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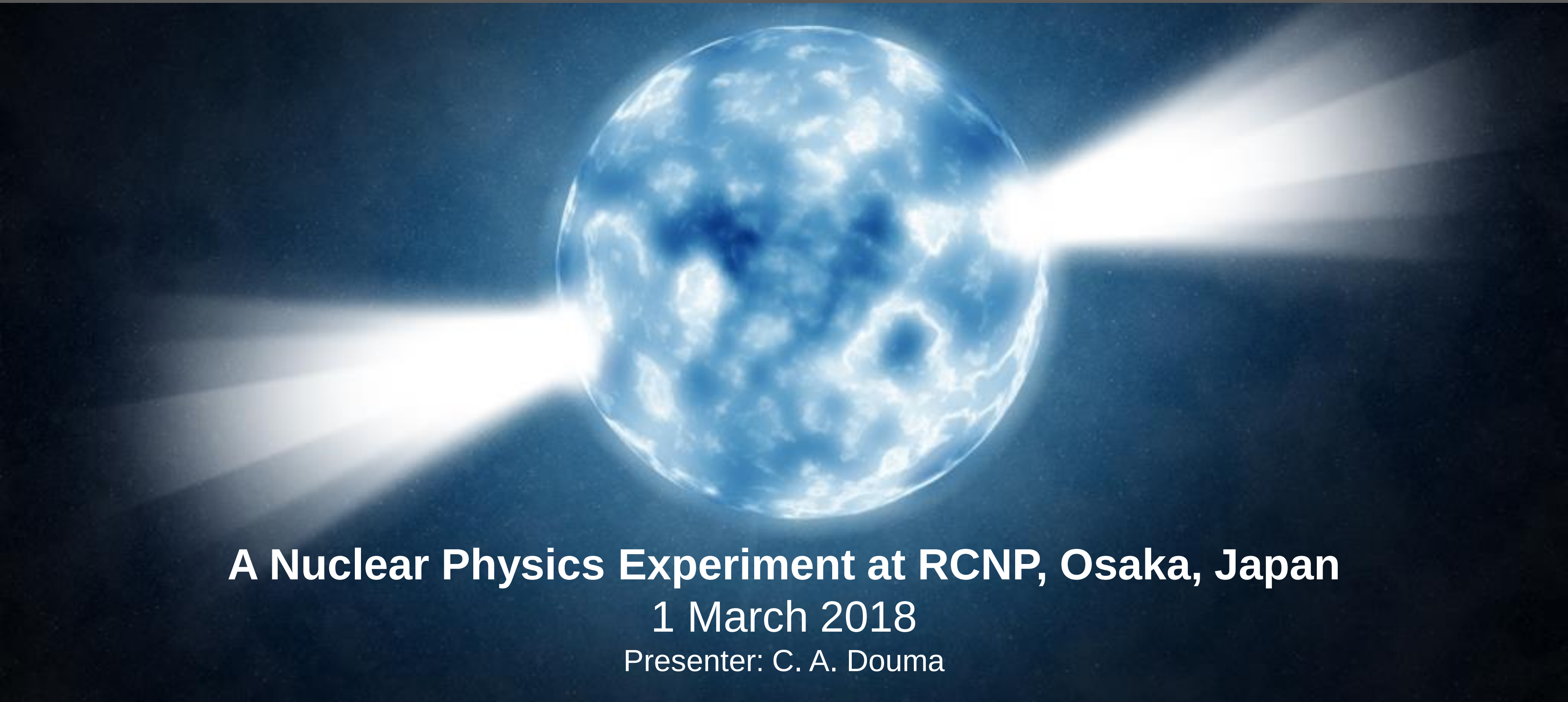
Measurement of the Gamow-Teller transitions in Sn-116/122 through the (^{3}He,t) charge-exchange reaction



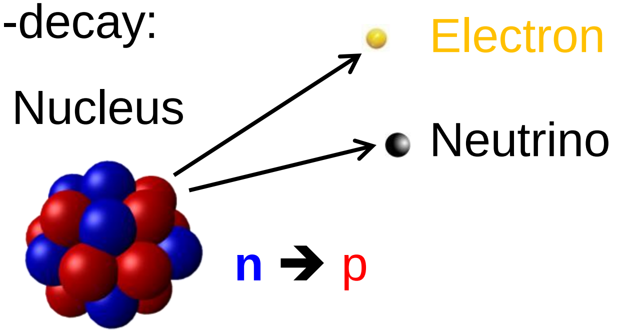
A Nuclear Physics Experiment at RCNP, Osaka, Japan

1 March 2018

Presenter: C. A. Douma

Gamow-Teller transitions

β-decay:



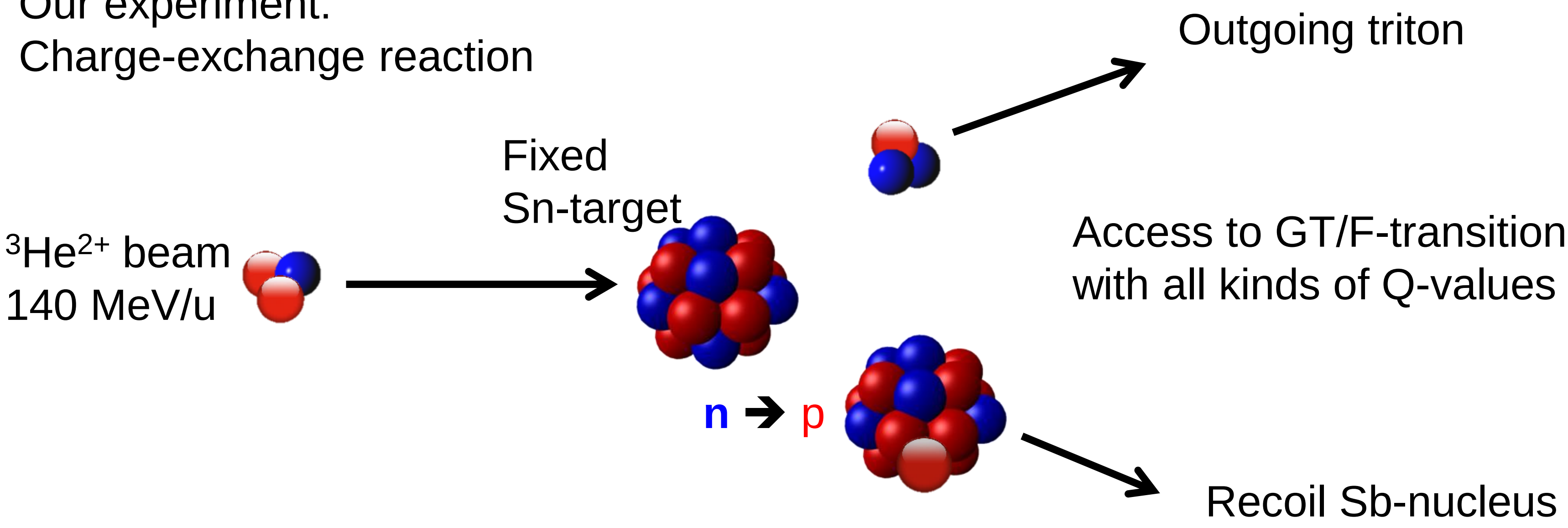
Fermi (F) decay:
$\Delta L = 0$, $\Delta S = 0$, $\Delta T = 1$

