Charge-exchange reaction and neutrino physics

Bingshui Gao
Institute of Modern Physics,
Chinese Academy of Sciences

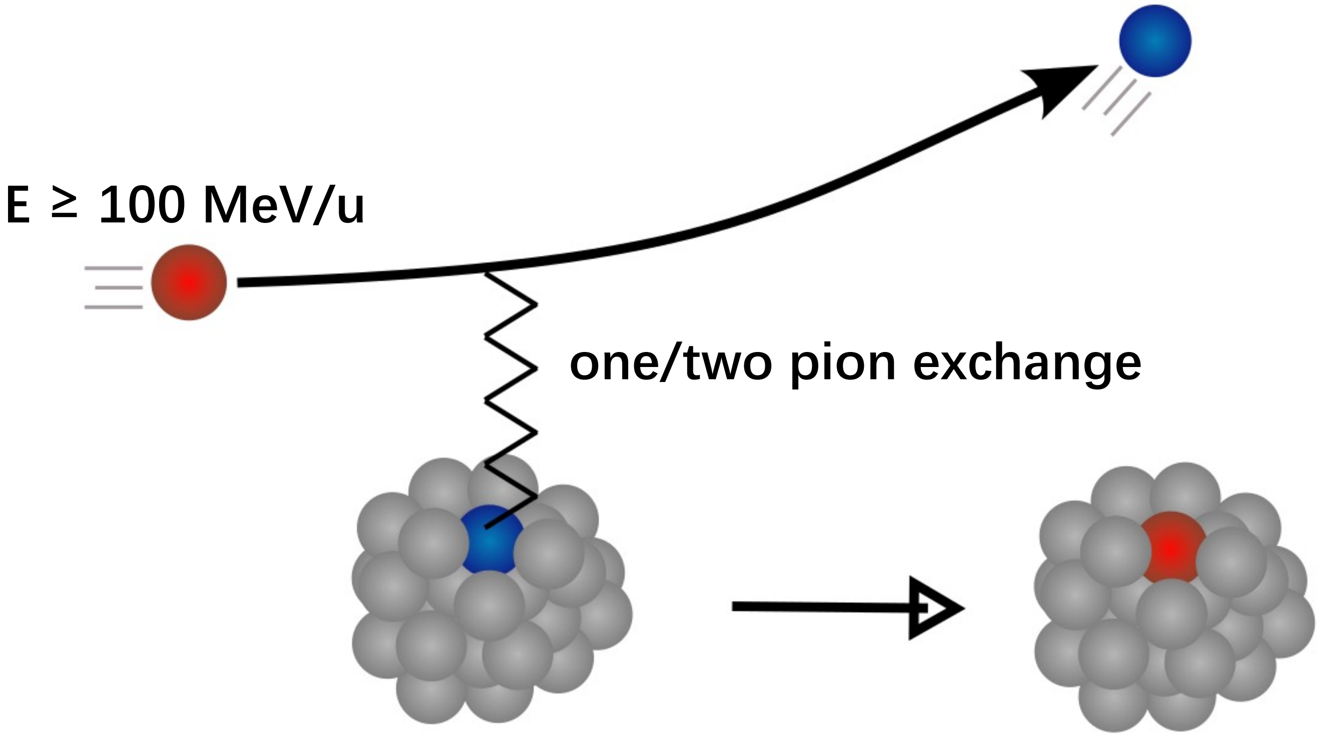
Korea-China joint workshop for rare isotope physics
Jul 6 – 10, 2025, Jeju island, Korea

