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Fermilab

Dark matter beams at LBNF

with Pilar Coloma, Bogdan Dobrescu and Roni Harnik

hep ph 1508.xxx

with Bogdan Dobrescu

PRL 113, 061801 (2014)

JHEP 1502 (2015) 019

Dark matter is a strong evidence for BSM physics, but we do not know anything about its properties

Dark matter is a strong evidence for BSM physics, but we do not know anything about its properties

One or more DM particles?

What is its mass?

Does it interact with us only gravitationally?

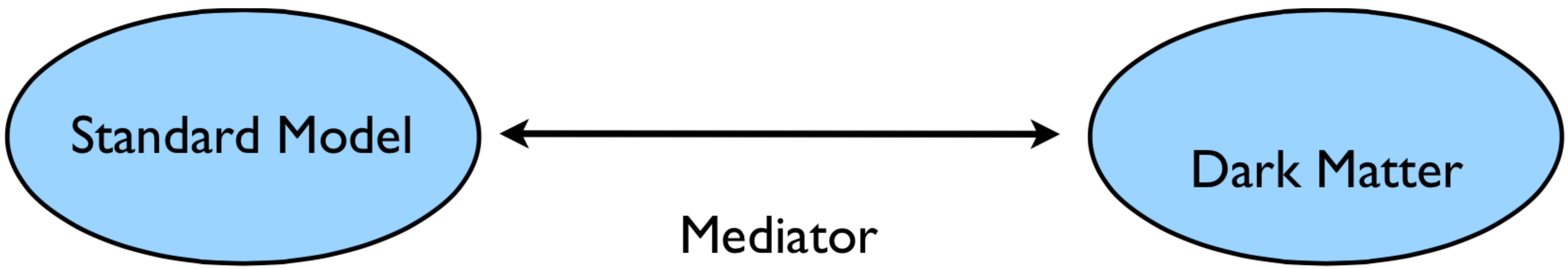
Dark matter is a strong evidence for BSM physics, but we do not know anything about its properties

One ass?

Does ally?

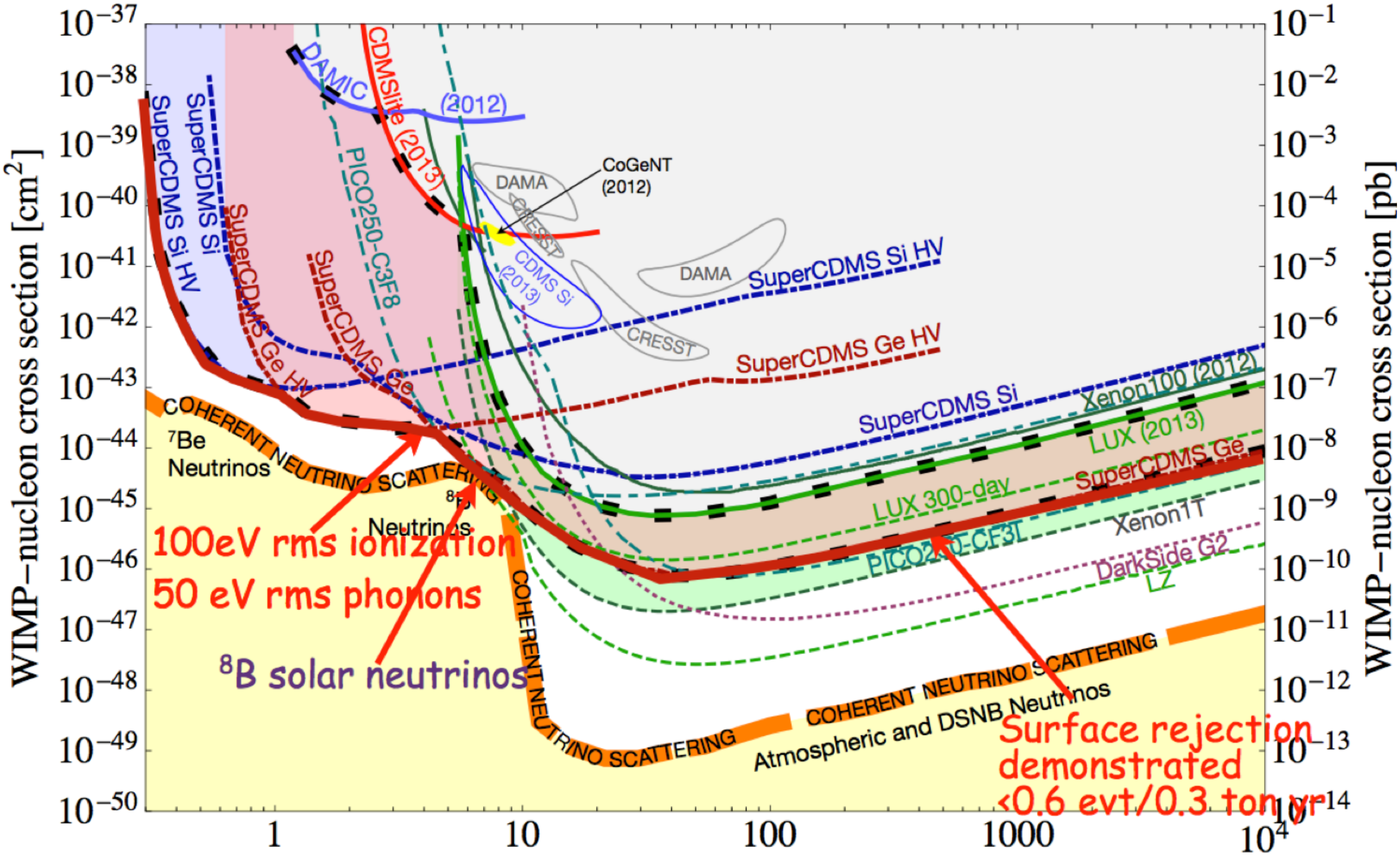
We must look everywhere!
Broad experimental program required!

How do we look for DM?



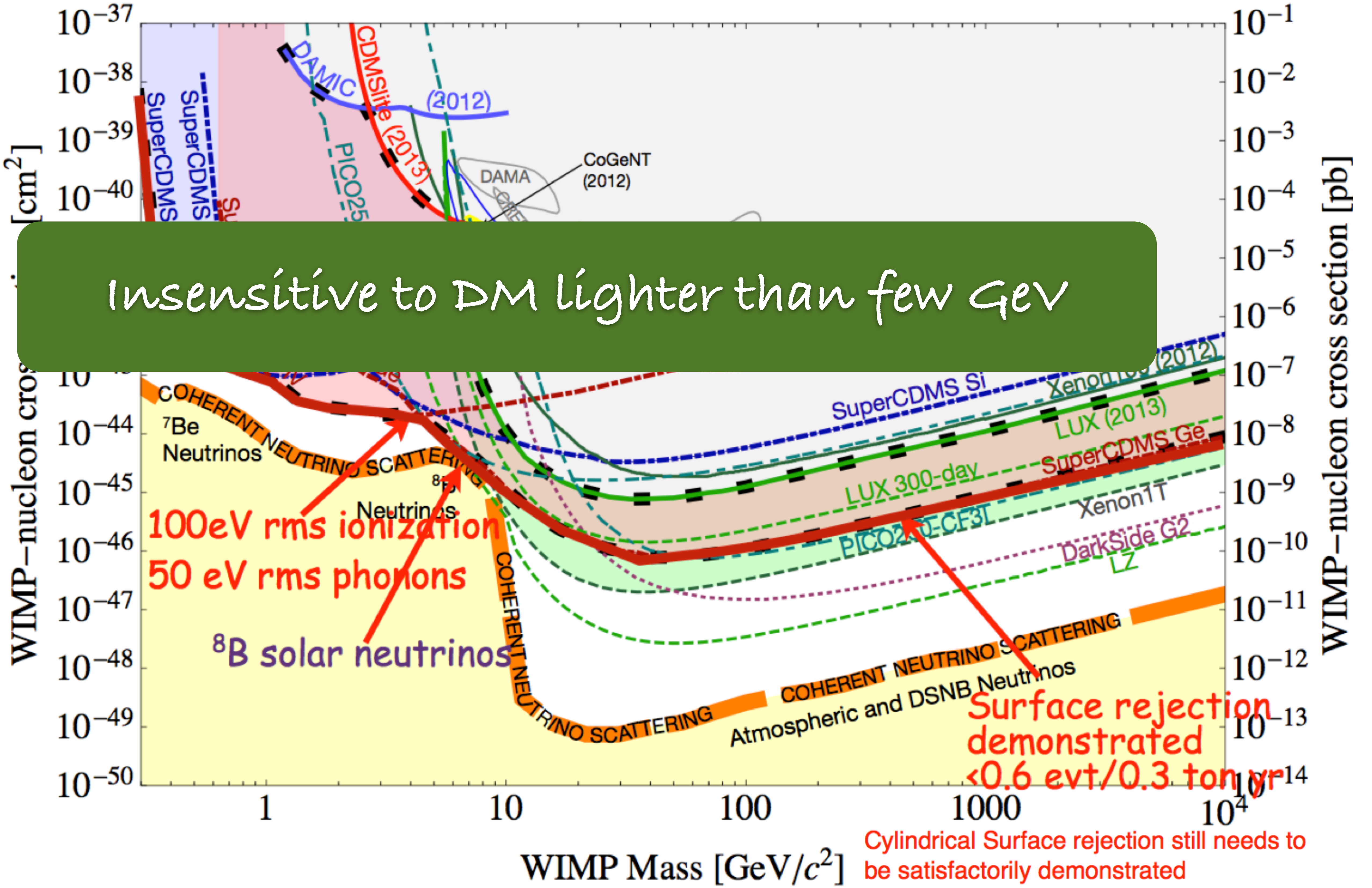
- Direct detection
- Indirect detection
- Collider searches
- Low energy frontier

