Beta-decay through broad resonances

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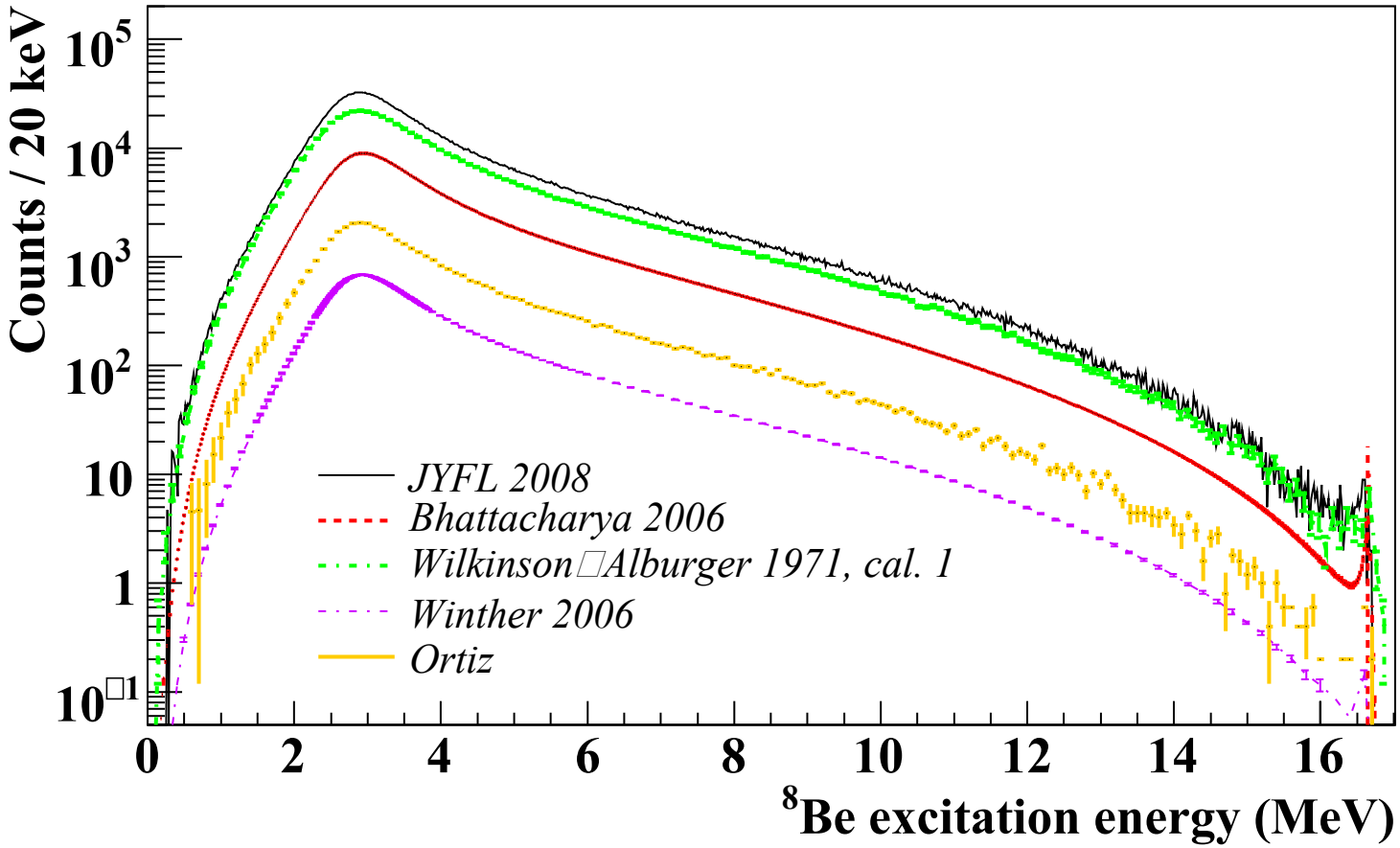
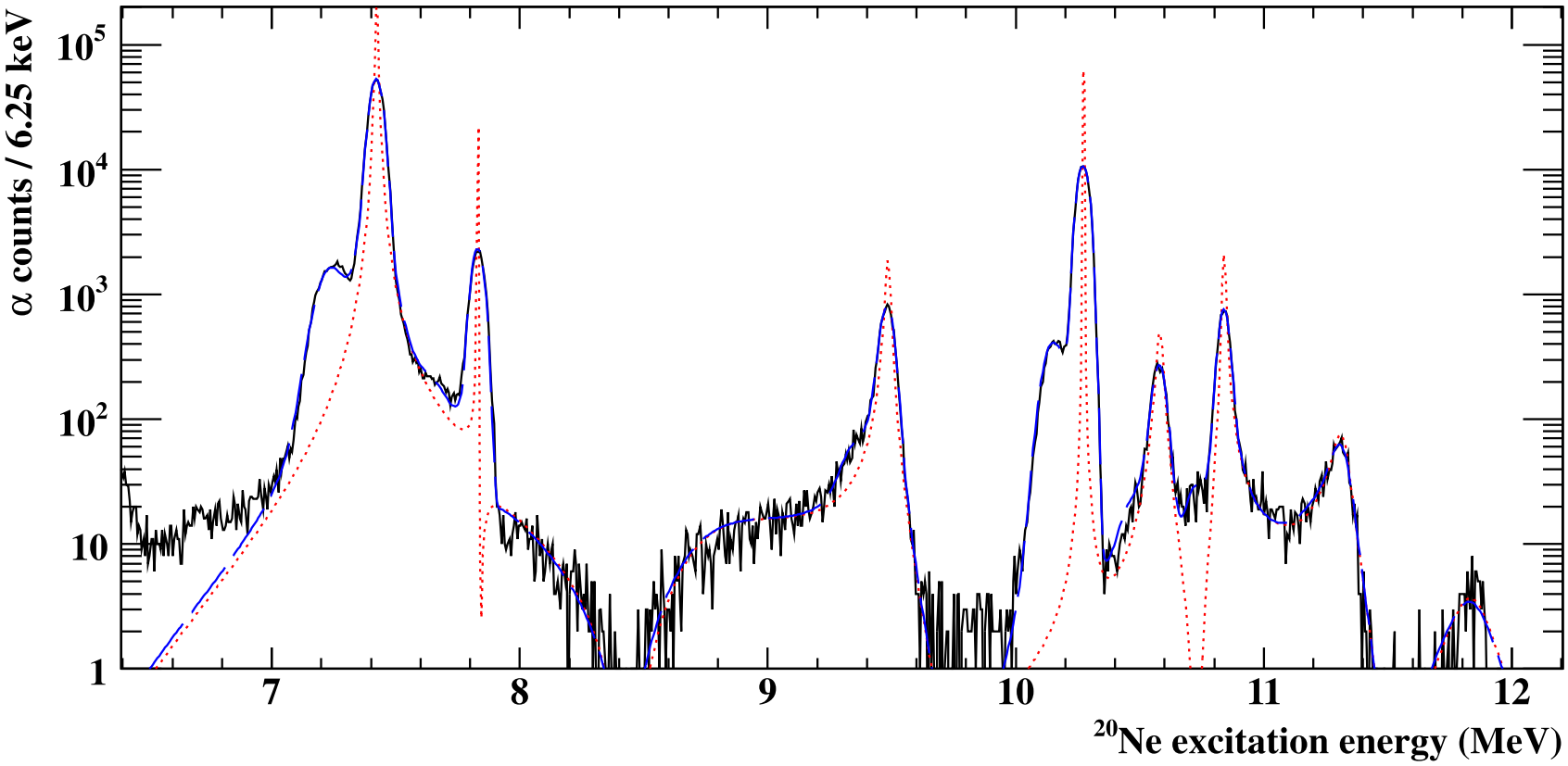
The main points

