Opportunities with JLAB Energy and Luminosity Upgrade
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New physics perspectives @ JLAB with secondary beams

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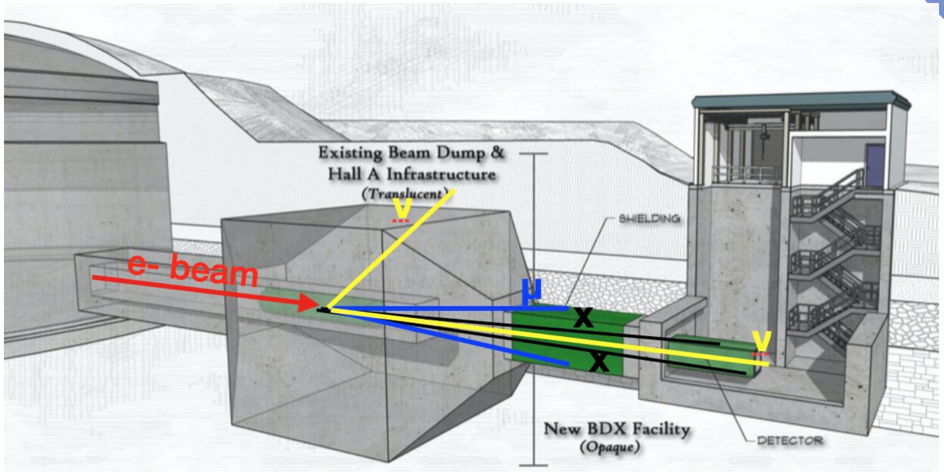
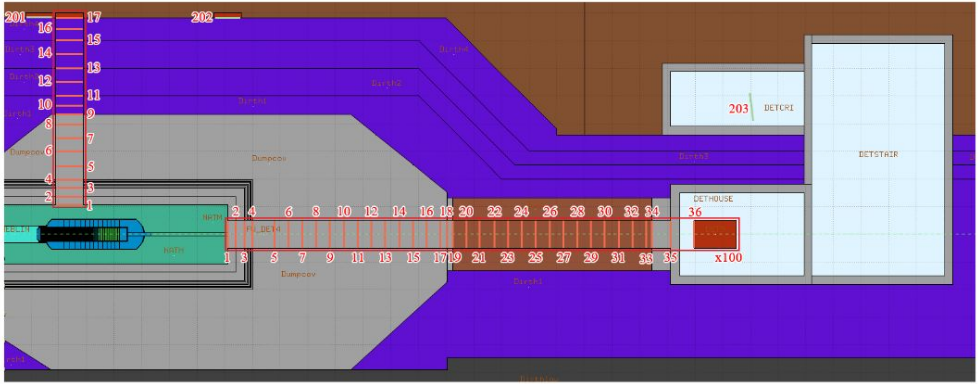
Producing secondary beam @ JLAB

- **JLAB-CEBAF offers the highest intense O(GeV) e- beam in the world**
- Use the primary e- beam to produce high intensity secondary beams
  - Interaction of high-current (*O*(100μA)), medium-energy (*O*(10GeV)) electron beam with a thick target (dump).
    - **Muons**
    - **Neutrinos**
    - **Light Dark matter (if exists)**
    - …..
    - …..
    - ….
- Estimation of secondary beam produced by the interaction of e- beam with HALL-A beam dump

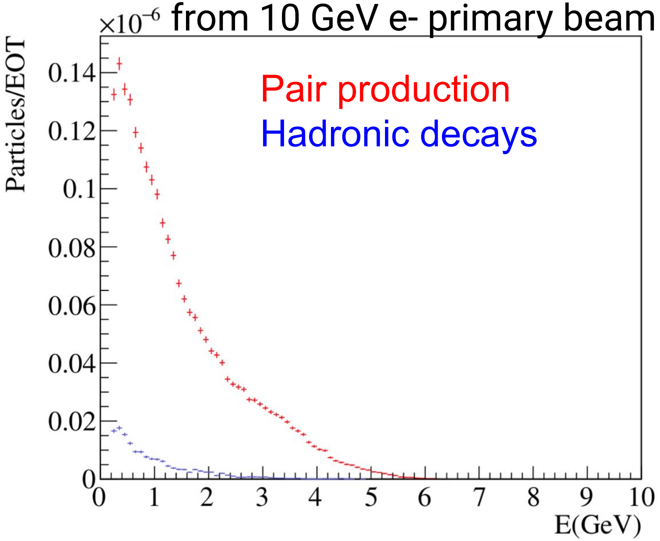


Muon beam @ JLAB

- Muon flux estimation through MC simulation based on FLUKA both for 10 GeV and 20 GeV e- beam
  - Used Hall-A beam dump description implemented in FLUKA by the JLAB RadCon
- High energy muons are produced in the dump via 2 processes:
  - Photo-production of π and k
  - Pair-production: γN -> μμN



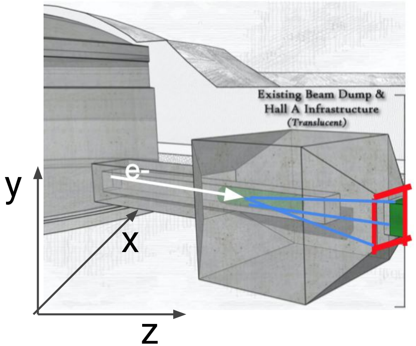
Muon energy distribution from 10 GeV e- primary beam



