Quasi-free proton knockout reactions of ^{23,25}F

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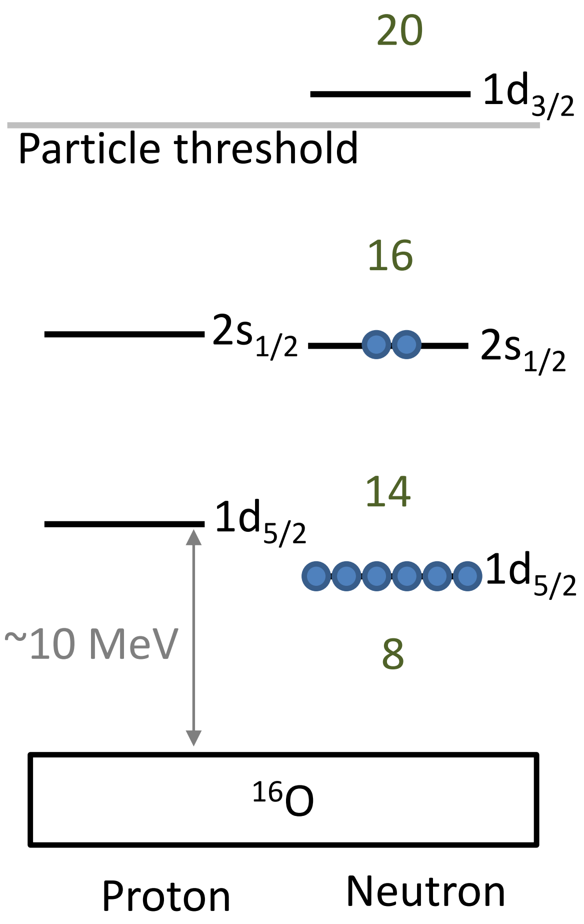
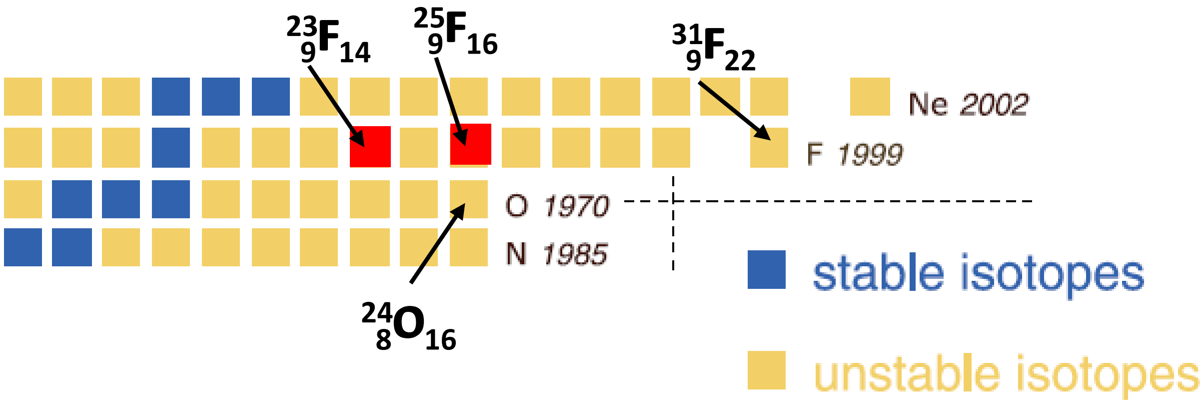
RCNP for supporting data analysis

