De-excitations of residual nuclei based on the TALYS and GEMINI++ codes

Poster ID: 33

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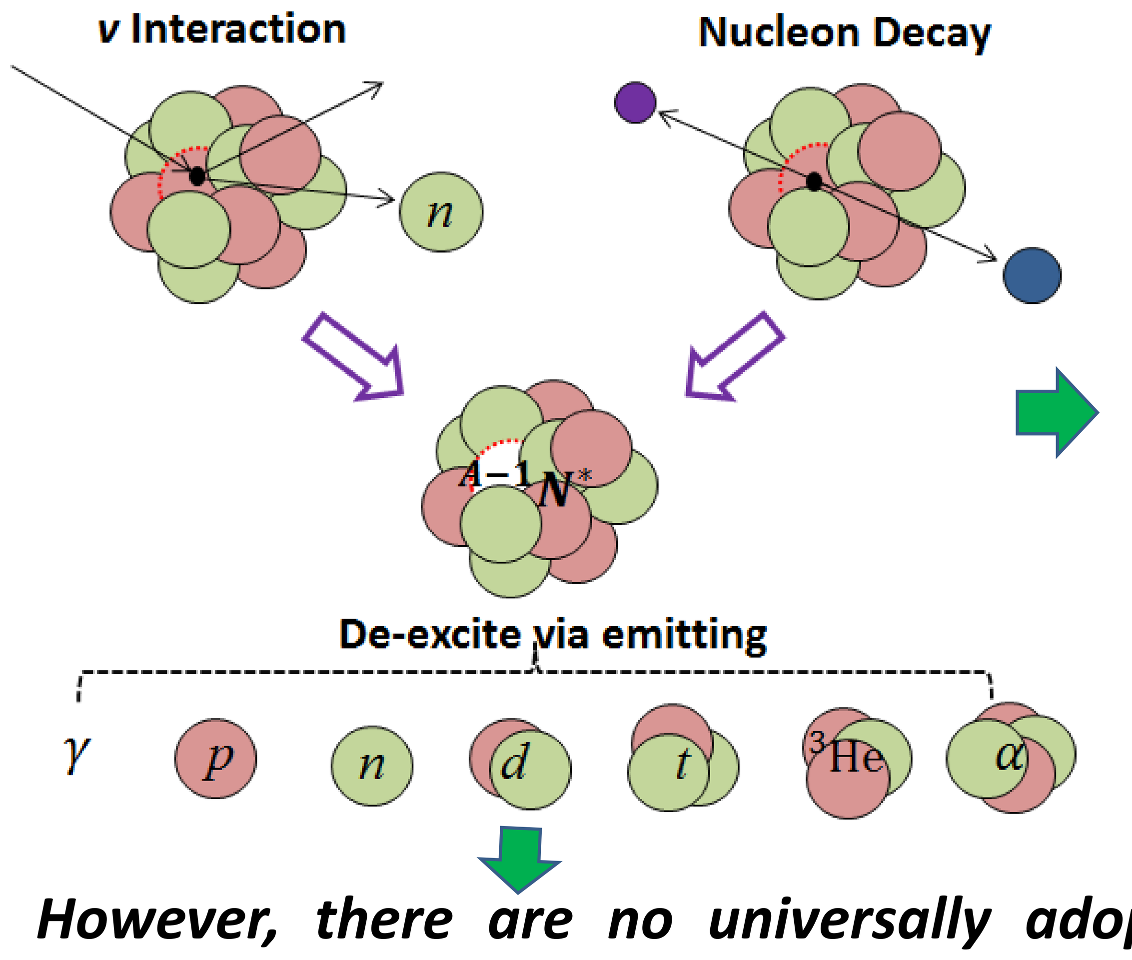
1. Nuclear de-excitations in neutrino experiments

are playing an increasingly significant role associated with



- **Liquid scintillator**
  - *neutrons*
  - *unstable isotopes*
- **Water Cherenkov**
  - *monoenergetic γ*
  - *neutrons*
- **Liquid Argon TPC**
  - *Emitted particles*

↑ Signal/BKG

However, there are no universally adopted and quantitatively accurate models to describe the complete de-excitation cascade

