Los Alamos NATIONAL LABORATORY

The LANL-TerraPower ^{35}Cl: Covariances & ENDF/B-IX

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Outline:

- Evaluated covariances for chief n + ^{35}Cl channels
- Preliminary extension to ^{37}Cl
- Final formatting & looking ahead to ENDF/B-IX

LA-UR-24-28548

Motivation & Methods (Refresher)

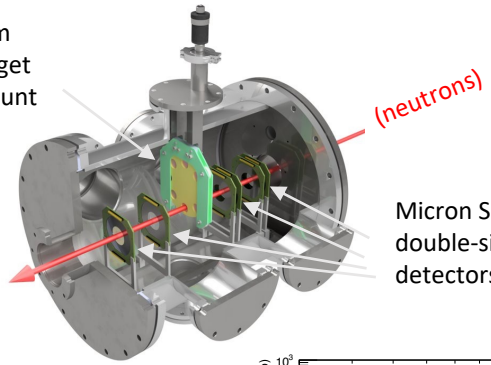
>> ^{35}Cl(n,p) evaluation in desperate need of updating (esp. for molten salt fast reactor designs)

>> LANL partnered with TerraPower for both new measurements & subsequent re-evaluation (DOE GAIN)

>> (n,p) and (n,α) measurements performed at LANSCE using the LENZ instrument @ WNR (unmoderated neutrons ~ "fast" spectrum)

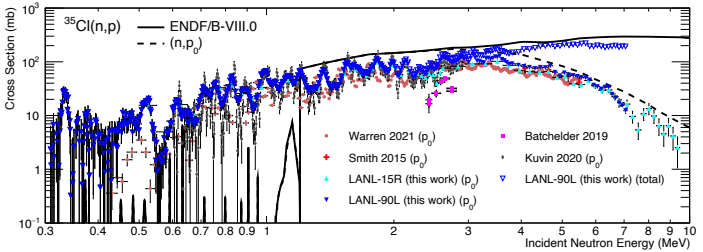
>> Statistical (Hauser-Feshbach) part of analysis updated using code CoH_3

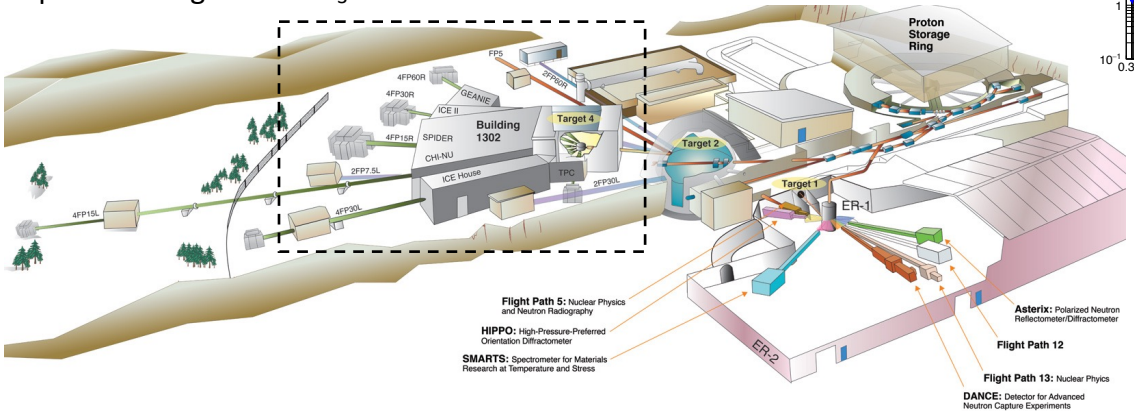
The LENZ Instrument @ WNR

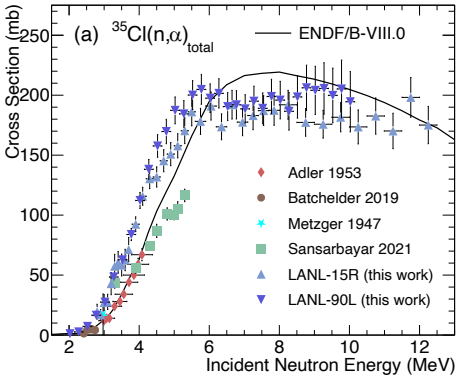


Micron S-type (annular) double-sided silicon detectors (DSSDs)

