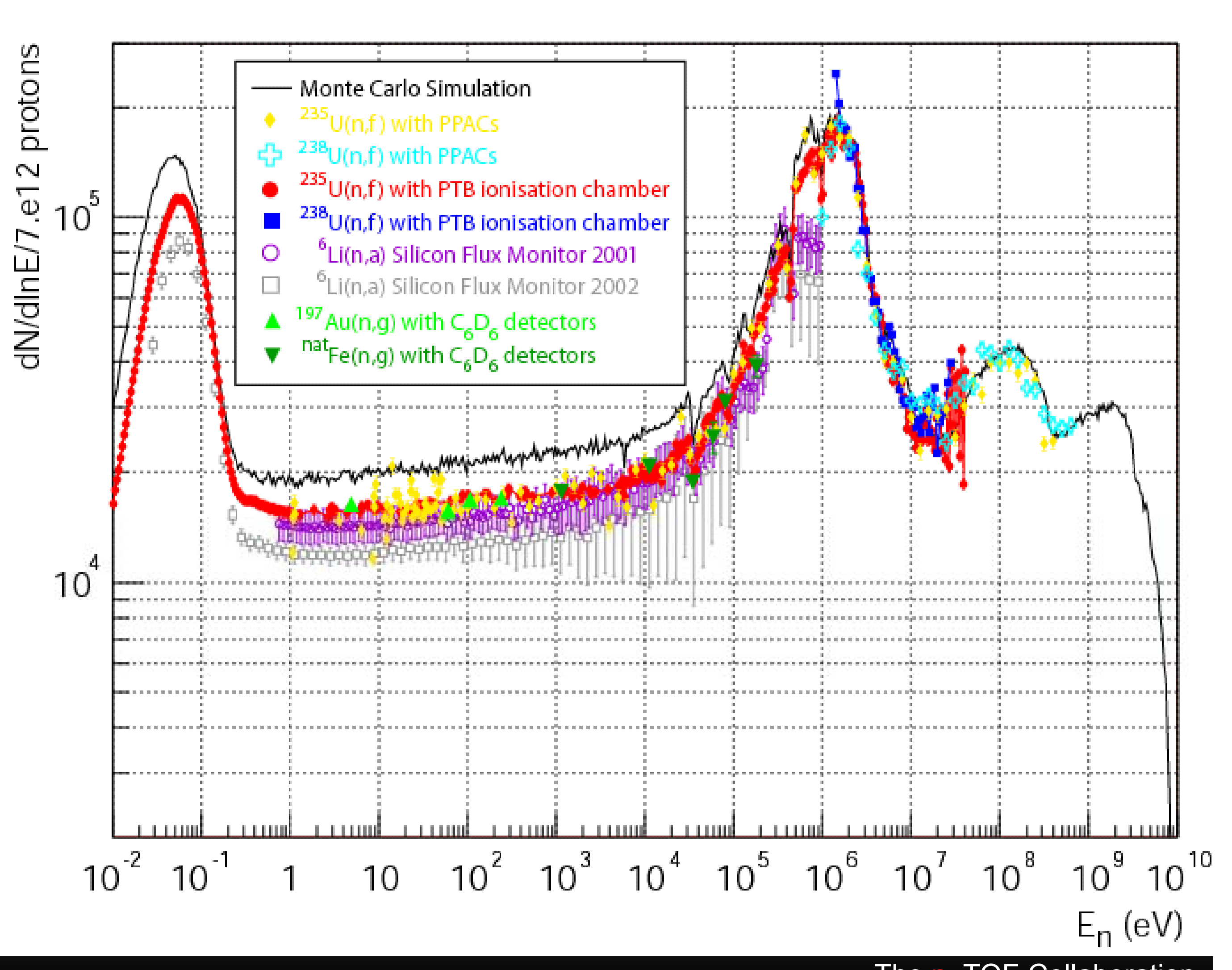
Future Physics and Detectors at n_TOF

Alberto Mengoni
IAEA , Vienna

- Experimental characteristics of the n_TOF beam & detection setup
- n_TOF-Phase 2

Basic characteristics of experiments at n_TOF

- wide energy range

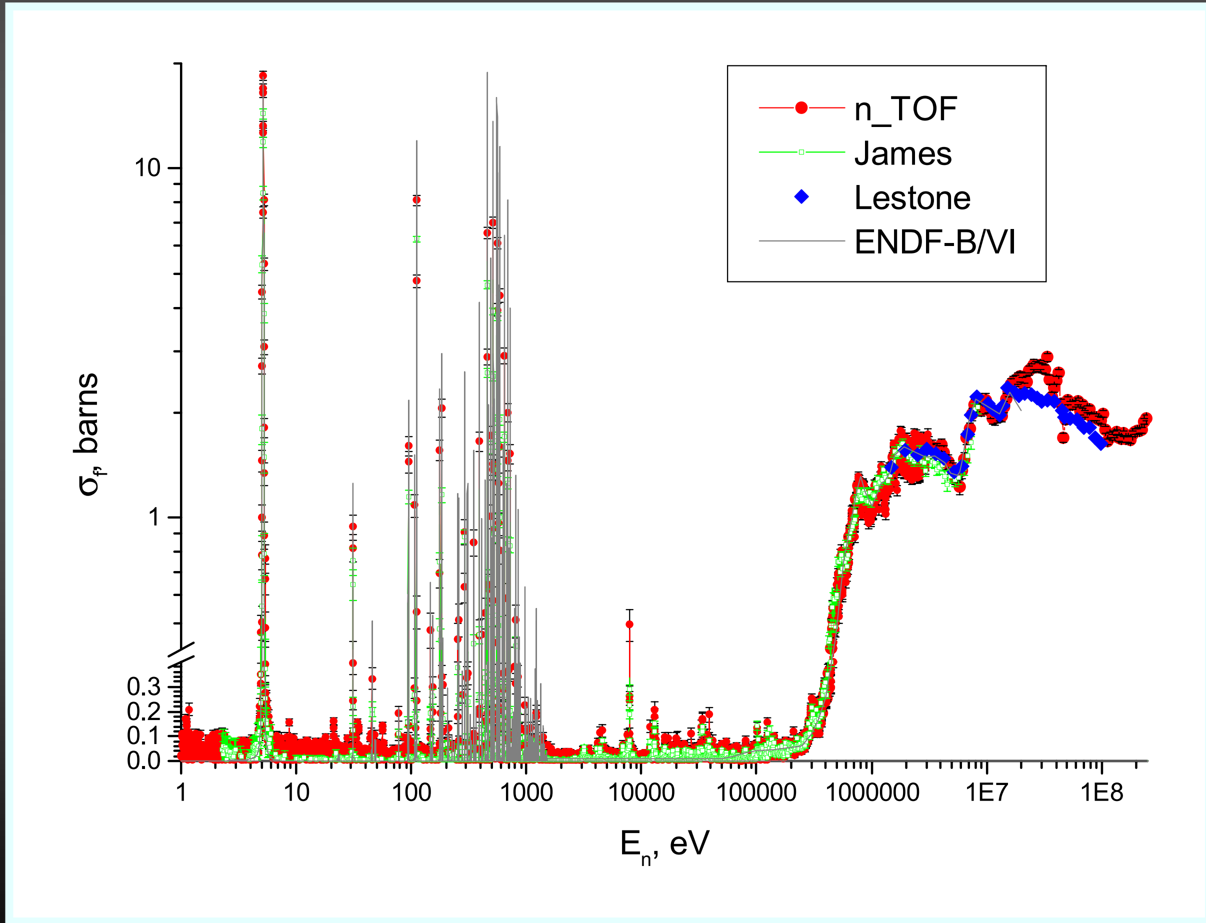


Basic characteristics of experiments at n_TOF

- wide energy range

PPACs & FIC-0 (2003)

$^{234}U(n,f)$

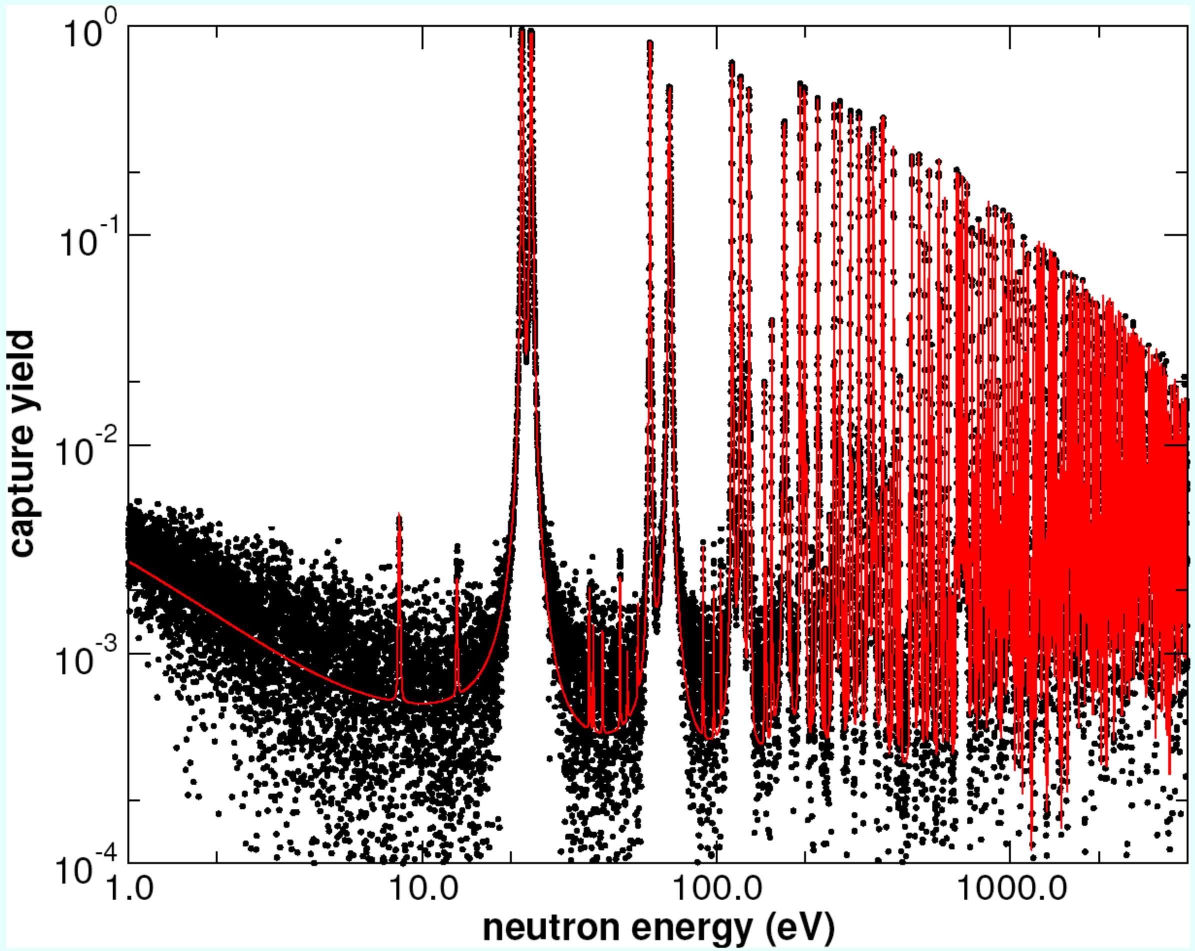


Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution

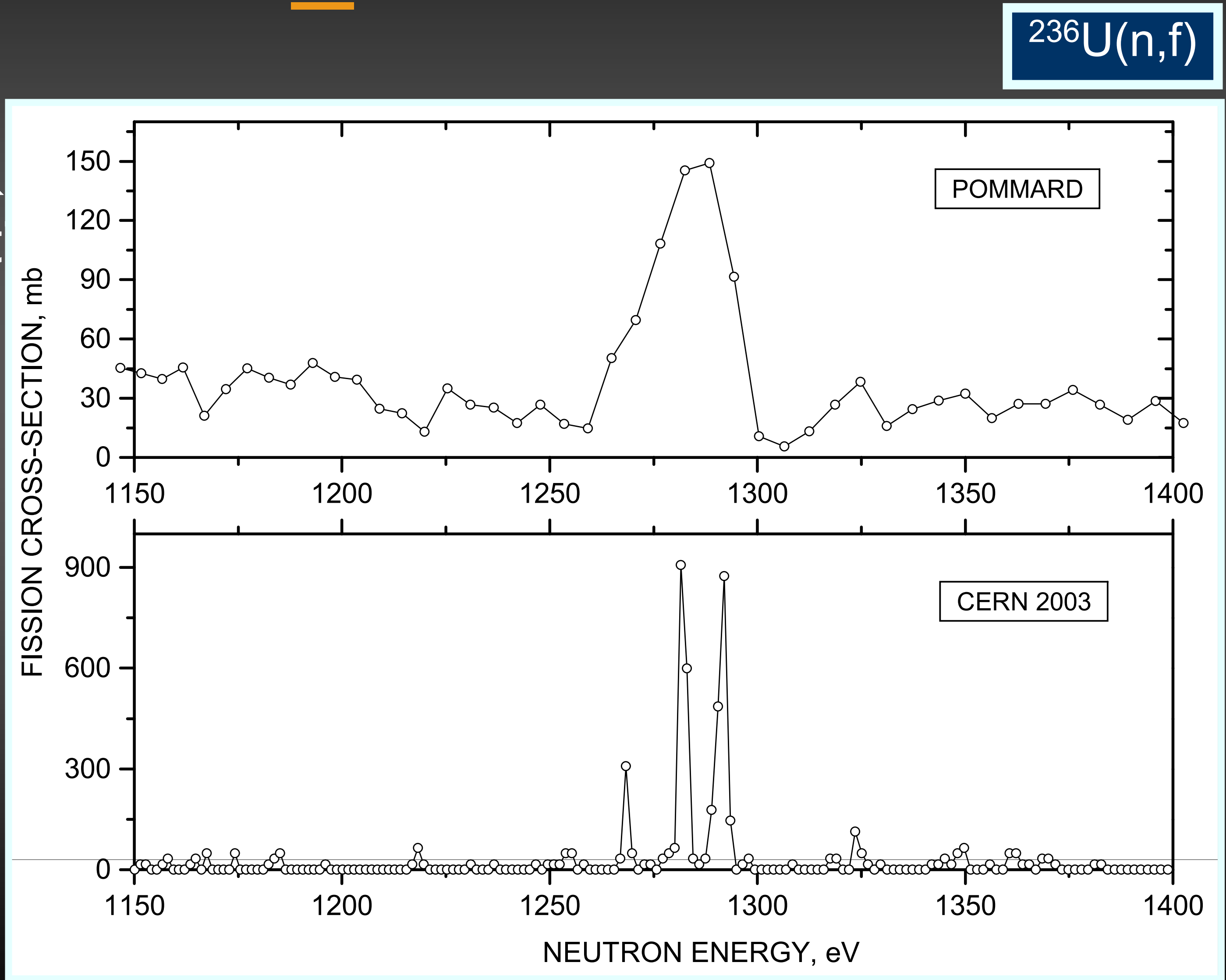
small samples

$^{232}Th(n,\gamma)$



Basic characteristics of experiments at n_TOF

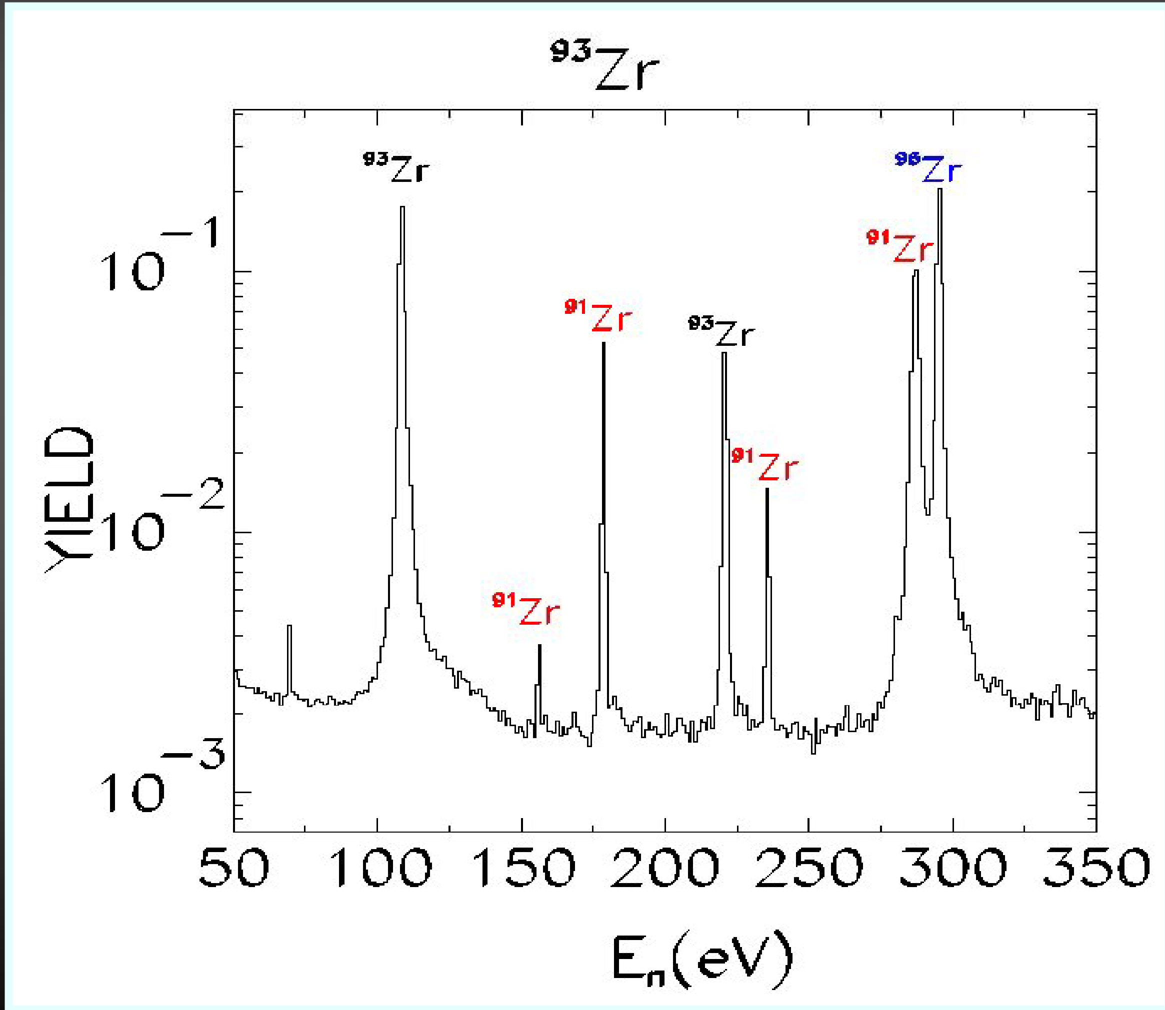
- wide energy range
- high neutron flux & high energy resolut



