

Validation and application of the nuclear deexcitation simulator **NucDeEx** for precise prediction of neutrino-nuclear interactions

168

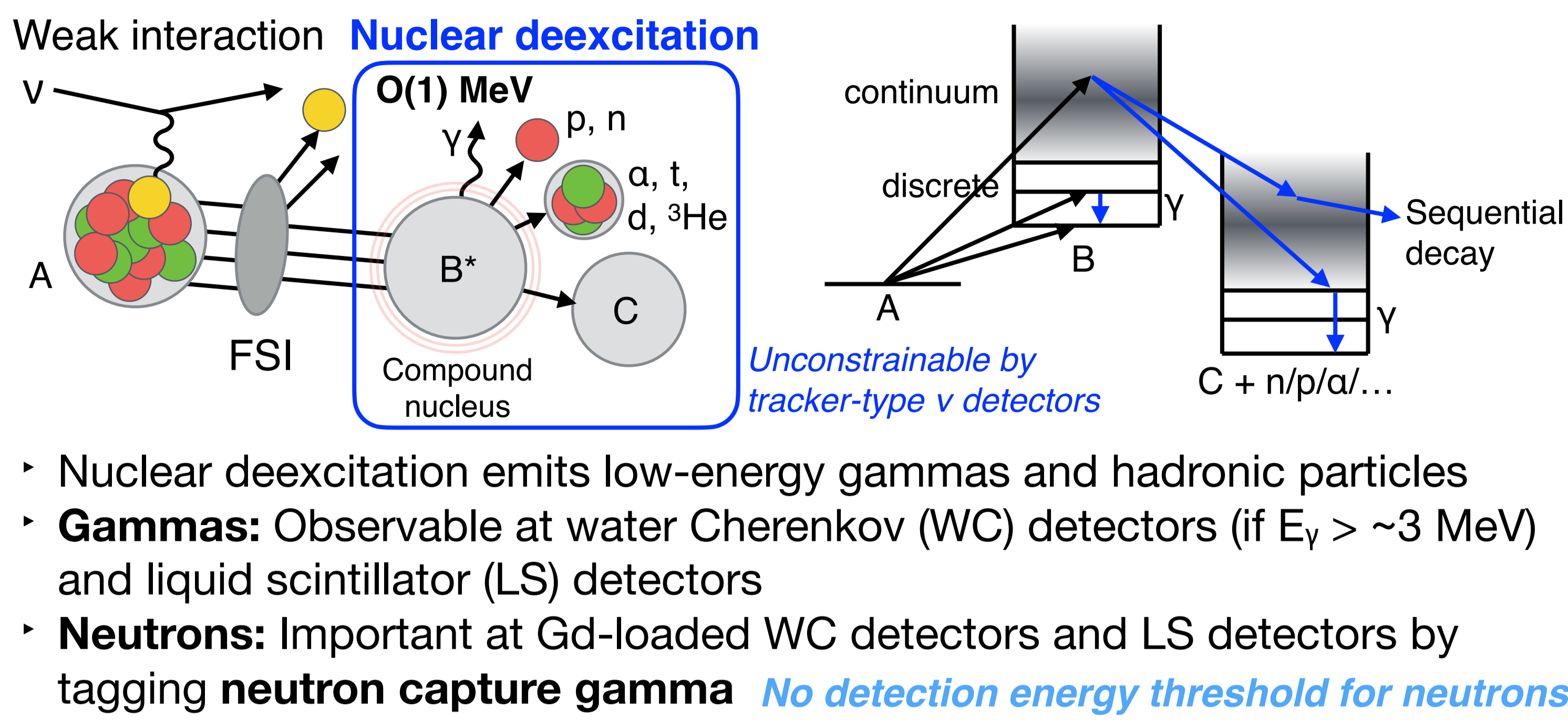


S. Abe, Phys. Rev. D 109, 036009 (2024)
<https://github.com/SeishoAbe/NucDeEx>

Seisho Abe - Kamioka Obs., ICRR, the University of Tokyo

seisho@icrr.u-tokyo.ac.jp

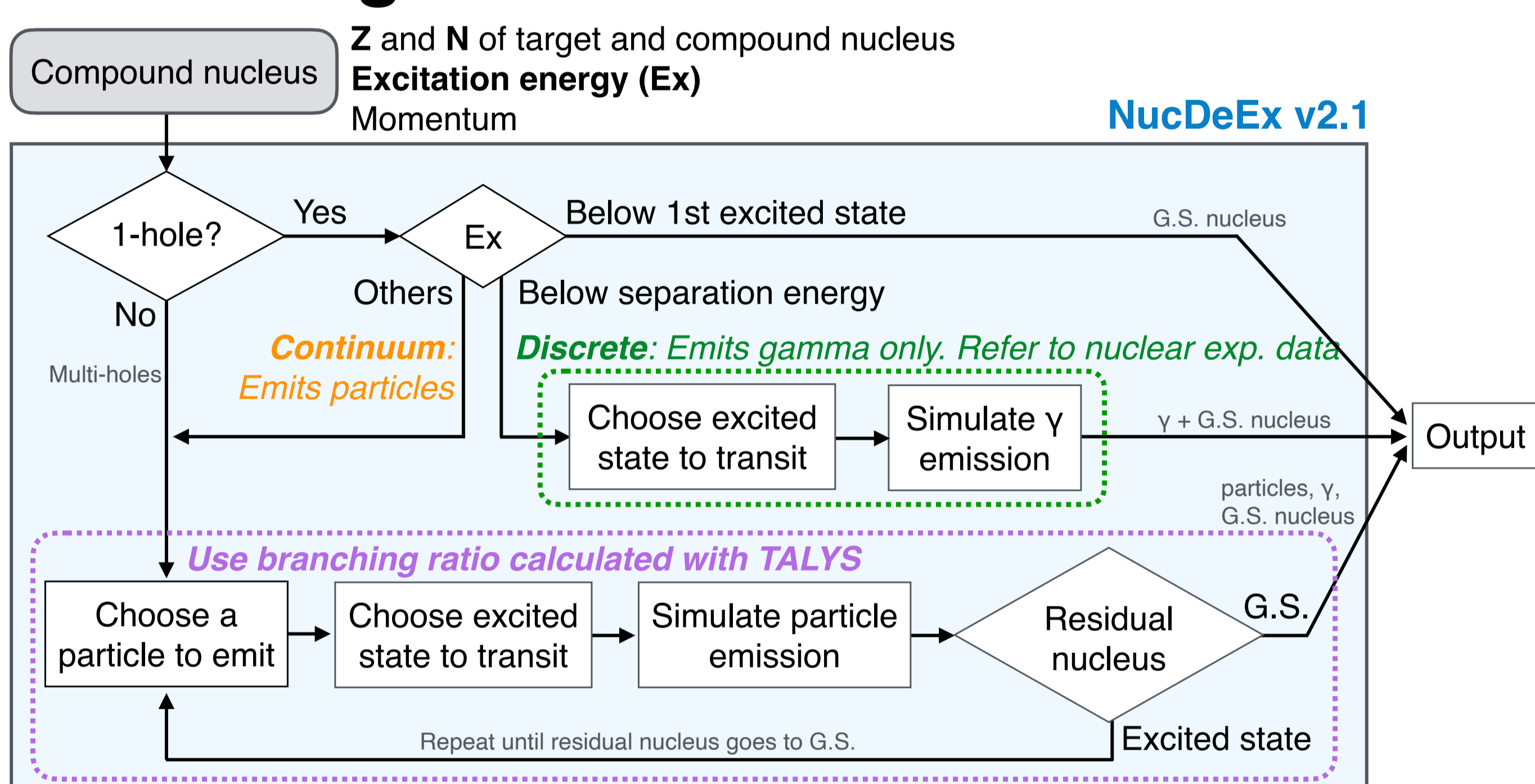
1. Neutrino-Nucleus interaction



2. Nuclear deexcitation in ν generators

- Simplified (e.g., in NEUT)** or not simulated in many cases
 - Simulation studies so far:
 - Outside of ν generators: Using nuclear reaction simulators
 - Closed-source. Not implemented into ν generators.
 - Within ν generators: **INCL++/ABLA in NuWro**
 - A. Ershova et al. Phys. Rev. D 108, 112008
 - Cascade model INCL++ has ABLA as a deexcitation module
 - Known issue in ABLA: Missing proper treatment of gamma**
 - Acceptable at tracker detectors but NOT in LS and WC detectors
- Newly develop** **NucDeEx** S. Abe, Phys. Rev. D 109, 036009 (2024)
- Open-source deexcitation event generator based on **TALYS**
 - For WC and LS detectors, i.e., supports ^{16}O and ^{12}C
 - Standalone** and easy to implement into various simulators
 - NEUT, GENIE, NuWro, INCL++, and Geant4.