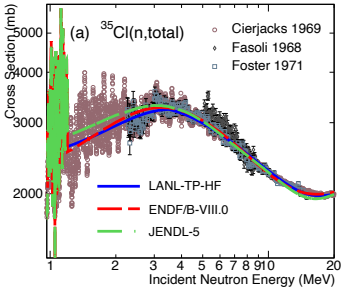
T. Kawano, Eur. Phys. J. A **57** (2021)

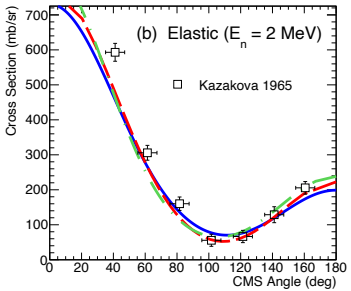


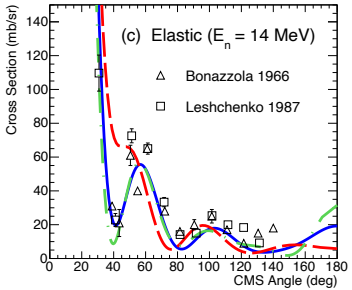




Summary of Key Channels



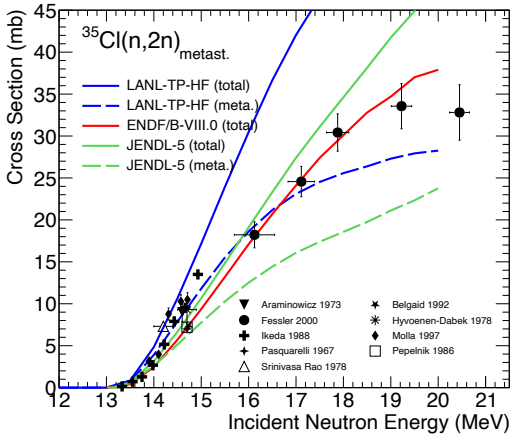




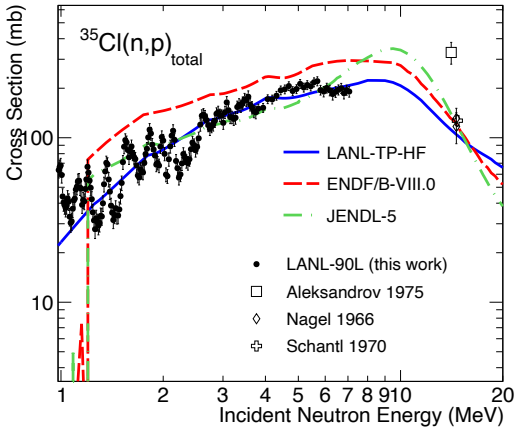
Most noteworthy findings:

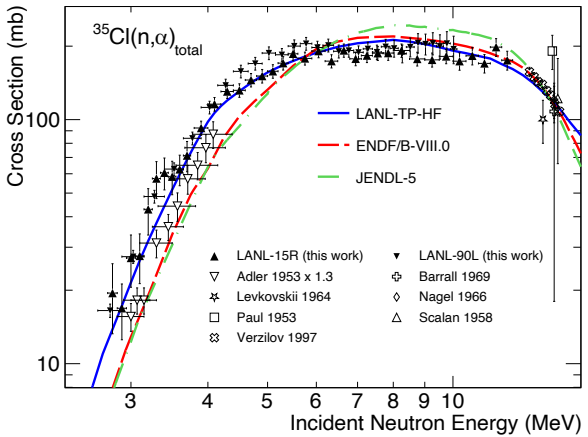
→ (n,p) <u>reduced</u> by ~50% compared to ENDF/B-VIII.0
→ (n,a) *increased* by a similar amount along leading edge
→ previous (n,2n) calculations apparently tuned to metastable data
→ large (150%) pre-equilibrium adjustments needed for highest E

* Lack of good *inelastic* data, which would be key for future improvements



(finer details in **imminent** PRC paper...)





