The Beam Dump eXperiment

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for the BDX Collaboration

Possible connection between Hidden sector and SM: "Vector" portal

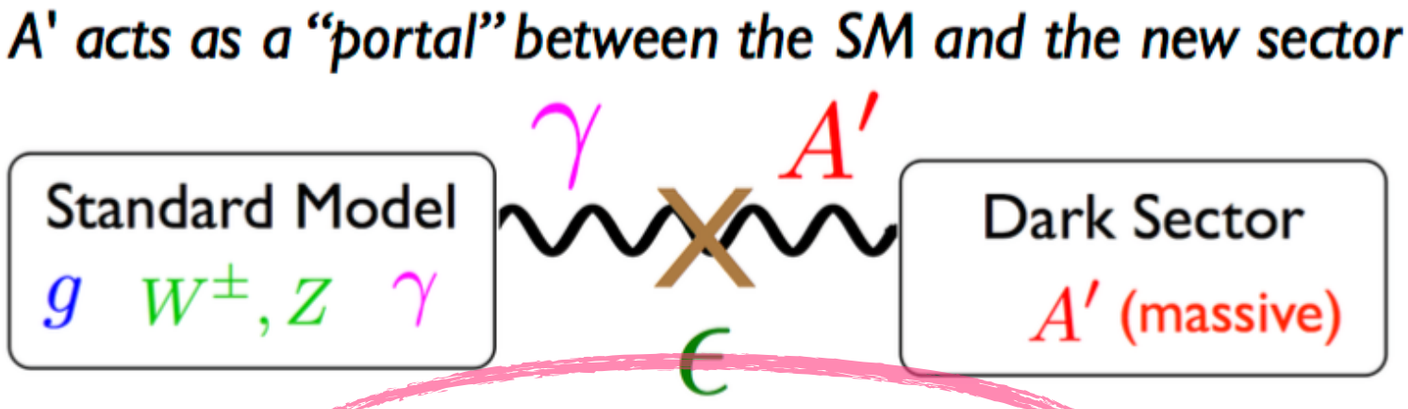
Consider a theory in which nature contains an additional Abelian gauge symmetry U'(1)

B. Holdom, Phys. Lett., B166:196-198, 1986

$$\mathcal{L} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F'_{\mu\nu}F_{\mu\nu} + \frac{m^2_{A'}}{2}A'_\mu A'^{\mu} + g_D A'_\mu J^\mu_\chi + eA_\mu J^\mu_{\rm EM}$$

This gives rise to a Kinetic Mixing term where the photon mixes with a new gauge boson ("Dark/Heavy Photon" or A') through the interactions of massive fields:

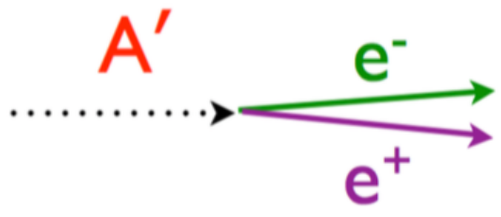
Mixing induces an effective weak coupling εe to electric charge



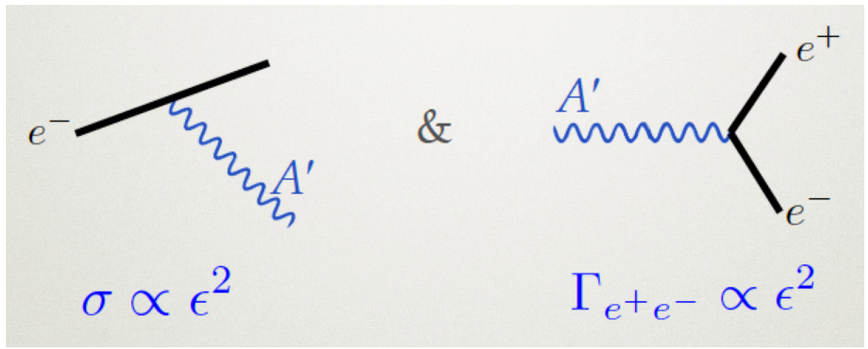
4 parameters: $M_{A'}$, M_X, ε, g_d

Dark photon decays

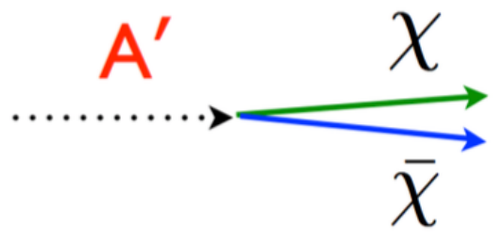
Visible decay



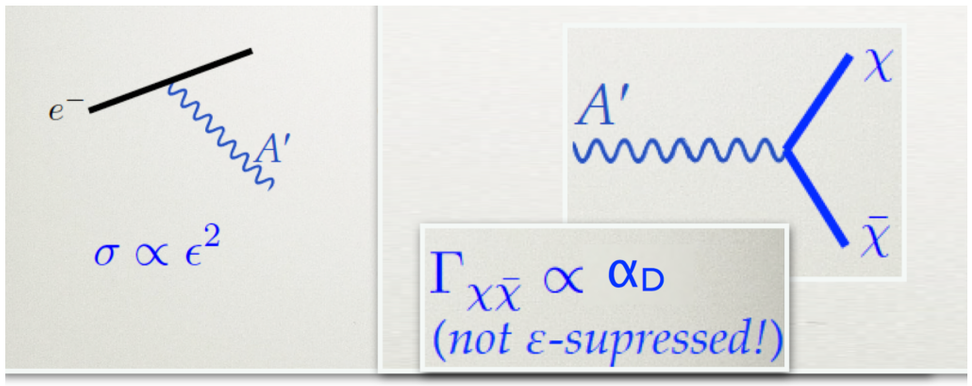
- Decay regulated by ε^2
- Independent on m_χ
- Requires $m_{A'}<2\ m_\chi$



Invisible decay



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



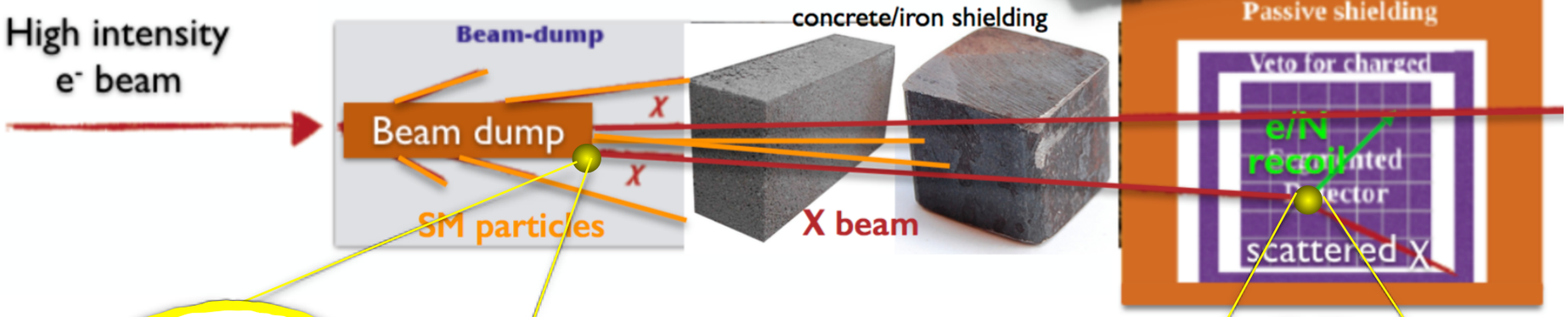
e⁻ - Beam Dump eXperiment

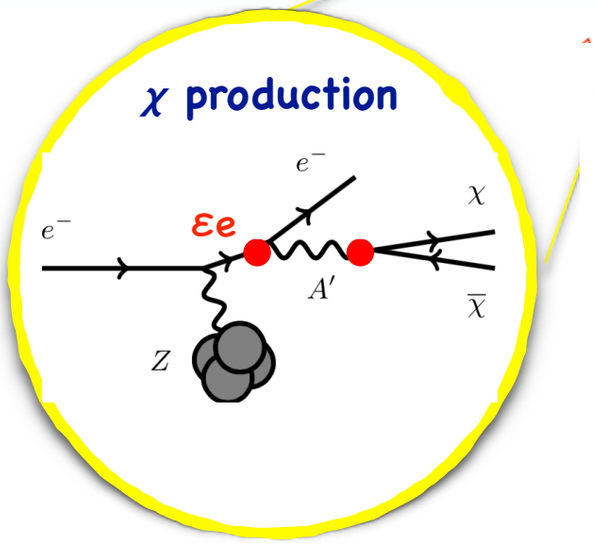
PHYSICAL REVIEW D 88, 114015 (2013)

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

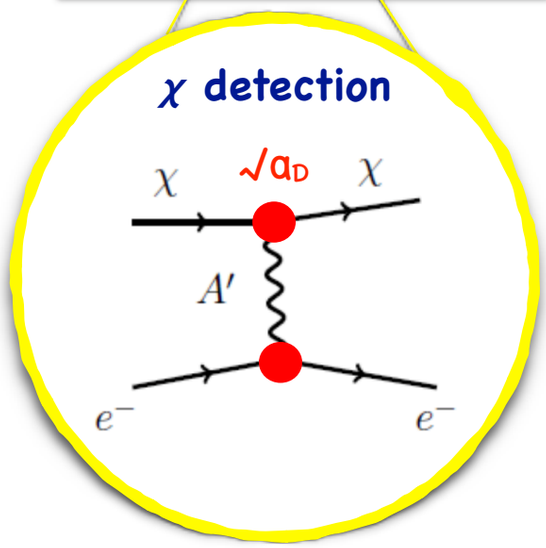




A' yield: $N_{A'} \propto \frac{\varepsilon^2}{m_{A'}^2}$

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

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



1 Step: LDM production

- Xs produced via A' emission and invisible decay
  - ➡ GeV - high intensity e- beam

2 Step: LDM detection

- X scatter off nucleons, nuclei, or electrons in the detector volume, giving rise to a detectable signal.

