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Search for Two-Proton Radioactivity of ^{30}Ar with In-Flight Decay Spectroscopy

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Outline

- Introduction to the two-proton (2p) radioactivity
- In-flight decay experiment
- Results on the 2p radioactivity of ^{19}Mg and tracking the 2p decay of ^{30}Ar
- Summary

GSI

Overview of 2p Radioactivity

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- **Two-proton emission**
  - Direct 2p emission predicted for very neutron-deficient nuclei
  - Energy conditions

V. Goldansky, Nucl. Phys. 19, 482 (1960)

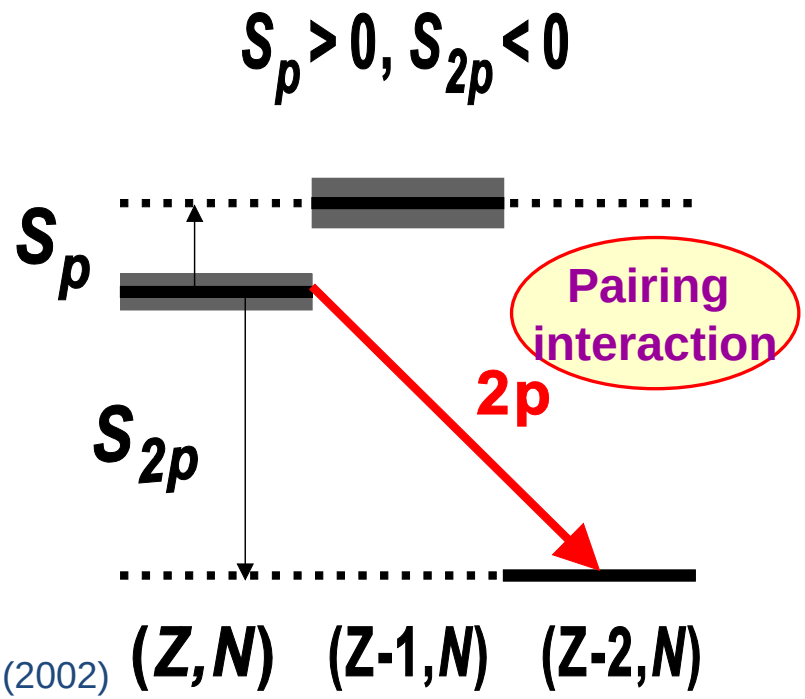
- **2p radioactivity**
  - True 2p decay in the case of short-lived states

L. V. Grigorenko et al., Phys. Rev. C 84 021303(R) (2011)

  - Discovered at 2002
    - ✓ 2p decay of ^{45}Fe
    - ✓ GSI, GANIL

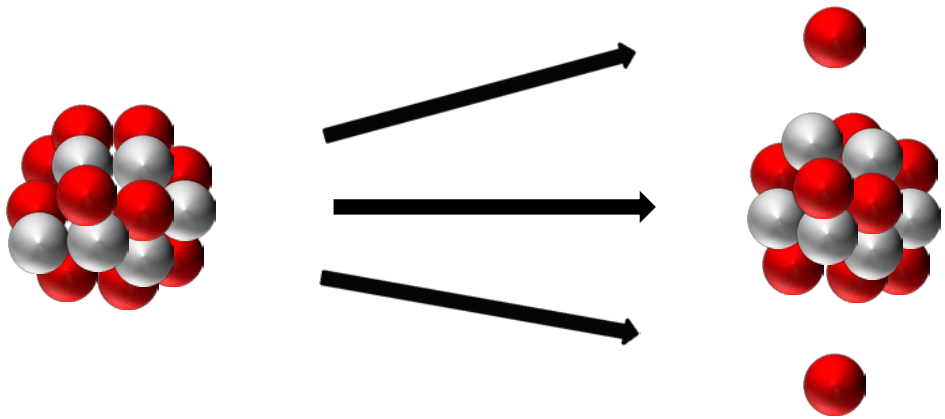
M. Pfützner, et al., Eur. Phys. J. A 14, 279 (2002)

J. Giovinazzo, et al., Phys. Rev. Lett. 89, 102501 (2002)

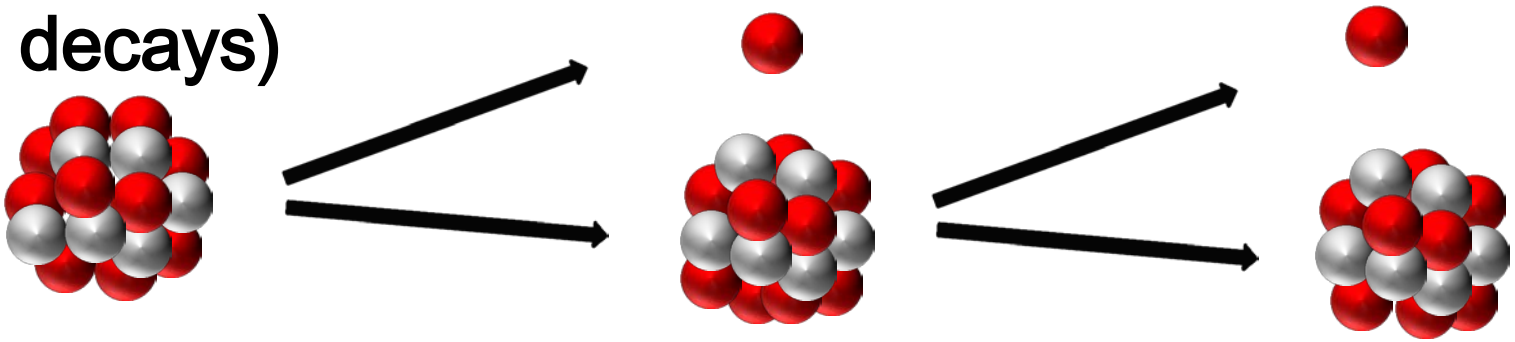


What Is 2p Radioactivity?

