Searches for dark particles at LBNF

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Based on work in collaboration with
Bogdan Dobrescu, Claudia Frugiuele and Roni Harnik,
arXiv: 1512.03852

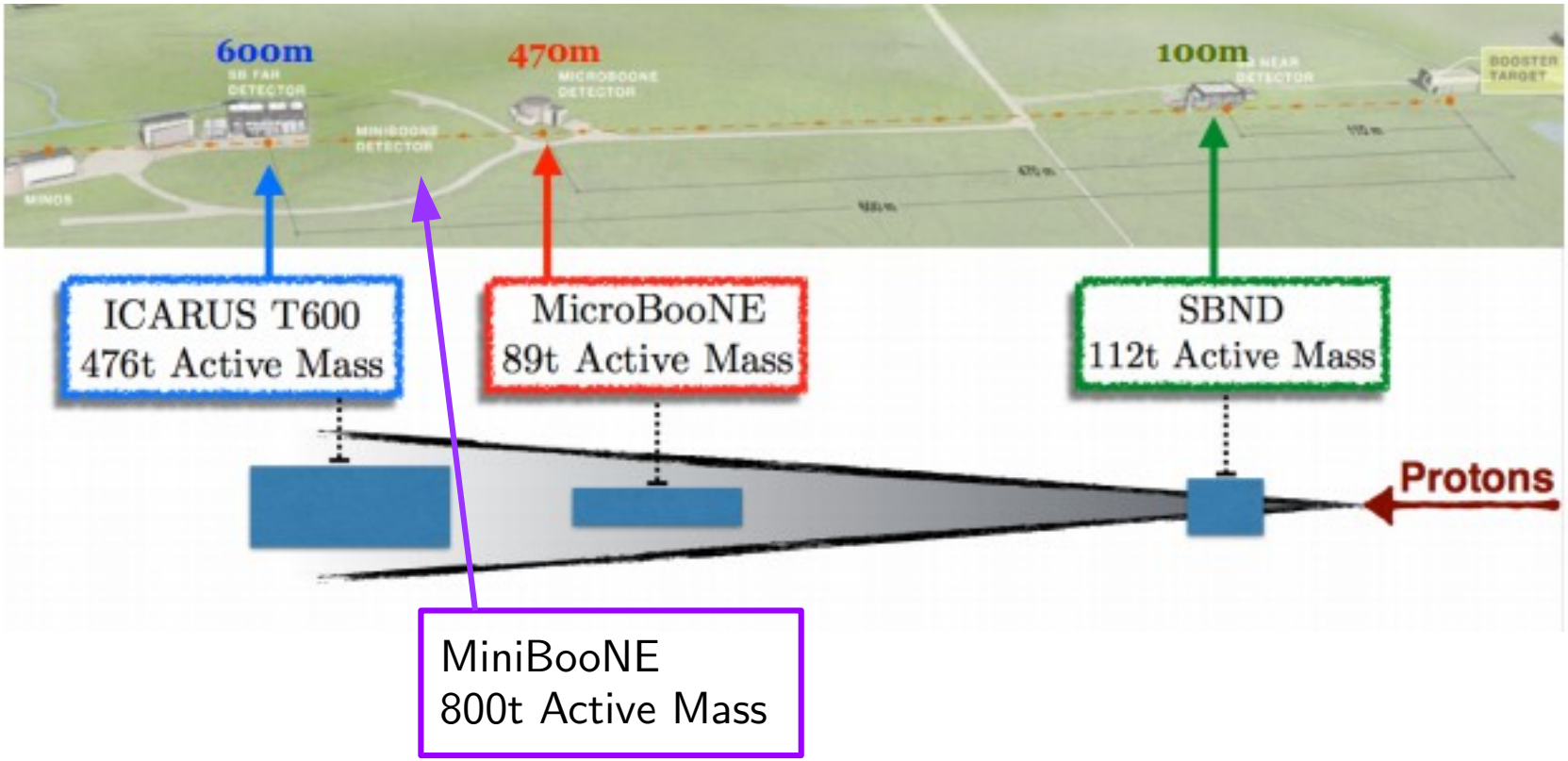
Simplicity II workshop
Fermilab, Sep 6th, 2016

Outline

- Introduction
- Searches using low energy neutrino experiments – low mass Z' ($<$ GeV)
- Current bounds on a leptophobic Z' above the GeV scale
- Our results for an LBNF-like setup
  - Expected signal/background
  - Expected sensitivity
- Conclusions

Fermilab short-baseline ν program

Three neutrino detectors located along the Booster neutrino beamline (8 GeV protons):

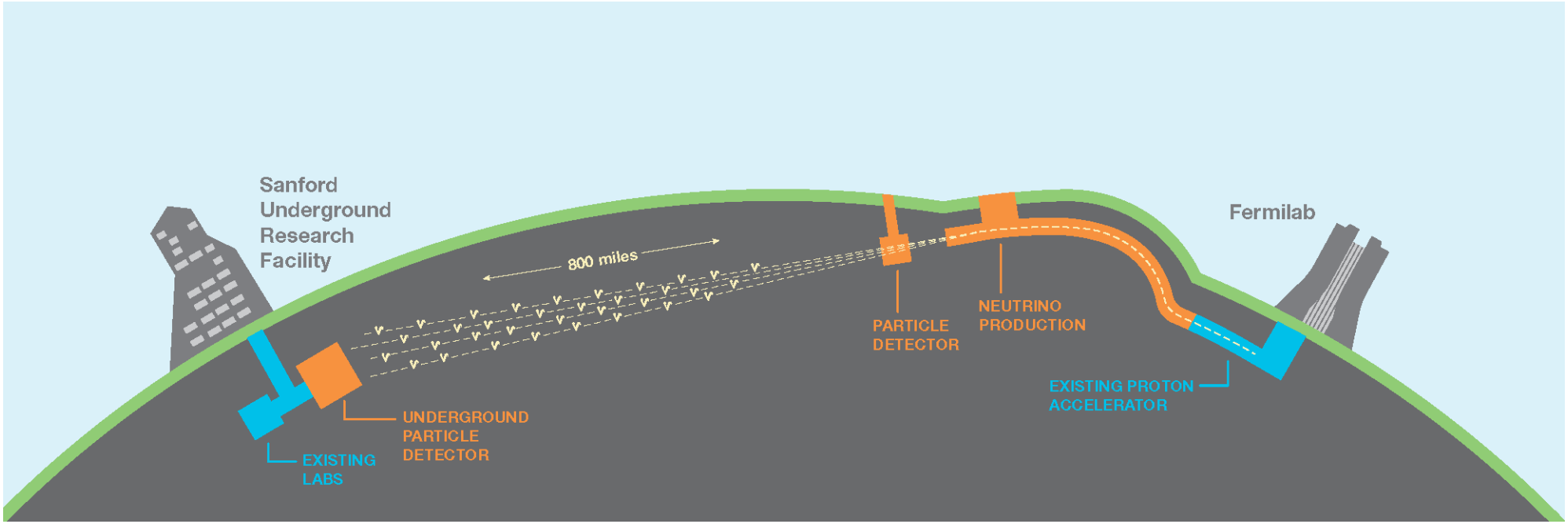


The long-baseline program

- NOvA and MINOS use the NuMI beamline (120 GeV protons)
- MINOS is on-axis
- NOvA is located 0.8 degrees off-axis
- Both experiments have near detectors in the Fermilab campus

The DUNE/LBNF experiments

DUNE will aim to reach a high significance for CP violation and the ordering of neutrino masses. A new beamline (LBNF) will be needed



The Deep Underground Neutrino Experiment (DUNE)

The Long-Baseline Neutrino Facility (LBNF)

Can neutrino oscillation experiments be exploited beyond neutrino physics?

We know that there is a dark sector...

