# ENDF/B-VIII Library status, cleanups and $^{86}Kr$

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BROOKHAVEN NATIONAL LABORATORY
*a passion for discovery*

U.S. DEPARTMENT OF ENERGY | Office of Science

# ENDF/B-VIII Status

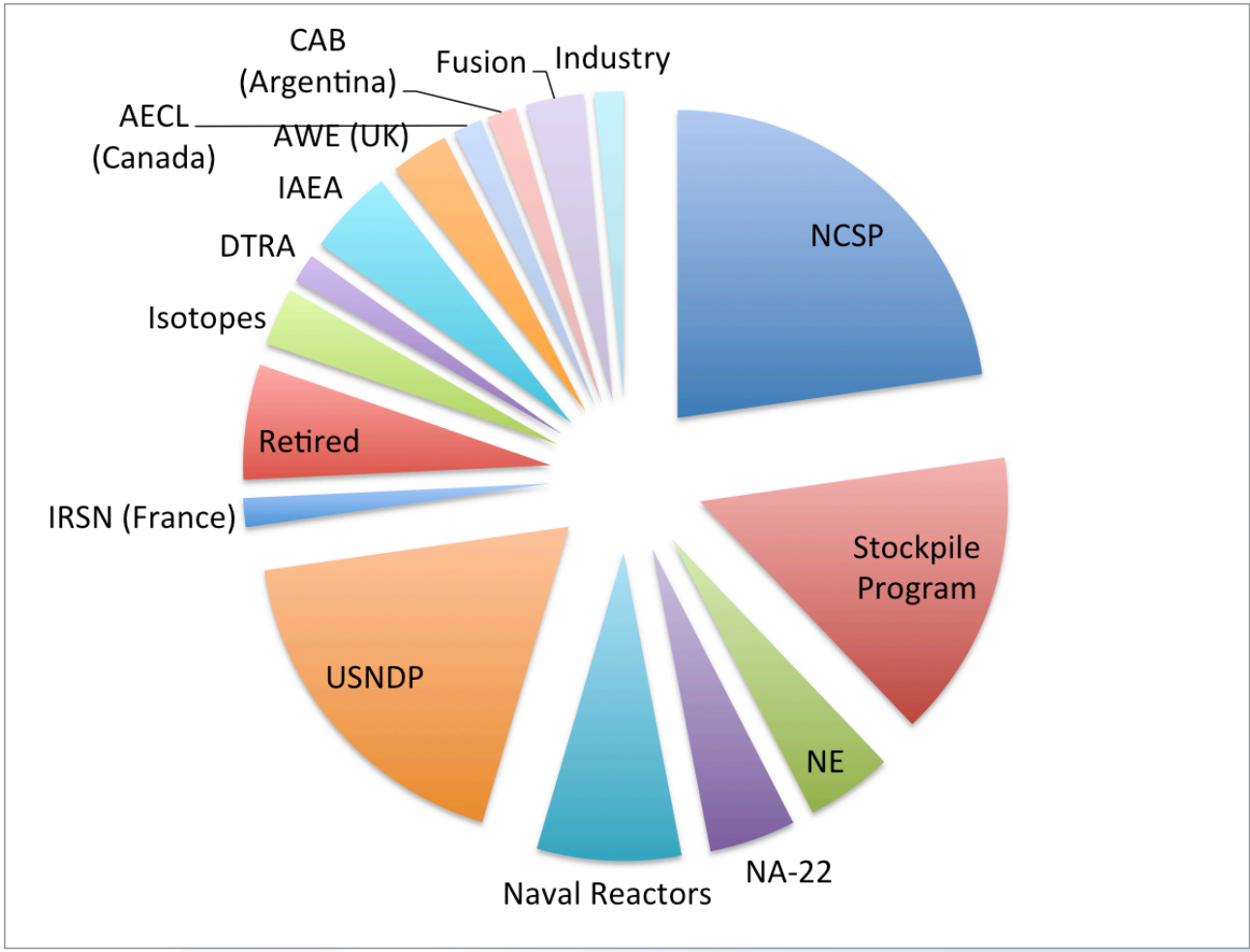
- **ENDF/B library is product of CSEWG, an informal yet very long running collaboration (50 year in June 2016)**
- **ENDF/B is the US's most important data library for nuclear applications**
- **Next major release due in FY17-18 time frame**
- **Major new items, *so far*:**
  - CIELO evaluations: $^{16}O$, $^{56}Fe$, $^{235,238}U$, $^{239}Pu$
  - Neutron standards
  - EPICS2014 (atomic reaction data)
  - New TSL evaluations
  - Many bugs fixes & other improvements
- **Release in legacy ENDF and new GND formats**


ENDF/B-VII.0 contains 393 evaluations;
*1325 citations since 2006 (Google Scholar)*

ENDF/B-VII.1 contains 423 evaluations
*669 citations since 2010 (Google Scholar)*

# There are many contributors to CSEWG

- Due to CSEWG's informal nature, it is hard to assess precise contribution to ENDF/B in either $$ or FTEs
- Chart reflects attendance of CSEWG meeting
- *Double counting alert:* some people counted twice since funded from multiple pots of $$



# Contributions to CSEWG are not just evaluations

| Program | Measurement | Theory | Compilation | Evaluation | QA (V&V, IE) | Infrastructure (Gforge, etc.) |
|---|---|---|---|---|---|---|
| DTRA | ✓ | | | | | |
| International (IAEA, NEA, …) | | ✓ | ✓ | ✓ | ✓ | ✓ |
| NA-22 | ✓ | ✓ | | ✓ | | |
| Naval Reactors | ✓ | | | | ✓ | |
| NCSP | ✓ | ✓ | | ✓ | ✓ | |
| NE | | | | | ✓ | |
| Other (NP, Fusion, …) | ✓ | ✓ | | | ✓ | |
| Stockpile | ✓ | ✓ | | ✓ | ✓ | ✓ |
| USNDP | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

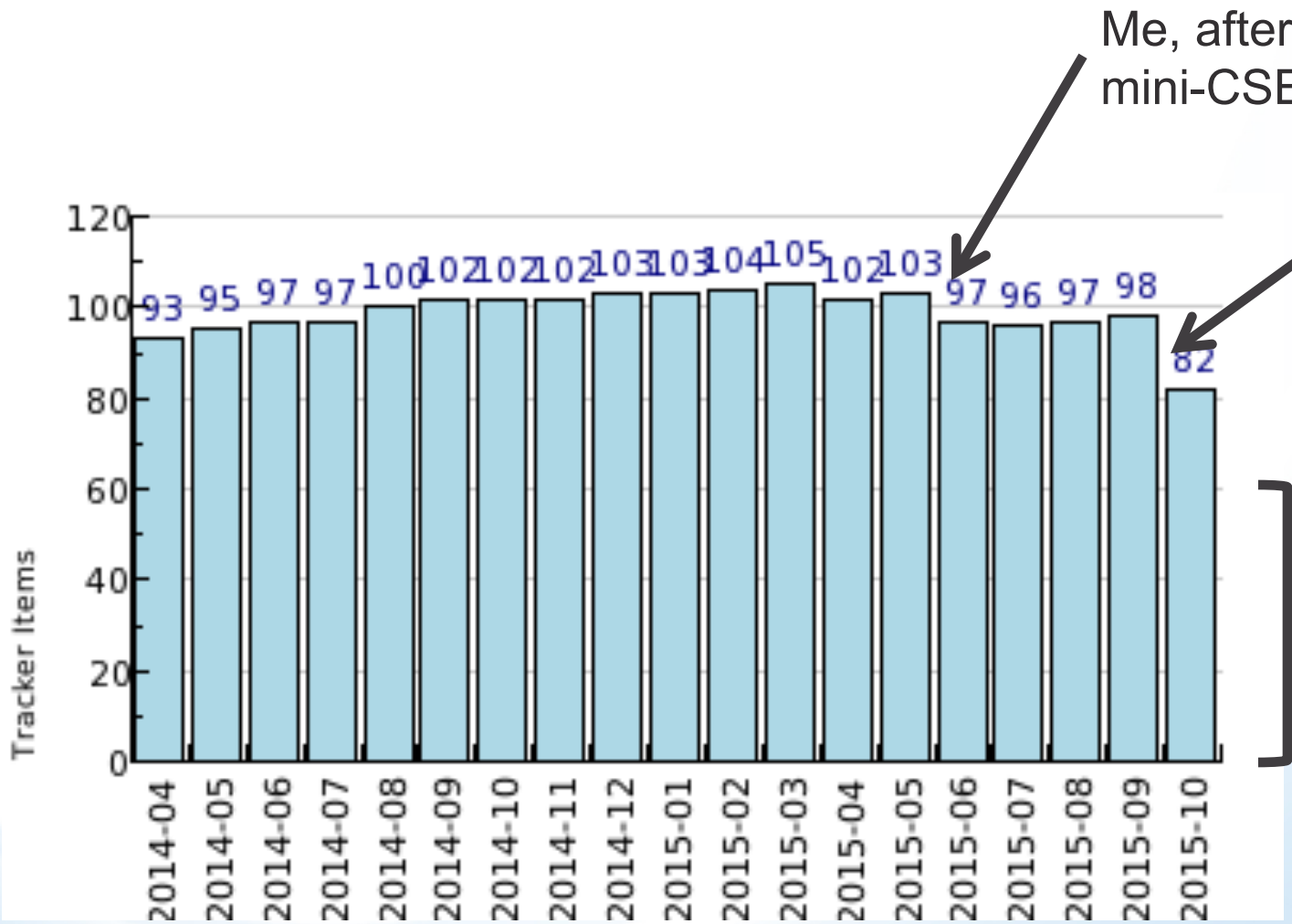
# Unlike other data projects, we do not restrict who can contribute: FY15 evaluations

| Program | Full evaluations | Partial evaluations | Bug fixes |
|---|---|---|---|
| NCSP | 1 | | |
| AECL (Canada) | 1.5 | | |
| CAB (Argentina) | 1.5 | | |
| JAEA (Japan) | 18 | | |
| Retirees | | | 305 |
| Stockpile Program | | | 16 |
| USNDP | | 9 | 33 |

