^{19}Mg Two-Proton Decay Lifetime: A New Application of the Recoil Distance Method

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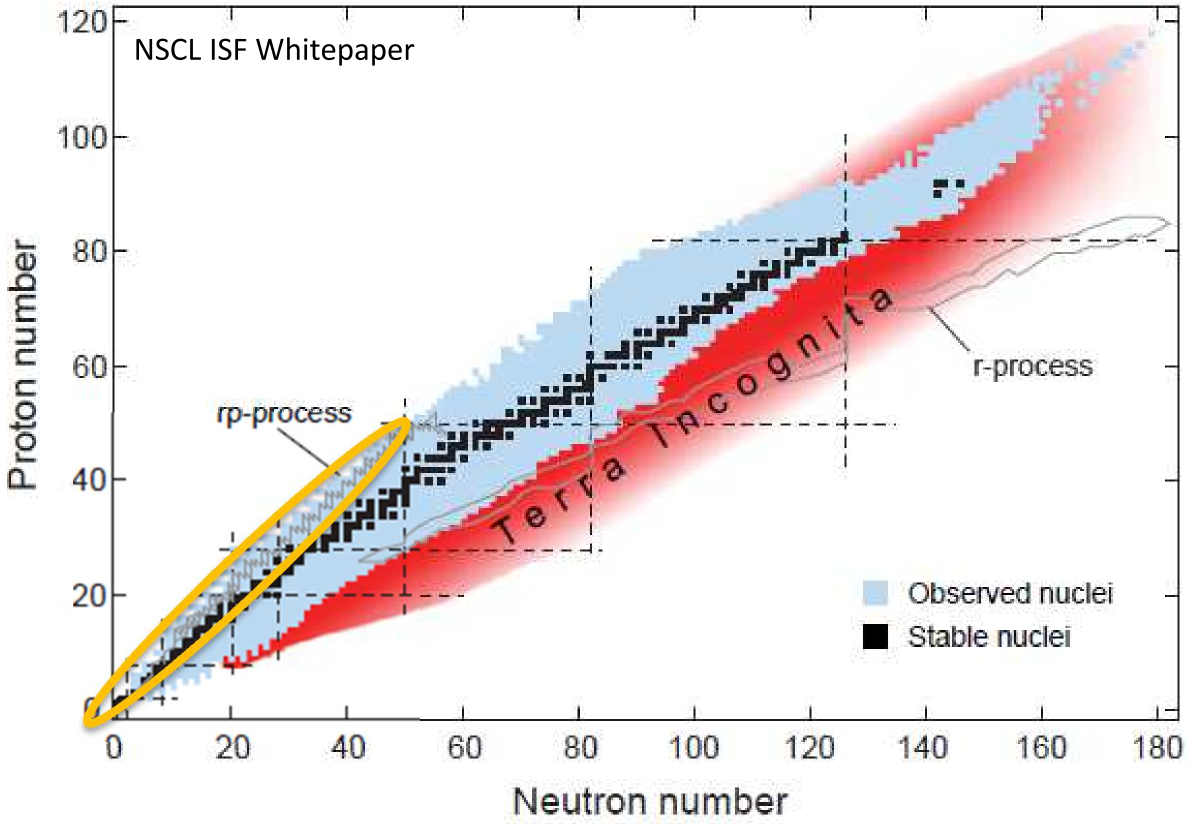
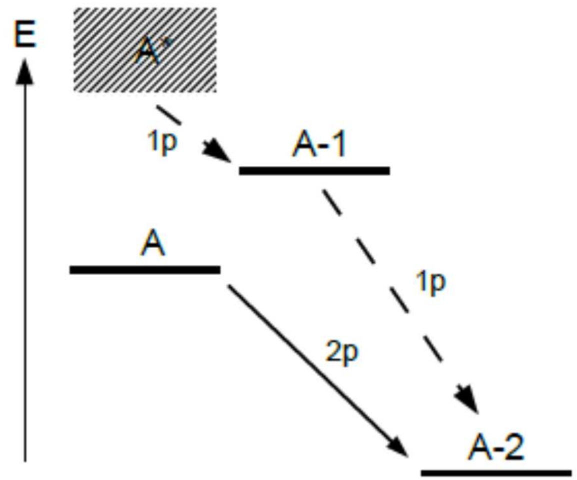
Two-Proton Radioactivity





- Even-Z isotopes beyond the proton drip line may decay by 2p emission.
- The decay lifetime can shed valuable information on the structure of the 2p decay precursor; lifetime is indicative of valence proton orbital configuration.

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Variations on Time of Flight Method

- Compared to heavier systems with millisecond lifetimes, the low Coulomb and centrifugal barriers for light even-Z isotopes result in picosecond lifetimes.
- Use intermediate energy beams (0.3c) to translate the study of fast decay events (10-12 s) into the study of decay-signature variations as a function of easily measurable distances (0.1 mm).
    - Decay vertex reconstruction
    - Köln/NSCL particle plunger

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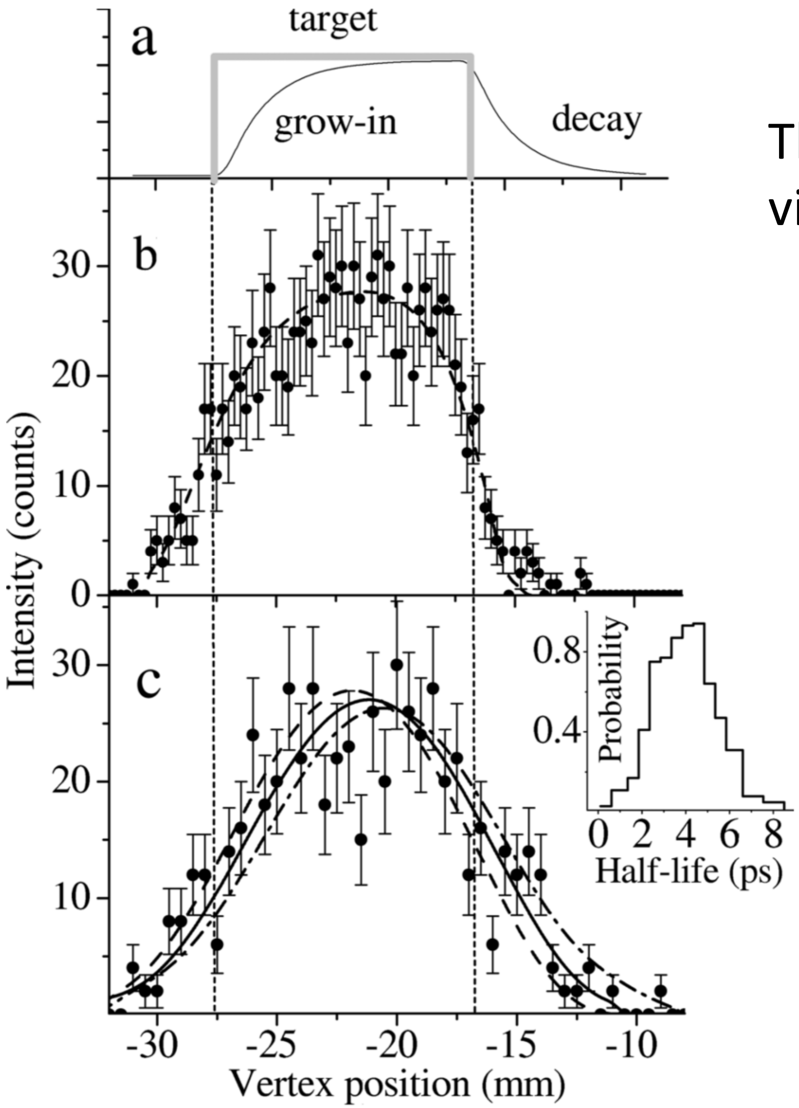
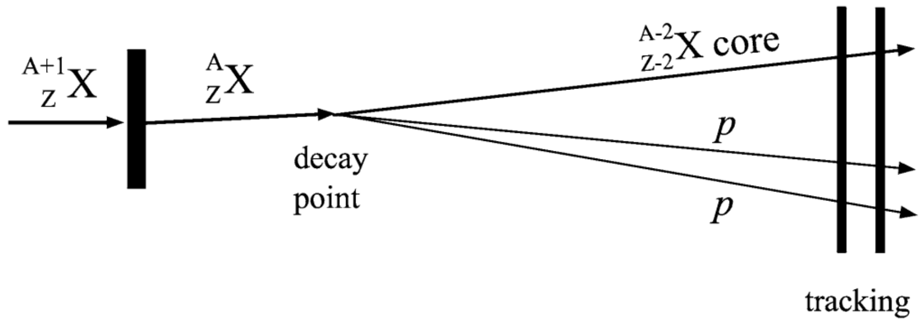
First ^{19}Mg Lifetime Measurement



I. Mukha et al., Phys. Rev. Lett. **99**, 182501 (2007).

The ^{19}Mg ground state 2p decay lifetime was measured via decay vertex reconstruction to be 5.8(2.2) ps.

