Claudia Frugiuele

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Probing light dark matter nucleon coupling @ neutrino facilities

U.S. Cosmic Visions: New Ideas in Dark Matter

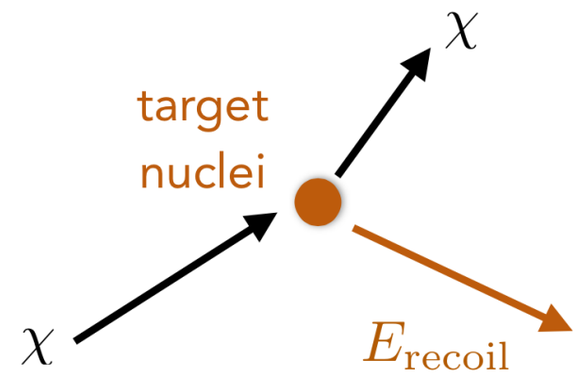
23-25 March 2017 Stamp Student Union, University of Maryland, College Park

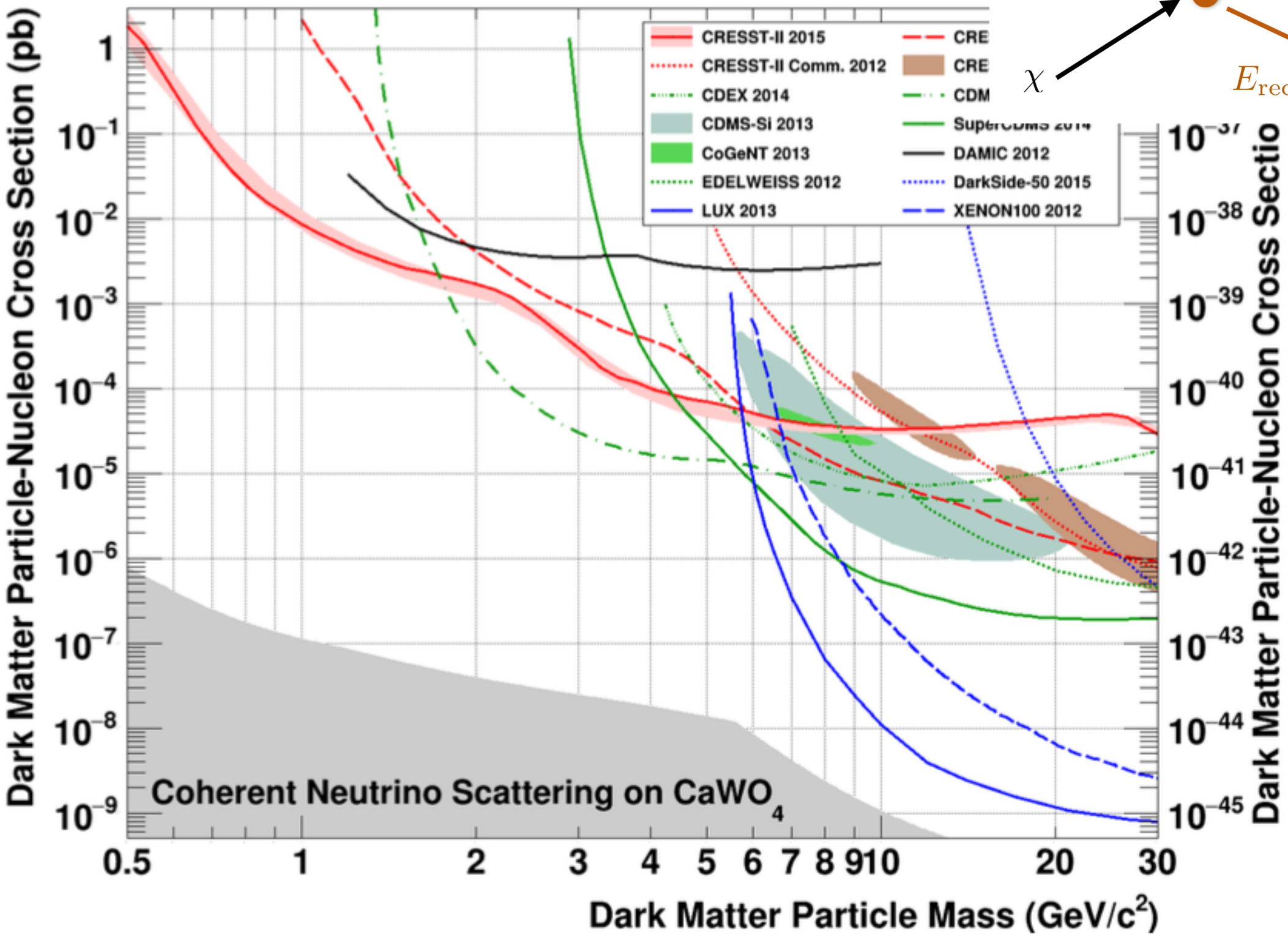
With P.Coloma, B. Dobrescu and R. Harnik JHEP 1604 (2016) 047

CF hep ph 1701.05464 With B. Dobrescu JHEP 1502 (2015) 019

Dark matter direct detection

dark matter scattering off nuclei





Dark matter direct detection

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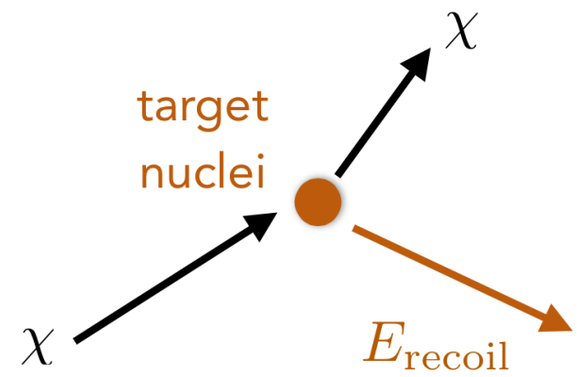
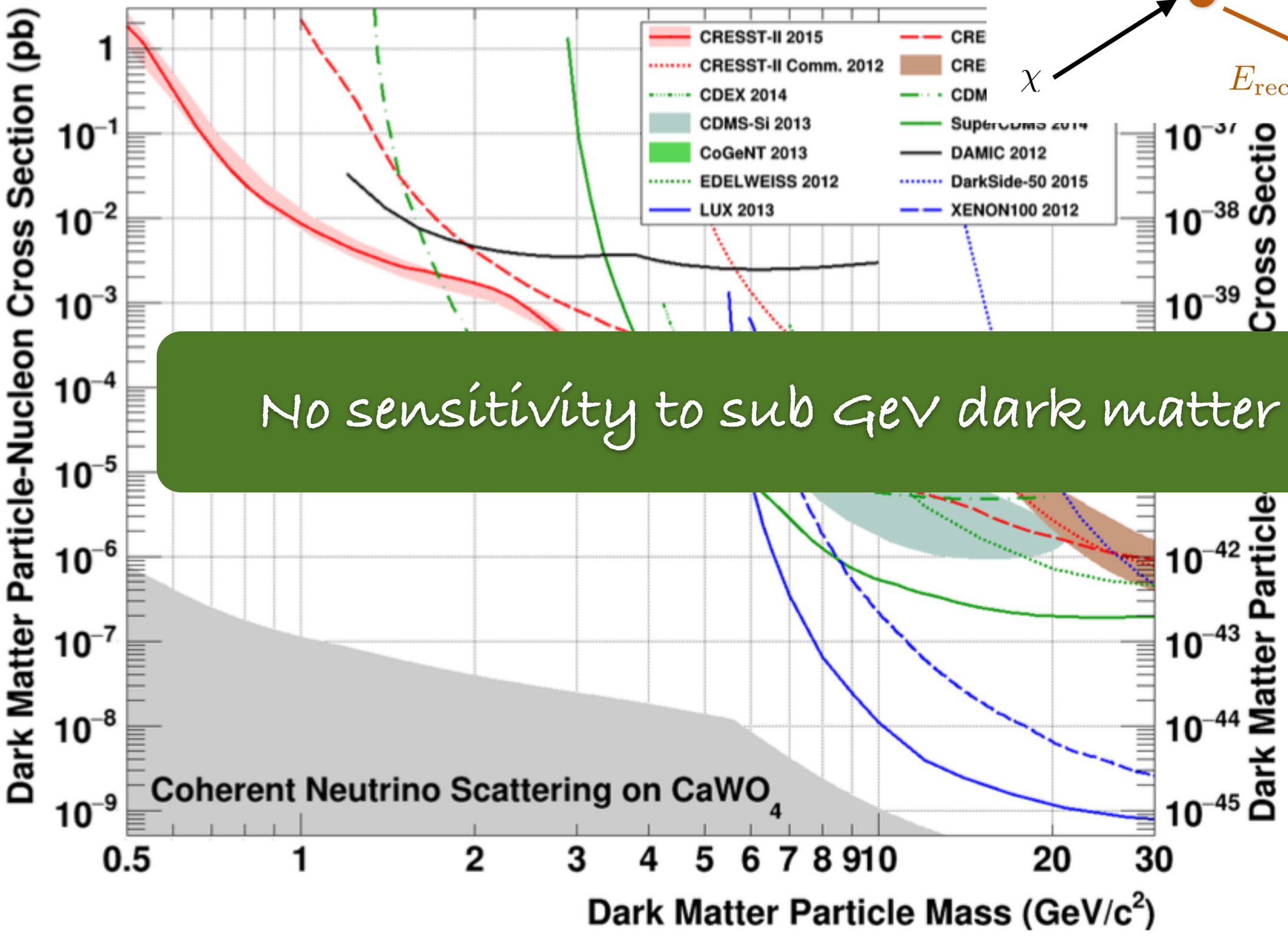




No sensitivity to sub GeV dark matter

What about light (sub-GeV) dark matter?

Recently a lot of effort has been put on filling this loophole by the theory community

★ Direct detection:
electron-DM interaction more promising direction

Essig, Mardon, Volansky 2011 Essig et al 2015 Zurek et al. 2015

★ Can we probe nucleon dark matter coupling?

