C12-16-001

PR12-16-001 update to Jefferson Lab PAC45

July 12 2017

BDX
Dark Matter search in a Beam Dump eXperiment
an update on PR12-16-001

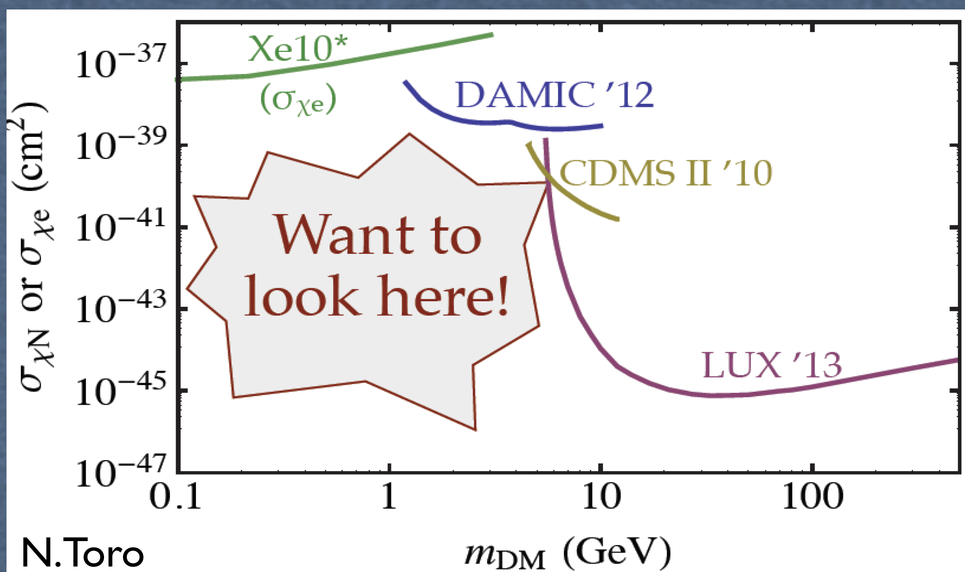
M.Battaglieri, *A.Celentano, M.DeNapoli, R.DeVita, E.Izaguirre, G.Krnjaic, E.Smith*

and the BDX Collaboration

- ★ Summary of BDX proposal (*Conditionally approved - C2*)
- ★ Beam-on background evaluation using FLUKA
- ★ Beam-on background assessment via onsite measurements

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)

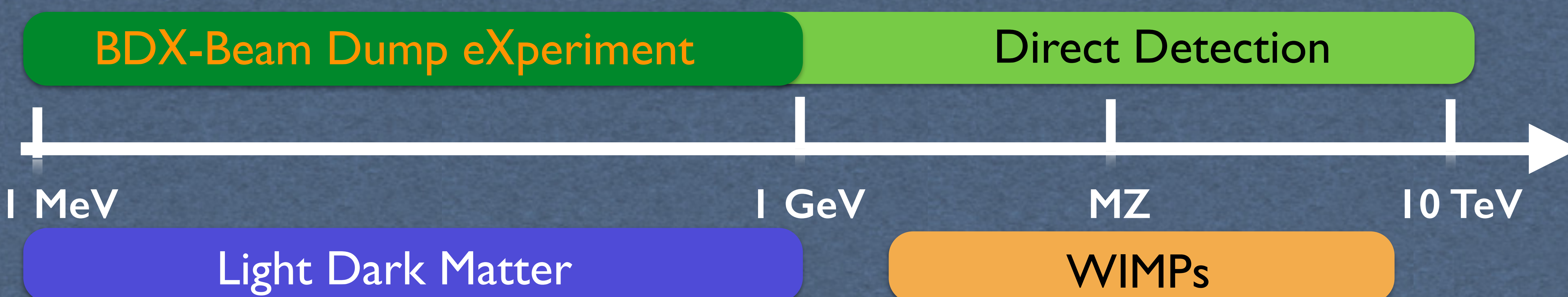


- Negative results call for extending the DM hunting territory to unexplored regions

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



JLab is the world-leading facility for LDM search (HPS, APEX, DARK-LIGHT)

Progress in LDM searches from PAC44

- ★ 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."

White paper in preparation will be available soon

- ★ 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

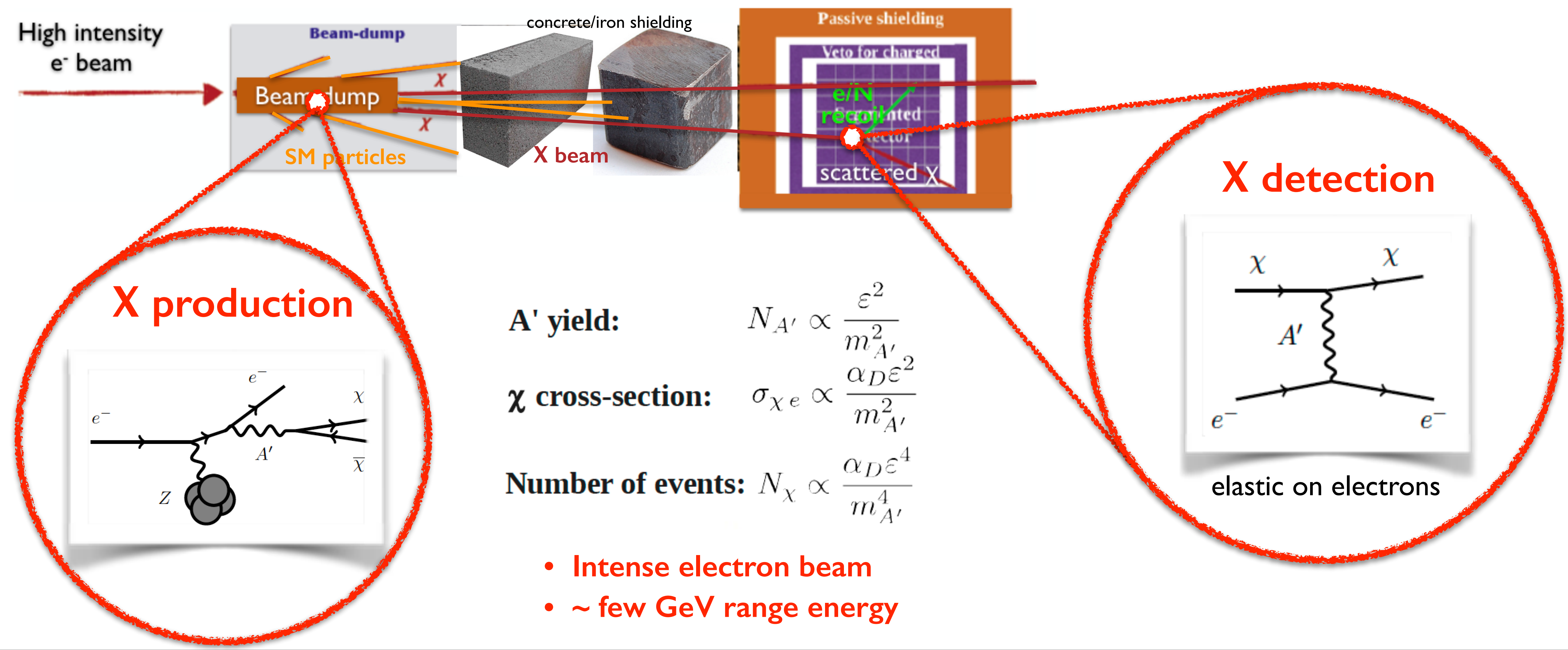
The BDX experiment

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

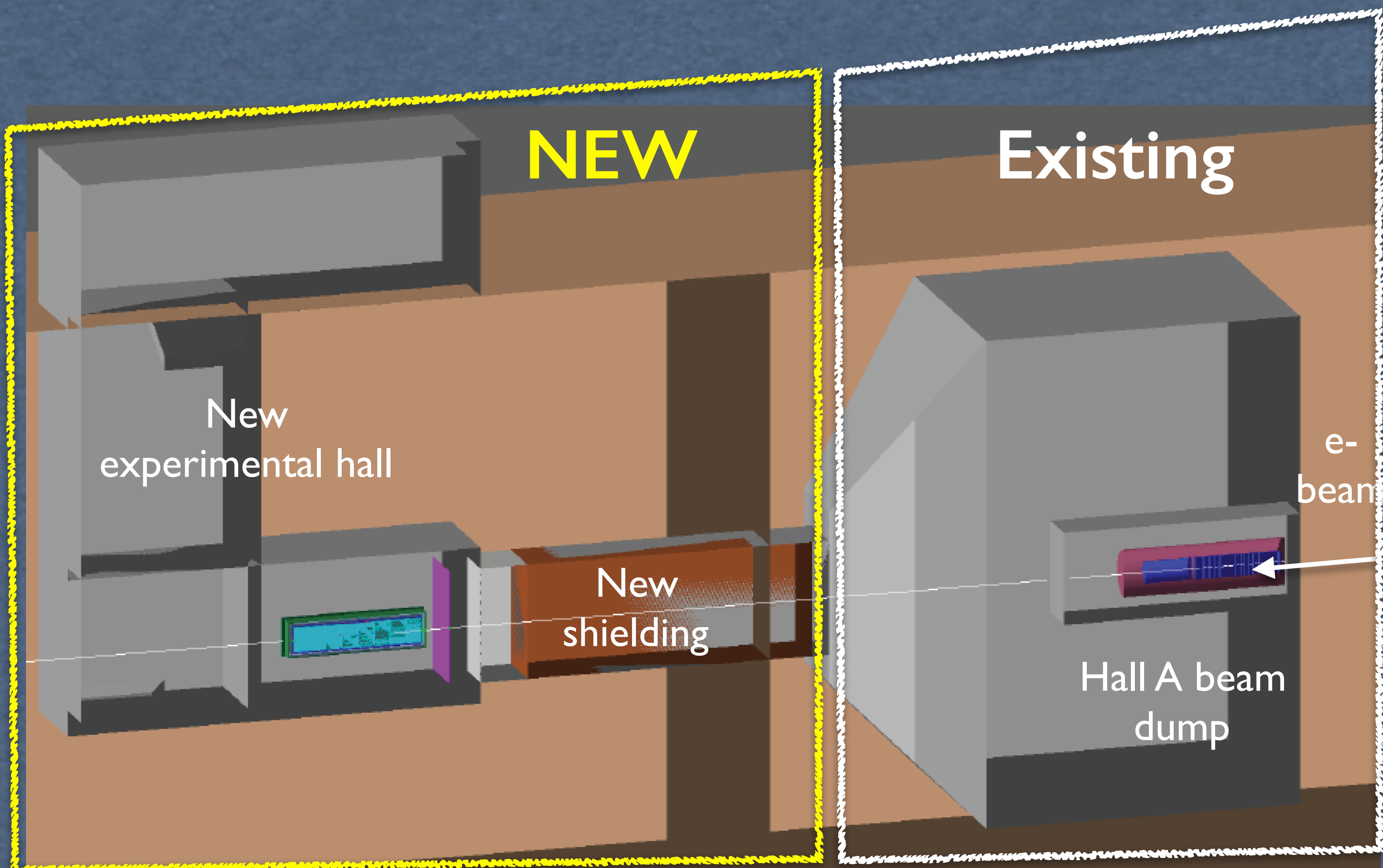
Experimental signature in the detector:

X-electron → EM shower ~GeV energy

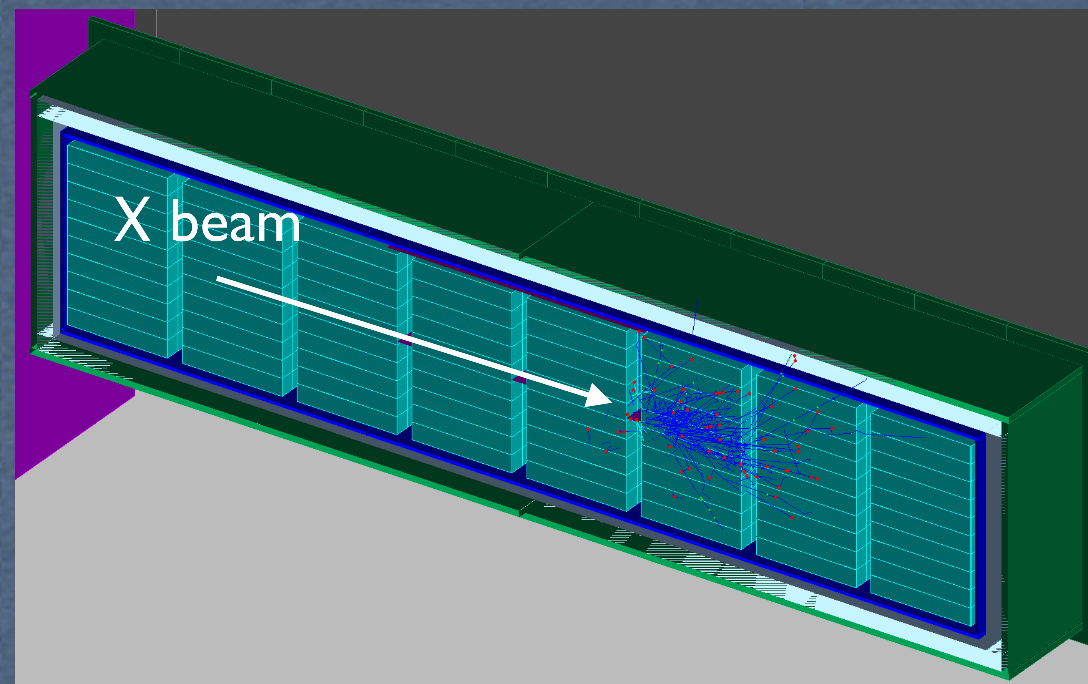
BDX at JLab

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

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



The BDX detector



Detecting the X

E.M. Calorimeter

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

Rejecting the bg

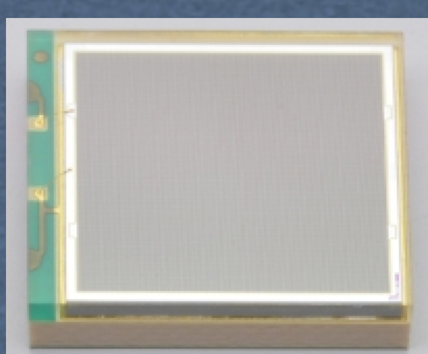
- Cosmic
- Beam-on

Active veto

Two layers: of **plastic scintillator**

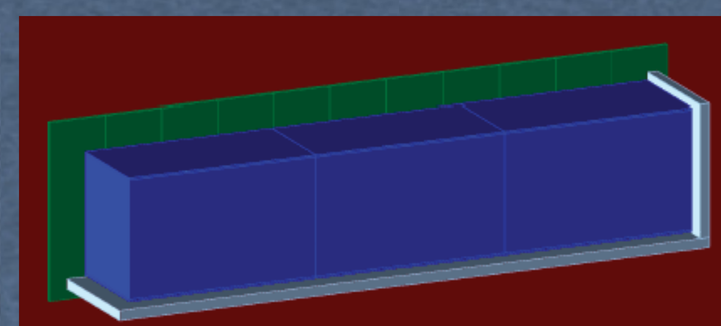
OV: light guide + PMT

IV: WLS + SIPM

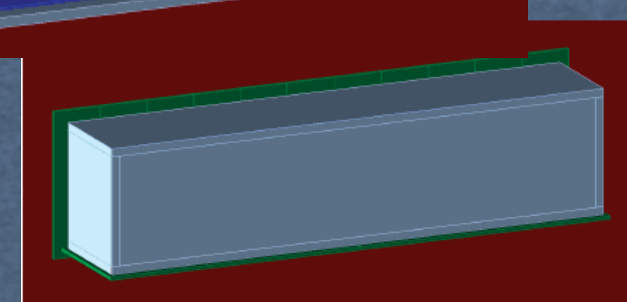


Modular EM calorimeter

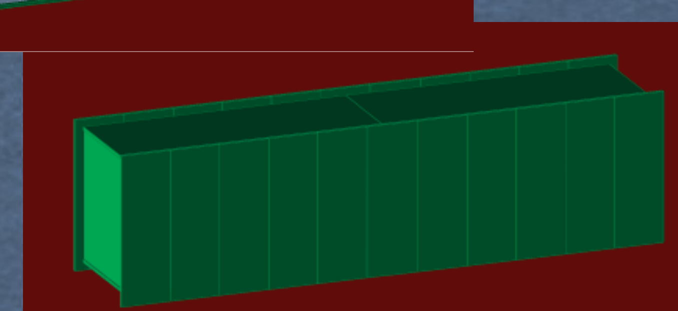
- 8 modules 10x10 crystals each
- 800 CsI(TI) crystals (from BaBar EMCal)
- 6x6 mm^2 Hamamatsu SiPM readout
- 50 x 55 x 295 cm^3



