H2020 MSCA RISE 2020
GA 101003460

Work Package 2: Hadron Physics Data Analysis

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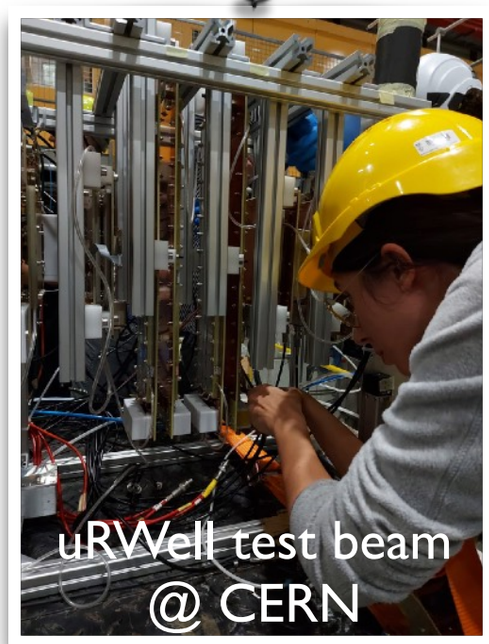
Outlook:

- Data Analysis workflow
- From nuclei to neutron stars
- 3D imaging of the nucleon
- Dark sector

About me……



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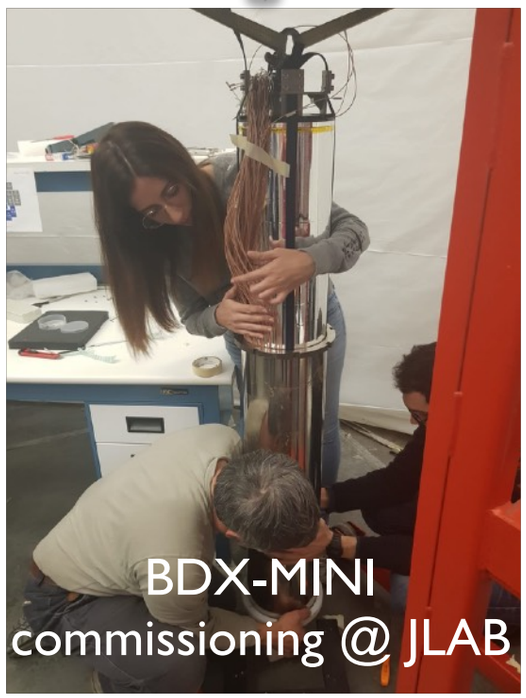
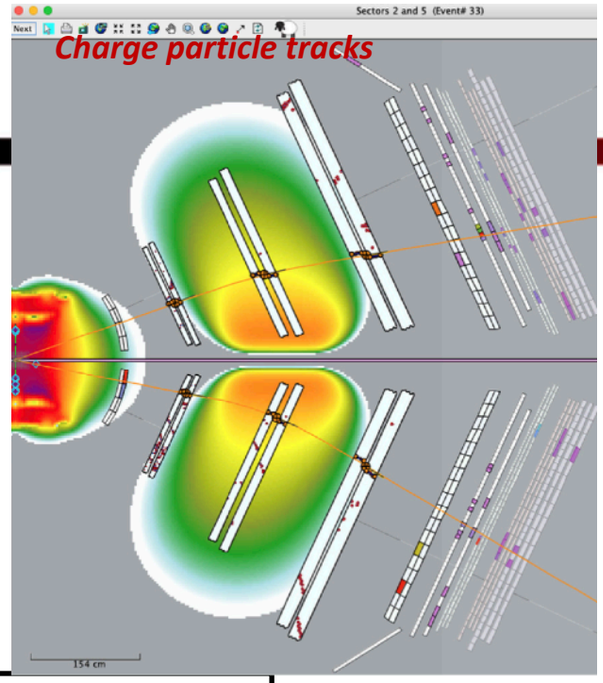
Affiliation: INFN - Sezione Catania
Job position: Technologist
Fields of interest:

- Dark Matter
- Nuclear physics
- Nuclear science application
- Detectors
- Outreach

