Claudia Frugiuele

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

# Dark matter beams @ neutrino facilities

Invisible 2017, Zurich 16/06/2017

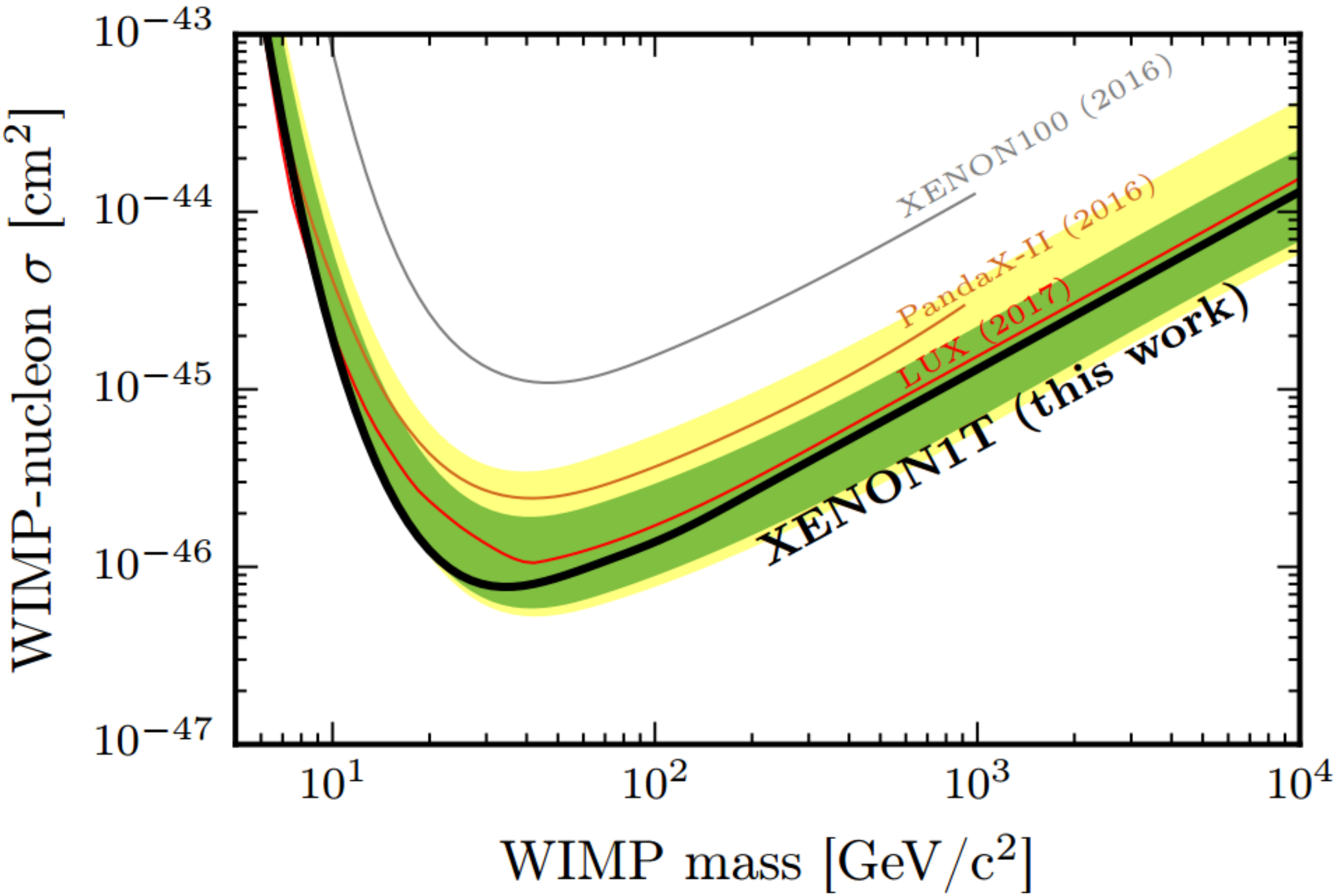
# Outline

- what type of dark matter scenarios neutrino facilities can probe

- brief intro to sub GeV dark matter and its probes

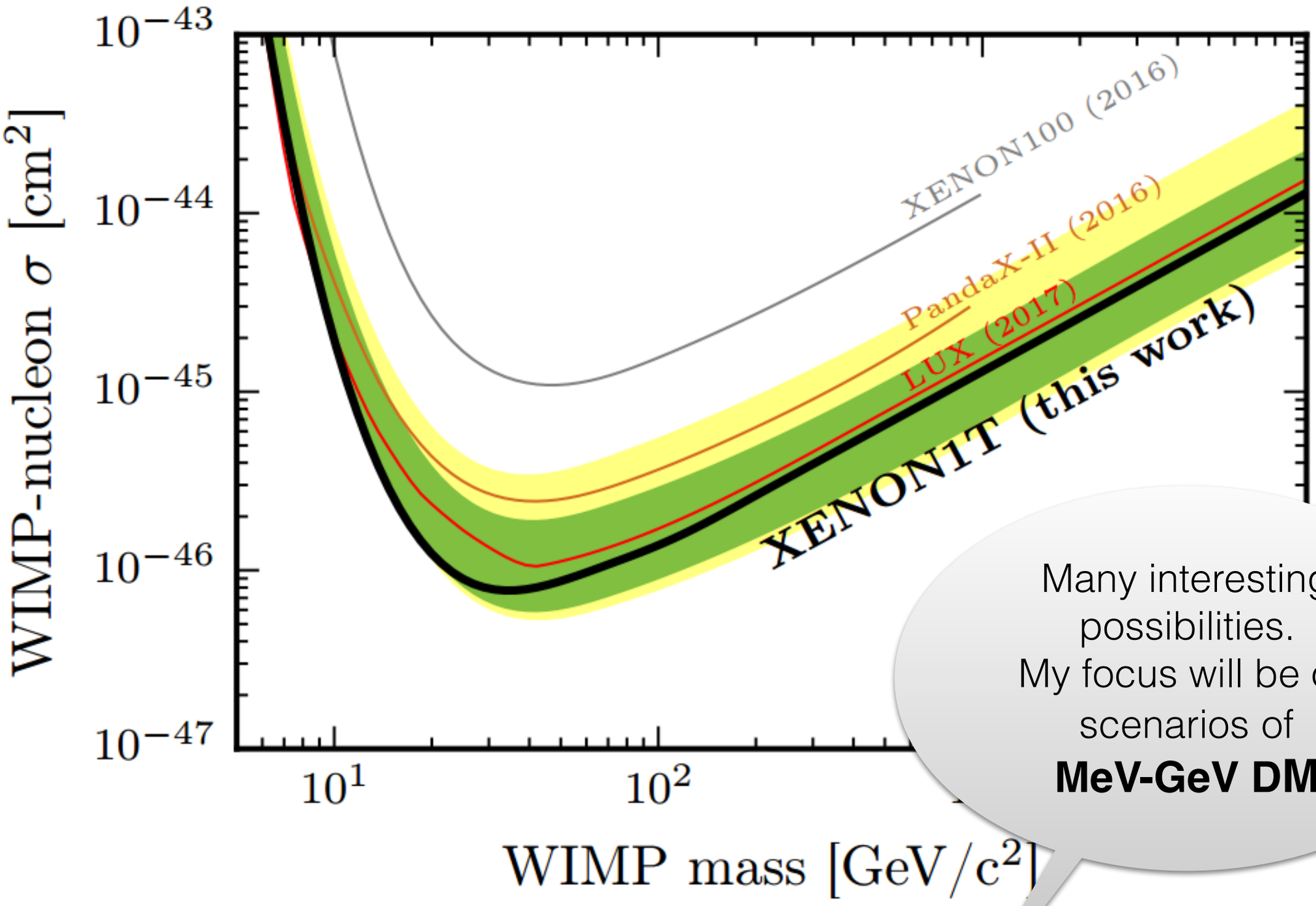
- how neutrino facilities can possibly discover light dark matter

# Dark matter beyond WIMPs?




A discovery might be around the corner, but time to explore more scenarios beyond WIMP DM

# Dark matter beyond WIMPs?

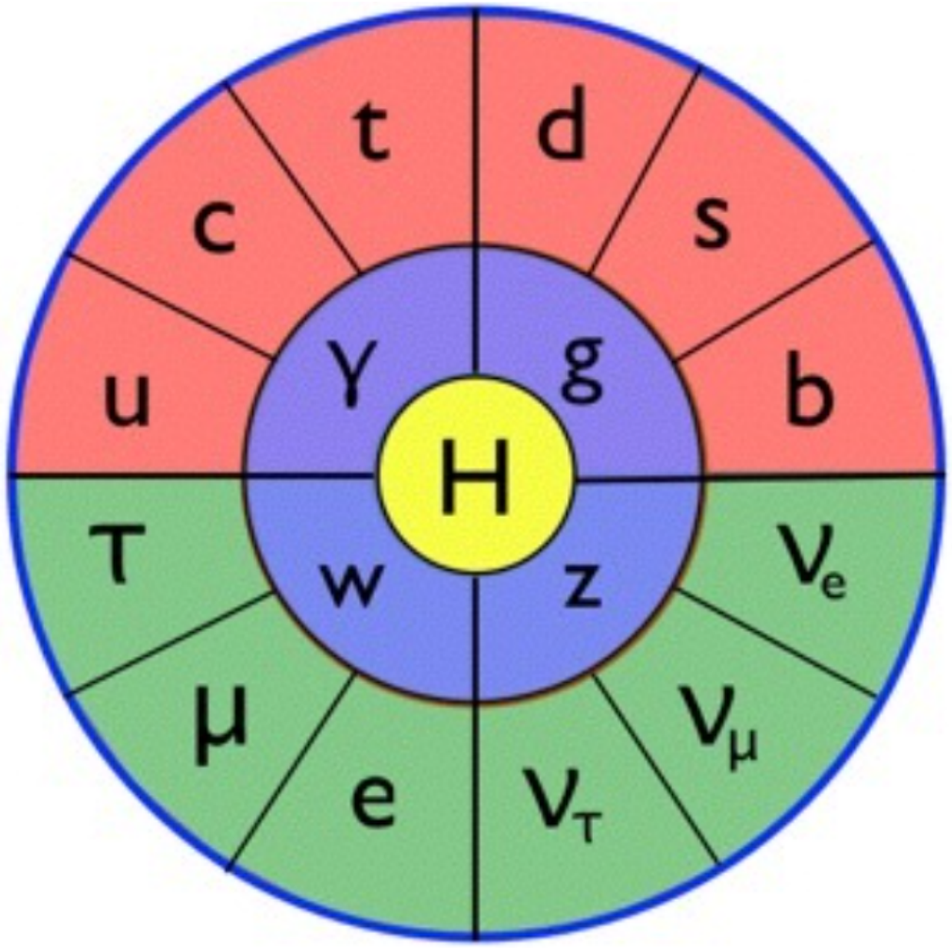



Many interesting possibilities.
My focus will be on scenarios of
**MeV-GeV DM**

A discovery might be around the corner, but time to explore more scenarios beyond WIMP DM

# MeV-GeV dark matter

A MeV-GeV particle interacting with
the visible sector via new MeV-GeV forces
could account for the
observed DM abundance in the universe

