

# High Resolution Spectroscopy with Primary Beams at $0^\circ$

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RCNP

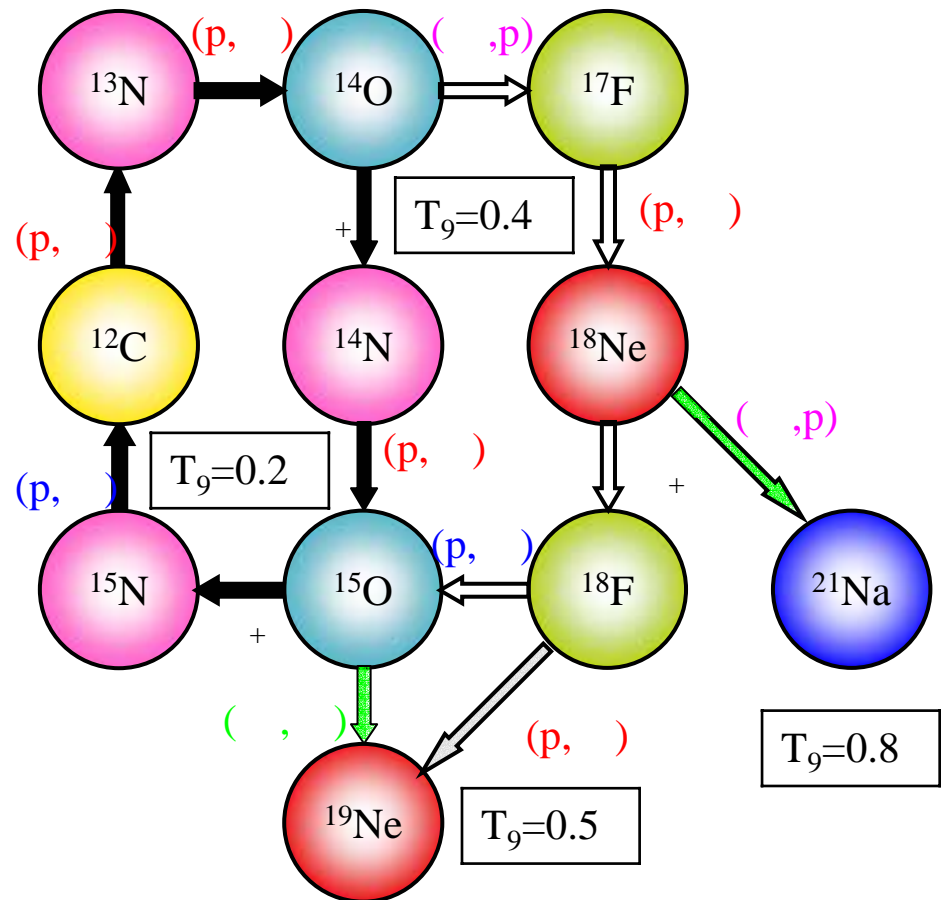
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# Spectroscopy at $0^\circ$

- ◆ Gamow-Teller strength studied via
  - $(^3\text{He}, t)$
  - $(^{12}\text{C}, ^{12}\text{N})$
  - $(^{12}\text{C}, ^{12}\text{B}) \dots$
- ◆ Advantage
  - **$L=0$  dominant at  $0^\circ$**
  - **Spin-Flip (GT) dominant**
  - **Smallest distortion effects**  
 **$\sim 300 \text{ MeV/u}$  covered by RIBF**
- ◆ High resolution spectroscopy
  - Measure GT states observed with  $\beta$ -decays  
**(100-200 keV resolution is required for heavy nuclei)**
  - **Give GT unit cross sections**
- ◆ Spectroscopy via
  - $(^4\text{He}, ^6\text{He})$
  - $(^4\text{He}, ^8\text{He})$
- ◆ Access to proton-rich side
  - Astro-physics interest
  - rp-process
- ◆ Advantage
  - **Only  $E_x$  and  $\Gamma$  are needed**
  - **Can be measured at  $0^\circ$**
- ◆ High res. Spectroscopy
  - **100-200 keV resolution is required to measure  $E_x$  and  $\Gamma$**