# More detail on this year's evaluations

- **New evaluations**
  - CAB-AECL: OinD2O (TSL), DinD2O (TSL), HinH2O (TSL)
  - NCSU: Lucite (TSL)
  - Stolen from JENDL-4: Yb, Os, $^{154,159}$Dy, $^{181,182}$Hf
- **Small changes with large impact**
  - LLNL-LBNL EGAF: $^{6,7}$Li, $^{11}$B, $^{19}$F, $^{23}$Na, $^{27}$Al, $^{28}$Si, $^{35,37}$Cl
  - D.E. Cullen EPICS: 300 evaluations in photo-atomic, electro-atomic, and atomic-relaxation libraries
  - BNL resonances: $^{120,122,124}$Sn, $^{185,187}$Re
- **Bug fixes**

# Outstanding ENDF/B Tracker Items



# “Festival of Fixes 2015”
## *9-11 September 2015*

- **Idea (Thanks T.K.):**
  - Get a bunch of experts together with their laptops and evaluation tools and lock them in a room for a few days.
  - Together we went though outstanding Tracker Items and CSEWG Action Items
- **Immediate feedback from the ENDF library manager and the continuous integration system made for rapid turn around**

# “Festival of Fixes 2015”
## *9-11 September 2015*

- **Un(officially) planned convergence of visits at the NNDC:**
  - **Thompson**: $^{123,124}$Xe, $^{180,181}$Ta, $^{185,187}$Re
  - **Kawano**: n, $^{11}$B, $^{18}$O, $^{35}$Cl, $^{124}$Sb, $^{151}$Sm,$^{153}$Eu
  - **Sleaford** (in absentia): EGAF commits
- **Plus NNDC folks**:
  - **Mughabghab**: $^{122,124}$Sn
  - **Brown**: Steal evaluations from JENDL-4, discover & fix bugs in FUDGE and ADVANCE

This was very successful, I would love to make it a regular thing!

# Most of trackers still in neutron sublibrary

# Non-neutron bugs covered in mini-CSEWG, no progress to report

# Deficiencies in Decay Sub Library

| TrackerItemID | Summary | Priority | Status | Open Date | Close Date | Last Modified Date |
|---|---|---|---|---|---|---|
| 218 | Unspecified: Inconsistencies in half-lives | 4 | Closed | 2009-12-07 | 2015-05-05 | 2009-12-07 |
| 237 | Unspecified: Fission beta-spectra 40% lower than in VI.8 | 4 | Closed | 2009-12-07 | 2015-05-05 | 2009-12-07 |
| 238 | Unspecified: Masses (AWR) inconsistent | 4 | Closed | 2009-12-07 | 2015-05-05 | 2009-12-07 |
| 239 | Sb-129: Inconsistency in beta decay | 4 | Closed | 2009-12-07 | 2015-05-05 | 2009-12-07 |
| 240 | Rh-102  Rh-102m: Warning statement in MT451 | 4 | Open | 2009-12-07 | | 2009-12-07 |
| 816 | a problem with the Half-life of Rf-261 or Rf 261m in ENDF VII 1 | 3 | Closed | 2013-09-25 | 2015-05-05 | 2013-09-25 |
| 826 | Kr-90 | 3 | Open | 2013-10-31 | | 2013-10-31 |
| 840 | Er-145 listed as stable | 4 | Open | 2014-03-11 | | 2014-03-14 |
| 895 | Se-80 listed as radioactive with zero half life | 3 | Open | 2014-09-02 | | 2014-09-02 |

green == fixed

yellow == easy fix

# Deficiencies in Thermal Scattering Law Sub Library

| TrackerItemID | Summary | Priority | Open Date | Follow-ups |
|---|---|---|---|---|
| 232 | O in BeO  U in UO2: MAT numbers for thermal scat. | 4 | 2009-12-07 | TO DO: trivial fix |
| 233 | H in H2O: Wrong ZA value | 4 | 2009-12-07 | TO DO: trivial fix |
| 692 | U(UO2) and O(UO2) reversed | 3 | 2012-06-25 | TO DO: trivial fix |

green == fixed
yellow == easy fix

# Gamma sublibrary

| TrackerItemID | Summary | Status | Open Date | Follow-ups |
|---|---|---|---|---|
| 858 | Mass of deuteron incorrect | Open | 2014-05-07 | e- mass taken off here, not done in neutron sub library. ENDF manual says to use atomic mass for all targets, so we need to put the electrons back. This will mess up kinematics. Need new evaluation or better rule. |
| 860 | Th-232 fissile goofs part 1 | Closed | 2014-06-05 | LFI flag flipped |
| 861 | Th-232 fissile goofs part 2 | Open | 2014-06-05 | laudable goal to have prompt and delayed nubar, but often best we can do is the total nubar, such as was done here. |

green == fixed
yellow == easy fix
white == isotope fix
red == major fix spanning several isotopes

# Deuteron sublibrary

| TrackerItemID | Summary | Status | Open Date | Follow-ups |
|---|---|---|---|---|
| 236 | H-2: Energy range too short in the (d n) reaction | Open | 2009-12-07 | need new evaluation, evaluation stops at 10 MeV |
| 857 | Mass of deuteron incorrect d+d evaluation | Open | 2014-05-07 | e- mass taken off here, not done in neutron sub library. ENDF manual says to use atomic mass for all targets, so we need to put the electrons back. This will mess up kinematics. Need new evaluation or better rule. |

green == fixed
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# Proton sublibrary

| TrackerItemID | Summary | Status | Open Date | Follow-ups |
|---|---|---|---|---|
| 234 | H-3: Energy range too short in the 3H(p n)3He reaction | Open | 2009-12-07 | need new evaluation, all cross section stop at 12 MeV |
| 235 a | Ca-40: Inconsistent energy ranges in MF3 and MF6 | Open | 2009-12-07 | |
| 235 b | Cu-63: Inconsistent energy ranges in MF3 and MF6 | Open | 2009-12-07 | |
| 669 | Pb207 outgoing energies out of order | Open | 2012-02-23 | |

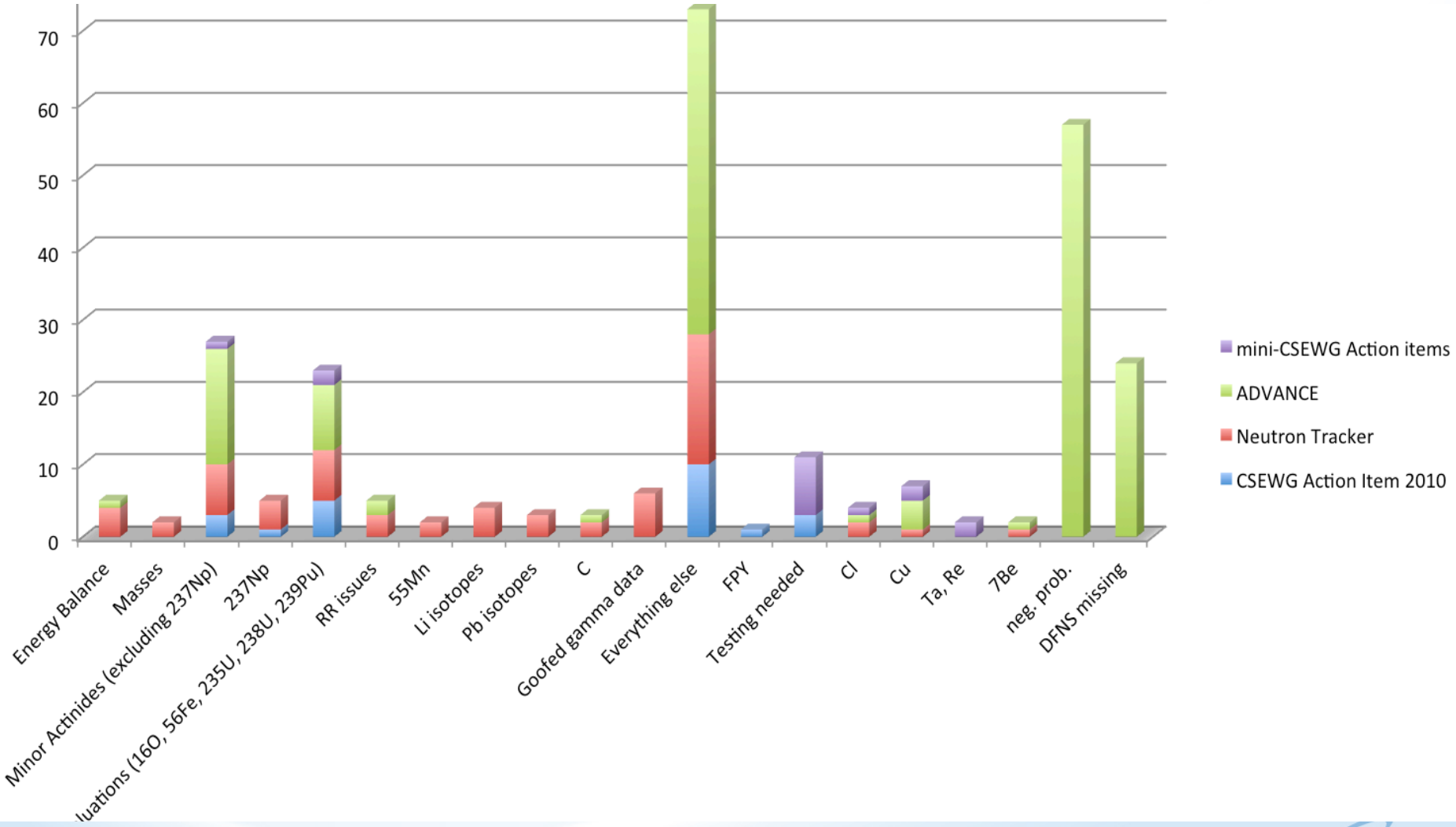
green == fixed
yellow == easy fix
white == isotope fix
red == major fix spanning several isotopes

