Leptophobic GeV dark matter at neutrino experiments

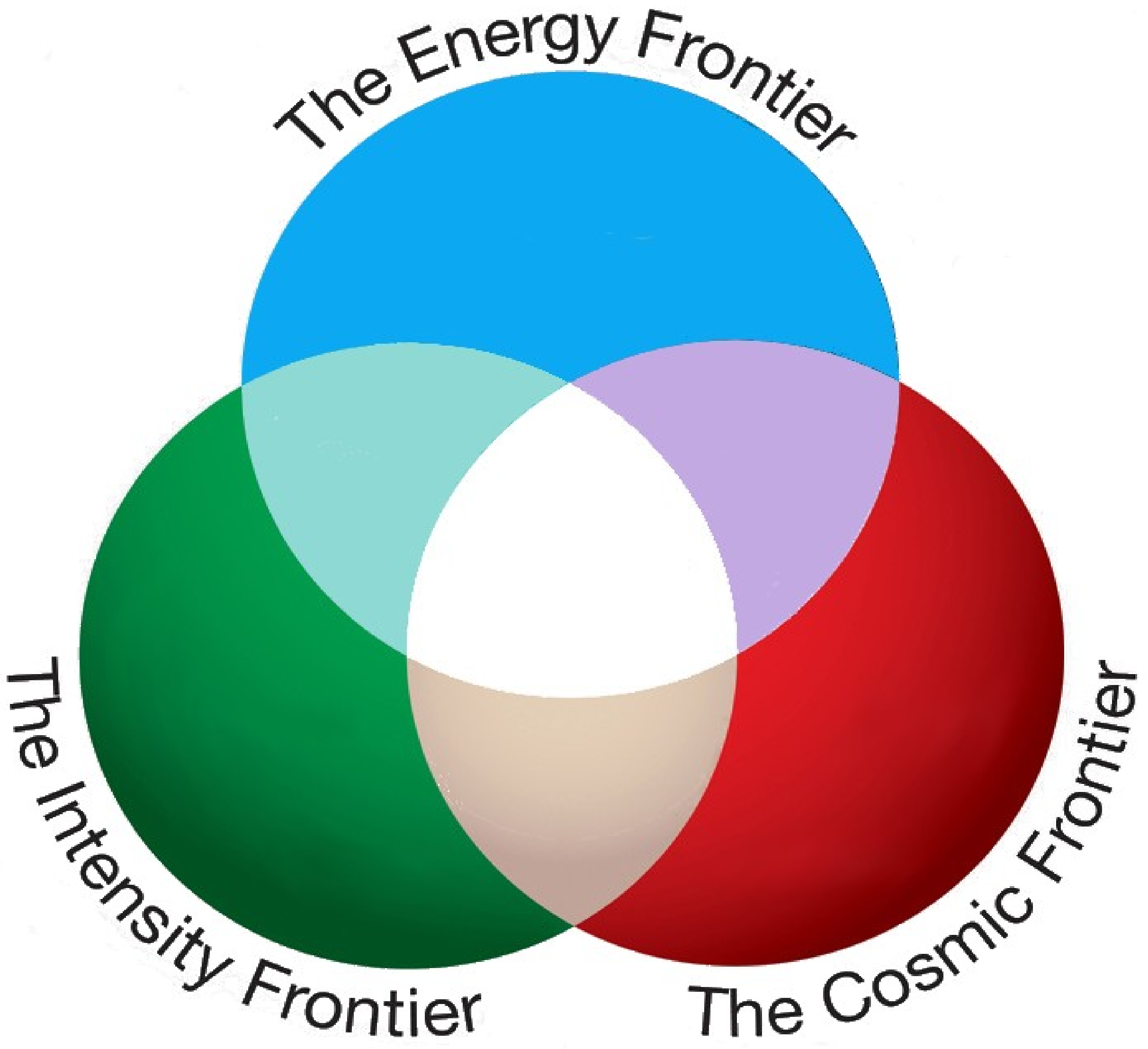
Pilar Coloma

Fermilab

Work in collaboration with
Bogdan Dobrescu, Claudia Frugiuele and Roni Harnik (to appear)

Invisibles 2015
IFT and Thyssen-Bornemisza Museum,
Madrid, Spain
June 23rd, 2015

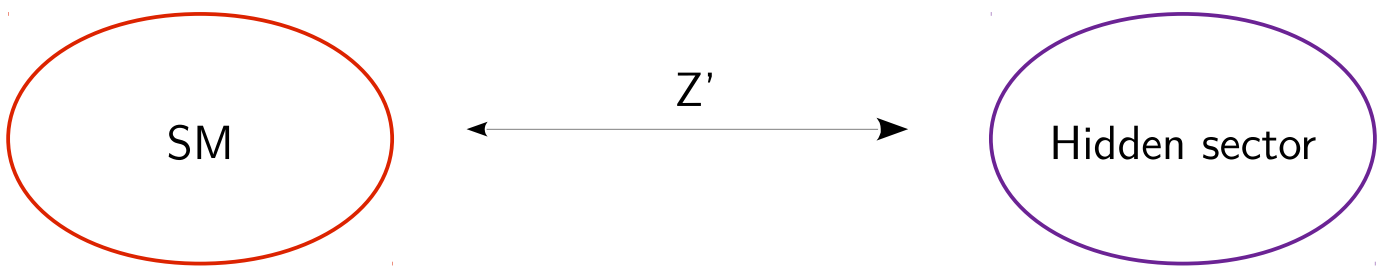
Have we discovered all the forces/matter in Nature yet?



A vector portal to the dark sector

- For light dark matter masses to give a significant contribution to the relic density, a light mediator is needed.

  Simple possibility: a new U(1) symmetry



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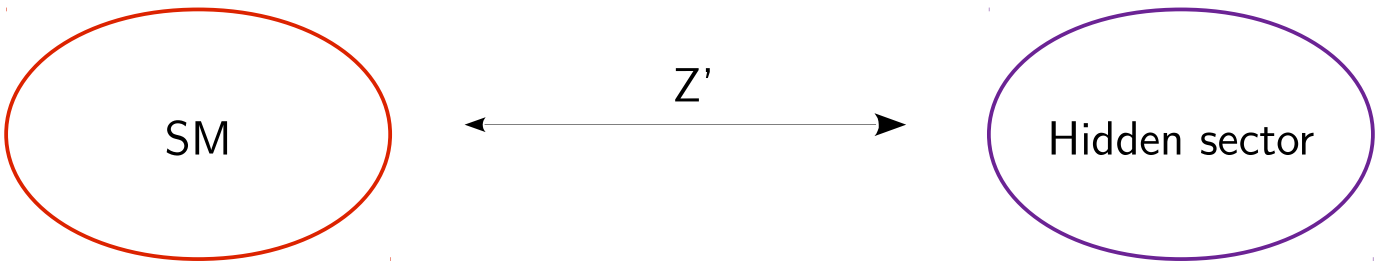


- The couplings of the dark sector do not have to be equal for leptons and hadrons. In particular, the Z' could be leptophobic:
  - For Mz'$<$ 200 GeV, collider bounds are generally mild
  - Direct detection bounds fade away if DM mass $<$ 5 GeV

Leptophobic Z'

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

Main possibilities to couple the Z' to the visible sector:

