SAMURAI WS@RIKEN
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TOHOKU
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Search for unbound excited states of proton rich nuclei

Naohito IWASA

Department of Physics, Tohoku University

Motivation

- *E*(2$^+$) and *B*(E2) in even-even nuclei
  collectivity/shell structure
- Systematical studies

  → magicity disappearance around ^{32}Mg-^{32}Ne
  new magic number *N*=14, 16 in ^{22,24}O
  B(E2) anomaly of ^{16,18}C
- ^{24}Si, ^{28}S (T_z=-2): small *B*(E2)
  0$^+$→2$^+$: neutrons plays important role
  subshell closure (Z=14,16) effect?
  E(2$^+$) is not high, not magic, yet.
- ^{36}Ca: *B*(E2): smallest in Ca isotopes
  E(2$^+$): 0.3MeV smaller than that of
  mirror nucleus ^{36}S.

Isotope **$E_x(2^+)$** **B(E2;↑)**

preliminary → ^{36}Ca, ^{28}S

						^{46}Fe	^{48}Fe
					^{42}Cr	^{44}Cr	^{46}Cr 0.892 900±10
					^{40}Ti	^{42}Ti 1.55 870±250	^{44}Ti 1.08 650±160
				^{36}Ca 3.02	^{38}Ca 2.21 96±21	^{40}Ca 3.90 99±17	^{42}Ca 1.52 420±30
			^{32}Ar 1.82 266±68	^{34}Ar 2.09 240±40	^{36}Ar 1.97 300±30	^{38}Ar 2.17 130±10	^{40}Ar 1.46 330±40
		^{28}S 1.51	^{30}S 2.21 324±41	^{32}S 2.23 300±13	^{34}S 2.13 212±12	^{36}S 3.29 104±28	^{38}S 1.29 235±30
^{22}Si	^{24}Si 1.88 60±20?	^{26}Si 1.80 356±34	^{28}Si 1.78 326±12	^{30}Si 2.24 215±10	^{32}Si 1.94 113±33	^{34}Si 3.33 85±33	^{36}Si 1.40 190±60
^{20}Mg 1.61 177±32	^{22}Mg 1.25 370±130	^{24}Mg 1.37 432±11	^{26}Mg 1.81 305±13	^{28}Mg 1.47 350±50	^{30}Mg 1.48 295±26	^{32}Mg 0.885 454±78	^{34}Mg 0.656 631±126
^{18}Ne 1.89 176±30	^{20}Ne 1.63 340±30	^{22}Ne 1.28 230±10	^{24}Ne 1.98 170±60	^{26}Ne 2.02 228±41	^{28}Ne 1.32 132±23	^{30}Ne 0.79	^{32}Ne 0.72
^{16}O 6.92 41±4	^{18}O 1.982 45±2	^{20}O 1.67 28±2	^{22}O 3.17 21±8	^{24}O 4.72			
^{14}C 7.01 18±3	^{16}C 1.77 2.7±0.7	^{18}C 1.62 4.3±1.0	^{20}C 1.59	^{22}C			

Proposals

1. Coulomb dissociation/proton inelastic scattering of ^{22}Si
2. Search for 0^+ and 2^+ states in ^{34}Ca by fragmentation of ^{36}Ca
3. Proton inelastic scattering of ^{42}Cr, ^{46}Fe

Isotope
$E_x(2^+)$
B(E2;↑)