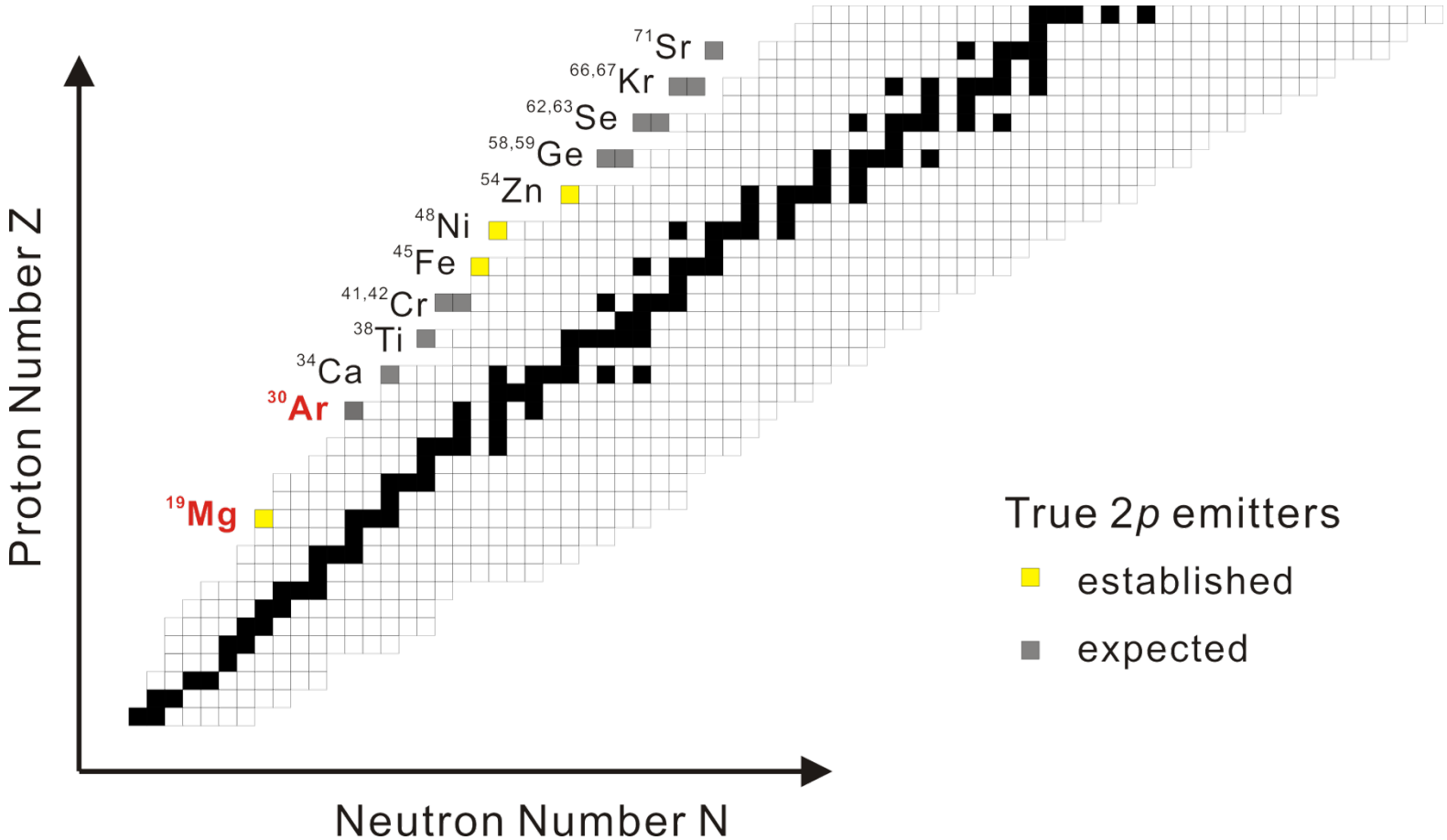
- Direct 2p decay (three-body decay)



- Sequential 2p emission (successive two-body decays)

