Beyond hadronic physics with secondary beams @JLAB:

Mariangela Bondì
INFN - Sezione di Roma Tor Vergata
Università di Roma Tor Vergata

Istituto Nazionale di Fisica Nucleare

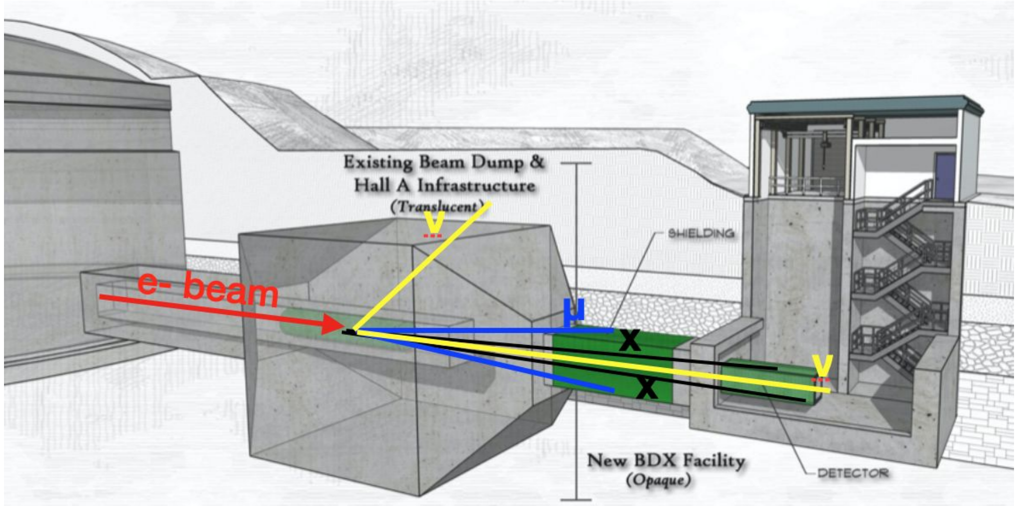
Jefferson Lab

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

New research lines using secondary beams

❖ The interaction of high-current (O(100μA)), medium-energy (O(10GeV)) electron beam with a dump produces intense secondary beams:

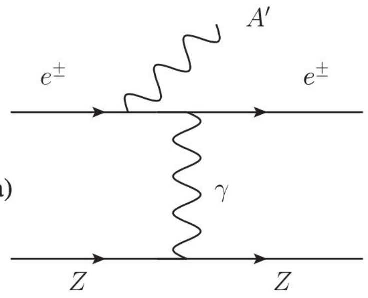
- ➢ Light Dark Matter (if exists)
  - ■ BDX
- ➢ Neutrinos
  - ■ CEvNS
- ➢ Muons
  - ■ Proton radius



Light Dark matter beam: production

In the "dark sector" scenario, 3 main LDM production mechanisms in fixed-target, lepton-beam experiments

(a)



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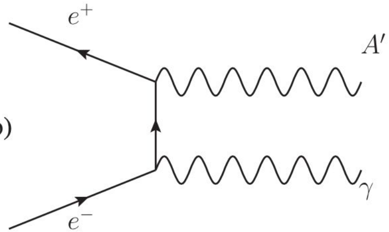

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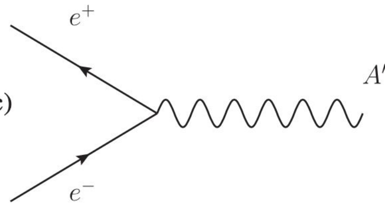
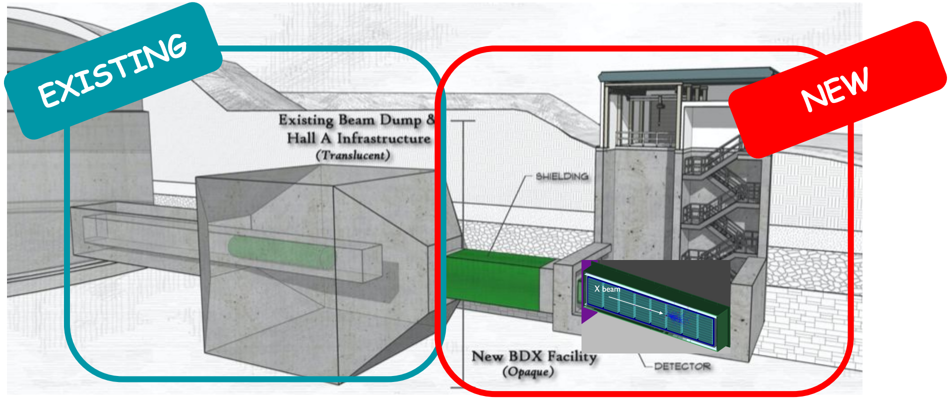


