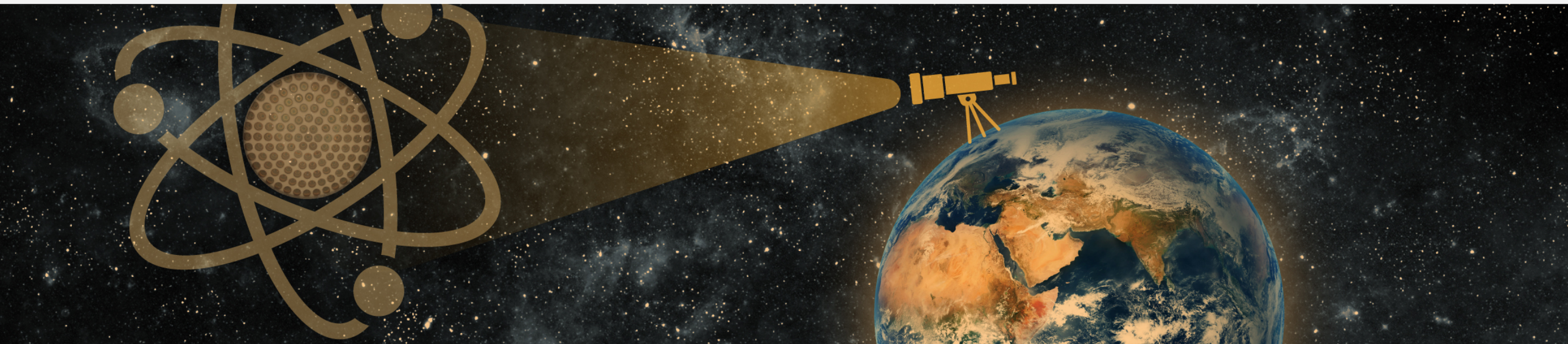
MeV-GeV dark matter searches @ fixed target experiments

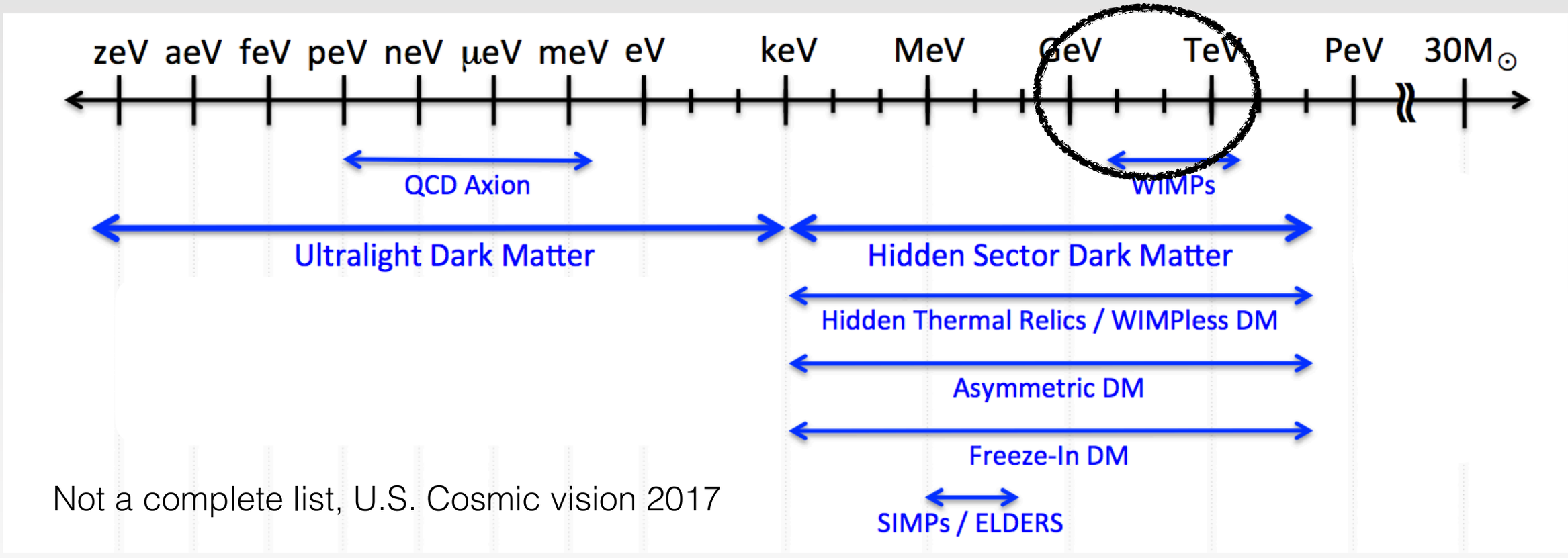
Claudia Frugiuele

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE



DM theoretical landscape is broad

Most of the experimental efforts focus on a small region.



Not a complete list, U.S. Cosmic vision 2017

Many compelling scenarios to guide the experimental searches:
cosmological history of DM ?
Connection to other particle physics long standing questions (e.g. strong CP problem) ?

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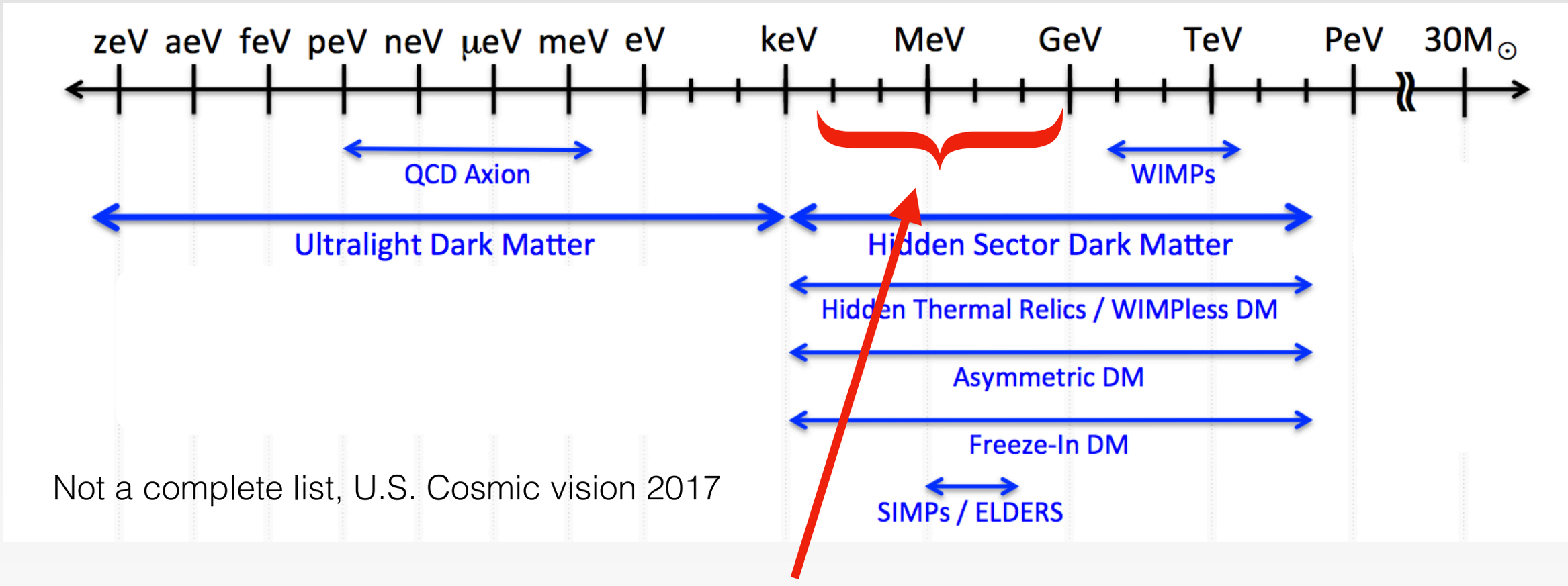
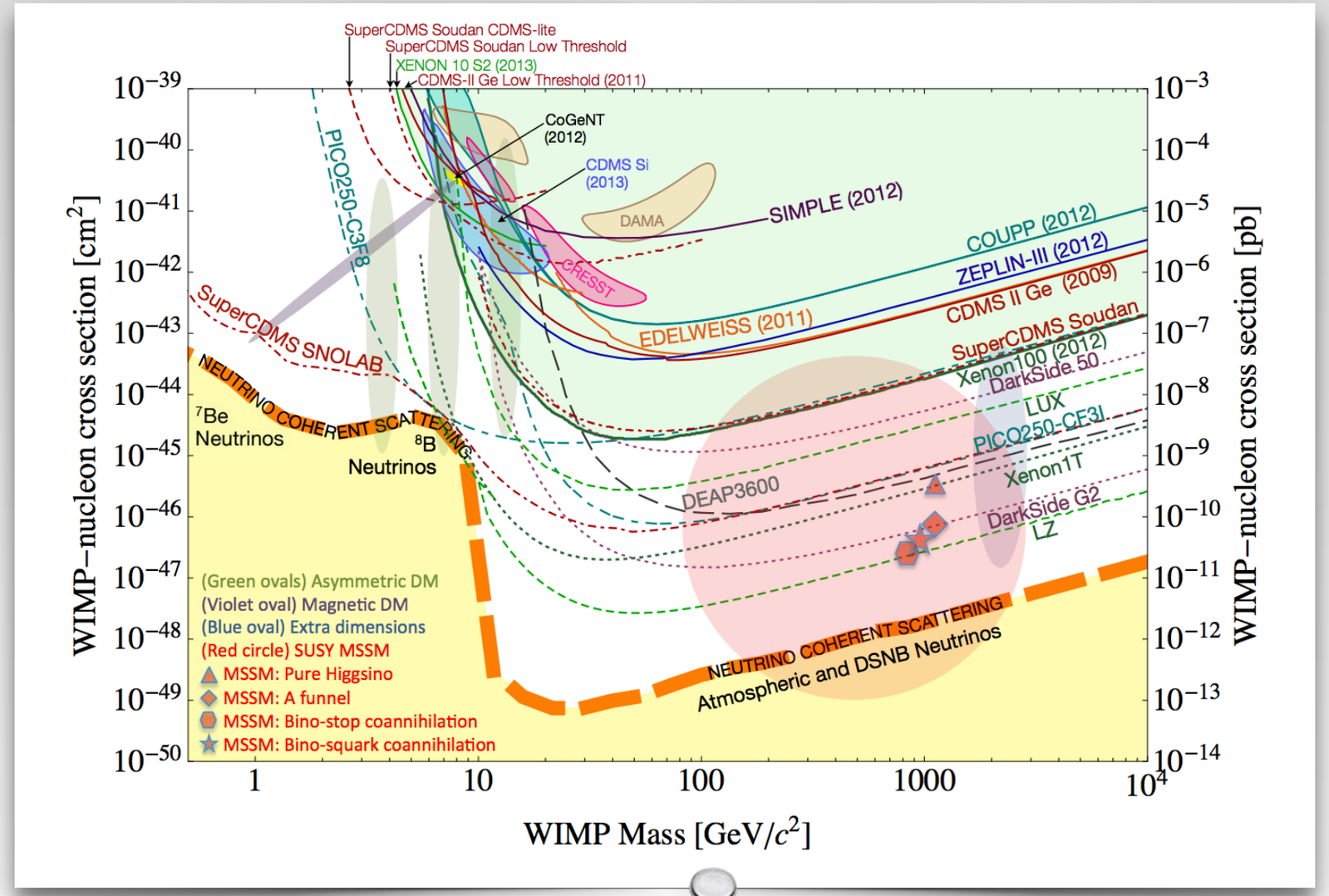


