Beam Dump Experiments at JLab and SLAC

- Brief History (E137 at SLAC)
- BDX at Jefferson Lab
  - Detector and signal
  - Backgrounds
- Expected Sensitivity

Elton S. Smith, Jefferson Lab

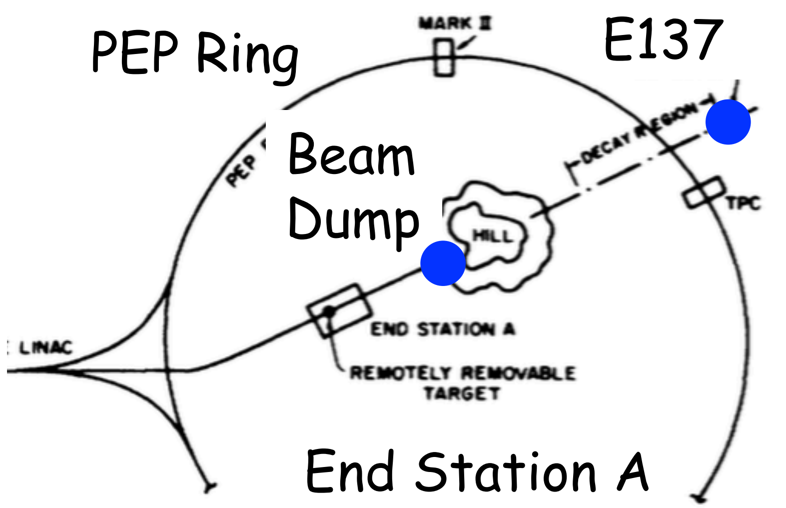
On behalf of the BDX Collaboration

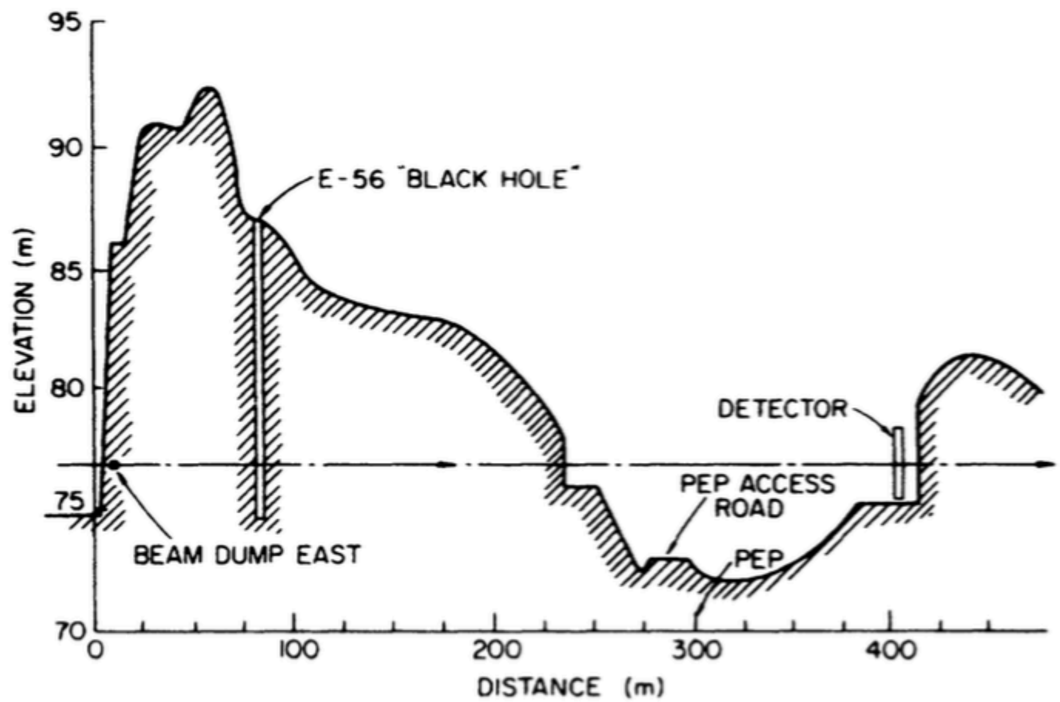
Light Dark Matter at Accelerators – *May 24-28, 2017*

SLAC E137 Beam Dump

"Search for neutral metastable penetrating particles"

- Axions
- Photinos
- EM calorimeter and multi-wire proportional chambers
- Masses < 100 MeV, small production σ, long lifetime



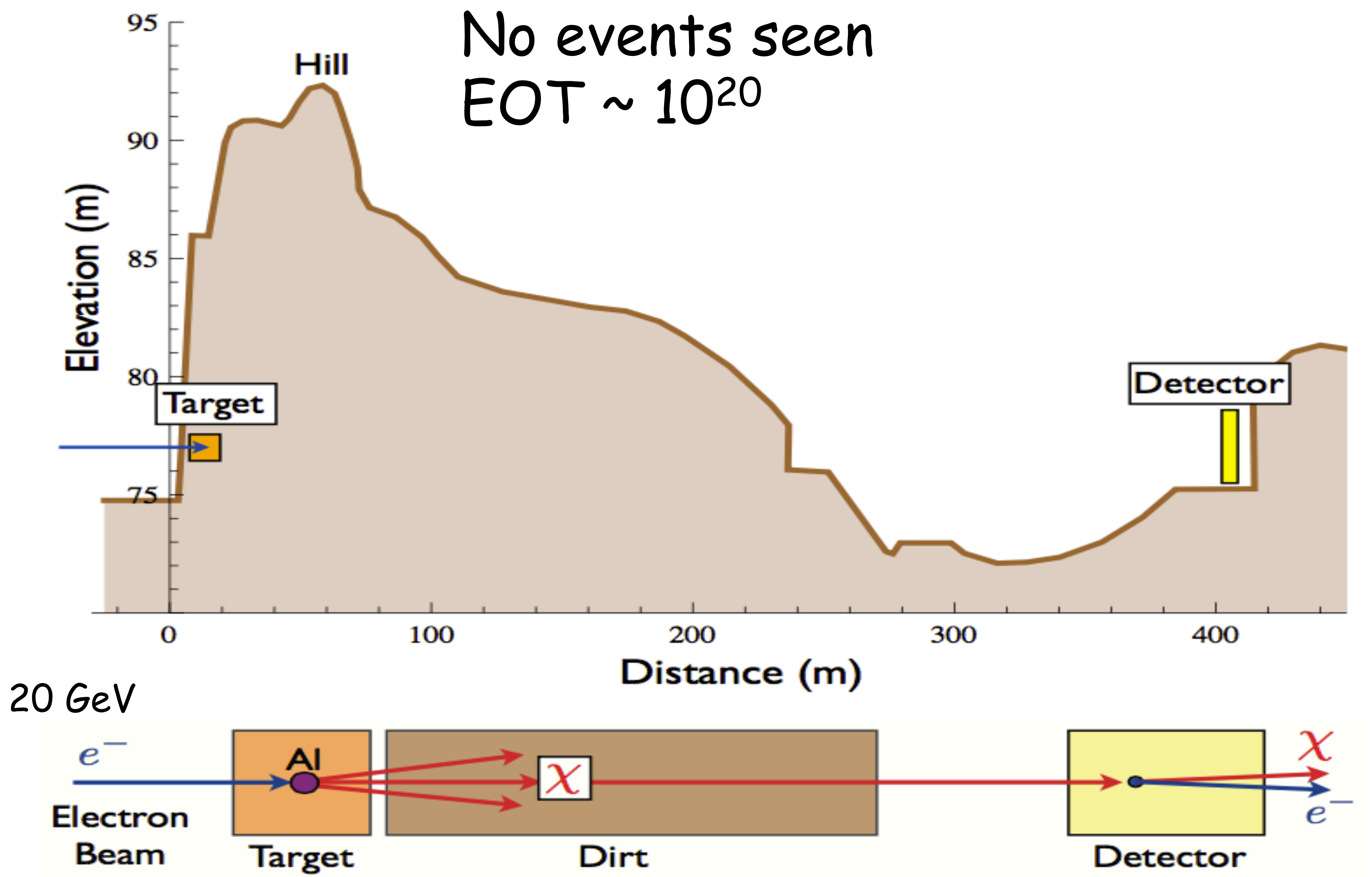


Bjorken PRD 38 (1988) 3375

FIG. 2. Layout of SLAC experiment E137.

SLAC E137 – LDMA limits

No events seen
EOT ~ 10^{20}



Battel PRL 113 (2014) 171802

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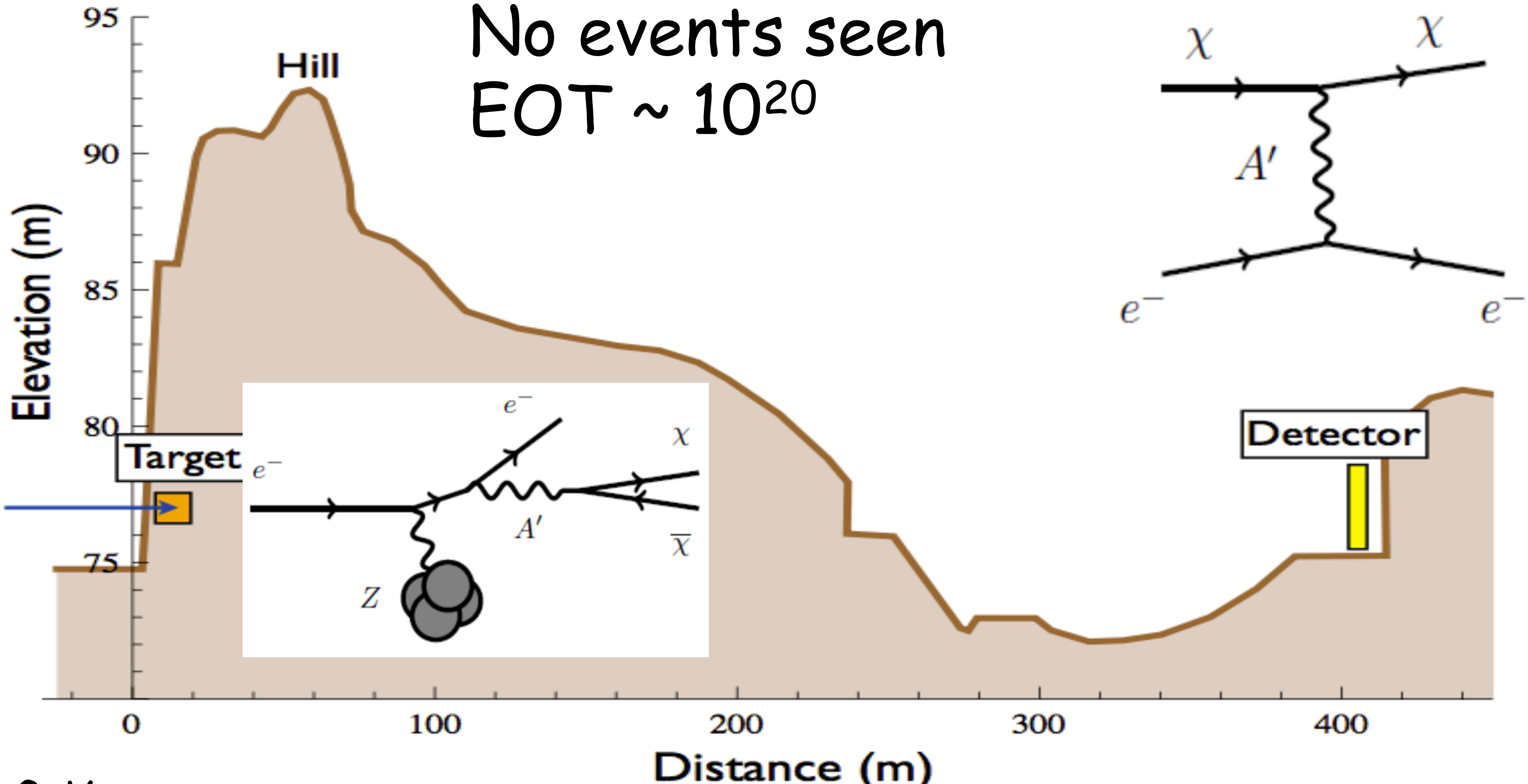
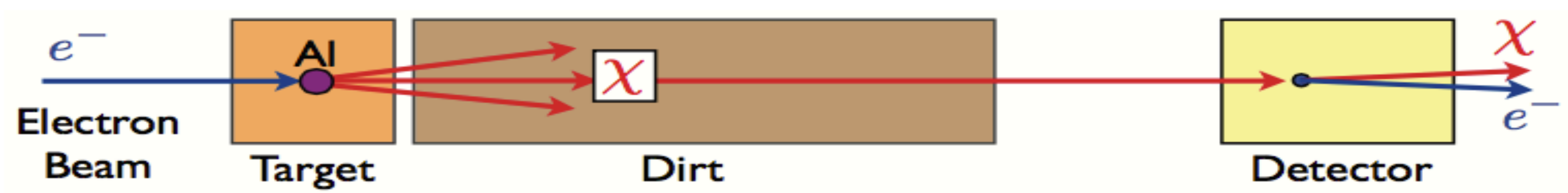


20 GeV



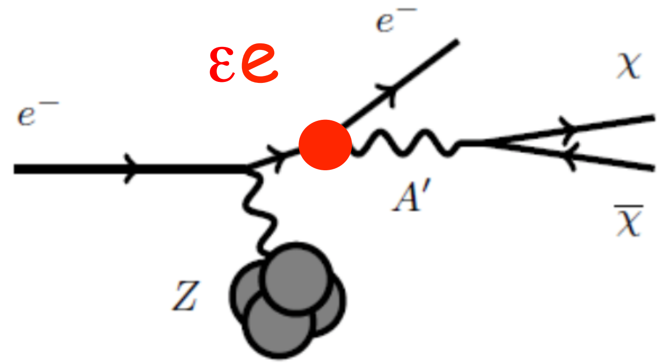
Battel PRL 113 (2014) 171802

Beam Dump Experiments

Izaguirre PRD 88 (2013) 114015

- Parasitic to experimental program. Use electrons that are otherwise thrown away
- Produce "invisible decays" of heavy photon (Beam Dump)

$$A' \to \chi\overline{\chi}$$

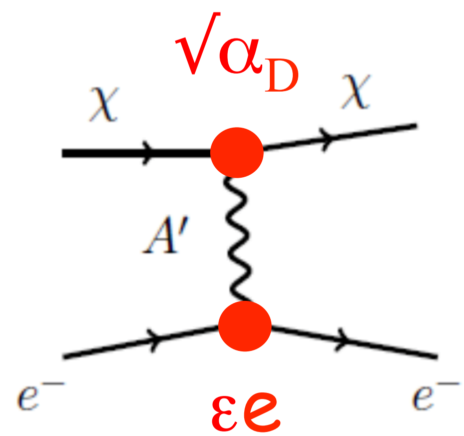


- Detect dark matter particle interaction (Experiment Detector)
- Signature is EM shower E > 0.5 GeV

