BDX
Dark Matter search in a Beam Dump eXperiment at Jefferson Lab

INFN Sezione di Catania

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on behalf of the BDX Collaboration

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Physics Motivation

An extensive experimental program based on WIMPs paradigm is searching for DM
Up to now no results from DM direct search and no evidence of new physics at the weak-scale from LHC

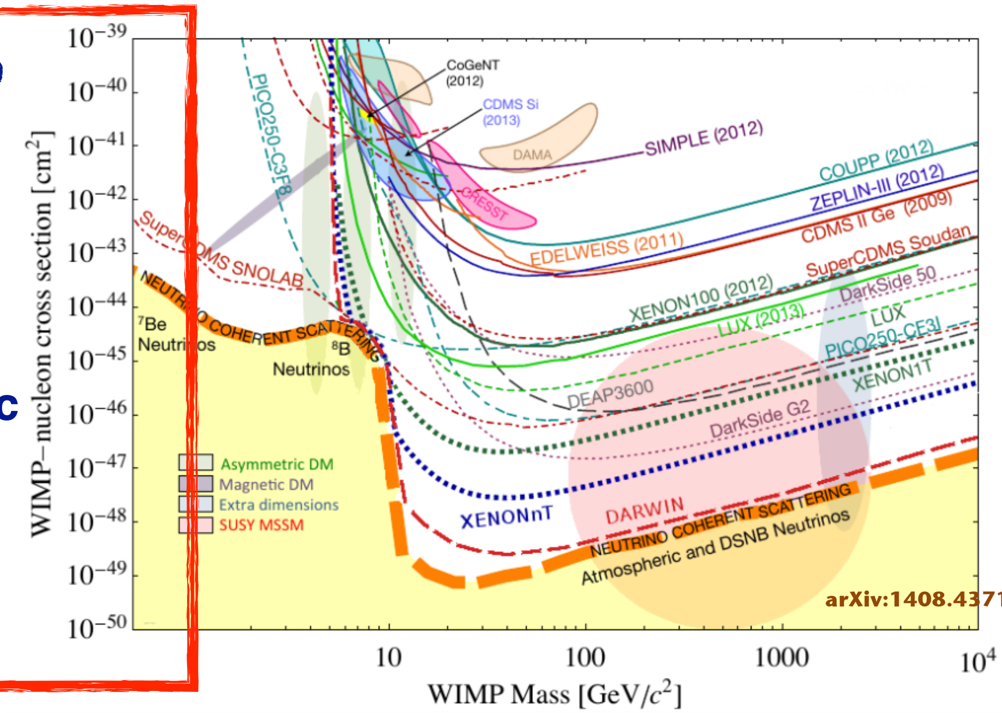
EXTENDING THE DM HUNTING TERRITORY TO UNEXPLORED REGIONS

DARK SECTORS

Light Dark Matter (χ) in the 1-1000 MeV mass range

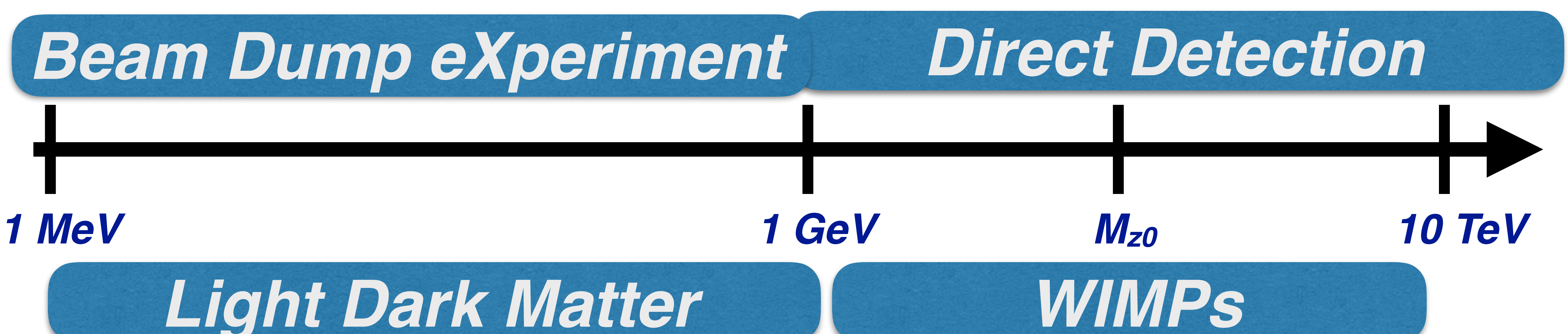
Requires a new Force - U'(1) to achieve the correct thermal relic

Light DM couples to SM trough the new Force



Mass range where (traditional) Direct Detection is (almost) impossible

High intensity beam makes accelerator-based DM search highly competitive



Heavy/Dark Photons

Volume 166B, number 2 PHYSICS LETTERS 9 January 1986

AN OLD IDEA: IF THERE IS AN ADDITIONAL U(1) SYMMETRY, THE NEW VECTOR BOSON <u>A' KINETICALLY MIXES WITH THE SM PHOTON</u>

TWO U(1)'S AND ϵ CHARGE SHIFTS

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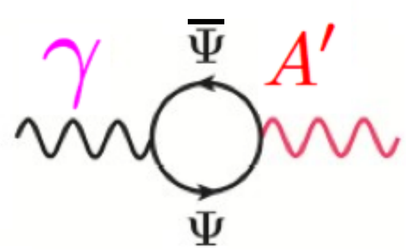
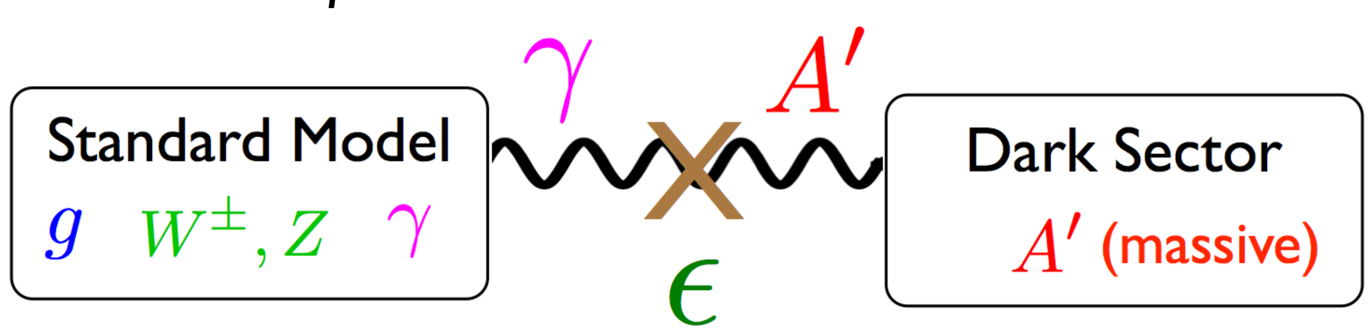
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic mixing"

Loops of heavy particles charged under photon and A'

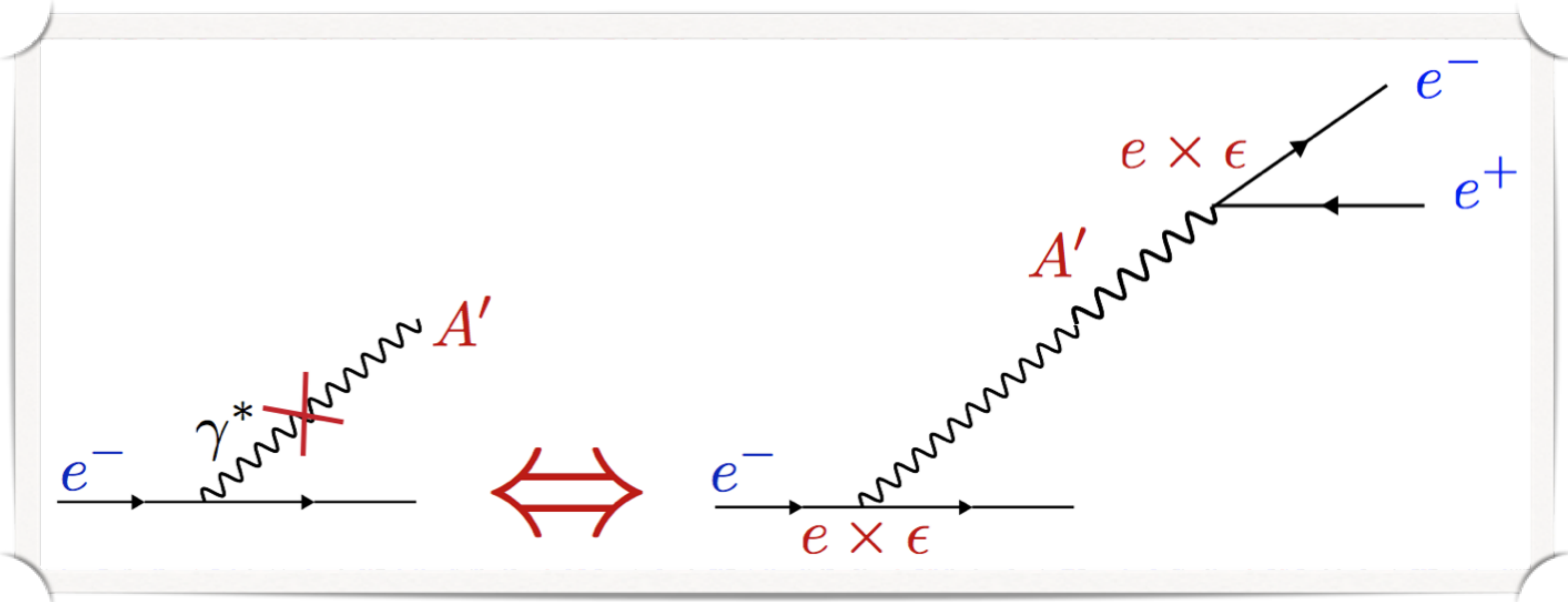


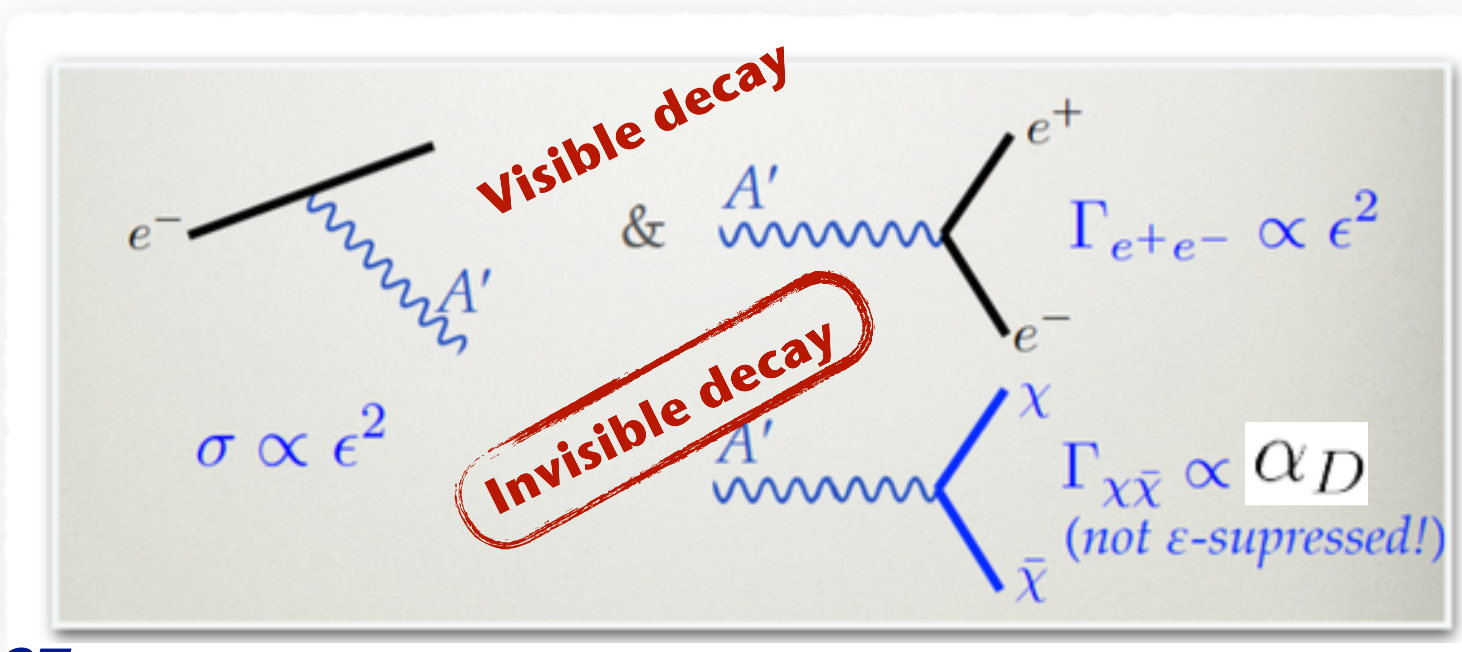
A' acts as a "portal" between the SM and the new sector



