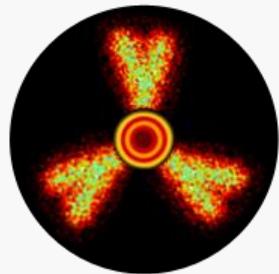
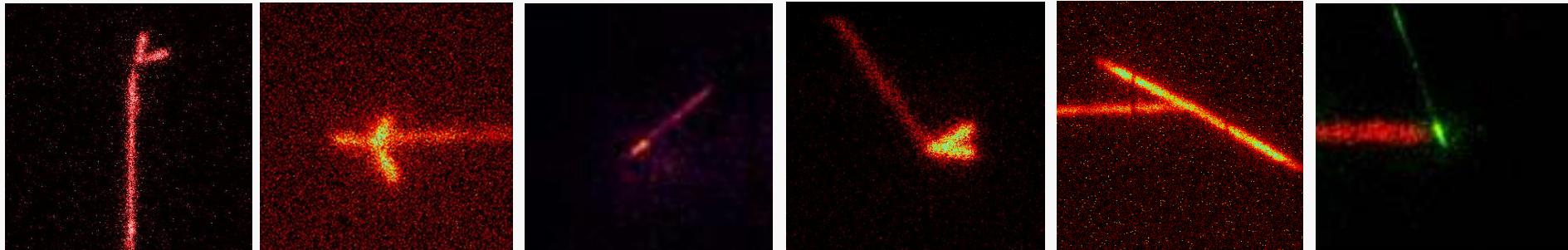


Charged-particle spectroscopy of exotic nuclei with the Optical TPC



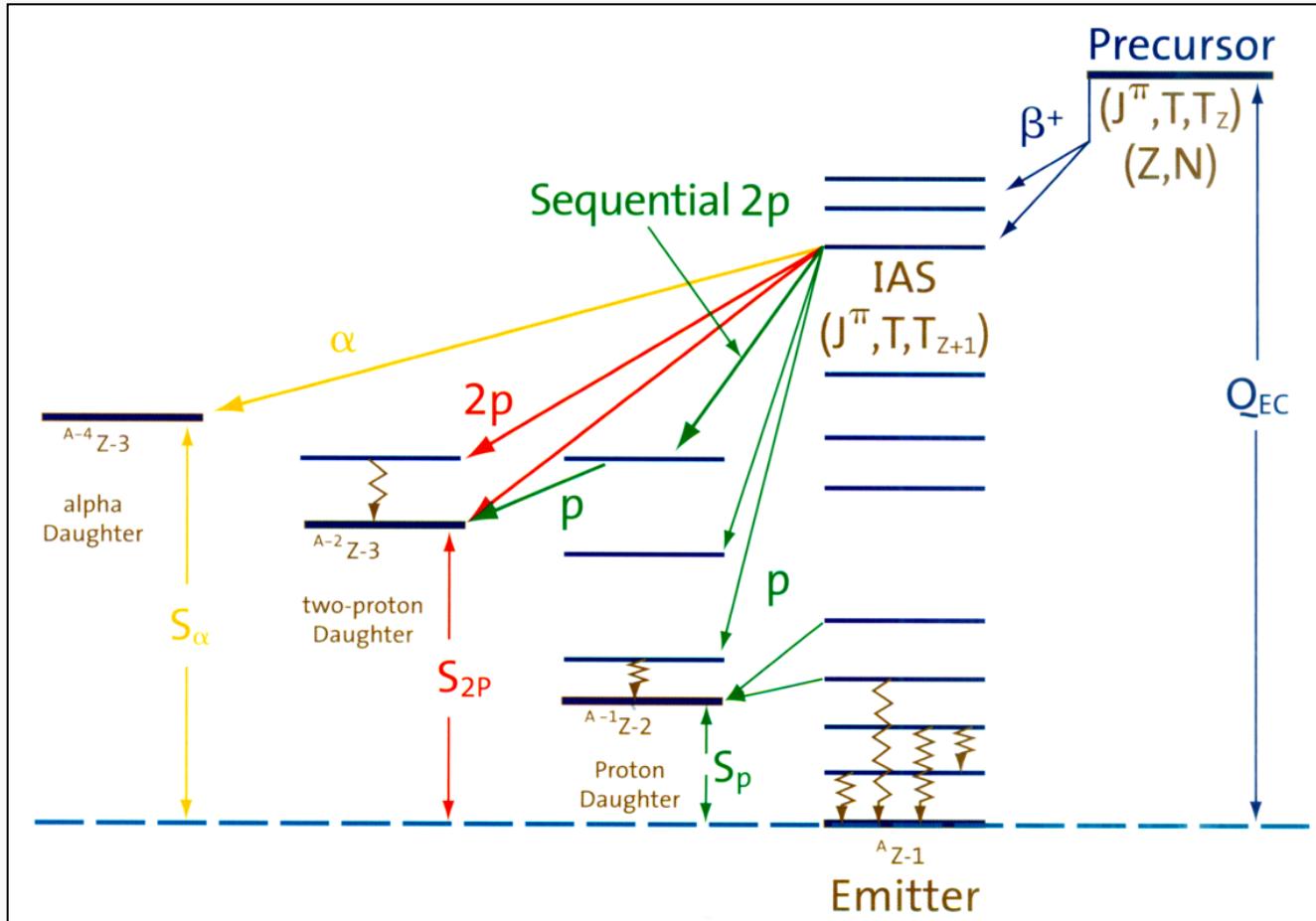
Marek Pfützner

Faculty of Physics, University of Warsaw



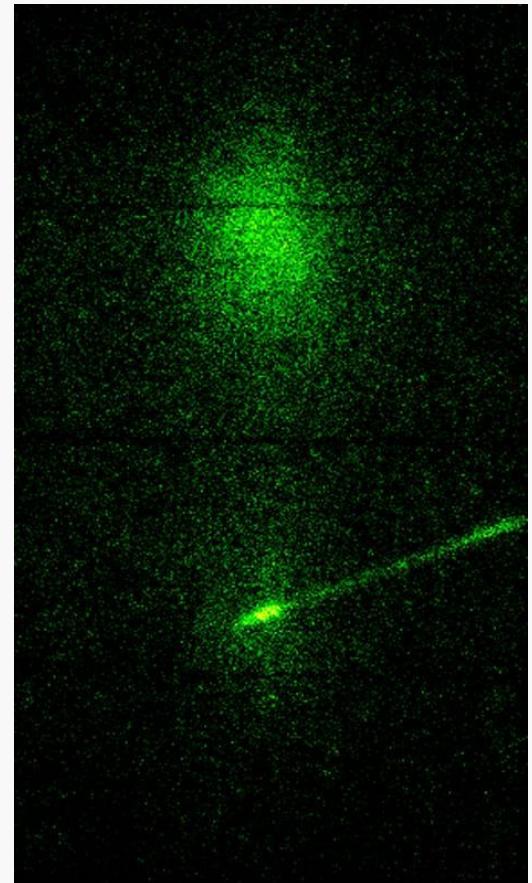
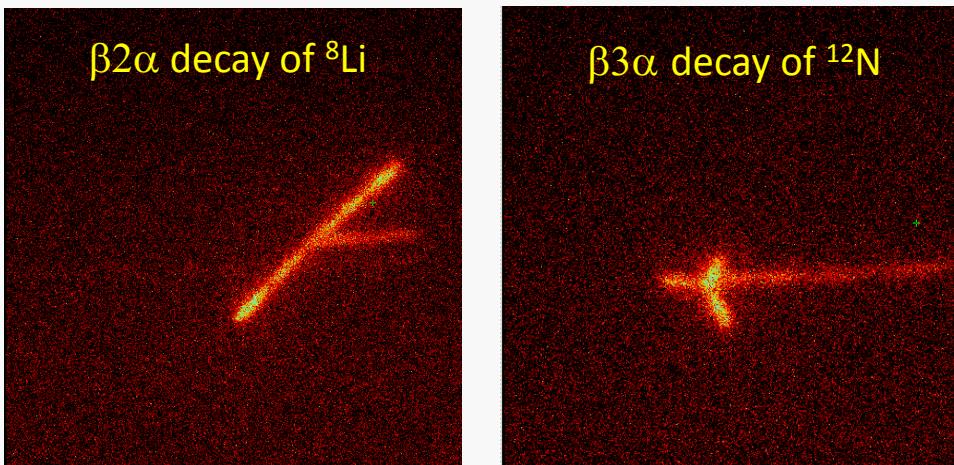
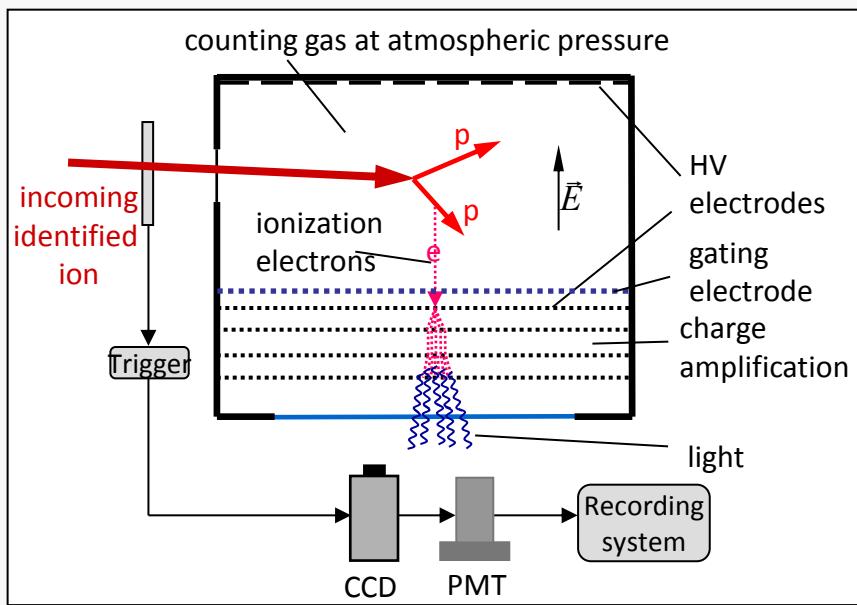
β -delayed particle emission

- When the β decay energy is large, many exotic channels are available



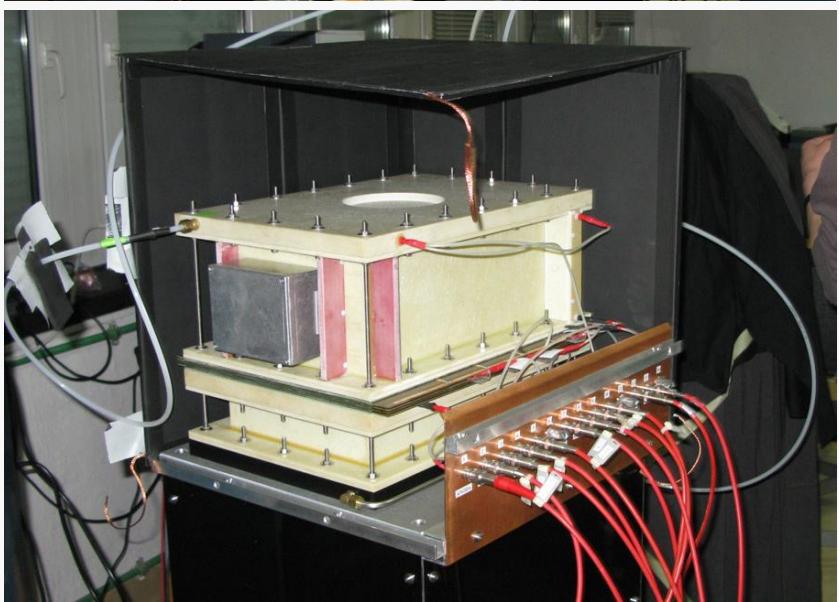
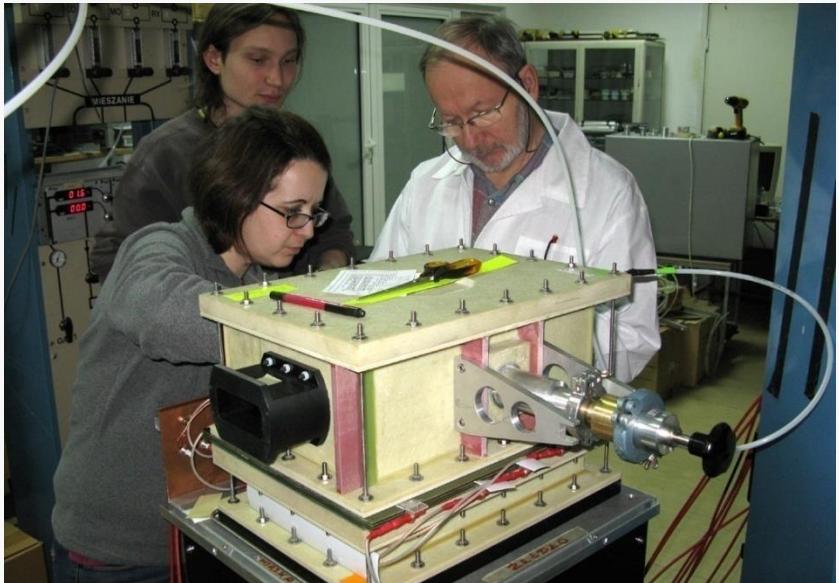
Blank and Borge, Progress in Part. Nucl. Phys. 60 (2008) 403