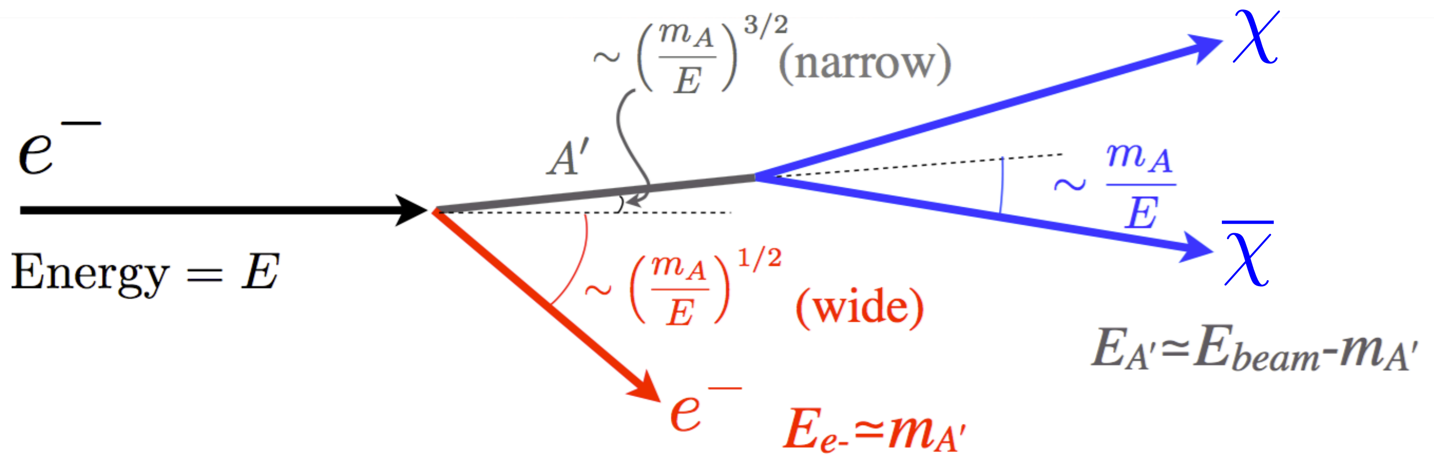
$$y = \epsilon^2 \alpha_D (m_\chi / m_{A'})^4$$

$$\text{Yield} \sim y^2 \times \frac{1}{\alpha_D} \times \left(\frac{m_{A'}}{m_\chi}\right)^4$$

$(m_{A'} > 2\, m\chi)$

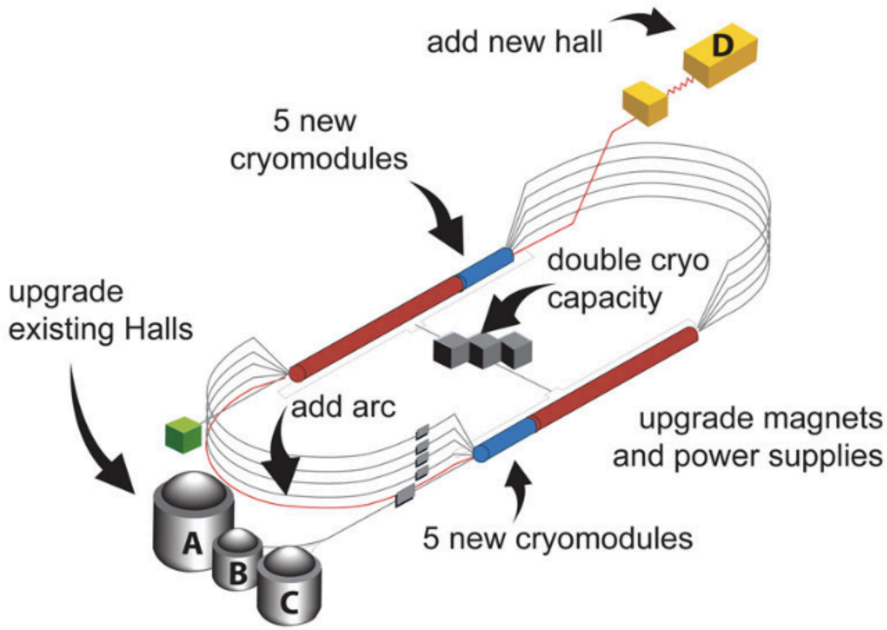


Kinematics



- Main features follow from thin-target kinematics and e^- energy loss and secondary emission in dump
- A' emitted with forward kinematics, $E_{A'} \sim E_{beam}$
- High-energy χ beam strongly focused along primary beam direction
- e- in dump: lower electrons in shower contributes broadening of χ kinematics
- χ-e^- elastic scattering detected in detector with $E_{shower} > 0.5$ GeV

Jefferson Lab site

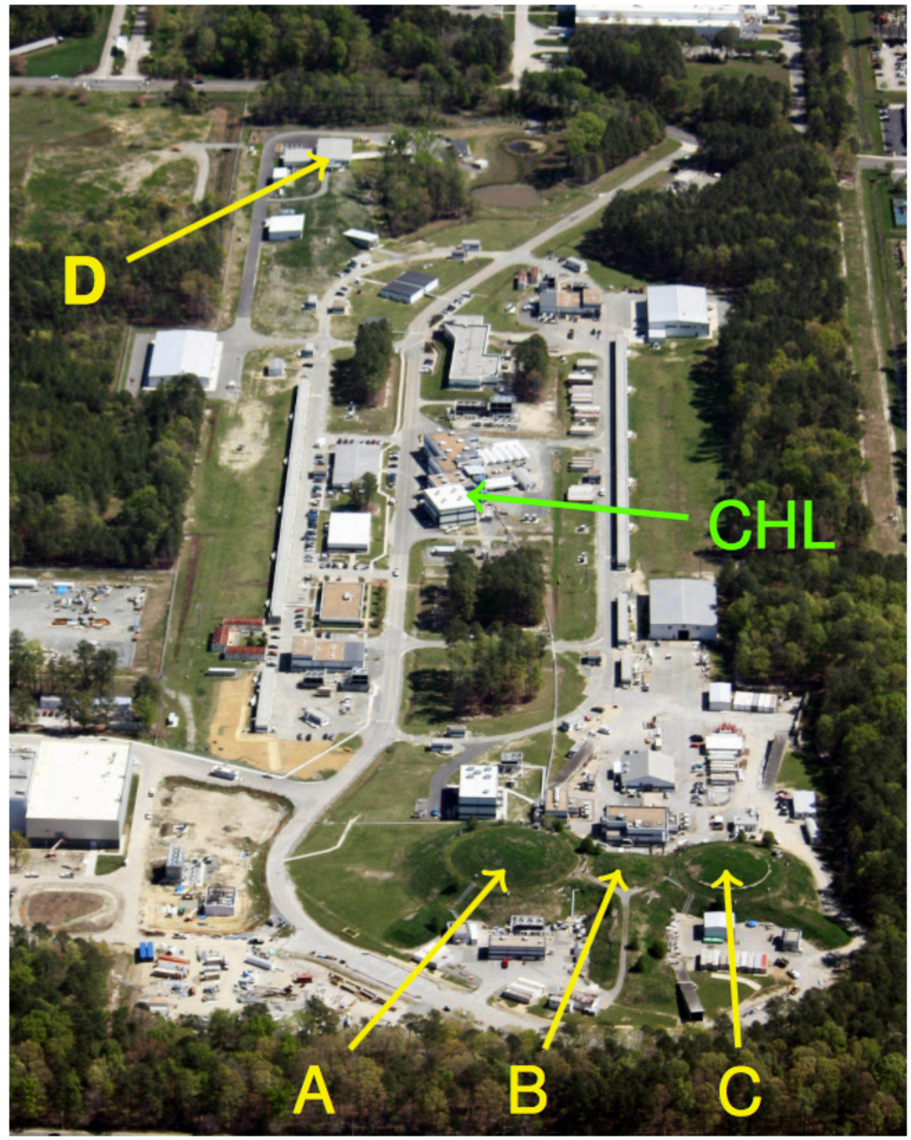


Upgrade Goals

- Accelerator: 6 GeV $\Rightarrow$ 12 GeV
- Halls A,B,C: e^- $<$11 GeV, $<$ 100 μA
- Hall D: e^- 12 GeV $\Rightarrow$ γ-beam

Upgrade Status

99.7% Complete



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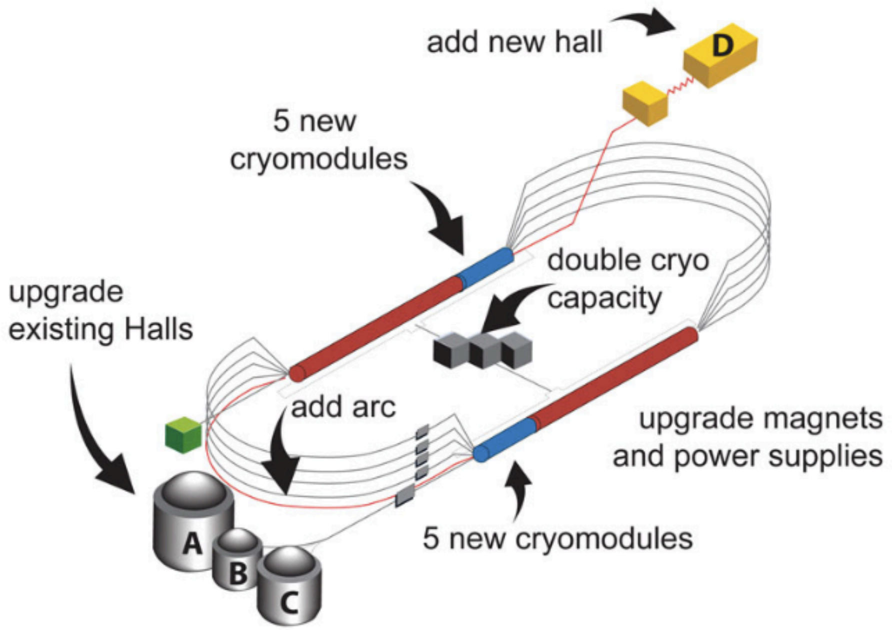

