Investigation of phenomena arising in medium-mass nuclei at the neutron dripline

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For the MoNA Collaboration

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Outline

- Introduction

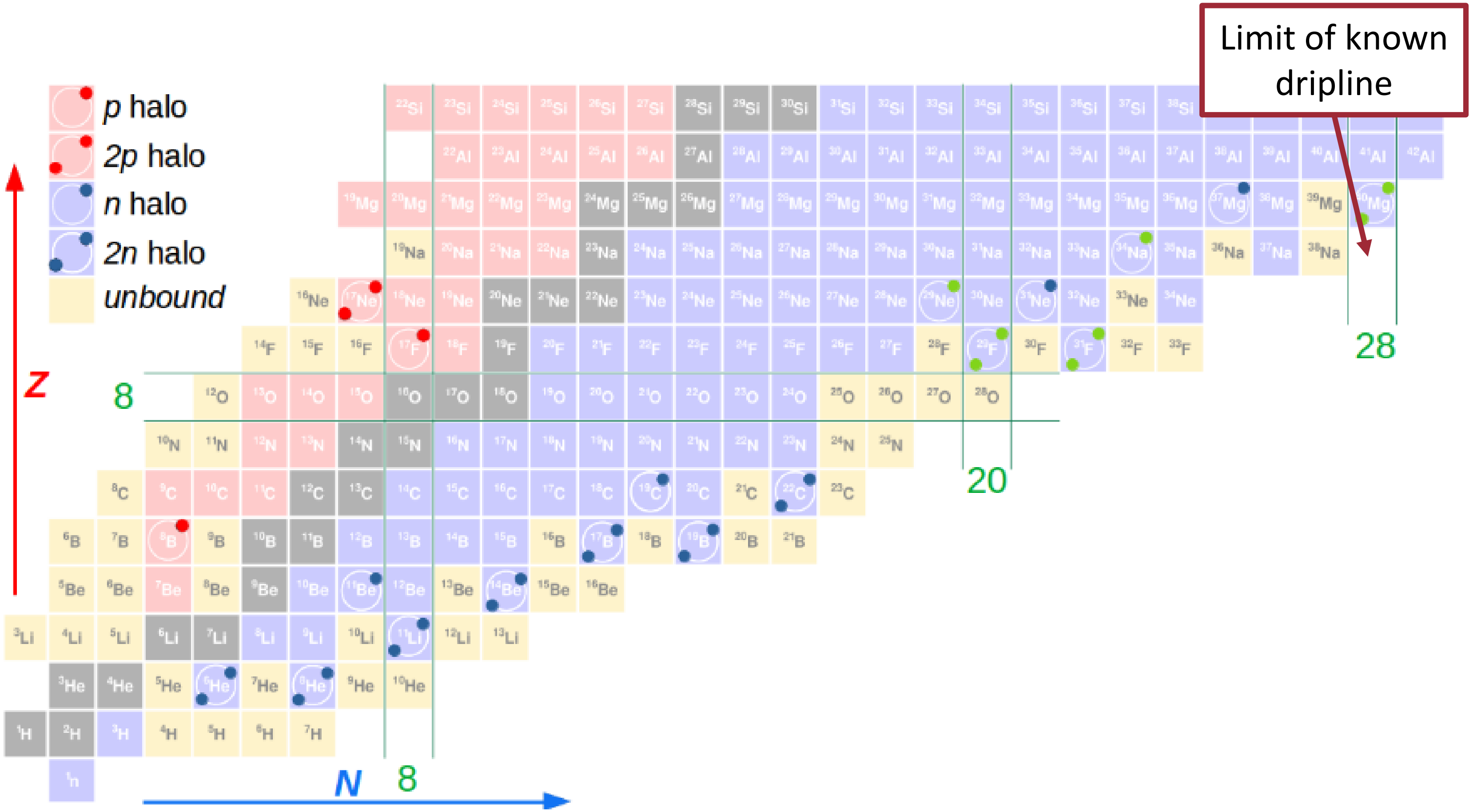
- Coulomb breakup experiments as a tool to study neutron halo nuclei

- Upgrades of the MoNA experimental setup
  - Development of a next generation neutron (NGn) detector
  - Perspectives for a thick liquid hydrogen target and vertex tracker for invariant-mass measurement at FRIB
  - Future location of MoNA at FRIB

- Conclusion and Outlook

Investigating Phenomena at the neutron dripline

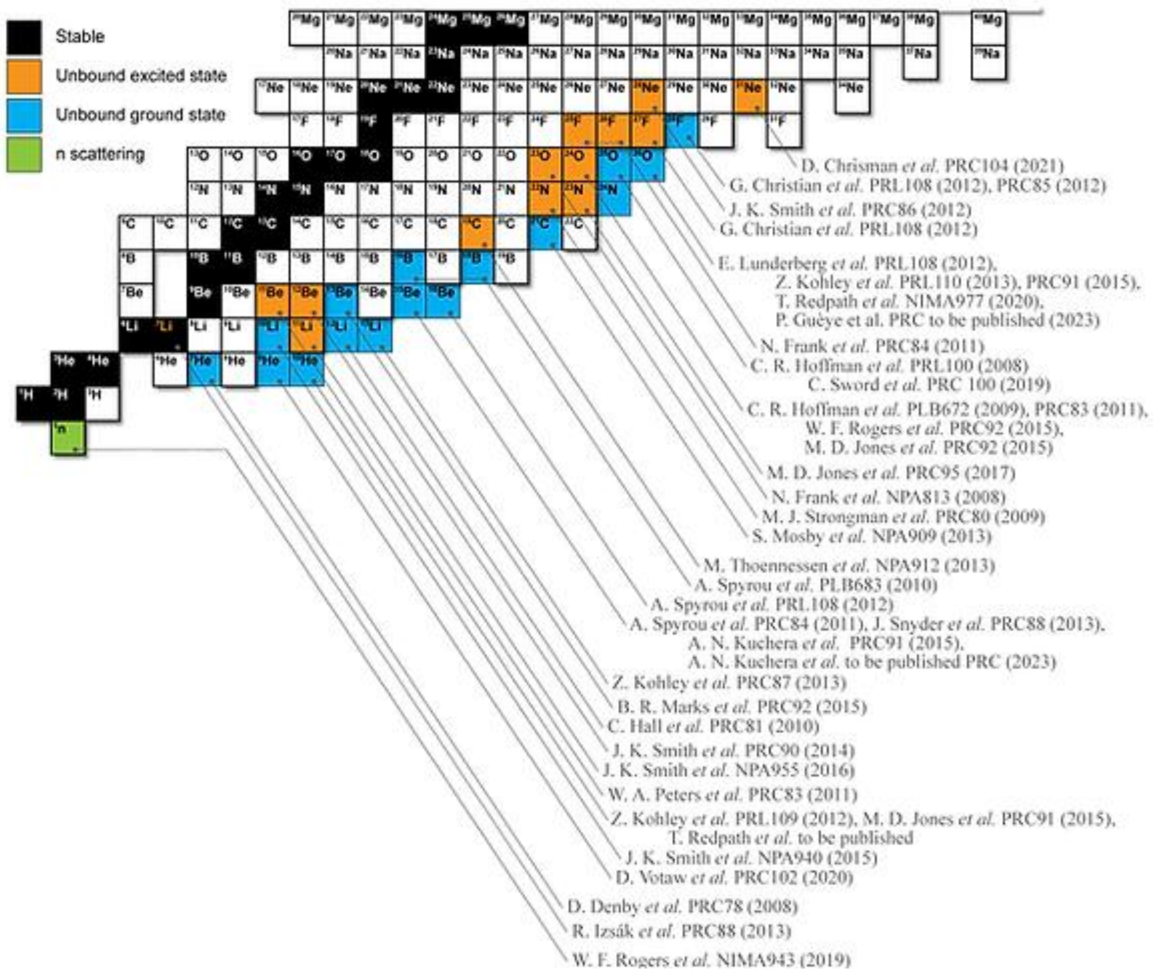
- Predicting properties or existence of near dripline nuclei remains a challenge
- Many emerging phenomena
  - Shell Evolution
  - Coupling to Continuum
  - Role of 3-Body forces
  - Pairing
  - Halo Formation
- Experiments are needed to understand the interplay of these effects



Previous results from the MoNA Collaboration

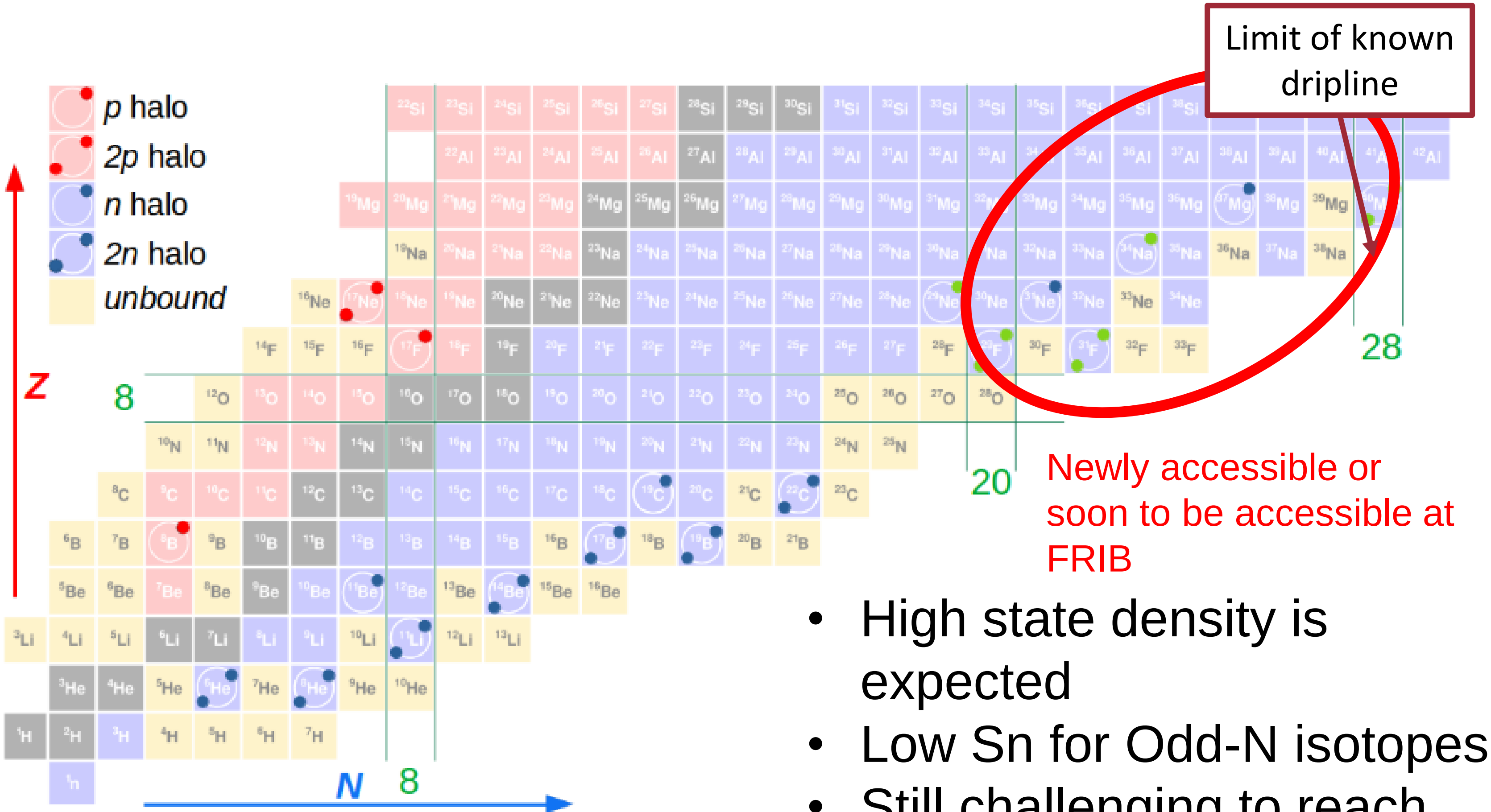
- One of the leader in investigating the structure of nuclei at and beyond the neutron dripline