- Occurs frequently in light nuclei
- No single, simple way to analyse the decays
- Consequences:
  - not unique Gamow-Teller strength (B_{GT}) ?
  - care needed when interpreting R-matrix fits

Example – ^{8}B(βα)



Example – ^{20}Na(βα)



KL Laursen et al., Eur. Phys. J A (2013) **49**: 79

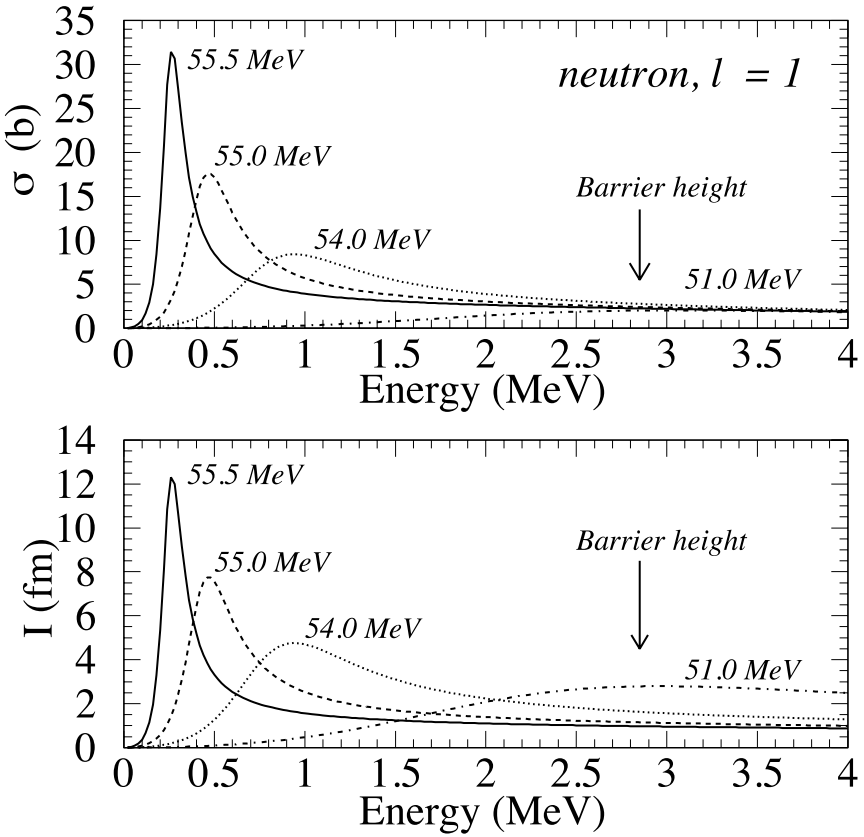
Why are levels broad ?

- Strong coupling to continuum
- Small barrier

Example:

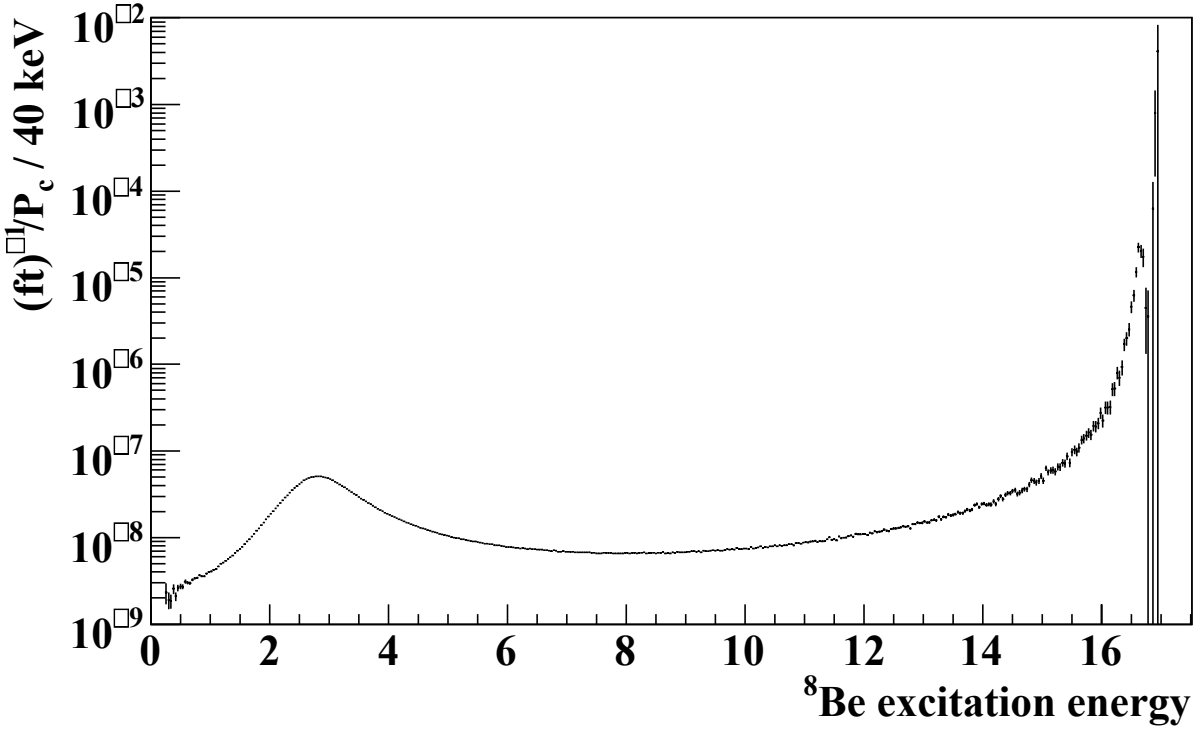
σ, elastic scattering of n

I, integral of wavefunction squared inside potential

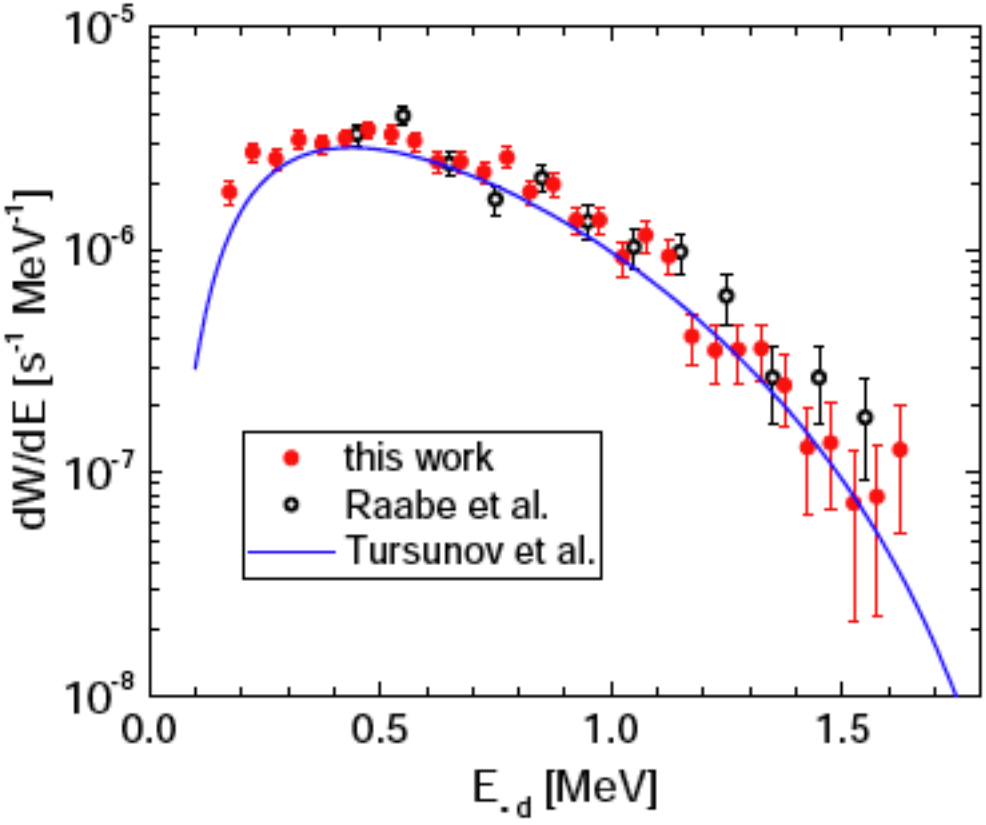


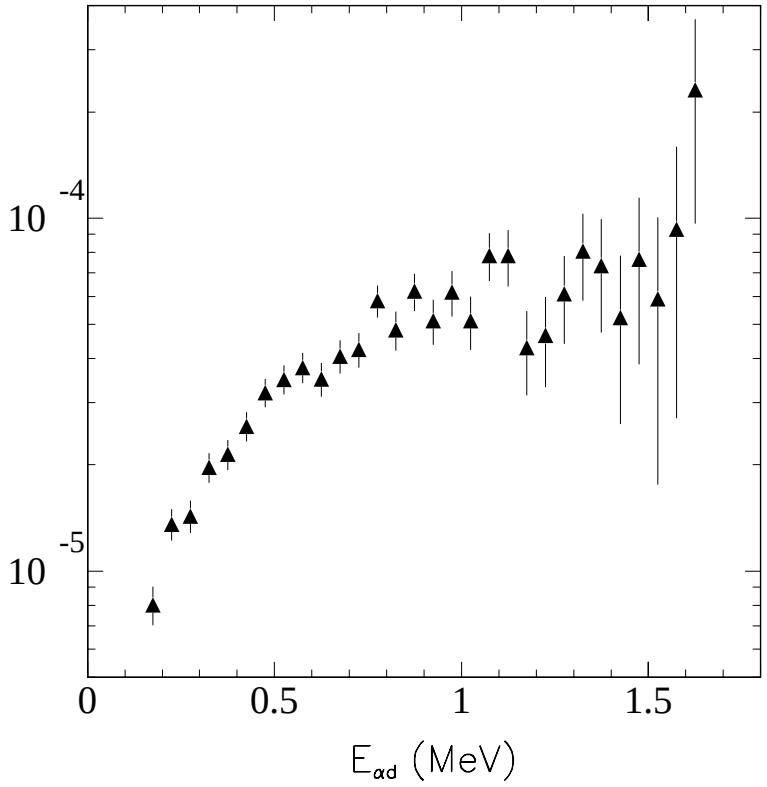
Remove “phase space”

- Decay rate $w \approx P_l(E-E_{th})\, f(Q-E)\, M_{GT}^2$
- E.g. ^{8}B:



Do. for ^{6}He(βd)





Data from: M. Pfützner et al., Phys. Rev. C 92, 014316 (2015)

Decay mechanism

- Two different approaches
  - Sequential through (overlapping) levels, e.g. ^{8}B(βα)