Heavy/Dark Photons

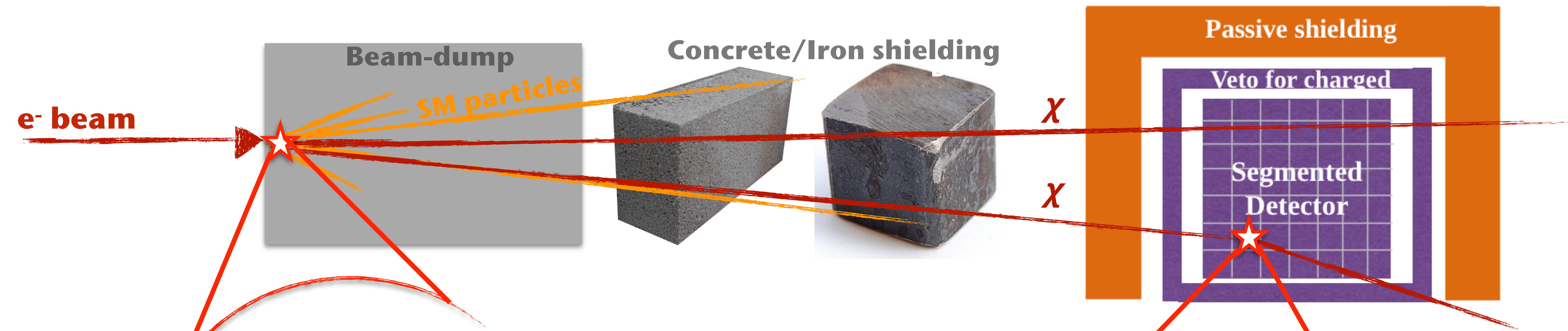
Mixing induces an effective weak coupling ε · e to electric charge