						^{46}Fe	^{48}Fe
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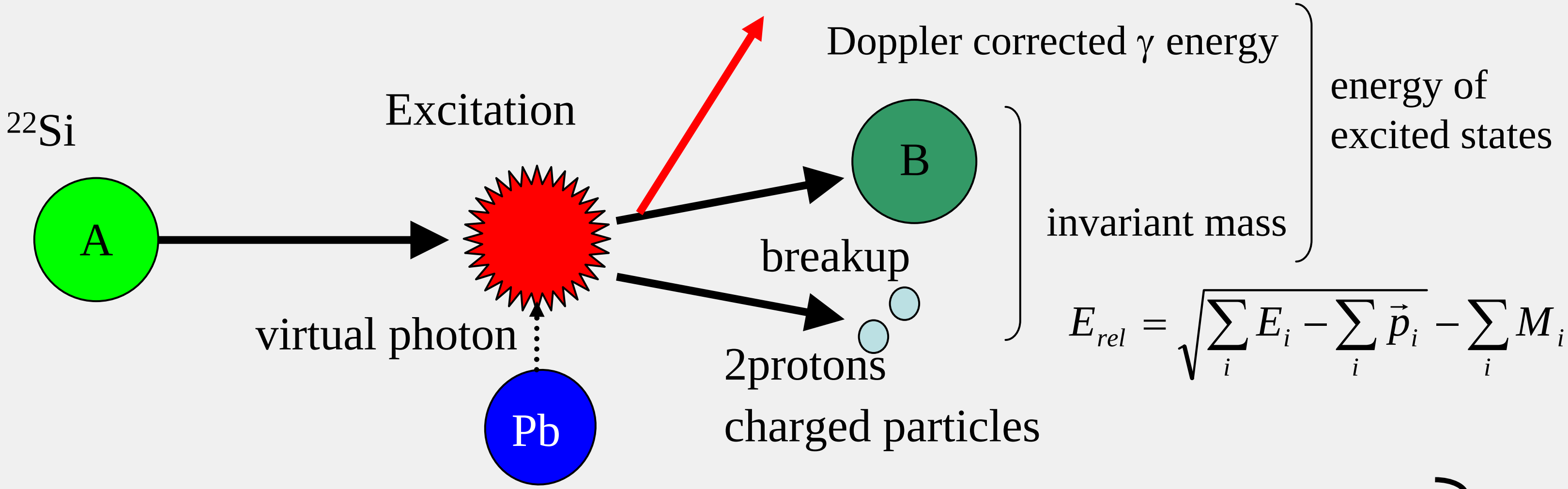
Coulomb dissociation of ^{22}Si

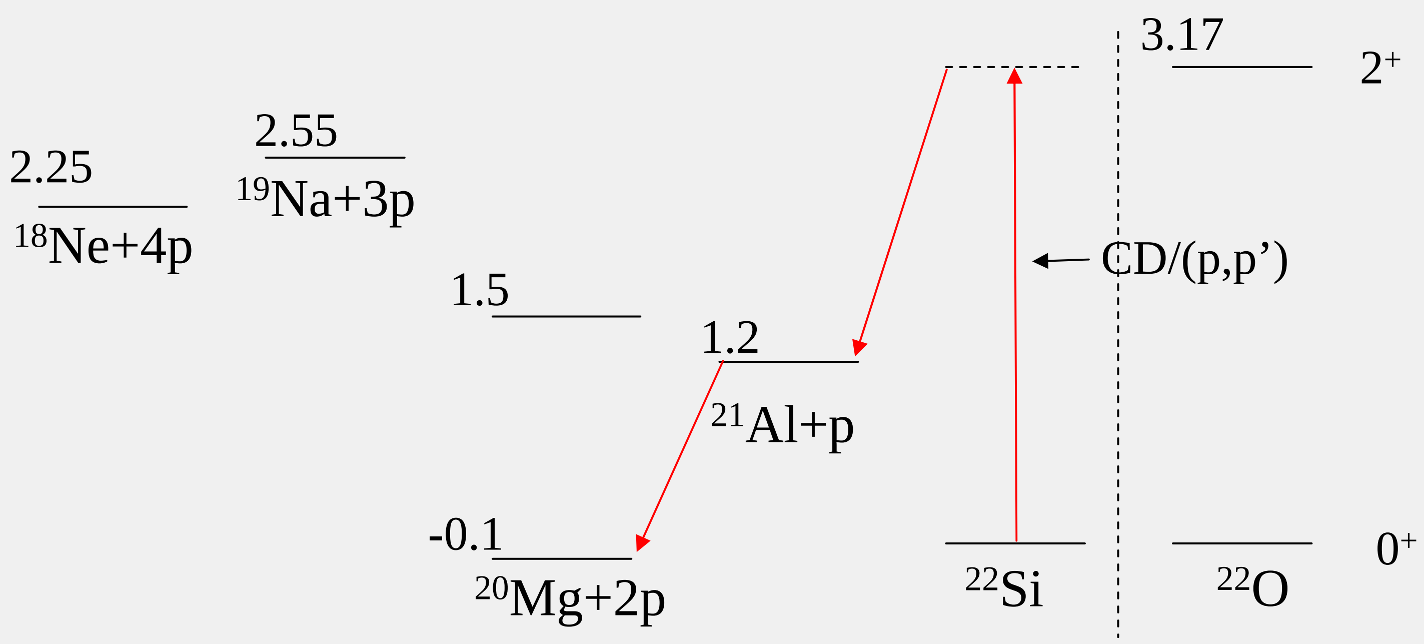
- Z=14(subshell), N=8(magic)
  S_p=1.2 MeV
- No excited states are known
- Mirror ^{22}O: $E(2^+)$=3.17MeV
  larger than surrounding N=8 nuclei
  → subshell closure?
- $B(E2\uparrow) \sim 200 e^2fm^4$: ^{16}O+6p
- $B(E2\uparrow) < 100 e^2fm^4$: Z=14 subshell colsure is significant
- To determine $E(2^+)$, B(E2), and M_n/M_p in ^{22}Si, CD and proton inelastic scattering experiments are desired.



