Preliminary evaluation of $^{9}Be(a,n)^{12}C$ experimental data at below 4 mev

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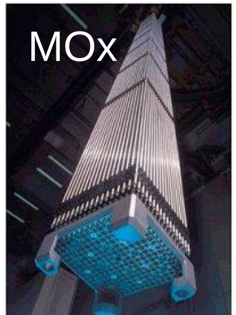
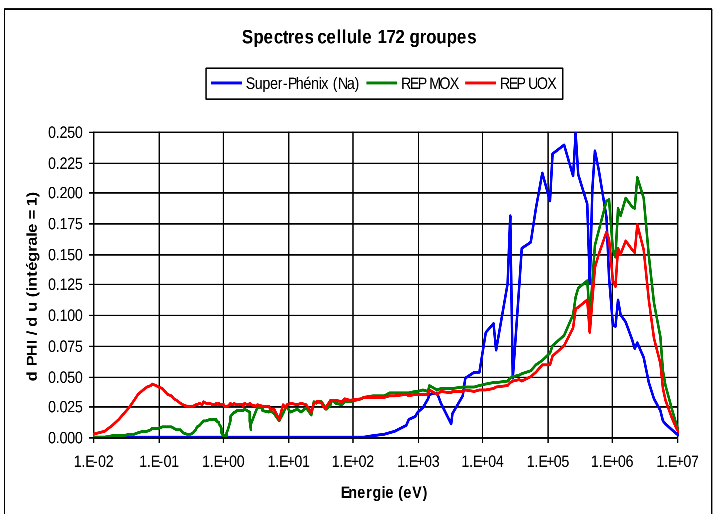
IAEA MEETING INVITATION: IAEA TM ON (ALPHA,N) NUCLEAR DATA EVALUATION AND DATA NEEDS

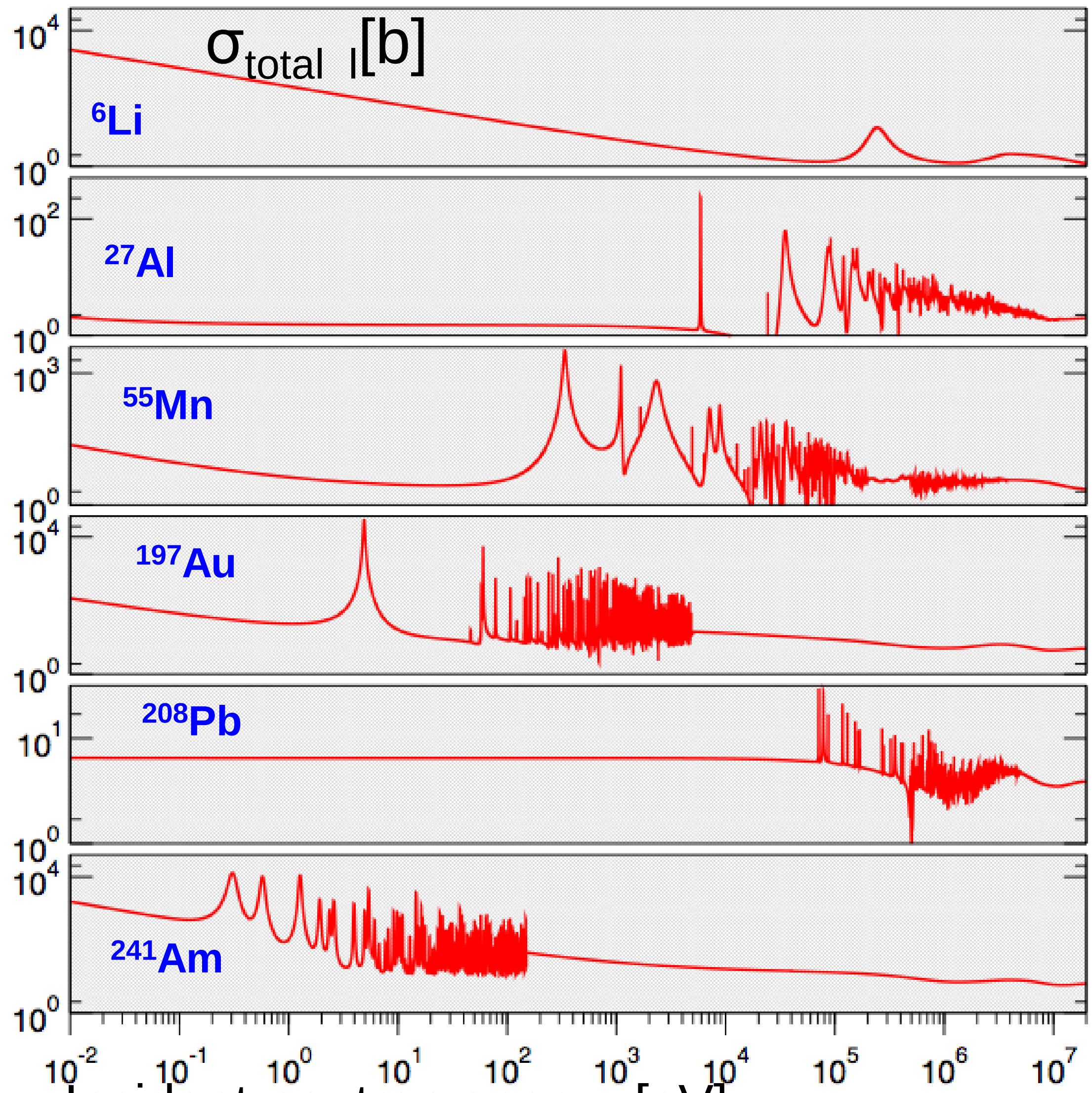
NOVEMBER 8-12, 2021 VIRTUAL

Cadarache Research Center
Main gate

Primary concern : the neutron interaction with the target







SAMMY, EDA, CONRAD, etc.

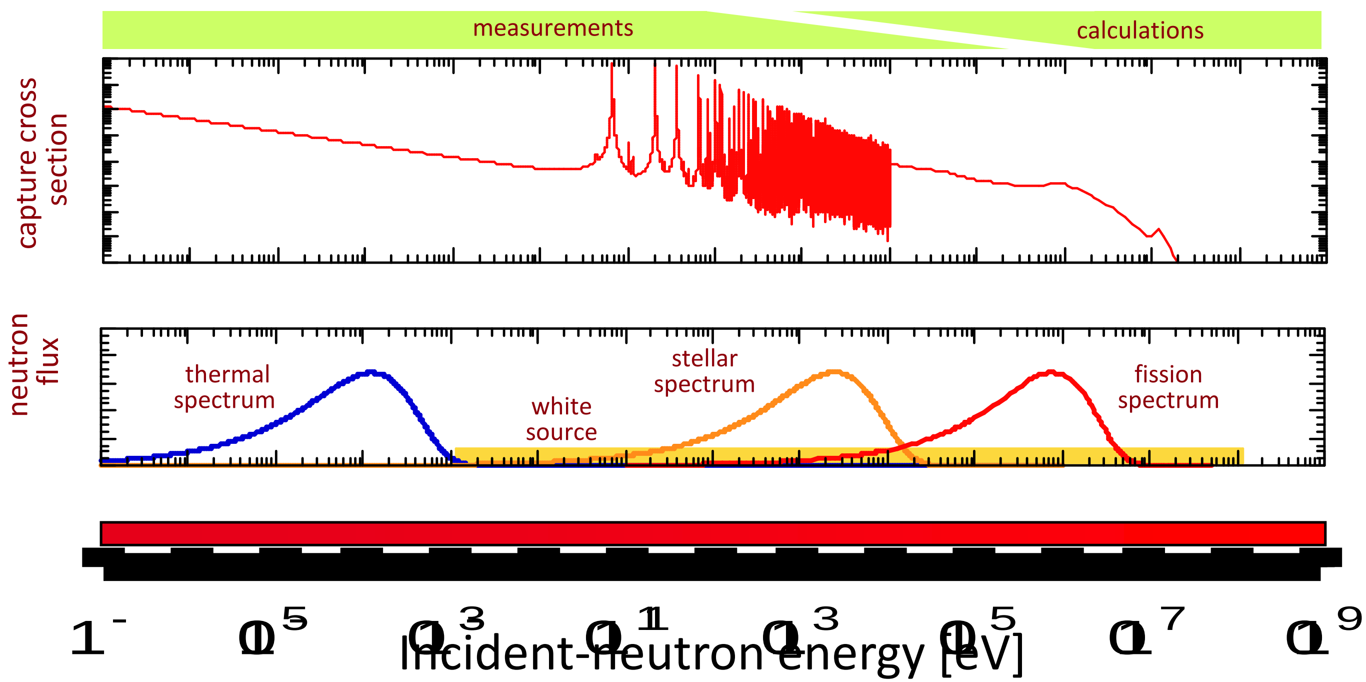
R-matrix description

- ✓ fine structure (resonances)
- ✓ strong fluctuations
- ✓ Low energy, few channels

