Recent developments and research projects at the low-energy RI beam facility CRIB

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Daid Kahl (Postdoc.)

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東京大学 THE UNIVERSITY OF TOKYO

with an Aid of Technical Staff:

N. Yamazaki (CRIB/Wien Filter), K. Yoshimura, T. Senoo, Y. Ohshiro (Hyper ECR ion source), S. Yamaka

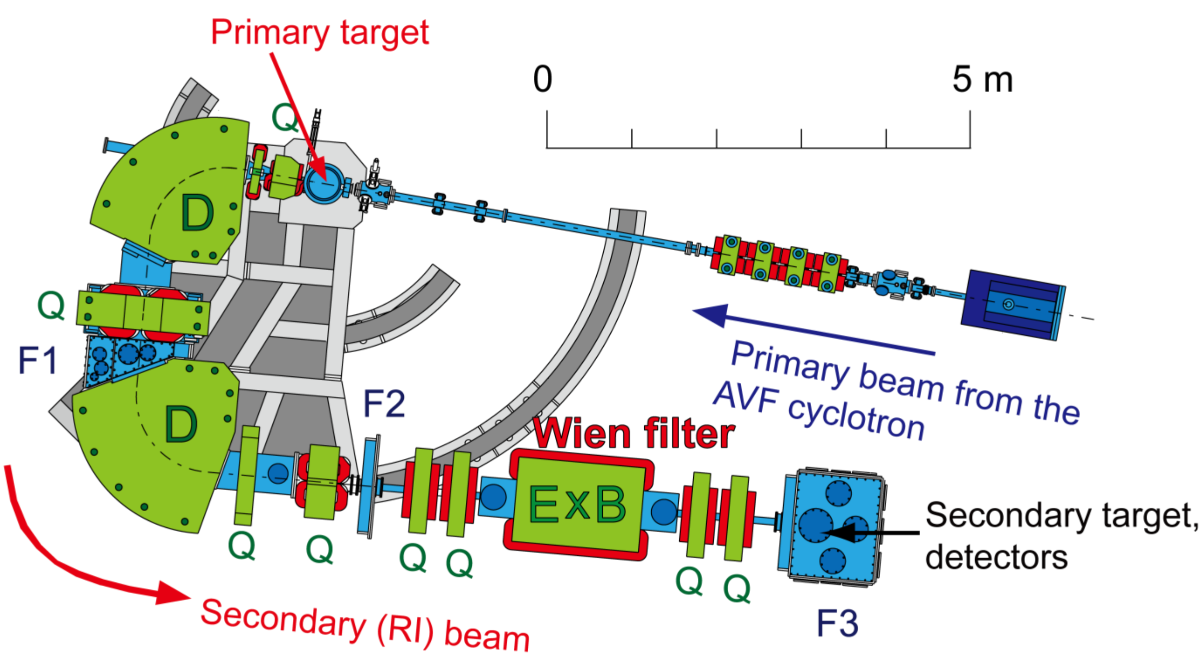
in Collaboration with:

RIKEN, KEK, Kyushu, Tsukuba, Tohoku, Osaka, … (Japan)

McMaster (Canada), CIAE, IMP (China), Chung-Ang, Ehwa, SNU (Korea), INFN Padova/Catania (Italy), IOP(Vietnam) and others.

CRIB

- CNS Radio-Isotope Beam separator , operated by CNS (Univ. of Tokyo), located at RIBF (RIKEN Nishina Center).
  - Low-energy(<10MeV/u) RI beams by in-flight method.
  - Primary beam from K=70 AVF cyclotron.
  - Momentum (Magnetic rigidity) separation by "double achromatic" system, and velocity separation by a Wien filter.
  - Orbit radius: 90 cm, solid angle: 5.6 msr, momentum resolution: 1/850.



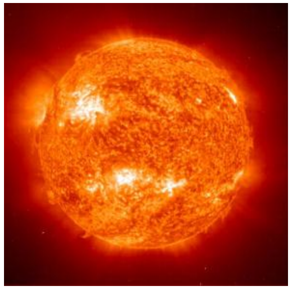
Why low-energy RI beam?

- Stellar astrophysical reactions :

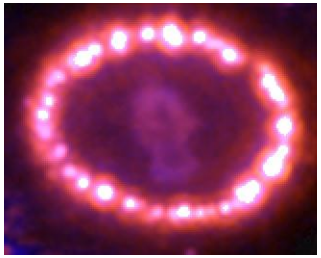
  T ~ 10^6-10^9 K (typically keV to a few MeV).

  ⇒ Low energy is not bad energy!

  It is an advantage for nuclear astrophysics and structure study.



The Sun

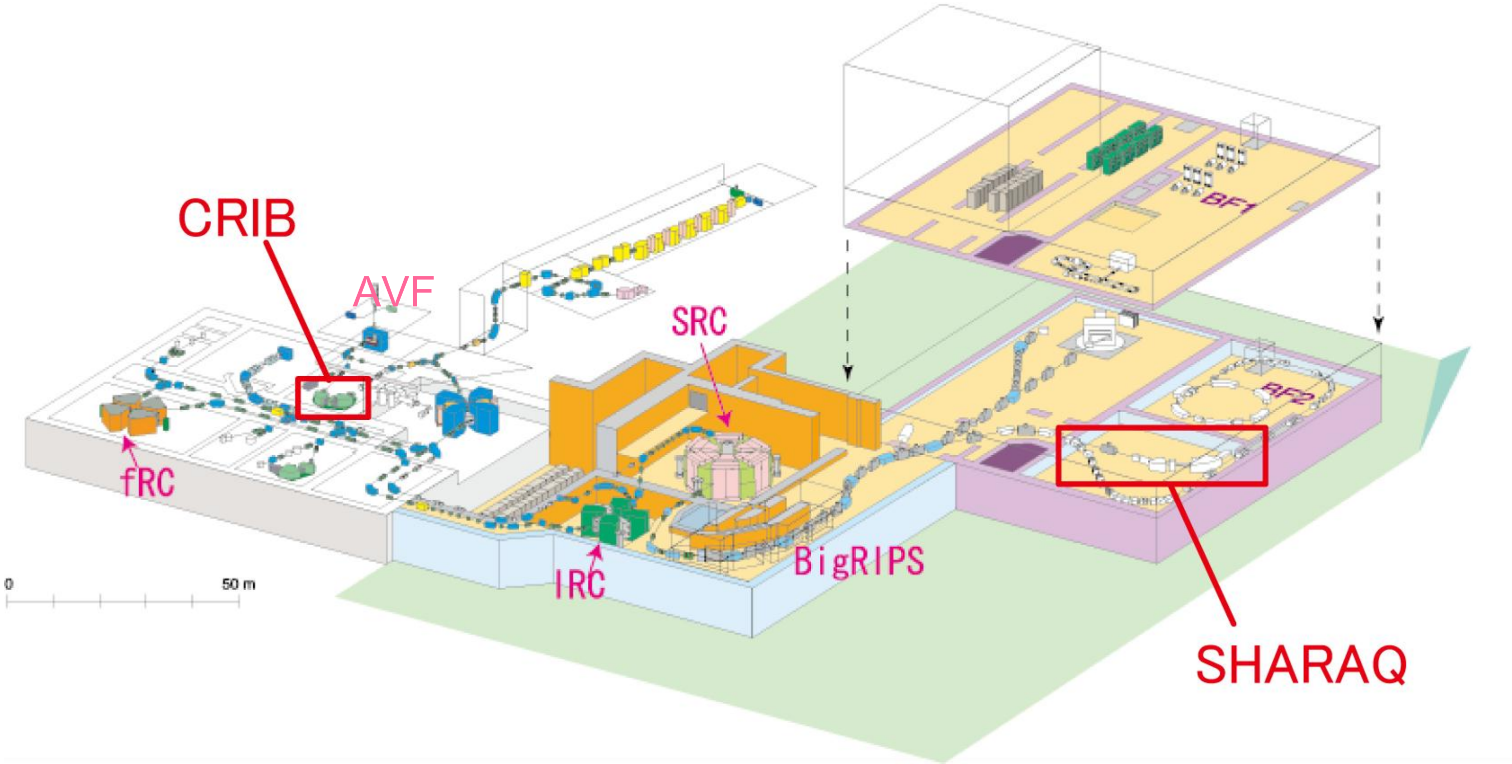


SN1987A

•Nucleosynthesis proceeds through unstable nuclei in some processes(p-p chain, CNO cycle, r-, rp-, processes etc.)

CRIB in RIBF

- AVF alone, operation cost ~1/10 of BigRIPS.
- Ion source / AVF/ CRIB…have been developed under CNS-RIKEN collaboration (joint venture).