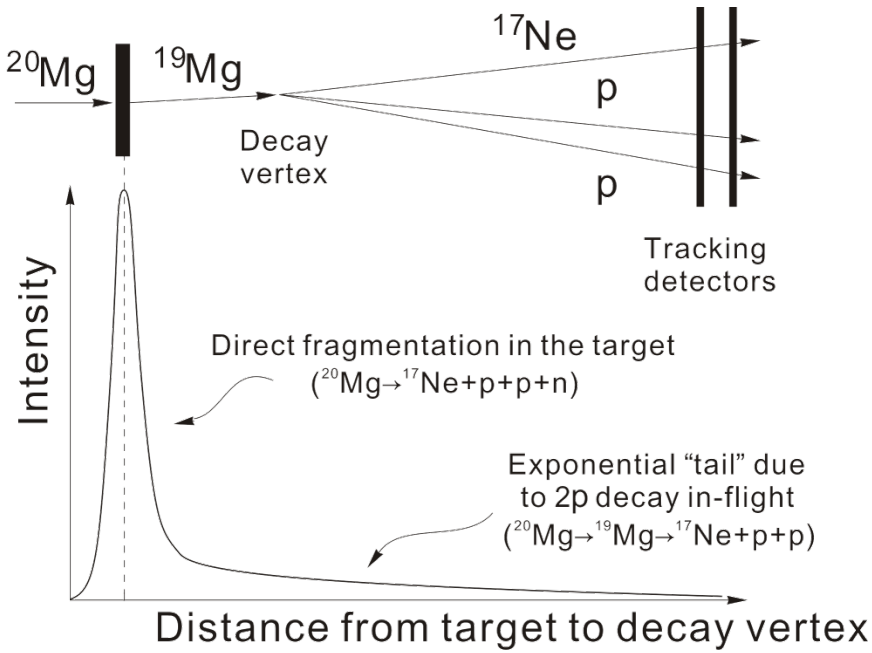


2p Radioactivity Landscape



L. Grigorenko et al., Phys. Rev. C 68, 054005 (2003)

Decay In-Flight Method



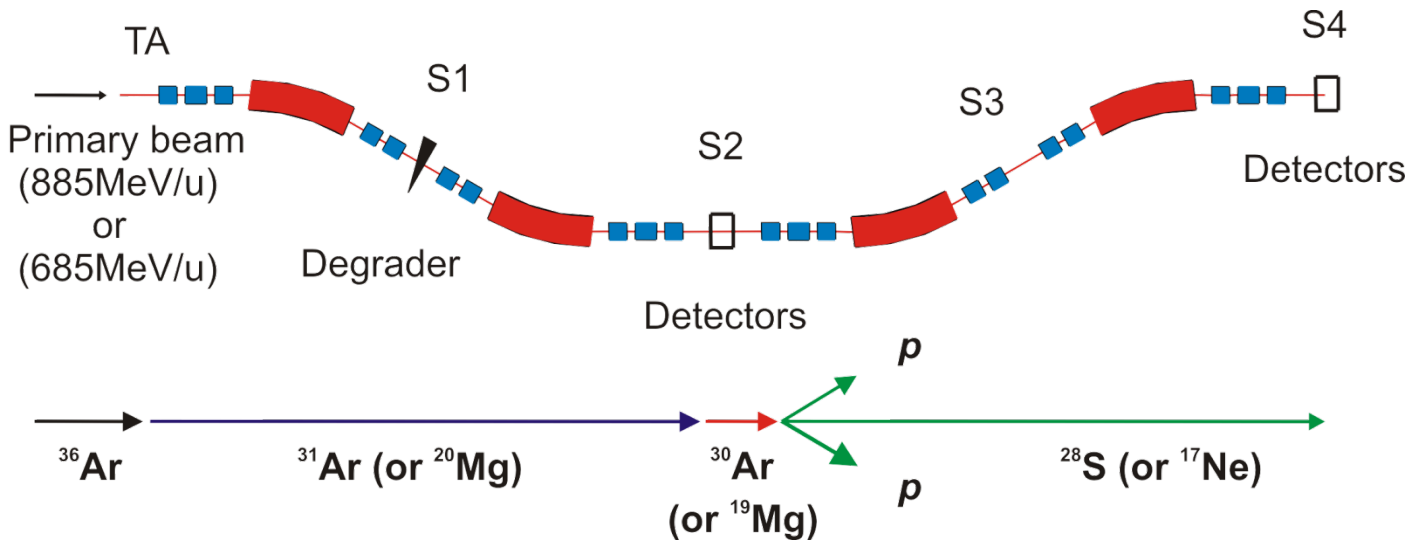
I. Mukha and G. Schrieder, Nucl. Phys. A 690, 280 (2001); I. Mukha, Phys. Atom. Nucl. 66, 1519 (2003)

- ✓ Measurements of in-flight decays of proton-unbound nuclei with ps lifetimes
- ✓ Intensive production of 2p emitters with large-acceptance high energetic beams
- ✓ High precision measurement of decay energy on the basis of small statistics
- ✓ Three-body angular correlations

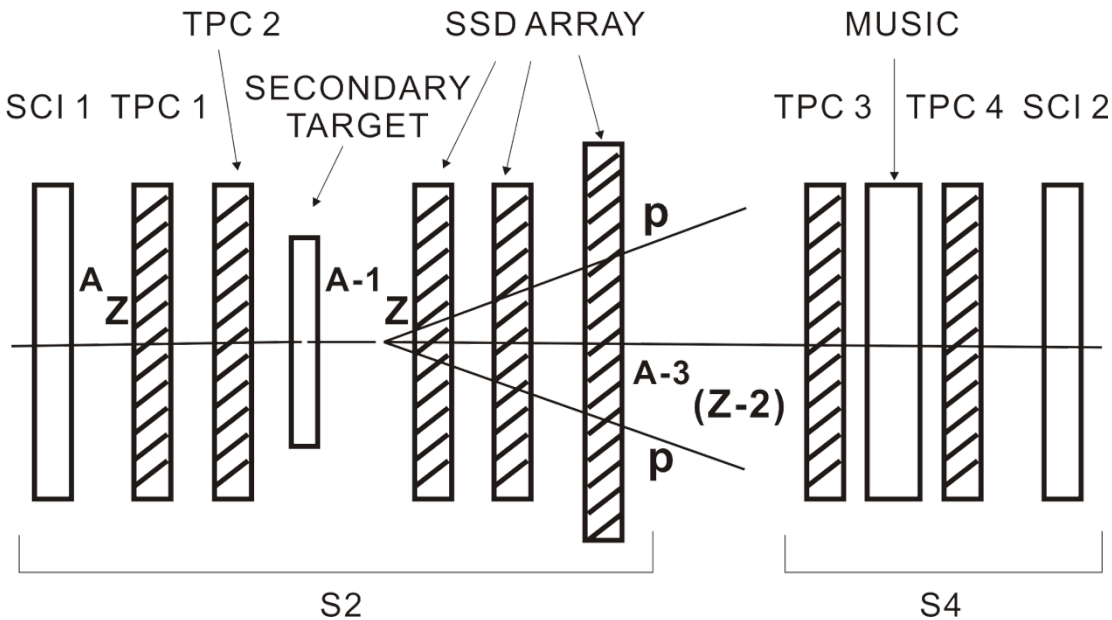
Discovery of 2p radioactivity of ^{19}Mg! I. Mukha et al., Phys. Rev. Lett 99, 182501 (2007)

Overview of the Experiment

- **Objectives**
  - Discover the unknown isotope: ^{30}Ar
  - Study the 2p decay of ^{30}Ar and ^{19}Mg (reference nucleus)
  - Deduce spectroscopic information on the low-lying states of ^{30}Ar
- **FRagment Separator (FRS)**



Detector Setup at S2 and S4



- ✓ Secondary target: ^{9}Be, ~5 g/cm^{2}
- ✓ Time-projection chambers (TPC1, TPC2): tracking secondary beams
- ✓ Silicon micro-strip detector (SSD) array: measuring trajectories of decay products
- ✓ Scintillators (SCI1, SCI2): time-of-flight (TOF) measurement
- ✓ Ionization chamber (MUSIC): energy loss (ΔE) measurement

