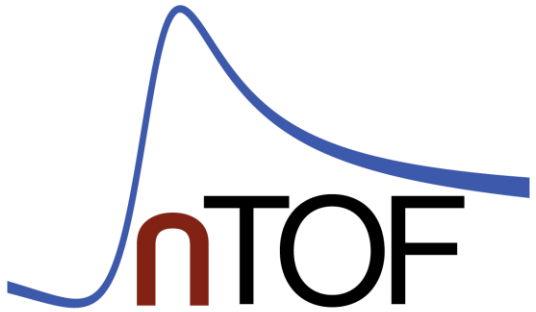

Multiple Argon Experiments (MArEX) at n_TOF, CERN

CPAD Workshop
8 November 2023

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On behalf of the MArEX collaboration

OUTLINE

- Motivation
- n_TOF Facility
- Experimental Setup
- Preliminary Plots
- Conclusion

Motivation for the MArEX Initiative

- **Liquid Argon (LAr):** primary detector material in many neutrino and dark matter experiments
  - DUNE, SBND, ICARUS, MicroBooNE, DarkSide, etc.
- Neutron production from neutrino interaction brings a large uncertainty on neutrino energy reconstruction in the form of **missing energy**.
  - Stringent requirements to accurately measure, for example, the neutrino oscillation parameters
  - Need to understand the detector response to neutrons to reduce the systematics
- Neutrons are also useful for **calibrating** multi-kiloton experiments, like DUNE, as neutron captures in LAr release a distinct 6.1 MeV gamma ray cascade

$$n + {}^{40}Ar \rightarrow {}^{41}Ar + 6.1\ MeV$$

- Neutron total cross section on argon has a dip around 57 keV
  - Important for the **rare event searches** such as dark matter and v-less double beta decay
- Important to understand neutron propagation and capture in liquid argon

Neutron Total Cross Section

- Need to measure the total cross section
  - below 20 keV and between 50-100 MeV (no data in EXFOR)
  - above 100 MeV (current data has large error bars)
- Need a better measurement of the cross section dip in the total cross section at 57 keV
  - Initial effort was made by the ARTIE experiment (https://arxiv.org/abs/2212.05448v3)
  - New experiment, ARTIE-II has been approved

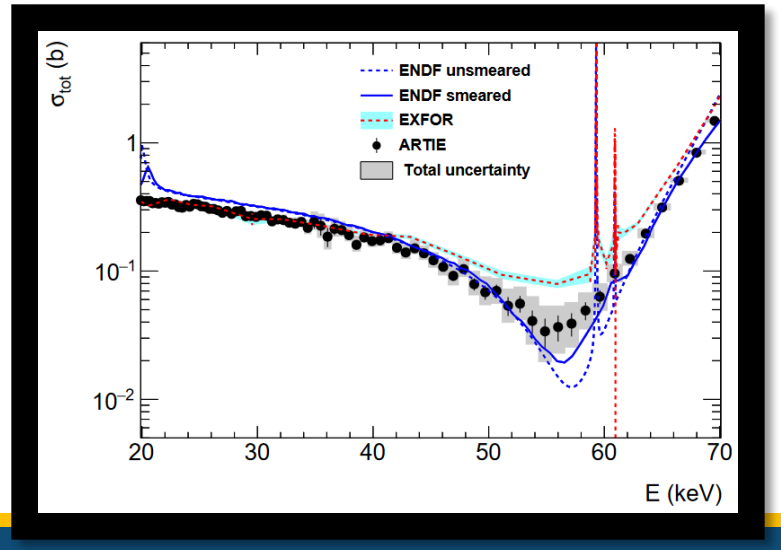


Fig. (Left) Plot shows the measured neutron-argon total cross section, by ARTIE, as a function of energy.

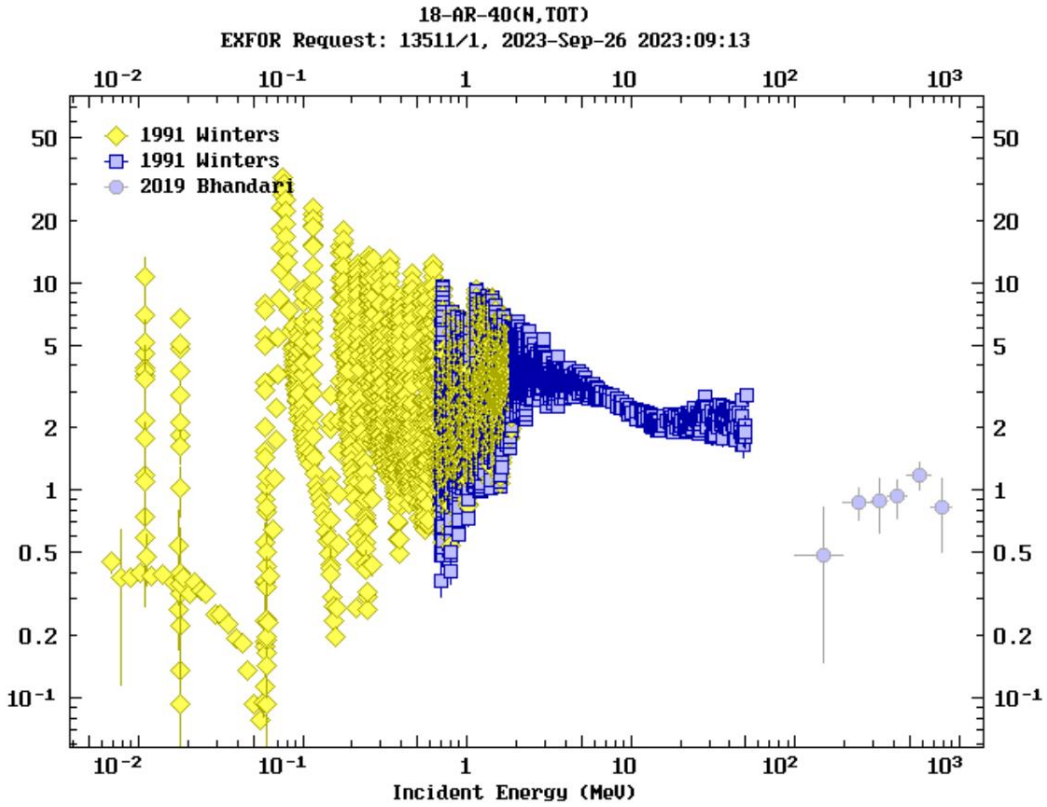


Fig. (Top) Plot of the currently available data of the neutron total cross section on Argon from EXFOR.