$$|\nu e\rangle = |\uparrow\downarrow\rangle$$

Gamow-Teller (GT) decay:
$\Delta L = 0$, $\Delta S = 1$, $\Delta T = 1$

$$|\nu e\rangle = |\uparrow\uparrow\rangle$$

Our experiment:
Charge-exchange reaction



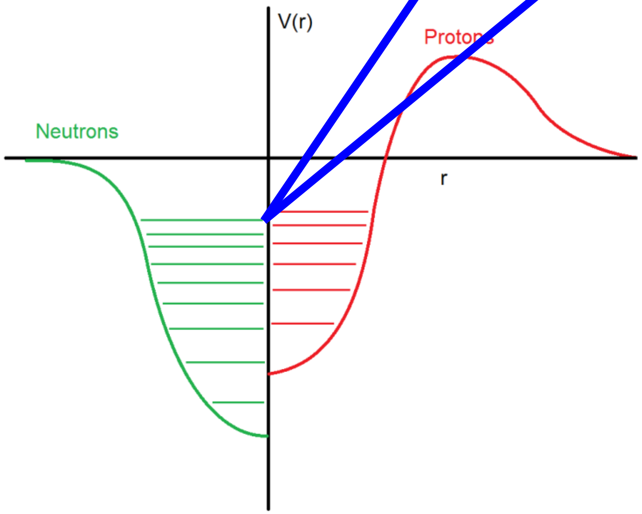
Access to GT/F-transitions
with all kinds of Q-values

The Gamow-Teller Observable

We are interested in the strength of the GT (or F) transitions:

$$B(GT) = \frac{1}{2J_i+1} |\langle \Psi_f | \boldsymbol{\sigma\tau} | \Psi_i \rangle|^2 \qquad B(F) = \frac{1}{2J_i+1} |\langle \Psi_f | \boldsymbol{\tau} | \Psi_i \rangle|^2$$

These can be extracted from the differential cross section of the reaction.



Measuring B(GT/F) gives information about the nuclear wave functions.

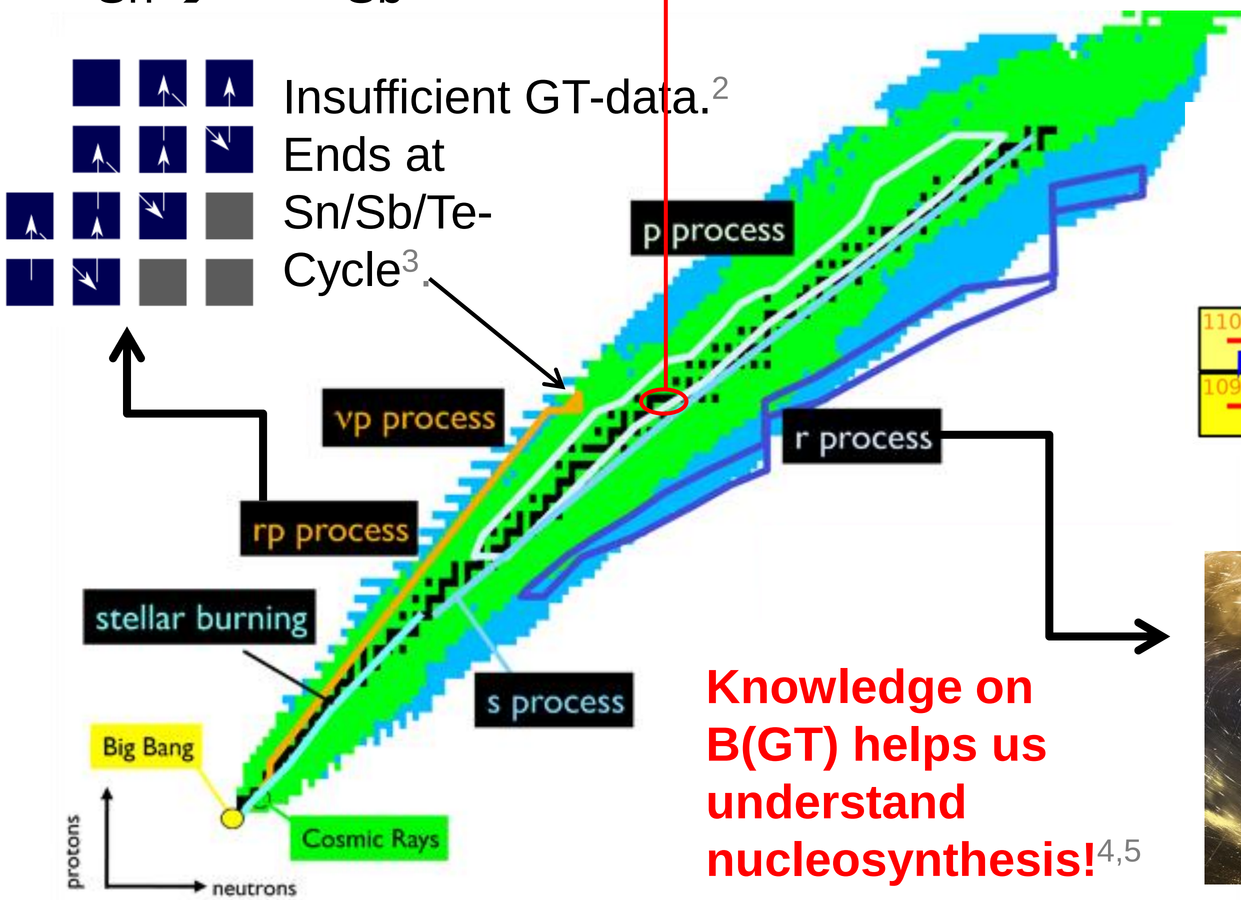
Exp. data on B(GT/F) leads to a better understanding of the underlying nuclear structure.

