Update on New ^{35}Cl(n,Z) Fast Reaction Measurements to Guide Data Evaluation

Kenneth Hanselman (khanselman@lanl.gov)
Sean Kuvin
Hye Young Lee
P-3 Nuclear and Particle Physics and Applications
Toshihiko Kawano
T-2 Nuclear and Particle Physics, Astrophysics and Cosmology
Tommy Cisneros
TerraPower LLC

Outline:

- Why ^{35}Cl
- Summary of New Data
- Prelim. Evaluation & Testing

LA-UR-23-32833

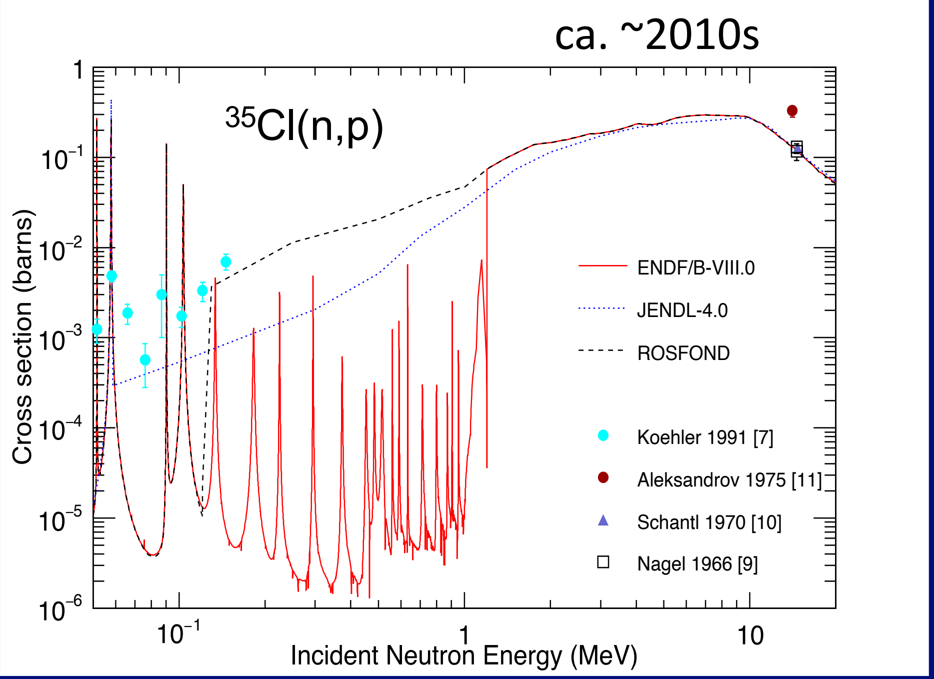
>>> CSEWG 2023 – BNL <<<

Why ^{35}Cl?

(~100s keV – few MeV)

- ^{35}Cl(n,p)^{35}S is dominant in fast-spectrum molten salt reactors (chloride salts = coolant)
  - → significant changes in reactivity (thousands of pcm) between ENDF/B versions
  - → long-lived contaminant: ^{35}S ($T_{1/2}$ ~ 75 days)
- Also important for CLYC detector efficiency & characterization
  - → Main contributer to fast energy sensitivity (~3-4 MeV)

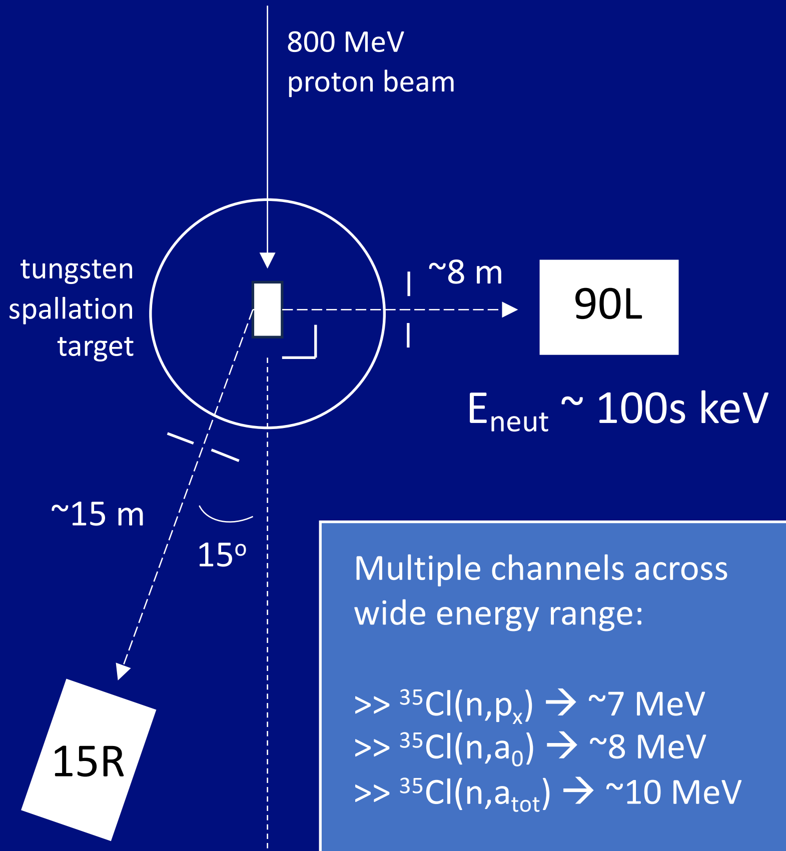
As of ENDF/B-VIII.0:
> RRR: R-matrix at ORNL (R. O. Sayer et al. 2007)
> Statistical: GNASH by P. Young (LANL 2000)



- Previous evaluations did not have sufficient experimental data from 100 keV to 14 MeV
  → unphysical "jump" around 1.2 MeV
- Many experiments since (including at LANL) able to bridge this gap
- New STATISTICAL part of evaluation performed at LANL in conjunction (CoH_3)

Experimental Overview

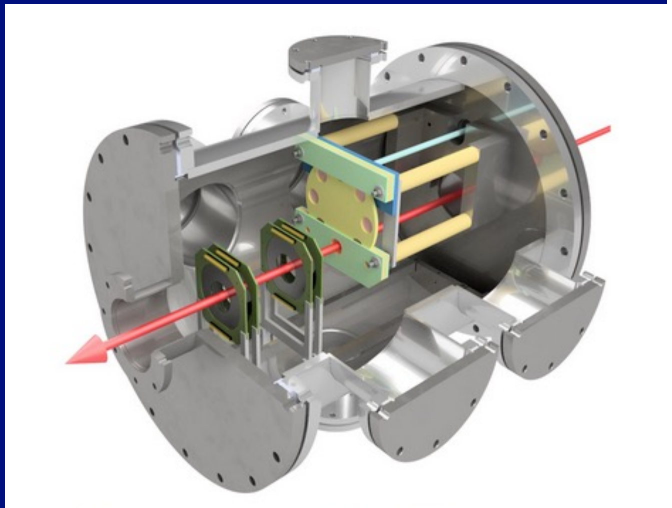
(Funded by GAIN voucher + CRADA with TerraPower LLC)