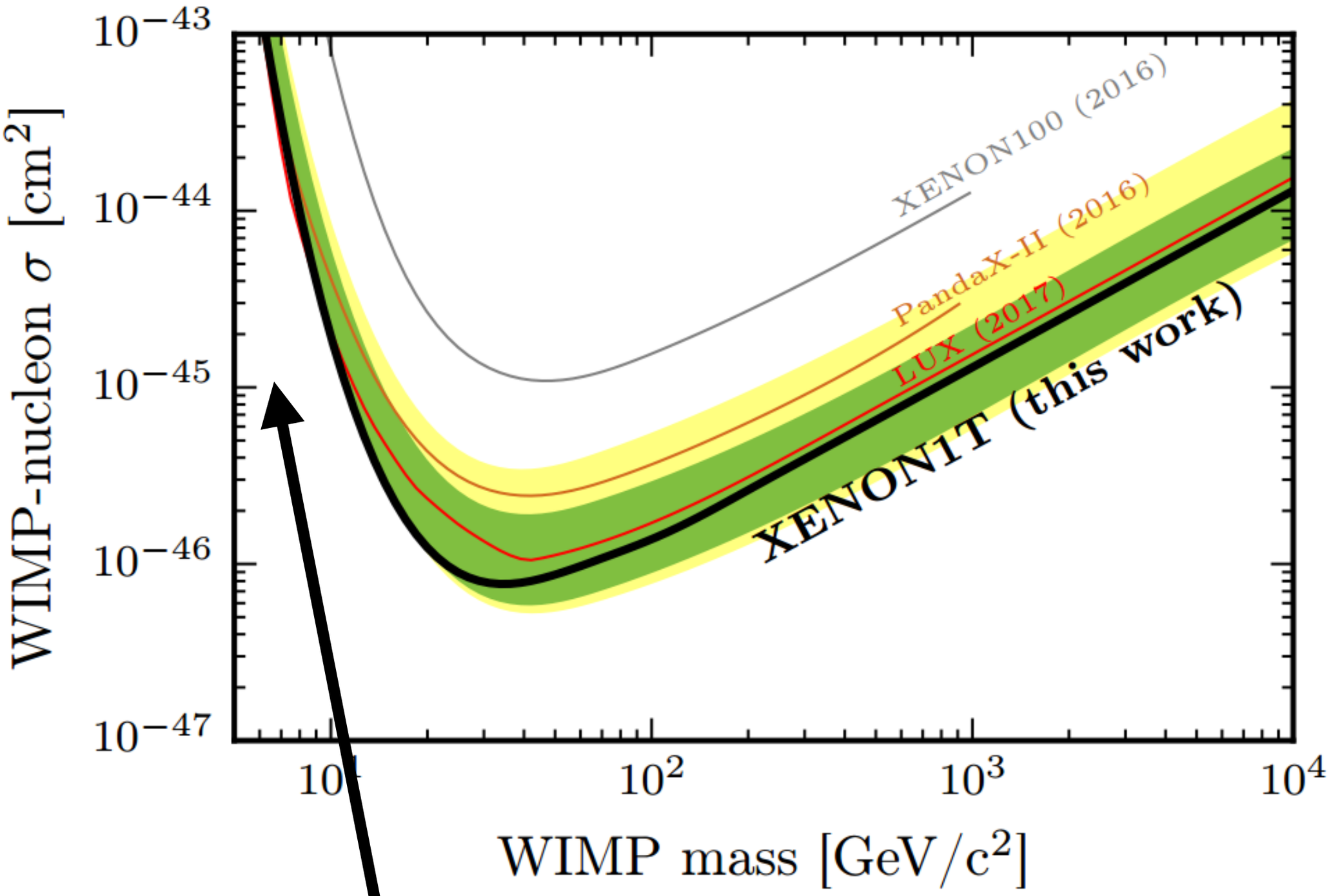



MeV-GeV
dark force

DM

dark photon, Z', Higgs portal…

# MeV-GeV DM probes

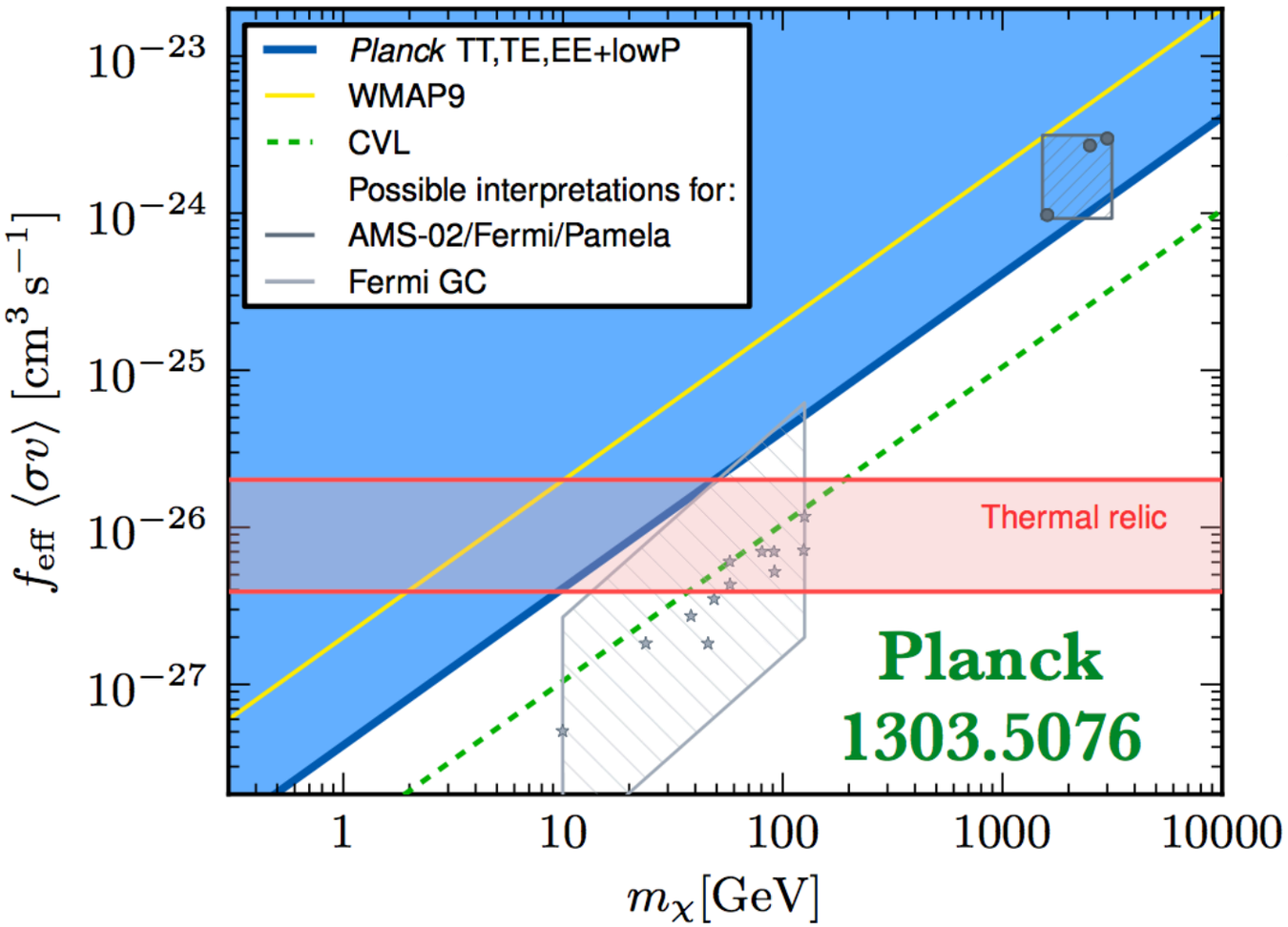



Limited sensitivity to sub GeV dark matter.

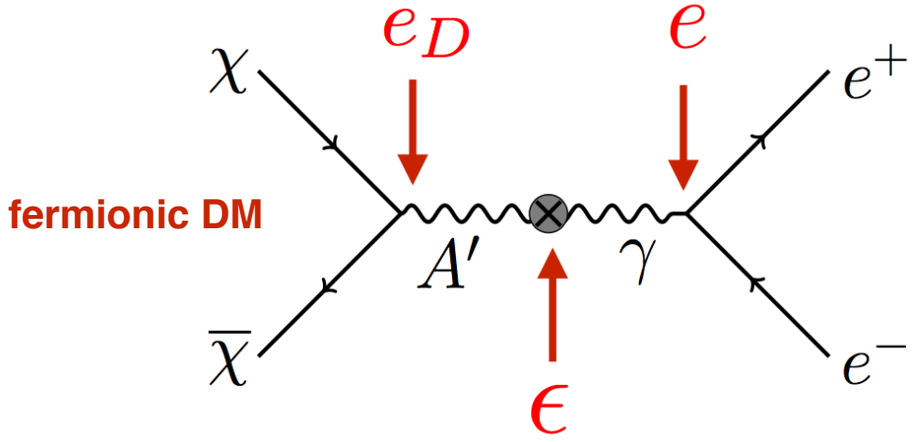
Also LHC searches are less effective in this region

# MeV-GeV DM

We are not entering an unexplored territory…




Annihilation is s-wave Ruled out by CMB

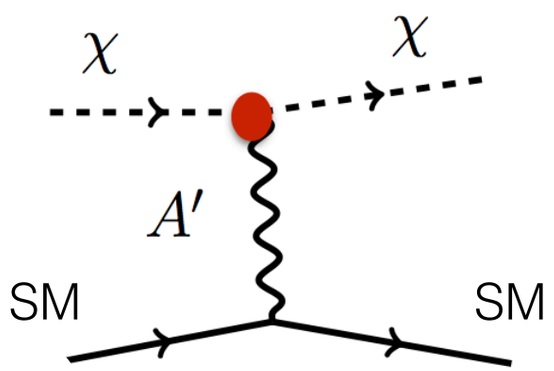



however, a lot of parameter space is still open

# MeV-GeV DM

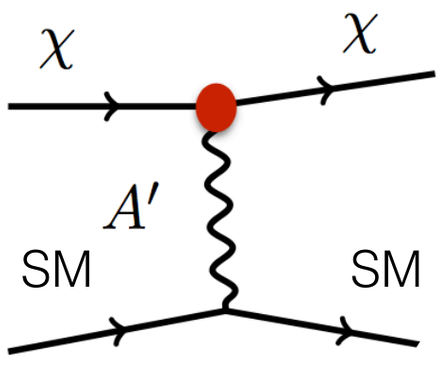
MeV-GeV thermal relic is a simple viable scenario for DM..

**Scalar DM**



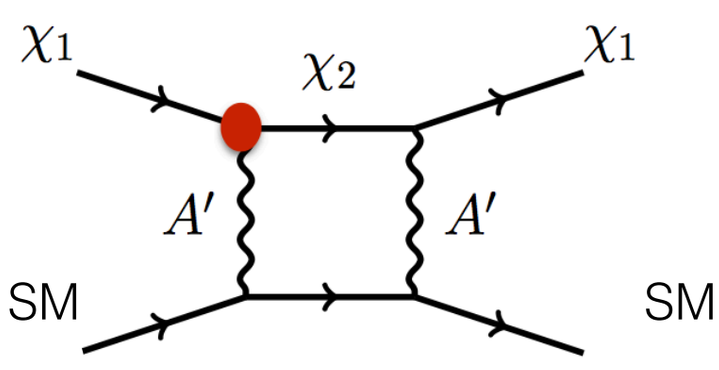

$A'_\mu \chi^* \partial_\mu \chi$

**Majorana DM**




$A'_\mu \bar{\chi} \gamma^\mu \gamma^5 \chi$

**Pseudo-Dirac DM inelastic**




$A'_\mu \bar{\chi}_1 \gamma^\mu \chi_2$

diagrams taken from G.Krnjaic's talk at CERN-Korea Institute

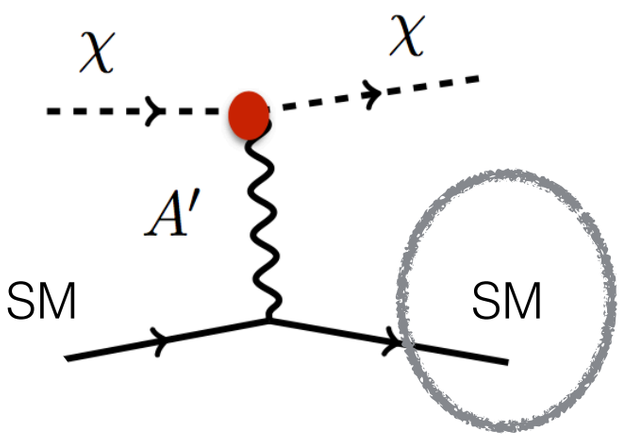
The sensitivity of DD experiments and LHC is limited

**How do we probe its existence?**

# MeV-GeV DM

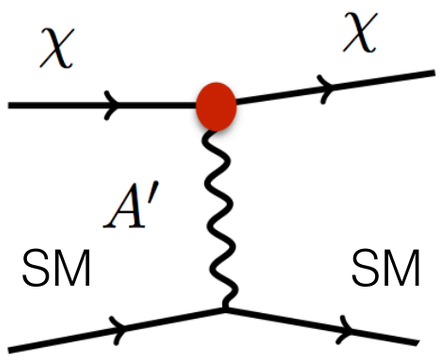
MeV-GeV thermal relic is a simple viable scenario for DM..