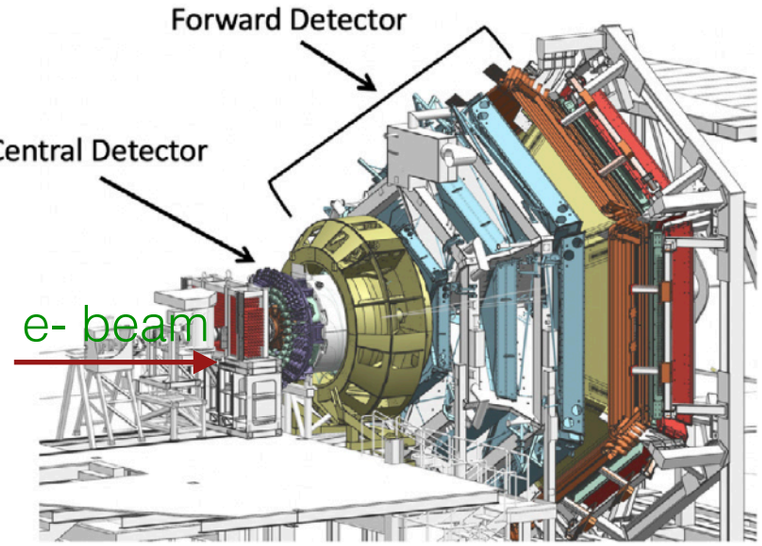


Data Analysis workflow



Charge particle tracks

DATA TAKING



ROW DATA FROM SEVERAL SUBSYSTEMS

CLARA

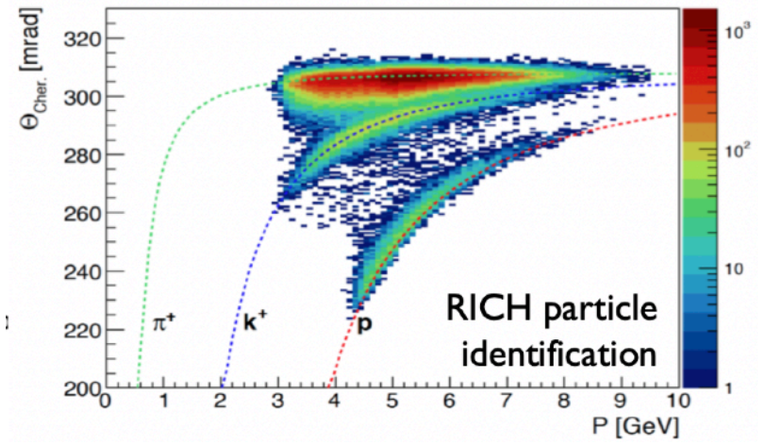
- ***CALIBRATION***
- ***RECONSTRUCTION***
- ***EVENT SELECTION***

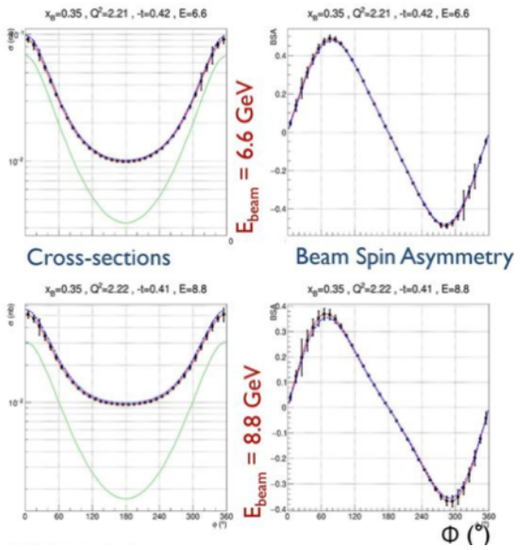
RECONSTRUCTED EVENTS

PHYSICS ANALYSIS

↓

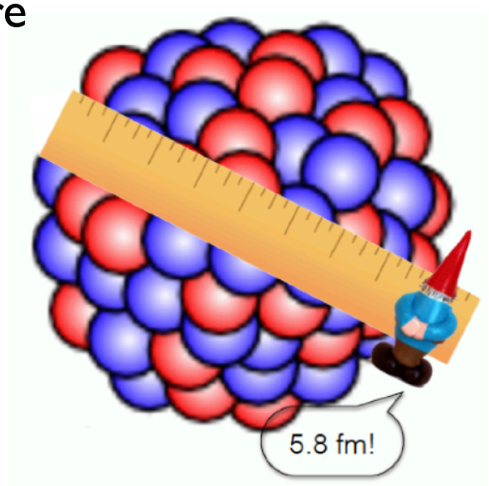
PHYSICS QUANTITIES

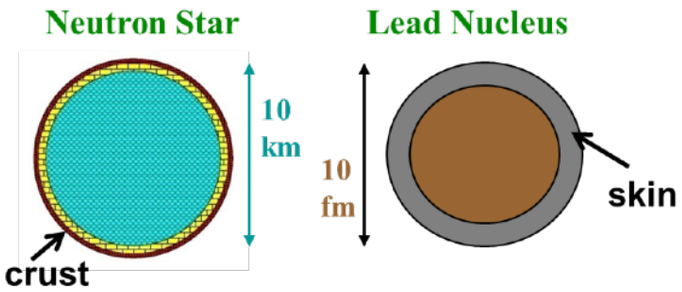




From nuclei to Neutron stars

- For nuclei with Z=N, proton and neutron density distributions are expected to have a similar shape
- For nuclei with N>>Z, the excess neutrons are pushed out to the periphery forming a **neutron skin**

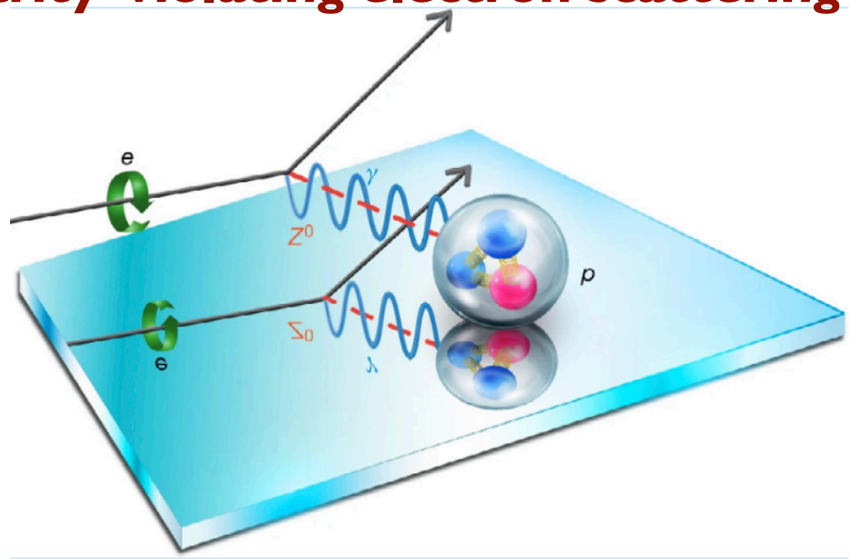




The thickness of the neutron skin is sensitive to the equation of state for nuclear matter, providing a terrestrial laboratory to study the behavior of the extremely dense nuclear matter contained within neutron stars

- Proton distribution:
  - Owing to the electric charge, this has been accurately measured for many atomic nuclei
- Neutron distribution:
  - Poorly known
  - Parity-violating electron scattering: via the weak charge