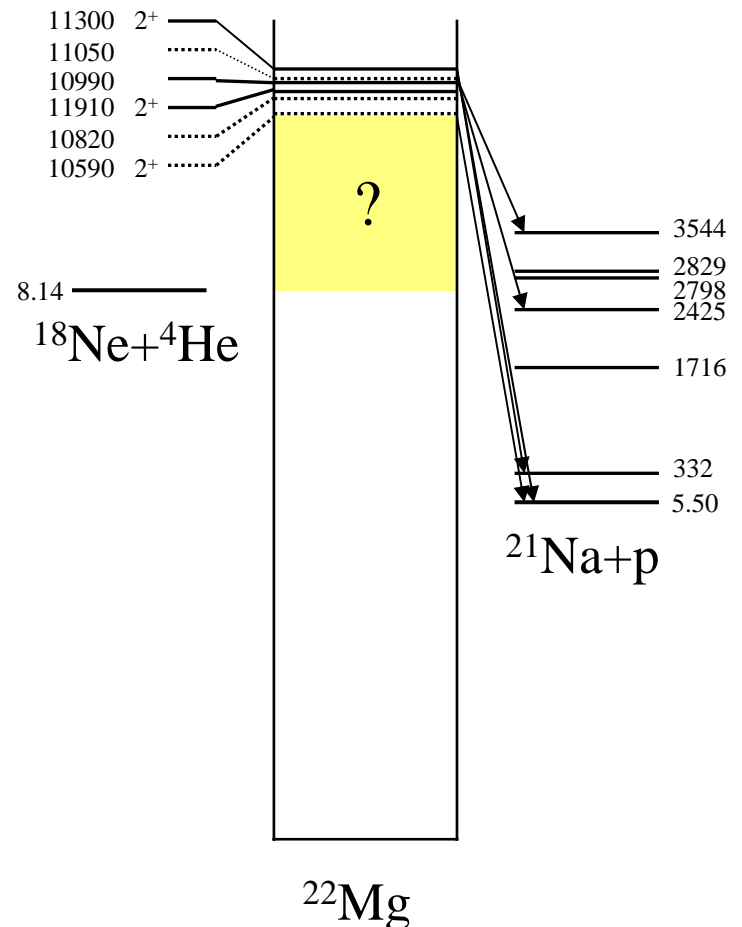
# H-CNO Cycle

- ◆ At  $T_9=0.2$   
CNO cycle only
- ◆ At  $T_9=0.4$   
Start bypass cycle through  $^{14}\text{O}(\alpha,p)^{17}\text{F}$
- ◆ At  $T_9=0.5$   
Breakout from CNO cycle through  $^{15}\text{O}(\alpha,p)^{19}\text{N}$
- ◆ At  $T_9=0.8$   
Breakout from CNO cycle through  $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$



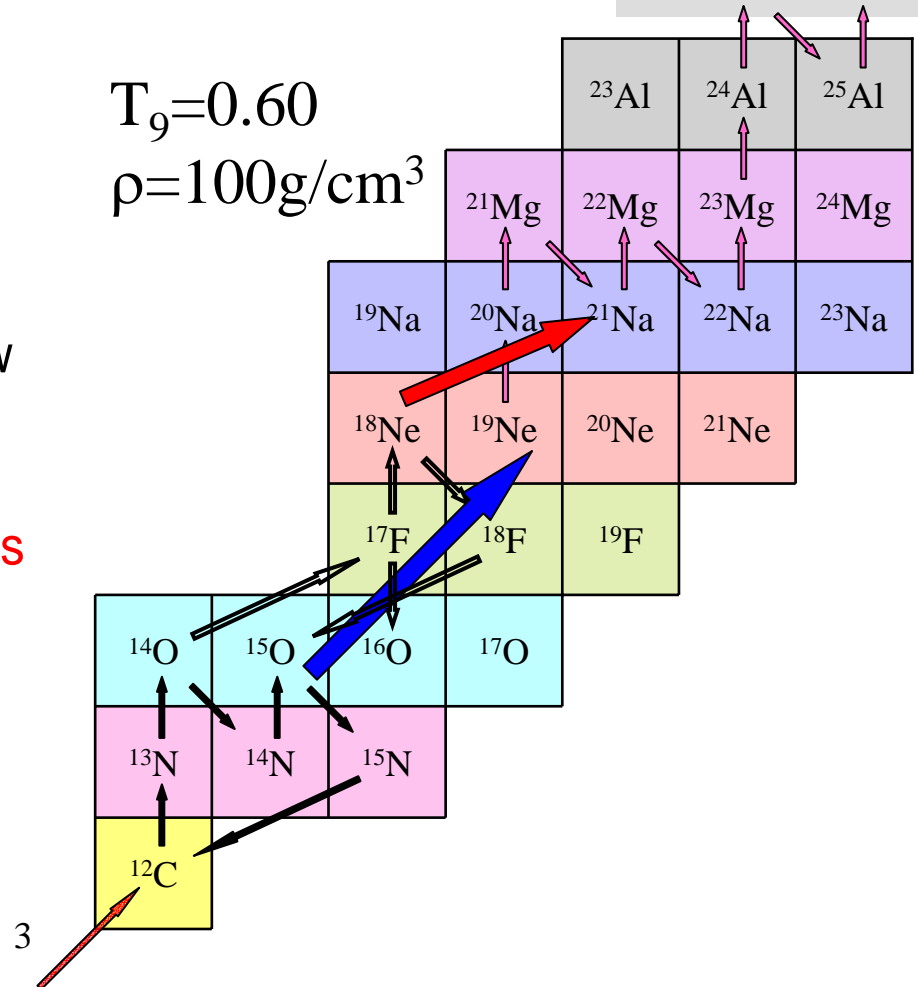
# Level scheme of $^{22}\text{Mg}$

- ◆ Level scheme of  $^{22}\text{Mg}$  is determined by the  $^{21}\text{Na}+p$  reaction (Inverse kinematics)
- ◆ Levels at  $E_x=8-10.6$  MeV are unknown
- ◆ If there are some levels, breakout of CNO cycle is accelerated through  $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$  at  $T_9=0.8$