Optical model description

- ✓ gross structure (resonances)
- ✓ average cross sections
- ✓ CCOM potential
- ✓ high energy, many channels

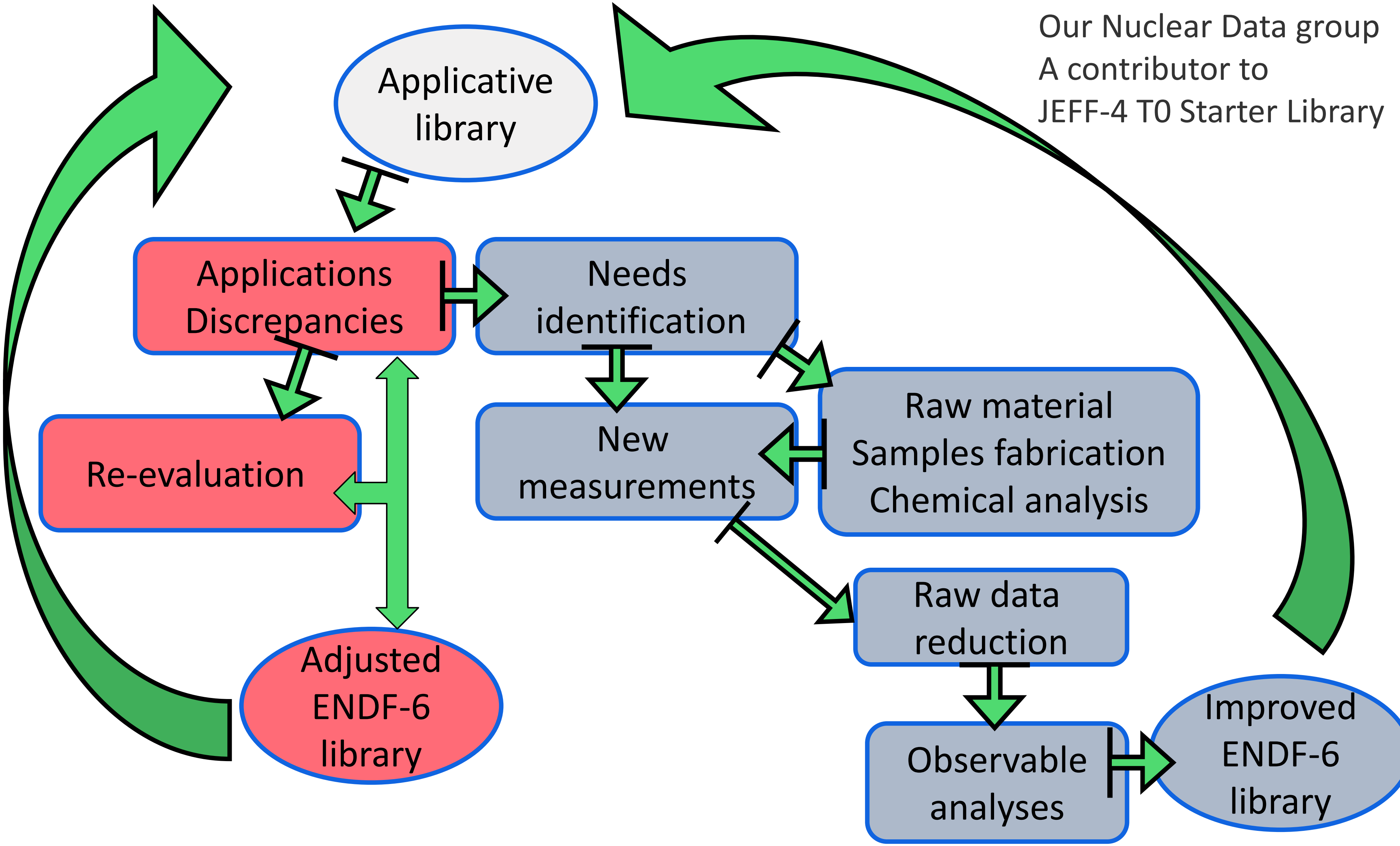
ECIS, TALYS, EMPIRE, etc.



Evaluation process at CEA: 2 alternatives

Short run | Long run

Our Nuclear Data group
A contributor to
JEFF-4 T0 Starter Library



(α,n) reactions are also our concern according to

- ❑ Intrinsic neutron sources (neutron reactor stopped for maintenance),
- ❑ Fuel production, storage and transportation of spent fuel,
- ❑ Shielding of people and equipment
- ❑ Sealed neutron sources (Am-Be, Cm-Be, etc.) for detector calibration, industrial process controls ,
- ❑ Sealed neutron sources for the start-up of nuclear reactors (first and second cycles).

Historically, CEA Cadarache hosts a code designed for calculating the neutron source in a homogeneous mixed oxide matrix since the 80^{th}

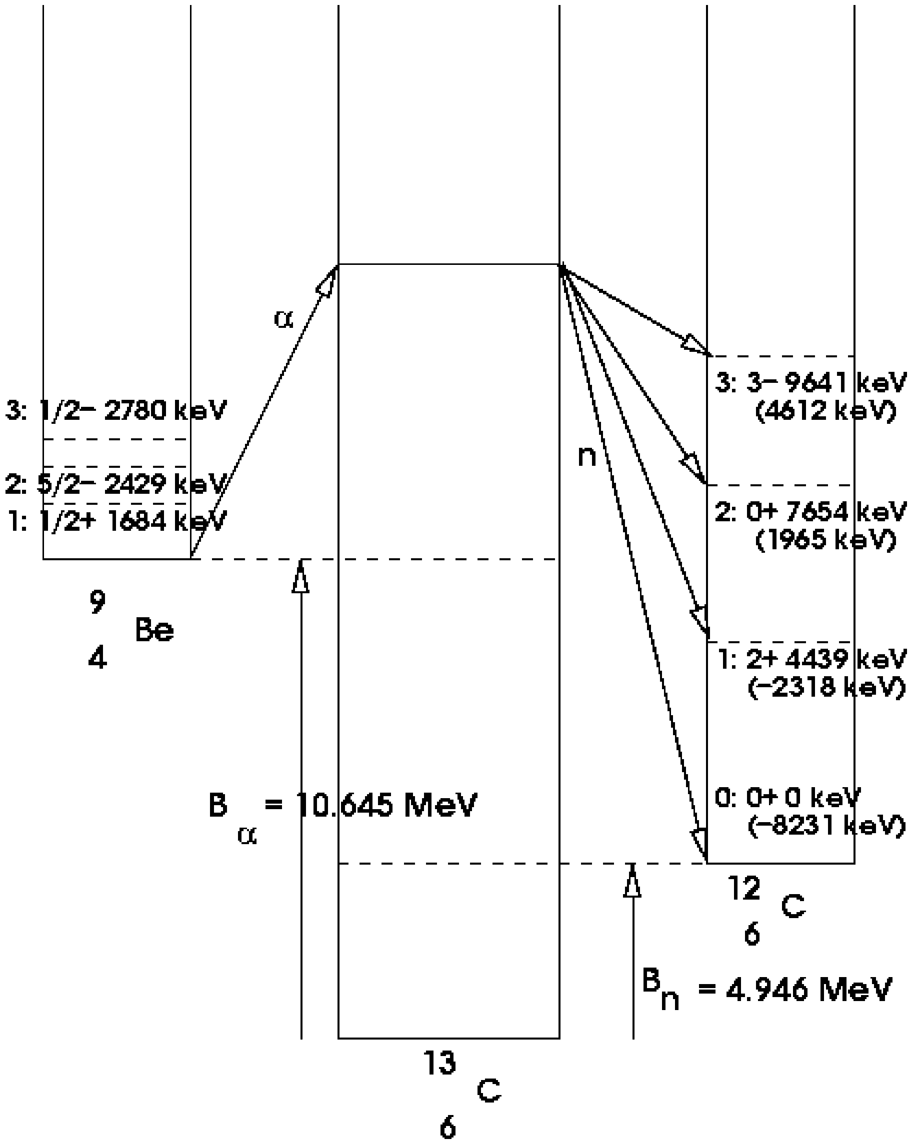
Last decade a modern version of this code (iSourceC in C++) has been written with extended application range

Obviously the code needs (α,n) cross section data
2 standard data libraries (JENDL/AN 2005 and TENDL) are released to the community

Our interest is also to be able to evaluating (α,n) data (also for the estimation of the uncertainties): still in the learning stage

1 – Preliminary evaluation of $^{9}Be(\alpha,n)^{12}C$ cross section data below 4 mev using the SAMMY code

