Estimation of neutron cross-sections for ^{16}O up to 5.2 MeV through R-matrix analysis

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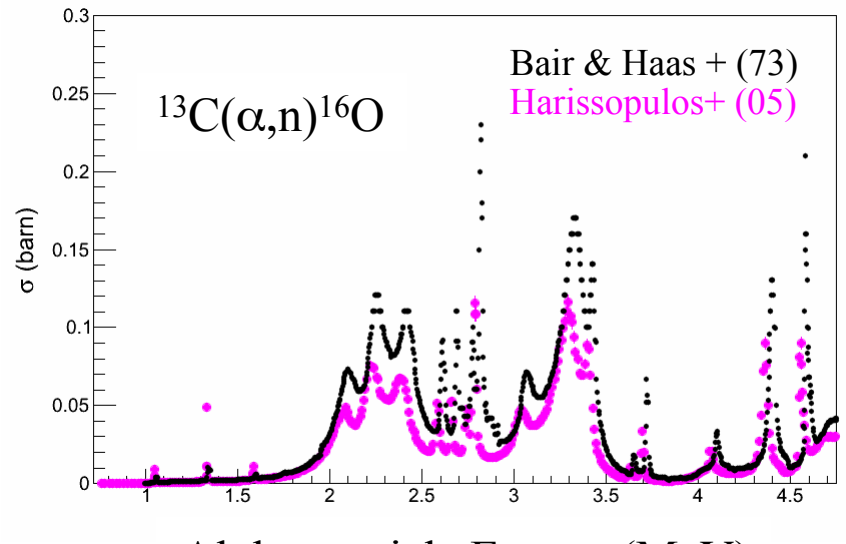
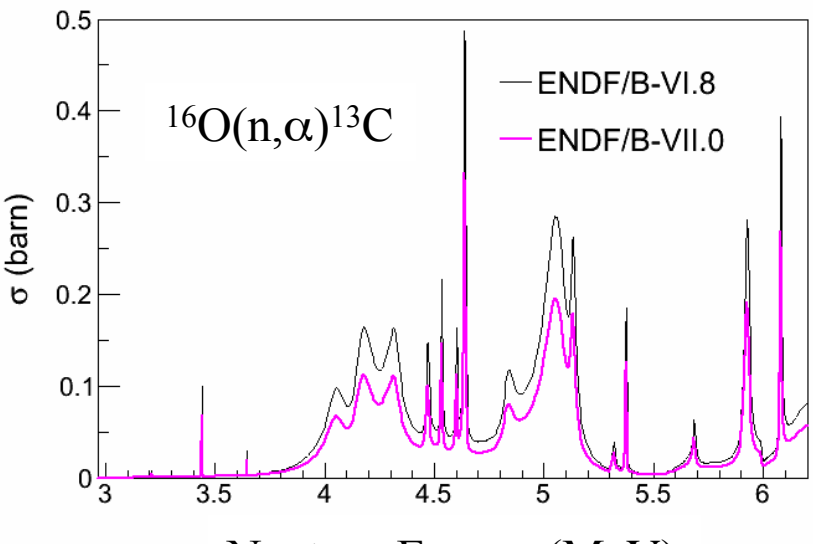
Motivation -I

Large difference in (n,α) or (α,n) cross sections



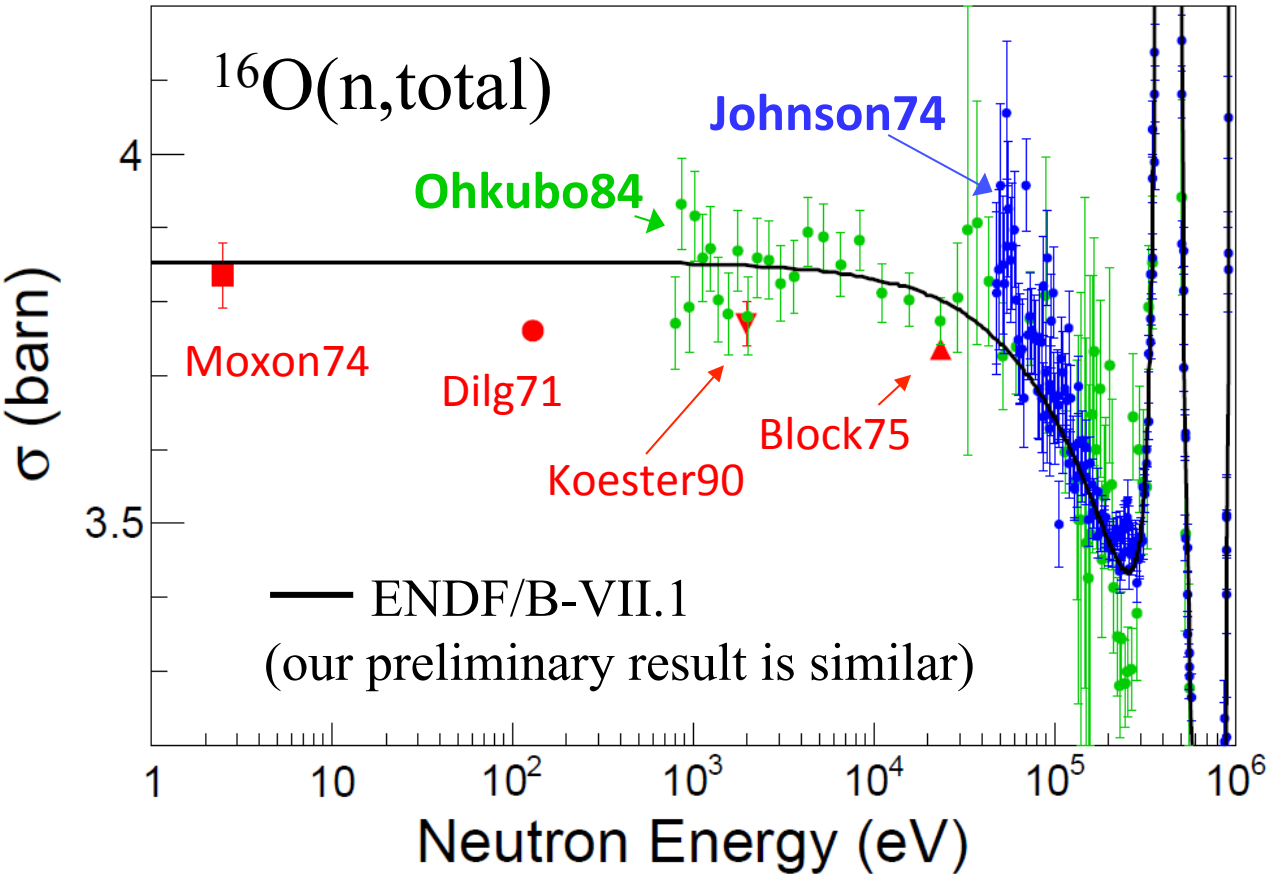


More than 30% of differences are seen between the measurements

Affect criticality benchmark calculations slightly

Motivation -II

Issue in lower energy region



Thanks :
A. Plompen
C. Lubitz

- difference among the measurements (~3% or more)
- Ohkubo84, Johnson74 have <u>plausible amount of hydrogen</u>