Direct detection experiments strongly constraint matter-DM interactions

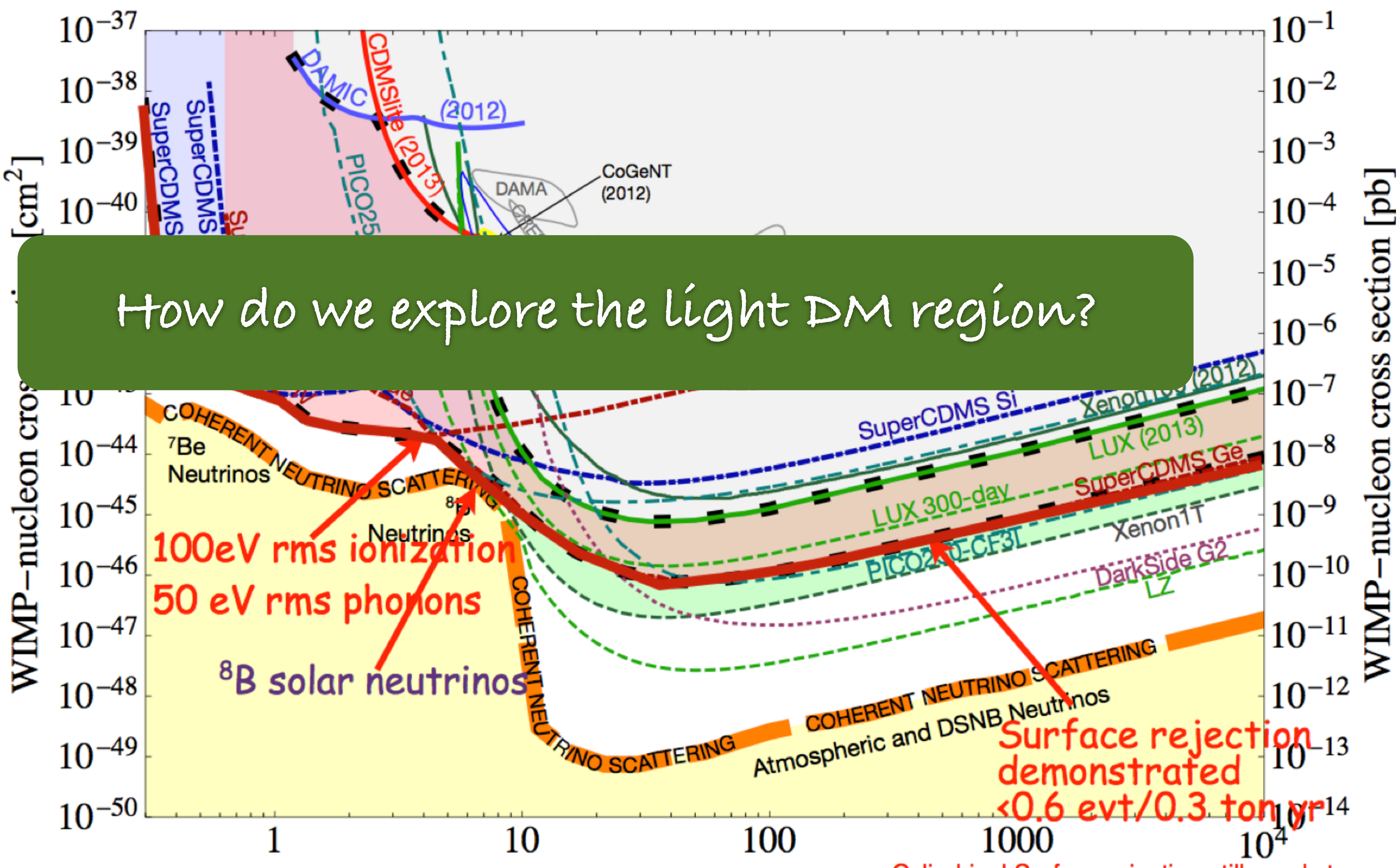


Cylindrical Surface rejection still needs to be satisfactorily demonstrated

Direct detection experiments strongly constraint matter-DM interactions



Direct detection experiments strongly constraint matter-DM interactions

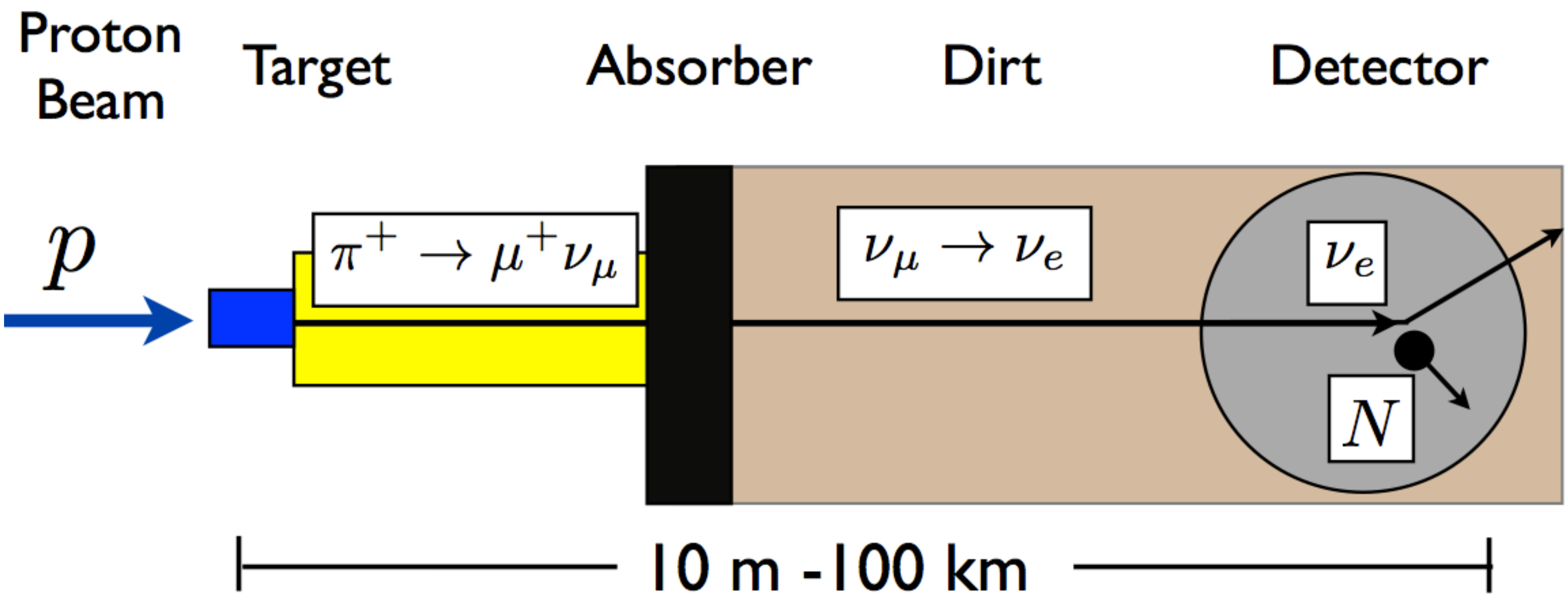


Cylindrical Surface rejection still needs to be satisfactorily demonstrated

Proton fixed target experiments!

Batell,Pospelov,Ritz 2009

Proton fixed target & neutrino near detectors



The idea:

a relativistic DM beam together with a neutrino beam!

Batell, Pospelov and Ritz 2009

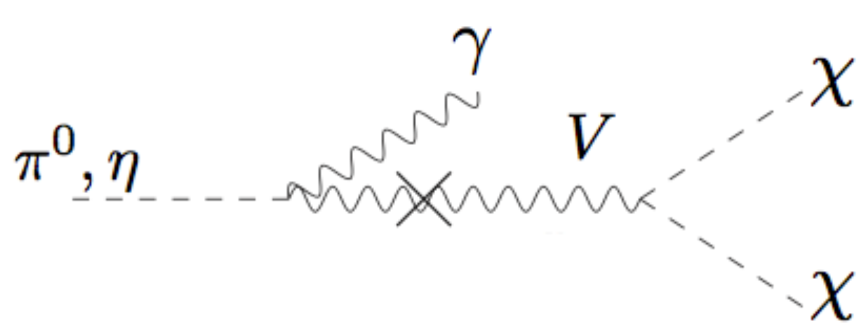
The model: a leptophobic Z′

$$\frac{g_z}{2} Z'^{\mu} \frac{1}{3} \sum_q \bar{q}\gamma_\mu q \qquad\qquad \frac{g_z}{2} Z'^{\mu} z_\chi \bar{\chi}\chi$$

it could the DM particle or a particle of a more complex dark sector

We produce a dark matter beam!

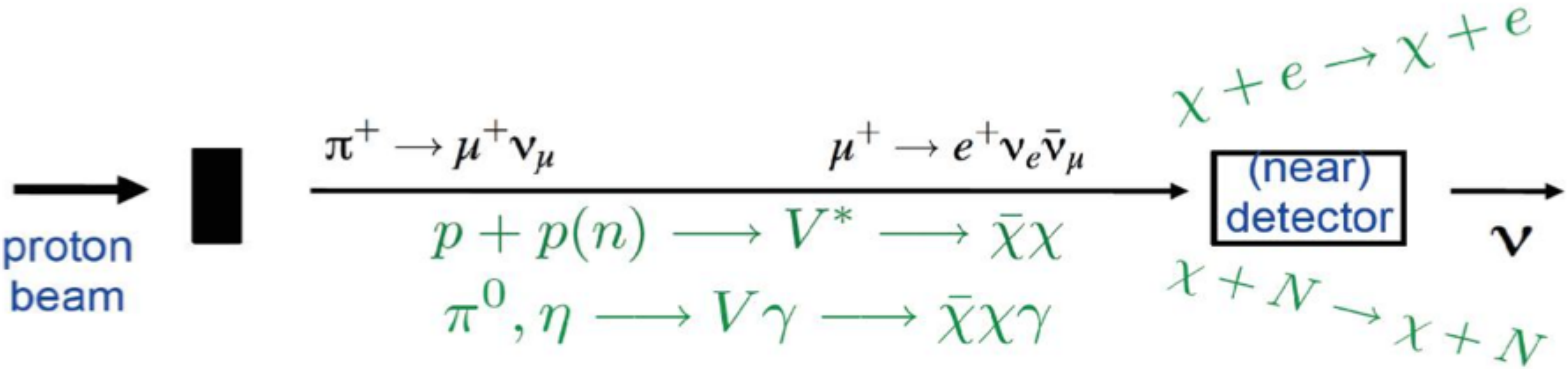
- indirect production, i.e. mesons decays