Different neutron dripline



^{24}O



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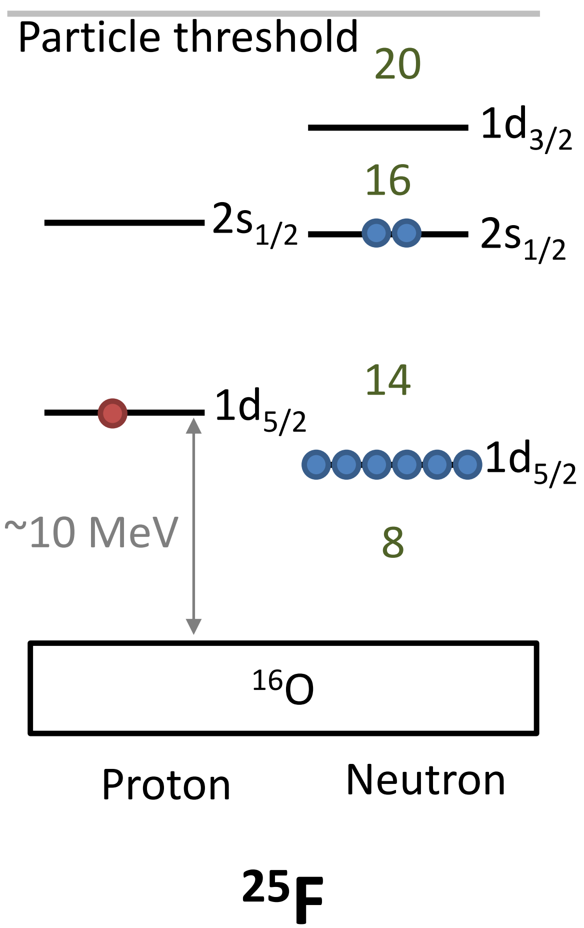
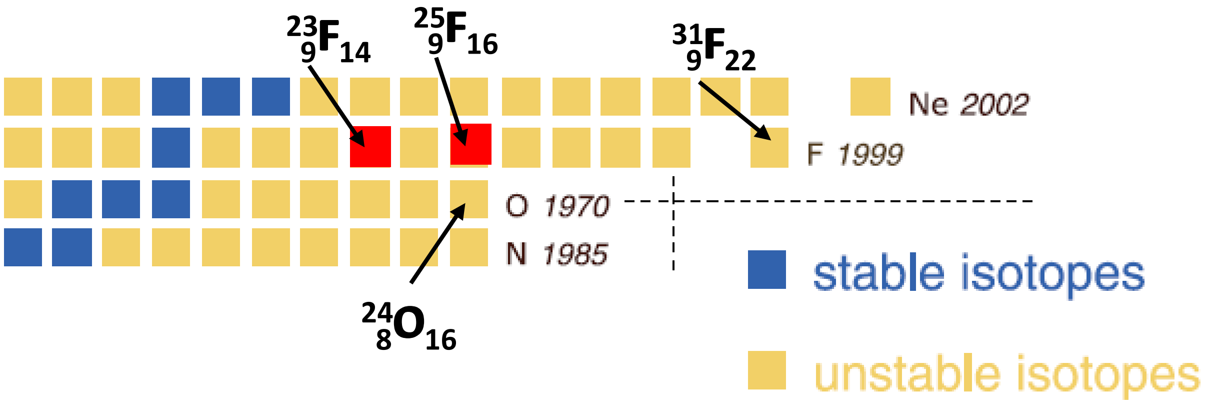
- How the $1d_{5/2}$ proton changes the neutron shell structure?
- Proton removal spectroscopy on ^{23,25}F

If neutron-shell does not change
→ spectroscopic factor of the ground state of oxygen = 1.

Different neutron dripline





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If neutron-shell does not change
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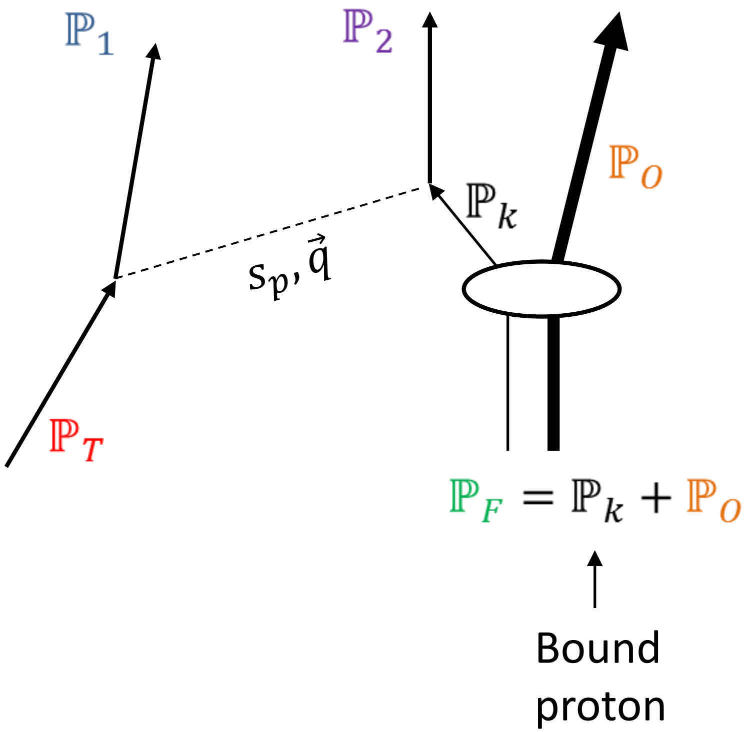
Quasi-free (p,2p) knockout

- <u>Cleanest reaction</u>
  - proton is a clean probe
  - Intermediate energy
    →Direct reaction

- Complete kinematics



$$\mathbb{P}_F + \mathbb{P}_T = \mathbb{P}_1 + \mathbb{P}_2 + \mathbb{P}_O$$

$$s_p(nlj) + m(\mathbb{P}_F) = m(\mathbb{P}_2) + m(\underbrace{\mathbb{P}_F + \mathbb{P}_T - \mathbb{P}_1 - \mathbb{P}_2}_{\mathbb{P}_O})$$