# Breakout from CNO Cycle

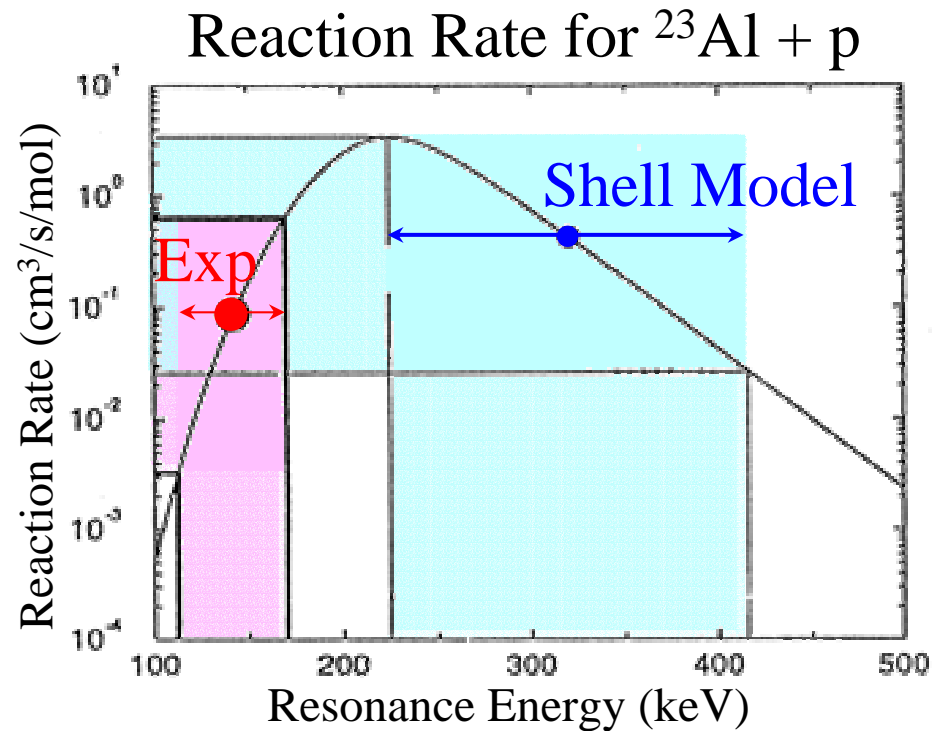
- At  $T_9=0.60$   
Breakout from CNO cycle is mainly via  $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$
- At  $T_9=0.8$   
If there are some levels in low energy region  
( $E_x > 8$  MeV)  
Breakout from CNO cycle is accelerated through  
 $^{18}\text{Ne} + \alpha$   $^{22}\text{Mg}^*$   $^{21}\text{Na} + p$



# Requirement for High-Resolution Spectroscopy

- ◆ Reaction cross section
$$\sigma = \frac{\Gamma^2}{(E - E_R)^2 + (\Gamma/2)^2}$$

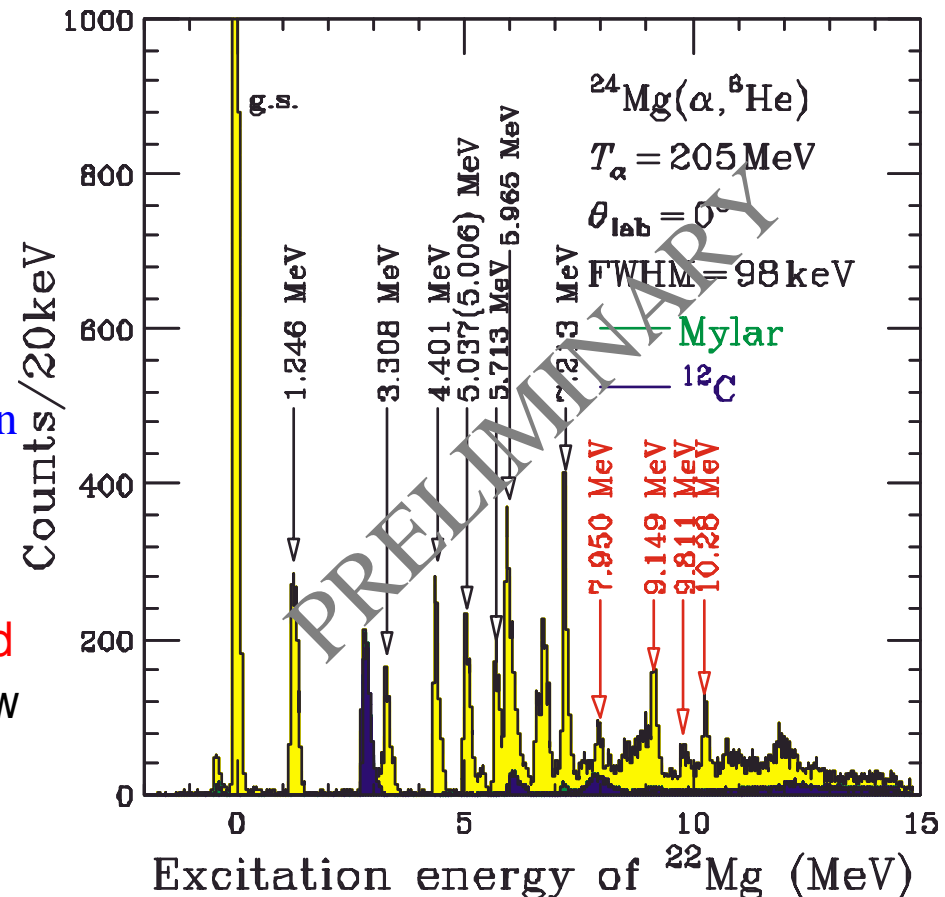
$E_R$ : Resonance energy  
 $\Gamma$ : Resonance Width
- ◆ Luminosity  
Boltzmann distribution  
with stellar temperature
- ◆ Reaction rate is sensitive to resonance energy  
 **$E_R$  should be determined experimentally with high accuracy (high resolution)**
- ◆ Experimentally determined reaction energy  $E_R$  is significantly different with theoretical one



