Measurement of (n, *x*nγ) reaction cross sections in tungsten isotopes.

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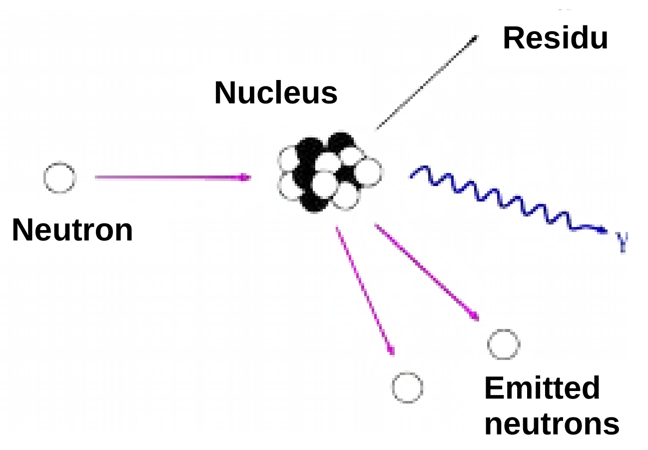
Interest of (n, *x*n) reactions for evaluations

Nuclear reactor developments use evaluated databases for numerical simulation.

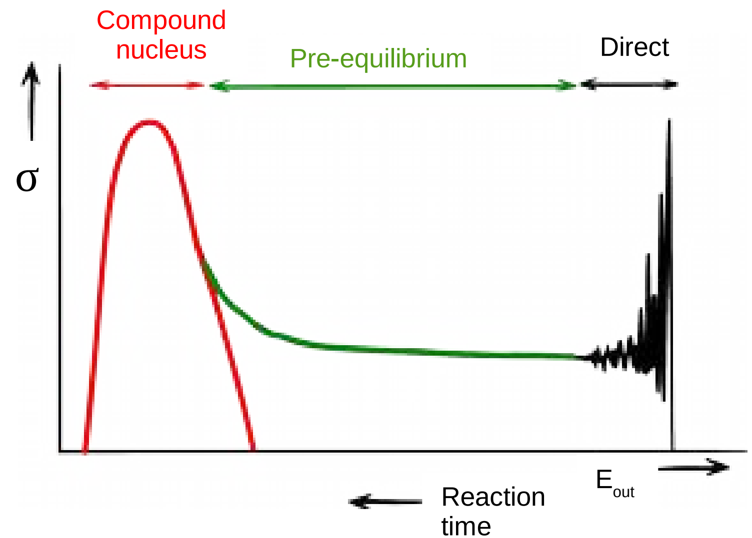
But, the evaluations still present large uncertainties → improvement needed via new measurements and theoretical developments.



Impact on reactors of (n, xn) reactions:

Change the number and energy of neutrons, create new isotopes.

Fundamental interest: The mechanism probes different reaction regimes.

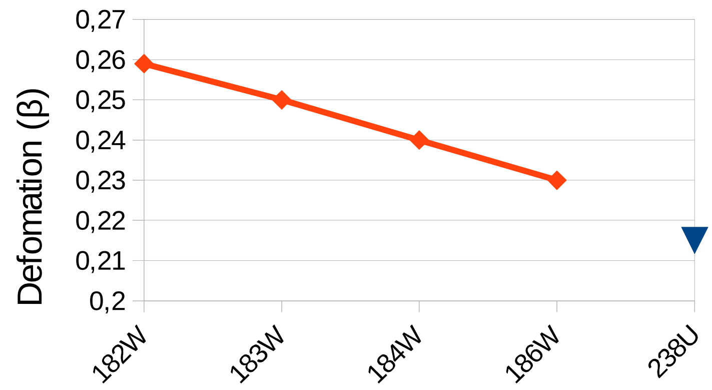


Experimental study of (n, xn γ) reactions brings strong constraints on models (combines reaction mechanism, nuclear de-excitation and nucleus level structure).

