Mechanism of two-proton emission from ^{23}Al and ^{22}Mg

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Outline

- Introduction
- Experiment description
- Mechanism of two proton emission from ^{23}Al、^{22}Mg
- β-delayed two proton emission experiment for ^{23}Si 、 ^{22}Al
- Conclusions

Introduction

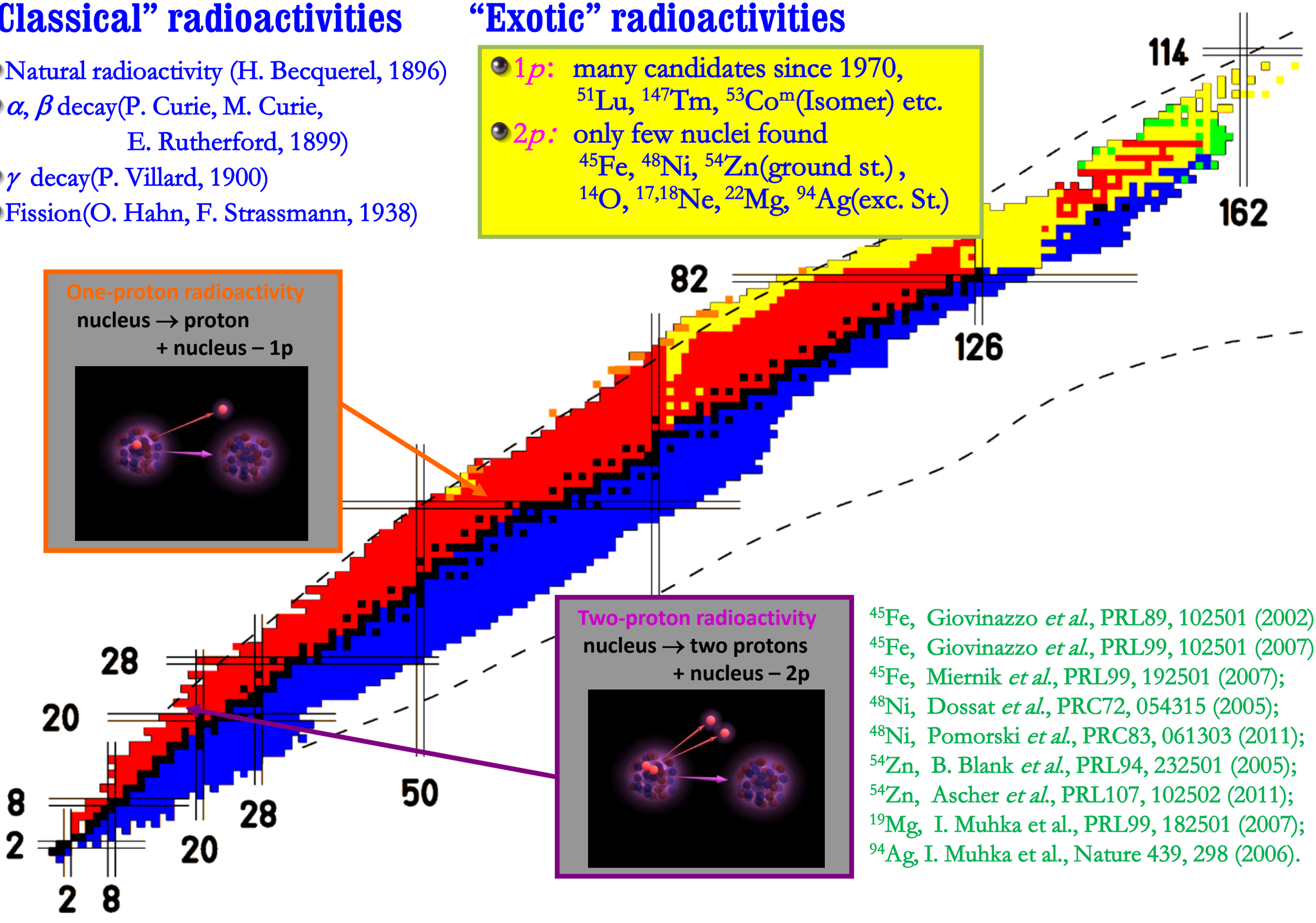
V. Goldanskii ... 1960

"Classical" radioactivities

- Natural radioactivity (H. Becquerel, 1896)
- α, β decay(P. Curie, M. Curie, E. Rutherford, 1899)
- γ decay(P. Villard, 1900)
- Fission(O. Hahn, F. Strassmann, 1938)

"Exotic" radioactivities

- $1p$: many candidates since 1970, ^{51}Lu, ^{147}Tm, ^{53}Co^{m}(Isomer) etc.
- $2p$: only few nuclei found ^{45}Fe, ^{48}Ni, ^{54}Zn(ground st.) , ^{14}O, ^{17,18}Ne, ^{22}Mg, ^{94}Ag(exc. St.)

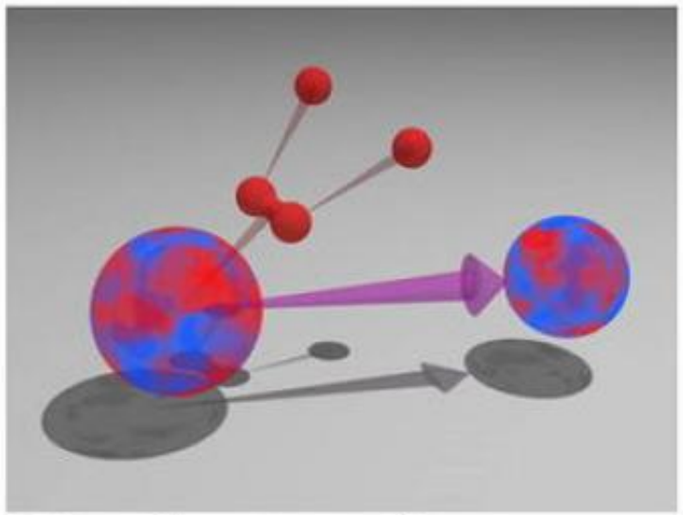


^{45}Fe, Giovinazzo *et al.*, PRL89, 102501 (2002);
^{45}Fe, Giovinazzo *et al.*, PRL99, 102501 (2007);
^{45}Fe, Miernik *et al.*, PRL99, 192501 (2007);
^{48}Ni, Dossat *et al.*, PRC72, 054315 (2005);
^{48}Ni, Pomorski *et al.*, PRC83, 061303 (2011);
^{54}Zn, B. Blank *et al.*, PRL94, 232501 (2005);
^{54}Zn, Ascher *et al.*, PRL107, 102502 (2011);
^{19}Mg, I. Muhka et al., PRL99, 182501 (2007);
^{94}Ag, I. Muhka et al., Nature 439, 298 (2006).

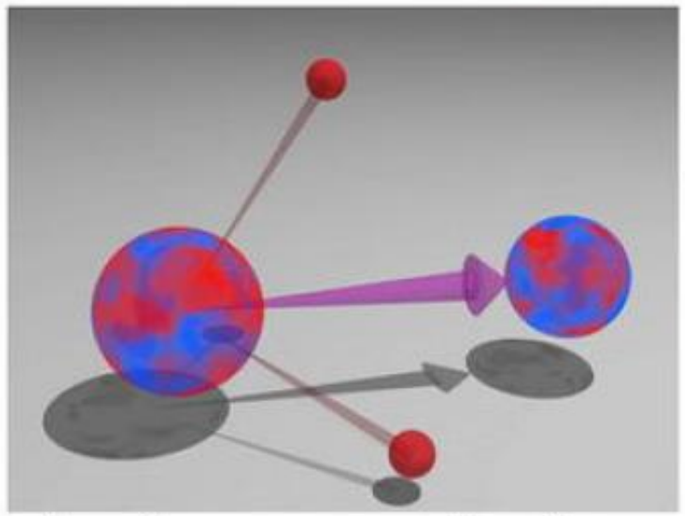
Different mechanism of two-proton emission

Three extreme decay modes

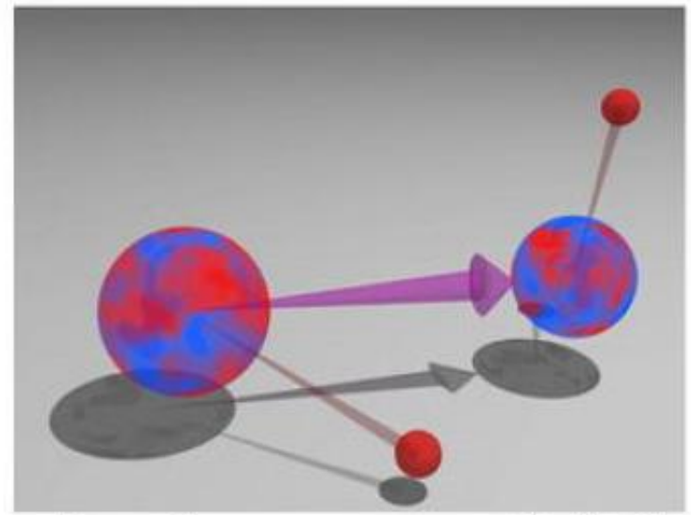
B. Blank et al.