Nucleosynthesis

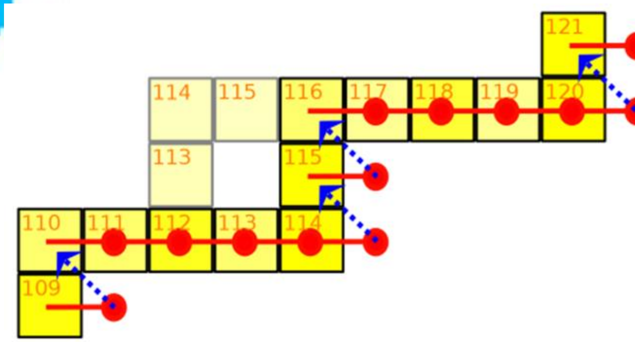
1) B. J. Shappee *et al.*, *Science* 10.1126 (2017)
2) K. Langanke, *et al.*, Rev. Mod. Phys. 75 (2003)
3) H. Schatz *et al.*, Phys. Rev. Letters 86 16 (2001)
4) D. Frekers *et al.*, Nucl. Phys. A 916 (2013)
5) Y. Fujita *et al.*, Phys. Rev. C 88 014308 (2013)

We measured cross sections of $^{116,122}Sn \rightarrow {}^{116,122}Sb$

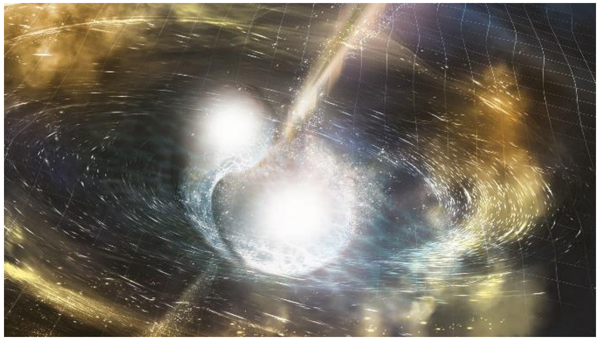
Insufficient GT-data.[2]
Ends at Sn/Sb/Te-Cycle[3].



Knowledge on B(GT) helps us understand nucleosynthesis![4,5]



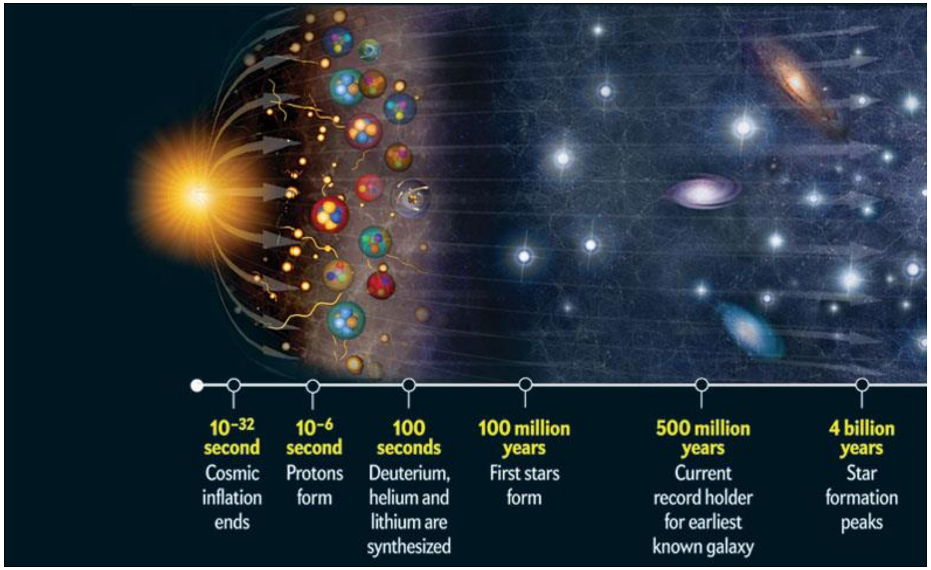
17 August 2017[1]



1) D. Frekers *et al.*, Nucl. Phys. A 916 (2013)
2) J. D. Vergados, Phys. Rep. 361 (2002)
3) H. Ejiri, Phys. Rep. 338 (2000)
4) J. D. Vergados *et al.*, https://arxiv.org/pdf/1205.0649.pdf
5) T. Brunner *et al.*, Nucl. Phys. News, 27 3 (2017)

Neutrino physics

- ➔ Need B(GT) for $0\nu\beta\beta$-decay models[1]
  - ➔ neutrino = Majorana ?[2]
  - ➔ Hints to GUT & SUSY?[2,3,4]
  - ➔ Matter/antimatter asymmetry explanations[5]
  - ➔ neutrino mass might be constrained to meV[4]



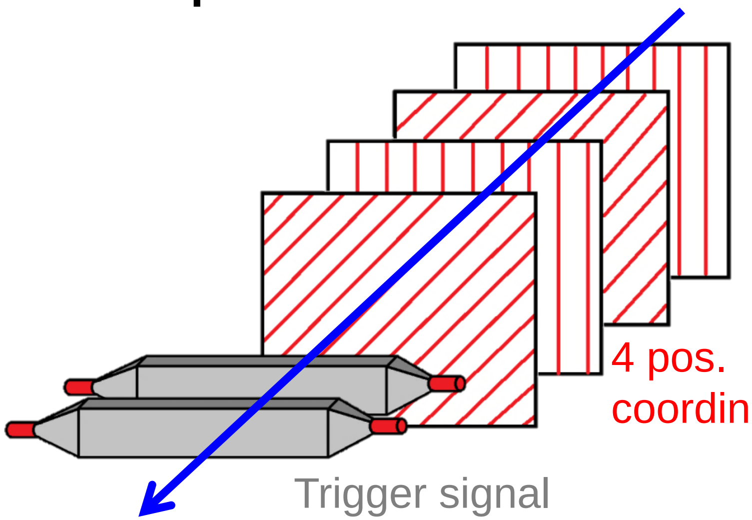
For understanding the evolution of the universe, we need to understand:

- ➔ Nuclear structure
- ➔ Nucleosynthesis
- ➔ matter/antimatter asymmetry
- ➔ Neutrino nature