- Limited to the Z<11 region due to challenging beam intensities



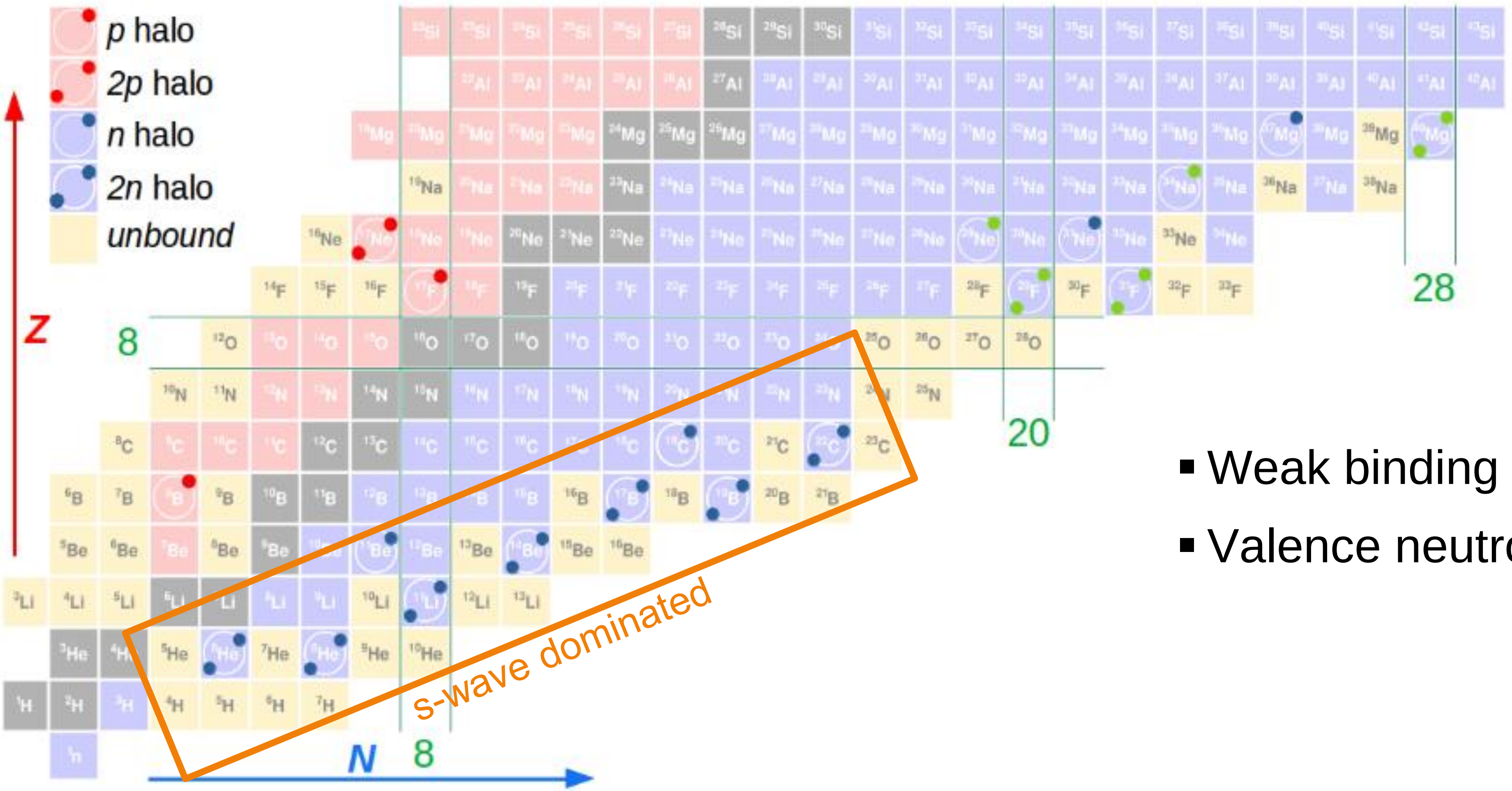
An uncharted region with new challenges

- 20kW for FRIB PAC3
- 400kW ultimate power
- One or two order of magnitude in beam intensities compared to other facilities
- Unique opportunities for such studies



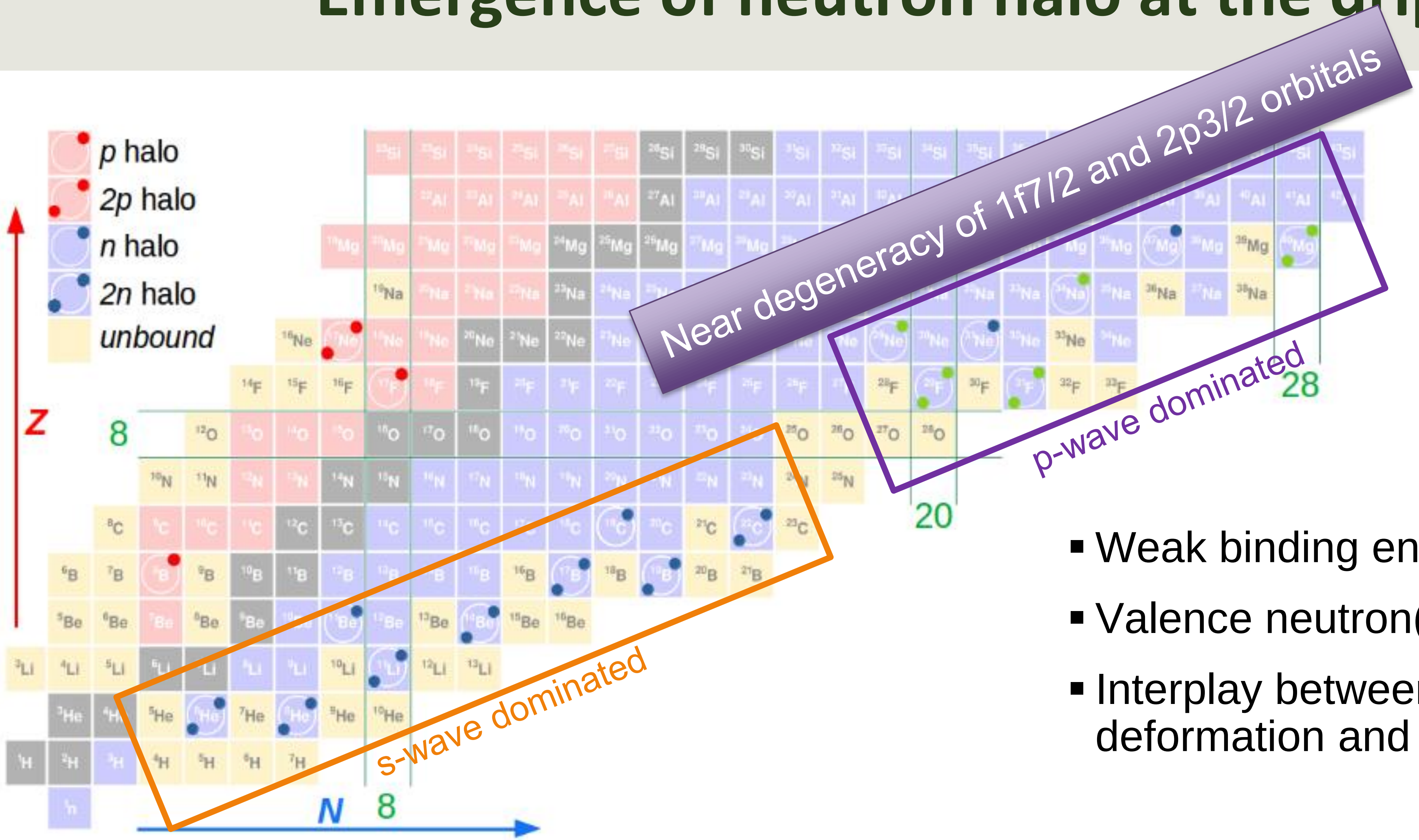
- High state density is expected
- Low Sn for Odd-N isotopes
- Still challenging to reach the dripline

Emergence of neutron halo at the dripline



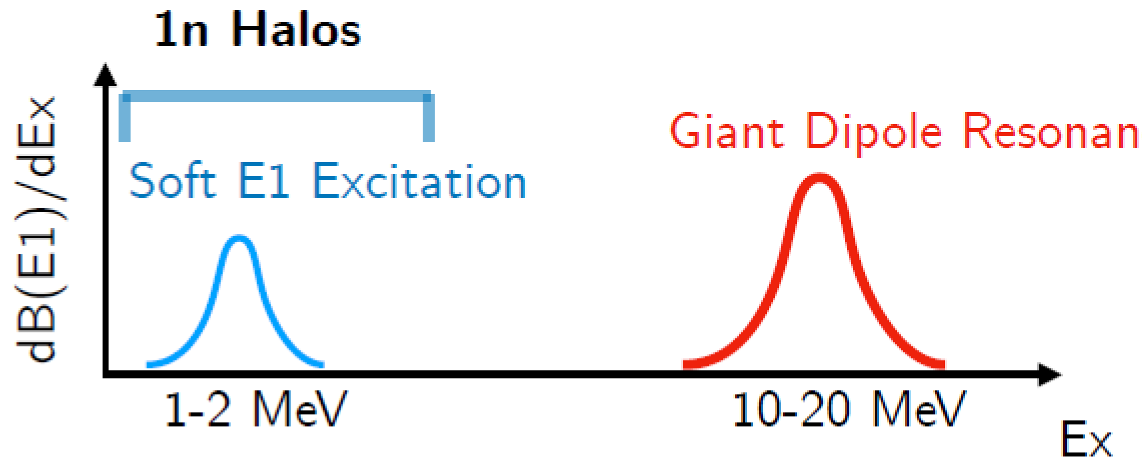
- Weak binding energy
- Valence neutron(s) in l=0,1 orbitals

Emergence of neutron halo at the dripline



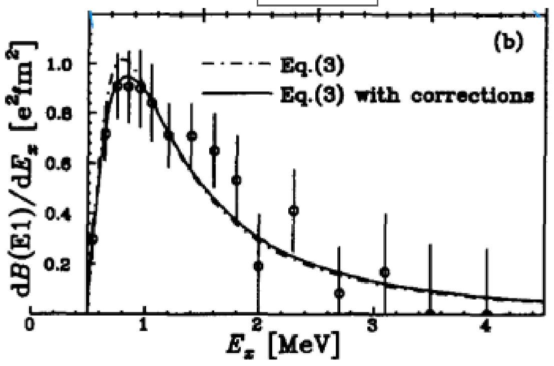
- Weak binding energy
- Valence neutron(s) in l=0,1 orbitals
- Interplay between halo formation, deformation and shell evolution ?