Parity-violating electron scattering

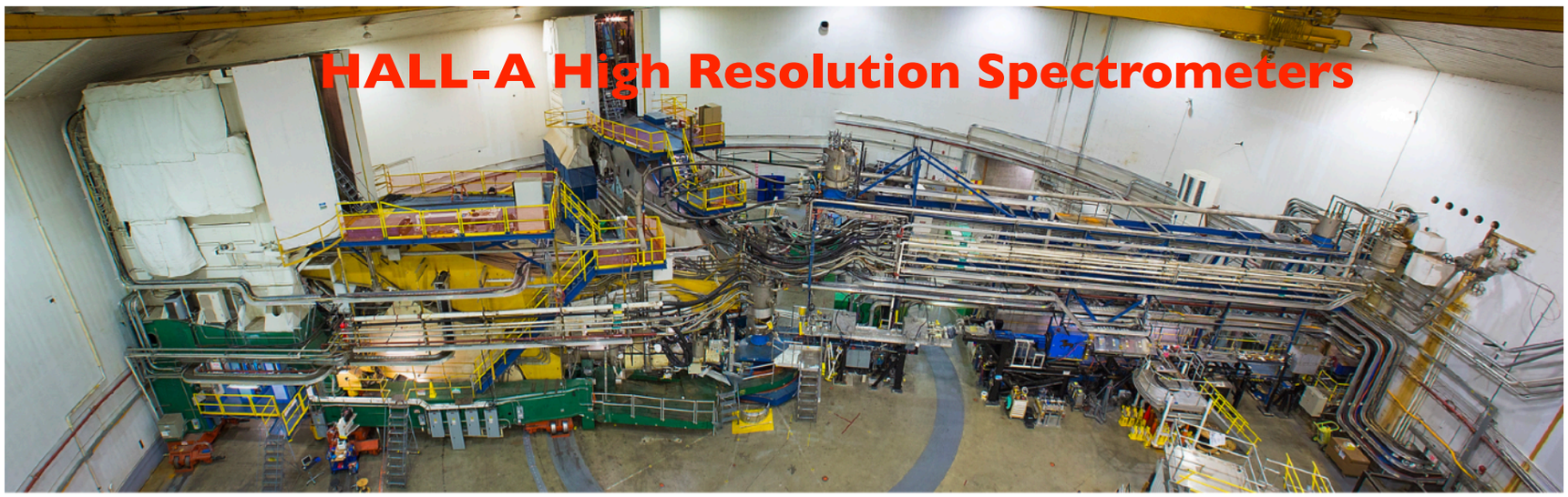


The weak interaction causes a difference between scattering left-handed electrons and its mirror image, scattering of right-handed electron

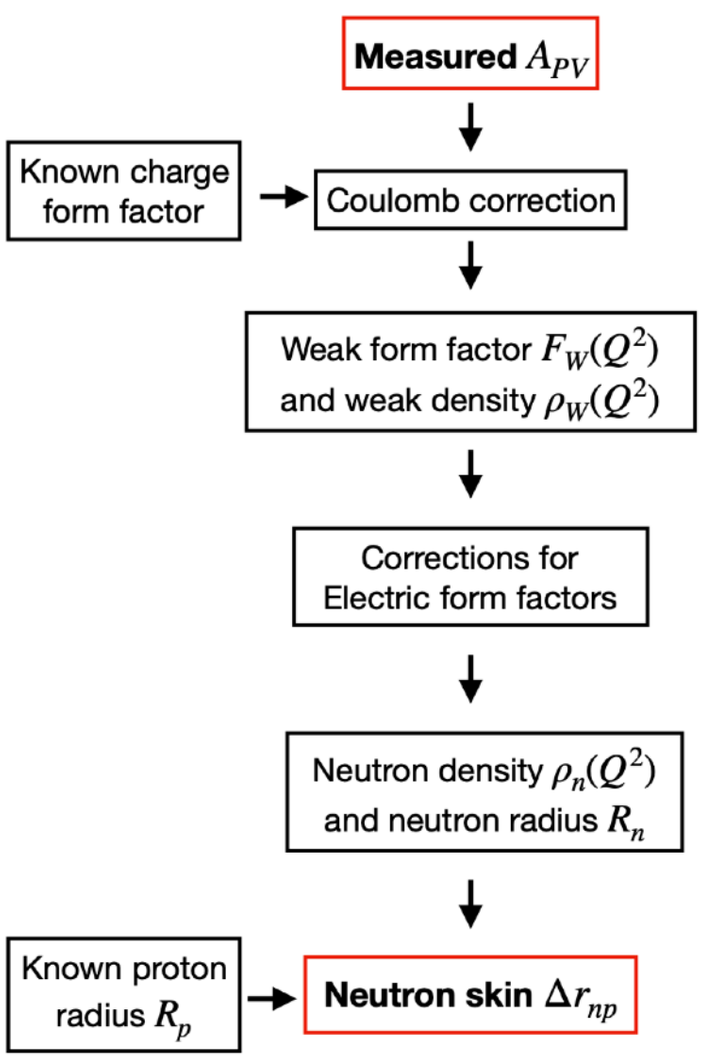
PREX / CREX Experiments at JLAB: ^{208}Pb and ^{48}Ca Neutron skin measurements.

T2.2: Investigate strongly correlated fermionic systems

High-precision PVES measurements at JLAB-HALL-A aimed to estimate the neutron skin of lead-208 and calcium-48

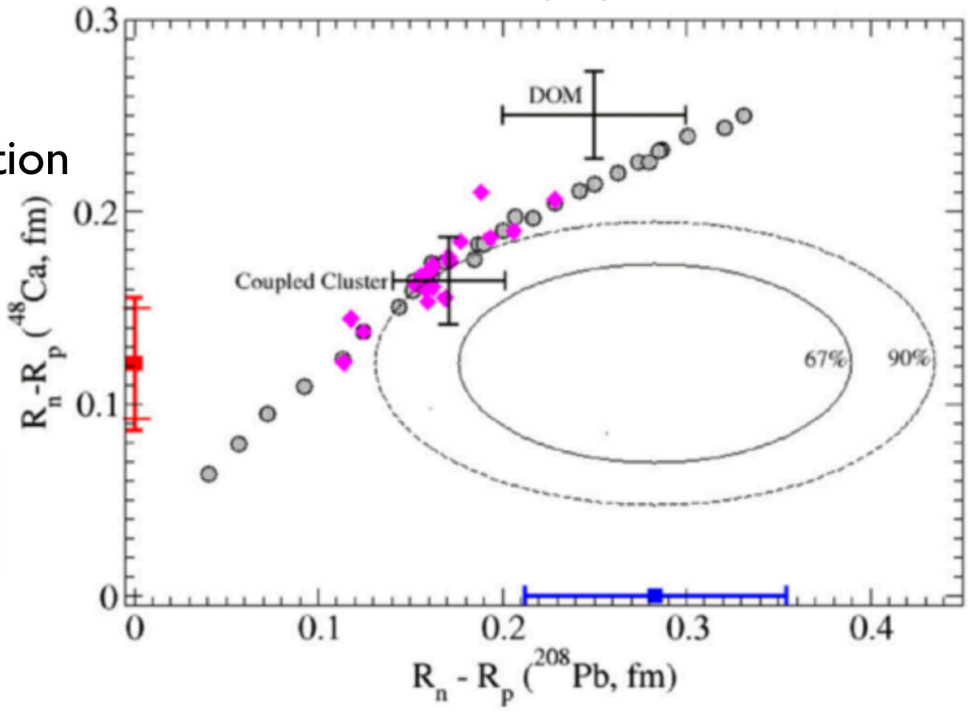


Precise determination of the neutral weak form factor of ^{48}Ca.
PRL 129 (2022) 042501



