Secondary Beams at Jefferson Lab Workshop (BDX & Beyond)

4–5 Sept 2025
Jefferson Lab
US/Eastern timezone

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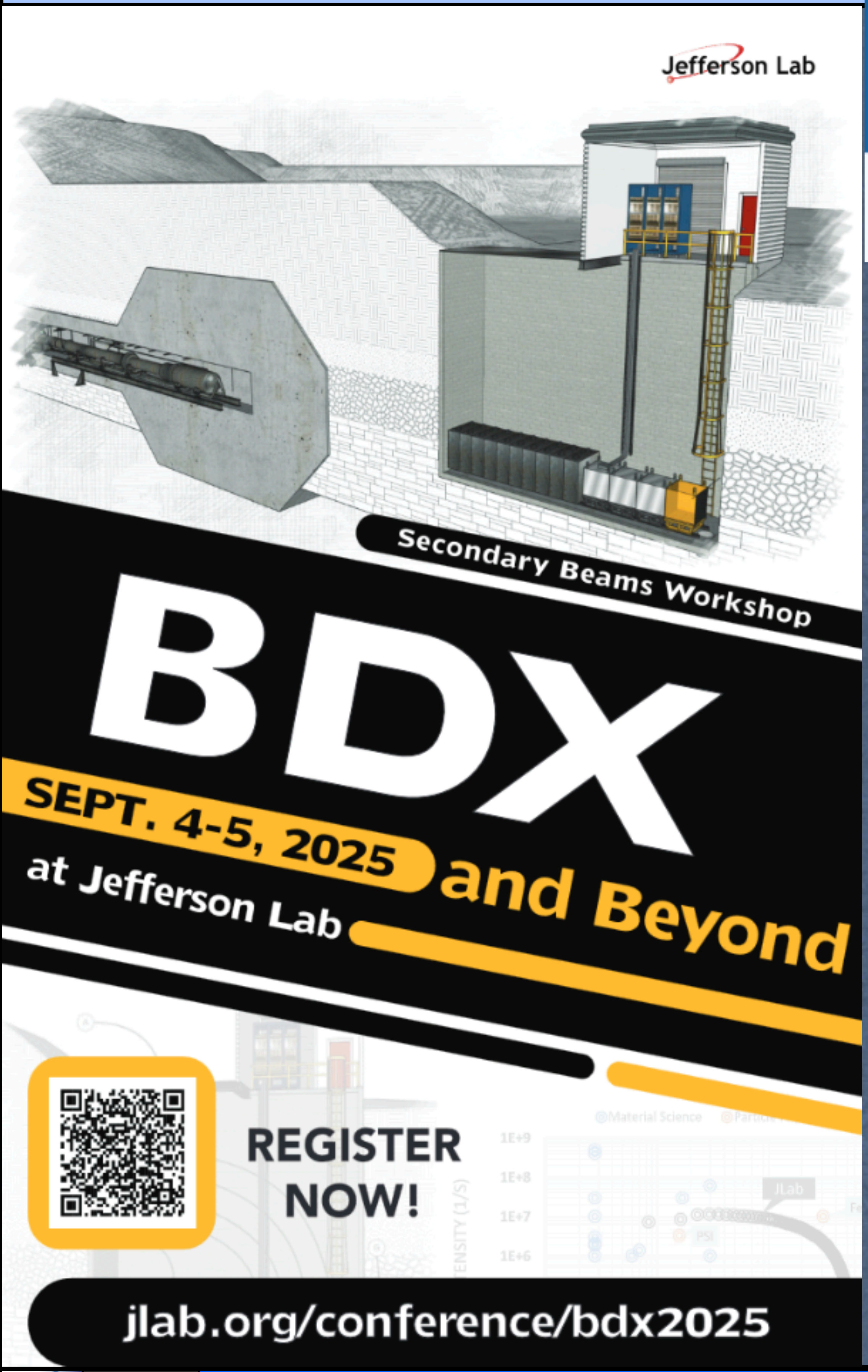


Introduction to secondary beams at Jefferson Lab

M.Battaglieri (INFN)


Jefferson Lab's accelerator site

BDX & Beyond workshop

Goal

explore opportunities offered by secondary beams at Jefferson Lab to leveraging BDX infrastructures

Format

sharing thoughts and ideas on muon, neutrino, neutron and LDM beams @ JLab

Program

two days of presentations, discussion time, flash talks

Expected outcome

to build a new user community e deliver soon after a white paper with results of the brainstorming

Thursday, September 4, 2025

Jefferson Lab and BDX Facility (tbc)	F113, Jefferson Lab		09:00 - 09:15
Future Initiatives for the JLab Experimental Program	F113, Jefferson Lab	Cynthia Keppel	09:15 - 09:30
Introduction to Secondary Beams at Jefferson Lab	F113, Jefferson Lab	Marco Battaglieri	09:30 - 09:45
The BDX & Beyond Infrastructure	F113, Jefferson Lab	Walt Akers	09:45 - 10:00
Simulation of Secondary Beam Fluxes	F113, Jefferson Lab	Antonino Fulci	10:00 - 10:15
Light dark matter searches with BDX	F113, Jefferson Lab	Marco Spreafico	10:50 - 11:15
Probing Millicharged Particles at BDX with Ultralow-Threshold Sensors (remote)	F113, Jefferson Lab	Zhen Liu	11:15 - 11:40
Measuring Proton Form Factors and Two-Photon Exchange with the Future BDX Muon Beam	F113, Jefferson Lab	Ethan Cline	11:40 - 12:05
Neutrino Physics Opportunities with Pion and Kaon Decay-at-Rest Neutrino Source	F113, Jefferson Lab	Vishvas Pandey	12:05 - 12:
Precision physics with low-energy muons (remote)	F113, Jefferson Lab	Adrian Sig	14:00 - 14
Directional muon beams using Laser Plasma Acceleration at the BELLA Center (remote)	F113, Jefferson Lab	Davide Terz	14:15 - 14
Liquid Argon-based technologies for neutrino and dark matter detection	F113, Jefferson Lab	Claudio Montar	14:40 - 15
FAMU and beyond: muonic atoms in fundamental and applied physics	F113, Jefferson Lab	Riccardo Ros	15:05 - 15
Muon-philic dark matter search at the BDX facility	F113, Jefferson Lab	Mariangela Bo	16:00 - 16
Cooling Demonstrator Program for the Muon Collider (remote)	F113, Jefferson Lab	Diktys Strata	16:20 - 16
Muon beamlines at J-PARC MLF (remote)	F113, Jefferson Lab	Takayuki Yamazaki	16:40 - 17
Collaborative NSF MRI Grants with Primarily Undergraduate Institutions	F113, Jefferson Lab	Michael Wo	17:00 - 17
Brainstorming	F113, Jefferson Lab		17:20 - 17

