New Probes for Physics Beyond the Standard Model
April 9 2012
Santa Barbara

The BDX experiment: light dark matter search at accelerators

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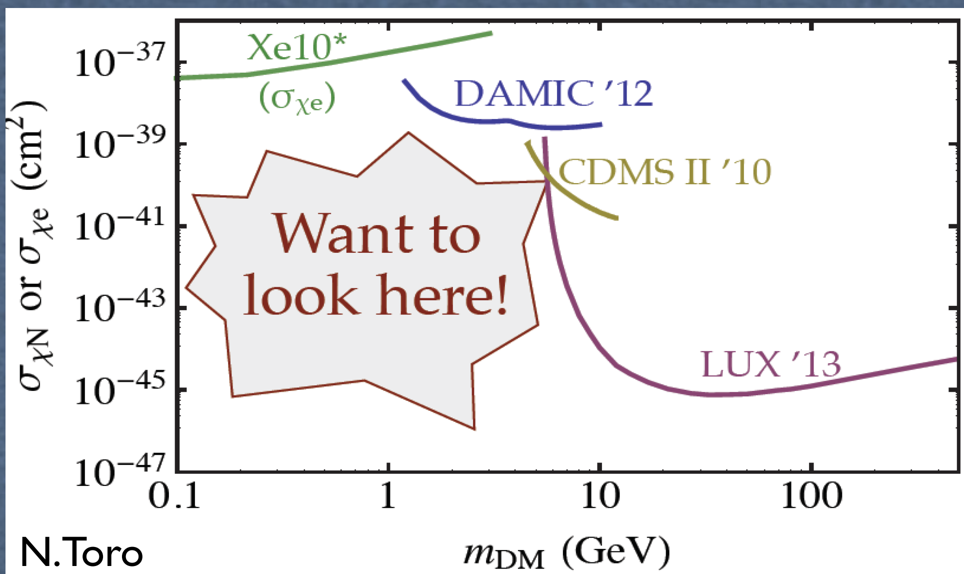
Searching for (Light) Dark Matter

- Compelling astrophysical indications of DM existence but no prove of particle-behaviour
- An extensive experimental program based on WIMPS paradigm is searching for DM via nuclear recoil (Direct Detection)



- Negative results call for extending the DM hunting territory to unexplored regions

Dark/Hidden Sector
Light Dark Matter couples to SM with a new force

- Light Dark Matter (X) in 1-1000 MeV mass range where (traditional) Direct Detection is (almost) impossible
- High intensity beam makes accelerator-based DM search highly competitive

BDX-Beam Dump eXperiment | Direct Detection

1 MeV — 1 GeV — MZ — 10 TeV

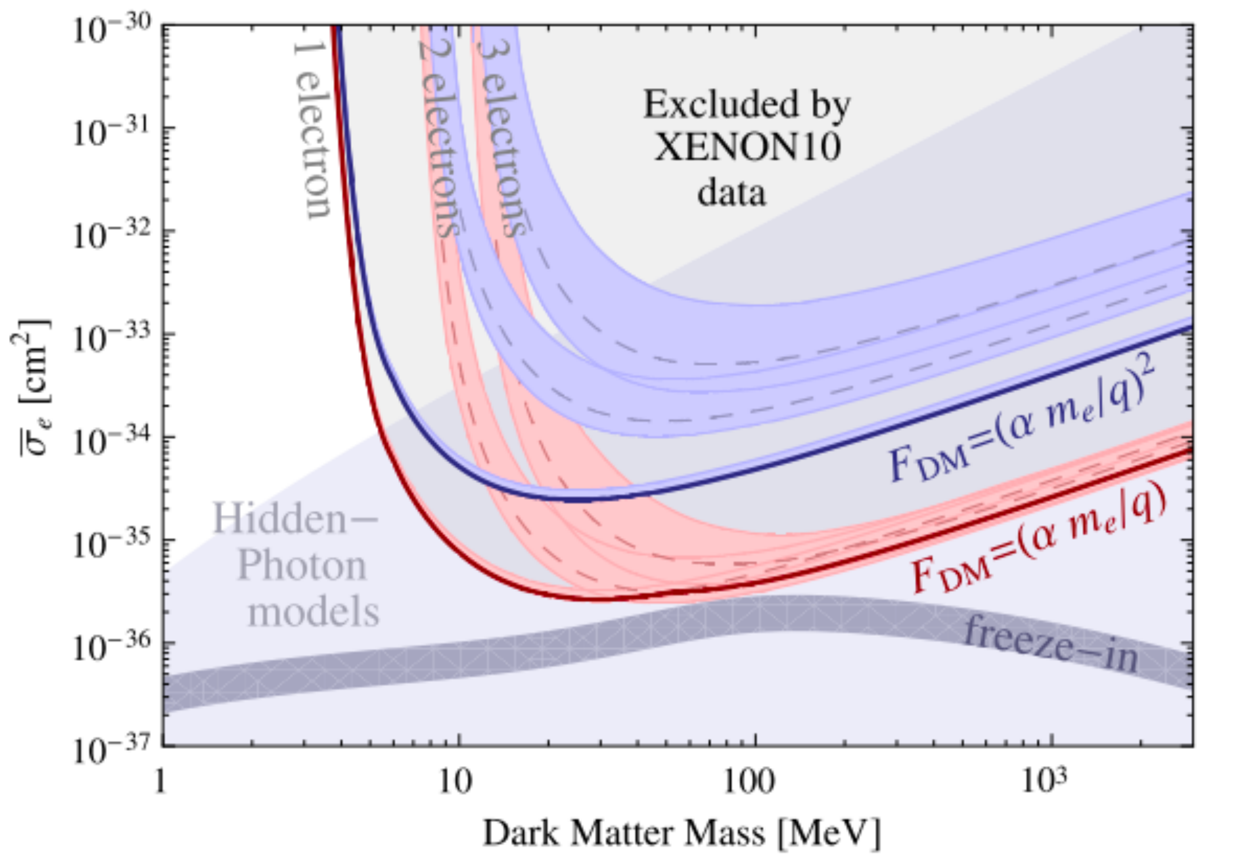
Light Dark Matter | WIMPs

Dark Sector or Hidden Sector (DM not directly charged under SM interactions)

Can be explored at accelerators!

LDM - Direct Detection limits

Limits from XENON10



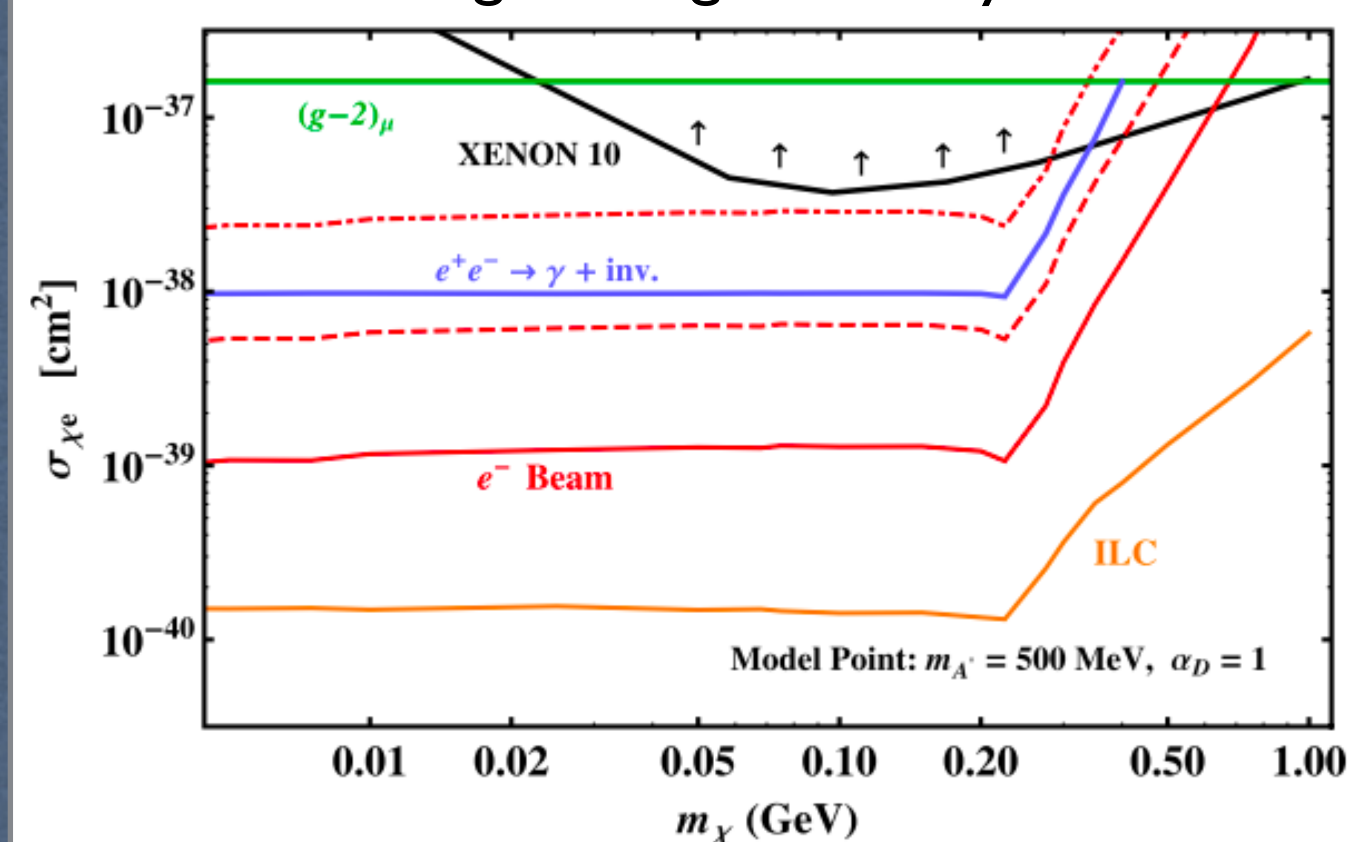
PhysRevLett. 109.021301 R.Essig, A.Manalaysay, J.Mardon, P.Sorensen, T.Volansky,

- Best limits on LDM interaction cross section obtained by direct DM detection (XENON10 and LUX)
  - χ_{cosmic}-e scattering
  - 1-electron ionization sensitivity
  - No FF for the scattering

- Fixed target electron beam experiments can be 10^3 - 10^4 more sensitive in the 1 MeV - 1 GeV mass range

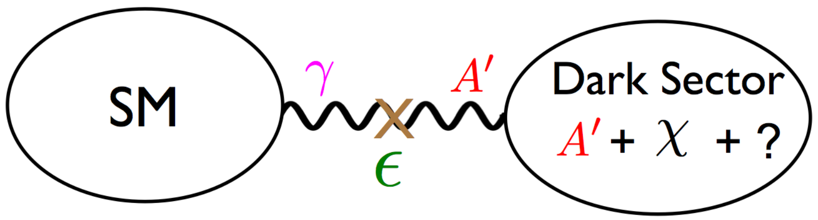
- Only one experiment (NA64) designed to measure LDM (all limits come from reinterpretation of old experiments)

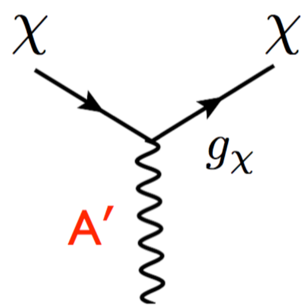
Fixed target & high intensity e$^-$ beam

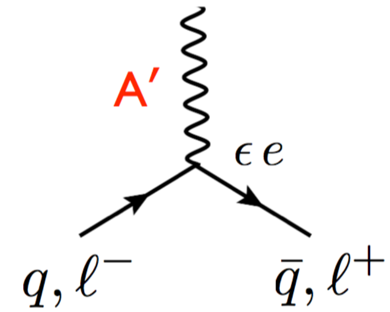


PhysRevD.88.114015 E.Izaguirre, G.Krnjaic, Gordan, P.Schuster, N.Toro

Dark forces and dark matter
(Light WIMPs - light mediators)



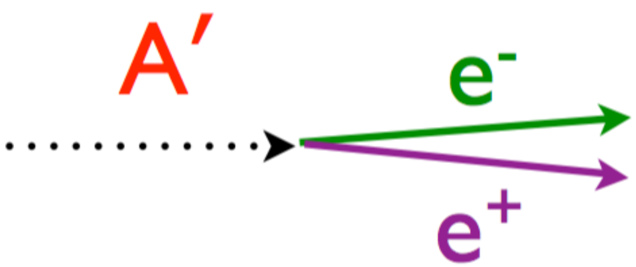




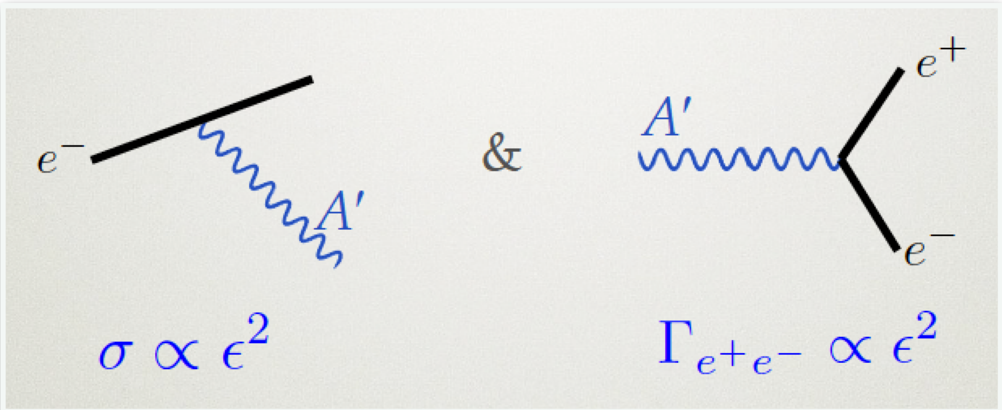
4 parameters: $m_\chi, m_{A'}, \epsilon, g_\chi$

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

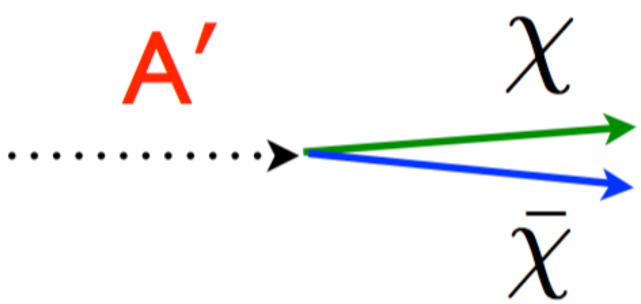
Visible



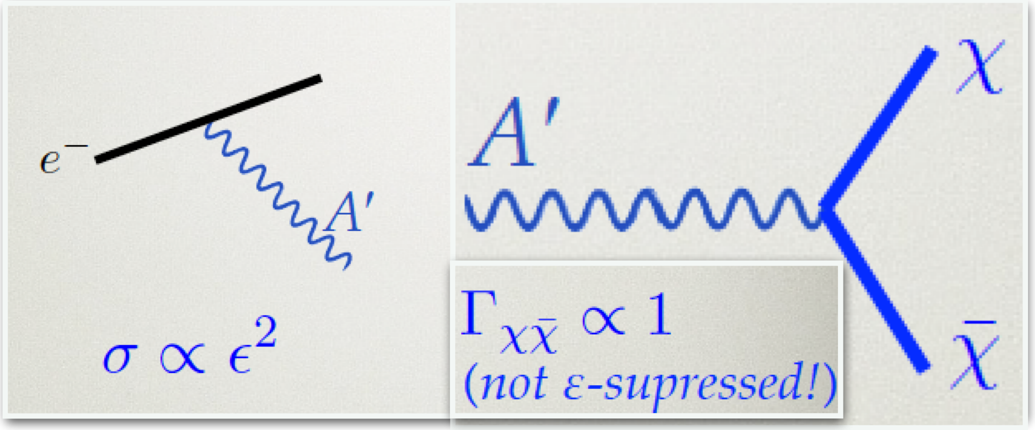
- *Minimal* decay
- Decay regulated by ε^2
- Independent of m_χ
- Requires $m_{A'} < 2m_\chi$



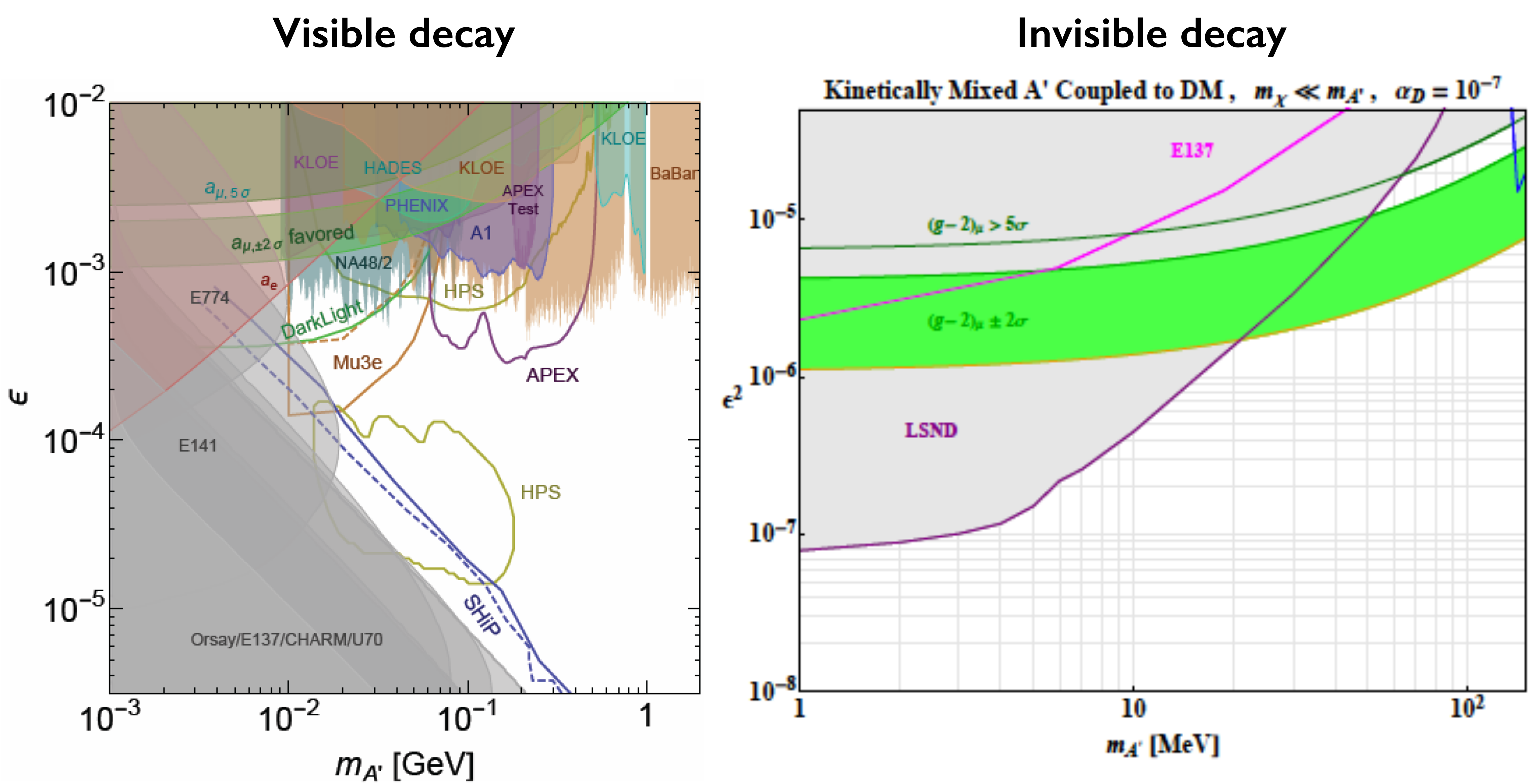
Invisible



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



Visible vs Invisible: complementarity $(g-2)_\mu$



Strong Constraints on Sub-GeV Dark Matter from SLAC Beam Dump E137
PhysRevLett.113.171802 Brian Batell, Rouven Essig, Ze'ev Surujon

- *(g-2)*$_\mu$ favoured region ruled out if DM ONLY decays to SM particles
- Exclusion limits are model dependent: if invisible decay is included limits do not hold!