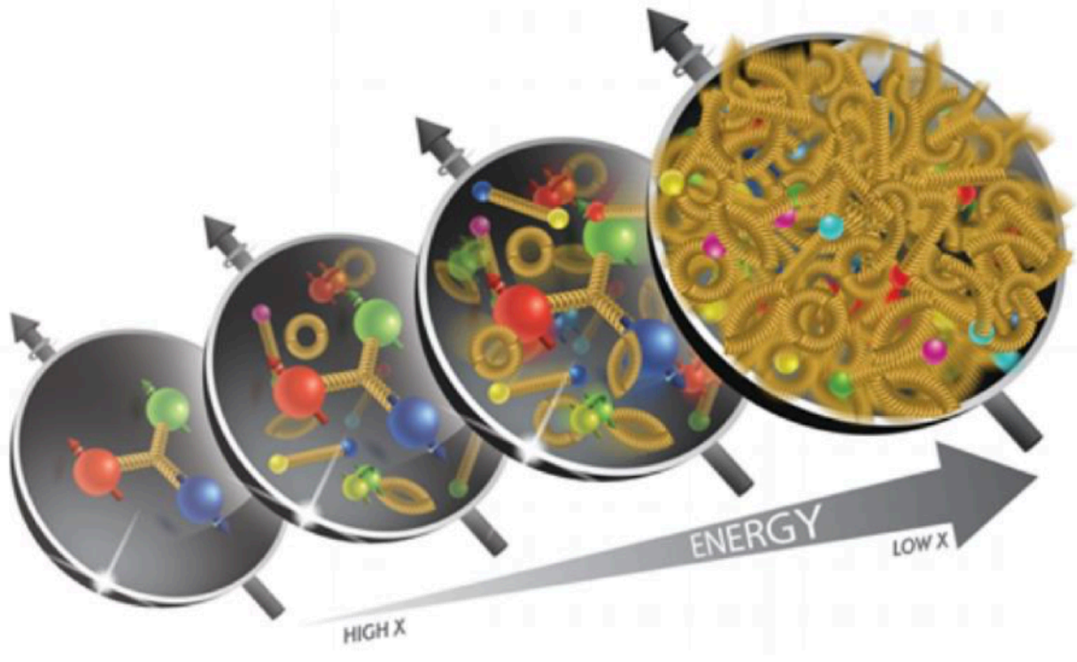
From the asymmetry A_{PV} (fractional difference in the e- target cross section when the polarization of e- beam is reversed) to the Neutron Skin

$$A_{PV} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[1 - \underbrace{4\sin^2\theta_W} - \frac{F_N(Q^2)}{F_P(Q^2)}\right]$$

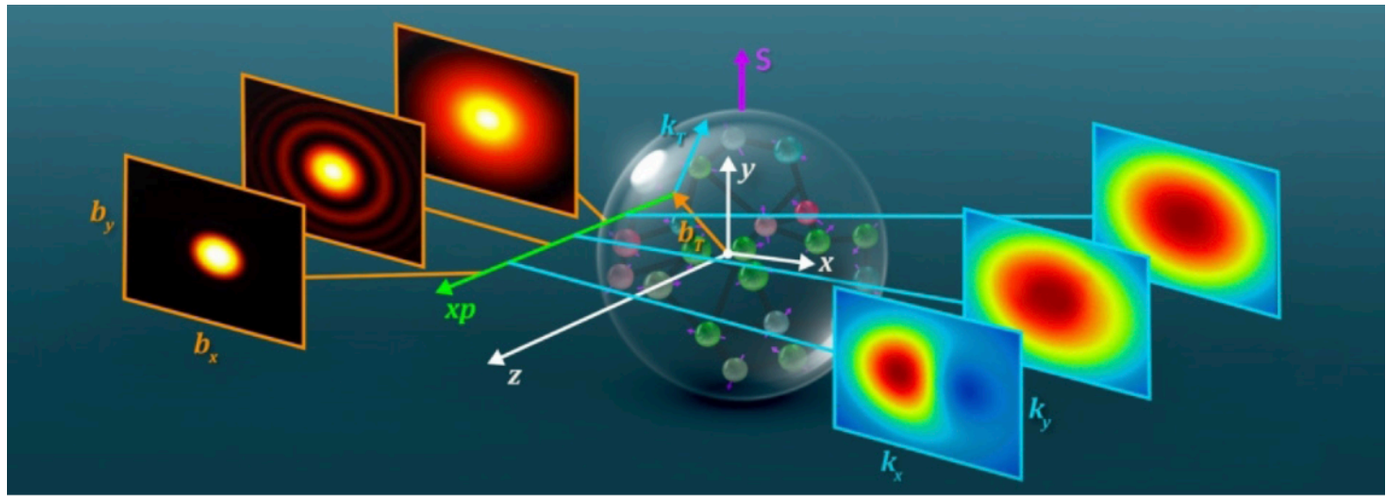


3D imaging of the nucleon

The 3D imaging of the nucleon, is made possible by electron scattering measurements and has the potential to describe the nucleon's internal structure as completely as possible.



Spatial distribution in transverse location known as **Generalized Parton Distribution GPD**



Transverse momentum distribution (TMD) encode information on how the momentum of quarks and gluons are correlated with the parent hadron properties