^{2}He cluster decay



3-body democratic decay



2-body sequential decay

Two types of 2p emission

- – emission from ground-state
- long lived: ^{45}Fe, ^{48}Ni, ^{54}Zn
- short lived: ^{6}Be, ^{12}O, ^{16}Ne, ^{19}Mg
- – emission from excited states
- β delayed: ^{22}Al, ^{31}Ar, ...
- others: ^{14}O, ^{17}Ne, ^{18}Ne, ^{94}Ag

Objectives of studying 2p emission

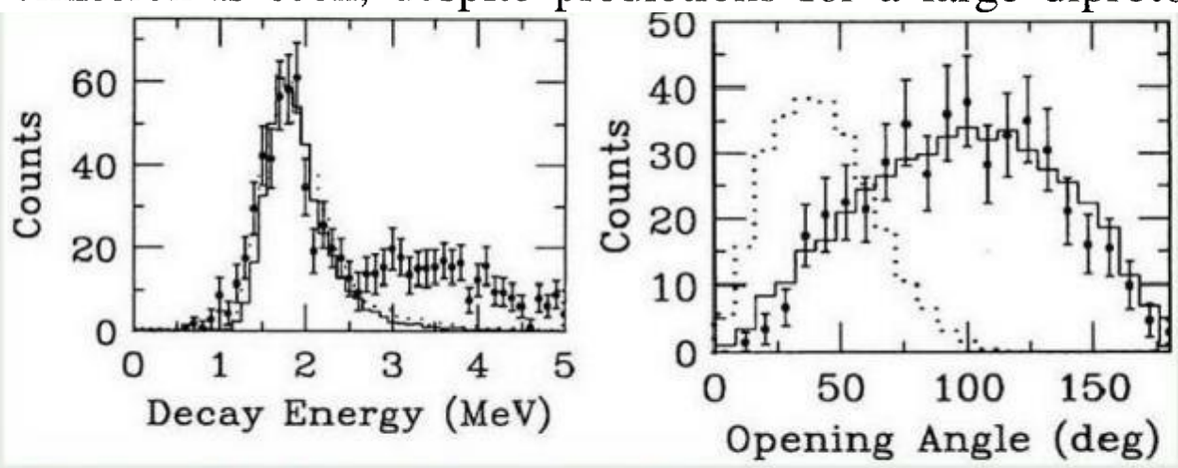
- masses of nuclei beyond drip line
- p-p pair correlation inside nuclei
- nuclear structure information for proton-rich nuclei (single-particle levels, deformation)
- tunneling process

Two protons can be emitted as an ^{2}He resonance or as independent particles. The relative momentum and angular distribution in the two cases will be quite different.

^{2}He: the enhanced peak around q=20MeV/c due to the strong nuclear and Coulomb interaction forming a singlet S wave when two protons emit at close proximity in space and time.

Two-proton emission from ^{12}O ground state

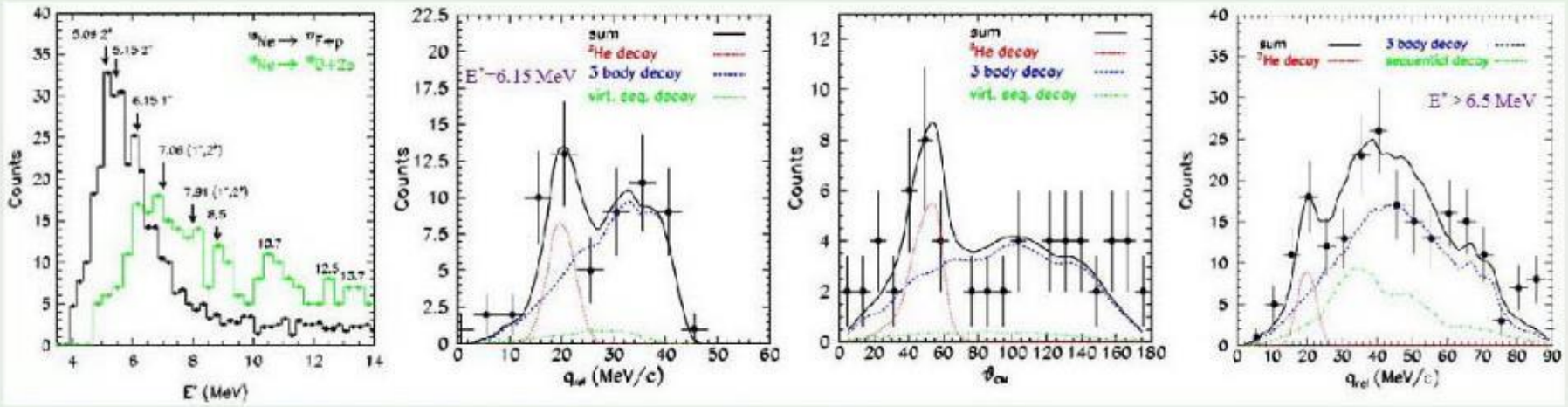
No evidence for ^{2}He emission is seen, despite predictions for a large diproton branching ratio.



Solid line: sequential decay; dot-line: di-proton decay.

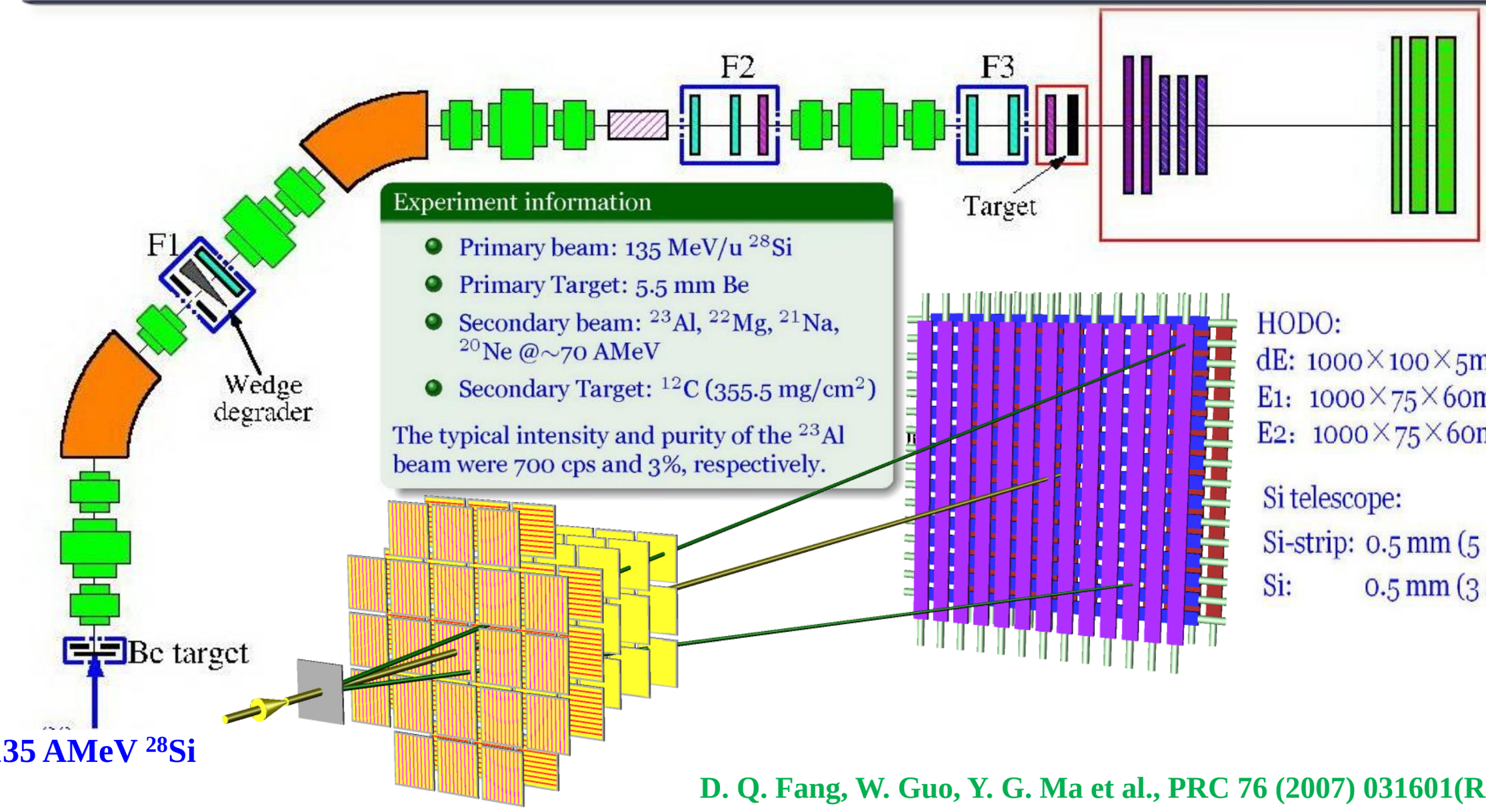
MSU: R. A. Kryger et al., Phys. Rev. Lett. 74 (1995) 860.

