Investigating neutron halo nuclei using Coulomb breakup at FRIB

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CNRS-MSU IRL Kickoff Meeting, FRIB

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U.S. DEPARTMENT OF ENERGY | Office of Science

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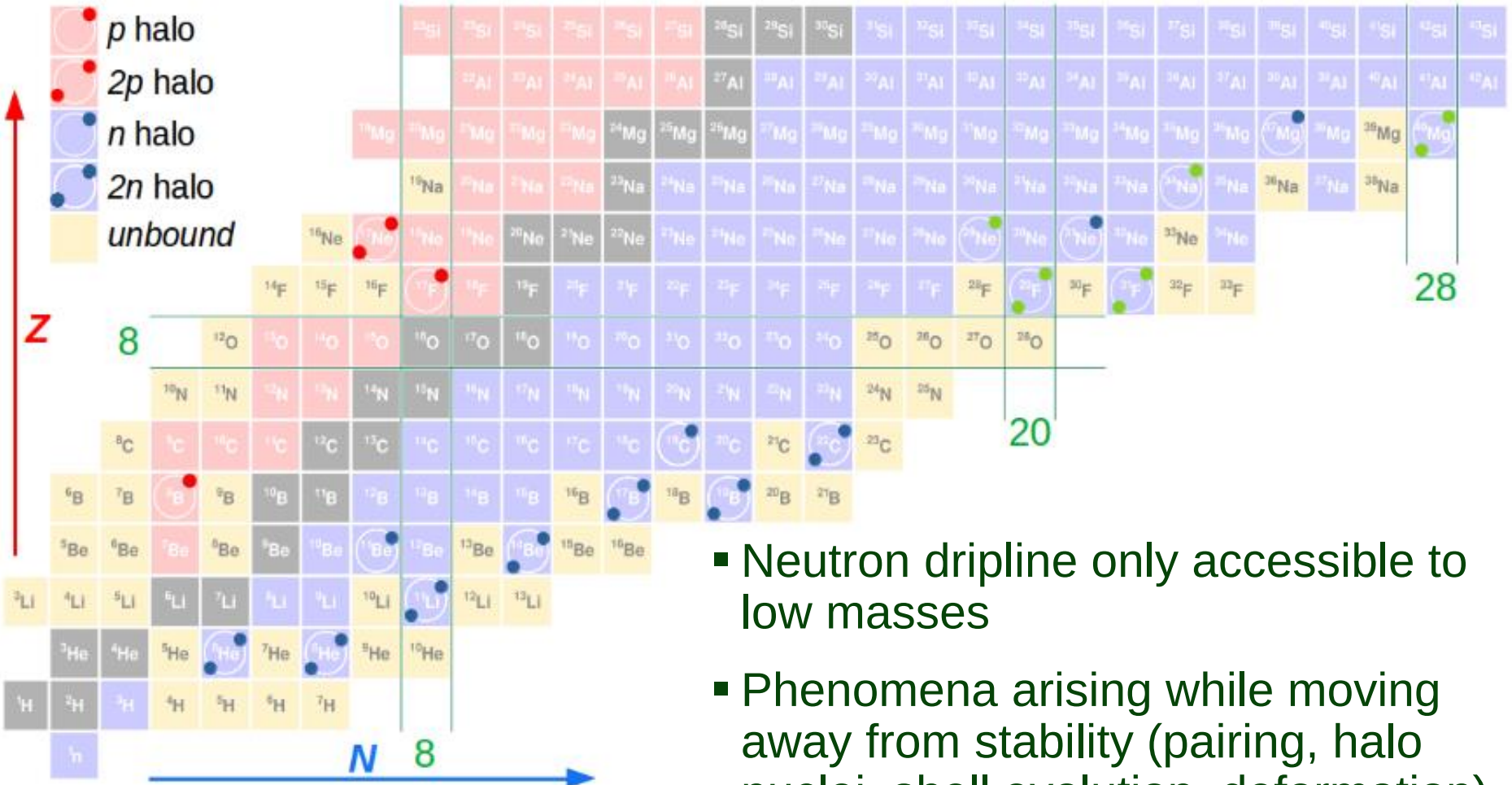
Outline

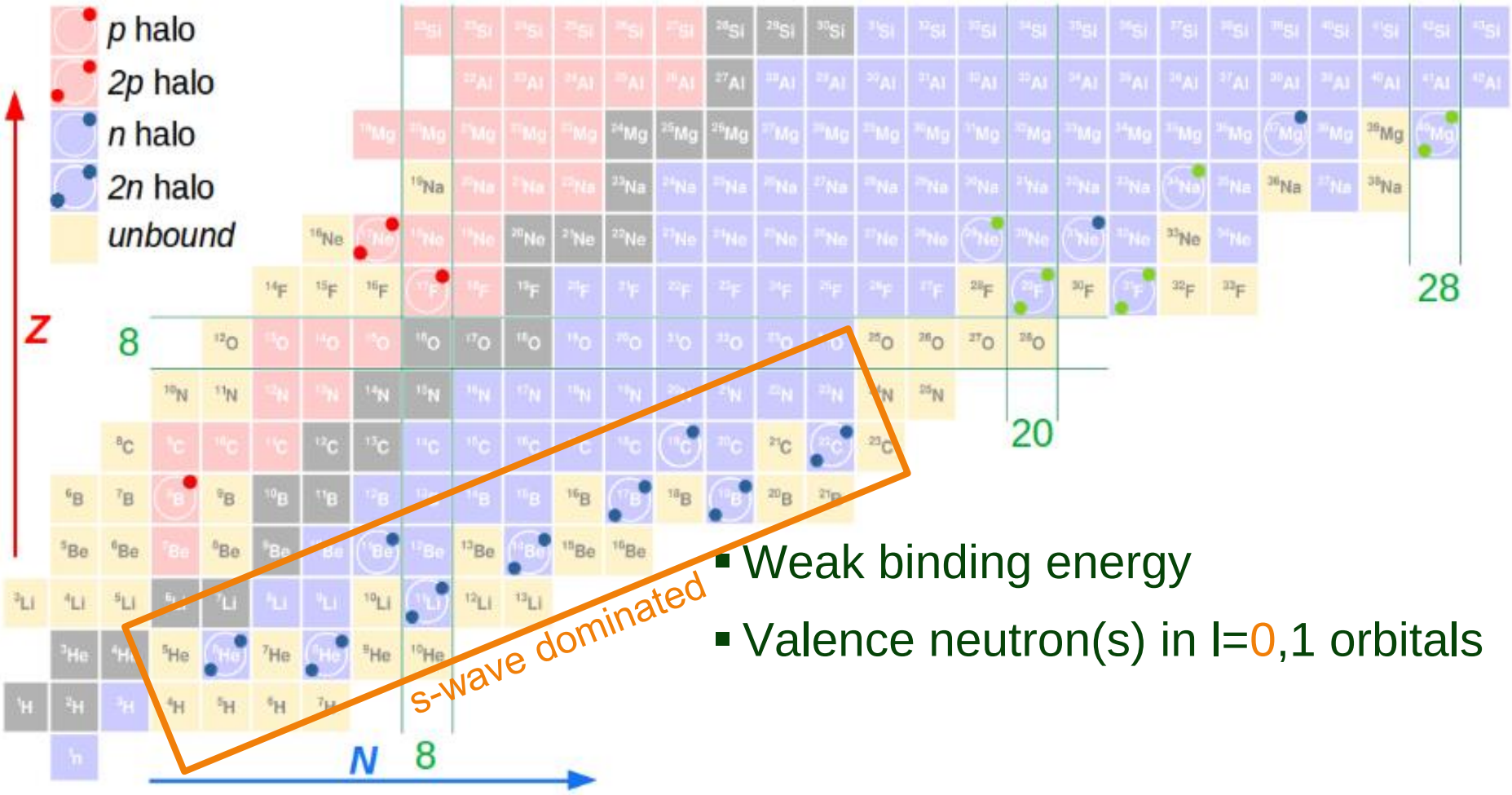
- Motivations
- Coulomb breakup as a tool to investigate halo nuclei
- Two FRIB PAC approved experiments
- Future technical improvements
- Conclusion and Outlook