# RCNP E163

Y. Kitamura, GPA. Berg et al.

- ◆ Resonance states in  $^{22}\text{Mg}$  studied via the  $^{24}\text{Mg}(\alpha, ^6\text{He})^{22}\text{Mg}$  reaction
- ◆ Experimental conditions
  - $^{22}\text{Mg}$ : 1.8 mg/cm<sup>2</sup>
  - $\alpha$ -beam: 205 MeV, 80 nA
  - Beam resolution: >150 keV
  - Final resolution after dispersion matching: 98 keV (determined by target multiformity)
- ◆ Several levels have been observed
- ◆ Peak assignment ( $E_R$  and  $\Gamma$ ) is now in progress



# WS Beam Line at RCNP

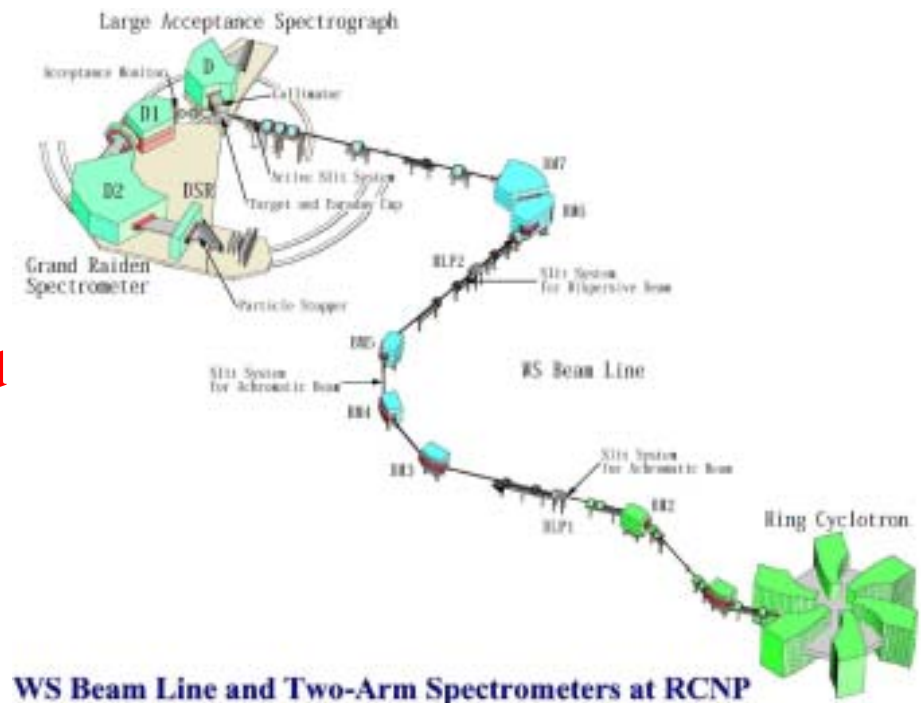


- ◆ RCNP new beam line for GR/LAS
- ◆ Constructed in 1999-2000
- ◆ Experiments with WS after April 2000
- ◆ Complete matching with GR
- ◆ Double achromatic mode is also available

West Experimental Hall at RCNP

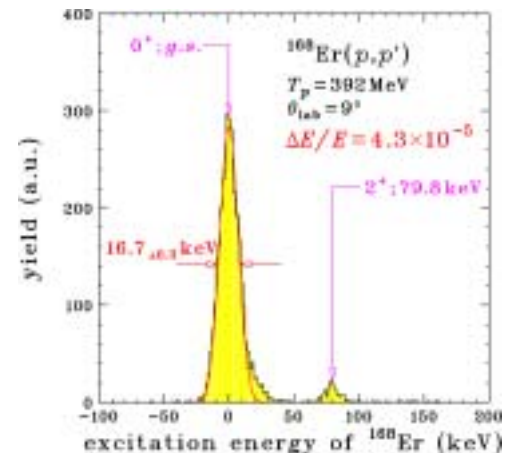
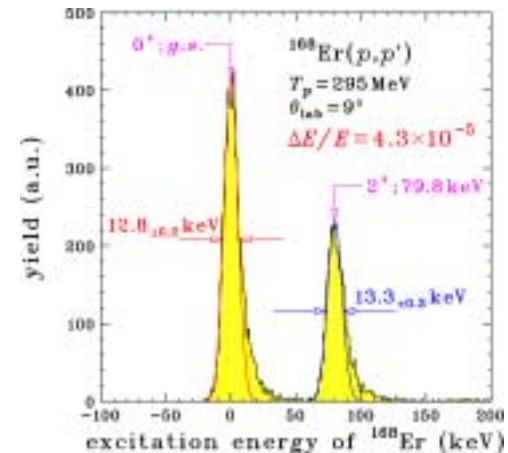
# Specifications of WS

- ◆ Total length: 65.46m
- ◆ Total bending angle:  $270^\circ$
- ◆ Five double-focus points (Two for BLP)
- ◆ Dispersive mode
  - Dispersion: 37.1 m
  - Angular dispersion: 20.0 rad
  - Compete matching with GR
- ◆ Achromatic mode
  - Lateral dispersion: 0 m
  - Angular dispersion: 0 rad
  - Double achromatic beam



