Possible dark sector signals via direct production at neutrino experiments

Pilar Coloma

Fermilab

Work in collaboration with:

Bogdan Dobrescu, Claudia Frugiuele and Roni Harnik

Crossroads in Neutrino Physics

MITP, Johannes Gutenberg University

Mainz, Aug 11th, 2015

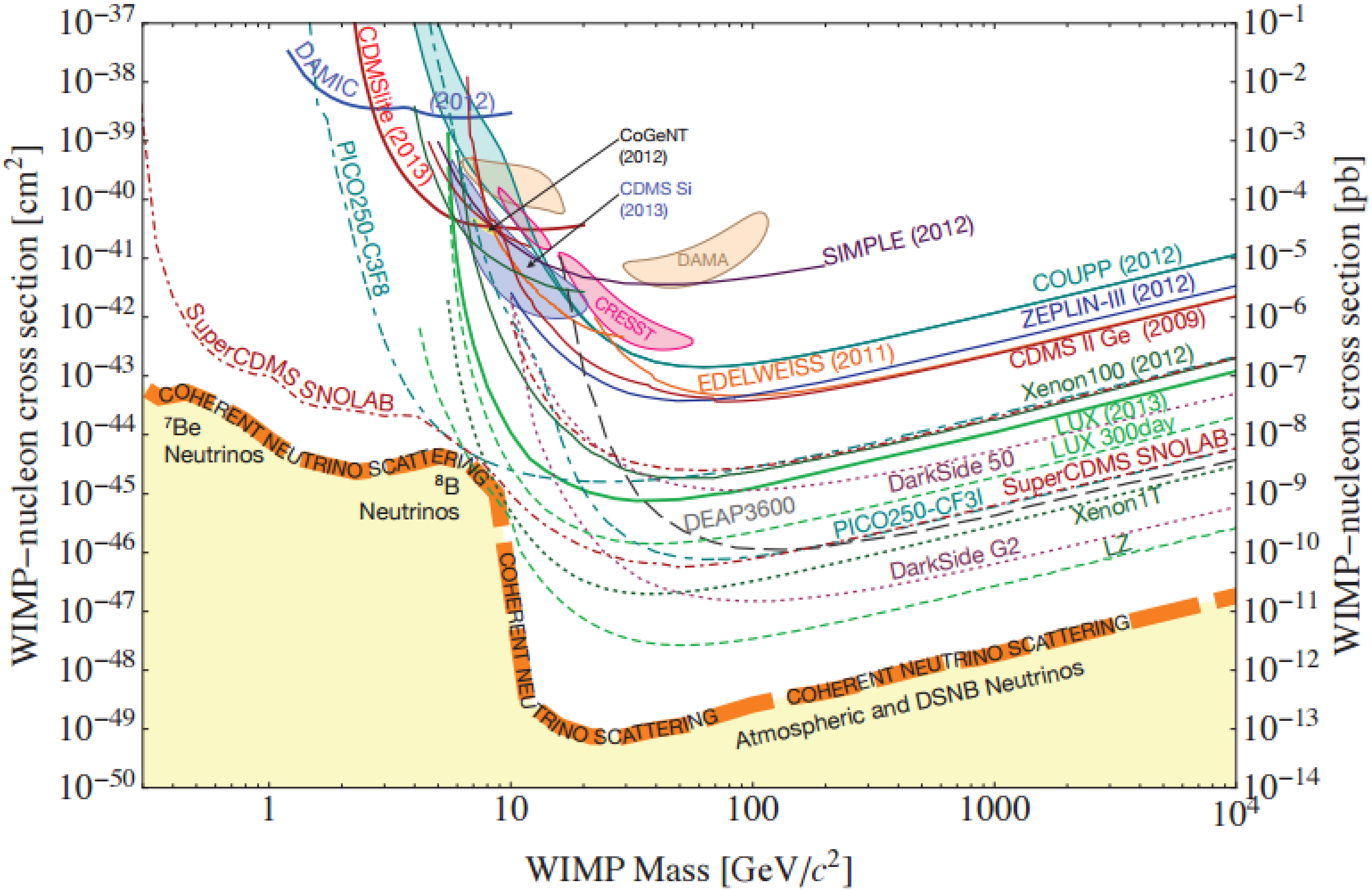
Outline

- Motivation
- Previous literature, and intro to our model
- Energy and angular dependence of signal and bg
- Expected sensitivity
- Conclusions

Have we discovered all the forces/matter in Nature yet?

We know about the existence of DM...

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



A vector portal to the dark sector

- The dark sector could be complex and have many particles
- The dark matter could be light
  - For light dark matter masses to give a significant contribution to the relic density, a light mediator is needed.

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:

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

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

Leptophobic scenarios

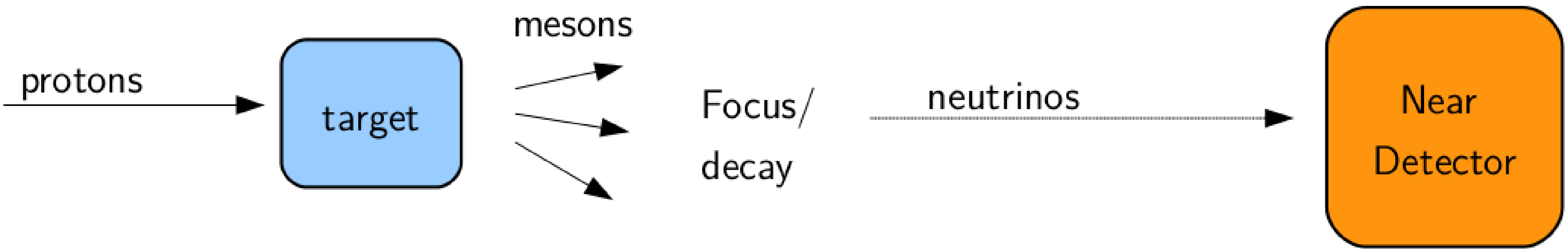
We consider a leptophobic Z' corresponding to a $U(1)_B$ symmetry:

$$\mathcal{L}_q = \frac{g_z}{2} Z'^{\mu} \times \frac{1}{3} \sum_q \bar{q} \gamma_\mu q$$

For Mz'$<$ 200 GeV, collider bounds are generally mild

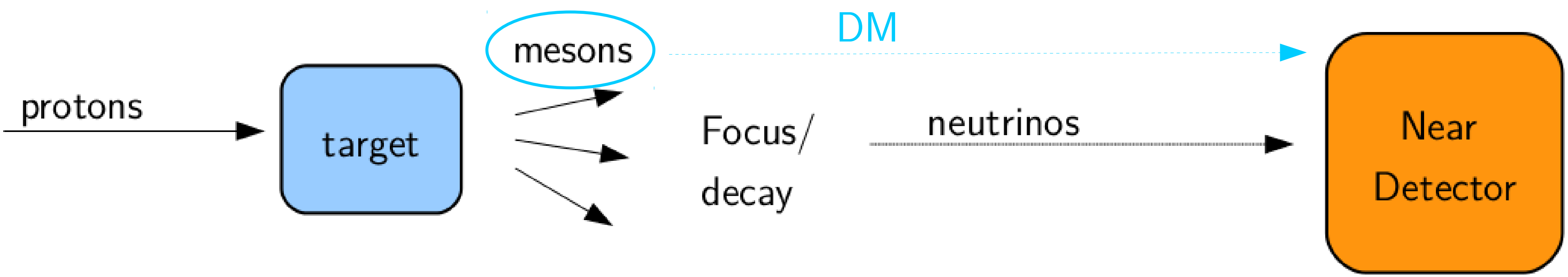
Direct detection bounds fade away if DM mass $<$ 5 GeV

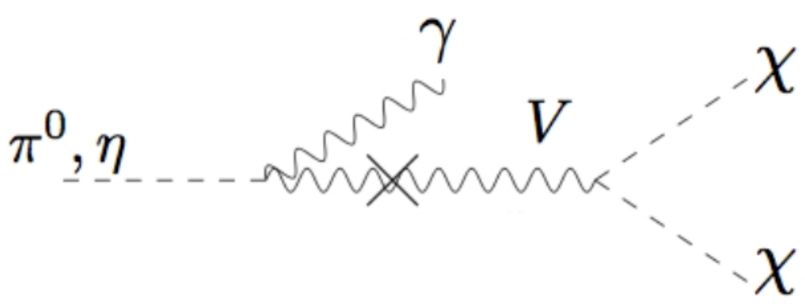
Dark matter at neutrino experiments



Dark matter at neutrino experiments

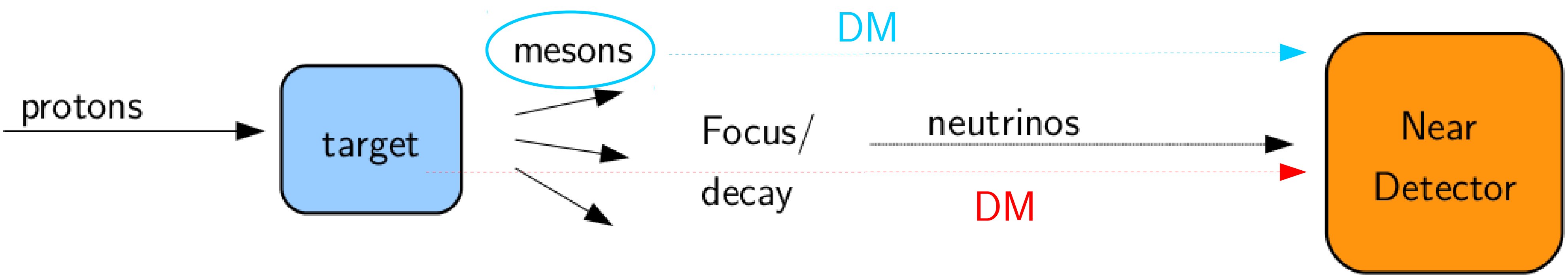
- DM searches at neutrino experiments were first proposed by Batell, Pospelov and Ritz 0906.5614 [hep-ph]