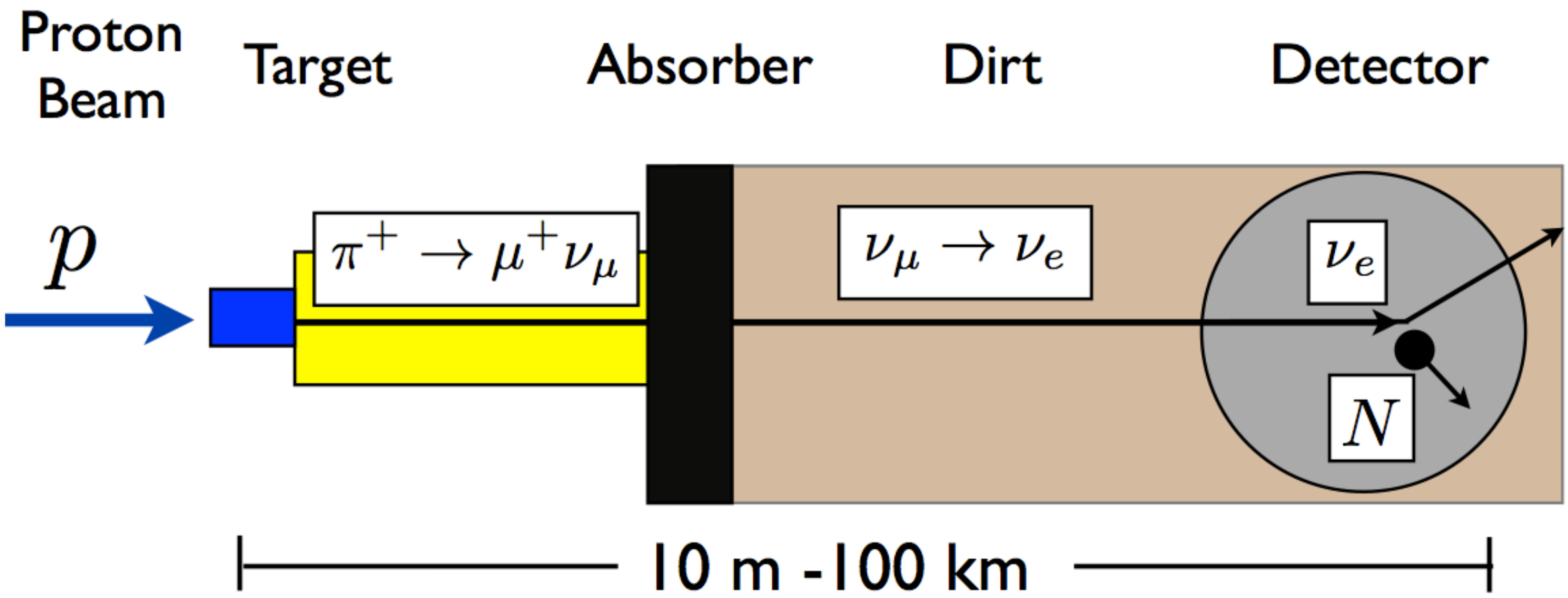
Yes at neutrino facilities

we can produce relativistic DM beams

Batell, Pospelov and Ritz 2009

Looking for light dark matter @ neutrino short baseline experiments

Batell, Pospelov and Ritz 2009

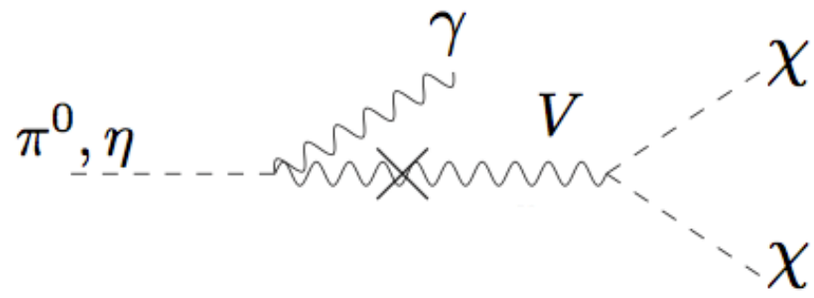


Quarks/DM vector portal

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

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

- Production via meson decay

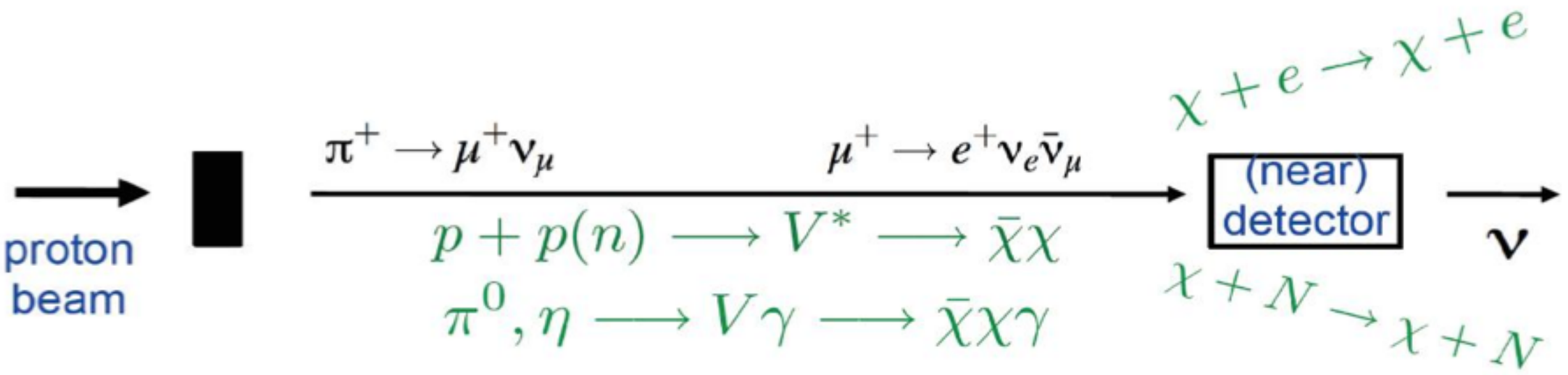


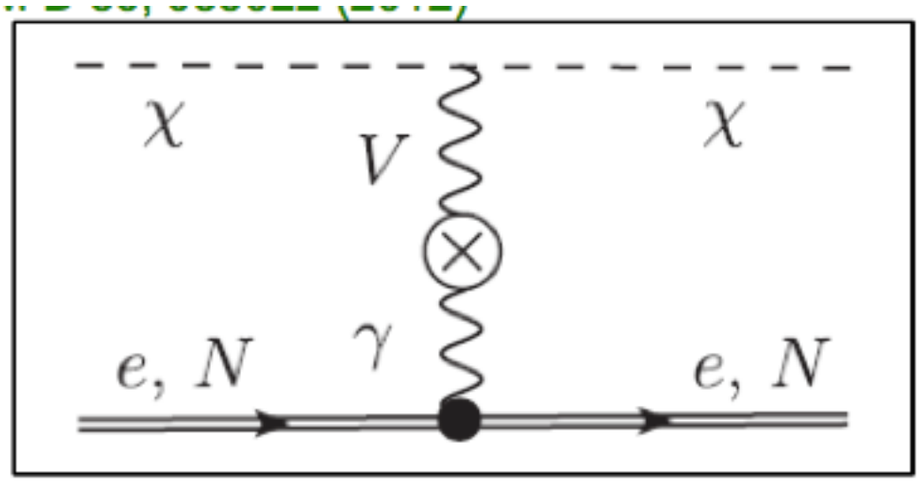
- Direct production

$$pp \to Z' \to \chi\chi \qquad pp \to Z' j \to \chi\chi j$$

We produce a dark matter beam!

Basic idea: we produce a DM beam



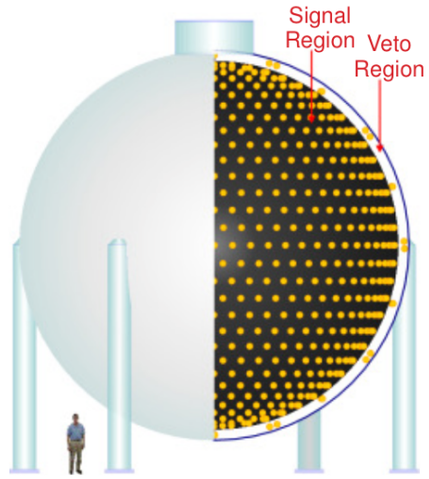


and we look for DM-nuclei scattering inside the near detector

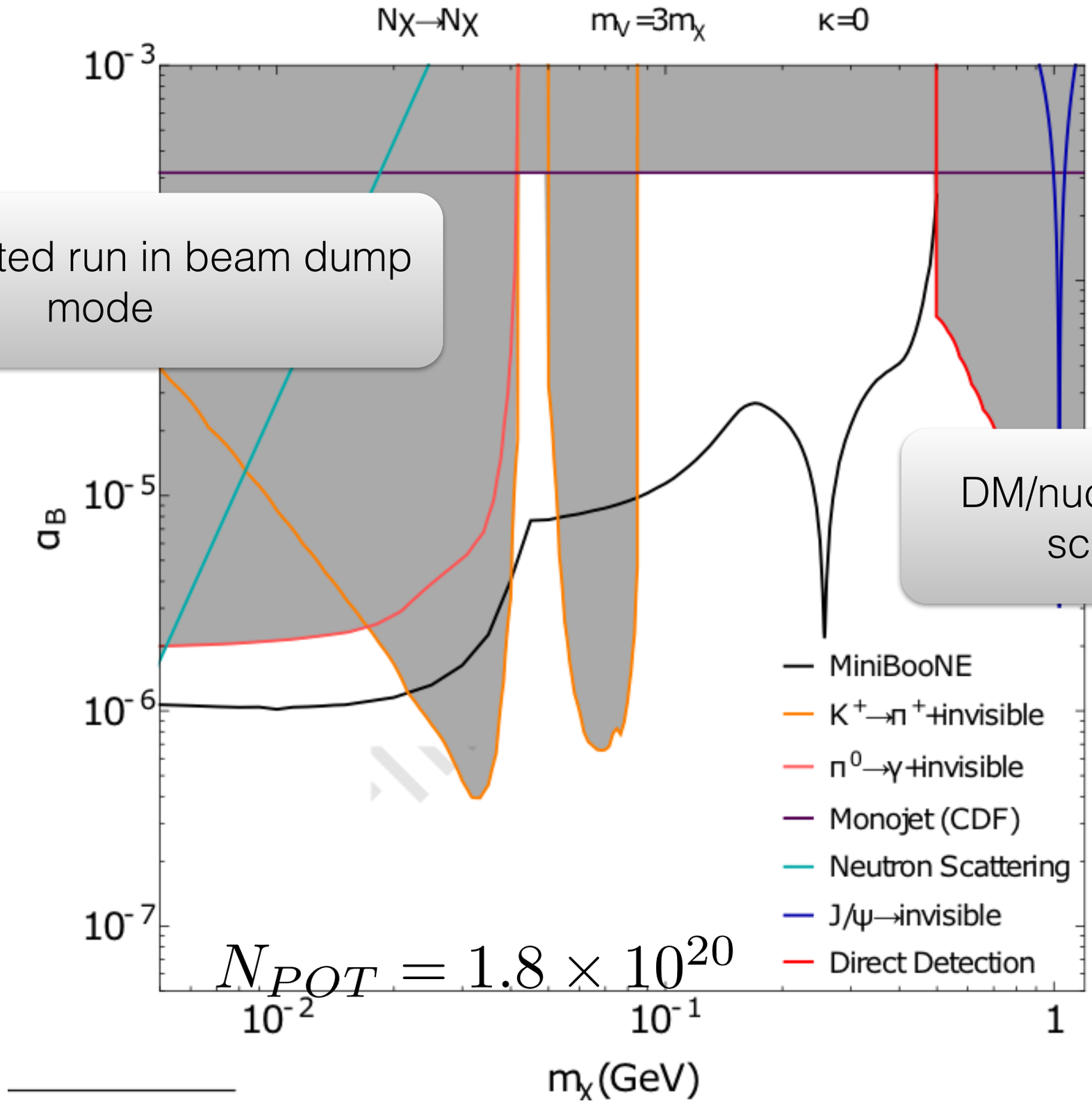
Weak point: neutrino background irreducible bkg