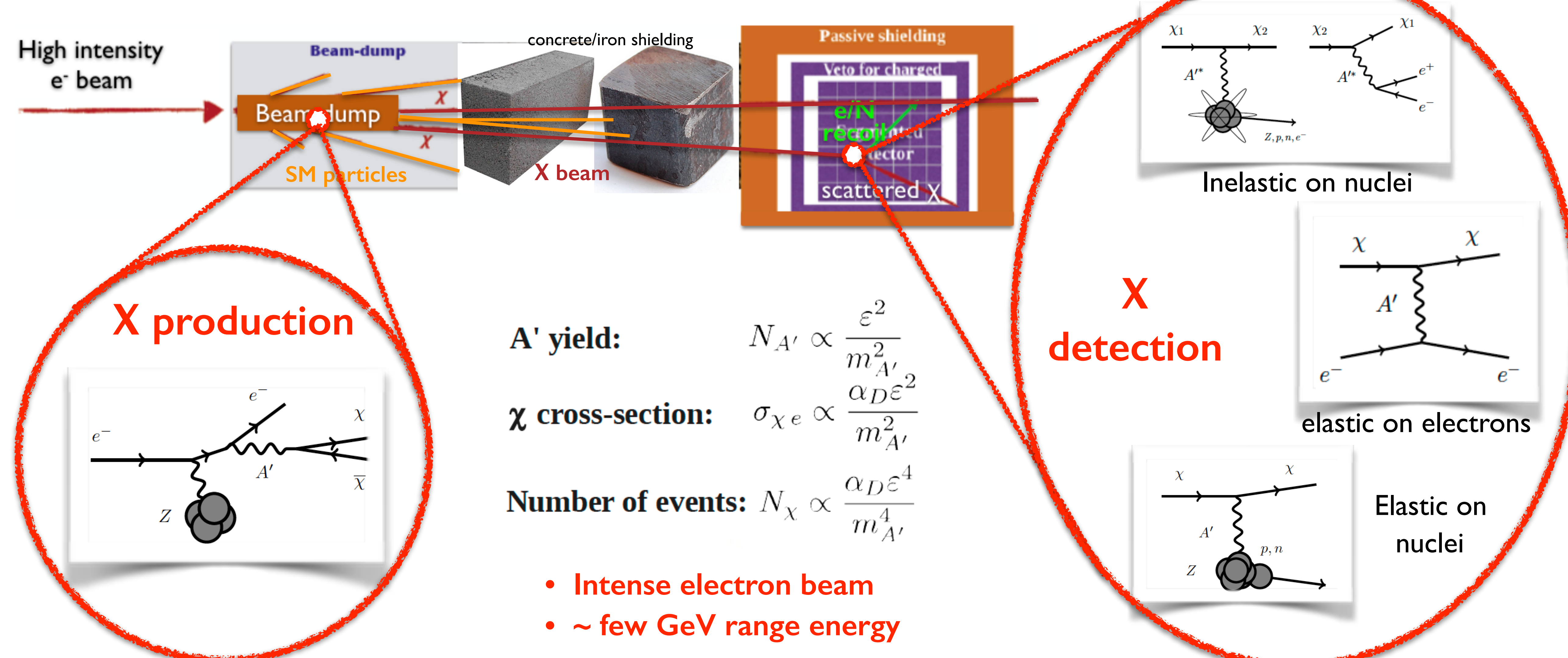
The BDX experiment

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: $N_{A'} \propto \frac{\varepsilon^2}{m^2_{A'}}$

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

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

- Intense electron beam
- ~ few GeV range energy

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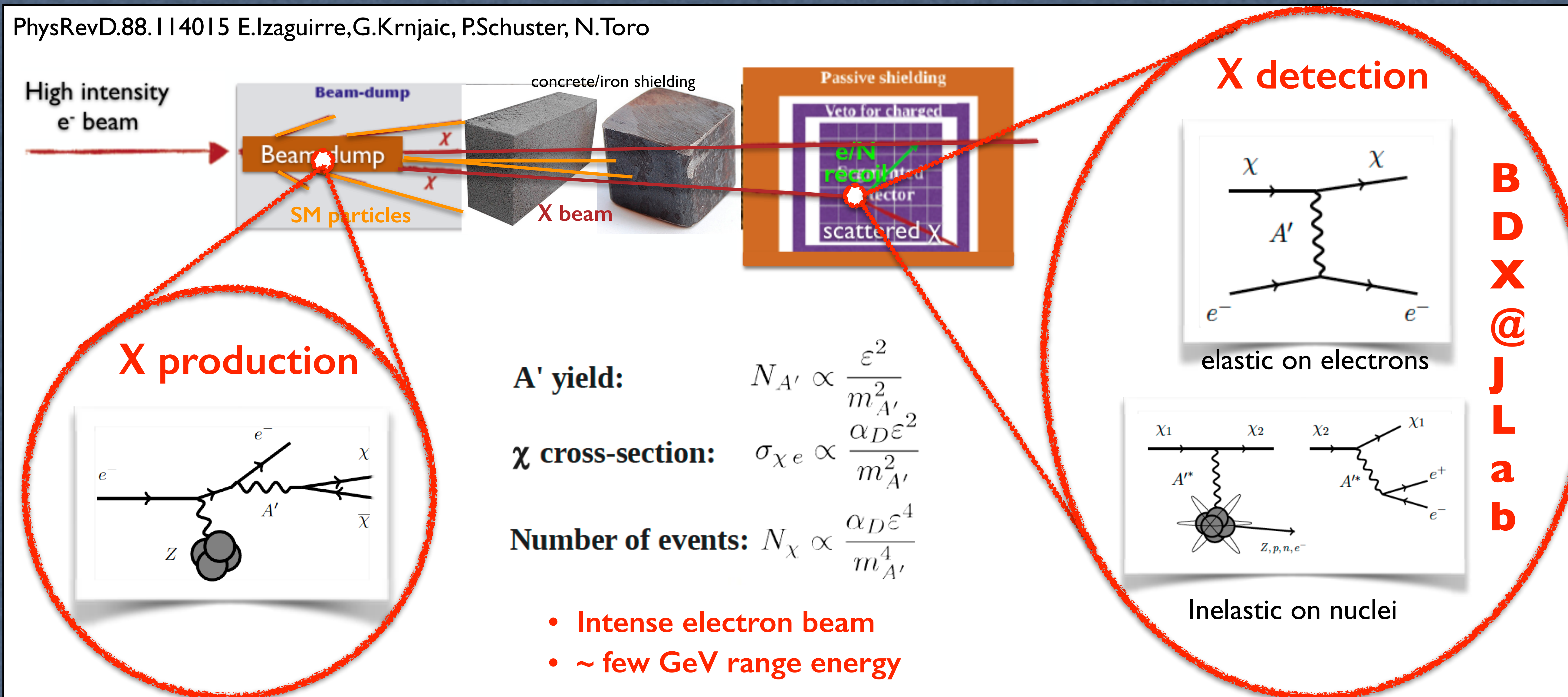

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- Intense electron beam
- ~ few GeV range energy

Experimental signature in the detector:

X-electron → EM shower ~GeV energy

The BDX detector

Detecting the X

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 between active layers for low energy gamma

BDX technology

E.M. calorimeter

↓

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

Active veto

↓

Two layers: of **plastic scintillator**
OV: light guide + PMT
IV: WLS + SIPM

The BDX crystals

Requirements:

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

Possible options:

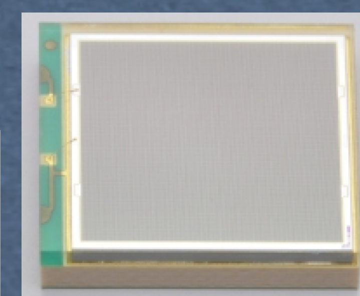
BaF2
CsI
BSO

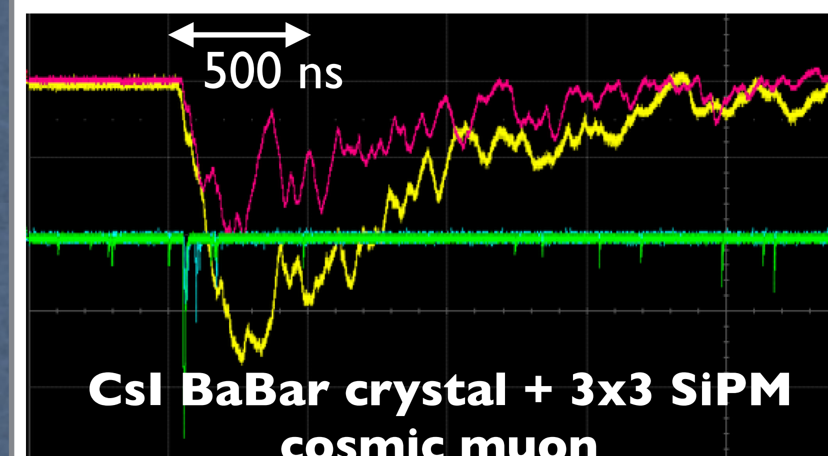
A dedicated measurement campaign to characterise the crystal properties

- Light yield (with SiPM readout!)
- Intrinsic decay time / time resolution

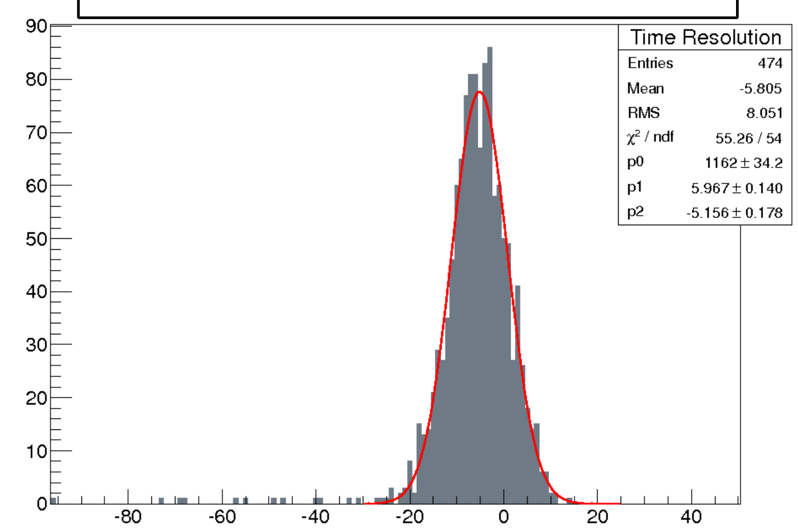
Parameter	Values
Radiation length	1.85 cm
Molière radius	3.8 cm
Density	4.53 g/cm^3
Light yield	50,000 γ/MeV
Light yield temp. coeff.	0.28%/°C
Peak emission λ_{max}	565 nm
Refractive index (λ_{max})	1.80
Signal decay time	680 ns (64%)
	3.34 μs (36%)

CsI(Tl) + SiPM readout





CsI BaBar crystal + 3x3 SiPM
Time resolution: σ = 6ns



Crystals are available from BABAR em calorimeter

- Size: (5x5)cm^2 front face, (6x6)cm^2 back face, 30cm length
- 820 crystals available from end cap
- Decay time: fast 900ns, slow 4000ns
- LY= 50k γ/MeV

SiPM readout

- Size: (6x6) mm^2, 25μm, 57.6k cells, trenched, pde=25%
- SPE capability
- CsI(Tl): 40 pe/MeV
- Time resolution: ~6ns (MIPs)

★ Due to the large LY signals at ~MeV level are detectable
★ Despite a long scintillation time a few ns time coincidence is possible

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

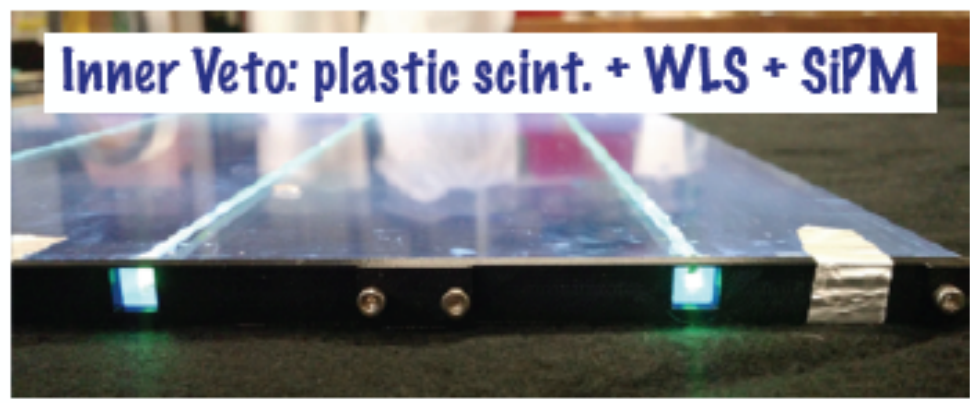
R&D on different technologies:

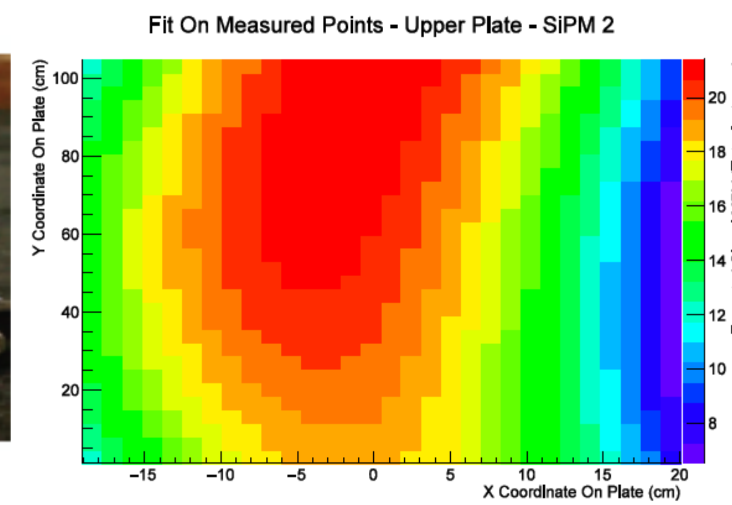
- Plastic scintillator + light guide + PMT
- Plastic scintillator + WLS + PMT
- Plastic scintillator + WLS + sipm

Plastic scintillator + WLS and SipM/PMT readout

Inner veto:

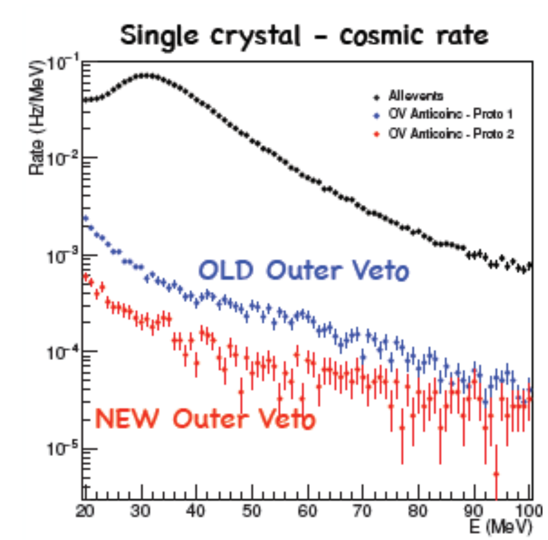
- 1cm (all clear) Plastic scintillator +WLS fiber placed in grooves
- 3x3 SiPM readout
- LY= 15-50 pe/MIP





Outer veto:

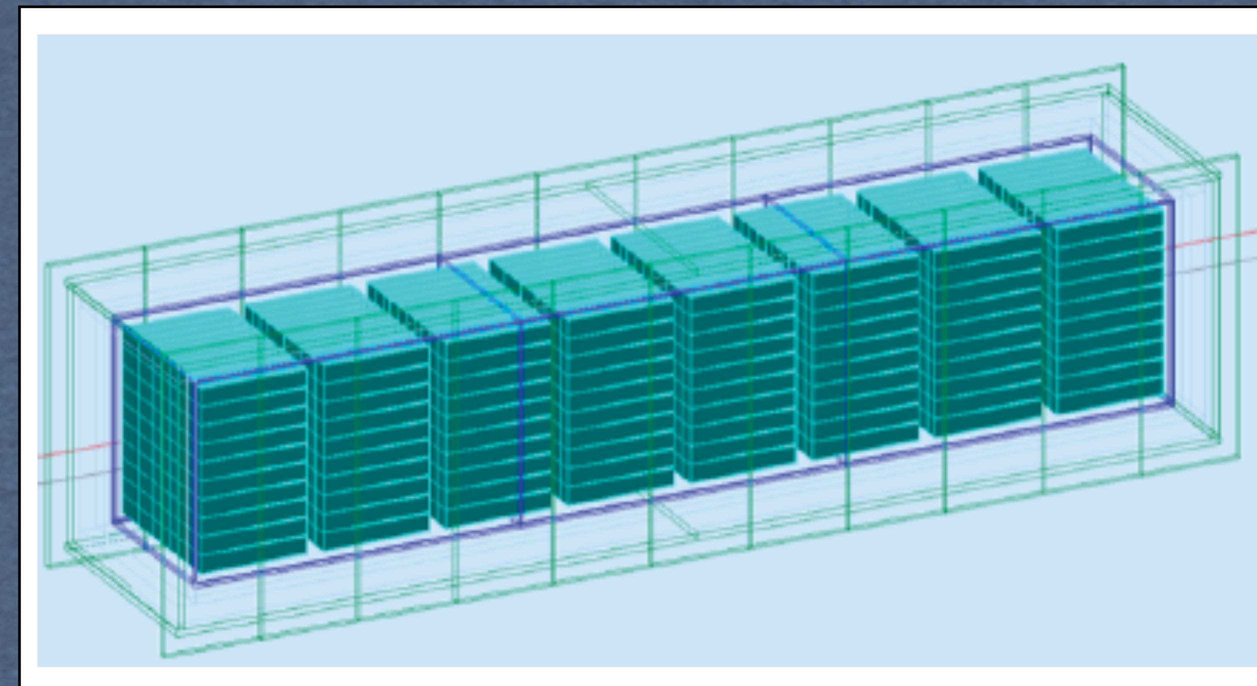
- Plastic scintillator + Light guide + PMT
- Plastic scintillator +WLS fiber



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

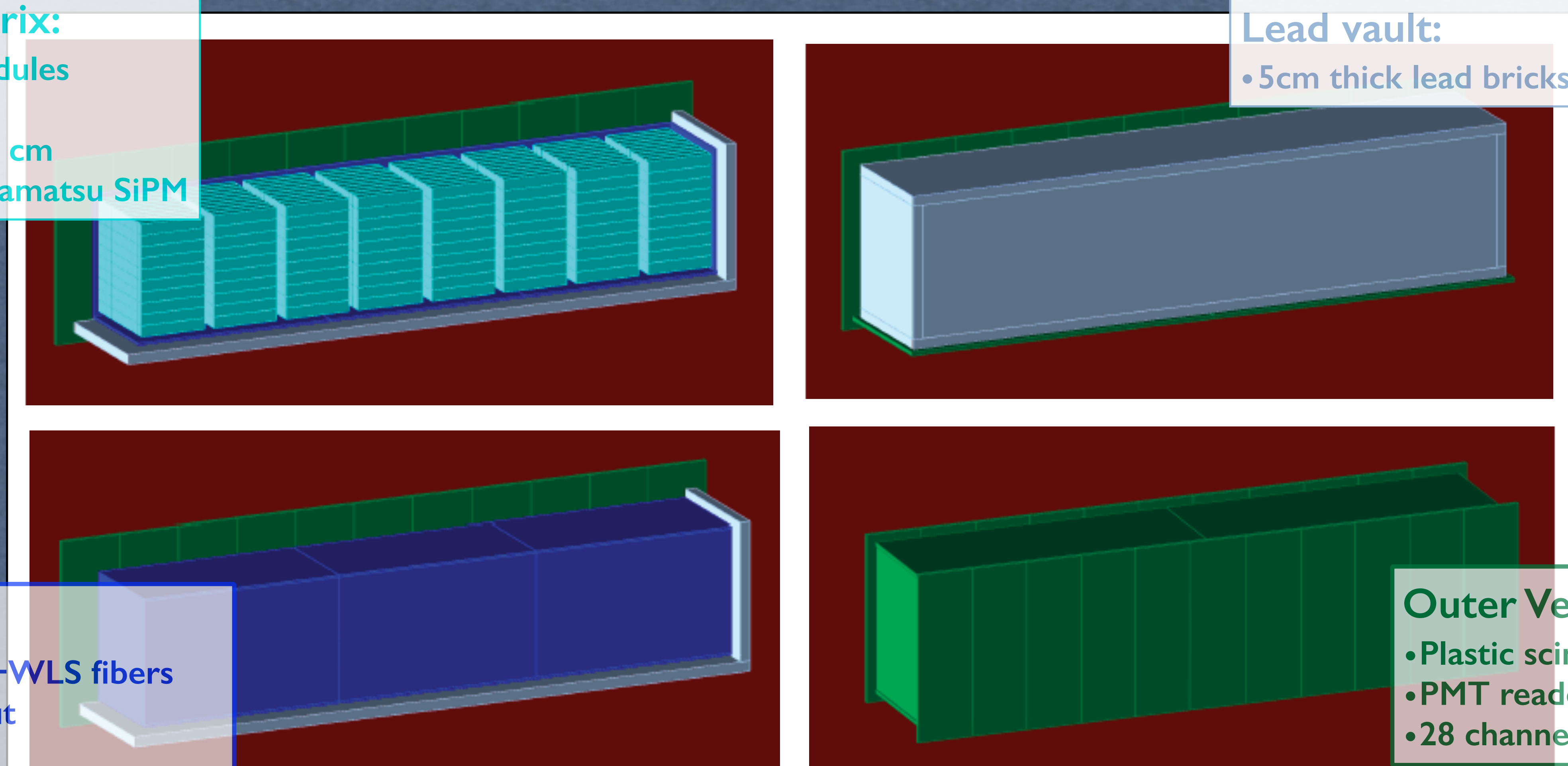
The BDX detector

★ Modular EM calorimeter: 8 modules 10x10 crystals each
★ 800 CsI(Tl) crystals (former BaBar EMCal) + SiPM readout
★ Inner Veto: plastic scintillator + WLS + SiPM
★ Outer Veto: plastic scintillator + PMTs
★ Passive shielding: lead vault