Motivations



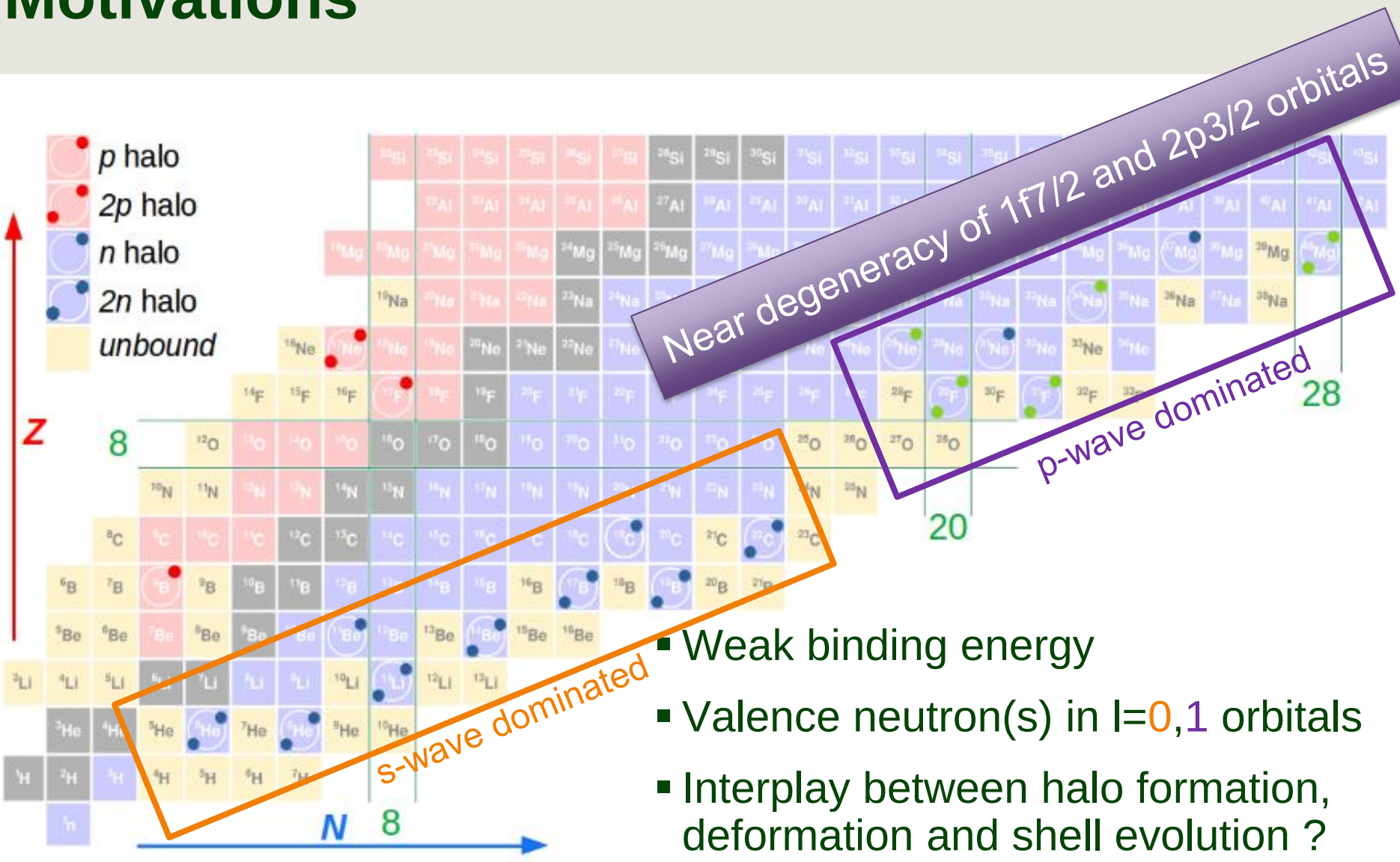
- Neutron dripline only accessible to low masses
- Phenomena arising while moving away from stability (pairing, halo nuclei, shell evolution, deformation)

Motivations



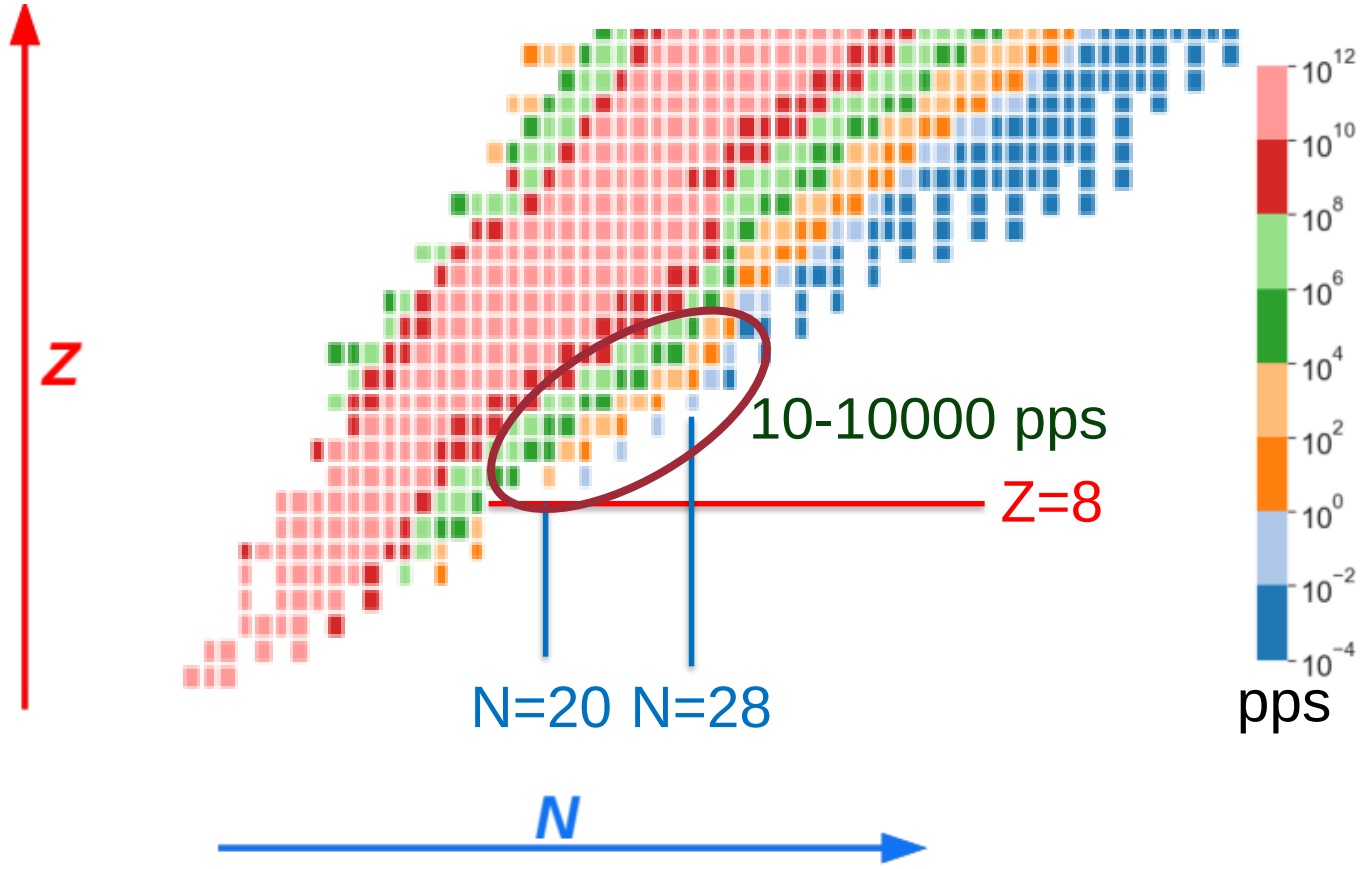
- Weak binding energy
- Valence neutron(s) in l=0,1 orbitals