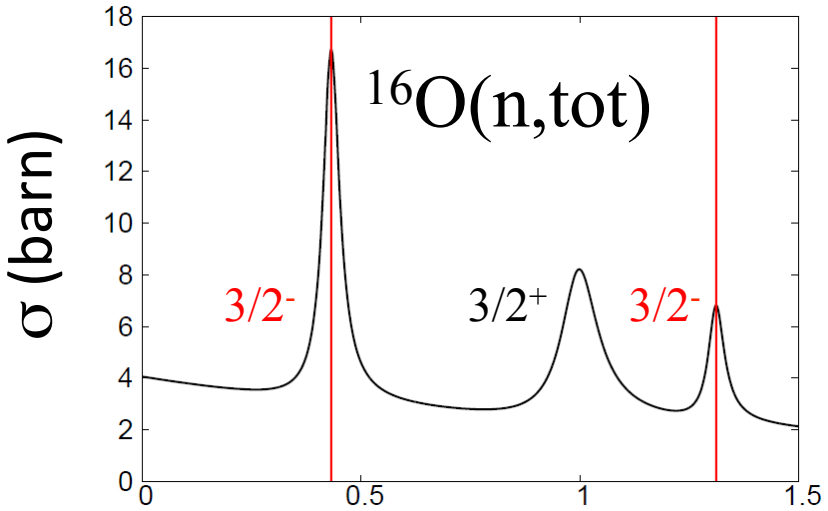
Purpose

Solve/reduce those issues

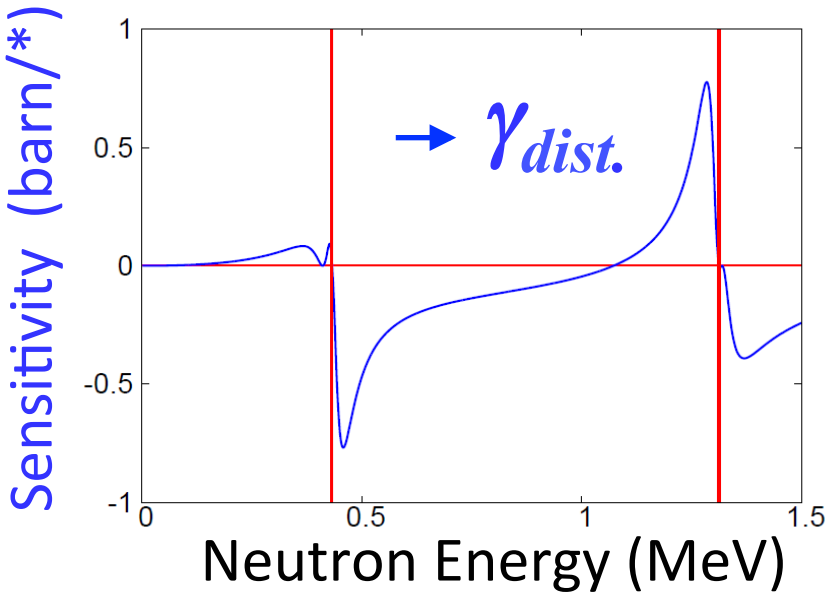
-> R-matrix analysis to measurements

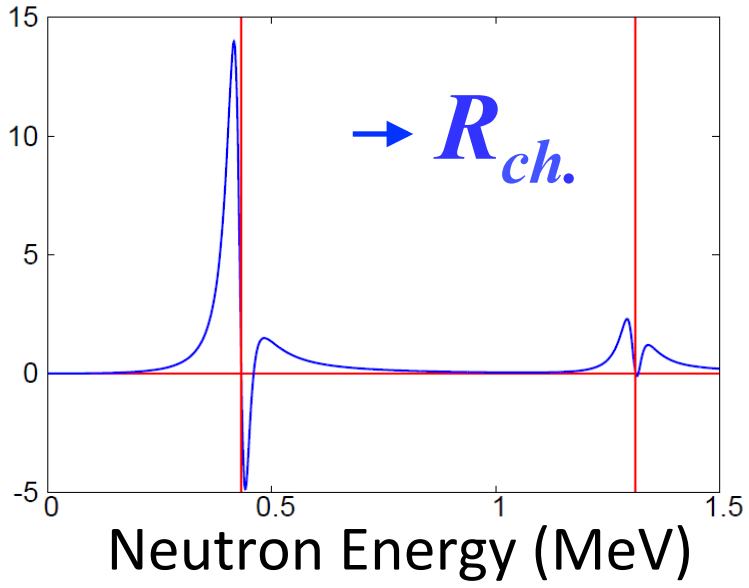
- Experimental knowledge
- Theoretical knowledge

Physical Constraint from R-matrix



Sensitivity of all the R-matrix parameter is always "zero" at peak positions due to the "unitarity limit" of S-matrix

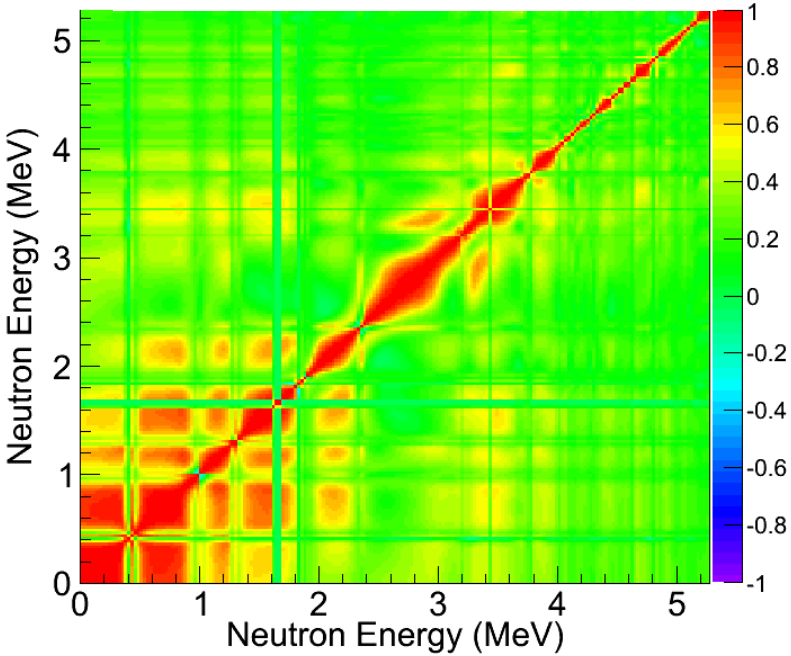




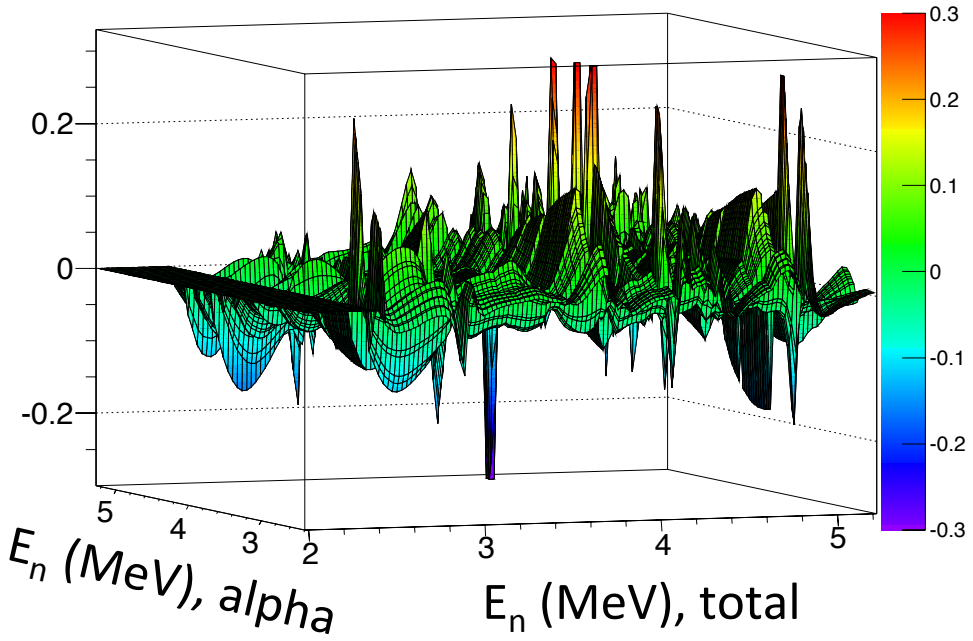
Physical Constraint from R-matrix -II

Correlation matrices

Total cross-section



Total v.s. (n,α)

