The parity-transfer reaction (^{16}O,^{16}F) for studies of pionic 0^- mode

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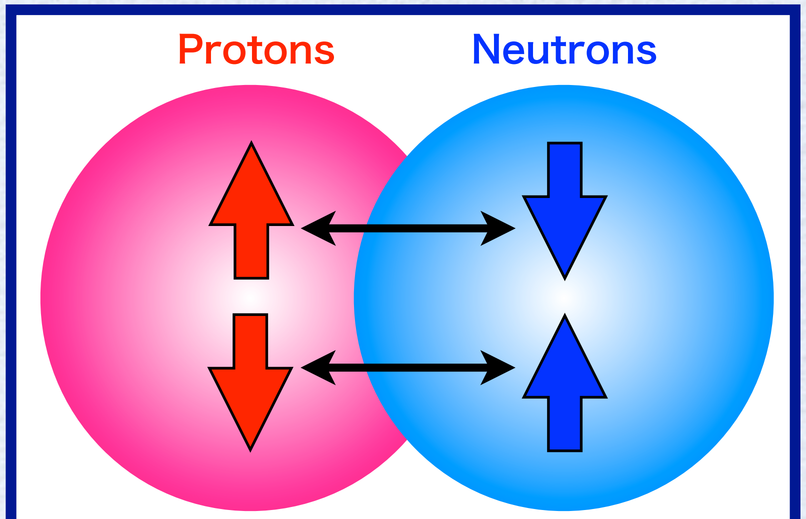
Tensor correlations in nuclei

- Tensor force
  - NN Int. is originally due to meson exchange
    ⇒ Essential in understanding of nuclear properties
    g.s. properties (total binding energy, radii, ...)
    excited state properties (excitation energy, strength, ...)
- Spin-Dipole (SD) mode
  - (Isovector) SD operator

$$\hat{O}_{\pm}^{\lambda,\mu} = \sum_i \tau_{\pm}^i r_i [Y_1(\hat{r}_i) \times \sigma_i]_\mu^\lambda$$

  - $\Delta L=1$, $\Delta S=1$, $\Delta T=1$
  - $\Delta J^{\pi}=0^-, 1^-, 2^-$



・Anti-phase vibration between protons and neutrons ($\Delta L=1$, $\Delta T=1$)
・Spin-flip mode ($\Delta S=1$)

- SD 0^- mode
  - Carries quantum numbers of pion ($J^{\pi}=0^-$, $T=1$)
  - Reflects pion-like (tensor) correlations in nuclei

Tensor Effects on 0$^-$ Strengths

C. L. Bai, H. Sagawa et al., PRC 83, 054316 (2011); Private communication

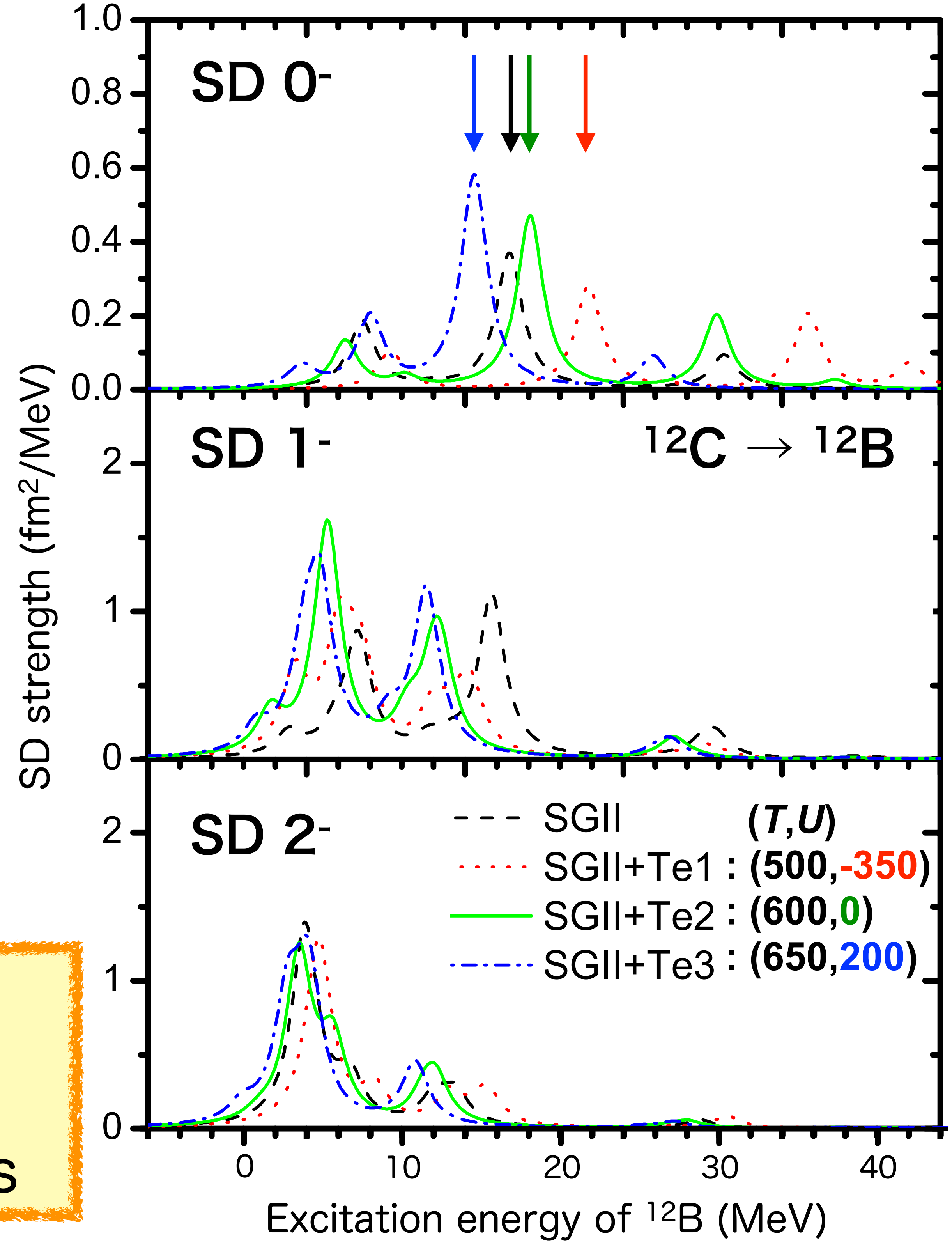
- Results of HF+RPA calc.
  - Tensor effects
    - 0$^-$ peak shifts by several MeV
  - Skyrme-type tensor int.
    - Triplet-Even : Constrained by GT data
    - Triplet-Odd : NOT well constrained

$$V^T = \frac{T}{2}\left\{\left[(\sigma_1\cdot\mathbf{k}')(\sigma_2\cdot\mathbf{k}') - \frac{1}{3}(\sigma_1\cdot\sigma_2)\mathbf{k}'^2\right]\delta(r) + \delta(\mathbf{r})\left[(\sigma_1\cdot\mathbf{k})(\sigma_2\cdot\mathbf{k}) - \frac{1}{3}(\sigma_1\cdot\sigma_2)\mathbf{k}^2\right]\right\}$$

Triplet-Even (T)

$$+\frac{U}{2}\left\{(\sigma_1\cdot\mathbf{k}')\delta(\mathbf{r})(\sigma_2\cdot\mathbf{k}) + (\sigma_2\cdot\mathbf{k}')\delta(\mathbf{r})(\sigma_1\cdot k) - \frac{2}{3}[(\sigma_1\cdot\sigma_2)\mathbf{k}'\cdot\delta(\mathbf{r})\mathbf{k}]\right\}.$$

Triplet-Odd (U)