n_TOF Facility at CERN

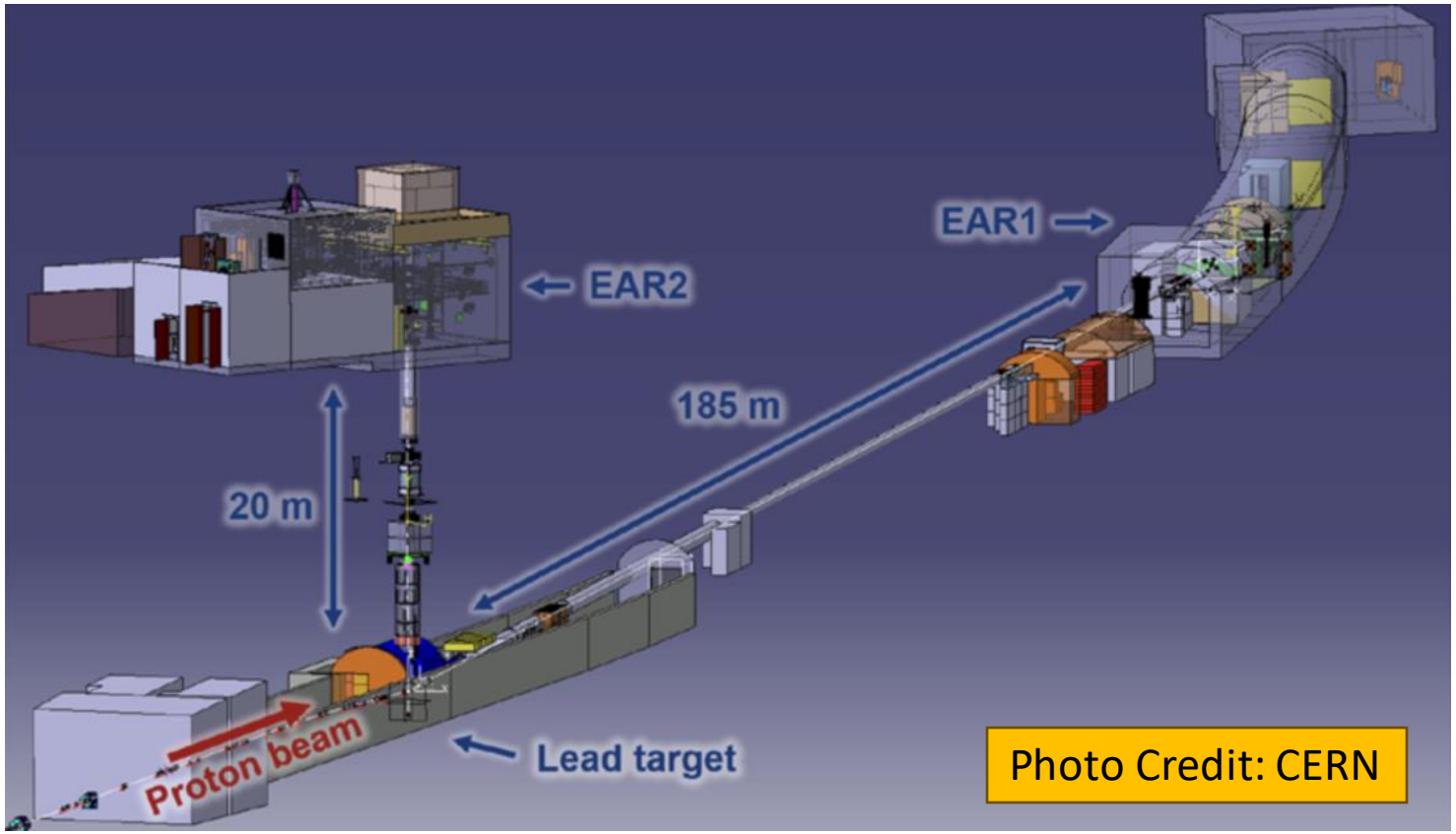
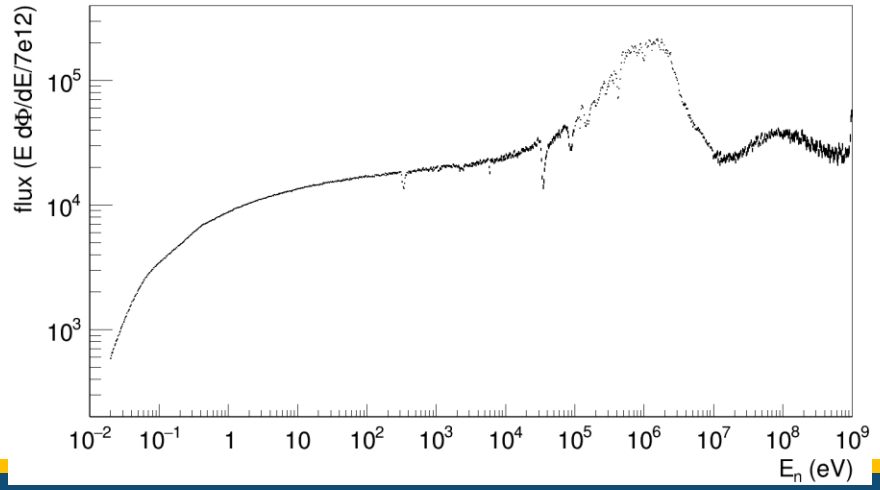


Fig. (Top) Schematic of the n_TOF facility; (Right) Neutron Flux at EAR 1 (Credit: n_TOF)

- n_TOF is a neutron time of flight facility located at CERN
- Two experimental areas (EAR) with different flight paths
  - EAR 1: 182.3 - 190.2 m
  - EAR 2: 18.16 - 23.66 m
- EAR 1:
  - Wide energy range neutron beam
  - Long flight path; High energy resolution



Motivation for the first test at n_TOF

- To test the feasibility of transmission measurements at n_TOF
  - Transmission experiments haven't been performed previously at n_TOF
  - Measure the cross section of known materials like Bi, Al, and C.
- To test the feasibility of transmission measurements on Ar at n_TOF
  - Carbon fiber SCUBA tank filled with gaseous Argon
  - Measure the argon cross section
  - Proof of concept for a transmission measurement with LAr

Transmission Measurement

Transmission is given by

$$T(E) = \frac{N_{in} - B_{in}}{N_{out} - B_{out}} \frac{Q_{out}}{Q_{in}}$$

- E – Energy of the neutron (converted from the measured time of flight)
- N – Number of neutrons reaching the detector
- B – Number of background events
- $\frac{Q_{out}}{Q_{in}}$ - Beam flux normalization for target in and target out

Cross section is given by

$$\sigma(E) = -\frac{1}{n}\ln[\mathrm{T(E)}]$$

- n – Number density of the target sample (atoms/barn)