TPC with optical readout



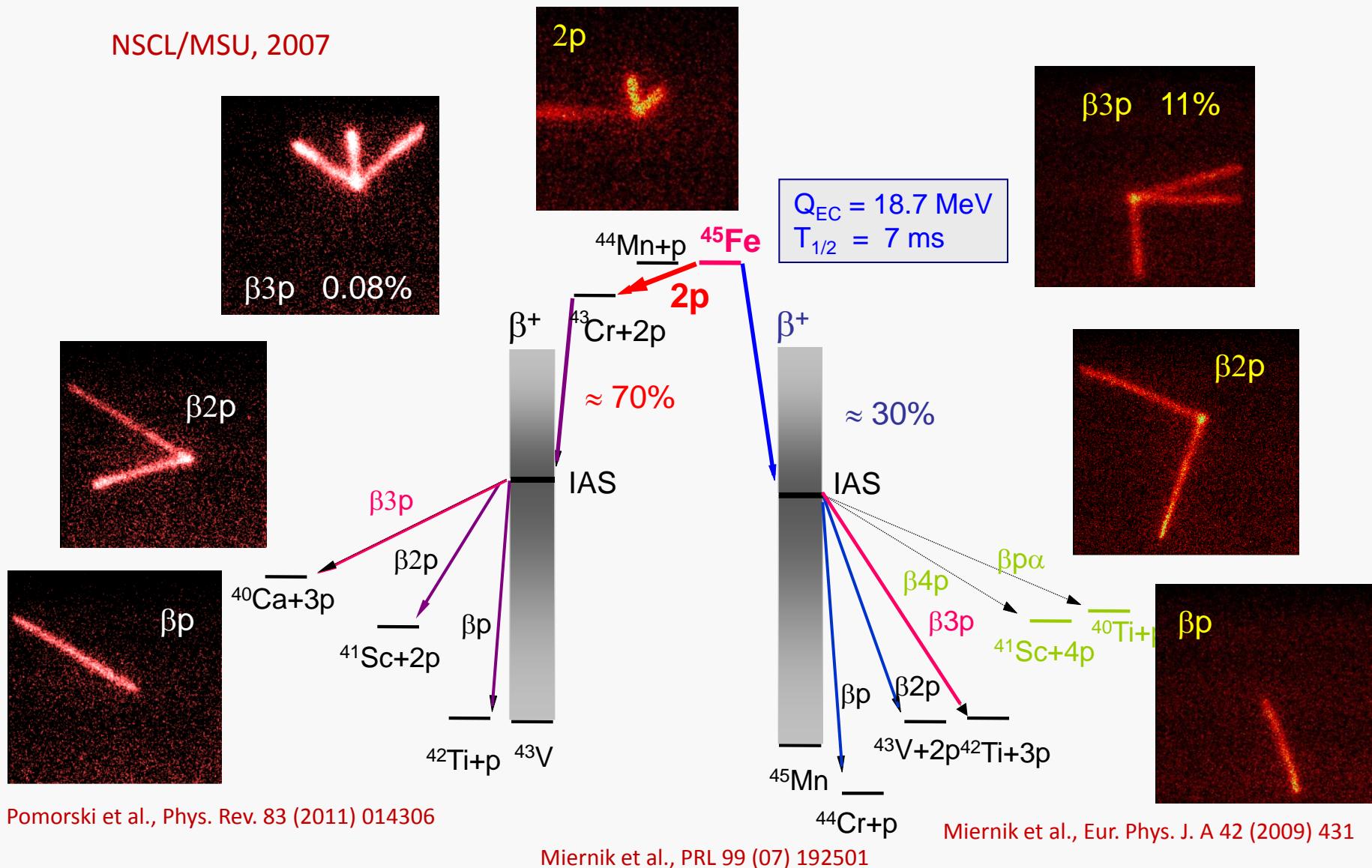
→ Decay event ${}^6\text{He} \rightarrow \alpha + d$
seen on the background of
about 10^4 beta rays

OTPC

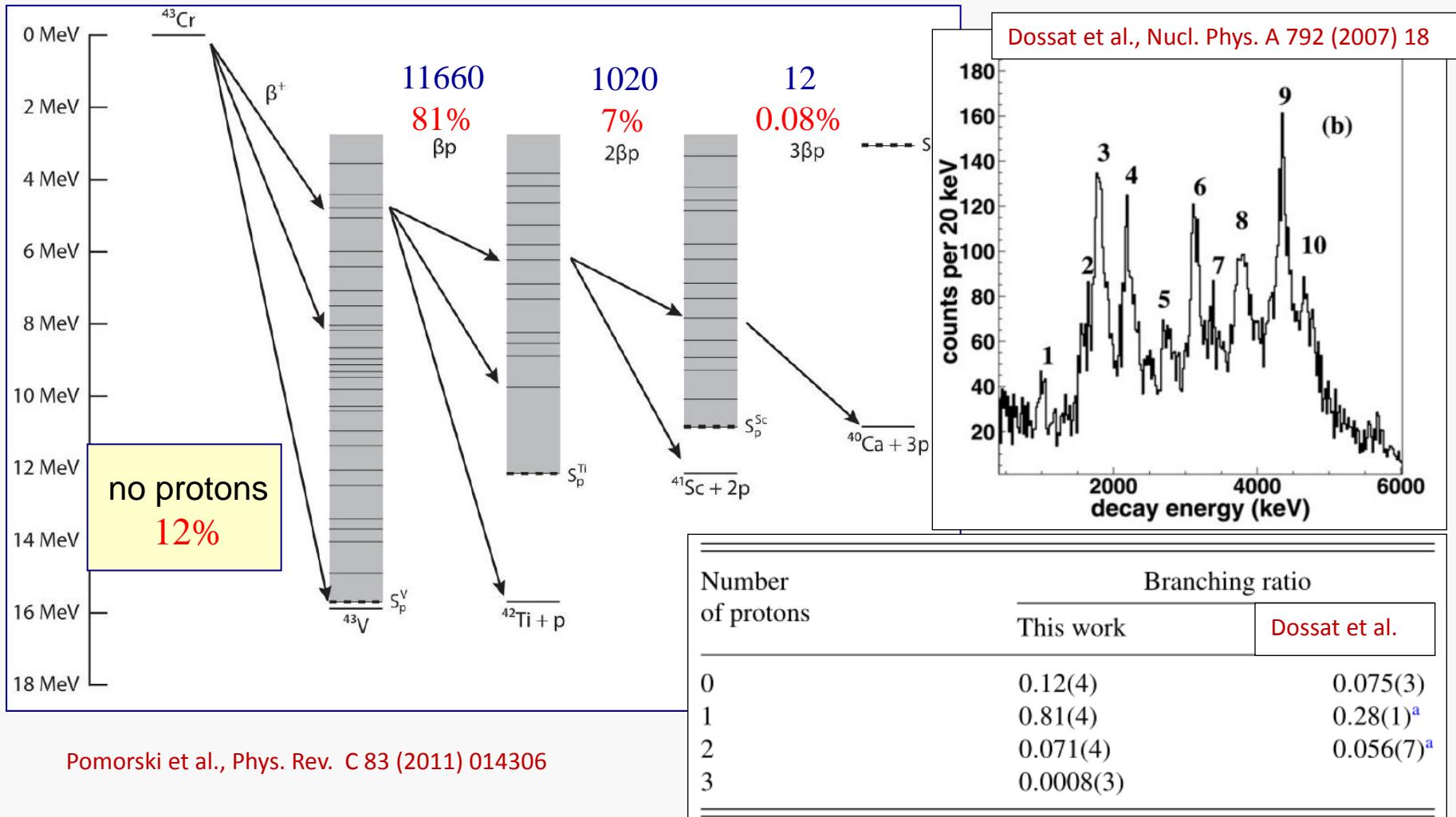


Decays of ^{45}Fe and ^{43}Cr

NSCL/MSU, 2007

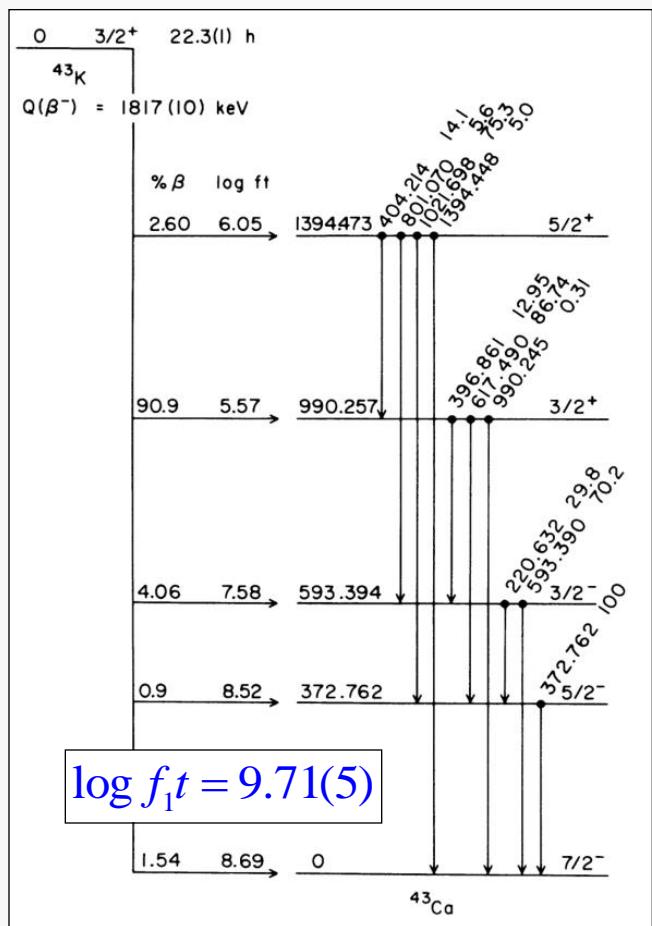


Decay channels of ^{43}Cr

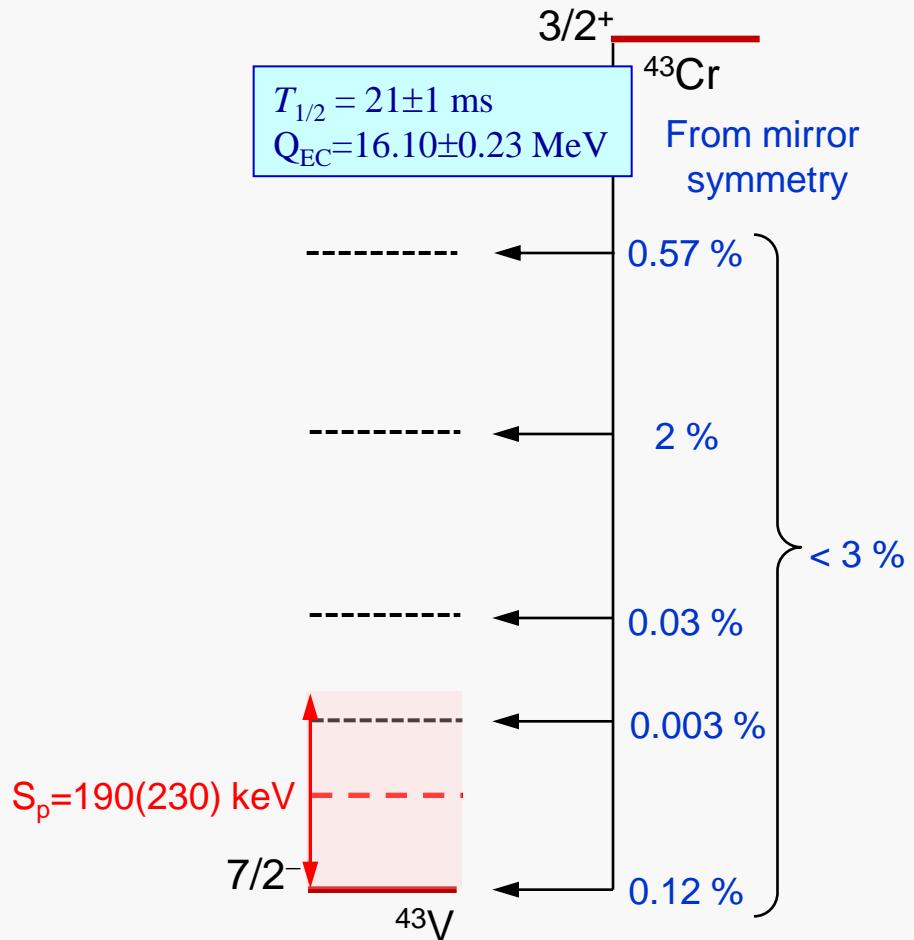


^{43}Cr puzzle

► 12% for the β -no-proton branch of in ^{43}Cr is surprisingly large!