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

中国科学院
CHINESE ACADEMY OF SCIENCES

CONTENTS

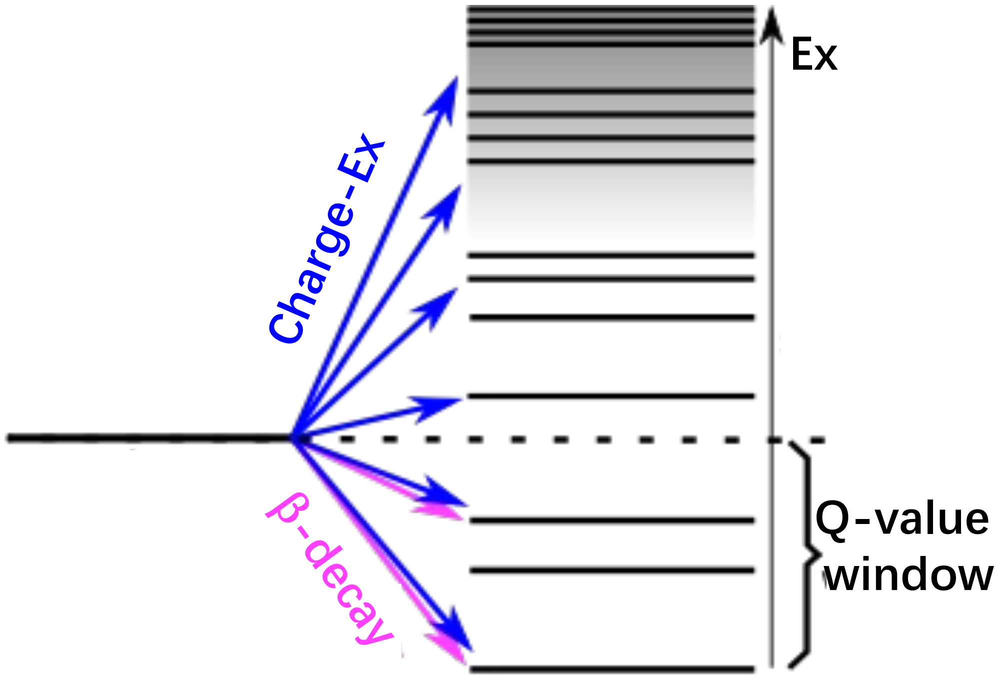
(Hadronic) Charge-exchange reaction

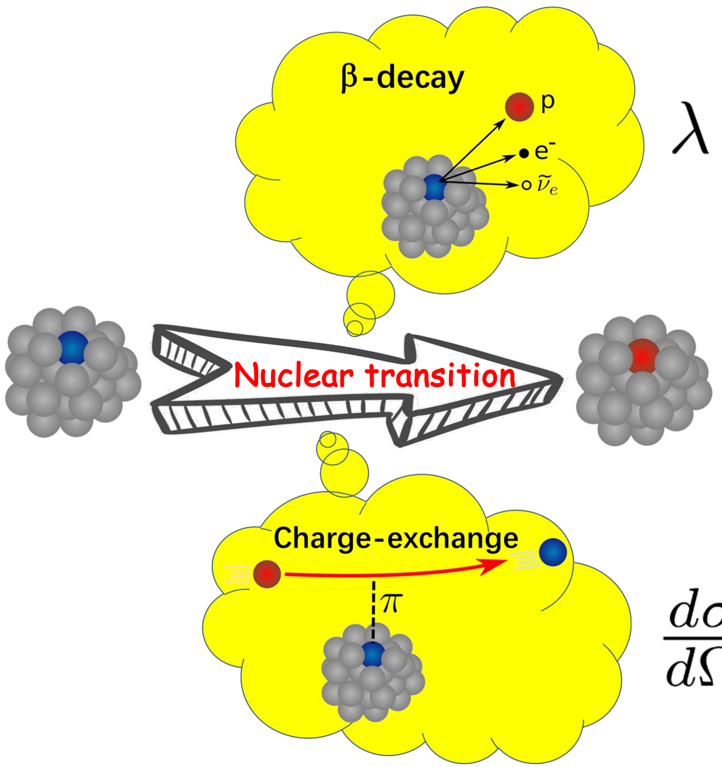


$$\frac{d\sigma}{d\Omega}(q \to 0) = C \cdot \langle f \left| \hat{\sigma}\hat{\tau} \right| i \rangle^2 = C \cdot B(\mathrm{GT})$$

(Hadronic) Charge-exchange reaction

Both charge-exchange reaction and beta-decay measurements provide information of B(GT), but charge-exchange reaction is not limited by the Q-value window.

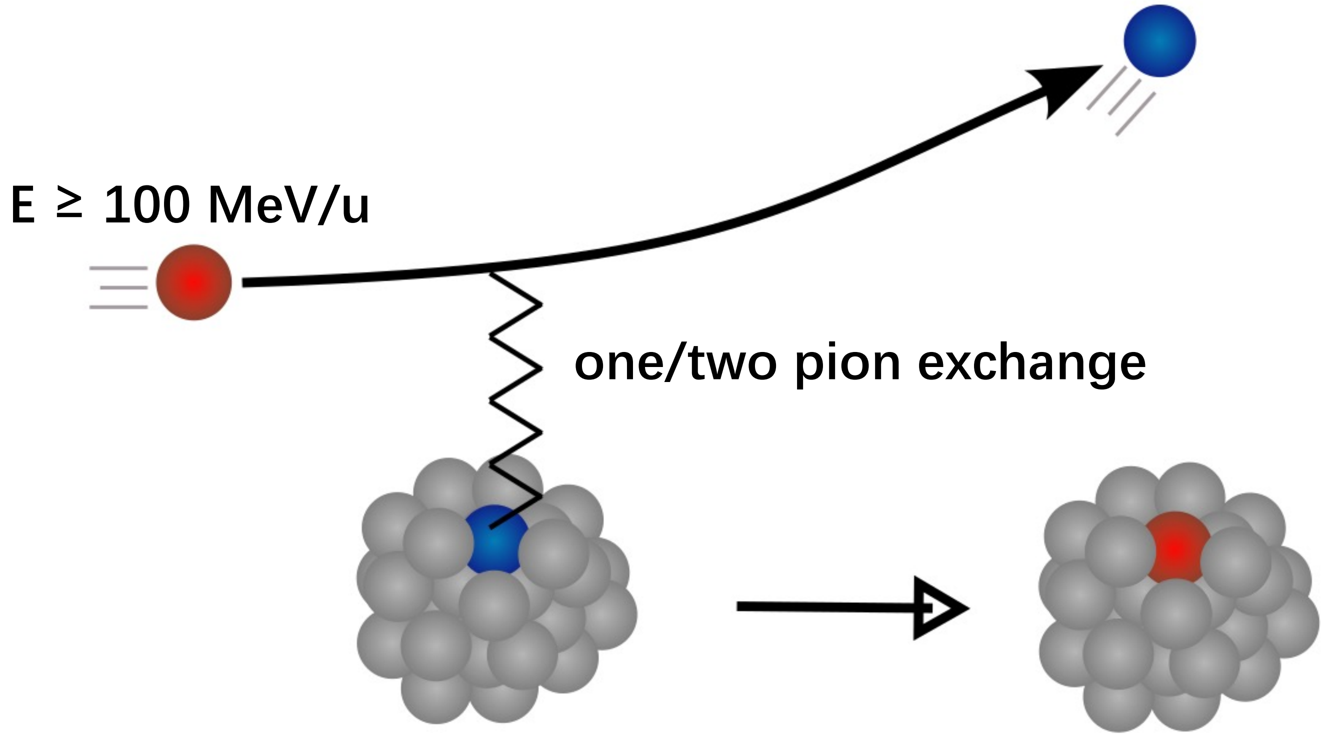




$$\lambda = C' \cdot B(\mathrm{GT}) \cdot \Phi$$

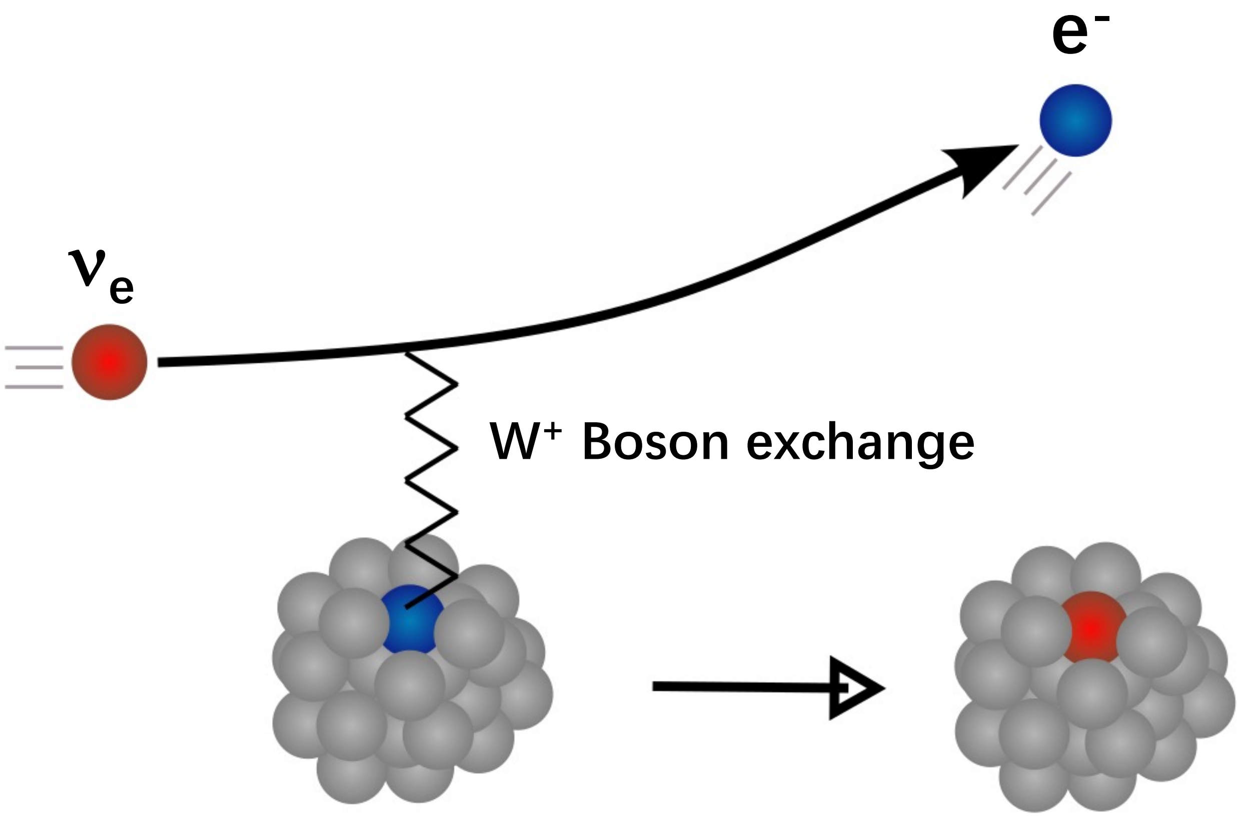
$$\frac{d\sigma}{d\Omega}(q \rightarrow 0) = C \cdot B(\mathrm{GT})$$

