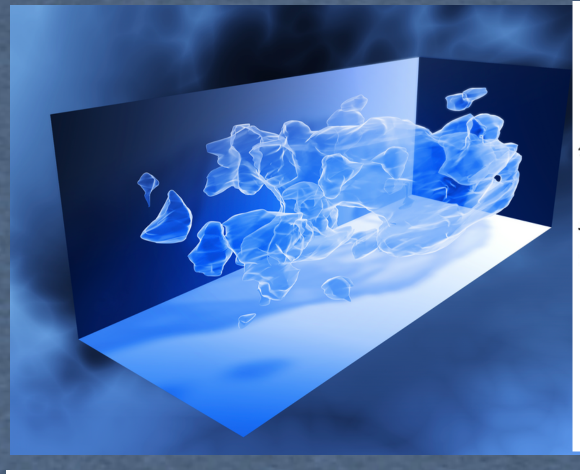
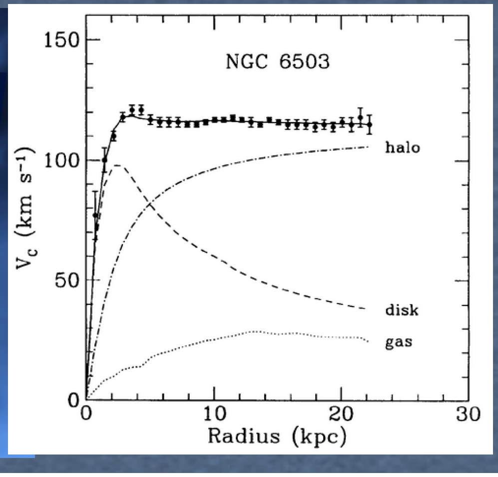
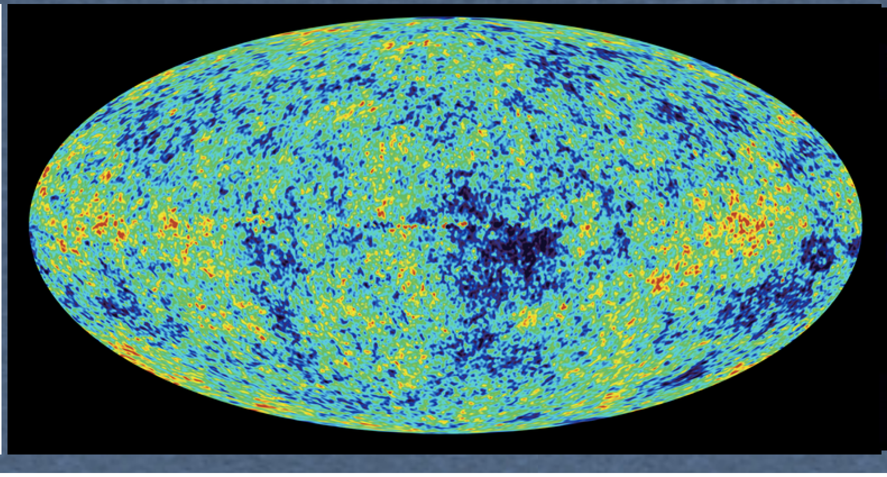
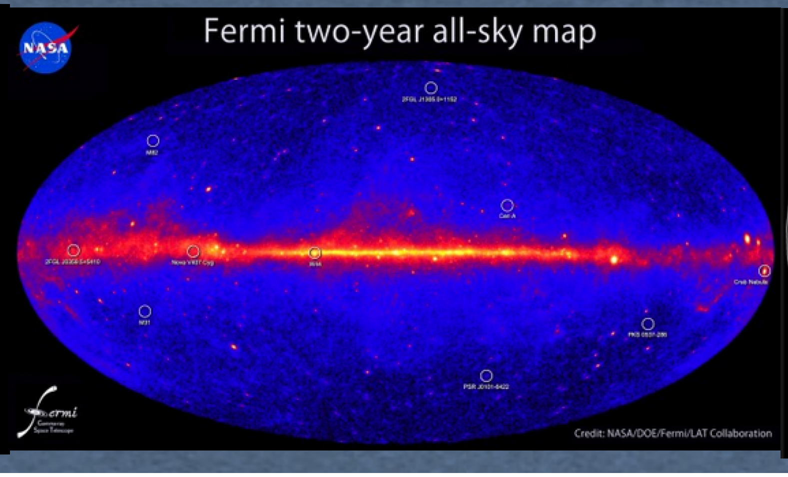
WORKSHOP: Multi-Aspect Young-ORiented Advanced Neutrino Academy (MAYORANA) - International Workshop II edition

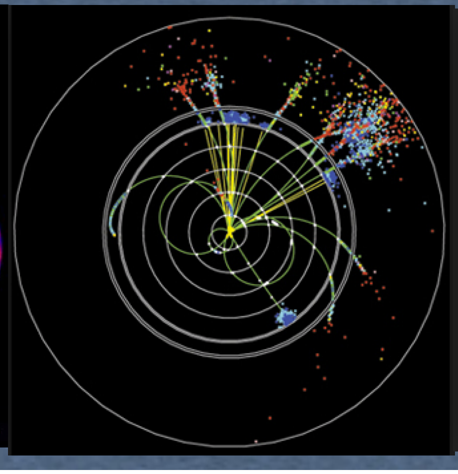
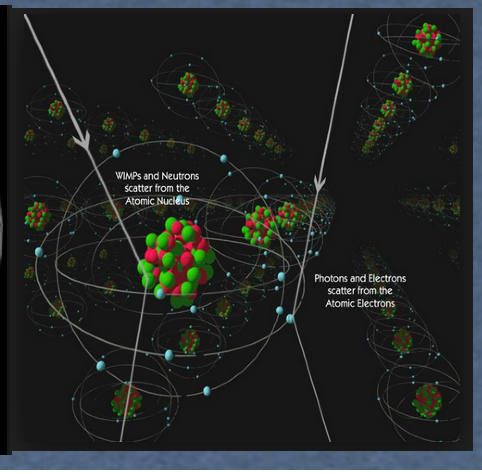
Jun 16 – 18, 2025
Modica

Light Dark Matter searches at accelerators: the BDX experiment at Jerfferson Lab

M.Battaglieri (INFN)

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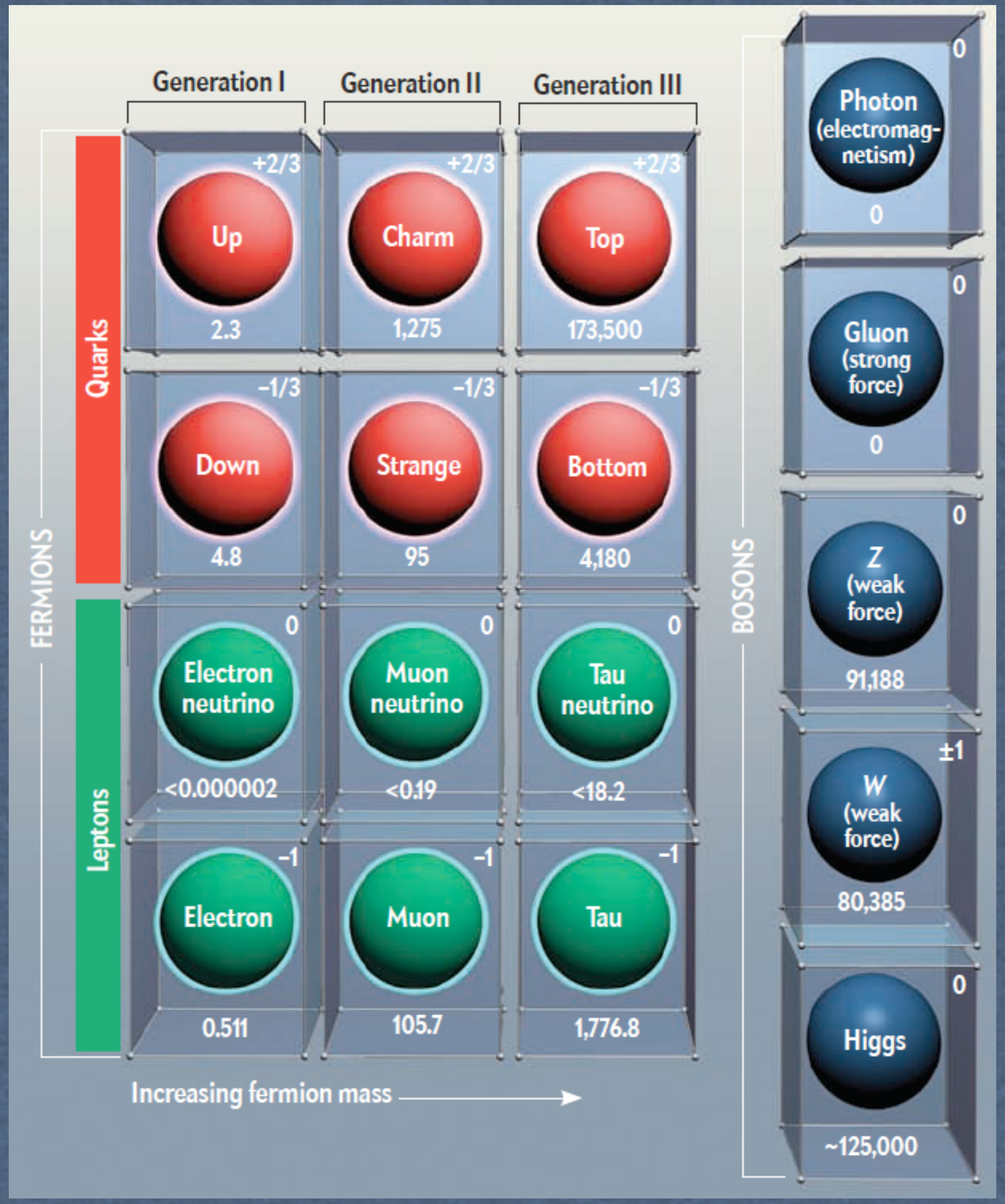
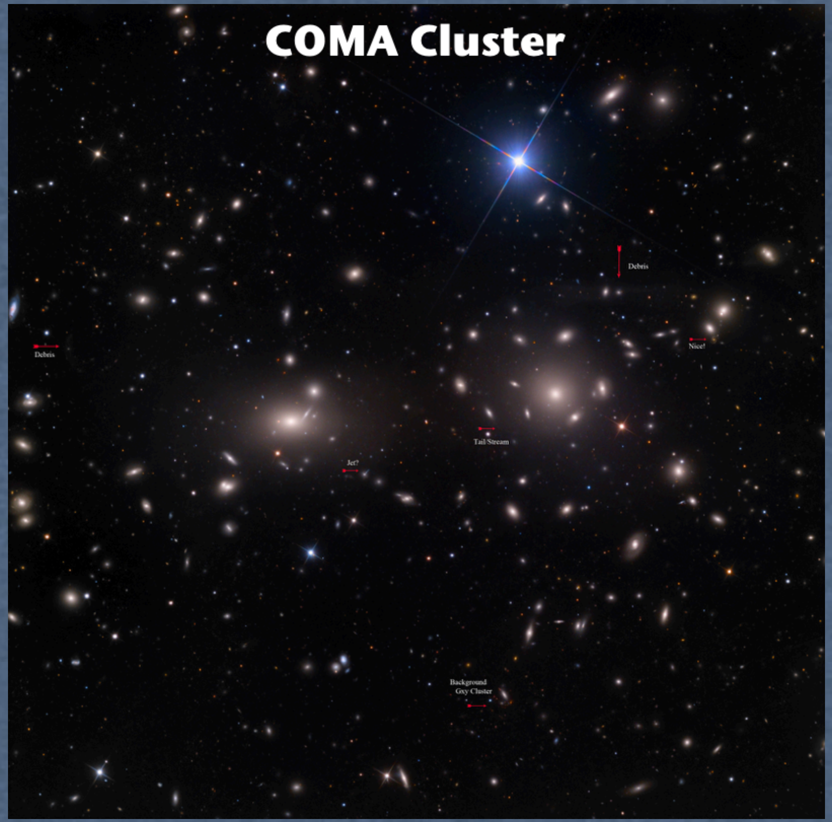
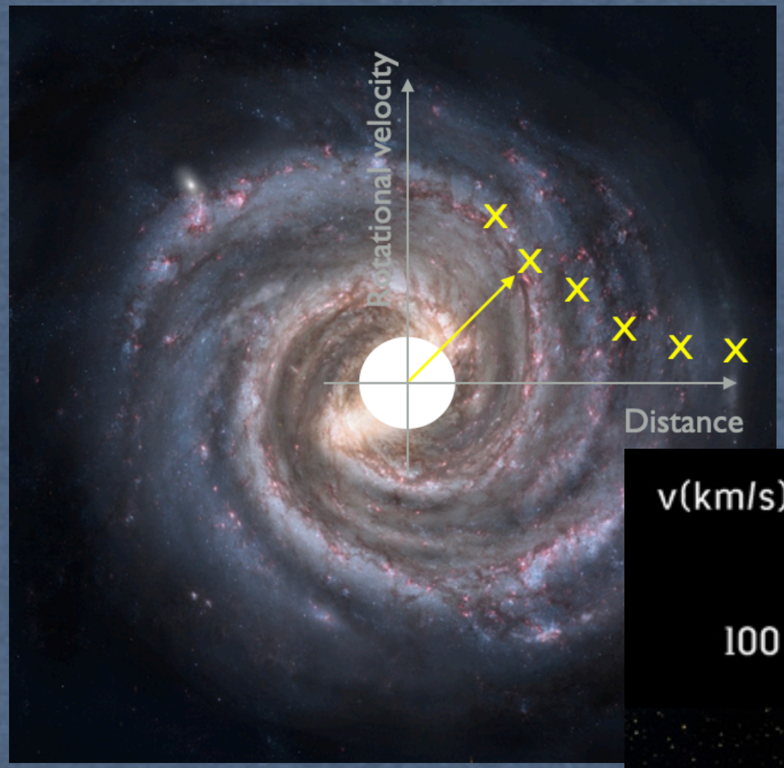
Standard Model of particles and interaction



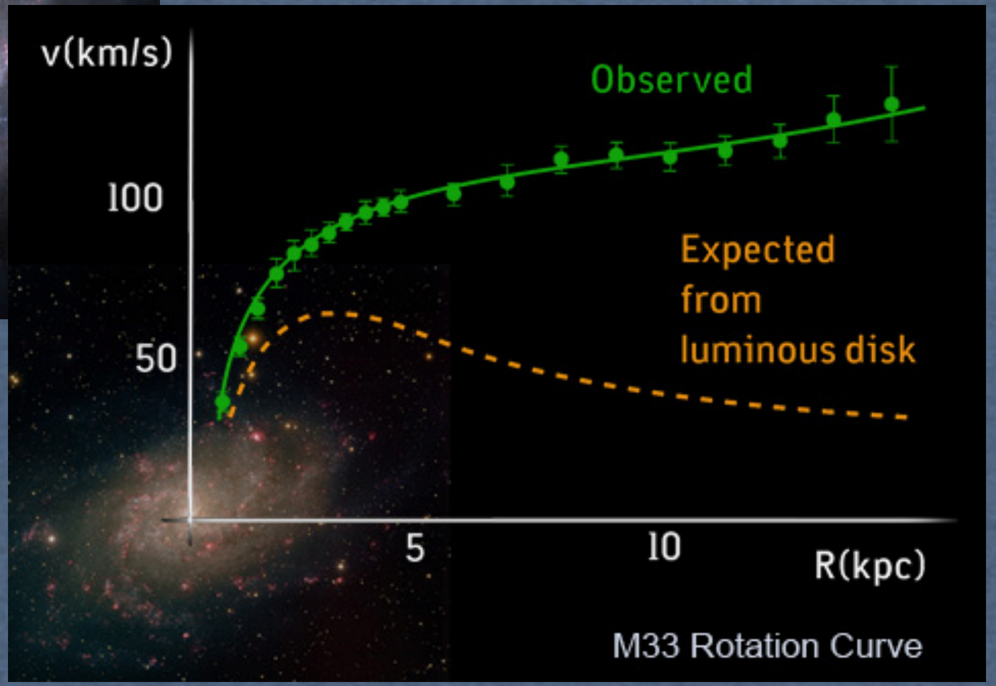
some anomalies ...

1935: Zwicky, Coma and Dark Matter
The gravity of the Stars is not enough to hold clusters together





1970s: Rubin and Flat Rotation Curves



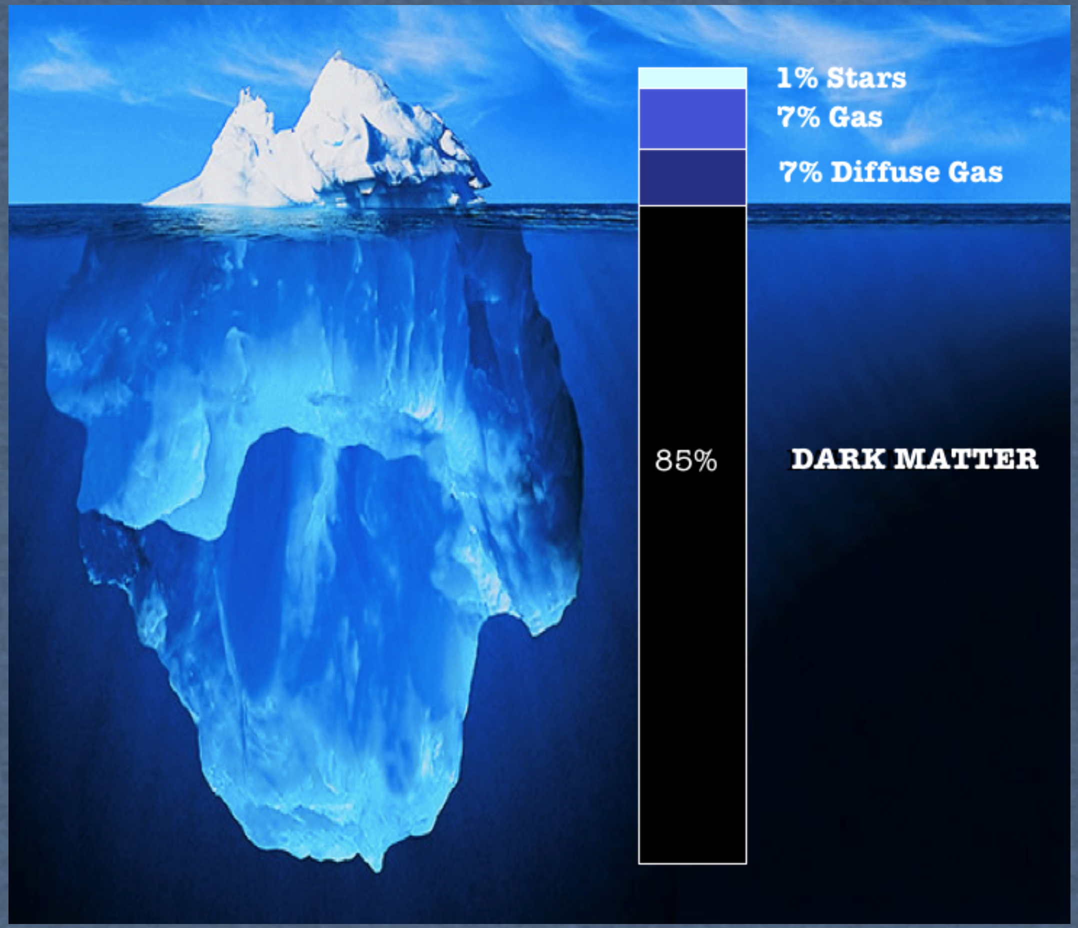
beside visible matter there should be something else ➨ DARK MATTER

- ★ Gravitational lensing
- ★ Mass balance
- ★ CMB
- ★ Clusters of galaxies
- ★ Cluster collisions
- ★ …

Compelling astrophysical indications about DM existence

Dark Matter (DM) vs Baryonic Matter (BM)

★ How much DM w.r.t. BM?



★ Does DM participate to non-gravitational interactions?
★ Is DM a new particle?

★ Constraint on DM mass and interactions

- should be '*dark*' (no em interaction)
- should weakly interact with SM particles
- should provide the correct relic abundance
- should be compatible with CMB power spectrum

… assuming that the gravity is not modified and DM undergoes to other interactions

★ We can use what we know about standard model particles to build a DM theory

Use the SM as an example: $SM = U(1)_{EM} \times SU(2)_{Weak} \times SU(3)_{Strong}$

Particles, interactions and symmetries

Known particles & new force-carriers

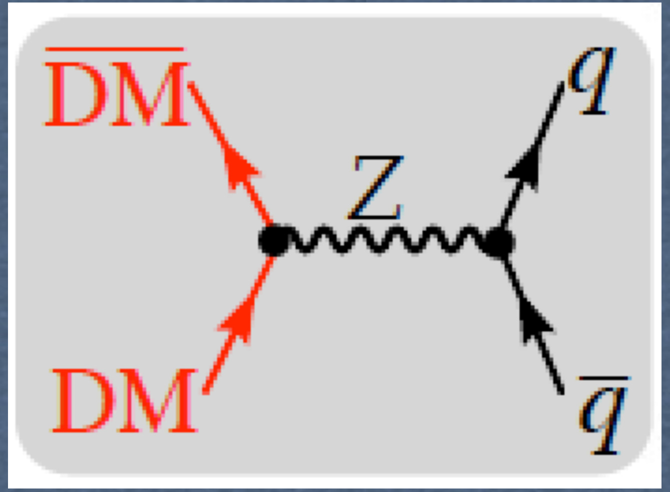
Particles:
quarks, leptons

Force-carriers:
gluons, γ, W, Z, graviton (?), Higgs, ...

Two options:

★ New matter interacting trough the same forces
★ New matter interacting through new forces

Any guess about the DM mass and interaction?