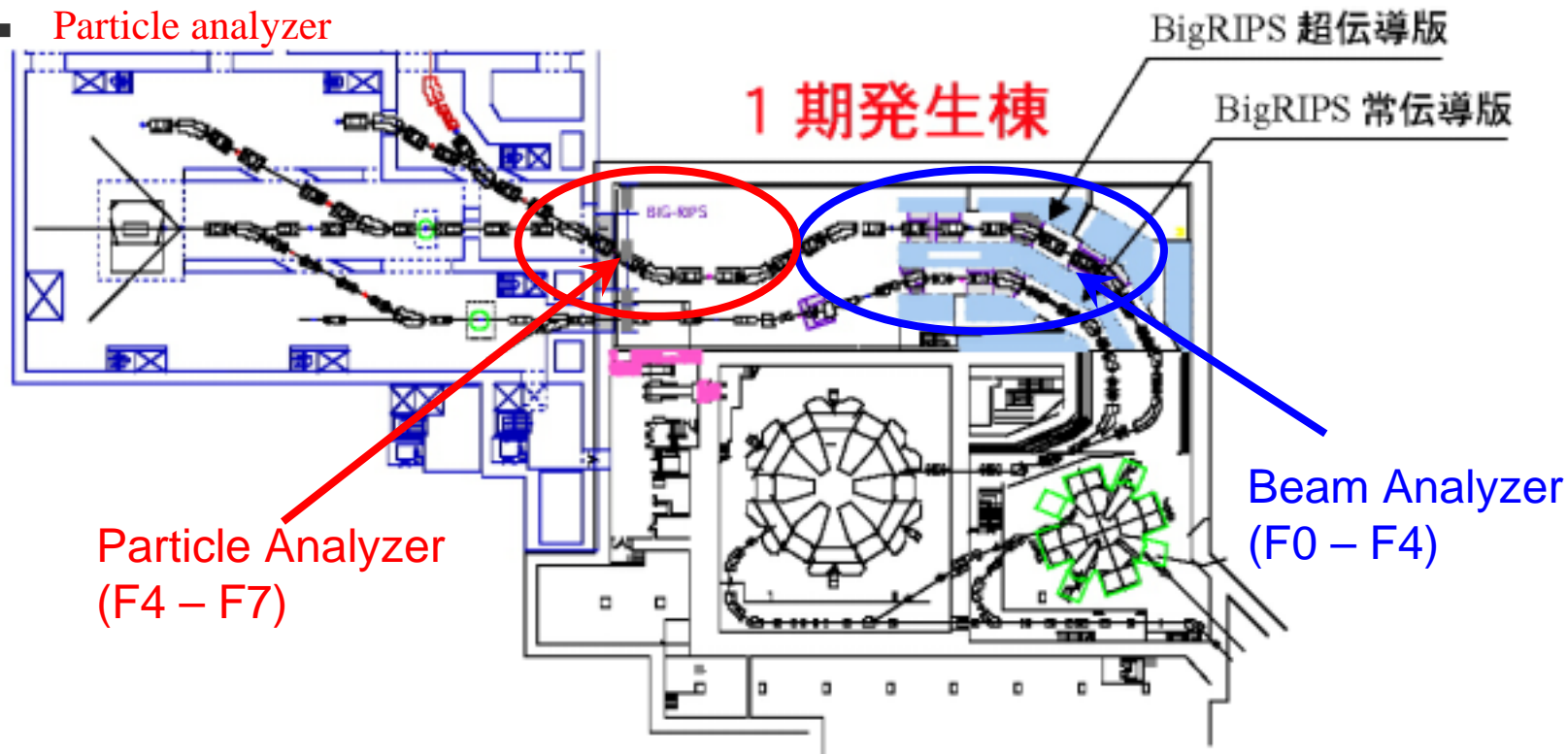
# Typical Spectrum of $^{168}\text{Er}(p,p')$ after Employing Dispersion Matching

- ◆ Bean energy
  - 295 MeV (April 2000)
  - 392 MeV (June 2000)
- ◆ Beam energy spread  
 $\Delta E$ : 150 keV(FWHM)
- ◆ Target  
 $^{168}\text{Er}$ : 2 mg/cm<sup>2</sup>
- ◆ Energy resolution
  - 13.0 keV for 295 MeV
  - 16.7 keV for 392 MeV
- ◆ Energy resolutions are consistent with the resolving power limit of Grand Raiden



# Possibility for High Resolution Spectroscopy with Big-RIPS

- ◆ Use Big-RIPS as
  - Beam analyzer for dispersion matching
  - Particle analyzer