Crystal matrix:
- 10x10 x 8modules
- 800 crystals
- 50 x 55 x 295 cm
- 800 6x6 Hamamatsu SiPM

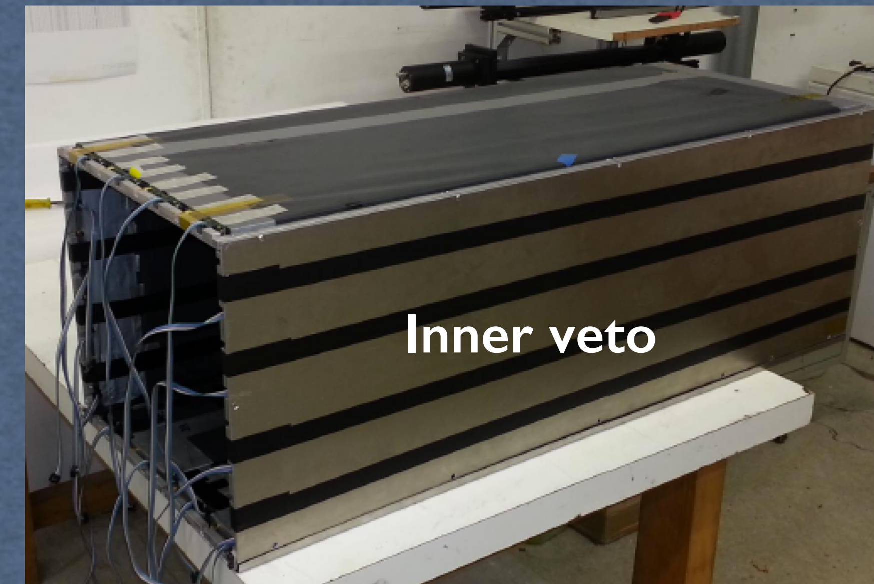
Lead vault:
- 5cm thick lead bricks



Inner Veto:
- Plastic scint+WLS fibers
- SiPM readout
- 88 channels

Outer Veto:
- Plastic scint +light guides
- PMT readout
- 28 channels

The BDX prototype

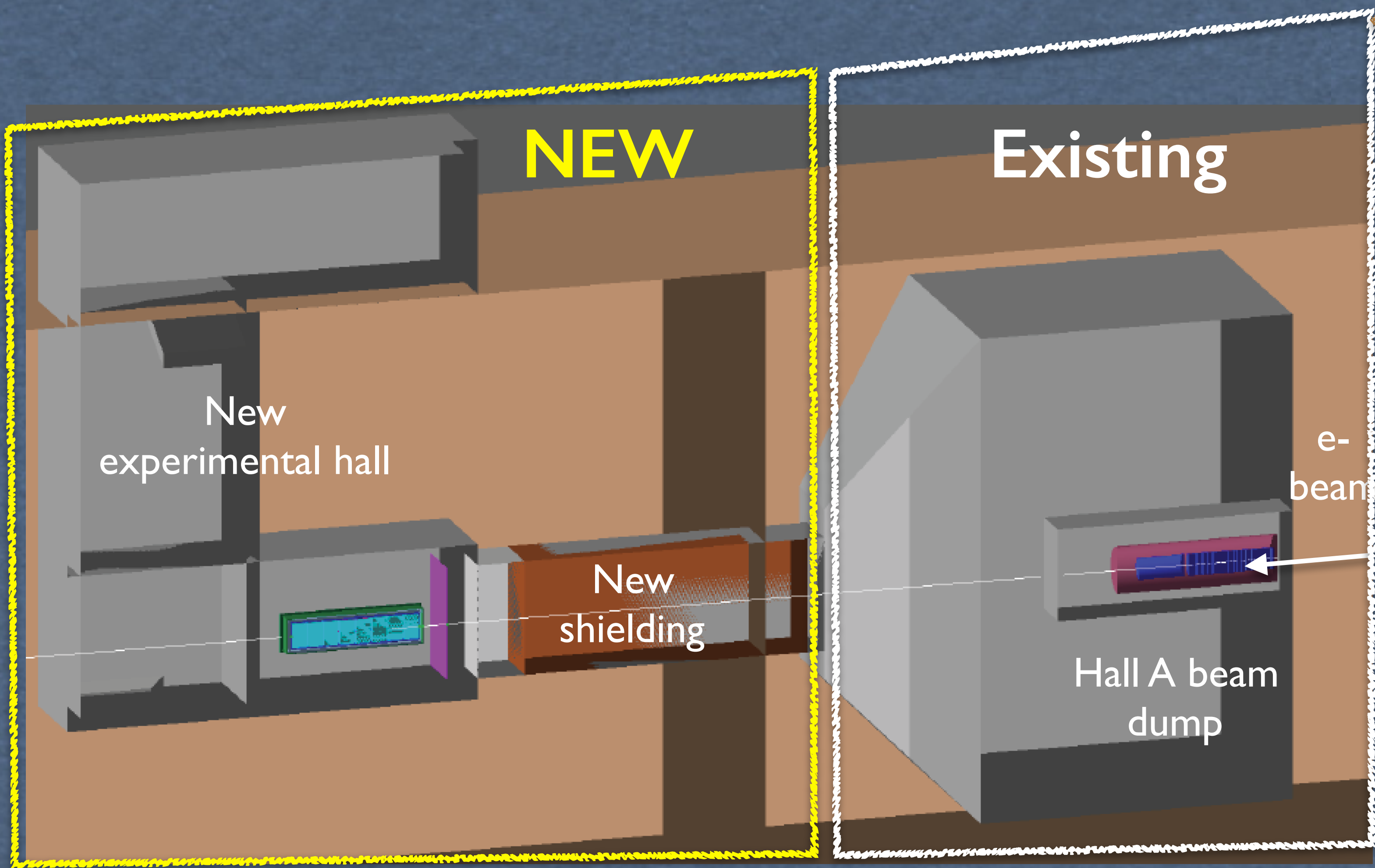


- EM Cal
  - 4x4 CsI(Tl) crystals
  - 6x6 mm^2 SiPM
- Outer Veto
- Lead vault
- Inner Veto

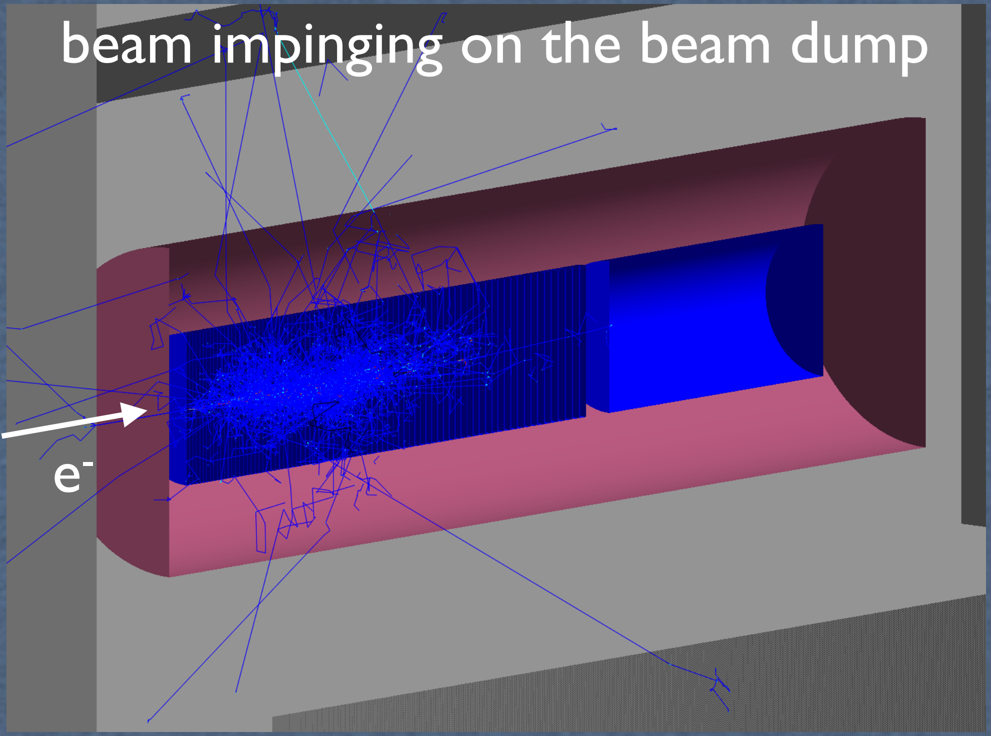
BDX at JLab

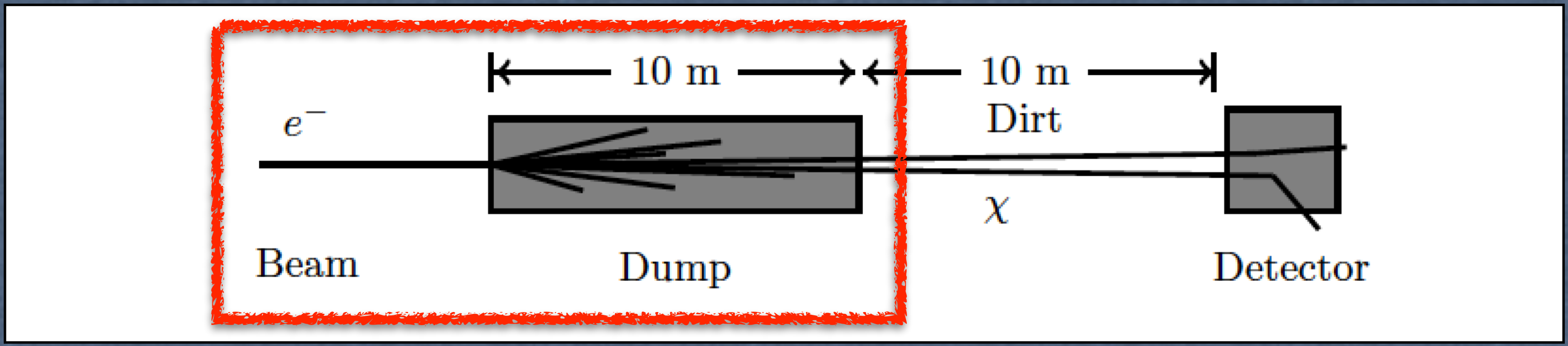
★ High energy beam available: 11 GeV
★ The highest available electron beam current: ~65 uA
★ The highest integrated charge: 10^{22} EOT (41 weeks)

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



X production in the BD





- MadGraph to describe the A' production and decay (A' → χ $\bar{\chi}$)
- Detailed description of Hall-A beam dump (aluminium and water)
- Sampling of em shower simulated with GEANT4

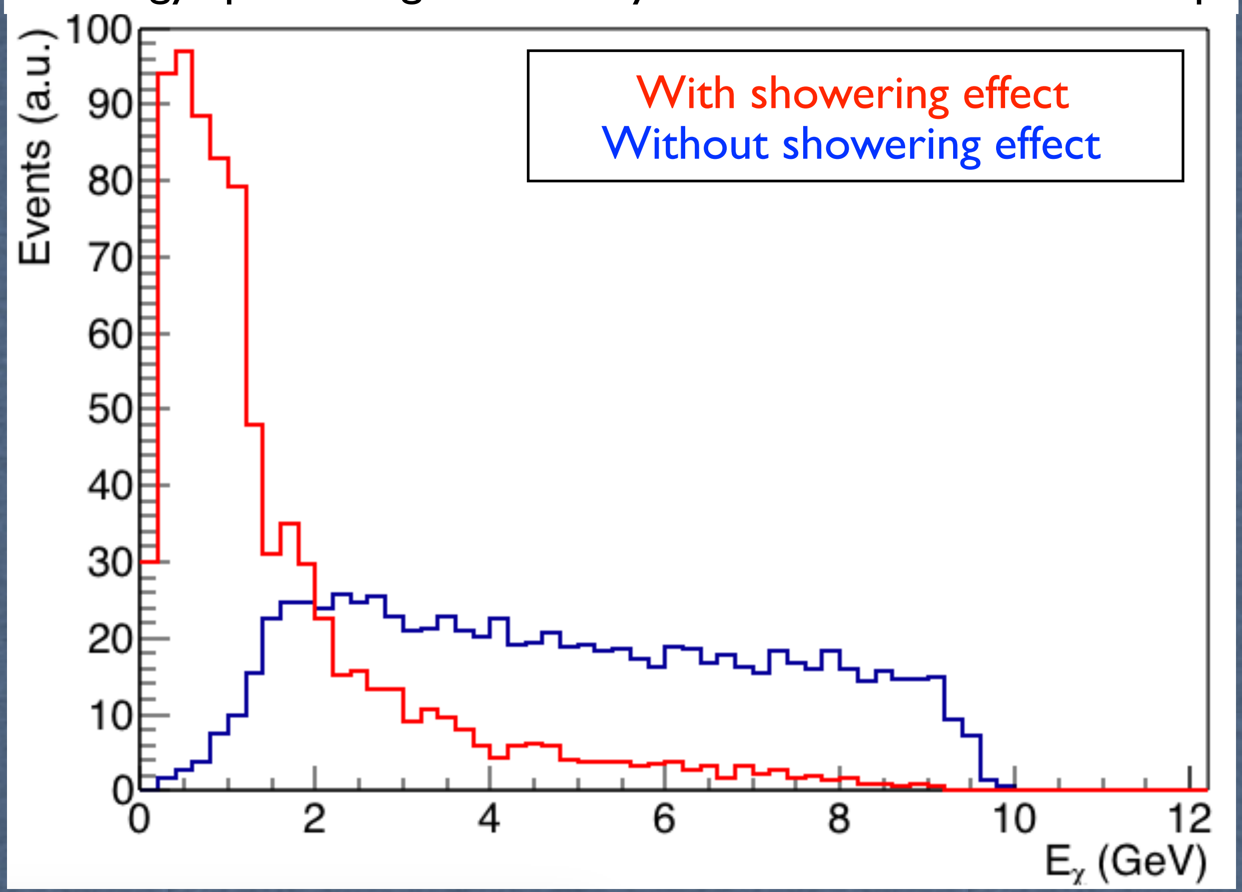
The em shower in the dump was neglected in previous works

Significant effect on energy distribution and X production angle

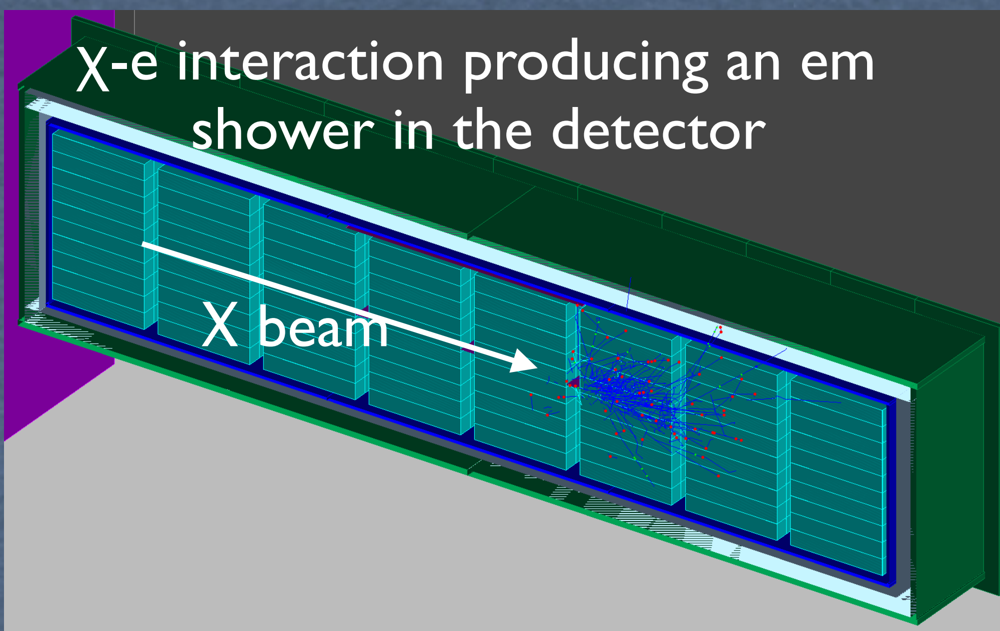
JLab kinematics

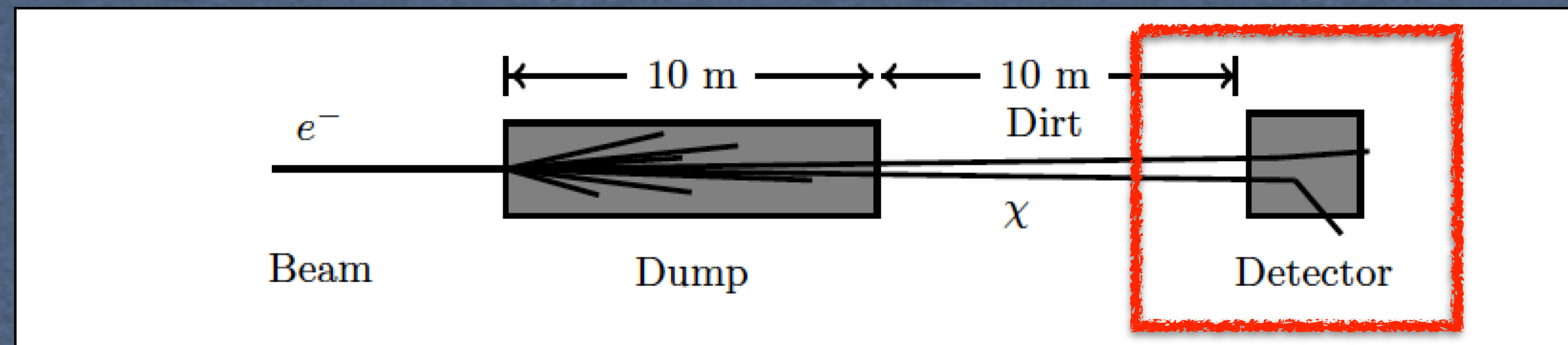
- X beam softer (significant)
- X beam defocused (less important)
- X beam intensity almost untouched

X energy spectrum generated by 10 GeV e-beam in the dump

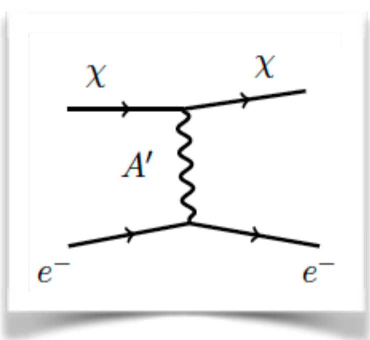


X detection in the BDX detector

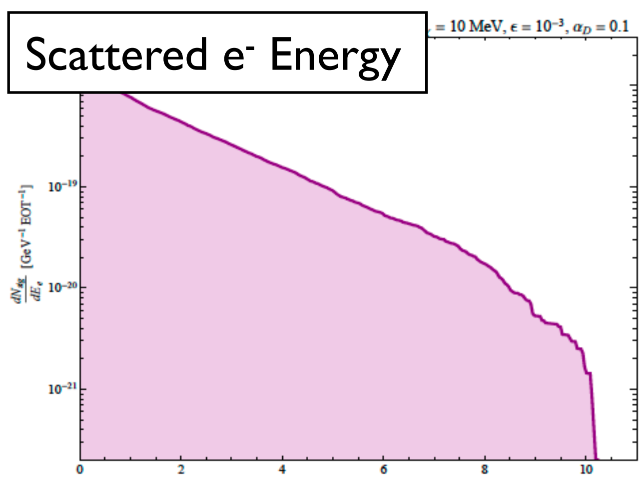


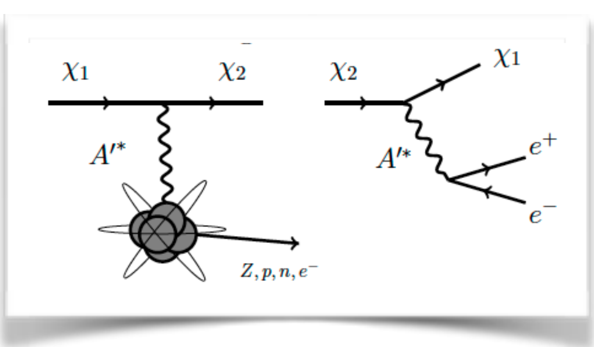


- GEANT4 simulations of X-e and X-N interaction
- Detection efficiency derived as a function of the energy threshold included in all BDX reach estimates

