Dark matter signatures in NOvA

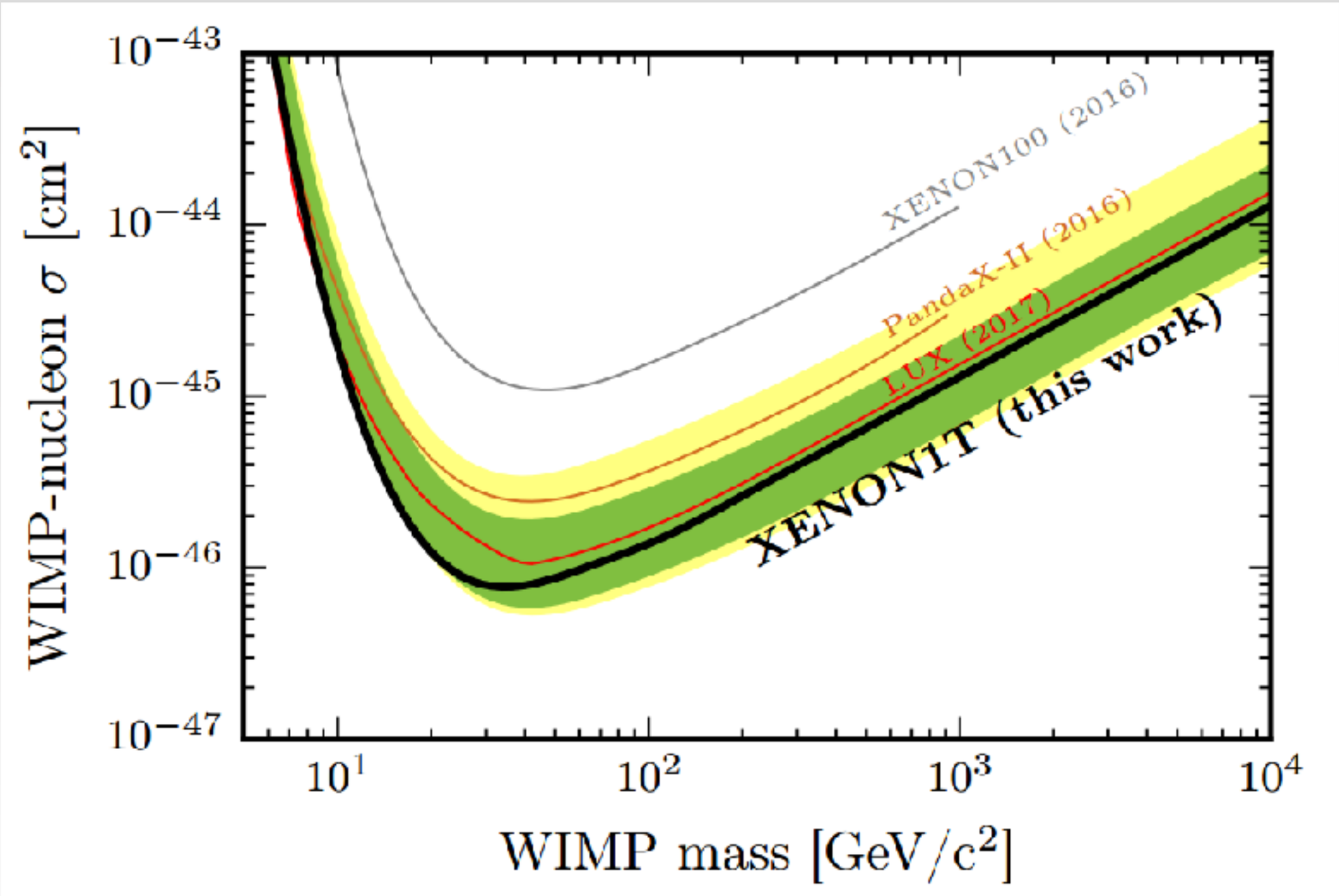
Claudia Frugiuele

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Preliminary work in collaboration with P. DeNeverville and A. Hatzikoutelis

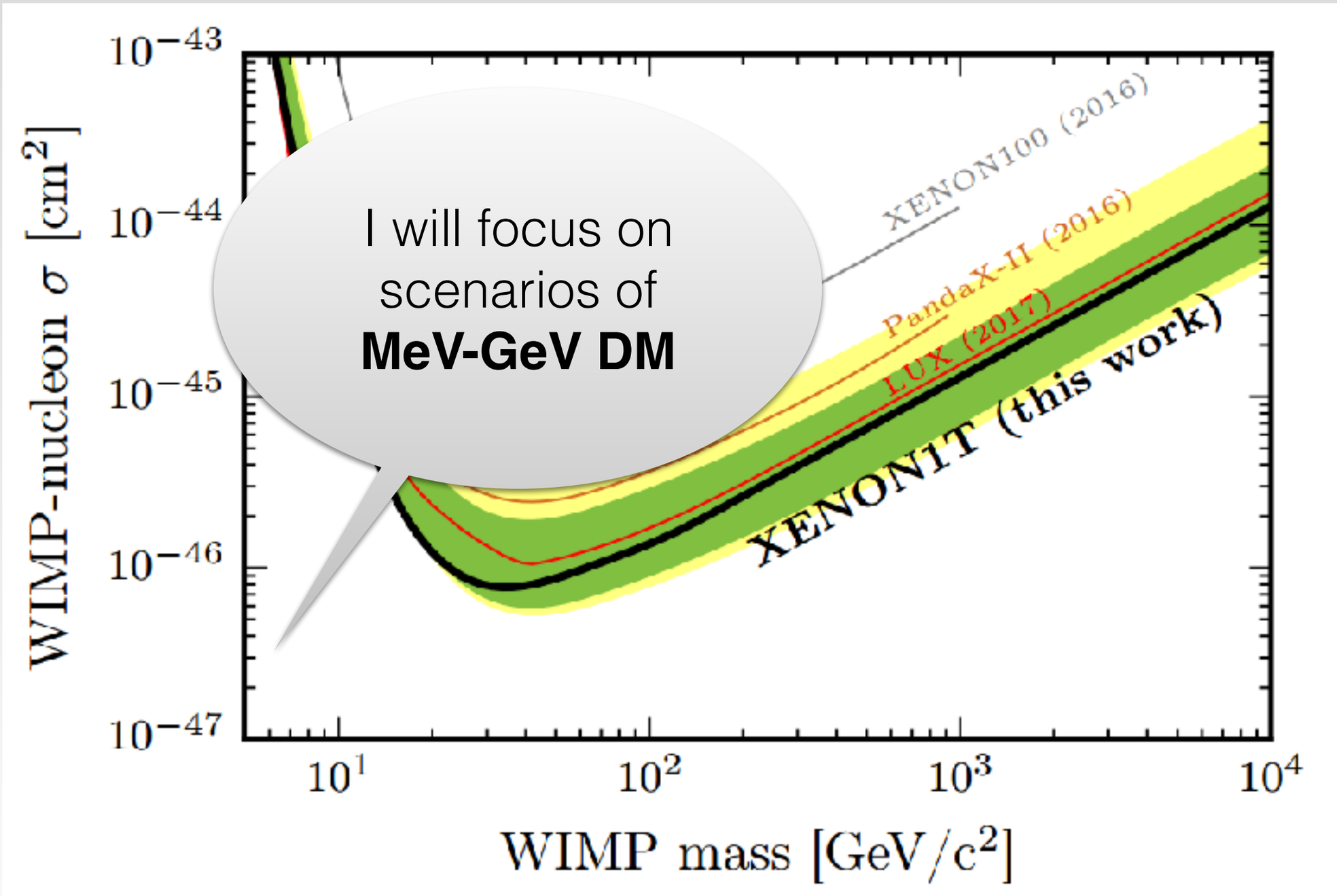
Aspen Winter 2018 “ The Particle Frontier”

Dark matter beyond WIMPs?



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

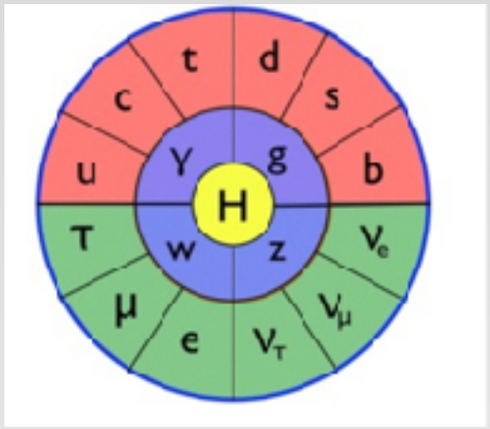
Dark matter beyond WIMPs?