Inner Veto
plastic scintillator
+ WLS + SiPM

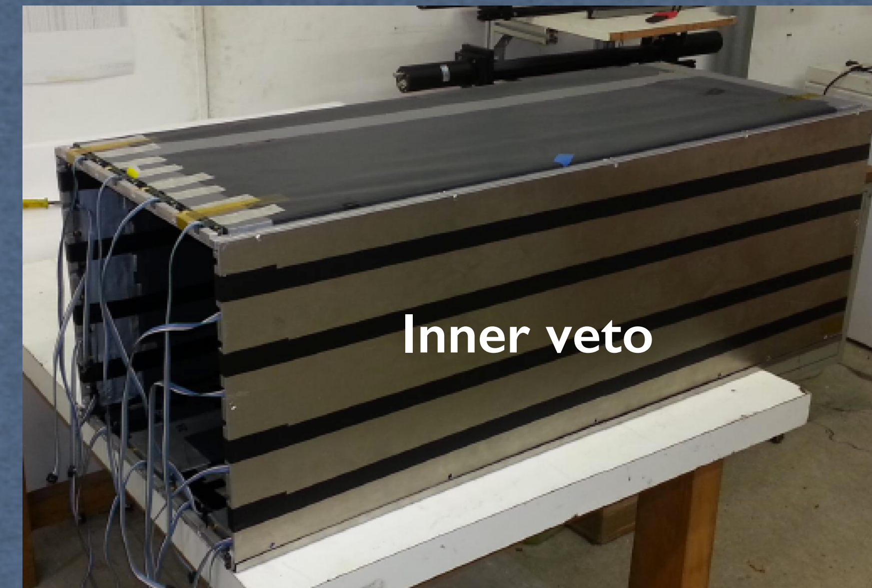


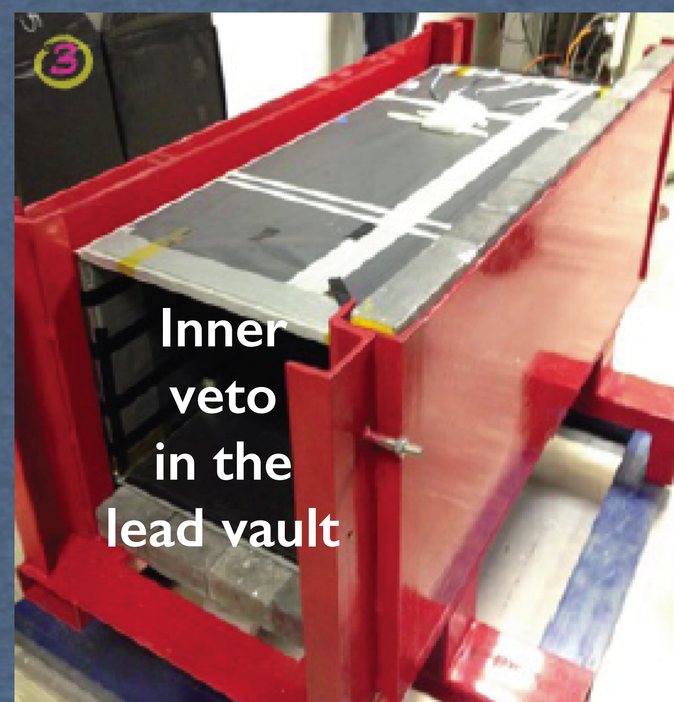
Passive shielding
lead vault 5cm thick



Outer Veto
plastic scintillator
+ PMTs

The BDX prototype



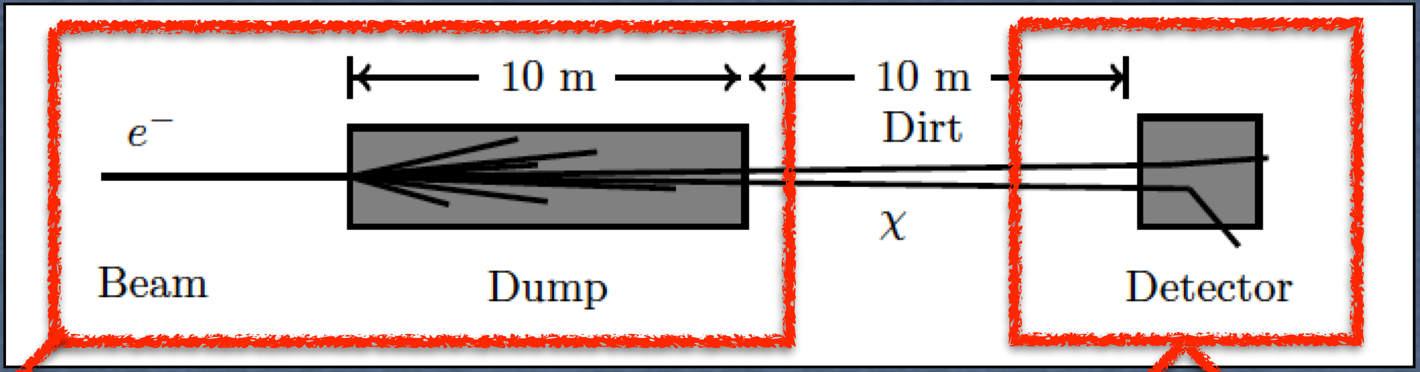


- EM Cal
  - 4x4 CsI(Tl) crystals
  - 6x6 mm^2 SiPM
- Outer Veto
- Lead vault
- Inner Veto

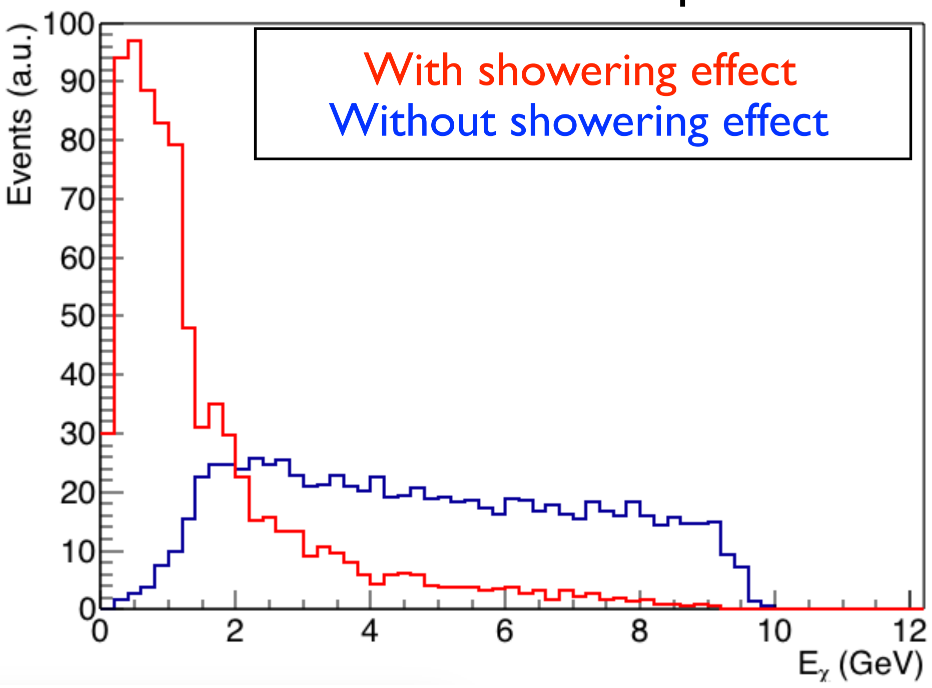
X production and detection

• Detailed simulations using MadGraph to describe the A' production, decay (A' →χ χ) and interaction in the BDX detector (X-e)

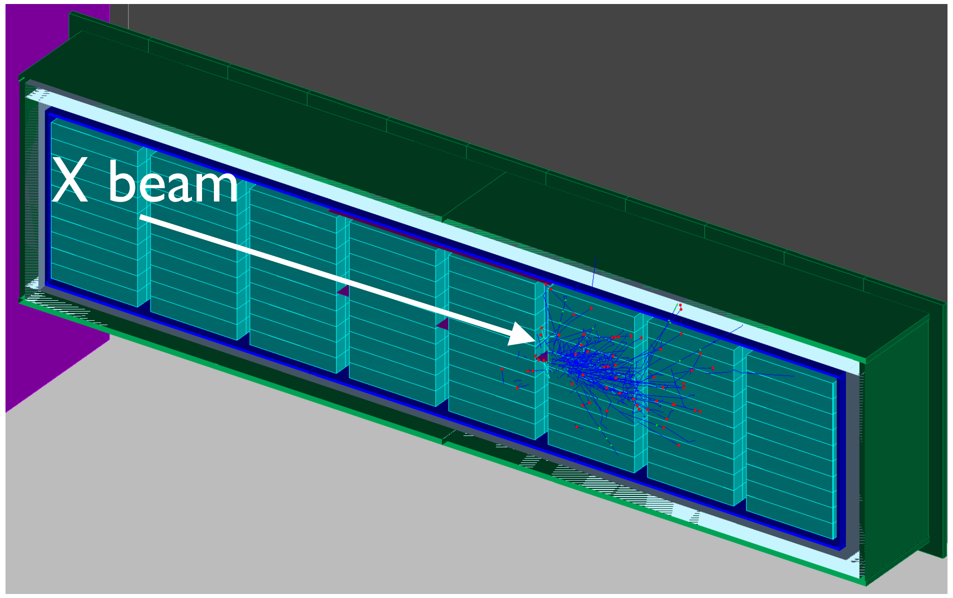
• Detailed description of Hall-A beam dump (production) and BDX detector (detection) using GEANT4



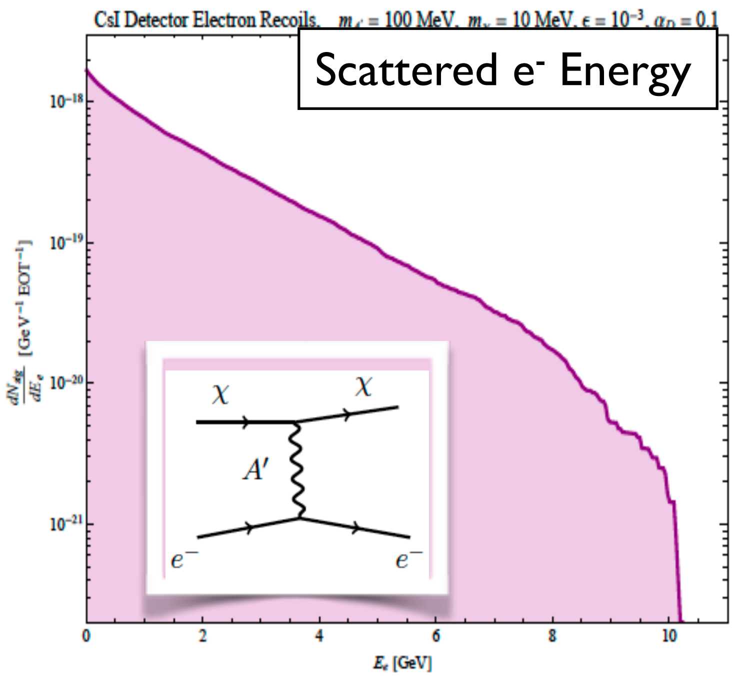
X energy spectrum generated by 10 GeV e-beam in the dump



χ-e interaction producing an em shower in the detector

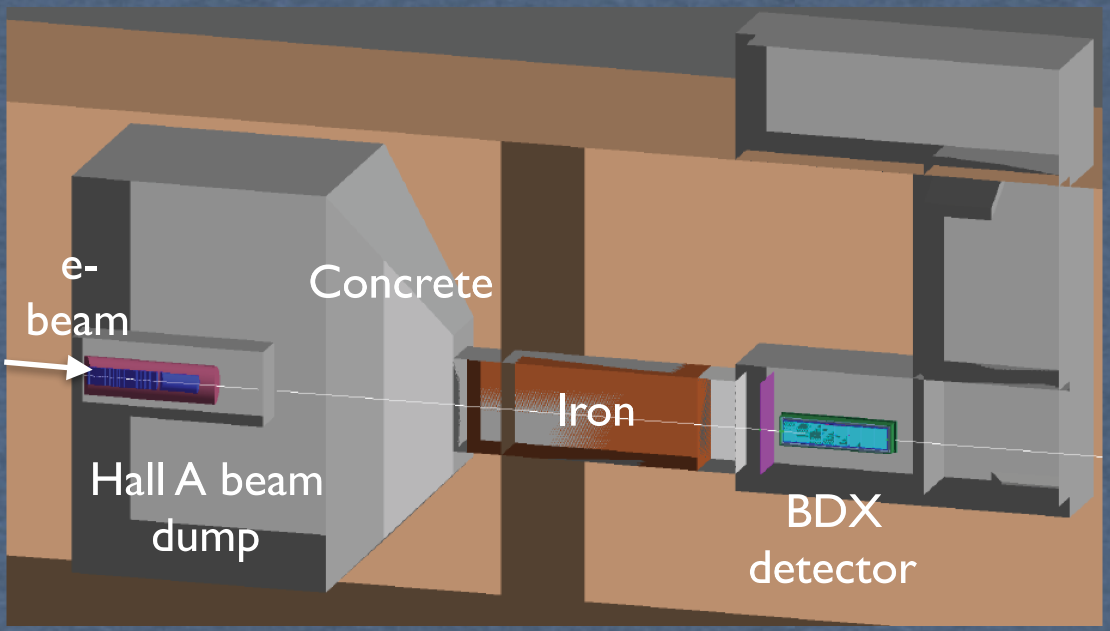


Elastic on electrons



Background

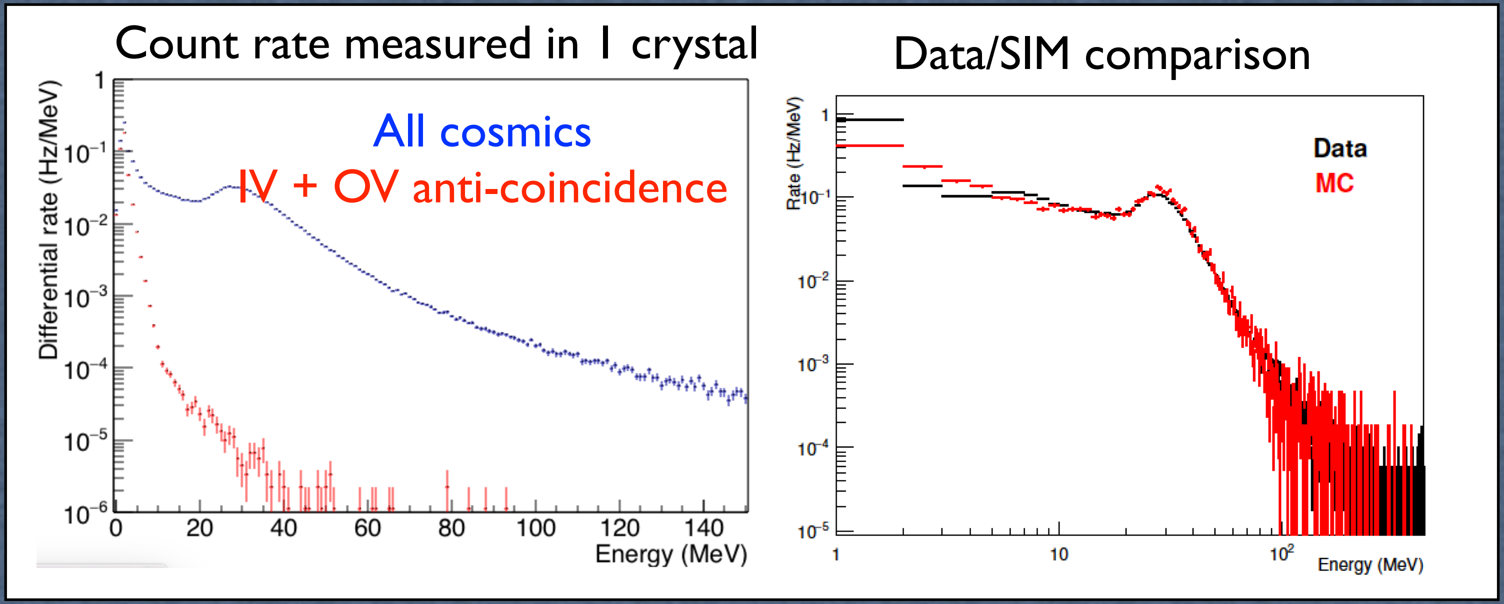
Bg estimated using GEANT4, tracking particles with $E>E_{Thr}$



Cosmic

- ★ Cosmic background measured with the BDX detector prototype in CT
- ★ GEANT4 simulations reproduce muon rate