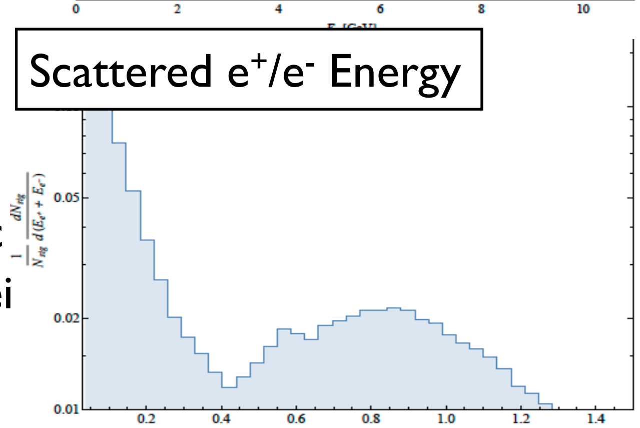


Elastic on electrons





Inelastic on nuclei



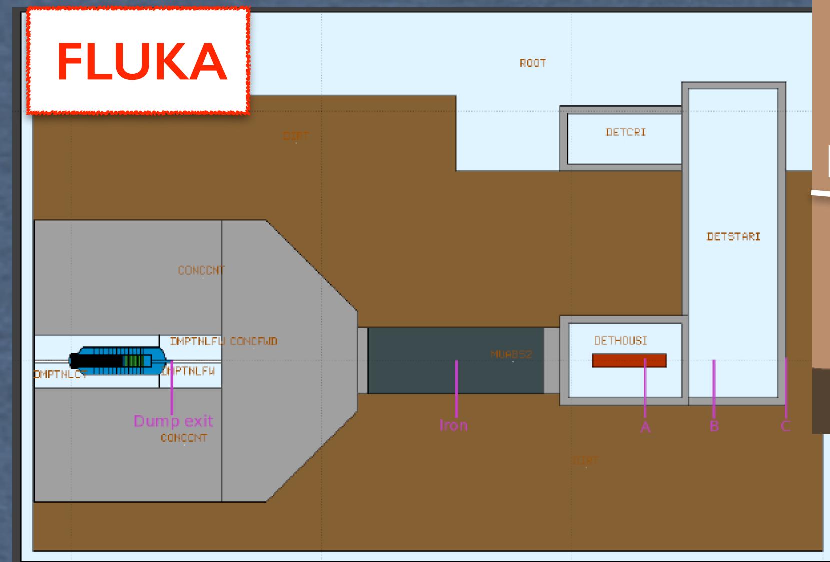
BDX detector response to X-e^- elastic and X-N inelastic scattering (em shower)

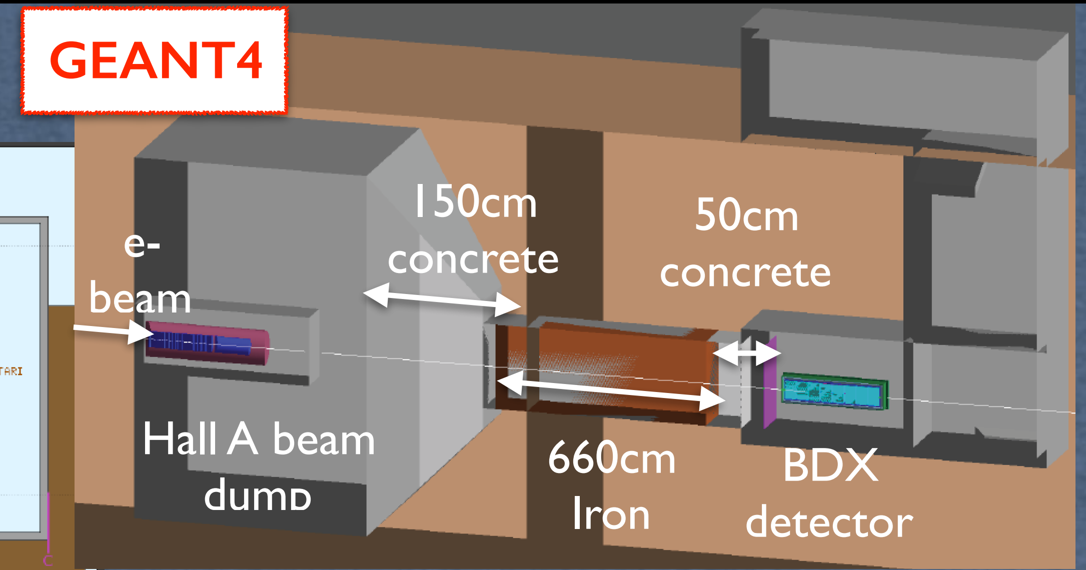
Parameters: m_X = 30 MeV $m_{A'}$ = 90 MeV	
X-e^- scattering inside the fiducial volume $E_{e^-} \geq 300$ MeV	100%
$E_{Seed} \geq 300$ MeV	↓ 61%
Veto anticoincidence	↓ 13% (10% - 20%)

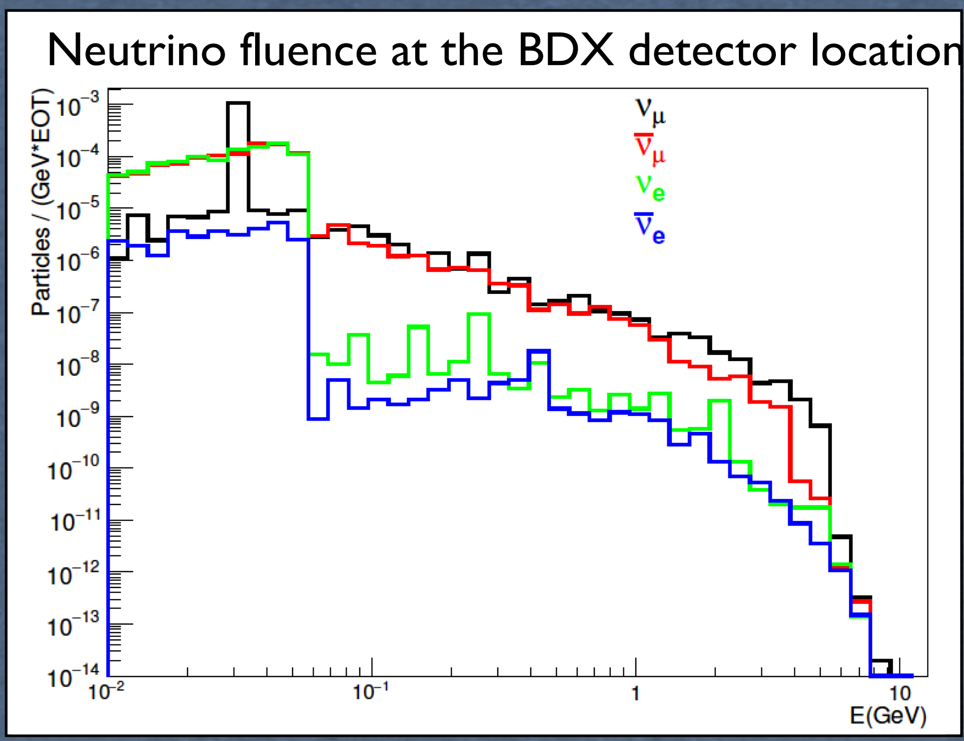
- E_{Seed} = max crystal energy in the em cluster
- Veto anti-coincidence to account for cosmic bg cut
- Consistent with prototype measurement
- Conservative (refined cuts on em shower will be possible)

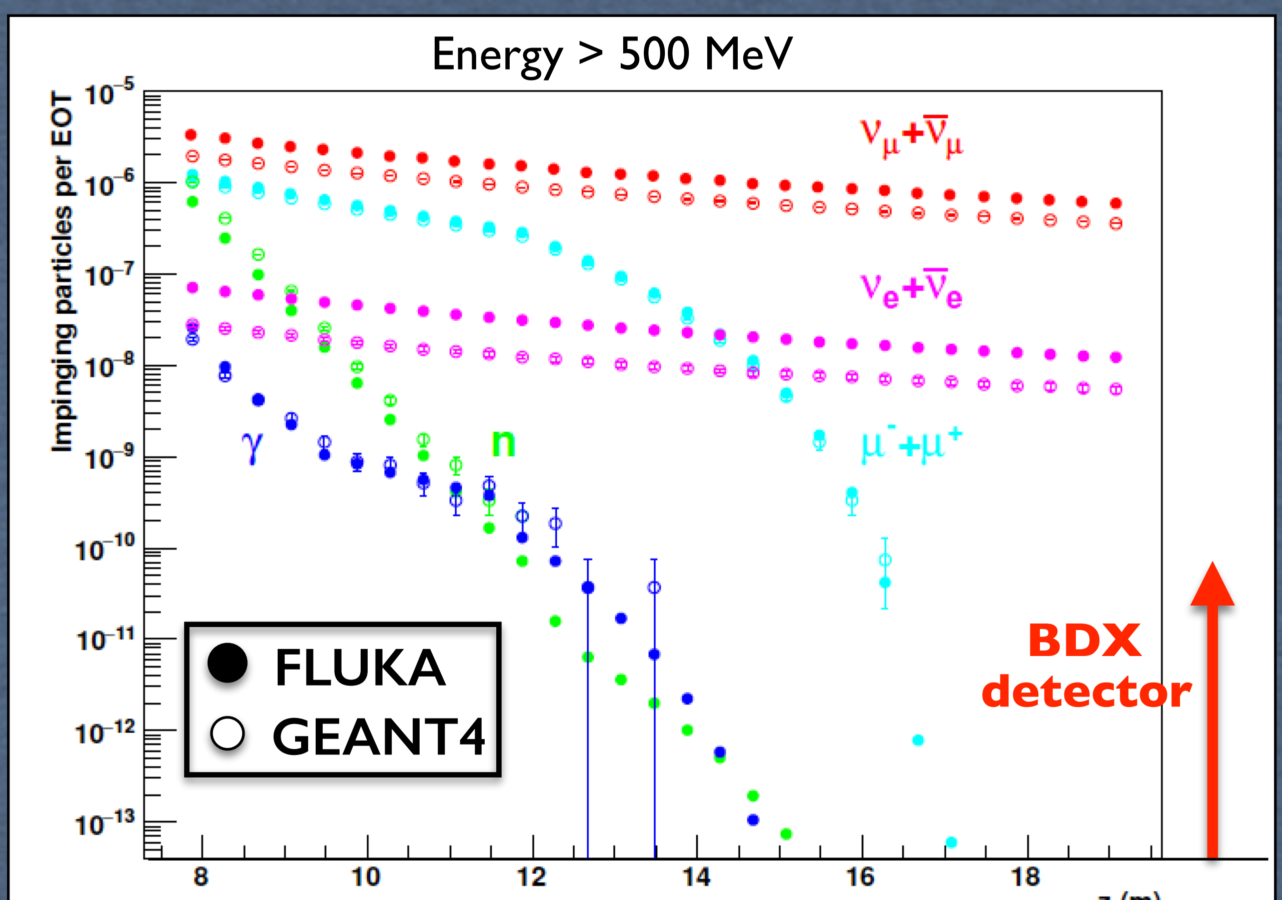
Beam-on background

- ★ Muons 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
- ★ No μ, n and γ with E>100 MeV are found at the detector location
- ★ 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 detector by CC:

$\nu + N \rightarrow X + e^-$

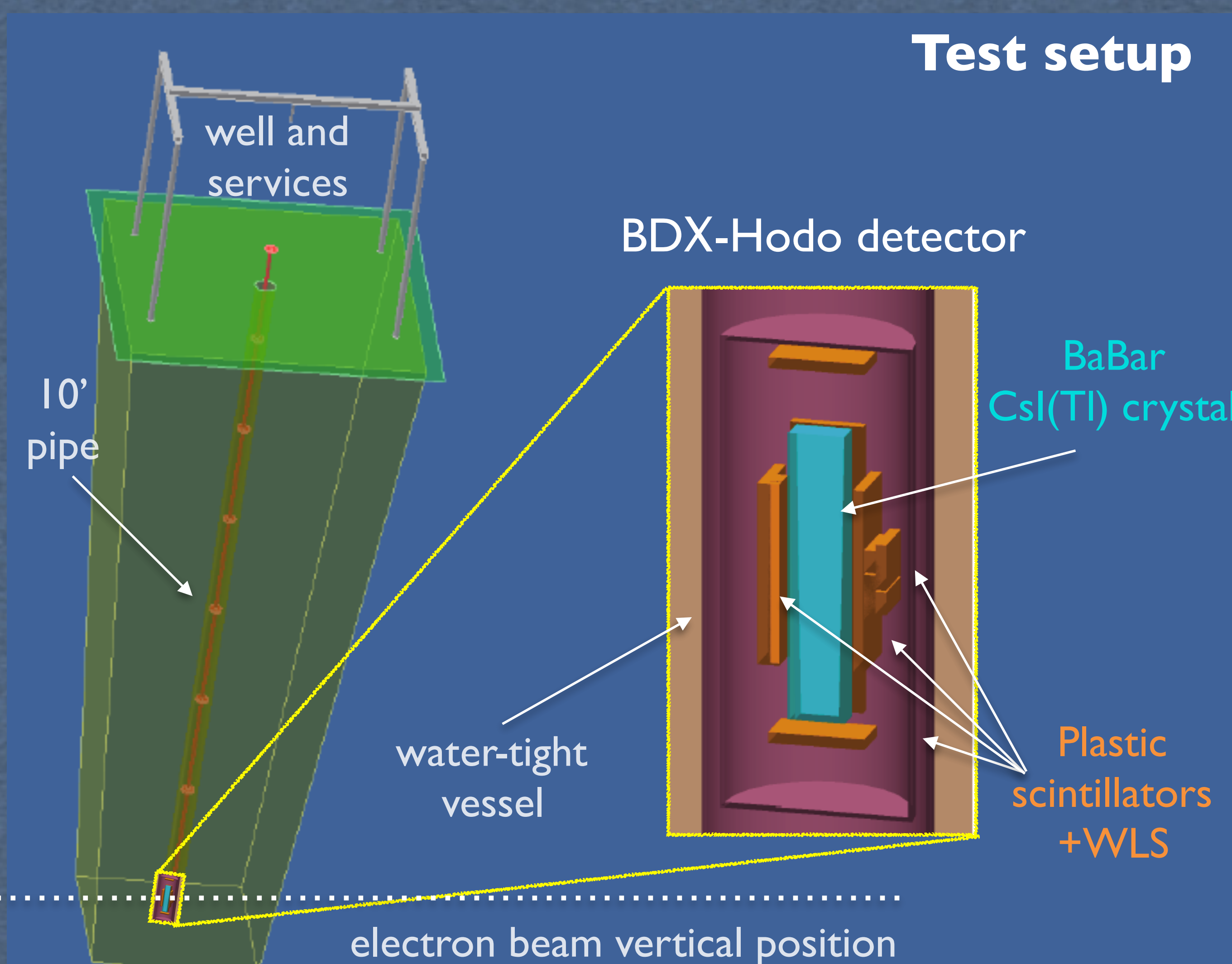
$\nu + e^-$ suppressed

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

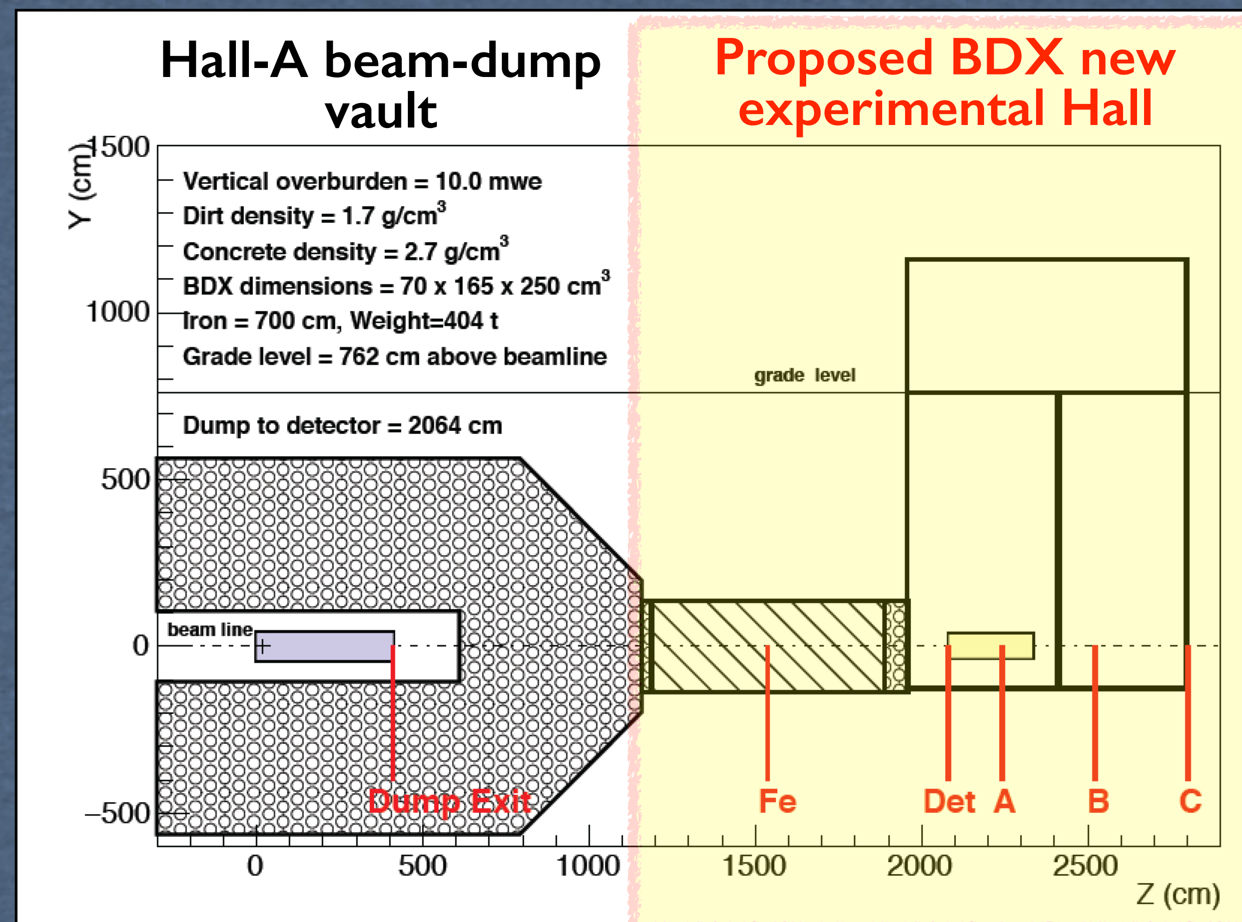
Tests to measure the beam-on background

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

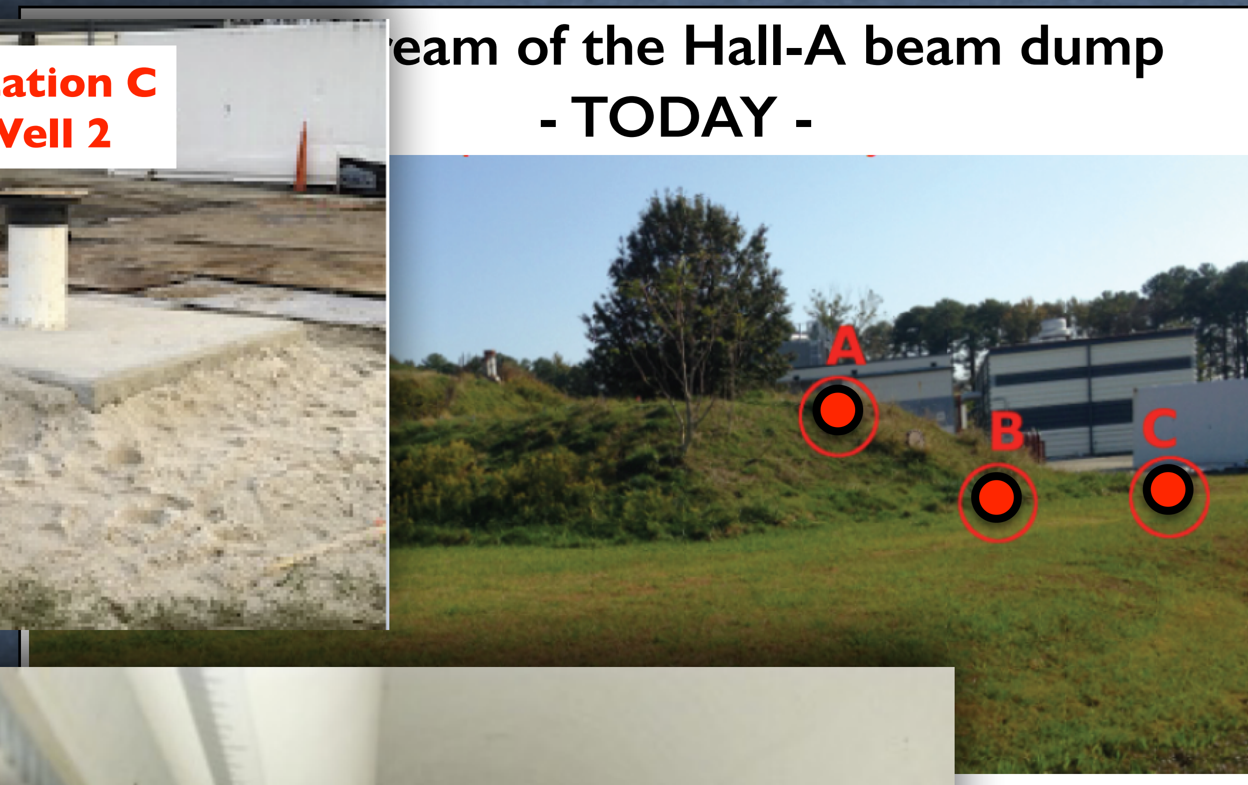
- Pipe downstream of Hall-A beam-dump at BDX location
- Insert a CsI(Tl) crystal surrounded by plastic scintillators
- Same detector technology proposed for BDX detector
- Measure μ flux when 11-GeV beam is on