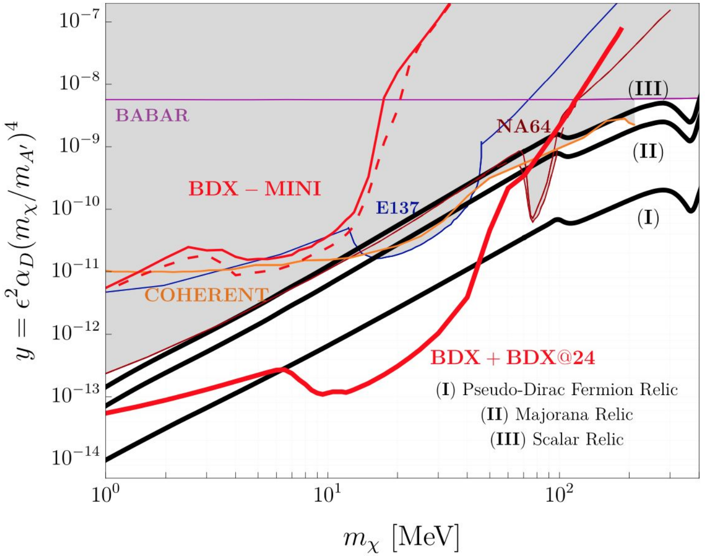
- **A) A'-strahlung**:
  - Radiative A' emission in nucleus EM field followed by A'->XX
  - Scales as $Z^2\alpha^3$
  - Forward-boosted, high-energy A' emission
- **B) Non-resonant e+e- annhilation**:
  - e+e- -> A'γ followed by A'->XX
  - Scales as $Z\alpha^2$
  - Forward-backward A' emission in the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

BDX @ 20 GeV e- beam

- The Beam Dump Experiment is **optimized** to run @ **12 GeV e- beam**
  - Fully parasitic wrt Moller experiment
  - New facility (Civil construction + passive shielding) downstream HallA beam dump
  - Detector : EM calorimeter + Veto systems



- BDX can benefit of **24 GeV e- beam** extending the reach
  - Pro: Increase number of secondary particles in the dump -> enhanced DM production
  - WARNING: beam-related background need to be studied