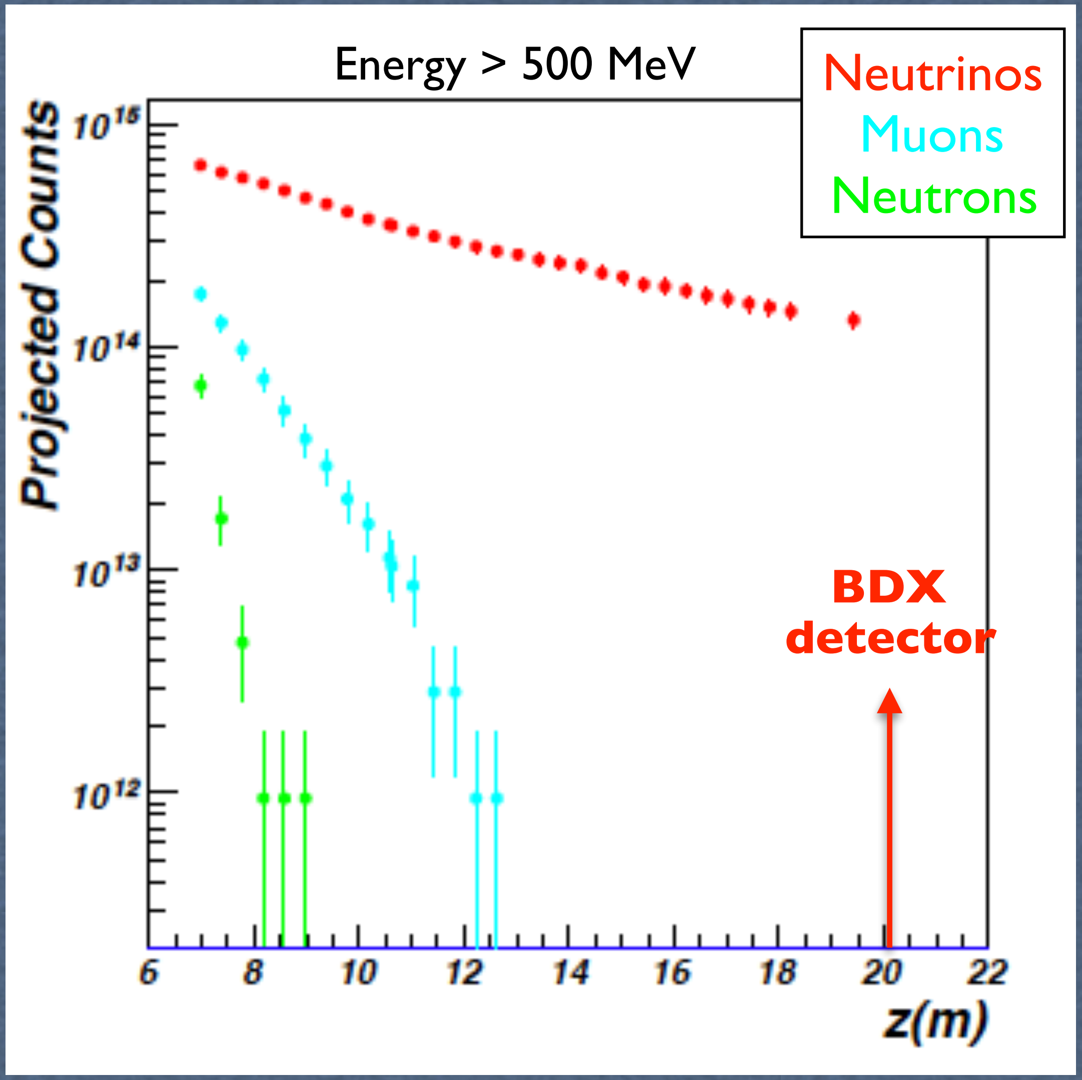
Expected cosmic bg counts in BDX lifetime < 2 counts



Beam-related

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

Expected beam-related counts in BDX lifetime ~ 10 counts



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)

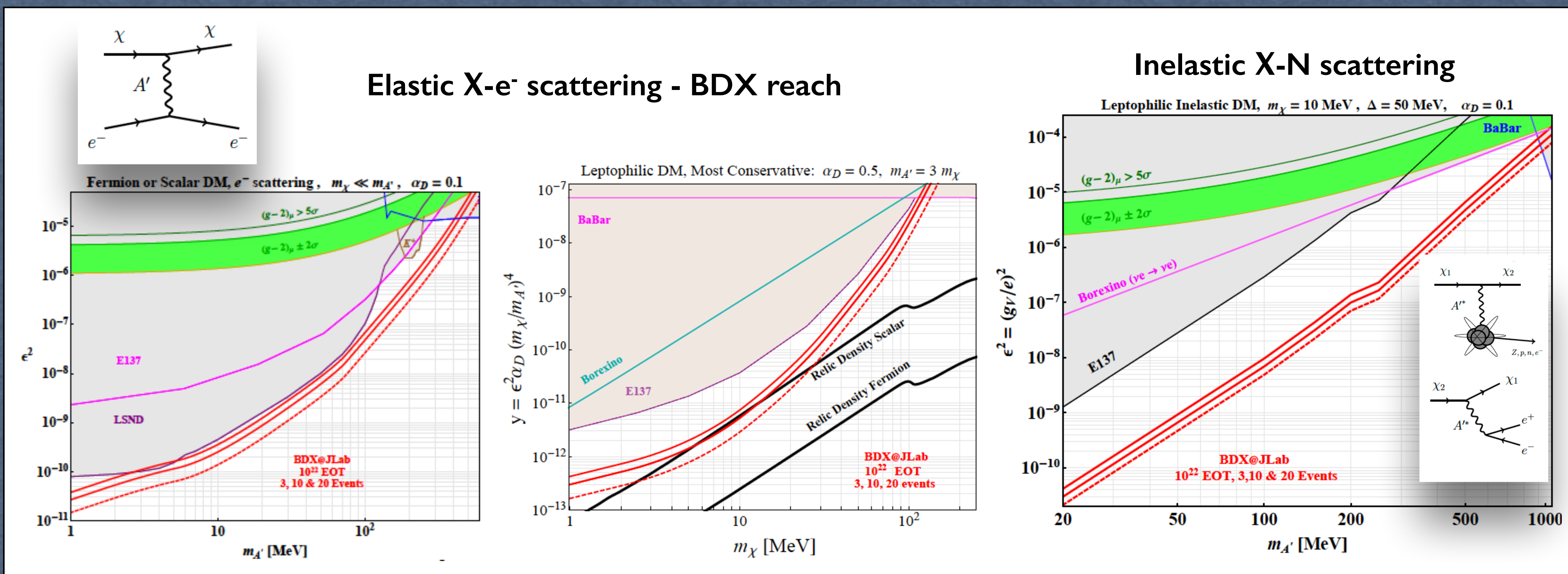
Beam-related background

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



Beam-related background

BDX presented in July 2016 to JLab PAC44 receiving a C2 - Conditionally Approval
The main concern expressed on BDX experiment in the PAC44 report

From the introduction:
… and the beam dump experiment was "C2" Conditionally Approved because **we would like to see them carry out some onsite measurements of the neutron flux when the accelerator is running**.

From the report:
While simulations are an essential tool in understanding background conditions, they are not sufficient to design an experiment. The BDX collaboration is therefore encouraged to think more about **benchmarking their simulations with measurements on site**.

Since no direct measurement in the proposed BDX set-up is possible, we are addressing the PAC44 concern in two ways:

★ implementing MC simulations with GEANT4 and FLUKA tools (in collaboration with JLab RadCon Group)

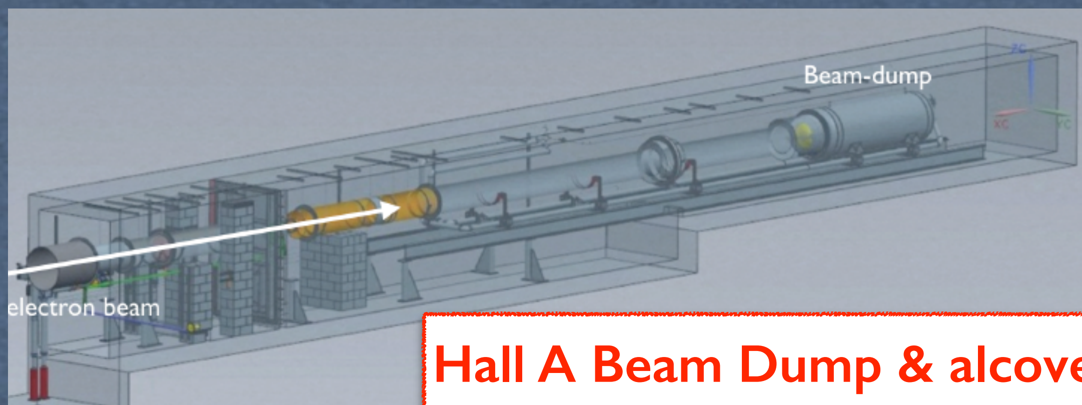
- to compare results obtained in the two frameworks
- to simulate an equivalent number of EOT in the range expected in BDX (10^{22}EOT) using biasing weights
- to better handle low energy particles background (neutrons)

★ assessing the beam-related bg measuring the muon flux in the current Hall-A dump configuration

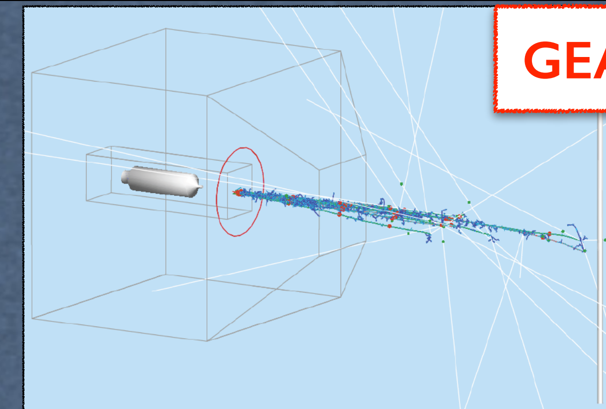
- to validate MC for forward particles production with an absolute normalization point
- to demonstrate [CsI(Tl) crystal + SiPM]$_{EMCal}$ & [Plastic scintillator + WLS +SiPM]$_{Veto}$ works in a high low-energy background (neutron)

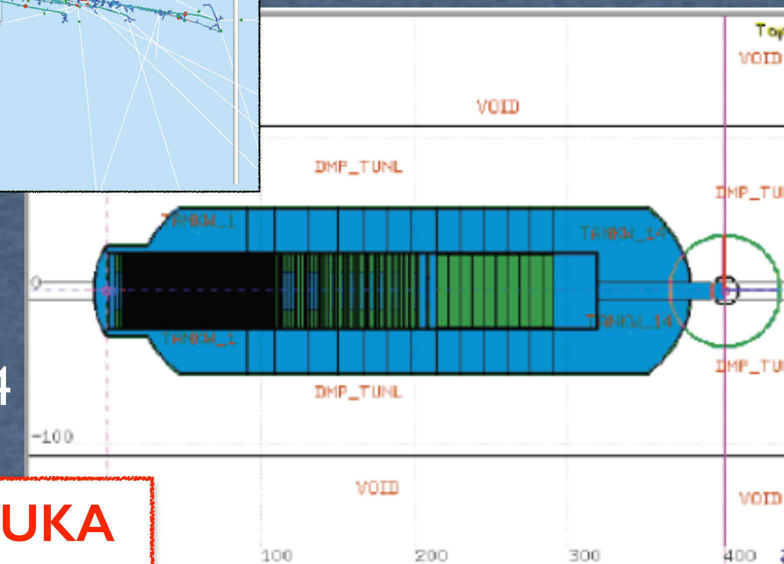
The proposed tests aim to respond to PAC44 concern and obtain full approval for BDX proposal

MC Simulations: beam/BD interaction



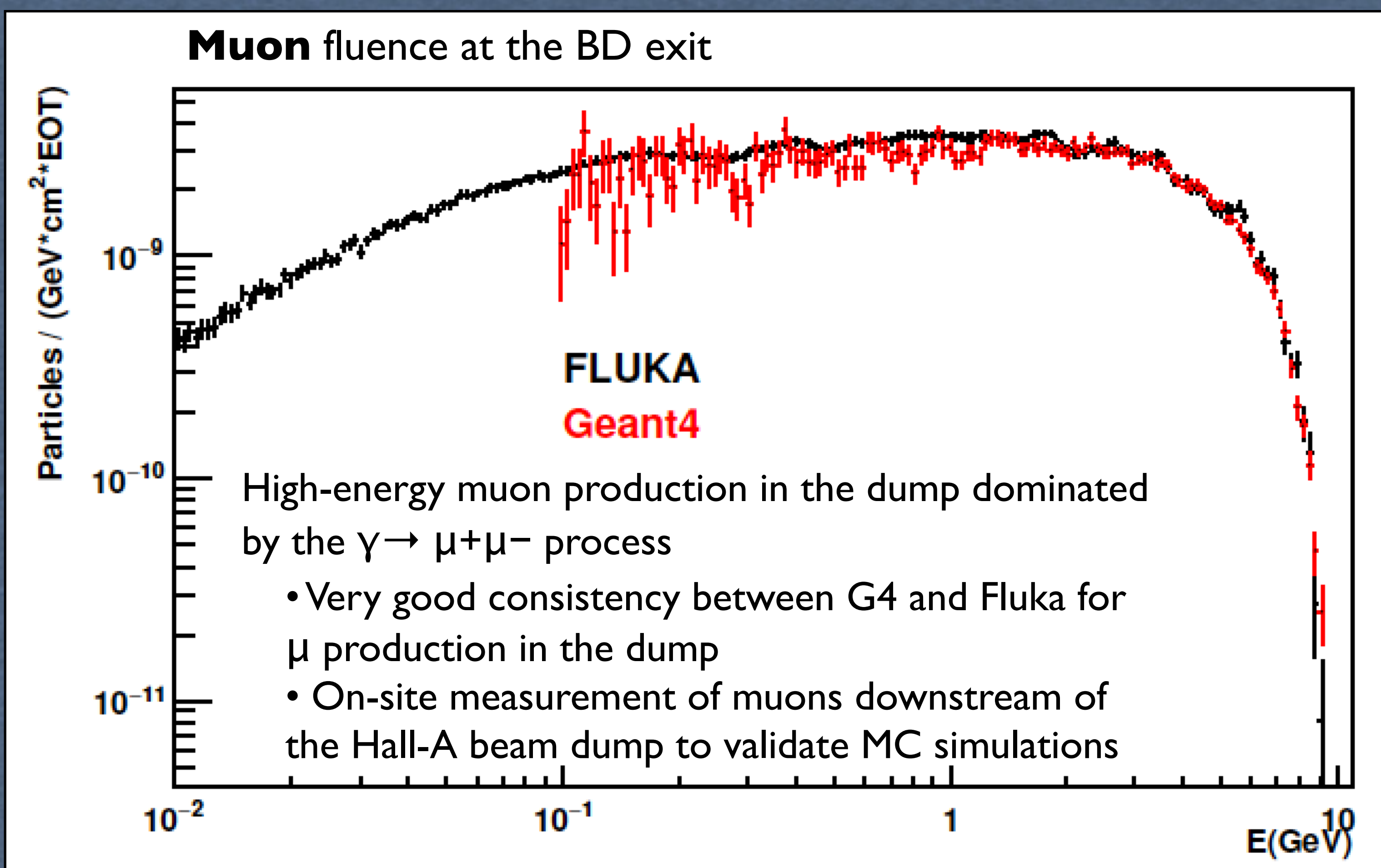
Hall A Beam Dump & alcove


GEANT4



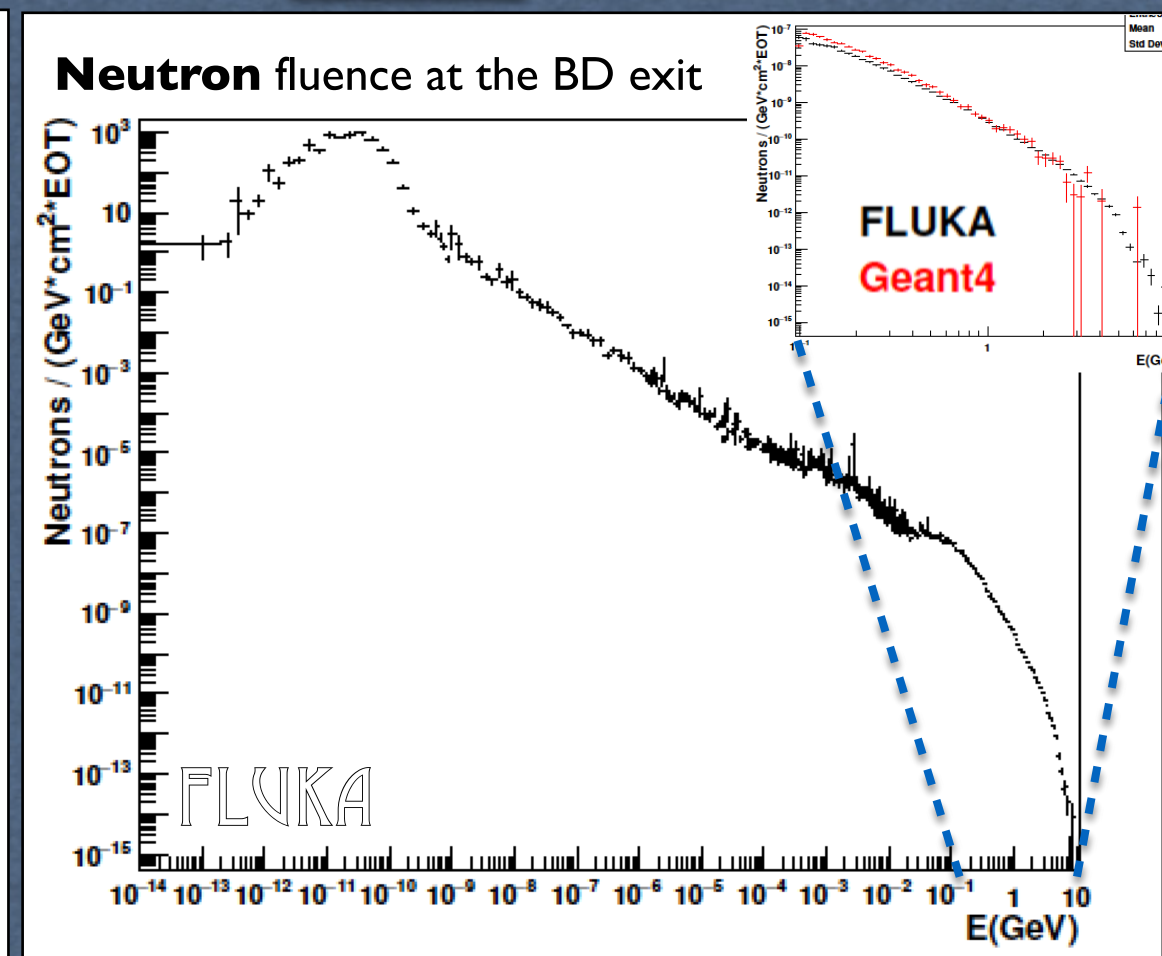
FLUKA

- 11 GeV beam interaction with the Hall-A beam dump using FLUKA and GEANT4
- Beam-dump geometry/material implemented in FLUKA by JLab RadCon Group
- Surrounding material/geometry implemented in both FLUKA and GEANT4