**Scalar DM**




$$A'_\mu \chi^* \partial_\mu \chi$$

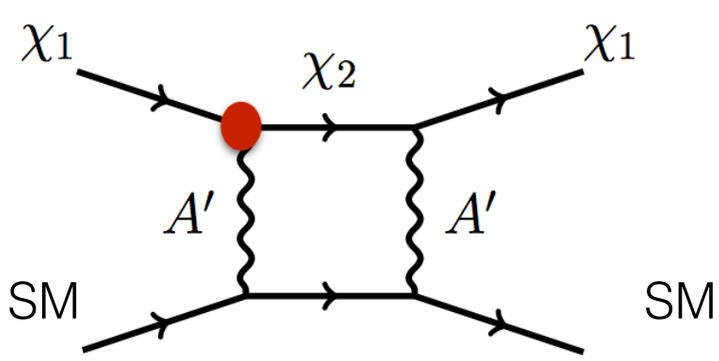
**Majorana DM**




SM

$$A'_\mu \bar{\chi} \gamma^\mu \gamma^5 \chi$$

**Pseudo-Dirac DM inelastic**



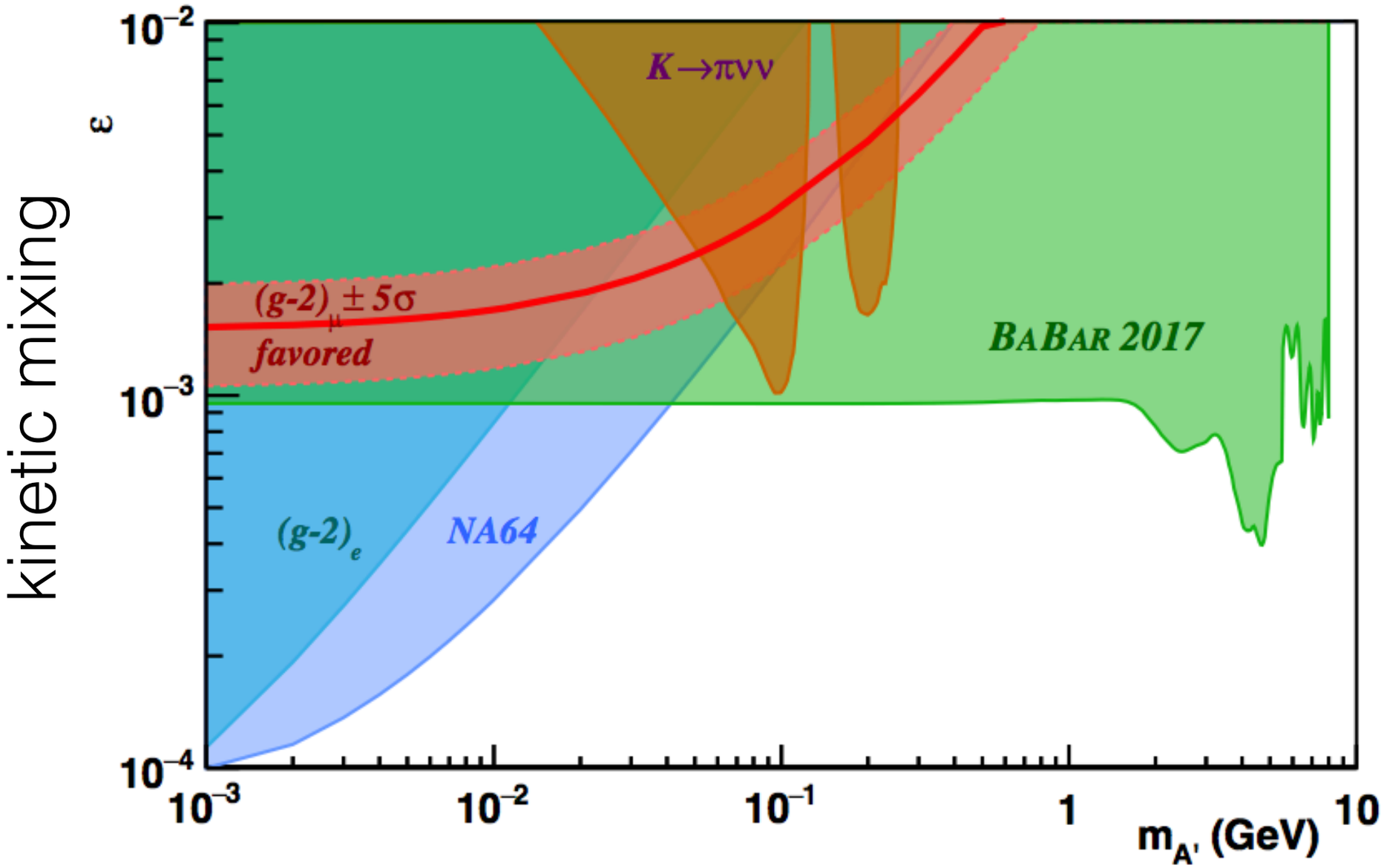

$$A'_\mu \bar{\chi}_1 \gamma^\mu \chi_2$$

diagrams taken from G.Krnjaic's talk at CERN-Korea Institute

It depends on the SM particles it interacts with

**Many high-intensity/low energy experiments have a good sensitivity to it**

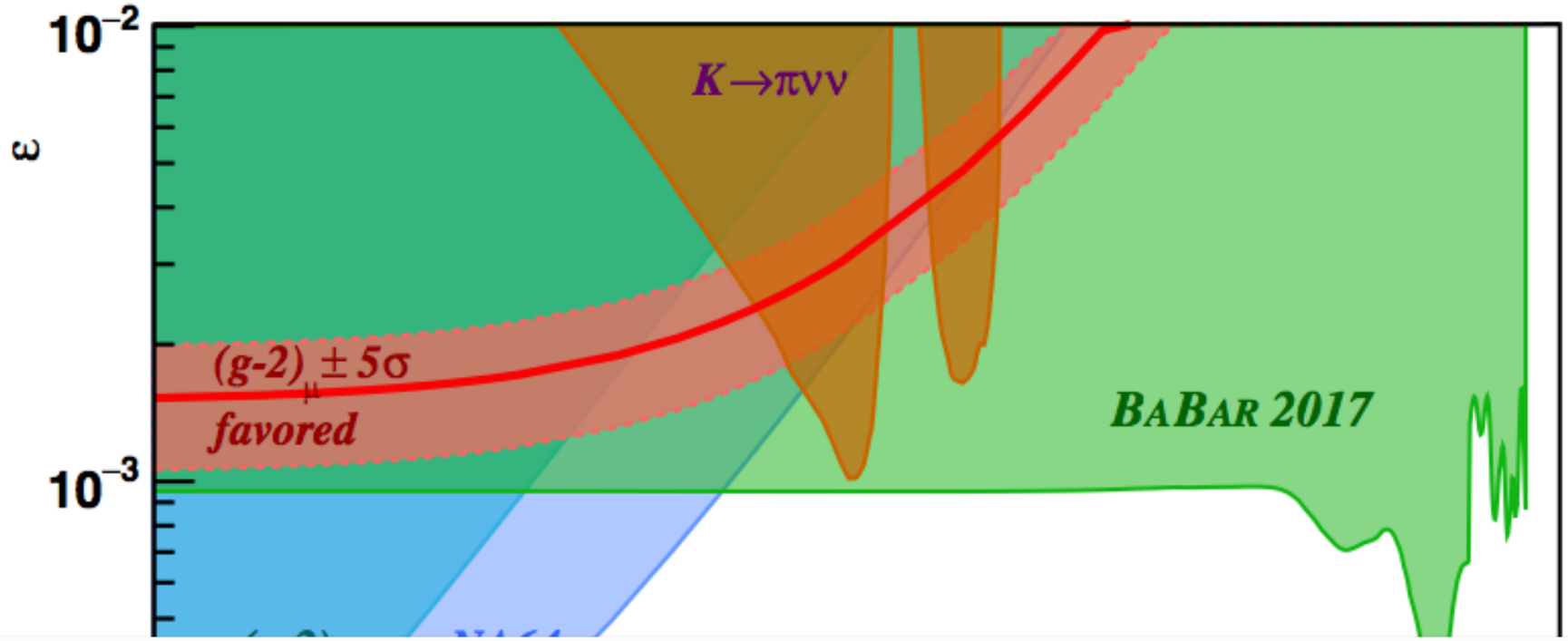
# Invisible decays of dark photon




Many new results  on the way….

NA62 beam dump run, LDMX, BDMX, Belle..