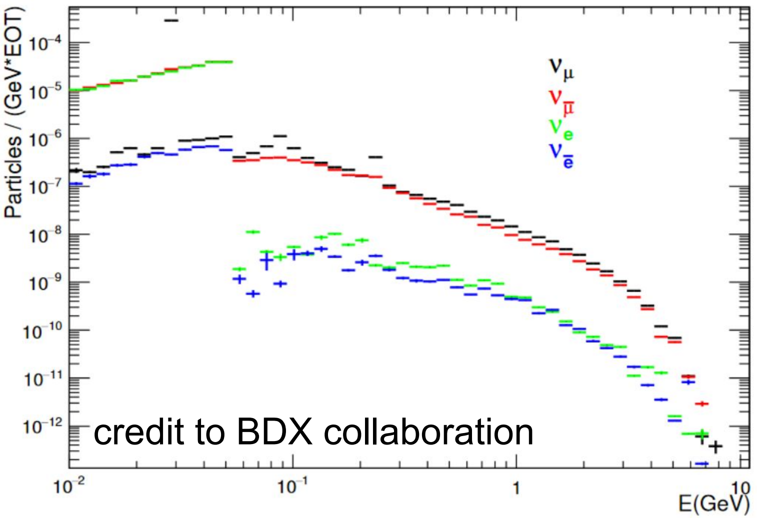


see M. Spreafico talk

Neutrino production in the dump

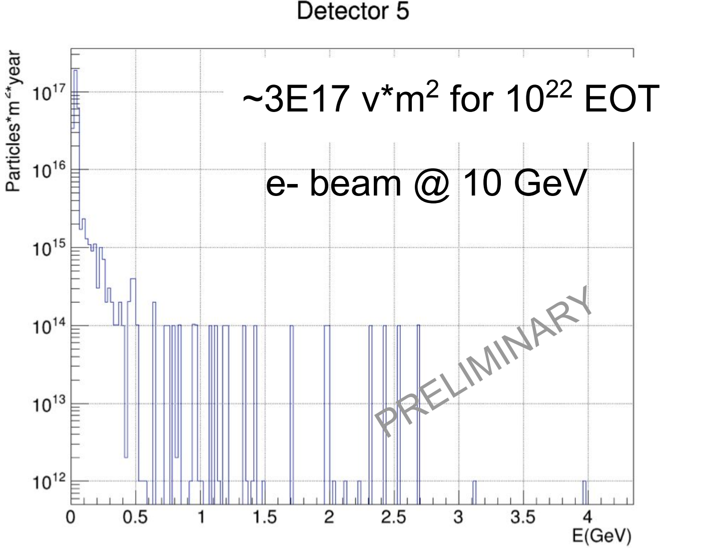
- Neutrinos production in the dump due to muon and pion decays
  - The majority (low-energy v) come from pion and muon decay at rest
    - π decay produces a prompt 28.5 MeV v_μ along with a μ which subsequently decay producing v_e e v_m
    - Weak angular dependence
  - High-energy v from in-flight pion and muon decay

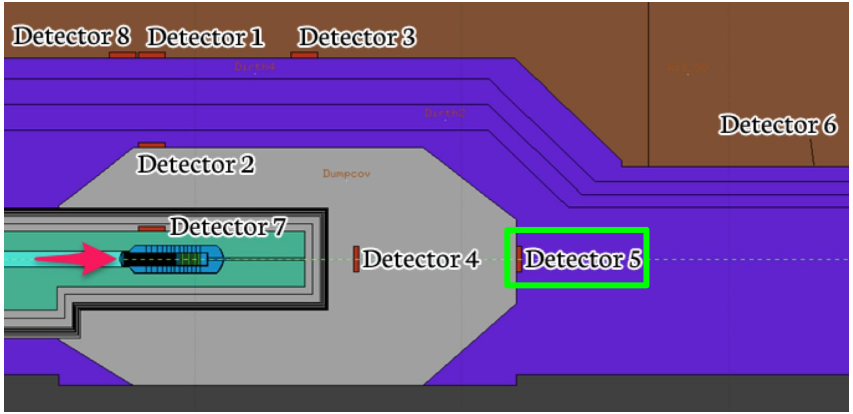
FLUX scored on a plan 25 m downstream
HALLA-BD - 10GeV e- beam

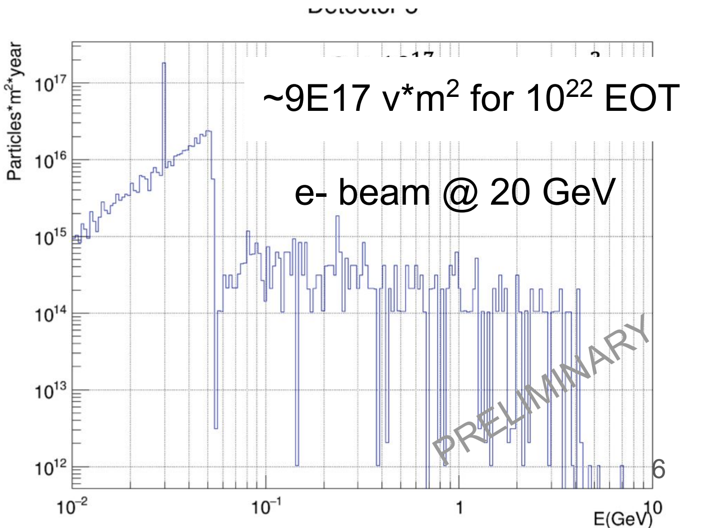


Neutrino secondary beam

- Neutrinos flux estimated through MC simulations based on FLUKA
  - Used Hall-A beam dump description implemented in FLUKA by the JLAB Rad Con
  - Neutrino flux evaluated both for 10Gev e- beam and 20GeV e- beam
    - used current dump (not optimized) for 20GeV simulation
  - Flux computed on several planes located both downstream and on top of Hall-A beam dump







