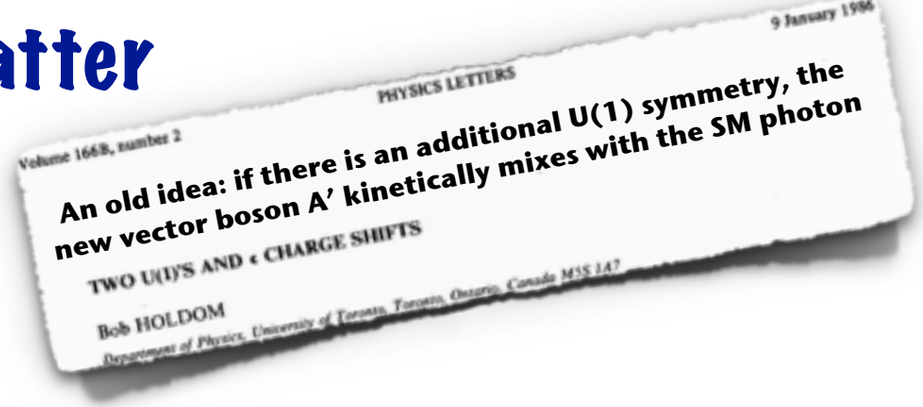
The Beam Dump eXperiment @ JLAB

Mariangela Bondì on behalf of BDX collaboration

INFN Sezione di Catania

International Symposium:
Advances in Dark Matter and Particle Physics 2016
23 - 27 October 2016 Messina, Italy

Dark forces and dark matter
(Light DM - light mediator)


Volume 166B, number 2 PHYSICS LETTERS 9 January 1986

An old idea: if there is an additional U(1) symmetry, the new vector boson A' kinetically mixes with the SM photon

TWO U(1)'S AND ε CHARGE SHIFTS

Bob HOLDOM

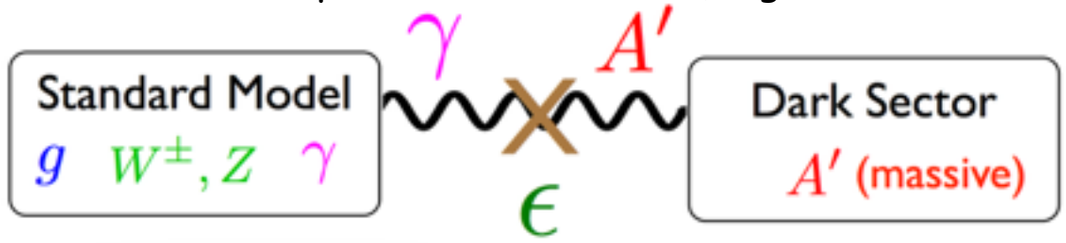
Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7

A well motivated scenario.....

4 parameters: $M_{A'}$, M_X, ε, g_d

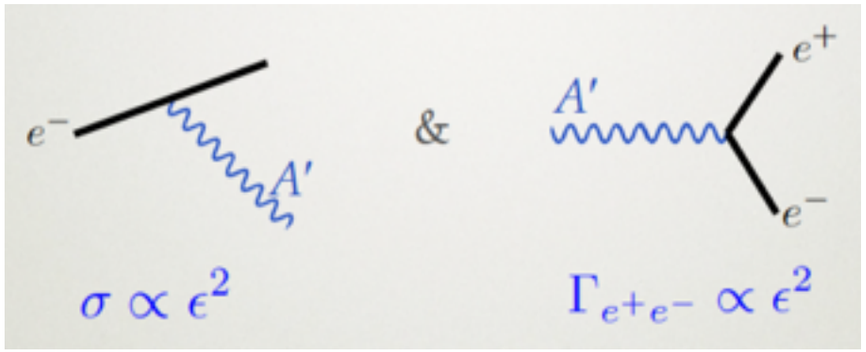
Supposed that:

- A' interacts with γ-kinetic mixing
- MeV - GeV DM particles χ interact with A'



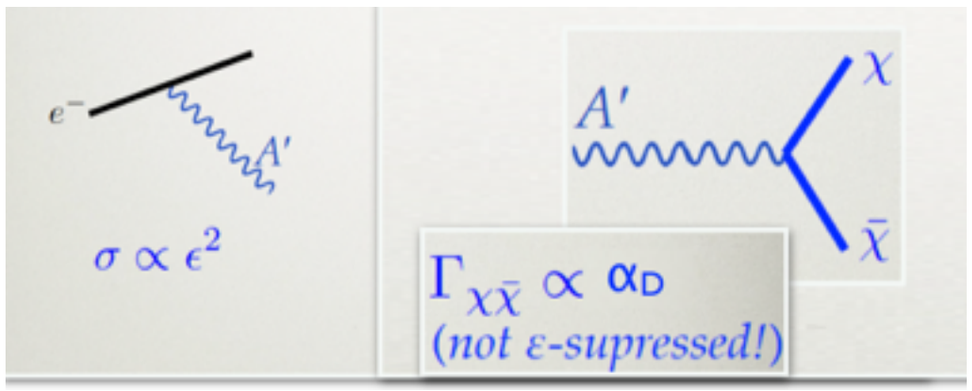
Visible decay

- Decay regulated by ε^2
- Independent on m_χ
- Requires $m_{A'}<2\ m_\chi$



Invisible decay

- Requires $m_{A'}>2\ m_\chi$
- Independent on ε



BDX is searching for the A' invisible decay to Light Dark Matter

Mariangela Bondì

ADMPP16 23 - 27 October 2016 Messina, Italy

LDM direct detection in an e- beam, fixed-target setup


PHYSICAL REVIEW D 88, 114015 (2013)

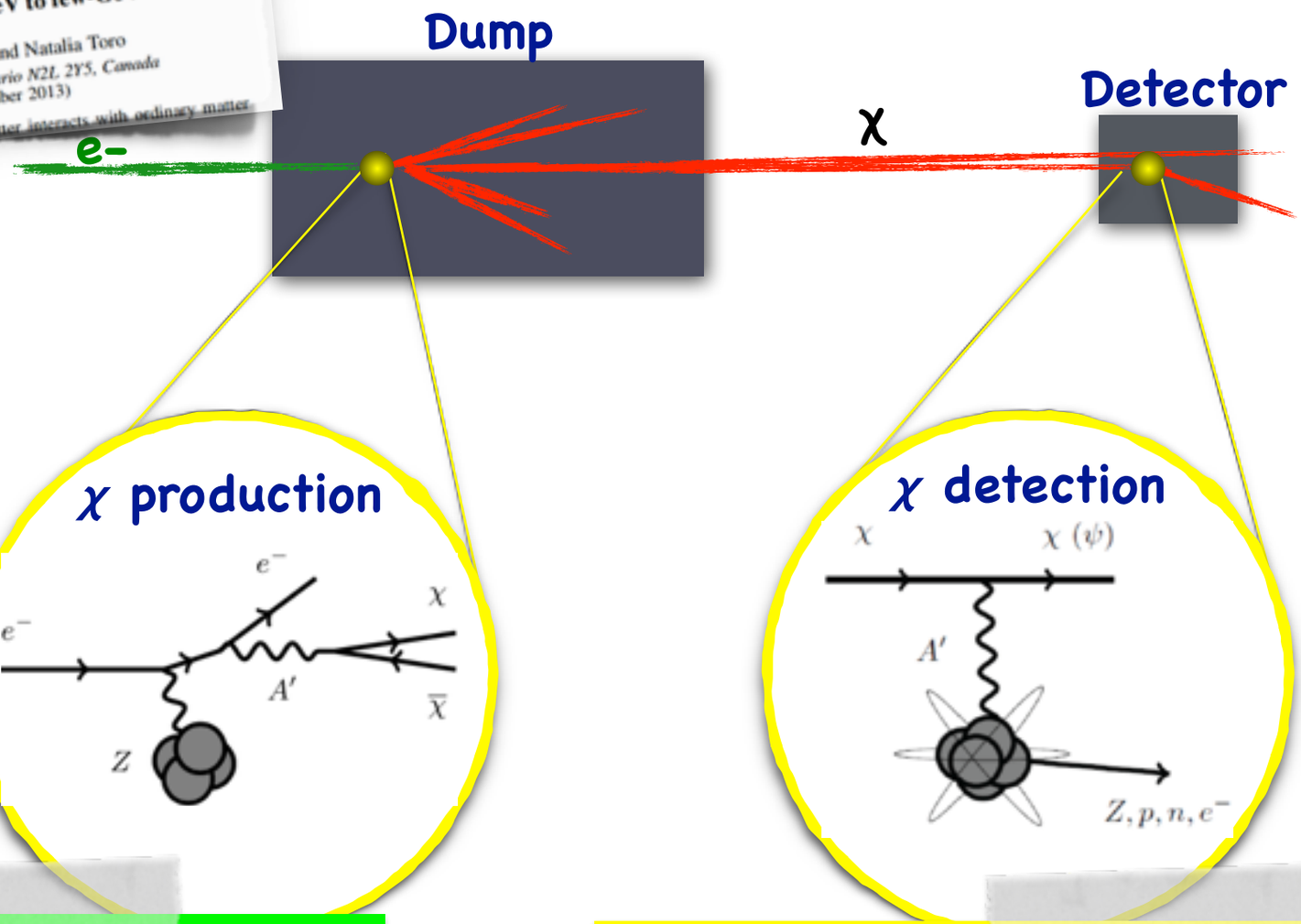
ew electron beam-dump experiments to search for MeV to few-GeV dark matter

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

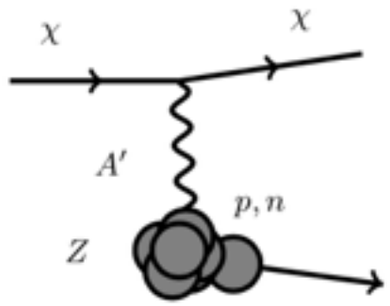


- High energy, high intensity e^- impinging on a dump
- χ particles pair produced through A' emission and decay

- Detector placed behind the dump, O(10m)
- Neutral current χ scattering A' exchange, recoil releasing visible energy
- Different signals depending on the interactions (e- elastic, p quasi-elastic,….)

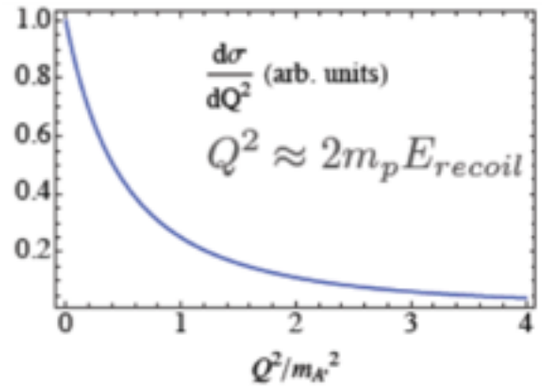
χ detection

χ - nucleon scattering

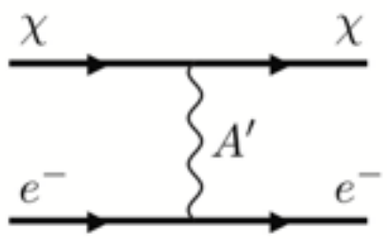


Detection of low energy ~MeV recoil protons

- **Low energy thresholds**
- **Background rejection capability**



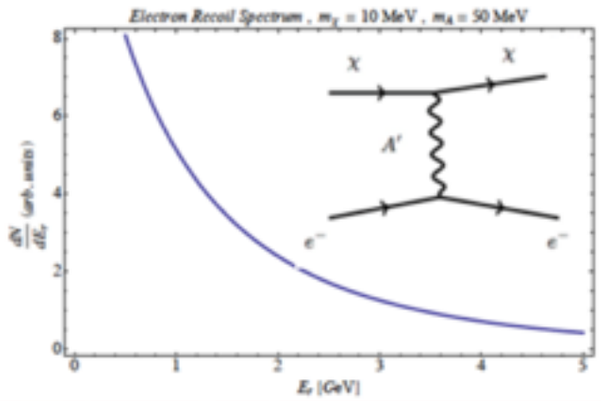
χ - electron scattering



Detection of ~GeV electrons

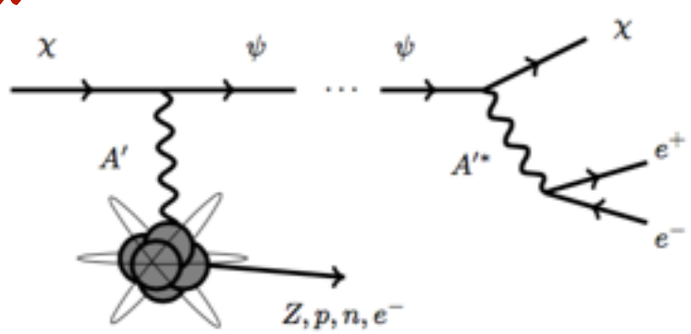
- **EM showers**

➡ **Easy background rejection**



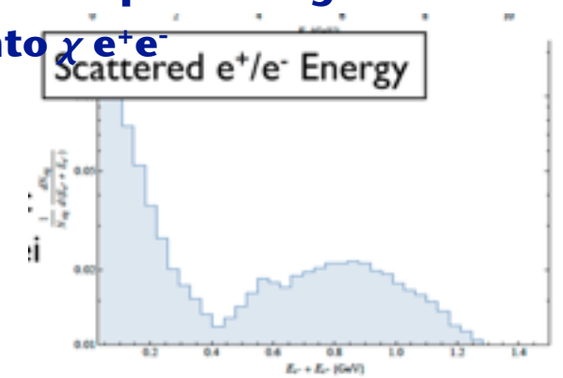
χ - e/N inelastic scattering

χ scatters inelastically on a nucleon/electron producing an excited state Ψ that decays into χ e⁺e⁻