2. Statistical codes to model de-excitations

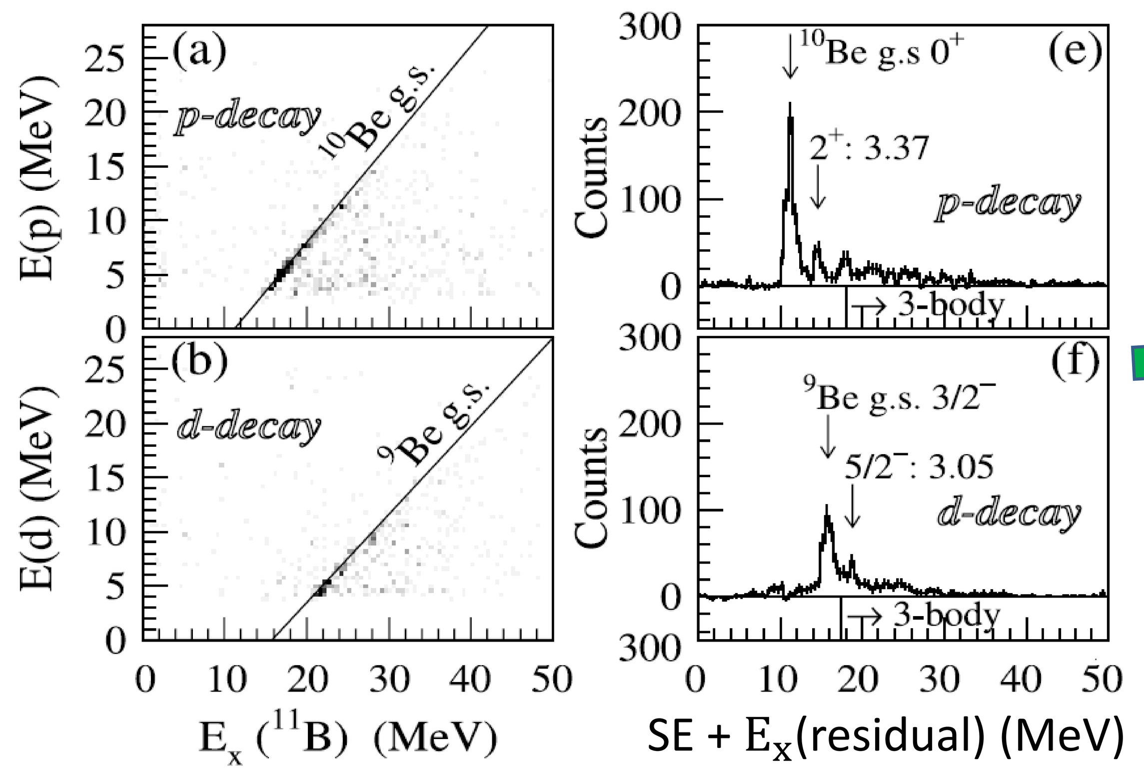
- TALYS[1], GEMINI++[2], ABLA[3], CASCADE[4] … are widely used
- De-excitations in these codes are dealt with as a sequential binary decays of compound nucleus

Code	TALYS	GEMINI++
Input	Nucleus, Excited energy table (spin, parity)	Nucleus, Excited energy, Spin
Formulism of width Γ_i	Hauser-Feshbach (HF)	HF or Weisskopf-Ewing (WE)
Output	Statistical branching ratios and energy spectra	Complete de-excitation cascade
Convenience	Not event-by-event, Inconvenience	***Event-by-event, Convenience***

TALYS and GEMINI++ are designed for heavy nuclei, light nuclei ?