➔ **<u>Hence, we have to measure B(GT) strengths.</u>**

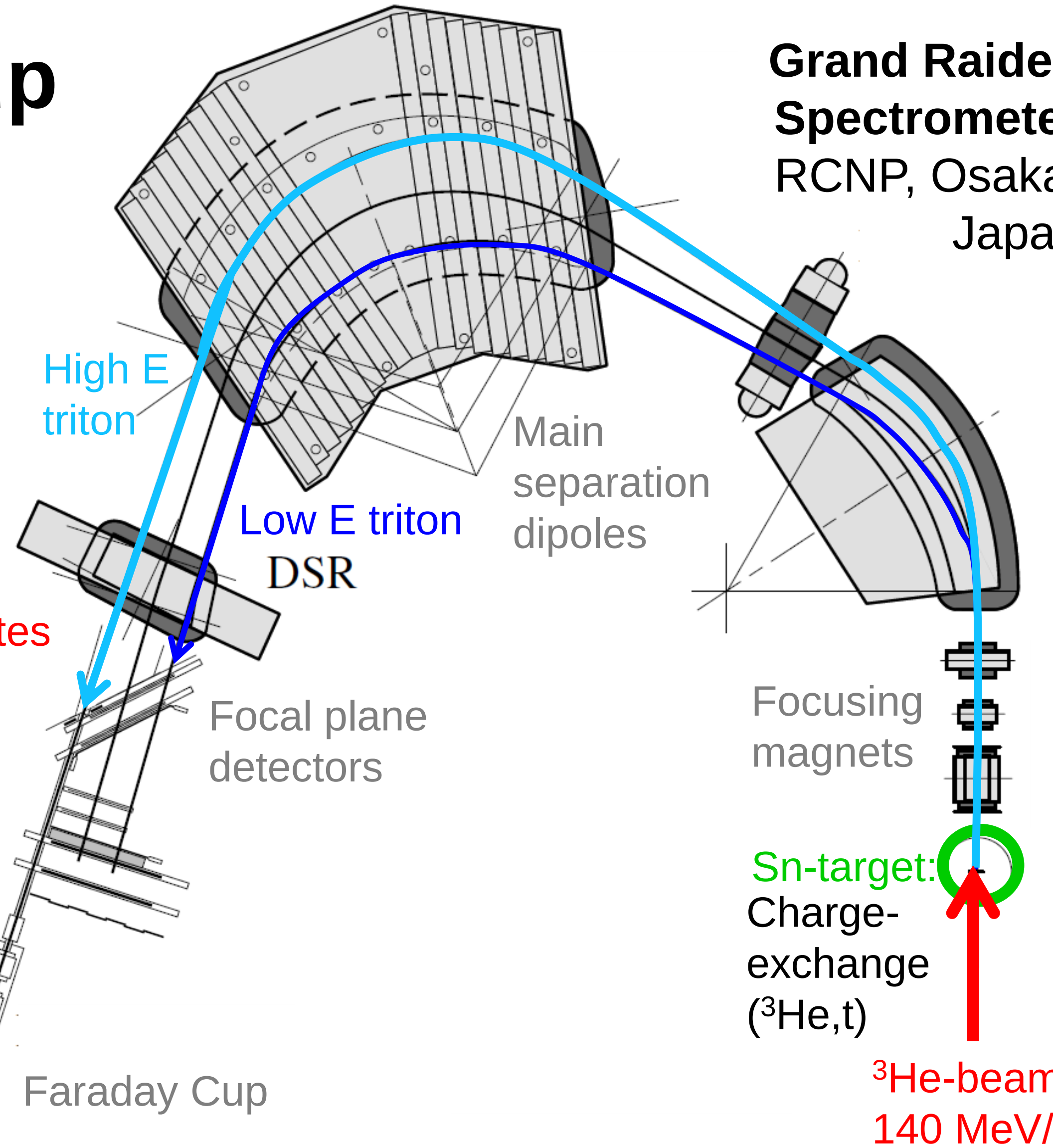
Experimental setup

Focal plane detectors:

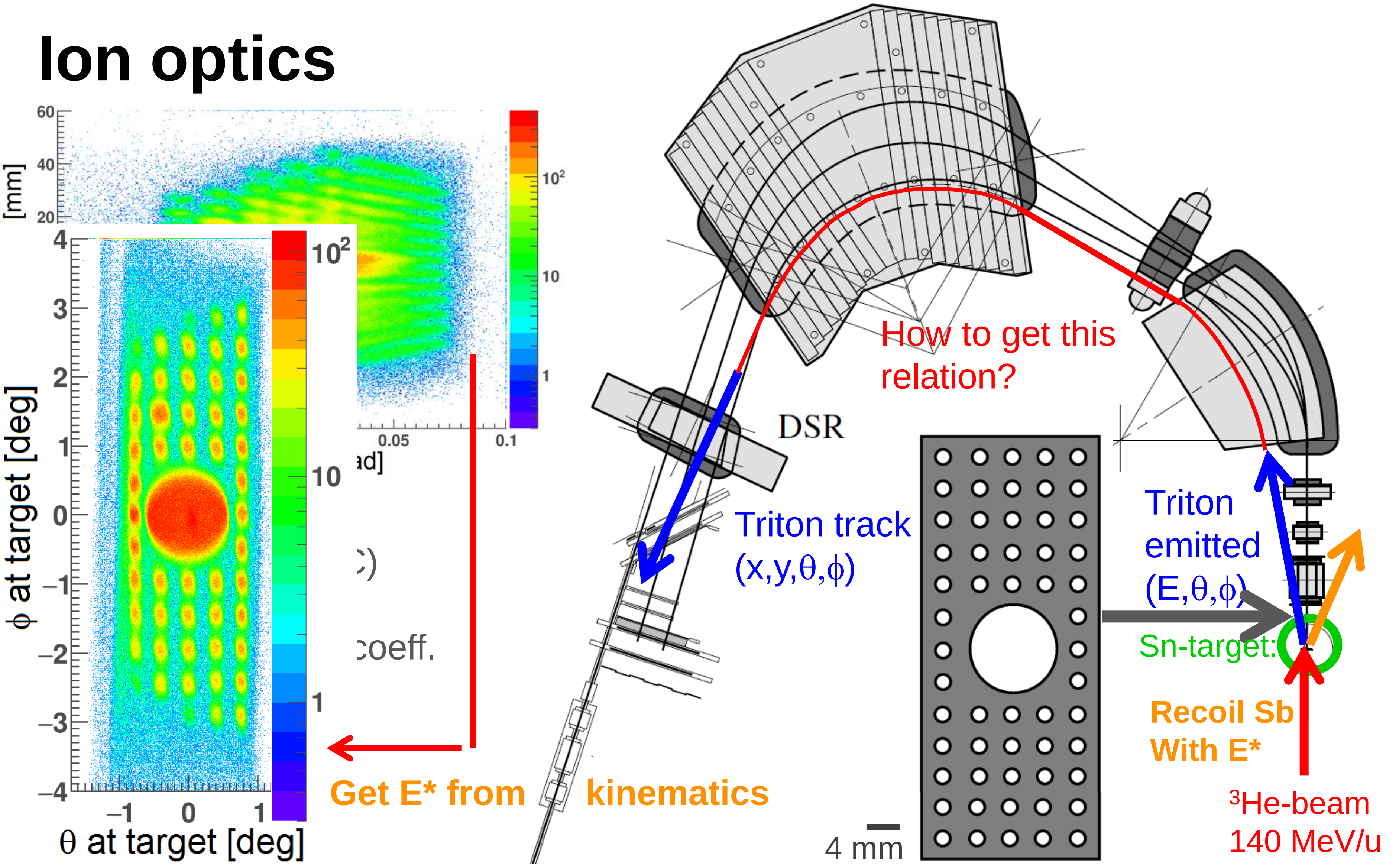


➔ **Reconstruct the track by fitting a line (x,y,θ,ϕ)**

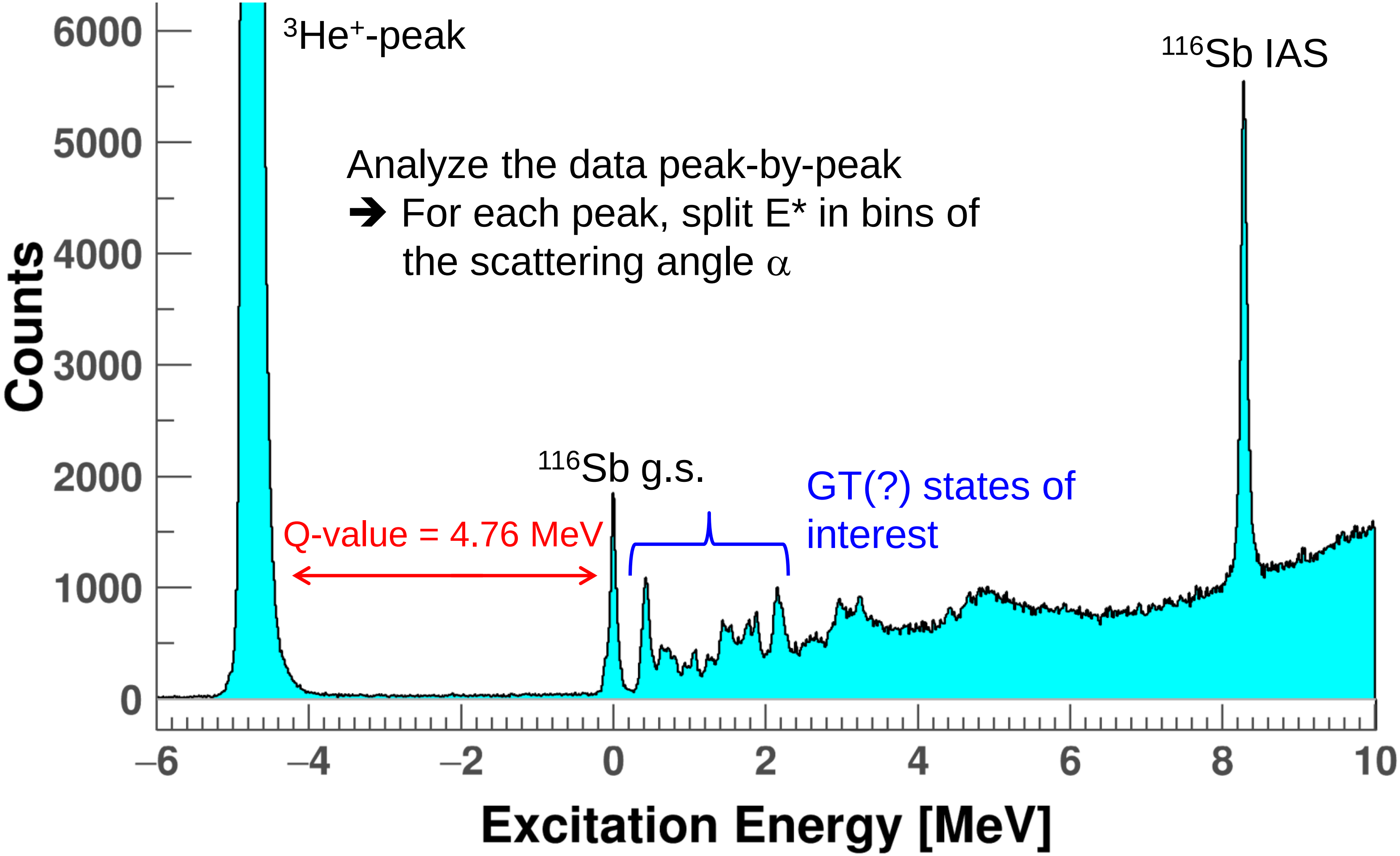
Grand Raiden Spectrometer
RCNP, Osaka, Japan



Ion optics


[mm]
60
40
20
0.05
0.1
10^2
10
1
4
3
2
1
0
−1
−2
−3
−4
−1
0
1
φ at target [deg]
θ at target [deg]
10^2
10
1
How to get this relation?
DSR
Triton track (x,y,θ,φ)
Triton emitted (E,θ,φ)
Sn-target:
4 mm
Recoil Sb With E*
^{3}He-beam 140 MeV/u
Get E* from kinematics

Extraction of the cross section



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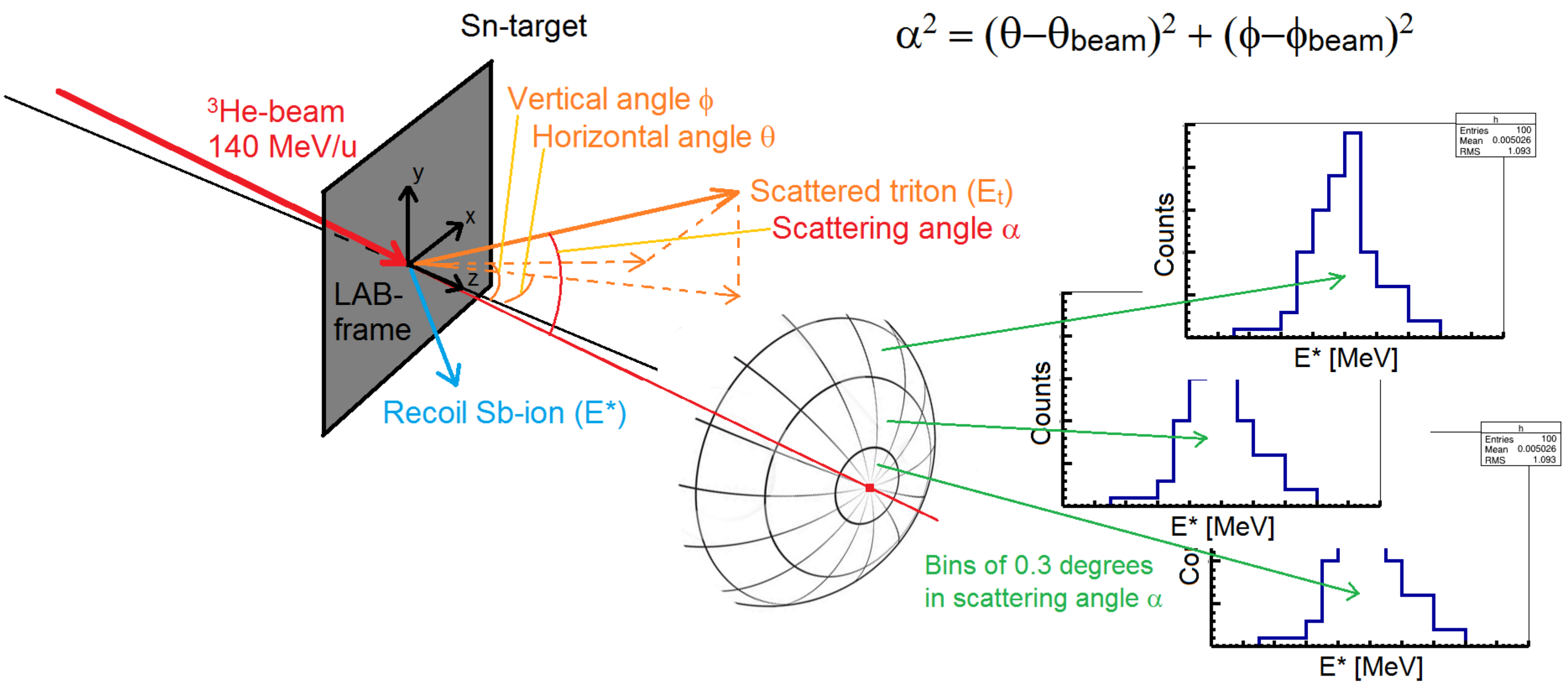
Extraction of the cross section