- **~100 MeV proton recoil**
- **~GeV electrons (EM showers)**
- **high energy e⁺- e⁻ pair**

➡ **Easy background rejection**



BDX experimental signatures : X-electron/X-N inelastic -> EM shower ~ GeV energy

- The X-nucleon elastic scattering transfer a limited energy (few MeV)
- It could be used to check systematics

BDX

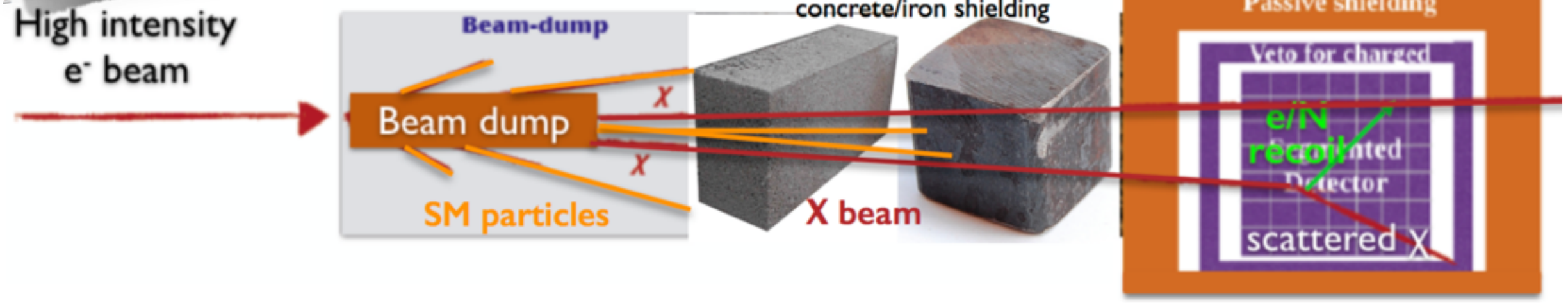
BDX layout

arXiv:1607.01390 [hep-ex]

Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab

The BDX Collaboration

Jul 2016



the eternal fight in physics: signal vs background

Producing and detecting LDM

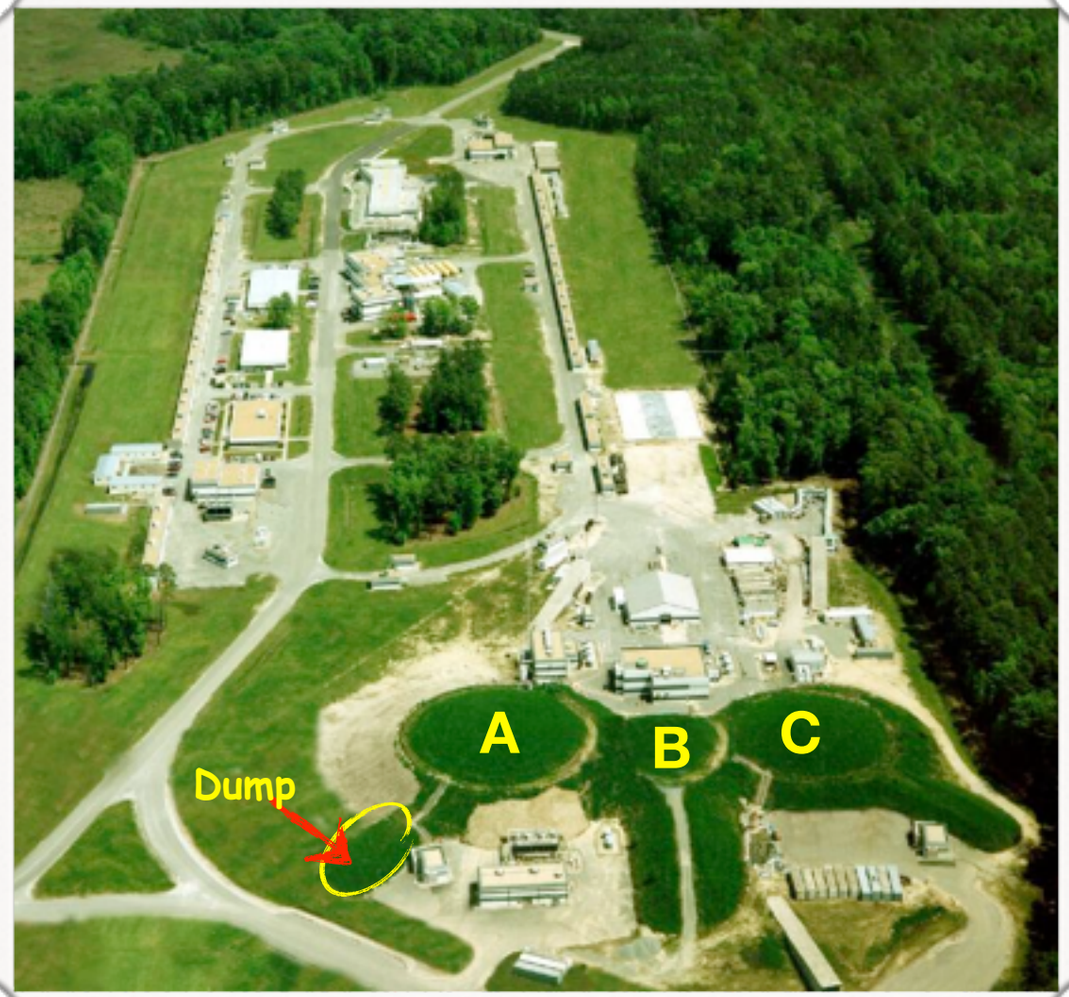
- High intensity ~ GeV e- beam, O(10^{22}) EOT
- 1m3 (1-5 tons) detectors
- EM-showers detection capability

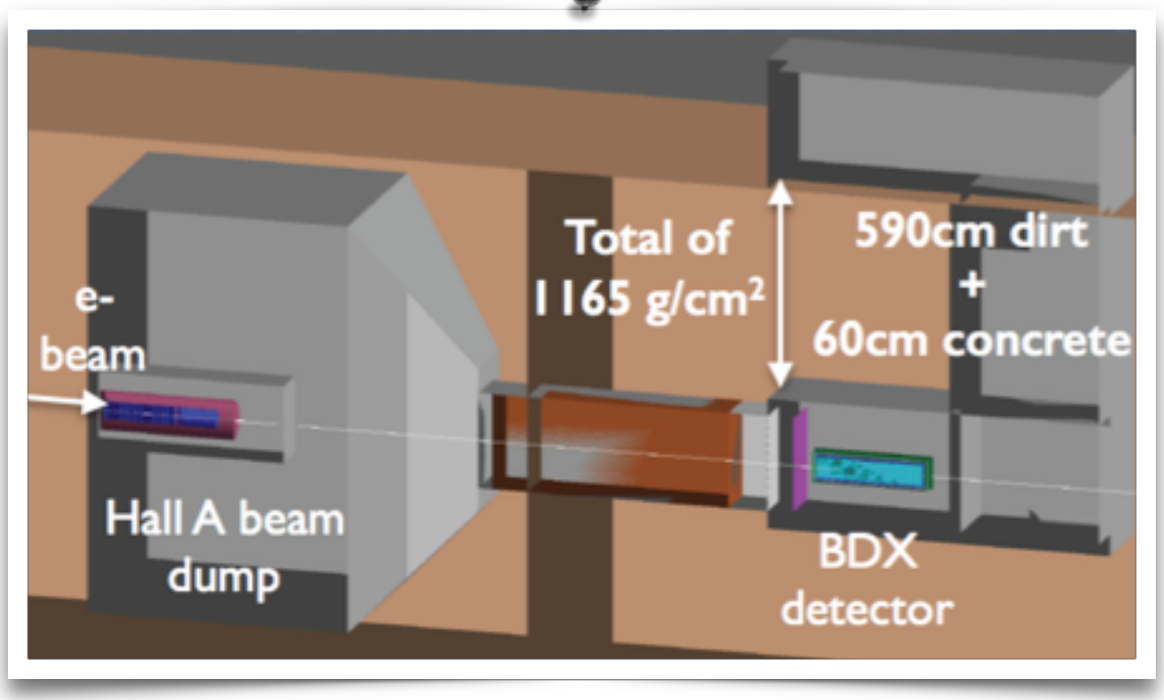
Reducing background

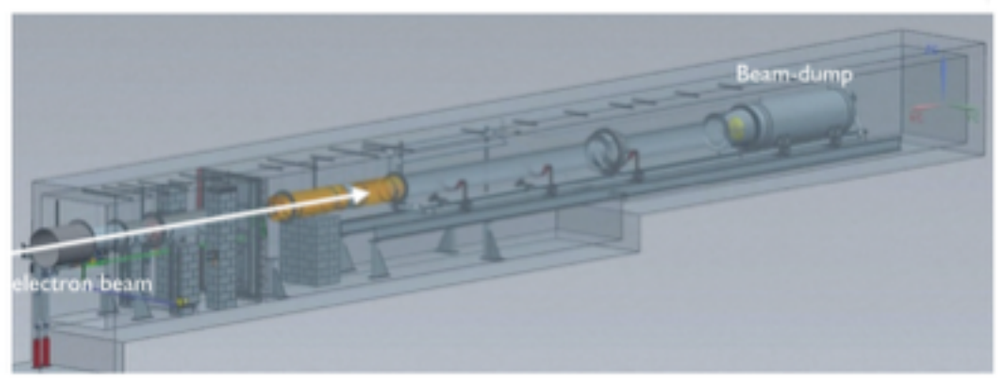
- Active vetos
- Passive shielding
- Segmented detector for events discrimination (topology, directionality)

BDX @ JLAB:
ideal location is behind the Hall-A beam dump

- ✓ High electron beam current ~ 65 μA (integrated charge 10^{22} EOT in 41 weeks)
- ✓ Energy beam available: 11 GeV
- ✓ Almost continuos beam (4ns bunch separation)
- ✓ New underground experimental Hall







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BDX detector concept

Detecting the X

Detector Requirements

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

Active Veto Requirements

- ✓ High efficiency & hermetic
- ✓ Fast (~ns) for time coincidence with the calorimeter