Yes, if we do a couple of assumptions:

★ DM thermal origin

in the early Universe DM was in thermal equilibrium with regular matter (via annihilation)

★ DM as thermal relic from the hot early Universe

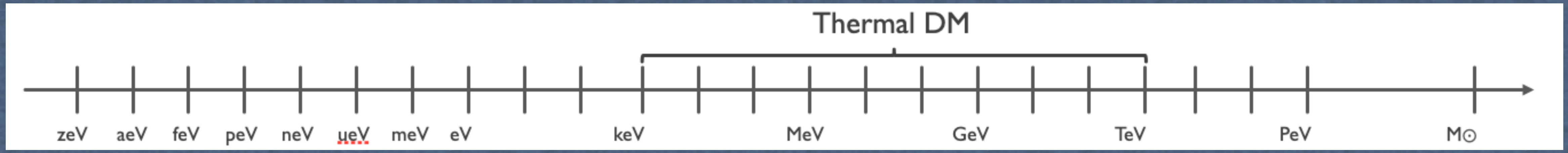
Minimal DM abundance is left over to the present day

$\langle \sigma v \rangle \sim M^2_{DM}/M^4_{mediator}$

Correct DM density for an annihilation xsec: $\langle \sigma v \rangle \sim 3\times10^{-26}$ cm^3/s $\sim 1/(20\text{ TeV})^2$

★ Mass constraints:

- mass too low: can not become non-relativistic in time
- mass too high: overproduced in early Universe



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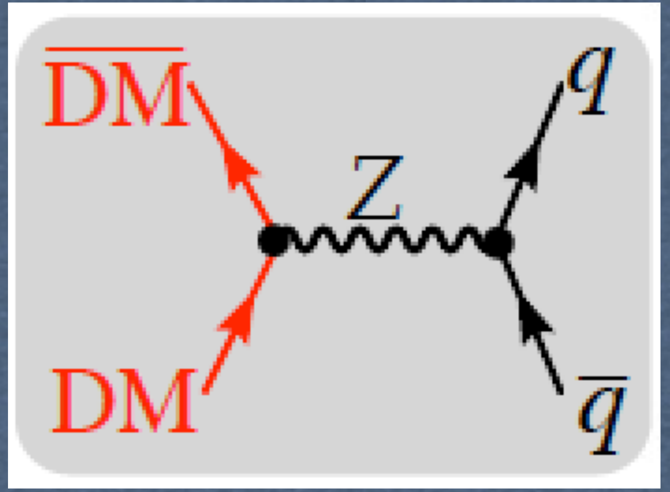

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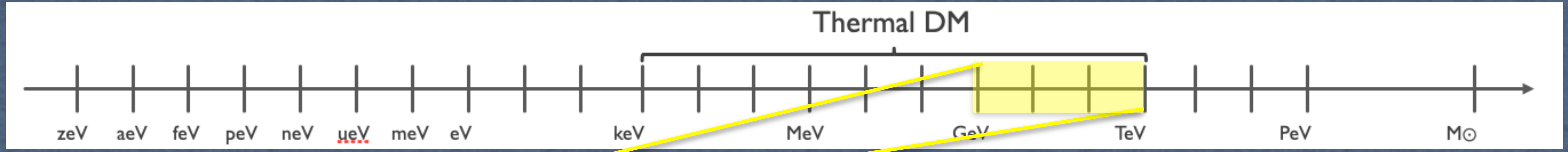
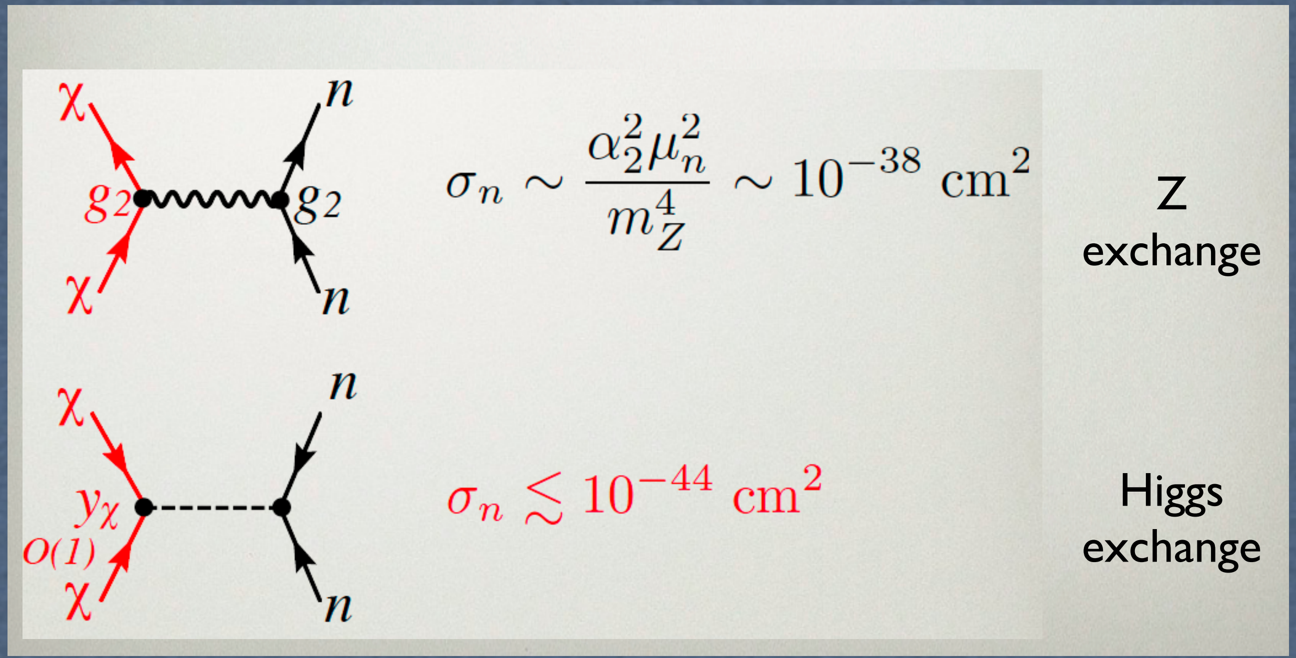


WIMPs (Weakly Interacting Massive Particles)

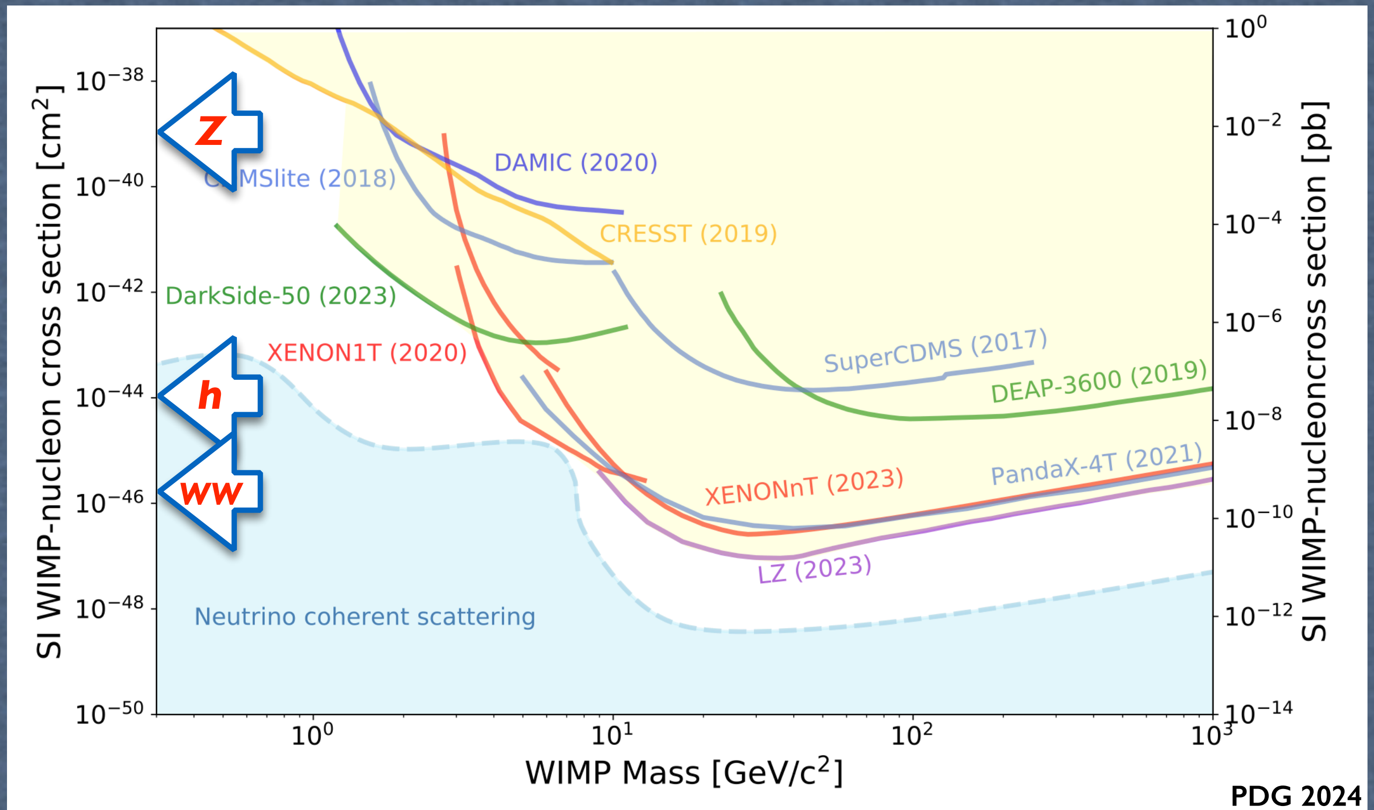
- Massive DM with massive mediator
- For ~100 GeV DM mass, weak-scale mediators provide reasonable annihilation rate and range of DM-scattering rates



Thermal origin suggests DM interactions and mass in the vicinity of the weak-scale

Exploring the WIMP's option

★ Experimental limits



Slow-moving cosmological weakly interacting massive particles

- DM detection by measuring the (heavy) nucleus recoil
- Constraints on the interaction strength from the DM Direct Detection limits
  - Scattering through Z boson ($\sigma \sim 10^{-39}$ cm^2): ruled out
  - Approaching limits for scattering through the Higgs ($\sigma \sim 10^{-45}$ cm^2)
  - Close to irreducible neutrino background

✳ No signal observed in Direct Detection

✳ Experiments have reduced sensitivity to (light) DM (<1 GeV)

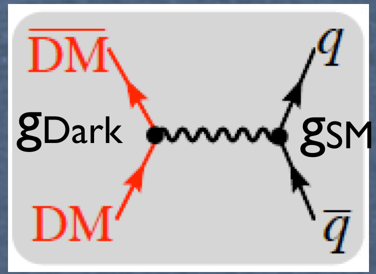
Direct Detection

1 MeV — 1 GeV — Mz — 10 TeV

WIMPs

WIMPs paradigm is not the only option (keeping the DM thermal origin)

$\langle \sigma v \rangle \sim g^2_{Dark}\, g^2_{SM}\, M^2_{DM}/M^4_{mediator}$



Light Dark Matter

Light Dark Matter (<TeV) naturally introduces light mediators

New interaction

Introducing a new force in nature

- Hidden sector (HS)
  present in string theory and super-symmetries

  - HS not charged under SM gauge groups (and v.v.)
    no direct interaction between HS and SM
    HS-SM connection via messenger particles

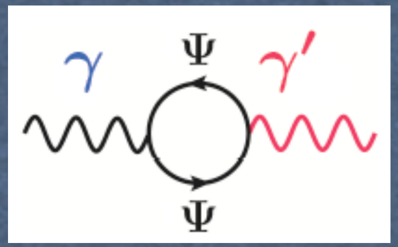
A simple way to go beyond the SM (not yet excluded!):

$SU(3)_C \times SU(2)_L \times U(1)_Y$ **x extra U(1)**

Color   Electroweak   Hypercharge   Hidden sector

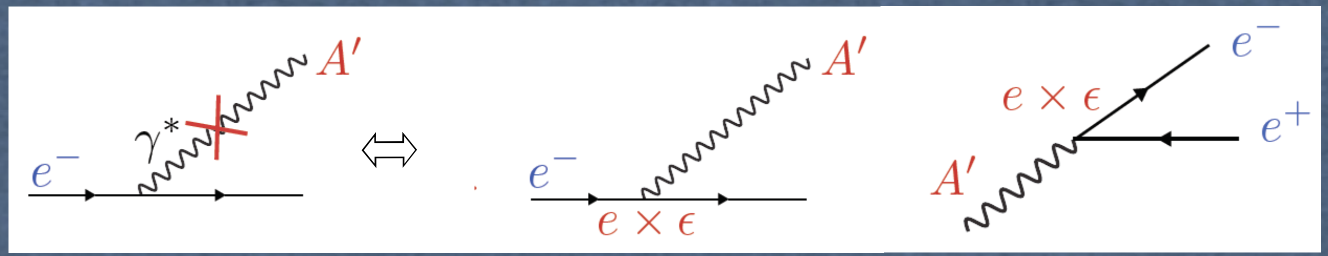
$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} - \frac{\chi}{2} X_{\mu\nu} F^{\mu\nu} + \frac{m^2_{\gamma'}}{2} X_\mu X^\mu$$

Hidden / Visible

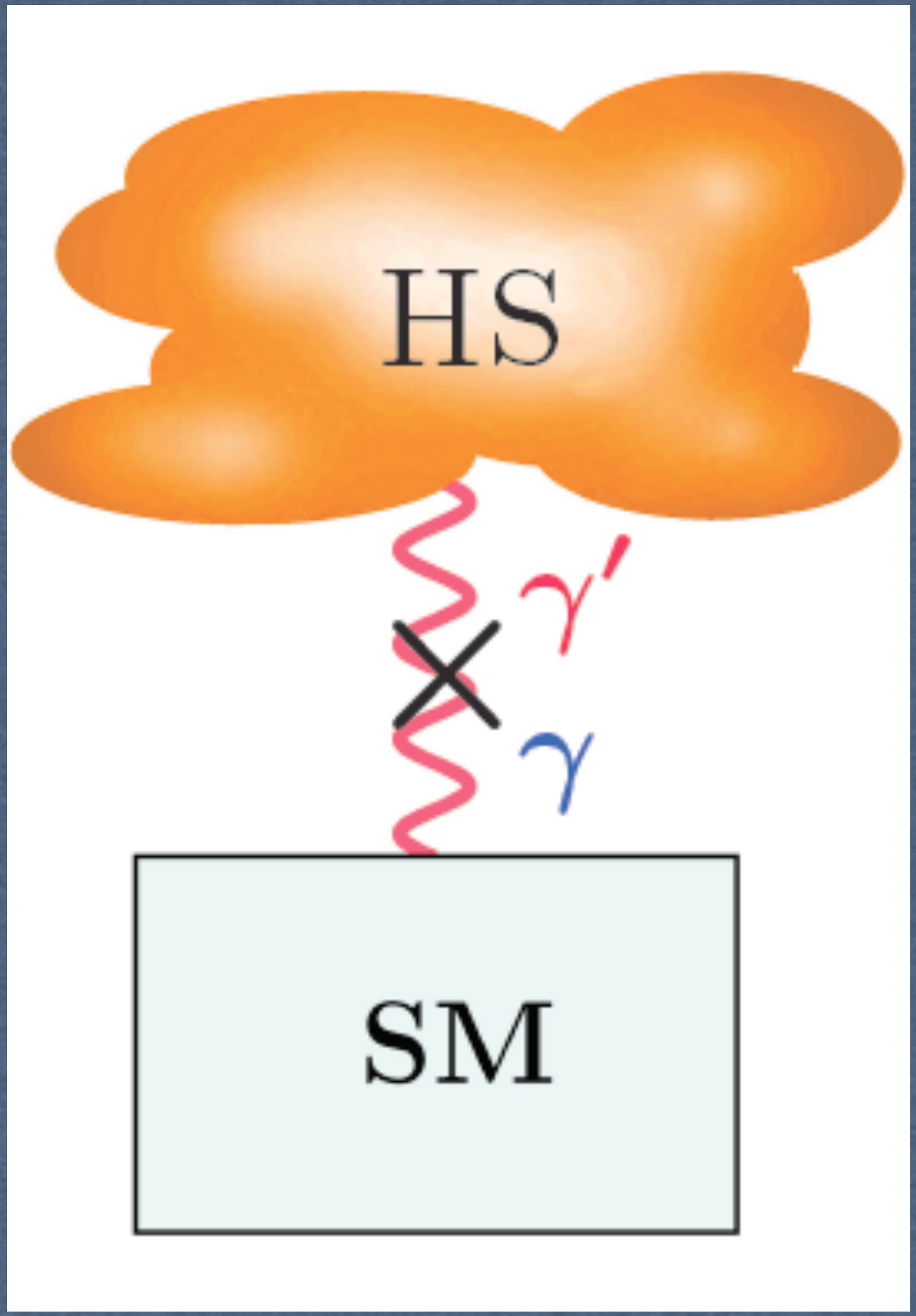


γ'/A' couples to SM via electromagnetic current (kinetic mixing)

➜ $A_\mu \rightarrow A_\mu + \varepsilon a_\mu$ $\chi = \varepsilon \sim 10^{-6}$-$10^{-2}$ ($\alpha^{DarkProton} = \varepsilon^2 \alpha_\mu$)



Ψ can be a huge mass scale particle (M_Ψ~1EeV) coupling to both SM and HS



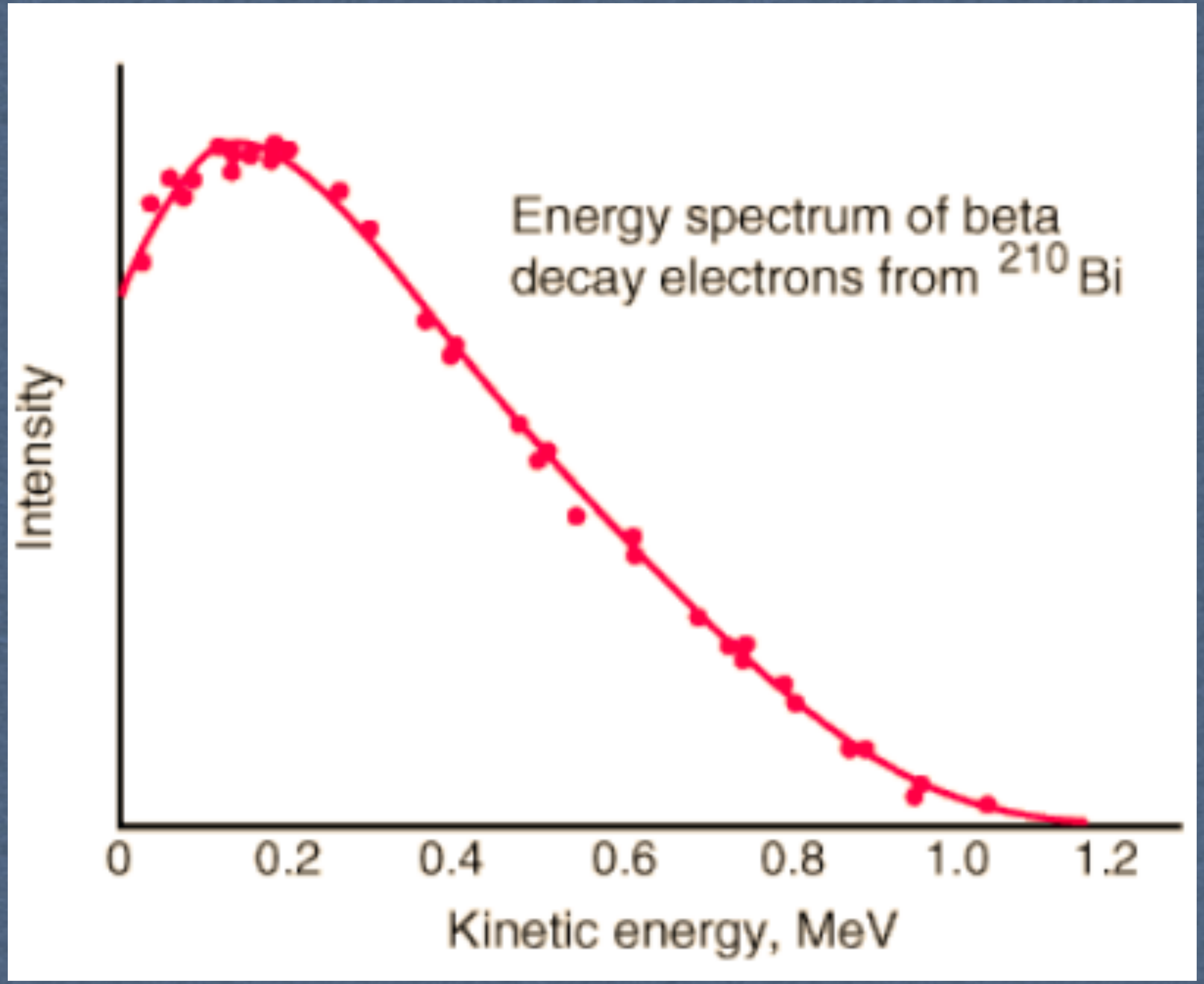
A lesson from history

An historical example of a 'Standard Model' and 'hidden sector'

★ Back in the '30 the Standard Model of the elementary particles was: photon, electron and nucleons

★ Beta decay:

$n \rightarrow p + e^-$ Continuous spectrum!



★ Pauli proposes a radical solution - the neutrino!

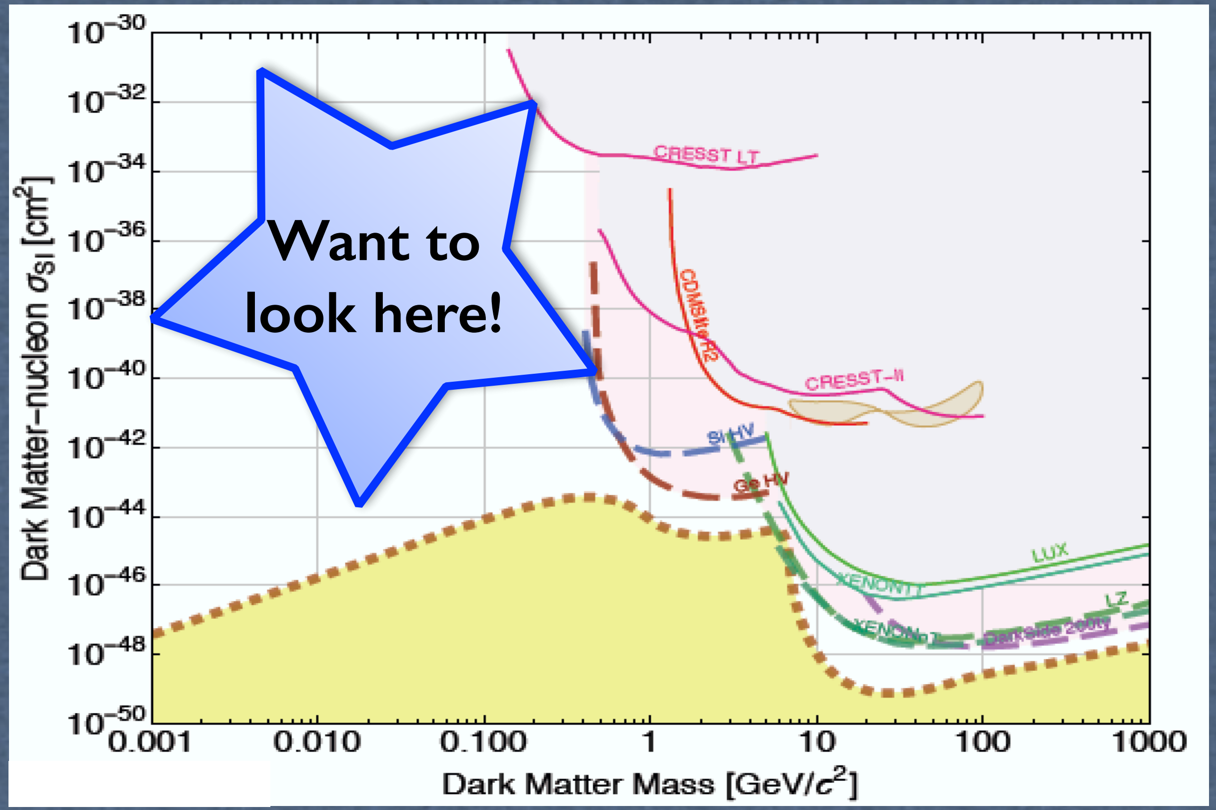
$n \rightarrow p + e^- + \bar{\nu}$

★ Perfect example of a hidden sector!