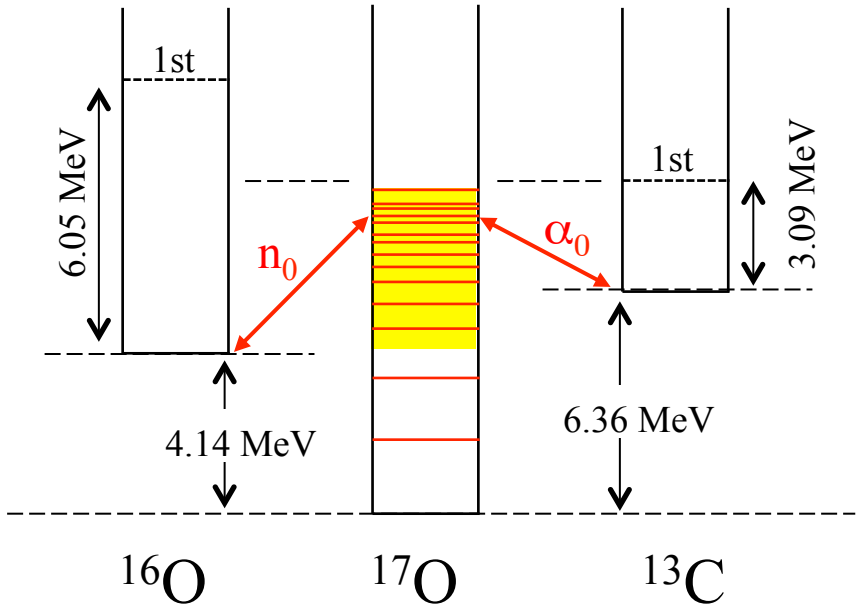


- Traces of the unitary limit
- Certainly there are "correlations"

R-matrix Analysis for ^{17}O system

Code : AMUR

- Wigner-Eisenbuds' formalism
- Charged-particle reaction
- Generalized least-square method
- KALMAN method



- Neutron energy : $E_n \leq 5.2$ MeV
- Two partitions : $(n+^{16}O_{g.s.})$ and $(\alpha+^{13}C_{g.s.})$
- Levels in ^{17}O : ENSDF + negative/distant levels

Measurements Adopted

Reaction	Author	Year	Lab.	Adopted range
O(n,total)	Cierjacks+	1968	KIT	$0.5\ MeV < E_n < 5.2\ MeV$
	Schrack+	1972	NBS	$0.5\ MeV < E_n < 5.2\ MeV$
	Perey+	1972	ORNL	$0.5\ MeV < E_n < 5.2\ MeV$
	Johnson+	1974	ORNL	$50\ keV < E_n < 5.2\ MeV$
	Cierjacks+	1980	KIT	$3.1\ MeV < E_n < 5.2\ MeV$
$^{16}O(n,total)$	Ohkubo	1984	JAEA	$1\ keV < E_n < 940\ keV$
$^{13}C(\alpha,n)^{16}O$	Harissopulos+	2005	RUB	$E_{thre} < E_\alpha < 3.5\ MeV$
$^{16}O(n,\alpha)^{13}C$	Giorginis+	2007	IRMM	$3.9\ MeV < E_n < 5.2\ MeV$

Cross-sections only (preliminary)

Parameters to be fitted

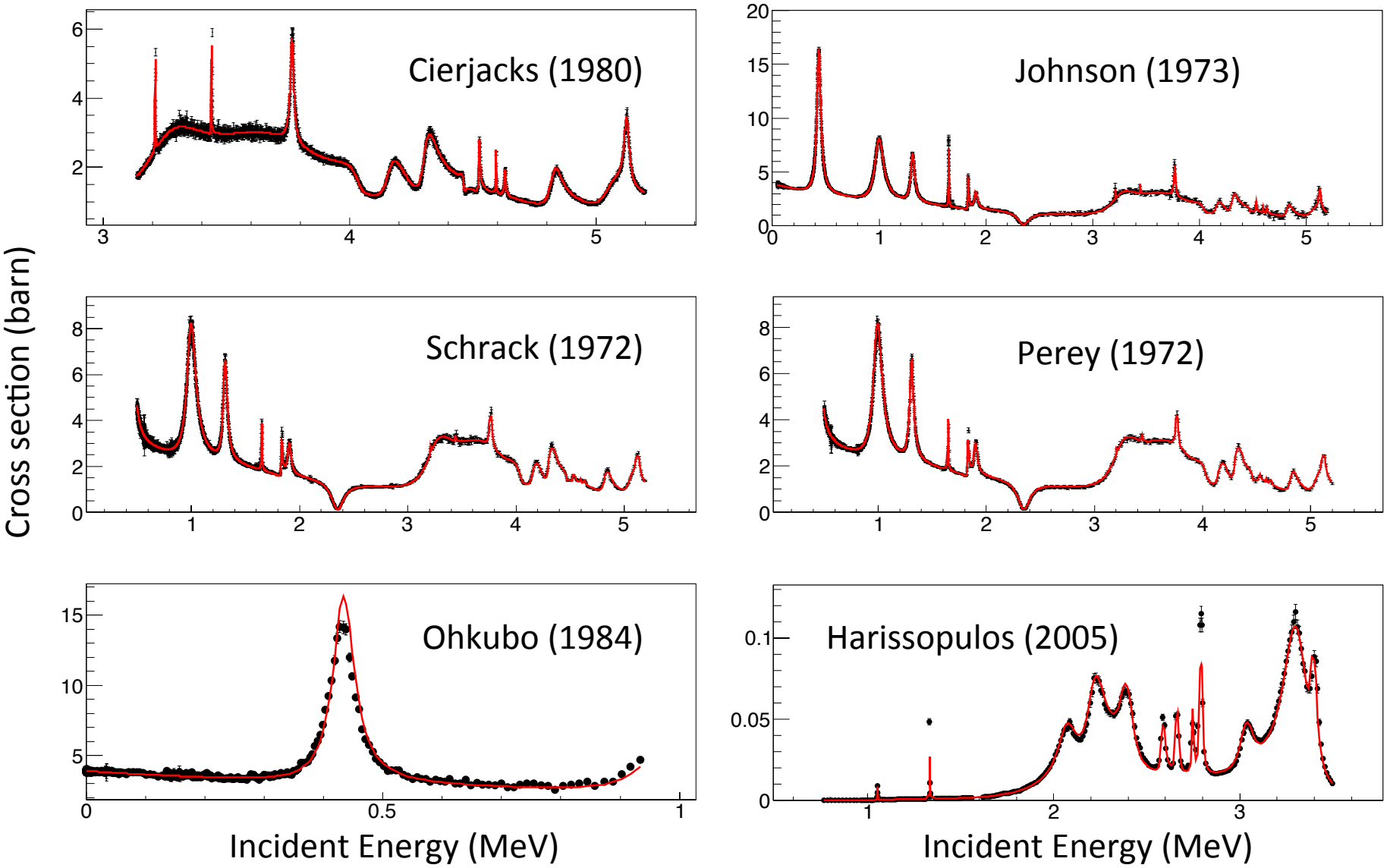
R-matrix parameters

- Channel radii (dependent on *l* and partition)
- Reduced width amplitudes
- Energy eigenvalues (level energies of ^{17}O)