Main challenge: its suppression

Light DM @ MiniBOOne



DM dedicated run in beam dump mode



DM/nucleon elastic scattering

$N_{POT} = 1.8 \times 10^{20}$

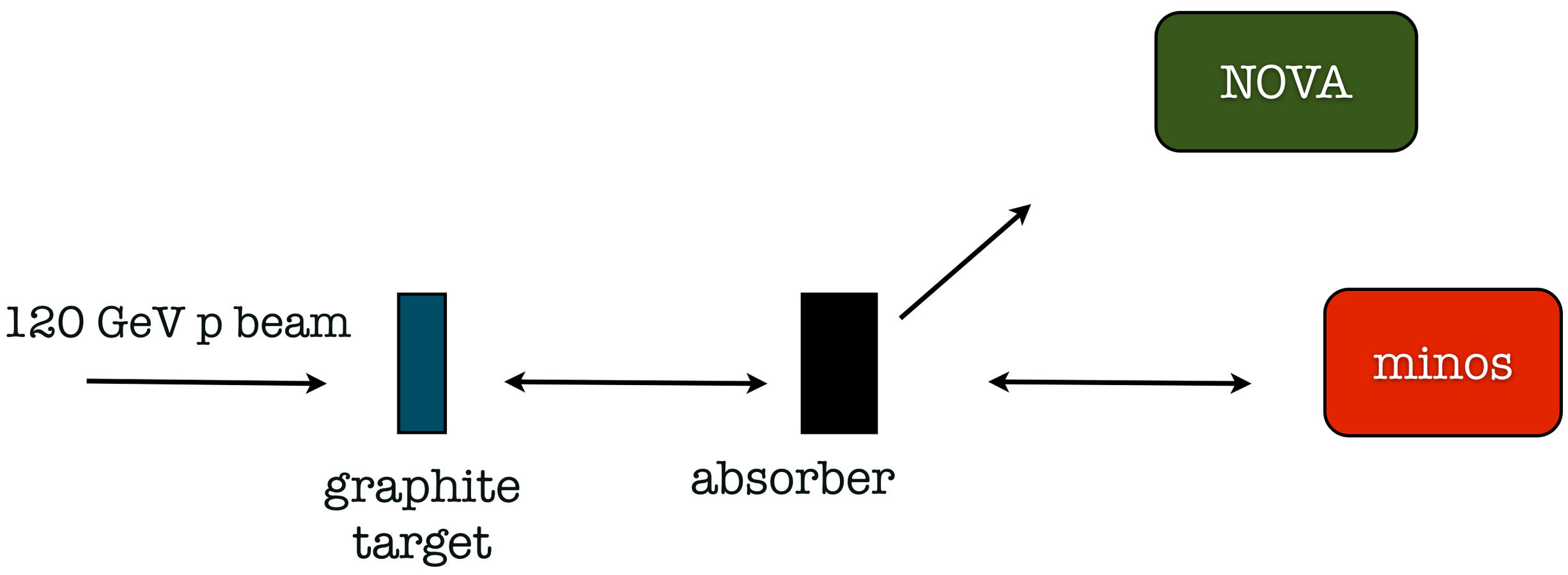
What about other neutrino facilities?

In particular high energy proton fixed target experiments such as CERN SPS and FNAL Main Injector facilties

- We can extend the mass reach to few GeV mediators mass
- How their reach compare to the MB BD run for lighter masses?
- Can the DM program be symbiotic to the neutrino program?

Light DM @ Main Injector

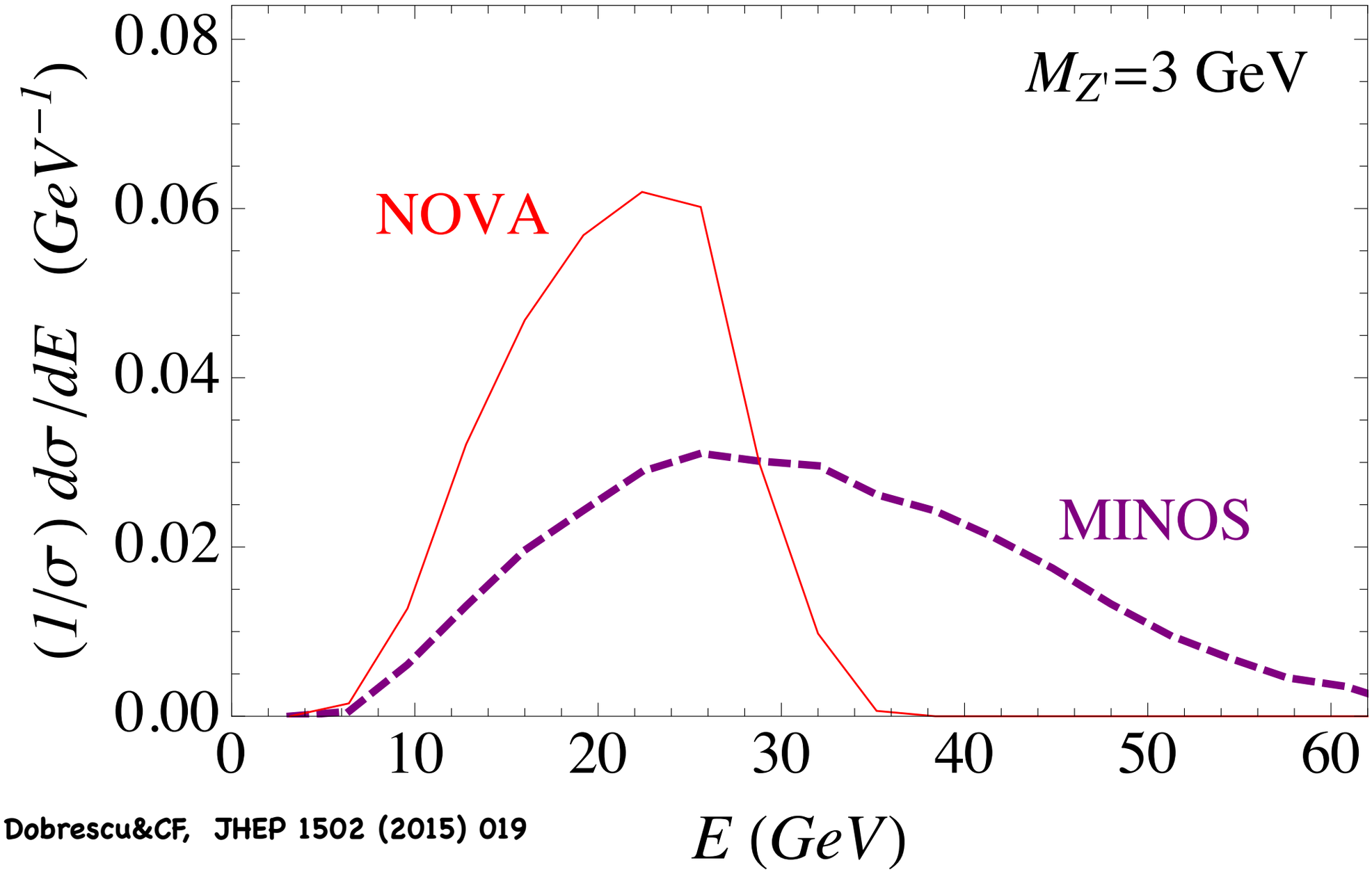
Several detectors (MINOS, NOVA and MINERVA)
potentially good for DM detection



Higher proton beam. We can extend MB reach to few GeV Z'

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

What is the DM signal inside these detectors?



Dobrescu&CF, JHEP 1502 (2015) 019

DM particles are fairly energetic

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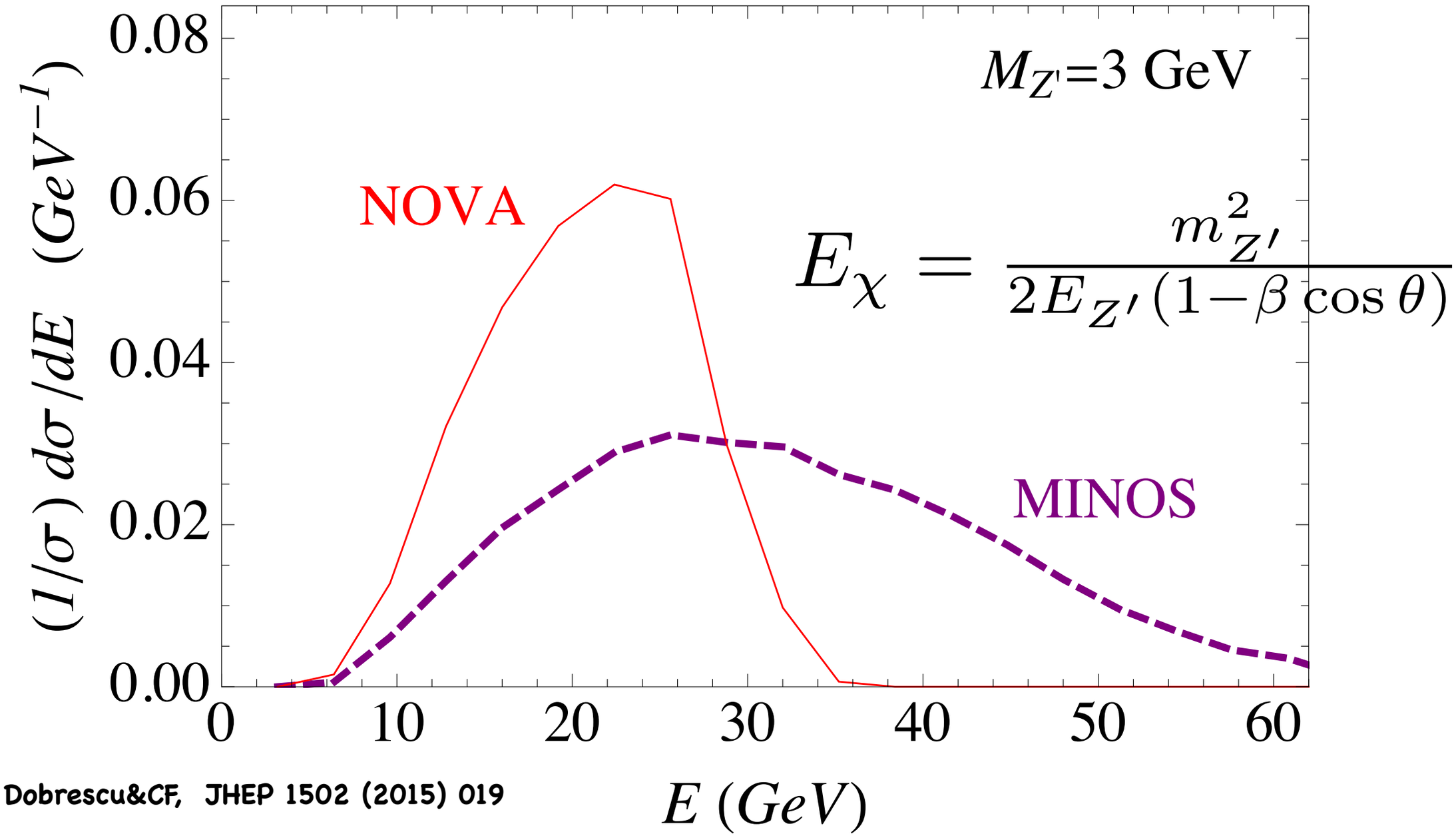