^{19}Mg → ^{17}Ne + p + p



L.V. Grigorenko et al., Nucl. Phys. A **713** (2003) 372–389.

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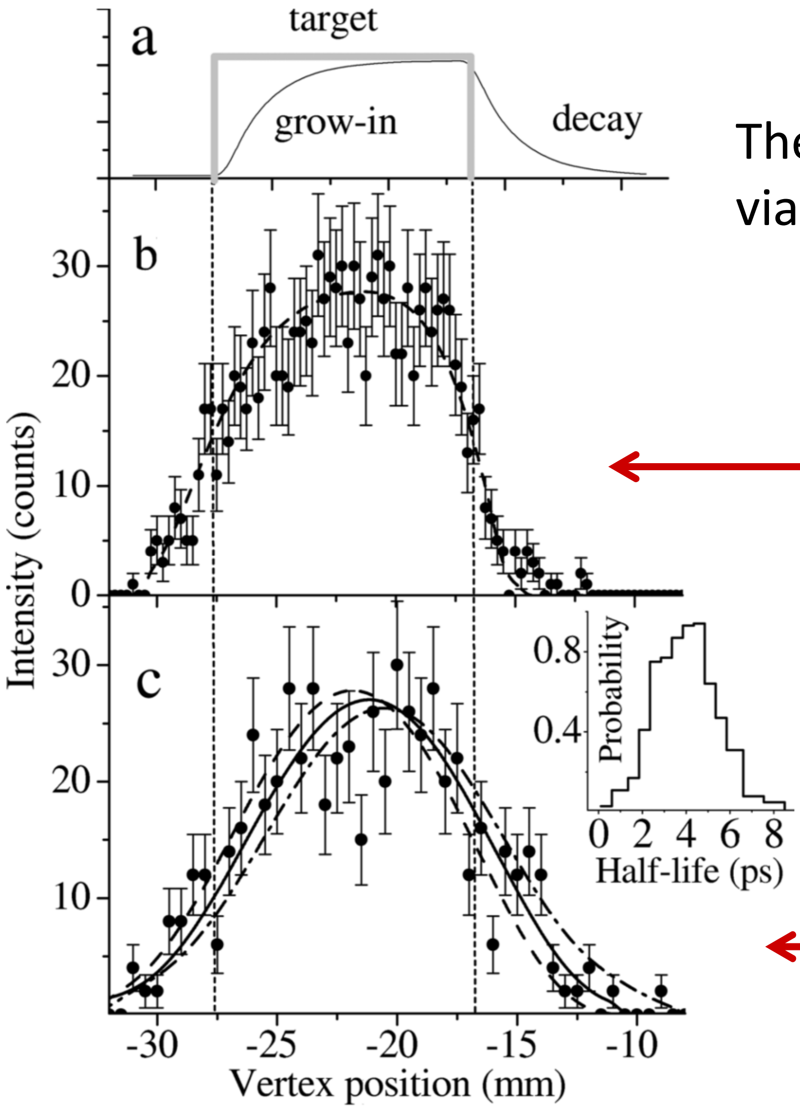

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Prompt Production

$^{20}\mathrm{Mg} \rightarrow {}^{17}\mathrm{Ne} + p + p + n$

$^{19}\mathrm{Mg}^{*} \rightarrow {}^{18}\mathrm{Na} + p \rightarrow {}^{17}\mathrm{Ne} + p + p$

Delayed Production

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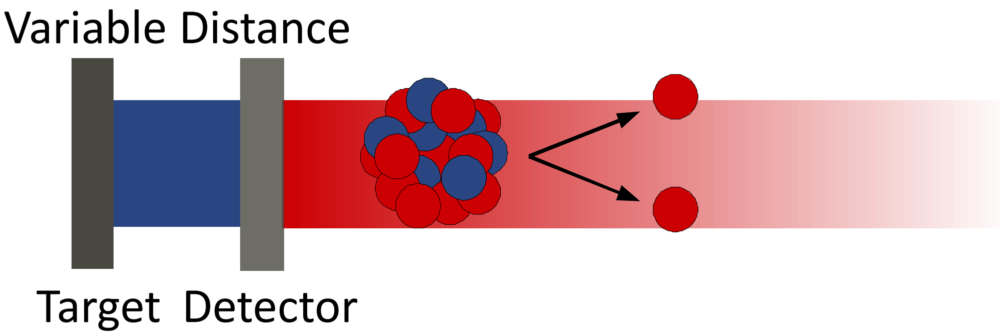
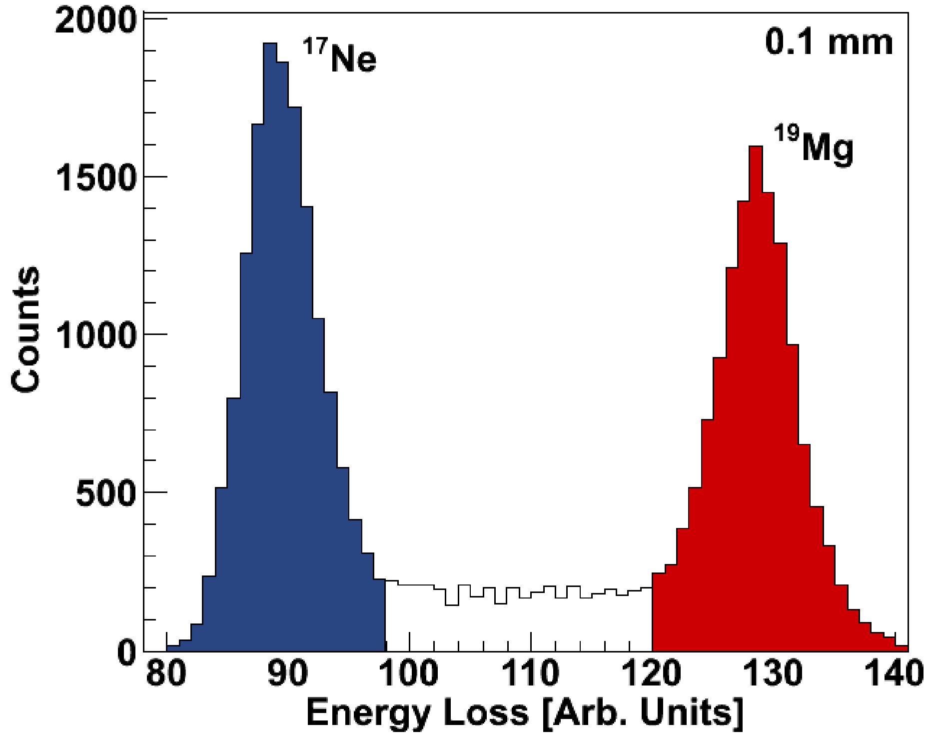
Adaptation of the Recoil Distance Method at NSCL



$^{19}Mg \rightarrow {}^{17}Ne + p + p$

Simulated lifetime: 5 ps



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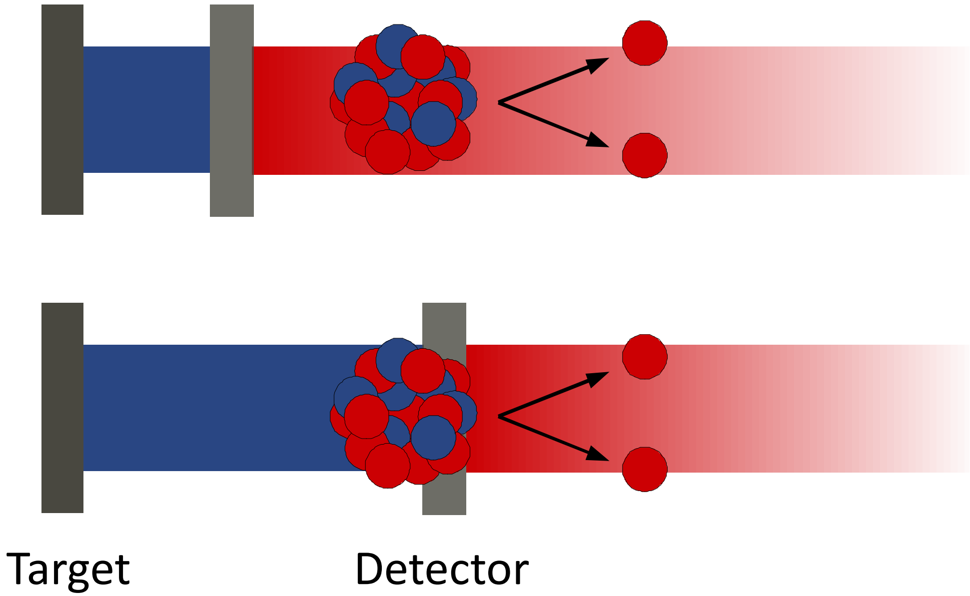