SSDs for Tracking

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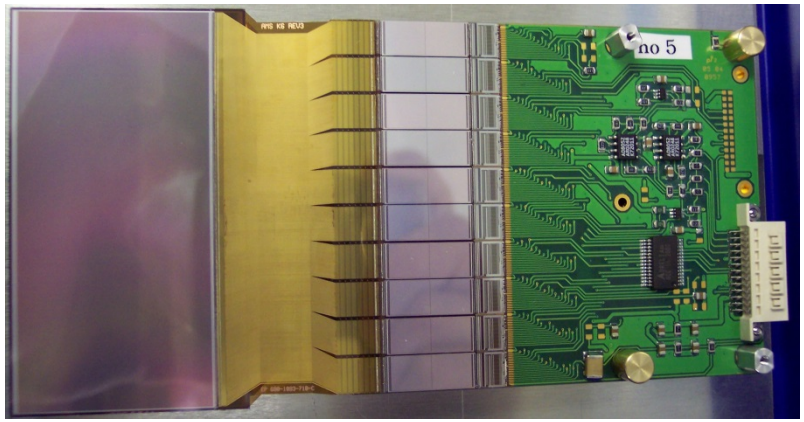
- **Introduction of the SSD**
  - 72 * 41 mm^2, 0.3 mm thick
  - S-side (x): 640 readout strips
  - K-side (y): 384 readout strips
  - 16 VA64 chips, 64 strips each
  - SIDEREM



M. Stanoiu et al., Nucl. Inst. Meth. B 266, 4625 (2008)

- **SSD array for tracking**
  - Ion hit ⇨ creation of electron-hole pairs along the ion track
    ⇨ a group of neighboring strips "firing" (cluster)
  - Position resolution: usually better than the strip pitch (~100μm)
  - Precise tracking, vertex determination, energy measurement with high efficiency and acceptance

Heavy-Ion Identification

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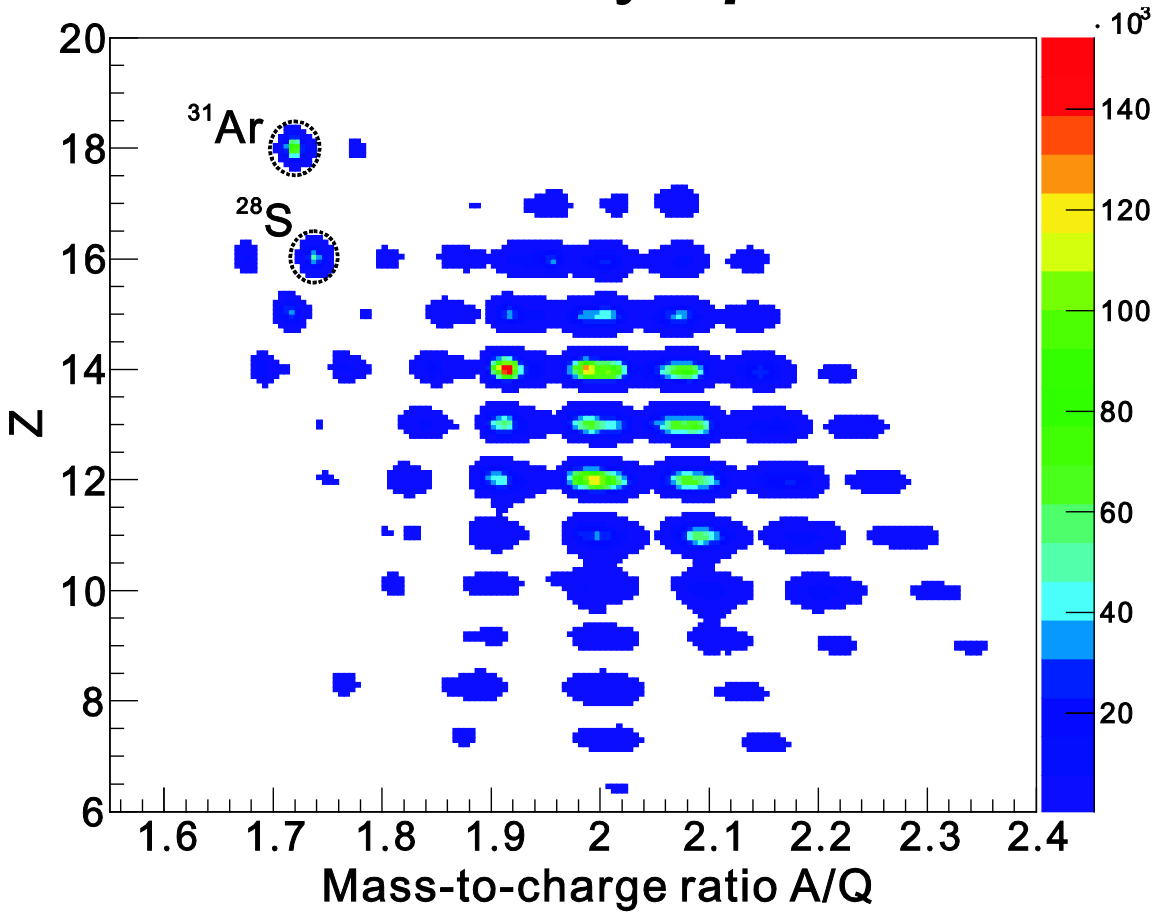
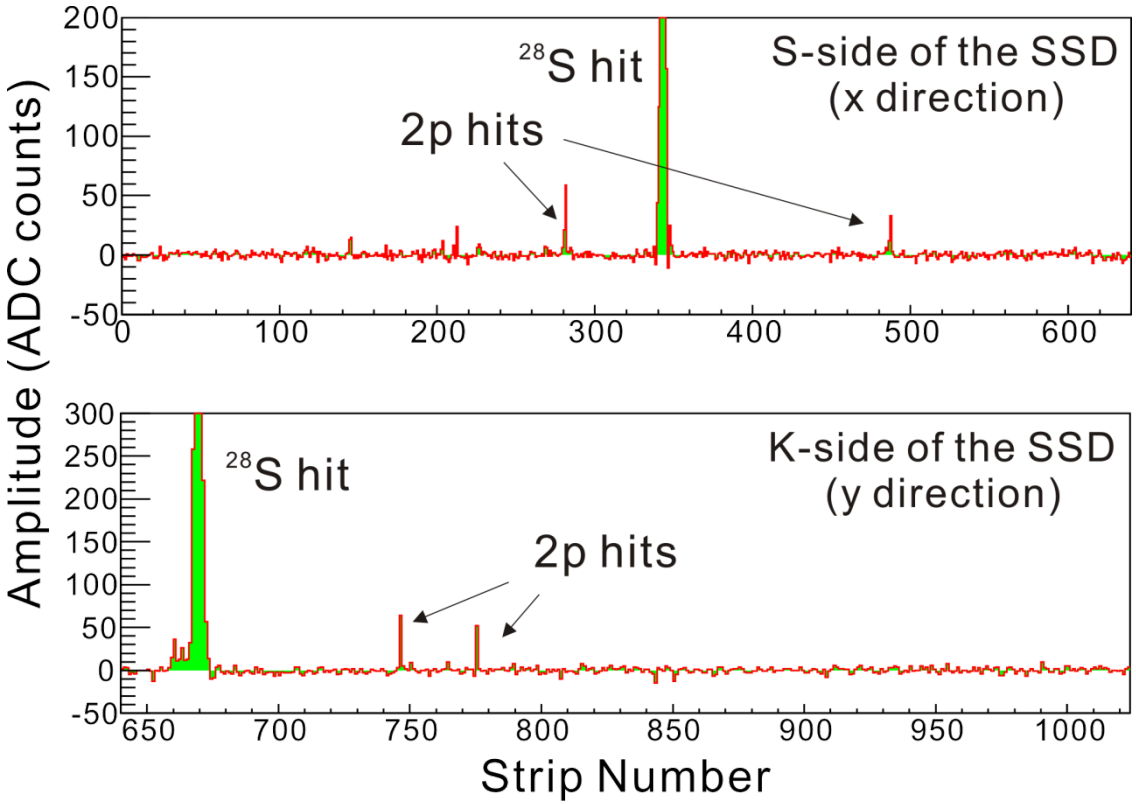
- Particle identification by Bρ – ToF – ΔE method