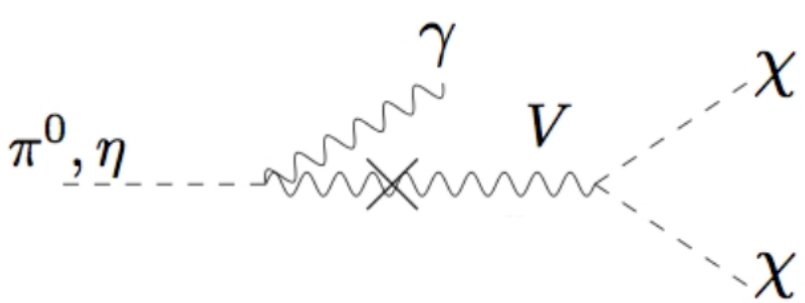


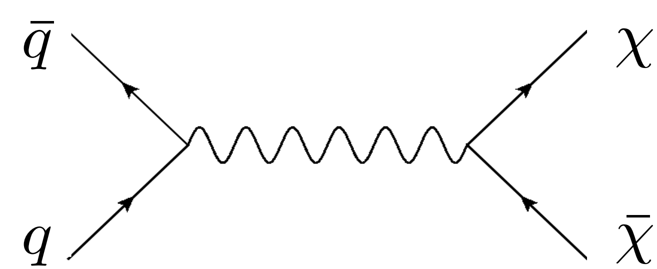


Dark matter at neutrino experiments

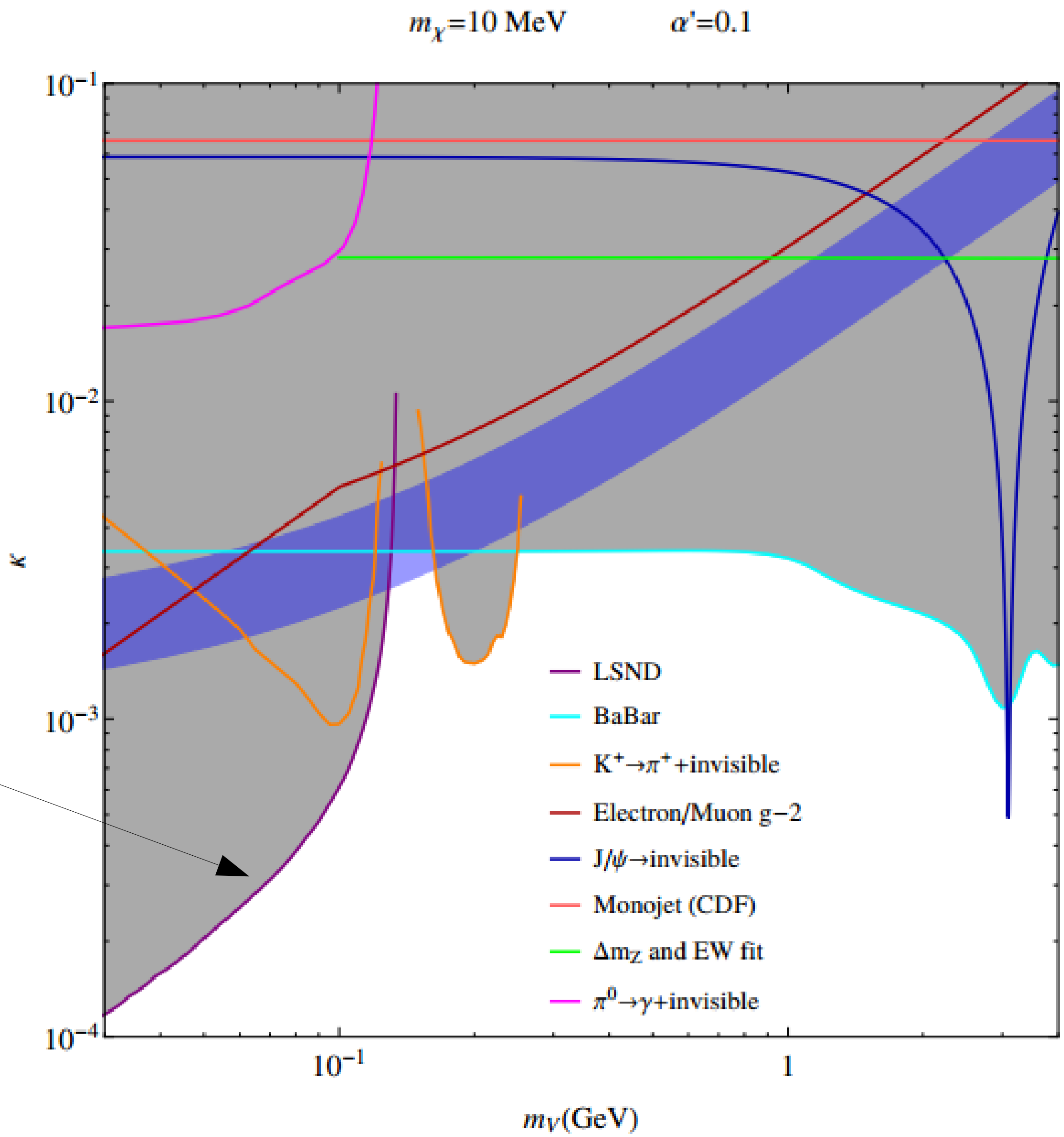
- DM searches at neutrino experiments were first proposed by Batell, Pospelov and Ritz 0906.5614 [hep-ph]







Dark matter at neutrino experiments

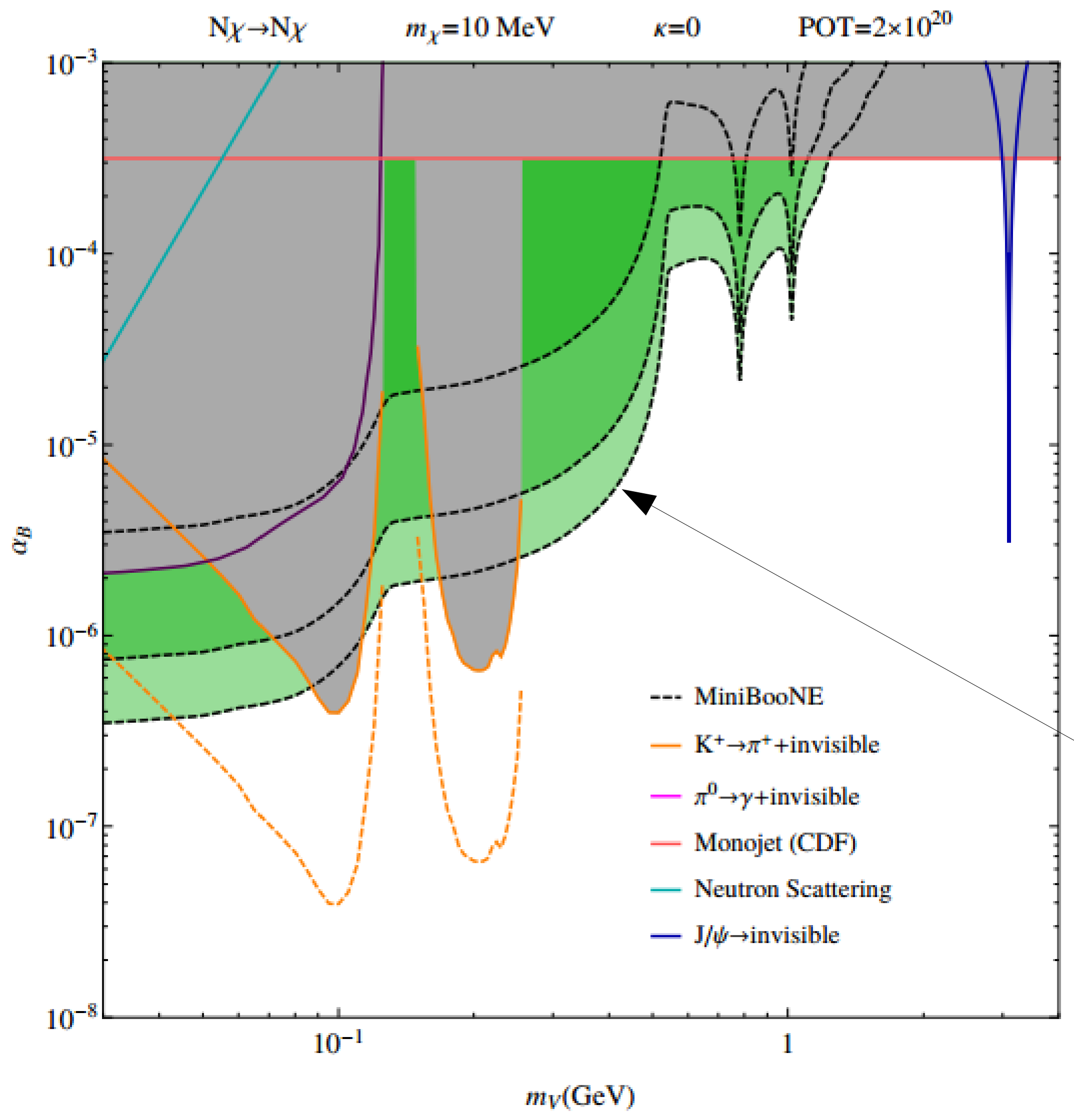


LSND

Batell,deNiverville, McKeen,Pospelov, Ritz, 1405.7049

DeNiverville, Pospelov, Ritz, 1107.4580

Dark matter at neutrino experiments

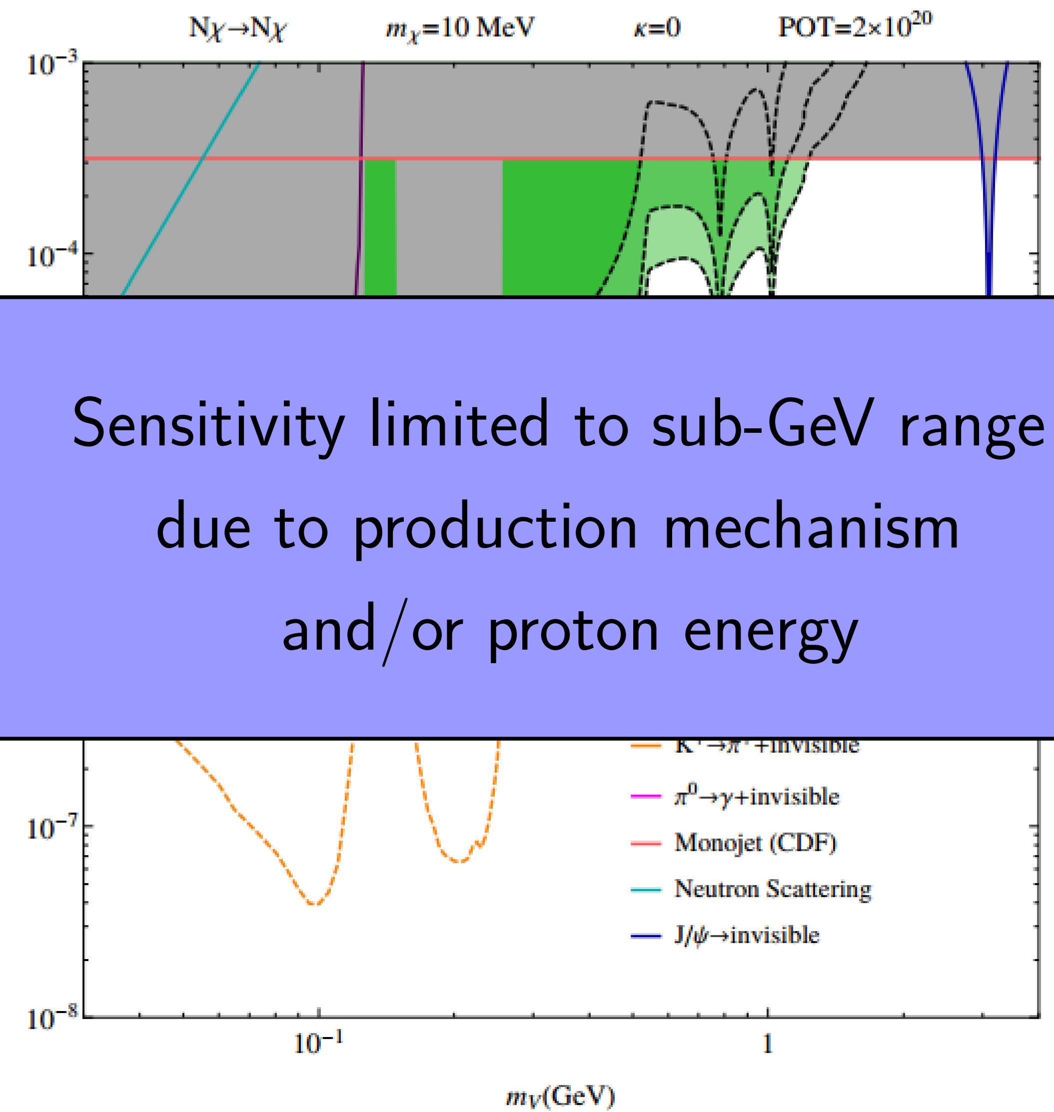


Batell,deNiverville, McKeen,Pospelov, Ritz, 1405.7049

MiniBooNE coll., 1211.2258

MiniBooNE (event lines, not contours)