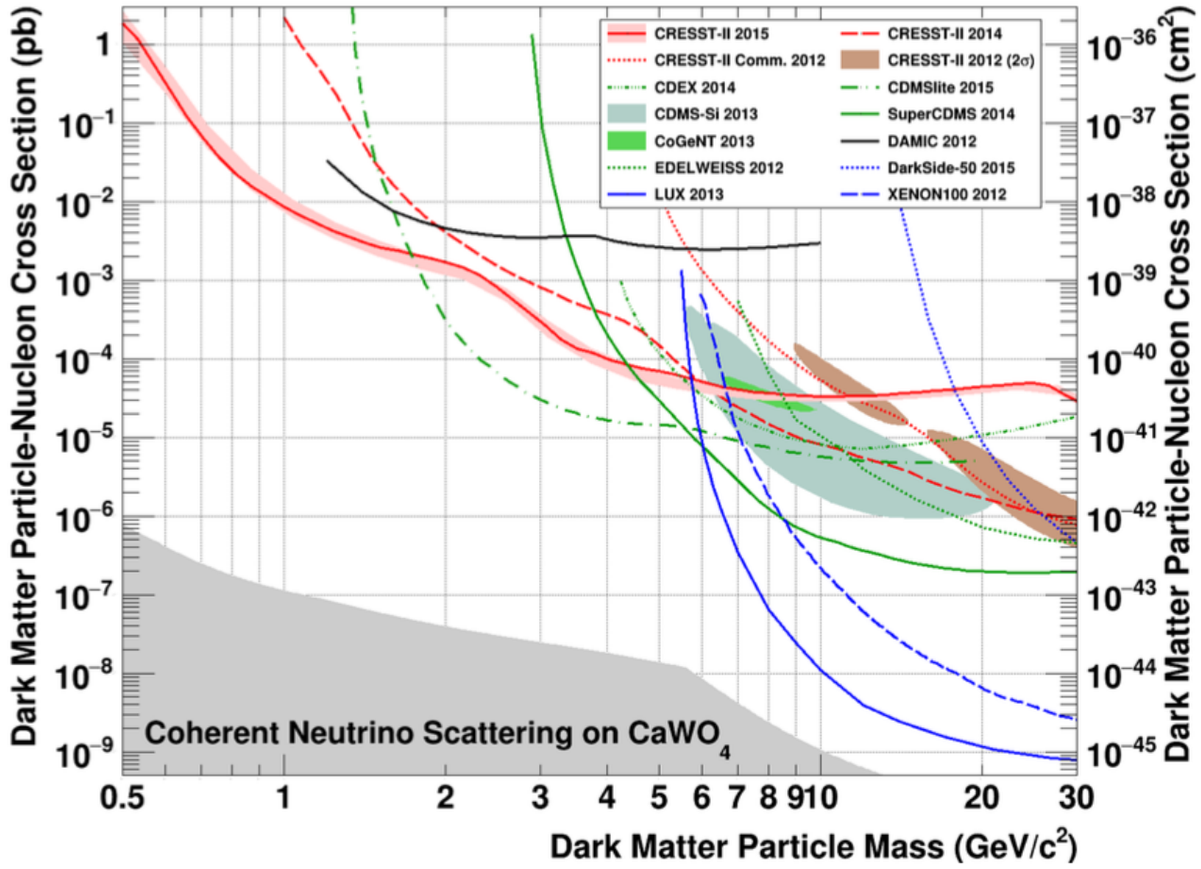
# Invisible decays of dark photon




netic mixing

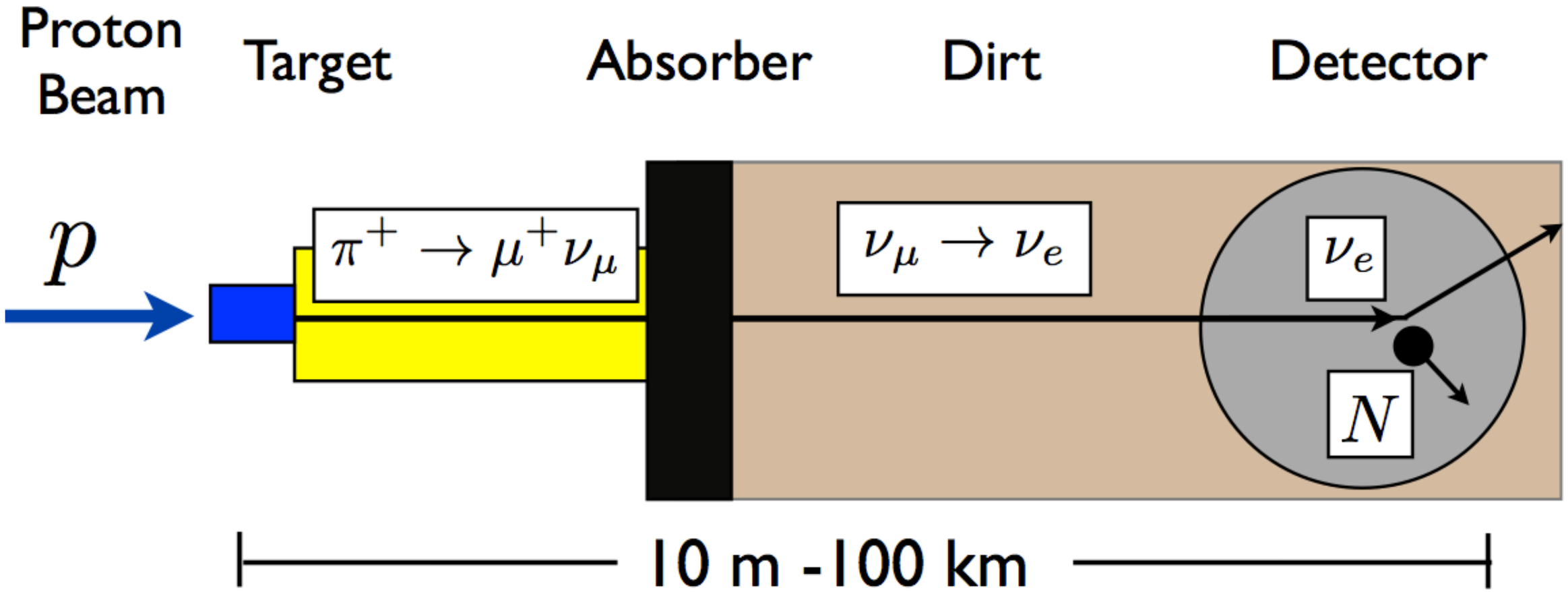
‘Exotic’ applications  of existing data and facilities.
Also dedicated run proposed to extend the reach

# Probing light DM/nucleon coupling @ neutrino facilities



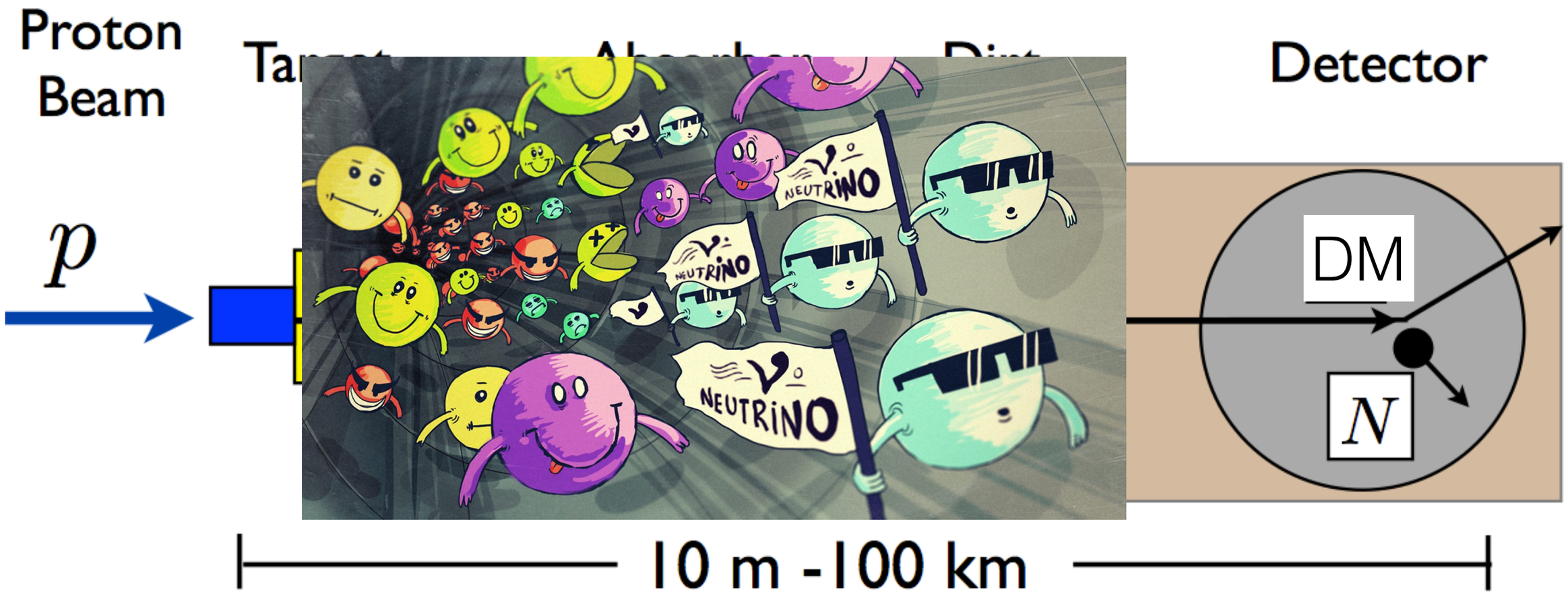

Direct detection (DD) experiments have limited sensitivity for sub-GeV DM.. targeted DD experiments can probe light DM-electron coupling

# Neutrino facilities physics goal: $\nu$ masses and mixings



# A new goal: discover light dark matter

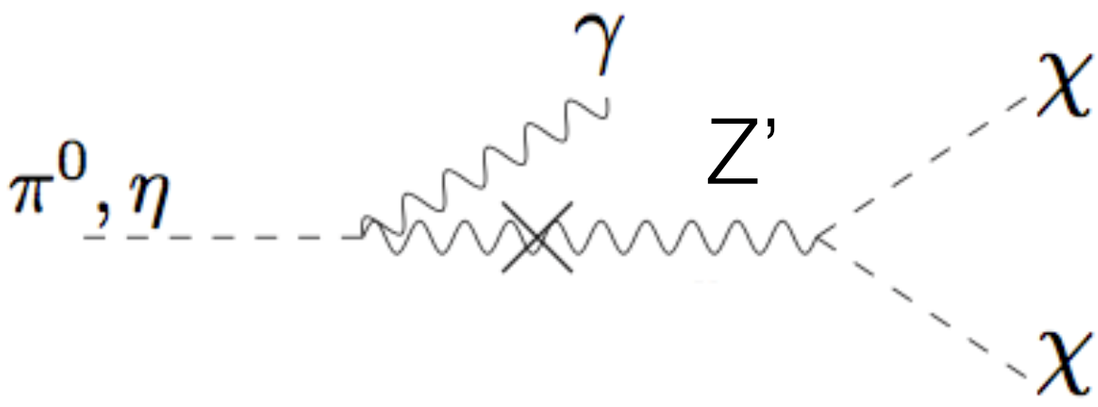
*[Batell, Pospelov and Ritz, 2009]*



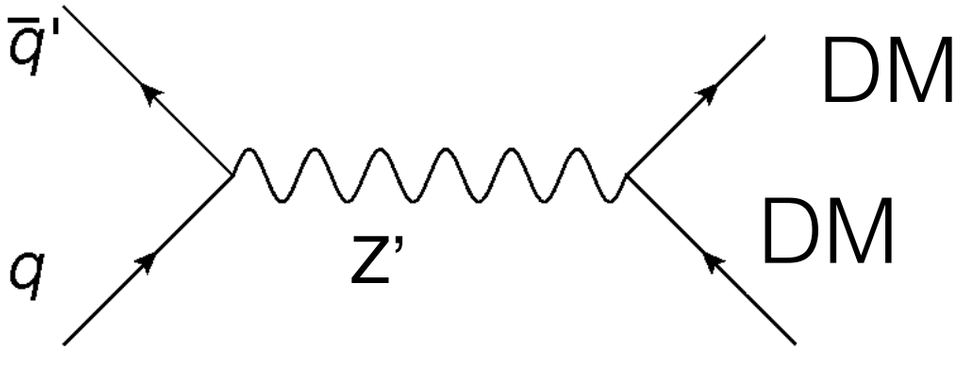
# How is a DM beam produced?

Assume dark matter interacts with quarks via a new force mediated by a Z' boson with mass in **MeV-GeV** range