Experimental signatures of neutron halo



- Soft E1 excitation (~1MeV)
- Large B(E1) strength (>1 e^2fm^2)
- Large cross-sections (>0.5 b)
- Narrow momentum dist. (s or p)
- Forward peaked angular distributions

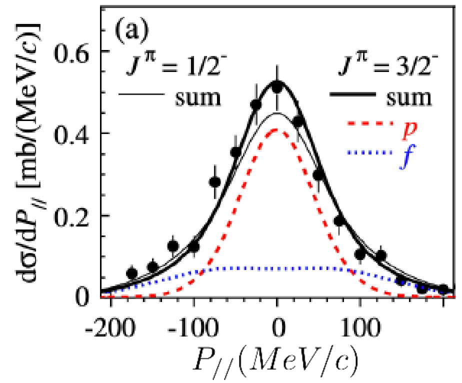
11Be



T. Nakamura et al., PLB 331 (1994)

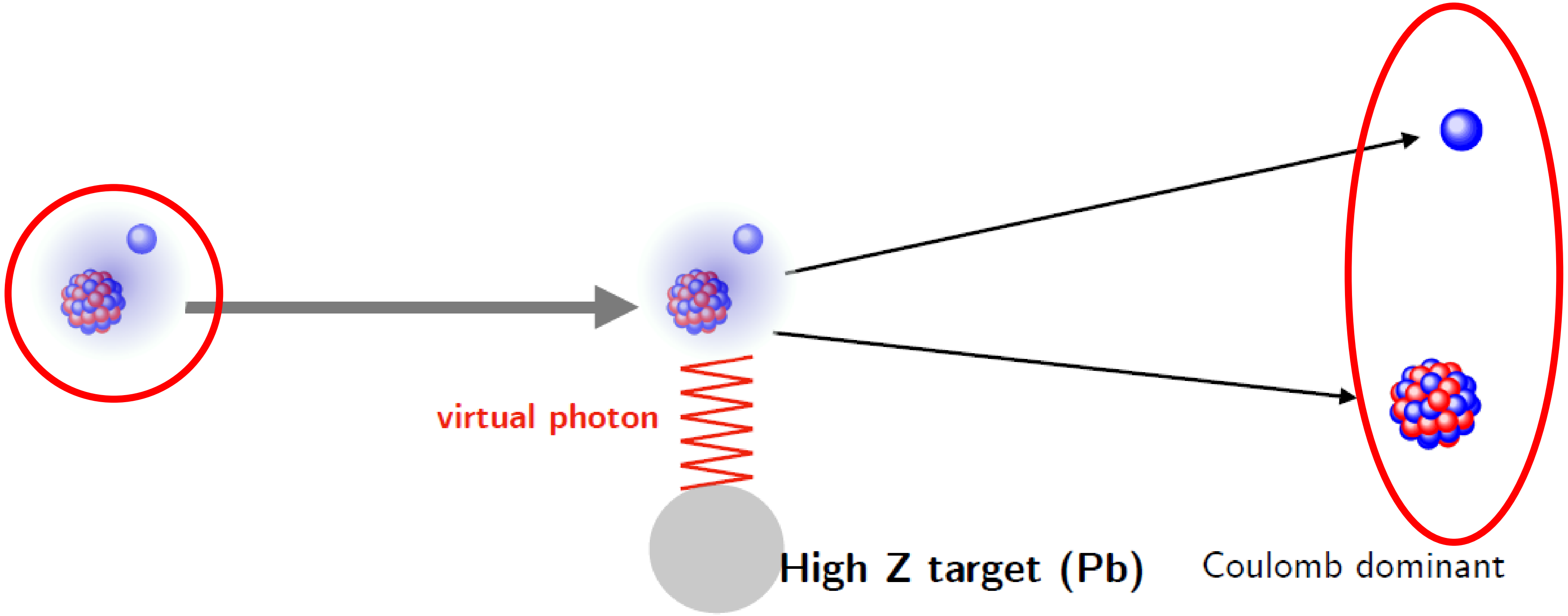
$B(E1) = 1.3 \pm 0.3\ e^2fm^2$

37Mg



N. Kobayashi et al., PRL 112 (2014)

Coulomb breakup of one-neutron halo nuclei



- Invariant-mass (Erel) from decay products
- Coulomb breakup cross-section (σ)
- Reaction on low-Z target to subtract Nuclear breakup contribution

Coulomb breakup of one-neutron halo nuclei

- Breakup cross-section distribution
- E1 strength distribution

$$\frac{d\sigma}{dE_{rel}} \xrightarrow{\text{Equivalent Photon Method}} \frac{dB(E1)}{dE_{rel}}$$

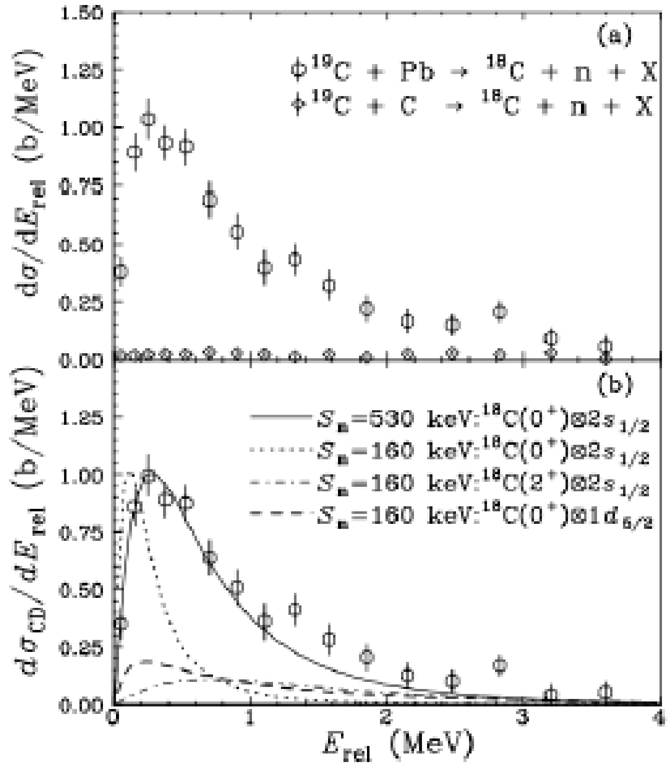
- Integrated Breakup cross-section
- B(E1) strength

- Geometrical information on the halo: $$B(E1) = \frac{3}{4\pi}\frac{Ze^2}{A}r_{c,n}^2$$

Experimental signatures of neutron halo

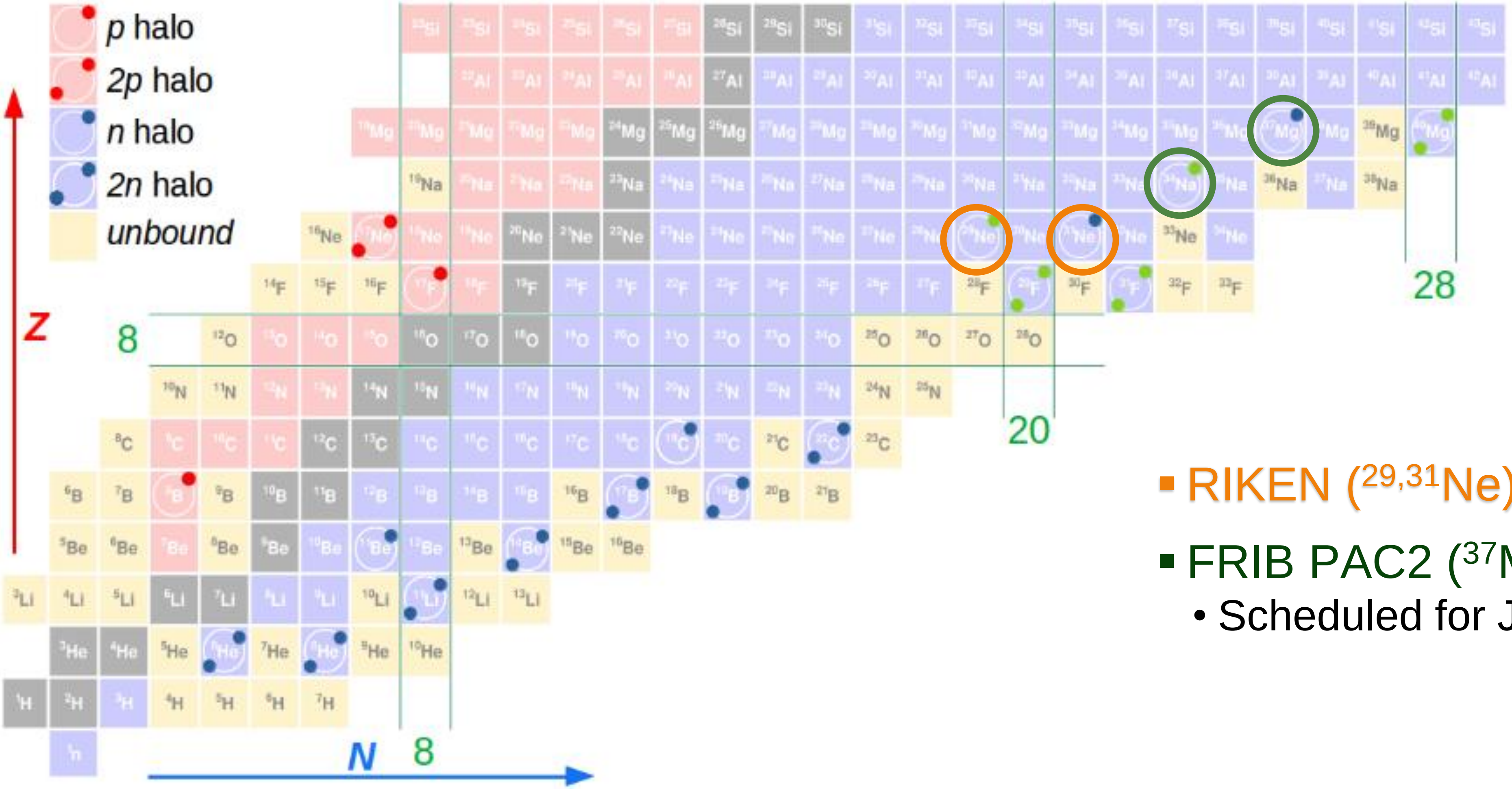
- The signatures of the halo are revealed by the data but we need theory for a complete characterization and interpretation
- The line shape of the dσ/dErel and dB(E1)/dErel distributions sensitive to characteristics of the halo:
  - Configuration of g.s. and C2S
  - Neutron separation energy
  - Deformation ?

19C



T. Nakamura et al., PRL 83 (1999)

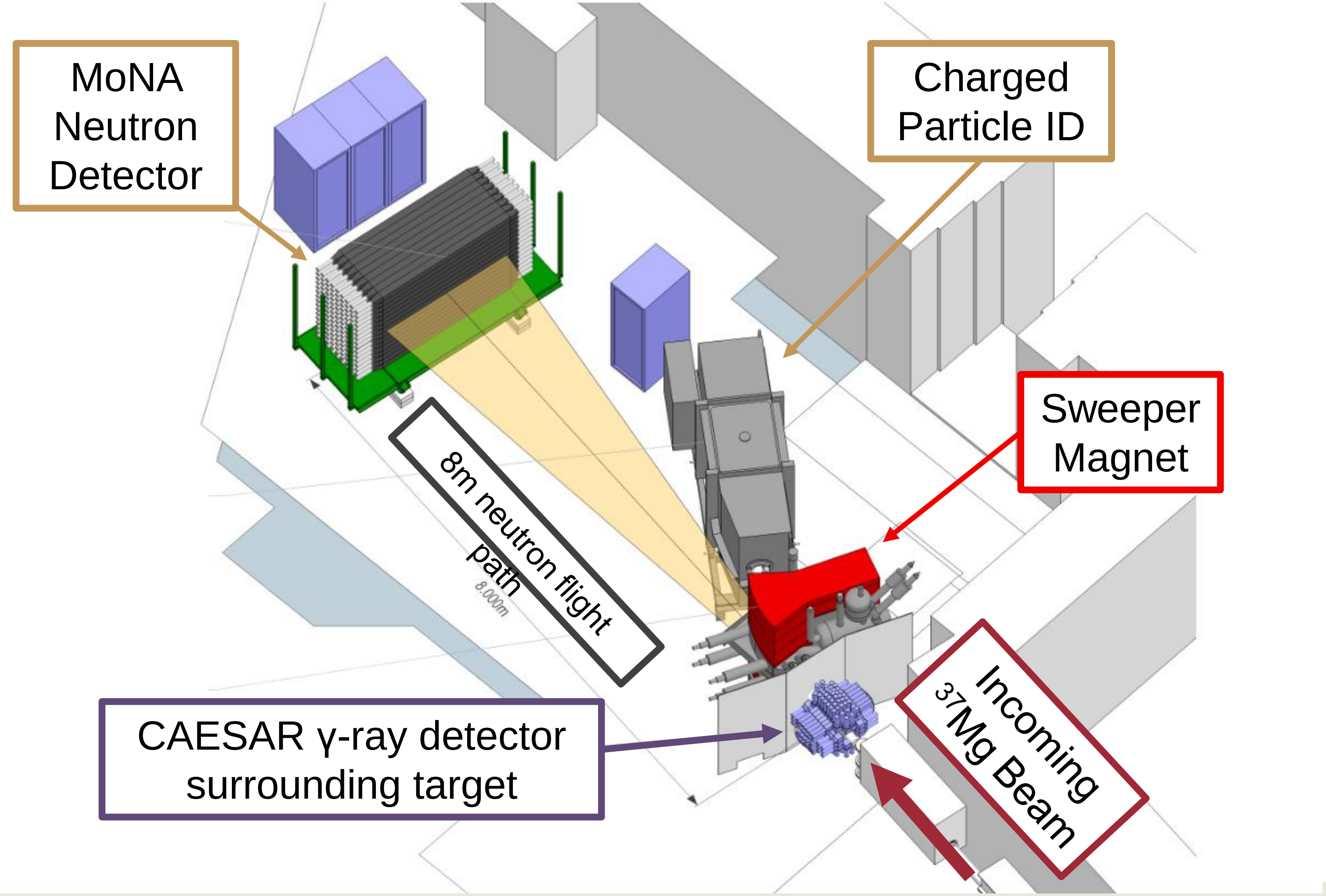
Status of p-wave halo studies (Kin. Comp. CB)



