Inelastic neutrino scattering on argon

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Neutrino interactions on ^{40}Ar at low energies ($\lesssim$ 100 MeV)

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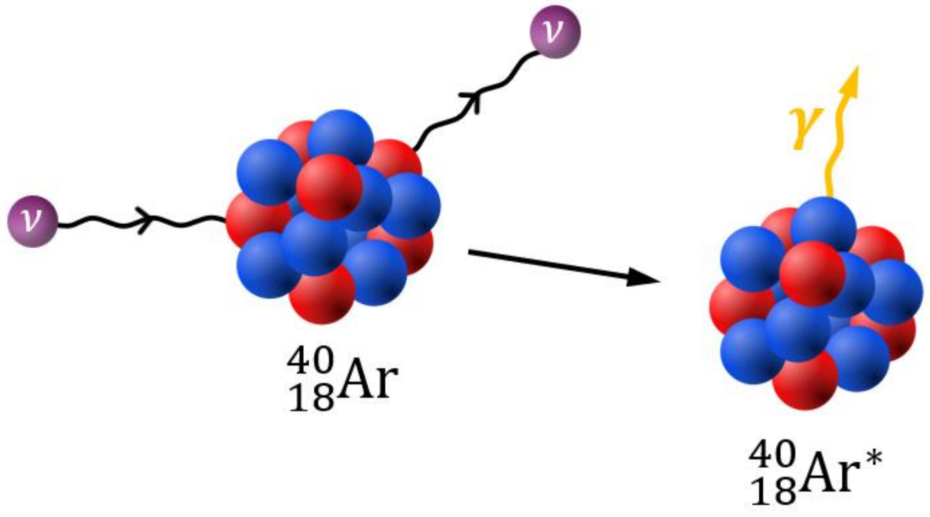
Neutral Current (NC)

$$\nu_e + {}^{40}_{18}\mathrm{Ar} \longrightarrow \nu_e + {}^{40}_{18}\mathrm{Ar}^*$$



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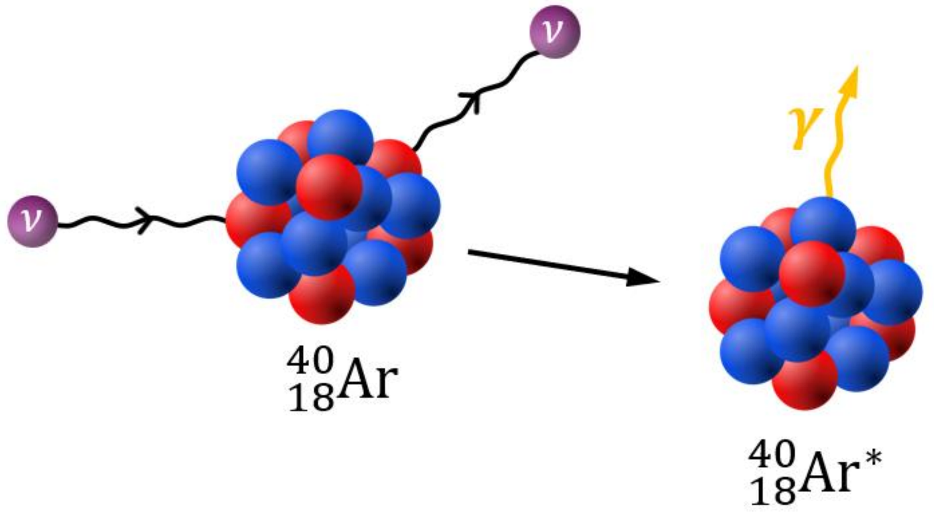
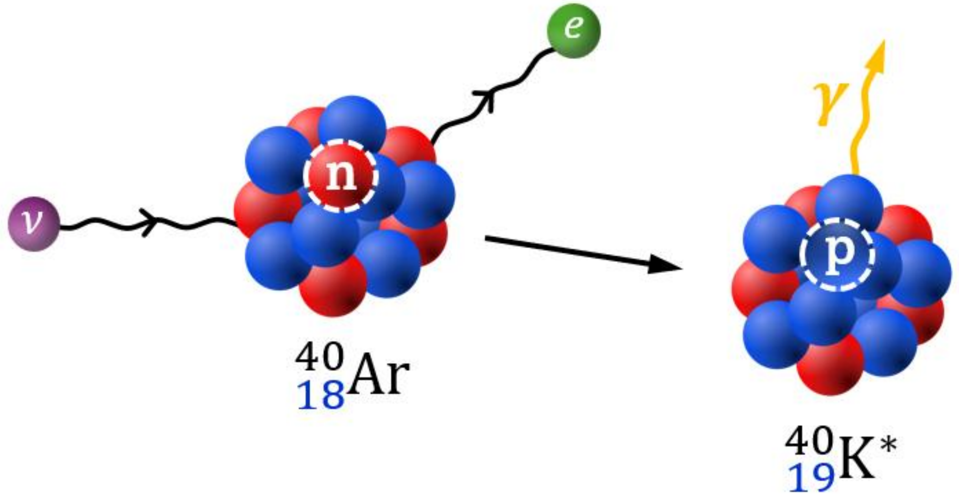