Not a complete list, U.S. Cosmic vision 2017

Focus on sub GeV thermal DM (mainly on MeV-GeV mass range)

MeV-GeV DM

Direct detection experiments lose sensitivity for masses below a few GeV

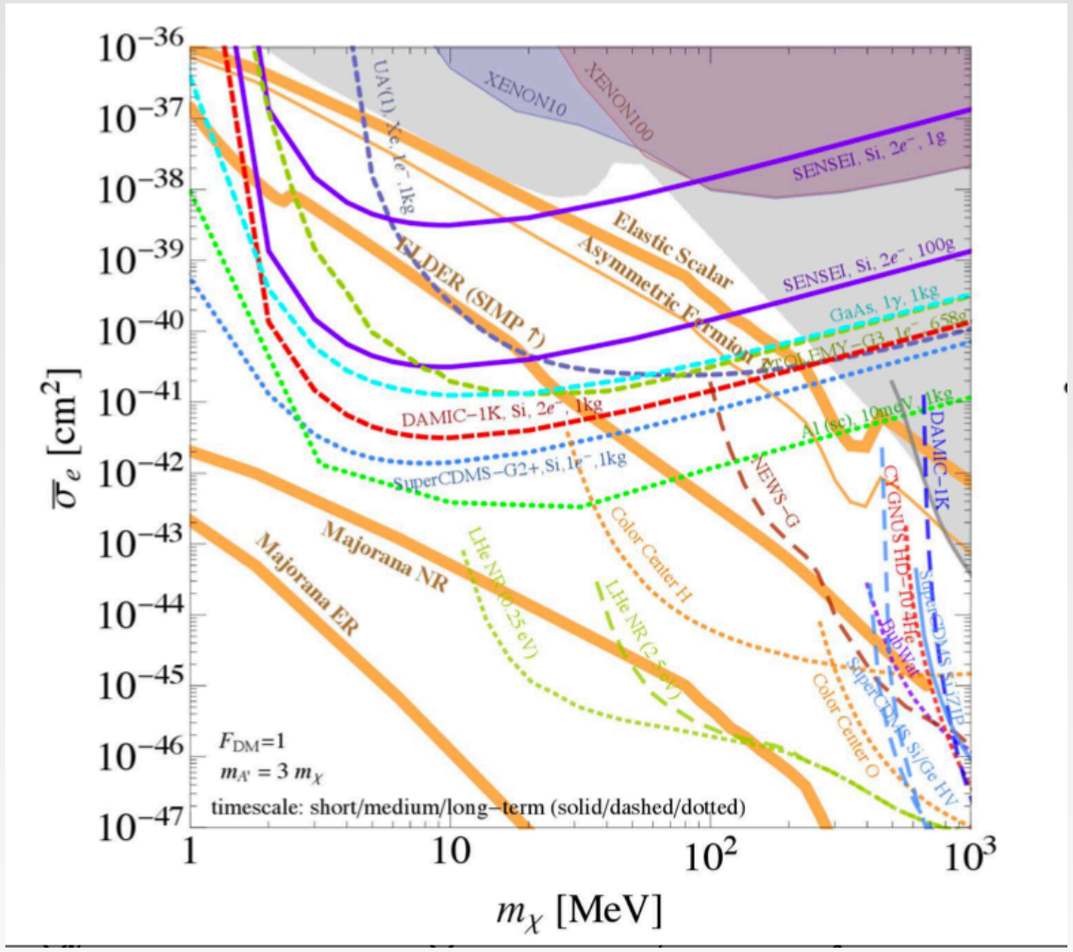


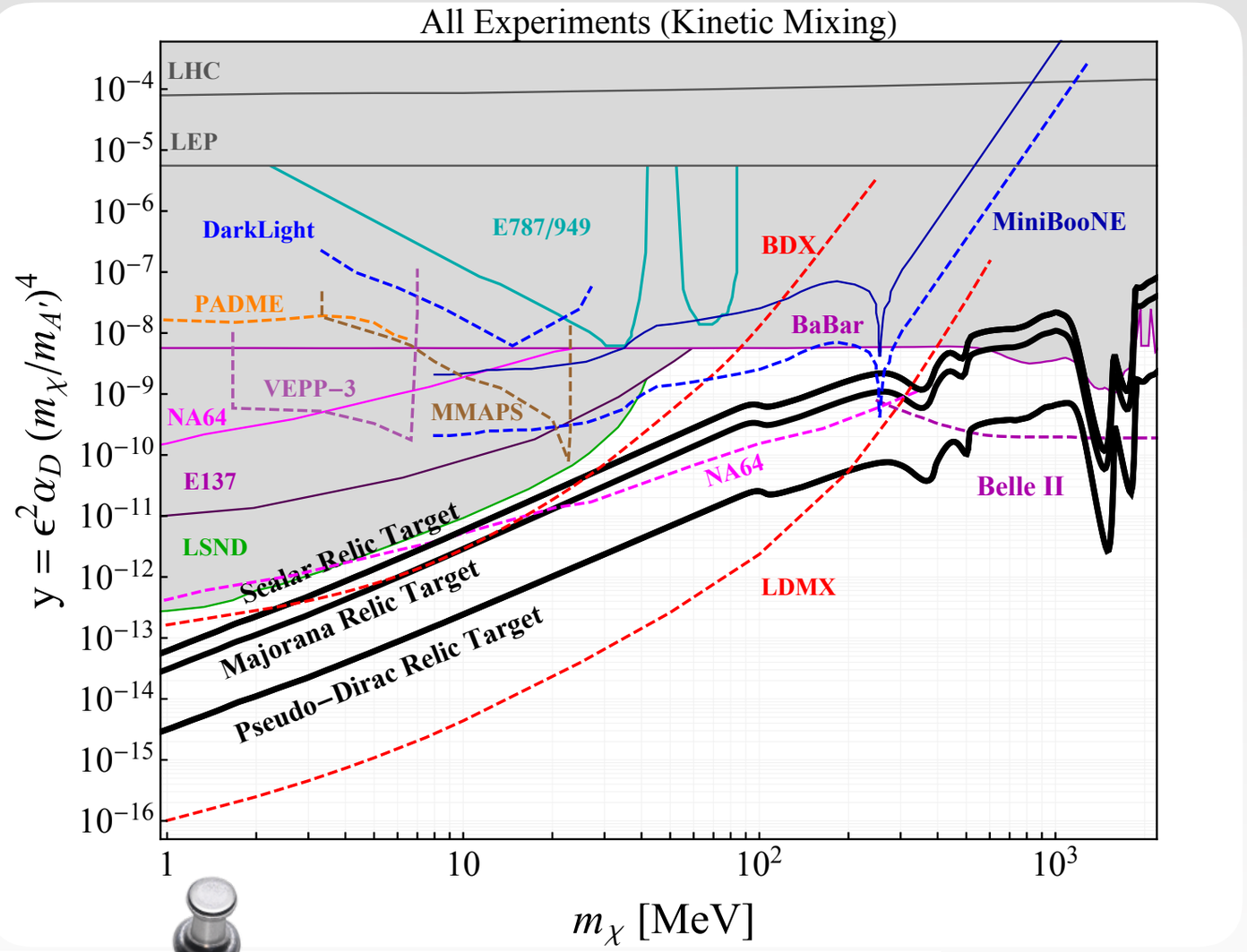
1. DM-electron direct detection experiments (e.g. Essig, Mardon, Volansky, 2012)
2. Accelerator based searches(fixed target experiments, B factories)

Many proposals

New generation direct detection experiments and new accelerator based searches

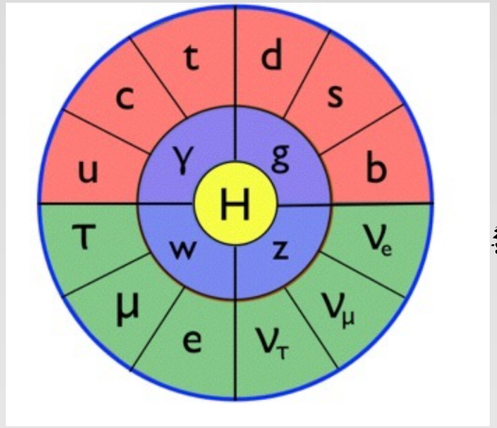
From US Cosmic Vision 2017





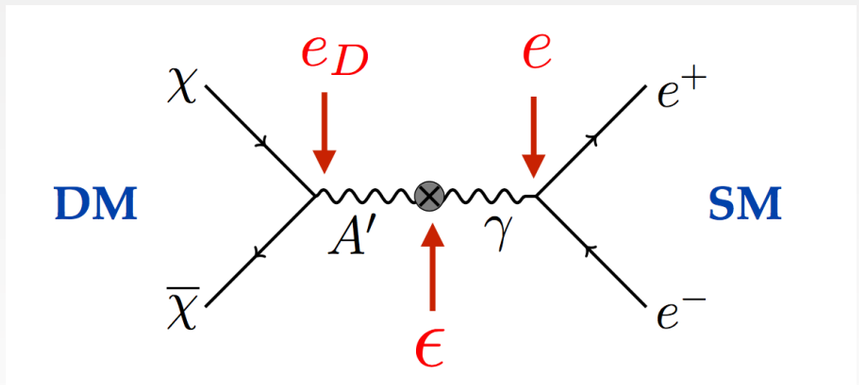
Focus of the talk: accelerator based searches