B(E2), M_p from CD cross section
$\delta_{(p,p)}$ from (p,p') cross section
→ M_n

Coulomb dissociation of ^{22}Si

If excited states in ^{21}Al exist between 0.3〜2.0MeV,

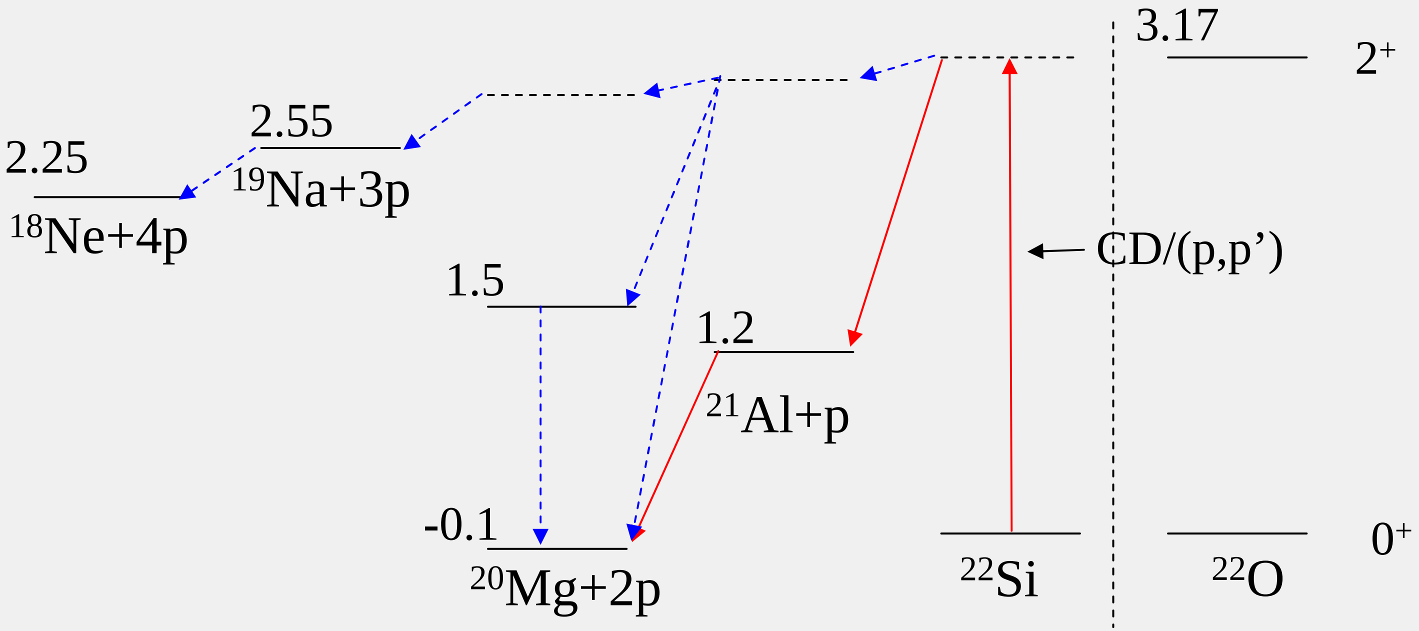


Coulomb dissociation of ^{22}Si

If excited states in ^{21}Al exist between 0.3〜2.0MeV,

Measurements of ^{20}Mg+2p+γ, ^{18}Ne+4p channels

$$E_{rel} = \sqrt{\sum_i E_i - \sum_i \vec{p}_i} - \sum_i M_i$$



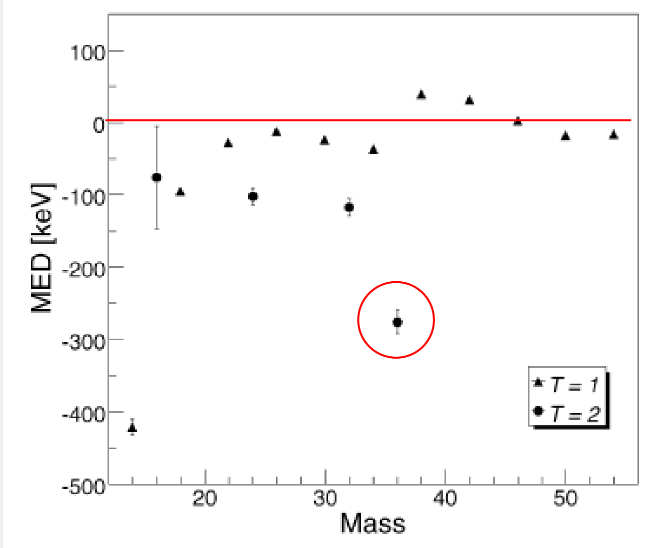
Measurement of all the channel → excitation cross section can be measured

0^+ and 2^+ states in ^{34}Ca

- P. Doornenbal,… T.Otsuka et al. suggested the island of inversion in proton rich region may start at $N = 14$ in ^{34}Ca.
- Shell mode calculations with an isospin symmetric USD based interaction using experimental proton and neutron SPE from the $A = 17$, $T = 1/2$ isospin doublet, can be explained the extremely large mirror energy difference of ^{36}Ca and ^{36}S, $E(2^+, {}^{36}\mathrm{Ca})$-$E(2^+, {}^{36}\mathrm{S})$.

  This model predictes the island of inversion in proton rich region may start at $N = 14$ in ^{34}Ca.
- To confirm the model, $E(2^+)$ and B(E2) of ^{34}Ca are desired.