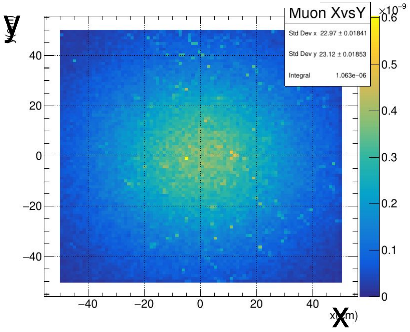
Credit to A. Fulci

Muon beam @ JLAB

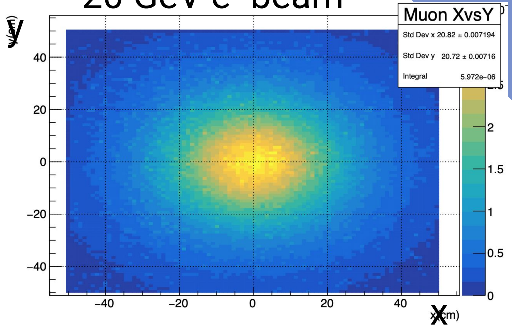
- Muon beam shows a Bremsstrahlung-like energy spectrum
- Flux increases with the energy of primary beam:
  - Muon flux from 10 GeV e- beam: 9E-7 μ/EOT
    - Rate ~ 3E8 μ/s
  - Muon flux from 10 GeV e- beam: 5.3E6 μ/EOT
    - Rate ~2E9 μ/s
  - Flux larger than CERN's M2 beam line one (E_μ>100GeV - Rate ~2E7)
- Muon flux profile: σx and σy ~ 20 cm

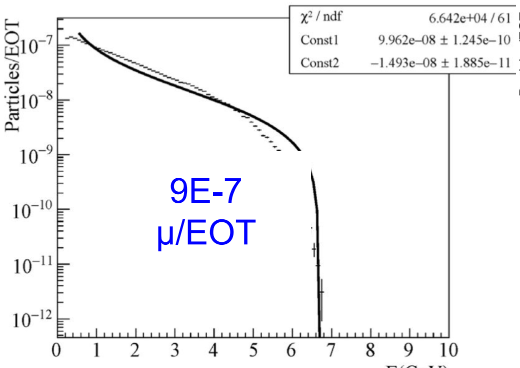


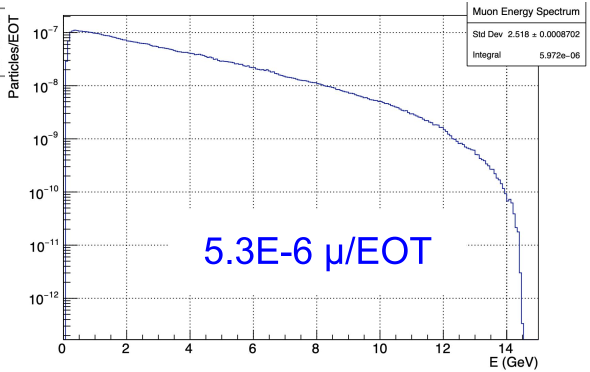
Muons from
10 GeV e- beam



Muons from
20 GeV e- beam



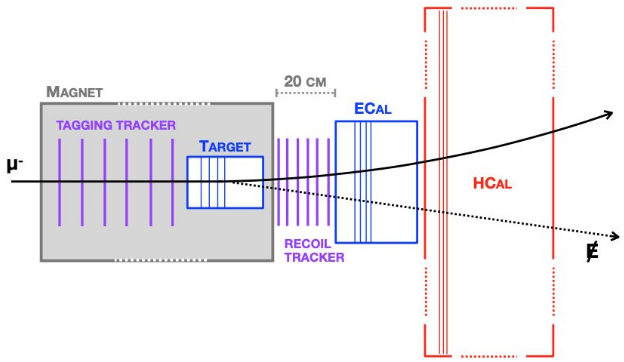


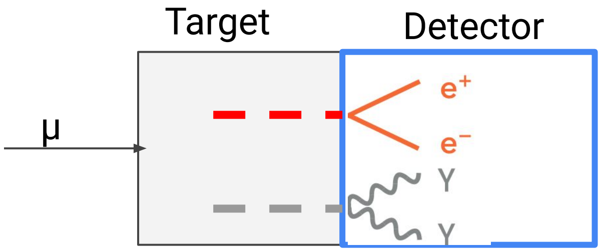


Credit to A. Fulci

Muon beam @ JLAB

- Exploiting muon beams would enable the search for a possible light gauge boson, which would couple predominantly to muons and/or taus
  - Such a light boson could be either a scalar or a vector mediator
  - Its existence would be a viable explanation of g-2 anomaly
- Fixed-target, missing-momentum search strategy to probe invisibly decaying particles (similar to proposed M3 experiment @ Fermilab)
- Muon beam dump experiment to probe the visible decay into e+e-(γγ).