Experimental parameters

- Renormalization (EDA method, unitarity constraint)
- Hydrogen content in Ohkubo84 and Johnson74
  (the shape of σ_H is taken from ENDF/B-VII.1, G.Hale)
- Resolution (preliminary, to be shown later)

Results of R-matrix fit (examples)



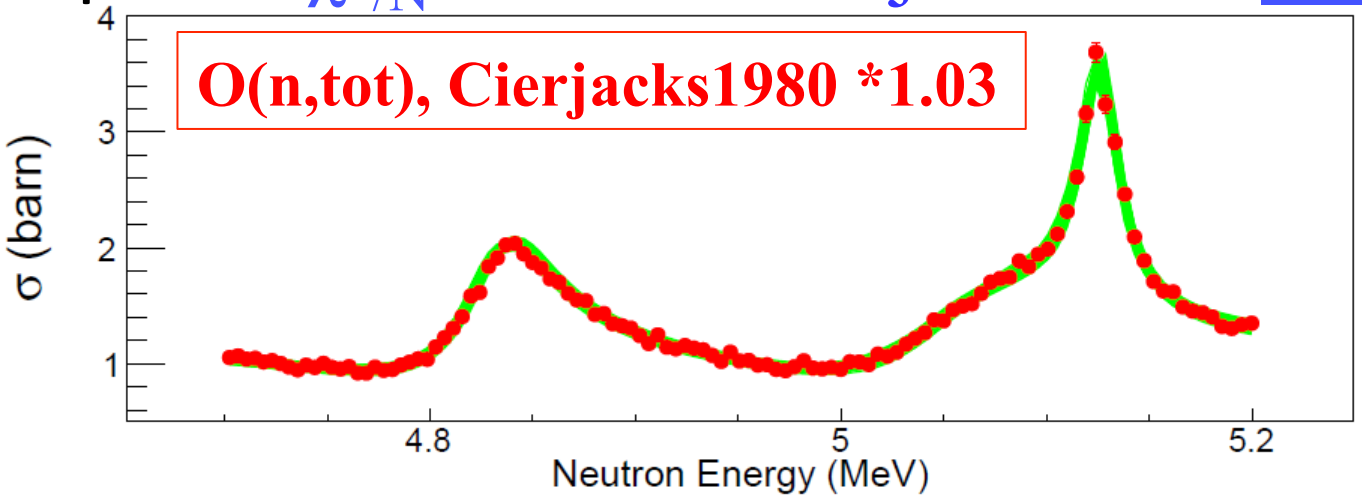
Renormalization

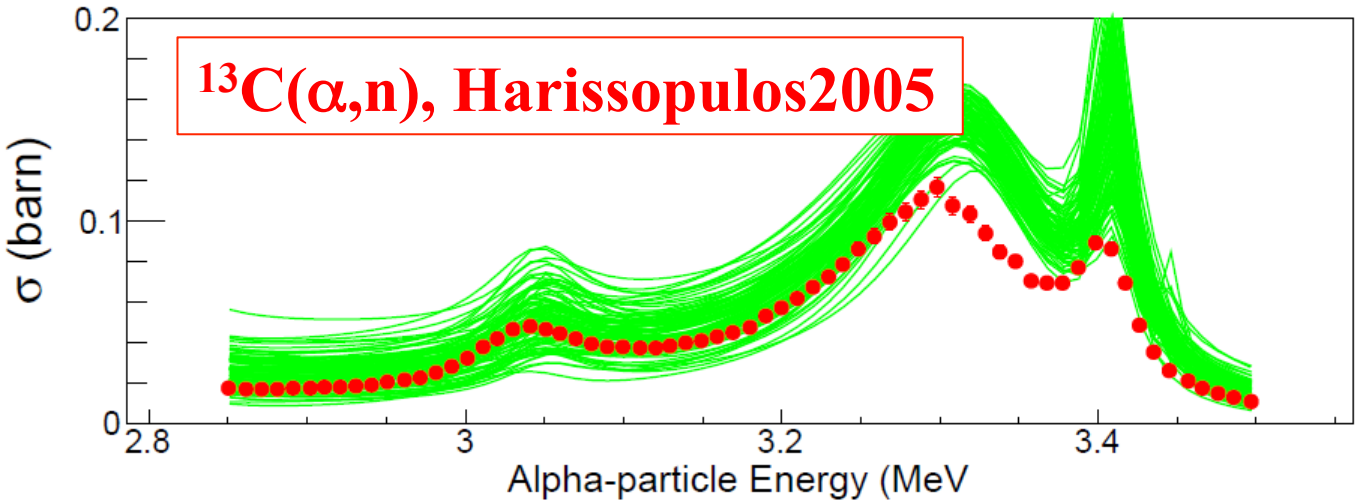
Reaction	Measurement	χ^2/N	Renormalization to measurement
O(n,total)	Cierjacks68+	2.48	0.967 ± 0.15%
	Schrack+	1.31	0.982 ± 0.09%
	Perey+	1.75	0.996 ± 0.09%
	Johnson+	1.54	1.018 ± 0.09%
	Cierjacks80+	1.39	1.032 ± 0.35%
^{16}O(n,total)	Ohkubo	1.90	0.997 ± 0.02%
^{13}C(α,n)^{16}O	Harissopulos+	9.24	1.521 ± 1.14%
^{16}O(n,α)^{13}C	Giorginis+	-2.98 (limited points)	1.487 ± 1.31%

Renormalization is large both for (α,n) and (n,α)