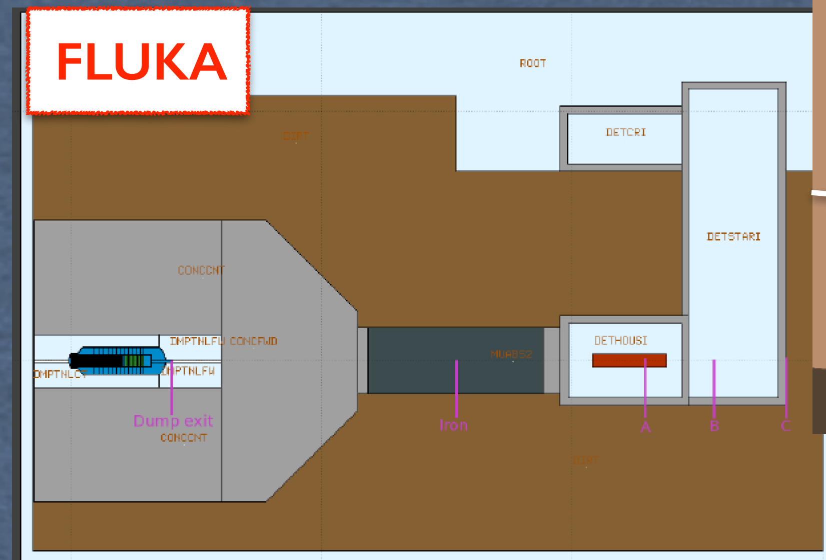
High-energy muon production in the dump dominated by the $\gamma \to \mu^+\mu^-$ process

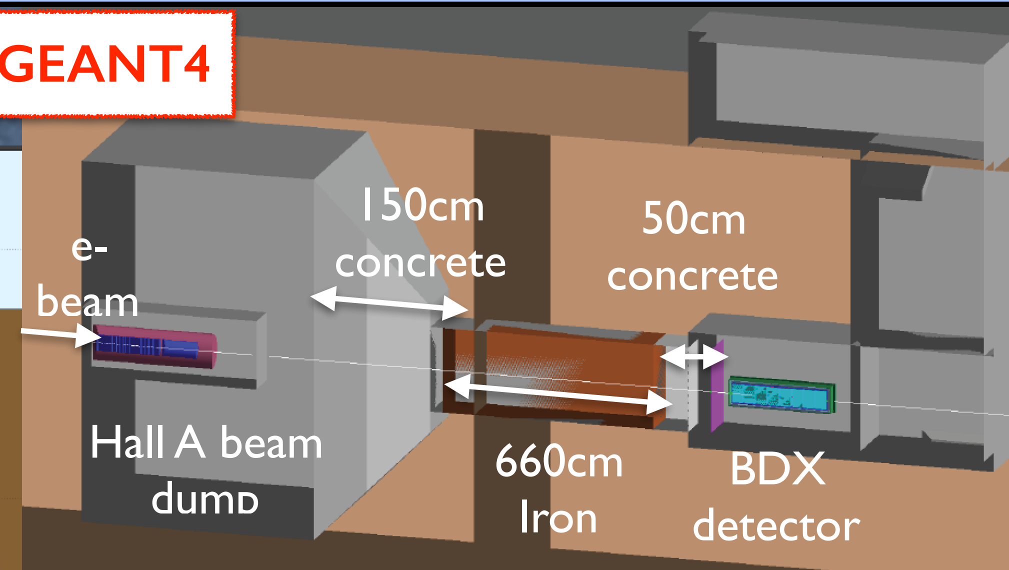
- Very good consistency between G4 and Fluka for μ production in the dump
- On-site measurement of muons downstream of the Hall-A beam dump to validate MC simulations

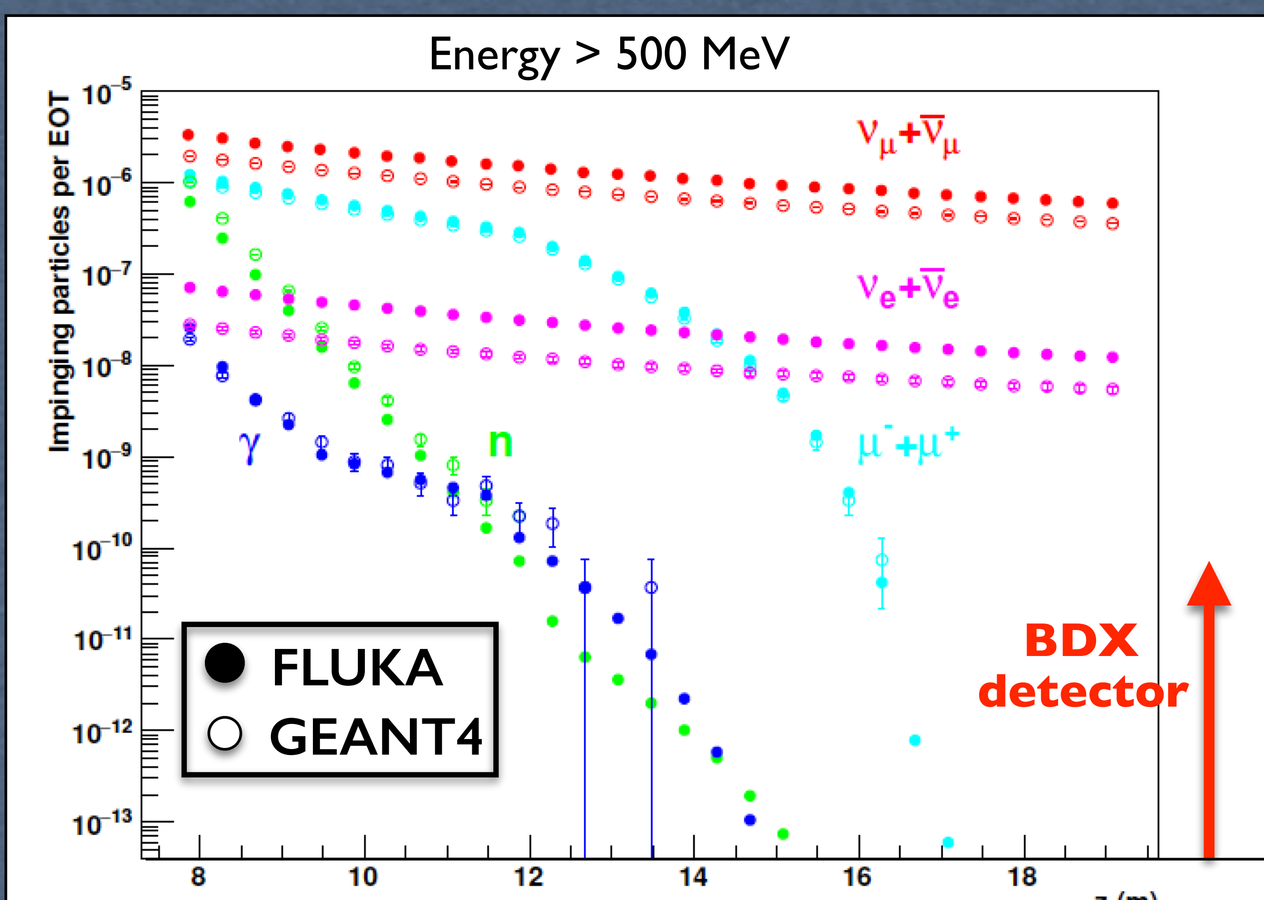


MC Simulations: BDX set up

- ★ 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



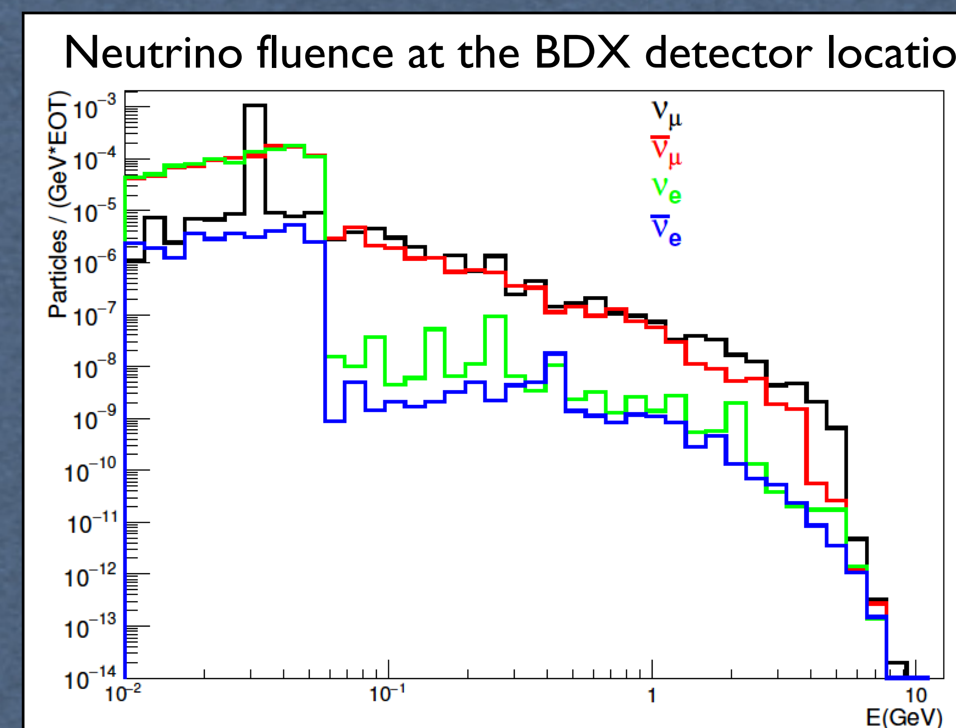




Non-negligible contribution of high energy ν interacting in the detector by CC:

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

$\nu + e^-$ suppressed



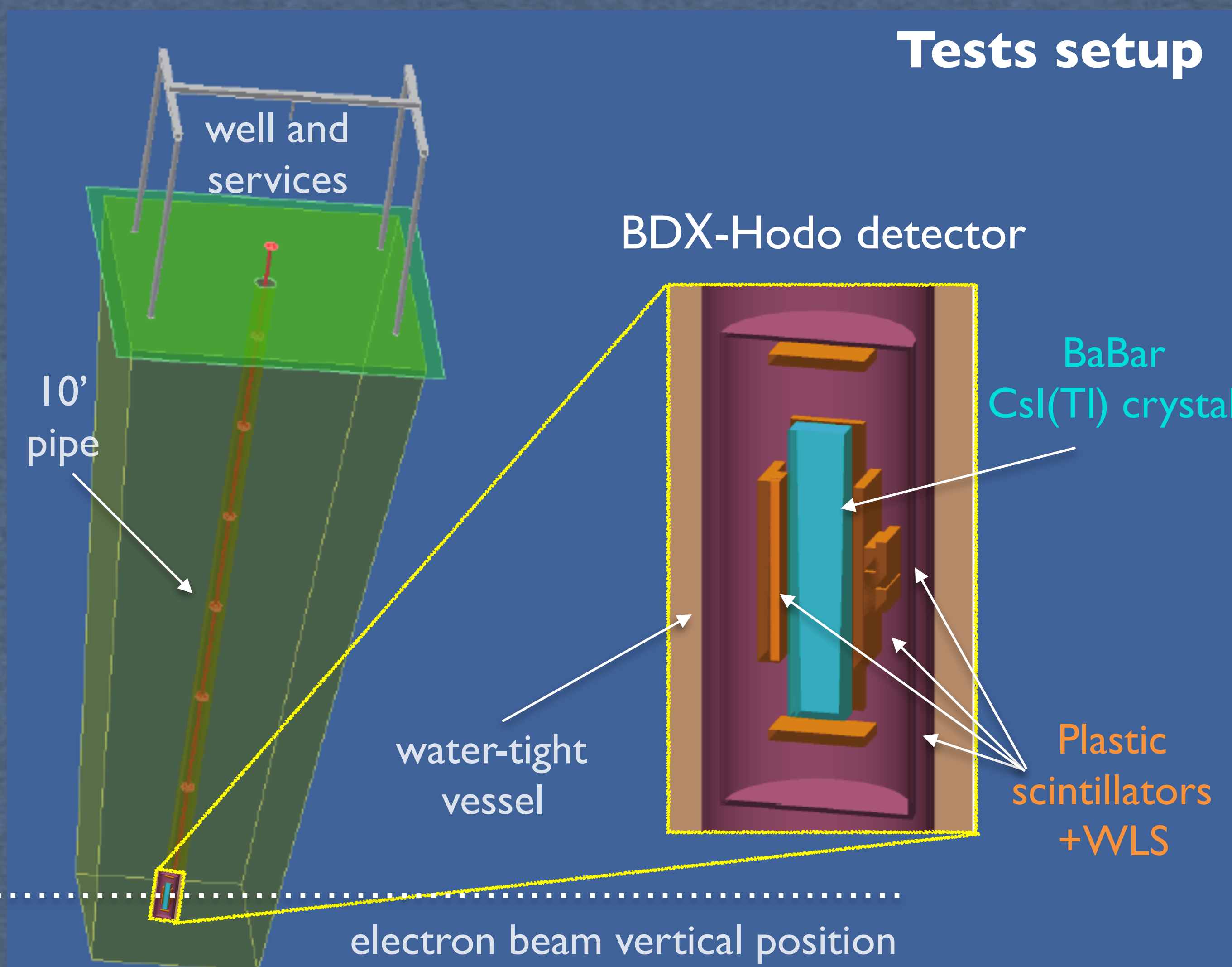
FLUKA simulations confirm results presented in BDX proposal to PAC44

- ✳ BDX only limited by the ν *irreducible* bg
- ✳ Expected beam-related bg counts ~10 events

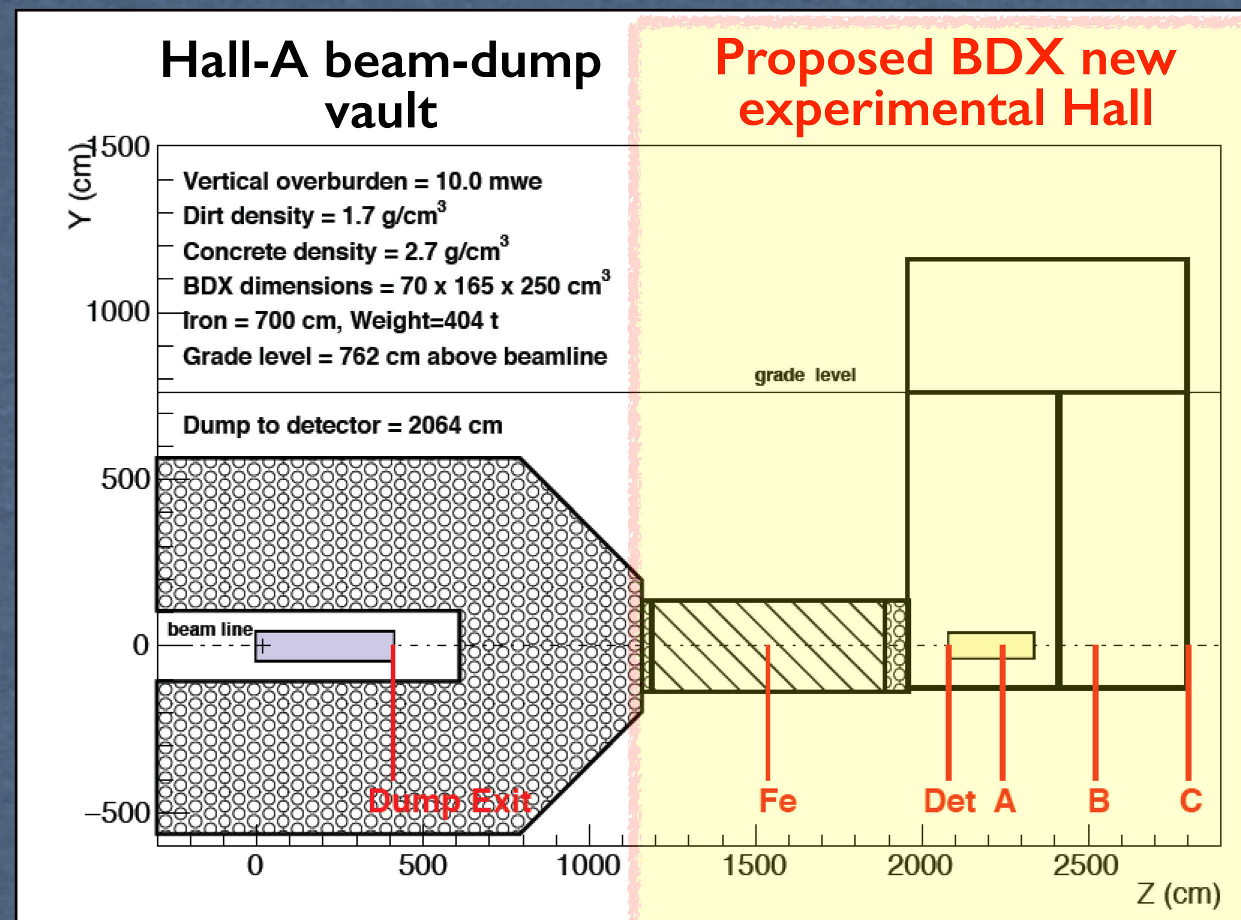
Proposed test to measure the beam-on background