MeV-GeV thermal DM



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

s-wave annihilation into charged particles ruled out by CMB observations

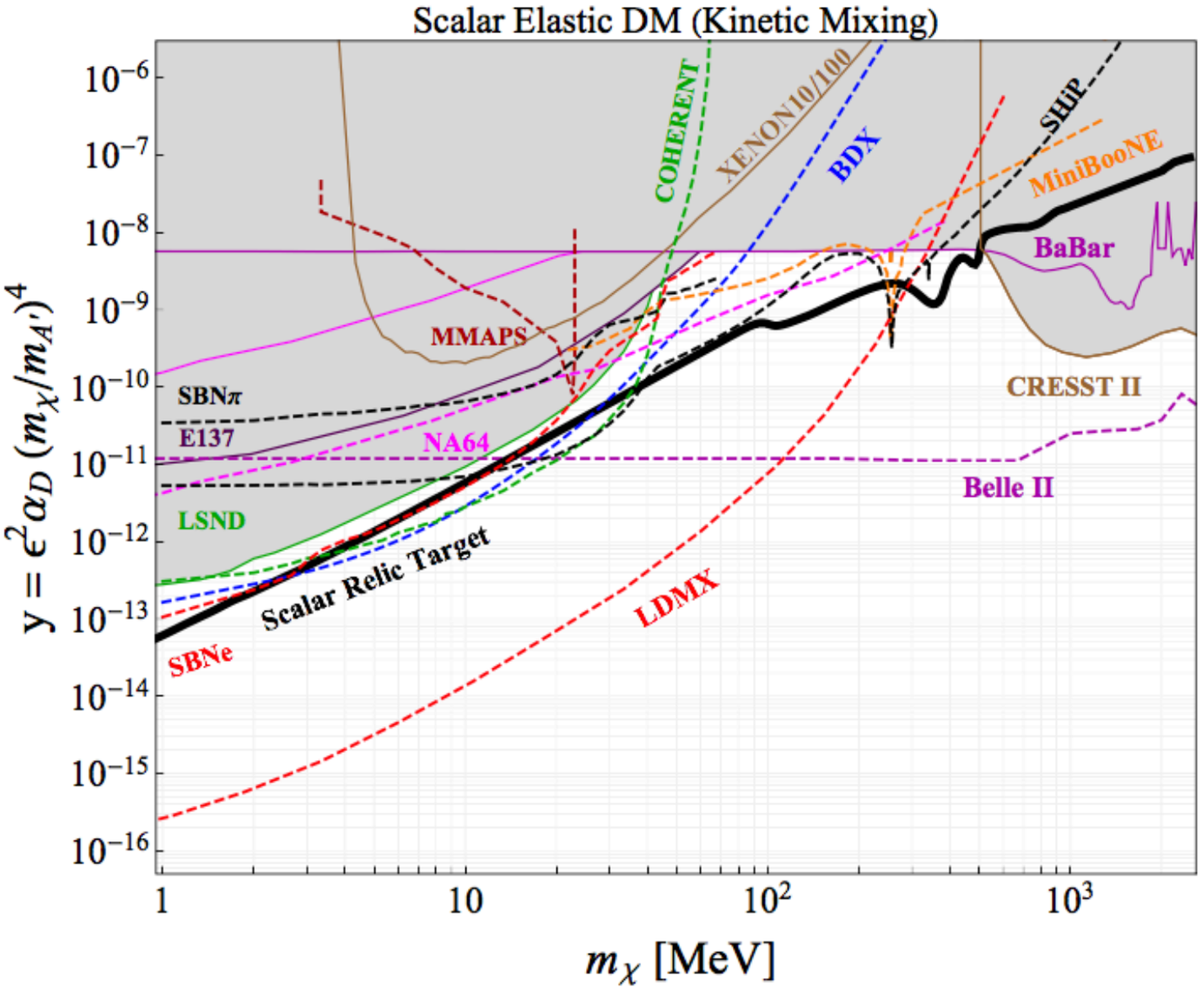


NO s-wave annihilation
YES p-wave annihilation

Type of signature: MeV-GeV mediator decaying into DM

Accelerator based searches

Important role played by fixed target experiments



US cosmic vision 2017
Izaguirre, Krnjaic, Schuster, Toro, 15

Dark photon benchmark model

$$< \sigma v > \sim \alpha_D \epsilon^2 \frac{m_\chi^2}{m_A^2} \sim \frac{Y}{m_\chi^2}$$

$$Y \equiv \epsilon^2 \alpha_D \frac{m_\chi^4}{m_A^4}$$

$$\alpha_D = 0.5 \ , \ m_{A'} = 3 m_\chi$$

Dark photon invisible decay

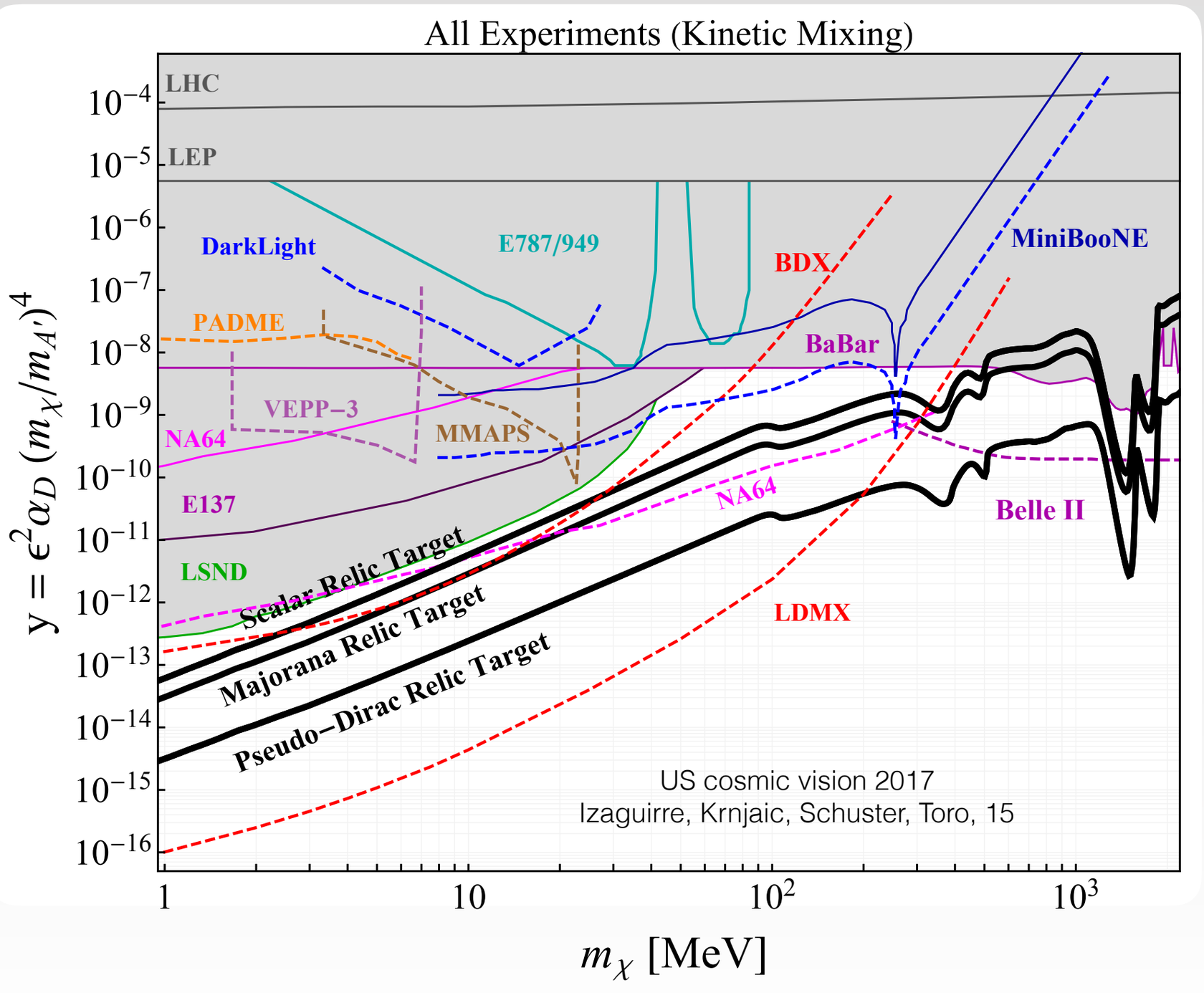
BDX: electron beam dump experiment
DM-electron scattering signatures

LDMX: electron fixed target experiment
missing momentum signatures

Izaguirre, Krnjaic, Schuster, Toro,2014

Accelerator based searches

Important role played by fixed target experiments



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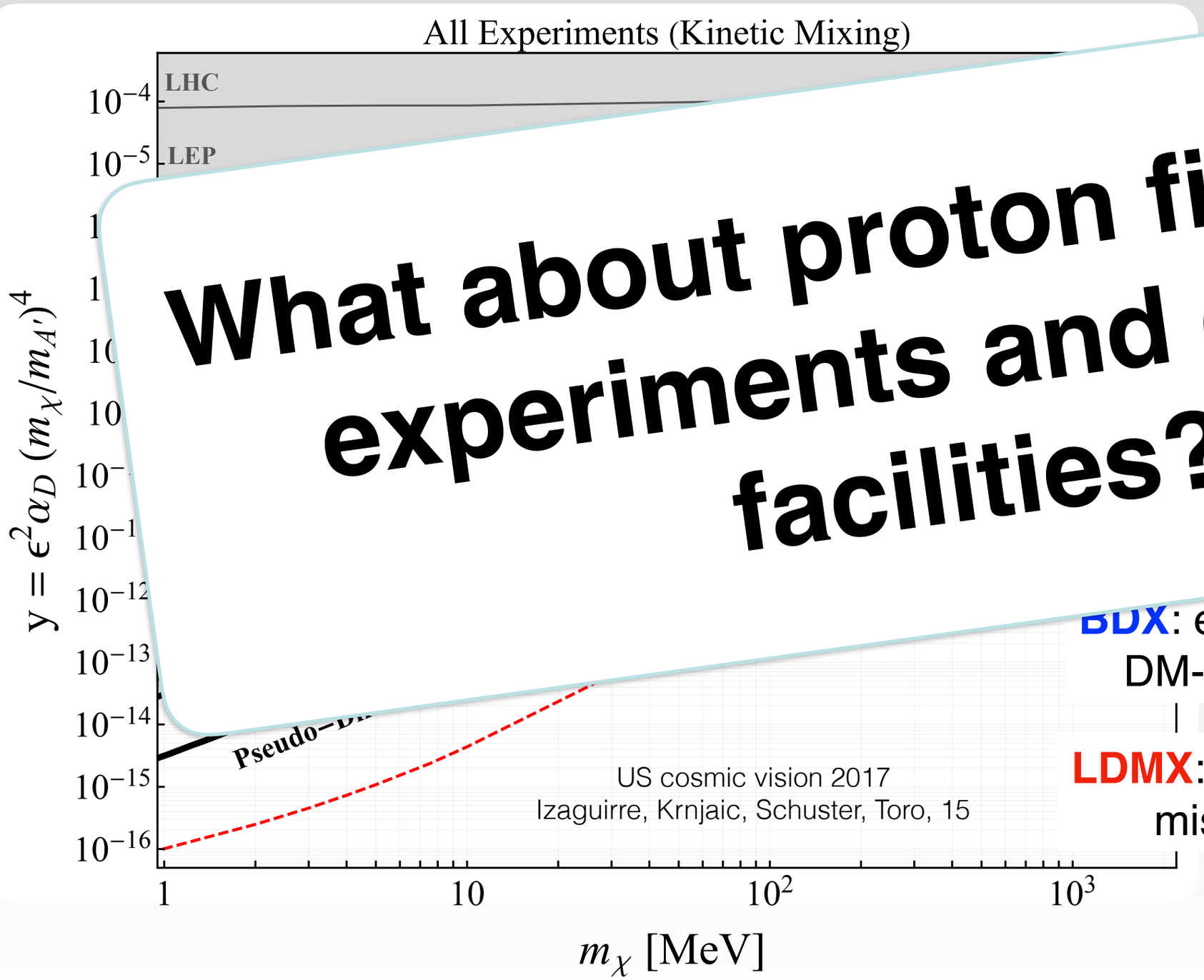
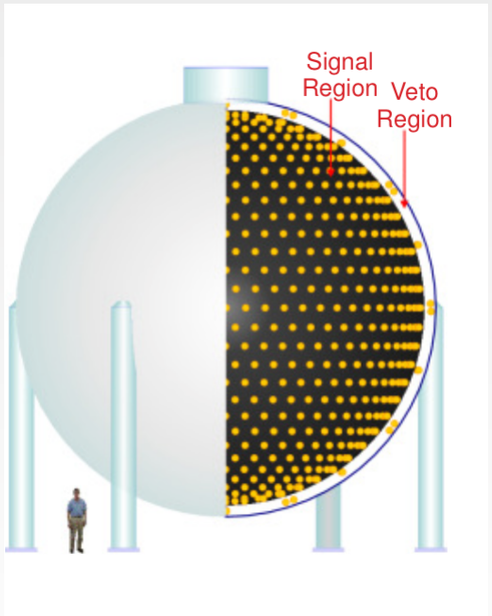