^{2}He emission from ^{18}Ne excited states



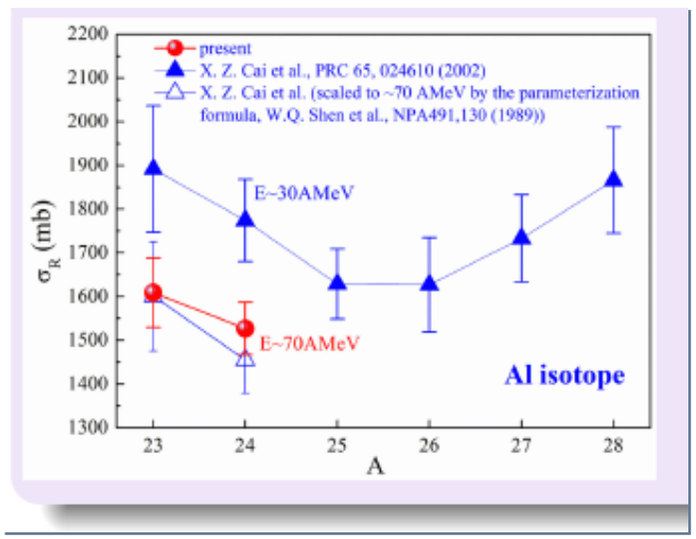
INFN: G. Raciti et al., Phys. Rev. Lett. 100 (2008) 192503.

