Study of ^{36}Ca: broken mirror and two proton decay

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Strasbourg, France

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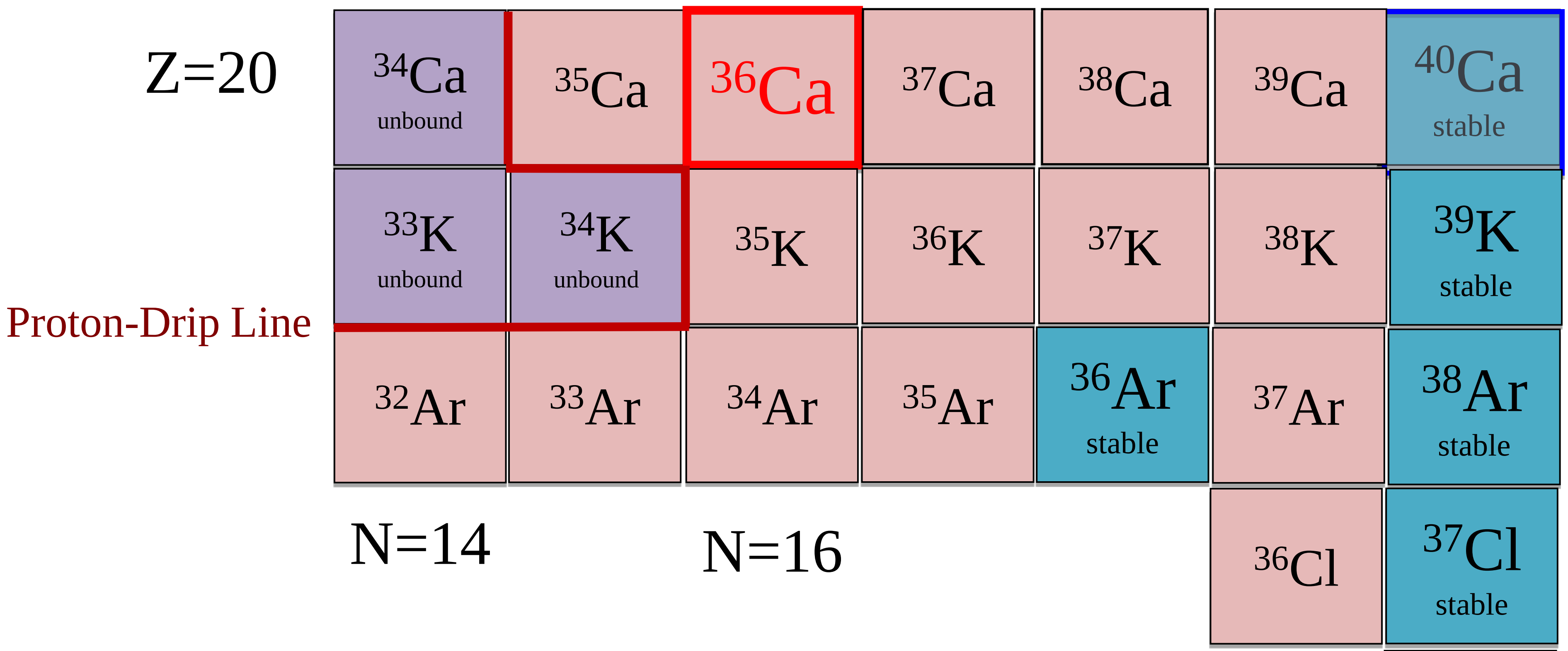
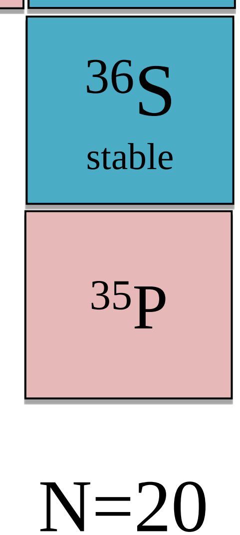
Introduction



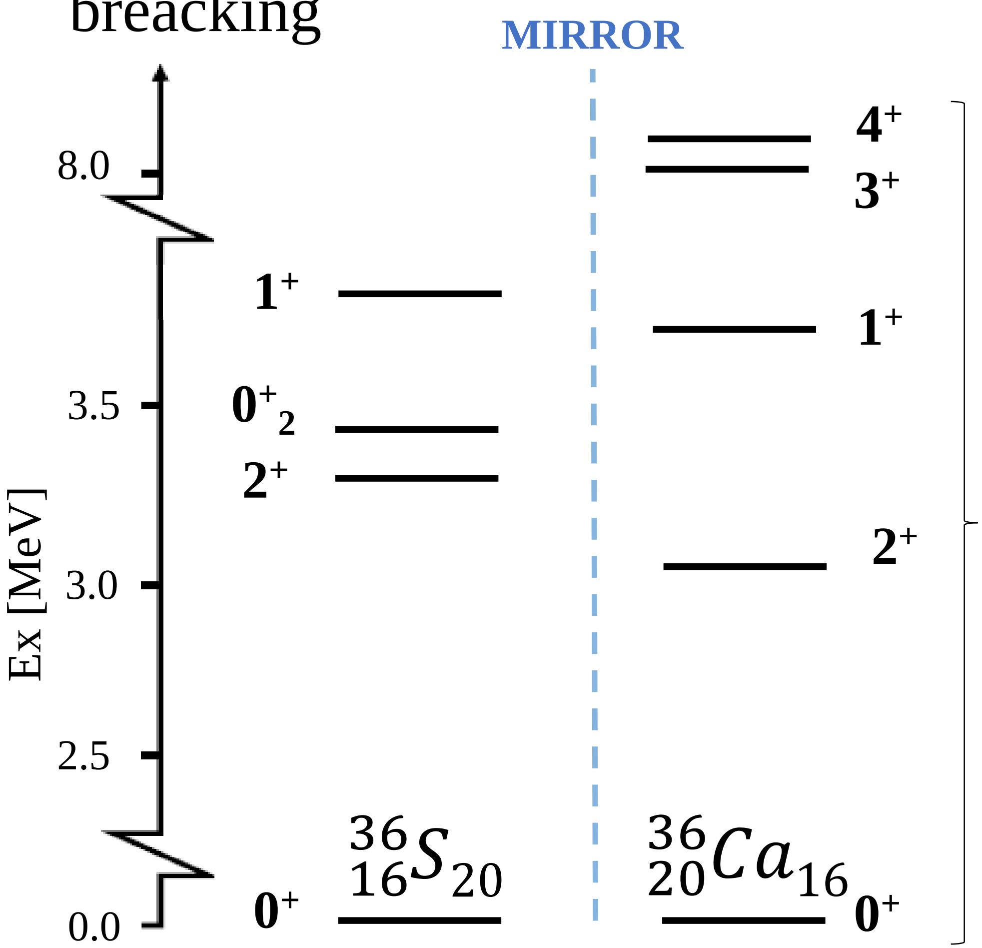
- **<u>General context:</u> Study nuclear structure at the non-binding limit of the nucleus in proton rich region**



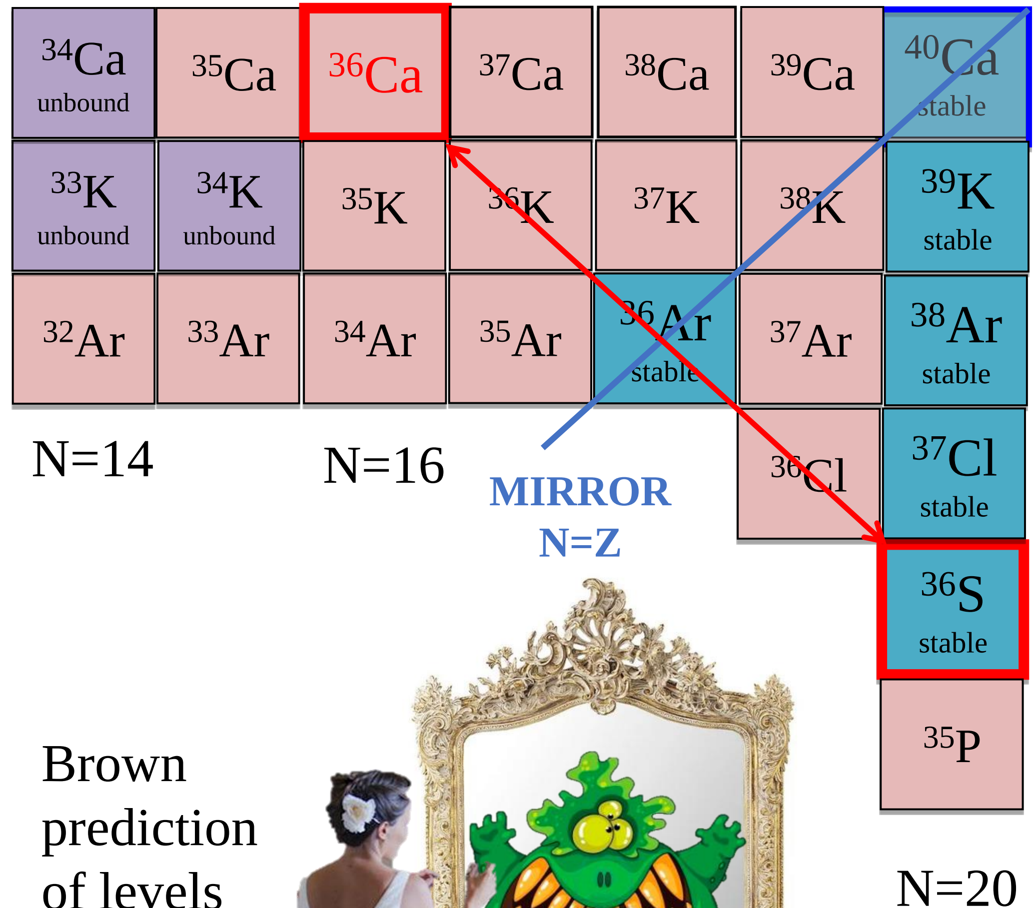
- ^{35}Ca: last bound Ca isotope
- Only g.s. of ^{35,36}Ca are bound
- g.s and 2+ states of ^{36}Ca are known

Shell Structure and Isospin Symmetry Breaking

- The shell structure and shell gap evolution is studied by spectroscopy
- Comparing it to its mirror nuclei one can study isospin symmetry breacking