Basic characteristics of experiments at n_TOF

$^{93}Zr(n,\gamma)$

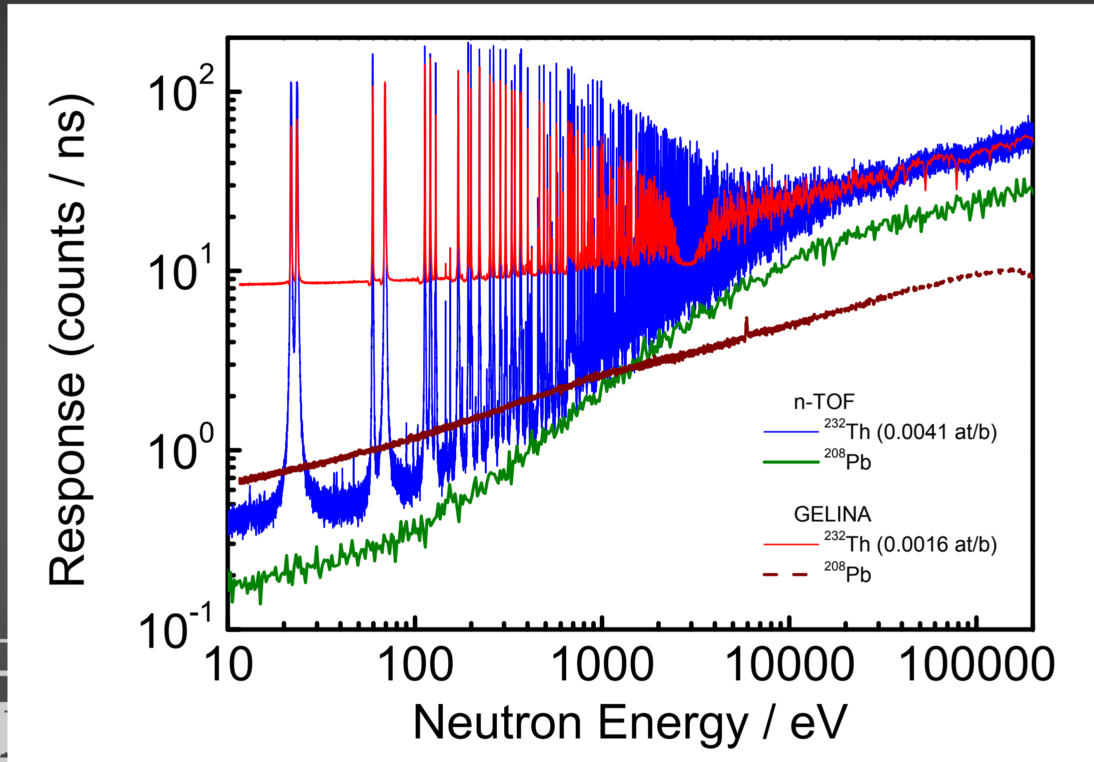
- wide energy range
- high neutron flux & high energy resolution



Basic characteristics of experiments at n_TOF

^{232}Th(n,γ)

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver



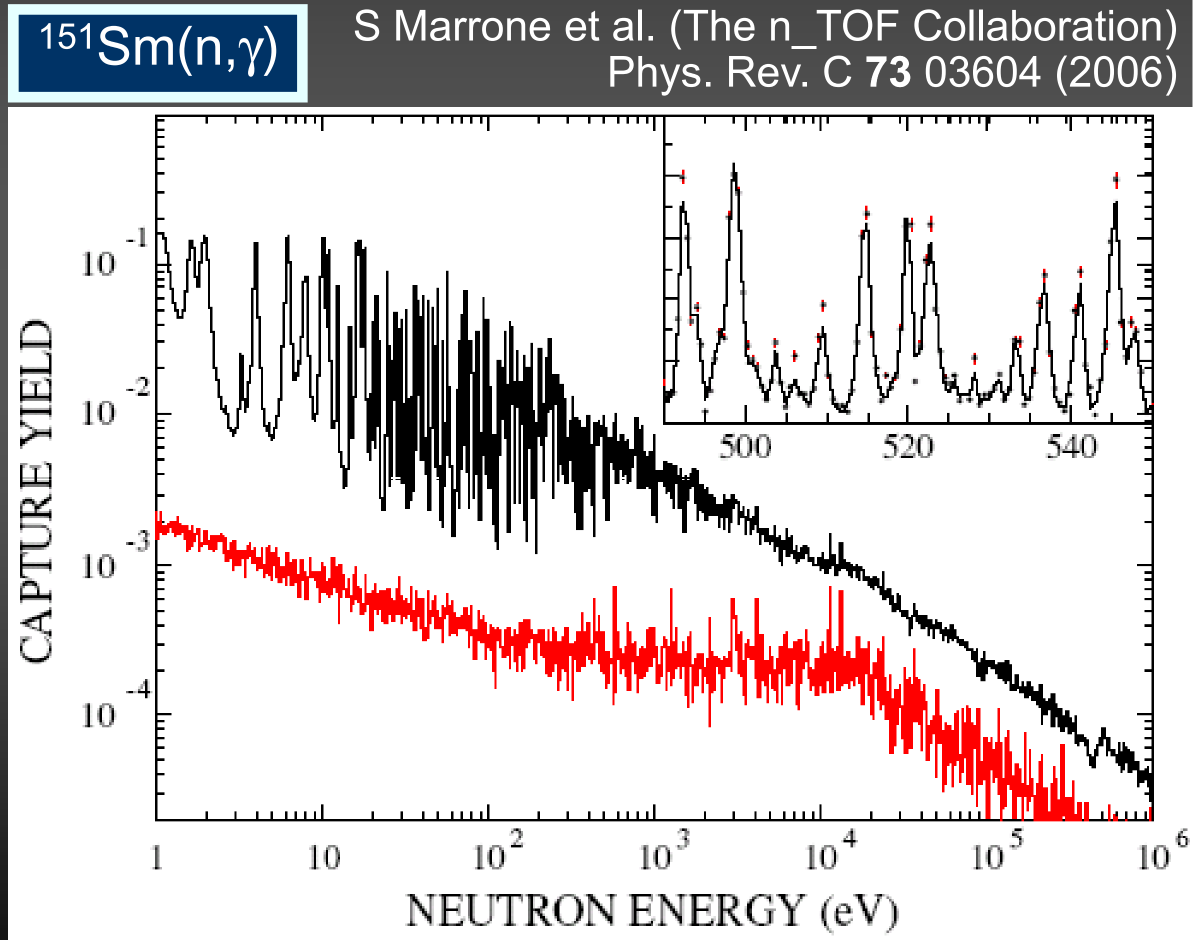
source: P Rullhusen (GELINA)

comparison with GELINA (~ same average flux at 30m)

Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

U Abbondanno et al. (The n_TOF Collaboration) Phys. Rev. Lett. **93** (2004), 161103
&
S Marrone et al. (The n_TOF Collaboration) Phys. Rev. C **73** 03604 (2006)

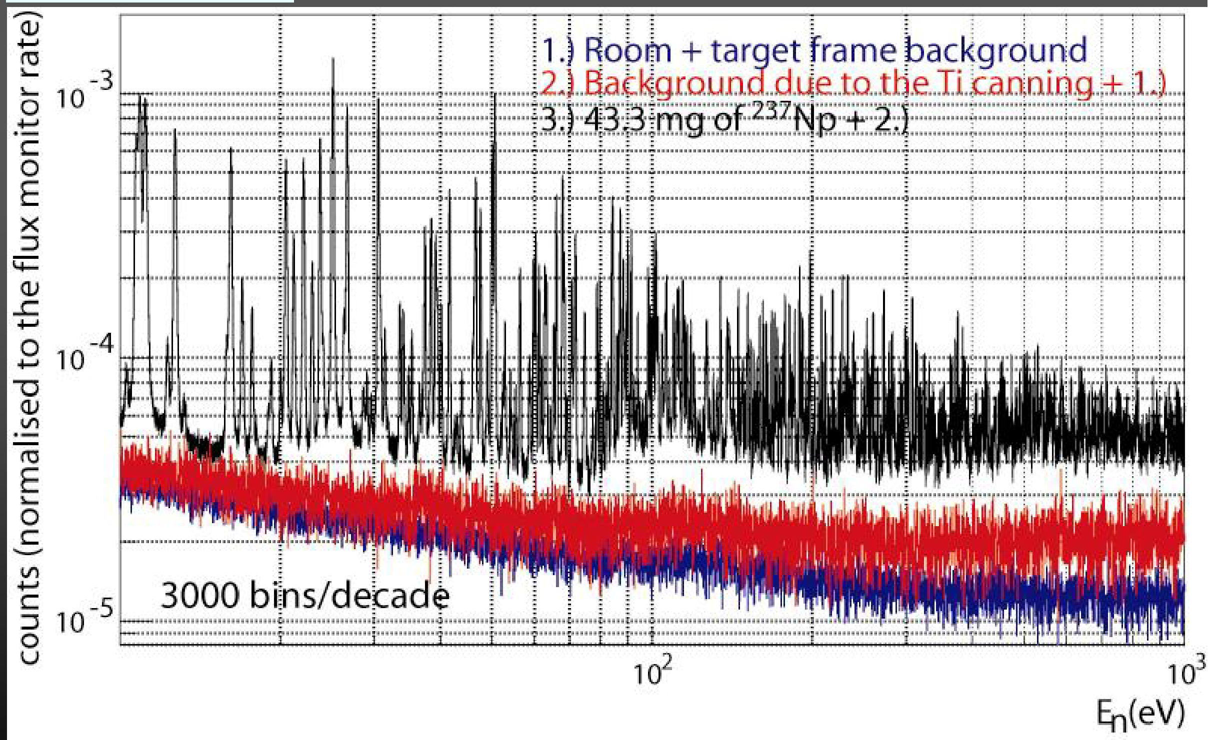


Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux &
  high energy resolution
- low repetition rate
  of the proton driver
- low background conditions

$^{237}Np(n,\gamma)$

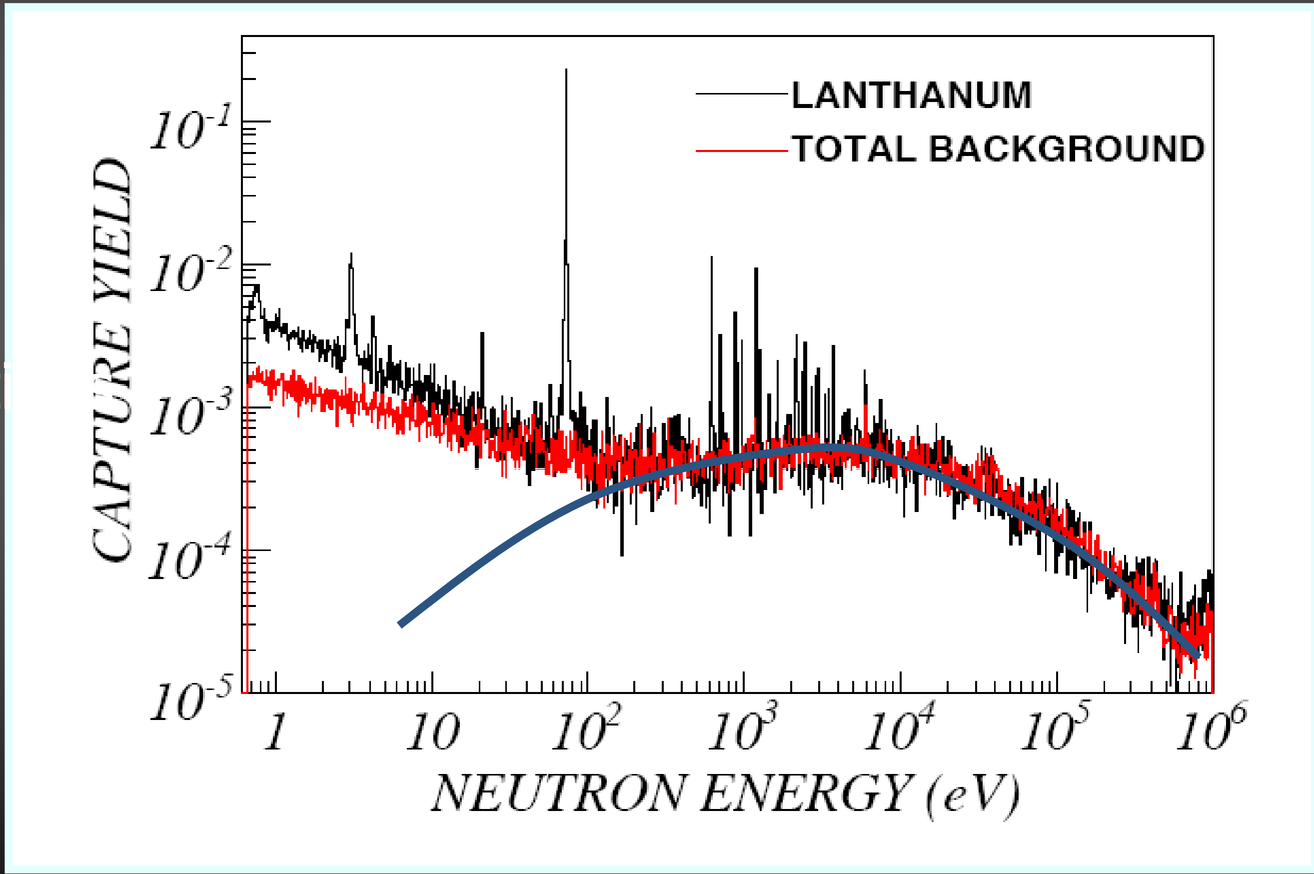
D Cano-Ott, *et al.* (The n_TOF Collaboration)
ND2004 Conference, Santa Fe, NM – Sept. 2004



Basic characteristics of experiments at n_TOF

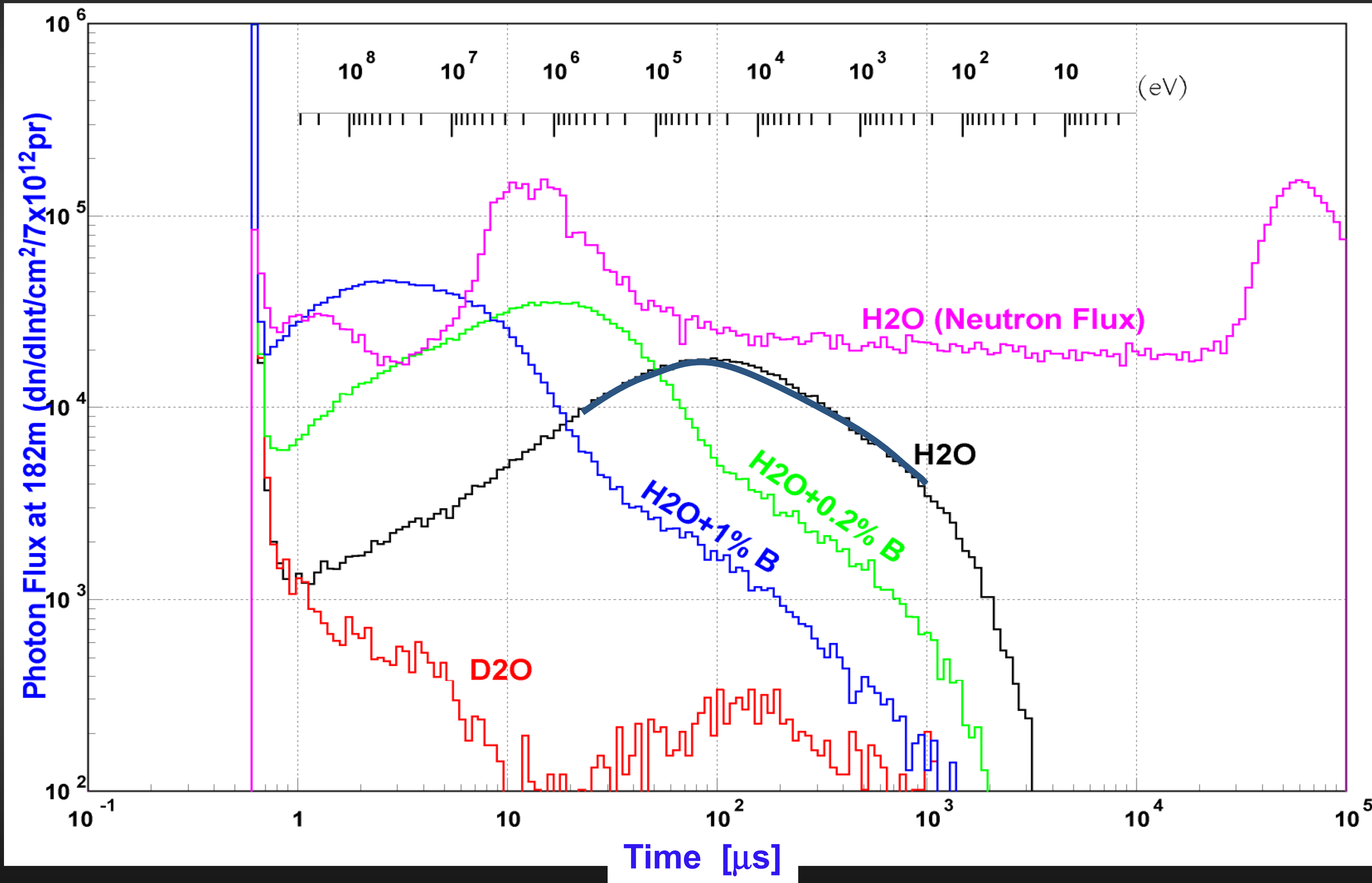
- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditi