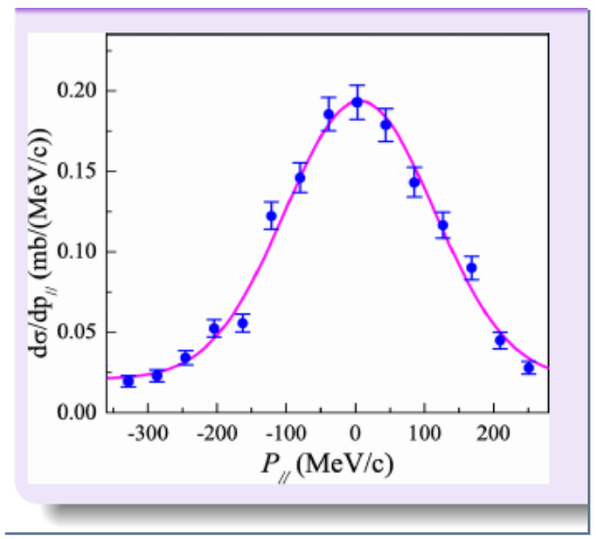
Experiment description

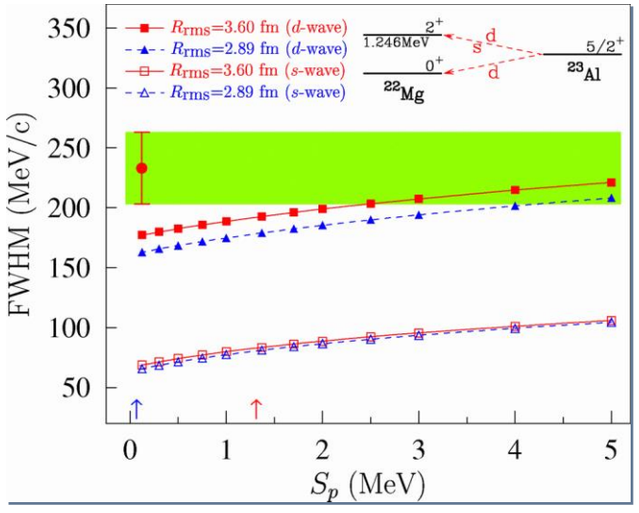


135 AMeV ^{28}Si

D. Q. Fang, W. Guo, Y. G. Ma et al., PRC 76 (2007) 031601(R).

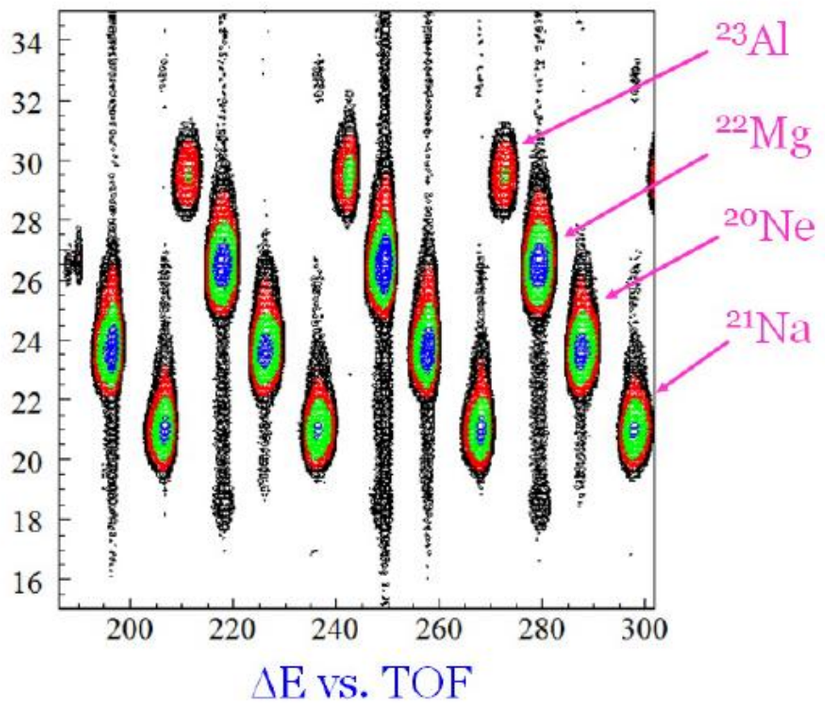




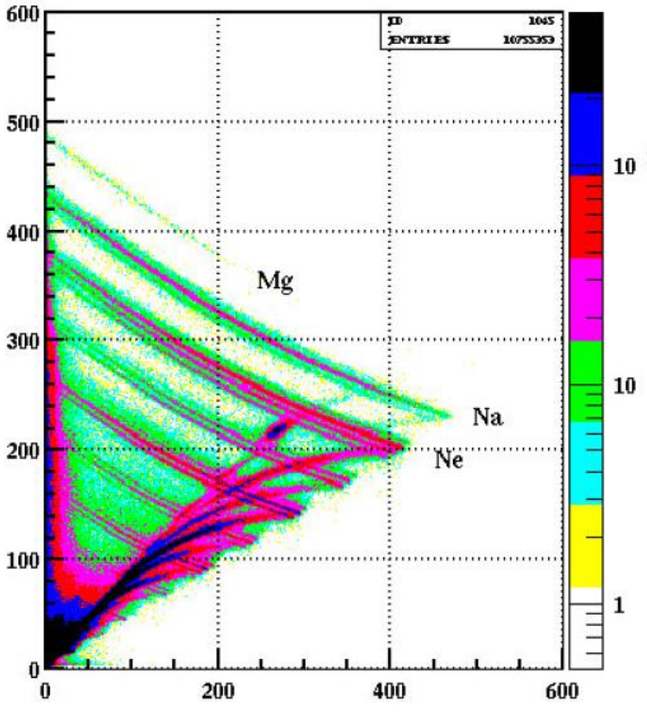


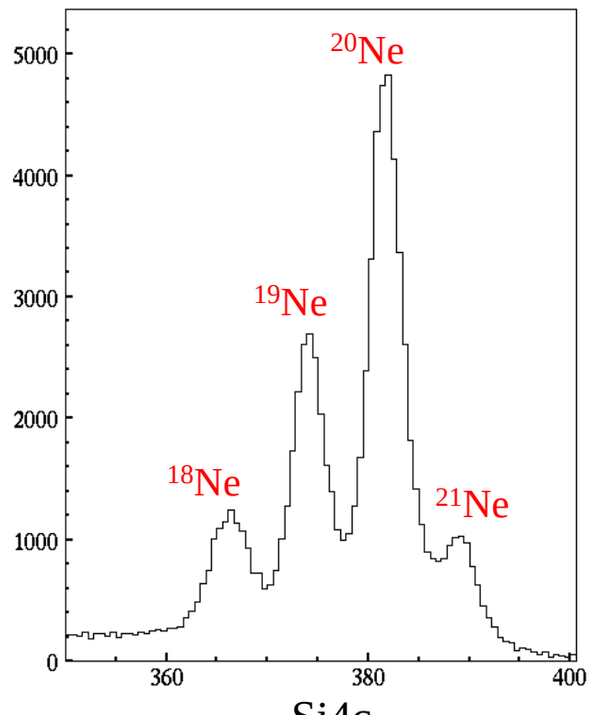
Particle identification

- Before C target: $B\rho - \Delta E$–TOF

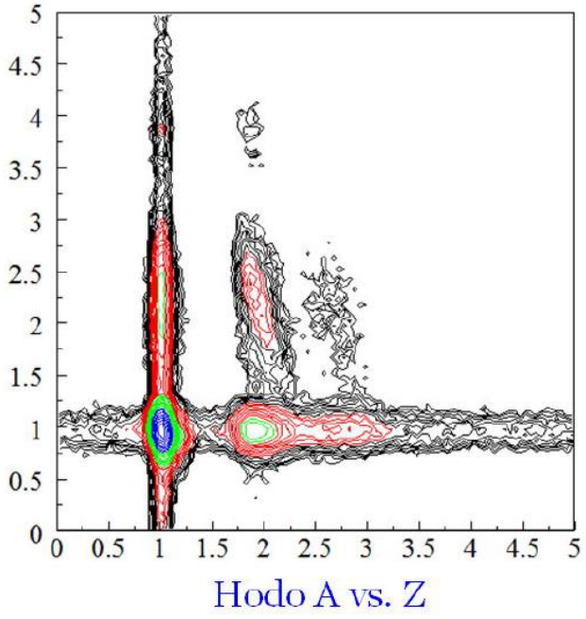


- After C target: Si telescope and hodoscope
  - ★ Fragments: $\Delta E - E$ from the Si telescope

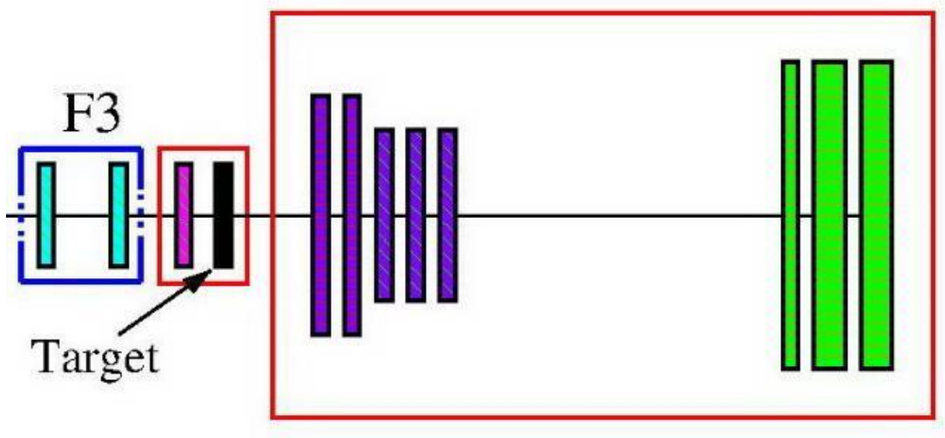




- ★ Protons: $\Delta E - E$ from hodoscope and TOF between the target and HODO



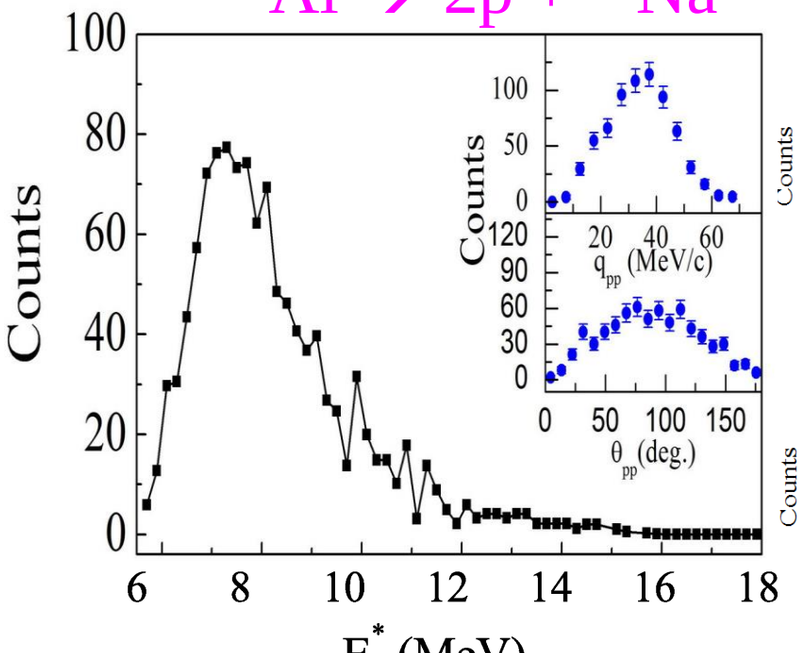
- ★ Emitting angles: strip Si in the 1st and 2nd layers of the telescope (fragments and proton) and HODO (proton)