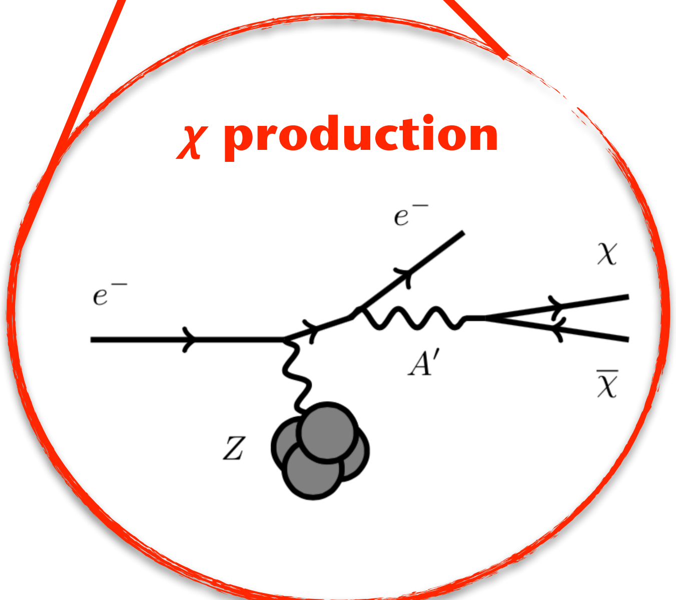




BDX in a nutshell

LIGHT DARK MATTER SEARCH IN AN ELECTRON BEAM-DUMP EXPERIMENT

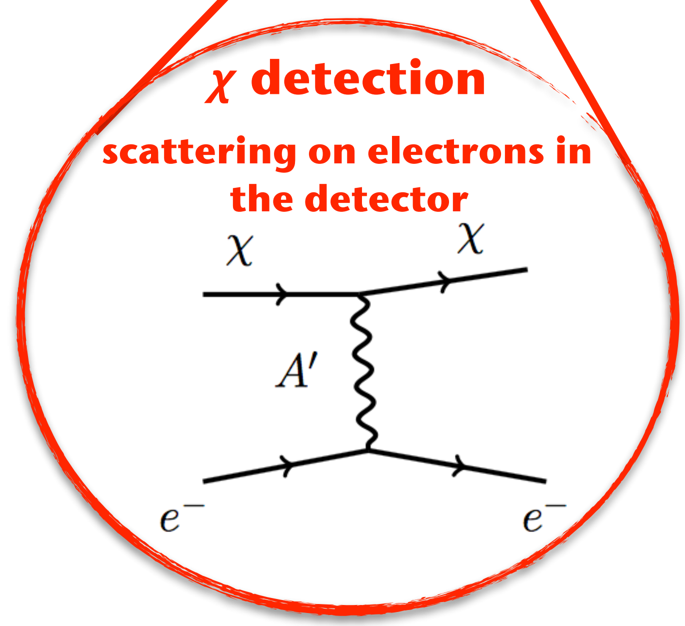




A' yield: $N_{A'} \propto \frac{\varepsilon^2}{m_{A'}^2}$

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

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



HIGH INTENSITY BEAM

Sensitivity scales **linearly** with the total number of EOT

O(10) GEV BEAM ENERGY

High energy helps cross-sections and kinematics

KINEMATICS: DM PARTICLES STRONGLY FORWARD FOCUSED

DM SIGNATURE IN THE DETECTOR

EM SHOWER ~GEV ENERGY

⬇

HIGH ENERGY THRESHOLDS

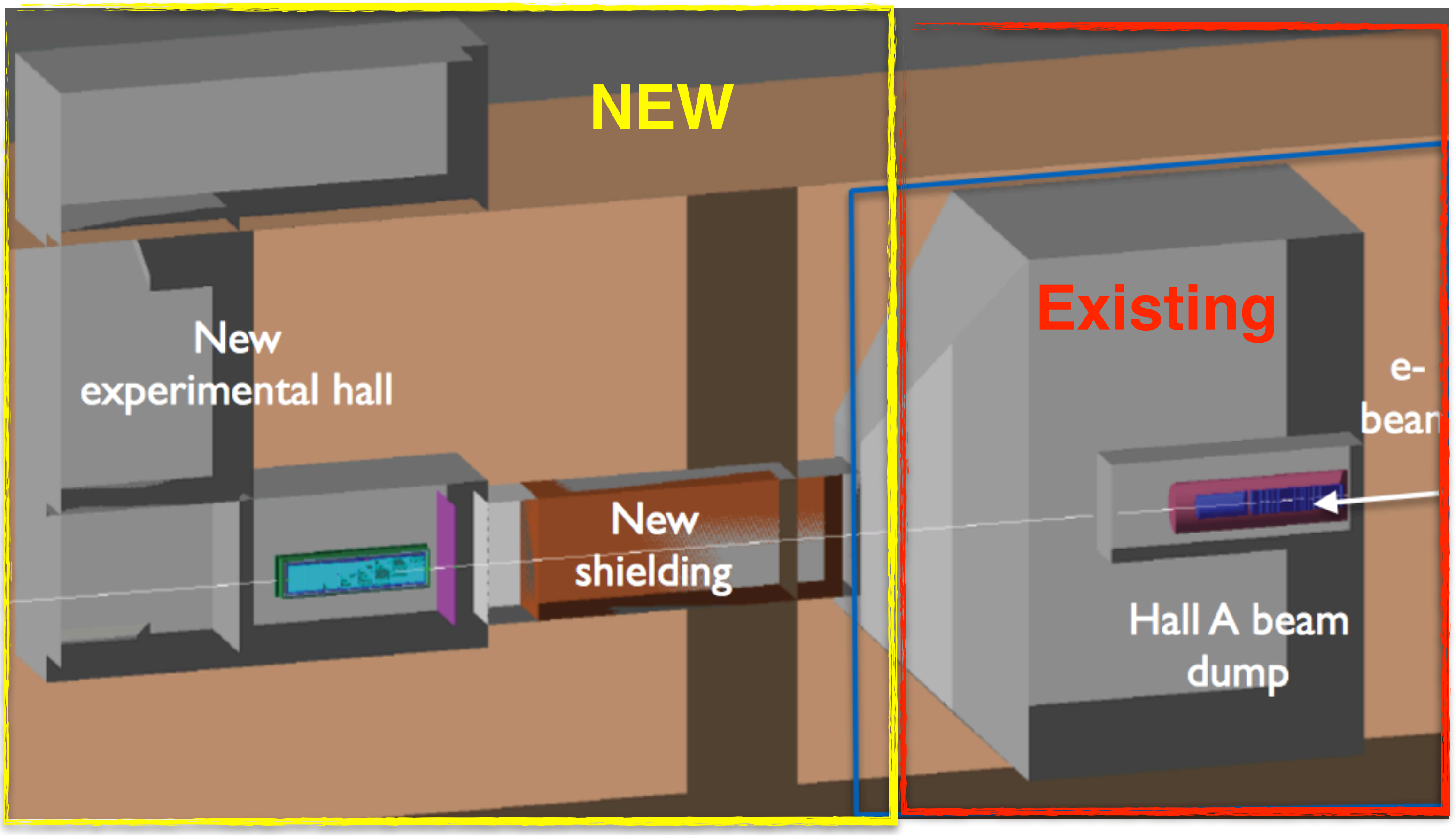
BDX at JLAB

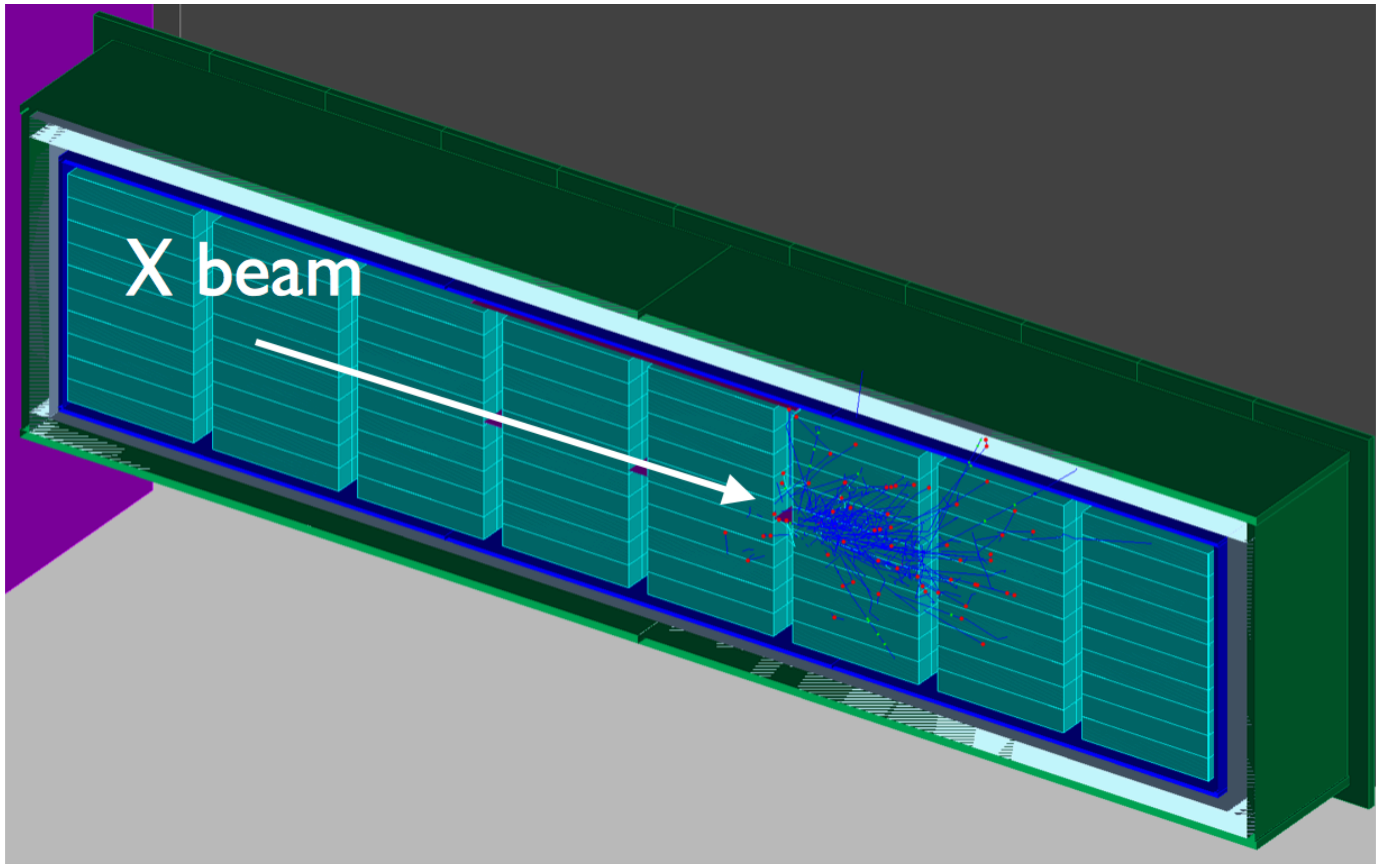
High energy beam available : 11GeV

The highest available beam current ~65 μA

Integrated charge: 10^{22} EOT in ~10 months

- BDX detector located downstream of Hall-A beam-dump (~ 8m ug)
- New underground experimental hall





The BDX detector

DM DETECTION

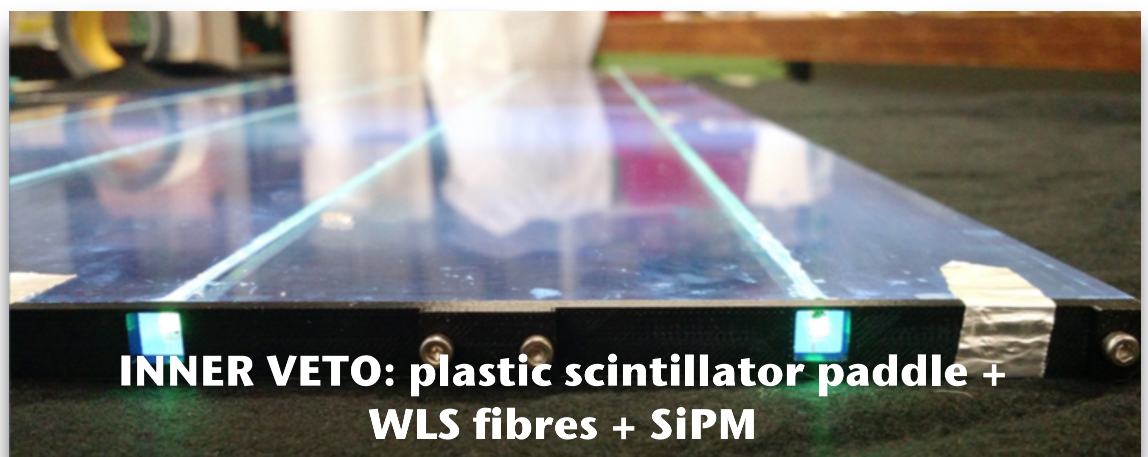
modular EM Calorimeter

- 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

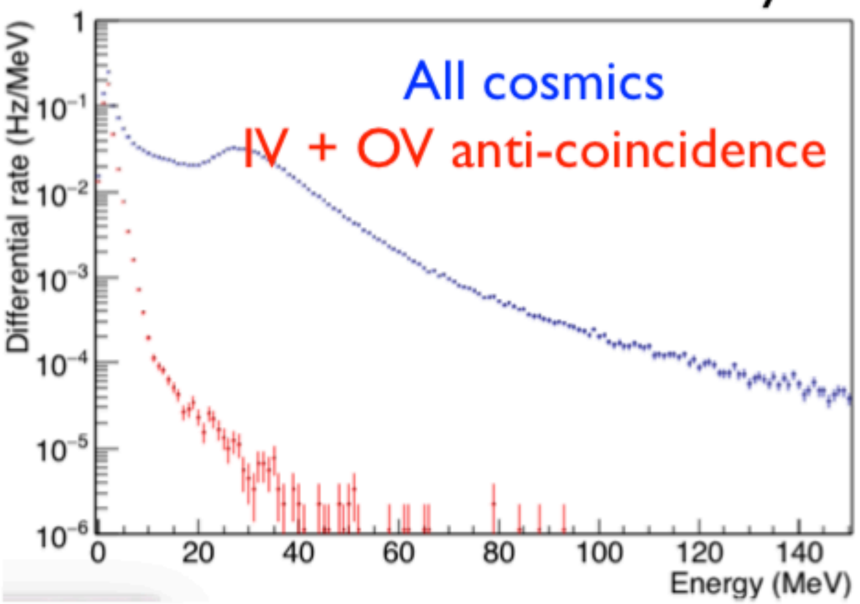
Two active veto layers

Plastic scintillators + WLS + SiPM

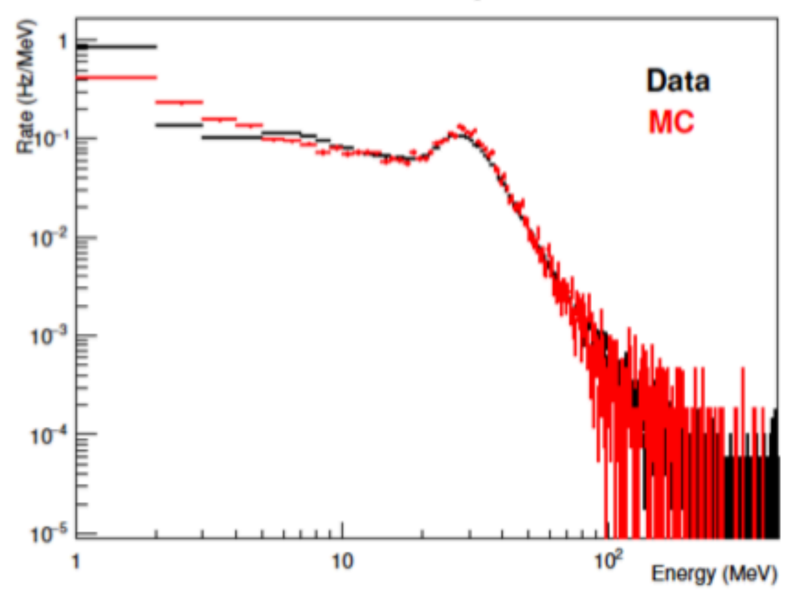


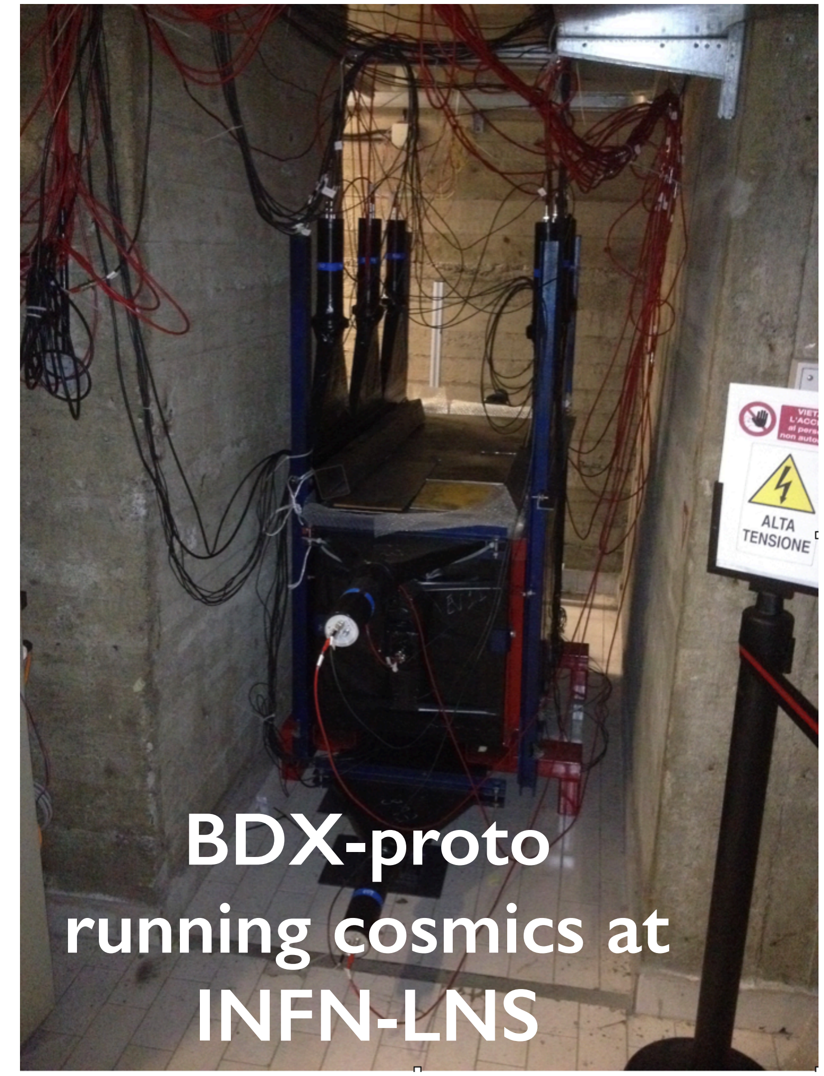
Cosmic background measured with the BDX detector prototype in Catania and LNS (similar overburden expected at JLab) and conservatively projected to the full detector