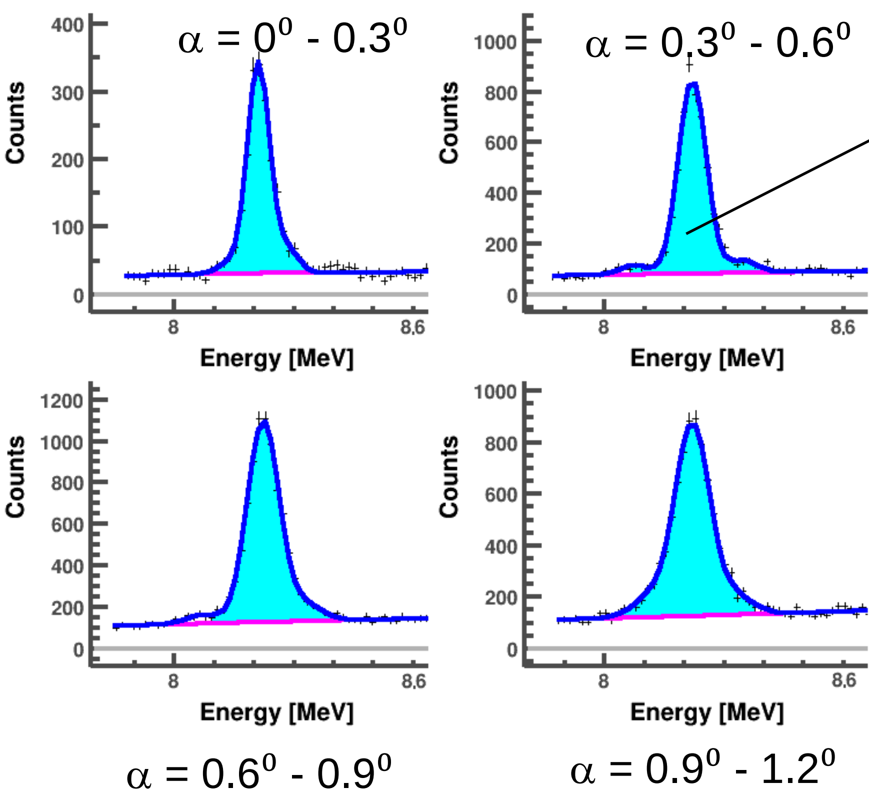
$$\alpha^2 = (\theta - \theta_{beam})^2 + (\phi - \phi_{beam})^2$$



Extraction of the cross section

➔ Fit Background + Gauss with tails: $f(x) = C\, e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)} \cdot \left(1 + A e^{a(x-\mu)} + B e^{b(\mu-x)}\right)$

➔ Compute area: ~ Cσ ➔ Convert to absolute nr. of counts.



$$\frac{\text{Area}}{A_\alpha \cdot \epsilon} = \left.\frac{d\sigma}{d\Omega}\right|_\alpha \cdot \frac{s}{m} \cdot \frac{Q}{2e}$$

A_α: Detector acceptance

ϵ: Detector Efficiency

s: Target thickness

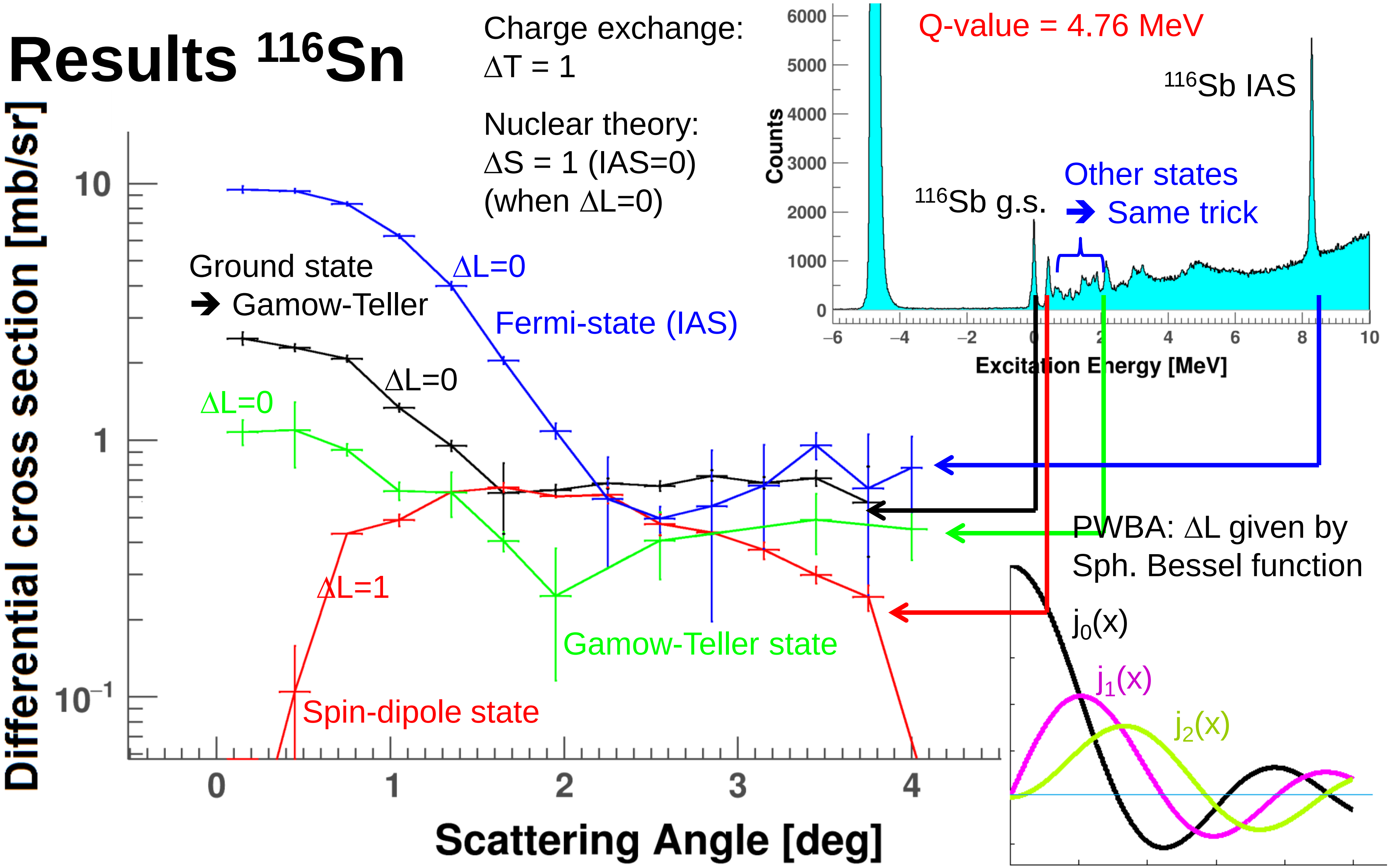
Q: Integrated beam charge

This example: IAS-state near 8.2 MeV of Sn-116 (ΔS=ΔL=0, ΔT=1)