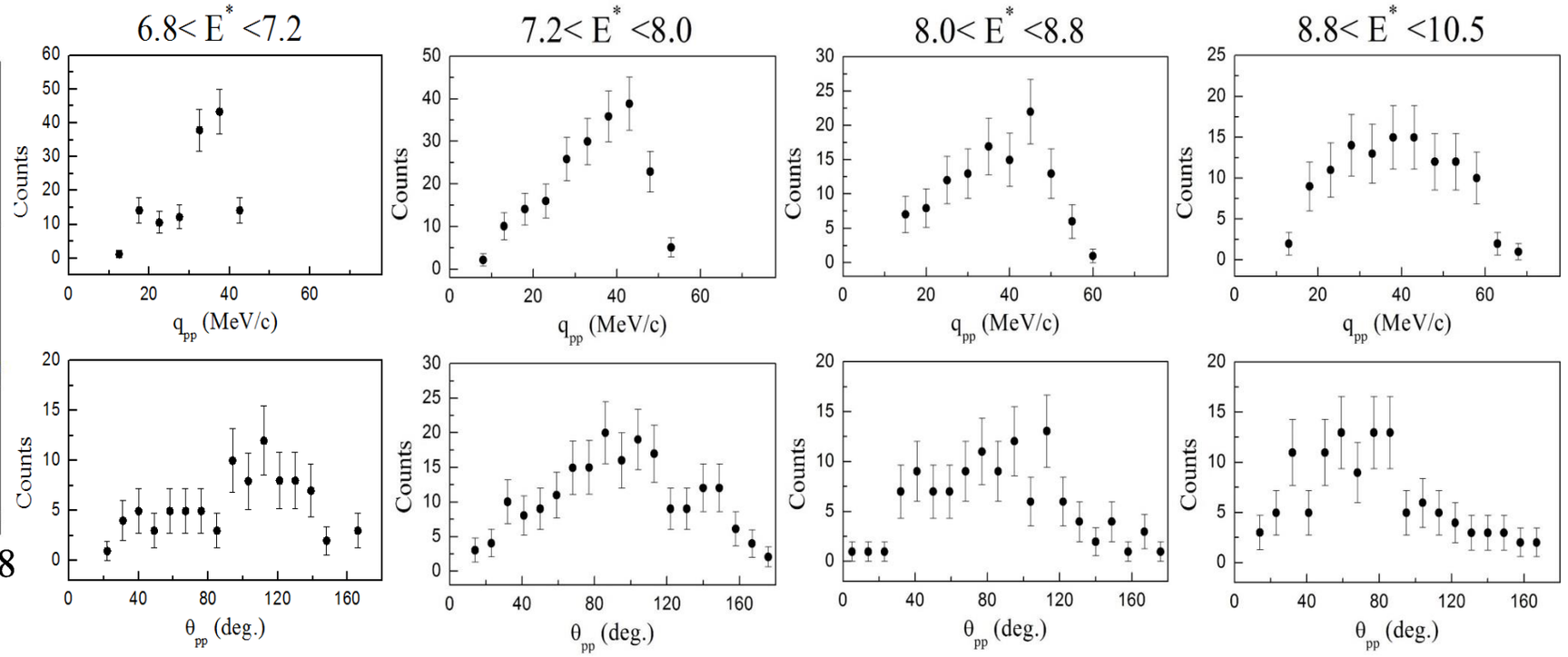


Excitation energy, 2p relative momentum and openning angle for two proton emission processes of ^{23}Al and ^{22}Mg

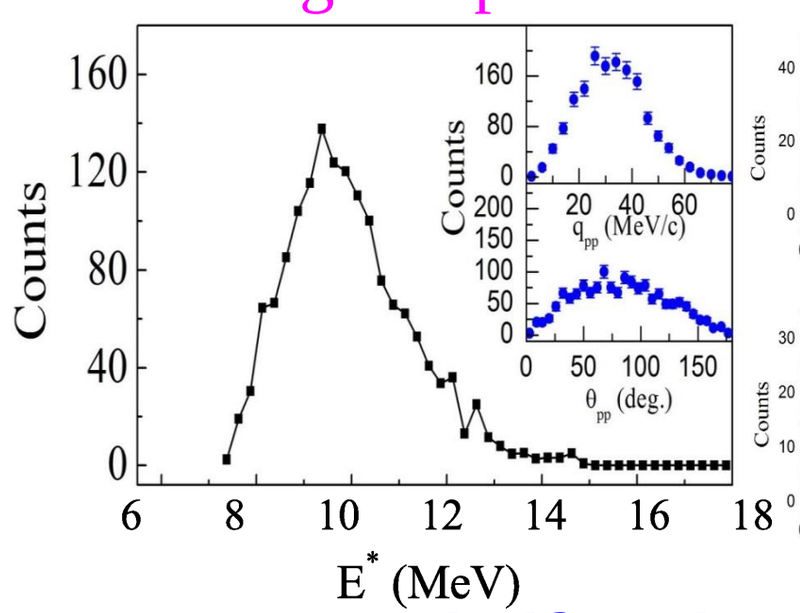
E* is constructed from invariant mass: $E^* = W - M = \sqrt{(\sum E_i)^2 - (\sum \vec{P}_i c)^2} - (M_{^{23}Al})$.

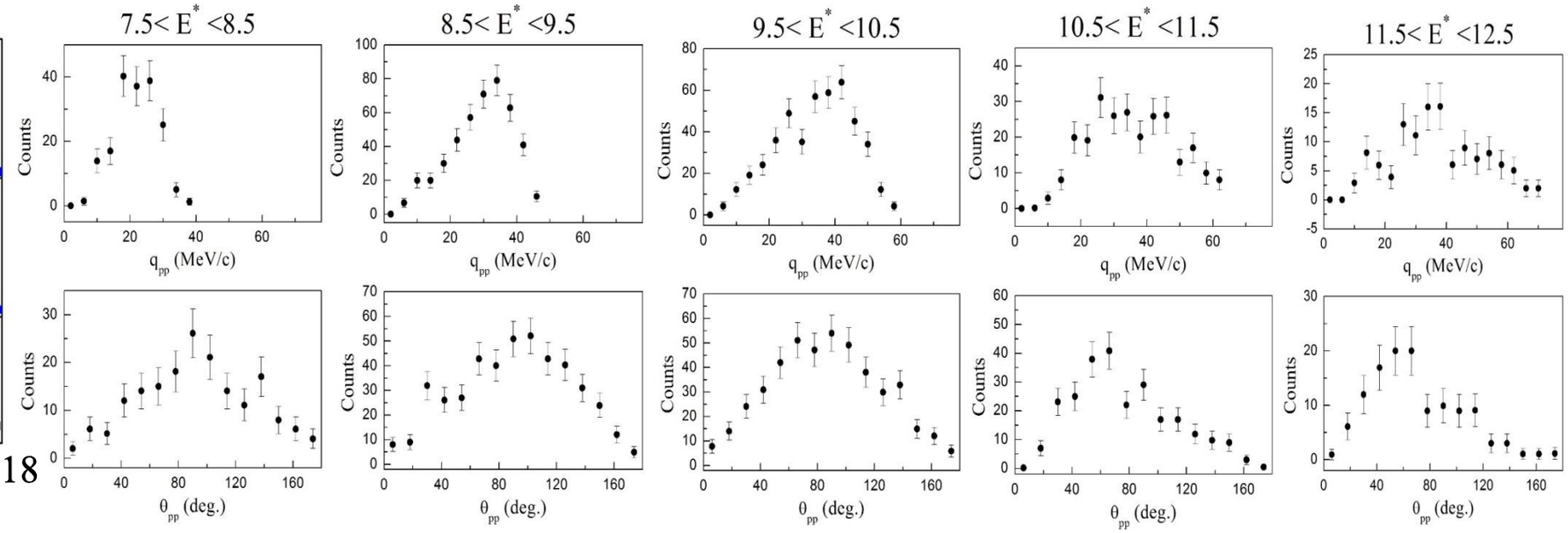
^{23}Al → 2p + ^{21}Na





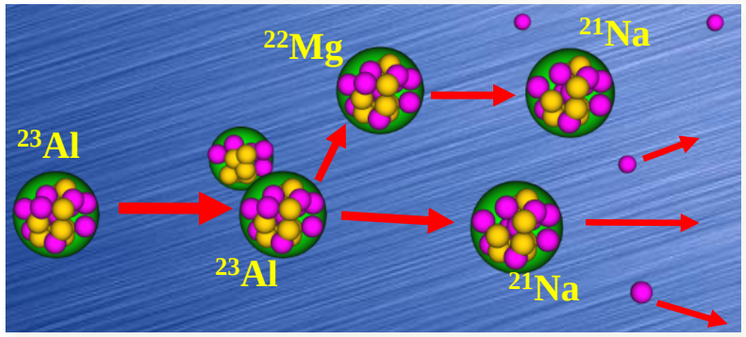
^{22}Mg → 2p + ^{20}Ne



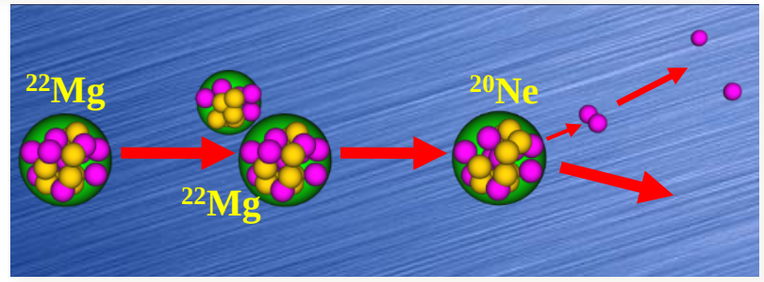


No signal of ^{2}He cluster emission is observed in the relative momentum and opening angle distributions between two proton for low excitation states of ^{23}Al and ^{22}Mg.