Application: Neutrino Detectors



$$\frac{d\sigma}{d\Omega}(q \to 0) = C \cdot \langle f \,|\hat{\sigma}\hat{\tau}|\, i\rangle^2 = C \cdot B(\mathrm{GT})$$

Application: Neutrino Detectors

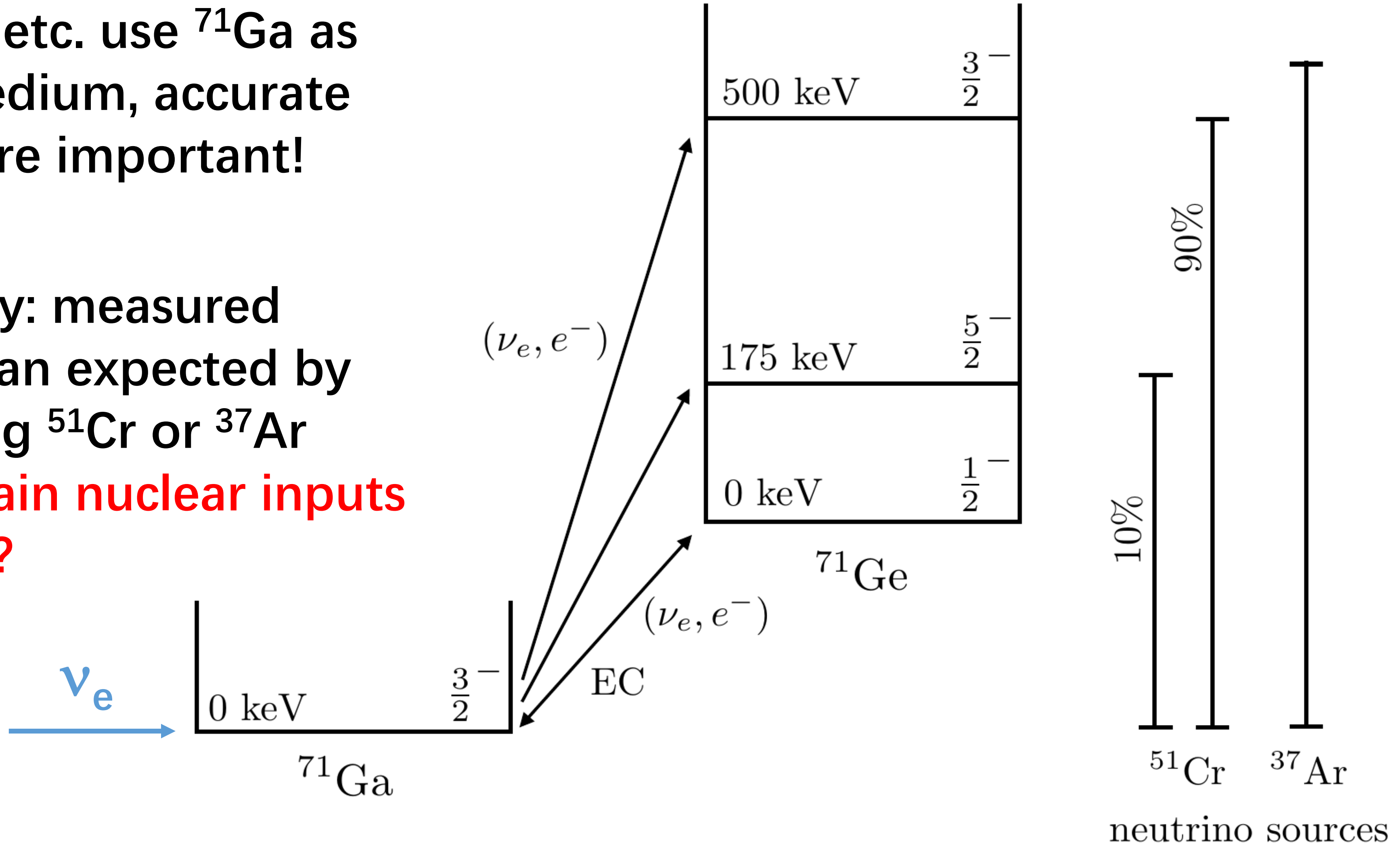


$$\sigma(E_{\nu_e}) = \frac{G_F^2 \cos^2\theta_c}{\pi} k_e E_e F(Z+1, E_e) \times [\ B(\mathrm{F}) + (g_A^{\mathrm{eff}})^2\, B(\mathrm{GT})],$$

Application: Neutrino Detectors

GALLEX、SAGE etc. use ^{71}Ga as the detector medium, accurate cross sections are important!