R-matrix parameters are "randomly" generated

Imposed $\chi^2_{/N} < 4.0$ for Cierjacks1980 *1.03

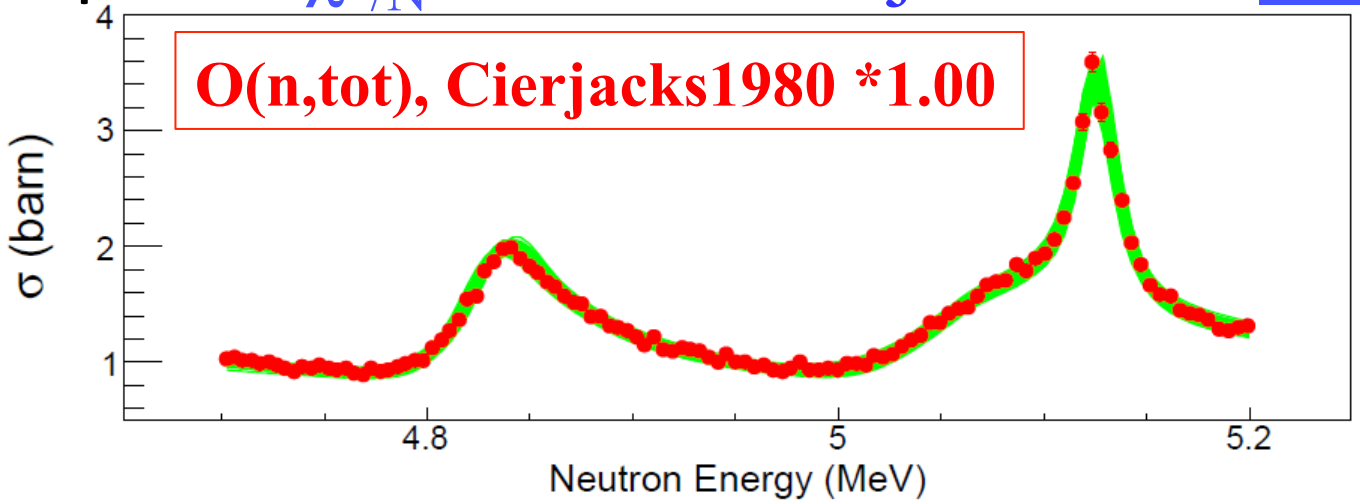


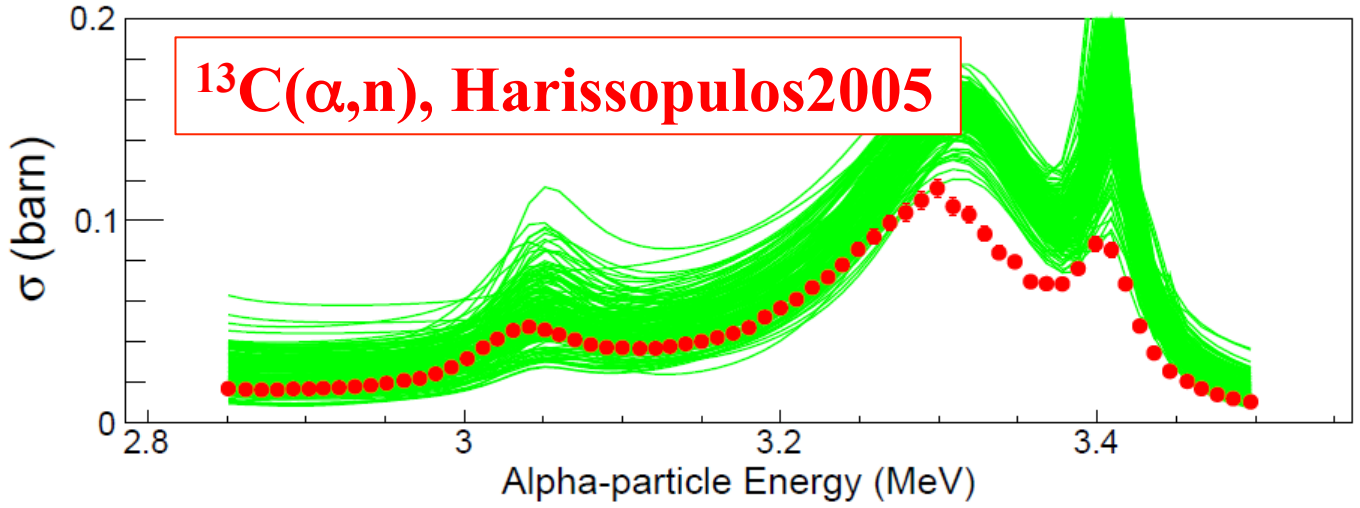


reasonable solutions are NOT found for $^{13}C(\alpha,n)^{16}O$

R-matrix parameters are "randomly" generated

Imposed $\chi^2_{/N} < 5.0$ for Cierjacks1980 *1.00





Situation is similar, but seems rather worse

Experimental Resolution (preliminary)

Reaction	Measurement	L (m)	Δt/L (ns/m) fixed	ΔL/L searched
O(n,total)	Cierjacks (68)	57.5	0.063	0.00269 ± 3.2%
	Schrack (72)	40.0	0.100	0.00489 ± 2.0%
	Perey (72)	47.4	0.120	0.00423 ± 2.1%
	Johnson (74)	198.3	-	0.00097 ± 3.9%
	Cierjacks (80)	189.3	0.016	NA
^{16}O(n,total)	Ohkubo (84)	47.0	-	NA

Reasonable ??

Reaction	Measurement	Const. FWHM (keV)	
		Searched	Literature
^{13}C(α,n)^{16}O	Harissopulos+	34.6 ± 3.3%	suggested 13 ~ 39
^{16}O(n,α)^{13}C	Giorginis+	Fixed to literature value	