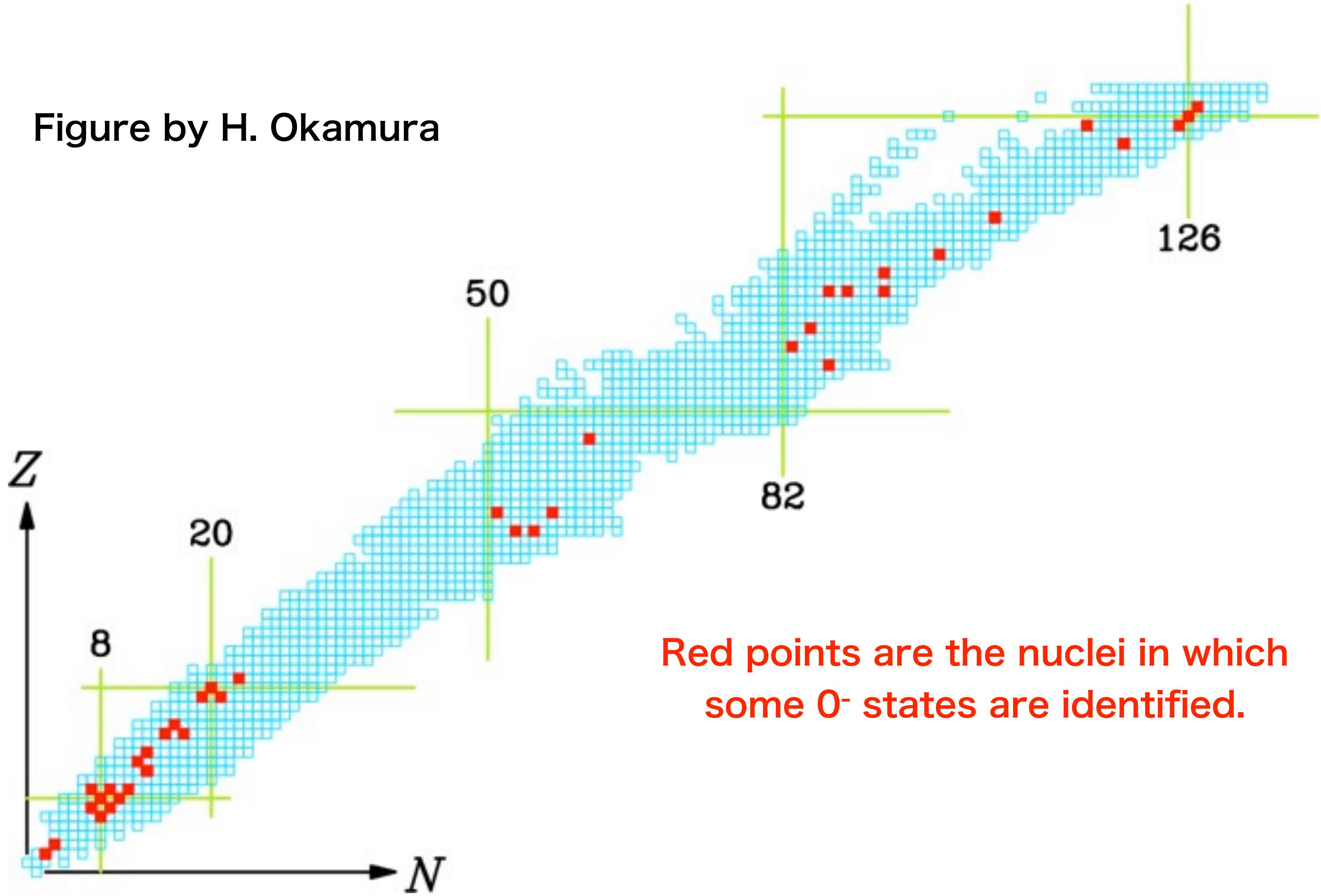


0$^-$ distribution is sensitive to tensor
⇒ Exp. data of 0$^-$ are important
to pin down tensor force effects

Status of 0^- Identification

Exp. information on 0^- states is very limited

Figure by H. Okamura



Red points are the nuclei in which some 0^- states are identified.

Exp. data of 0^- are highly desired

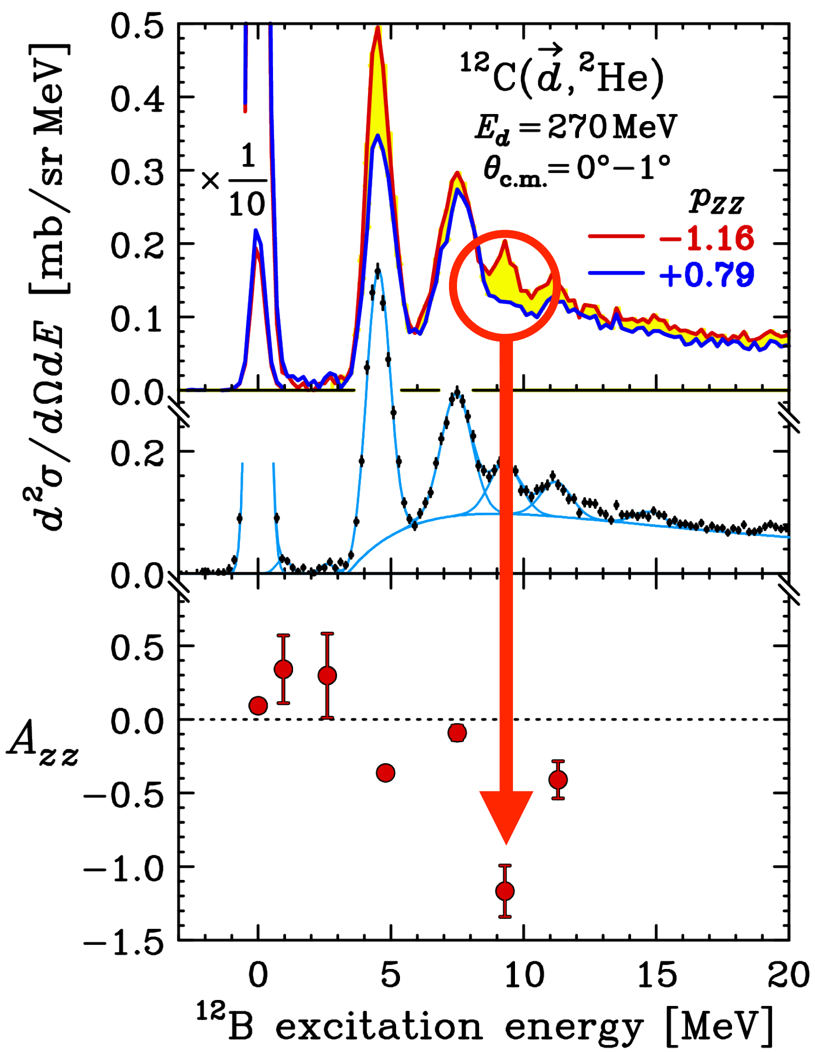
0^- Search via Polarization Measurements