low background conditions, but…



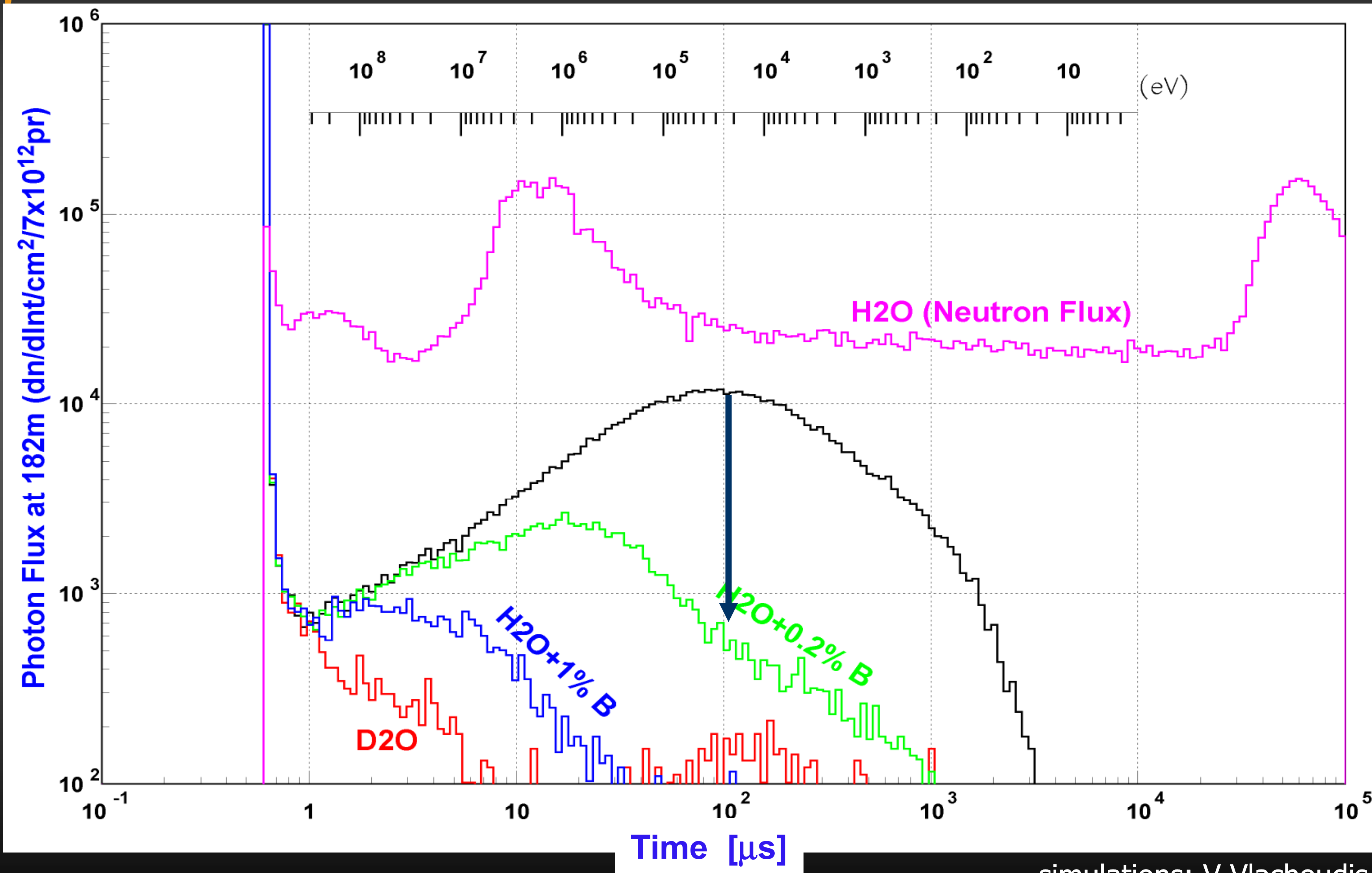
WARNING:
important in-beam
γ-ray BG present

In-beam photon time distribution



simulations: V Vlachoudis

In-beam photon time distribution (E_γ>1MeV)



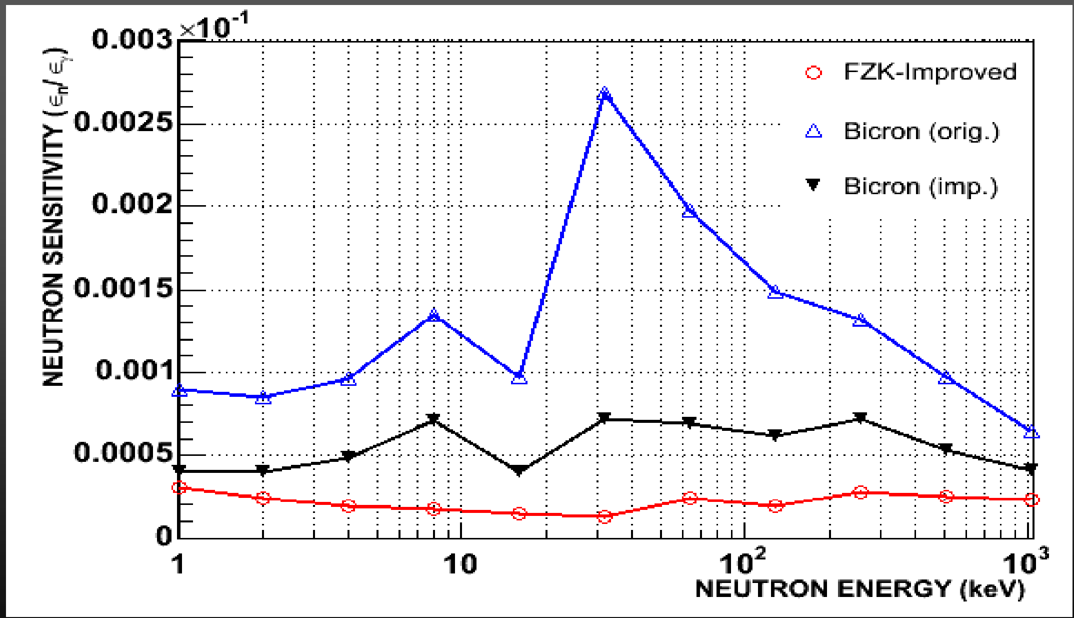
simulations: V Vlachoudis

Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

- detectors with extremely low neutron sensitivity

R Plag et al. (The n_TOF Collaboration)
NIMA 496 (2003) 425



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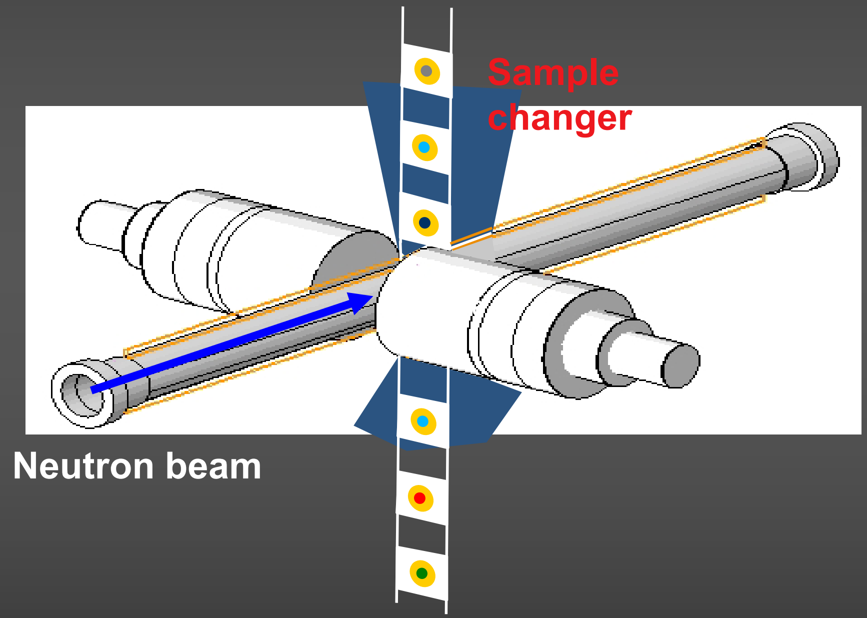

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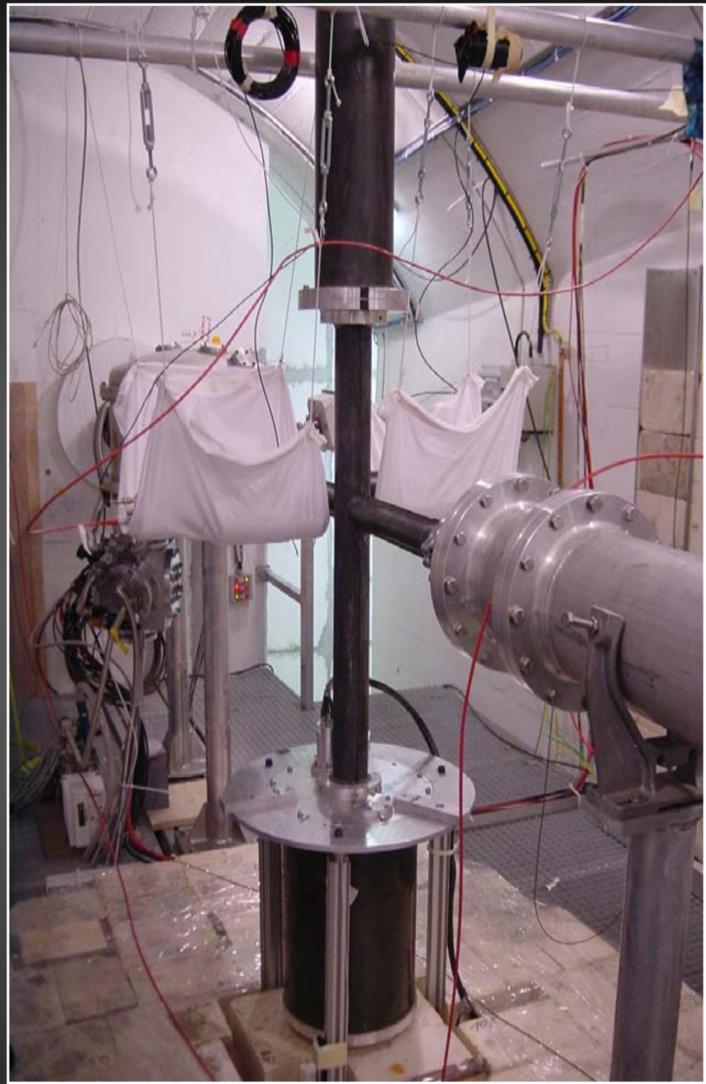
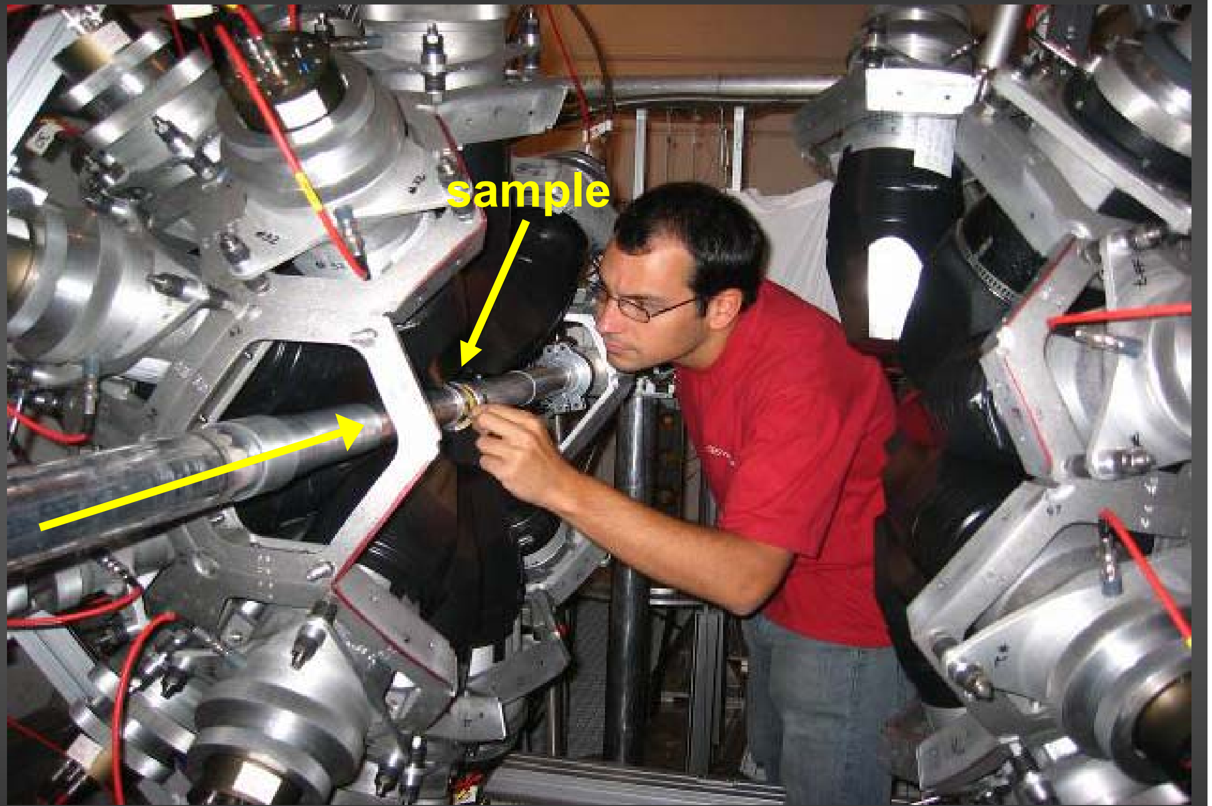


sample changer and beam pipe
made out of carbon fiber

Basic characteristics of experiments at n_TOF

- $40\ BaF_2$ crystals
- high detection efficiency ≈100%
- good energy resolution
- so far, only used for (n,γ) measurements in 2004



- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions
- detectors with extremely low neutron sensitivity
- high-efficiency detectors (TAC)

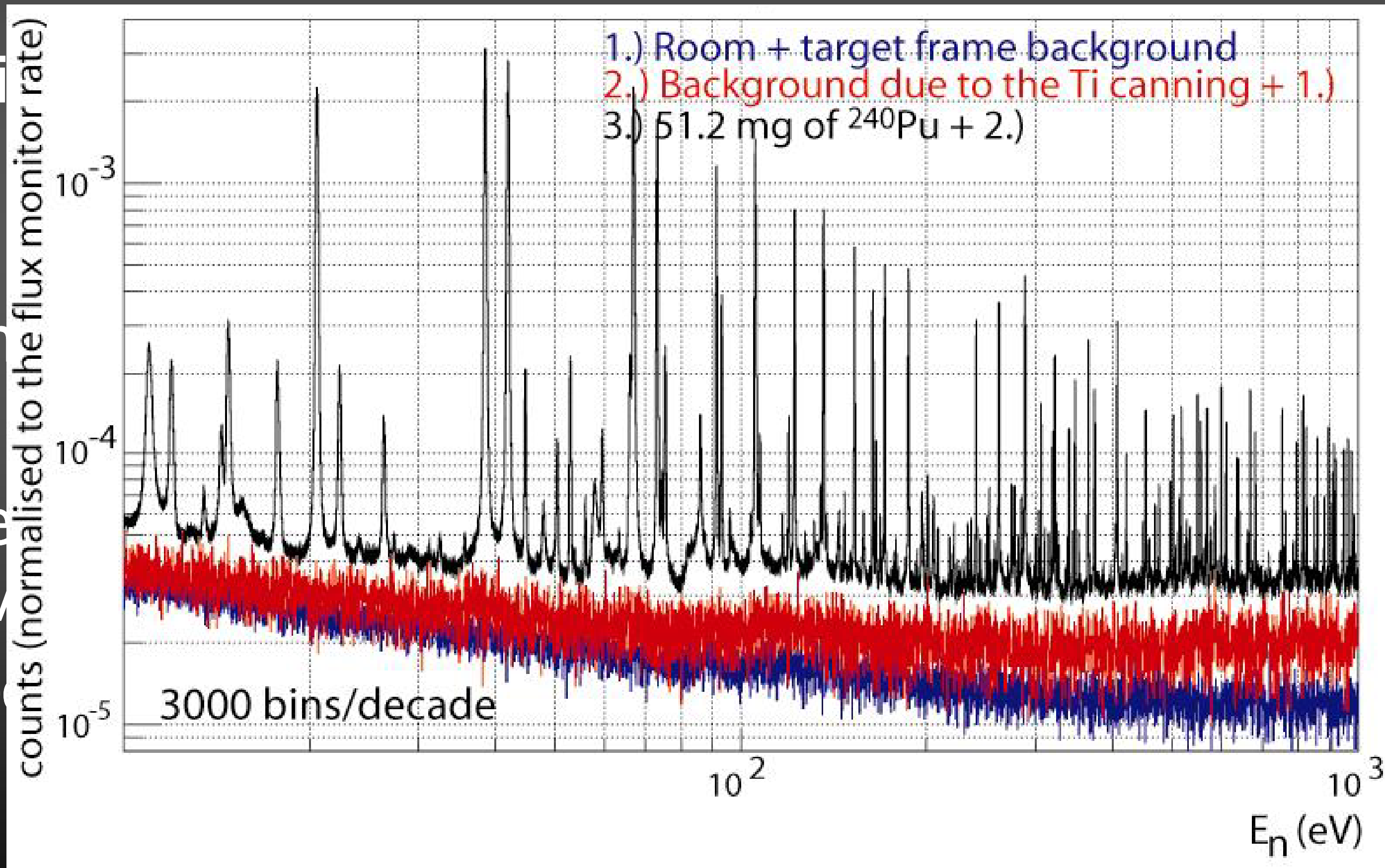
$\sigma(\varepsilon) \leq 2\%$

Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resoluti
- low repetition rate of the proton driver
- low background con
- detectors with extre low neutron sensitiv
- high-efficiency dete

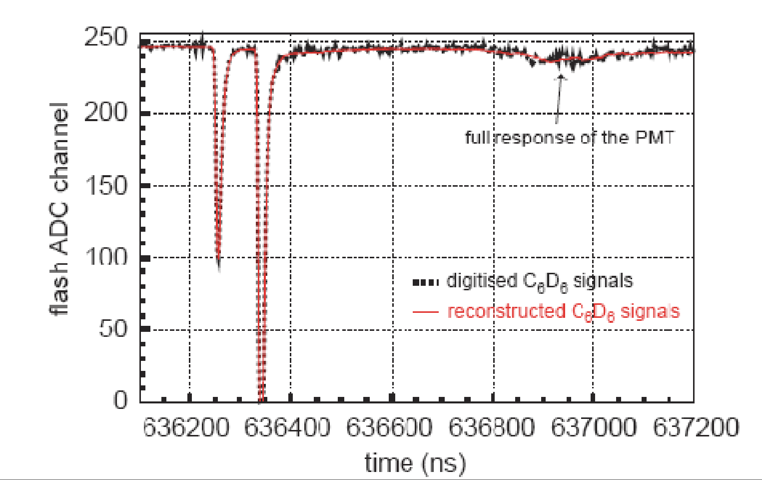
^{240}Pu(n,γ)