3. Algorithm of NucDeEx v2.1



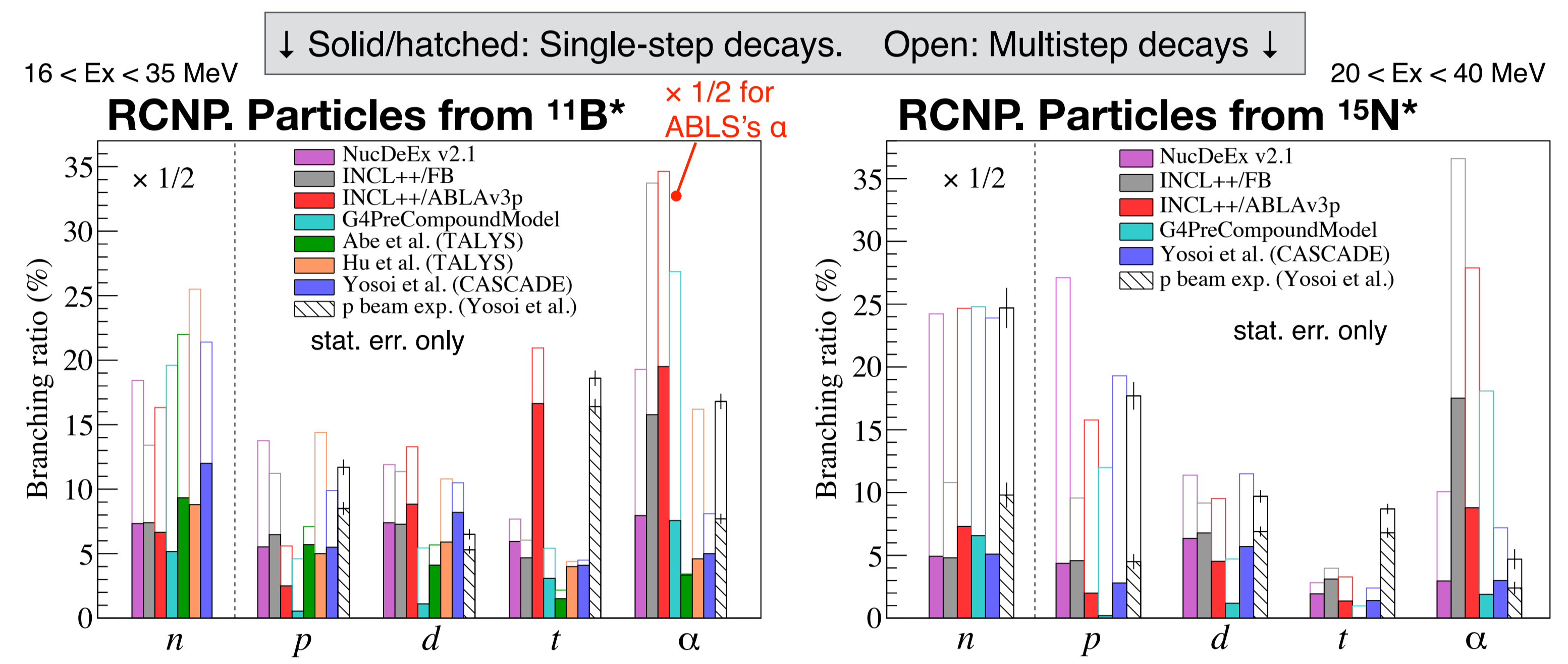
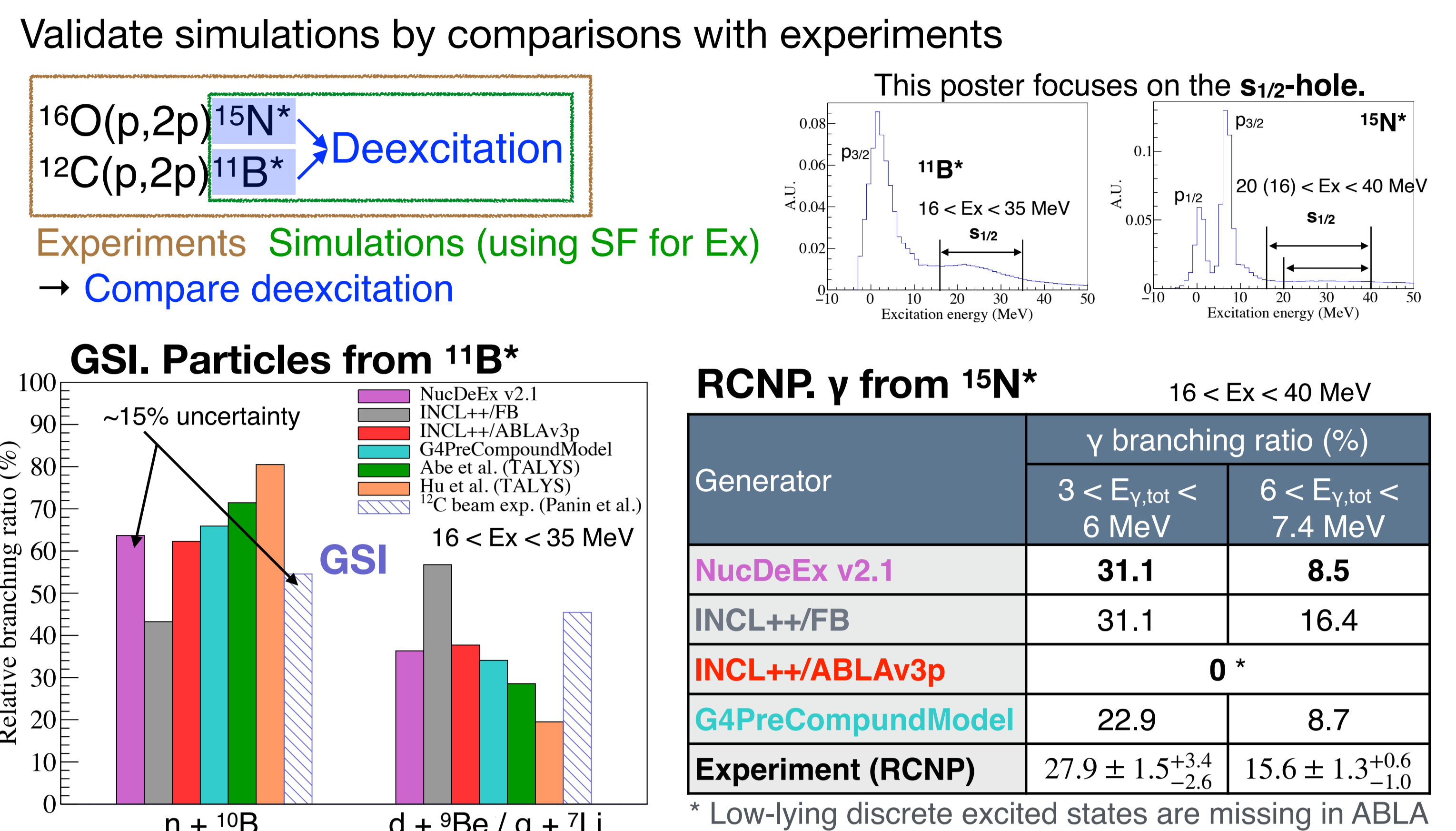
- Discrete:** Simple process. Refer to experimental data.
 - Separating this part is essential to obtain good γ 's spectra
- Continuum + Multi-holes:** Complicated. Needs reliable nuclear theory
 - Use branching ratios calculated with **TALYS** (Hauser-Feshbach model)