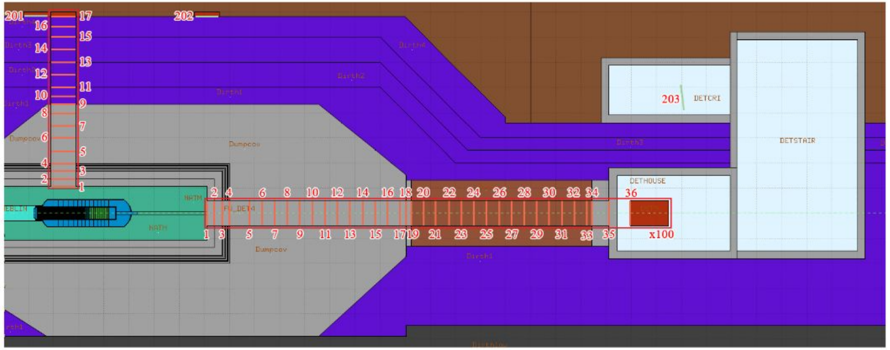




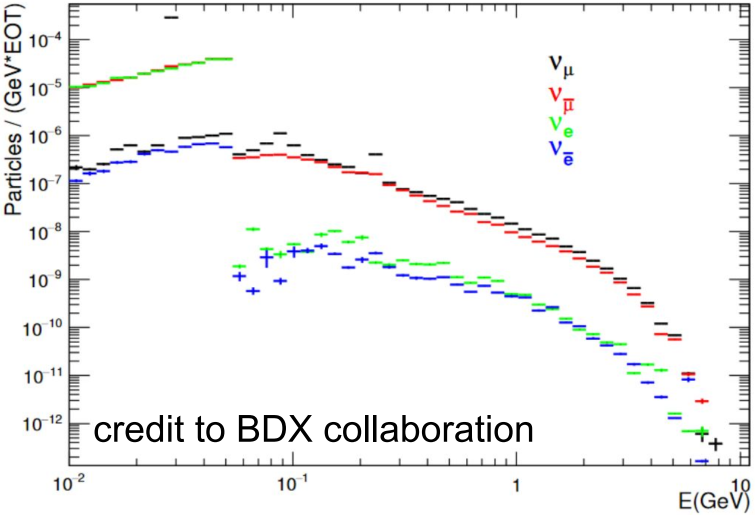
Credit to G. Krnjaic

Neutrino beam @ JLAB

- Neutrinos flux estimated through MC simulations based on FLUKA
- Neutrino flux evaluated both for 10Gev e- beam and 20GeV e- beam
- **Production mechanisms**:
  - Low energy vs are due pion and muon decay at rest
    - π decay produces a prompt 28.5 MeV v_{μ} along with a μ which subsequently decay producing v_e e v_m
    - Weak angular dependence
  - High-energy v from in-flight pion and muon decay



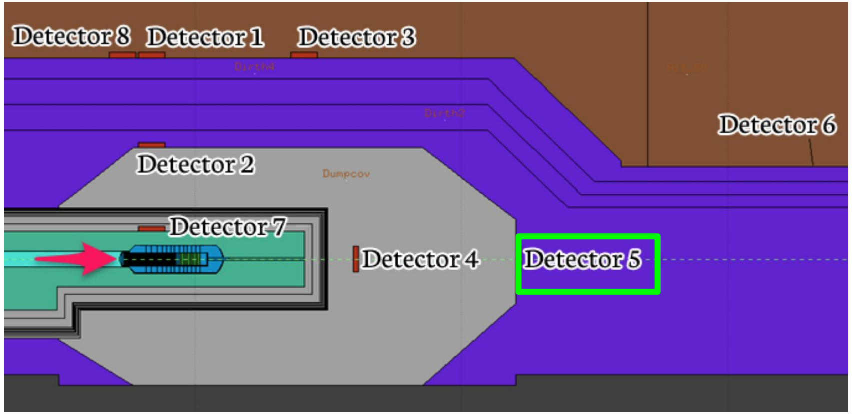
FLUX scored on a plan 25 m downstream
HALLA-BD - 10GeV e- beam