Rejecting the bg

- Beam - related
- Cosmic

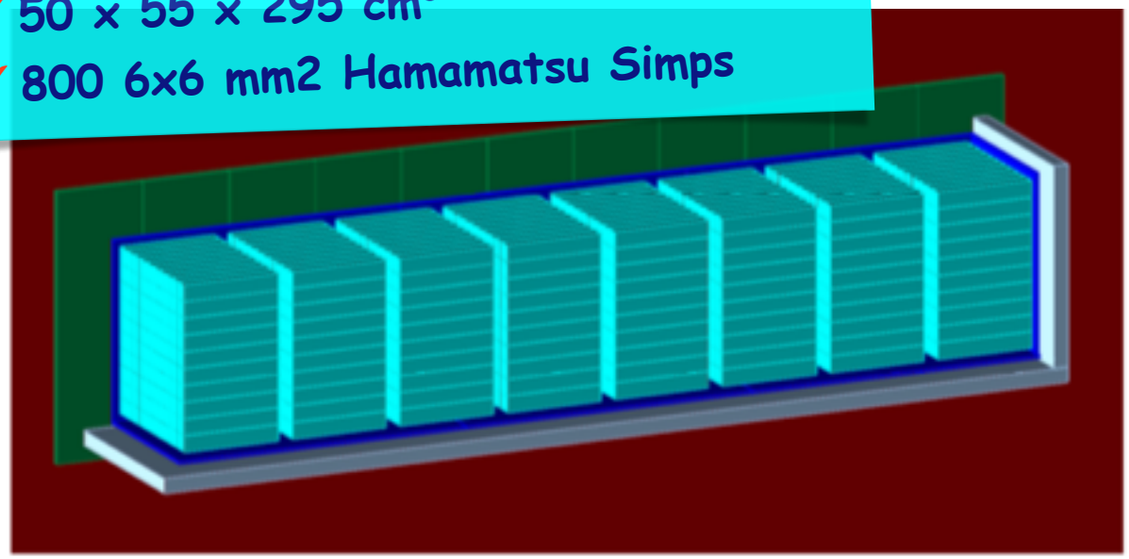
Passive Veto by lead bricks

- ✓ Lead vault between active layers for low energy gamma

BDx detector

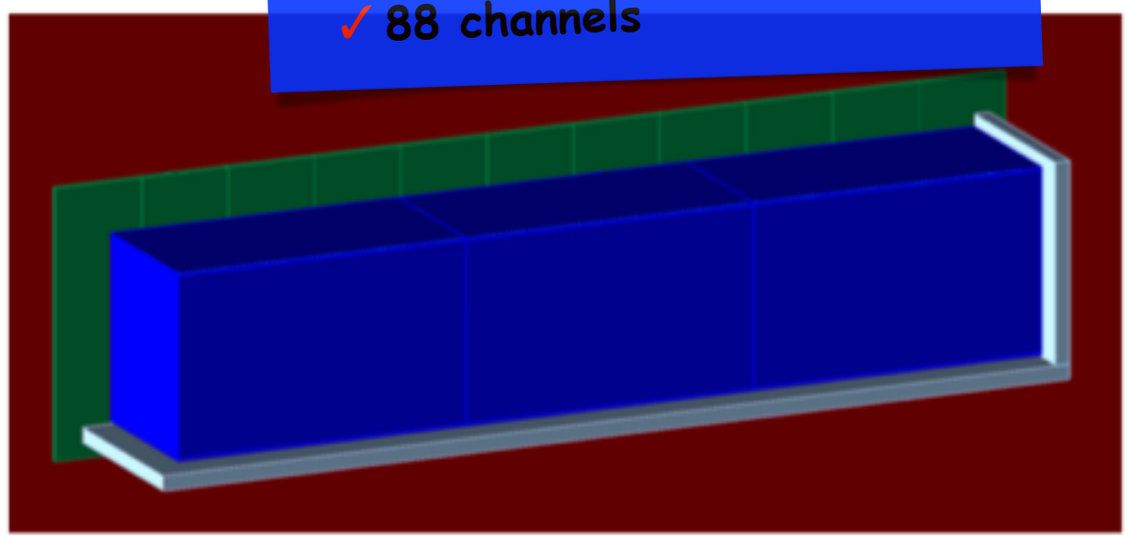
Calorimeter

- ✓ 10x10x8blocks
- ✓ 800 CsI(Tl) crystals
- ✓ 50 x 55 x 295 cm^3
- ✓ 800 6x6 mm2 Hamamatsu Simps



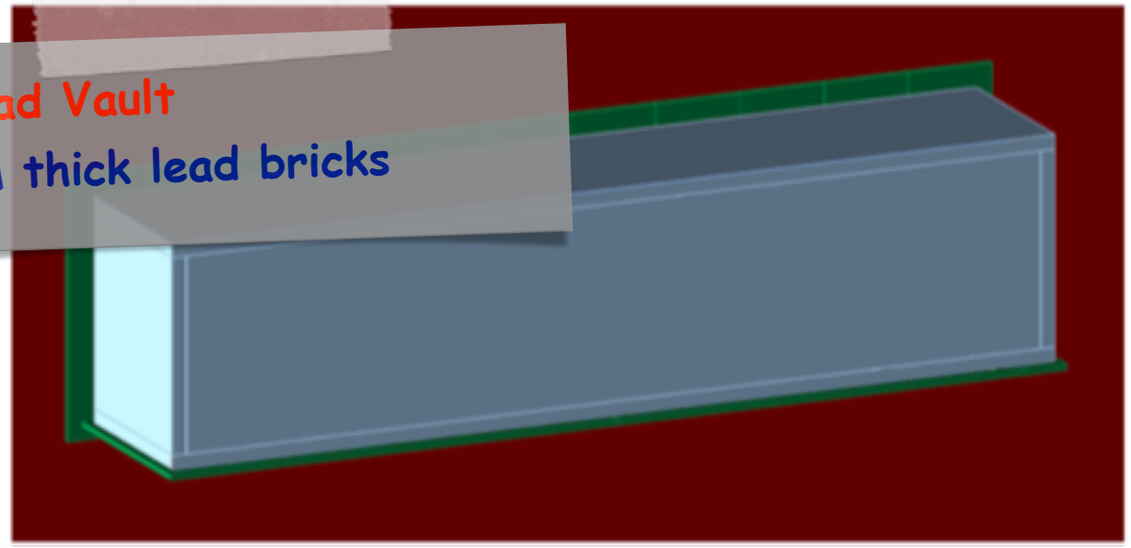
Inner Veto

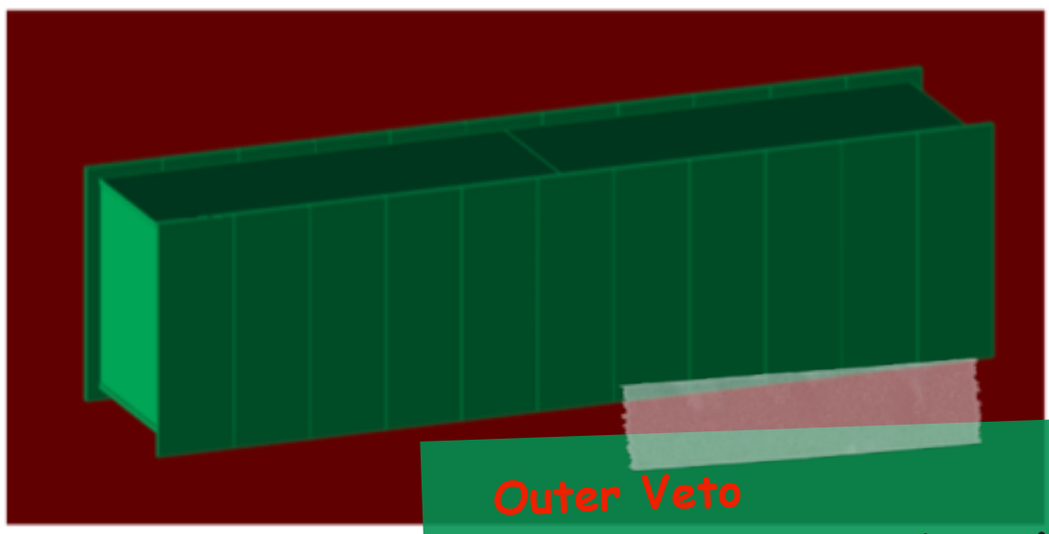
- ✓ Plastic scint + WLS fibers
- ✓ SIPM readout
- ✓ 88 channels



Lead Vault

5 cm thick lead bricks



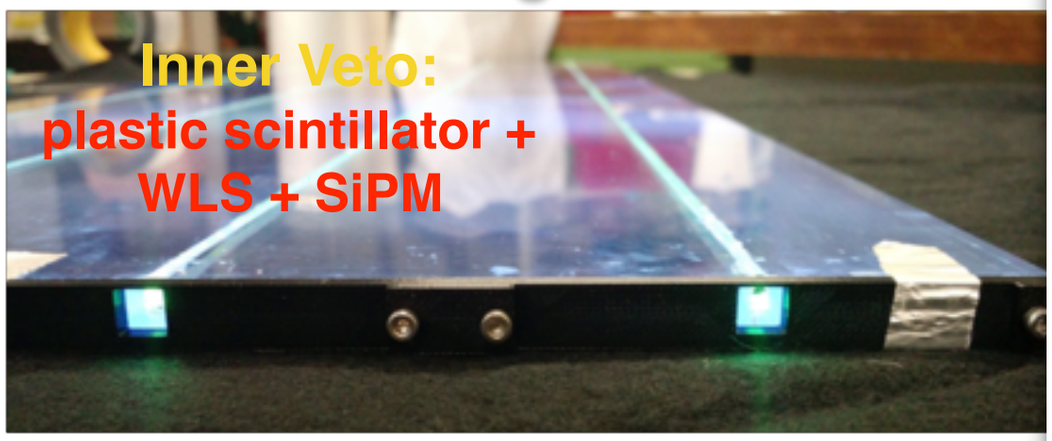


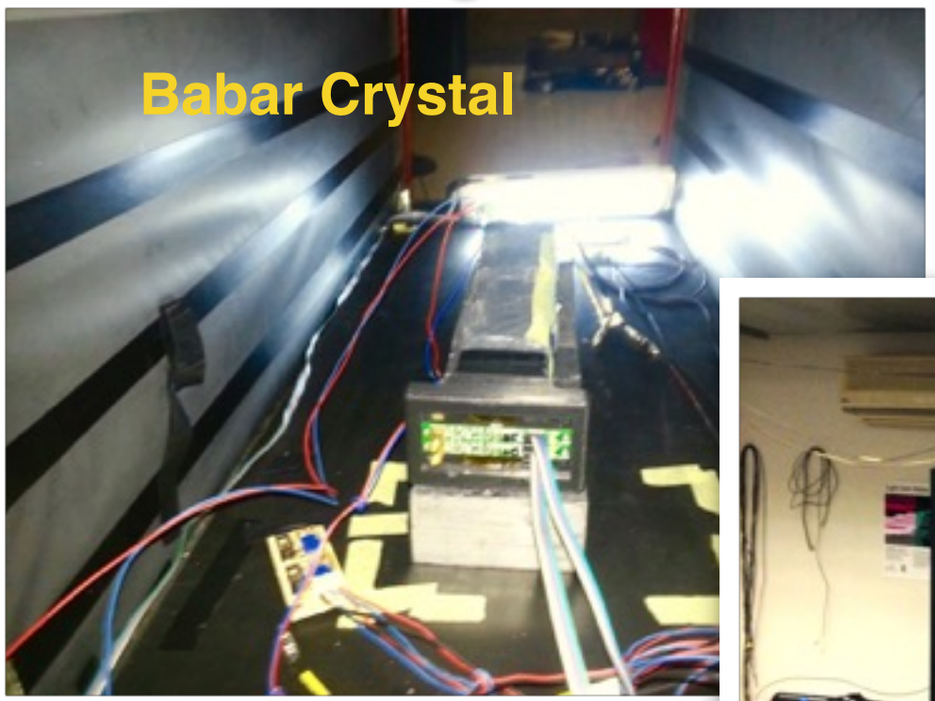
Outer Veto

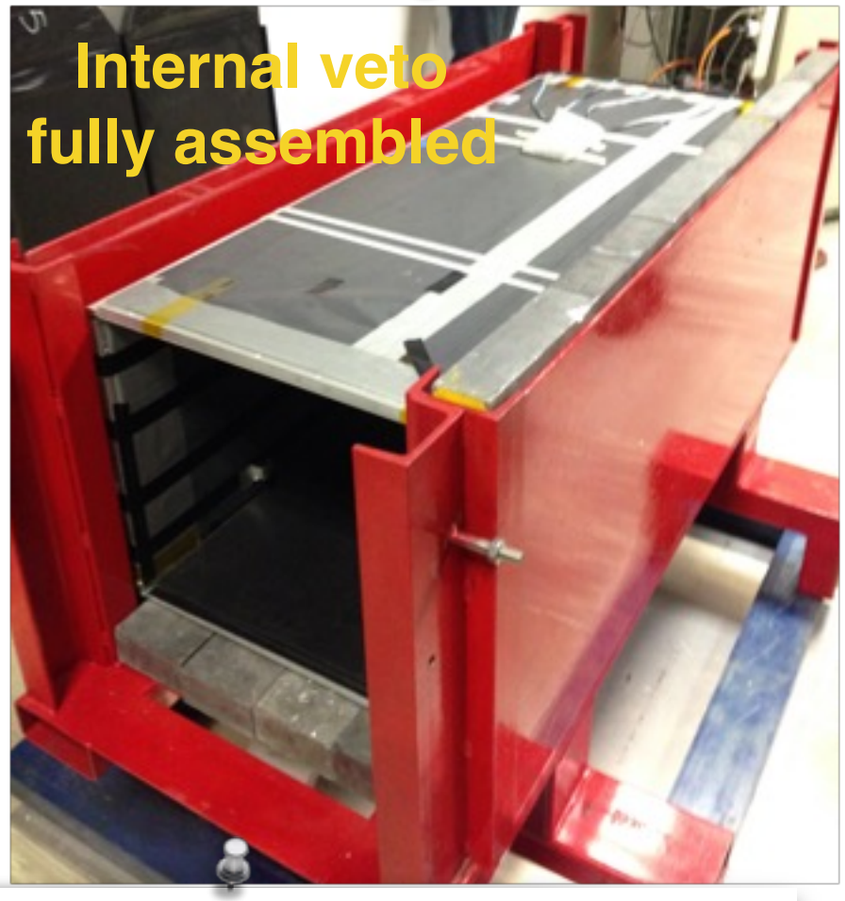
- ✓ Plastic scint + light guides
- ✓ PMT readout
- ✓ 28 channels