I will focus on scenarios of **MeV-GeV DM**

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

MeV-GeV thermal DM



MeV-GeV dark force

DM

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

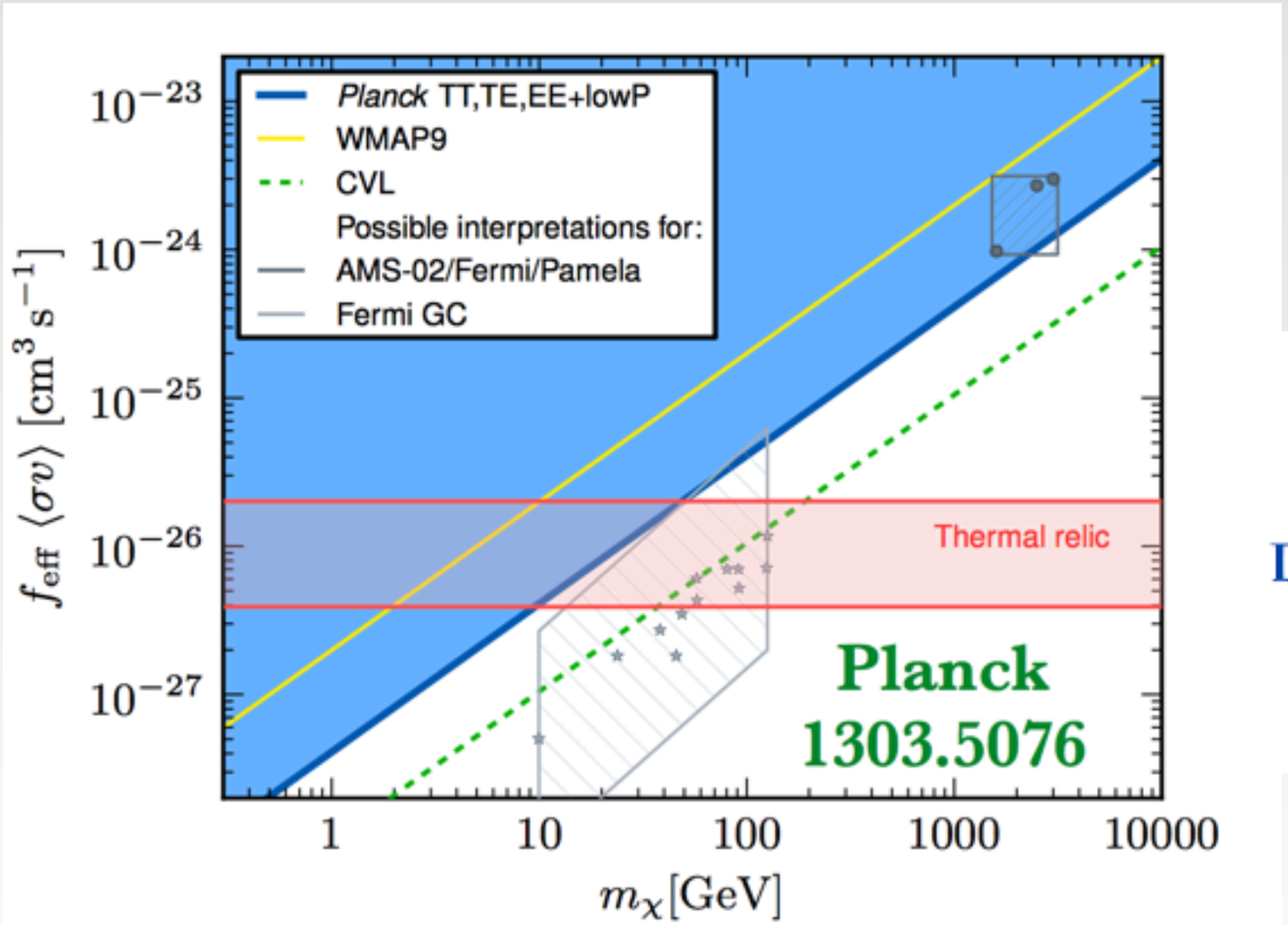
Minimal and predictive framework
Unconstrained by standard DM laboratory probes

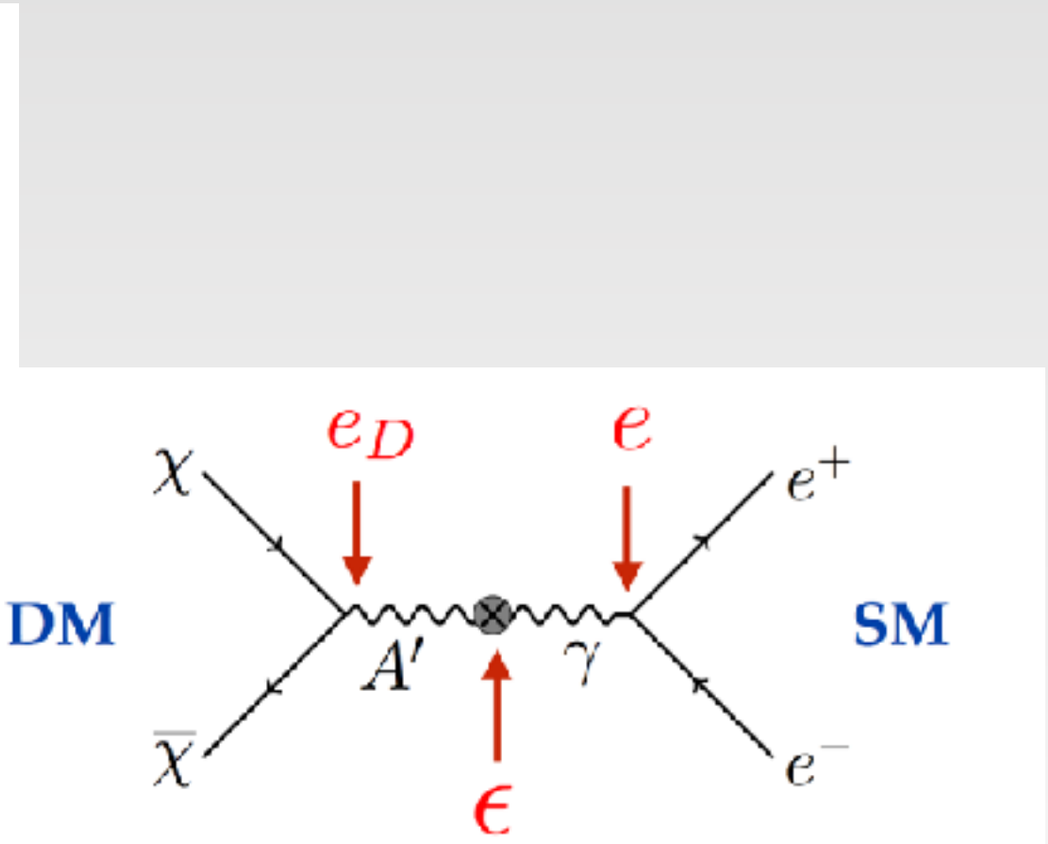
How do we look for such a DM candidate?