Warburton & Alburger, Phys. Rev. C 38 (1988) 2822

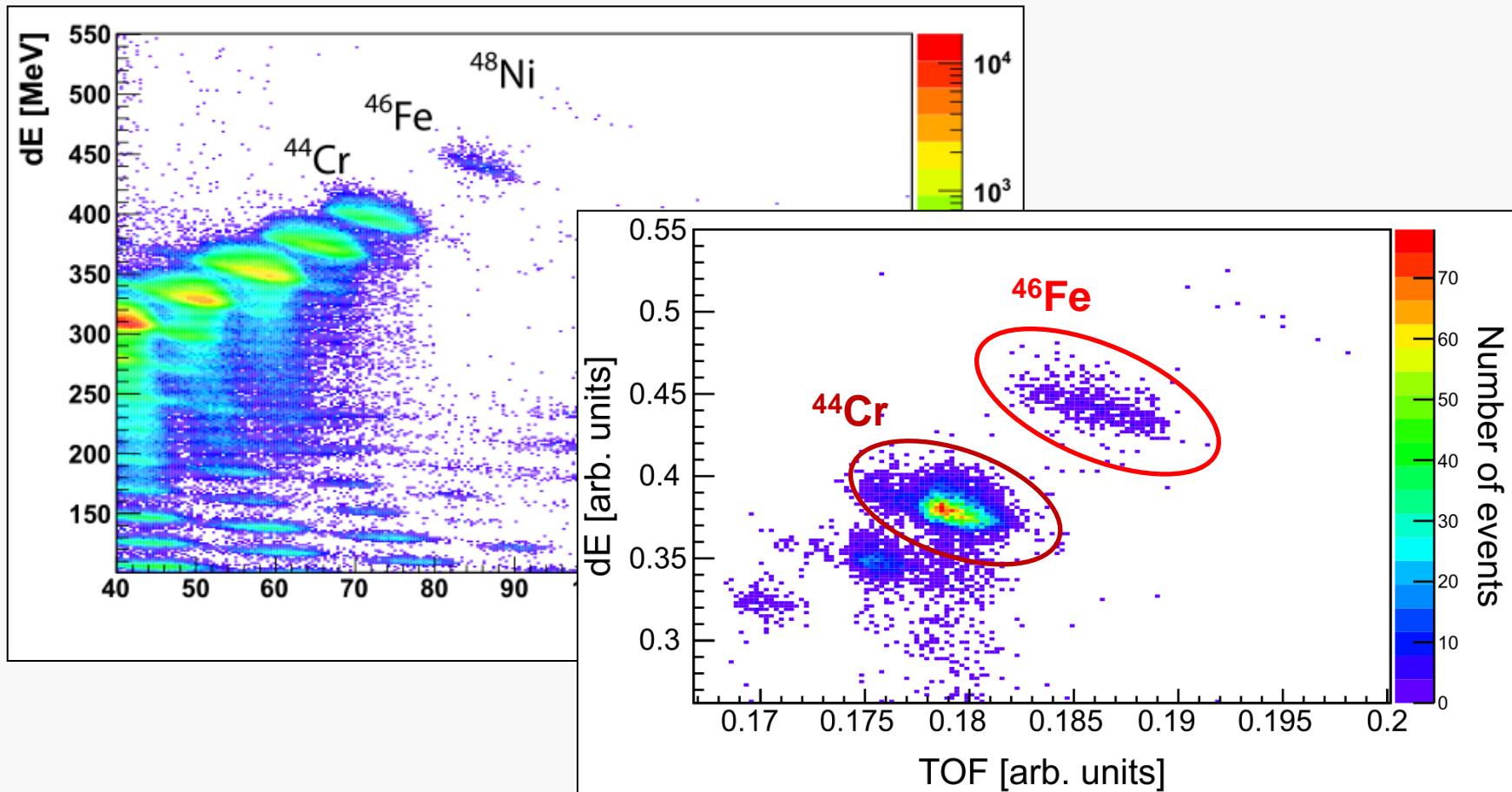


Pomorski et al., Phys. Rev. C 83 (2011) 014306

Study of ^{48}Ni

NSCL/MSU, 2011

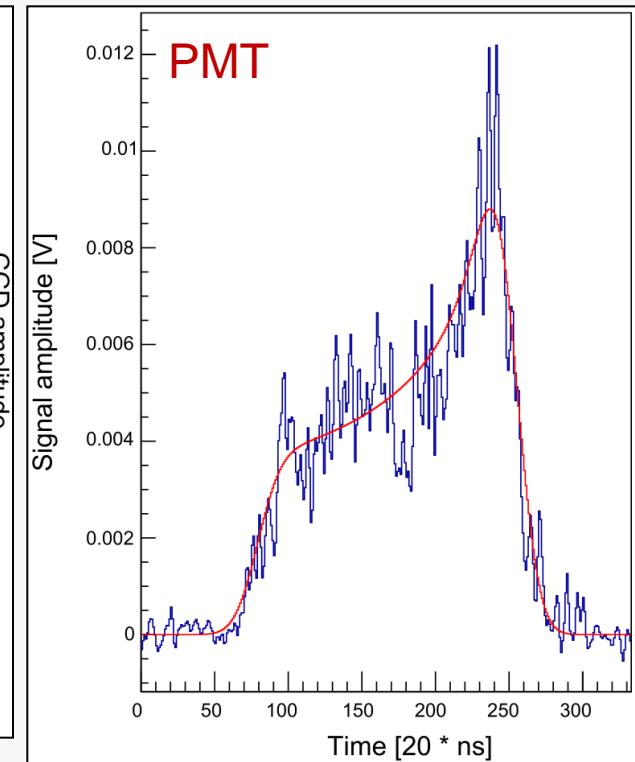
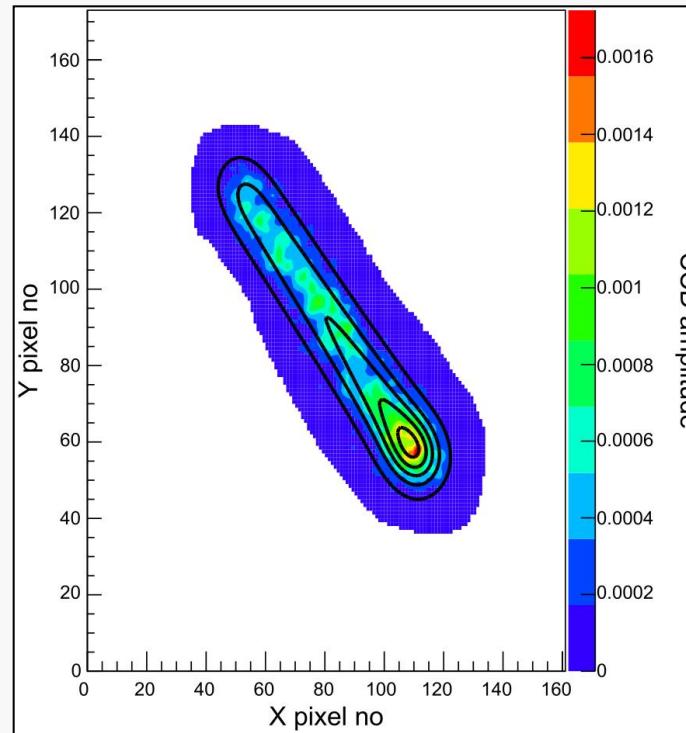
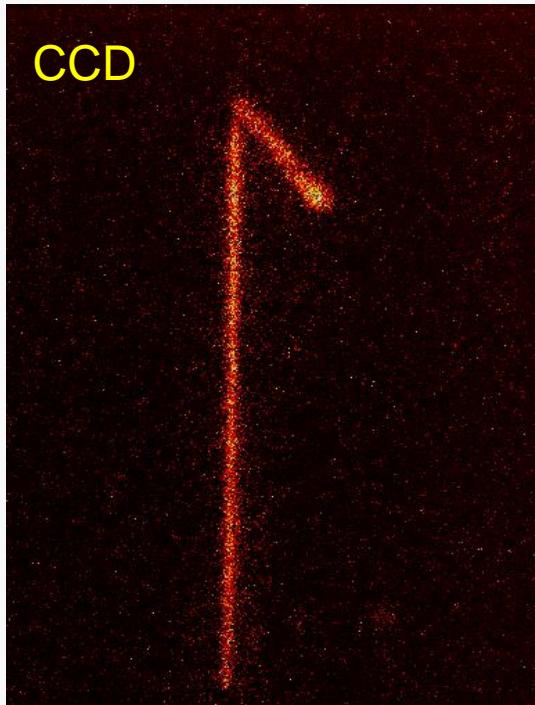
^{58}Ni @ 160 MeV/u + $^{\text{nat}}\text{Ni} \rightarrow ^{48}\text{Ni}$



Pomorski et al., PRC 83 (11) 061303(R)

Track reconstruction

► Example reconstruction of β -delayed proton from ^{44}Cr



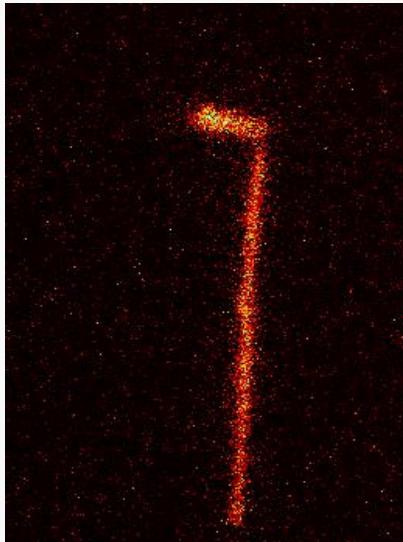
Pomorski et al., to be published

$$E_p = 1280 (30) \text{ keV}$$
$$\Theta = 24(4)^\circ$$

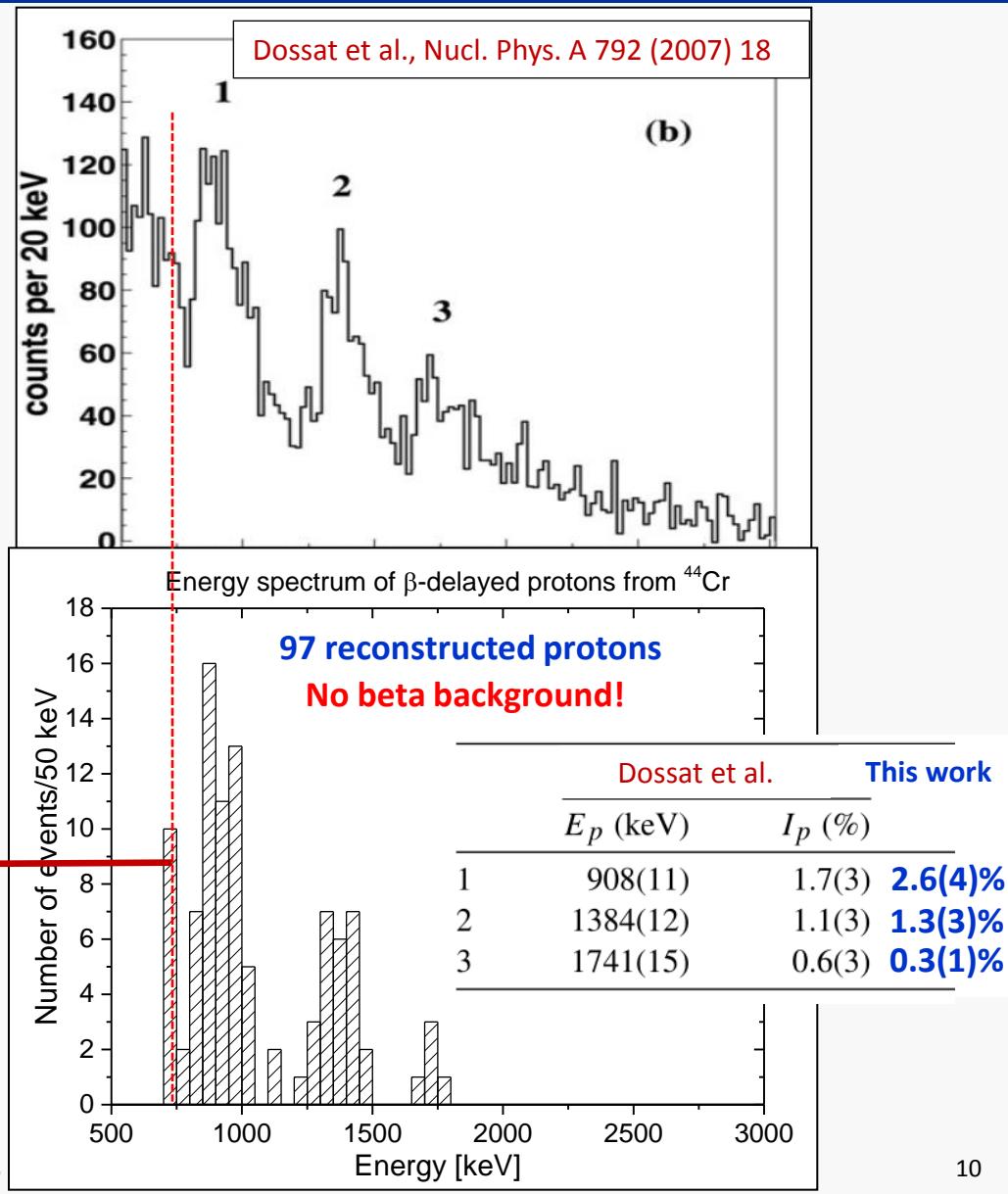
β -delayed protons from ^{44}Cr

5542 identified ions of ^{44}Cr
4098 properly stopped
210 decays observed
 $\rightarrow b_p = 10.3(8)\%$
Dossat : $b_p = 14.0(9)\%$