↑ Effective separation energy

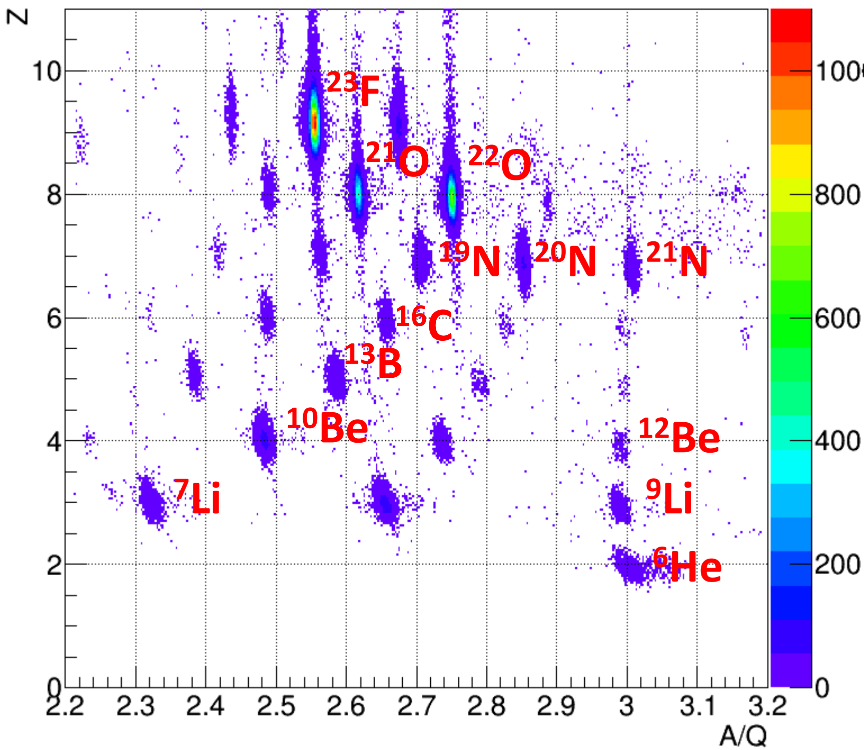
Production ^{23,25}F at ~300*A* MeV

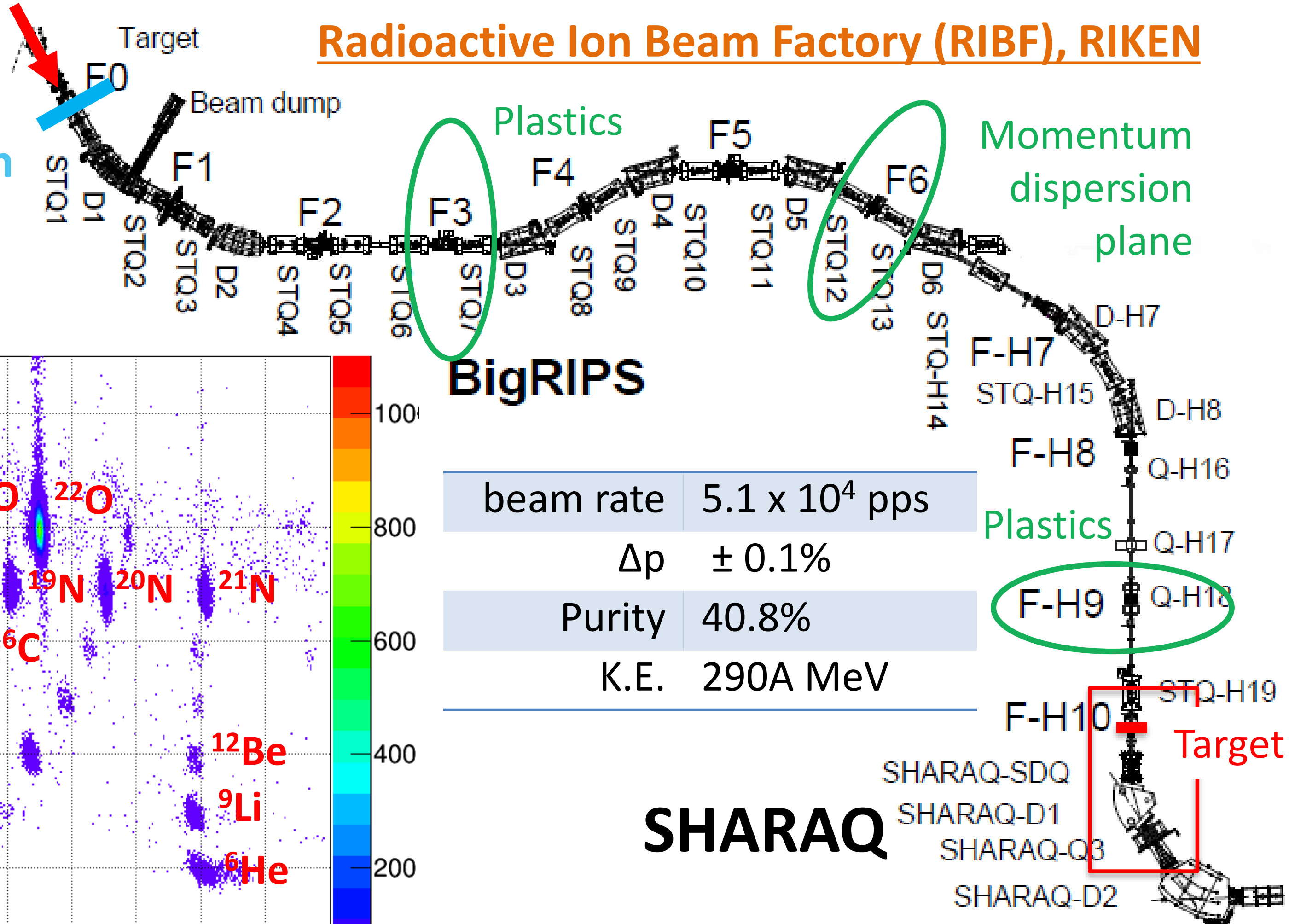
^{48}Ca, 345*A* MeV, 200pnA

^{9}Be 30mm

Radioactive Ion Beam Factory (RIBF), RIKEN