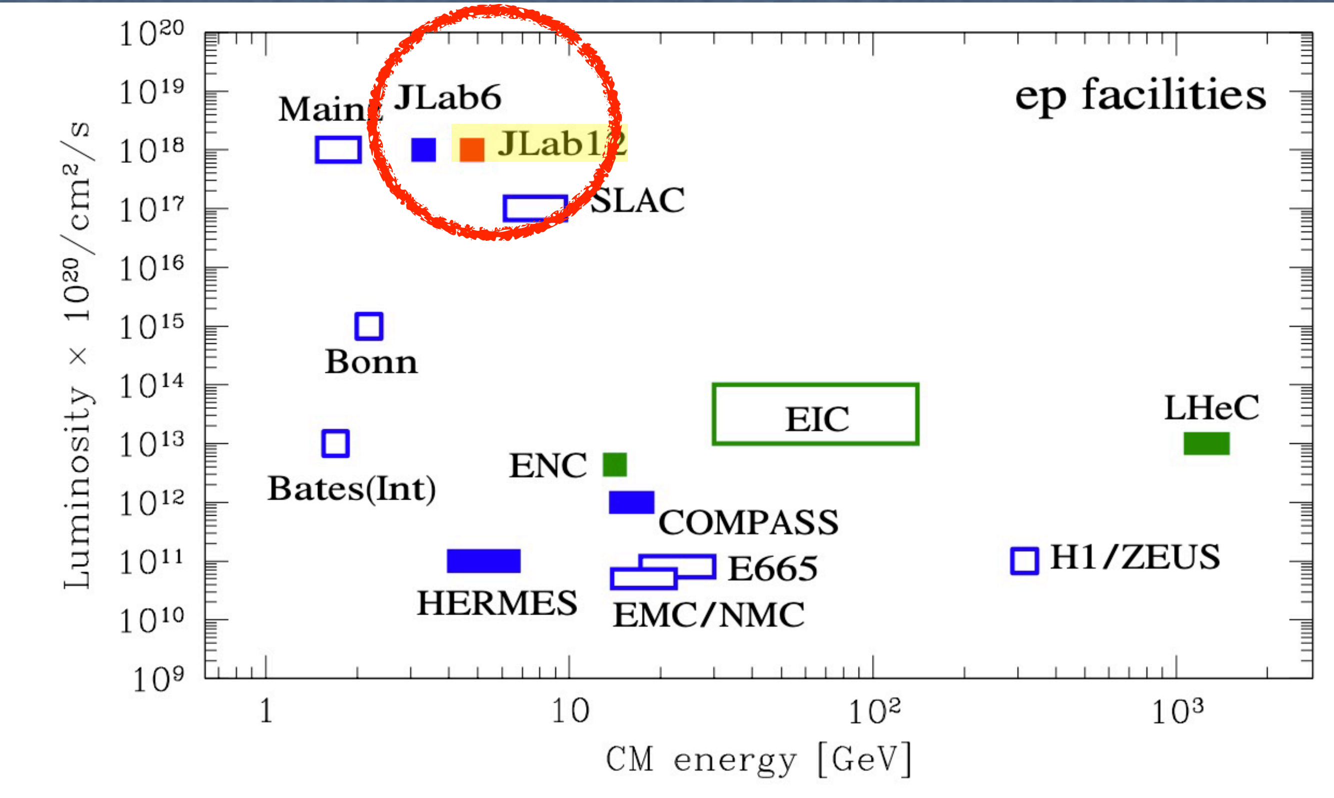
Scientific Program Committee

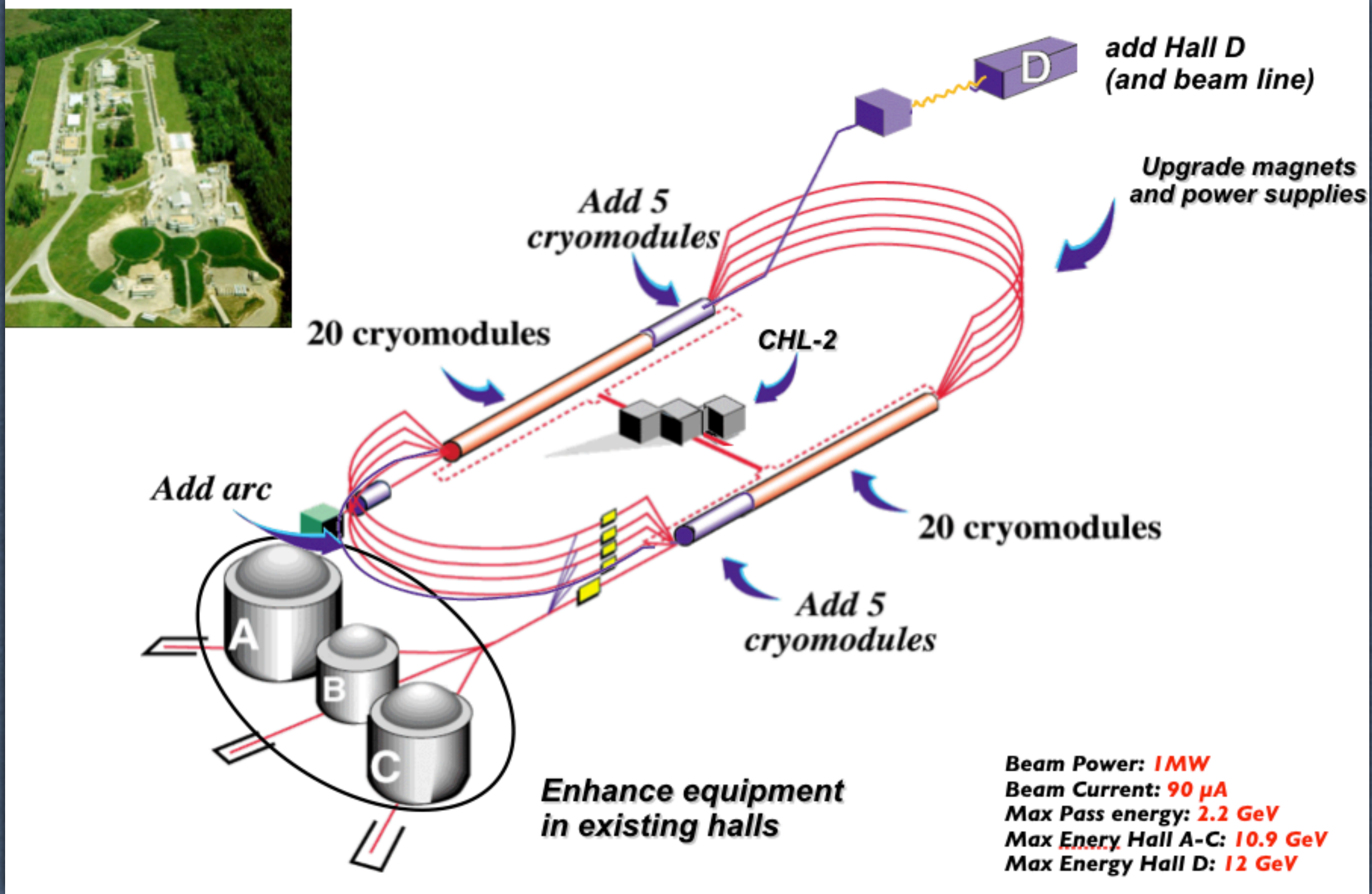
Patrick Achenbach (Jefferson Lab)
Adi Ashkenazi (Tel Aviv U)
Marco Battaglieri (INFN Genova)
Jay Benesch (Jefferson Lab)
Mariangela Bondi (INFN Catania)
Eric Christy (Jefferson Lab)
Simona Giovannella (INFN-LNF)
Thia Keppel (Jefferson Lab)
Michael Kohl (U Hampton)
Camillo Mariani (Virginia Tech)
Kevin McFarland (U Rochester)
Jianwei Qiu (Jefferson Lab Theory Center)
Adrian Signer (PSI)

Friday, September 5, 2025

Probing neutrino interaction simulations with electron scattering data (remote)	F113, Jefferson Lab	Júlia Tena-Vidal	09:00 - 09:25
Discussion on neutrino scattering in the BDX facility (remote)	F113, Jefferson Lab	Júlia Tena-Vidal et al.	09:25 - 09:40
Overview of CERN secondary beam lines (remote)	F113, Jefferson Lab	Dipanwita Banerjee	09:40 - 10:05
Physics Opportunities with Muon Beams from Low to High Energies	F113, Jefferson Lab	Andrei Afanasev	10:05 - 10:25
Detector Technologies for beam-dump experiments at MESA and JLab (remote)	F113, Jefferson Lab	Luca Doria	11:00 - 11:25
Muon physics infrastructure and program at PSI (remote)	F113, Jefferson Lab	Klaus Kirch	11:25 - 11:50
Prospects for muon on electron scattering at JLab	F113, Jefferson Lab	Michael Kohl	11:50 - 12:00
Possible muon beam lines for BDX	F113, Jefferson Lab	Jay Benesch	12:00 - 12:15
Facility Tour	CEBAF	Eric Christy	13:30 - 15:00
Coffee Break	F113, Jefferson Lab		15:00 - 15:30
Whitepaper Discussion	F113, Jefferson Lab		15:30 - 17:00