Why study Tungsten ?

Practical interests:

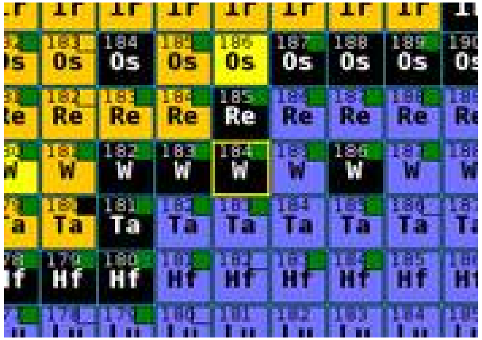
- Present in many alloys in reactors (fission and fusion).
- High melting point, strong mechanical resistance,
  low thermal expansion, resists to oxidation, acids, alkalines.
- Easier experiments to setup (compared to actinides).



Theoretical interests:

- Deformation similar to uraniums.
- No fission channel (B_f^{LD} ~ 20 MeV)
  → simpler description by models.

- Only a few measurements available today,
  the majority of points comes from one experiment.
- Applications use natural tungsten.
- Need to study
  - ^{182}W (26.5 %),
  - *^{183}W (14.3 %)*,
  - ^{184}W (30.6 %),
  - ^{186}W (28.4 %).



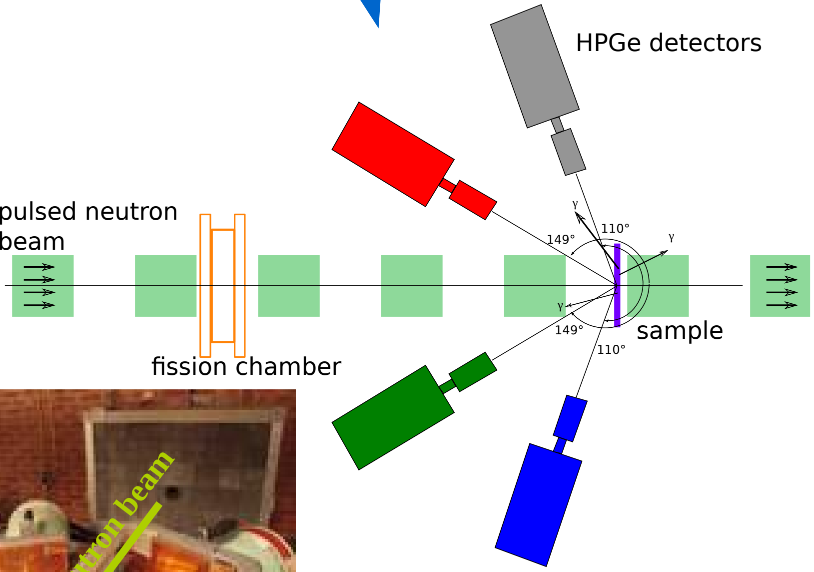
Experimental study of (n, xn γ) reactions

Neutron beam at GELINA (EC-JRC, Geel, BE):

- Electrons accelerated on Uranium target, neutron production by fission,
- Pulsed beam (800 Hz), E_n between keV and 20 MeV,
- Our experiment set up at 30 m.

GRAPhEME setup

- Fission chamber to measure neutron flux,
- Large sample,
- Detection of γ rays emitted in (n, xn) reactions using 4 planar Ge detectors,
- Connected to a digital acquisition recording time and energy in list mode.