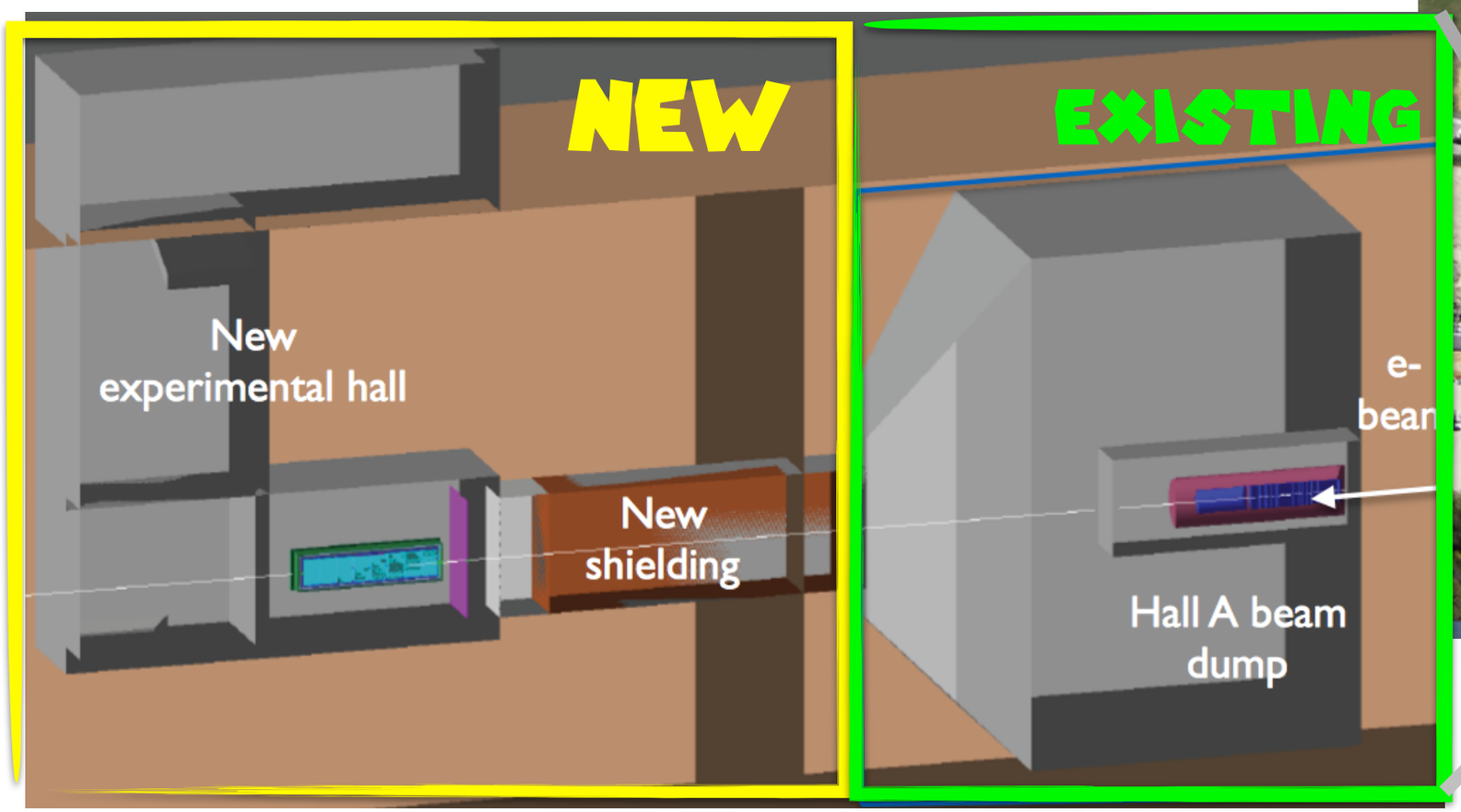
the eternal fight in physics: signal vs background

BDX @ JLAB

Key points:

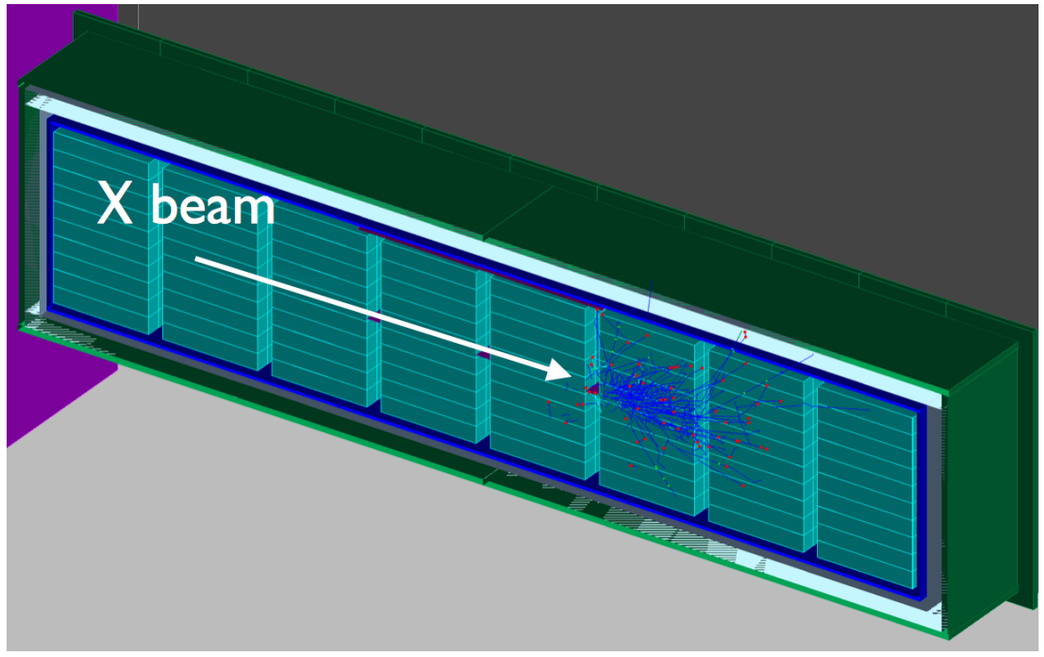
- High energy beam : 11 GeV
- the Highest available beam current ~ 65 μA
- Integrated charge: 10^{22} EOT in ~ 10 months

- BDX detector located underground, downstream of Hall-A beam-dump
- BDX beam-time fits the Hall-A experimental program (already-approved experiments with more than 10^{22} (11 GeV) EOT, e.g. Moeller exp.)
- New underground experimental hall



BDX detector

LDM signal in the Detector : X-electron -> EM shower ~ GEV

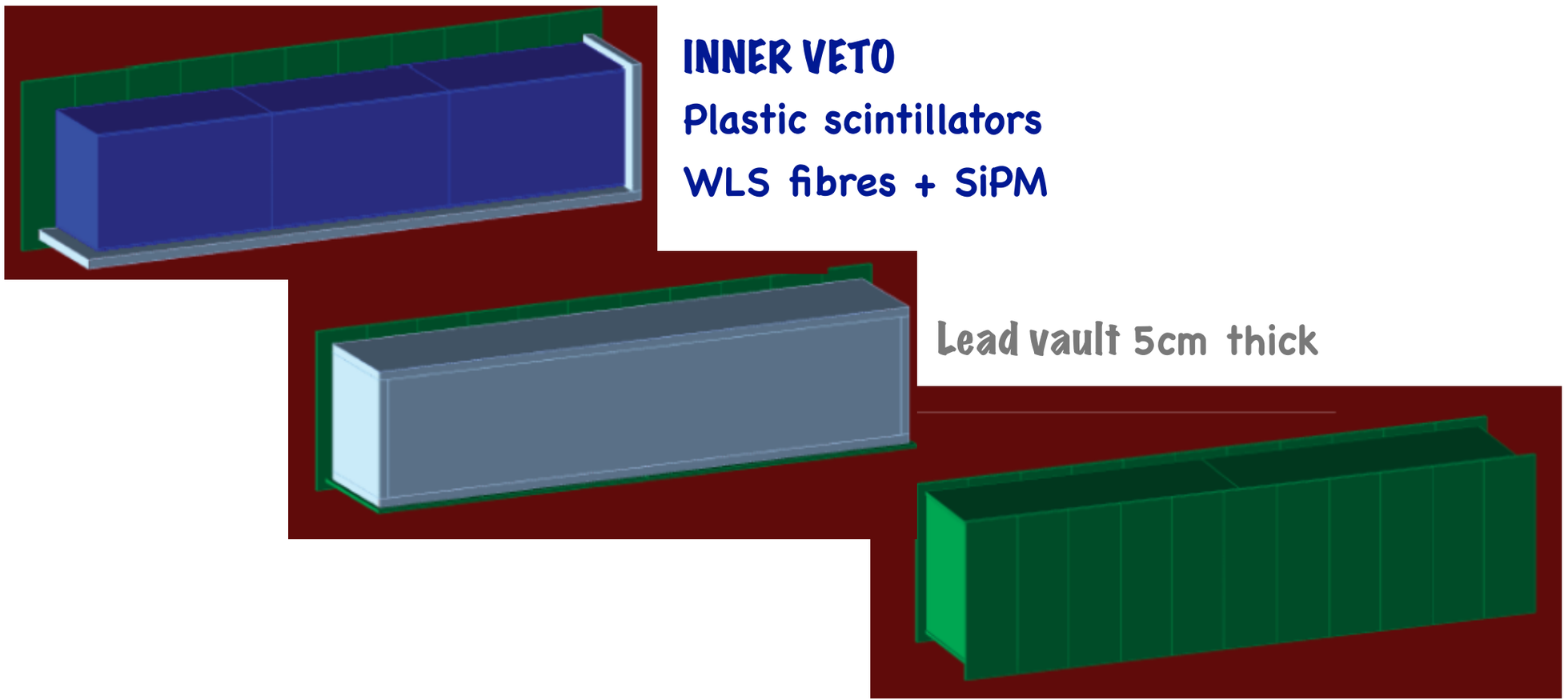


LDM detection

Modular EM calorimeter

- 800 CsI(Tl) crystals (from BaBar EMCal)
- 8 modules 10x10 crystals each
- ~ 3 m long , ~ 50x50 cm^2 front face
- 6x6 mm^2 SiPM readout

Background rejection



INNER VETO

Plastic scintillators

WLS fibres + SiPM

Lead vault 5cm thick

OUTER VETO

Plastic scintillators

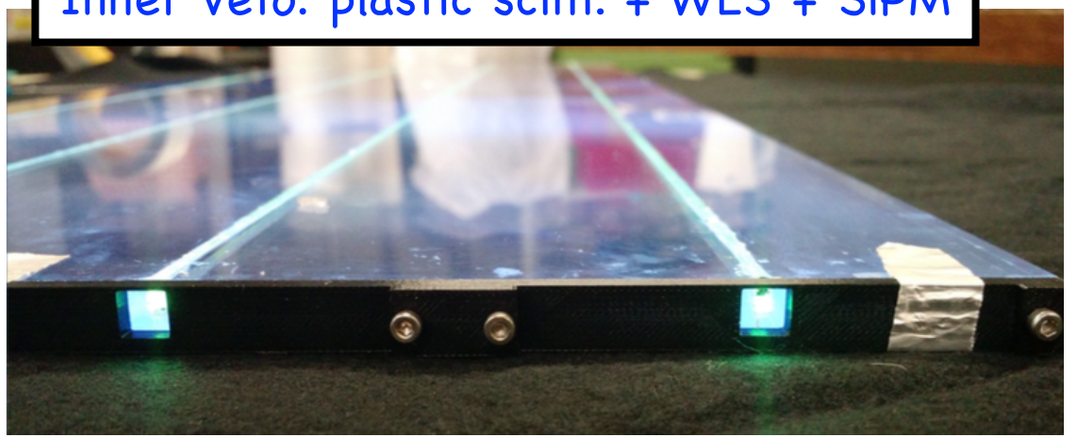
LightGuide/WLS scint.