Count rate measured in 1 crystal



Data/SIM comparison



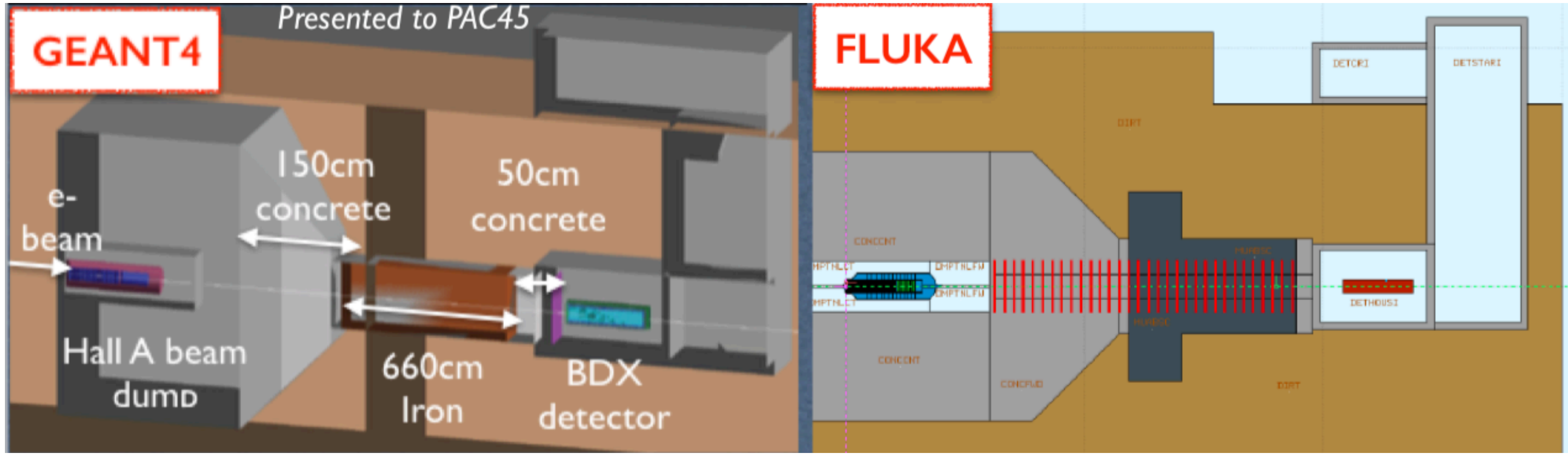


Expected cosmic background counts in the BDX lifetime

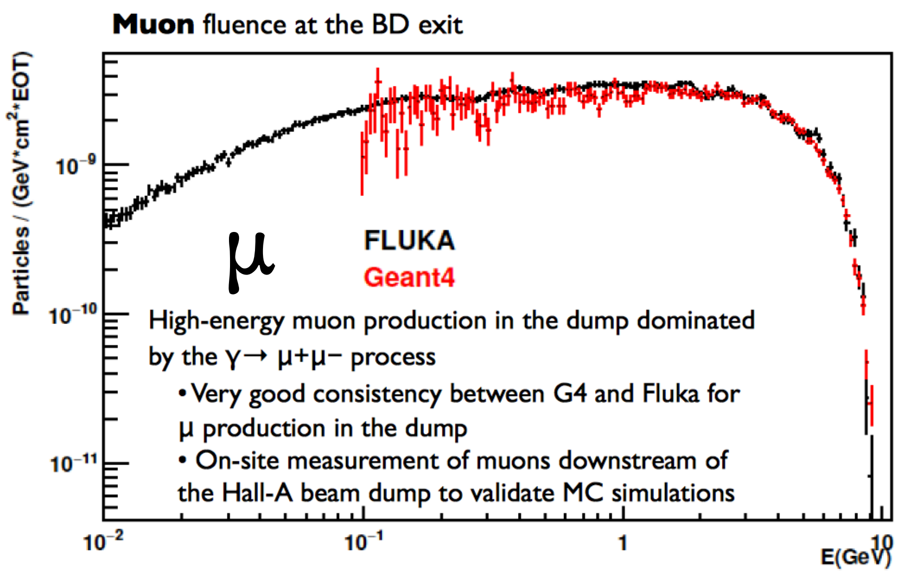
Energy Thresold (MeV)	Expected Counts (285 days meas.)
200	740 ± 300
250	57 ± 25
300	4.7 ± 2.2
350	0.037 ± 0.022

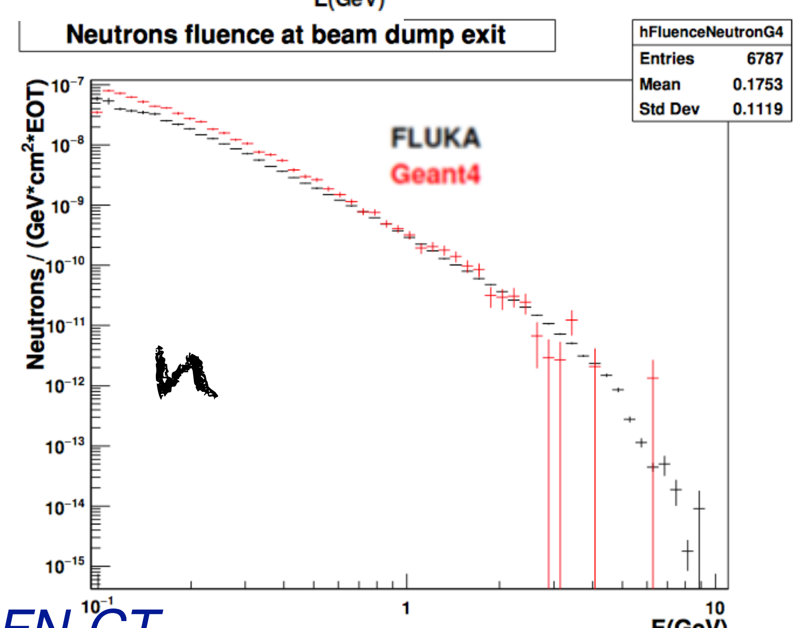
Beam-related Background - Simulations

Beam-dump and surrounding geometry/materials implemented in FLUKA and Geant4

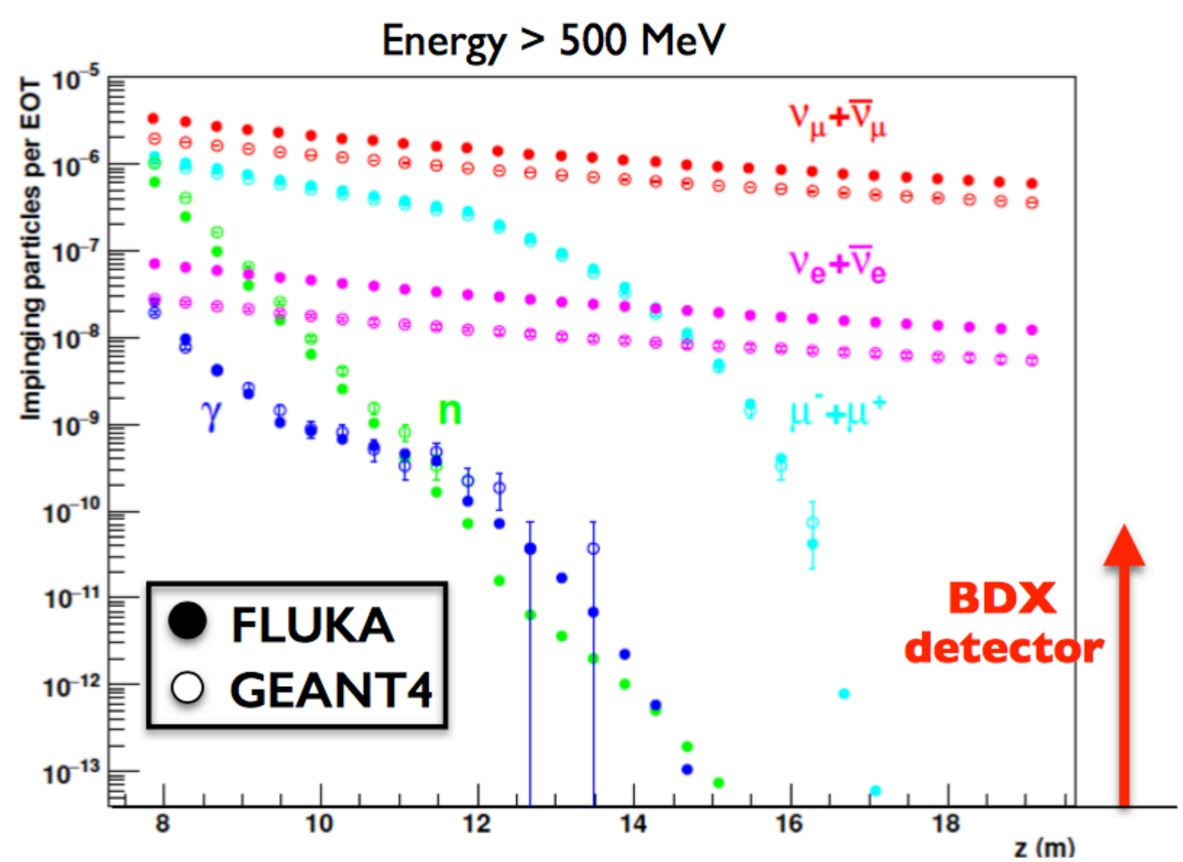


FLUKA vs GEANT4 at the beam-dump exit





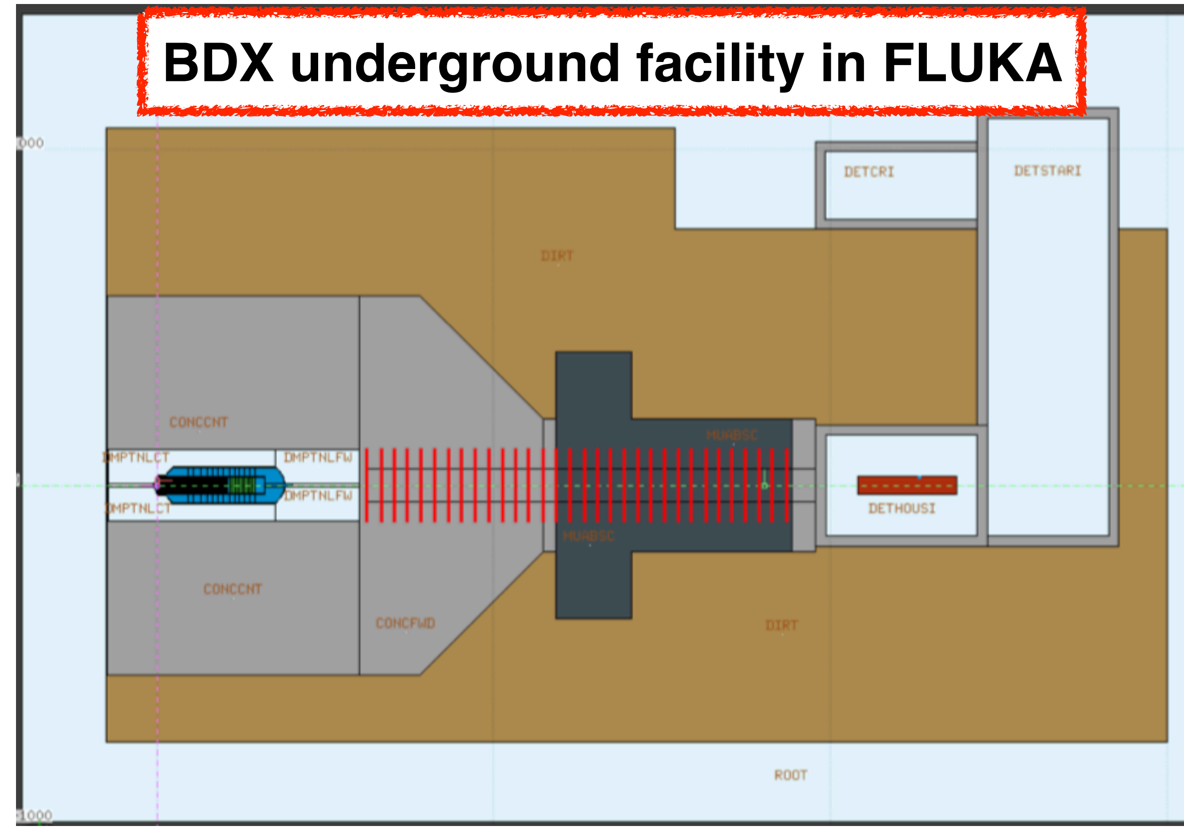
FLUKA vs GEANT4 at different distances from the dump