Need to separate SD $0^-,1^-,2^-$ ⇒ Polarization observables

A_{zz} in $^{12}C(d,{}^2He)$

H. Okamura et al., PRC 66, 054602 (2002).

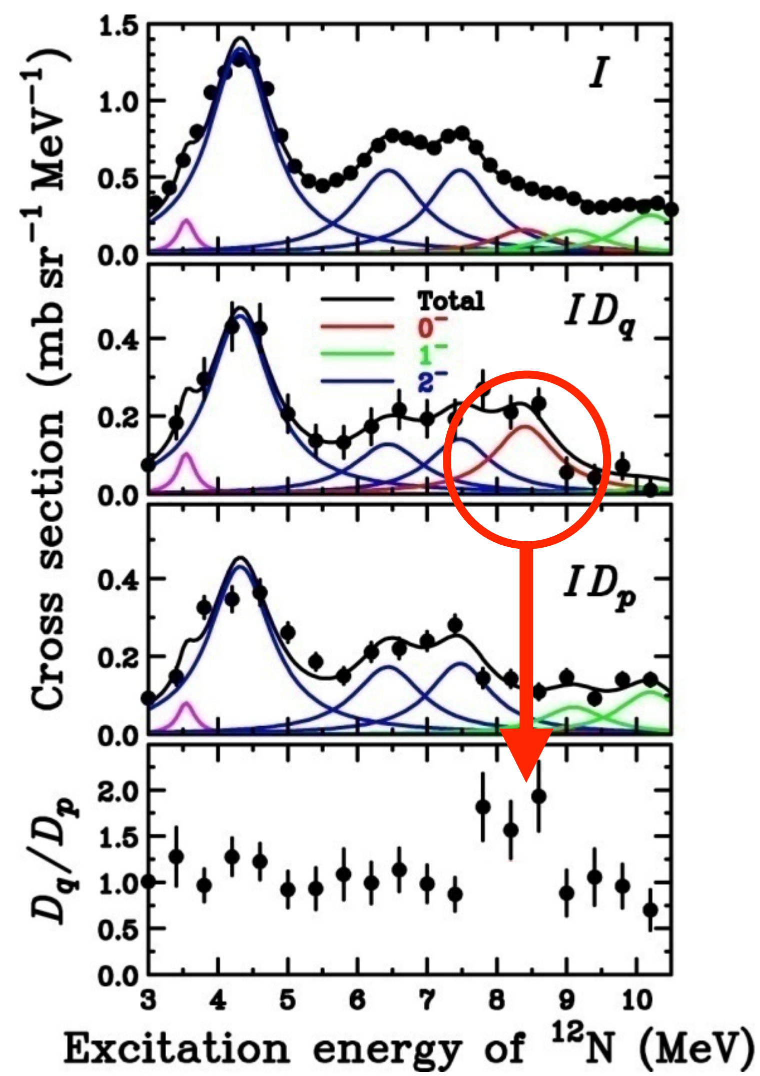
SDR	$A_{zz}(0^o)$
0^-	-2
1^-	+1
2^-	~0



D_{ij} in $^{12}C(p,n)$

M. Dozono et al., JPSJ 77, 014201 (2008).

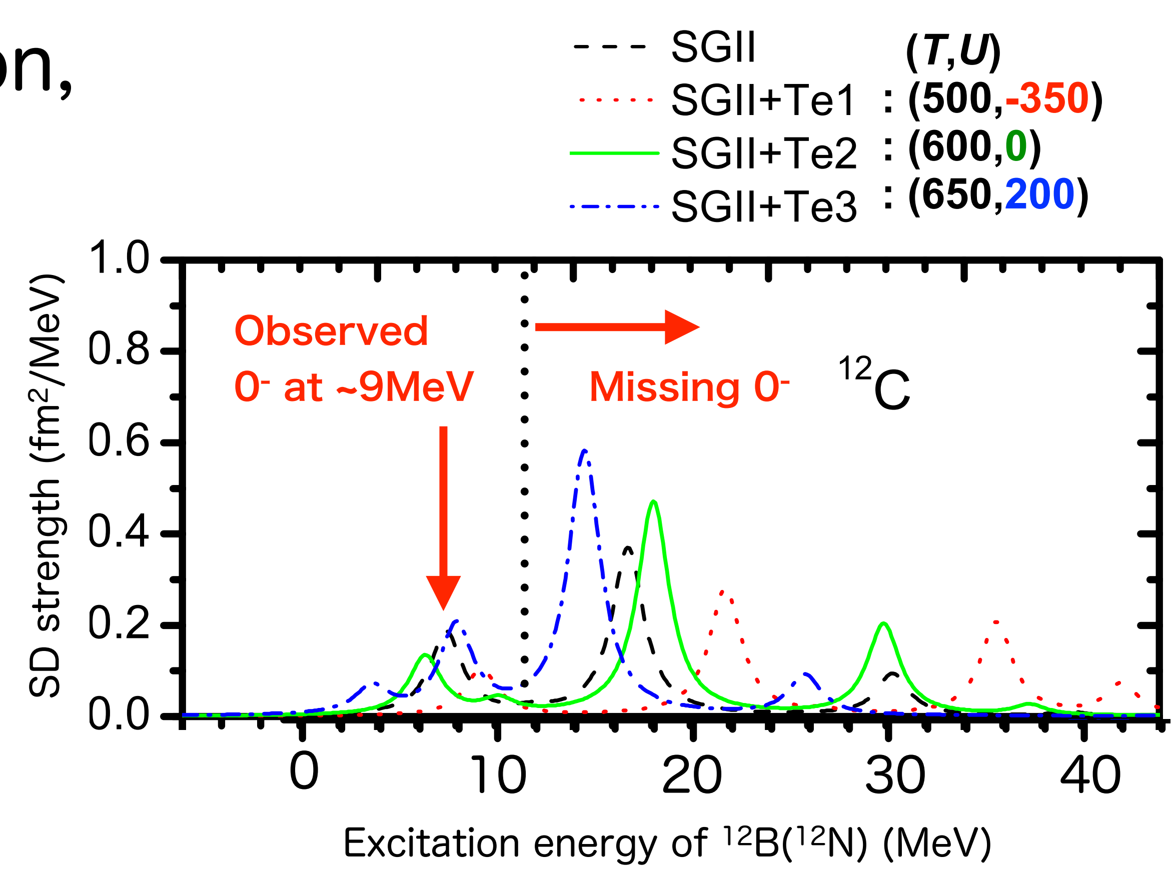
SDR	D_q/D_p
0^-	∞
1^-	0
2^-	~1



Clear observation of 0^- at E_x~9MeV in A=12 system

0^- Search via Polarization Measurements

- $^{12}C(d,^2He)$ and (p,n) experiments
  - Revealed the existence of 0^- at E_x~9MeV
  - More than half of the expected strengths are missing
    - In particular, absence of the higher-energy peak at around E_x~15MeV is still a mystery.
- Why 0^- strengths are missing ?
  - At higher excitation-energy region, Relatively large physical B.G. [Other SD, Other L (L=0,2,...)]
  - Signature of 0^- may be hindered



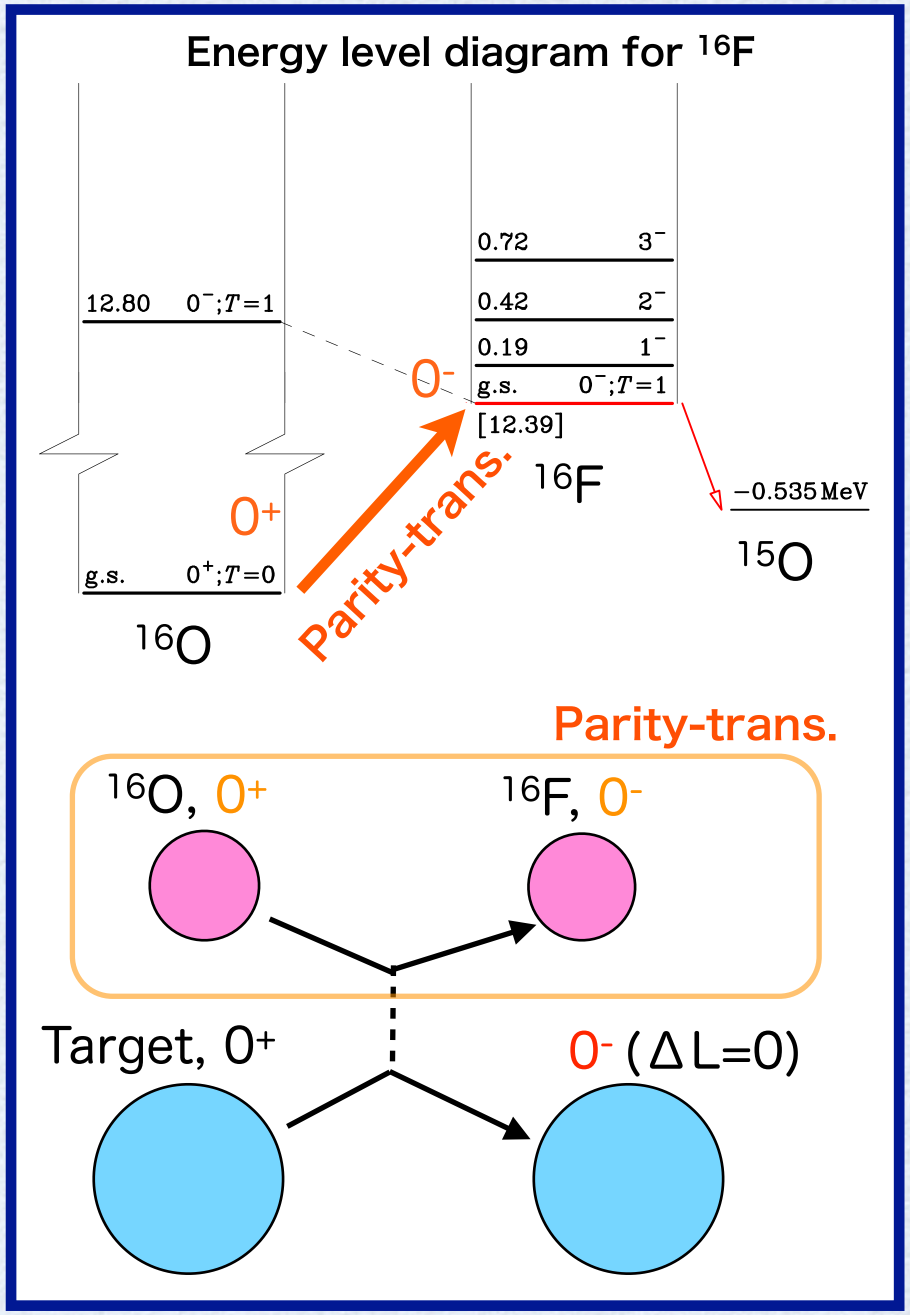
Selective tool for 0^- !

