Charge Exchange Reactions of Unstable Nuclei and the GT Strength

[Based on the paper in PTEP 043D05 (2016)]
and future perspective]

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Relation between cross sections and GT and F strength.

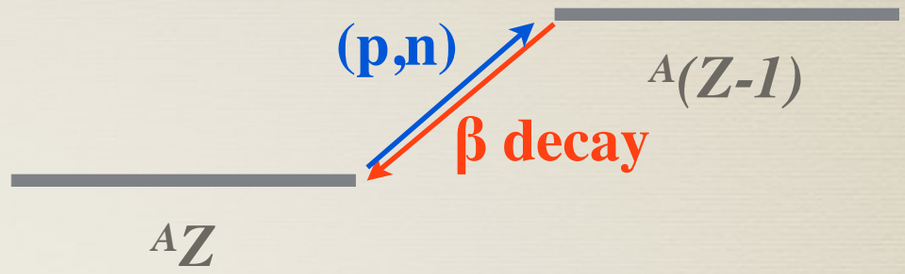
(p,n) cross section

$$\sigma = \hat{\sigma}_i F_i(q,\omega) B(i)$$

unit cross section

Form factor (= 1 at q=ω=0)

Beta-decay strength

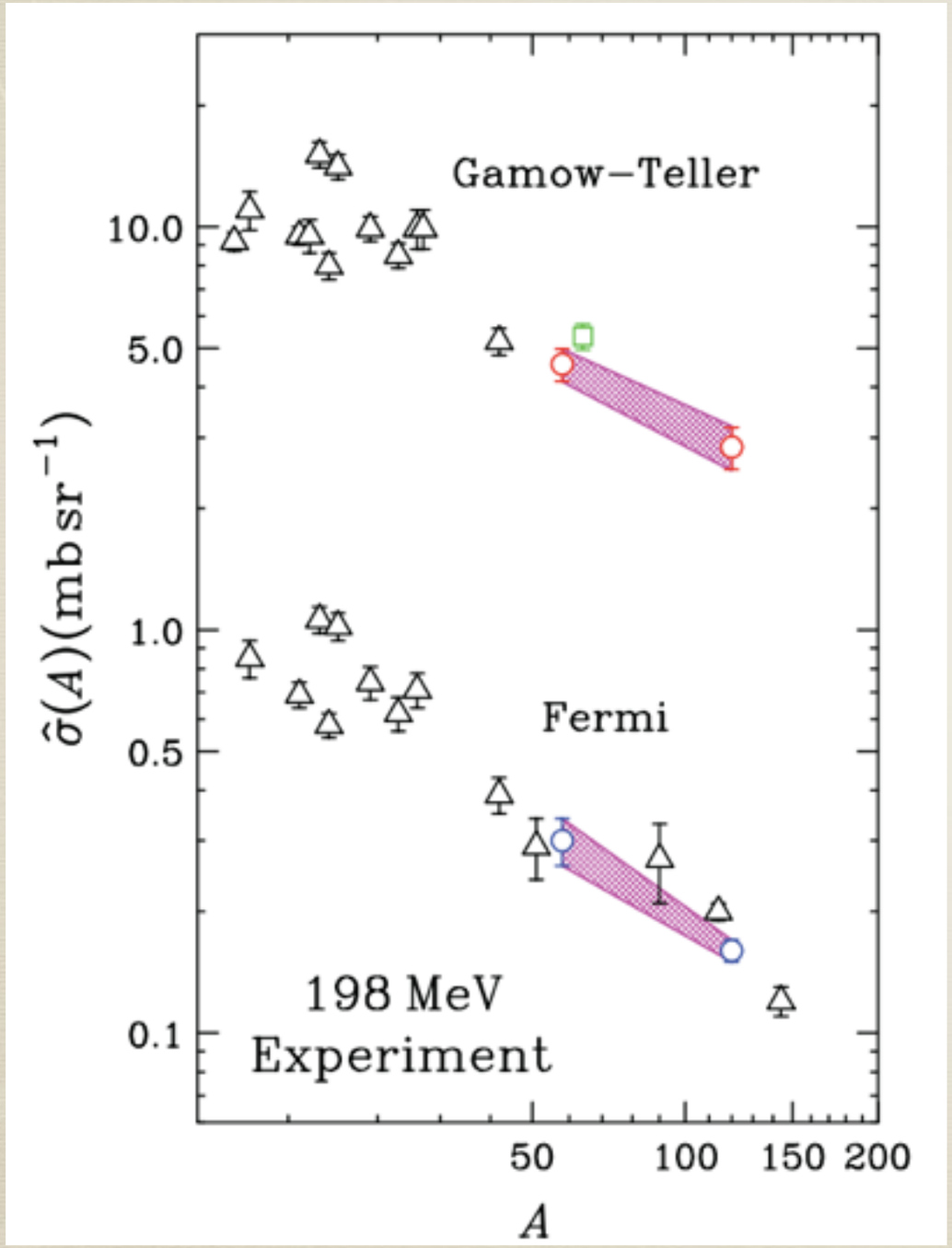


T. N. Taddeucci, C. A. Goulding, T. A. Carey et al., Nucl. Phys. **469** (1987) 125.
and recent study of unit cross section:
M. Sasano, H. Sakai, K. Yako et al., Phys. Rev. C **79** (2009) 024602.