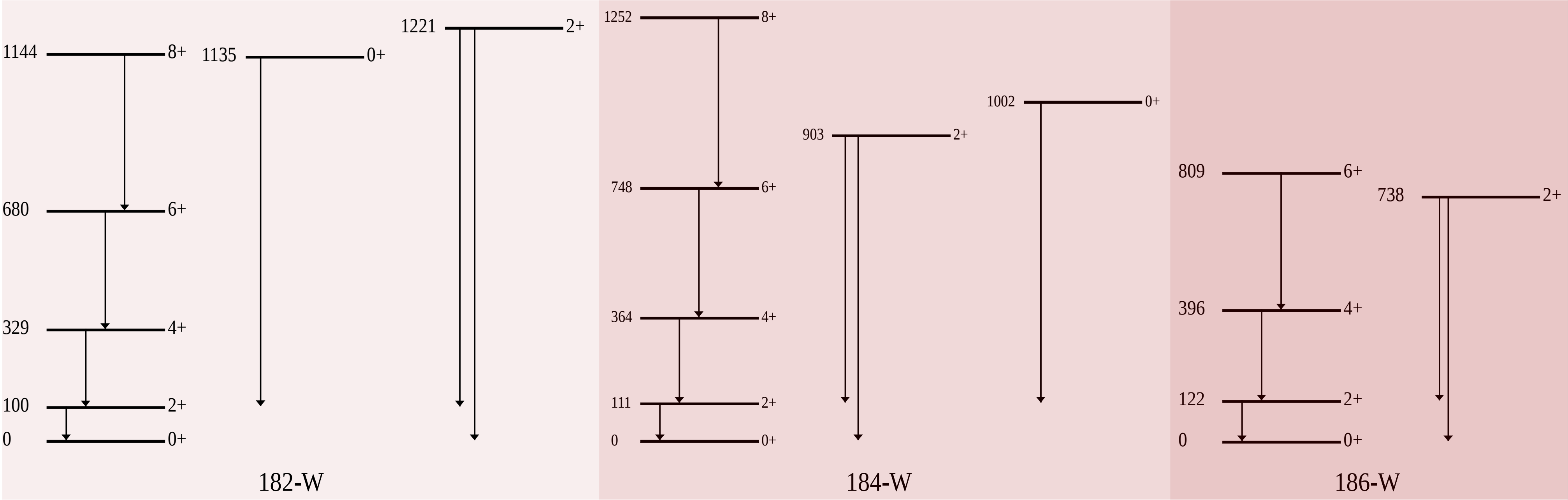


- The ratio of the intensity of the gamma line to the flux gives the production cross section.

$$\frac{d\sigma}{d\Omega}(E_n,\gamma;\theta)=\frac{N_\gamma(E_n,\gamma;\theta)}{\varepsilon(E_\gamma)}\frac{1}{N_{target}}\frac{\sigma_{^{235}U(n,f)}(E_n)\varepsilon_{CF}}{N_{CF}(E_n)}$$