- neutrino is electrically neutral
- very weakly interacting and light
- interacts with "Standard Model" through "portal" - $(p\gamma^\mu n)(e\gamma^\mu \nu)$

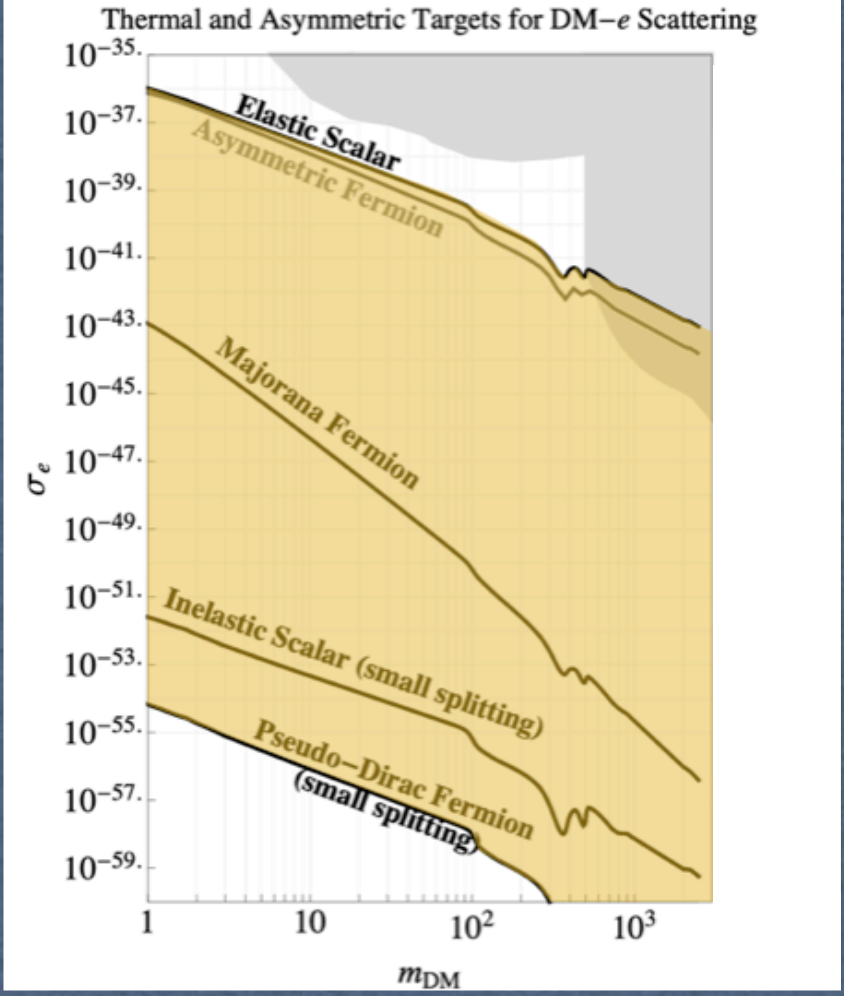
Light Dark Matter

Light Dark Matter with a (almost) weak interaction (new force!)



- Direct Detection is difficult
  - Low mass elastic scattering on heavy nuclei: small recoil
  - Large model dependence
  - Strong dependence on velocity distribution
  - eV-range recoil requires a different detection technology
  - Directionality may help to go behind existing limits at large masses

- **Direct Detection**



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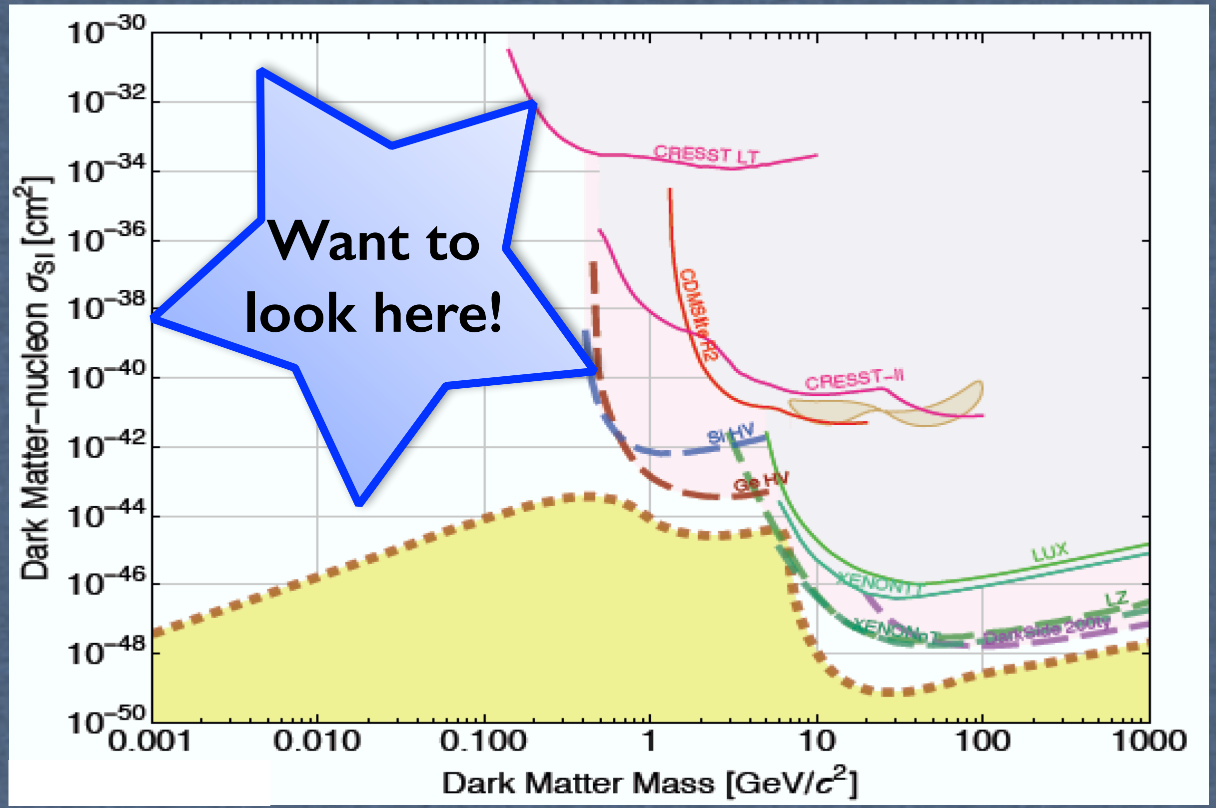

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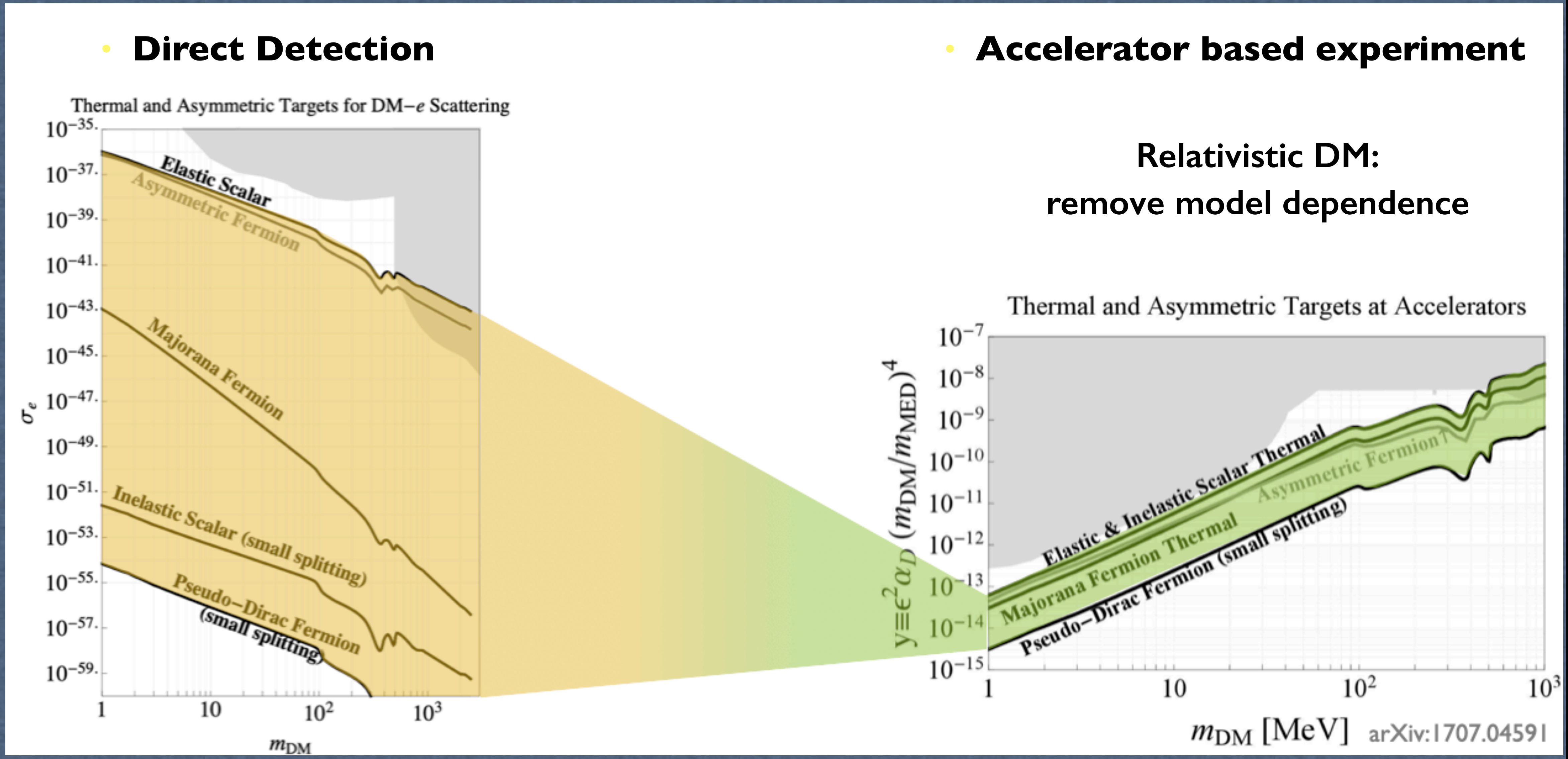
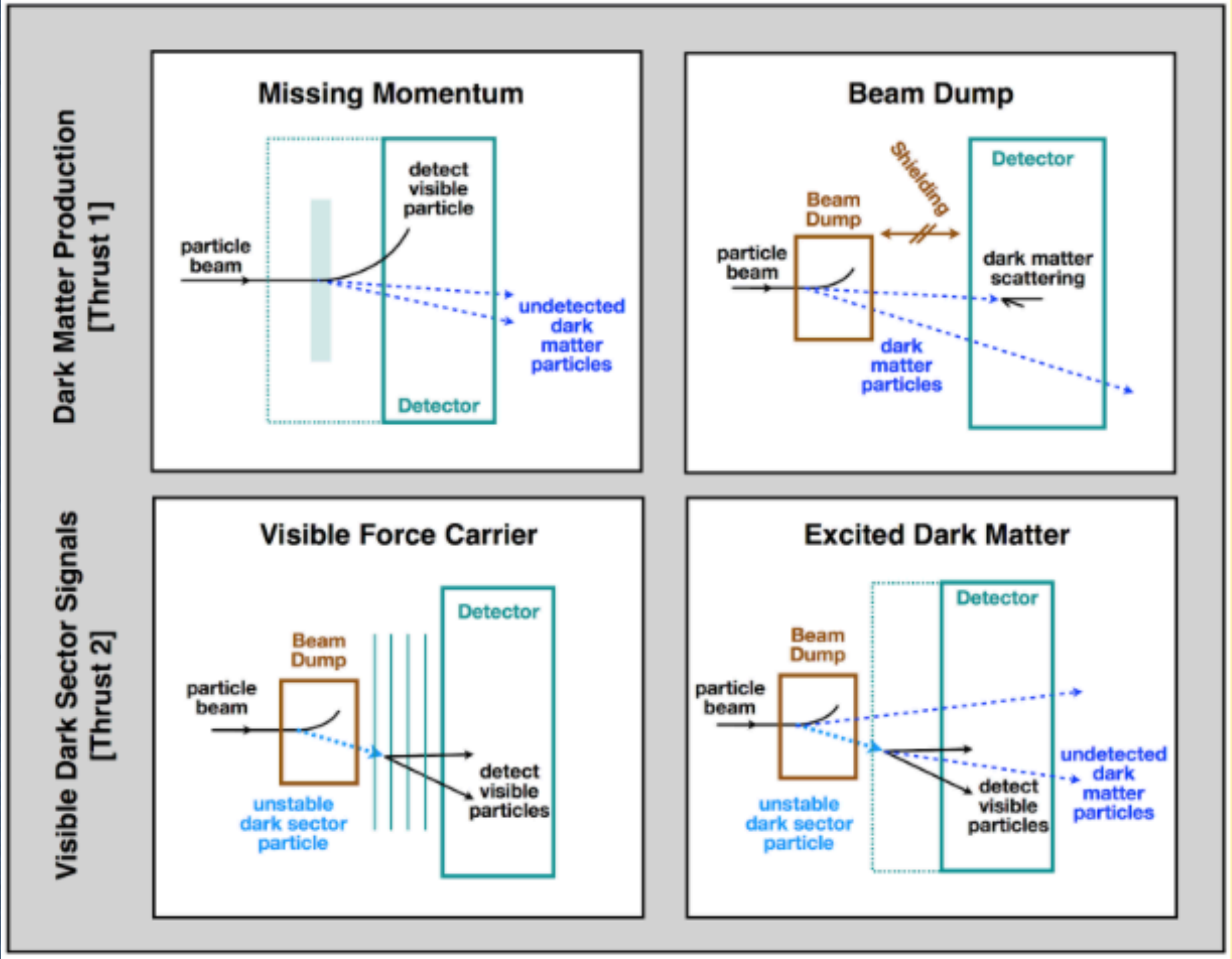
- Accelerators-based DM search
  - covers an unexplored mass region extending the reach
  - outside the classical DM hunting territory

Particle beams
- High intensity
- Moderate energy

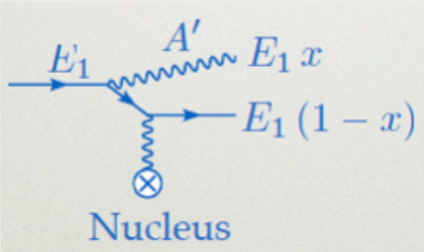
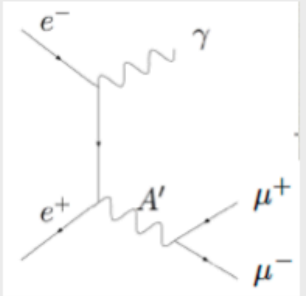
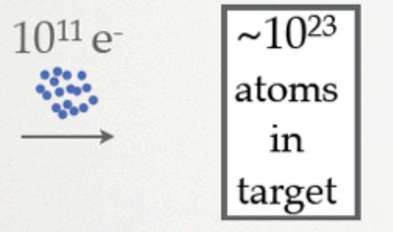
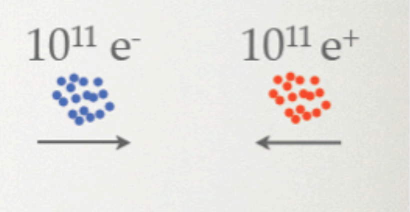
Intensity frontier



Experimental techniques



Fixed target vs. collider

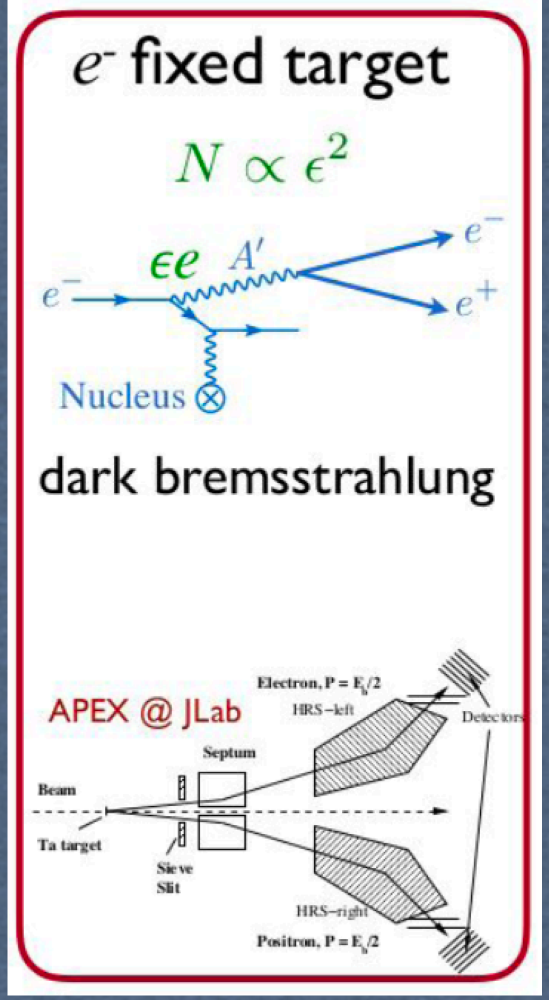
	Fixed Target	e+e- colliders
Process		
Luminosity		
Cross-Section	$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$	$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$

Fixed target:
- high backgrounds
- limited A' mass

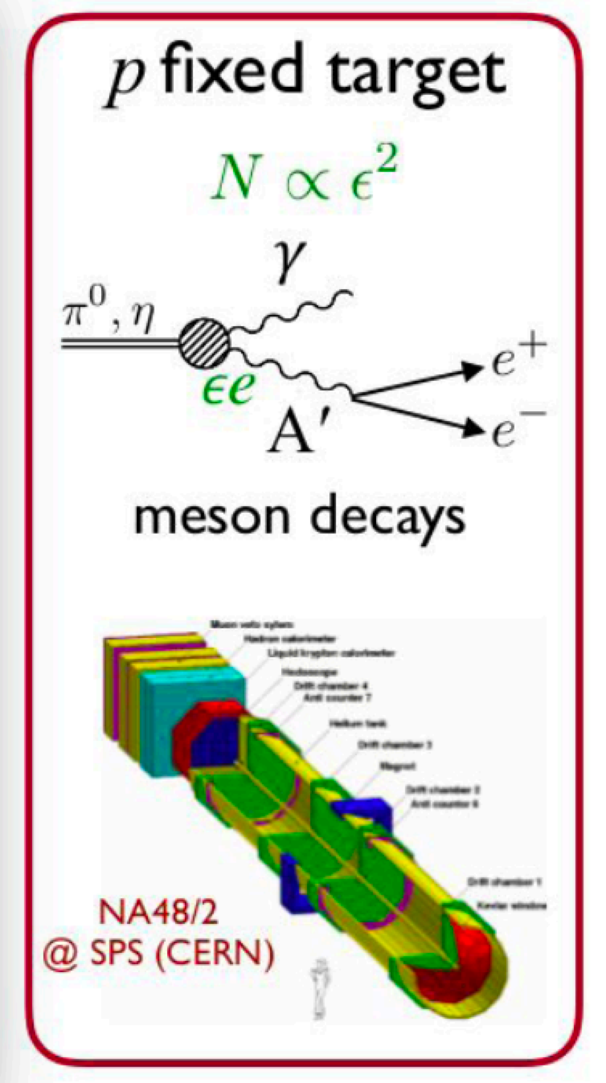
e+e- colliders:
- low backgrounds
- higher A' mass

✳ $1/M_{A'}$ .vs. $1/E_{beam}$
✳ Coherent scattering from Nucleus (~Z^2)

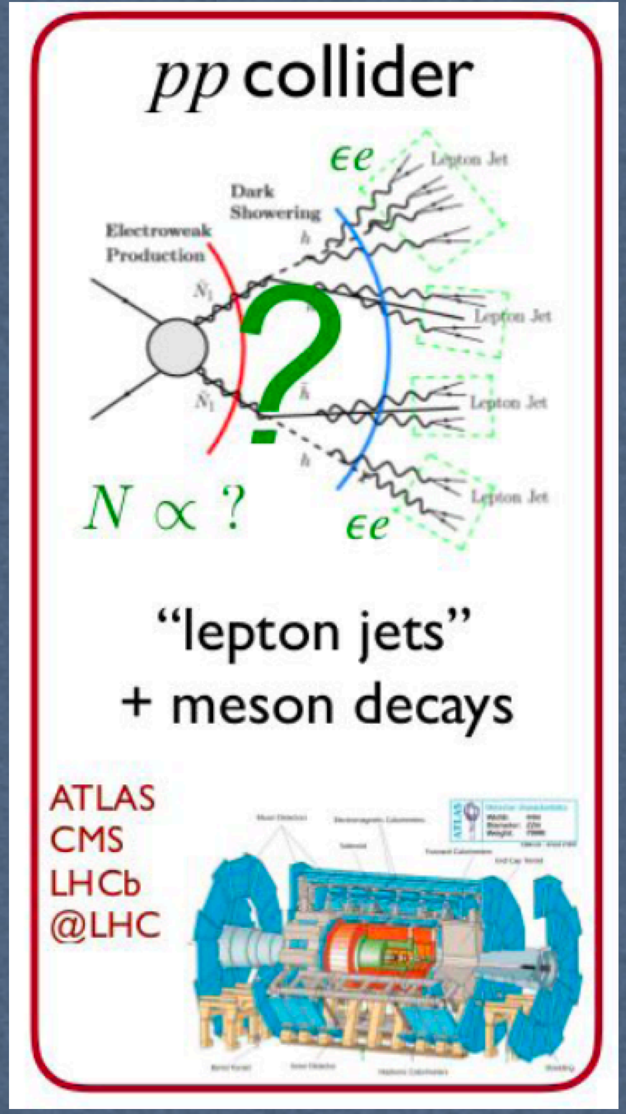
A' visible and invisible decay at accelerators