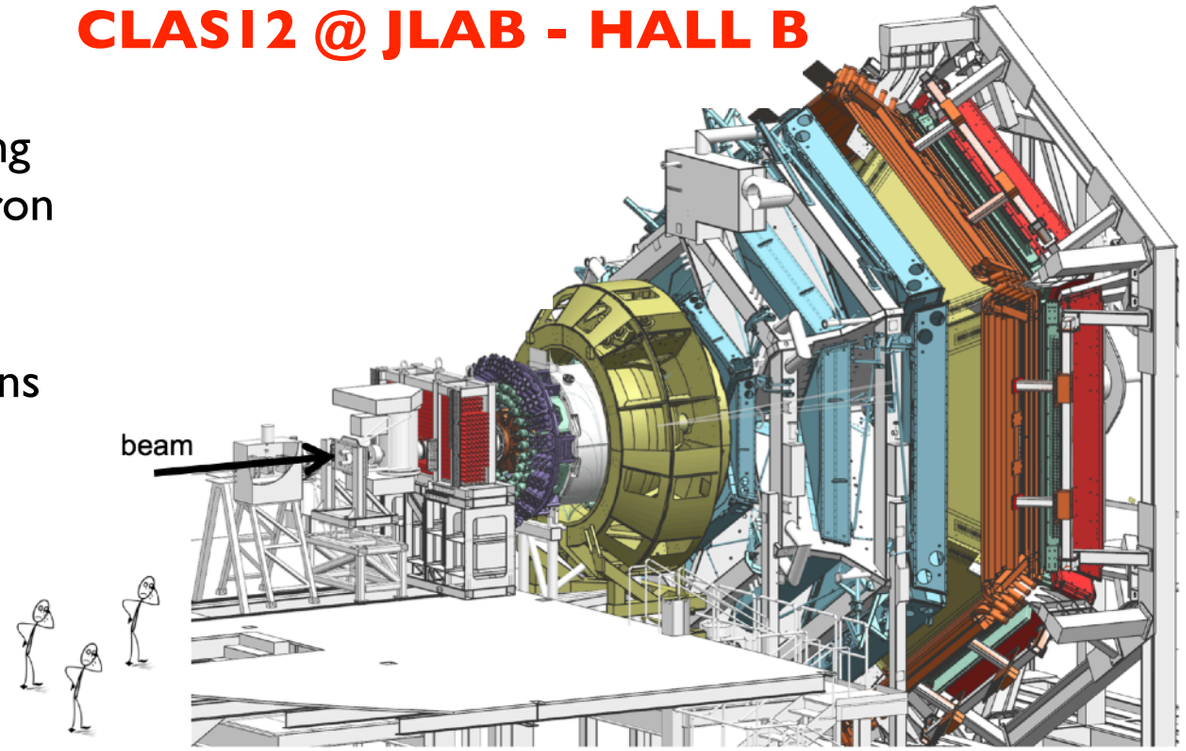
3D imaging of the nucleon at CLAS12

T2.3: Nucleon tomography at femto-scale

- First measurement of the DVCS beam-spin asymmetry using the CLAS12 spectrometer with a 10.2 and 10.6 GeV electron beam scattering from unpolarised protons (ep -> e'p'γ) .

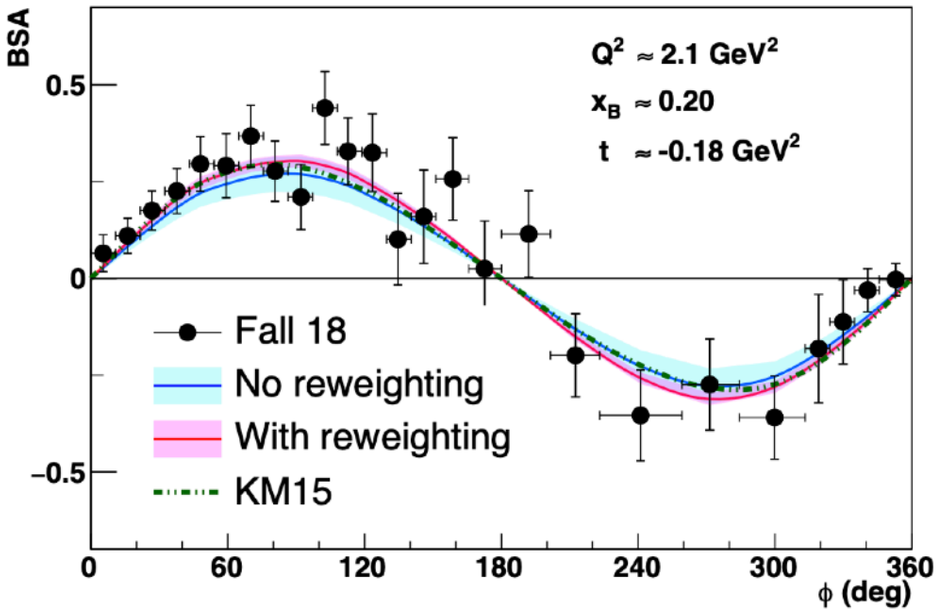
- DVCS allows one to probe Generalized Parton Distributions (GPDs) describing the 3D structure of the nucleon.

CLAS12 @ JLAB - HALL B



First CLAS12 Measurement of DVCS Beam-Spin Asymmetries in the Extended Valence Region

PRL 130 (2023) 21, 211902



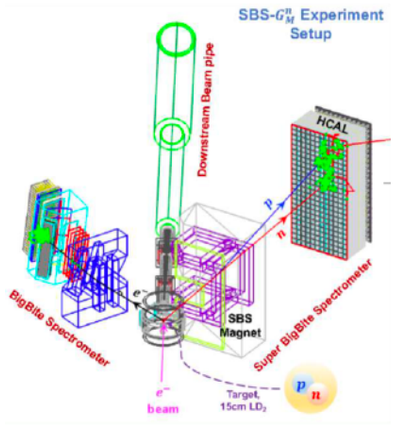
This measurement greatly extends the x and Q^2 phase space beyond the existing data in the valence region with unprecedented statistical precision.

