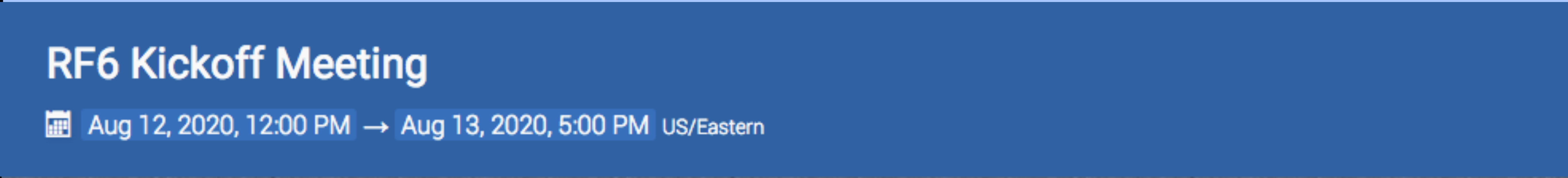


RF6 Kickoff Meeting

Aug 12, 2020, 12:00 PM → Aug 13, 2020, 5:00 PM US/Eastern

Dark Sectors with Electron Beam Dumps and Positron Beams (on fixed targets)

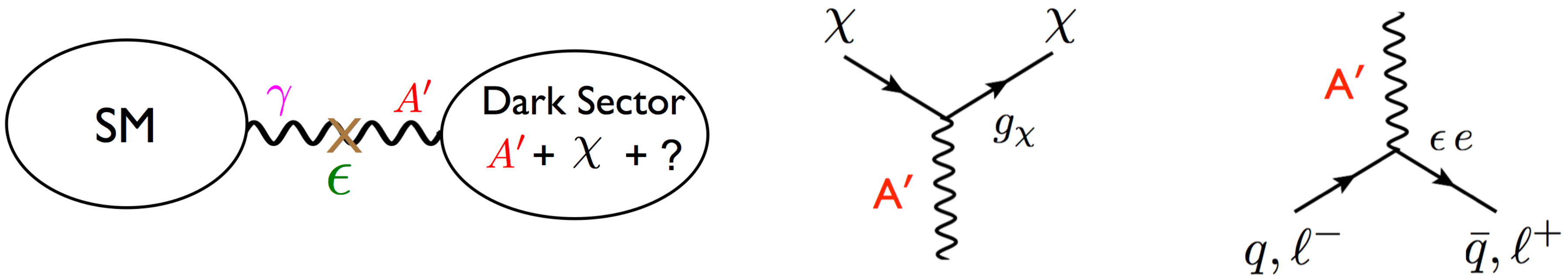
M.Battaglieri
JLab/INFN

Outline

- Beam dump experiments
- BDX and other proposals
- Positron beams
- PADME & other proposals

Dark forces and dark matter

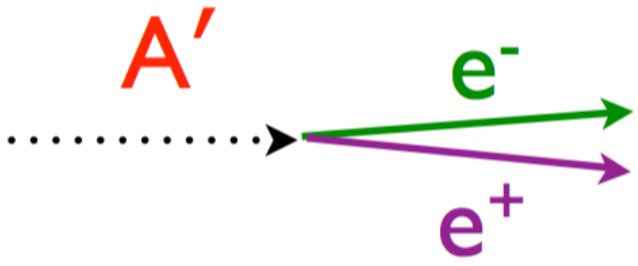
(Light WIMPs - light mediators)



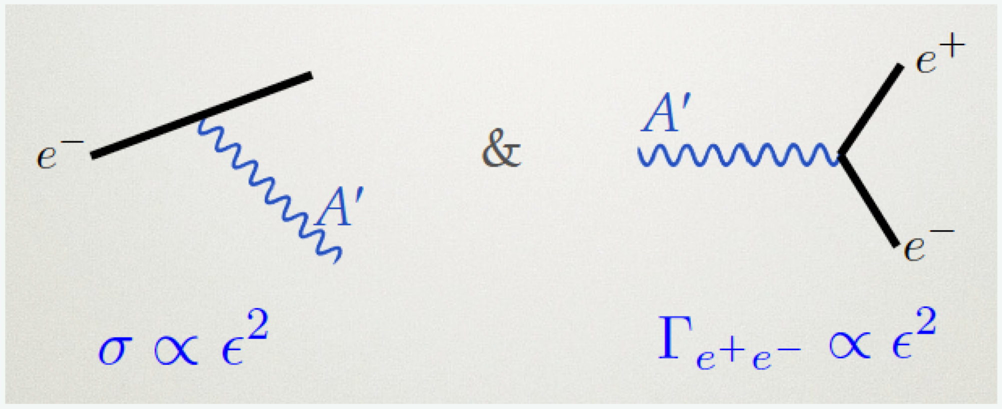
4 parameters: $m_\chi, m_{A'}, \epsilon, g_\chi$

$m_\chi \sim m_{A'} \sim \mathrm{MeV} - 5\ \mathrm{GeV}$

Visible



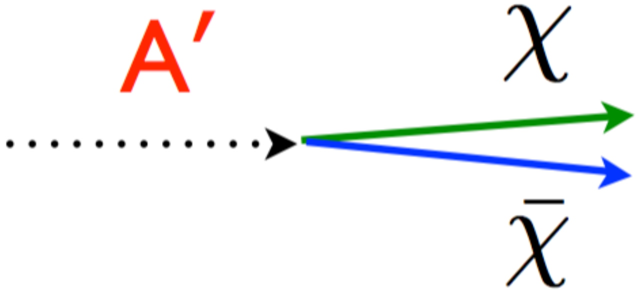
- *Minimal* decay
- Decay regulated by ε^2
- Independent of m_χ
- Requires $m_{A'} < 2m_\chi$



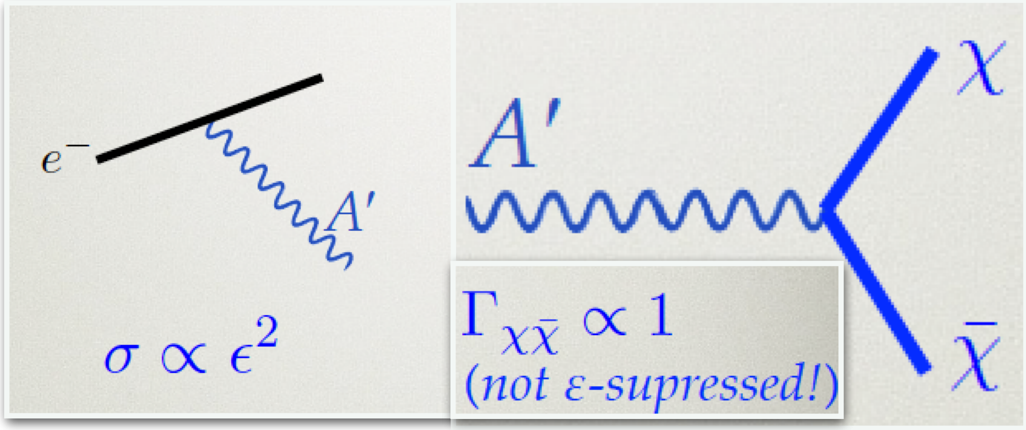
$\sigma \propto \epsilon^2$

$\Gamma_{e^+e^-} \propto \epsilon^2$

Invisible



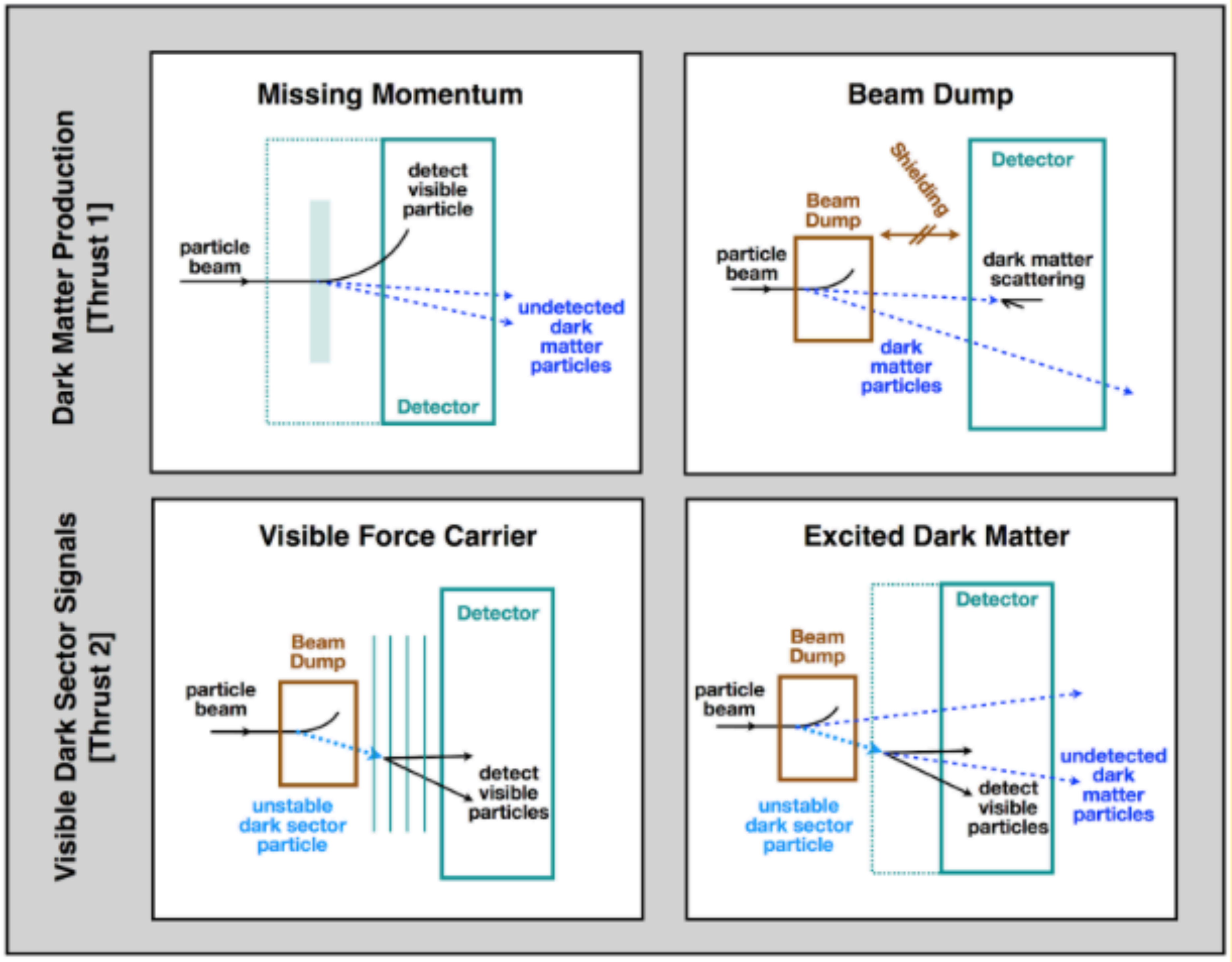
- Depends on 4 parameters
- $m_{A'} > 2m_\chi$ (on-shell)
- $\alpha_D = g^2_\chi/4\pi >> \varepsilon^2\alpha_{EM}$



$\sigma \propto \epsilon^2$

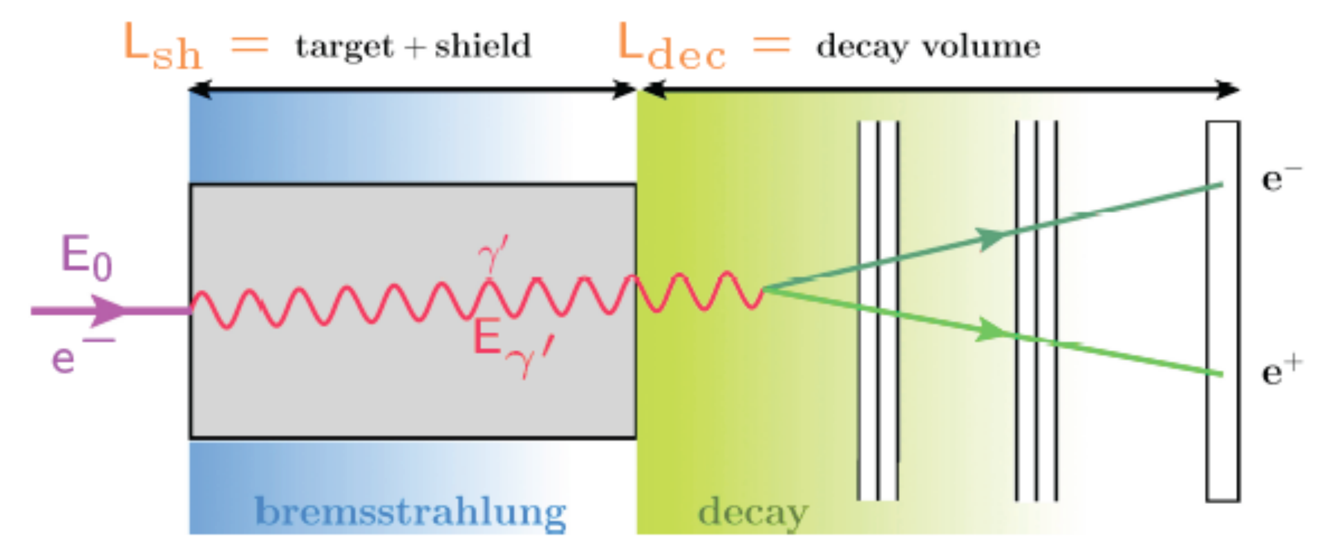
$\Gamma_{\chi\bar{\chi}} \propto 1$
(not ε-supressed!)

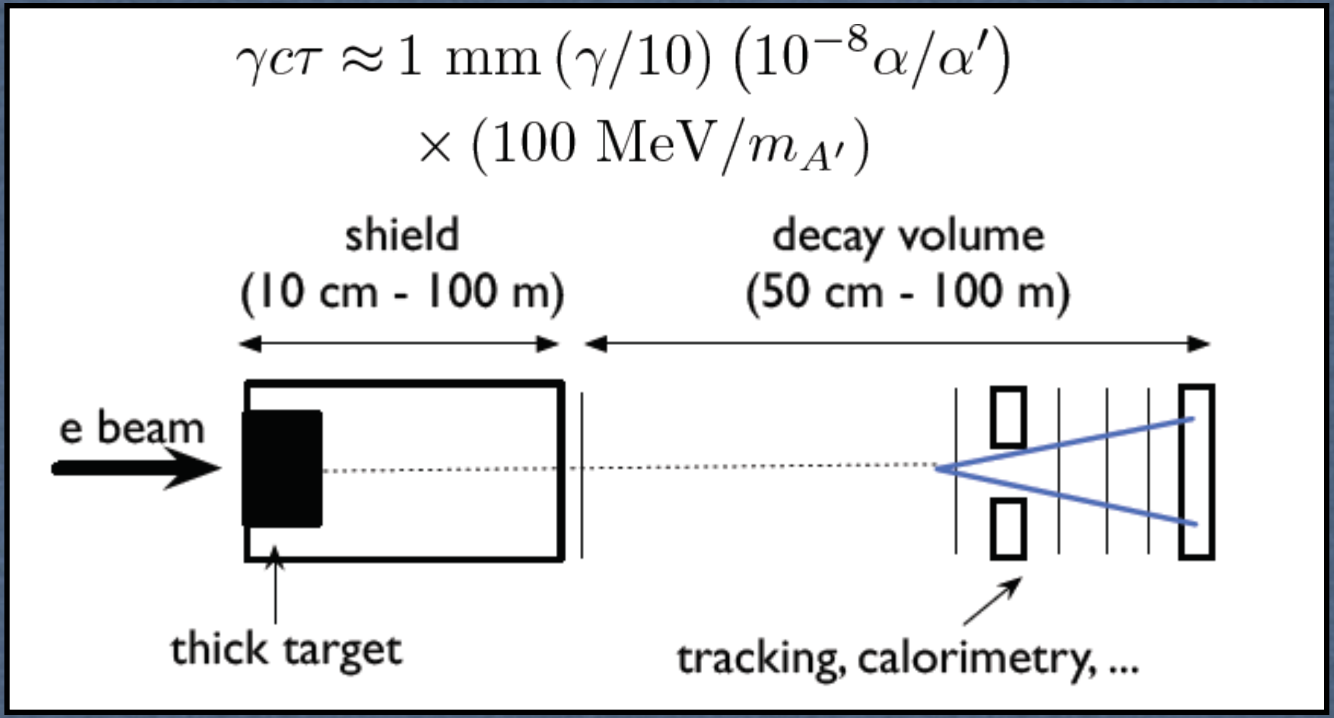
Experimental techniques



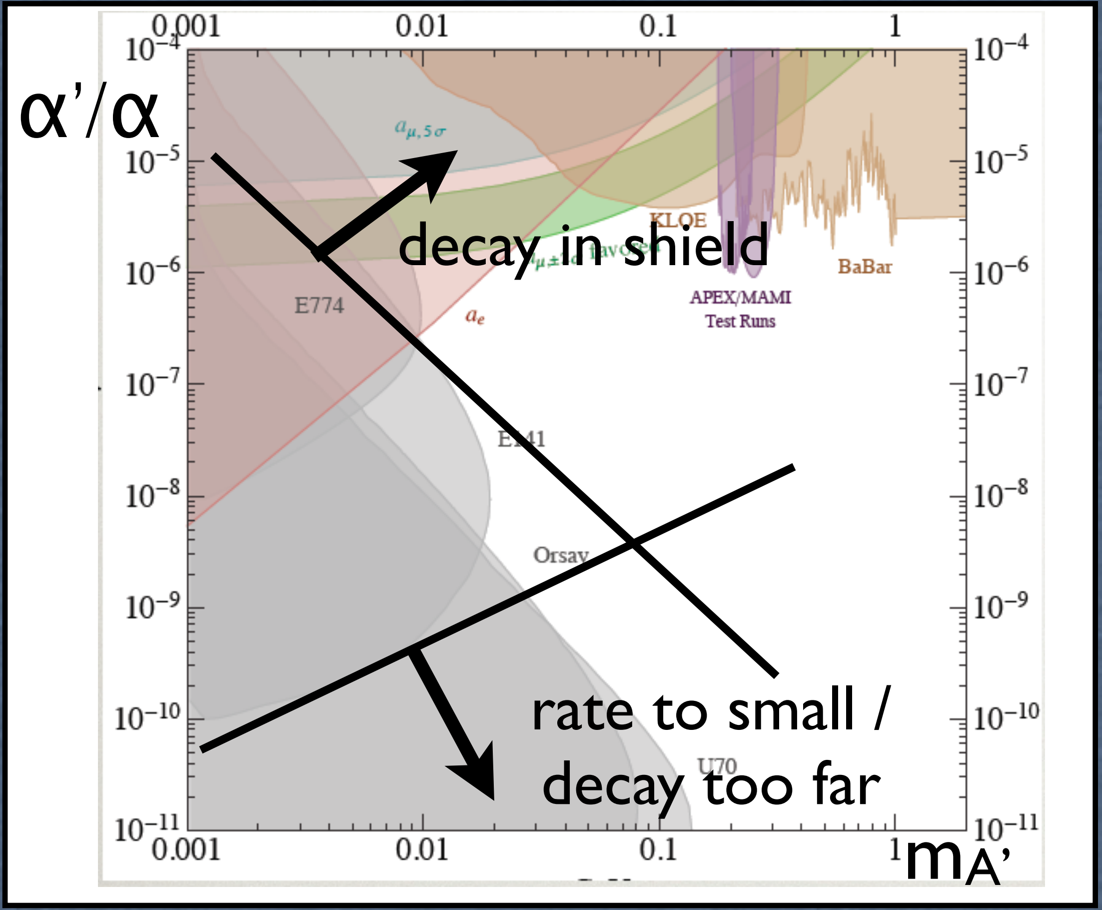
Beam-dump experiments - visible -

- ✳ e- beam incident on thick target
- ✳ A’ is produce in a process similar to ordinary Bremsstrahlung
- ✳ A’ carries most of the beam energy
- ✳ A’ emitted forward at small angle
- ✳ A’ decays before the detector

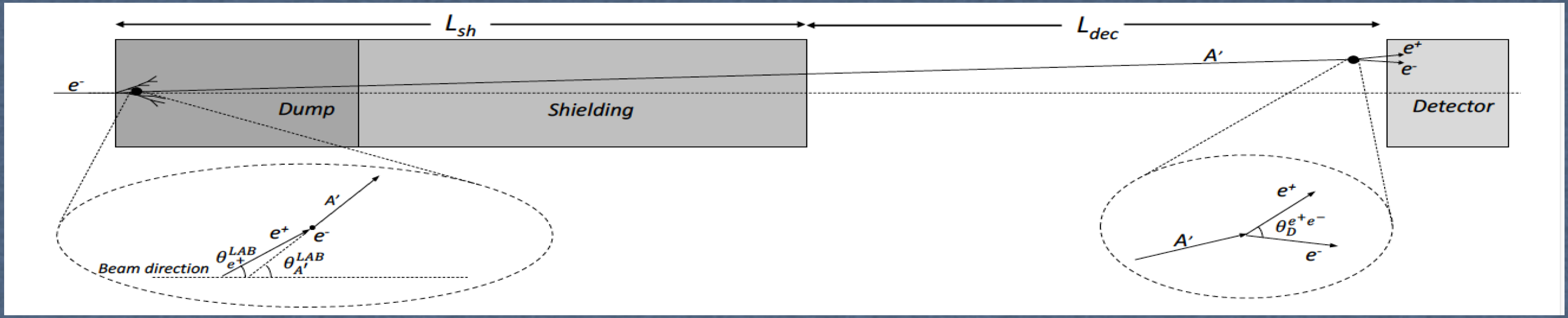


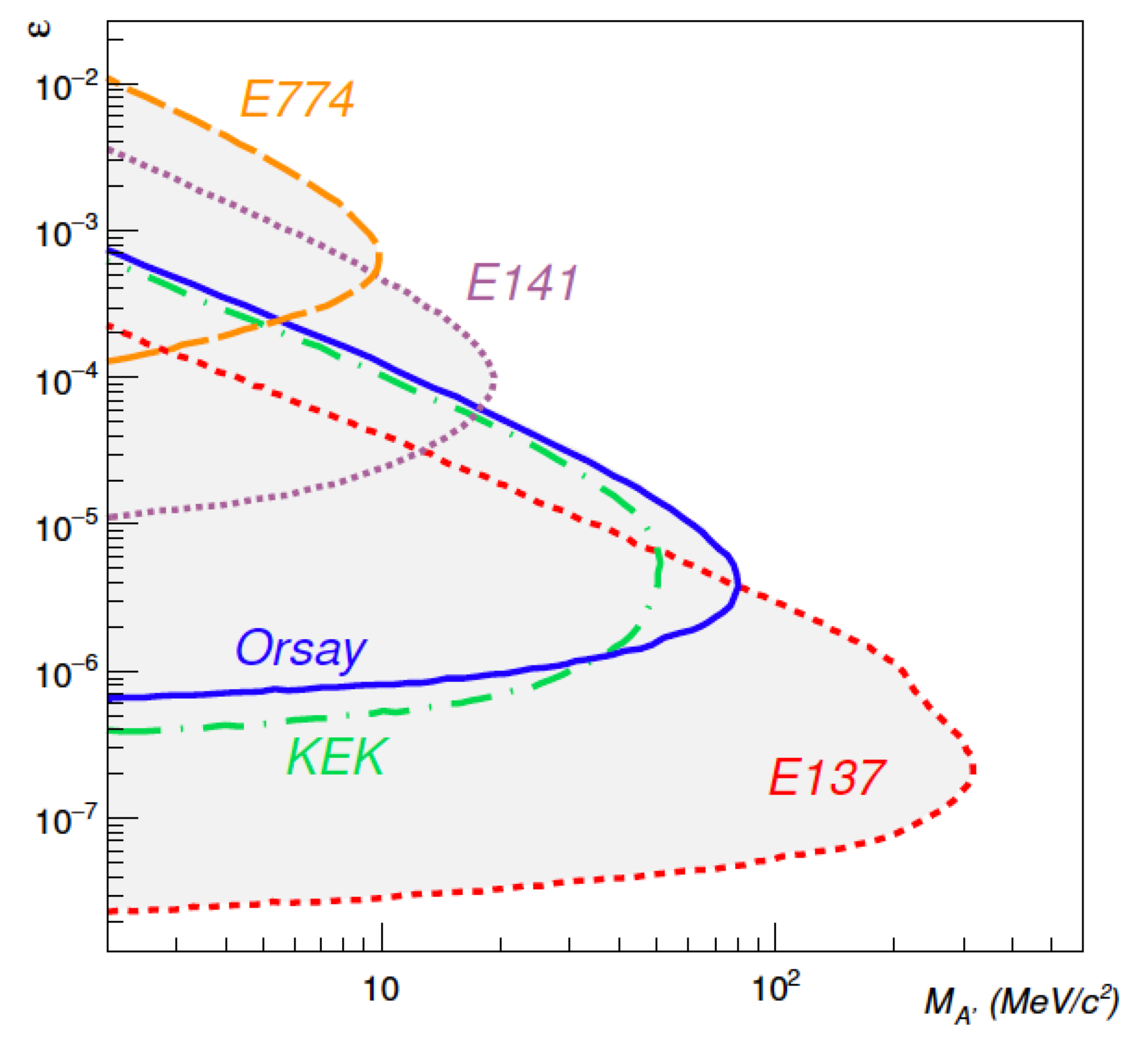


$$\gamma c\tau \approx 1\ \mathrm{mm}\,(\gamma/10)\,\left(10^{-8}\alpha/\alpha'\right)$$
$$\times\,(100\ \mathrm{MeV}/m_{A'})$$