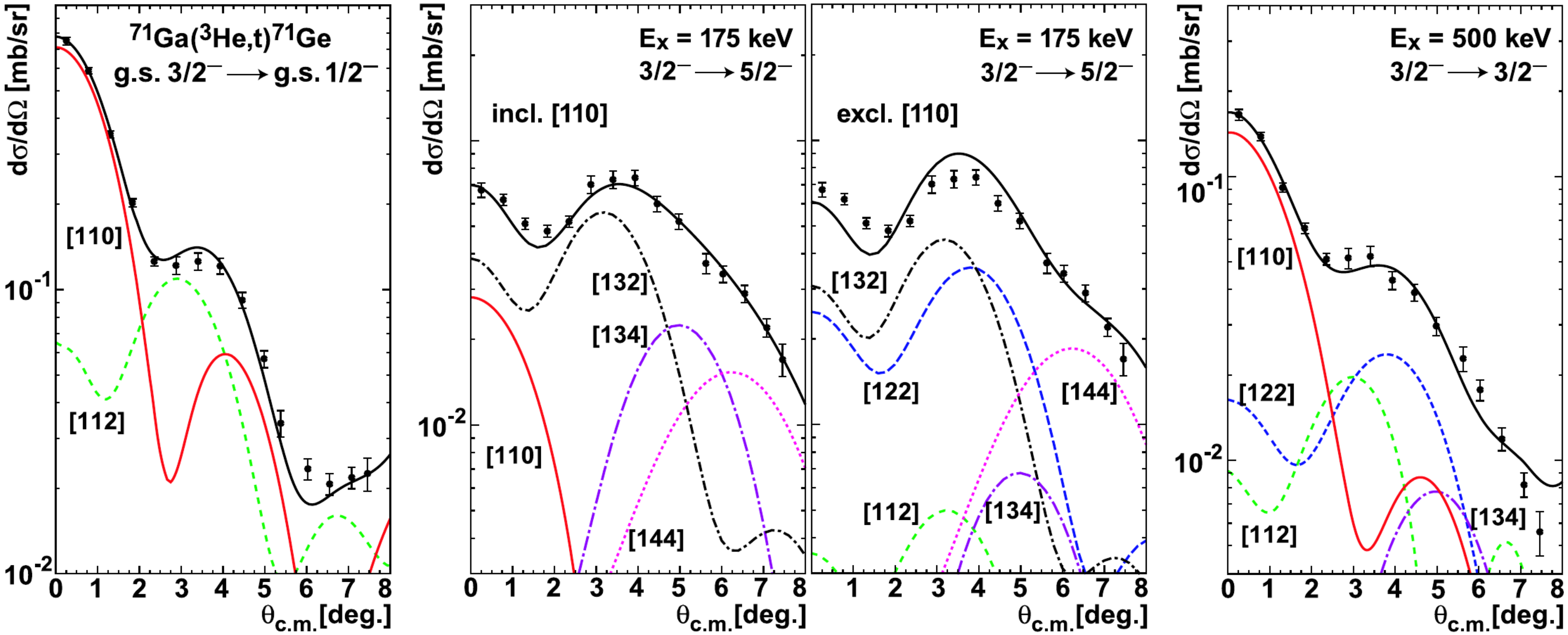
Gallium anomaly: measured counts lower than expected by ~20% when using ^{51}Cr or ^{37}Ar sources. Uncertain nuclear inputs or new physics ?



Application: Neutrino Detectors

The $^{71}Ga(^{3}He,t)^{71}Ge$ charge-exchange experiment:

Frekers et al., PLB 706, 134 (2011)



(1) g.s.:
B(GT) = 0.085(4)
(from ^{71}Ge β decay)

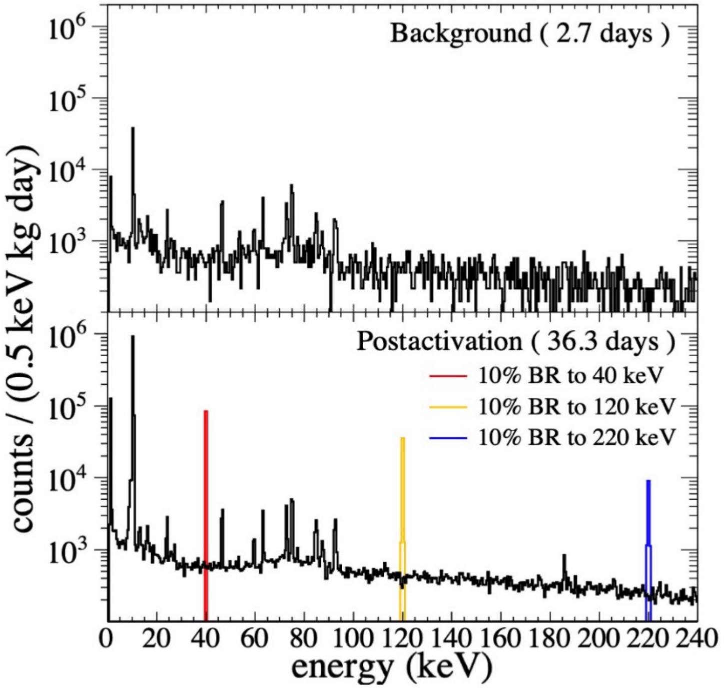
(2) 175-keV state:
B(GT) = 0.0034(26)

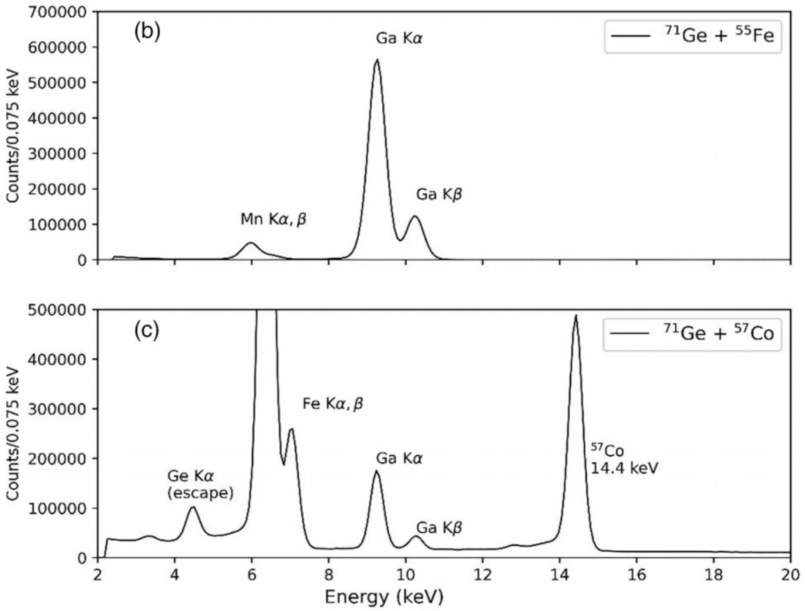
(3)500-keV state:
B(GT) = 0.017(2)