# nFPY sublibrary

| TrackerItemID | Summary | Status | Open Date | Follow-ups |
|---|---|---|---|---|
| 702 | 241Pu in the rare earth region | Open | 2012-08-29 | need revaluation |
| 703 | As-84m doesn't exist  but we have a fission yield for it | Open | 2012-08-29 | need revaluation |
| 812 | FPY has non-existent metastable states | Open | 2013-09-06 | need revaluation |
| 841 | IFPY > CFPY for Pu-239 | Open | 2014-03-14 | need revaluation |

green == fixed
yellow == easy fix
white == isotope fix
red == major fix spanning several isotopes

# Breakdown of bugs in neutron sublibrary



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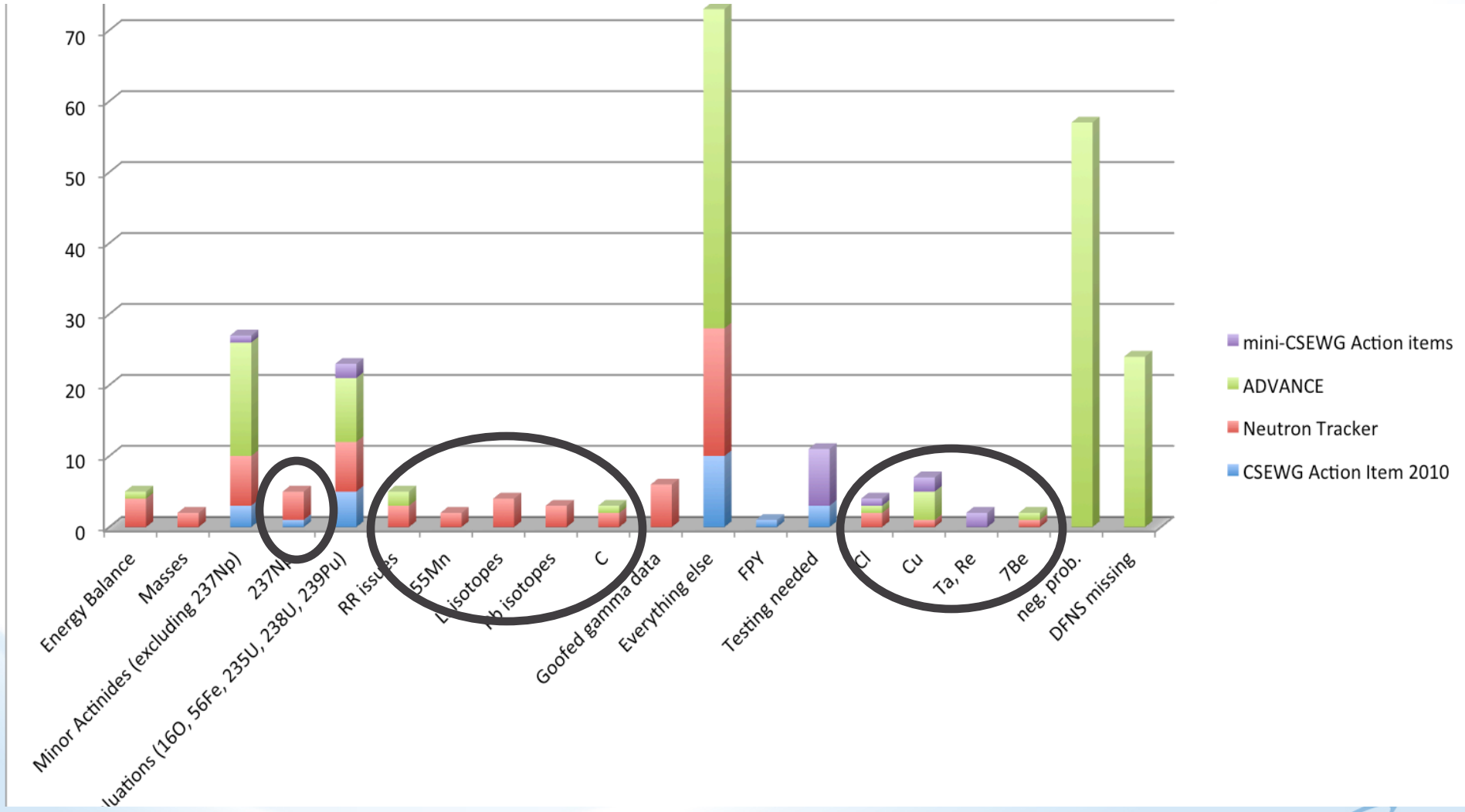


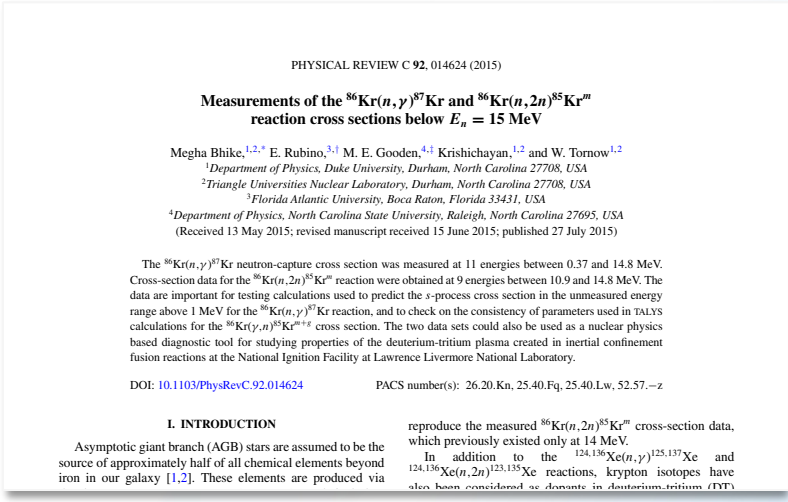
# Big issues remaining

- **Overall**:
  - d mass: with e- or without e-
  - Legendre moment data with absurd Lmax
  - Incomplete evaluation (usu. through $^{8}$Be*)
  - Total nubar, but no prompt or delayed nubar
  - Missing DFNS
  - Various RR issues

- **Specific cases:**
  - $^{237}$Np: 4 trackers,
    1 Action item
  - Li: 4 trackers
  - Pb: 3 trackers
  - Cl: 2 trackers,
    1 ADVANCE complaint,
    1 action item
  - Cu: 1 tracker,
    4 ADVANCE complaints,
    2 action items
  - C: 2 trackers,
    1 ADVANCE complaint

# A confluence of events led us to attempt to evaluate $^{86}$Kr

- **A need:**
  - Radiochemical diagnostic
  - Can mix into d-t fuel say at NIF
- **New data just made available:**
  - TUNL just published results on $^{86}$Kr(n,g) and $^{86}$Kr(n,2n)
  - LANSE published $^{86}$Kr(n,n')
- **Cheap labor:**
  - Elizabeth Rubino, a SULI student at BNL
  - Last year she was REU student at TUNL, measuring $^{86}$Kr cross sections!



PHYSICAL REVIEW C **92**, 014624 (2015)

**Measurements of the $^{86}$Kr$(n,\gamma)^{87}$Kr and $^{86}$Kr$(n,2n)^{85}$Kr$^m$ reaction cross sections below $E_n = 15$ MeV**

Megha Bhike,[1,2,*] E. Rubino,[3,†] M. E. Gooden,[4,‡] Krishichayan,[1,2] and W. Tornow[1,2]
[1]*Department of Physics, Duke University, Durham, North Carolina 27708, USA*
[2]*Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA*
[3]*Florida Atlantic University, Boca Raton, Florida 33431, USA*
[4]*Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*
(Received 13 May 2015; revised manuscript received 15 June 2015; published 27 July 2015)

The $^{86}$Kr$(n,\gamma)^{87}$Kr neutron-capture cross section was measured at 11 energies between 0.37 and 14.8 MeV. Cross-section data for the $^{86}$Kr$(n,2n)^{85}$Kr$^m$ reaction were obtained at 9 energies between 10.9 and 14.8 MeV. The data are important for testing calculations used to predict the *s*-process cross section in the unmeasured energy range above 1 MeV for the $^{86}$Kr$(n,\gamma)^{87}$Kr reaction, and to check on the consistency of parameters used in TALYS calculations for the $^{86}$Kr$(\gamma,n)^{85}$Kr$^{m+g}$ cross section. The two data sets could also be used as a nuclear physics based diagnostic tool for studying properties of the deuterium-tritium plasma created in inertial confinement fusion reactions at the National Ignition Facility at Lawrence Livermore National Laboratory.