2 – Neutron source calculation using the iSourceC code: Application to $Pu^{9}Be$



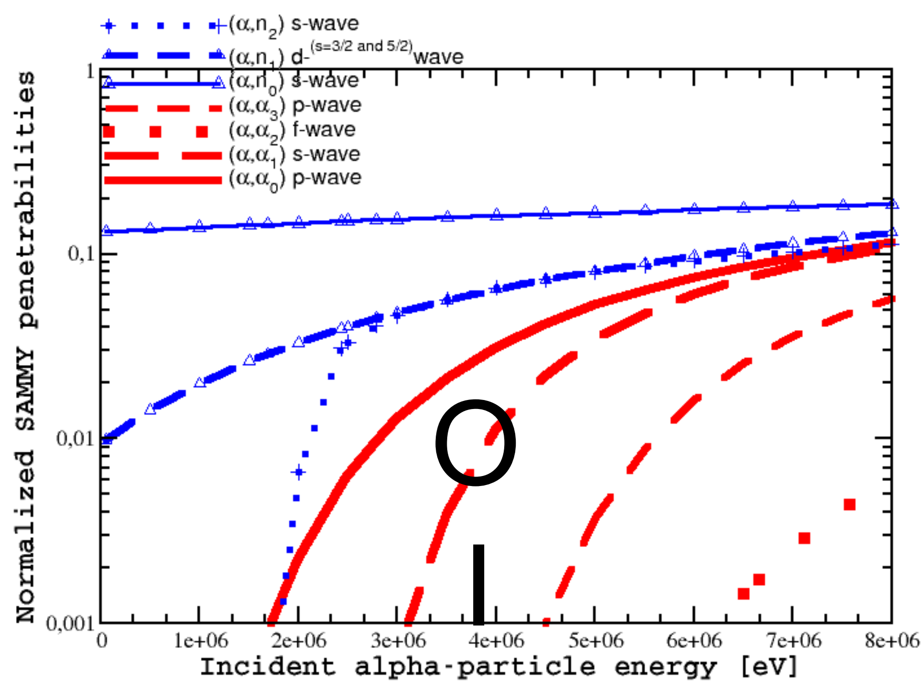
(α, n) interaction shematic

Neutron emission (α,n_0), (α,n_1) open, (α,n_2) [1965 keV] and (α,n_3) [4612 keV],

Obviously elastic (α,α_0),

Inelastic (α,α_1) from 1684 keV, moved up to higher energy (Coulomb penetrability) ~4 MeV --> low cross section

Capture (small $\Gamma\gamma_{tot}$ ~4 eV)



SAMMY SEQUENTIAL ANALYSIS OF $^{9}Be(\alpha,n)^{12}C$ CHANNELS

Framework:

- ❑ Reich-Moore approximation of R-Matrix,
- ❑ Prior RM resonance parameters assessed from F. Ajzenberg-Selove (A=13) or the Atlas of resonance (**Thanks to astrophysics and neutron reactor information**),
- ❑ Major bound levels included
- ❑ No time reversed experimental data included as $^{12}C(n,\alpha)^{9}Be$ for instance
- ❑ Two-body interactions only (no breakup)

Picture already complicated: J^{π} states reported below 4 MeV up to 9/2- states

Easy quantum number case

J^{π} =1/2- ⇔ 6 +1(γ)

6 widths per state to fit

J^{π} = 1/2-	(α, α	(α,n_0)	(α,n_1)	(α,n_2)
Multiplicity L wave number	1 2	1 1	2 1, 3	1 1

More complex

J^{π} = 9/2- ⇔ 9 +1(γ)

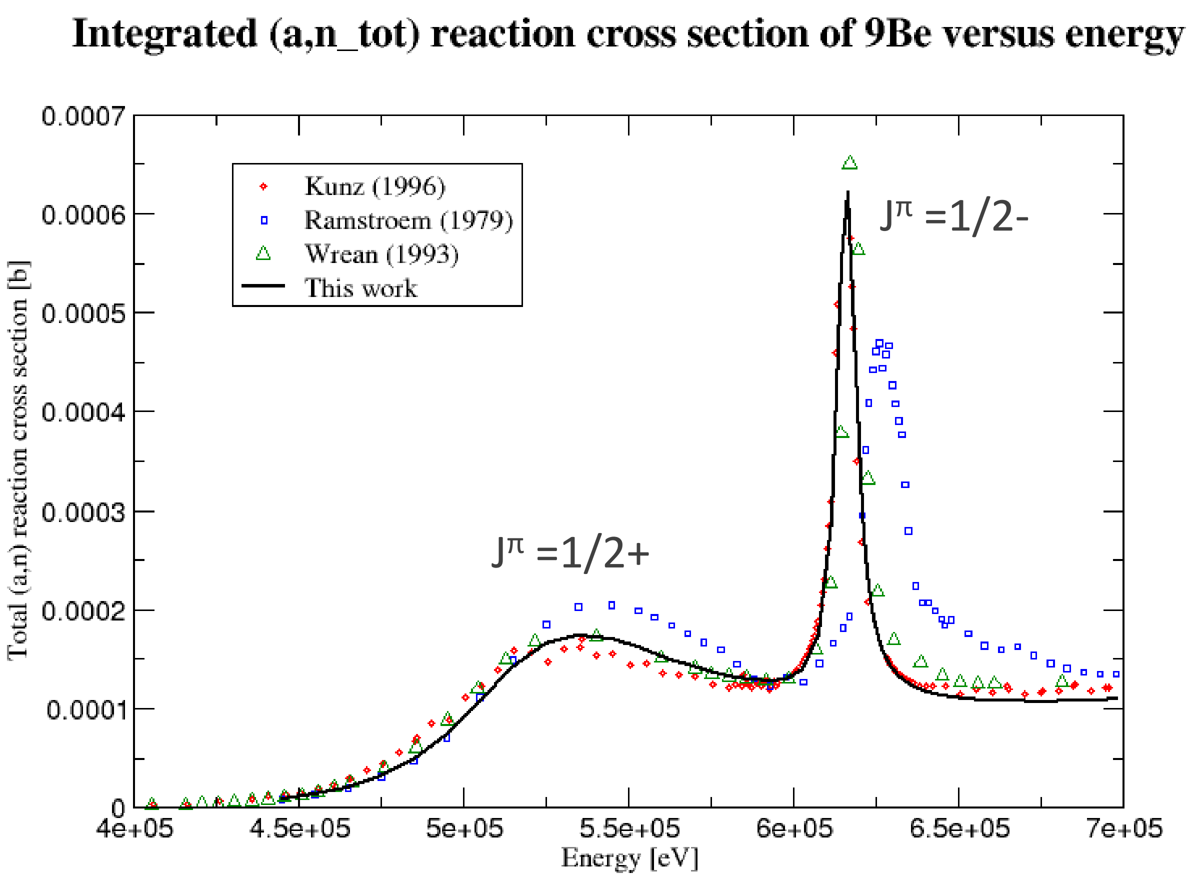
9 widths per state to fit

J^{π} = 9/2-	(α, α)	(α,n_0)	(α,n_1)	(α,n_2)
Multiplicity L wave nmber	2 4, 6	1 5	5 3(x2), 5(x2), 7	1 5