  - Direct to continuum, e.g. ^{6}He(βd)

- Does it matter ??
  - Incomplete exp ➔ model dependent results
  - How do you interpret “structureless” distributions?
  - It may influence the extracted B_{GT} value

Sequential: R-Matrix approach

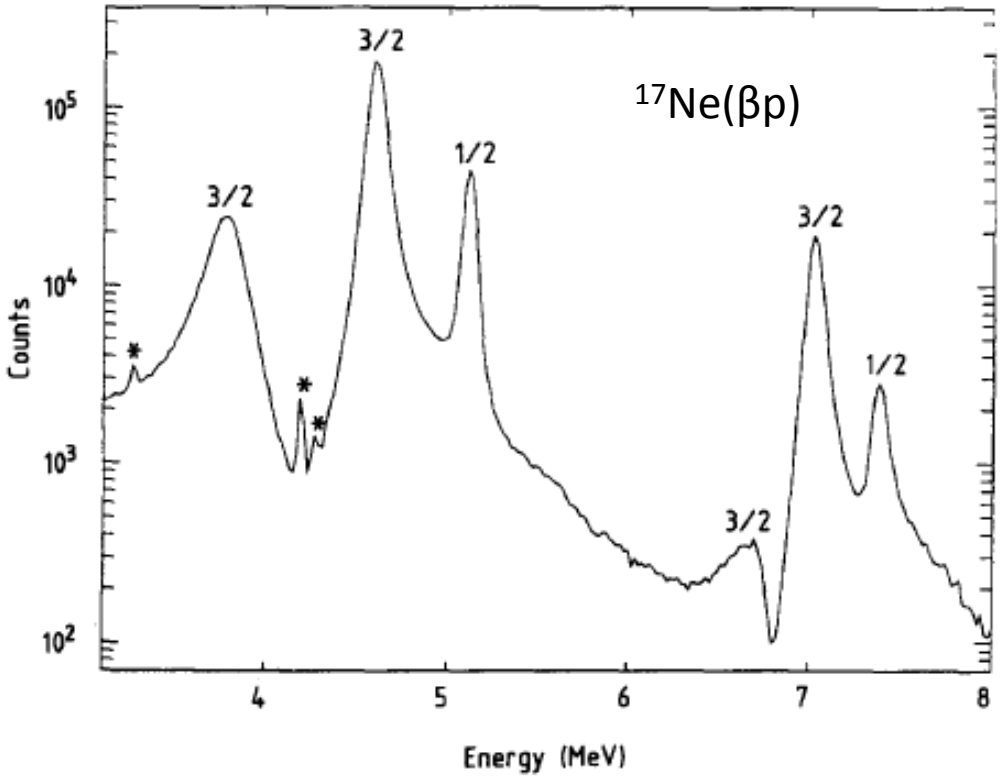
Applied to beta-decay:

FC Barker

Internal region with levels that couple to "outside" channels.
Level widths:

$\Gamma = 2\ P\ \gamma^2$

so levels may overlap and interfere.