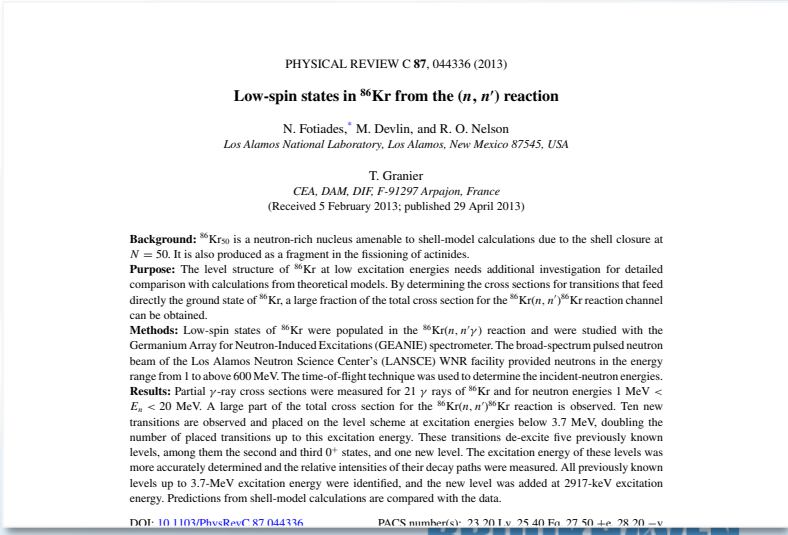
DOI: 10.1103/PhysRevC.92.014624 PACS number(s): 26.20.Kn, 25.40.Fq, 25.40.Lw, 52.57.−z

**I. INTRODUCTION**

Asymptotic giant branch (AGB) stars are assumed to be the source of approximately half of all chemical elements beyond iron in our galaxy [1,2]. These elements are produced via

reproduce the measured $^{86}$Kr$(n,2n)^{85}$Kr$^m$ cross-section data, which previously existed only at 14 MeV.

In addition to the $^{124,136}$Xe$(n,\gamma)^{125,137}$Xe and $^{124,136}$Xe$(n,2n)^{123,135}$Xe reactions, krypton isotopes have also been considered as dopants in deuterium-tritium (DT)



PHYSICAL REVIEW C **87**, 044336 (2013)

**Low-spin states in $^{86}$Kr from the $(n, n')$ reaction**

N. Fotiades,* M. Devlin, and R. O. Nelson
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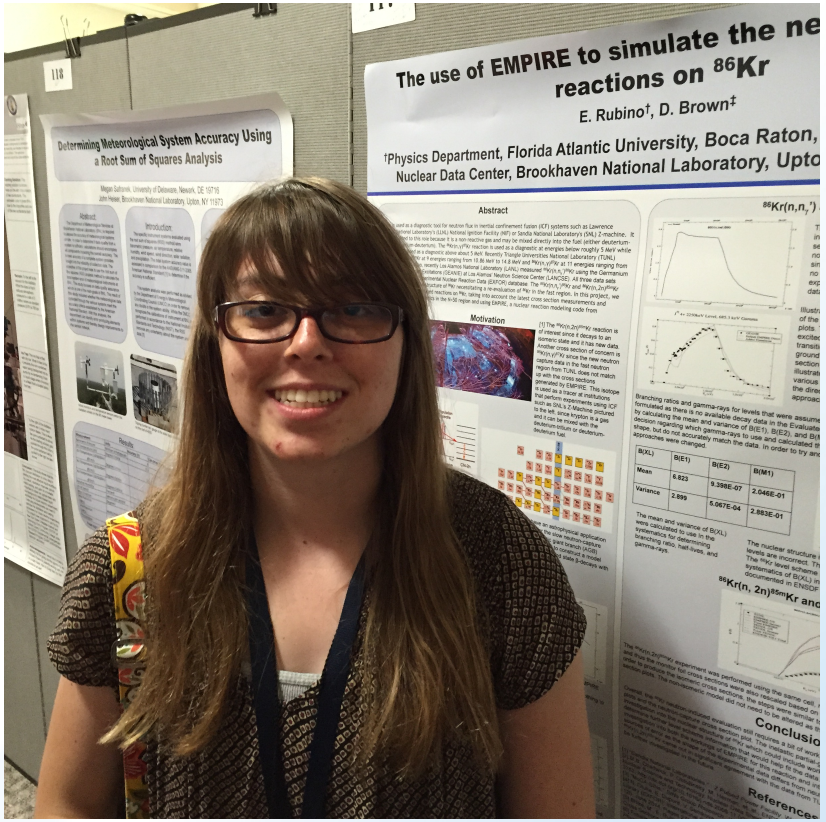
T. Granier
*CEA, DAM, DIF, F-91297 Arpajon, France*
(Received 5 February 2013; published 29 April 2013)

**Background:** $^{86}$Kr$_{50}$ is a neutron-rich nucleus amenable to shell-model calculations due to the shell closure at $N = 50$. It is also produced as a fragment in the fissioning of actinides.
**Purpose:** The level structure of $^{86}$Kr at low excitation energies needs additional investigation for detailed comparison with calculations from theoretical models. By determining the cross sections for transitions that feed directly the ground state of $^{86}$Kr, a large fraction of the total cross section for the $^{86}$Kr$(n, n')^{86}$Kr reaction channel can be obtained.
**Methods:** Low-spin states of $^{86}$Kr were populated in the $^{86}$Kr$(n, n'\gamma)$ reaction and were studied with the Germanium Array for Neutron-Induced Excitations (GEANIE) spectrometer. The broad-spectrum pulsed neutron beam of the Los Alamos Neutron Science Center's (LANSCE) WNR facility provided neutrons in the energy range from 1 to above 600 MeV. The time-of-flight technique was used to determine the incident-neutron energies.
**Results:** Partial $\gamma$-ray cross sections were measured for 21 $\gamma$ rays of $^{86}$Kr and for neutron energies 1 MeV $< E_n <$ 20 MeV. A large part of the total cross section for the $^{86}$Kr$(n, n')^{86}$Kr reaction is observed. Ten new transitions are observed and placed on the level scheme at excitation energies below 3.7 MeV, doubling the number of placed transitions up to this excitation energy. These transitions de-excite five previously known levels, among them the second and third $0^+$ states, and one new level. The excitation energy of these levels was more accurately determined and the relative intensities of their decay paths were measured. All previously known levels up to 3.7-MeV excitation energy were identified, and the new level was added at 2917-keV excitation energy. Predictions from shell-model calculations are compared with the data.

DOI: 10.1103/PhysRevC.87.044336 PACS number(s): 23.20.Lv, 25.40.Fq, 27.50.+e, 28.20.−v

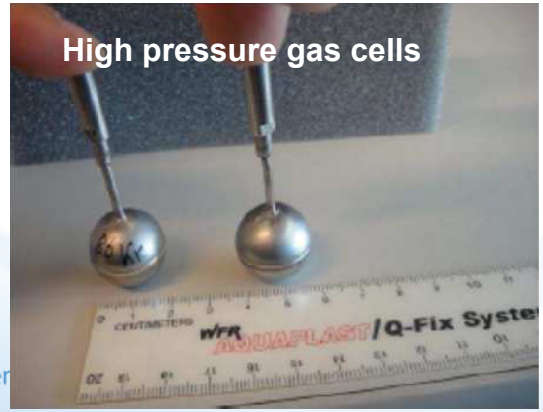
# Evaluation is heroic effort of one summer student

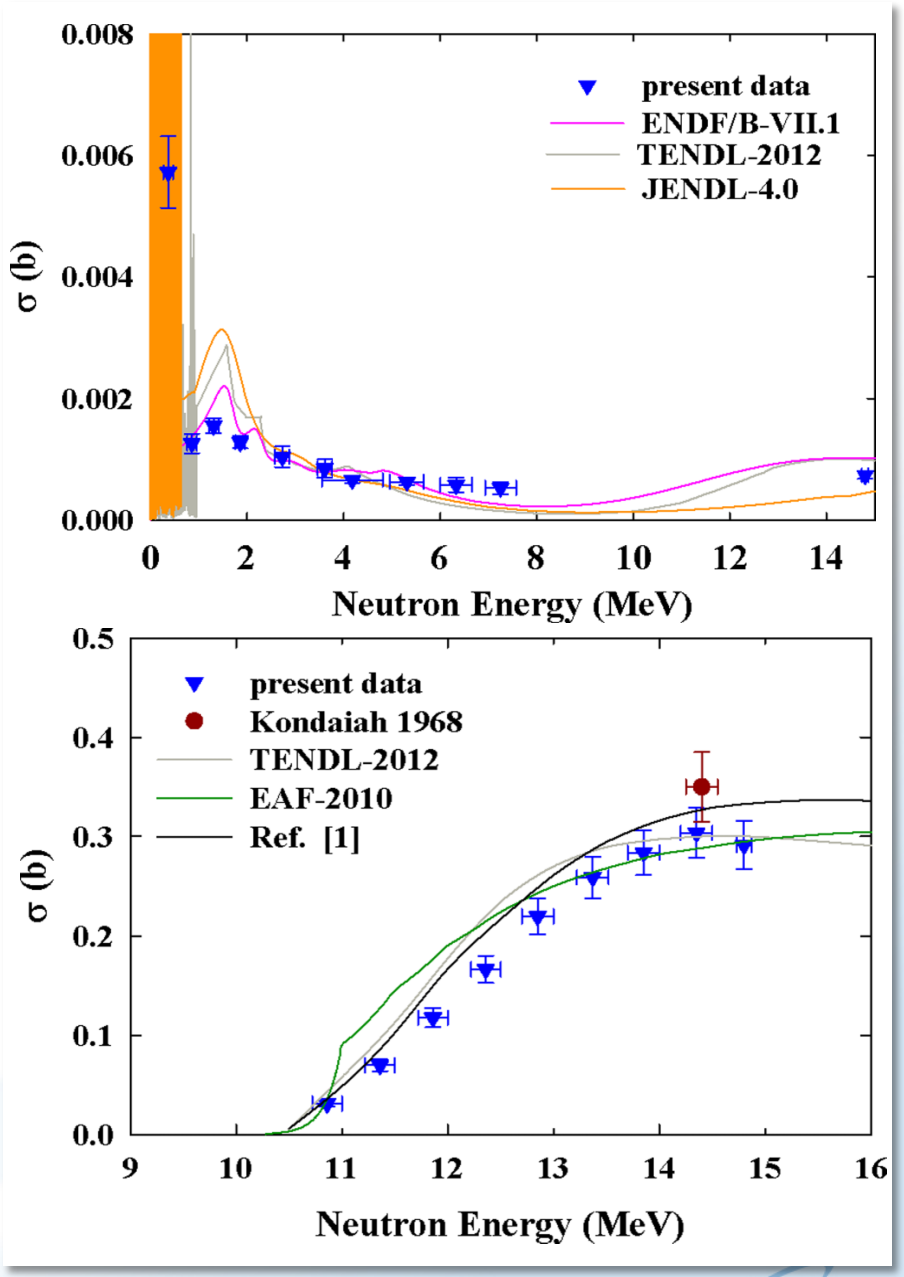
- Elizabeth Rubino
- Graduated from Florida Atlantic University in 2015
- Just started graduate school at Florida State University
- SULI student at NNDC over summer
- Hopefully not traumatized by summer experience