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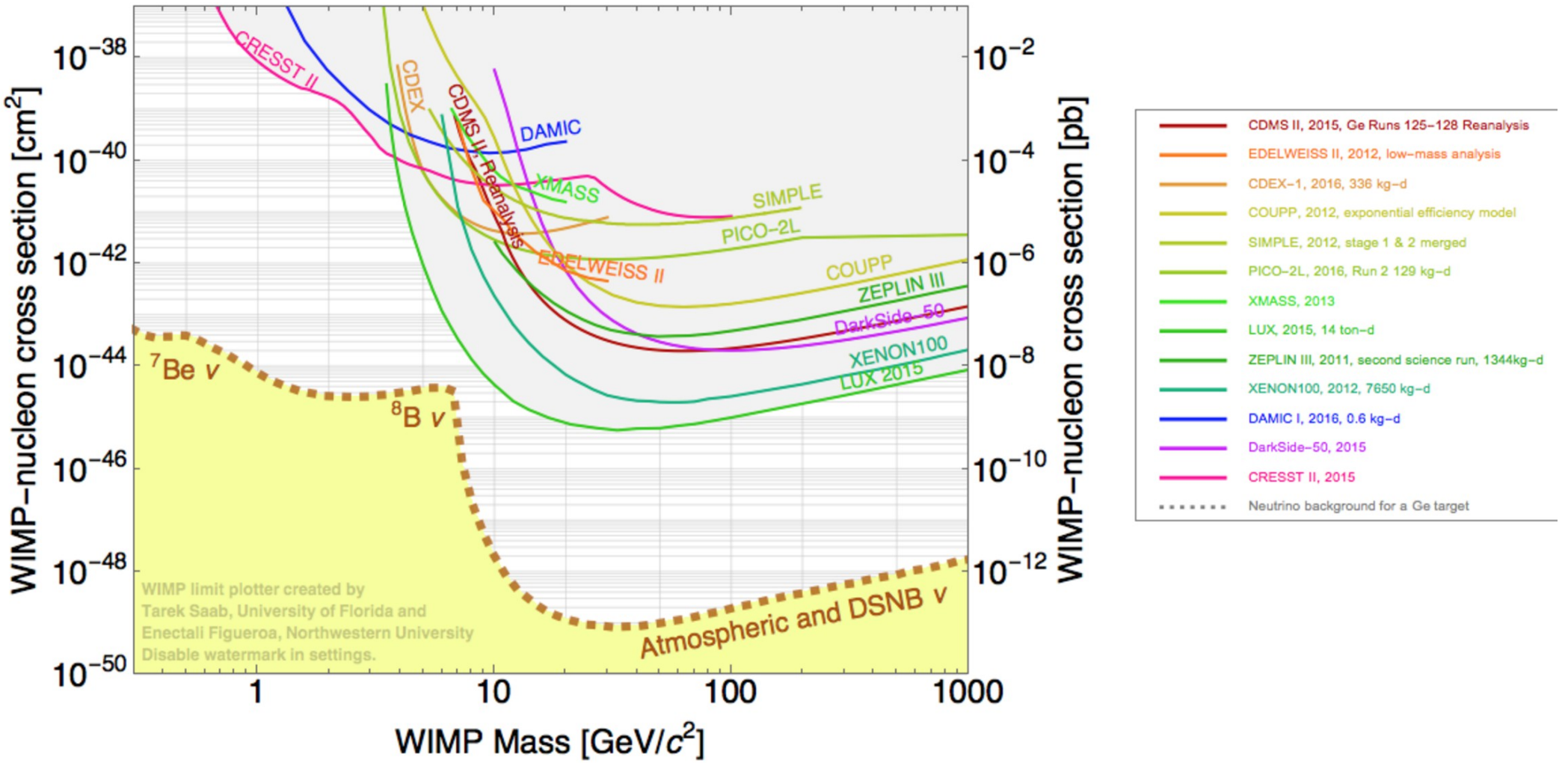
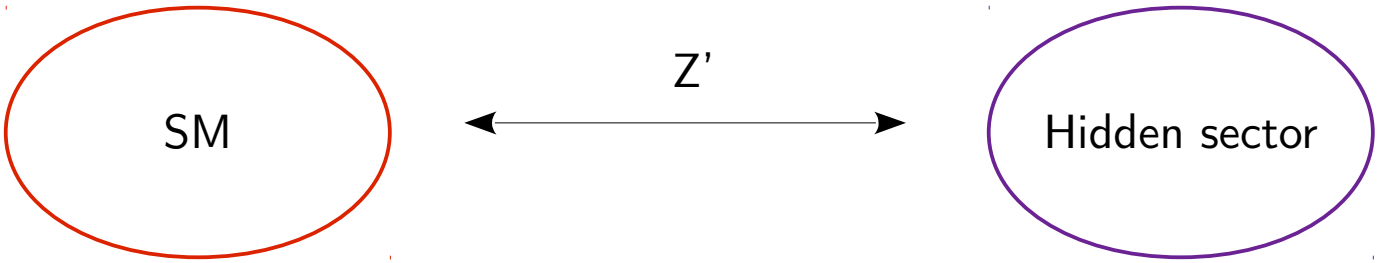
...but we don't know much about it.



http://cdms.berkeley.edu/limitplots/mm/WIMP_limit_plotter.html

A vector portal to the dark sector

- The dark sector could be complex and have many particles
- The dark matter could be light. Direct detection bounds fade away for masses below a few GeV
- Simple possibility to extend the SM: a new U(1) symmetry



A vector portal to the dark sector

Two main possibilities to couple the Z' to the visible sector:

1) via kinetic mixing to the SM hypercharge boson (dark photon)

$$\epsilon F^{Y}_{\mu\nu} F^{\mu\nu}_{dark}$$

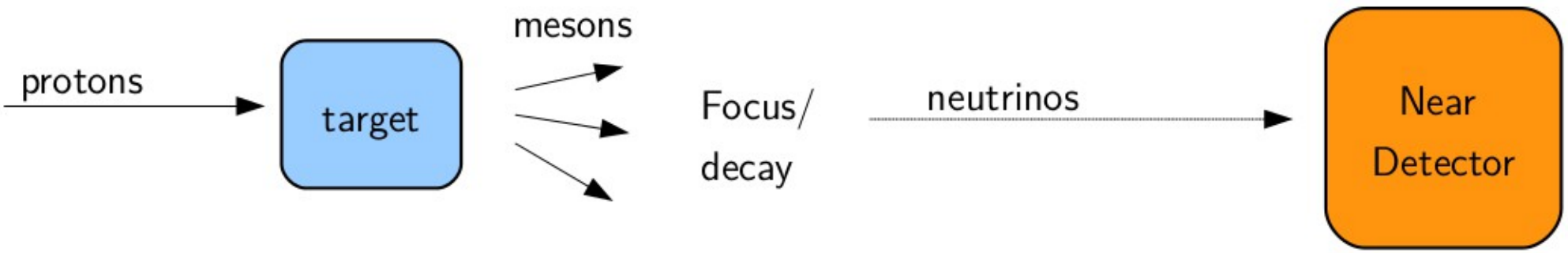
2) via direct coupling to quarks:

$$\mathcal{L}_q = \frac{g_z}{2} Z'^{\mu} \sum_{f=q,\ell} z_f \bar{f} \gamma_\mu f$$

$$\mathcal{L}_\chi = \frac{g_z}{2} Z'^{\mu} \times \begin{cases} z_\chi \bar{\psi}_\chi \gamma_\mu \psi_\chi & \text{(Dirac fermion)} \\ i z_\chi \left[(\partial_\mu \phi^\dagger_\chi) \phi_\chi - \phi^\dagger_\chi \partial_\mu \phi^\dagger_\chi \right] & \text{(Complex scalar)} \end{cases}$$

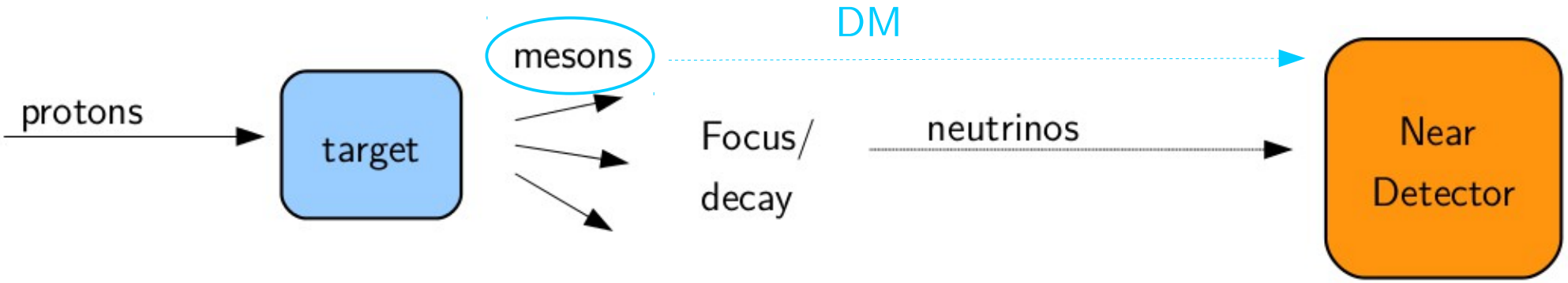
$\rightarrow$ We will consider a leptophobic Z´ corresponding to an extra $U(1)_B$