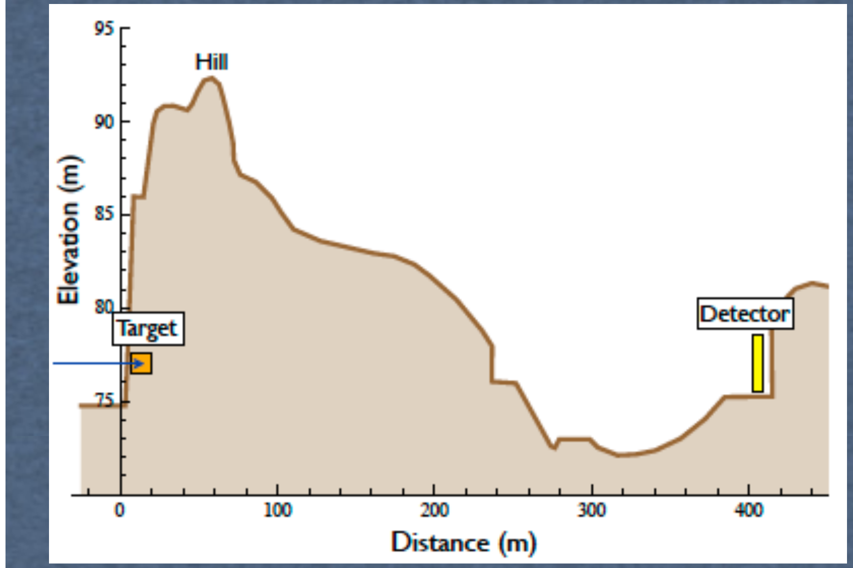
Exclusion limits (BD - visible)





Best exclusion limit from E137

- SLAC electron beam: 20 GeV, $2\text{x}10^{20}$ EOT
- Detector: 8 r.l. em calorimeter (hodo + cvrt + MWPC)
- Size: 1.5m x1.0 m at ~380m from the BD
- Cosmic bg suppressed by directionality and time coincidence



- Detection Thr (X-e scattering only): 1-2 GeV
- 0 EVENTS DETECTED

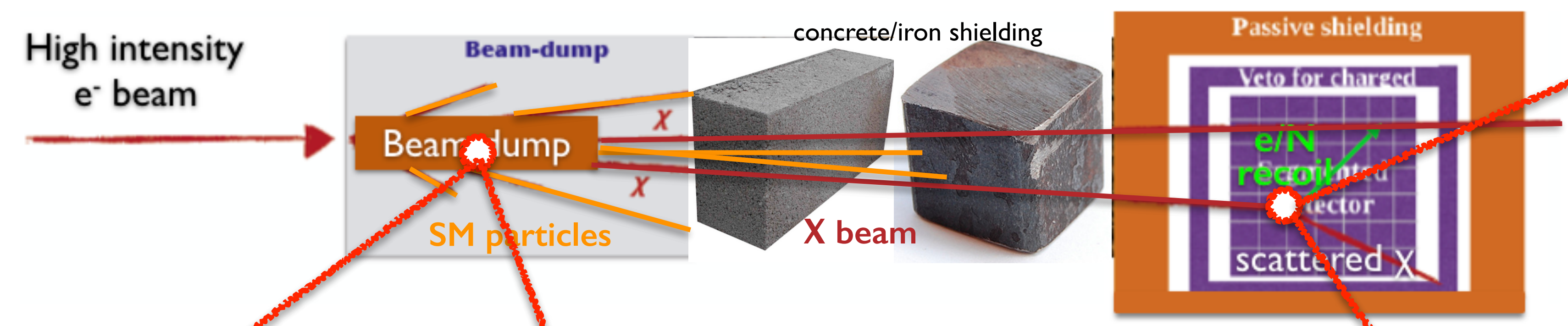
The BDX experiment

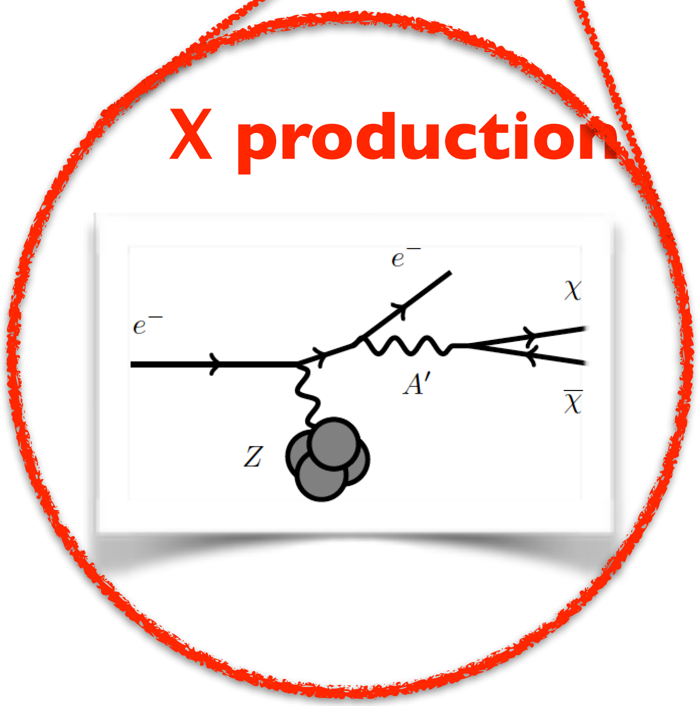
Two step process

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)

PhysRevD.88.114015 E.Izaguirre,G.Krnjaic, P.Schuster, N.Toro



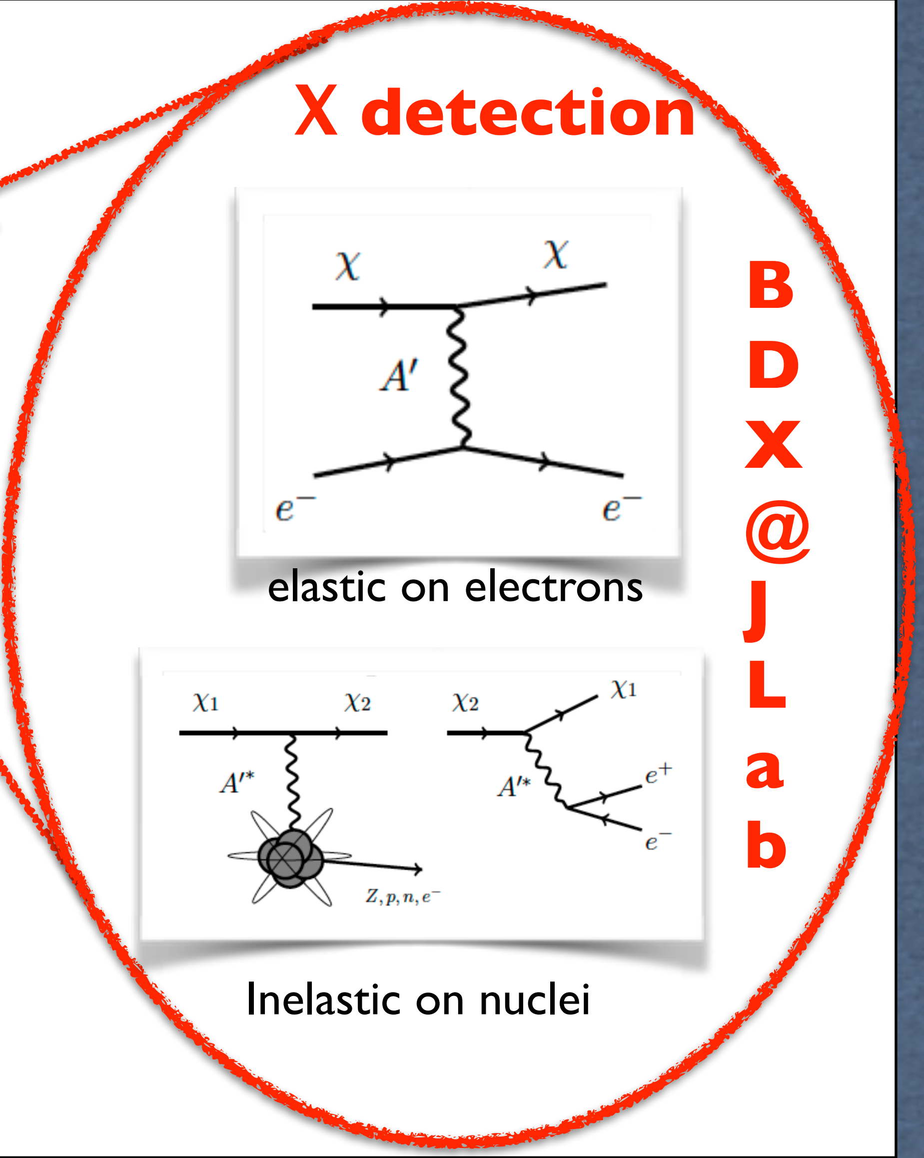


A' yield: $N_{A'} \propto \frac{\varepsilon^2}{m_{A'}^2}$

χ cross-section: $\sigma_{\chi e} \propto \frac{\alpha_D \varepsilon^2}{m_{A'}^2}$

Number of events: $N_\chi \propto \frac{\alpha_D \varepsilon^4}{m_{A'}^4}$

- **Intense electron beam**
- **~ few GeV range energy**



elastic on electrons

Inelastic on nuclei

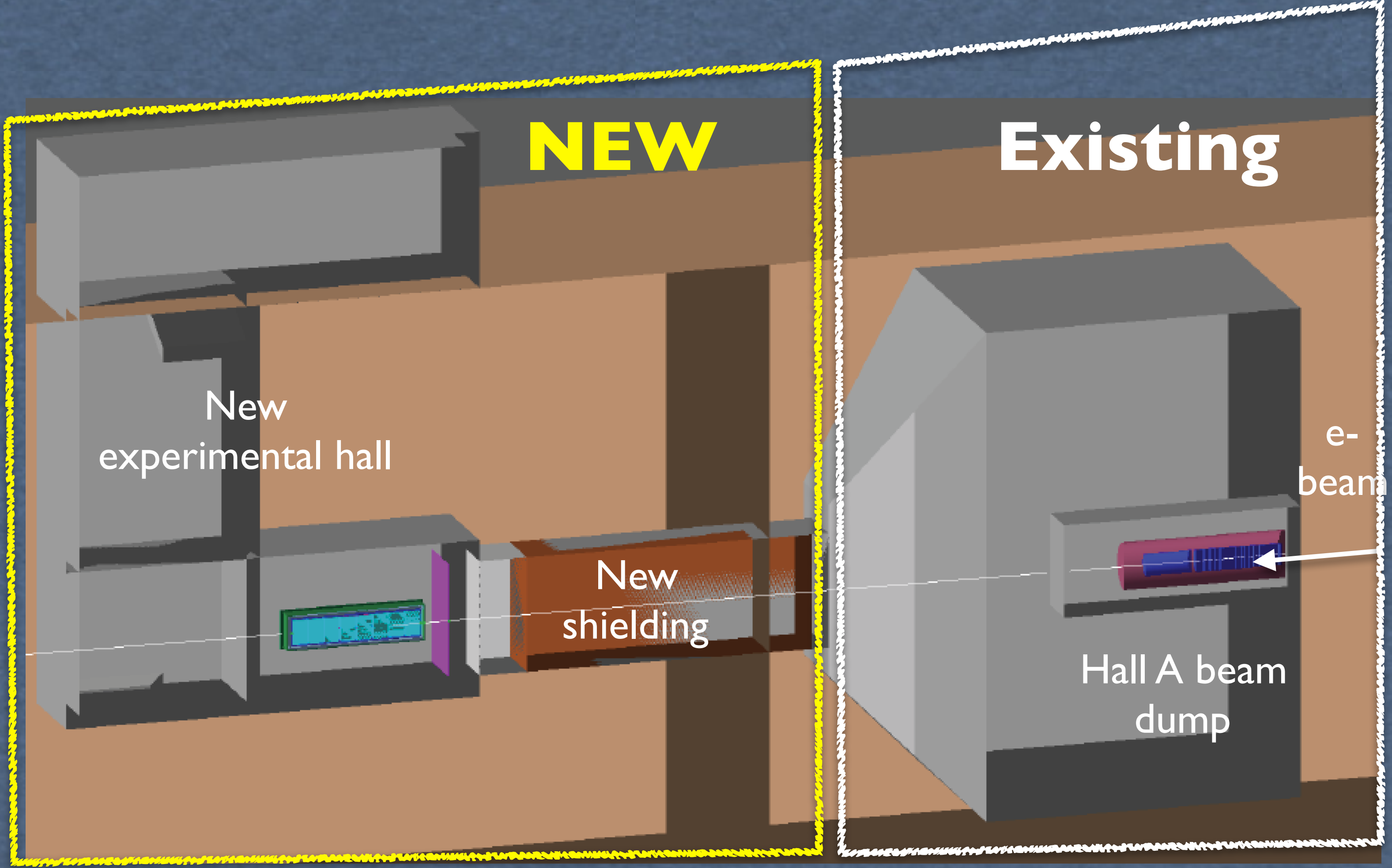
Experimental signature in the detector:

X-electron → EM shower ~GeV energy

BDX at JLab

★ High energy beam available: 11 GeV
★ The highest available electron beam current: ~65 uA
★ The highest integrated charge: 10^{22} EOT (41 weeks)

★ BDX detector located downstream of Hall-A beam dump
★ New underground experimental hall



The BDX detector

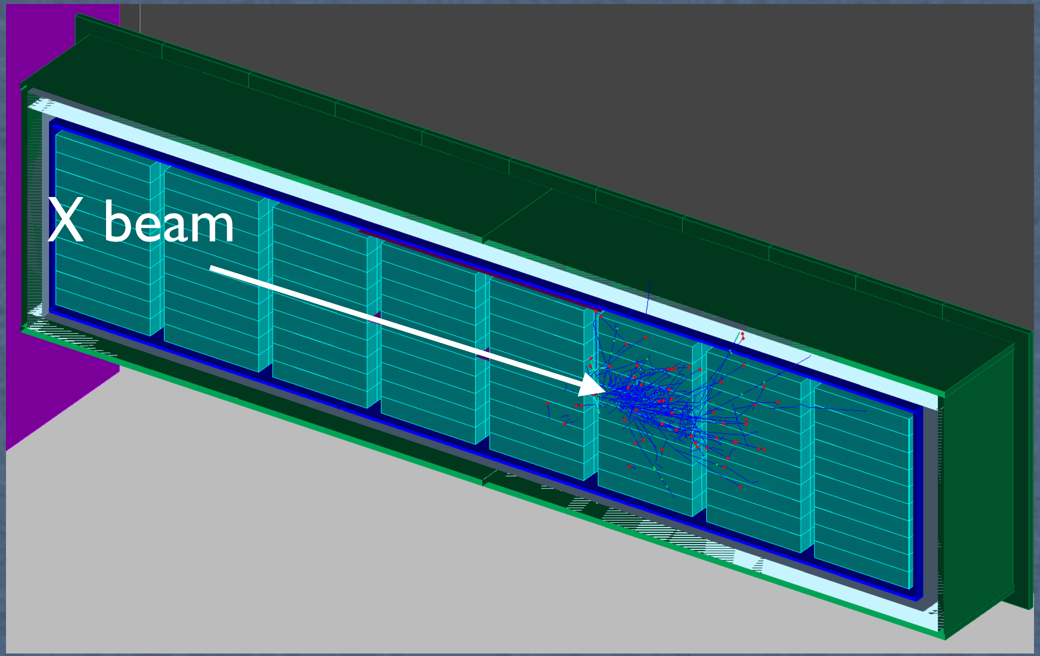
Detecting the X

E.M. Calorimeter

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

Modular EM calorimeter

- 8 modules 10x10 crystals each
- 800 CsI(Tl) crystals (from BaBar EMCal)
- 6x6 mm^2 Hamamatsu SiPM readout
- 50 x 55 x 295 cm^3



Rejecting the bg

- Cosmic
- Beam-on

Two active veto layers

Plastic scintillator +WLS with SiPM and PMT readout

- Outer Veto: 2cm thick
- Inner Veto: 1 cm thick
- Lead Vault: 5cm thick

BDX detector technology validated with:

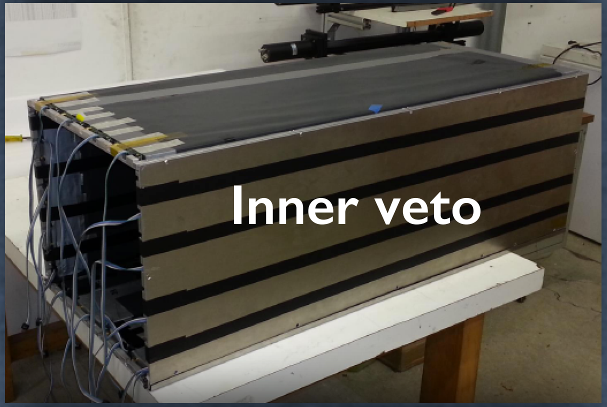
BDX-Proto

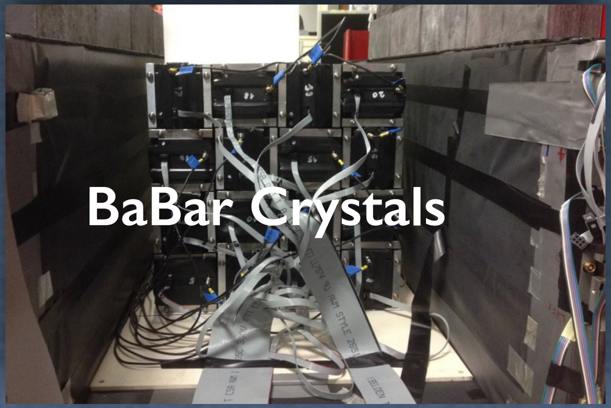
- EM Cal
  - 4x4 CsI(Tl) crystals
  - 6x6 mm^2 SiPM
- Outer Veto
- Lead vault
- Inner Veto