Parity-transfer (^{16}O,^{16}F) Reaction

Parity-transfer reaction is selective tool for 0^- !

- Parity-trans. (^{16}O,^{16}F)
  - ^{16}O (g.s., 0^+) → ^{16}F (g.s.,0^-)
- Advantages
  - Selectively excite unnatural-parity states
    - 1^- contribution is negligible
  - Single J^π for each ΔL
    - J^π (0^-, 1^+, 2^-,...) can be assigned only by the angular distribution (⇔ ΔL)

	ΔL=0	ΔL=1	ΔL=2	···
Parity-trans.	0^-	1^+	2^-	···
(p,n),(d,^{2}He) etc.	0^+, 1^+	0^-, 1^-, 2^-	1^+, 2^+, 3^+	···



Clean extraction of 0^- strength

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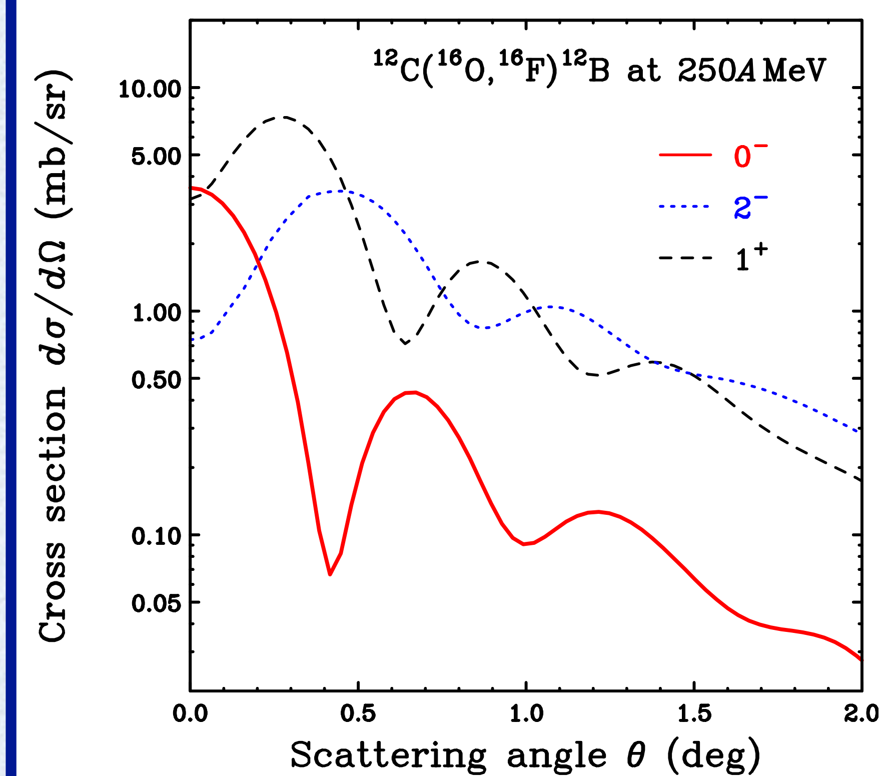
(p,n),(d,^{2}He) etc.	0^+, 1^+	0^-, 1^-, 2^-	1^+, 2^+, 3^+	…

DWBA calculations with FOLD/DWHI



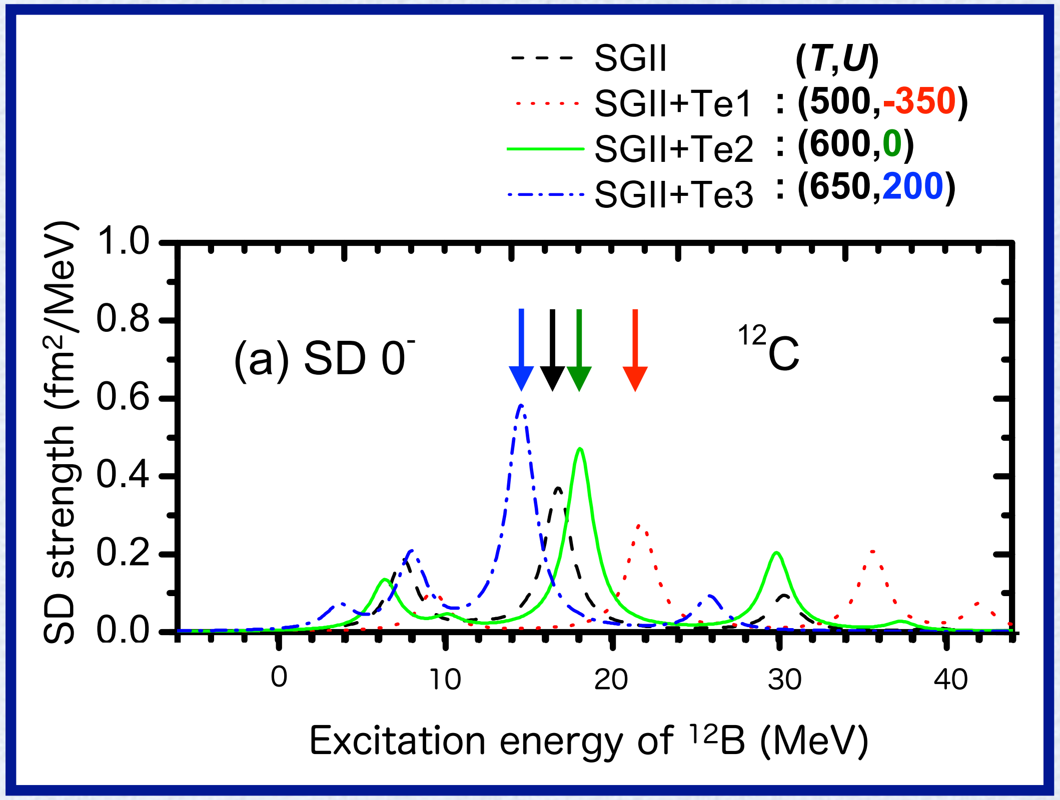
Clean extraction of 0^- strength

Proposed Experiment at RI Beam Factory

We apply parity-trans. reaction to ^{12}C target

[$^{12}C(^{16}O,^{16}F)^{12}B$ at 250A MeV]