Jefferson Lab
The intensity frontier





✳Primary Beam: Electrons

✳ Beam Energy: 12 GeV

- 10 > λ > 0.1 fm
- nucleon → quark transition
- baryon and meson excited states

✳100% Duty Factor (cw) Beam

- coincidence experiments
- Four simultaneous beams
- Independent E and I

✳ Polarization

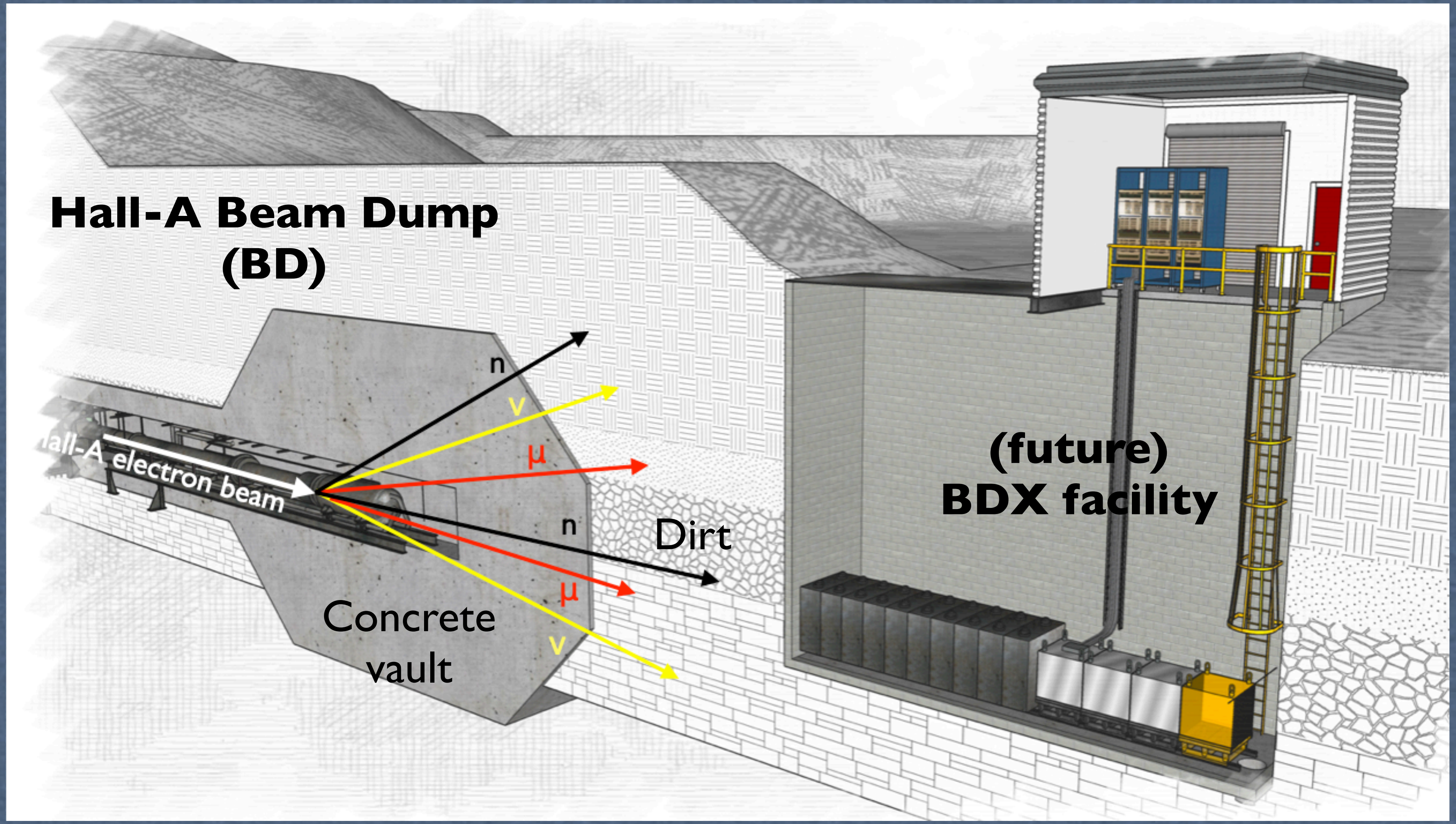
- spin degrees of freedom
- weak neutral currents

New physics perspectives at Jlab with secondary beams

- CEBAF provides a high-intensity 11 GeV (in future 20+ GeV) electron beam for extracted-beam experiments
- High-intensity secondary beams are produced in the dump(s) fully opportunistically
- The machine can sustain up to ~MW power (100 uA @ 10 GeV, 200 uA @ 5 GeV)
- Hall-A routinely receives ~50-70 nA @ 11 GeV, Hall-D 7-8 uA @ 12 GeV

- High-intensity secondary beams:
  - Muon
  - Neutrino
  - Neutrons
  - Light Dark Matter (if it exists)

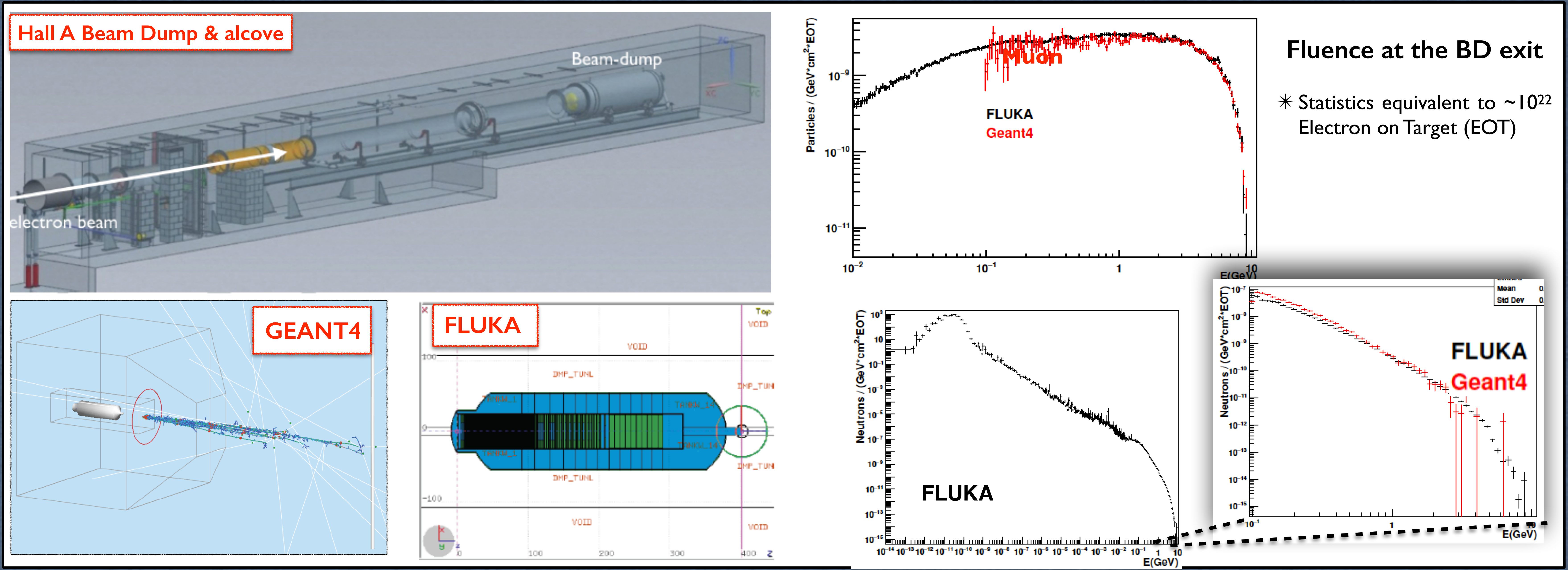
- A positron beam is expected in the near future as part of the 22 GeV upgrade of the machine



https://www.mdpi.com/2410-390X/8/1/1/pdf

The simulation framework

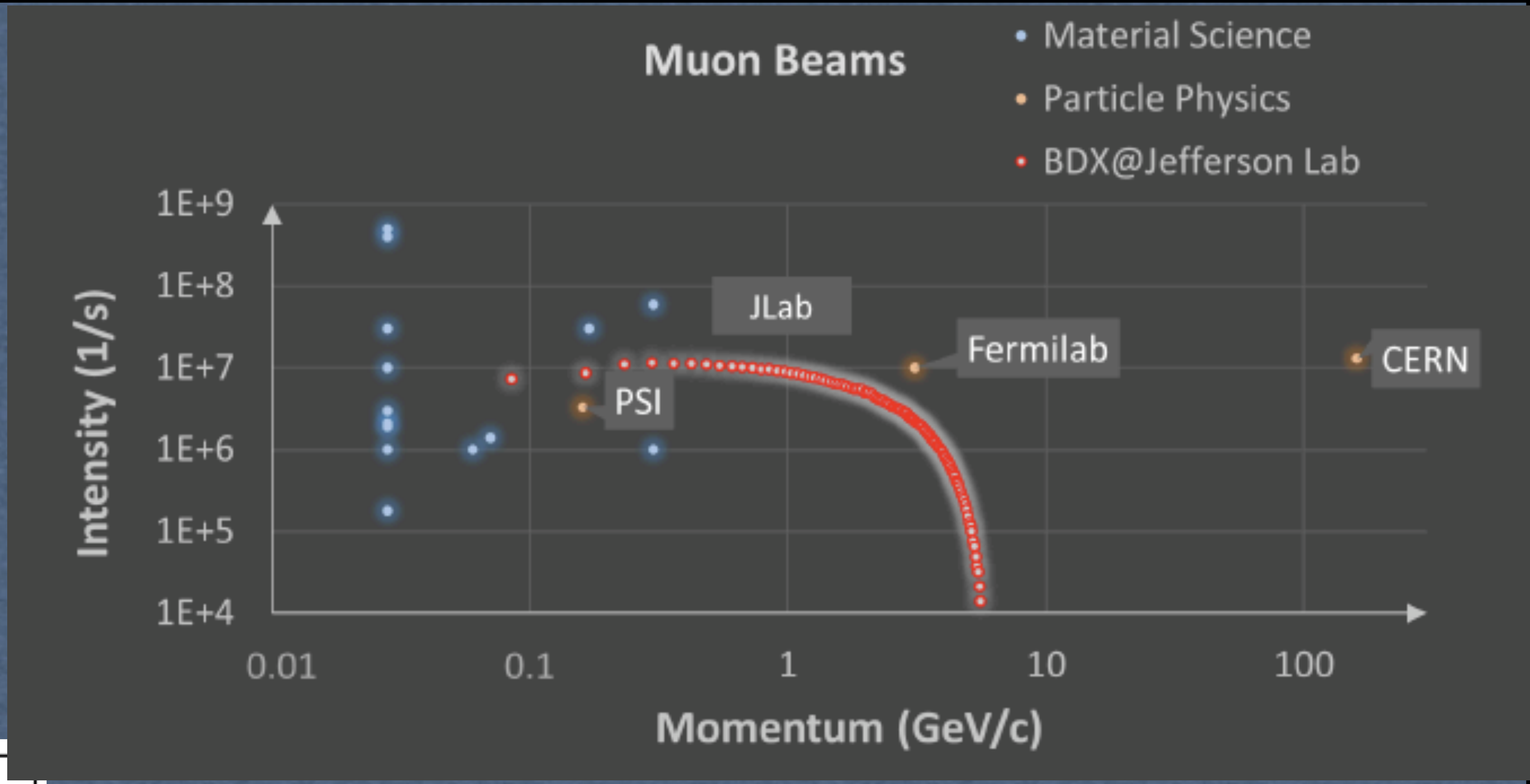
- Hall-A beam-dump geometry/materials implemented in FLUKA (with JLab RadCon Group)
  - FLUKA biasing: xsecs enhancement, 'leading particle', importance sampling, threshold T>100 MeV
  - GEANT: detailed and realistic descriptions of the detector active volume response