Beta decay strength:

$$G_V^2 B(\mathrm{F}) + G_A^2 B(\mathrm{GT}) = \frac{K}{ft}$$

The unit cross section is slowly varying function of *A*



- **The unit cross sections are same for different transitions within a final nucleus.**
- **The unit cross section changes smoothly with A.**
- **The unit cross sections of Fermi transitions are about 1/10 of Gamow-Teller transitions.**

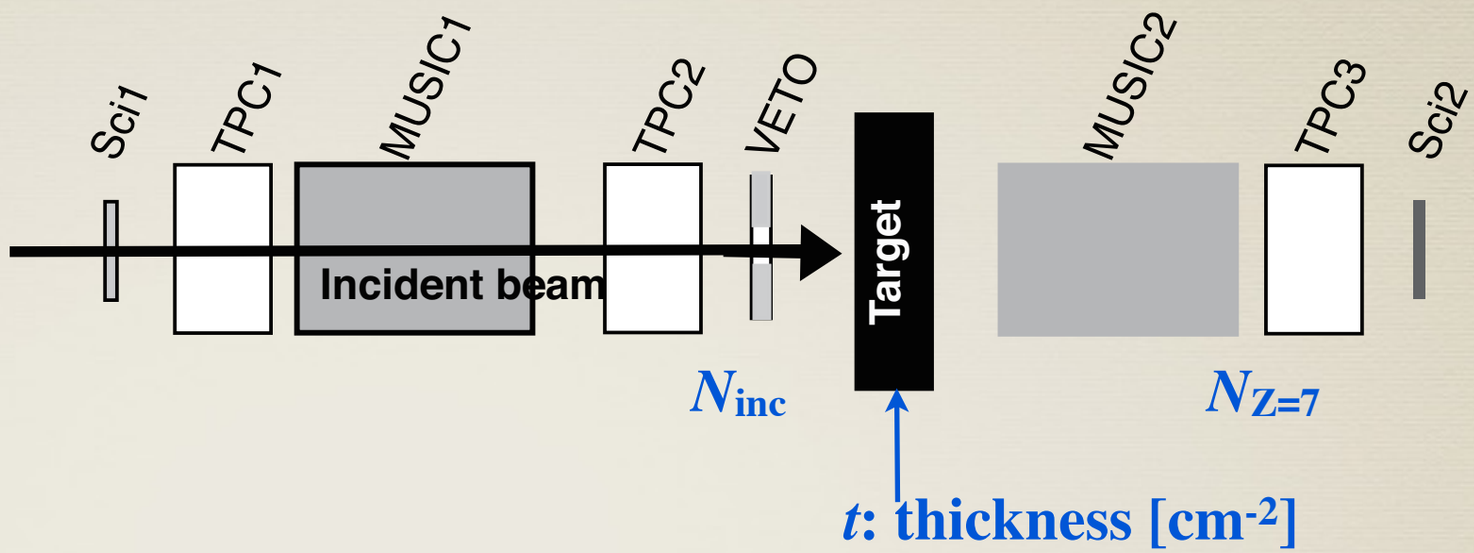
- **Although so far the discussion is based on the dσ(0)/dΩ.**
- **The integrated cross-section should have close relation but it has to be proved.**

M. Sasano, H. Sakai, K. Yako et al., Phys. Rev. C **79** (2009) 024602.

Charge Exchange Cross section

σ_{ex}

$$N_{Z+1} = N_{inc}\sigma_{ex}t$$



- Measurement is at 0 degrees but include almost all c.m. angles.
- If proton(s) is removed from a fragment, the (p,n) reaction to that state is not included in the σ_{ex}.
- If only neutron(s) is emitted from the fragment, it is included in the σ_{ex}.