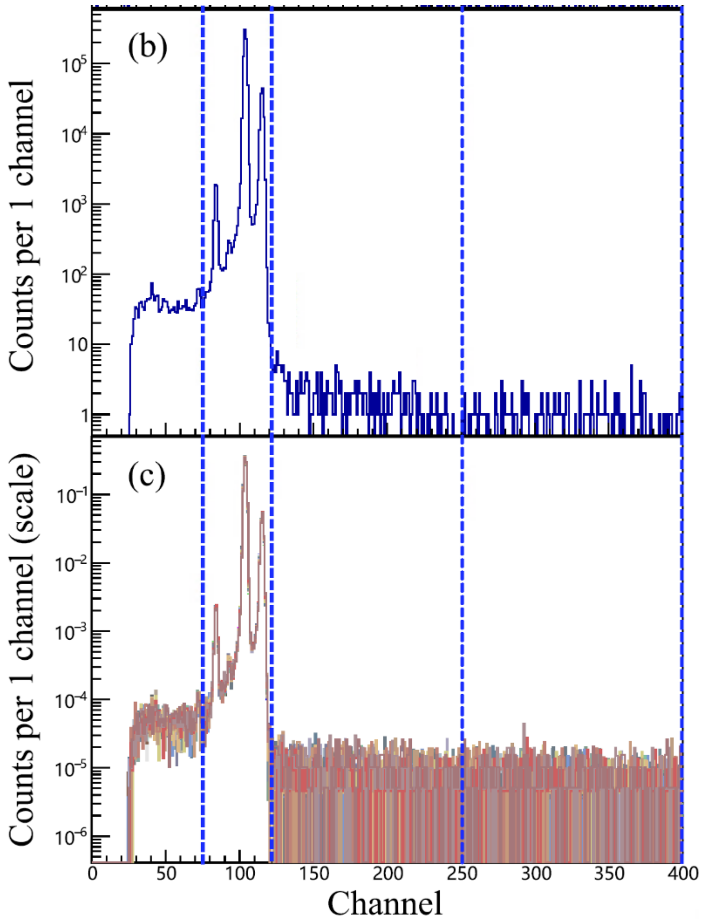
7(2)%

Application: Neutrino Detectors

New life-time measurements of ^{71}Ge
(literature value $T_{1/2}$ = 11.43 ± 0.03 days):







$T_{1/2}$ = 11.46 ± 0.04 days

$T_{1/2}$ = 11.468 ± 0.008 days

$T_{1/2}$ = 11.477 ± 0.004 days

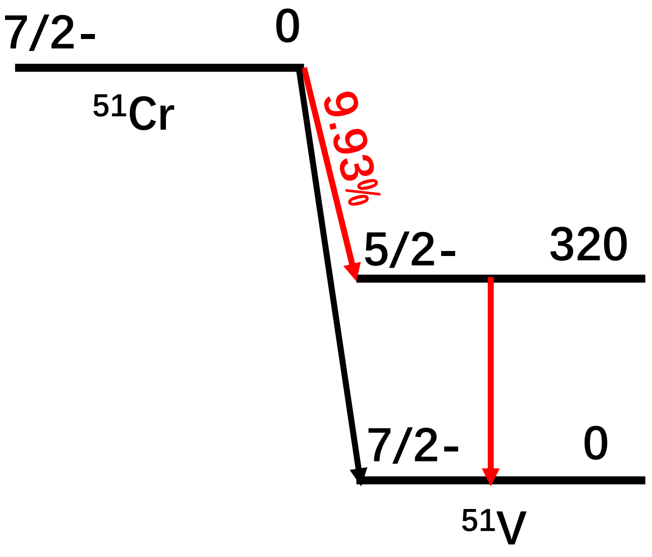
Collar and Yoon, PRC 108, L021602 (2023)

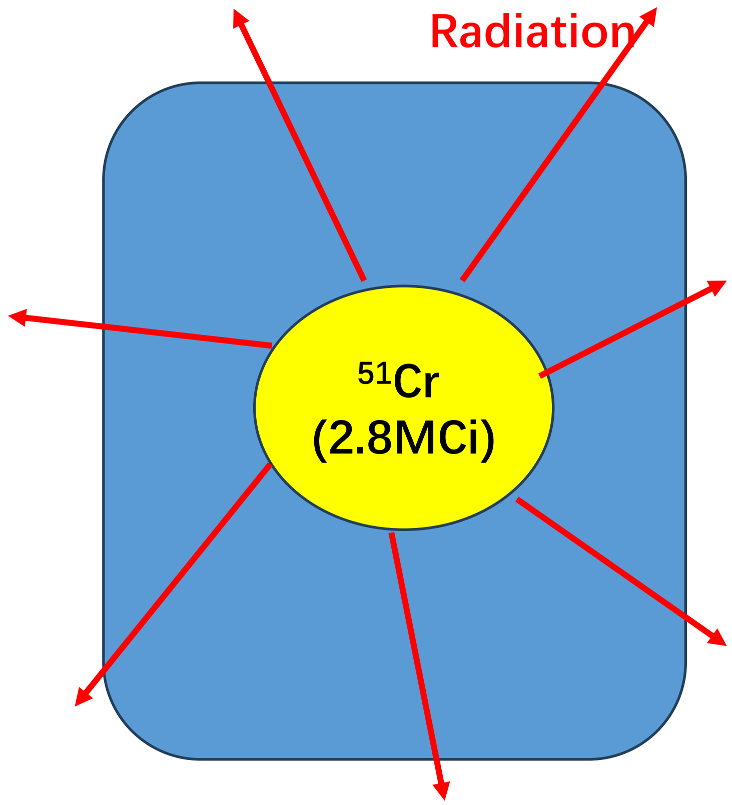
Norman *et al.,* PRC 109, 055501 (2024)