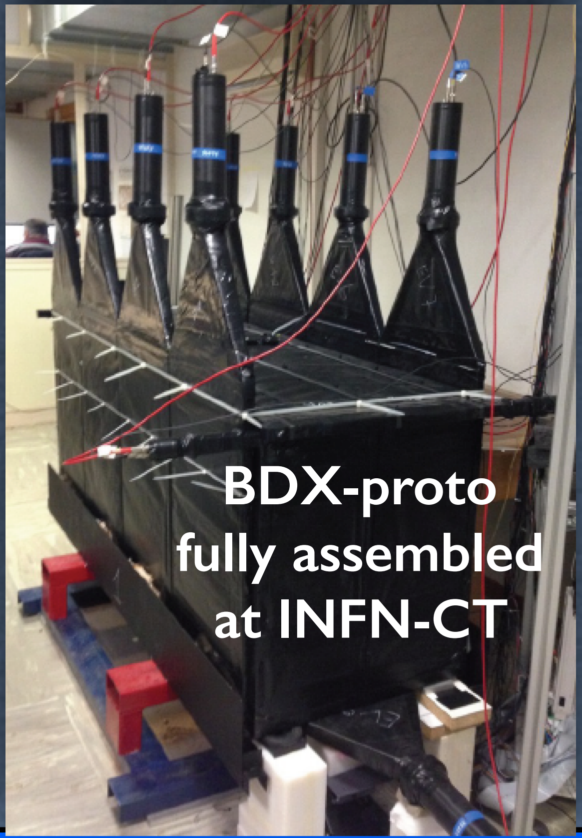

Outer veto plastic scintillators paddle + light guide + PMT


Scintillator paddles + WLS + SiPM


Inner veto in the lead vault

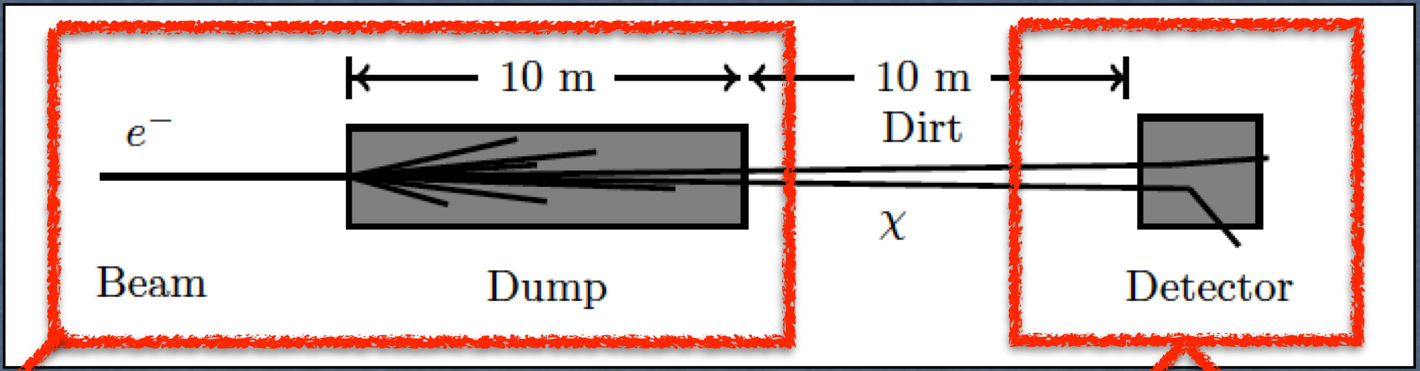

Inner veto


BaBar Crystals

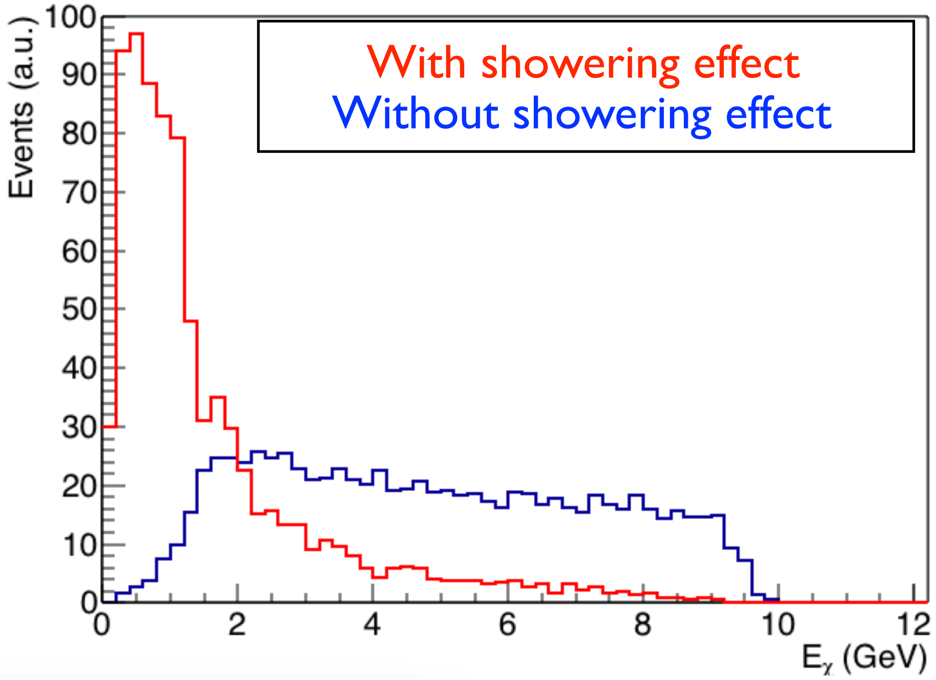

BDX-proto fully assembled at INFN-CT

X production and detection

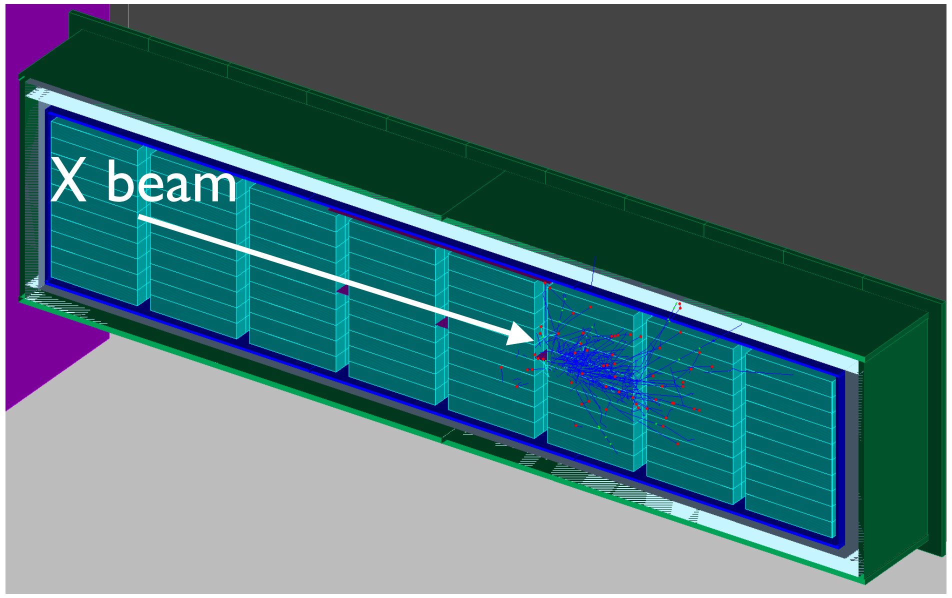
- Detailed simulations using ad-hoc MC code to describe the A’ production, decay (A’ $\rightarrow \chi\ \chi$) and interaction in the BDX detector (X-e)
- Detailed description of Hall-A beam dump (production) and BDX detector (detection) using GEANT4



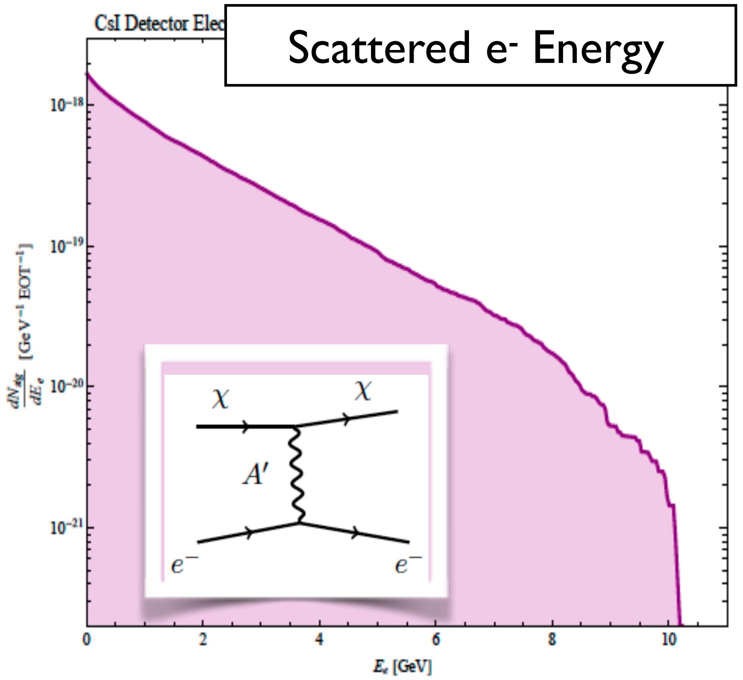
X energy spectrum generated by 11 GeV e-beam in the dump



χ-e interaction producing an em shower in the detector



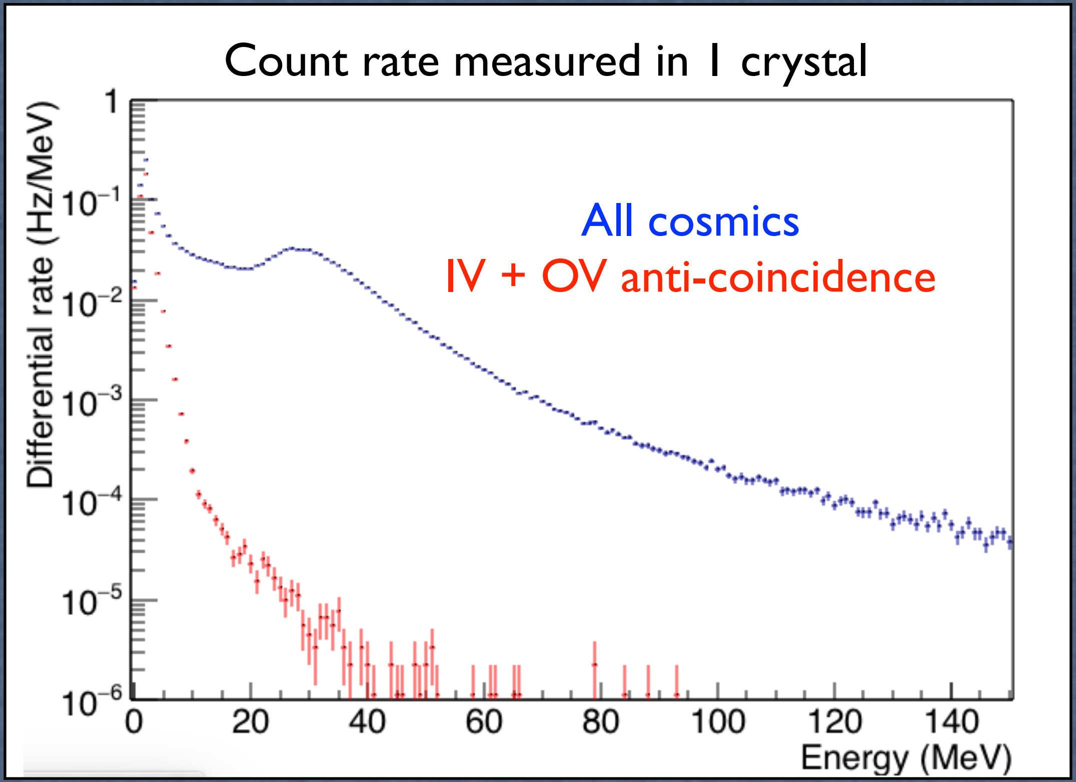
Elastic on electrons



Background

Cosmic

- ★ Cosmic background measured with the BDX detector prototype in CT



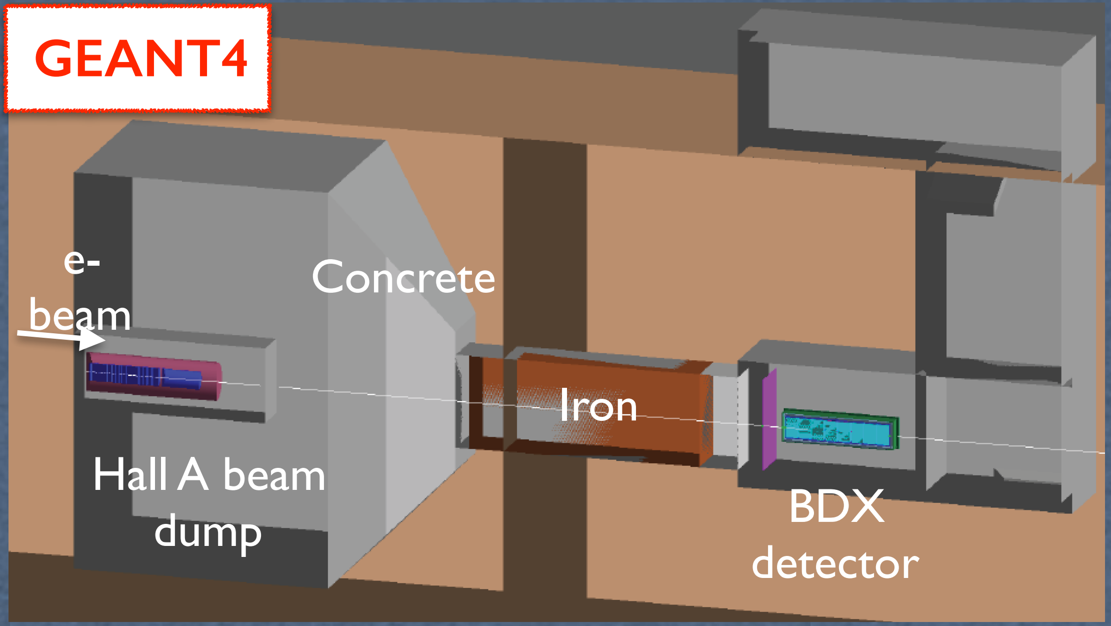
Expected cosmic bg counts in BDX lifetime < 2 counts

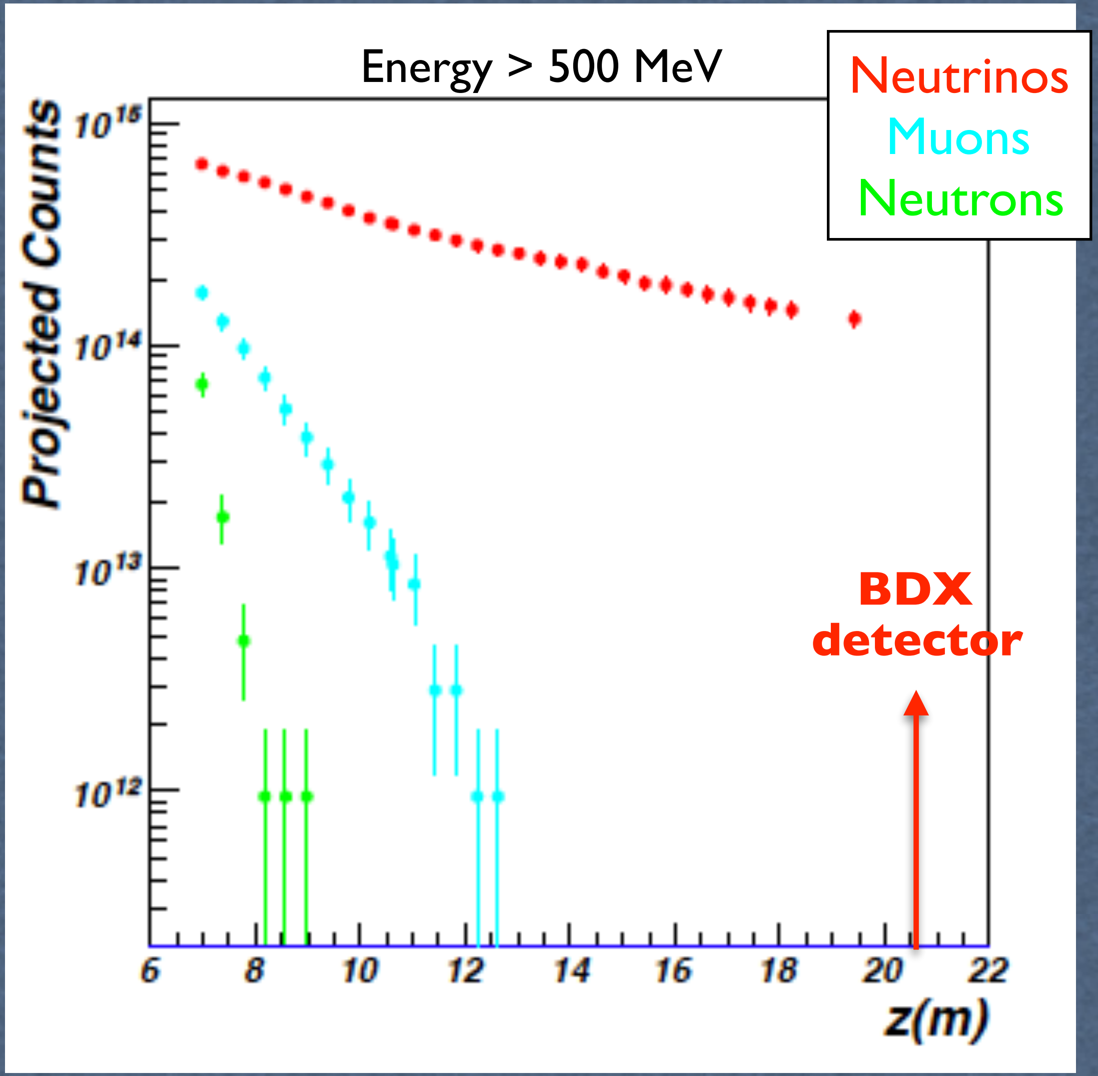
Beam-related

Bg estimated using GEANT4, tracking particles with E>E_{Thr}

- ★ Muons are ranged out by the iron shielding
- ★ Non-negligible contribution of high energy neutrino interacting in the detector by CC: $\nu + N \rightarrow X + e^-$

Expected beam-related counts in BDX lifetime ~ 10 counts

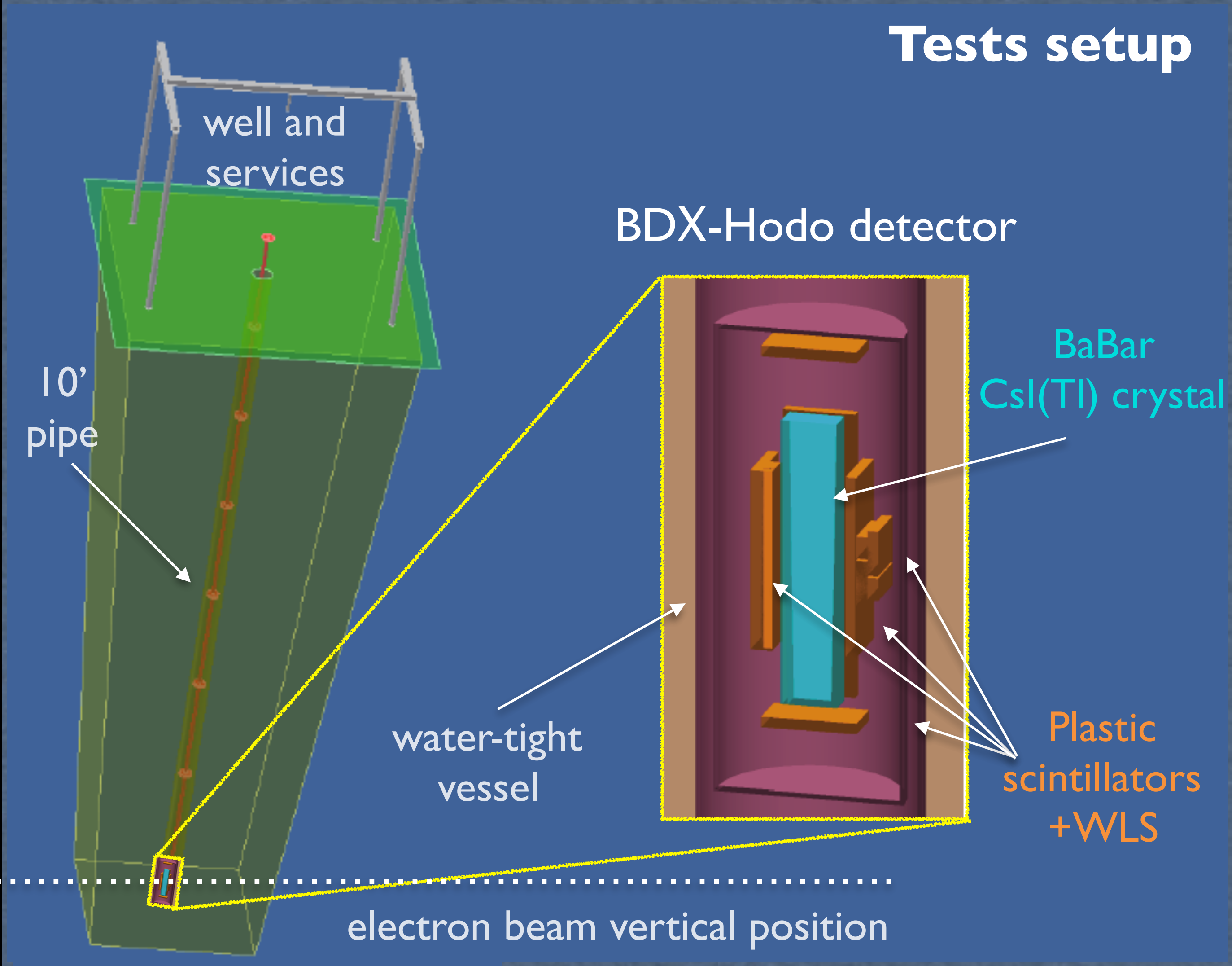




Test to measure the beam-on background

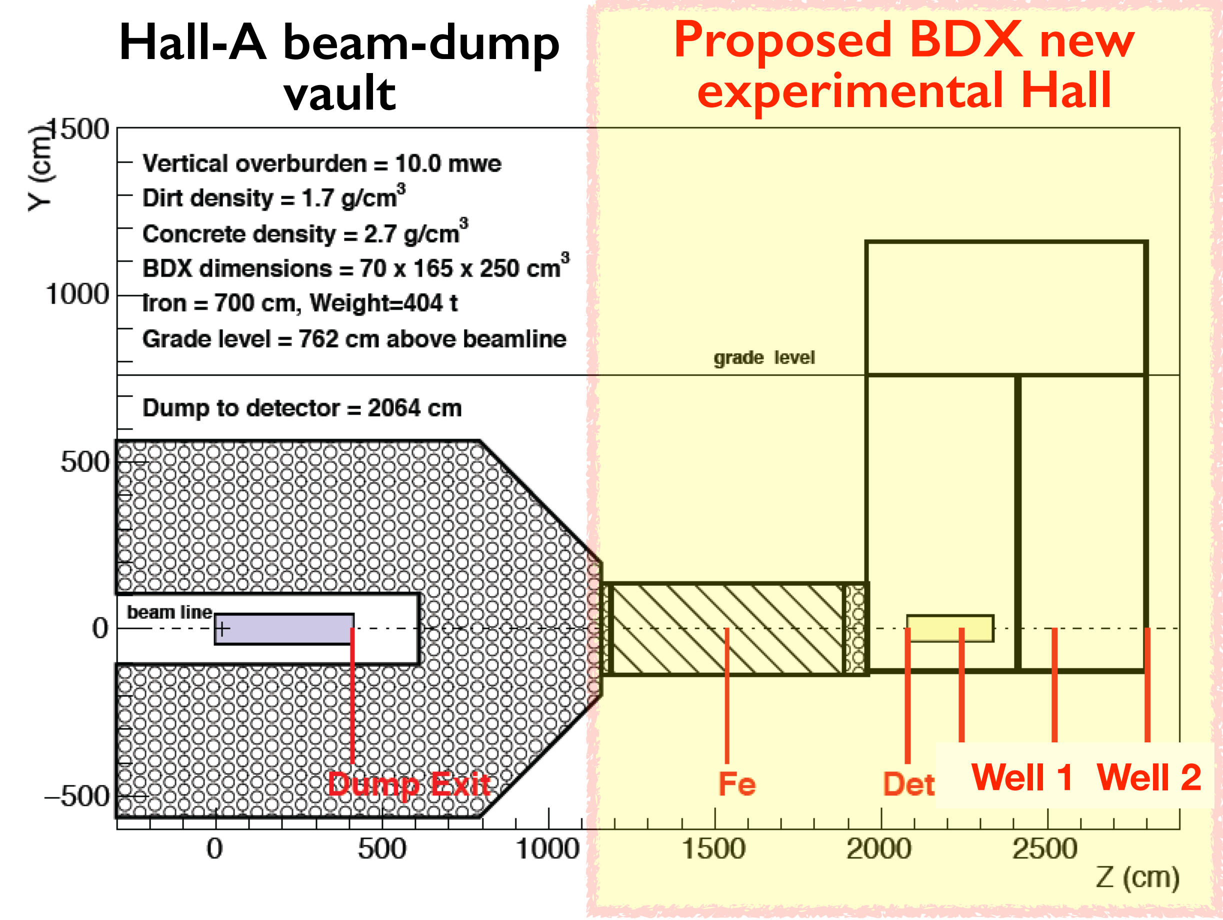
Measurement campaign to characterize the flux of high-energy μ produced in the Hall-A beam dump

- Pipe downstream of Hall-A beam-dump at BDX location
- Insert a CsI(Tl) crystal surrounded by plastic scintillators
- Same detector technology proposed for BDX detector
- Measure μ flux when 11-GeV beam is on