Results ^{116}Sn

Charge exchange:
$\Delta T = 1$

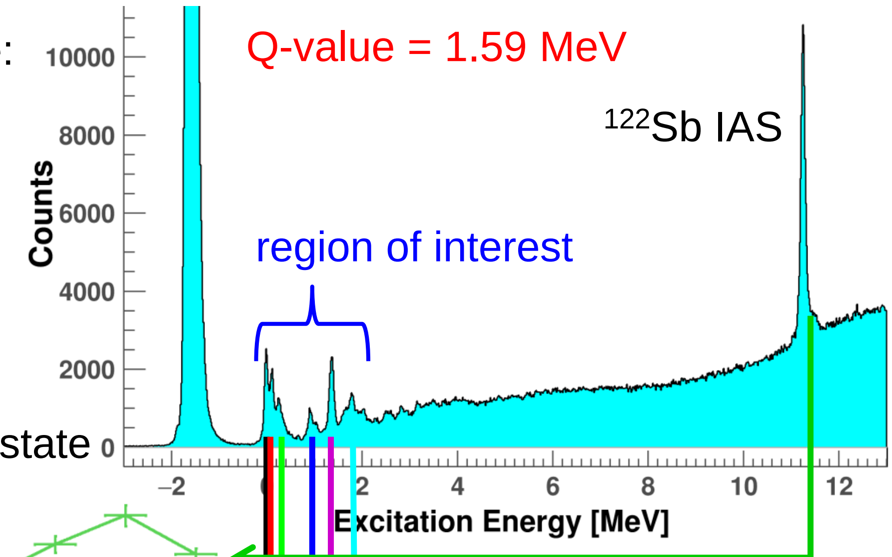
Nuclear theory:
$\Delta S = 1$ (IAS=0)
(when $\Delta L=0$)

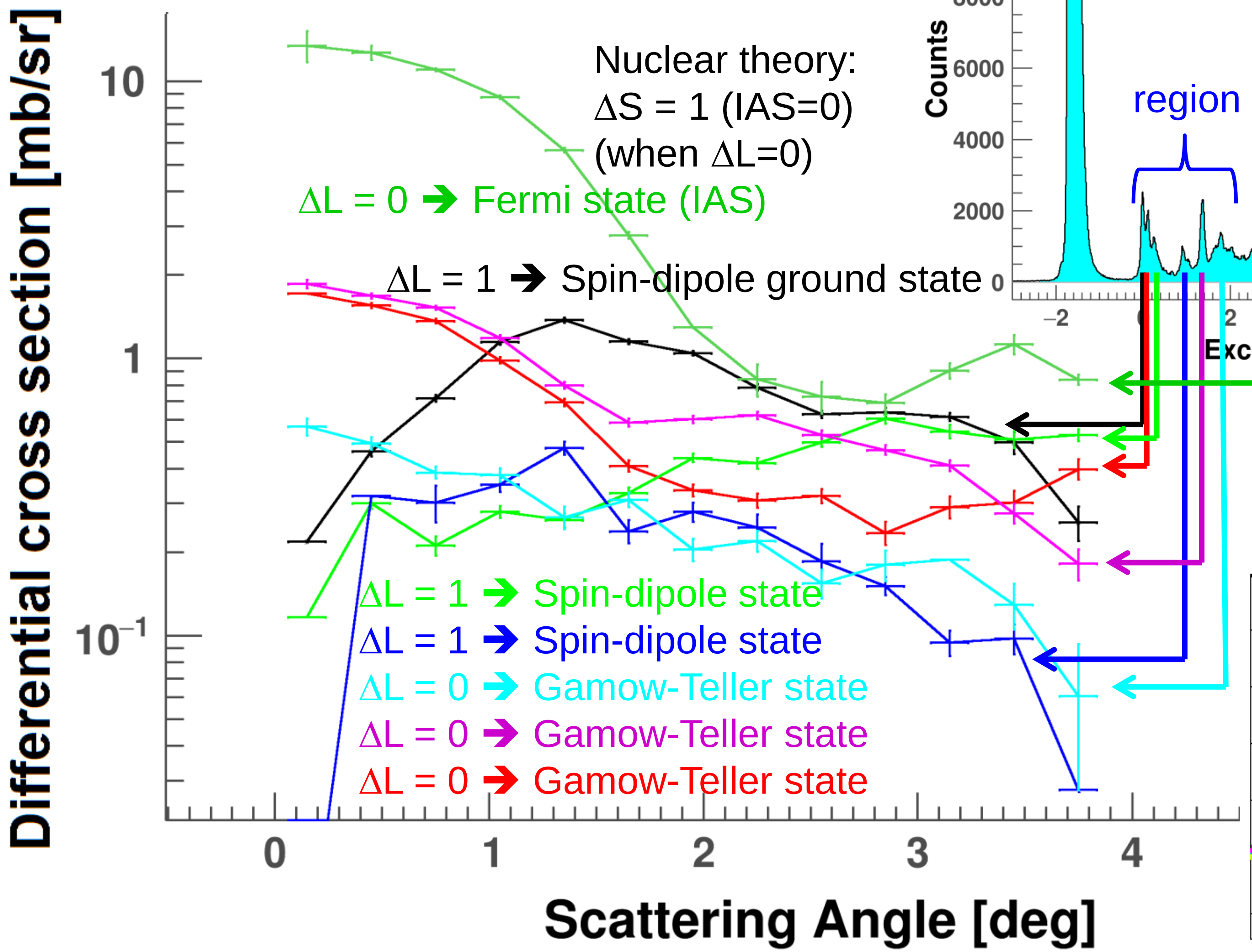


Results ^{122}Sn

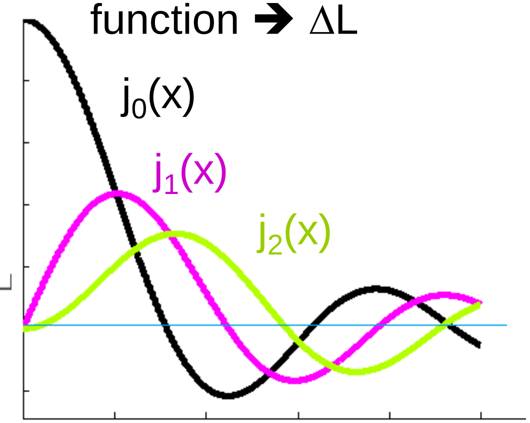
Charge exchange:
$\Delta T = 1$

Nuclear theory:
$\Delta S = 1$ (IAS=0)
(when $\Delta L=0$)





Spherical Bessel function ➔ ΔL



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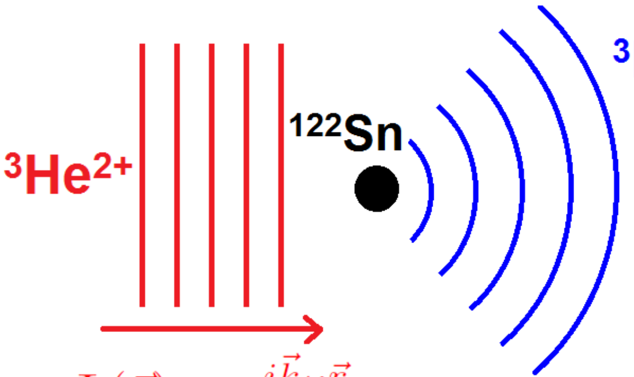
Obtaining B(GT/F)

Asymp. behaviour of scattering exp:

$$\Psi(\vec{r}) = f(\alpha) \cdot \frac{1}{r} e^{irk_f}$$



$$\Psi(\vec{r}) = e^{i\vec{k}_i \cdot \vec{r}}$$

$$\frac{d\sigma}{d\Omega} = |f(\alpha)|^2$$

Outgoing plane wave (α–dep.)