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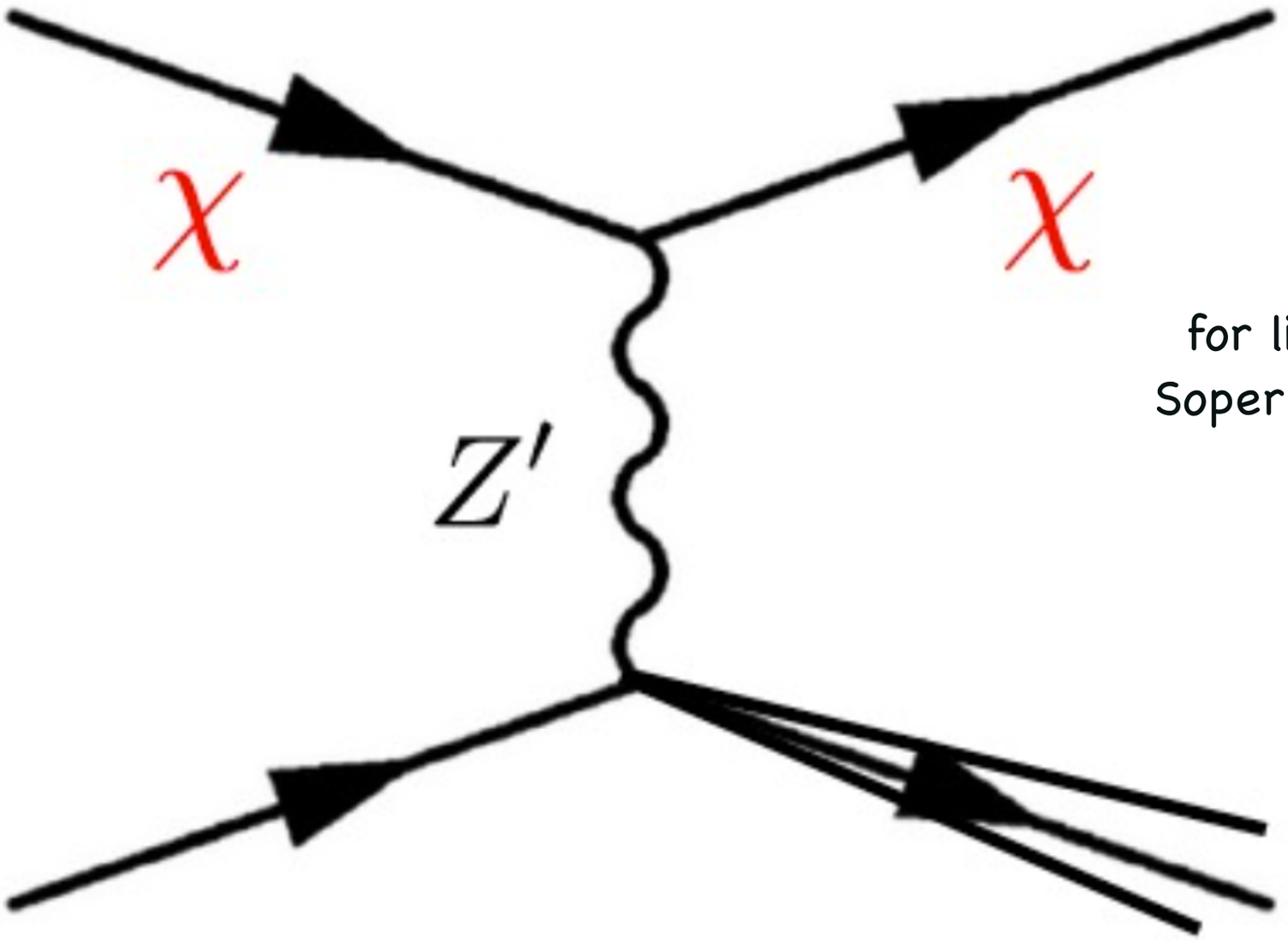
DM particles are fairly energetic

DM energy profile inside the detector

DM energetic - deeply inelastic events

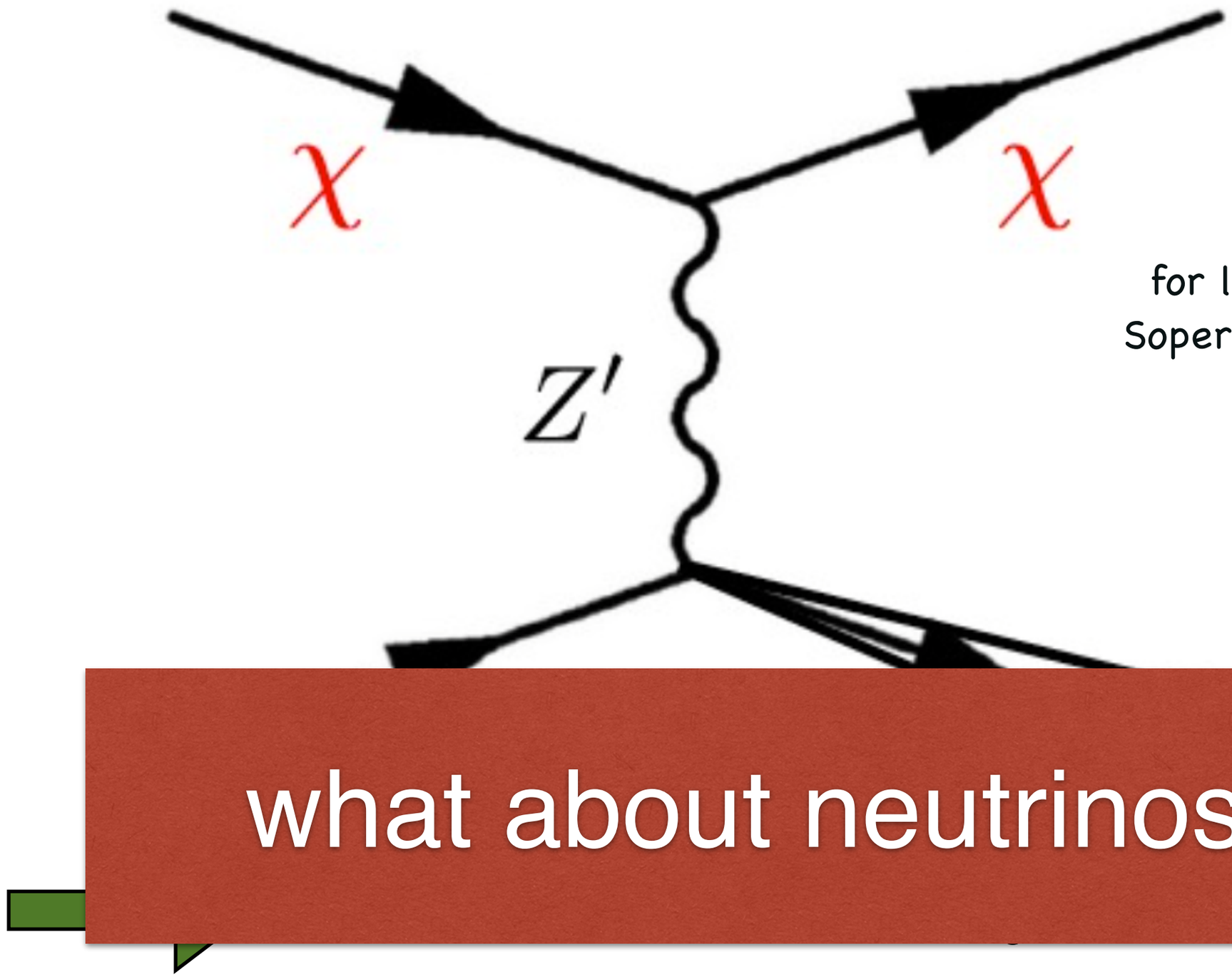


for lighter DM
Soper et al. 2014

DM particles are fairly energetic

DM energy profile inside the detector

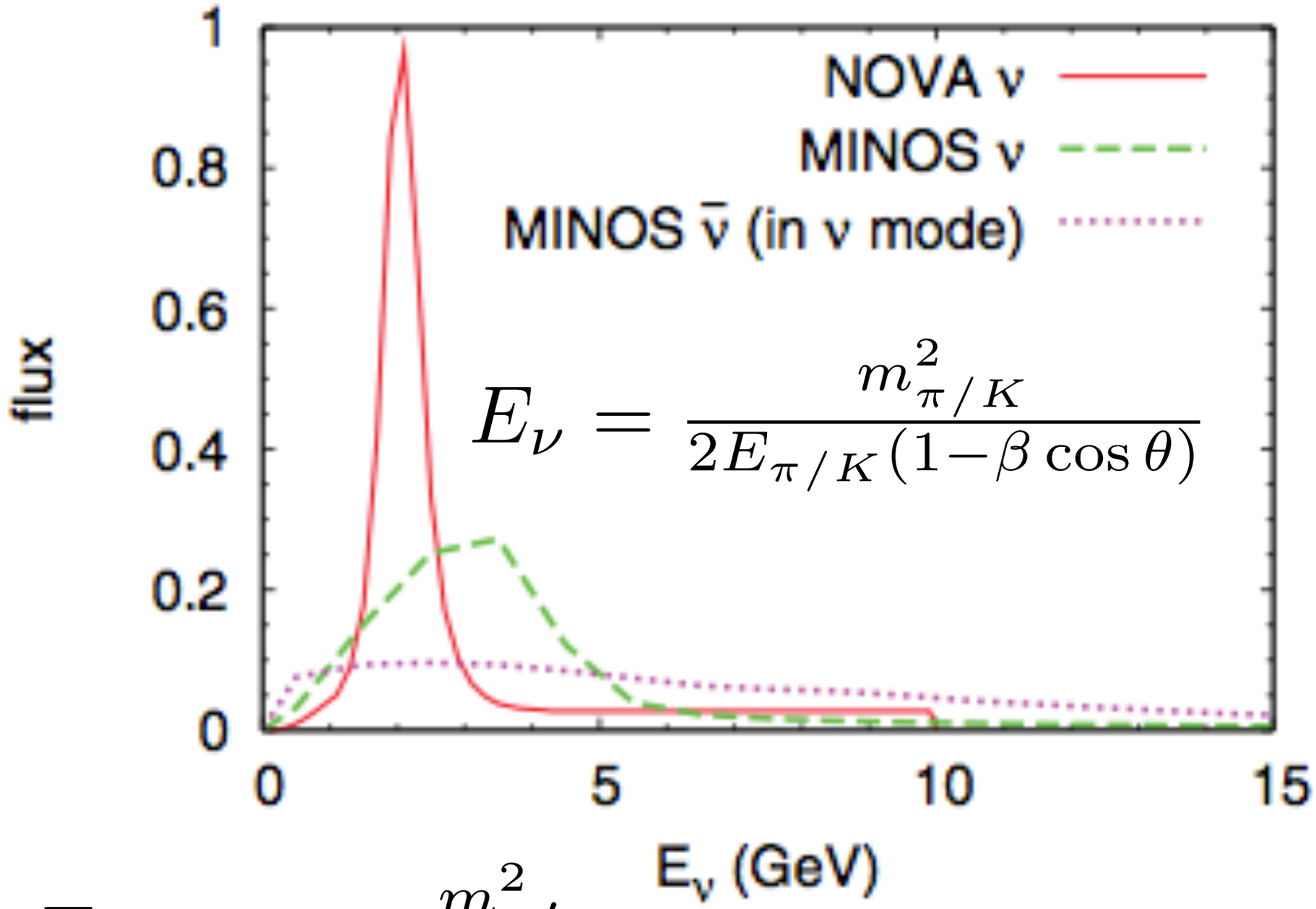
DM energetic - deeply inelastic events



for lighter DM
Soper et al. 2014

what about neutrinos?