What about proton fixed target experiments and existing facilities?

BDX: electron beam dump experiment
DM-electron scattering signatures

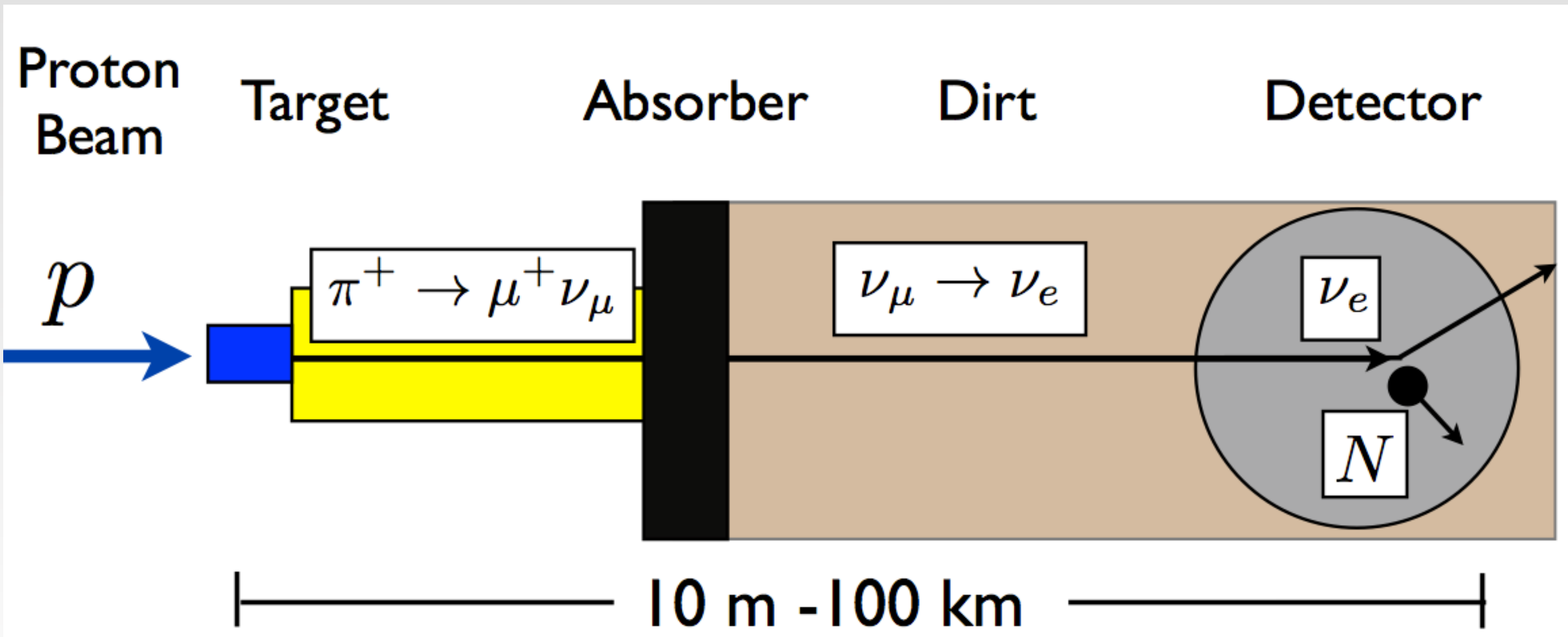
LDMX: electron fixed target experiment
missing momentum signatures

Searching for MeV-GeV DM @neutrino facilities



Original goal

measuring neutrino masses and mixings



New complementarity goal

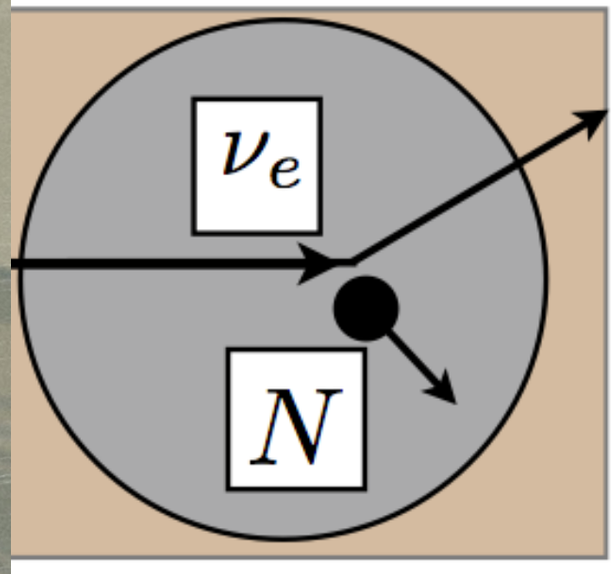
Dark matter discovery

[Batell, Pospelov Ritz, 2009]

Proton Beam

p

Detector



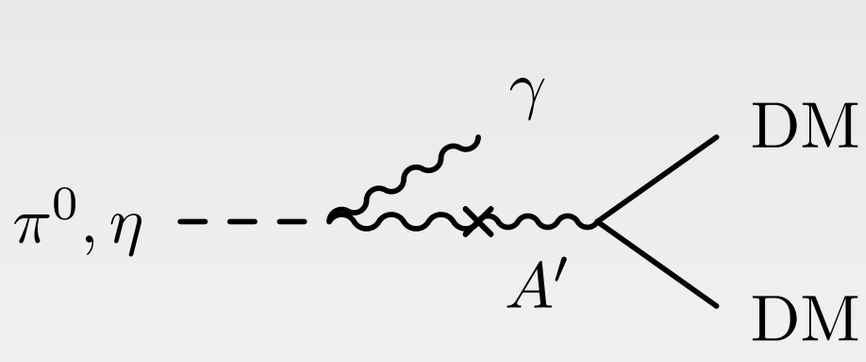
10 m -100 km

How is the DM beam produced?

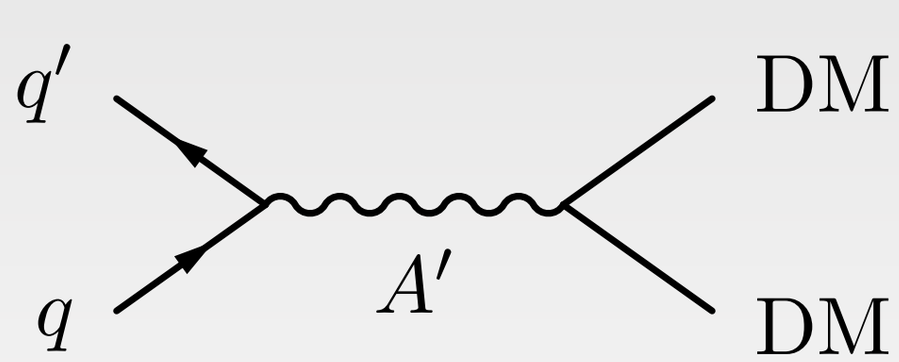
MeV-GeV gauge boson kinetically mixed with the photon $g_{A'}^{\rm SM} = \epsilon e x_{\rm f}$

MeV-GeV scalar DM (no tension with CMB) $g_{A'}^{\phi} \sim \mathcal{O}(1)$

- Production via meson decay



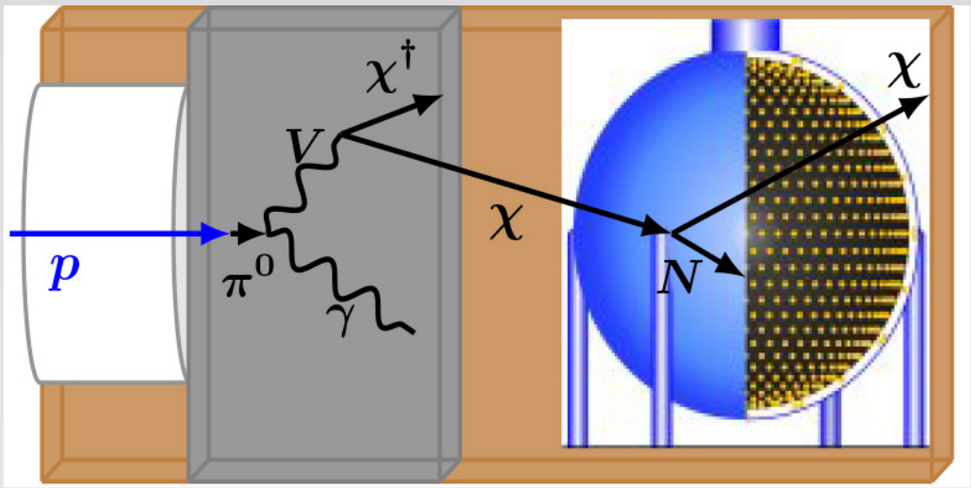
- Direct Production



On shell production of the mediators is essential

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

How do we detect DM ?