Charged Current (CC)

$$\nu_e + {}^{40}_{18}\text{Ar} \longrightarrow e^- + {}^{40}_{19}\text{K}^*$$



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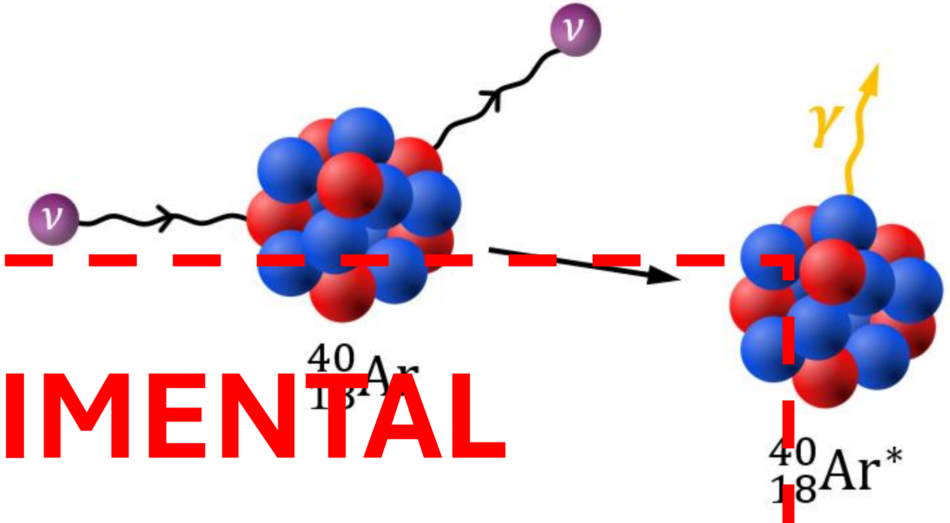

NO EXPERIMENTAL MEASUREMENTS

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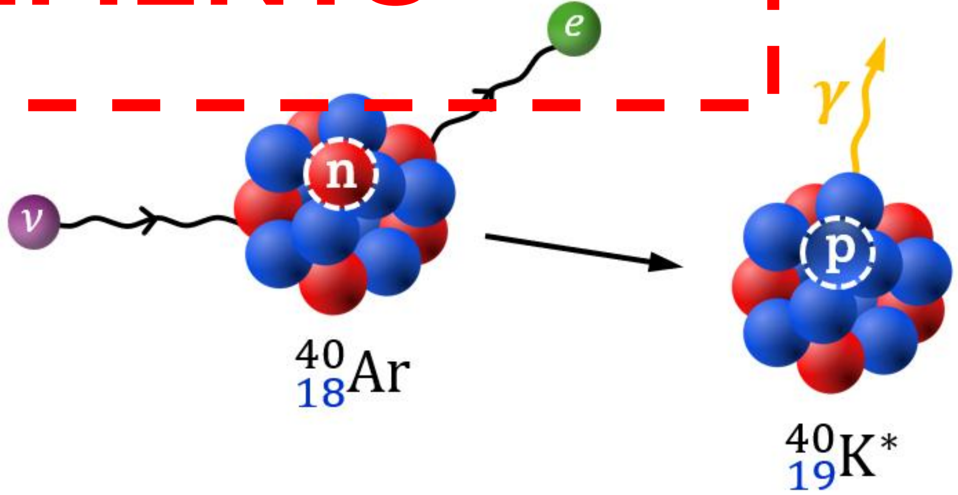
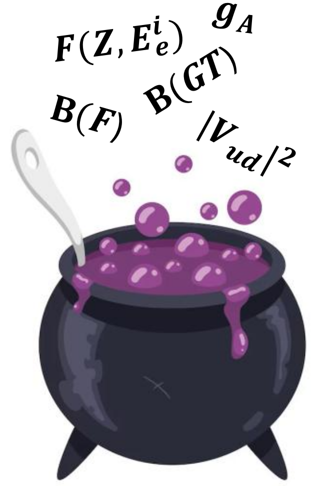


Inelastic cross sections recipe



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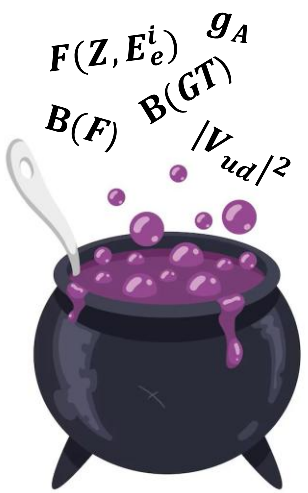


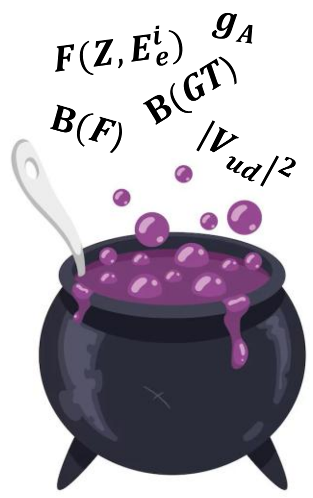
NC

Nuclear excitation energy

$$\sigma_{GT}^{(NC)} = \sum_i \frac{G_F^2\, g_A^2}{\pi} (E_v - \omega)^2 B_i(GT)$$