Neutrinos energy profile

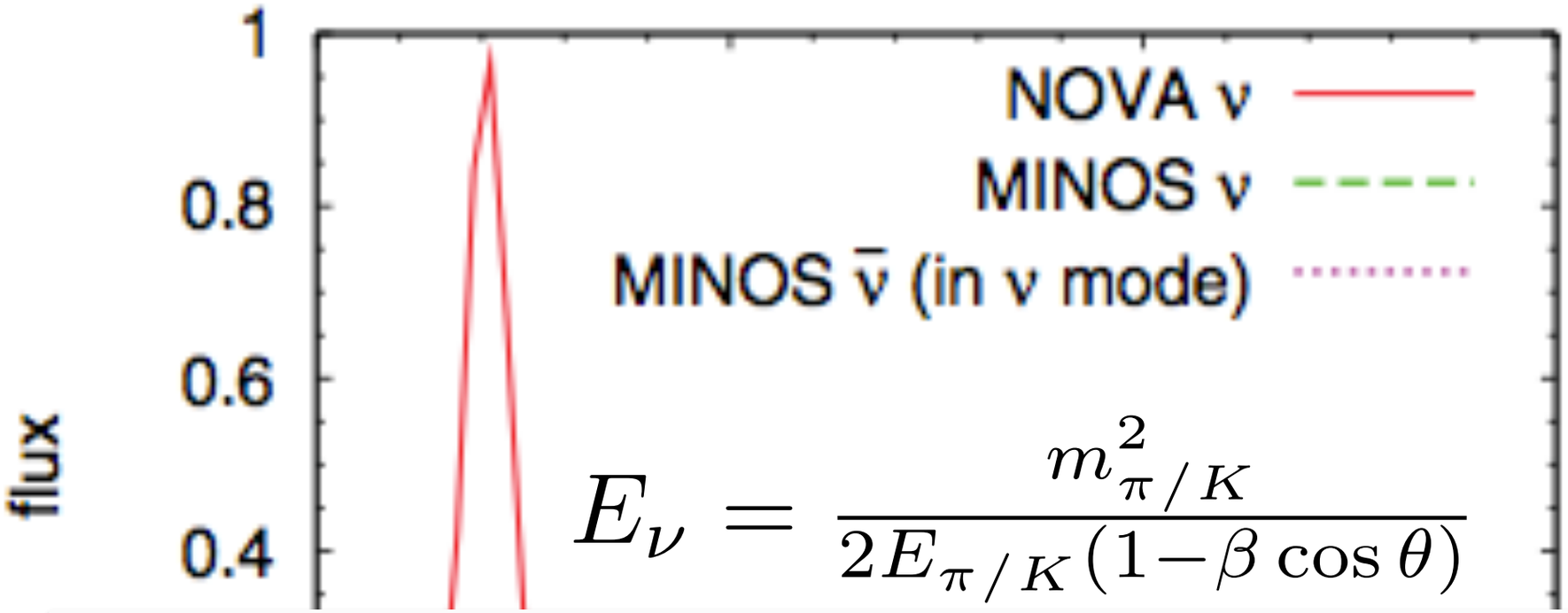


$$E_\nu = \frac{m^2_{\pi\,/\,K}}{2E_{\pi\,/\,K}(1-\beta\cos\theta)}$$

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

Dark matter more energetic
(peak around 20-30 GeV)

Neutrinos energy profile



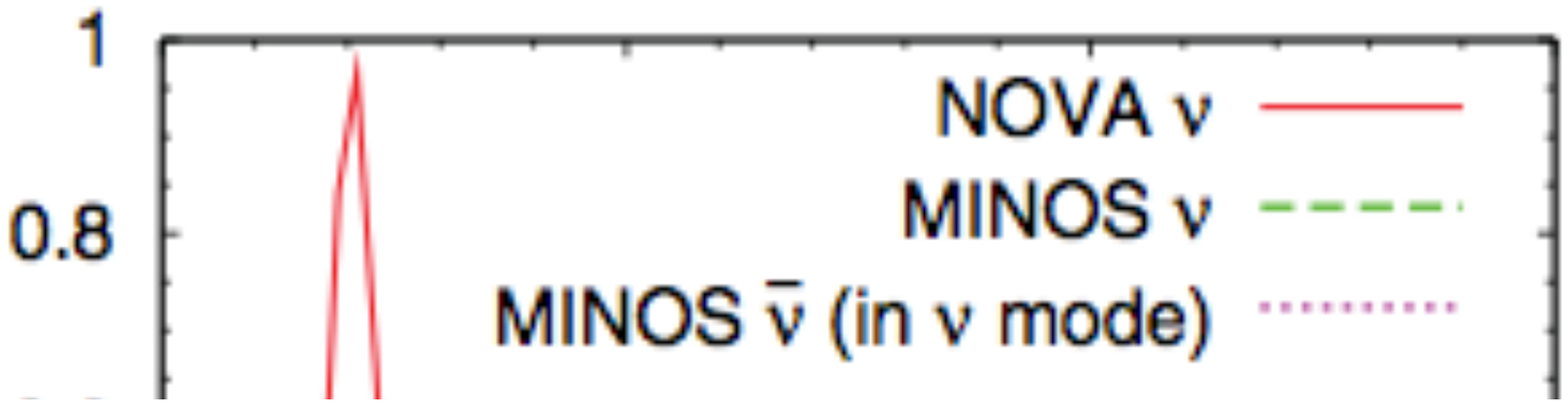
$$E_\nu = \frac{m^2_{\pi\,/\,K}}{2E_{\pi\,/\,K}(1-\beta\cos\theta)}$$

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

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

Dark matter more energetic
(peak around 20-30 GeV)

Neutrinos energy profile



flux

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

Solution:

off axis detector!

B.Dobrescu, P. Coloma, C.Frugiuele, R. Harnik 2015

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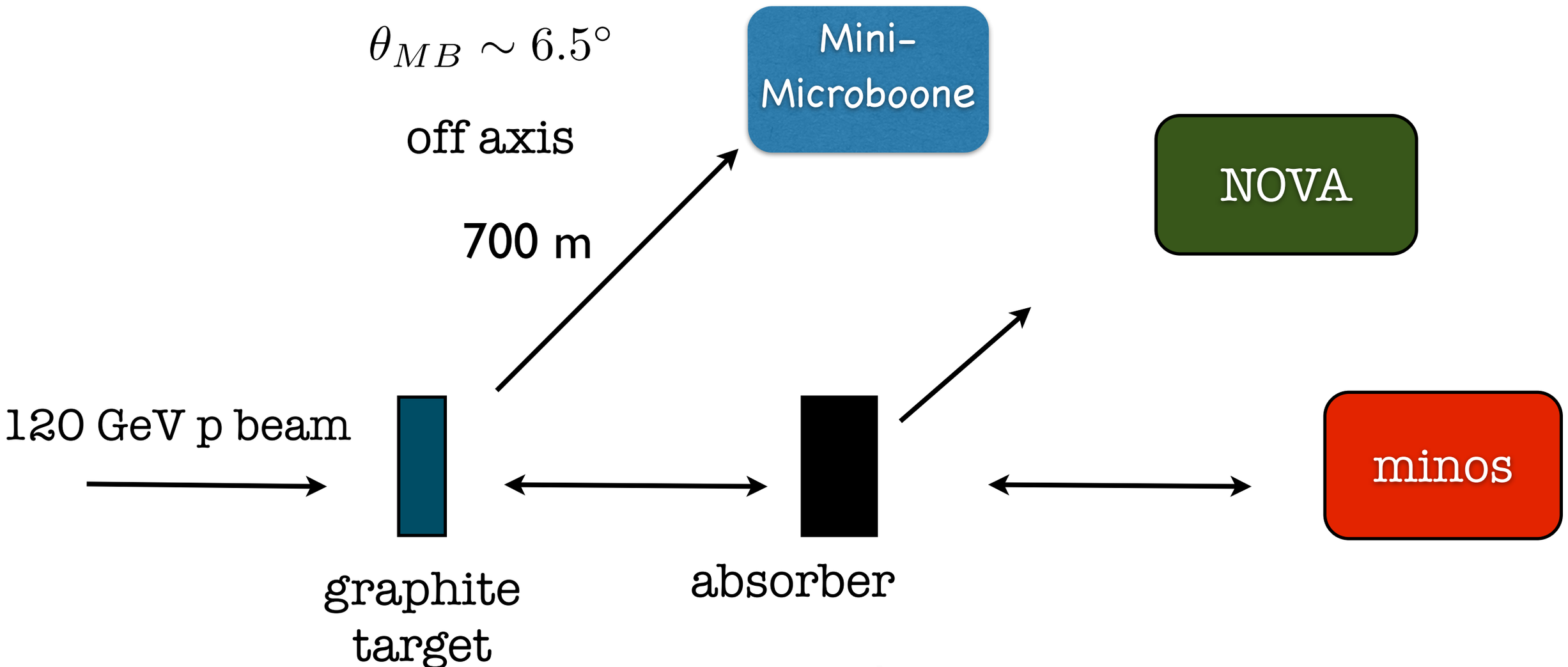
ev)

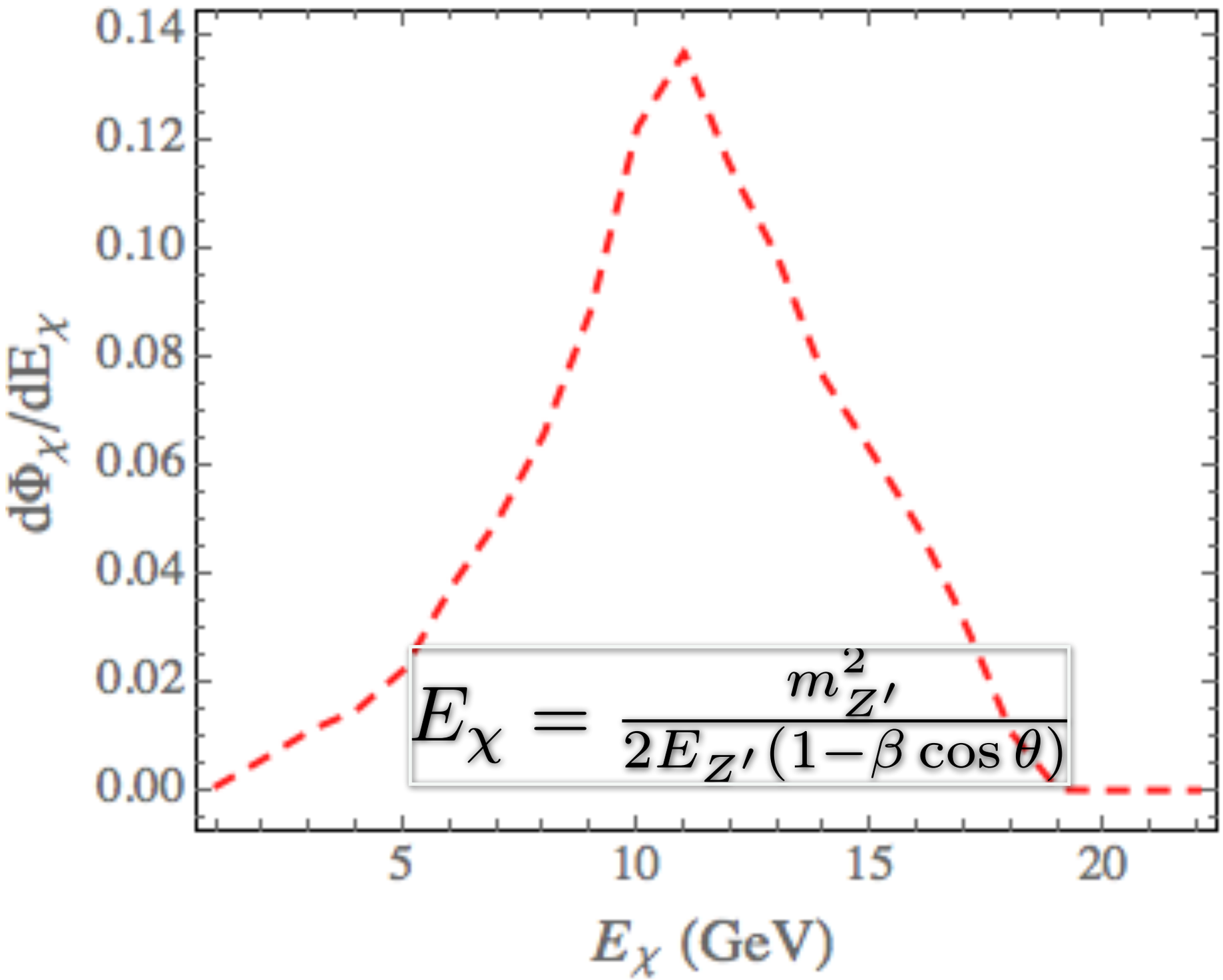
We have already an off axis detector!