Tests setup

Downstream of the Hall-A beam dump
- TODAY -



Hall-A beam-dump vault

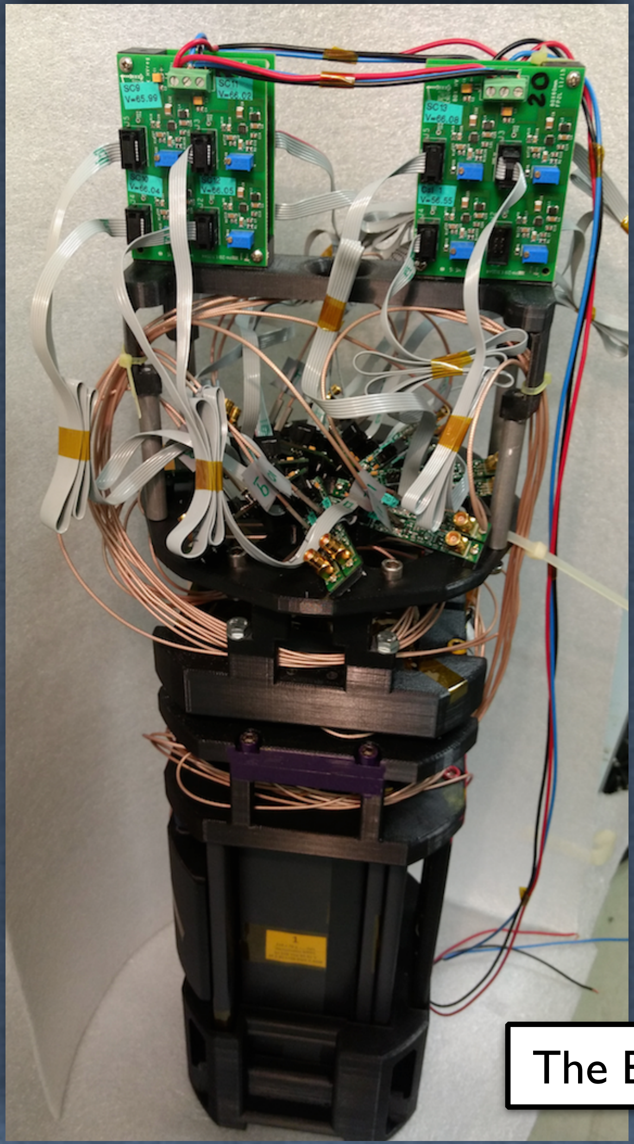
Proposed BDX new experimental Hall

Vertical overburden = 10.0 mwe
Dirt density = 1.7 g/cm^3
Concrete density = 2.7 g/cm^3
BDX dimensions = 70 x 165 x 250 cm^3
Iron = 700 cm, Weight=404 t
Grade level = 762 cm above beamline
Dump to detector = 2064 cm

BDX-Hodo tests at JLab


Two wells


The tent

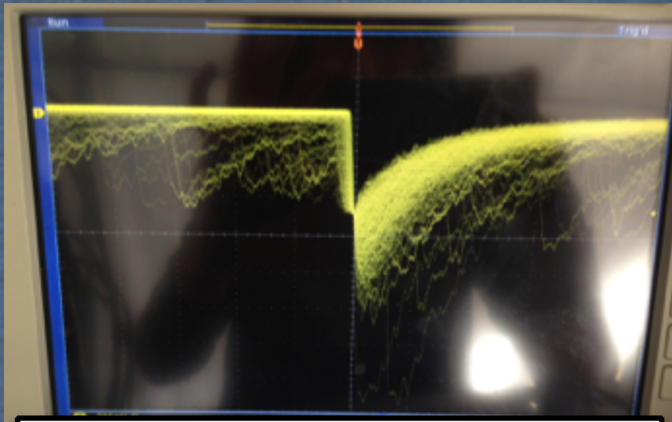

The BDX-Hodo


BDX-Hodo in the tent

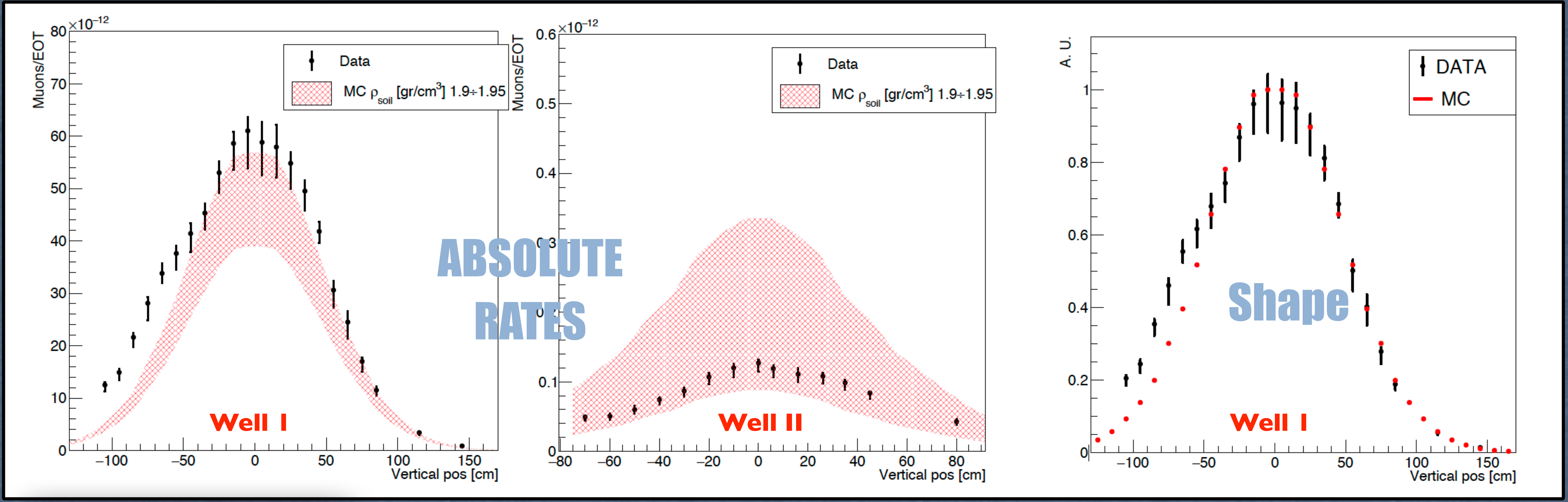

The BDX-Hodo lowered in well 1

- Run: from Feb 22nd to May 2nd 2018
- Hall-A beam parameters
  - I_{Beam} ~ 22uA
  - E_{Beam} = 10.6 GeV
  - Diffuser: ON

+ 1 week taken in Well II with E_{beam}=4 .3 GeV


The first muon signal on the scope

Data/Sim comparison



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journal homepage: www.elsevier.com/locate/nima

Measurements of the muon flux produced by 10.6 GeV electrons in a beam dump

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Dark photon
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ABSTRACT

This paper presents the results of an experiment to assess the muon flux produced by the interaction of a 10.6 GeV electron beam with the Hall-A beam dump at Jefferson Lab (JLab). The goal was to benchmark Monte Carlo simulations that are an essential tool for estimating beam-related backgrounds in beam-dump experiments aimed at searching for rare events, such as the Beam Dump eXperiment (BDX) planned at JLab. Beam-produced muons were measured with a CsI(Tl) crystal sandwiched between a set of segmented plastic scintillators placed at two different distances from the dump: 25.7 m and 28.8 m. At each location the muon flux was sampled at different vertical positions with respect to the beam height. Data have been compared with detailed Monte Carlo simulations using FLUKA for the muon production in the dump and propagation to the detector, and GEANT4 to simulate the detector response. The good agreement between data and simulations, within the uncertainties of the soil composition and density, demonstrate the validity of our simulation tools to predict the beam-related muon background in electron beam-dump experiments at ~ 10 GeV.

1. Introduction

Background is usually the limiting factor in experiments searching for rare events. This is the case for Dark Matter (DM) searches in beam-dump experiments where a high intensity O(GeV) electron/proton beam is directed into a dump producing an overwhelming shower of Standard Model particles in addition to the rare DM particles of interest. While most of the radiation (gamma, electron/positron and neutron) is contained in the dump or degraded down to harmless energy levels, deep penetrating radiation, such as muons, propagate for long distances before depositing their energy far from the point of origin.[1] Monte Carlo simulations are used to find the best combination of shielding and analysis cuts to minimize such background. However, they need to be validated with actual measurements. In this work we present the results of a measurement performed downstream of the JLab Hall-A beam-dump to assess the muon background produced in the interaction of the CEBAF 10.6 GeV electron beam with the dump. Experimental results have been compared to simulations performed with FLUKA [1,2] and GEANT4 [3] that include a realistic model of the dump, the surrounding materials and the detector response. This study is relevant for the Beam Dump eXperiment (BDX) planned at Jefferson Lab. BDX is an electron-beam thick-target experiment aimed to produce and detect light Dark Matter particles (MeV-GeV mass range), in the framework of the theoretical paradigm where DM is charged under a new U(1) symmetry whose interaction is mediated by a new light vector boson (a *heavy photon* or A', also called *dark photon*) [4]. The A' is expected to be produced in the interaction of the high power (~1 GW) electron beam with the Hall-A beam dump via $A'-$*strahlung* processes [5] and e^+e^- annihilations [6]. The A' could then decay into forward-boosted DM particles (χ) that may interact with the BDX detector located ~ 25 m downstream of the dump. An electromagnetic calorimeter with ~800 CsI(Tl) crystals will measure the EM shower produced by high-energy e^- produced by the scattering of a χ with atomic electrons. Two large-area plastic-scintillator veto systems and a massive passive shielding placed downstream of the dump will be used to reject high energy backgrounds that can mimic a DM signal, except for neutrinos. In order to benchmark Monte Carlo simulations, an on-site experimental campaign was performed to measure the muon flux in the present

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E-mail address: mariangela.bondi@ct.infn.it (M. Bondí).

[1] Neutrinos are copiously produced in the dump but due to the low interaction cross section, they deserve a separate discussion.

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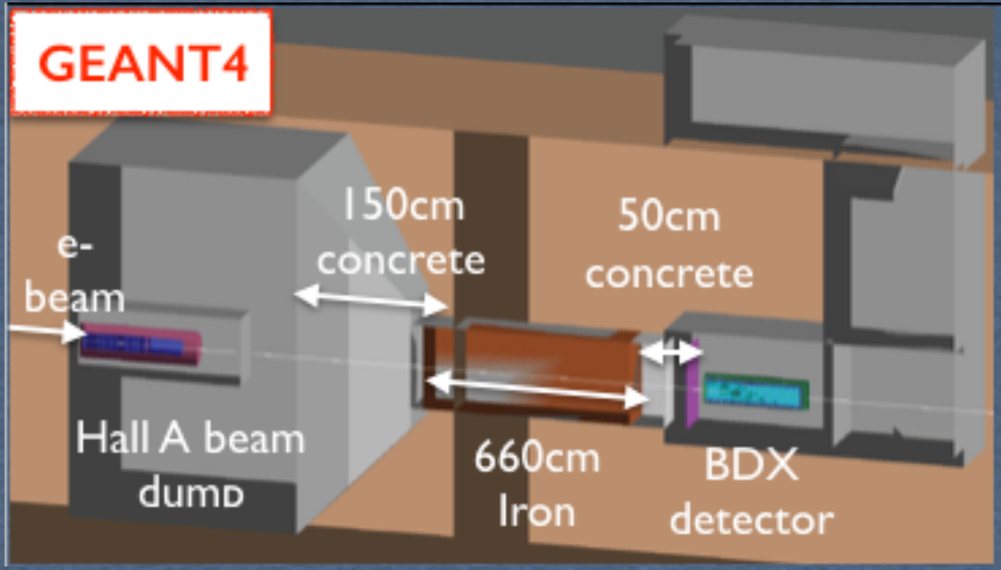
Available online 6 February 2019

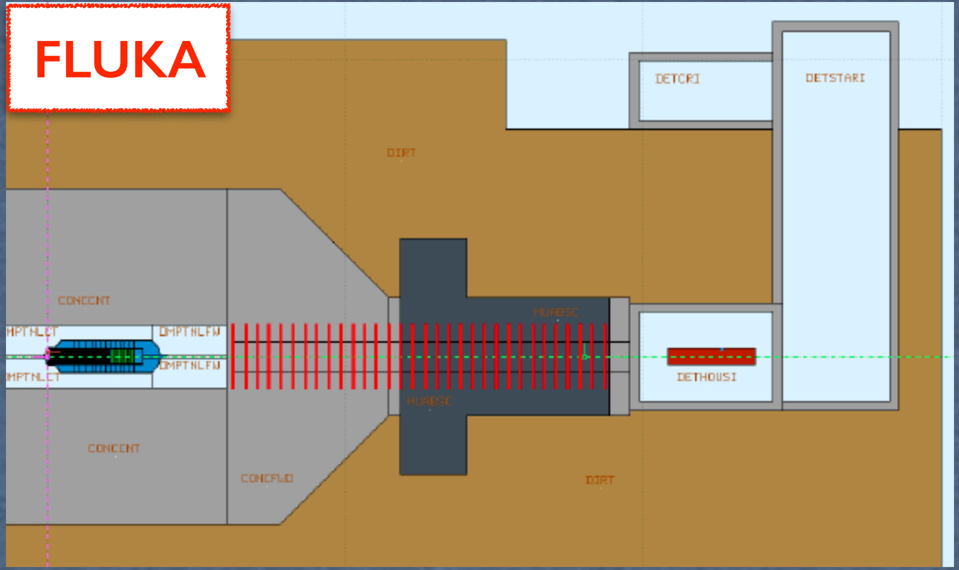
- **Absolute rates** for data and simulations in agreement within the density-related uncertainty band
- The **shape** of rates sampled at different heights is well reproduced by simulations (gaussian with the same σ)

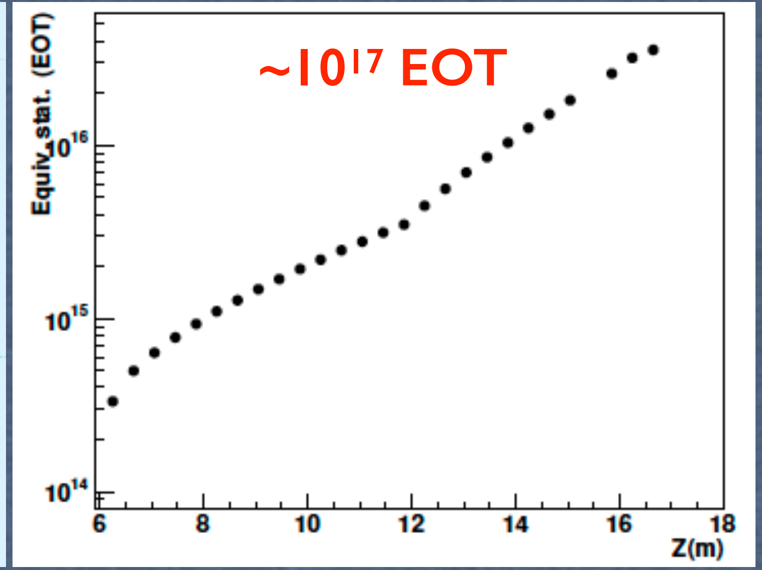
Good agreement between data and simulations prove:

- the BDX simulation framework is reliable
- no significant contribution from n bg (high energy n and/or pile-up effects)

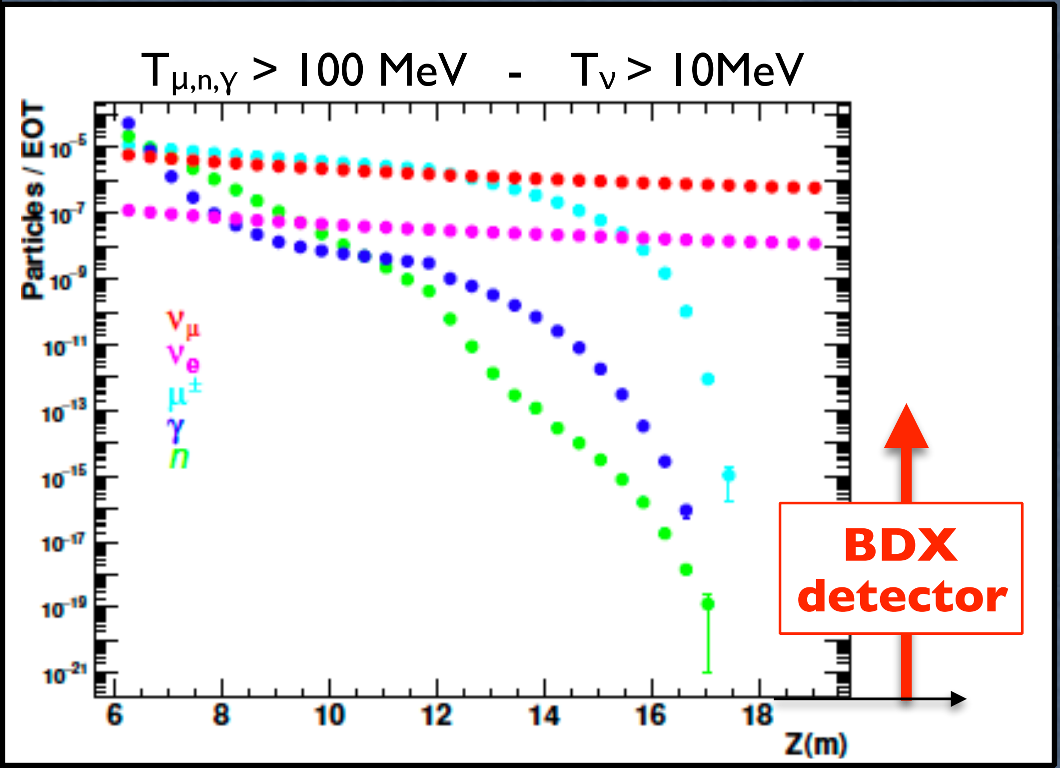
High statistics MC sim the BDX set-up







- ★ Particles produced in the BD by the 11 GeV beam are tracked to BDX detector location
  - 6.6m iron shield (+2m concrete) to stop high energy muons
  - different shielding configuration tested
- ★ High statistics simulations: 300 cores x 3 months simulating ~10^{17} EOT equivalent at BDX detector location



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

★ **Muons**

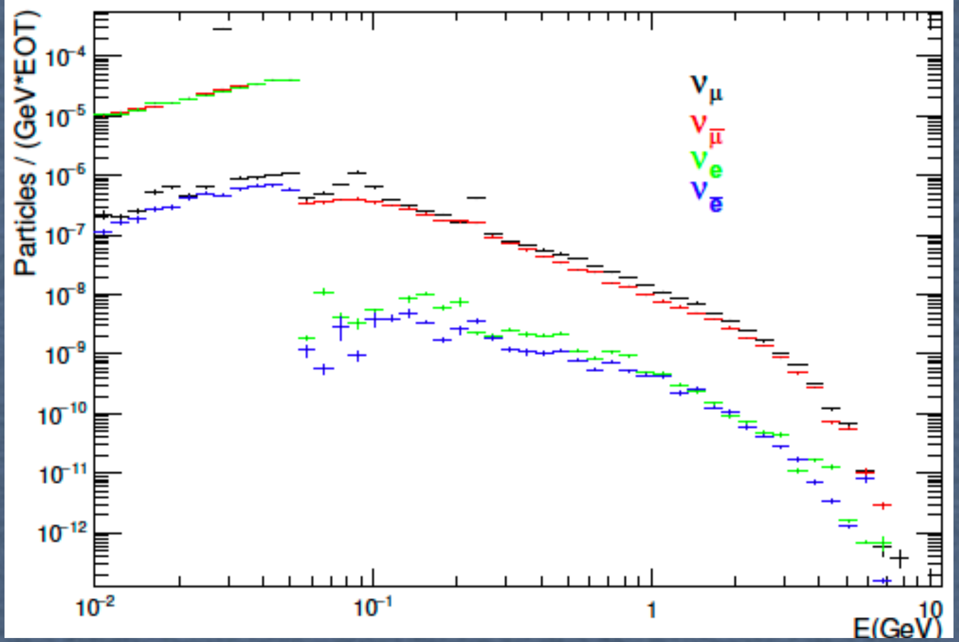
- All forward-going muons are ranged out
- Large angle μs may enter in BDX volume (R~0.02 Hz)
- They are rejected by combination of veto and threshold
- Shielding configuration leading to 0 bg events found
- An optimized shielding will be defined at the time of the new experimental Hall design

MC Simulations: neutrino background

★ **Neutrino**

- $\pi \rightarrow \mu\, \nu_\mu \quad \mu \rightarrow e\, \nu_\mu\, \nu_e$
- Mainly low energy (<60 MeV) from decay at rest
- Some ν produced in HadShower and boosted to BDX detector

Non-negligible contribution of high energy ν interacting in the BDX detector



- FLUKA to generate and propagate ν (1.5x ν flux obtained by G4)
- FLUKA NUNDIS/NUNRES to simulate ν interaction with CsI(Tl) BDX crystals
- G4 to simulate the detector response to ν-CsI(Tl) interaction products

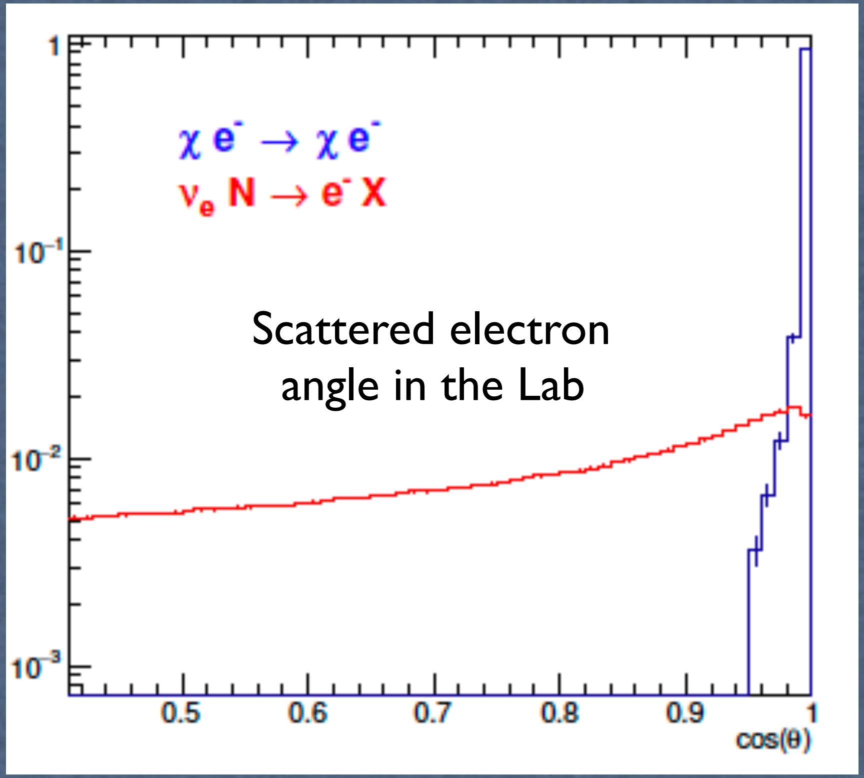
NC $\nu_\mu + N \rightarrow \nu_\mu\, X$: all rejected by the det. threshold (limited energy transfer to N)
$\nu_e + N \rightarrow \nu_e\, X$: all rejected by the det. threshold (limited energy transfer to N)

CC $\nu_\mu + N \rightarrow X + \mu$: all rejected by identifying the scattered muon
$\nu_{e-} + N \rightarrow X + e^-$: the largest contribution to over-tresh. hits in BDX

Different scattered e⁻ angle for signal and bg:

- $X_{DM} + e^- \rightarrow X_{DM} + e^-$:forward peaked for
- $\nu_{e-} + N \rightarrow X + e^-$:spread over all angles

neutrino BG can be identified and suppressed!