REASONABLE AGREEMENT ON HIGH-ENERGY PARTICLE FLUXES BETWEEN FLUKA AND GEANT4

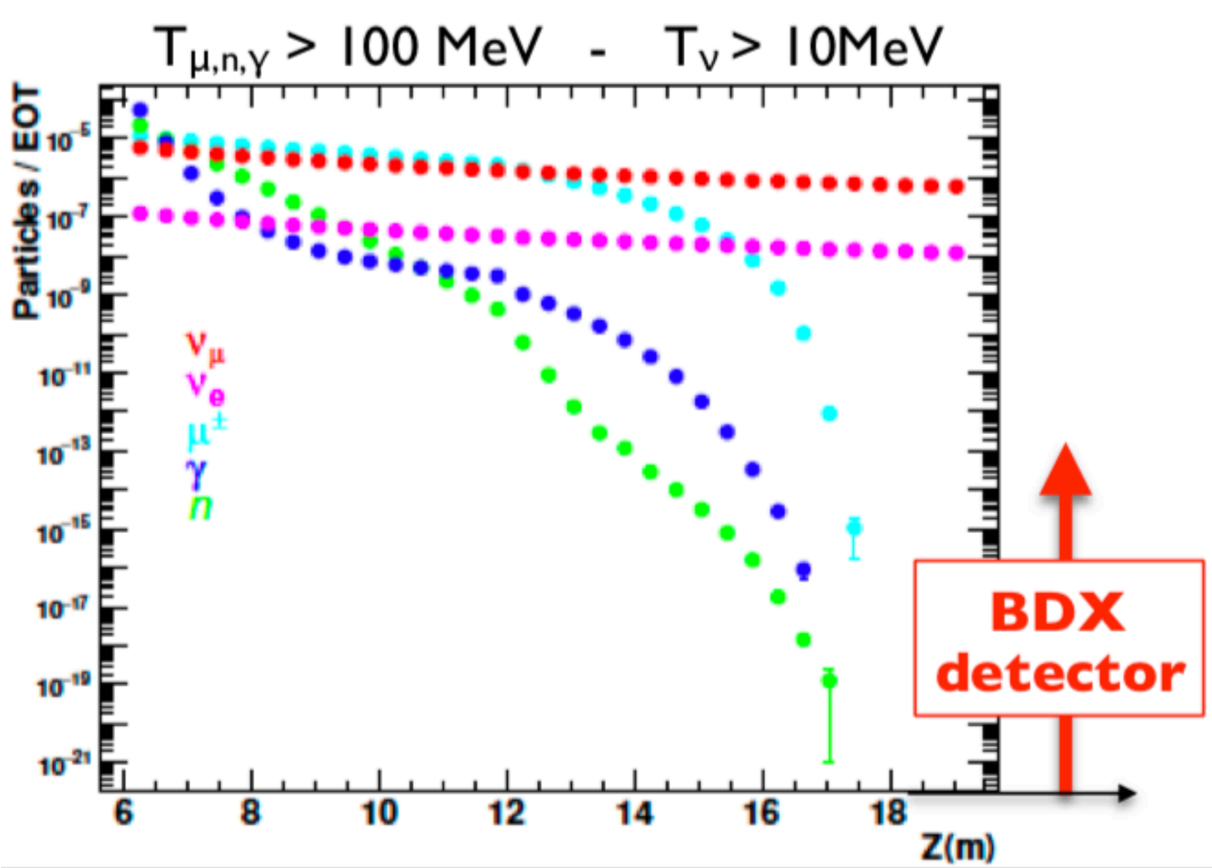
Beam-related Background - Results

- FLUKA: **biasing techniques**
- **High statistics** simulations: 300 cores x 3 months simulating **~10^{17} EOT equivalent at BDX detector location**



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*



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

★ **All the μ emitted forward and passing through the shielding are ranged-out**

★ **μ emitted at a large angle in the dump, propagating in the dirt, and then, after a hard interaction, re-scattering in the detector result to a non-zero background rate but they have a kinetic energy lower than 300 MeV**

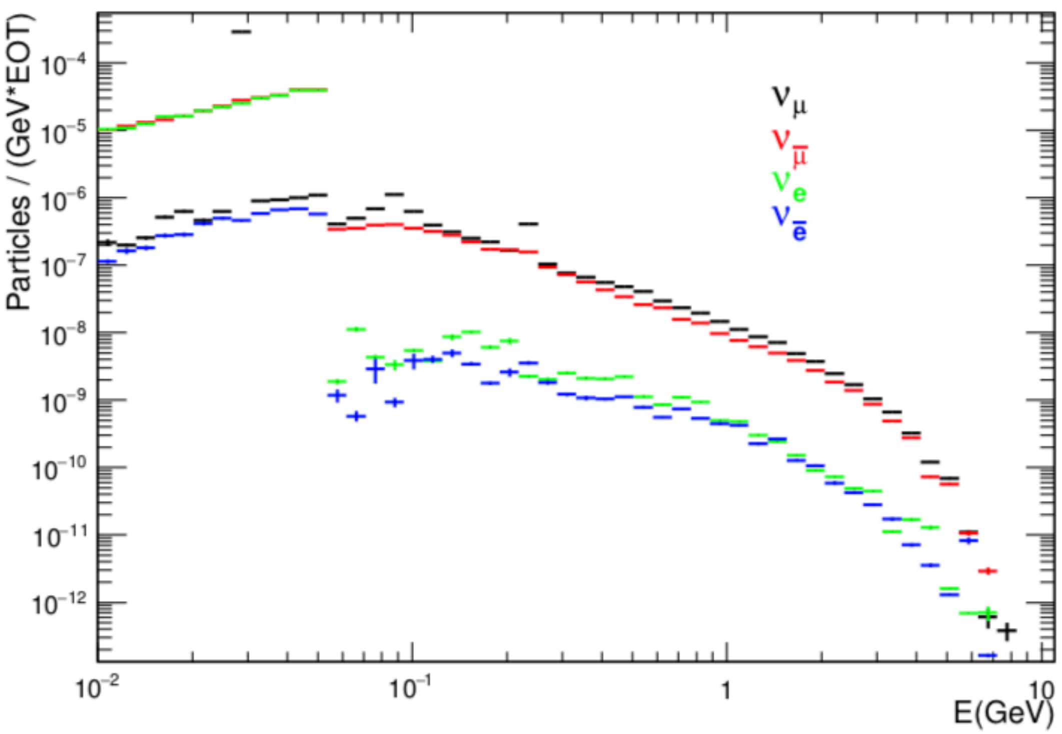
All high energy SM particles ranged-out except neutrinos

Beam-related Background - Neutrinos

Neutrino

- $\pi \to \mu + \nu_\mu \quad \mu \to e + \nu_\mu + \nu_e$
- Mainly low energy (<60MeV) 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



Neutrino interactions in the detector

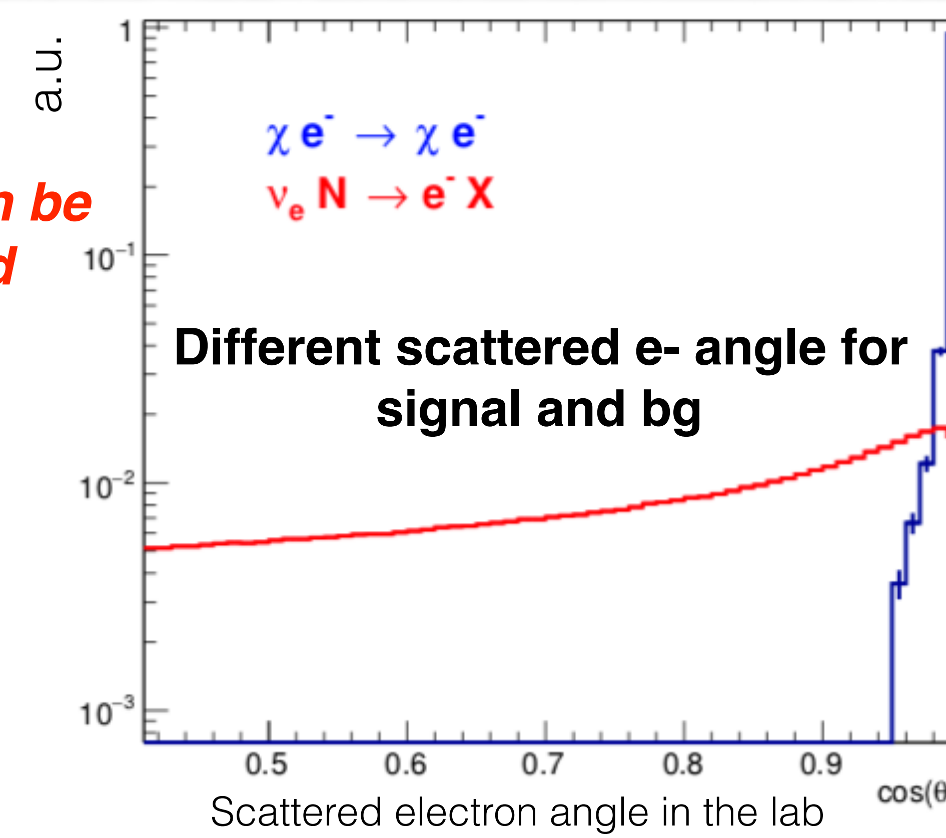
NC	$\nu_\mu + N \to \nu_\mu + X$ $\nu_e + N \to \nu_e + X$	*all rejected by the detector threshold (limited energy transfer to N)*
CC	$\nu_\mu + N \to X + \mu$	*all rejected by identifying scattered μ*
	$\nu_e + N \to X + e$	*could produce an high energy e in the detector that mimics the signal*

Different kinematics for signal and bg

$X_{DM} + e^- \to X_{DM} + e^-$ forward peaked

$\nu_{e^-} + N \to X + e^-$ spread over all angles

Neutrino BG can be identified and suppressed



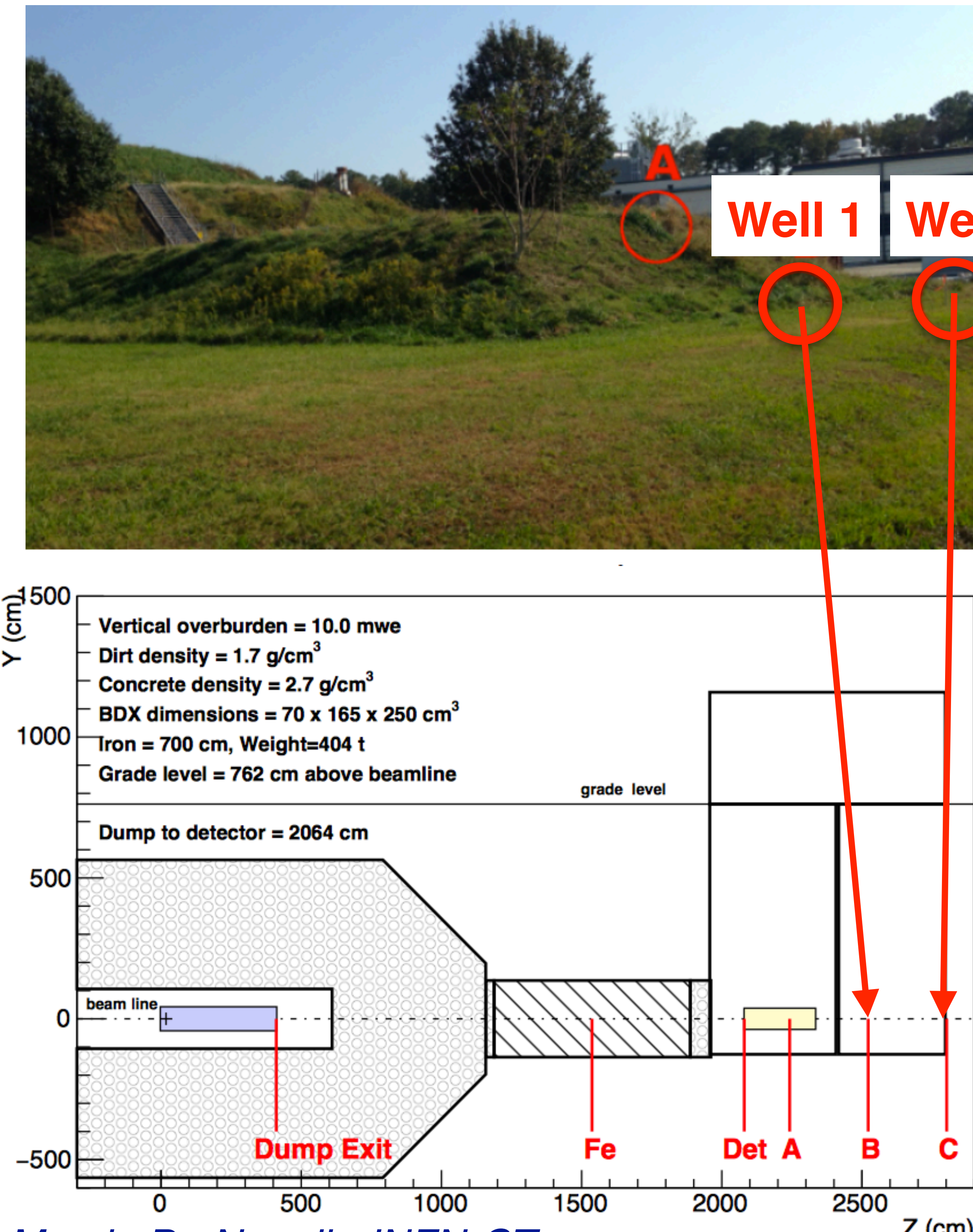
★ ***BDX only limited by the ν irreducible bg***