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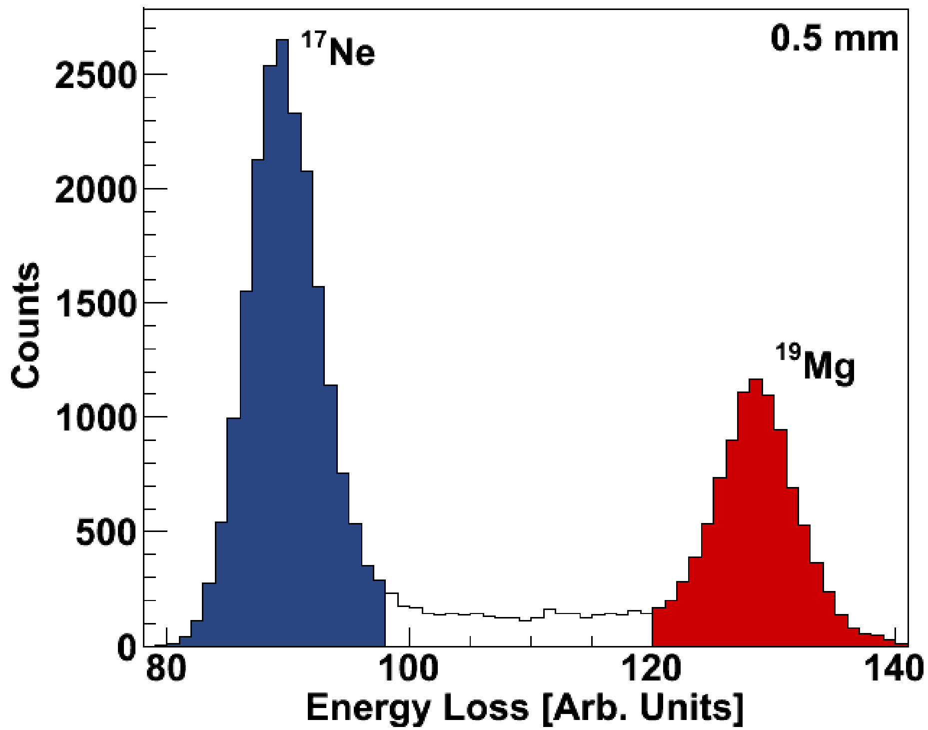

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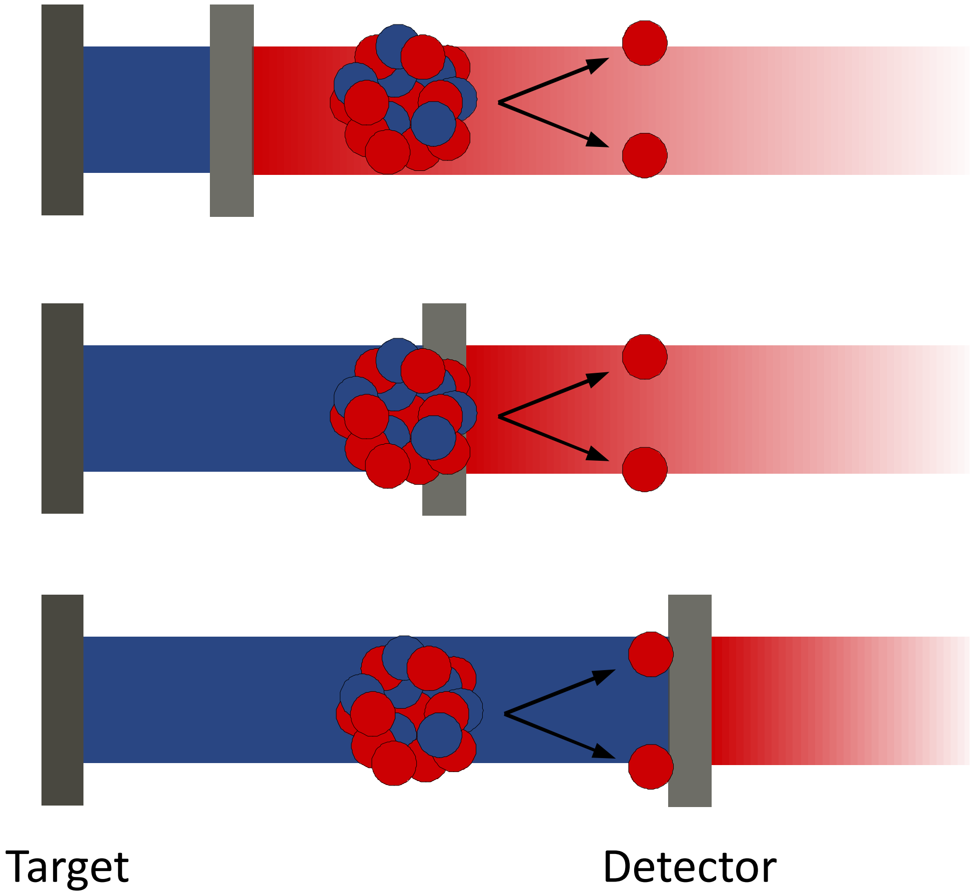

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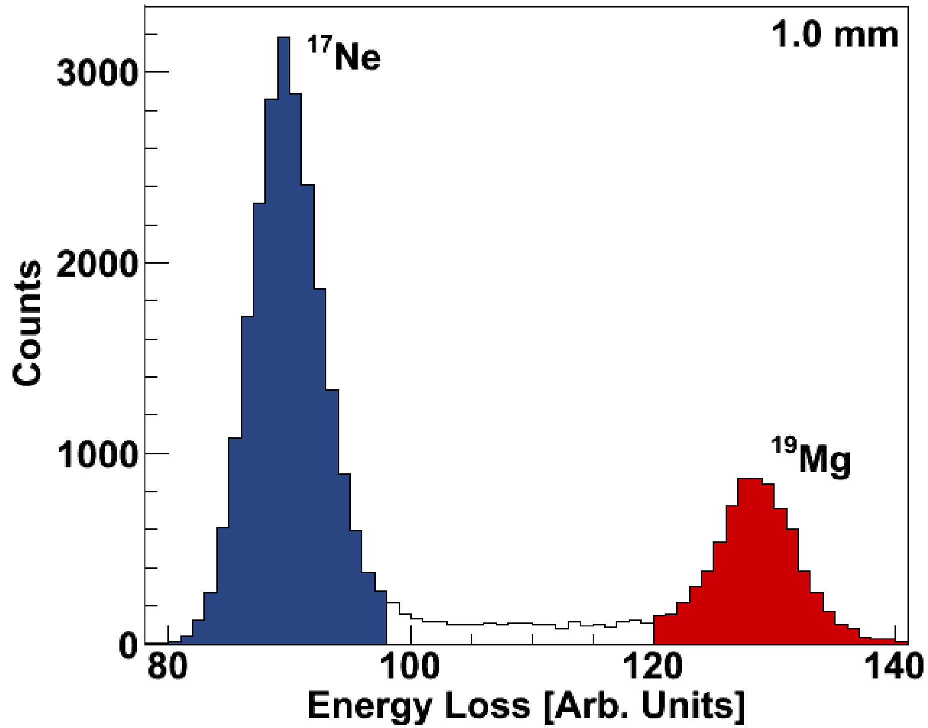