A clear new line at 730(20) keV
 $I_p = 0.5(2)\%$



Pomorski et al., to be published



β -delayed protons from ^{46}Fe

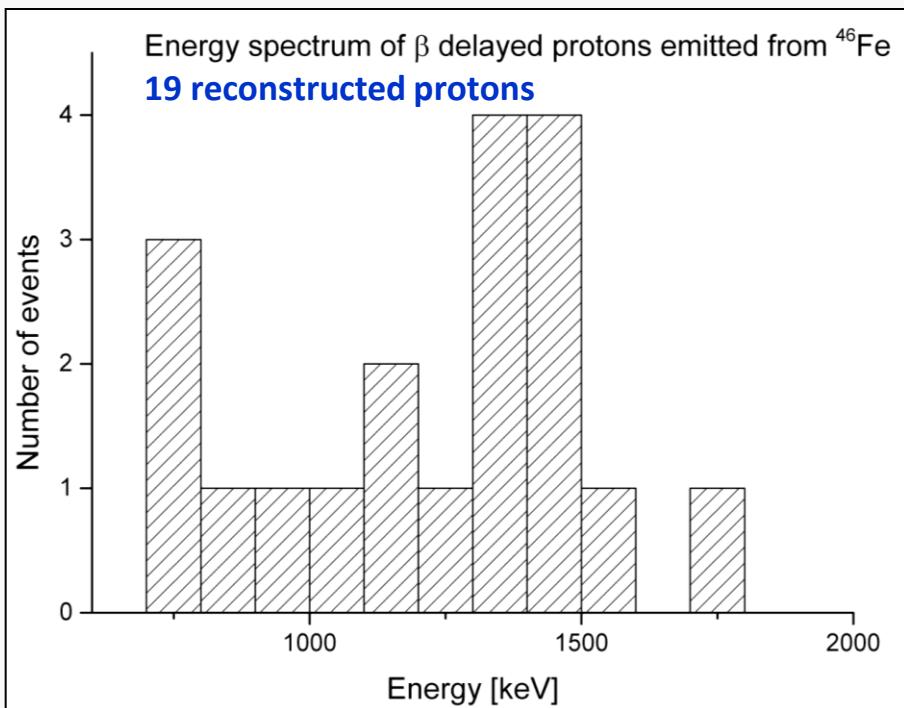
471 identified ions of ^{46}Fe

269 properly stopped

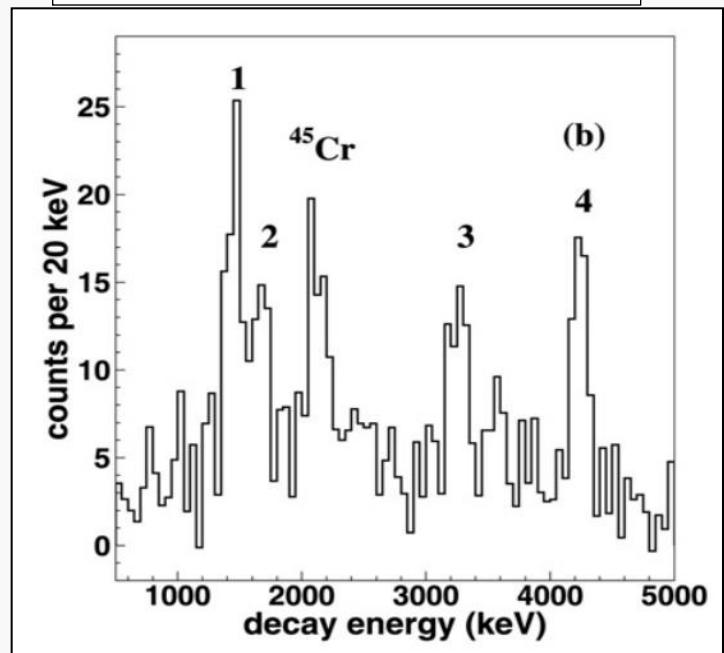
148 decays observed

$$\rightarrow b_p = 66(4)\%$$

Dossat : $b_p = 79(4)\%$

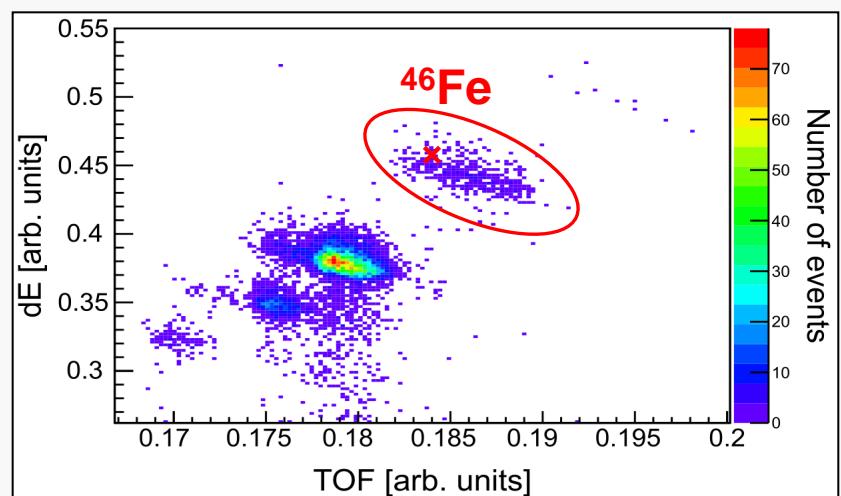
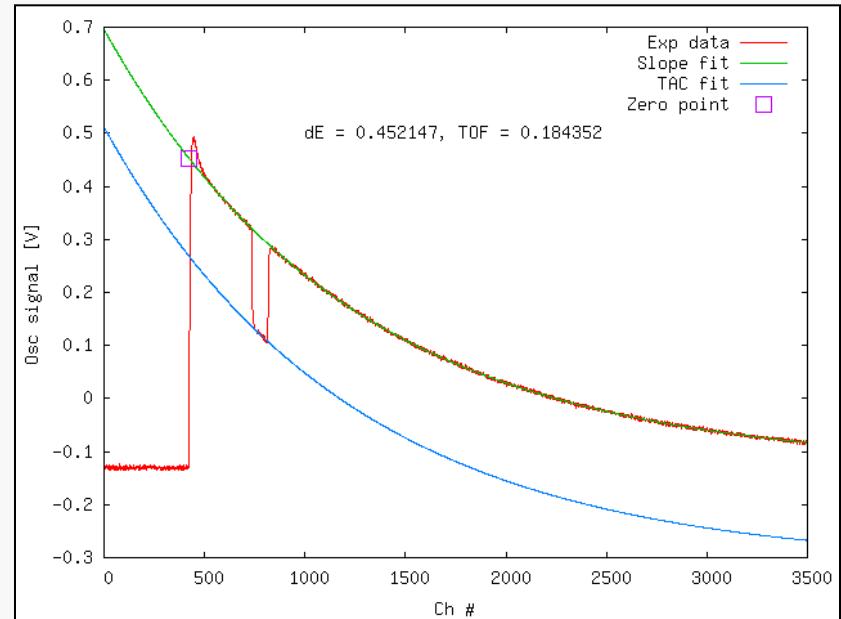
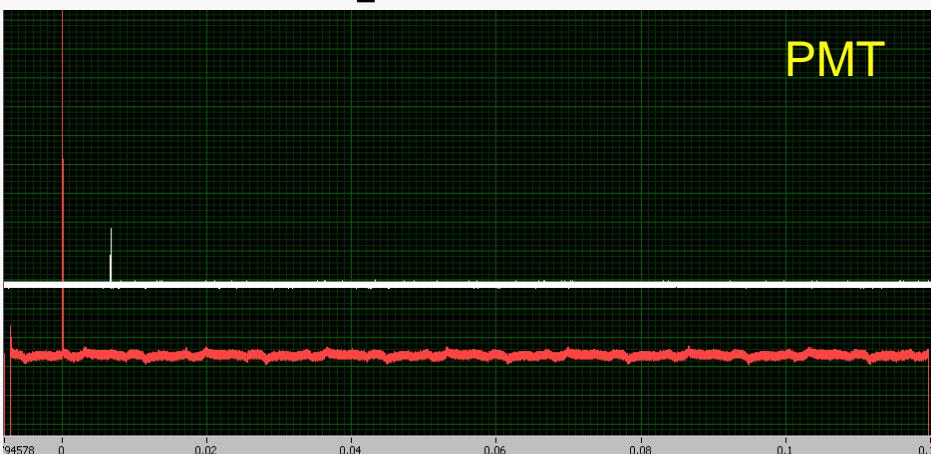
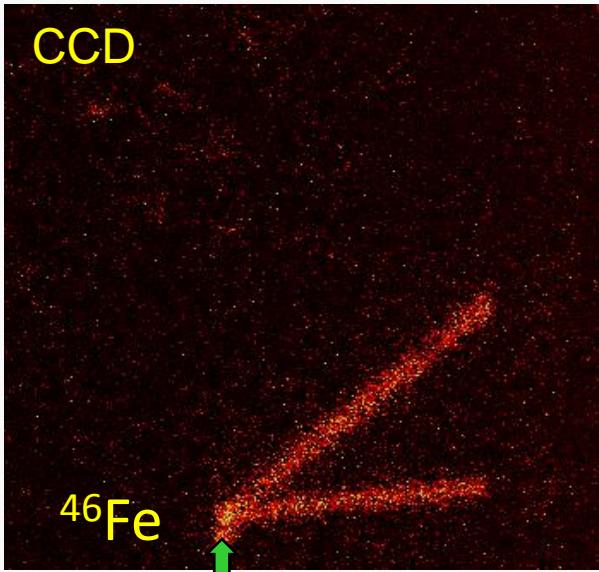


Dossat et al., Nucl. Phys. A 792 (2007) 18



β 2p channel in ^{46}Fe

► One good event!