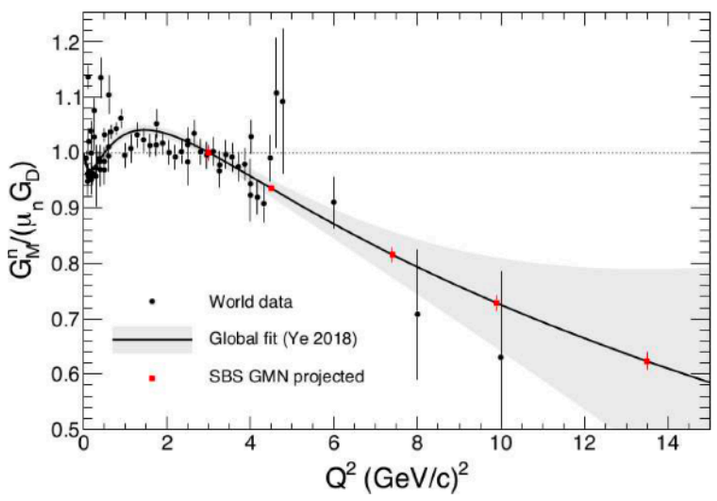
FORM FACTORS @ HALL A-SBS

T2.3: Nucleon tomography at femto-scale

G_M^n

D/H ratio method

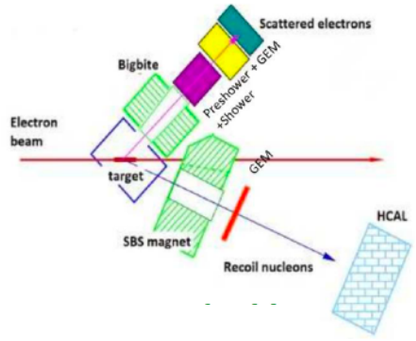


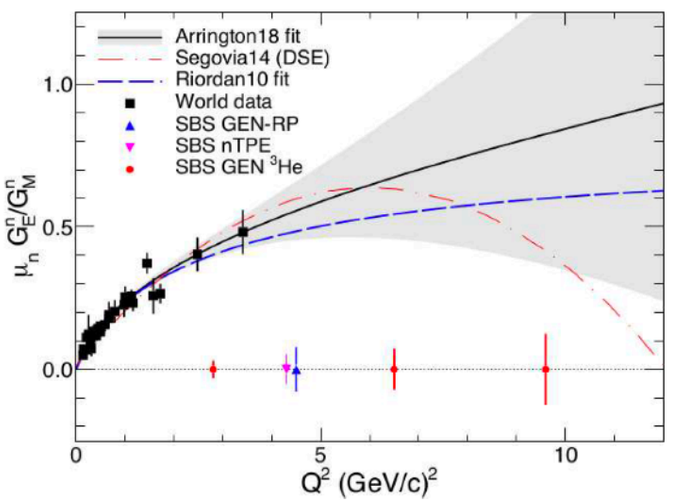


Done

G_E^n / G_M^n

Double-spin asymmetry

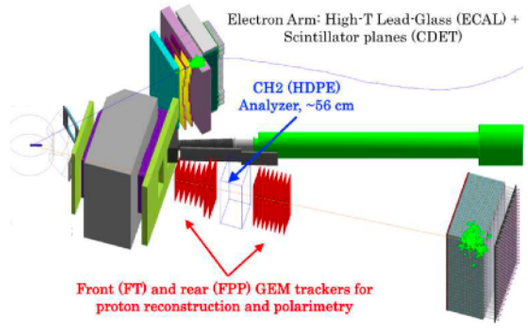


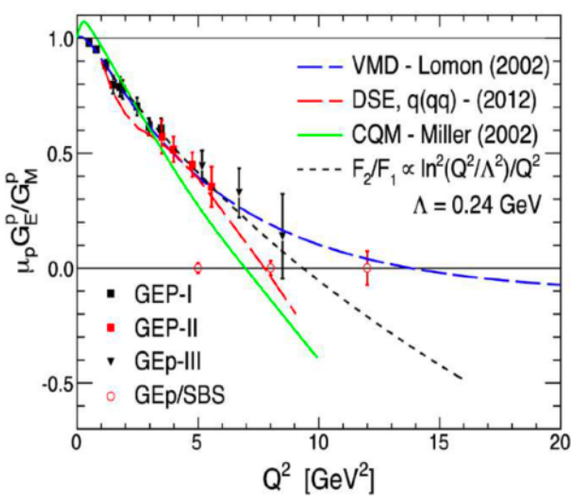


2023

G_E^p / G_M^p

Polarization transer





2024-2025

Dark sector search @ JLAB

Dark Matter mystery

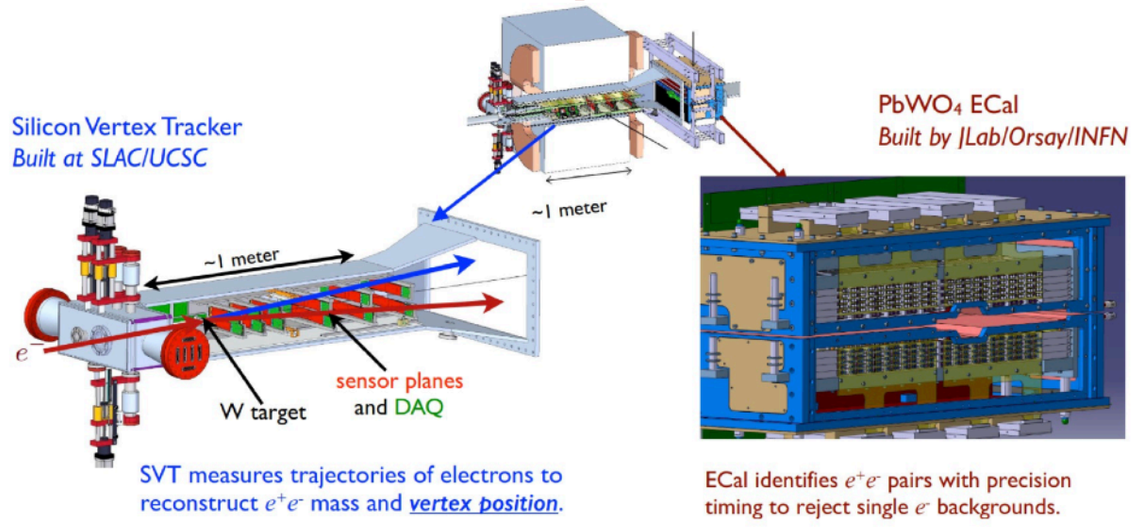
Dark Matter is "invisible" matter that exerts gravitational effects on light and ordinary matter

The Universe consists of:
5% ordinary matter, 27% dark matter and 68% dark energy

