Advancements in nuclear data evaluations in the unresolved resonance region

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MOTIVATION

- **Overarching goal**
  - To generate nuclear evaluated data in the unresolved neutron resonance region (URR) for charged-particle outgoing reaction channels including fluctuating behaviour of measured data
- **Assumptions**
  - Expanding current capabilities, e.g. SAMMY and ENDF (and/or GNDS) format
  - Avoiding overly complicated nuclear reaction modeling
  - Efficient evaluation procedure to optimally describe measured data, e.g. fluctuations
- **Current procedure**
  - URR analyses are performed below the inelastic reaction channel's threshold
  - Evaluated data can be reported as energy-dependent average resonance parameters or (related) average cross sections
  - Although URR reaction codes can include (n,$n_{0,1,2,\ldots,n}$) channels, ENDF-format only defines a competitive reaction channel and rudimental description of covariance information

REACTION MODELING AND PROPOSED UPDATES

- The URR reaction modeling implemented in the SAMMY tool system is based on the Hauser-Feshbach (HF) theory with width fluctuation corrections
- The essential parameters are the channel pole strengths s_c closely related to the particle-channel (neutron) transmission coefficients*

$$T_c = 1 - |\bar{U}_{cc}|^2 = \frac{4\pi s_c P_c}{|1 - \bar{R}_{cc} L_c^0|^2},$$

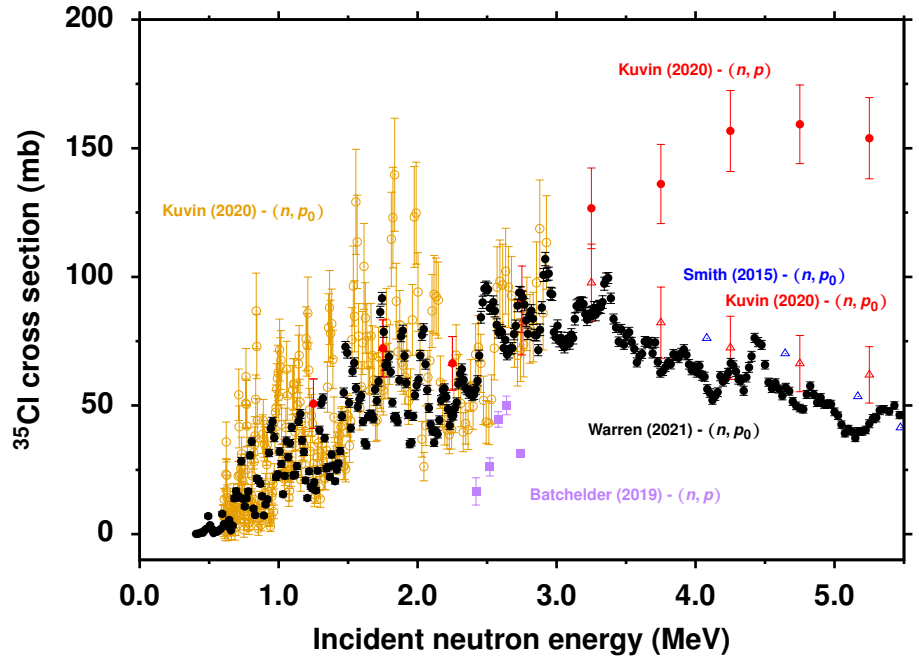
with $\bar{R}_{cc} = R_c^\infty + \imath\pi s_c$ and $L_c^0 = S_c + \imath P_c - B_c$.