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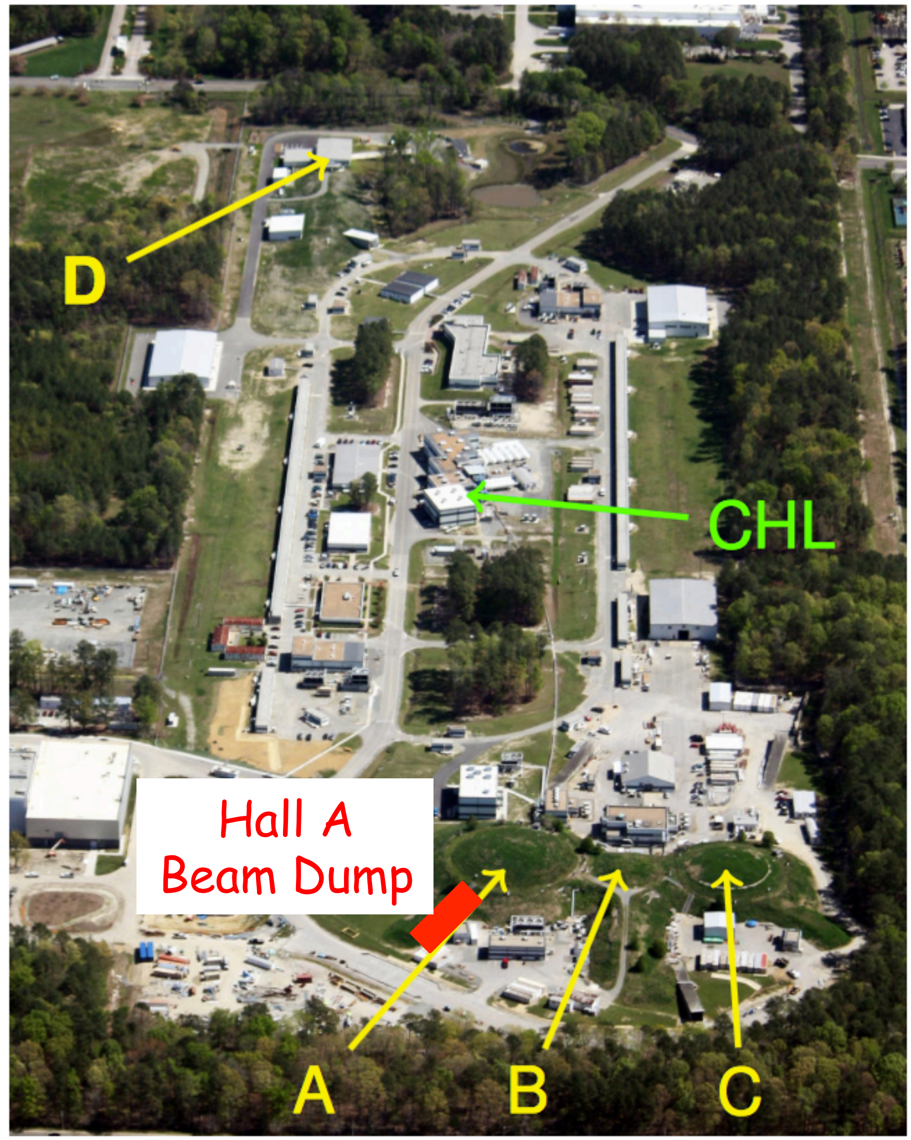
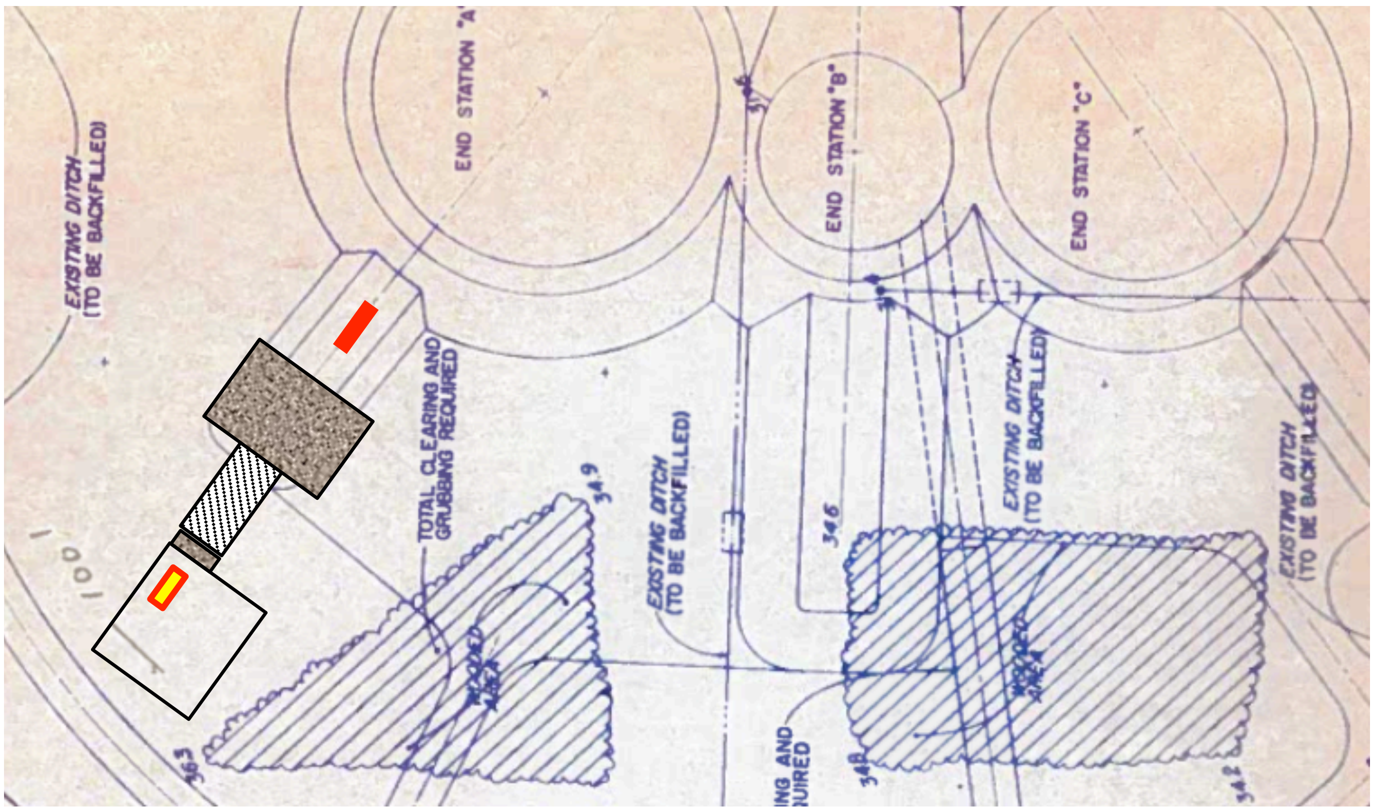


Location of BDX at JLab

- Highest beam current ~ 65 μA
- Integrated charge ~ 10^{22} EOT (41 weeks)
- E_{beam} up to 11 GeV
- New underground facility ~$1.5M



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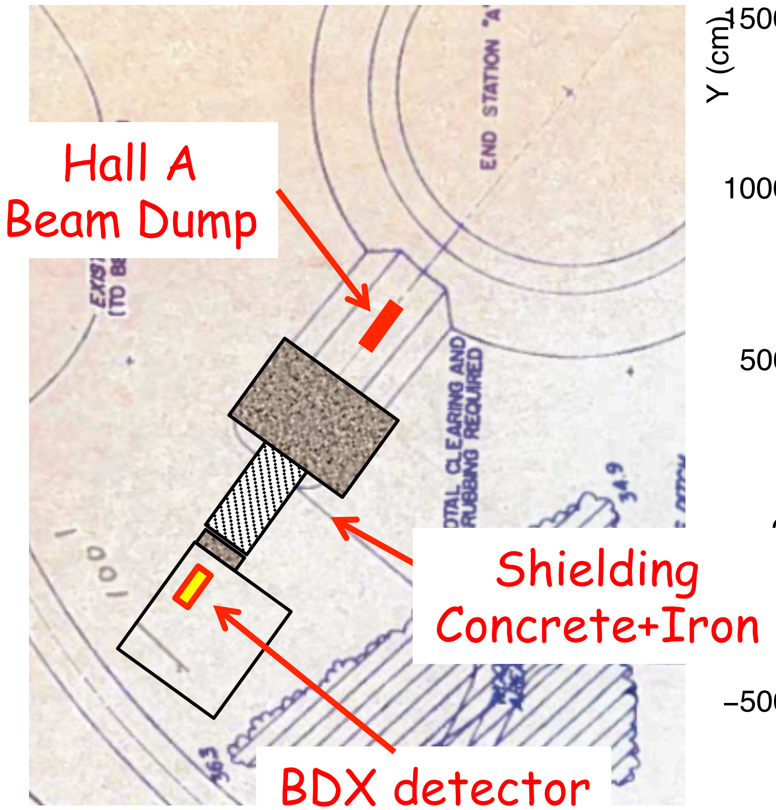
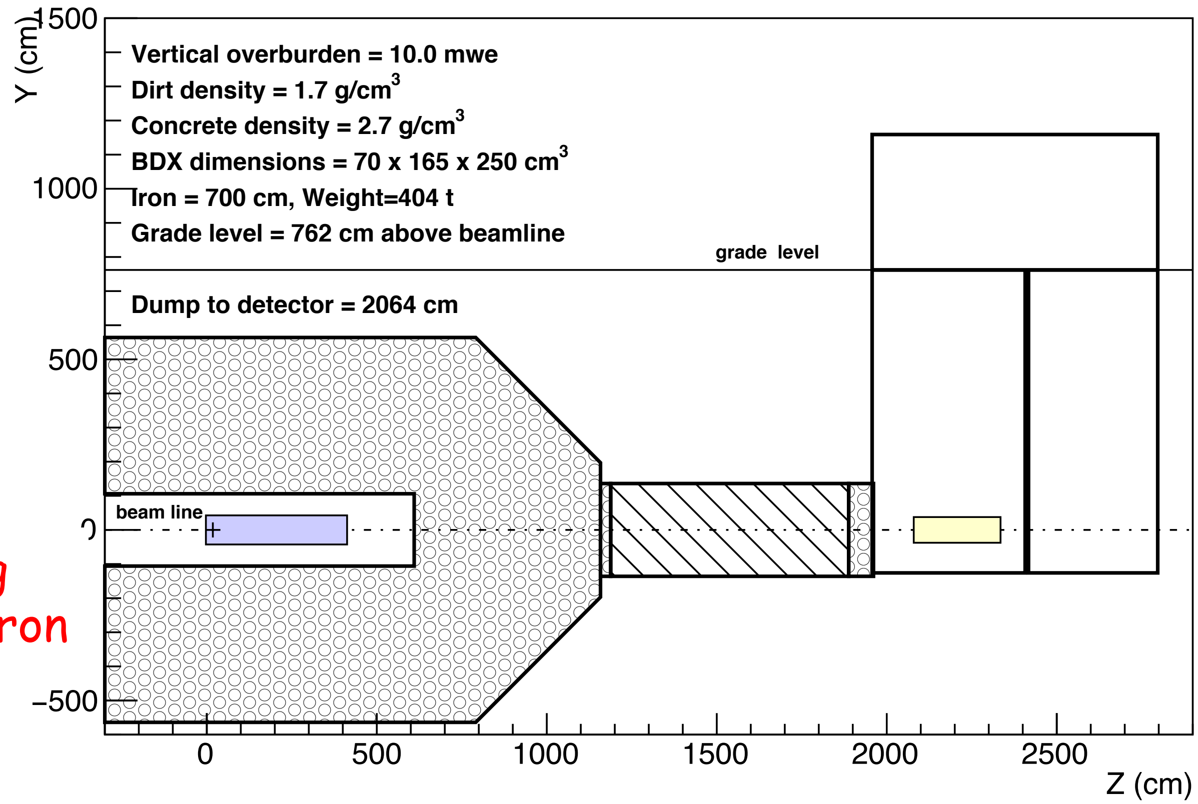




Detector

- Signal requirements
  - Sensitivity to GeV EM showers
  - Low thresholds
  - Compact footprint and good segmentation
- Background rejection
  - High efficiency, fast timing
  - Active veto
  - Passive veto

Crystal based detector

Plastic scintillator
Lead
Plastic scintillator

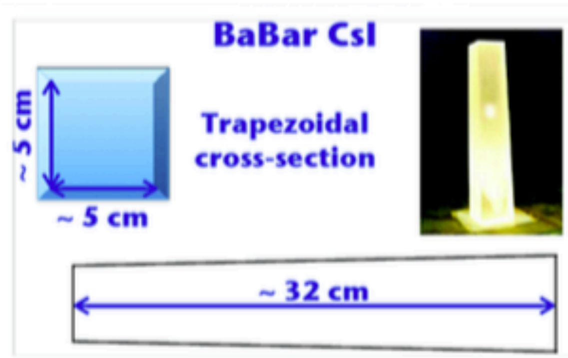
- BUT… multiple detectors can be stacked behind each other!
- Add complementarity with DRIFT
  - Completely different technology and sensitivities
  - Directionality

See this session: Dan Snowden-Ifft

BDX inner detector

BDX detector: state-of-the-art EM calorimeter, CsI(Tl) crystals with SiPM-based readout.
Possibility to re-use existing BaBar CsI(Tl) crystals (informal agreement already discussed)
Detector design:

- $\simeq$ 800 CsI(Tl) crystals, total interaction volume $\simeq 0.5m^3$
- Modular detector: change front-face dimesions and total lenght by re-arranging crystals

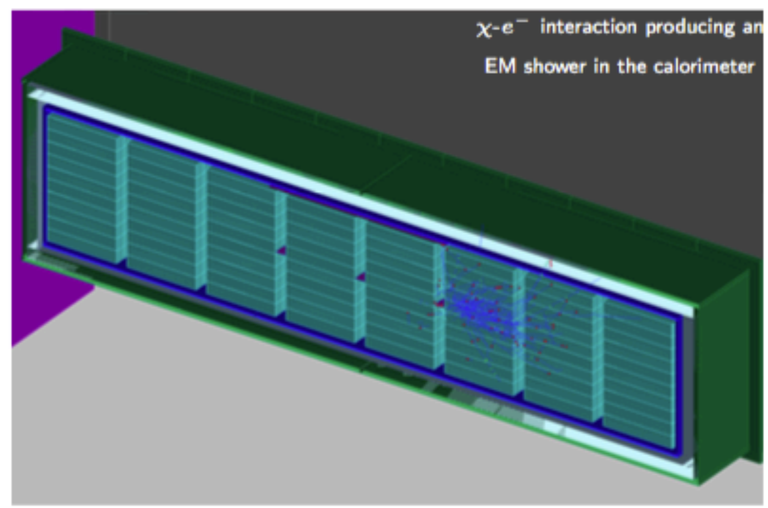


Arrangement:

- 1 module: 10x10 crystals, 30-cm long. Front face: 50x50 cm^2
- 8 modules: interaction length 2.6 m

Signal:

- EM-shower, $E_{thr} \simeq 300$ MeV, anti-coincidence with IV and OV
- Efficiency (conservative): O(10%) - refined cuts on EM shower directionality can improve this



A. Celentano

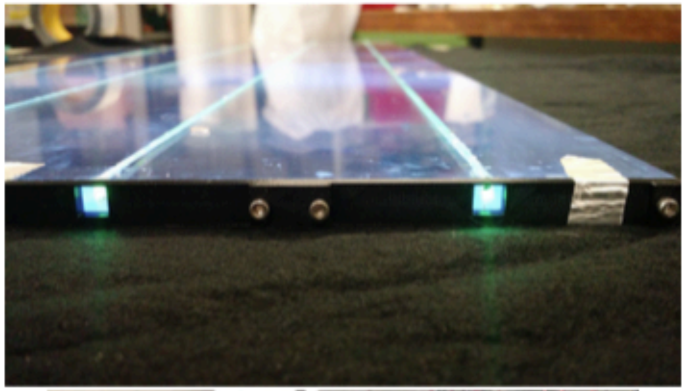
BDX active veto

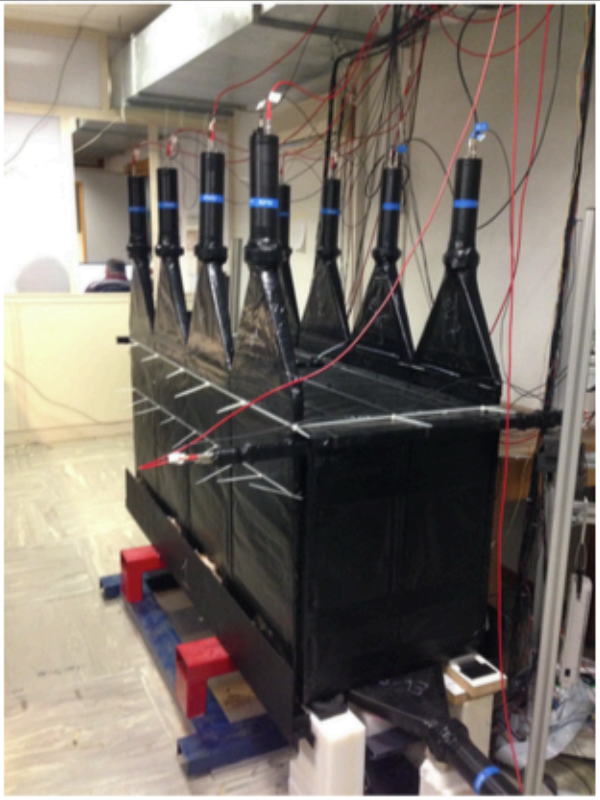
Active veto requirements: high efficiency for charged particles detection, hermeticity, compactness