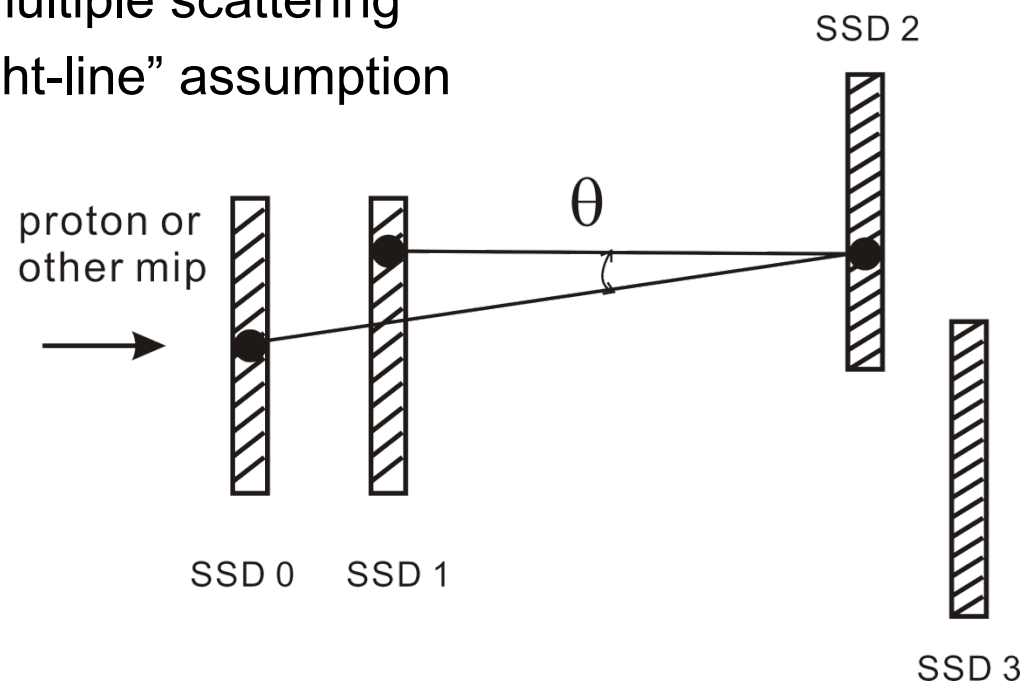
Measure ^{28}S+p+p Trajectories

- 2p decay of ^{30}Ar by tracking ^{28}S+p+p trajectories (triple coincidence)



Identification of Protons

- **Simple way to separate the protons from other minimum ionizing particles (e.g., δ electrons)**
  - Energy loss in SSDs
  - Less multiple scattering
  - "Straight-line" assumption