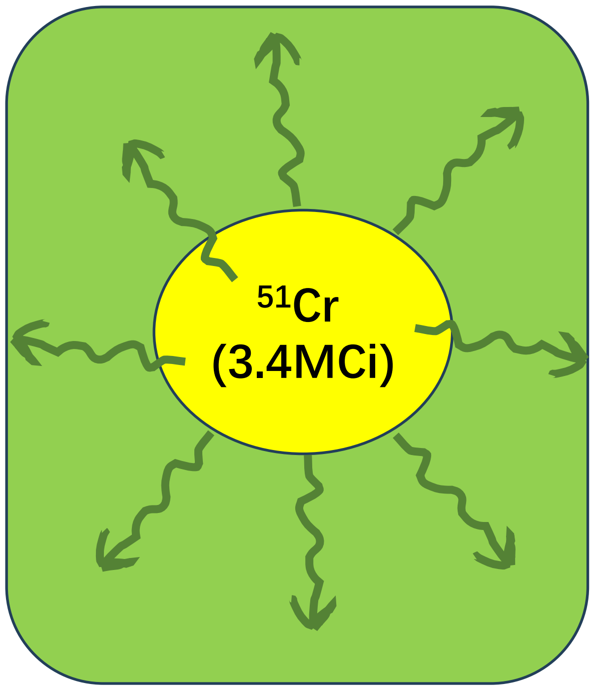
Cai *et al.,* to be submitted

Application: Neutrino Detectors

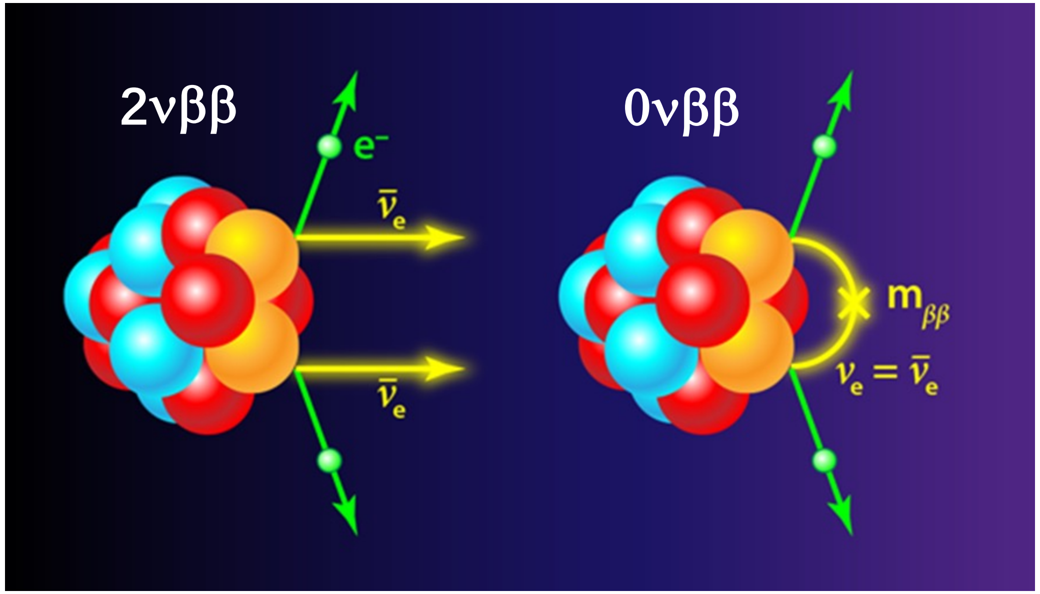
Branching ratios of the ^{51}Cr decay (ν_e source):





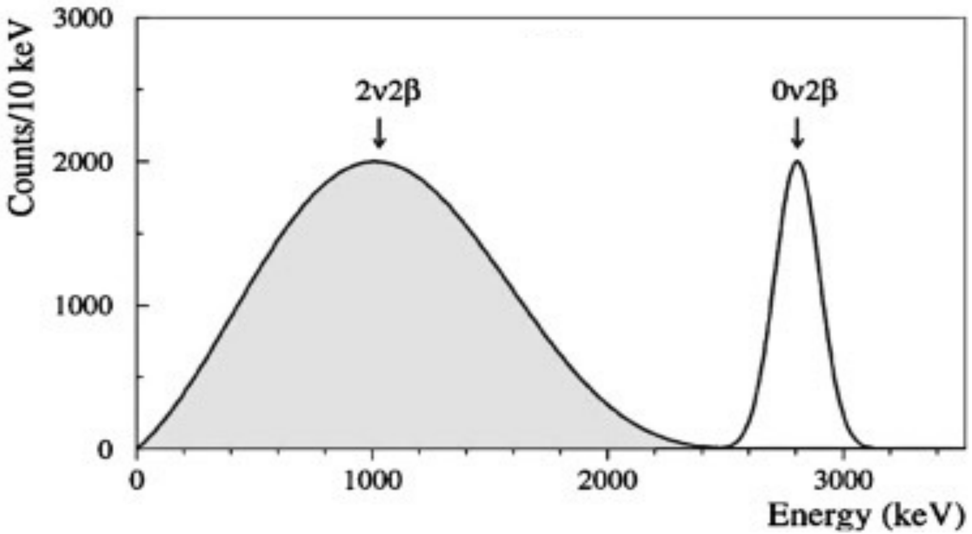


Application: Double beta decay



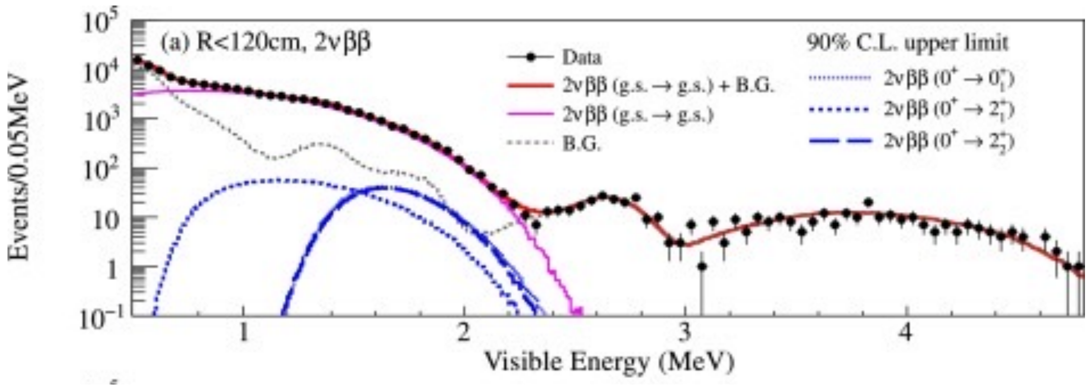
$2\nu\beta\beta$ have been observed and $T_{1/2}$ obtained for ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd, ^{238}U, ^{78}Kr, ^{124}Xe and ^{130}Ba have been obtained.

- absolute neutrino mass scale
- Majorana particles
- matter-antimatter asymmetry of the Universe
- New physics…