MeV-GeV thermal DM

We are not entering an unexplored territory…

Annihilation if s-wave is ruled out by CMB

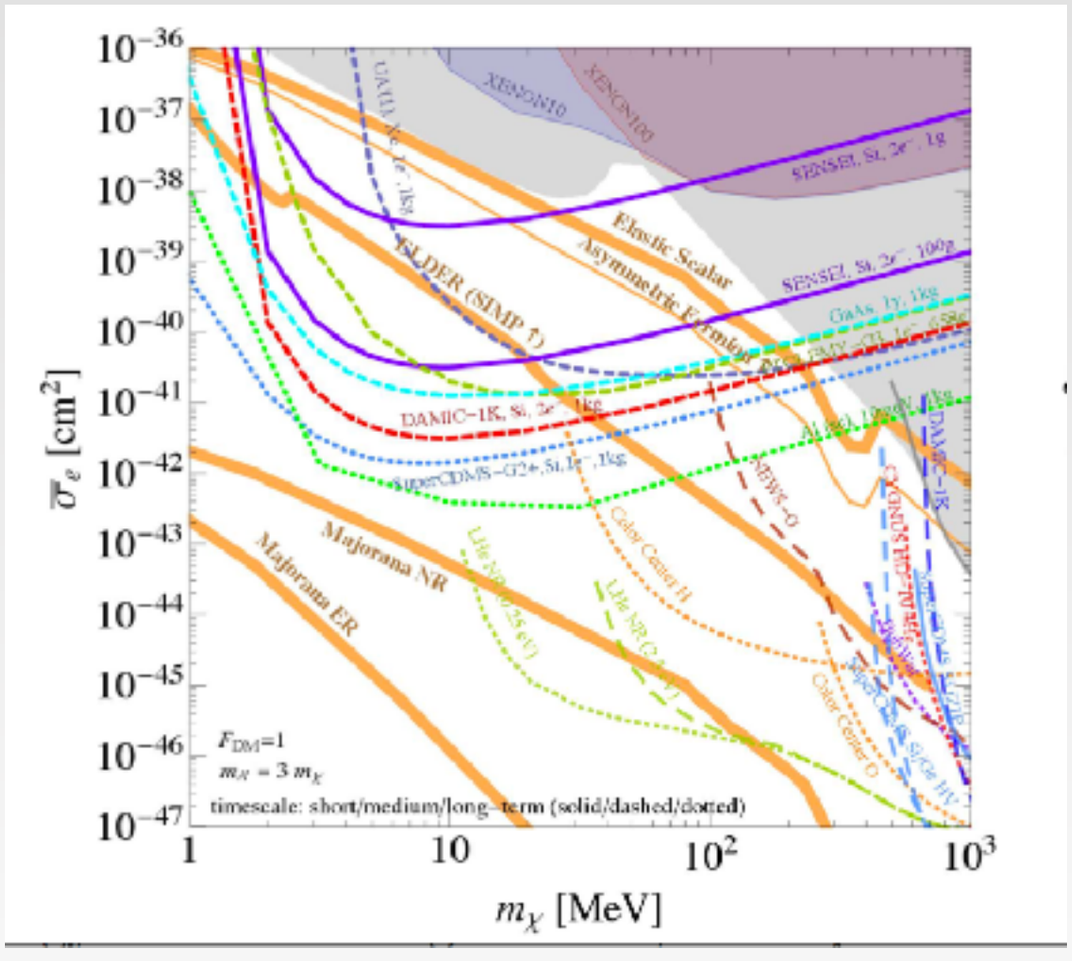


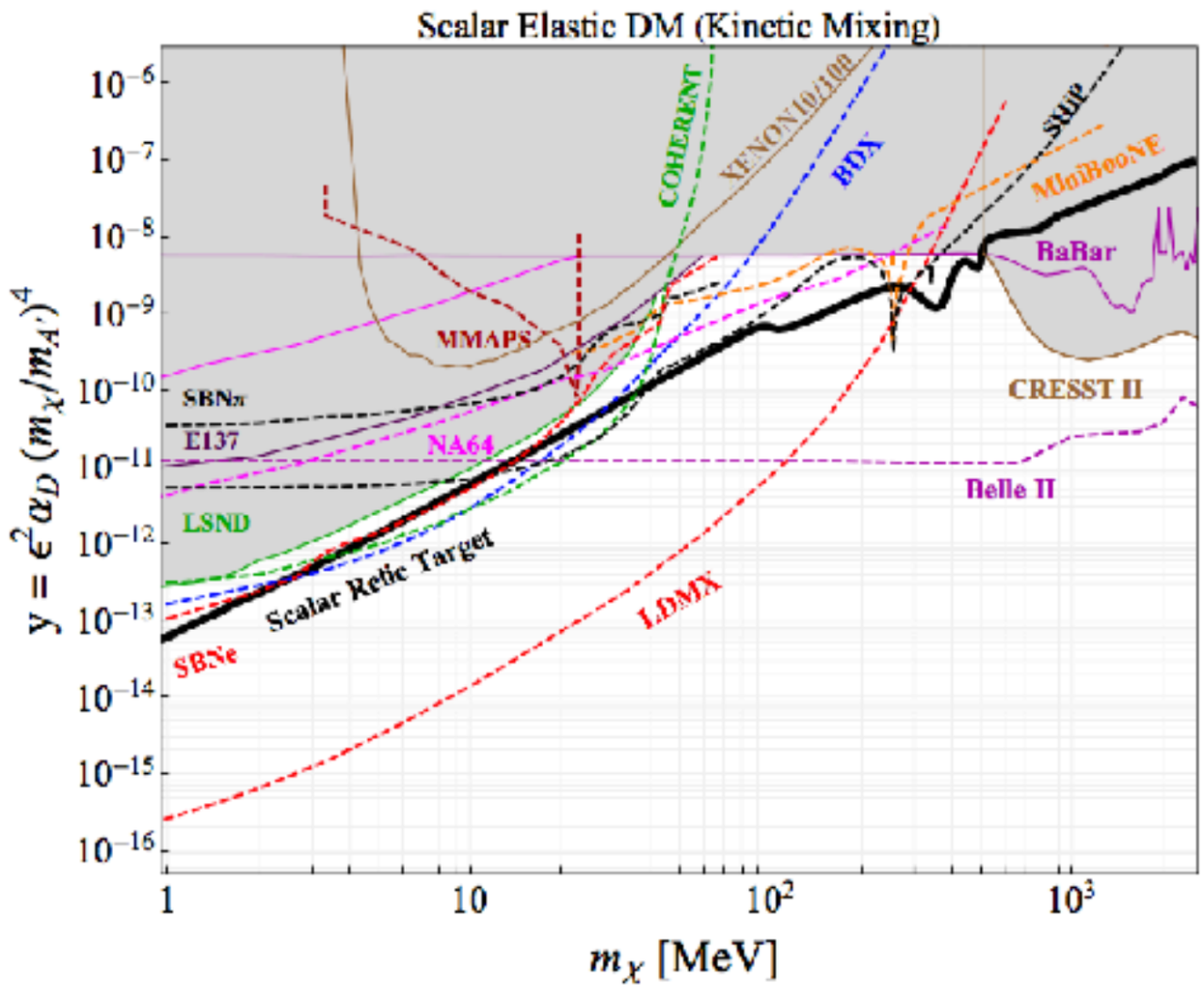


However, a lot of parameter space is still open
(scalar, pseudo-Dirac, and Majorana DM)

Many proposal for new ways to look for DM in this window

From US Cosmic Vision 2017





New generation direct detection experiments , LDMX, BDX…

Many proposal for new ways to look for DM in this window

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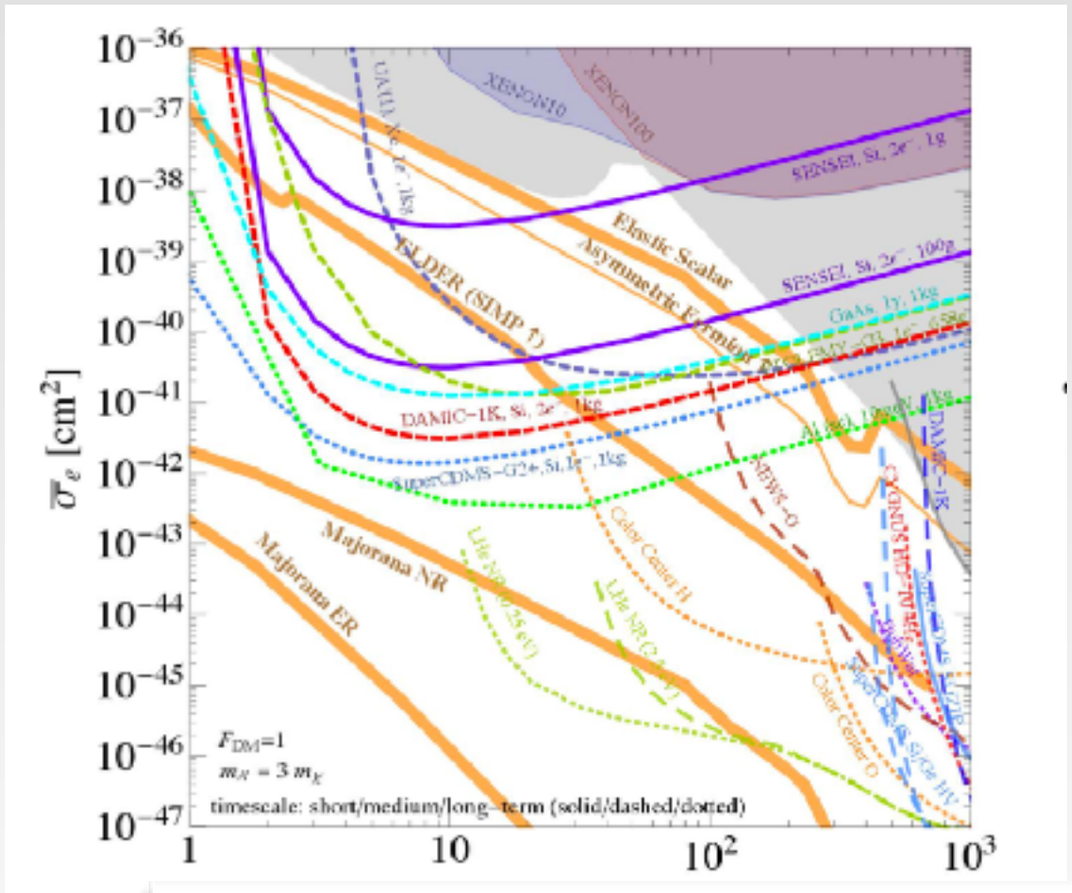
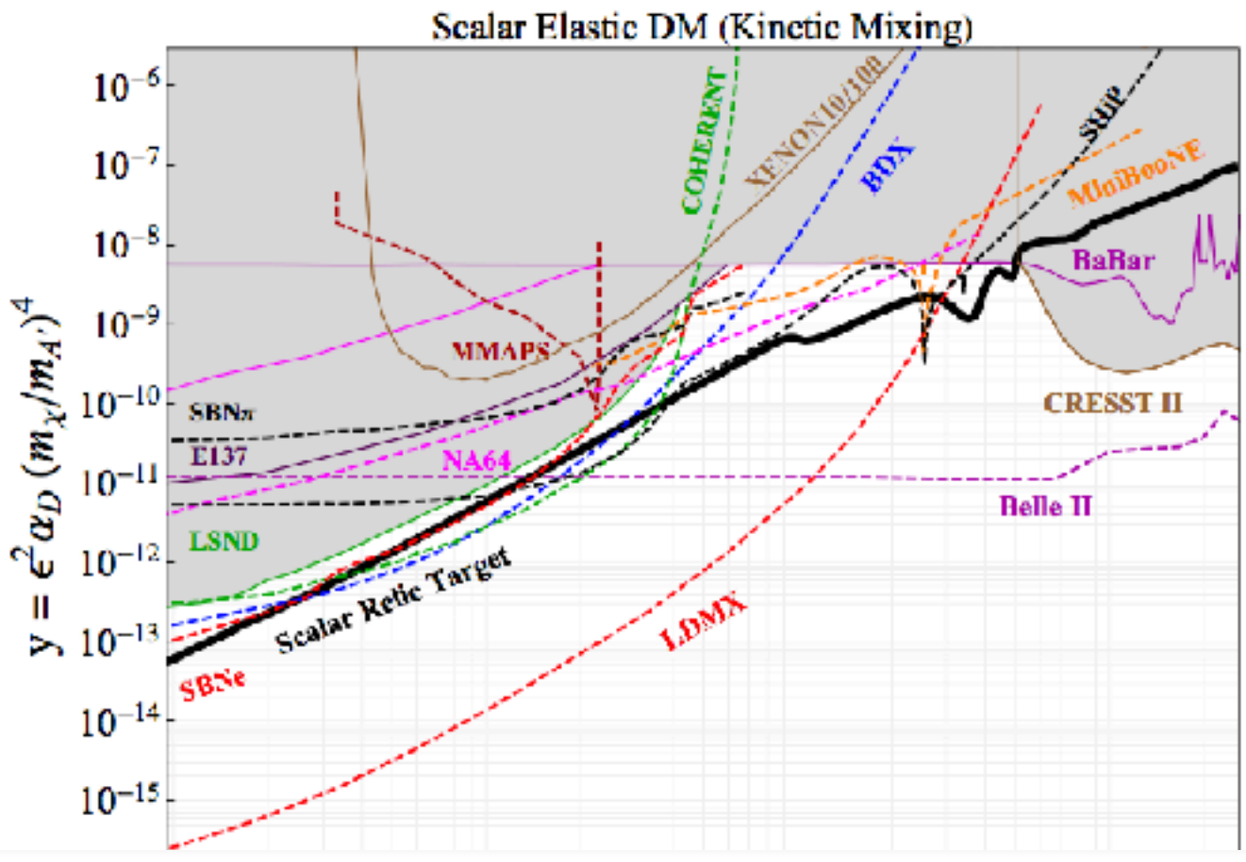
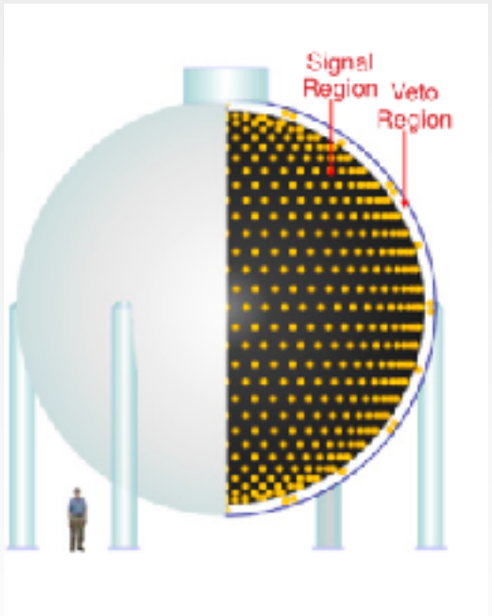