Technology: two layers of plastic scintillator counters, made of different paddles, each read by WLS fibers + SiPMs (IV) / PMTs (OV). 5-cm lead vault between two layers to shield photons

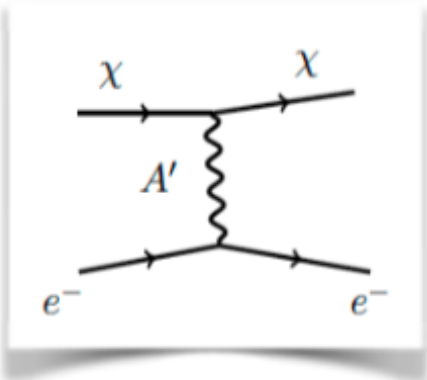
R&D:

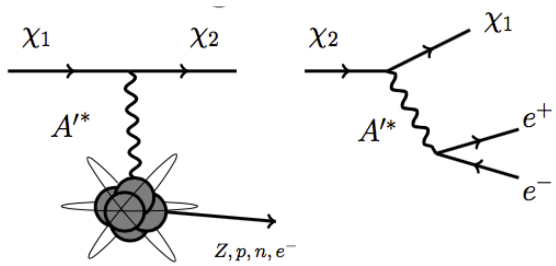
- Veto efficiency for charged particles measured with cosmics-ray setup, in different positions: $\bar{\varepsilon} > 99\%$
- On-going effort to replace light guides by slim wavelength-shifting plastics to reduce dead spaces and simplify mechanical supports

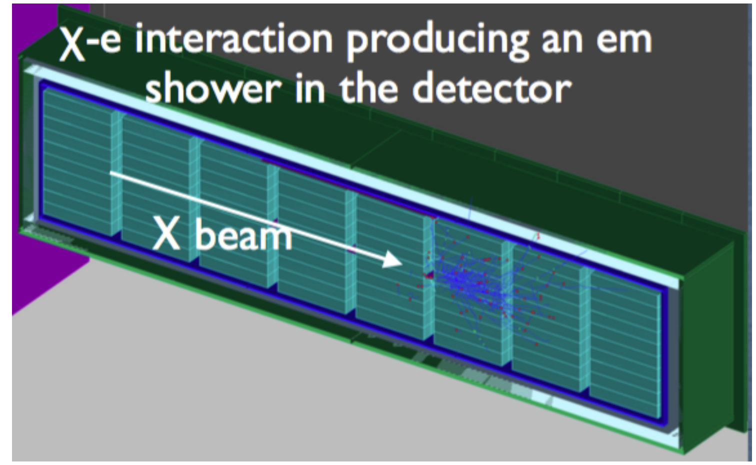


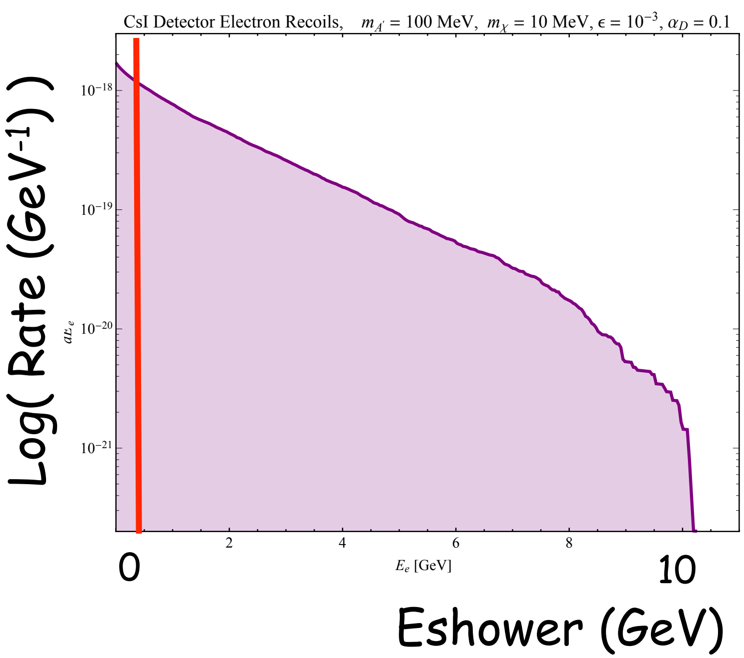


Signal: χ interaction in detector





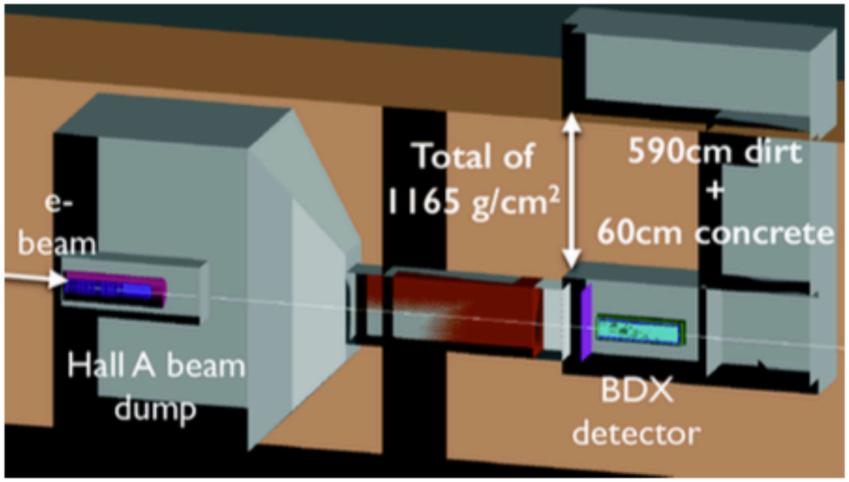


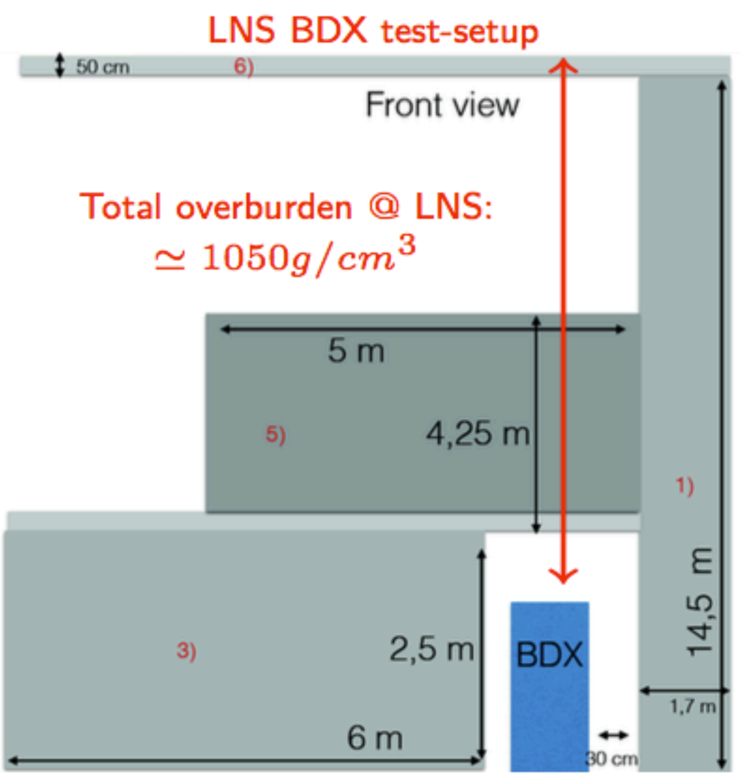


Signal Efficiency ~ 20% for E_{thresh} > 0.3 GeV

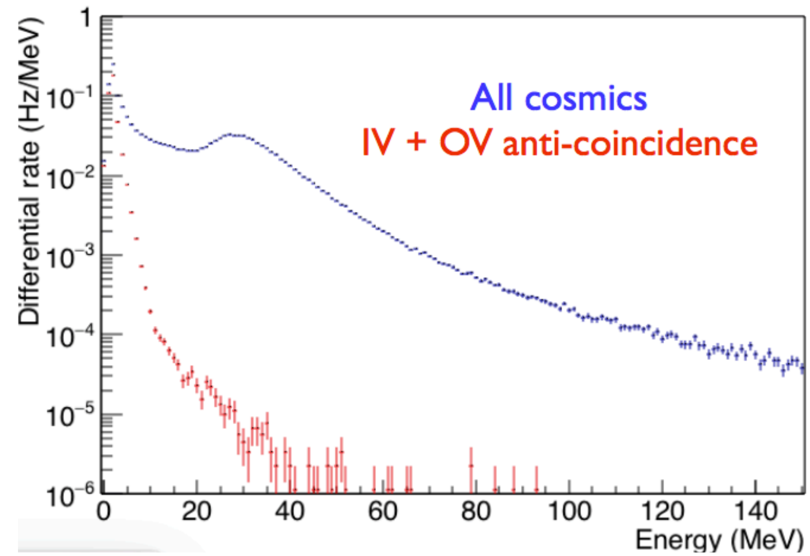
Parameters:
M_χ=10 MeV, $m_{A'}$=100 MeV

Cosmic-ray Backgrounds

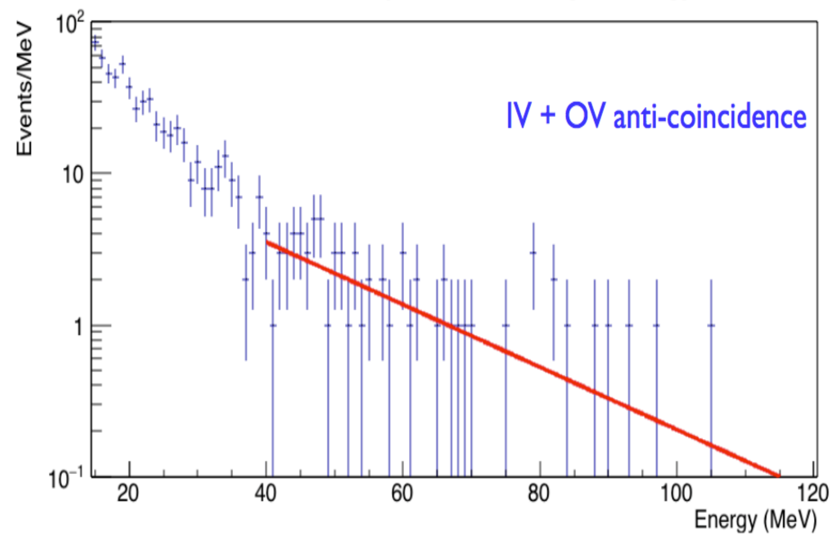




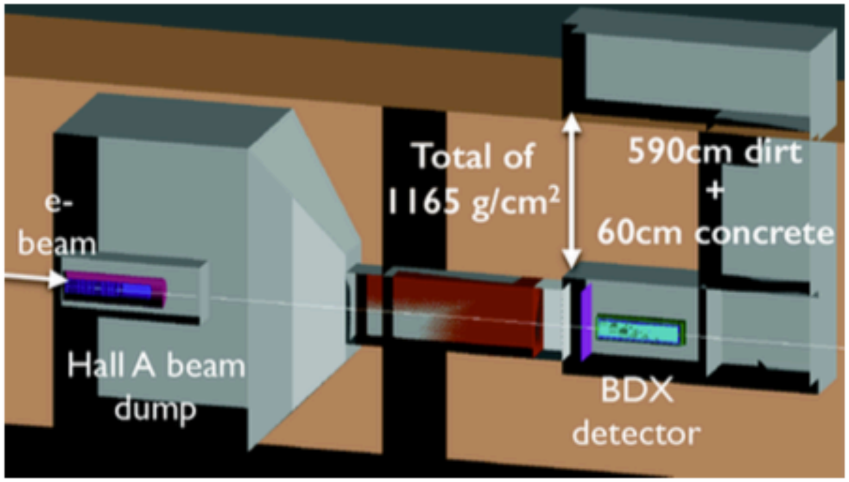
Count rate measured in 1 crystal



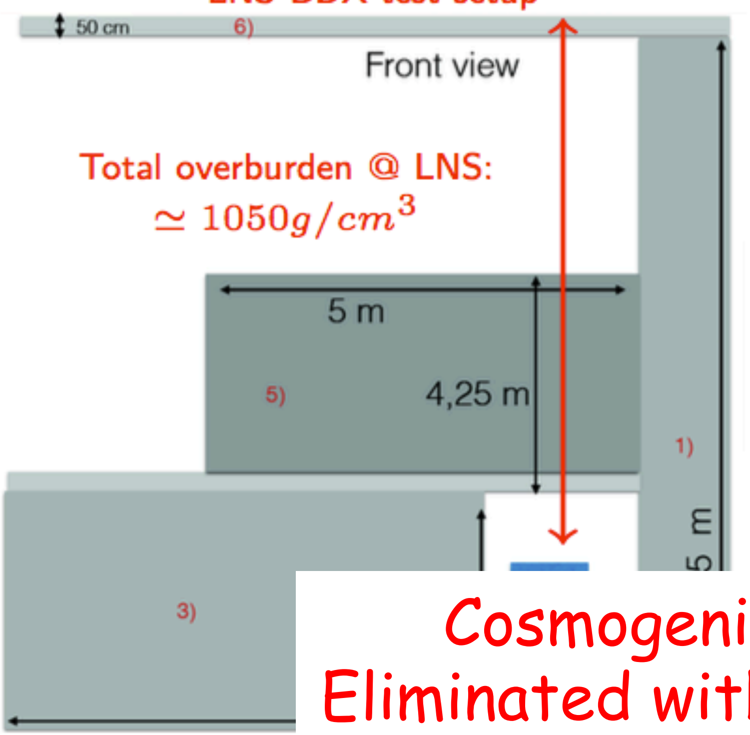
Count rate extrapolation to high energy



Cosmic-ray Backgrounds



LNS BDX test-setup



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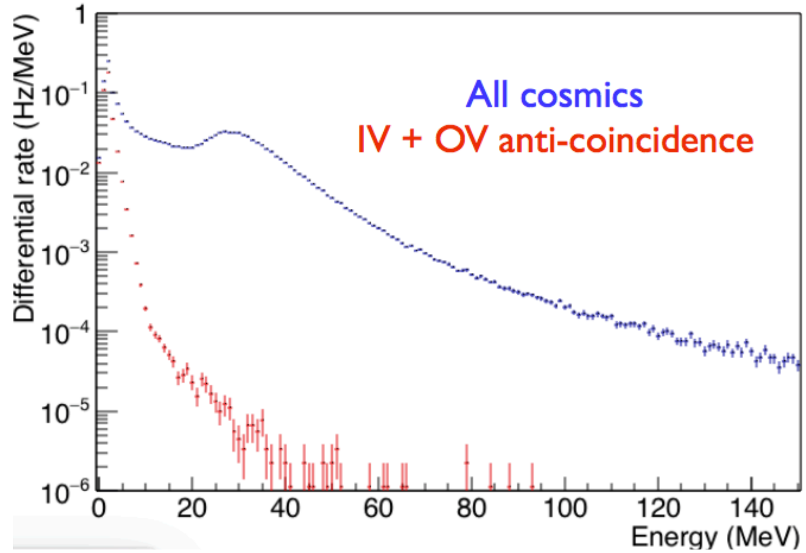