^{9}Be: one of the most exhaustive α-incident database among light nuclei

Periodic experimental campaigns essentially last century

E_α < 700 keV : 2 resonances only

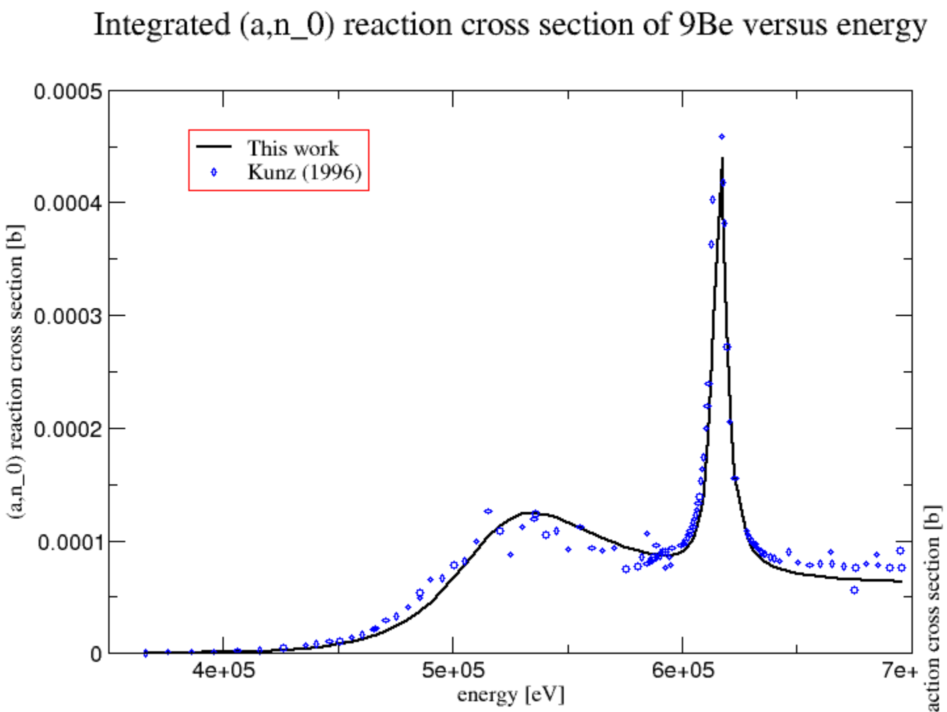


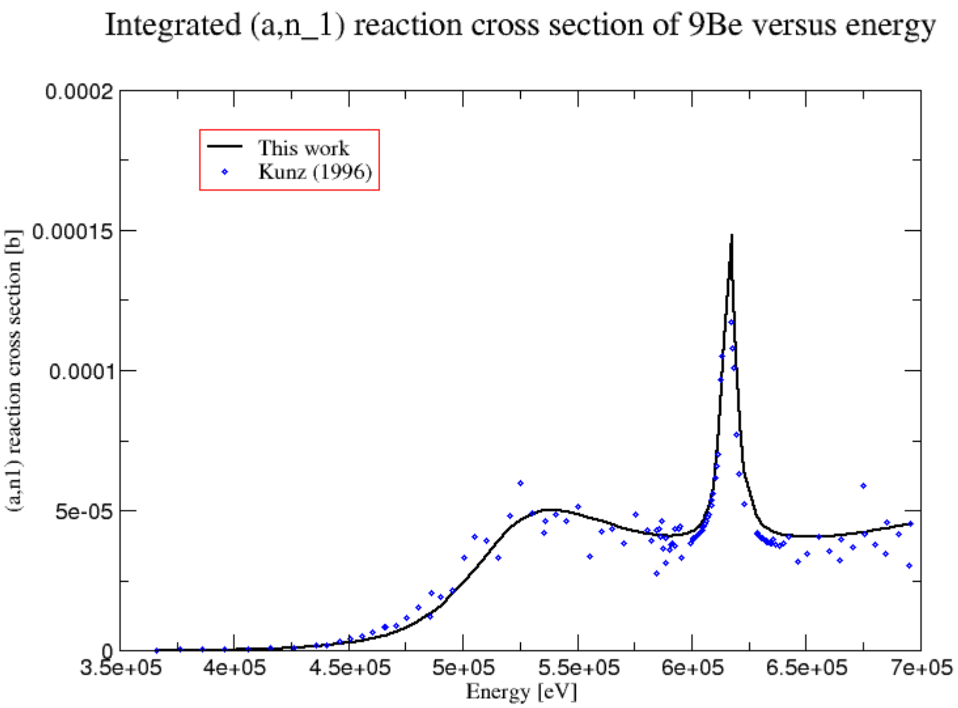
Consistency between Wrean (1993) and Kunz (1996)

Ramstroem (1979) broadened by experimental biases (calibration, resolution and neutron background).

Low energy fit (E < 700 kev) : σ (α,n_0) and σ (α,n_1)

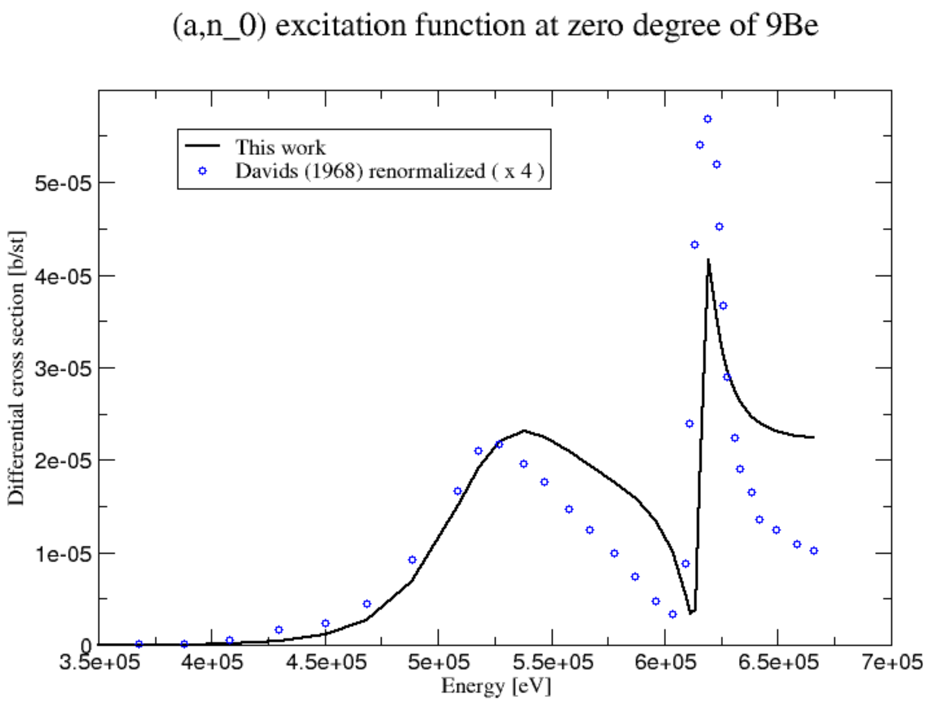
Simultaneous fit on (α,n_0) et (α,n_1) 4π measurements (Kunz)

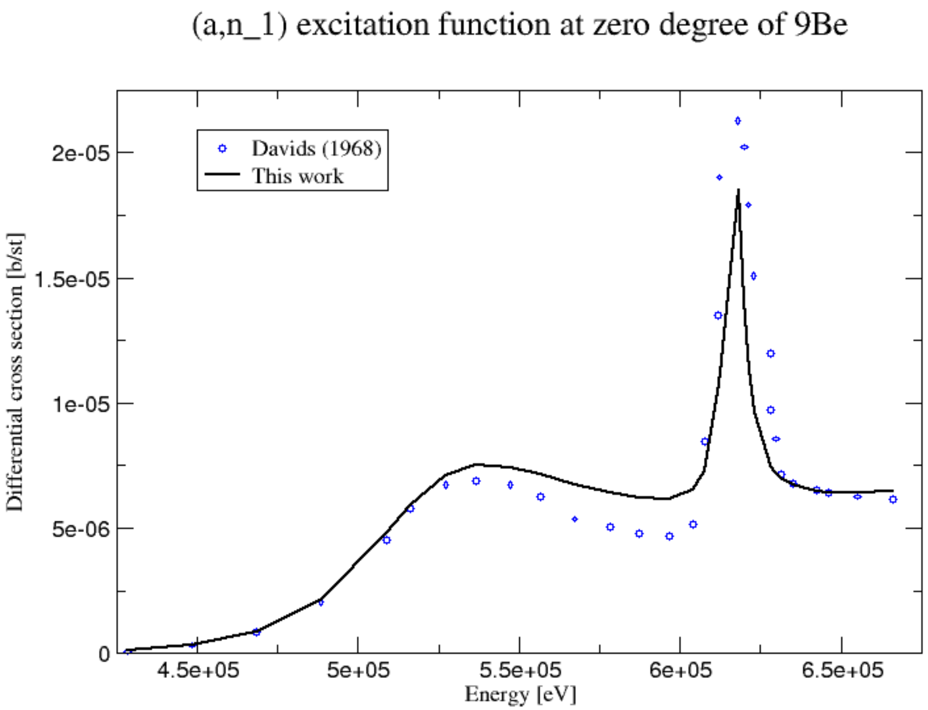




Comparison with Davids (1968) :