- RIKEN (^{29,31}Ne)
- FRIB PAC2 (^{37}Mg and ^{34}Na)
  - Scheduled for June 2025

MoNA experimental setup

- Secondary beam from FRIB impinge on reaction target after:
  - Timing start scintillator
  - Two PPACs
- Charged fragments are deflected by the Sweeper magnet then identified
  - Two drift chambers
  - Ionization chamber
  - Timing stop scintillator
- Neutrons are detected by MoNA
- CAESAR (CsI) surrounding target



MoNA experimental setup

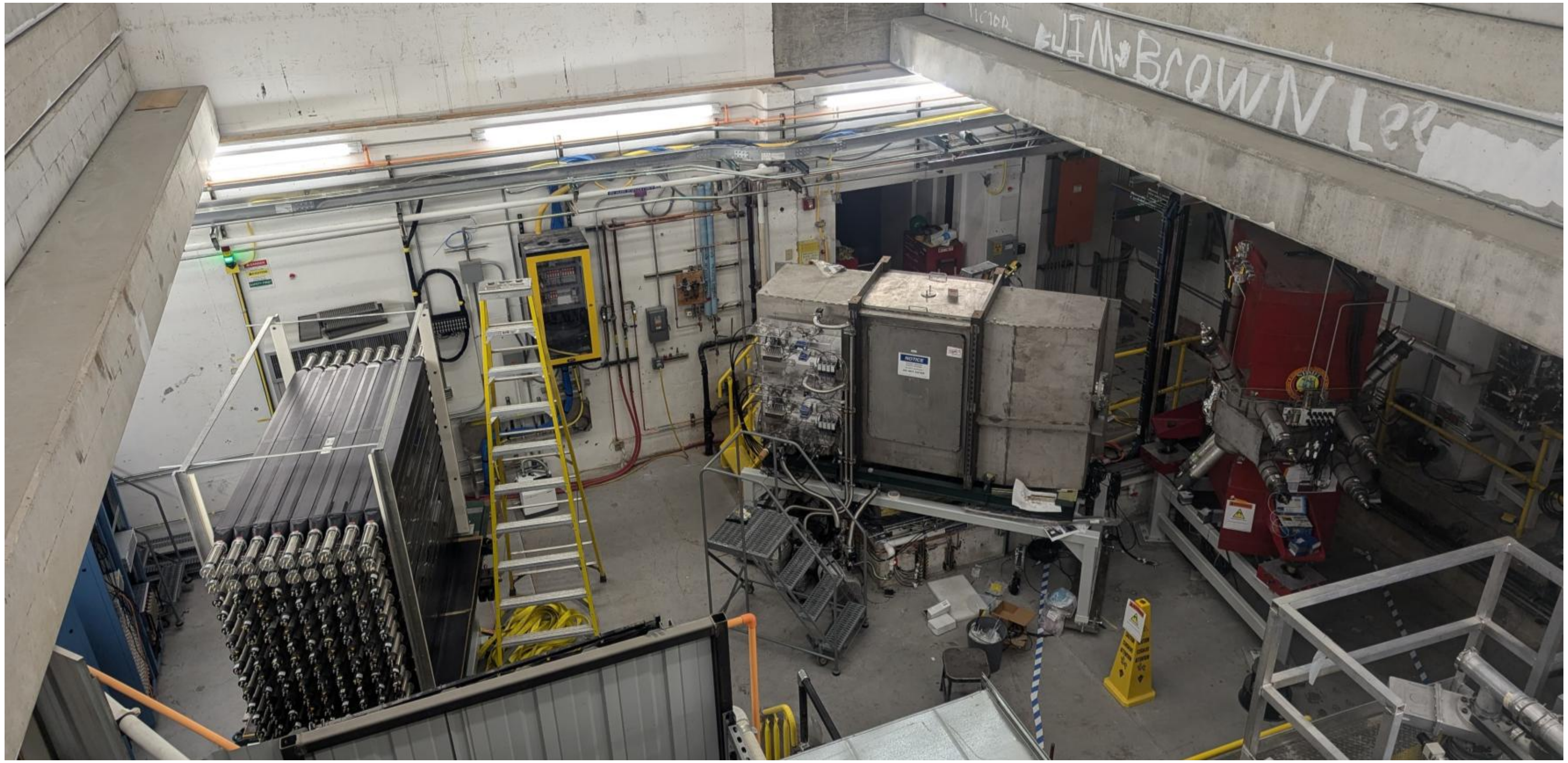
- Installation of the sweeper and MoNA setup took place in the last few months in the S2 vault at FRIB

- Sweeper was not used since 2017
  - All detectors are new except the IC

- MoNA not used since 2020

- Two commissioning were performed in the past few weeks

- Experiments in mid-June



FRIB
Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science | Michigan State University
640 South Shaw Lane • East Lansing, MI 48824, USA
frib.msu.edu

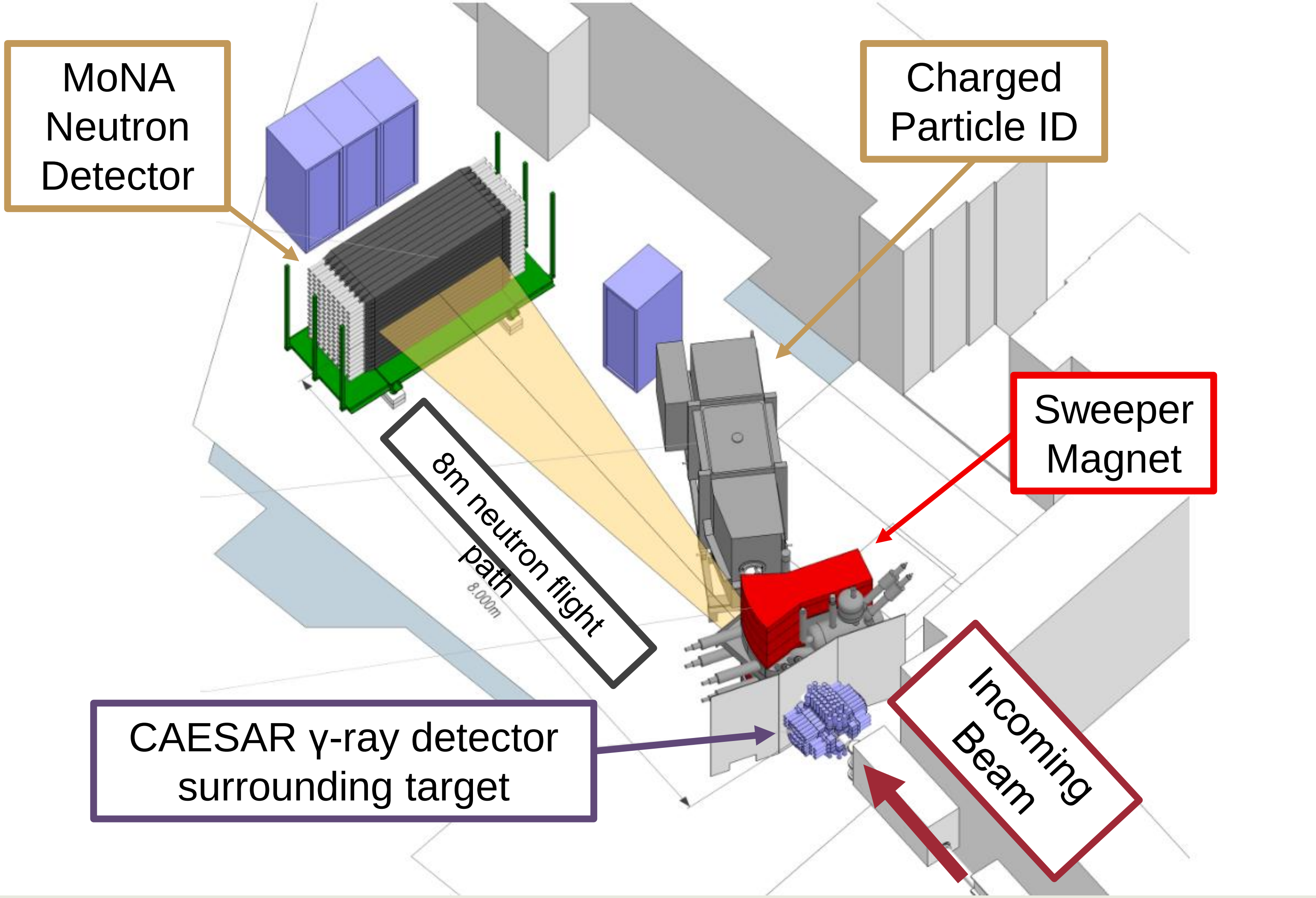
MoNA experimental setup - Limitations

The current setup has several limitations:

- Relatively short flight path and higher beam energies results in limited resolution

- Beam intensities will be high at FRIB but still challenging for the spectroscopy of dripline nuclei in the medium-mass region

- The sweeper magnet does not allow to bend the most neutron-rich isotopes at FRIB energies (200MeV/u)