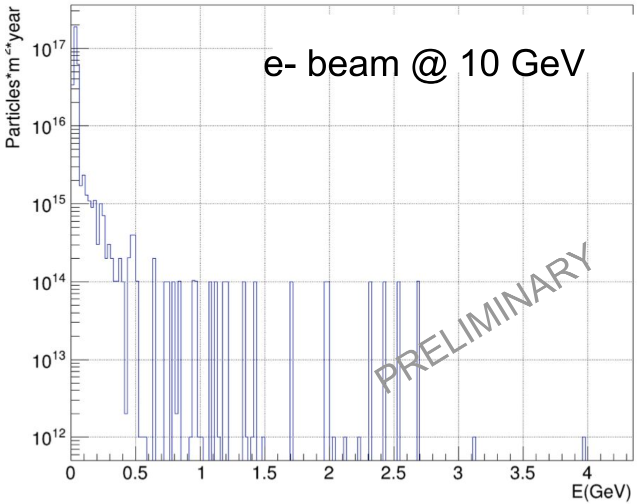
Credit to A. Fulci

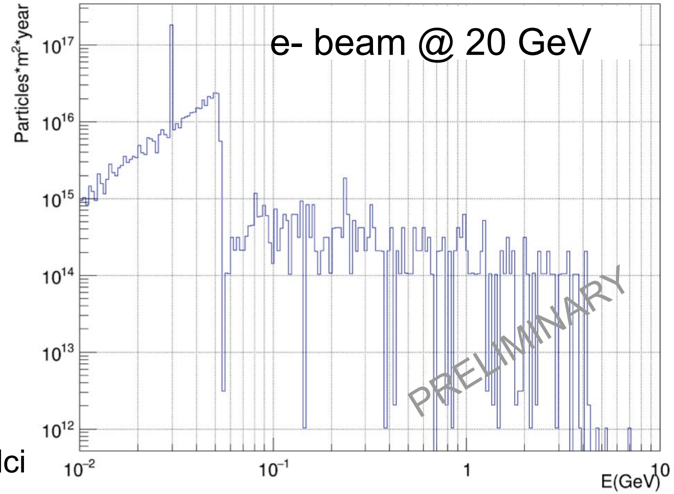
Neutrino flux on-axis

- Neutrinos flux estimated through MC simulations based on FLUKA
- Neutrino flux evaluated both for 10Gev e- beam and 20GeV e- beam
- Flux scored on a plane downstream Hall-A beam dump (detector 5):
  - Flux from 10 GeV e- beam: 3E17 ν/m2/year (1year corresponding to 1E22 EOT)
  - Flux from 20 GeV e- beam: 9E17 ν/m2/year (1year corresponding to 1E22 EOT)



Detector 5

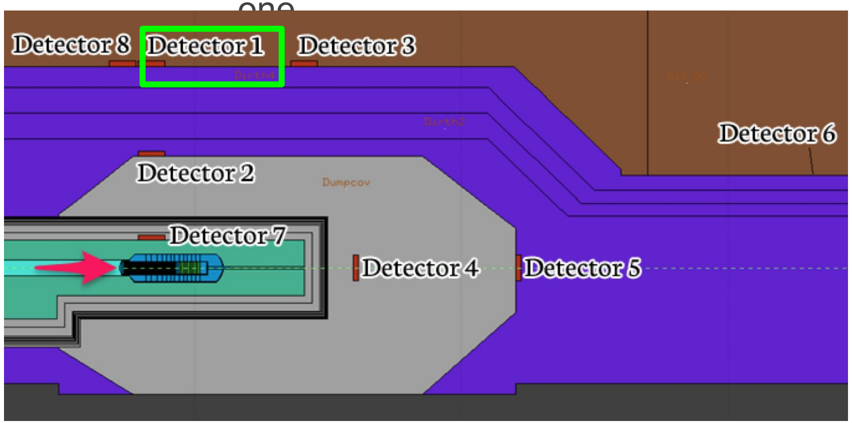




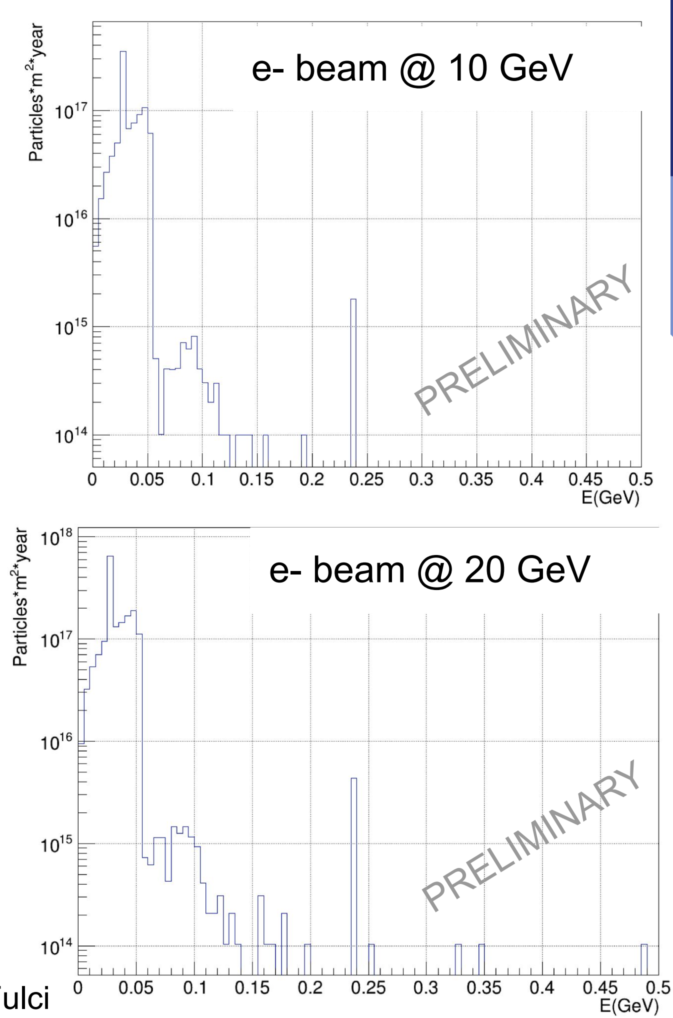
Credit to A. Fulci

Neutrino flux off-axis

- Neutrinos flux estimated through MC simulations based on FLUKA
- Neutrino flux evaluated both for 10Gev e- beam and 20GeV e- beam
- Neutrino flux with a DAR spectrum
- Flux scored on a plane 10 m above Hall-A beam dump (detector 1):
  - Flux from 10 GeV e- beam: 9E17 v/m2/year (1year corresponding to 1E22 EOT)
  - Flux from 20 GeV e- beam: 1.8E18 v/m2/year (1year corresponding to 1E22 EOT)
    - Flux comparable to SNS@ Oak Ridge National Lab one