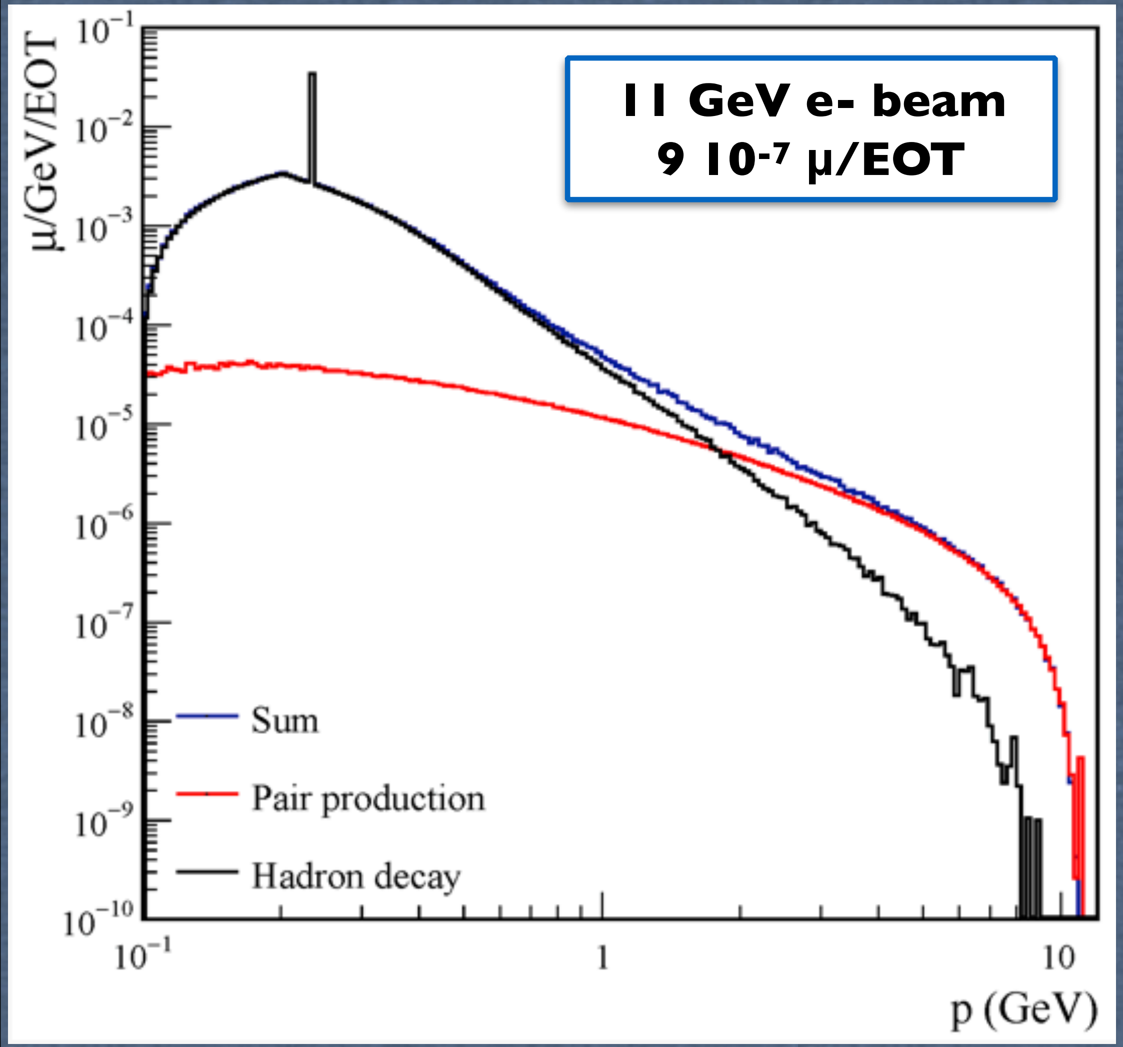


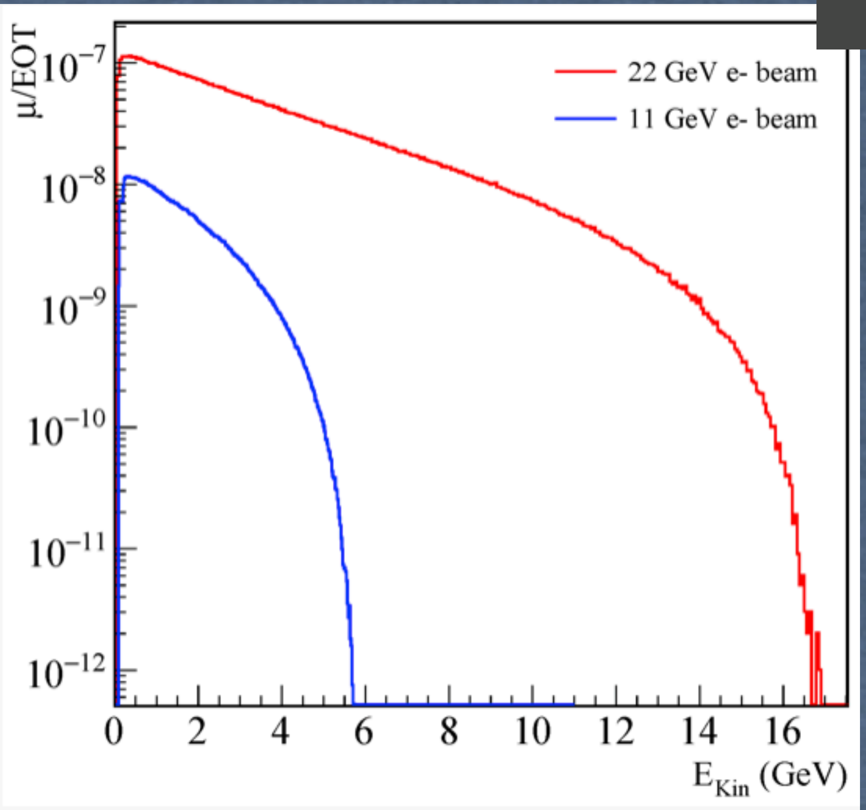
- Good consistency between G4 and FLUKA for μ and high energy neutrons (T_n>100 MeV) in the BD

Muon beam

- Muon flux estimated using FLUKA for 11 GeV and 22 GeV e- beam on Hall-A BD
- High-energy muon produced via two processes:
  - Photo-production of π and k and decay
  - Pair-production: $\gamma N \rightarrow \mu\mu N$







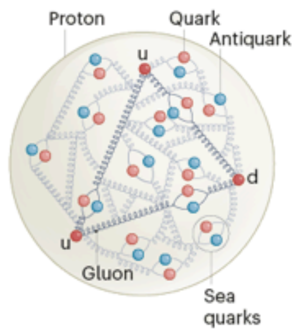
- Bremsstrahlung-like energy spectrum
- Significant advantage at 22 GeV (higher muon flux and higher energ

- The flux increases with the energy of primary beam:
- Muon flux (11 GeV e- beam): $9\ 10^{-7}$ μ/EOT
  - Rate ~ $3\ 10^{8}$ μ/s
- Muon (22 GeV e- beam): $5.3\ 10^{-6}$ μ/EOT
  - Rate ~ $2\ 10^{9}$ μ/s
- CERN's M2 beamline (E_μ>100GeV - Rate ~$2\ 10^{7}$)
- Muon flux profile: σ_x and σ_y ~ 20 cm