Nuclear transition probabilities

Inelastic cross sections recipe



Nuclear excitation energy

NC

$$\sigma_{GT}^{(NC)} = \sum_i \frac{G_F^2\, g_A^2}{\pi} (E_\nu - \omega)^2 B_i(GT)$$

Nuclear transition probabilities

CKM matrix element

CC

$$\sigma_{GT+F}^{(CC)} = \sum_i \frac{G_F^2 |V_{ud}|^2}{\pi} E_e^i\, p_e^i [B_i(F) + B_i(GT)] F(Z, E_e^i)$$

Fermi function

Quantifies the Coulomb interaction between the outgoing electron and protons of the ^{40}K nucleus

Inelastic cross sections recipe

NC

Nuclear excitation energy

$$\sigma_{GT}^{(NC)} = \sum_i \frac{G_F^2\, g_A^2}{\pi} (E_\nu - \omega)^2 B_i(GT)$$

Nuclear transition probabilities

No direct experimental measurements
No reliable theoretical predictions

CC

CKM matrix element

$$\sigma_{GT+F}^{(CC)} = \sum_i \frac{G_F^2 |V_{ud}|^2}{\pi} E_e^i\, p_e^i [B_i(F) + B_i(GT)] F(Z, E_e^i)$$

Fermi function

Quantifies the Coulomb interaction between the outgoing electron and protons of the ^{40}K nucleus

HOW? Estimation of nuclear matrix elements

1 Theoretical approach

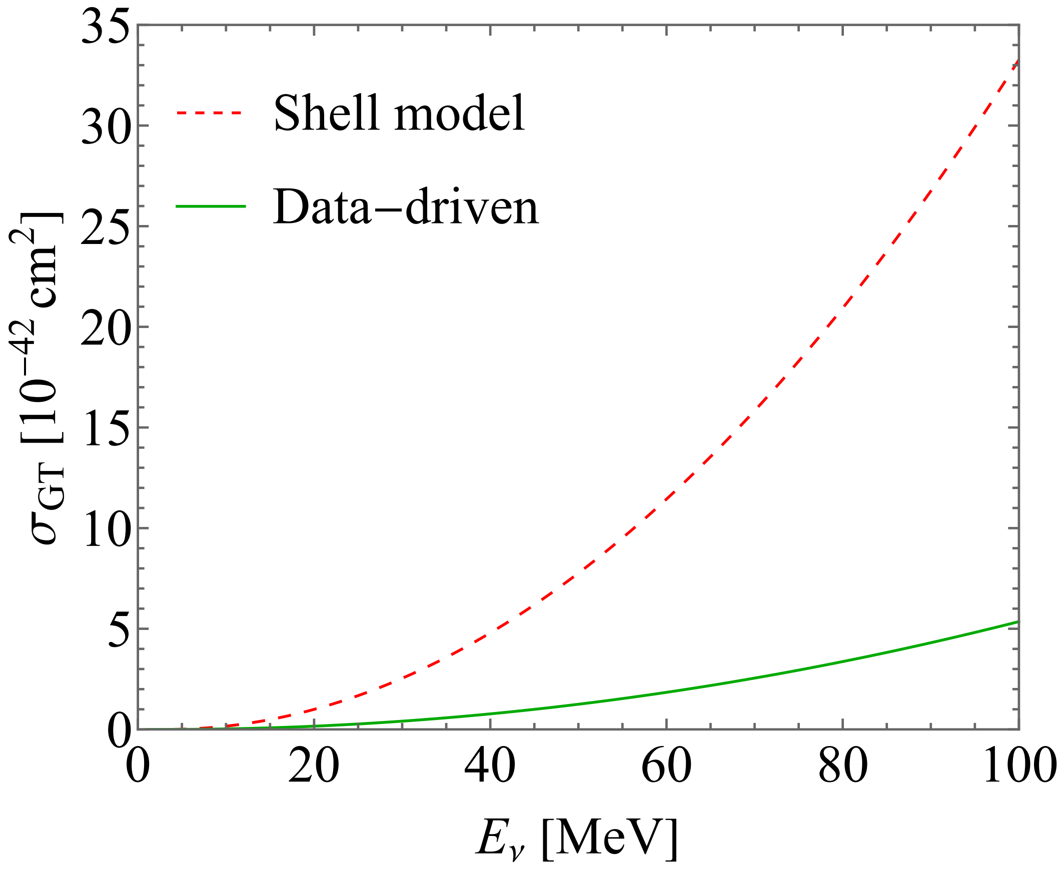
Transition probabilities are computed through BIGSTICK, a **nuclear shell model** code.