Motivations

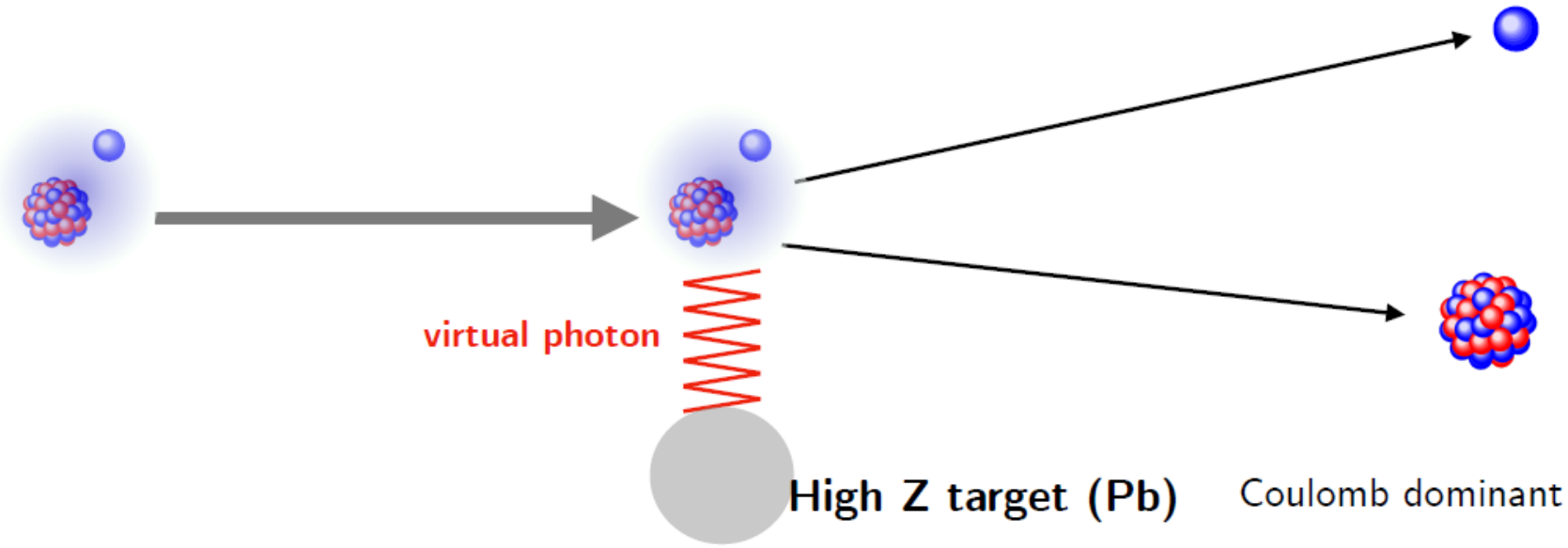


- Weak binding energy
- Valence neutron(s) in l=0,1 orbitals
- Interplay between halo formation, deformation and shell evolution ?

FRIB extends reach towards medium-mass dripline



Coulomb breakup of one-neutron halo nuclei



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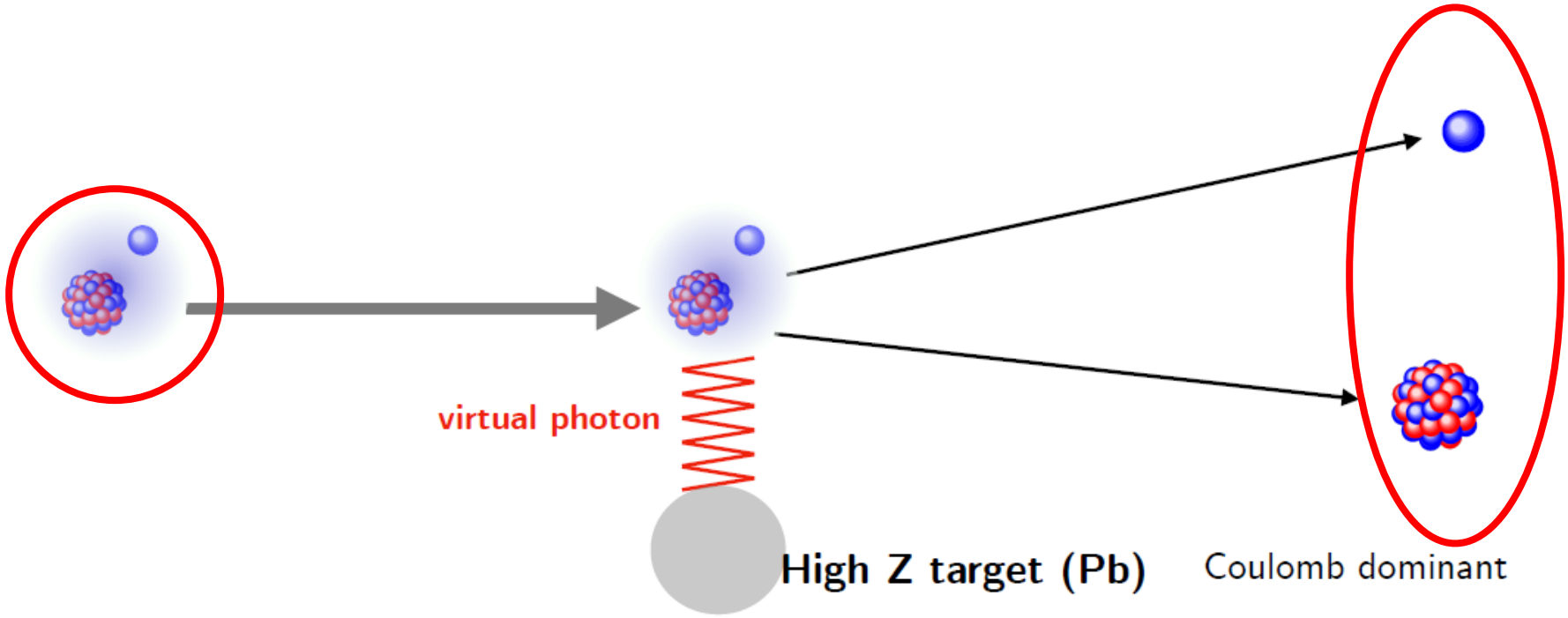


- Invariant-mass (Erel) from decay products
- Coulomb breakup cross-section (σ)
- Reaction on low-Z target to subtract Nuclear breakup contribution