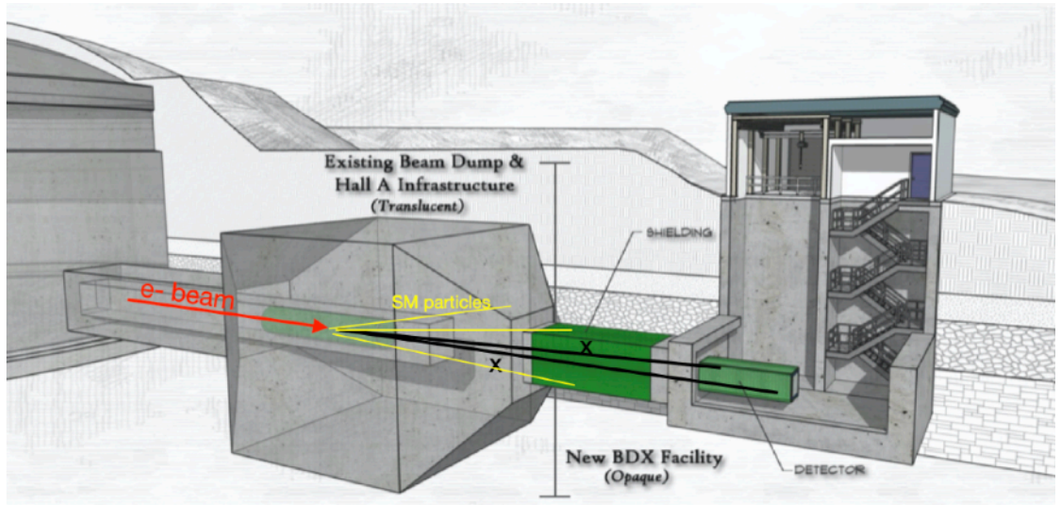
We know nothing about the particle content of DM

Light Dark Matter is made by sub-GeV particles, interacting with SM via a new force

Searching for new mediator with HPS experiment



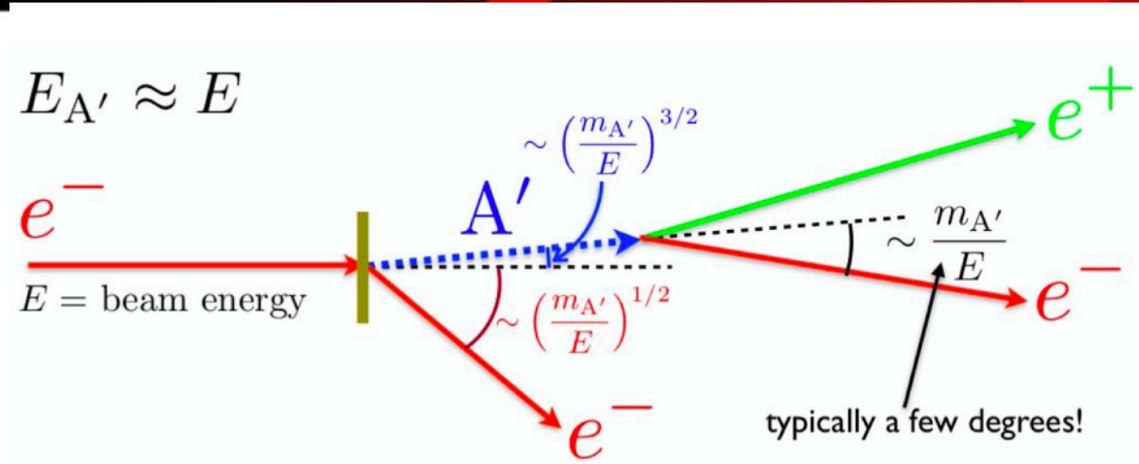
Searching for DM particles with BDX experiment



HPS @ JLAB

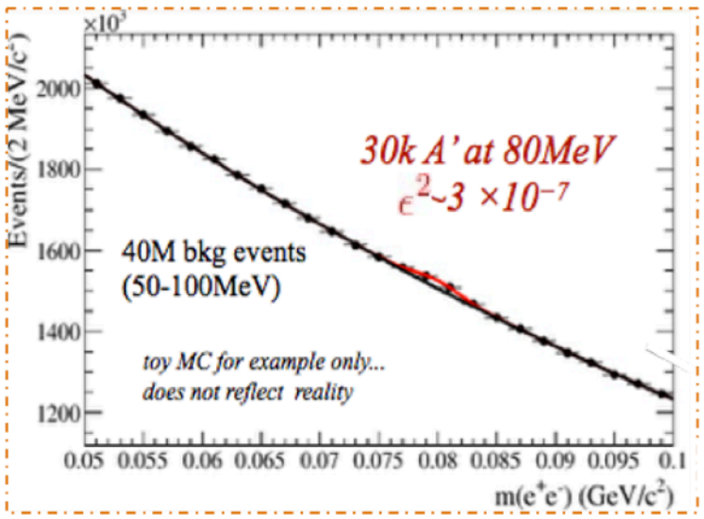
T2.1: Search for relativistic light dark matter

e- fixed target experiment installed in JLAB-HALL B searching for "new" force mediator (dark photon or A').



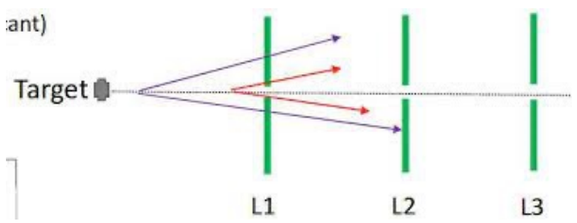
Data Analysis strategies:

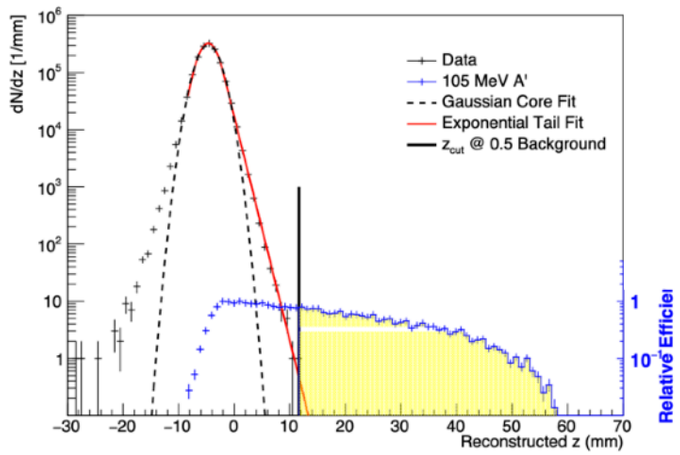
- Resonant search: Narrow e+e-resonance over a QED background
- Detached vertex search: Search for two tracks showing a common production vertex downstream the target