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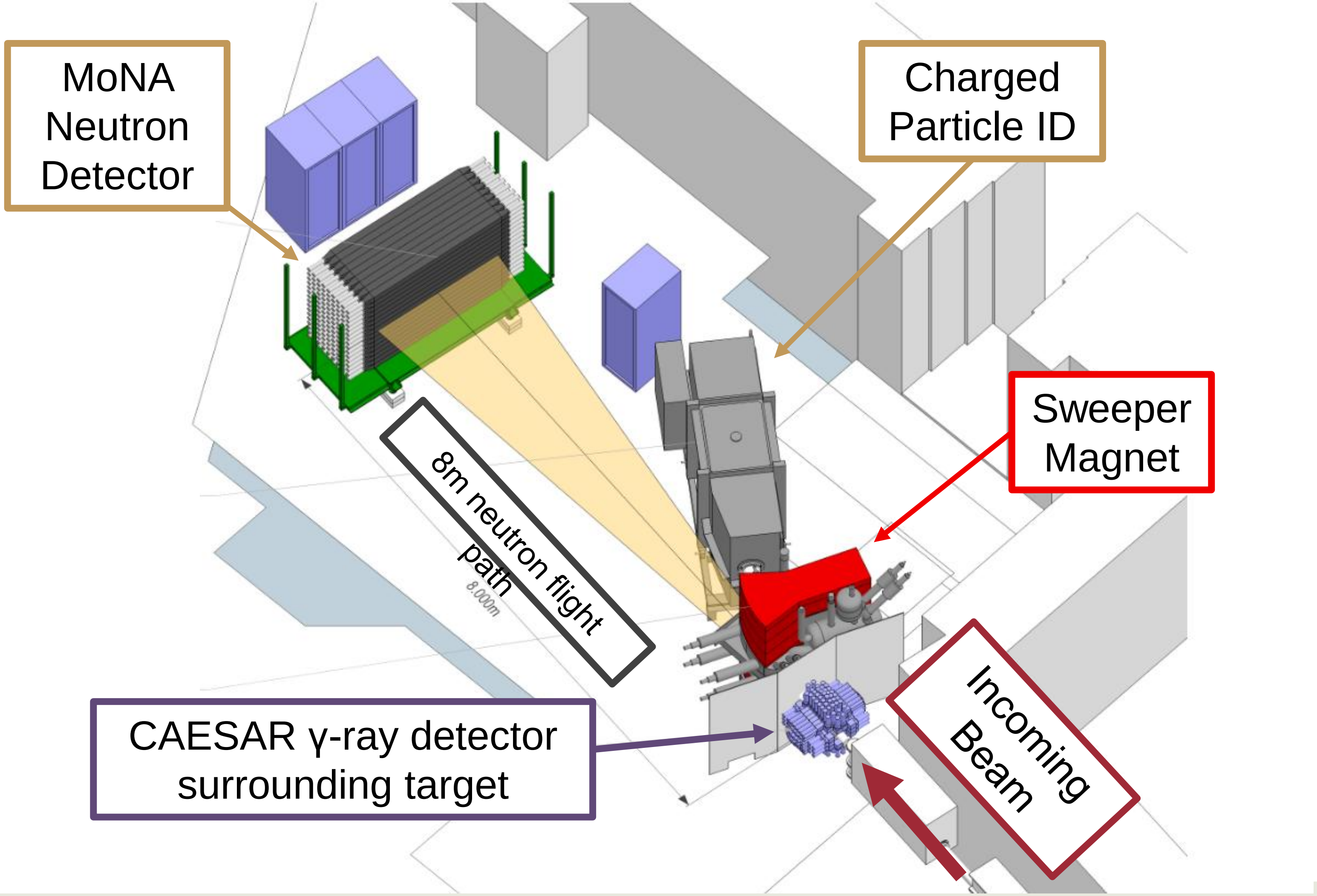
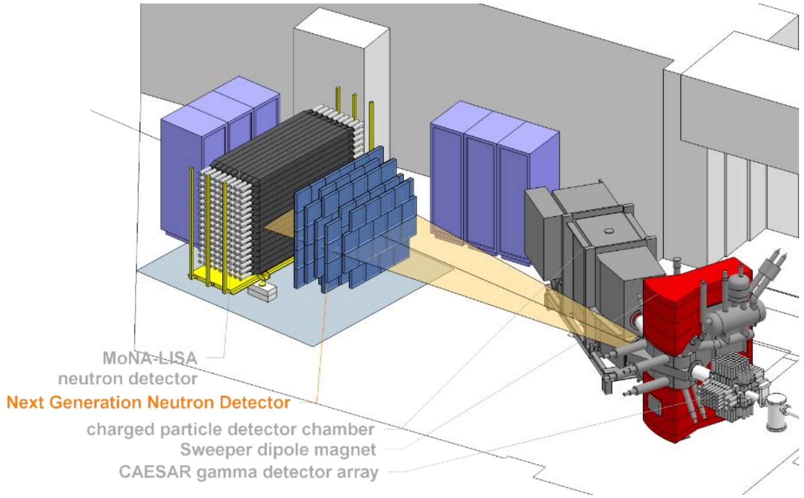
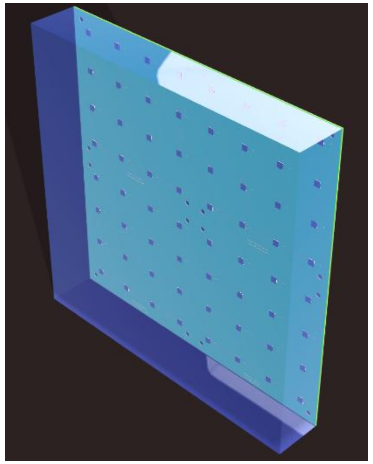
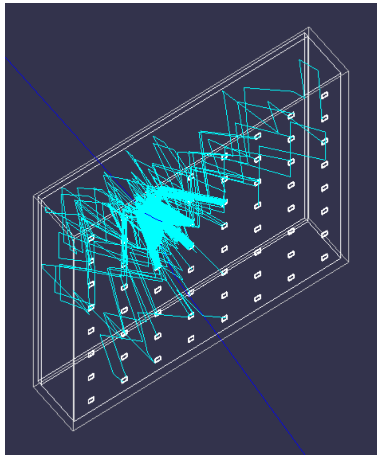


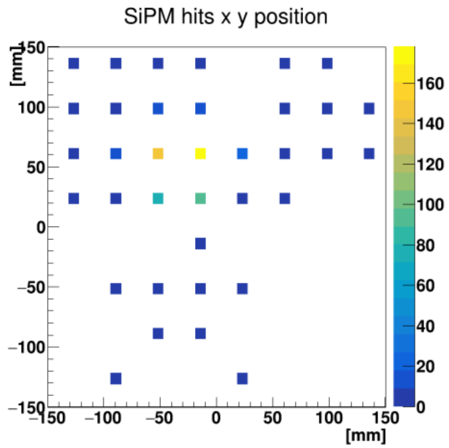
Next Generation Neutron Detector

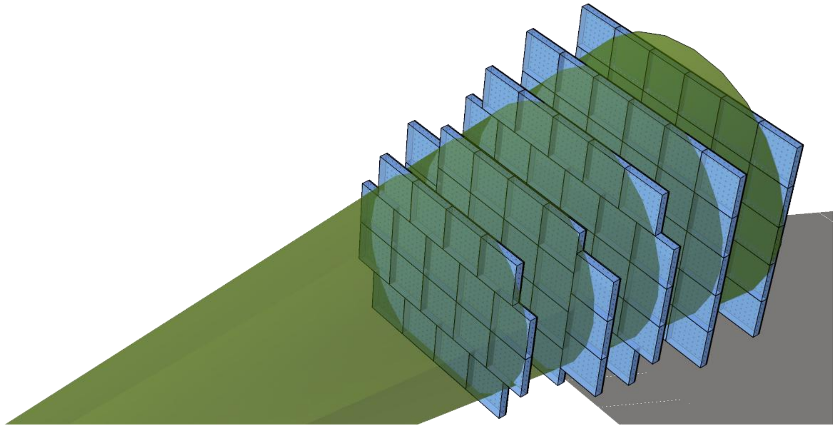
- Development of a next generation neutron detector
  - Optimized for position resolution.
  - To be used in combination with MoNA-LISA in order to increase neutron detection capabilities.
  - Detector tiles allow for optimized setups.





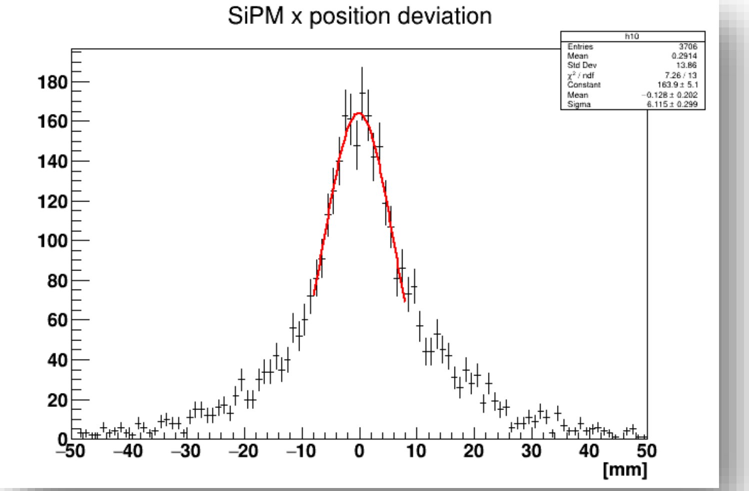


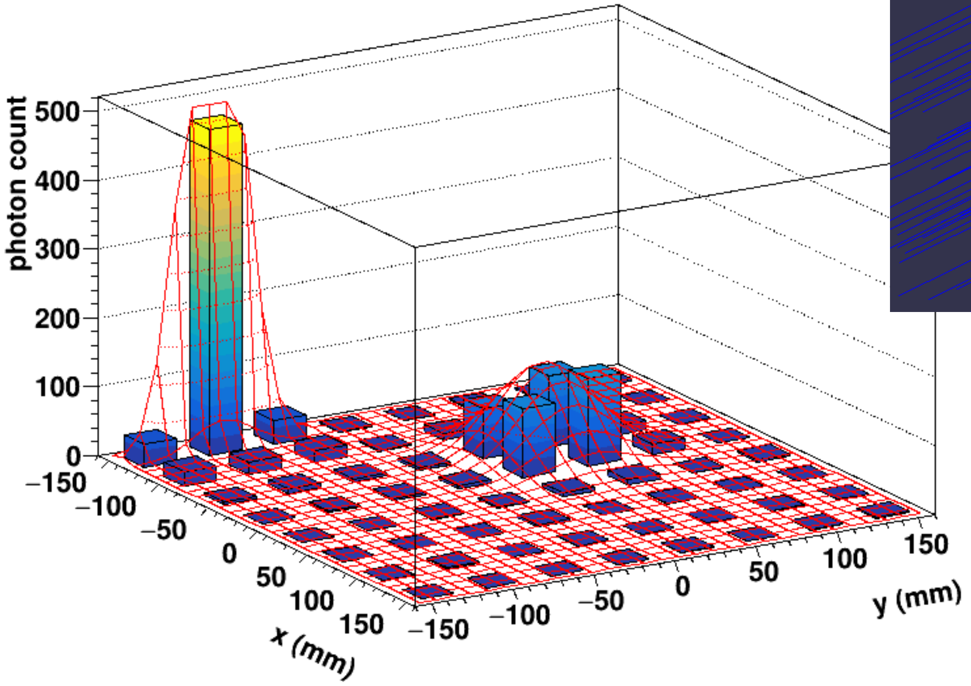


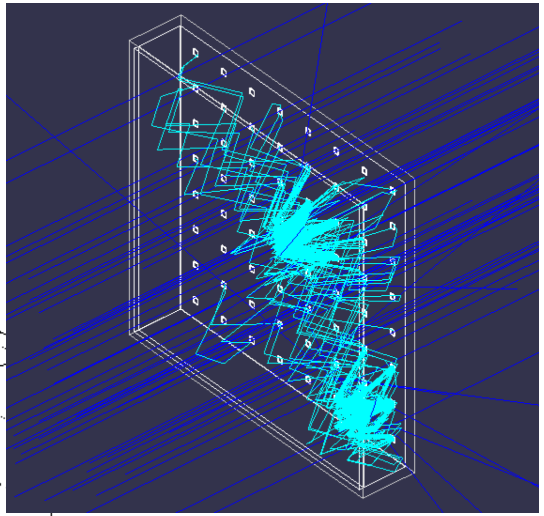


Next Generation Neutron Detector

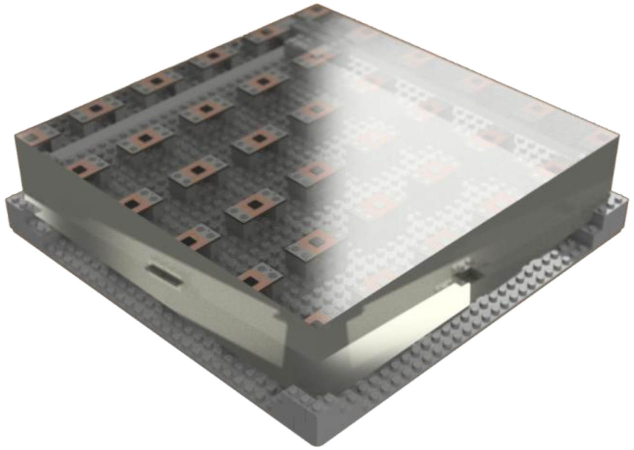
- Position determination by 2D SiPM array
  - Determine interaction point by 2 dimensional photon-count distribution.
  - Resolution not limited by time-difference measurement.
  - Multi-hit capability.