2 Data-driven approach

We consider **experimental measurements** of the magnetic dipole amplitudes B(M1) for the process:

$$\gamma + {}^{40}Ar \longrightarrow \gamma + {}^{40}Ar$$

At low energies: $B(GT)^{exp} = \frac{B(M1)}{g_A^2 (2.2993\, \mu_N)^2}$



W. Tornov et al., Phys. Lett. B 835 (2022)

HOW? Estimation of nuclear matrix elements

CC

1. (p,n) scattering on ^{40}Ar: $p + {}^{40}Ar \longrightarrow n + {}^{40}\mathrm{K}^*$

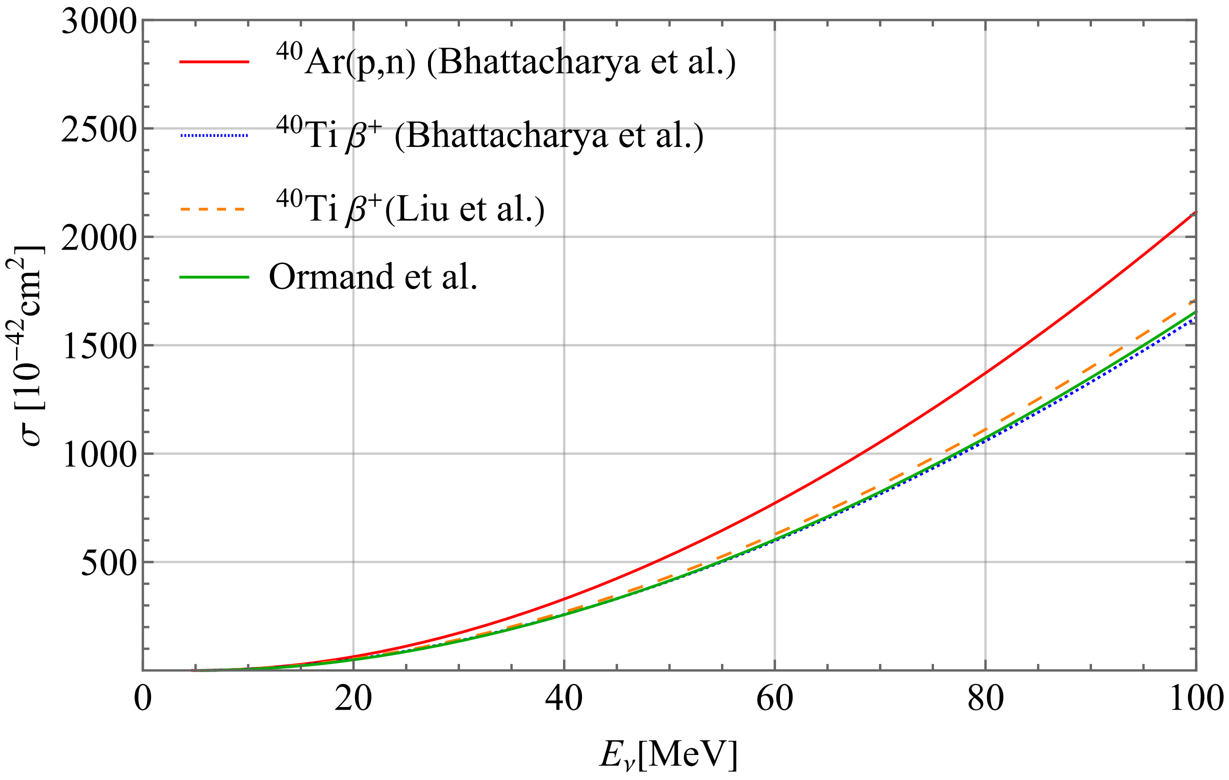
   Bhattacharya et al., Phys. Rev. C 80, 055501 (2009).

2. β decay of the mirror nucleus: $^{40}\mathrm{Ti} \longrightarrow {}^{40}\mathrm{Sc}^* + e^+ + \nu_e$

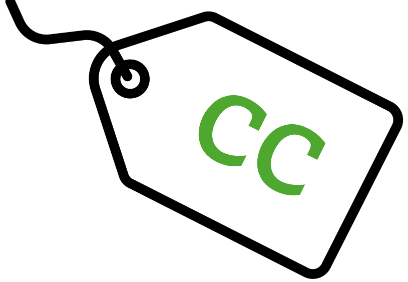
   Bhattacharya et al., Phys. Rev. C 58, 36773687 (1998)
   Liu et al., Phys. Rev. C 58, 26772688 (1998)