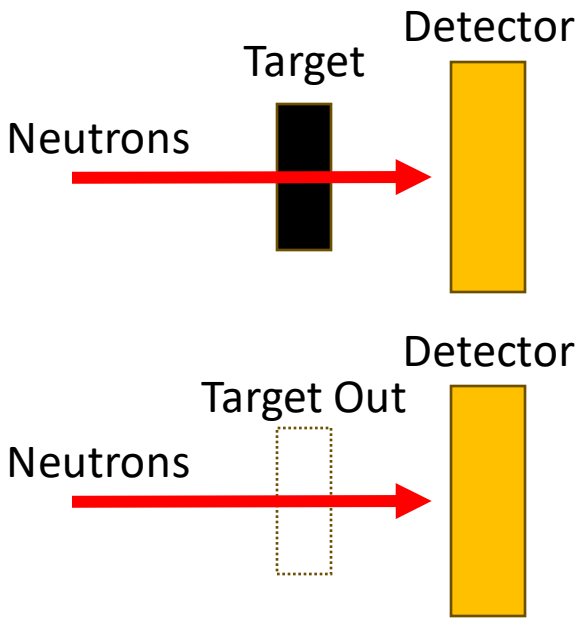
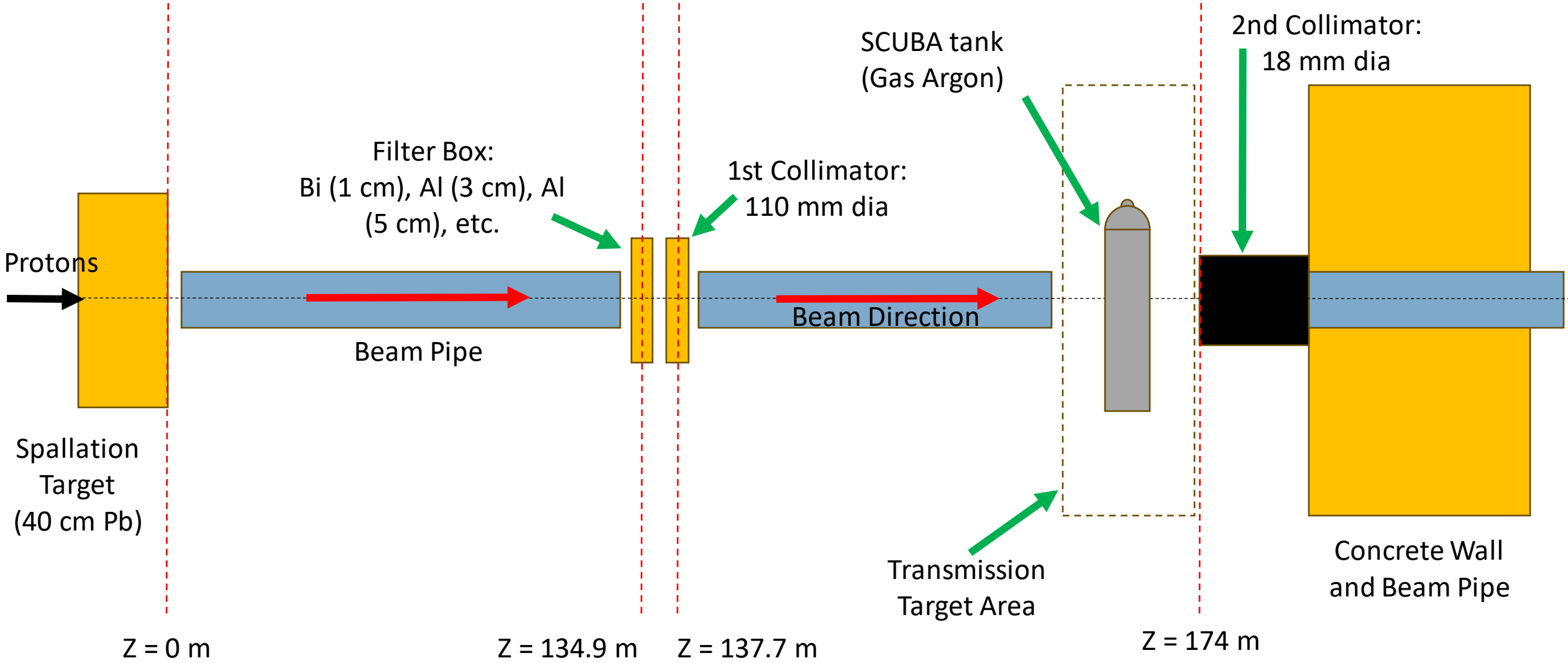
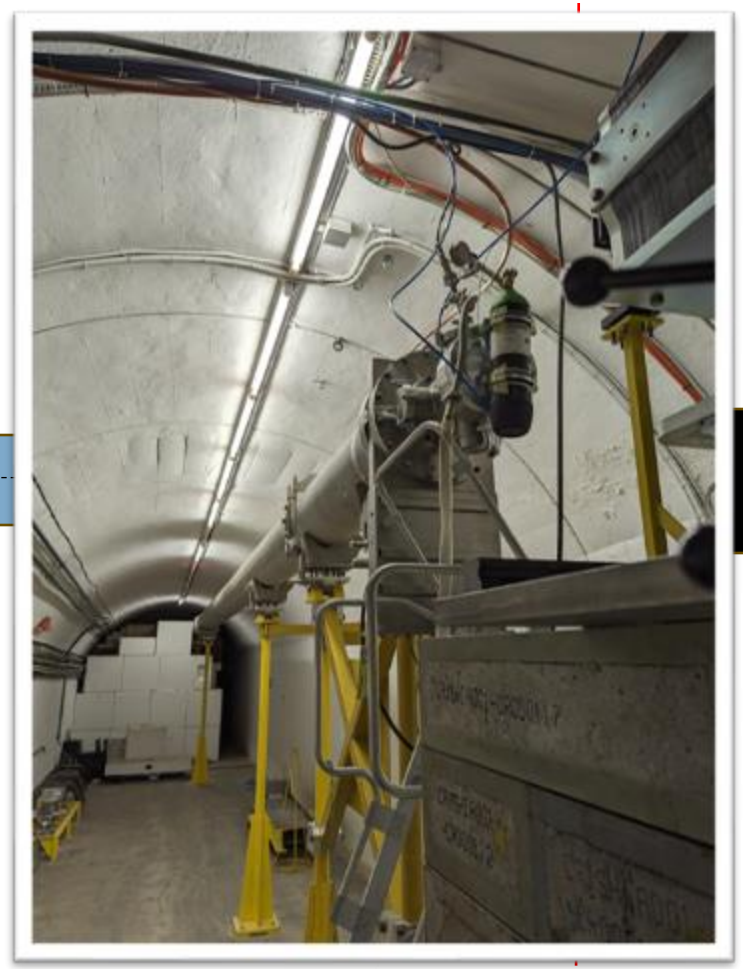


Fig. (Top) Target in measurement; (Bottom) Target out measurement. Ideally should be vacuum in place of target.

Experimental Setup – Beam Line Area



Experimental Setup – Beam Line Area



Protons

Spallation Target (40 cm Pb)