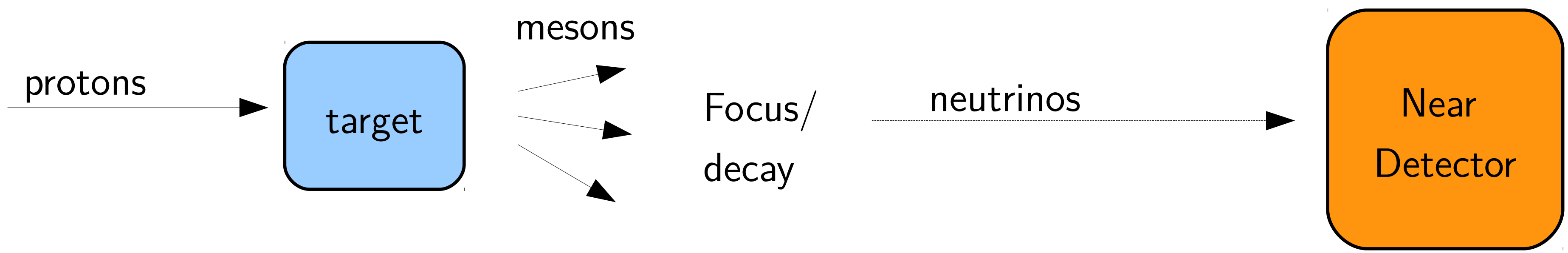
1) via kinetic mixing to the SM hypercharge boson (dark photon)

2) via direct coupling to quarks*:

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

*We consider a $U(1)_B$ symmetry (ie, same coupling for all quarks).

Dark matter at neutrino experiments



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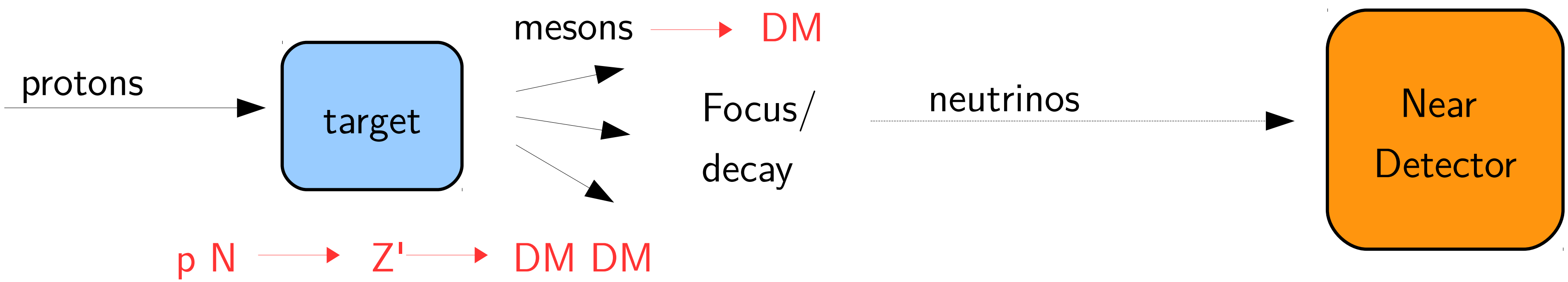
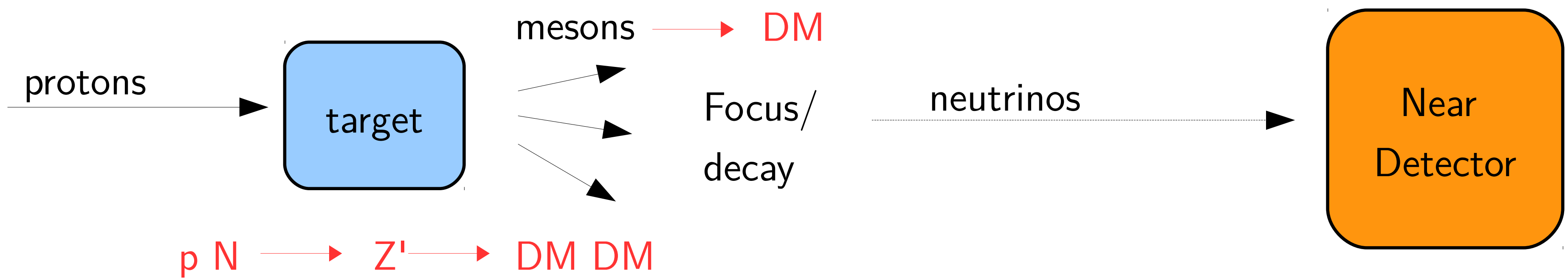


Dark matter at neutrino experiments

- This method to test DM scenarios was first proposed by deNiverville, Pospelov and Ritz in 1107.4580 (see talk by Batell)



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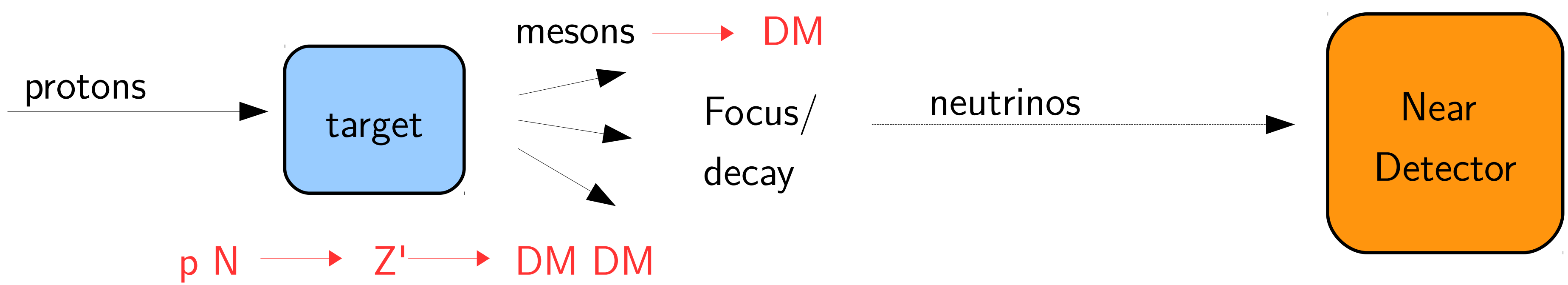

- At the NuMI beamline, $E_p = 120$ GeV
  (as opposed to 8 GeV in the Booster)

- This allows to extend the reach in $M_{Z'}$ → GeV

Previous constraints

Quarkonium invisible decays

BaBar, 0908.2840

BES, 0710.0039

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

$$\Upsilon \to Z'^* \to \chi\chi$$

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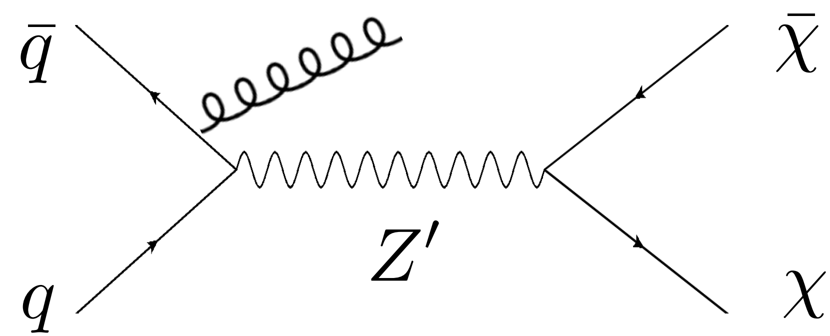
Monojets @ colliders