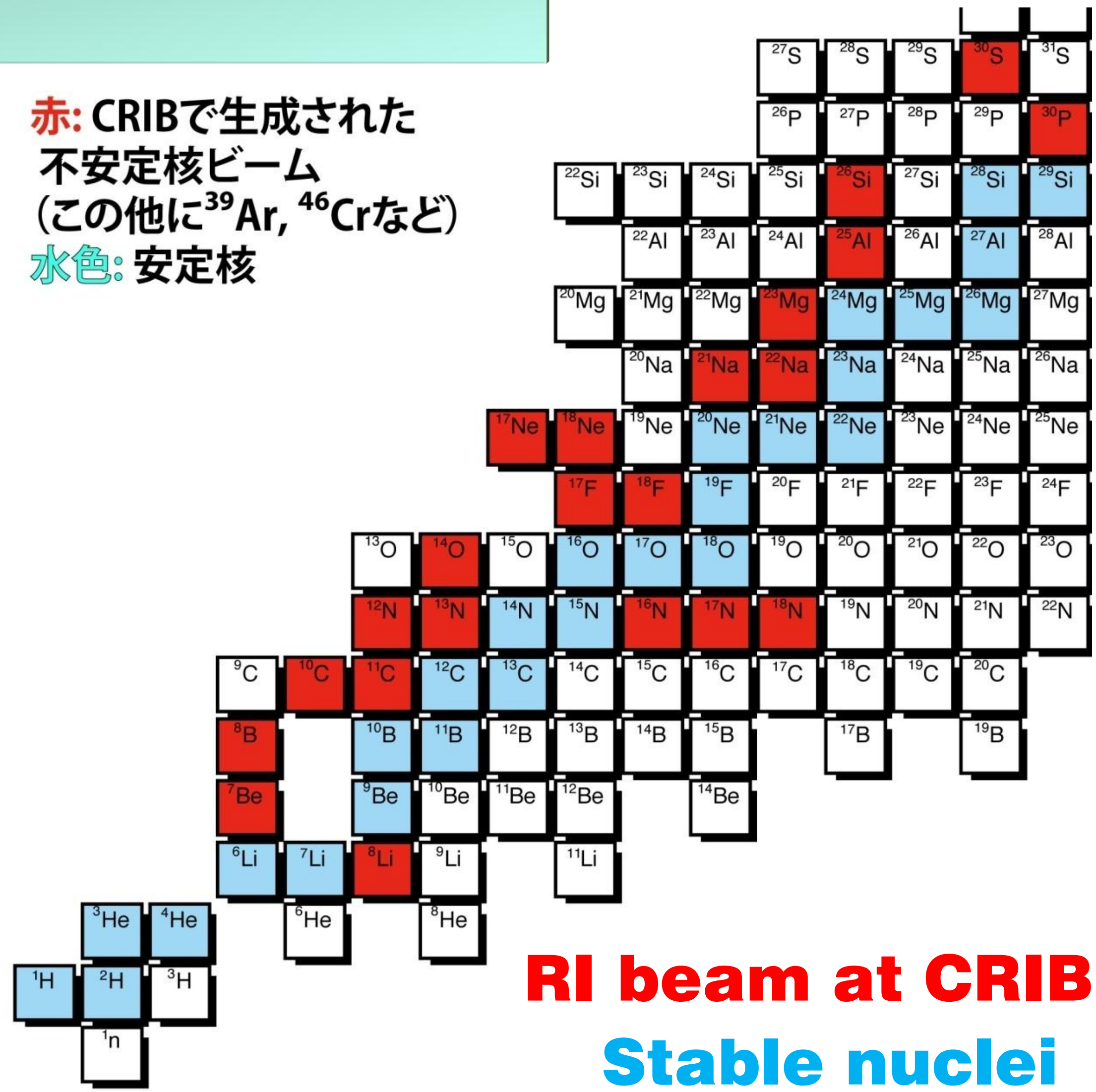


Low-Energy RI beam Productions at CRIB

Direct reactions such as (p,n), (d,p) and (^{3}He,n) in inverse kinematics are mainly used for the production….large cross section

Many RI beams have been produced at CRIB: typically 10^4-10^6 pps

赤: CRIBで生成された
不安定核ビーム
(この他に^{39}Ar, ^{46}Crなど)
水色: 安定核



RI beam at CRIB / Stable nuclei

Recent developments at CNS/CRIB

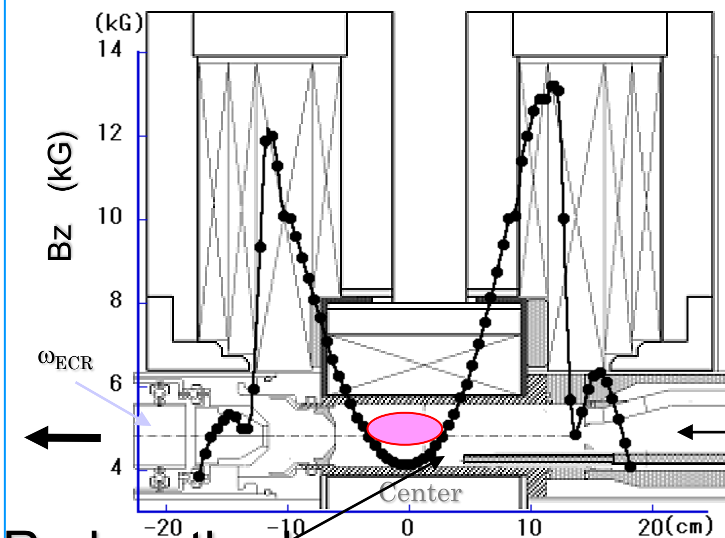
- Ion source more intense / new beams (^{6}Li, ^{42}Ca),
- Accelerator/Beam line "Core monitor" for non-destructive readout of the beam current

  S. Watanabe et al., NIM A (2011).
- Cryogenic target Used in most of experiments.

  H.Yamaguchi et al., NIM A (2008).
- Wien filter Improvement of insulators, monitoring system.
- Active target (GEM-MSTPC) Used in (α,p) reaction measurements.

Metal ion production at HyperECR… by Y. Ohshiro (CNS)

◆For stable ion extraction…crucible position is important



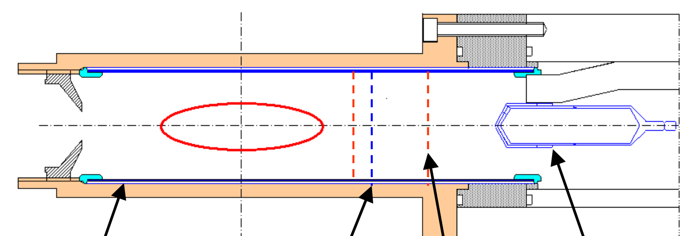
◆Using a crucible with many exit holes

・ Holes: Φ 2 m m × 5

・ Crucible Positioning At first, move it close to ECR zone to heat, then move it back.

⇒ $^{7}Li^{2+}$ stable production at ~40mm

⇒$^{87}Rb^{20+}$ at stable production ~15mm

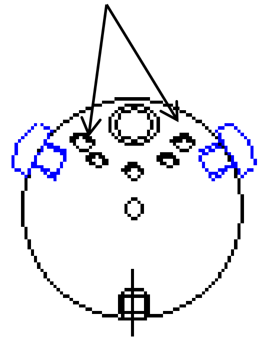


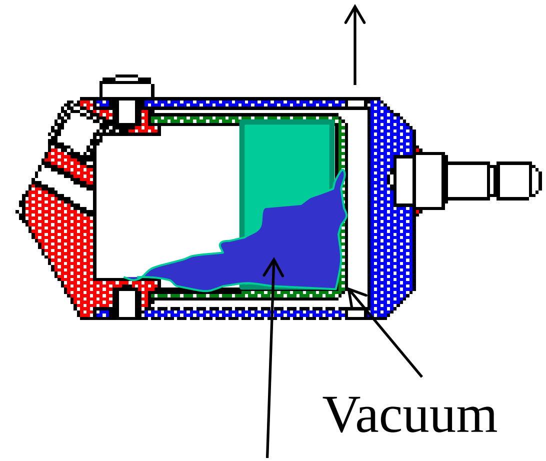
Dewar crucible with multiple holes

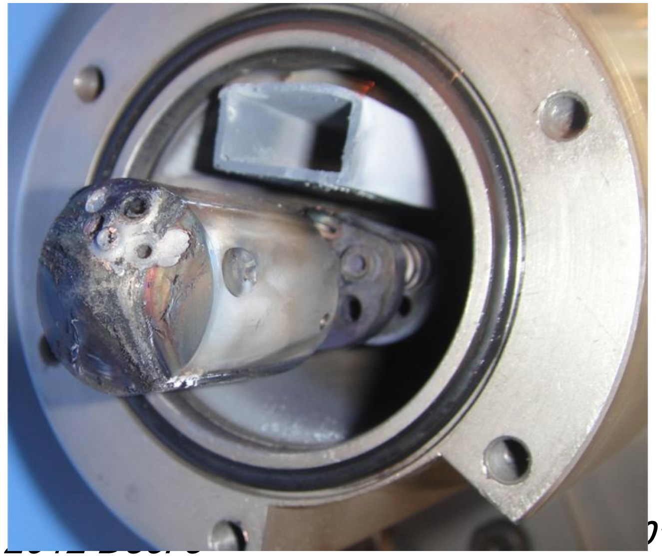
◆Important points:

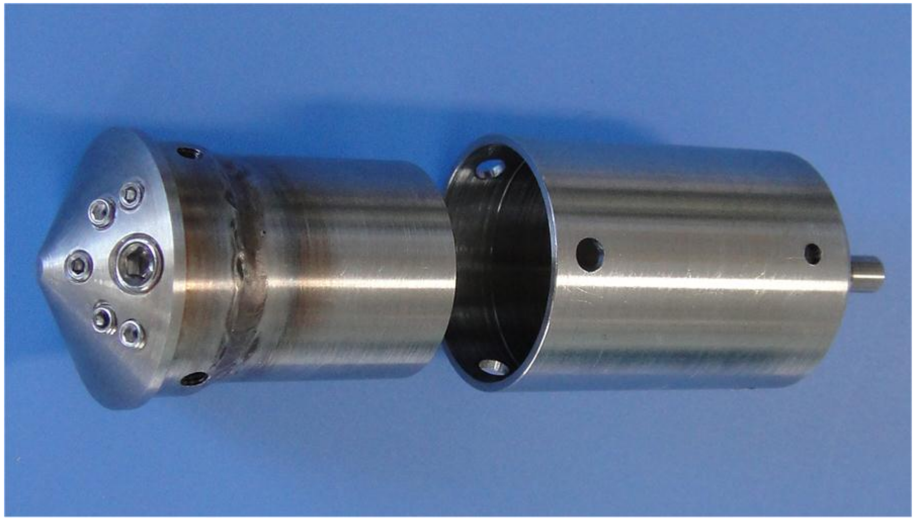
Multiple Holes…helps stable ion extraction.