Detector 1

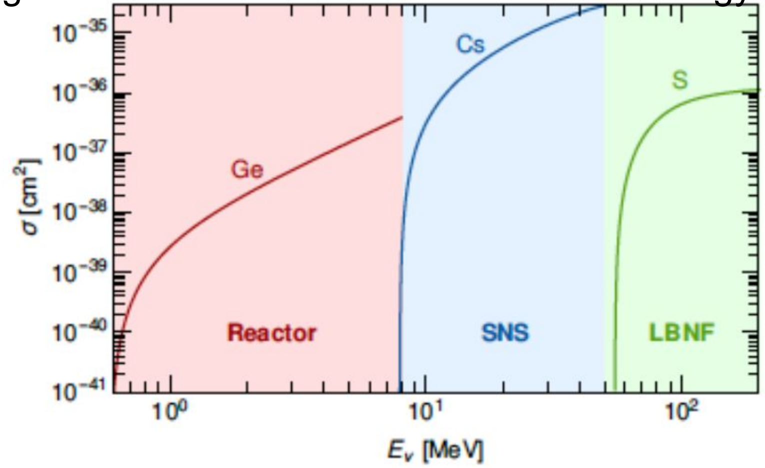


Credit to A. Fulci

CEvNS measurement

- Low energy neutrinos (< 100 MeV) coherently scatter on entire target nucleus q < $(1/R_N)$
- Cross section scaling with N^2
- The largest cross section among neutrino scattering channels for Ev < 100 MeV
- Low recoil energy due to kinematics O(10 keV)
- First measurement in 2017 on CsI by COHERENT collaboration (~134 events)

Integrated cross section as a function of ν energy

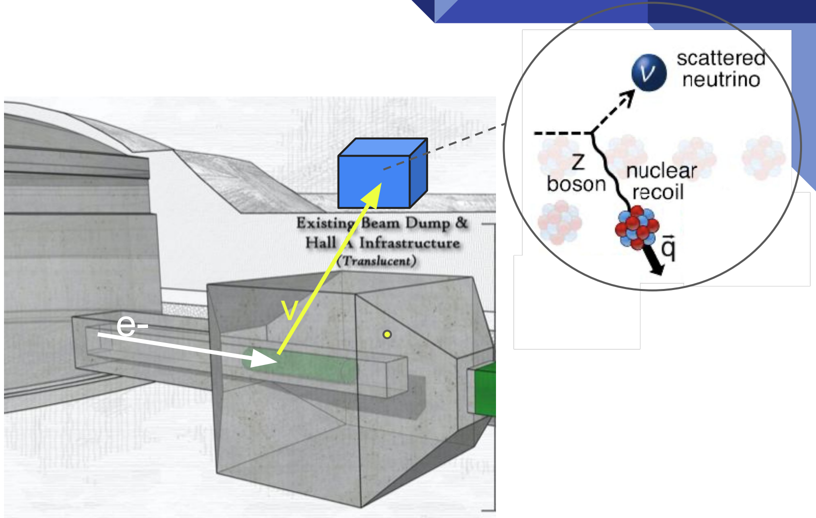


- **why interesting?**:
  - weak parameters -> mixing angle
  - nuclear properties -> neutrons distribution radius
  - sterile neutrino
  - neutrino magnetic moment
  - non standard interaction mediated by exotic particles

- **Requirements**:
  - High-intense ν-flux
  - ν-flux energy range: few MeV - few 100 MeV
  - detector has be sensitive to small energy depositions
  - backgrounds need to be sufficiently small to observe the signal.

CEvNS measurement @ JLAB

- **Beam**
  - Produced by the interaction between e- beam and Hall A dump in a energy range: 10MeV - 300 MeV
  - Neutrino flux @ 10 GeV : ~10^{18} ν/m^2 at ~10 m above the dump for 10^{22}EOT
  - **Neutrino flux @ 20 GeV : ~2x10^{18} ν/m^2** at ~10 m above the dump for 10^{22}EOT



- **Detector**:
  - Detector located 10m on top of the dump
  - Two detection technology are under study:
    - CsI
    - LAr-TPC
  - Veto system: active (plastic …) and passive (lead, water, borate silicone and/or cadmium sheet layers…)

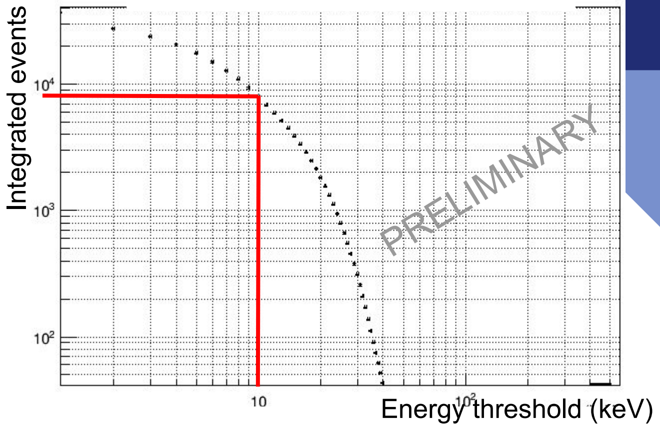
- **Backgrounds**:
  - beam-related background: neutron
  - beam-unrelated background: cosmic, radioactive detector contamination, environmental radioactivity
  - Backgrounds studies on-going using MC simulation
    - Measurements in situ to validate MC framework are necessary