C Guerrero *et al.* (The n_TOF Collaboration)
ND2007 Conference, Nice, France, April 2007



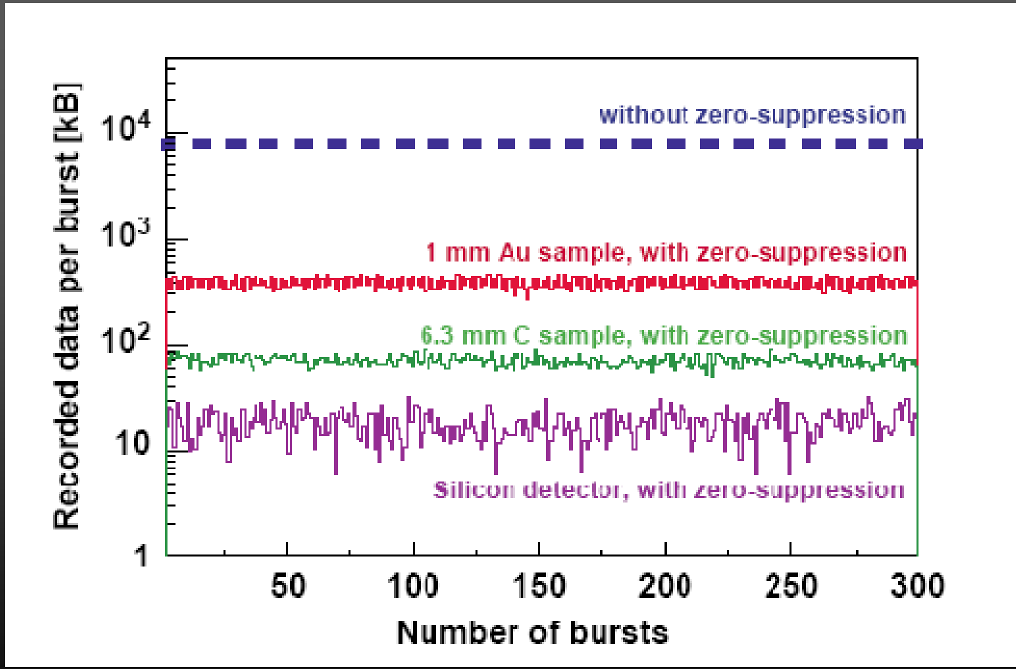
Basic characteristics of experiments at n_TOF

R Plag et al. (The n_TOF Collaboration)
NIMA 538 (2005) 693



- wide energy range
- high neutron flux &
  high energy resolution
- low repetition rate
  of the proton driver
- low background conditions

- detectors with extremely
  low neutron sensitivity
- high-efficiency detectors (TAC)
- state of the art daq system



Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

n_TOF beam characteristics and experimental setup proved to be a unique combination for high accuracy measurements

- detectors with extremely low neutron sensitivity
- high-efficiency detectors (TAC)
- state of the art daq system

n_TOF experiments 2002-4

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

- Measurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies
  - Th/U fuel cycle (capture & fission)
  - Transmutation of MA (capture & fission)
  - Transmutation of FP (capture)
- Cross sections relevant for Nuclear Astrophysics
  - s-process: branchings
  - s-process: presolar grains
- Neutrons as probes for fundamental Nuclear Physics
  - Nuclear level density & n-nucleus interaction

The n_TOF-Ph2(*) experiments 2008 and beyond

- Measurements of neutron cross sections relevant for Nuclear Waste Transmutation and Advanced Nuclear Technologies
- Cross sections relevant for Nuclear Astrophysics
- Neutrons as probes for fundamental Nuclear Physics

(*) The physics case and the related proposal for measurements at the CERN Neutron Time-of-Flight facility n_TOF in the period 2006-2010

CERN-INTC-2005-021; INTC-P-197

April 2005

The n_TOF-Ph2 experiments 2008 and beyond

Capture measurements	
Mo, Ru, Pd stable isotopes	r-process residuals calculation isotopic patterns in SiC grains
Fe, Ni, Zn, and Se (stable isotopes) ^{79}Se	s-process nucleosynthesis in massive stars accurate nuclear data needs for structural materials
A≈150 (isotopes varii)	s-process branching points long-lived fission products
^{234,236}U, ^{231,233}Pa	Th/U nuclear fuel cycle
^{235,238}U	standards, conventional U/Pu fuel cycle
^{239,240,242}Pu, ^{241,243}Am, ^{245}Cm	incineration of minor actinides

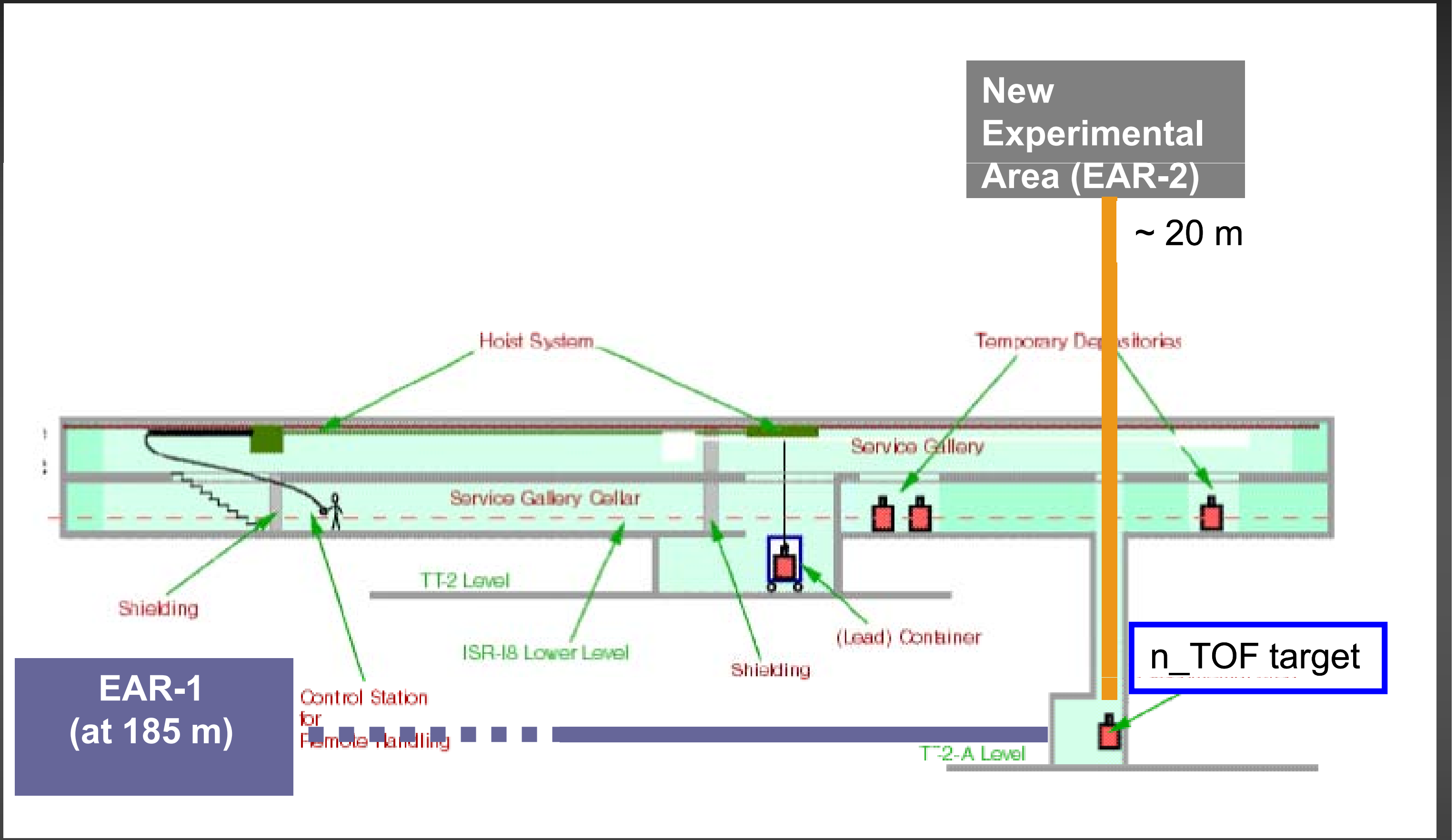
(*) endorsed by CERN INTC (execution in 2008?)

The n_TOF-Ph2 experiments 2008 and beyond

Fission measurements	
MA	ADS, high-burnup, GEN-IV reactors
$^{235}U(n,f)$ with p(n,p')	new $^{235}U(n,f)$ cross section standard
$^{234}U(n,f)$	study of vibrational resonances at the fission barrier

Other measurements	
$^{147}Sm(n,\alpha)$, $^{67}Zn(n,\alpha)$, $^{99}Ru(n,\alpha)$ $^{58}Ni(n,p)$, other (n,lcp)	p-process studies gas production in structural materials
Al, V, Cr, Zr, Th, $^{238}U(n,lcp)$	structural and fuel material for ADS and other advanced nuclear reactors
He, Ne, Ar, Xe	low-energy nuclear recoils (development of gas detectors)
$n+D_2$	neutron-neutron scattering length

The second n_TOF beam line & EAR-2



Flight-path length : ~20 m
at 90° respect to p-beam direction
expected neutron flux enhancement: ~ 100
drastic reduction of the t_0 flash

EAR-2: Optimized sensitivity

Improvements (ex: ^{151}Sm case)		consequences for sample mass
▪ sample mass / 3 s/bkgd=1		✓ 50 mg
▪ use BaF_2 TAC	ε x 10	✓ 5 mg
▪ use D_2O	Φ_{30} x 5	▪ 1 mg
▪ use 20 m flight path	Φ_{30} x 100	▪ 10 µg

boosts sensitivity by a **factor of 5000 !**

→ problems of sample production and safety issues relaxed

Summary & conclusion

- n_TOF unique for high precision cross section measurements
- plan for measurements in EAR-1 already available

ready to restart activities!

- possible improvements for the present setup for EAR-1:
  - reduction of in-beam γ-ray (use Borated H_2O or D_2O)
  - mods to safe use of radioactive samples

- future perspectives:
  - second beam line construction plan
  - Class-A as EAR-2

The n_TOF Collaboration

U.Abbondanno[14], G.Aerts[7], H.Álvarez[24], F.Alvarez-Velarde[20], S.Andriamonje[7], J.Andrzejewski[33], P.Assimakopoulos[9], L.Audouin[5], G.Badurek[1], P.Baumann[6], F. Bečvář [31], J.Benlliure[24], E.Berthoumieux[7], F.Calviño[25],D.Cano-Ott[20],R.Capote[23],A.Carrillo de Albornoz[30],P.Cennini[4], V.Chepel1[7], E.Chiaveri[4], N.Colonna1[3], G.Cortes[25], D.Cortina[24], A.Couture[29], J.Cox[29], S.David[5], R.Dolfini[15], C.Domingo-Pardo[21], W.Dridi[7], I.Duran[24], M.Embid-Segura[20], L.Ferrant[5], A.Ferrari[4], R.Ferreira-Marques[17], L.Fitzpatrick[4], H.Frais-Koelbl[3], K.Fujii[13], W.Furman[18], C.Guerrero[20], I.Goncalves[30], R.Gallino[36], E.Gonzalez-Romero[20], A.Goverdovski[19], F.Gramegna[12], E.Griesmayer[3], F.Gunsing[7], B.Haas[32], R.Haight[27], M.Heil[8], A.Herrera-Martinez[4], M.Igashira[37], S.Isaev[5], E.Jericha[1], Y.Kadi[4], F.Käppeler[8], D.Karamanis[9], D.Karadimos[9], M.Kerveno[6], V.Ketlerov[19], P.Koehler[28], V.Konovalov[18], E.Kossionides[39], M.Krtička[31], C.Lamboudis[10], H.Leeb[1], A.Lindote[17], I.Lopes[17], M.Lozano[23], S.Lukic[6], J.Marganiec[33], L.Marques[30], S.Marrone[13], P.Mastinu[12], A.Mengoni[4], P.M.Milazzo[14], C.Moreau[14], M.Mosconi[8], F.Neves[17], H.Oberhummer[1], S.O'Brien[29], M.Oshima[38], J.Pancin[7], C.Papachristodoulou[9], C.Papadopoulos[40], C.Paradela[24], N.Patronis[9], A.Pavlik[2], P.Pavlopoulos[34], L.Perrot[7], R.Plag[8], A.Plompen[16], A.Plukis[7], A.Poch[25], C.Pretel[25], J.Quesada[23], T.Rauscher[26], R.Reifarth[27], M.Rosetti1[1], C.Rubbia[5], G.Rudolf[6], P.Rullhusen[16], J.Salgado[30], L.Sarchiapone[4], C.Stephan[5], G.Tagliente[13], J.L.Tain[21], L.Tassan-Got[5], L.Tavora[30], R.Terlizzi[13], G.Vannini[35], P.Vaz[30], A.Ventura[11], D.Villamarin[20], M.C.Vincente[20], V.Vlachoudis[4], R.Vlastou[40], F.Voss[8], H.Wendler[4], M.Wiescher[29], K.Wisshak[8]

40 research teams
120 researchers

MoU for Phase-2
ready for signature

The End

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

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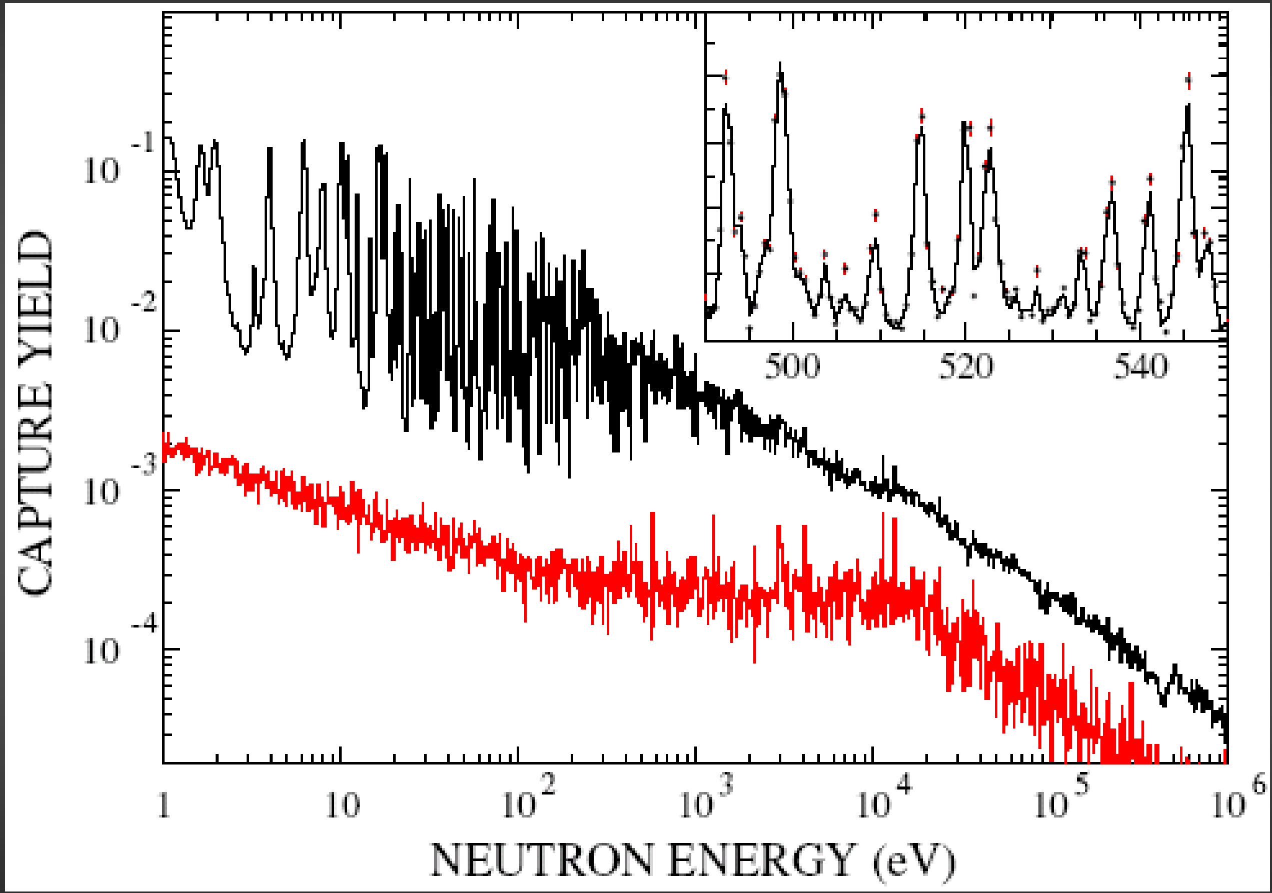
U Abbondanno et al. (The n_TOF Collaboration)
Phys. Rev. Lett. **93** (2004), 161103