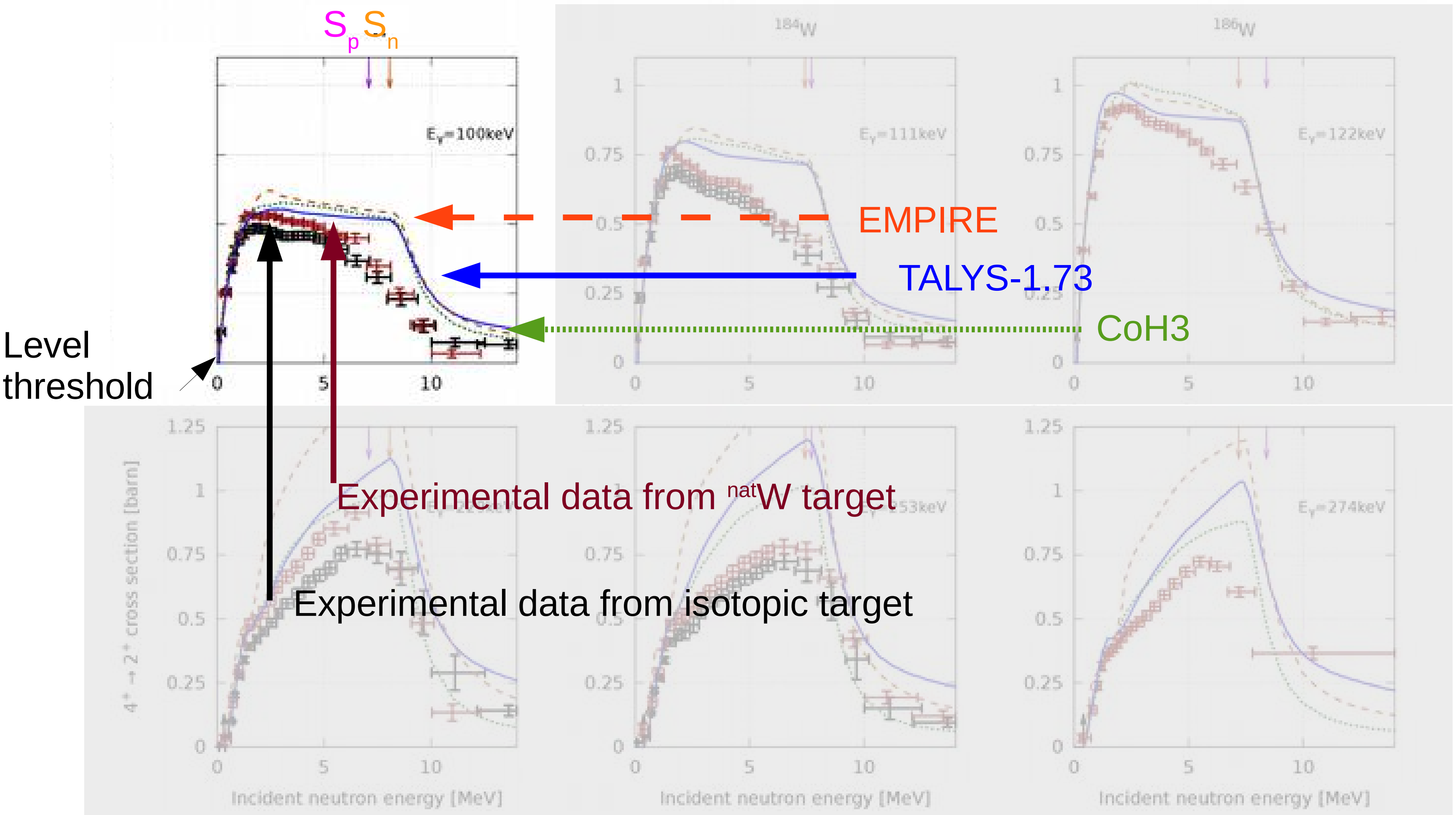
Structure of Tungsten

- Focus on even-even isotopes: 182, 184, 186.
- Studied
  - at the same time in ^{nat}W sample,
  - and separately in isotopic targets.
- Structure: Rotor-like: ground state rotational band, 2^+ (γ) and 0^+ (β) bands.