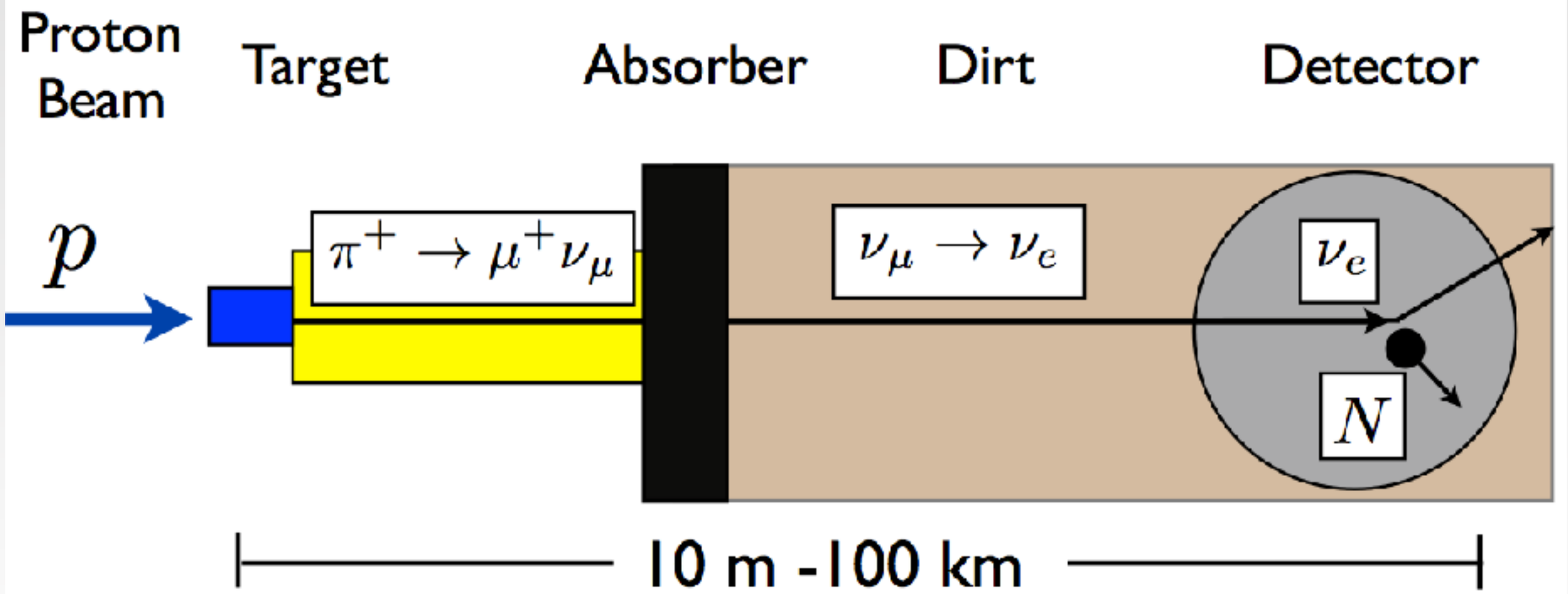
What about existing data?
Did we exhaust their "power"?

Searching for light dark matter @ neutrino facilities



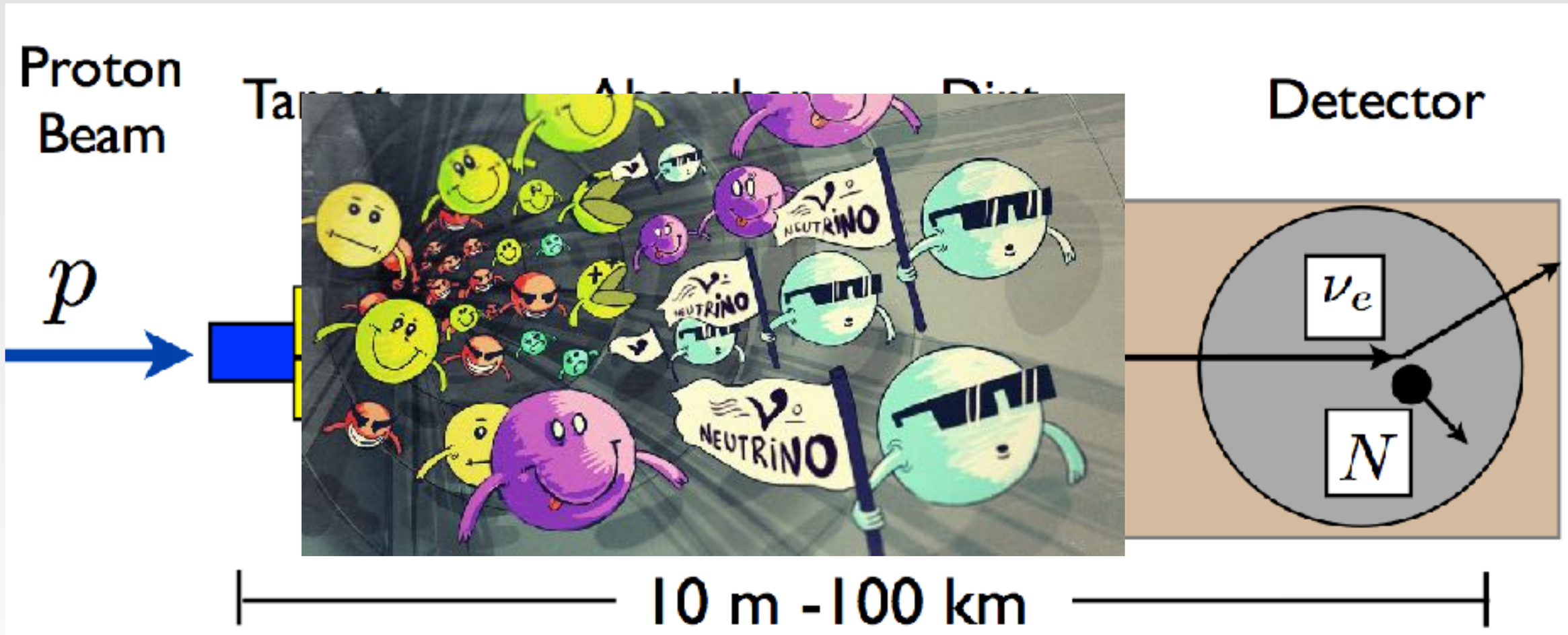
New proposal: use neutrino facilities to search for light dark matter

Original goal: measuring neutrino masses and mixings



New proposal: use neutrino facilities to search for light dark matter

New complementary goal: dark matter (DM) discovery



A relativistic DM beam is produced along the neutrino one.
DM particles also enter the detector and scatter off electrons and nuclei

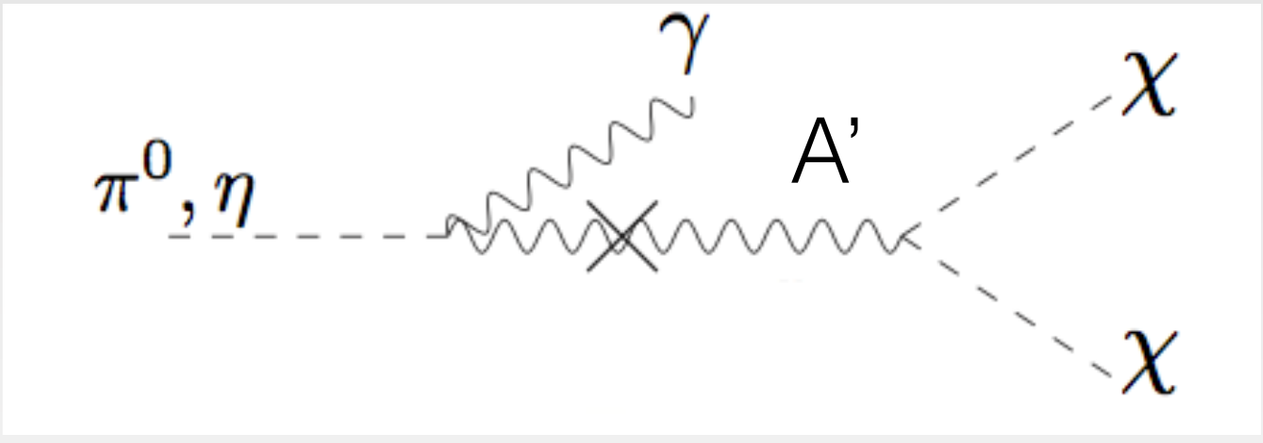
How is a DM beam produced?

Vector portal

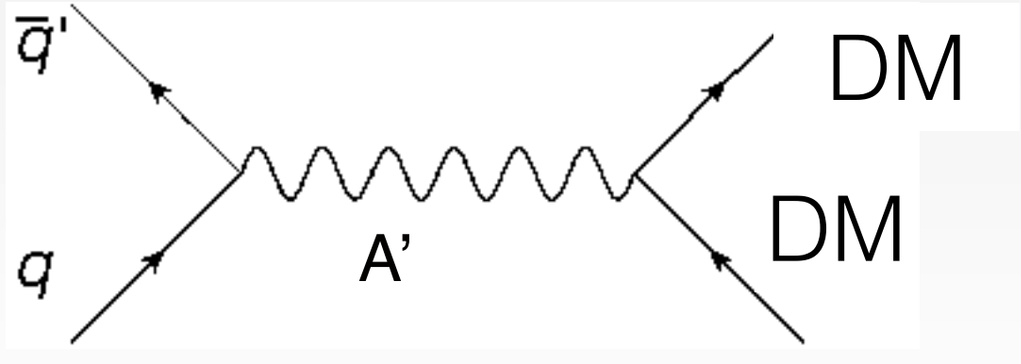
Assume dark matter interacts with quarks via a new force mediated by a Z' boson with mass in MeV-GeV range

- Production via meson decay

[Batell, Pospelov and Ritz, 2009]