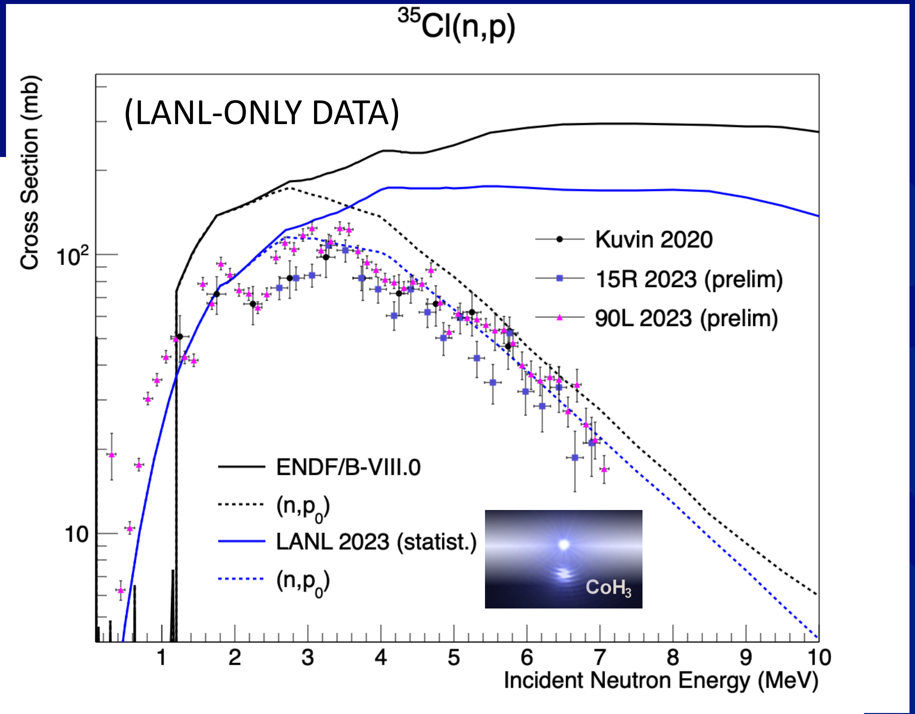


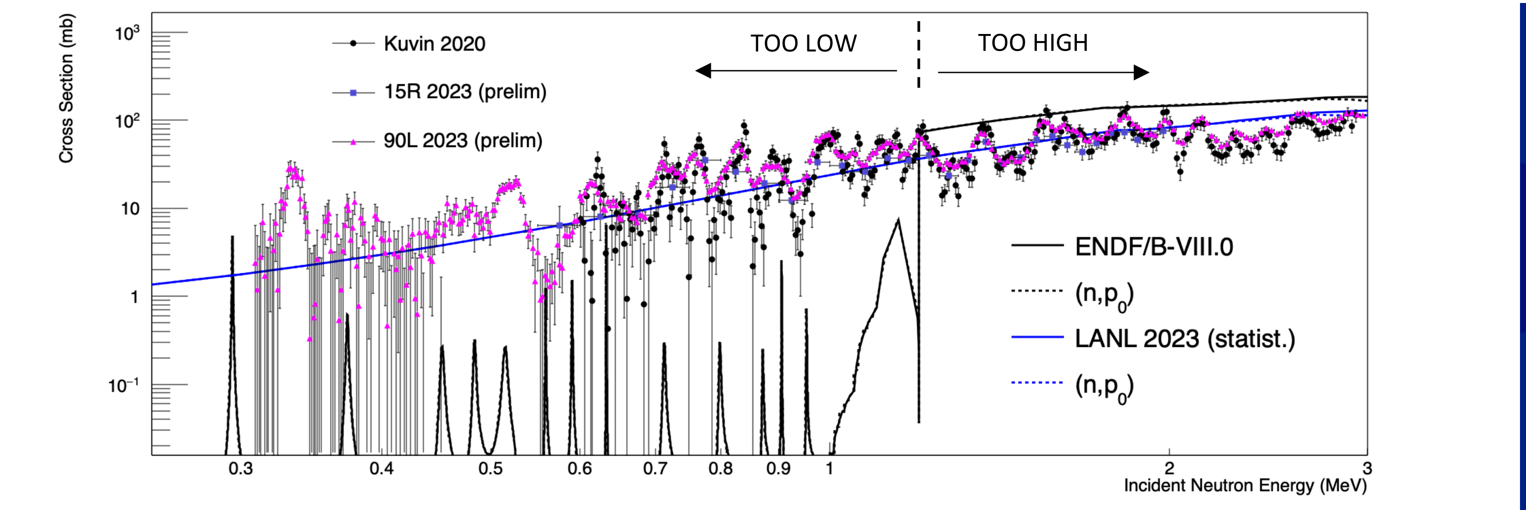
E_{neut} ~ few MeV

(LENZ-focused energies)

LENZ: Low-Energy (n,Z)







Multiple channels across wide energy range:

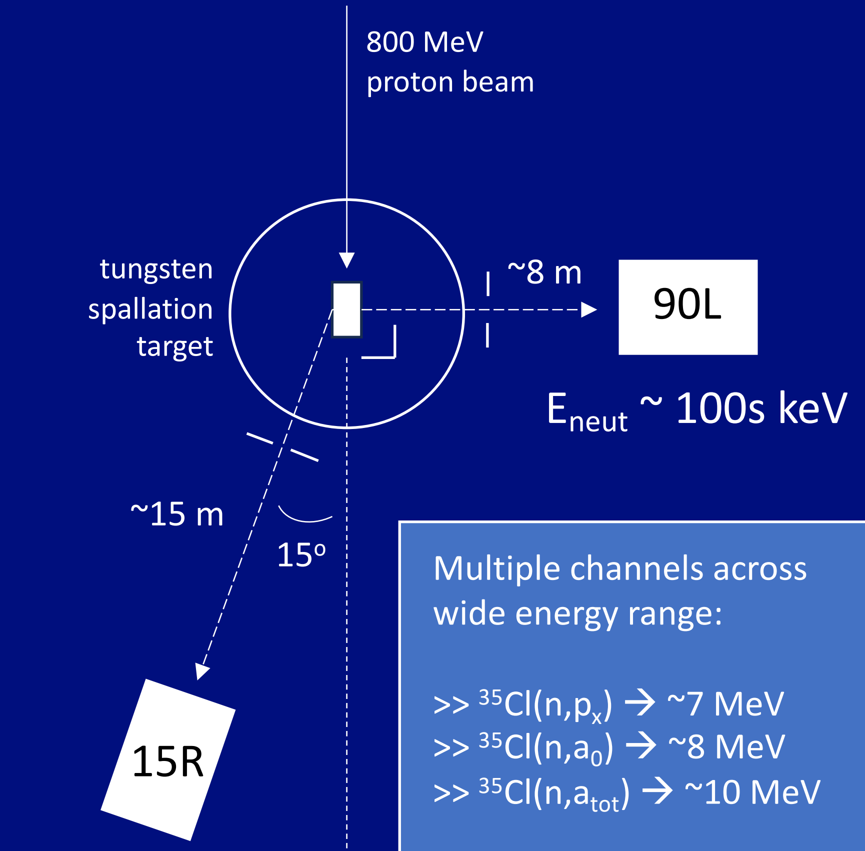
>> ^{35}Cl(n,p$_x$) → ~7 MeV
>> ^{35}Cl(n,a$_0$) → ~8 MeV
>> ^{35}Cl(n,a$_{tot}$) → ~10 MeV

*more in progress up to ~14 MeV...

Experimental Overview

(Funded by GAIN voucher + CRADA with TerraPower LLC)

LENZ: Low-Energy (n,Z)

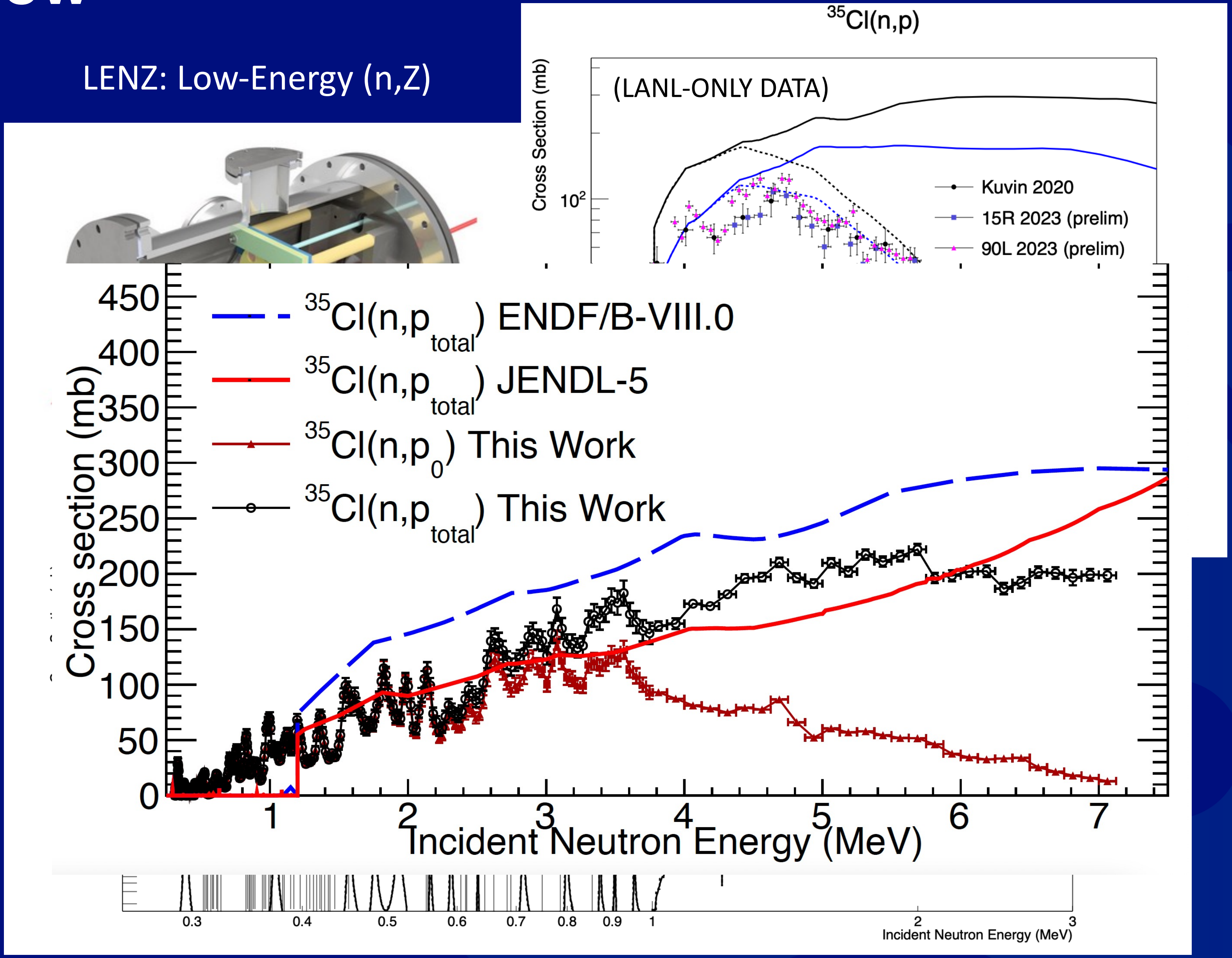


(LENZ-focused energies)

Multiple channels across wide energy range:

>> $^{35}Cl(n,p_x)$ → ~7 MeV
>> $^{35}Cl(n,a_0)$ → ~8 MeV
>> $^{35}Cl(n,a_{tot})$ → ~10 MeV

*more in progress up to ~14 MeV...