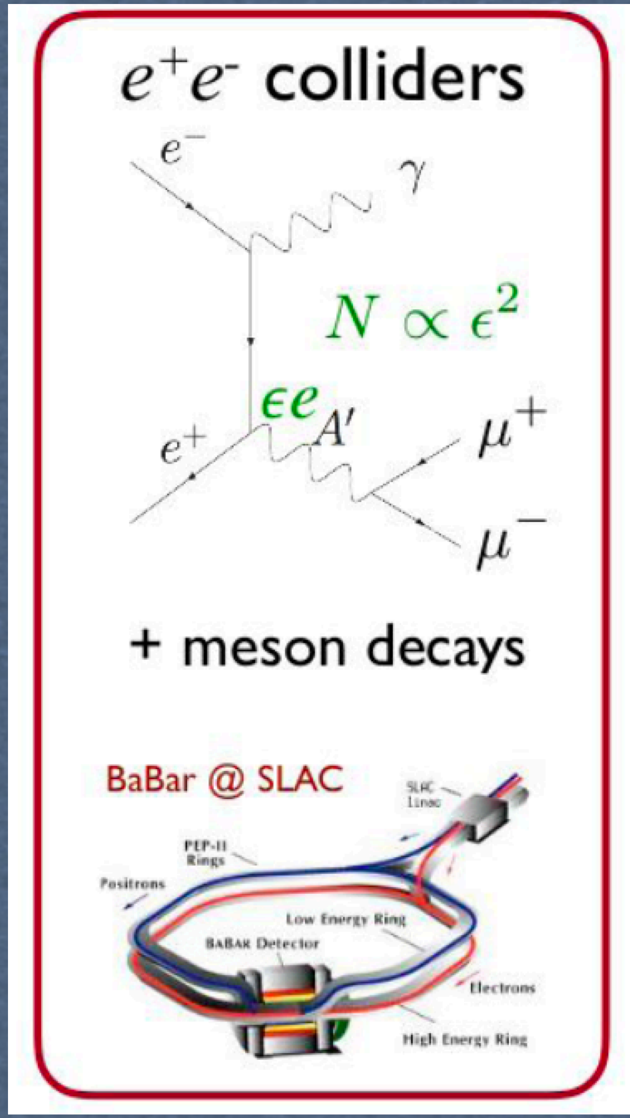


Fixed target:
e N →N γ'→ N Lepton Lepton+
→ **JLAB, MAINZ**

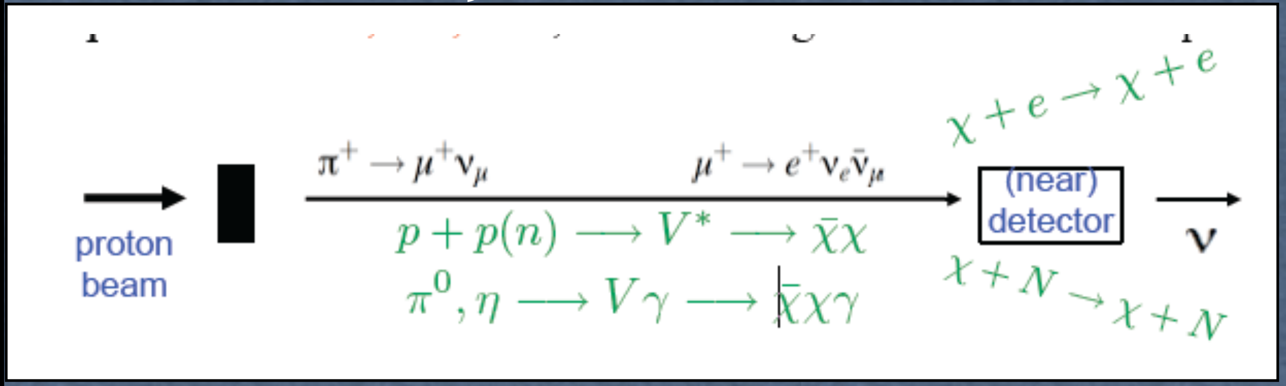


High Energy
Hadron Colliders:
pp → lepton jets
→ **ATLAS, CMS,**
CDF&D0





Fixed target:
p N →N γ'→ p Lepton Lepton+
→ **FERMILAB, SERPUKHOV**

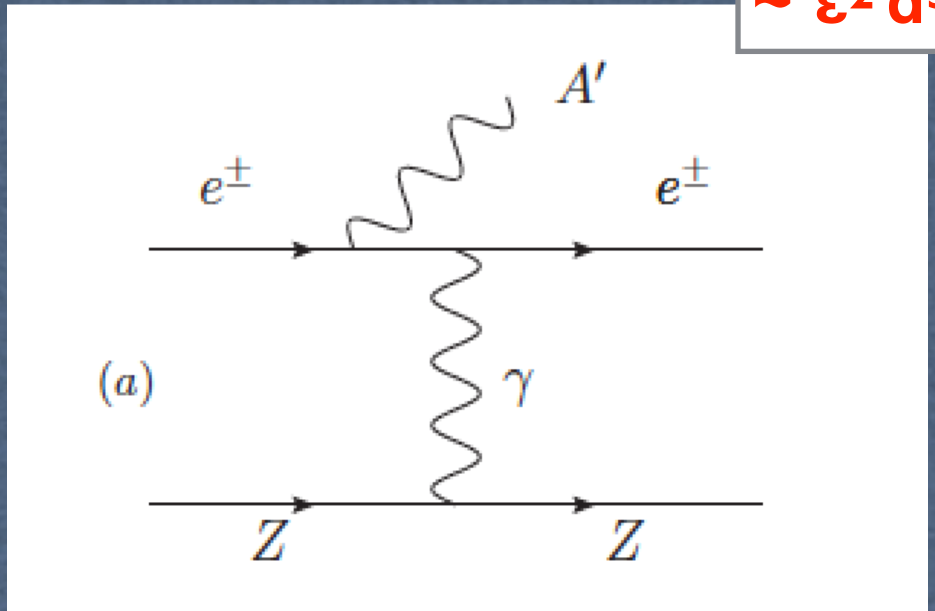


Meson decays:
π^0, η, η', ω,' → γ' γ (M)
→Lepton Lepton + γ (M)
→ **KLOE, BES3,**
WASA-COSY, PHENIX

Annihilation:
e+e- → γ' γ → μμ γ
→ **BABAR, BELLE-II,**
KLOE, CLEO

A’ Production mechanisms - $e^{\pm}$

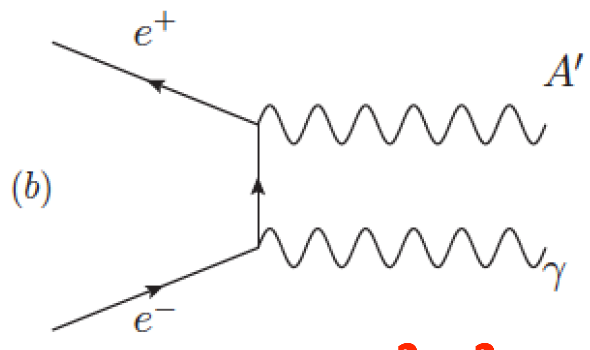
~ $\varepsilon^2 \alpha^3$



The Weizsacker-Williams approximation (*A’-strahlung*)

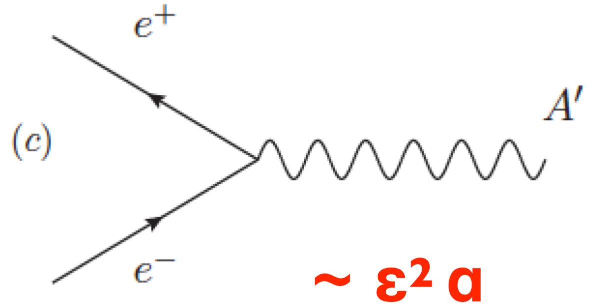
- The incoming electron ‘see’ a fast-moving cloud of effective photons to scatter from
- Photons are almost on-shell (low Q2) → transverse photons ~ $e^- \gamma_{Real}$ scattering
- Same treatment as the regular *bremstrahlung*
- Regularisations occurs in the case of interest $M_{A'} >> M_{e-}$
- Effective photon flux χ is critical, accounting for nuclear effect using FF

A’ Production - positrons



~ $\varepsilon^2 \alpha^2$

- **NON-RESONANT annihilation**
  - **A’ along (e^+e^-) direction**



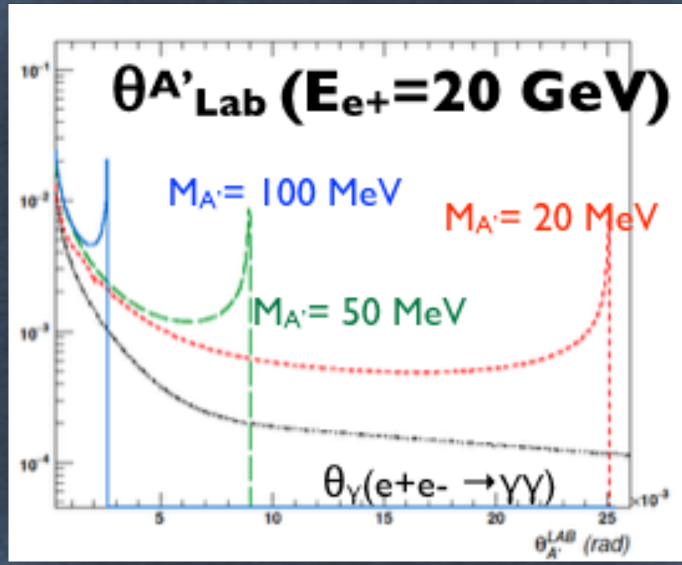
~ $\varepsilon^2 \alpha$

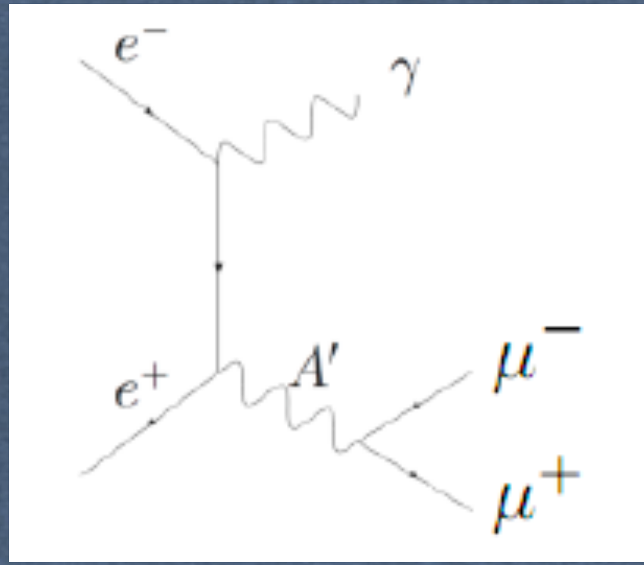
- **RESONANT annihilation**

$$\sigma_r = \sigma_{\rm peak} \frac{\Gamma^2_{A'}/4}{(\sqrt{s} - m_{A'})^2 + \Gamma^2_{A'}/4} \,,$$

- **Two-body process**
- **A’ forward-peaked along e^+ direction**
- **$E_{A'} = E_R = m^2_{A'}/2m_e$**

L.Marsicano et al. Phys.Rev.Lett. 121 (2018) 4, 041802





- Known and used
- Collider (missing mass experiments)
- Thin target experiments (visible decay)

$e^+e^- \rightarrow \gamma' \gamma \rightarrow \mu\mu\, \gamma$

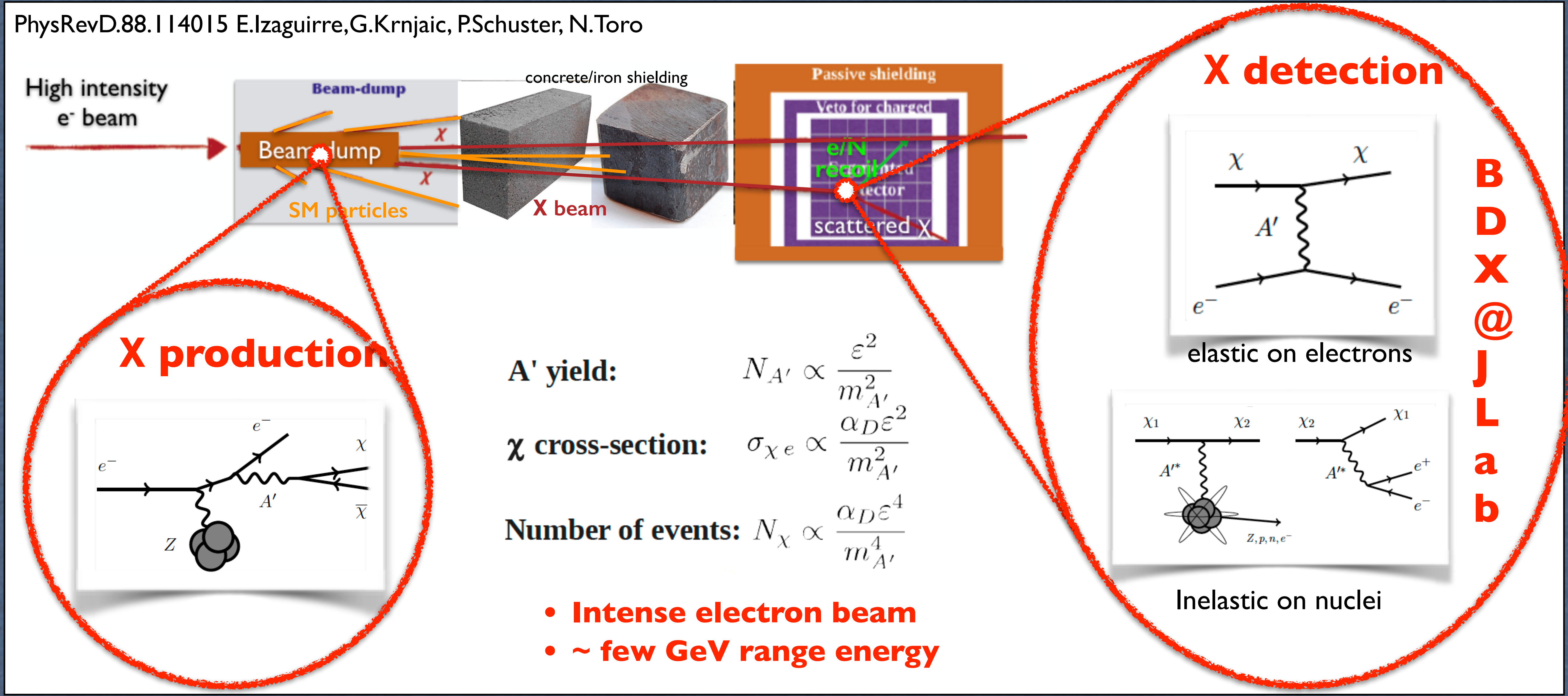
➜ BABAR, BELLE, KLOE, CLEO

The BDX experiment

Two step process

I) An electron radiates an A' and the A' promptly decays to a χ (DM) pair

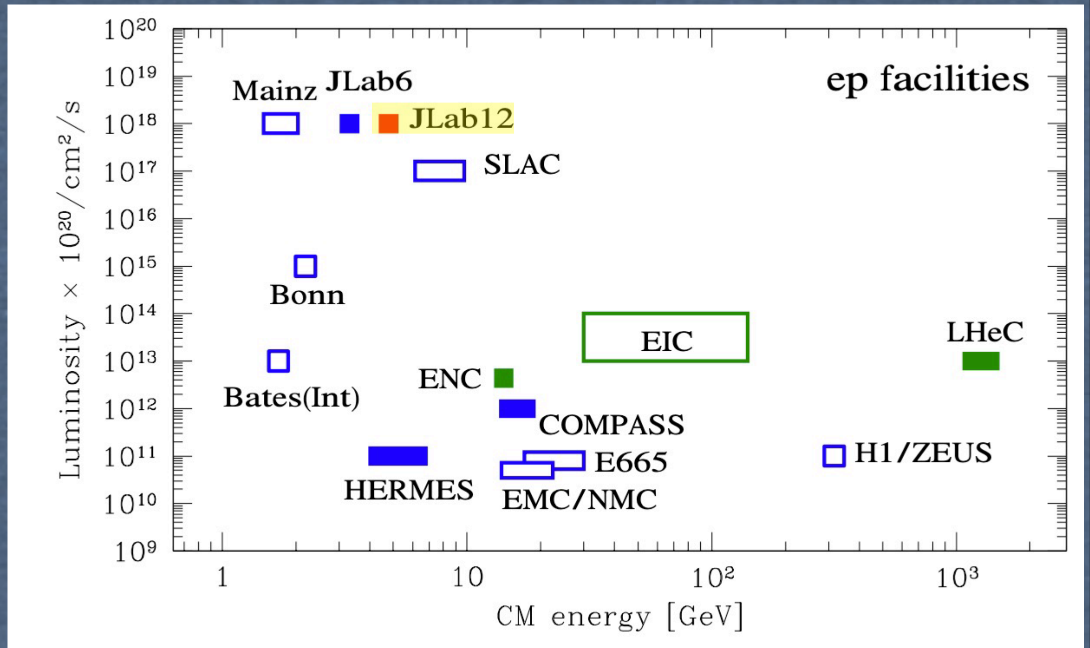
II) The χ (in-)elastically scatters on a e⁻/nucleon in the detector producing a visible recoil (GeV)



Experimental signature in the detector: X-electron → EM shower ~GeV energy

Jefferson Lab
The intensity frontier

- CEBAF @ Jefferson Lab in Virginia (US)
- Electron beam up to 11 GeV
- The highest available e- beam current: ~65 uA
- The highest integrated charge: 10^{22} EOT



BDX@JLab

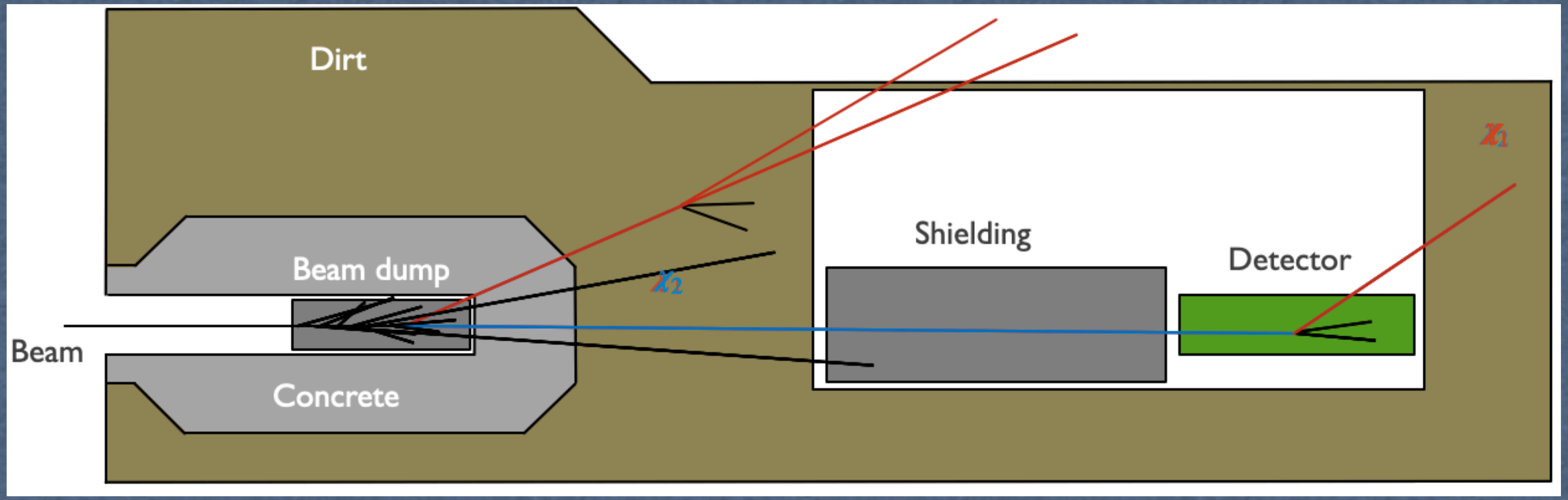
- Drilled shaft downstream of Hall-A BD
- Parasitic run in parallel to the Moeller experiment in Hall-A
- Included in SNOWMASS-21 report (RF6-RF0)
- BDX would run with future 11 GeV positron beam and 20+ GeV upgrade
- BDX Collaboration: more than 100 researchers from 18 institutions (US, Italy, Germany, Japan, UK, Korea) signed the BDX proposal

Approved by JLab 2018 PAC with max rate (A)
expected to run in 2027-29

Signal vs. background

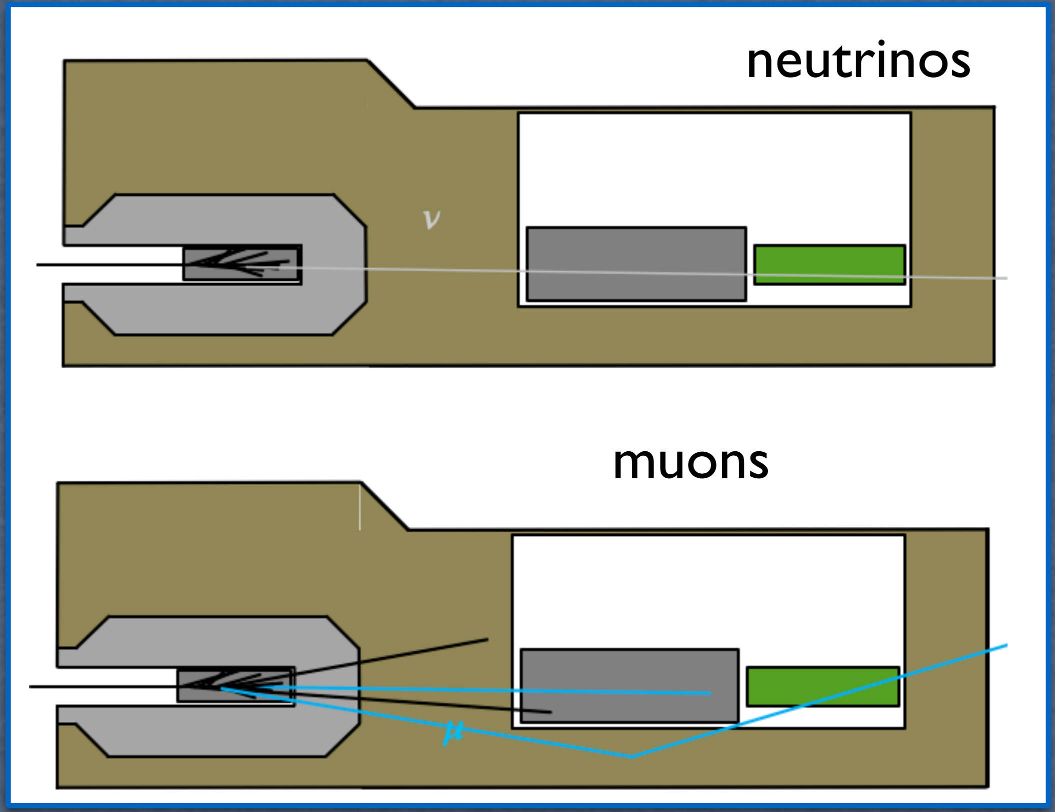
Signal

- **Light Dark Matter** can interact with electrons and nuclei producing an e.m shower with large energy deposition (>100 MeV) in the detector