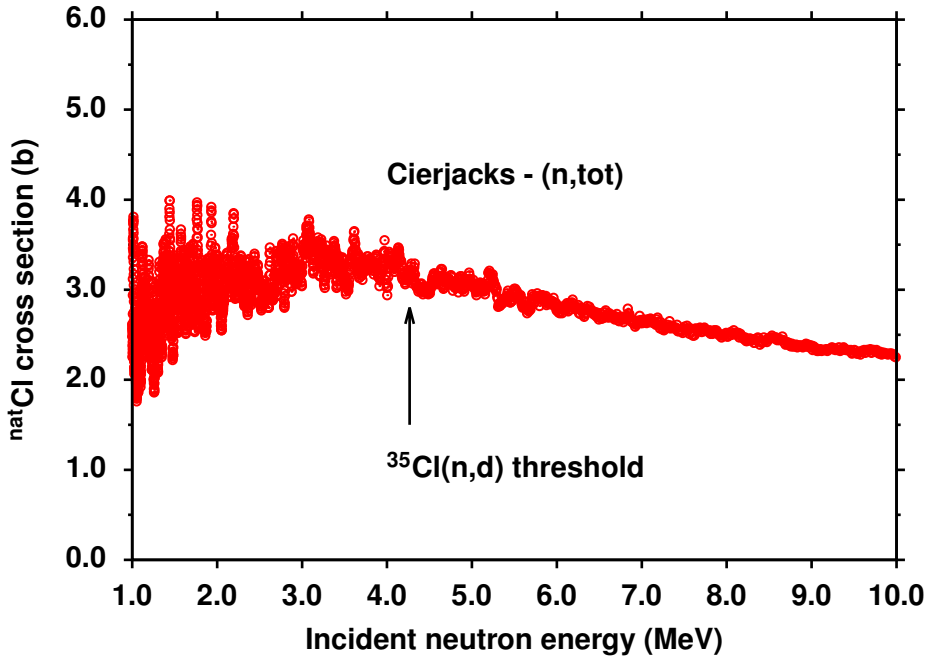
- Expanding SAMMY capabilities
  - Inclusion of particle-channel T_c for charged particles such as proton and α-particle
  - Inclusion of strength functions for inelastic channels

If average resonance parameters ought to be reported, updates to ENDF-format are also needed

*Photon and fission transmission coefficients are defined as $T_\gamma = 2\pi\bar{\Gamma}_\gamma/D_c$ and $T_\mathrm{f} = 2\pi\bar{\Gamma}_\mathrm{f}/D_c$ for an average level spacing D_c.

EVALUATION CASES: MEASURED DATA





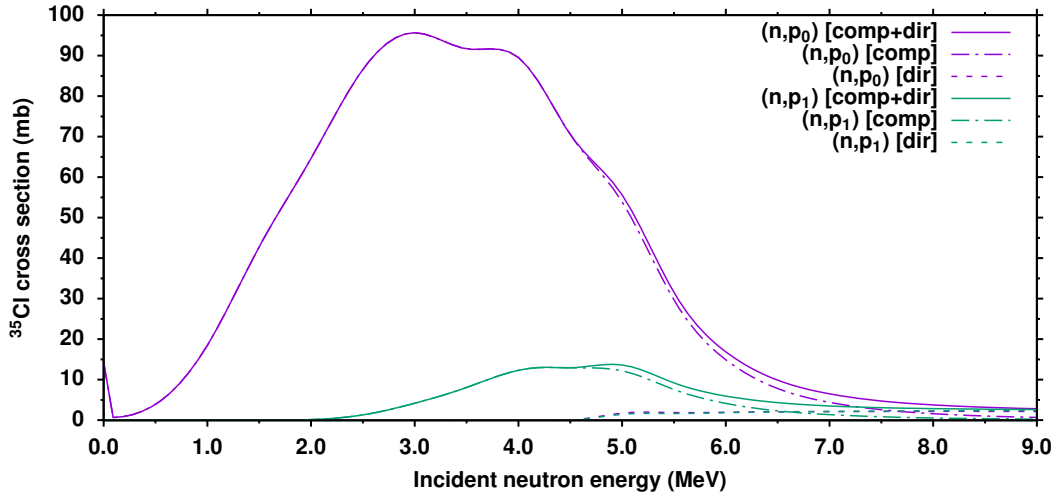
Fluctuating measured data available for (n,tot) and (n,p) channels. E=4.266 MeV, coinciding with the ^{35}Cl(n,d) threshold, looks like a good energy for the transition from URR to fast neutron range