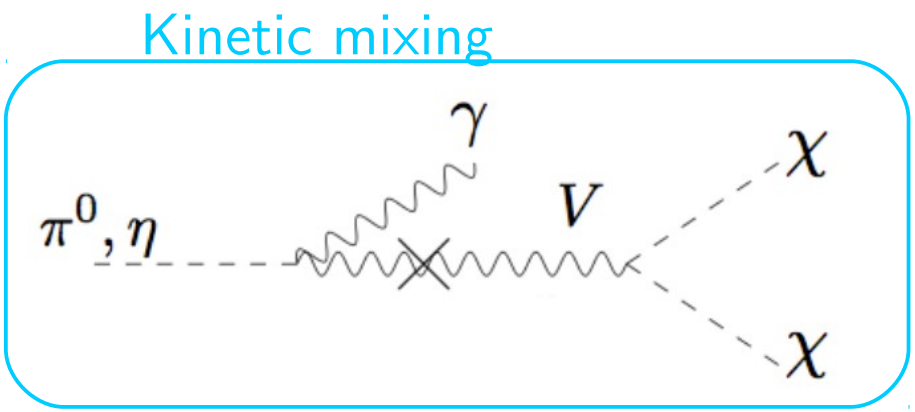
Dark matter at neutrino experiments



Dark matter at neutrino experiments

- DM searches at neutrino experiments were first proposed by Batell, Pospelov and Ritz 0906.5614 [hep-ph]





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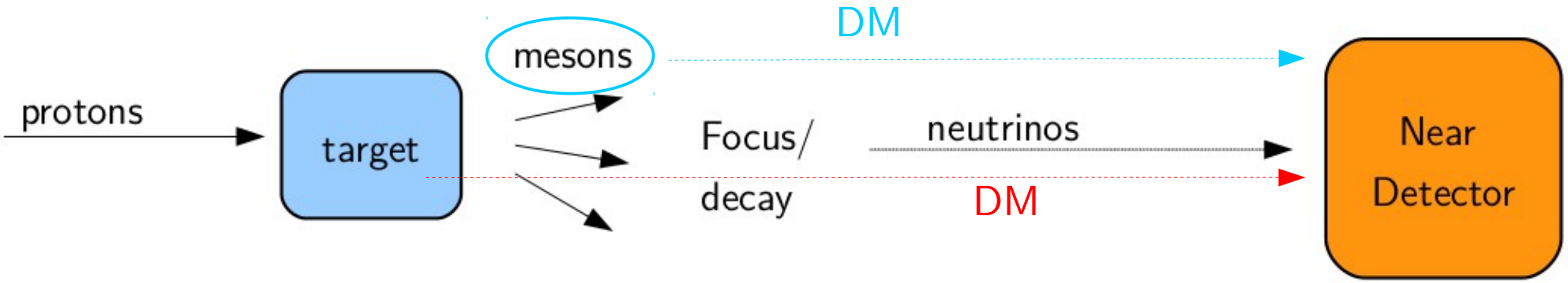
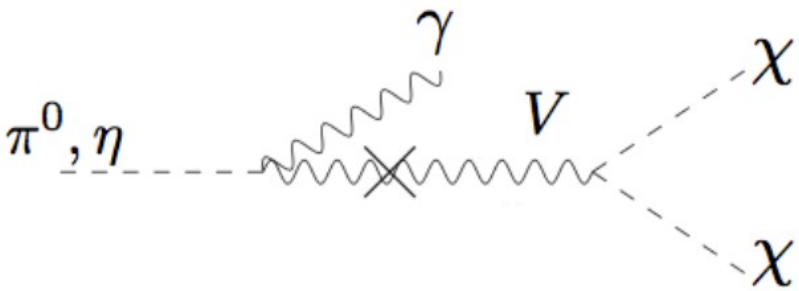
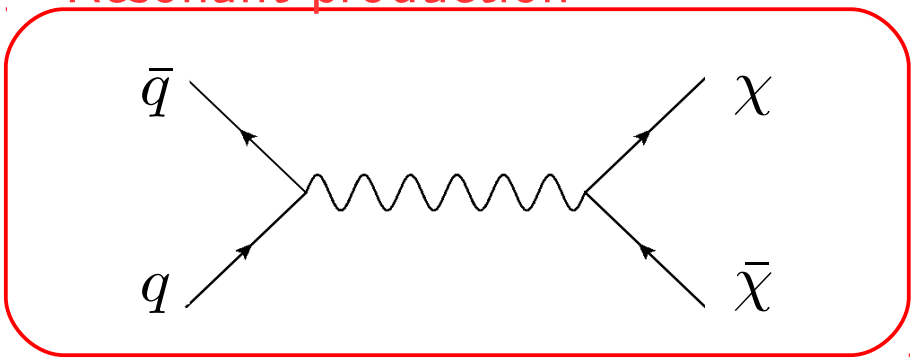