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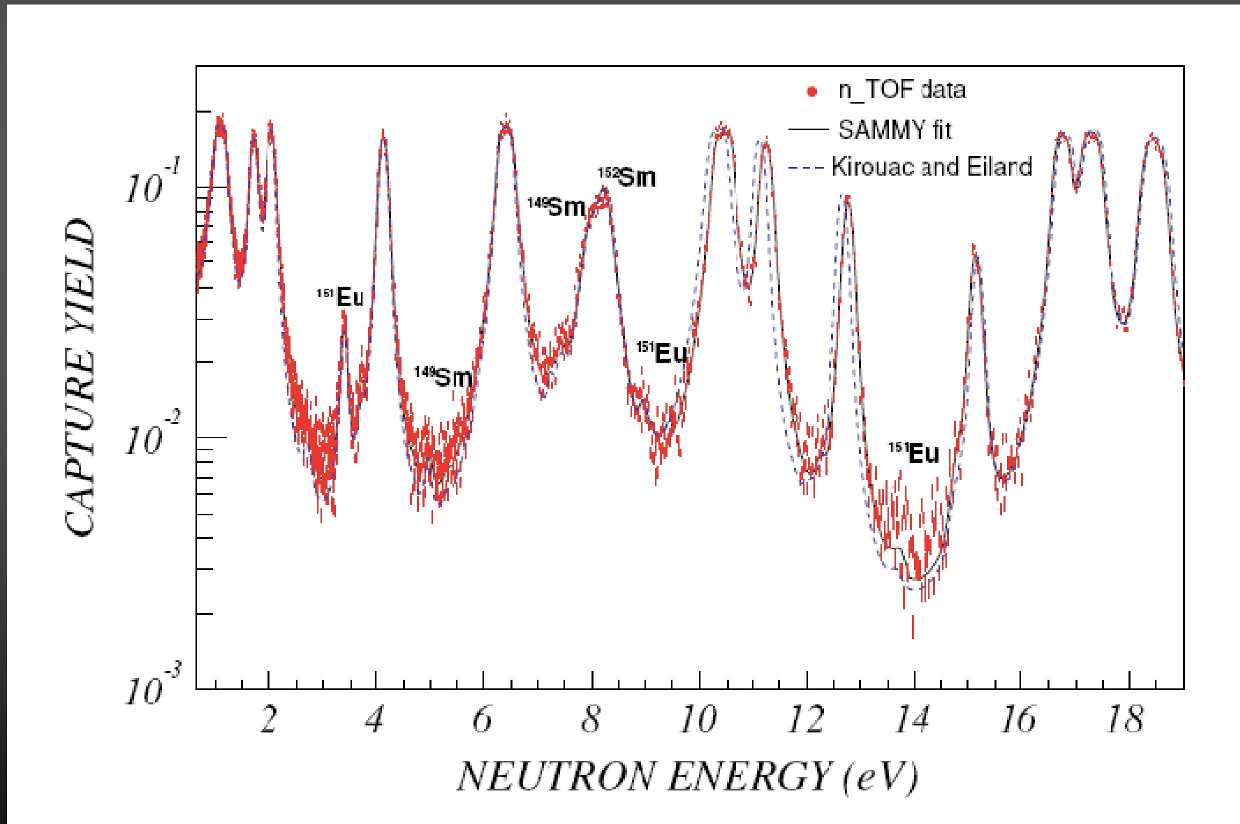

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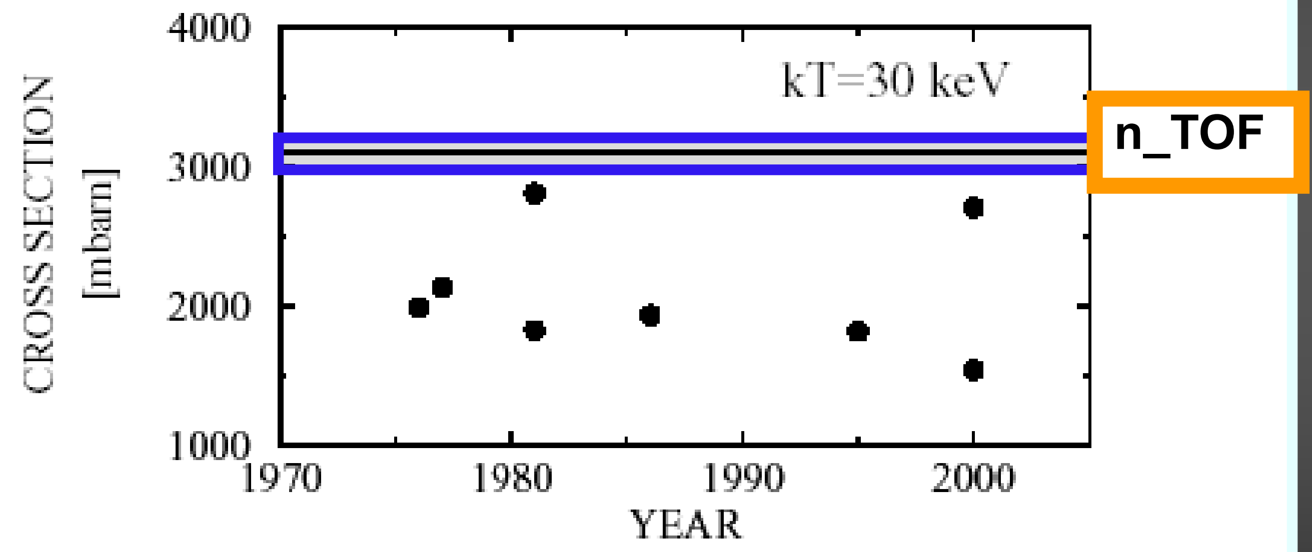

$\langle D_0 \rangle = 1.49 \pm 0.07$ eV
$S_0 = (3.87 \pm 0.33)\times10^{-4}$
$R_I = 3575 \pm 210$ b

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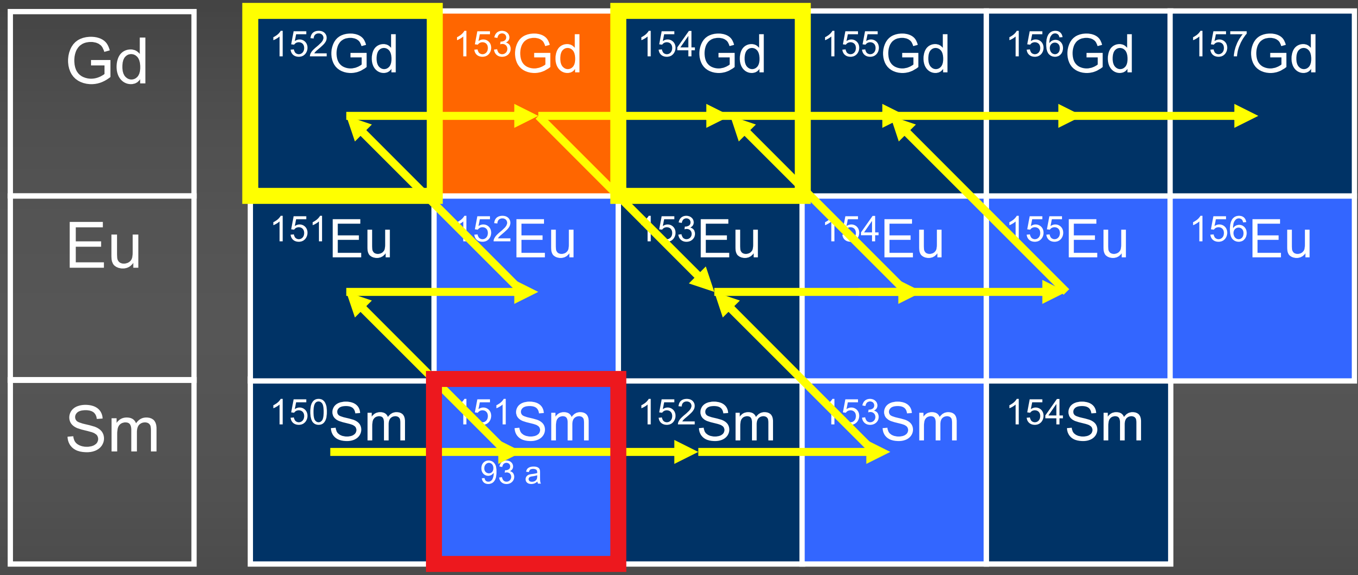

- $T_8 > 4$ using the "classical" s-process model
- from AGB modeling: 71% of ^{152}Gd

Present main uncertainty: $\lambda_\beta(T)$ of ^{151}Sm

n_TOF experiments

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for nuclear data evaluators:
all infos available in refereed journal publications
&
on the n_TOF website
www.cern.ch/ntof

TABLE IX. The ^{151}Sm(n,γ) cross section in the unresolved resonance region from 1 keV to 1 MeV.

Energy bin (keV)	$\sigma_{(n,\gamma)}$ (b)	Uncertainty (%) Stat.	Syst.	Tot.
1–1.2	24.52	0.8	4.4	4.5
1.2–1.5	23.68	0.8	4.3	4.4
1.5–1.75	21.94	1.0	4.2	4.3
1.75–2	19.76	1.2	4.2	4.3
2–2.5	15.43	1.1	4.1	4.3
2.5–3	15.36	1.3	4.1	4.3
3–4	12.78	1.2	4.1	4.3
4–5	10.04	1.4	4.1	4.3
5–7.5	8.91	2.1	2.9	3.6
7.5–10	5.85	3.0	3.1	4.3
10–12.5	5.38	3.9	2.9	4.8
12.5–15	4.26	4.9	3.2	5.8
15–20	3.82	3.8	3.2	4.9
20–25	3.52	4.6	3.5	5.8
25–30	3.13	4.5	3.1	5.5
30–40	2.69	4.4	3.2	5.5
40–50	2.17	4.8	3.4	5.9
50–60	1.90	5.2	3.3	6.2
60–80	1.66	4.1	3.6	5.5
80–100	1.30	5.1	4.6	6.9

n_TOF experiments

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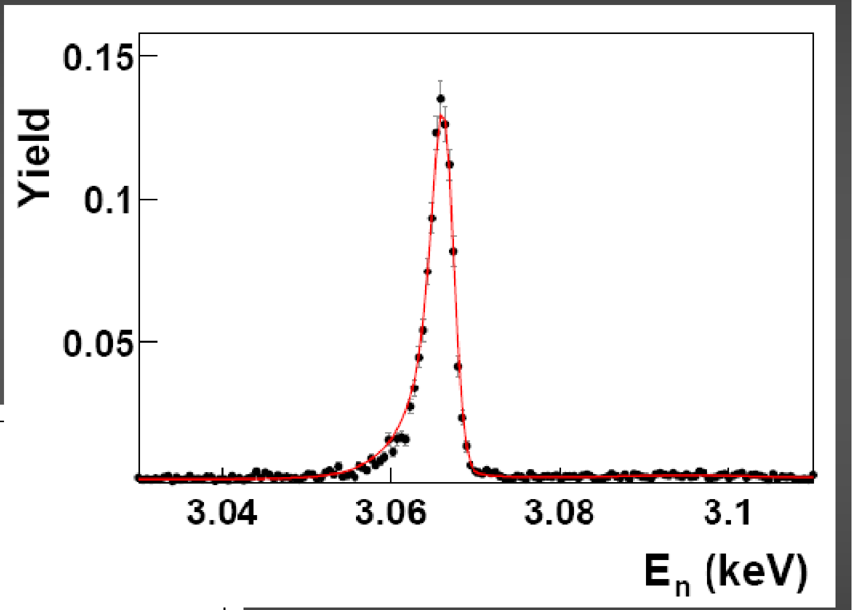
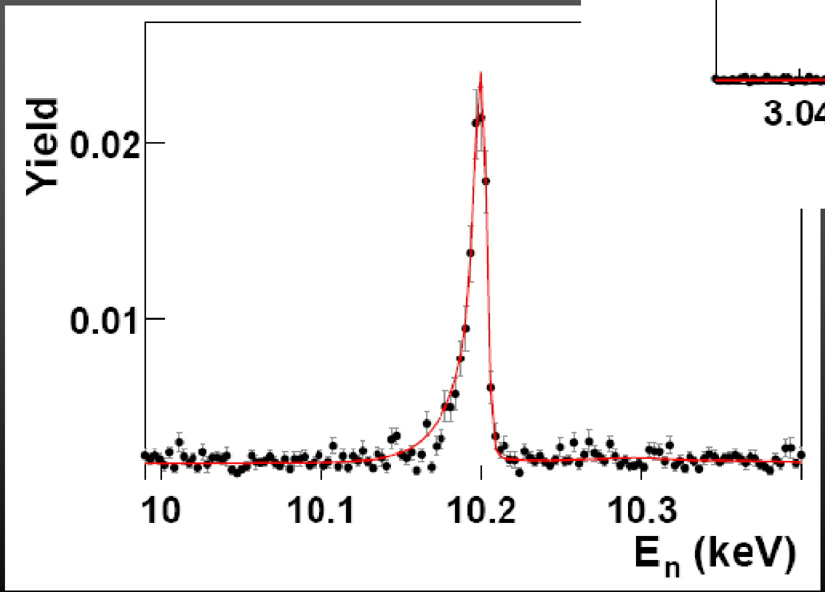
$^{207}Pb(n,\gamma)$

C Domingo-Pardo, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004
&
accepted for publication in PRC (in press)





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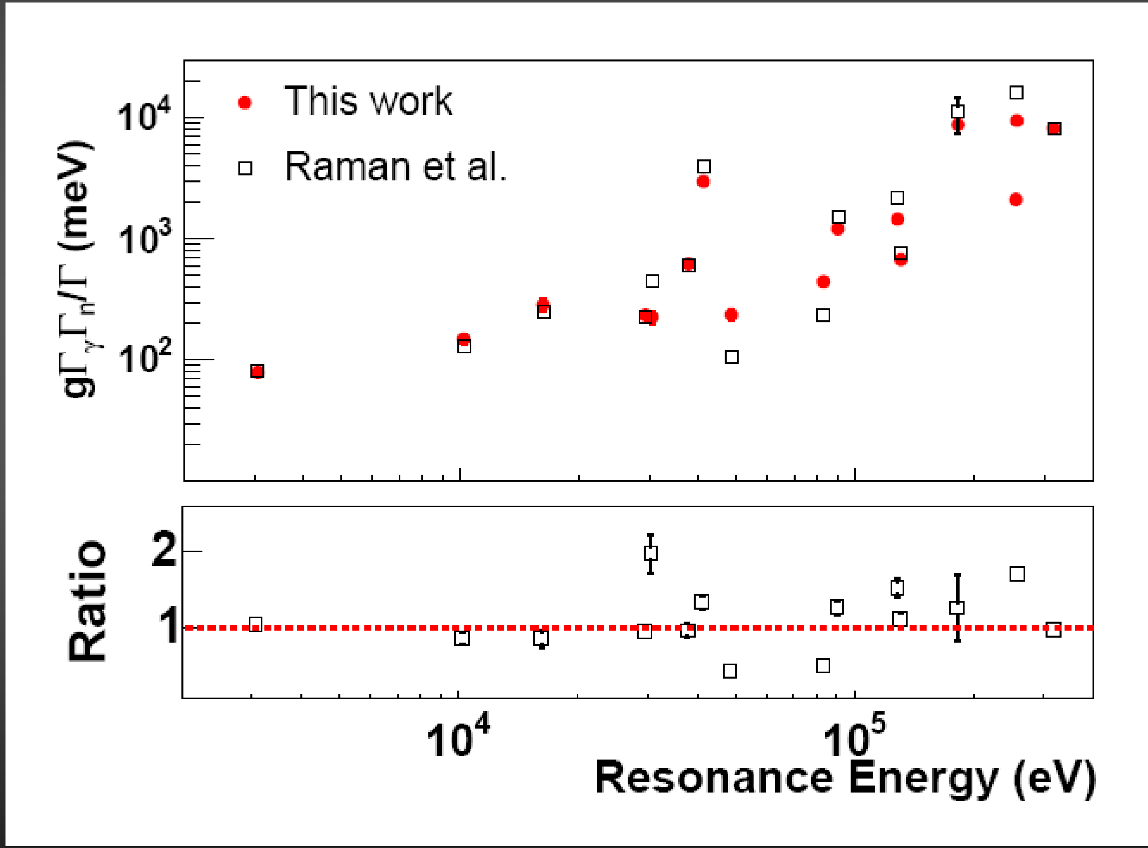

substantial disagreement for E_n > 45 keV

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{207}Pb(n,\gamma)$

C Domingo-Pardo, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004
&
accepted for publication in PRC (in press)

TABLE II: Resonance parameters and radiative kernels from the analysis of the $^{207}Pb(n,\gamma)$ data measured at n_TOF[a].

$E_\circ$ (eV)	l	J	Γ_n (meV)	Γ_γ (meV)	$g\Gamma_\gamma\Gamma_n/\Gamma$ (meV)
3064.700(3)	1	2	111.0(8)	145.0(9)	78.6(9)
10190.80(4)	1	2	656(50)	145.2(12)	149(14)
16172.80(10)	1	2	1395(126)	275(3)	287(30)
29396.1	1	2	16000	189(7)	234(9)
30485.9(5)	1	1	608(45)	592(50)	225(30)
37751(3)	1	1	50×10^3	843(40)	620(30)
41149(46)	0	1	1.220×10^6	3970(160)	2970(120)
48410(2)	1	2	1000	230(20)	235(20)
82990(12)	1	2	29×10^3	360(30)	444(30)
90228(24)	1	1	272×10^3	1615(100)	1200(80)
127900	1	1	613×10^3	1939(150)	1449(120)
130230	1	1	87×10^3	900(80)	675(60)
181510(6)	0	1	57.3×10^3	14709(500)	8780(300)
254440	2	3	111×10^3	1219(90)	2110(150)
256430	0	1	1.66×10^6	12740(380)	9482(280)
317000	0	1	850×10^3	10967(480)	8120(350)

[a]Orbital angular momenta l and resonance spins J are from Ref. [17].