CDF, 1203.0742

Shoemaker, Vecchi, 1112.5457



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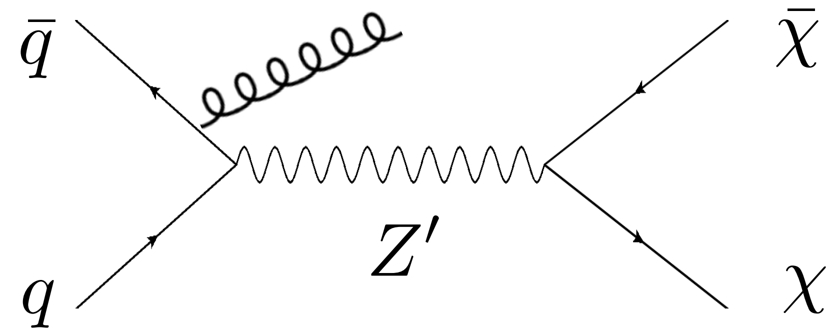
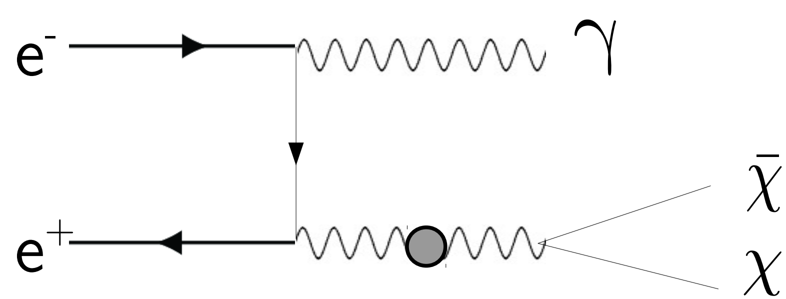


Monophoton @ BaBar

Essig, Mardon, Papucci, Volansky, 1309.5084



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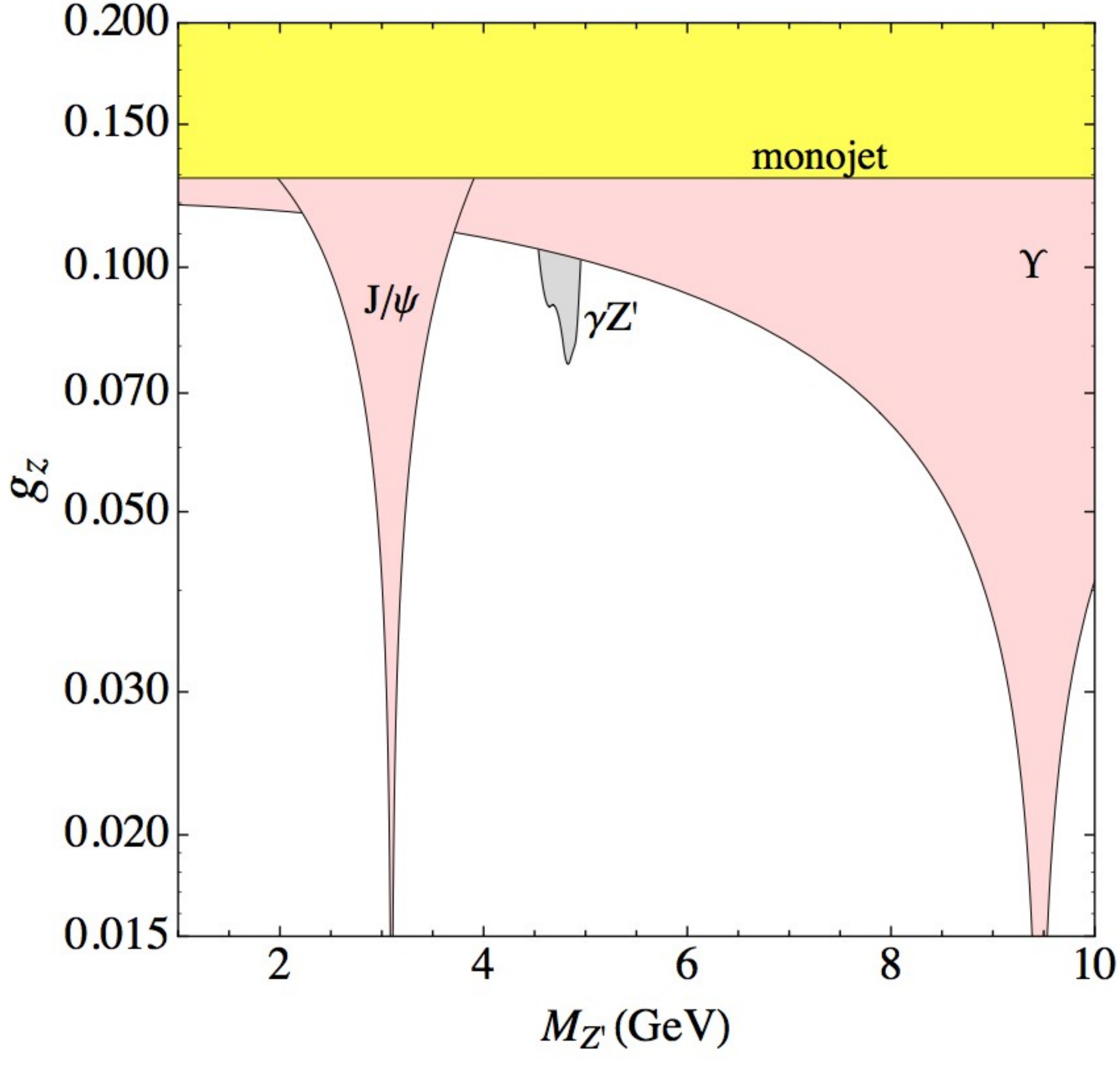
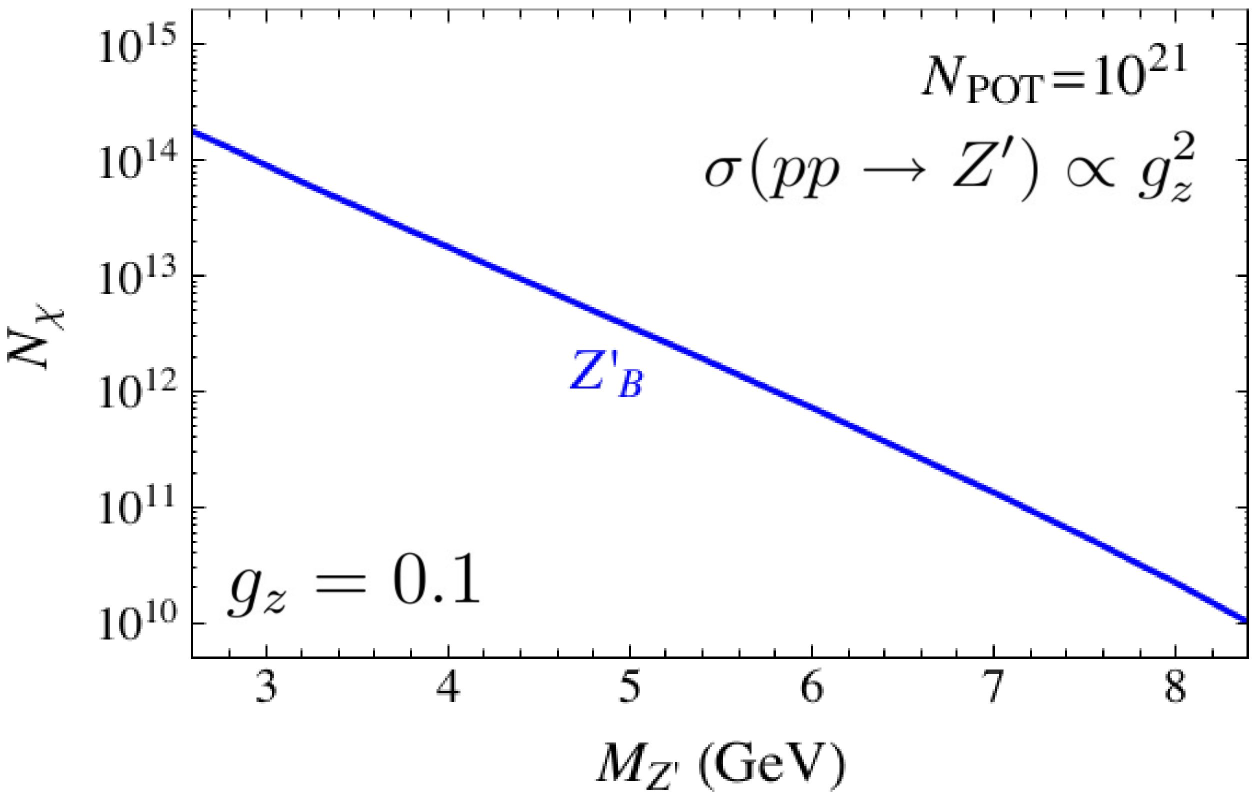