Dark matter at neutrino experiments



Batell,deNiverville, McKeen,Pospelov, Ritz, 1405.7049

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

Dark matter at neutrino experiments

- Possible proton energies:
  - LSND: 800 MeV
  - MiniBooNE: 8 GeV
  - MINOS/NOvA: 120 GeV
  - T2K: 50 GeV
  - DUNE/LBNF: 80 GeV (maybe 120 GeV)

Previous constraints

Quarkonium invisible decays

BaBar, 0908.2840

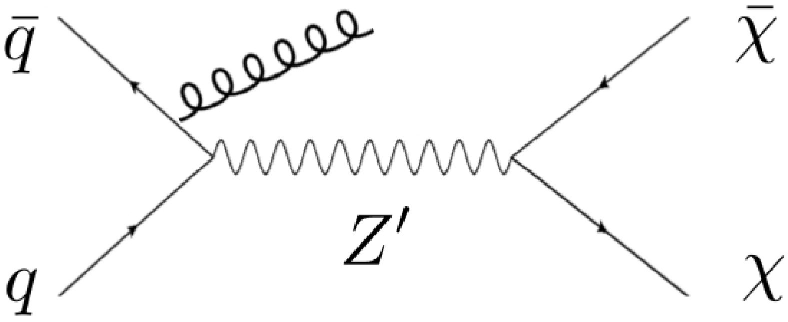
BES, 0710.0039

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

Monojets @ colliders

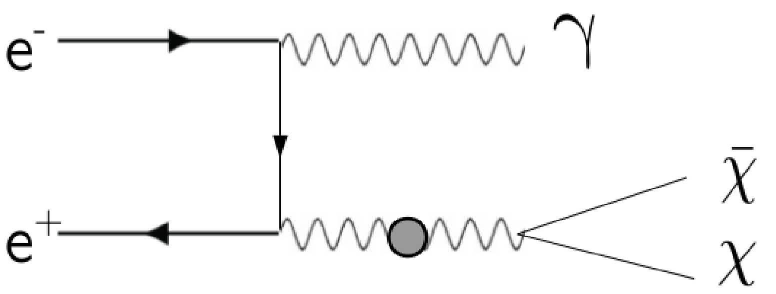
CDF, 1203.0742

Shoemaker, Vecchi, 1112.5457

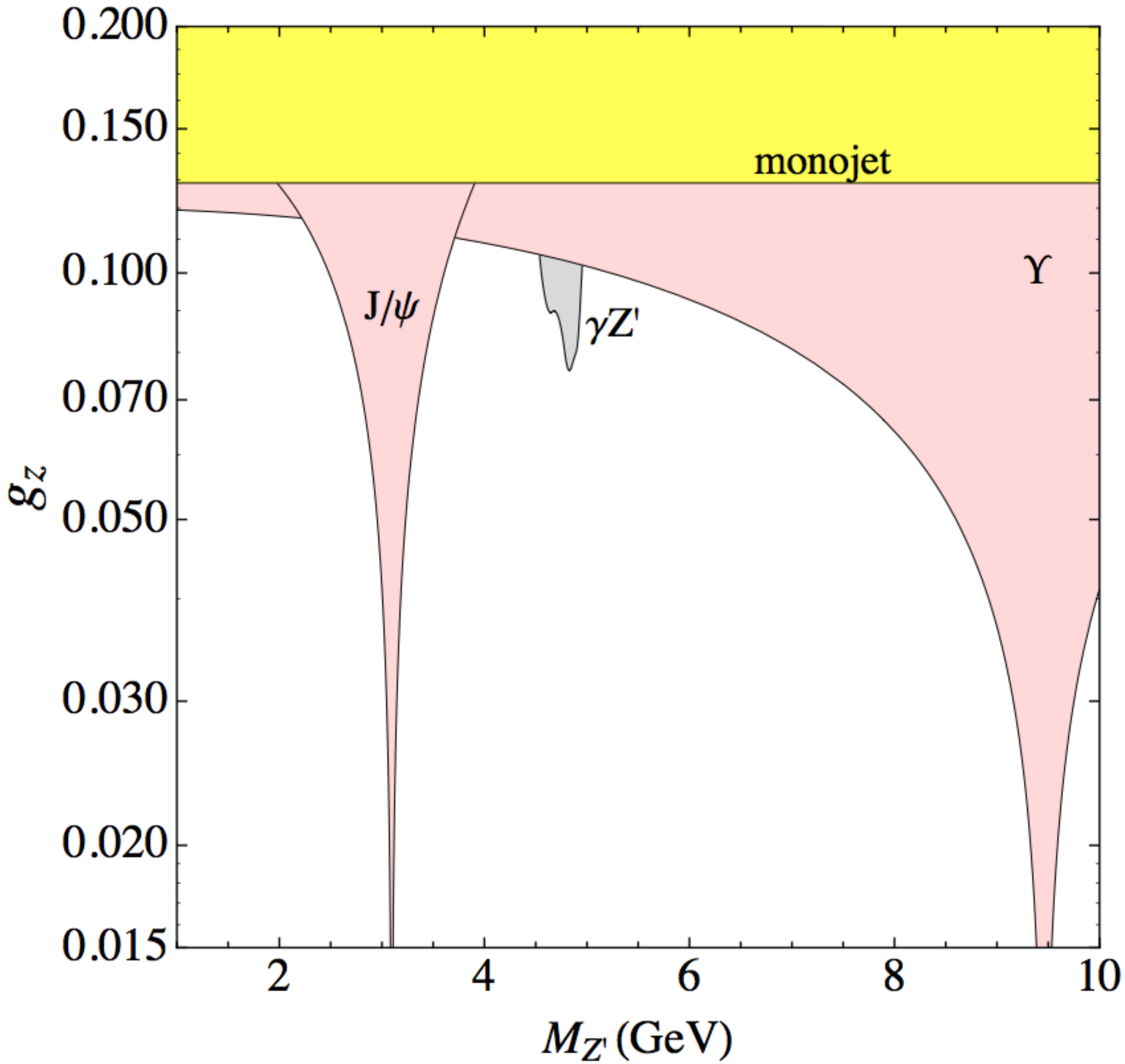


Monophoton @ BaBar

Essig, Mardon, Papucci, Volansky, 1309.5084



Previous constraints

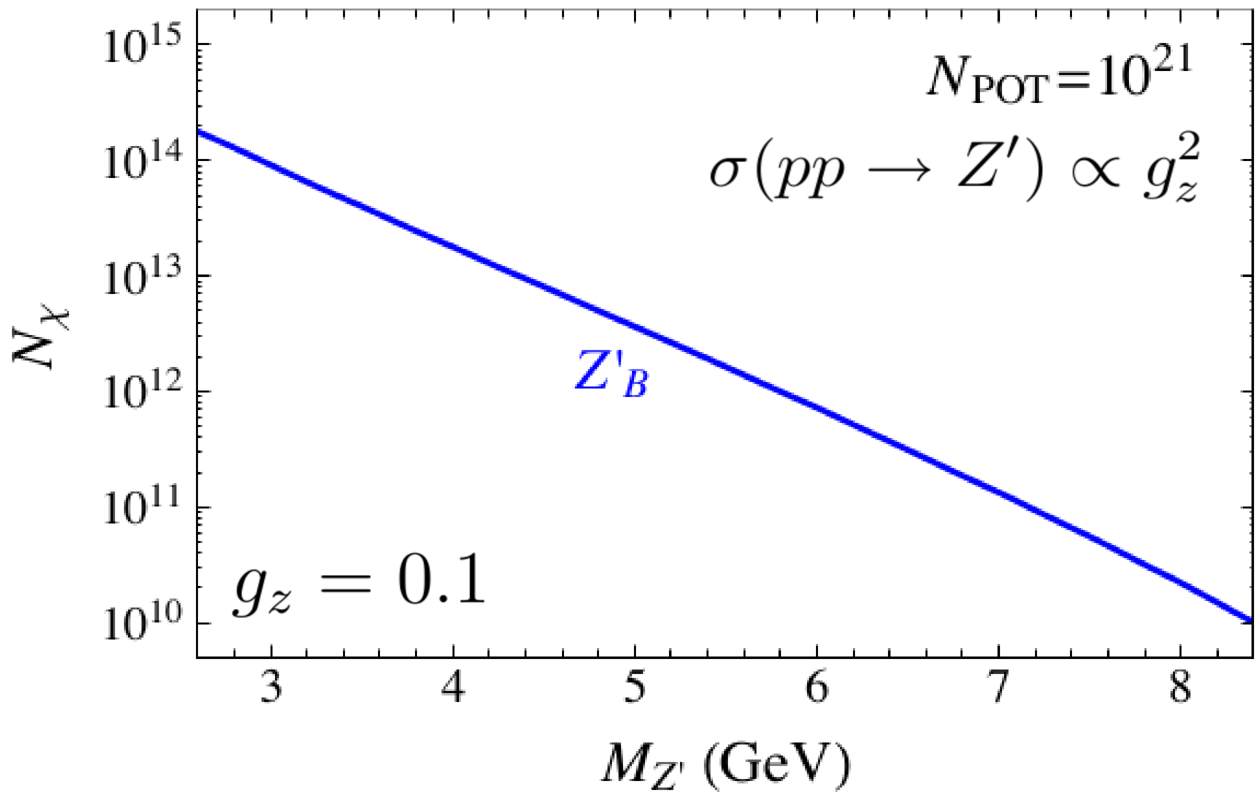


Dobrescu, Frugiuele, 1410.1566

How much can we improve over this?