Coulomb breakup of one-neutron halo nuclei

- Breakup cross-section distribution
- E1 strength distribution

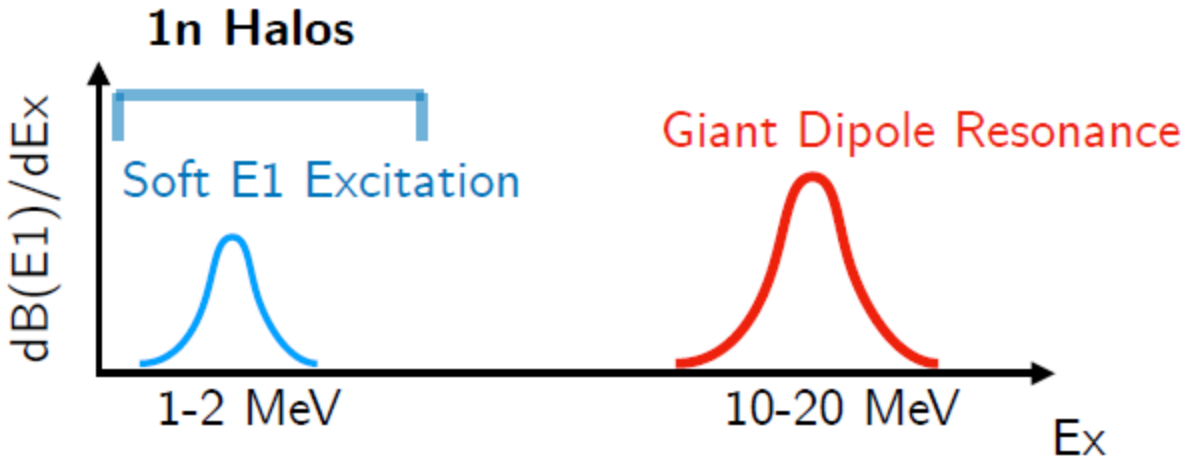
$$\frac{d\sigma}{dE_{rel}} \xrightarrow{\text{Equivalent Photon Method}} \frac{dB(E1)}{dE_{rel}}$$

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

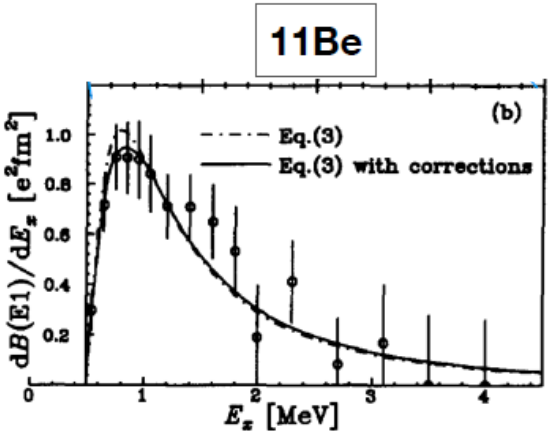
- Geometrical information on the halo:

$$B(E1) = \frac{3}{4\pi}\frac{Ze^2}{A} r_{c,n}^2$$

Experimental signatures of neutron halo

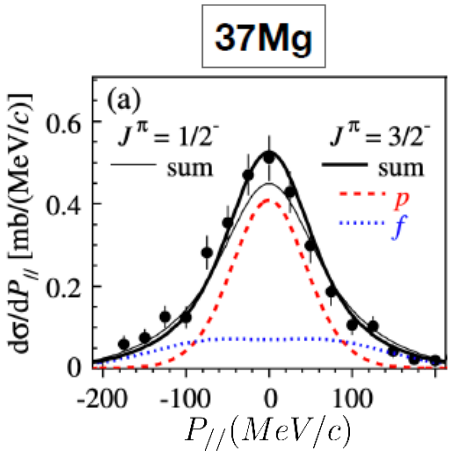


- Soft E1 excitation (~1MeV)
- Large B(E1) strength (>1 e^2fm^2)
- Large cross-sections (>0.5 b)
- Narrow momentum dist. (s or p)
- Forward peaked angular distributions