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

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



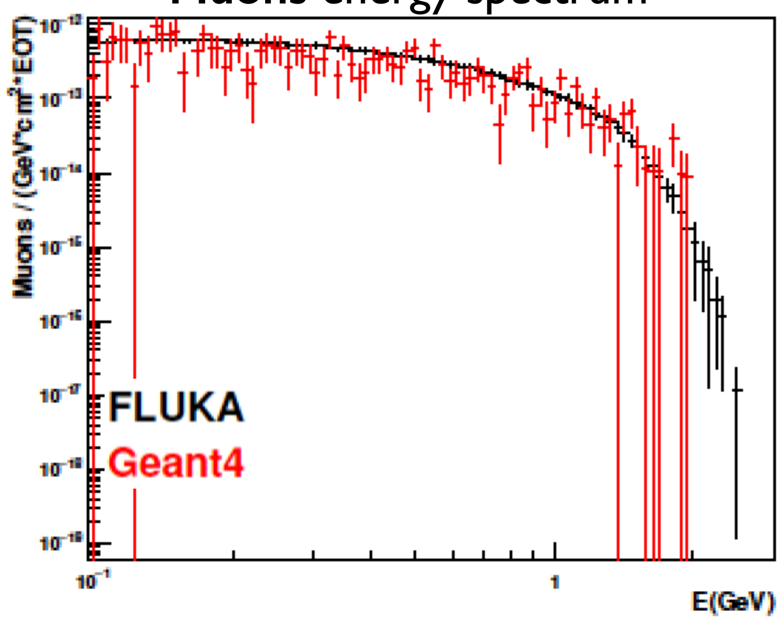
Downstream of the Hall-A beam dump - TODAY -



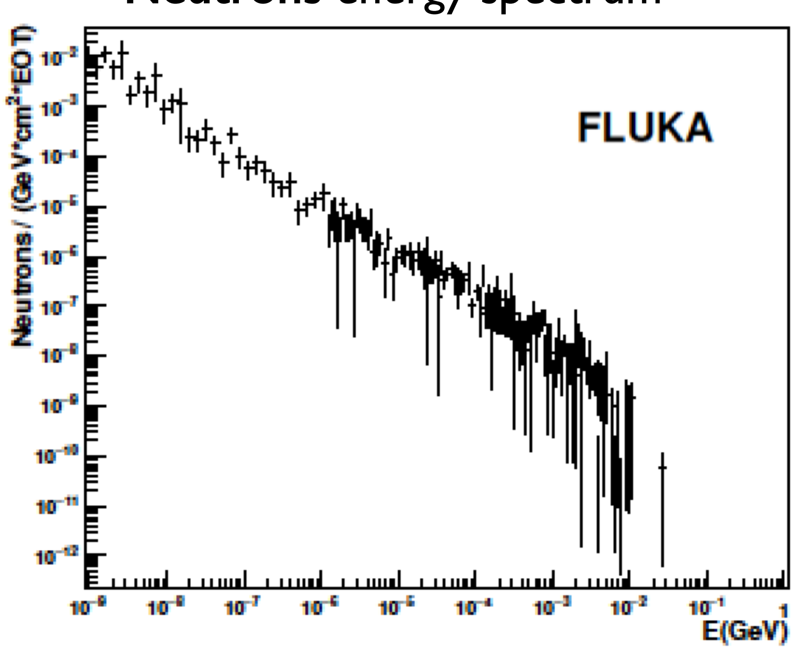
Expected Results

Expected μ and n energy spectra in location B (d = 25.2m, beam height)

Muons energy spectrum

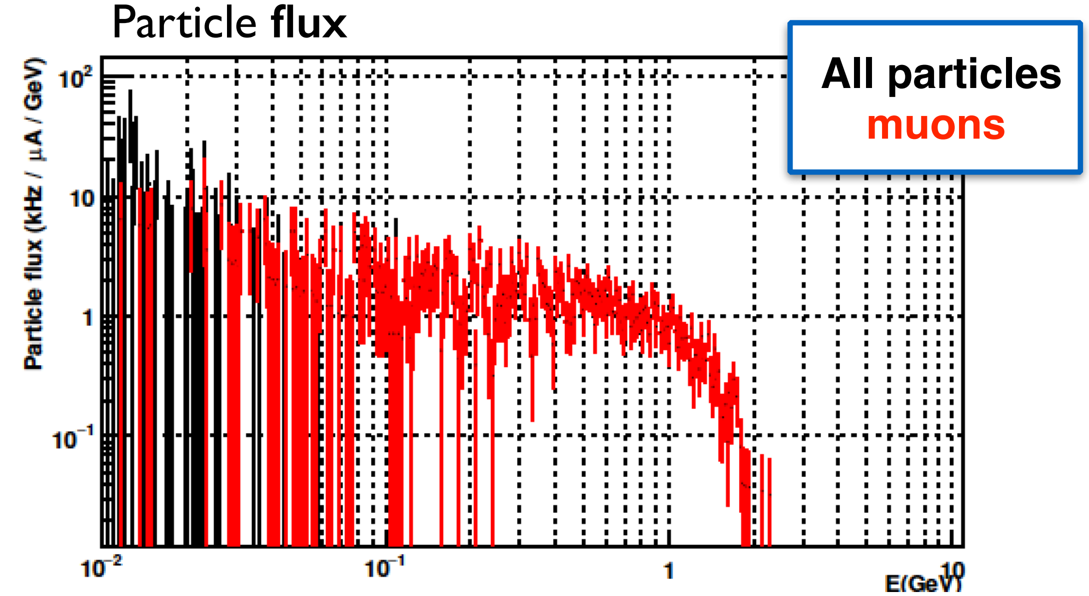


Neutrons energy spectrum

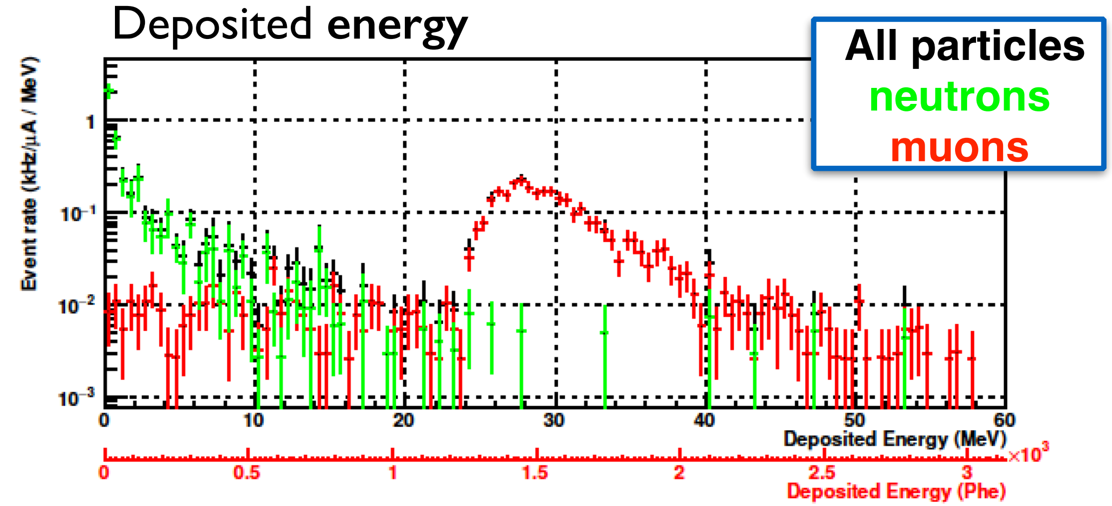


Expected particle flux and energy deposition in the CsI(Tl) crystal (FLUKA) in location B

Particle **flux**



Deposited **energy**



- Only muons and neutrons reach the area of interest
- Rate from cosmic muons is negligible (and measurable)

Expected Results

Expected μ rates in BDX-Hodo

Beam
- $I = 10\ \mu A$
- $E = 10$ GeV

Thresholds
- $Th_{CsI} = 2$ MeV
- $Th_{Scint} = 400$ keV

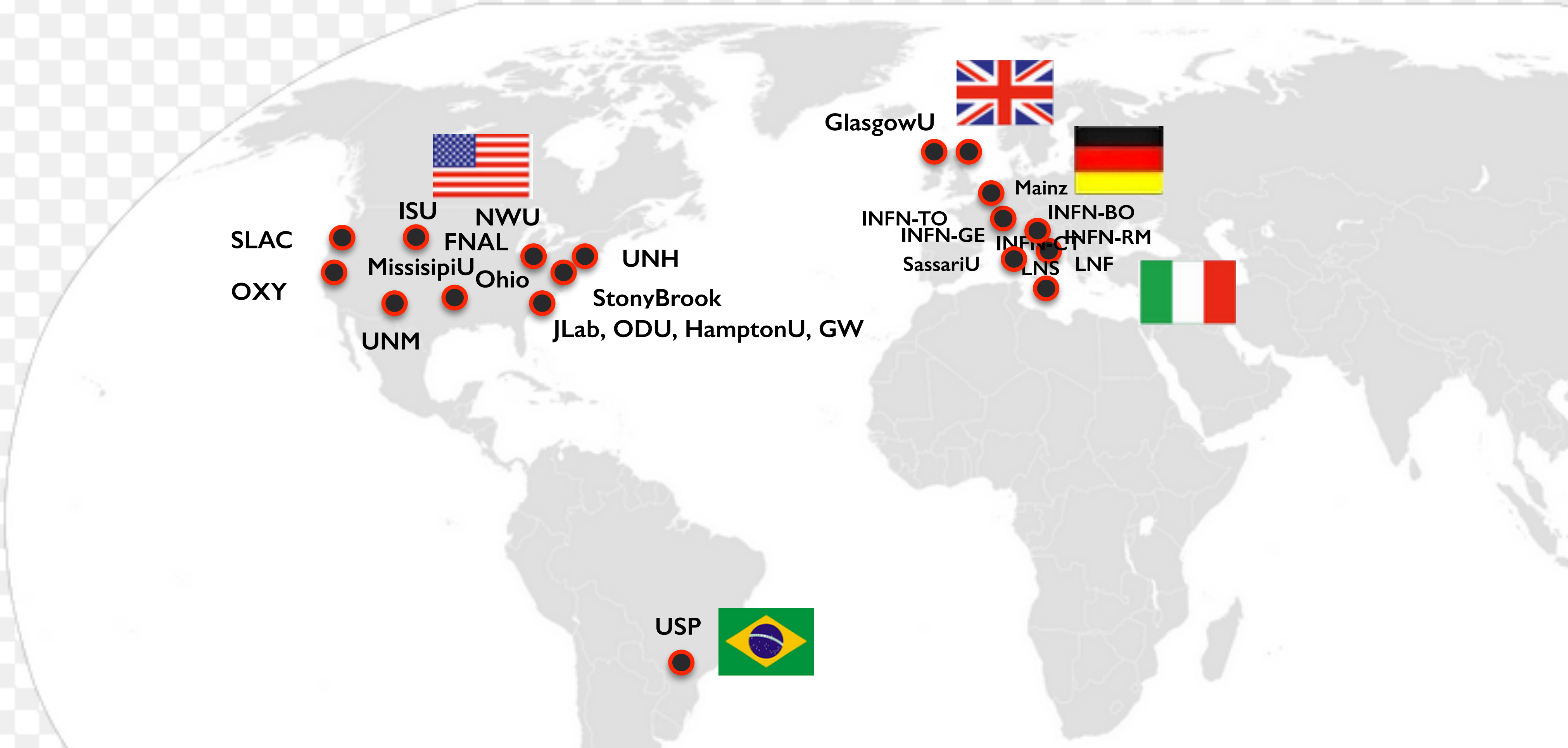
Location		Rate (Crystal only)	Rate (Crystal + scintillator)
A		120 KHz	24 KHz
B	on-axes ΔVertical = 0 (beam height)	20 KHz	3.7 KHz
C		2 KHz	0.5 KHz
C	off-axes ΔV=+ 40cm up	1.4 KHz	170 Hz
C	off-axes ΔV=+ 80cm up	0.6 KHz	80 Hz

- Few days tests at 11 GeV, 1uA< I_{beam} < 100uA (fully parasitic to any Hall-A operations)
- Beam current scan (compatible with HAll-A needs) if possible
- Relative and absolute μ rates to be compared to MC simulations
- Test of BDX detector technology (CsI(Tl) crystal + SiPM) and DAQ in a low-energy background-rich environment to demonstrate the insensitivity to low-energy neutron-induced pile-up
- Pipes available for further/other experimental installations (TAC comment) for bg assessment (e.g. JLab RadCon Group expressed interest in deploying a low-energy neutron detector)

Summary

- ✳ Collecting 10^{22} EOT in 285 days of parasitic running (~4y-calendar) at 11 GeV the BDX experiment would be 10-100 times more sensitive than previous experiments
- ✳ Implemented two strategies for a more reliable beam-related background estimate:
  - strengthening simulation tools
  - performing a measurement on site when the accelerator is running
- ✳ With the support of JLab RadCon Group, the BDX experimental set-up has been implemented in FLUKA
- ✳ FLUKA confirmed GEANT4 results presented in PR12-16-001
- ✳ Following PAC44 review indications, we propose to run a ~1 week tests in the actual JLab configuration to assess the beam-on background
- ✳ Test results will be used to validate MC simulations and prove BDX detector technology in a realistic condition
- ✳ This update address the concern expressed by PAC44 aiming to obtain the full approval of PR12-16-001 (now *Conditionally Approved - C2*)

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
Mainz 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

C12-16-001 TAC report responses

1. Measurement as proposed is assumed to be entirely parasitic. However, it will undoubtedly be necessary to access the BDX detector area(s) for debugging during active run periods. It should be verified if this will be possible during beam delivery and to develop any needed access protocols.

R.
- No radiations are expected in the location where the tests will be located.
- During the well drilling RadCon Group will monitor radiation level of removed dirt

2. How will the (potentially) large data files be transferred from the local DAQ systems to the JLab tape silo, Farm, etc. for archiving and analysis? WiFi (if it's even available in that area) may not be sufficient for online data analysis, or for reliably integrating EPICS and other desired 'slow control' data into the otherwise standalone DAQ.

R.
- No data transfer is required (the expected 5TB will be stored on a portable device)
- EPICS variables will be accessed off-line via MYA DB (~1s time resolution level is good enough to correlate beam parameters to data)
- In case of need a mobile LTE connection will be activated

3. The proposed generator power may need to be conditioned to meet requirements for low noise DAQ systems. (Test well beforehand.)

R.
- Noise could be an issue to be mitigated
- FACILITY may provide some other power source (as backup solution)

4. Weatherproofing high-voltage and signal cable paths between the temporary van/out-building into the wells may introduce additional cost.

R.
- Detector costs will be fully covered by INFN
- Detailed plans and costs estimate will be defined and discussed with JLab management once the tests will be endorsed

5. Multiple experimental runs at different periods are strongly encouraged to explore issues of data reproducibility and detector stability that will be critical for the proposed 4 year full measurement.

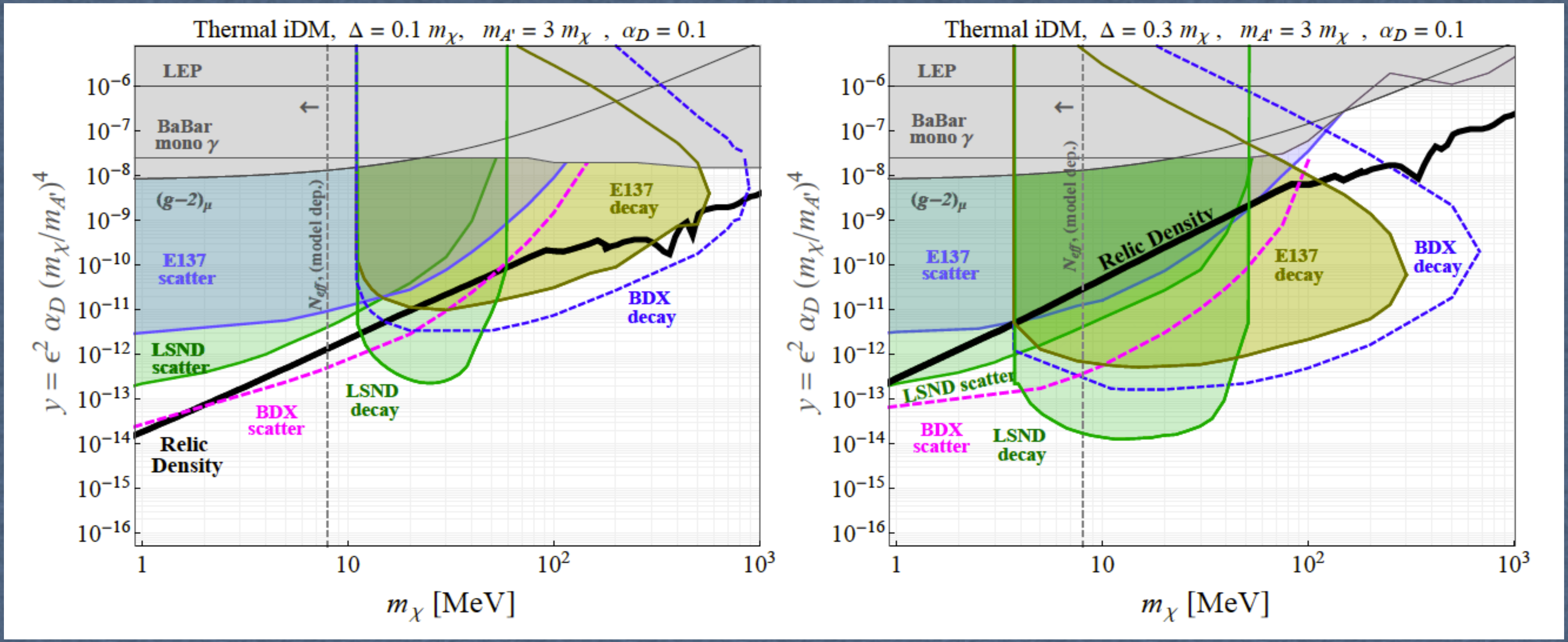
R.
- Tests are expected to run for a week
- Pipes will remain in place available for future/further measurements

6. The initial proposal suggested using timing cuts against the CEBAF pulse structure. This was not mentioned for this test run. Perhaps it is not wanted for this test? *If* this or other 'external' signals need to be transmitted to this DAQ, then plans/costs for engineering the necessary cable runs should be outlined.