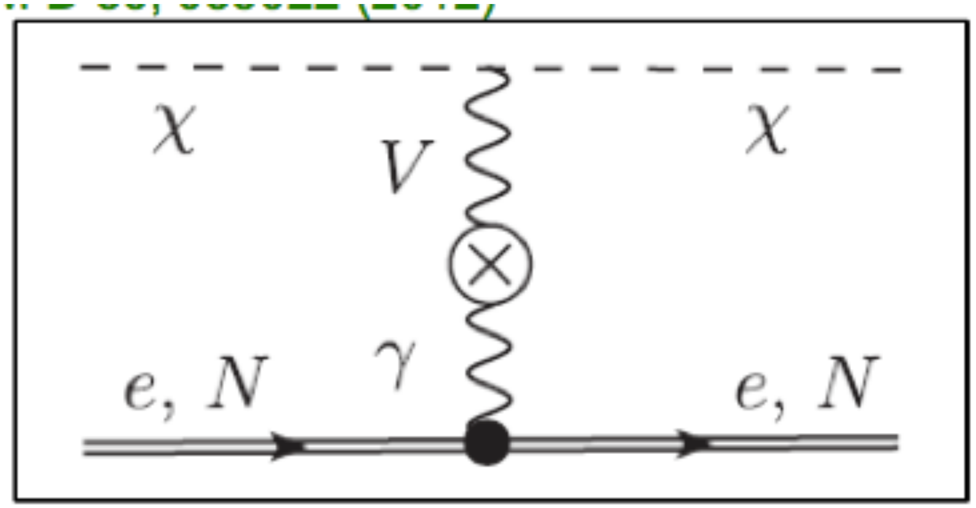


- direct production, i.e Drell-Yan production

$$pp \to Z' \to \chi\chi$$

Basic idea: we produce a DM beam





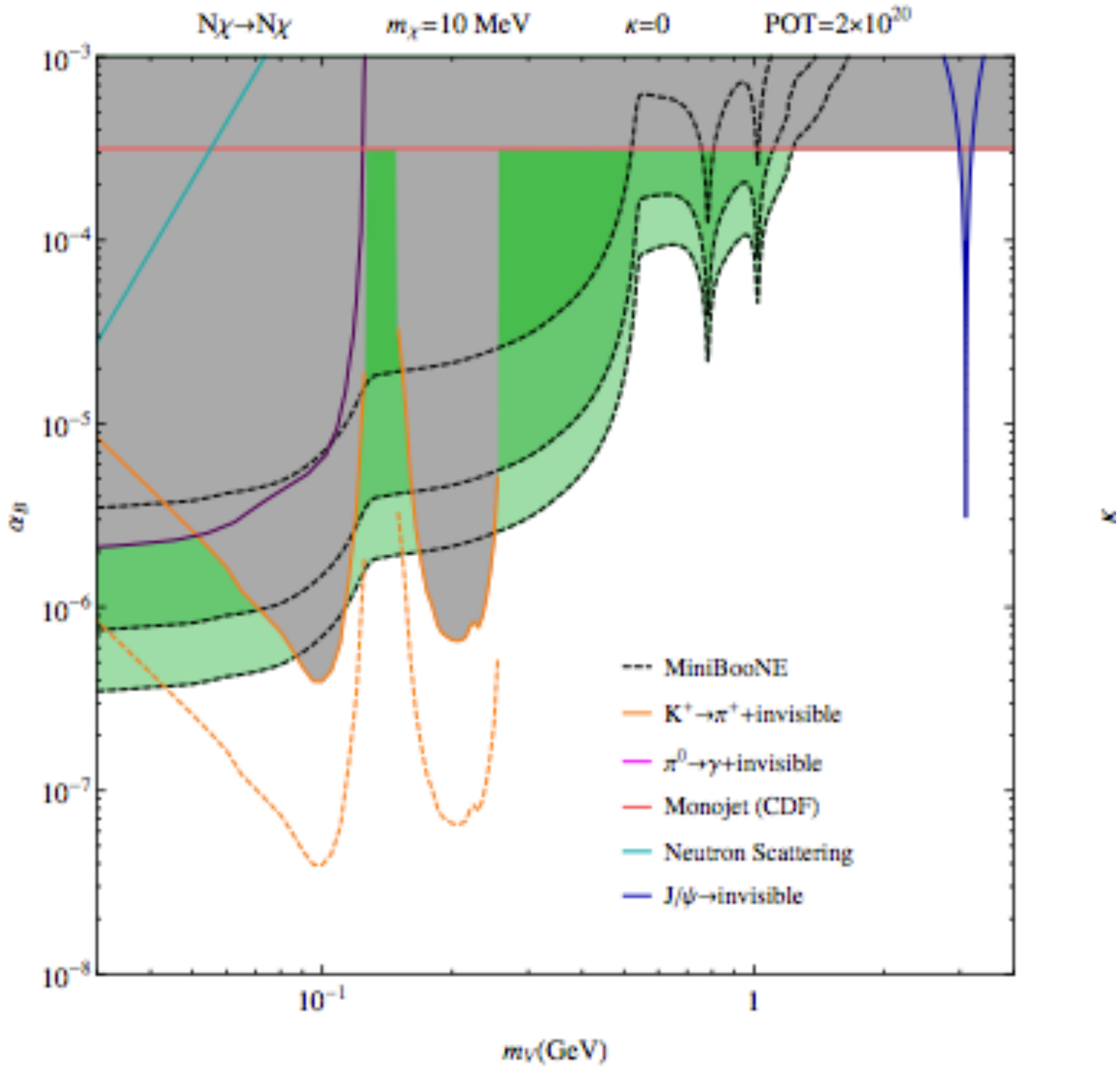
and we look for DM-nuclei scattering inside the near detector

Weak point: neutrino background irreducible bkg

Very large number of events required

DM search at Miniboone

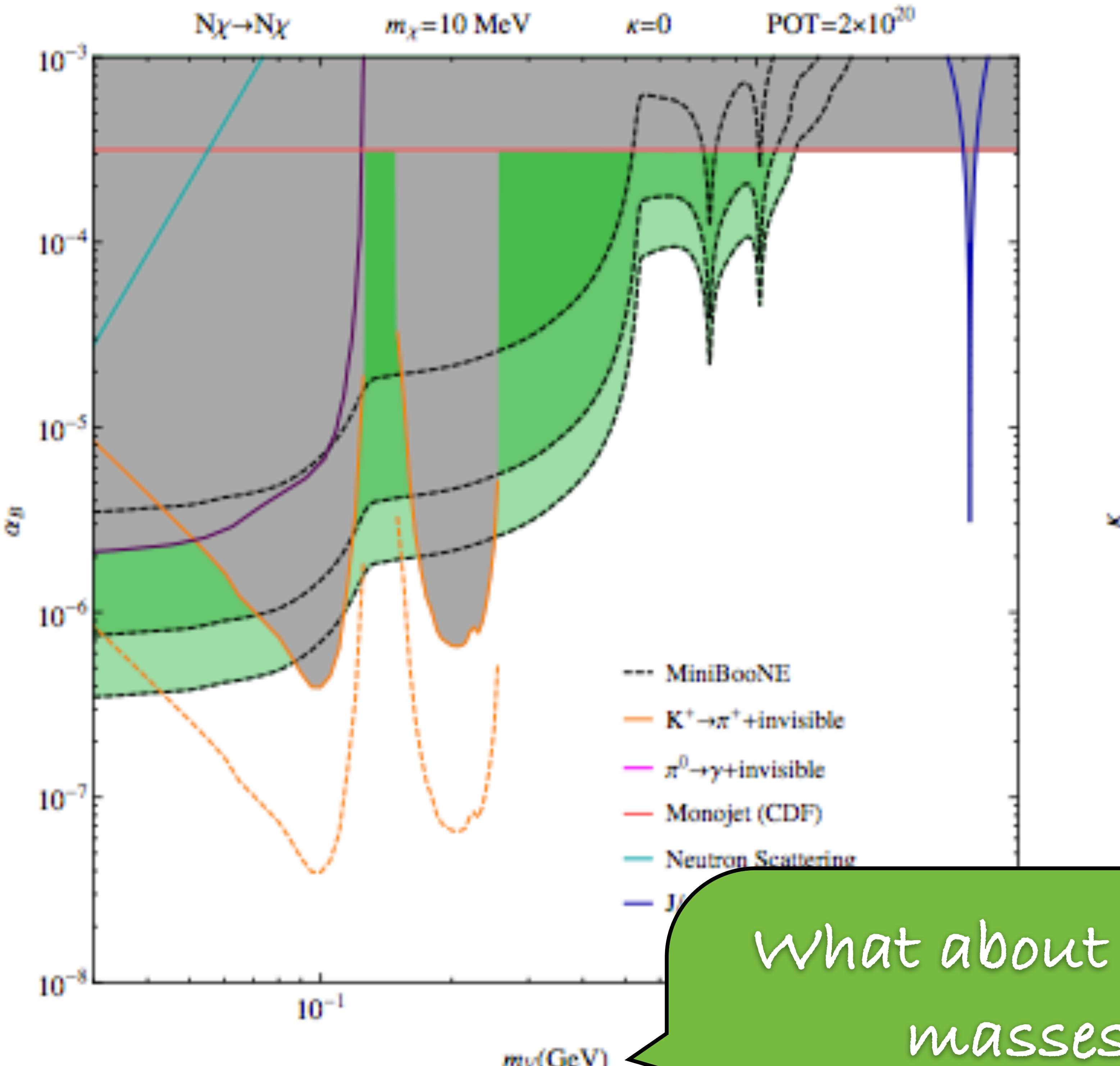
Batell et al, 2013



Neutrino Bkg reduced by proton beam dump mode + time flight decay

DM search at Miniboone

Batell et al, 2013



What about larger masses?

Dark matter beam at the Fermilab main injector

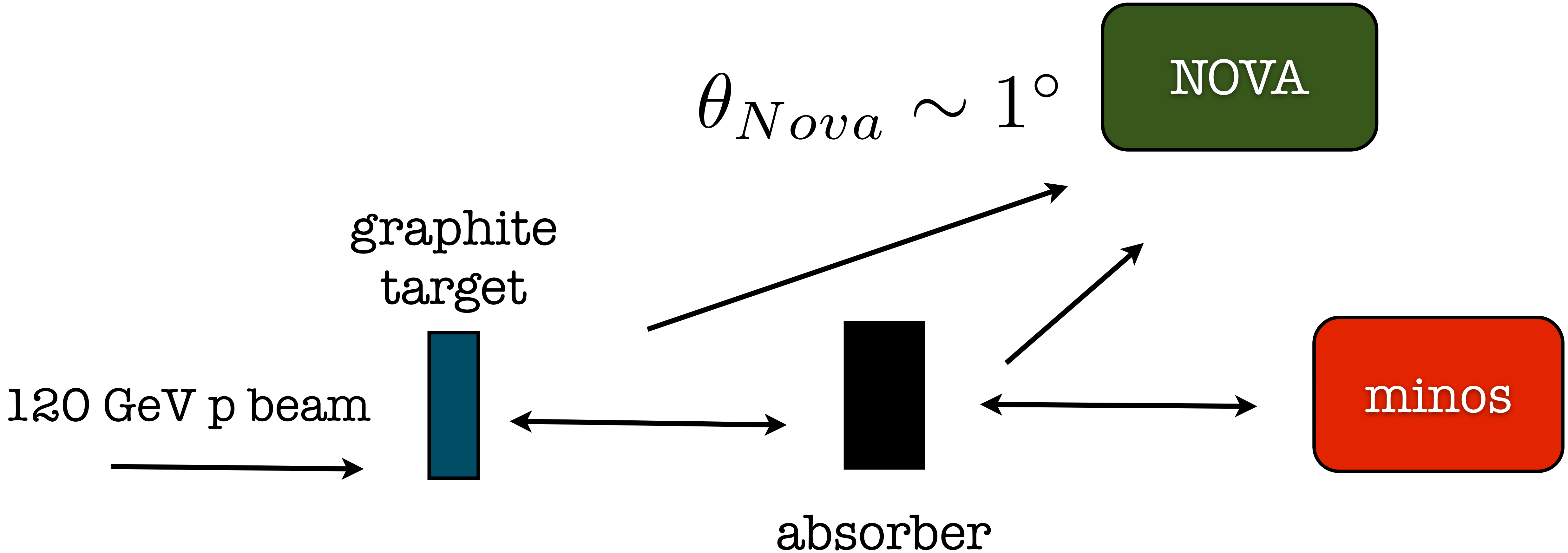
- 120 GeV protons from Main Injector at Fermilab hitting a carbon target

it can extend the reach of MiniBoone towards heavier DM and Z'!