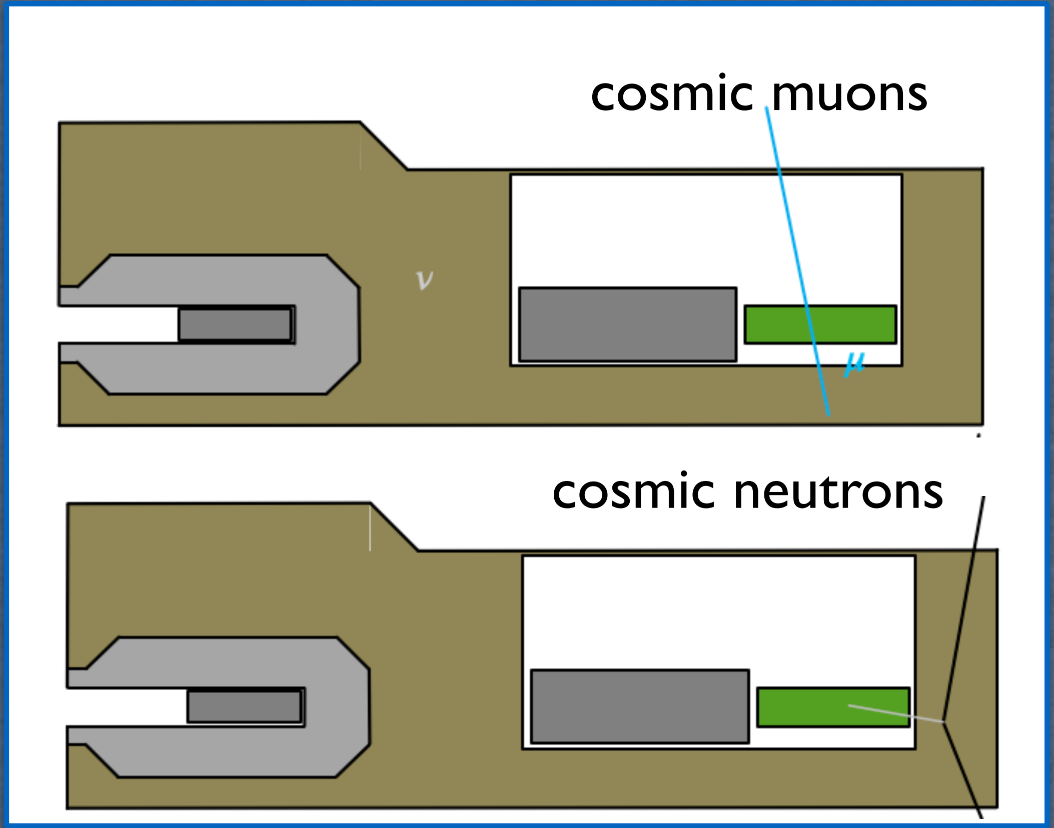
Beam related background:

- Neutrinos can mimic DM interaction
- High energymuons can propagate through shielding reaching the detector



Cosmic background

- CW beam prevents time coincidence
- Cosmic muons
- Cosmic nueutron (spallation)



The BDX detector

Detecting LDM

Detector requirements

- EM showers detection capability (~GeV)
- Compact foot-print
- Low DAQ threshold to include nucleon recoil detection (~MeV)
- Segmentation for topology id

Rejecting the bg

- Beam-related
- Cosmic

Active veto requirements

- High efficiency (>99%) to MIPs
- Fast (~ns) for time coincidence with the calorimeter
- Segmentation for bg rejection

Passive veto made by lead bricks

- Lead vault for low energy gamma and avoid self-veto

BDX technology

E.M. calorimeter

↓

A **homogeneous crystal**-based detector combines all necessary requirements

Active veto

↓

Two layers: of **plastic scintillator**
IV/OV: WLS + SIPM

Passive veto

Lead vault

The BDX calorimeter

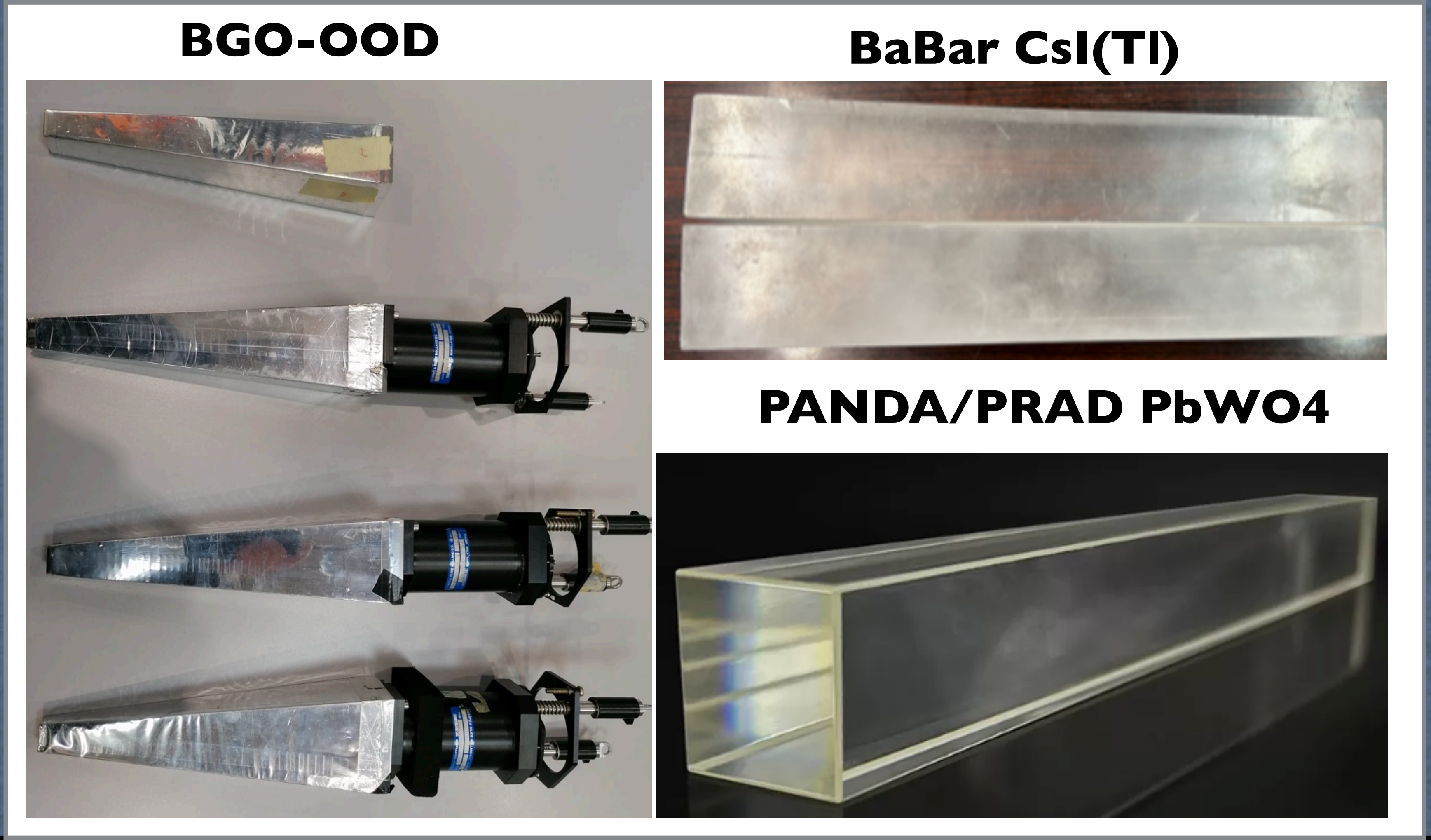
Requirements:
- High density
- High light yield
- Cost-affordable for a ~ m^3 detector volume (repurposing)
- Good timing (desirable)

Homogeneous calorimeter of inorganic scintillator crystals

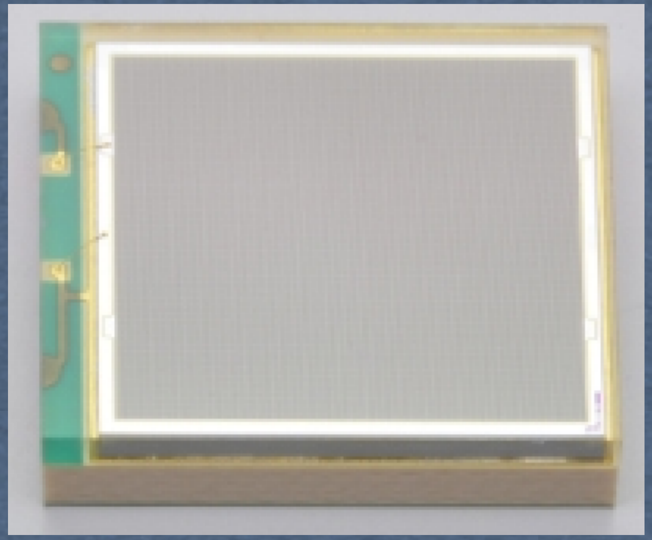
Possible options
- CsI(Tl) (BaBar)
- PbWO4 (PANDA/PRAD)
- BGO (BGO-OD)

PANDA PbWO4
- Size: $(2x2)cm^2$ 20-22 cm length
- 800+800 crystals available from PANDA and PRAD EMCals
- Decay time: 6ns
- LY = ~10 pe/MeV

BGO-OD
- Size: $(2x2/5.5x5.5)cm^2$ 24 cm leng
- 480 crystals available from PAND
  EMCal spsares
- Decay time: 6ns
- LY = ~50 pe/MeV



+ SiPM readout



SiPM readout
- Size: $(6x6)$ mm^2, 50µm, 14.4k cells, trenched, pde=50%
- SPE capability
- CsI(Tl): 40 pe/MeV
- Time resolution: ~ns (MIPs)

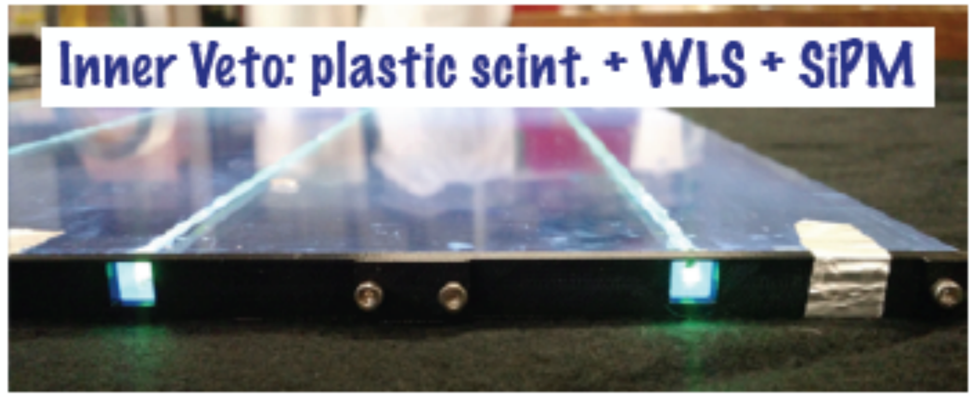
M.Bondi et al. **Nucl.Instrum.Meth.A** *867 (2017) 148-153*

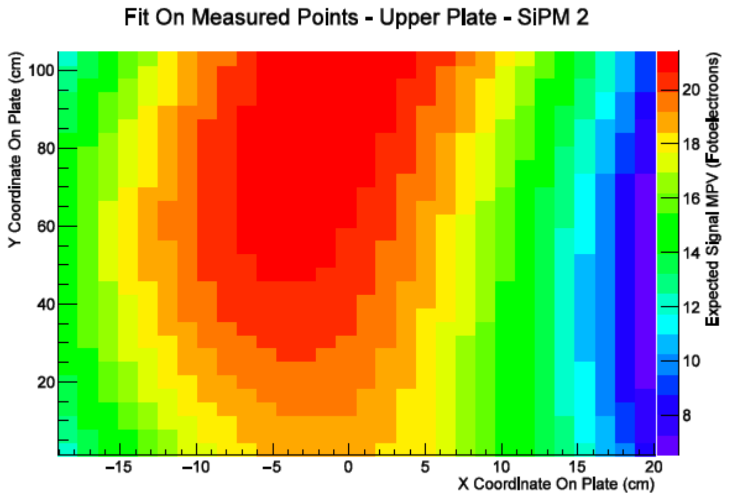
The BDX active veto

Requirements:
- Hermeticity
- Segmentation
- Cost-affordable for several m^2 detector surface
- Good timing (desirable)

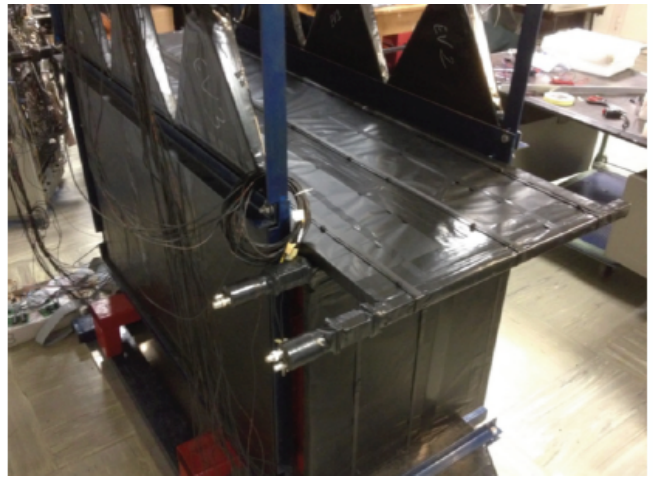
Possible options:
plastic scintillator
liquid scintillator
passive vetos

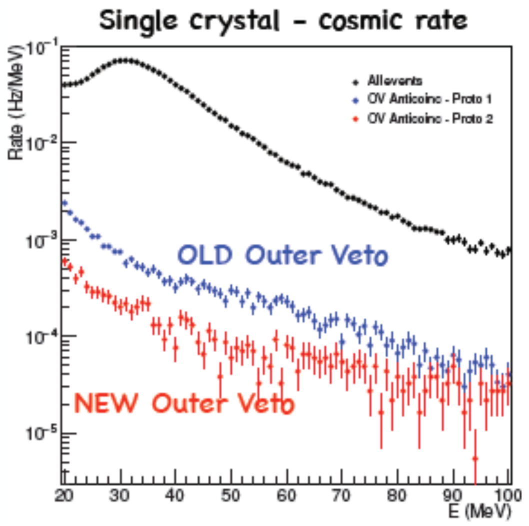
R&D on different technologies:
- Plastic scintillator + light guide + PMT
- Plastic scintillator + WLS + PMT
- Plastic scintillator + WLS + sipm





Plastic scintillator + WLS and (redundant) SipMs readout





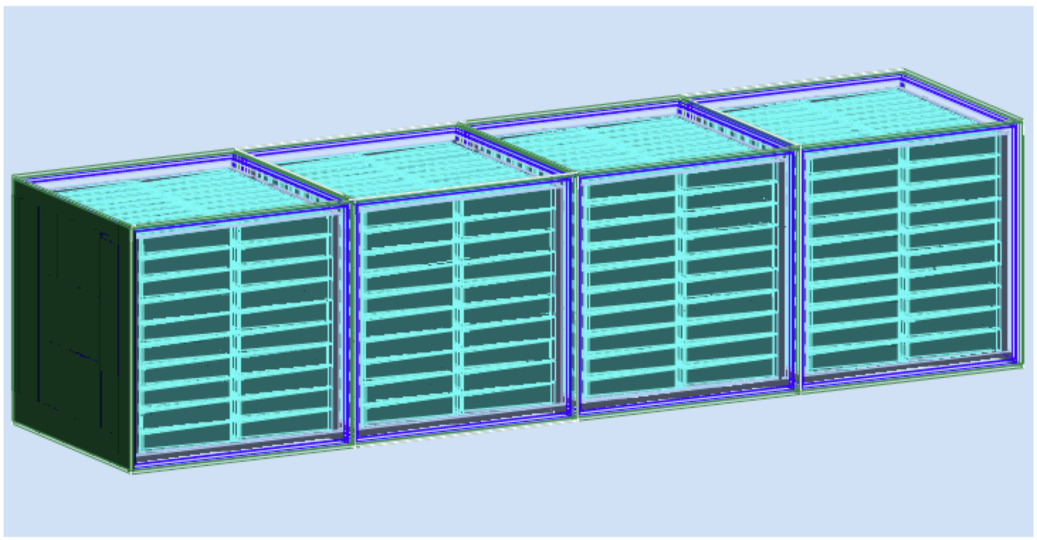
Inner veto:
- 1cm (all clear) Plastic scintillator +WLS fiber placed in grooves
- 3x3 SiPM readout
- LY= 15-50 pe/MIP

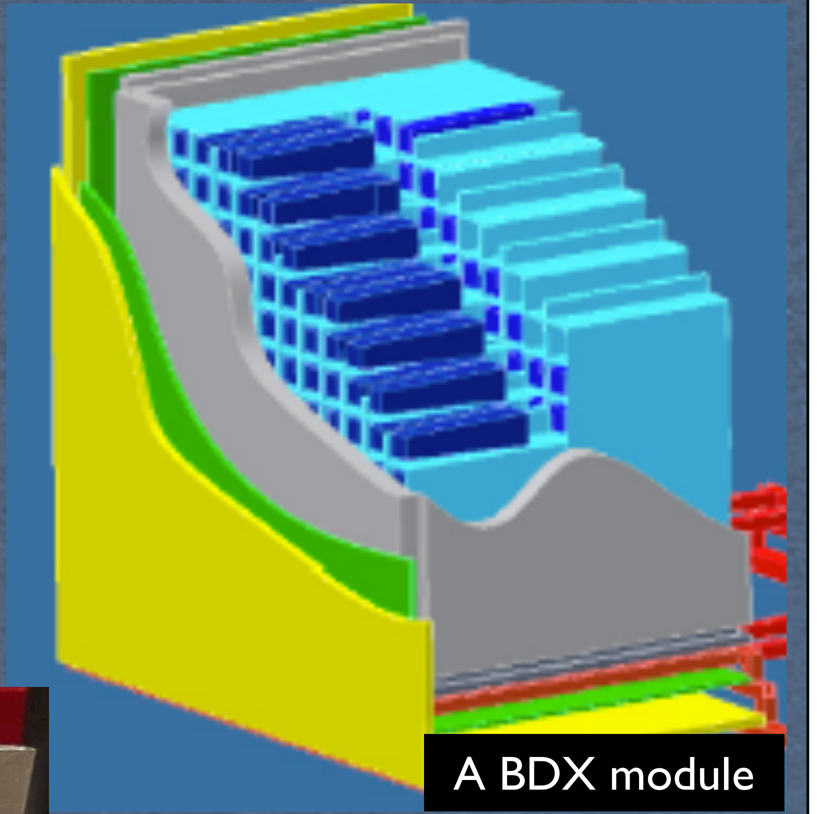
Outer veto:
- Plastic scintillator + Light guide + PMT
- Plastic scintillator +WLS fiber

★High efficiency to MIPs (>99%)
★Robust and simple technology

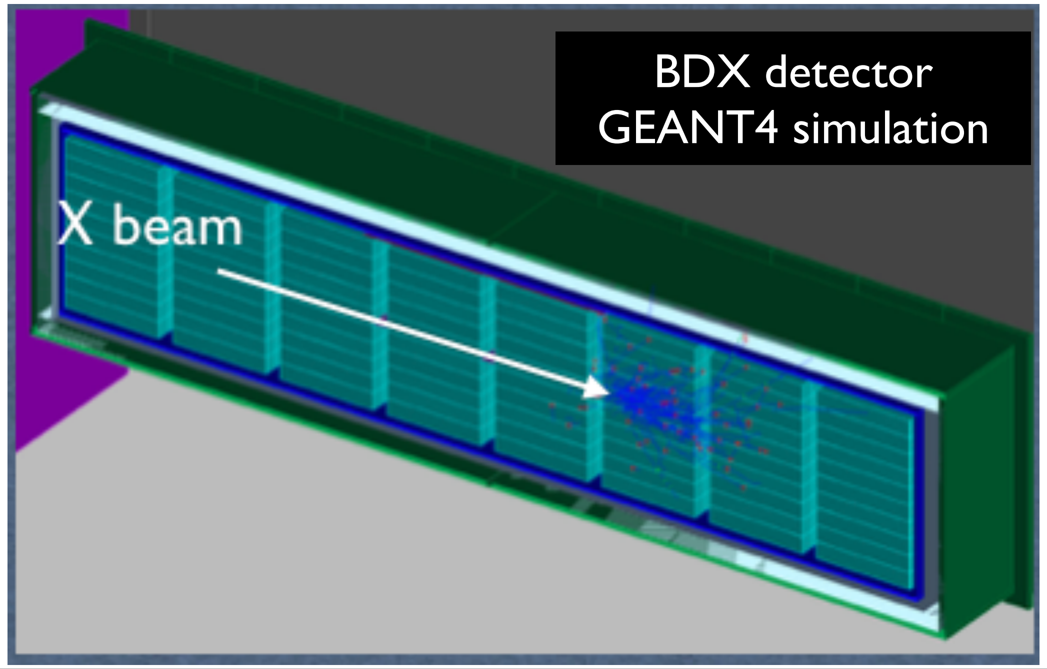
The BDX detector

- ★ Modular EM calorimeter: 2 modules 10x10 crystals each
- ★ Crystals in regular 8x8x30 cm3 Al alveoli making matrices of 480 (BGO), 800 (PANDA-PbWO), 1200 (PRAD-PbWO) crystals
  - BGO: matrix of 9x9 (front face) x3 (longitudinal), 90x90x100 cm^3
  - PRAD-PbWO: matrix of 12x12 (front face) x2 (longitudinal), 80x80x60 cm^3
  - PANDA-PbWO: matrix of 10x10 (front face) x2 (longitudinal), 80x80x60 cm^3
- ★ Total of 3 tons of active volume
- ★ Inner/Outer Veto: plastic scintillator + WLS + SiPM
- ★ Passive shielding: lead vault