- Production via meson decay



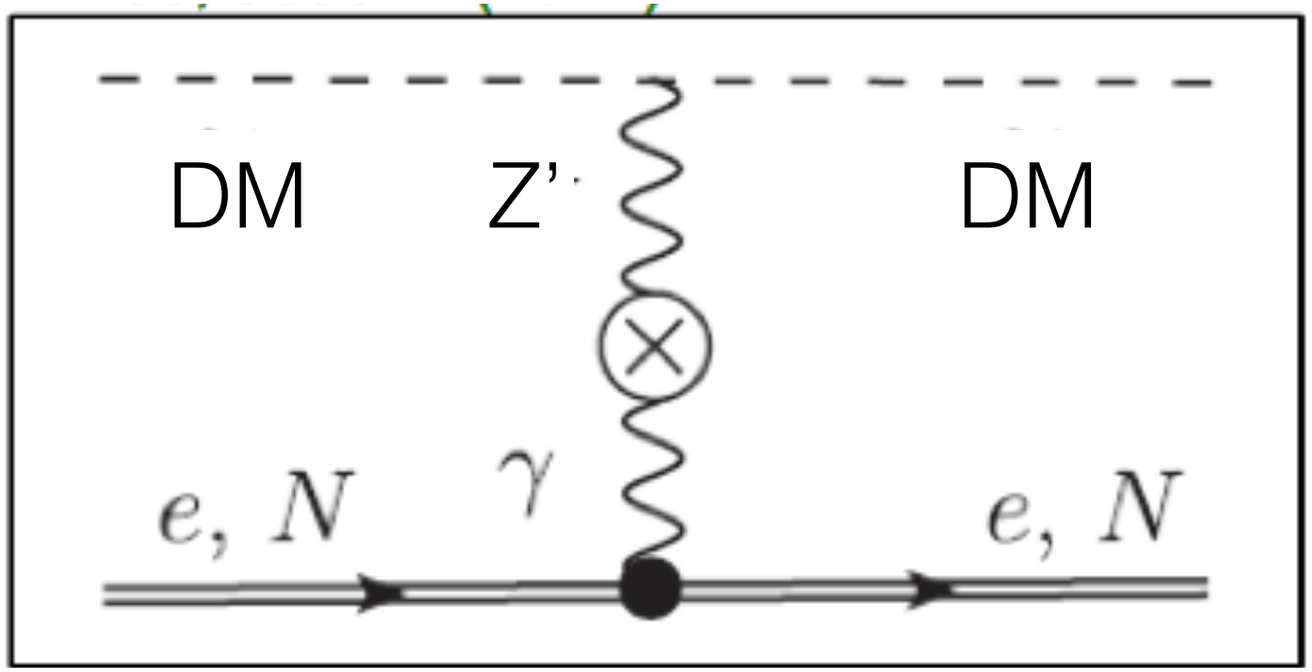

- Direct production




NLO process

$$pp \to Z' j$$

# How do we detect DM ?



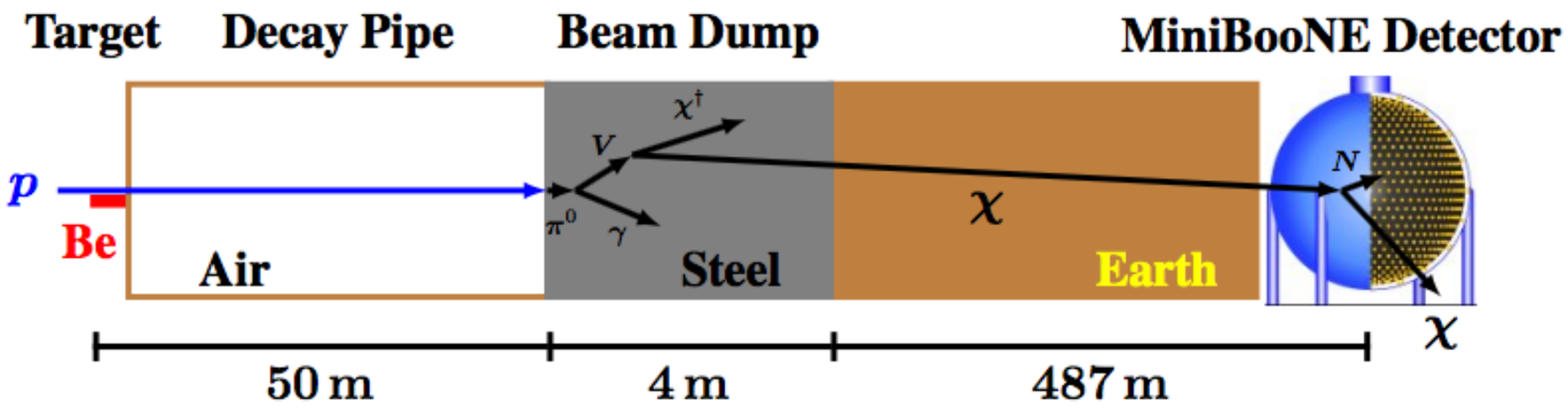

dark matter-nuclei scattering
inside the neutrino near detector

Main challenge:

suppression of neutrino background

# DM searches @ MiniBooNE

MiniBooNE:800 tons detector




- Light dark matter search published by the collaboration February 2017 [A.A. Aguilar-Arevalo et al. 2017]

- Strong constraints for sub GeV Z'

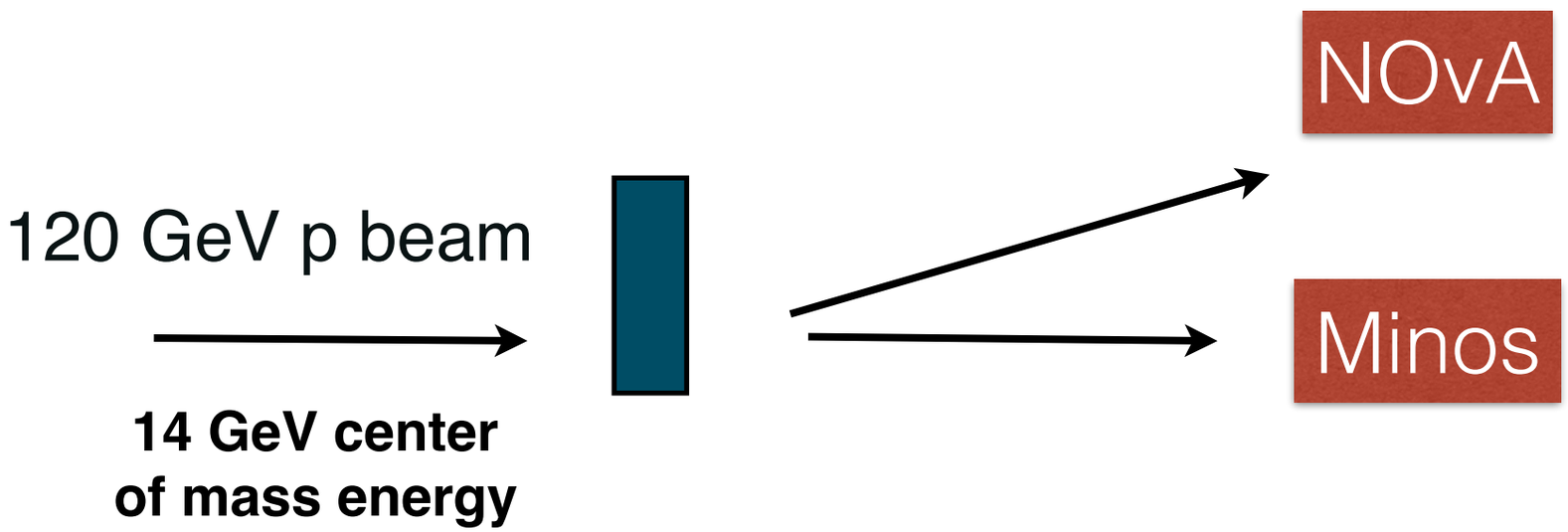
- Light dark matter program calls for a special run to suppress the neutrino background

What are the possibilities at other neutrino facilities?

# Main injector facility @ FNAL

[Dobrescu, CF 2014]
[Dobrescu, Coloma, CF, Harnik 2015]
[CF 2017]

What are the physics opportunities of a higher proton beam?

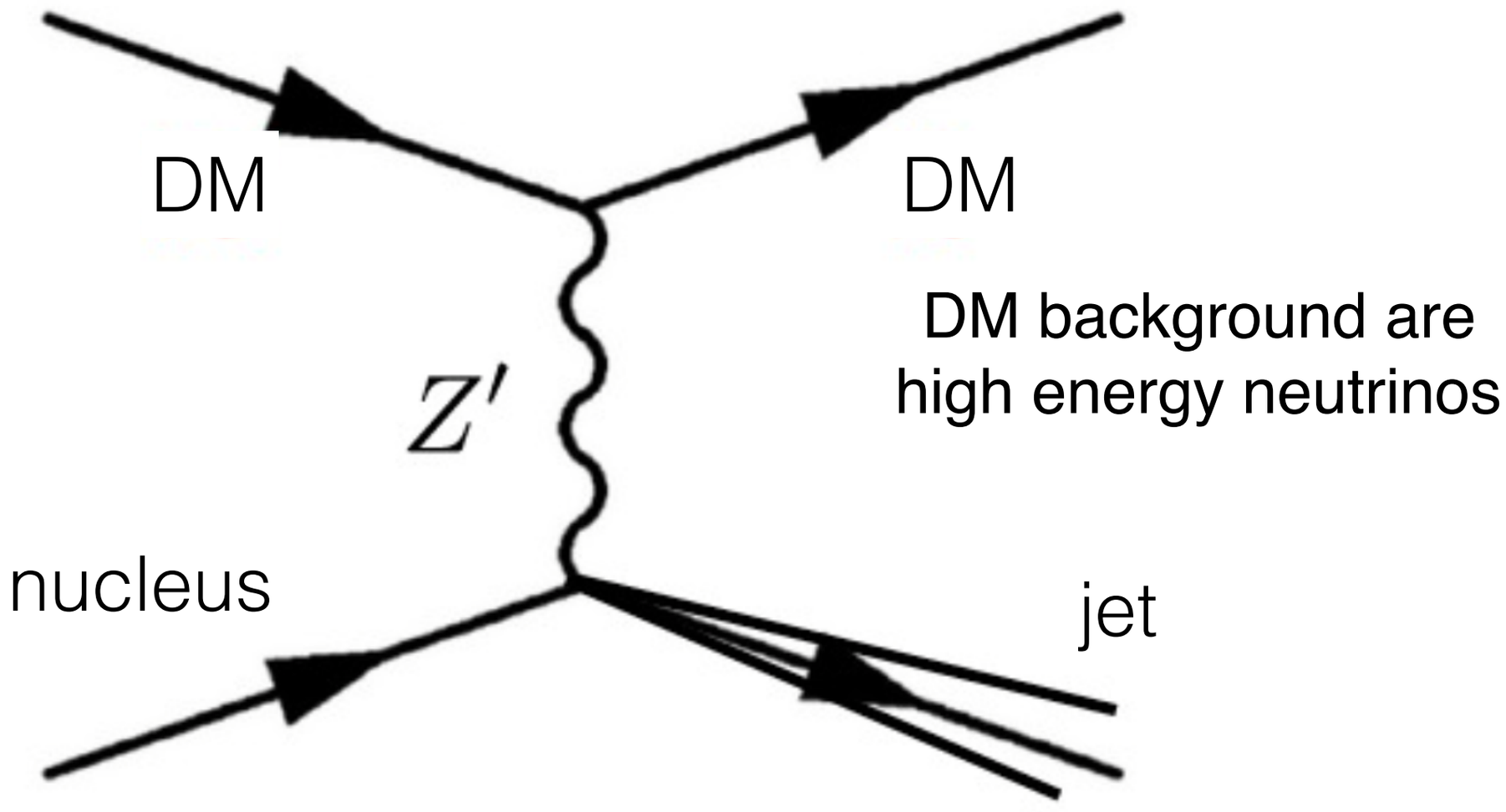



We can produce a large number of Z' gauge bosons with mass up to 7-8 GeV

# DM detector signal

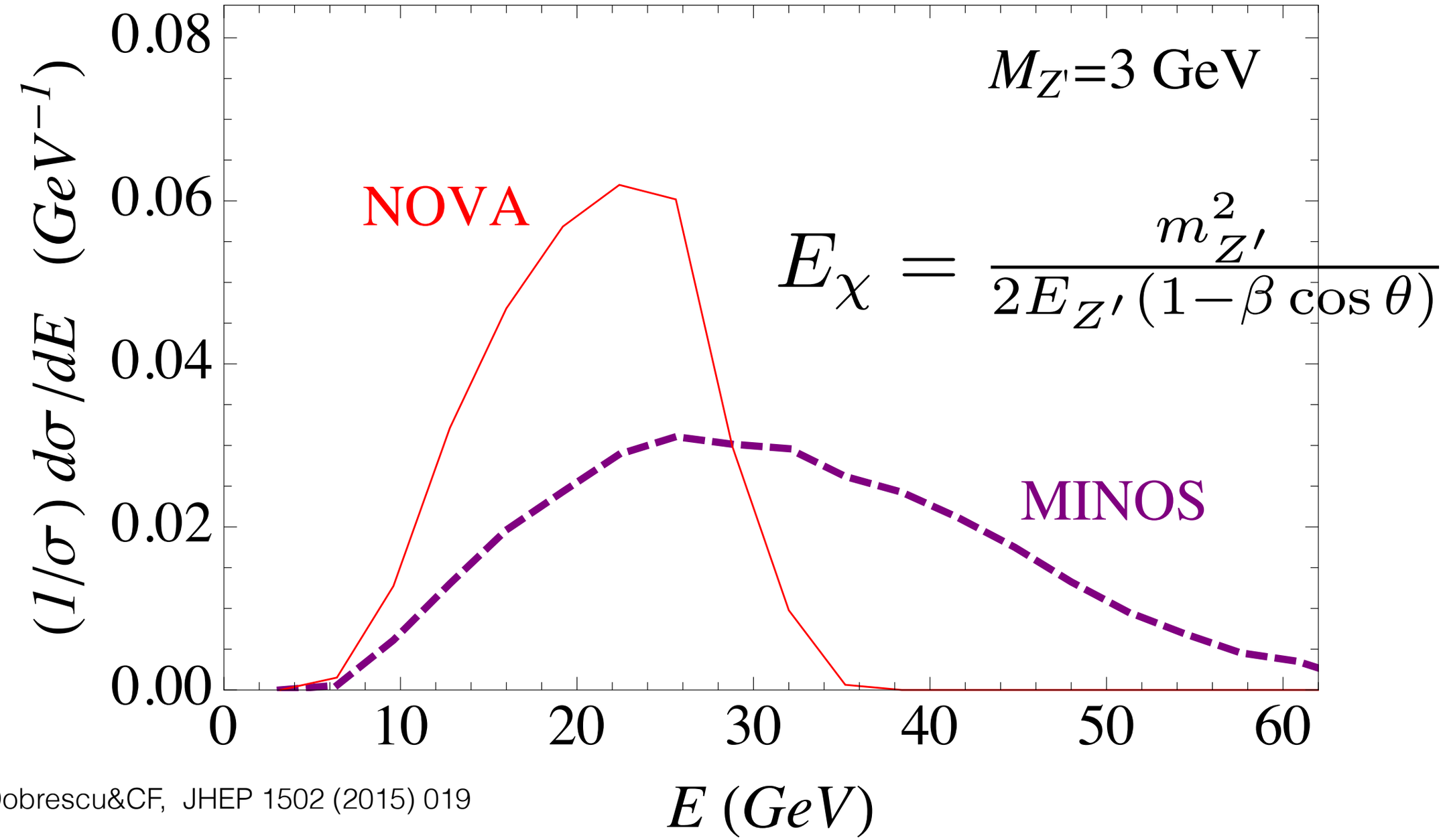
DM enters the detector with high energy

Characteristic signal is deep inelastic scattering with nucleons!