- Drell Yan production $pp \to Z' \to \chi\chi$

Several near detectors to consider

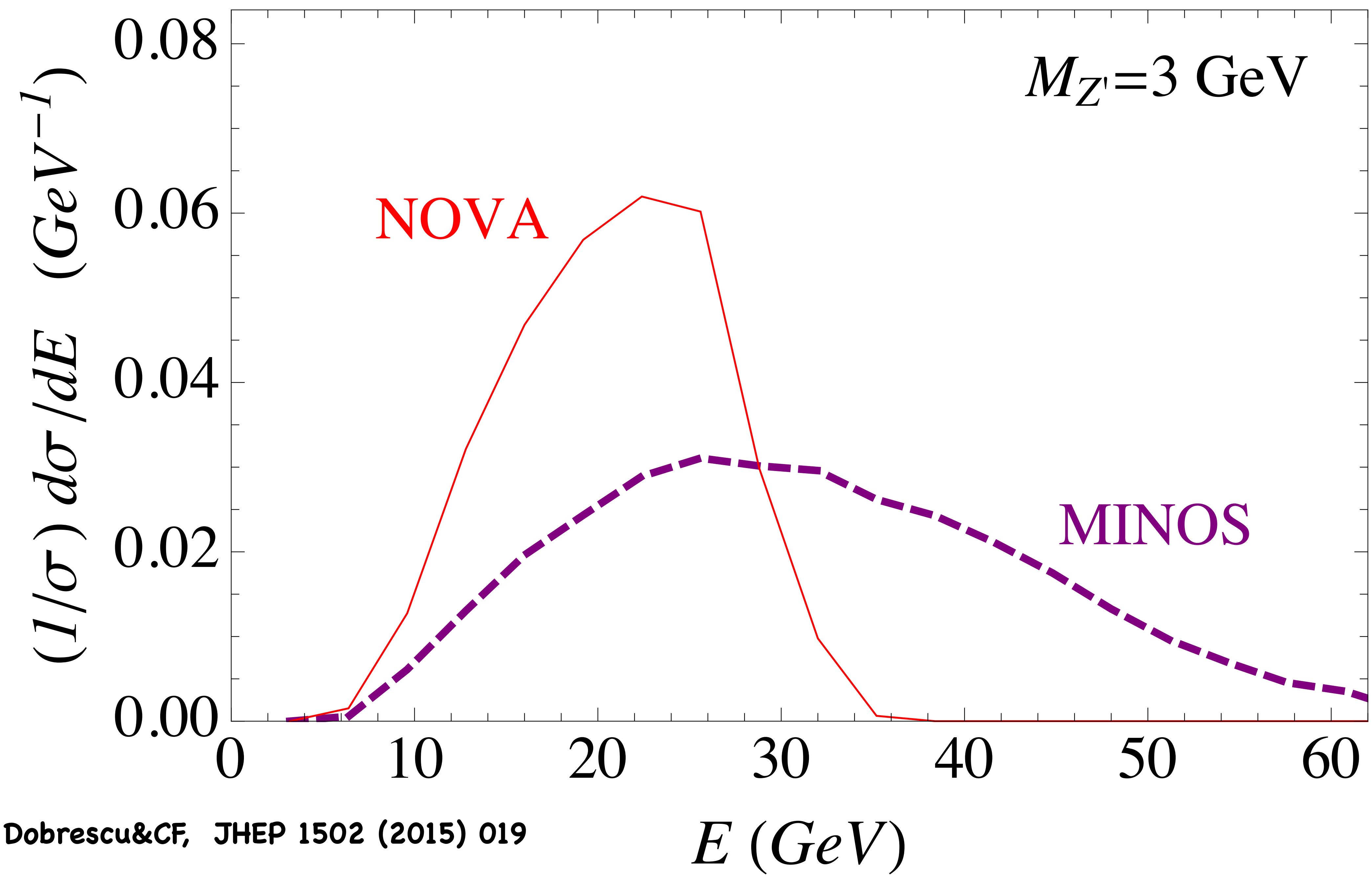
NuMi facility



$$pp \to Z' \to \chi\chi$$

DM particle enter the near detector and scatter with nuclei

DM energy profile inside the detector

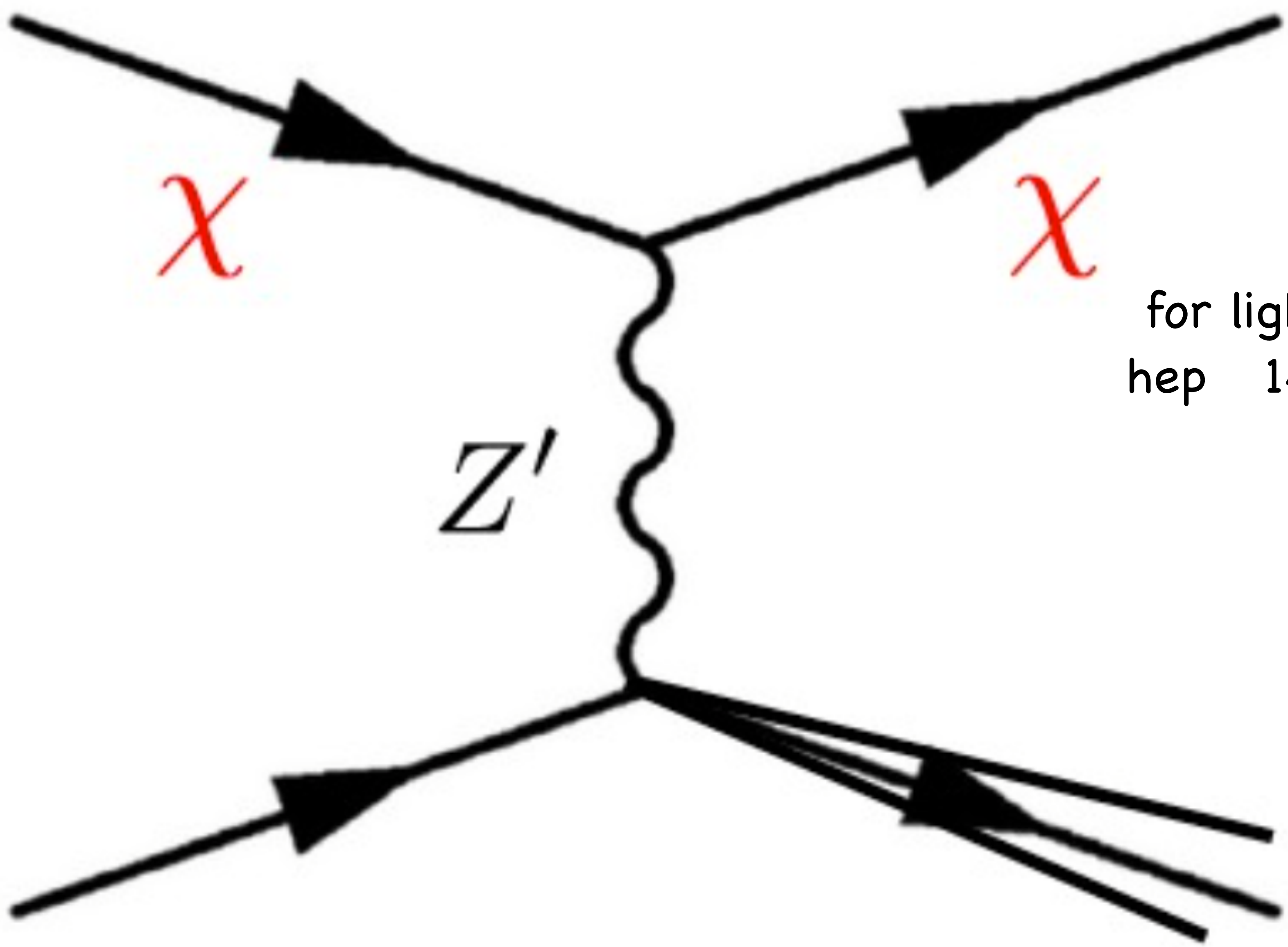


Dobrescu&CF, JHEP 1502 (2015) 019

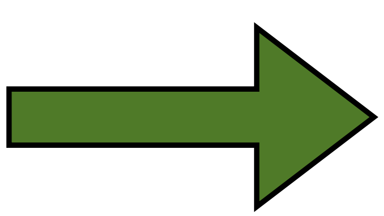
→ DM particles are fairly energetic

DM energy profile inside the detector

DM energetic - deeply inelastic events

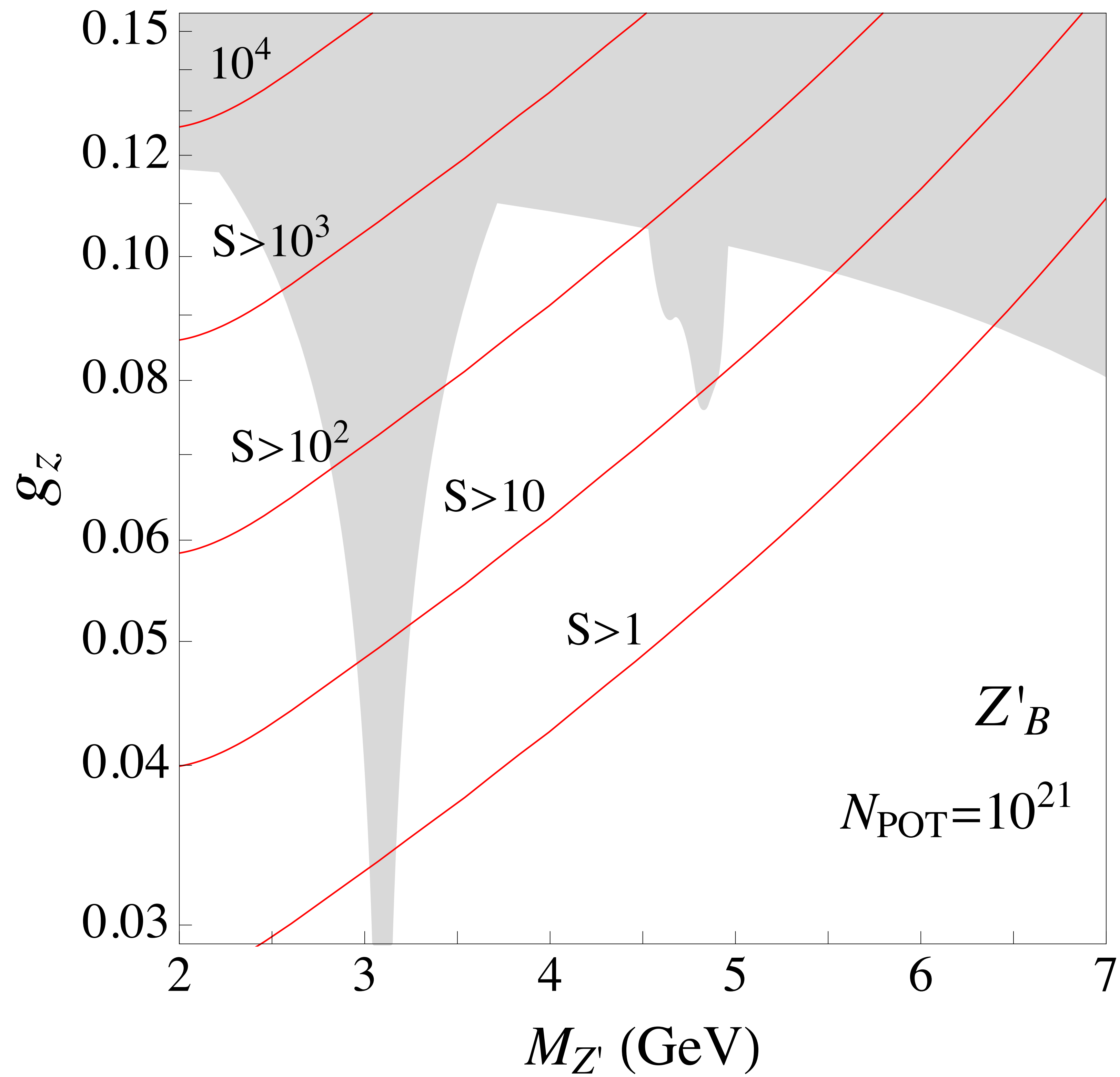


for lighter DM
hep 1407.2623



DM particles are fairly energetic

Number of DM DIS scattering events in NOVA



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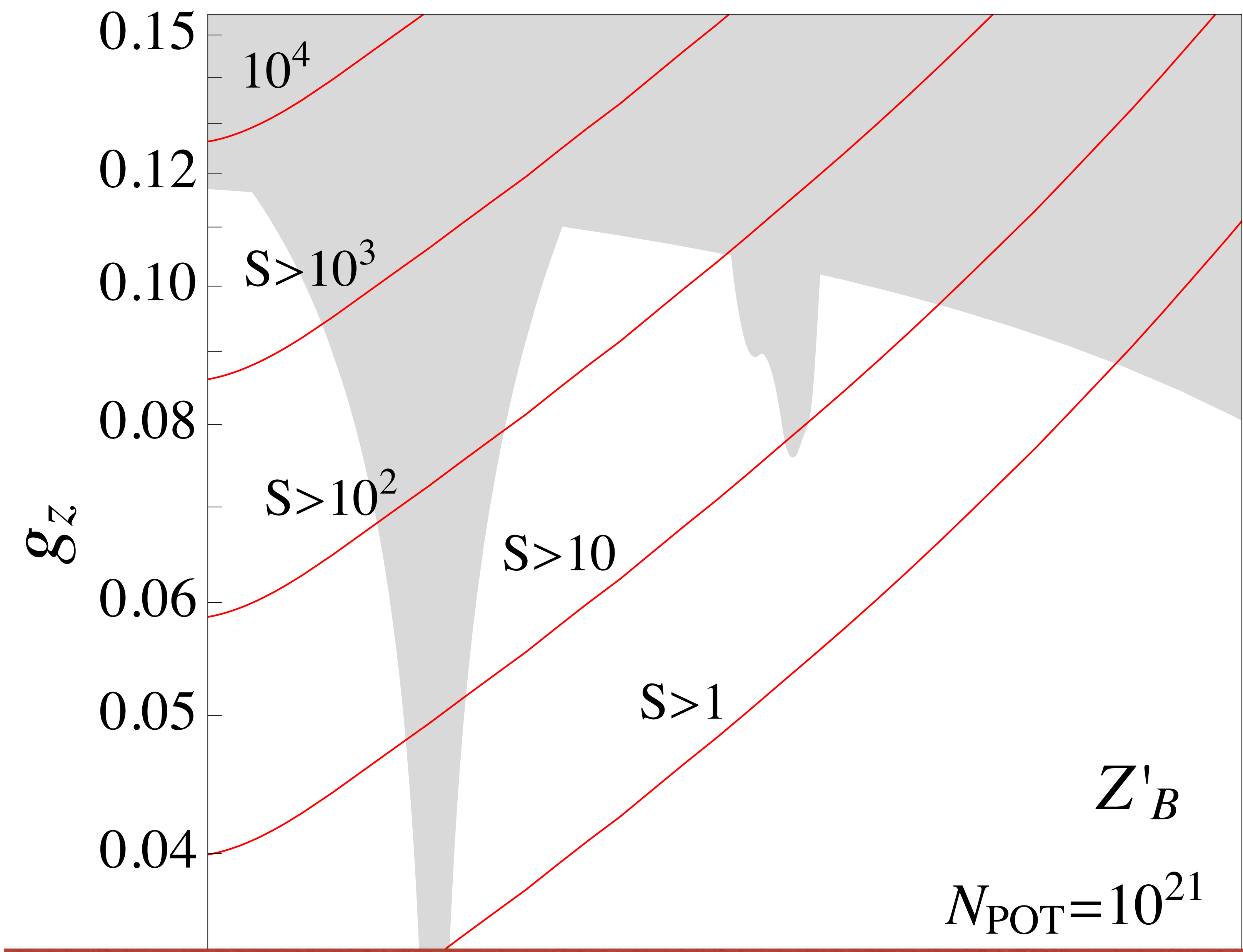