Projectile fragment with larger *Z*

* **900*A* MeV ^{18}C + p reaction at GSI**

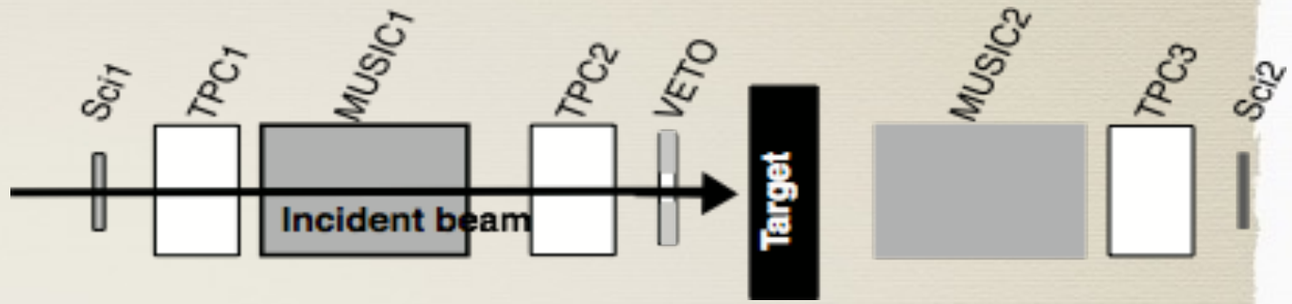
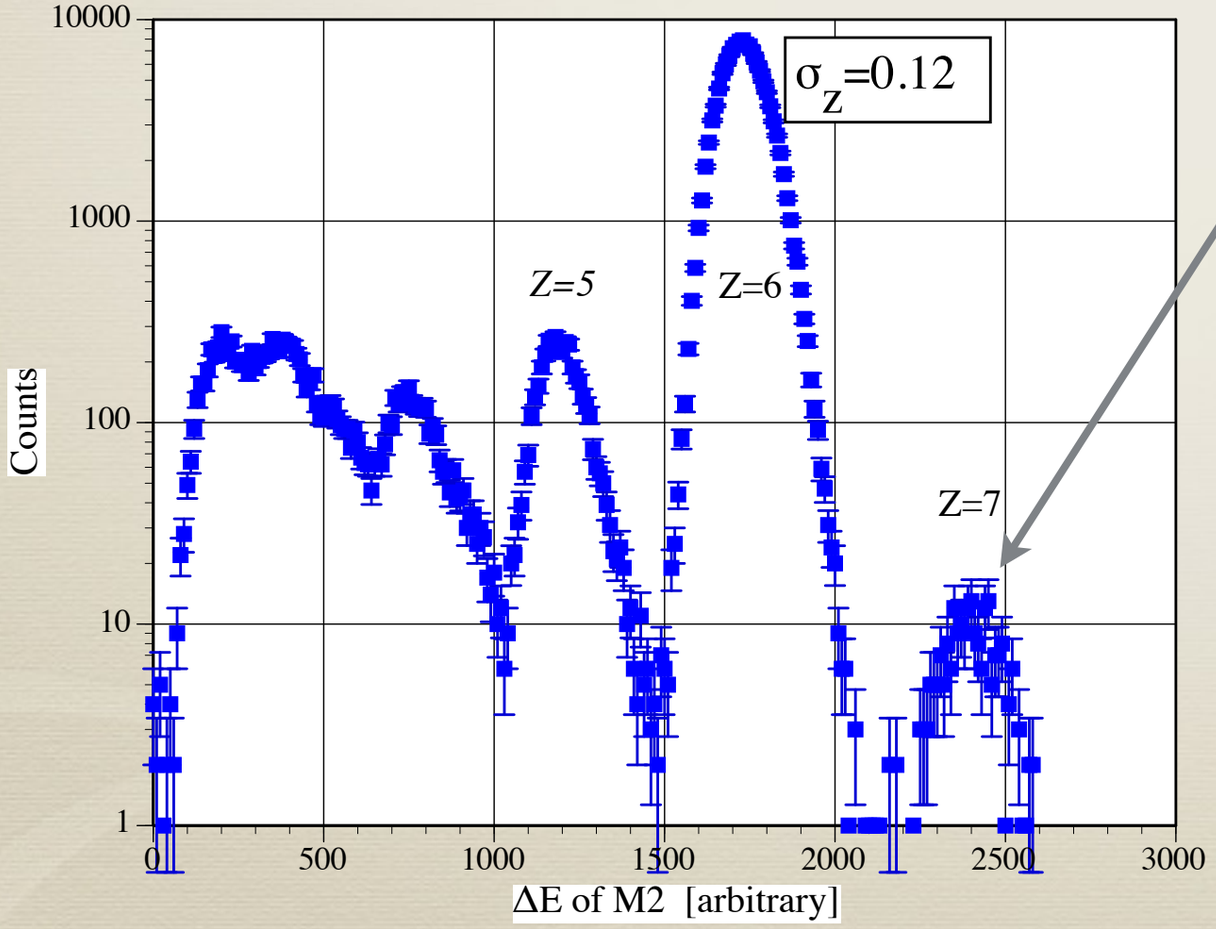


Fig. 2 Experimental setup. Sci: plastic scintillation detector, TPC:



Charge exchange reaction

Mostly,
^{18}C + p -> ^{18}N + n

σ_{ex} for C isotopes

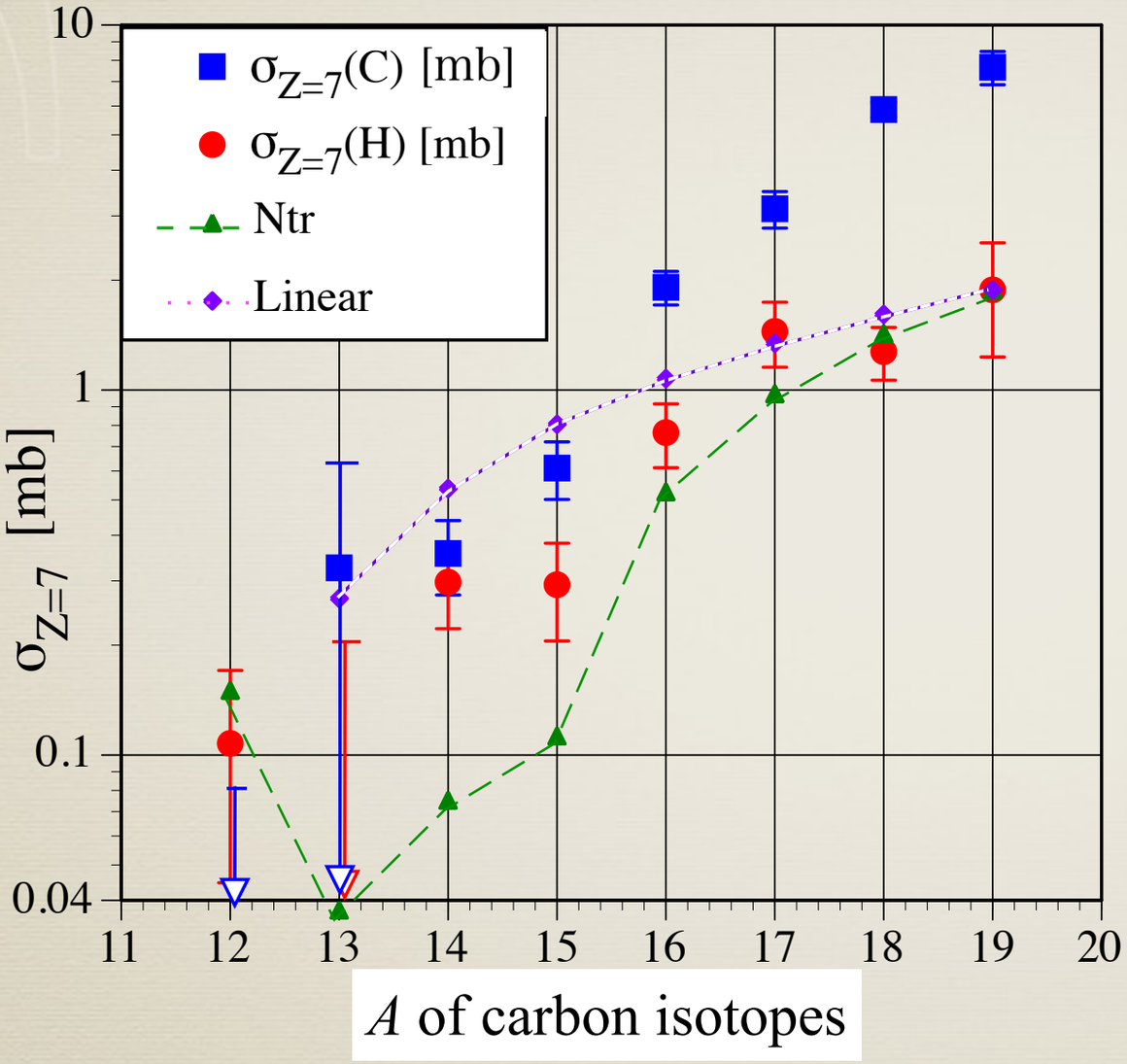


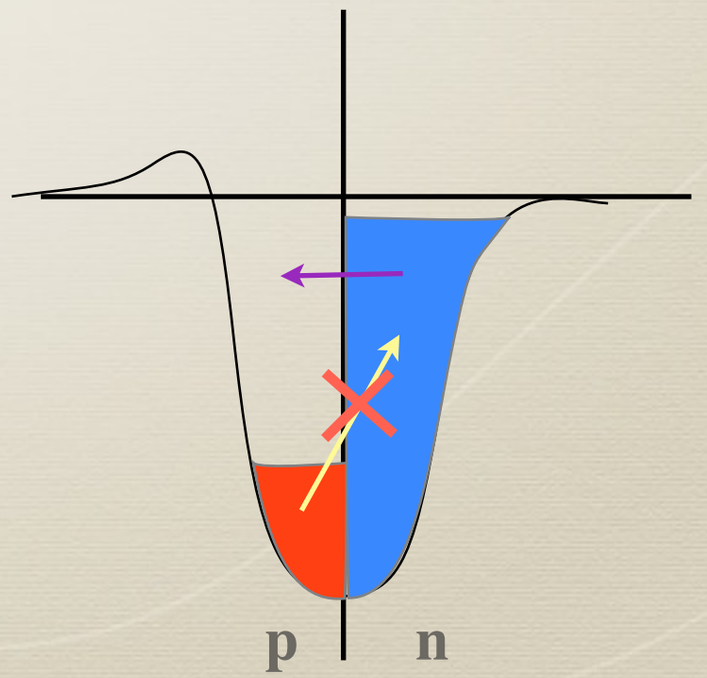
Fig. 4 Observed charge exchange cross sections of C isotopes on H and C