β 2p channel in ^{46}Fe

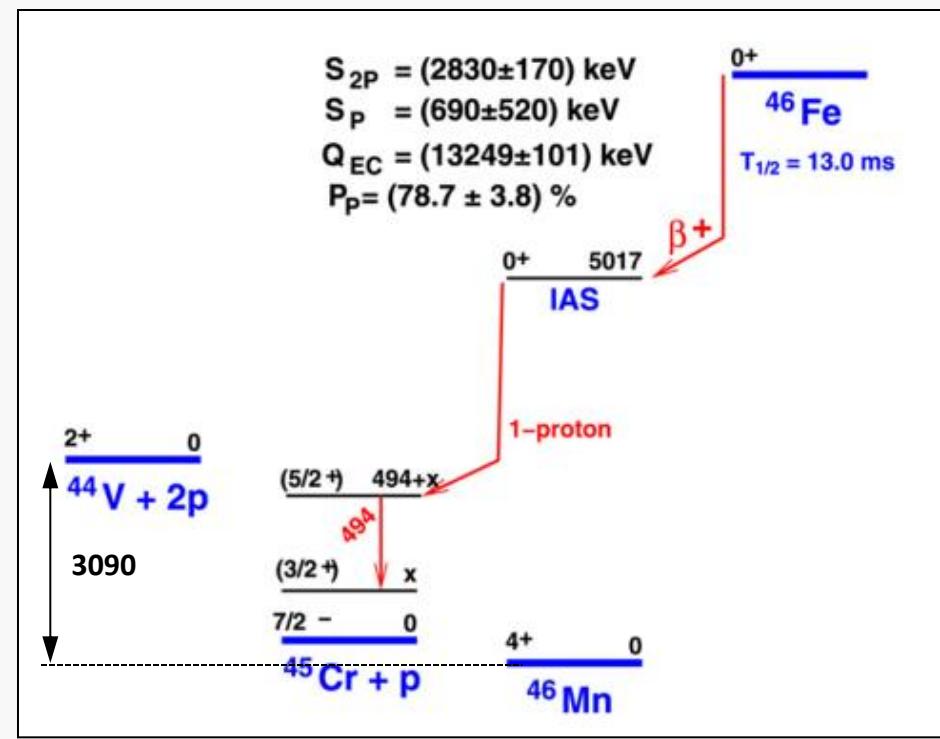
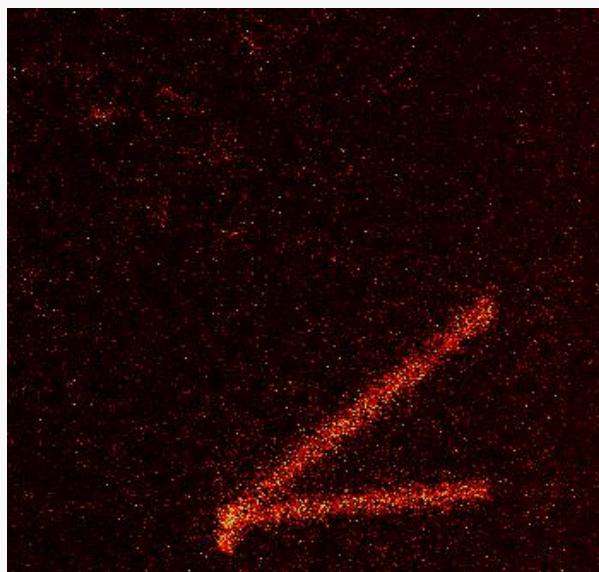
- Both protons escaped the detector. From the length of tracks we know only that:

$$E_1 > 1.9 \text{ MeV}$$

$$E_2 > 1.6 \text{ MeV}$$

$$E_1 + E_2 > 3.5 \text{ MeV}$$

This cannot go through the IAS!

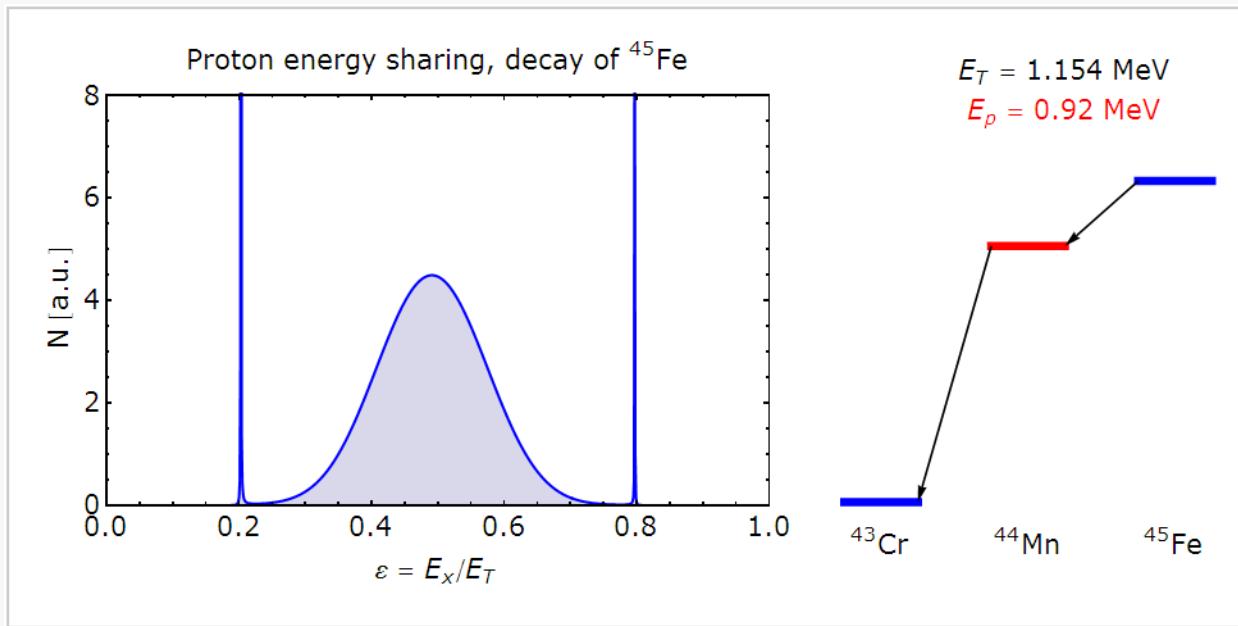


Pomorski et al., to be published

Dossat et al., Nucl. Phys. A 792 (2007) 18

Simultaneous vs. sequential

- ▶ In all cases investigated, the $\beta 2p$ emission proceeds sequentially.
In principle, however, both protons can go simultaneously.
- ▶ A simple direct model of 2p emission describes both mechanisms.



$Q_{2p} = 1.15 \text{ MeV}$, $Q_{1p} = 0.23 \text{ MeV}$ ➔ Both sequential and simultaneous modes visible.

- ▶ According to this model, as long as $Q_{1p} < 0.2Q_{2p}$ the simultaneous emission dominates.

β 3p in ^{31}Ar

PHYSICAL REVIEW C

VOLUME 45, NUMBER 1

JANUARY 1992

Decay modes of ^{31}Ar and first observation of β -delayed three-proton radioactivity

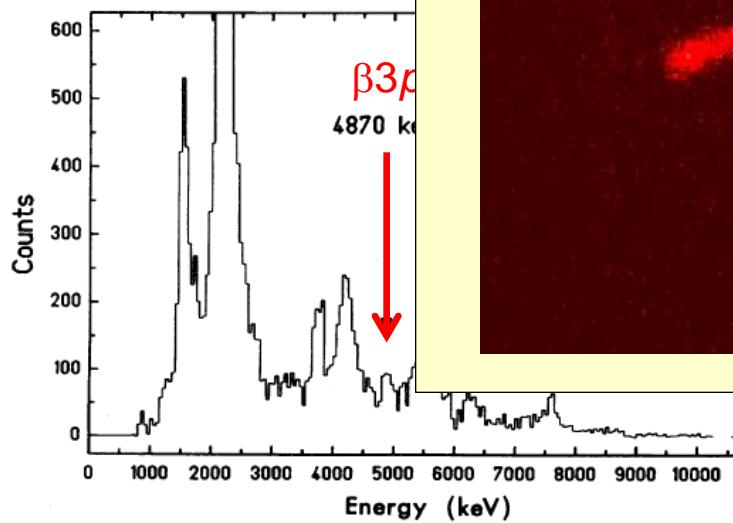
D. Bazin,* R. L.