P. Doornenbal et al., PLB 647 (2007) 237



Search for 0^+ and 2^+ states in ^{34}Ca

P. Doornenbal et al., PLB 647 (2007) 237

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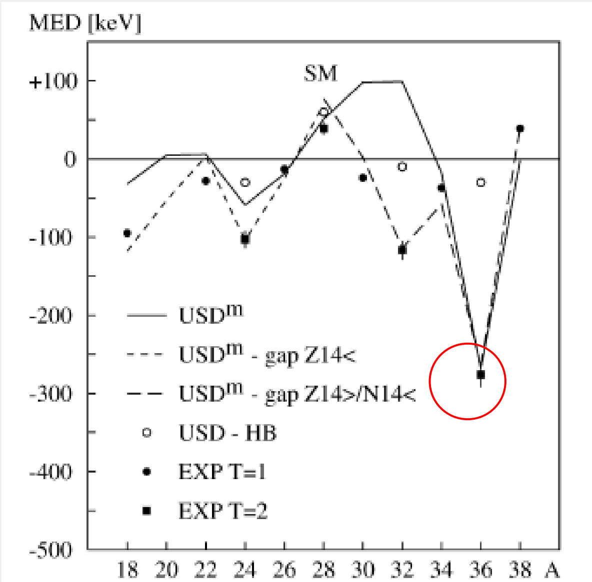
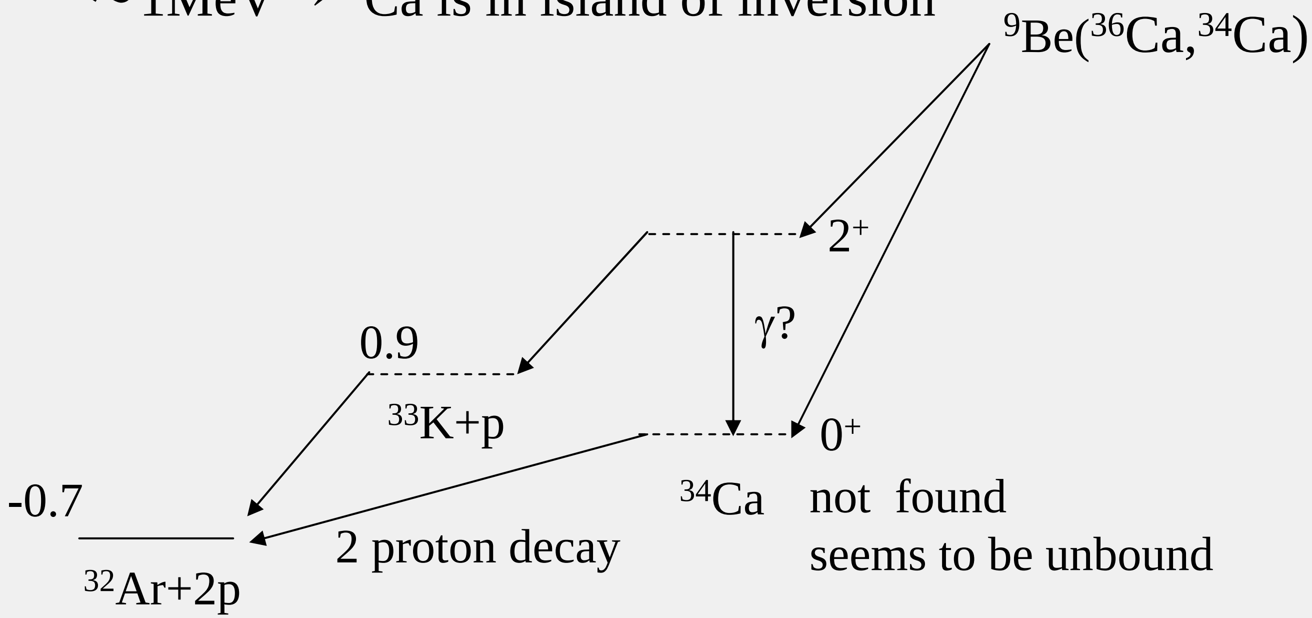