Credit to A. Fulci

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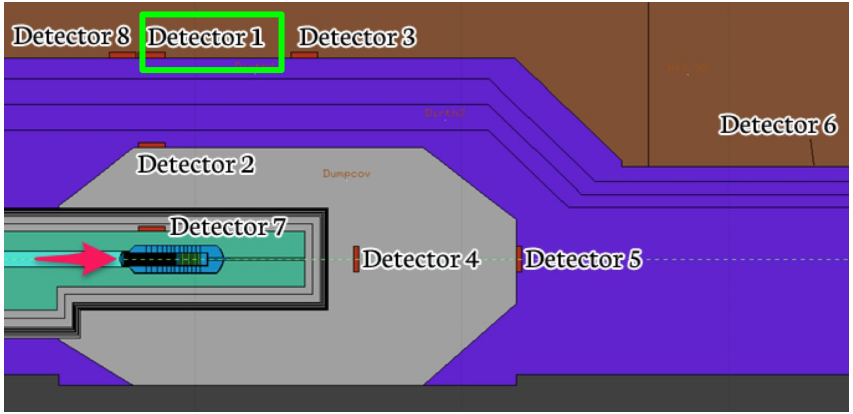
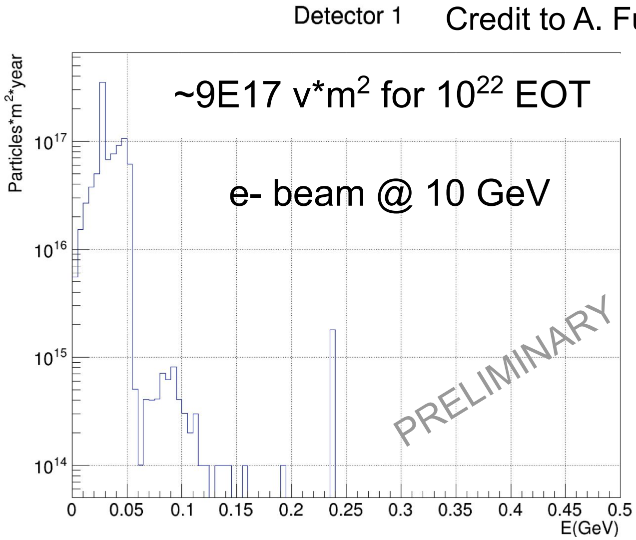
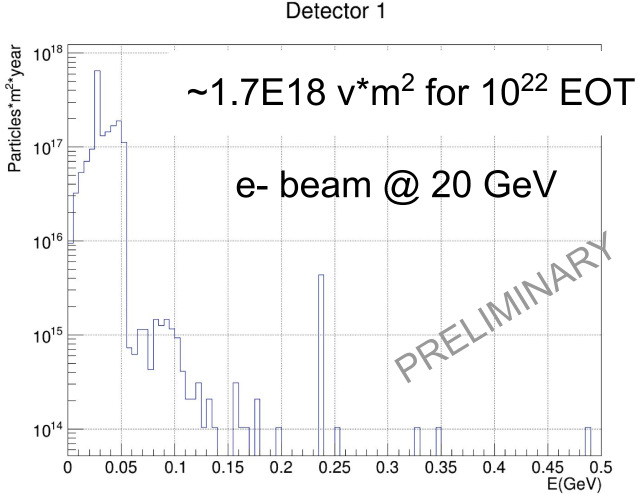
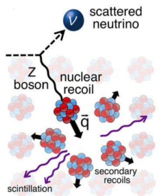
  - ➢ Flux computed on several planes located both downstream and on top of Hall-A beam dump
  - ➢ Flux comparable to SNS@ Oak Ridge National Lab one







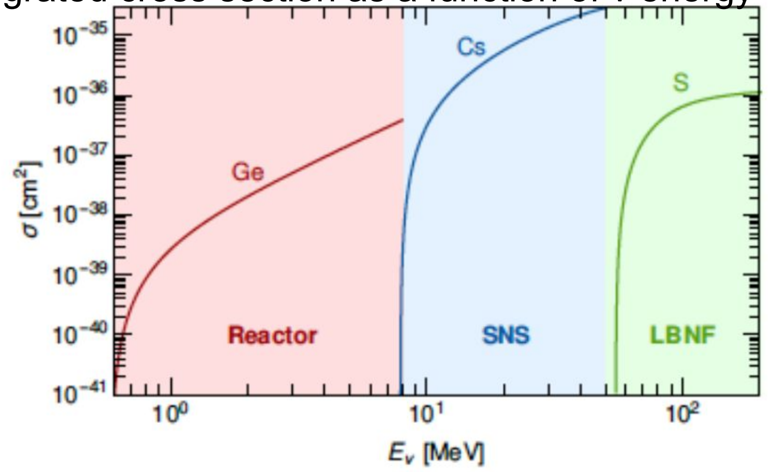
Physics case for a Neutrino beam @ JLAB



❖ **Coherent Elastic ν-Nucleus Scattering**

- ➢ 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 Eν < 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?**:

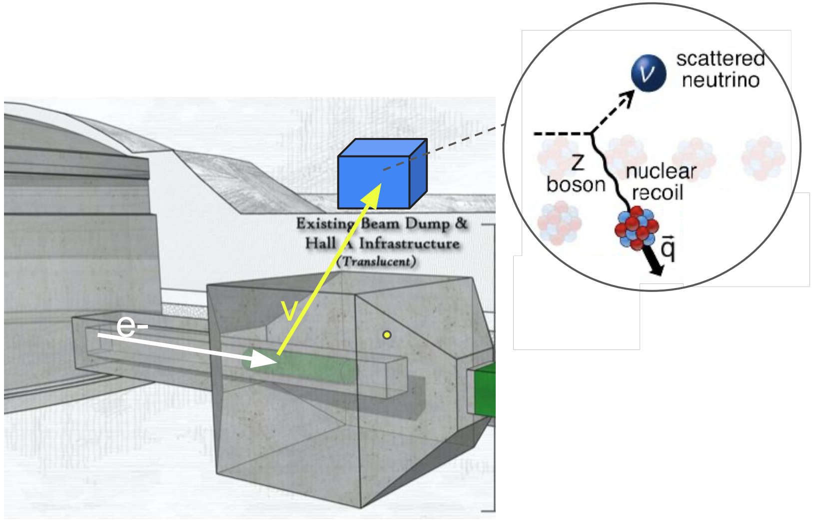
- ➢ weak parameters -> mixing angle
- ➢ nuclear properties -> neutrons distribution radius
- ➢ sterile neutrino
- ➢ neutrino magnetic moment
- ➢ non standard interaction mediated by exotic particles

❖ **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

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

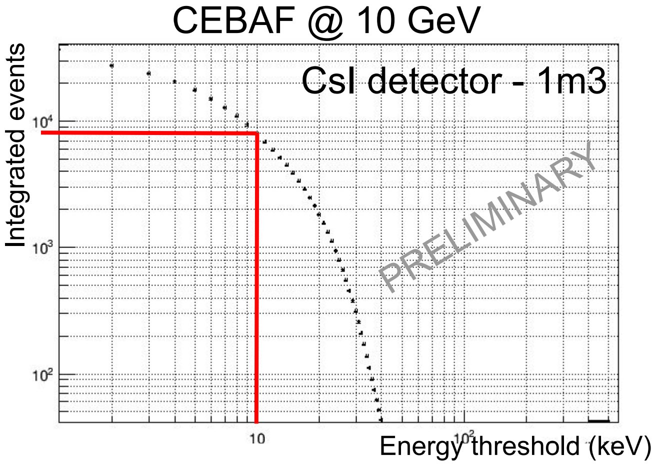


- **Detector technologies**:
  - Detector located 10m on top of the dump
  - Two detection technology are under study:
    - CsI
    - LAr-TPC
  - Veto system: active (plastic …) and passive (lead, water, borate silicone and/or cadmium sheet layers…)

- **Backgrounds**:
  - beam-related background: neutron
  - beam-unrelated background: cosmic, radioactive detector contamination, environmental radioactivity
  - Extensive Monte-Carlo simulations and measurements campaign in situ are necessary

CEvNS measurement @ JLAB

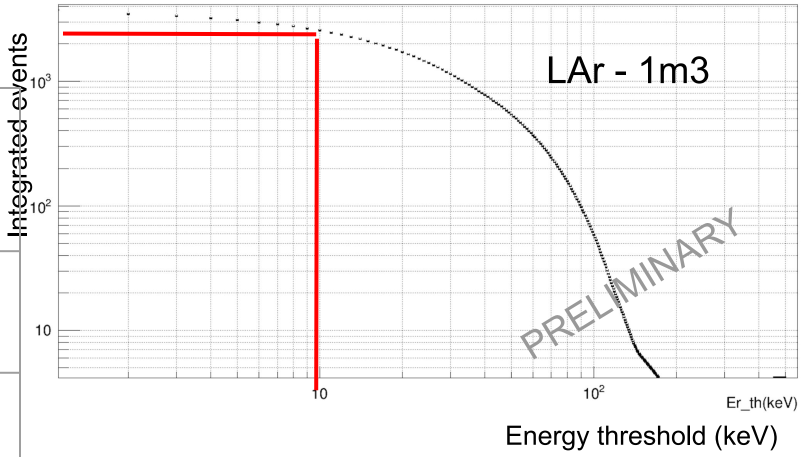
- **Two targets under study:**
  - CsI(TI) crystal:
    - Pro: High-density, high LY, heavy nuclei
    - Cons: radioactive material, afterglow
  - Liquid Argon based detector:
    - Pro: Low threshold, directionality
    - Cons: depleted Ar