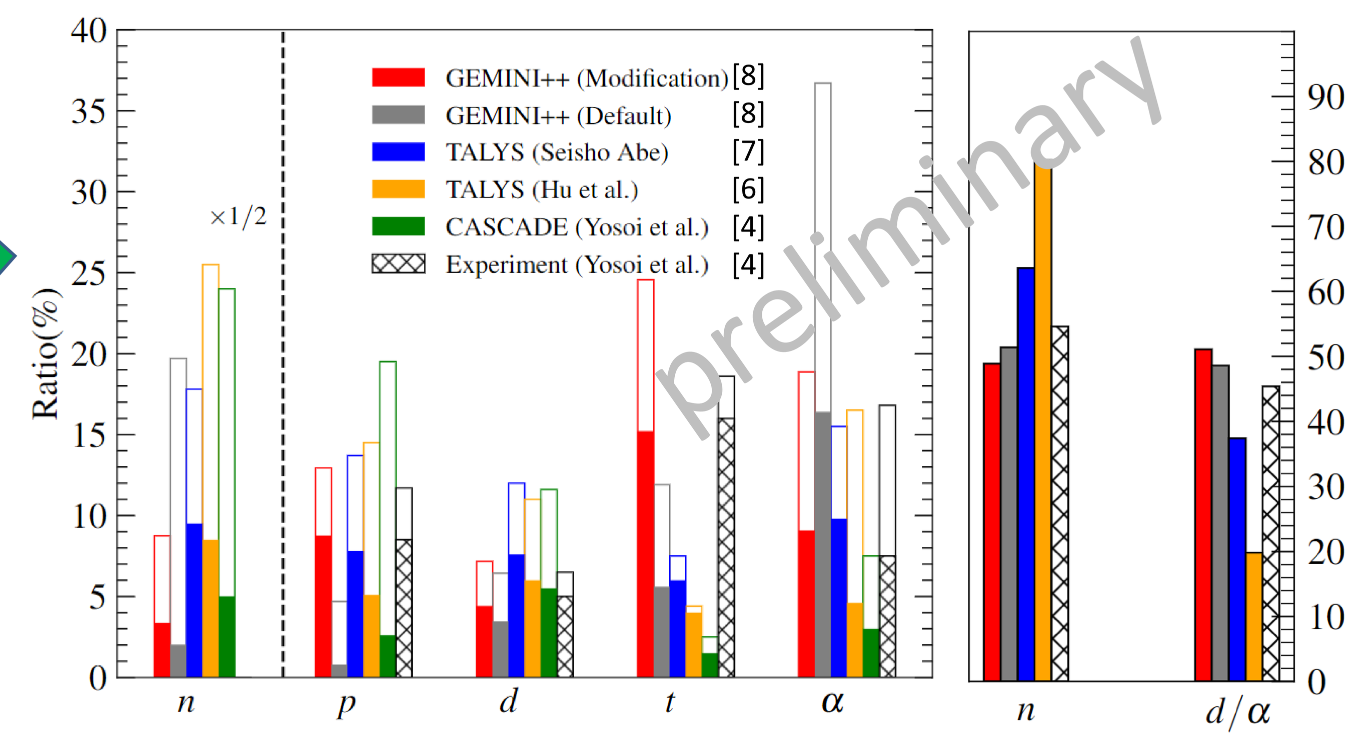
3. Measure $^{11}\mathrm{B}^*$ de-excitations from nuclear physical experiments

3.1 quasi-free $^{12}\mathrm{C}(p,2p)^{11}\mathrm{B}^*$ reaction (Yosoi et al [4])



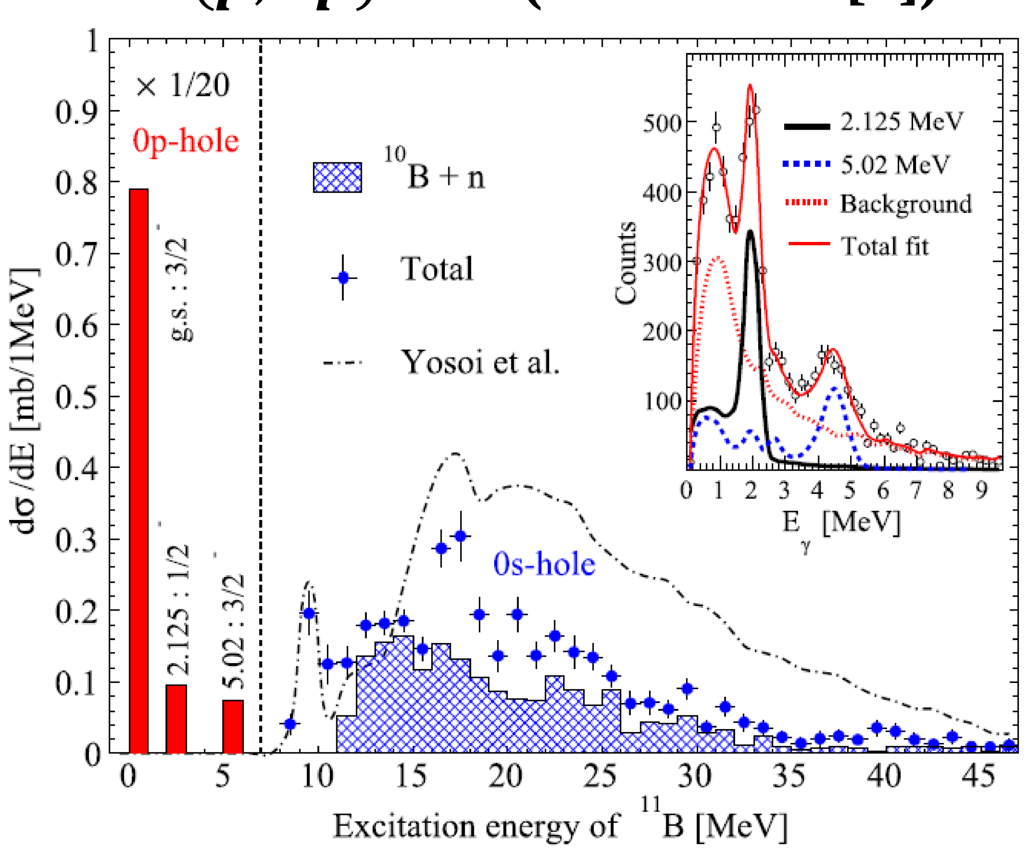
Measure emitted charged particles [*E* lower limit]:
p [3.1 MeV], ***d*** [4.0 MeV], ***t*** [4.6 MeV], ***α*** [4.5 MeV]