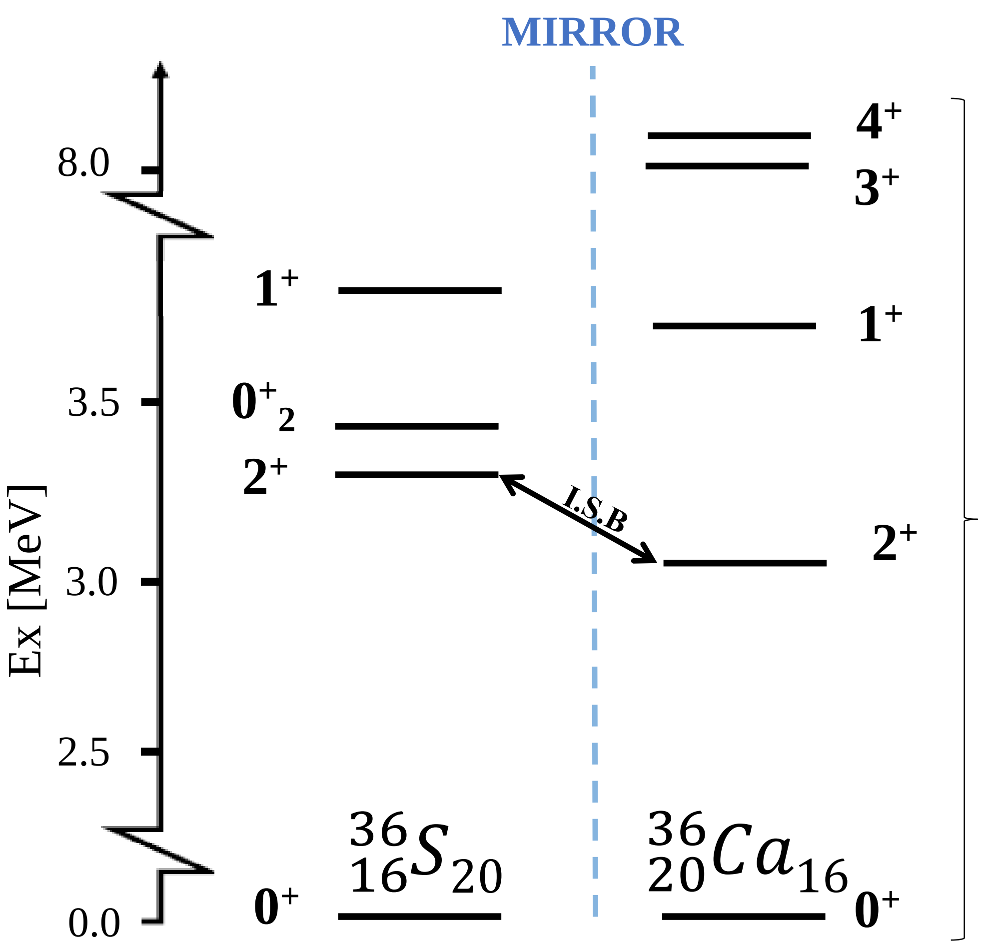


Brown prediction of levels populated by (p,d)



Shell Structure and Isospin Symmetry Breaking

- Mirror symmetry implies that spectra between mirror nuclei are identical
- Isospin symmetry breaking is observed far from the stability



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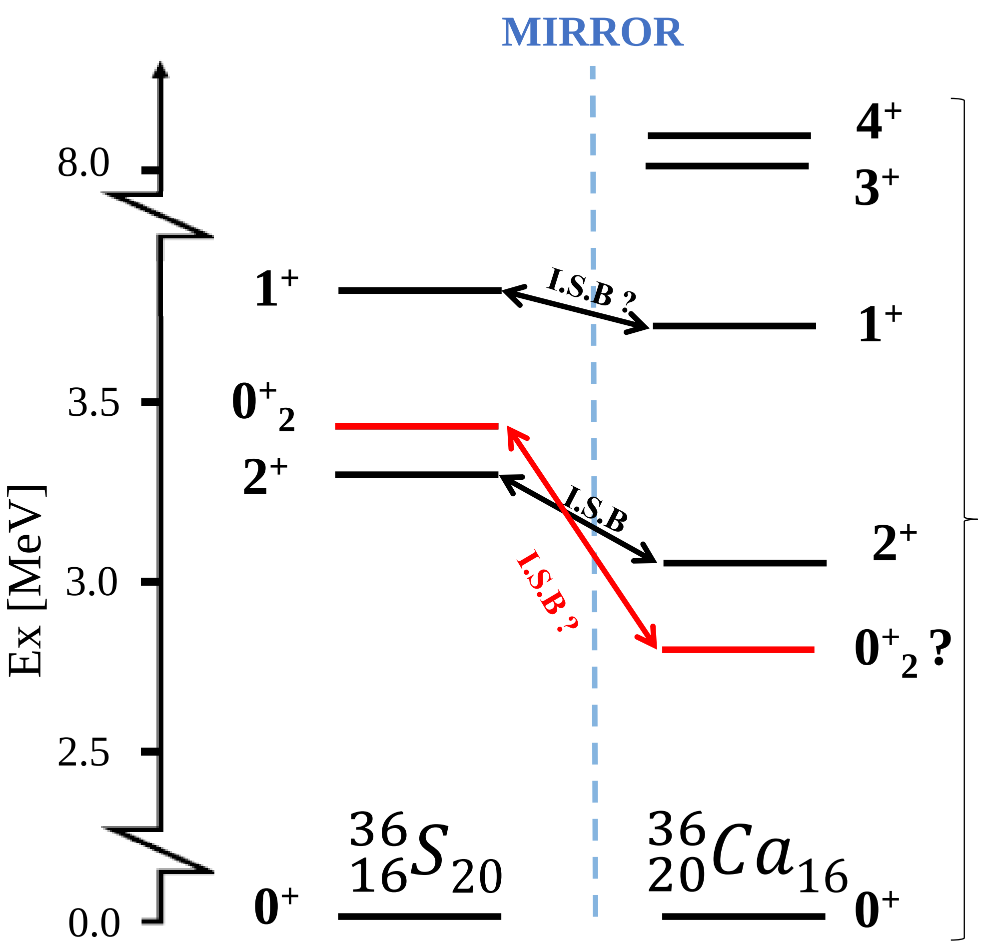
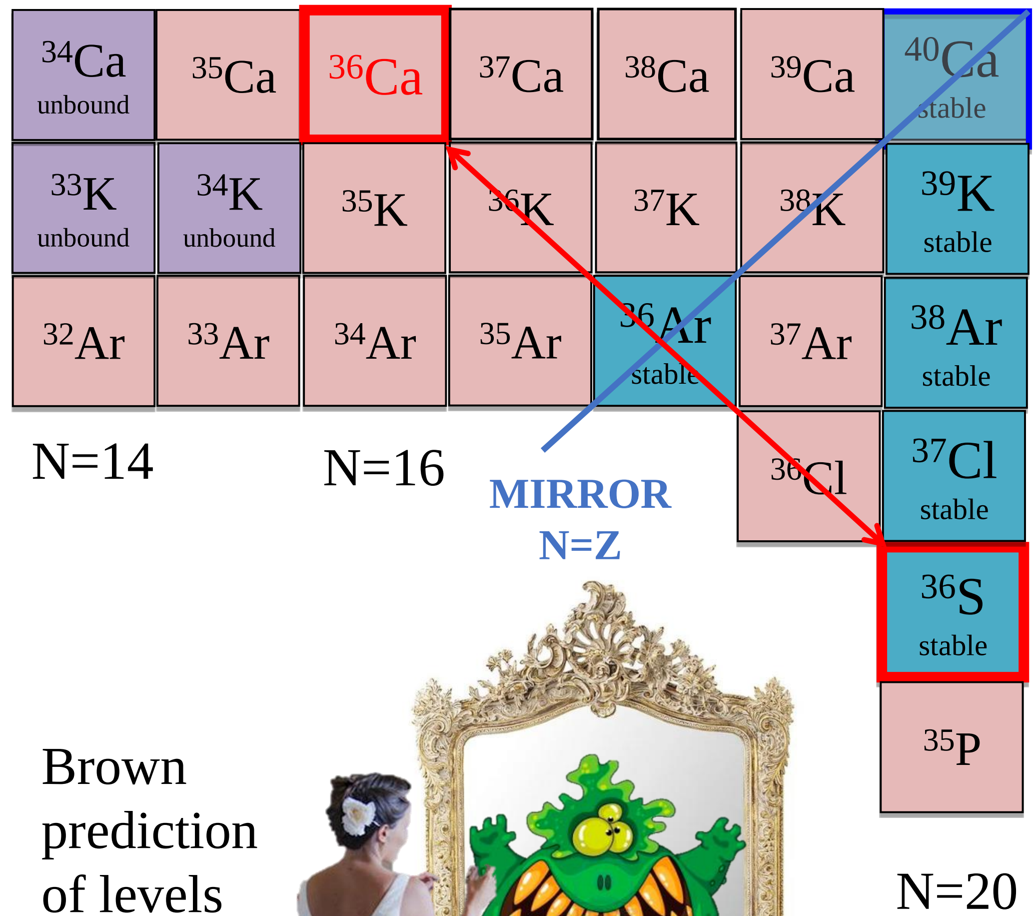


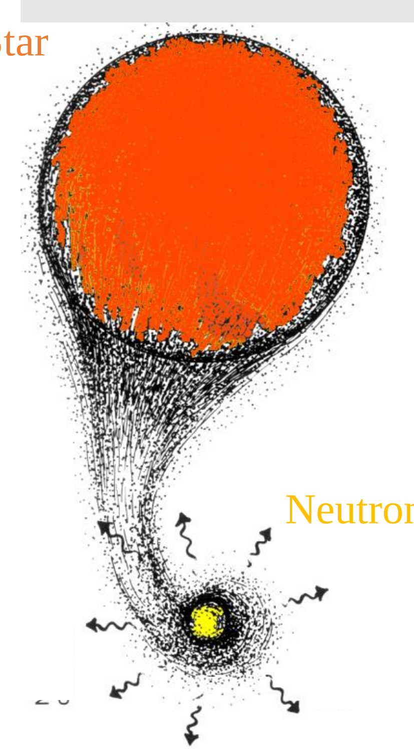


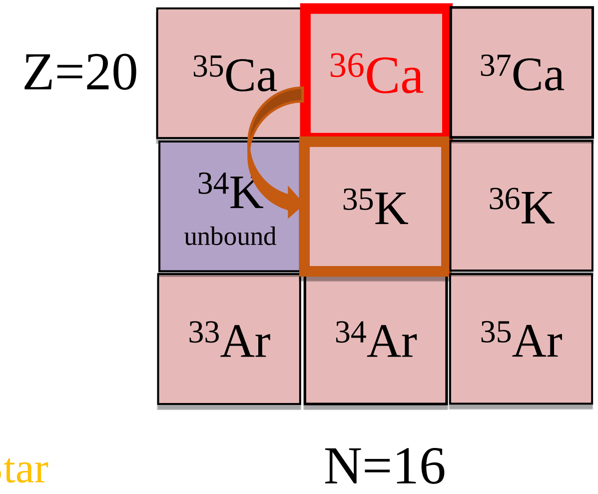
Brown prediction of levels populated by (p,d)