Application: Double beta decay

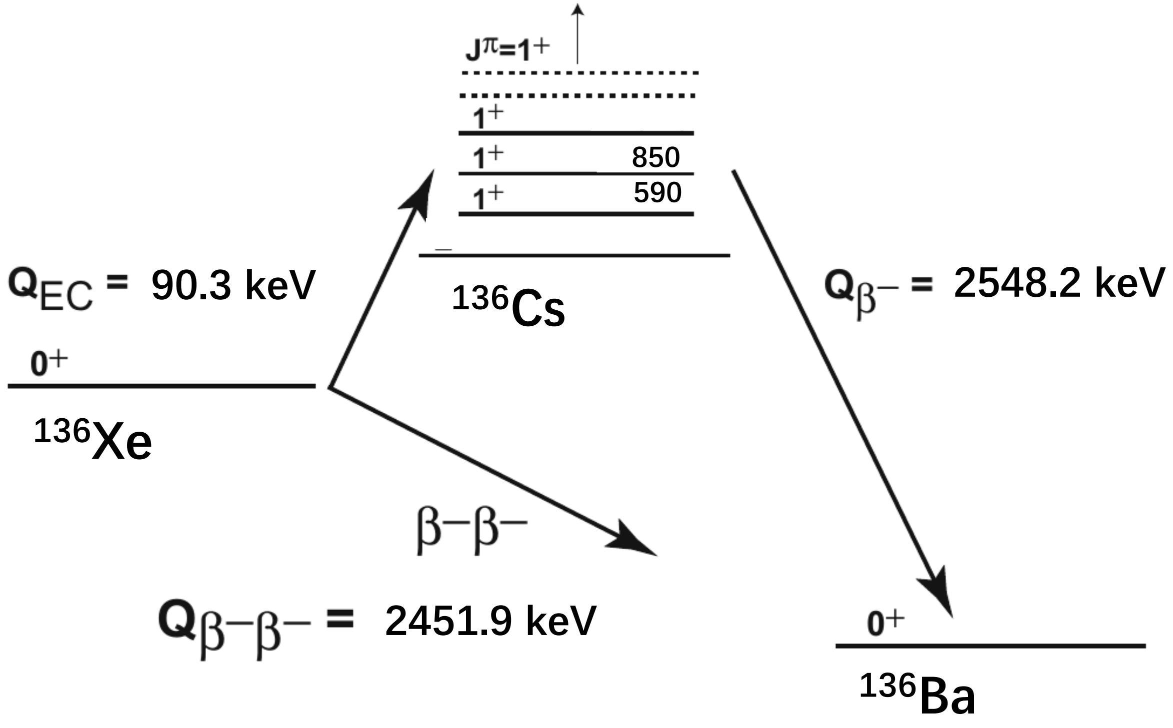
^{136}Xe ββ decay: EXO-200, nEXO, KamLAND-Zen, NEXT PandaX-III etc.



$$\Gamma_{\beta^-\beta^-}^{2\nu} = G^{2\nu}(Q,Z)g_A^4\left|M_{\rm DGT}^{(2\nu)}\right|^2$$

Why is the ^{136}Xe $M_{DGT}^{2\nu}$ so small ?
0.0181(6) for ^{136}Xe vs. 0.03~0.32 for others

The two-leg structure of $M_{DGT}^{2\nu}$:

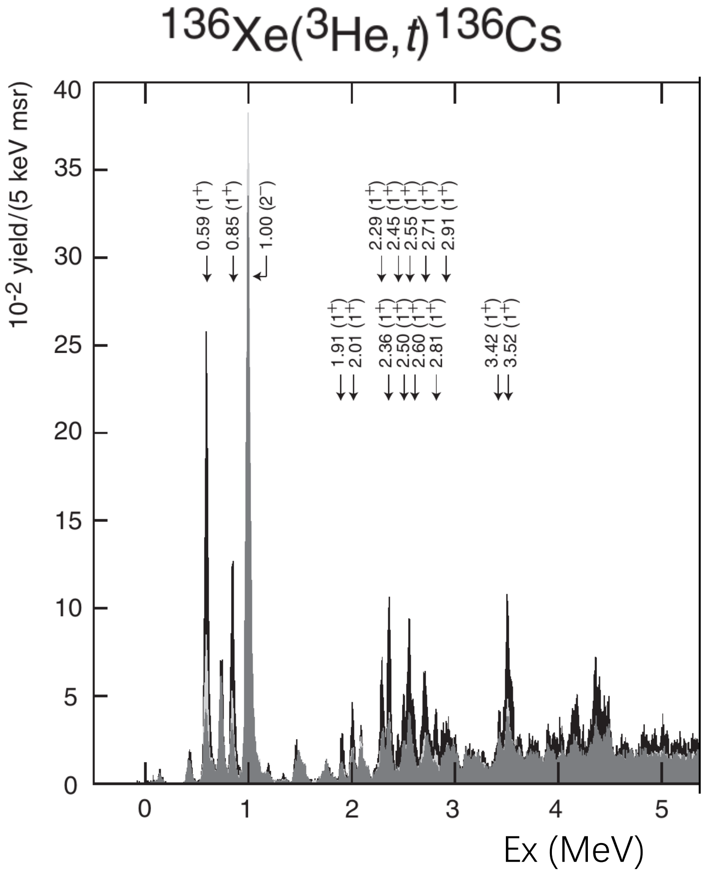


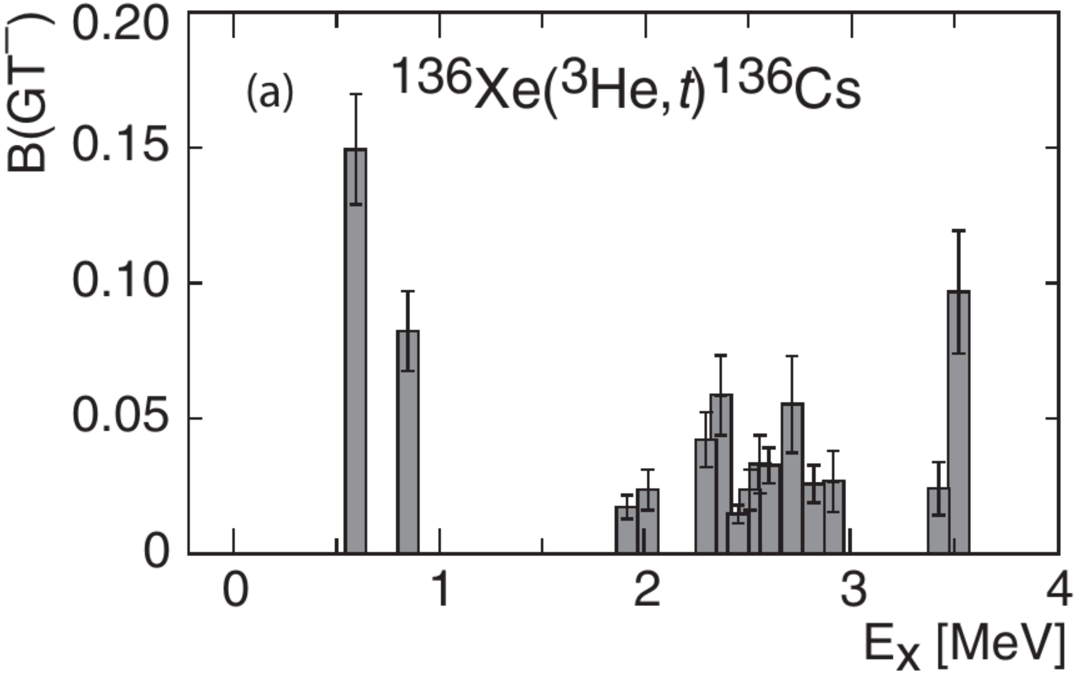
$$M_{\rm DGT}^{2\nu} = \sum_m \frac{\langle 0_{g.s.}^f|\sum_k \sigma_k\tau_k^-|1_m^+\rangle\langle 1_m^+|\sum_k \sigma_k\tau_k^-|0_{g.s.}^i\rangle}{\frac{1}{2}Q_{\beta\beta}(0_{g.s.}^{(f)}) + E(1_m^+) - E_0}$$
$$= \sum_m \frac{M_m(\mathrm{GT}^+)M_m(\mathrm{GT}^-)}{E_m}.$$