Concrete Wall and Beam Pipe

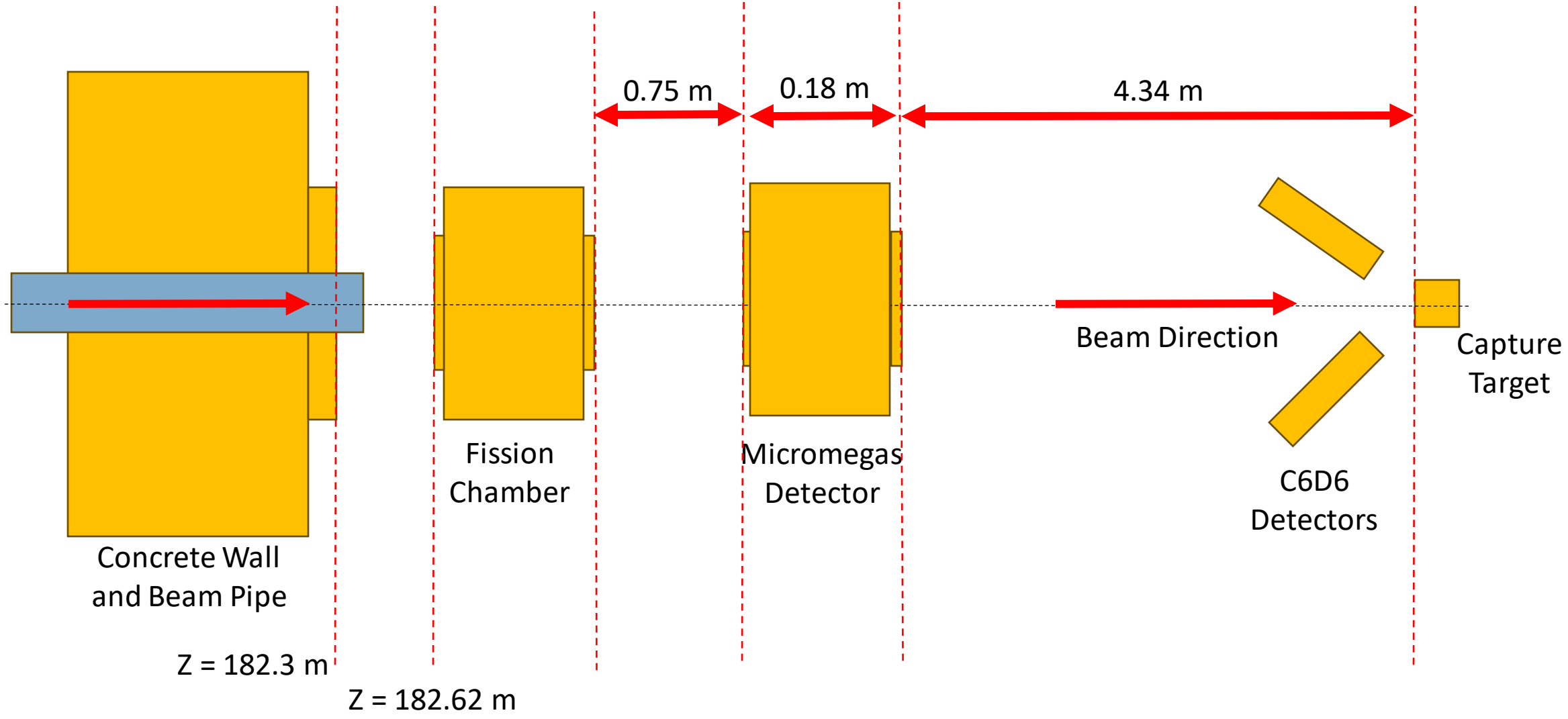
Z = 0 m

Z = 134.9 m

Z = 137.7 m

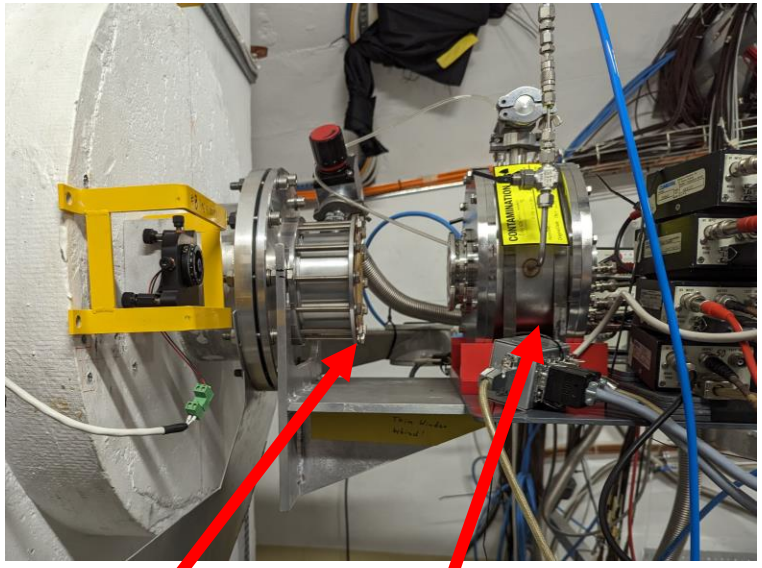
Z = 174 m

Experimental Setup – Detector Area



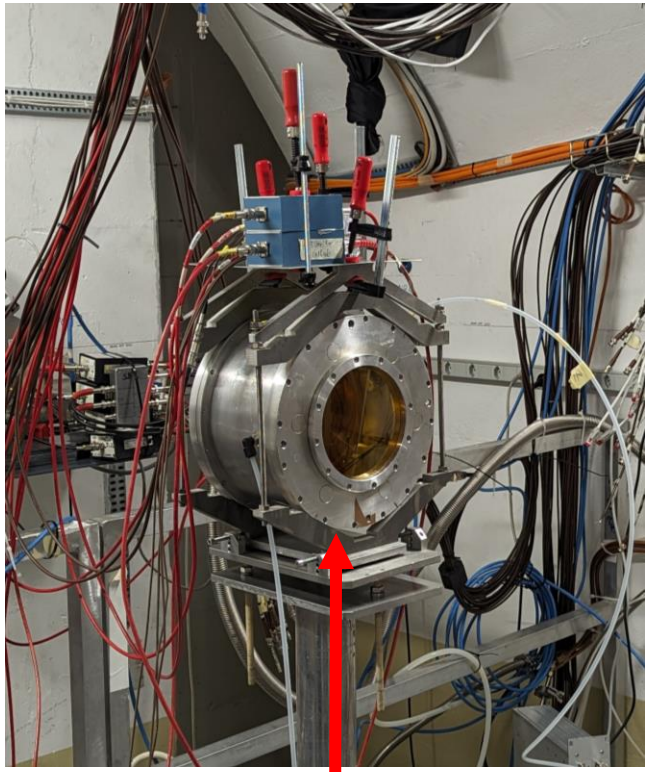
Experimental Setup - Detectors

Beam Direction

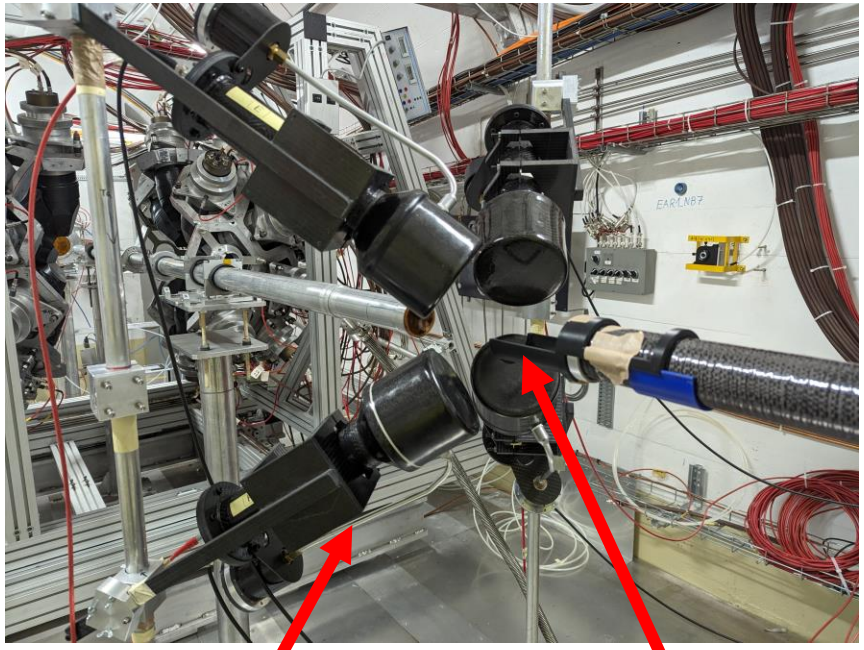


Beam Pipe End

U235 Fission Chamber (PTBC)
- 8 Detectors in the chamber
- 42 mm diameter U235 sample