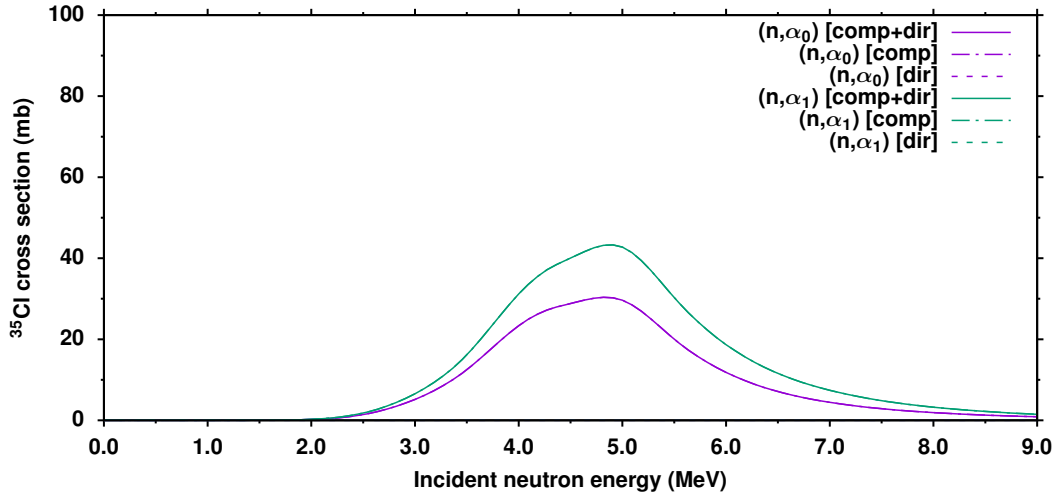
EVALUATION CASES

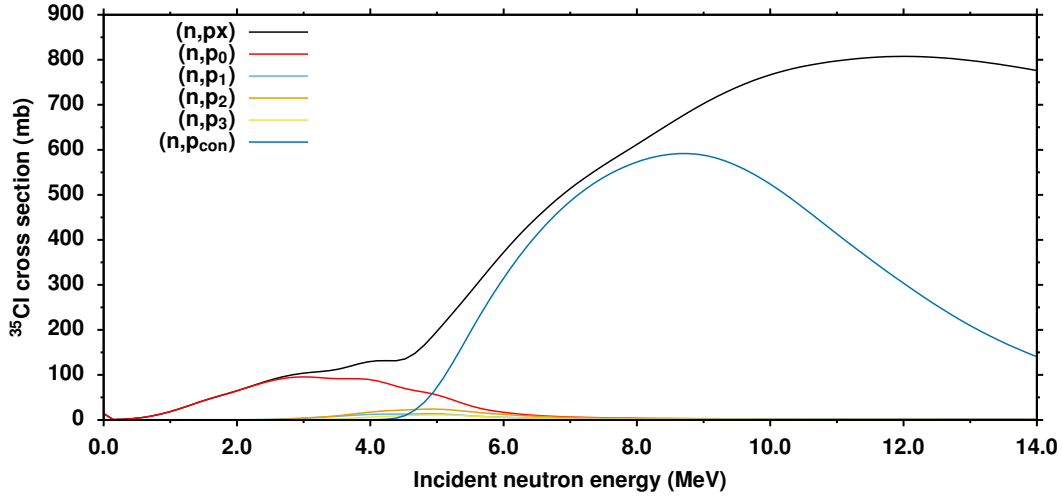
- The recently released n+^{181}Ta evaluation was confronted with the limitations of the ENDF format's particle-channel formalism. The current format cannot include the inelastic channel contribution for average resonance parameters
- ENDF-format limitations are also evident for n+^{35}Cl reactions
  - (n,p_0) and (n,α_0) reaction channels with fluctuating behavior energetically possible for any incident neutron energy
  - (n,$p_{1,2}$) and (n,$\alpha_{1,2}$) also to be included up to about 4.3 MeV