- **Expected yield:**

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

(*) for 10^{22} EOT



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

vBDX-CEvNS @ 20 GeV

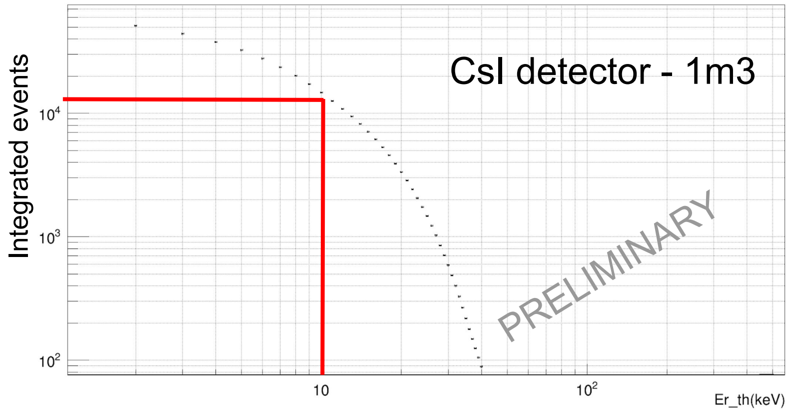
- **Two targets under study:**
  - CsI(Tl) crystal:
    - Pro: High-density, high LY, heavy nuclei
    - Cons: radioactive material, afterglow
  - Liquid Argon based detector:
    - Pro: Low threshold, directionality
    - Cons: depleted Ar