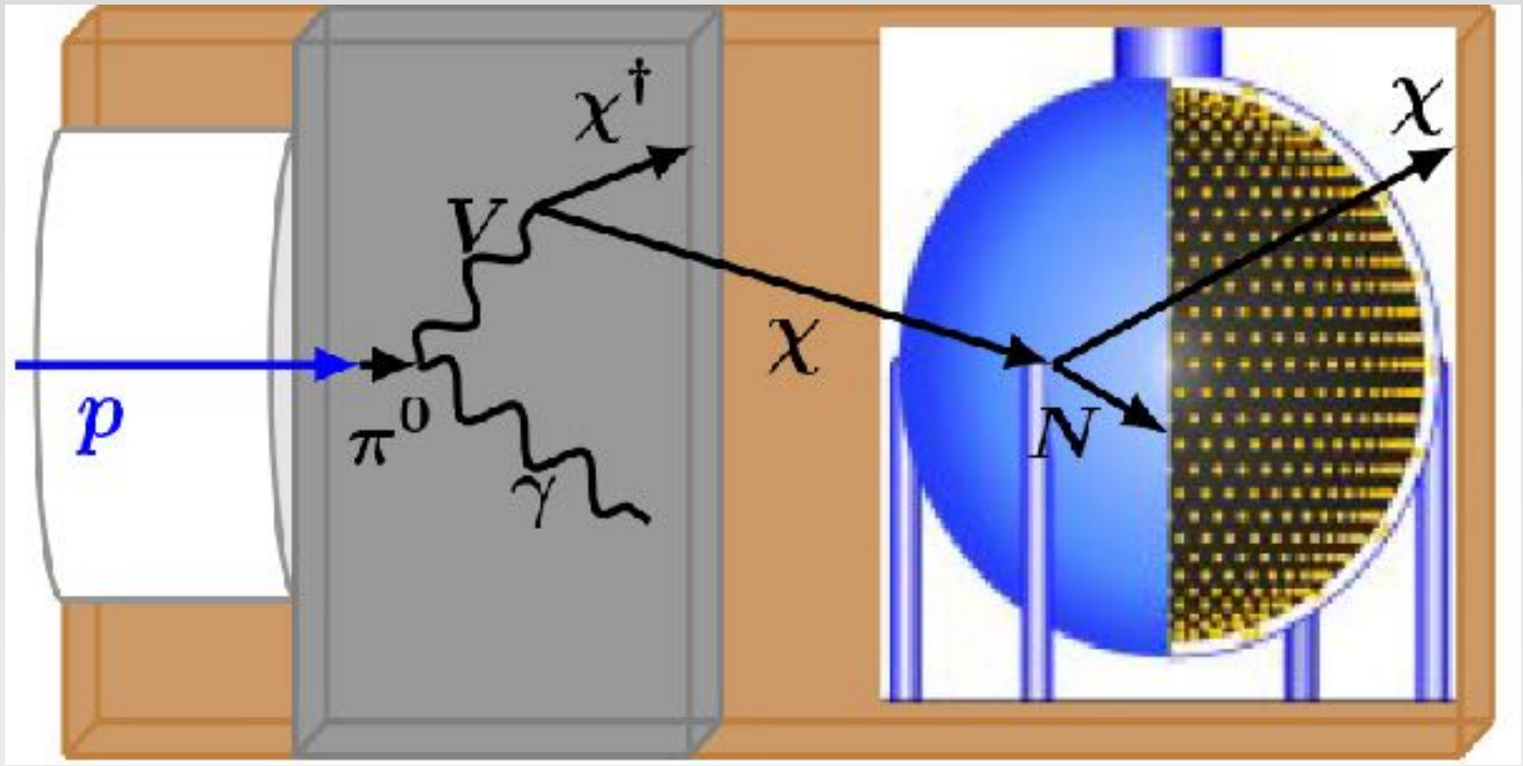


- Direct production



High intensity experiments:
order 10^20
protons on target per year!

How do we detect DM ?



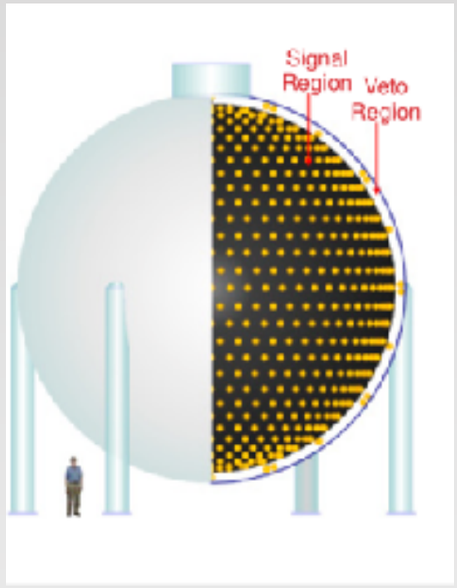
dark matter-nuclei/electron scattering
inside the neutrino near detector

Main challenge:
suppression of neutrino background…

DM search @ MiniBooNE

8 GeV p beam

540 m



MiniBooNE:800 tons detector

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

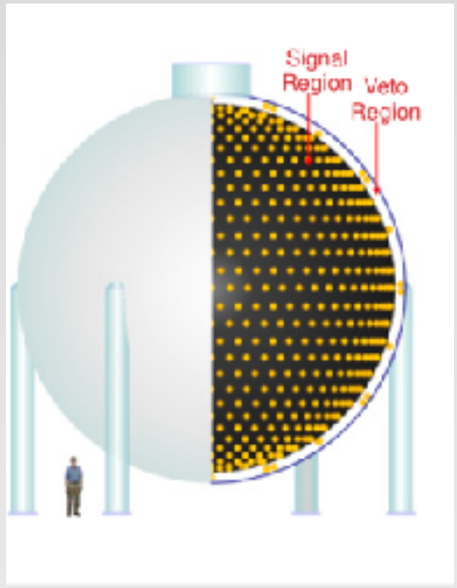
- Constraints for sub GeV vector mediator

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

DM search @ MiniBooNE

8 GeV p beam

540 m



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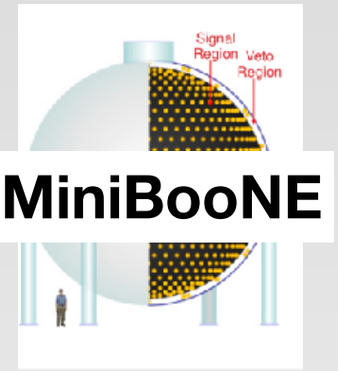
What are the possibilities at other neutrino facilities?
Can we make the DM program symbiotic to the neutrino one?

Can we build a DM search program @ FermiLab NuMI facility?

[Dobrescu, **CF,** JHEP 2014]
[Dobrescu, Coloma, **CF**, Harnik, JHEP 2015]
[**CF ,**PRD 2017]

8 GeV p beam

540 m



MiniBooNE

not to scale

$\theta_{MB} \sim 6.5°$

700 m

900 m

120 GeV p beam

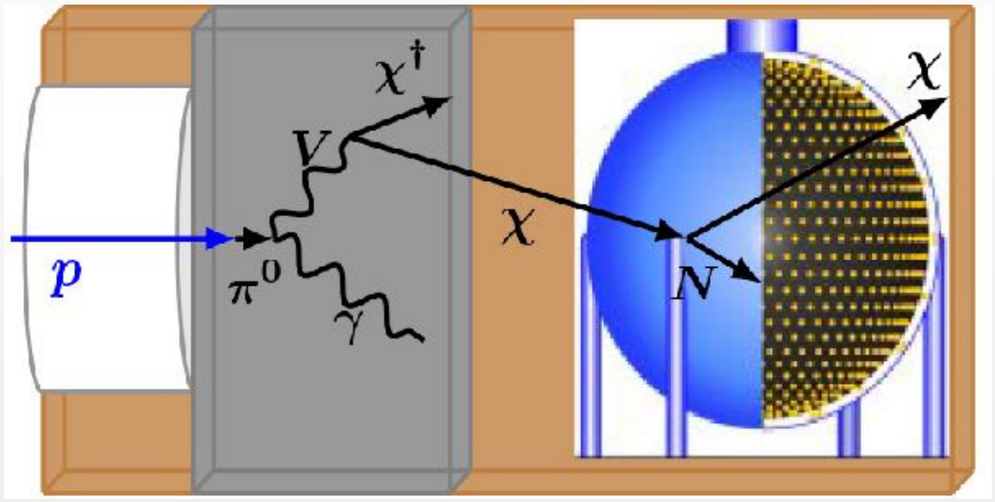
14 GeV center of mass energy

NoVA

Minos

Fermilab, Batavia, IL

Many possibilities (and existing data) to explore DM parameter space



DM quark scattering

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

Complementarity with the direct detection program in this mass range

Leptophobic forces

Leptophobic force

Leptophobic vector model is also strongly constrained due to anomalies. [Dobrescu,**CF**,2014] [Dror et al. 2017]

$$g_l = 0, g_q = \frac{g_z}{3}, g_\phi = 3g_z$$

$$\mathcal{L}_{Z'} = \frac{g_z}{2} Z'_\mu (\frac{1}{3}\bar{Q}_L \gamma^\mu Q_L + \frac{1}{3}\bar{u}_R \gamma^\mu u_R + \frac{1}{3}\bar{d}_R \gamma^\mu d_R)$$

$$\mathcal{L}_\phi \supset \frac{g_z}{2} Z'_\mu (3[(\partial_\mu \phi^\dagger)\phi - \phi^\dagger \partial \mu \phi)]$$

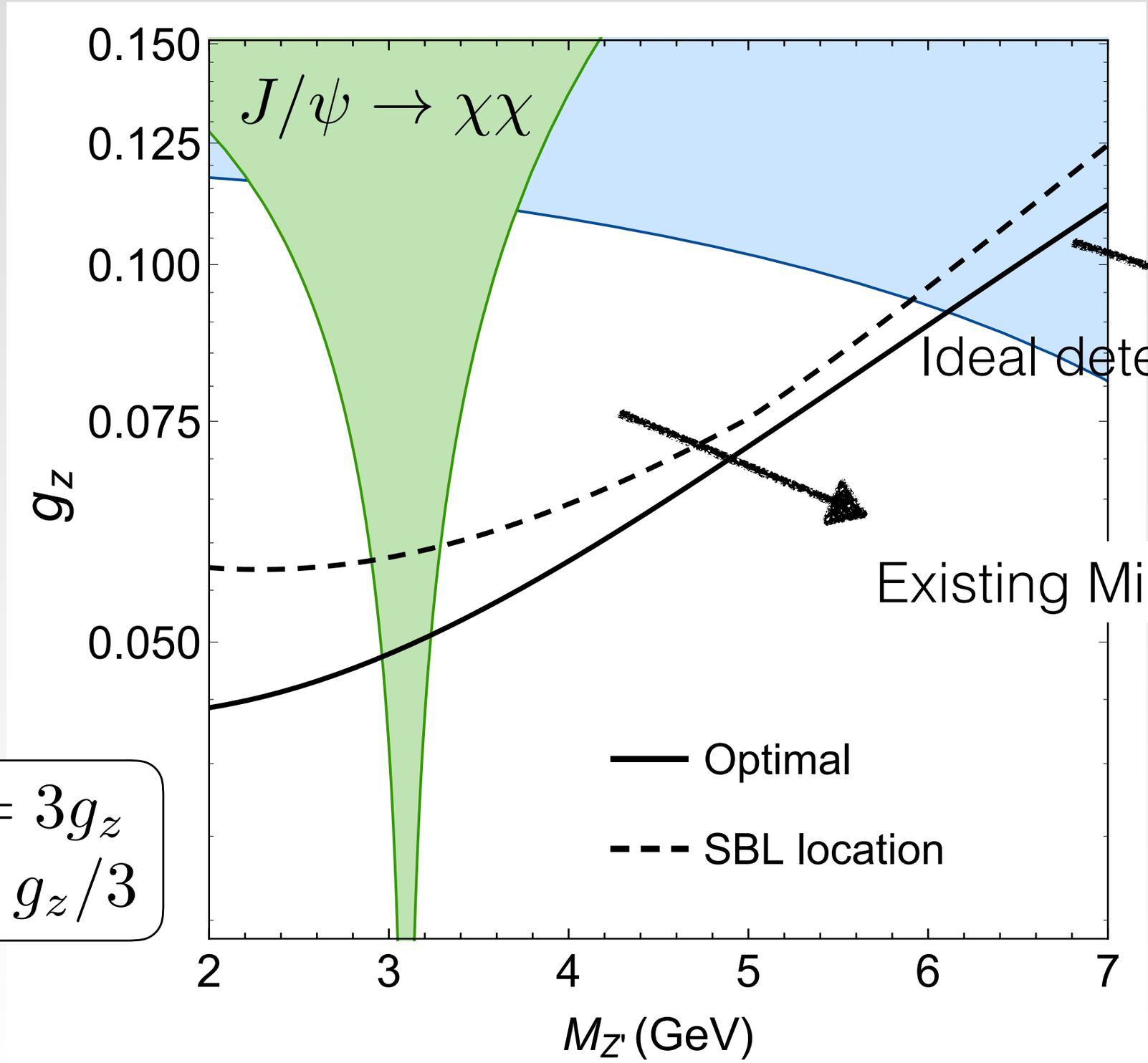
Leptophobic scalar

$$\mathcal{L}_S \supset y_u \bar{u} S u + y_d \bar{d} S d + y_\chi \ \bar{\chi} S \chi$$