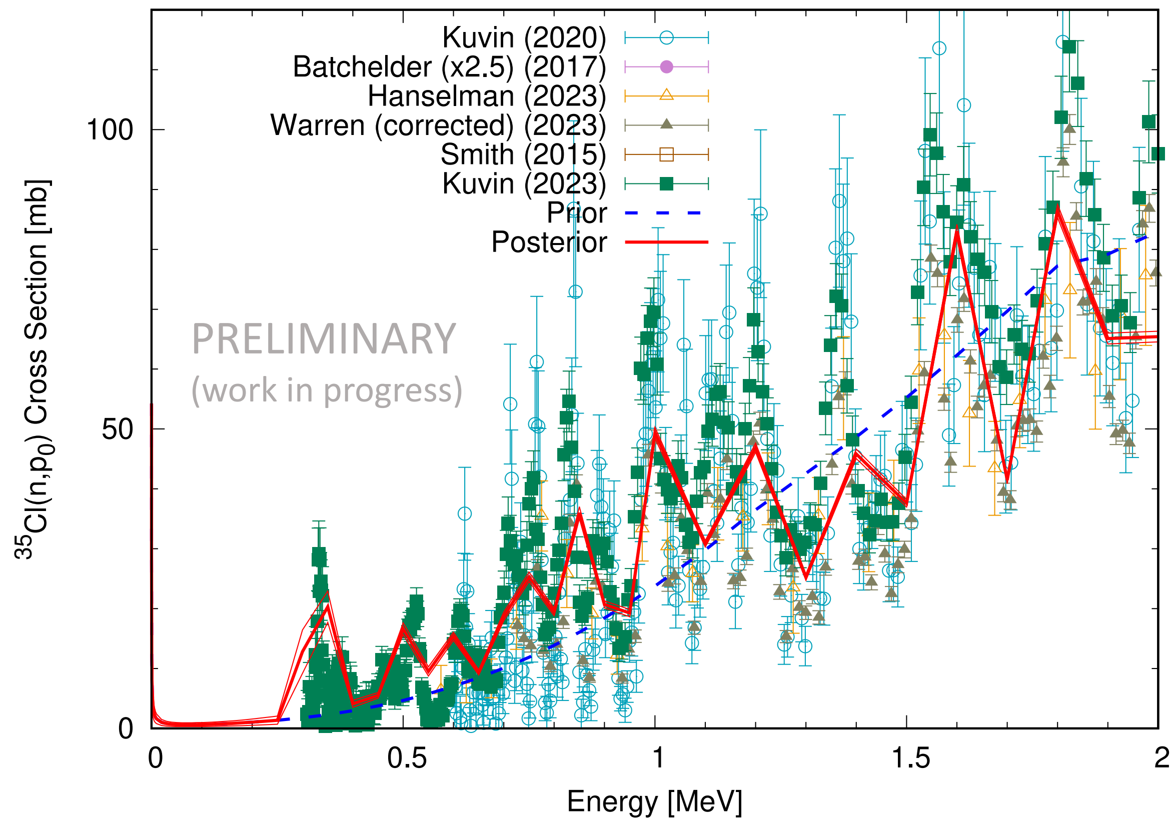


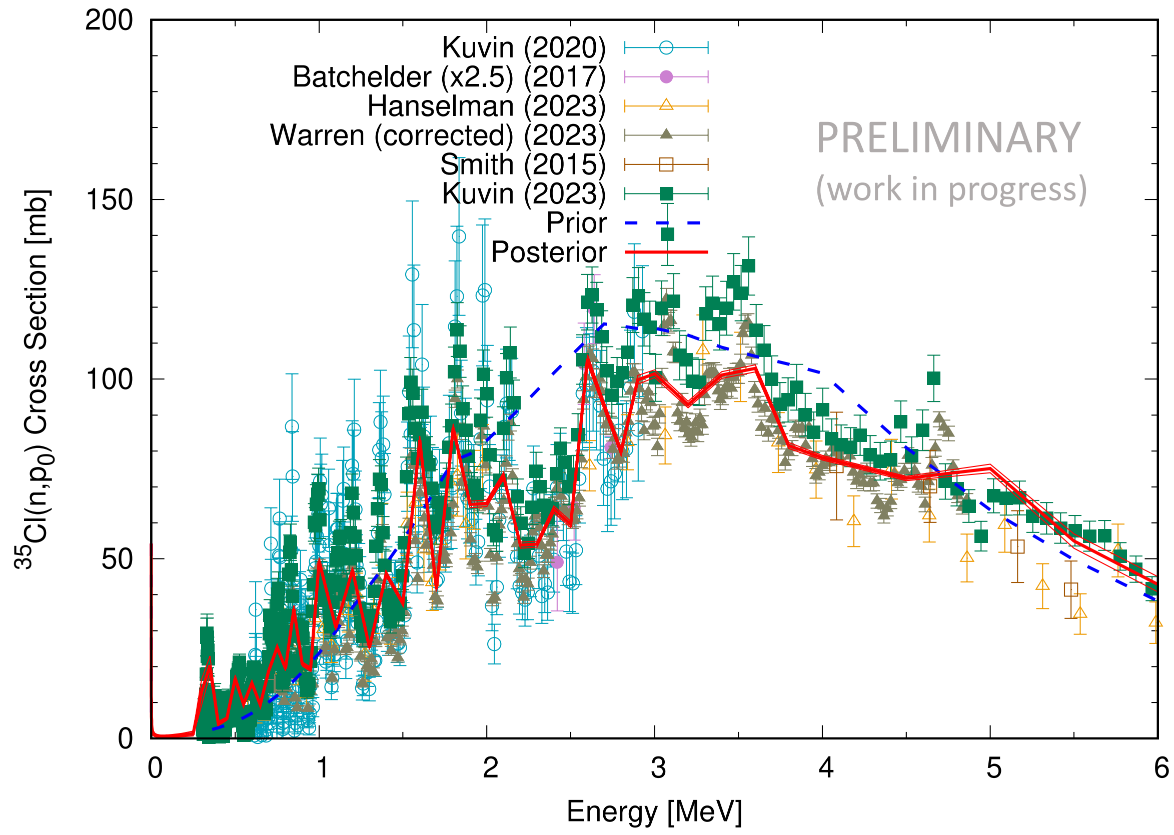
Current Working Evaluation

(anticipating new data from Ohio, Berkeley, & U. Mass Lowell as well)

→ on ALL available data (some tweaks)
→ including higher-energy (>10 MeV) channels – e.g. (n,2n)
→ blend current RRR analysis with new statistical

* try to capture all "macroscopic" features
(e.g. large dip around ~2.3 MeV)





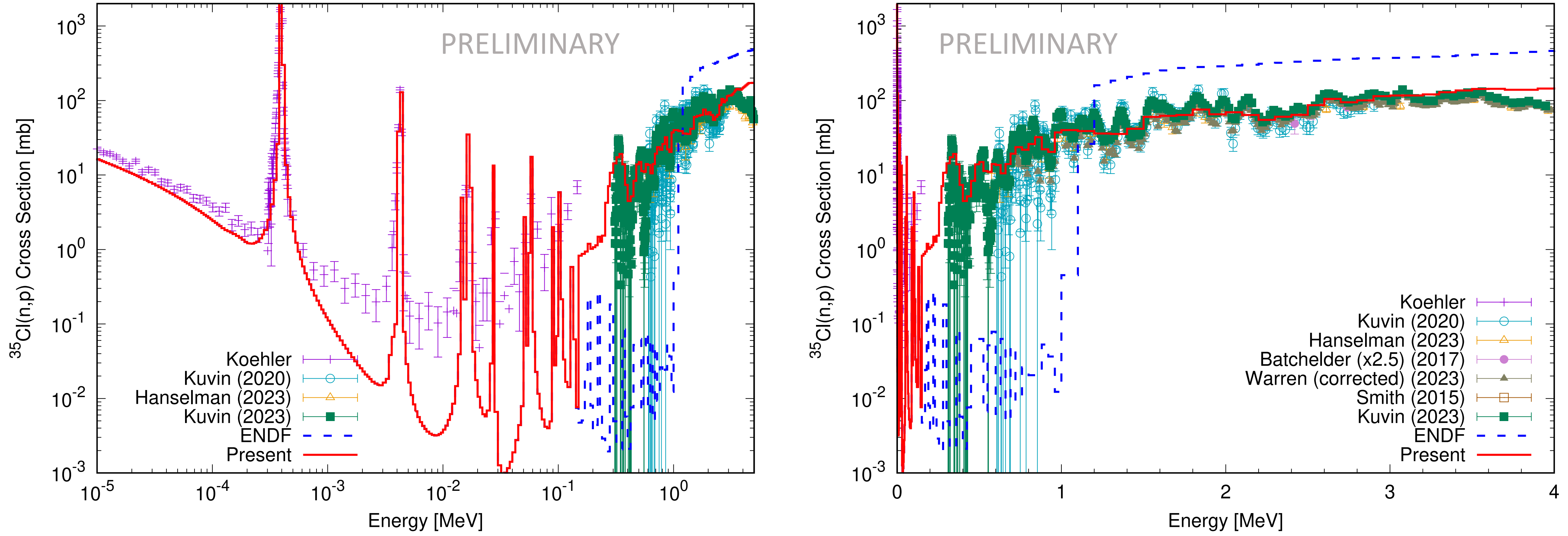
Current Working Evaluation

(anticipating new data from Ohio, Berkeley, & U. Mass Lowell as well)

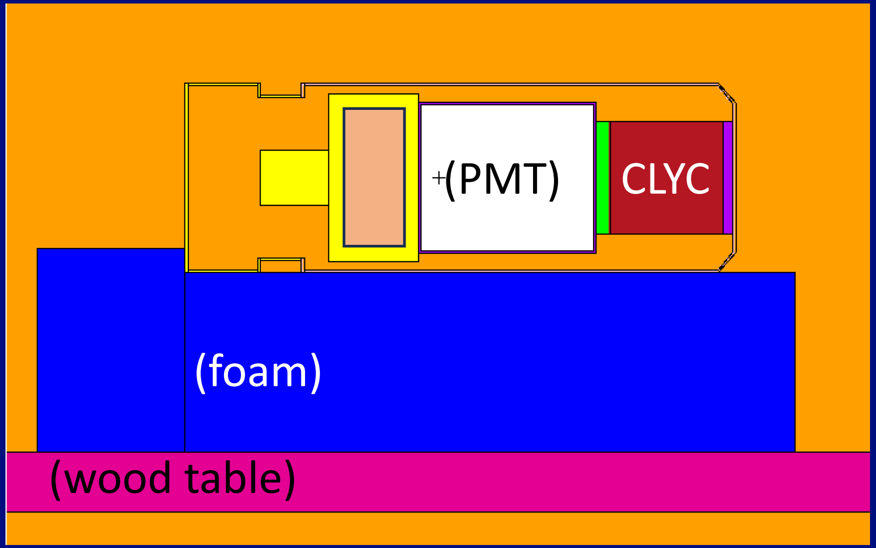
→ on ALL available data (some tweaks)
→ including higher-energy (>10 MeV) channels – e.g. (n,2n)
→ blend current RRR analysis with new statistical