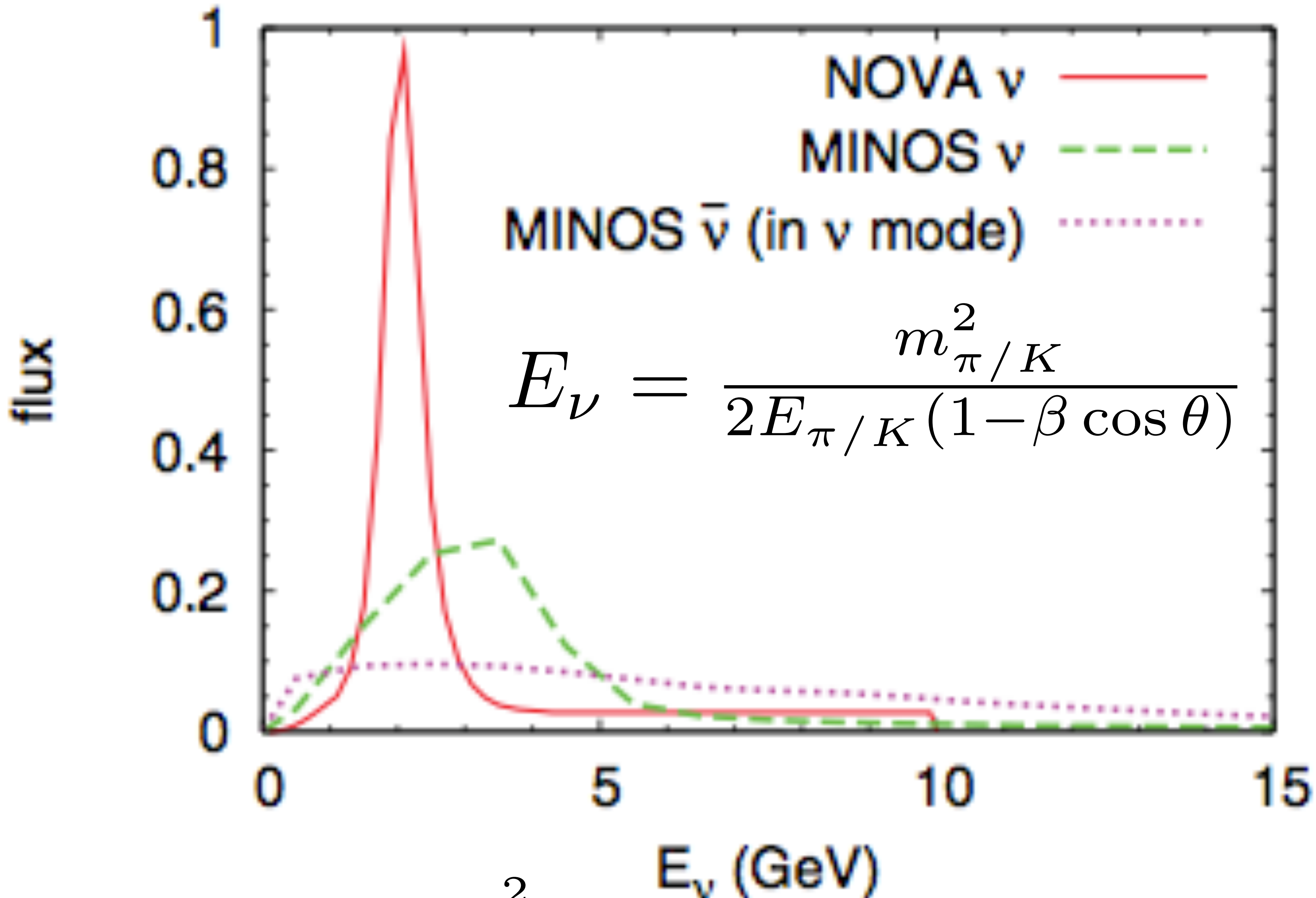


what about neutrinos?

Neutrinos energy profile



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

Dark matter more energetic

Neutrino energy profile peaked at a few GeV

Naive idea: in order to reduce neutrino bkg we focus on the more energetic events

Deep inelastic scattering

Cut on hadronic energy $E_j > 2\ \mathrm{GeV}$

Neutrino energy profile peaked at a few GeV

Naive idea: in order to reduce neutrino bkg we focus on the more energetic events

Deep inelastic scattering

Cut on hadronic energy $E_j > 2 \text{ GeV}$

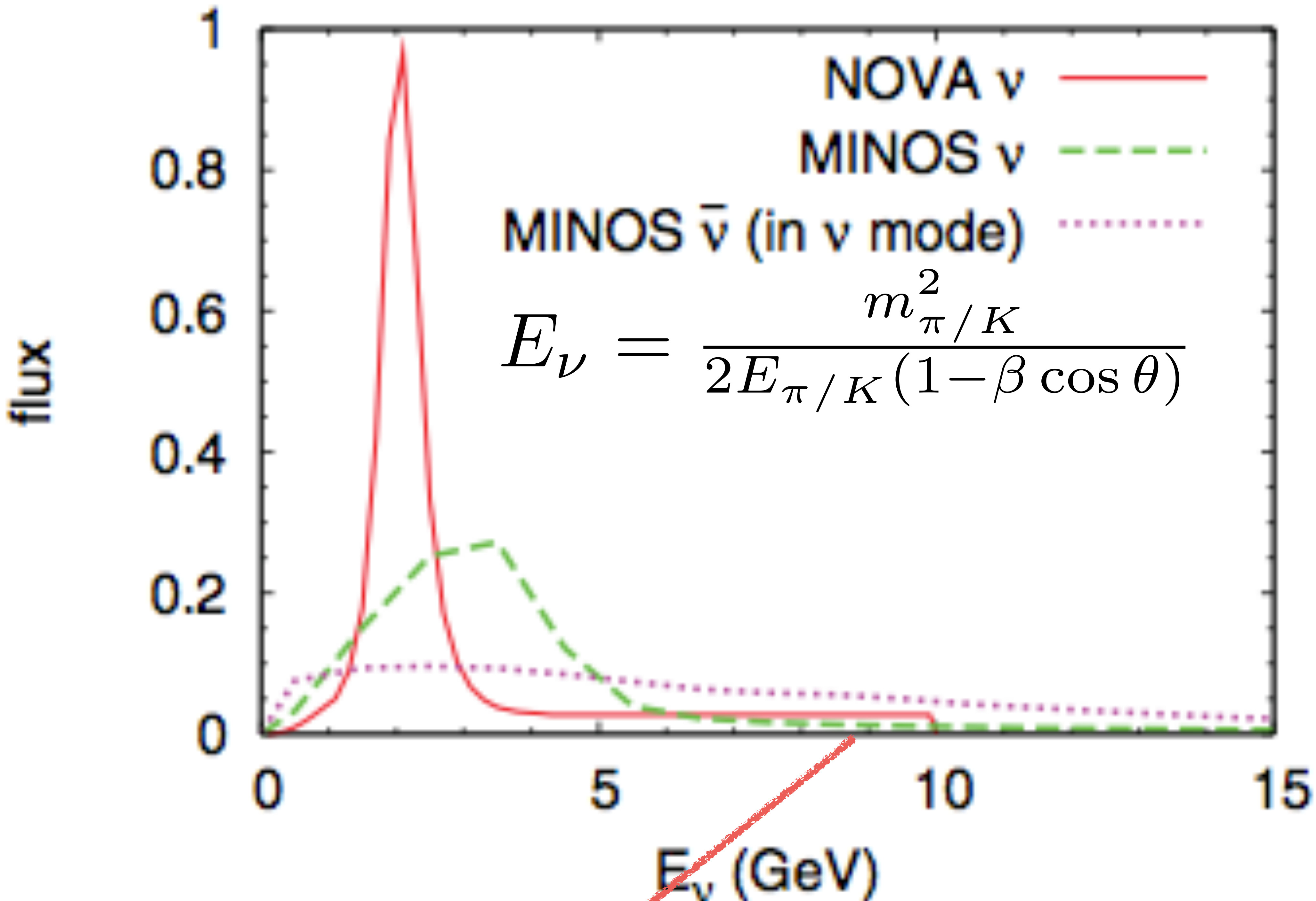
still a big neutrino tail!
10^6 bkg NC DIS events-
not enough to have sensitivity!