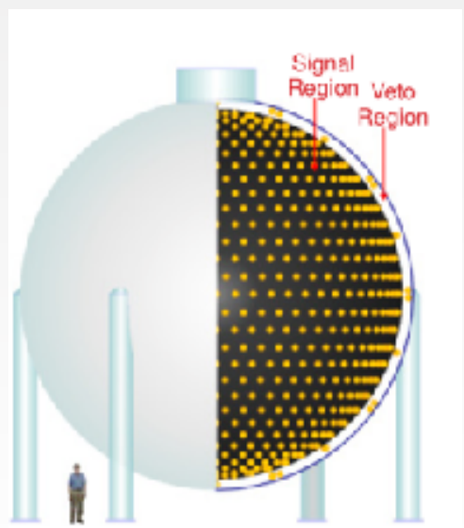
Probing DM/quark coupling

Deep inelastic scattering events

[Dobrescu, **CF, JHEP** 2014]
[Dobrescu, Coloma, **CF**, Harnik, JHEP 2015]



$$g_\chi = 3 g_z$$
$$g_q = g_z/3$$



Probing DM/quark coupling

Improving over the dedicated MiniBooNE dump run using existing \data from the Main Injector

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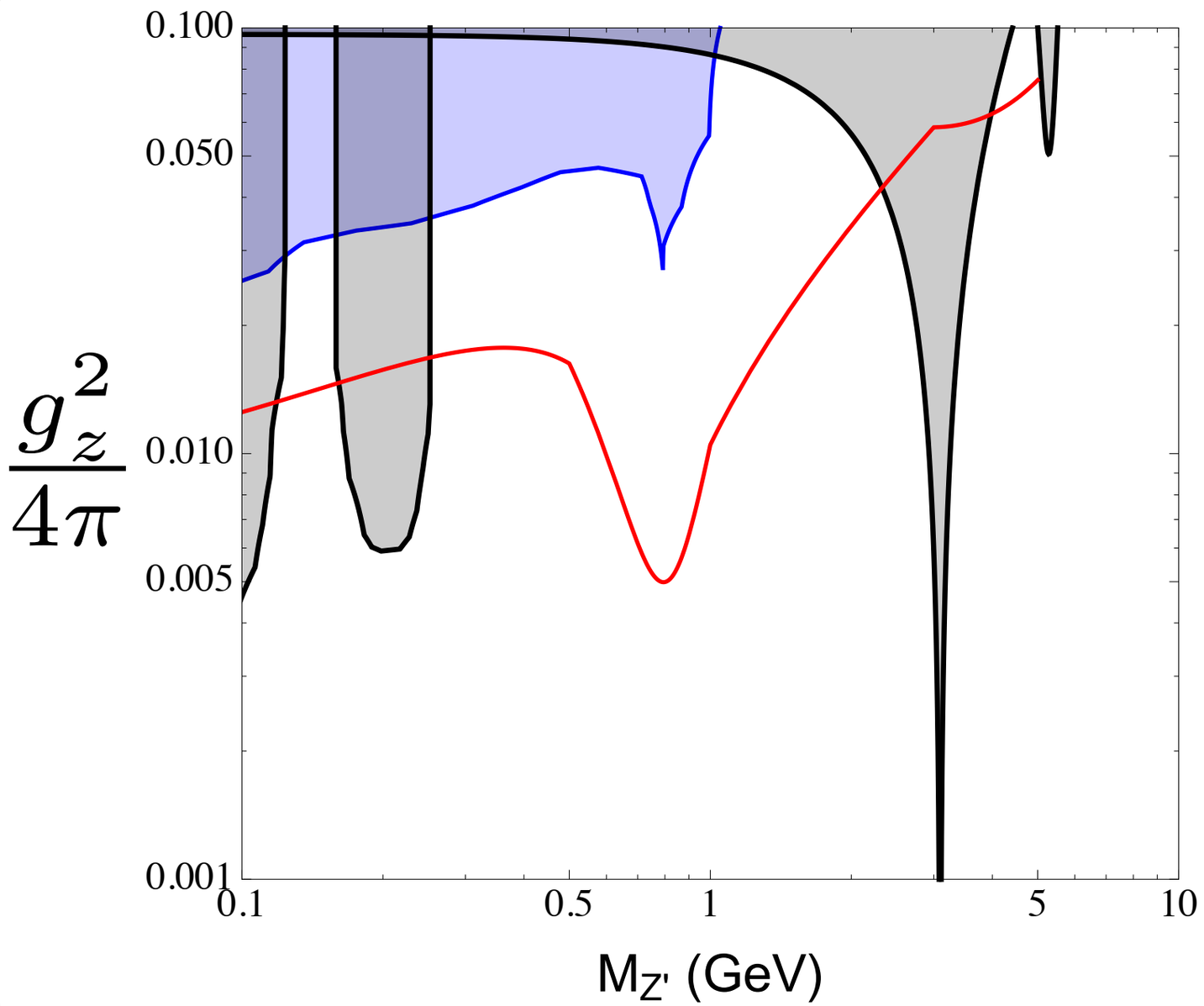
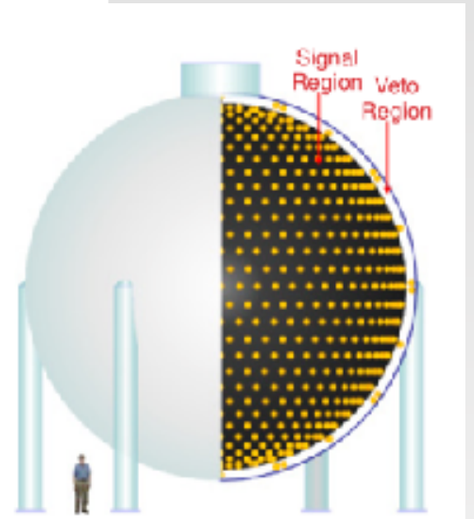
$$g_q = g_z/3$$



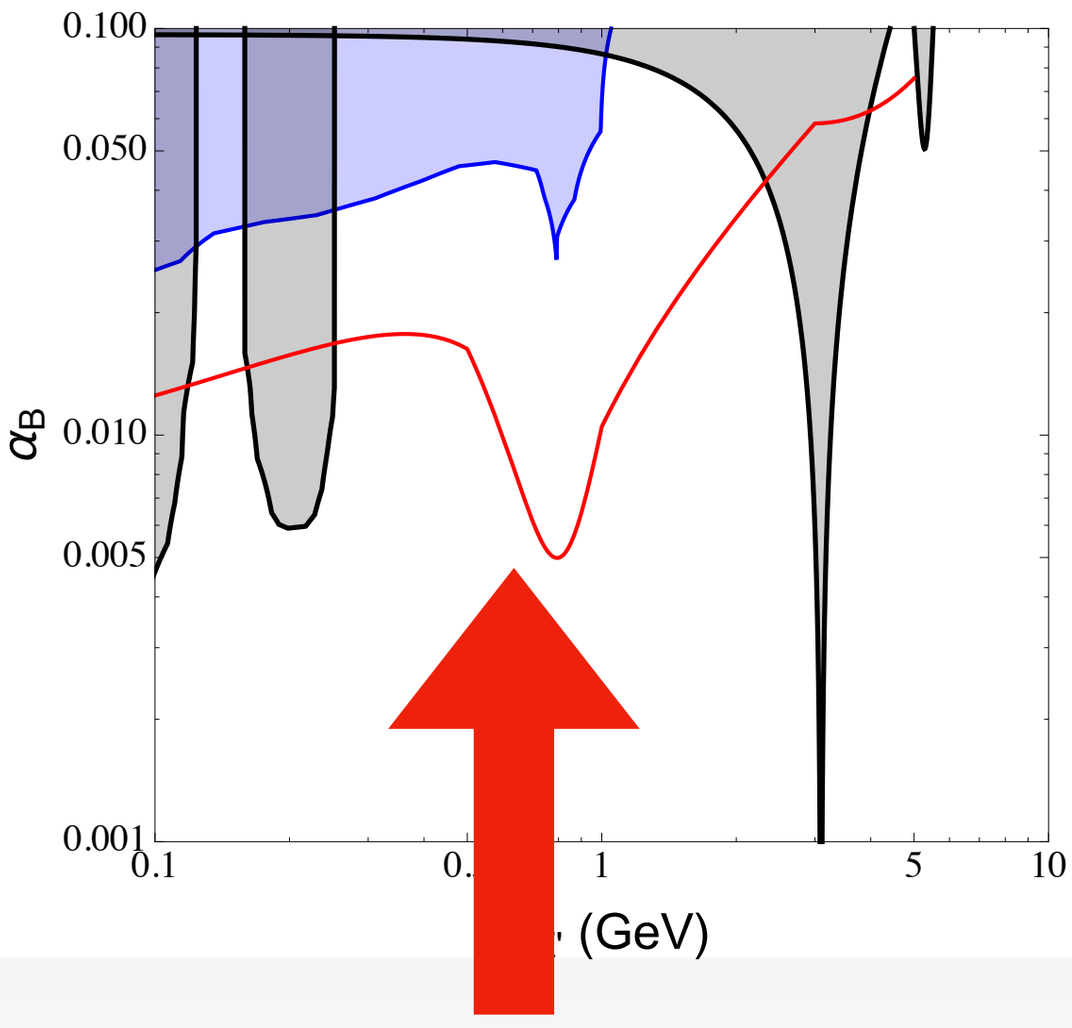


[**CF** 2017][DeNeverville,**CF**,2018 in progress]