High-stats FLUKA simulations demonstrate:

- ✳ BDX only limited by the ν *irreducible* bg
- ✳ Expected beam-related bg counts ~5 events

BDX expected reach

Beam time request

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

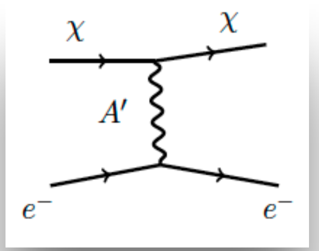
Beam-related background

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

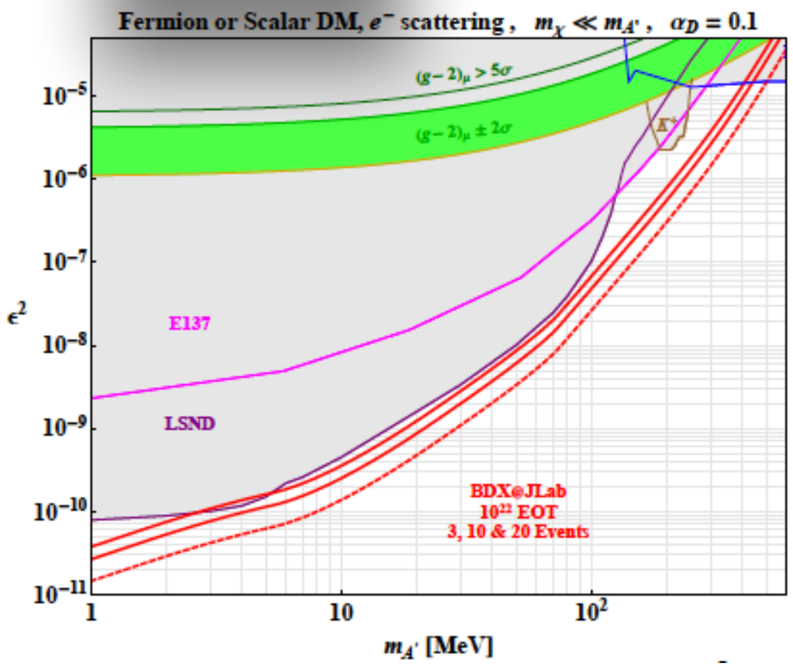
Cosmic background

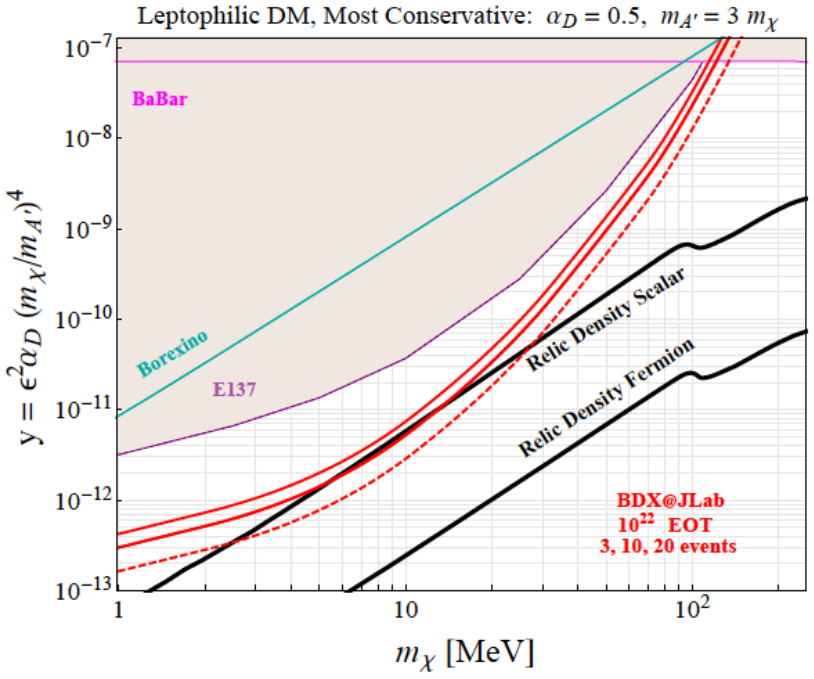
Energy threshold	$\sqrt{Bg}$ (285 days)
300 MeV	<2 counts

BDX sensitivity is 10-100 times better than existing limits on LDM

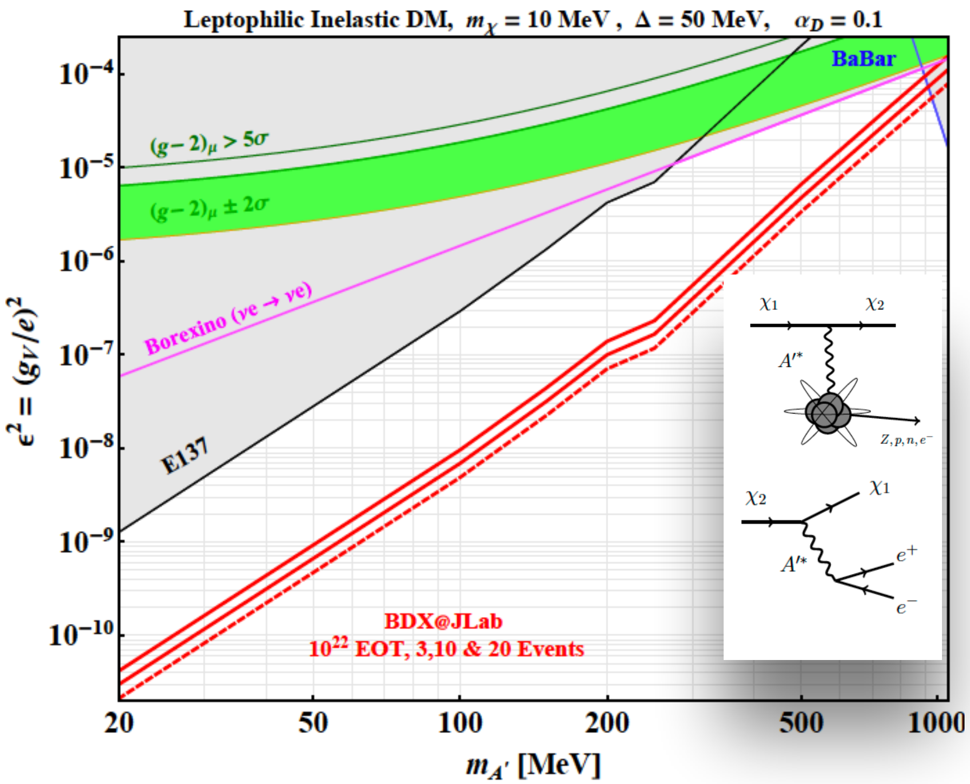


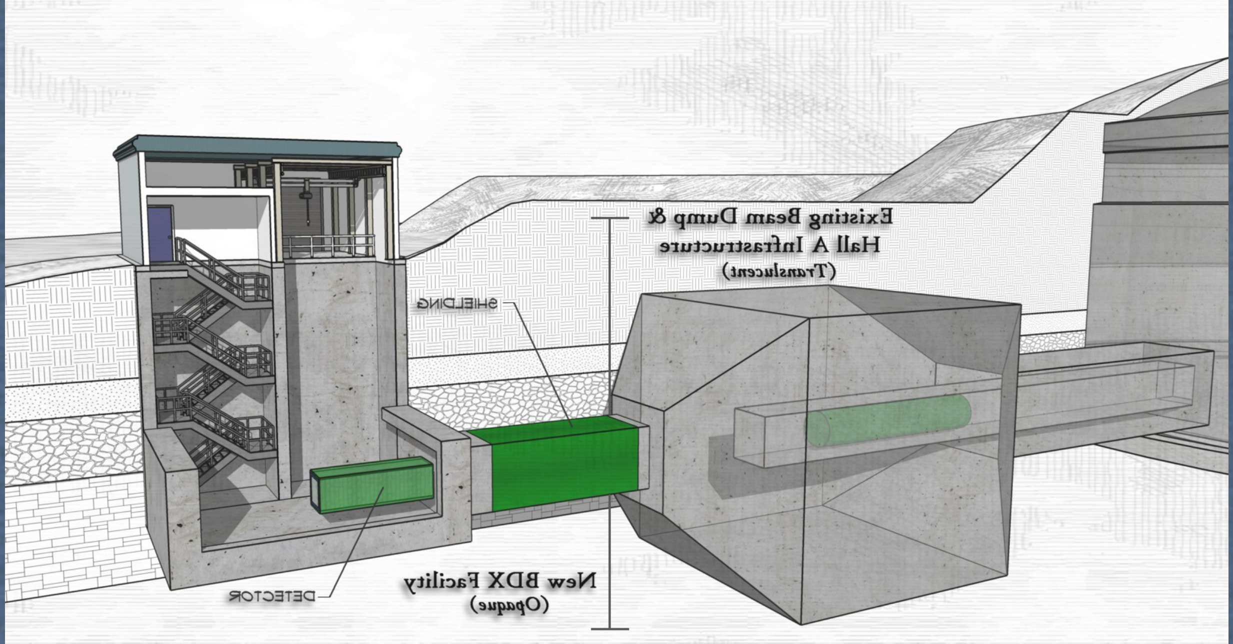
Elastic X-e- scattering - BDX reach


Fermion or Scalar DM, e^- scattering, $m_\chi \ll m_{A'}$, $\alpha_D = 0.1$


Leptophilic DM, Most Conservative: $\alpha_D = 0.5$, $m_{A'} = 3\,m_\chi$

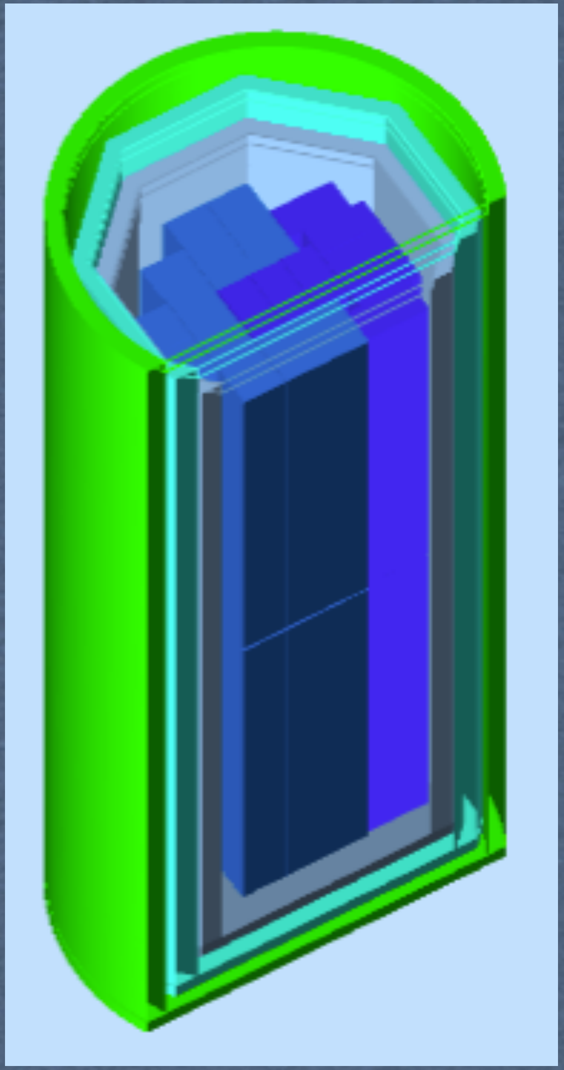
Inelastic X-N scattering

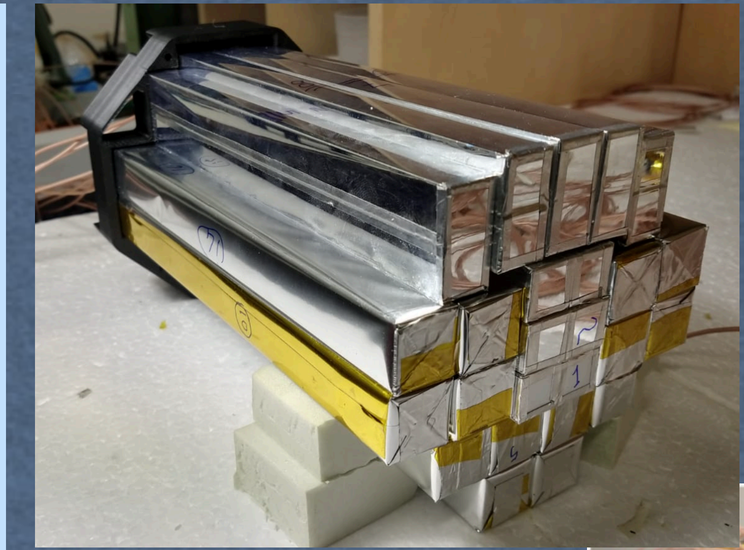

Leptophilic Inelastic DM, $m_\chi = 10$ MeV, $\Delta = 50$ MeV, $\alpha_D = 0.1$



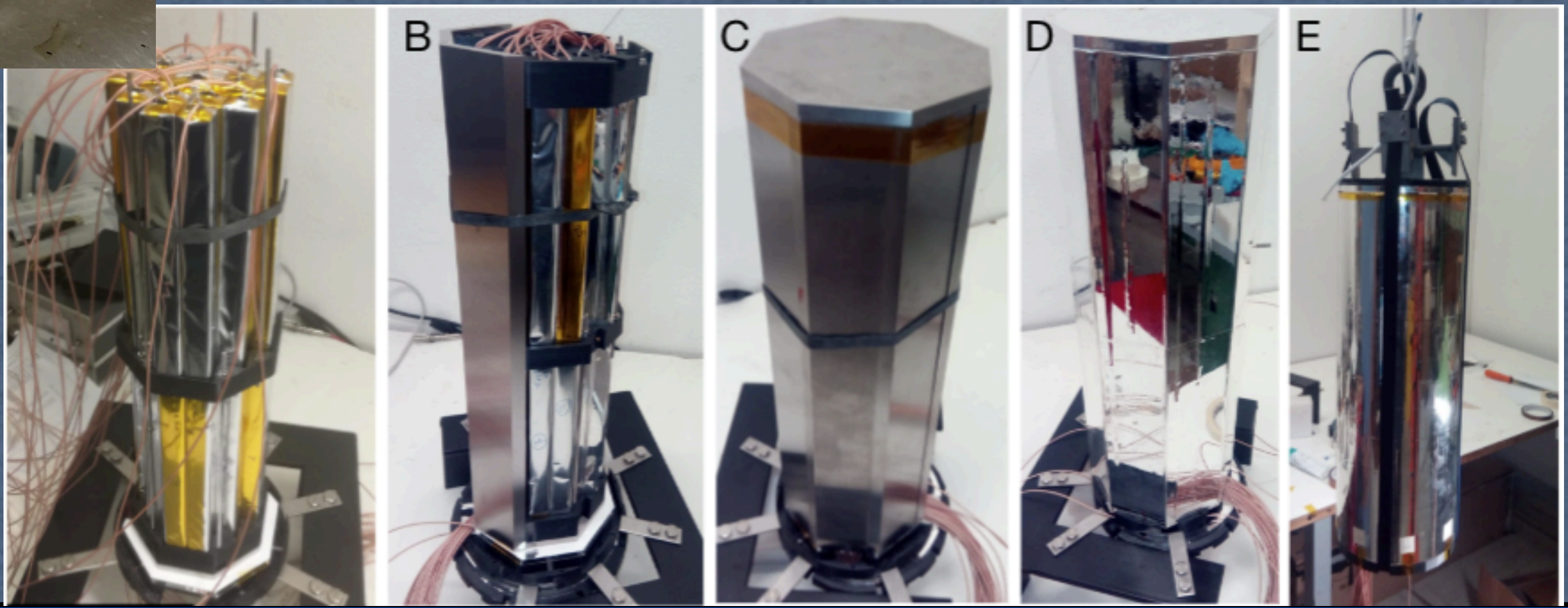
BDX-MINI

- While waiting for the new BDX experimental hall …
- Take advantage of two wells dug for muon tests
- E_{beam}=2.2 GeV, 5x10^{21} EOT expected for 2019/20, no muons at well locations
- Opportunistic measurement to test BDX experiment in real conditions (cosmic/acc bg, data analysis)
- limited reach but first BDX@JLAB result!



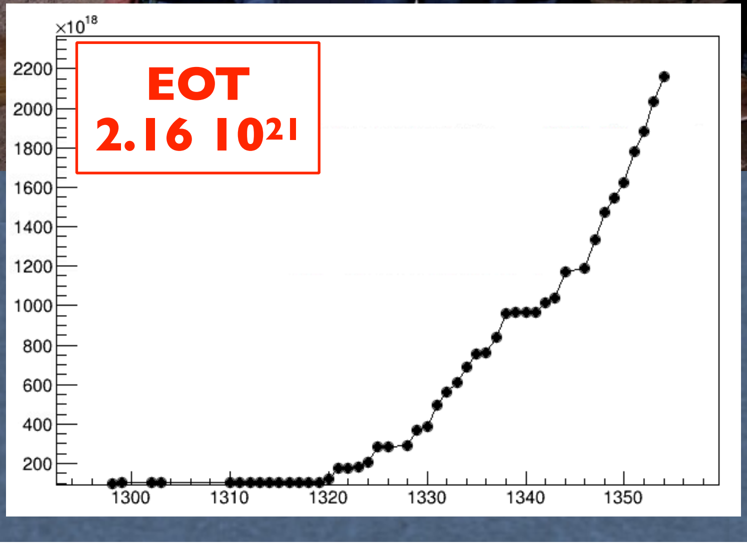


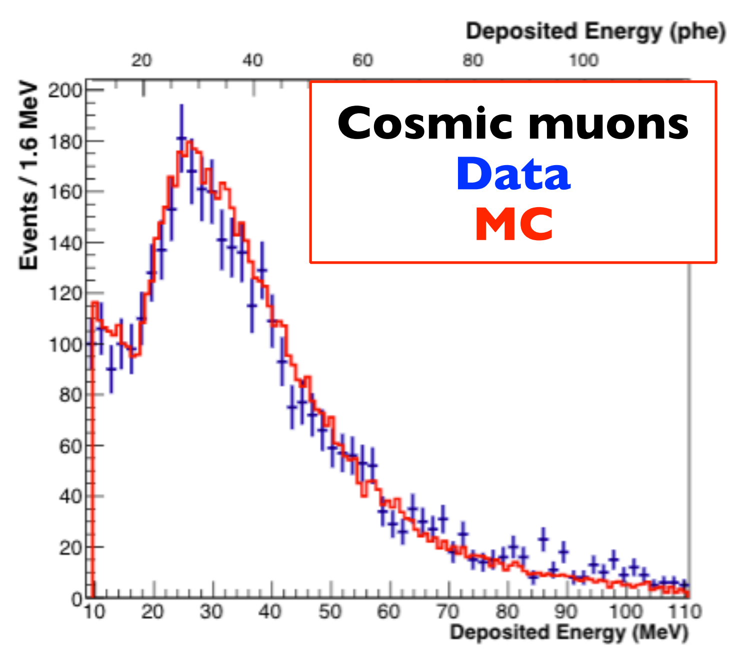
- Same technology proposed for BDX
- BDX-MINI fits in BDX-HODO vessel
- 44 PbWO4 PANDA/FT-Cal crystals (~1% BDX active volume)
- 6x6 mm2 SiPM readout
- 2 active plastic scintillator vetos: cylindrical and octagonal (8 sipm each) + 2x lids
- Passive W shielding

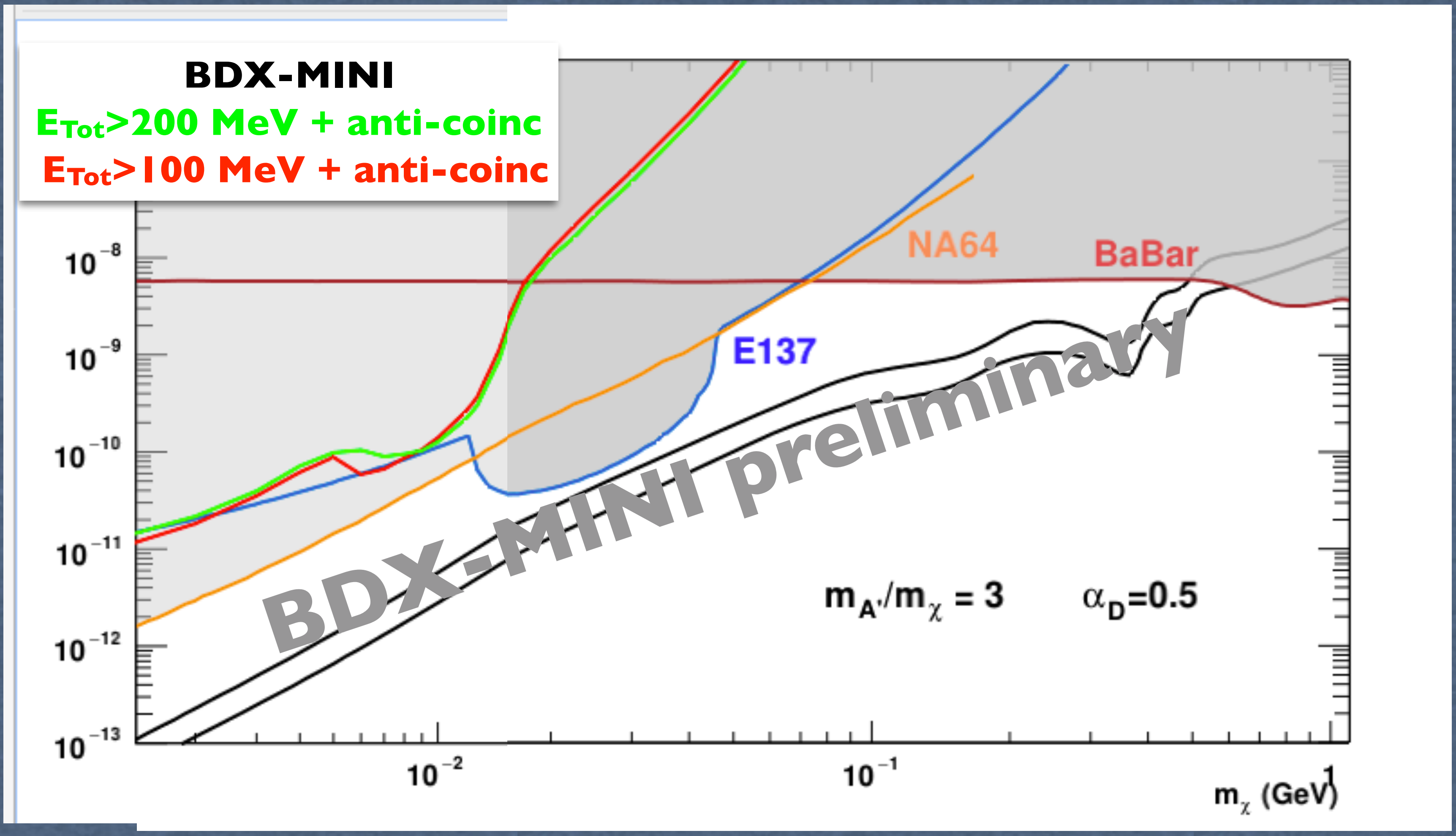


BDX-MINI

- Installed in March 2019
- Run started in Dec 2019
- Collected 2e21 EOT (20% BDX!) in ~4 months
- Collected an equivalent time of cosmic
- Good detector performance with high duty factor
- Data analysis in progress
- First physics results!
- Same sensitivity of E137!!