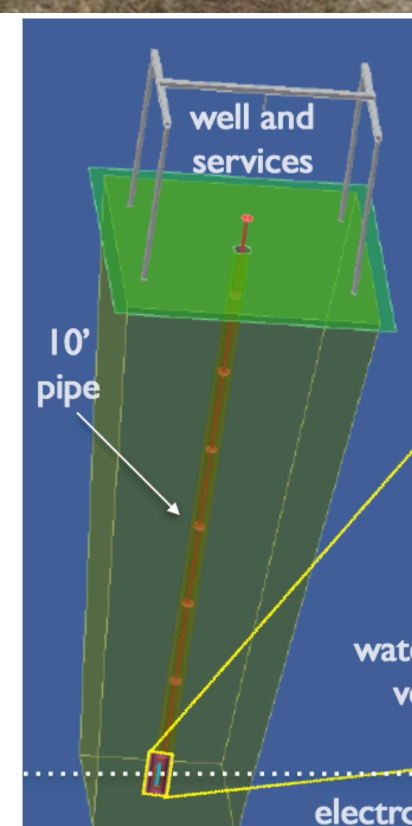
★ ***Expected beam-related bg counts (after analysis cuts) ~5 events***

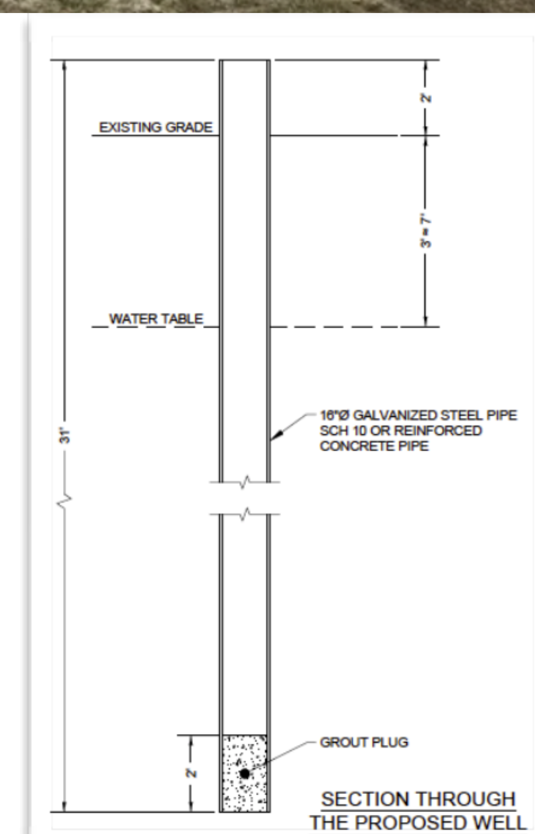
Beam-related Background - On-site measurements

Measuring the flux of μ produced in the Hall-A beam-dump at the BDX location as a benchmark for simulations

- Two wells equipped with 10" pipes drilled at ~25m and ~28m from the dump
- A detector (BDX-Hodo) lowered into the pipes down to beam height to measure the μ flux when 11 GeV beam is on





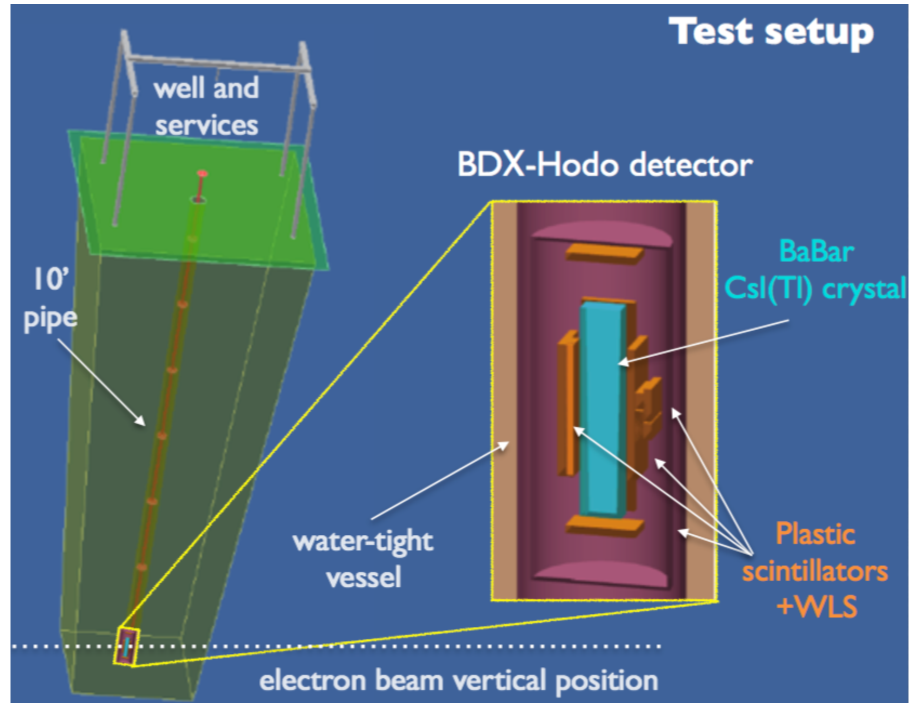


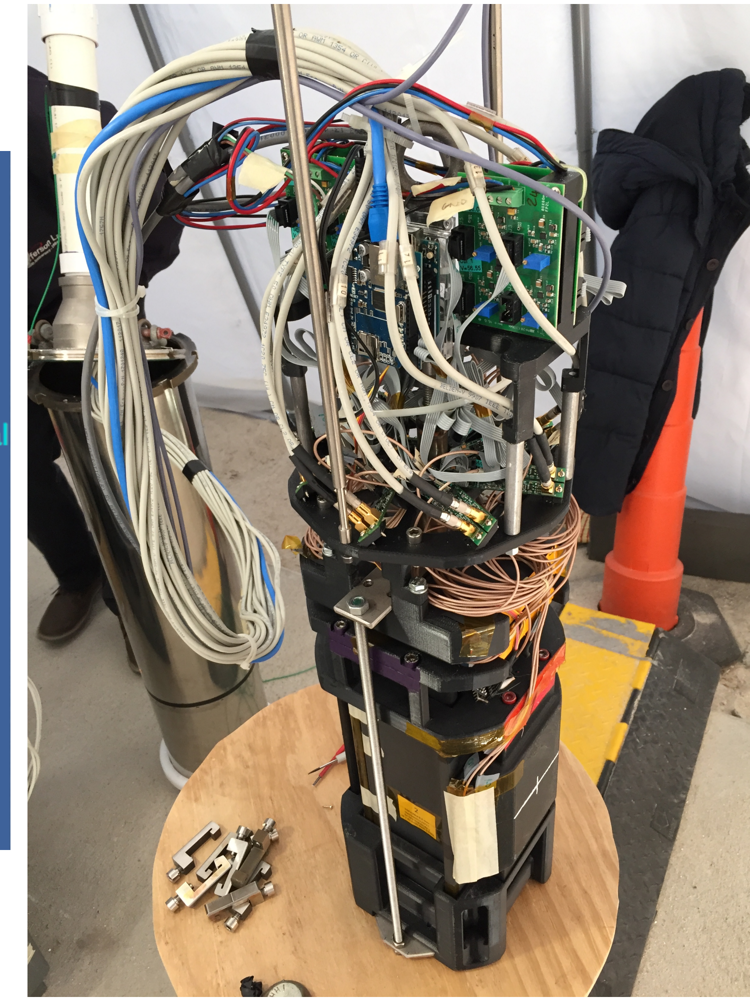
Beam-related Background - On-site measurements

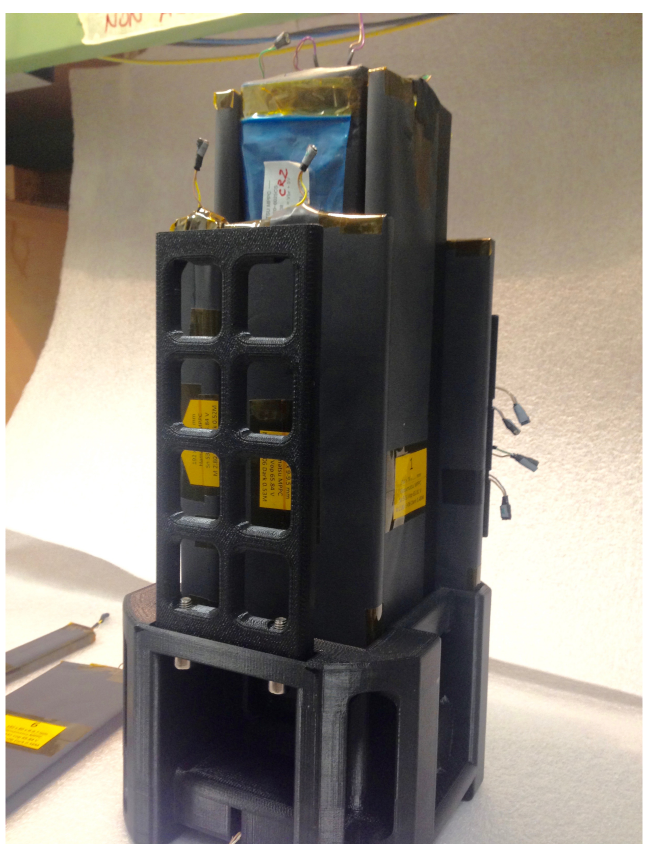
BDX HODO

same technologies proposed in the final experiment

- CRISTAL
  - CsI(Tl) crystal (5x5 x 30 cm²)
  - 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)
  - Stainless steel, water-tight