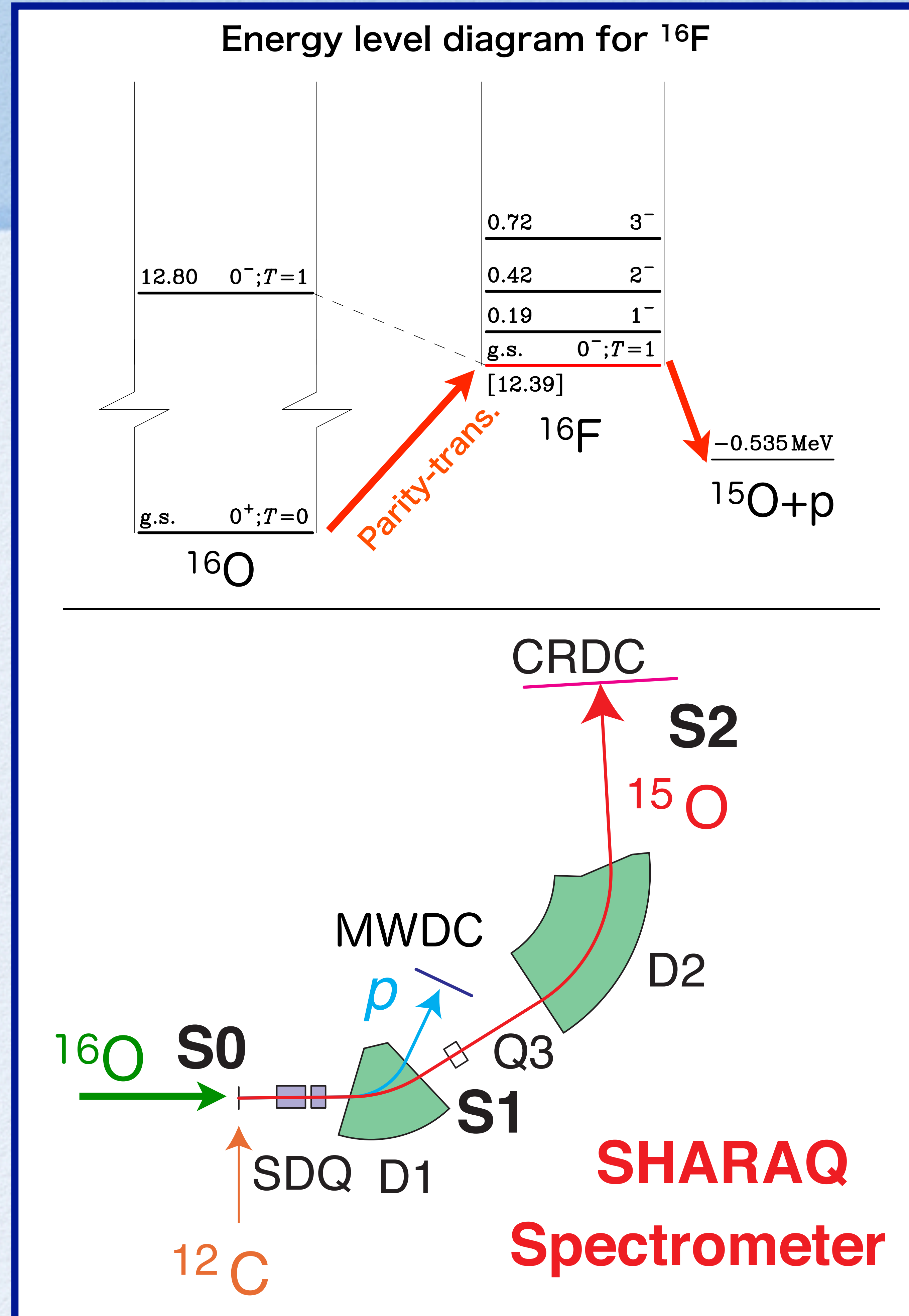
- Why ^{12}C ?
  - Known 0^- at E_x=9.3MeV in ^{12}B
    ⇒ Confirm effectiveness of parity-trans. reaction
  - Missing 0^- at E_x~15MeV
    - The position should be sensitive to tensor force effects
  - Experimentally more feasible
    - High luminosity, Low B.G. compared with heavier nuclei



Goal: Establish the parity-trans. reaction as a new tool for the 0^- study

Experimental Setup

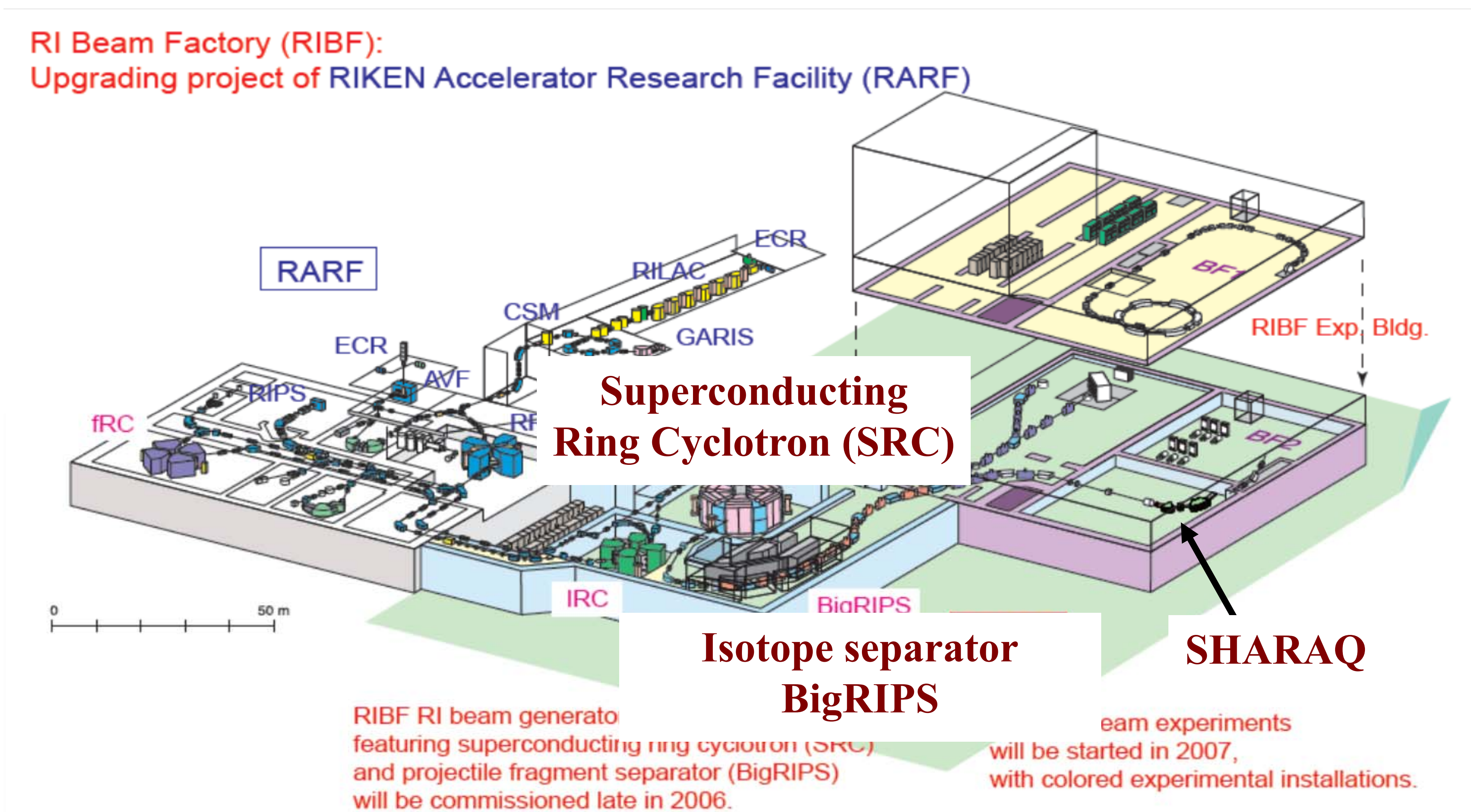
- Beam : ^{16}O
  - 250A MeV, 10^7 pps
- Target : ^{12}C
  - ^{nat}C(^{12}C,98.9%), 300mg/cm^2
- ^{16}F : unbound to ^{15}O + p
  - ^{15}O: Focal-plane detector of SHARAQ
  - p: MWDC @ exit of D1
- Methods
  - Invariant-mass of ^{15}O+p
    ⇒ Identify 0^- g.s. of ^{16}F
  - Missing-mass
    ⇒ Deduce E_x in ^{12}B and θ



RI Beam Factory at RIKEN

RIBF provides the world's most intense RI beam at 200~300MeV/u over the whole range of atomic masses.