PMTs/SiPM

BDX Prototype

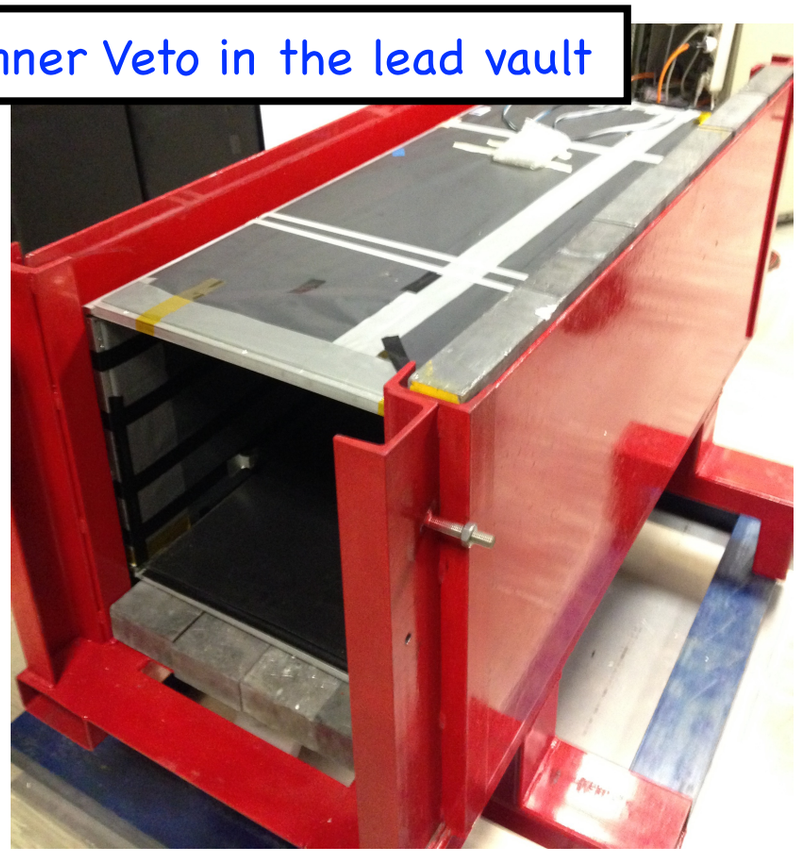
CsI(Tl) crystals + SiPMs

Inner Veto: plastic scint. + WLS + SiPM



Outer Veto:
plastic + WLS plastic + PMT

Inner Veto in the lead vault



Outer Veto:
plastic scint. + Light guide + PMT

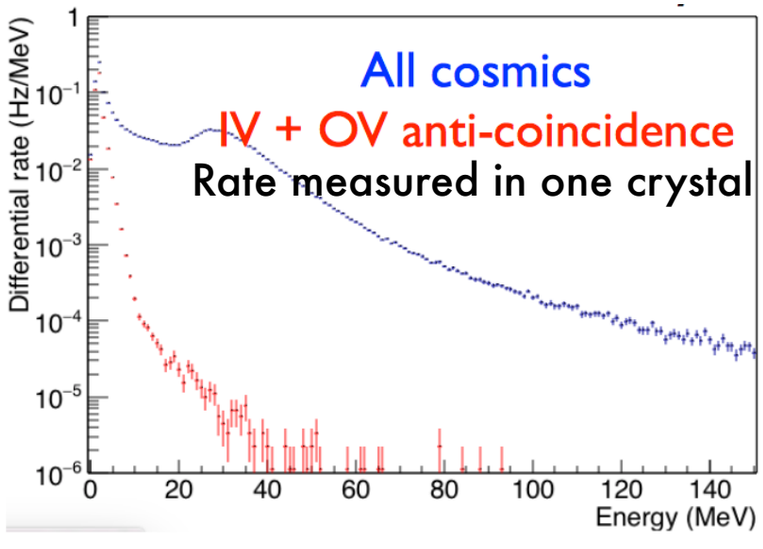
Goals:

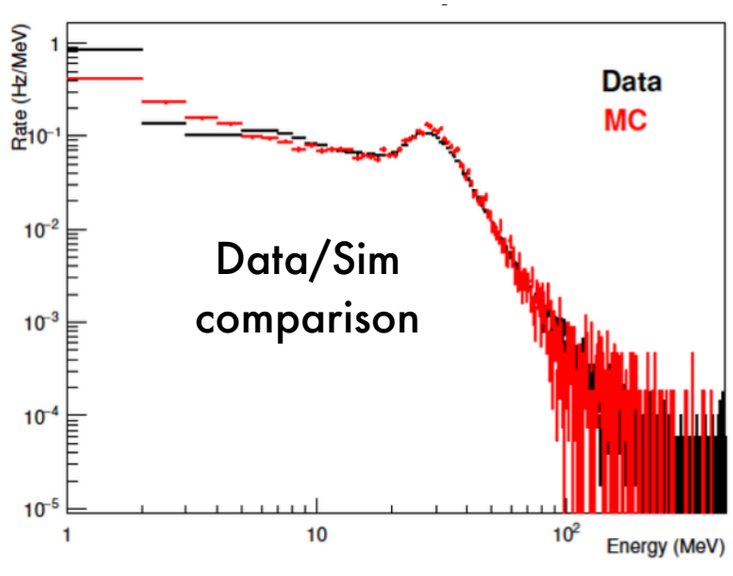
1) validate the proposed design and technical choices

2) measure the capability of rejecting cosmic background and project conservatively experimental data to full detector.

Background

Cosmic Background : measured with the BDX prototype in Catania/LNS



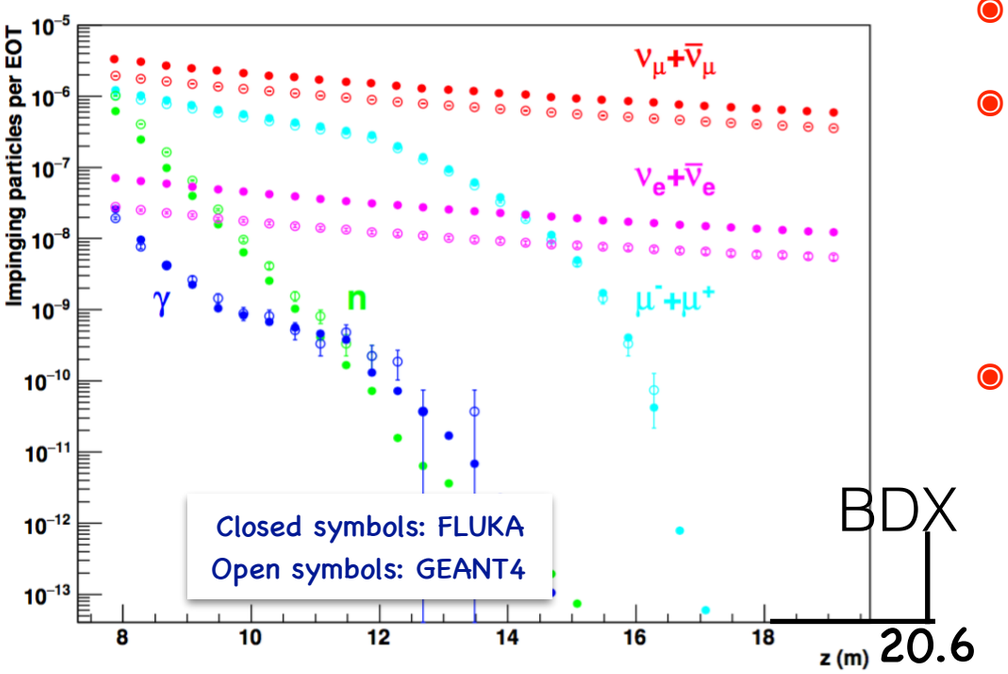


Using Vetos in anti-coincidence and high energy thresholds O(0.35GeV):

expected cosmic bg in the BDX lifetime < 2 counts

Beam-related Background :

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



- No n and γ with E>100 MeV are found at detector location
- we have a rate of beam-related muons (E<300 MeV) on the detector of ~ 0.02 Hz at 65 uA. This background is completely get rid of with veto and shielding.
- Neutrinos survives to the detector -> For a simulated statistics of 3.5×10^9 EOT we obtained, after all rejection cuts and extrapolation to 10^{22} EOT ~ 5 ν.

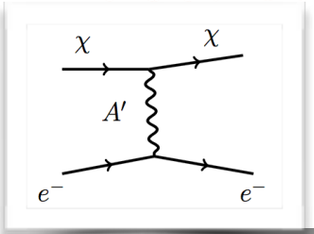
BDX expected Reach

Beam time request

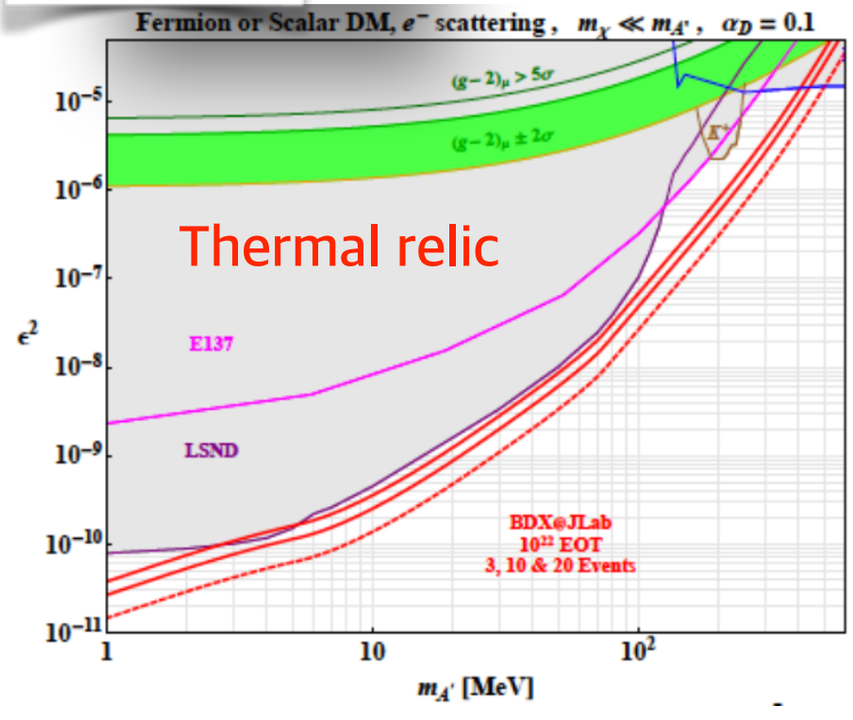
- 10^{22} EOT (65 uA for 285 days)
- BDX can run parasitically to any Hall-A Ebeam>10 GeV experiments (e.g Moller)