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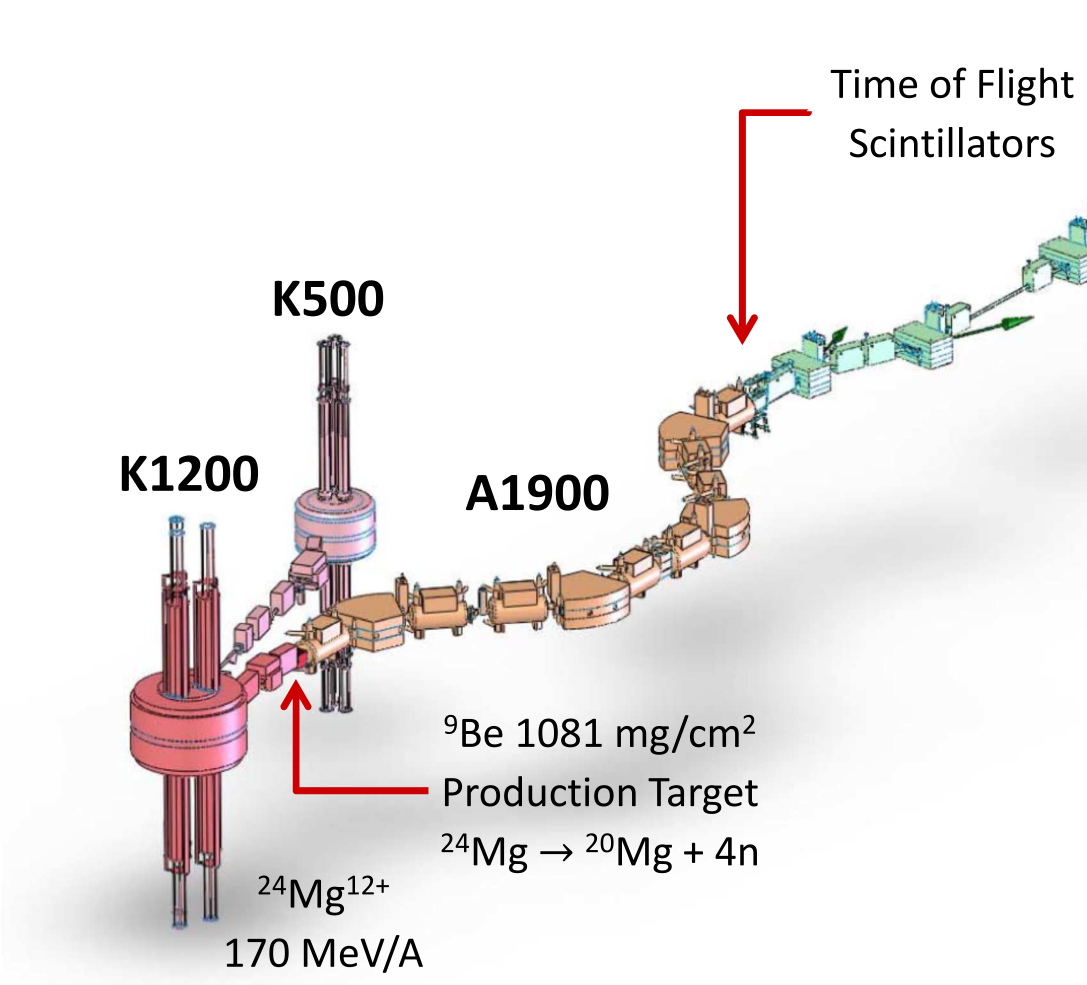
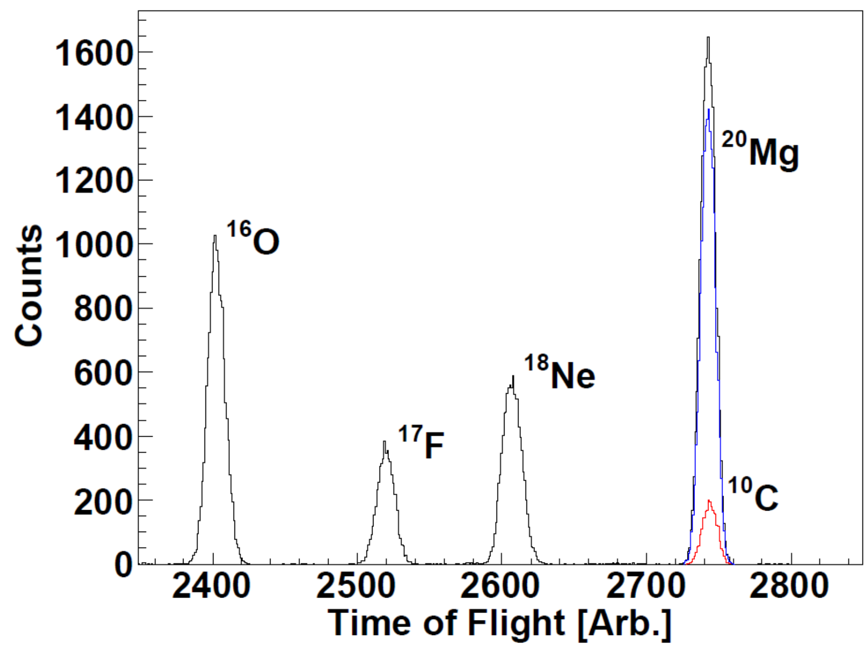
Radioactive Beam Production and Identification





^{19}Mg production. Secondary beam components were identified by time of flight measurements.

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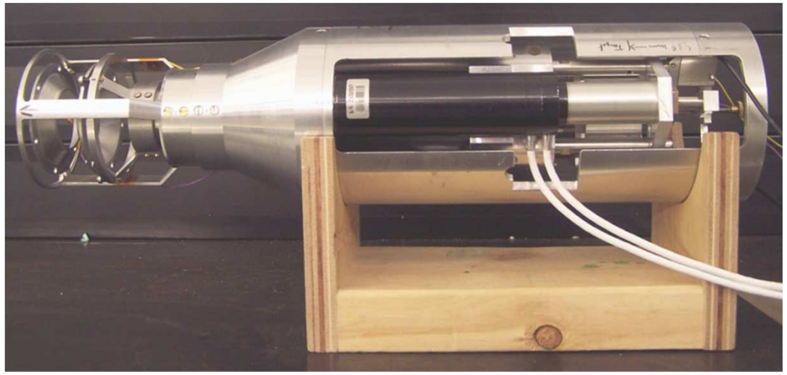
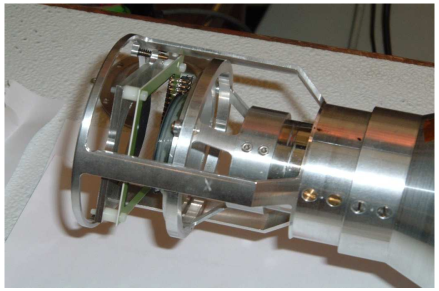
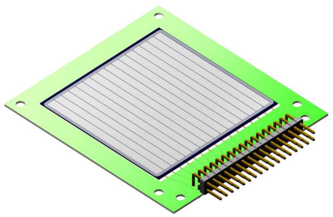
The Experimental Devices

Köln/NSCL Particle Plunger
300 μm DSSD from Micron Semiconductor
In-beam energy resolution of 4% at 60 MeV