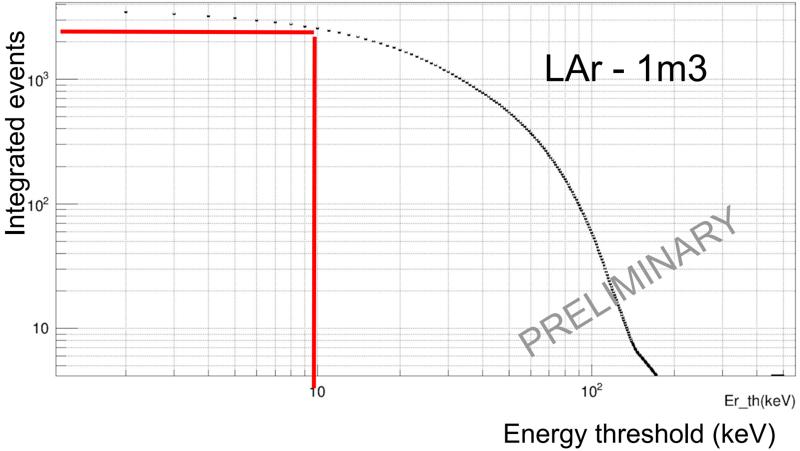
CEvNS @JLAB: expected yield

Detector	e- @ 10 GeV v flux: 1E8 v/m^2/year	e- @ 20 GeV v flux: 2E8 v/m^2/year
CsI (1m^3) [thr : 10 keV]	8000	
LAr (1m^3) [thr: 10 keV]	2500	

Credit to A. Fulci, S. Grazzi, A. Pilloni

e- beam @ 10 GeV

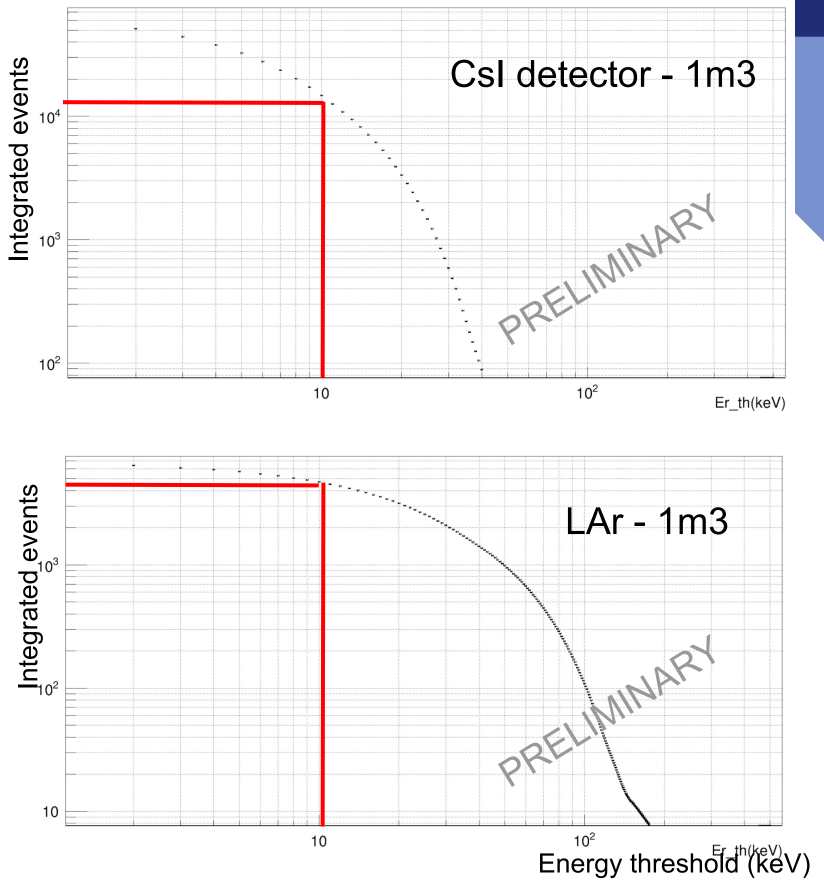




CEvNS @JLAB: expected yield

Detector	e- @ 10 GeV v flux: 1E8 v/m^2/year	e- @ 20 GeV v flux: 2E8 v/m^2/year
CsI (1m^3) [thr : 10 keV]	8000	~15000
LAr (1m^3) [thr: 10 keV]	2500	~4500