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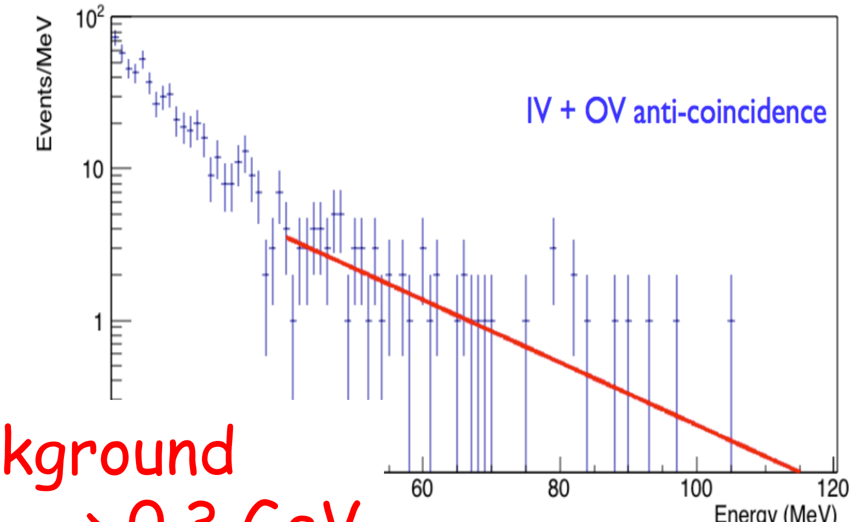
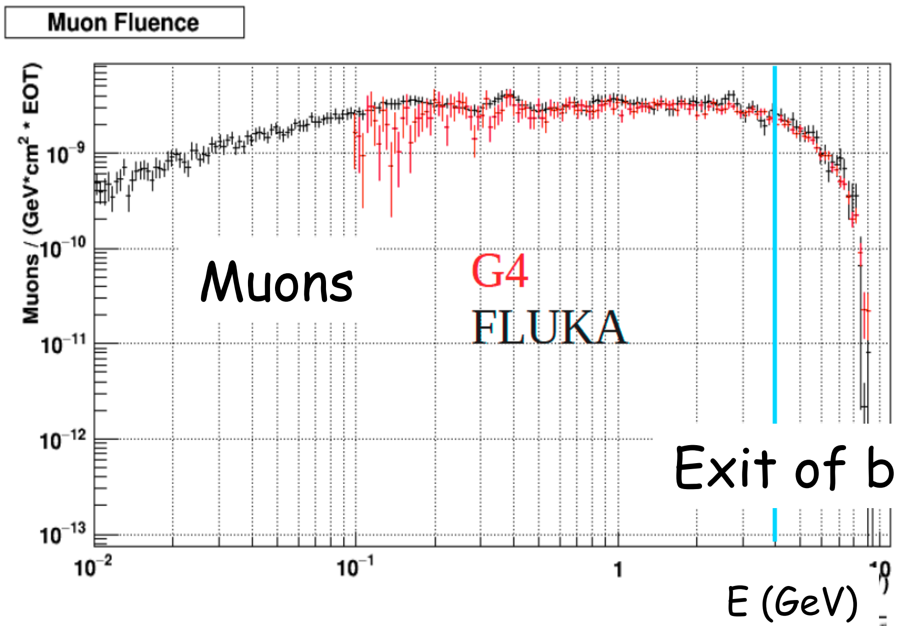
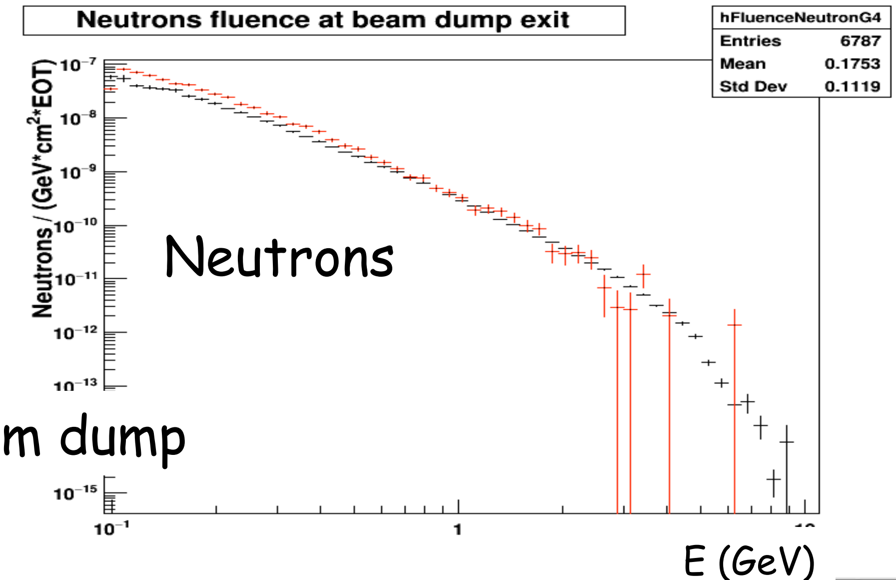


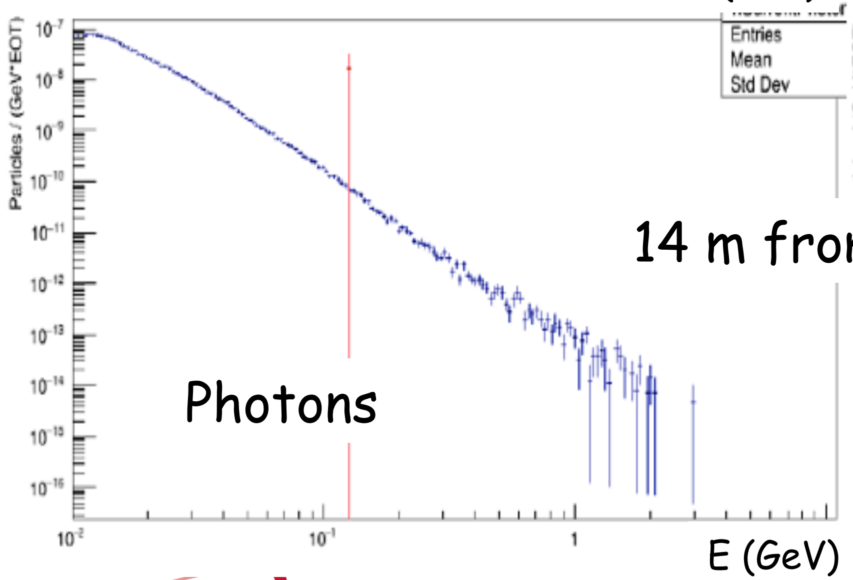
Cosmogenic Background
Eliminated with E_{thresh} > 0.3 GeV

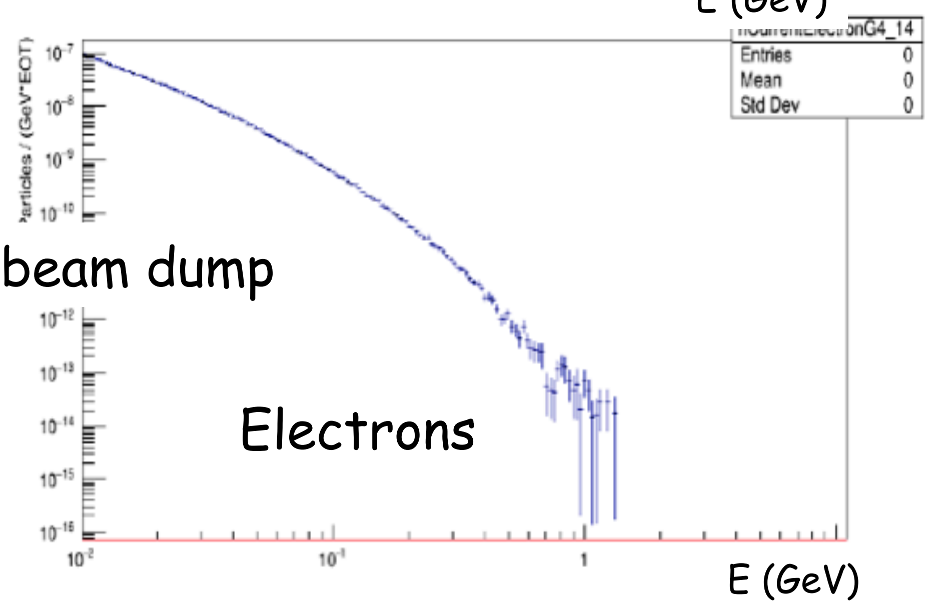
Detector simulations (GEANT4 and FLUKA)