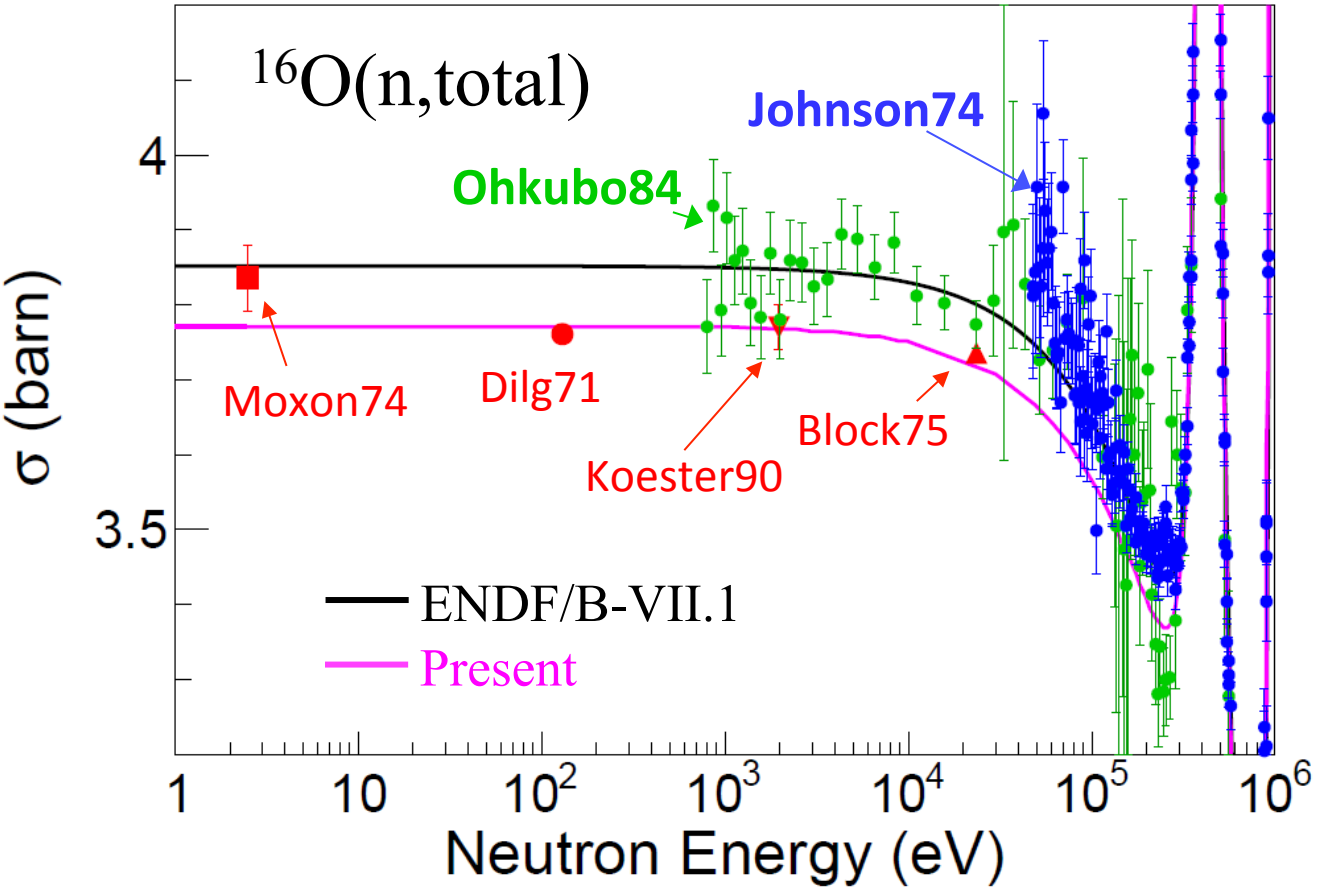
Plausible Hydrogen Contents

Reaction	Exp.	Ratio to $\sigma_H(E)$	Effective $\sigma_H(E_{thermal})$
(n,total)	Johnson+	0.01665 (± 6.02%)	346 mb (± 21 mb)*
	Ohkubo	0.00988 (± 8.38%)	205 mb (± 17 mb)*

* Uncertainty of hydrogen cross-section from ENDF/B-VII.1 is NOT considered

Plausible hydrogen (effective) cross-sections are obtained with uncertainty < 10%

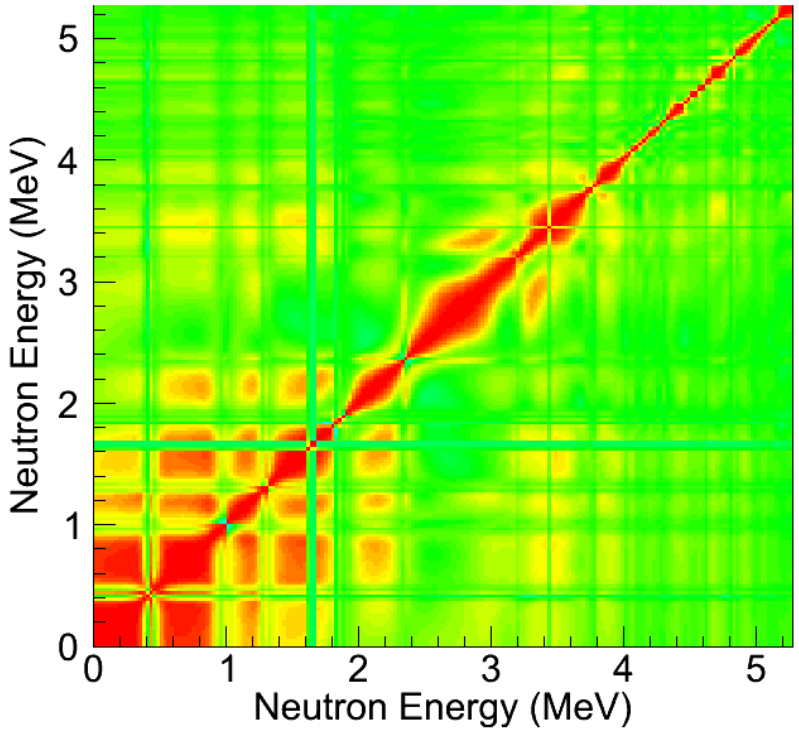
Total Cross-section in Lower-energy



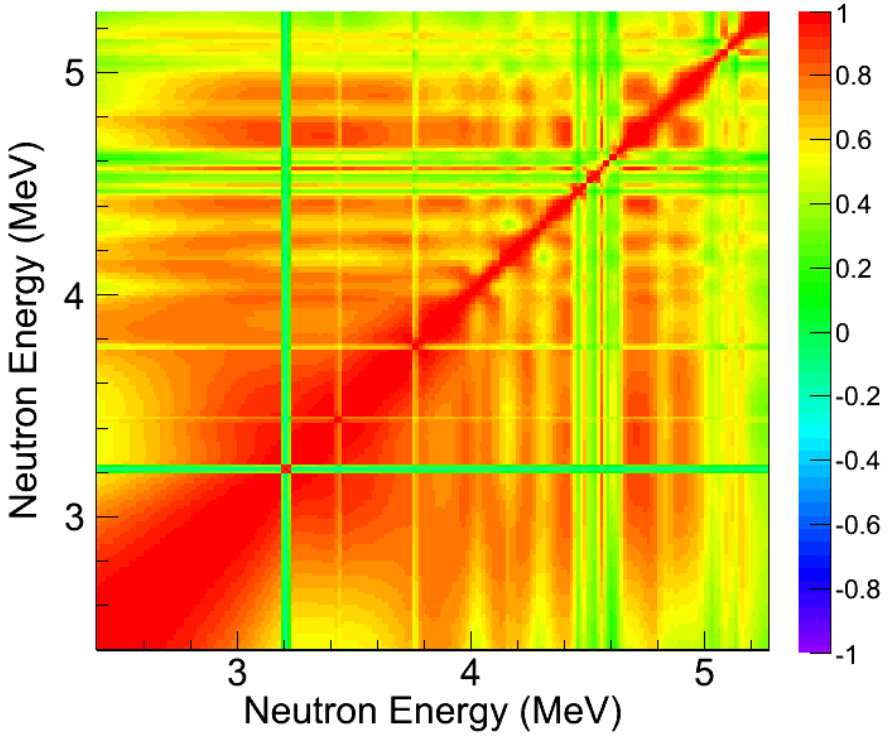
R-matrix cross-section is essentially reduced, as present $\sigma_{thermal}$ is 3.77 (barn) $\pm$ 0.35%