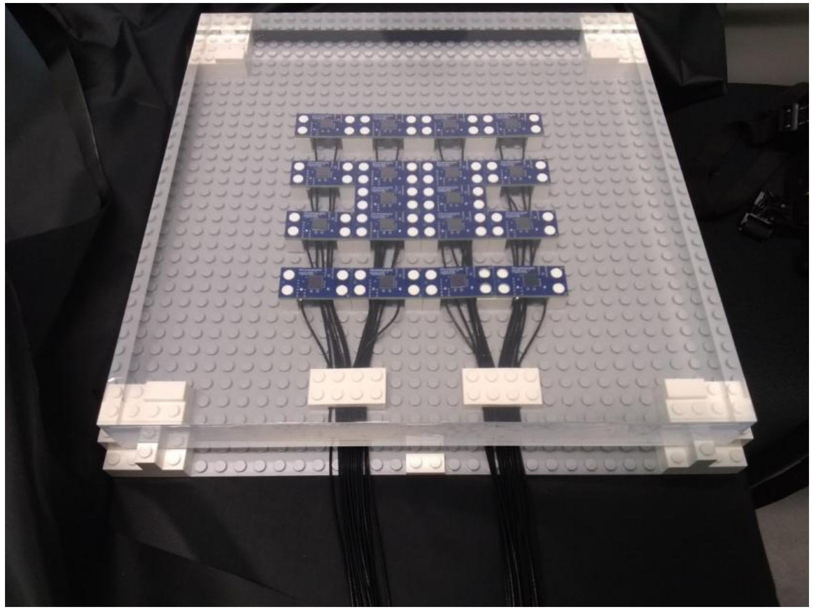




Next Generation Neutron Detector



- Conceptual rendering of a single scintillator tile backed with a 5 x 5 SiPM matrix



- Prototype detector with 16 SiPMs

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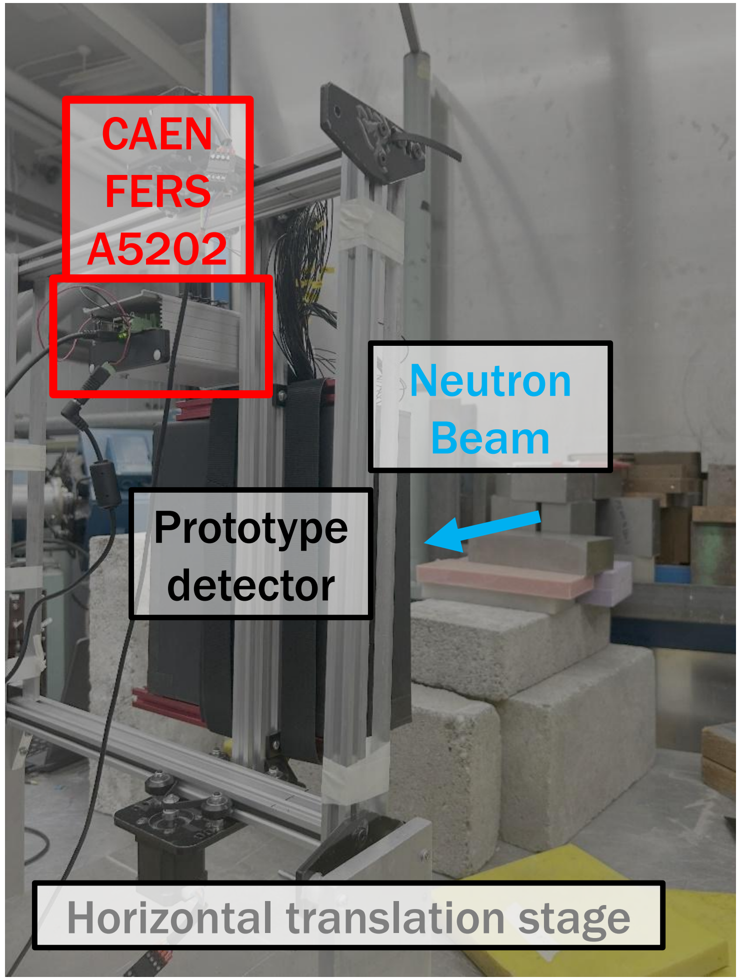
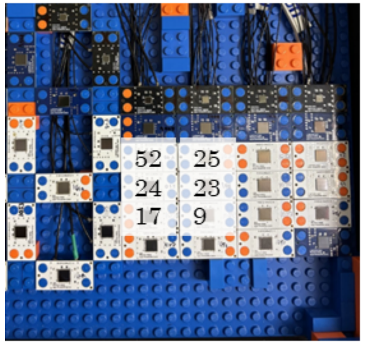
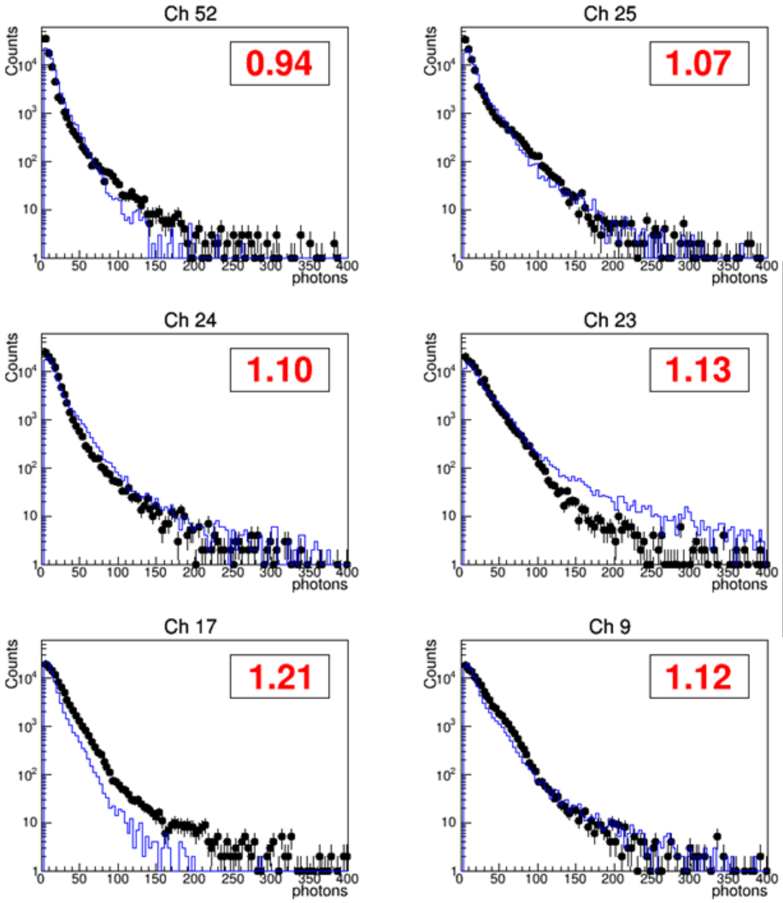
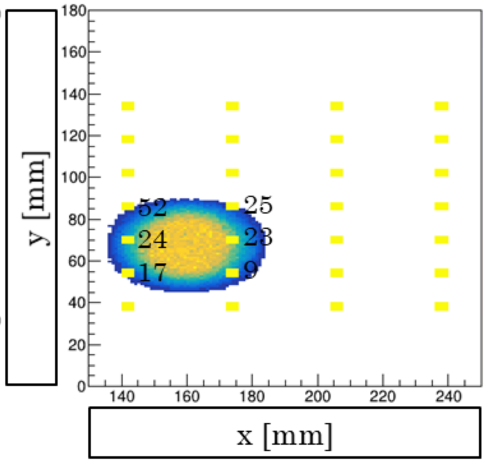
Next Generation Neutron Detector









- A preliminary comparison between the TUNL measurements and simulation.

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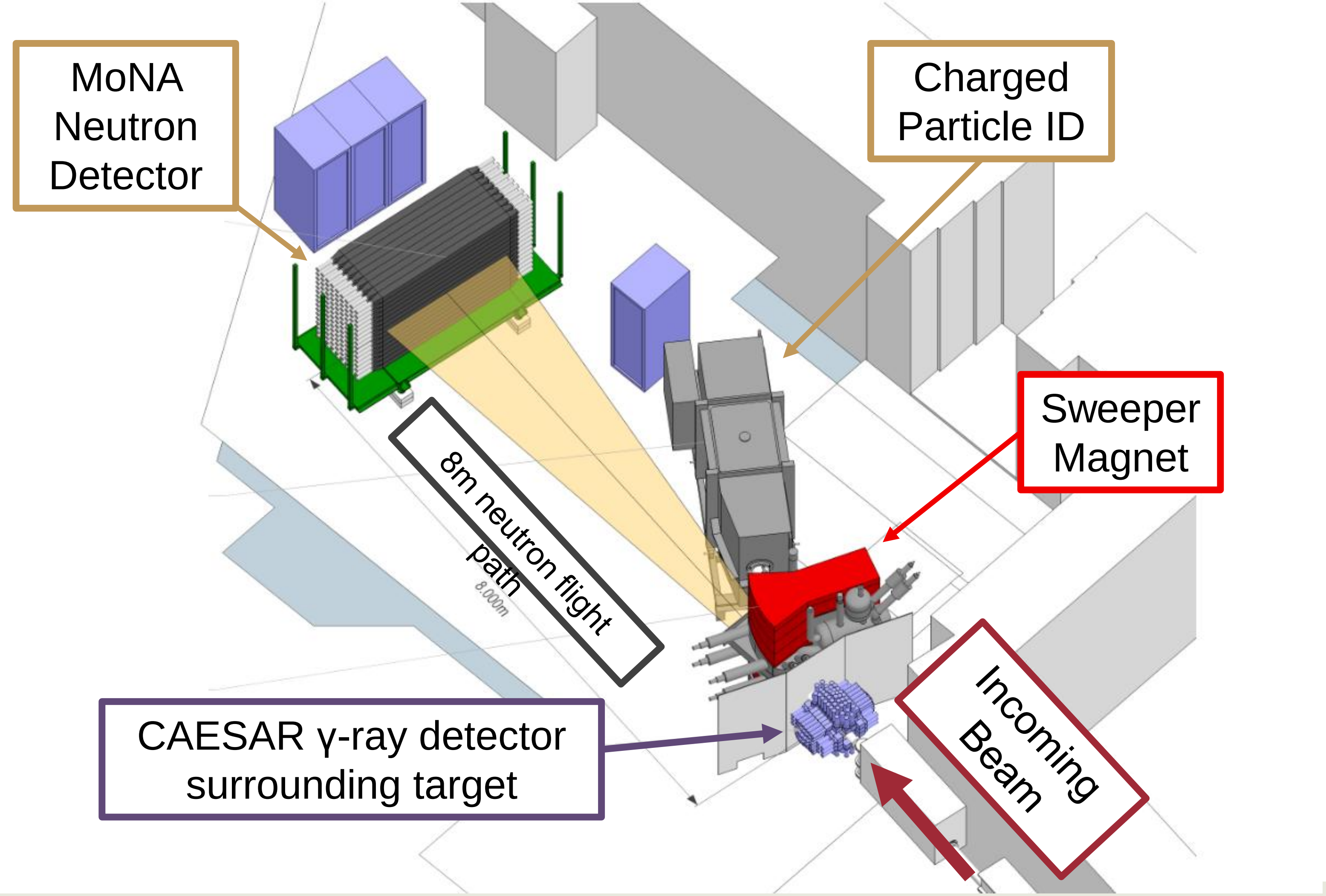
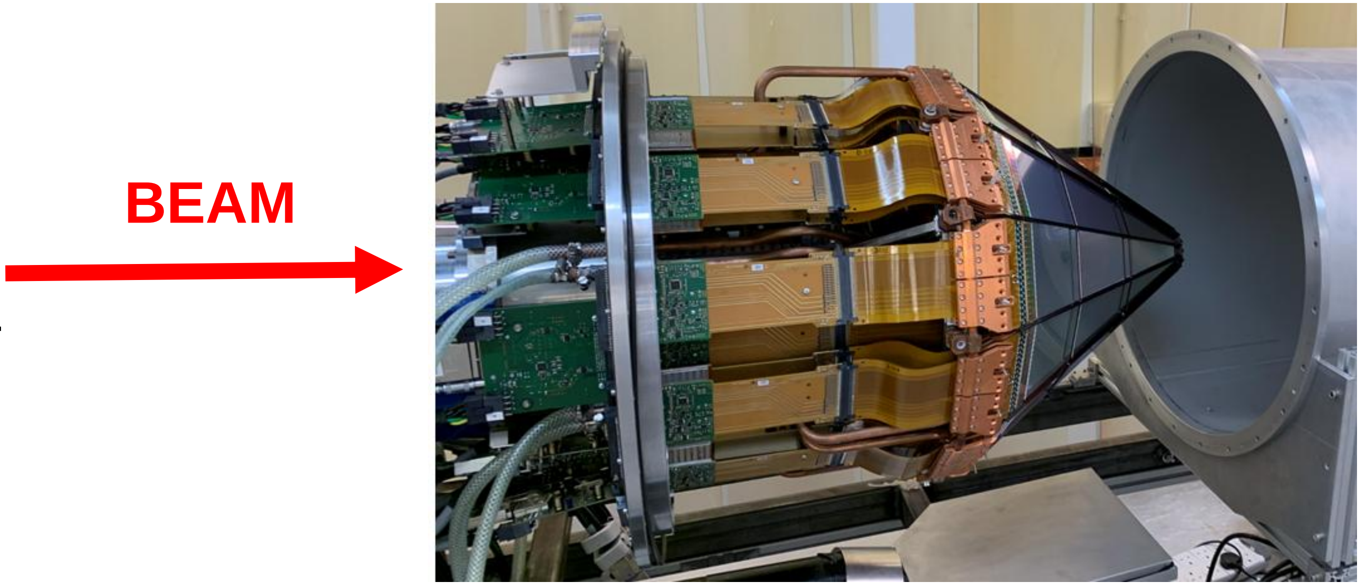
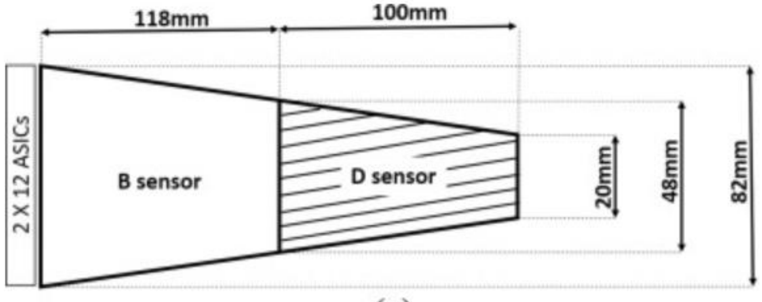