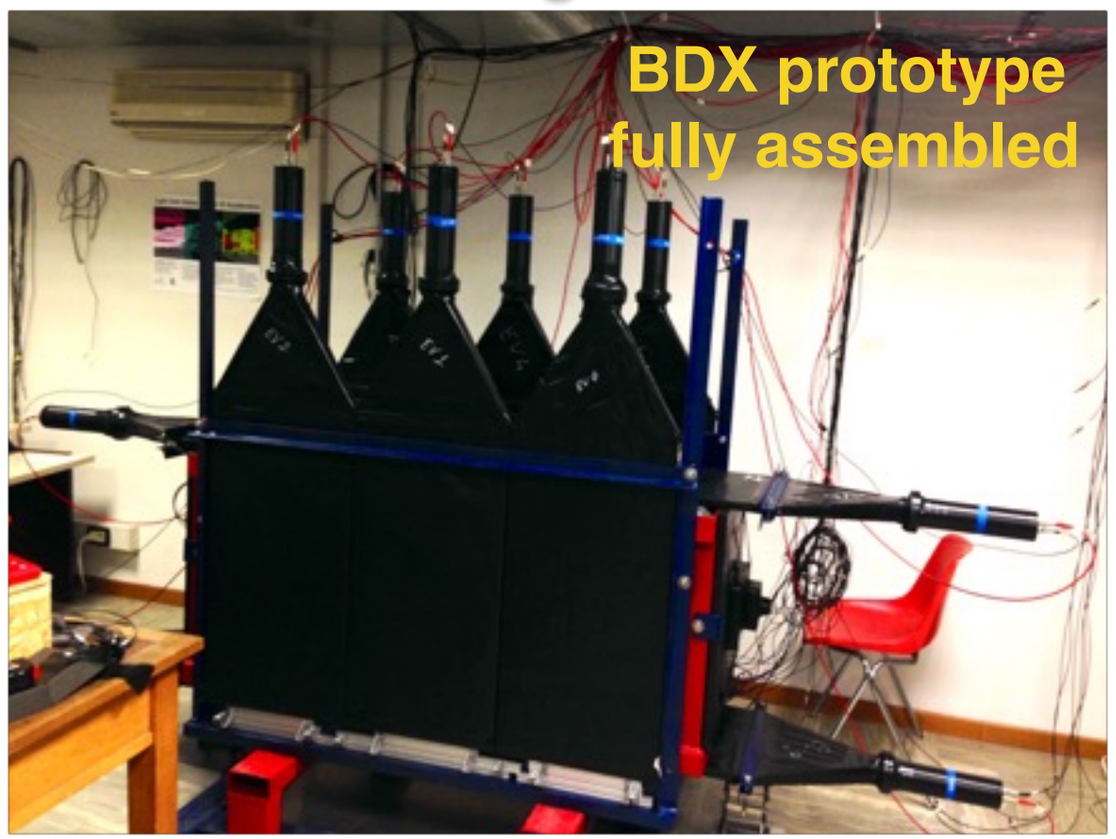
The detector design has been validate using cosmogenic background measurements with a small-scale prototype and results from MC simulations

BDx prototype







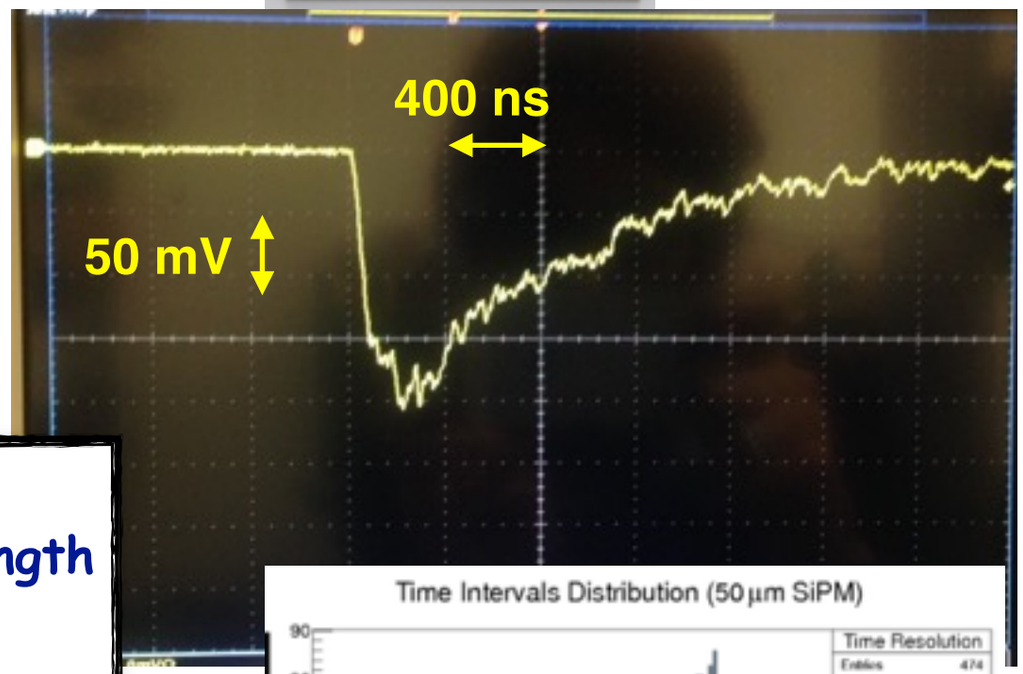


BDX detector: Calorimeter R&D

Characterization campaign to measure crystal + SiPM properties

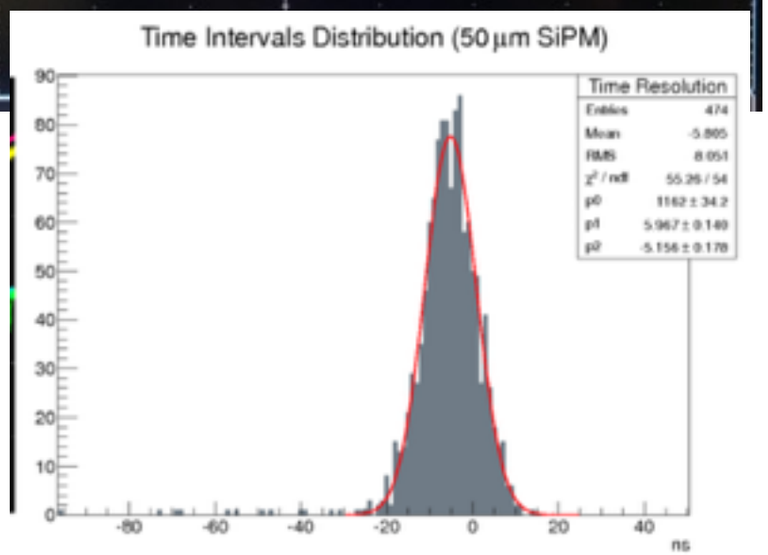
Parameter	Values
Radiation length	1.85 cm
Molière radius	3.8 cm
Density	4.53 g/cm^3
Light yield	50,000 γ/MeV
Light yield temp. coeff.	0.28%/°C
Peak emission λ_{max}	565 nm
Refractive index (λ_{max})	1.80
Signal decay time	680 ns (64%)
	3.34 μs (36%)

+



CsI(Tl) crystals are available from BABAR em calorimeter

- ✓ Size: (5x5)cm^2 front face, (6x6)cm^2 back face, 30cm length
- ✓ Decay time: fast 900ns, slow 4000ns
- ✓ LY = 50kγ/meV



SiPM readout

- ✓ Size: (6x6)mm^2, 25μm, 57.6k cells, trenched. pde=25%

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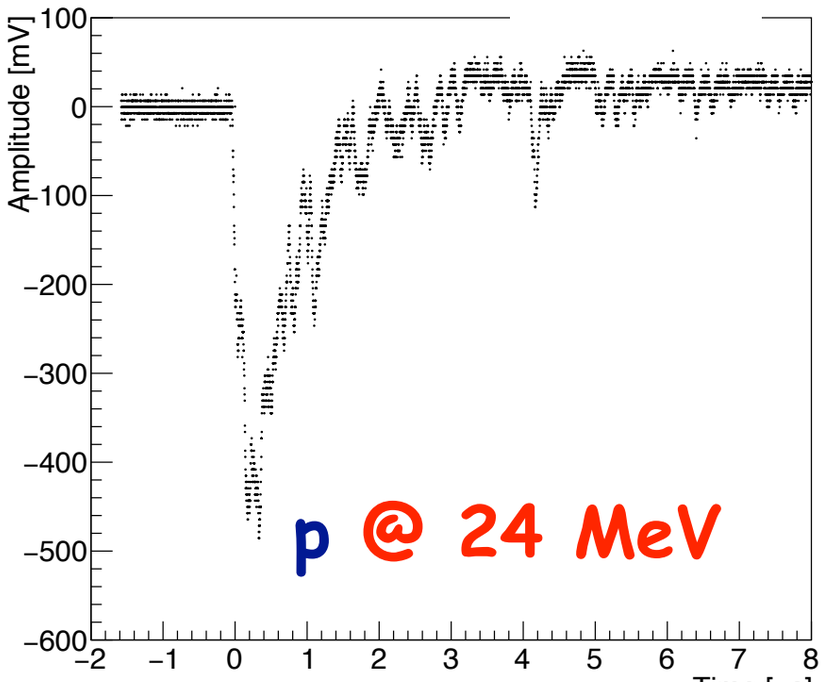
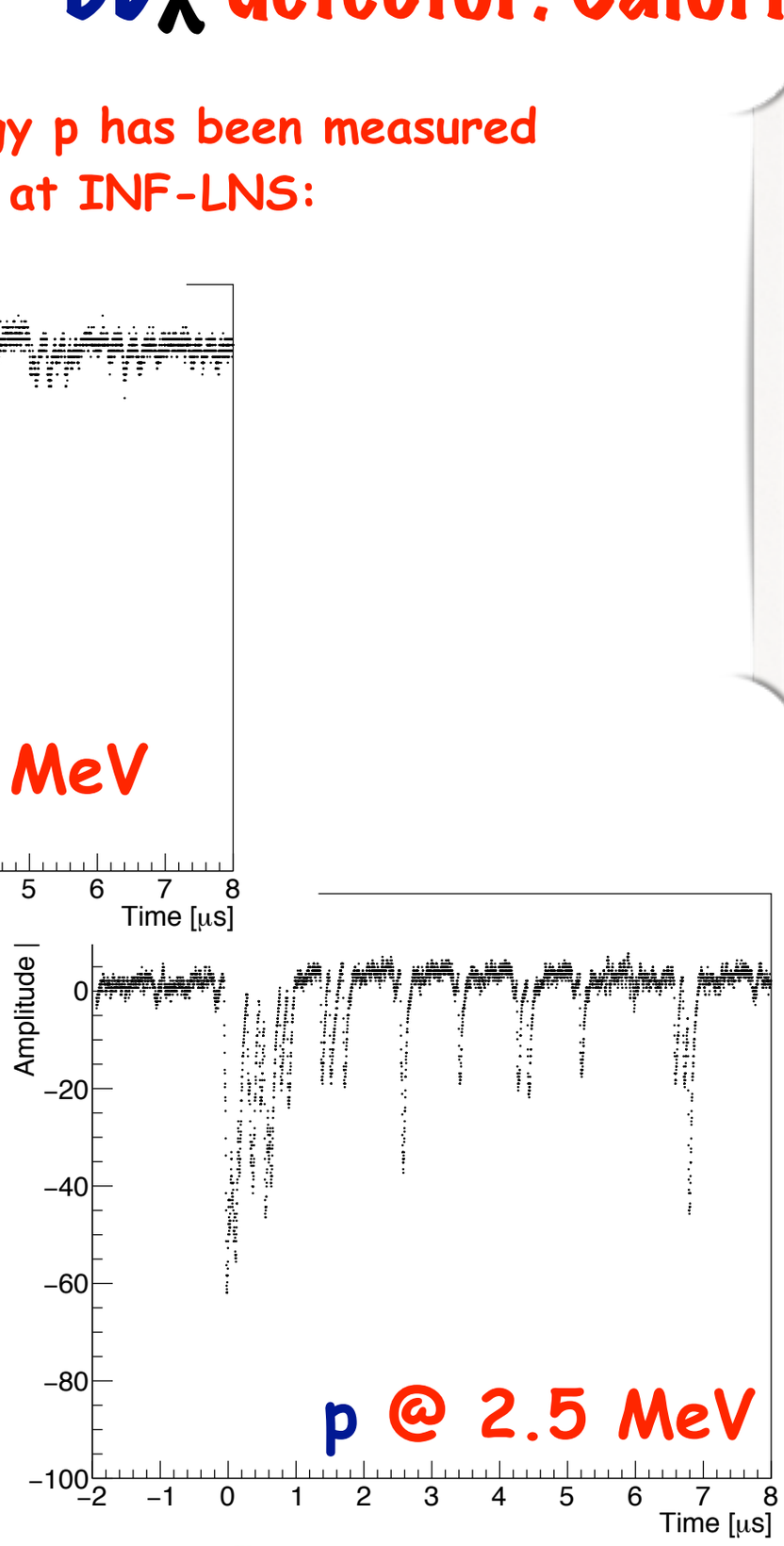
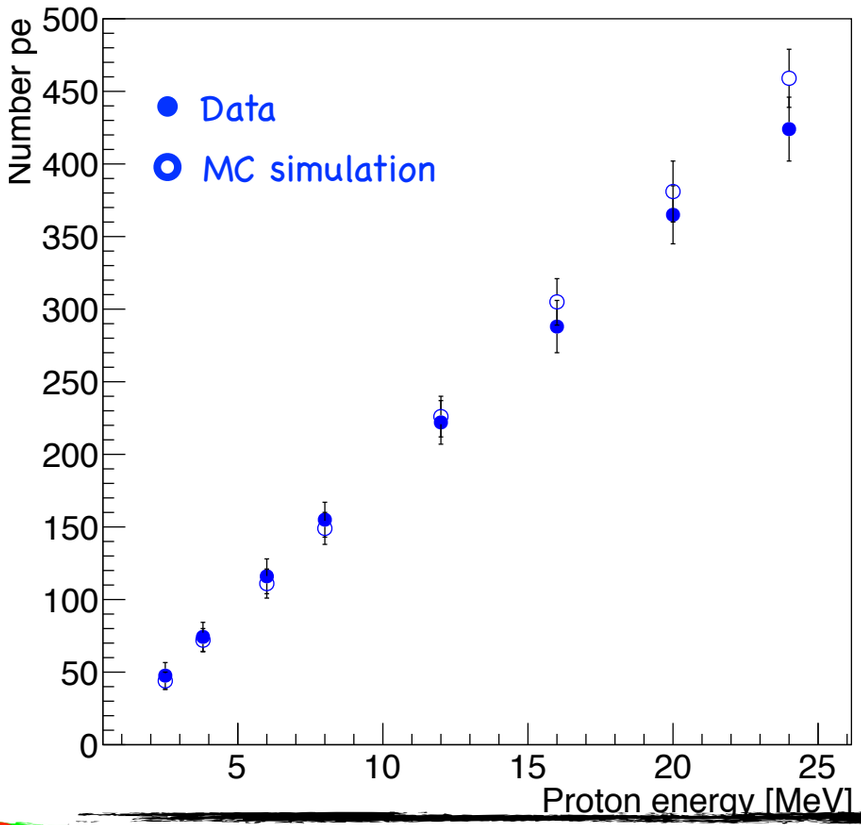
BDX detector: Calorimeter R&D