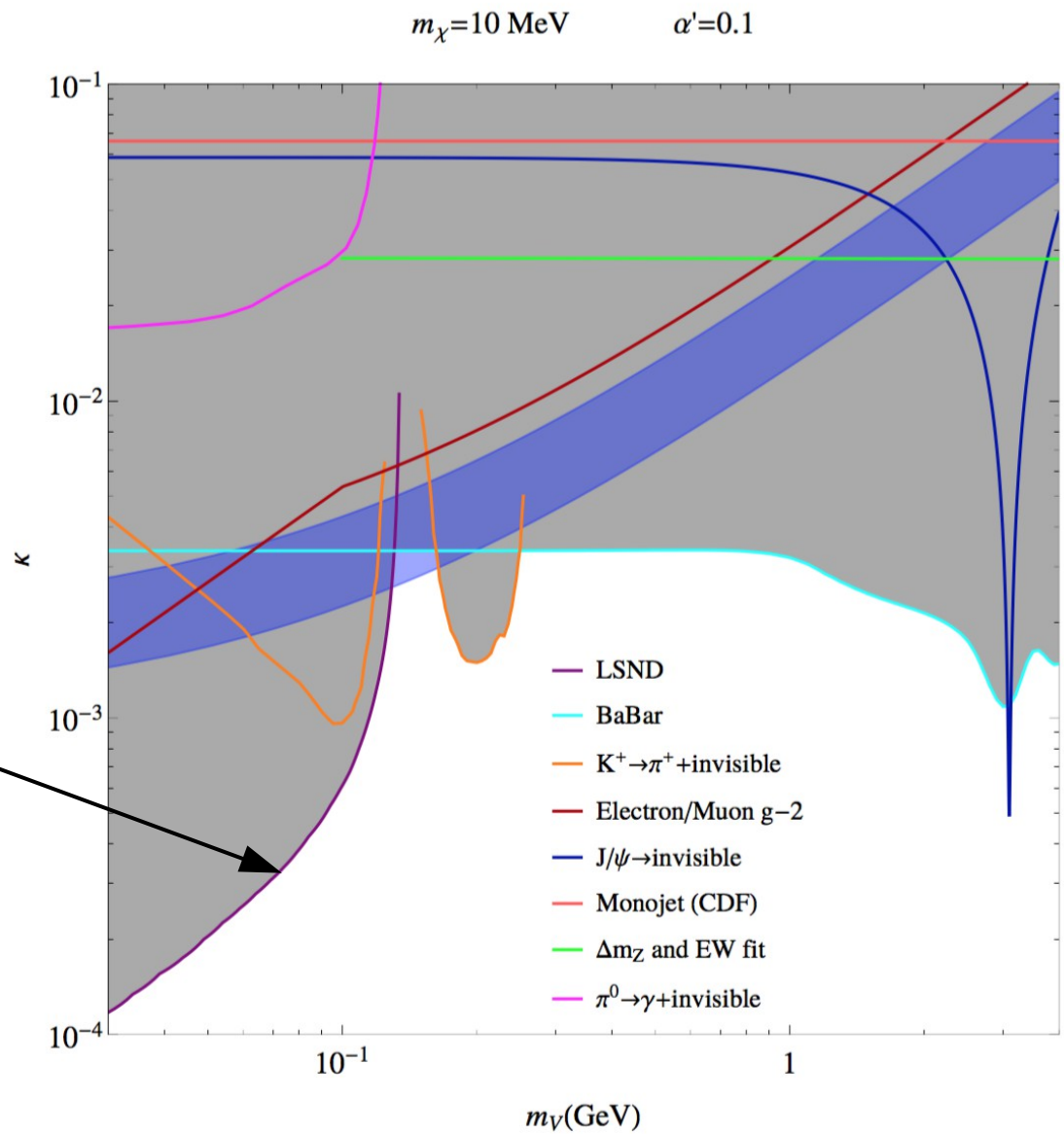


Resonant production



Dark matter at neutrino experiments

LSND

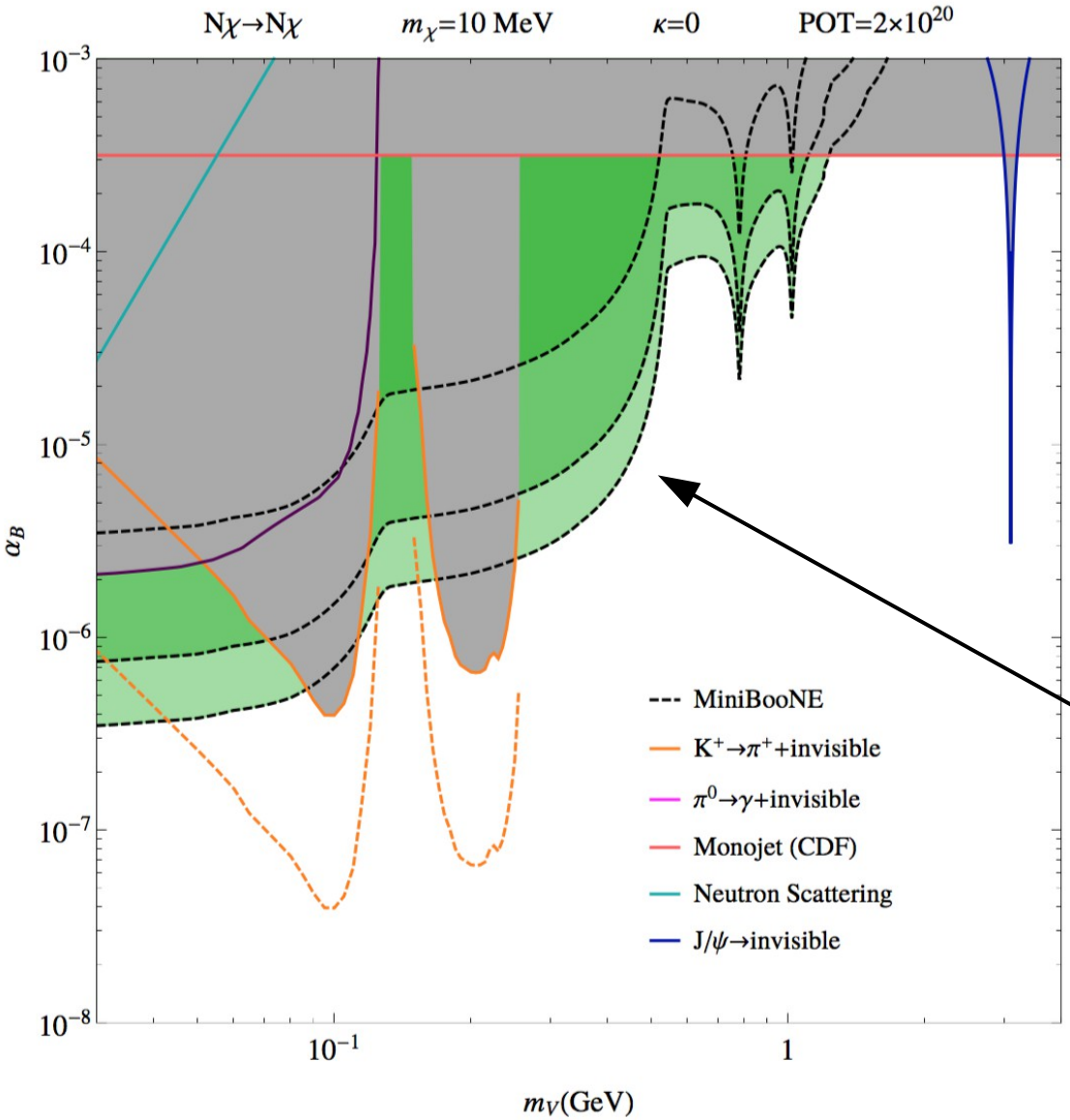


Batell,deNiverville, McKeen,Pospelov, Ritz, 1405.7049

DeNiverville, Pospelov, Ritz, 1107.4580

(See also Kahn, Krnjaic, Thaler and Toups, 1411.1055 and Batell, Essig and Surujon, 1406.2698)

Dark matter at neutrino experiments

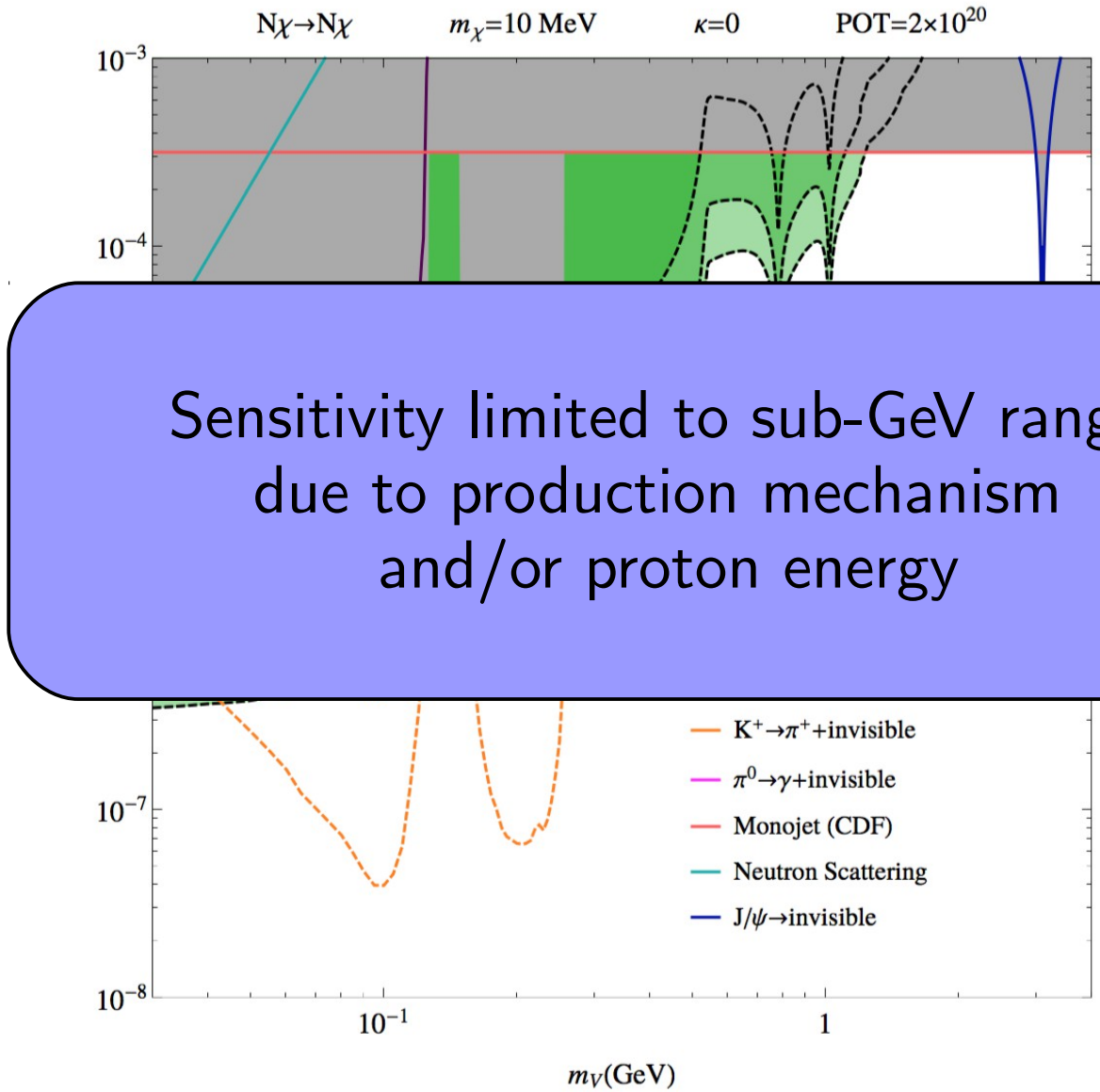


Batell, deNiverville, McKeen, Pospelov, Ritz, 1405.7049

MiniBooNE coll., 1211.2258

MiniBooNE event lines (1,10,1000)

Dark matter at neutrino experiments



Batell, deNiverville, McKeen, Pospelov, Ritz, 1405.7049

NE coll.,
3

Sensitivity limited to sub-GeV range due to production mechanism and/or proton energy