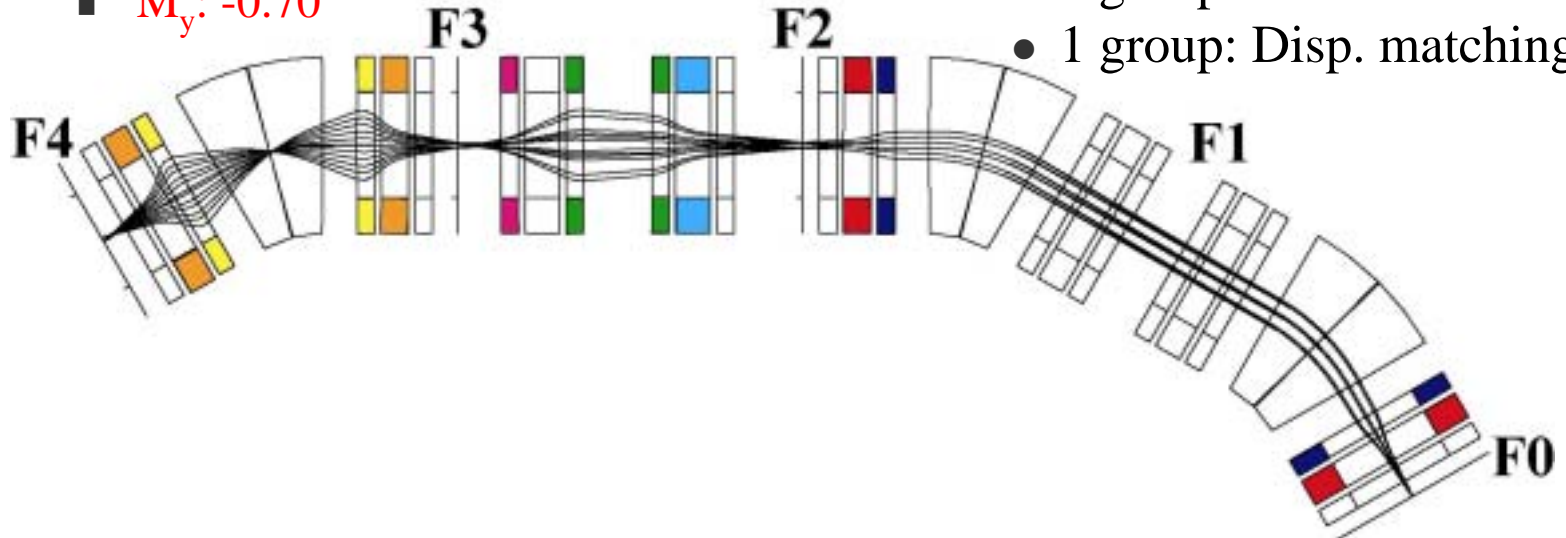
# Requirements

- ◆ To achieve 100 keV resolution
  - $\Delta p = 1.5 \times 10^{-4}$
  - Resolution of spectrometer  $> 7000$   
(if the object size of beam = 1mm)
  - Dispersion matching is required  
(the energy spread of beam  $> 100$  keV)
- ◆ To perform experiments efficiently
  - Angular acceptance:  $\Delta\theta = \pm 10$  mrad,  $\Delta\phi = \pm 30$  mrad (1.2 msr)  
(cf. 5.6 msr for Grand Raiden)
  - Momentum acceptance:  $\Delta p = \pm 1\%$   
(cf.  $\Delta p = \pm 2.5\%$  for Grand Raiden)

# Beam Envelopes of Beam Line (From F0 to F4)

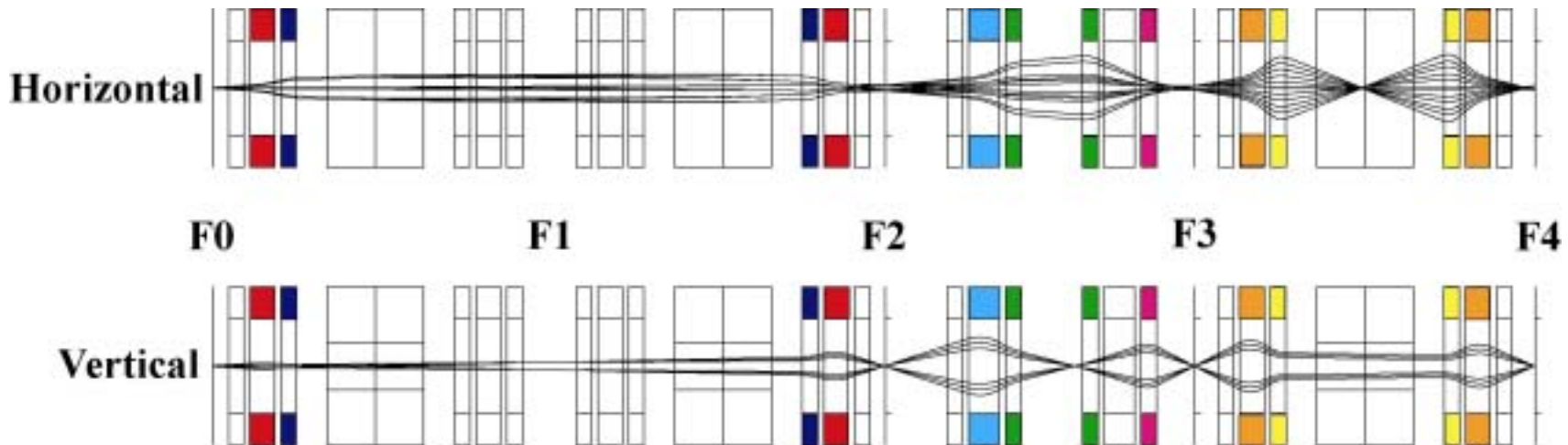
- ◆ Divided into 3 sections
  - F0-F2: Dispersive
  - F2-F3: Matching
  - F3-F4: Achromatic
- ◆ Ion-optical properties
  - $M_x$ : 0.76
  - $D$ : 4.47 m
  - $M_y$ : -0.70