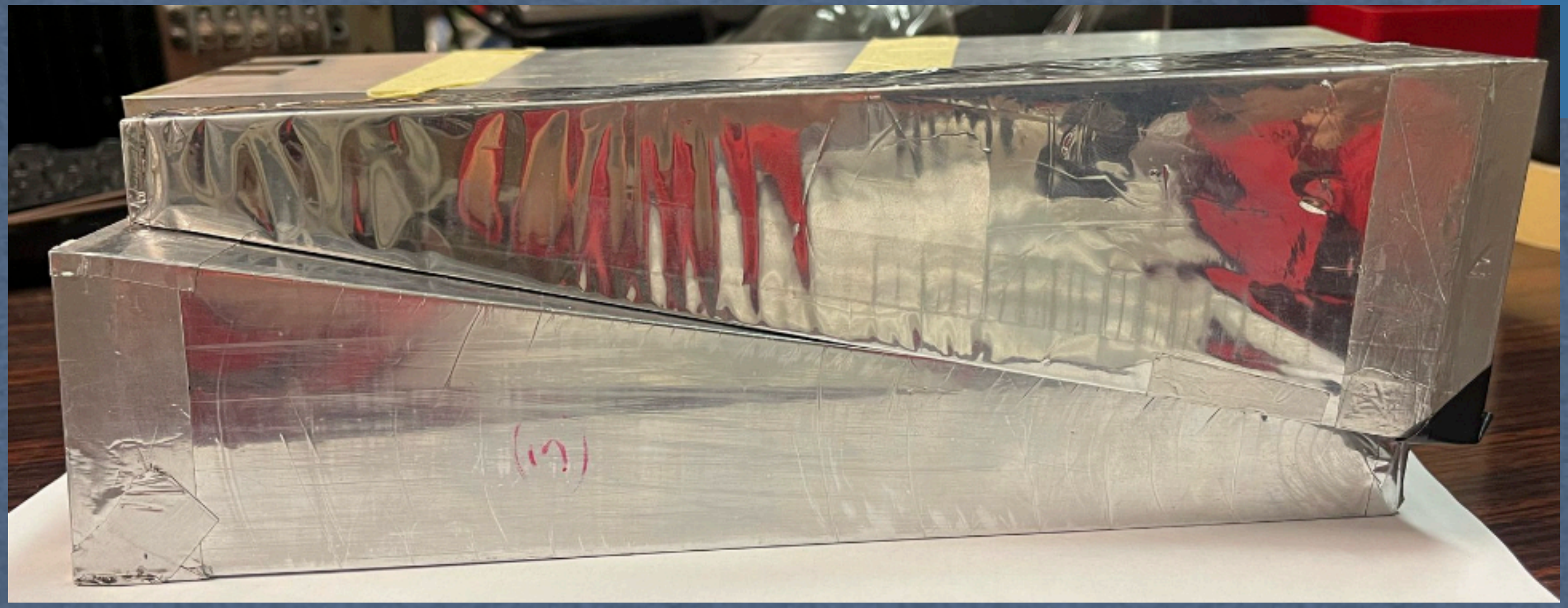


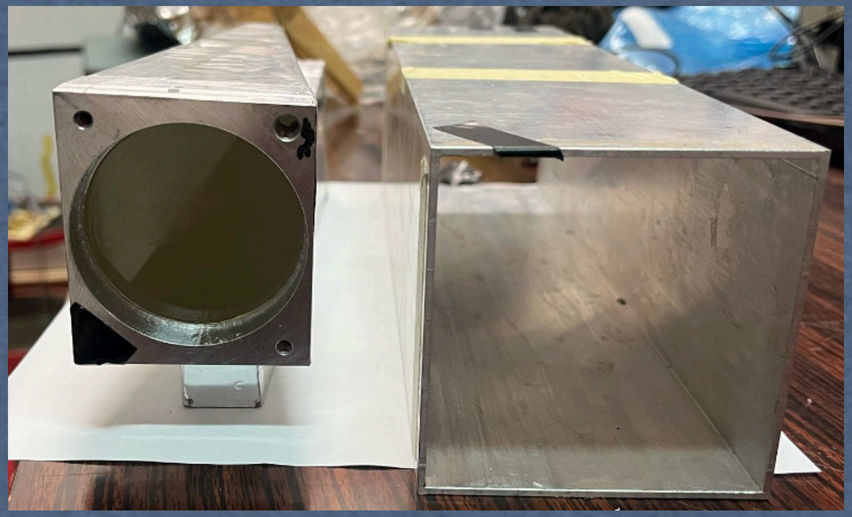


A BDX module



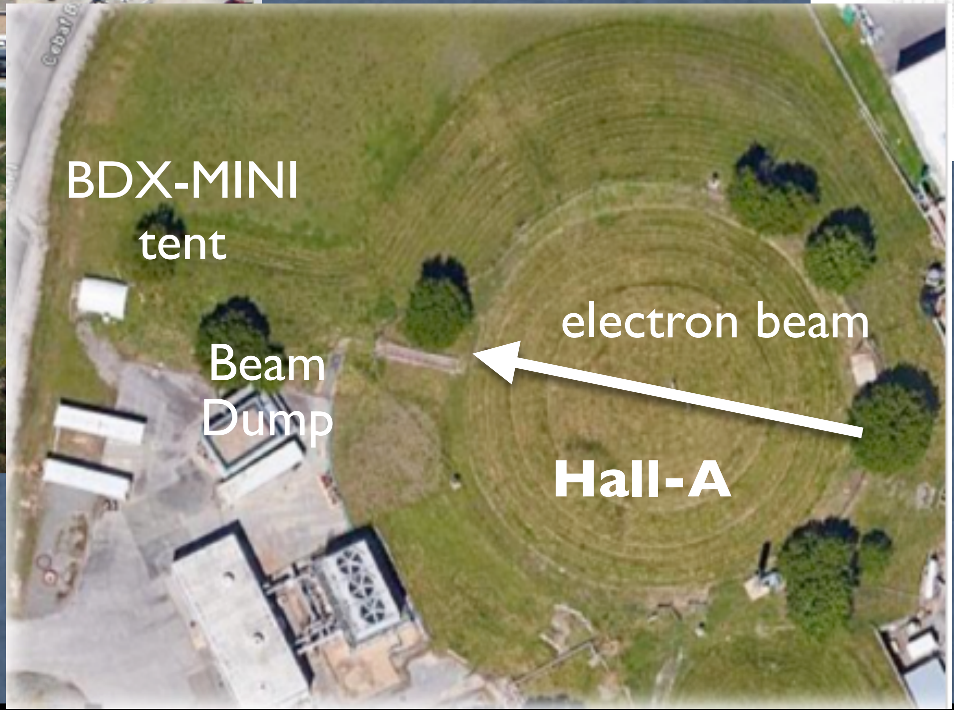
BDX detector
GEANT4 simulation



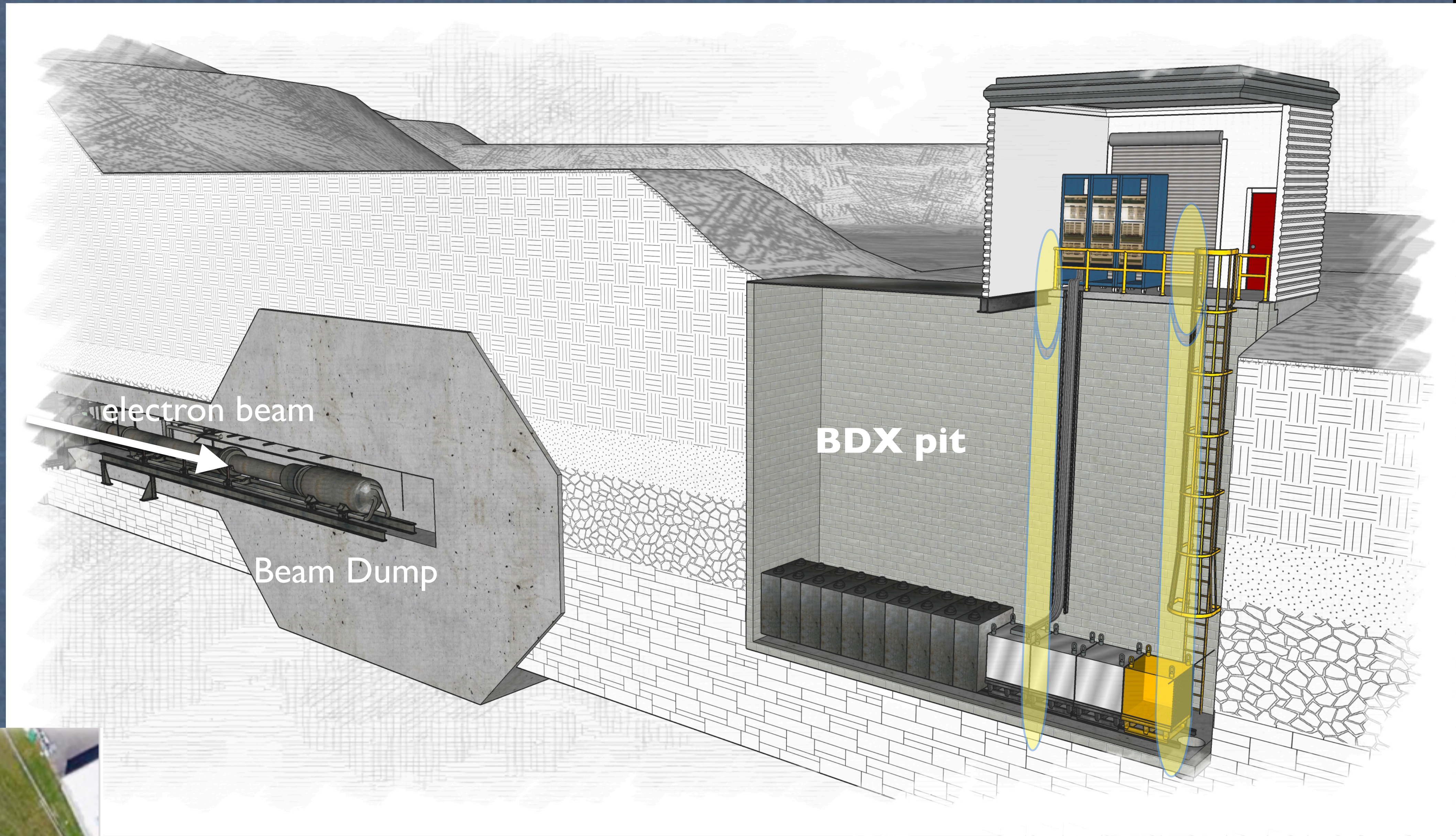


BDX at JLab

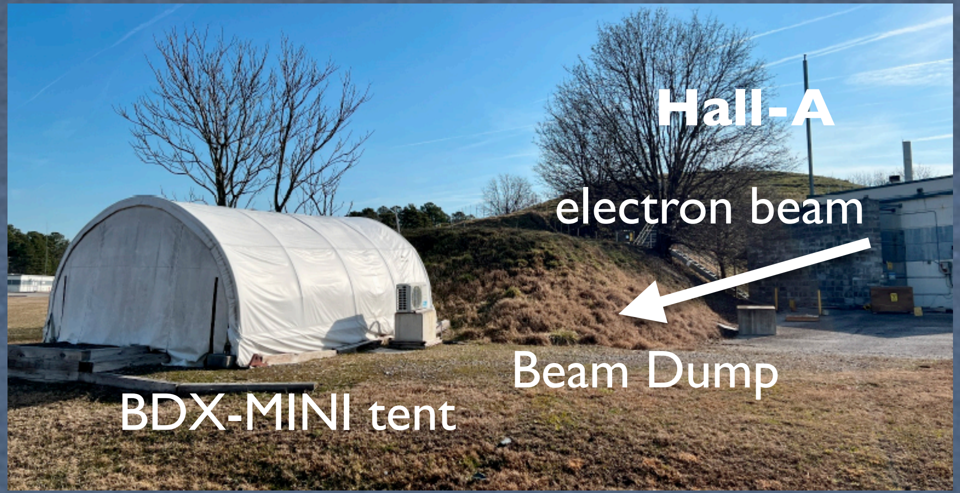
electron beam
Hall-A
Beam Dump



BDX-MINI tent
Beam Dump
electron beam
Hall-A



electron beam
Beam Dump
BDX pit



Hall-A
electron beam
Beam Dump
BDX-MINI tent

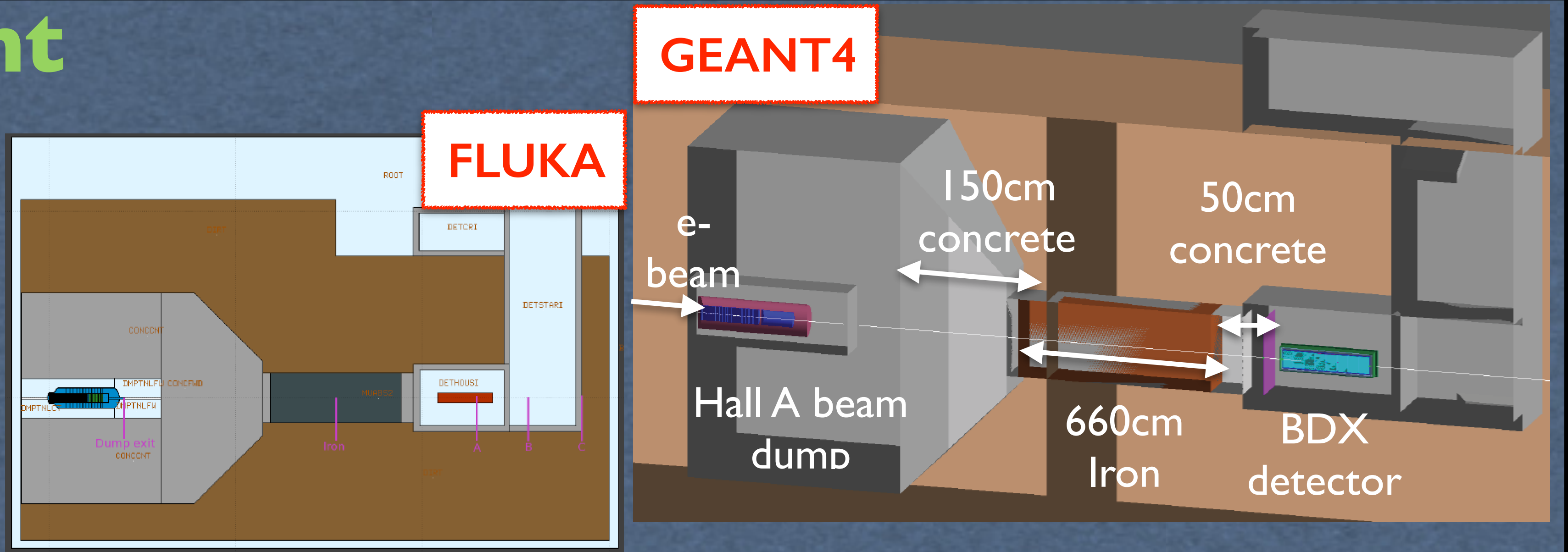
BDX pit
BDX-MINI tent

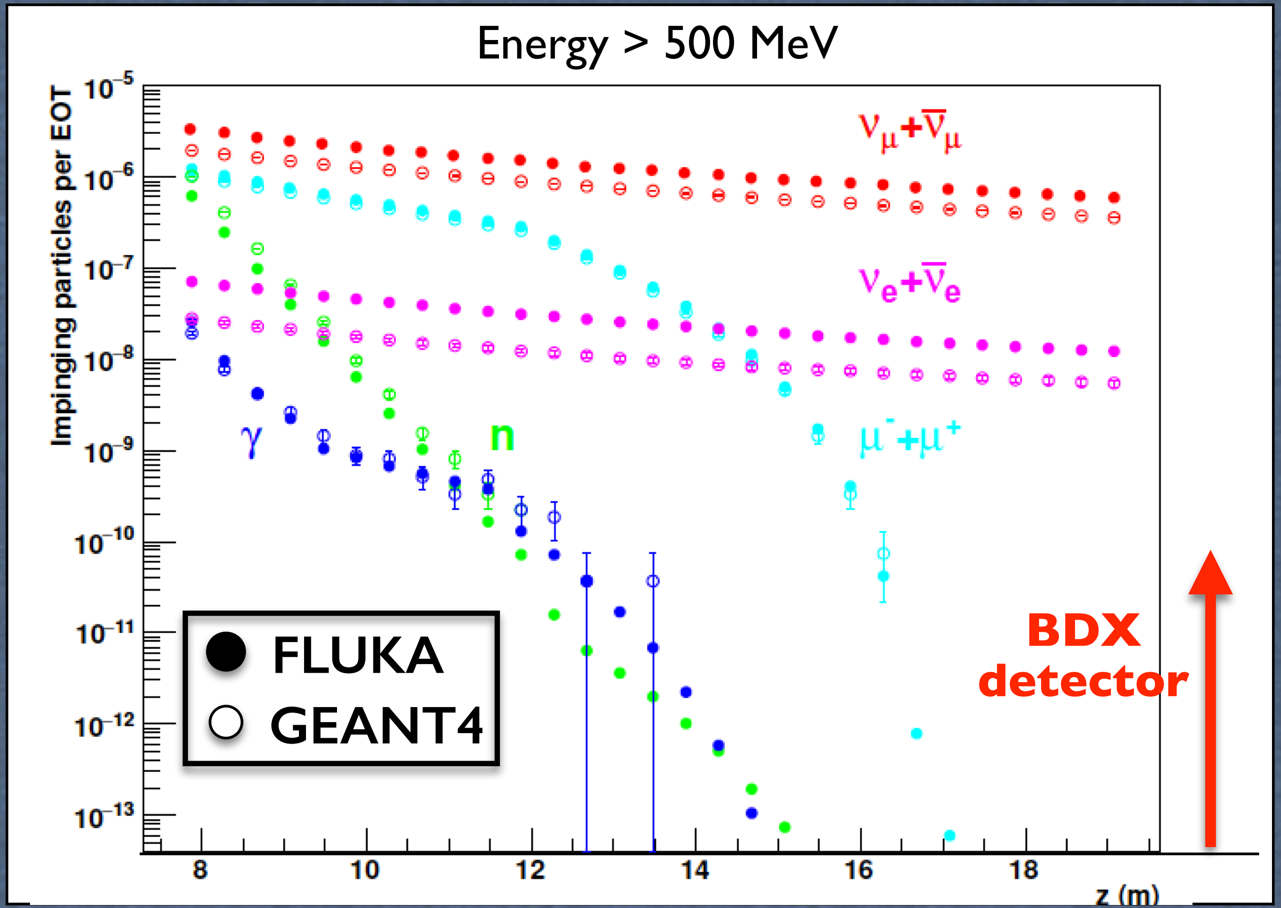
Background assessment

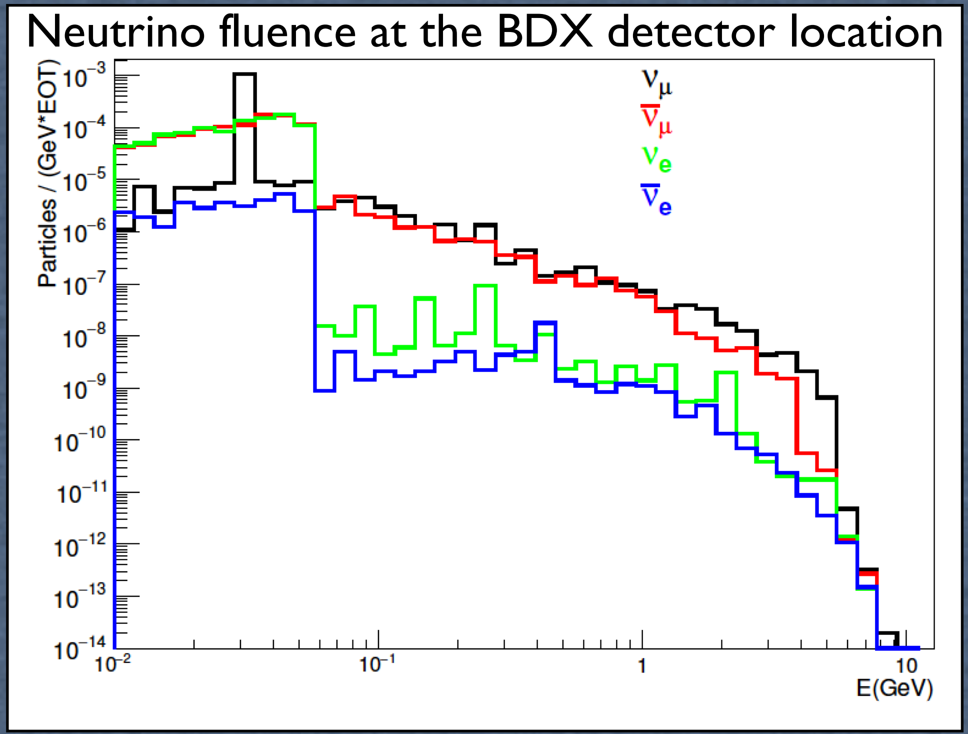
★ Muons produced in the BD by an 11 GeV beam are tracked to BDX detector location

- 6.6m iron shield (+2m concrete) to stop high energy muons

★ No μ, n and γ with E>100 MeV are found at the detector location







★ **Neutrino**

- $\pi \to \mu\, \nu_\mu$ $\mu \to e\, \nu_\mu\, \nu_e$
- Mainly low energy (<60 MeV) from decay at rest
- Some ν from hadronic shower are boosted to BDX

Non-negligible contribution of high energy ν interacting in the detector by CC:

$\nu + N \to X + e^-$ **$\nu + e^-$ suppressed**

Neutrino *irreducible* bg represents the ultimate limitation for BDX
(~10 counts in BDX life time)

★ Beam-related muons measured in a dedicated campaign in the future BDX location (Nucl.Instrum.Meth.A 925 (2019) 116-122)

★ Cosmic background measured using a detector prototype

BDX sensitivity

Beam time request (parasitic to Hall-A ops)

- 10^{22} EOT (65 uA for 285 days)
- BDX can run parasitically with any Hall-A E_{beam}>10 GeV experiments (e.g. Moeller)