Dewar…Temperature stable



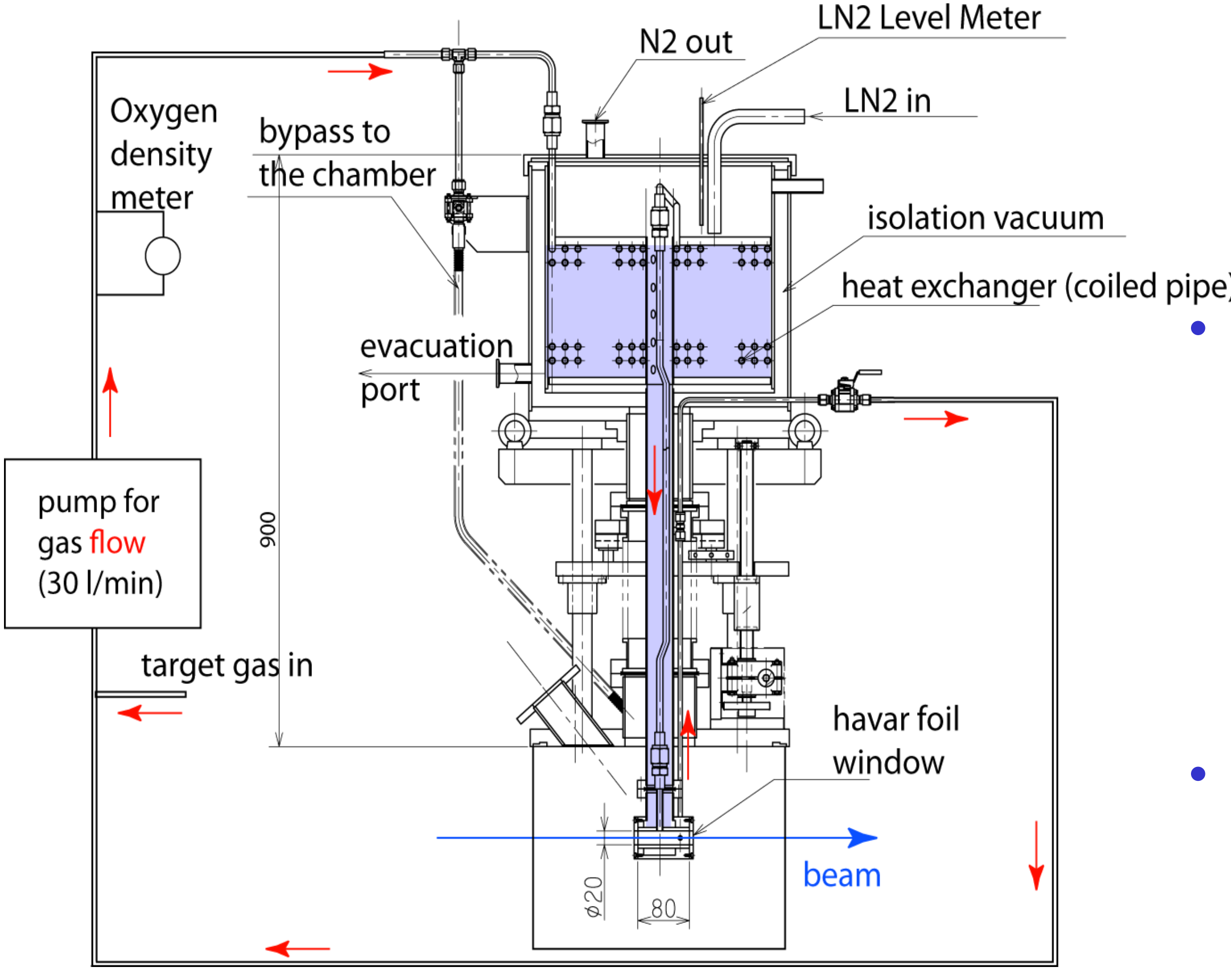






Dewar crucible

Cryogenic target: design

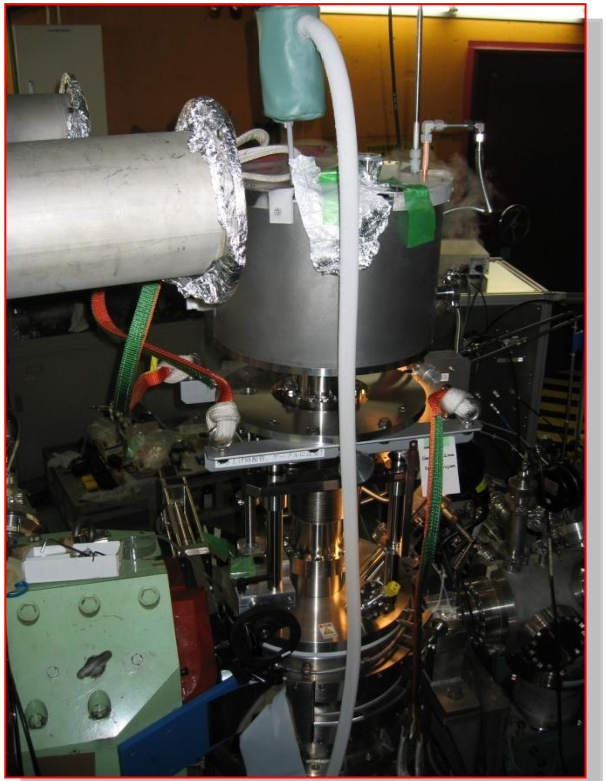


Features:

- Lq. N_2 cooling (automatic refill)

  for the better cooling power (~100 W) and thicker target.
- Forced target gas flow (>30 l/min) to have a better cooling, and to avoid target thickness reduction by the high-current beam.
- Oxygen density monitoring

Intense secondary beam production using cryogenic gas target



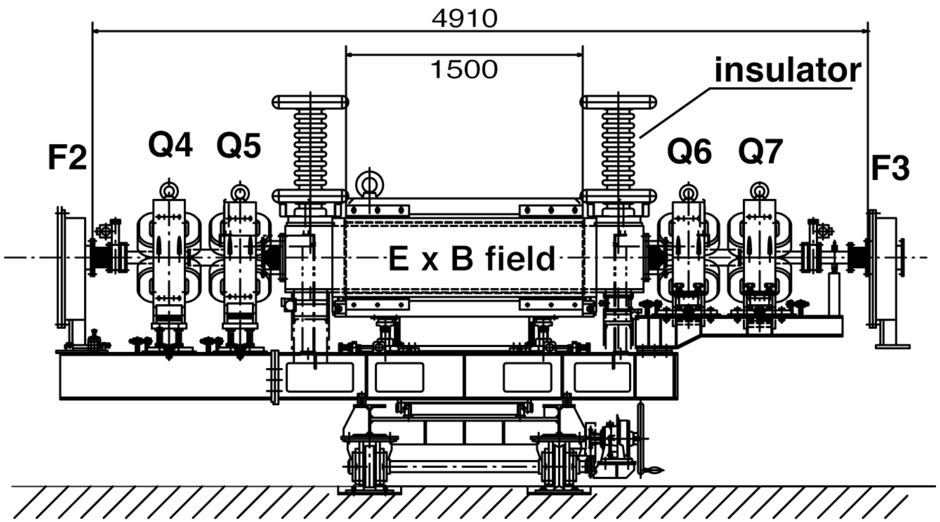
- H_2 gas target of 760 Torr and 80 mm-long worked at 85K stably for a $^{7}Li^{2+}$ beam of 1.3 pμA. (which deposits heat of 7.4W).
- Secondary beam: $^{7}Be^{4+}$ at 4.0 MeV/u, purity 75% (without degrader/ WF),

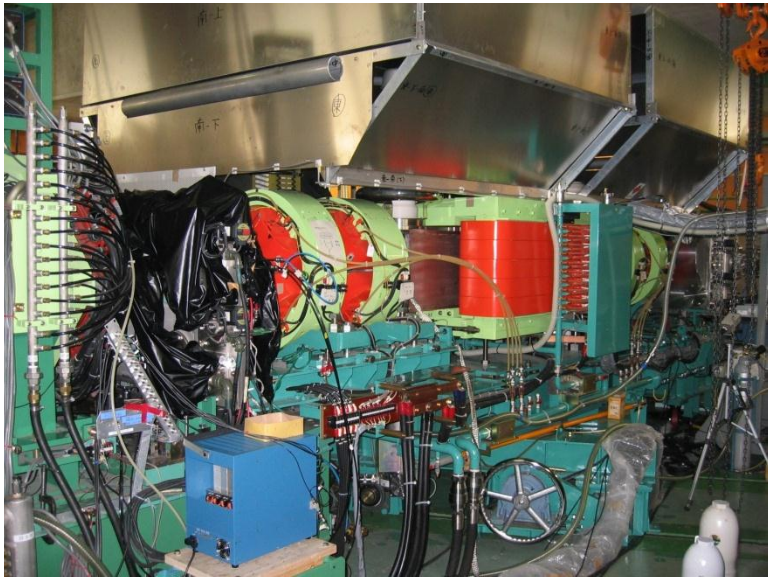
  $2x10^8$ pps was achieved.