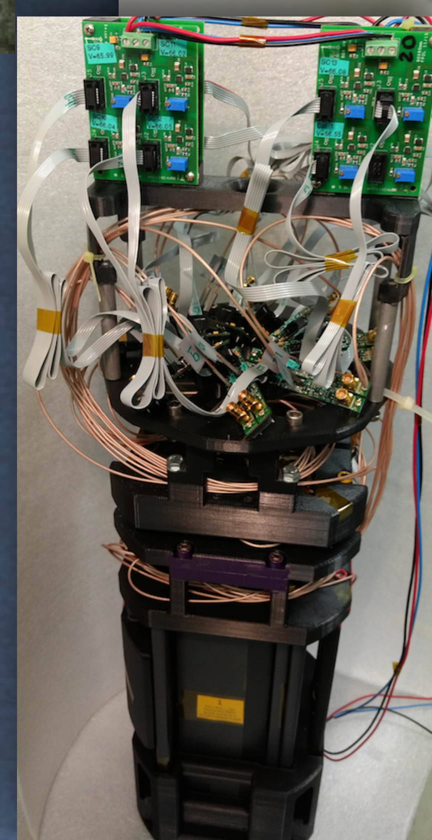


Downstream of the Hall-A beam dump
- TODAY -

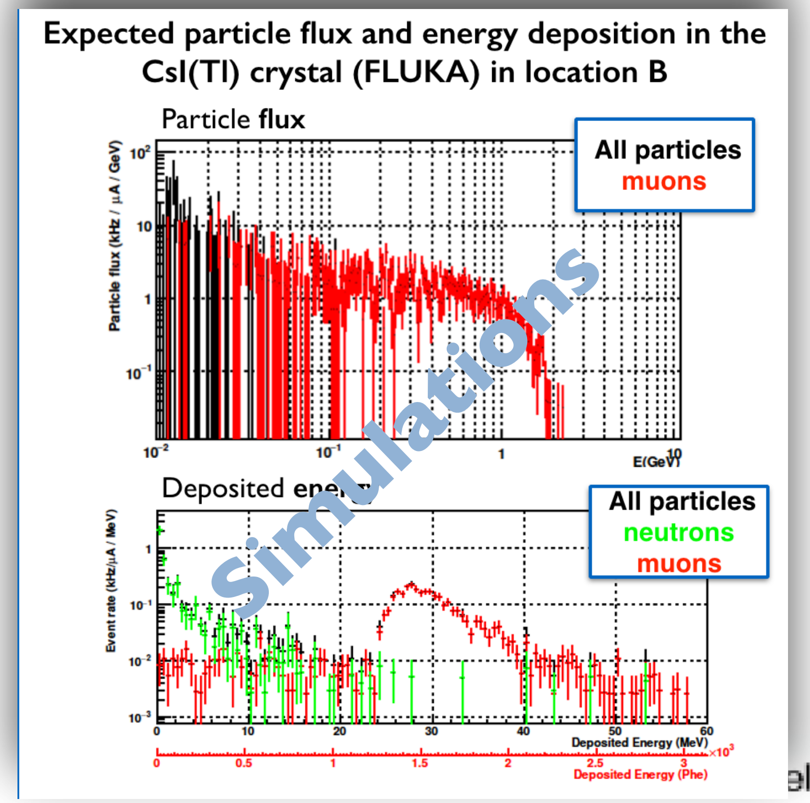


Test set-up: the new: "T"(ent)-Hall at JLab

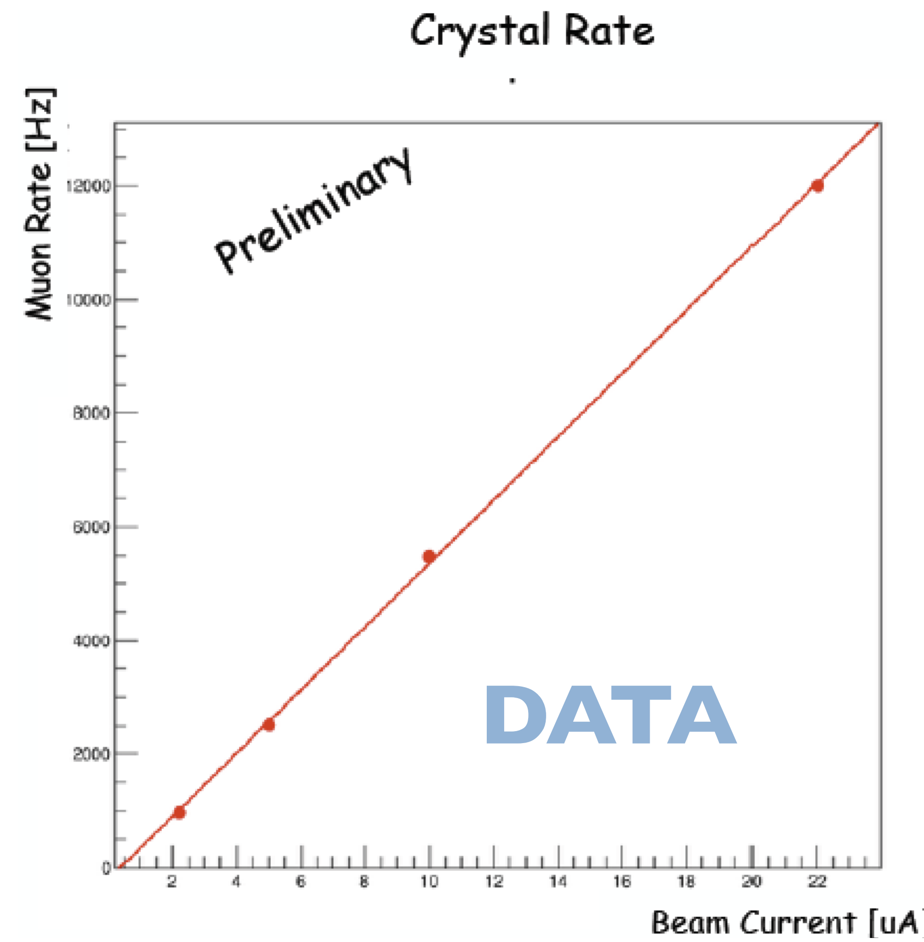




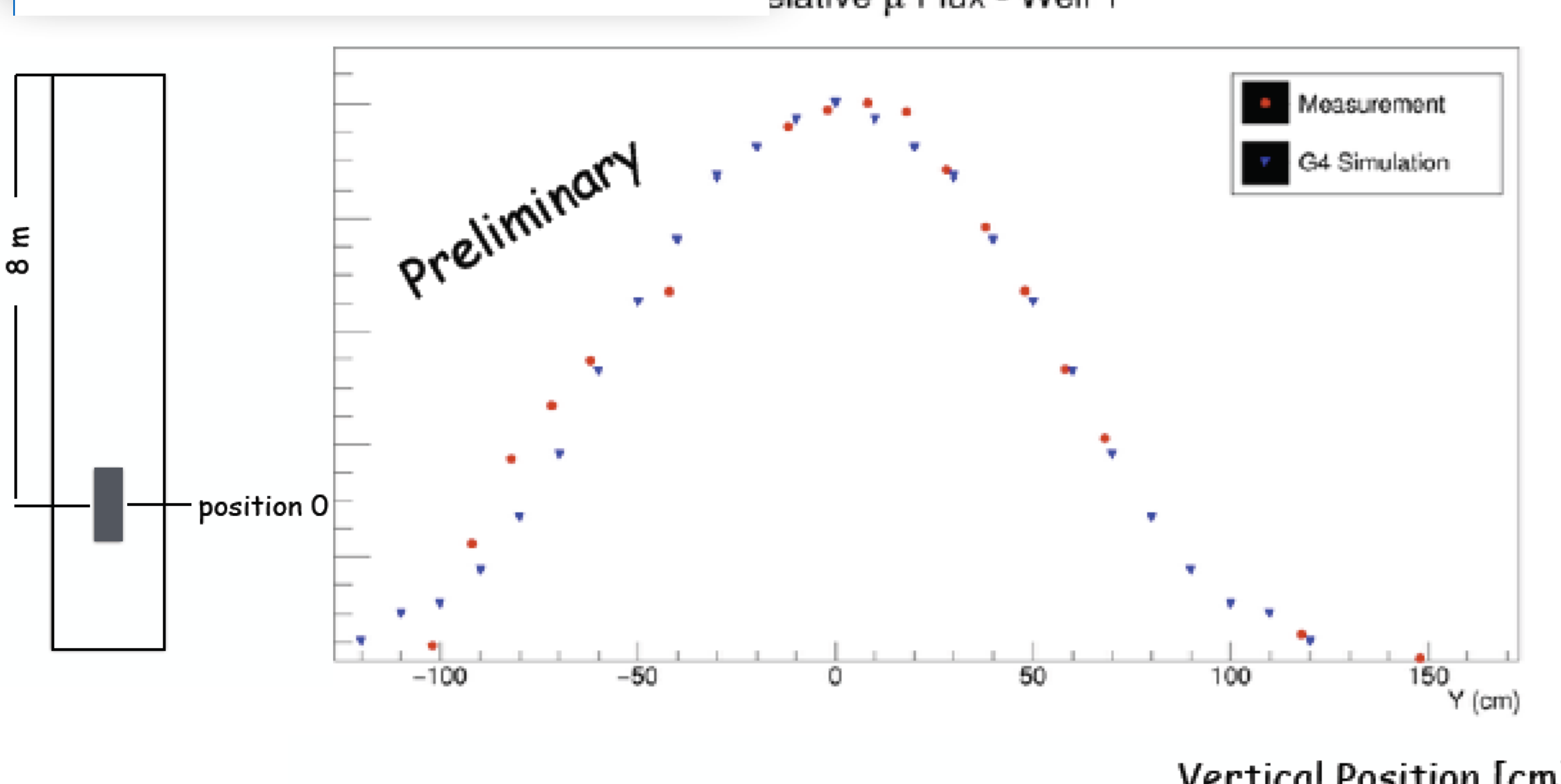
Beam-on background test preliminary results



- Beam current scan: linear rate vs. current
- Vertical position scan: good agreement in shape and rates estimated with simulations (GEANT4)
- Strong dependence on dirt density (sampled in few points ρ~1.95 gr/cm³)



elative µ Flux - Well 1



Preliminary conclusions (beam-on bg)

- FLUKA/GEANT reproduce well (~10%) absolute and relative beam-on rates
- No effect of thermal neutrons
- Bema-on bg evaluated in a realistic condition (1 day at 22 uA ~10^{19} EOT)

Cosmic background

★ Cosmic background measured with the BDX detector prototype with similar overburden

★ GEANT4 simulations reproduce muon rate w/wo overburden

★ The majority of cosmic muons detected and rejected by the combination of the two veto detectors

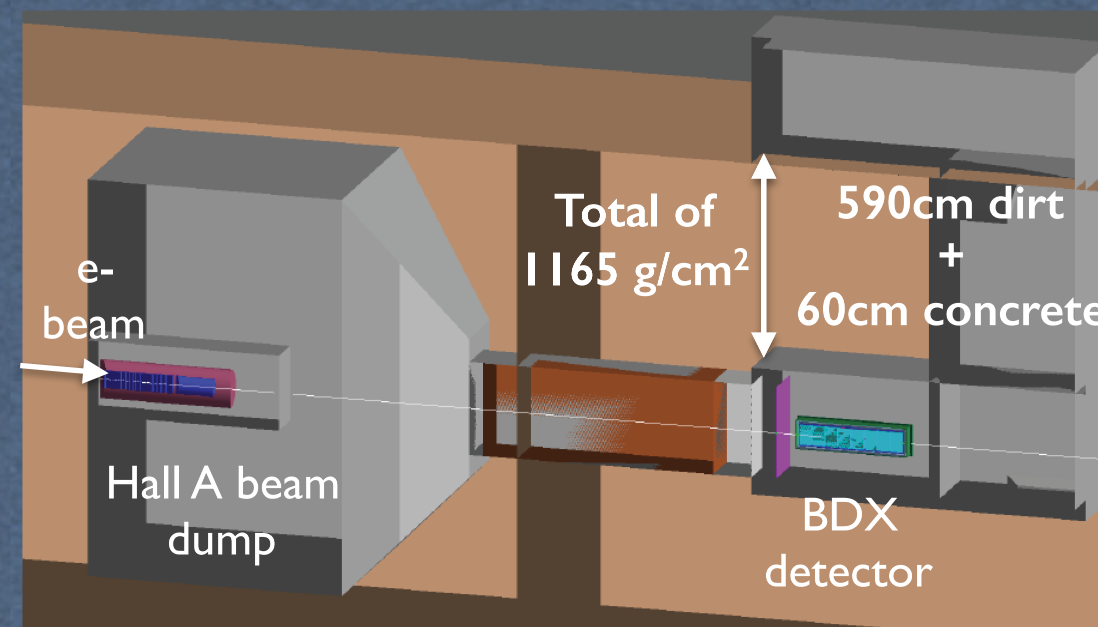
★ The most part of cosmic neutrons are shielded by the overburden

★ Low energy (<100 MeV) background due to neutrals

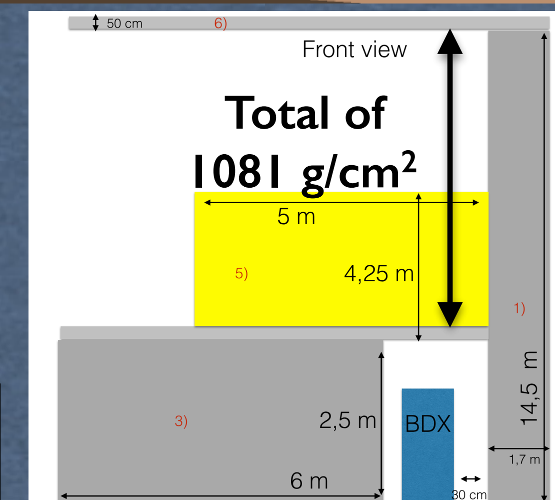
★ Measured Rate (E_{Thr}~300MeV) < 2 counts

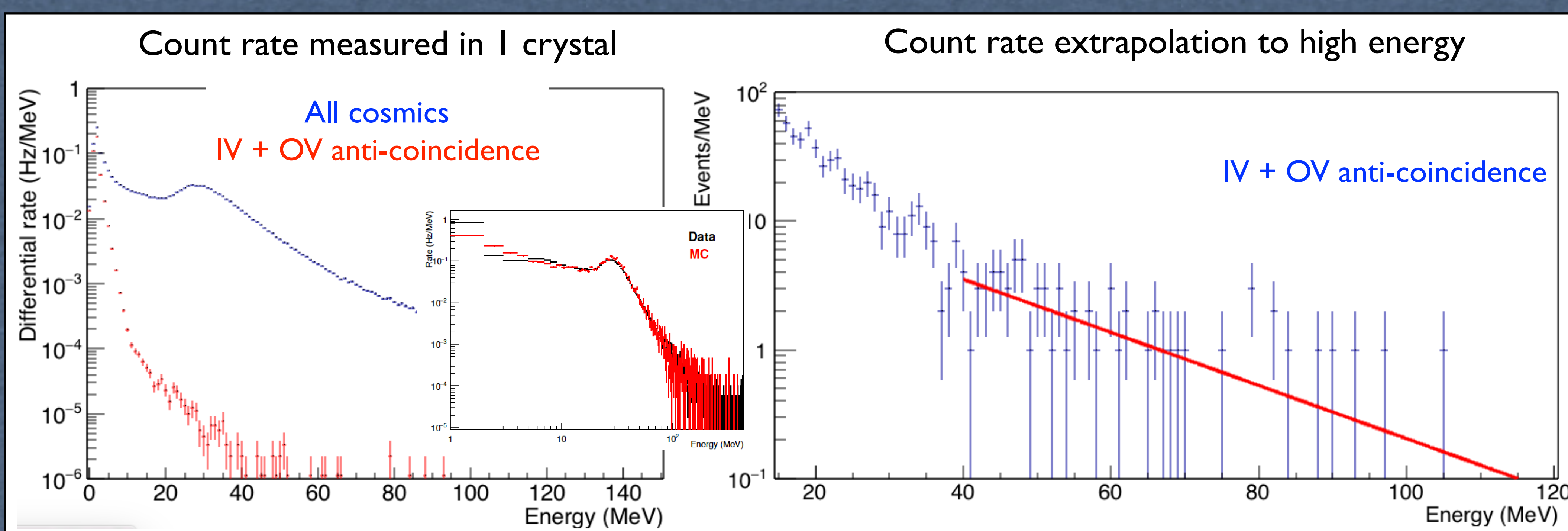
- Conservatively extrapolated from the (lower E) non-0 counts region
- Measured rate scaled to the JLab set-up (x800 crystals)

★ Perfect agreement with MC simulation



LNS set-up of BDX prototype





Cosmic background will be continuously and accurately measured during the experiment with **4x more** statistics

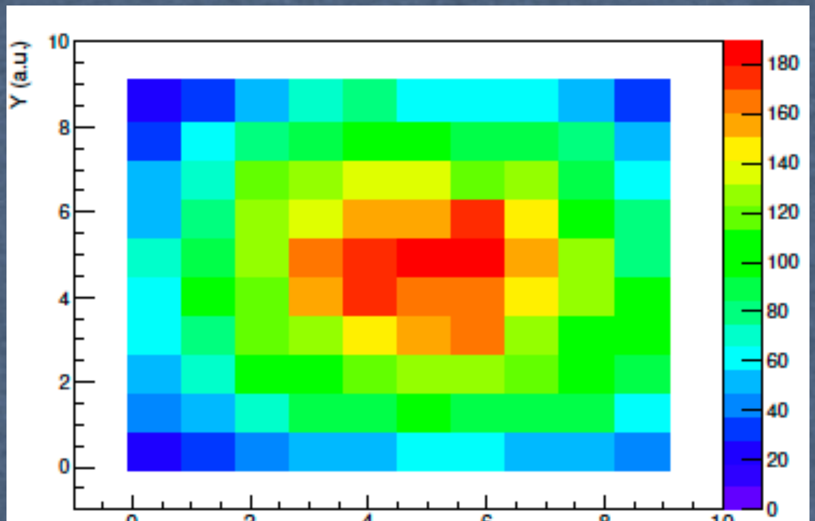
Signal vs cosmogenic background

- No time cuts applied (best timing with CsI ~ 10ns would require a dedicated matched beam structure)

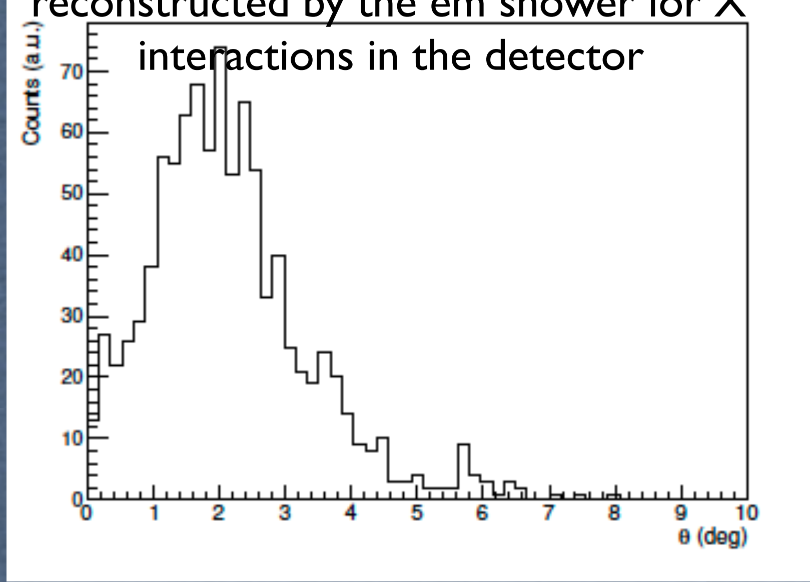
We can do better!