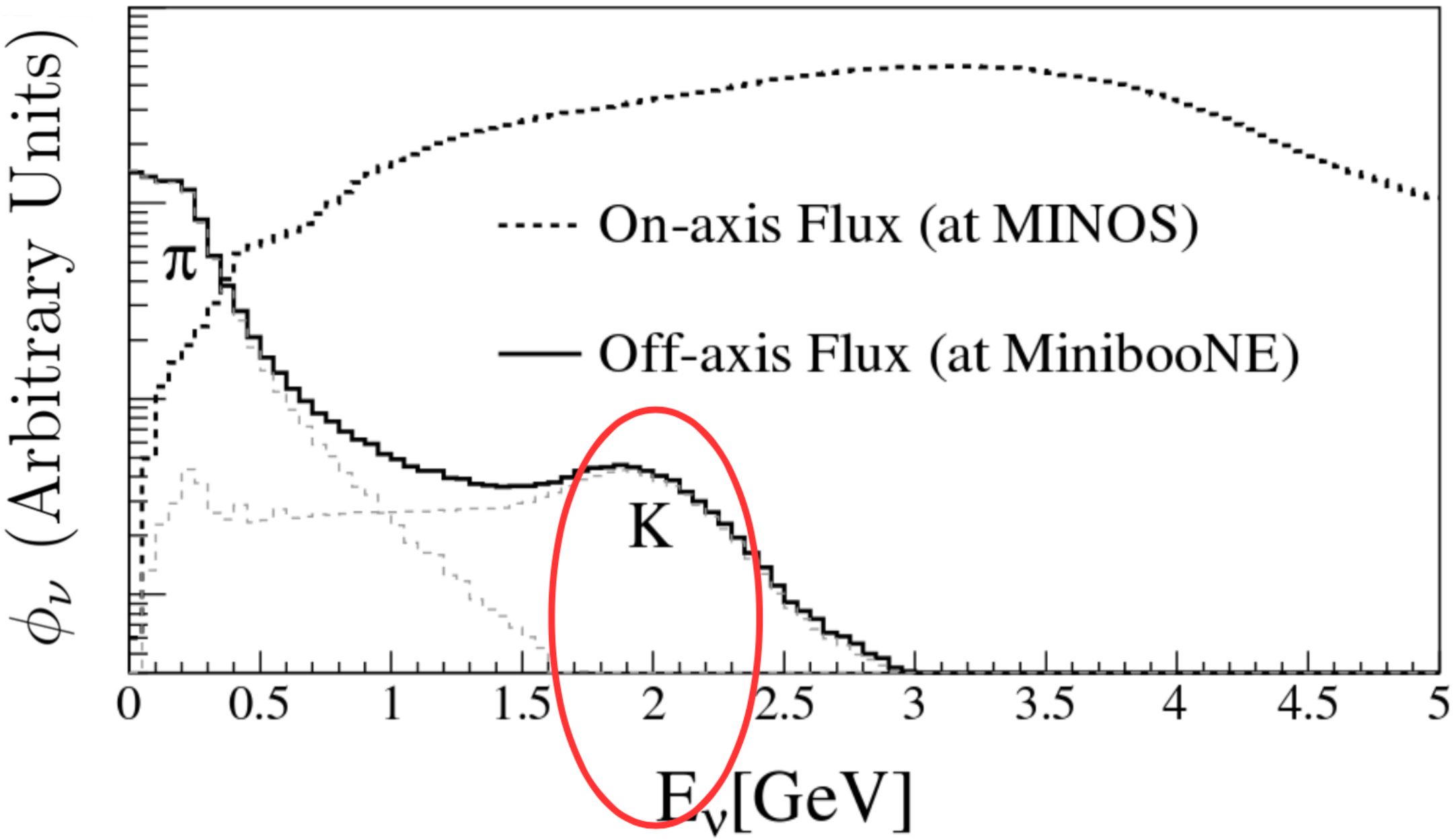
$$pp \to Z' \to \chi\chi$$

DM particle enter the near detector and scatter with nuclei

Dm energy inside MinibooNE



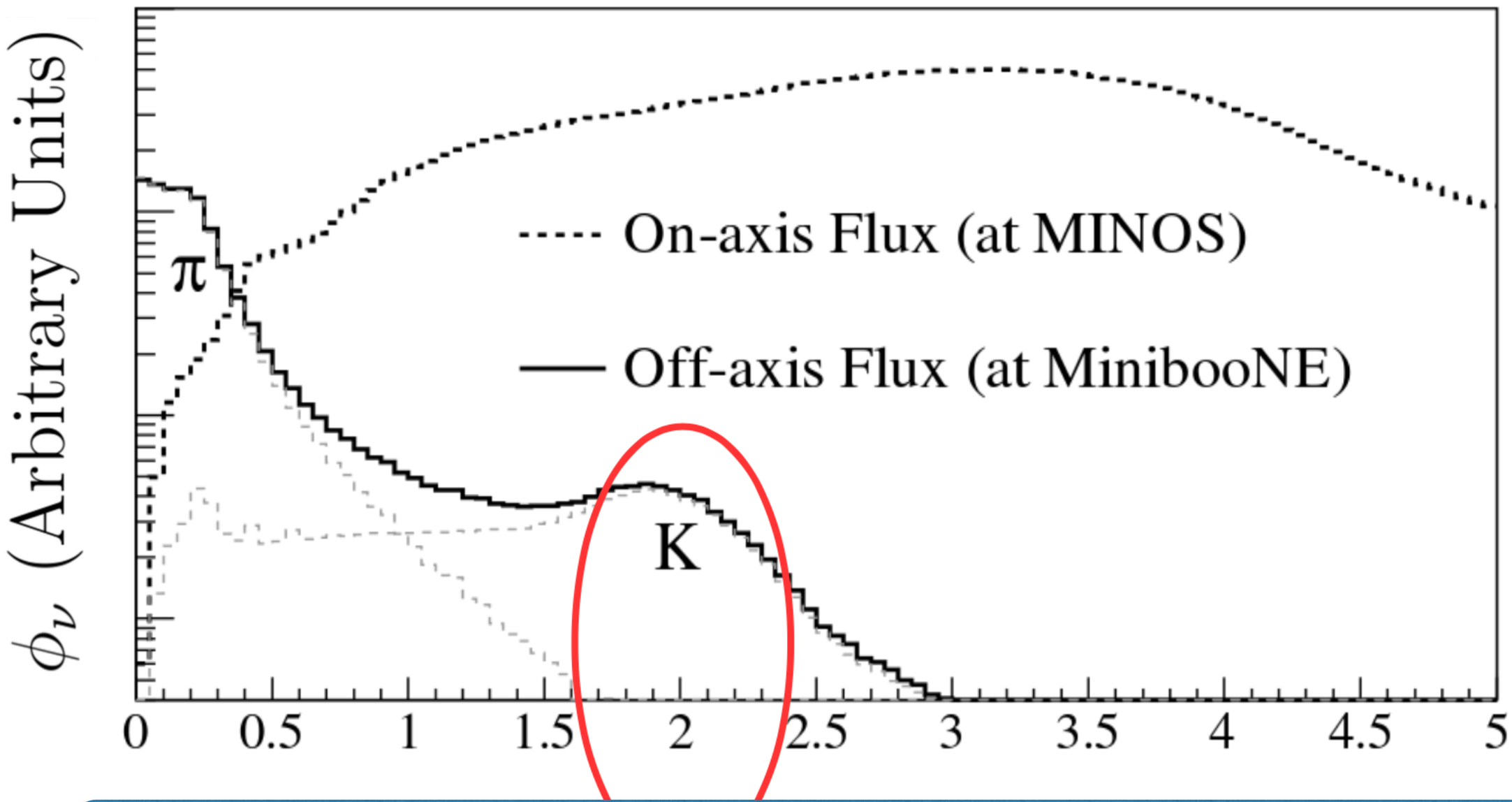
Off axis versus on axis bkg



0.25 GeV pion average energy

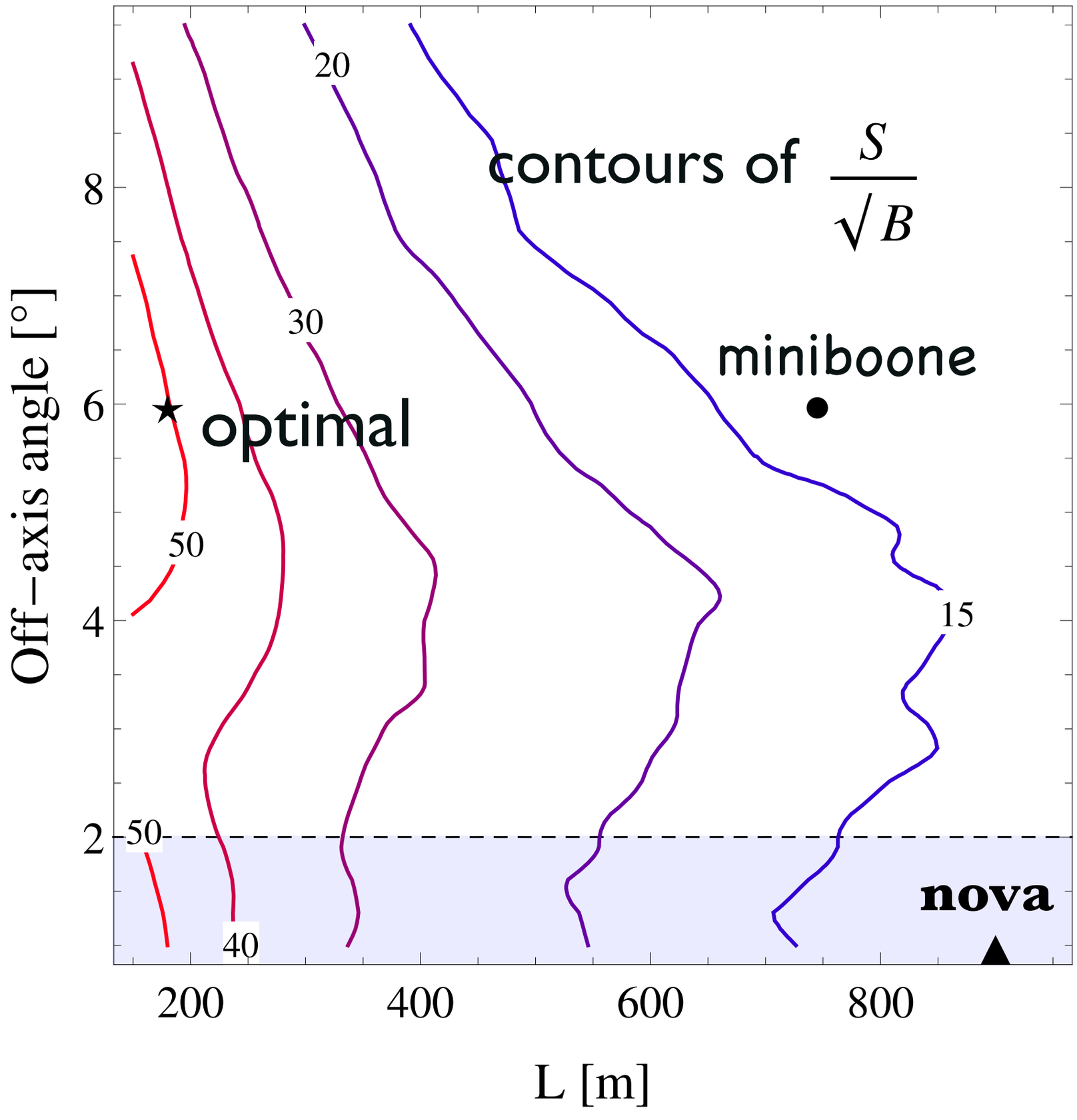
$$E_\nu = \frac{m^2_{\pi/K}}{2E_{\pi/K}(1-\beta\cos\theta)}$$