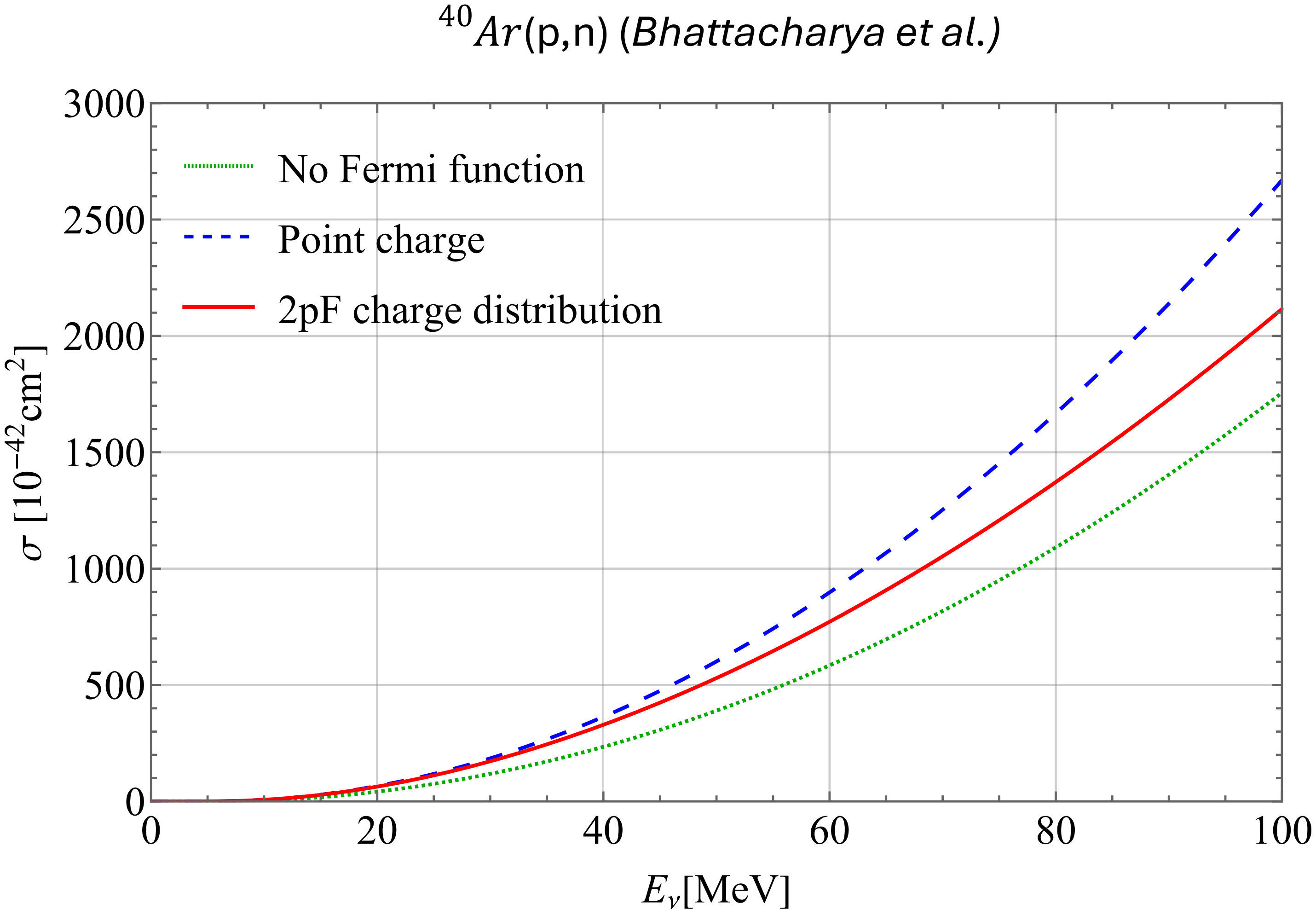
3. Theoretical shell model prediction

   W. E. Ormand et al., Phys. Lett. B345, 343 (1995)



HOW? Estimation of nuclear matrix elements + Fermi function

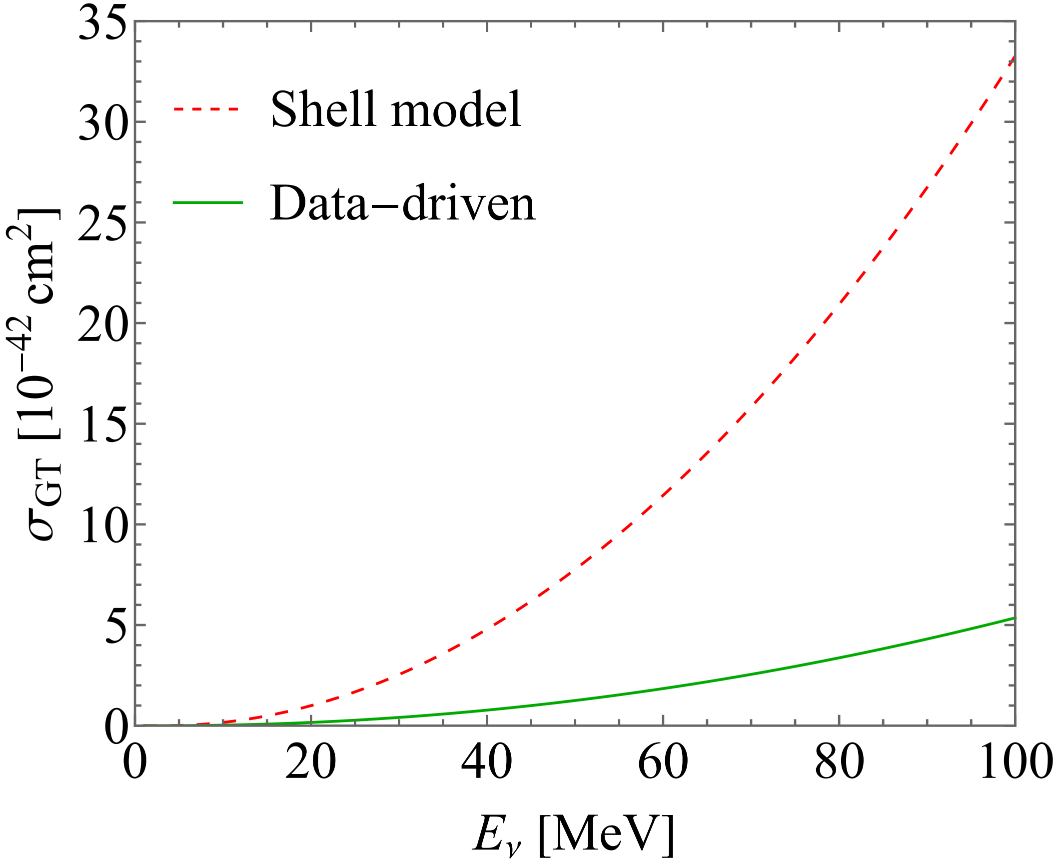