4. Models and generators of deexcitation

Generator	Model	Comments
NucDeEx v2.1	HF	Developed by the author. Based on TALYS.
INCL++/FB	FB	Default model for light nuclei ($A \leq 16$) in INCL++.
INCL++/ABLA v3p	WE	Alternative model in INCL++.
G4PreCompoundModel	GEM and FB	Default model in Geant4.
CASCADE	HF	Closed-source. Citing numbers from paper.

- HF:** Hauser-Feshbach. A statistical model that **considers angular momentum conservation (while other models do not)**
- WE:** Weisskopf-Ewing. A statistical model that does NOT consider angular momentum.
- GEM:** A specific model based on WE.
- FB:** Fermi breakup. Generally only applicable for light nuclei ($A \leq 16$)
- The more sophisticated HF model is known to be generally favored, but that's for heavy nuclei.
- There is (almost) no consensus on which model is better for light nuclei, carbon and oxygen.**

5. Validations of pure deexcitation process

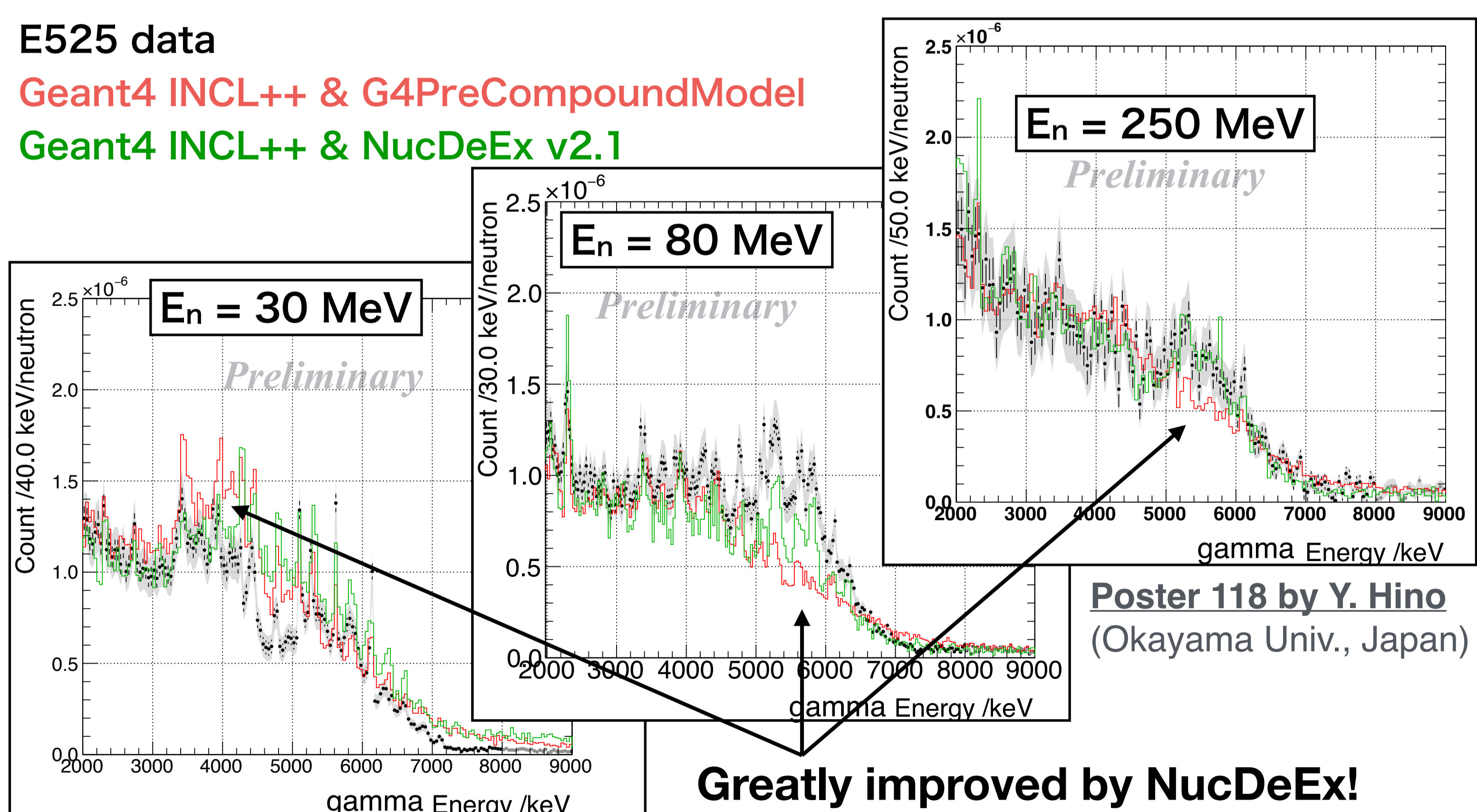


Generator	χ^2/ndf		stat. err. only
	$^{11}\text{B}^*$	$^{15}\text{N}^*$	
NucDeEx v2.1	483 / 8	280 / 10	← The best or comparable to the best
INCL++/FB	1038 / 8	1409 / 10	← Largely overestimates α .
INCL++/ABLA v3p	7320 / 8	737 / 10	← Overestimates α . Underestimates single-step p. Not good.