MJG Borge et al., Nucl. Phys. A490 (1988) 287

R-matrix formulae

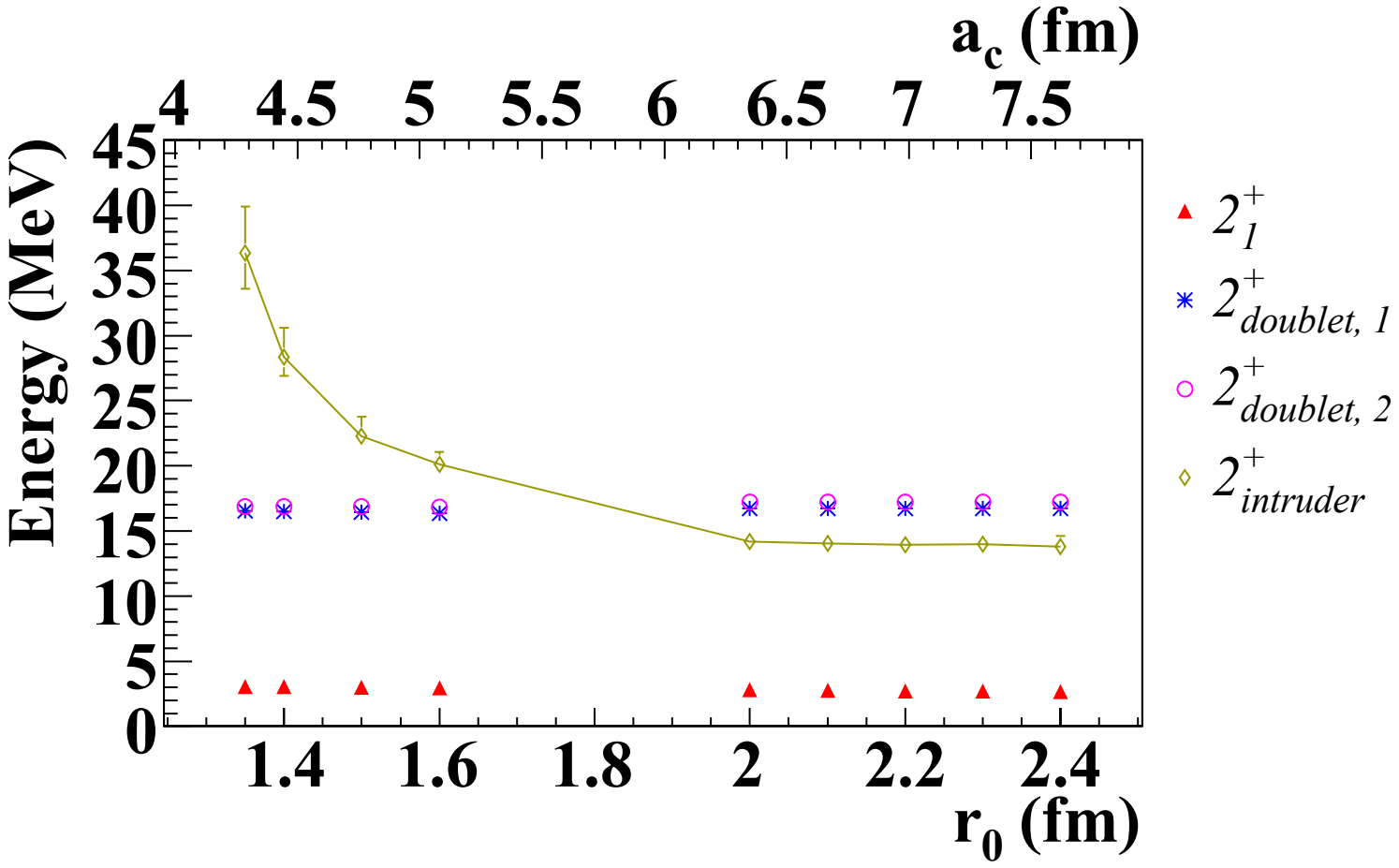
$$\mathcal{F}(E_x) = \frac{N t_{1/2}}{\pi B} f_\beta(E_x) P_\ell(E_x)$$
$$\times \left\{ \left| \sum_{\lambda\mu} \widetilde{g}_{\mathrm{F},\lambda} \widetilde{\gamma}_\mu \widetilde{A}_{\lambda\mu} \right|^2 + \left| \sum_{\lambda\mu} \widetilde{g}_{\mathrm{GT},\lambda} \widetilde{\gamma}_\mu \widetilde{A}_{\lambda\mu} \right|^2 \right\}, \qquad \text{where}$$