R.
- All results reported in PR12-16-001 do not consider any timing cuts
- BDX does not require special beam time structure
- Slow-control information will be correlated off-line

Other LDM scenarios

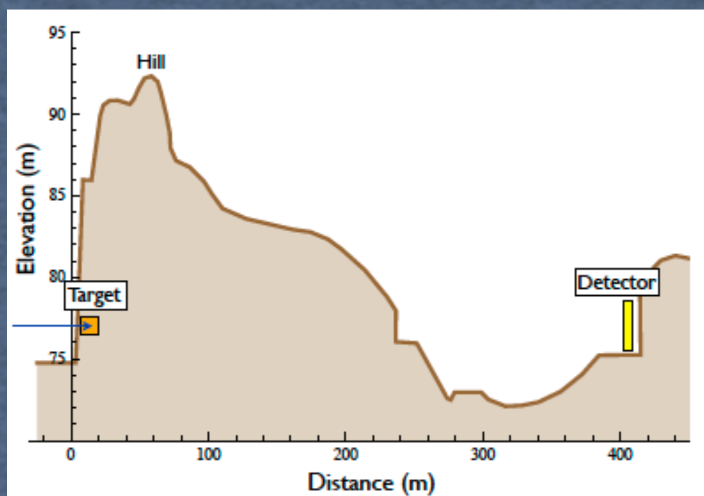
- ★ *inelastic Dark Matter* assumes off-diagonal interaction predicting the existing of 2 states X_1 X_2 with mass splitting Δm
- ★ If Δm exceeds few MeV the $X_2 \rightarrow X_1\ e^+\ e^-$ is expected to be the dominant decay
- ★ Beam dump experiment show a unique sensitivity to iDM scenarios
- ★ Boosted decay electrons and positrons produce in the detector high-energy E.M. showers easy to detect



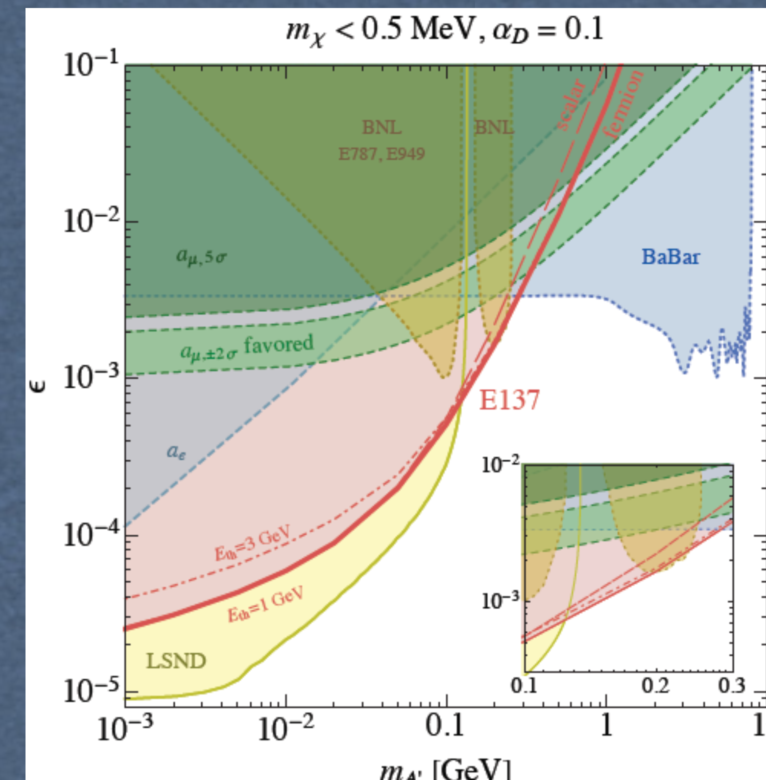
BDX will cover a significant iDM parameter's region testing the DM relic origin target

A critical review of upper limits derived from old experiments

E137@SLAC (<1988)

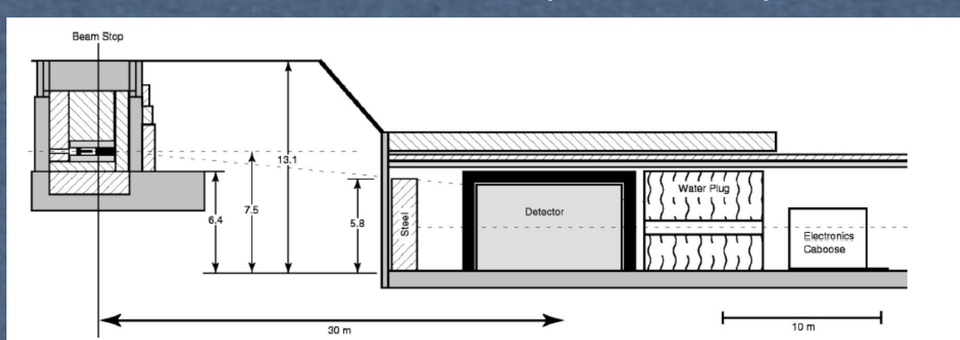


- SLAC electron beam: 20 GeV 2x10^{20} EOT
- Detector: 8 r.l. em calorimeter (hodo + converter + MWPC)
- Size: 1.5m x1.0 m at ~380m from the BD
- Cosmic bg suppressed by directionality and time coincidence
- Detection Threshold: 1-2 GeV
- 0 events detected

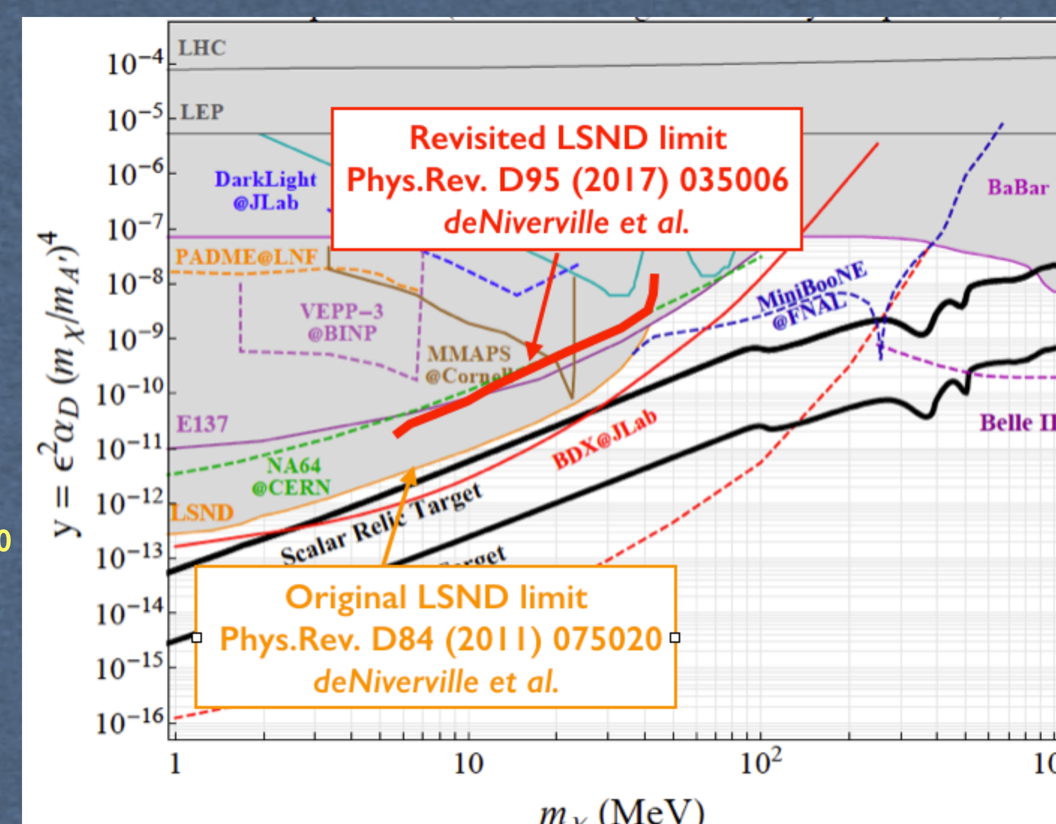


- Extracted upper limits suffer by poor knowledge of experimental details
- No e$^-$ showering in the BD included: softer DM E spectrum and defocused DM beam
- Limits are overestimated by a factor ~3-4 (depending on the kinematics)

LSND@LosAlamos (1994/98)



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



- 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

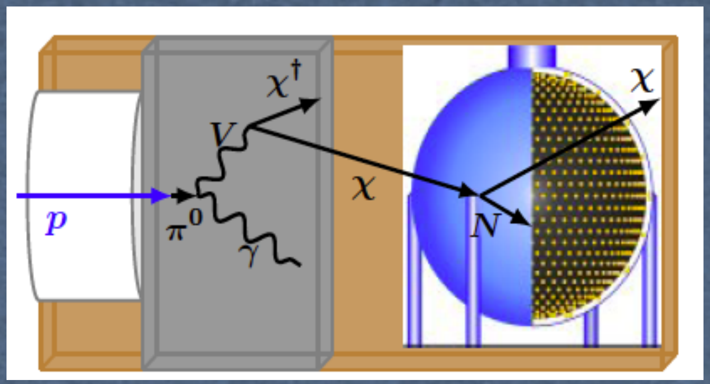
BDX is the first beam-dump experiment optimised for LDM searches

New experimental results since PAC44

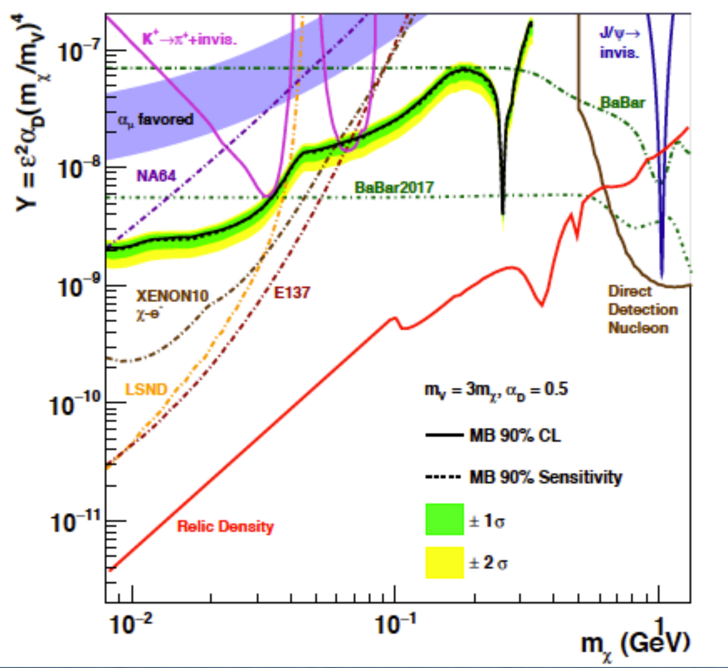
MiniBooNE@FERMILAB

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

Dark Matter Search in a Proton Beam Dump with MiniBooNE



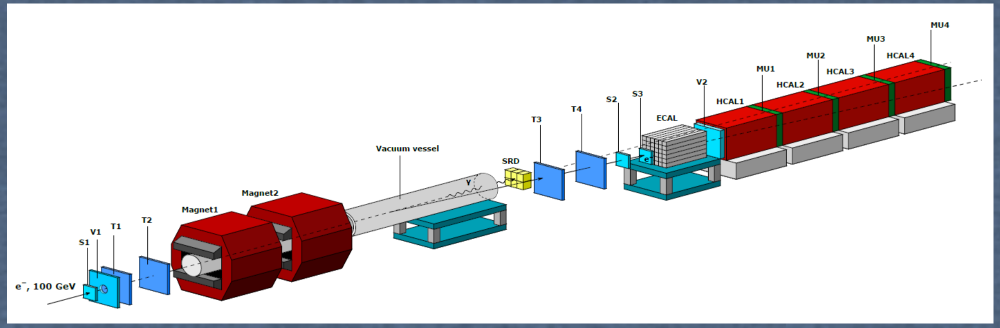
- BDX-like with an 8 GeV proton beam
- Cherenkov response of 12 m spherical detector with 800 tons mineral oil (CH2)
- Typical operation: 2×10^{20} protons on target (POT) per year