- ◆ Double focused at the end of each section
  - 2 groups of Q for F0-F2 and F3-F4: Unique (Envelope min. Focus point)
  - 3 groups of Q for F2-F3
    - 2 groups: Double focus
    - 1 group: Disp. matching



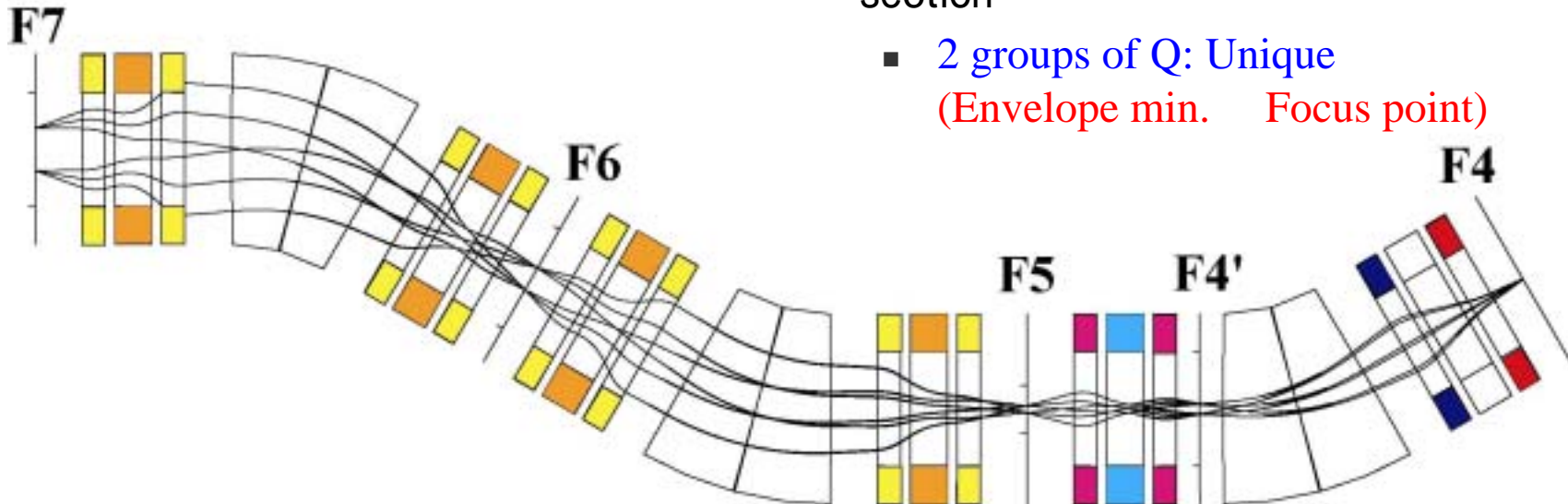
# Beam Envelopes of Beam Line (From F0 to F4)

- ◆ Beam Envelopes
  - $\Delta x = \pm 1\text{mm}$ ,  $\Delta y = \pm 1\text{mm}$
  - $\Delta\theta = \pm 5\text{mrad}$ ,  $\Delta\phi = \pm 5\text{mrad}$
  - $\Delta p = \pm 0.1\%$



# Beam Envelopes of Spectrometer (From F4 to F7)

- ◆ Divided into 3 sections
  - F4-F4': Dispersive
  - F4'-F5: Rotate dispersion
  - F5-F7: Dispersive
- ◆ Ion-optical properties
  - $M_x$ : 0.55
  - $D$ : 4.47 m ( $R=8100$  for 1mm)
  - $M_y$ : 19.1
- ◆ Double focused at the end of each section
  - 2 groups of Q: Unique  
(Envelope min.    Focus point)



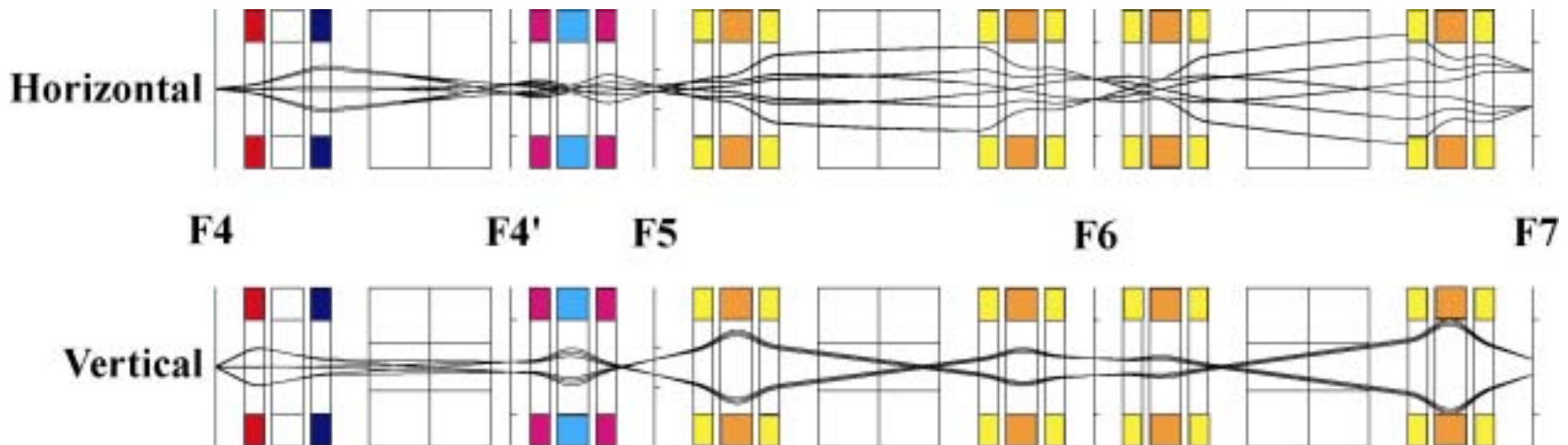
# Beam Envelopes of Spectrometer (From F4 to F7)