Correlation Matrices

Total

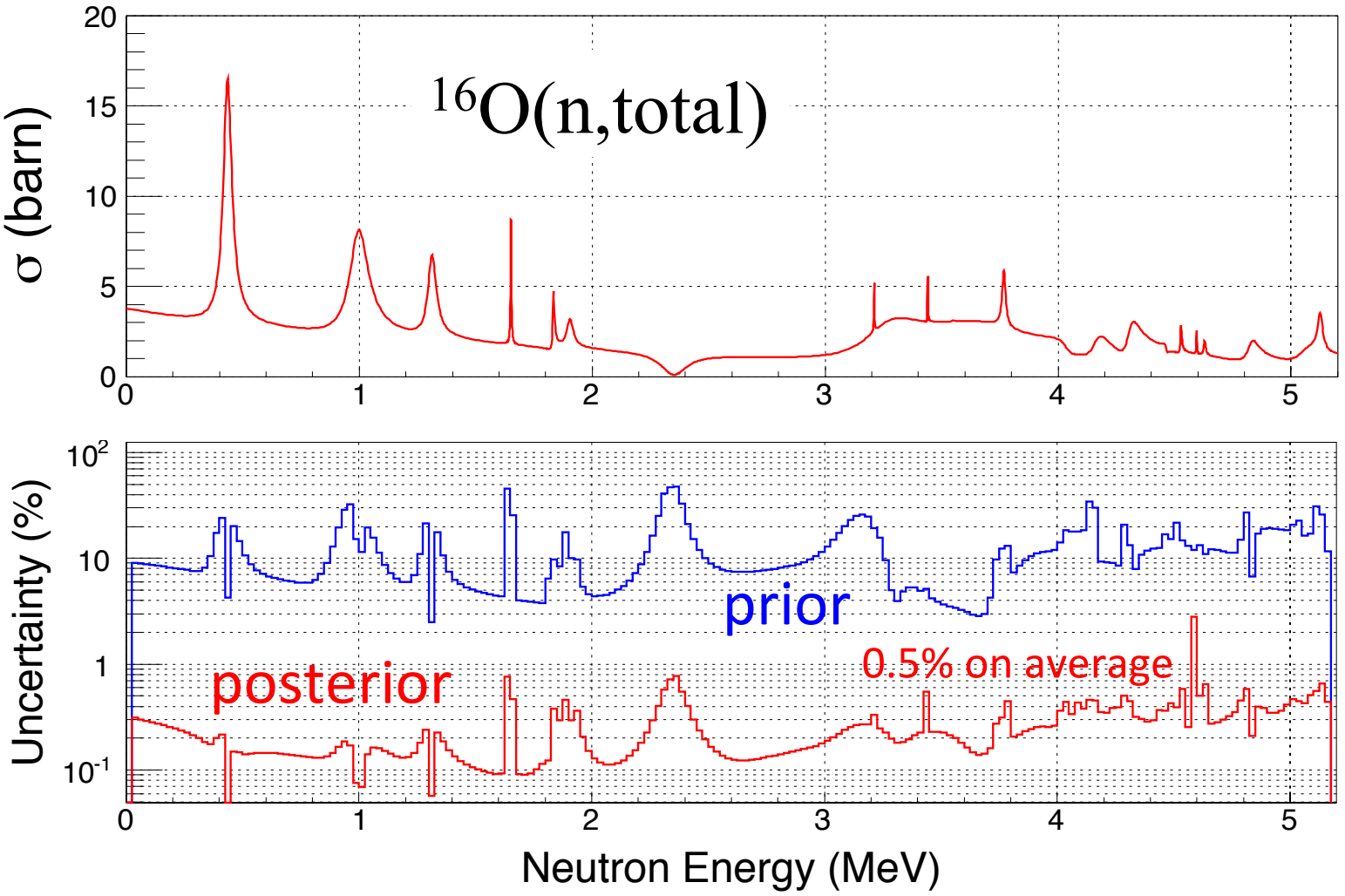


(n,α)

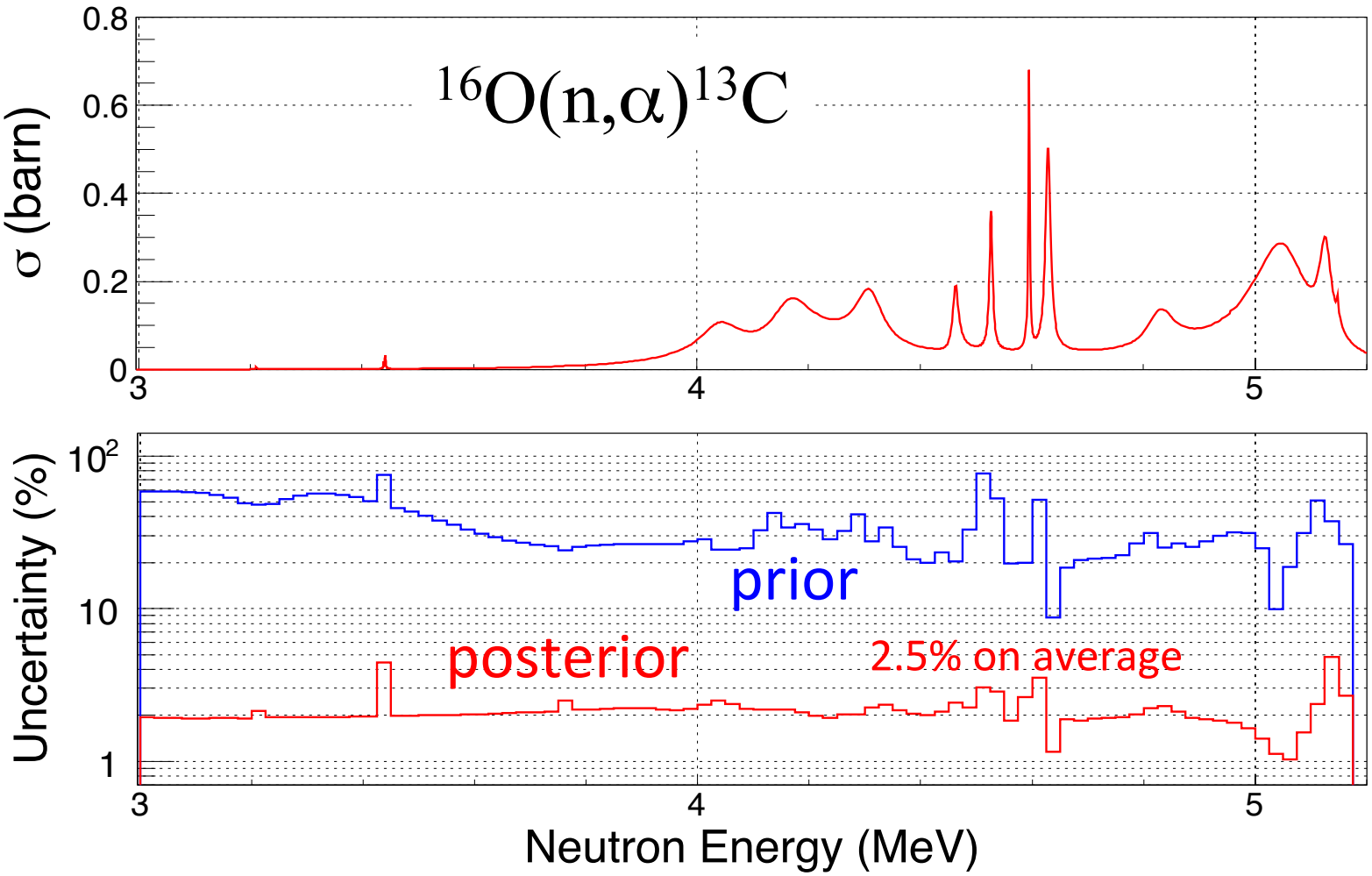


- Traces of the unitary limit
- Long- and medium-range correlations

Total Cross-sections with Uncertainty



(n,α) Cross-sections with Uncertainty



Summary, Preliminary Conclusions

- R-matrix analysis is carried out for ^{17}O system (entrusted the physical constraint)
- A large renormalization is needed for $^{16}O(n,a)^{13}C$ and $^{13}C(a,n)^{16}O$ measurements
- Plausible hydrogen contents are obtained for total cross-sections of Ohkubo84, Johnson74
- Neutron cross-sections are preliminary estimated up to 5.2 MeV with covariance/uncertainty