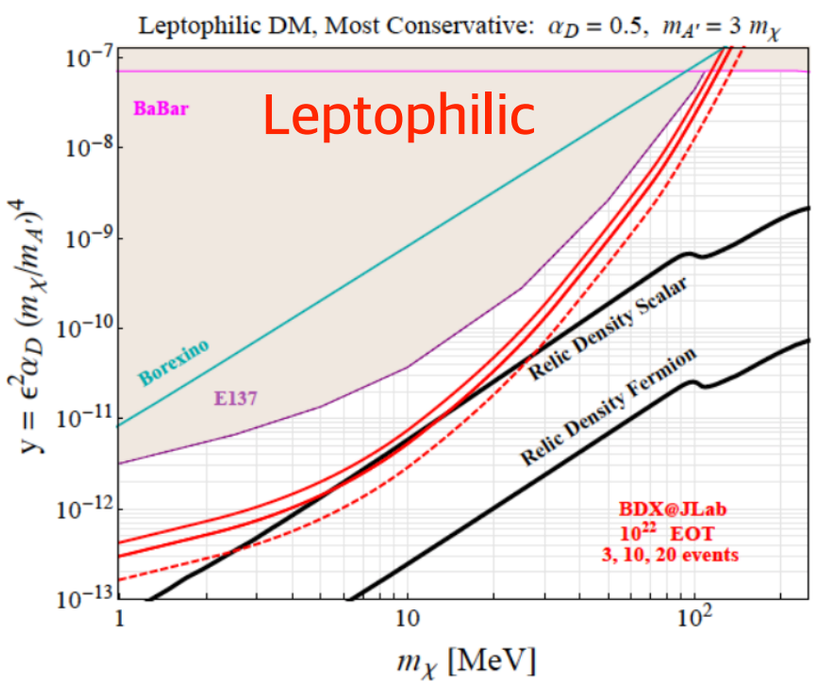
Beam-related background		Cosmic background	
Eseed thr	N_ν (285 days)	Eseed thr	$\sqrt{}$ Bg (285 days)
350 MeV	~ 5	350 MeV	<2 counts

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

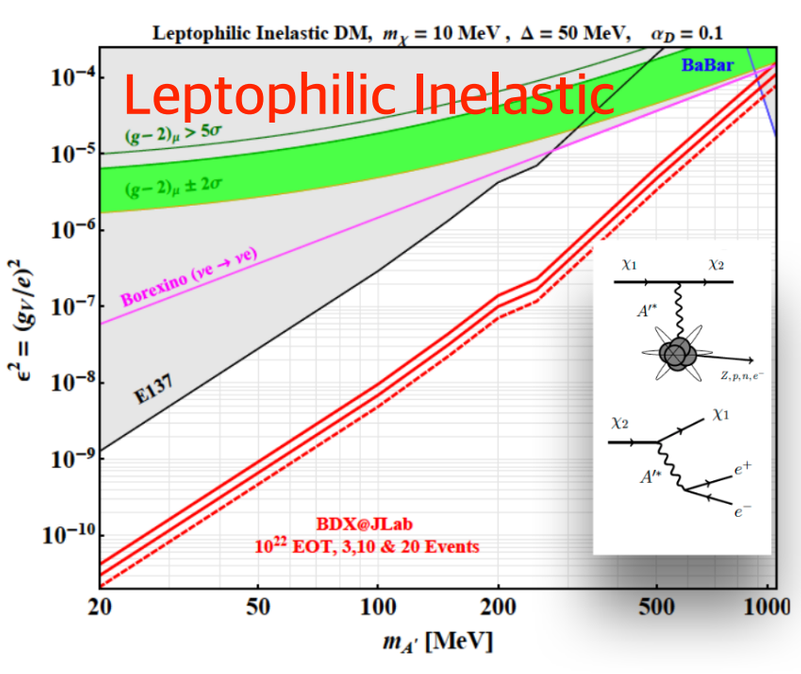


Elastic X-e- scattering





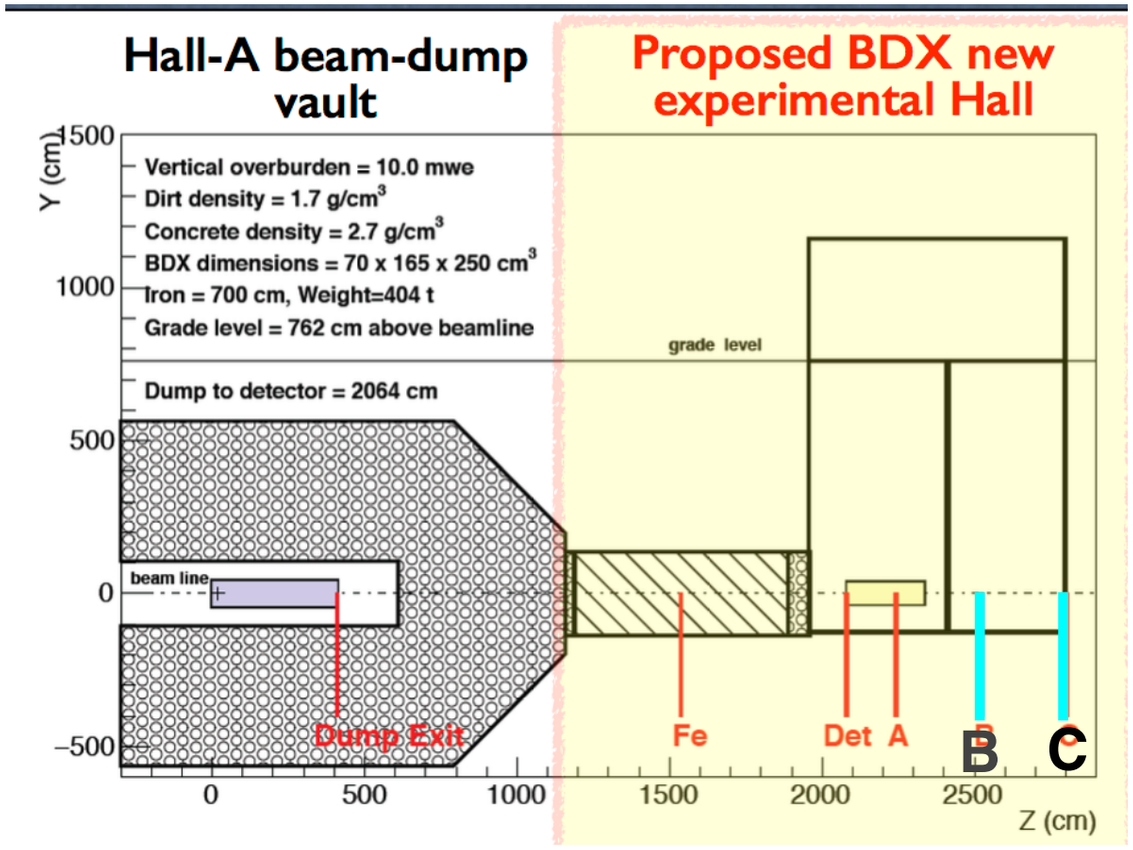
Inelastic X-N scattering



BDX Status

- Received C2 condition approval by JLAB-PAC44
- PAC45 affirmed our plan to address the concerns raised by PAC44
  - measuring the muon flux behind the Hall-A dump when 11 GeV e- beam is on with the current shielding configuration
  - compare MC results obtained in two frameworks: Geant4 and FLUKA (in col with RadCon)
- PAC46: request full approval

BDX Muon test

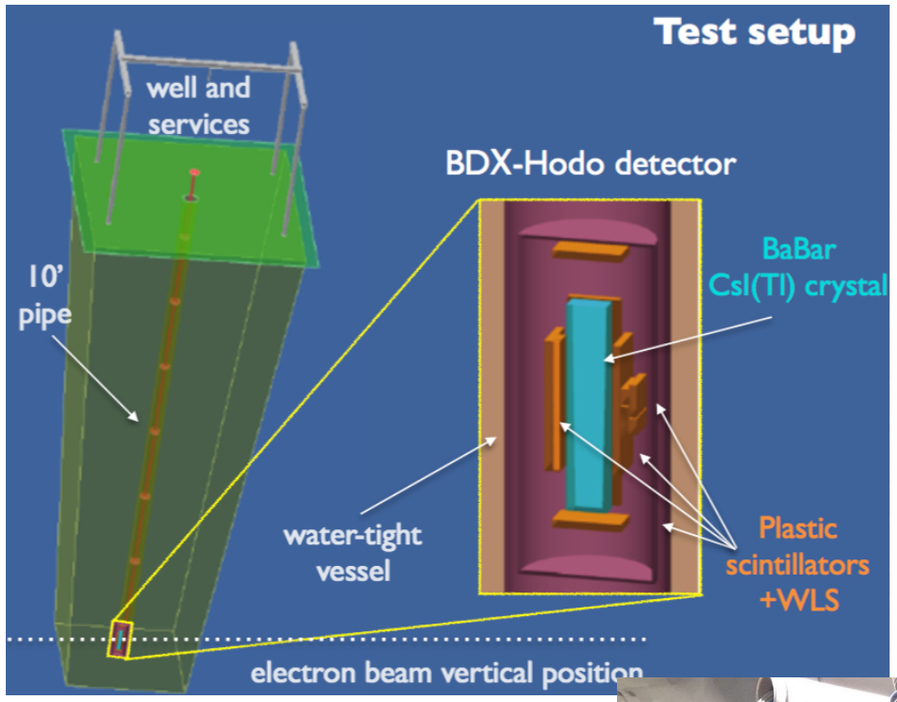


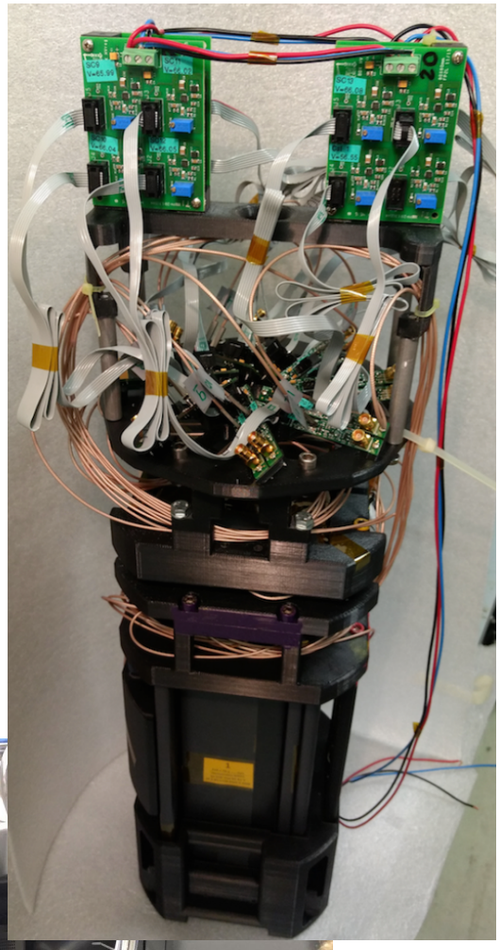
- We have measured the flux of high-energy muon behind the hall A beam-dump with the current shielding configuration when 11 GeV e- -beam is on
- The measurements is a benchmark for MC simulation and helping to understand background
- 2 10" pipes downstream of Hall-A beam-dump were drilled down to beam height (8 m) and aligned with the beam-line n 2 different positions B (25 m) and C (28 m)