Dobrescu,
Frugiuele,
1410.1566

How much can we improve over this?

Dark matter production

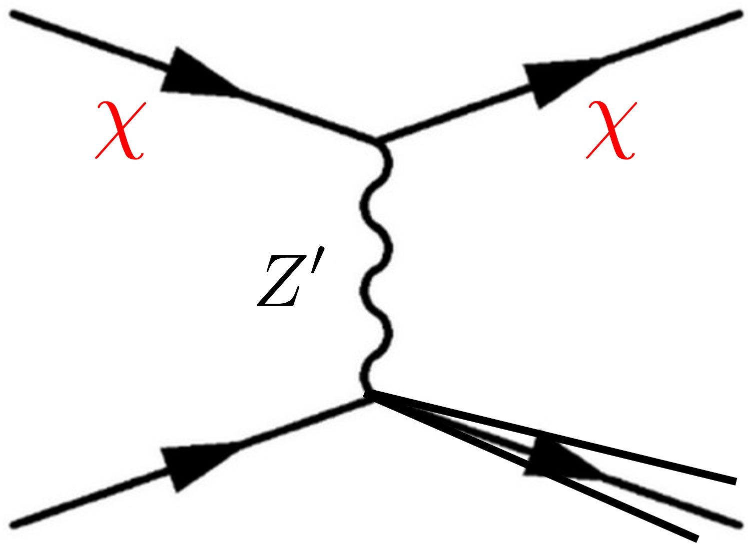
Particles produced at the target:



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 a shower with more than 2-3 GeV energy

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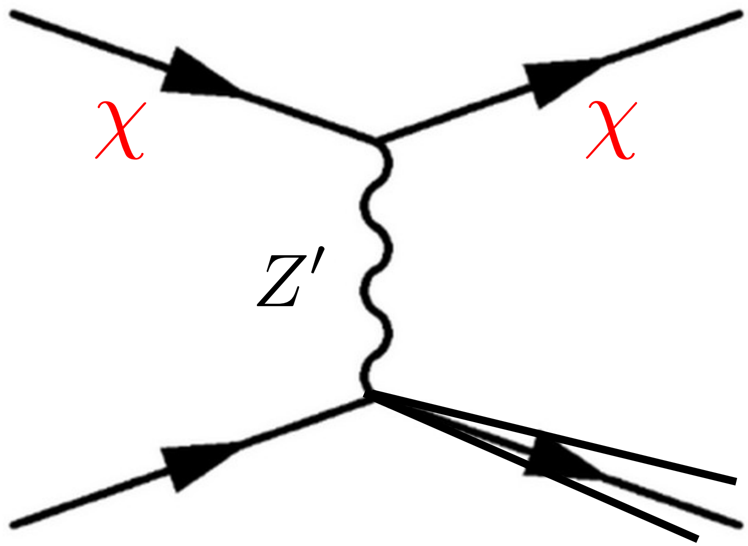
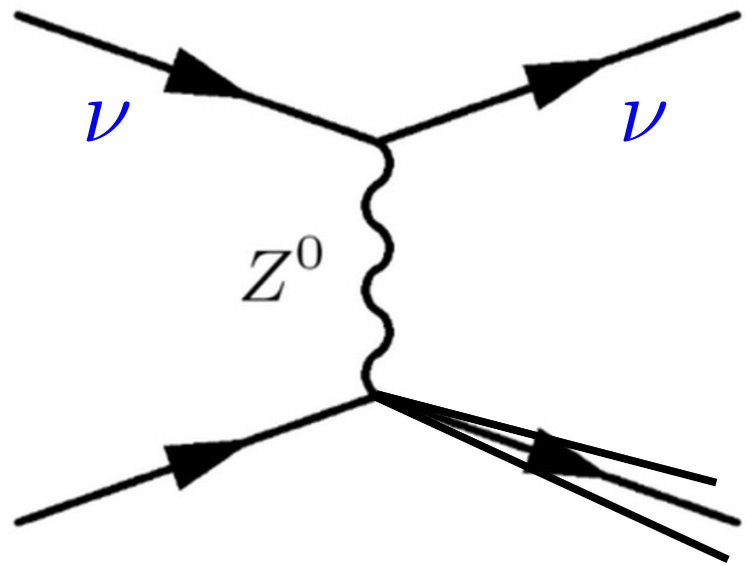




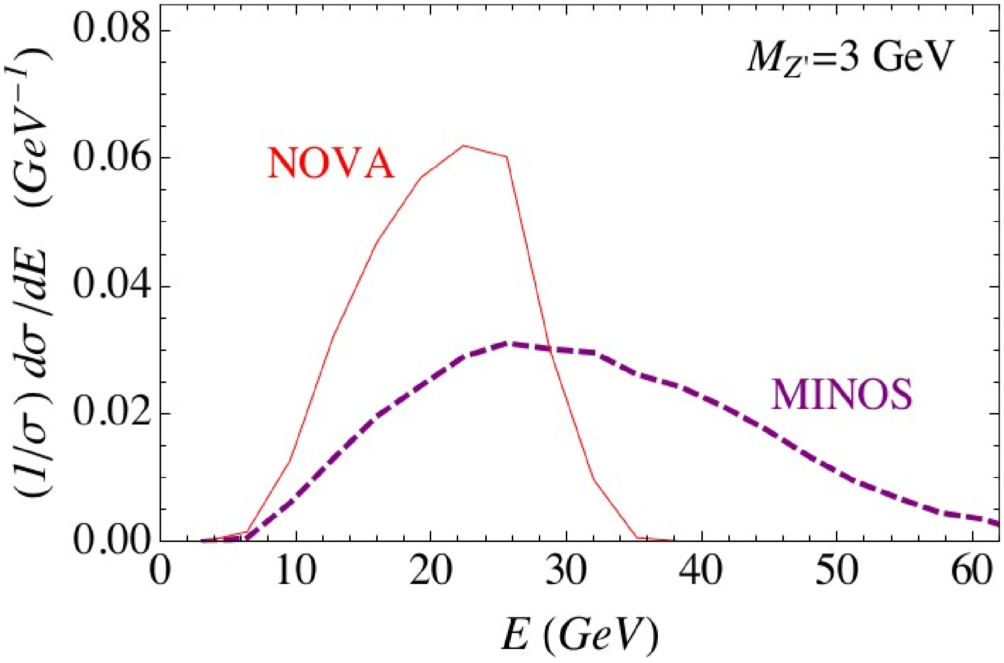
If energetic enough, a hadron shower
will be produced