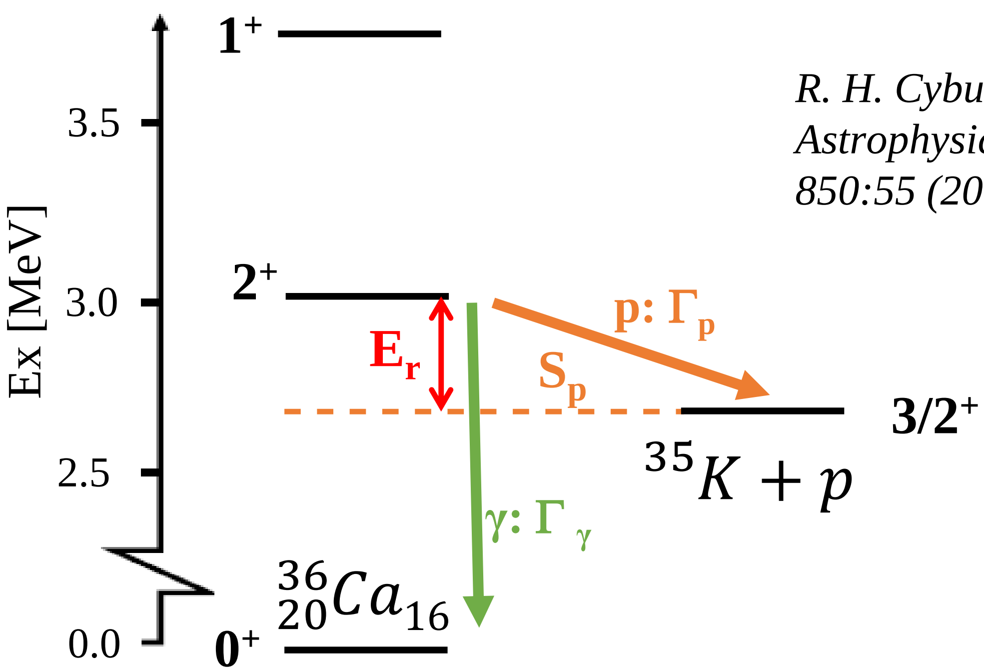
Valiente-Dobon, Poves PRC (2019)

One Proton Decay and X-Ray Burst

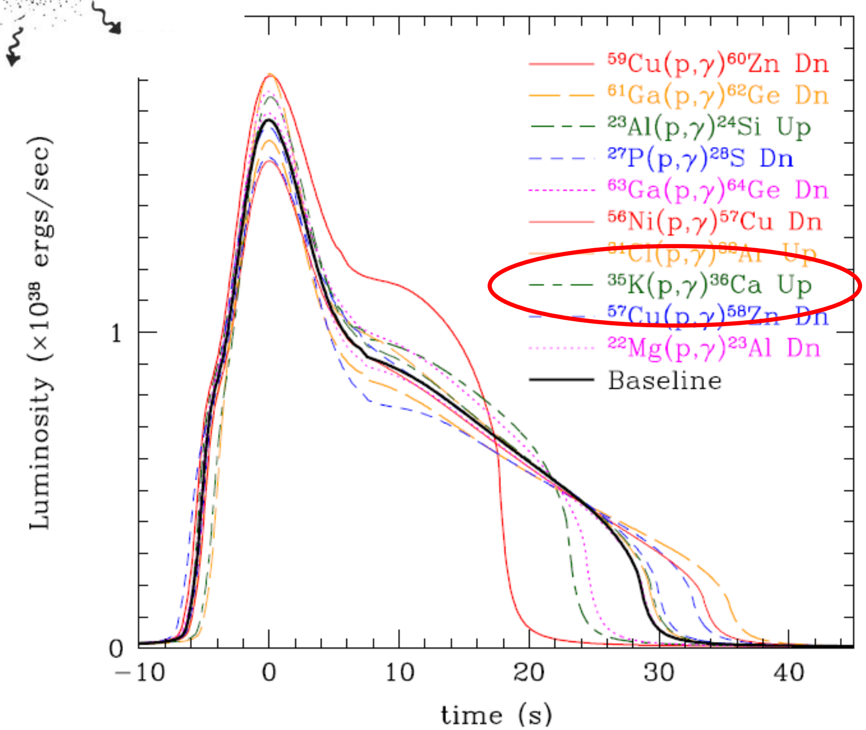
- X-ray bursts are thermonuclear flashes occurring when a neutron star accretes matter from a normal star.
- Proton Capture reaction rate $^{35}K+p \rightarrow {}^{36}Ca+\gamma$ has strong impact on the burst light curve.
- Reaction rate can be constrained from E_r, Γ_p, Γ_γ and J^π of the states





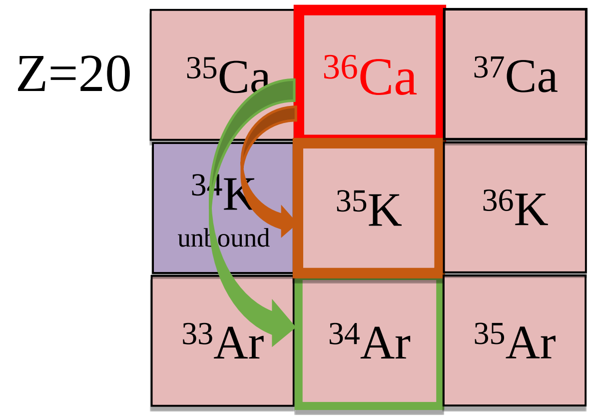


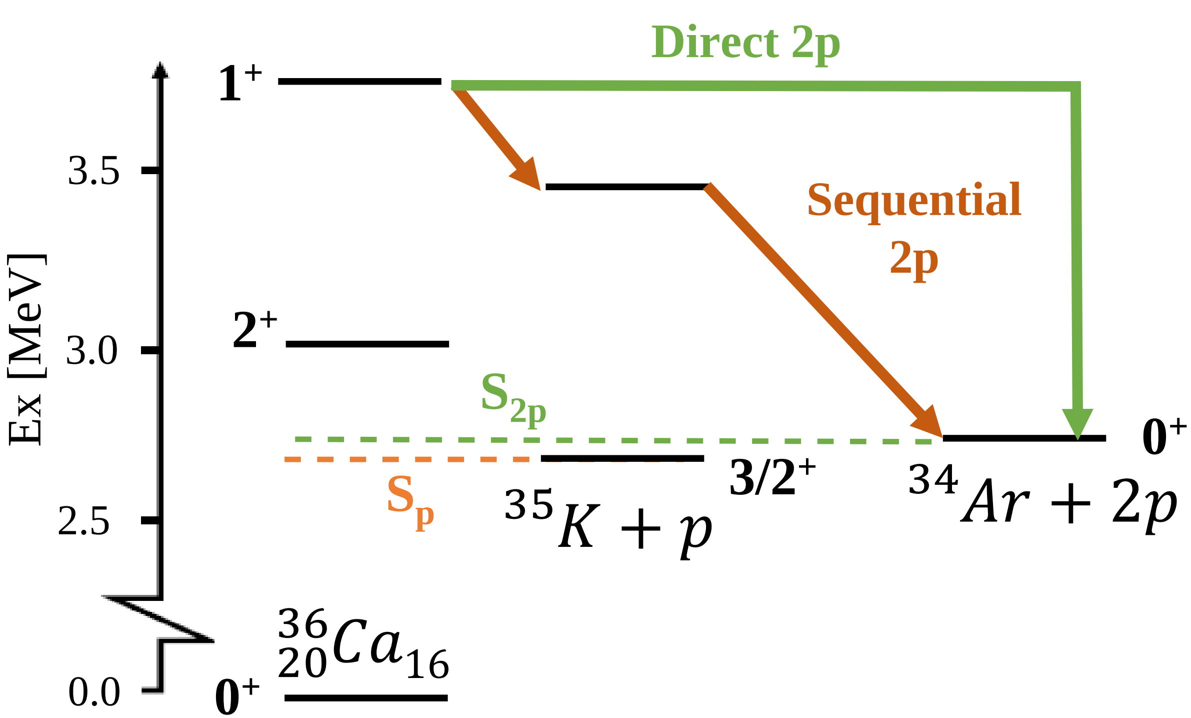
R. H. Cyburt et al.
Astrophysical Journal
850:55 (2016)

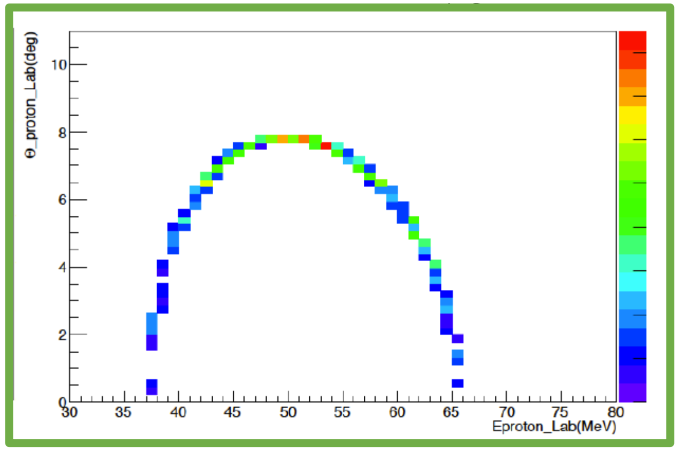


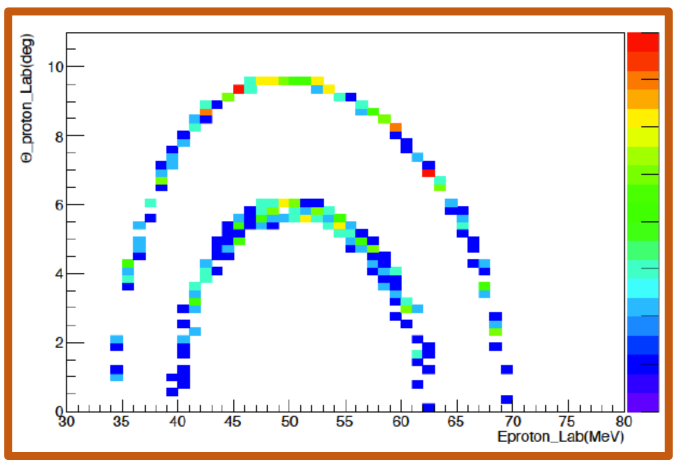
Two Proton Decay

- Two 2p decay channels: direct or sequential
- Only three direct 2p emitter known
- By studying protons correlation we will determine if the 2p decay is direct or sequential and probe proton interaction inside the nuclei.