3% accuracy
of the capture kernel

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

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^{232}Th

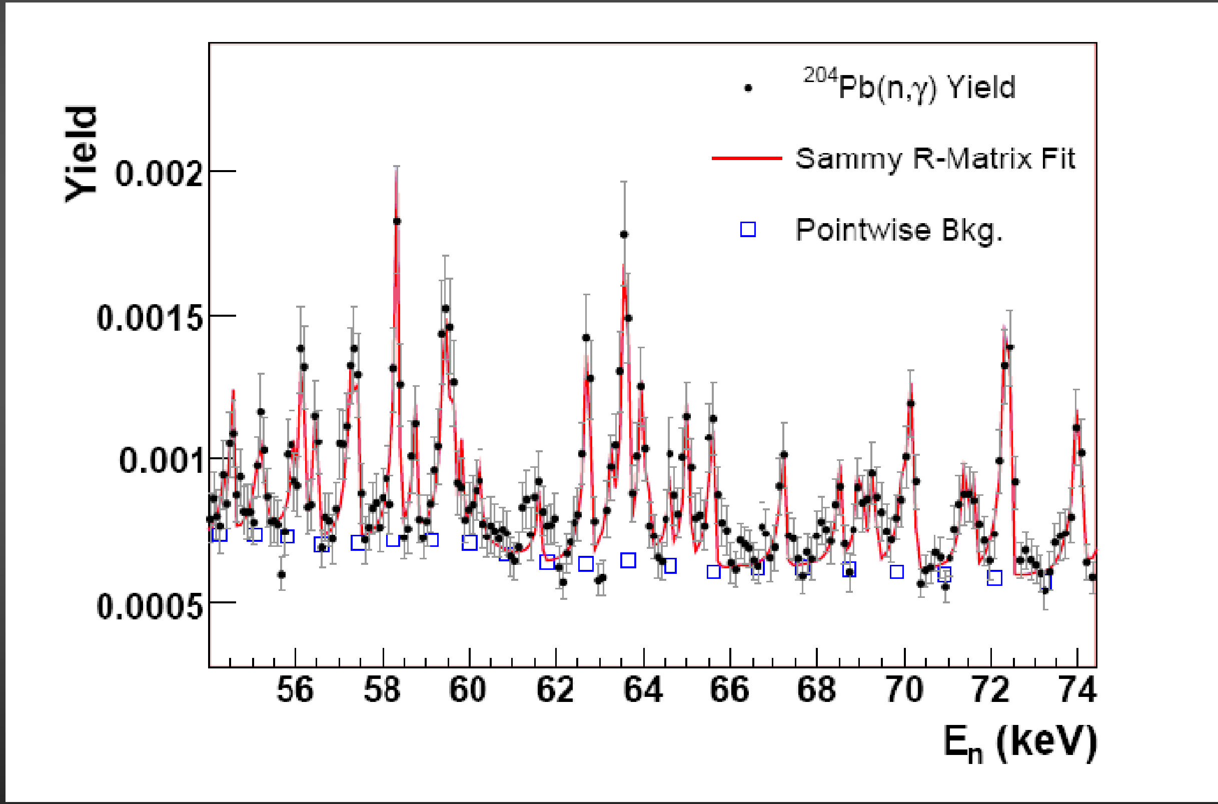
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{204}Pb(n,\gamma)$

C Domingo-Pardo, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004
&
submitted for publication to PRC, October 2006



Very low neutron sensitivity of capture γ-ray detection systems & high resolution

n_TOF experiments

Capture

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$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

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$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{204}Pb(n,\gamma)$

C Domingo-Pardo, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004
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submitted for publication to PRC, October 2006

$E_\circ$ (eV)	l	J	Γ_γ (meV)	$\Delta\Gamma_\gamma$ (%)	Γ_n (meV)	K_r (meV)	ΔK_r (%)
480.3	1	1/2	1.33	4	3.0	0.92^a	2.7
1333.8	1	1/2	105	4	46.3^b	32.1^a	1.3
1687.1	0	1/2	1029	0.7	3340	787^a	0.5
2481.0	0	1/2	514	1.1	5470	470^a	1.0
2600.0						8.35	6
2707.1	1	3/2	31.2	9	11.5	16.8	2
3187.9	0	1/2	316	10	1.7	1.69	0.1
3804.9	1	1/2	280	8	66.4	53.7	1.6
4284.1	1	3/2	111	9	24.0	39.4	1.7
4647.5						2.57	9
4719.4	1	3/2	41.2	5	95.0	57.5	3
5473.2	1	1/2				79.0	1.6
5561.4		(1/2)	1.03	10	1.9	0.67	6.4
6700.5	0	1/2	312	3	4540	292	3
7491.0						19.0	0.5
8357.4	0	1/2	1286	1.9	45000	1250	1.9
8422.9						11.3	7
8949.6						22.9	3
9101.0		(1/2)	193	8	150	84.4	4
9649.3	0	1/2	1076	2	7860	946	2
10254						37.0	8
11366	1	3/2	39.0	10	226	66.5	9
11722						22.8	9
12147						54.4	8

TABLE IV: Average neutron capture cross section for ^{204}Pb.

E_{low} (keV)	E_{high} (keV)	Cross section (barn)	Statistical uncertainty^a (%)
88.210	92.404	0.059	9
92.404	96.748	0.059	5
96.748	101.406	0.058	11
101.406	106.408	0.057	8
106.408	111.790	0.057	7
111.790	117.591	0.056	8
117.591	123.855	0.056	7
123.855	130.634	0.055	7
130.634	137.985	0.054	6
137.985	145.974	0.054	6
145.974	154.678	0.053	6
154.678	164.185	0.053	7
164.185	174.596	0.052	7
174.596	186.030	0.051	6
186.030	198.625	0.051	5
198.625	212.544	0.050	5
212.544	227.981	0.049	5
227.981	245.162	0.049	5
245.162	264.363	0.048	4
264.363	285.911	0.047	4
285.911	310.207	0.046	4
310.207	337.739	0.046	4
337.739	369.107	0.045	4
369.107	405.060	0.044	4
405.060	443.512	0.043	3

[a] This value has to be added in quadrature with the overall systematic uncertainty of 10%.

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

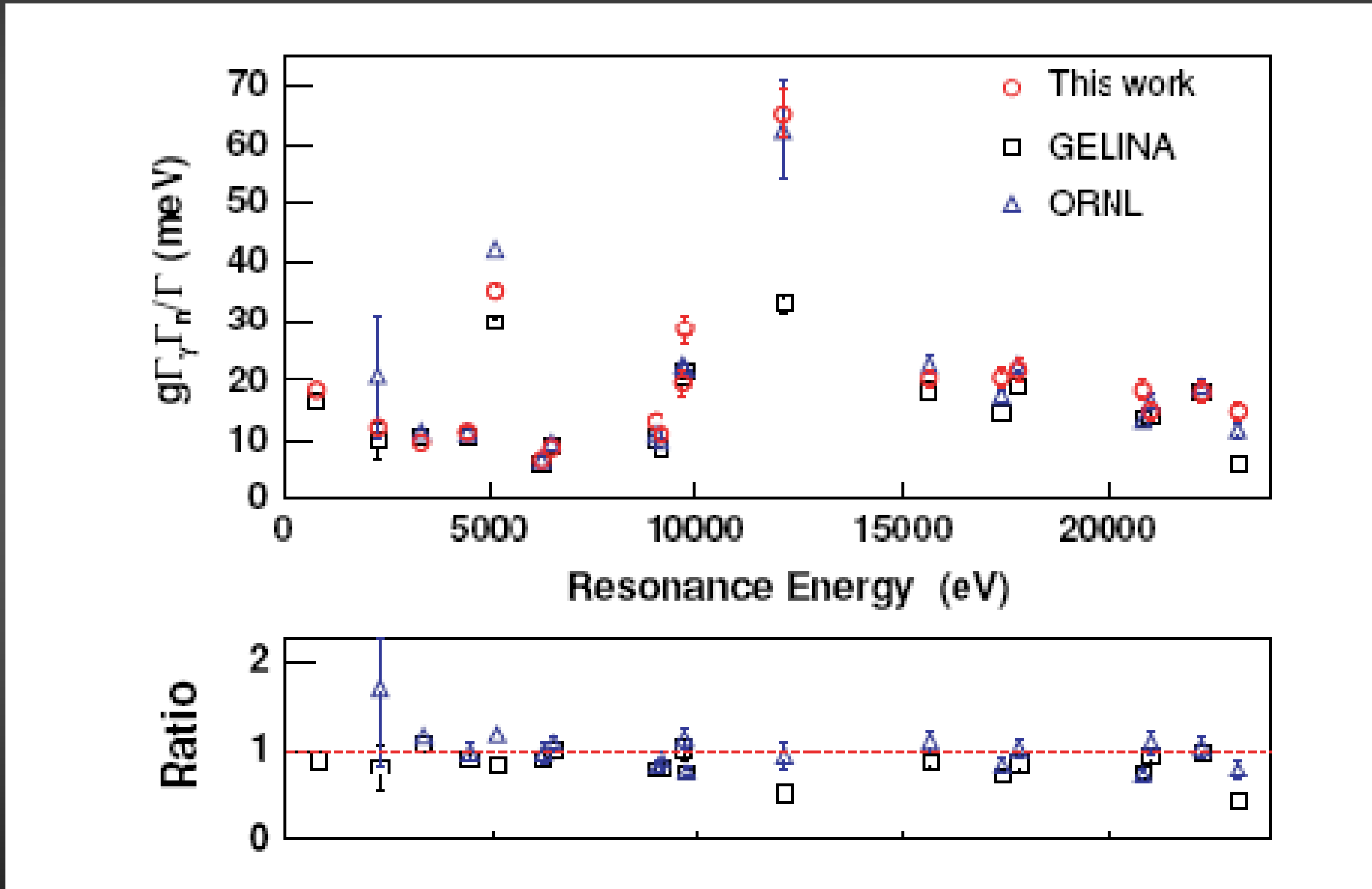
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{209}Bi(n,\gamma)$

C Domingo-Pardo, et al. (The n_TOF Collaboration)
Phys. Rev. C **74**, 025807 (2006)



Very low neutron sensitivity of capture γ-ray detection systems & high resolution

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{209}Bi(n,\gamma)$

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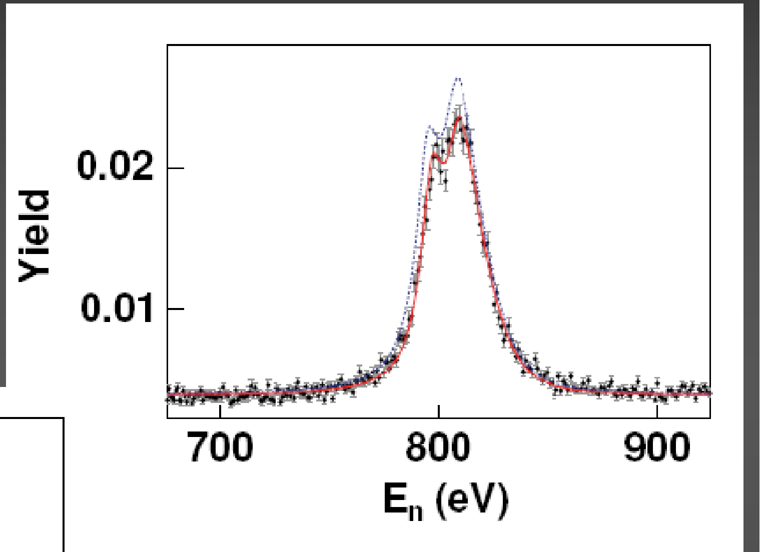

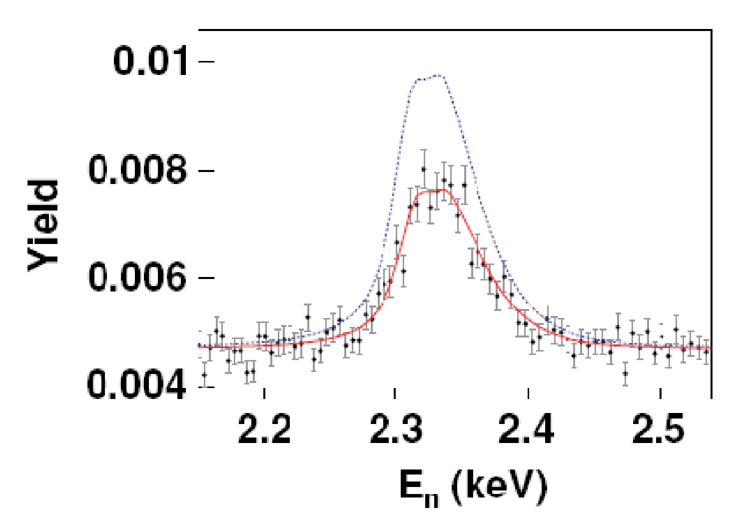

Very low neutron sensitivity of capture γ-ray detection systems & high resolution

n_TOF experiments

Capture

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$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

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$^{186,187,188}Os$

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^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{209}Bi(n,\gamma)$

C Domingo-Pardo, et al. (The n_TOF Collaboration)
Phys. Rev. C **74**, 025807 (2006)

TABLE II. Resonance parameters[a] and radiative kernels[b] for ^{209}Bi.

$E_\circ$ (eV)	l	J	Γ_n (meV)	Γ_γ (meV)	$g\Gamma_\gamma\Gamma_n/\Gamma$ (meV)
801.6(1)	0	5	4309(145)	33.3(12)	18.2(6)
2323.8(6)	0	4	17888(333)	26.8(17)	12.0(8)
3350.83(4)	1	5	87(9)	18.2(3)	9.5(2)
4458.74(2)	1	5	173(13)	23.2(22)	11.3(11)
5114.0(3)	0	5	5640(270)	65(2)	35.3(11)
6288.59(2)	1	4	116(18)	17.0(17)	6.7(7)
6525.0(3)	1	3	957(100)	25.3(14)	8.6(5)
9016.8(4)	1	6	408(77)	21.1(14)	13.0(9)
9159.20(7)	1	5	259(45)	21.4(21)	10.9(11)
9718.910(1)	1	4	104(22)	74(7)	19.5(21)
9767.2(3)	1	3	900(114)	90(8)	28.7(26)
12098					65(4)[c]
15649.8(1.0)	1	5	1000	47(4)	20.2(17)
17440.0(1.3)	1	6	1538(300)	32(3)	20.4(18)
17839.5(9)	1	5	464(181)	43(4)	21.7(20)
20870	1	5	954(227)	34.4(33)	18.3(17)
21050	1	4	7444(778)	33(3)	14.8(13)
22286.0(9)	1	5	181(91)	33.6(32)	15.1(15)
23149.1(1.3)	1	6	208(154)	25.3(25)	14.7(15)

[a]Angular orbital momenta, l, resonance spins J, and neutron widths, Γ_n, are mainly from Refs. [27,28].
[b]Uncertainties are given as 18.2(6)≡18.2±0.6.
[c]This area corresponds to the sum of the areas of the broad s-wave resonance at the indicated energy, plus two p-wave resonances at 12.092 and 12.285 keV.

16% higher MACS for kT = 5-8 keV
81% r-process abundance for ^{209}Bi

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

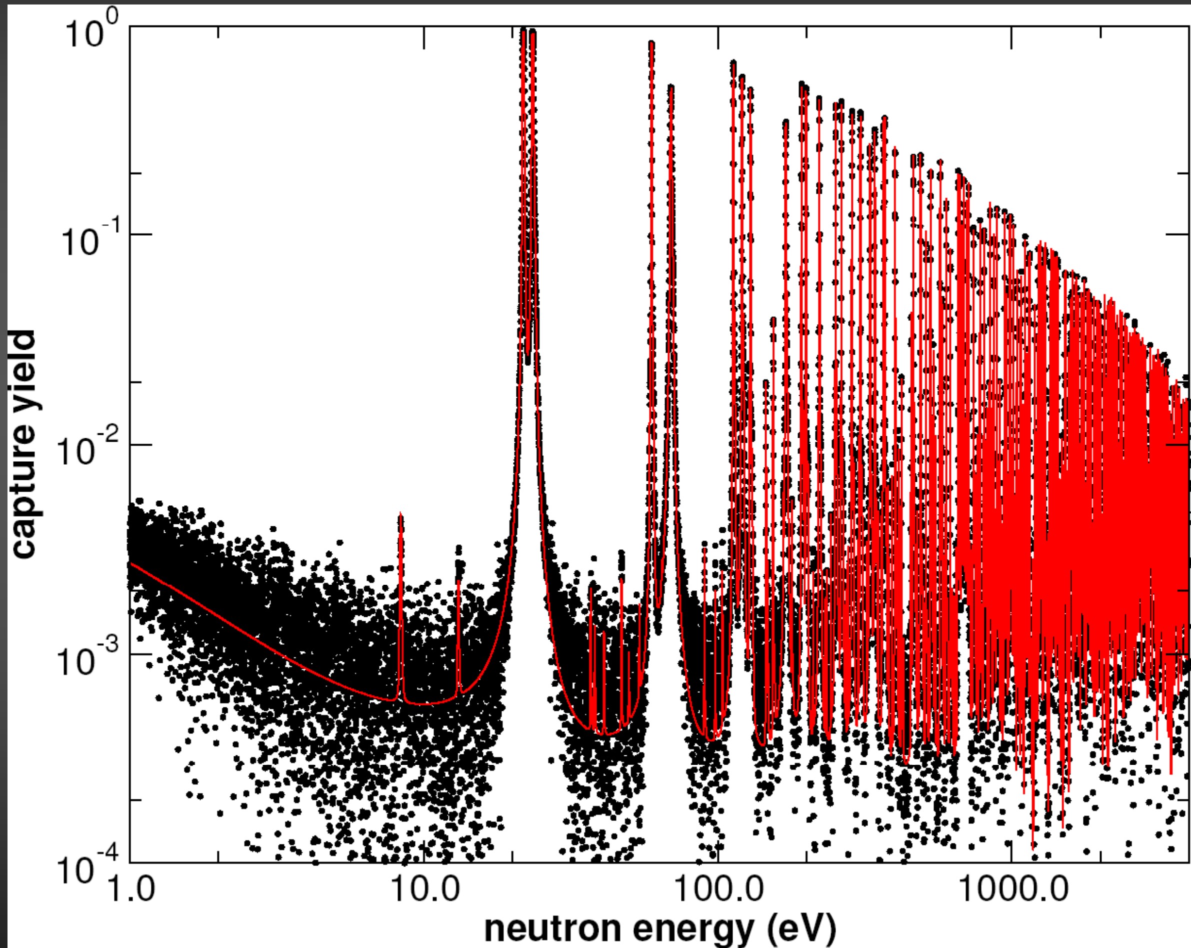
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{232}Th(n,\gamma)$

F Gunsing, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004



extremely high-resolution data!