Small ambiguities in reaction mechanism



SHARAQ spectrometer

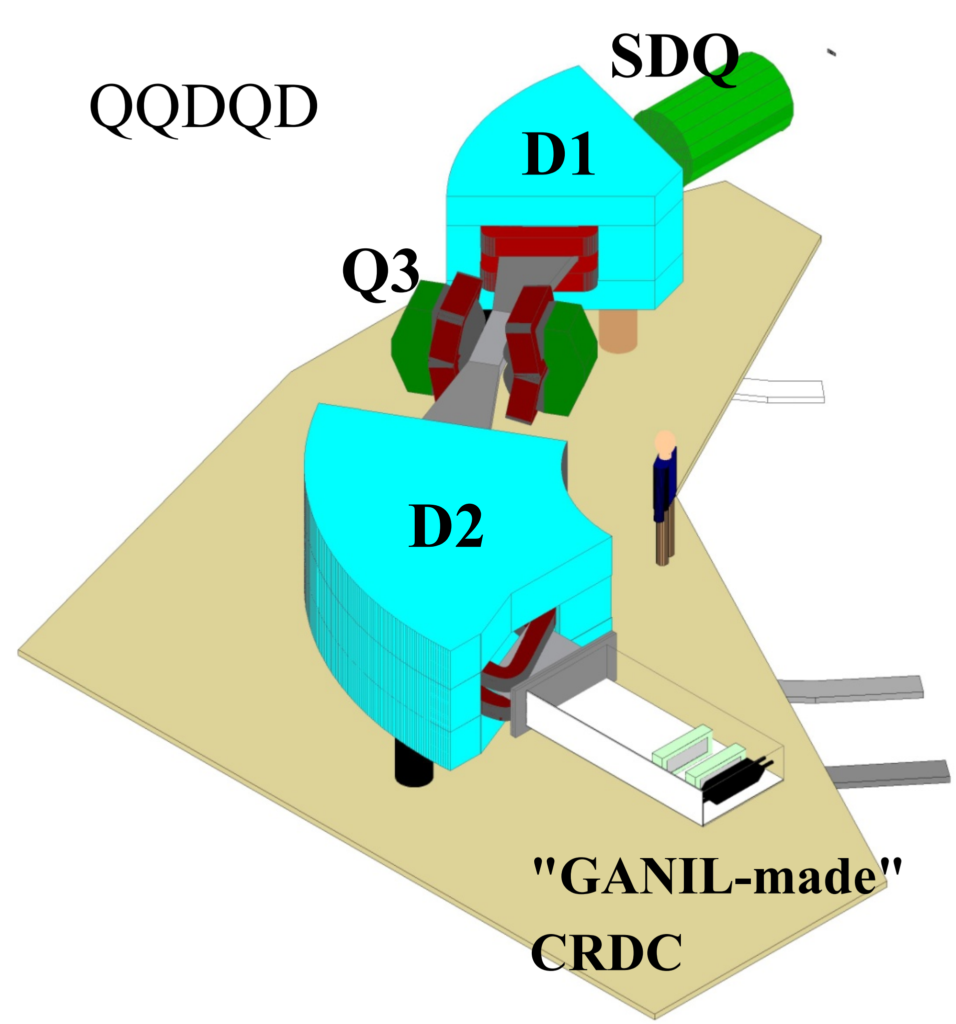
SHARAQ is a HIGH-RESOLUTION magnetic spectrometer
constructed at RIBF by Univ. of Tokyo - RIKEN collaboration

T. Uesaka et al., NIMB 266, 4218 (2008).

- Design specfication
  - Maximum rigidity : 6.8 Tm
  - Momentum resolution : dp/p = 1/14700
  - Angular resolution : ~ 1mrad
  - Momentum acceptance : ±1%
  - Angular acceptance : ~ 5msr

We can use heavy-ion reaction as a nuclear spectroscopy tool !

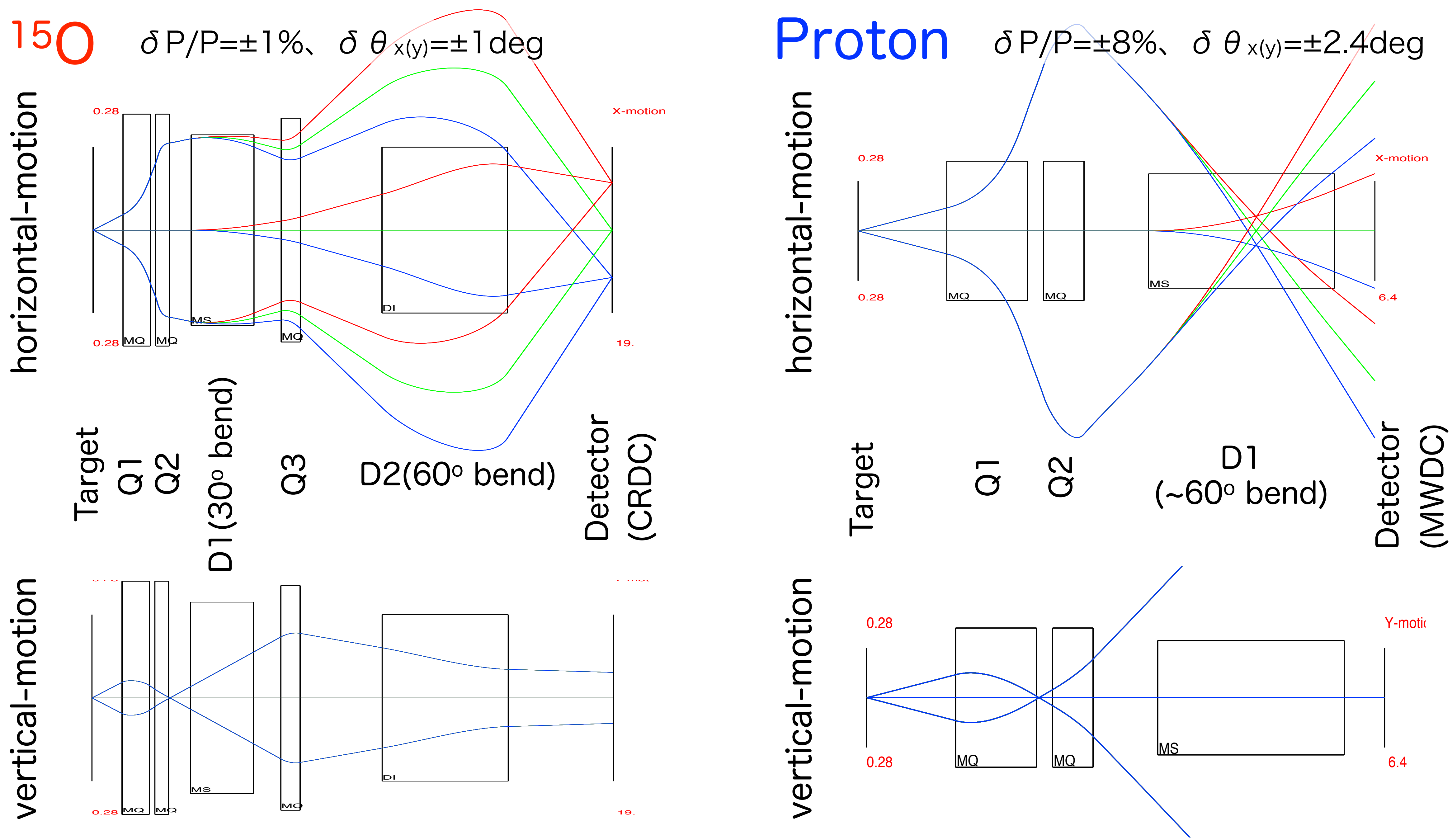
SHARAQ :
Spectroscopy with High-resolution Analyzer of Radio-Active Quantum beams



Coincidence measurement mode of SHARAQ

We simulated ion optics of SHARAQ by using program code COSY.