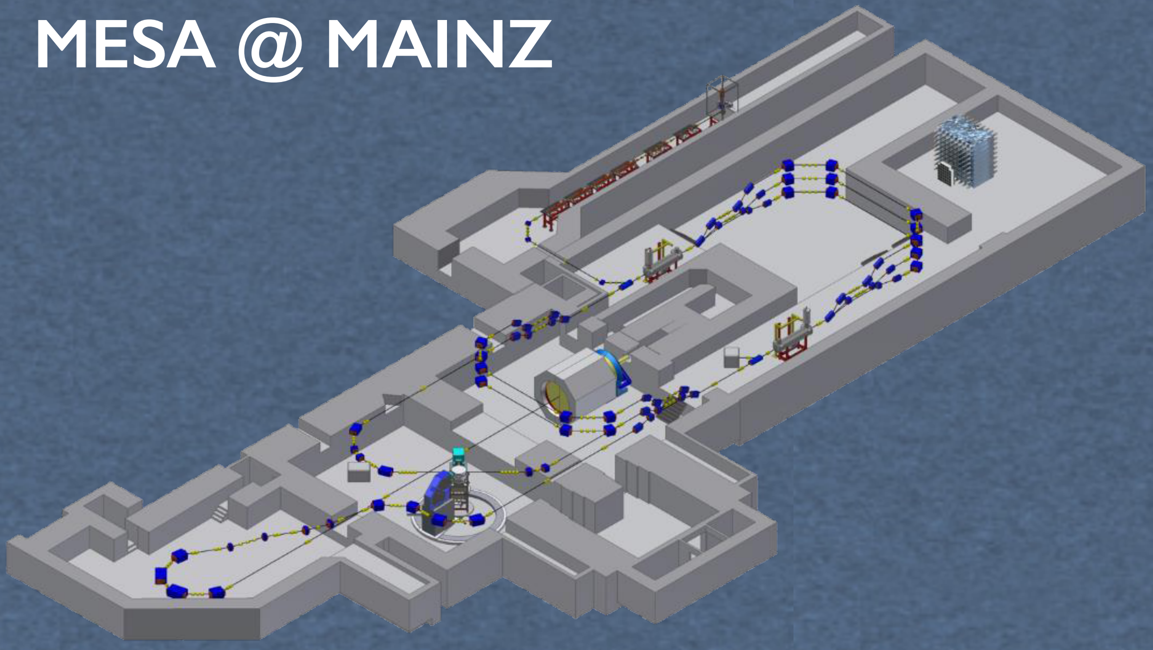


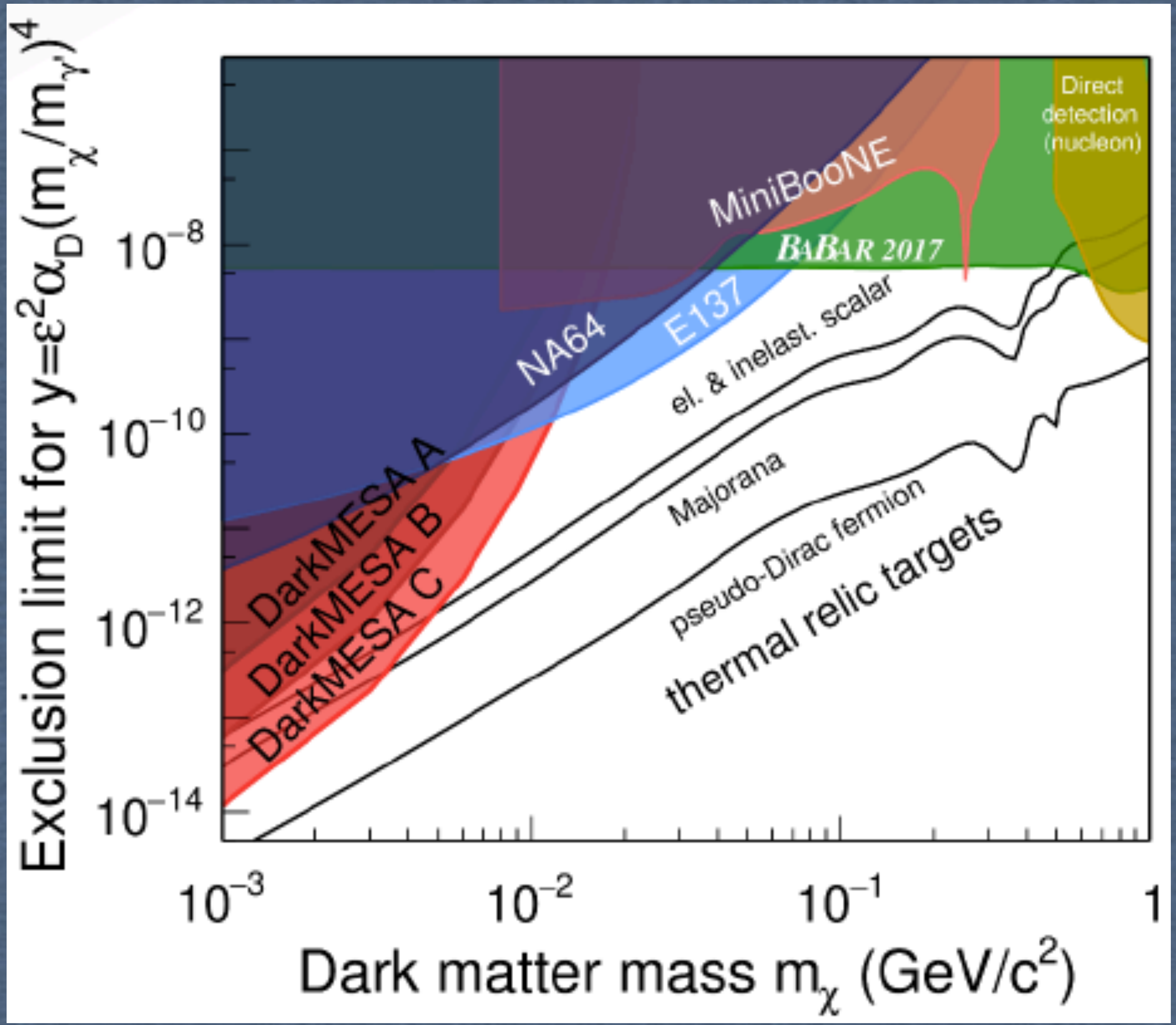


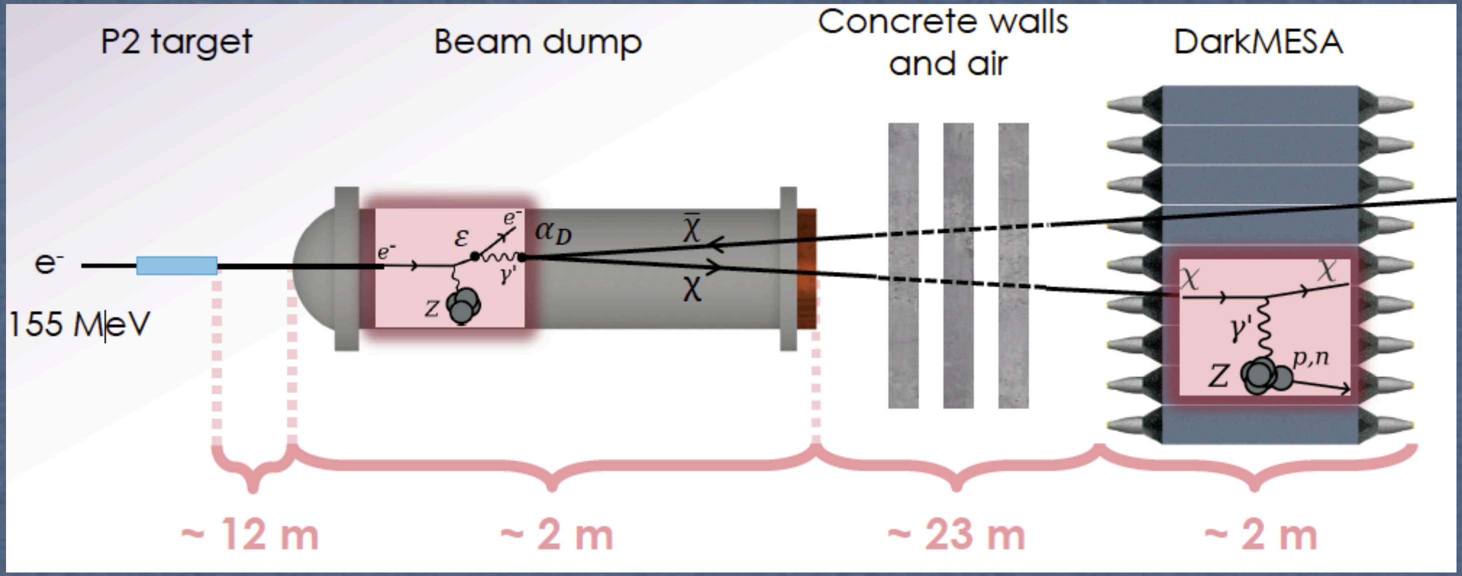


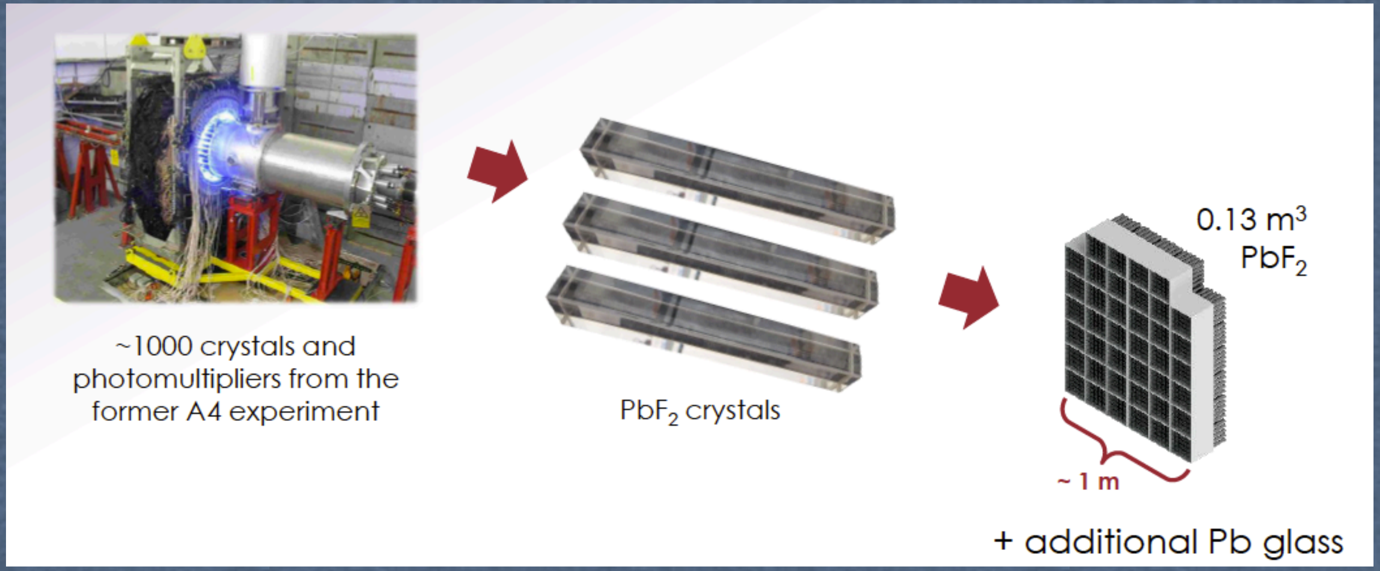
BeamDump@MAINZ DARKMESA

MESA @ MAINZ



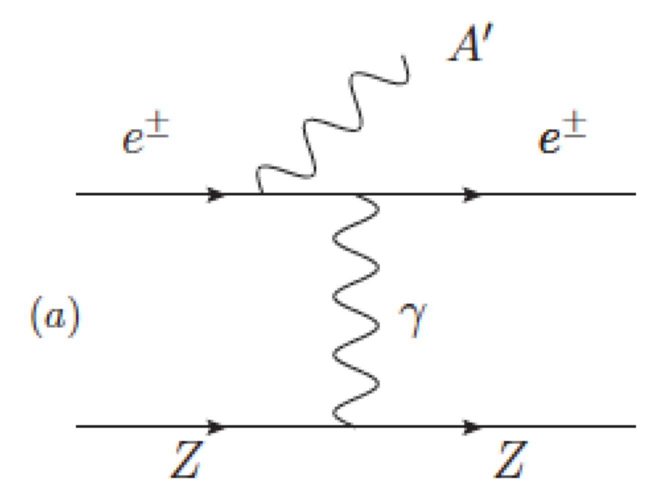






- αD=0.5and $m\gamma'=3\cdot m\chi$
- $3\cdot10^{22}$ EOT
- Energy detection threshold 14 MeV
- Detector efficiency 90%
- No backgrounds

A’ Production mechanisms - e±



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

$$\sigma \approx \frac{8}{3}\frac{\alpha^3\epsilon^2\beta_{A'}}{m_{A'}^2}\chi\log\left(\frac{1}{(1-x)_c}\right),$$

$$(1-x)_c = \max\left(\frac{m_e^2}{m_{A'}^2}, \frac{m_{A'}^2}{E_0^2}\right).$$

- **t min/max energy**
- **G el/in FF**

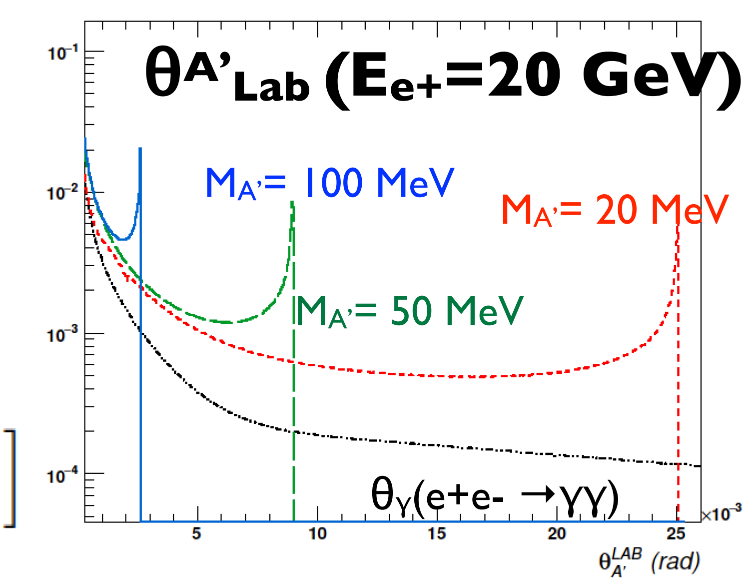
$$\chi \equiv \int_{t_{\min}}^{t_{\max}} dt \frac{t - t_{\min}}{t^2} G_2(t).$$

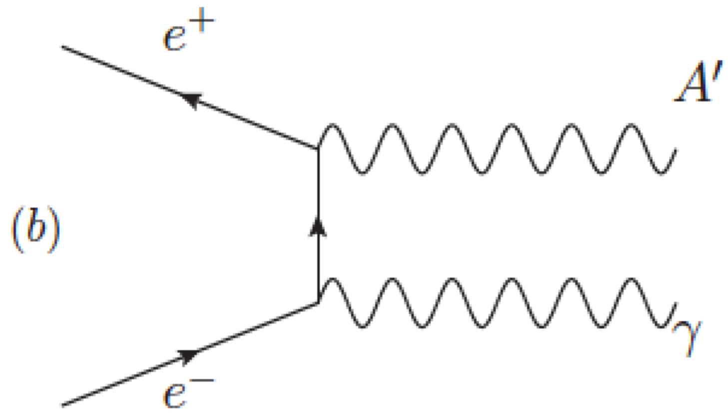
$$G_{2,el}(t) = \left(\frac{a^2 t}{1 + a^2 t}\right)^2 \left(\frac{1}{1 + t/d}\right)^2 Z^2$$

$$G_{2,in}(t) = \left(\frac{a'^2 t}{1 + a'^2 t}\right)^2 \left(\frac{1 + \frac{t}{4m_p^2}(\mu_p^2 - 1)}{(1 + \frac{t}{0.71\,\mathrm{GeV}^2})^4}\right)^2 Z$$

- A more rigorous treatment has been proposed in Phys.Rev. D95 036010 (Yu-Sheng Liu, David McKeen, and Gerald A. Miller) to overcome the WW approximation, the simplification in PS calculation and other approximations

A' Production - positrons

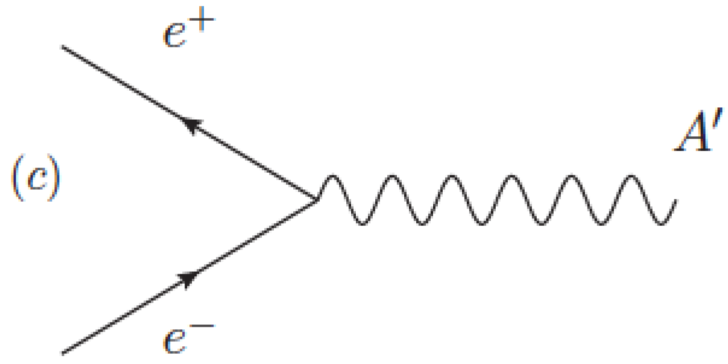




- **NON-RESONANT annihilation** ~ $\varepsilon^2\,\alpha^2$

$$\sigma_{nr} = \frac{8\pi\alpha^2\varepsilon^2}{s}\left[\left(\frac{s-m_{A'}^2}{2s}+\frac{m_{A'}^2}{s-m_{A'}^2}\right)\log\frac{s}{m_e^2}-\frac{s-m_{A'}^2}{2s}\right]$$

- **A' along (e^+e^-) direction**

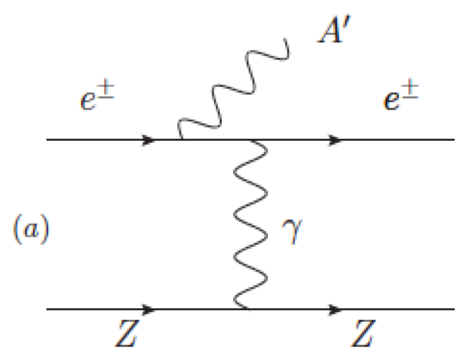


- **RESONANT annihilation** ~ $\varepsilon^2\,\alpha$

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

$$\Gamma_{A'} = \tfrac{1}{3}m_{A'}\varepsilon^2\alpha \qquad \sigma_{\rm peak} = 12\pi/m_{A'}^2$$

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

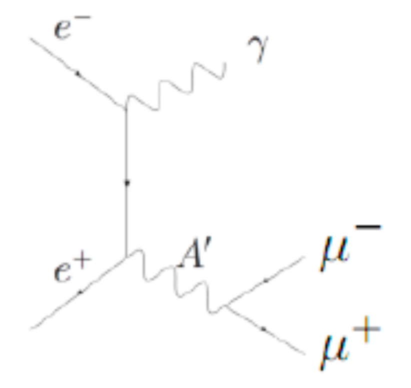


~ $\varepsilon^2\,\alpha^3$

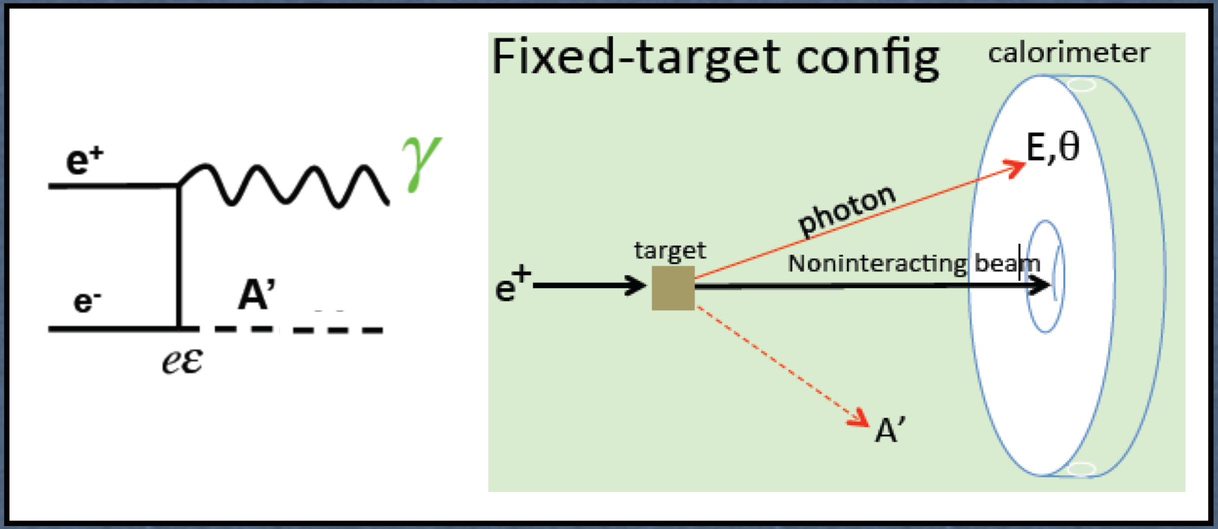
- Known and used
- Collider (missing mass experiments)
- Thin target experiments (visible decay)