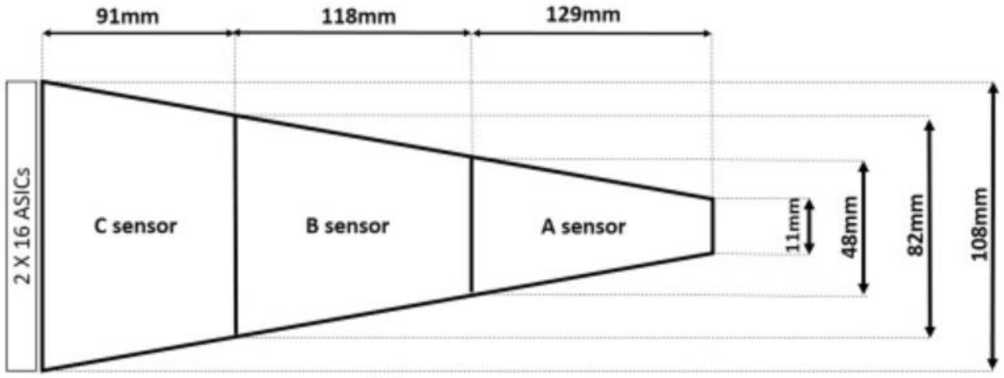
LH2 target and Lamp shape Low mass Light particle Tracker (L3T)[1]

- Two layers of 300um DSSSD
- Covers angles between 6 and 103 degrees
- Inner Layer: 6 trapezoid shaped detector units and 1536 strips (50um pitch)
- Outer Layer: 12 trapezoid shaped detector units and 2048 strips (50um pitch)





(a)

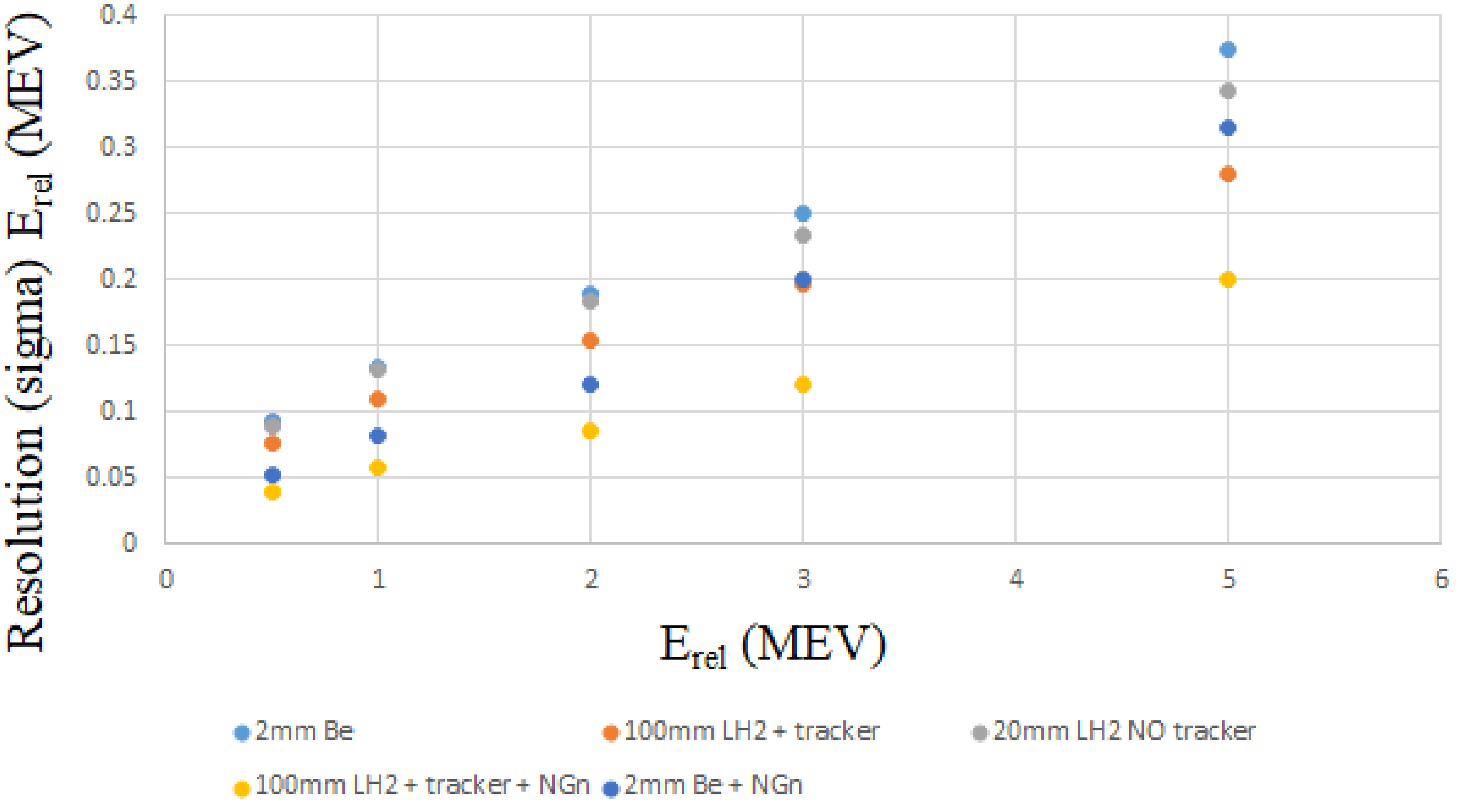


(b)

1. M. Borri, NIM A 836, 105 (2016)

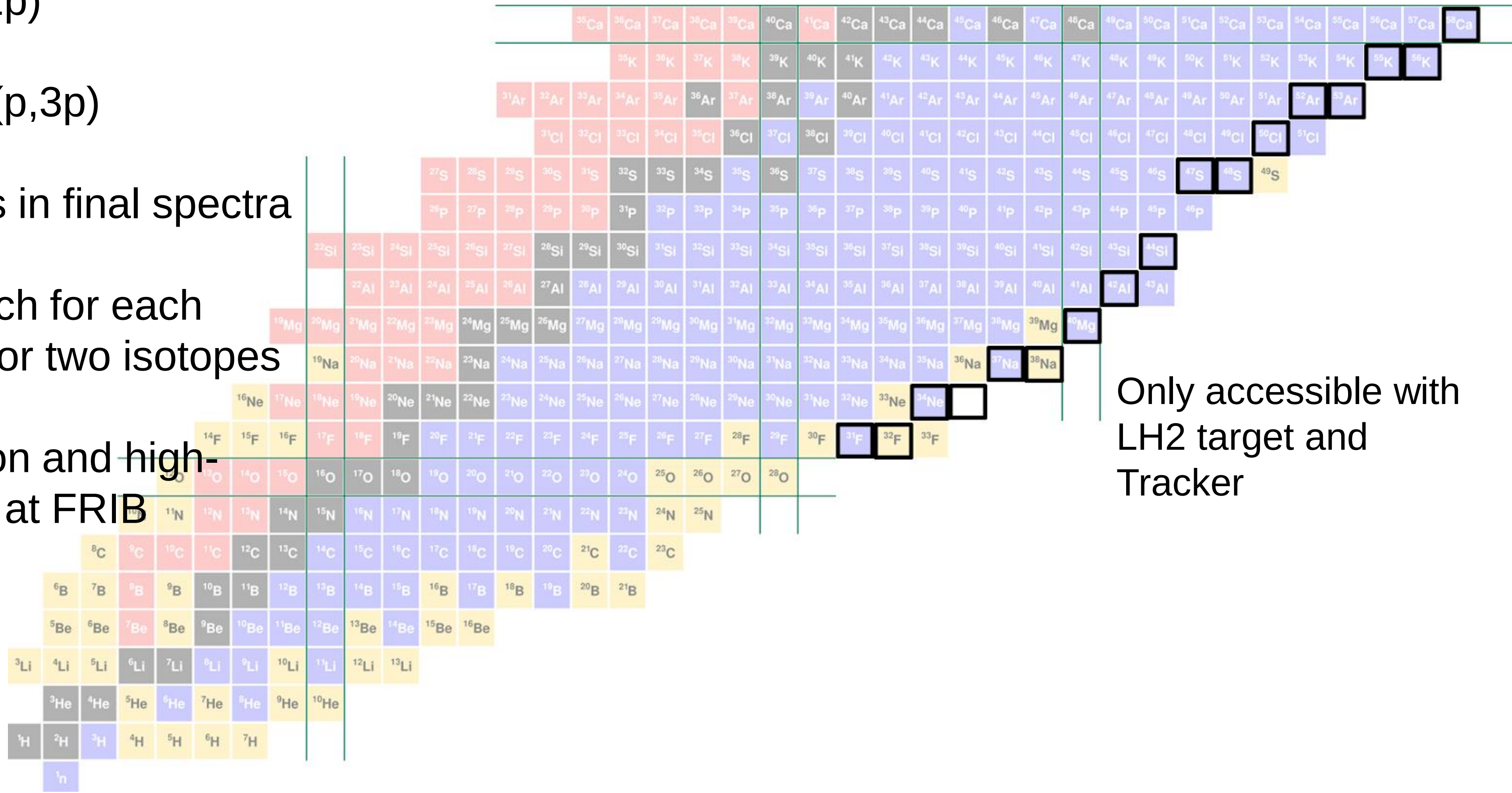
Simulated performances

- > 80% efficiency for (p,2p)
- ~1mm resolution on the vertex (MINOS ~3mm)
- At least 20% improved resolution compared to solid target (2mm)
- In combination to NGn, less than 80keV (sigma) under 2MeV will be achieved
- 100mm thick LH2 target provides an order of magnitude more luminosity (x10 more statistics or /10 beam time required)



Extended reach to the neutron dripline

- Assuming 2mb for (p,2p)
- Assuming 0.02mb for (p,3p)
- Assuming 1500 events in final spectra
- We will extend the reach for each isotopic chain by one or two isotopes
- Allow for high-resolution and high-statistics experiments at FRIB