  H. Yamaguchi et al., NIMA (2008)

Price of ^{3}He gas became 10 times higher in the last 4 years….a recycling system for ^{3}He gas was built.

Wien filter

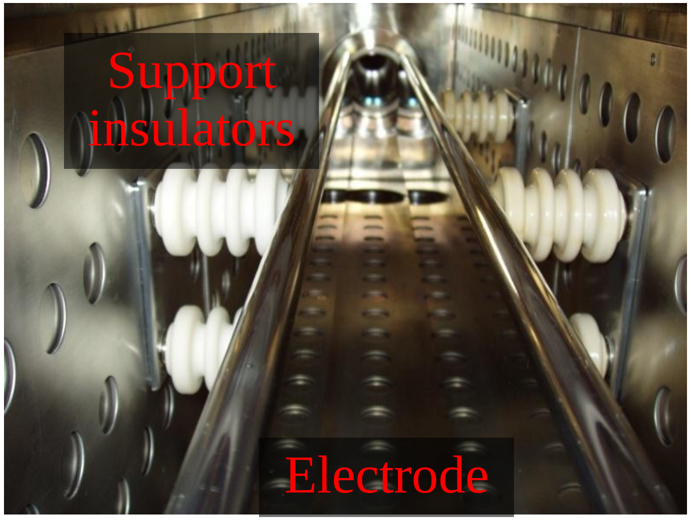




- 1.5 m-long HV electrodes, 8 cm distant from each other, ±200 kV applicable (stable up to ± 120kV), horizontal E field.
- Dipole magnet, max. 0.3 T vertical magnetic field.
- Spending much effort for the stabilization against discharge.

Improvement on the insulators

- The ceramic insulators for the negative high voltage had black trails of discharges. (due to small fragments on the surface?)



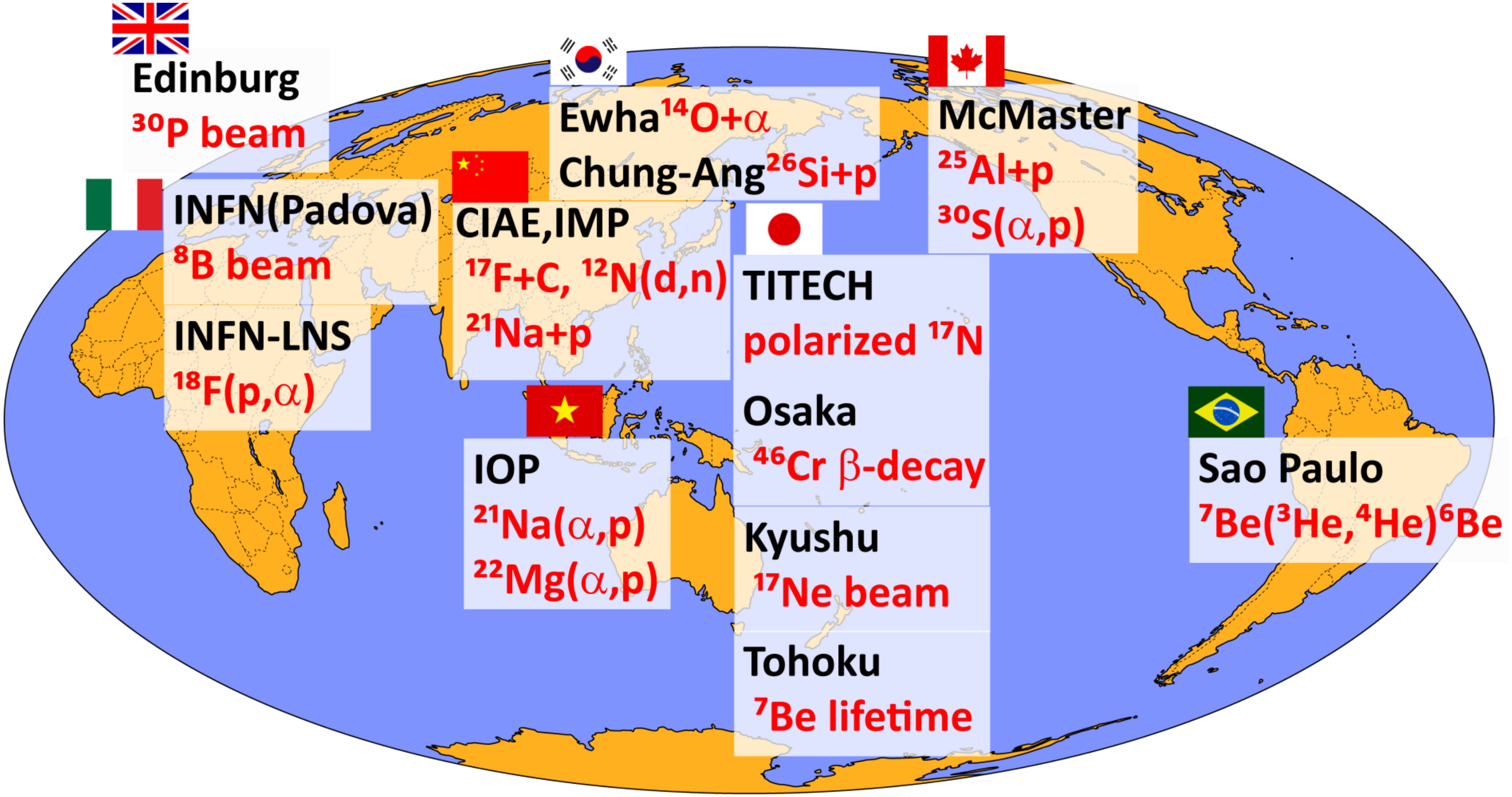
Recent works:

- Water-jet cleaning.
- A new type of high-voltage capable insulator (Kyocera).

International collaborations at CRIB

- CRIB experiments performed in 2007-2011,

by collaborated members of CNS and other institutes:



Research projects (2010-)

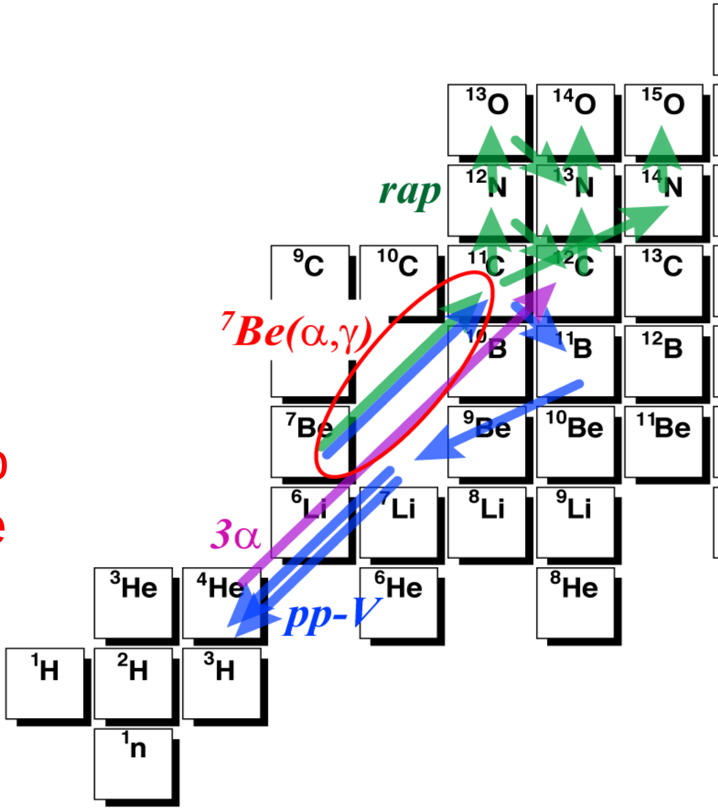
- Proton/alpha resonant scattering
  - ✓^{26}Si+p (Collaborated with Chung-Ang, Korea) H.S. Jung et al., published at PRC (2012).
  - ✓^{7}Li/^{7}Be+α (CNS) H. Yamaguchi et al., PRC (2011).
  - ✓^{21}Na+p, ^{22}Na+p [^{18}Ne(α,p), Ne-Na cycle] (IMP/CIAE, China)
  - ✓^{17}F+p [Resonances for ^{14}O(α,p)](IMP/CIAE, China) ←Latest measurement in June!
- (α,p) reaction measurement, Active target (GEM-MSTPC)
  - ✓^{18}Ne(α,p) (CNS, Hashimoto (now at RCNP))
  - ✓^{30}S(α,p) (CNS, Daid Kahl)
  - ✓^{22}Mg(α,p) (IOP, Vietnam , Nguyen Ngoc Duy)
  - ✓^{44}Ti(α,p) (KEK, Ishiyama) …^{44}Ti beam test in May successful.
- (α,γ)
  - ^{16}N⇒^{16}O*⇒^{12}C+α for ^{12}C(α,γ) (Catania, Italy, S. Cherubini)
- Reaction mechanism
  - ✓^{8}B+Pb (Padova, Italy, C. Signorini)
- β-decay
  - ✓^{7}Be lifetime in metal (Tohoku Univ, Otsuki)