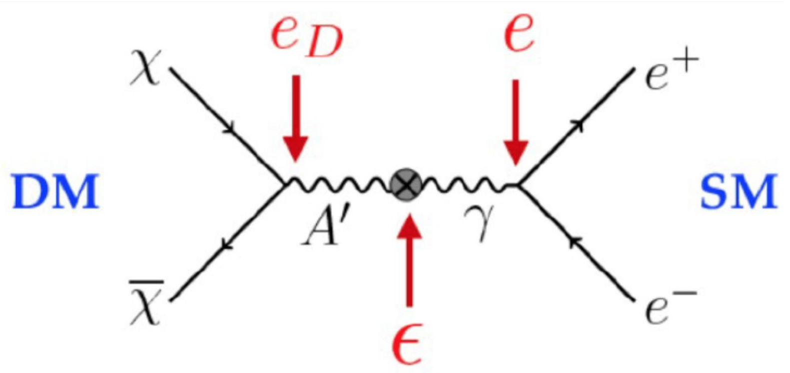
e- beam @ 20 GeV



Credit to A. Fulci, S. Grazzi, A. Pilloni

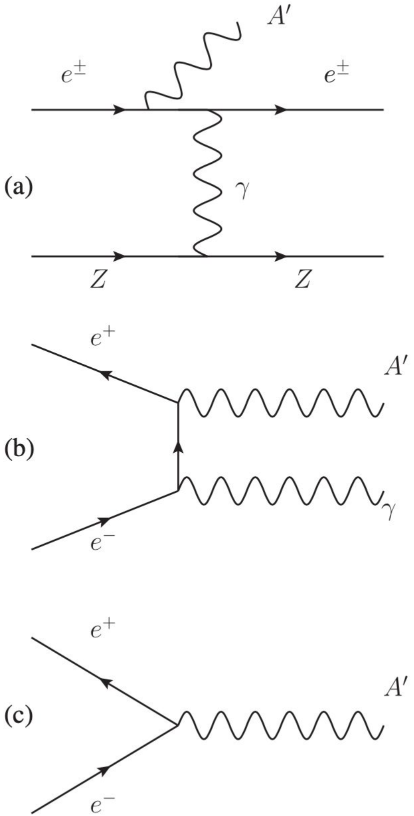
Light Dark Matter @ JLAB

- Dark Matter is there but **we know nothing about the particle content of DM**
- **New promising hypothesis: Light Dark Matter in the mass range 1MeV - 1GeV**
- Simplest possibility**: vector-portal:** DM-SM interaction through a new U(1) gauge-boson ("dark photon") coupling to electric charge
- Model parameters:
  - Dark-photon mass, $M_{A'}$ and coupling to electric charge ε
  - Dark matter mass, M_{x} and coupling to dark photon g_{D}



Light Dark Matter: production

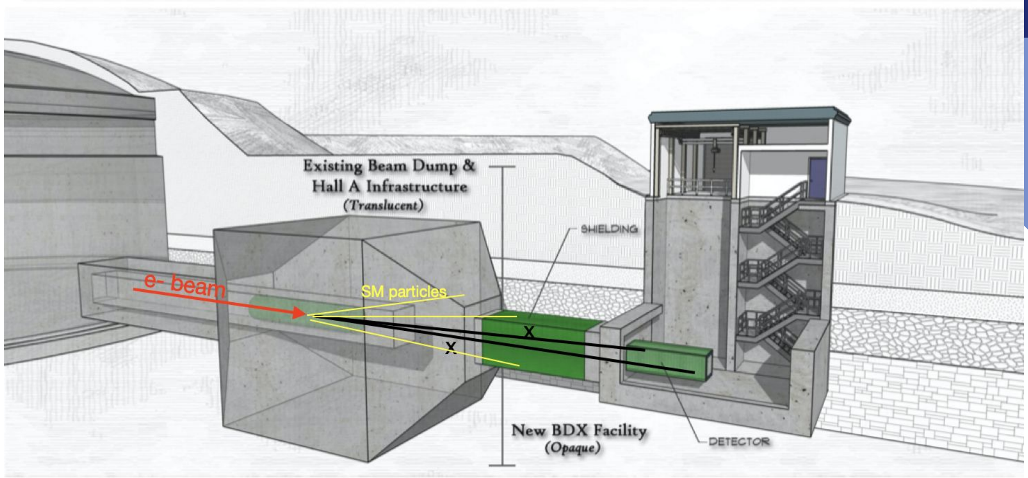
Three main production mechanisms in fixed targets, lepton beam experiments:



- **A) A'-strahlung**:
  - Radiative A' emission in nucleus EM field followed by A'->XX
  - Scales as $Z^2\alpha^3$
  - Forward-boosted, high-energy A' emission
- **B) Non-resonant e+e- annhilation**:
  - e+e- -> A'γ followed by A'->XX
  - Scales as $Z\alpha^2$
  - Forward-backward A' emission in the CM
- **C) Resonant e+e- annhilation**:
  - e+e- -> A'->XX
  - Scales as $Z\alpha$
  - Breit-Wigner like cross section with $M_{A'} = \sqrt{2m_e E}$

Beam Dump eXperiment @ JLAB

- BDX is a **JLAB experiment** approved by PAC46
- Unique experiment able to **PRODUCE** and **DETECT** light dark matter
- Two step experiment:
  - **production** of LDM beam
  - **detection** of LDM particle: χ scatters on e- in the detector realising visible signal



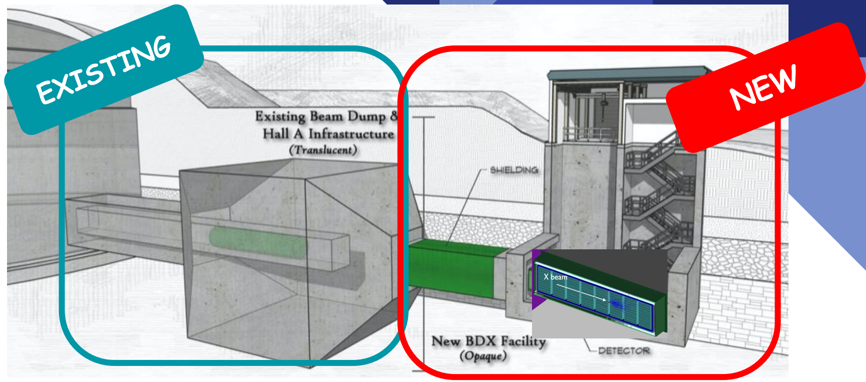
The experiment is designed with two goals