Summary of Key Channels

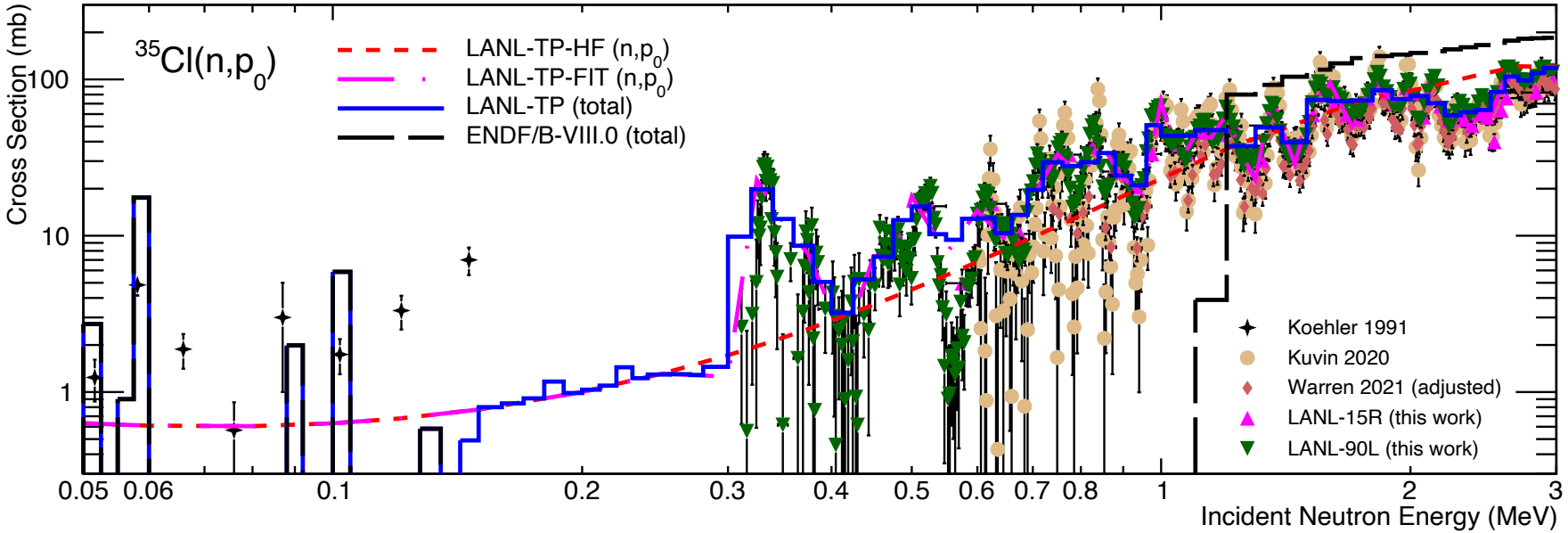
Final solution to (n,p0) fluctuations:

>> tweak H-F manually to represent average

>> coarse, least-squares fit of data to capture macroscopic features

>> extend below 1.2 MeV to ~140 keV & add as “background” to resonance analysis

>> uncertainty of method on same order as Kalman analysis (following)



Covariance Generation: Kalman Filter

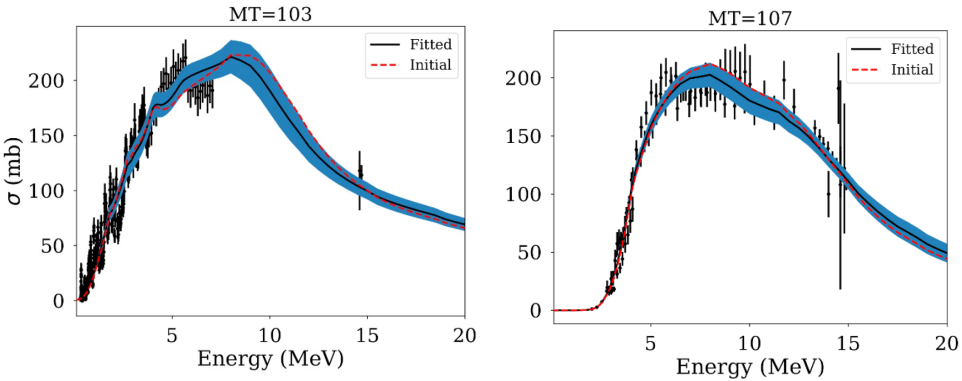
Method similar to that in M. E. Rising et al., Nuc. Sci. & Eng., 175:1, 81-93 (2017)