Search for 0^+ and 2^+ states in ^{34}Ca

- ^{36}Ca + ^{9}Be $\rightarrow$ ^{34}Ca*(gs, 2^+) $\rightarrow$ ^{32}Ar+2p

  $E(2^+)$-$E(0^+)$ = ∼3MeV → ^{34}Ca is not in island of inversion

  ∼1MeV → ^{34}Ca is in island of inversion

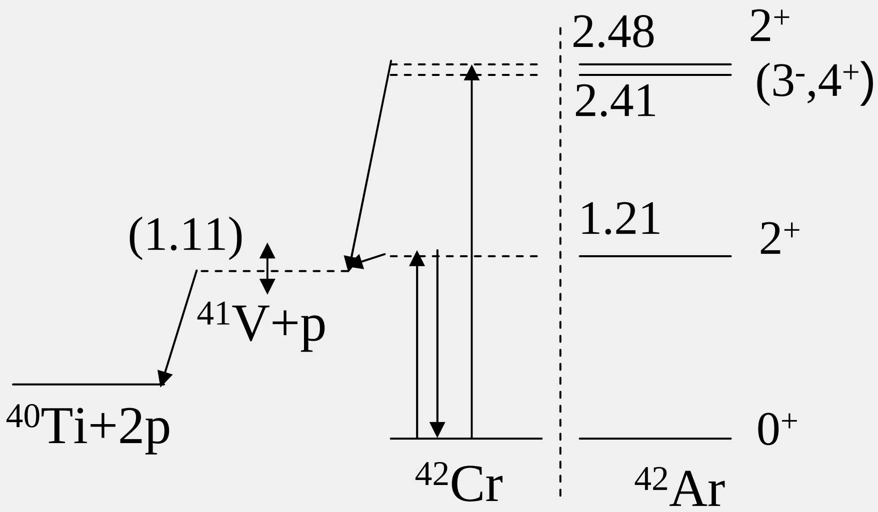


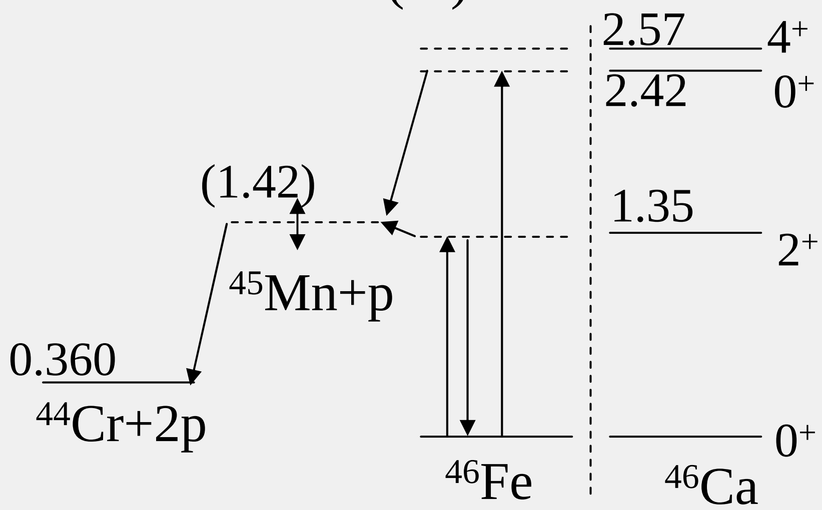
$$E_{rel} = \sqrt{\sum_i E_i - \sum_i \vec{p}_i} - \sum_i M_i$$