- The muon flux predicted by FLUKA was validated in a dedicated experiment μBDX in the future BDX area

SM Physics: the proton radius

Proton charge radius

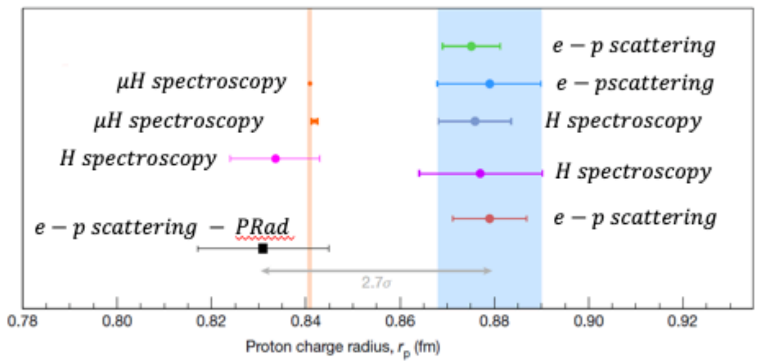


- Protons are not elementary particles, thus is possible to define a proton charge radius

The proton charge radius can be measured by:

1. Leptonic scattering
2. Spectroscopic measurement

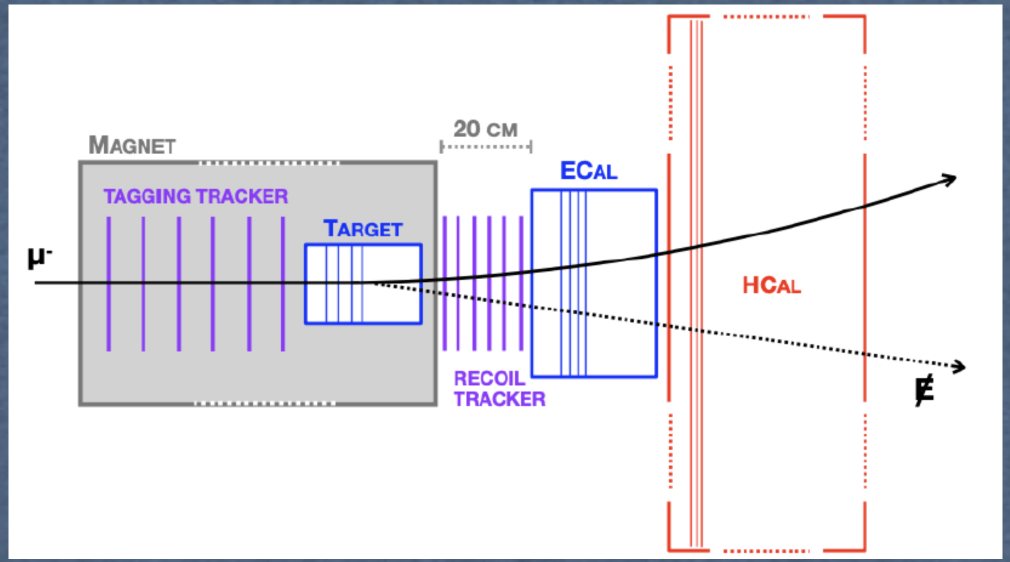
«Proton radius puzzle»



- Smaller Bohr radius / closer probing
- Reduced radiative effects
- Higher momentum transfer at same energy
- Independent cross-check
- AMBER @ CERN (M2 beam line)

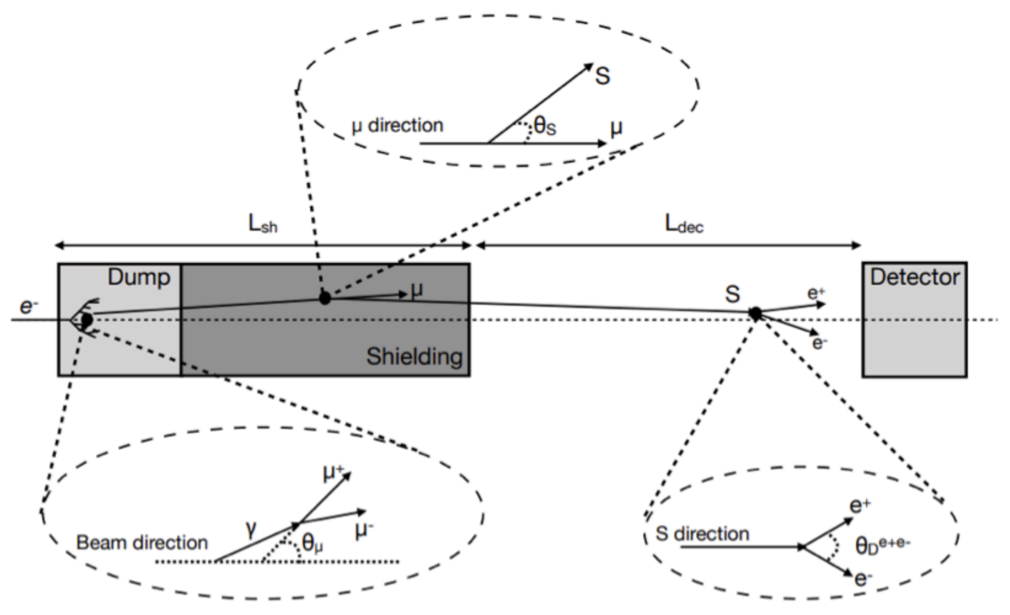
BSM Physics: muon-phillic forces

μ³BDX @ JLab



- Fixed-target, missing-momentum experiment to probe invisibly decaying particles
- Scalar or vector mediator of a new force
- This experiment is similar to M³ experiment proposed at FERMILAB

μBDX @ JLab



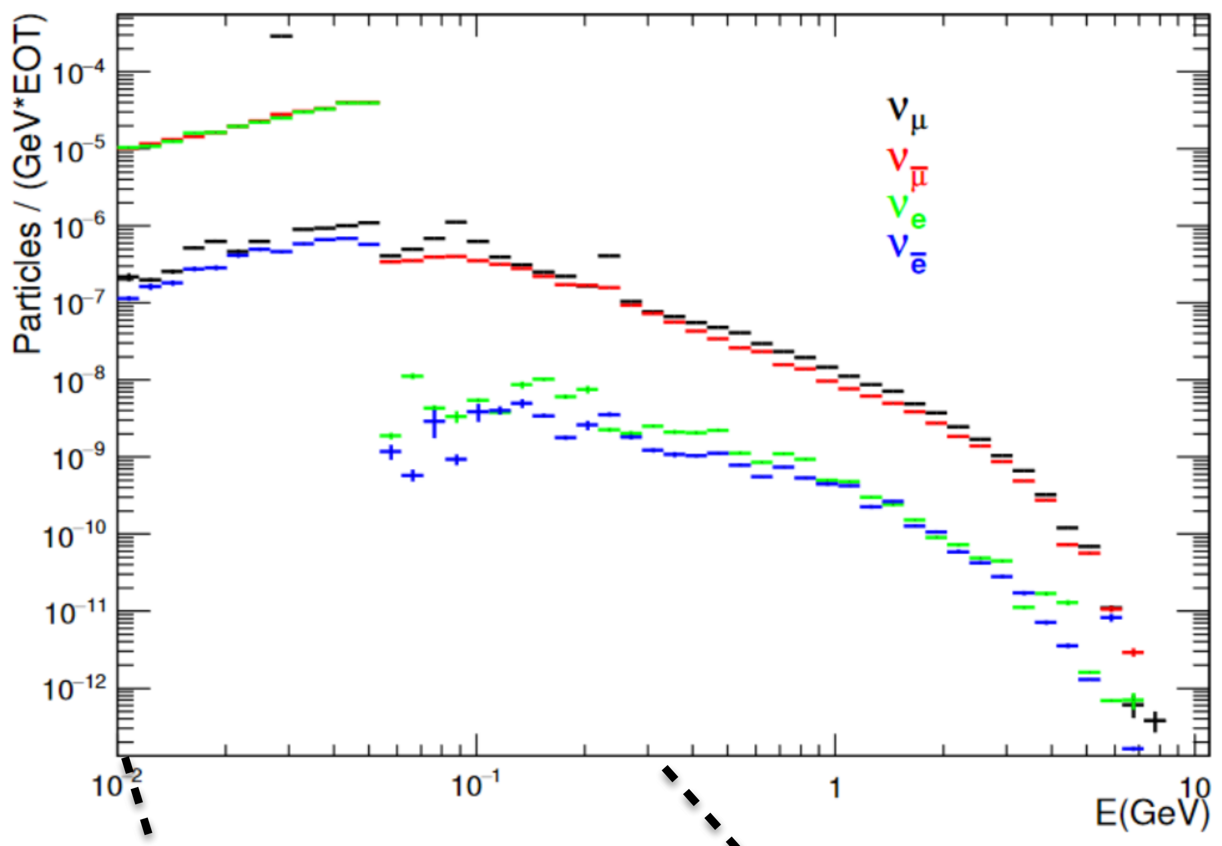
- Muon beam dump experiment to probe the visible decay into e+e-(γγ)
- Same infrastructure requested by BDX