Dark matter production

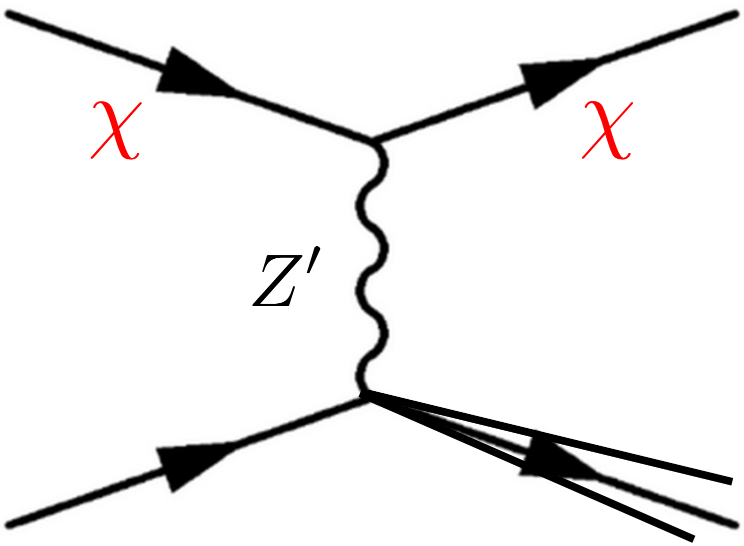
Particles produced at the target:



Dobrescu, Frugiuele, 1410.1566

Detection

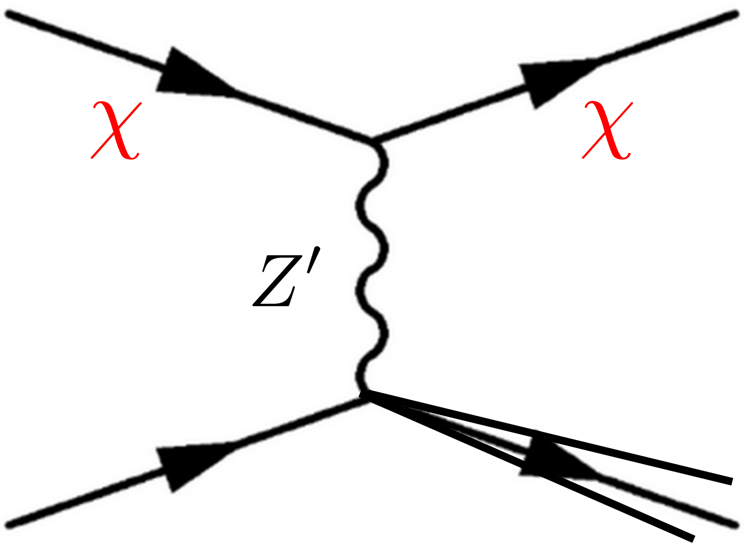
The dark matter can interact at the detector via a NC process:

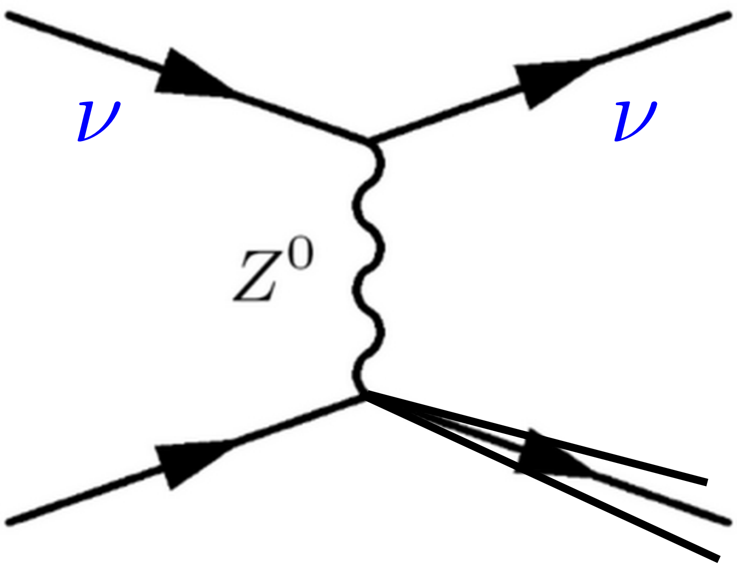


If energetic enough, a hadron shower will be produced → We require more than 2-3 GeV for the shower energy

Detection

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

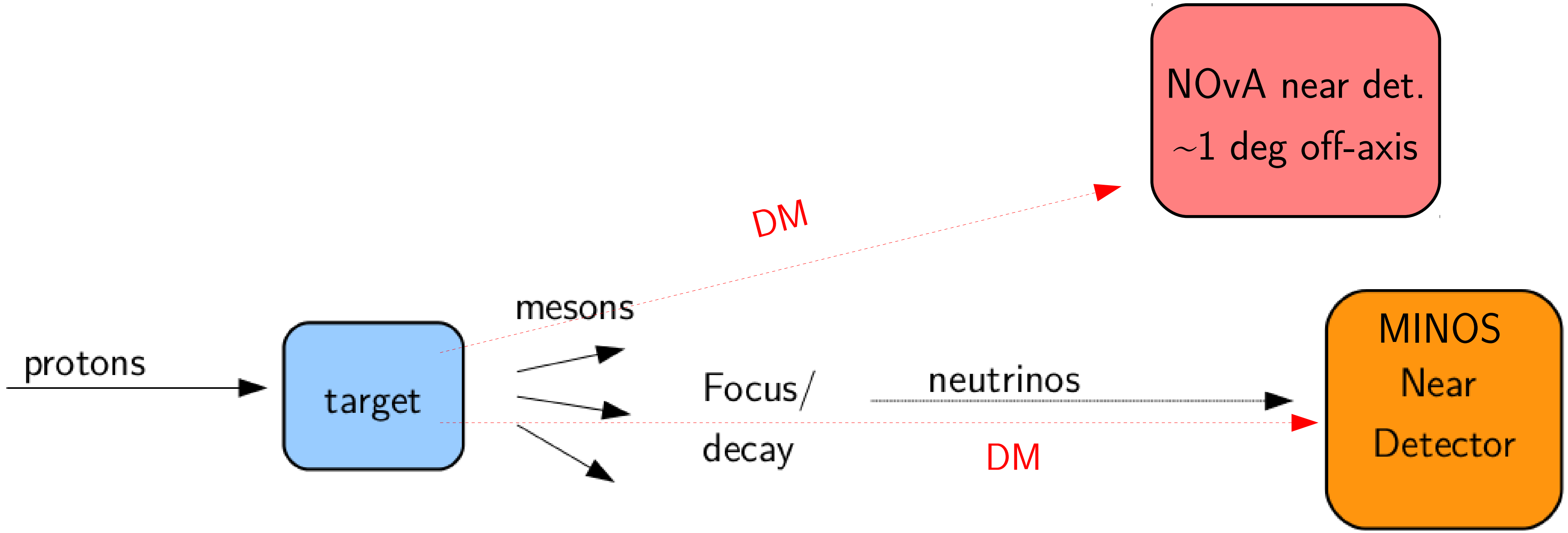




If energetic enough, a hadron shower will be produced

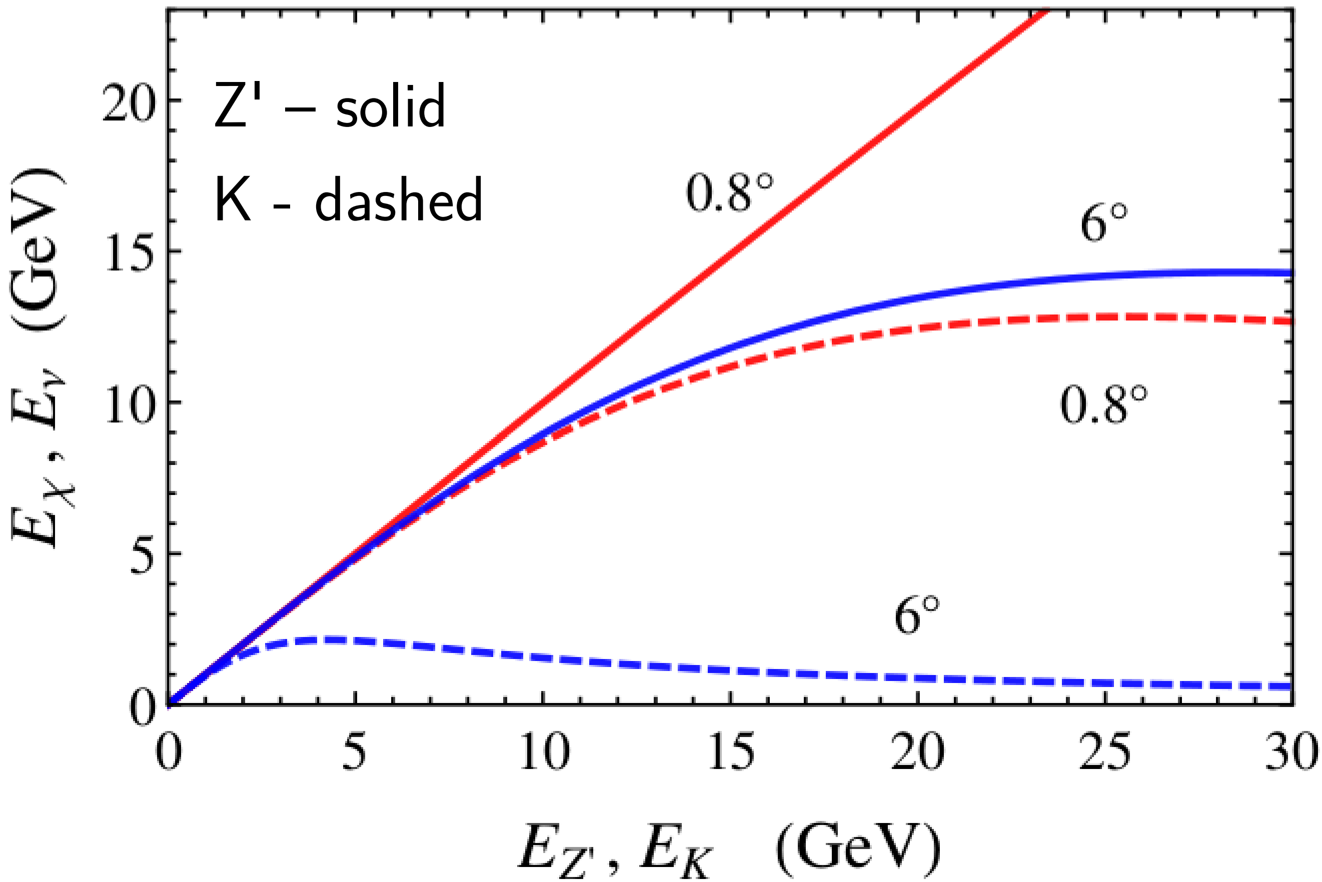
$$\frac{\sigma(\chi N \to \chi N)}{\sigma(\nu N \to \nu N)} \sim 300 z_\chi^2 \left(\frac{g_z}{0.05}\right)^4 \left(\frac{1\ \mathrm{GeV}}{M_{Z'}}\right)^4$$