Two observables

- DM-nucleus scattering
- DM-electron scattering

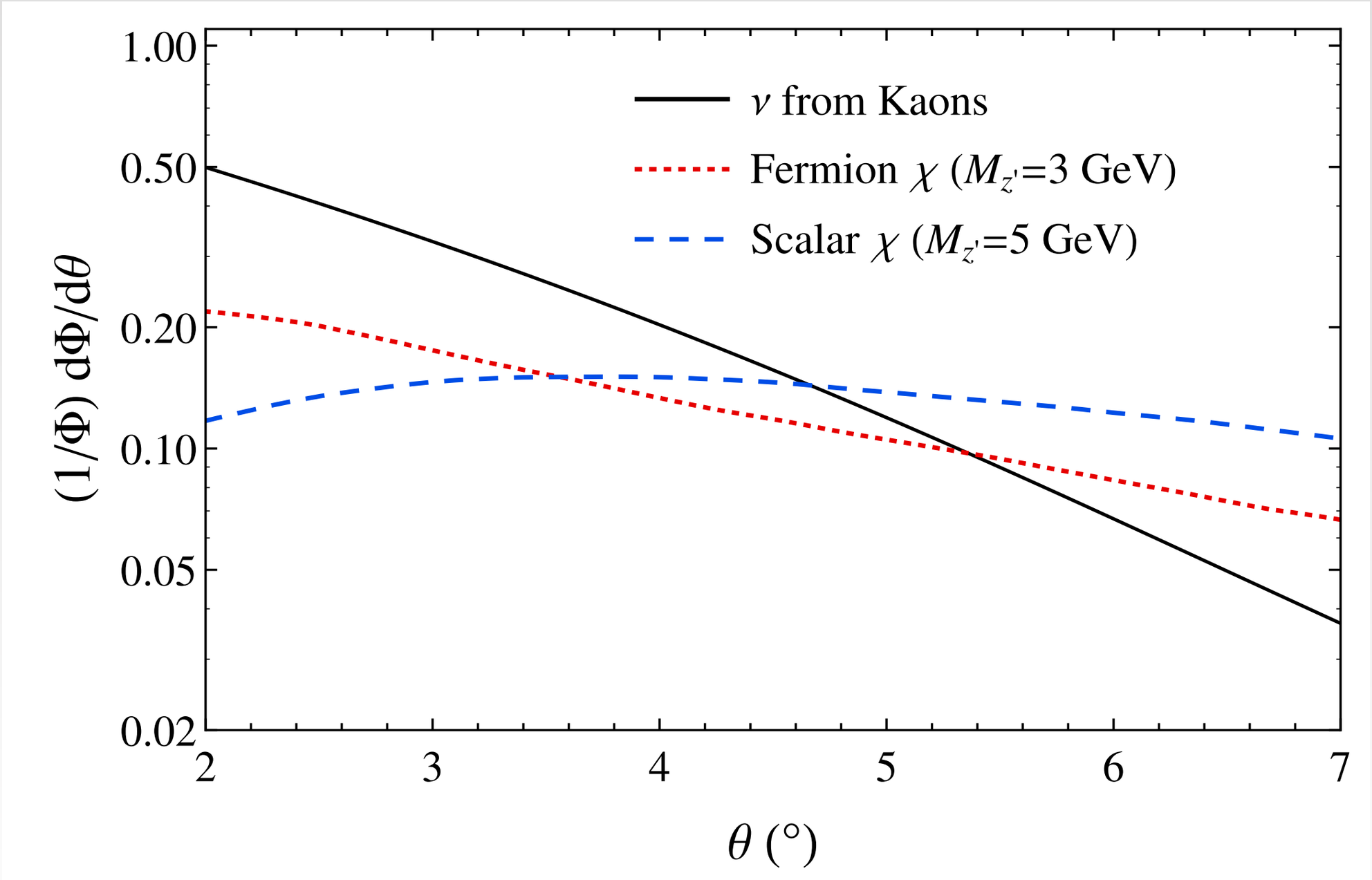
Main challenge: suppression of neutrino background.

Is it possible to build a DM program symbiotic to the neutrino one?
YES- a crucial role is played by off-axis detectors

[Dobrescu, Coloma, CF, Harnik, 2015]

Off-axis detectors for DM

Difference angular distribution of DM and neutrino flux



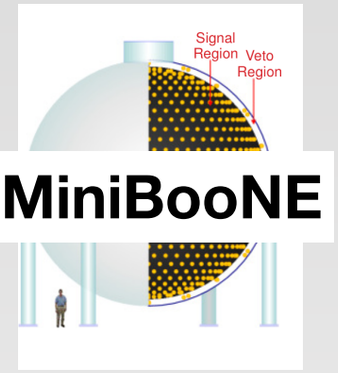
[Dobrescu, Coloma, CF, Harnik 2015]

Neutrinos @ Main Injector (NuMI)

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

8 GeV p beam

540 m



MiniBooNE

not to scale

$\theta_{MB} \sim 6.5°$

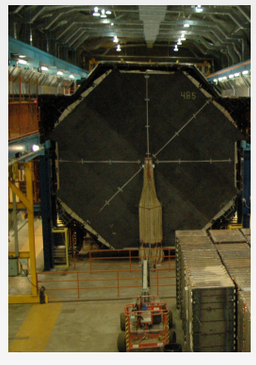
700 m

900 m

NOvA

120 GeV p beam

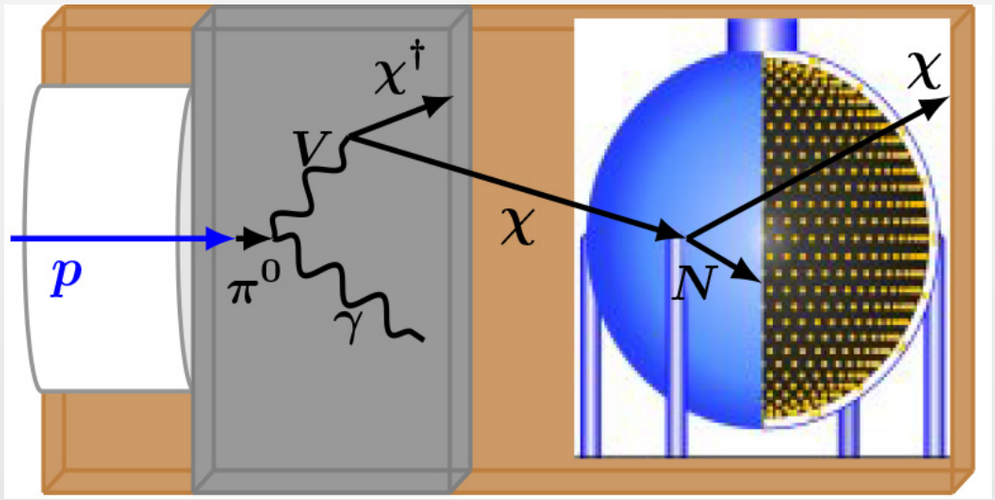
14 GeV center
of mass energy



Minos
Minerva

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

DM-electron scattering



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

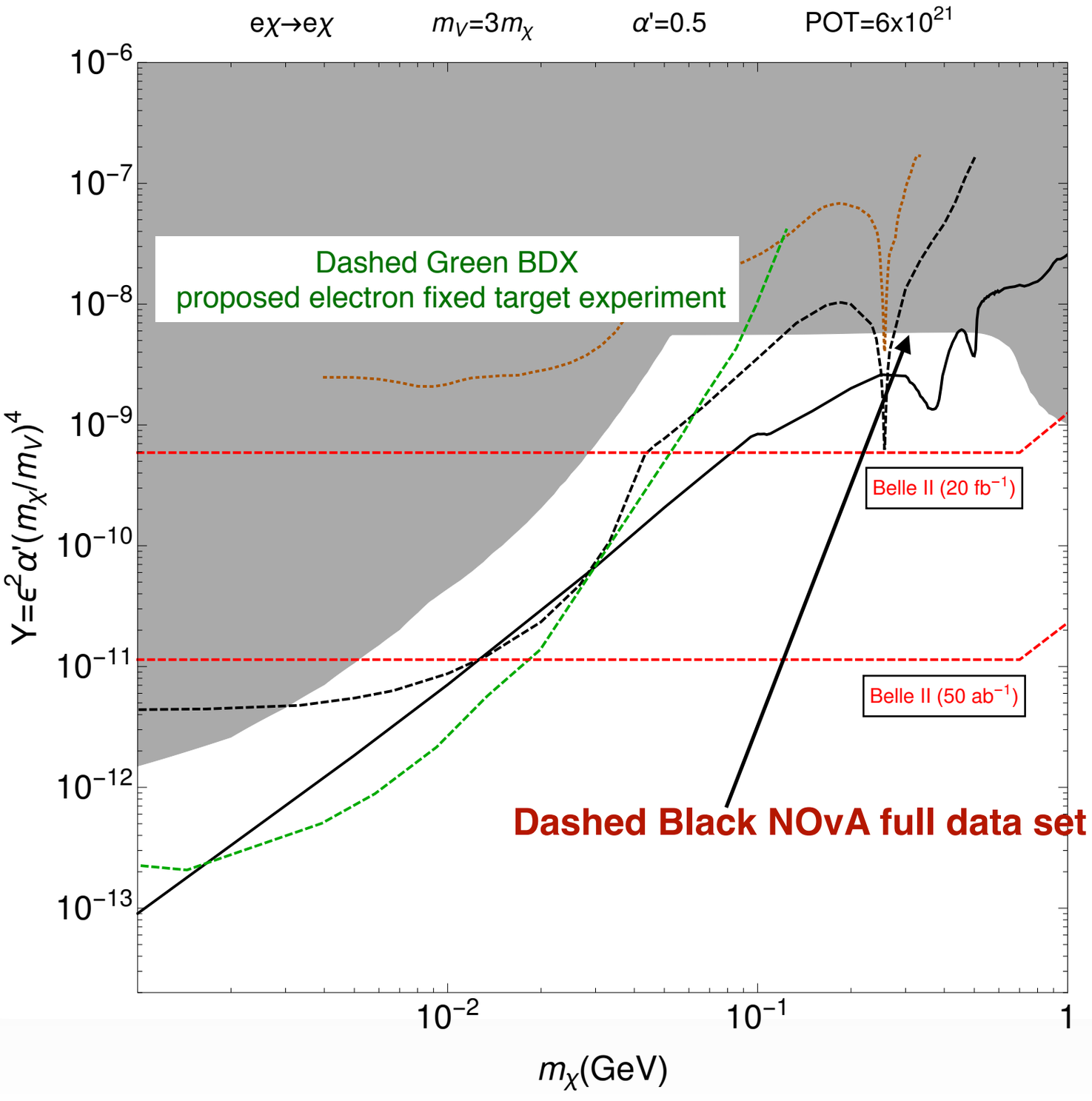
Small neutrino background

NOvA as a DM detector

[DeNeverville,CF,2018, in progress]

$$Y \equiv \epsilon^2 \alpha_D \frac{m_\chi^4}{m_A^4} \quad < \sigma v > \propto \frac{Y}{m_\chi^2}$$