Decay Vertices and Proton-HI Angular Correlations

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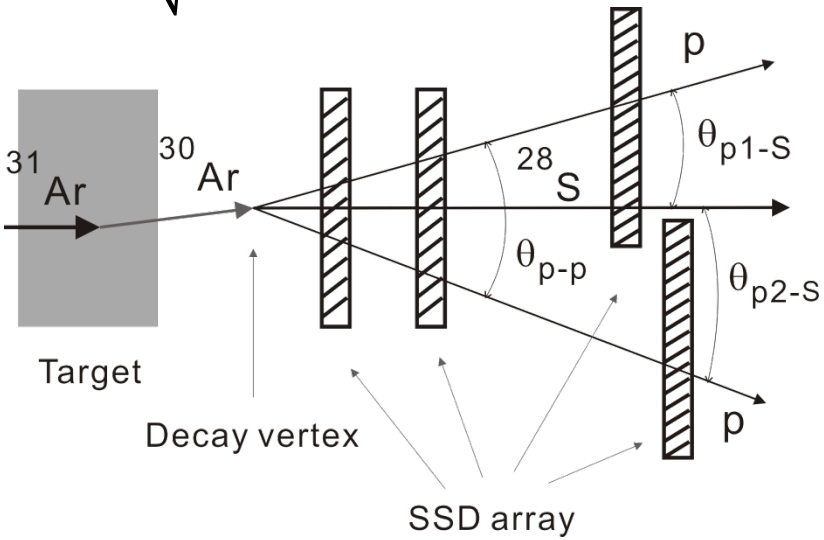
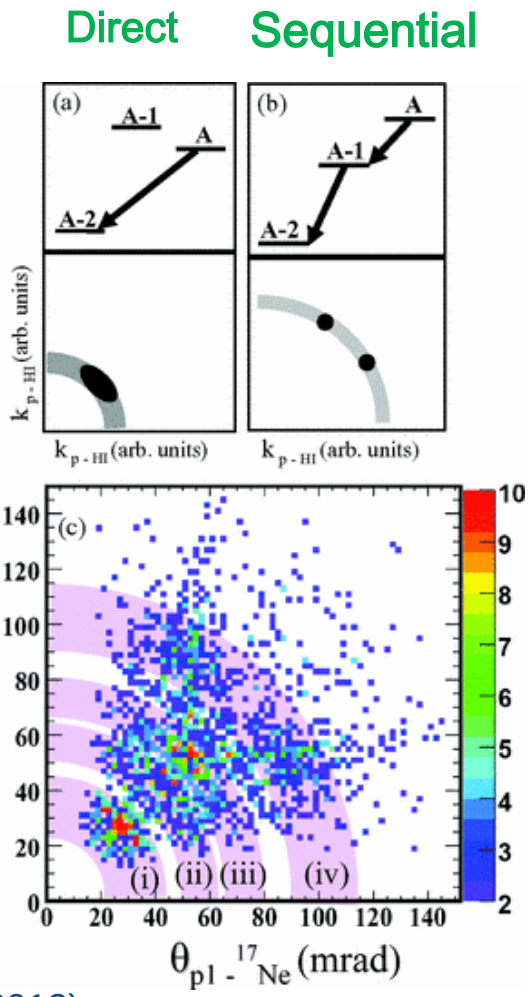
- **Decay vertex**
  - Vertex of coincident HI+p+p trajectories
- **Angular correlation between p and HI**
  - $\rho = \sqrt{\theta_{p1-\mathrm{HI}}^2 + \theta_{p2-\mathrm{HI}}^2} \propto \sqrt{Q_{2p}}$