Off axis versus on axis bkg



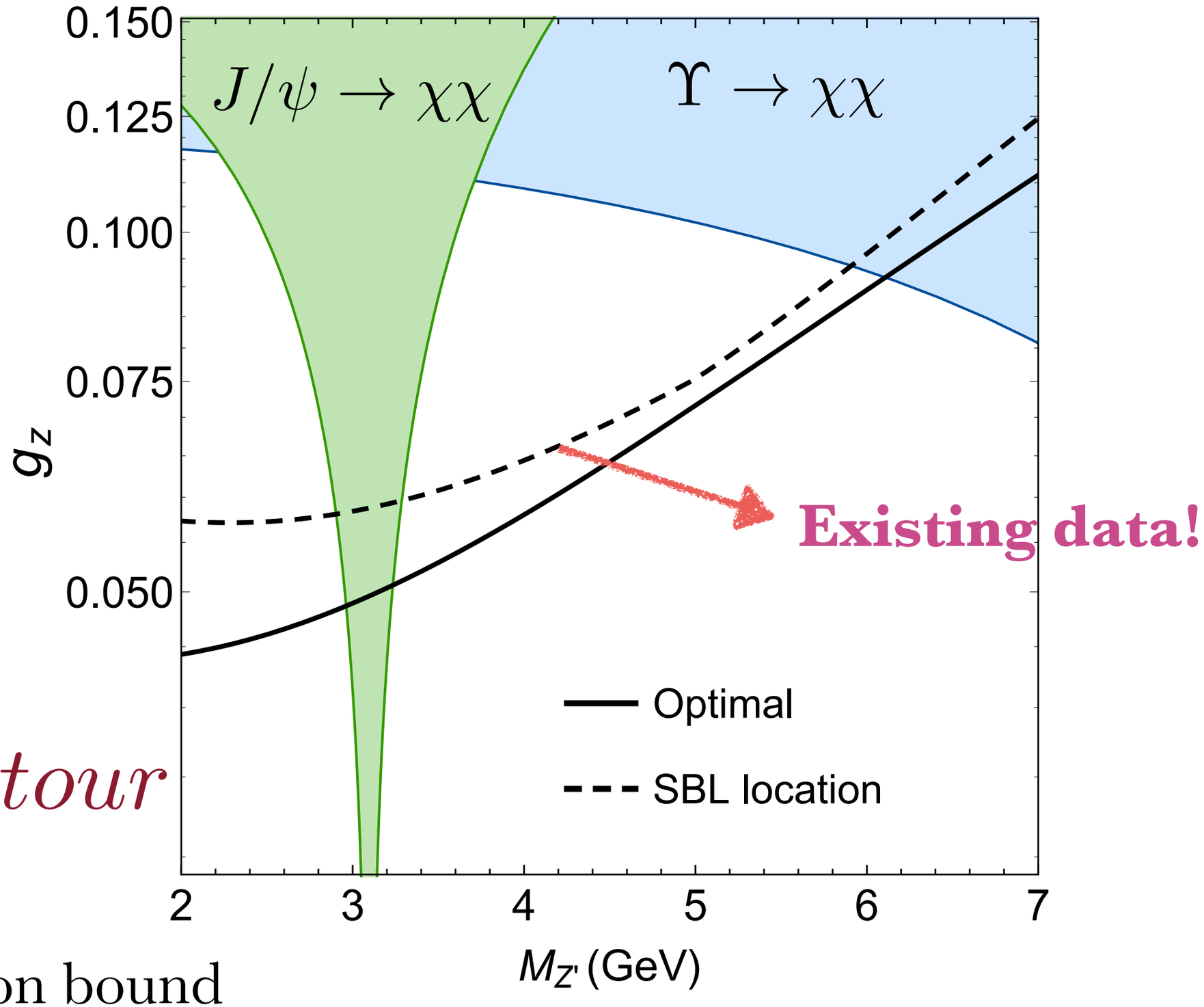
Going off axis we kill efficiently neutrino bkg- 10^6 DIS events in MINOS/NOVa reduced to 10^3 in MinibooNE!

Ideal position for a future LBNF detector



$g_z = 0.1$

Projected sensitivity



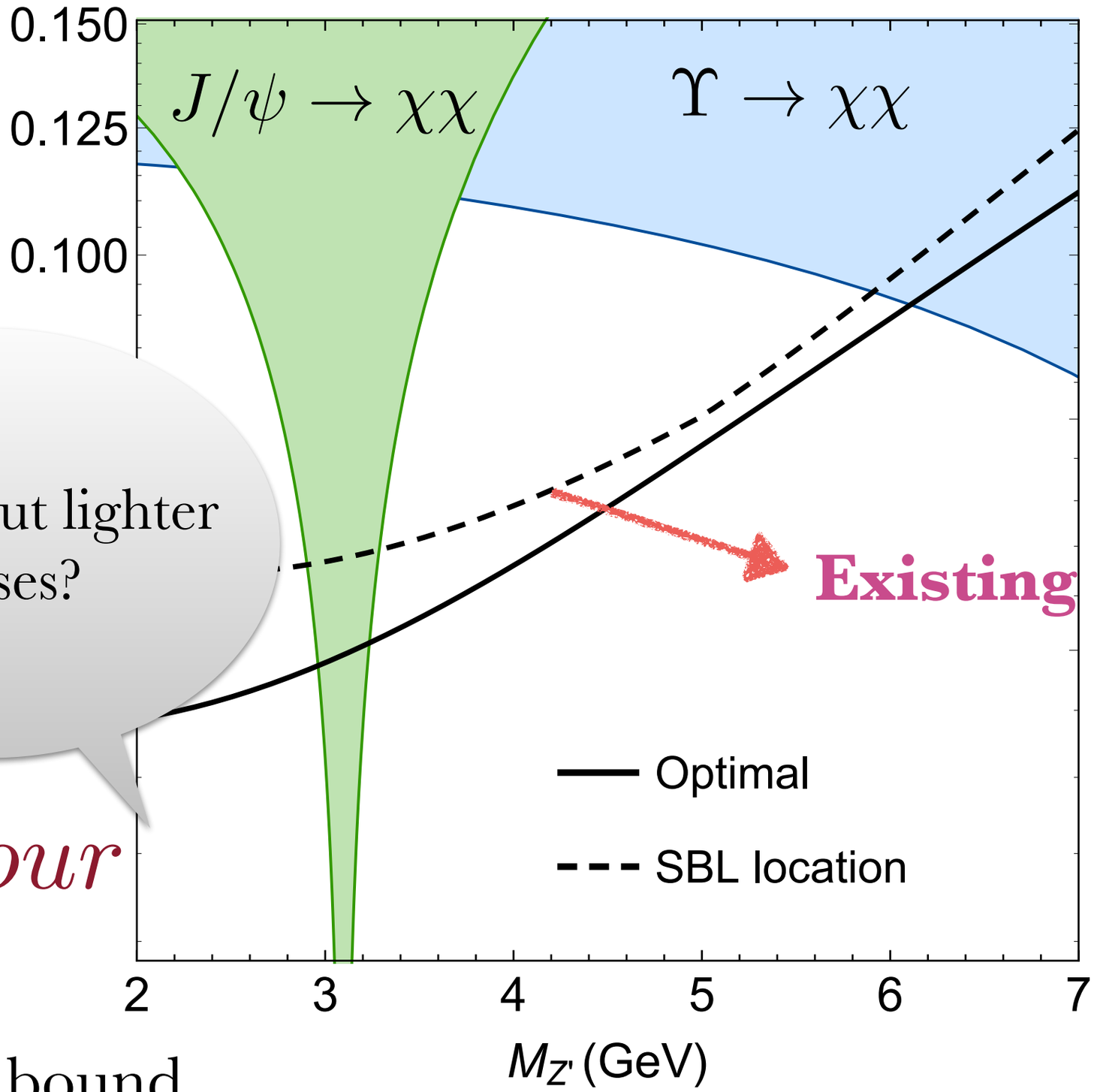
$\chi^2 contour$

Dark photon bound

$\epsilon \sim 10^{-2}$

Weaker than the Babar bound

Projected sensitivity



What about lighter masses?

$\chi^2 contour$

Dark photon bound

$\epsilon \sim 10^{-2}$

Weaker than the Babar bound

Can we constraint sub-GeV Z' mass with an off-axis detector?

CF hep ph 1701.05464

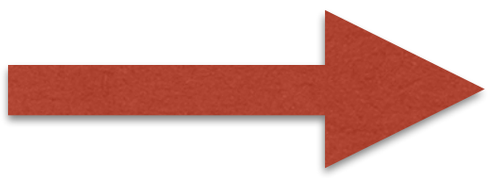
For lighter Z' in principle signal
and background are not distinguishable!

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

similar to Kaon and Pion masses

We expect a very soft spectrum of DM particles
inside an off axis detector!

However, this is a problem ONLY if DM is emitted
by a collimated
Z' beam parallel to the beam line



uncollimated part of the beam!

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how do we produce it?

uncollimated part of the beam!

Can we constraint sub-GeV Z' mass with an off-axis detector?