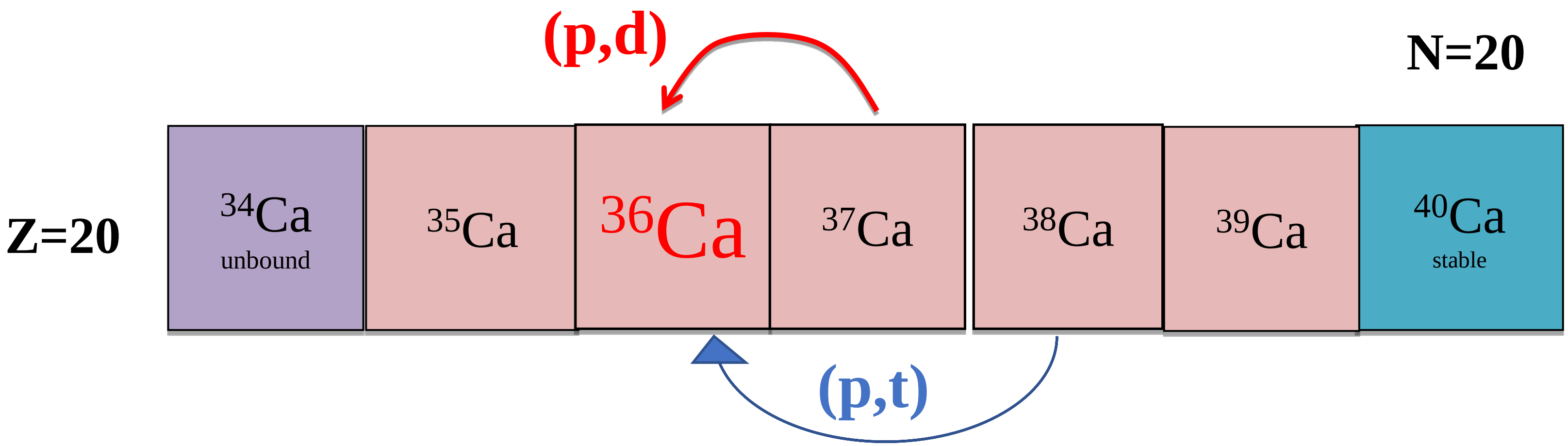






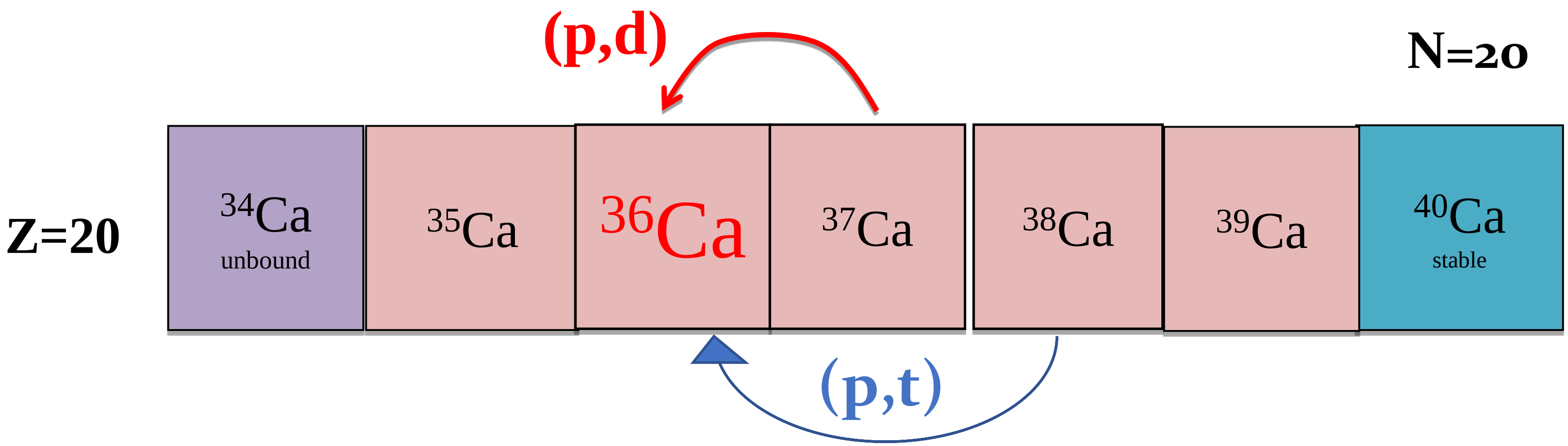


Production of ^{36}Ca

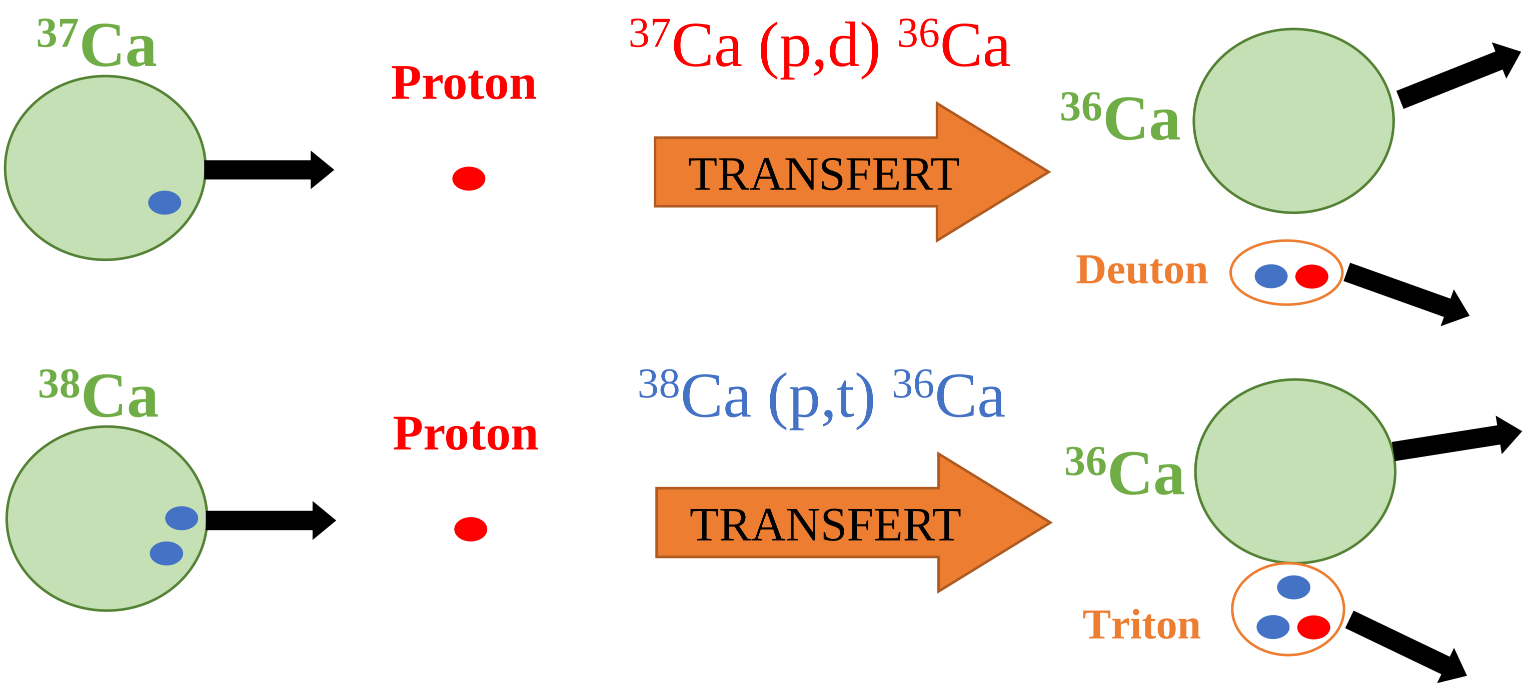


- Use of a ^{37}Ca and ^{38}Ca at the LISE spectrometer
  - ➔ Produced by fragmentation of ^{40}Ca at 2µA on a ^{9}Be target
  - ➔ ^{37}Ca beam @ 50MeV/A I = 10^3pps
  - ➔ ^{38}Ca beam @ 50MeV/A I = 10^4pps

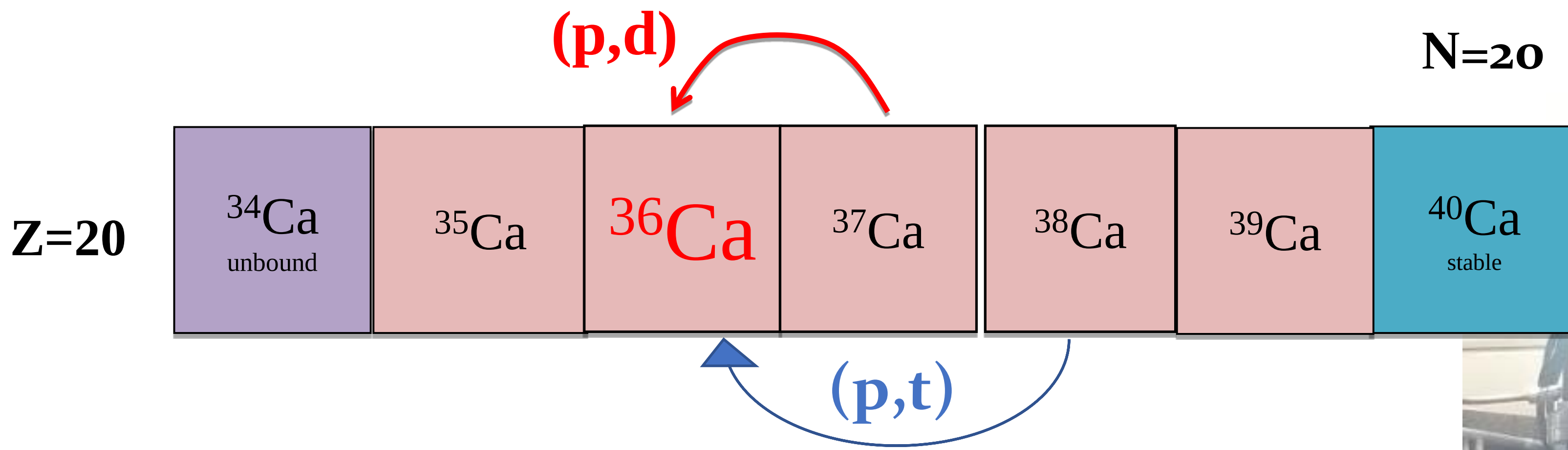
Production of ^{36}Ca



- Use of a ^{37}Ca and ^{38}Ca at the LISE spectrometer
- Produce ^{36}Ca with (p,d) and (p,t) using a proton target



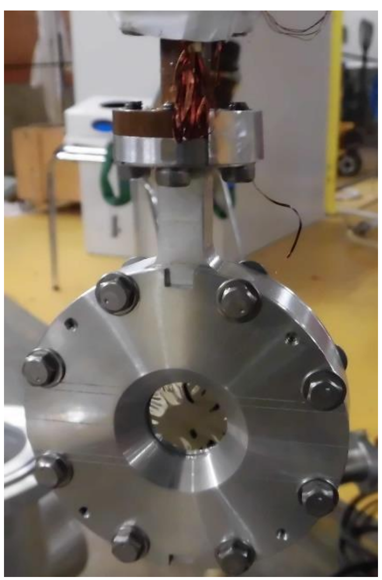
Production of ^{36}Ca



- Use of a ^{37}Ca and ^{38}Ca at the LISE spectrometer
- Produce ^{36}Ca with (p,d) and (p,t) using a proton target
- ^{37}Ca beam at few 10^3 pps for 6 days