Comparison with other probes

“ Electronic “ probes are significantly stronger, i.e Babar Monophoton or NA64

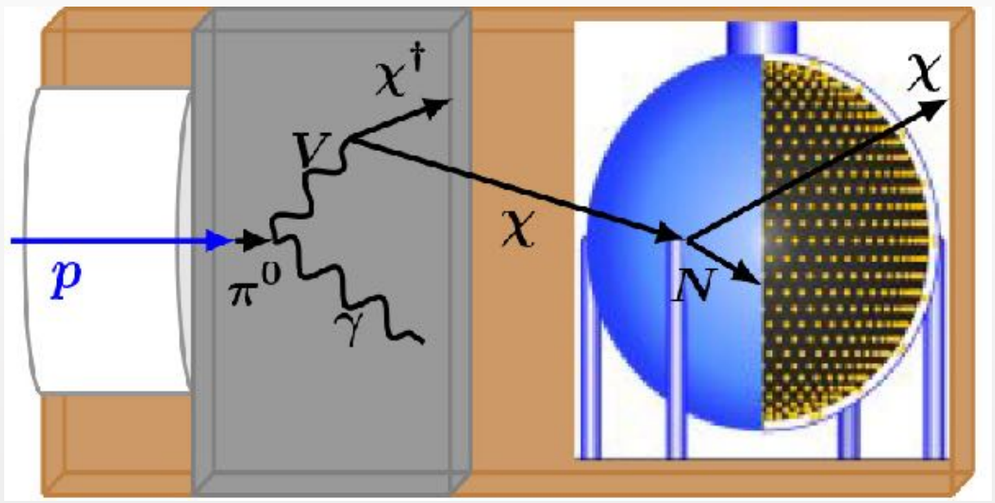
$$\frac{g_z^2}{4\pi}$$



Babar 2017 monophoton

Leptophobic vector model is also strongly constrained due to anomalies.

[Dobrescu,CF,2014]
[Dror et al. 2017]



DM electron scattering

[DeNeverville, **CF**, 2018 work in progress]

Sub-GeV dark photon and DM

[Holdom 1986]

MeV-GeV new gauge boson kinetically mixed with the photon

$$\mathcal{L}_{A'} = -\frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{m^2_{A'}}{2} A'^{\mu} A'_{\mu} - \frac{1}{2}\epsilon\, F'_{\mu\nu} F^{\mu\nu}$$

Dark photon-SM fermion coupling

$$g^{\rm SM}_{A'} = \epsilon e x_{\rm f}$$

Scalar dark matter charged under the dark gauge symmetry

$$\mathcal{L}_{\phi} = |D_{\mu}\phi|^2 - V(\phi)$$

Not constrained by CMB

Dark photon-dark matter coupling

$$g^{\phi}_{A'} \sim \mathcal{O}(1)$$

It can be a thermal relic

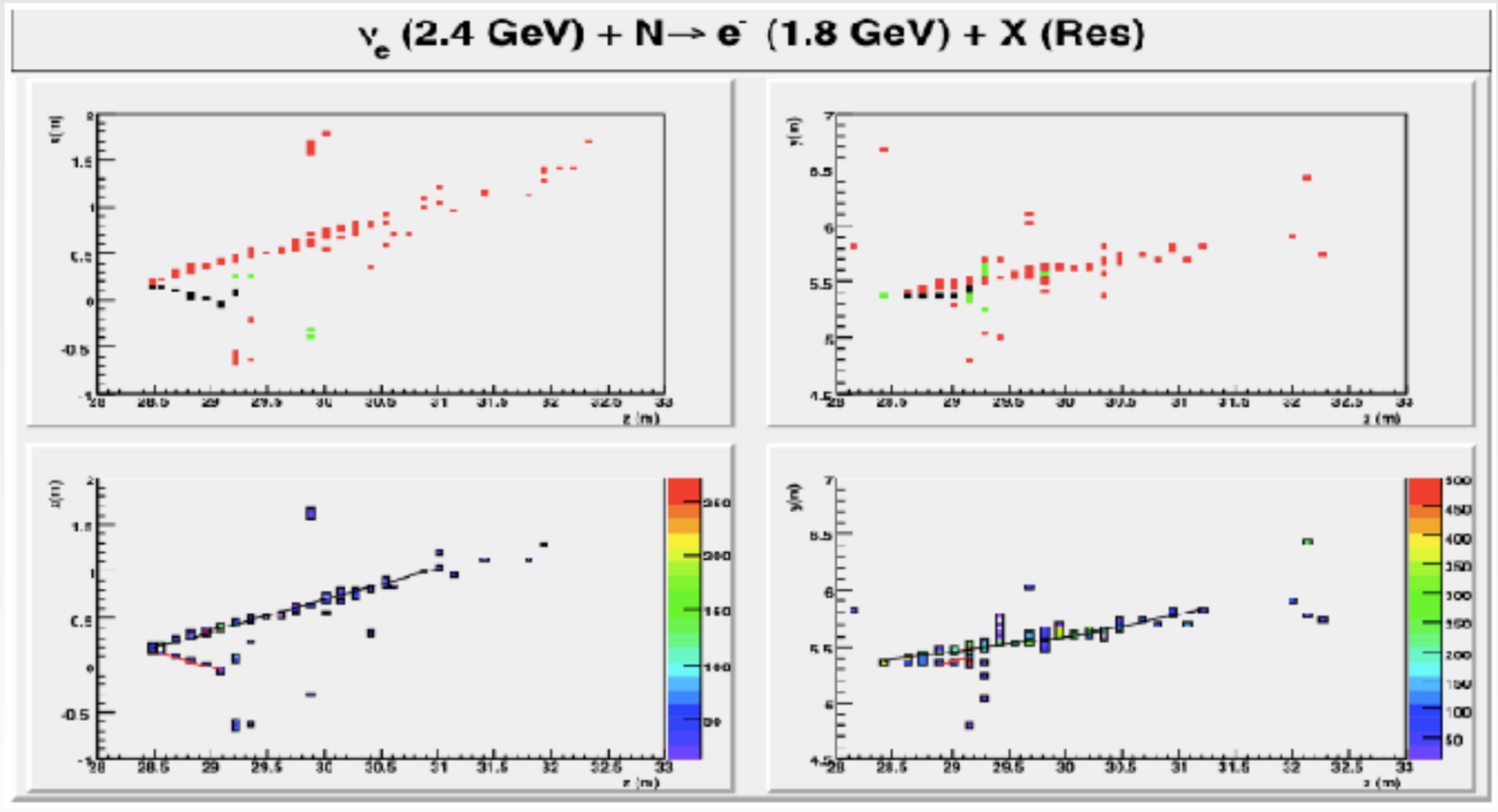
$$< \sigma v > \sim \alpha_D \epsilon^2 \frac{m^2_{\chi}}{m^2_A} \sim \frac{Y}{m^2_{\chi}} \qquad Y \equiv \epsilon^2 \alpha_D \frac{m^4_{\chi}}{m^4_A}$$

NOva as DM detector

300 tons detector located several hundreds of meters away from the target and 14 mrad off axis

It is optimized to observe the oscillation of muon neutrinos to electron-neutrinos

<u>Can resolve electrons!</u>



[DeNeverville,**CF**,2018, in progress]

NOva as DM detector

Preliminary analysis on neutrino- electron elastic scattering presented at DPF 2017

[DeNeverville,**CF**,2018, in progress]

$$2.97 \times 10^{20}\ \mathrm{POT}\ N_{DMbkg} = 140 + 20$$

Neutrino-electron elastic events

Background

We can constraint DM parameter space directly using this analysis!

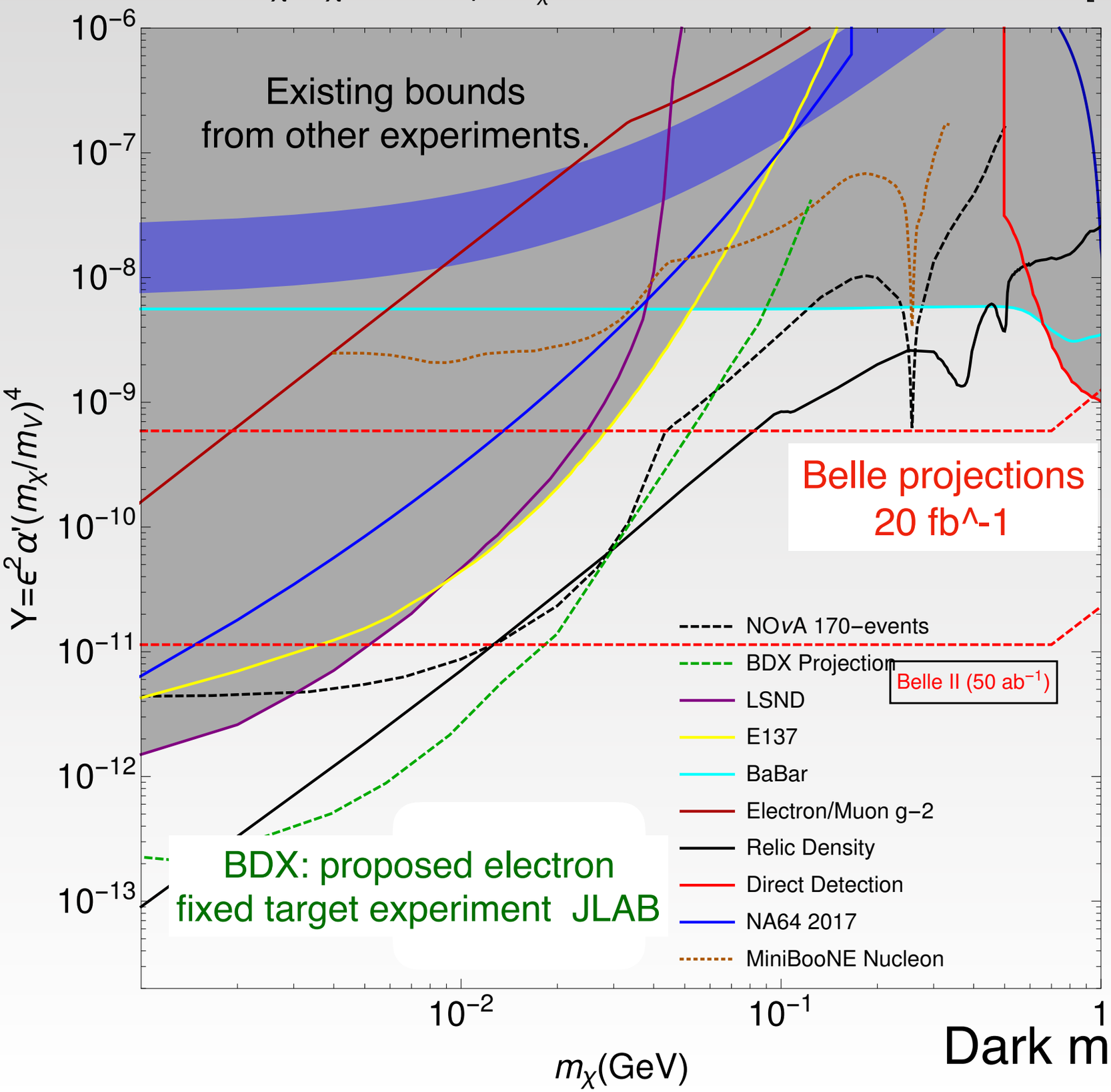
No need to dedicated program

(would be interesting

to study the possibility of an optimization)