σ (α,n_0) normalization doubtful

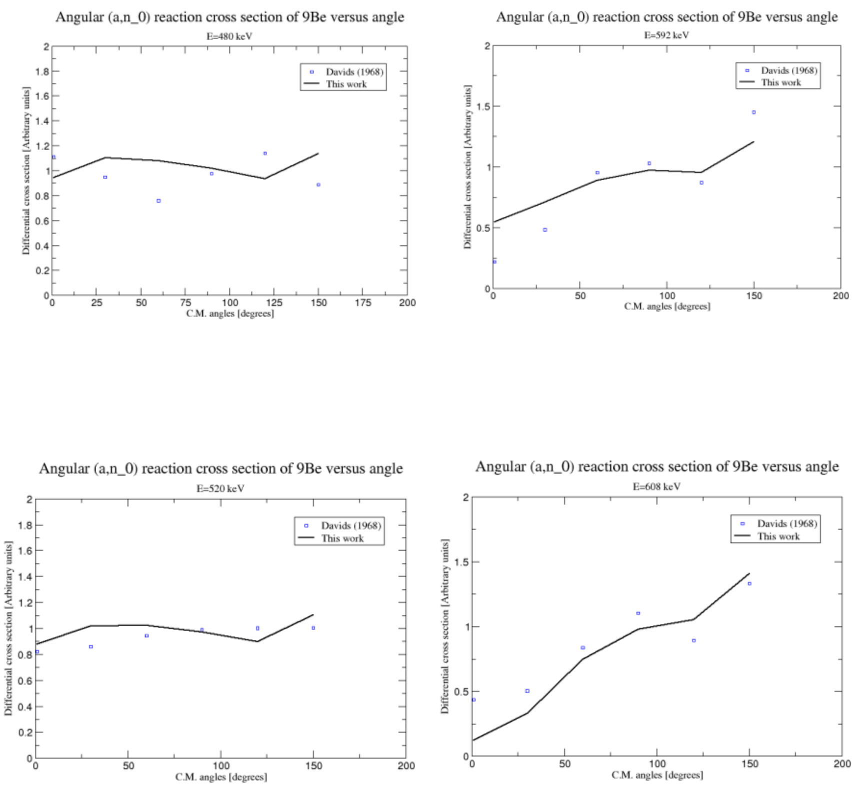




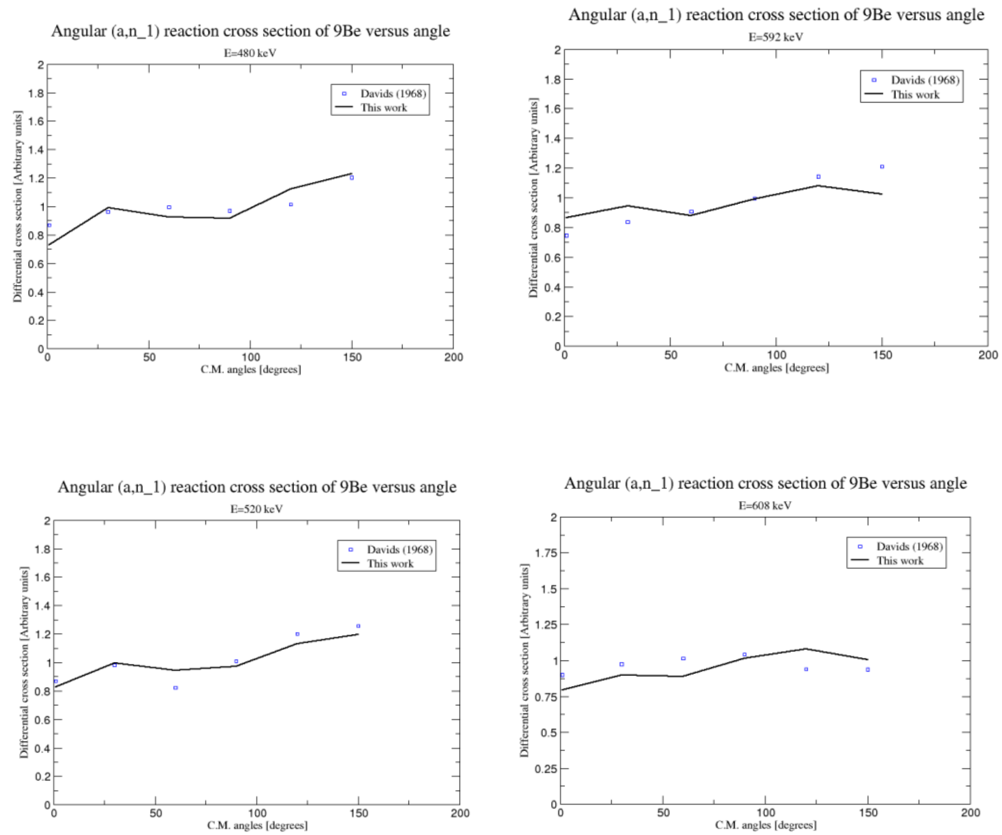
Low energy fit (E < 700 kev) : σ (α,n_0) and σ (α,n_1) angular

Davids (1968) σ (α,n_0) σ (α,n_1) angular dist. at 480, 520, 592.5 and 608 keV
Spin assignment checks

σ (α,n_0) angular dist.



σ (α,n_1) angular dist.



Experimental database

Integrated : evaluation

- ❑ (α,n_{tot}) 4π Van der Zwan and Geiger (1970); 1500-7900 keV

Integrated :

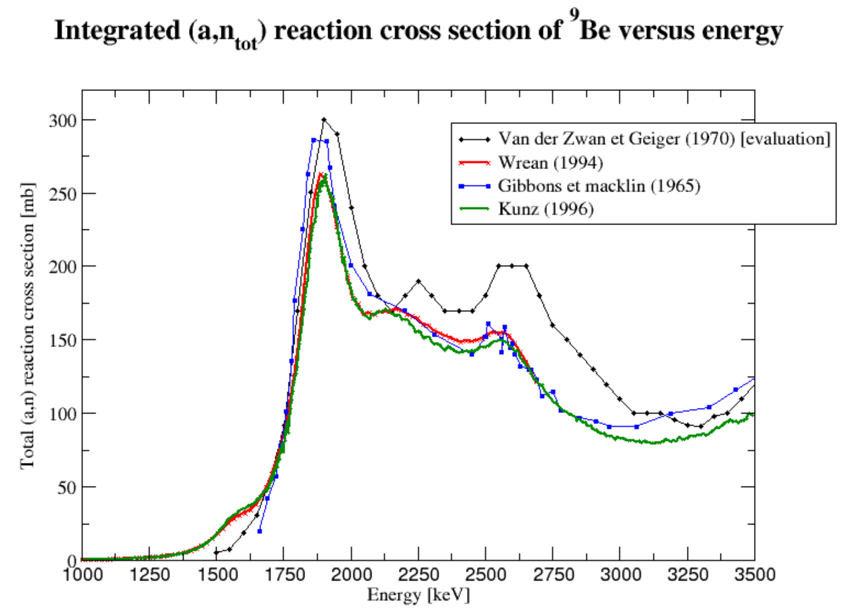
- ❑ (α,n_{tot}) 4π Gibbons and Macklin (1965); 1660-10300 keV
- ❑ (α,n_{tot}) 4π Wrean (1993); 0-2670 keV
- ❑ (α,n_0), (α,n_1) 4π Kunz (1996); 0-3500 keV

Excitation function at zero : 3 sets

- ❑ (α,n_0) à 0° Risser (1957); 1600-4830 keV
- ❑ (α,n_1) à 0° Risser (1957); 3100-4777 keV
- ❑ (α,n_0) et (α,n_1) à 0° Obst (1972); 1600-6500 keV
- ❑ (α,n_0), (α,n_1) et (α,n_2) à 0° Van der Zwan (1970); 1470-7480 keV

Excitation function at various angles :

- ❑ (α,n_0) 1750, 1960 keV 12 angles Klages (1969)
- ❑ (α,n_0) 2020, 2290, 2500 et 2690 keV Risser (1957)



(α,n_{tot}) 4π Kunz(1996) and Wrean (1993) agree

Gibbons OK

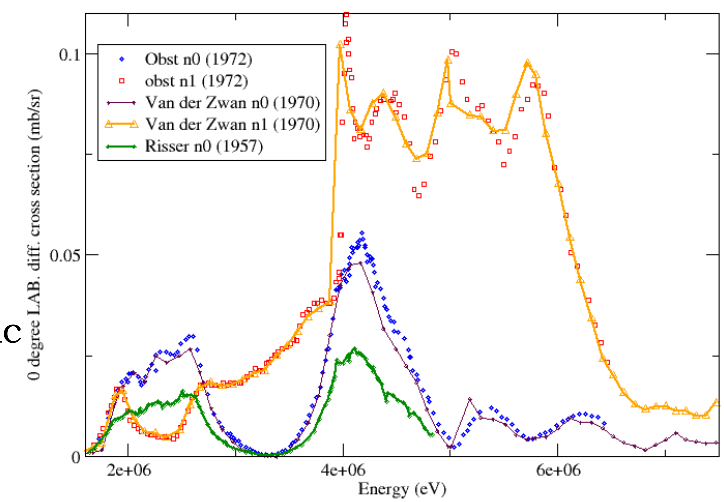
Van der Zwan and Geiger (1970) up to +40% difference at 4MeV