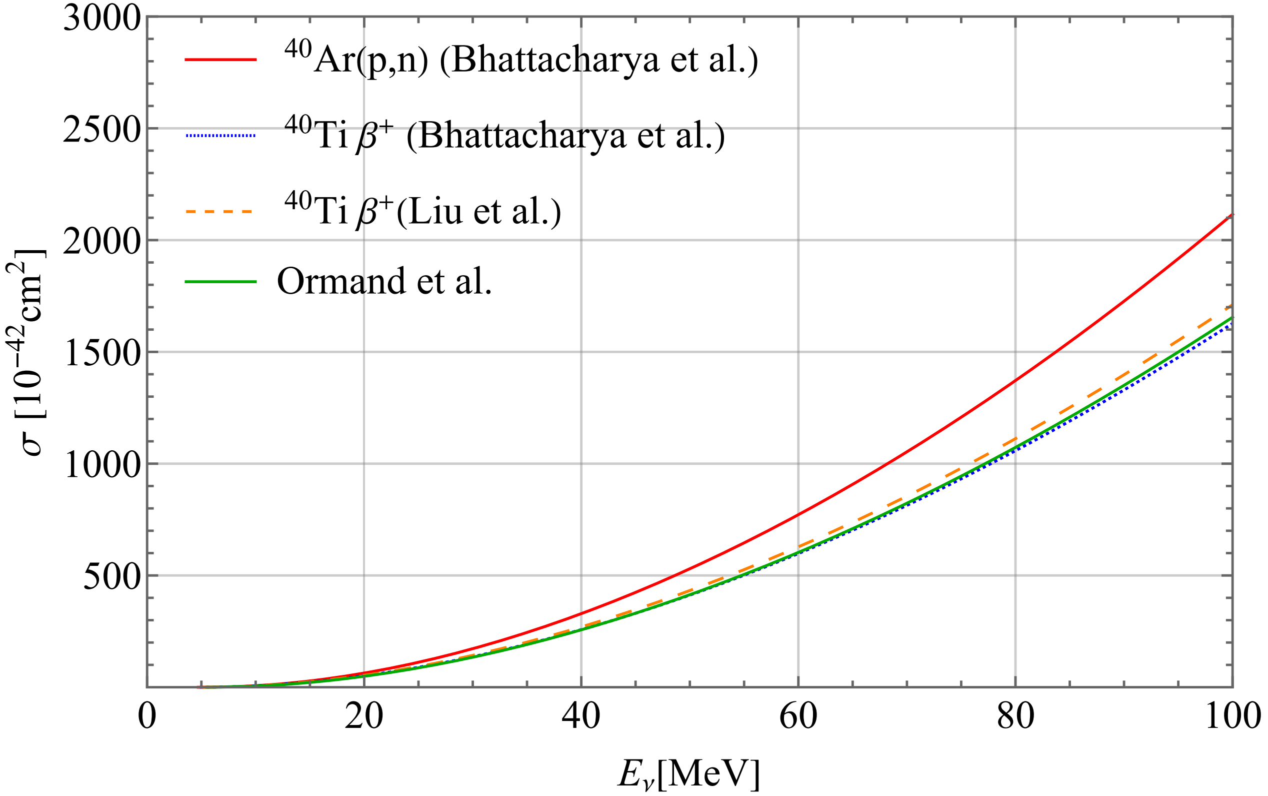
Summary: preliminary results

NC+CC

NC



CC



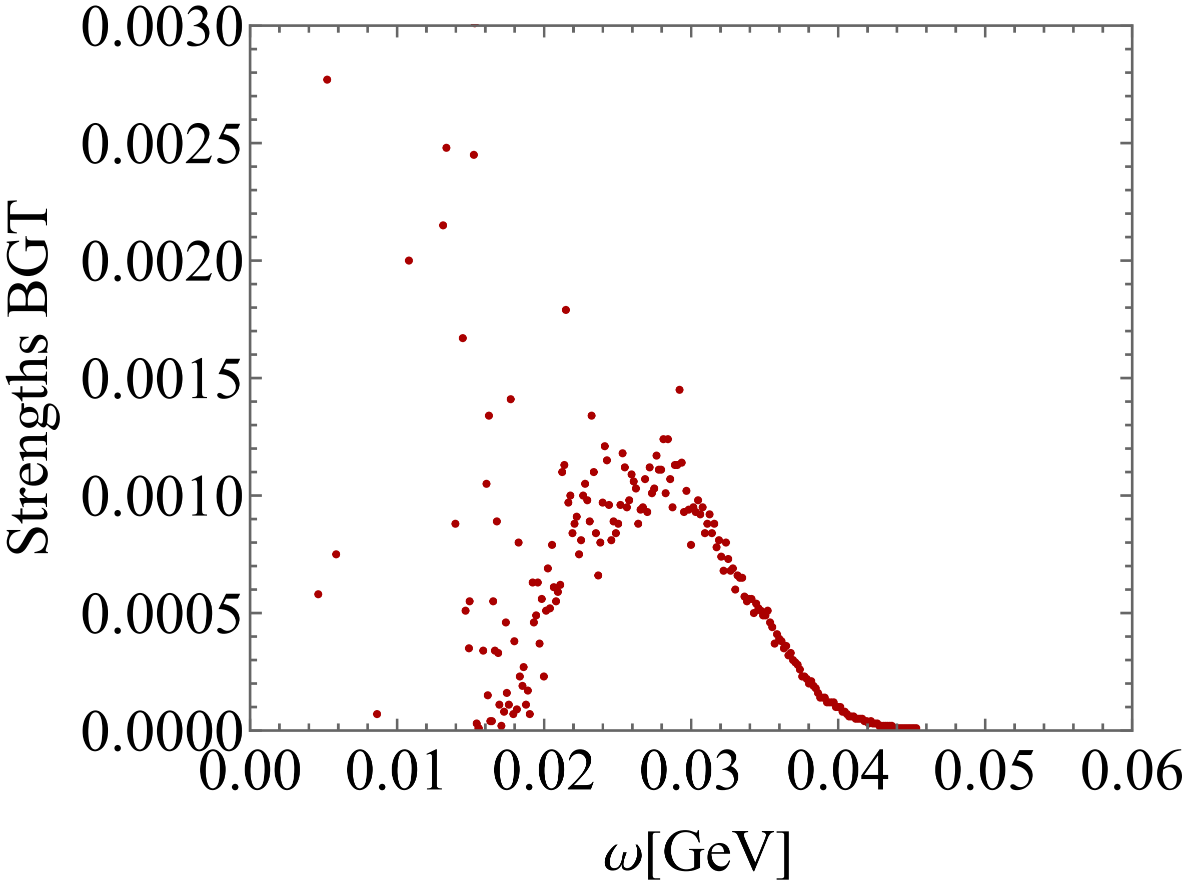

Thanks for your attention!

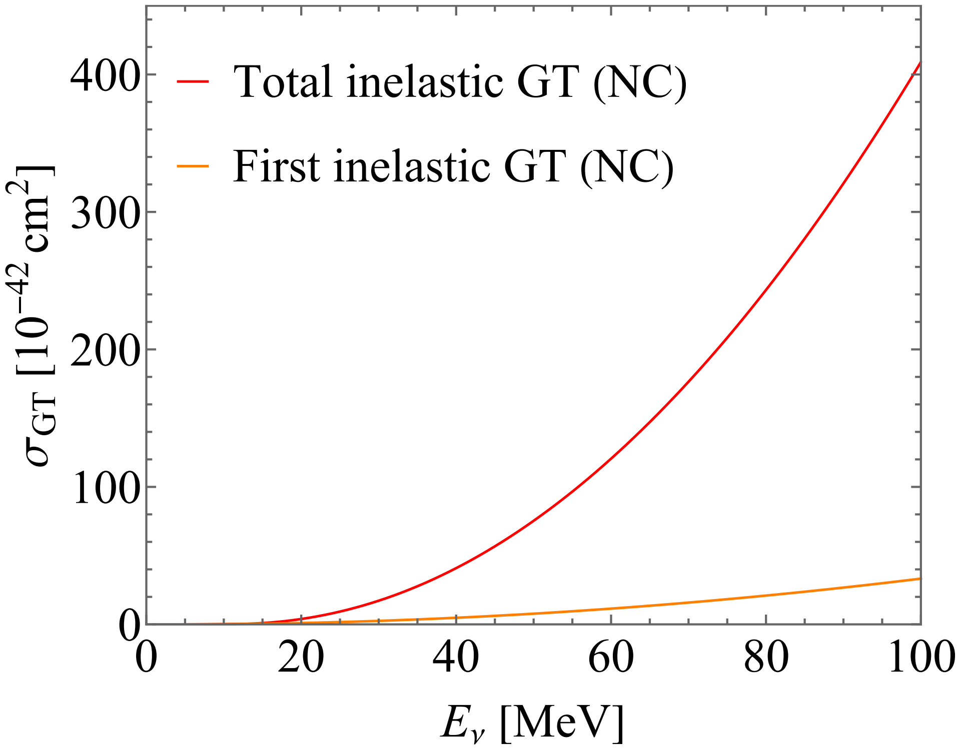
Estimating B(GT): theoretical shell model prediction

NC

C. W. Johnson et al. (2018), arXiv:1801.08432v1 [physics.comp-ph]

1. B(GT) matrix elements are estimated through **BIGSTICK**, a nuclear shell model code used to compute transition probabilities.