Response to low-energy p has been measured with p beam at INF-LNS:







Signals at MeV level are detectable

BDx prototype: a campaign of cosmic measurements in CT

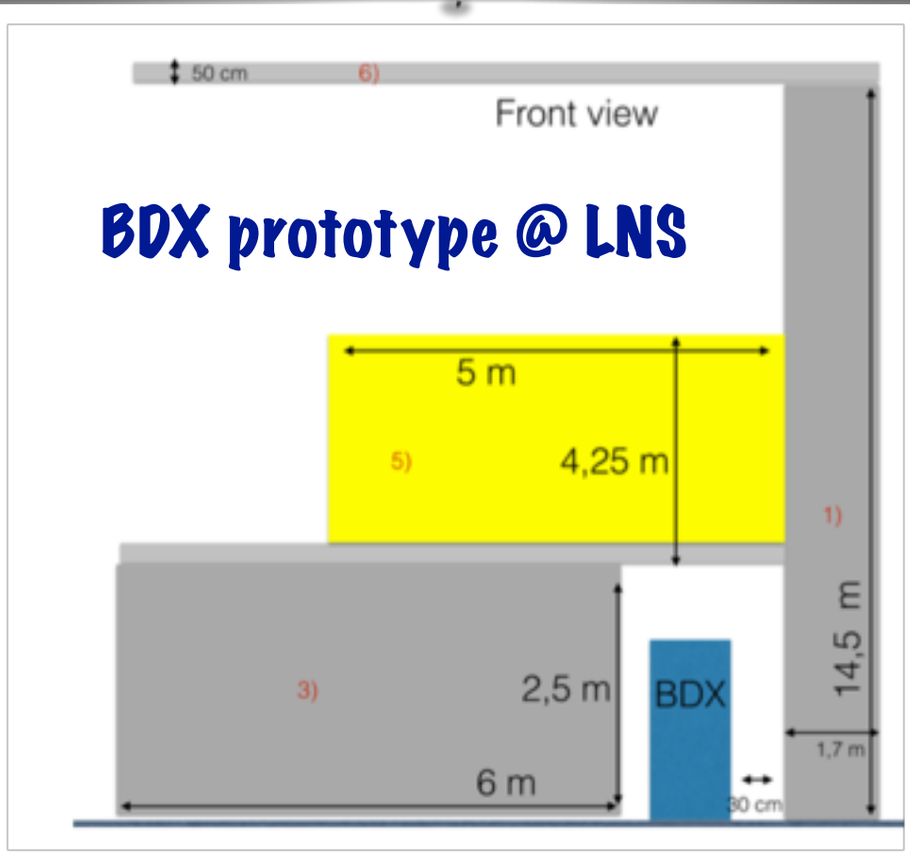
Goals:

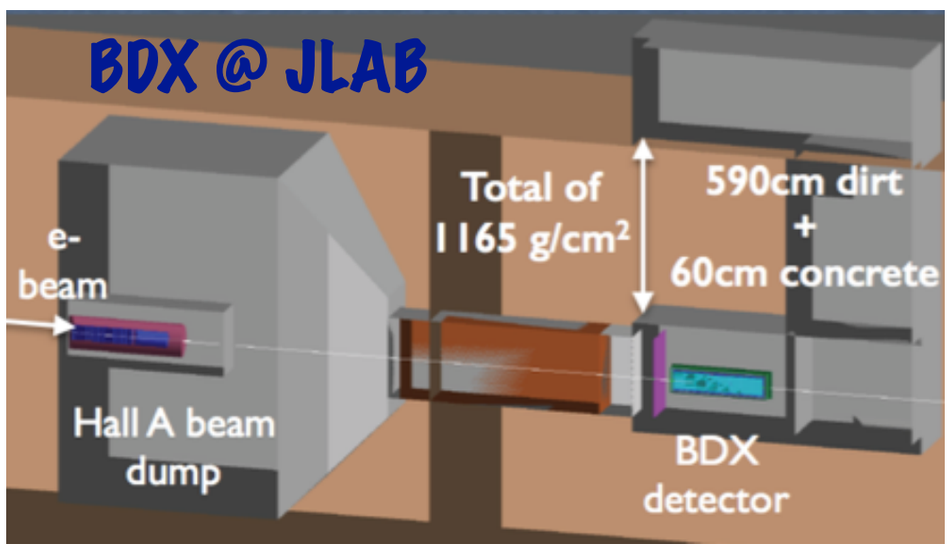
- provide informations useful for the full detector design
- test the proposed technology (CsI(Tl) crystals read by SIPM, plastic scintillator read by PMT for the OV and plastic scintillator coupled to SIPM by WLS fibers)
- check the effect of the lead shielding and the overburden
- validate Monte Carlo simulations
- estimate the cosmic background

BDX: Beam - Unrelated Background

beam-unrelated background: cosmic neutrons, muons and their decay products

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



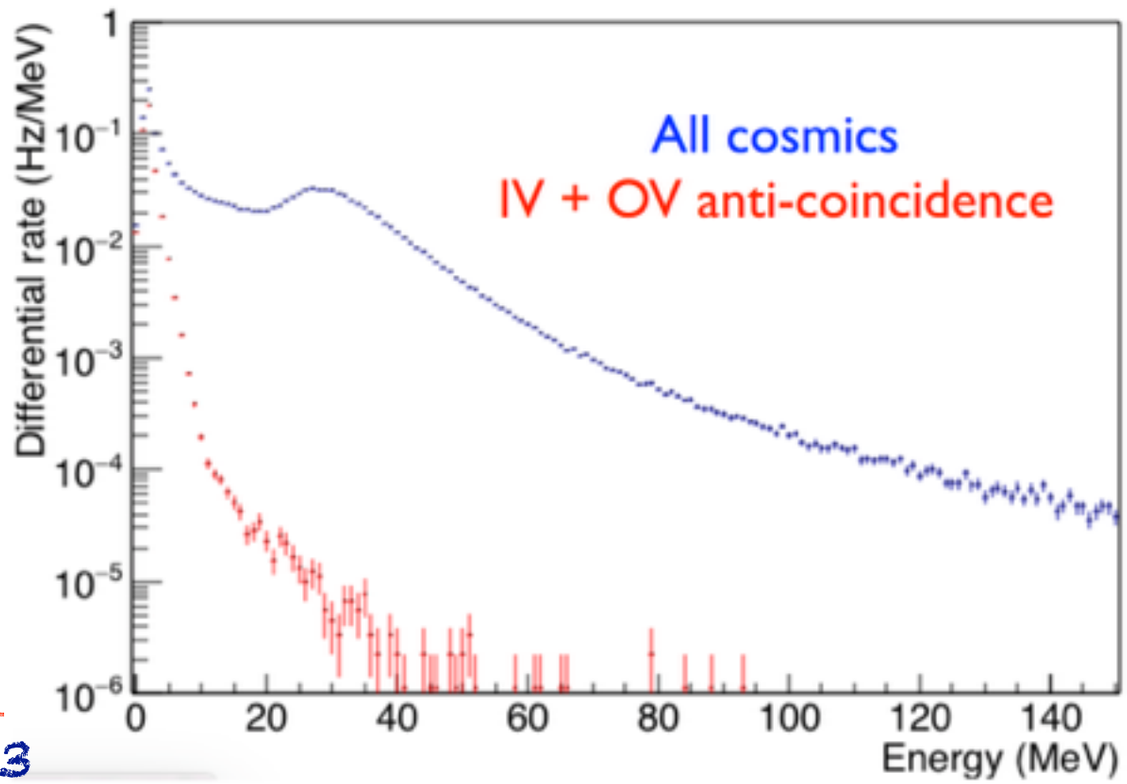


BDX: Beam - Unrelated Background

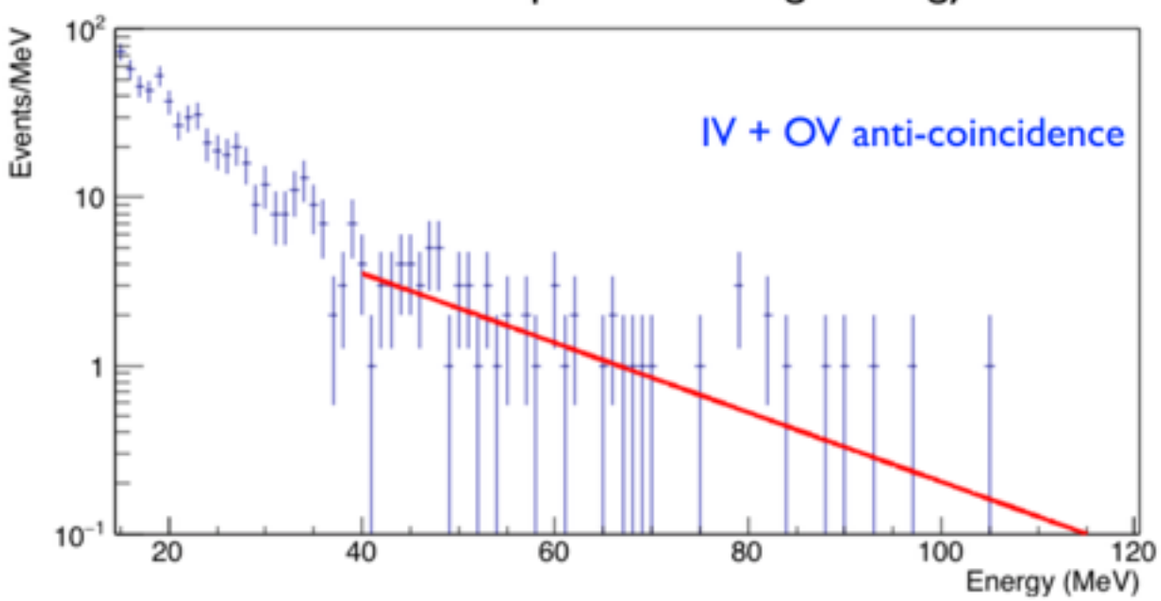
beam-unrelated background: cosmic neutrons, muons and their decay products

- Cosmic background measured with the BDX detector prototype with similar overburden
- Geant 4 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
- 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)