Mechanism of two proton emission from excited states of ^{23}Al、^{22}Mg

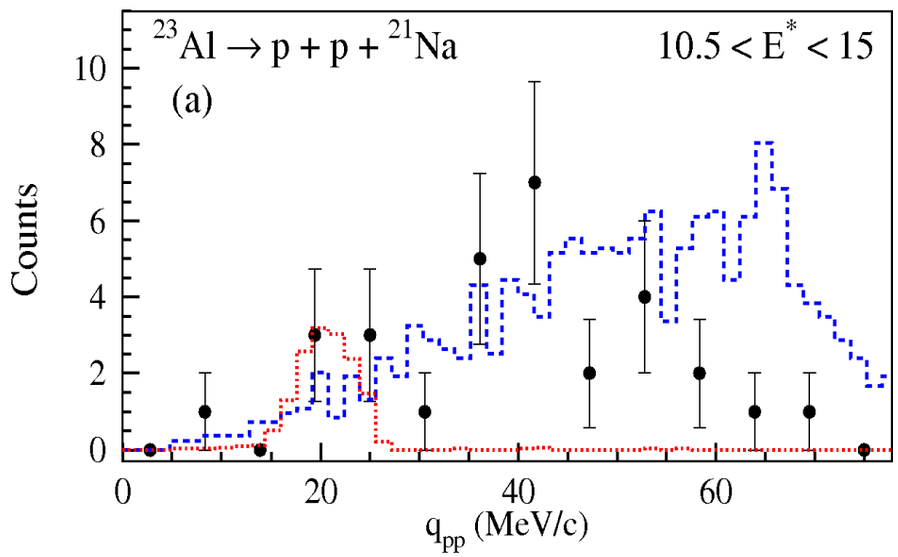


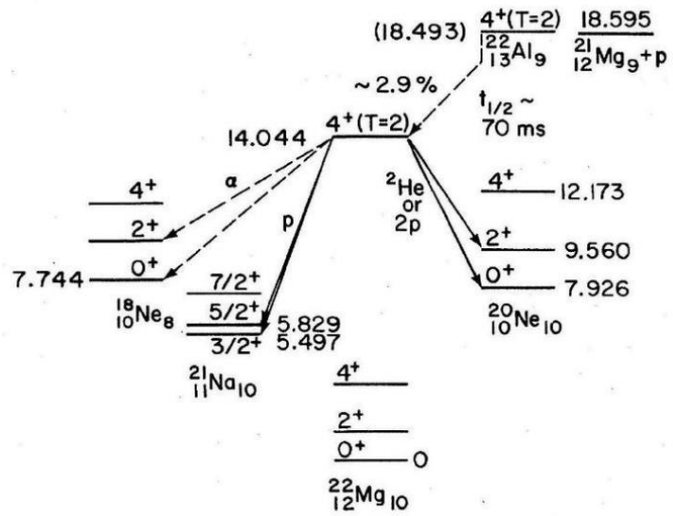
1773 35	(3/2)+	A C		%p=100.
2575 34		C		%p=100.
3197 19	(3/2)+	A C		%p=100.
3718 31	(5/2)+	A C		%p=100.
4200 40	(7/2)+	A		%p=100.
11780 40	(5/2)+	A		%p=0.10 5; %2p=3.6 4.
				Jπ: IAS to ^{23}Si parent.