NoVa as DM detector

[DeNeverville,**CF**,2018, in progress]

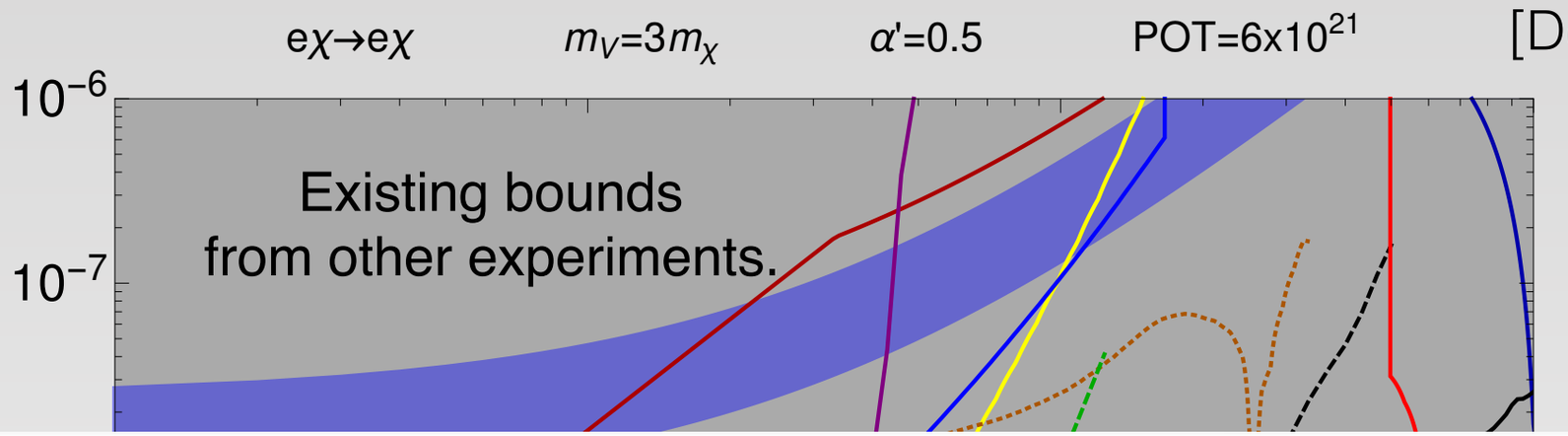


Correct amount of
Scalar DM in the universe

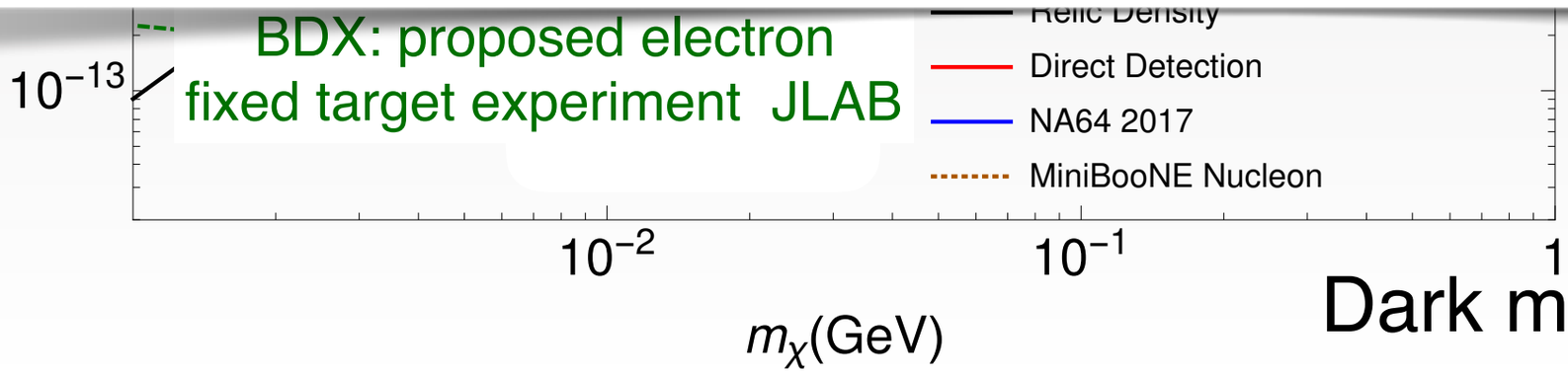
NOVA data
and analysis
on neutrino/electron
scattering

Dark matter mass

NoVa as DM detector



NOvA is an ideal position (slightly off axis) to look for DM!
Neutrino bkg dies faster going off axis than DM one
It can probe symbiotically regions of parameter space
which would be explored by future experiments



More to explore

- MiniBooNE and NOVA dedicated analysis (including systematics, etc) using Main Injector data
- Prospects for inelastic DM and other dark sectors
- Study what is the reach of LBNF/DUNE detector for sub GeV mediators- how can we optimize it
- What are the prospects to probe LDM at SHiP (Search for Hidden Particles, the new proposed CERN proton fixed target experiment)?

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MadDump plugin

Work in progress with L.Buonocuore, F.Maltoni, O. Mattaler, F. Tramontano

MadDump plugin

Work in progress with L.Buonocuore, F.Maltoni, O. Mattaler, F. Tramontano

A program that, given a specific model, combines the operation of MadGraph and other MG plugins, automatically:

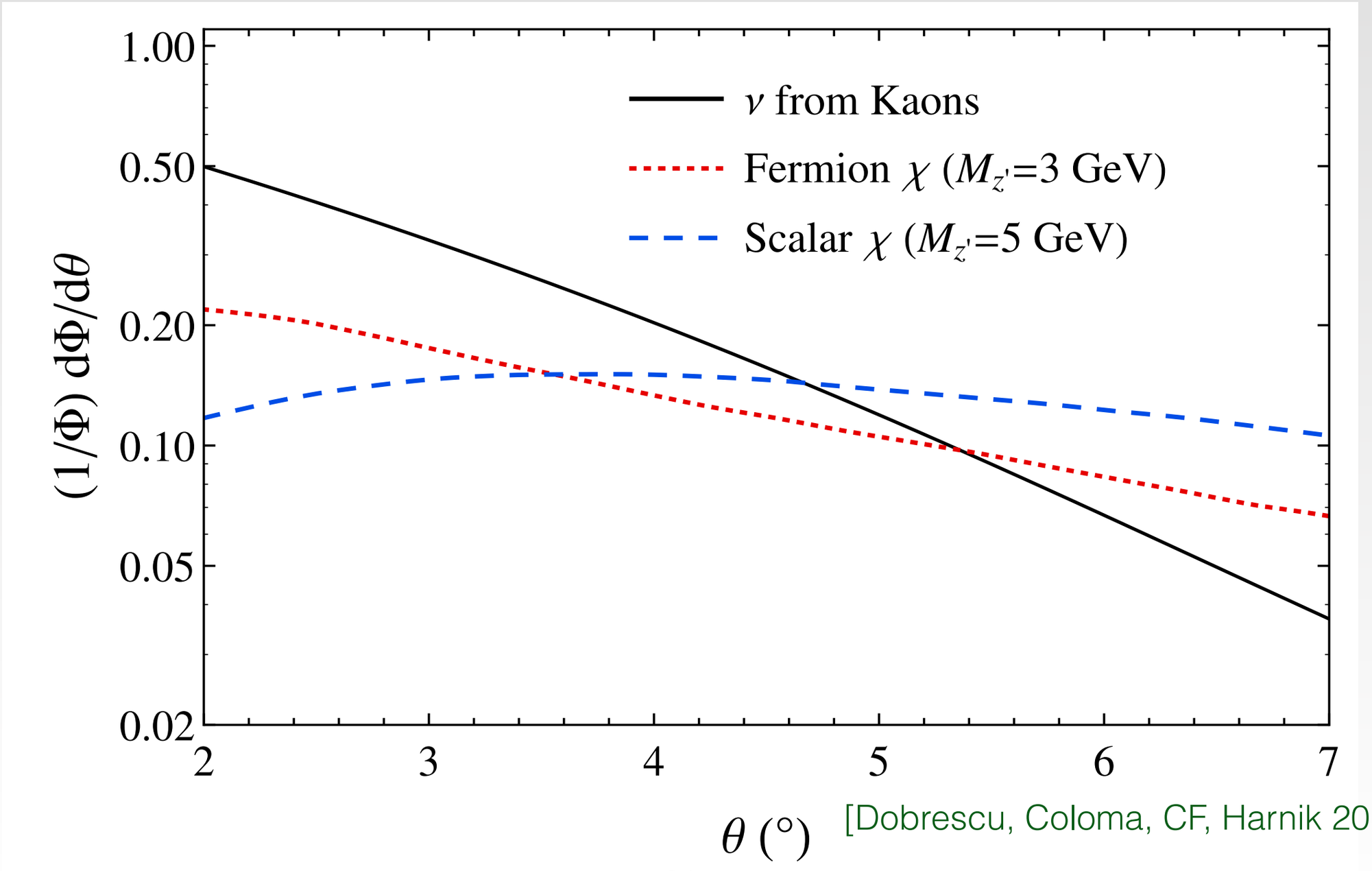
- computes the decay of mesons (generated with pythia for example) to the hidden particle (HP) or HP prompt production

- stores the relevant HP differential distributions and uses them to both compute HP decays or its interaction cross sections and generate unweighted events samples


Thanks!

Off-axis detectors for DM

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



[Dobrescu, Coloma, CF, Harnik 2015]

DM electron scattering in MiniBooNE