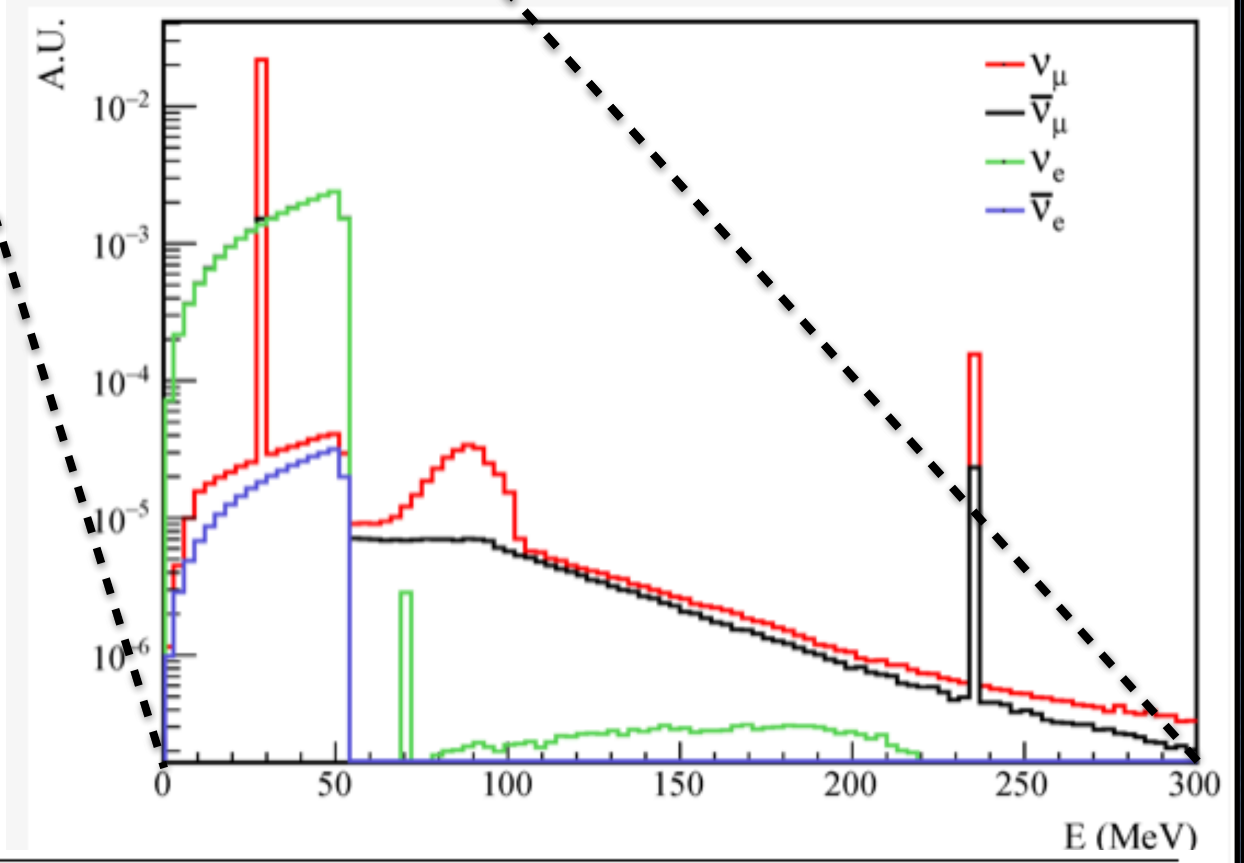
Neutrino beam

- Low energy νs due pion and muon decay at rest
  - π decay produces a prompt 28.5 MeV ν_μ along with a μ which subsequently decays producing a ν_e and a ν_μ
  - Weak angular dependence
- High-energy ν from in-flight pion and muon decay

$$\pi^+ \to \mu^+ + \nu_\mu,\ E_\nu \sim 29.8 \text{ MeV, almost monochromatic;}$$
$$\mu^+ \to \bar{\nu}_\mu + \nu_e + e^+,\ E_\nu \text{ in the range 0–52.8 MeV;}$$
$$K^+ \to \mu^+ + \nu_\mu,\ E_\nu \sim 236 \text{ MeV, almost monochromatic.}$$

- Neutrino flux estimated using FLUKA for 11 GeV and 22 GeV primary e- beam on Hall-A BD
- Flux scored on a plane downstream Hall-A beam dump:
  - 11 GeV e- beam: 3 10^{17} ν/m²/year (1 year corresponding to 10^{22} EOT)
  - 22 GeV e- beam: 9 10^{17} ν/m²/year (1 year corresponding to 10^{22} EOT)
- Decay-At-Rest (DAR) energy spectrum





Beam Energy	Off-Axis Flux [ν/EOT/m²]	On-Axis Flux [ν/EOT/m²]
11 GeV	6.7×10^{-5}	2.9×10^{-5}
22 GeV	1.9×10^{-4}	6.3×10^{-5}

vBDX @ JLab

CEvNS (Coherent Elastic nu-Nucleus Scattering)

- Low-energy neutrinos (<100 MeV) coherent scatter on nucleus
- The largest xsec for E_ν < 100 MeV
- First detected in 2017 on CsI by COHERENT (~134 events)
- Low recoil energy due to kinematics O(10 keV)

Why interesting?

- weak parameters -> mixing angle
- nuclear properties -> neutrons distribution radius
- sterile neutrino
- neutrino magnetic moment
- non standard interaction mediated by exotic particles

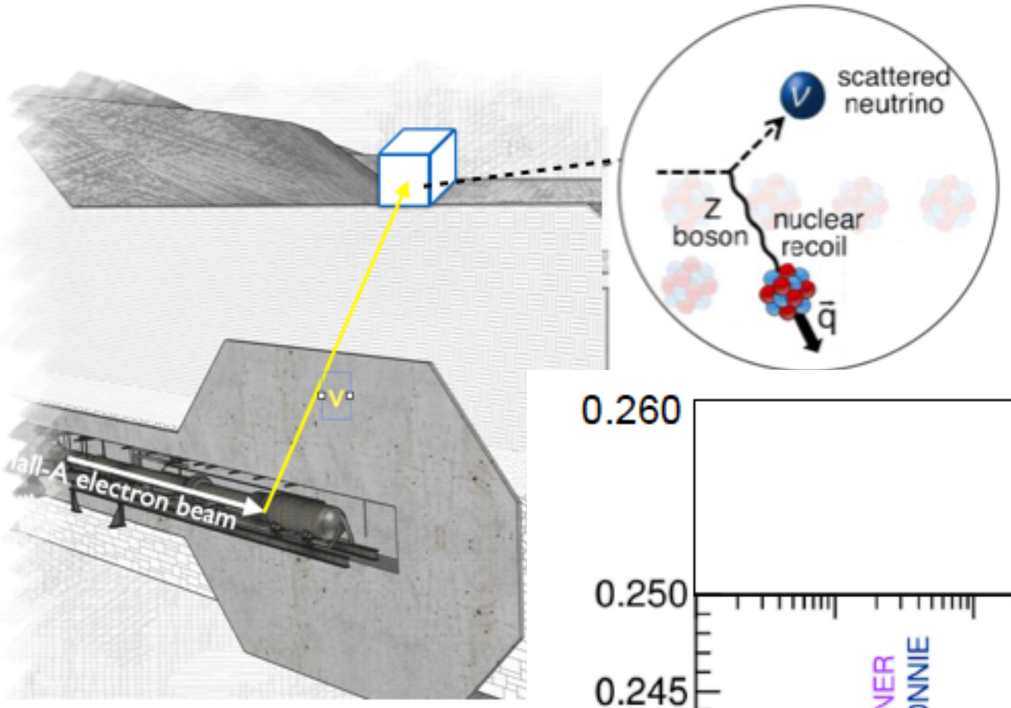
Requirements

- High-intense ν-flux
- ν-flux energy range: few MeV - few 100 MeV
- detector sensitive to small energy deposition
- small background