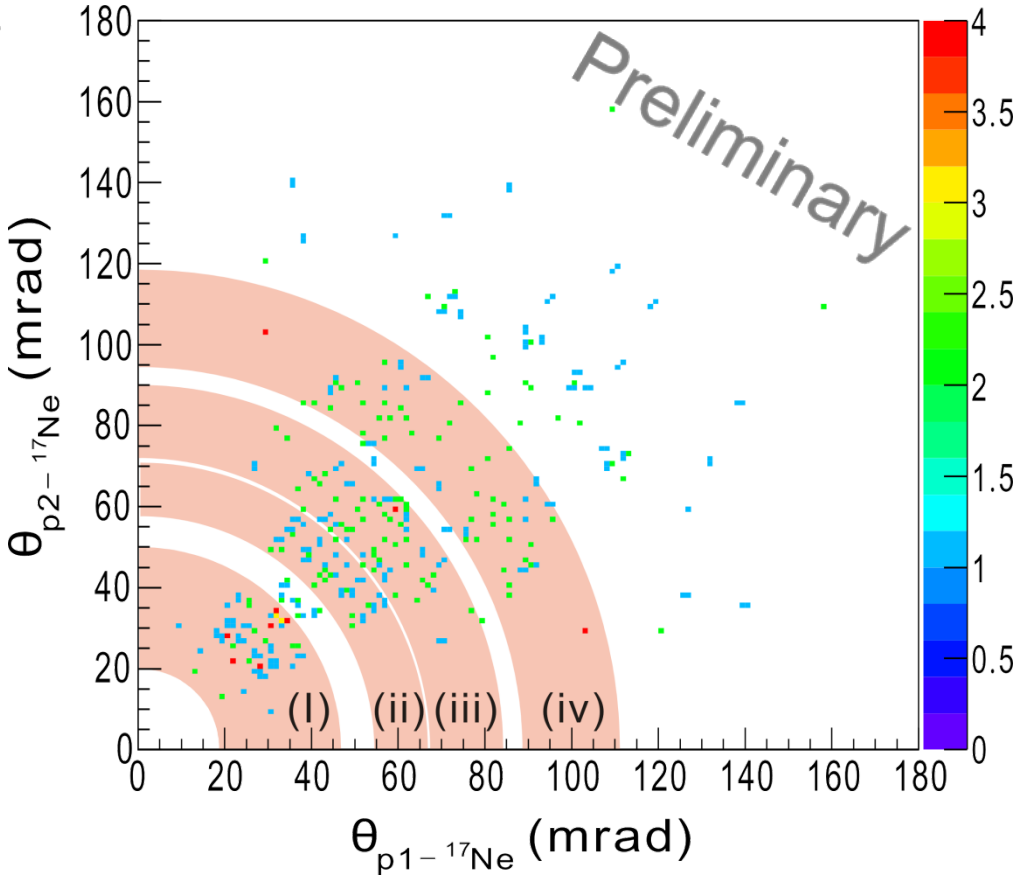




I. Mukha, et al., Phys. Rev. C **85**, 044325 (2012)

^{19}Mg -> ^{17}Ne+p+p

- Angular correlations from ^{19}Mg -> ^{17}Ne+p+p events



Simulations of 2p Decay of ^{19}Mg Ground State

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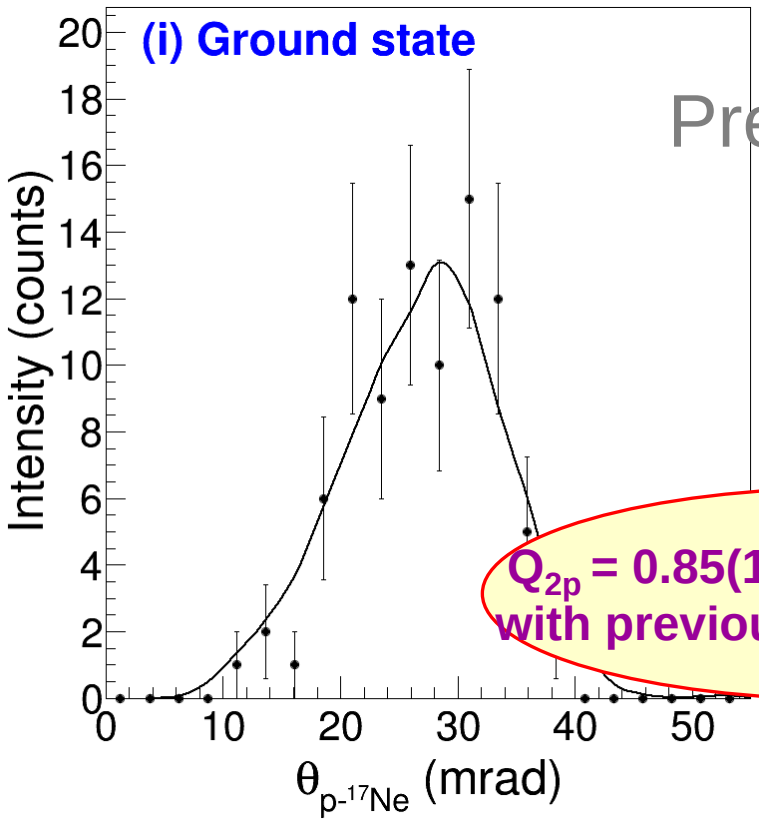
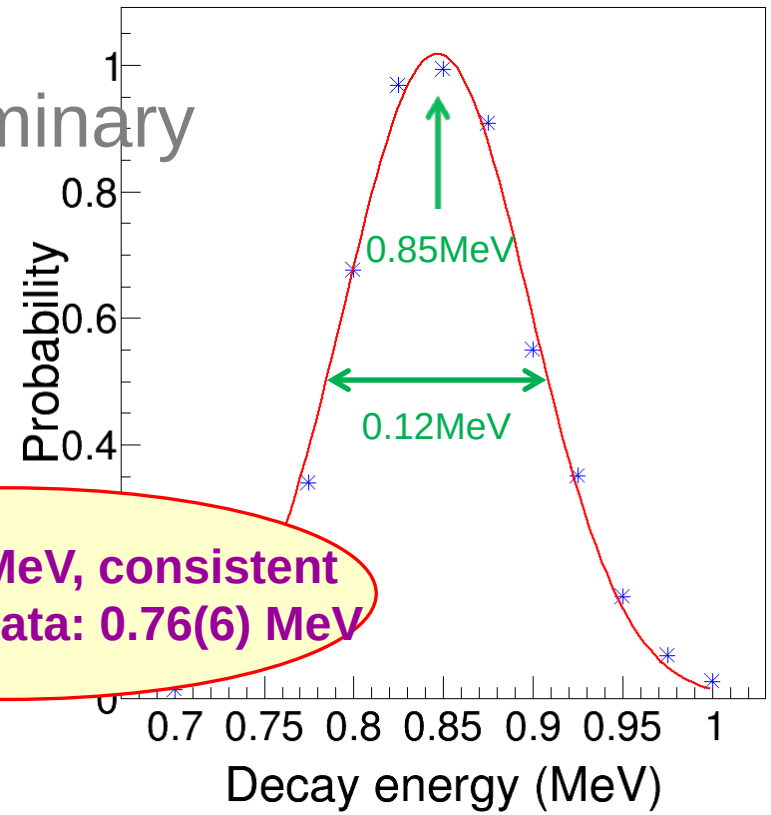
Measured and simulated $\theta_{p\text{-Ne}}$ distribution