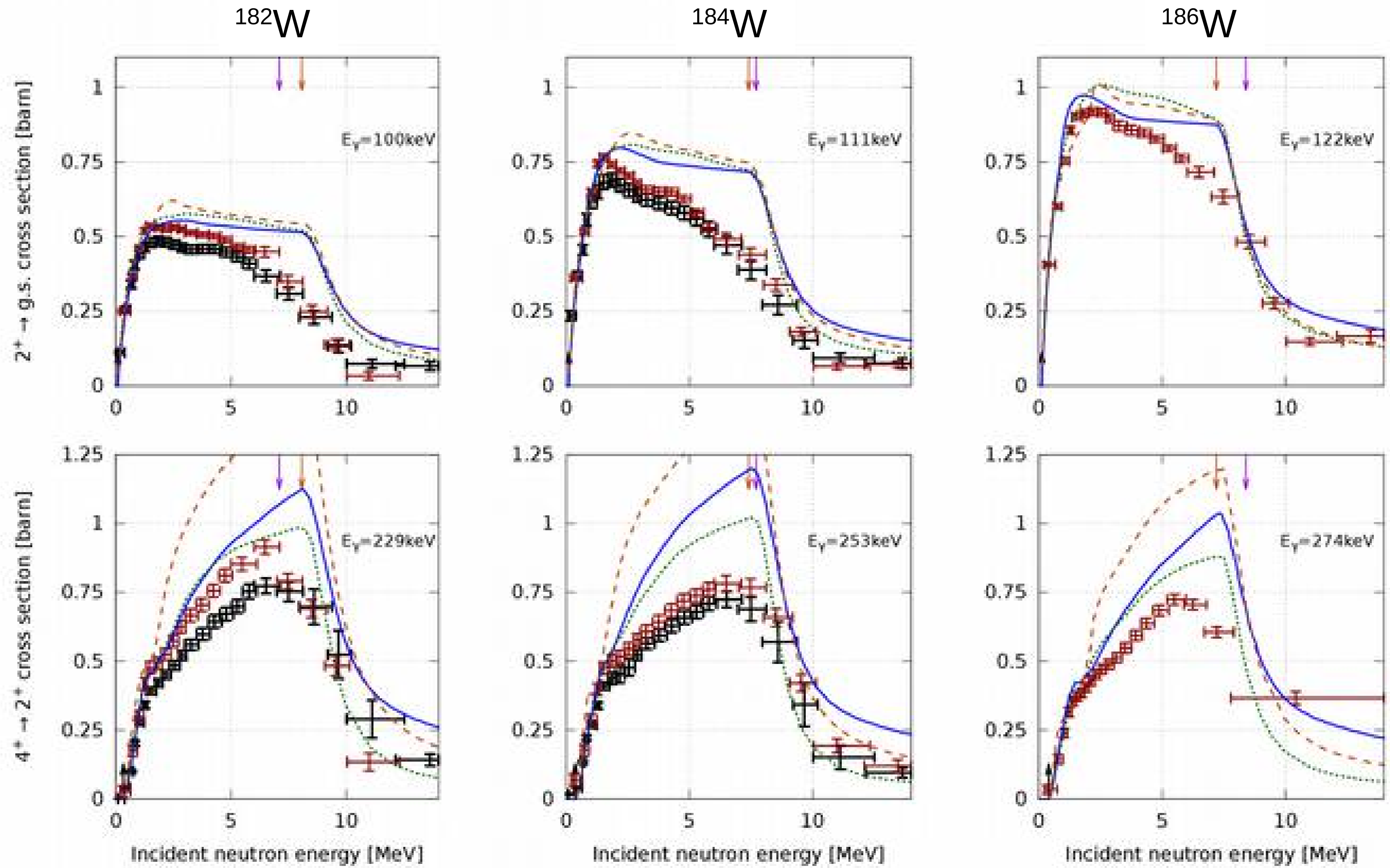
Transition cross sections

PRELIMINARY



Ground state rotational band

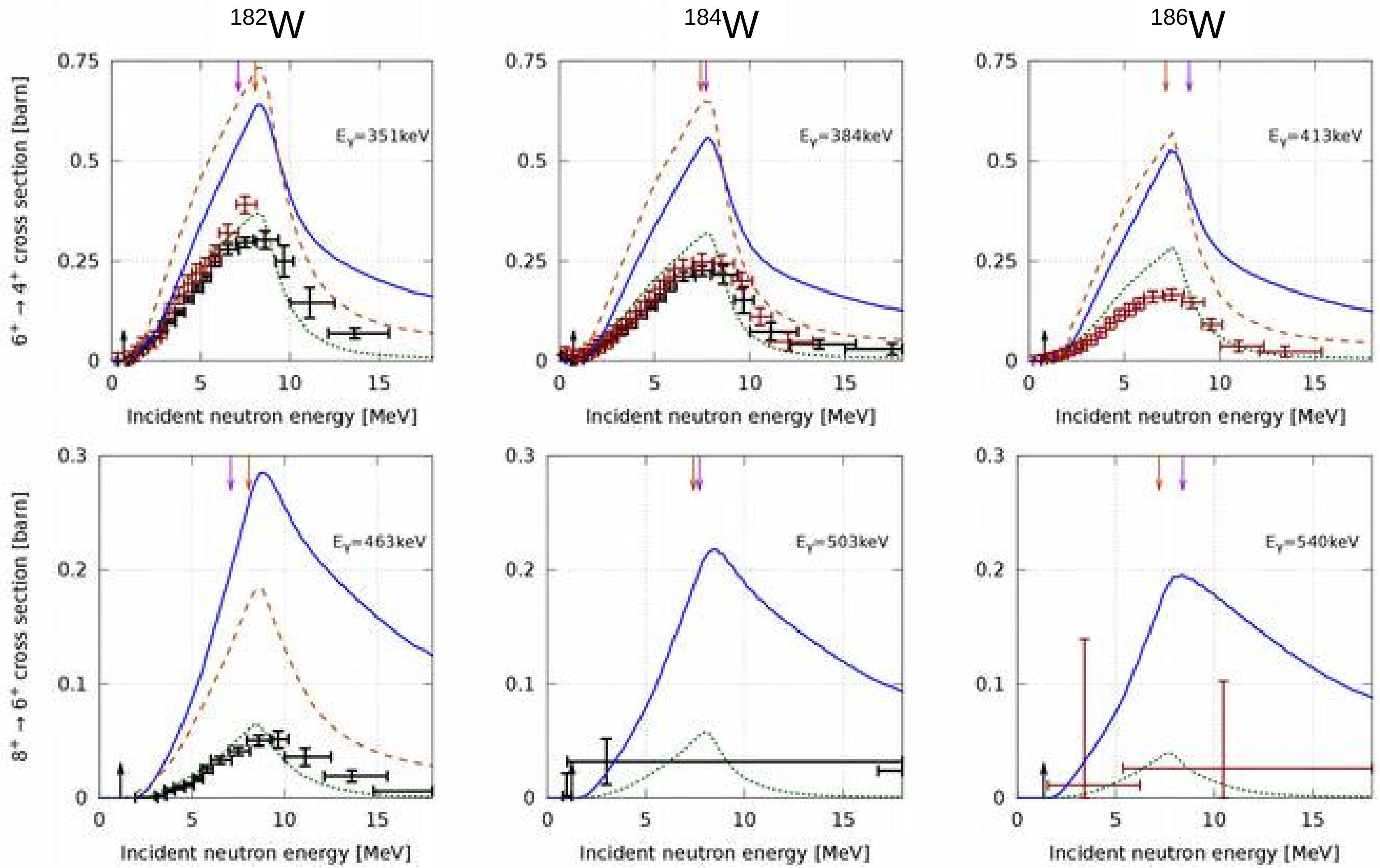
PRELIMINARY



+ : iso. Target,
+ natW target,
– TALYS-1,73,
··· CoH3,
- - Empire
↓ S_p, ↓ S_n,
↑ Lvl thresh.

Ground state rotational band (From higher spin states)

