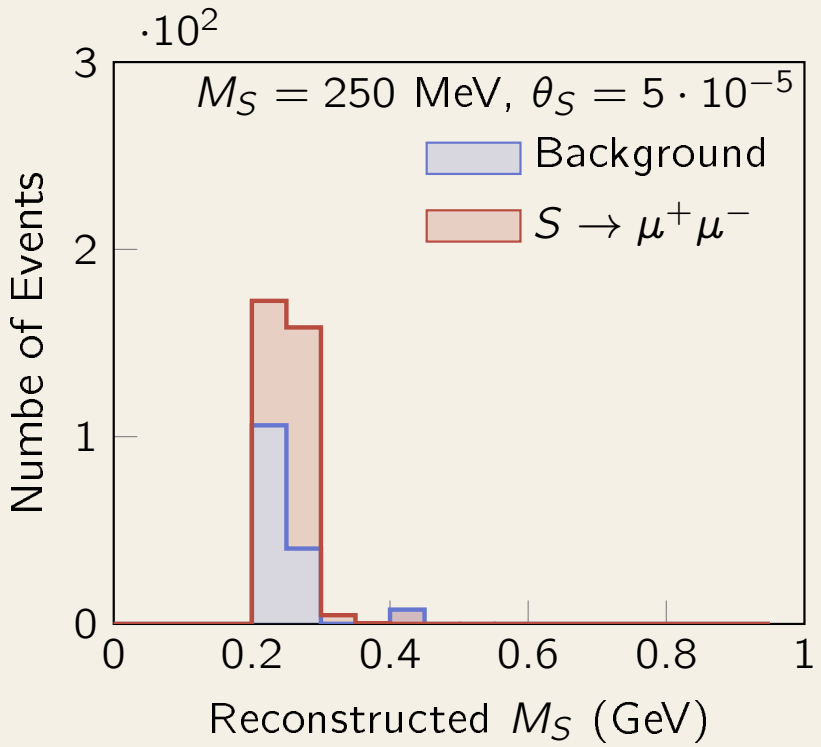
$S \to \mu^+\mu^-$ background

Current Analysis Strategy

- So far: kinematic cuts only
  - One pair of S daughters, no other activity
  - Reconstruct S and require $\theta_{S,z} < 4^\circ$
  - ± 40 MeV invariant mass bump peak
- e^+e^-: separation of 10° eliminates most bkg
- $\mu^+\mu^-$: Cut on E ratio, individual angles

Current Distributions





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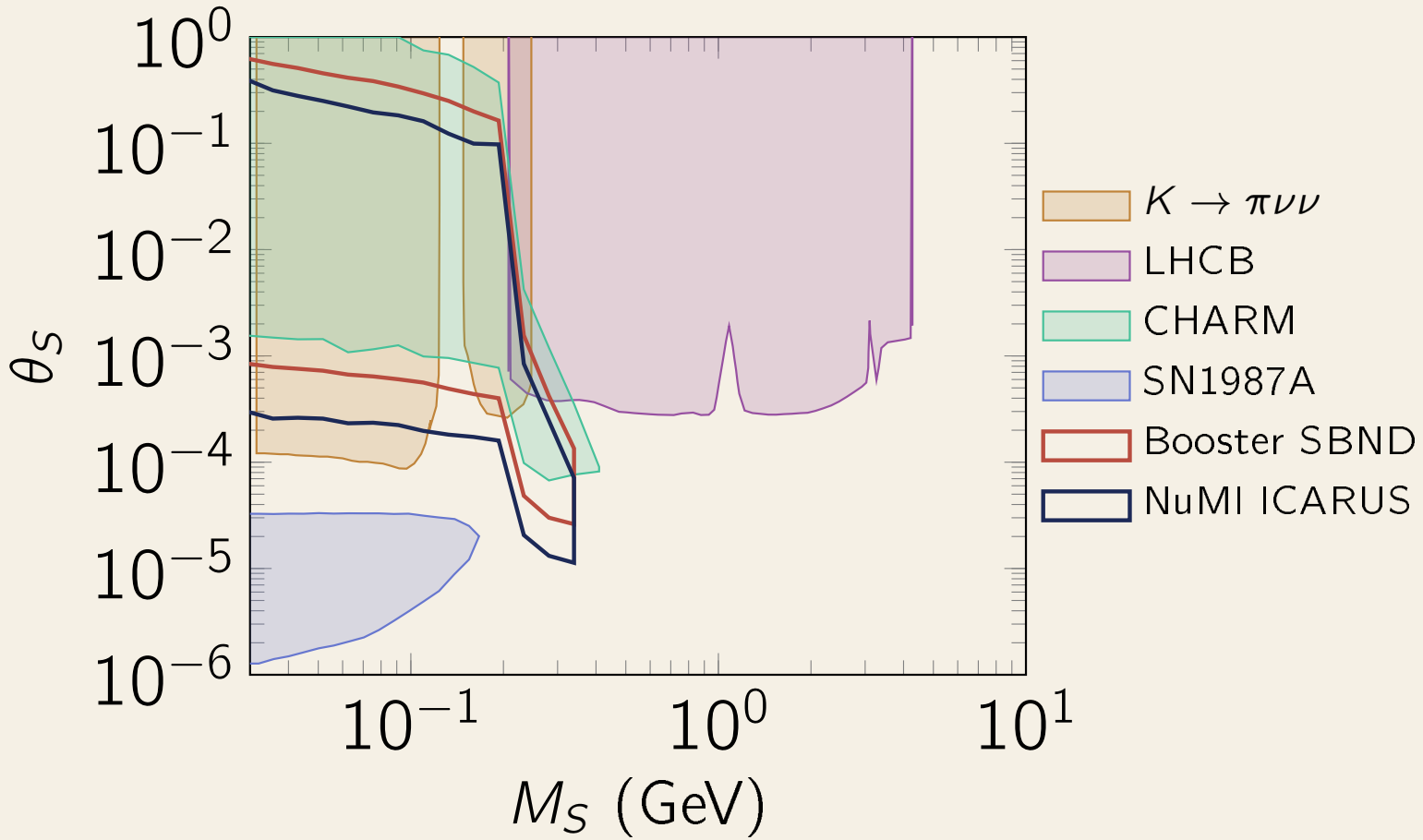

Conclusions

- There is a lot of room to explore non-neutrino BSM at neutrino detectors
- Opportunities with beams at short-baseline & astrophysical sources at long-baseline detectors
- Need more understanding of LAr TPC‘ to fully determine capabilities for BSM