Count rate measured in 1 crystal

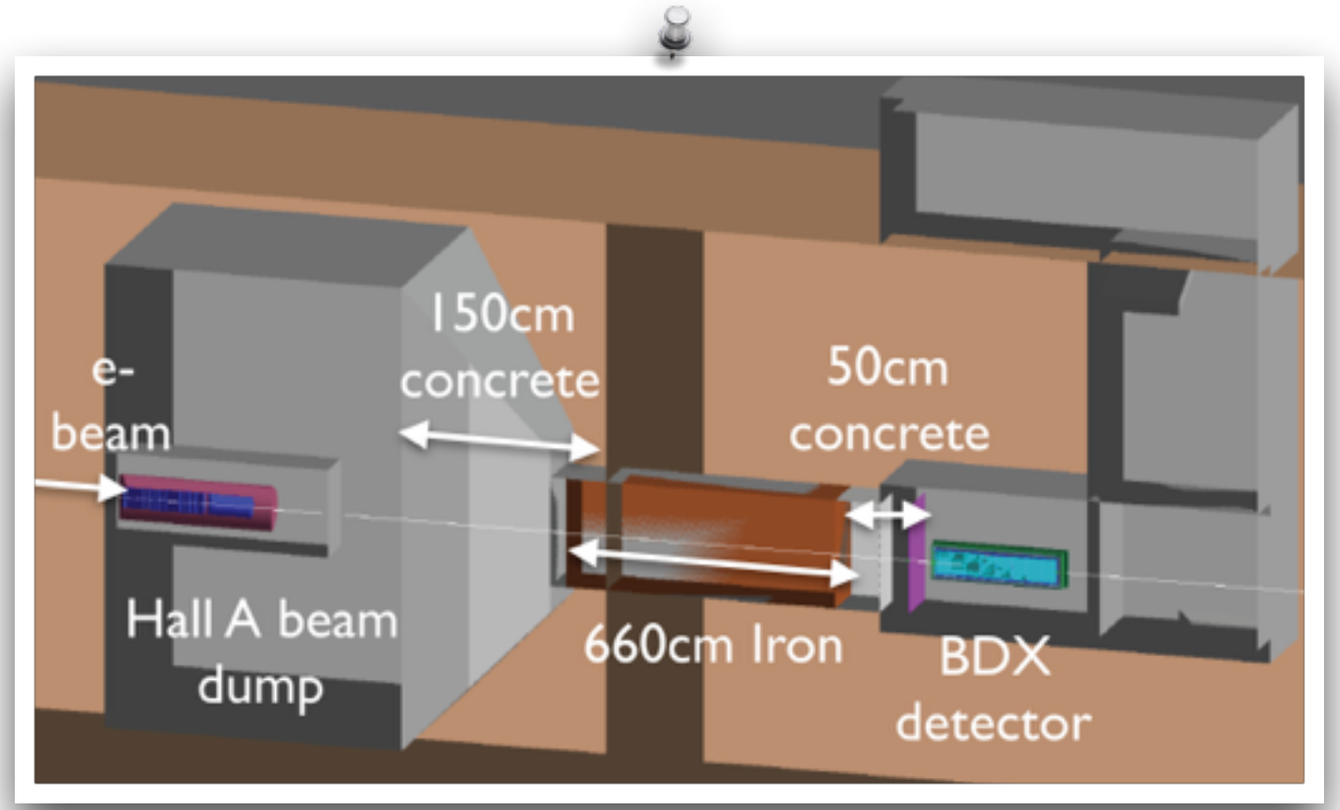


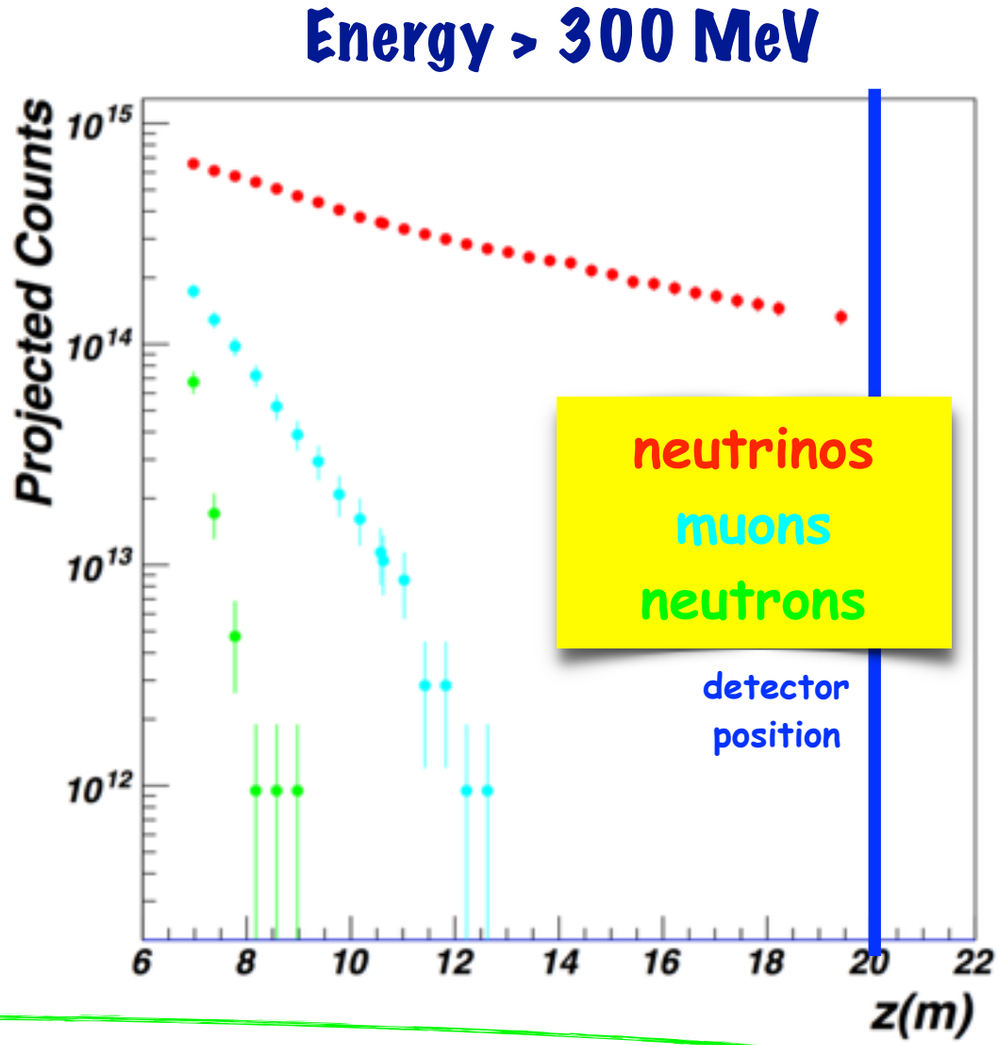
Count rate extrapolation to high energy



BDX: Beam - Related Background

To evaluate these backgrounds, the interaction of the 11 GeV electron beam in the dump was simulated and the flux of secondaries was studied as a function of the distance from the dump…..





Beam-related Background can be reduced to zero (except ν) with sizable shielding (660cm of iron and 150cm of concrete)

Neutrino irreducible bg represents the ultimate limitation for BDX

BDX: Backgrounds

Detection thresholds define the bg level

Beam related:

Geant4 simulations

E_{thr}	Nv (285 days)
300 MeV	~ 10 counts

Beam unrelated:
Cosmic Background

Measurements with BDX prototype

Similar experimental set-up (same overburden)

+

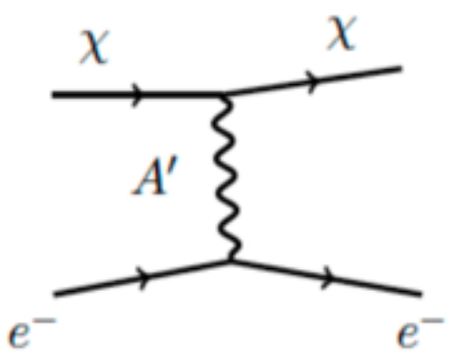
extrapolation to full detector

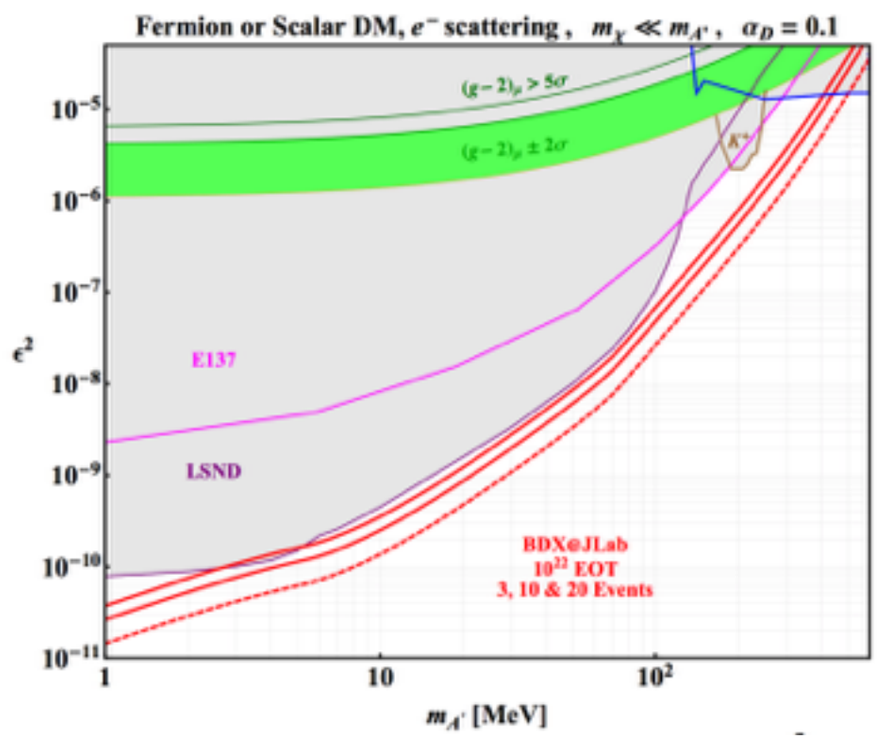
E_{thr}	✔ Bg (285 days)
300 MeV	< 10 counts

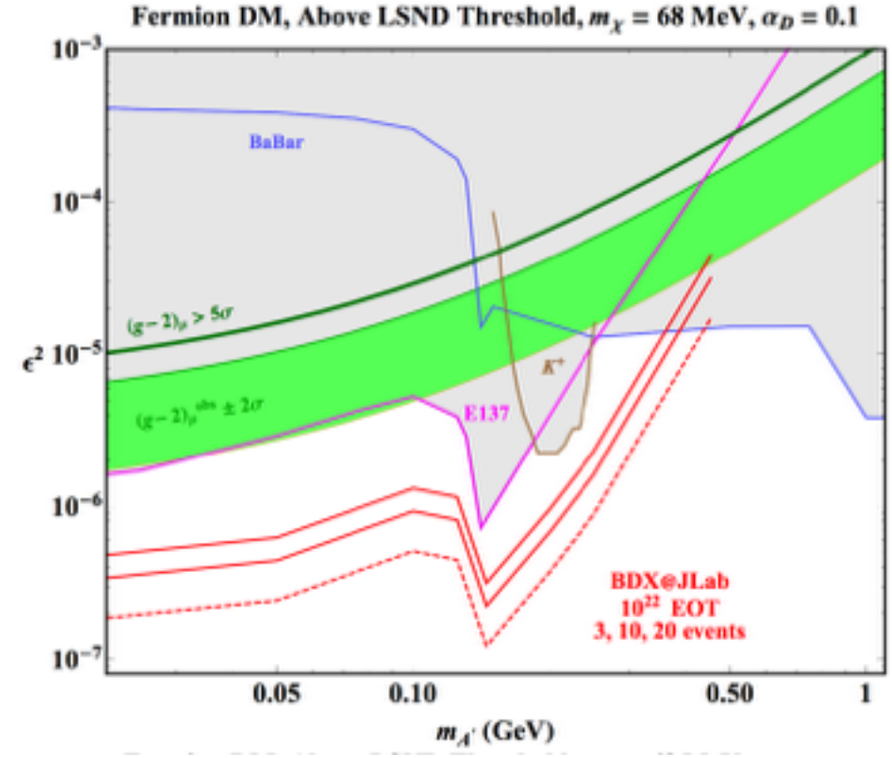
For an energy threshold high enough (>200-300 MeV) BDX hits the ultimate limit from ν interactions