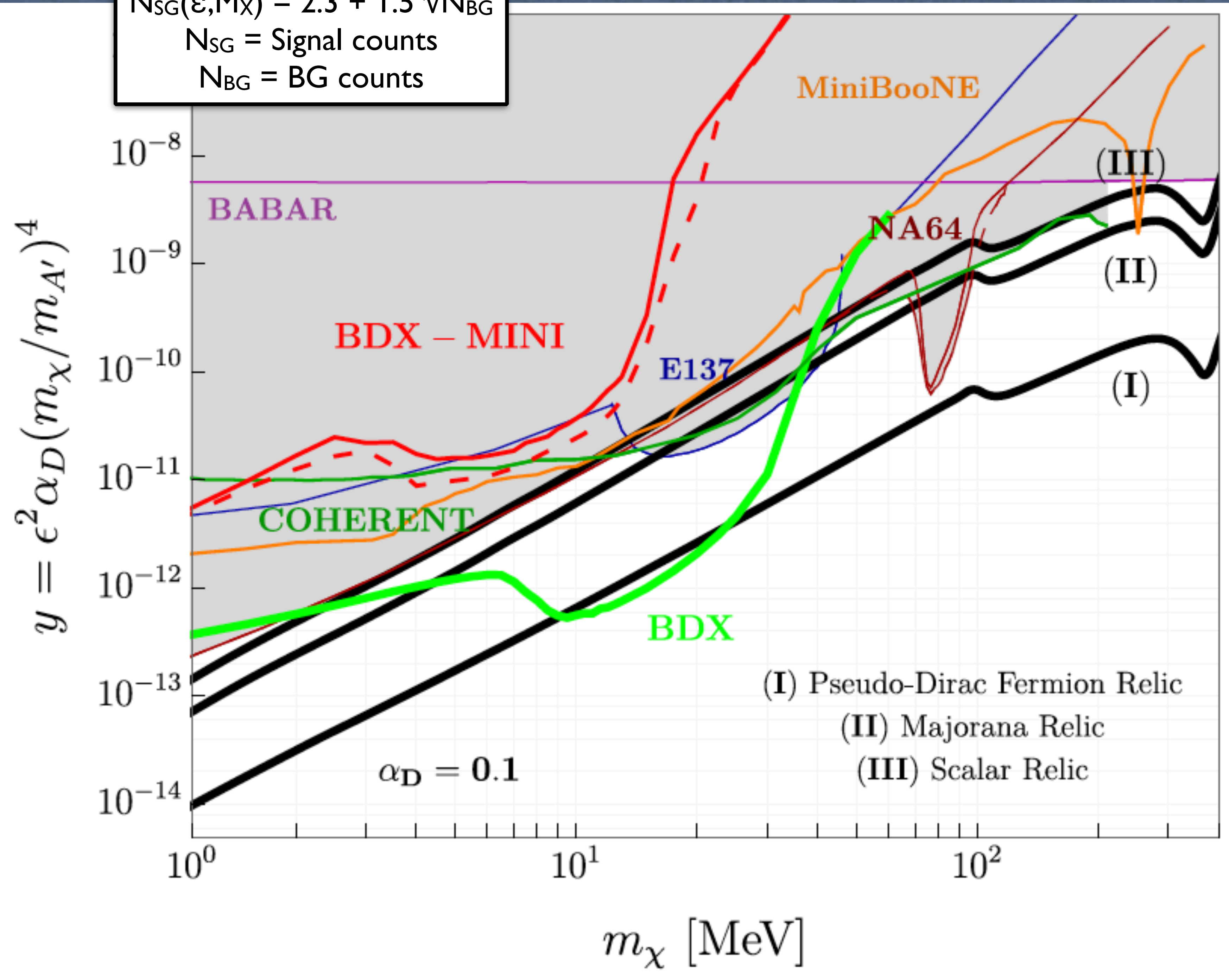
Beam-related background

Energy threshold	N_ν (285 days)
300 MeV	~10 counts

Cosmic background

Energy threshold	$\sqrt{Bg}$ (285 days)
300 MeV	<2 counts

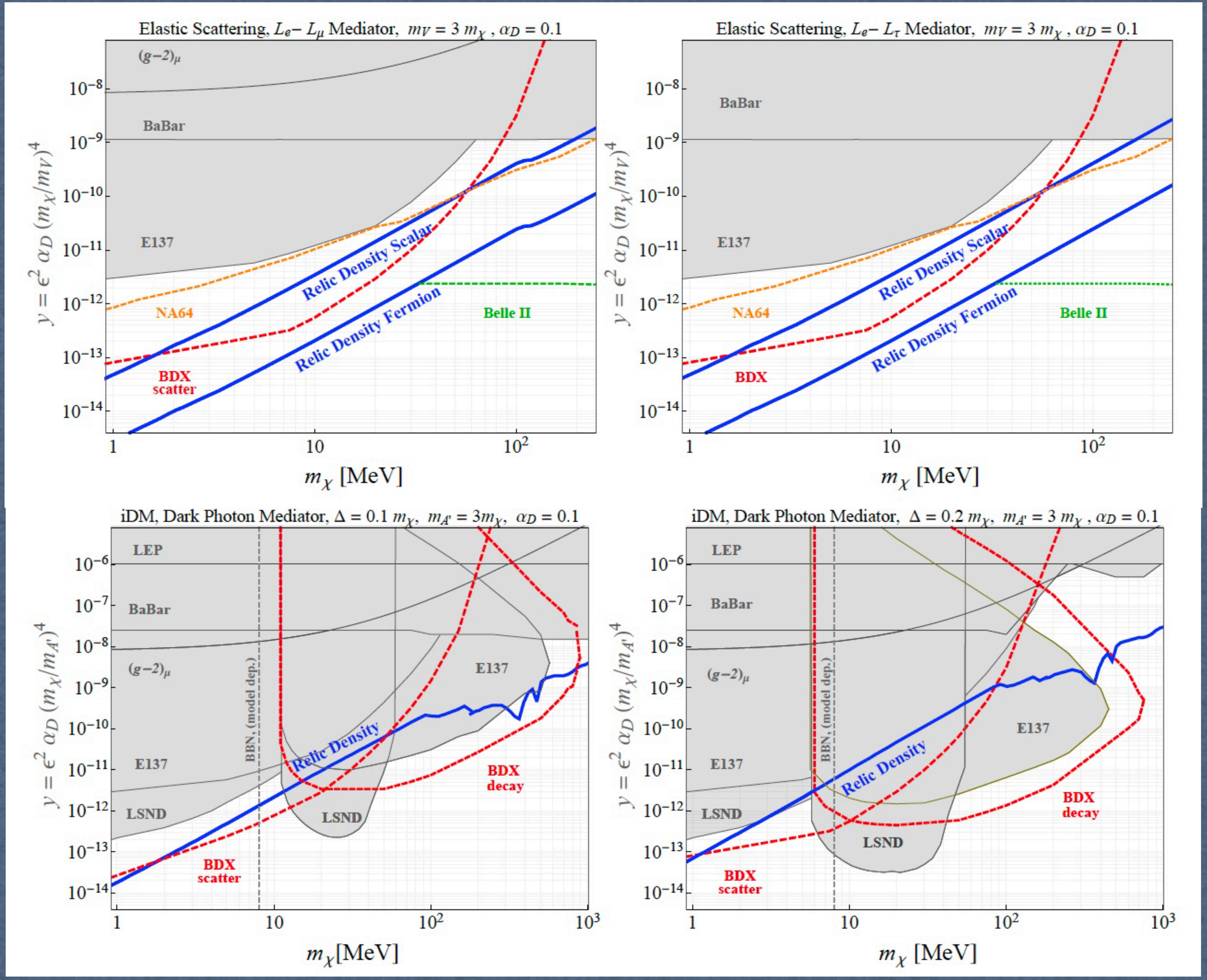
90%CL sensitivity
$N_{SG}(\varepsilon,M_X) = 2.3 + 1.5\sqrt{N_{BG}}$
N_{SG} = Signal counts
N_{BG} = BG counts



- Calculation includes resonant positron annihilation
- Sensitivity to inelastic LDM is not shown

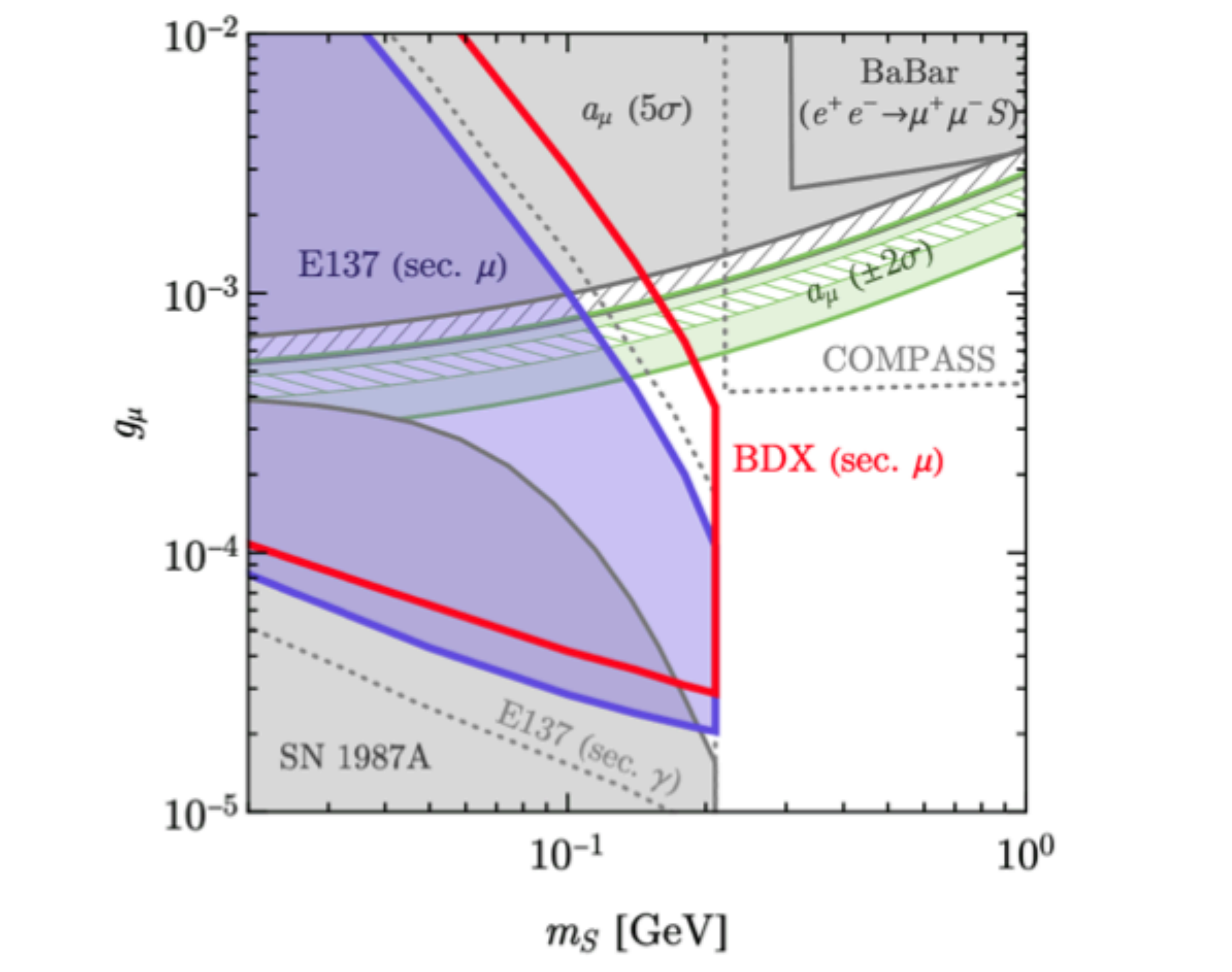
Accumulating 10^{22} EOT in ~2y BDX sensitivity is 10-100 times better than existing limits on LDM

BDX physics reach



Sensitivity beyond the minimal model (A'-mediated)

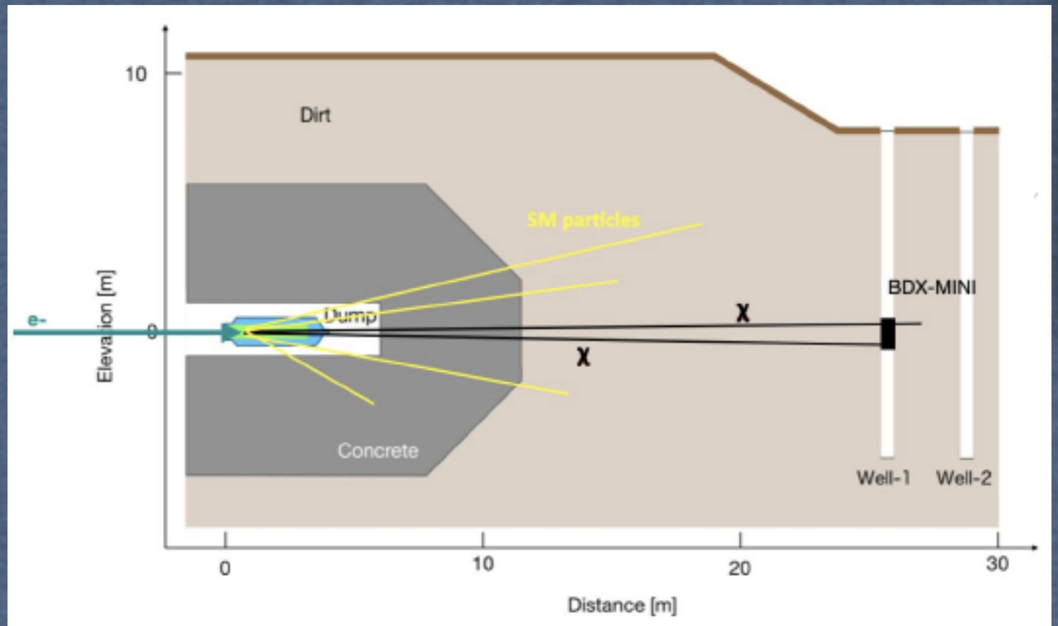
- BDX can prove lepto- and baryo-phillic DM (coupling to lepton and/or quark only scenarios)
- elastic fermionic DM scattering via (L_e-L_μ) and (L_e-L_τ) mediators
- inelastic fermonic DM scattering (with A' mediator)
- elastic scalar DM scattering



arXiv:1607.01390, arXiv:1910.03532, Phys.Rev.D 98 (2018) 11, 115022

BDX-MINI @JLab

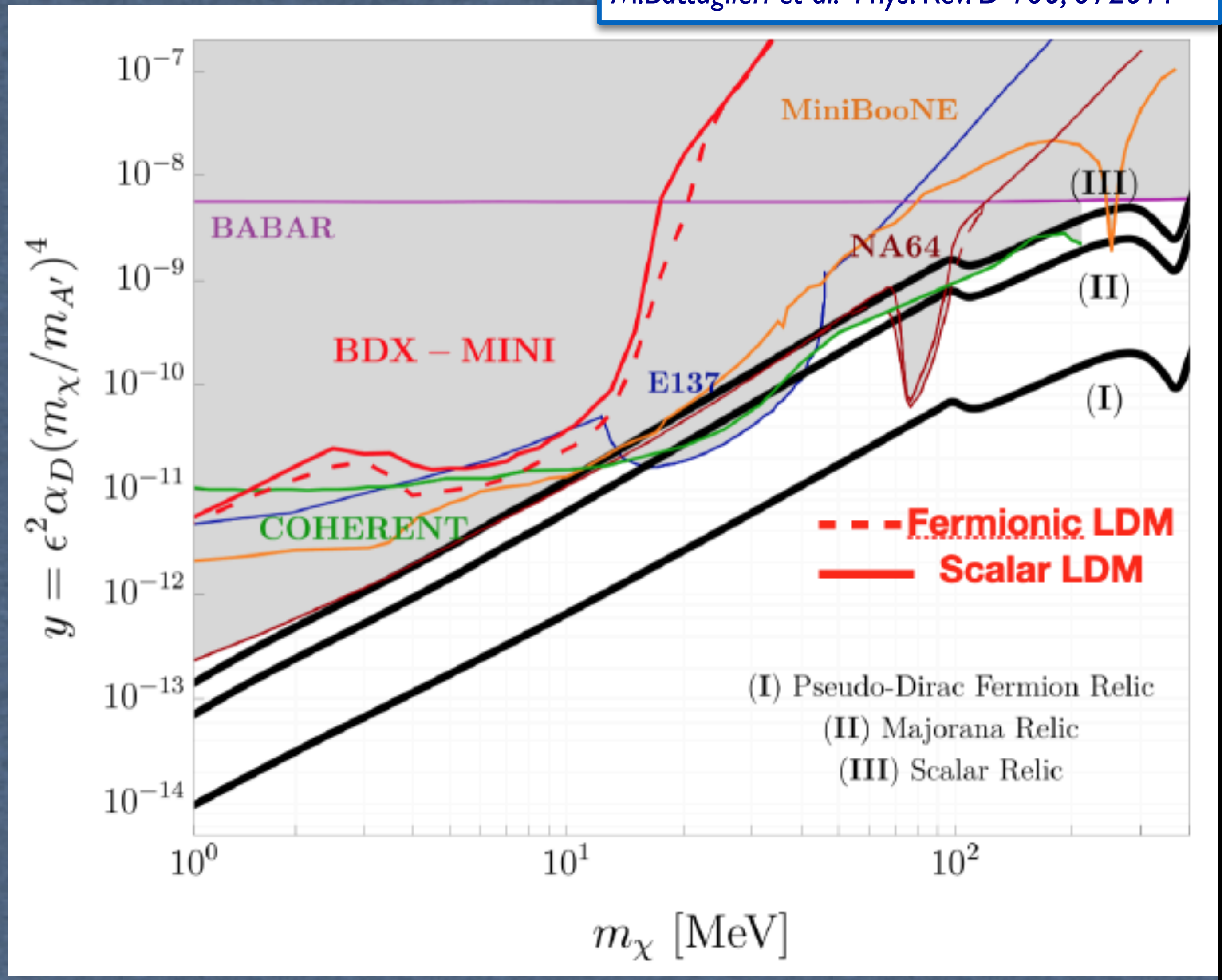
BDX-MINI: pilot experiment to prove the validity and feasibility of the BDX experiment



- Installed in March 2019
- Run form Dec 2019 to Aug 2020
- Collected 4e21 EOT (40% BDX!) in ~4 months (+ cosmics)
- Good detector performance with high duty factor

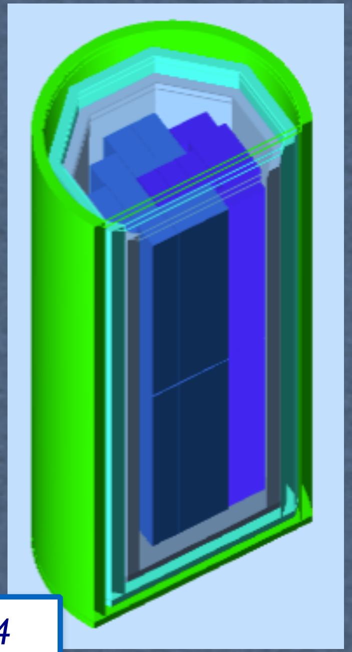
- Two wells dug for bg muon tests
- E_{beam}=2.2 GeV, no muons
- Limited reach but first physics result!

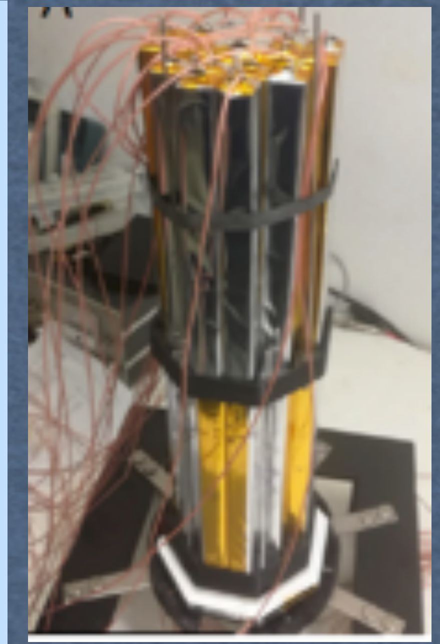
M.Battaglieri et al. Phys. Rev. D 106, 072011

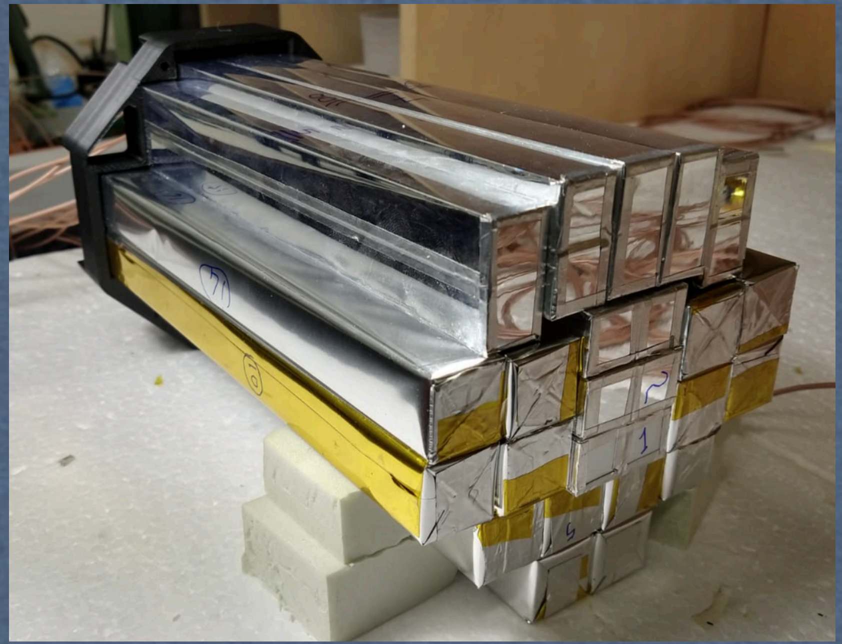


- Data-taking completed, analysis completed
- Results provide exclusion limits similar to the best existing experimnts (E137, NA64, BaBar, …)

- 44 PbWO4 PANDA/FT-Cal crystals (~1% BDX active volume)
- 6x6 mm2 SiPM readout
- 2 active plastic scintillator vetos: cylindrical and octagonal (8 sipm each) + 2x lids + Passive W shielding