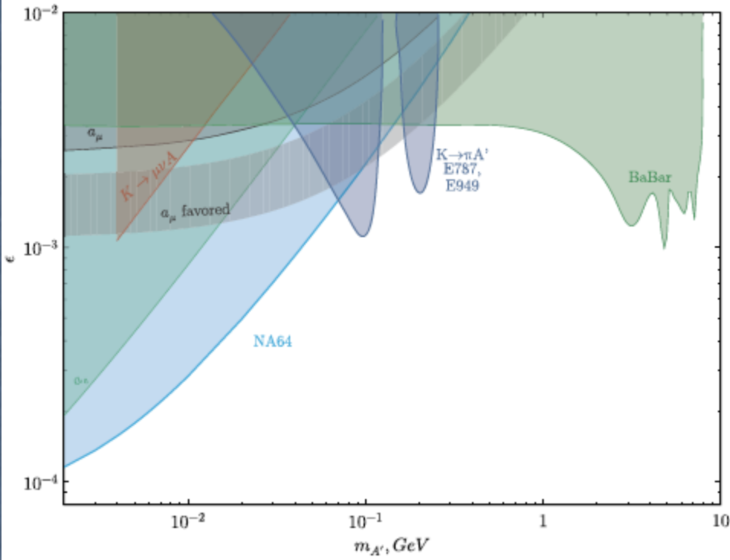
NA64@CERN

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

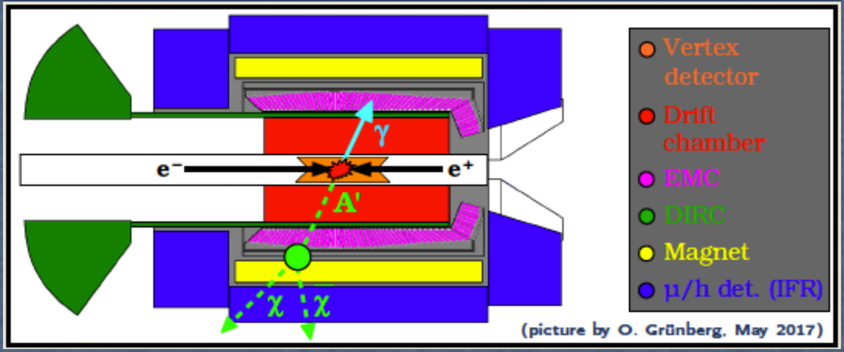


BaBar@SLAC

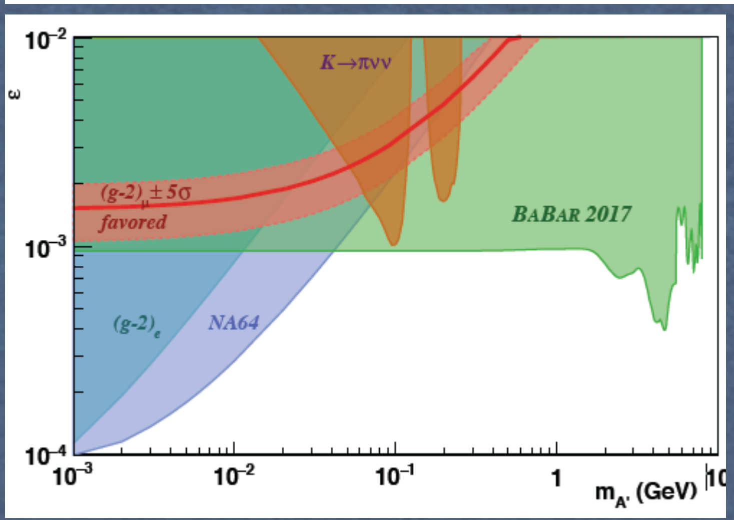
BABAR-PUB-17/001
SLAC-PUB-16923

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}



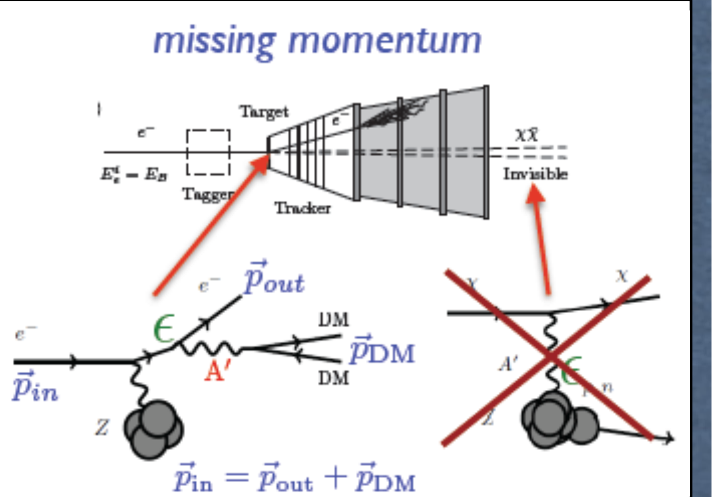
BDX & future experiments

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

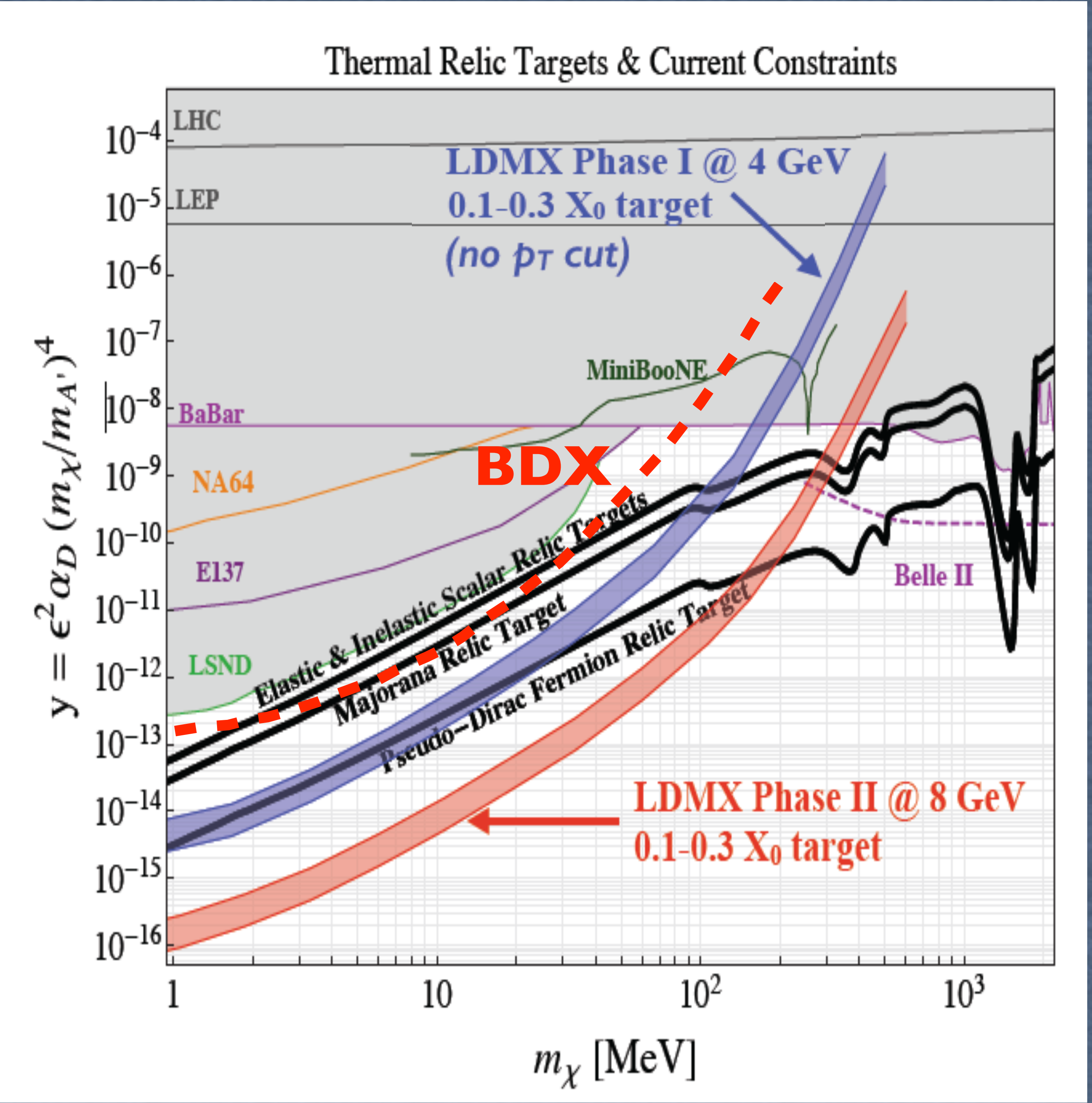
MissingMomentum vs BeamDump
(*disappearance* vs *appearance*)

… **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



High statistics MC simulations

★ Simulation of full statistics (10^{22} EOT) not feasible because of computing resources limitation [GEANT4: 1y, 2000 cores→10^{11}-10^{12} EOT]

★ FLUKA uses a tuned set of biasing weights to efficiently simulate low probability processes

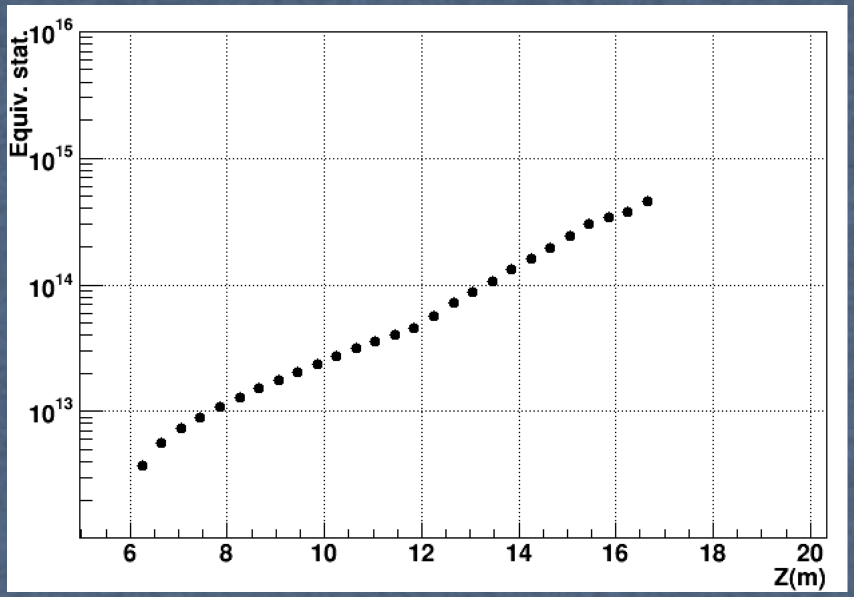
- *Leading particle biasing* for e^+ e^- and γ
- *Region importance biasing* for hadrons and muons in the forward direction
- Photon inelastic cross section biased by a factor 10^2 and $\gamma \rightarrow \mu^+\mu^-$ biased by a factor 10^4
- Accurate treatment of low-energy neutron propagation and neutrino interaction

★ Final bias configuration obtained after running multiple tests to optimize simulation parameters (discussed with JLab Radiation Control Group)

- For each parameters settings, score muons current across concrete and iron shielding
- Use a FOM defined as $\sigma^2 T$ (σ = FLUKA error, T = CPU time) to evaluate effect of parameters change

★ **Equivalent number of primary particles (ENPP)** is the number of primary particles necessary to simulate in a full (unbiased) run to obtain the same statistical error

★ **Extrapolating results obtained in a run of 2 days on 200 cores show that an equivalent statistics of $10^{17\text{-}18}$ EOT is collectable in 6 months**



The BDX-Hodo detector

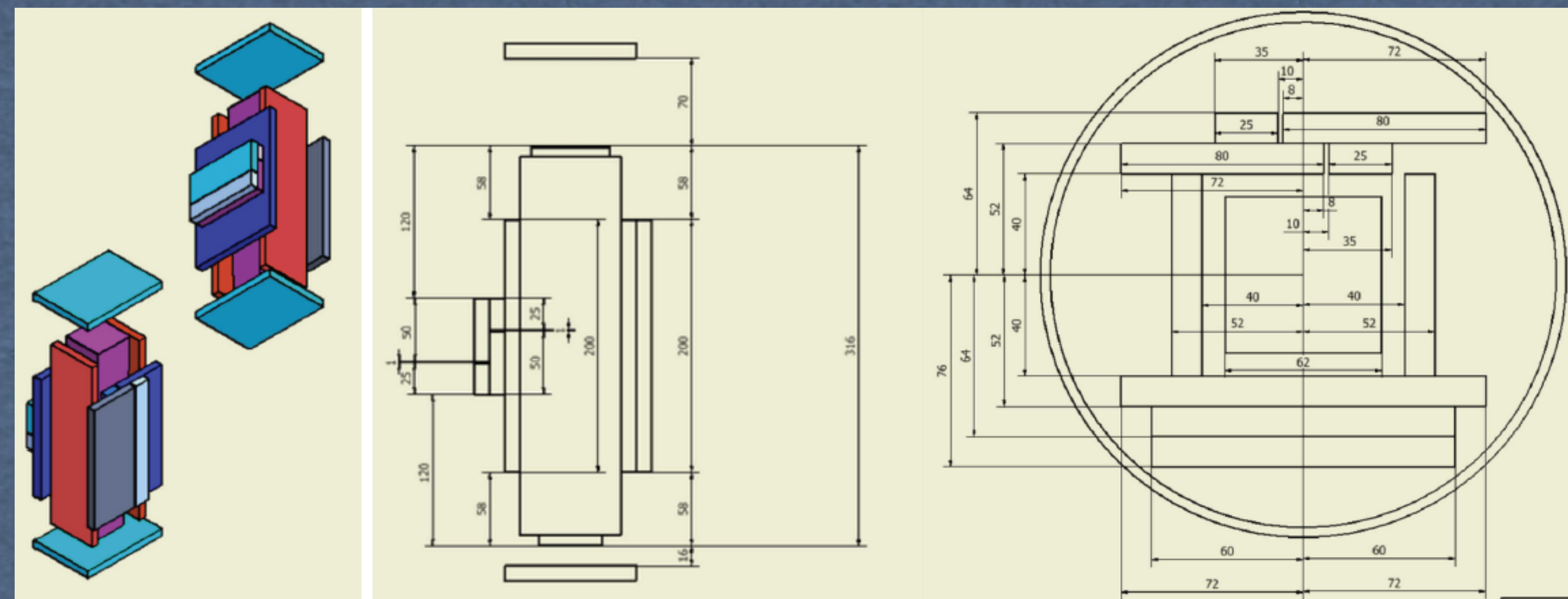
Crystal
- CsI(Tl) crystal [5x5 (4x4) x 30 cm^3]
- 6x6 mm^2 SiPM photosensor
- The same set-up of BDX ECal
- MIPs signal: 32 MeV (1670 pe)

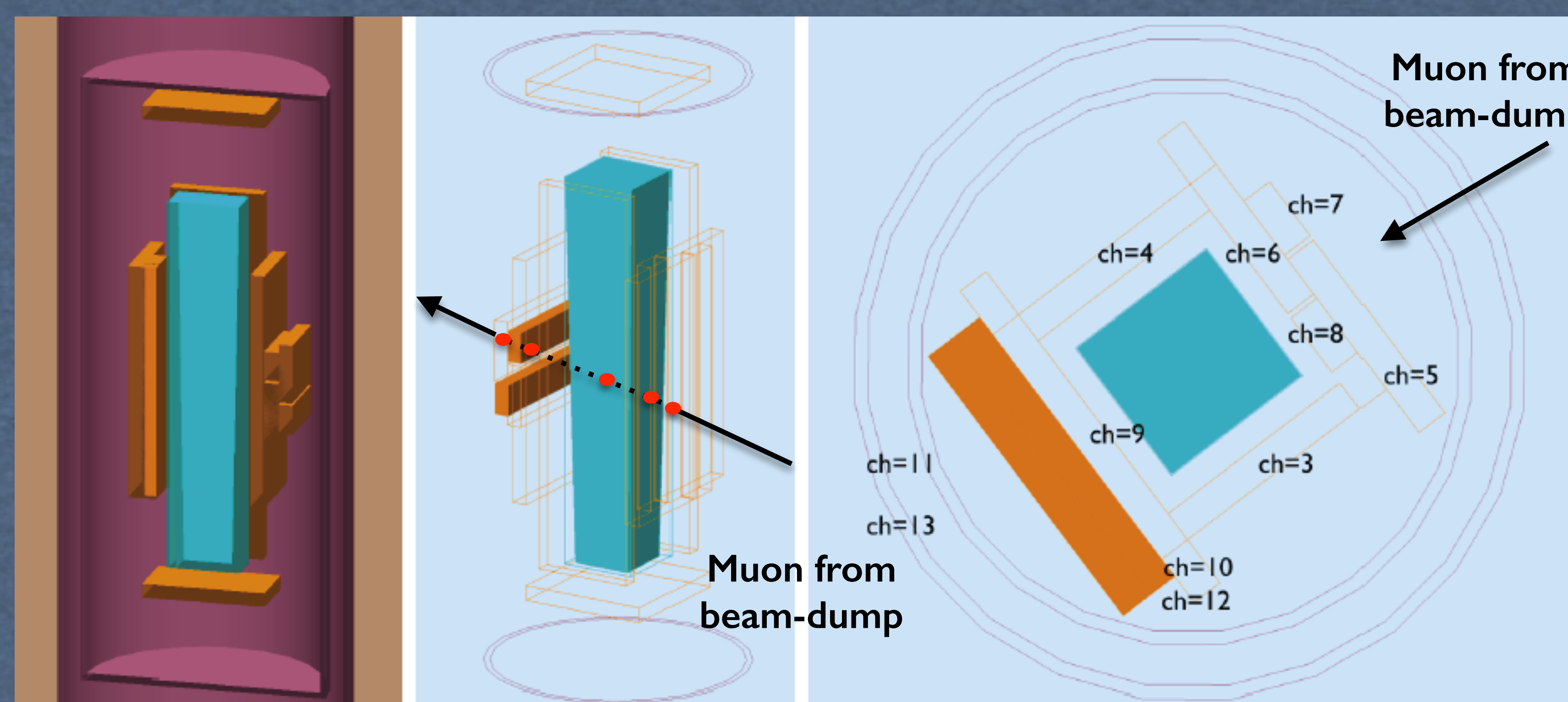
Scintillator
- 13 plastic scintillator paddles 1cm thick
- 3x3 mm^2 SiPM coupled via WLS fibers
- Same technology used in BDX IV
- MIPs signal: 2 MeV (50 pe)

Container
- Cylindrical vessel (d=20cm, h=52cm)
- Stainless steel, water-tight

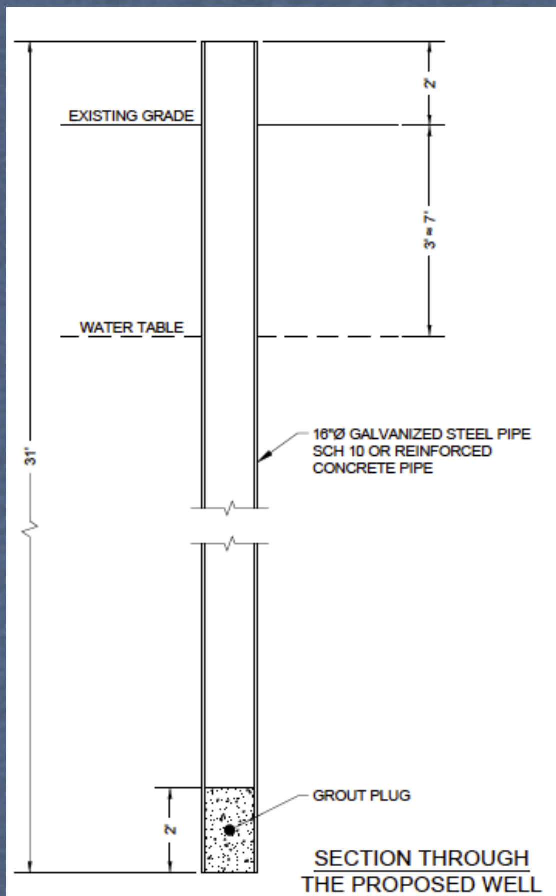
Performance
- Trigger provided by CsI(Tl) alone
- front: 2H strips
- back: 2V strips + 1 large paddle
- 9 x 2.5x2.5 cm^2 XY grid
- 5-fold coincidence (2H + crystal + 2V) to identify muons
- top/bottom/lateral veto's for cosmic

- Geometry, material and response implemented in GEANT4
- Simulated response matched to BDX-Protoype detector running in CT





Test plan and costs estimate



Date: 1/27/17

Cost Estimate for BDX Experiment - Two 10" Wells

NUMBER	DESCRIPTION	QUANTITY	UNITS	RATE	AMOUNT	Sub's O&P	Contingency	Total
1	Well Installed 10" diameter - (Cost Based on bid for 16" well)	2.00	Ea.	$10,000	$20,000		25%	$25,000
2	Backfill & compaction	2.00	Ea.	$2,000	$4,000	25%	25%	$6,250
3	Generator	1.00	Ea.	$1,000	$1,000	25%	25%	$1,563
4	Concrete slab on grade 5'x5'x6" (To act also as Wt. against uplift)	2.00	Ea.	$500	$1,000	25%	25%	$1,563
5	Ground exploration	1.00	Ea.	$1,200	$1,200	25%	25%	$1,875
6	Air Blower to keep the well dry	2.00	Ea.	$1,000	$2,000	25%	25%	$3,125
	Grand Total							$39,375

NOTES:

1) The Estimate is based on the assumption that **no radioactive contamination** of underground soil or water is encountered during drilling of the well.