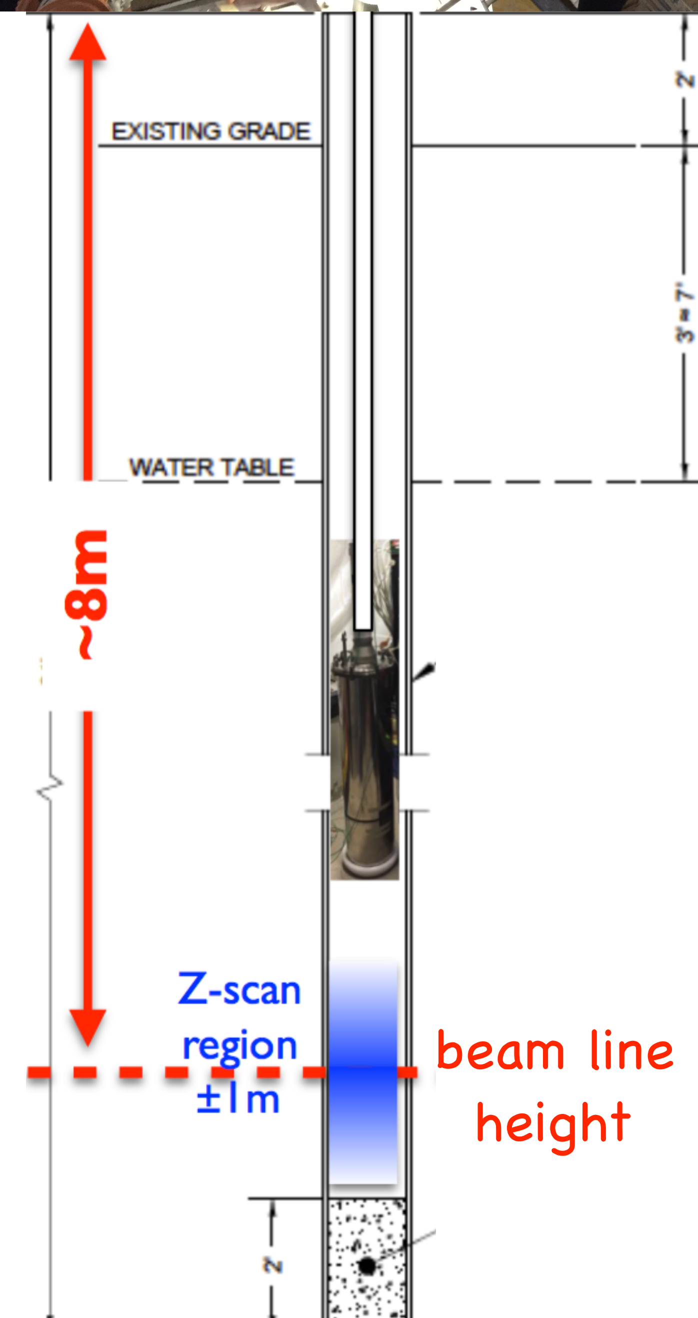






BDX muon test

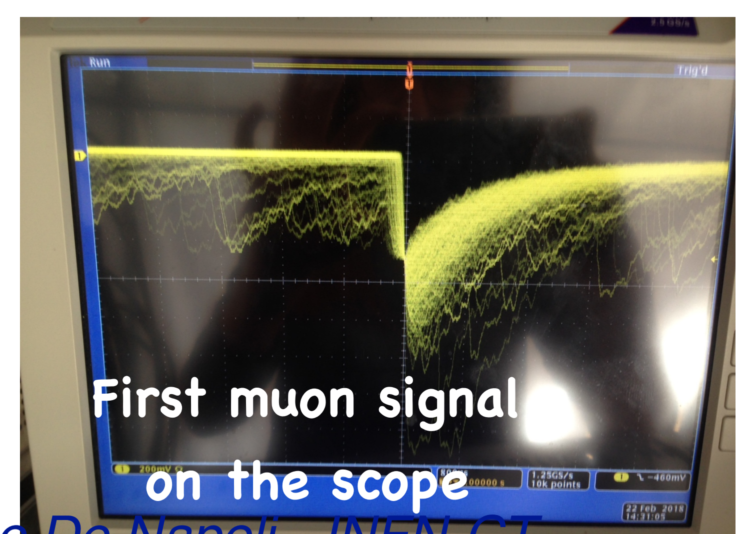
Run: from Feb 22nd to May 2nd 2018

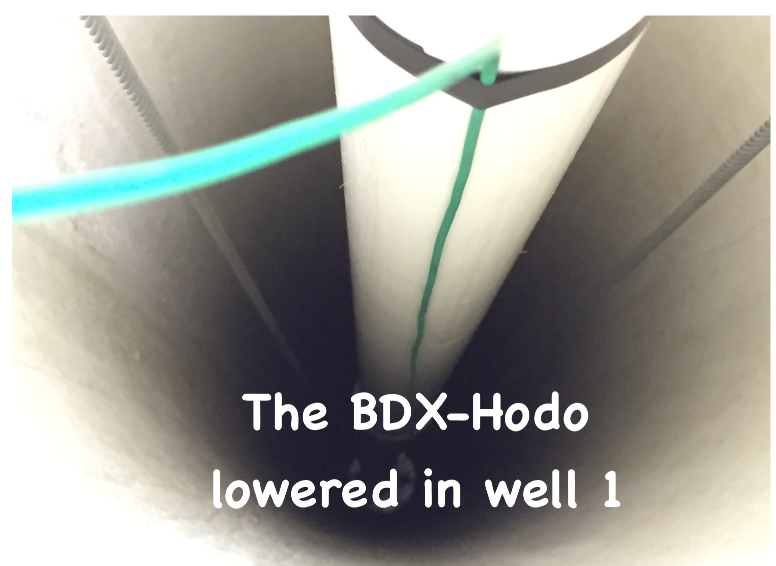


Hall-A beam parameters:

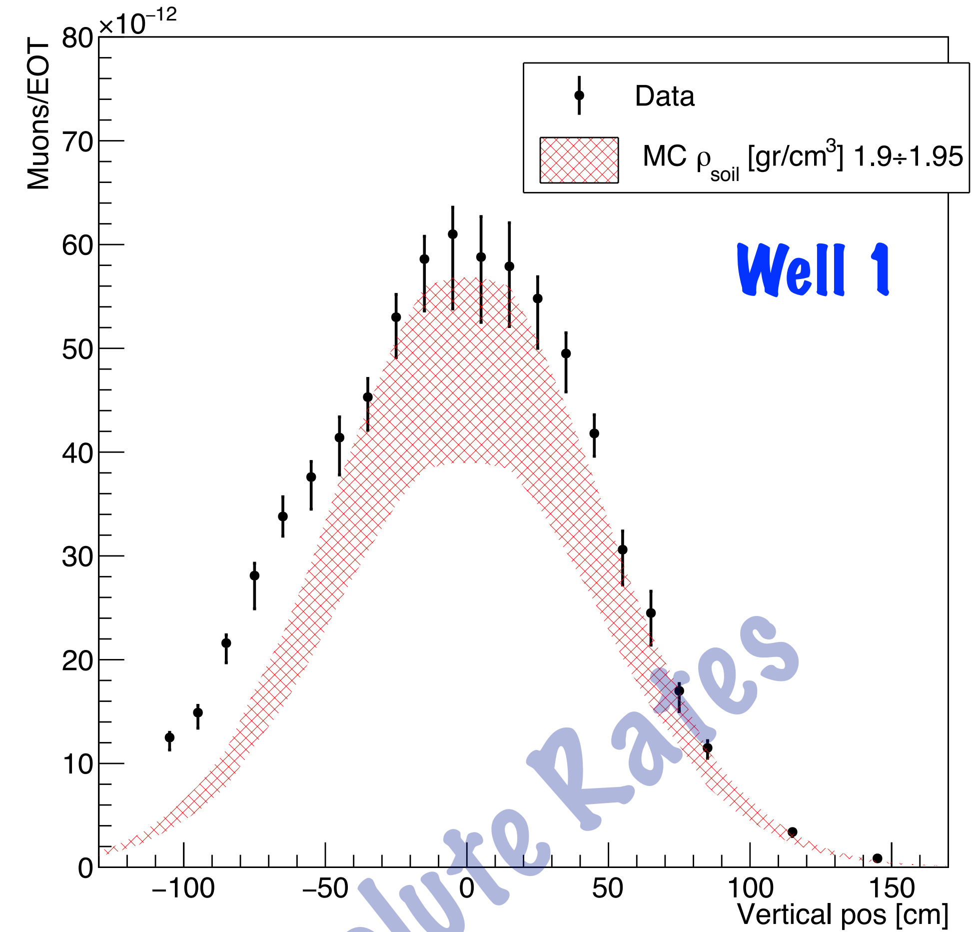
- $I_{Beam} \sim 22uA$
- $E_{Beam} = 10.6$ GeV
- Diffuser:ON

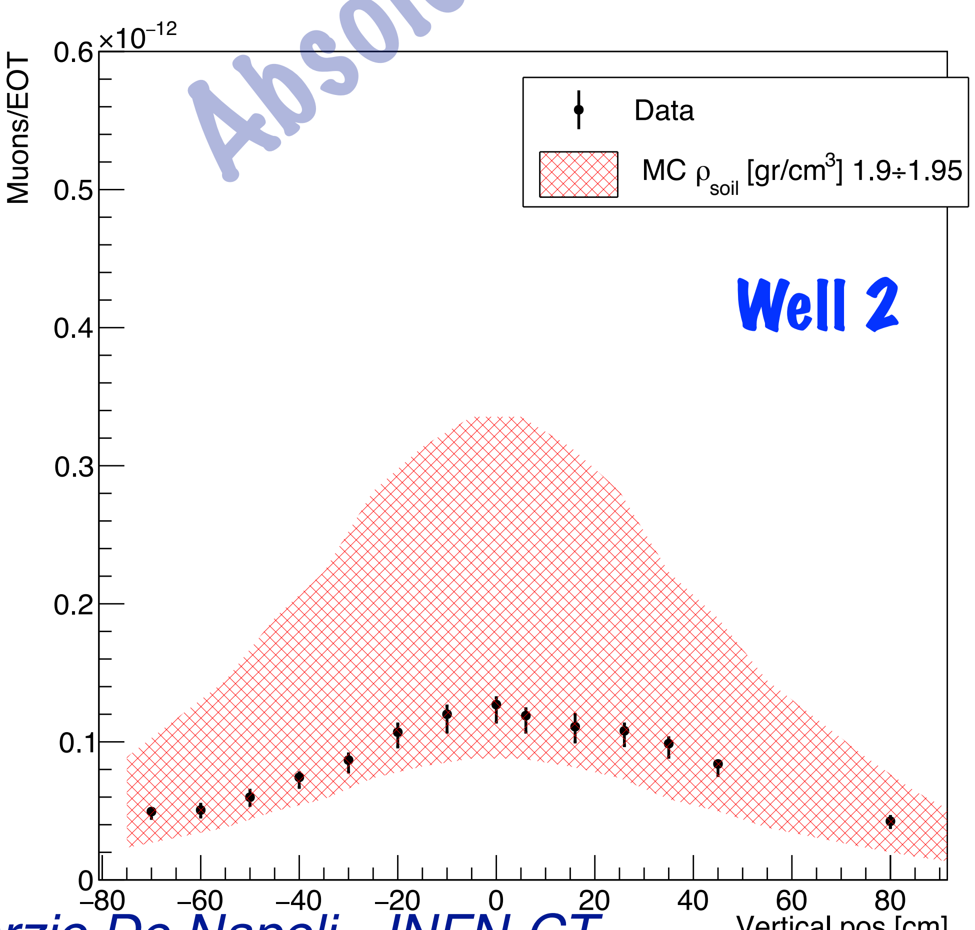
\+ 1 week taken in Well II with Ebeam=4 .3 GeV





Beam-related Background: On-site measurements

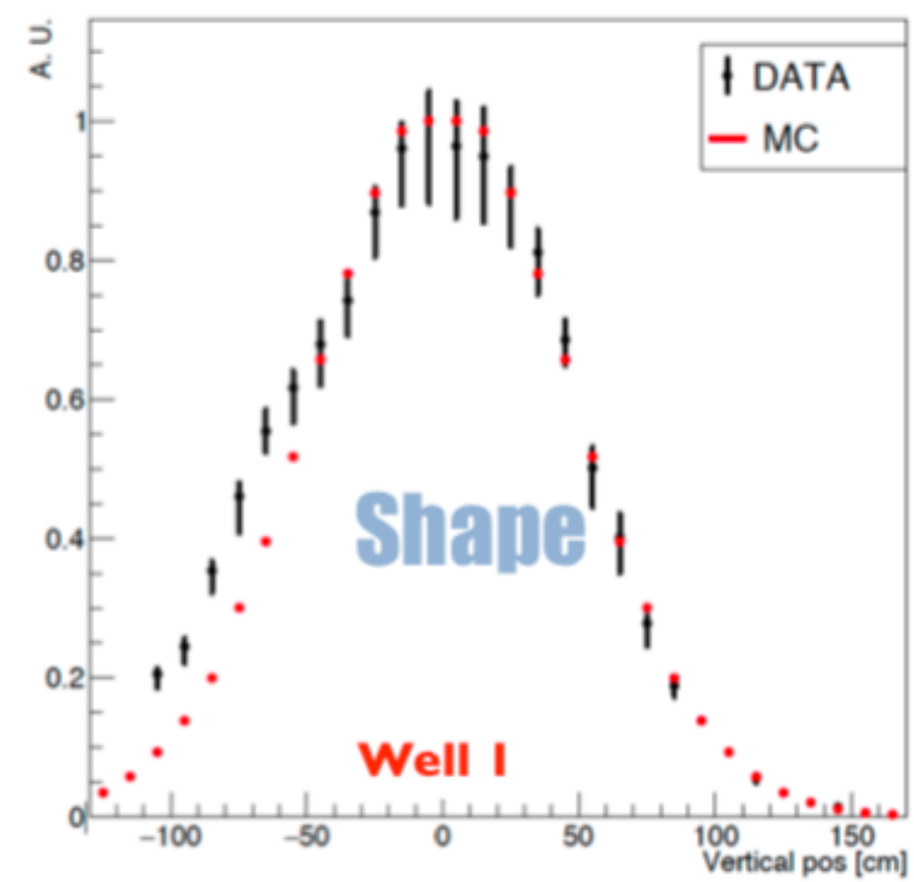




BDX Muon test
DATA/SIM comparison

★ 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)



Agreement between data and simulations proves:

✳ **the BDX simulation framework is reliable**

✳ **no significant contribution from neutron bg (high energy n and/or pile-up effects)**

BDX expected reach

- 10^{22} EOT (65 uA for 285 days)
- BDX can run parasitically to any Hall-A - 10GeV experiment