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

→ BABAR, BELLE, KLOE, CLEO



e^+ annihilation on fixed (thin) target - invisible -



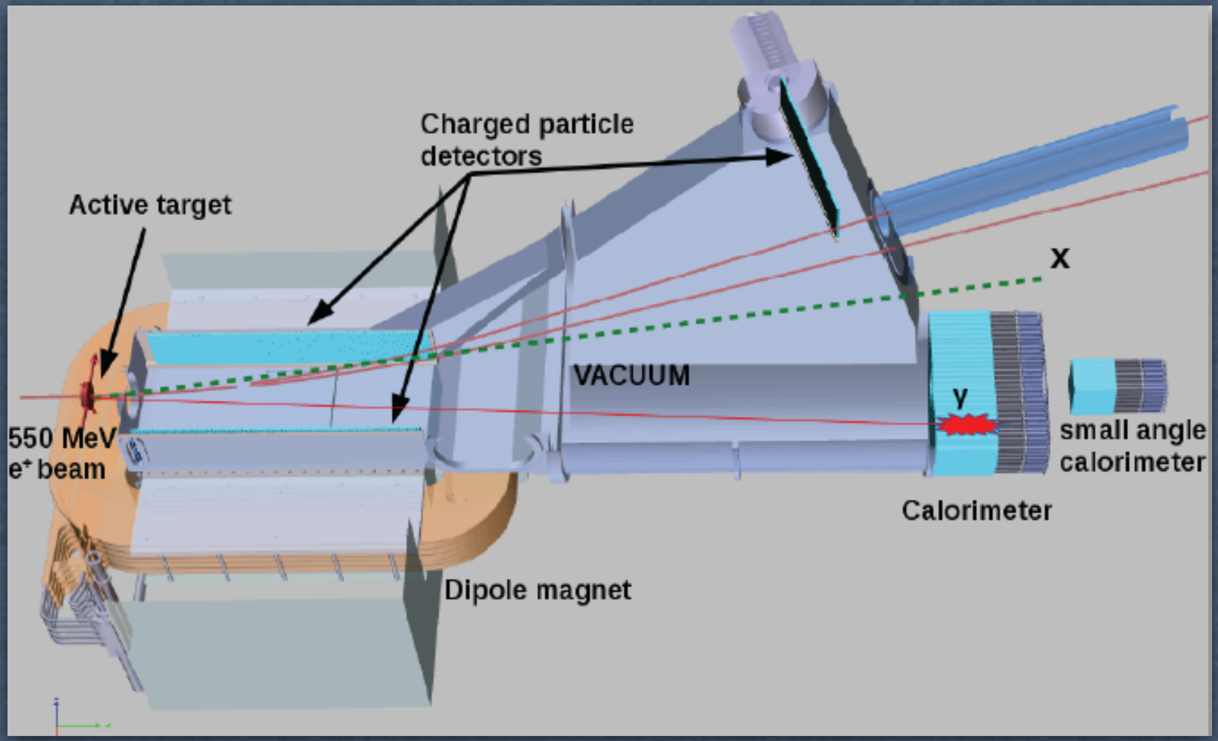
Missing mass search:

- Independent of A' decay mechanism
- Bump hunt (monophoton@collider)

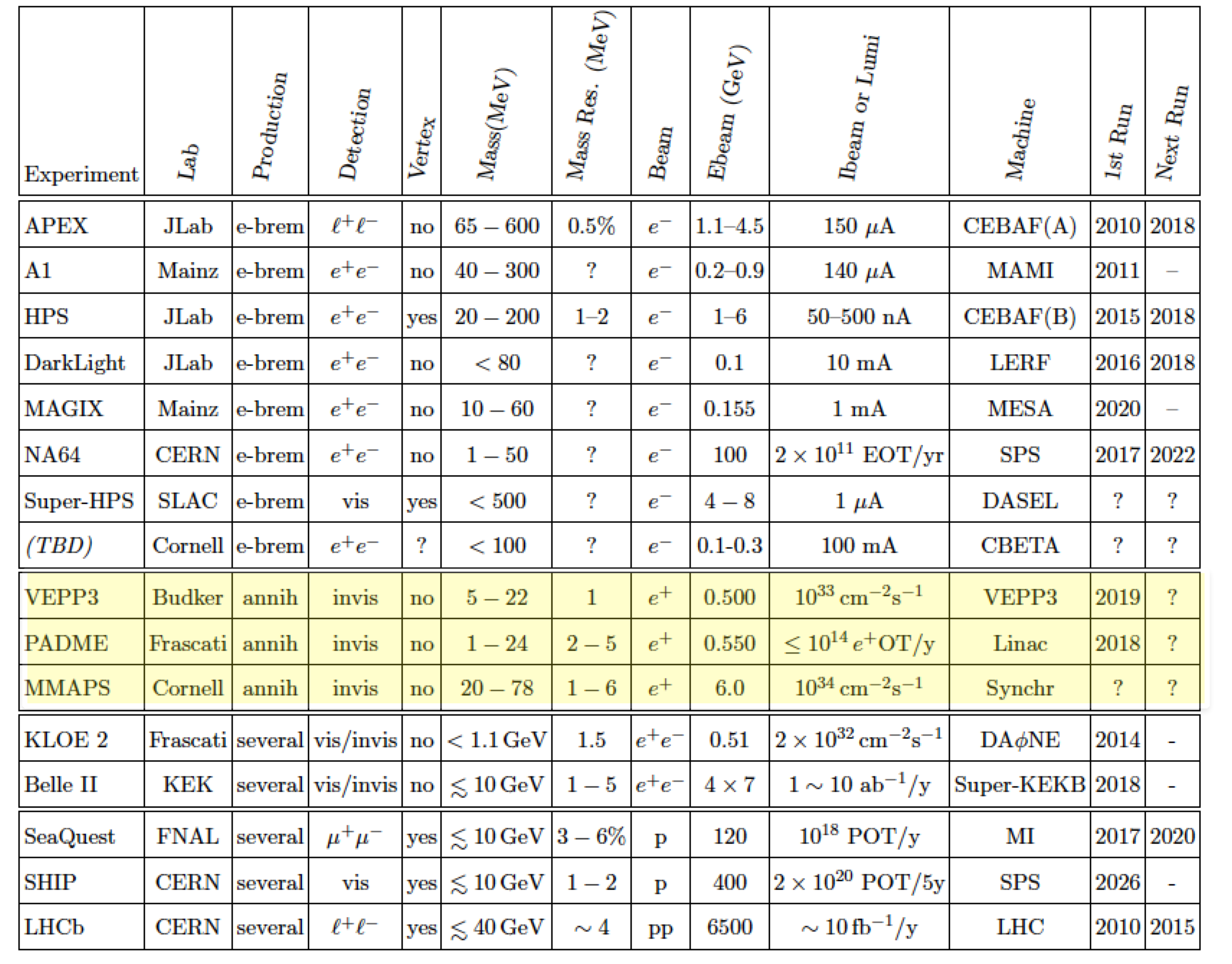
- Need a positron beam
- Limited $M_{A'}$ accessible
  - 1 GeV beam: $M_{A'} < 31$ MeV
  - 5 GeV beam: $M_{A'} < 71$ MeV

PADME@LNF

- **Beam**: e+ form LNF LINAC, 550MeV, multiplicity ~ 20k e+/bunch, bunch duration 250 ns, frequency 49 Hz.
- Diamond active **target** 100 μm thickness: position, size and intensity of incoming beam
- Dipole **magnet** of 0.45 T to deflect charged particles out calorimeter
- Plastic scintillators **veto** system + high energy positron veto in order to detect charged particles bent by magnet
- Electromagnetic calorimeter (**ECAL**) composed of 616 BGO crystals
- Small angle calorimeter **(SAC**) composed of 25 PbF2 crystals
- Already collected 5 10^{12} POT (expected 10^{13} POT)



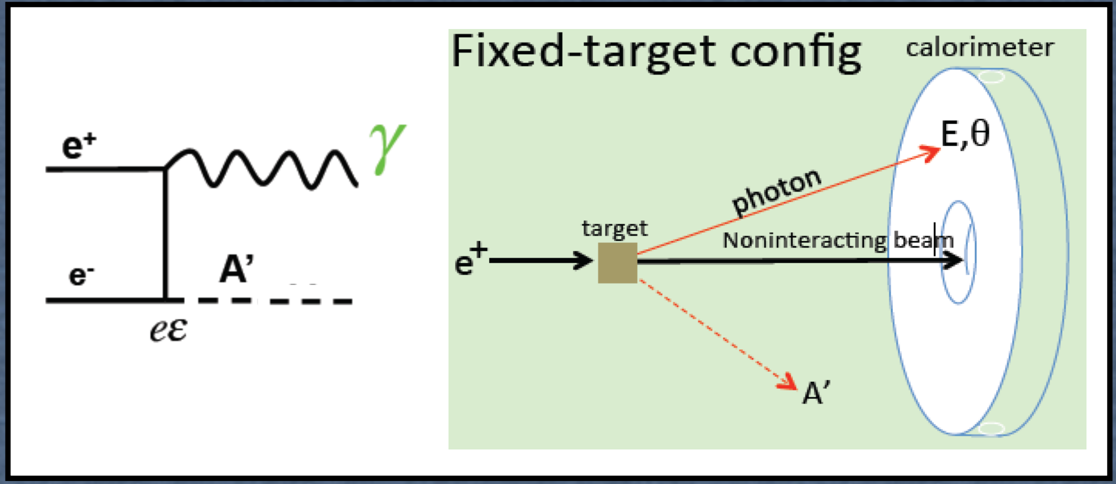
Positrons in light DM searches



Experiment	Lab	Production	Detection	Vertex	Mass(MeV)	Mass Res. (MeV)	Beam	Ebeam (GeV)	Ibeam or Lumi	Machine	1st Run	Next Run
APEX	JLab	e-brem	$\ell^+\ell^-$	no	$65 - 600$	0.5%	e^-	1.1–4.5	$150\ \mu$A	CEBAF(A)	2010	2018
A1	Mainz	e-brem	e^+e^-	no	$40 - 300$	?	e^-	0.2–0.9	$140\ \mu$A	MAMI	2011	–
HPS	JLab	e-brem	e^+e^-	yes	$20 - 200$	1–2	e^-	1–6	50–500 nA	CEBAF(B)	2015	2018
DarkLight	JLab	e-brem	e^+e^-	no	< 80	?	e^-	0.1	10 mA	LERF	2016	2018
MAGIX	Mainz	e-brem	e^+e^-	no	$10 - 60$	?	e^-	0.155	1 mA	MESA	2020	–
NA64	CERN	e-brem	e^+e^-	no	$1 - 50$	?	e^-	100	2×10^{11} EOT/yr	SPS	2017	2022
Super-HPS	SLAC	e-brem	vis	yes	< 500	?	e^-	$4 - 8$	$1\ \mu$A	DASEL	?	?
(TBD)	Cornell	e-brem	e^+e^-	?	< 100	?	e^-	0.1-0.3	100 mA	CBETA	?	?
VEPP3	Budker	annih	invis	no	$5 - 22$	1	e^+	0.500	$10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	VEPP3	2019	?
PADME	Frascati	annih	invis	no	$1 - 24$	$2 - 5$	e^+	0.550	$\leq 10^{14}\ e^+$OT/y	Linac	2018	?
MMAPS	Cornell	annih	invis	no	$20 - 78$	$1 - 6$	e^+	6.0	$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	Synchr	?	?
KLOE 2	Frascati	several	vis/invis	no	< 1.1 GeV	1.5	e^+e^-	0.51	$2 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	DAϕNE	2014	-
Belle II	KEK	several	vis/invis	no	$\lesssim 10$ GeV	$1 - 5$	e^+e^-	4×7	$1 \sim 10\ \mathrm{ab}^{-1}$/y	Super-KEKB	2018	-
SeaQuest	FNAL	several	$\mu^+\mu^-$	yes	$\lesssim 10$ GeV	$3 - 6\%$	p	120	10^{18} POT/y	MI	2017	2020
SHIP	CERN	several	vis	yes	$\lesssim 10$ GeV	$1 - 2$	p	400	2×10^{20} POT/5y	SPS	2026	-
LHCb	CERN	several	$\ell^+\ell^-$	yes	$\lesssim 40$ GeV	~ 4	pp	6500	$\sim 10\ \mathrm{fb}^{-1}$/y	LHC	2010	2015

arXiv:1608.08632v1 [hep-ph] 30 Aug 2016

e^+ annihilation on fixed (thin) target - invisible -

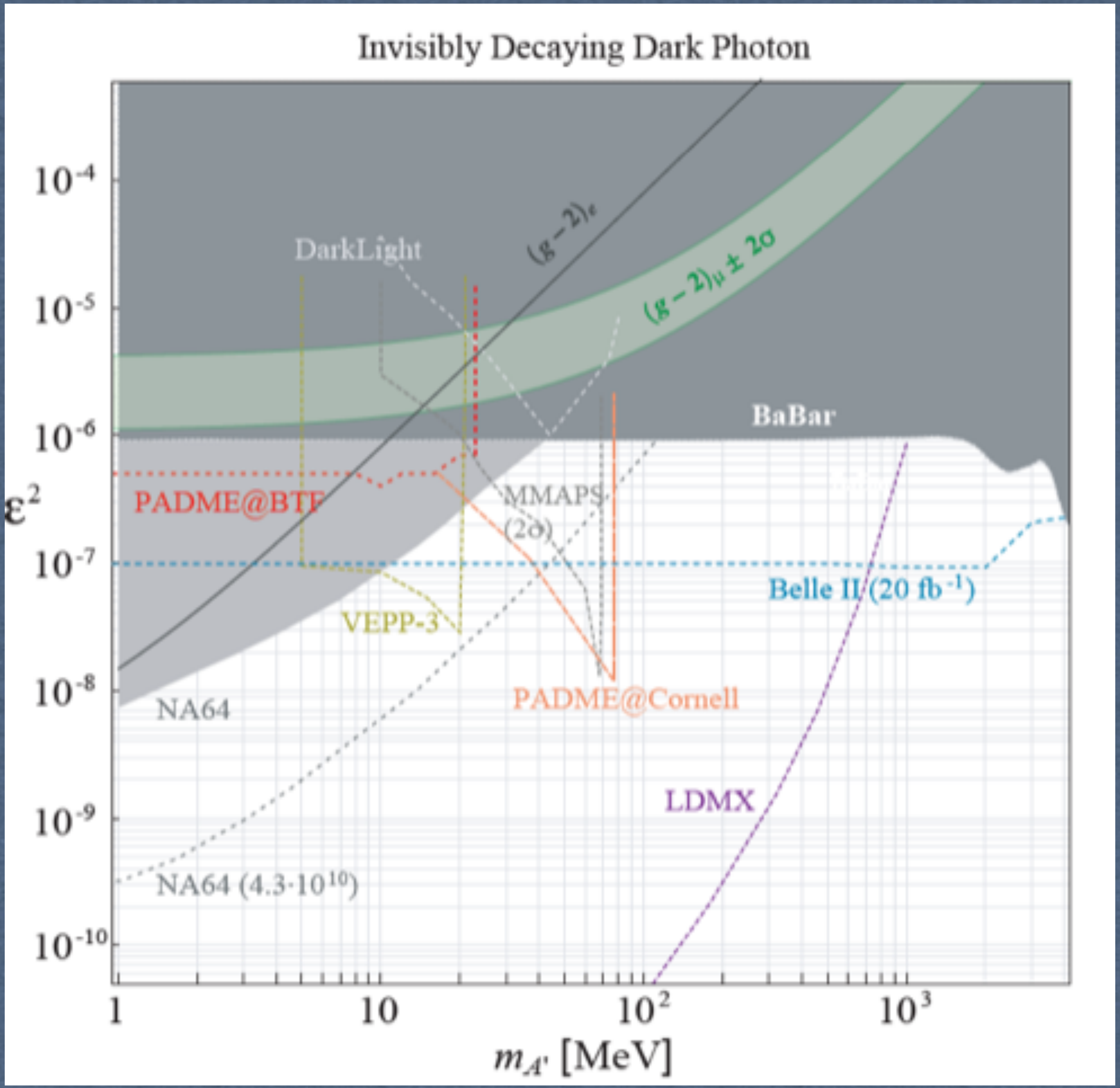


VEPP3
- E_{e+} = 500 MeV
- EOT ~ 10^{15} - 10^{16} year^{-1}

LNF
- E_{e+} = 550 MeV
- EOT ~ 10^{13} - 10^{14} year^{-1}

Cornell
- E_{e-} = 5.3 GeV
- EOT ~ 10^{17} - 10^{18} year^{-1}

JLab (future)



PADME@JLAB

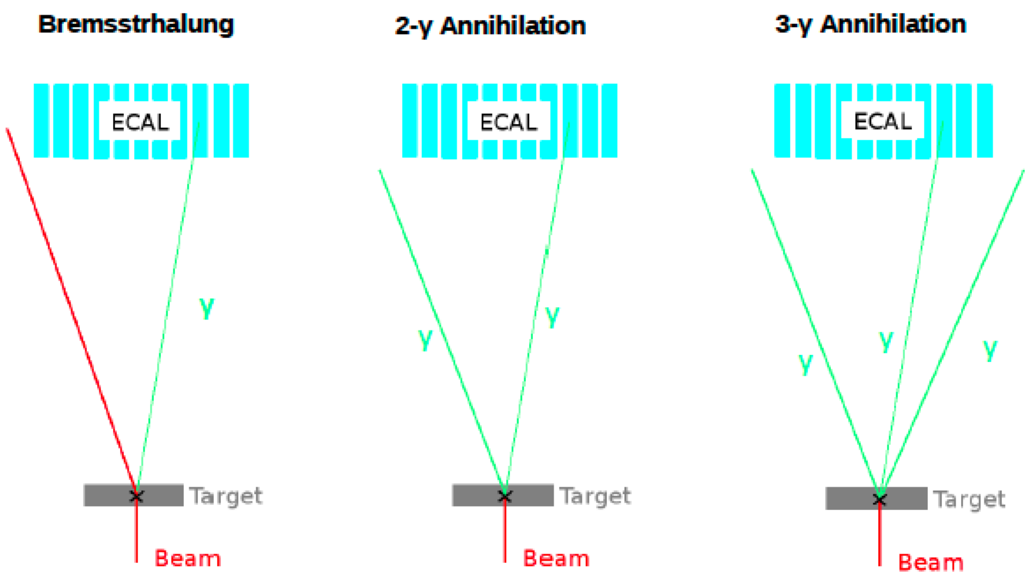
Reusable PADME components:
- Target - PADME carbon target can be installed at CEBAF
- Calorimeter - PADME Ecal meets all requirements of the experiment (energy resolution, angular resolution, size)
- Veto System - technology and front-end electronics from PADME veto can be reused

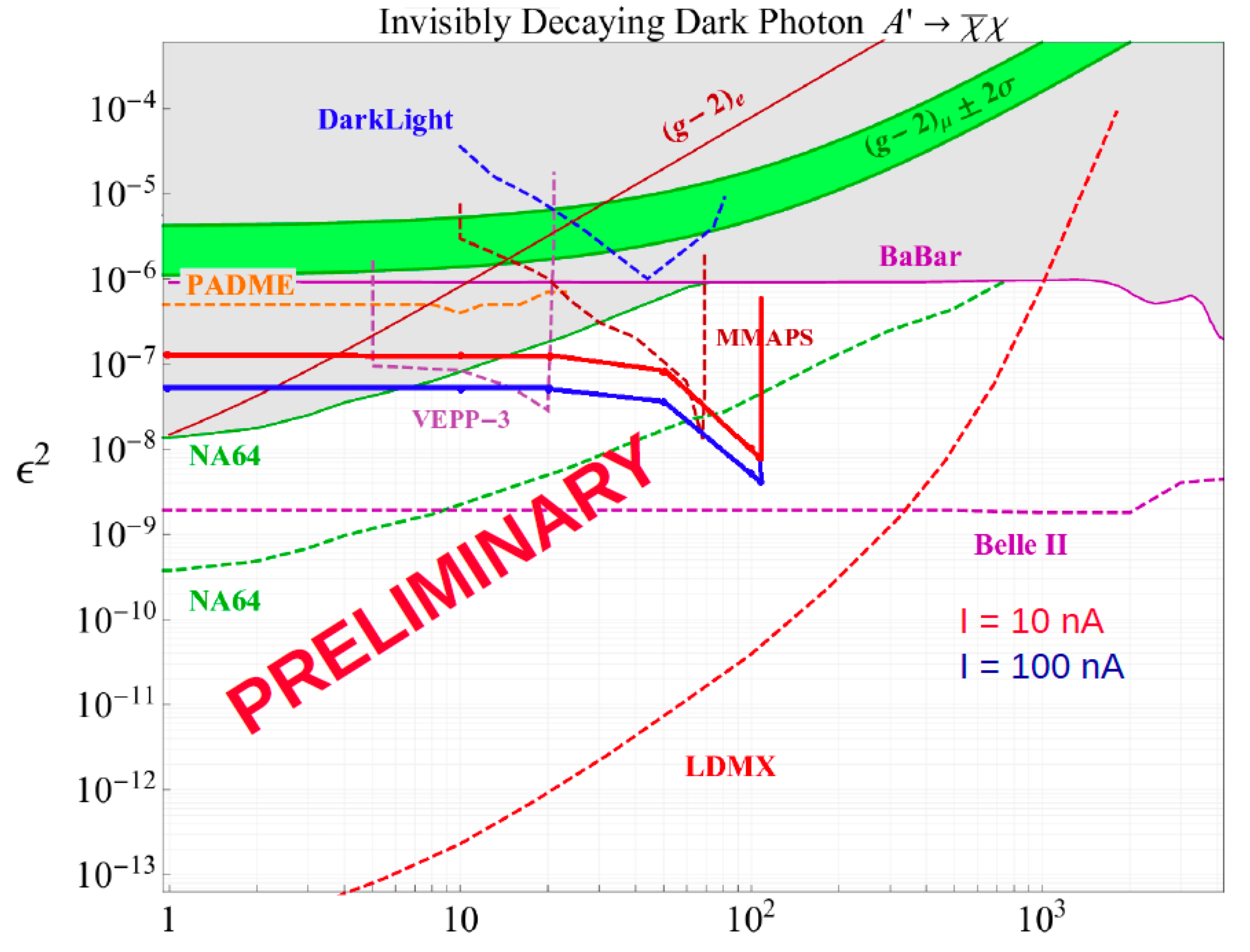
New equipment:
- DAQ system - suitable for a CW beam

- Main limitation: limited energy in the CM ~ sqrt(E_{beam})
- High energy positron beams are not (yet) available
- The highest energy at JLab (~11 GeV) Max $M_{A'}$ ~ 106 MeV

Main Background Processes

Main processes that result in a single gamma hitting the ECal:

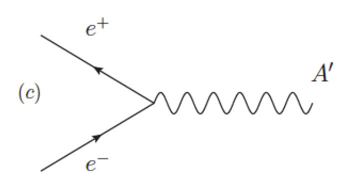




Positrons@beam-dumps

- An electromagnetic shower is a powerful source of positrons!