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

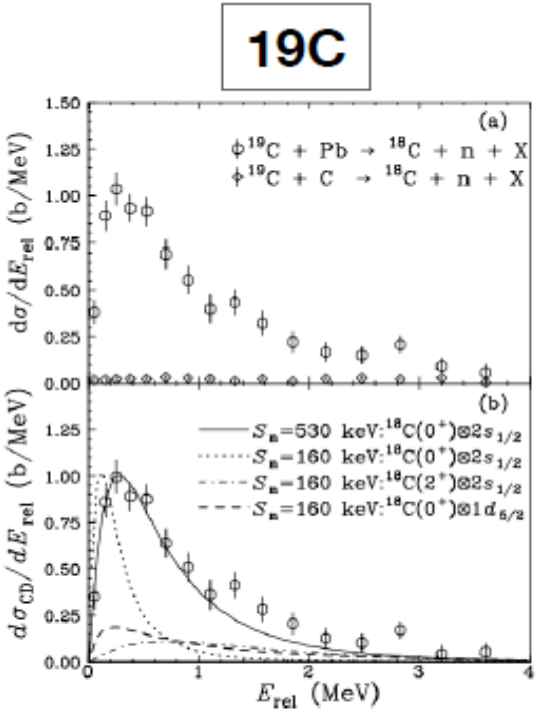
$B(E1) = 1.3 \pm 0.3\ e^2fm^2$



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

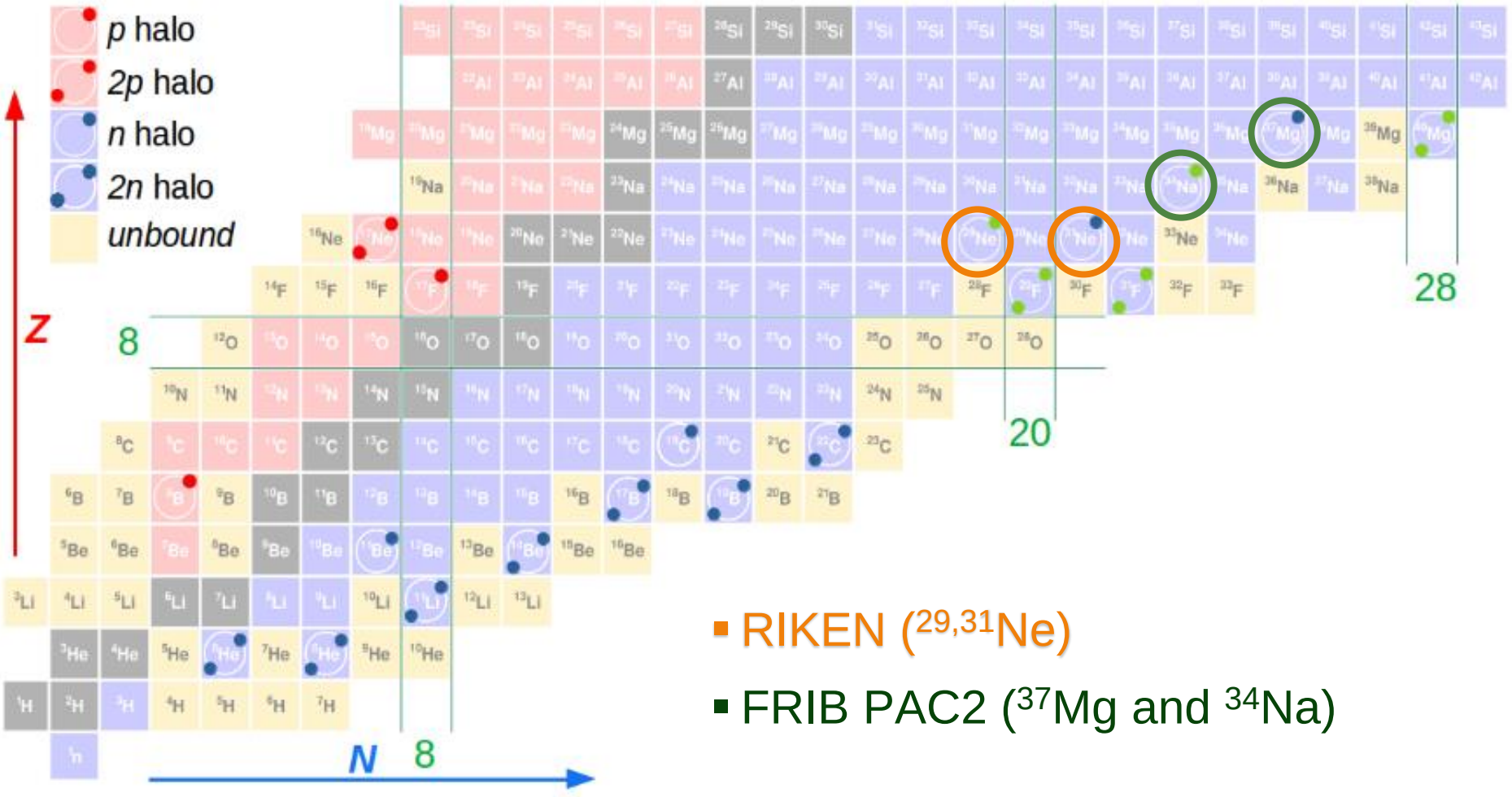
Experimental signatures of neutron halo

- 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 ?



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

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



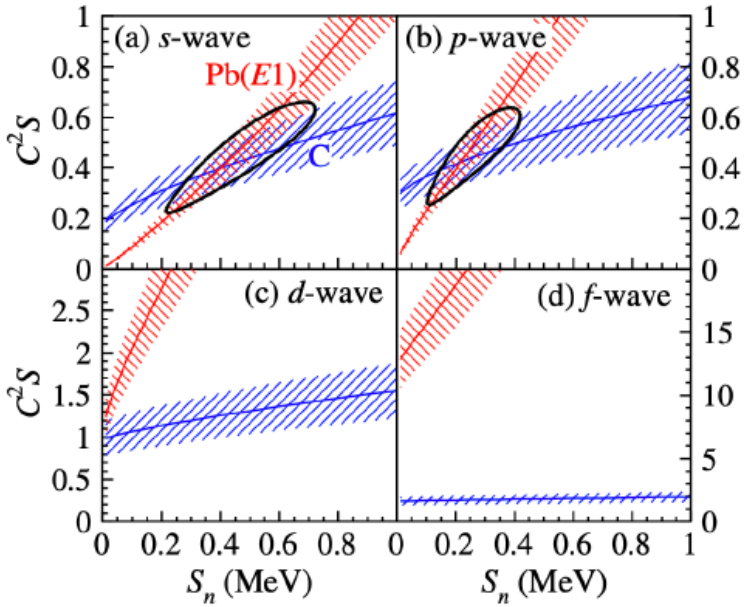
- RIKEN (^{29,31}Ne)
- FRIB PAC2 (^{37}Mg and ^{34}Na)

E23033: ^{37}Mg, the heaviest p-wave halo?

- Heaviest confirmed p-wave halo (^{40}Mg?)

Spokesperson: AR

- Inclusive cross-sections measured at RIKEN:
  - Sn=220 keV
  - $p_{3/2}$ neutron (C2S=0.42). Consistent with deformation.
  - g.s. assignment of J=3/2- or J=1/2-

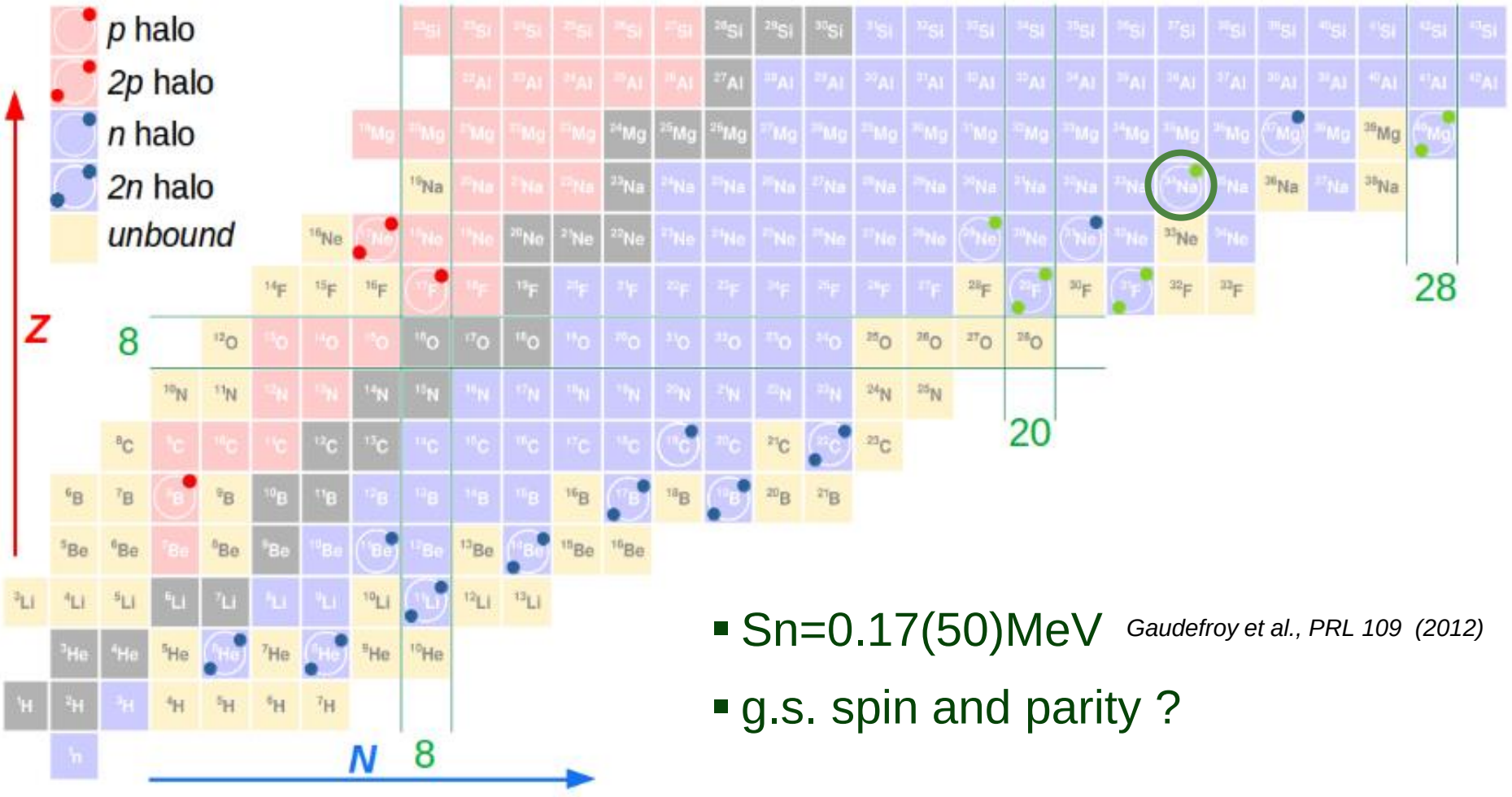


N. Kobayashi et al., PRL 112 (2014)

- First kinematically complete Coulomb breakup measurement at FRIB to obtain unambiguous determination of configuration, C2S and Sn.
- Local support for theoretical calculations (C. Hebborn)

E23068: ^{34}Na, p-wave halo candidate?