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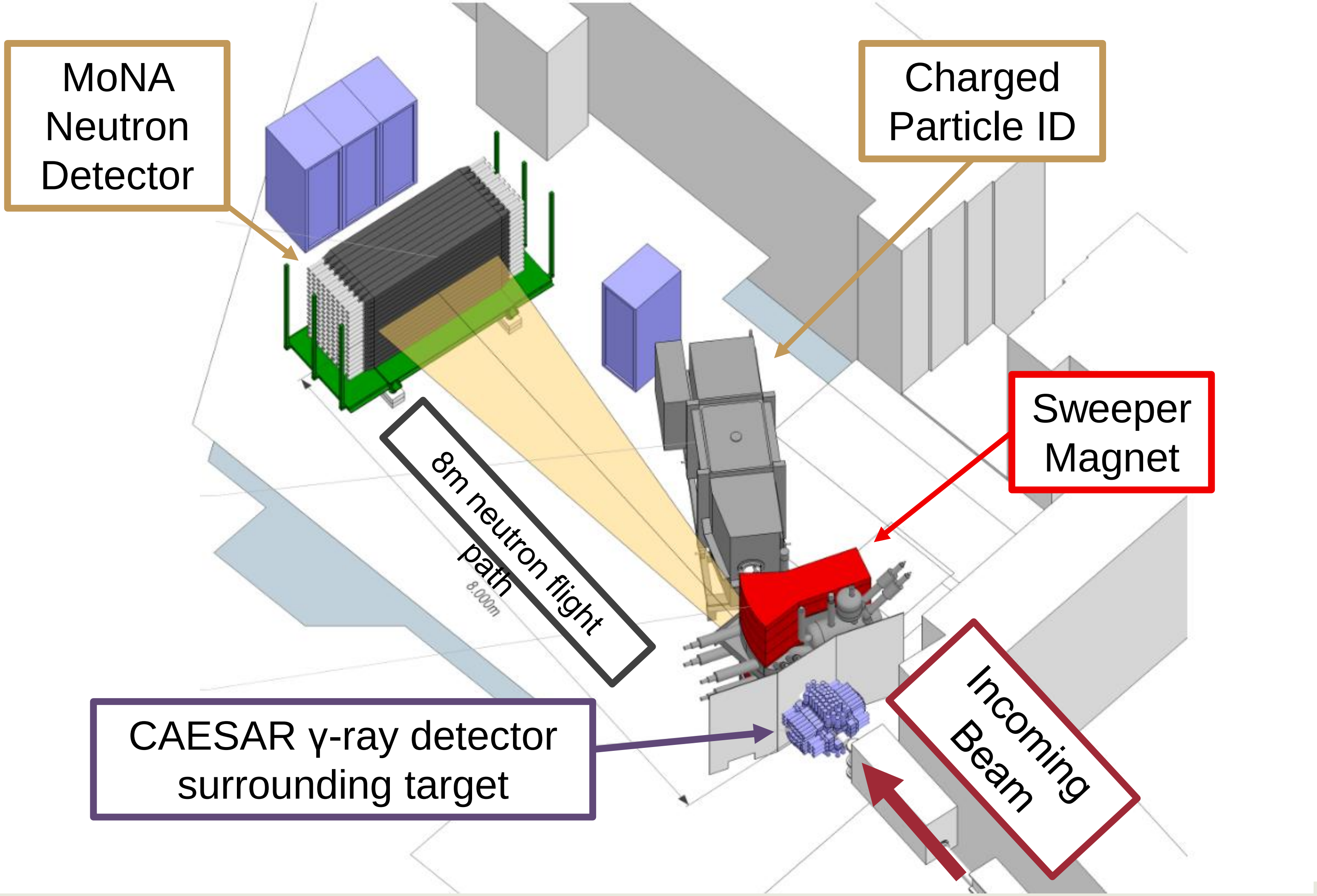
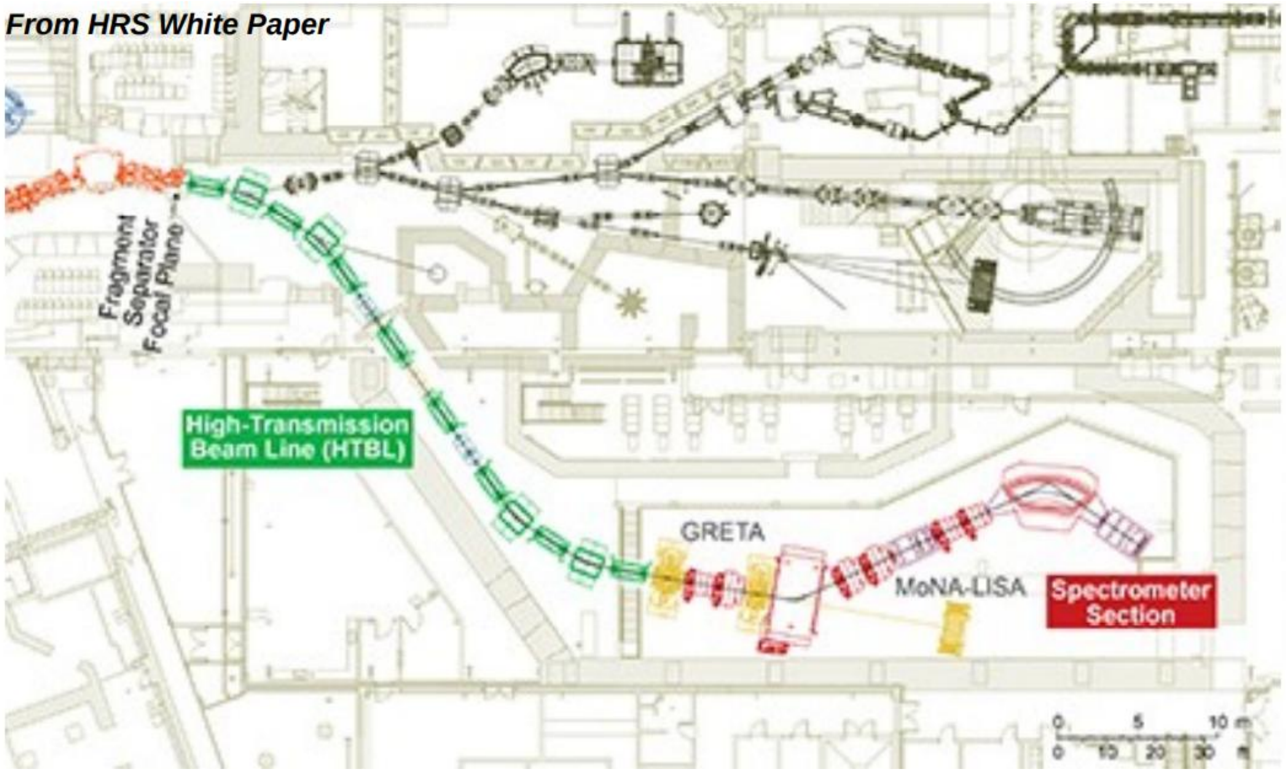
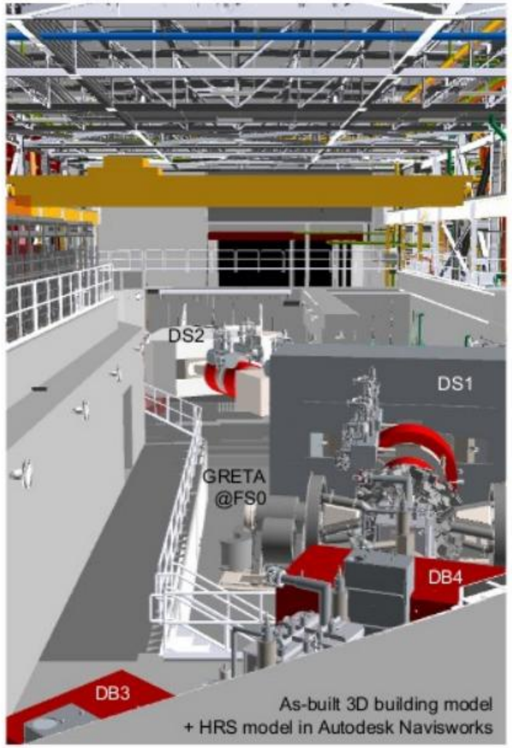


Future location at the HRS (High Rigidity Spectrometer)





- 8Tm magnetic rigidity
- Longer neutron flight path (~12m)

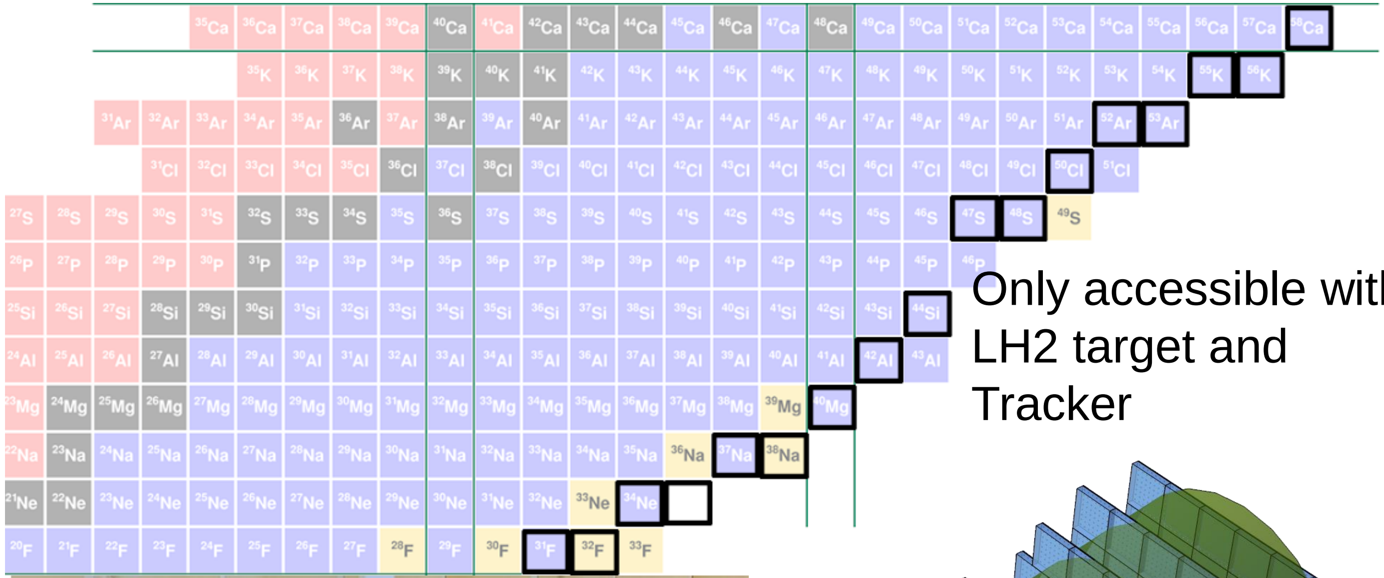
Conclusion and Perspectives

- Exciting time for the MoNA collaboration as we are getting ready for the first MoNA experiments of the FRIB era

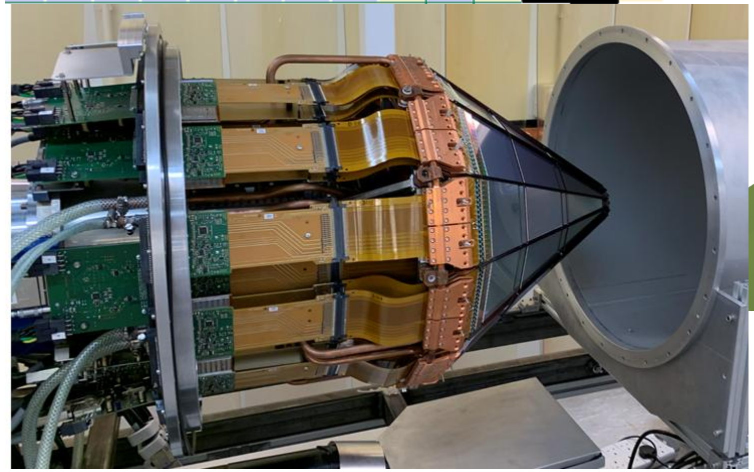
- Two Coulomb breakup experiments (^{37}Mg and ^{34}Na) will be performed in June 2025

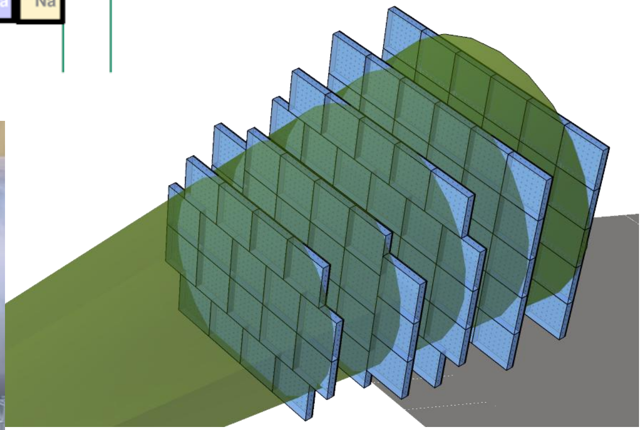
- Efforts ongoing to improve on the currently available setup (neutron detection and LH2 target + tracker) in order to improve resolution and luminosity

- This will extend the reach of neutron invariant-mass experiments to the medium-mass region



Only accessible with LH2 target and Tracker





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A. Banu - James Madison University

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A. N. Kuchera – Davidson College

M. Labiche – Daresbury Laboratory

S. Paschalis – Shool of Physics, York

M. Petri - Shool of Physics, York

T. Redpath – Virginia State University

W. F. Rogers – Indiana Weslayan