Ikeda sum rule:

$$S_{GT^+} - S_{GT^-} \propto 3(N-Z)$$

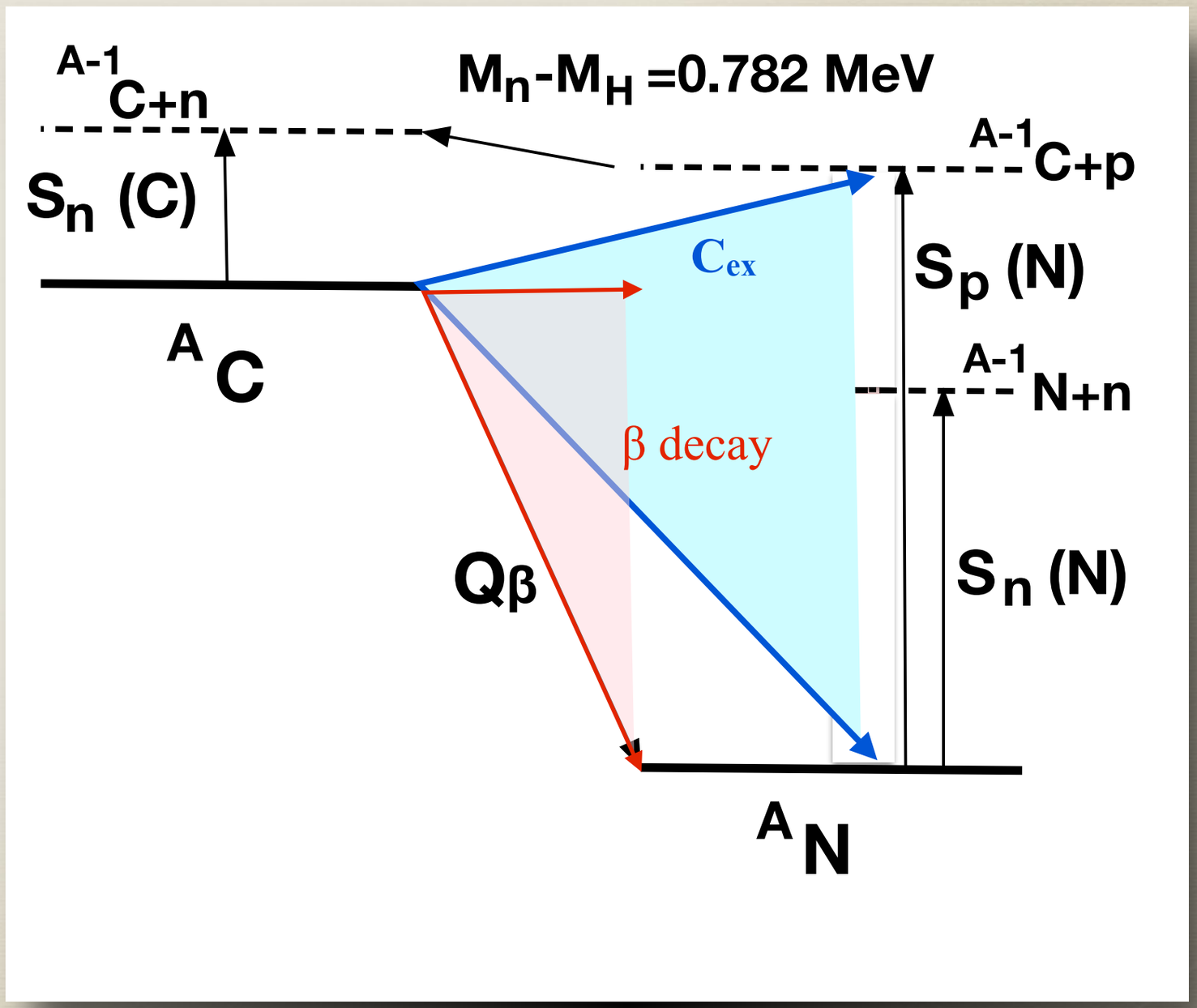
In neutron rich nuclei,

$$S_{GT^+} \propto 3(N-Z)$$



The relation between β decay and (p,n) charge exchange reaction for neutron rich nuclei

- **For neutron rich nuclei**
  - ***Beta-decay window and charge exchange reaction window is very similar.***
  - ***It can be used to find the total strength of the beta decay for neutron rich nuclei.***
  - ***in r-process $S_n \sim 1MeV$. Two windows are same.***