PRELIMINARY



+ : iso. Target,
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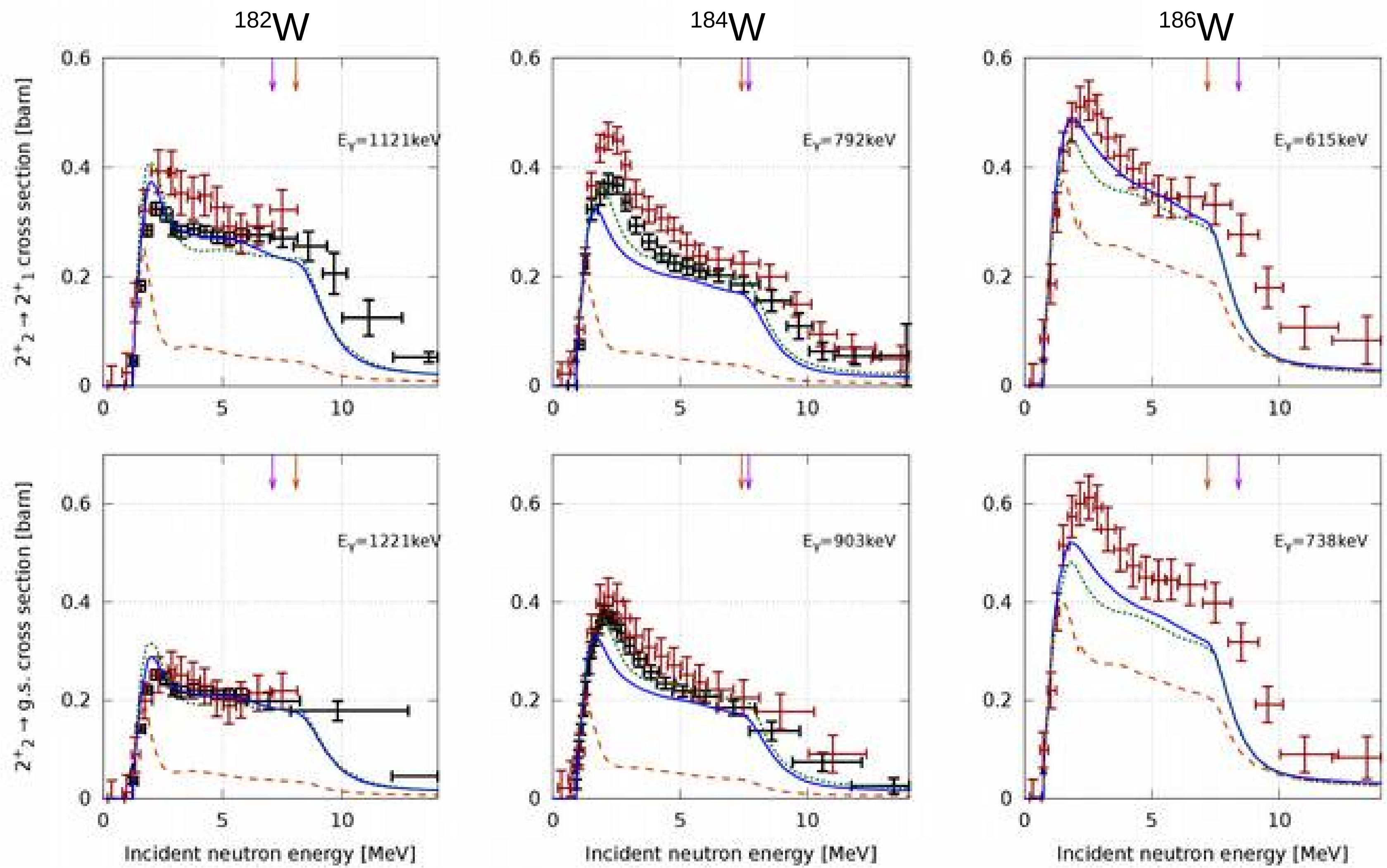
↓ S_p, ↓ S_n,
↑ Lvl thresh.