Thermal target : solid Black line relic density (scalar)



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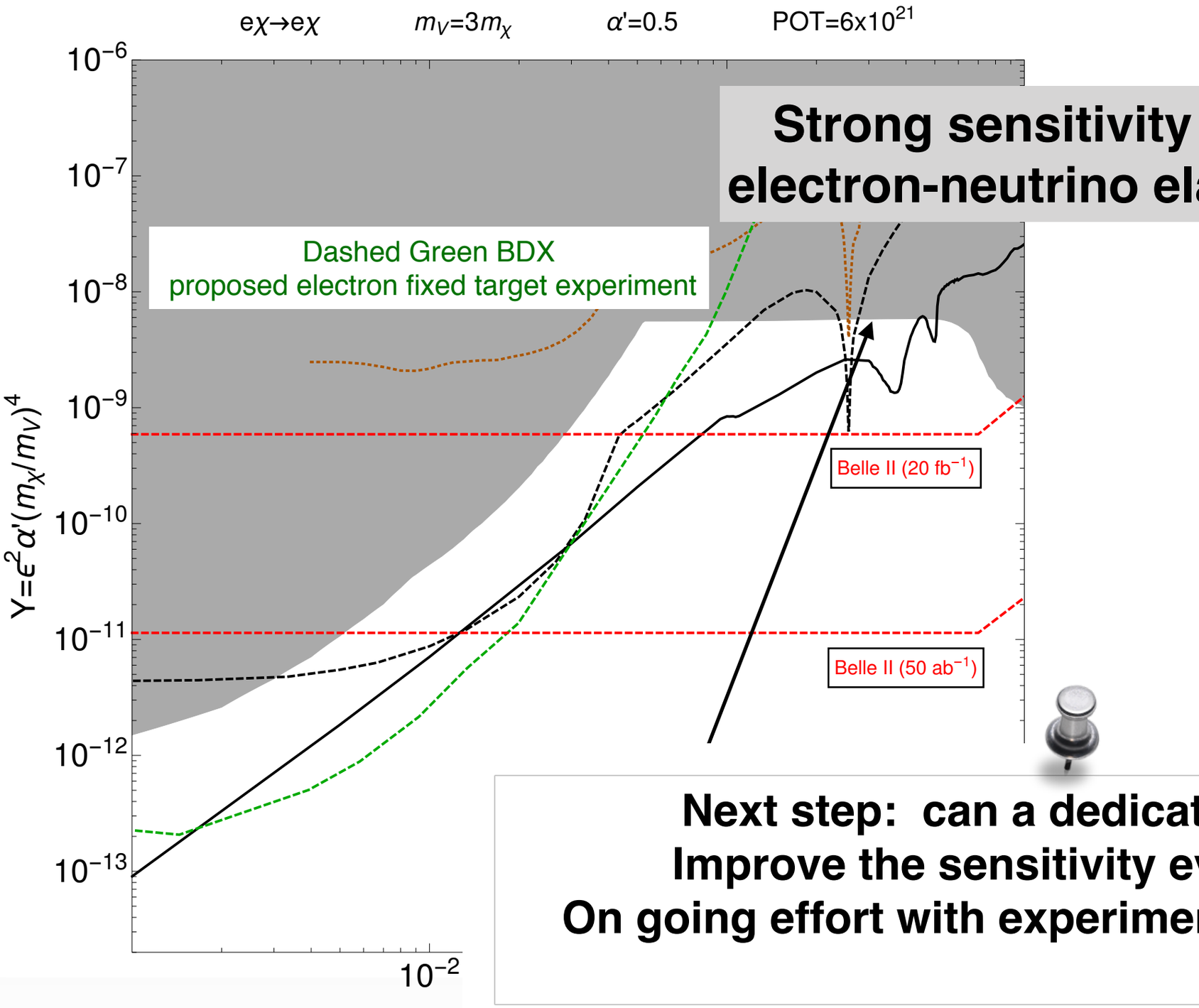
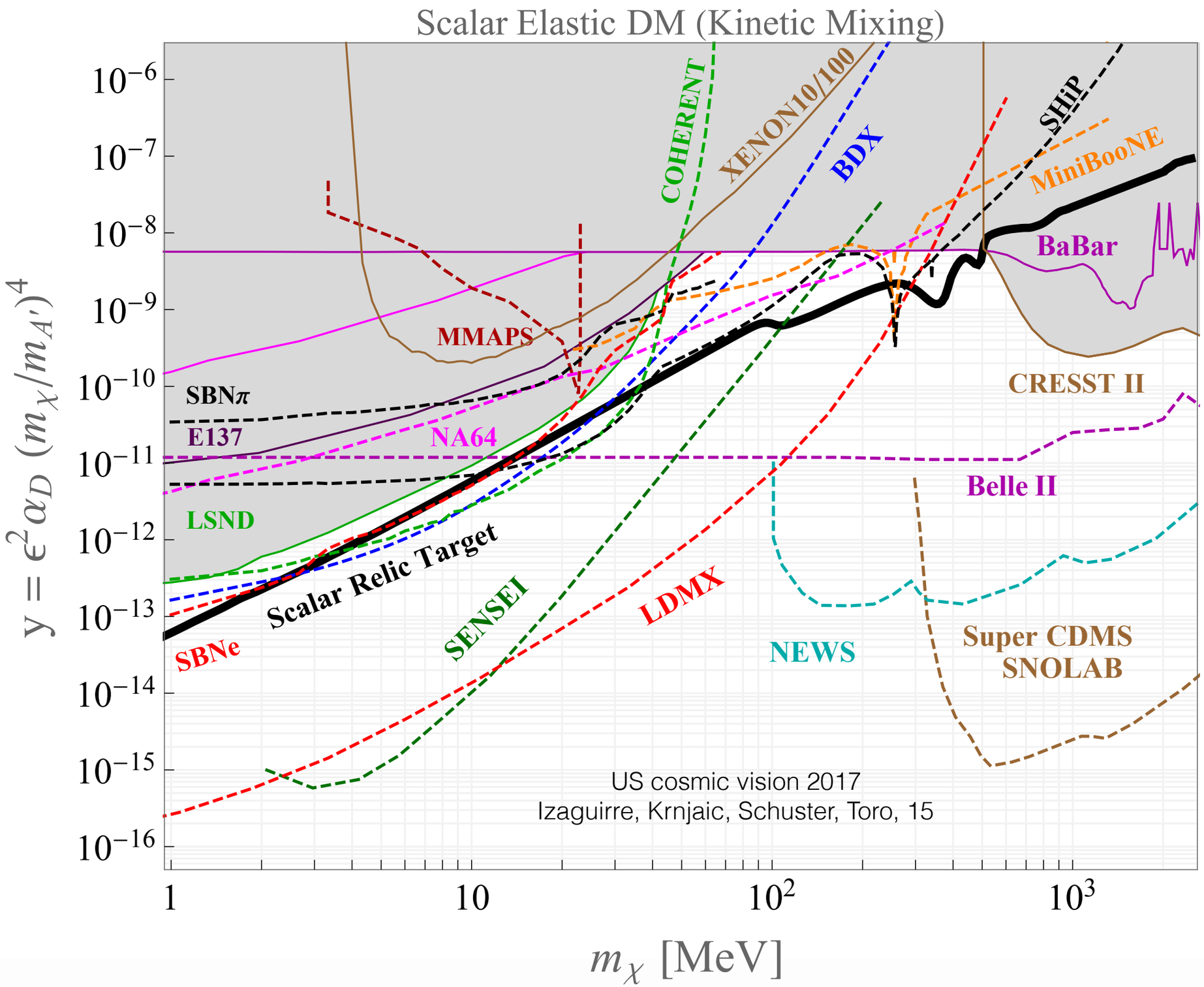


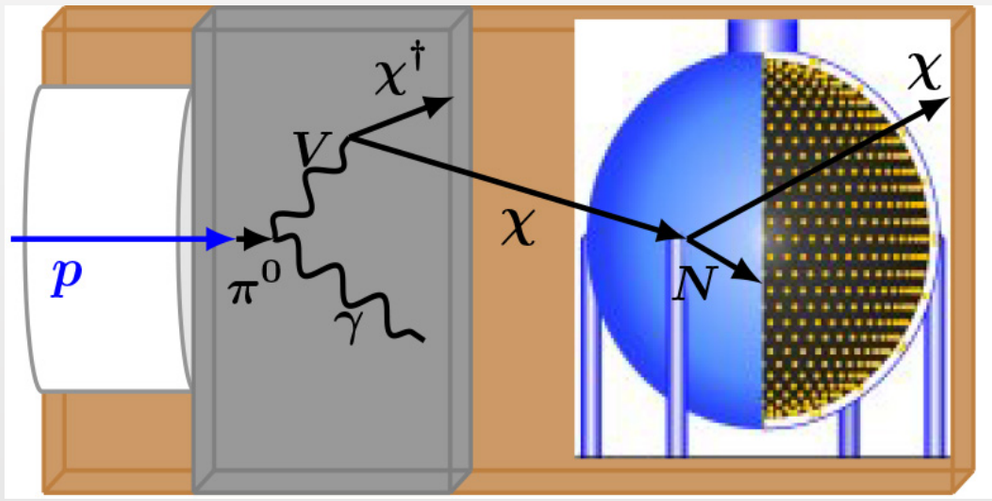
Strong sensitivity achieved by recasting electron-neutrino elastic scattering analysis

Next step: can a dedicated analysis Improve the sensitivity even further? On going effort with experimental collaboration