First-order approach (derived from Bayes's theorem)

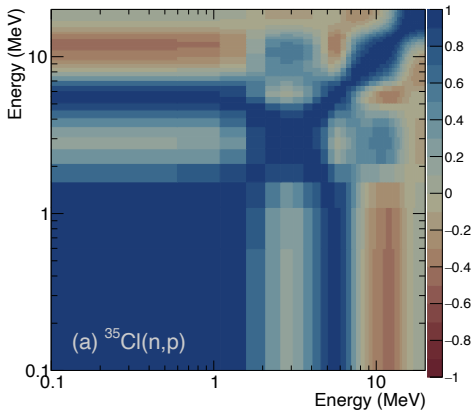
- assumed 20% energy corr's per data set
- NO cross-channel or cross-experiment

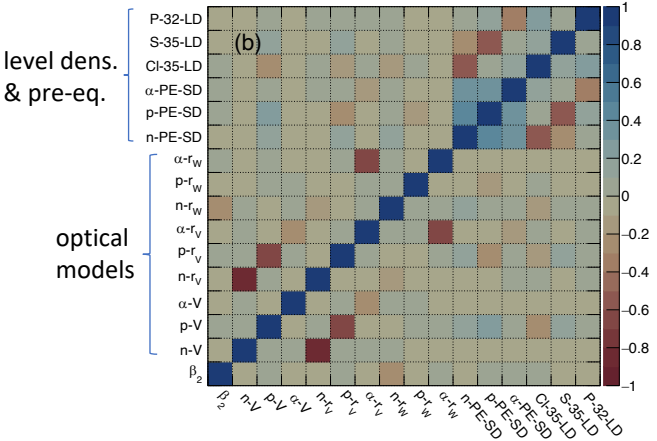
>> take manually tuned "prior" calculations as input
>> establish pre-set model parameter uncertainties
>> run the filter with select data sets (& weights)
>> check if posterior and prior calculations are within uncertainty
(if NOT, tweak prior calc or data weights & iterate)
>> apply posterior (relative) uncertainties to prior calculations

Examples:



Example Correlations

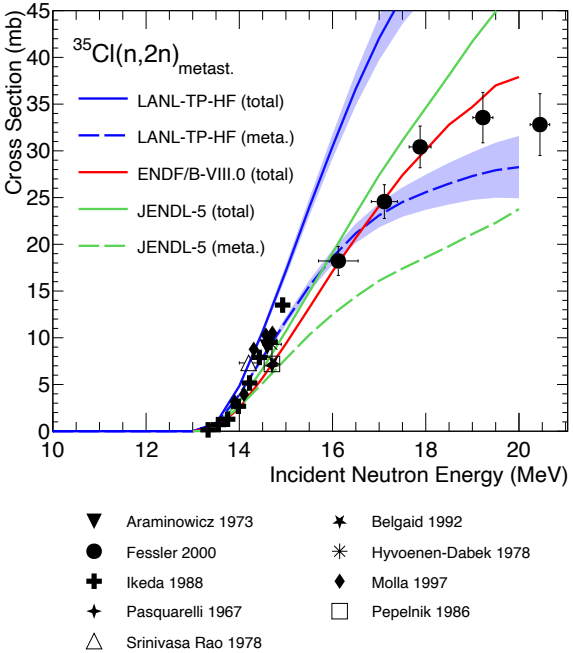


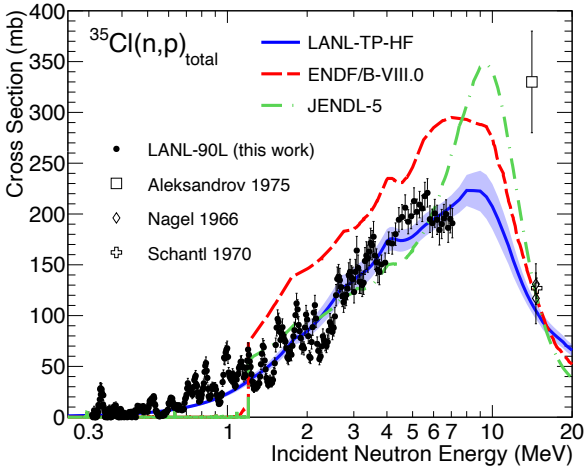


Covariance Generation: Kalman Filter

MF=33 generated for MTs: 1 2 4 16 102 103 107

Weighted preference given to data in TP energy range to control fit & produce more realistic uncertainties



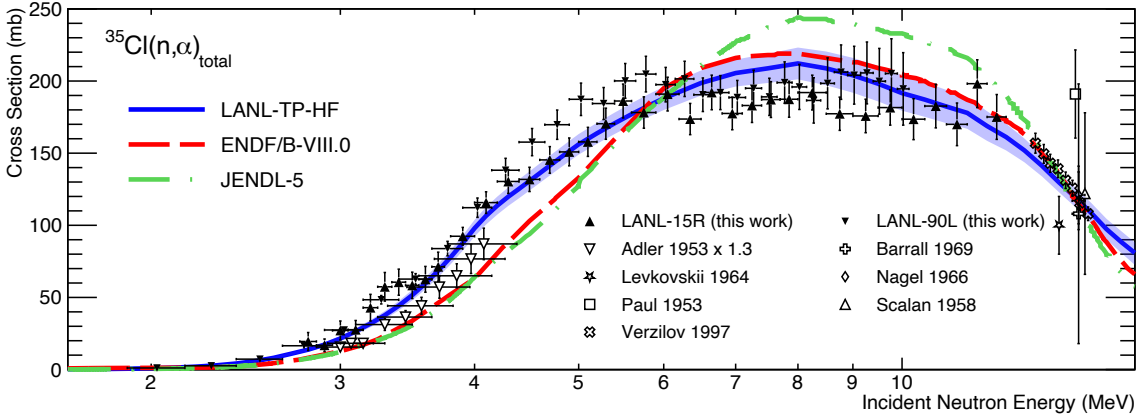


(n,p) uncertainty ~10-15% in TP's energy range

>> MCRE integral (reactivity) uncertainty reduced from >50% down to ~10%

>> reactivity itself increased by ~50% in latest TP estimations

(compared to estimates using ENDF/B-VIII.0)