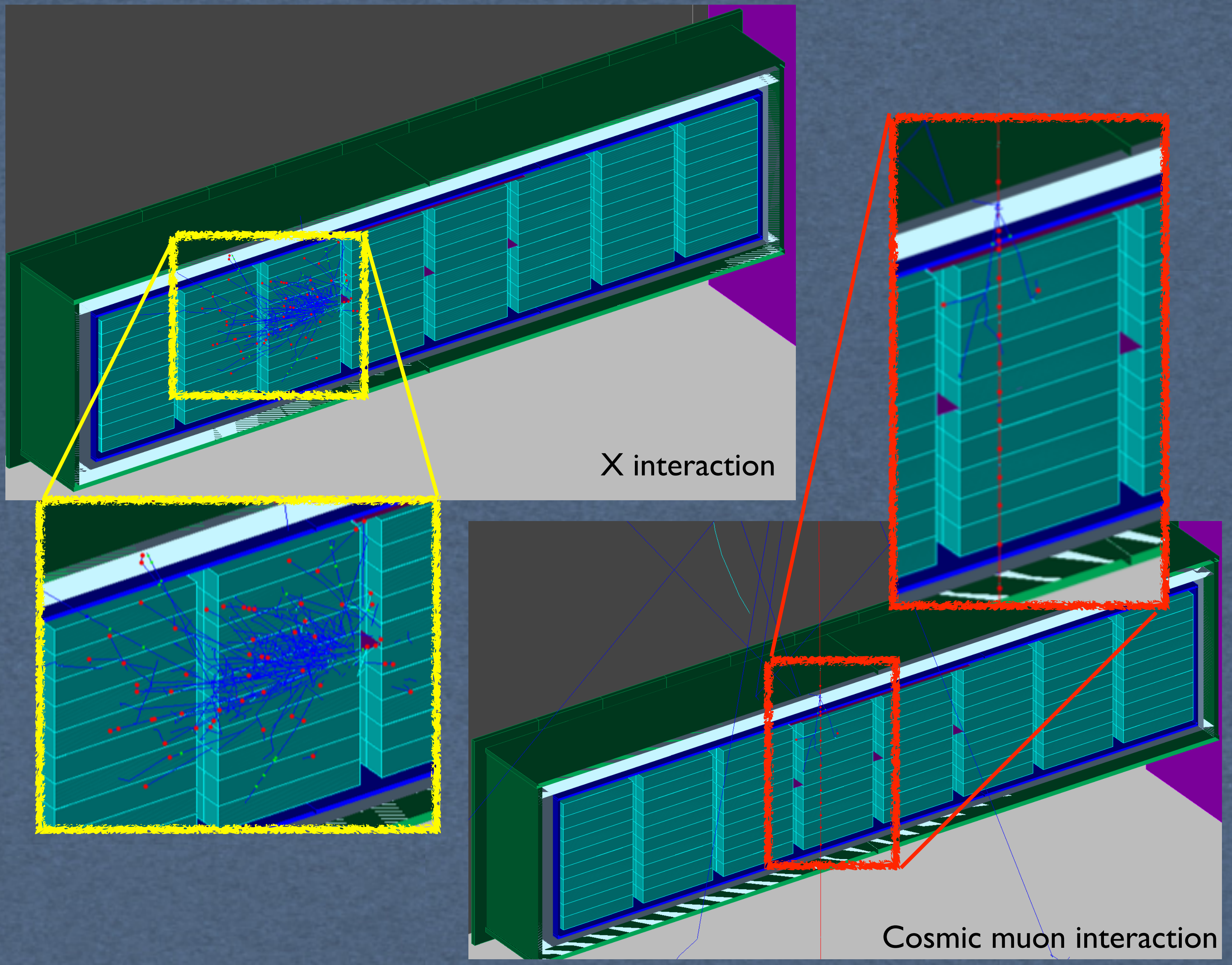
- No topology cuts applied

- No directionality cuts



theta angle (from the beam direction) reconstructed by the em shower for X interactions in the detector





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)

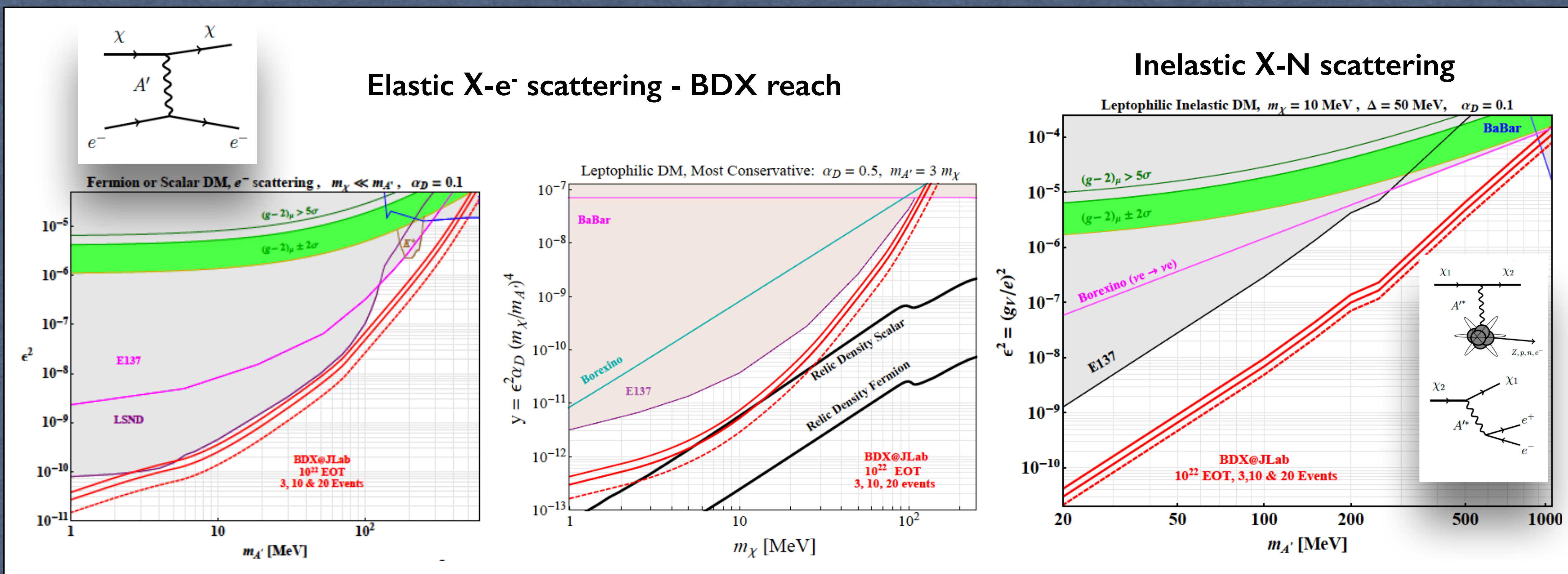
Beam-related background

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

Cosmic background

Energy threshold	√ Bg (285 days)
300 MeV	<2 counts

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



A roadmap towards BDX	Completion
Theory and physics case	100%
Detector R&D: signal detection and BG rejection	100%
Detector prototyping: cosmic BG assessment	100%
Detector prototyping: beam-related BG assessment	spring 2018 (10 GeV available in Hall-A)
BDX proposal submission to JLab Program Advisory Comm	C2-Approved; full approval summer 2018
Costs estimate	baseline fully defined
Funds procurement	full PAC approval required
The BDX Collaboration	Lobbying started
Costs optimization	custom electronics ready for 2018
TDR	2018-2019
Infrastructure and detector construction	2020-2022 (?)
Running BDX	2022-2025 in parallel to Moeller exp

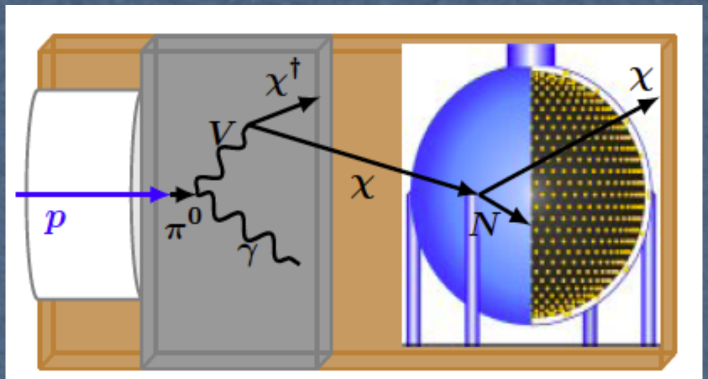
2014	2015	2016	2017	2018	2019	2020 - 2022
Theory and physics case	BDX prototype	R&D cosmic bg assessment	R&D cosmic EM shower	R&D BDX-Hodo	R&D Streaming RO DAQ	BDX detector construction
BDX Conceptual design	R&D cosmic bg assessment	R&D 16ch CsI matrix	R&D custom fADC	R&D beam-on assessment	BDX TDR	

New experimental results in 2017

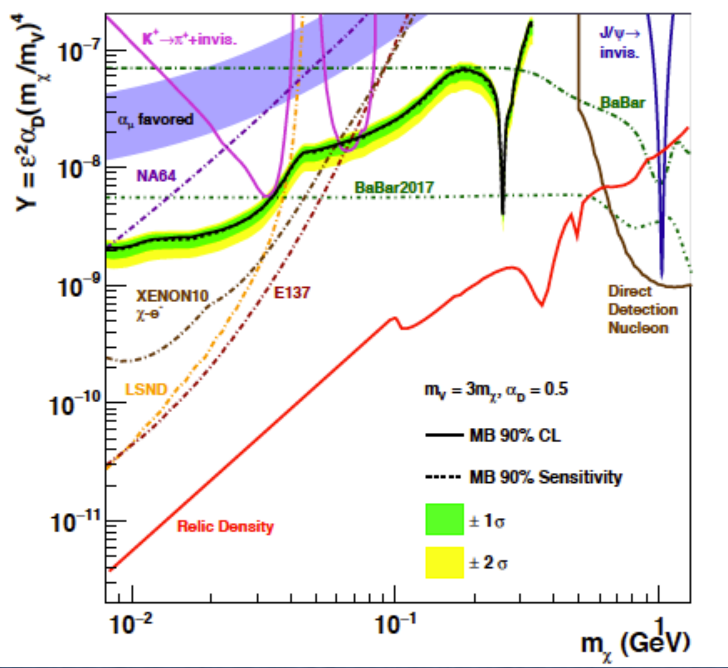
MiniBooNE@FERMILAB

PRL 118, 221803 (2017) PHYSICAL REVIEW LETTERS week ending 2 JUNE 2017

Dark Matter Search in a Proton Beam Dump with MiniBooNE



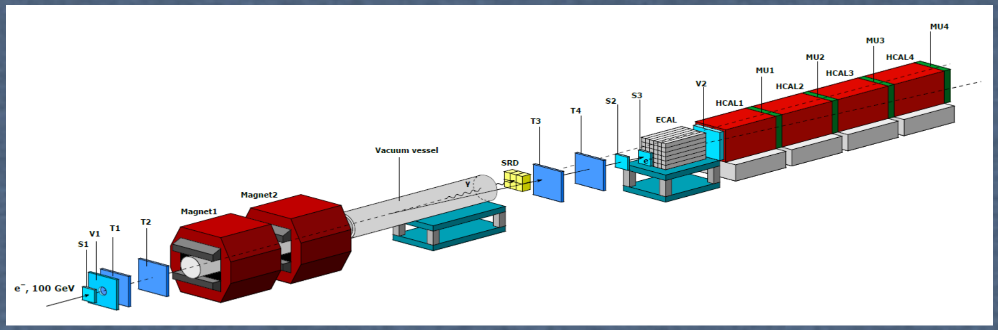
- BDX-like with an 8 GeV proton beam
- Cherenkov response of 12 m spherical detector with 800 tons mineral oil (CH2)
- Typical operation: 2×10^{20} protons on target (POT) per year



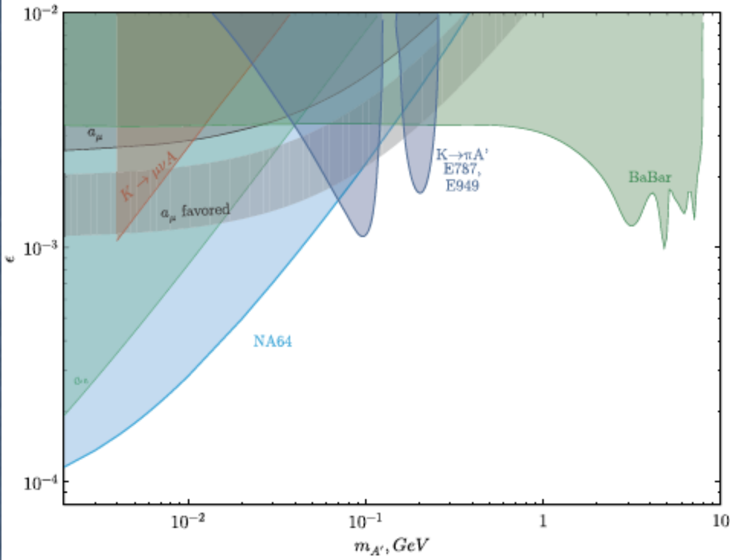
NA64@CERN

PRL 118, 011802 (2017) PHYSICAL REVIEW LETTERS week ending 6 JANUARY 2017

Search for Invisible Decays of Sub-GeV Dark Photons in Missing-Energy Events at the CERN SPS



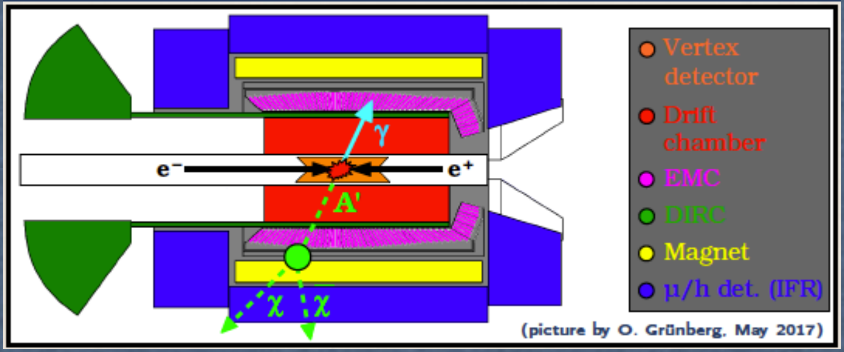
- Missing energy exp (e Z → e Z' A' with A' → invisible)
- 100 GeV SPS electron beam at SPS
- Active target (calorimeter)
- Exclusion plots based on 3×10^9 EOT



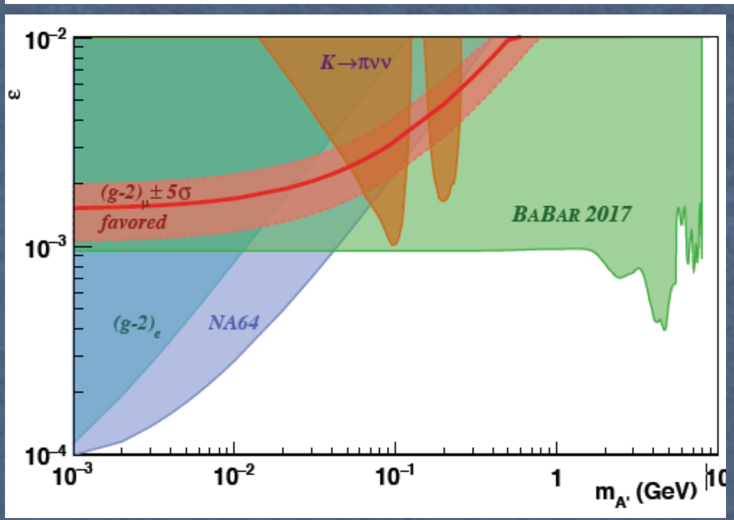
BaBar@SLAC

BABAR-PUB-17/001
SLAC-PUB-16923
arXiv:1702.03327v1 [hep-ex] 10 Feb 2017

Search for invisible decays of a dark photon produced in e^+e^- collisions at BABAR



- Missing mass exp (e- e+ → γ A' with A' → invisible)
- Mono-photon trigger
- Exclusion plots based on ~50 fb^{-1}



LDM searchers: a growing community

- ★ Growing word-wide (CERN, Mainz, LNF) and US (JLab, Fermilab SLAC, Cornell) interest for LDM searches
- ★ DOE-organized workshop in March 2017 at University of Maryland to identify new small projects for DM searches to complement the already approved program

U.S. Cosmic Visions: New Ideas in Dark Matter

23-25 March 2017 *Stamp Student Union, University of Maryland, College Park*
US/Eastern timezone

"To respond to the 2014 P5 report recommendations in the search for dark matter particles and maintaining a diversity of project scales in our program, **DOE Office of High Energy Physics (HEP) is interested in identifying new, small projects for dark matter searches in areas of parameter space (i.e. mass ranges or types of particles) not currently being (or on track to be) explored.** HEP is asking for community input in the spring 2017 timeframe in order to plan the program forward. Input is requested on the possibilities for small (the whole project is ~ $10 million or less) dark matter projects in unexplored parameter space. A community workshop, followed by a White Paper would be a good path to provide the input needed. We encourage you to collect information from the community, including theorists and experimentalists involved in non-accelerator and accelerator-based efforts."

US Cosmic Visions: New Ideas in Dark Matter 2017 : Community Report

Marco Battaglieri (SAC co-chair),[1] Alberto Belloni (Coordinator),[2] Aaron Chou (WG2 Convener),[3] Priscilla Cushman (Coordinator),[4] Bertrand Echenard (WG3 Convener),[5] Rouven Essig (WG1 Convener),[6] Juan Estrada (WG1 Convener),[3] Jonathan L. Feng (WG4 Convener),[7] Brenna Flaugher (Coordinator),[3] Patrick J. Fox (WG4 Convener),[3] Peter Graham (WG2 Convener),[8] Carter Hall (Coordinator),[2] Roni Harnik (SAC member),[3] JoAnne Hewett (Coordinator),[9,8] Joseph Incandela (Coordinator),[10] Eder Izaguirre (WG3 Convener),[11] Daniel McKinsey (WG1 Convener),[12] Matthew Pyle (SAC member),[12] Natalie Roe (Coordinator),[13] Gray Rybka (SAC member),[14] Pierre Sikivie (SAC member),[15] Tim M.P. Tait (SAC member),[7] Natalia Toro (SAC co-chair),[9,16] Richard Van De Water (SAC member),[17] Neal Weiner (SAC member),[18] Kathryn Zurek (SAC member),[13,12] Eric Adelberger,[14] Andrei Afanasev,[19] Derbin Alexander,[20] James Alexander,[21] Vasile Cristian Antochi,[22] David Mark Asner,[23] Howard Baer,[24] Dipanwita Banerjee,[25] Elisabetta Baracchini,[26] Phillip Barbeau,[27] Joshua Barrow,[28] Noemie Bastidon,[29] James Battat,[30] Stephen Benson,[31] Asher Berlin,[9] Mark Bird,[32] Nikita Blinov,[9] Kimberly K. Boddy,[33] Mariangela Bondì,[34] Walter M. Bonivento,[35] Mark Boulay,[36] James Boyce,[37,31] Maxime Brodeur,[38] Leah Broussard,[39] Ranny Budnik,[40] Philip Bunting,[12] Marc Caffee,[41] Sabato Stefano Caiazza,[42] Sheldon Campbell,[7] Tongtong Cao,[43] Gianpaolo Carosi,[44] Massimo Carpinelli,[45,46] Gianluca Cavoto,[22] Andrea Celentano,[1] Jae Hyeok Chang,[6] Swapan Chattopadhyay,[3,47] Alvaro Chavarria,[48] Chien-Yi Chen,[49,16] Kenneth Clark,[50] John Clarke,[12] Owen Colegrove,[10] Jonathon Coleman,[51] David Cooke,[25] Robert Cooper,[52] Michael Crisler,[23,3] Paolo Crivelli,[25] Francesco D'Eramo,[53,54] Domenico D'Urso,[45,46] Eric Dahl,[29] William Dawson,[44] Marzio De Napoli,[34] Raffaella De Vita,[1] Patrick DeNiverville,[55] Stephen Derenzo,[13] Antonia Di Crescenzo,[56,57] Emanuele Di Marco,[58] Keith R. Dienes,[59,2] Milind Diwan,[11] Dongwi Handiipondola Dongwi,[43] Alex Drlica-Wagner,[3] Sebastian Ellis,[60] Anthony Chigbo Ezeribe,[61,62] Glennys Farrar,[18] Francesc Ferrer,[63] Enectali Figueroa-Feliciano,[64] Alessandra Filippi,[65] Giuliana Fiorillo,[66] Bartosz Fornal,[67] Arne Freyberger,[31] Claudia Frugiuele,[40] Cristian Galbiati,[68] Iftah Galon,[7] Susan Gardner,[69] Andrew Geraci,[70] Gilles Gerbier,[71] Mathew Graham,[9] Edda Gschwendtner,[72] Christopher Hearty,[73,74] Jaret Heise,[75] Reyco Henning,[76] Richard J. Hill,[16,3] David Hitlin,[5] Yonit Hochberg,[21,77] Jason Hogan,[8] Maurik Holtrop,[78] Ziqing Hong,[29] Todd Hossbach,[23] T. B. Humensky,[79] Philip Ilten,[80] Kent Irwin,[8,9] John Jaros,[9] Robert Johnson,[53] Matthew Jones,[41] Yonatan Kahn,[68] Narbe Kalantarians,[81] Manoj Kaplinghat,[7] Rakshya Khatiwada,[14] Simon Knapen,[13,12] Michael Kohl,[43,31] Chris Kouvaris,[82] Jonathan Kozaczuk,[83] Gordan Krnjaic,[3] Valery Kubarovsky,[31] Eric Kuflik,[21,77] Alexander Kusenko,[84,85] Rafael Lang,[41] Kyle Leach,[86] Tongyan Lin,[12,13] Mariangela Lisanti,[68] Jing Liu,[87] Kun Liu,[17] Ming Liu,[17] Dinesh Loomba,[88] Joseph Lykken,[3] Katherine Mack,[89] Jeremiah Mans,[4] Humphrey Maris,[90] Thomas Markiewicz,[9] Luca Marsicano,[1] C. J. Martoff,[91] Giovanni Mazzitelli,[26] Christopher McCabe,[92] Samuel D. McDermott,[6] Art McDonald,[71] Bryan McKinnon,[93] Dongming Mei,[87] Tom Melia,[13,85] Gerald A. Miller,[14] Kentaro Miuchi,[94] Sahara Mohammed Prem Nazeer,[43] Omar Moreno,[9] Vasiliy Morozov,[31] Frederic Mouton,[61] Holger Mueller,[12] Alexander Murphy,[95] Russell Neilson,[96] Tim