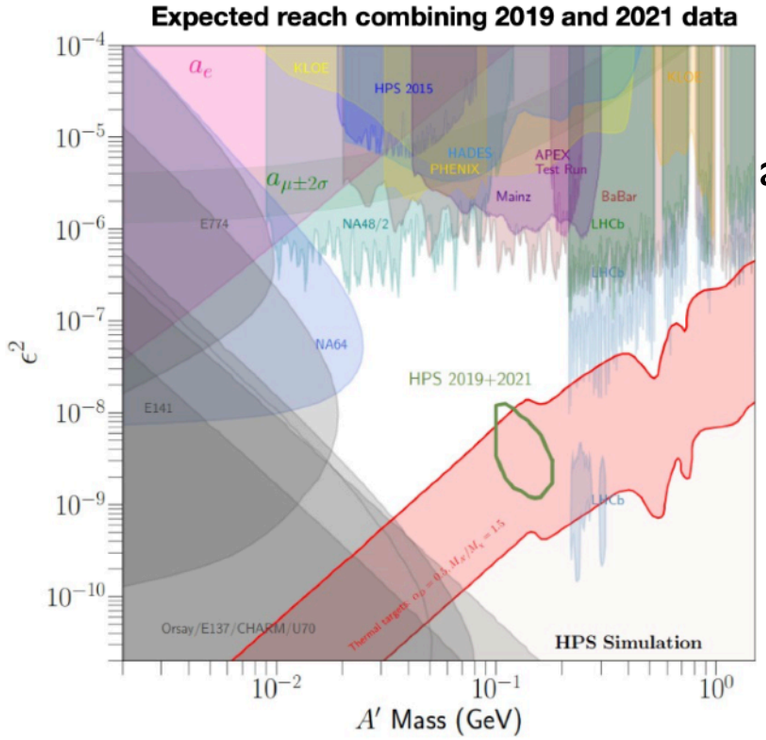


Resonant search

Detached vertex search







- Color regions are already excluded: Dark photon is not there
- Green line: HPS is exploring this region
- Red band: Region motivated by thermal light dark matter

HPS Collaboration, PRD 108 (2023) 1, 012015

BDX @ JLAB

T2.1: Search for relativistic light dark matter

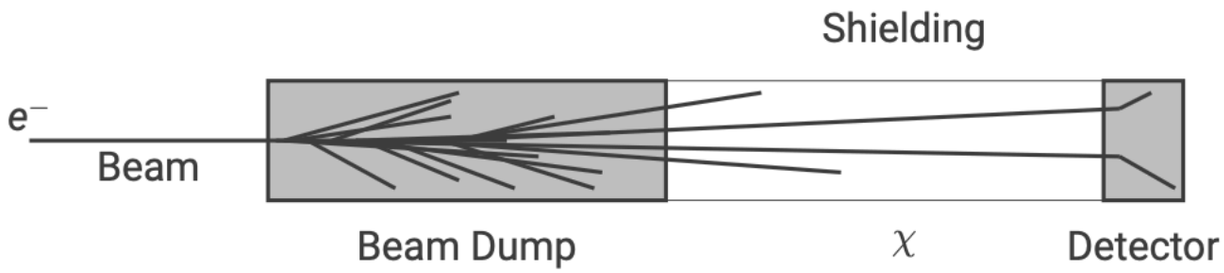
BDX will run at JLAB in 2026. Unique experiment able to PRODUCE and DETECT Light Dark Matter

Production:

- LDM particles produced by the interaction of e- beam with thick target.

Detection:

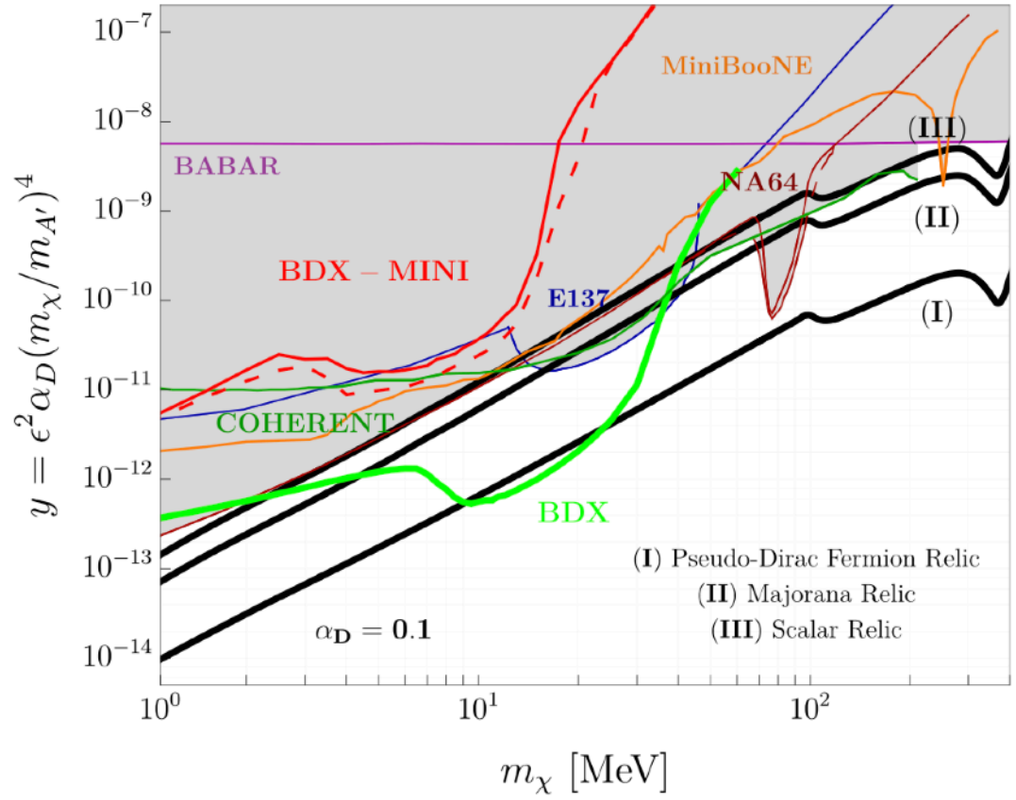
- Detector placed behind the thick target
- LDM particles scattering through A' exchange, recoil releasing visible energy
- **Challenge:** reduce and reject the background events that can mimic dark matter signal



Data analysis approach :

- **Blind analysis**:
  - fix the selection cuts by optimizing the experiment sensitivity looking at beam-off data
  - Afterwards selection cuts applied to the beam-on data
    - In case of negative results, upper limit will be derived in the LDM parameters space

LDM parameter space



In red BDX Demonstrator result . M. Battaglieri et al, PRD 106 (2022), 7,072011