Beam-related background

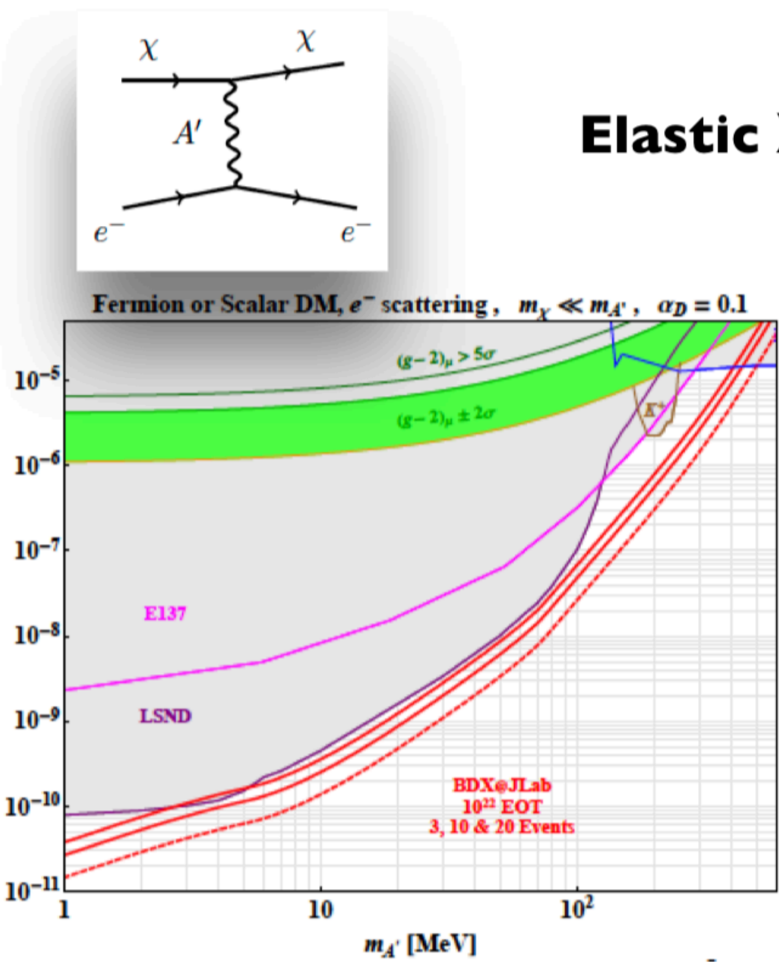
Energy threshold	N_ν (285 days)
300 MeV	~10 counts

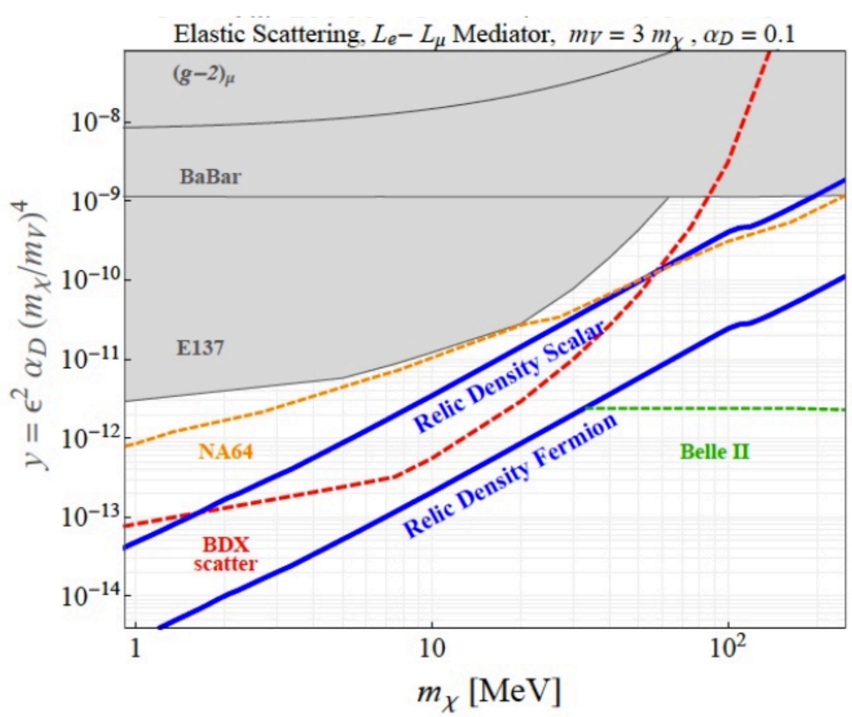
Cosmic background

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

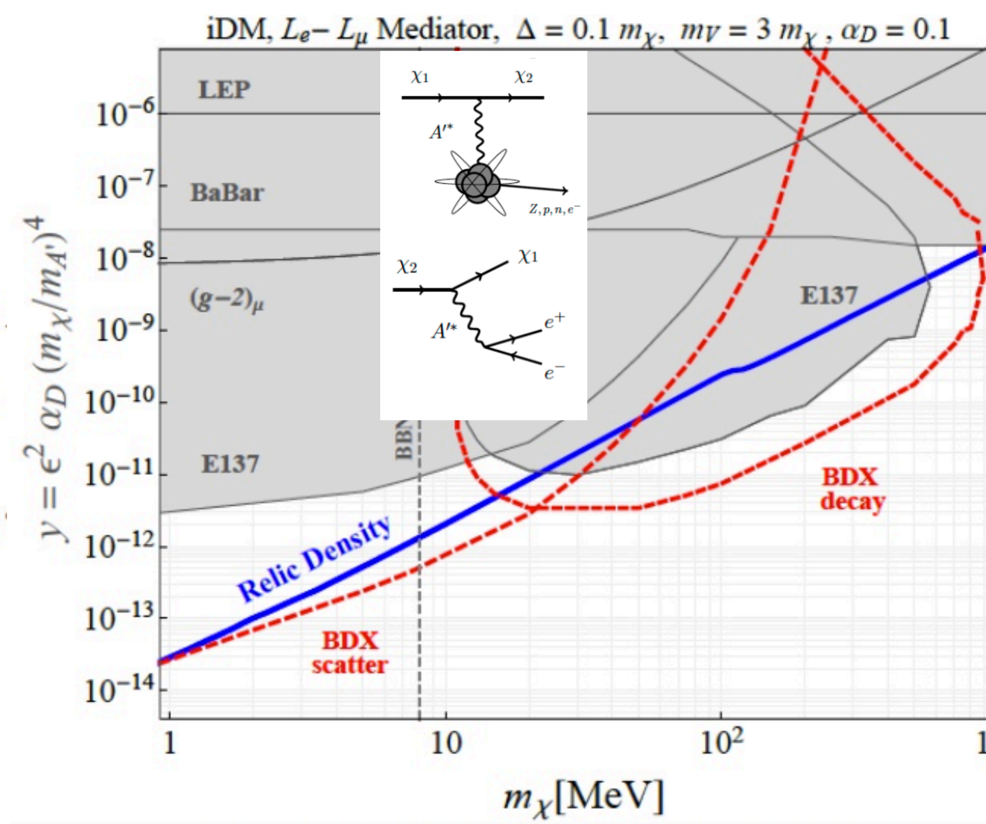
BDX SENSITIVITY IS 10-100 TIMES BETTER THAN EXISTING LIMITS ON LDM

Elastic X-e⁻ scattering - BDX reach





Inelastic X-N scattering



Conclusions

✦ BDX is a beam-dump experiment at JLab aimed to investigate the existence of Light Dark Matter (1 MeV - 100 MeV)

✦Collecting 10^{22} EOT in 285 days of parasitic running (~4y-calendar) at 10 GeV the BDX experiment can be 10-100 times more sensitive than previous experiments, excluding a significant area of the the parameter space in case of null results

✦A new experimental hall, downstream of Hall-A beam-dump, will host the BDX detector based on ~800 CsI(Tl) crystals + InnerVeto + OuterVeto

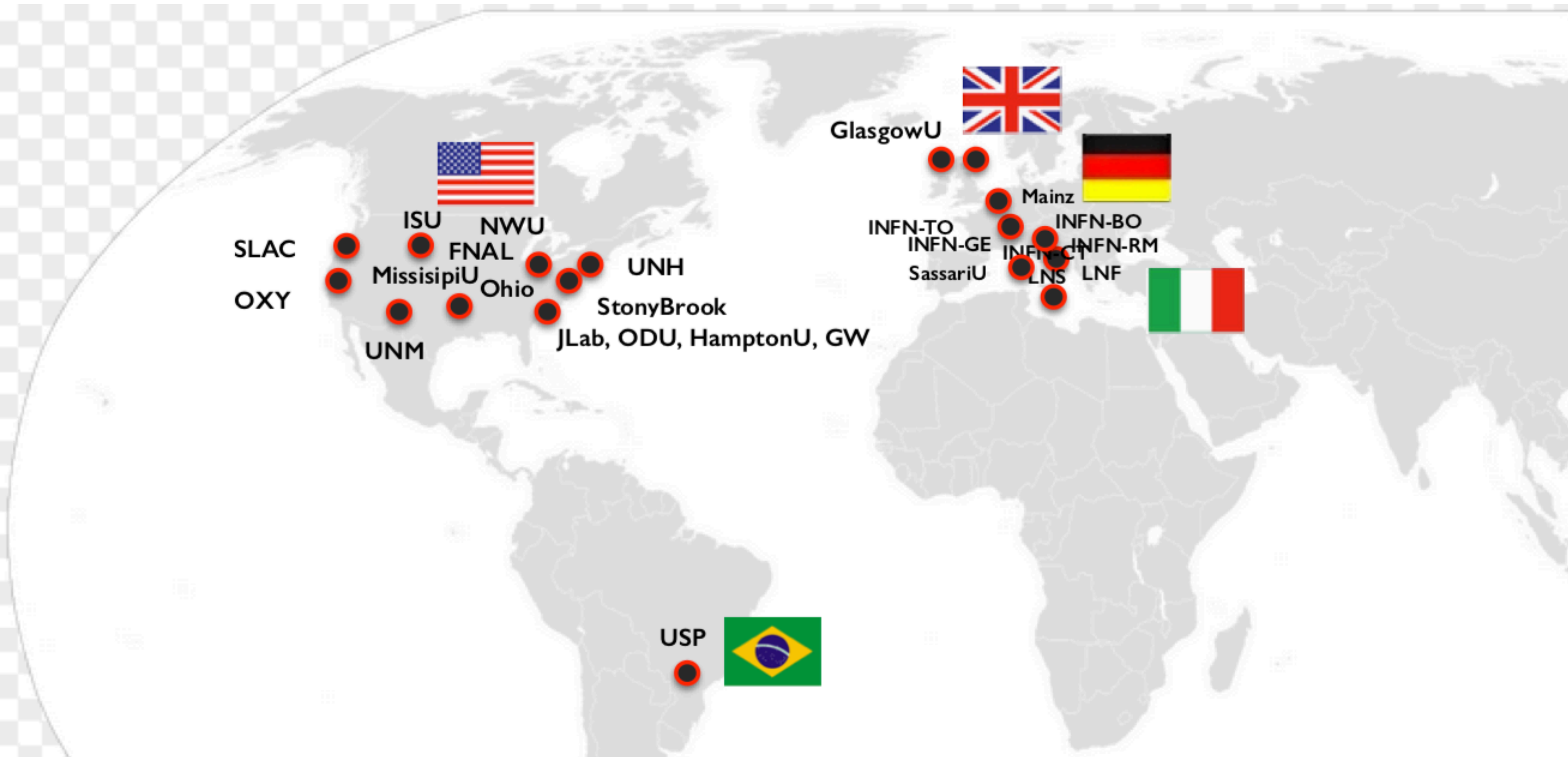
✦A BDX detector prototype was constructed and used to validate the proposed technology and measure cosmic background rates

✦ We implemented two strategies for a reliable beam-related background estimate:

- ✓high statistics simulations: biasing method in FLUKA, simulating ~10^{17} EOT (equivalent)
- ✓measurement on site when the accelerator is running

✦ **In July BDX has been approved by the JLab-PAC46 with the maximum scientific rate**

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
Mainz University
Gulch
GlasgowU
IPN-Orsay

- More than 120 researchers signed the BDX proposal

Thank you for your attention