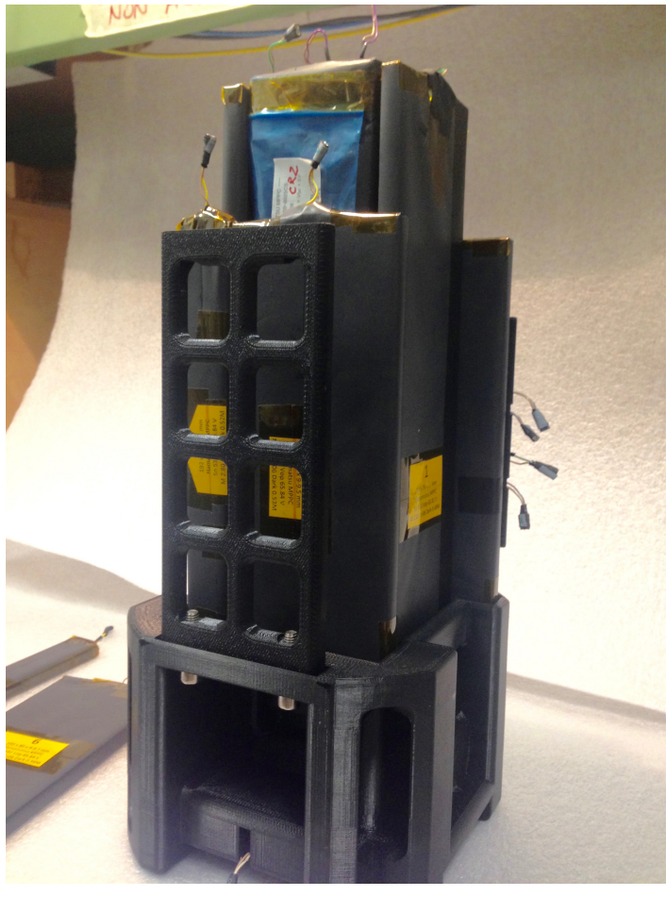
BDX Muon test: Detector

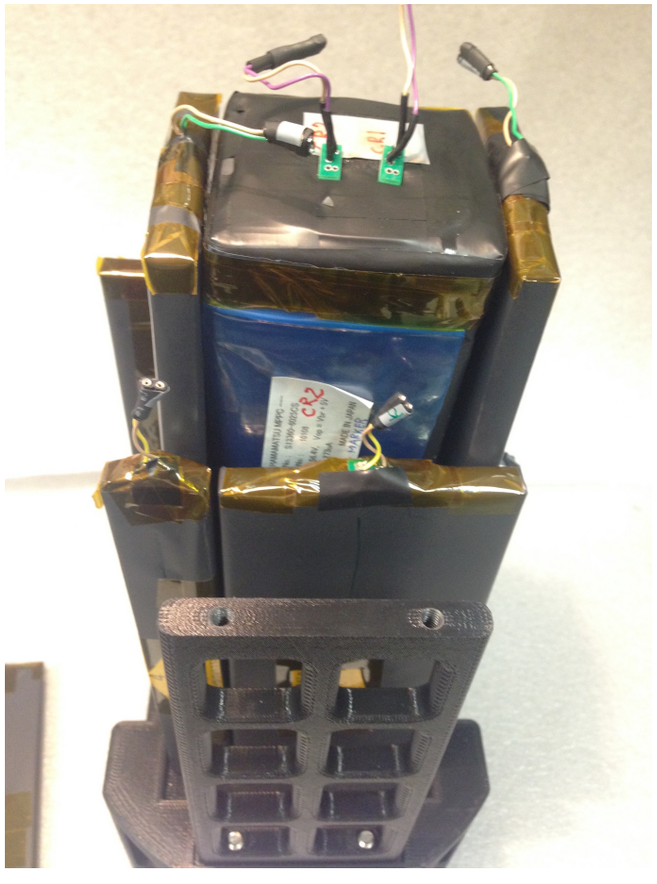
same technologies proposed in the final experiment

- **CRISTAL**
  - CsI(Tl) crystal (5x5 x 30 cm^2)
  - 6x6 mm2 Hamamatsu SiPMs
- **SCINTILLATORS**
  - 13 plastic scintillator paddles 1 cm thick
  - 3x3 mm2 SIPM coupled via WLS fibers
- **CONTAINER**
  - Cylindrical vessel (d=20cm, h=52cm)



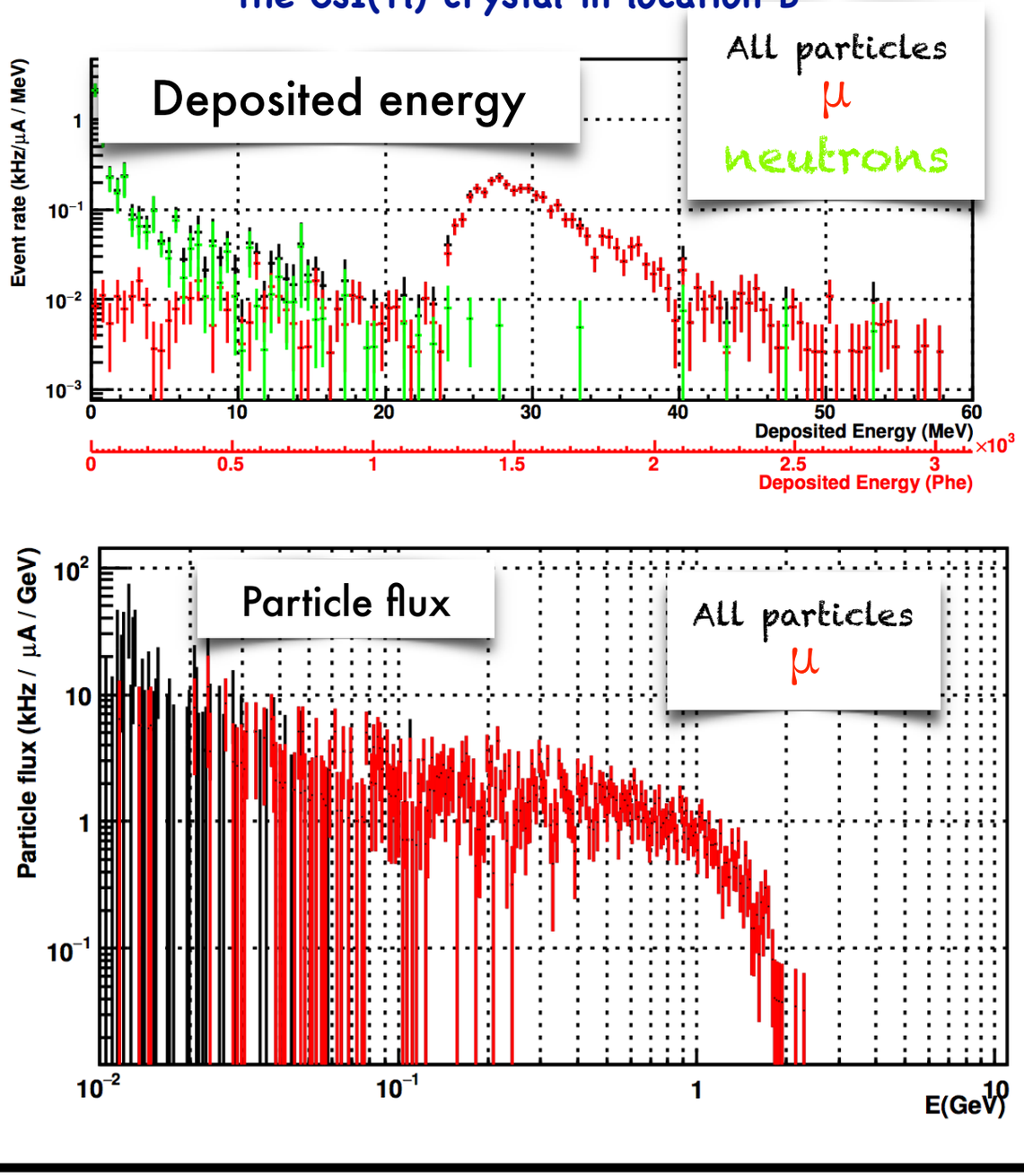






BDX Muon test
Expected results: MC simulation

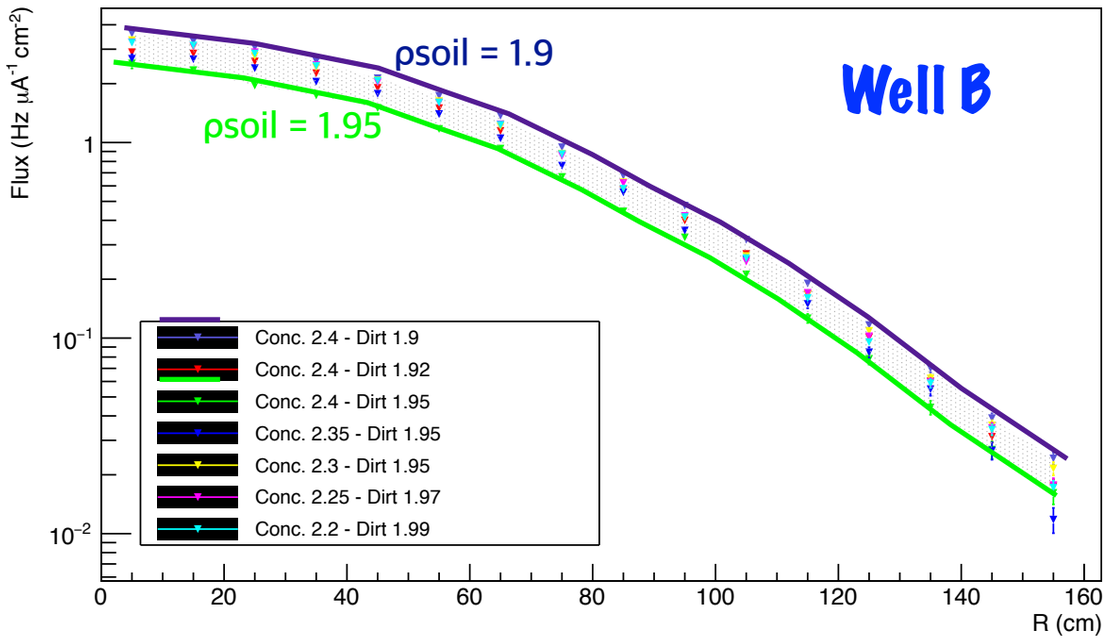
Expected particle flux (FLUKA) and energy deposition in the CsI(Tl) crystal in location B