G4PreCompoundModel	1181 / 8	777 / 10	← Predecessor of NucDeEx
Abe et al. (TALYS)	947 / 8	-	
Hu et al. (TALYS)	674 / 8	-	
Yosoi et al. (CASCADE)	676 / 8	263 / 10	← Comparable to NucDeEx. Closed-source

- NucDeEx is better than G4PreCompoundModel
- It's worth using NucDeEx instead of G4PreCompoundModel in Geant4.**

6. Validation in combination with Geant4

- NucDeEx provides an interface for **INCL++** of **Geant4**
- First validation of **Geant4** coupled with **NucDeEx** was made by E525
- E525 measured **gamma spectra** from inclusive $n + ^{16}\text{O}$



Model	χ^2/ndf @30 MeV	χ^2/ndf @80 MeV	χ^2/ndf @250 MeV
G4PreCompound	1063.7 / 151	3599.6 / 201	303.1 / 121
NucDeEx v2.1	925.7 / 151	647.3 / 201	200.9 / 121

- NucDeEx is better than G4PreCompoundModel in all neutron energies!**
- Application and investigation using Super-K Geant4 has started.

7. Summary and prospects

- A new standalone deexcitation event generator, **NucDeEx**, based on the Hauser-Feshbach model, has been released.
- Various validation results of **NucDeEx**, not only for the pure deexcitation process but also for the inclusive process (combined with INCL++), were shown.
- Investigation using Super-K Geant4 has started. **NucDeEx** will be implemented into NEUT soon.