$$(\widetilde{A}^{-1})_{\lambda\mu} = (\widetilde{\mathcal{E}}_\lambda - E_x)\delta_{\lambda\mu} - \widetilde{\gamma}_\lambda \widetilde{\gamma}_\mu [\, S_\ell(E_x) + i\, P_\ell(E_x)\,]$$
$$+ \begin{cases} \widetilde{\gamma}_\lambda^2 \mathcal{S}_\lambda & , \quad \lambda = \mu, \\ \widetilde{\gamma}_\lambda \widetilde{\gamma}_\mu \frac{\mathcal{S}_\lambda(E_x - \widetilde{\mathcal{E}}_\mu) - \mathcal{S}_\mu(E_x - \widetilde{\mathcal{E}}_\lambda)}{\widetilde{\mathcal{E}}_\lambda - \widetilde{\mathcal{E}}_\mu} & , \quad \lambda \neq \mu, \end{cases}$$

F/GT matrix element:
$$M_{\mathrm{X},\lambda} = \frac{\widetilde{g}_{\mathrm{X},\lambda}}{\left(1 + \widetilde{\gamma}_\lambda^2 \frac{dS_\ell}{dE_x}|_{E_x = \widetilde{E}_\lambda}\right)^{1/2}},$$

Brune formulation, cf. S Hyldegaard, PhD thesis 2010

Problems with R-matrix – (1) ^{8}B

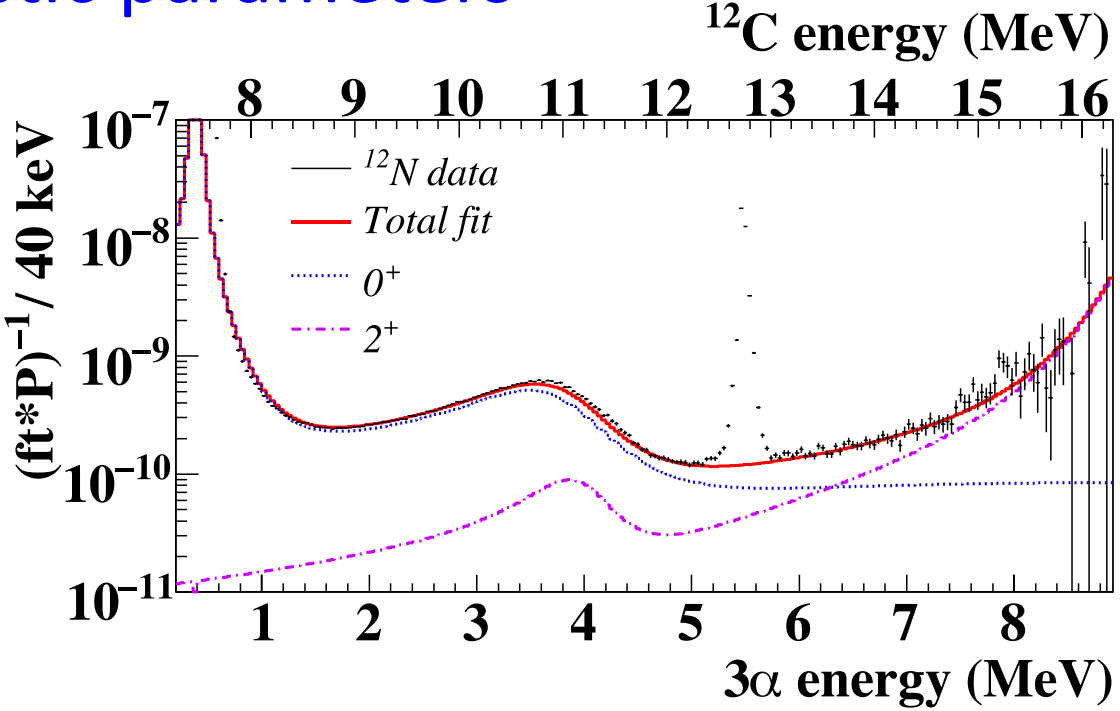


Fits with 3 MeV resonance, the 16 MeV doublet and one extra 2^{+} level.

Problems with R-matrix – (2) ^{12}N

- Exp. spectrum indicates high-lying resonances with unrealistic parameters

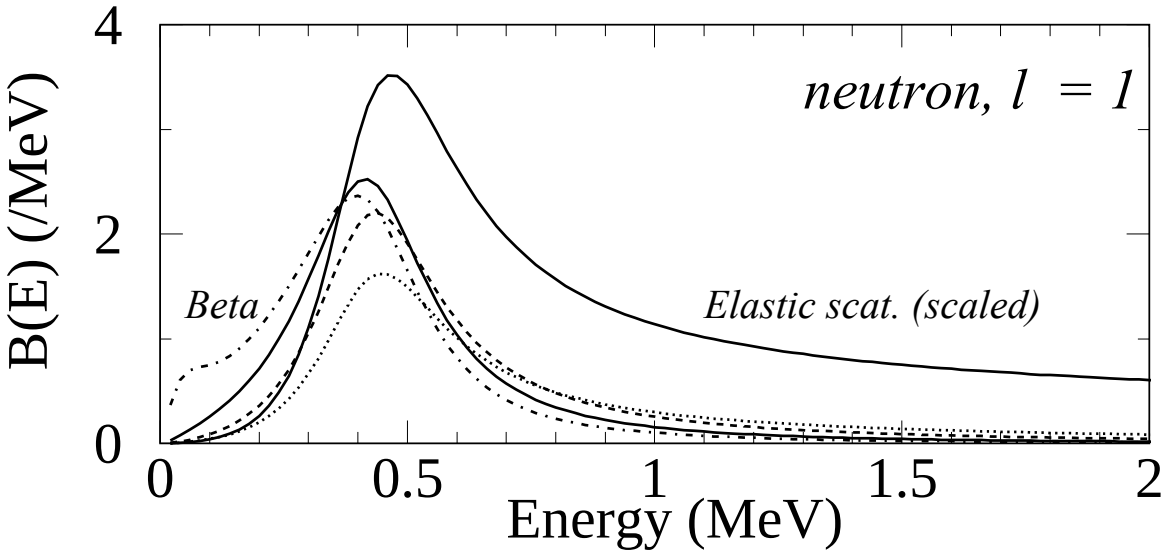