Interband transitions from γ band (2^+)

PRELIMINARY



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··· CoH3,
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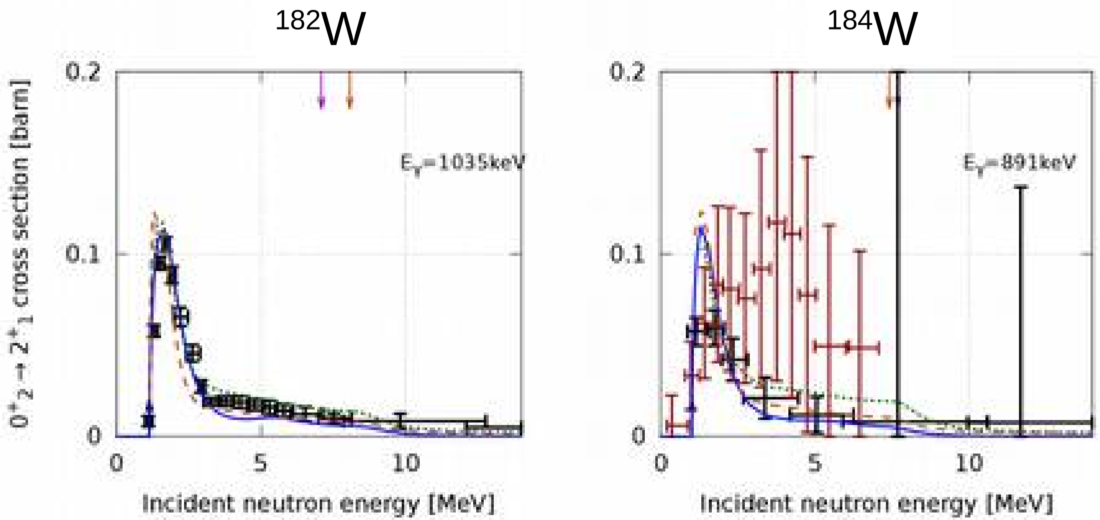
↓ S_p, ↓ S_n,
↑ Lvl thresh.

Interband transitions, from β band (0^+)

PRELIMINARY

$+$: iso. Target,
$+$ natW target,
– TALYS-1,73,
··· CoH3,
- - Empire
↓ S_p, ↓ S_n,
↑ Lvl thresh.



Models

PRELIMINARY

TALYS-1.73
- Optical potential and coupled channels.
- M1 modes in gamma-strength function.
- 30 discrete states.

P. Romain (CEA/DAM)

EMPIRE
- Not optimized yet for (n, xnγ).
- Phenomenological spin distribution model.
- Better coupling and structure needed.

R. Capote (IAEA)

CoH3
- Coupled-channels neutron optical potential.
- Deformation parameters taken from FRDM.
- Gilbert-Cameron level density.
- Pre-equilibrium spin distribution from FKK calculations.
- 70 discrete levels with levels inside the continuum.

T. Kawano, R. Capote, S. Hilaire, and P. Chau Huu-Tai
Phys. Rev. C 94, 014612

→ $2^+ \rightarrow$ g.s. transition shape is not right. Discrete level structure and/or experimental effect.

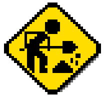
→ Fundamental rotational band: TALYS and EMPIRE overestimate transitions from high spin states.
CoH3, with microscopic calculation of spin distribution in the entrance channel, does not suffer this.

→ Overall agreement of data with both calculations within 2-3 standard deviation.

Conclusion and perspectives

Preliminary analysis on ^{182,184,186}W in ^{nat}W, ^{182}W and ^{184}W:

- TALYS, EMPIRE over estimates population of high spin states in the ground state band → Linked to spin distribution.
- Good agreement of data with calculations from TALYS, CoH3, less with EMPIRE (more work needed).
- No (n, 2nγ) data because of long lived isomers in odd mass isotopes.
- Extraction of structure independent level cross-section → Upper limit only.



Perspectives:

- 5 consistent data sets (^{nat,182,183,184,186}W) to analyze → cross check and normalization,
- About 20 transitions to study per isotope,
- Will produce a very rich and constraining set of experimental values to compare with the models.
- ^{183}W: great interest as a proxy for odd masses actinides (like ^{235}U).

Part of larger (n, xn γ) study program on isotopes from ^{7}Li to ^{238}U in collaboration with IRMM, IFIN-HH, CEA/DAM, CEA/DEN.

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