Micromegas (FIMG)
- 2 detectors with B10 samples



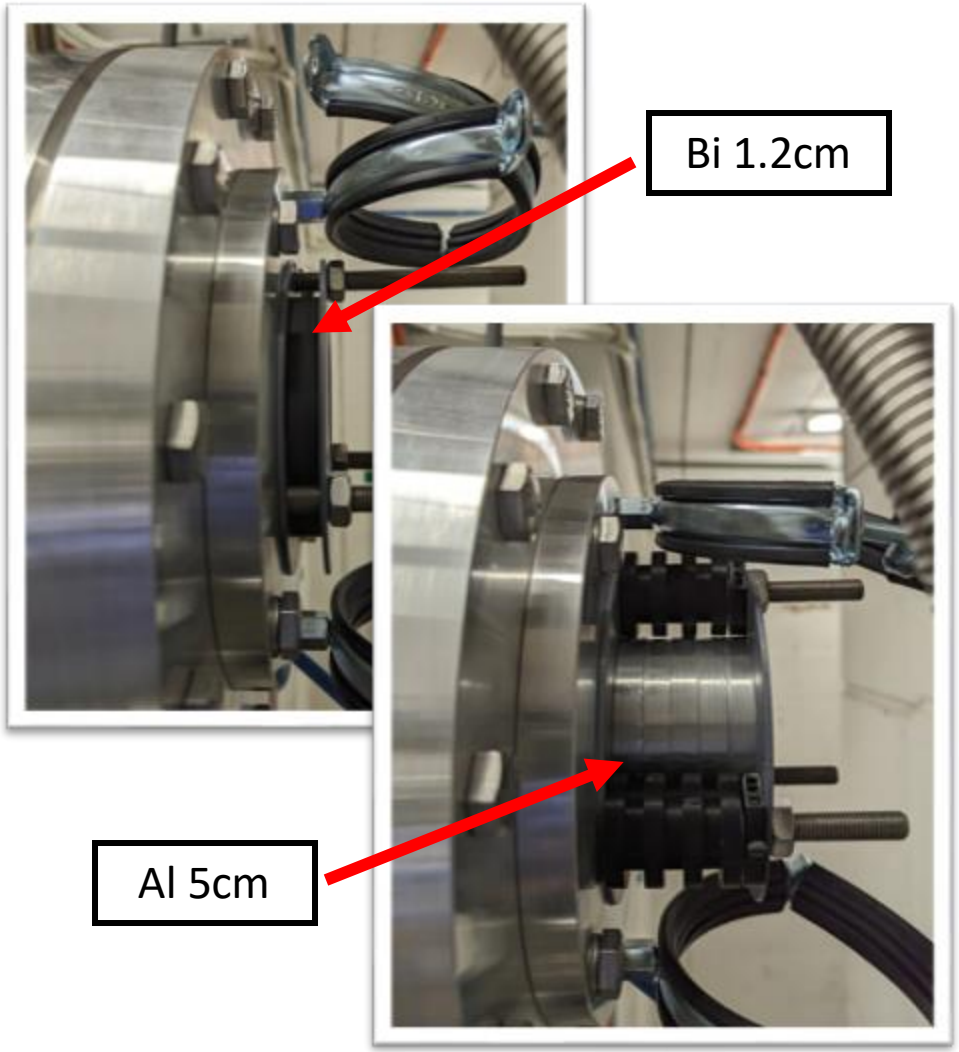
Capture Target Stand

C6D6 Capture Setup
- 4 scintillation detectors
- Placed 125º wrt the beam line

Preliminary Analysis

- We finished data taking on October 26th; About 50 days for beam time
- An average of 1.1e17 protons per day
- Took data with the following materials as targets
  - Al: 3cm, 5cm, 8cm
  - Bi: 1cm, 1.2cm
  - C: 1.2cm
  - Empty carbon fiber SCUBA tank
  - SCUBA tank filled gaseous argon at 200 bar
  - SCUBA tank filled gaseous argon at 1 atm

- For a preliminary analysis, I implemented the known detector background subtractions
  - More work needs to be done in understanding the backgrounds



Aluminum (5 cm)

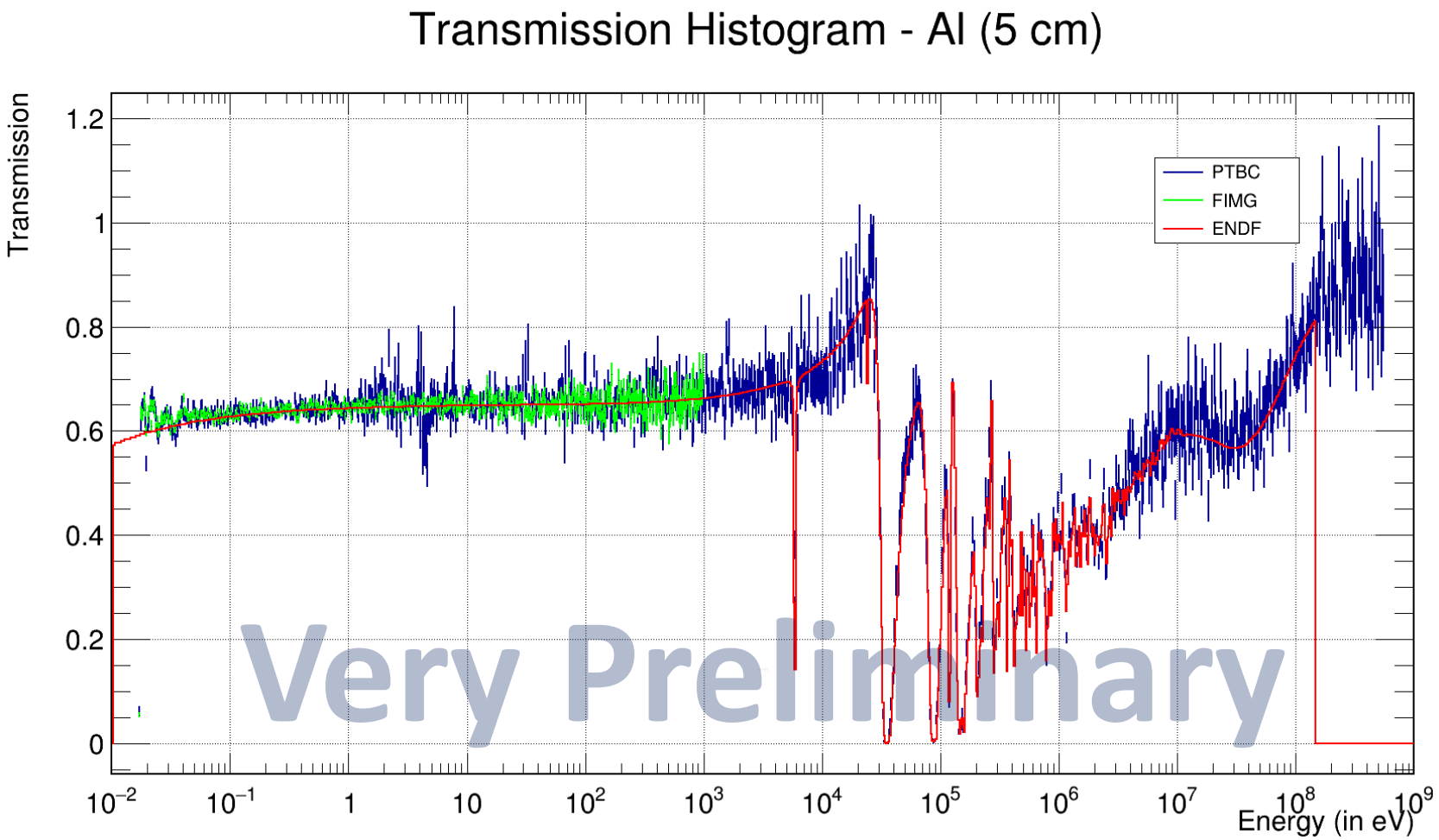


Fig. A very preliminary plot of the measured transmission of a 5 cm aluminum sample compared to the ENDF evaluation.