Spokesperson: B. Monteagudo



- Sn=0.17(50)MeV *Gaudefroy et al., PRL 109 (2012)*
- g.s. spin and parity ?

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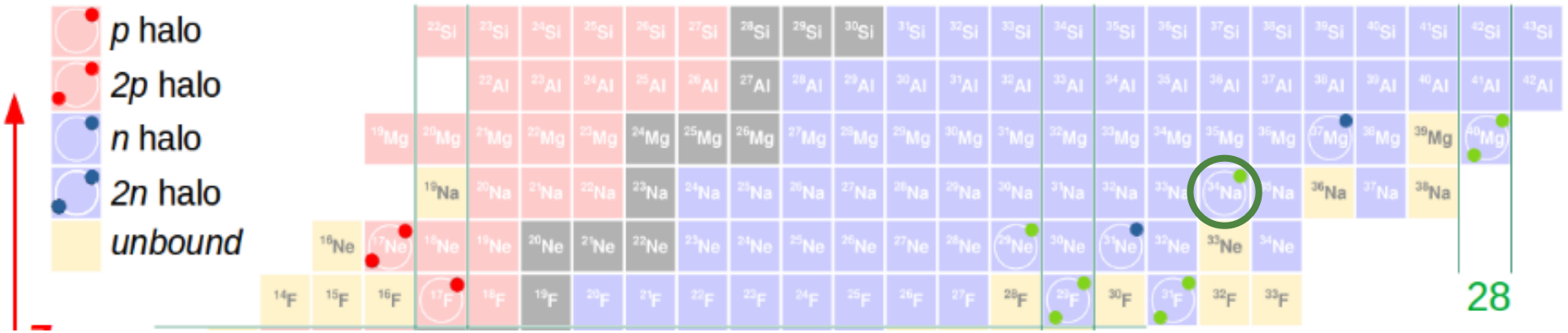

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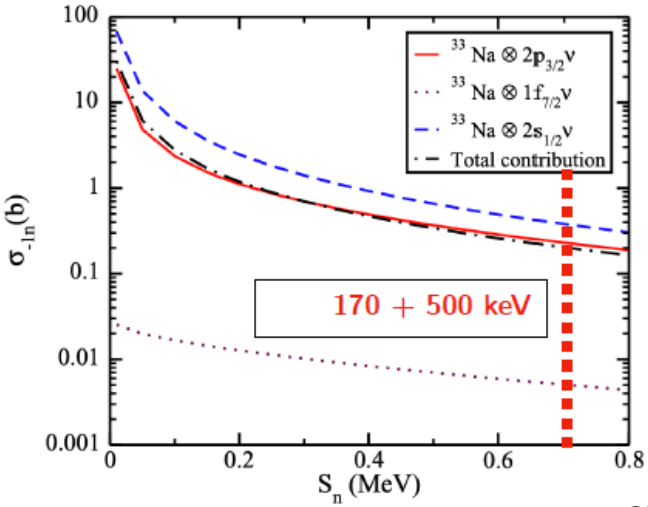
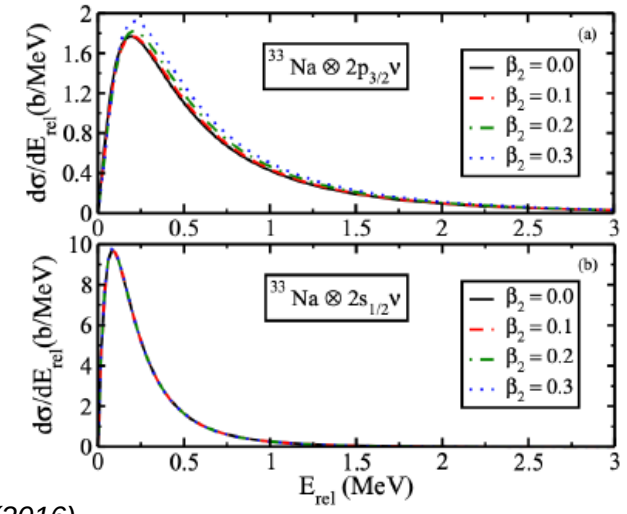




Singh et al., PRC (2016)

Experimental setup

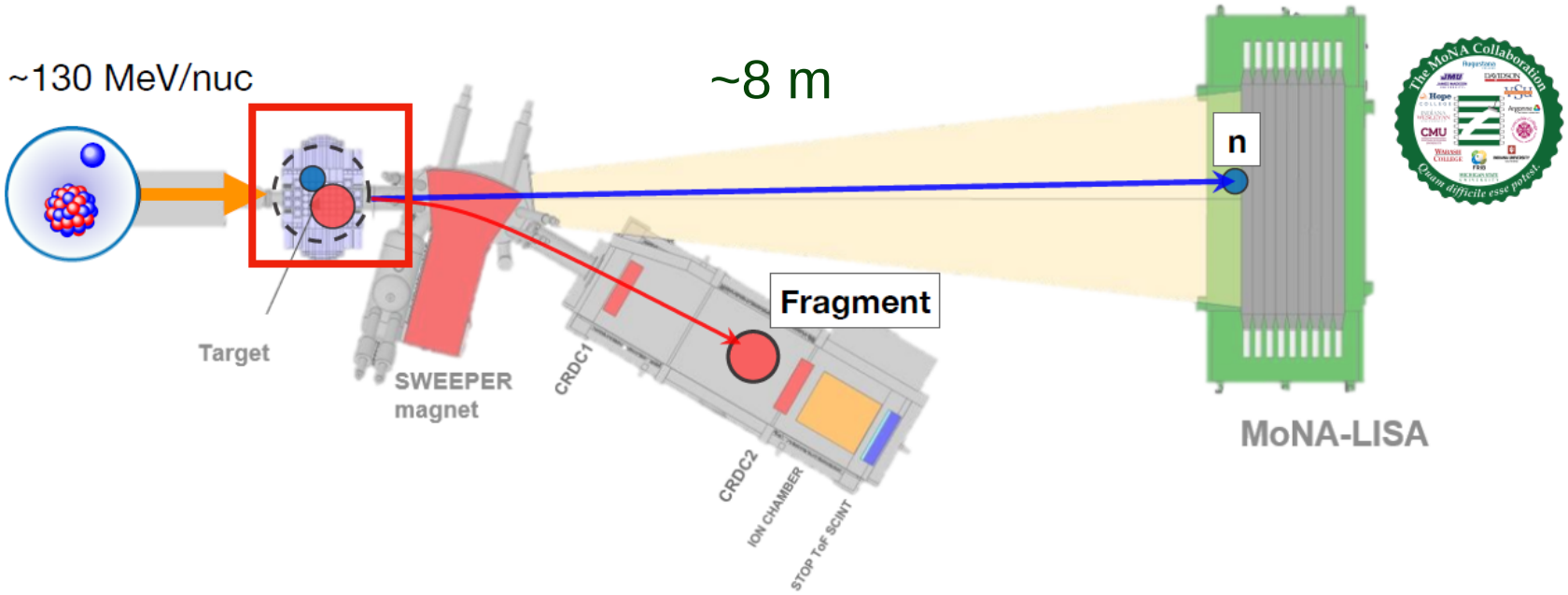
Beam energies

Limited by Sweeper setup
(100-200 MeV/nuc)