Neutrino energy profile peaked at a few GeV

Naive idea: in order to reduce neutrino bkg we focus on the more energetic events

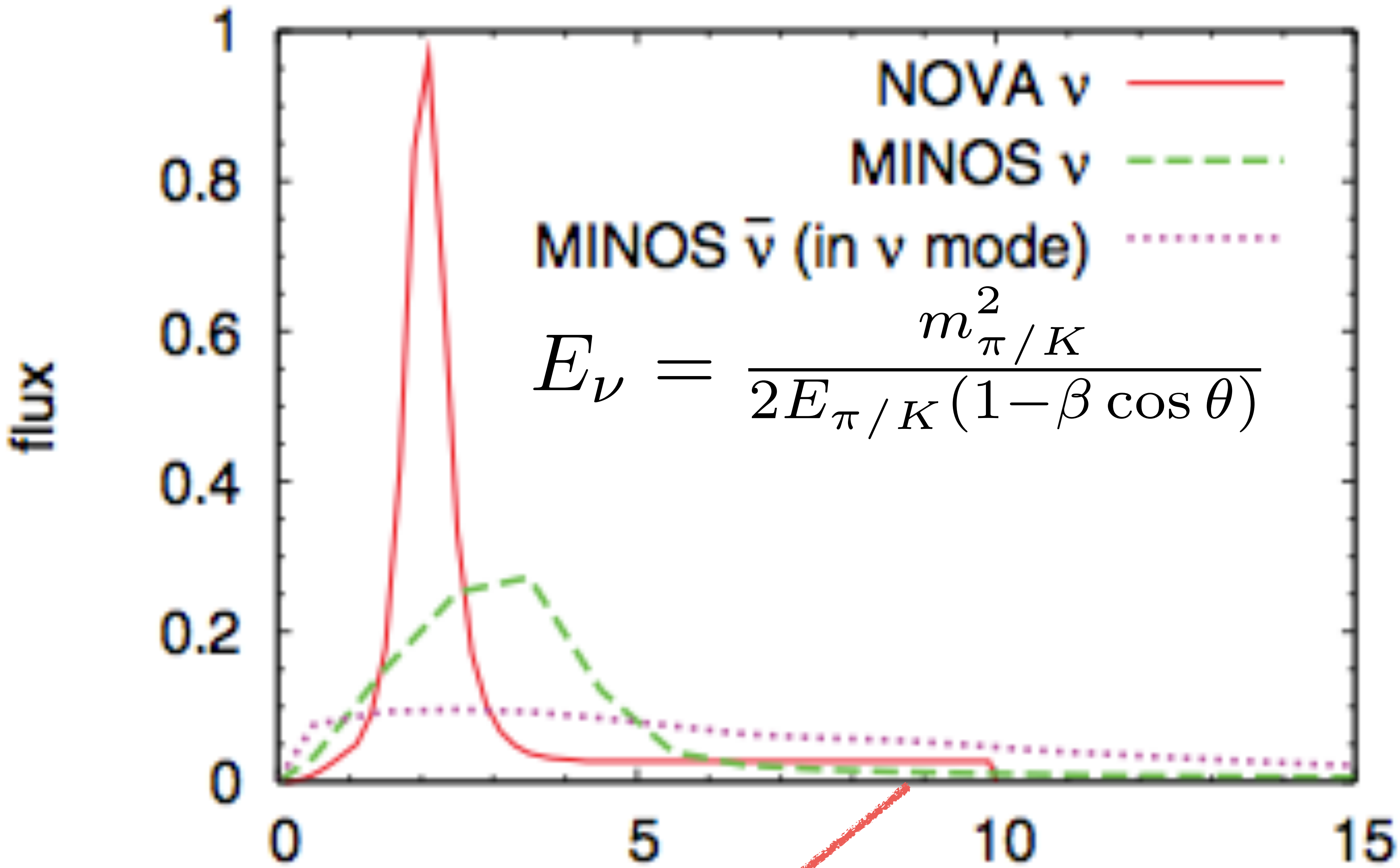
Can we kill neutrino bkg more efficiently or
shall we forget about these experiments?

Neutrinos energy profile



large tail of neutrinos coming from kaon decays

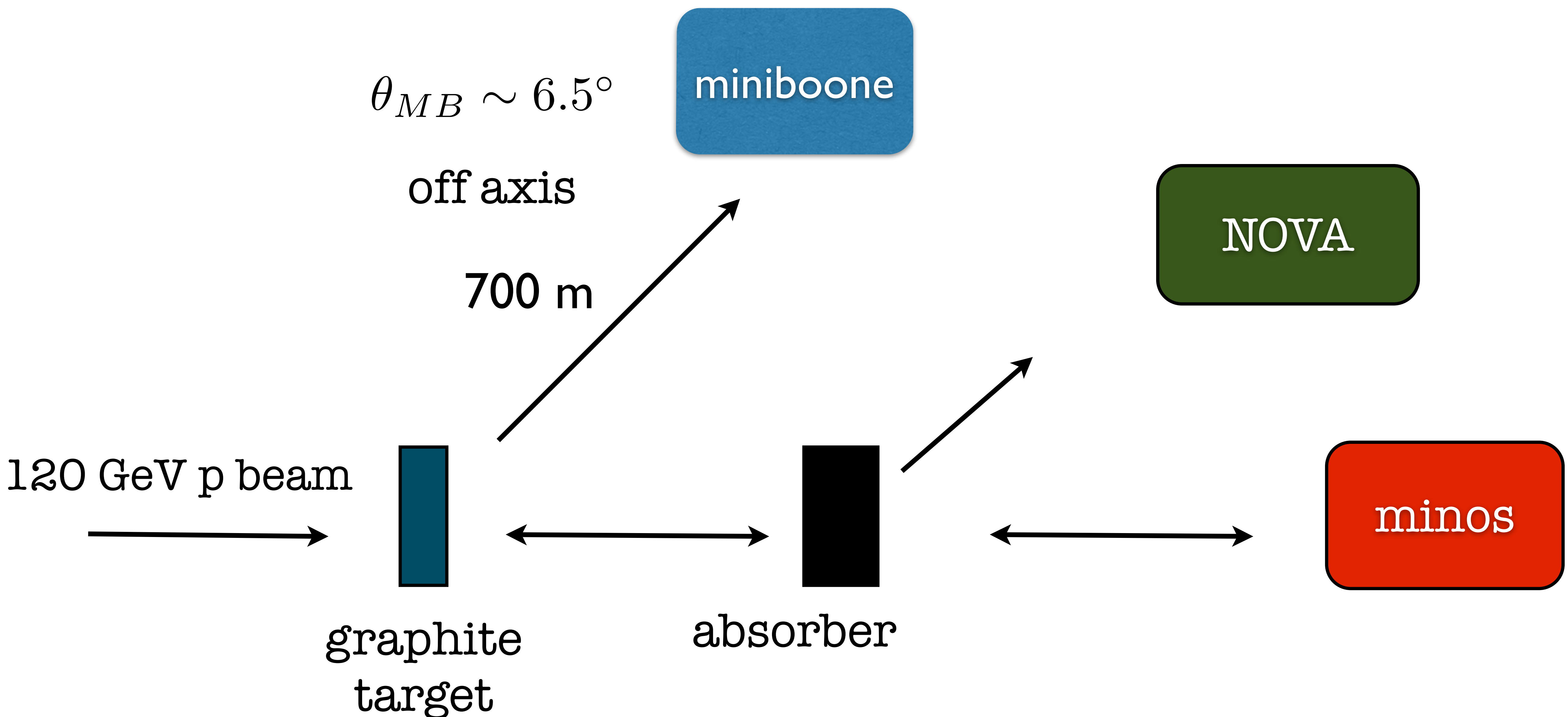
Neutrinos energy profile



off axis detectors to kill bkg!

large tail of neutrinos coming from kaon deca[illegible]s

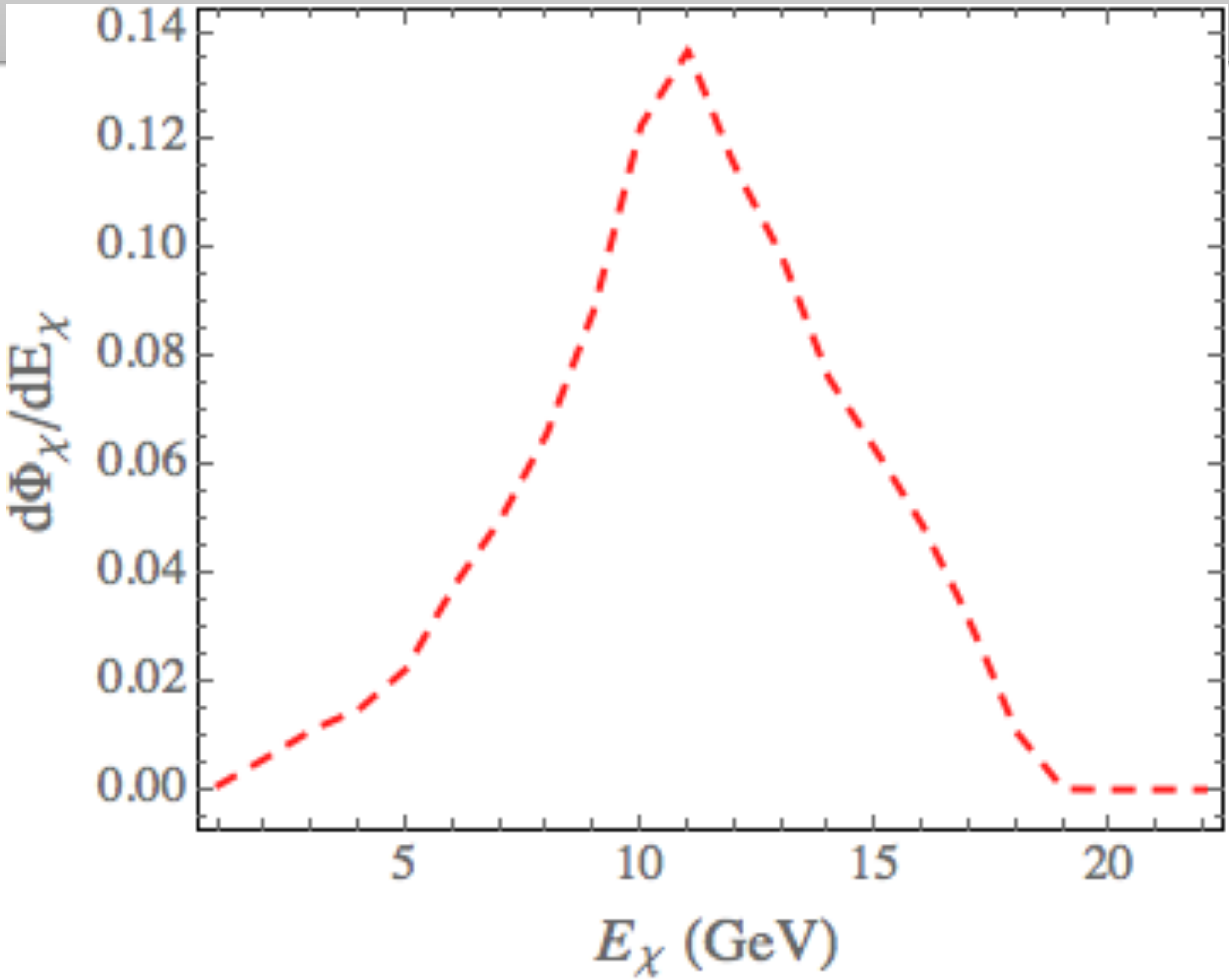
We have already an off axis detector!