Direct detection reach for scalar



DM-quark scattering

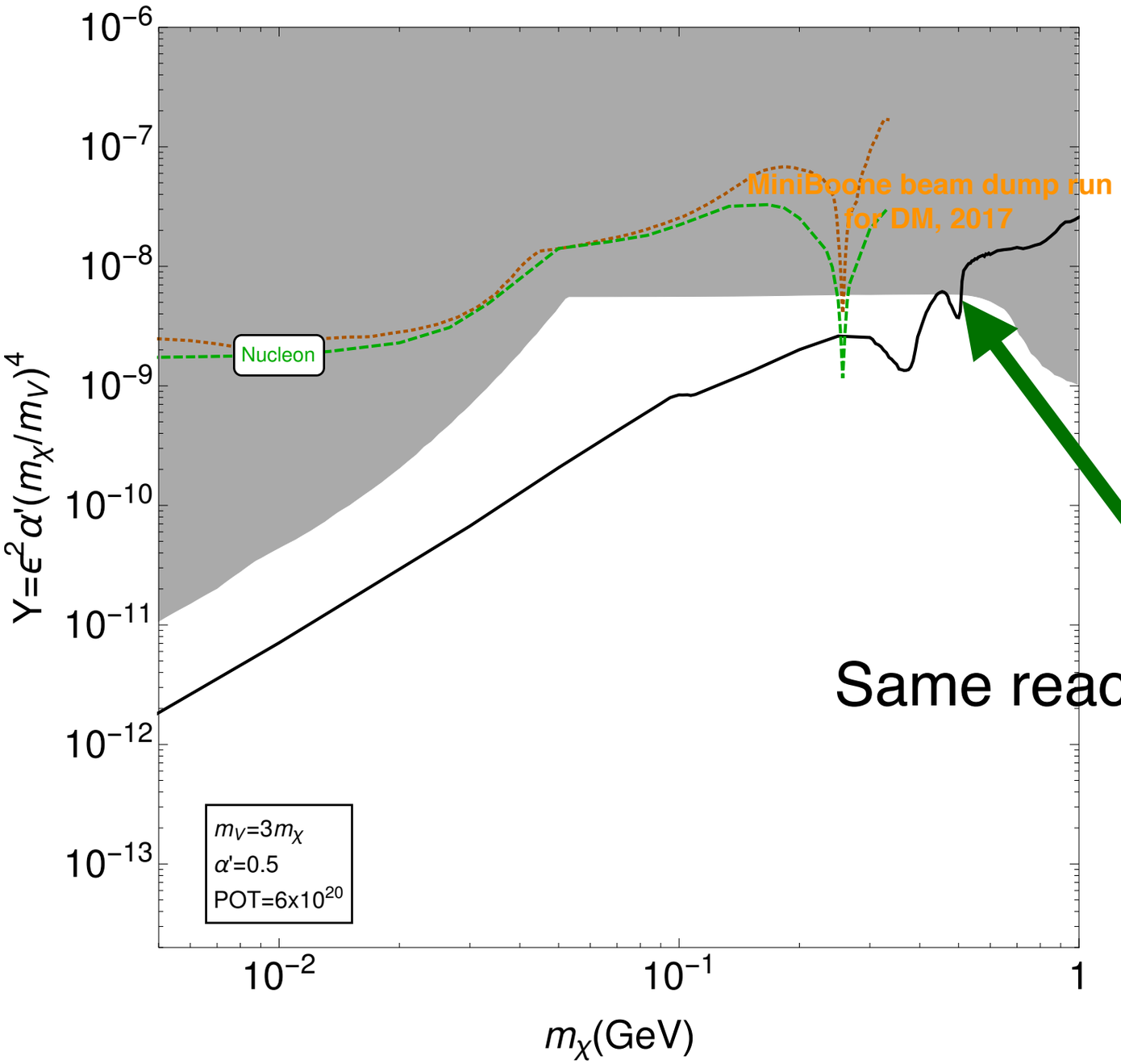


[Dobrescu, CF 2014]
[Dobrescu, Coloma, CF, Harnik 2015]
[CF 2017]

Complementarity with direct detection program for sub GeV mass range

DM-quark scattering in MiniBooNE

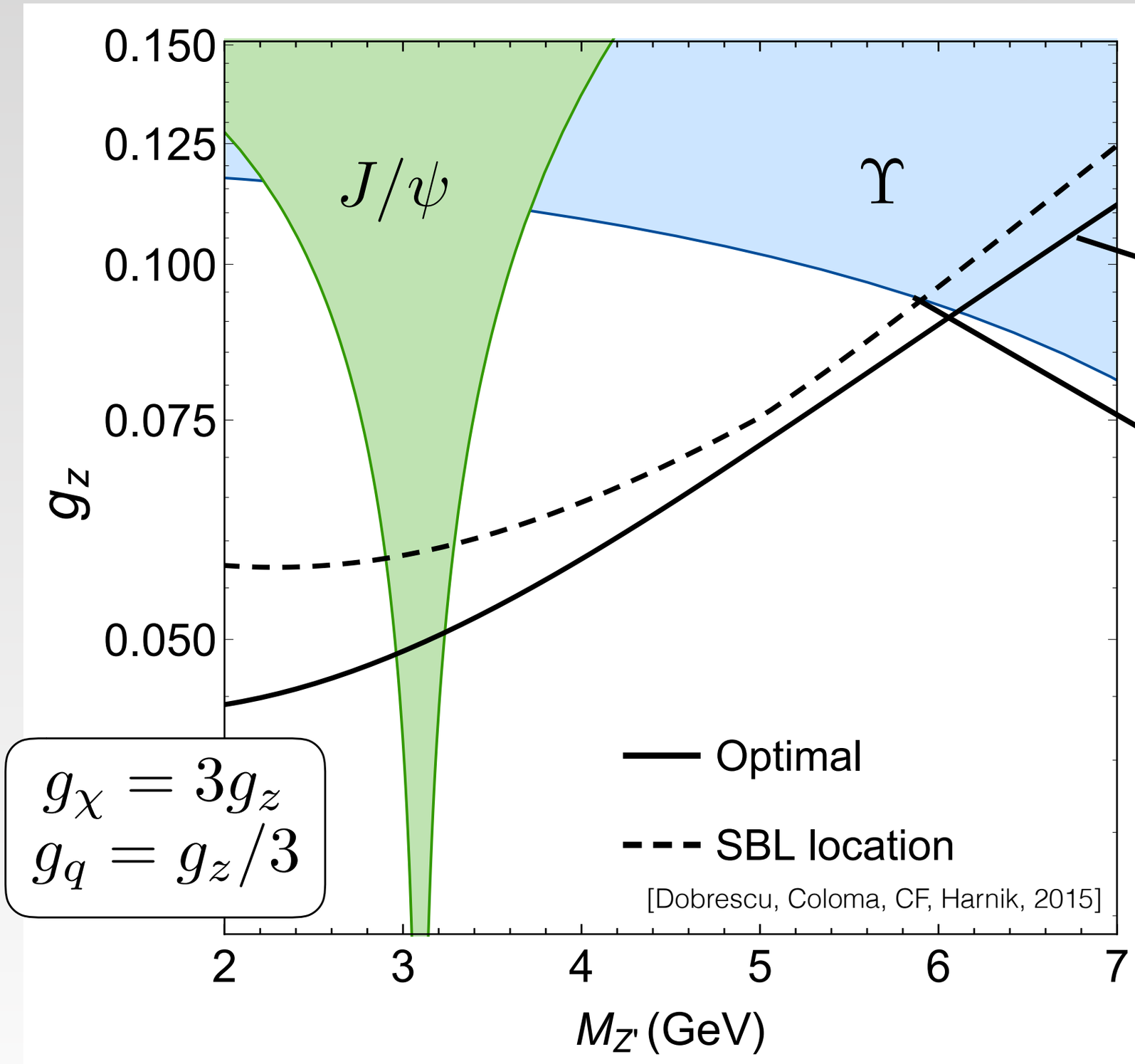
Larger neutrino bkg: going very off axis helps



Same reach with existing data!

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

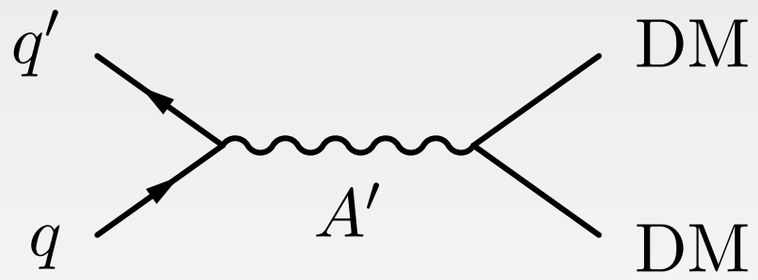
DM-quark scattering in MiniBooNE



Analysis of deep inelastic scattering events

Ideal detector (DUNE/LBNF)

Existing MiniBooNE data



In this mass range
Drell-Yan production

UV dependent constraints from anomalies
[Dobrescu,CF, 2014] [Dror,Lasenby,Pospelov,2017]

Symbiotic neutrino/DM programs

- NOvA & MiniBooNE dedicated analysis to light dark matter
- Study of potential sensitivity at SBND (liquid argon detector) and ICARUS 8 GeV FNAL Booster beam line
- Study of the sensitivity to non-minimal dark sectors (e.g. inelastic DM) both @ FNAL facilities and @ CERN (i.e. NA62)
- What are the prospects to probe DM at proposed facilities like LBNF or SHiP (Search for Hidden Particles)