S800 Magnetic Spectrograph
Detection of reaction- and heavy-ion decay residues

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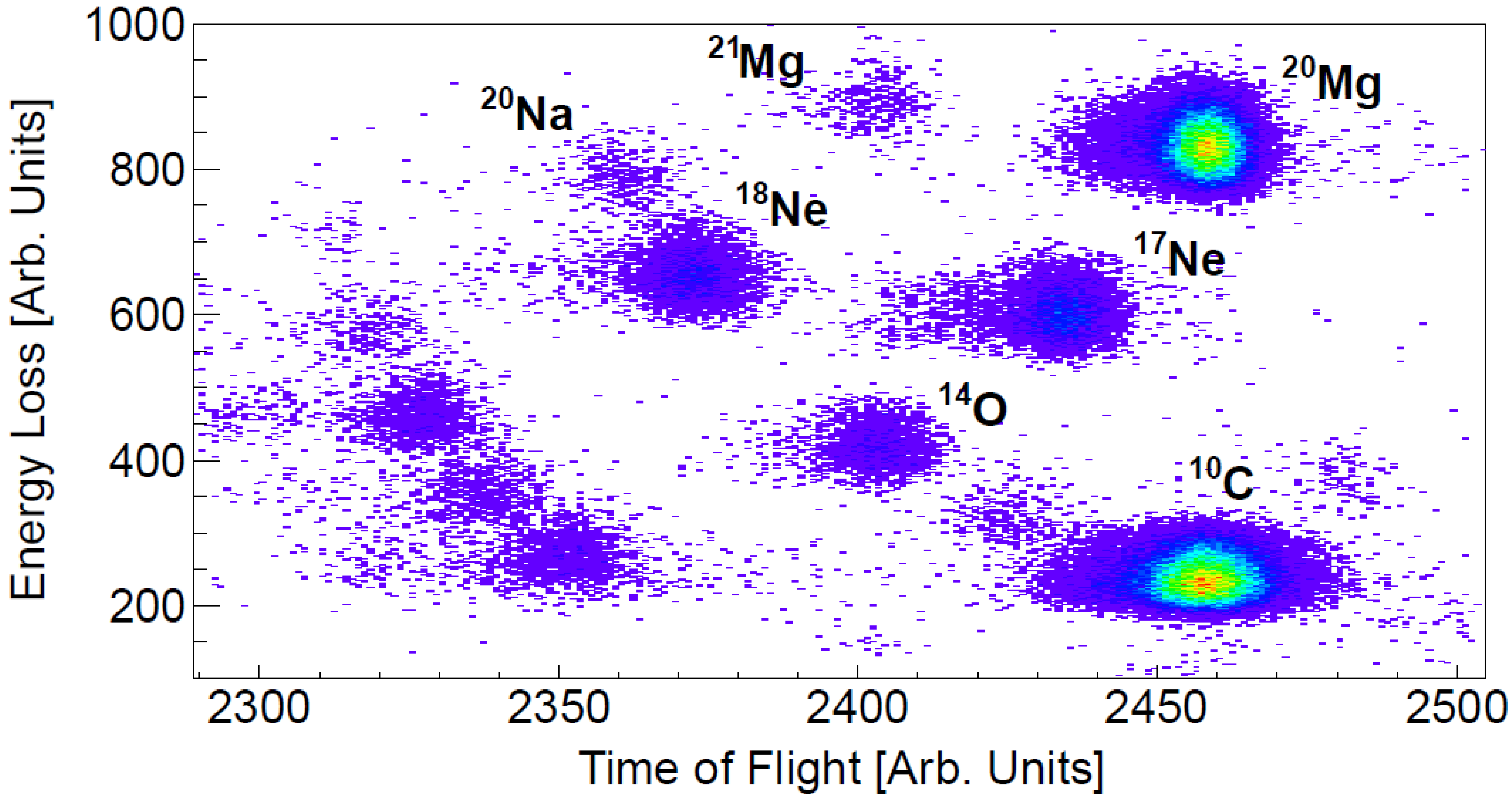
Outgoing Residues Gated on Incoming ^{20}Mg



Incoming ^{20}Mg-gated reaction- and heavy-ion decay residues identified by time of flight and energy-loss in the S800 tuned for ^{17}Ne acceptance.

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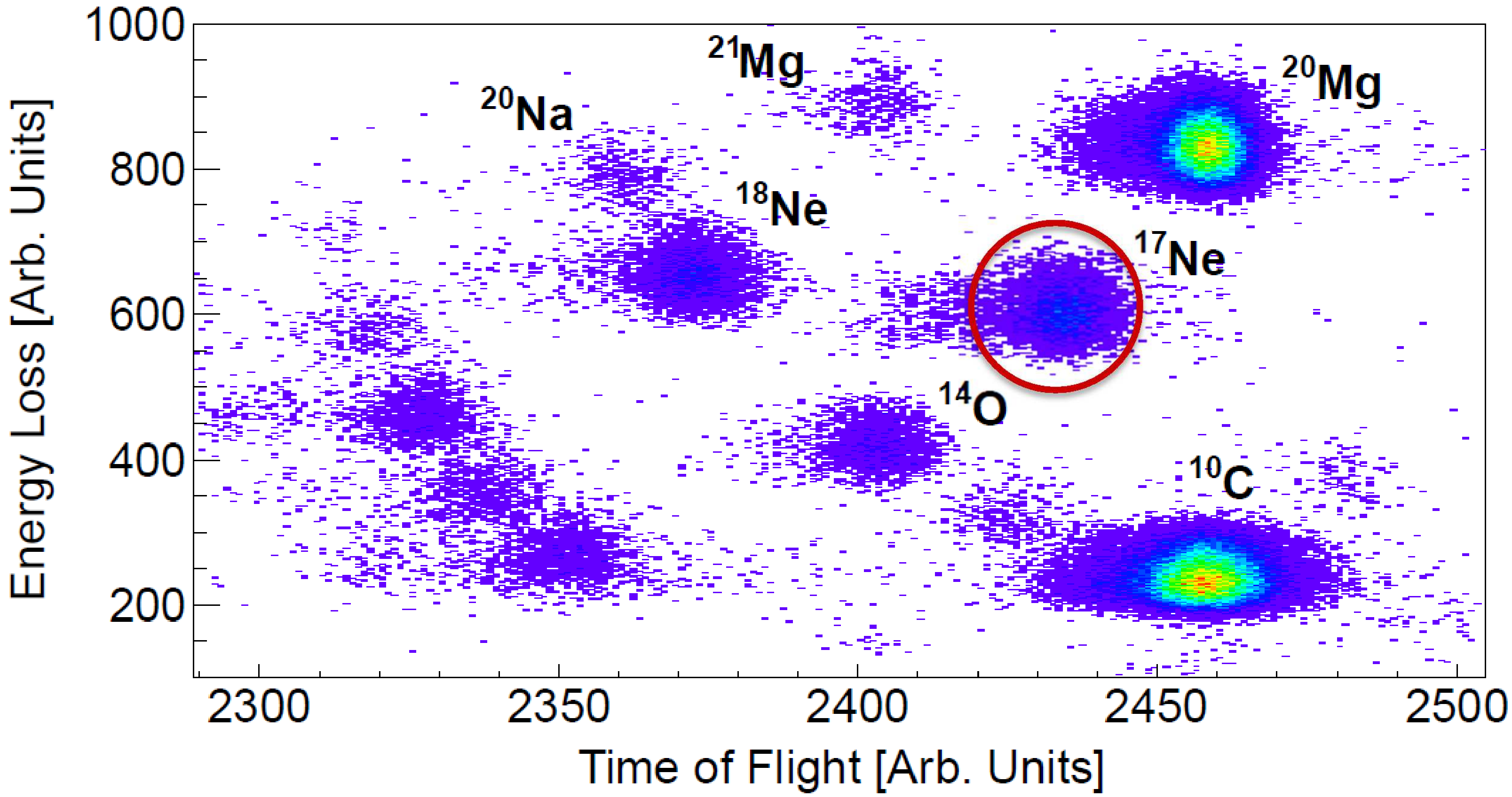

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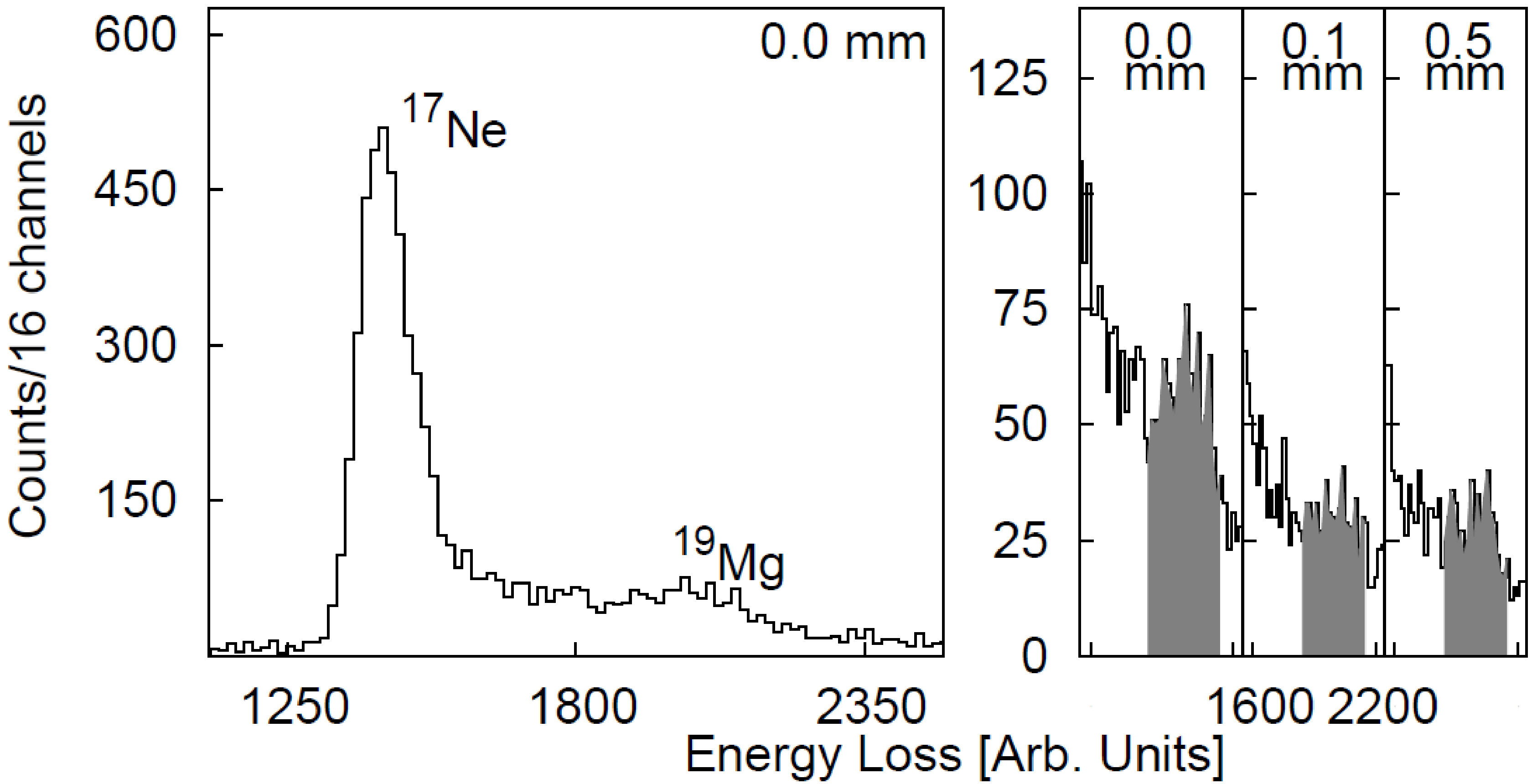
^{19}Mg Two-Proton Decay Energy Loss Spectra