2) Ground exploration will need to be done before detailed design done. This will also be used to ascertain no radioactive contamination in the well area.

- Two 10" wells ~20-30m downstream of the Hall-A beam-dump, insert pipes and lower the BDX-Hodo detector to measure the muon/bg rate at different depth
- A realistic quote shows drilling costs in the range of $40k

Preparation, quick scan at different depth, ~ 3h

Position	Depth (cm)	$\text{Rate}_{Crystal}(kHz)$	Run time (mn)	N_{Evnt} collected (M)
B	0	20	10	6
B	40	10	20	6
B	80	4	40	5
				Total time ~ 2h
				Configuration change ~ 3h
C	0	2.8	30	5
C	40	1.4	60	5
C	80	0.6	120	4.5
				Total time ~ 4h

- 2x 8h shifts (4 calendar days, including 50% CEBAF efficiency) will suffice to complete the test
- BDX Collaboration will be in charge of providing the detector and run tests

Fall 2017
Hall-A schedule

279	10/02/17	Monday	2.1	NOTE 17.4		
280	10/03/17	Tuesday	2.1			
281	10/04/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
282	10/05/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
283	10/06/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
284	10/07/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
285	10/08/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
286	10/09/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
287	10/10/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
288	10/11/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
289	10/12/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
290	10/13/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
291	10/14/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
292	10/15/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
293	10/16/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
294	10/17/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
295	10/18/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
296	10/19/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
297	10/20/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
298	10/21/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
299	10/22/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
300	10/23/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
301	10/24/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
302	10/25/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
303	10/26/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
304	10/27/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
305	10/28/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
306	10/29/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
307	10/30/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
308	10/31/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
309	11/01/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
310	11/02/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
311	11/03/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
312	11/04/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
313	11/05/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
314	11/06/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
315	11/07/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
316	11/08/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
317	11/09/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
318	11/10/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
319	11/11/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
320	11/12/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
321	11/13/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
322	11/14/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
323	11/15/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
324	11/16/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
325	11/17/17	Friday	2.1	3+ halls	E12-10-103	10.6/20/-
326	11/18/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
327	11/19/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
328	11/20/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
329	11/21/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
330	11/22/17	Wednesday	down			
331	11/23/17	Thursday	down			
332	11/24/17	Friday	down			
333	11/25/17	Saturday	down			
334	11/26/17	Sunday	down			
335	11/27/17	Monday	down			
336	11/28/17	Tuesday	2.1	Restore		
337	11/29/17	Wednesday	2.1	Restore		
338	11/30/17	Thursday	2.1	NOTE 17.4	E12-10-103	10.6/20/-
339	12/01/17	Friday	2.1		E12-10-103	10.6/20/-
340	12/02/17	Saturday	2.1	3+ halls	E12-10-103	10.6/20/-
341	12/03/17	Sunday	2.1	3+ halls	E12-10-103	10.6/20/-
342	12/04/17	Monday	2.1	3+ halls	E12-10-103	10.6/20/-
343	12/05/17	Tuesday	2.1	3+ halls	E12-10-103	10.6/20/-
344	12/06/17	Wednesday	2.1	3+ halls	E12-10-103	10.6/20/-
345	12/07/17	Thursday	2.1	3+ halls	E12-10-103	10.6/20/-
346	12/08/17	Friday	2.1	3+ halls	Pass change (12hrs)	
347	12/09/17	Saturday	2.1	3+ halls	E12-10-103	6.6/20/-

- Tests will be parasitic wrt the Hall-A operations making use of 11 GeV beam to the dump (and 1uA< I_{beam} < 100uA)
- If possible, a current scan will be coordinated with Hall-A program

The BDX crystals

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

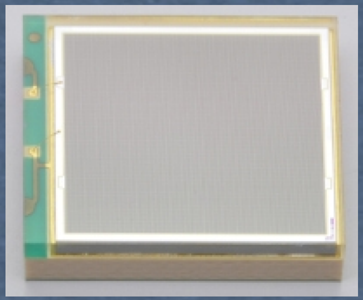
Possible options:

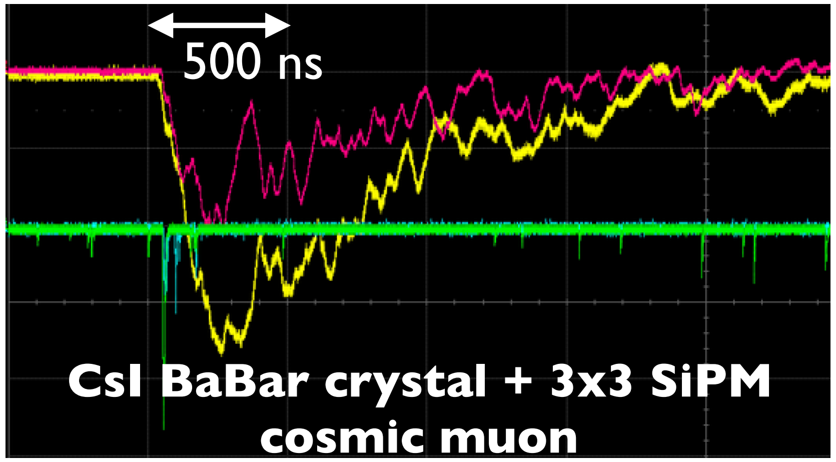
BaF2
CsI
BSO

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

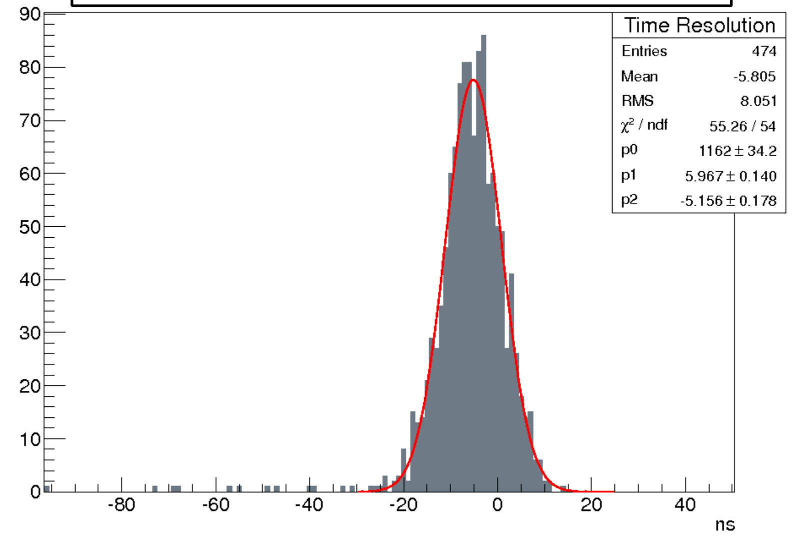




Crystals are available from BABAR em calorimeter
- Size: (5x5)cm^2 front face, (6x6)cm^2 back face, 30cm length
- 820 crystals available from end cap
- Decay time: fast 900ns, slow 4000ns
- LY= 50k γ/MeV

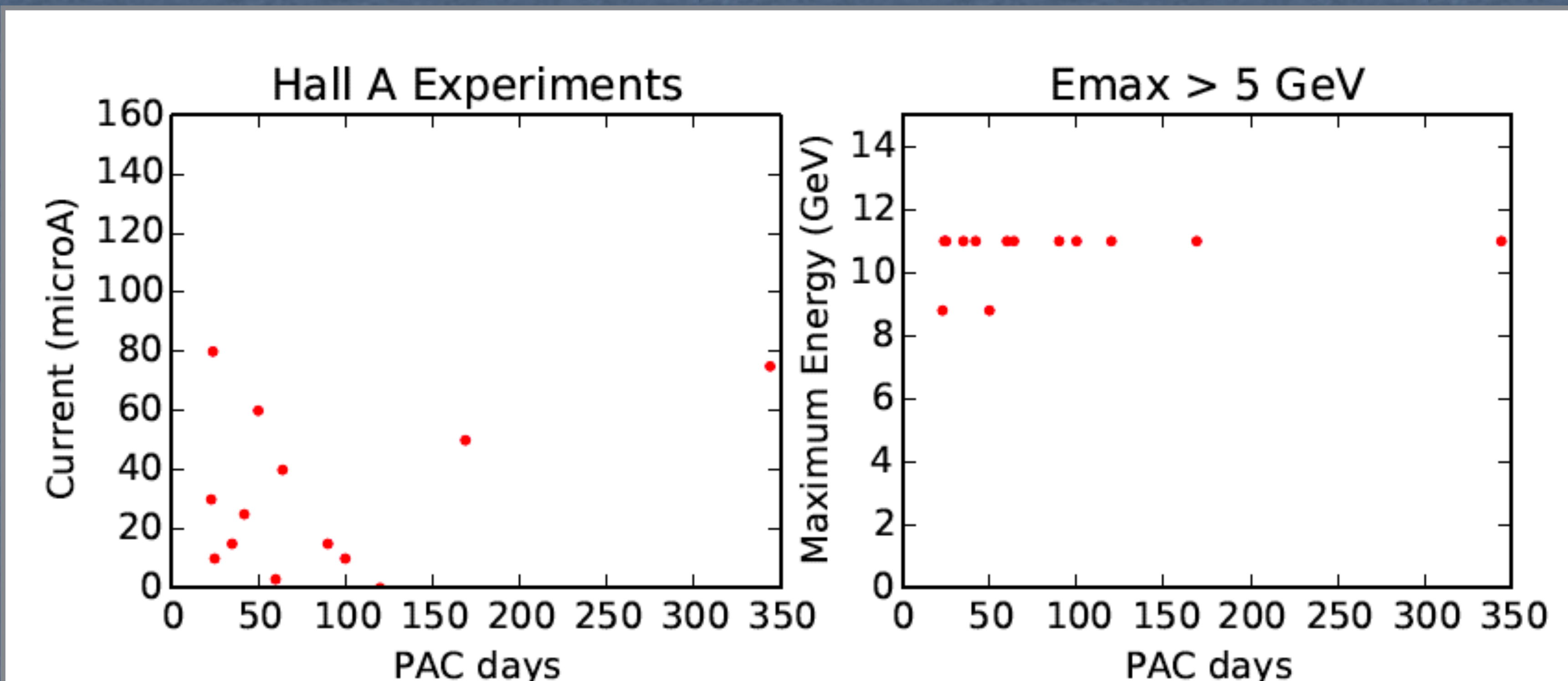
SiPM readout
- Size: (6x6) mm^2, 25μm, 57.6k cells, trenched, pde=25%
- SPE capability
- CsI(Tl): 40 pe/MeV
- Time resolution: ~5ns (MIPs)

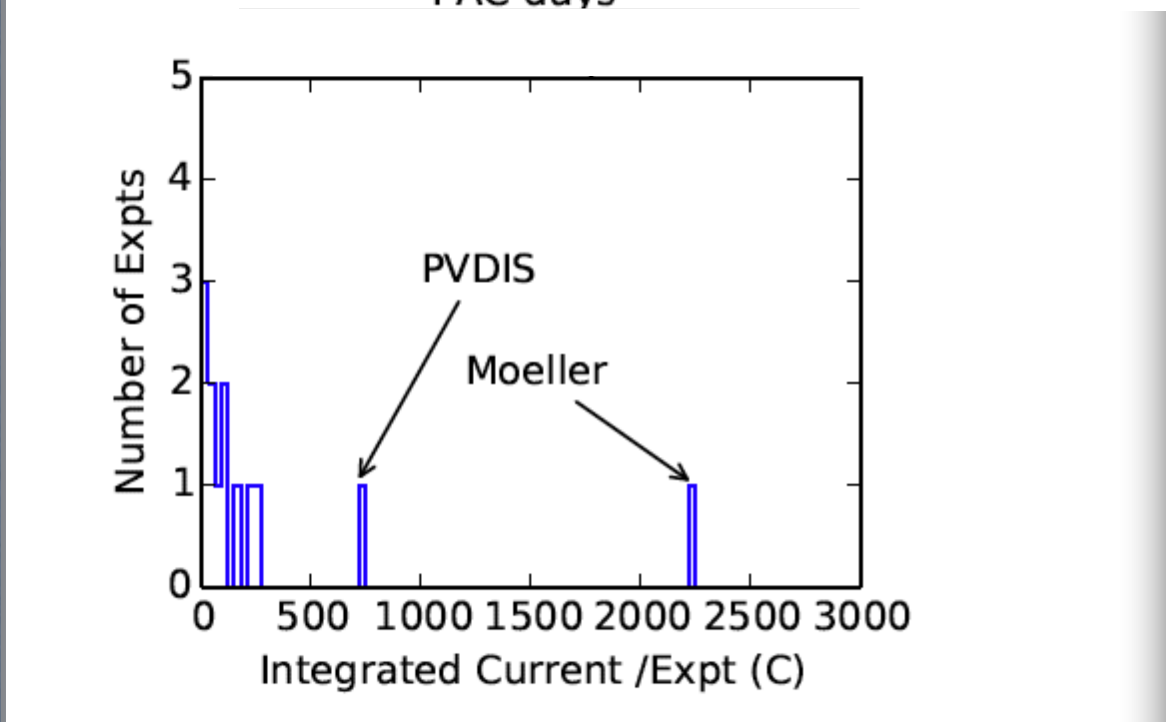
CsI BaBar crystal + 3x3 SiPM
Time resolution: σ = 6ns



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

Hall A approved experiments





Total Charge = 4042 C
EOT = 2.5 10^{22} electrons

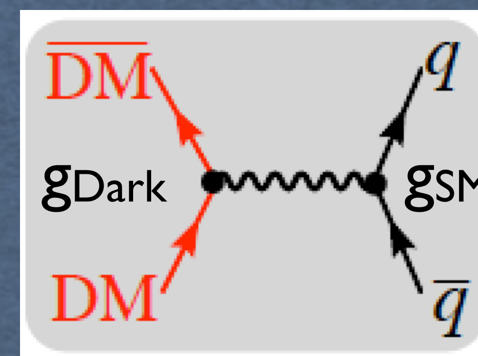
BDX beam-time request almost saturated by *Moeller* and *PVDIS (11GeV)* exps

		Approved days	Energy1 (GeV)	Energy2 (GeV)	Energy3 (GeV)	Energy4 (GeV)	Current (microA)
E12-06-122	A1n	23	0	0	6,6	8,8	30
E12-07-108	ep elastic	24	0	6,6	8,8	11	80
E12-09-005	Moeller	344	0	0	0	11	75
E12-09-016	Gen/Gmn	50	0	4,4	6,6	8,8	60
E12-09-019	Gmn (SBS)	25	4,4	6,6	8,8	11	10
E12-10-007	PVDIS	169	0	0	6,6	11	50
E12-10-009	APEX A1	34	1,1	2,2	3,3	4,4	75
E12-10-103	F2n/F2p	42	0	0	0	11	25
E12-06-114	DVCS e-helicity	100	0	6,6	8,8	11	10
E12-10-018	Transversity 3He	64	0	0	8,8	11	40
E12-10-006	Trans tgt asym 3He	90	0	0	8,8	11	15
E12-11-007	SIDIS PI+ (SOLID)	35	0	0	8,8	11	15
E12-11-101	PREX II	35	0	0	0	1	70
E12-11-108	Trans tgt asym (SOLID)	120	0	0	8,8	11	0,1
E12-11-112	Isospin dep 2N, 3N SRC	19	0	0	2,2	4,4	25
E12-12-006	J/Psi	60	0	0	0	11	3
E12-12-004	CRES	45	0	0	0	1,1	150
E12-14-009	GE 3He/3H	1,5	0	0	0	1,1	5
E12-14-011	p, n moment distr A=3	12	0	0	0	4,4	25
E12-14-012	Spec Func 40Ar	9	0	0	0	2,2	100
		1301,5					

Any guess about the DM mass and interaction?

★ (Obvious) first guess: DM interaction in the range of the weak force scale (WIMPS) with DM mass in the range of TeV

WIMPs paradigm is not the only option (keeping the DM thermal origin)



$\langle \sigma v \rangle \sim g^2_{Dark}\, g^2_{SM}\, M^2_{DM}/M^4_{mediator}$

Light Dark Matter

Light Dark Matter (<TeV) naturally introduces light mediators

New interaction

★ Definition of [adimensional] variable $y \sim g^2_{Dark}\, g^2_{SM}\, (M_{DM}/M_{mediator})^4 \sim \langle \sigma v \rangle\, M^2_{DM}$

$$\langle \sigma v \rangle \propto \epsilon^2 \alpha_D \frac{m_\varphi^2}{m_{A'}^4} = \epsilon^2 \alpha_D \frac{m_\varphi^4}{m_{A'}^4} \frac{1}{m_\varphi^2} = \frac{y}{m_\varphi^2}$$

Computed for $m_{A'}/m_{\varphi/X} = 3$

But thermal target
largely insensitive to this ratio