➔ Advising Kunz

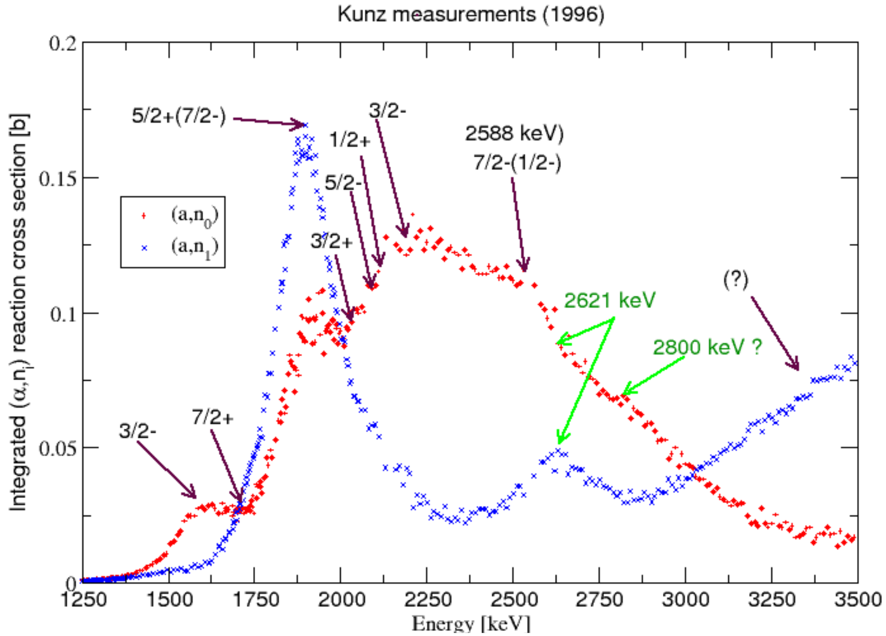
(α,n_0) 0° Obst, Van der Zwan/ Risser (1957) factor 2

(α,n_1) 0° Obst, Van der Zwan/ Risser (1957) same diagnostic

➔ Advising Obst (Risser too old?)



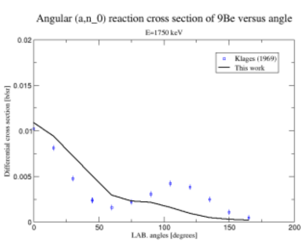
Integrated (a,n_0) and (a,n_1) reaction cross sections of ^{9}Be versus energy

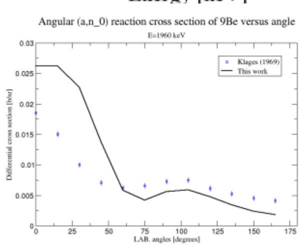


Black arrows: literature

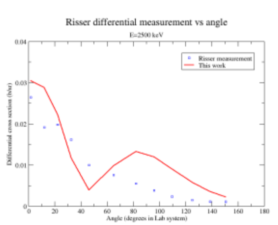
Green arrows: possible resonances

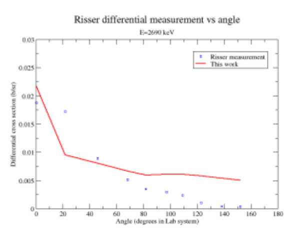
Angular measurements always needed to discriminate spins





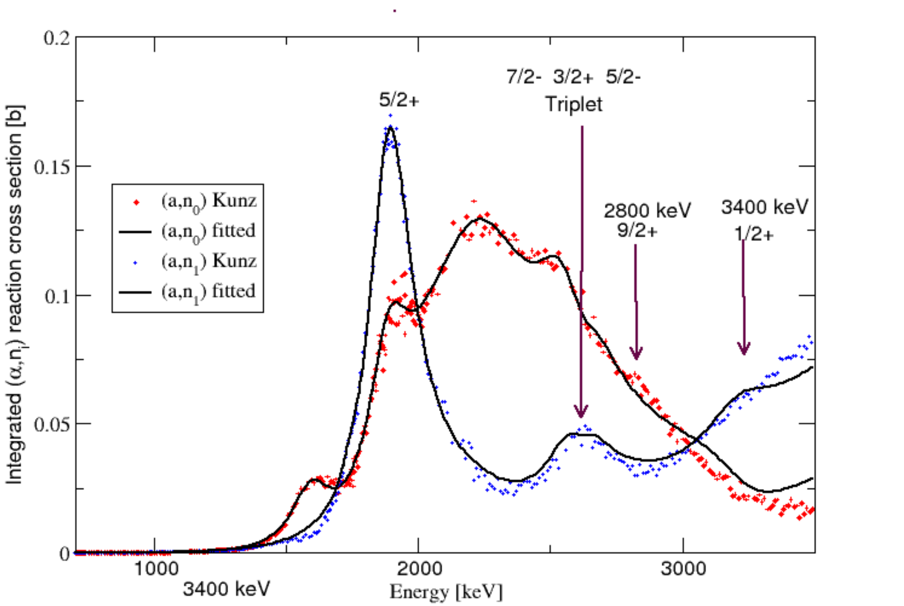
(α,n_0)
Klages (1968)
1750, 1960 keV





(α,n_0)
Risser (1957)
2500 2690 keV

Integrated (a,n_0) and (a,n_1) reaction cross sections of ^{9}Be versus energy

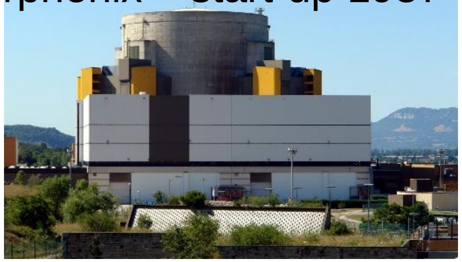


1 – ~~Preliminary~~ evaluation of ~~$^{9}Be(\alpha,n)^{12}C$~~ cross ~~section data~~ below 4 mev using the SAMMY ~~code~~

2 – Neutron source calculation using the iSourceC code: Application to $Pu^{9}Be$

Did we really need another code to calculate neutron fluxes and energy-differential neutron spectra off reactor ?