DSSD energy-loss spectra in coincidence with ^{17}Ne residues in the S800. The ^{19}Mg energy-loss region is examined at three target-DSSD distances.

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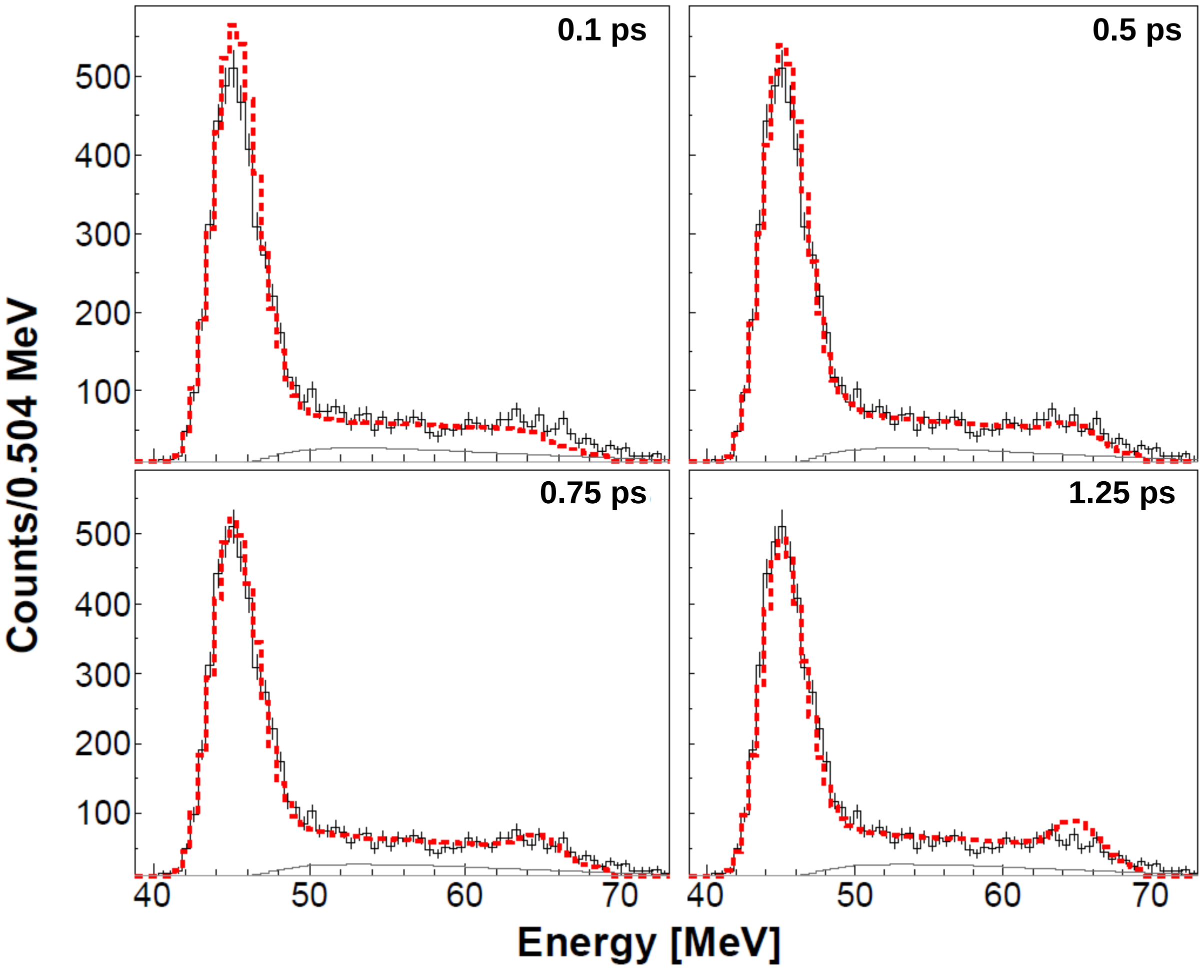
^{19}Mg Lifetime: Energy-Loss Line Shapes



A statistical analysis of the fit of **simulated line shapes** to **experimental DSSD energy-loss spectra** is used to extract the 2p decay lifetime.

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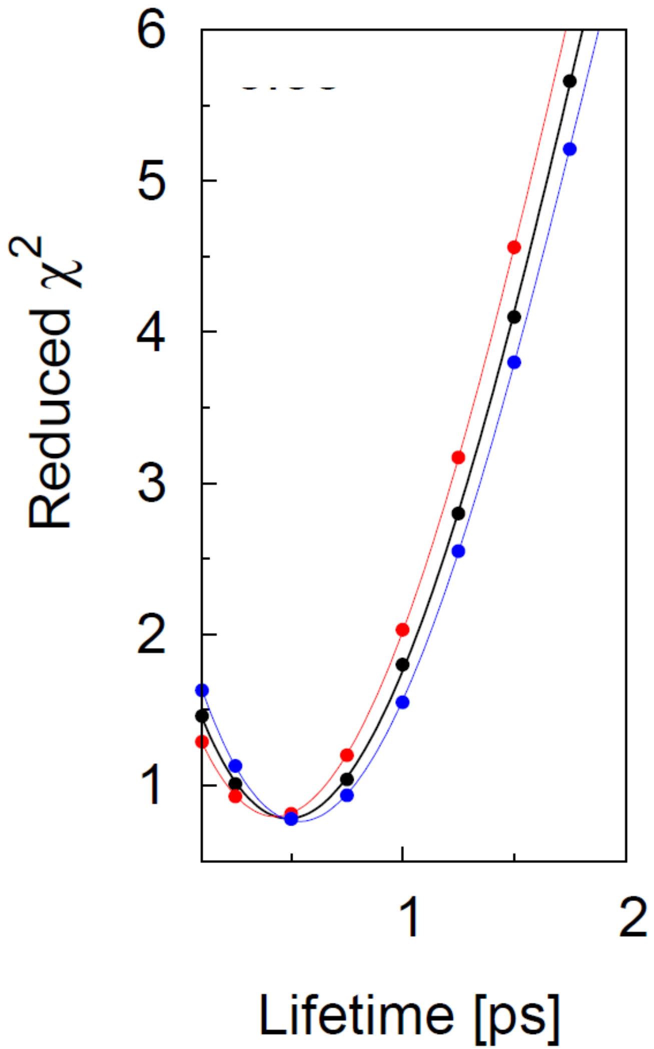
^{19}Mg Lifetime: Systematic Uncertainties Overview

- ^{17}Ne prompt production ratio.
  - Largest source of systematic uncertainty.
- One-neutron knockout reaction ratio on target and detector.
  - Well-constrained via knockout reaction calculations.
- Momentum distribution of reaction residues.
  - Impact energy loss in detector.
  - Contribution only half that of the previous uncertainty.