DM background are high energy neutrinos

# DM energy spectrum

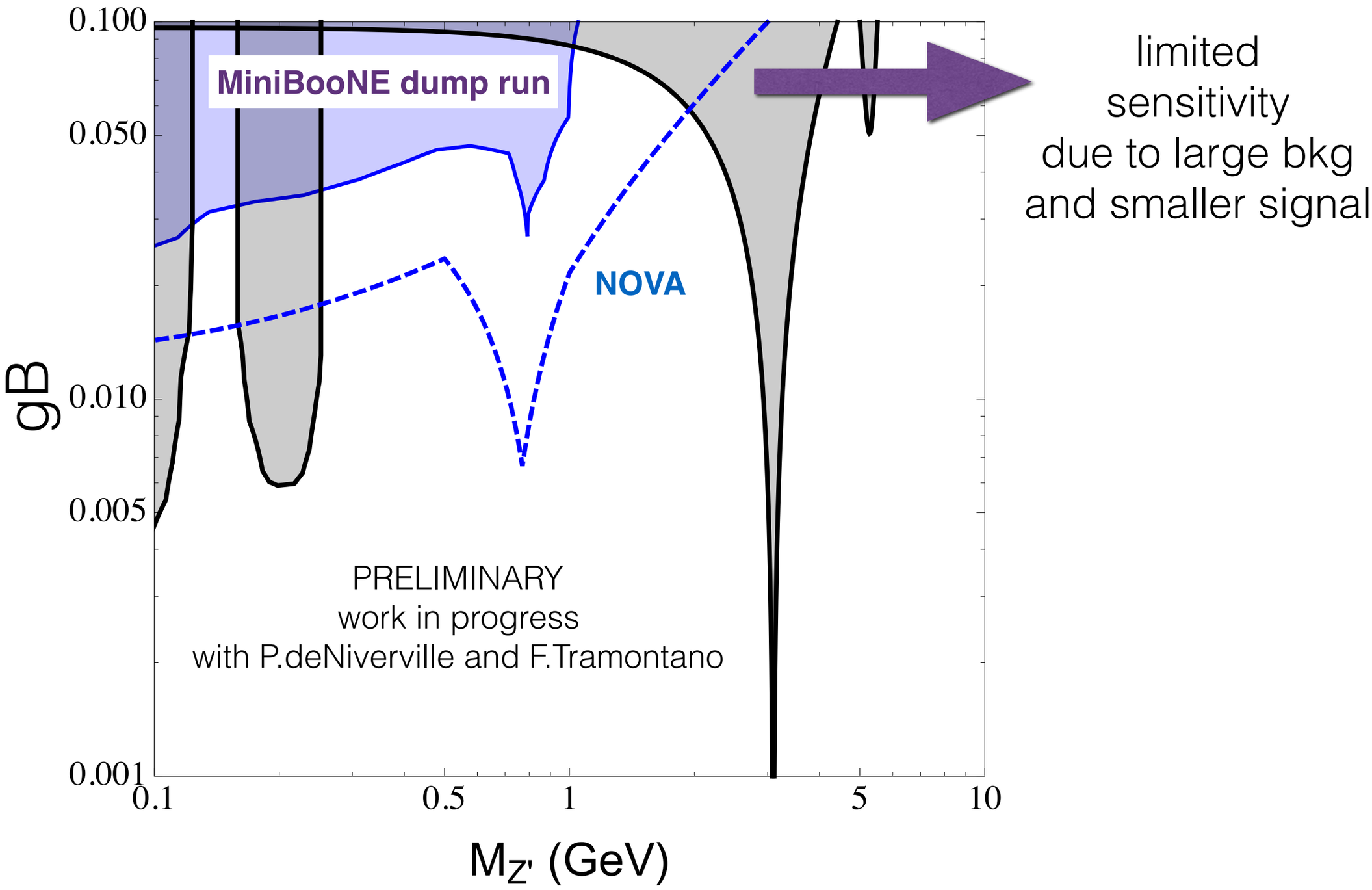



Dobrescu&CF, JHEP 1502 (2015) 019

DM energy peak is significantly higher than neutrino peak

# NOVA & MINOS limits

NC DIS neutrinos events $\sim 10^6$ $N_{\mathrm{POT}} = 10^{21}$




limited sensitivity due to large bkg and smaller signal

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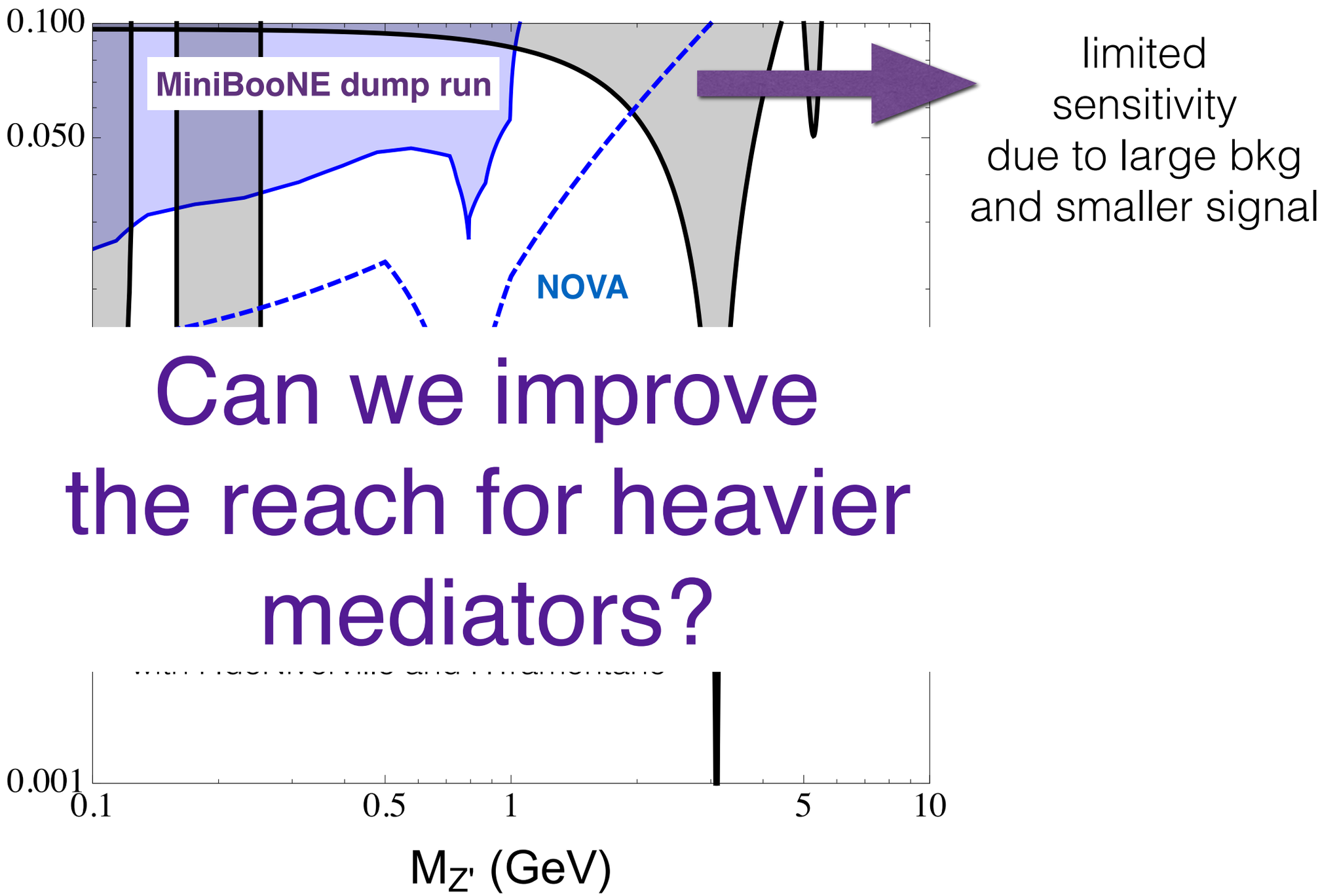
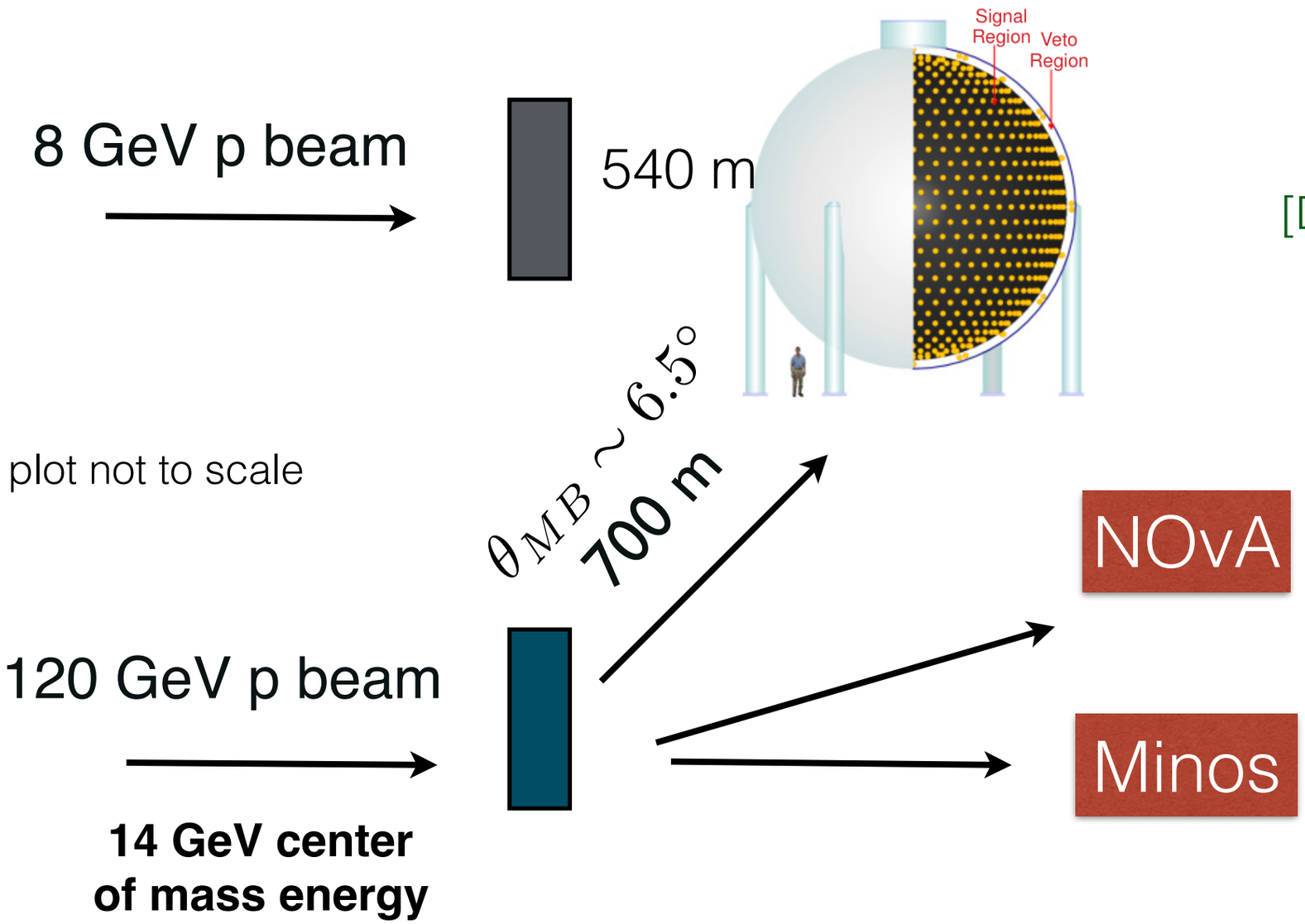



limited sensitivity due to large bkg and smaller signal

Can we improve the reach for heavier mediators?