New project: industrial application of ^{7}Be…

A. Yoshida-san's talk

^{7}Li+α/ ^{7}Be+α study

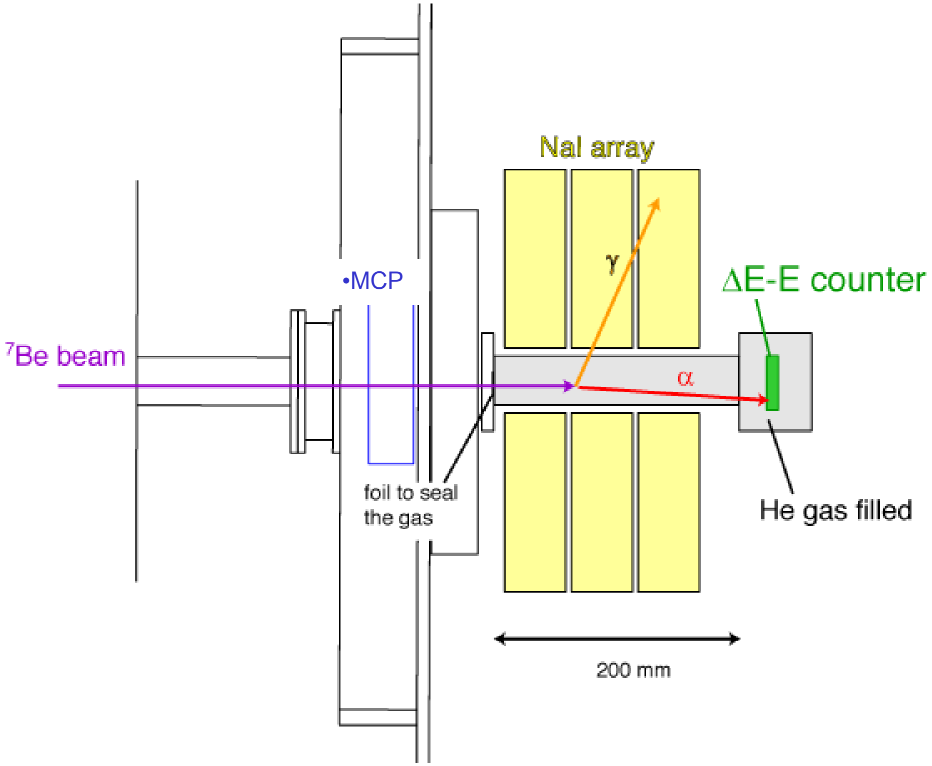
- $^{7}Li(\alpha,\gamma)^{11}B$ …important at high-T, as a production reaction of ^{11}B (the ν-process in core-collapse supernovae).
- $^{7}Be(\alpha,\gamma)^{11}B$ … one of the reaction in hot *p-p* chain, relevant at high-T. νp-process calculation predicts a contribution for the synthesis of carbon as much as the triple-α process.
- α-cluster structure in ^{11}B/^{11}C :
  - 2α+*t* / 2α+^{3}He cluster states are known to exist (similar to the dilute cluster structure in ^{12}C.)
  - Several “bands” which have α-cluster structure could be formed. We can study the band and cluster structure more in detail.



^{7}Li/^{7}Be+α; method

- "Thick target with inverse kinematics" Resonant elastic scatterings can be measured at θcm=180 deg.

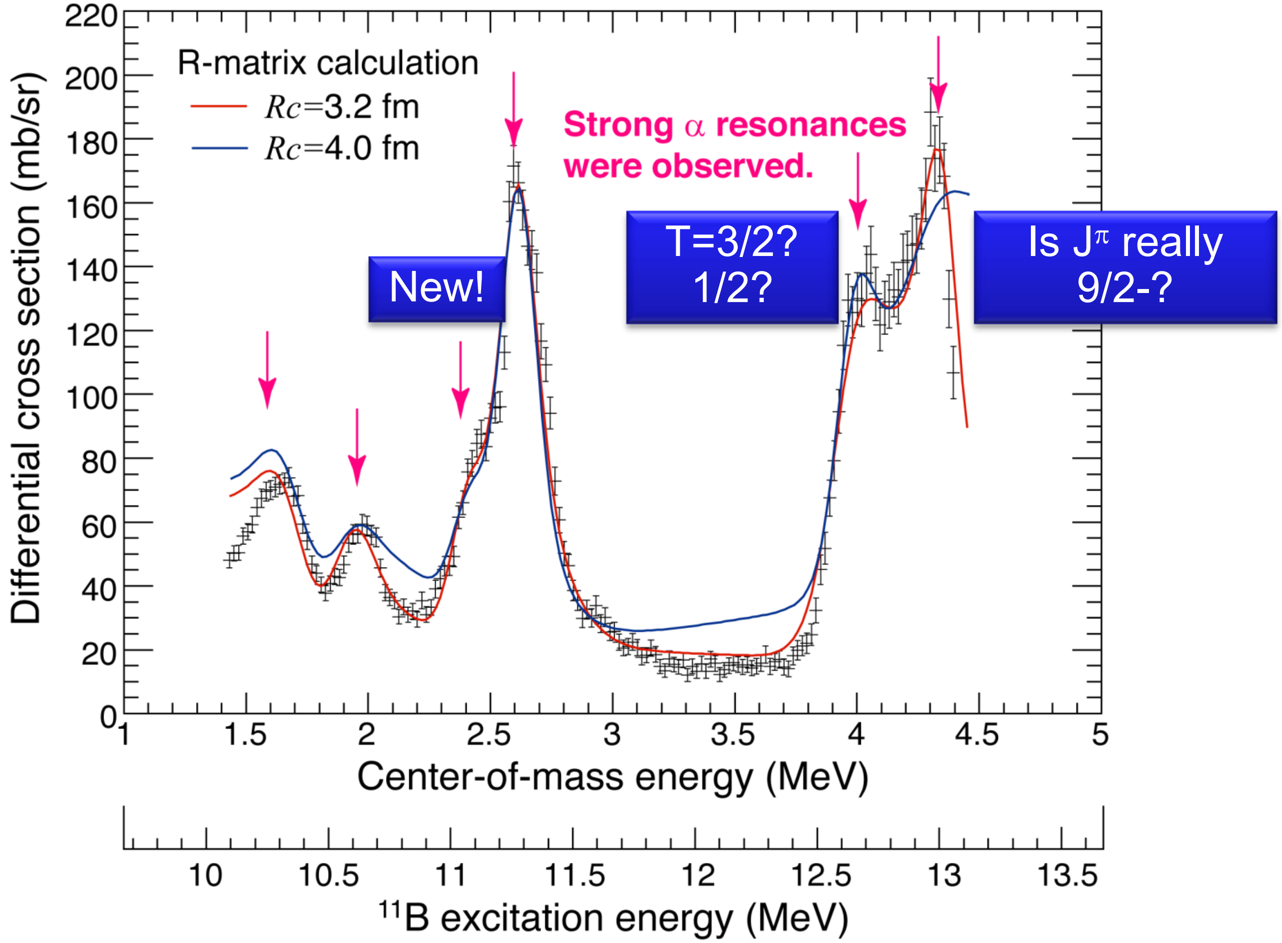
- ^{11}C+p; T. Teranishi et al., Phys. Lett. B (2003).
- ^{13}N+p; T. Teranishi et al., Phys. Lett. B (2007).
- ^{21}Na+p, ^{22}Mg+p; J.J. He et al, Eur Phys. J (2008) and Phys. Rev. C (2007).
- ^{7}Be+p; H. Yamaguchi et al., Phys. Lett. B (2009).



- We applied the method for proton +RI beams, but how good it can work for alphas? (Especially for light nuclei, where Z is not much different from 2.)