Kolmogorov-Smirnov test of compatibility



Preliminary

Q_{2p} = 0.85(12) MeV, consistent with previous data: 0.76(6) MeV

Simulations of 2p Decay of Low Lying Excited States of ^{19}Mg

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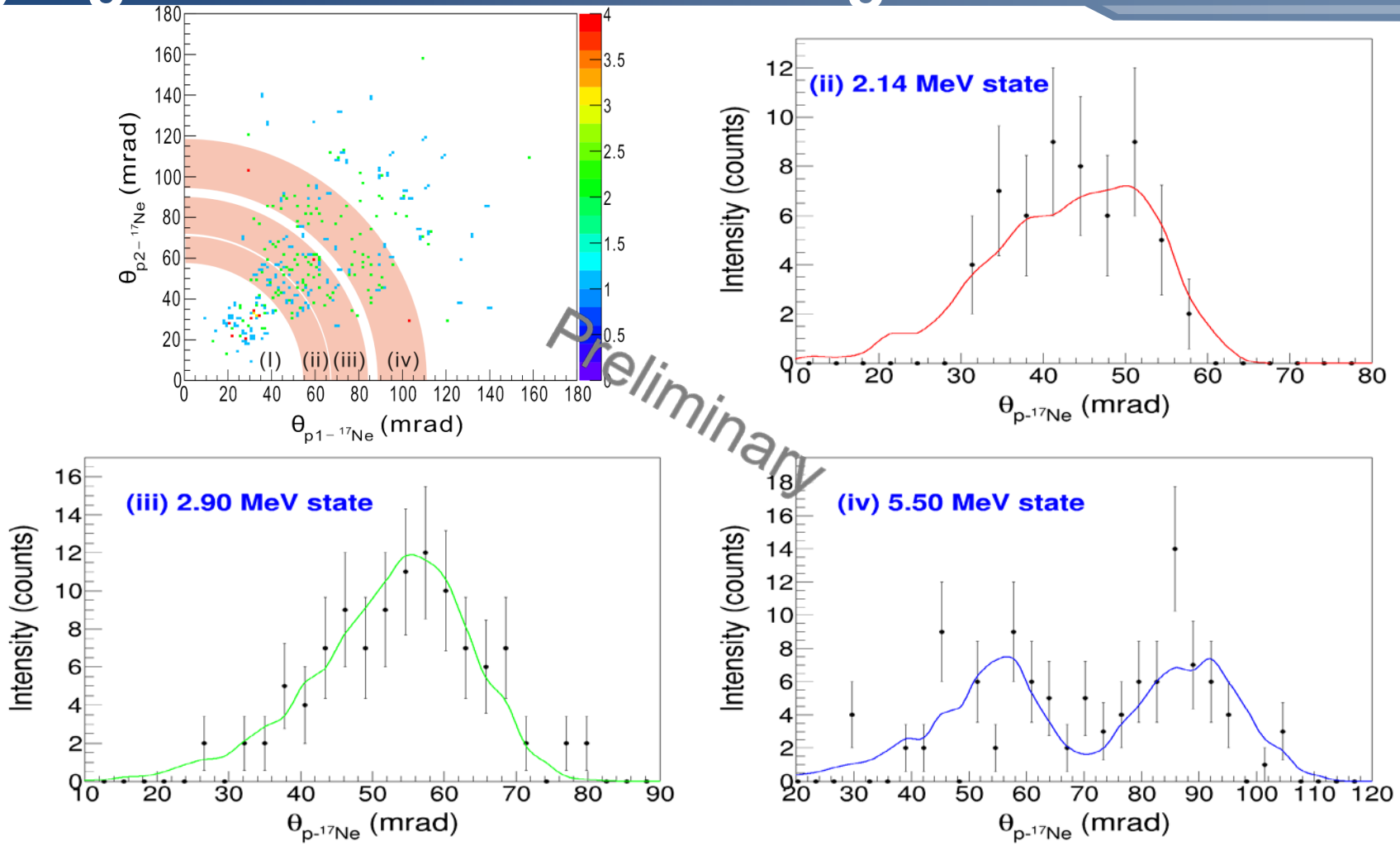
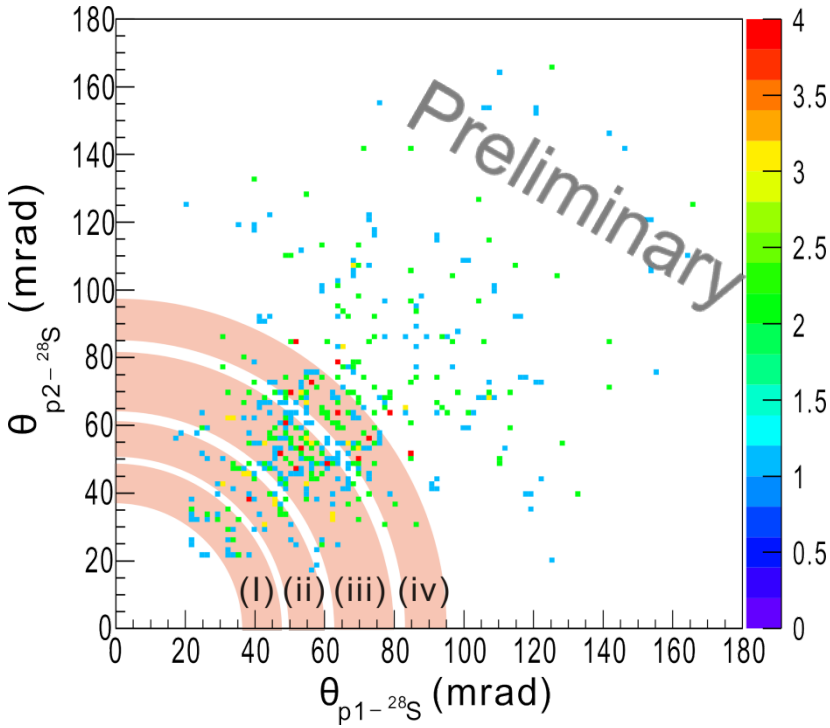
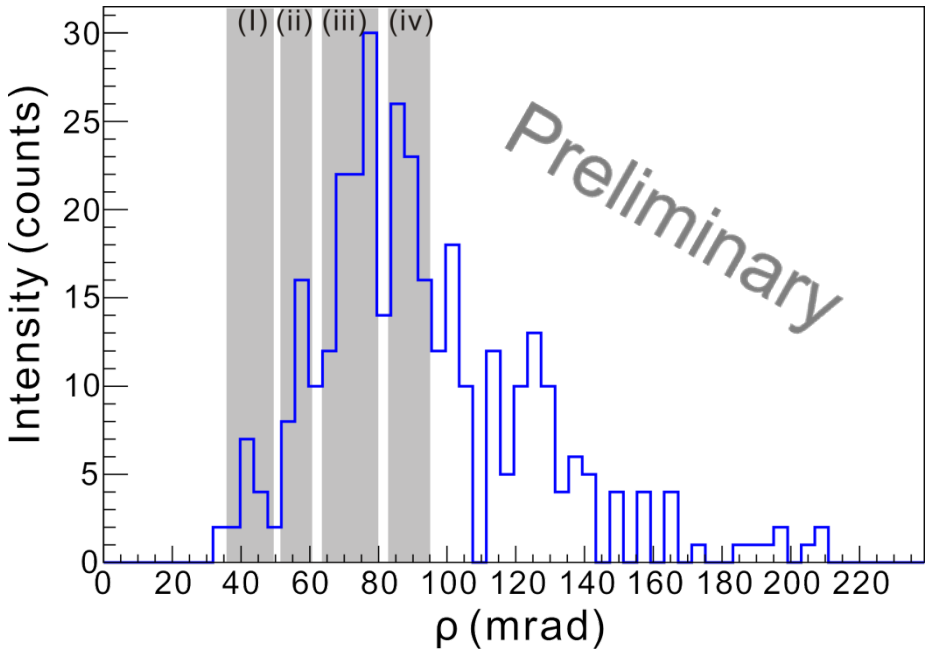


Sequential emission of protons via the resonance in ^{18}Na is confirmed!

^{30}Ar -> ^{28}S+p+p

- Angular correlations from ^{30}Ar -> ^{28}S+p+p events





2p decays of ^{30}Ar are observed!

Summary

- In-flight decay experiment @ GSI: Search for 2p radioactivity of unknown nucleus - ^{30}Ar
- Study of the 2p decay of ^{19}Mg by tracking ^{17}Ne+p+p trajectories (reference measurement)
- Reconstruction of the 2p decay vertices
- Analyze proton-HI angular correlations both for ^{19}Mg and for ^{30}Ar
- Simulations of experimental response to the 2p decay of ^{19}Mg
- Confirm the 2p-decay energy of ^{19}Mg
- Study of the 2p decay of ^{30}Ar by tracking ^{28}S+p+p trajectories

Acknowledgements

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Collaborators

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Thanks for your attention!