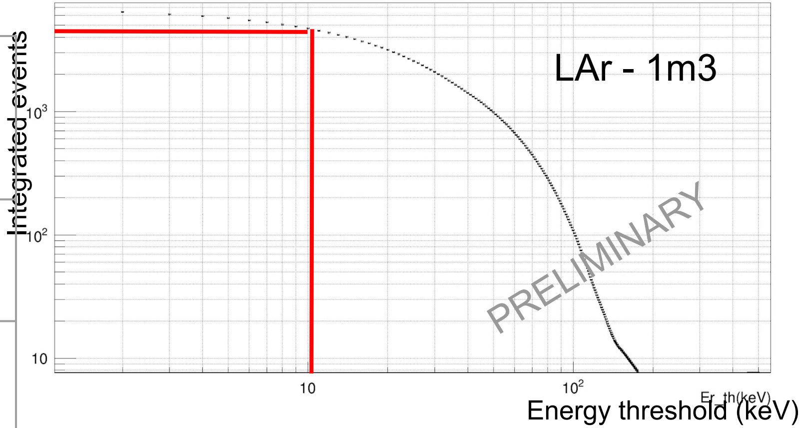
- **Expected yield:**

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

(*) for 10^{22} EOT

CEBAF @ 20 GeV

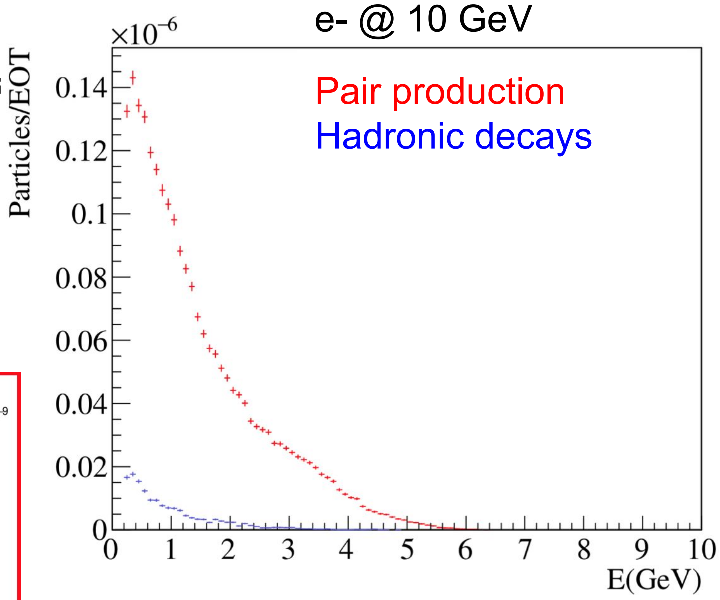




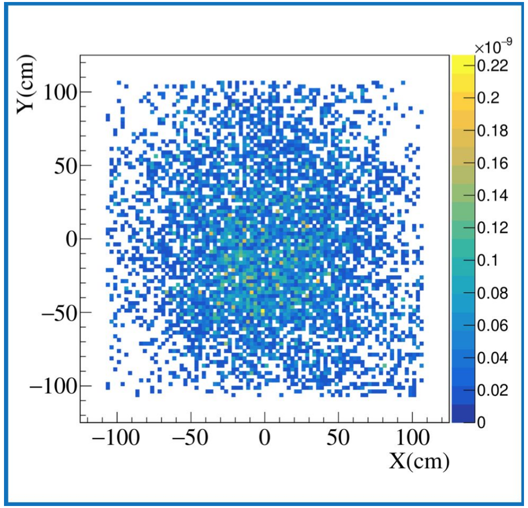
Credit to A. Fulci, S. Grazzi, A. Pilloni

Muon production in the dump

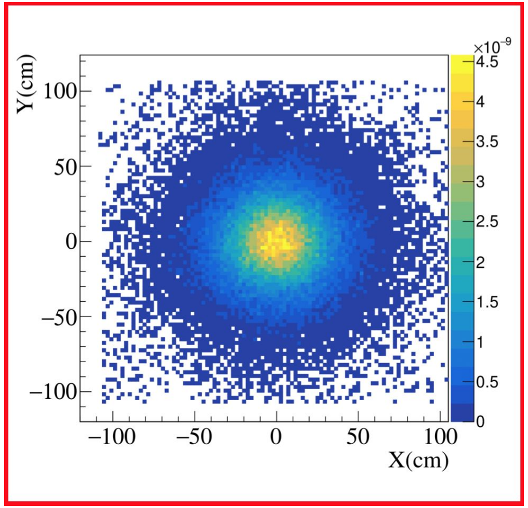
- Muon flux estimated using the same FLUKA setup used for neutrinos
- High energy muons are produced in the dump via 2 processes:
  - Photo-production of π and K
  - pair production: $\gamma N \to \mu\mu N$



Spatial distribution



Hadronic decays

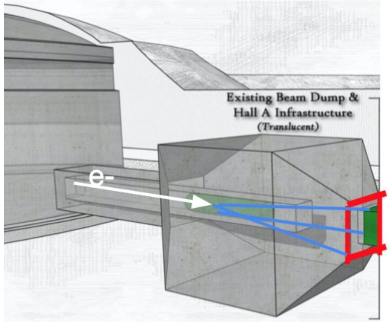


Pair production

Credit to A. Fulci

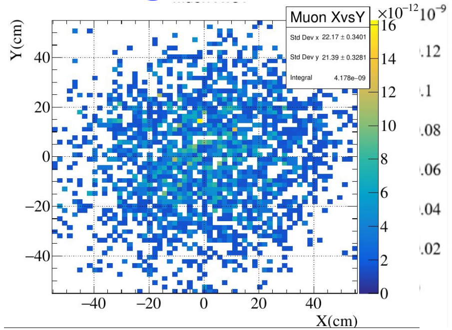
Credit to A. Fulci

Muon secondary beam

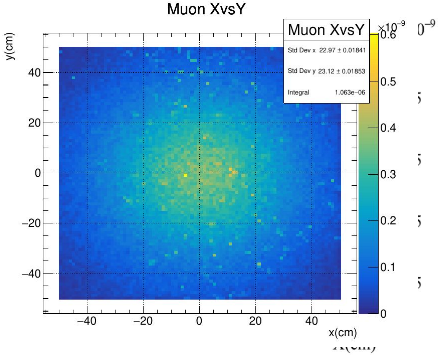


- Muon flux estimated using the same FLUKA setup used for neutrinos
  - Flux scored on a plane to exit of the concrete dump
  - Flux is larger than CERN's M2 beam line one (Eμ>100GeV)