Previous constraints

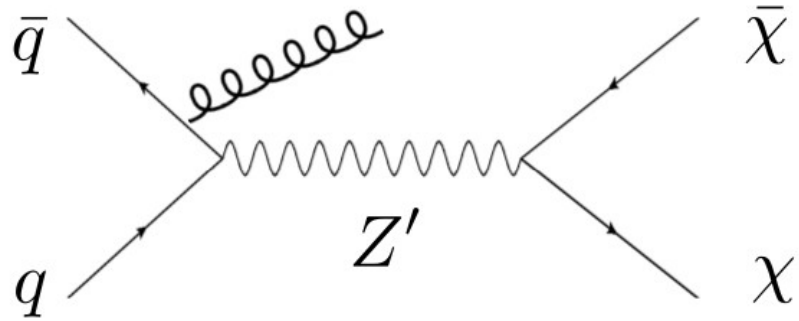
Quarkonia invisible decays

BaBar, 0908.2840
BES, 0710.0039

$$J/\psi \to Z'^* \to \chi\chi$$
$$\Upsilon \to Z'^* \to \chi\chi$$

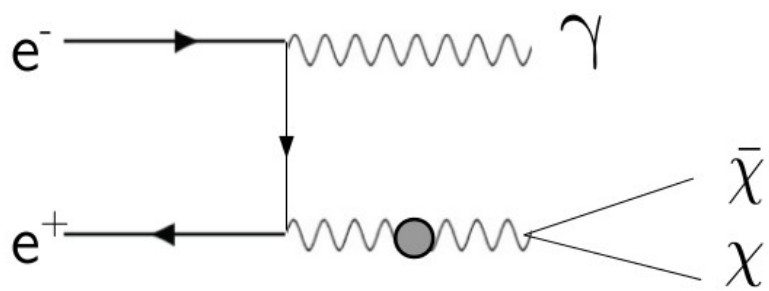
Monojets @ colliders

CDF, 1203.0742
Shoemaker, Vecchi, 1112.5457



Monophoton @ BaBar

Essig, Mardon, Papucci, Volansky, 1309.5084



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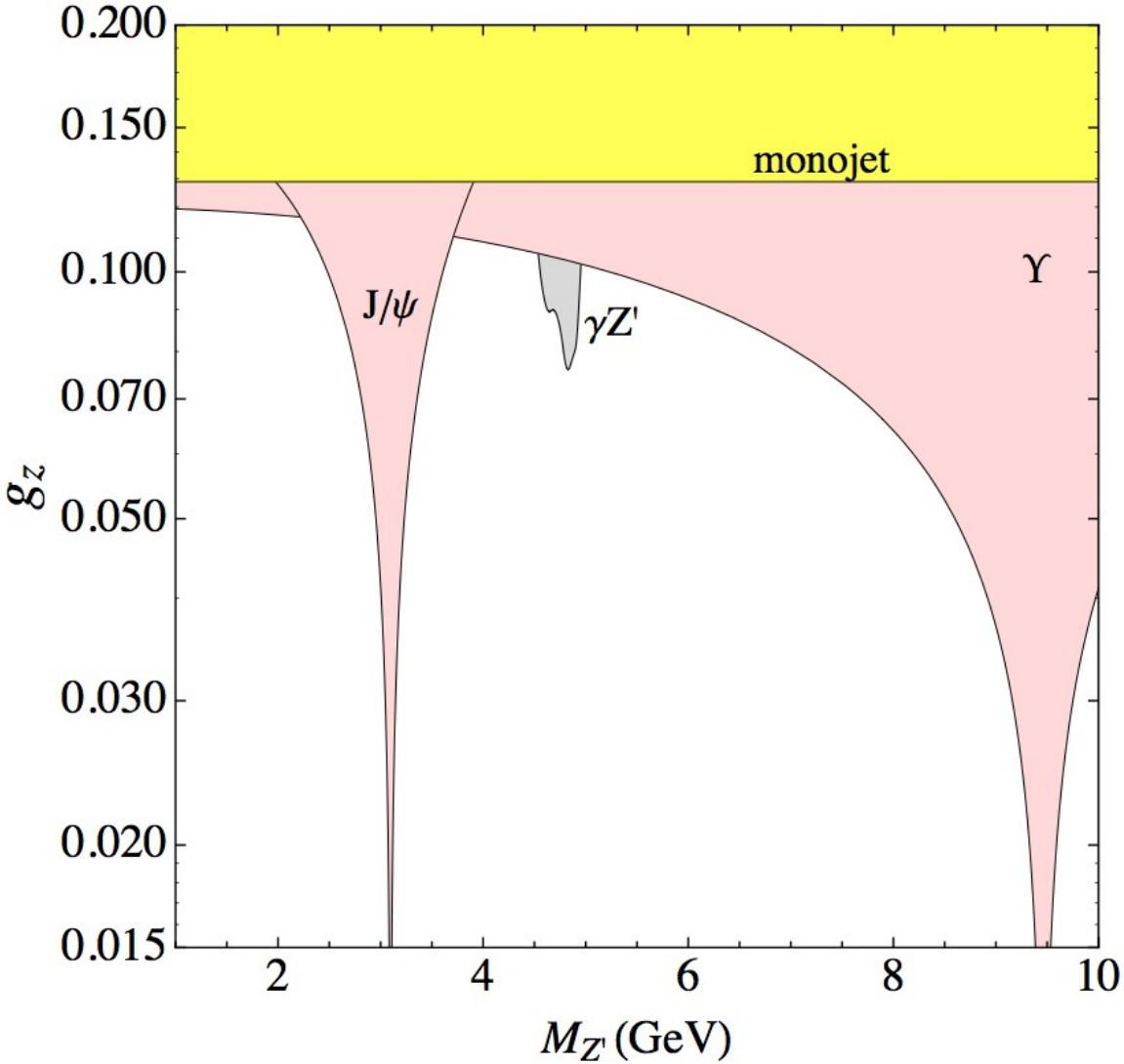
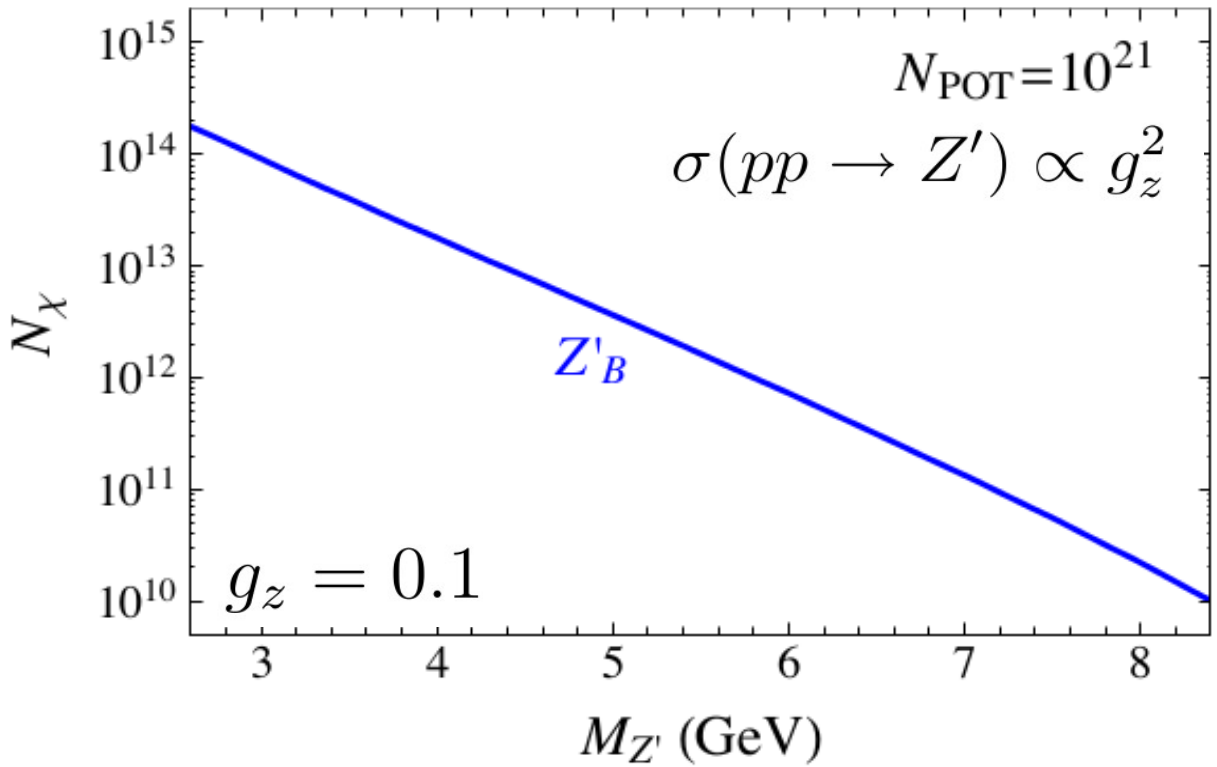


Dobrescu, Frugiuele, 1410.1566

How much can we improve over this?