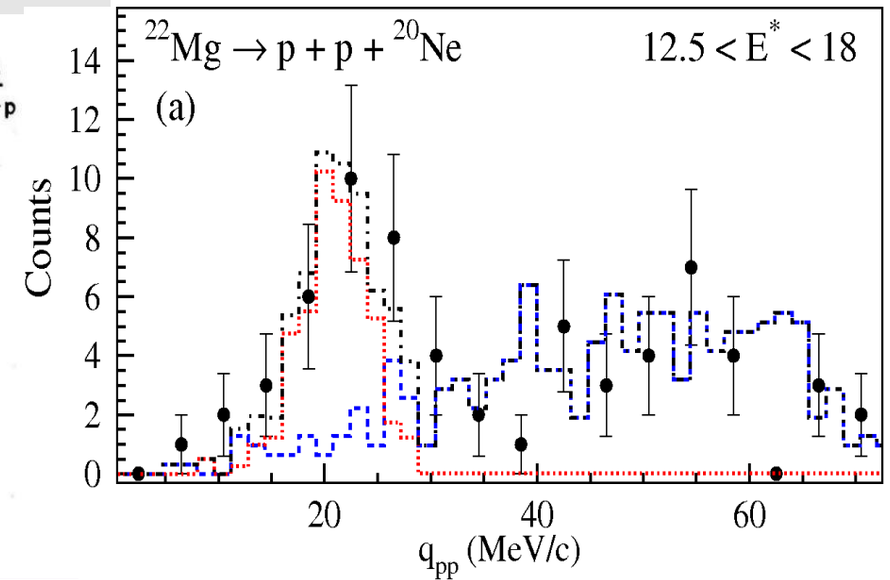


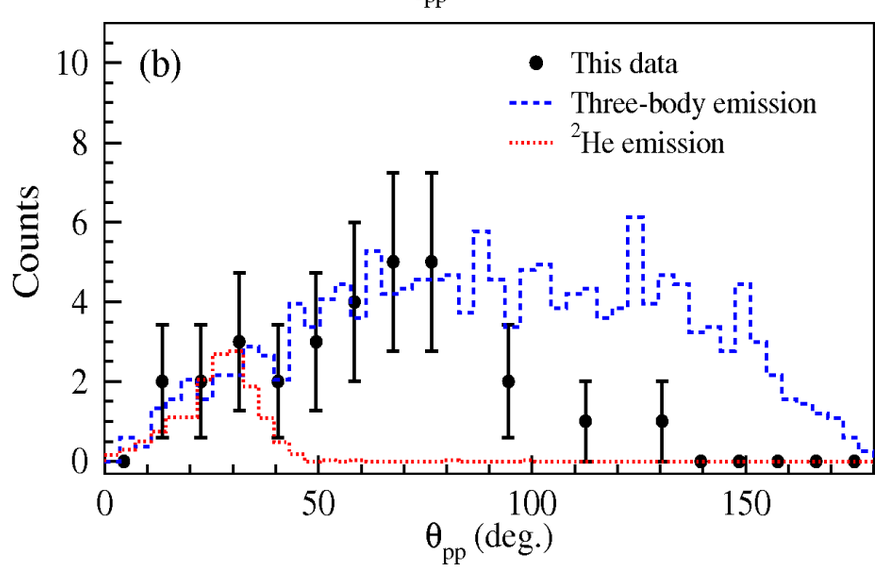
^{23}Al → ^{21}Na + 2p

^{22}Mg → ^{20}Ne + 2p

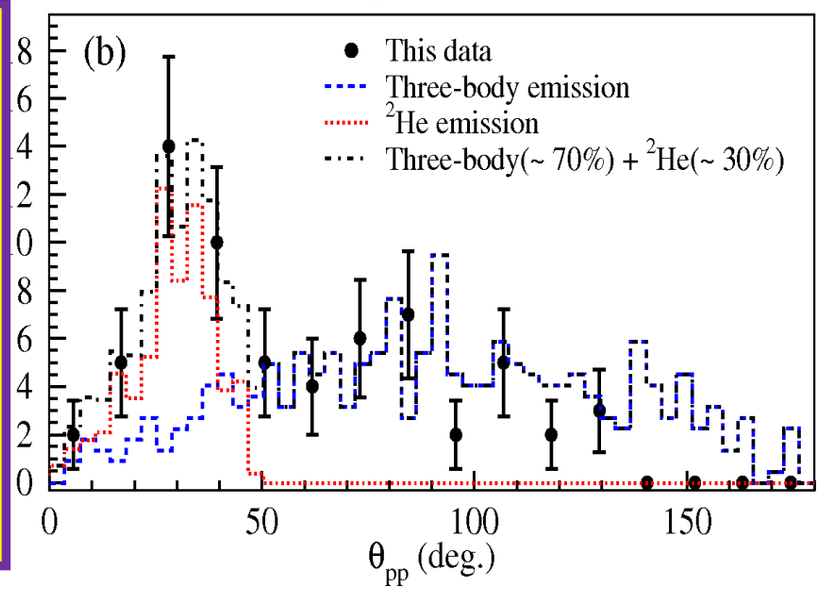




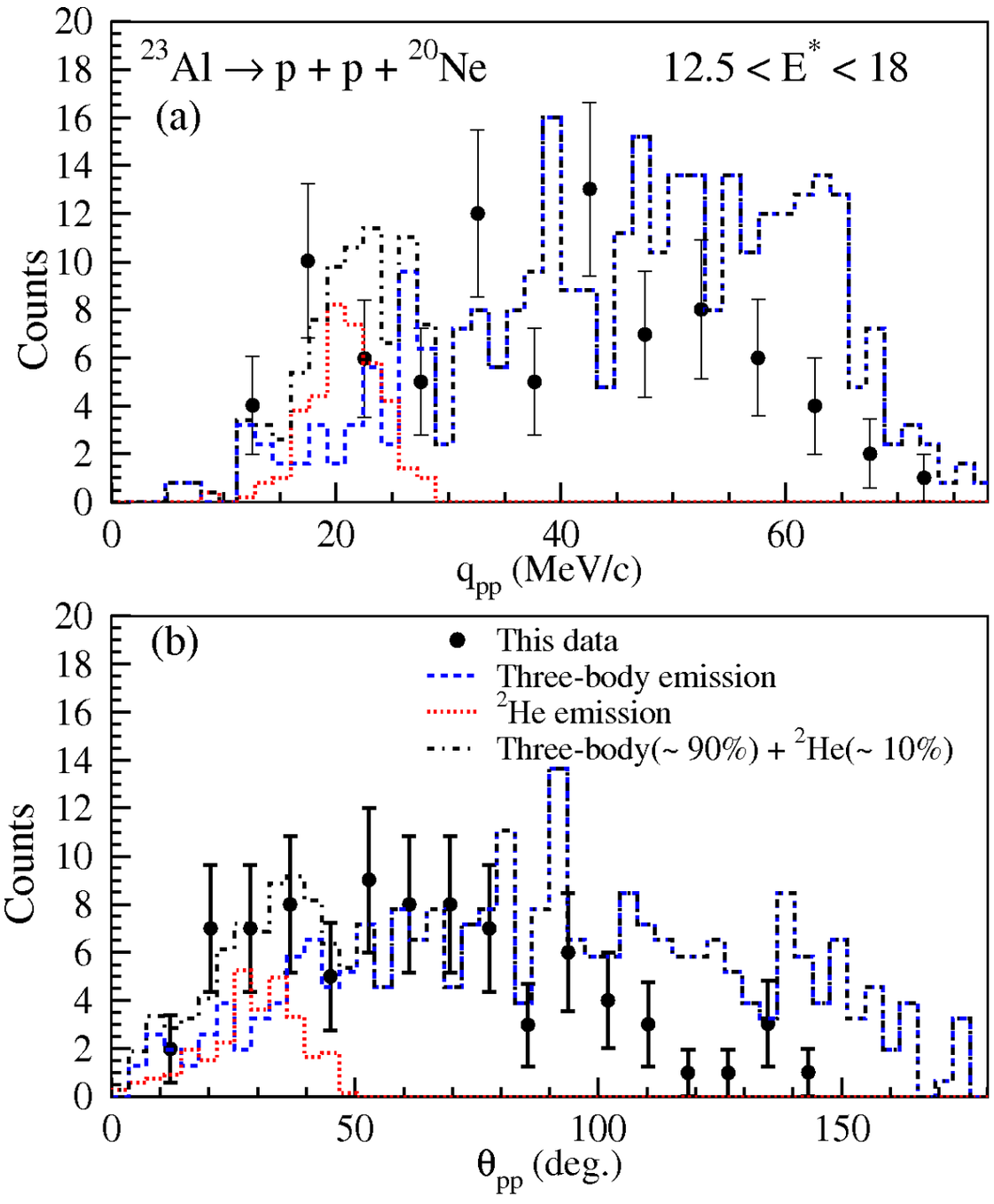




1. ^{23}Al: no clear peak at q=20 MeV/c and small open ange of 2p, three-body/sequential decay is the main mechanism
2. ^{22}Mg: clear peak at q=20 MeV/c and small open ange of 2p, strong component of ^{2}He emission



$^{23}Al \rightarrow {}^{20}Ne + 2p$



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Different mechanism of two-proton emission from proton-rich nuclei ^{23}Al and ^{22}Mg

Y.G. Ma [a], D.Q. Fang [a], X.Y. Sun [a], P. Zhou [a], Y. Togano [b], N. Aoi [b], H. Baba [b], X.Z. Cai [a], X.G. Cao [a], J.G. Chen [a], Y. Fu [a], W. Guo [a], Y. Hara [c], T. Honda [c], Z.G. Hu [d], K. Ieki [c], Y. Ishibashi [e], Y. Ito [e], N. Iwasa [f], S. Kanno [b], T. Kawabata [g], H. Kimura [h], Y. Kondo [b], K. Kurita [c], M. Kurokawa [b], T. Moriguchi [e], H. Murakami [b], H. Ooishi [e], K. Okada [c], S. Ota [g], A. Ozawa [e], H. Sakurai [b], S. Shimoura [g], R. Shioda [c], E. Takeshita [b], S. Takeuchi [b], W.D. Tian [a], H.W. Wang [a], J.S. Wang [d], M. Wang [d], K. Yamada [b], Y. Yamada [c], Y. Yasuda [e], K. Yoneda [b], G.Q. Zhang [a], T. Motobayashi [b]

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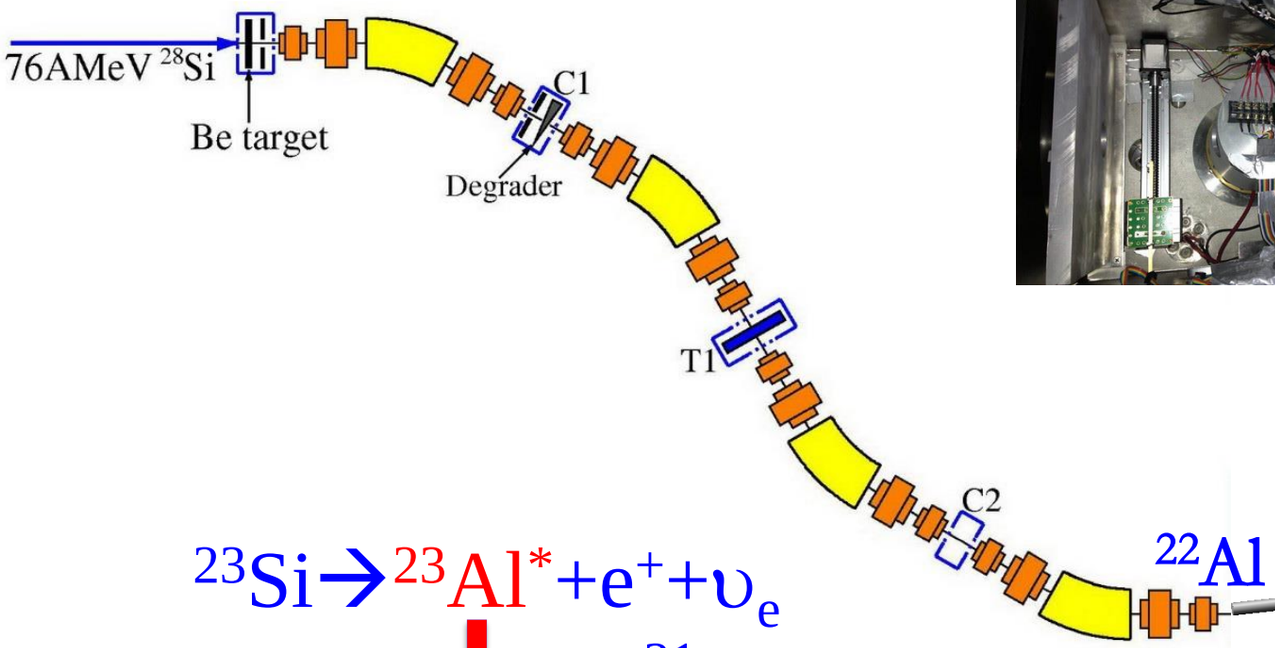
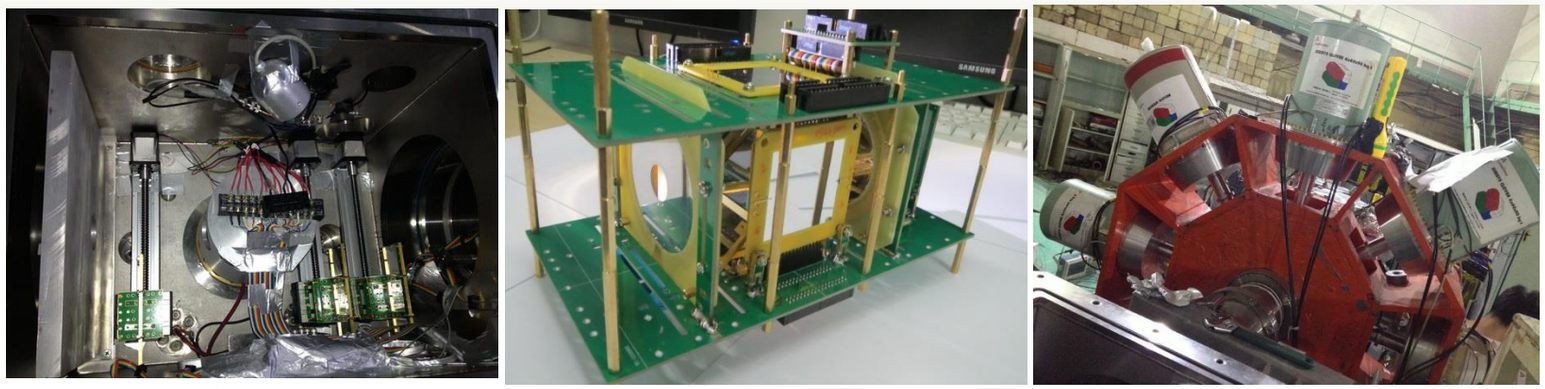
ABSTRACT