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

Energy profiles

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

Dark matter flux



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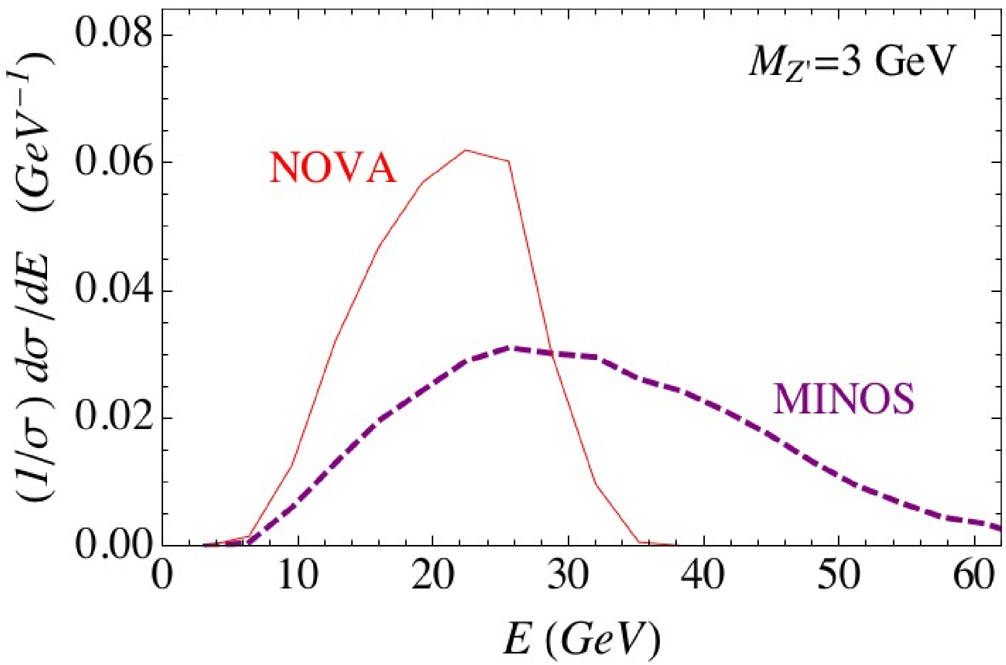
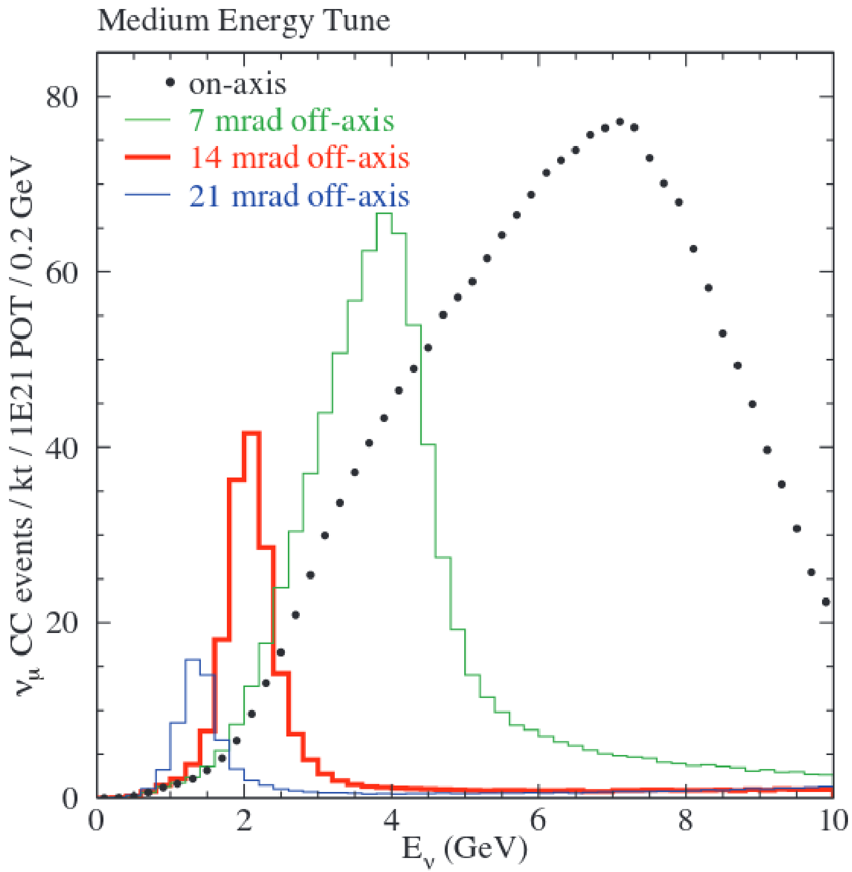