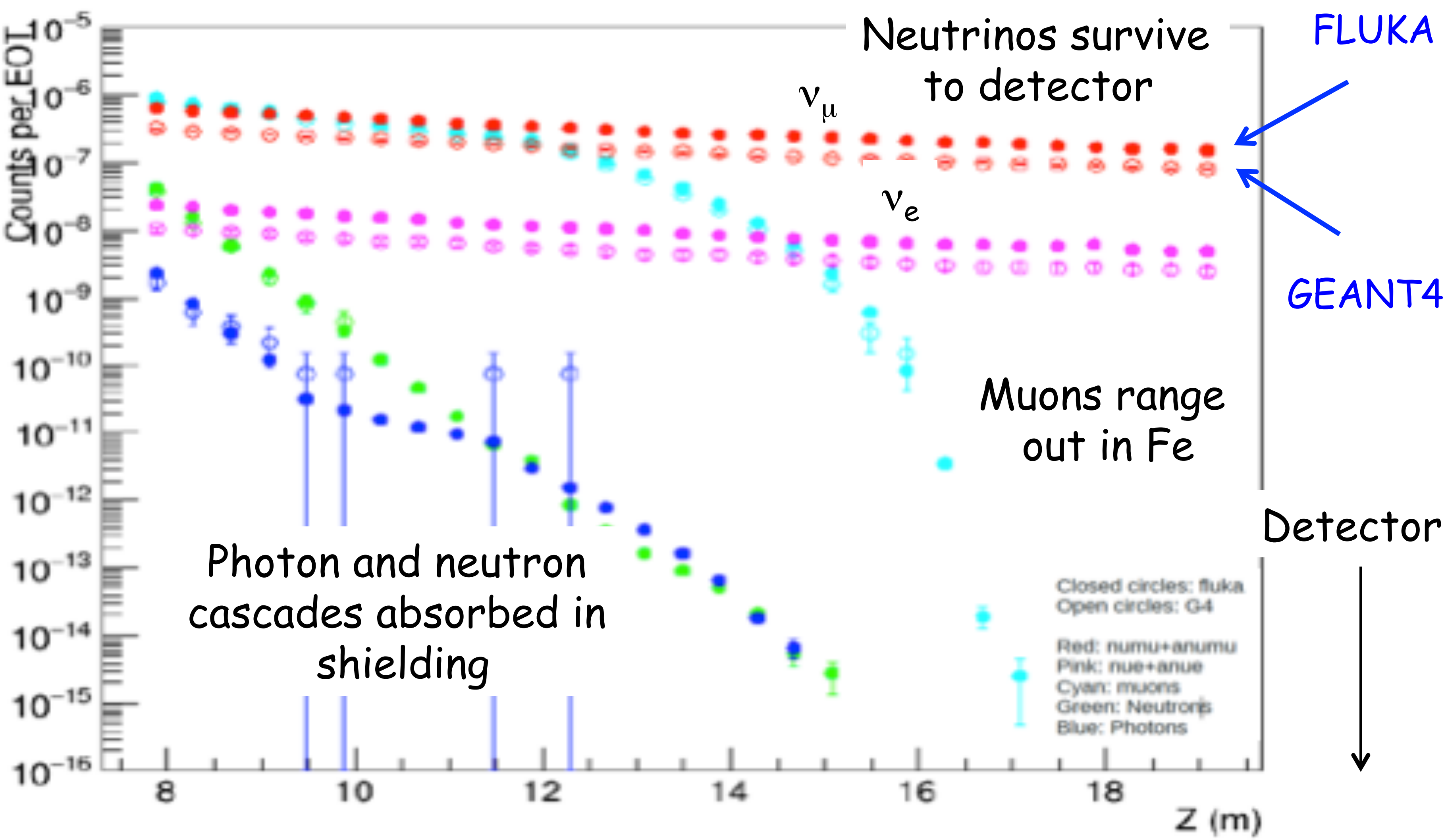
Exit of beam dump



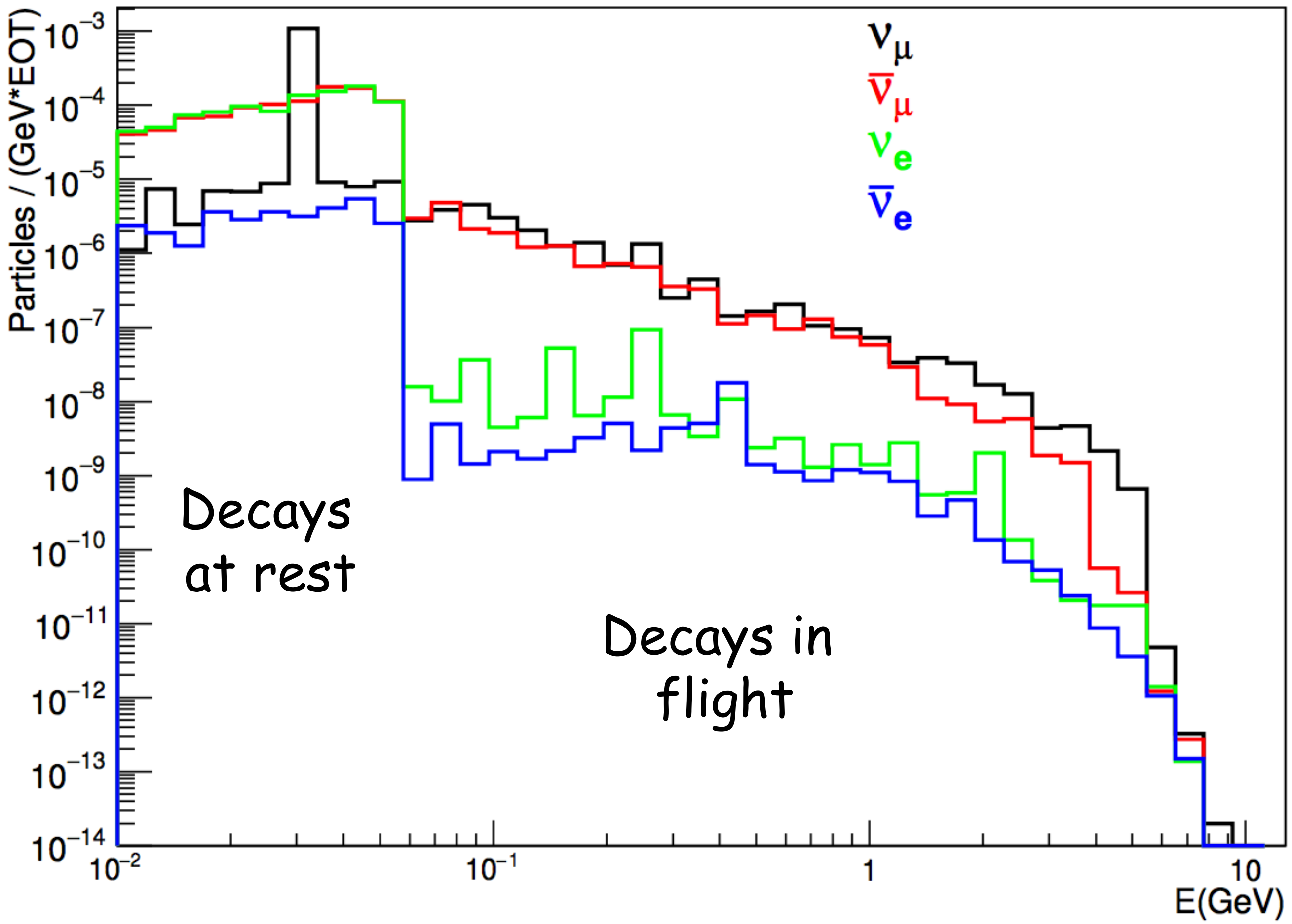


14 m from beam dump

Beam Backgrounds



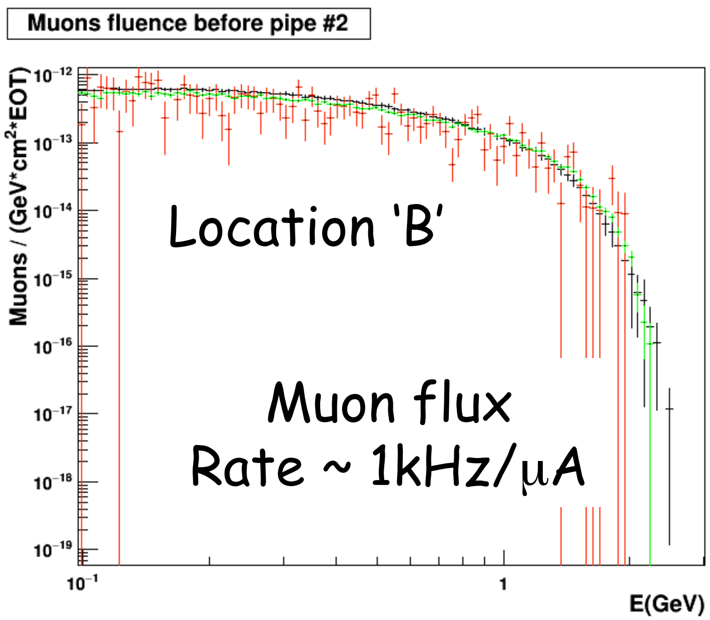
Estimated neutrino fluxes at the detector

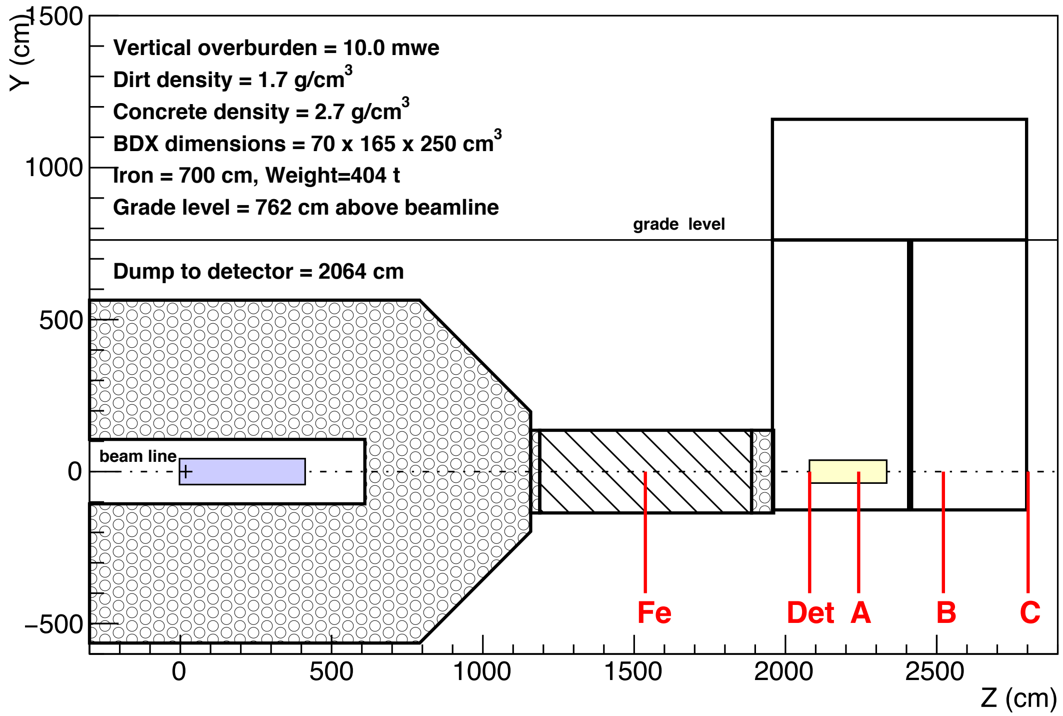


- Expect < 10 ν_e background interactions for 10^{22} EOT
- There are 10 times more ν_μ interactions, but they are identifiable and can be used to normalize the ν rate.

Test plan to measure muon flux

- We have a test plan to measure the muon flux behind the existing Hall A beam dump.
- The measurements will validate MC and help understand backgrounds





Background summary

- Cosmic-ray Backgrounds
  - Measured (beam-off) and subtracted
  - Several meters of overburden
  - Time uncorrelated (CW beam prevents fast time coincidence)

Cosmic sensitivity

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

Solution: Measurements with BDX prototype and expected overburden, extrapolation to Jlab. Measured during experiment and beam-off

- Beam-related Backgrounds
  - Detection thresholds define the background level
  - Charged particles easy to shield, neutrals more difficult
  - Low-energy particles are below threshold

Beam-related background

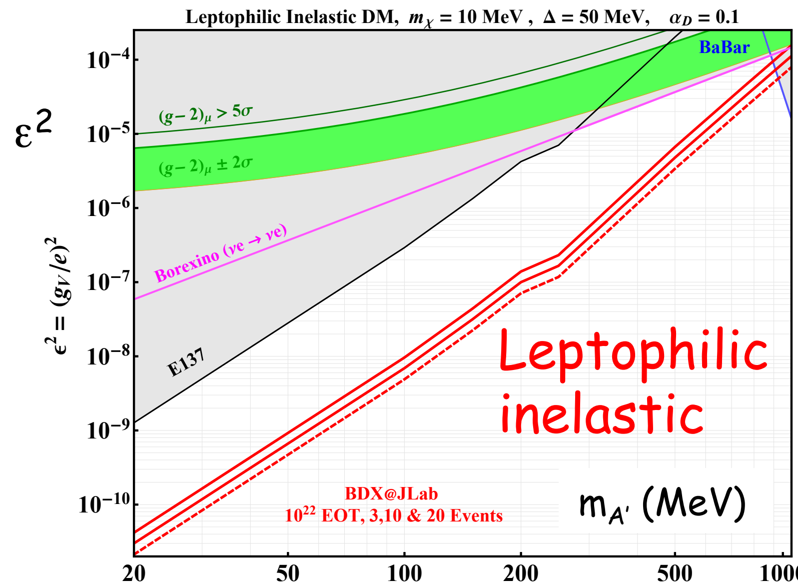
Energy threshold	N_ν (285 days)
300 MeV	~10 counts

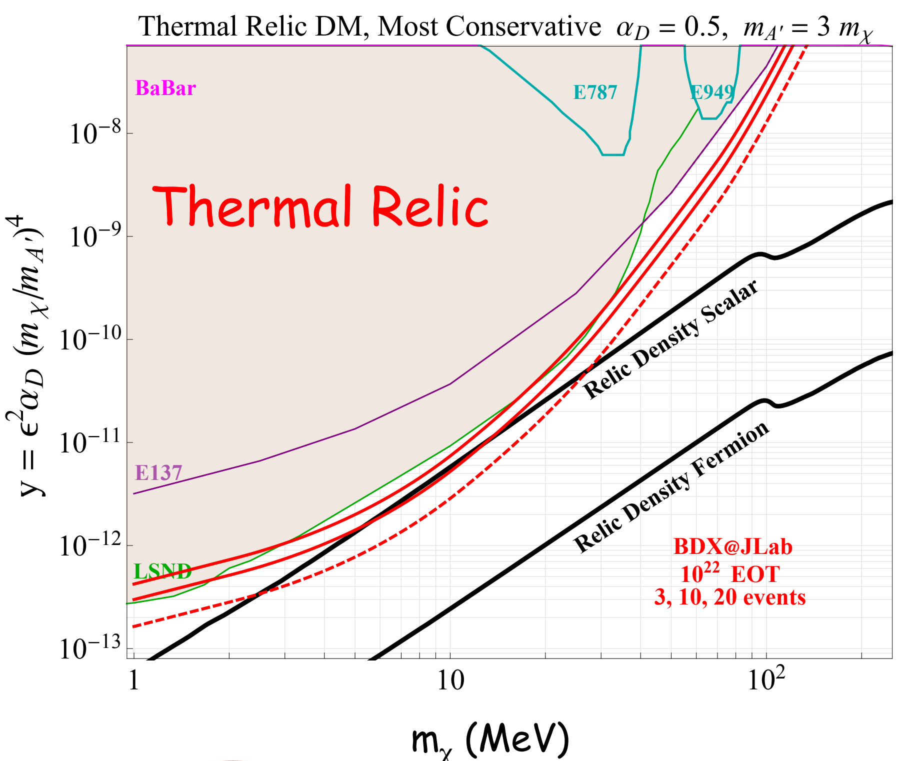
Solution: Heavy Shielding
Simulations for irreducible backgrounds

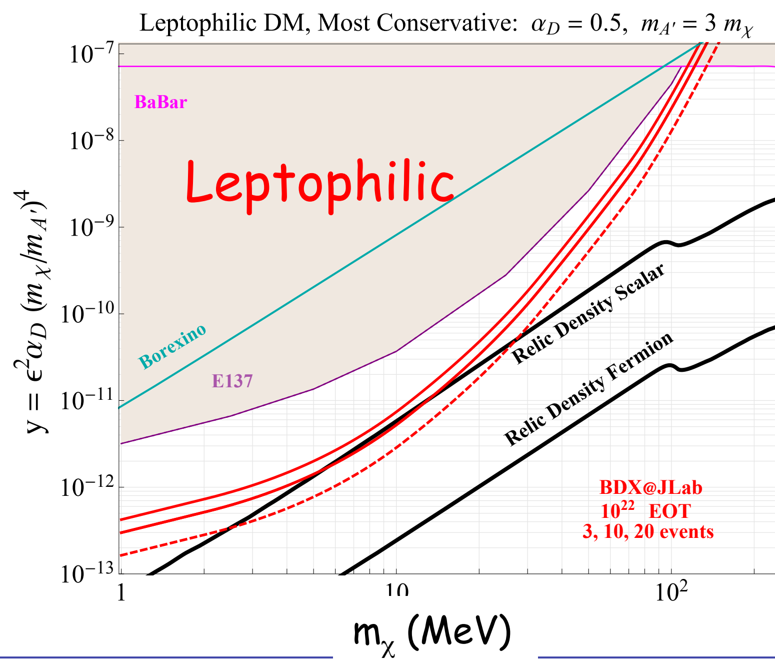
For E_{thresh}>0.3 GeV ν are ultimate background