$$Br_i = \frac{\int n_i (4\pi/\Delta\Omega_{\mathrm{SSD}})\, dE_x}{\int N\, dE_x}, \quad i = p, d, t \text{ and } \alpha,$$



Exp data vs Predictions

3.2 $^{12}\mathrm{C}(p,2p)^{11}\mathrm{B}^*$ (Panin et al [5])



Measure exclusively 3 two-body modes:
$^{11}\mathrm{B}^* \to n + {}^{10}\mathrm{B}; \to d + {}^{9}\mathrm{Be}; \to \alpha + {}^{7}\mathrm{Li}$

Relative ratios: $\frac{n+{}^{10}\mathrm{B}}{\mathrm{Total}}$, $\frac{(d+{}^9\mathrm{Be})+(\alpha+{}^7\mathrm{Li})}{\mathrm{Total}}$

4. TALYS predictions

Using Hauser-Feshbach with $E_x = 16 - 35$ MeV, $J^\pi = 1/2^+$ and **changing discrete level number** [6]:

Nuclide	^{10}B	^{9}B	^{8}B	^{10}Be	^{9}Be	^{8}Be	^{7}Be	^{9}Li	^{8}Li	^{7}Li	^{6}Li	others
Default	10	10	4	10	5	5	8	7	5	9	10	10
Modified	5	5	3	5	5	5	5	3	3	3	3	1

Because all discrete states in TALYS **only emit γ**, finally decay into their ground state → Lead to **wrong** results for some cases, such as

If $^{11}\mathrm{B}^* \to p + {}^{10}\mathrm{Be}^*(7.542\ \mathrm{MeV})$:

Default TALYS: $^{11}\mathrm{B}^* \to p + {}^{10}\mathrm{Be}$

NNDC: 6.3 keV 8, % α = 3.5 12, % n > 0

$$\begin{cases} ^{11}\mathrm{B}^* \to p + \alpha + {}^6\mathrm{He}^* \\ ^{11}\mathrm{B}^* \to p + n + {}^9\mathrm{Be}^* \end{cases}$$

^{9}Be*:

E(level) (keV)	J^π(level)	$T_{1/2}$(level)
0.0	3/2−	STABLE
1684 20	1/2+	214 keV 5, % IT = 1.4×10^{-6}, % n ≈ 100
2429.4 13	5/2−	0.78 keV 13, % IT = 1.2×10^{-4}, % n > 7.0 10, % α > 1
2.78E+3 12	1/2−	1.10 MeV 12, % n ≈ 100

TALYS can partly account for experiment data, bad for t mode [6,7]