More “continuous” now between 0.1-1 MeV region

(group cross sections)

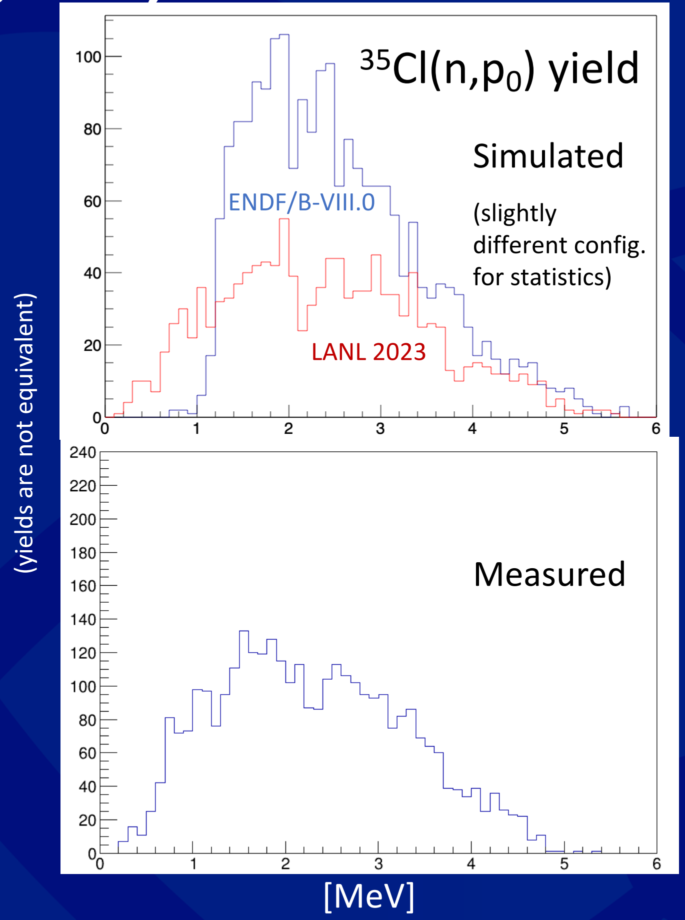


IN-HOUSE VALIDATION: measurement & simulation of CLYC (Cs_2LiYCl_6:Ce) detector



- ^{7}Li-enriched 1.5"x1.5" CLYC
- 1 m away from ^{252}Cf source (n-fluence shape ~ TP reactor)
- ~4 days of data collection
- simulated in MCNP6.3 (still a major work in progress)

Preliminary results show improved agreement between simulated and measured observables



Also collaborating with TerraPower on their own internal validations

Looking Ahead

GAIN collaboration with TerraPower until March

Recently finished new measurements with different angular coverage & improved beam/backgrounds

→ better statistics & channel separation at highest energies (compared to previous studies)

Updating working evaluation with new data (Berkeley, Ohio U., U. Mass. Lowell, nTOF...)

Continue work with TerraPower on peer-reviewing existing data, testing, and publishing

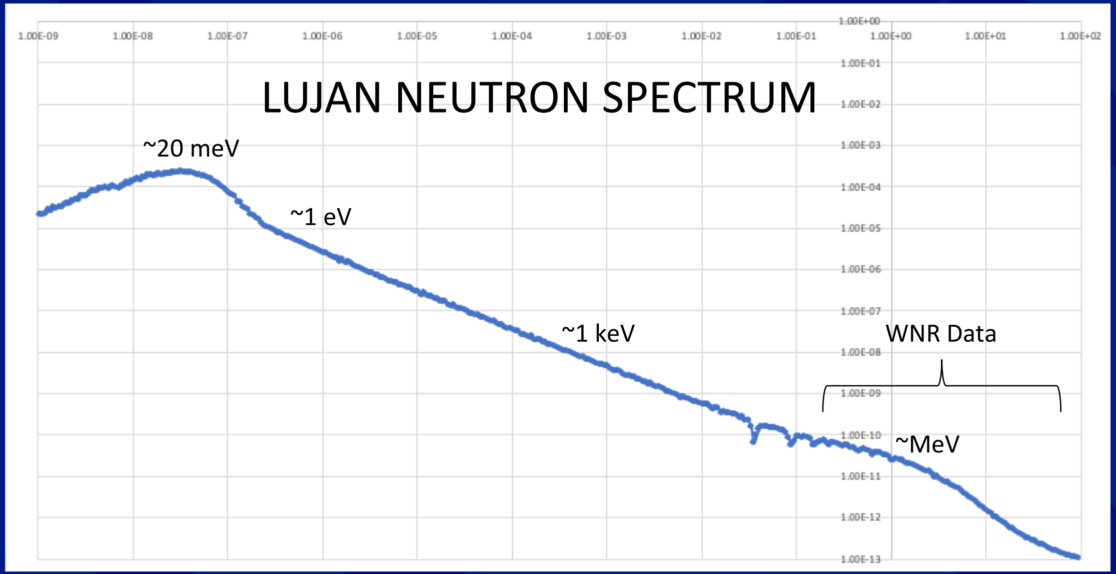
Plan also to take data at Lujan scattering facility next Jan-Feb (funding: NCSP)

→ moderated neutron source
→ overlap in energy range with prev. WNR (unmoderated) measurements

* Ongoing characterization of Mark IV neutron source upgrade

CLYC validation:

>> more data (and improved setup)
>> sim improvements for 1:1 comparisons



END GOAL: final updated evaluation for TerraPower and future ENDF/B

ACKNOWLEDGEMENTS

GAIN Gateway for Accelerated Innovation in Nuclear

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

Partner: TerraPower LLC (POC Tommy Cisneros)

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

TerraPower A Nuclear Innovation Company

PHYSICS SINCE 1943

THEORETICAL DIVISION Since 1943

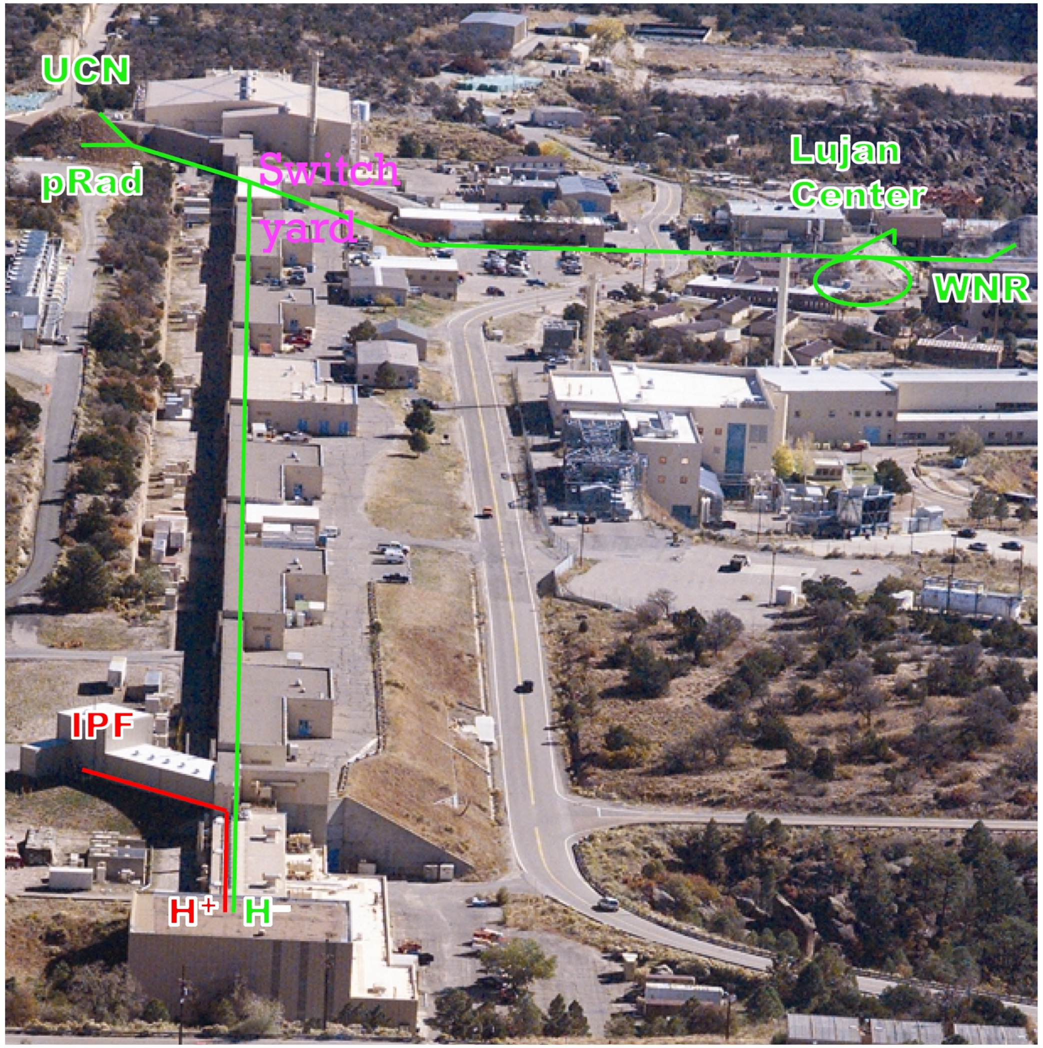
LANSCE

K.H. contact: khanselman@lanl.gov

QUESTIONS?