BDX: expected reach

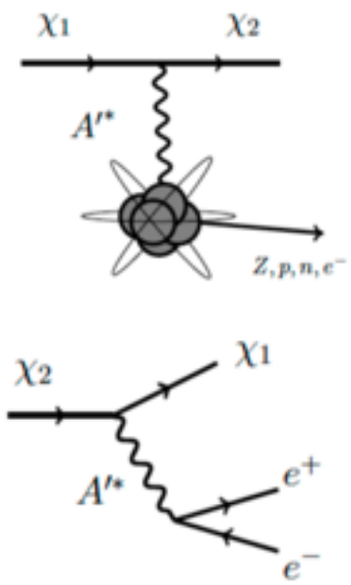
χ - e elastic scattering

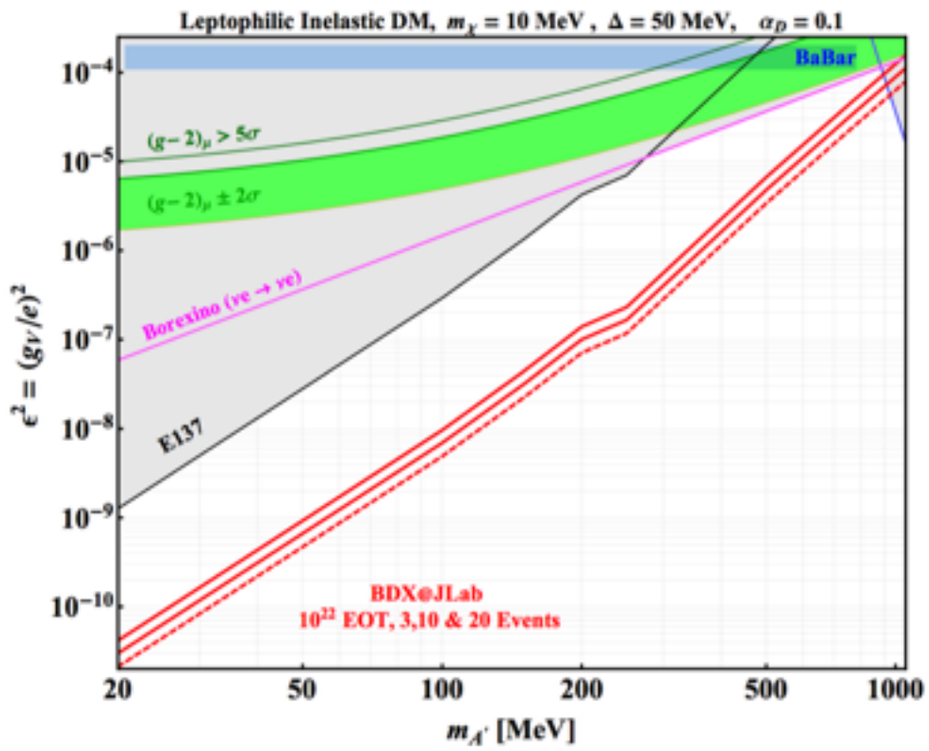






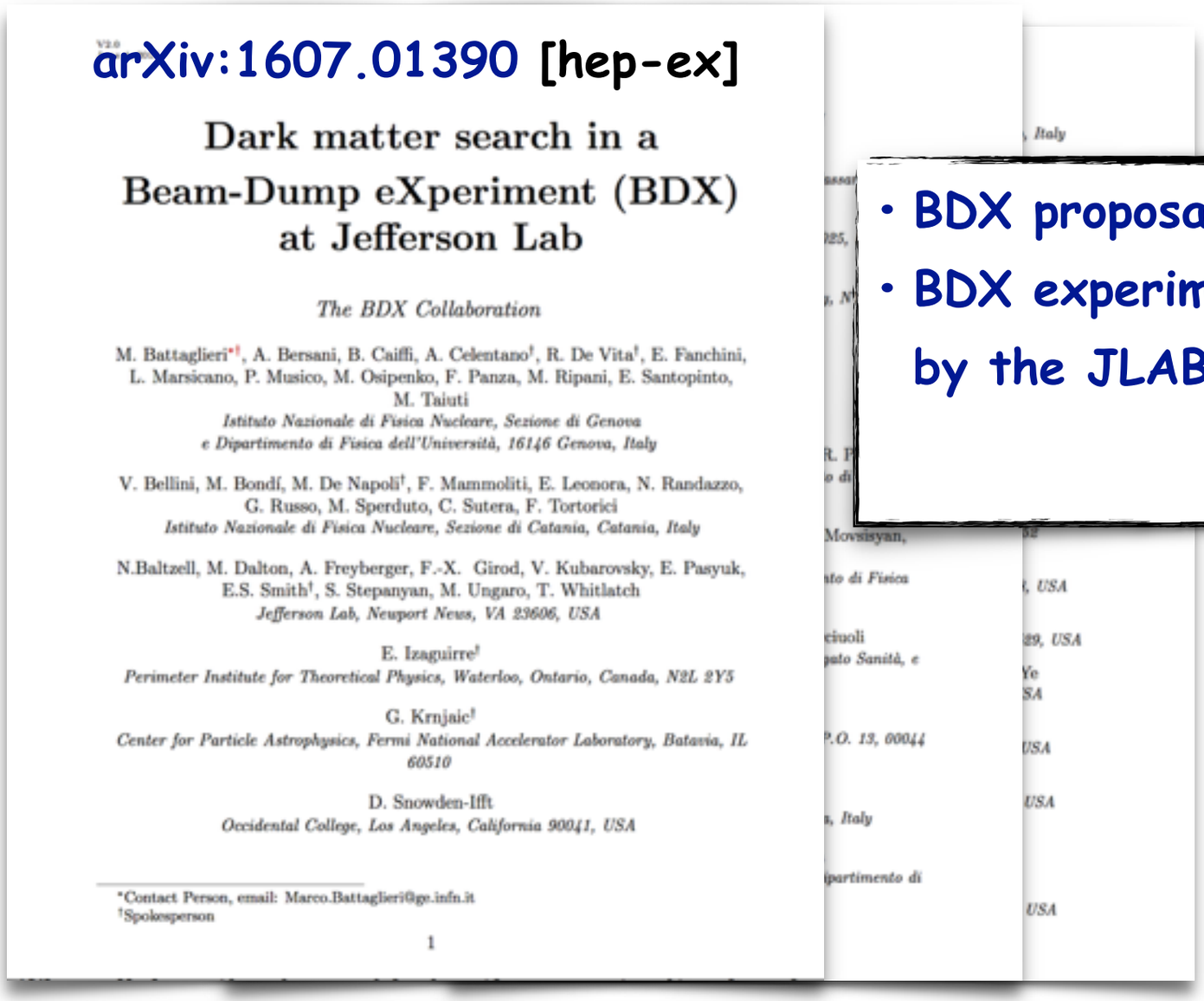
χ - N inelastic scattering





BDX can be 10-100 times more sensitive than previous experiments excluding a significant area of the parameter space

BDX: status



arXiv:1607.01390 [hep-ex]

Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab

The BDX Collaboration

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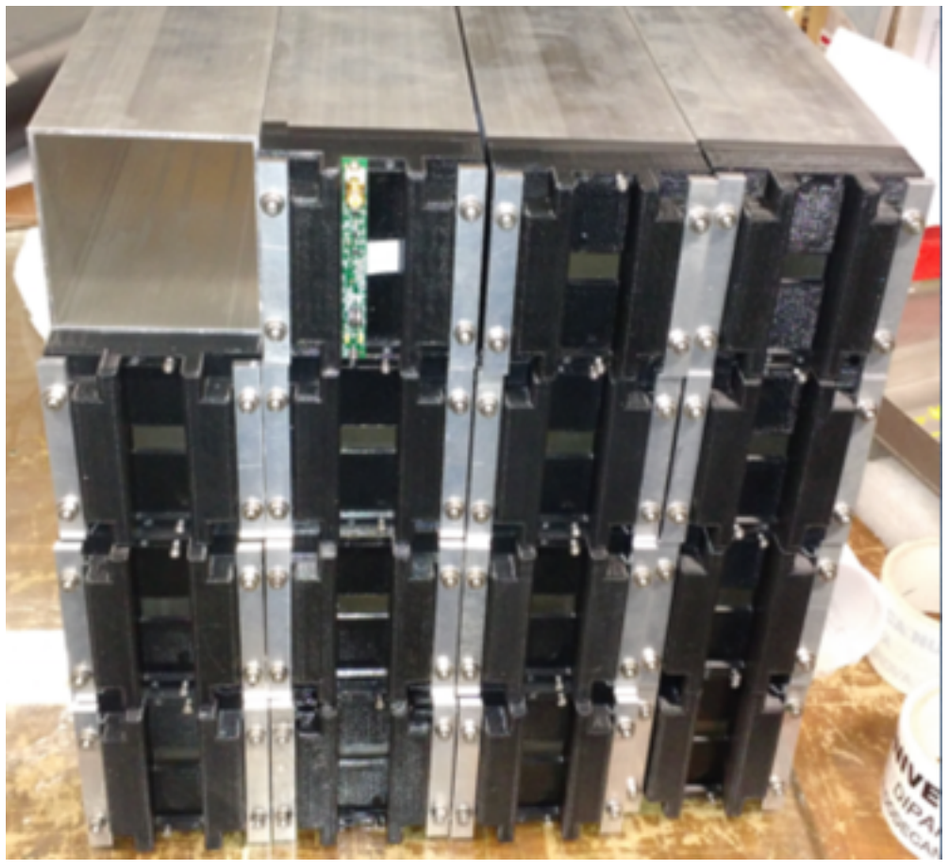
- BDX proposal submitted to JLAB-PAC44
- BDX experiment has been conditionally approved by the JLAB PAC44

Future plans:

- new cosmogenic measurement campaign at INFN-CT/LNS with the upgraded prototype
- The collaboration is considering to measure beam-related bg in a realistic experimental set-up

BDX: prototype upgrade

- A CsI(Tl) matrix made of 4 x 4 crystals



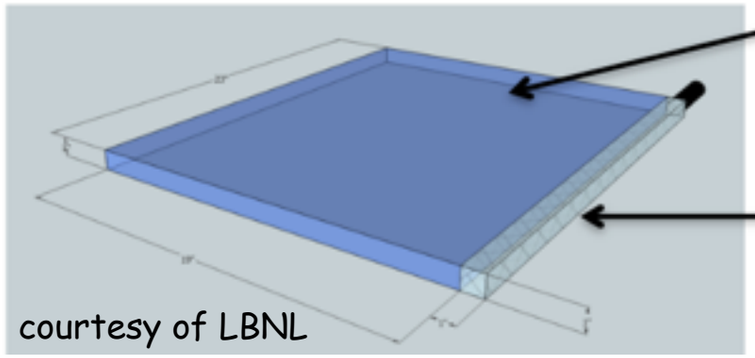
- Read out: SiPM (6x6) mm^2, 25µm, 57.6k cells, trenched, pde=25%.
- each crystal tested with cosmic muons in Genova last week

- Upgrade of Inner Veto:
  - replaced the 4 independent extruded scintillator bars (IV bottom)
  - New clear plastic scintillator fully instrumented

BDX: prototype upgrade

Upgrade of Outer Veto:

- Tested a new solution for the OV scintillator read-out -> replace light guides with wavelength shifting plastics

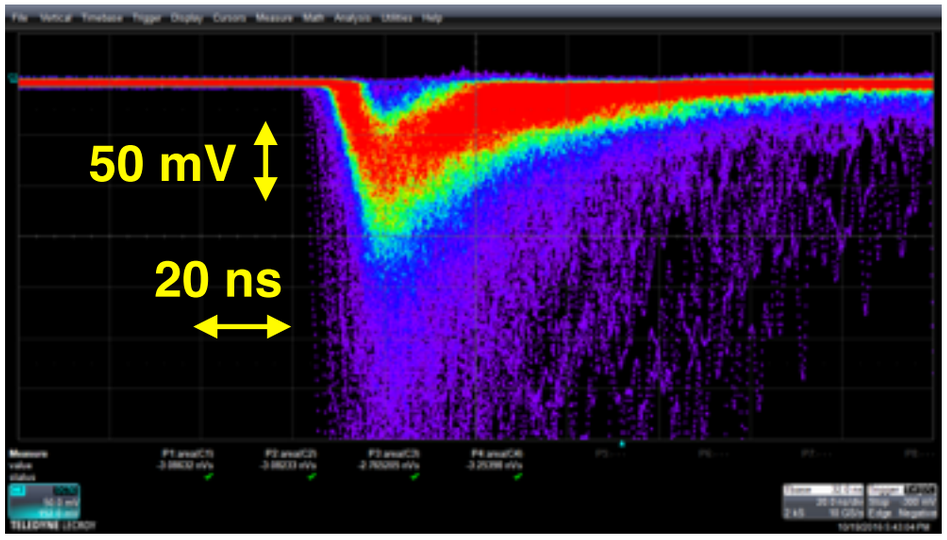


EJ200 scintillator
- front edge 'frosted' w/600 grit sand paper
- 0.25mm air gap between PS & WLS
- all other edges diamond milled

EJ280 wavelength shifting plastic
- re-emission in line of sight with PMT
- More compact construction than using typical trapezoidal acrylic light guides

" Hamamatsu PMT (R1924A)

- 3 new scintillator in this configuration: top, upstream, downstream



- **Next weeks:** Internal veto and 4x4 crystals matrix shipped to Catania
- **November 2016:** New BDX prototype full assembled
- **December 2016:** Starting measurements at CT

BDX: Conclusions

- The BDX experiment @ JLAB, submitted at PAC44, has been conditional approved: search for light dark matter particles in the 10 ÷ 1000 MeV mass range
- A dedicated Beam Dump eXperiment will naturally complement the extensive program already running at the major electron- and proton-beam facility (JLAB, LNF, SLAC, CORNELL, Mainz, FNAL and CERN)
- A new experimental hall, downstream of Hall A beam dump, will host the BDX detector based on ~ 800 CsI(Tl) crystals + Inner Veto + Outer Veto
- Full GEANT4 simulations have been run to optimize experimental set-up and estimate beam-related background
- Dedicated cosmogenic measurement campaign at LNS/CT-INFN with a BDX detector prototype, has been used to test the proposed technology, validate MC simulations and measure cosmic background rates
- The BDX experiment, collecting 10^{22} EOT in 285 days of parasitic running would be 10-100 times more sensitive than previous experiments excluding a significant area of the parameter space in case of null results