➔ few thousands of ^{36}Ca

➔ need a thick cryogenic target of liquid Hydrogen

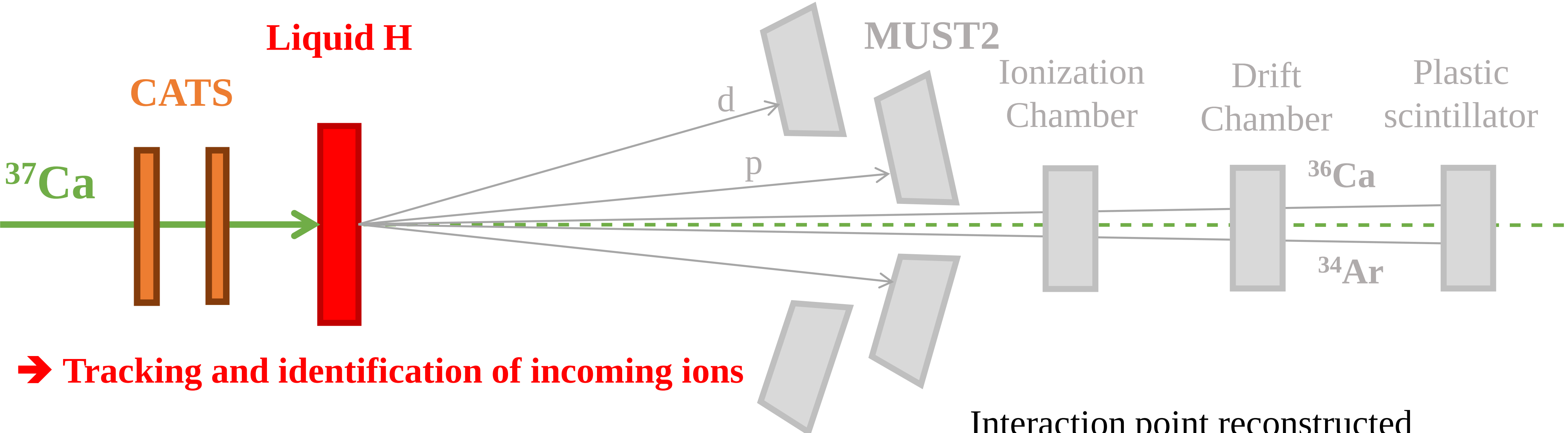


- RIKEN target: CRYPTA

H. Ryuto *et al.*, Nucl. Instrum. Methods Phys. Res., Sect A 590, 204 (2008).

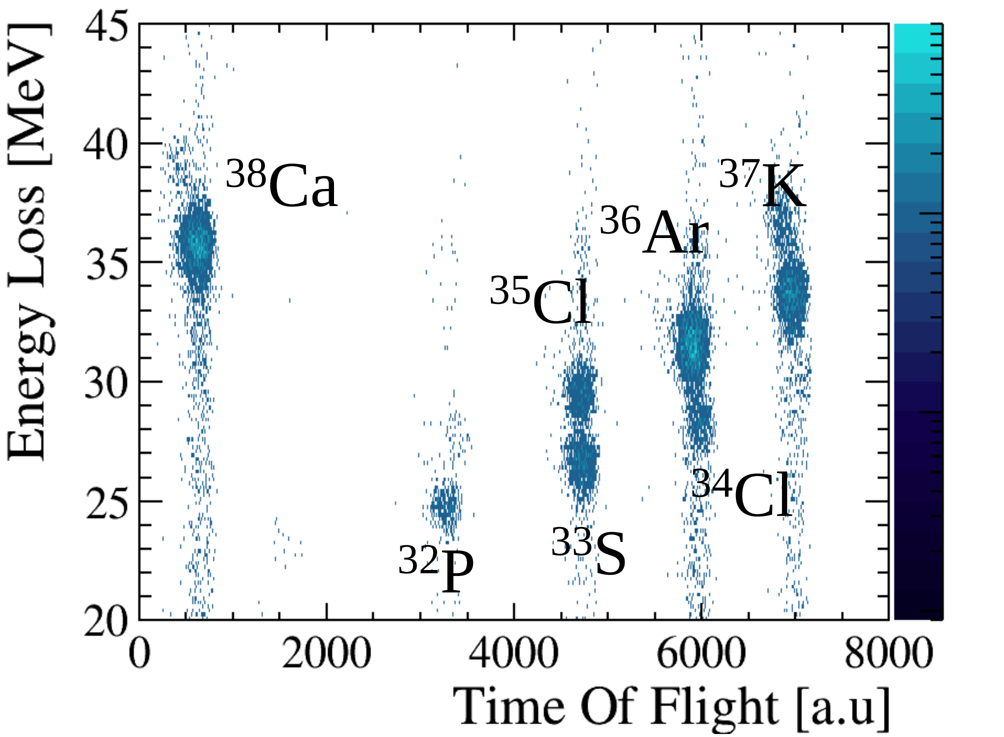
- Density: 75mg/cm^3
- Thickness: 1.5mm

Experimental Setup: CATS

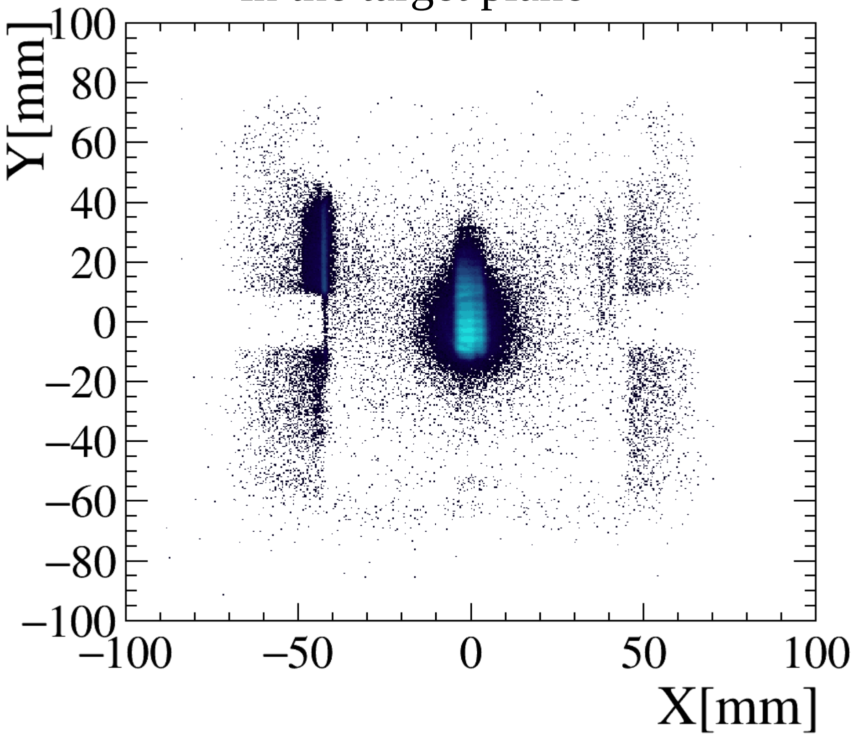


➔ Tracking and identification of incoming ions

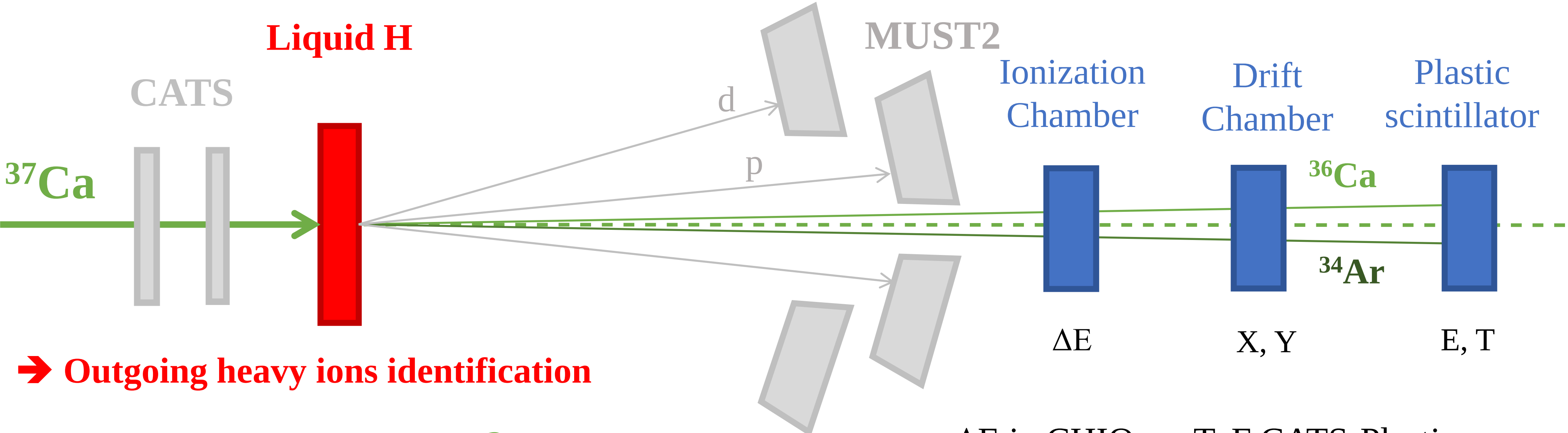
ΔE vs ToF Identification of the 38Ca cocktail beam



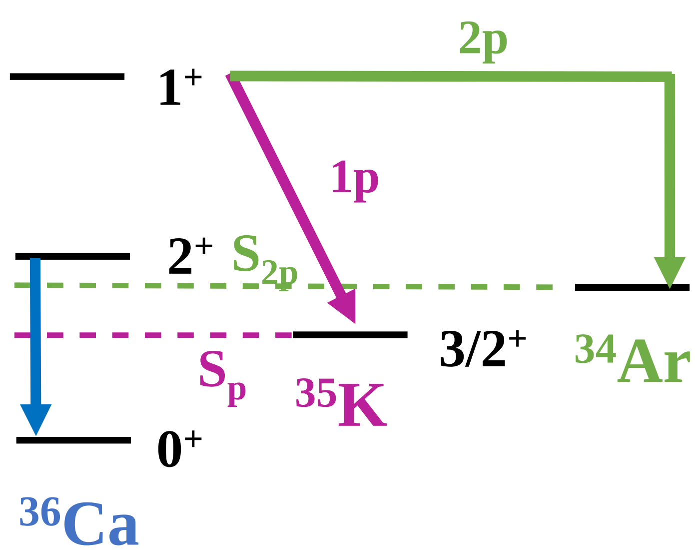
Interaction point reconstructed in the target plane