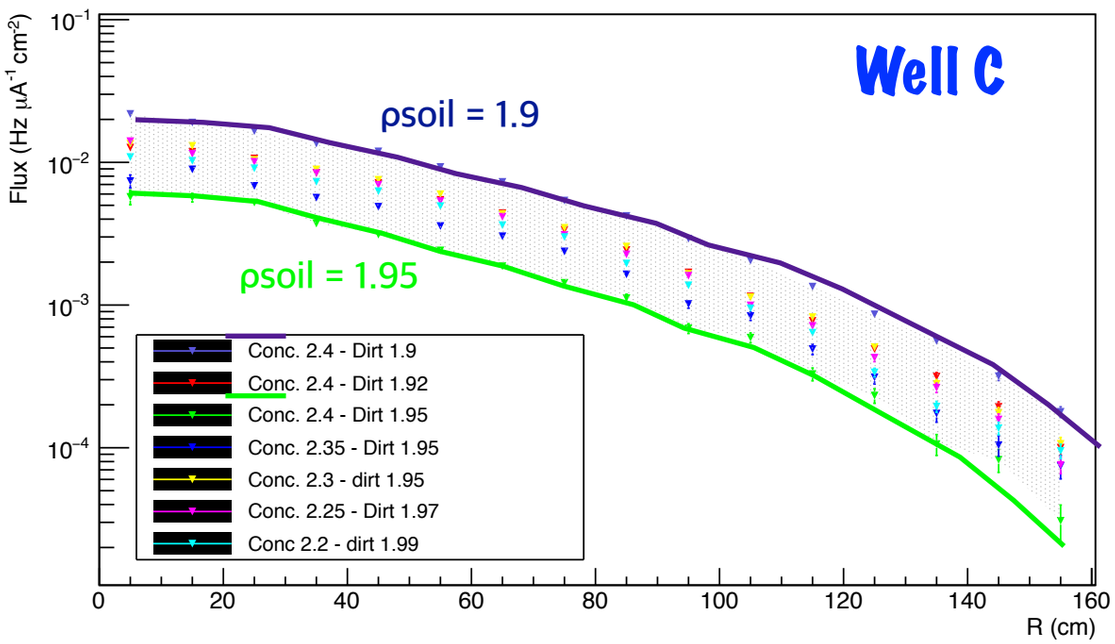


- Simulation performed using FLUKA/GEANT4 framework
  - generating muons by primary electron interaction on Hall-A beam dump (FLUKA)
  - propagating muons to the pipe positions using GEANT4
  - BDX-HODO response with GEANT4
- **Only muons** and low-energy neutrons **reach the area of interest**
- Rate from cosmic muons is negligible (and measurable !)

BDX Muon test
Expected results: MC simulation

Flux vs vertical position





✦ **Significant dependence on soil density :**

- **soil density measured** in correspondence of the two wells : **1.93 - 1.95 g/cm3**
- soil density along the muon flight path unknown : constant ??
- concrete density: no measurement available

- Rate well B: $\Delta\rho$ ~ 2.5% -> Δrate ~ 30%
- Rate Well C $\Delta\rho$ ~ 2.5% -> Δrate ~ 60%

✦ **Expected Rate :**

- Rate Well B: O(kHz)
- Rate Well C: O(Hz)

BDX Muon test
Experimental Campaing

★ **Positions scan**: the muon flux sampled at different heights with respect to nominal beam height (8 m underground).

◉Beam: CEBAF e- beam @ **10.6 GeV** and current of 22 uA

➡ Well B : 22 positions (ranged between -110 cm and 150 cm). Each measurement was repeated at least 2 times

➡ Well C: 14 positions (ranged between -80 cm and 80 cm). Each measurement was repeated at least 2 times

★ **Currents scan**: the muon flux sampled at nominal beam height (8 m underground) changing the current .

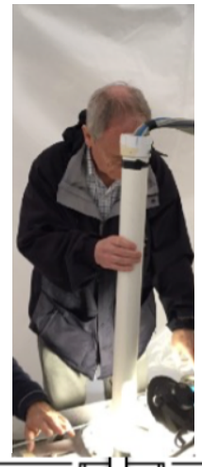
◉Beam: CEBAF e- beam @ **10.6 GeV**

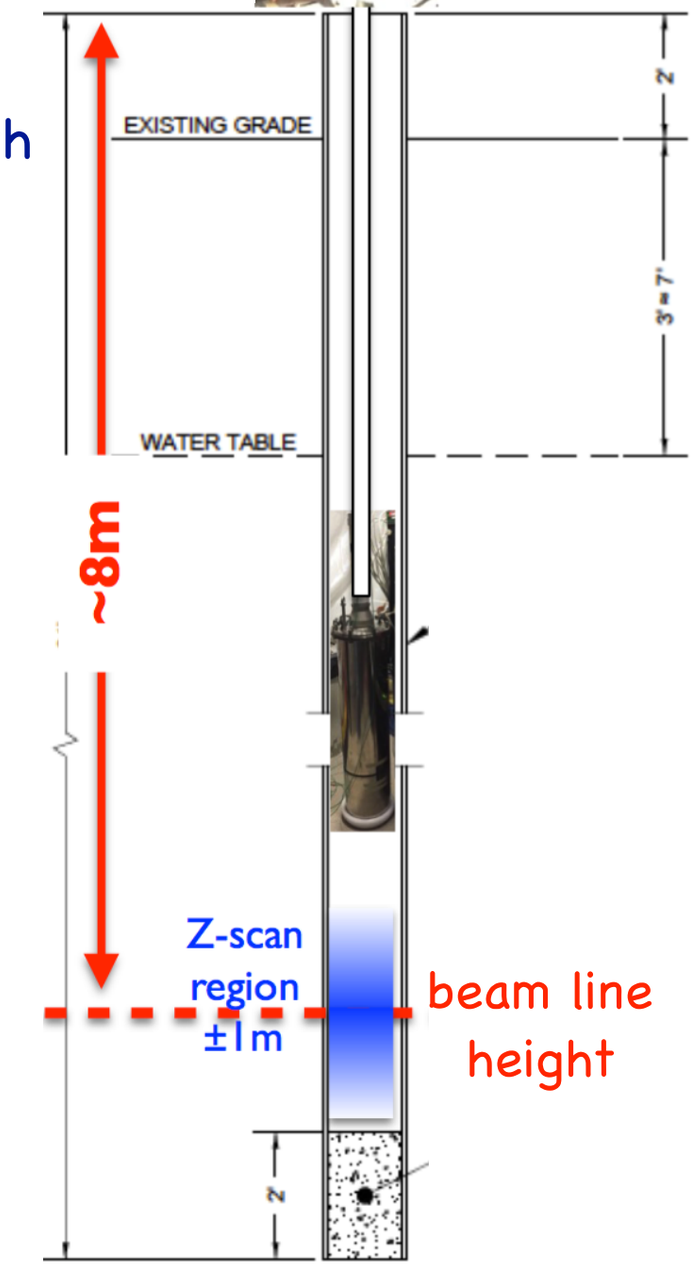
➡ Current = 2.2uA, 5uA, 10uA, 22uA

➡ Well1 : 1 position (position 0)