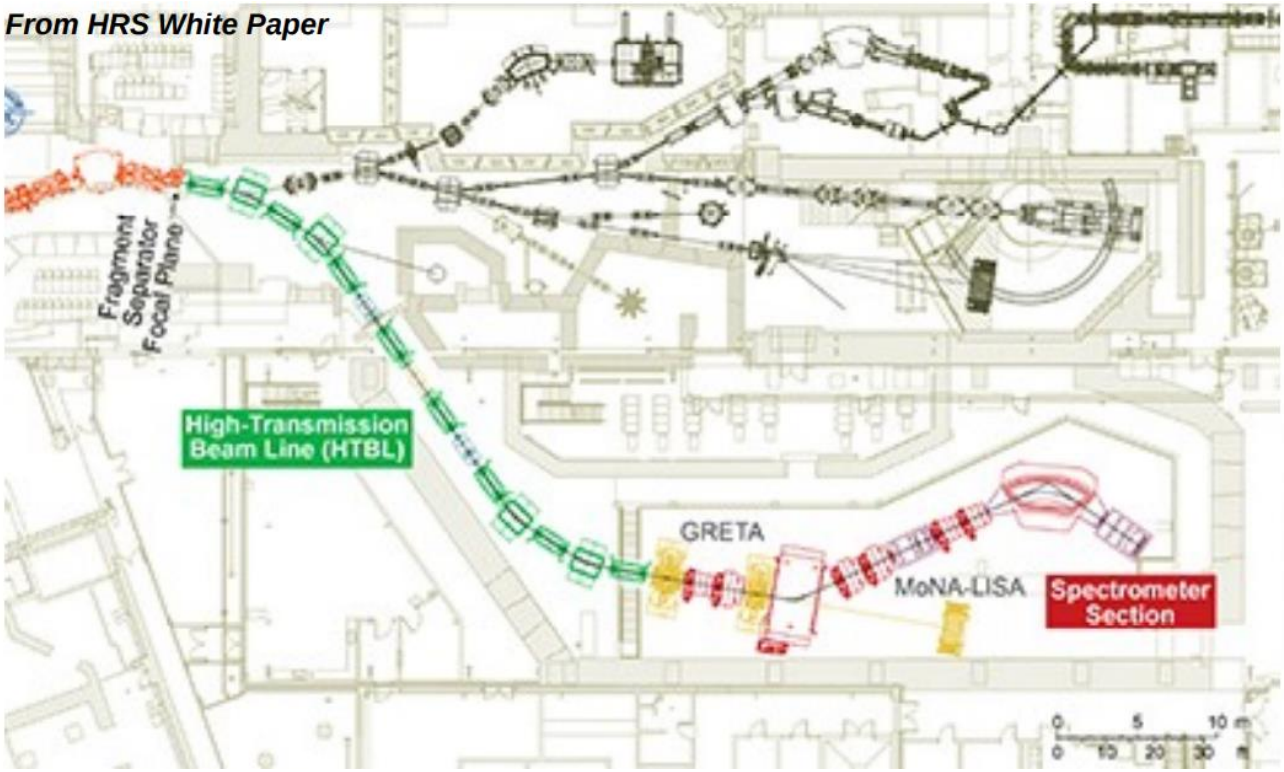
S2

- Sweeper Upgrade
- MoNA-LISA
- CAESAR
- Beam Tracking

INVARIANT MASS SPECTROSCOPY



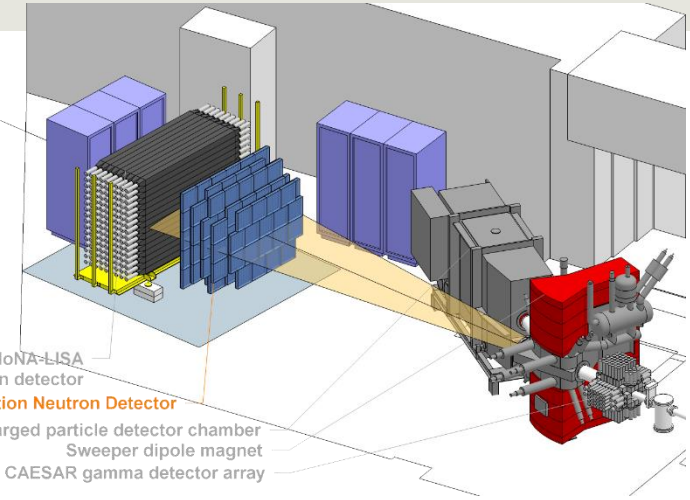
HRS : High Rigidity Spectrometer

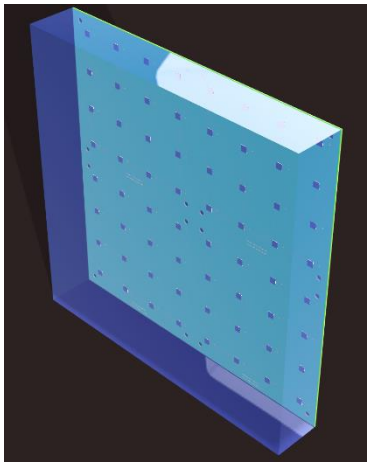


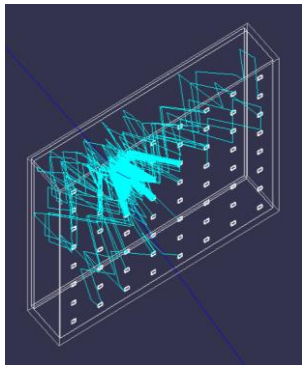
- 8Tm magnetic rigidity
- Longer neutron flight path (~12m)

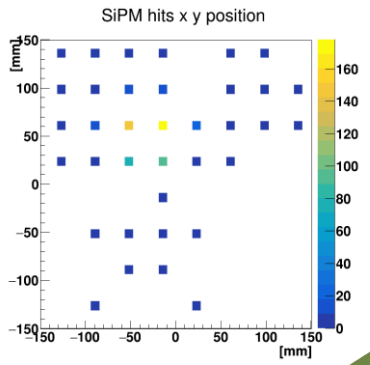
Next Generation Neutron Detector

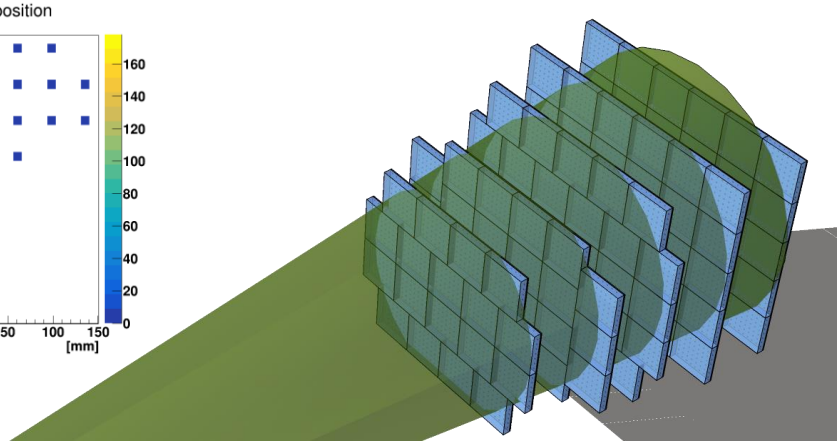
- Development of a next generation neutron detector
  - Optimized for position resolution.
  - To be used in combination with MoNA-LISA in order to increase neutron detection capabilities.
  - Detector tiles allow for optimized setups.