S. Hyldegaard et al,
PRC 81 (10) 024303



Simple model + R-matrix fits

Same model as earlier, beta decay from initial states with binding energy E = 5 / 1 / 0.2 / 0.02 MeV:

R-matrix:
level energy
depends on E
+ need more
(unreasonable)
levels…



Differences due to contributions from extra-nuclear distances !

Proposed B_{GT} (re)definition

- Discrete states $w = C\, f(Q-E)\, B_{GT}$, $C = \ln 2\, g_A^2/K$
- Continuum $w(E) = C\, f(Q-E)\, B_{GT}(E)$
- Gamow-Teller sum-rule $\Sigma B_{GT}^- - \Sigma B_{GT}^+ = 3(N-Z)$ is still ok (the sum extended with an integral)

Completeness relation: T Berggren, PL B44 (73) 23; WJ Romo, NP A237 (75) 275

- Easy for experimentalists but cannot extrapolate…
- Manageable for theoreticians

Summary

- Conceptually: approaching reaction theory
- Careful when extracting B_{GT} !
- Danger of misinterpreting R-matrix fits

  Can $^{16}N(\beta\alpha)$ be used to constrain $^{12}C(\alpha,\gamma)$?

Thanks to many collaborators:

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More info: NP A940 (2015) 119, NP A925 (2014) 112 + 298 (E)
arXiv:1503.05792, arXiv:1312.0479