Dark matter production



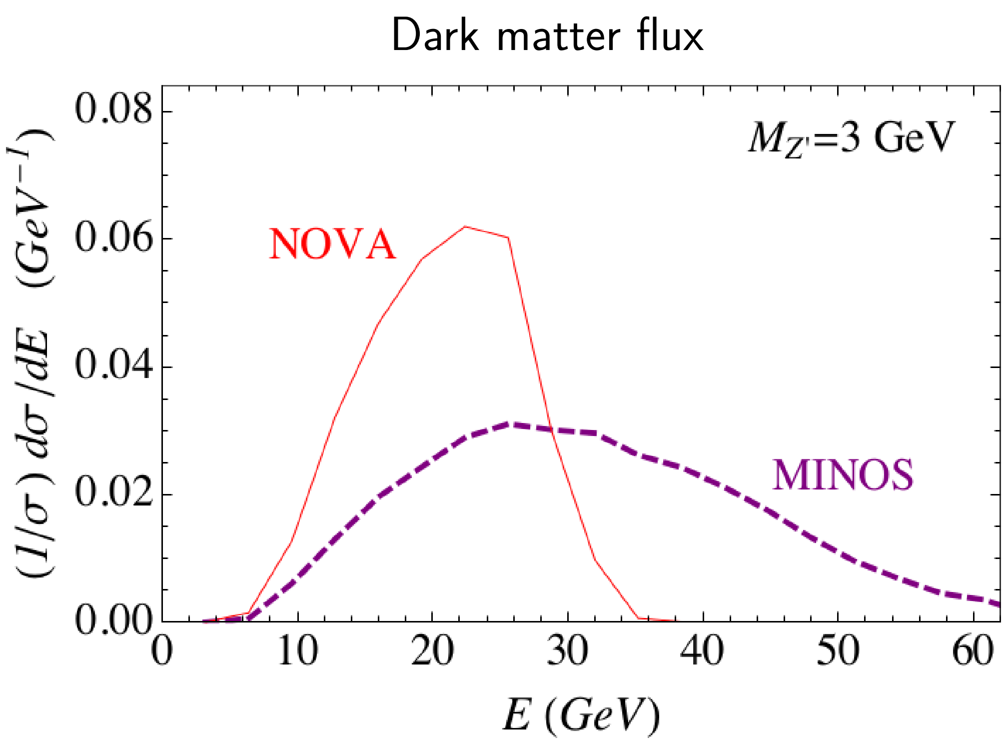
The off-axis concept

For two body decays neglecting the mass of the second particle produced in the decay:

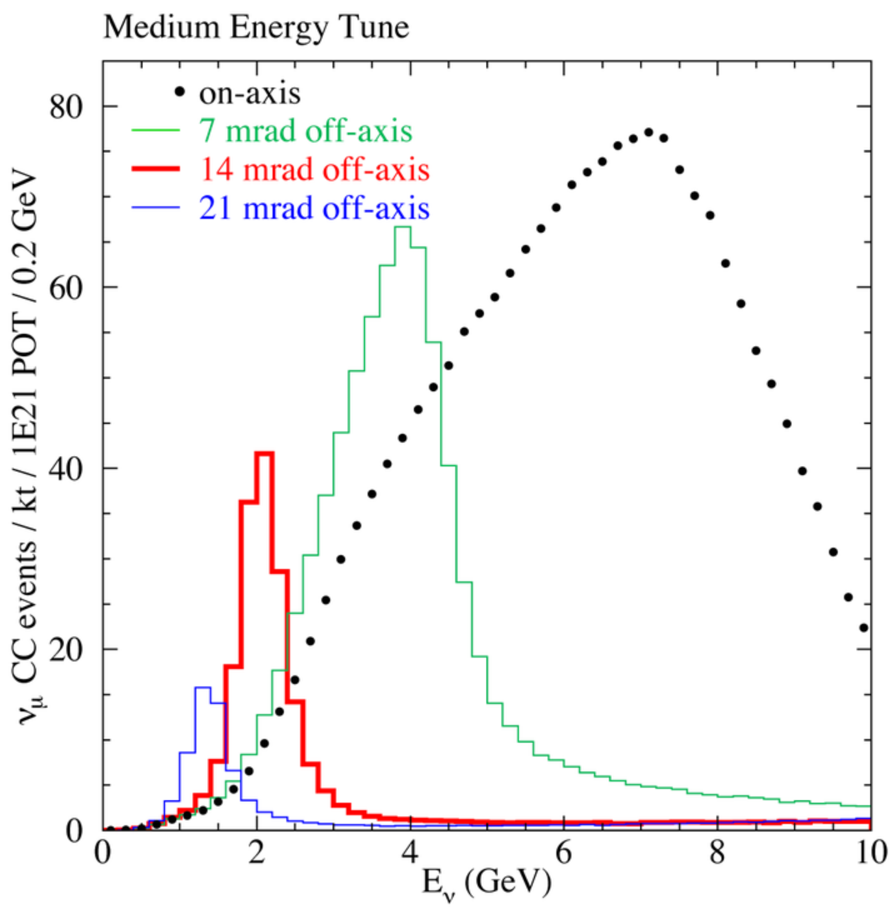


Energy profile

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

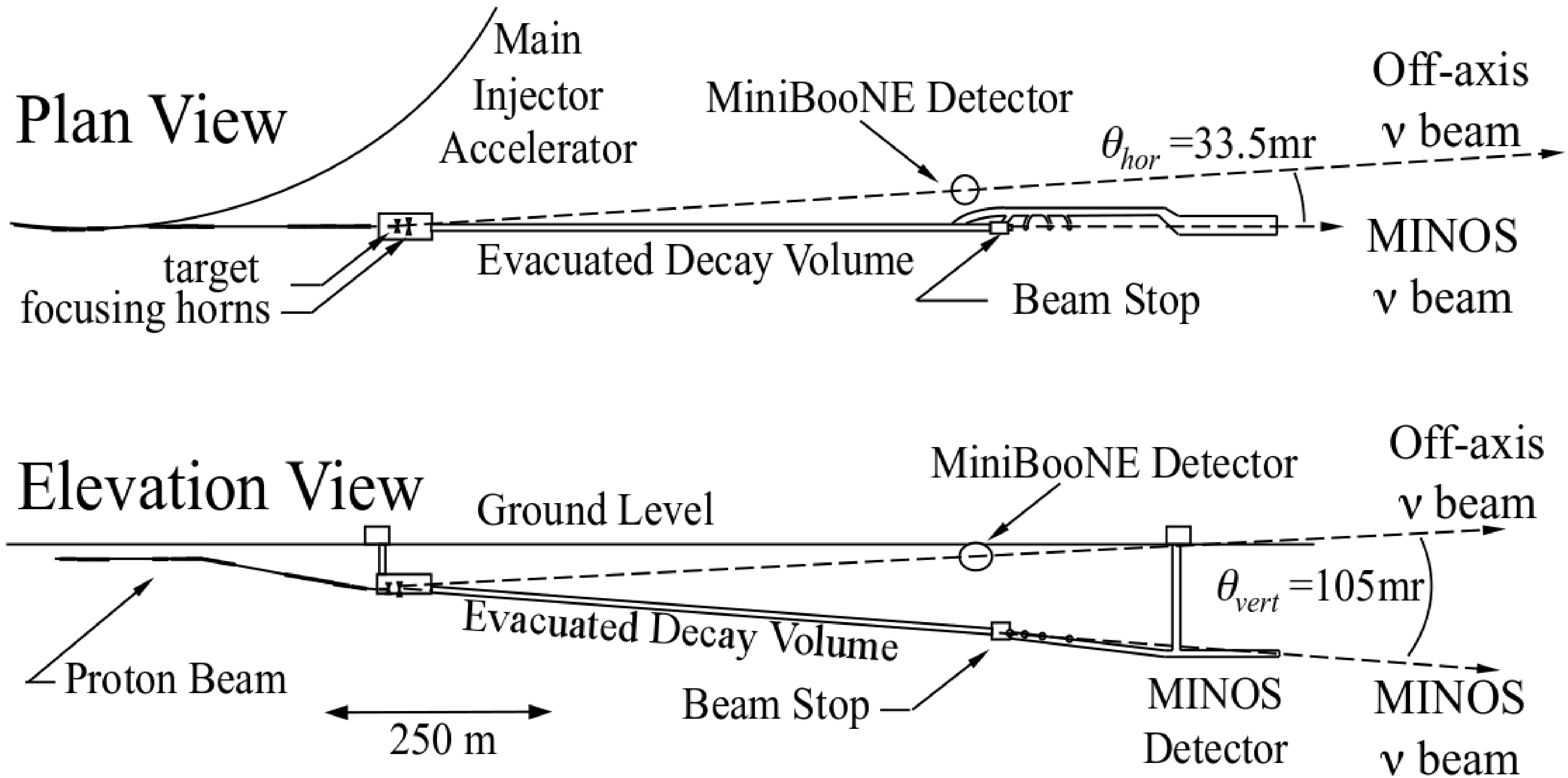


Dobrescu, Frugiuele, 1410.1566



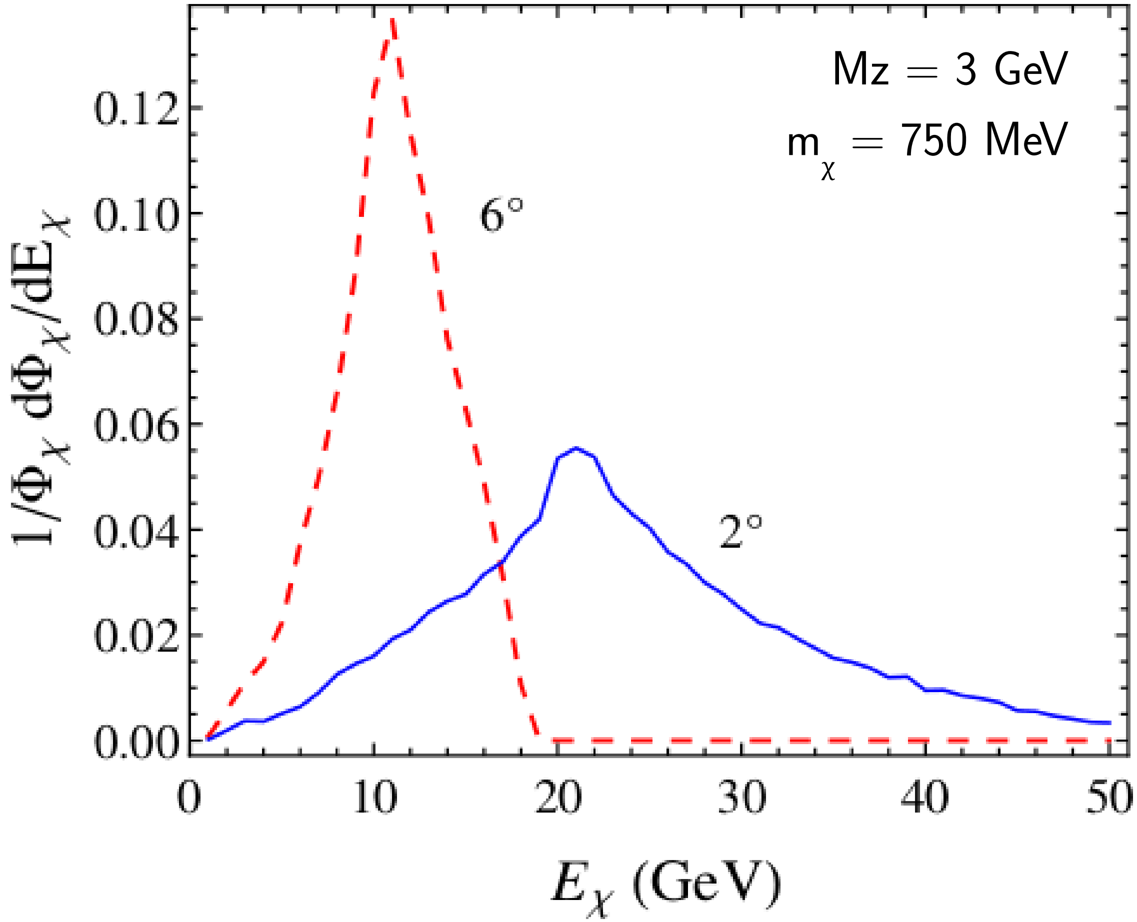
http://www-nova.fnal.gov

NuMI-MiniBooNE Map



MiniBooNE and MINOS collaborations, 0809.2447 [hep-ex]