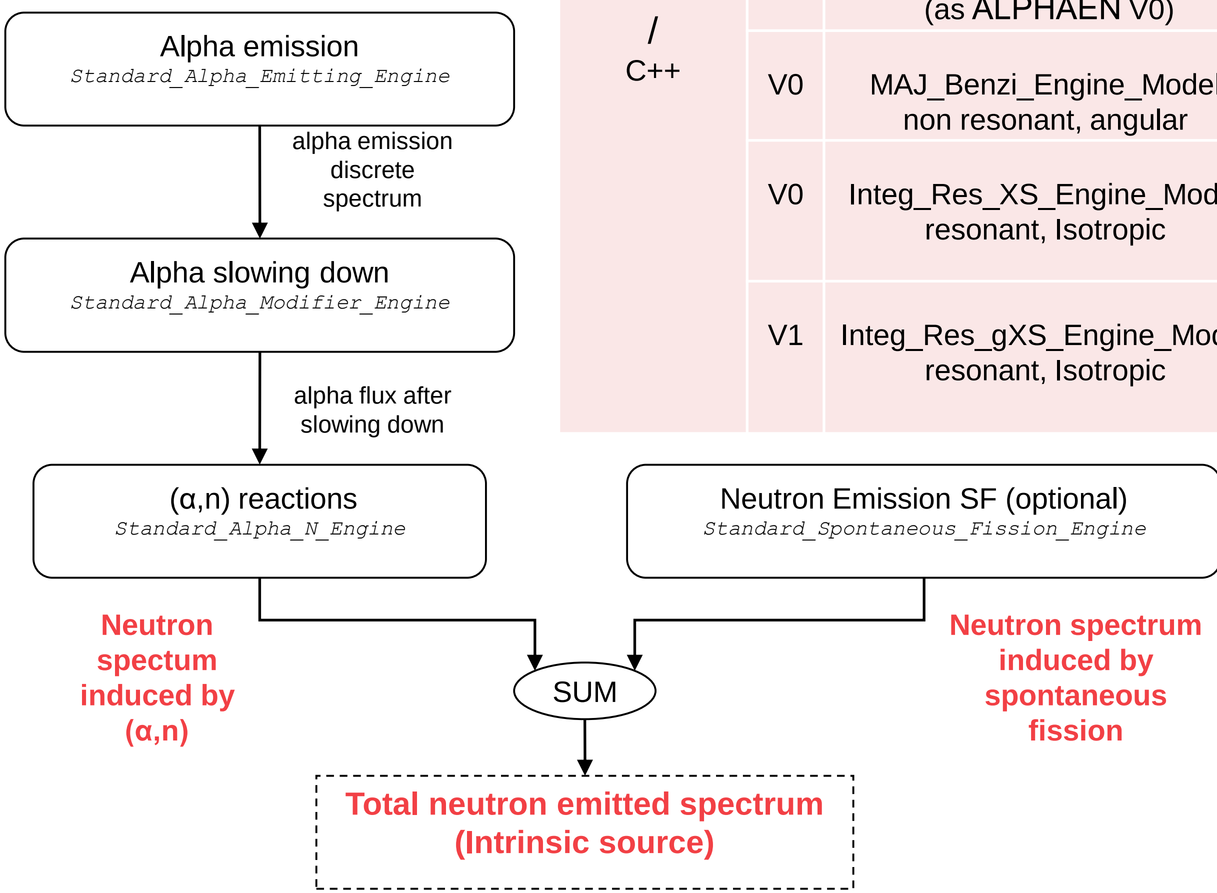
Superphenix – start-up 1987



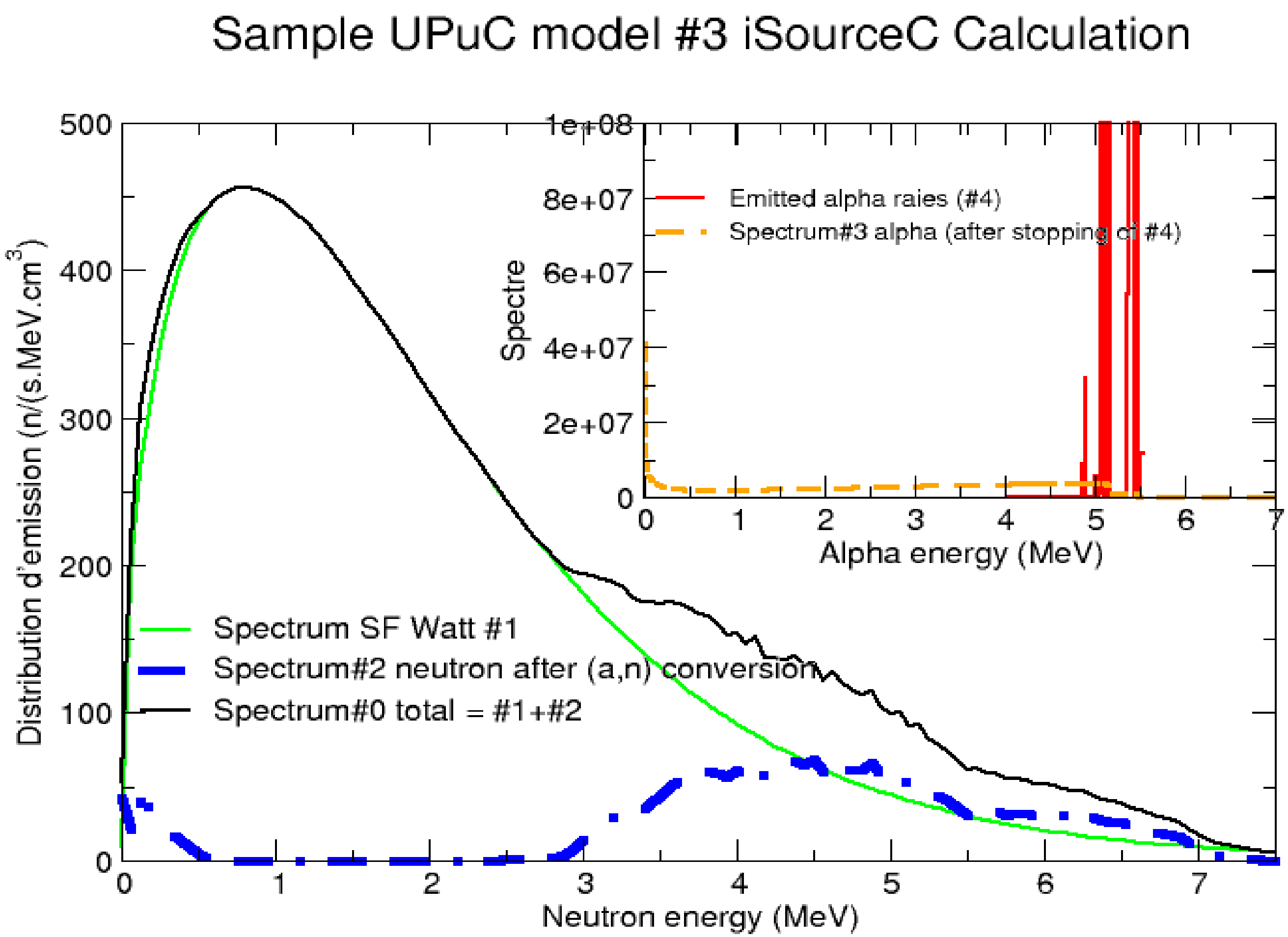
- Other codes making reference exist (SOURCES-4C, ORIGEN, etc.),
- Always good reasons (historical tradition, start from scratch, more flexible language, etc.)
- New version in C++, like LEGO bricks, benchmarked against SOURCES-4C, any type of homogenized mixture, users-friendly,
- Numerous applications such as $^{nat}UO_2$, $^{238}PuO_2$, $UPuAmO_2$, UPuC, $Pu^{15}N$, $UPuAm^{14}N$, CmBe, AmBe, PuBe, Cf
- Recent extension (2018) (γ ,n) sources; tested for SbBe neutron sources,
- Chained to the JENDL/AN-2005 (α,n) and JENDL/PD-2004 (γ ,n) cross section libraries

FEATURES (LANGUAGE, VERSION, PATH, APPLICATION, MASTER EQUATION)

ALPHAĒN / Fortran 77	V0	Original Benzi non resonant, angular	SF+(α,n) oxide	$C_{L,K,Oxygen}(E_\alpha)$
	V1	Alternative resonant, angular	SF+(α,n) oxide	$C_{L,,Oxygen}\ (E_\alpha)$
iSourceC / C++	V0	Benzi_Engine_Model (as ALPHAĒN V0)	SF+(α,n)oxide	$C_{L,K,Oxygen}(E_\alpha)$
	V0	MAJ_Benzi_Engine_Model non resonant, angular	SF Watt + (α,n)oxyde	$C_{L,K,Oxygen}(E_\alpha)$
	V0	Integ_Res_XS_Engine_Model resonant, Isotropic	SF Watt + (α,n) JENDL/AN-2005	$\frac{1}{4\pi}\sigma_{(\gamma,n),i,k}\left(E_\gamma\right)$
	V1	Integ_Res_gXS_Engine_Model resonant, Isotropic	(γ,n) JENDL/PD-2004	$\frac{1}{4\pi}\sigma_{(\alpha,n),i,k}\left(E_\alpha\right)$