Nuclear Interaction potential

DWBA:

$$f(\alpha) = \frac{-\mu}{2\pi\hbar} \langle \Phi | \hat{\mathbf{V}} | \Psi \rangle$$

Distorted wave: Incoming plane wave + scattered wave ($f(\alpha)$-dep!)

Exp. Physicist:

+

<u>FOLD-package:</u>
J. Cook *et al.*,
Phys. Rev. C 30 1538 (1984)
R. G. T. Zegers *et al.*,
Phys. Rev. C 74 024309 (2006)

Compute **V** from Franey & Love interaction: Phys. Rev. C 31, 488 (1985).

Solve $f(\alpha)$ by numerical iteration

➔ Compute $\frac{d\sigma}{d\Omega}$

Obtaining B(GT/F)

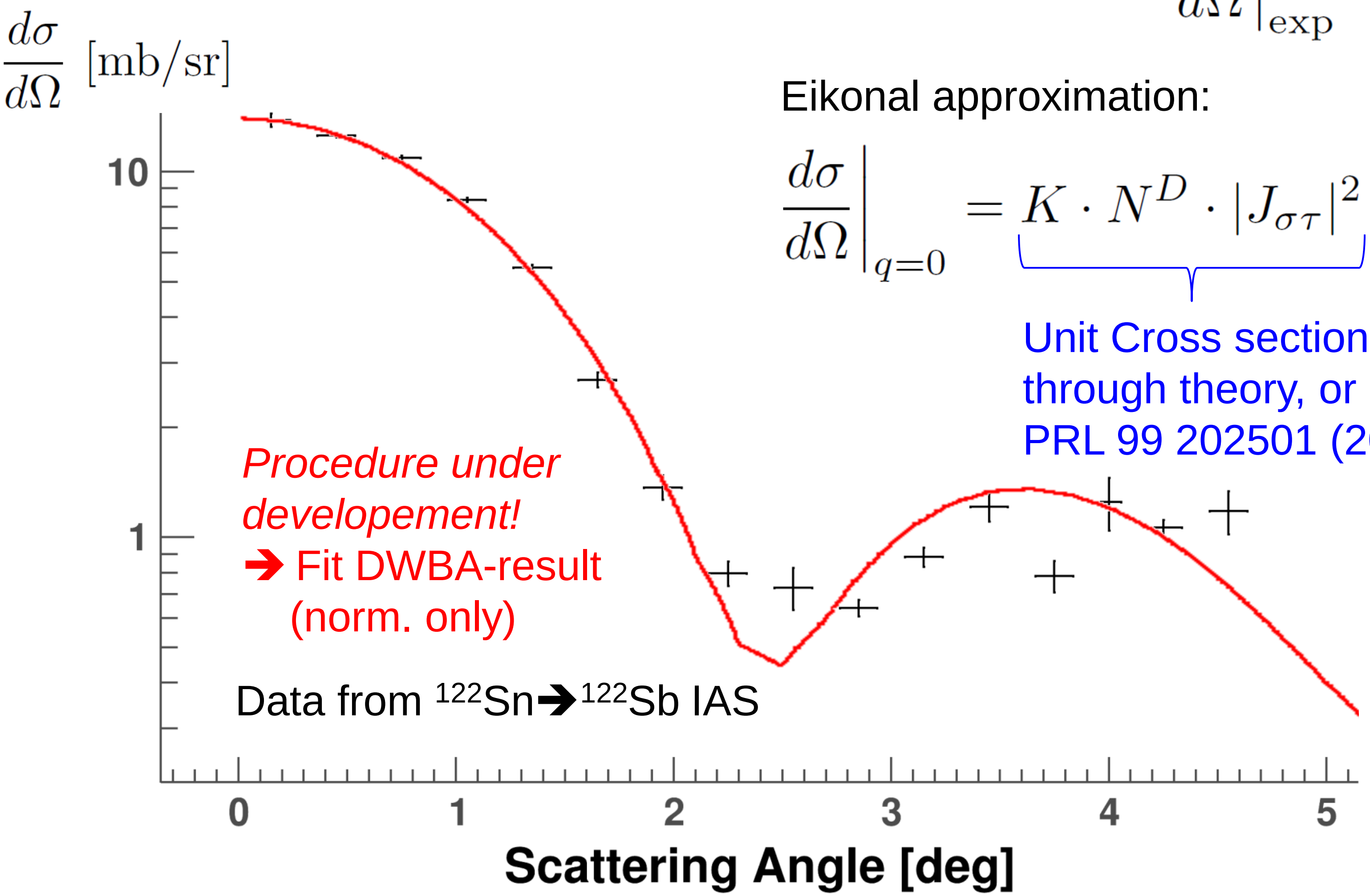
Extrapolate from fit: $\left.\frac{d\sigma}{d\Omega}\right|_{\exp} \longrightarrow \left.\frac{d\sigma}{d\Omega}\right|_{q=0}$

Eikonal approximation:

$$\left.\frac{d\sigma}{d\Omega}\right|_{q=0} = \underbrace{K \cdot N^D \cdot |J_{\sigma\tau}|^2}\cdot B(GT/F)$$

Unit Cross section: Calculate through theory, or use PRL 99 202501 (2007)

Observable of interest!



Conclusions

- ➔ Angular distributions of the cross sections of the low-lying states of $^{116,122}Sn(^{3}He,t)^{116,122}Sb$ were measured for the first time.
- ➔ Gamow-Teller states were identified through $\Delta L=0$, $\Delta S=1$, $\Delta T=1$
- ➔ We are now comparing our results to DWBA-calculations.
- ➔ We will extract B(GT) / B(F) from those comparisons.

Thank you!

C. A. Douma[1], N. Kalantar-Nayestanaki[1], M. N. Harakeh[1], H. Akimune[2], H. Ejiri[3], M. Alanssari[4], D. Frekers[4], Y. Fujita[5], M. Fujiwara[3], J. Gellanki[1], K. Hatanaka[3], M. Holl[4], C. Iwamoto[3], C. Kadono[2], A. Lennarz[1], T. Nakahara[2], C. Rigollet[1], T. Shima[3], J. Suhonen[6], K. Takashisa[3], A. Tamii[3], R. Zegers[7], T. Adachai[3], S. Austin[7], D. Basin[7], H. Dohmann[4], M. Dozono[8], K. Fujita[5], C. Guess[7], W. Hitt[7], S. Hollstein[4], E. Ihara[8], Y. Sakemi[3], Y. Shimbara[7], Y. Shimizu[3], Y. Tameshige[3], J. H. Thies[4], T. Wakasa[8], M. Yosoi[3] and K. Zuber[9]

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