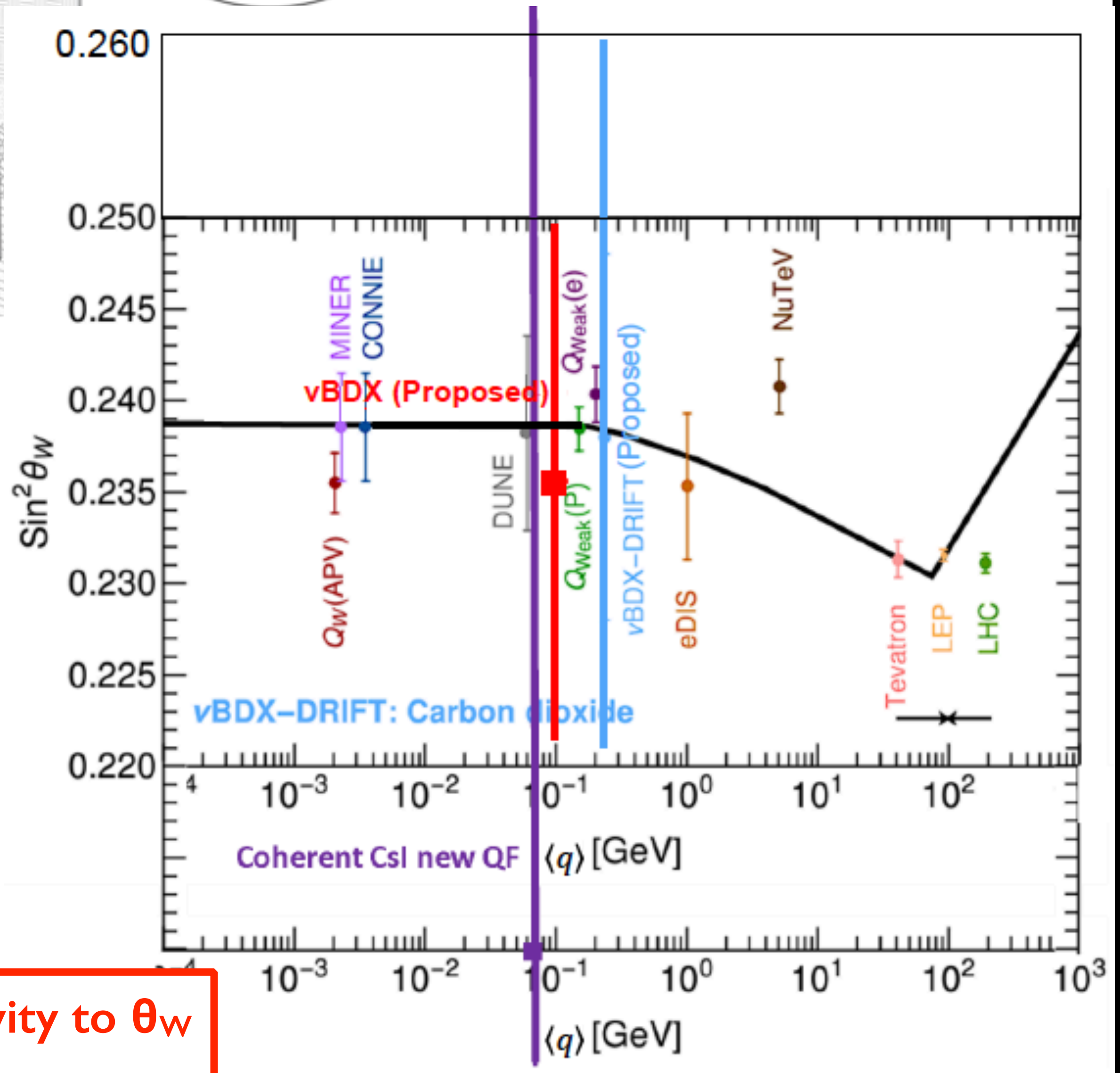
The νBDX detector

- 10m above the dump
- Two detection technologies under study: CsI and LAr-TPC
- Veto system: active (plastic …) and passive (lead, water, borate silicone and/or cadmium sheet layers…)

Detecting CEvNS at JLab

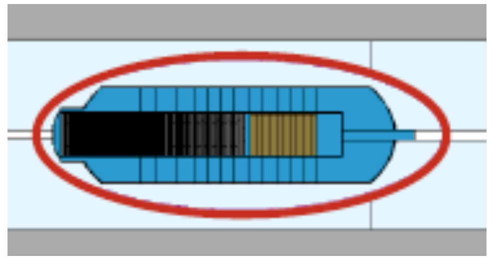


Detector	e- @ 10 GeV ν flux: 1E8 ν/m²/year	e- @ 20 GeV ν flux: 2E8 ν/m²/year
CsI (1m³) [thr : 10 keV]	8000	~15000
LAr (1m³) [thr: 10 keV]	2500	~4500