Search for excited states in ^{42}Cr, ^{46}Fe

- ^{42}Cr: Z=24, N=18
  S_p=1.11MeV(theory)
  No excited states are known.
  Mirror ^{42}Ar: $E(2^+)$=1.21MeV

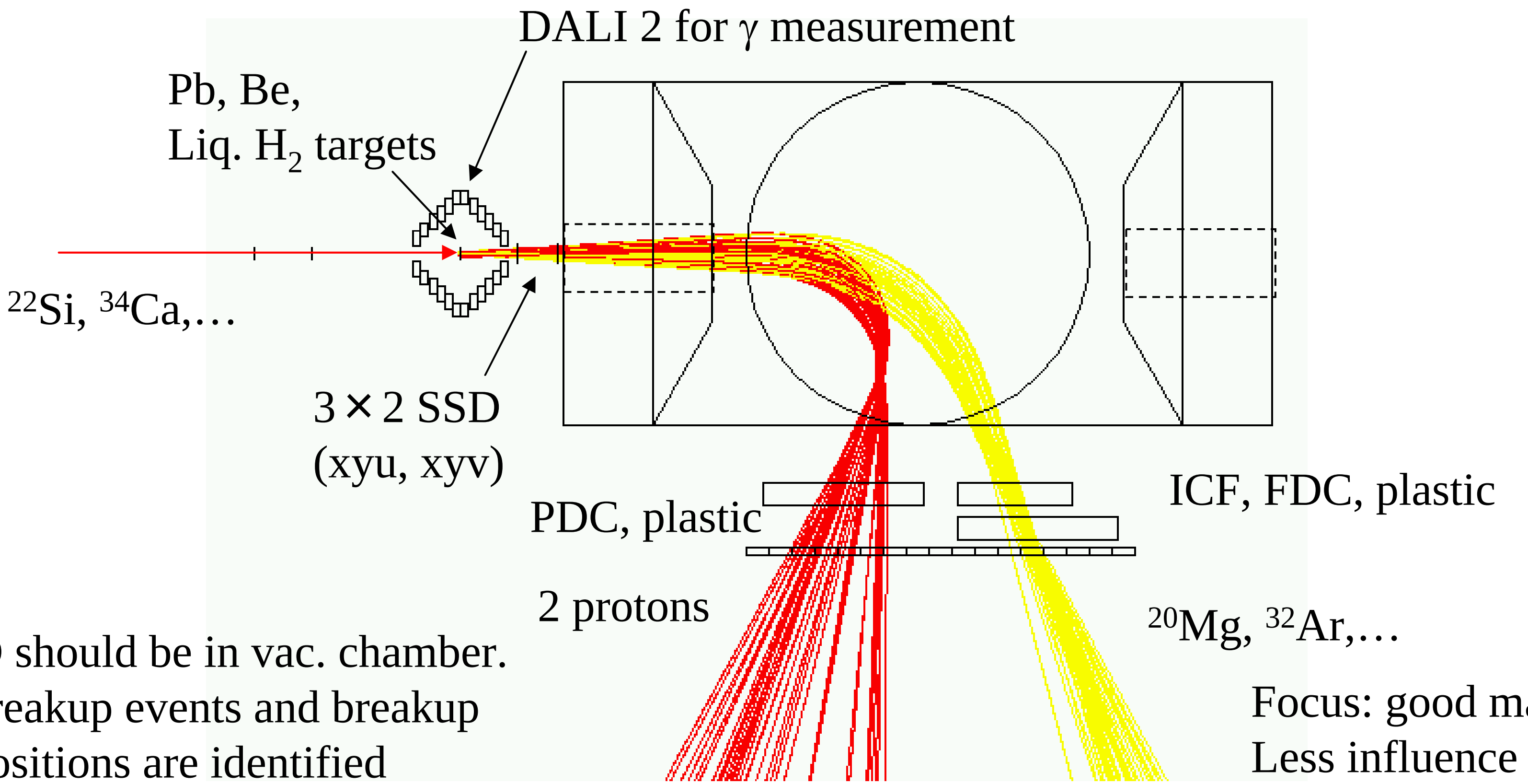
- ^{46}Fe: Z=26, N=20(magic)
  ^{40}Ca+6 protons
  S_p=1.42MeV (theory)
  No excited states are known.
  Mirror ^{46}Ca: $E(2^+)$=1.35MeV