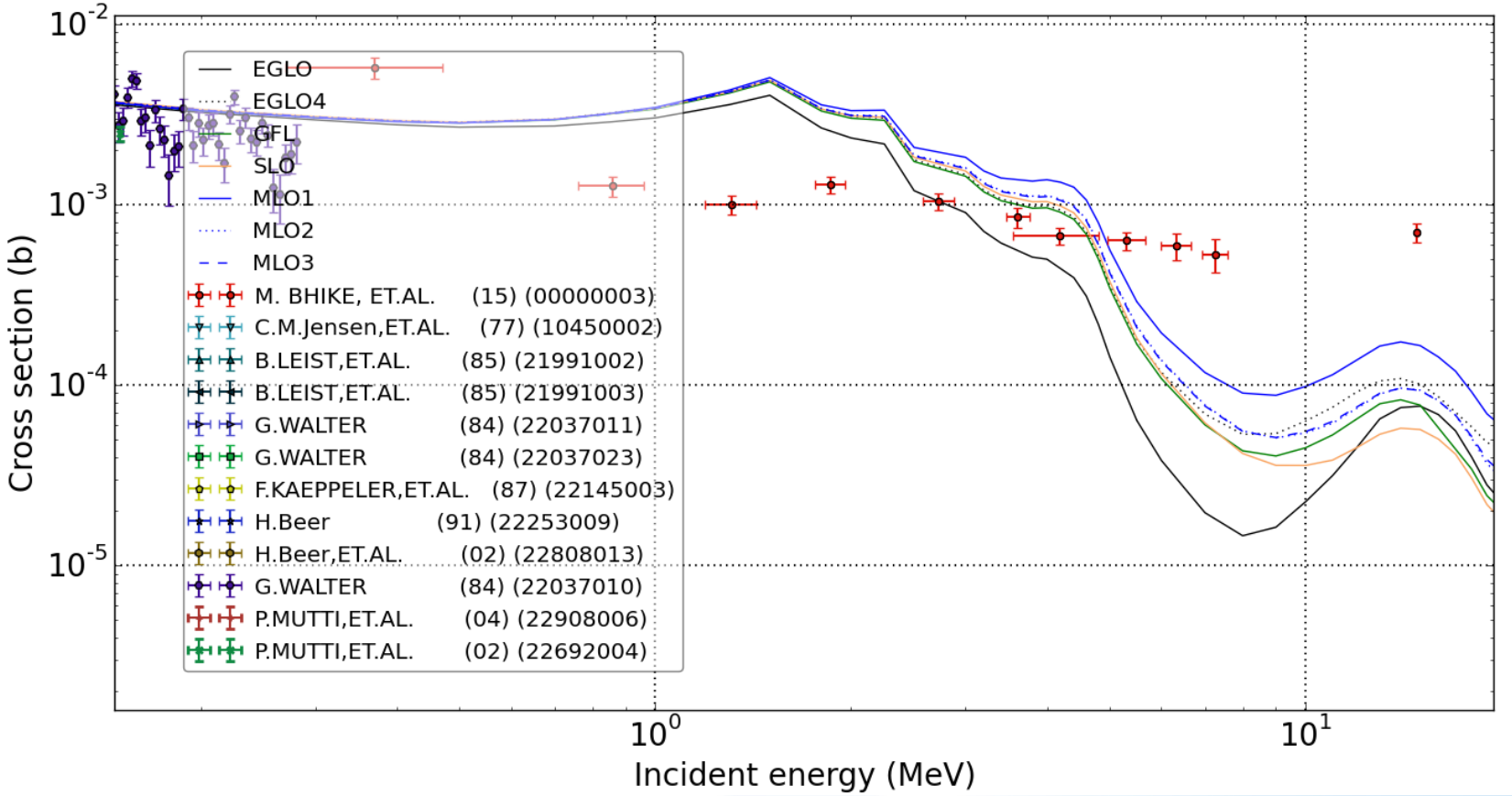
# M. Bhike *et al.*, Phys Rev. C 92 014624 (2015)

- Three sets of mono-energetic beams from $^{3}H(p,n)^{3}He$, $^{2}H(d,n)^{3}He$, $^{3}H(d,n)^{4}He$ reactions
- Determined by activation:
  - $^{87}Kr \rightarrow {}^{87}Rb$ for (n,g),
  - $^{86m}Kr$ for (n,2n)
- Reactions monitored with
  - $^{115}In(n,g)^{116m1}In$
  - $^{197}Au(n,2n)^{196}Au$