^{19}Mg Lifetime: Reaction Ratio Uncertainties



Target-detector knockout reaction ratio

$$R_\sigma = N_{\text{target}} / N_{\text{detector}}$$

- Constrained by one-neutron removal cross section calculations [1] on carbon target and silicon detector.
- Upper and lower limits provided by LISE++ calculations [2] with two different fragmentation parameterizations.
- The best-fit lifetime is taken from the central ratio.

***R_σ* Low = 3.0**   ***R_σ* Central = 3.2**   ***R_σ* High = 3.4**

[1] J. Tostevin, Private Communication (2010).
[2] O. B. Tarasov and D. Bazin, NIM B **266**, 4657 (2008).

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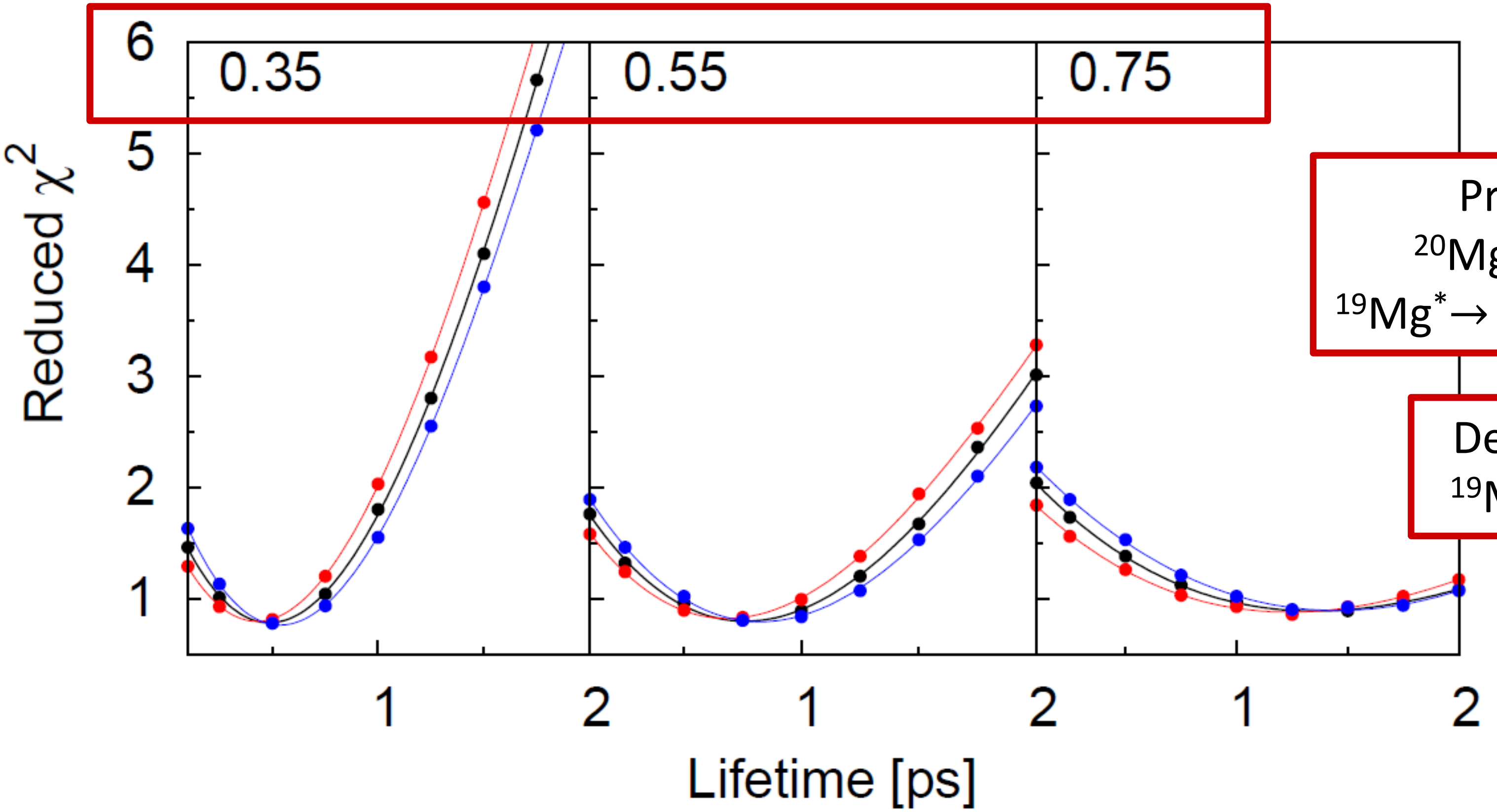
^{19}Mg Lifetime: ^{17}Ne Prompt Production Uncertainties

^{17}Ne prompt production ratio

$$R_p = N_{\text{prompt}} / (N_{\text{delayed}} + N_{\text{prompt}})$$

Increasing Prompt Production →



Prompt Production

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Delayed Production

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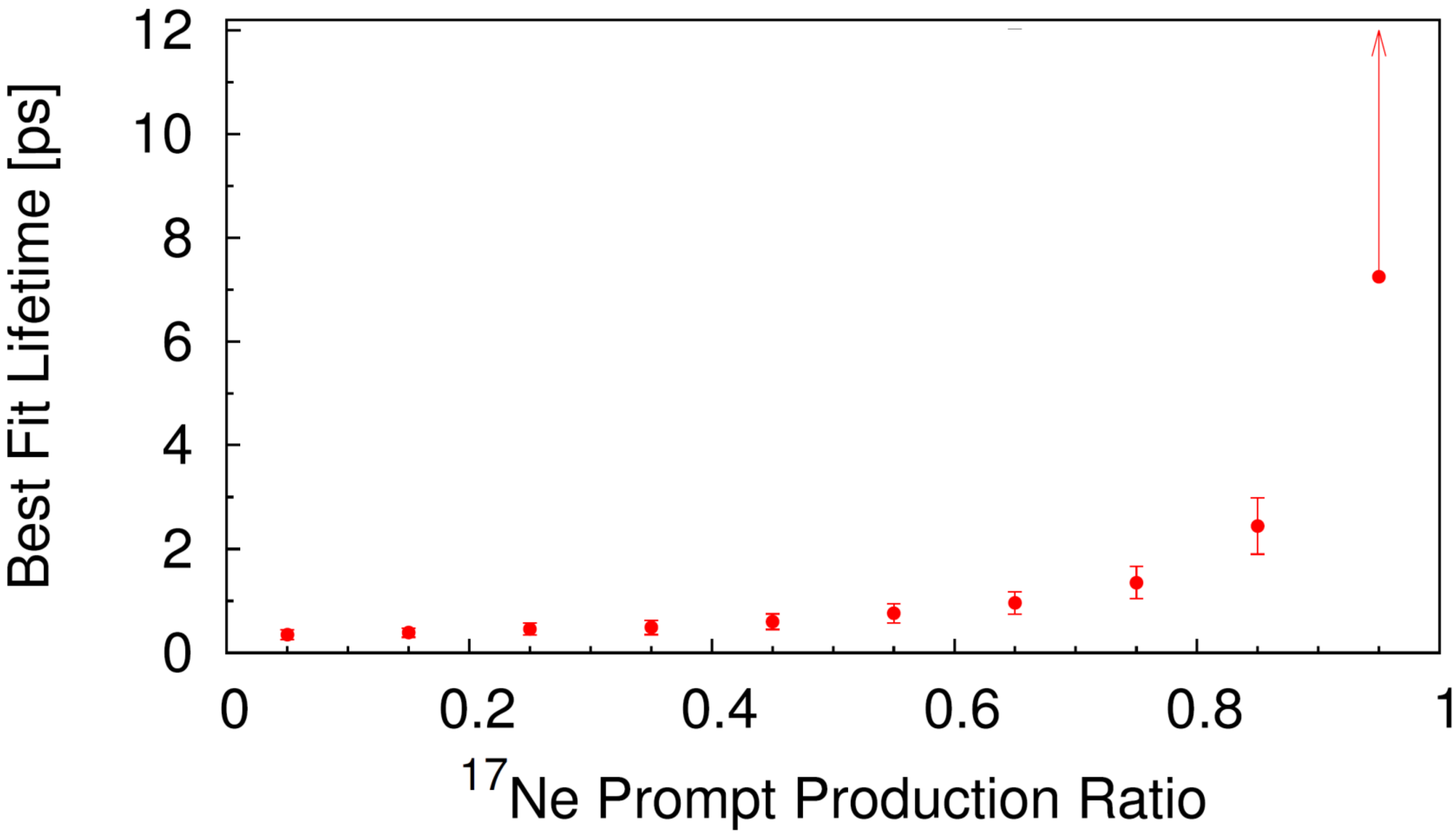
Results: Two-Proton Decay Lifetime Range