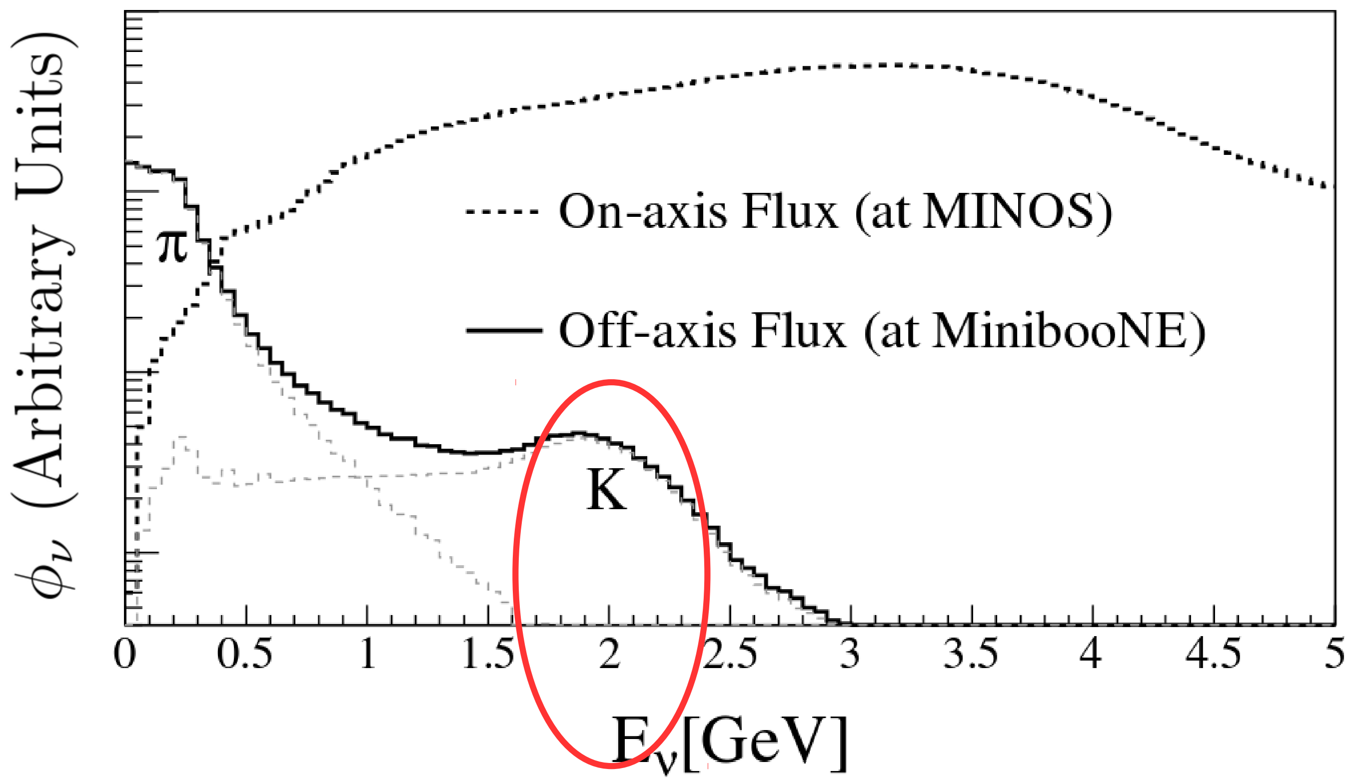
Dobrescu, Frugiuele, 1410.1566



http://www-nova.fnal.gov

The off-axis concept

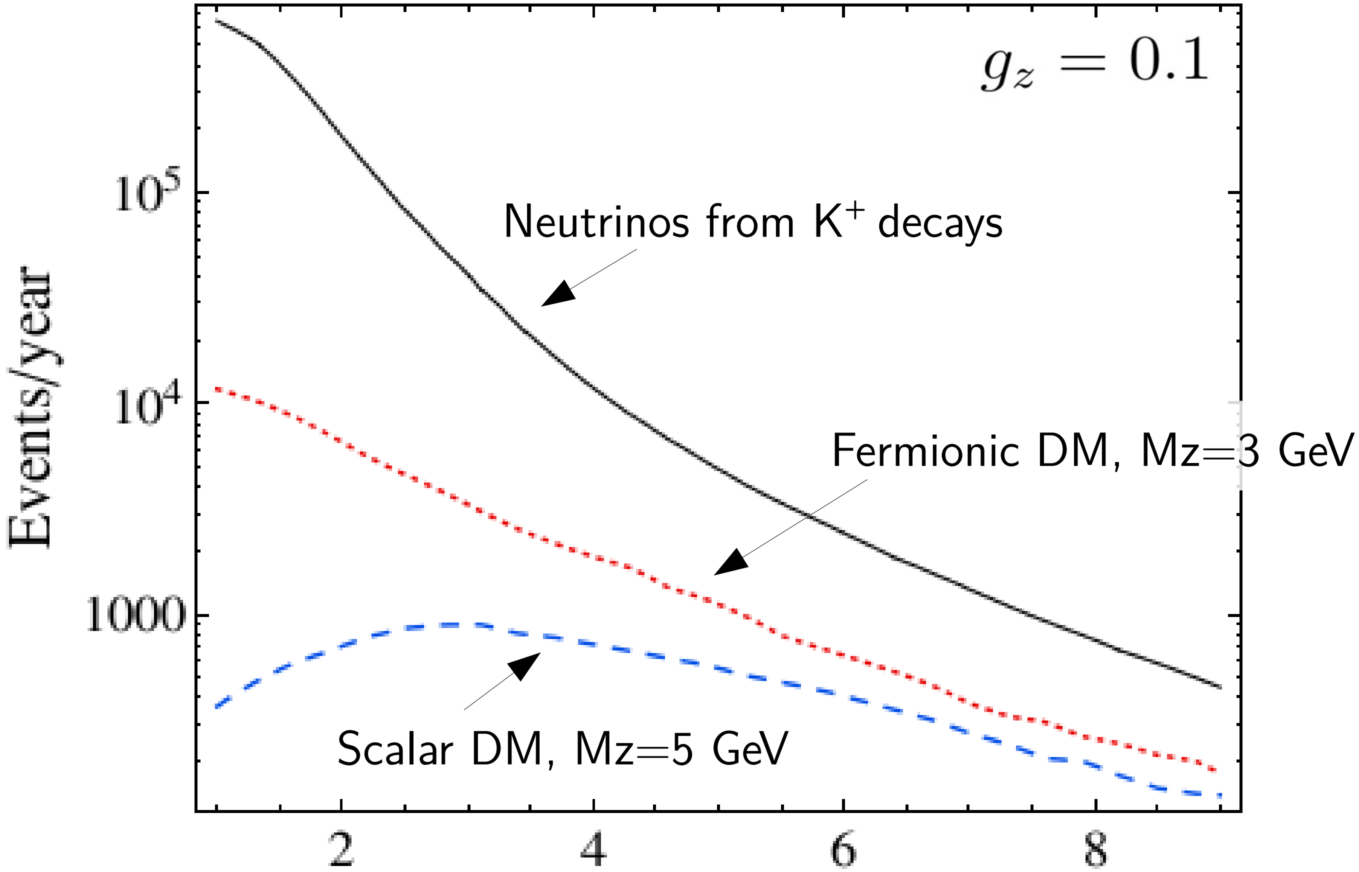
The neutrino background can be efficiently reduced by going off-axis:



MiniBooNE and MINOS collaborations, 0809.2447 [hep-ex]