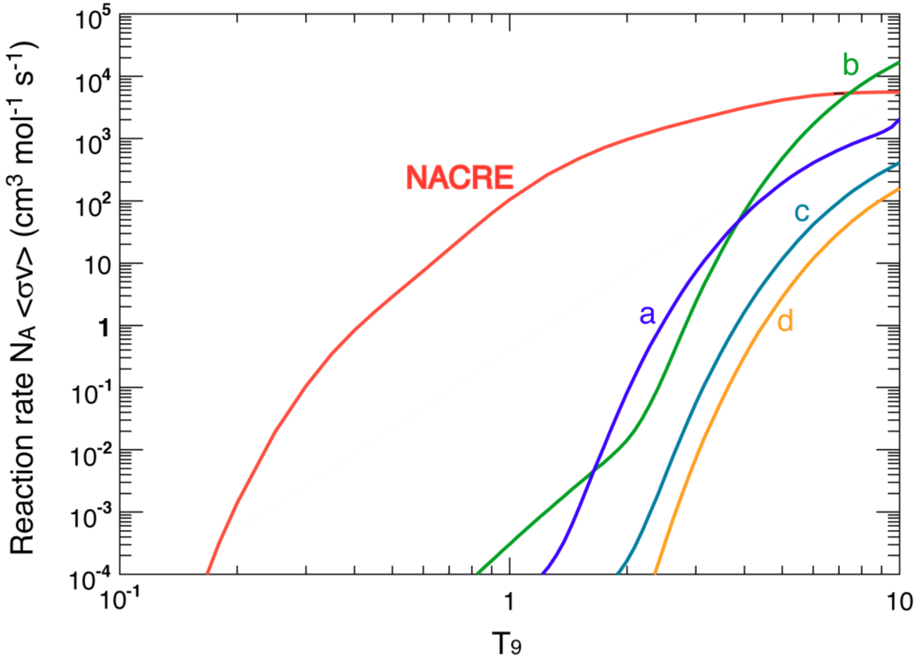
^{7}Li+α result

- Strong alpha resonances were successfully observed, and we determined the α widths (Γ_α). *H. Yamaguchi et al., Phys Rev. C (2011).*



^{7}Li+α; results

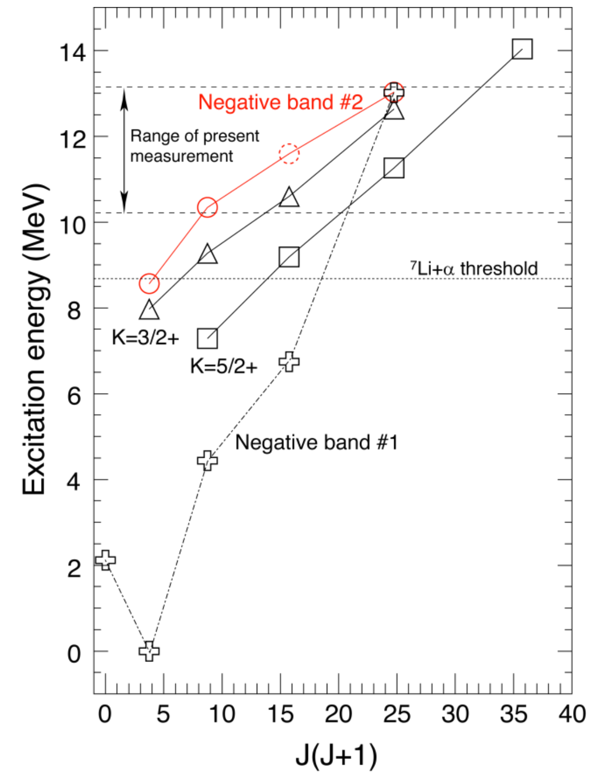
- Resonant reaction rates for the observed resonances are compared with NACRE evaluation (including resonances below 11 MeV).



Conclusion: No need to modify NACRE evaluation (for T_9<5).

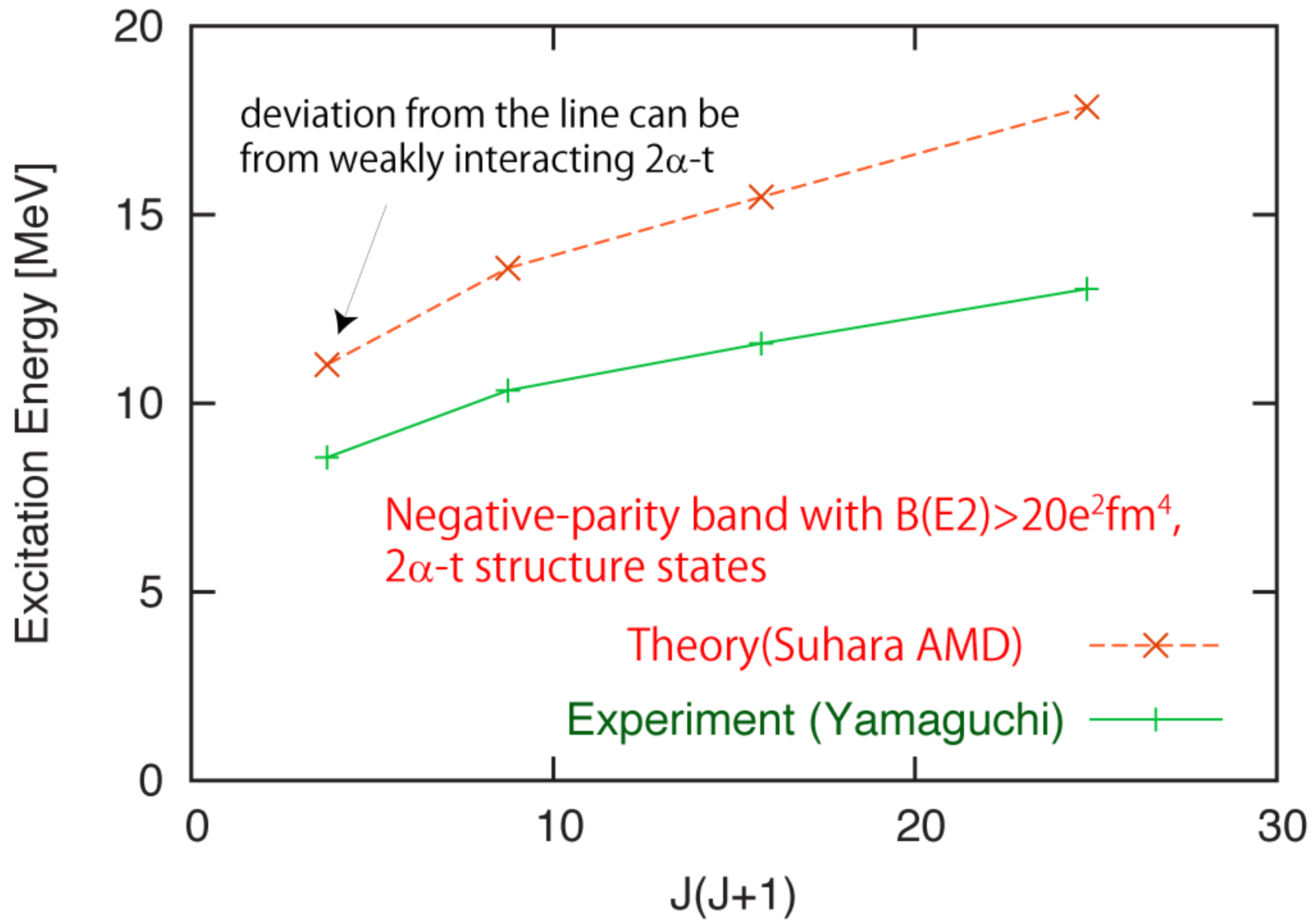
•Newly proposed a negative parity band.

•It may not be a simple rotational band, but corresponds to a 2α-t structure [AMD Calc. by Suhara & En'yo]



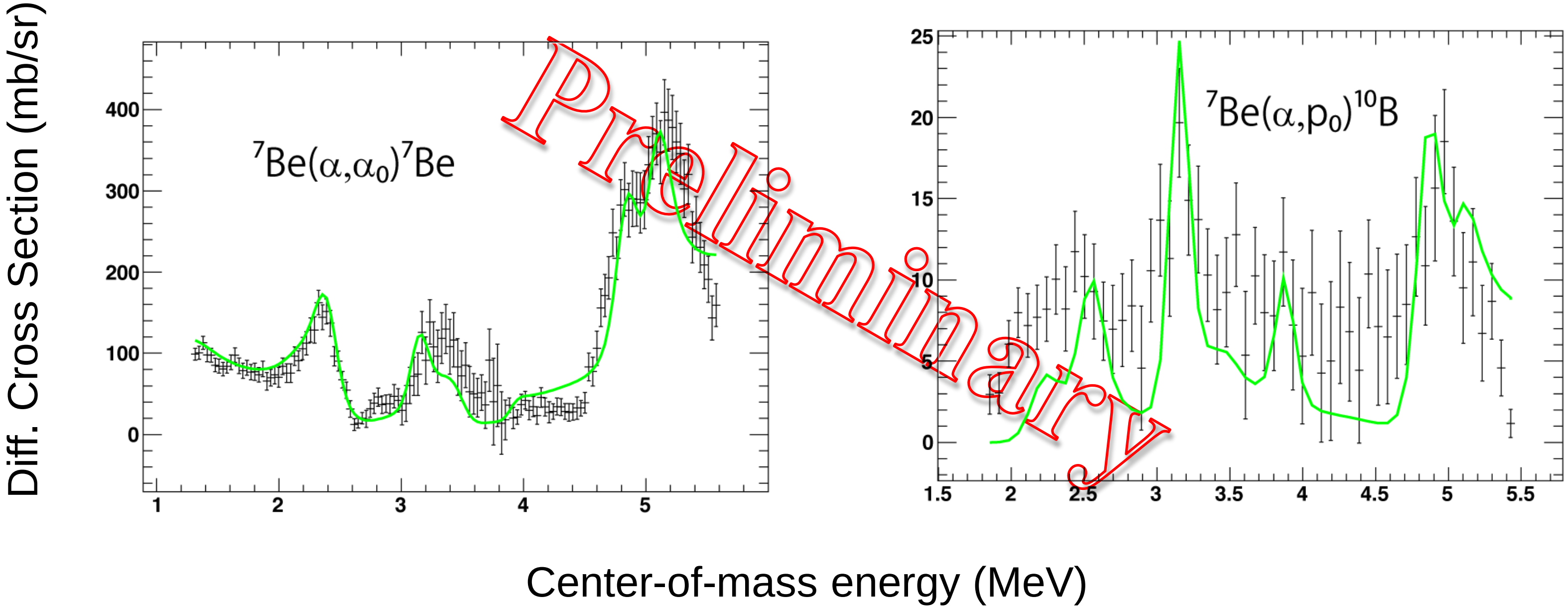
Interpretation of the new negative-parity band