Experimental Setup

High resolution mode of SAMURAI.



SSD should be in vac. chamber.
→breakup events and breakup positions are identified

Focus: good mass res.
Less influence of MS

Target chamber, SSD and SSD chamber should be constructed.

Yield estimation

^{22}Si

- 100cps from 100pnA ^{36}Ar @400*A*MeV
  100cps from 33pnA ^{28}Si @400*A*MeV
- Assuming σ_{CD}～8mb at 250*A*MeV
- Target 200mg/cm^2 Pb
  $^{22}Si+Pb \rightarrow ^{20}Mg+2p$
  coincidence efficiency
  20% (E_{rel}～3MeV, rough)
  8 events/day ～ 56 events/week

- Target 200mg/cm^2 Liq.H_2
  more than 200events are expected to be measured for 1days.

^{34}Ca

- 3kcps ^{36}Ca from 40pnA ^{40}Ca @400*A*MeV
  purity ～20%
- fragmentation cross section: 0.1mb
- target 500mg/cm^2 ^9Be
  efficiency: 20% (E_{rel}=3～4MeV)
  173events/day～1211 events/week

Efficiency is estimated using ^7Be+p coincidence efficiency of KaoS at GSI. Precise efficiency calculation is needed, using realistic magnetic field, because proton detection efficiency strongly depends on the fringing field.

Yield estimation for ^{42}Cr, ^{46}Fe

^{42}Cr

- 0.04cps from 30pnA ^{84}Kr

  10 times higher intensity beam is avaliable, (p,p') measurement is possible.

  $\sigma = 5mb$

  Target 200mg/cm^2 Liq. H_2

  4 events/day = 30 events/week

^{46}Fe

- 0.007cps from 30pnA ^{84}Kr

  60 times higher intensity beam is avaliable, (p,p') measurement is possible.

  $\sigma = 5mb$

  Target 200mg/cm^2 Liq. H_2

  4 events/day = 30 events/week

Summary

- Coulomb dissociation reaction and proton inelastic scattering are powerful too to study nuclear astrophysics and nuclear structure.
- Coulomb dissociation of ^{22}Si into ^{20}Mg+2p may provide information of Z=14 subshell closure near the drip line. Experiment in 2014?
- From fragmentation of ^{36}Ca, mass and $E(2^{+})$ of ^{34}Ca is expected to be determined. In 2015?
- Proton inelastic scattering experiments of ^{42}Cr and ^{46}Fe can be performed when high intensity ^{84}Kr beam intensity is available.