Number of Protons
Al 5 cm: 8.27284e+17
Target Out: 5.14825e+17

Note: Micromegas (FIMG) can measure up to a MeV. But I am not showing it here.

Aluminum (5 cm)

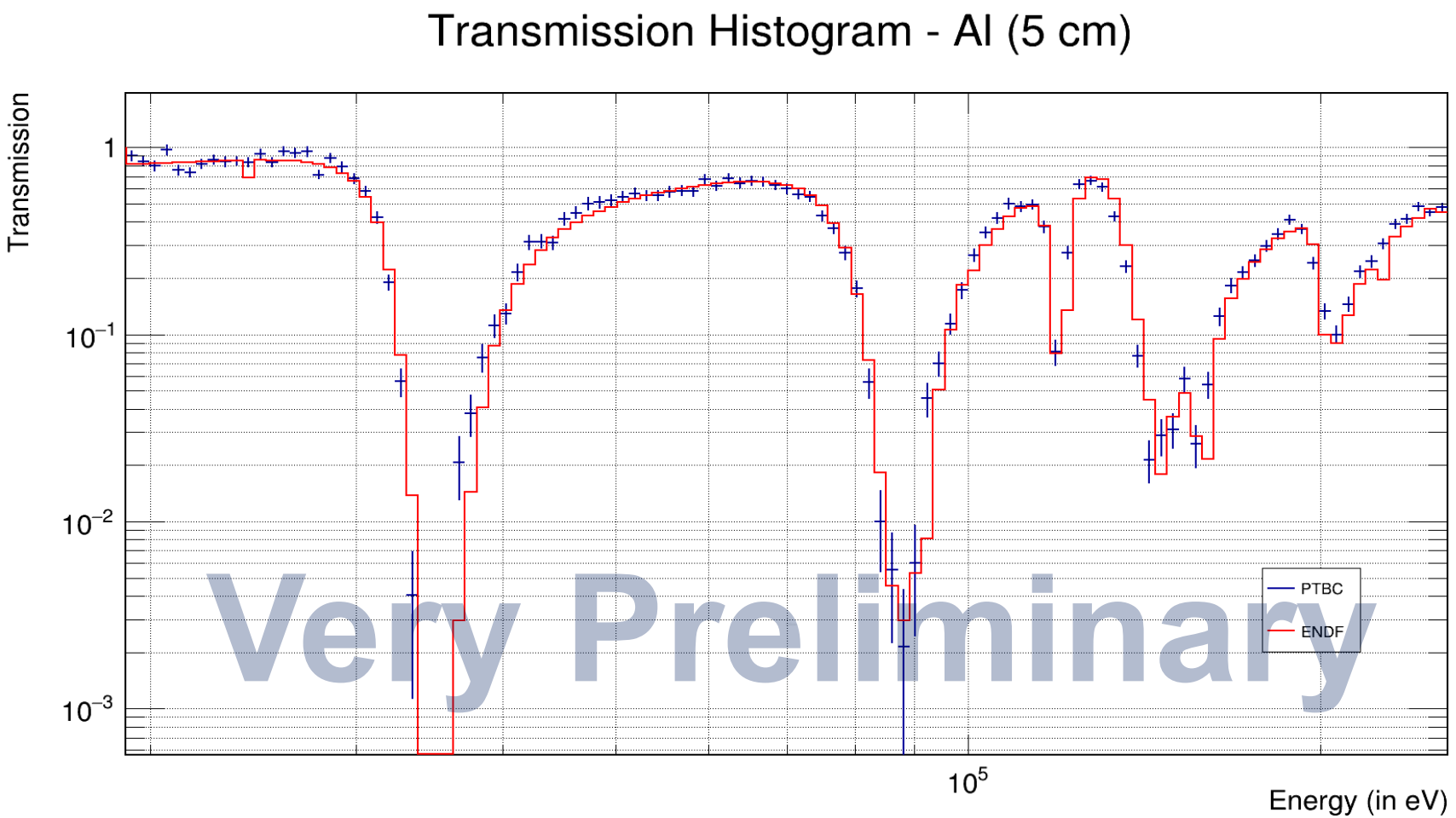


Fig. A very preliminary plot of the measured aluminum transmission between 20 keV and 110 keV.

Number of Protons

Al 5 cm: 8.27284e+17

Target Out: 5.14825e+17

- See no events in the transmission dip around 35 keV (**black resonance**)
- Very low background