Dark matter production

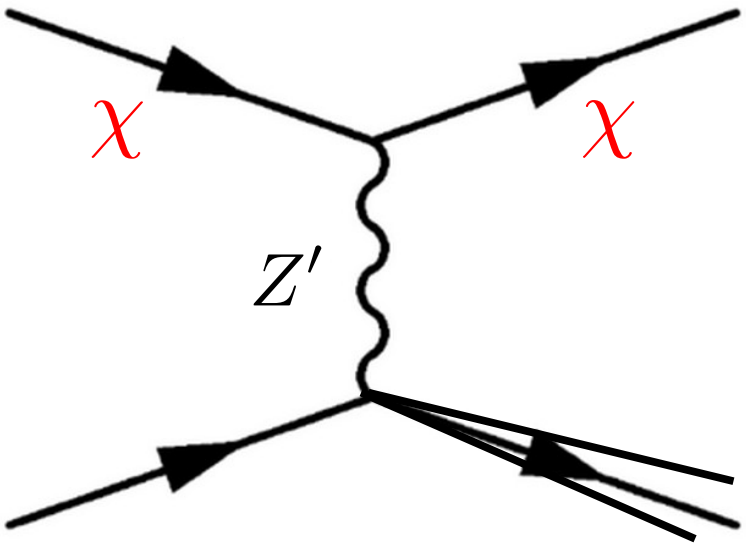
Particles produced per year at the target, using 120 GeV protons:



Dobrescu, Frugiuele, 1410.1566

Detection

The dark matter can interact at the detector via a NC process:



If energetic enough, a hadron shower will be produced → We require more than 2-3 GeV for the shower energy

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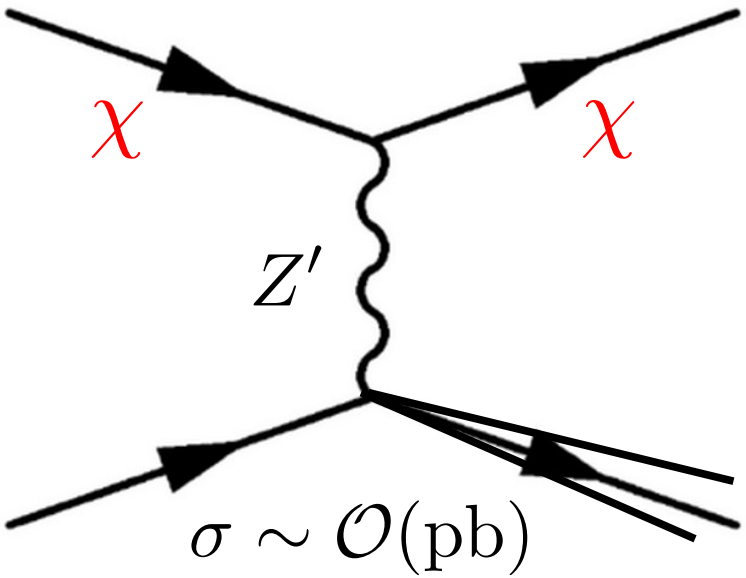
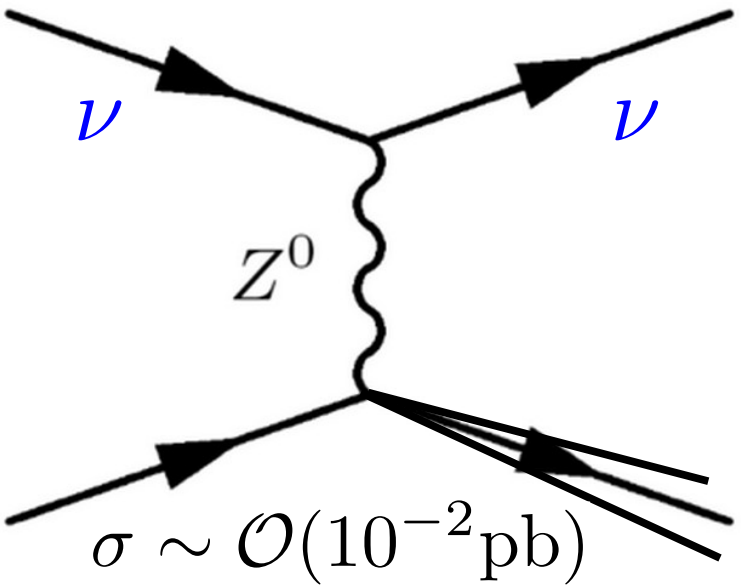


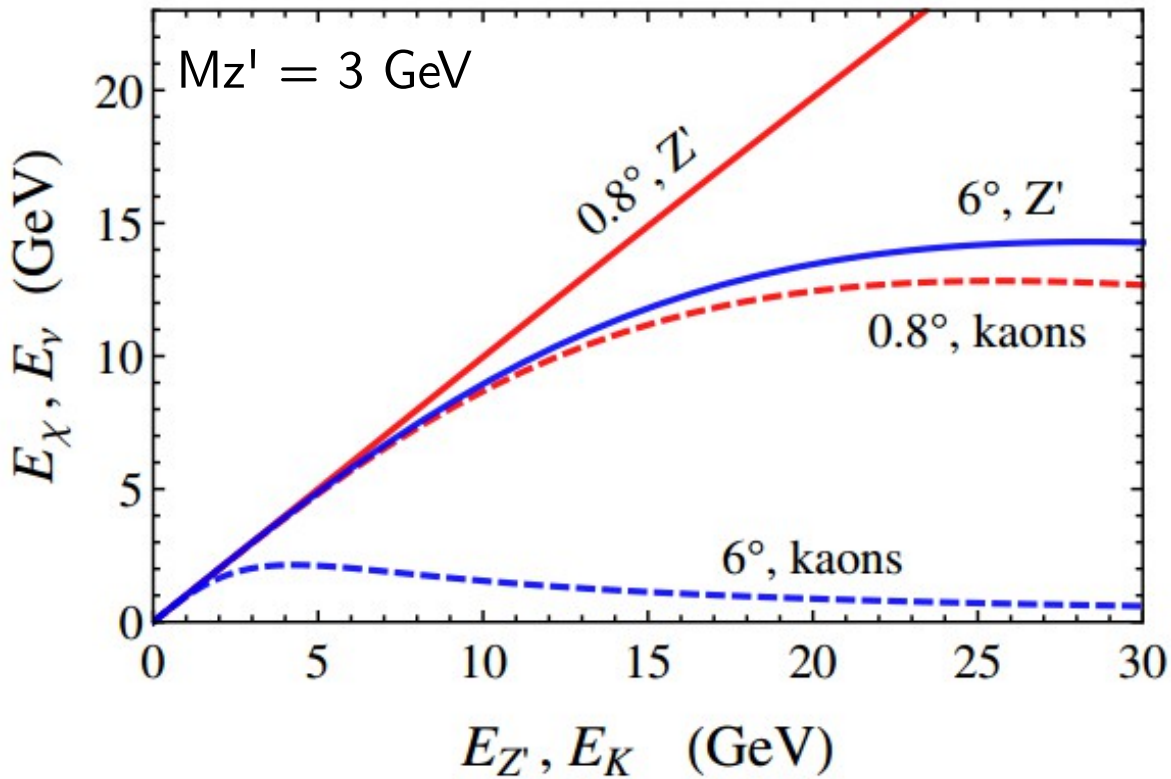


$$\frac{\sigma(\chi N \to \chi N)}{\sigma(\nu N \to \nu N)} \sim 300 z_\chi^2 \left(\frac{g_z}{0.05}\right)^4 \left(\frac{1\ \mathrm{GeV}}{M_{Z'}}\right)^4$$