Symbiotic neutrino/DM programs

- NOvA & MiniBooNE dedicated analysis to light dark matter
- Study of potential sensitivity at SBND (liquid
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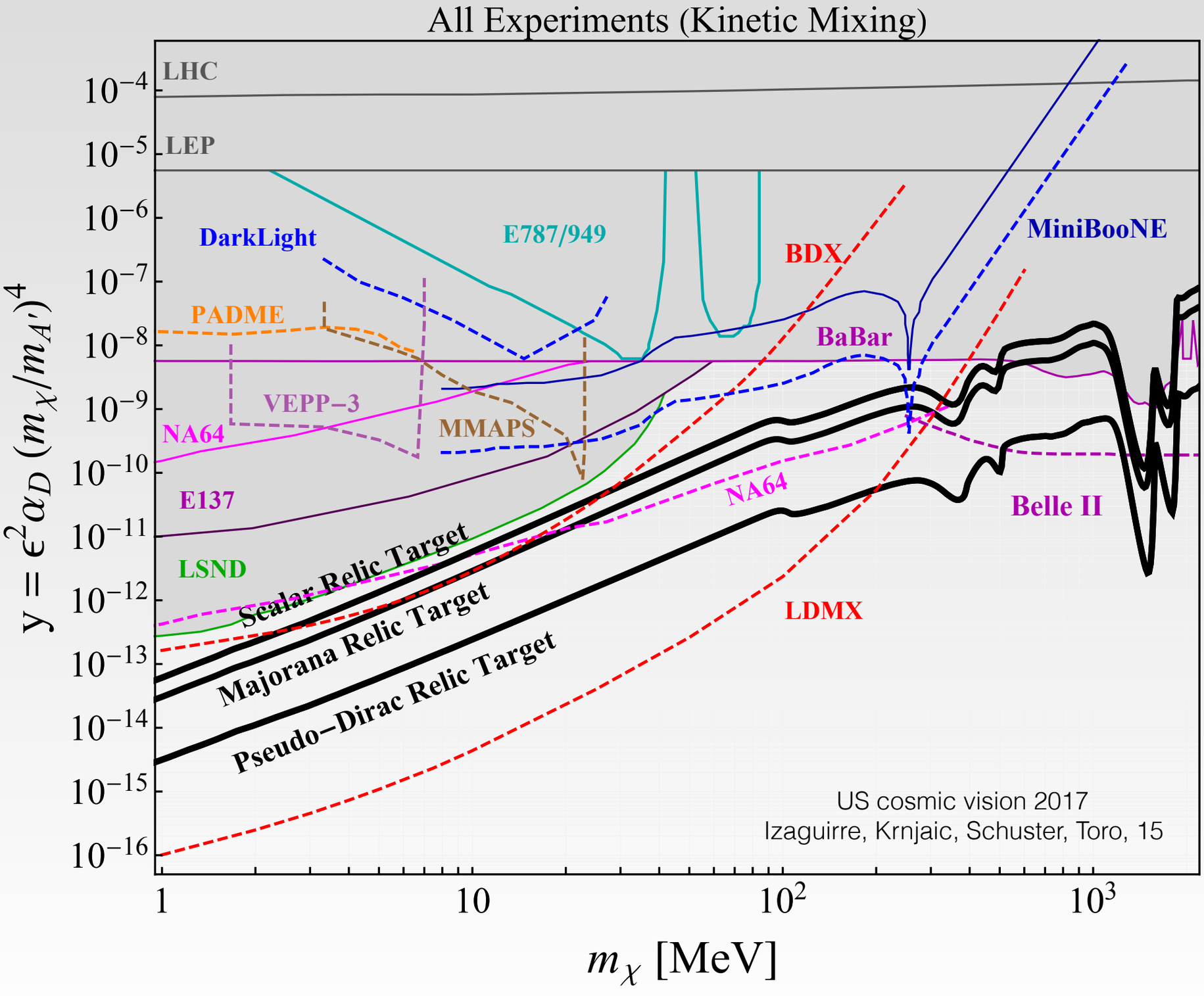
  ...NP of SHiP (Search for Hidden Particles)

Release of a MadGraph plugin (MadDump) to facilitate these analysis

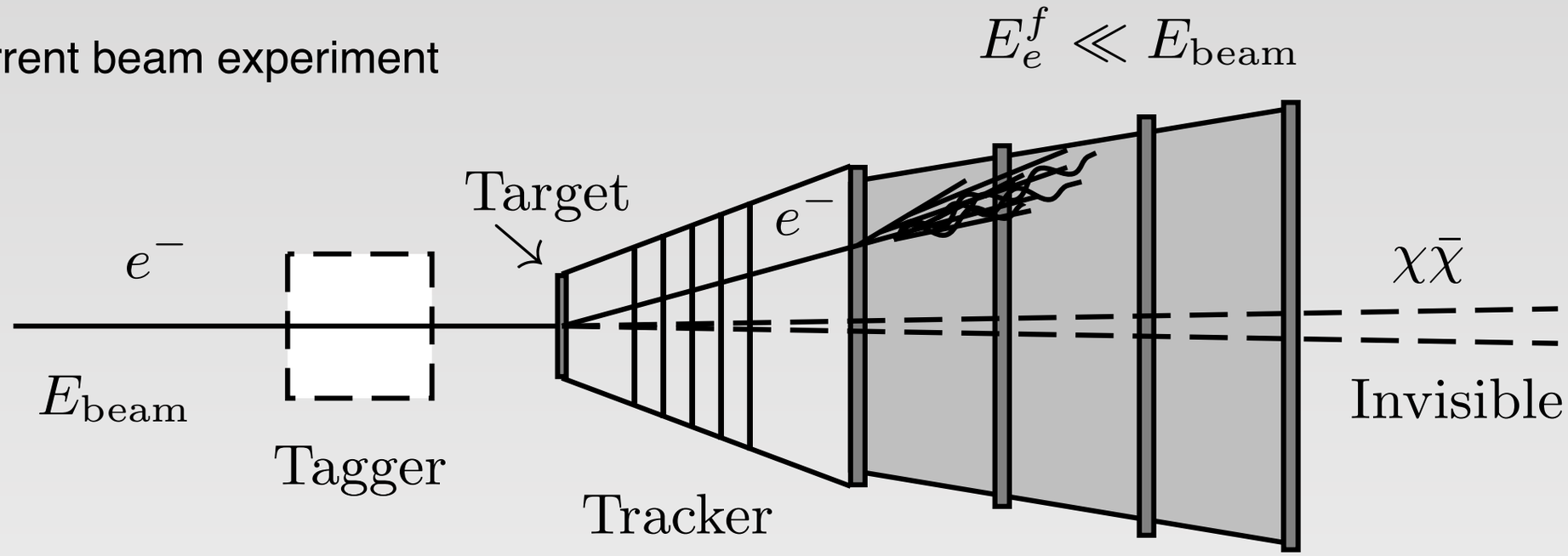
(L.Buonocore, CF, F.Maltoni,O.Mattelaer,F.Tramontano,in progress)

Missing Momentum Technique



Missing Momentum Technique

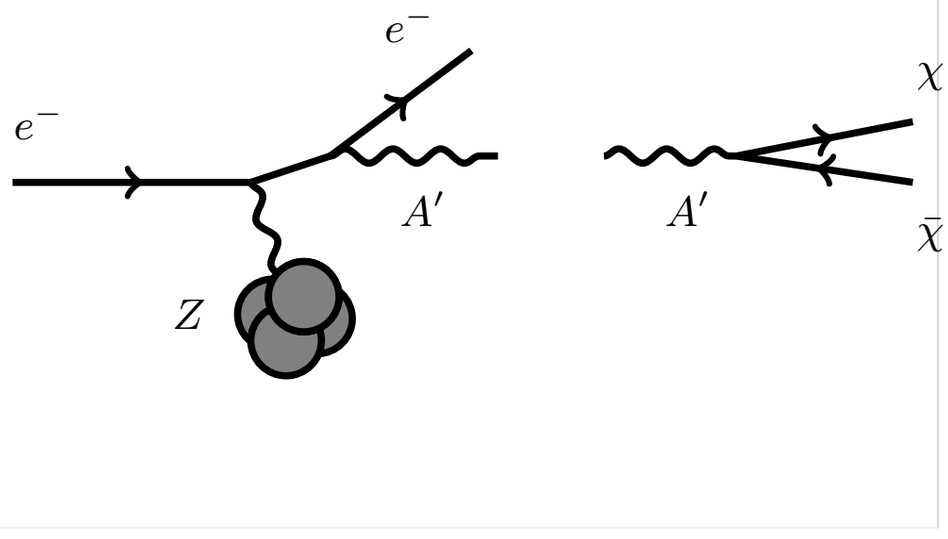
Low current beam experiment



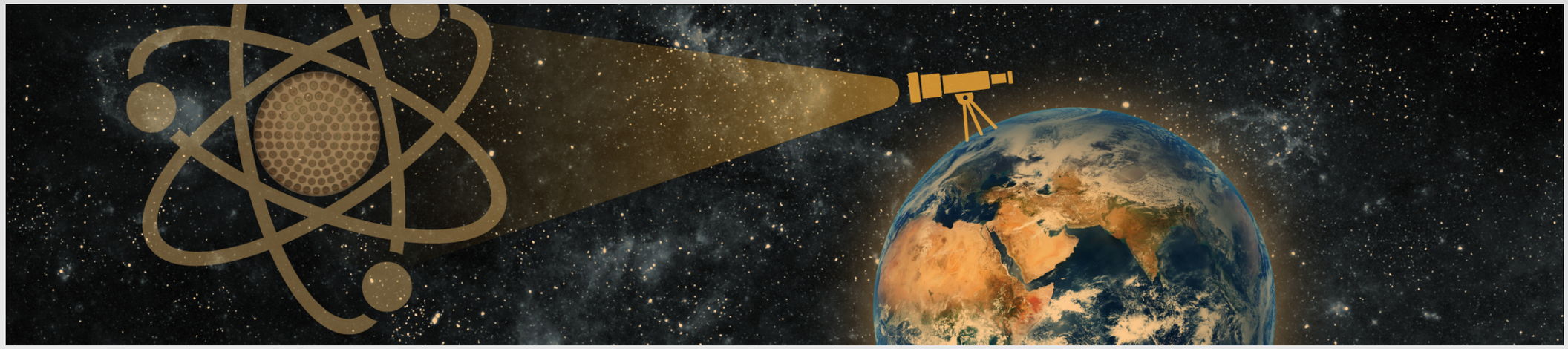
Signal: a low energy electron & no other activity

Payoff: Rate scales as $\sim \epsilon^2$

Izaguirre, Krnjaic, Schuster, Toro,2014



Outlook



The quest for sub GeV dark matter is in full swing

A discovery could be around the corner: new data and measurements in the next few years will probe interesting regions of the parameter space.

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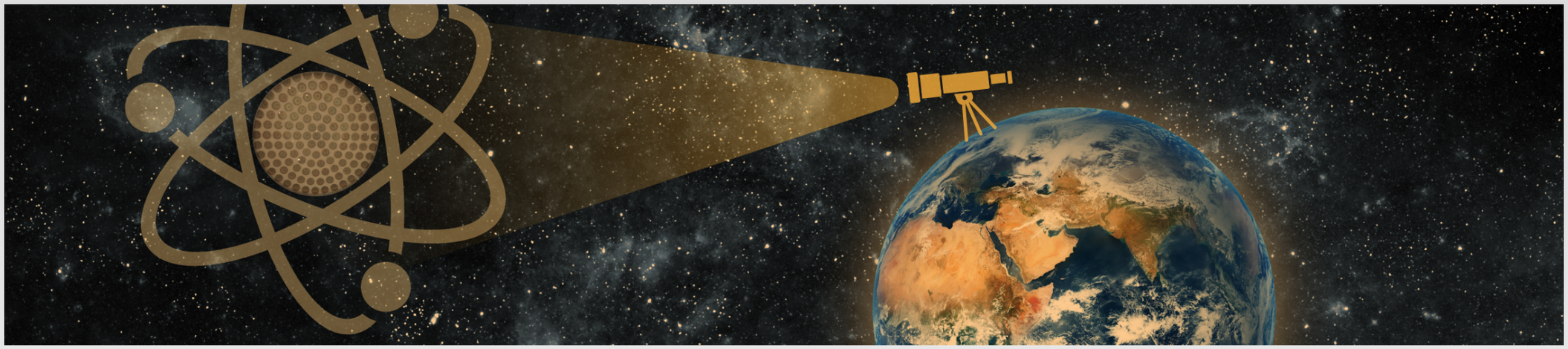

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Thank you!