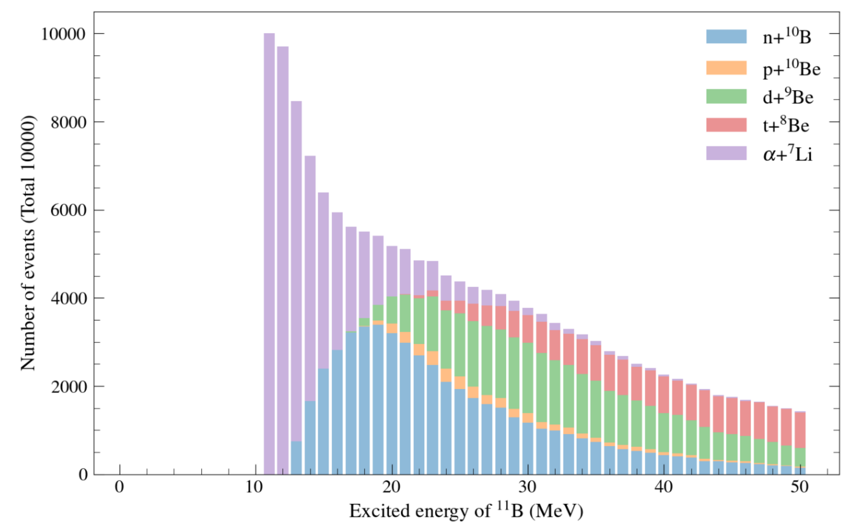
5. GEMINI++ predictions

5.1 Default Weisskopf-Ewing with $E_x = 16 - 35$ MeV, $J = 1/2$

Can not account for Yosoi data; better than TALYS for Panin data

5.2 Modified Weisskopf-Ewing with 3 reasonable changes:

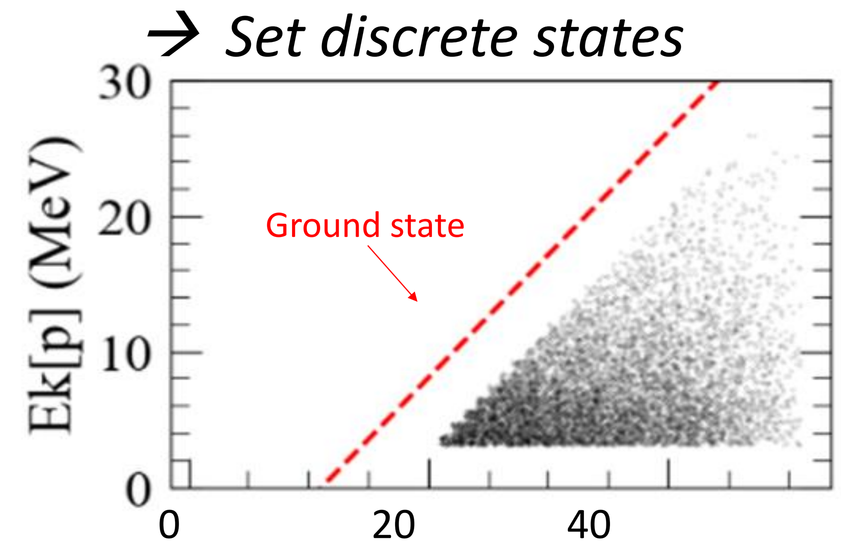
(1) Threshold Problem (2-body) → Remove back-shifted (BS) term in level density of BS Fermi gas model



$$\rho(E^*, J) \propto \frac{(2J+1)\exp\left[2\sqrt{a(E^* - \cancel{E_1})}\right]}{a^{1/4}(E^* - \cancel{E_1})^{5/4}}$$

Modes	Theory(MeV)	Default(MeV)	Modified(MeV)
$n + {}^{10}$B	11.5	12.2	12.2
$p + {}^{10}$Be	11.2	17.1	12.2
$d + {}^{9}$Be	15.8	16.6	16.6
$t + {}^{8}$Be	11.2	20.5	12.1
$\alpha + {}^{7}$Li	8.7	10.1	10.1

(2) Discrete states are absent → Set discrete states



(3) User given suppression factor → Modify

S factor	*n*	*p*	*d*	*t*	^{3}He	α
Default	1.0	1.0	0.5	0.5	0.5	1.0
Modified	1.0	1.0	1.0	1.0	1.0	1.0

Modified GEMINI++ gives the best prediction compared with data [8]

6. Summary

- De-excitations are playing an increasingly significant role in ν experiments
- Predictions from de-excitation codes should be compared with exp data
- TALYS can partly account for experimental data, is not event-by-event
- Modified GEMINI++ gives the best predictions, event-by-event output
- Email to niuyj@ihep.ac.cn, guowl@ihep.ac.cn for further discussions

References

[1] A.J. Koning, D. Rochman, Nucl. Data Sheets 113 (2012) 2841–2934
[2] D. Mancusi, R.J. Charity, J. Cugnon, Phys. Rev. C 82 (2010) 044610
[3] J.L. Rodríguez-Sánchez, J. Cugnon, et al., Phys. Rev. C 105 (2022) 014623
[4] M. Yosoi, H. Akimune, et al., Phys. Lett. B 551 (2003) 255–261
[5] V. Panin, J.T. Taylor, et al., Phys. Lett. B 753 (2016) 204–210
[6] H. Hu, W.L. Guo, et al., Phys. Lett. B 831 (2022) 137-183
[7] S. Abe, Phys. Rev. D 109 (2024) 036009
[8] Y.J. Niu, W.L. Guo, M. He et al., in preparing