# Main injector facility

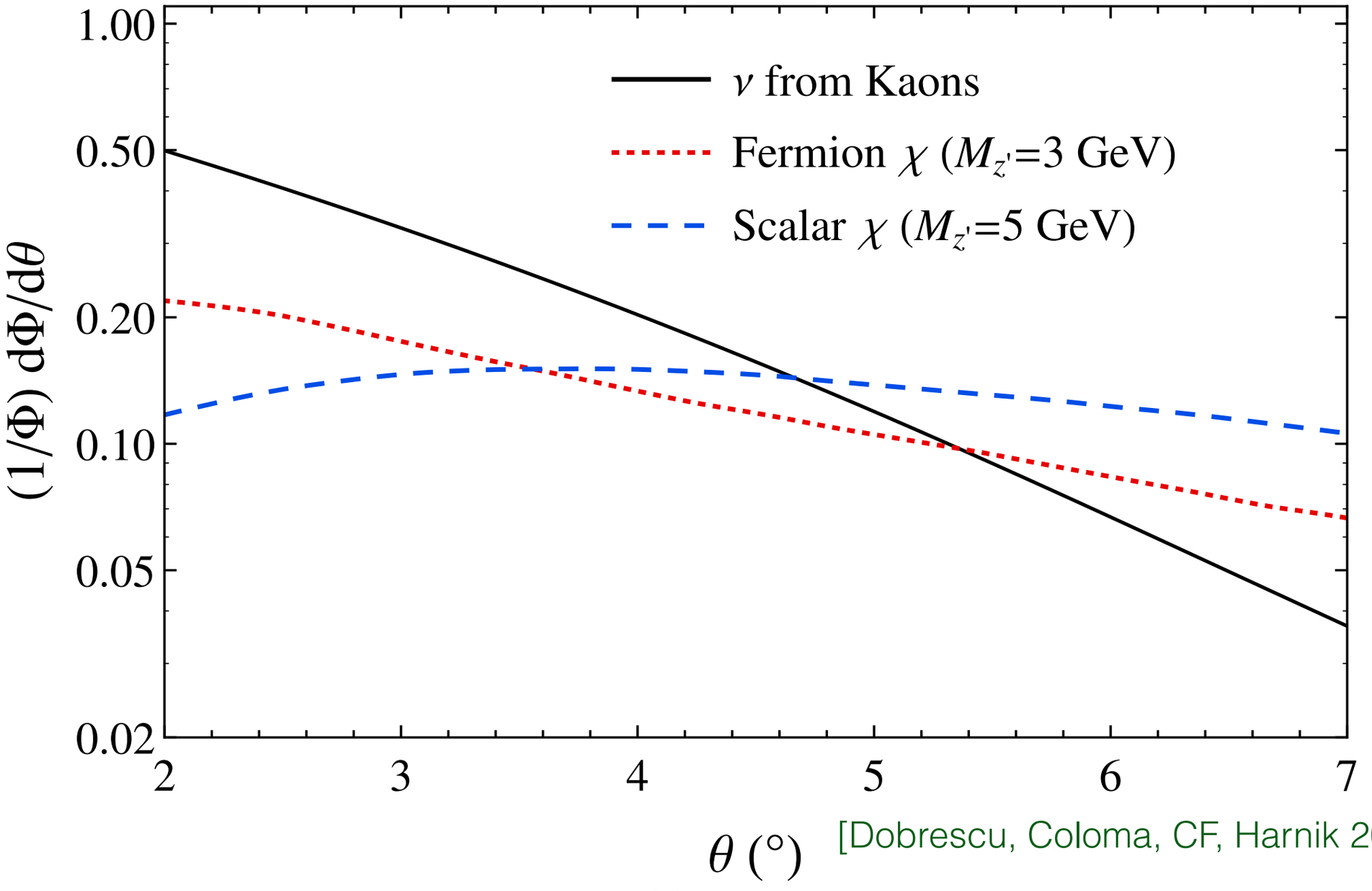



[Dobrescu, CF 2014]
[Dobrescu, Coloma, CF, Harnik 2015]
[CF 2017]

MiniBooNE is an off axis detector for the NuMI facility!

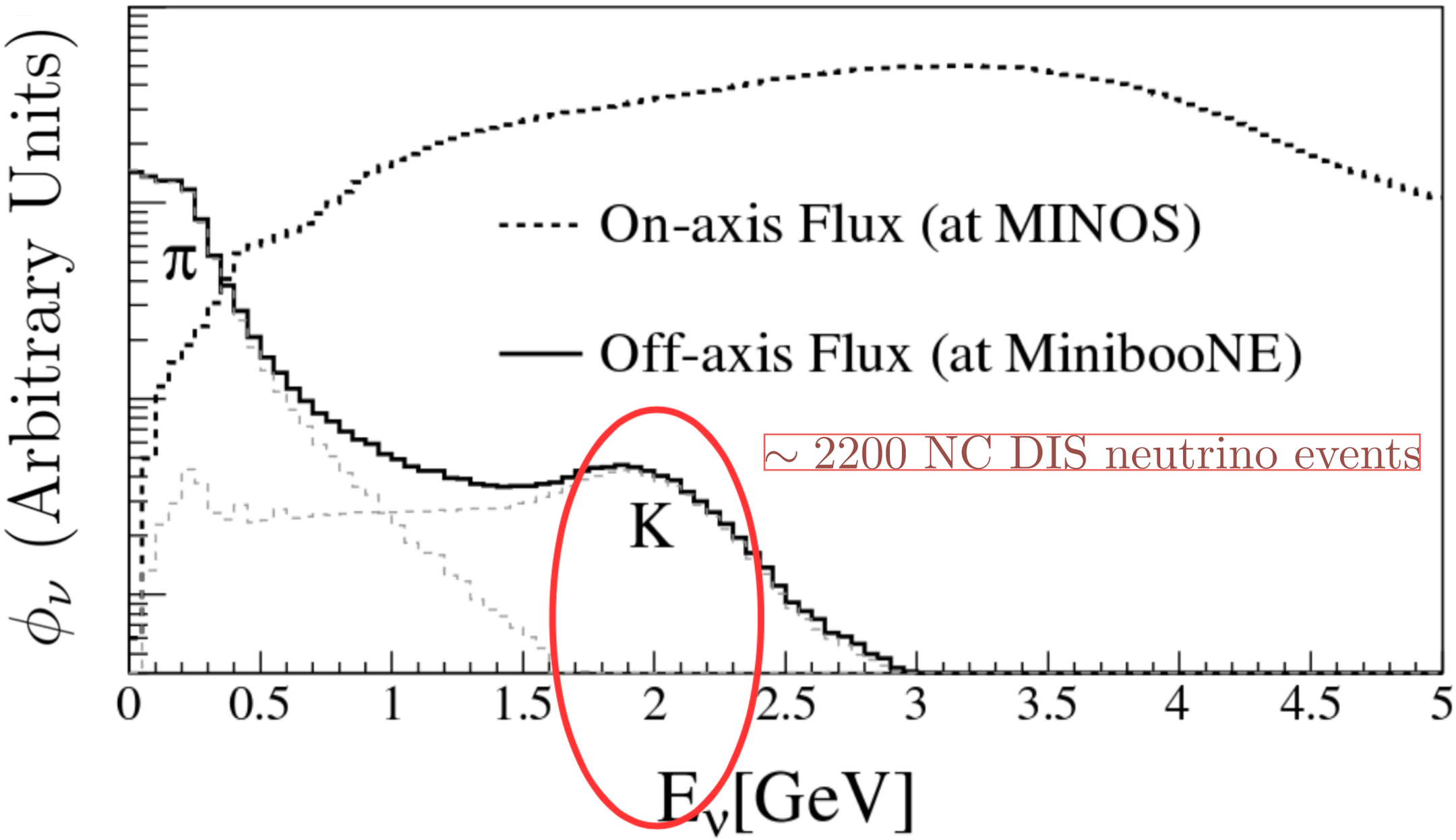
# Off-axis detectors for DM

MiniBoonNE's location with respect to the Main injector beam is ideal



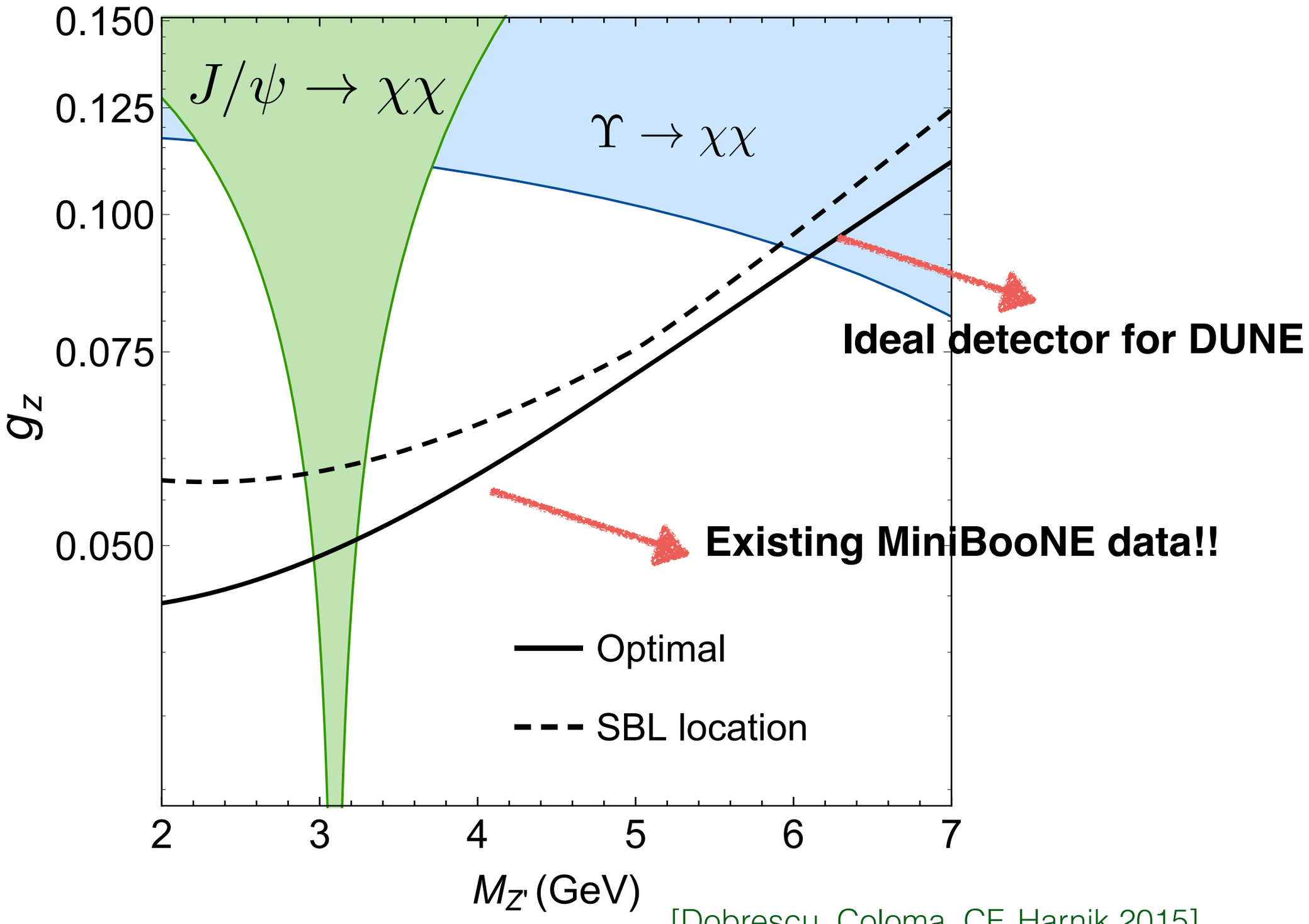

[Dobrescu, Coloma, CF, Harnik 2015]

# Off-axis neutrino background




The energy of neutrinos is too
small to give rise to numerous deep inelastic scattering events