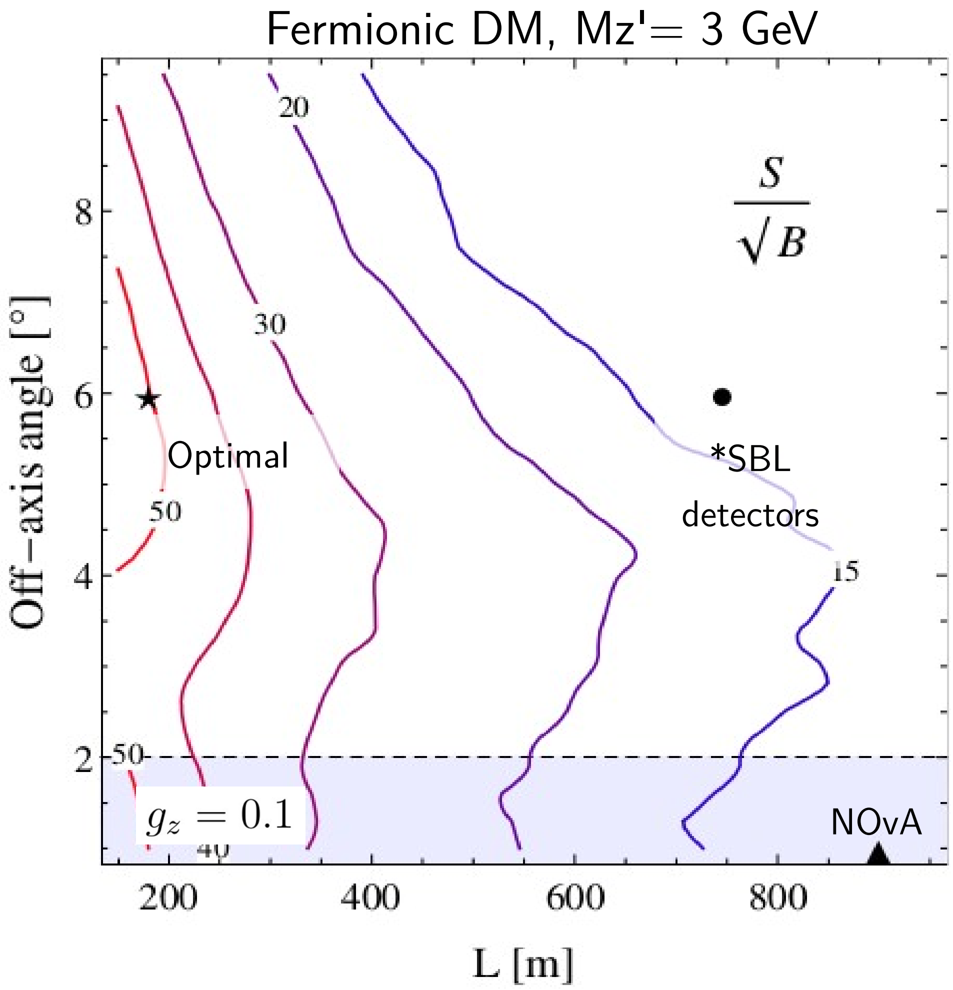
Angular dependence

Signal and bg for an ideal spherical detector at L = 750 m



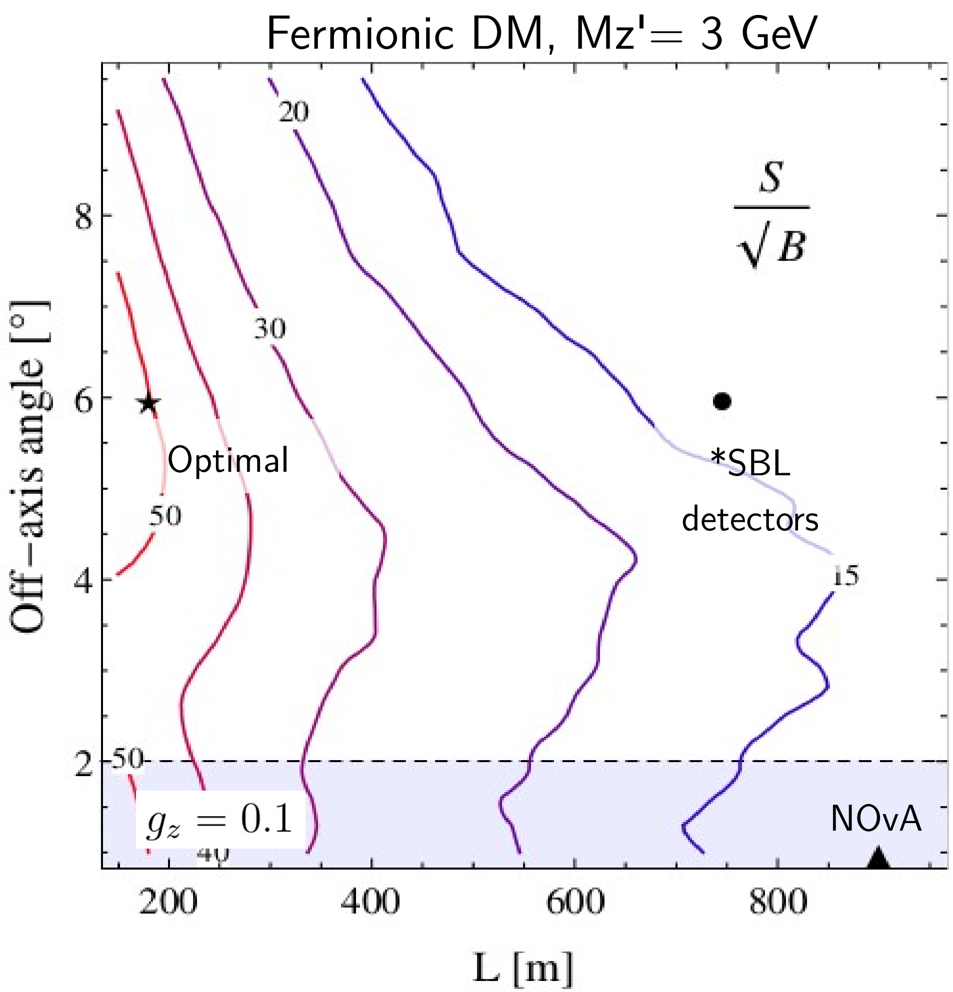
Off axis angle in degrees

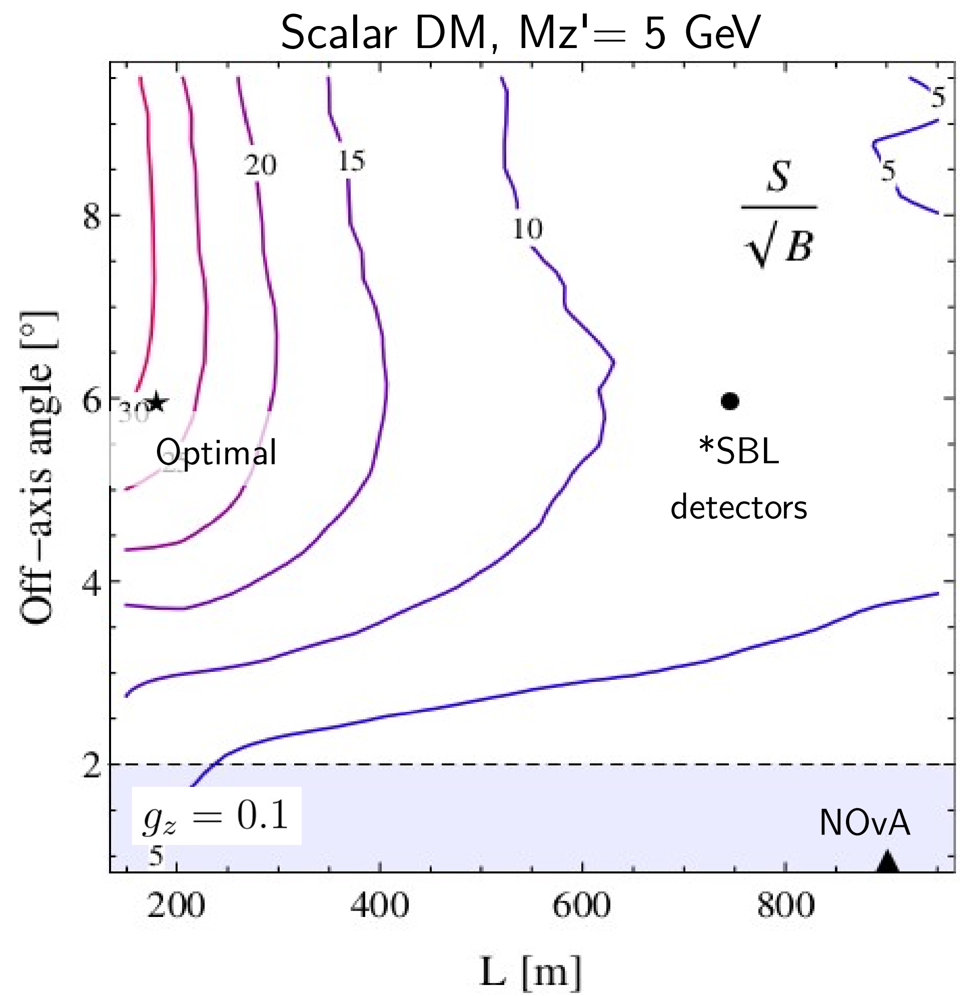
Optimal detector location



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

Optimal detector location





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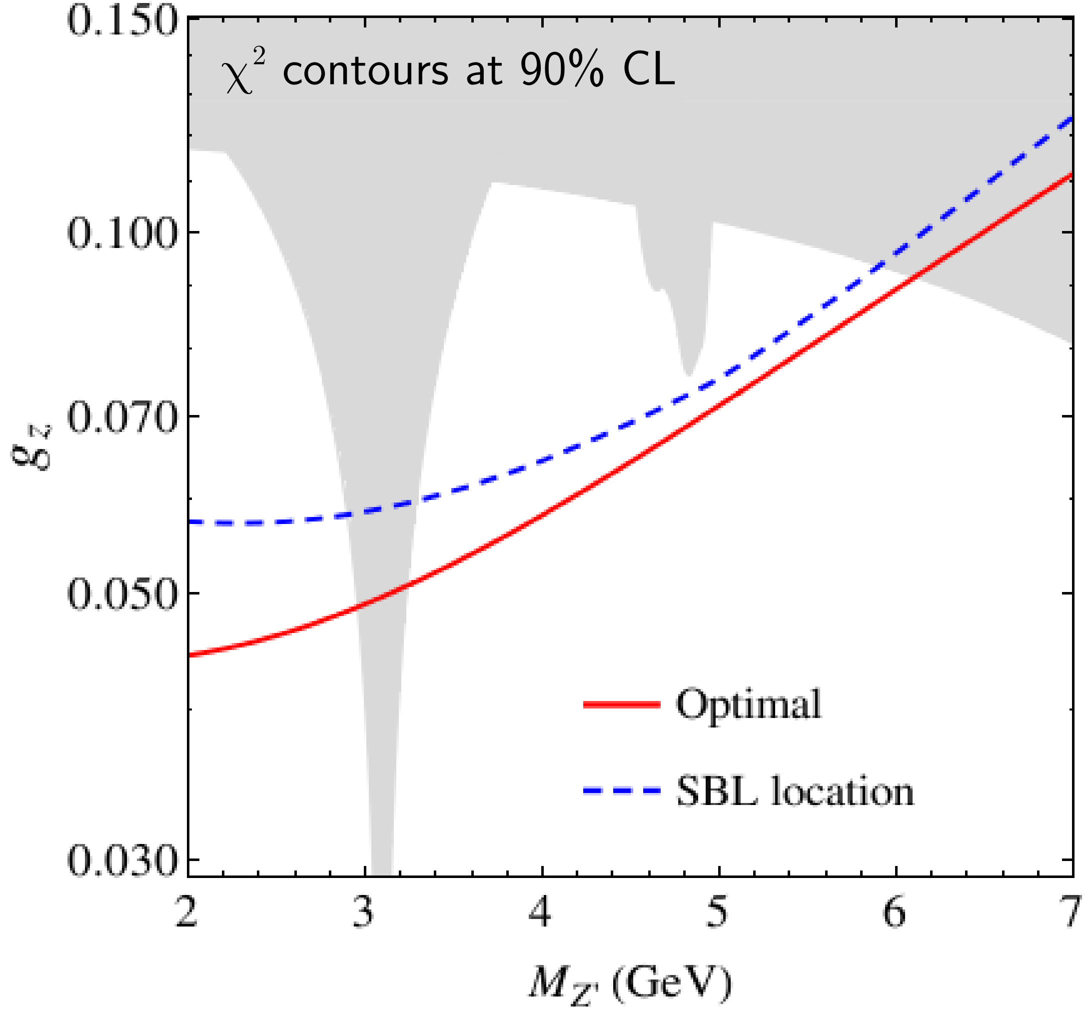
Sensitivity regions

Fermionic dark matter case

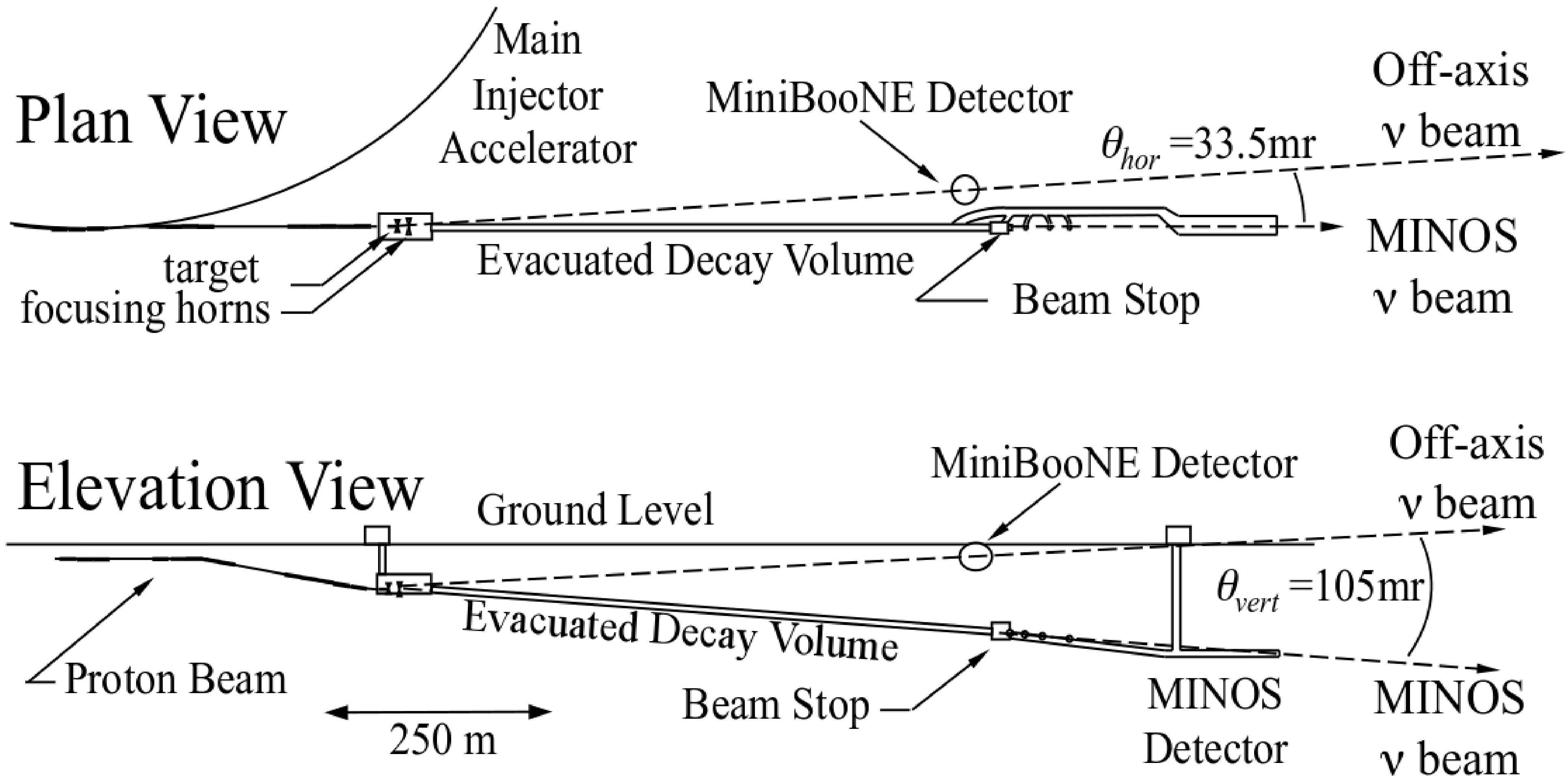


Conclusions

- We have showed that neutrino experiments can search for light dark matter and a new GeV force
- We have computed the neutrino background. It can be mitigated by going sufficiently off-axis
    - MiniBooNE may be able to get a limit with no additional running time. MicroBooNE will start soon
- Optimal location: 5-6 degrees off-axis
- 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

NuMI-MiniBooNE Map



MiniBooNE and MINOS collaborations, 0809.2447 [hep-ex]

Event rates

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

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

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

*Further reduction of the background may be achieved from a cut in time of flight

The signal: hadronic showers