BACKUP SLIDES

- Uniquely capable of accelerating H^+ and H^- simultaneously
- Can deliver 100 kW of H^- and 800 kW of H^+ beam
- 120 pulses per second shared among 5 facilities
- H^- beam:
  - Lujan Center (NNSA)
  - Weapons Neutron Research Facility (NNSA)
  - Proton Radiography (NNSA)
  - Ultra-Cold Neutron Source (DOE-Office of Science)
- H^+ beam:
  - Isotope Production Facility (DOE-Office of Science)



Latest data taken with LENZ instrument at WNR

WNR flight paths exposed to raw, unmoderated spallation target for higher energy neutrons (up to ~100 MeV)

→ best neutron flux for region of interest

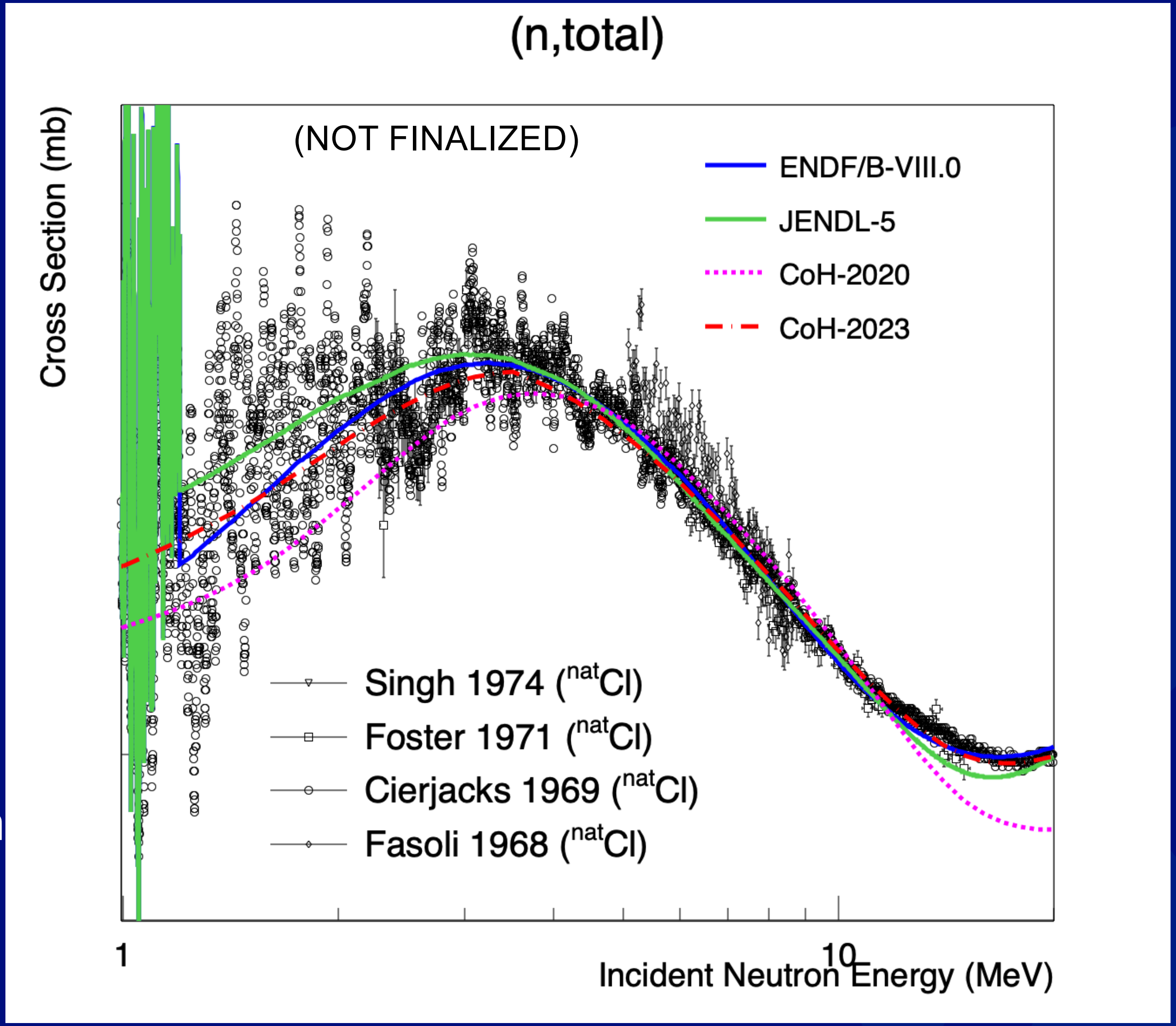
Neutron OMP

BASE: Kunieda (2007) – CC enabled

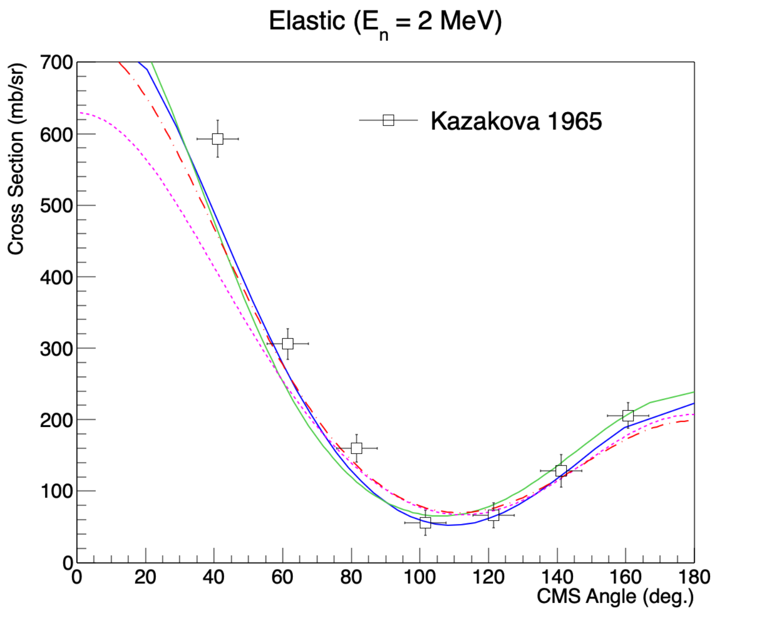
→ CC included: g.s. rot band ($3/2^+$-- $5/2^+$--$7/2^+$)

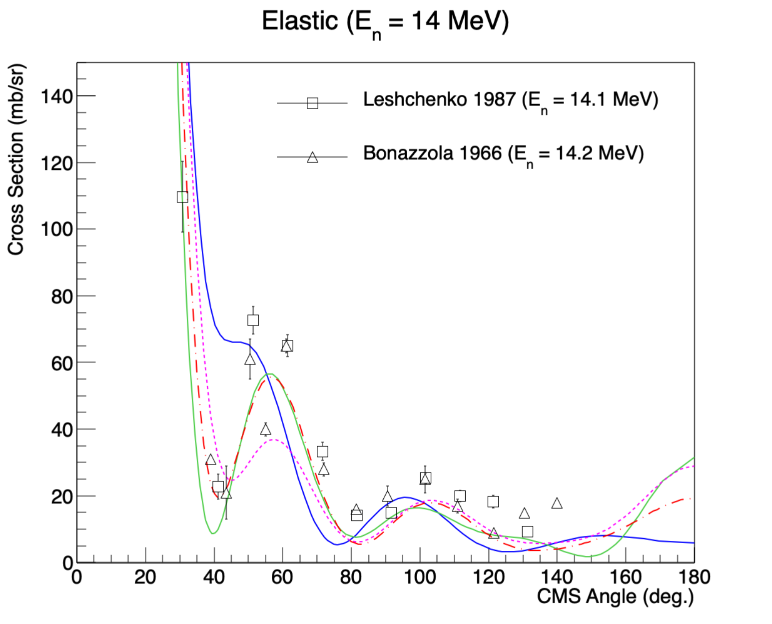
Major Tweaks:

- ~15-25% reduc. in absorp. strength (W & aW) up to 3.5 MeV
- motivated by low 35Cl LD
- compensations in V & radii to match higher energies



S. Kunieda et al., J. Nuc. Sci. & Tech. vol. 44 no. 6 p. 838 (2007)





LA-UR-23-32833

2017/2018 Measurements of $^{35}Cl(n,p_0)^{35}S_{gs}$

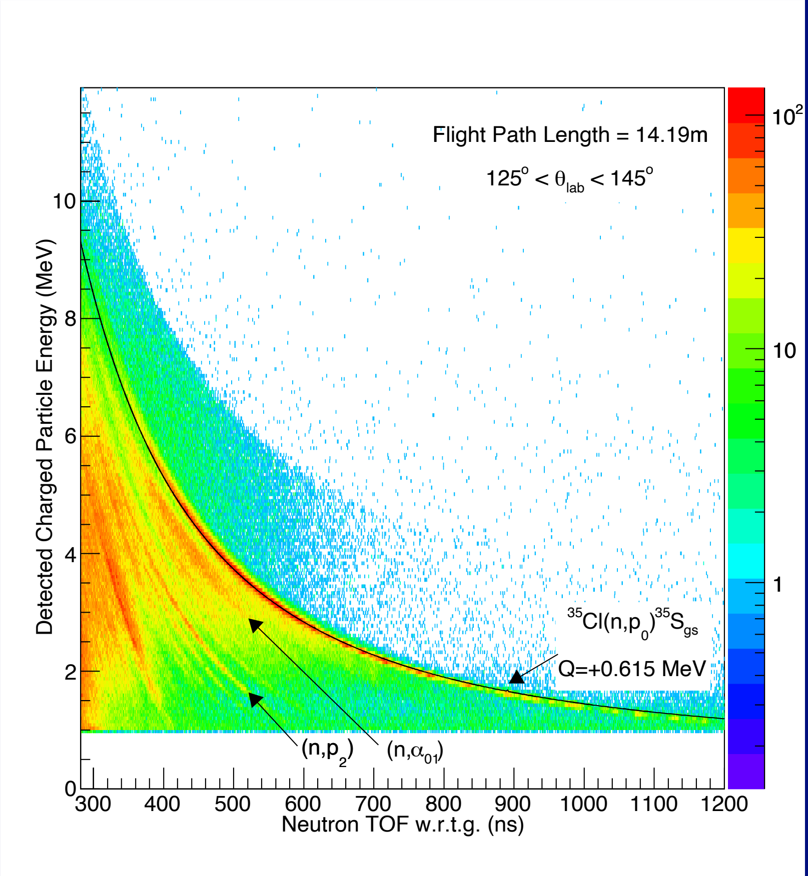
PRC **102** 024623 (2020)