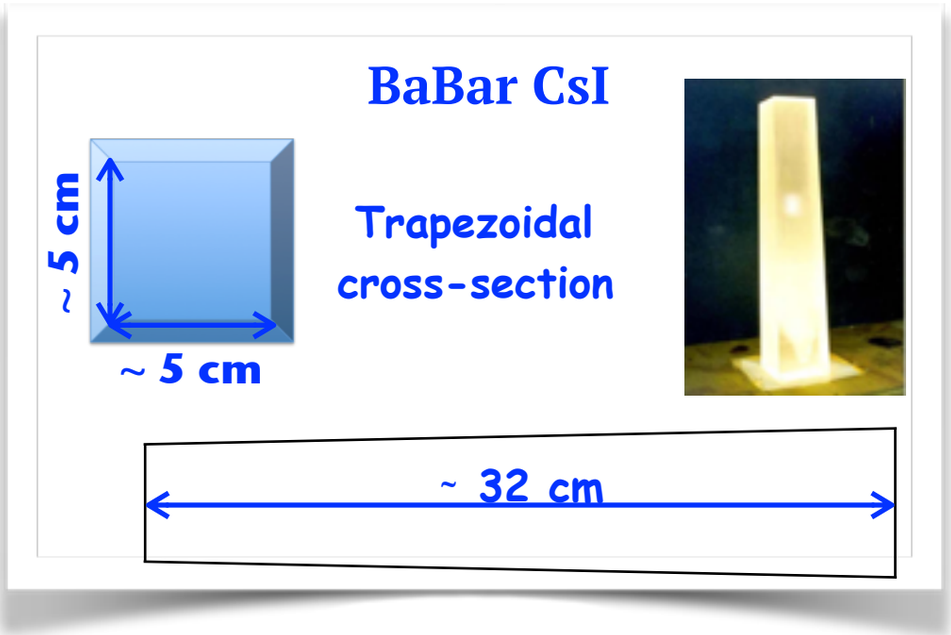
The BDX Collaboration

Thank you for your attention !

BDX

BDX detector: Calorimeter

use the exiting Babar CsI(Tl) crystals with improved SiPM-based readout

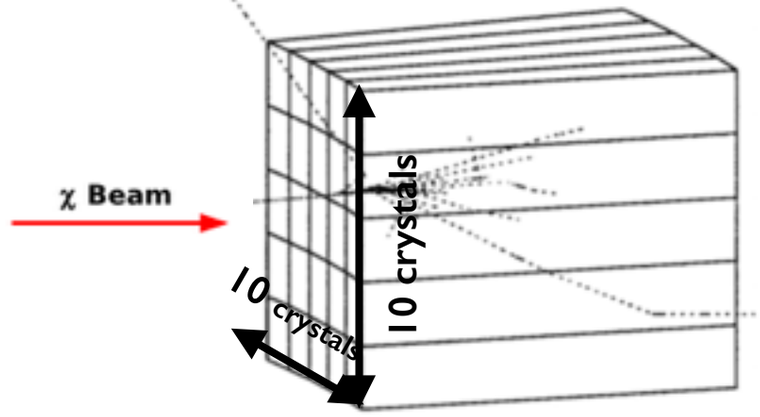


Requirements:

- ✓ ~800 BaBar crystals to build the detector
- ✓ Simplified assembly mechanism
- ✓ Modular detector: change front-face dimensions and total length by re-arranging crystals

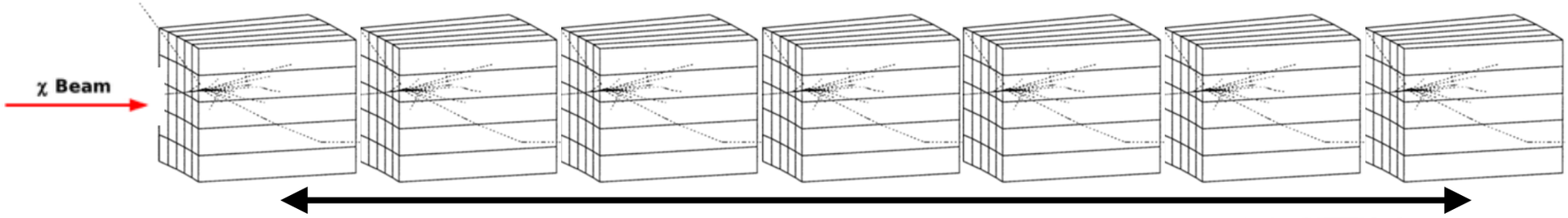
A possible layout:

- ✓ 1 block: 10 x 10 crystals
- ✓ Front face ~ 50 x 50 cm^2
- ✓ 8 blocks: interaction length ~ 3 m



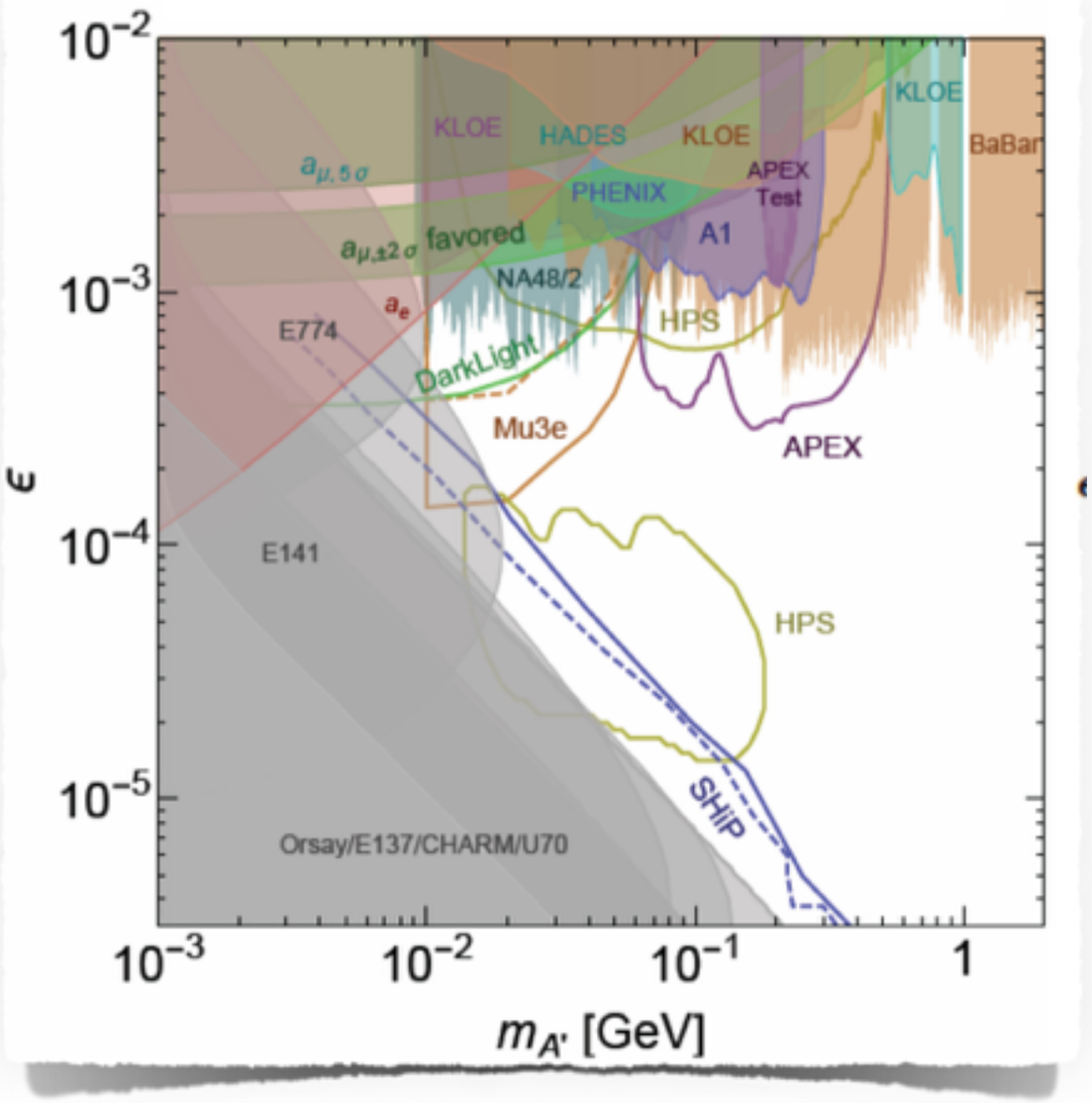
R.J. Barlow et al.NIMA 420 (1999) 162—180

8 Blocks: = 800 crystals

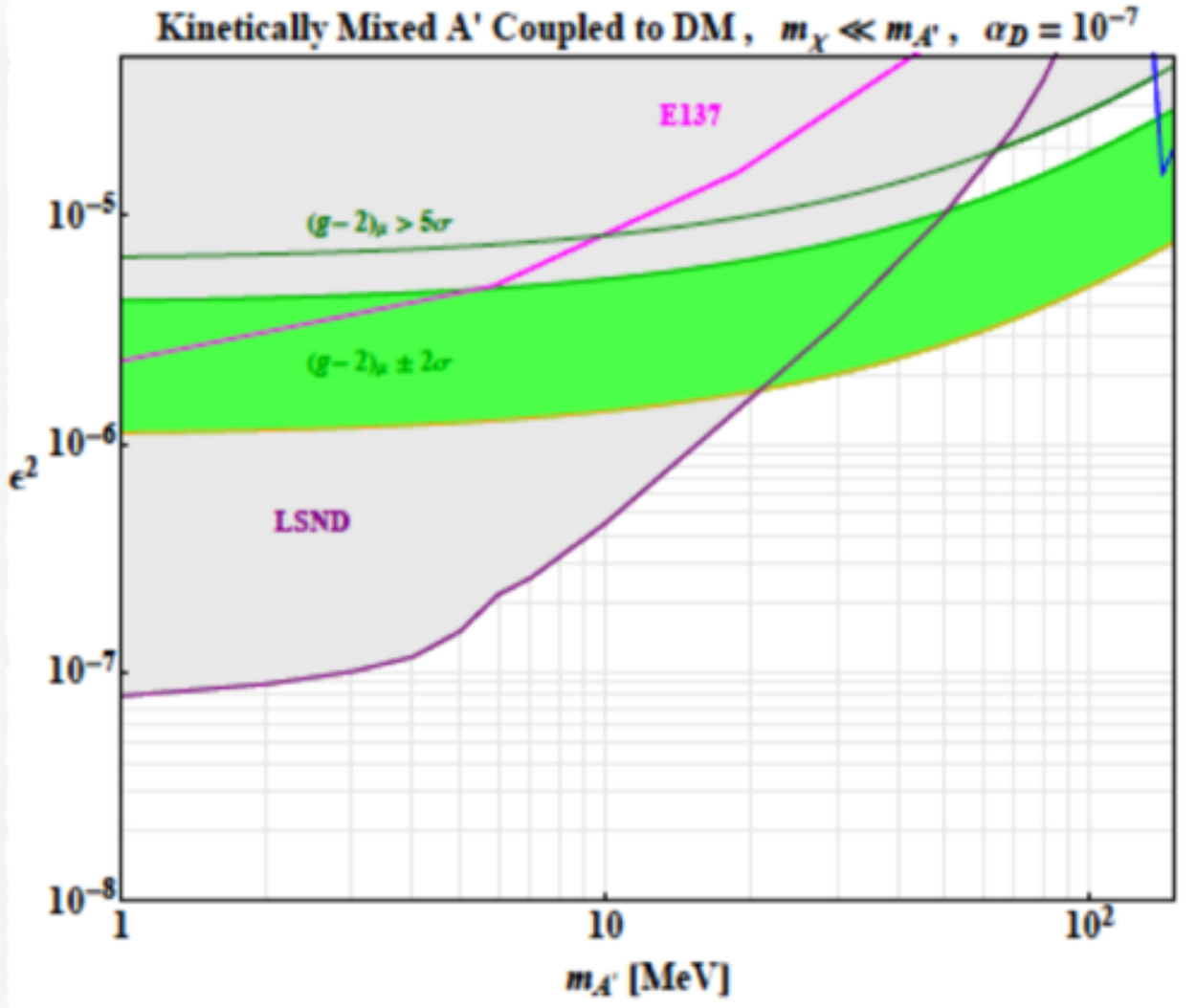


Visible vs Invisible: complementary

Visible decay



Invisible decay



Exclusion limits are model dependent: if invisible decay is included limits do not hold!

BDX: Background

Background = SM particles that mimic χ scattering signals in the detector

Beating down the Background

- active veto
- passive shield
- segmented detector ->Directionality
- time correlation (just in principle)

To evaluate the background:

Geant 4 MC studies to evaluate beam-related background

beam-unrelated background evaluates by extrapolating the results of the cosmic campaign in CT-LNS with BDX-prototype