Suhara & En'yo PRC (2012)



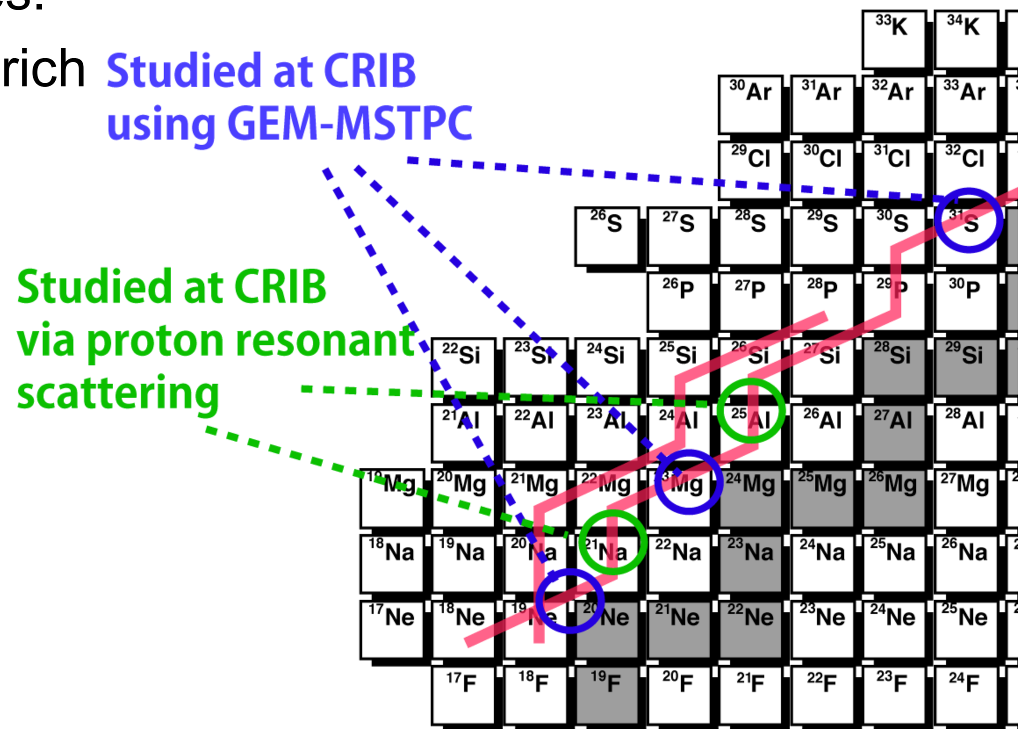
^{7}Be+α Excitation functions

- Excitation functions of ^{7}Be(α,α) and ^{7}Be(α,*p*) were obtained.
- ^{7}Be(α,*p*)…consistent with previous ^{10}B(*p* ,α) measurements.
- R-matrix analysis in progress….bringing new information on resonant widths, spin, and parity. Many resonant parameters are still unknown in such unstable nuclei.

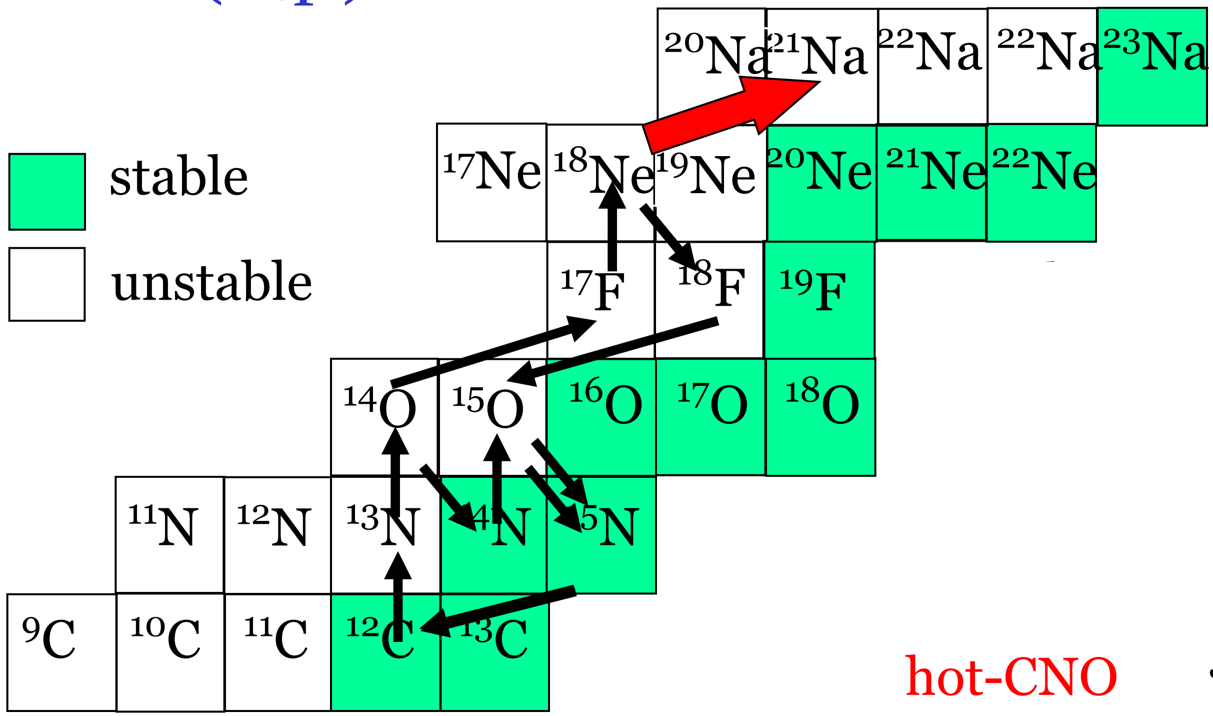


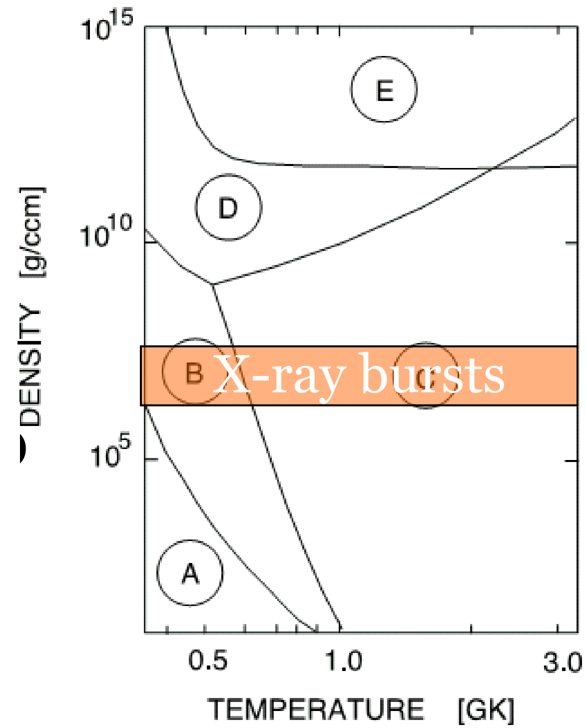
Study on the αp-process

- αp-process: (α,p),(p,γ) reactions occur faster than β-decay at high temperature. Accelerates the rp-process (Wallace and Woosley, 1981).
- Suitable objective for CRIB
  - ◆ Not many direct measurements of (α,p) reactions have been performed in other facilities.
  - ◆ Involves A=18-30, proton rich unstable nuclei.
  - ◆ T=1.5GK, close to the beam energy at CRIB.



^{18}Ne(α,p) (T. Hashimoto; RCNP)