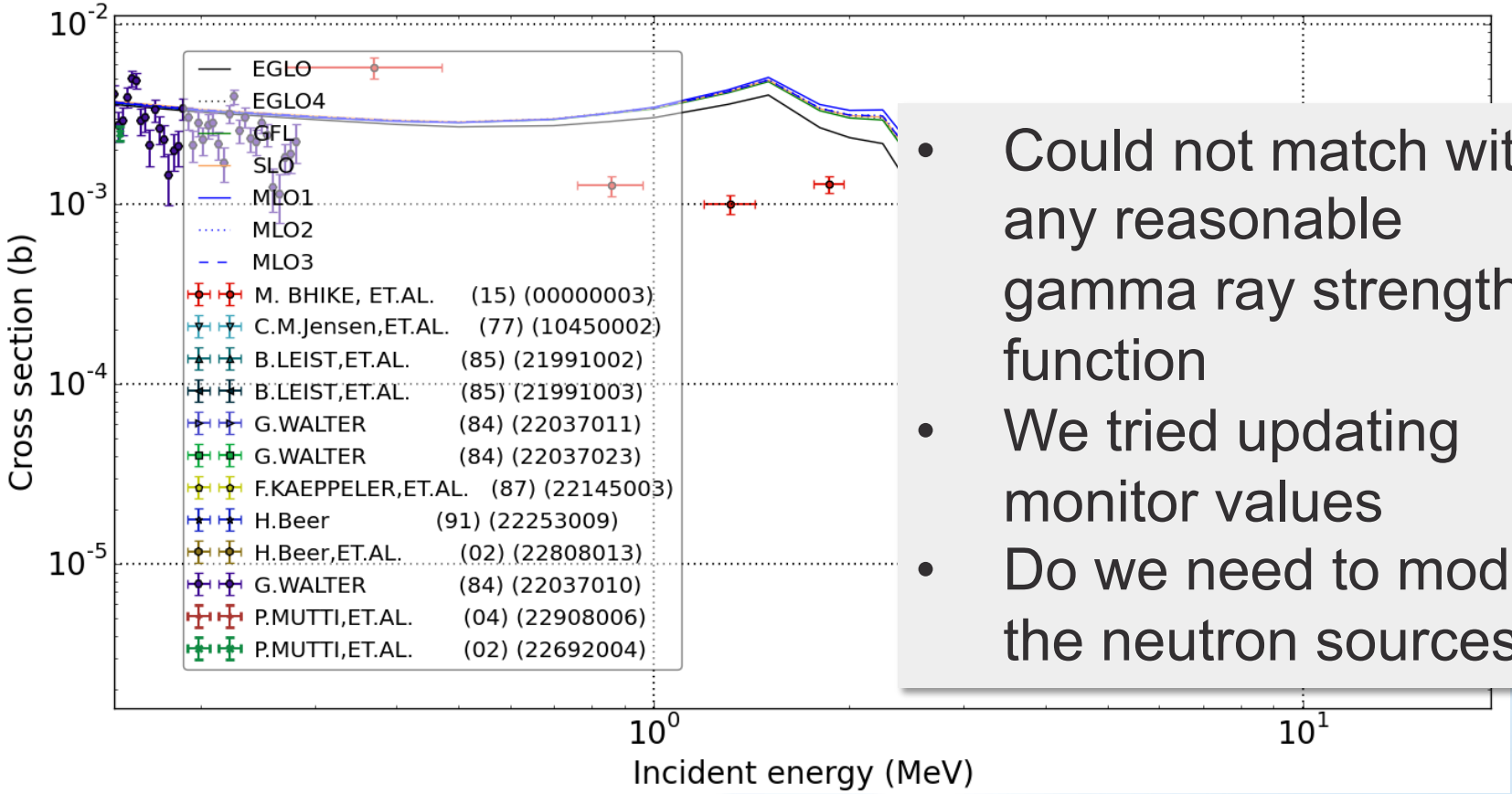



# We could not match (n,g), we suspect a data problem




- 14 MeV data point a bit low (~0.7 mb)
- Other points way too flat

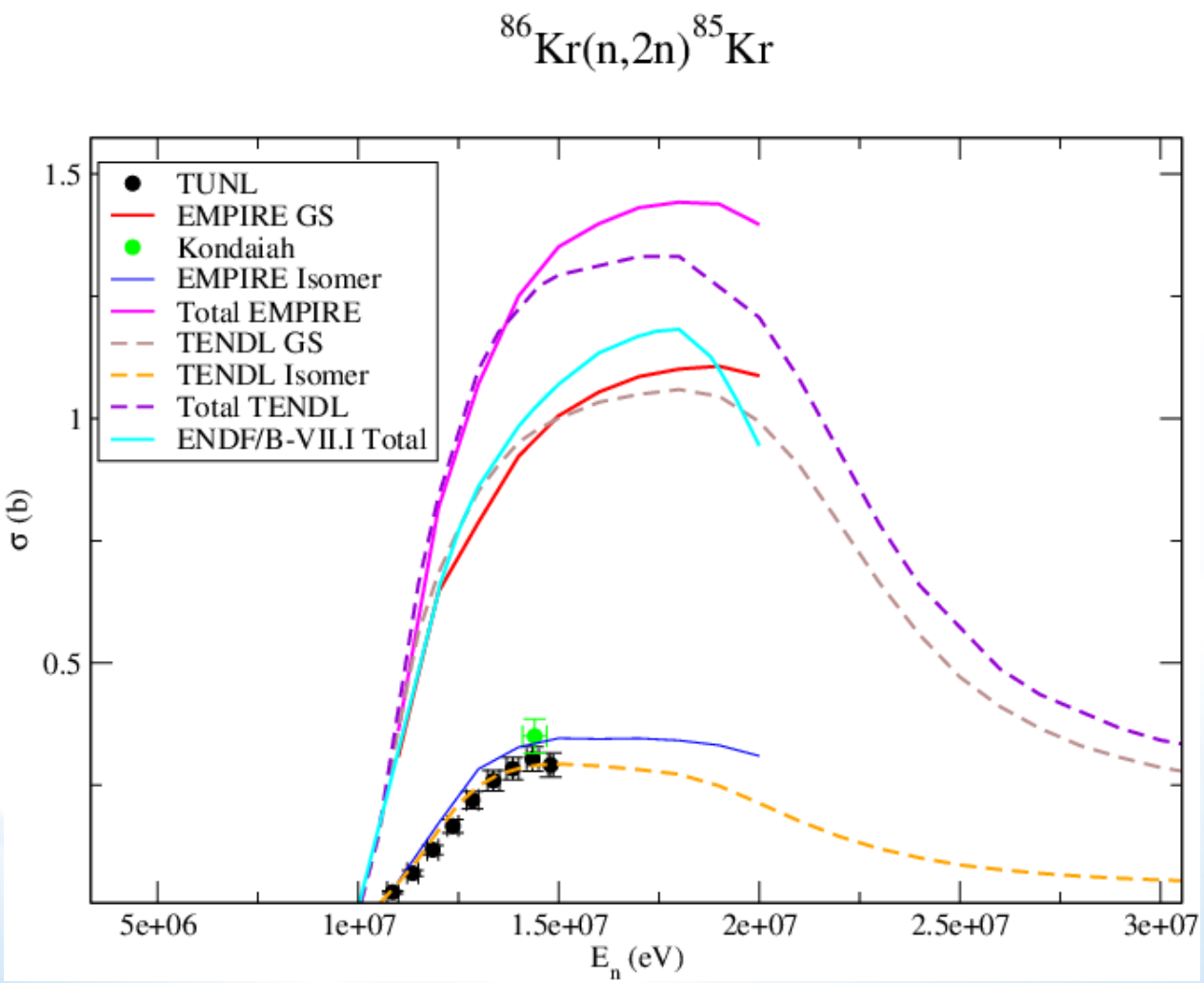
# We could not match (n,g), we suspect a data problem




- Could not match with any reasonable gamma ray strength function
- We tried updating monitor values
- Do we need to model the neutron sources?

- 14 MeV data point a bit low (~0.7 mb)
- Other points way too flat

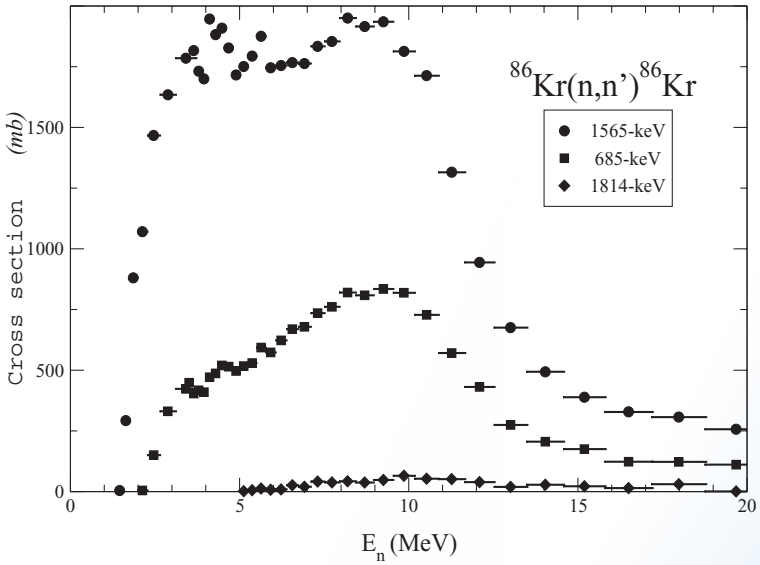
# $^{86}$Kr(n,2n) pretty good (no EMPIRE tuning yet!)

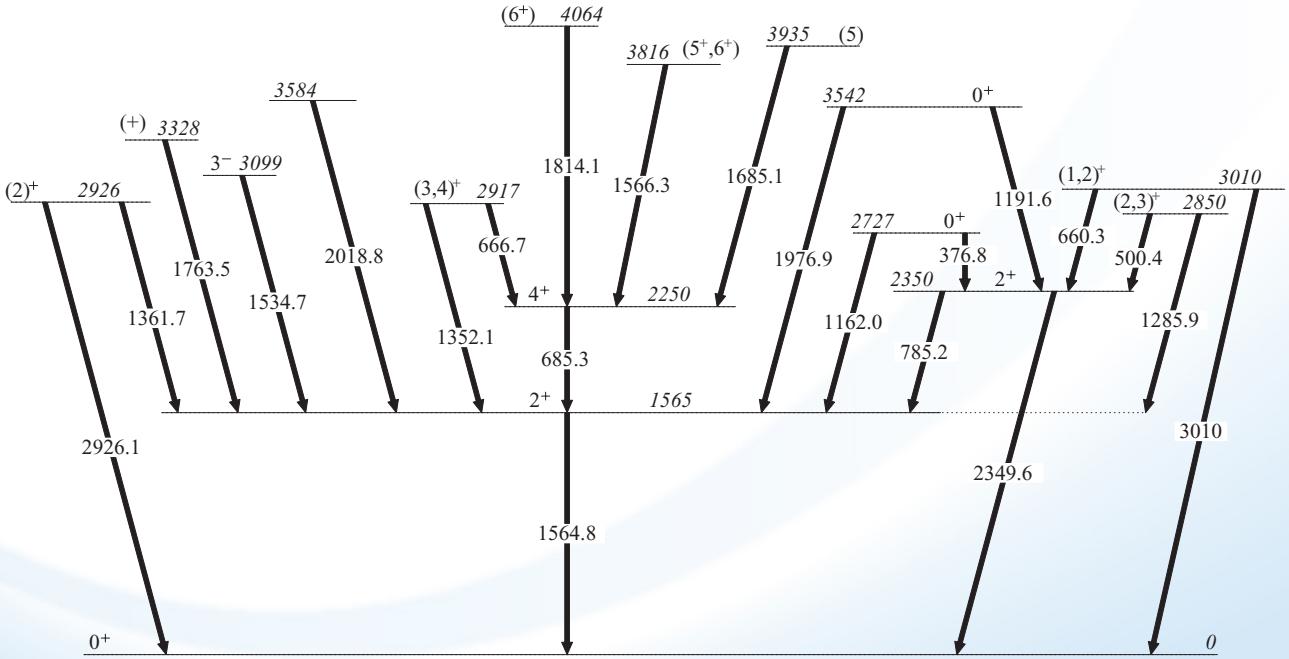



Not clear if undiagnosed experimental problems impact agreement with TUNL data here