E_ν [MeV]	$\sigma_{GT}[10^{-42}\text{cm}^2]$	$\sigma_{GT}^{first}[10^{-42}\text{cm}^2]$
20	3.9	1
50	75	7.8
80	243	21

Estimating B(GT): data-driven approach

NC

2 We determine the B(GT) amplitudes from the experimental measurements of the magnetic dipole amplitudes **B(M1),** conducted at the Triangle Universities Nuclear Laboratory (TUNL) for the process:

$$\gamma + {}^{40}Ar \longrightarrow \gamma' + {}^{40}Ar$$

W. Tornov et al., Phys. Lett. B 835 (2022)

At low energies, these amplitudes are related to the BGT amplitudes through the relation:

$$B(GT)^{exp} = \frac{B(M1)}{g_A^2 (2.2993\ \mu_N)^2}$$

K. Langanke et al., Phys.Rev.Lett. 93 (2004)

ω (keV)	J^π	Γ_0 (meV)	$B(M1\uparrow)$ ($10^{-3}\mu_N^2$)
9697.5 ± 1.4	1^+	233 ± 27	66 ± 8
9758.3 ± 1.1	1^+	692 ± 60	193 ± 17
9805.6 ± 1.3	1^+	272 ± 26	75 ± 7
9841.3 ± 1.3	1^+	566 ± 52	154 ± 14
9871.7 ± 1.2	1^+	223 ± 21	60 ± 6
9893.9 ± 1.4	1^+	116 ± 12	31 ± 3
10020.5 ± 1.7	1^+	71 ± 12	18 ± 3
10033.9 ± 1.4	1^+	210 ± 25	54 ± 6

$$B(M1)_{tot} = 651(98)\ \times\ 10^{-3}\,\mu_N^2$$

Fermi function

Fermi function: quantifies the Coulomb interaction between the outgoing electron and a proton of the ^{40}K nucleus

$$F(Z, p_e) = \frac{|\phi_e(0)_{Coulomb}|^2}{|\phi_e(0)|^2}$$

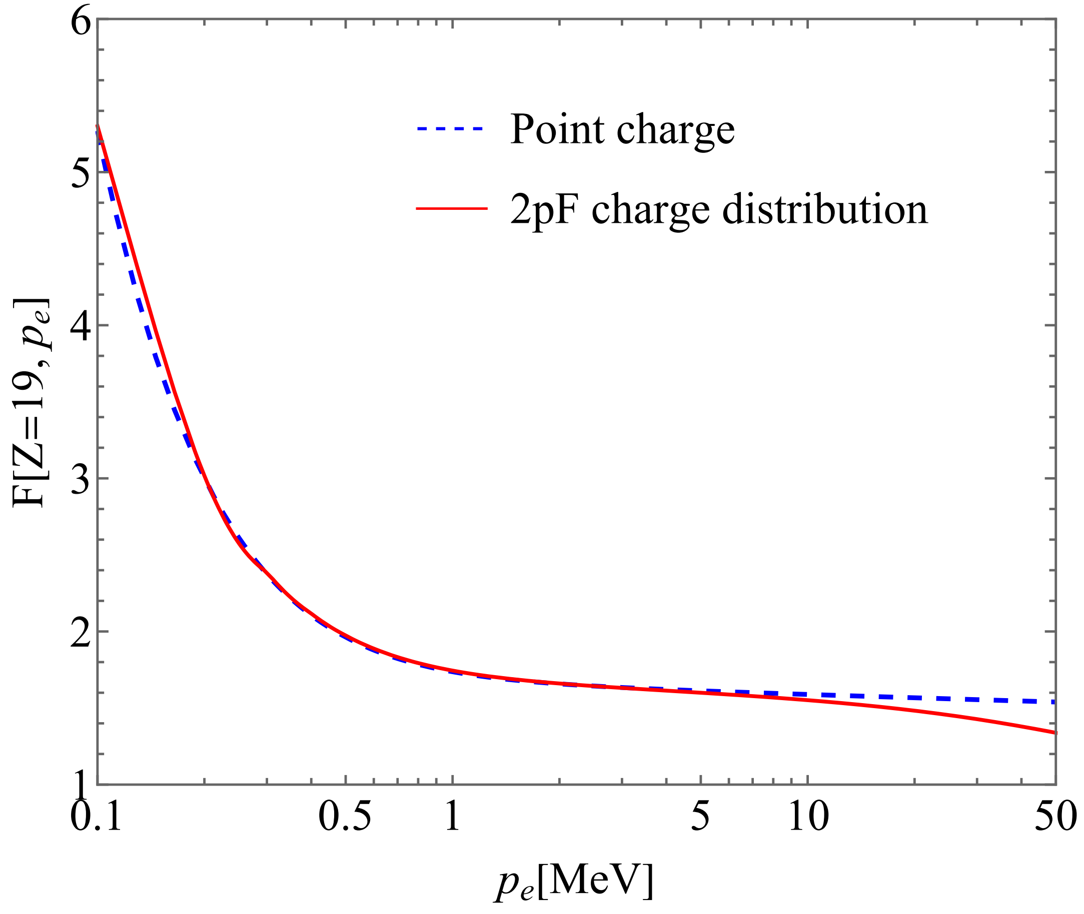
→ **Electron in a Coulomb field**

→ **Free electron**

1 **Point charge:** analytical solution

2 **Charge distribution:** different nuclear charge distributions (uniform, 2pF, 3pF,...)

only numerical solution



Elastic and inelastic cross sections