ΔE – TOF – Bρ method



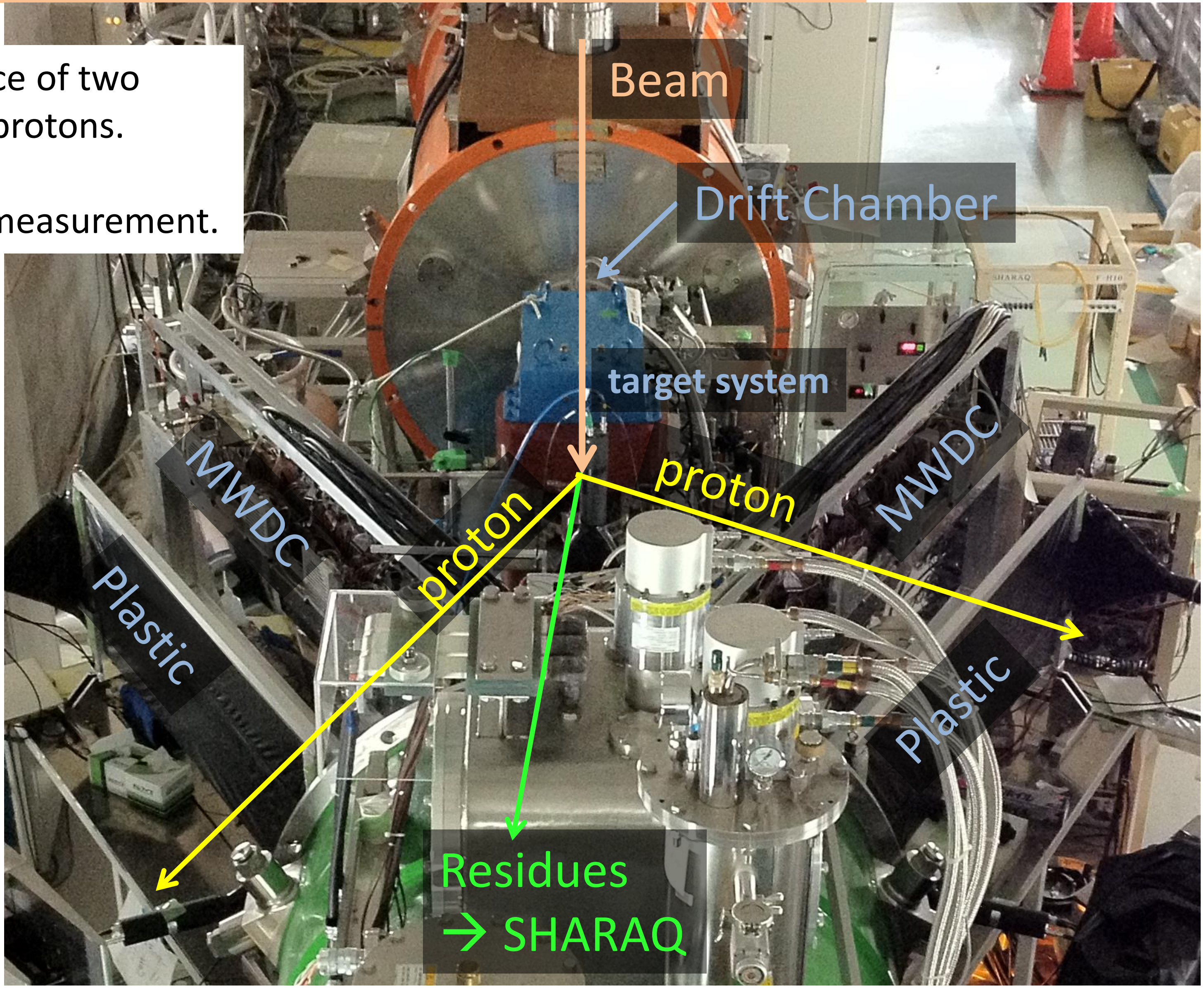


beam rate	5.1 x 10^4 pps
Δp	± 0.1%
Purity	40.8%
K.E.	290A MeV

- **^{25}F was produced in similar manner.**

Experimental Setup

1. Coincidence of two scattered protons.
2. Exclusive measurement.