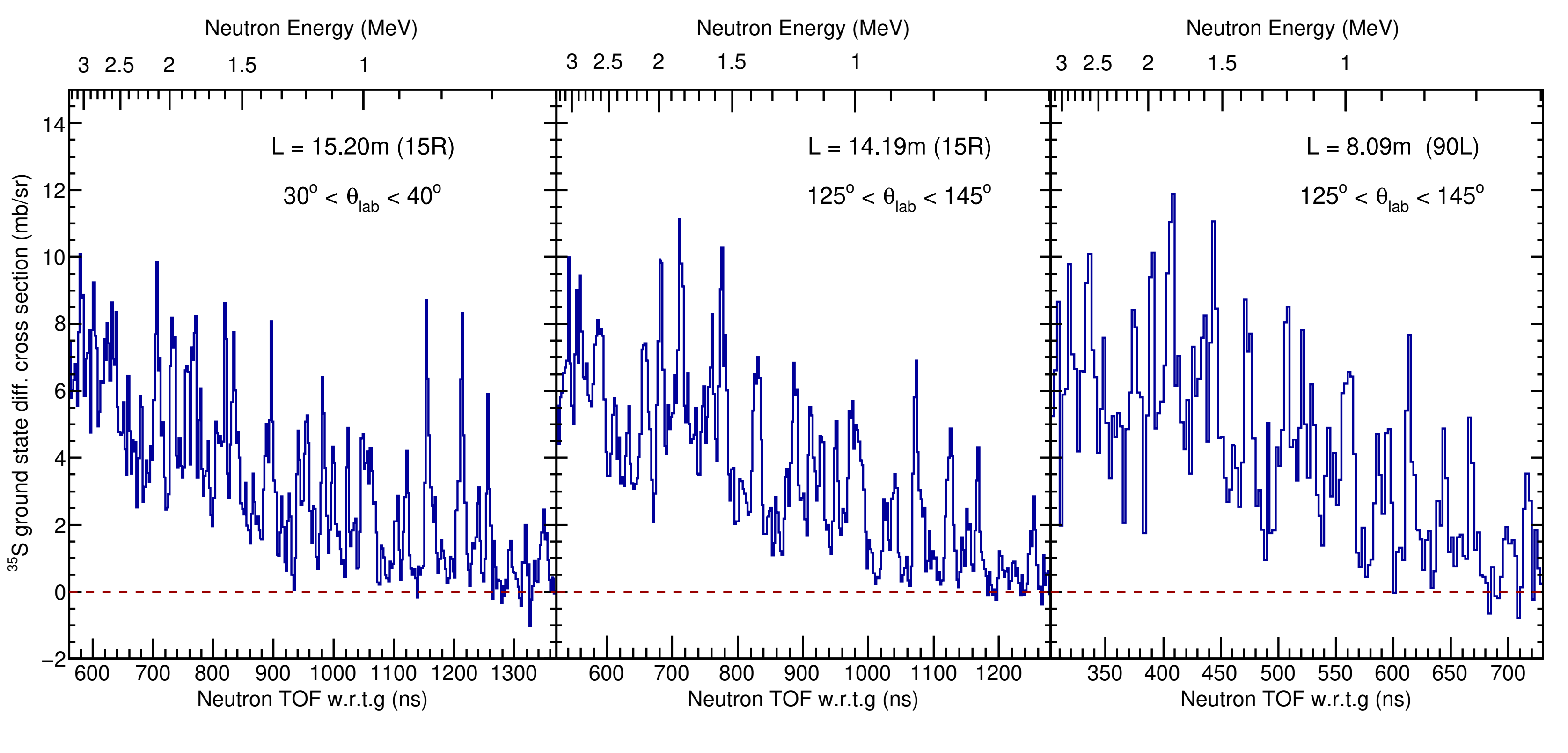
- Non-statistical fluctuations observed in the cross section up to ~3 MeV, consistent with other recent measurements (Batchelder 2019)

Nonstatistical fluctuations in the $^{35}Cl(n,p)^{35}S$ reaction cross section at fast-neutron energies from 0.6 to 6 MeV

S. A. Kuvin, H. Y. Lee, T. Kawano, B. DiGiovine, A. Georgiadou, C. Vermeulen, M. White, and L. Zavorka
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

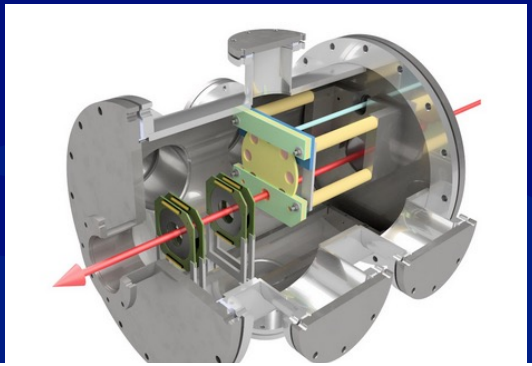
H. I. Kim
Nuclear Physics Application Research Division, Korea Atomic Energy Research Institute, Yuseong-gu, Daejeon, Korea

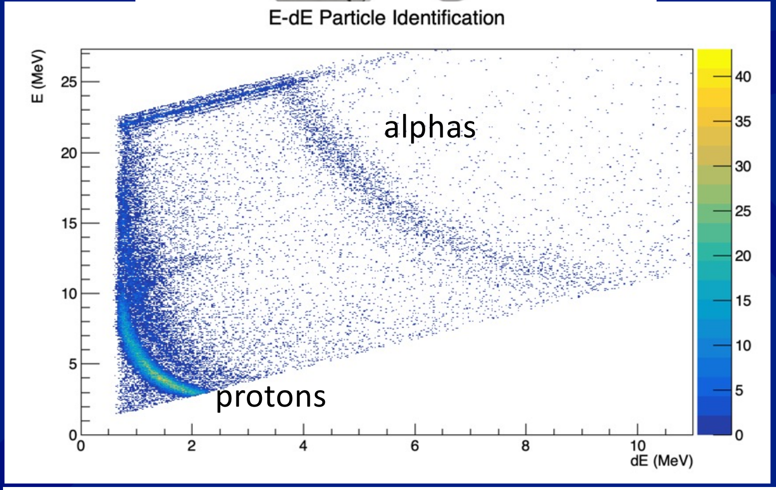




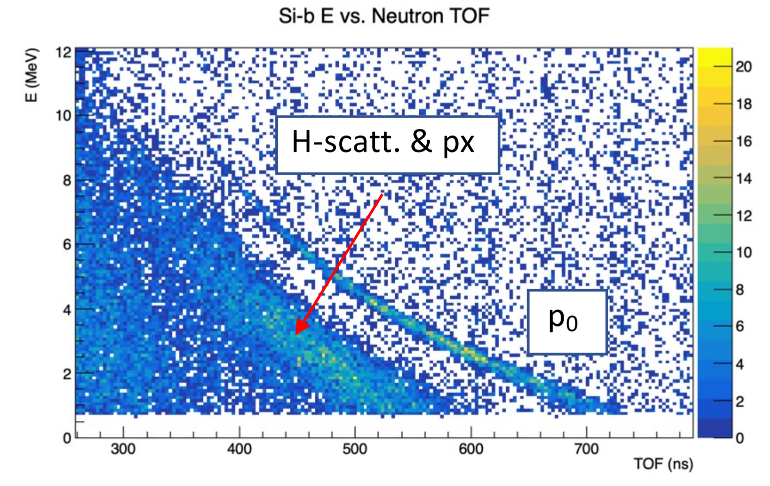
For other channels, include NEW DATA from 2022 run cycle (still very preliminary)

Two flight paths: 90L (~100 keV – few MeV)
15R (~500 keV – >10 MeV)

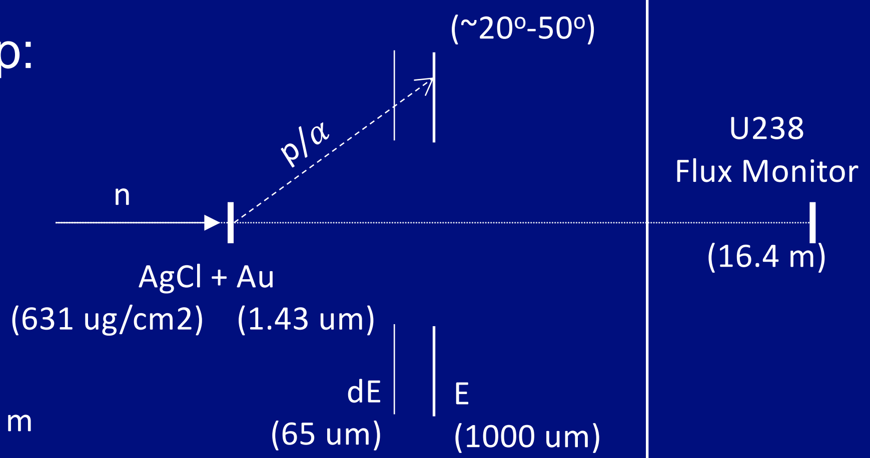




- clean particle separation
- p0 distinct and standalone
- biggest backgrounds: H-scattering and "dark current" (pulsed time bands)