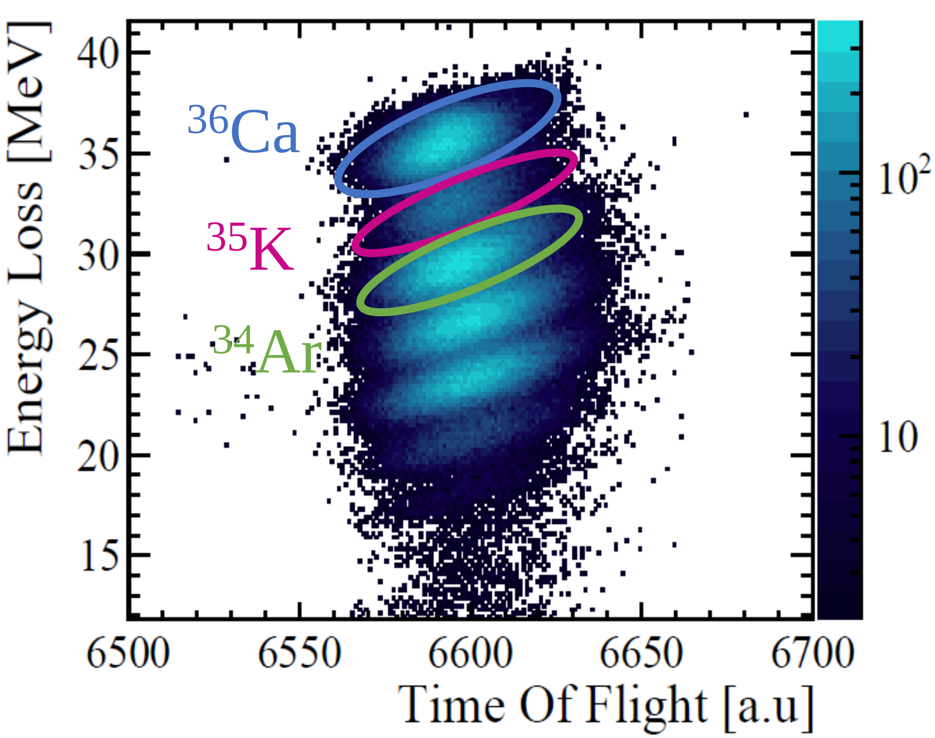
Experimental Setup: 0° Detection



➔ **Outgoing heavy ions identification**



ΔE in CHIO vs. ToF CATS-Plastic

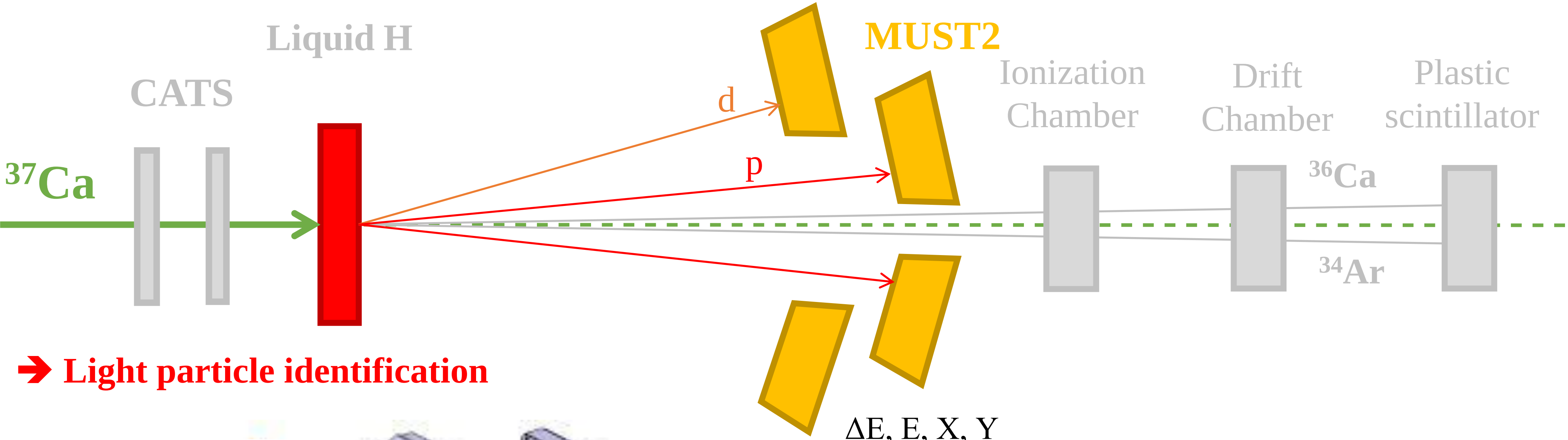


Unbound states of ^{36}Ca can decay by γ, p or 2p

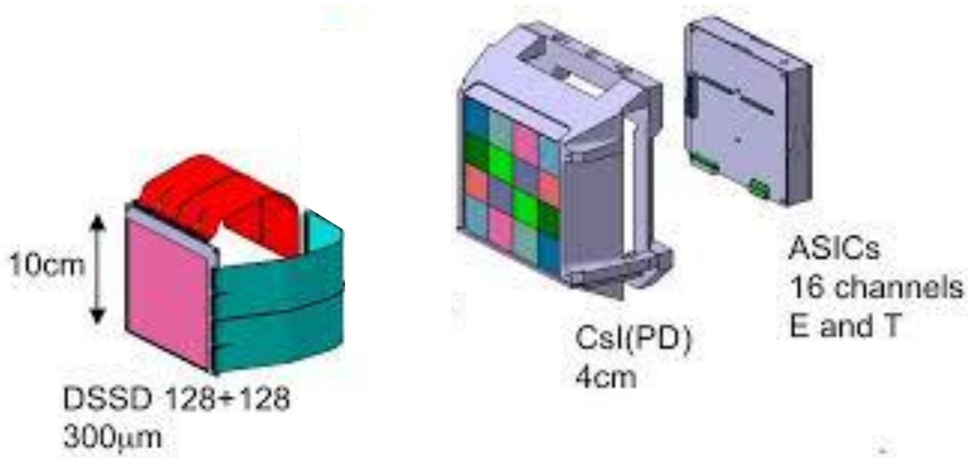
➔ Leading to ^{36}Ca, ^{35}K of ^{34}Ar

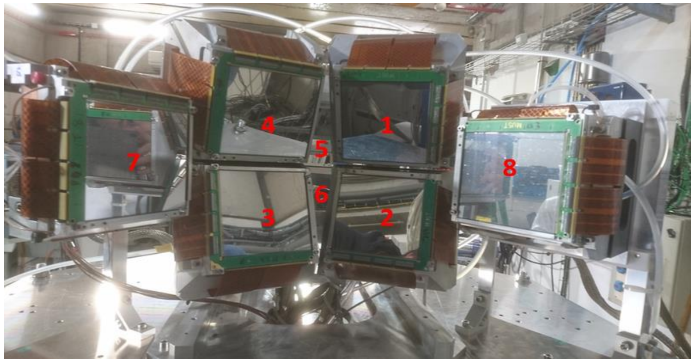
➔ **Heavy ions identification**

Experimental Setup: MUST2



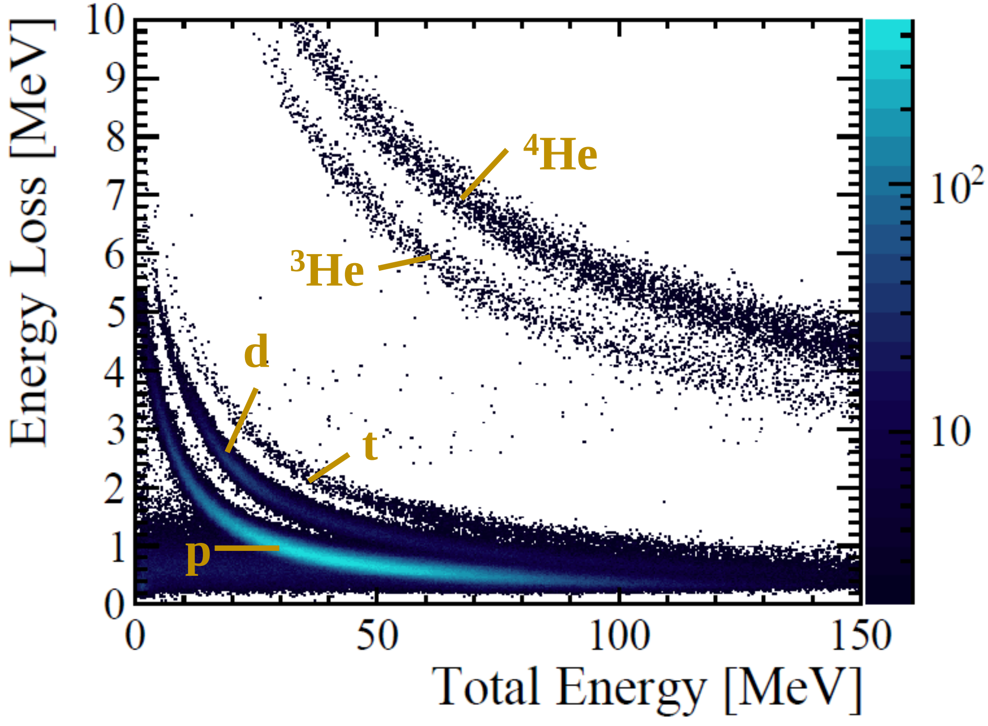
➔ **Light particle identification**



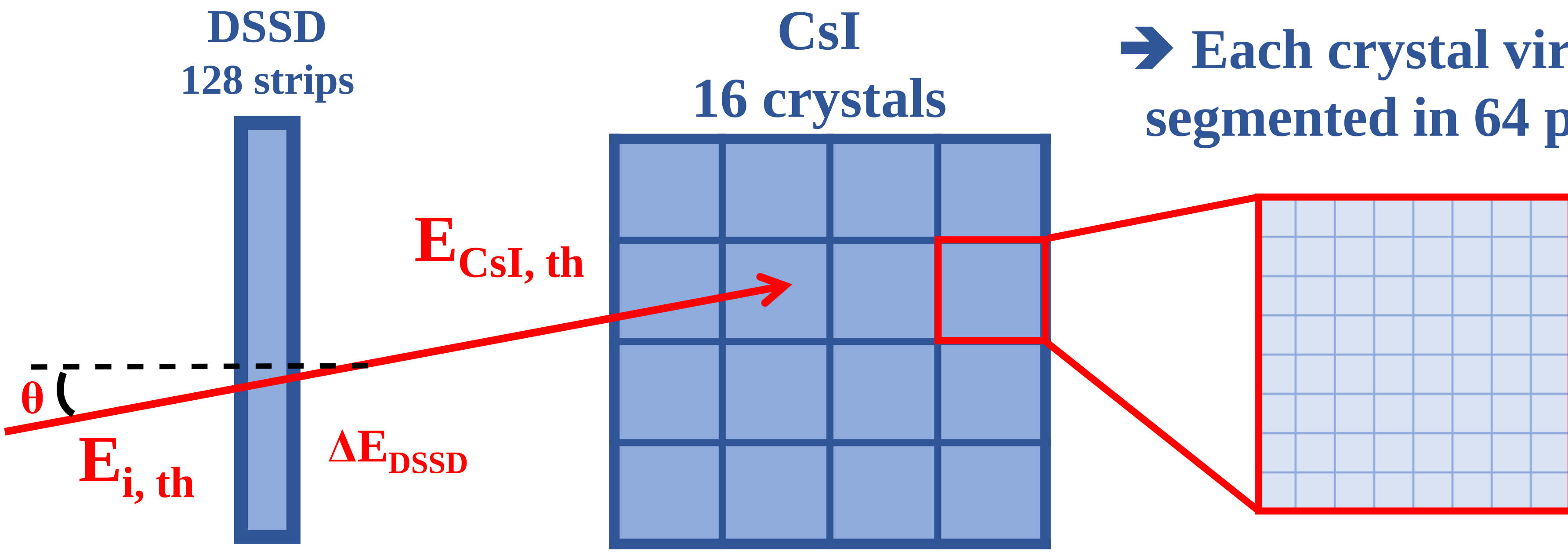


The 8 MUST2 telescopes used for the experiment

ΔE vs. E light particle identification

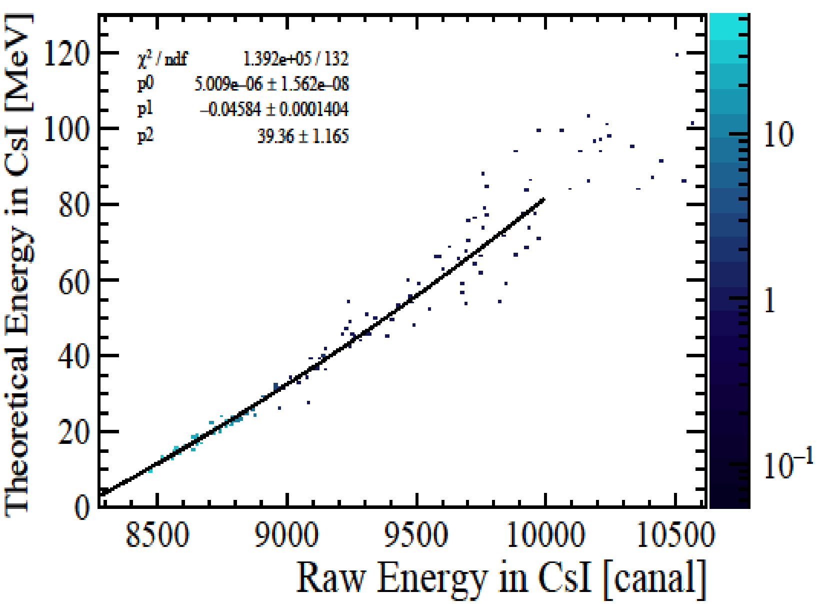


Energy Calibration of MUST2



➔ **Each crystal virtually segmented in 64 pixels**

Calibration curve for one pixel