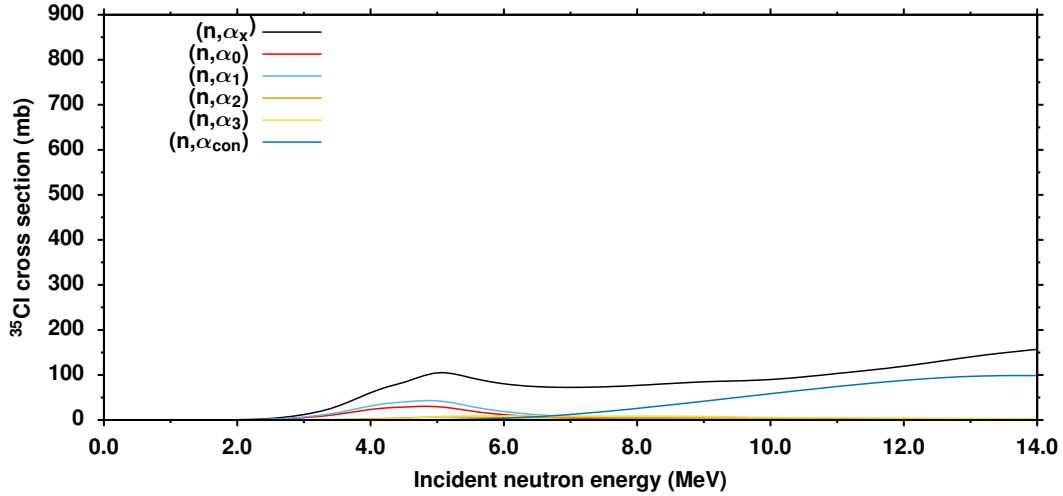
Reaction	Q-Value (MeV)	E_{thr} (MeV)
^{36}Cl+γ	8.59598	0.00000
^{32}P+α	0.93775	0.00000
^{35}S+p	0.61503	0.00000
^{35}Cl+n	0.00000	0.00000
^{34}S+d	-4.14625	4.26591

URR UPPER ENERGY LIMIT FOR ^{35}CL: 4.266 MeV









URR UPPER ENERGY LIMIT FOR ^{35}CL: 4.266 MeV

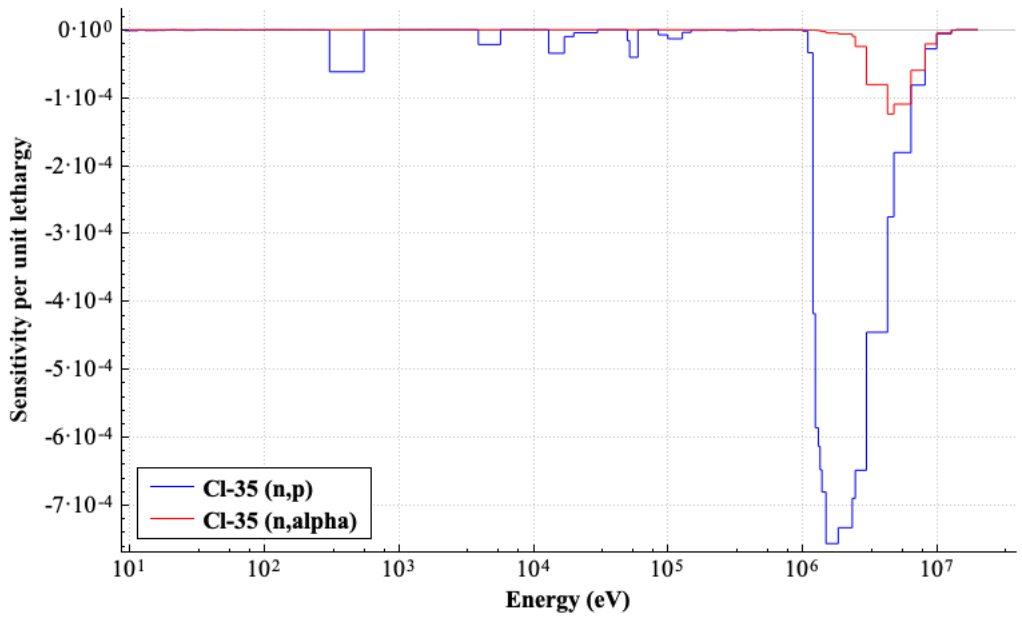
The ^{35}Cl(n,d) threshold is a good upper energy limit for the URR because