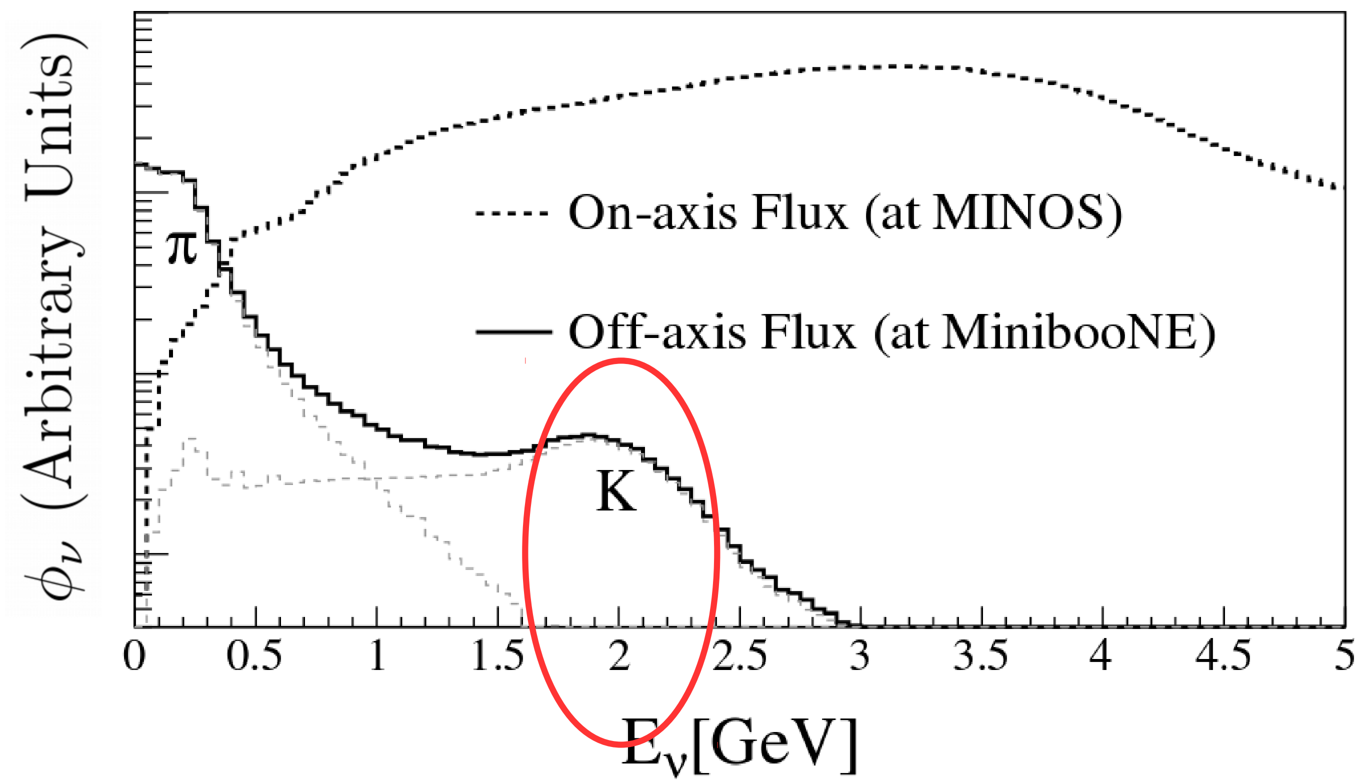
Energy profile



Coloma, Dobrescu, Frugiuele, Harnik, to appear

Angular dependence

The kaon neutrino background can be efficiently reduced by going off-axis:



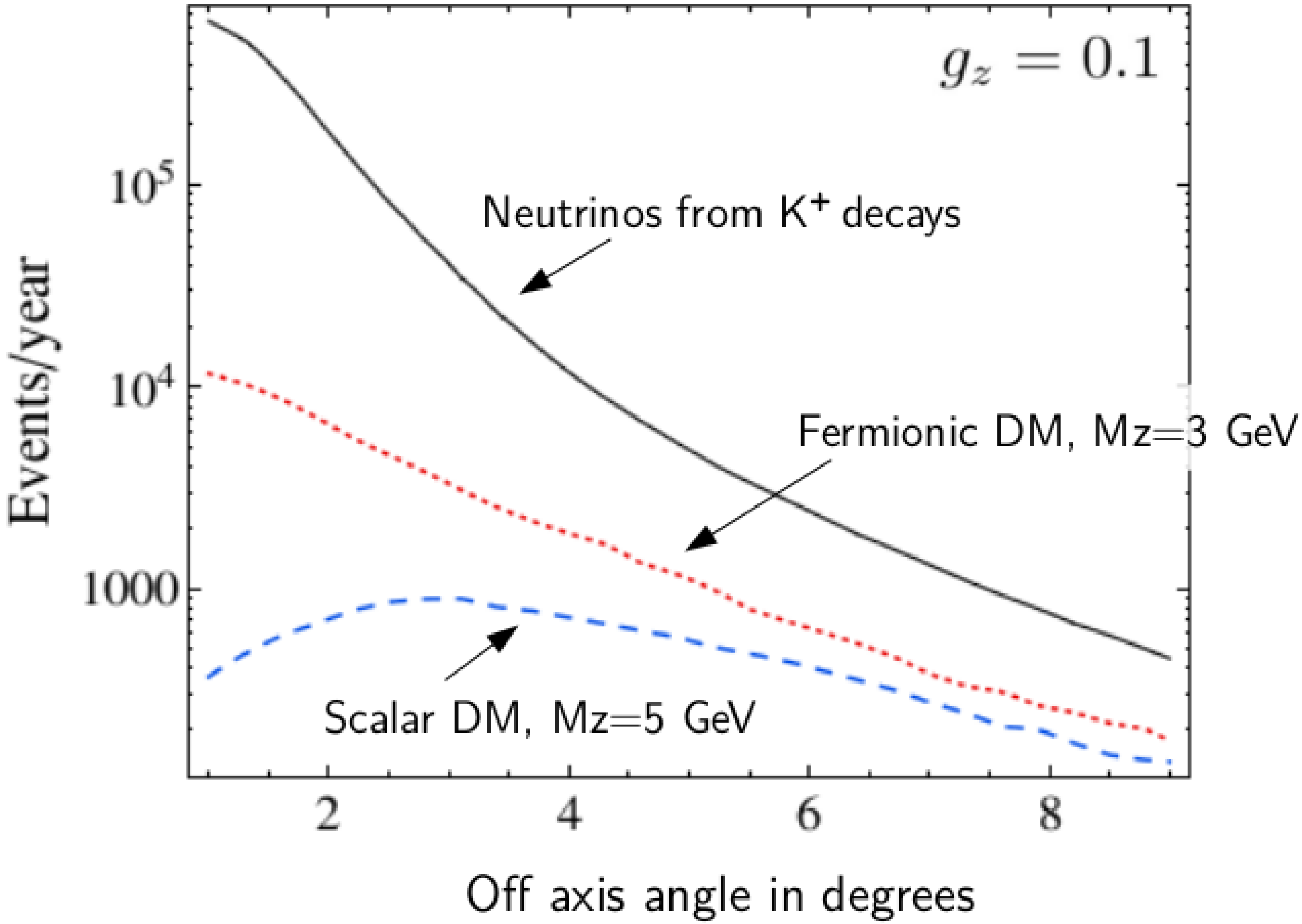
MiniBooNE and MINOS collaborations, 0809.2447 [hep-ex]

Angular dependence

- In case of a positive signal, one might find out the spin of the DM:

$$\frac{dP_{S,F}}{d\Omega} = \frac{1 \pm (m\cos\theta/\gamma - \beta)^2}{4\pi\gamma^2(1-\beta\cos\theta)^2}$$

Angular dependence



Coloma, Dobrescu, Frugiuele, Harnik, to appear

Event rates

Total event rates expected at an ideal spherical detector of 6m radius (~MiniBooNE-like), using the NuMI beamline:

Signal (for $g_z = 0.1$, Mz=3 GeV)	
NOvA -ND	~8,100
MiniBooNE	~650

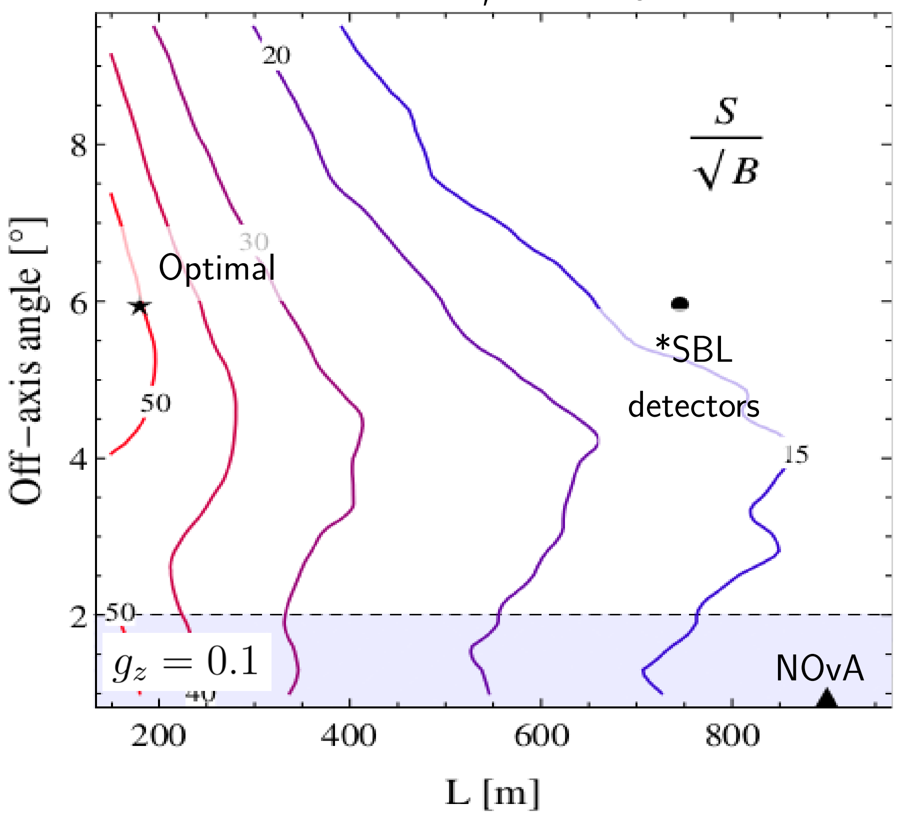
Background (from K only)	
NOvA -ND	~500,000
MiniBooNE	~2,500

$$N_{ev}^{sig} \propto g_z^6$$

Optimal detector location

Monte Carlo simulations of K production at the NuMI target gives the nu bg at different off-axis locations and distances:

Fermionic DM, Mz'= 3 GeV

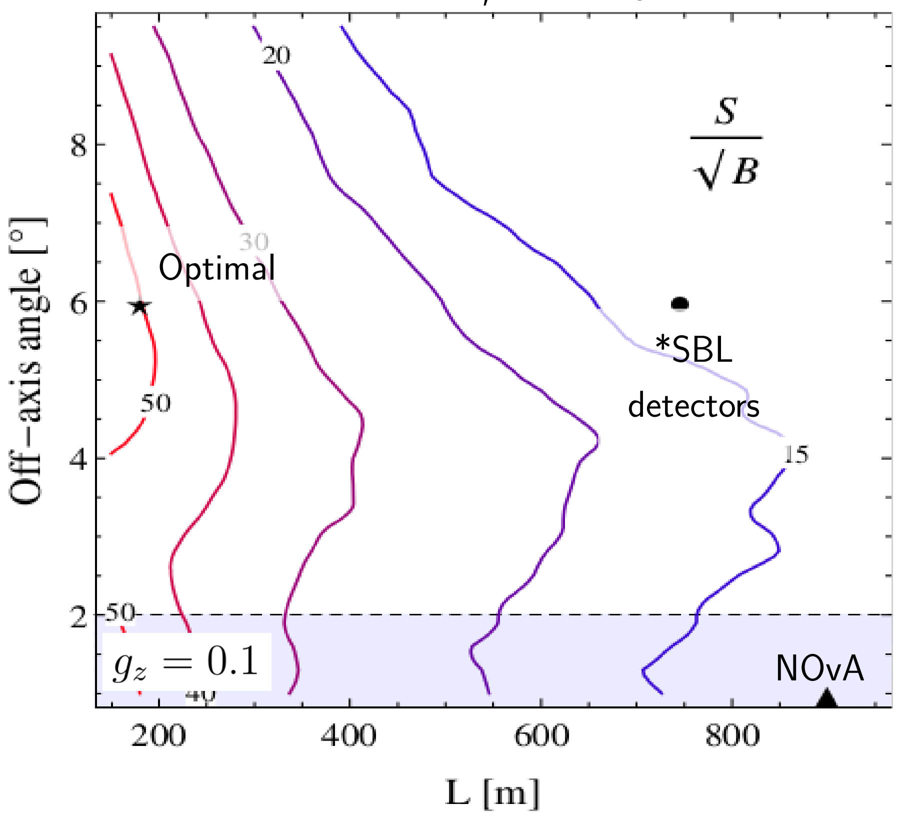


*SBL detectors include: MiniBooNE, microBooNE and ICARUS (NOvA NDOS is at similar off-axis angle)

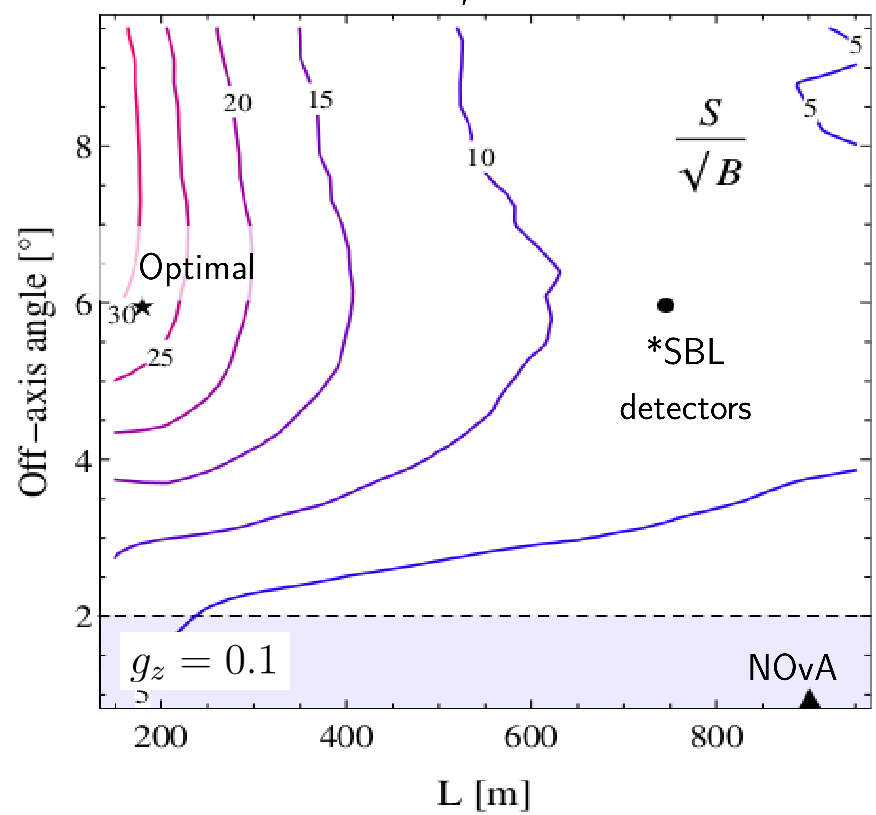
Optimal detector location

Monte Carlo simulations of K production at the NuMI target gives the nu bg at different off-axis locations and distances:

Fermionic DM, Mz'= 3 GeV

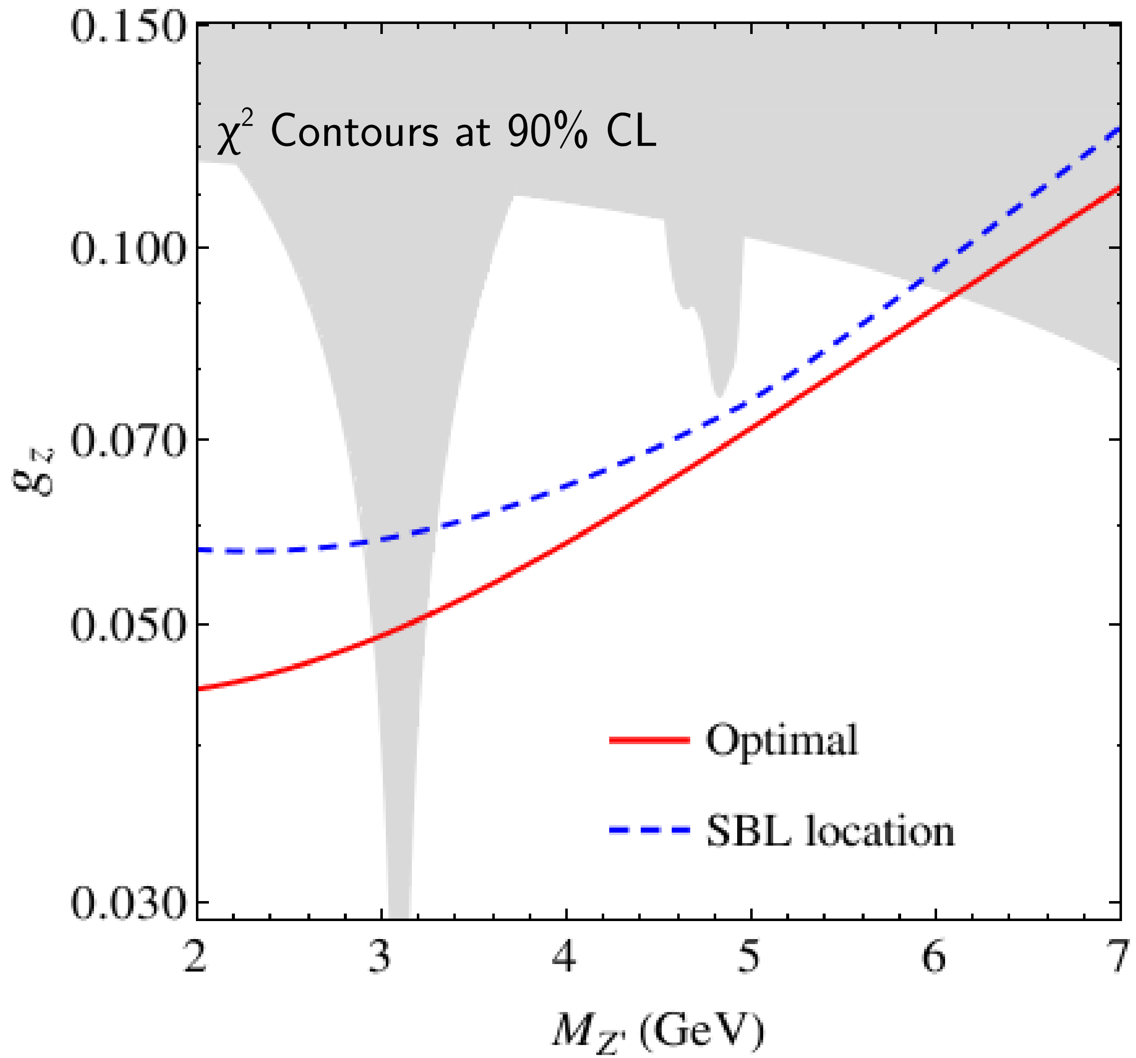


Scalar DM, Mz'= 5 GeV



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

Sensitivity regions



Coloma, Dobrescu, Frugiuele, Harnik, to appear

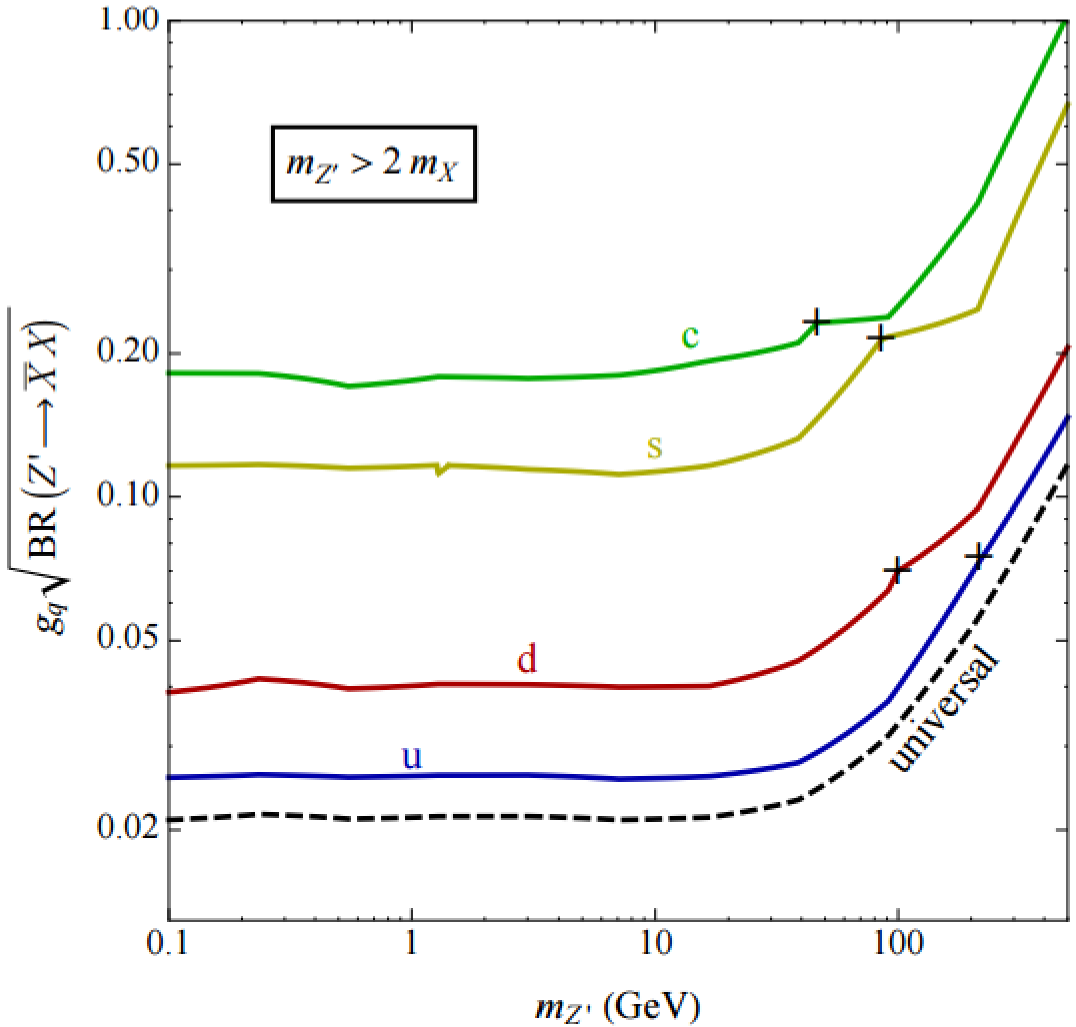
Conclusions

- We have showed that neutrino experiments can explore light dark sector scenarios
- We have computed the neutrino background for a particular model. It can be mitigated by going sufficiently off-axis
    - MiniBooNE may be able to get a limit with past data!
- Optimal location: 5-6 degrees off-axis $\rightarrow$ a possibility for DUNE?
- The model studied here is just a possible example of what neutrino experiments may be able to do in searches for New Physics!

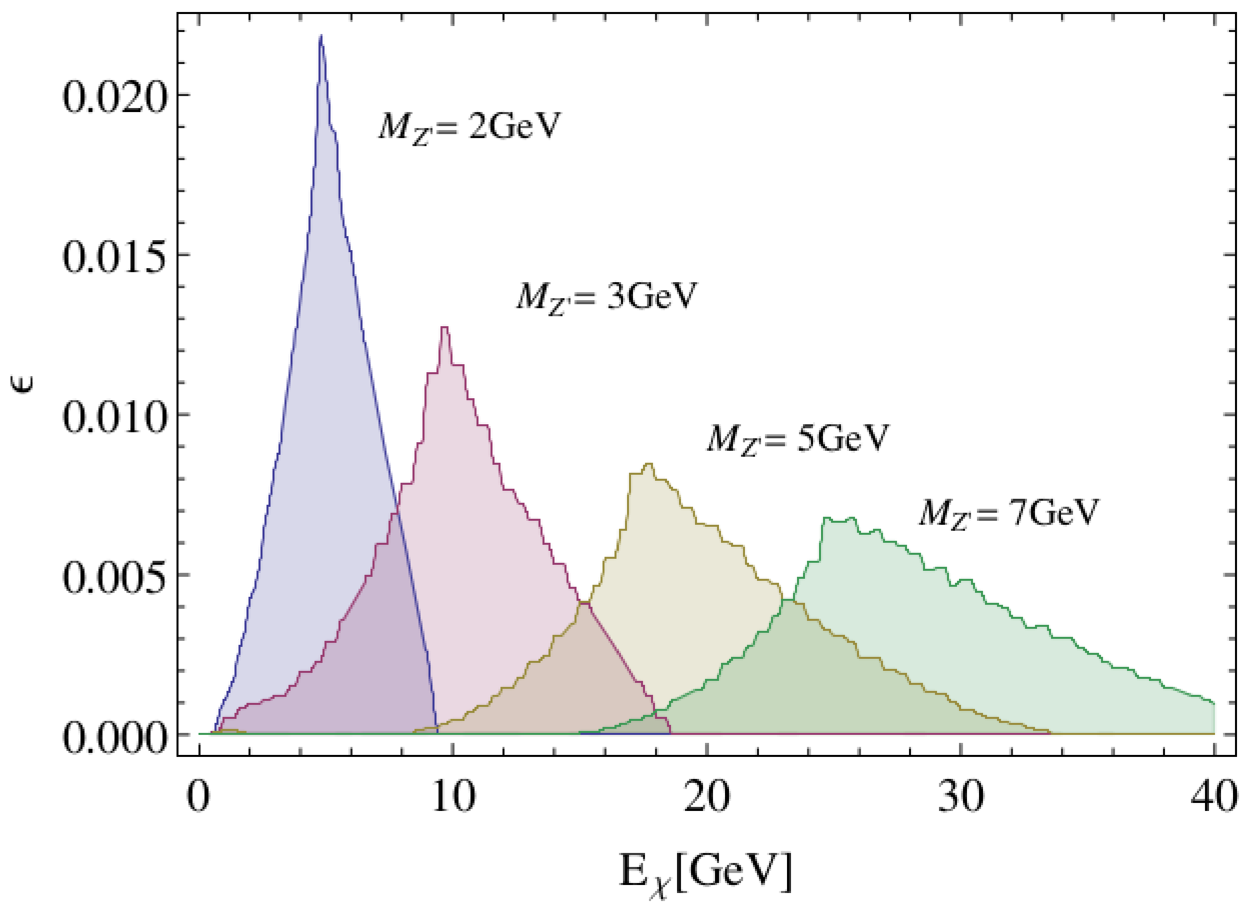
Backup slides

Monojet bounds

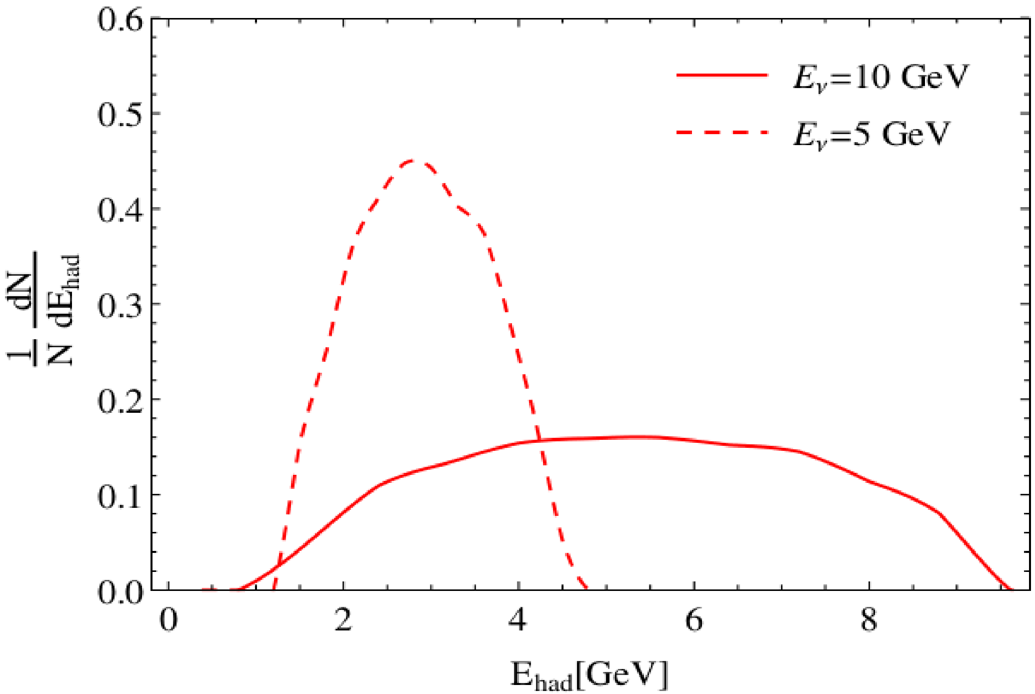
Shoemaker, Vecchi, 1112.5457

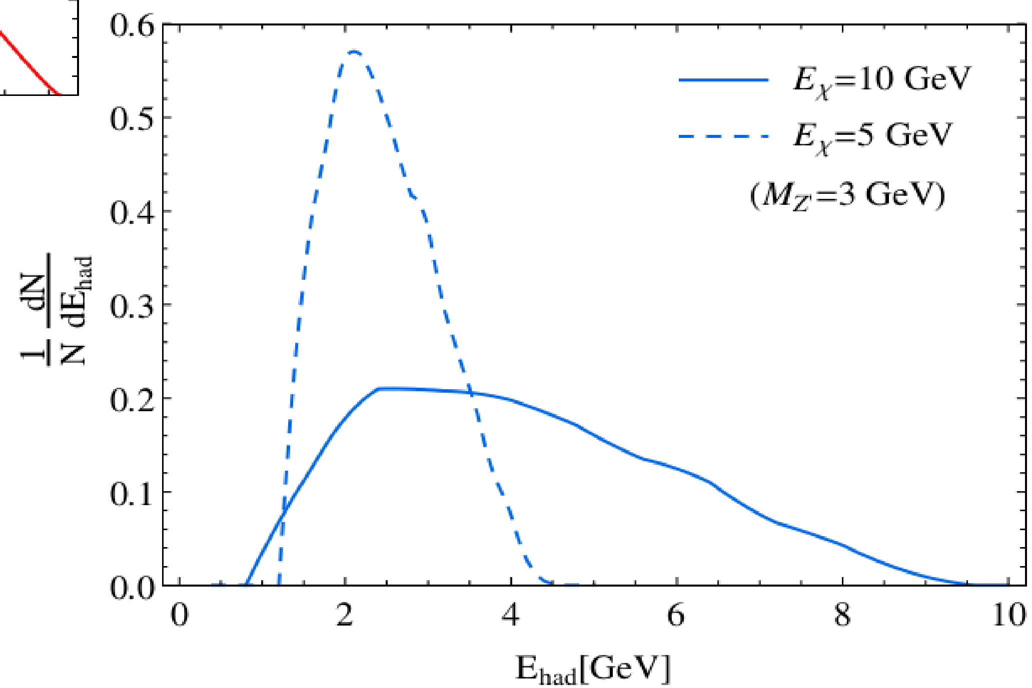


Energy profile for different values of Mz'



The signal: hadronic showers





Energy profile for different values of Mz'