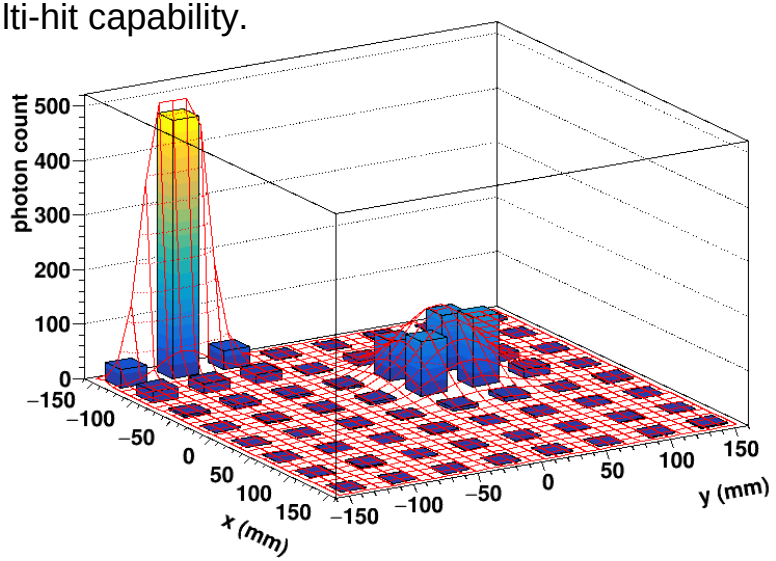


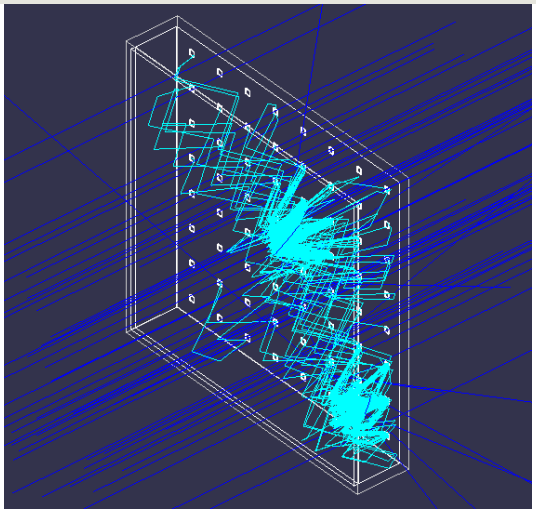


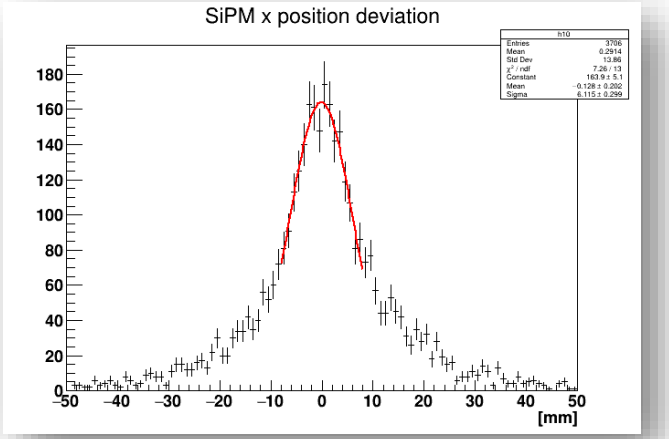


Next Generation Neutron Detector

- 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.



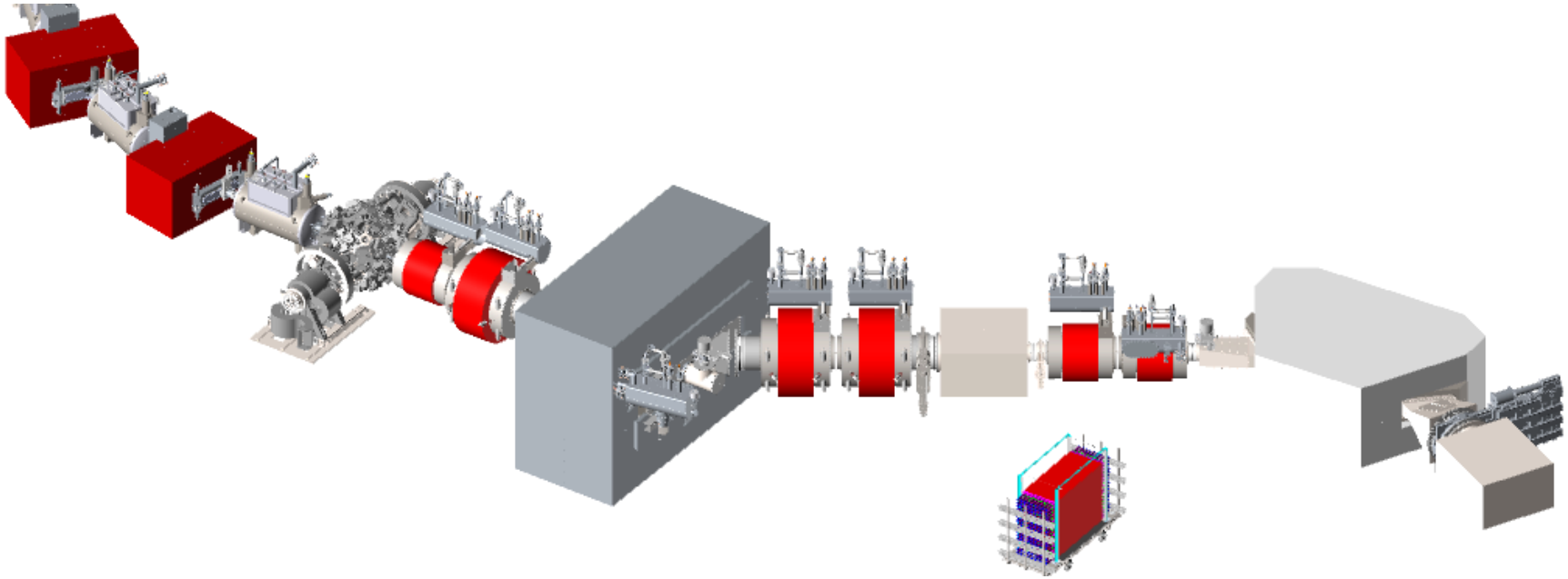




Conclusion and outlook

- FRIB unlocks studies on halo nuclei in the medium-mass region…
- …and spectroscopy studies at and beyond the dripline (^{30}F and ^{53}Ca)
- Study of two-neutron halo
- Odd-N display relatively low Sn values far from the dripline

Conclusion and outlook



- Relatively versatile setup allowing to combine neutron detectors with other devices
- e.g. with GRETA, allow simultaneous spectroscopy of bound and unbound states

Thank you for your attention

Collaborators

The members of the MoNA Collaboration are

- Michigan State University (Thomas Baumann, Paul Gueye, Aldric Revel)
- Hope College (Paul DeYoung)
- Hope College (Belen Monteagudo Godoy)
- Indiana University South Bend (Jerry D. Hinnefeld)
- Wabash College (James A. Brown)
- Central Michigan University (Joseph E. Finck)
- Concordia College at Moorhead (Bryan A. Luther)
- Indiana Wesleyan University (Warren F. Rogers)
- Augustana College Rock Island (Nathan Frank)
- Davisdson College (Anthony Kuchera)
- Argonne National Laboratory (Calem Hoffman)
- Virginia State University (Thomas Redpath)
- James Madison University (Adriana Banu)