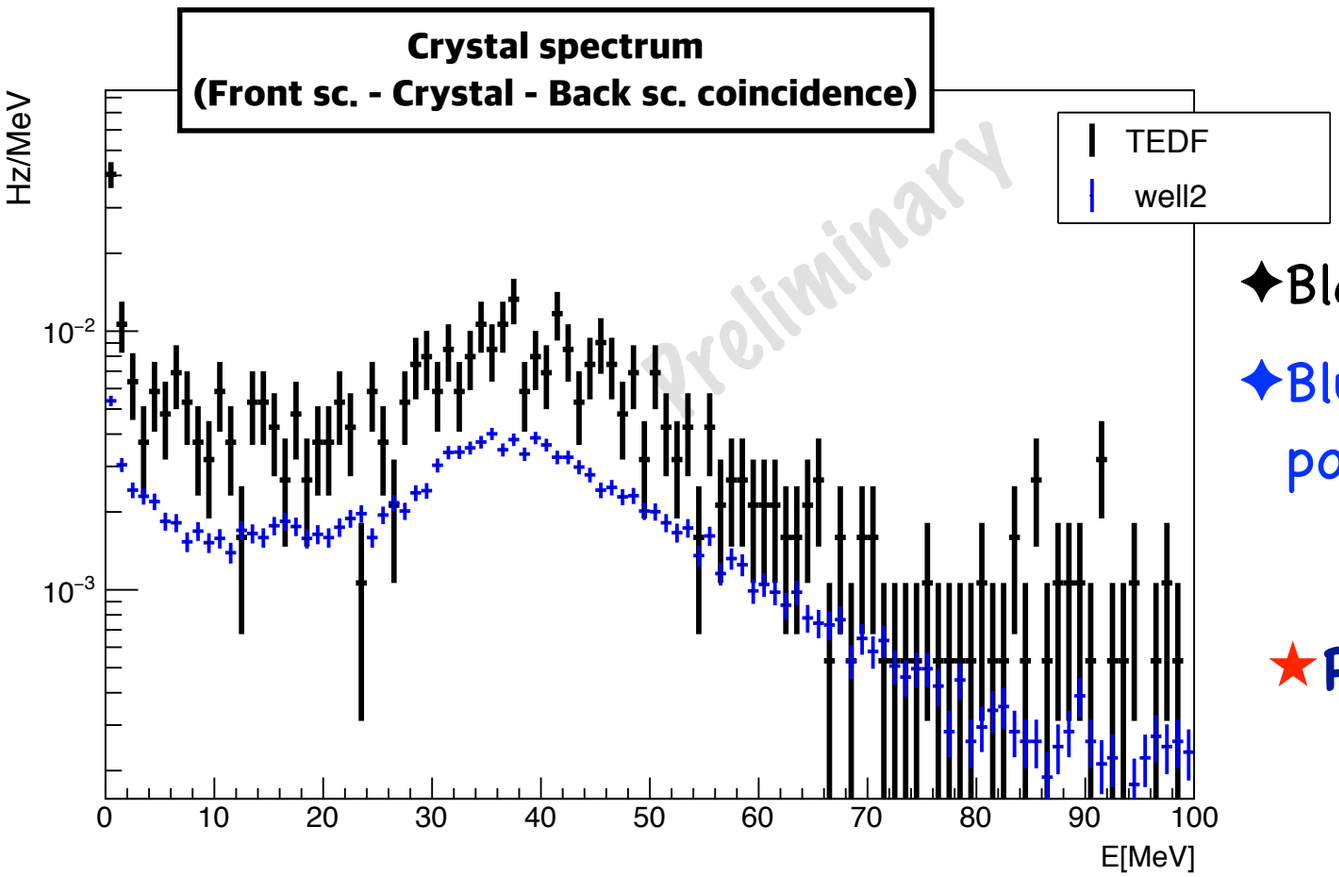
★ **Cosmic Background**

➡ measurement inside well C at beam-line height





BDX Muon test
Cosmic Background



✦Black spectra: measurement outside the well

✦Blue spectra: measurement inside well C at 0 position

★**Reduction factor is ~ 2.5**

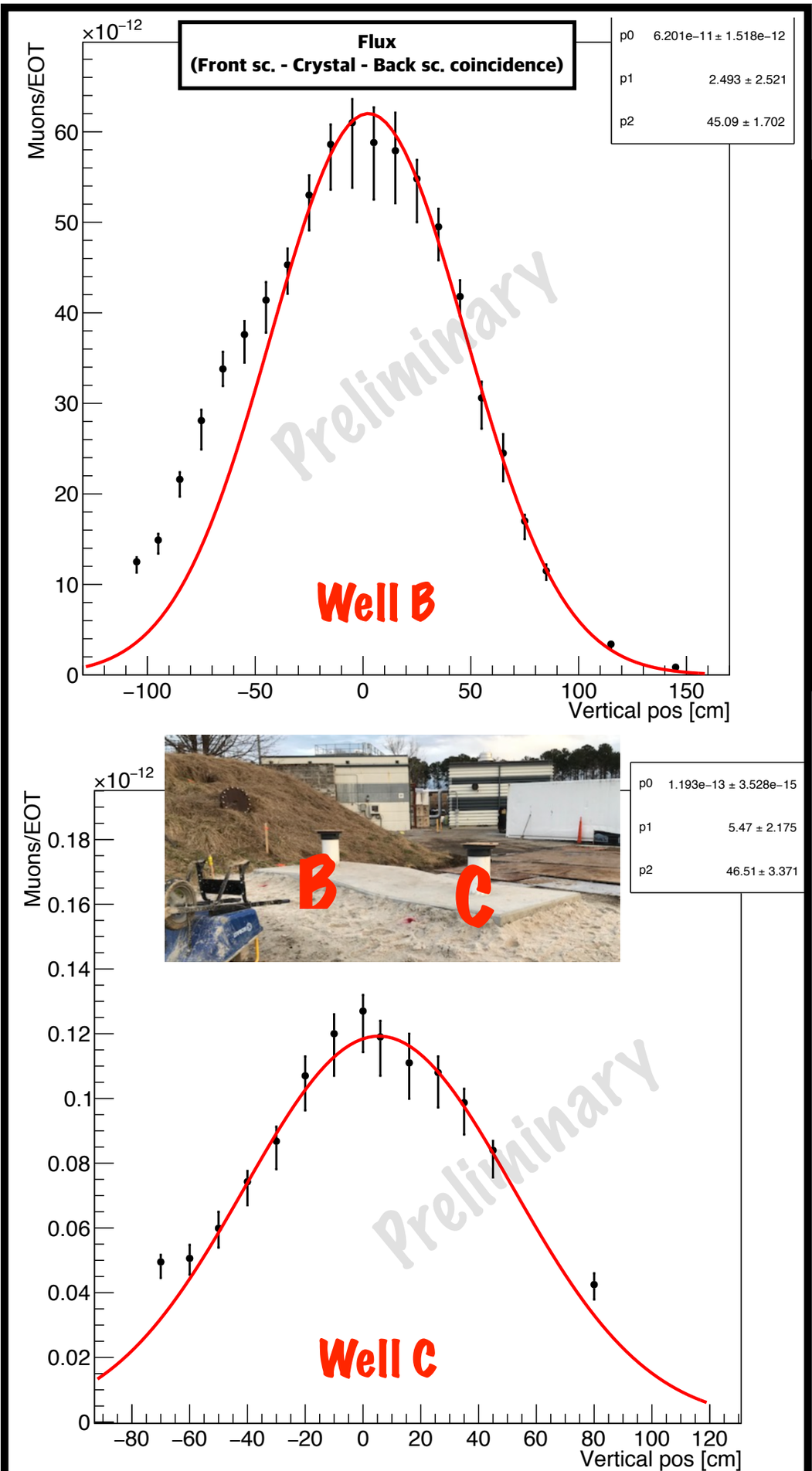
Cosmic inside the well

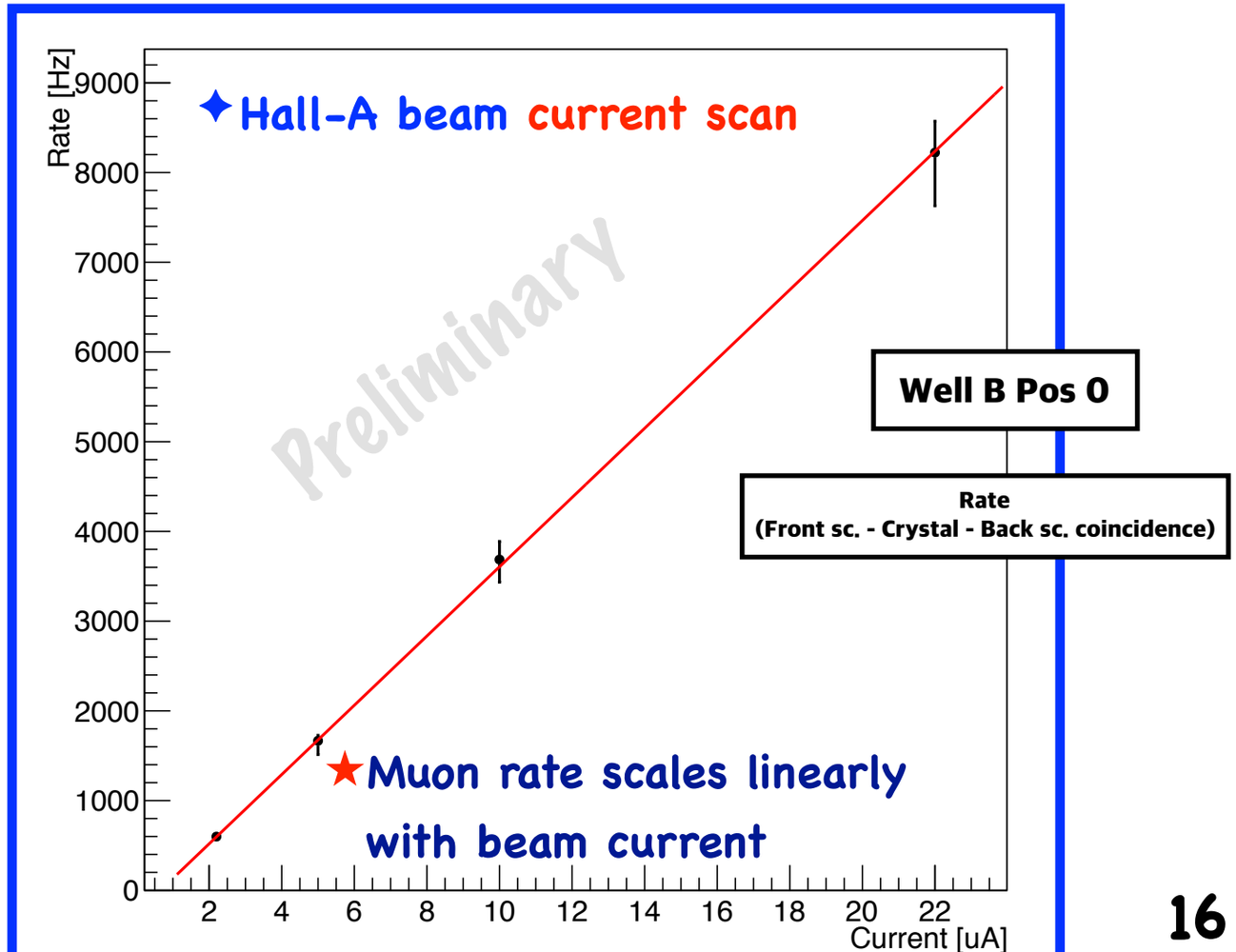
★Front/Back/crystal coincidence rate is ~ 0.1 Hz -> Negligible