Standard optics mode



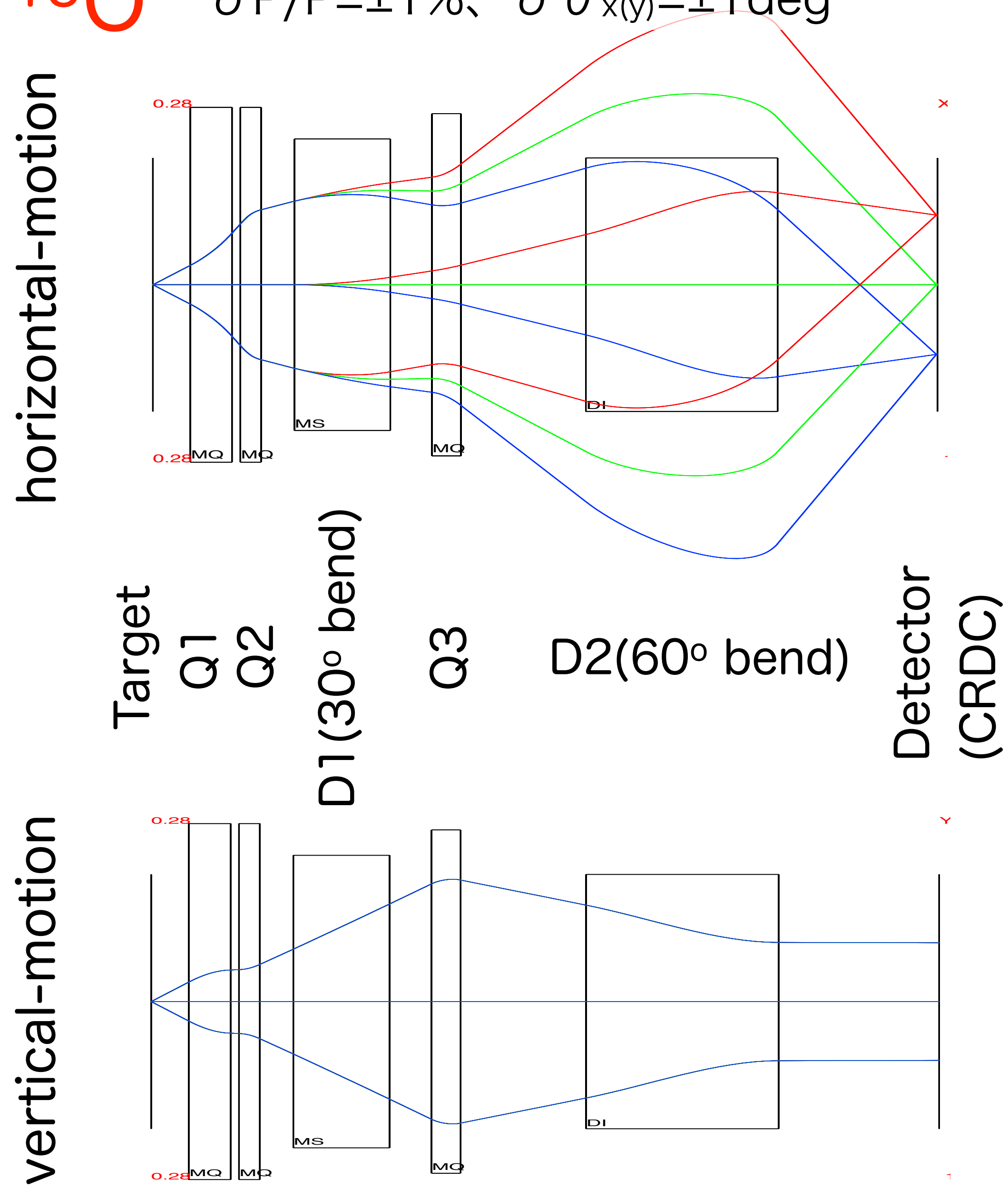
Coincidence measurement mode of SHARAQ

Acceptance for ^{16}F : 100%
$\delta p/p$ = 1/10000 for ^{15}O,
1/1200 for p

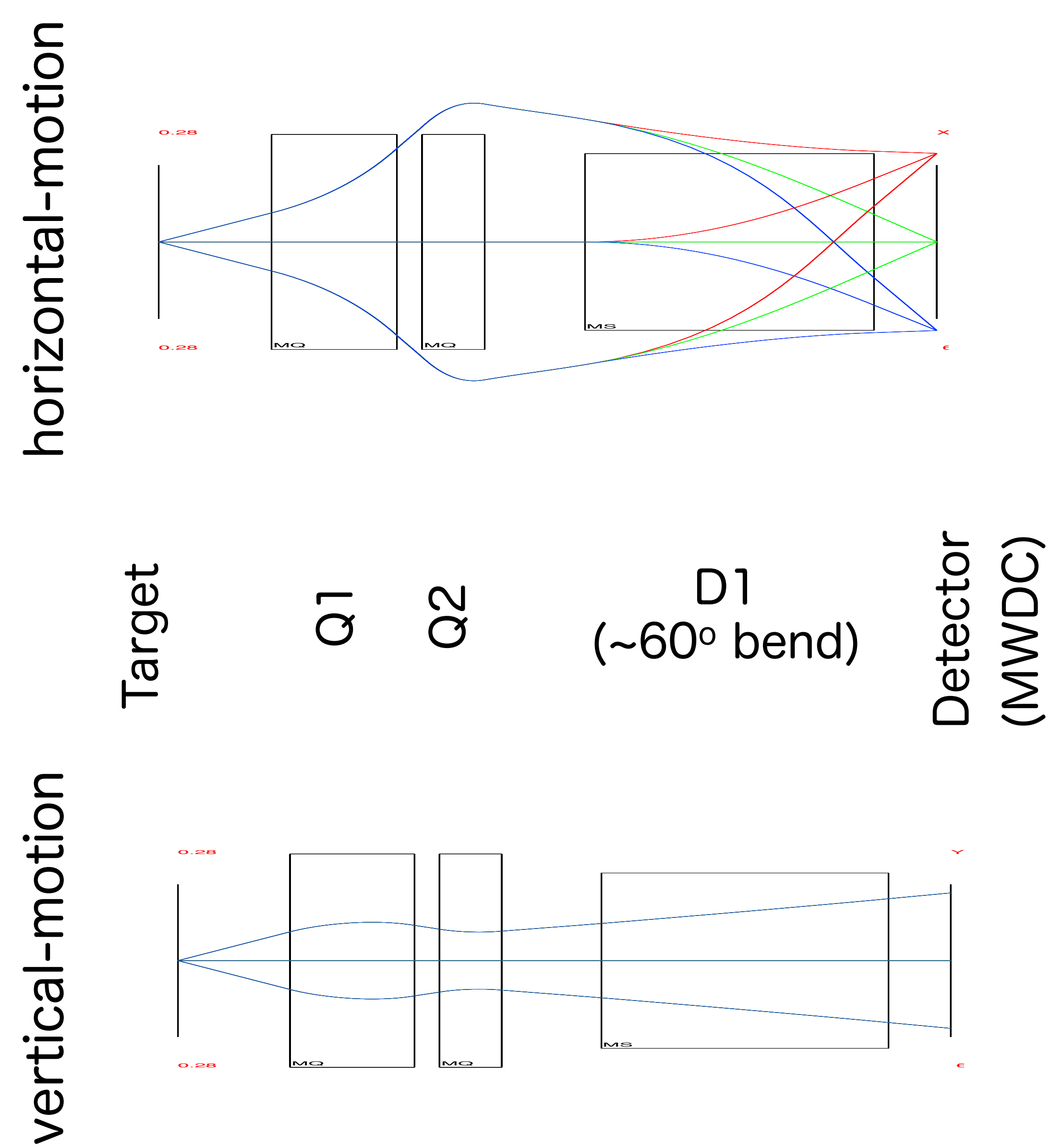
Coincidence measurement mode

- Optimized B of Q magnets, target position

^{15}O $\delta P/P=\pm 1\%$、$\delta \theta_{x(y)}=\pm 1$deg



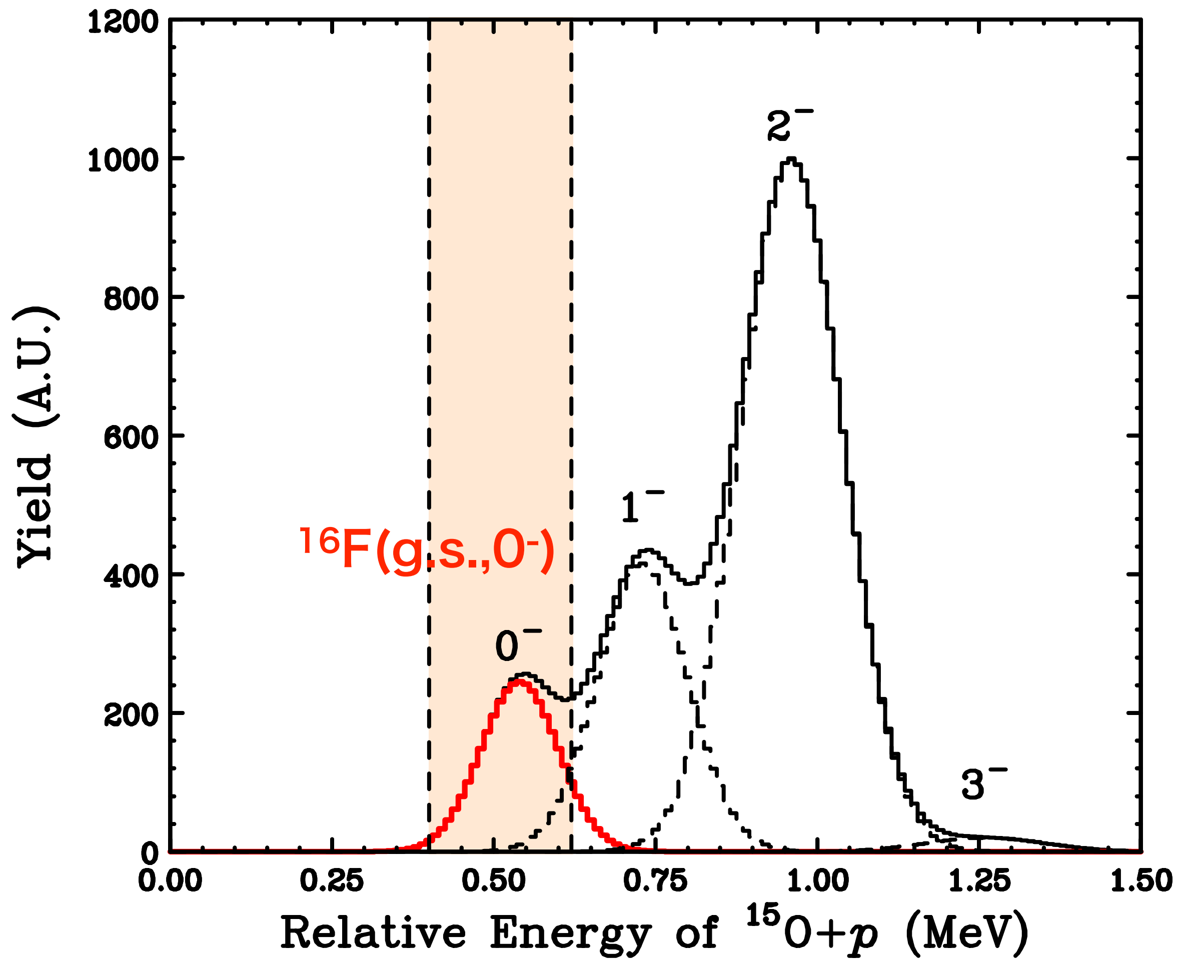
Proton $\delta P/P=\pm 8\%$、$\delta \theta_{x(y)}=\pm 2.4$deg



Expected Spectra

$\delta P_p = 1/1200, \delta\theta_p = 4$mrad
$\delta P_{15O} = 1/10000, \delta\theta_{15O} = 2$mrad

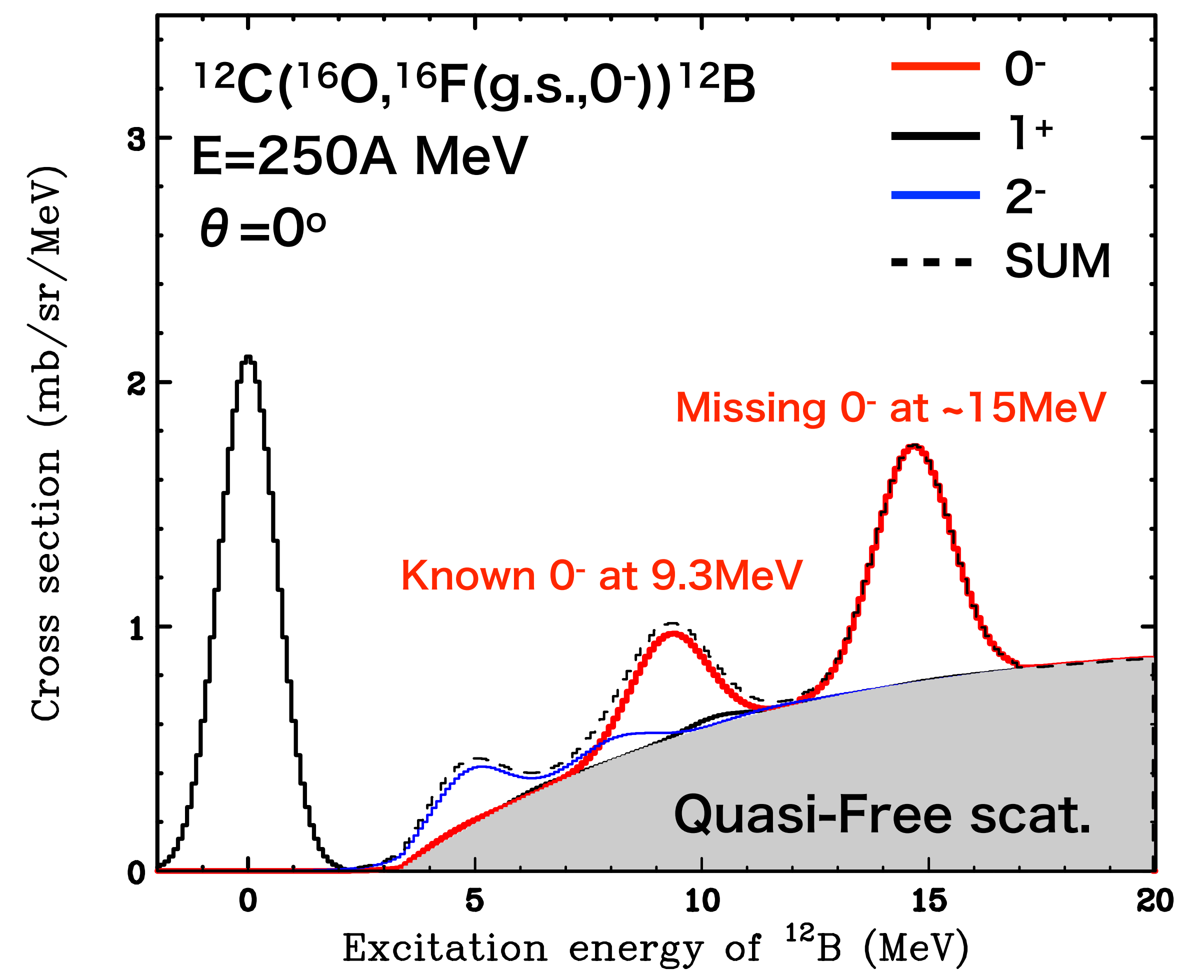
Relative energy of p+^{15}O



- δE_{rel}~160keV@0.54MeV

  ⇒ Select g.s. of ^{16}F from excited states

Missing-mass spectrum at 0^o



- δE_x~1.7MeV
- Good S/N ratio

  ⇒ Clear observation of 0$^-$

Summary

- We propose parity-transfer reaction (^{16}O,^{16}F) for 0^- study
- To confirm its effectiveness,
  we apply parity-transfer reaction to ^{12}C.
  ⇒ ^{12}C(^{16}O,^{16}F) at 250A MeV, Only possible at RIBF
- We determine the 0^- distributions in ^{12}B
  ⇒ Tensor correlation effects
- We'd like to perform the experiment in 2012.

This is FIRST-STEP study to apply parity-trans. reaction to
collective 0^- strengths in heavier nuclei
⇒ Systematic study of pionic (tensor) correlations in nuclei

Collaborators

- RIKEN Nishina Center
  - T. Uesaka, H. Sakai, T. Kubo, K. Yoshida, Y. Yanagisawa, N. Fukuda, H. Takeda, D. Kameda, N. Inabe
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- Kyushu University
  - T. Wakasa, K. Fujita, S. Sakaguchi
- Aizu University
  - H. Sagawa, M. Yamagami