Application: Double beta decay

One leg is known for ^{136}Xe

Puppe et al., PRC 84, 051305(R) (2011)

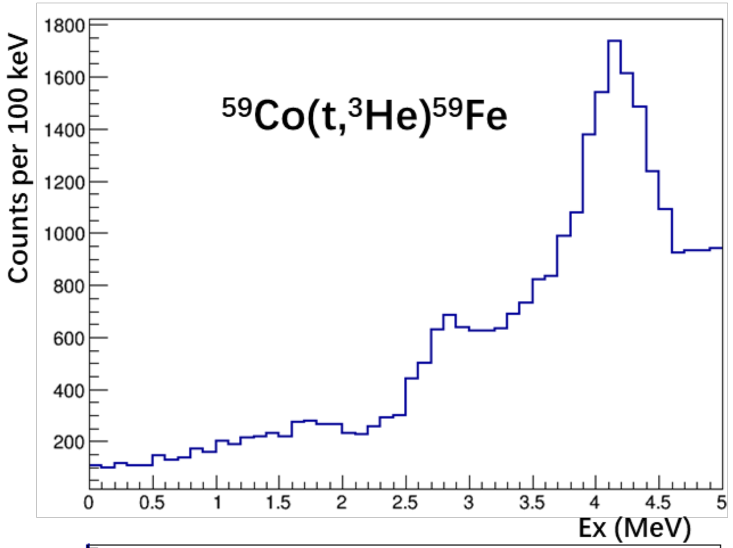


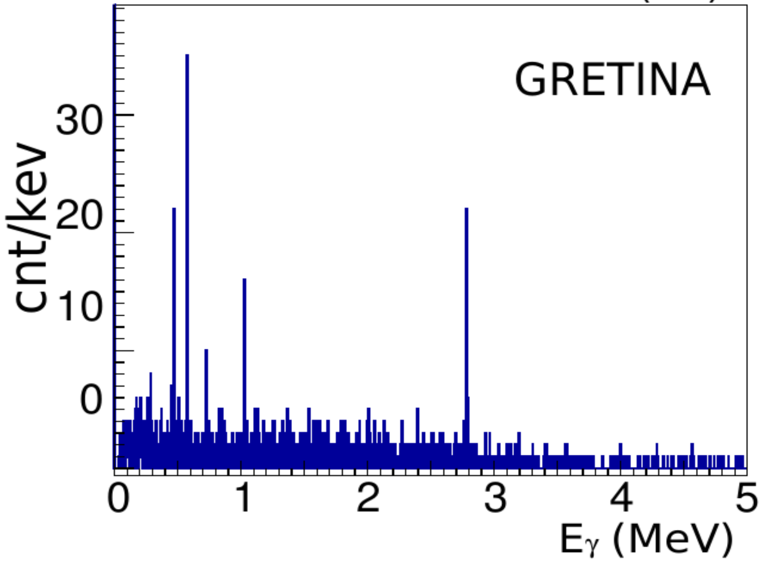


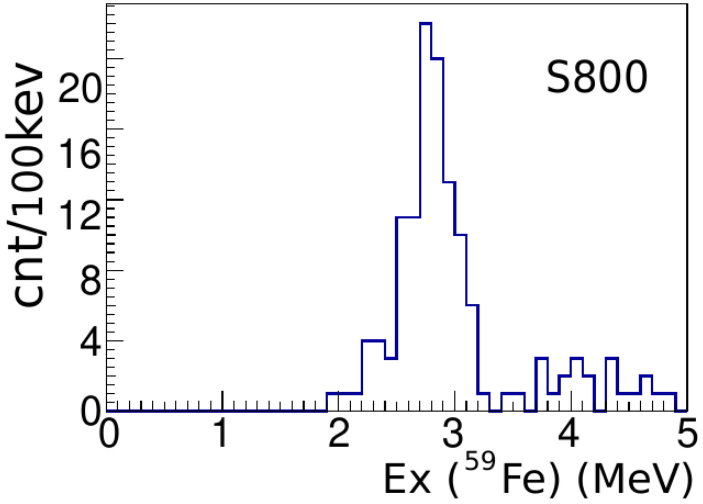
$$M_{\mathrm{DGT}}^{2\nu} = \sum_m \frac{M_m(\mathrm{GT}^+) M_m(\mathrm{GT}^-)}{E_m}$$

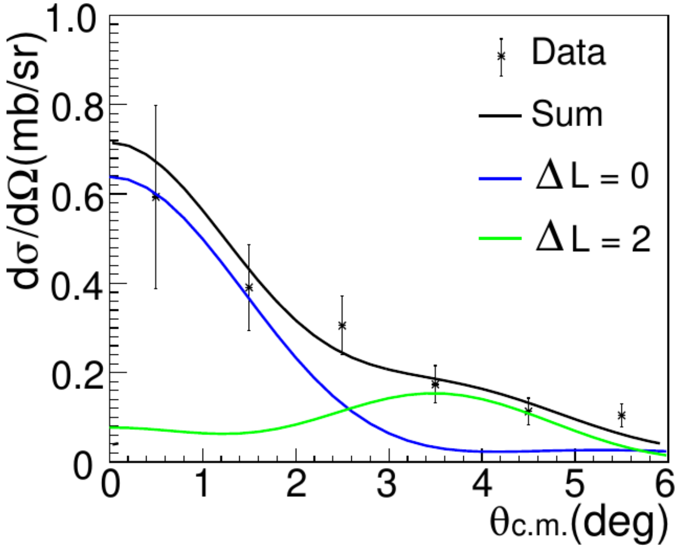
Application: Double beta decay

Let's measure the other leg via ^{136}Ba(t,^{3}He)^{136}Cs charge-exchange reaction!









Summary

- From charge-exchange reaction, B(GT) can be extracted (not limited by Q-value!)
- Useful in studying weak interactions: neutrino detectors, $\beta\beta$ decay, neutrino-induced nucleosynthesis, stellar beta-decay rates, isospin symmetry etc.
- Coincident γ-ray measurement significantly boosts the resolution

Thanks!