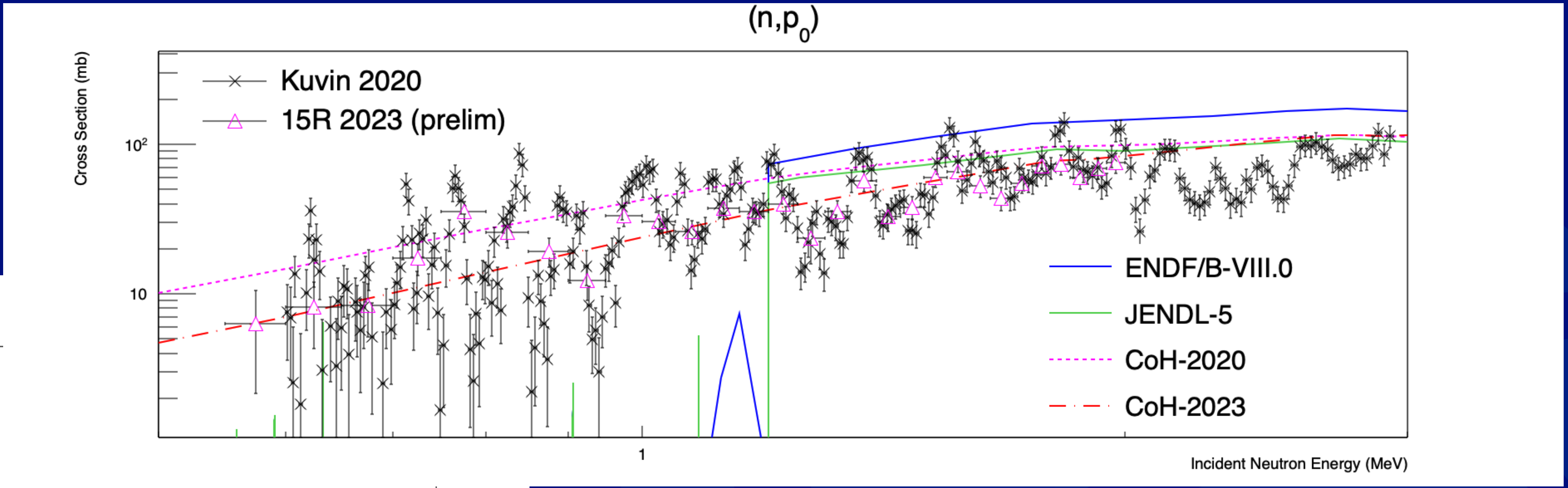
15R Setup:

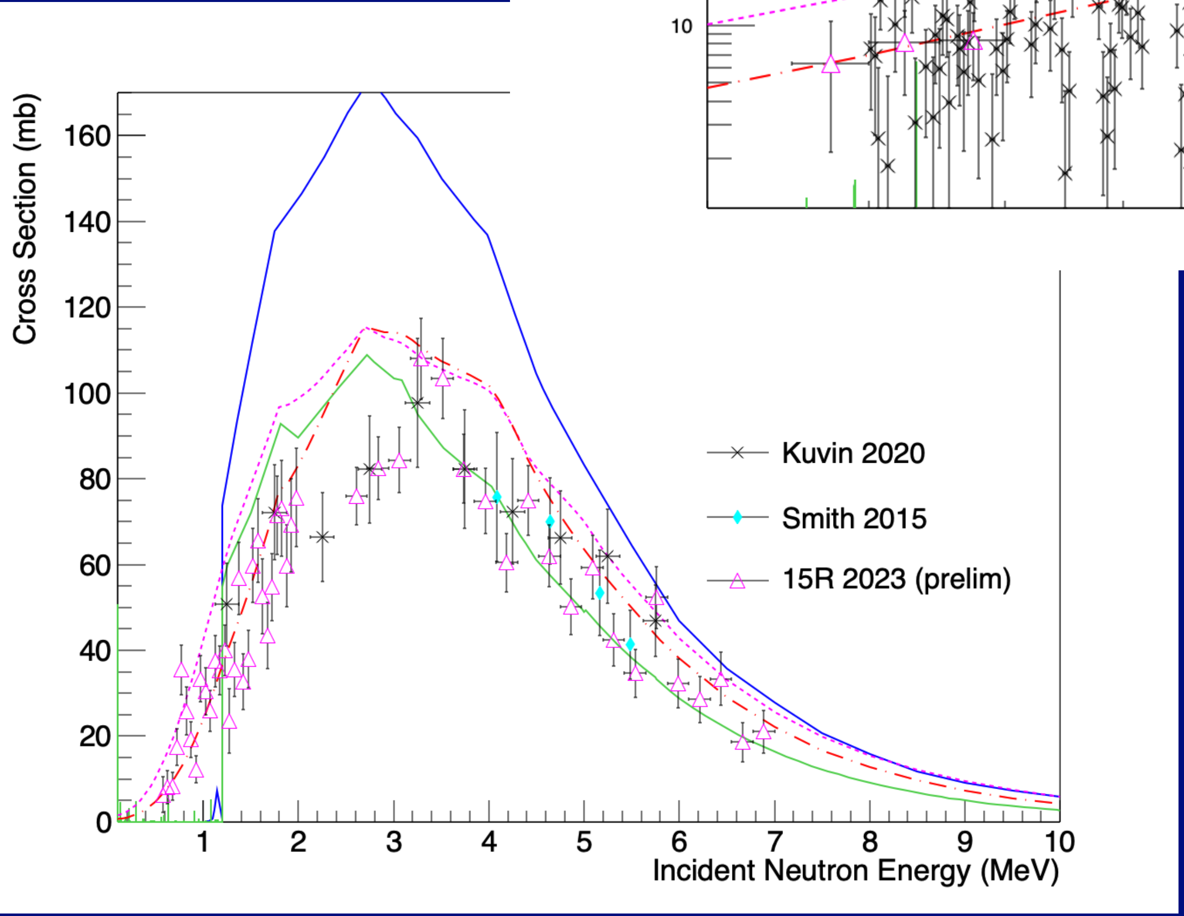


FP Length: 15.2 m

^{35}Cl(n,p) Q = +0.62 MeV
^{35}Cl(n,a) Q = +0.94 MeV

2023
$^{35}Cl(n,p)^{35}S$
(PRELIMINARY)





Old and new data agree well

Base proton OMP: still Kunieda (2007)
(isospin symmetry)

Slightly different tweaks:
- >> 5-15% adjustments to REAL term
- >> ~15% increase to ^{35}Cl & ^{35}S LDs (with discrete level cutoffs at 10-15)

*LDs concur w/ data from A. Voinov (priv. comm.)

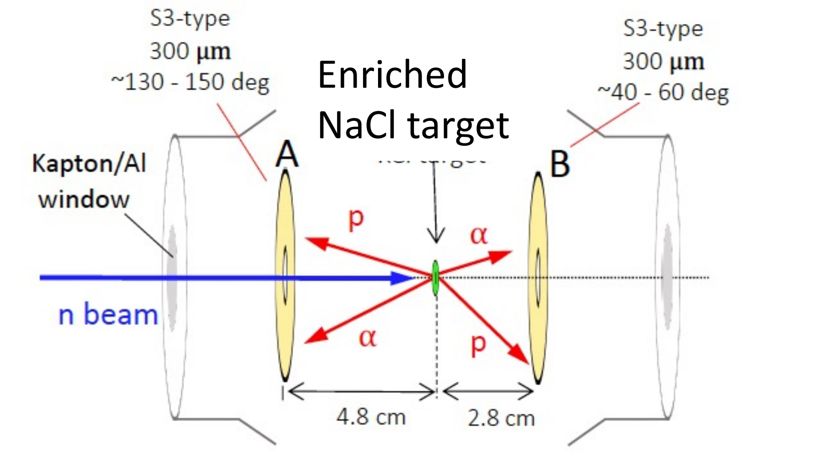
2023
^{35}Cl(n,p)^{35}S
(PRELIMINARY)

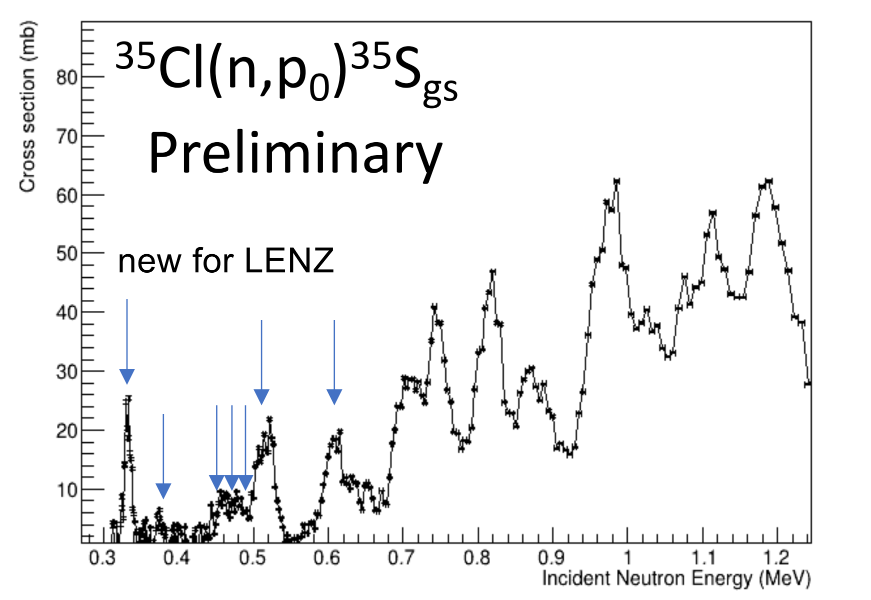
For (n,p) total: 90L data

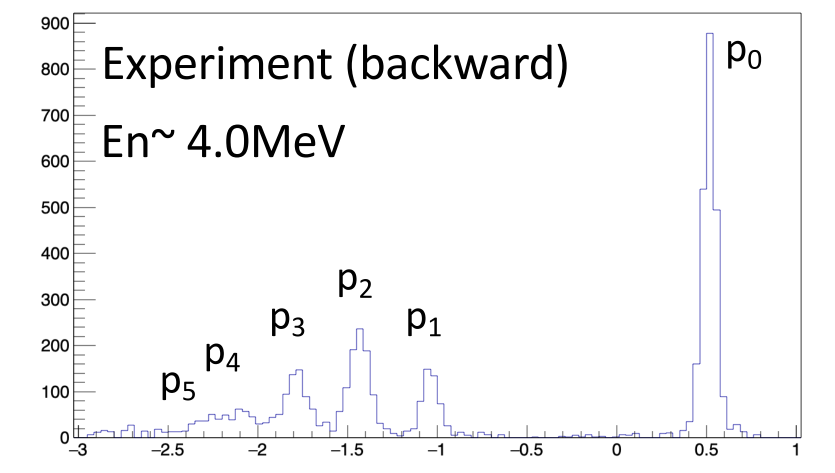
Lower resonances observed consistent with CLYC data by J. Warren (Ohio; priv. comm.)