Argon Transmission Setup

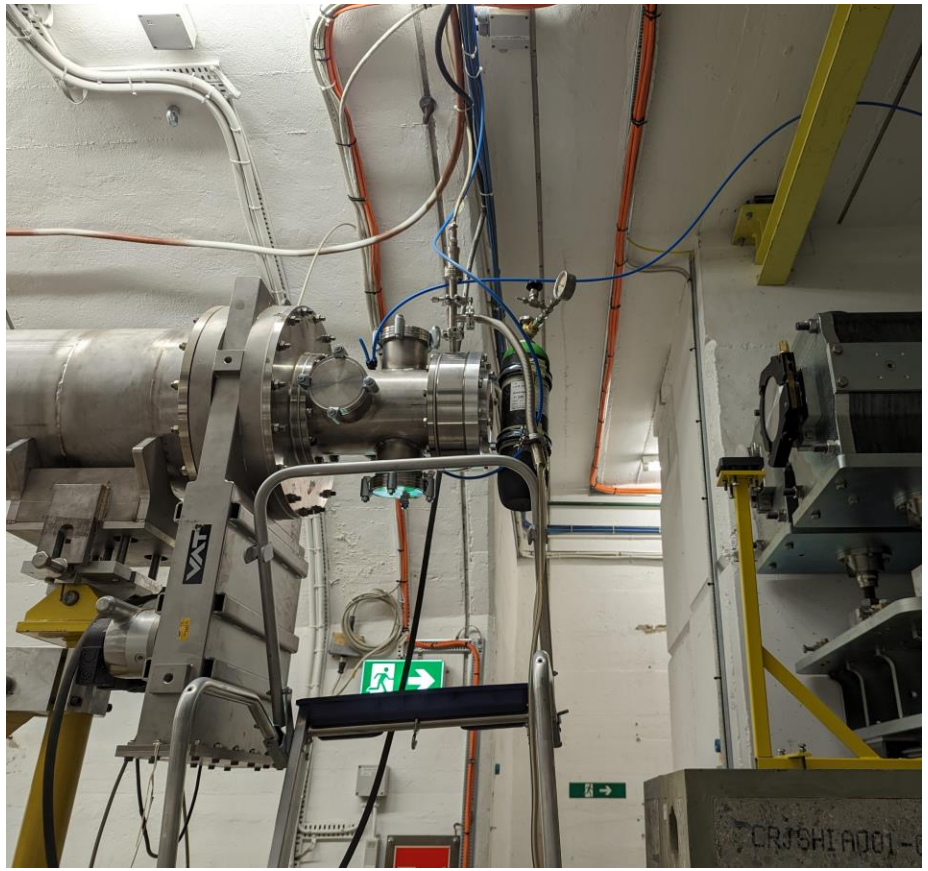
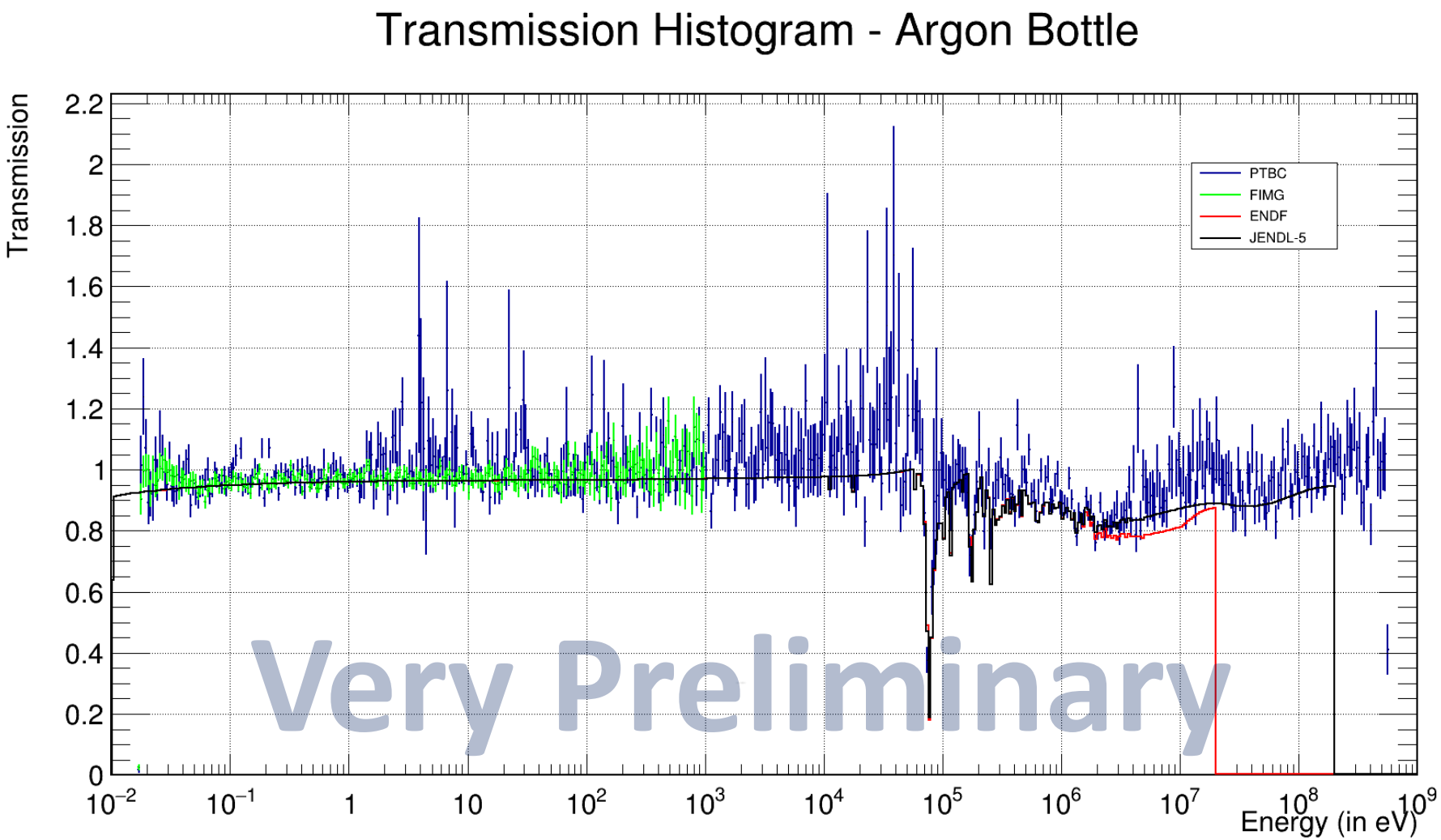


Fig. Argon tank in the transmission station

Argon tank specifics

- 3 L volume
- 200 bar pressure
- ~ 1 mm thick carbon fiber walls
- ~ 11 cm of Ar gas in the neutron path
- 0.05 atoms/barn

Gaseous Argon



Number of Protons
Argon: 5.42966e+17
Empty tank: 2.81024e+17

Note:

- Empty tank is 1 atm Argon
- Micromegas (FIMG) can measure up to a MeV. But I am not showing it here.

Fig. A very preliminary plot of the measured transmission of a 5 cm aluminum sample compared to the ENDF and JENDL-5 evaluations.

Conclusion

- Conducted a feasibility test for transmission measurements at n_TOF
  - Measured the cross section of known materials like Bi, Al, and C.
  - Took data with a carbon fiber SCUBA tank filled with gaseous Argon
- Need to do an in-depth analysis of the data
  - Implementing data quality cuts
  - Better understanding and fitting the backgrounds
  - Need to figure out the systematics

Next year and beyond:

- MArEX initiative is a 3-year program
  - Improvements to the experiment and more beam time next year
  - Plan to use a liquid target in the future runs
    - Would require a remote cryogenic infrastructure
    - Modifications to the beamline
  - Plan to do a capture cross section measurement

ARTIE-II

- To make a better measurement of the cross section dip at 57 keV, ARTIE-II experiment has been approved (at the LANSCE facility in Los Alamos)
  - Liquid argon target
  - Better target design; Improved facility
  - Waiting for the beam time; Possible beam time in February