# Fotiades, *et al.* Phys. Rev. C 87, 044336 (2013)

- Partial gammas cross sections measured with GEANIE array at LANSE

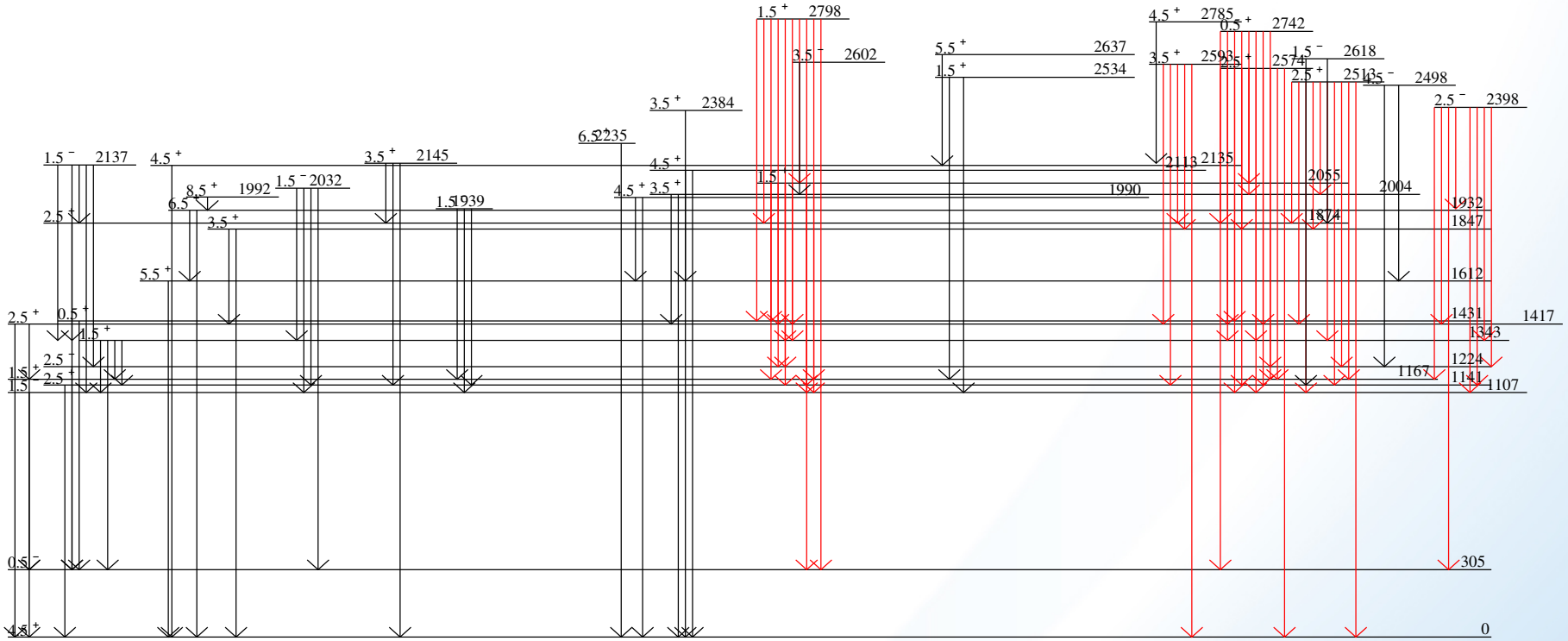


# To match partial $\gamma$ data, need complete level scheme as high as possible

- Completed level $J^{\Pi}$'s up to level #40; EMPIRE cannot extend the level scheme past ENDF max.
- Added BR's based on single particle systematics, added new $\gamma$'s for 6.
- From ENSDF, found average values
  - B(E1) = 6.823 ±1.450,
  - B(E2) = $9.398\times10^{-7}\pm 2.534\times10^{-4}$,
  - B(M1) = 0.2046 ± 0.1442
- Above, needed to tune level density