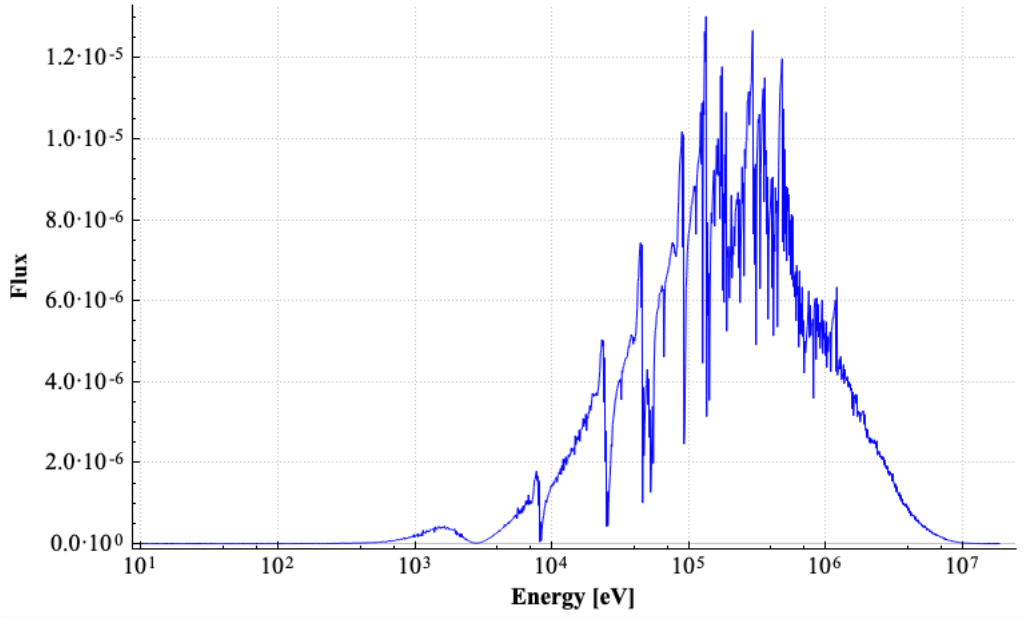
- The direct contribution to (n,p) and (n,α) cross section is negligible (upper plots on slide 6)
- The (n,p) and (n,α) contributions from the continuum is negligible (bottom plots slide 6)

- **Overall evaluation strategy**
  - RRR up to 1.2 MeV
  - URR up to 4.3 MeV
  - Inclusion of fluctuations of newly measured (n,p) and (n,α) data
  - Estimates of strength functions and level spacings for proton and α-particle reactions

SENSITIVITY AND FLUX PROFILES

SCALE/TSUNAMI calculations performed with TerraPower's Molten Chloride Fast Reactor Demonstration (MCFR-D) design[†]





Sensitivity profile for (n,p) and (n,α) confirms the importance of nuclear data (i.e. cross section) in the neutron energy range between 1–5 MeV!

[†]M. Wargon, M. Latkowski, T. Cisneros (2023). Representative Neutronics Models of MCFR Reactors. 10.13140/RG.2.2.15127.55208.

CONCLUSIONS

- Minimal updates to current capabilities (SAMMY/AMPX) and to the ENDF format are proposed to include threshold reaction for outgoing charged-particle channels in the URR formalism
- If average resonance parameters are reported, probability tables for newly defined reactions channels may be needed, implemented, and tested
- Nuclear data evaluation of n+^{35}Cl reactions can be considered the best case to apply the proposed updates
  - Chlorine is relevant for several advanced nuclear reactor designs such as the MCFR recently developed by TerraPower
  - (n,p) and (n,α) reaction channels are energetically available
  - The proposed upper energy limit of about 4.3 MeV, coinciding with the threshold of the ^{35}Cl(n,d) reactions, for the URR is consistent with sensitivity profile from SCALE/TSUNAMI calculations
  - From 4.3 MeV up to 10 MeV the number of energetically available channels is more than double and, therefore, the nuclear data may strongly rely on model calculations with corresponding large uncertainties

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Thank you!