We assume that the main contribution is from allowed transition

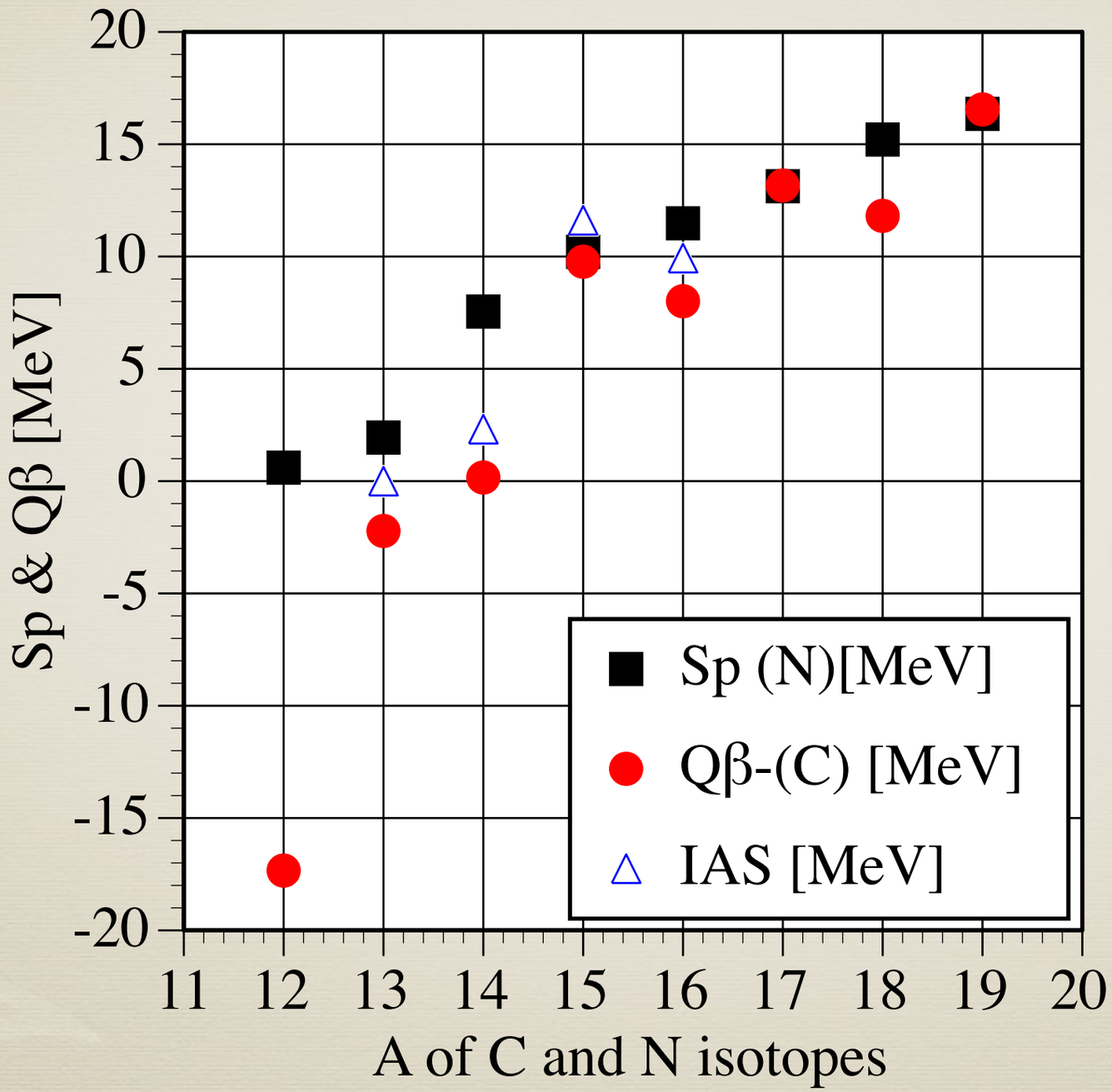
= This assumption has to be checked =

$$\sigma_{ex\beta} = \sum_{\text{all transitions}} \left[\hat{\sigma}_F B(\mathrm{F}) + \hat{\sigma}_{GT} RB(\mathrm{GT}) \right]$$

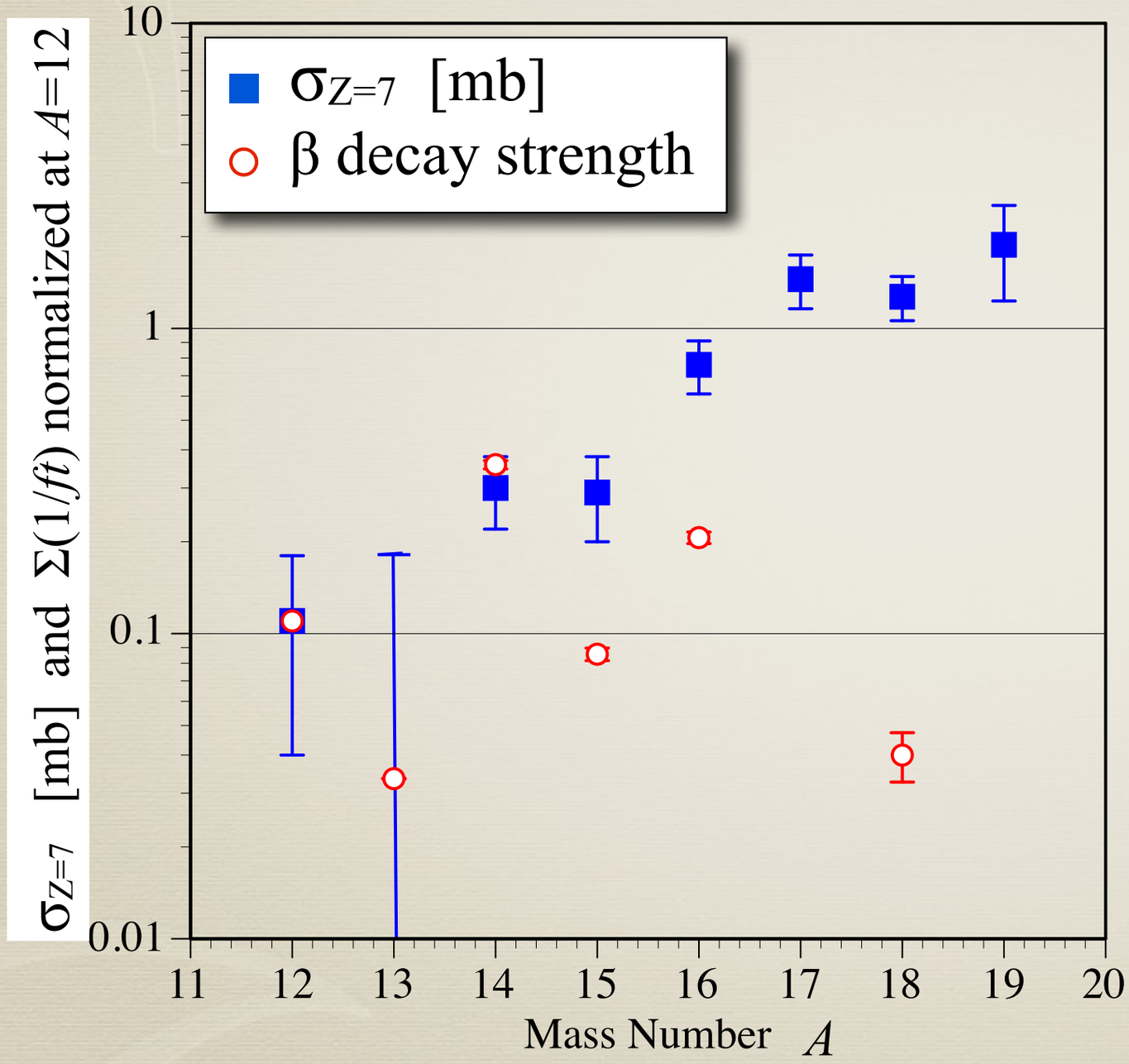
$$\sigma_{ex\beta} = \sum_{\text{all transitions}} \hat{\sigma}_{GT} \left[B(\mathrm{F})/10 + RB(\mathrm{GT}) \right]$$