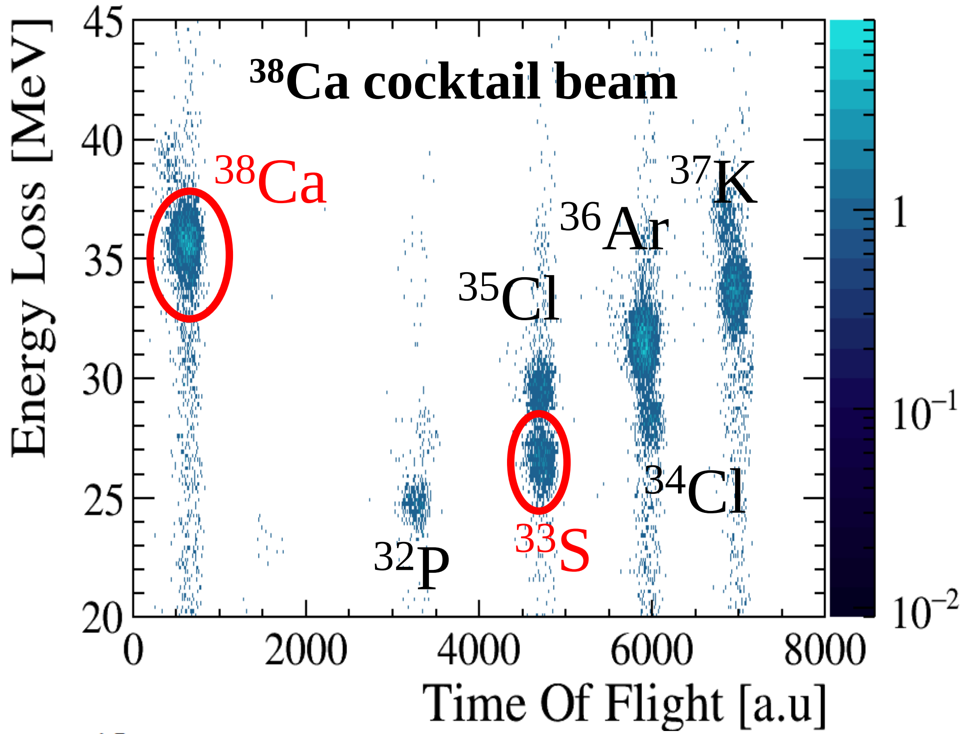
1) The calibration depend on the type of particles.

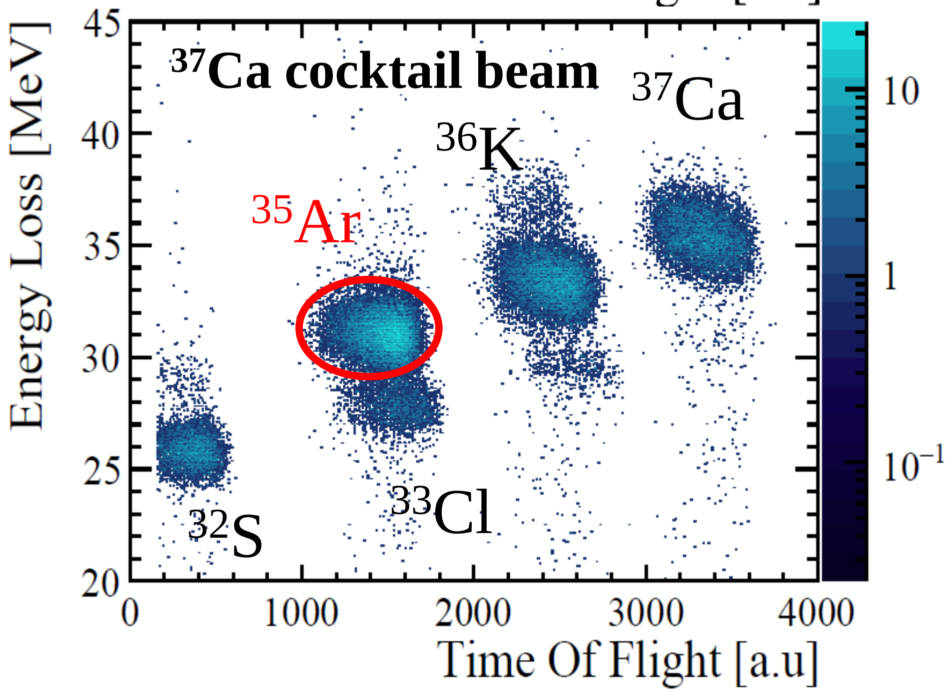
2) From ΔE in the DSSD the particle energy is reconstructed:

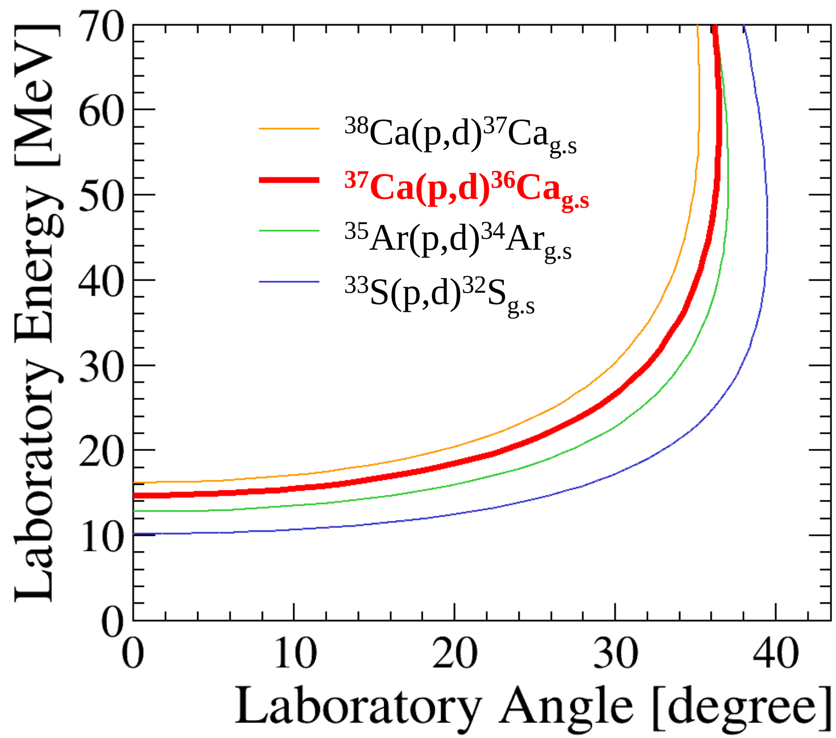
$$E_{i,\,th} = f(\Delta E_{DSSD}, \theta) \rightarrow E_{CsI,\,th}$$

3)The crystal inhomogeneity modifies the effective gain as a function of the position inside the crystal. To correct this effect, each CsI is segmented in 64 pixels.

Reference Reactions







References reactions:

^{38}Ca(p,d)^{37}Ca

^{35}Ar(p,d)^{34}Ar

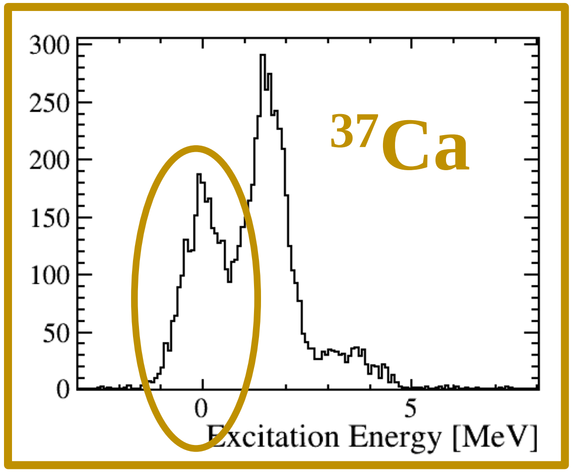
^{33}S(p,d)^{32}S

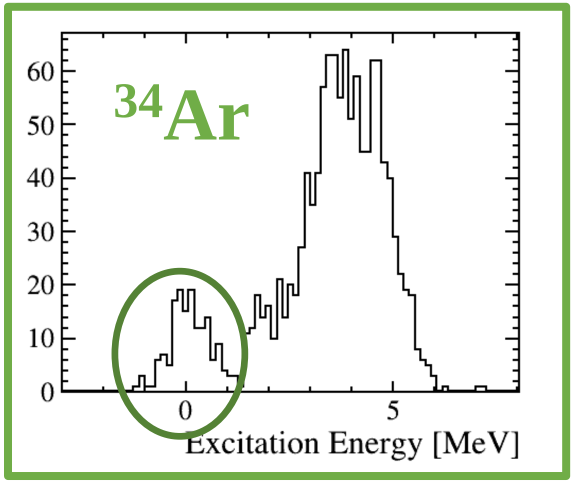
→ Masses are very well known

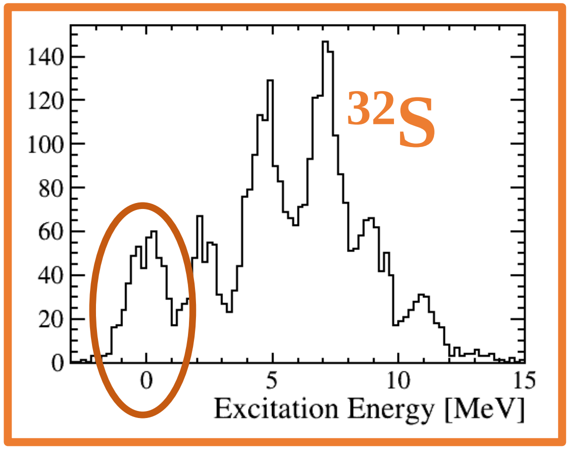
→ g.s. well separated from the first excited state