Centre d'Etudes Nucléai

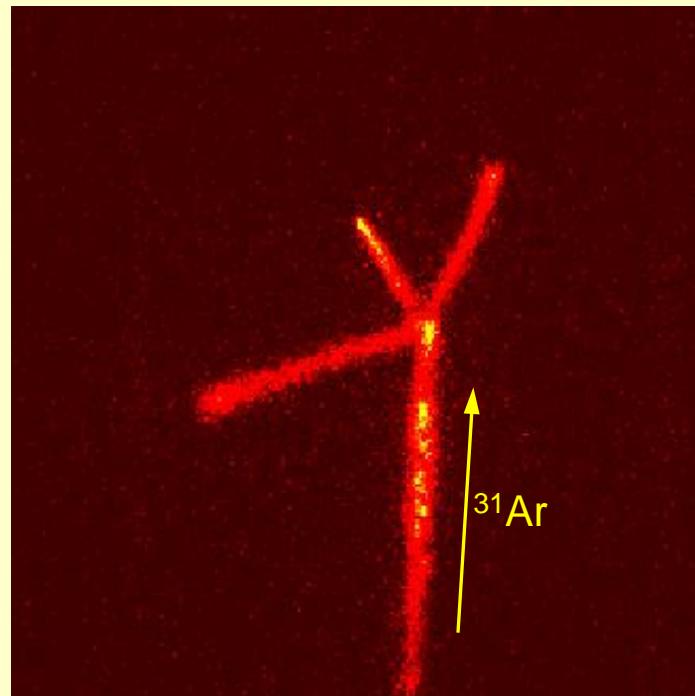
PHYSICAL REVIEW C

^{31}Ar exami

H. O. U. Fynbo,¹ L. Axelsson,²
A. Jokinen,³ B. Jonson,² I. Martel,
M. H. Smedb

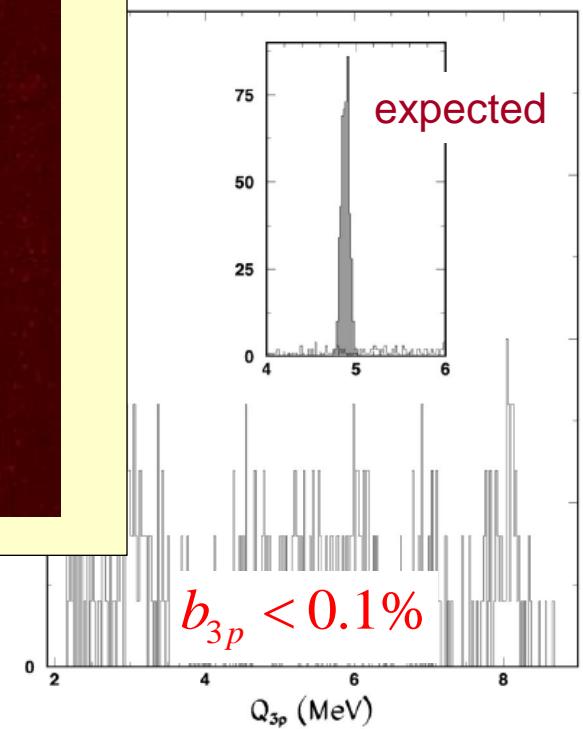


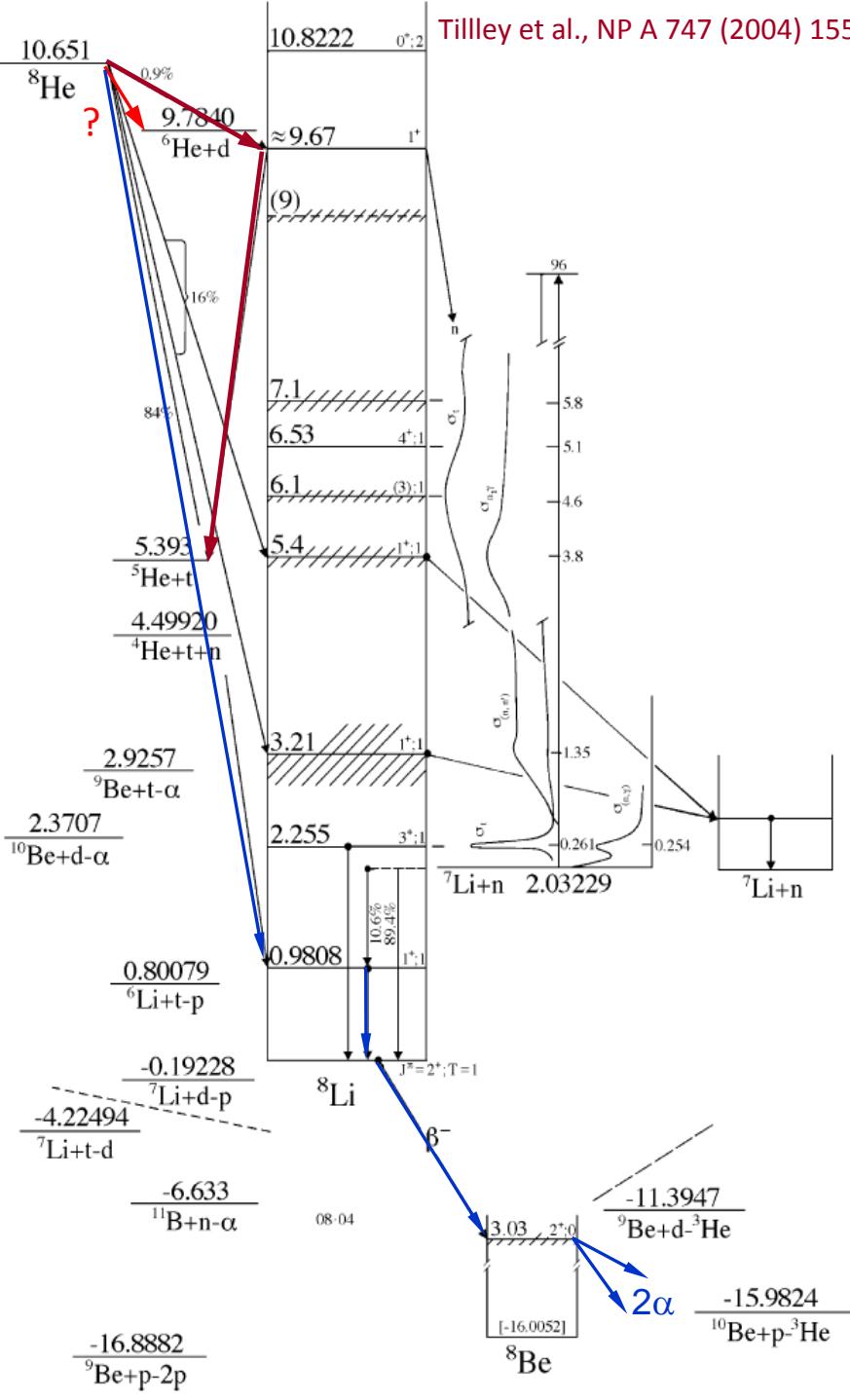
► Experiment at FRS, August 2012



France

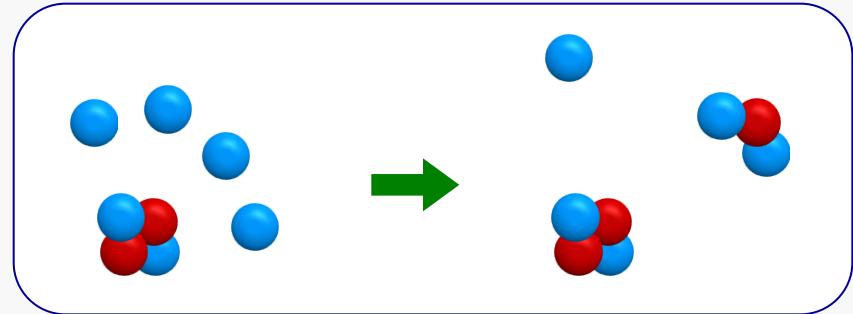
APRIL 1999





β decay of ^8He

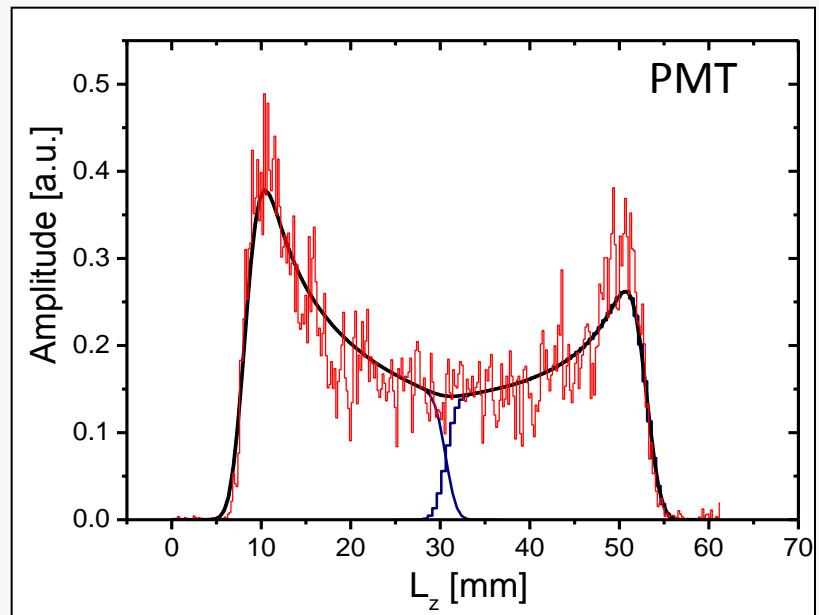
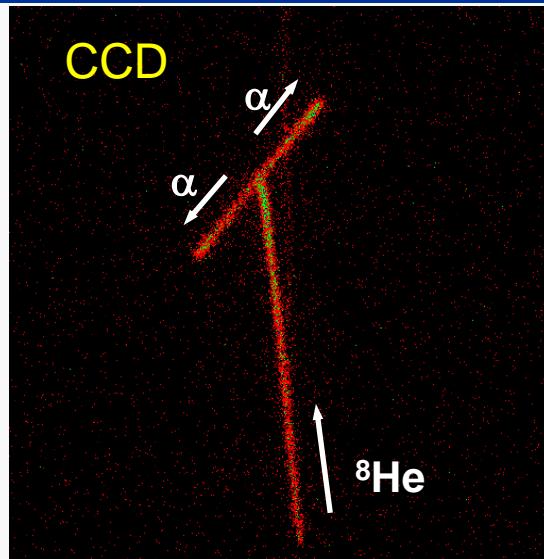
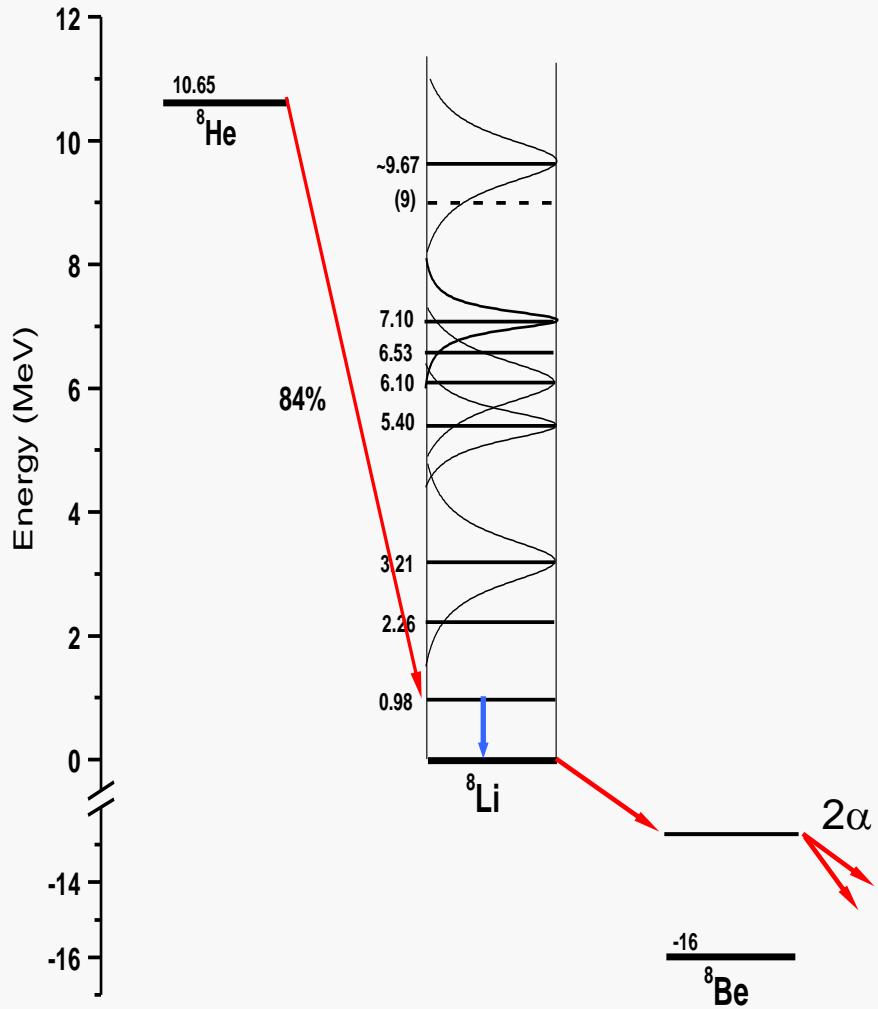
- The previous experiment on ^8He β decay :
ISOLDE (1992)
M. Borge et al., NP A 560 (1993) 664
- Observation of strong β -delayed triton channel
$$^8\text{He} \rightarrow ^8\text{Li}^* \rightarrow \alpha + \text{t} + \text{n}$$
- The branching: $(8.0 \pm 0.5) \times 10^{-3}$
- $B_{\text{GT}} \geq 5.2$, $\log ft = 2.9$!



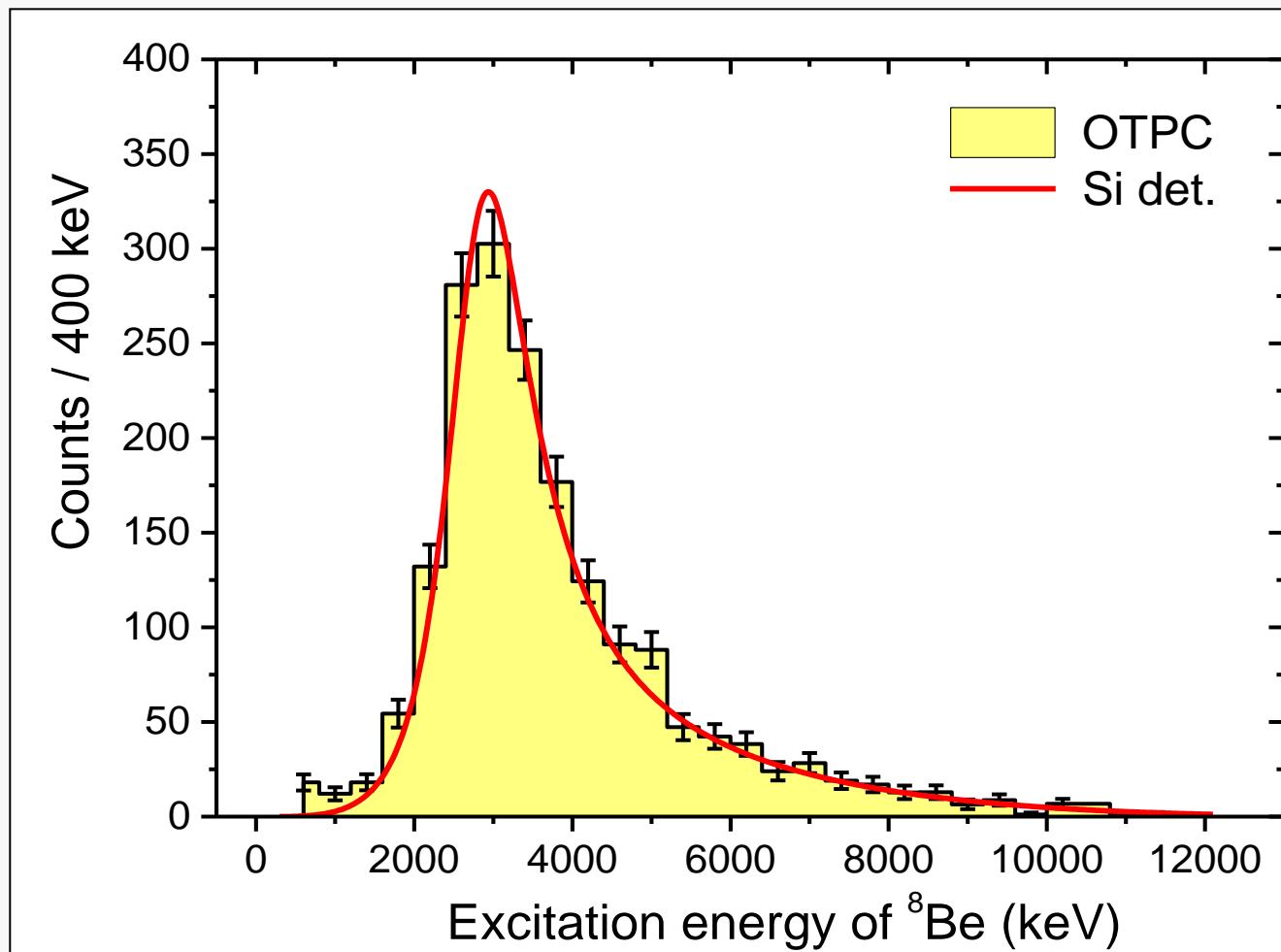
- Essentially, this is the tetra-neutron decay to a triton and a neutron! (If the clustering approximation is the good one).