$$B(\mathrm{F}) + RB(\mathrm{GT}) = \frac{6163}{ft}$$

Relation between S_p, Q_β,and IAS



Relation between β-decay strength and σ_{ex}



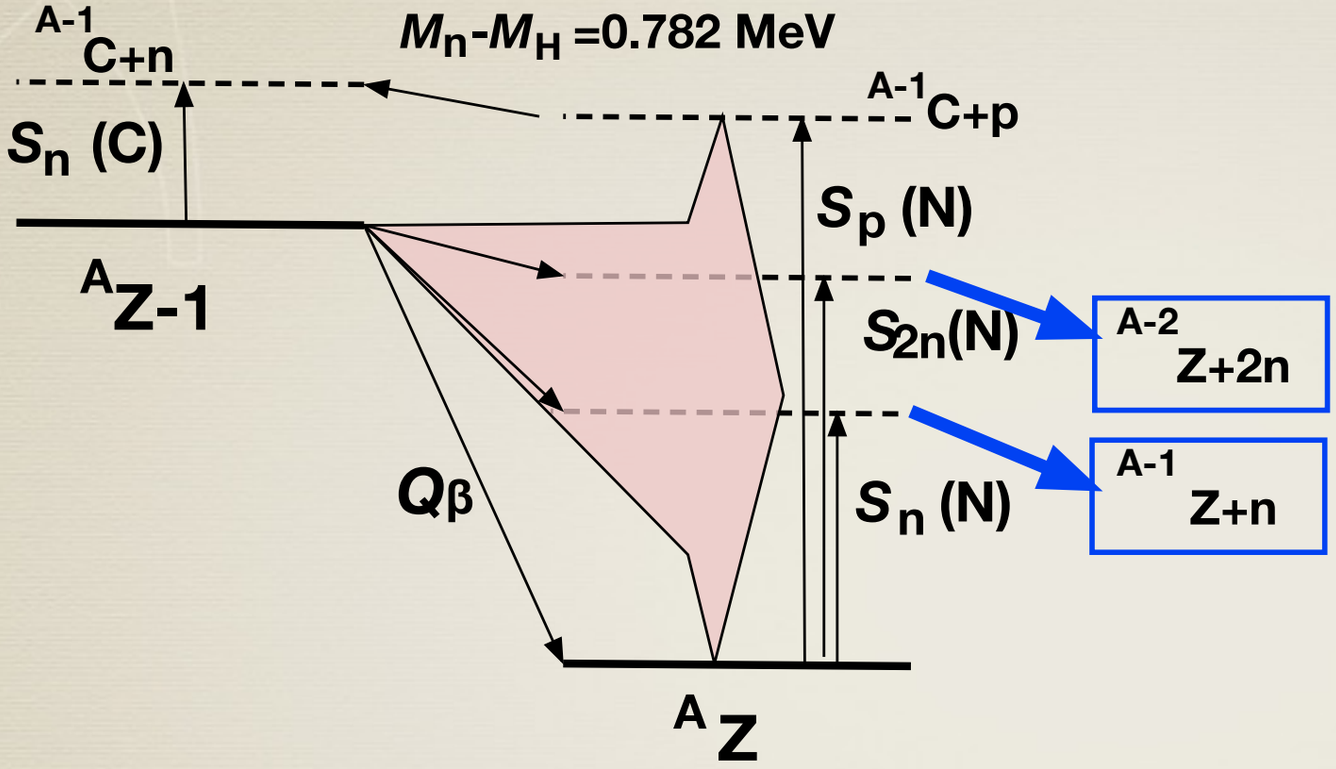
β-decay strength and σ_{ex} are in good proportion for nuclei in which all beta-decays are known.