Signal energy profile

The dark matter will be very energetic. This helps to discriminate signal from background, and increases the cross section:

$$E_\chi = \frac{m_{Z'}^2}{2E_{Z'}(1-\beta\cos\theta)}$$



PC, Dobrescu, Frugiuele, Harnik, 1512.03852

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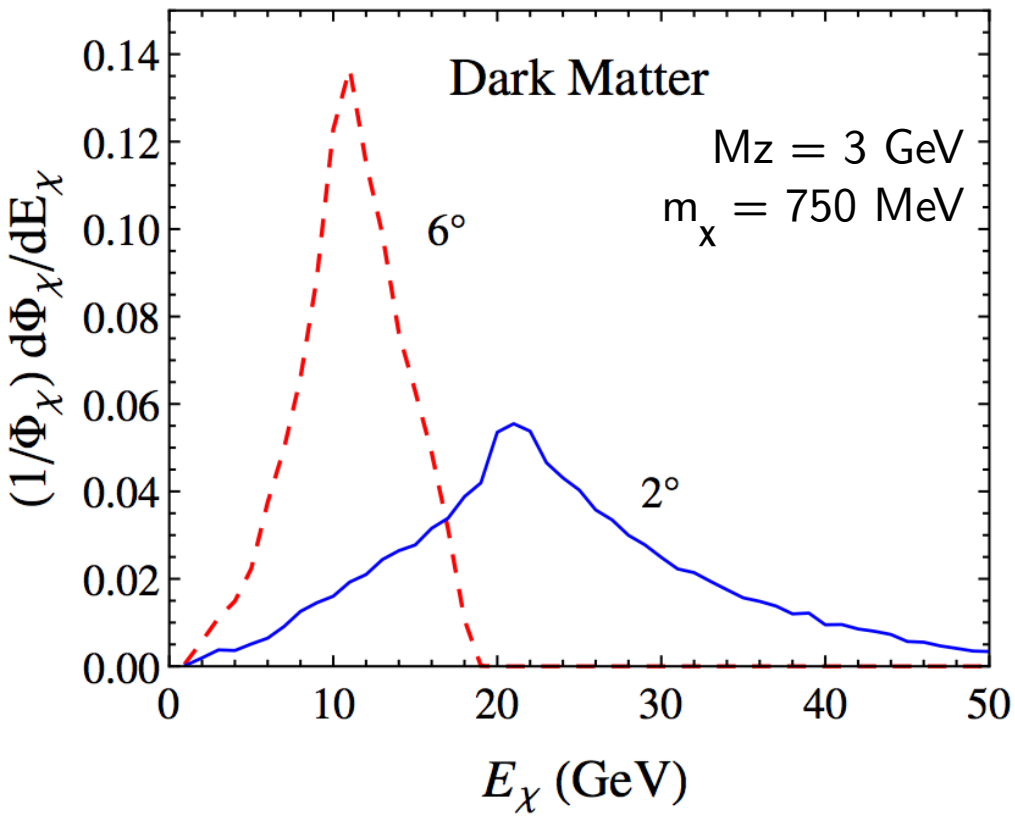
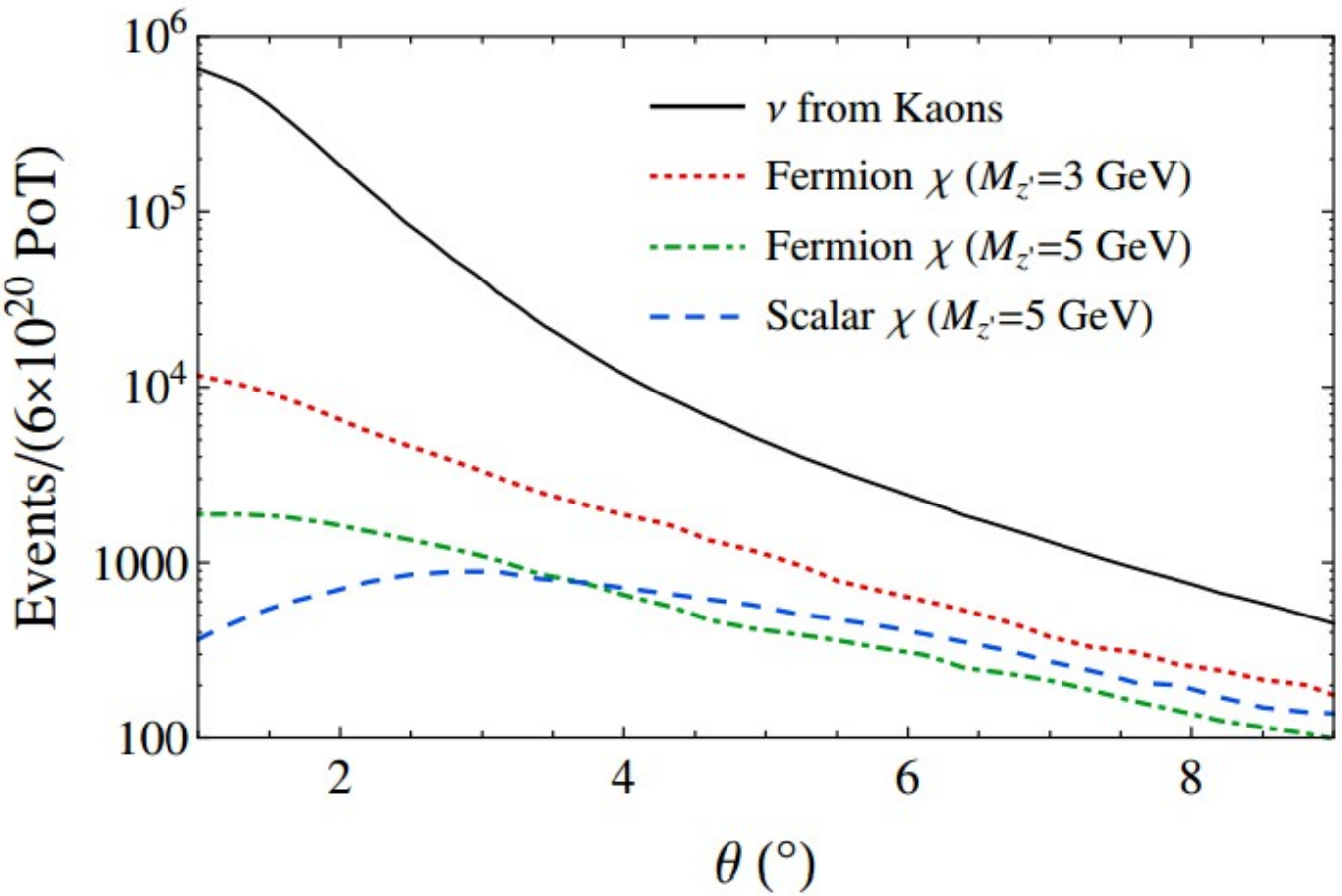


PC, Dobrescu, Frugiuele, Harnik, 1512.03852
(see also Dobrescu, Frugiuele, 1410.1566)

Angular profile

$$g_z = 0.1 \qquad z_\chi = 3 \qquad m_\chi = 750 \text{ MeV}$$



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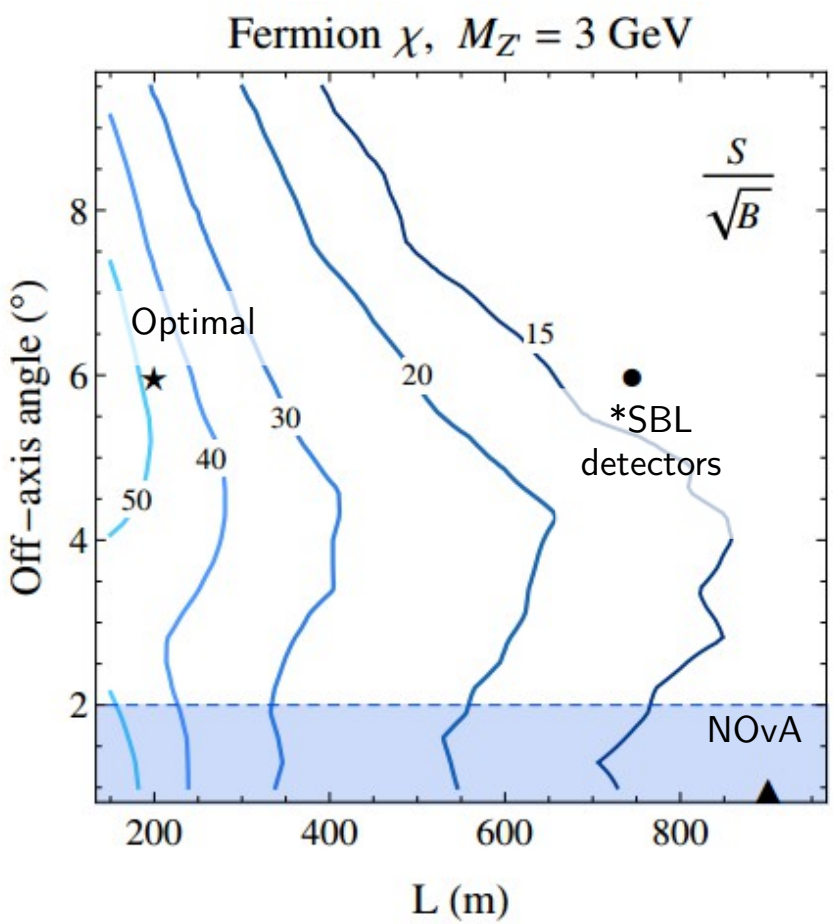
Optimal detector location