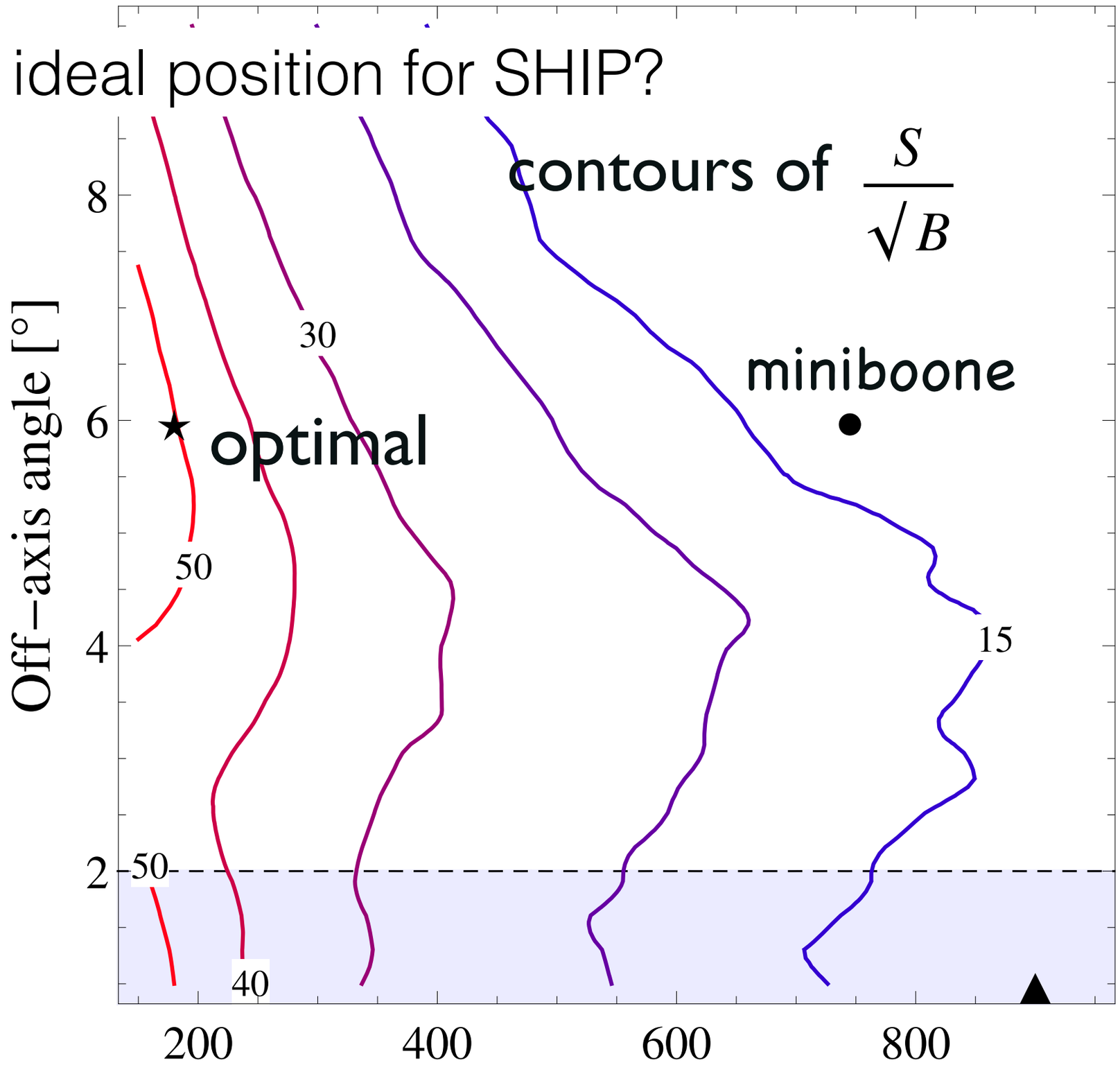
# Projected sensitivity




[Dobrescu, Coloma, CF, Harnik 2015]

# Ideal position for a future LBNF detector

What is the ideal position for SHIP?

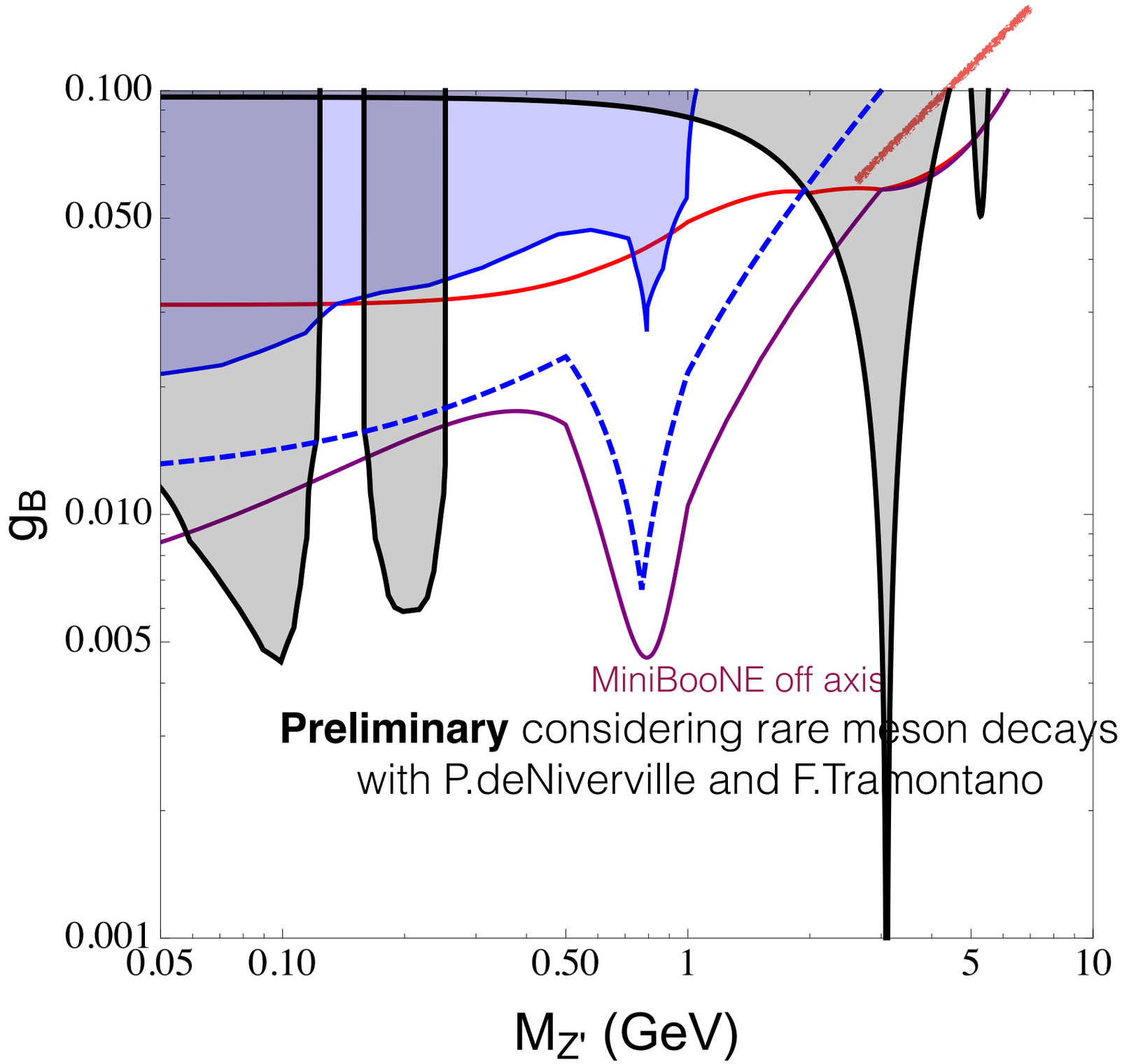



$g_z = 0.1$

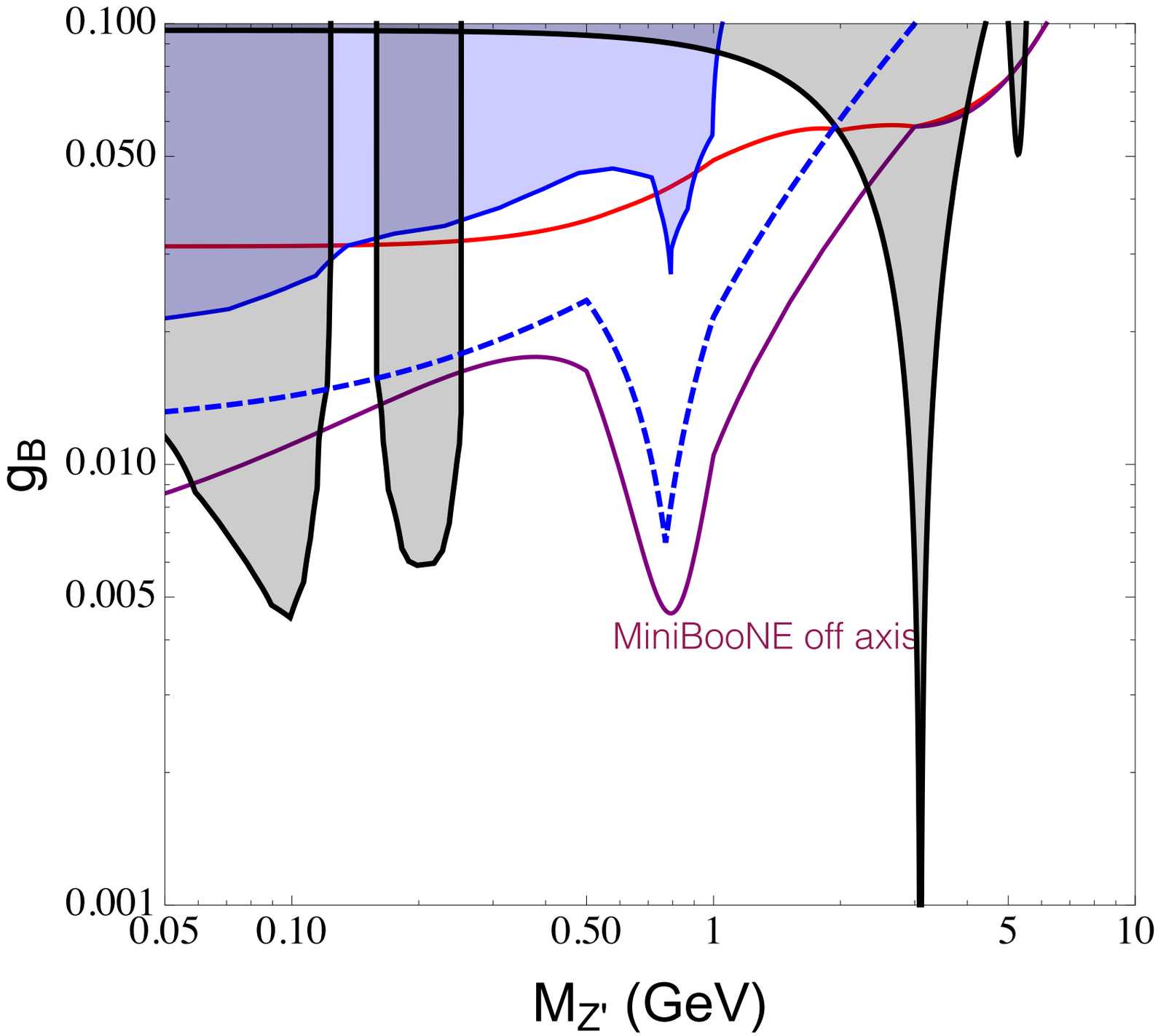
[Dobrescu, Coloma, CF, Harnik 2015]

# Looking at the entire region

CF, 2017 only considering pp->Z'j



# Improvement possible using EXISTING data!
# DM program can be fully symbiotic to the neutrino program!



# More to explore

- MiniBooNE dedicated analysis (including systematics, etc) using Main Injector data?

- Other possibilities to use MiniBooNE and the other NuMI detectors existing data for exotic signals?

- What are the prospects to probe dark matter/ nucleon coupling at SHiP (Search for Hidden Particles, the new proposed CERN proton fixed target experiment)?

Work in progress with P.deNiverville and F.Tramontano