J. Phys. G: Nucl. Part. Phys. 25 (1999)R133

hot-CNO

^{12}C(p, γ)^{13}N(p, γ)^{14}O(β)^{14}N(p, γ)^{15}O(β)^{15}N(p, α)^{12}C

second hot CNO cycle

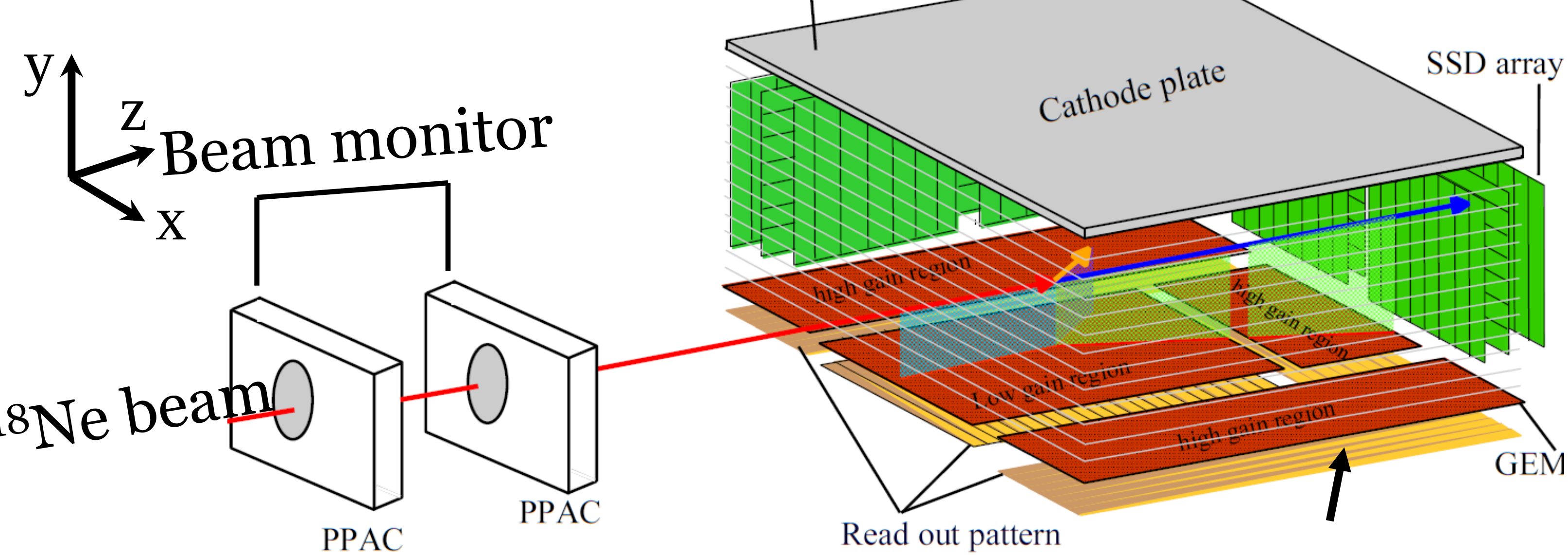
^{14}O(α, p)^{17}F(p, γ)^{18}Ne(β)^{18}F(p, α)^{15}O(β)^{15}O(p, α)^{12}C

→ ^{18}Ne(α, p)^{21}Na

^{18}Ne(α, p)^{21}Na is an important breakout reaction from hot-CNO cycle to the rp-process (B to C in the figure)

Relevant energy (temperature):
E_{cm} = 0.5 - 3.8 MeV (T = 0.6 - 3 GK).

Experimental Setup

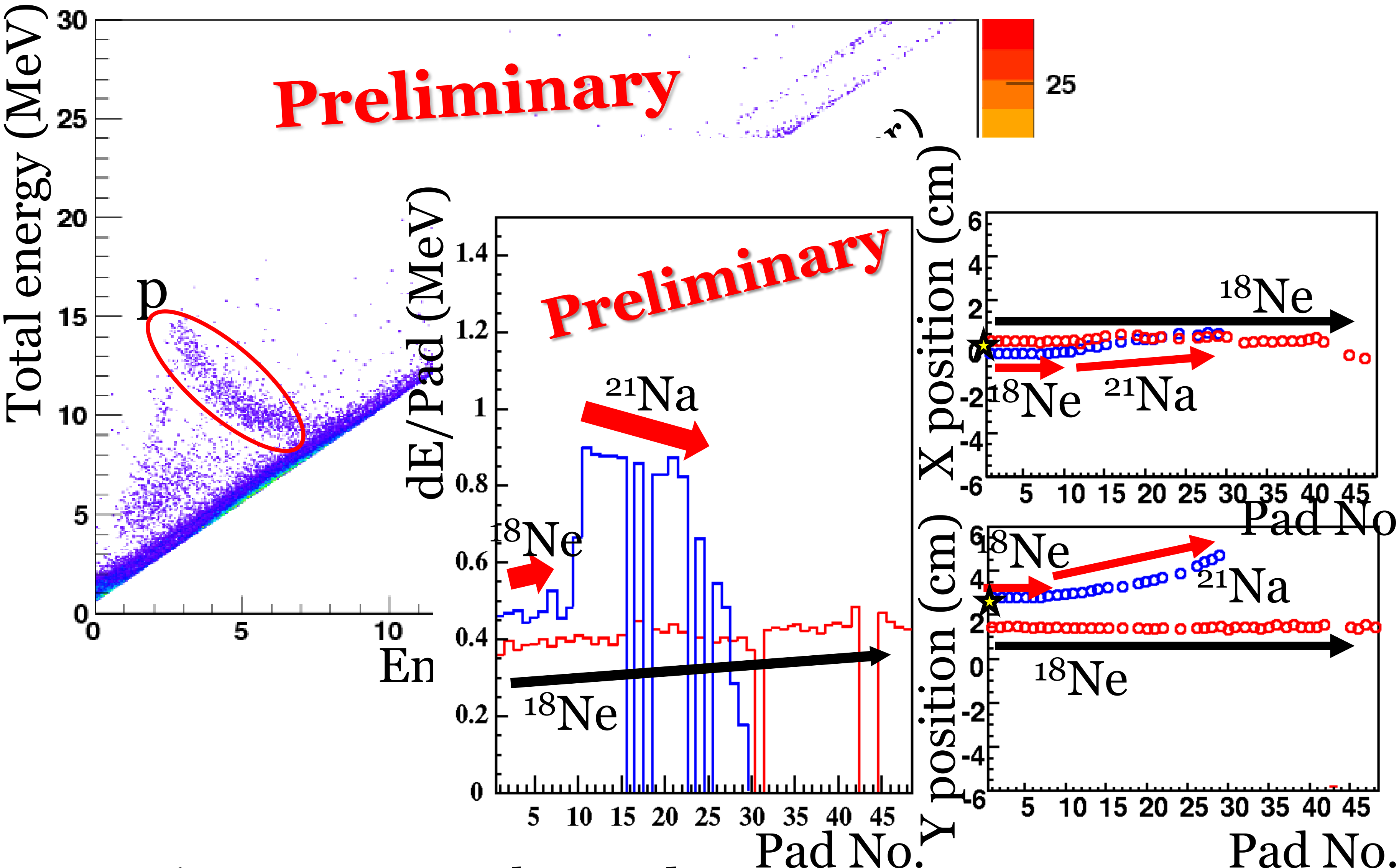


He (90%) +CO_2 (10%)
mixture gas(160 torr)

- Acts as a He target and a detector (TPC) simultaneously
- 3-dimentional trajectory and energy loss can be measured
  ⇒ Good event identification.

Typical event of $^{18}Ne(\alpha, p)^{21}Na$ reaction

Si telescopes



Reaction events are observed !

Analysis is in progress …

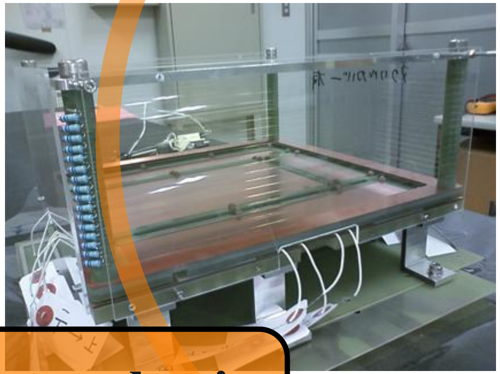
Development of Active Targets in CNS

CNS Active Target Dev. Collaboration

- RIKEN
- Kyoto
- Miyazaki
- MSU

•SHARAQ Gr. / Missing mass spectroscopy Gr.

•Ota, Tokieda, Lee et al.



•Astrophysics Gr.

•Yamaguchi, Daid, Nakao

•Quark phys.Gr.

•Hamagaki, Gunji, Yamaguchi, Akimoto, Sekiguchi et al.

2012 Dec. 5

Active target at SHARAQ group

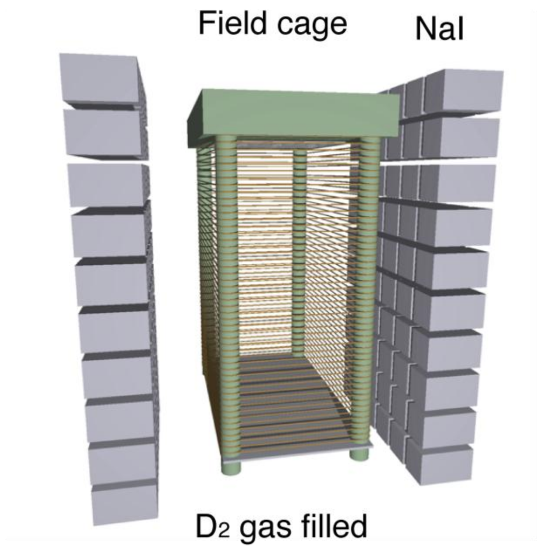
Physics Motivation:

(d,d') reaction at the forward angle

Giant Monopole Resonance/Gamow-Teller transition

Design:

- Angular coverage from 1 deg to 10 deg in c.m. frame with insensitive region around 4 deg corresponding to the inactive region between field cage and NaI
- Range and angular resolution are designed to be 0.4 mm and 30 mrad, which corresponds to 1-MeV excitation energy resolution



See S. Ota's poster

Summary

- CRIB is a low-energy RI beam facility operated by CNS, University of Tokyo, providing RI beams of good intensity and purity.
- Developments for RI beams….ion source, target, Wien filter
- Standard experiments: Proton/alpha resonant scattering, direct (α,p) reaction measurement using an active target (GEM-MSTPC)
- GEM-MSTPC
  - Has been used in several (α,p) measurements. Developments are on going, to make it a more reliable and stable system.

    (avoiding discharges, gating grid, trigger system, DAQ, analysis framework)
- Resonant elastic scattering
  - ^{7}Li+α,^{7}Be+α…strong resonances were observed. The "thick target method with inverse kinematics" could be applied to many nuclides. We can study astrophysical reactions and alpha-cluster structures.

We welcome your new ideas!