Decays to particle bound states of ${}^8\text{Li}$

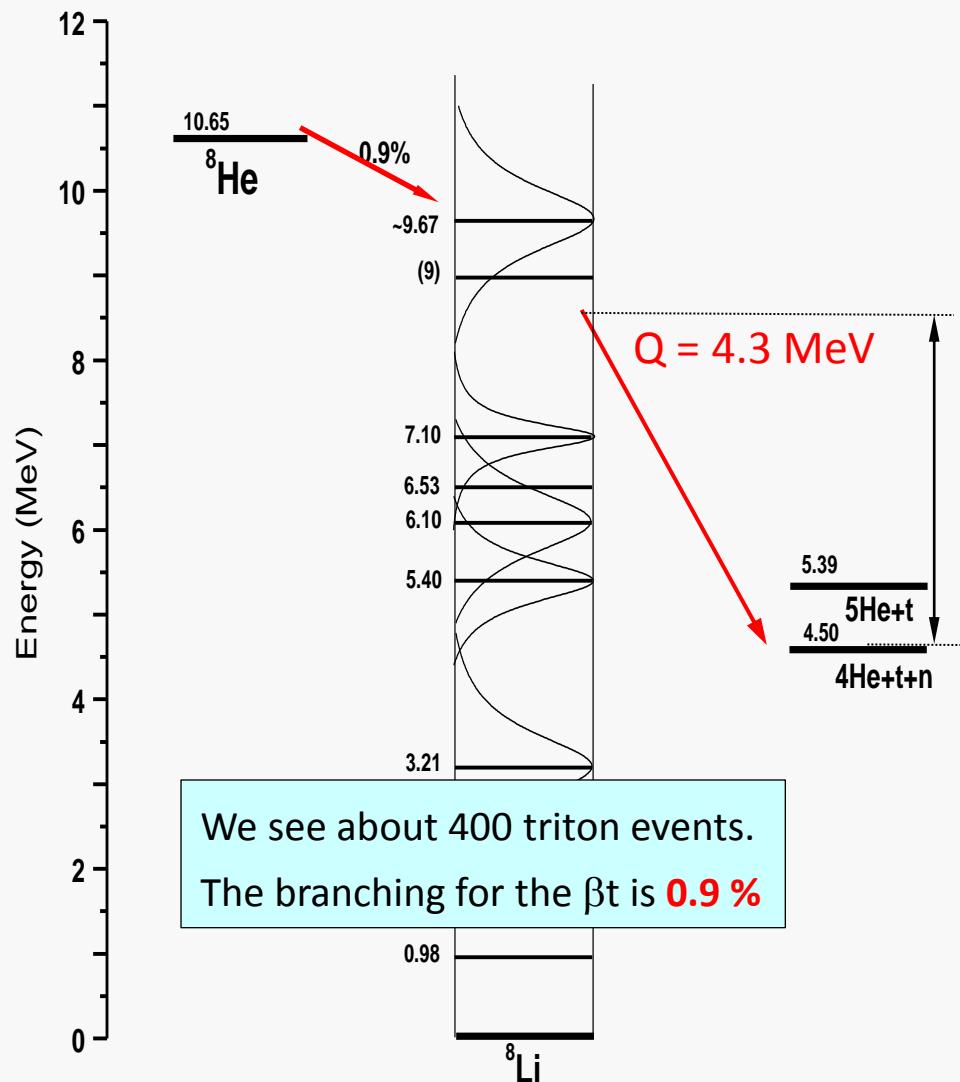
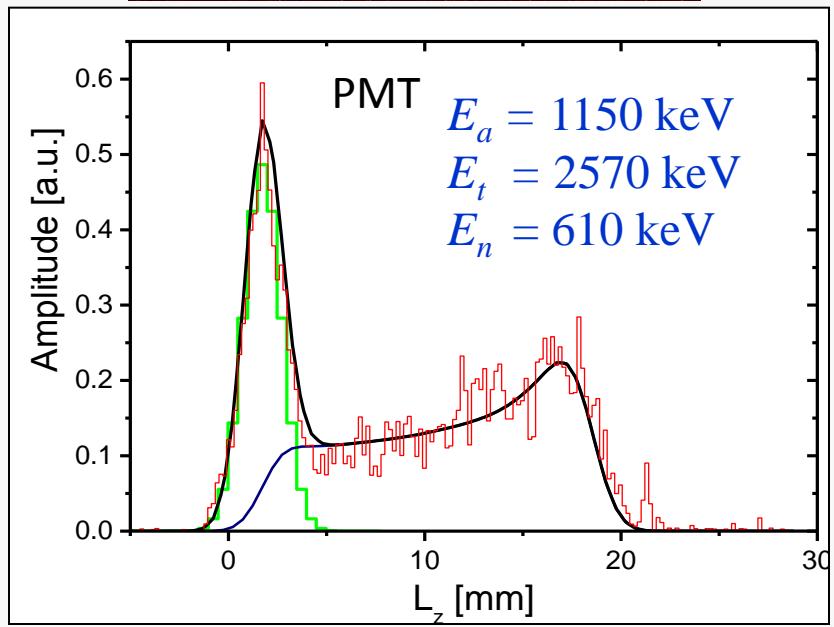
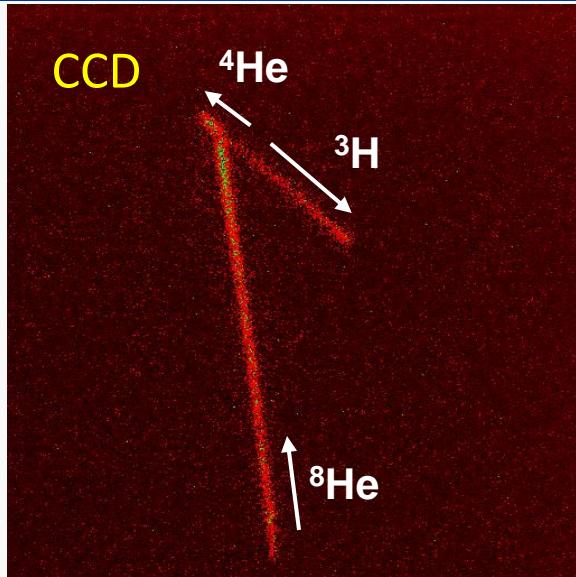
Dubna, Acculinna, 2009/2012



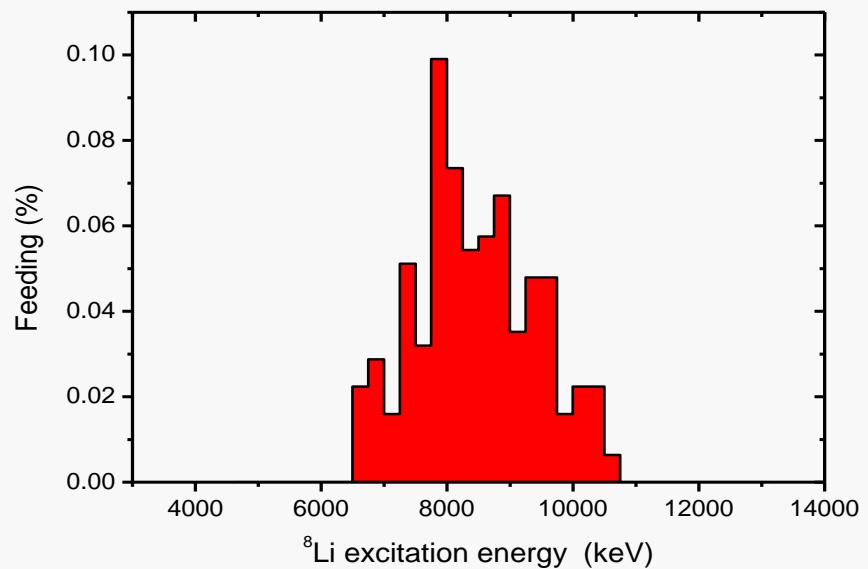
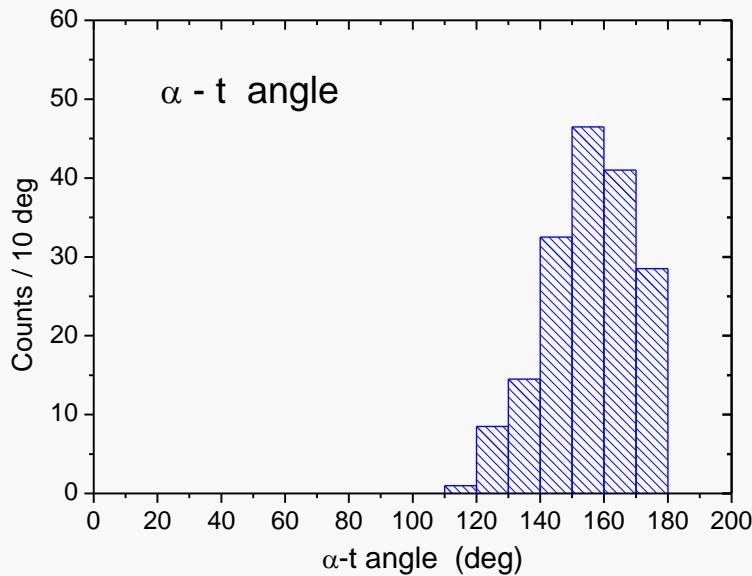
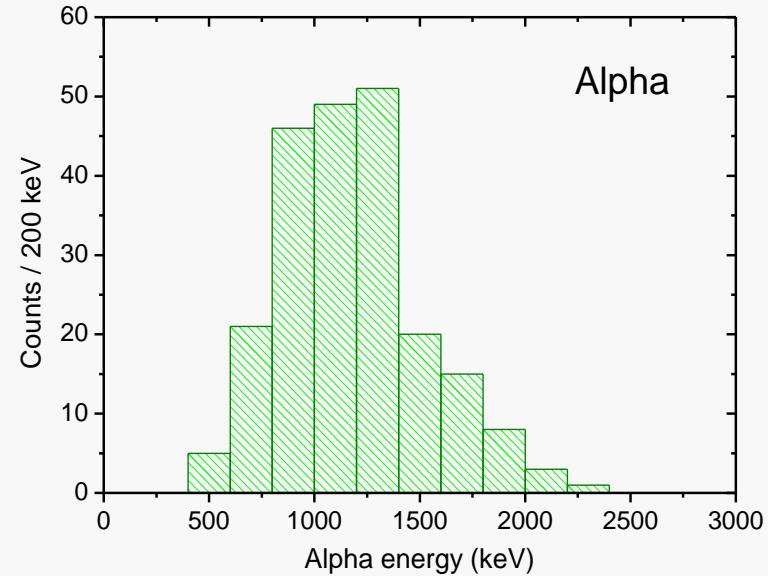
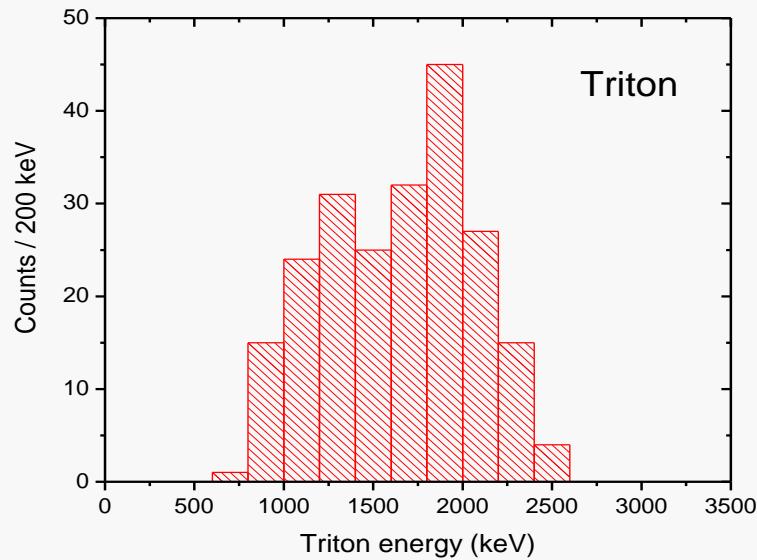
Final-state continuum in ${}^8\text{Li} \rightarrow 2\alpha$ decay