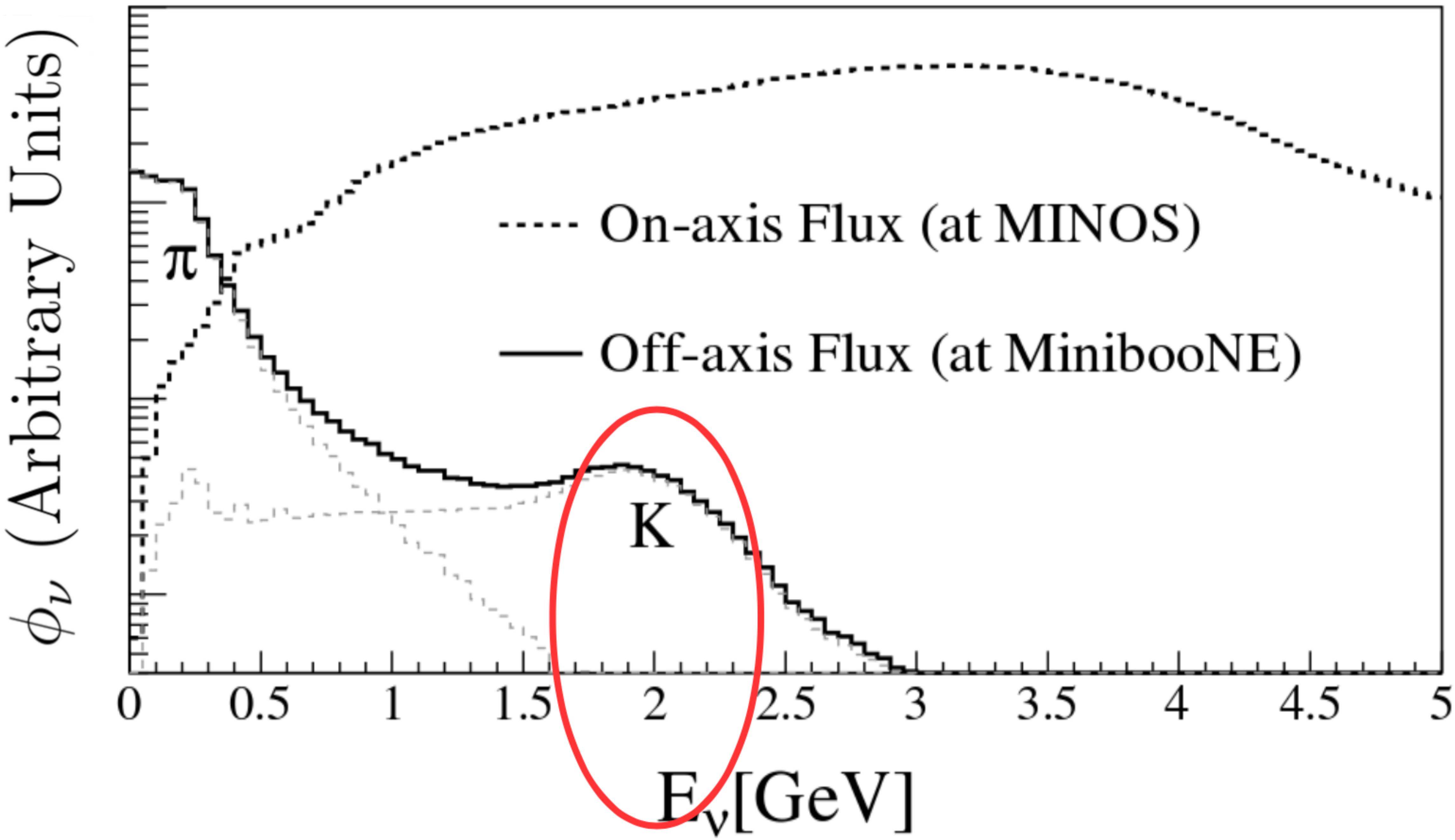
$$pp \to Z' \to \chi\chi$$

DM particle enter the near detector and scatter with nuclei

Dm energy inside Miniboone



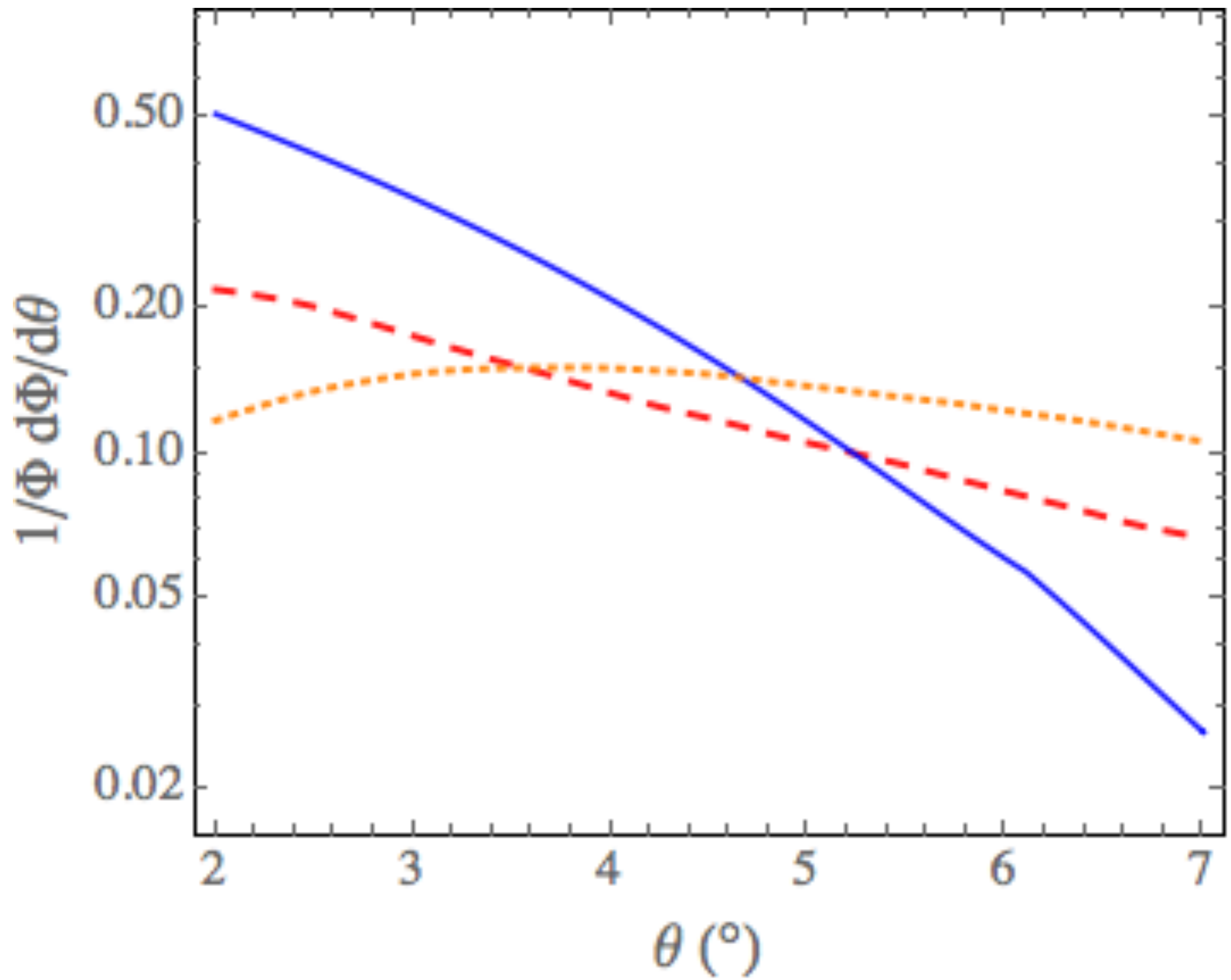
Off axis versus on axis bkg



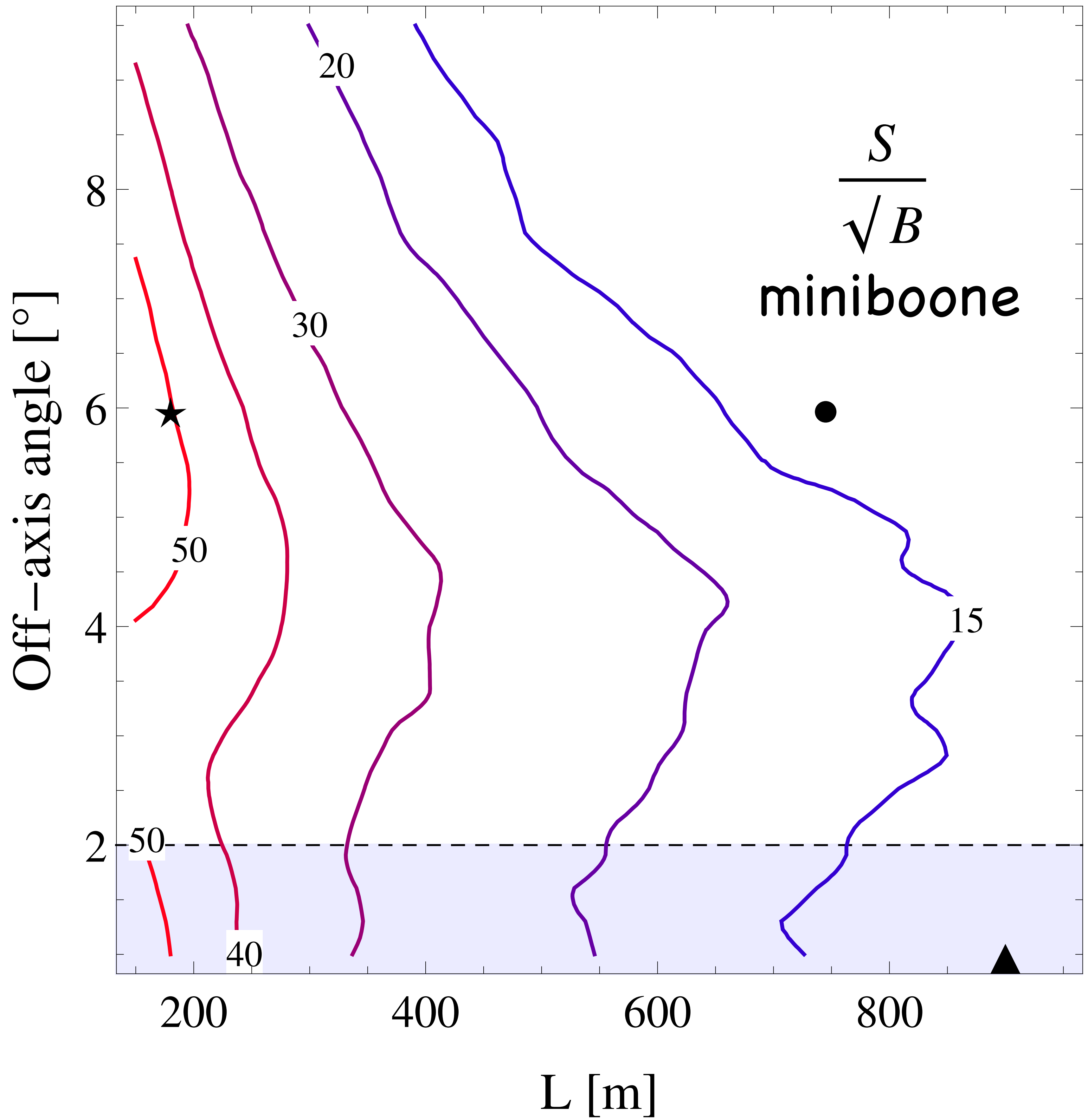
$$E_\nu = \frac{m_{\pi/K}^2}{2E_{\pi/K}(1-\beta\cos\theta)}$$

Neutrino bkg dies faster than signal!