R_p	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
τ (ps)	0.35	0.39	0.46	0.49	0.60	0.76	0.96	1.35	2.44	7.25
$\Delta\tau$ (ps)	0.09	0.09	0.12	0.14	0.15	0.18	0.22	0.31	0.54	–

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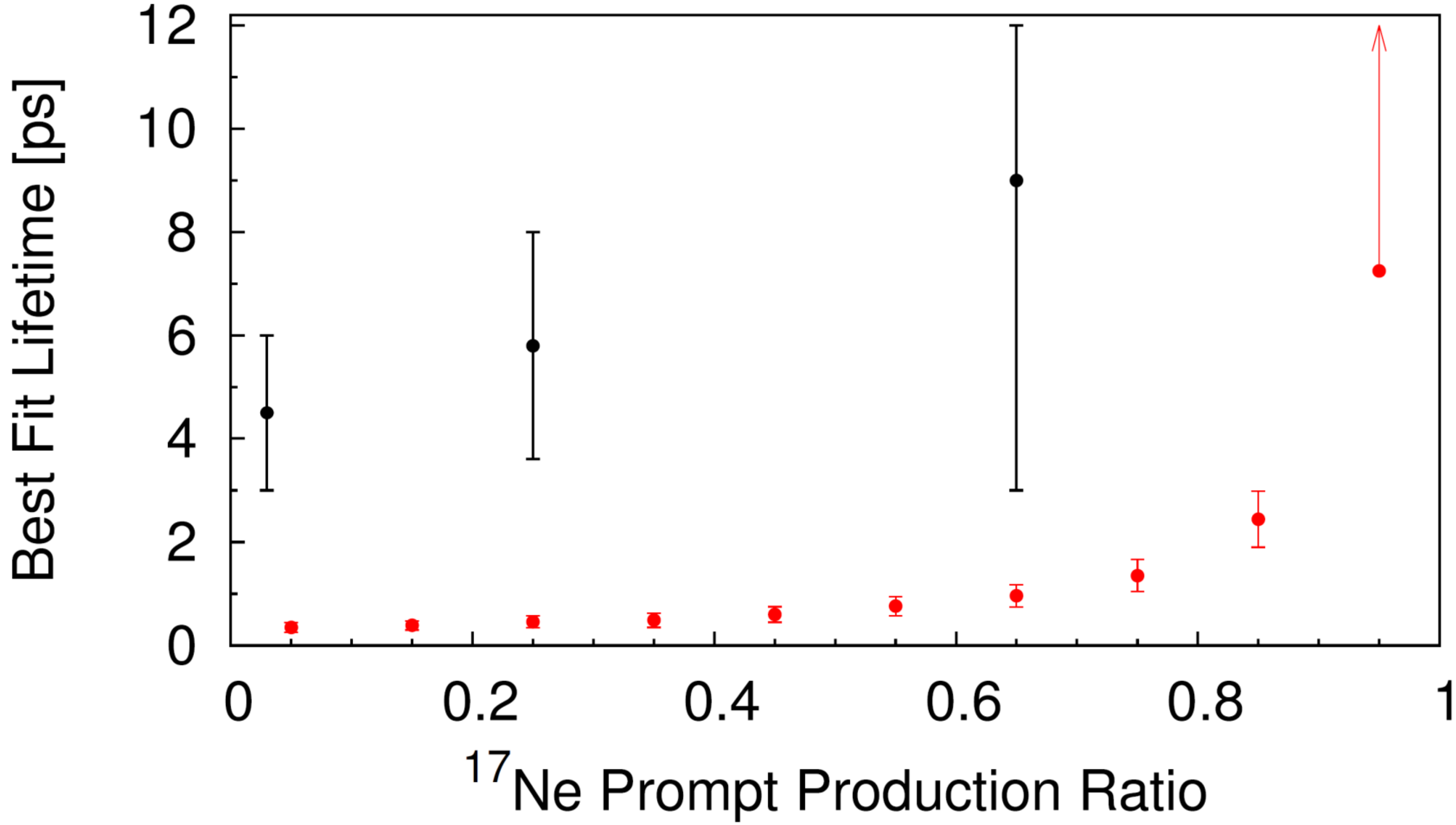
Results: Two-Proton Decay Lifetime Range



Comparison between the **present results** and **literature values** as a function of increasing prompt ^{17}Ne production. The two differ by an order of magnitude.

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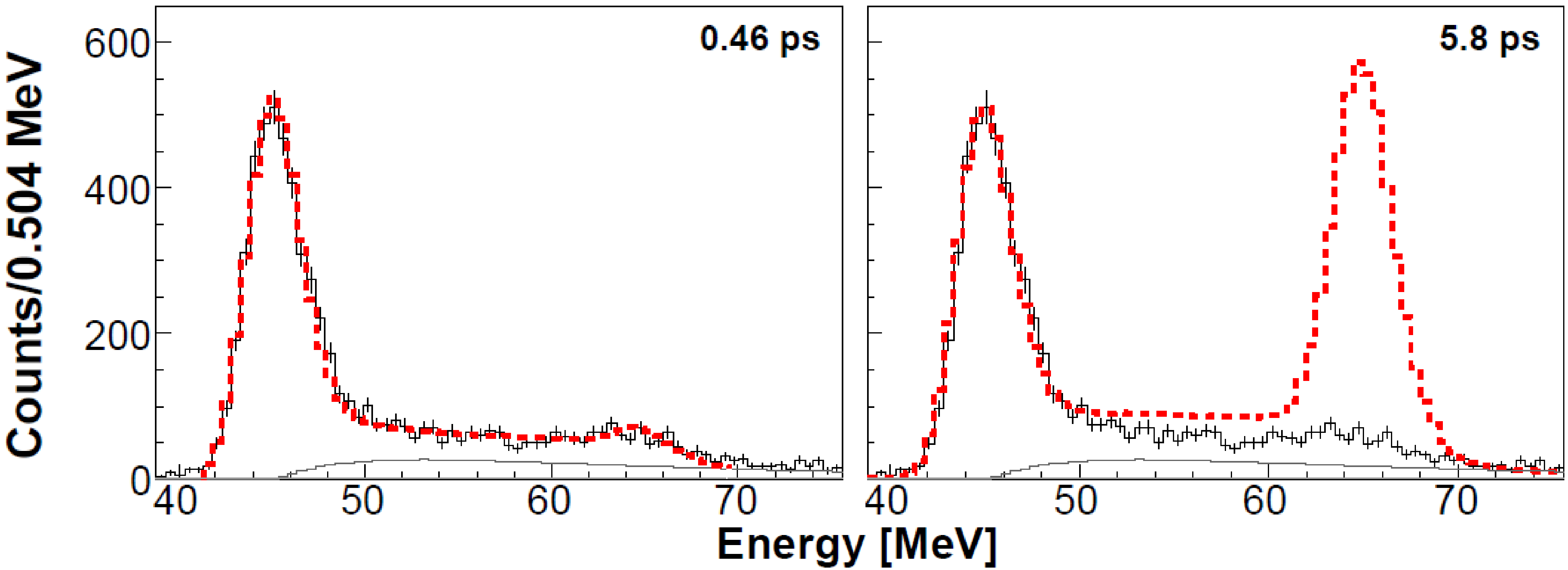
Results: Comparison With Previous Work



DSSD energy-loss spectra in coincidence with ^{17}Ne residues. Simulated line shapes with lifetimes from the present work and literature are compared at R_p = 0.25.

R_p	0.05	0.25	0.65
Present Results (ps)	0.35 ± 0.09	0.46 ± 0.12	0.96 ± 0.22
Literature Value (ps)	4.5 ± 1.5	5.8 ± 2.2	9^{+3}_{-6}

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Summary

A novel adaptation of Recoil Distance Method lifetime measurements for proton emitters has been demonstrated with the Köln/NSCL particle plunger.

The ground state two-proton emission lifetime of ^{19}Mg was measured. As a function of increasing prompt ^{17}Ne production, the best-fit lifetimes increased within the range 0.3 – 3.0 ps.

The results are significantly shorter than the previously reported measurement and indicate the need for more work regarding both the lifetime and valence proton orbital configurations in ^{19}Mg.

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University of Köln

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