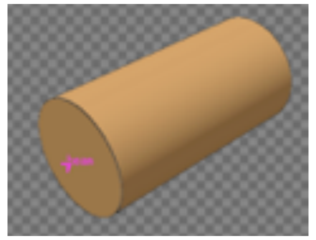


Projected vBDX sensitivity to θ_W
$\sin^2\theta_W = 0.209^{+0.072}_{-0.069}$

Neutrons

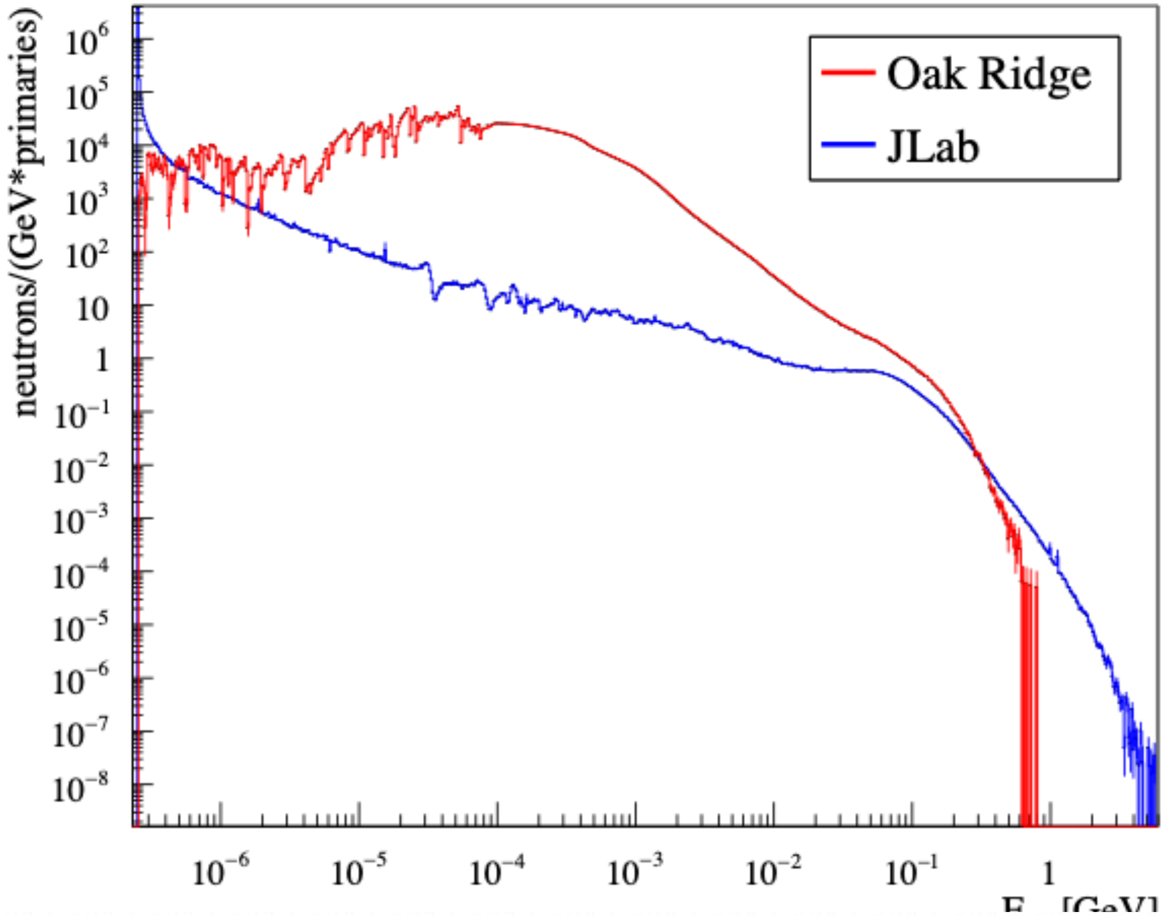


SecNeutrons@JLab
electron beam
11 GeV
100uA = 6.3 10^{14} e/s
Hall-A BD target



SNS@ORNL
proton beam
1 GeV
1.4 mA = 8.8 10^{15} p/s
Hg target

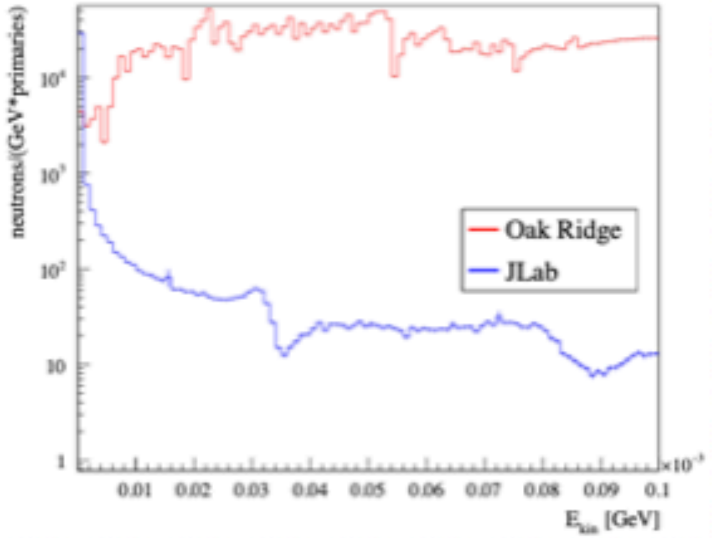
Energy Range	Jlab (n/s)	Oak Ridge (n/s)	Ratio (J/O)
0 - 6GeV	7.86e+13	1.41e+17	0.001
0.1eV - 100.0eV	0.00e+00	0.00e+00	inf
100.0eV - 100.0keV	2.13e+13	2.17e+16	0.001
100.0keV - 1.0MeV	4.51e+12	8.60e+16	0.000
1.0MeV - 100.0MeV	4.16e+13	3.26e+16	0.001
100.0MeV - 2.0GeV	1.14e+13	3.43e+14	0.033
2.0GeV - 11.0GeV	2.07e+09	0.00e+00	inf



- FLUKA simulation framework cross checked with SNS data
- Assuming the excavation of the BDX pit (no dedicated near facility)
- Neutron flux sampled around the BD, upstream/downstream of the concrete vault and BDX pit entrance

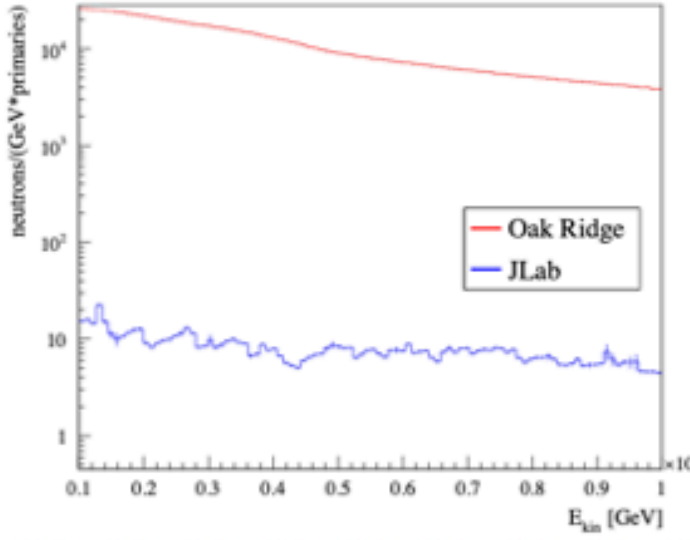
Tn [100 eV-100 keV]

Integral	JLab	SNS
n/primaries	3.42e-02	2.48e+00
n/s	2.13e+13	2.17e+16



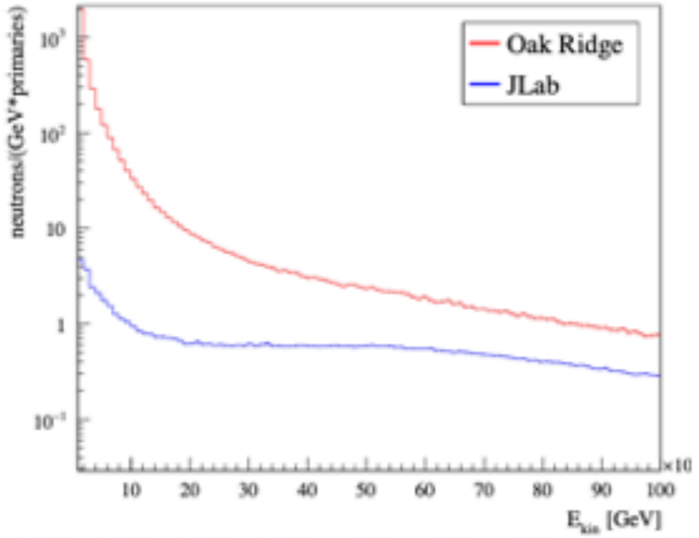
Tn [100 keV - 1 MeV]

Integral	JLab	SNS
n/primaries	7.23e-03	9.84e+00
n/s	4.51e+12	8.60e+16



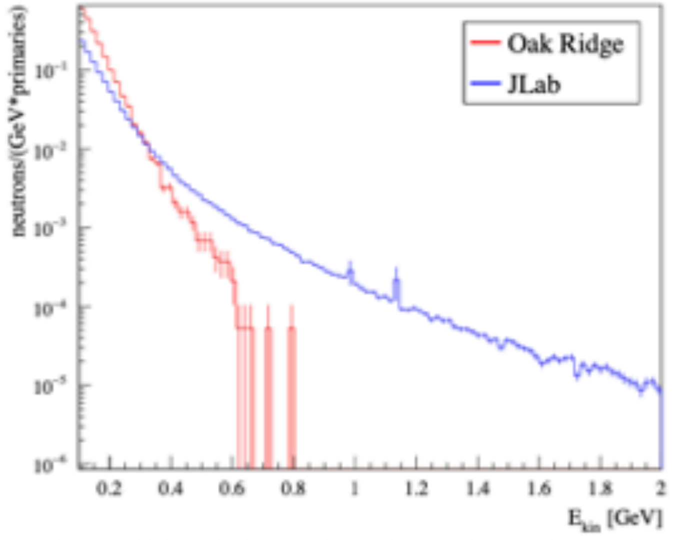
Tn [1 MeV - 100 MeV]

Integral	JLab	SNS
n/primaries	6.66e-02	3.73e+00
n/s	4.16e+13	3.26e+16



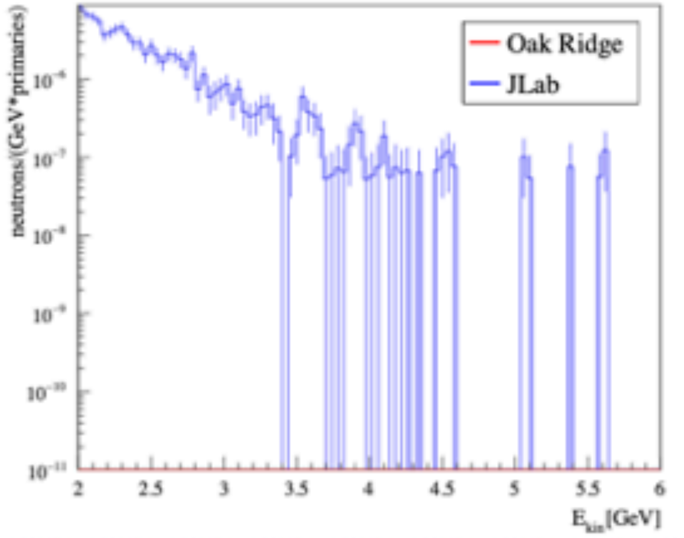
Tn [100 MeV - 1 GeV]

Integral	JLab	SNS
n/primaries	1.82e-02	3.92e-02
n/s	1.14e+13	3.43e+14



Tn [1 GeV - 11 GeV]

Integral	JLab	SNS
n/primaries	3.31e-06	0.00e+00
n/s	2.07e+09	0.00e+00



Summary

✳ High-intensity electron beams are a precious source of secondary beams:

✳ The high intensity (~100uA), medium energy (~10 GeV) CEBAF electron beam at Jefferson lab is ideal for producing secondary beams

- Light Dark Matter (if it exists)
- Neutrinos
- Muons
- Neutrons

✳ Realistic simulations performed with FLUKA and GEANT4

- LDM: best beam around the world for a beam-dump experiment
- Muon beams: Bremsstrahlung-like energy spectrum, (100 MeV - 5 GeV), $\sim 10^{-6}$ μ/EOT
- Neutrino beams: DAR energy spectrum , (0 - 50 MeV), $3\ 10^{17}$ ν/m^2/year
- Neutros beams: may be competitive in certain energy range with world leading facilities

✳ The 22 GeV upgrade of CEBAF will provide even better secondary beams (in particular muons)

✳ Secondary beams offer new (opportunistic) opportunities to extend the physics program of lepton-beam facilities

… more at the end of the BDX&Beyond workshop and in the white paper