## ◆ Beam Envelopes

- $\Delta x = \pm 1\text{mm}$ ,  $\Delta y = \pm 1\text{mm}$
- $\Delta\theta = \pm 10\text{mrad}$ ,  $\Delta\phi = \pm 10\text{mrad}$
- $\Delta p = \pm 1\%$

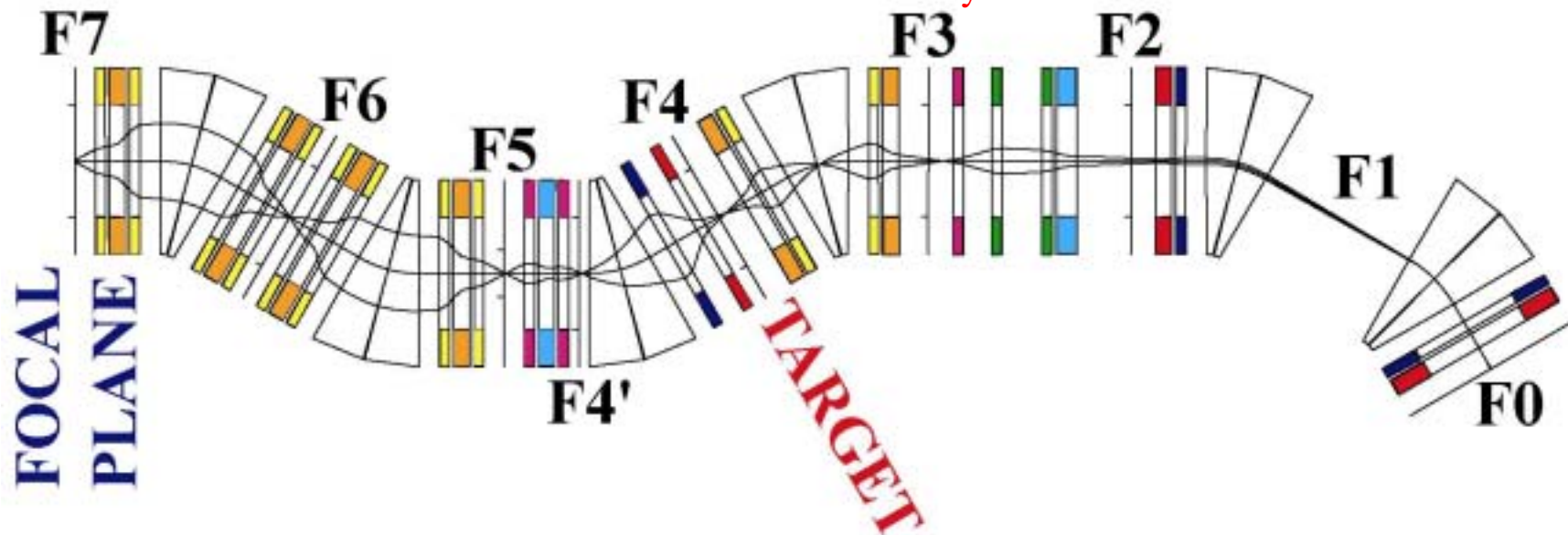
## ◆ Acceptance

- $\Delta x = \pm 1\text{mm}$ ,  $\Delta y = \pm 1\text{mm}$
- $\Delta\theta = \pm 8\text{mrad}$ ,  $\Delta\phi = \pm 30\text{mrad}$
- $\Delta p = \pm 1\%$



# Dispersion Matching between Beam Line and Spectrometer

- ◆ Beam Envelopes
  - $\Delta p = \pm 0.1\%$
- ◆ Ion-optical properties
  - $M_x: 0.42$
  - $D: 0 \text{ m}$
  - $M_y: 13.1$



# Summary

- ◆ Spectroscopy at  $0^\circ$ 
  - Charge exchange ( $^3\text{He}, t$ ), ( $^{12}\text{C}, ^{12}\text{N}$ ), ( $^{12}\text{C}, ^{12}\text{B}$ ) reactions  
Deduce GT unit cross sections and GT strengths
  - ( $^4\text{He}, ^6\text{He}$ ), ( $^4\text{He}, ^8\text{He}$ ) etc.  
Information for rp-process
  - High resolution spectroscopy
- ◆ Possibility for High Resolution Spectroscopy
  - $R = 8000$  (100 keV for 400 MeV)
  - Acceptance = 1.0 msr ( $\Delta\theta = \pm 8$  msr,  $\Delta\phi = \pm 30$  msr)
  - Momentum acceptance =  $\pm 1\%$
  - There will be much more appropriate usage of (part of) Big-RIPS for spectrometer (Large acceptance, high resolution etc.)  
(Just 1 day calculations)
- ◆ Dispersion matching is possible
  - Large dispersion of 10m will be possible with F0-F4 of Big-RIPS  
(Spectrometer part will be limit the total resolution)