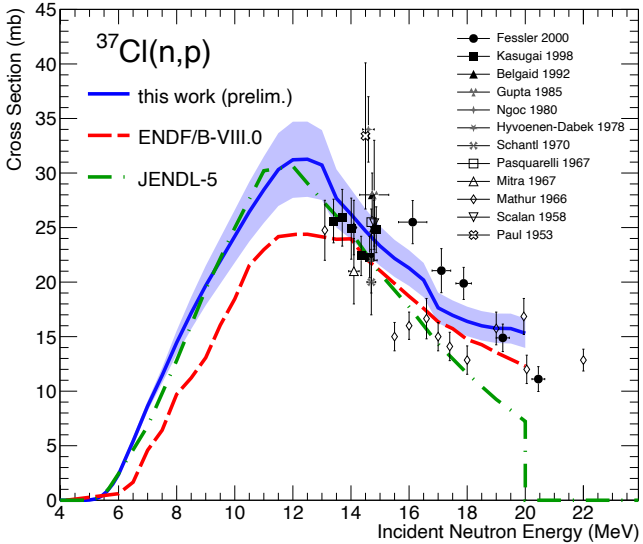
PRELIMINARY extension to ^{37}Cl

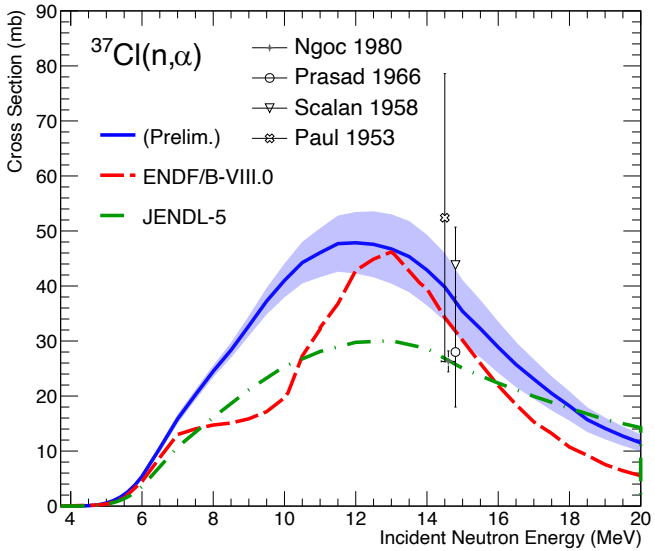
[n + ^{37}Cl data potentially impactful for **fusion systems**:
T. D. Bohm and B. A. Lindley, Fus. Sci. & Tech. 79, 995 (2023)]

Experimental data for ^{37}Cl are much poorer

Decided to fit in a "perturbative" way to ^{35}Cl, for now:
→ include both isotopes in same filter, but fit ^{35}Cl first
→ then fit ^{37}Cl with reduced weights relative to ^{35}Cl (~20%)
→ also remove clear outliers (many)

(Therefore ^{35}Cl results remain ~unchanged)





>> Multi-isotopic evaluations key for more consistent results (esp. uncertainties)

>> More data measurable with LENZ & being considered for future run-cycles

Summary of Results & Formatting (compared to ENDF/B-VIII.0)

Processed with DeCE code by T. Kawano
https://github.com/toshihikokawano/DeCE

- Modified:

  >> MF=3 (all MT), MF=4* (MT=2), MF=6 (non-elastic channels)

  *elastic ang. dist's now calculated from resonance param's – less asymm. on avg.

- Replaced:

  >> MF=12,14,15 (photon prod. & spectra; now contained in MF=6,MT=102)

- Untouched:

  >> MF=2,32 (resonance parameters & cov's) -- ORNL R-matrix (Sayer 2007)

- Brand New:

  >> MF=33, MF=8,10 for $(n,2n)_m$ (MT=16) information

Future Work & ENDF/B-IX...

All ^{35}Cl-specific work presented so far is **accepted in PRC** (publishing imminent), available on the **NNDC GitLab** (branch: ENDF/library/neutrons/saved_for_after_VIII.1), and intended for inclusion in **ENDF/B-IX**

→ GitLab version “LANL-TP” passed through TP-led peer review process

Preliminary new ^{35}Cl(n,p) data have been taken with LENZ from *thermal* energies up to ~500 keV, using the moderated neutron source at the Lujan Scattering Center (NNDC)

→ several known resonances reproduced, with coverage in the currently data-less 140-300 keV region
→ when all planned measurements completed, will further inform low-energy parts of statistical analysis AND provide for a potential update to the resonance component of the cross section **(IX?)**

Covariance methods continually under investigation, with an eye toward mitigating underestimation **(IX)**

→ this includes the prelim work on ^{37}Cl, which “could” be part of the ENDF/B-IX package with ^{35}Cl...

New LANSCE measurements on other relevant channels and isotopes are under discussion **(IX?)**, e.g.:

>> ^{37}Cl(n,p) & (n,α) with LENZ @ WNR
>> $^{35/37}$Cl(n,n’g) with COGNAC @ WNR
>> $^{39/40/41}$K(n,Z) with LENZ @ WNR

THANK YOU – QUESTIONS?

ACKNOWLEDGEMENTS

Voucher NE-22-28590: Chlorine Nuclear Data Measurement and Evaluation

POC: Tommy Cisneros

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Thanks to those who participated in the TerraPower-led peer review of the preliminary evaluation, esp. **M. Pigni** (ORNL); **L. Bernstein & T. Nagel** (UCB); **J. Warren, A. Voinov, & C. Brune** (Ohio U); **J. Praena** (n-TOF/U Granada).

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