arXiv:1707.04591v1 [hep-ph] 14 Jul 2017

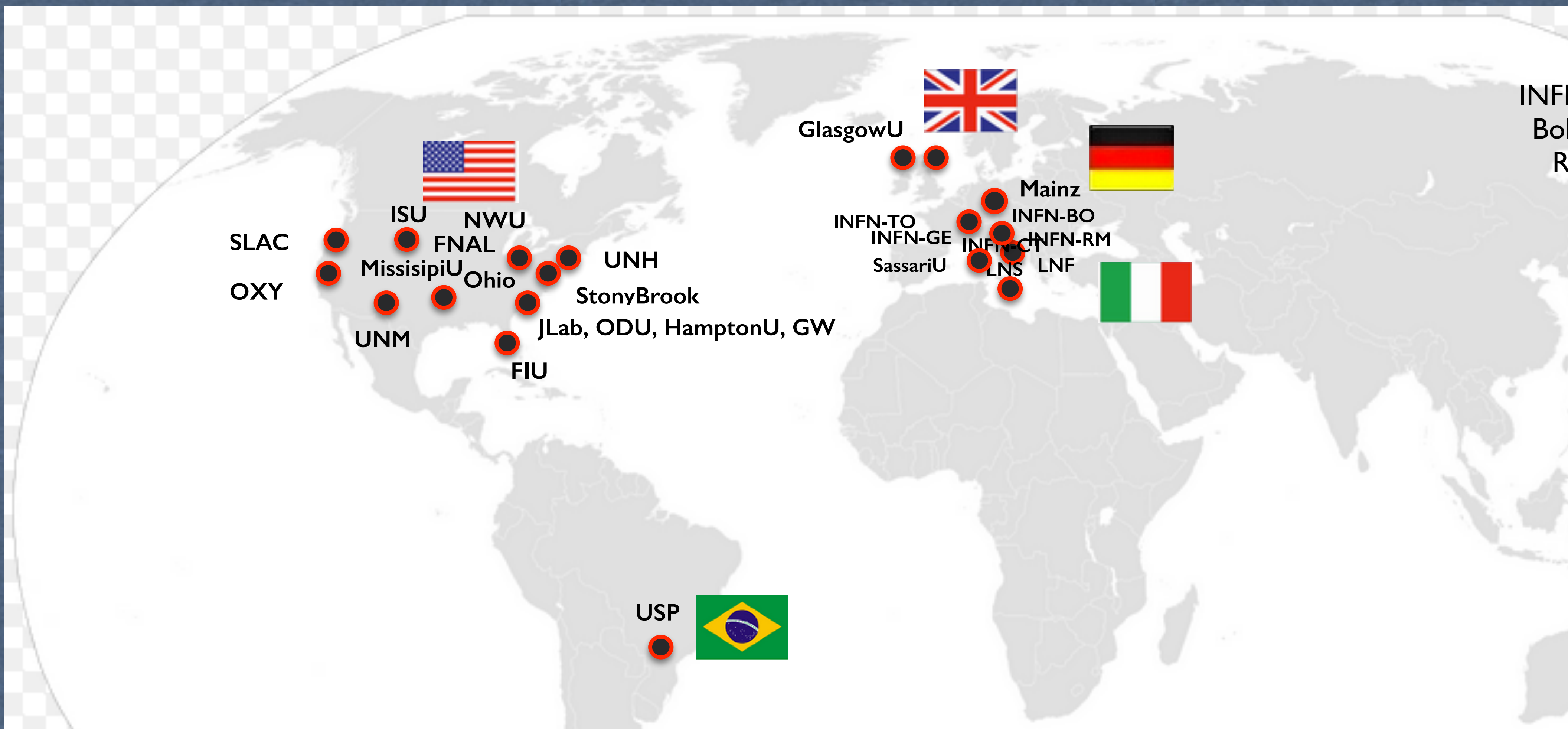
White paper submitted to DOE

- ★ The *white-paper* (signed by more than 200 researchers) will be used to evaluate the opportunity of DOE/NSF funding call for small (scale <$10M) project in the area to be launched soon (2018/19?)
- ★ **BDX has been included as a project in LDM searches with accelerators program**

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 to distinguish DM signal from any other cosmic anomalies or effects
- ✳Extensive experimental plans at high intensity e-facility: JLab, LNF, Cornell, Mainz, SLAC (+ p beam at FNAL and CERN)
- ✳ A detector based on CsI crystals + InnerVeto + Outer Veto running parasitically downstream of JLab Hall-A beam dump in 1y would set 10-100 times better limits
- ✳ Two BDX prototypes measured cosmic and beam-on background validating MC simulations and cosmic background estimates
- ✳We are ready to build a run the BDX experiment!
- ✳ Discovery or decisive tests of simplest scenarios will possible in the next ~5-8 years!

The BDX Collaboration



BDX Institutions

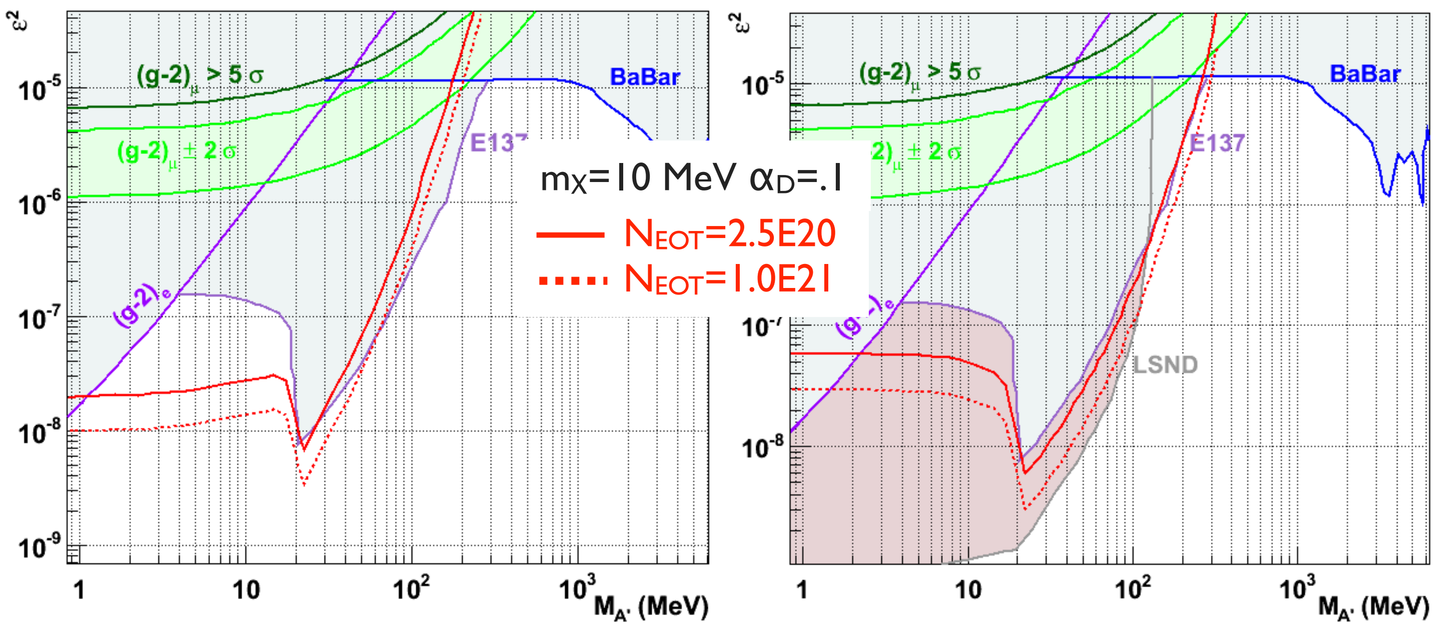
INFN-Italy: Genova, Catania, Roma, Bologna, Torino, LNS, LNF, Padova, RomaTV, SassariU, Ferrara, Bari, Lecce
Jefferson Lab
BNL
FNAL
Occidental College
University of New Mexico
SLAC
Ohio University
Stony Brook
Canisius College
University of New Hampshire
George Washington University
Missisipi Stae University
Hampton University
Old Dominio University
Northwestern University
Gulch
GlasgowU
IPN-Orsay

- More than 120 researchers signed the BDX proposal and this update
- Connection with groups involved in similar projects at SLAC, CERN, Mainz and LNF
- Core group working on different aspects: physics, detector, simulations
- Weekly meeting to check progresses and share information
- Wiki page to store documents and meetings minutes
- Organisation of dedicated workshops and satellite meetings at major venues
- R&D funds from INFN and grant requests submitted

Back up slides

Competition with other facilities

El scattering on electrons — El scattering on nucleon

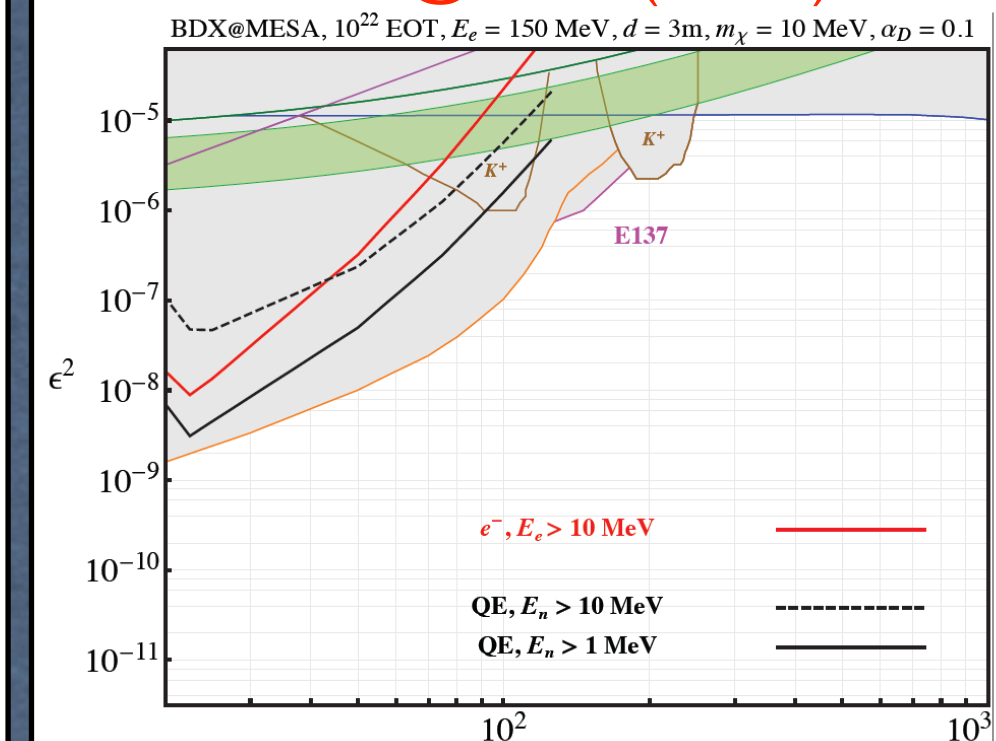


BDX @ LNF

- E_{e-} = 1.250 GeV (now 0.75GeV)
- EOT ~ 10^{20}-10^{21} year^{-1} (now 10^{19})
- Pulsed beam 50Hz
- Minimal infrastructure costs
- Re-use of BaBar crystals (~1080)
- Detector: 60x60x225 cm3 at 5m from the dump
- 1y run (within PADME Experiment)
- 2-3y from now

P.Valente

BDX@Mainz (MESA)

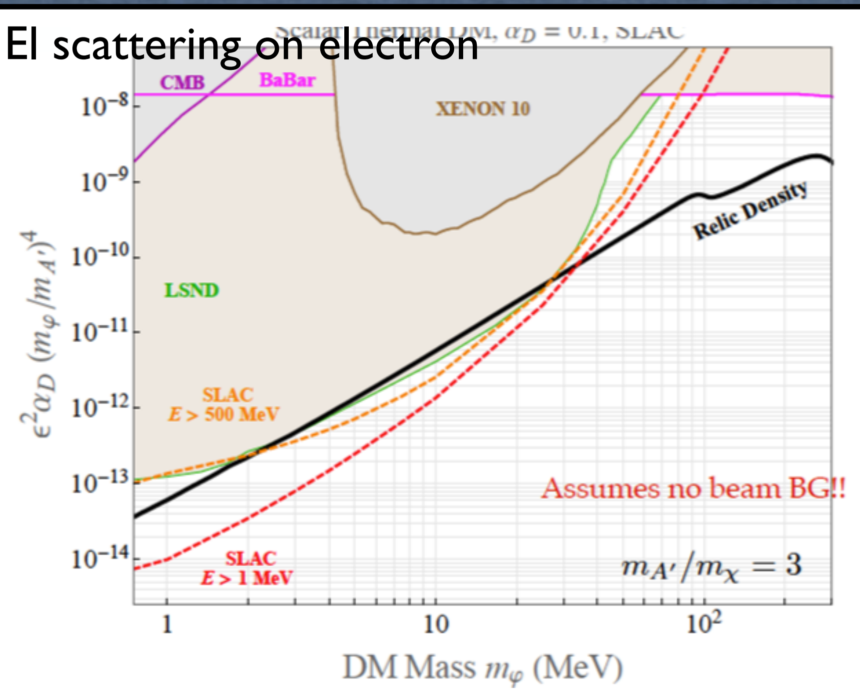


$m_{A'}$ (MeV)

- E_{e-} = 150 MeV
- EOT ~ 10^{22}
- CW beam (3ns)
- Infrastructure costs limited
- Time line ?
- Re-use of BaBar crystals (~1080)
- Detector: 60x60x225 cm3 at 3m from the dump
- 3y run (parasitic to PV exp)
- Proposal accepted

A.Denig

El scattering on electron



BDX@SLAC LCLSII

- E_{e-} = 4 (8) GeV
- EOT ~ 3 10^{21}
- Pulsed beam ~1MHz
- Reduced cosmogenic bg
- Beam dump area clear
- Infrastructure costs limited
- May be some bg from the X-ray line
- Time line: 2020

G.Krnjaic

BDX@Cornell

- E_{e-} = 200 MeV
- EOT ~ 2.5 10^{22}
- Energy Recovery machine with extracted beam
- Some interest for a BDX-like experiment
- Time line: 2019

J.Alexander

Theory and physics case

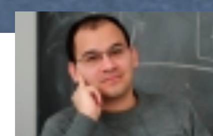

PHYSICAL REVIEW D **80**, 075018 (2009)

New fixed-target experiments to search for dark gauge forces

James D. Bjorken,[1] Rouven Essig,[1] Philip Schuster,[1] and Natalia Toro[2]
[1]*Theory Group, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[2]*Theory Group, Stanford University, Stanford, California 94305, USA*
(Received 20 July 2009; published 28 October 2009)


Fixed-target experiments are ideally suited for discovering new MeV–GeV mass $U(1)$ gauge bosons through their kinetic mixing with the photon. In this paper, we identify the production and decay properties of new light gauge bosons that dictate fixed-target search strategies. We summarize existing limits and suggest five new experimental approaches that we anticipate can cover most of the natural parameter space, using currently operating GeV-energy beams and well-established detection methods. Such experiments are particularly timely in light of recent terrestrial and astrophysical anomalies (PAMELA, Fermi, DAMA/LIBRA, etc.) consistent with dark matter charged under a new gauge force.

DOI: 10.1103/PhysRevD.80.075018 PACS numbers: 14.70.Pw, 95.35.+d




PHYSICAL REVIEW D **88**, 114015 (2013)

New electron beam-dump experiments to search for MeV to few-GeV dark matter

Eder Izaguirre, Gordan Krnjaic, Philip Schuster, and Natalia Toro
Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada
(Received 9 August 2013; published 3 December 2013)

In a broad class of consistent models, MeV to few-GeV dark matter interacts with ordinary matter through weakly coupled GeV scale mediators. We show that a suitable meter scale (or smaller) detector situated downstream of an electron beam dump can sensitively probe dark matter interacting via sub-GeV mediators, while B-factory searches cover the 1–5 GeV range. Combined, such experiments explore a well-motivated and otherwise inaccessible region of dark matter parameter space with sensitivity several orders of magnitude beyond existing direct detection constraints. These experiments would also probe invisibly decaying new gauge bosons ("dark photons") down to kinetic mixing of $\epsilon \sim 10^{-4}$, including the range of parameters relevant for explaining the $(g-2)_\mu$ discrepancy. Sensitivity to other long-lived dark sector states and to new millicharge particles would also be improved.

DOI: 10.1103/PhysRevD.88.114015 PACS numbers: 95.35.+d, 12.38.Qk


Running

- ★ APEX @JLab
- ★ HPS @JLab
- ★ Dark Light @ JLab
- ★ A1 @MAINZ
- ★ PADME @LNF
- ★ + Kloe, BaBar, NA62, LHCb, PHENOX, HADES, MiniBoone @FNAL

Future

- ★ MMAPS @Cornell
- ★ VEPP3 @BINP
- ★ NA64 @CERN
- ★ LDMX @SLAC
- ★ BELLE-II @KEK
- ★ SeaQuest @FNAL
- ★ MAGIC @MESA
- ★ SHIP @CERN

G.Krjnaic and E.Izaguirre are BDX spokespersons

Strong physics case with leading theorists involved in the experiment

arXiv.org > hep-ph > arXiv:1311.0029 Search or Article ID (Help | Advance

High Energy Physics – Phenomenology

Dark Sectors and New, Light, Weakly-Coupled Particles

R. Essig, J. A. Jaros, W. Wester, P. Hansson Adrian, S. Andreas, T. Averett, O. Baker, B. Batell, M. Battaglieri, J. Beacham, T. Beranek, J. D. Bjorken, F. Bossi, J. R. Boyce, G. D. Cates, A. Celentano, A. S. Chou, R. Cowan, F. Curciarello, H. Davoudiasl, P. deNiverville, R. De Vita, A. Denig, R. Dharmapalan, B. Dongwi, B. Döbrich, B. Eche D. Espriu, S. Fegan, P. Fisher, G. B. Franklin, A. Gasparian, Y. Gershtein, M. Graham, P. W. Graham, A. Haas, A. Hatzikoutelis, M. Holtrop, I. Irastorza, E. Izaguirre, J. Jaeckel, Y. Kahn, N. Kalantarians, M. Kohl, G. Krnjaic, V. Kubarovsky, H-S. Lee, A. Lindner, A. Lobanov, W. J. Marciano, D. J. E. Marsh, T. Maruyama, D. McKeen, H. Merk Moffeit, P. Monaghan, G. Mueller, T. K. Nelson, G.R. Neil, M. Oriunno, Z. Pavlovic, S. K. Phillips, M. J. Pivovaroff, (26 additional authors not shown)

(Submitted on 31 Oct 2013)

Dark sectors, consisting of new, light, weakly-coupled particles that do not interact with the known strong, weak, or electromagnetic forces, are a particularly compelling possibility for new physics. Nature may contain numerous dark sectors, each with their own beautiful structure, distinct particles, and forces. This review summarizes the physics motivation for dark sectors and the exciting opportunities for experimental exploration. It is the summary of the Intensity Frontier subgroup "New, Light, Weakly-coupled Particles" of the Community Summer Study 2013 (Snowmas We discuss axions, which solve the strong CP problem and are an excellent dark matter candidate, and their generalization to axion-like particles. We also review dark photons and other dark-sector particles, including sub-Ge dark matter, which are theoretically natural, provide for dark matter candidates or new dark matter interactions, and could resolve outstanding puzzles in particle and astro-particle physics. In many cases, the exploration of dark sectors can proceed with existing facilities and comparatively modest experiments. A rich, diverse, and low-cost experimental program has been identified that has the potential for one or more game-changing discoveries. These physics opportunities should be vigorously pursued in the US and elsewhere.

arXiv.org > hep-ph > arXiv:1608.08632 Search or Article ID (Help | Advanced search)

High Energy Physics – Phenomenology

Dark Sectors 2016 Workshop: Community Report

Jim Alexander, Marco Battaglieri, Bertrand Echenard, Rouven Essig, Matthew Graham, Eder Izaguirre, John Jar Gordan Krnjaic, Jeremy Mardon, David Morrissey, Tim Nelson, Maxim Perelstein, Matt Pyle, Adam Ritz, Philip Schuster, Brian Shuve, Natalia Toro, Richard G Van De Water, Daniel Akerib, Haipeng An, Konrad Aniol, Isaac Arnquist, David M. Asner, Henning O. Back, Keith Baker, Nathan Baltzell, Dipanwita Banerjee, Brian Batell, Da Bauer, James Beacham, Jay Benesch, James Bjorken, Nikita Blinov, Celine Boehm, Mariangela Bondí, Walter Bo Fabio Bossi, Stanley J. Brodsky, Ran Budnik, Stephen Bueltmann, Masroor H. Bukhari, Raymond Bunker, Massi Carpinelli, Concetta Cartaro, David Cassel, Gianluca Cavoto, Andrea Celentano, Animesh Chaterjee, Saptarsh Chaudhuri, Gabriele Chiodini, et al. (154 additional authors not shown)

(Submitted on 30 Aug 2016)

This report, based on the Dark Sectors workshop at SLAC in April 2016, summarizes the scientific importance of searches for dark sector dark matter and forces at masses beneath the weak-scale, the status of this broad international field, the important milestones motivating future exploration, and promising experimental opportun to reach these milestones over the next 5-10 years.

arXiv.org > hep-ph > arXiv:1707.04591 Search or Article ID (Help | Advanced search)

High Energy Physics – Phenomenology

US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report

Marco Battaglieri, Alberto Belloni, Aaron Chou, Priscilla Cushman, Bertrand Echenard, Rouven Essig, Juan Estrada, Jonathan L. Feng, Brenna Flaugher, Patrick J. Fox, Peter Graham, Carter Hall, Roni Harnik, JoAnne Hewett, Joseph Incandela, Eder Izaguirre, Daniel McKinsey, Matthew Pyle, Natalie Roe, Gray Rybka, Pierre Sikivie, Tim M. P. Tait, Natalia Toro, Richard Van De Water, Neal Weiner, Kathryn Zurek, Eric Adelberger, Andrei Afanasev, Derbin Alexander, James Alexander, Vasile Cristian Antochi, David Mark Asner, Howard Baer, Dipanwita Banerjee, Elisabetta Baracchini, Phillip Barbeau, Joshua Barrow, Noemie Bastidon, James Battat, Stephen Benson, Asher Berlin, Mark Bird, Nikita Blinov, Kimberly K. Boddy, Mariangela Bondi, Walter M. Bonivento, Mark Boulay, James Boyce, Maxime Brodeur, Leah Broussard, et al. (201 additional authors not shown)

(Submitted on 14 Jul 2017)

This white paper summarizes the workshop "U.S. Cosmic Visions: New Ideas in Dark Matter" held at University of Maryland on March 23-25, 2017.