BDX Reach

- BDX can be conclusive for some Light Dark Matter scenarios
- The BDX sensitivity has been evaluated assuming 10^{22} EOT







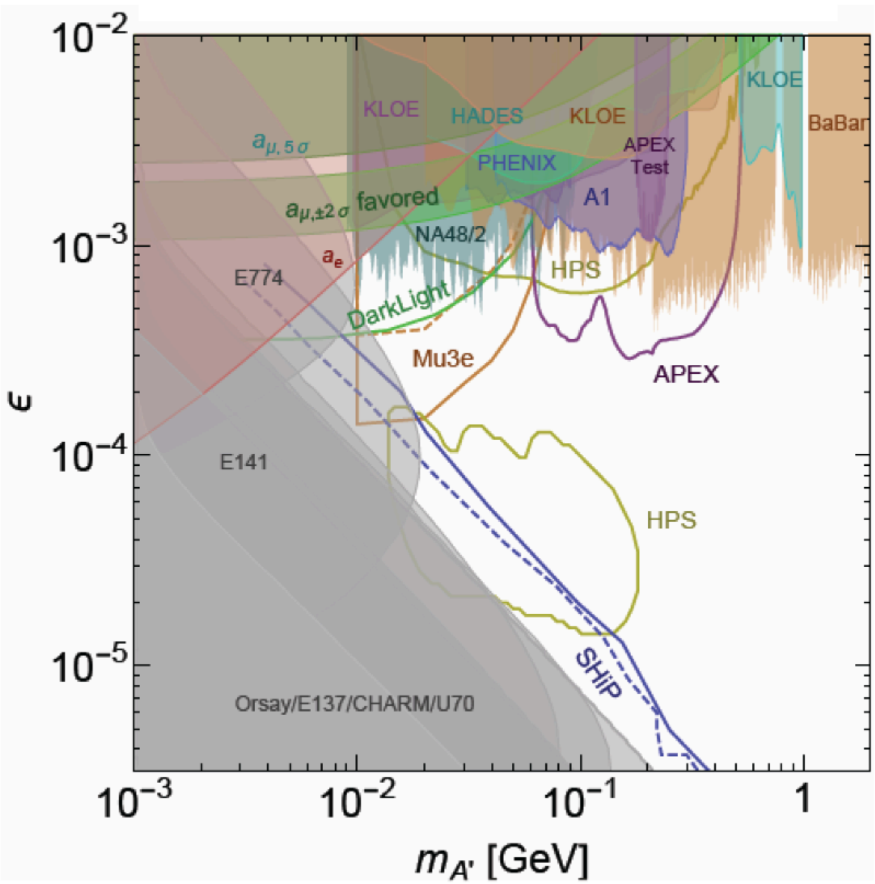
Summary and Status

- Beam-dump experiments are sensitive to invisible decays of dark photons, which probe regions of the parameter space that are not covered by visible decays.
- Beam-dump experiments at electron facilities have significantly reduced neutrino backgrounds compared to hadron beams
- 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.

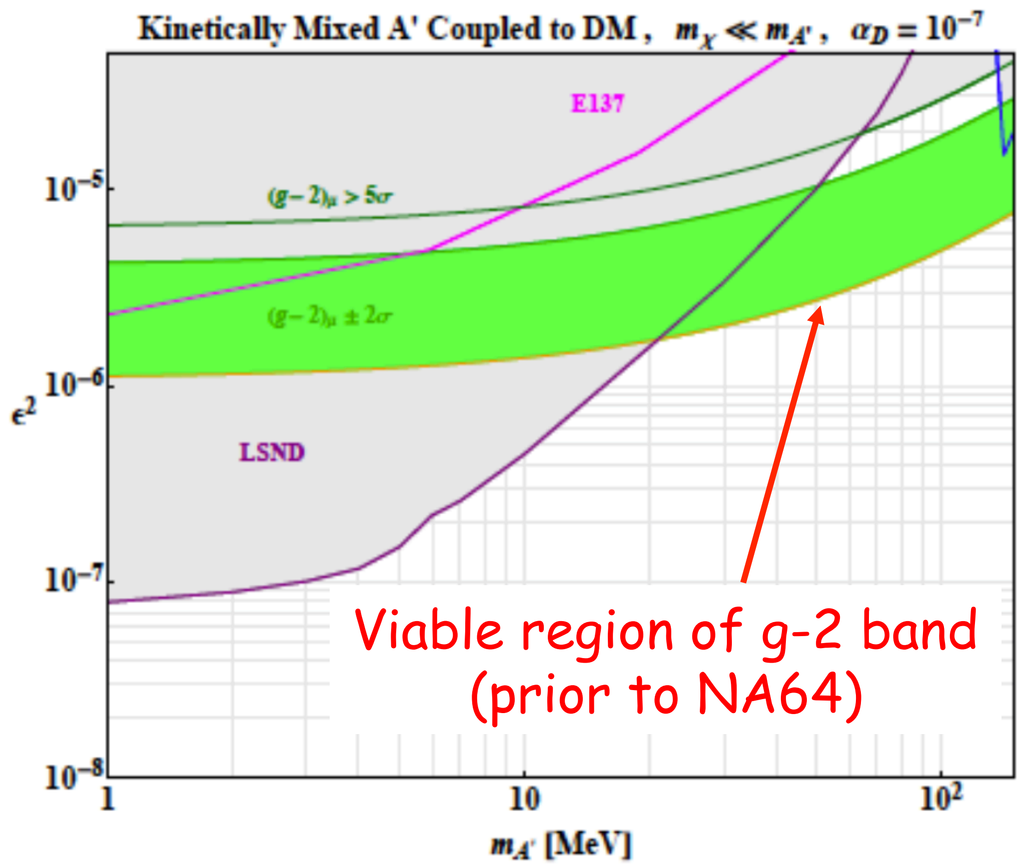
Backup Slides

Visible vs Invisible: Complementarity

Visible decay



Invisible decay



Invisible decay sensitivity

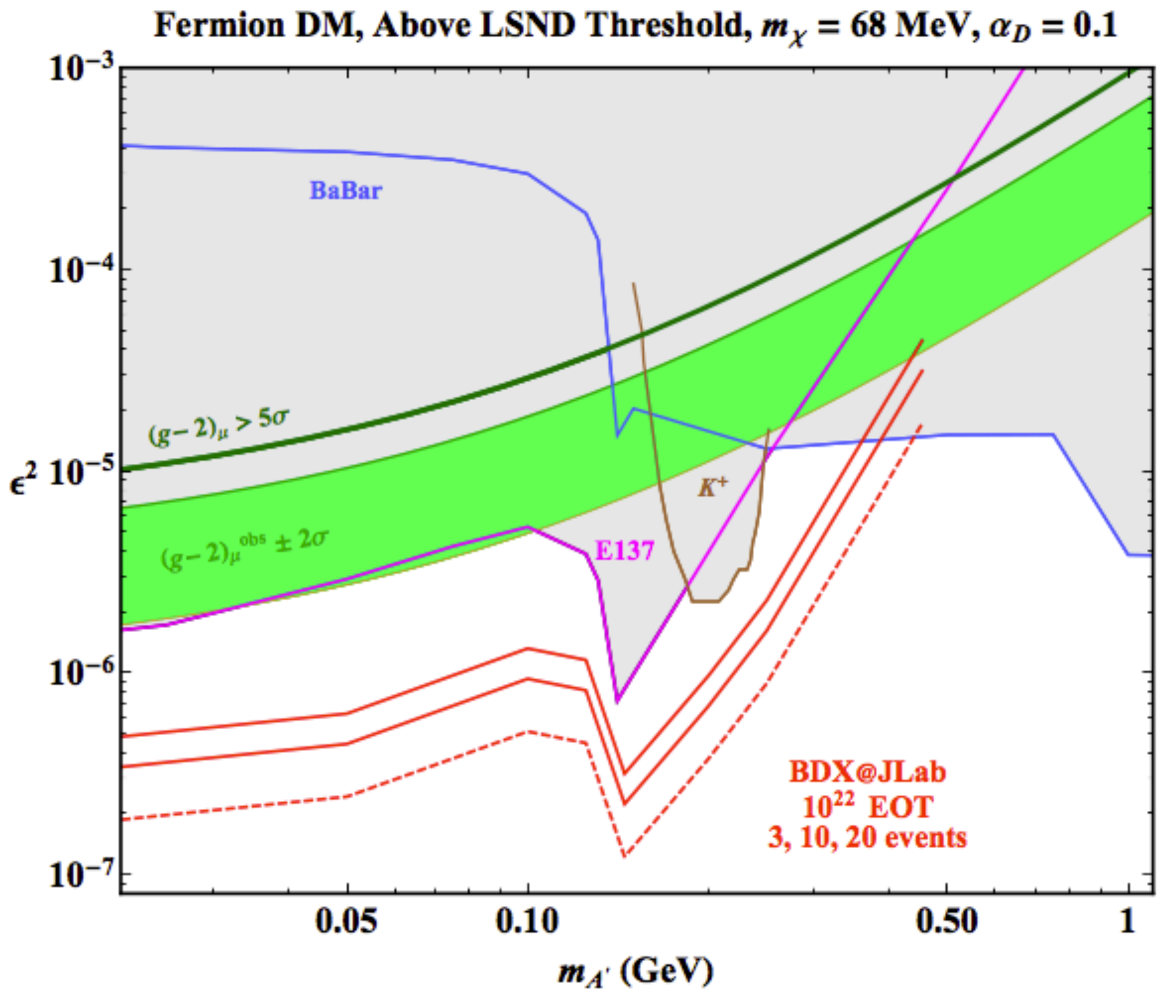


Figure 35: Same as Fig. 34 only here $m_\chi = 68$ MeV and we adopt $\alpha_D = 0.1$ and $\alpha_D = \alpha_{EM}$ for the two panels. This choice of m_χ represents the kinematic limit beyond which LSND can no longer produce pairs of χ via $\pi^0 \to \chi\chi$. Note that for $m_{A'} < 2m_\chi$ the dark photon will no longer decay to DM pairs and may be constrained by visible searches, but this is model dependent.

Inelastic DM scenario

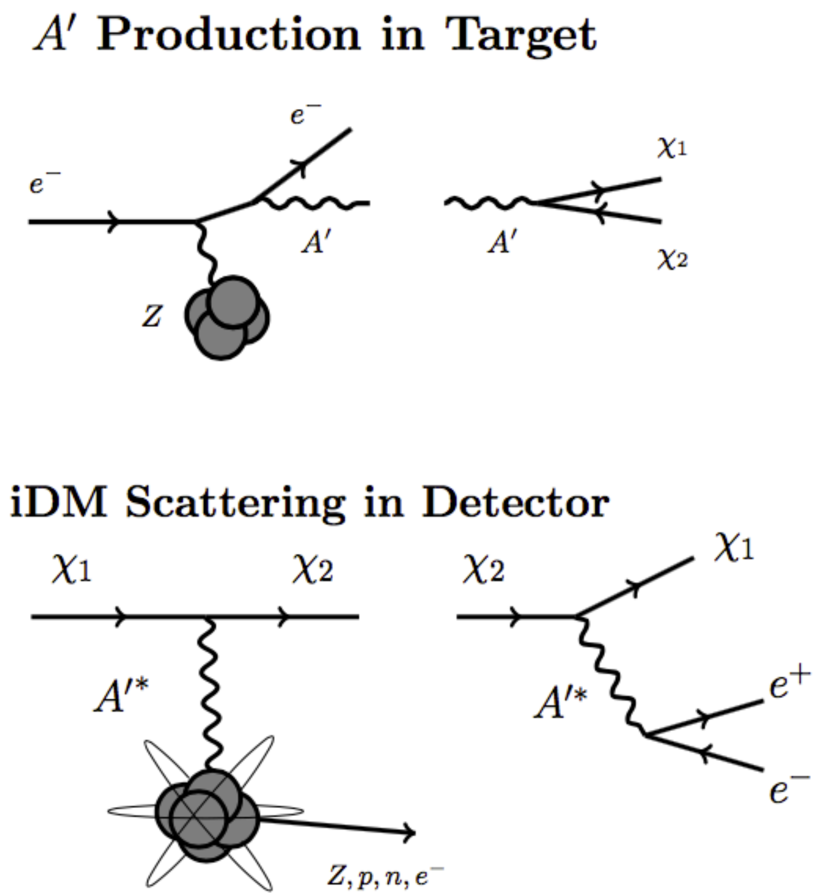
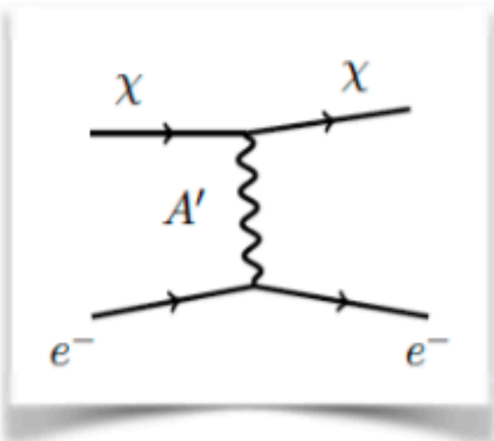
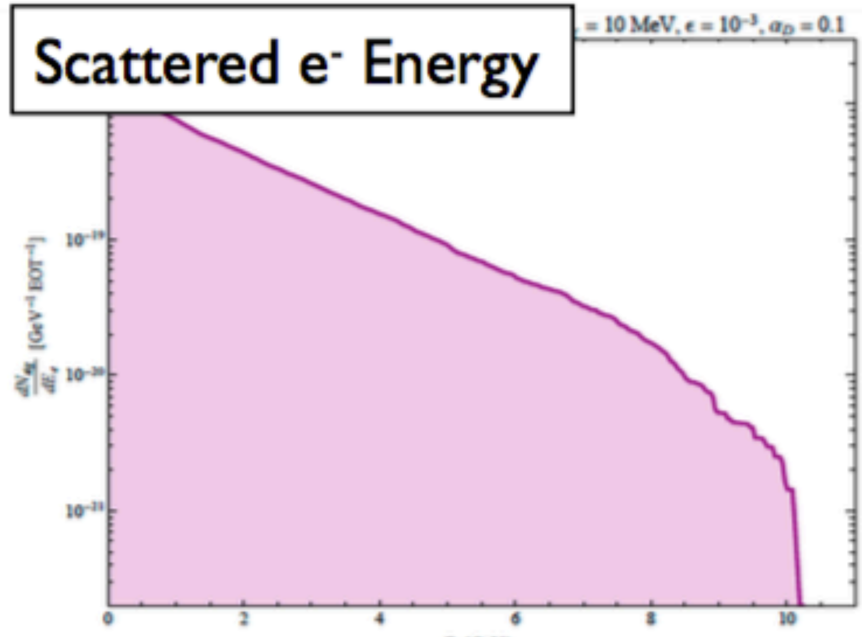