particles with E>2GeV

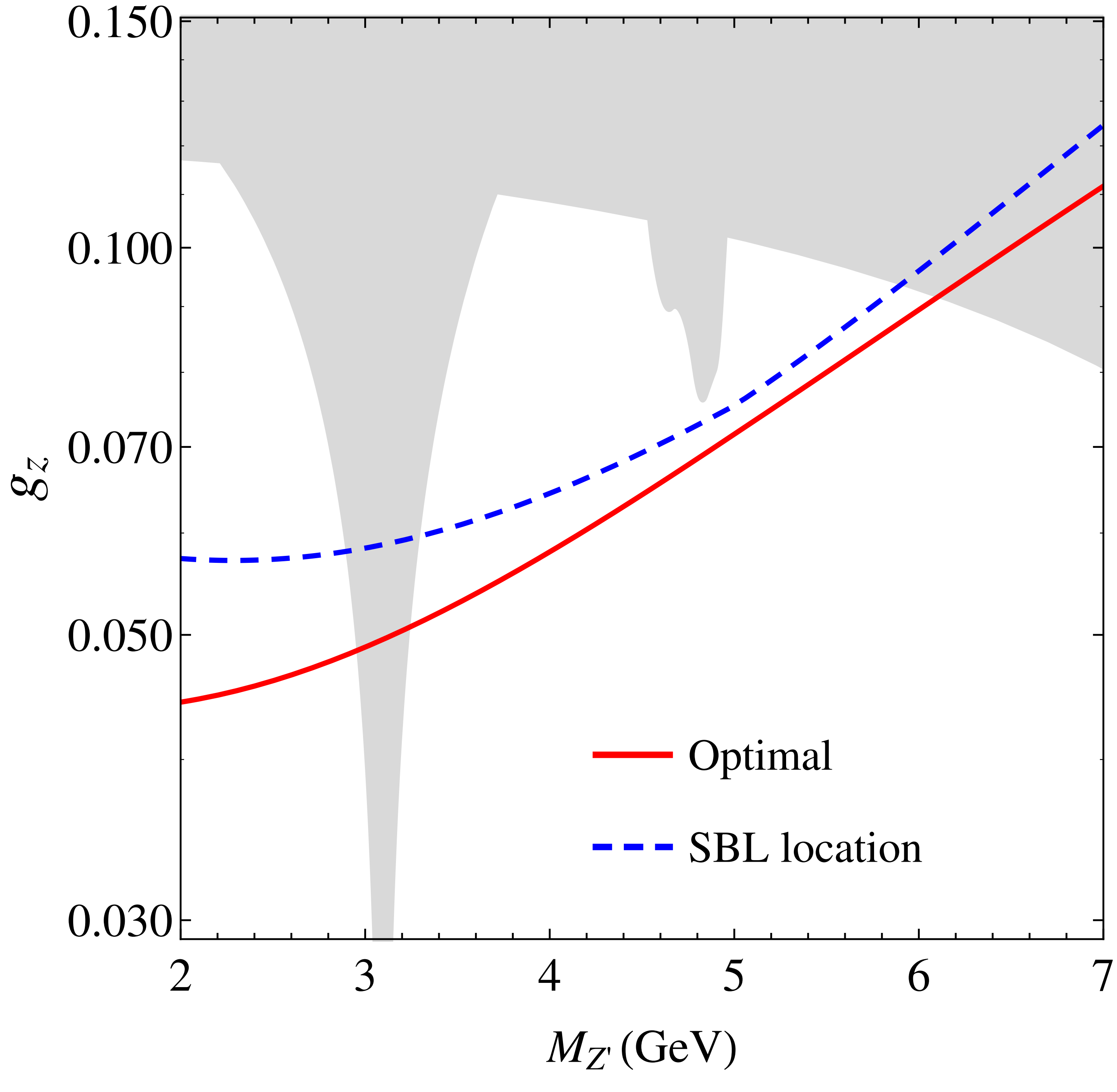


Ideal position for a future LBNF detector

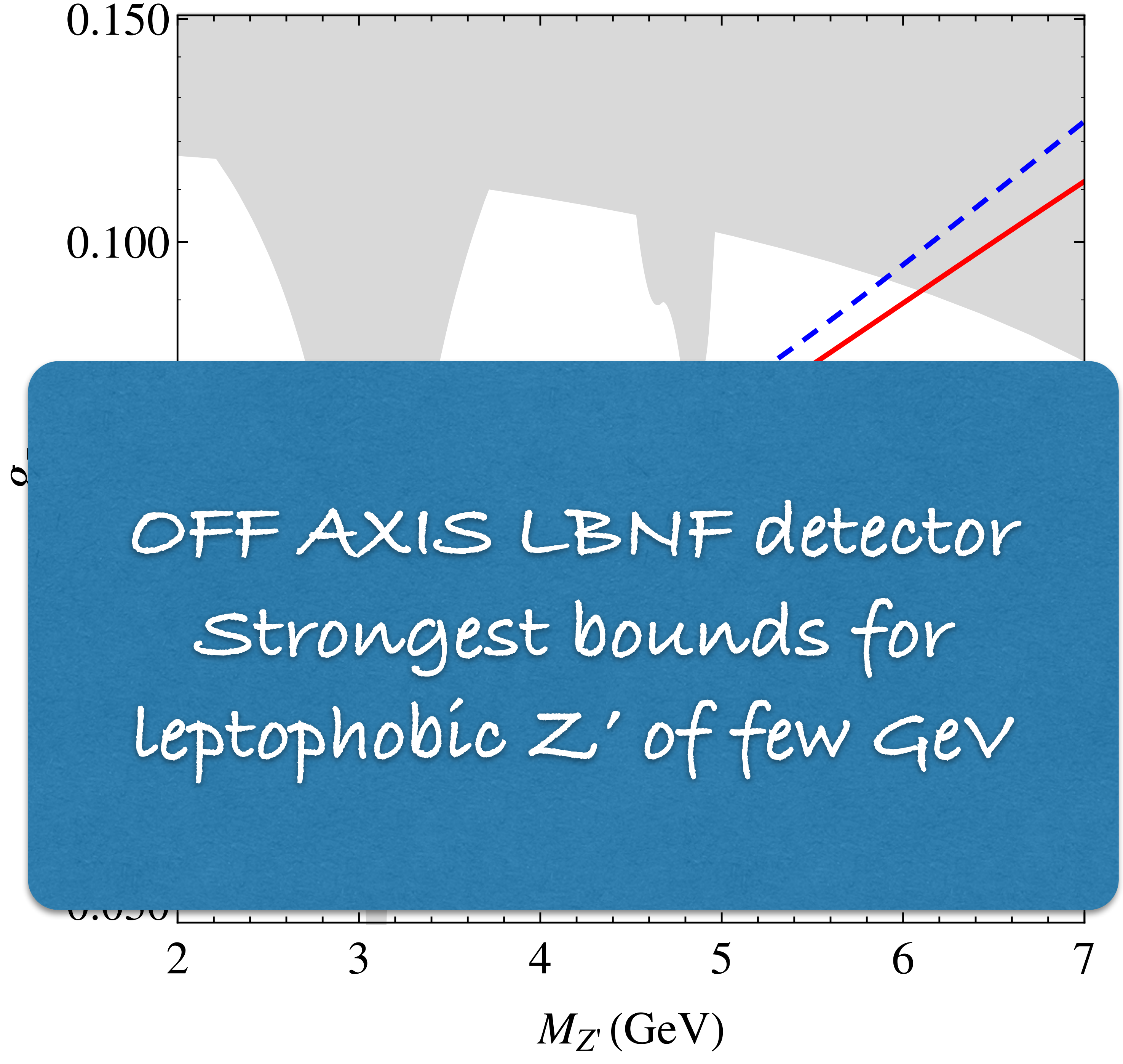


$g_z = 0.1$

$\chi^2 contour$



$\chi^2 contour$



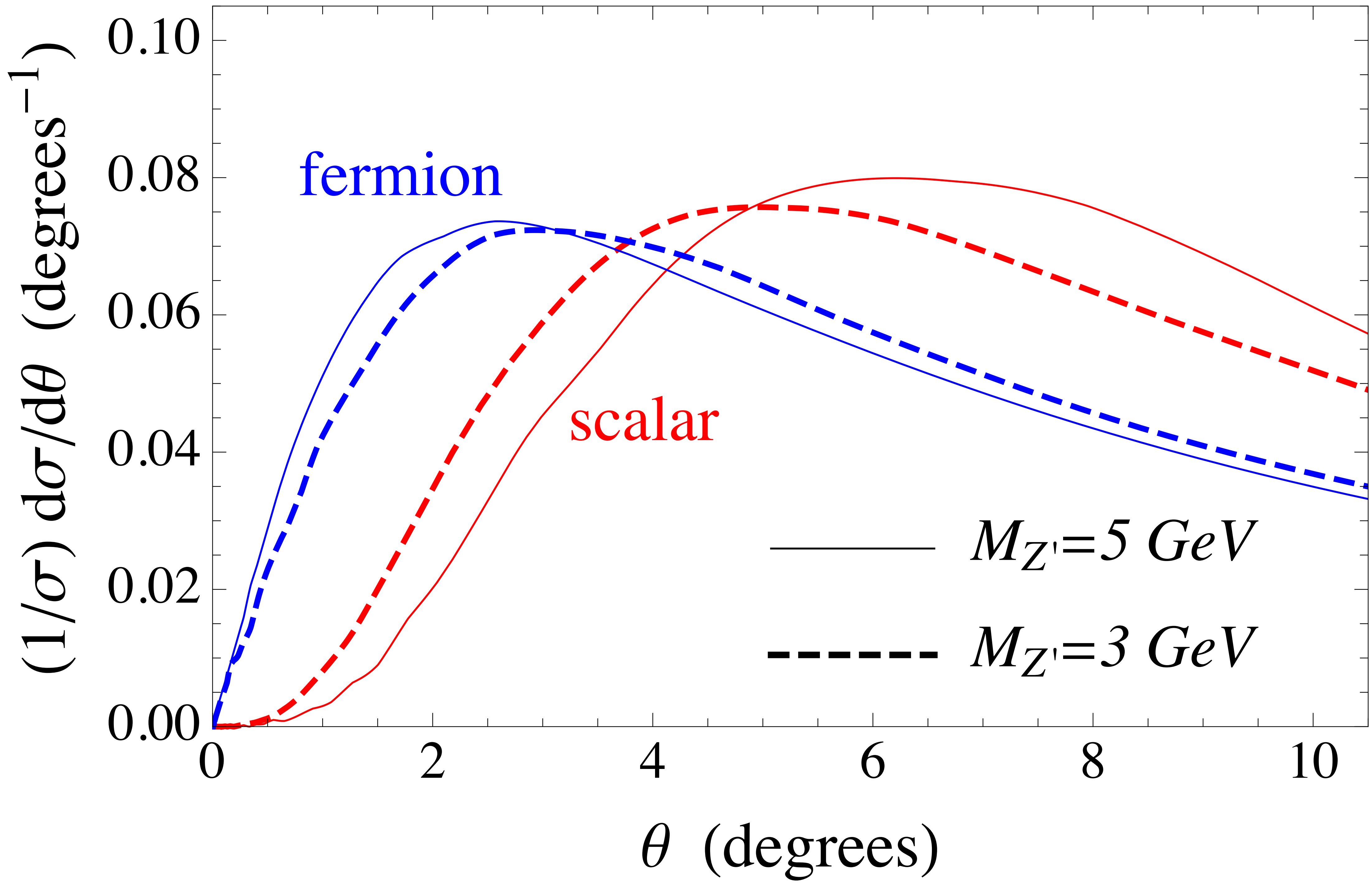
OFF AXIS LBNF detector
Strongest bounds for
leptophobic Z' of few GeV

Conclusions

- Proton fixed target experiments could offer the possibility to improve existing bounds on light DM/quarks couplings.
- Interesting opportunities for exploring physics BSM at LBNF!

Backup

DM angular distribution



DM beam less colimated than neutrino beam

Detectors acceptance

Detector	DM source	distance	$\theta_{\rm min}$	$\theta_{\rm max}$	$\phi_{\rm max}$	$\epsilon_{\rm det}$(fermion)	$\epsilon_{\rm det}$(scalar)
MINOS	absorber	270 m	0	0.48°	180°	6×10^{-3}	10^{-4}
MINOS	target	950 m	0	0.19°	180°	8×10^{-4}	3×10^{-6}
NOνA	absorber	240 m	2.6°	3.6°	18°	3×10^{-3}	2×10^{-3}
NOνA	target	920 m	0.68°	0.93°	18°	4×10^{-4}	3×10^{-5}

Angular distribution different of scalar and fermions

Having both an on-axis and off axis near detectors can reveal fundamental properties in case of discovery!

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Angular distribution different of scalar and fermions

MINOS acceptance significant only for fermions!