For lighter Z' in principle signal
and background are not distinguishable!

$$m^2 .$$

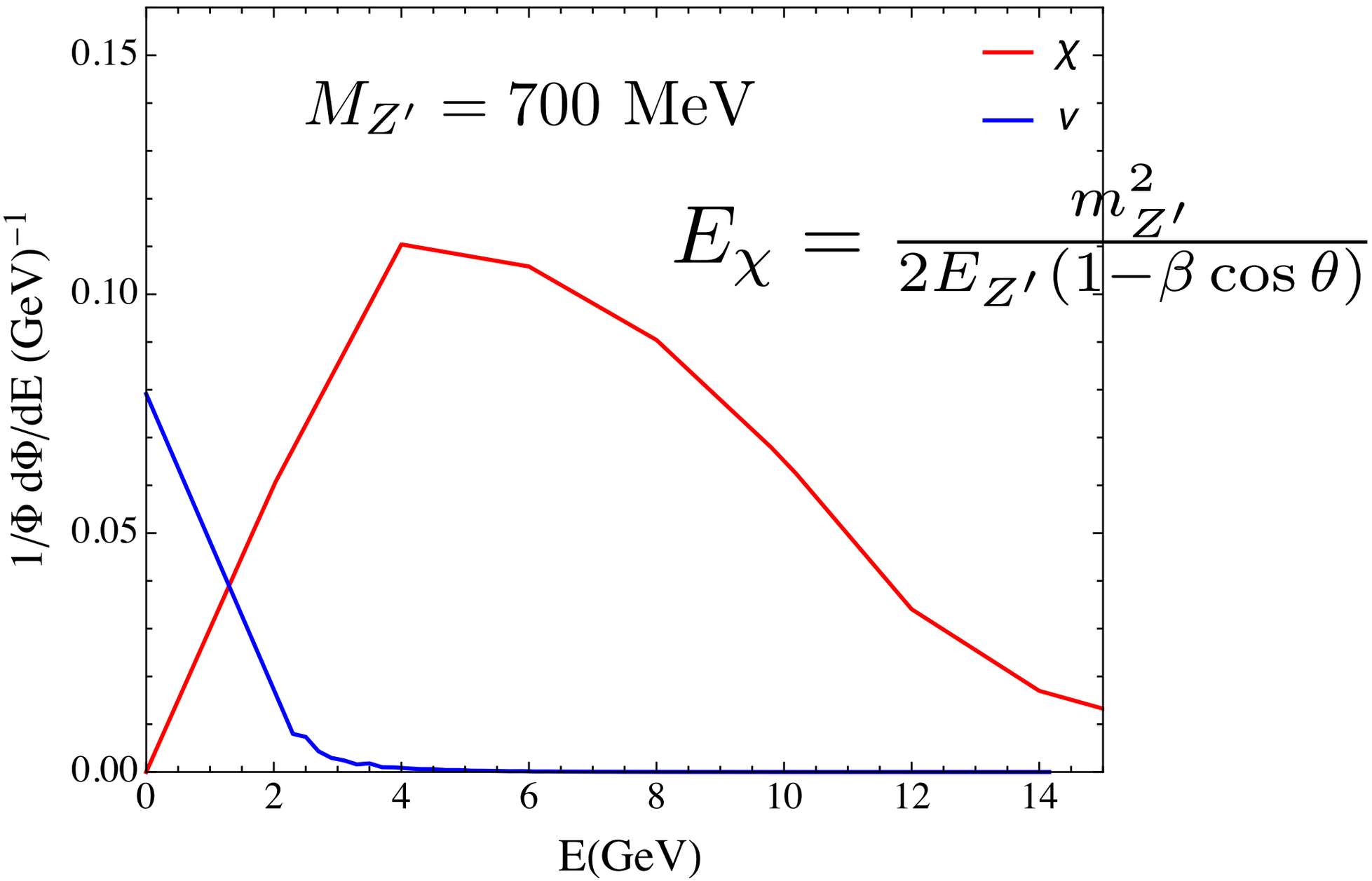
NLO process

$$pp \to Z' j \qquad p_t > 1 \text{ GeV}$$

produce it?

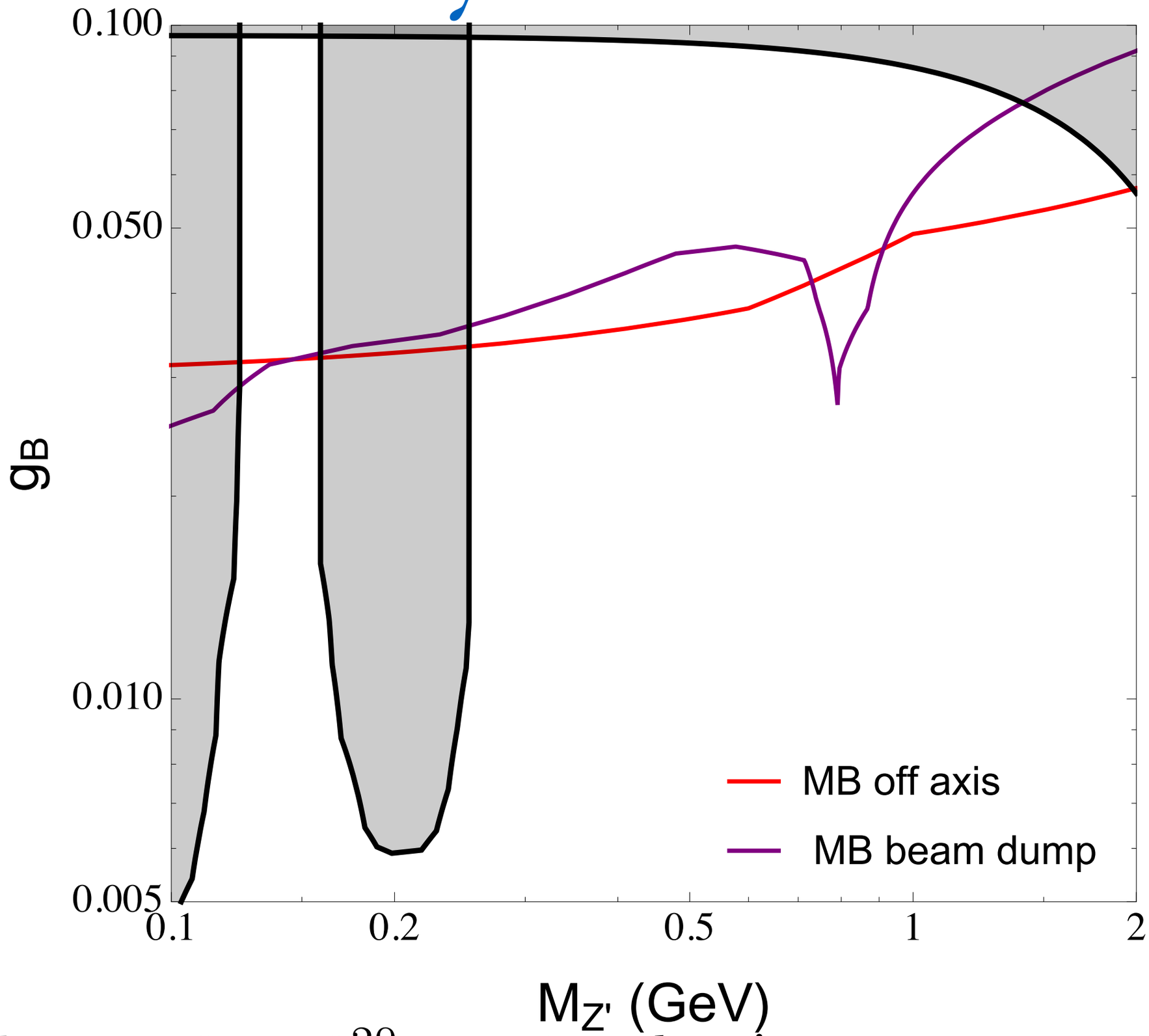
uncollimated part of the beam!

DM energy profile inside MiniBoone



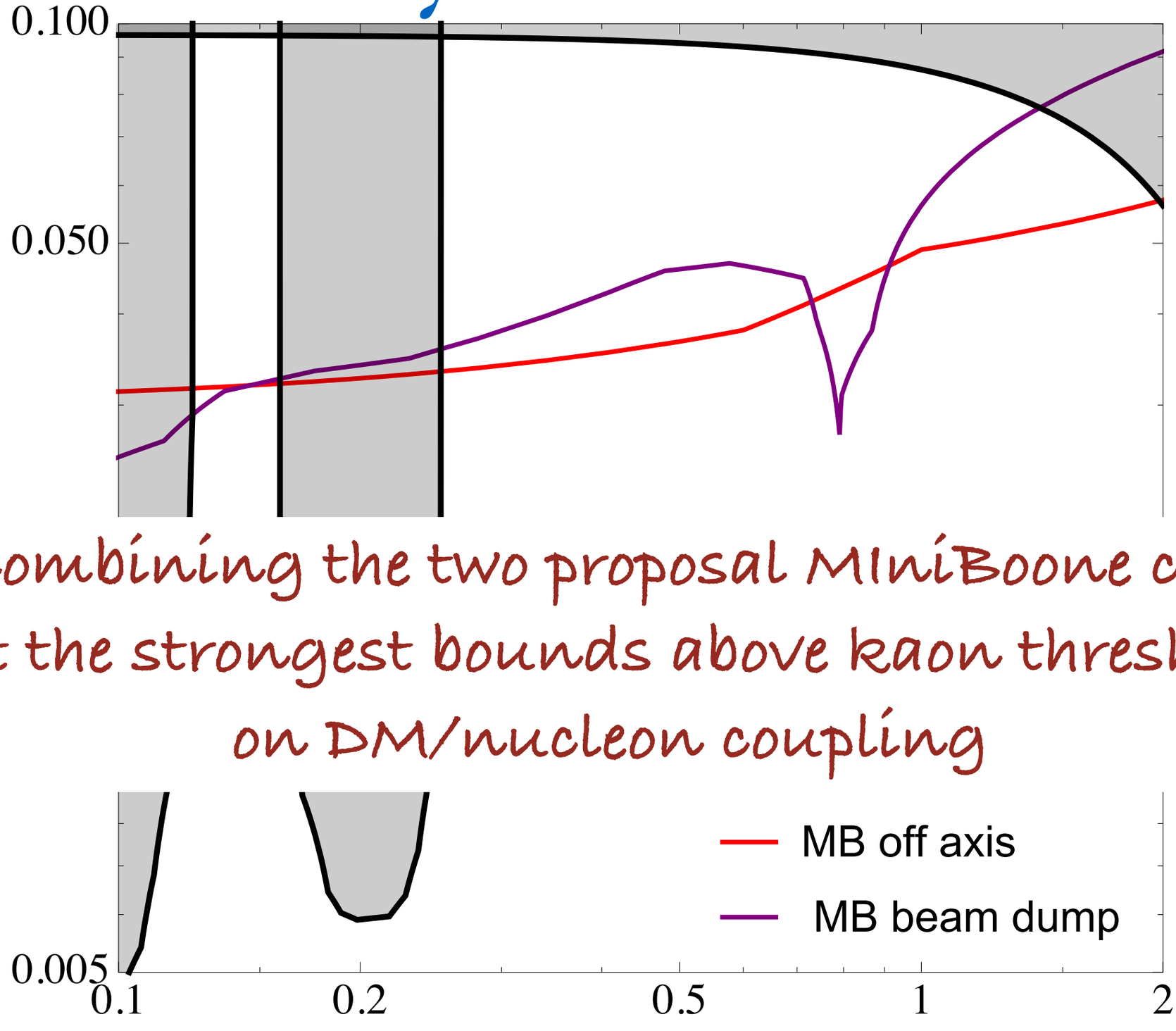
DIS scattering cross section enlarged by very light Z' mass!

Sensitivity to sub-GeV Z'



$N_{POT} = 2 \times 10^{20}$ existing data!

Sensitivity to sub-GeV Z'



Combining the two proposal MiniBoone can set the strongest bounds above kaon threshold on DM/nucleon coupling

$N_{POT} = 2 \times 10^{20}$ existing data!

Conclusions

- Neutrino facilities could offer the possibility to probe light DM/quarks couplings.
- Off axis LBNF detector for DM could set the strongest bounds, but Miniboone/ Microboone collaborations must look at their data!
- BSM physics program can be parasitic to the neutrino program!