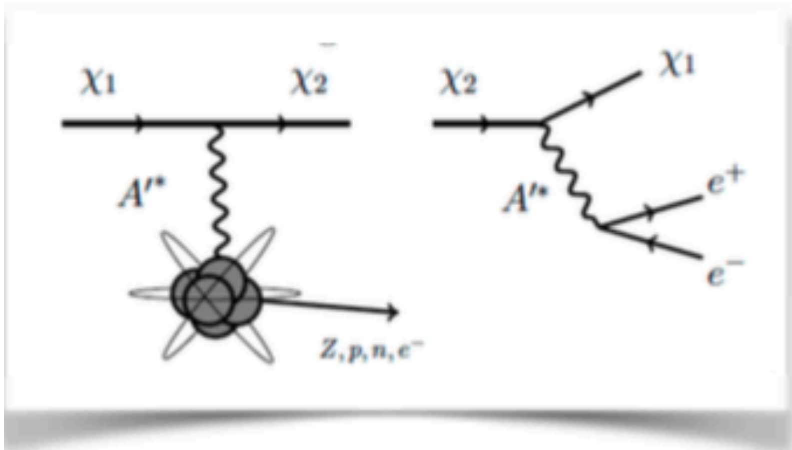
Figure 5: Top: Same as Fig. 2, but for an *inelastic* Majorana DM scenario in which the A' decays to a pair of different mass eigenstates. The unstable χ_2 decays in flight, so the flux at the detector is dominated by χ_1 states which upscatter off electron, nucleon, and nuclear targets (bottom) to regenerate the χ_2 state. Subsequently, the χ_2 promptly de-excites in a 3-body $\chi_2 \to \chi_1 e^+ e^-$ process, depositing significant $\sim$ GeV scale electromagnetic signal inside the BDX detector.

Signal detection

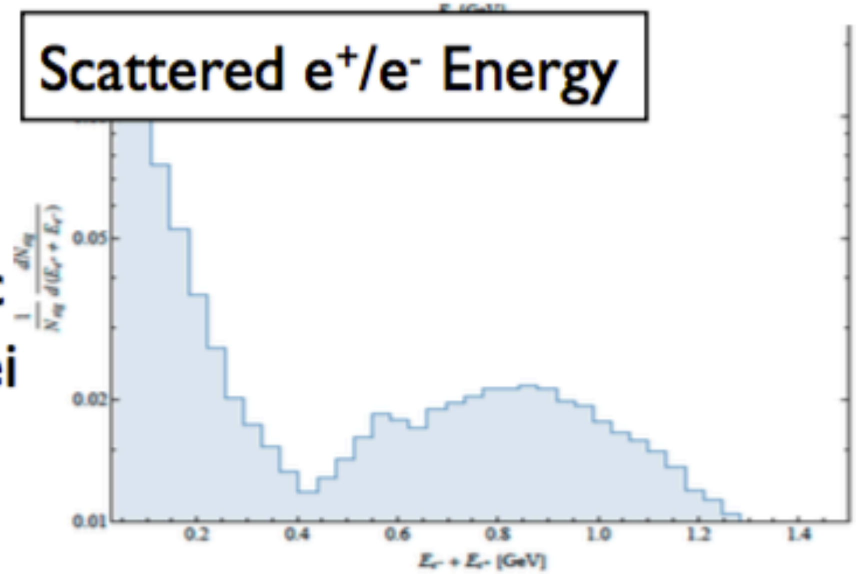


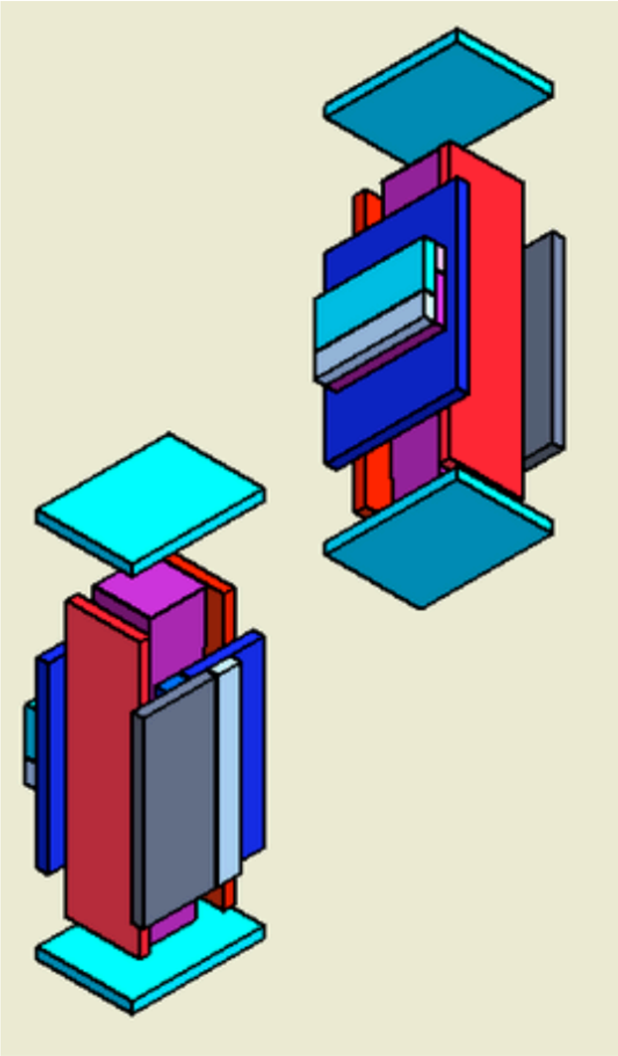
Elastic on electrons

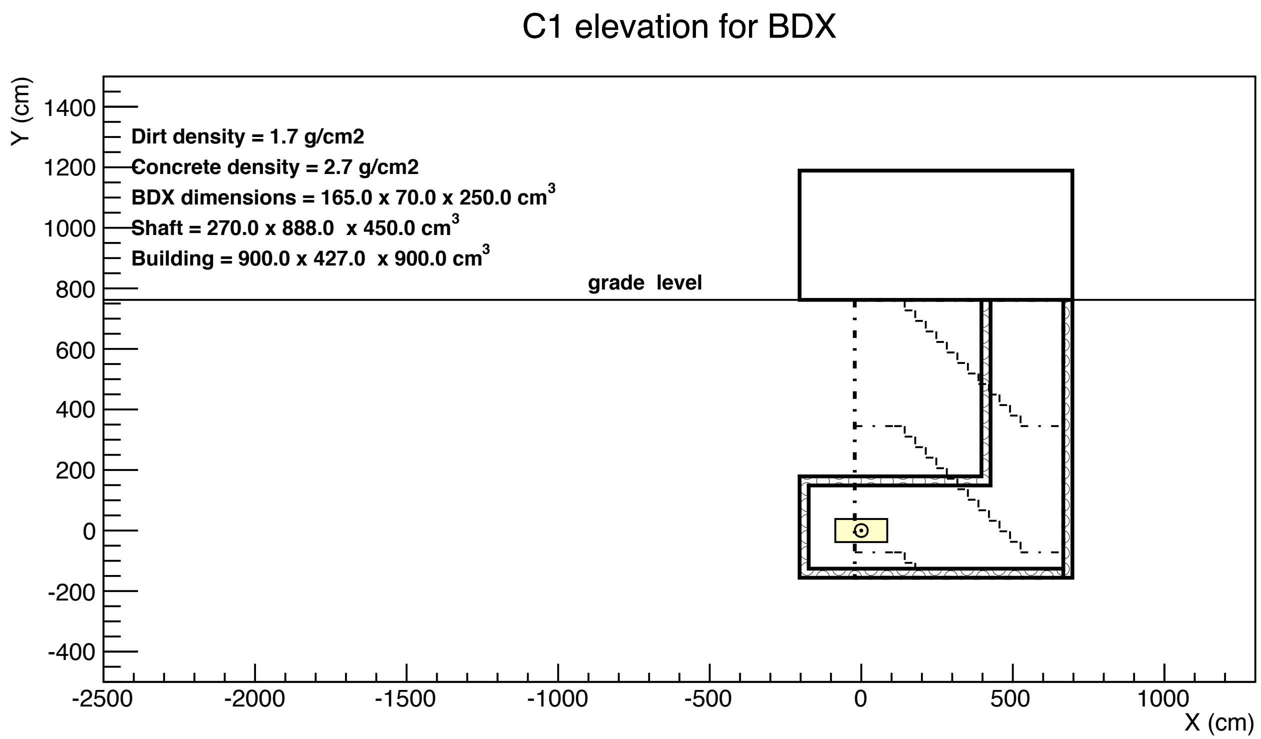


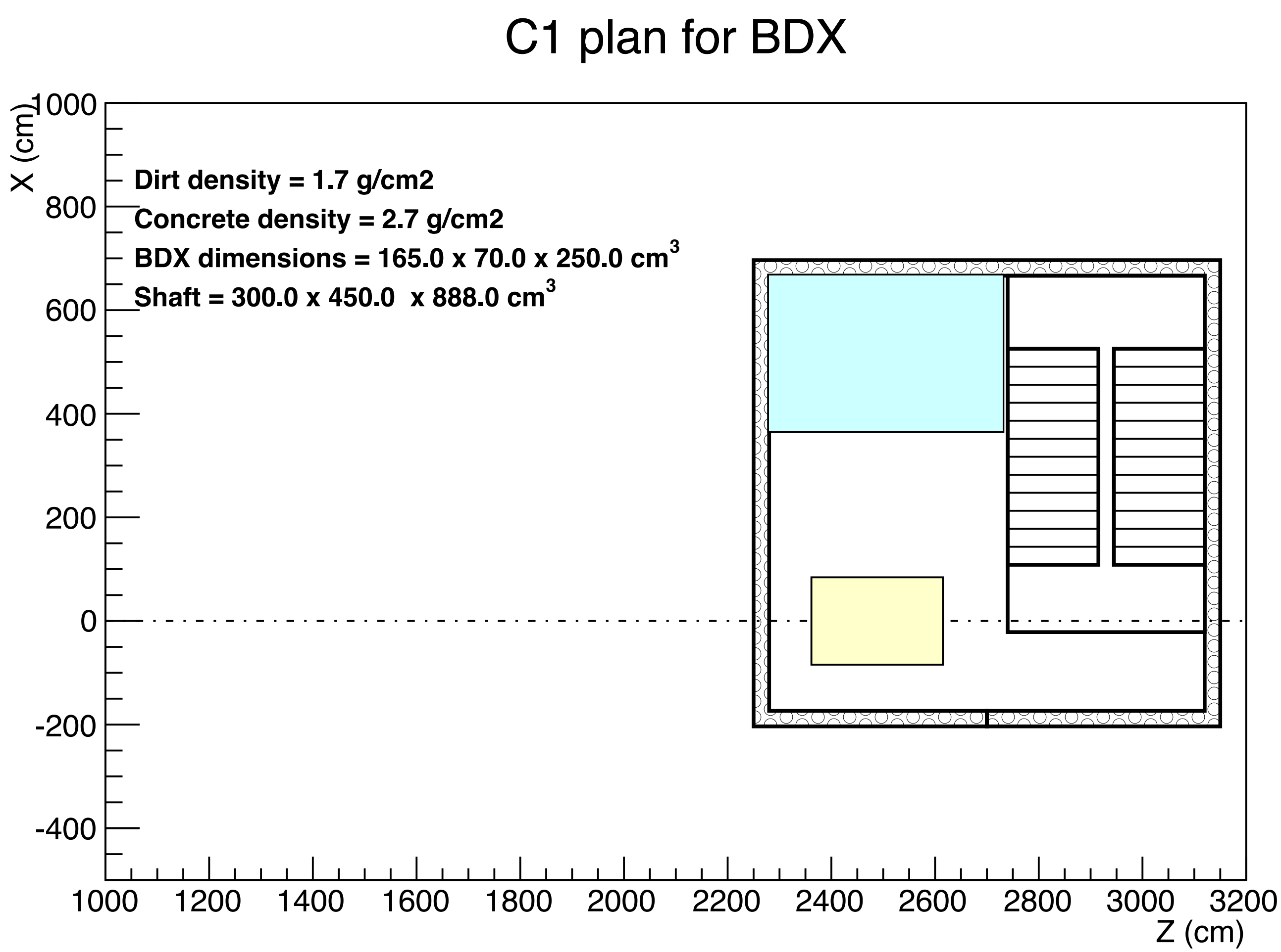


Inelastic on nuclei






C1 elevation for BDX
Dirt density = 1.7 g/cm2
Concrete density = 2.7 g/cm2
BDX dimensions = 165.0 x 70.0 x 250.0 cm3
Shaft = 270.0 x 888.0 x 450.0 cm3
Building = 900.0 x 427.0 x 900.0 cm3
grade level
Y (cm)
X (cm)
1400
1200
1000
800
600
400
200
0
-200
-400
-2500
-2000
-1500
-1000
-500
0
500
1000


C1 plan for BDX
X (cm)
Z (cm)
Dirt density = 1.7 g/cm2
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1000
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1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200