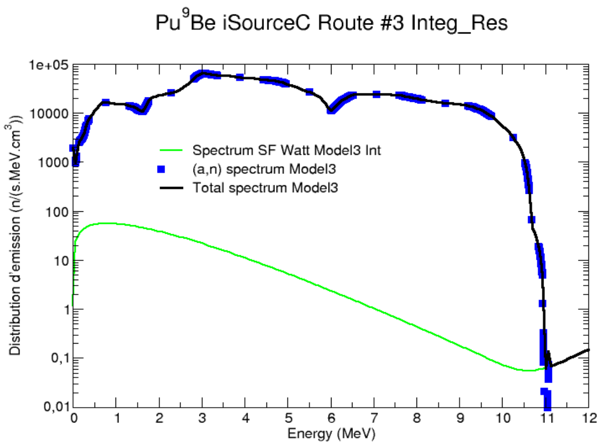
VARIOUS CALCULATED SPECTRA

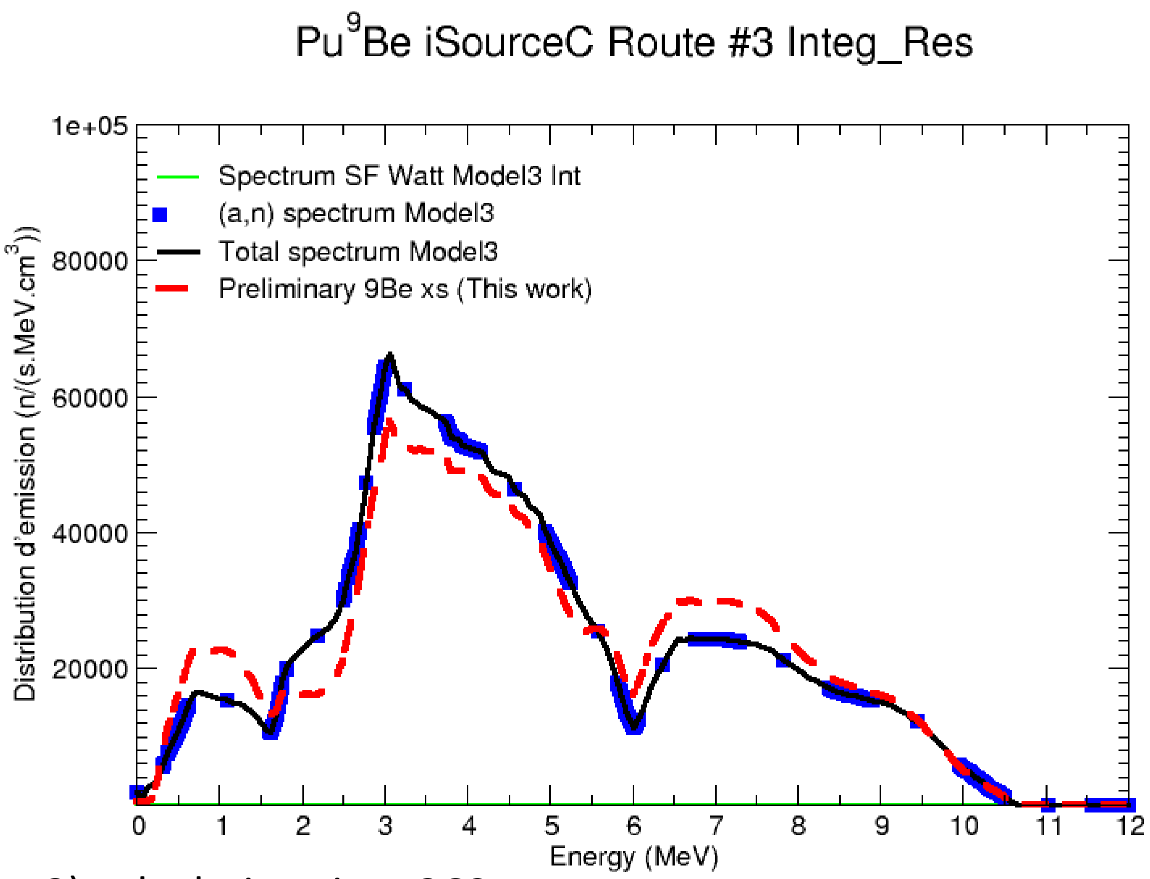


6	13
92	235
92	238
94	238
94	239
94	240
94	241
94	242
95	241

iSourceC
9Be(α,n)^{12}C preliminary results (new up to 5 Mev)

Composition PuBe13 (Stewart, 1953) extracted from Perry, Wilson, LA-13639_MS, p46



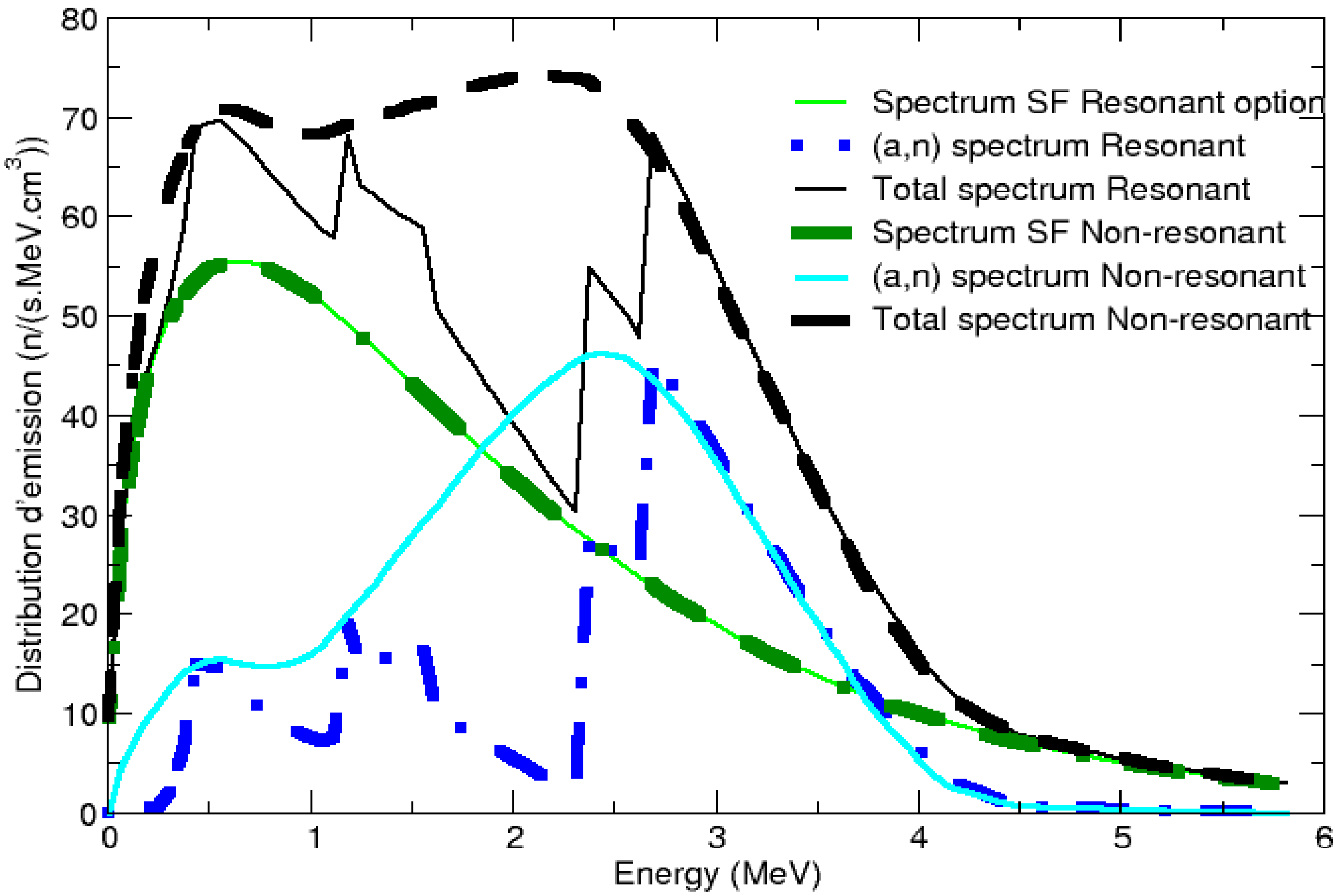


JENDL/AN 266597 n/(s.MeV.cm3) calculation time 360ms

This work 264916 n/(s.MeV.cm3) calculation time 18s

0.6% difference

$UPuAmO_2$ resonant Vs non-resonant ALPHAEN calculations



(α,n) neutron emission spectrum

with 17O(α,n) and 18O (α,n)

Resonant xs at low energy + smooth xs above

Smooth xs only

Evaluation

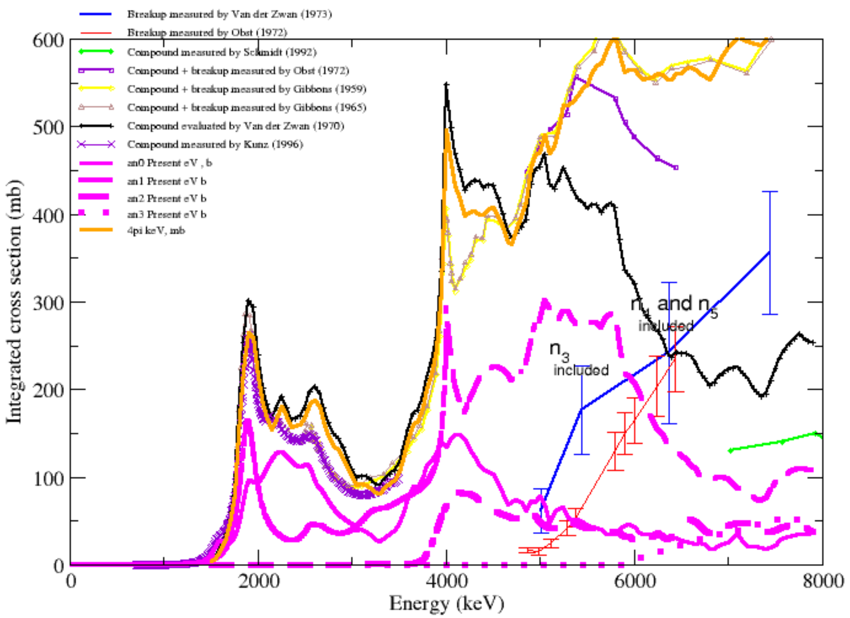
- σ (α,n_{tot}); only 2 measurements Gibbons (1965), Schmidt (1992) above 4 MeV
- No σ (α,n_0), σ (α,n_1), σ (α,n_2) individual measurements
- Disagreement between measurements observed (normalization)
- Accurate angular measurements needed for spin discrimination
- High L-waves observed → impact of angular distributions in the neutron source

Neutron source

- Resonant vs non resonant – obvious impact
- Strong (α,n) evaluations are needed for next generation fuel matrices (as UPuC, $Pu^{15}N$, $UPuAm^{14}N$ matrices for instance)
- Impact of angular resonant distributions still to be tested in *iSourceC*

Thanks for your attention

Various integrated ^{9}Be(a,n) cross sections versus energy



^{9}Be(a,n_0) cross sections for 12 angles