*SBL detectors include: MiniBooNE, microBooNE and ICARUS (NOvA NDOS is at similar off-axis angle)

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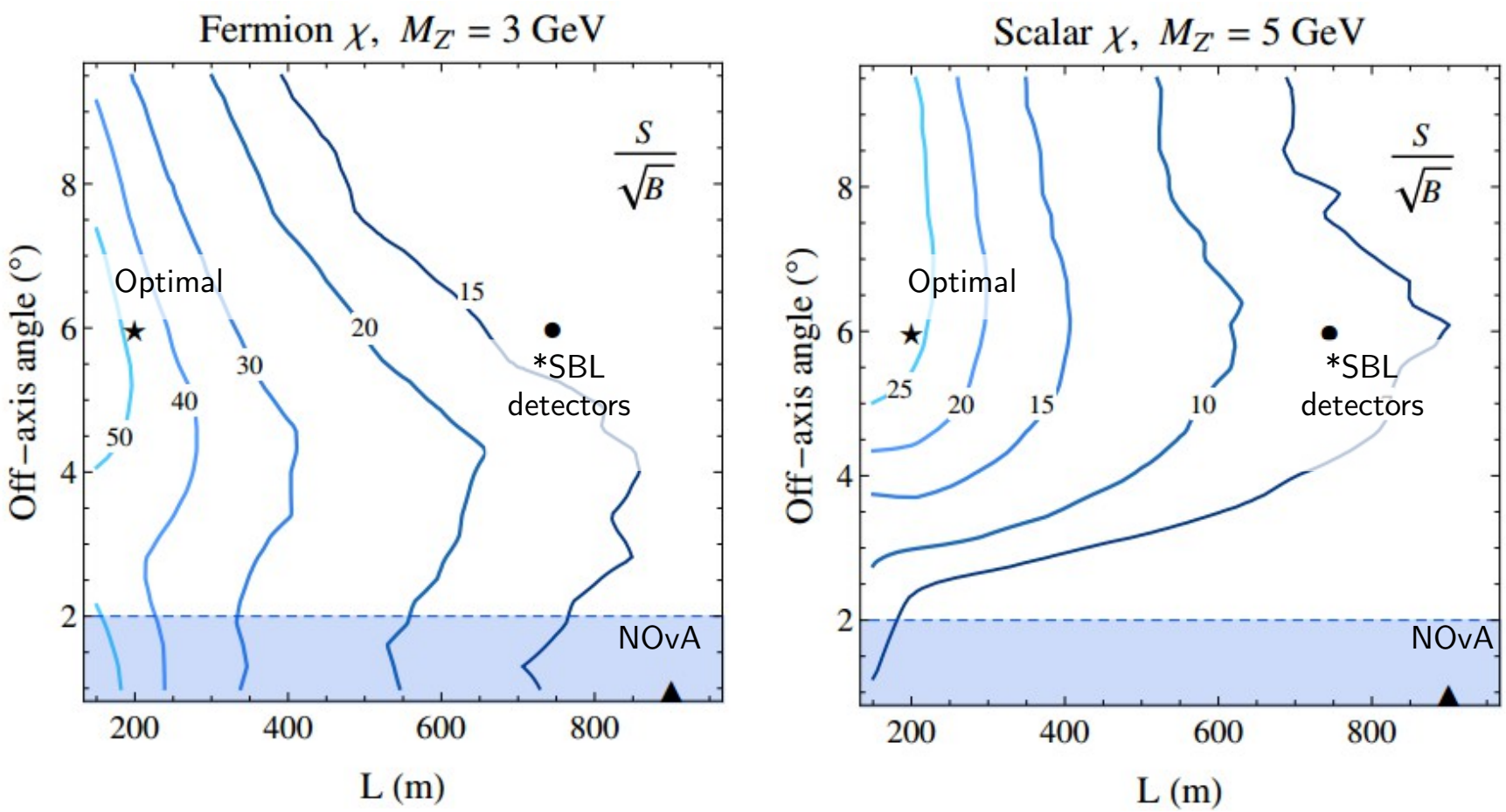

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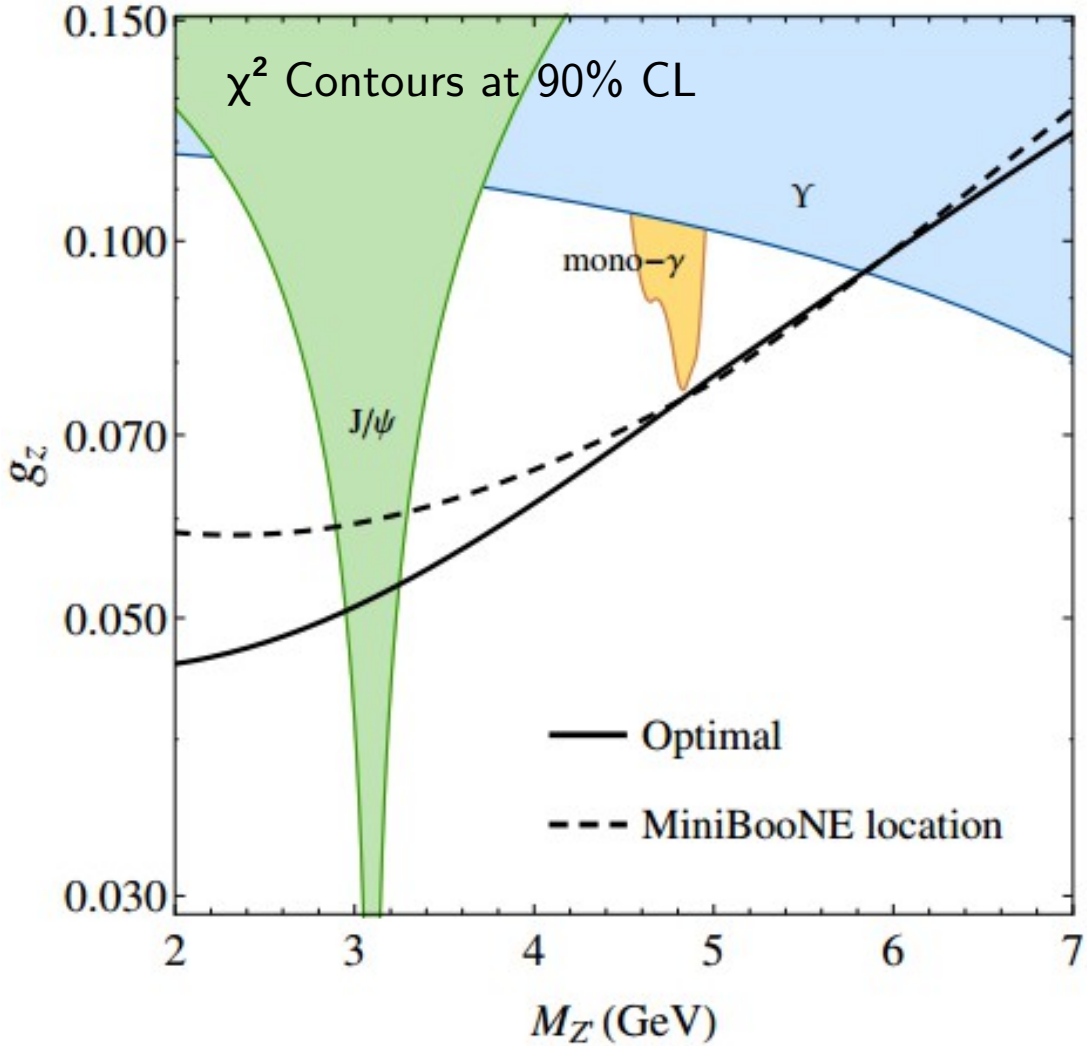
Sensitivity regions



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Conclusions

Neutrino experiments can (should!) be used to search for New Physics:

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Neutrino experiments can (should!) be used to search for New Physics:

- Near detector data at LBNF can be used to constrain new physics in other sectors as well!
  - As an example we have shown the potential to explore a portal to the dark sector via a leptophobic Z'
  - The parameter space in the few GeV range remains largely unconstrained
  - The search would not interfere with long-baseline program
  - MiniBooNE could do a search using existing NuMI data!

Thank you!!