Reaction Identification

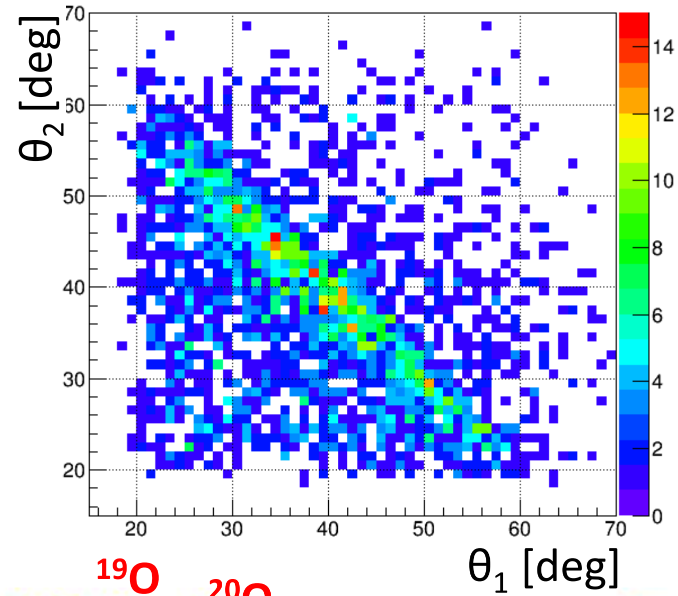
Upstream PID

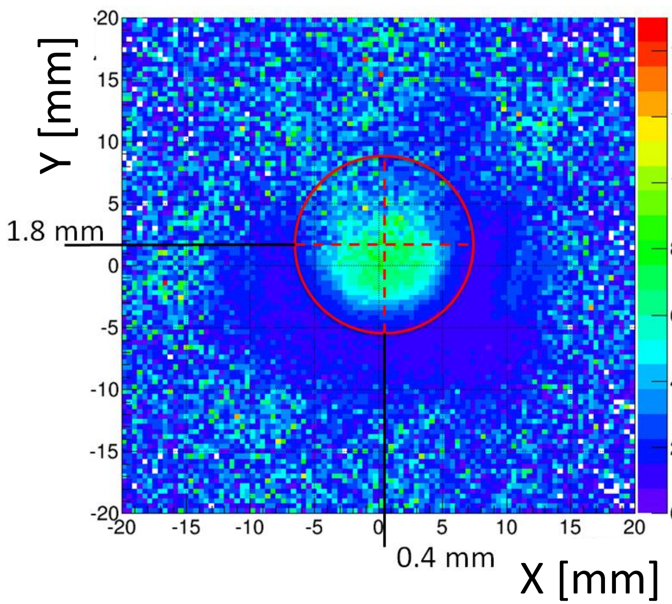
2p correlation

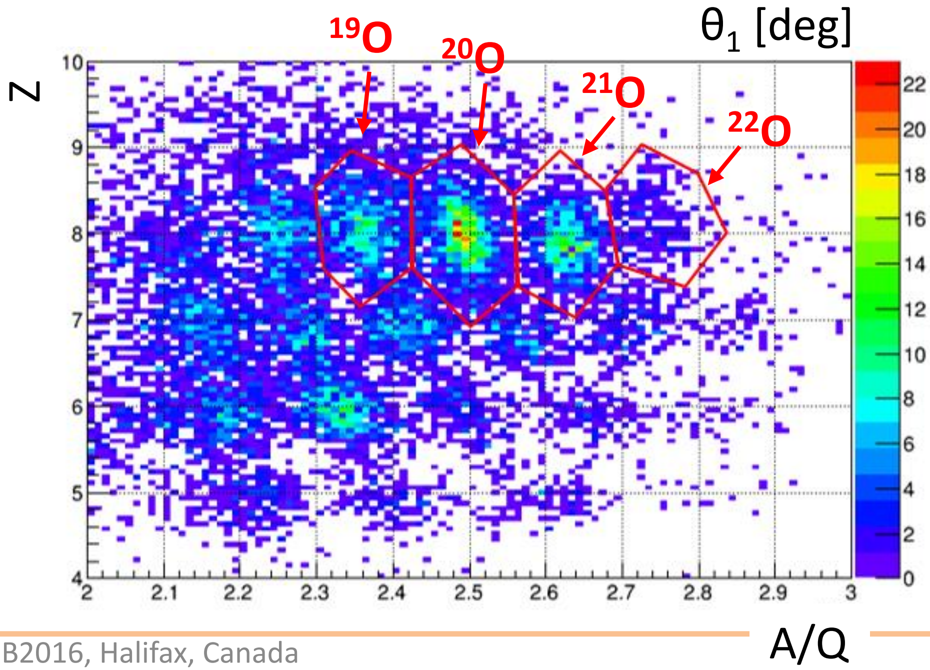
$^{23}F(p, 2p)^{22}O^*$ → $^{21}O + n$, $^{20}O + 2n$, ...