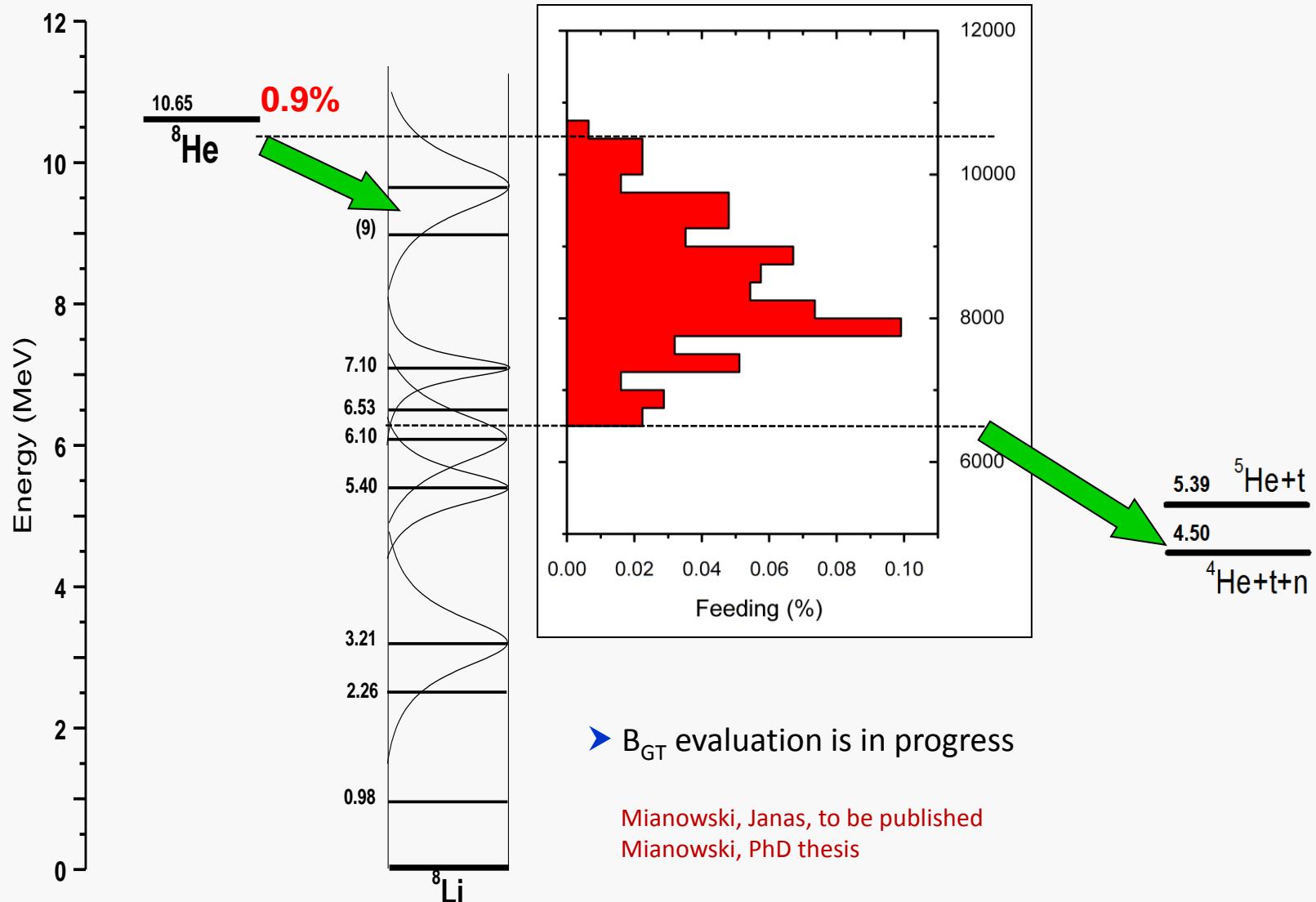
Reconstruction of α -t-n decay event



Feeding of α -t-n decaying states

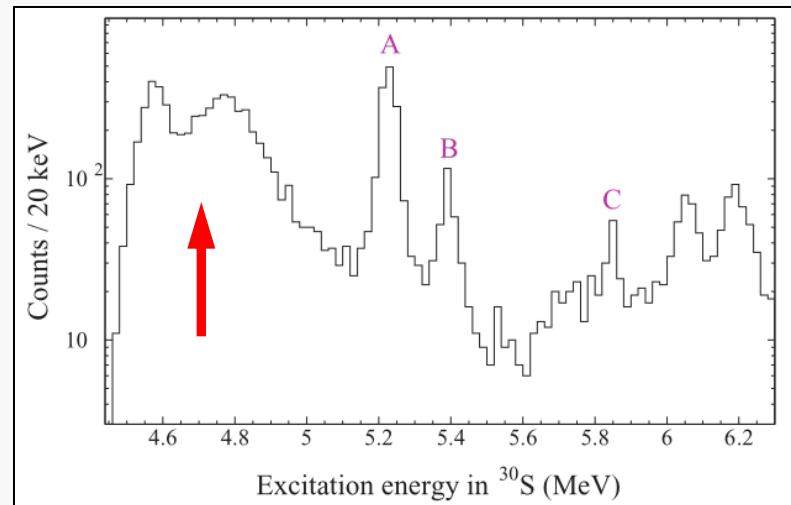
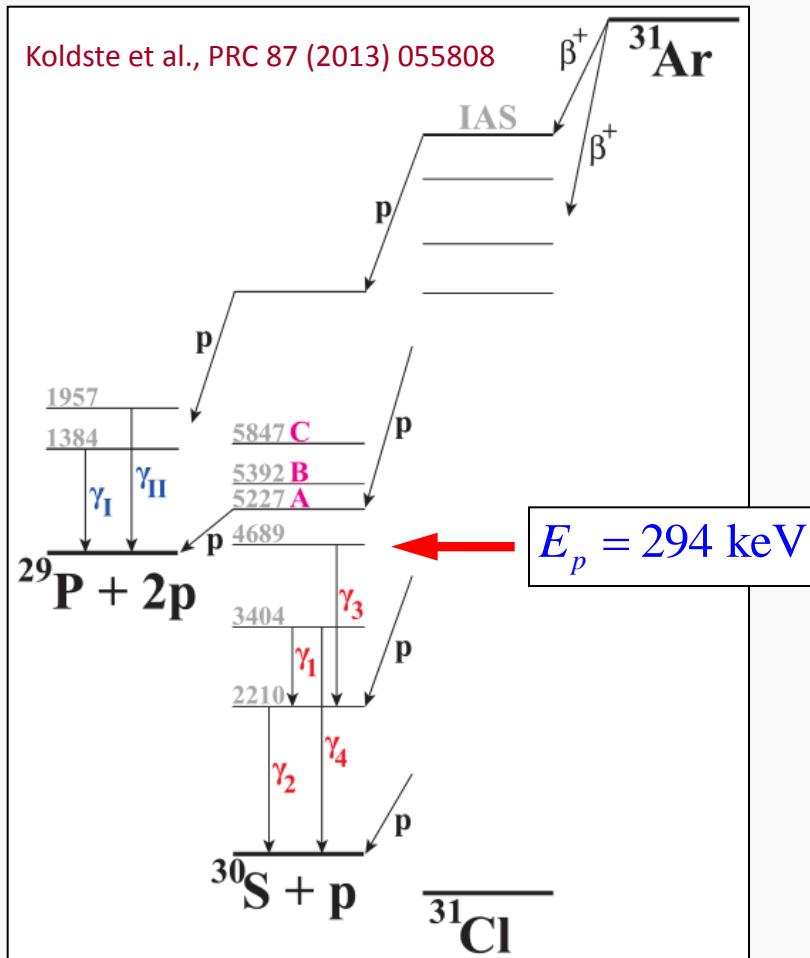


Feeding of α -t-n decaying states



Study of $^{29}\text{P}(\text{p},\gamma)$ via ^{31}Ar β 2p

- There is astrophysical interest in the reaction rate of $^{29}\text{P}(\text{p},\gamma)^{30}\text{Si}$. The proton width of the relevant states above $^{29}\text{P}+\text{p}$ threshold can be studied by β 2p decay of ^{31}Ar

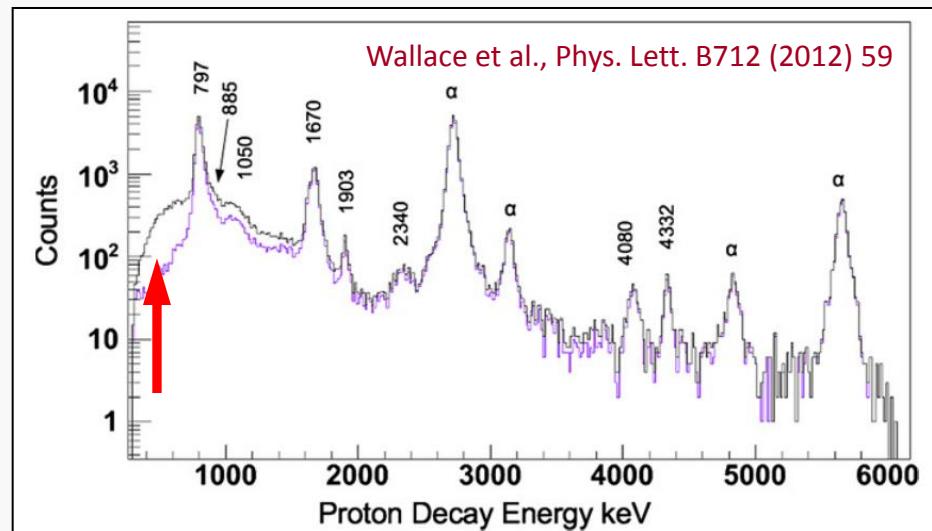
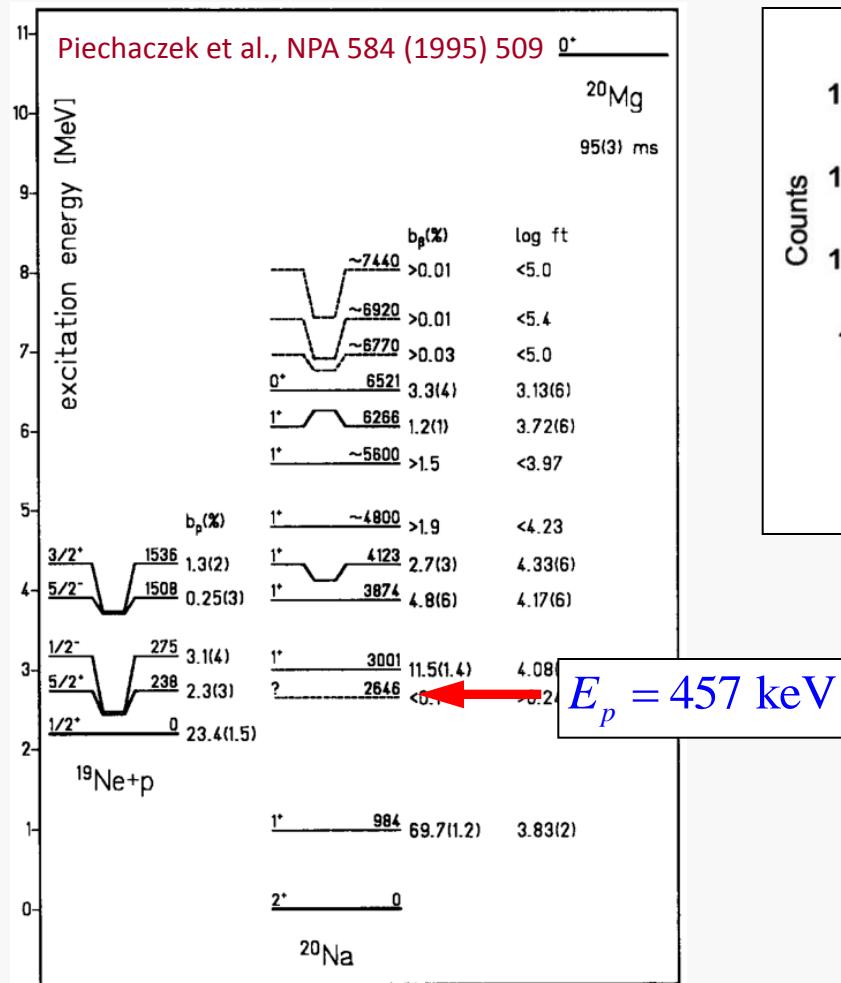


- Very hard to identify 300 keV line because of β -background and noise.
- OTPC offers a straightforward and clean method to detect such a transition

Proton ranges in pure helium:
 $300 \text{ keV} \rightarrow R = 20 \text{ mm}$
 $830 \text{ keV} \rightarrow R = 100 \text{ mm}$

Search for $^{19}\text{Ne}(\text{p},\gamma)$ via $^{20}\text{Mg} \beta\text{p}$

- The key reaction for the breakout from the hot CNO cycle into the rp-process is $^{19}\text{Ne}(\text{p},\gamma)^{20}\text{Na}$. It is expected to be dominated by a single resonance at 457 keV.



- Search for the 457 keV line in the $^{20}\text{Mg} \beta\text{p}$ spectrum failed. The present limit for the feeding of the state is 0.02%
- OTPC could be used to verify/improve this limit in the background free measurement

Summary

- The OTPC detector is an efficient tool to search for very rare multiparticle decays or to investigate particle decays obscured by beta background.
- Can provide precise branching ratios for β -delayed particle channels. Although the energy resolution is worse than for Si detectors, yields complementary data for low-energy particles.
- $\beta 2p$ emission discovered in ^{46}Fe . Decay of one atom observed!
- $\beta 3p$ emission finally observed in ^{31}Ar . See the Gunvor's talk later this session!
- Strong β -delayed triton emission confirmed for ^8He . By recording tracks of both α and t, the decay energies were reconstructed in the model independent way. Will shed light on the mechanism of the decay and provide the B_{GT} strength for the t-emitting states.
- Possible applications include search for low-energy β -delayed proton channels of astrophysical interest, like $^{31}\text{Ar} \beta 2p \rightarrow ^{29}\text{P}$ or $^{20}\text{Mg} \beta p \rightarrow ^{19}\text{Ne}$.

Thank you!

The main work was done by two PhD students:

Sławek Mianowski and Marcin Pomorski