Tasks Ahead

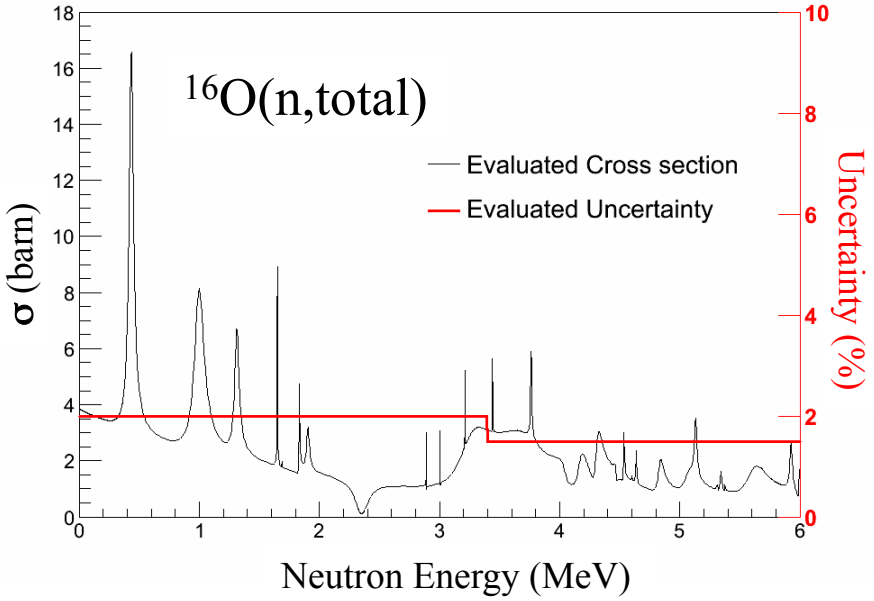
- Extend upper energy limit
- Inclusion of experimental angular-distribution in R-matrix analysis
- Inclusion of gamma-ray channel in AMUR
- Inclusion of another experimental parameter in R-matrix analysis if needed
- Evaluation for fast energy region (Optical model + Hauser-Feshbach ?)

Thank you for attention

Motivation

Uncertainty/Covariance issues

ENDF/B-VII.1



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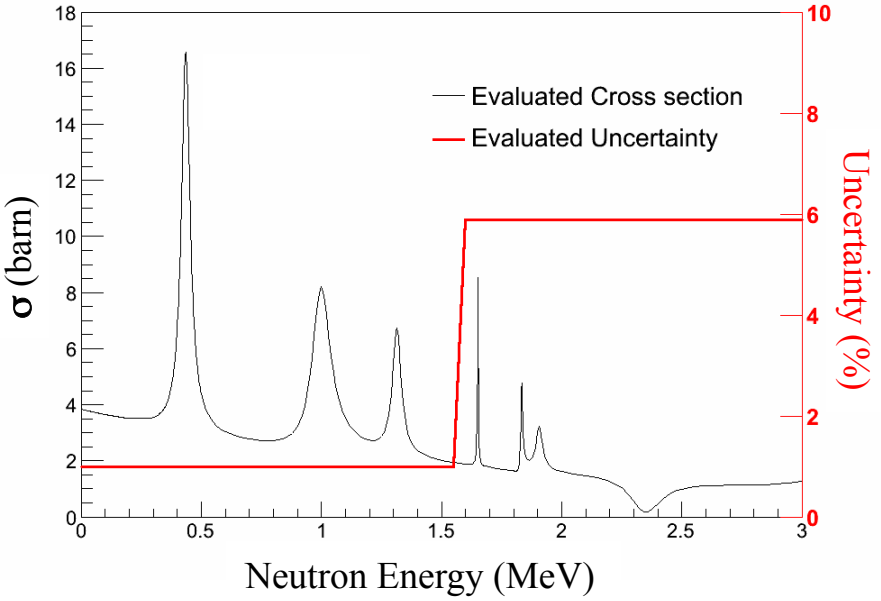

"*Low-fidelity data*" are given in the evaluated files

Heil *et al.*, PRC78 025803 (2008)

$^{13}C(\alpha,n)^{16}O$, S-factor from measurements

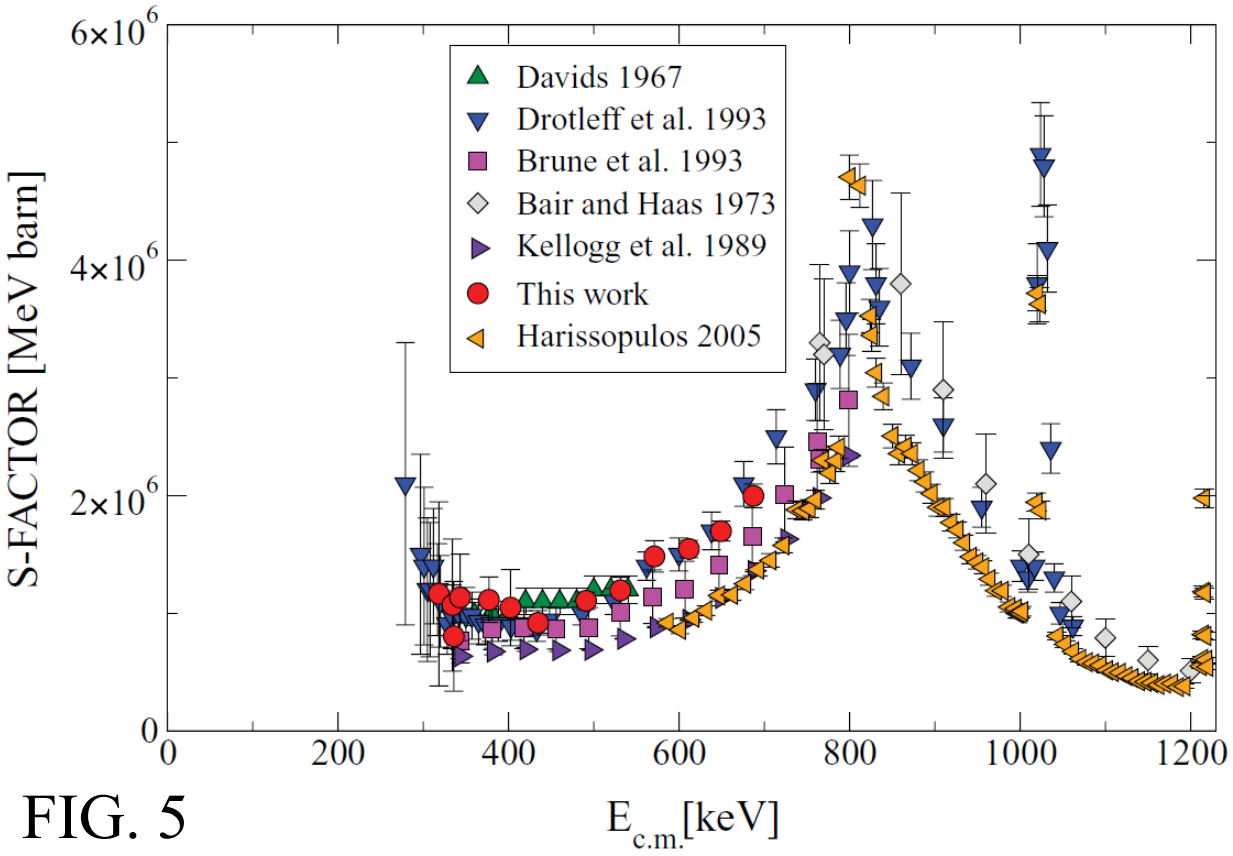

FIG. 5

Similar difference is seen between ● and ◀

Correlation Matrices