Target position

Residual
- Highly excited
- Neutron emission

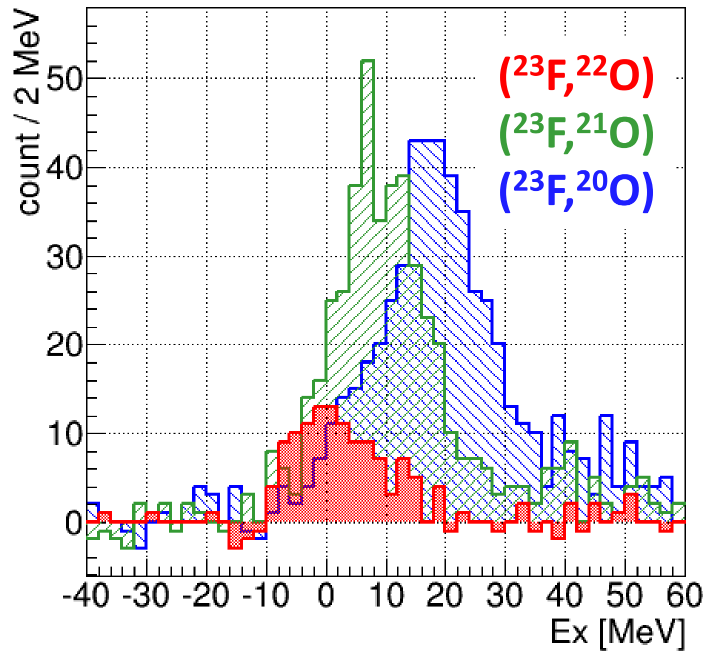






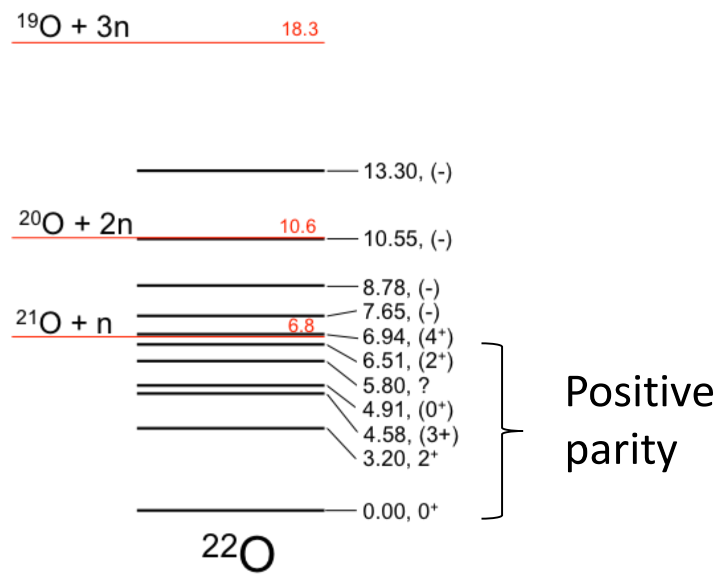
Excitation-energy Spectrum of ^{22}O

$^{23}F(p,2p)^{22}O^*$



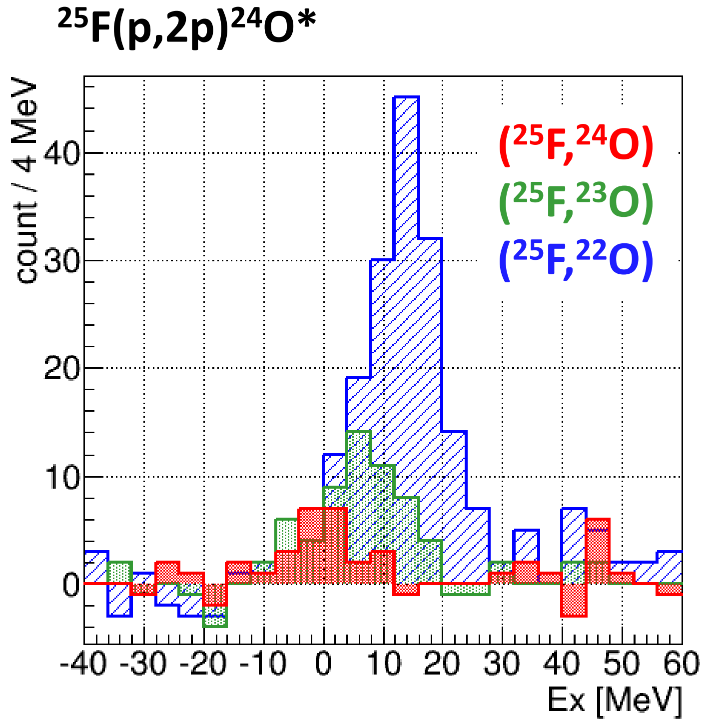
<u>Using residue identification</u>

<u>Orbit can be assigned into sd-shell or p-shell.</u>



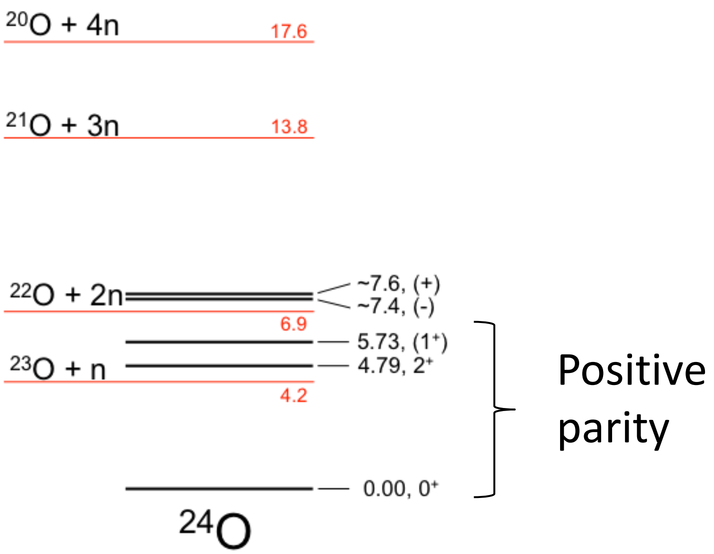
- $(^{23}F,^{22}O)$ is from sd-orbit.
- Mean energy of $(^{23}F,^{21}O)$ is ~ 10 MeV
  - p-orbit should dominate.

Excitation-energy Spectrum of ^{24}O



Using residue identification

Orbit can be assigned into sd-shell or p-shell.

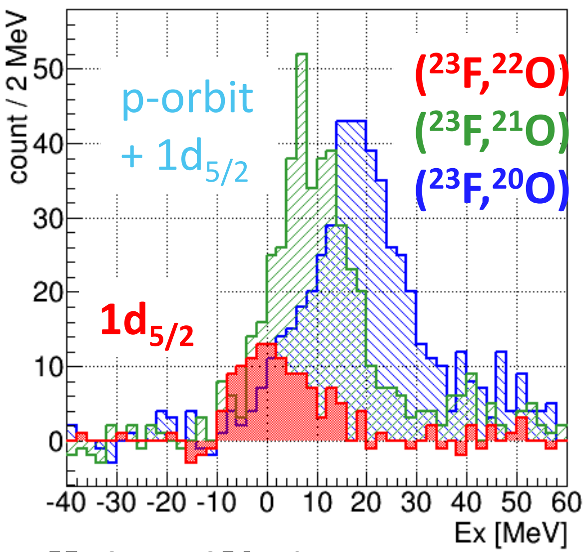


- $(^{25}F,^{24}O)$ is a single peak from $1d_{5/2}$ orbit.
- $(^{25}F,^{23}O)$ is from sd-orbit.

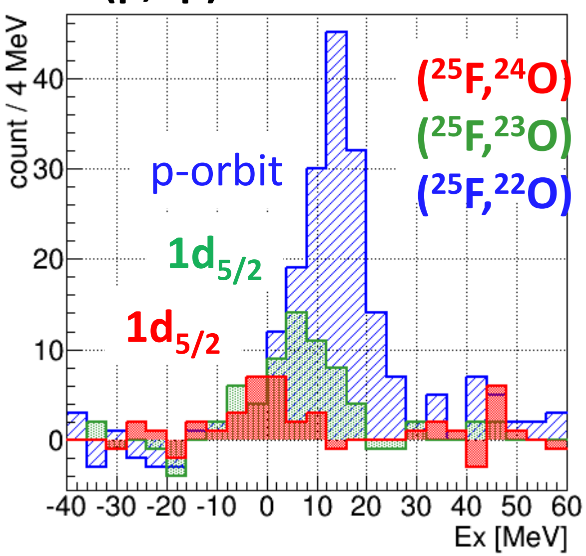
- Mean energy of $(^{25}F,^{22}O)$ is ~ 10 MeV
  - p-orbit should dominate.

Momentum analysis confirms orbits

$^{23}F(p,2p)^{22}O^*$



$^{25}F(p,2p)^{24}O^*$



- **Pervious orbit assignments were confirmed**.
- There is no significant s-orbit components.
    - **Using DWIA calculation.**
        - DWIA [N. S. Chant *et al.*, PRC 15 (1977) 57]
        - Dirac-Cooper potential

          [E. D. Cooper *et al.*, PRC 47 (1993) 297]

- **Spectroscopic factor** $\mathrm{SF_{exp}} = \dfrac{\sigma_{exp}}{\sigma_{DWIA}}$

	Orbit	$\mathrm{SF_{exp}}$	
$(^{23}F, ^{22}O)$	$1d_{5/2}$	0.37 ± 0.10	
$(^{25}F, ^{24}O)$	$1d_{5/2}$	0.38 ± 0.14	1.07 ± 0.29
$(^{25}F, ^{23}O)$		0.69 ± 0.25	

1. **The ground state SFs are small!!**
2. **The SFs of $1d_{5/2}$ proton are fragmented!!**

Physics is on the neutron side!