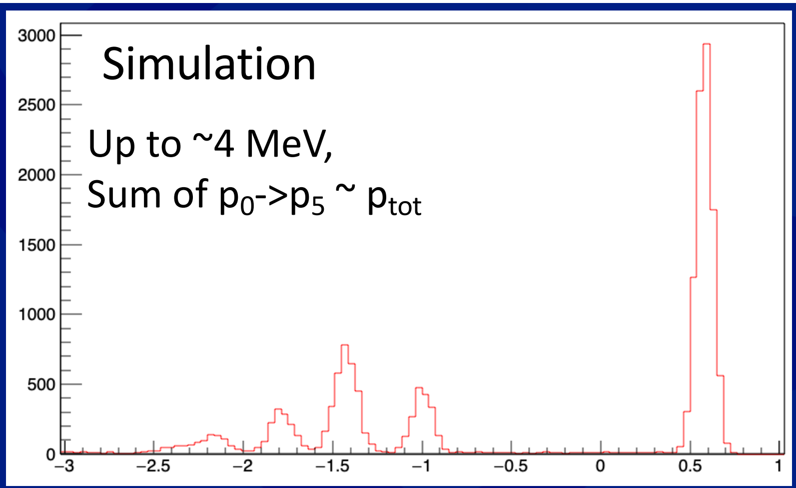
PSD to distinguish particle groups

→ clean (n,p) spectra to get (n,ptot) – IN PROGRESS...





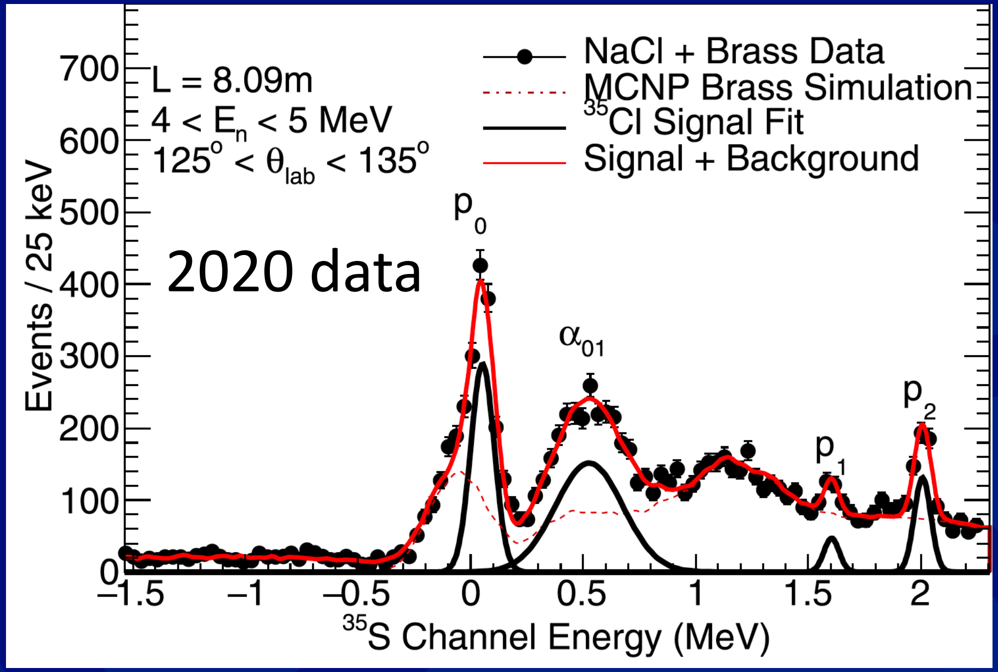


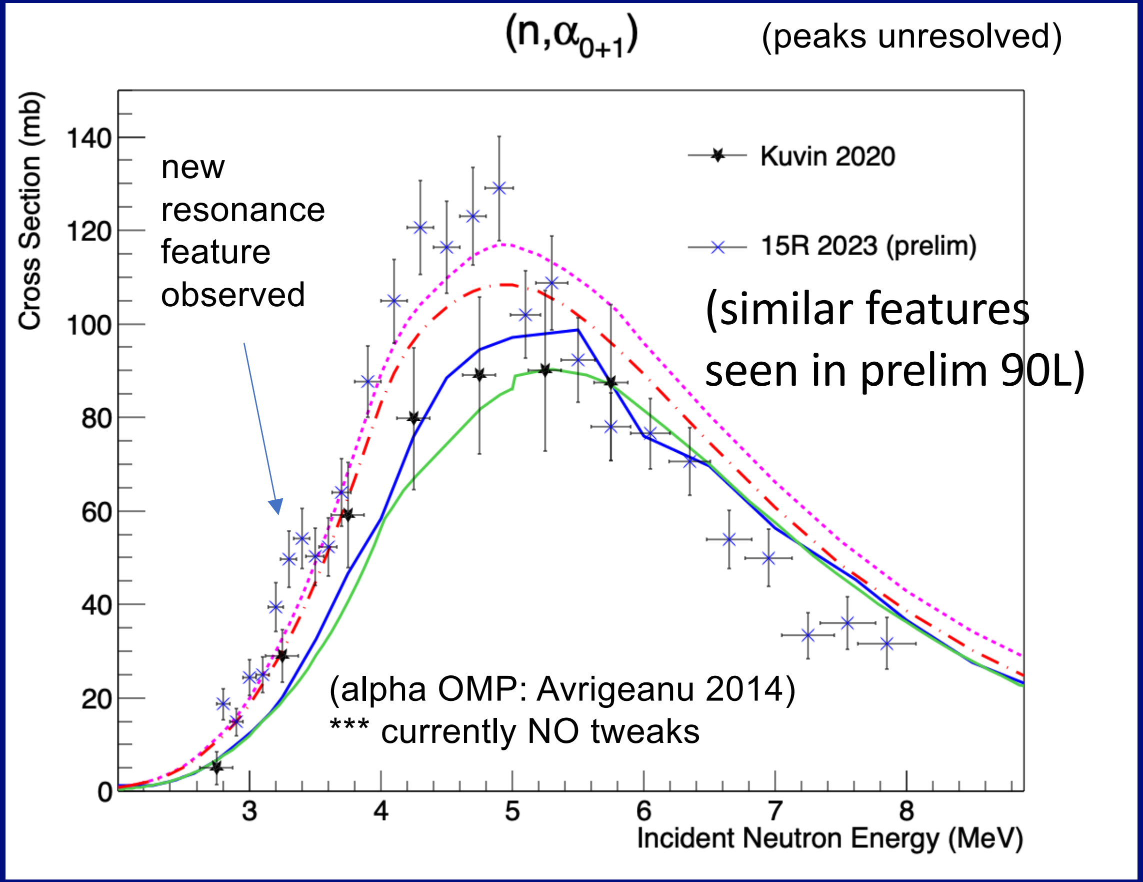


2023
$^{35}Cl(n,a)^{32}P$
(PRELIMINARY)

Most significant difference: backgrounds
>> 2020: target on brass backing
>> 2022: pure gold backing

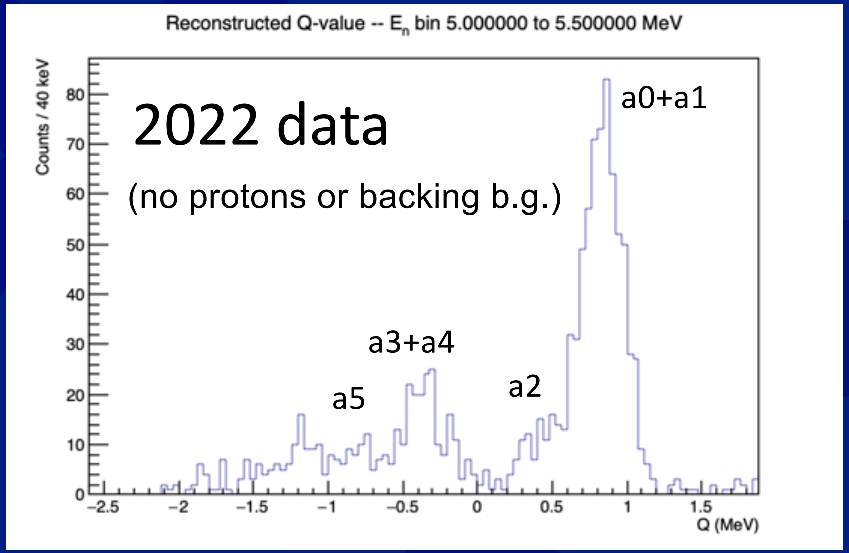
from S. A. Kuvin et al. PRC **102** 024623 (2020)





V. Avrigeanu et al. PRC **90** 044612 (2014)

*** if true, would help bring (n,p) down...



HIGHER ENERGIES (>10 MeV)

→ 3 competing channels with widely varying data

Current solution:

>> ~15% ^{35}Cl/S LD increases

>> ~15% reduction in alpha preequilibrium state density (i.e. ~knockout)

>> manual increase of (n,p) strength by tuning up imag. parts of prot OMP

** still no solution yet to match higher (n,p) data while keeping lower