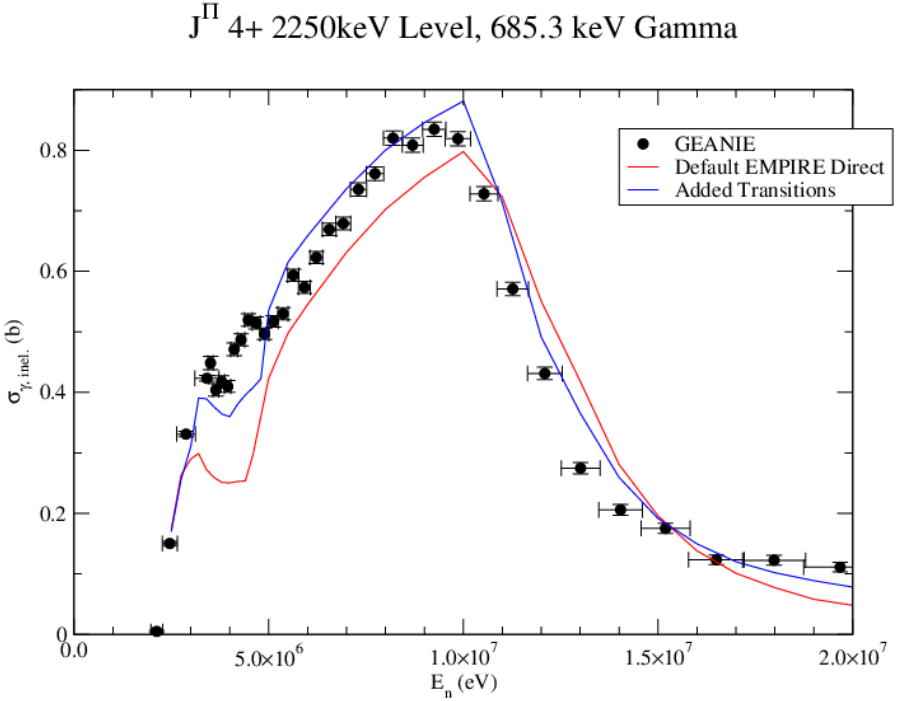
# Revised level scheme w/ new γ's

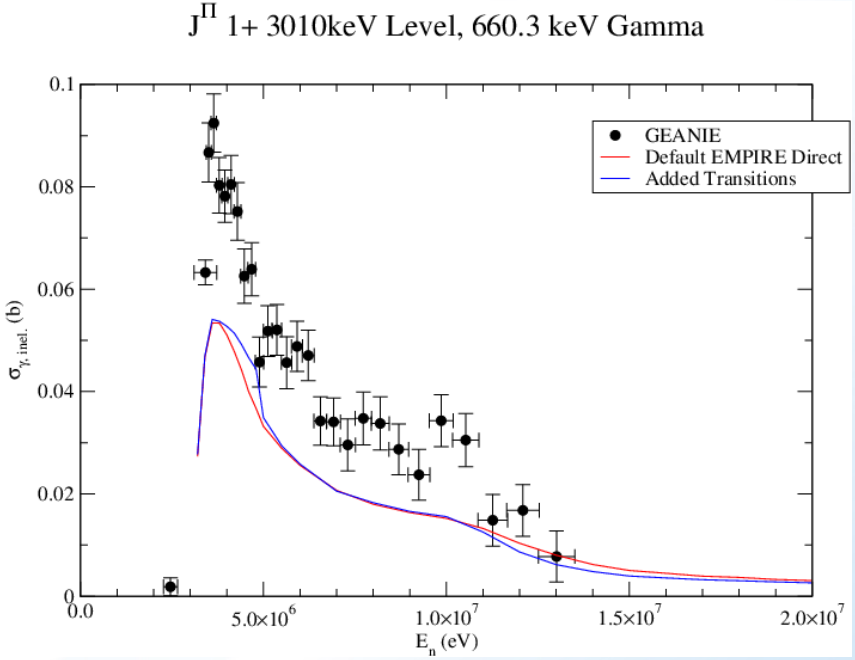



New γ's don't feed right levels enough to help much

Red γ's with fake BR's
Black other γ's

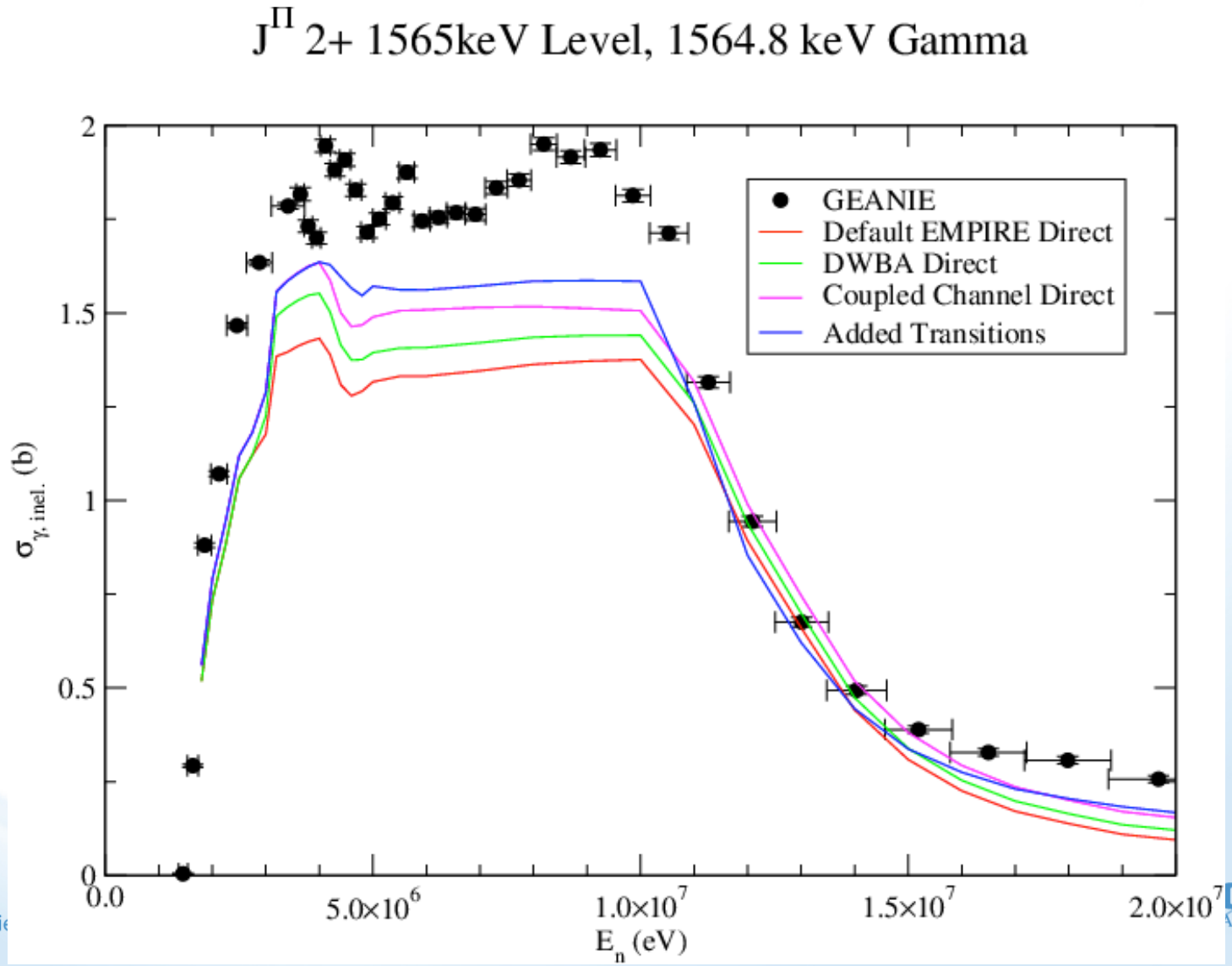
# Agreement with gammas hit-and-miss



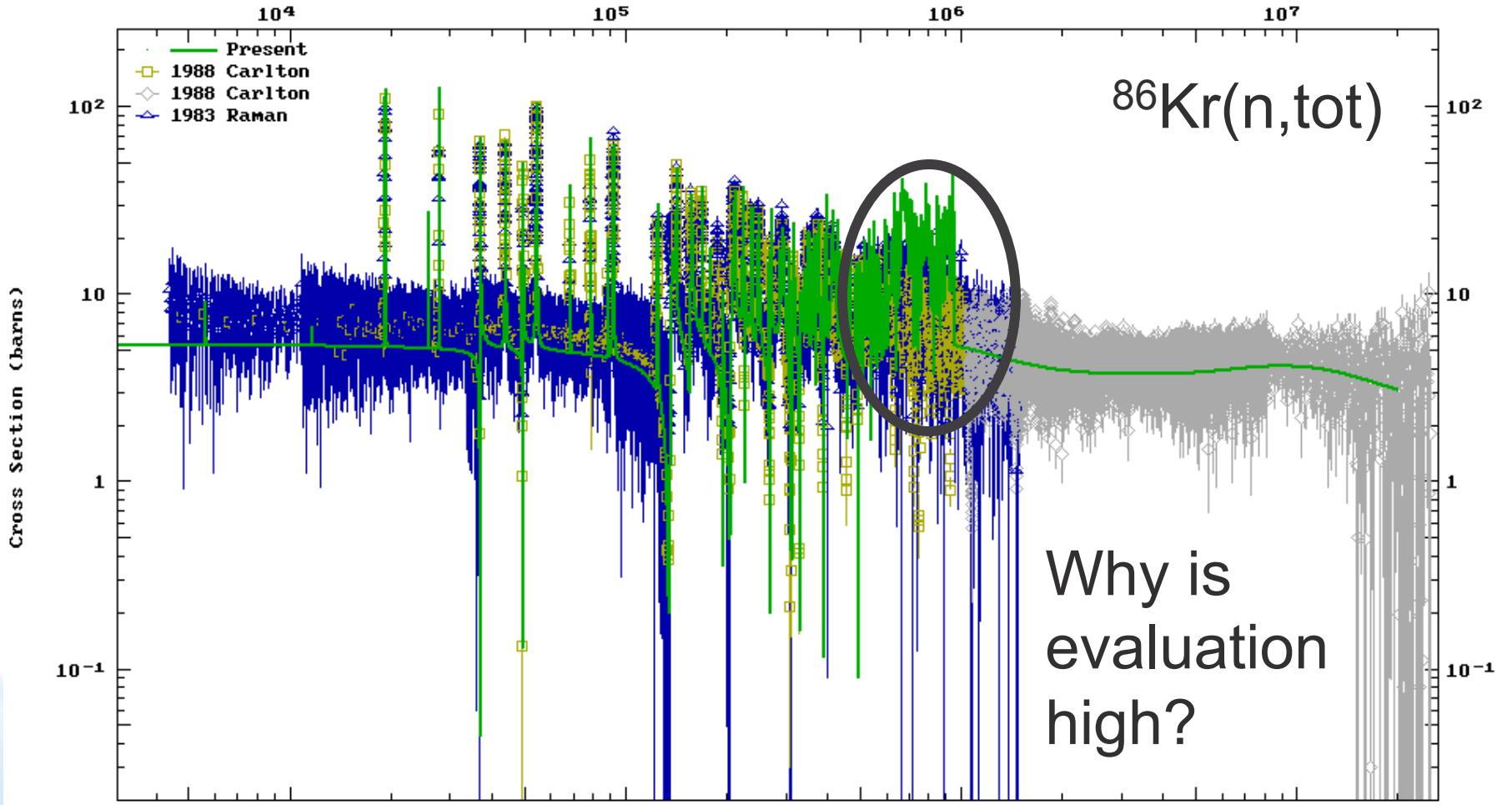




- Shape not terrible
- New BR's have only modest impact in many cases
- Suggests problem with spin-dependence of LD

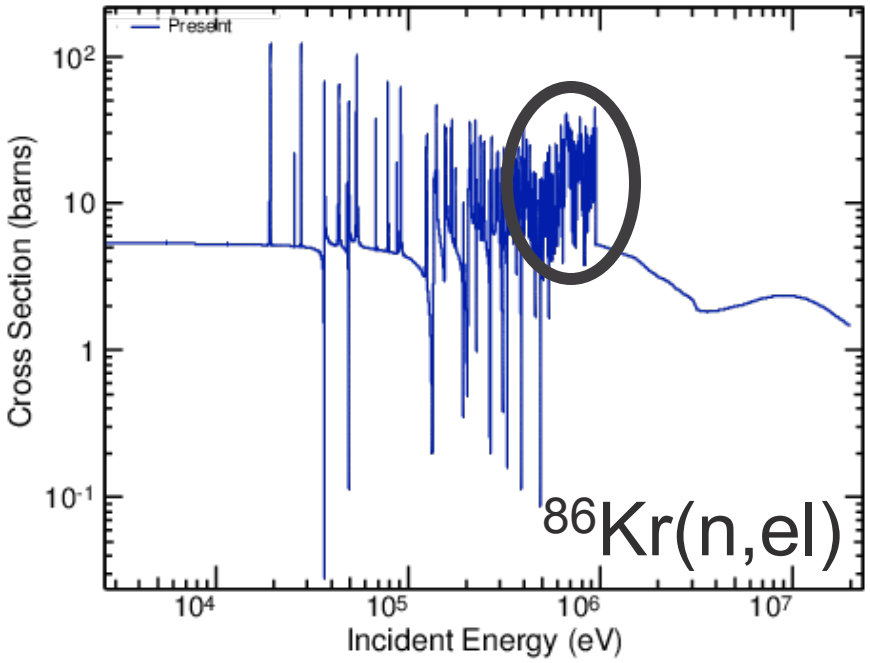
# That said, this data was important to determine how important direction reactions are in this case

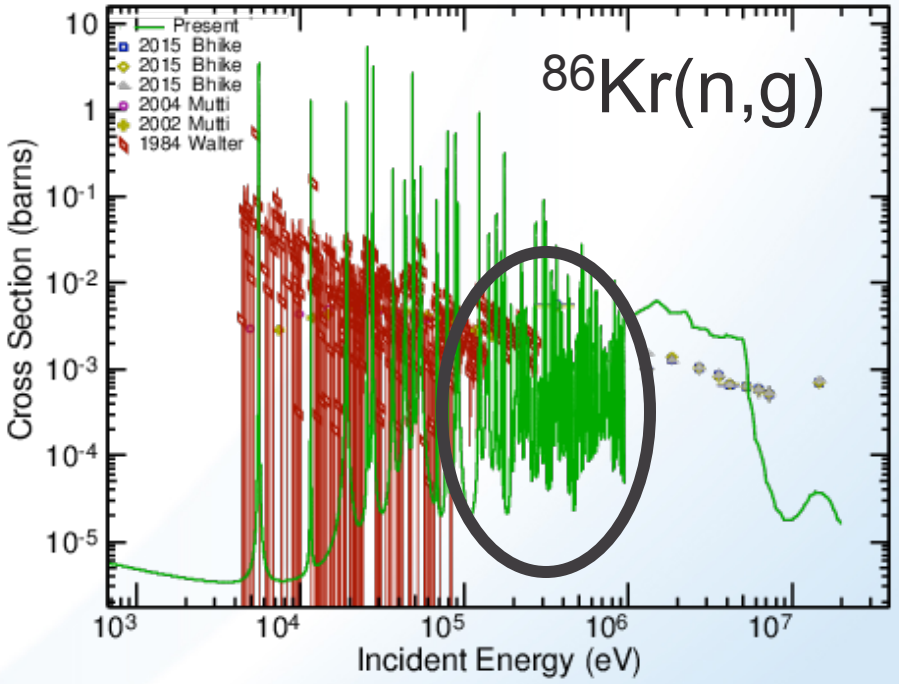


# Resonances also need a lot of work



# Appears to be driven by (n,el), but it impacts (n,g) too



# Conclusion

- **Evaluation fubar:**
  - (n,g) in fast region can't be matched to data
  - (n,n') can't be matched without a lot more effort, need detailed structure information
  - RRR messed up, must dig further
  - (n,2n) looks good, but I don't trust it
- **This is not the right project for a SULI student, no matter how good she is**
- **And, when we get an evaluation, how do we test it?**