Wave function of neutron-rich ^{25}F

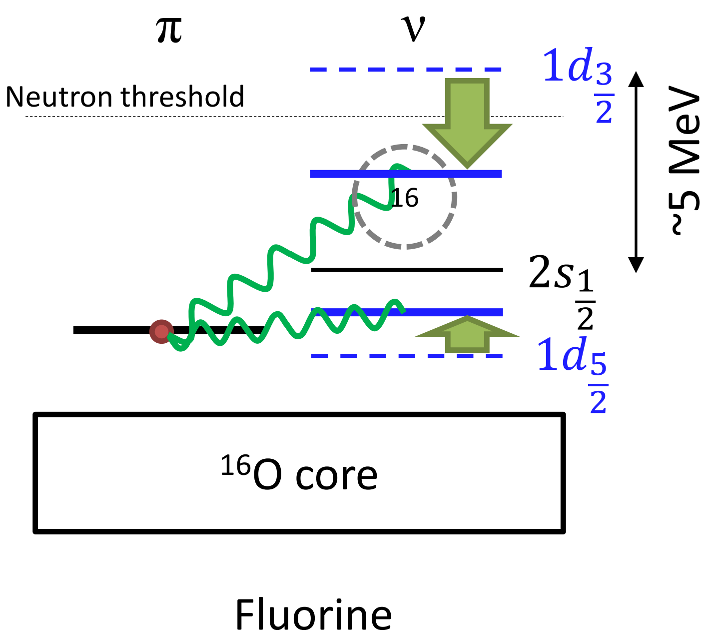
$$\left|{}^{25}F\right\rangle_{\frac{5}{2}} \approx \sqrt{0.35}\left[\left|\pi 1d_{\frac{5}{2}}\right\rangle\left|{}^{24}O_{g.s.}\right\rangle\right]_{\frac{5}{2}} + \sqrt{0.65}\left[\left|\pi 1d_{\frac{5}{2}}\right\rangle\left|{}^{24}O^{*}\right\rangle\right]_{\frac{5}{2}} + \cdots$$

- The $1d_{5/2}$ proton modifies the neutron shell → neutron configuration mixing increases.

- Indicates the shell gap becomes smaller.
- Disappearance of N = 16 magicity.

Mechanism:
<u>Type-I shell evolution</u> driven by tensor force

T. Otuska *et al.*, J. Phys. G: Nucl. Part. Phys. **43** (2016) 024009



Present SM interactions ….

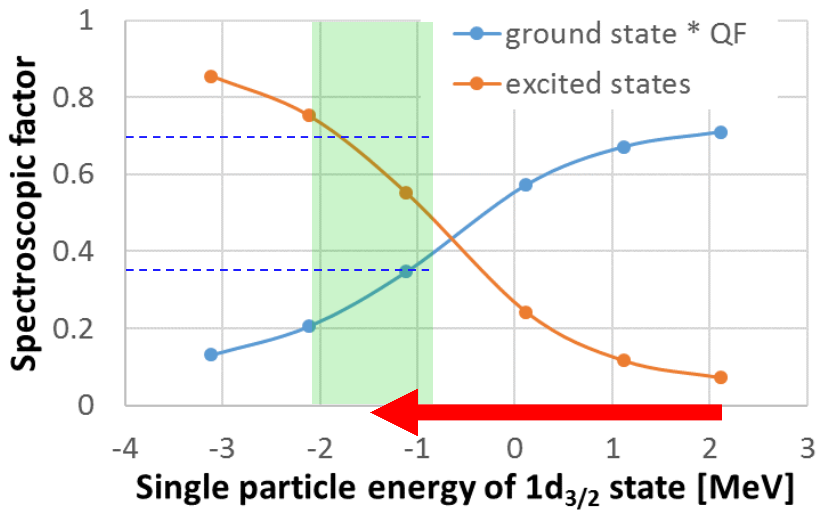
	Residue	Orbit	SF_{exp}	SF(SFO)	SF(USDB)	SF(SDPF-MU)
^{23}F(p,2p)	^{22}O	$1d_{5/2}$	0.37 ± 0.10	0.92	1.08	1.00
^{25}F(p,2p)	^{24}O	$1d_{5/2}$	0.38 ± 0.14	0.9	1.01	0.95
	^{23}O		0.69 ± 0.25	0.1	-	-
			Model space	p-sd	sd	sd-pf
			Reference	T. Suzuki et al., PRC **67** (2003) 044302	B. A. Brown et al., PRC **74** (2006) 034315	Y. Utsno et al., RPC **86** (2012) 051301

1. <u>**Give almost unity of ground state**</u>
2. <u>**Produce no/little fragmentation.**</u>

May be… The tensor force is not strong enough.

If the $1d_{3/2}$ orbit lowers by ~3 MeV
The SF_{exp} can be reproduced.
→ Indicate a stronger tensor force.

USDB interaction



Summary

- **How** the neutron shell structure is changed by the $1d_{5/2}$ proton in $^{23,25}F$?

- Using proton spectroscopy of quasi-free $^{23,25}F(p,2p)$ knockout reaction
    - Direct Reaction with Exotic Beams (DREB)
    - If neutron shell does not change → ground state spectroscopic factor = 1.

- The experimental results show

  → the ground state spectroscopic factor is much smaller than 1.

  → fragmentation of the spectroscopic strength.

    - **$^{23,25}F$ are examples of Type-I shell evolution driven by tensor force.**

- The discrepancy between the experimental results and the shell model interactions
    - the strength of the tensor force should be stronger.