Unmeasurable sum of β-decay strength may be obtained by σ_{ex}.

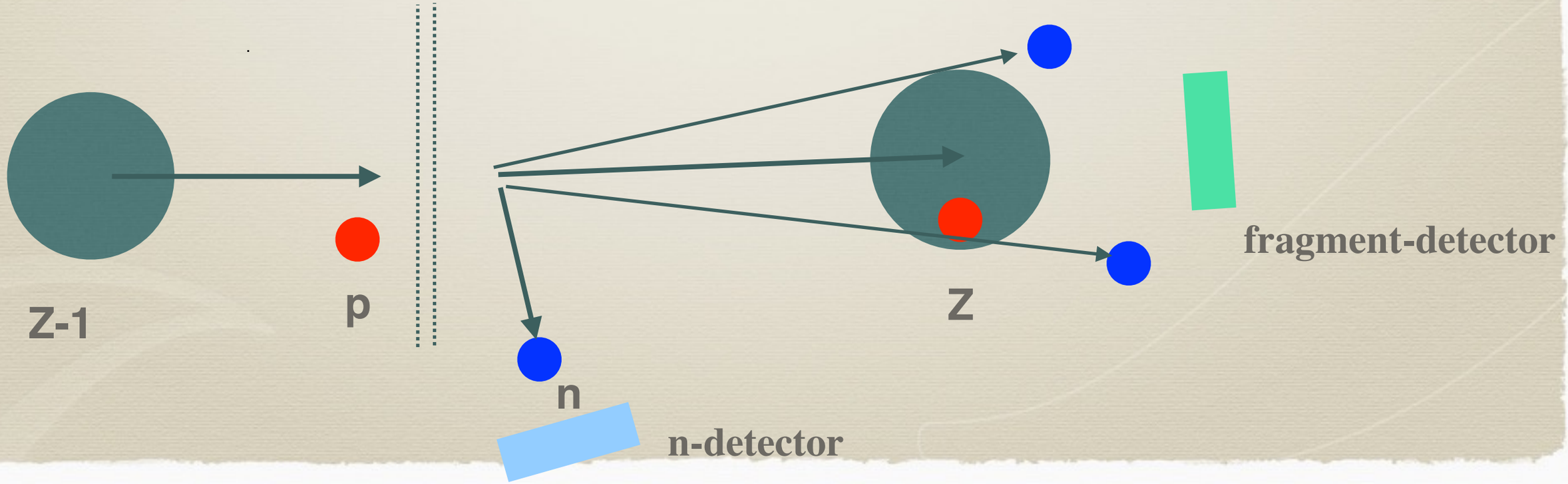
Summary I

- Charge exchange reactions of neutron rich nuclei have been determined in C isotopes.
- Beta-decay strength and σ_{ex} were compared and found that they are correlated very well.
- σ_{ex} can be used to estimate integrated β-decay strength up to proton separation energy. Handy method to obtain beta-decay strength of r-process nuclei.
- We need theory to calculate the total charge exchange cross section with proton and nuclear targets including forbidden transitions.
- Measurement of similar nuclei with neutron detection would be useful.

Future perspective



- Transitions to β delayed neutron emission channels can easily be studied by the detection of ^{A-1}Z +n, ^{A-2}Z+2n, … fragments.
- Detection of recall neutron (not evaporated neutron) will give even the separation of states in nucleus ^{A}Z.



Future necessary steps

1. **Measurements of fragmentation cross sections of $^{A}(Z-1)+p \rightarrow {}^{A'}Z + X$ for nuclei with well known beta-decay strength including forbidden transitions ($A' \leqq A$). Then continue to neutron rich nuclei.**
2. **Measurement of $^{A}(Z-1)+p \rightarrow {}^{A'}Z + n + X$ reaction when separations of final states are necessary.**
3. **Theoretically, we need to establish the relation between the transition matrix and the fragmentation cross sections. So far the proportionality between $d\sigma(0°)/d\Omega$ and transition matrix has been established.**
4. **How about $^{A}_{N}Z+d \rightarrow {}^{A-i}_{N+1}Z(Z-i) + X$ reaction instead of $(d, {}^{2}He)$.**

Collaborators

I. Tanihata[1,2,*], S. Terashima[1,*], R. Kanungo[3], F. Ameil[4], J. Atkinson[2], Y. Ayyad[2], D. Cortina-Gil[5], I. Dillmann[4,6], A. Estradé[3,4], A. Evdokimov[4], F. Farinon[4], H. Geissel[4,6], G. Guastalla[4], R. Janik[7], R. Knoebel[4], J. Kurcewicz[4], Yu. A. Litvinov[4], M. Marta[4], M. Mostazo[5], I. Mukha[4], C. Nociforo[4], H. J. Ong[2], S. Pietri[4], A. Prochazka[4], C. Scheidenberger[4,6], B. Sitar[7], P. Strmen[7], M. Takechi[4], J. Tanaka[2], H. Toki[2], J. Vargas[5], J. S. Winfield[4], and H. Weick[4]

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Thank you for your attention.