Costs

BDX detector	~0.725M (0.475M)
Infrastructure at JLab	~1.5M

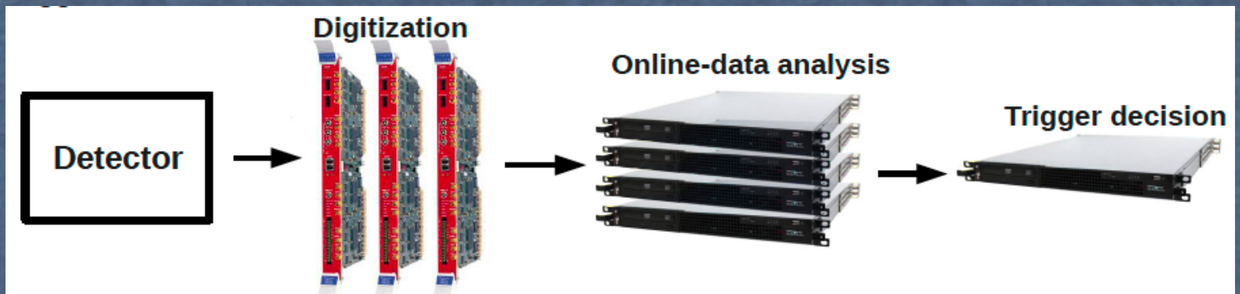
Calorimeter					120k
	CsI(Tl) crystals	~900	refurbishing, wrapping	20k	(new CsI ~3.5M!)
	(6x6) mm2 SiPM	~900	new procurement	50k	
	Front-End RO and cables	~900ch	new procurement	35k	
	Mechanical		design, procurement	15k	
Inner Veto					35k
	Plastic scintillator	~4 m^2, 8 paddles	new procurement	25k	
	(3x3) mm^2 SiPM	~90	new procurement	5k	
	mechanical		design, procurement	5k	
Outer Veto					65k
	Plastic scintillator	~12 m^2, 30 paddles	new procurement	50k	
	PMT	28	refurbishing	5k	
	mechanical		design, procurement	10k	
DAQ					
	CAEN V1725	1000	procurement (custom boards)		500k (250k)
Shielding	Lead bricks	~500	refurbishing		5k

Cost optimization: custom triggerless DAQ

BDX DAQ will be based on fADCs

- CsI(Tl) decay time & low thresholds are incompatible with "traditional" (TDC+QDC)-based DAQ
- Full waveform recording: reduce backgrounds and allow detailed off-line analysis
- Expected 16 MB/s data rate

16MB/s = 5Hz x 1000 crystals x 2048samples x 12 bit



Triggerless - commercial

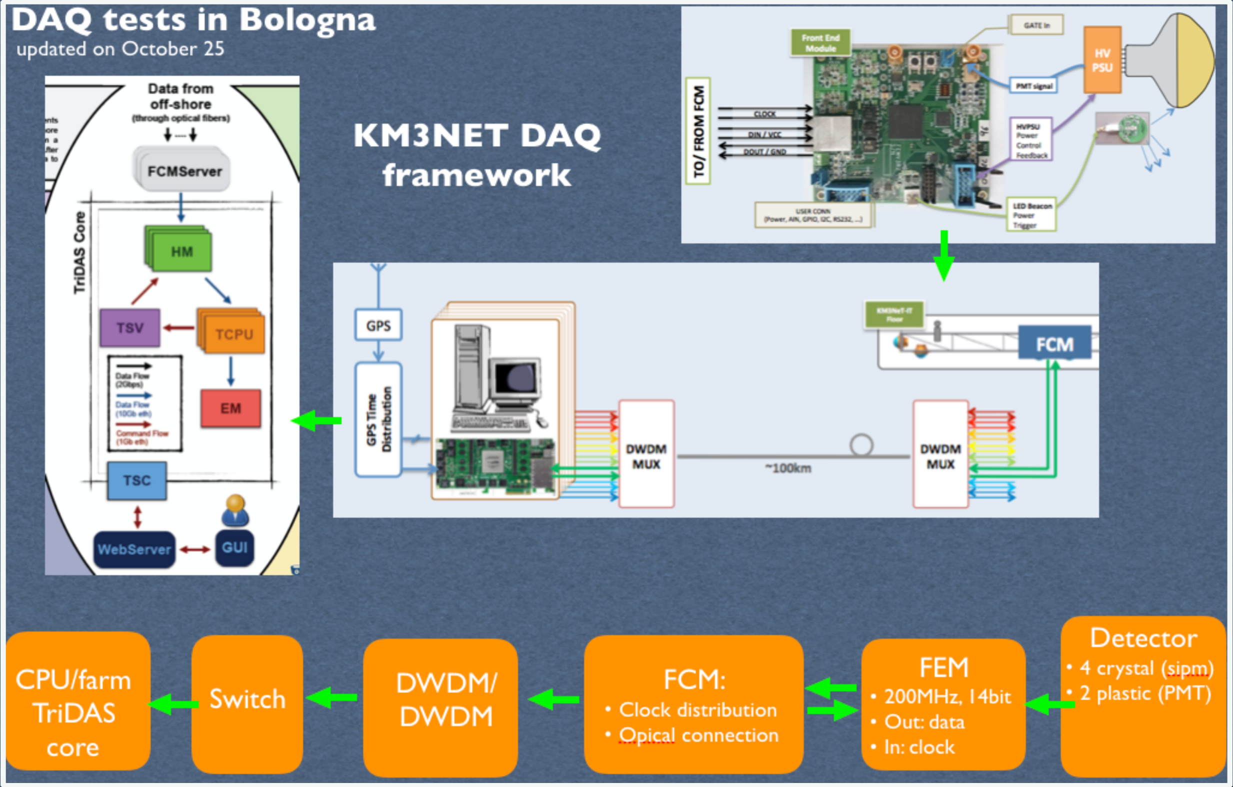
- trigger-less system, based on commercial fADC
- On the shelf but expensive

Triggerless - custom

- trigger-less, based on a custom DAQ: single-channels digitizers, integrated in the front-end electronic
- Requires ad-hoc hardware, firmware, and software development
- Similar approach used in other experiments (KM3, PANDA)
- May benefit of technology/solutions sharing with reduced costs

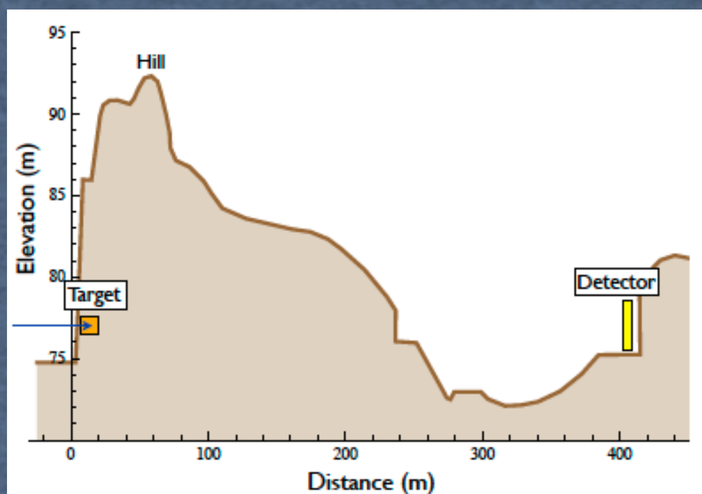
New fADC board development

- 12ch, 14bit, 250MHz, triggerless capability
- optimized for sipm ro (FE on board)
- estimate 50% saving on costs with superior performances
- Collaboration between:
  - INFN-GE Servizio Elettronica
  - LaSapienza - LabE
  - INFN-BO
- Reuse of the work done for KM3NET (hw and sw):

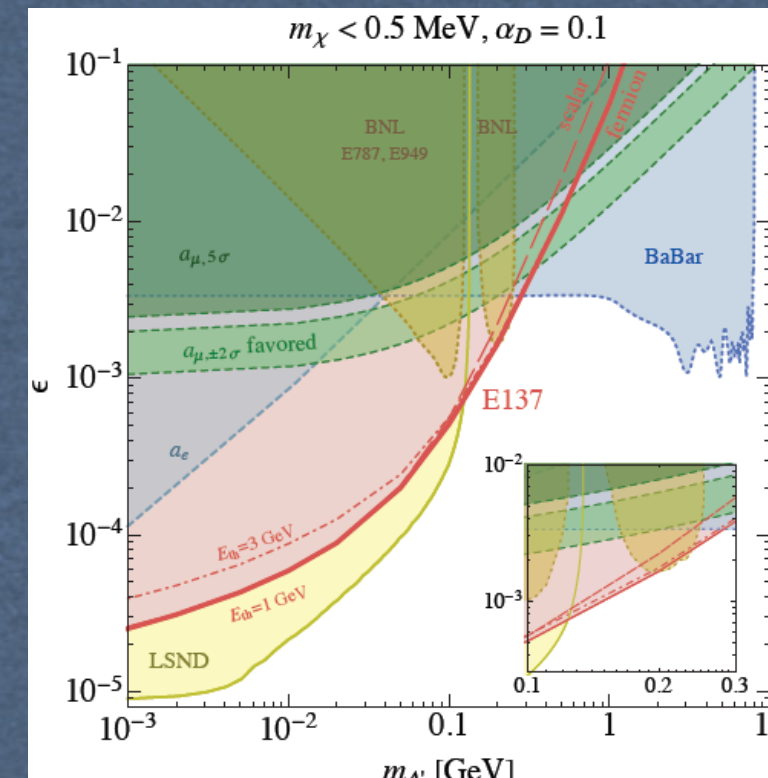


A critical review of upper limits derived from old experiments

E137@SLAC (<1988)

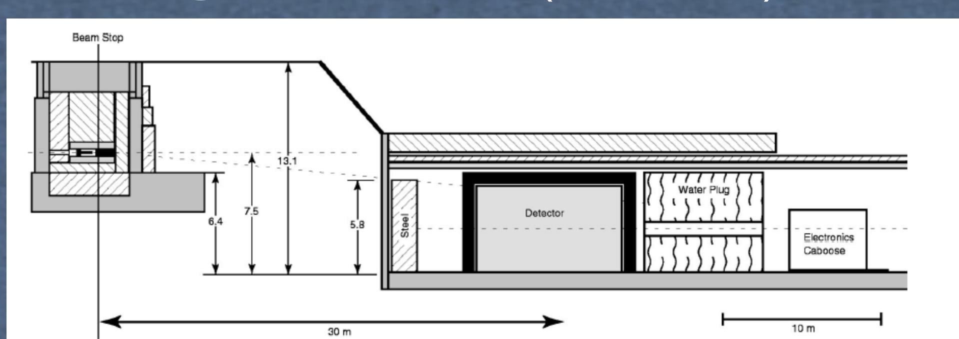


- SLAC electron beam: 20 GeV 2x10^{20} EOT
- Detector: 8 r.l. em calorimeter (hodo + converter + MWPC)
- Size: 1.5m x1.0 m at ~380m from the BD
- Cosmic bg suppressed by directionality and time coincidence
- Detection Threshold: 1-2 GeV
- 0 events detected

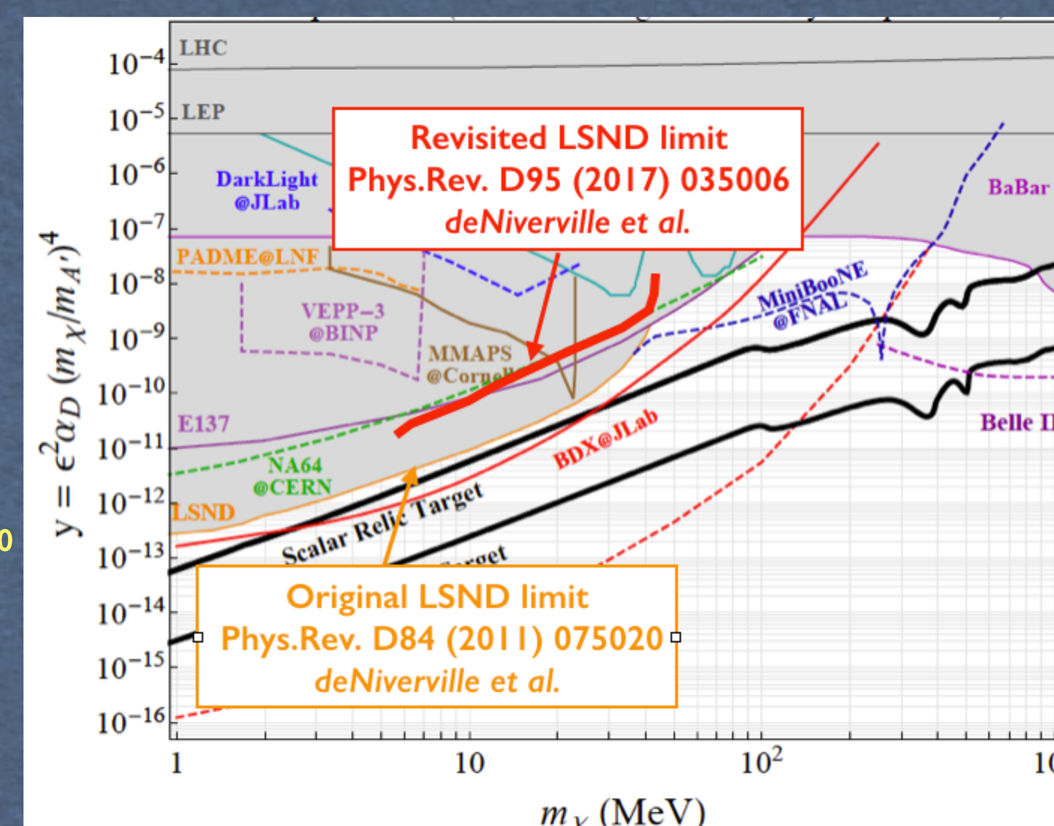


- Extracted upper limits suffer by poor knowledge of experimental details
- No e$^-$ showering in the BD included: softer DM E spectrum and defocused DM beam
- Limits are overestimated by a factor ~3-4 (depending on the kinematics)

LSND@LosAlamos (1994/98)



- 800 MeV protons to LANSCE beam dump
- From $\pi^0 \rightarrow A' \gamma$ decay (and A' → X X)



- Upper limits extracted in 2011 using a wrong π^+ spectrum to normalise π^0
- Recently recalculated, fund to be overestimated by a factor ~4-5

BDX is the first beam-dump experiment optimised for LDM searches

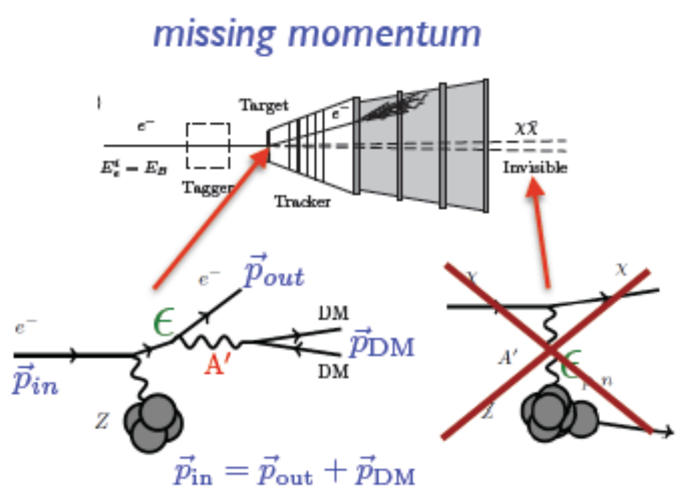
BDX & future experiments

LDMX@SLAC

Missing momentum experiments maximize sensitivity per luminosity using a challenging technique

LDMX

- If the experimental technique will be proved, Phase I (1e$^-$ / 25ns @ 4GeV) will be able to increase x10 BDX sensitivity
- When technical difficulties will be resolved Phase II (1e$^-$ / 1ns @ 8GeV) will gain another x40 in sensitivity

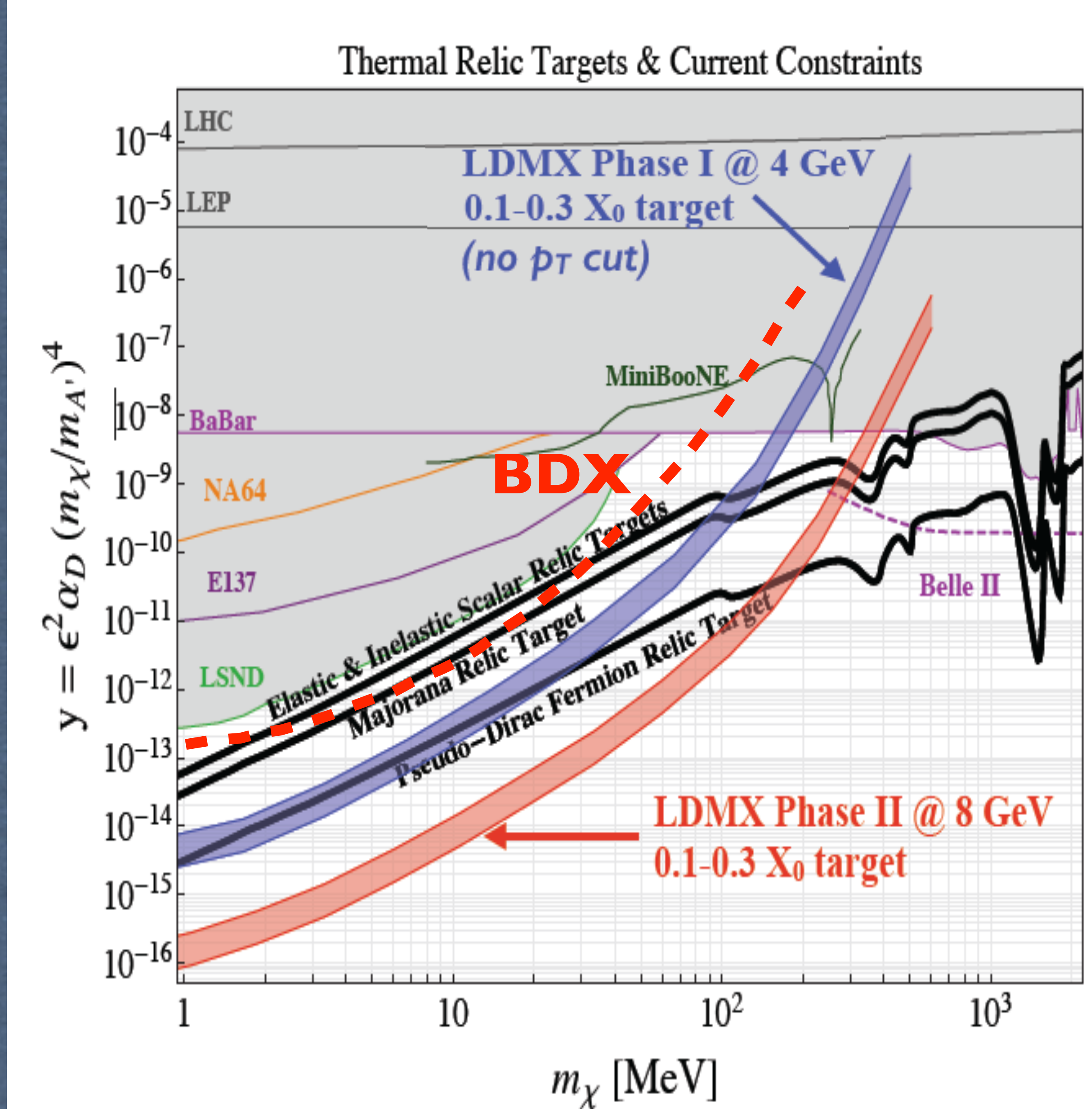


… but

MissingMomentum vs BeamDump
(*disappearance* vs *appearance*)

… **more sensitive** in the exclusion plots but
less reliable/convincing in case of positive finding!

The two experimental approaches are complementary



★BDX will reach the ultimate sensitivity of beam dump experiments hitting the irreducible ν bg with a consolidated technology ready-to-go

★LDMX presents challenges that if/when overcome will lead the 2nd generation LDM searches experiments