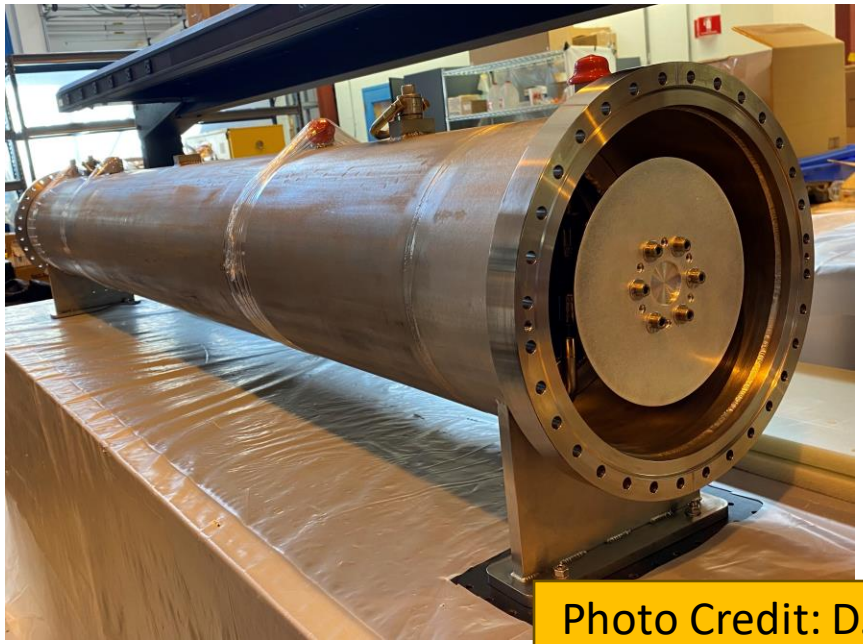
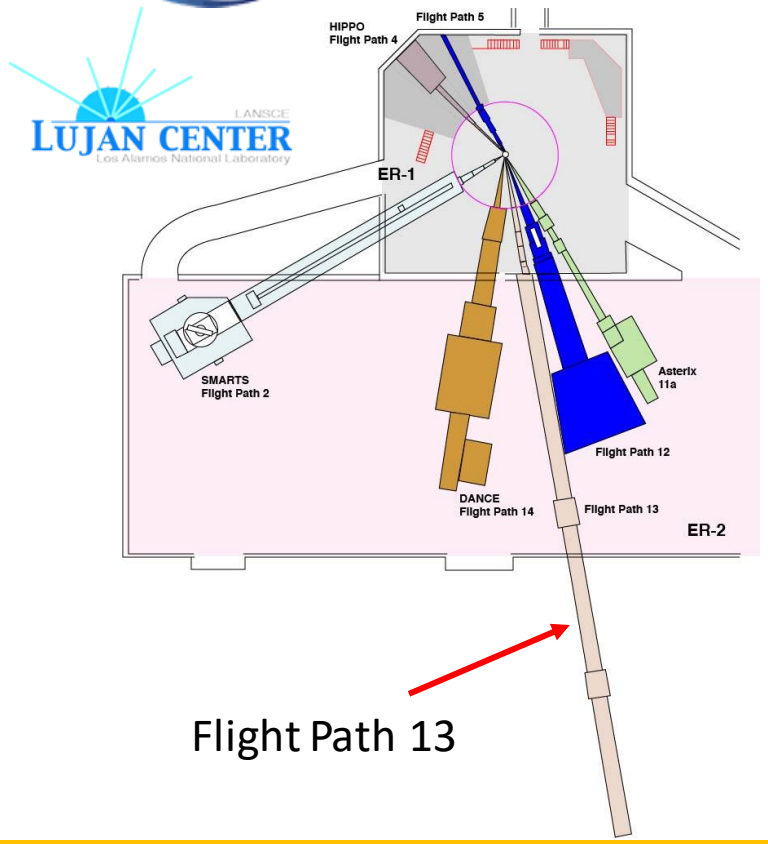


Photo Credit: D. Rivera, LANL

LANSCE
Los Alamos Neutron Science Center



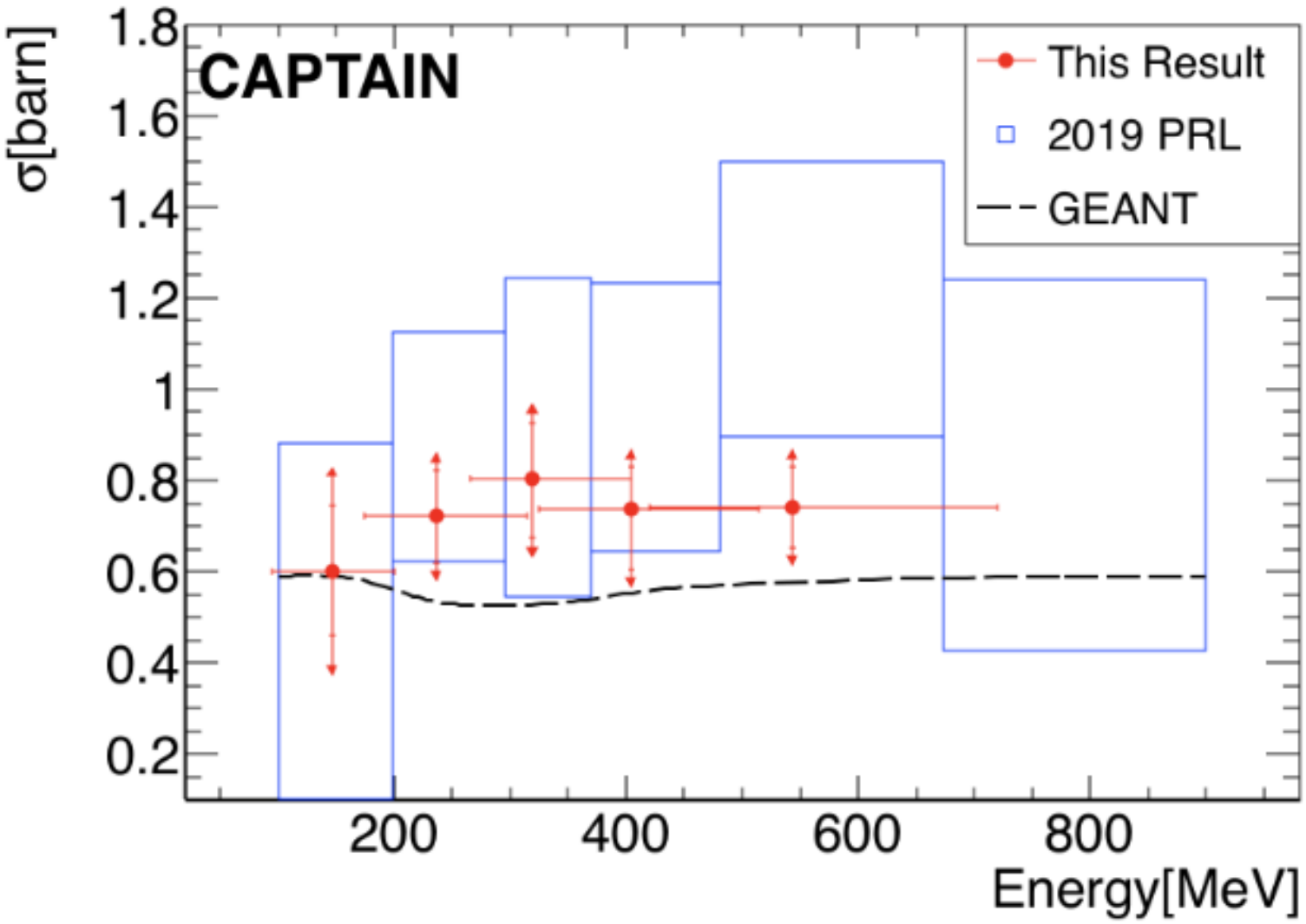
Thank You!

MArEX / n_TOF Collaboration:

S. Andringa, M. Bacak, Y. Bezawada,
J. Boissevain, D. Cano-Ott, N. Carrara,
A. Casanovas, S. Gollapinni, J. Huang,
W. Johnson, A. Junghans, A. Losko, V. Lozza,
A. Manna, P. Mastinu, E. Mendoza,
A. Mengoni, M. Mulhearn, E. Pantic,
N. Patronis, E. Renner, D. Rivera,
T. Stomatopolous, R. Svoboda, A. S. Tremsin,
J. Ullmann, J. Wang, T. Zhu,
and The n_TOF Collaboration

Back Up Slides

Mini-CAPTAIN Measurement



https://arxiv.org/abs/2209.13488v3