★No significant effect of cosmic muons on rates measured with beam-on

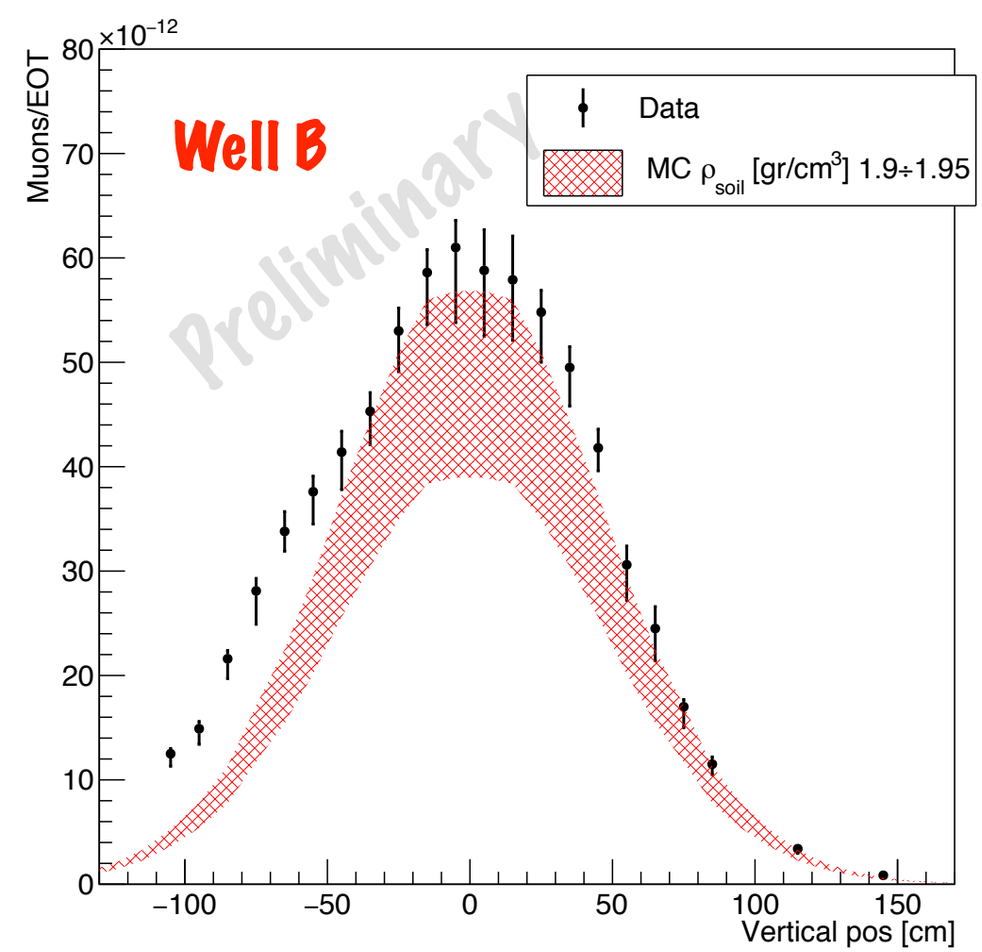
BDX Muon test
Experimental Results

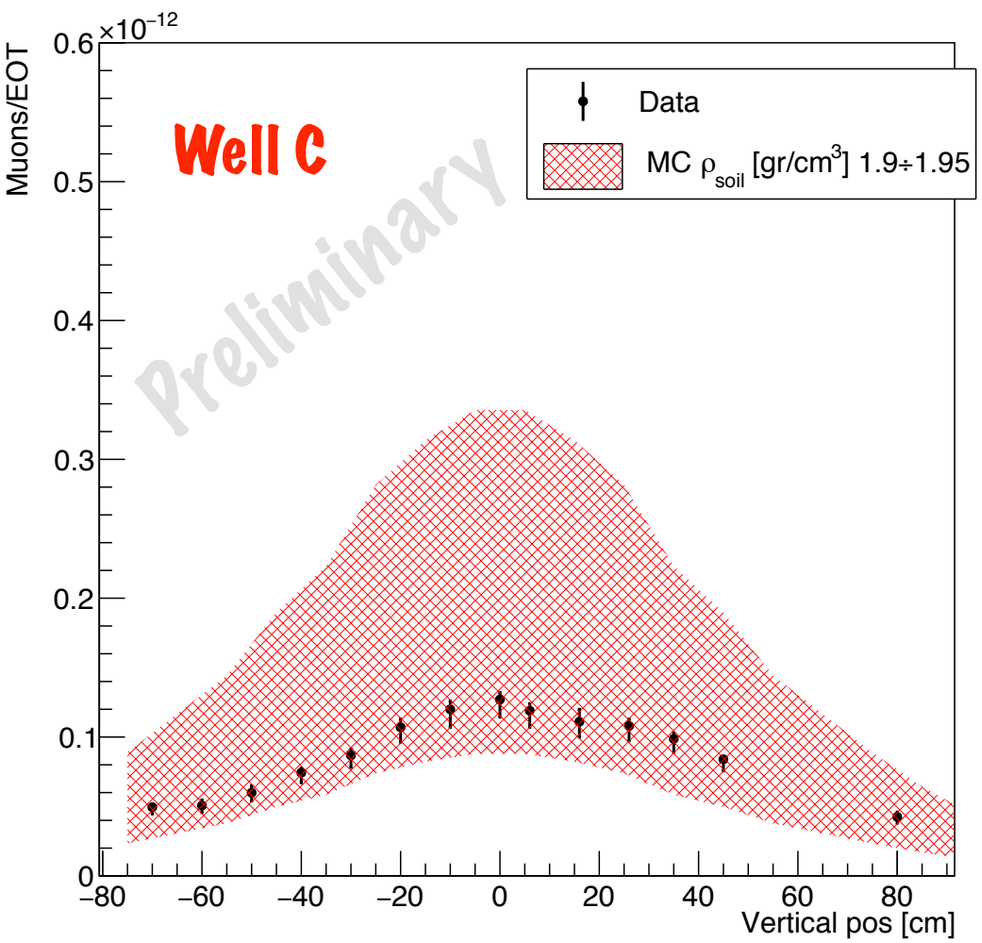
- **Scan Position**: Muon rate measured in the two wells at different distances from the beam-line height (Z=0)
  - ★Rate well B (Z=0, I=22 uA) ~ 8 KHz
  - ★Rate well C (Z=0, I=22 uA) ~ 15 Hz
  - ★Ratio of the two wells is ~ 500
  - ★**Similar bell shape** : both distributions are fitted to gaussian with the same width (σ ~ **45 cm**)
  - ★The asymmetric shape in the left part of well B distribution could be due to a no constant soil density





BDX Muon test
DATA/SIM comparison

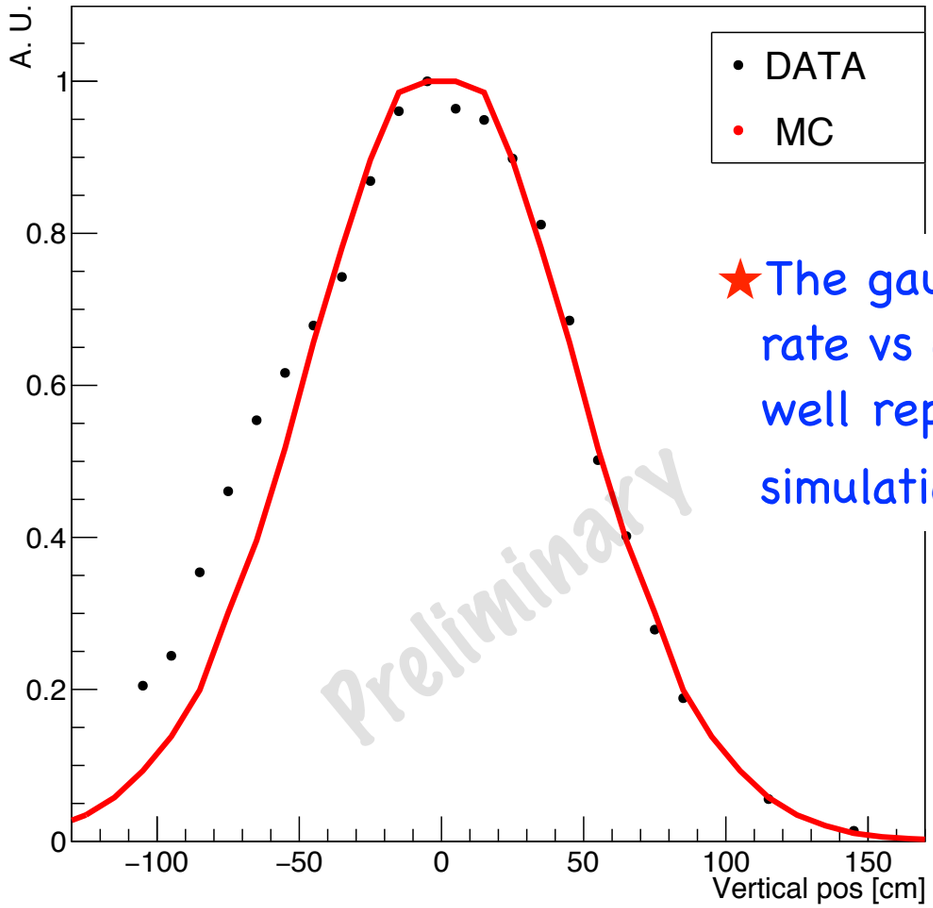




- **Significant dependence on soil density :**

  We assumed following range for density: 1.9 - 1.95 gr/cm^3

- ★ **Data in agreement with the simulation for the assumed density range**

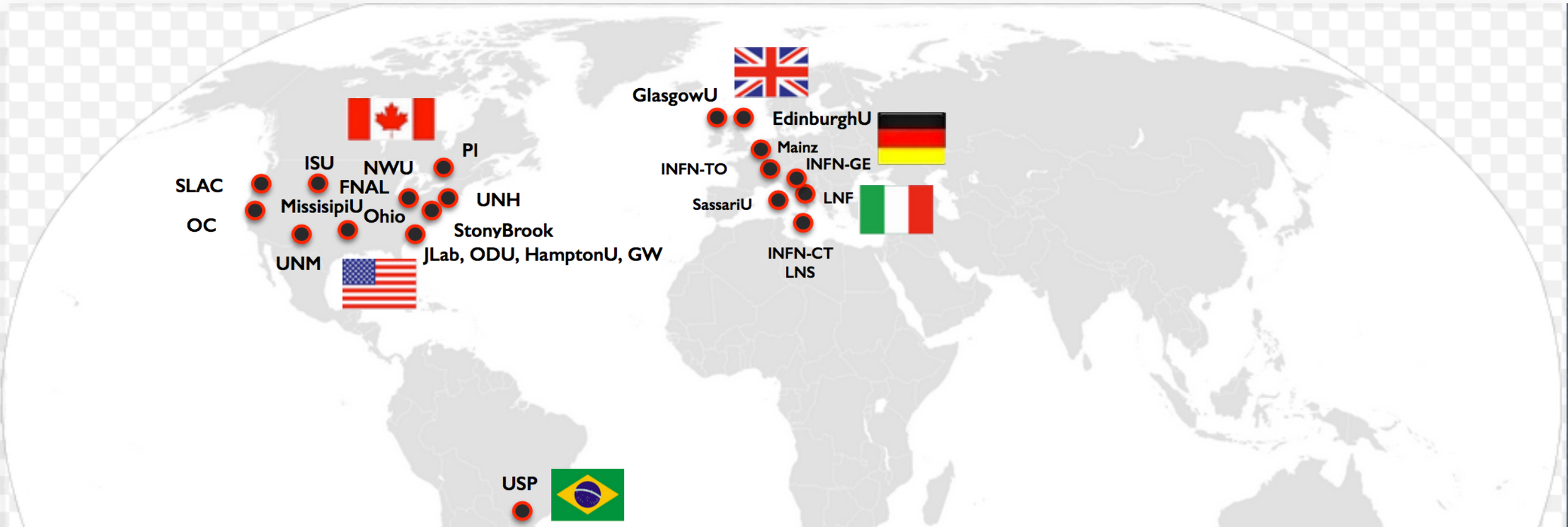


★The gaussian shape of the rate vs det. vertical position is well reproduced by simulations (**with the same** σ)

Conclusion

- ✦ BDX is a beam dump experiment aimed to investigate the existence of Light Dark Matter (1 MeV - 100 MeV)
- ✦ The **BDX experiment is conditionally approved** to run parasitically at Jefferson Lab for 41 weeks at ~11 GeV, which will allow it to collect ~10^{22} electrons on target.
- ✦ Measurements to assess the BDX beam-on bg proposed to PAC45, endorsed and supported by JLab
- ✦ The BDX-Hodo detector (CsI(Tl) + scintillator paddles) lowered in two wells located ~25m and ~28m downstream of the Hall-A beam-dump
- ✦ Despite the uncertainty in soil density, simulations reproduce both absolute rates and shape
- ✦ Ready to present results to PAC46 seeking for BDX proposal full approval

BDX Collaboration



Thank you for your attention !