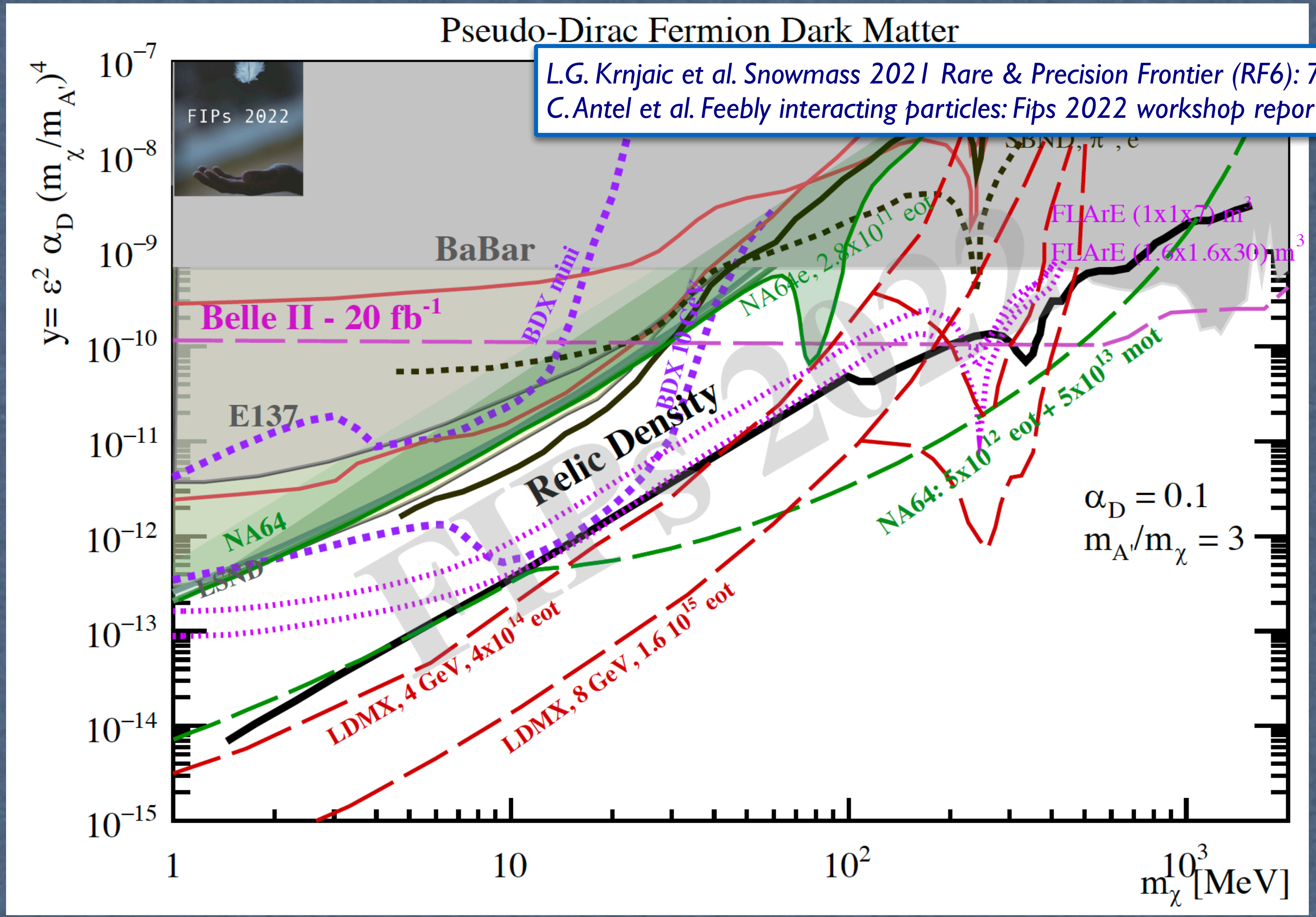




M.Battaglieri et al. EPJC (2021) 81: 164

LDM searches status

Experiment	lab	beam	particle yield/$\mathcal{L}$	technique	portals	timescale
current						
ATLAS [1382]	CERN	pp, 13-14 TeV	up to 3 ab^{-1}	visible, invis.	(1,2,3,4)	2042
Belle II [1219]	KEK	e^+e^-, 11 GeV	up to 50 ab^{-1}	visible, invis.	(1,2,3,4)	2035
CMS [1383]	CERN	pp, 13-14 TeV	up to 3 ab^{-1}	visible, invis.	(1,2,3,4)	2042
Dark(Spin)Quest [1256]	FNAL	p, 120 GeV	$10^{18} \to 10^{20}$	visible	(1,2,3,4)	2024
FASER [1052]	CERN	pp, 14 TeV	150 fb^{-1}	visible	(1,2,3,4)	2025
LHCb [1384]	LHC	pp, 13-14 TeV	up to 300 fb^{-1}	visible	(1,2,3,4)	2042
MicroBooNE [1385]	FNAL	p, 120 GeV (NuMi)	$\sim 7 \times 10^{20}$ pot	visible	(2,4)	2015-2021
NA62 [1174]	CERN	K^+, 75 GeV	a few 10^{13} K decays	visible, invis.	(1,2,3,4)	2025
NA62-dump [1386]	CERN	p, 400 GeV	$\sim 10^{18}$ pot	visible	(1,2,3,4)	2025
NA64$_e$ [1387]	CERN	e^-/e^+, 100 GeV	up to $1 \cdot 10^{13}$ e^-/e^+	$\not{E}$, visible	(1,3)	< 2032
PADME [1300]	LNF	e^+, 550 MeV	$5 \cdot 10^{12}$ e^+ot	missing mass	(1)	< 2023
T2K-ND280 [1388]	JPARC	p, 30 GeV	10^{21} pot	visible	(4)	running
proposed						
BDX [1389]	JLAB	e^-, 11 GeV	$\sim 10^{22}$ eot/year	recoil e	(1,3)	2024-2025
CODEX-b [1030]	CERN	pp, 14 TeV	300 fb^{-1}	visible	(1,2,3,4)	2042
Dark MESA [1390]	Mainz	e^-, 155 MeV	150 μA	visible	(1)	< 2030
FASER2 [1068]	CERN	pp, 14 TeV	3 ab^{-1}	visible	(1,2,3,4)	2042
FLaRE [1068]	CERN	pp, 14 TeV	3 ab^{-1}	visible, recoil	(1)	2042
FORMOSA [1068]	CERN	pp, 14 TeV	3 ab^{-1}	visible	(1)	2042
Gamma Factory [1391]	CERN	photons	up to 10^{25} γ/year	visible	(1,3)	2035-2038?
HIKE-dump [1392, 1191]	CERN	p, 400 GeV	$5 \cdot 10^{19}$ pot	visible	(1,2,3,4)	<2038
HIKE-K$^+$ [1392, 1191]	CERN	K^+, 75 GeV	10^{14} K decays	visible, inv.	(1,2,3,4)	<2038
HIKE-K$_L$ [1392, 1191]	CERN	K_L, 40 GeV	10^{14} K decays	visible, inv.	(1,2,3,4)	<2042
LBND (DUNE) [1393]	FNAL	p, 120 GeV	$\sim 10^{21}$ pot	recoil e, N	(1,2,3,4)	< 2040
LDMX [1271]	SLAC	e^-, 4,8 GeV	$2 \cdot 10^{16}$ eot	$\not{p}$, visible	(1)	< 2030
M^3 [1394]	FNAL	μ, 15 GeV	10^{10} (10^{13}) mot	$\not{p}$	(1)	proposed
MATHUSLA [1395]	CERN	pp, 14 TeV	3 ab^{-1}	visible	(1,2,3,4)	2042
milliQan [1070]	CERN	pp, 14 TeV	0.3-3 ab^{-1}	visible	(1)	< 2032
MoeDAL/MAPP [1396]	CERN	pp, 14 TeV	30 fb^{-1}	visible	(4)	< 2032
Mu3e [1397]	PSI	29 MeV	$10^8 \to 10^{10}\mu$/s	visible	(1)	< 2038?
NA64$_\mu$ [1398]	CERN	μ, 160 GeV	up to 2×10^{13} mot	$\not{p}$	(1)	< 2032
PIONEER [1399]	PSI	55-70 MeV, π^+	$0.3 \cdot 10^6 \pi$/s	visible	(4)	phase I approved
SBND [1400]	FNAL	p, 8 GeV	$6 \cdot 10^{20}$ pot	recoil Ar	(1)	< 2030
SHADOWS [1401]	CERN	p, 400 GeV	$5 \cdot 10^{19}$ pot	visible	(2,3,4)	<2038
SHiP [1402]	CERN	p, 400 GeV	$2 \cdot 10^{20}$ pot	visible, recoil	(1,2,3,4)	<2038

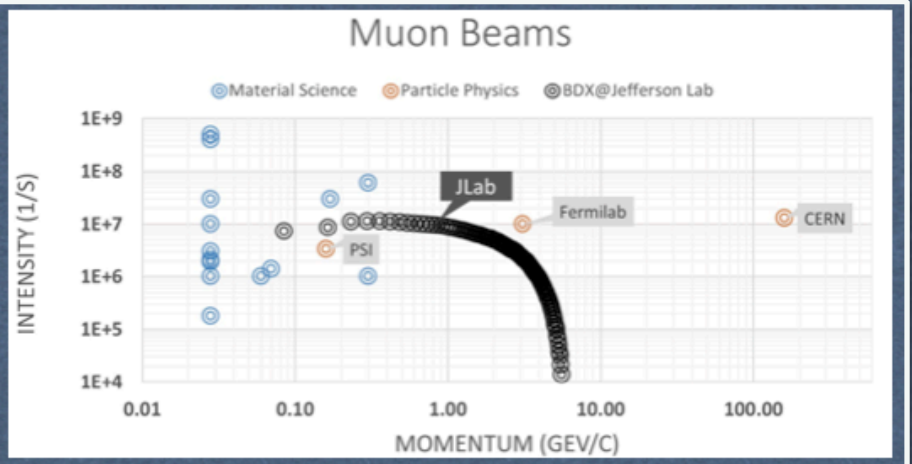


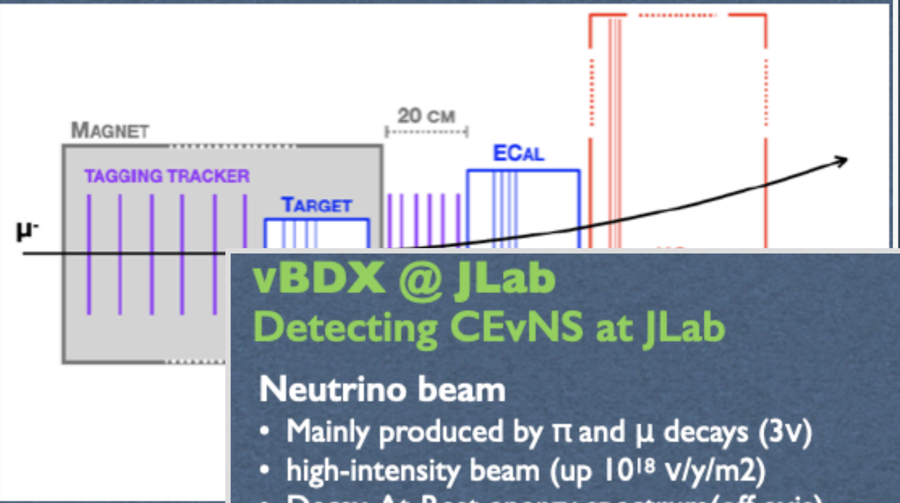
L.G. Krnjaic et al. Snowmass 2021 Rare & Precision Frontier (RF6): 7 2022
C.Antel et al. Feebly interacting particles: Fips 2022 workshop report, 2023

From CERN-FIPs workshop report, (SNOWMASS22): several experiments planned/proposed (LHC, SLAC, Mainz, FNAL, KEK, PSI, LPARC) with a variety of beams (proton, leptons, photons), energies (from 150 MeV to 14 TeV) and experimental techniques (visible, invisible, recoil, ..) with a timeline that reaches ~2042

New physics perspectives at Jlab with secondary beams

- CEBAF-JLAB the highest intensity 10 GeV electron beam in the word
- High-intensity secondary beams are produced in the dump
  - LDM (if it exists)
  - Muon
  - Neutrino



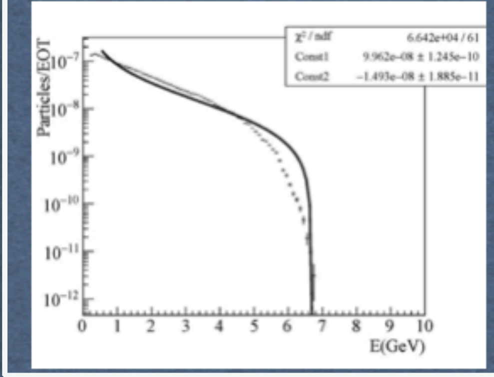


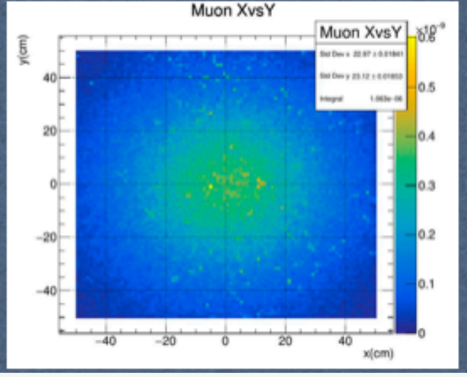
μ³BDX @ JLab

Probing muon-philic forces with secondary muon beam

Muon beam

- muons are mainly produced by Bethe-Heitler radiative process
- high-intensity beam (up 10^8 μ/s)
- Bremsstrahlung-like E spectrum, focused and compact muon beam





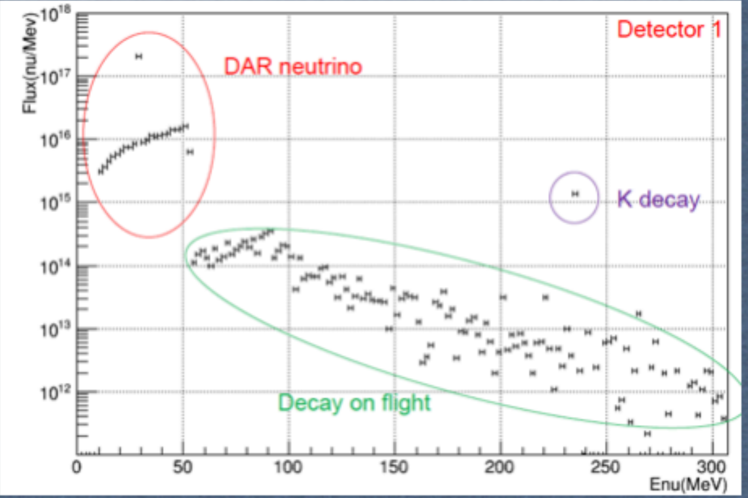
Fixed-target, missing-momen
decaying particles (similar to M

νBDX @ JLab

Detecting CEvNS at JLab

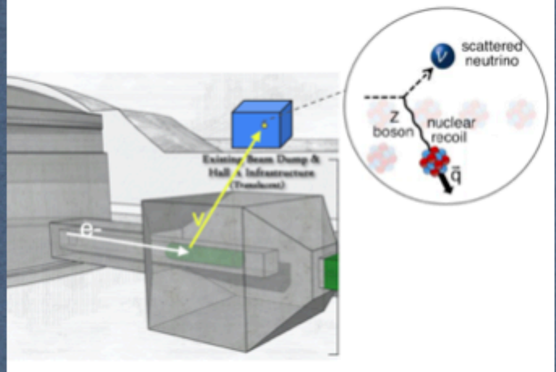
Neutrino beam

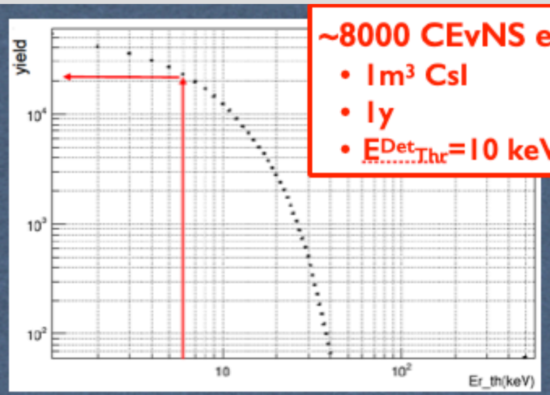
- Mainly produced by π and μ decays (3ν)
- high-intensity beam (up 10^{18} ν/y/m2)
- Decay-At-Rest energy spectrum(off-axis)



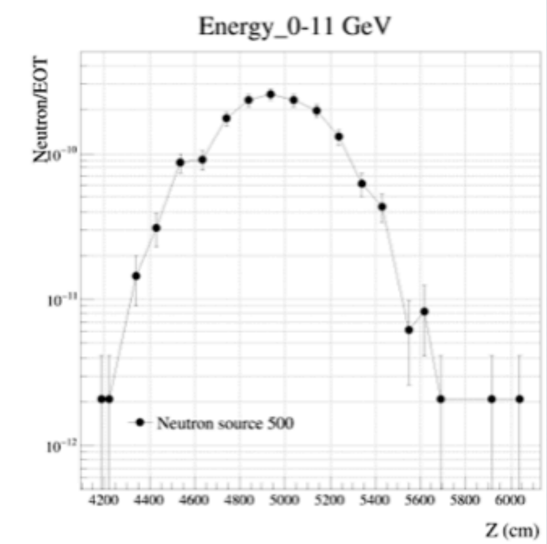
CEvNS (Coherent Elastic nu-Nucleus Scattering)

- Low-energy neutrinos (<100 MeV) coherent scatter on nucleus
- Cross-section scales as N^2
- The largest xsec for E_ν < 100 MeV
- First detected in 2017 on CsI by COHERENT (~134 events)
- Low recoil energy due to kinematics O(10 keV)

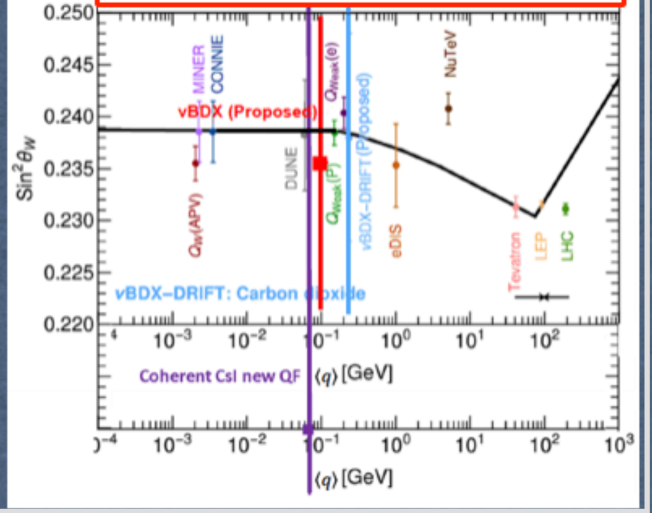




~8000 CEvNS events
- $1 m^3$ CsI
- 1y
- E^{Det}_{Thr}=10 keV



- Neutron background (beam-related and cosmics) included in νBDX reach



Projected νBDX sensitivity to θ_W
$\sin^2\theta_W = 0.209^{+0.072}_{-0.069}$

New physics perspectives at Jlab with

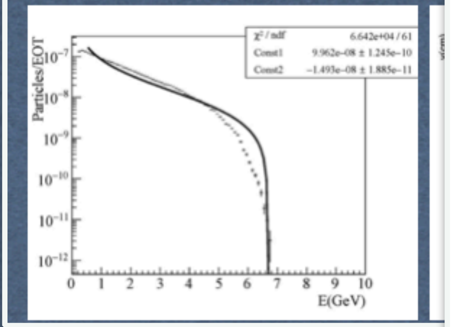
- CEBAF-JLAB the highest in
- High-intensity secondary be
  - LDM (if it exists)
  - Muon
  - Neutrino

μ³BDX @ JLab

Probing muon-philic forces

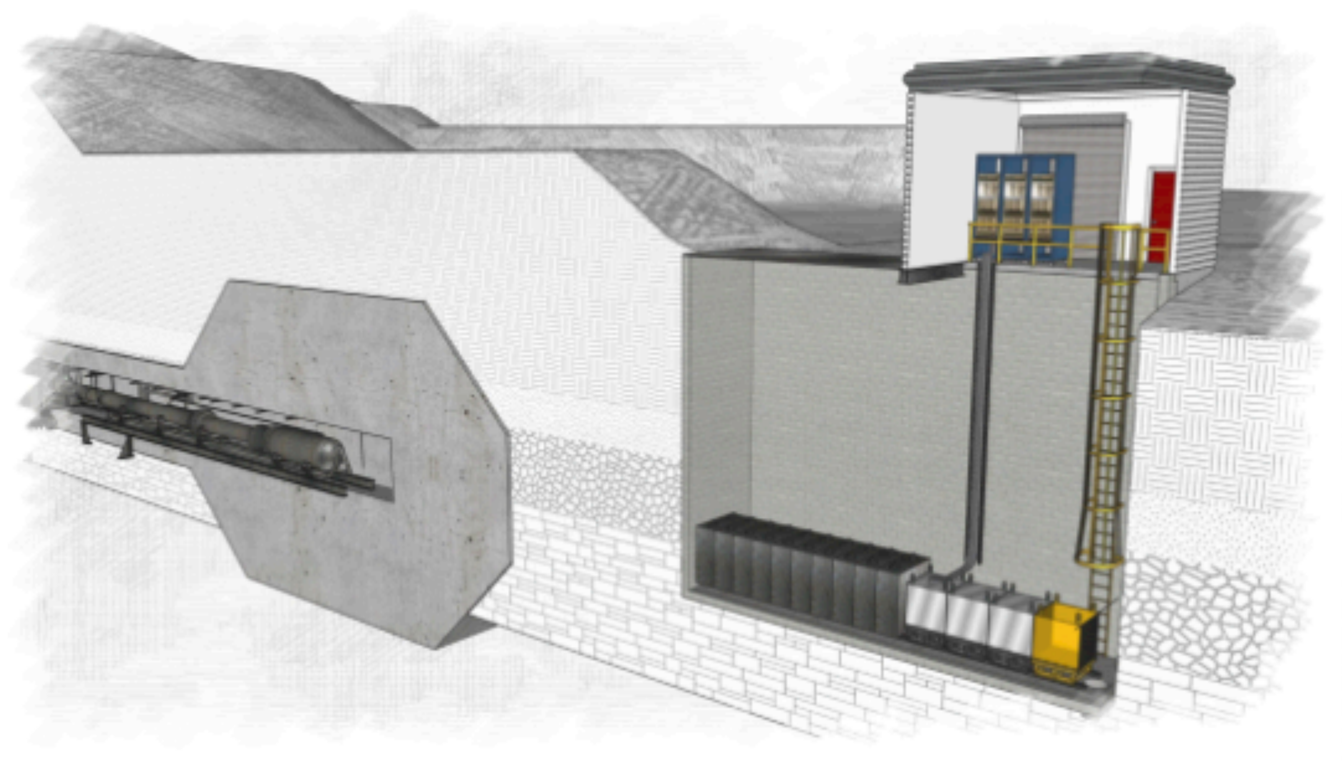
Muon beam

- muons are mainly produced by
- high-intensity beam (up 10^8 μ/
- Bremsstrahlung-like E spectru



Muon Beams

SECONDARY BEAMS AT JEFFERSON LAB WORKSHOP: BDX & BEYOND



Experimental Area Design Drawing

Conference Date

September 04, 2025 to September 05, 2025

Conference Location

Jefferson Lab, CEBAF Center rm. F113

The Secondary Beams at Jefferson Lab Workshop (BDX & Beyond) convenes scientists worldwide, will focus on optimizing the use of intense secondary beams at Jefferson Lab produced by the interaction of high-intensity electron beams with beamdumps, and it is anticipated to produce a White Paper summarizing the findings.

The workshop will include sessions on muon physics, neutrino physics, instrumentation/targets, and beamdump/beams and is encouraging new ideas for physics with particles in a planned underground vault behind the Hall A beamdump.

The BDX & Beyond Workshop at Jefferson Lab Workshop will be hosted by the Thomas Jefferson National Accelerator Facility (Jefferson Lab).

NS events

0 keV

ity to θ_W

0.069

- The largest xsec for E_ν < 100 MeV
- First detected in 2017 on CsI by COHERENT (~134 events)
- Low recoil energy due to kinematics O(10 keV)

- Neutron background (beam-related and cosmics) included in νBDX reach

https://www.jlab.org/conference/bdx2025

Conclusions

- Existence of Dark Matter is a compelling reason to investigate new forces and matter over a broad range of mass
- Accelerator-based (Light)DM search provides unique feature of distinguish DM signal from any other cosmic anomalies or effects (SNOWMASS 2022)
- Significant interests from funding agencies (DOE/NSF) and labs (CERN and JLab) to run small scale experiments with a great discovery potential
- Extensive experimental plans at high intensity e-facility to search for LDM: JLab, LNF, Mainz, SLAC (p-beam FNAL and CERN)
- A new generation of dedicated and optimised experiments at high intensity frontier will test the relic (light) dark matter scenarios
- Jefferson Lab is the world-leader facility for present and near-future LDM searches (APEX, HPS, DarkLight, BDX)
- The A-rated BDX experiment is designed to produce and detect (hypothetical) MeV-GeV DM in a beam dump experiment
- The BDX concept has been tested with prototypes, dedicated measurement campaigns and running a pilot experiment (BDX-MINI) demonstrating the technique and the physics reach
- Collecting 10^{22} EOT in 285 days of parasitic running at 11 GeV, the BDX experiment would be >10 times more sensitive than previous experiments
- High intensity muons and neutrino beams are produced and can be used for physics
- Discovery or decisive tests of simplest scenarios will possible in the next ~5-8 years!