→ The energy range of deuton is similar from the reaction of interest

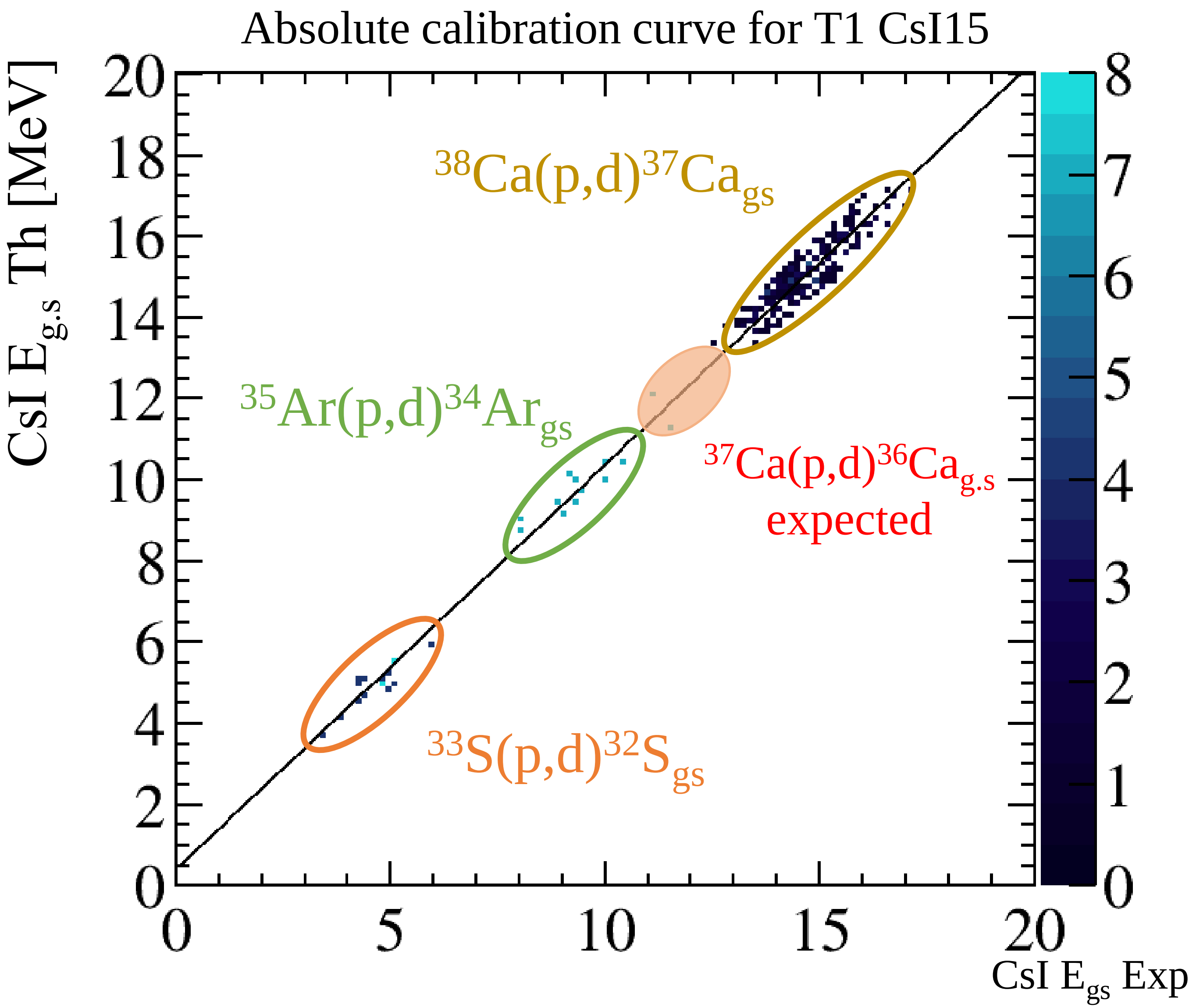
Absolute Calibration







To center ground states at 0 MeV, an absolute calibration has been performed using ground state of $^{38}Ca(p,d)^{37}Ca$, $^{33}S(p,d)^{32}S$ and $^{35}Ar(p,d)^{34}Ar$



Preliminary Results: $^{37}Ca(p,d)^{36}Ca$

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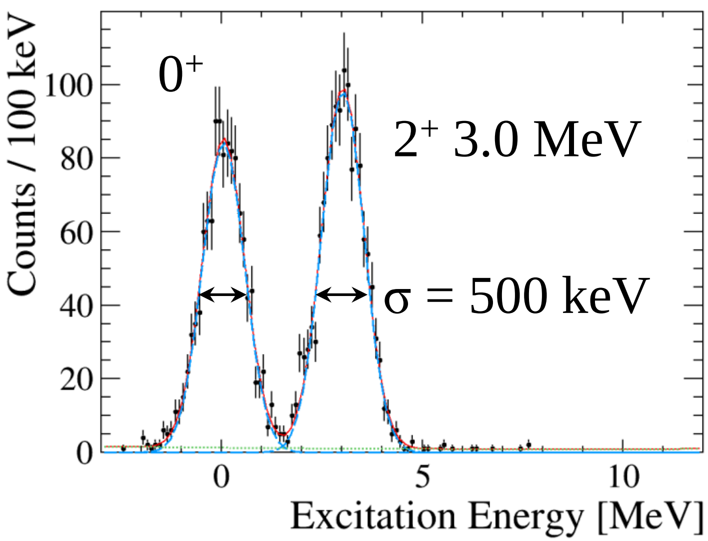

→ Good reconstruction of known states

→ Mass measurement with 40keV of precision in agreement with previous measurement

→ Sign for a 0^+_2 at 2.4MeV. To be confirm by the (p,t) channel.

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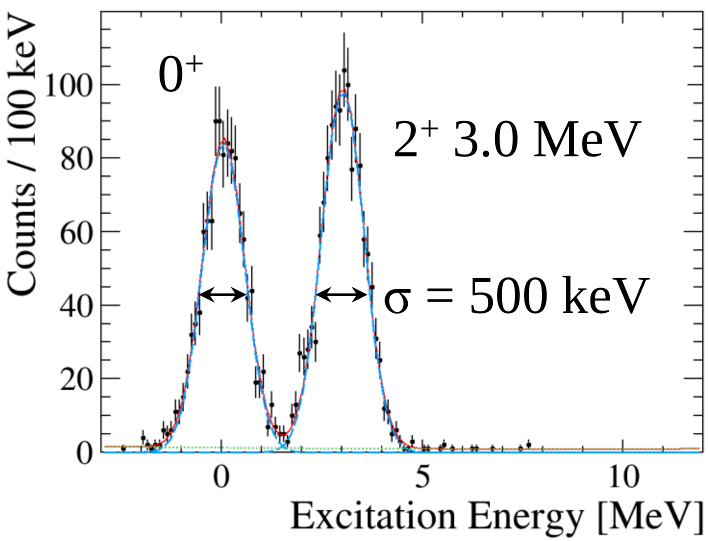
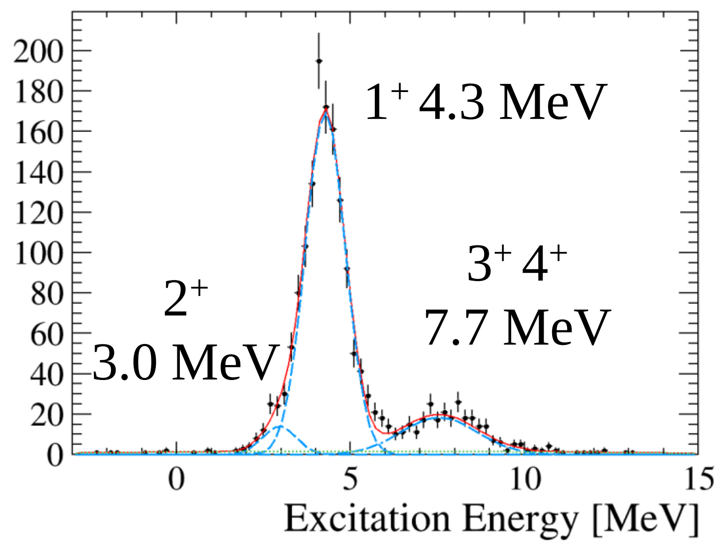


$^{36}Ca \rightarrow {}^{35}K + p$



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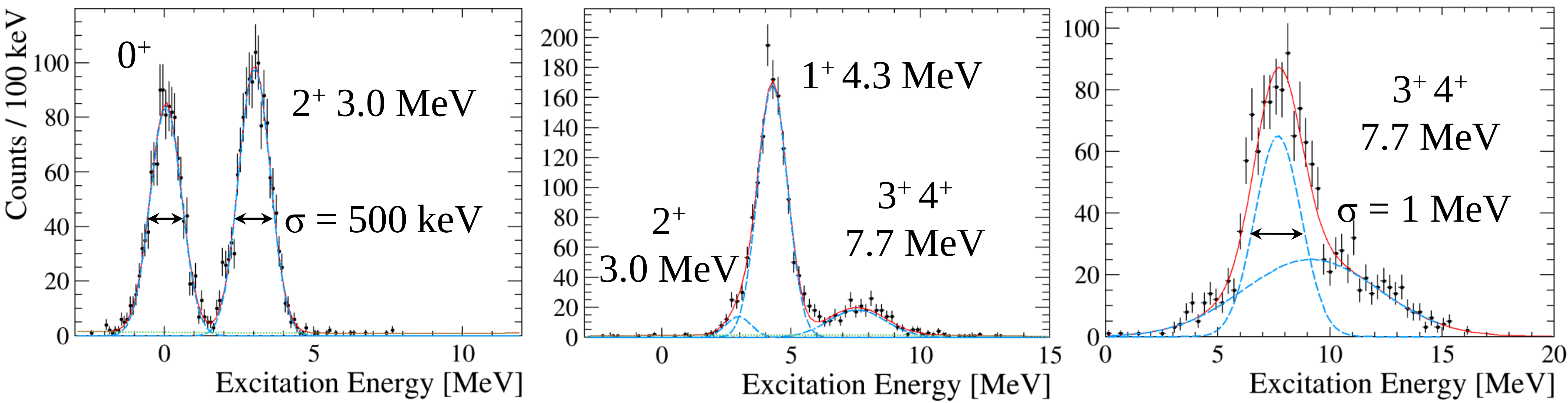
- → 2+ state decay by both γ and 1p. The $^{35}K(p,\gamma)^{36}Ca$ reaction rate can be constrained.
- → New 1+ state at 4.3 MeV
- → New 3+ 4+ doublet at 7.7MeV

Preliminary Results: $^{37}Ca(p,d)^{36}Ca$

$^{37}Ca(p,d)^{36}Ca$ | $^{36}Ca \rightarrow {}^{35}K + p$ | $^{36}Ca \rightarrow {}^{34}Ar + 2p$



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→ New 1+ state at 4.3 MeV

→ New 3+ 4+ doublet at 7.7 MeV

→ New 3+ 4+ doublet at 7.7 MeV in both 1p in 2p

→ Large resonance at 9.8 MeV

Perspective

- Study of the angular correlation of the two protons from the decay
- Angular distribution and shell model prediction to confirm the spin of the new state
- Same analysis will be performed on the ^{38}Ca(p,t)^{36}Ca channel
- Mass measurement and spectroscopy of ^{35}Ca with ^{37}Ca(p,t)^{35}Ca reaction
- Study of ^{36}Ca → ^{33}Cl + 3p and ^{36}Ca → ^{32}S + 4p