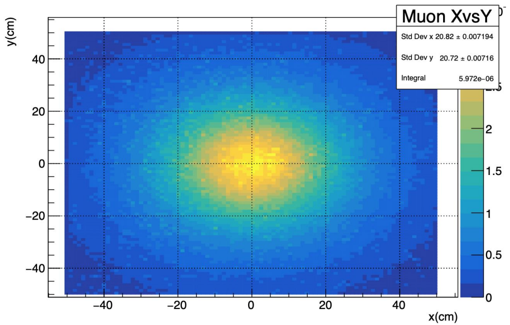
e- beam @ 6 GeV

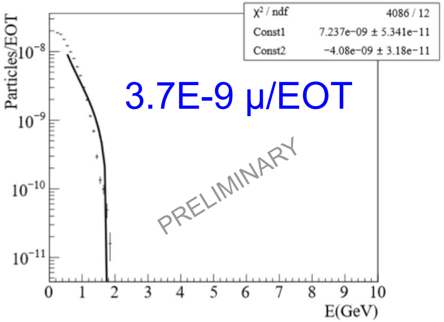


e- beam @ 12 GeV

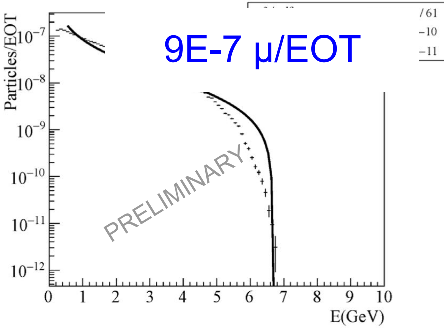


e- beam @ 24 GeV

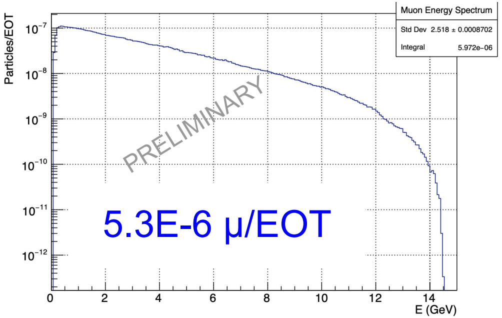




3.7E-9 μ/EOT



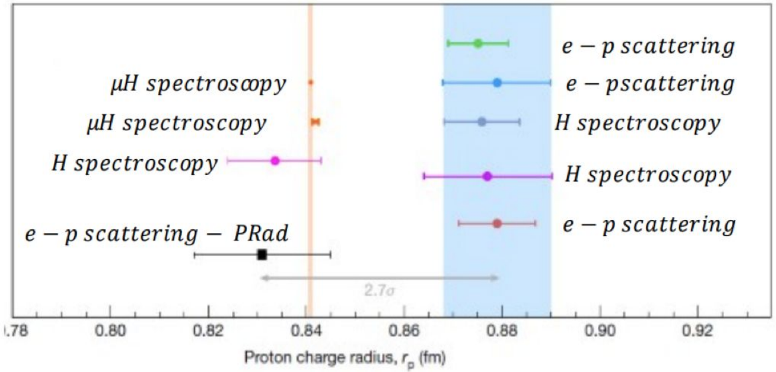
9E-7 μ/EOT



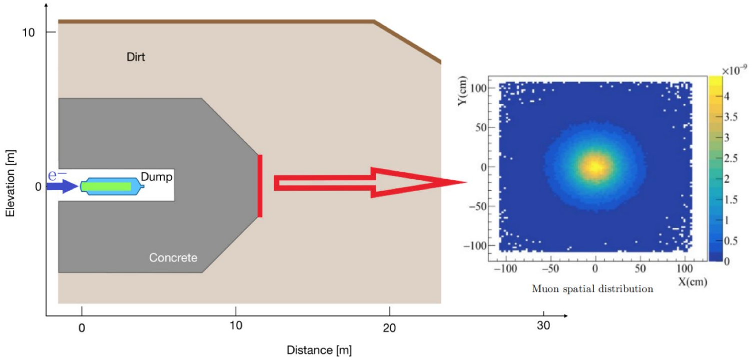
5.3E-6 μ/EOT

Proton radius measurement with muon beam

- Proton radius can be measured with 2 techniques:
  - Leptonic scattering
  - Spettroscopi measurement
- Persistent discrepancy between methods -> Proton radius puzzle



- Secondary muons produced in HALLA beam dump can be extracted and directed toward a new Hall
  - A magnet-based system to focus and to measure μ momentum -> study on going



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” physics scenario