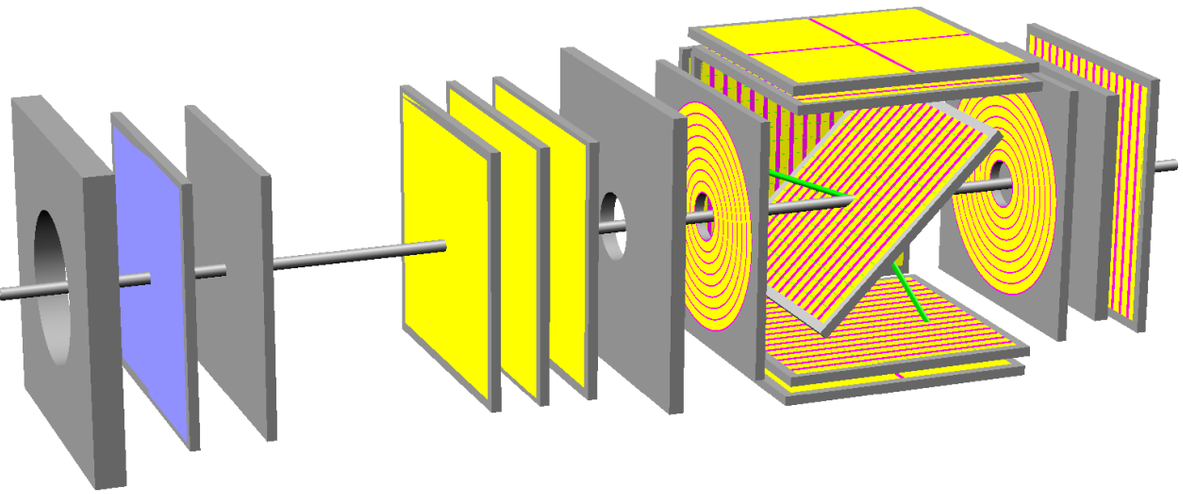
Two-proton relative momentum (q_{pp}) and opening angle (θ_{pp}) distributions from the three-body decay of two excited proton-rich nuclei, namely $^{23}Al \rightarrow p + p + {}^{21}Na$ and $^{22}Mg \rightarrow p + p + {}^{20}Ne$, have been measured with the projectile fragment separator (RIPS) at the RIKEN RI Beam Factory. An evident peak at $q_{pp} \sim 20$ MeV/c as well as a peak in θ_{pp} around 30° are seen in the two-proton break-up channel from a highly-excited ^{22}Mg. In contrast, such peaks are absent for the ^{23}Al case. It is concluded that the two-proton emission mechanism of excited ^{22}Mg is quite different from the ^{23}Al case, with the former having a favorable diproton emission component at a highly excited state and the latter dominated by the sequential decay process.

β-delayed two proton emissions

Collaborated with CIAE and IMP







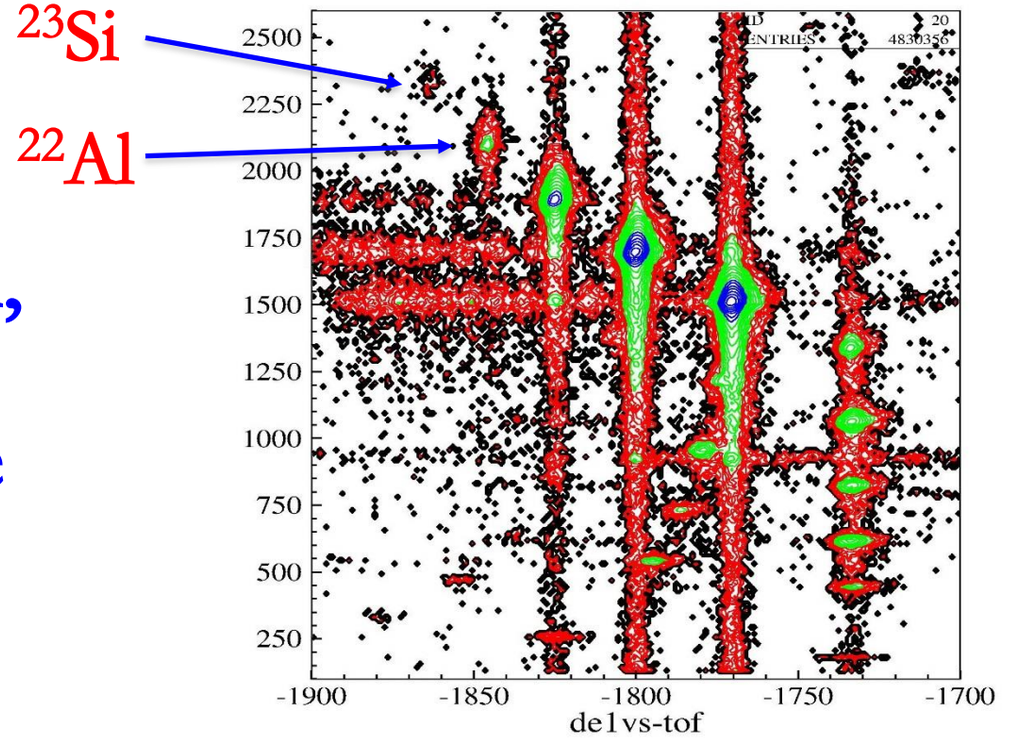
$^{23}Si \rightarrow {}^{23}Al^{*} + e^{+} + \upsilon_e$

$\rightarrow {}^{21}Na + p + p$

$^{22}Al \rightarrow {}^{22}Mg^{*} + e^{+} + \upsilon_e$

$\rightarrow {}^{20}Ne + p + p$

β-delayed 1p and 2p emissions from ^{23}Si, ^{22}Al and ^{20,21}Mg were measured on the radioactive ion beam line (RIBLL) at the heavy ion research facility in Lanzhou (HIRFL) .



Conclusions

1. Two-proton emission from proton-rich nuclei ^{23}Al and ^{22}Mg were measured by the reaction method, spectrum of relative momentum and open angle between two protons are obtained.
2. Strong component of ^{2}He-like cluster emission from high excitation energy states of ^{22}Mg was observed, but not for ^{23}Al.
3. Further studies by the β-delayed 2p emission measurement are in progress.

Collaborators

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