$$N_{A'} = \frac{N_A}{A} Z\rho \int_{E^R_{min}}^{E_0} dE_e \, T_+(E_e)\, \sigma(E_e) \ ,$$



for RESONANT annihilation and Γ smaller than T_+ variation

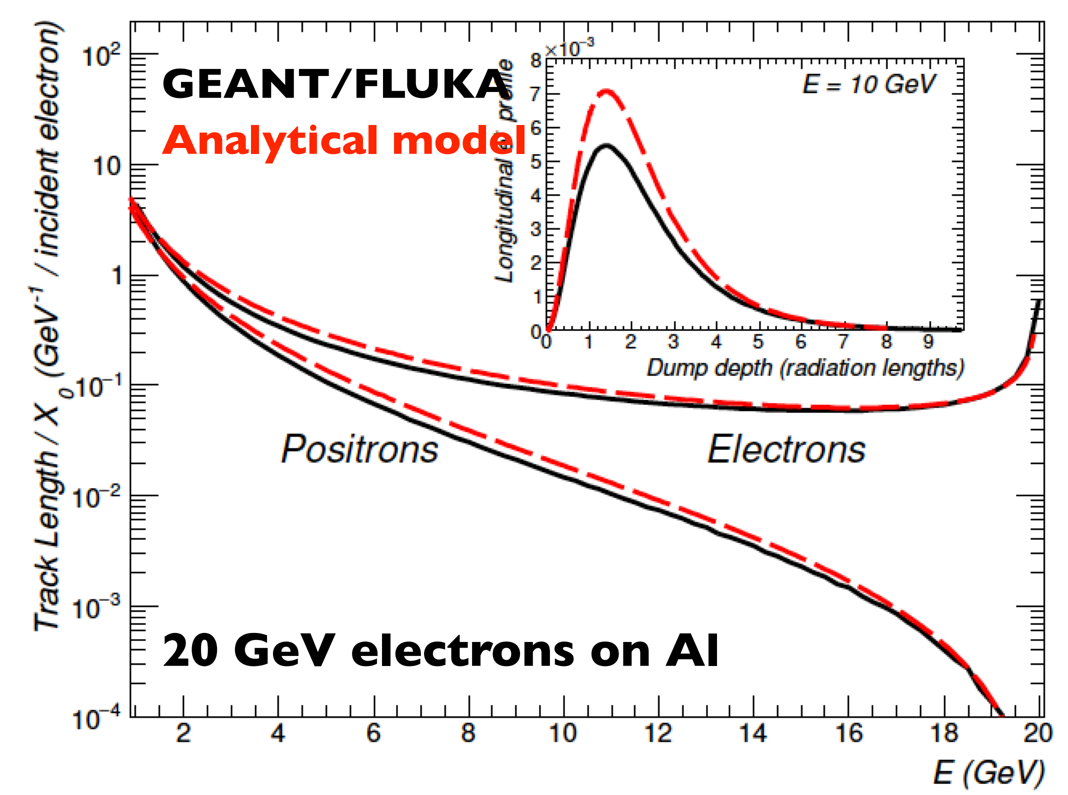
$$N_{A'} \simeq \frac{\pi}{2} \frac{N_A}{A} Z\rho\, \sigma_{\rm peak} \Gamma_{A'} \frac{m_{A'}}{m_e} T_+(E_R)$$

Track-length $T_+(E)$: integral of positron fluence over the beam-dump volume

- density of particles in the volume
- path length of a positron in the BD with energy between E and E+dE
- I^+_e = differential (time and energy) energy distribution (positron current)

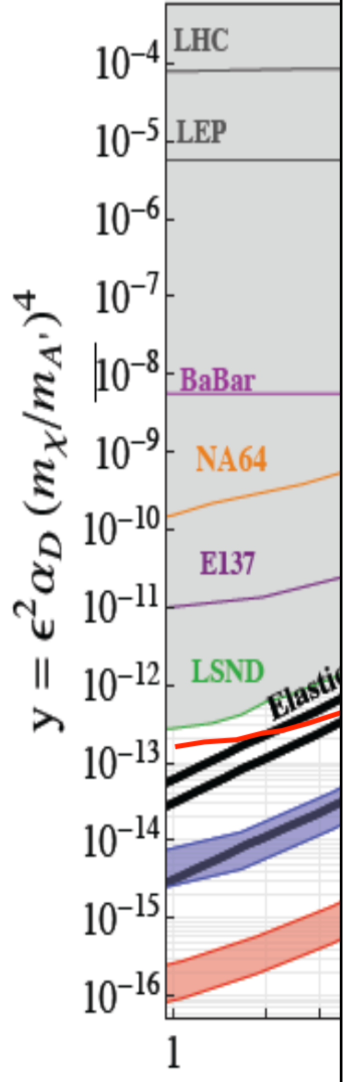
$$T_+(E) = \int_0^{L_{Dump}} I^+_e(E_e, t) dt$$

$T_+(E)$ can be evaluated analytically or by simulations (GEANT4/FLUKA) sampling the shower profile at different depth in the BD

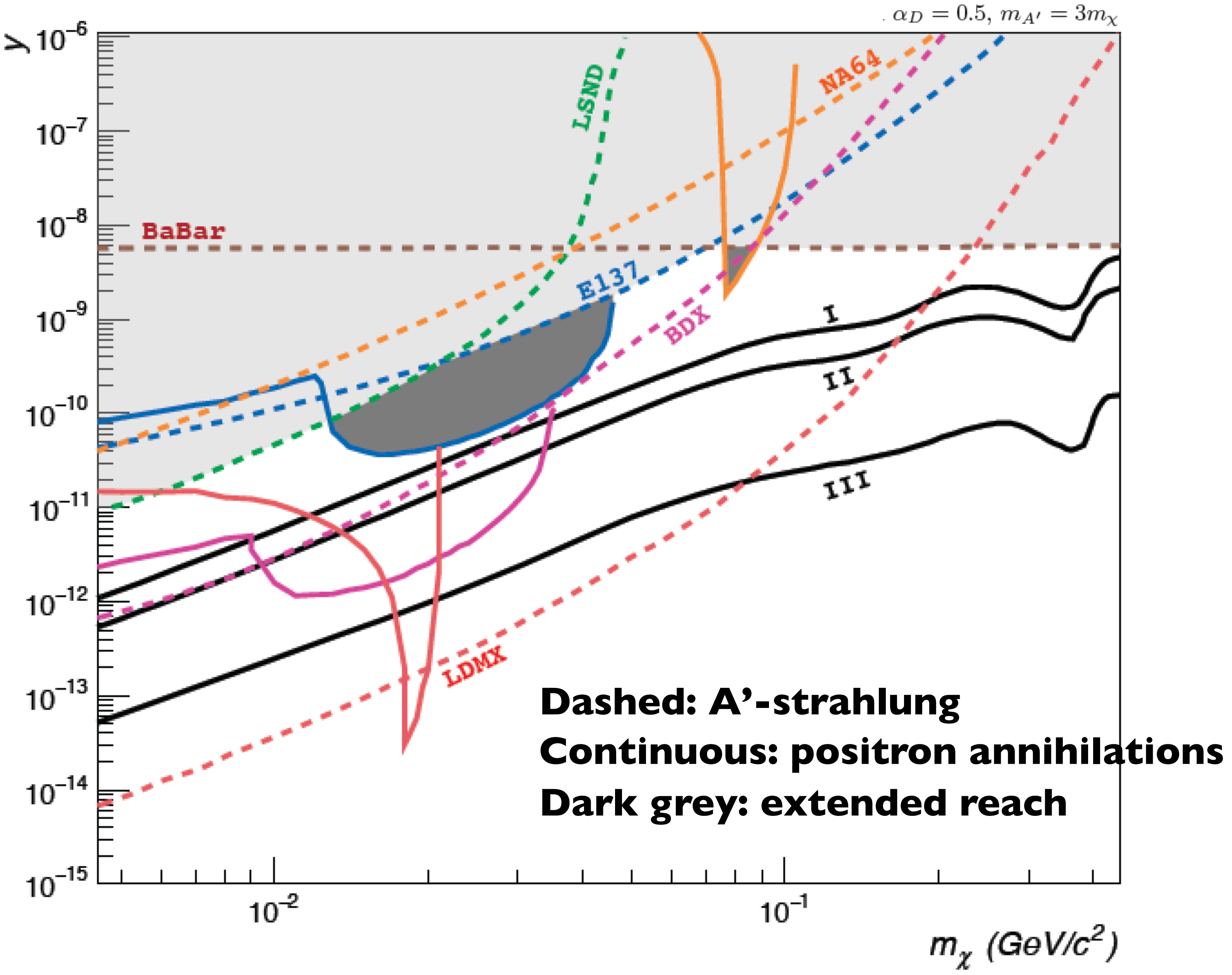


Good agreement (high energy) with analytical calculation by Y. S. Tsai and V. Whitis, Phys. Rev. 149, 1248 (1966)

Effects on current exclusion limits (BD - invisible)

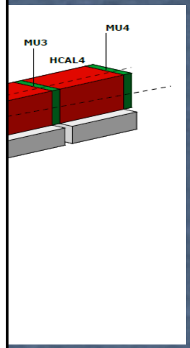


Inclusion of e$^+$ annihilation lowers the exclusion limits by x10 in 20 MeV < $M_{A'}$ <40 MeV



Dashed: A'-strahlung
Continuous: positron annihilations
Dark grey: extended reach

decay search

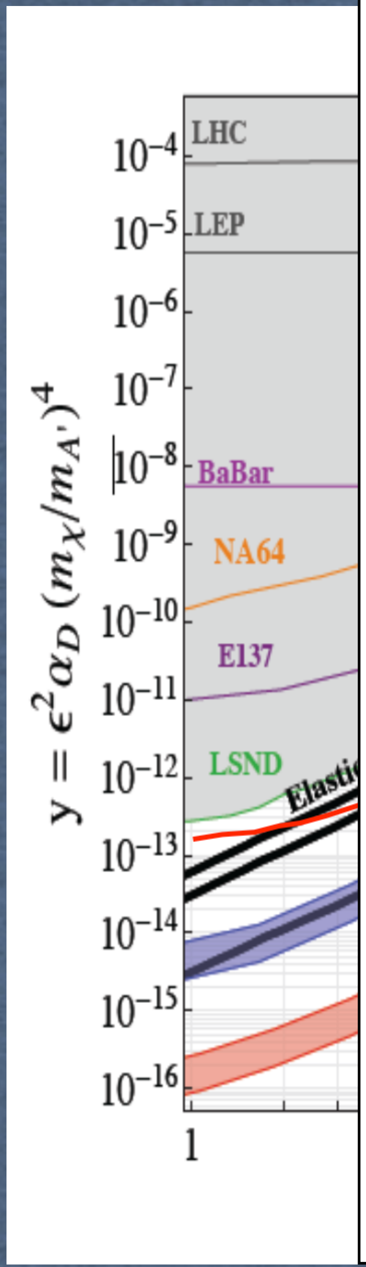


riments

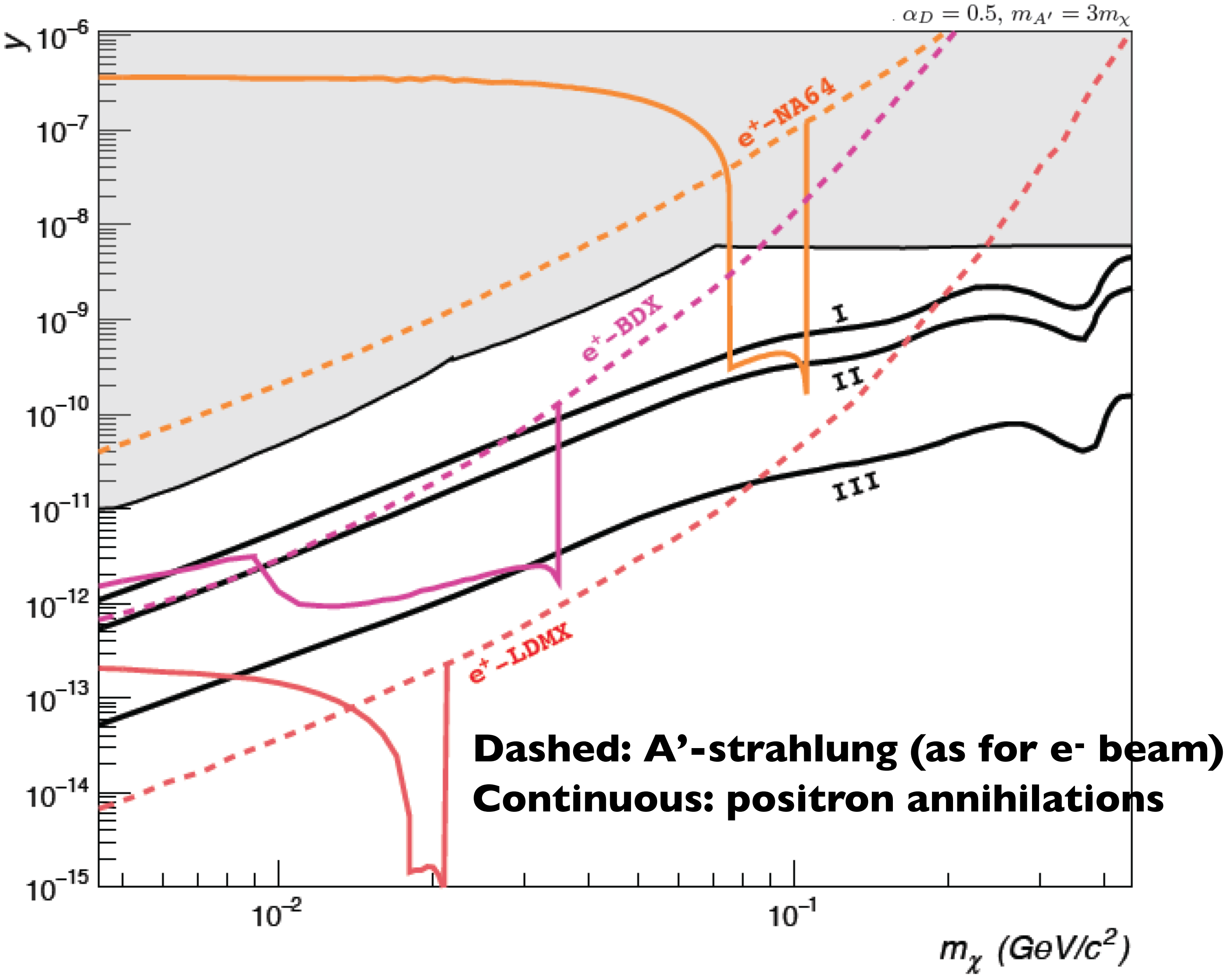
S-II 4 GeV e-

am with 10^{22}

Exclusion limits (BD - invisible)

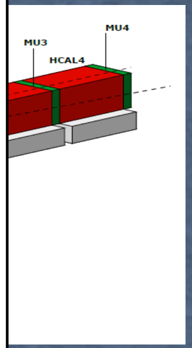


Exclusion limits in case of running the experiments with a positron beam (assuming the same experimental set-up)



Dashed: A'-strahlung (as for e^- beam)
Continuous: positron annihilations

decay search



riments

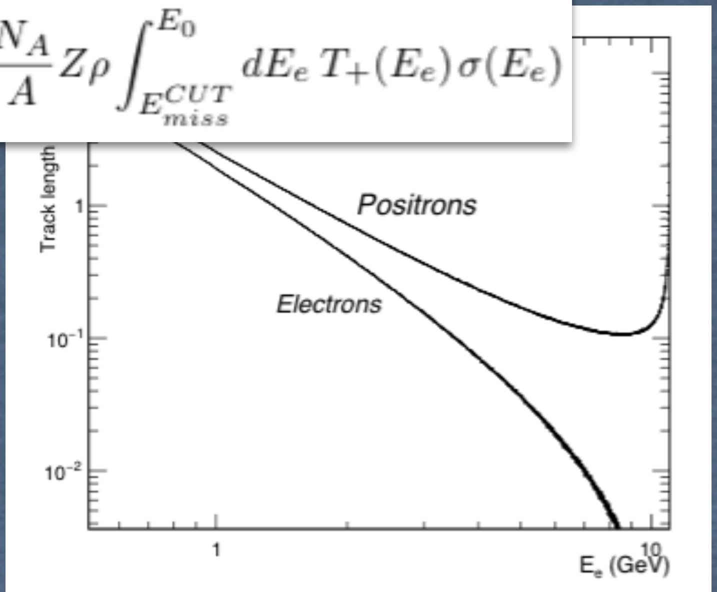
S-II 4 GeV e-

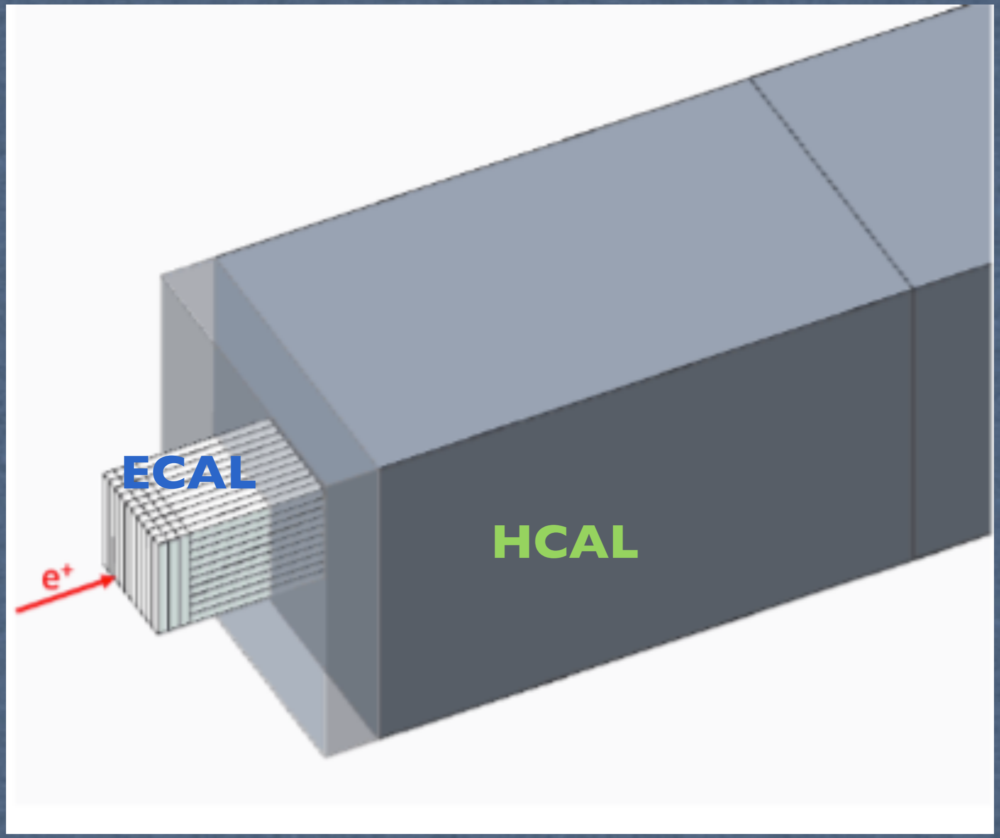
eam with 10^{22}

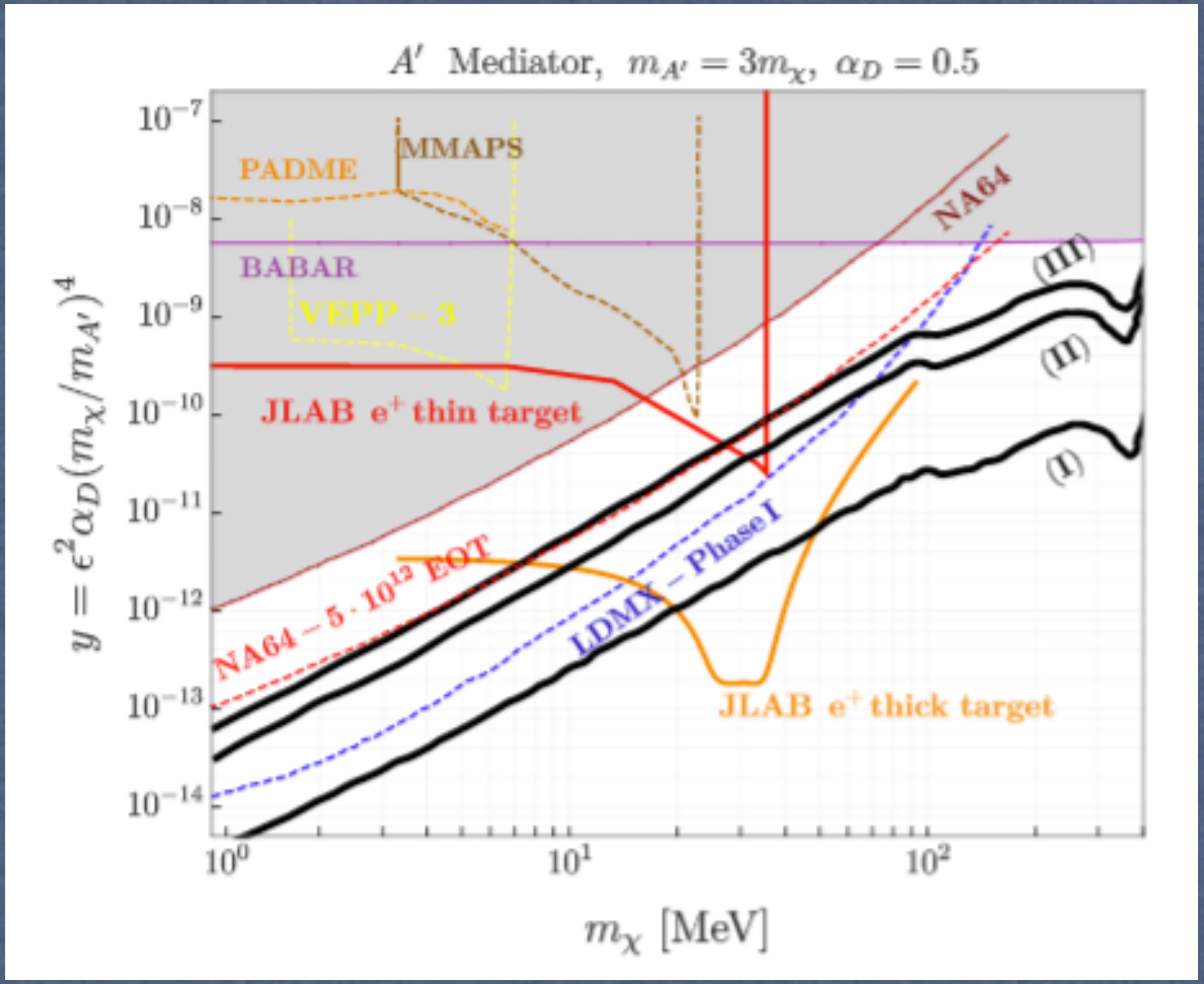
e^+ annihilation on fixed (thick) target - invisible -

- *Active* beam-dump experiment (*á la* NA64 but with positron!)
- Clear signal (peak!) due to the annihilation: $M_{A'} = \mathrm{Sqrt}(2\ m_e\ E_{miss})$
- Missing energy exp (e+ Z → e+ Z' A' with A' → invisible)
- 11 e+ beam, low current, 60 Hz
- Active target (calorimeter)
- Exclusion plots based on 10^{13} POT
- Detector: ECAL to measure e+; HCAL to veto

$$N_s = n_{POT}\frac{N_A}{A}Z\rho\int_{E_{miss}^{CUT}}^{E_0} dE_e\, T_+(E_e)\sigma(E_e)$$







Conclusions

- ✳ Extensive experimental plans at high intensity e-facility: JLab, LNF, Cornell, Mainz, SLAC (and proton beam at FNAL and CERN)
- ✳ Beam-dump experiments provided stringent limits for visible and invisible searches
- ✳BDX: CsI EM calorimeter + 2x activeVetos running parasitically downstream of JLab Hall-A beam dump in 1y would set 10-100 times better limits
- ✳ BDX-MINI validated BDX techique providing the first physics results hitting E137 limits
- ✳ Electron-positron annihilation has been extended from colliders to (thin) fixed target exps
- ✳ PADME is validating the technique and extensions are proposed in other labs
- ✳ Despite the A' narrowness of the straggling makes the resonant annihilation competitive wrt to the *A'-strahlung* in the A' production
- ✳When included, the positron annihilation lower the existing exclusion limits in selected kinematics x2 (x10) in visible invisible-decay experiments
- ✳ A dedicated physics program with a positron beam at JLab on thin and thick targets is under study