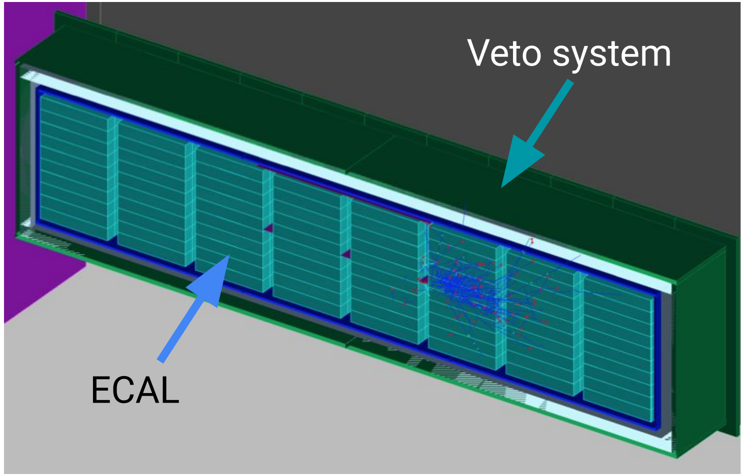
- **Maximize production and detection of LDM**
  - Number of expected events scales as ε^4
  - high intensity beam
  - ~1m3 detector - medium/high density material

- **Reduce backgrounds**
  - cosmic backgrounds
  - beam-related backgrounds
  - passive shielding material and active veto system

Beam Dump eXperiment @ JLAB

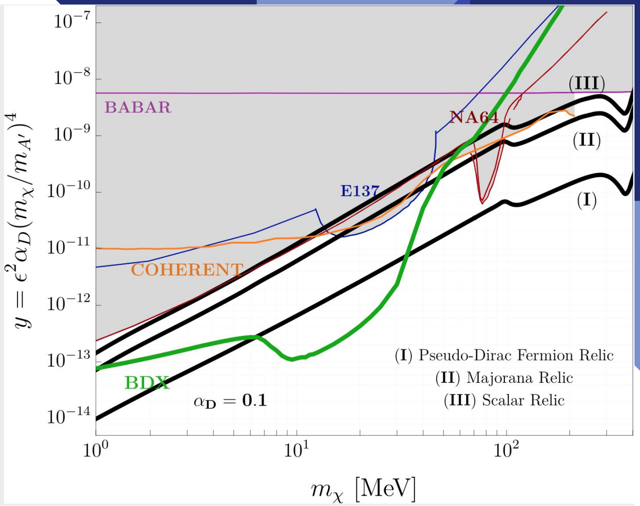
- **JLAB offers the best condition for BDX**
  - A high energy beam: 11 GeV
  - The highest available electron beam current: ~65uA (currently)
  - Charge : 10^22 EOT
  - Fully parasitic wrt Hall-A physics program
- **New facility to be built** in front of Hall-A beam dump
  - Passive shielding layer between beam dump and detector to reduce SM beam-related background
  - Sizeable overburden (~10 m water-equivalent) to reduce cosmogenic background
  - New underground hall (~8m) at 25 m downstream hall-A beam dump that will host the detector
- **Detector with 2 components:** Ecal + Veto system
  - ECAL: 800 CsI(Tl) crystals
  - Veto system:
    - two layers of plastic scintillator counters,
    - lead passive layer

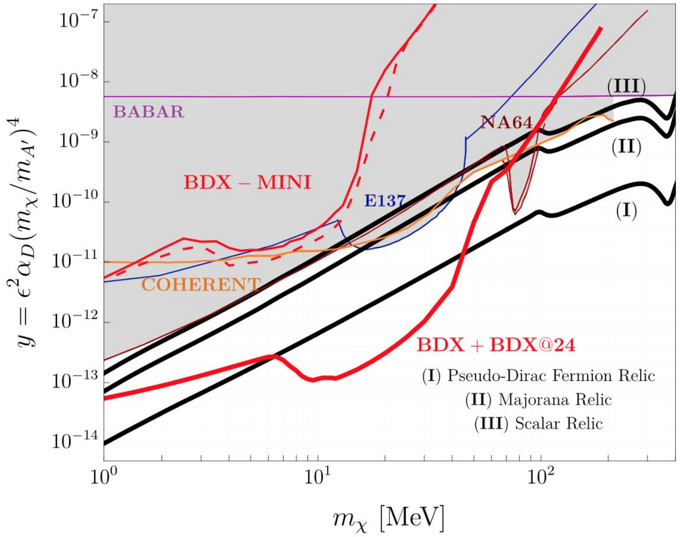




Beam Dump eXperiment @ JLAB

- The BDX experiment is meat to run with 12 GeV e- beam
- BDX can benefit of **24 GeV e- beam** extending the reach
    - Pro:
        - Increase number of secondary particles in the dump -> enhanced DM production
        - Some DM production mechanisms (resonant annihilation) are strongly dependent on the beam energy
    - Drawbacks:
        - Increased beam-related background
            - μ shielding may not be sufficient -> rethink experimental setup
            - ν background increased -> need to study





Summary

- High intensity extracted electron beams are a precious source of secondary beams:
  - Light Dark Matter (if exists)
  - Neutrinos
  - Muons
  -
- A 24 GeV primary electron beam impinged on Hall-A dump can produce higher intensity secondary beams then the 12 GeV one
  - Neutrino beam with a DAR spectrum : flux of 2E8 ν/m^2 for 10^{22} EOT - e-@ 20 GeV
  - Muon beam with a Bremsstrahlung-like spectrum. Energy range : O(10 MeV) - O(10 GeV). Flux @ 20 GeV : 5E-6 μ/EOT.
- Secondary beams can be exploited to explore “hot” physic cases