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

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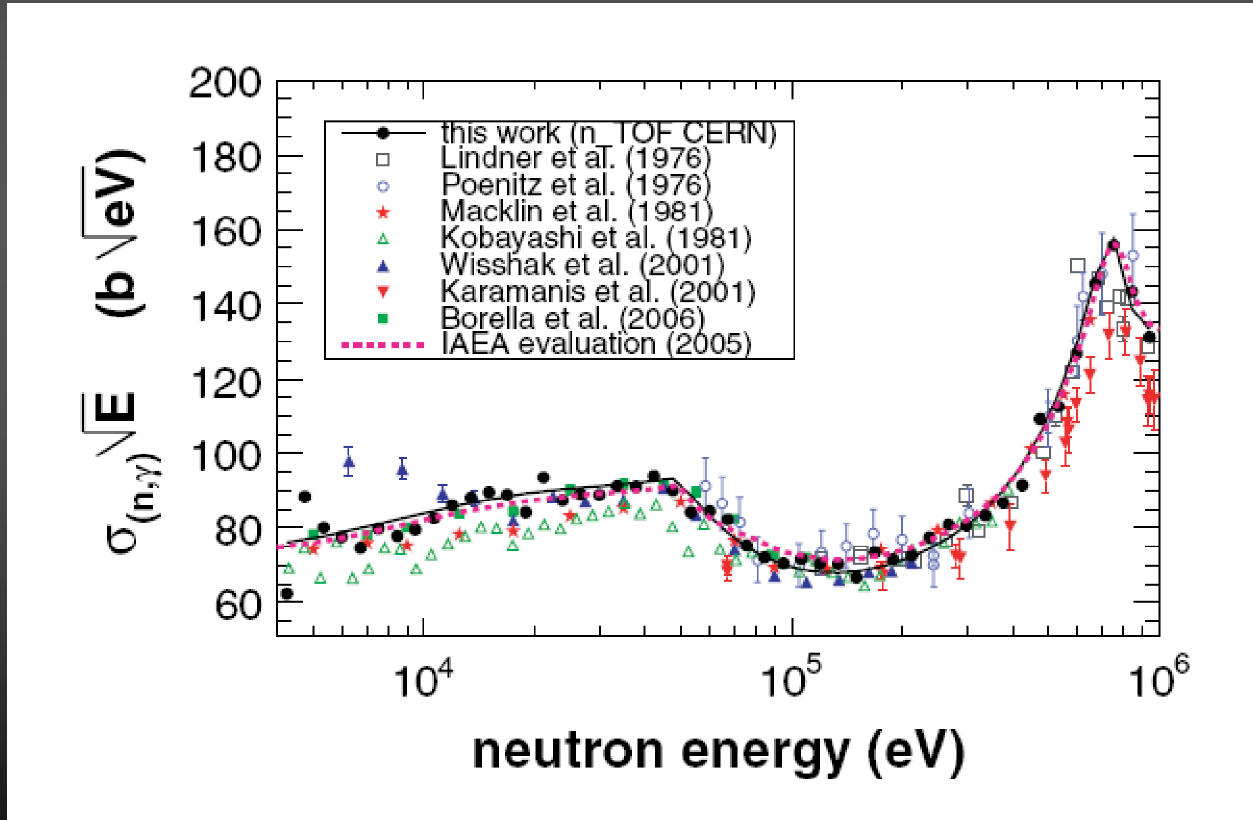
G Aerts et al. (The n_TOF Collaboration)
Phys. Rev. C 73, 054610 (2006)



n_TOF experiments

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$^{24,25,26}Mg$

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Phys. Rev. C 73, 054610 (2006)

TABLE II. Different components of estimated systematic or correlated uncertainty in the measured cross section.

Component	Uncertainty (%)
PHWT	0.5
Normalization	0.5
Background	2.5
Flux shape	2.0
Total	3.3

For E_n = 4 keV up to 1 MeV full dataset is available on the PRC publication

E_{low} (keV)	E_{high} (keV)	Cross section (b)	Uncertainty (b)
3.994	4.482	0.958	0.020
4.482	5.028	1.281	0.021
5.028	5.642	1.097	0.016
5.642	6.331	1.004	0.014
6.331	7.103	0.912	0.013
7.103	7.970	0.919	0.013
7.970	8.942	0.848	0.013
8.942	10.033	0.817	0.012
10.033	11.257	0.800	0.012
11.257	12.631	0.787	0.012
12.631	14.172	0.761	0.012
14.172	15.902	0.729	0.011
15.902	17.842	0.685	0.011
17.842	20.019	0.613	0.010
20.019	22.461	0.641	0.010
22.461	25.202	0.566	0.009
25.202	28.277	0.545	0.009
28.277	31.728	0.513	0.008
31.728	35.599	0.497	0.009
35.599	39.943	0.468	0.009
39.943	44.816	0.456	0.008
44.816	50.285	0.413	0.007
50.285	56.421	0.365	0.006
56.421	63.305	0.346	0.006
63.305	71.029	0.318	0.006
71.029	79.696	0.275	0.005
79.696	89.421	0.248	0.005
89.421	100.332	0.229	0.005
100.332	112.574	0.220	0.004
112.574	126.310	0.204	0.004
126.310	141.722	0.192	0.004

n_TOF experiments

Capture

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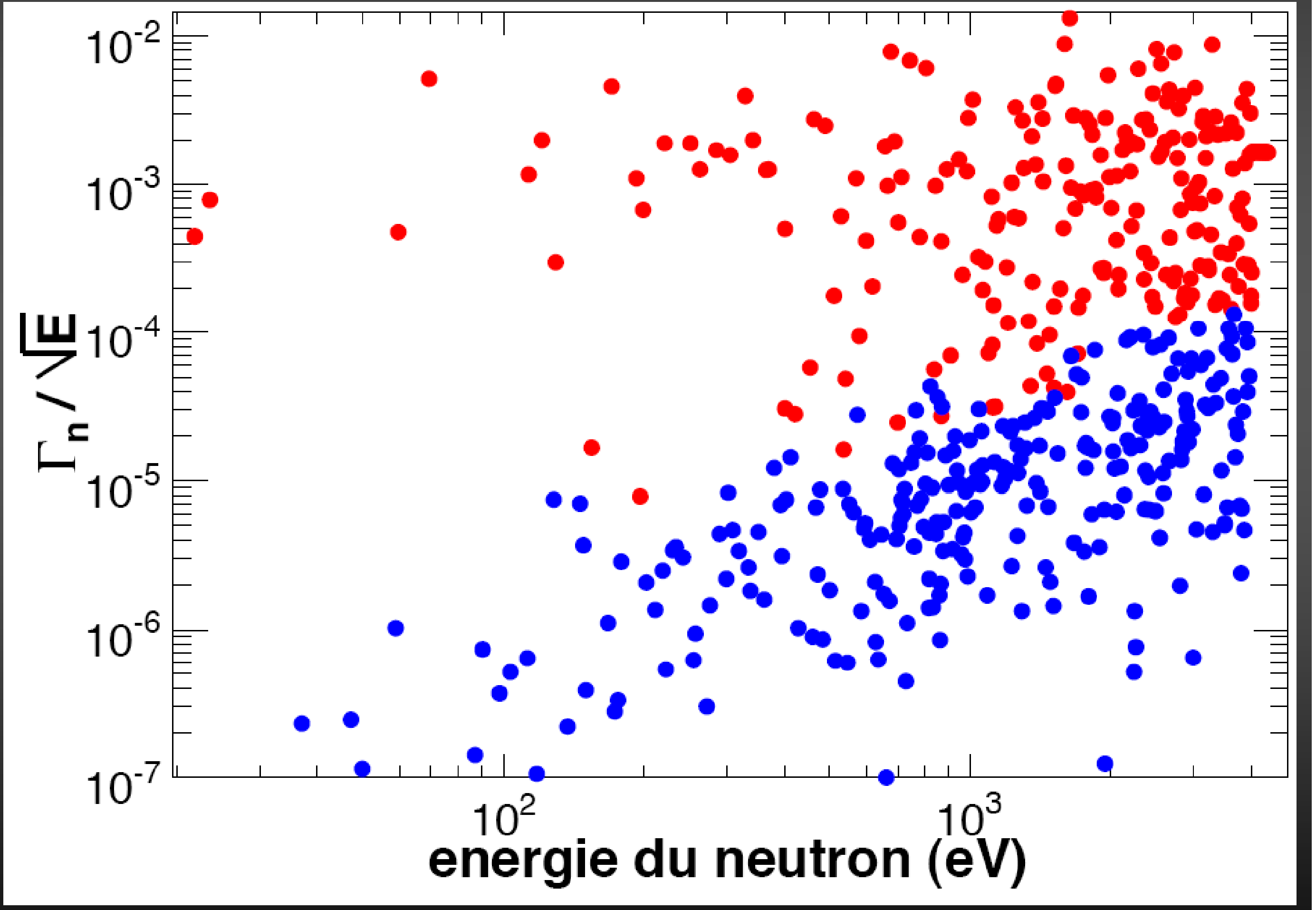
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{232}Th(n,\gamma)$

F Gunsing, et al. - The n_TOF Collaboration
analysis in progress



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n_TOF experiments

$^{232}Th(n,\gamma)$

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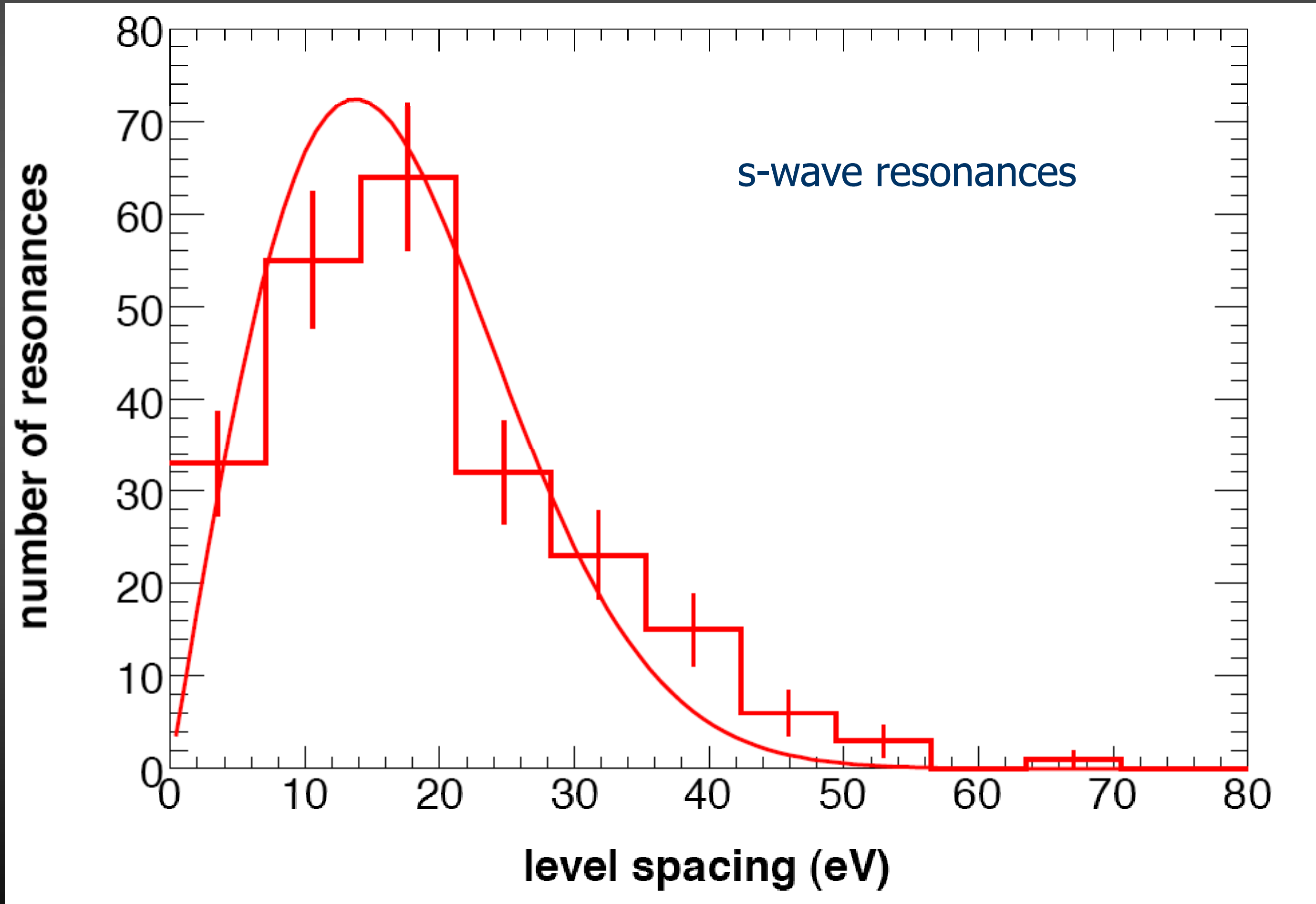

n_TOF experiments

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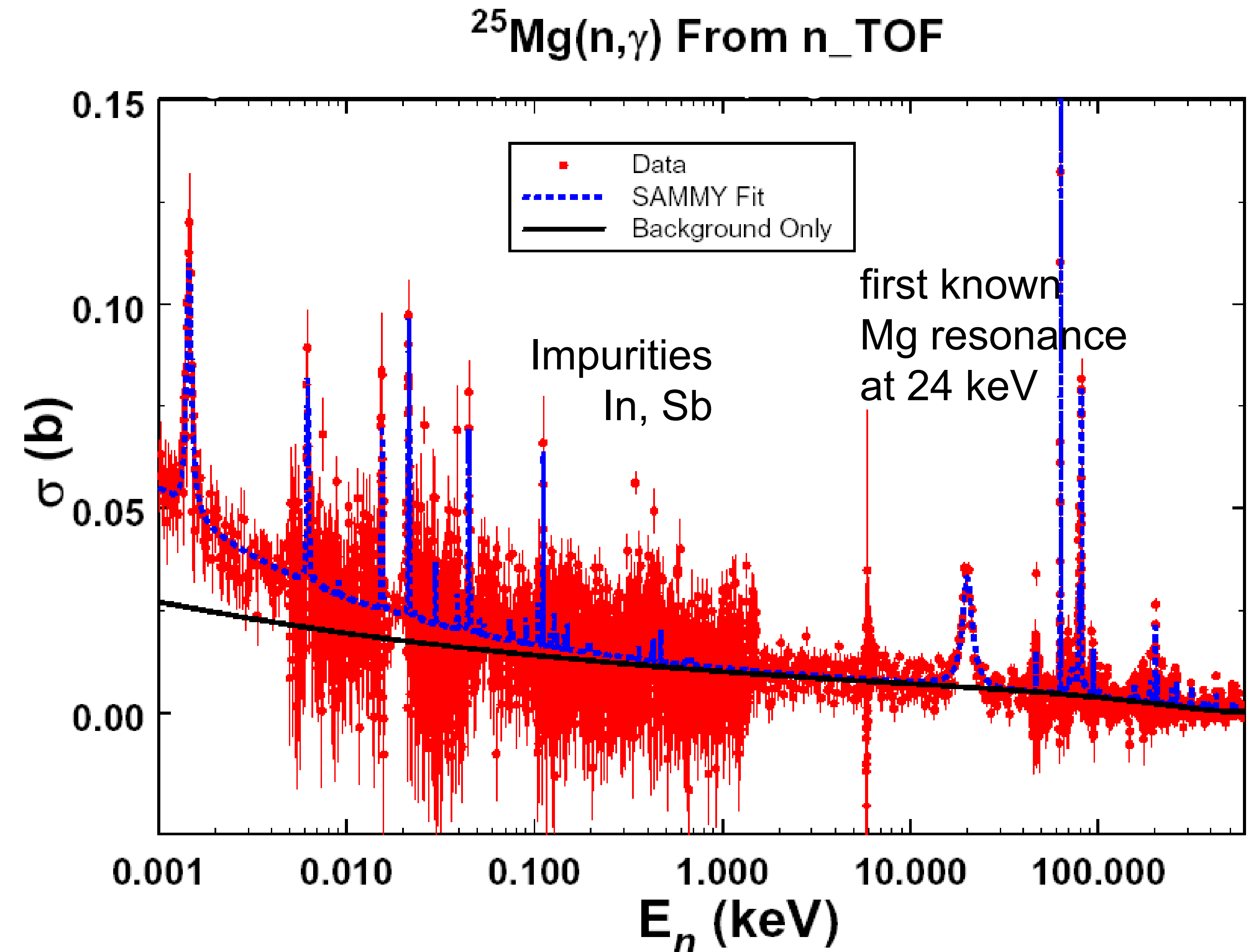

Very low neutron sensitivity of capture γ-ray detection systems & high resolution

The n_TOF Collaboration

n_TOF experiments

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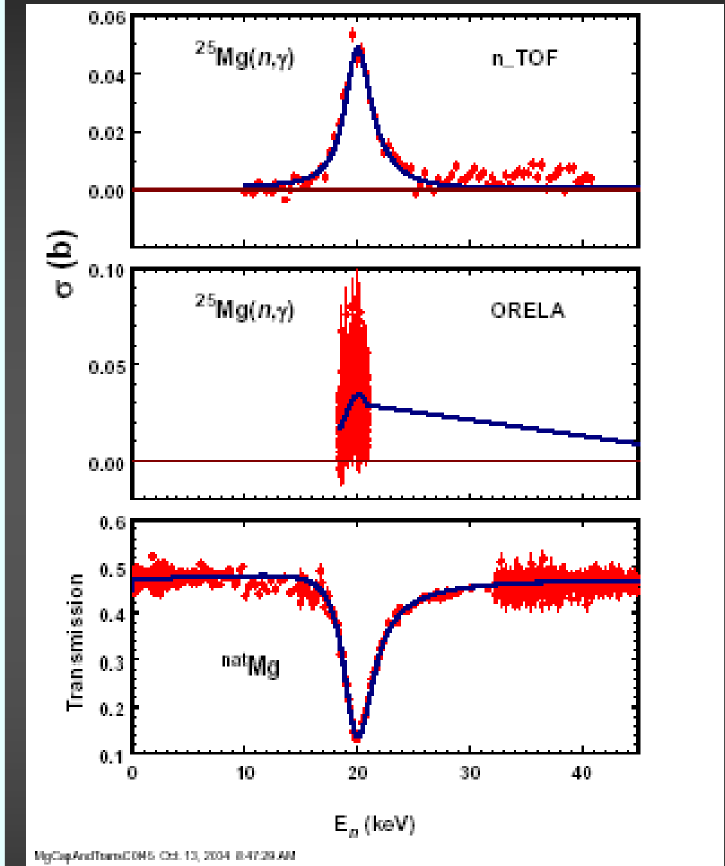
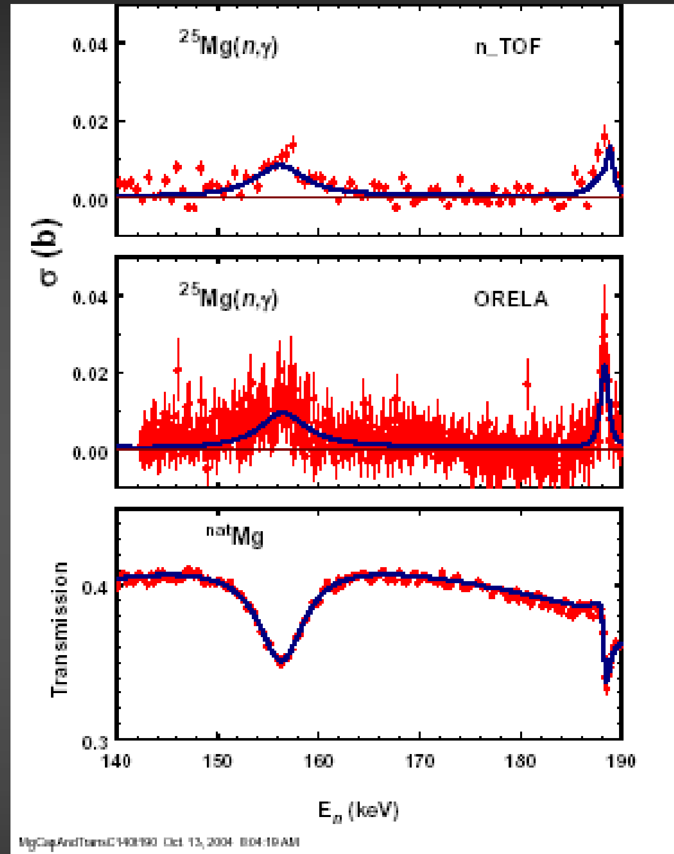
^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm





Source: P Koehler & S O'Brien

Capture & transmission data (from ORELA) analyzed simultanously

n_TOF experiments

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

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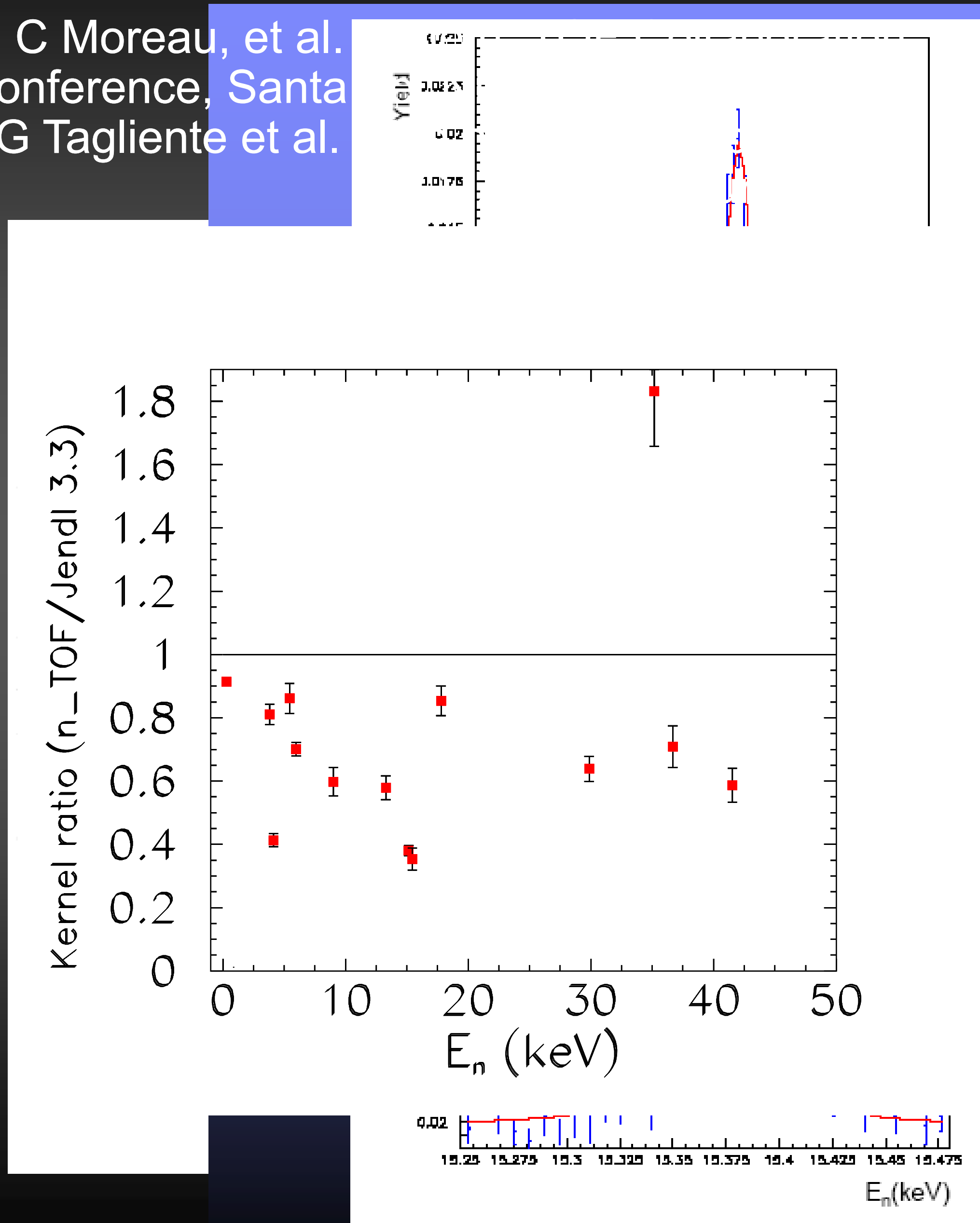
^{237}Np

^{241,243}Am, ^{245}Cm

C Moreau, et al.
ND2004 Conference, Santa
G Tagliente et al.

^{96}Zr(n,γ)

20% reduction in the capture strength (average)



n_TOF experiments

C Moreau, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – September 2004
G Tagliente et al. (The n_TOF Collaboration)
NIC-IX, CERN, June 2006

Capture

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$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

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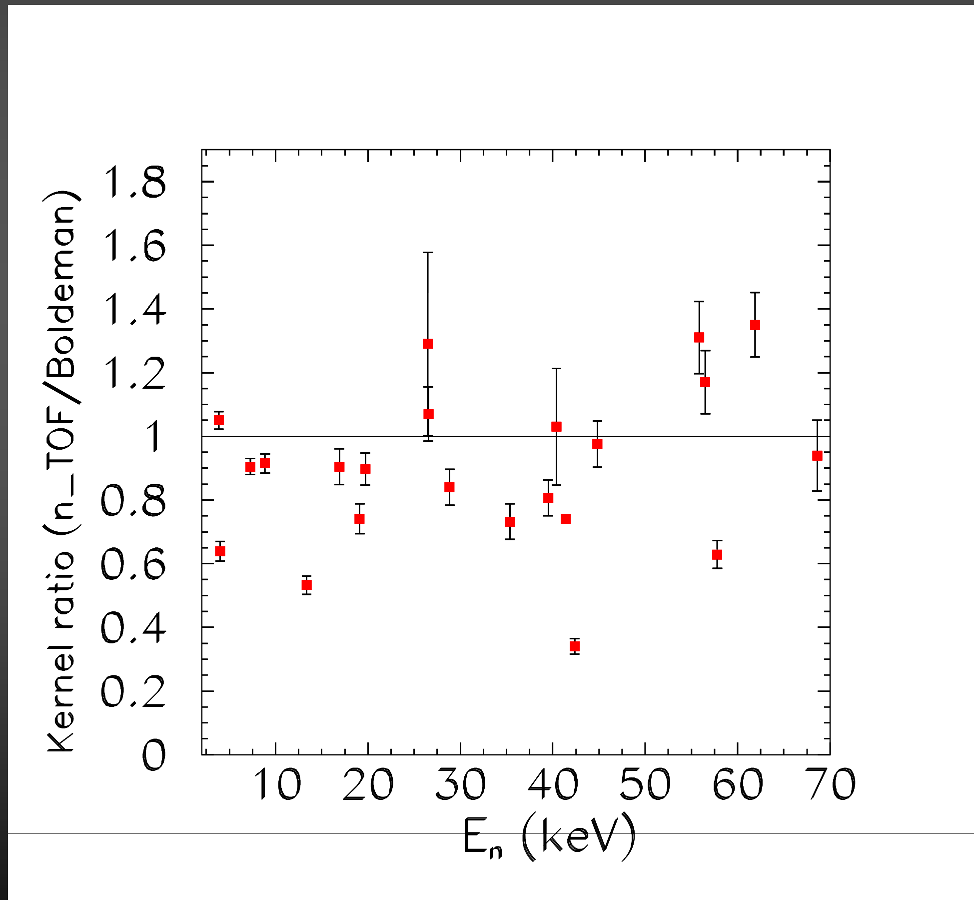
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{90}Zr(n,\gamma)$



n_TOF experiments

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

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^{90,91,92,94,96}Zr, ^{93}Zr

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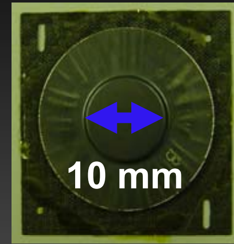
^{232}Th

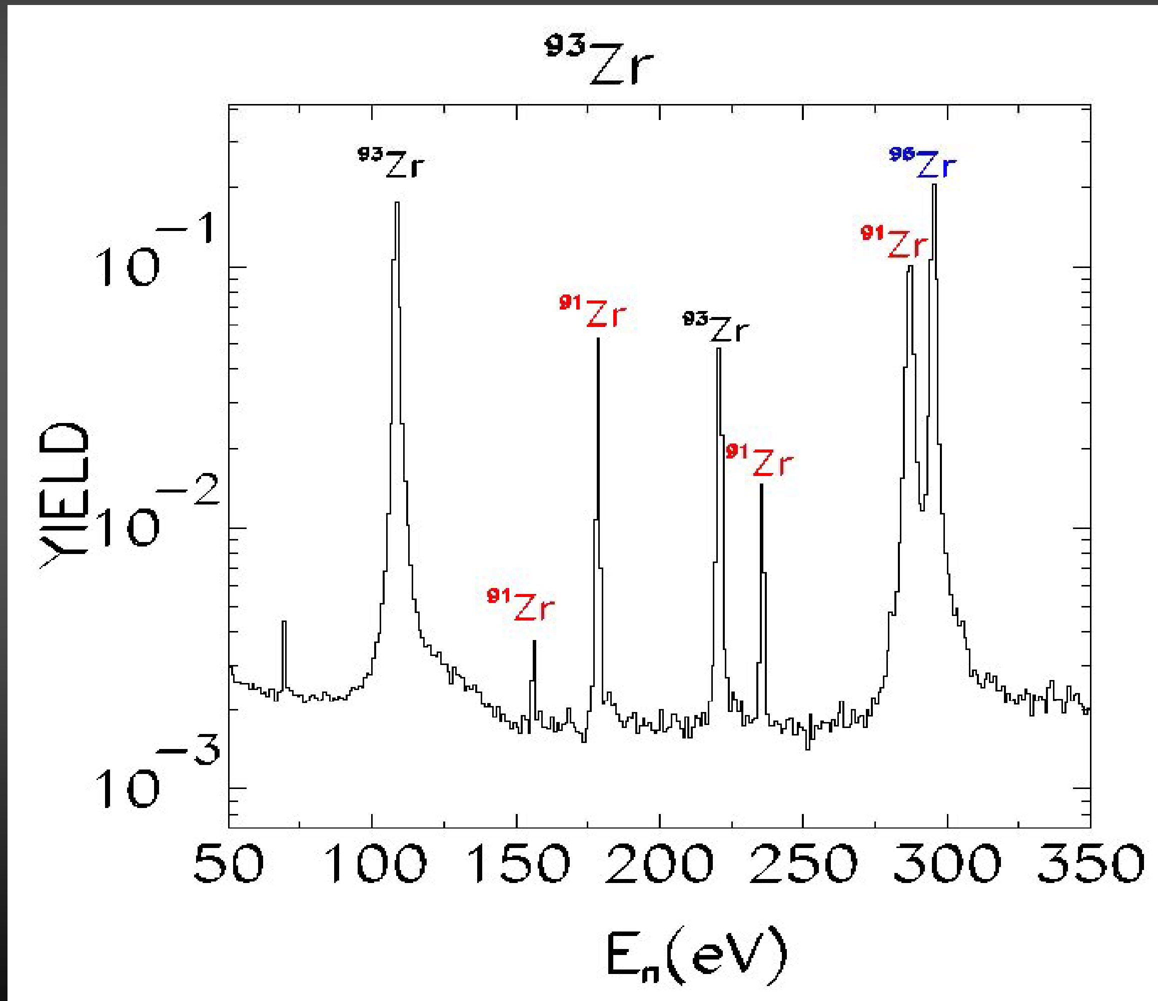
^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm

^{93}Zr(n,γ): raw data





n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

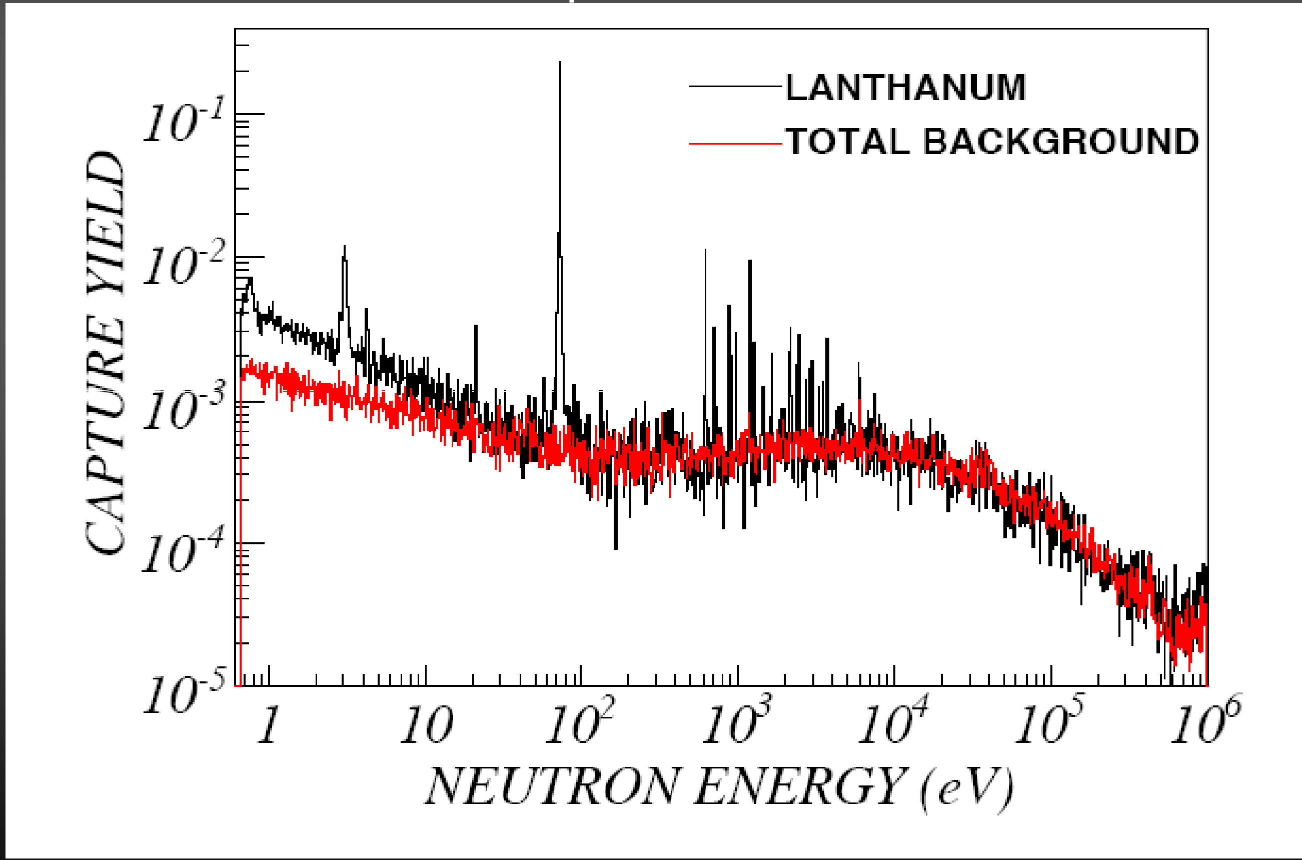
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{139}La(n,\gamma)$

R Terlizzi, et al. (The n_TOF Collaboration)
CGS12
Notre Dame, IN, USA
AIP Conference Proceedings 819
&
submitted for publication to PRC, October 2006



n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

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^{237}Np

$^{241,243}Am$, ^{245}Cm

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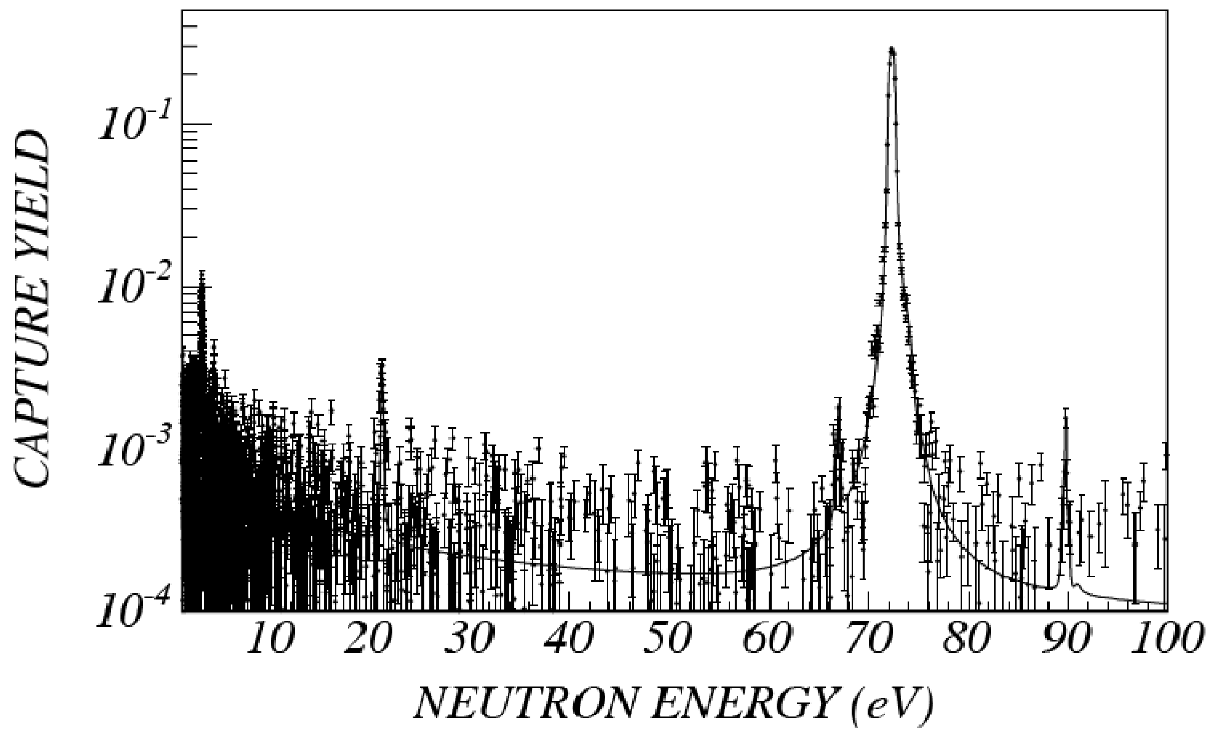

n_TOF experiments

Capture

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^{232}Th

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^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

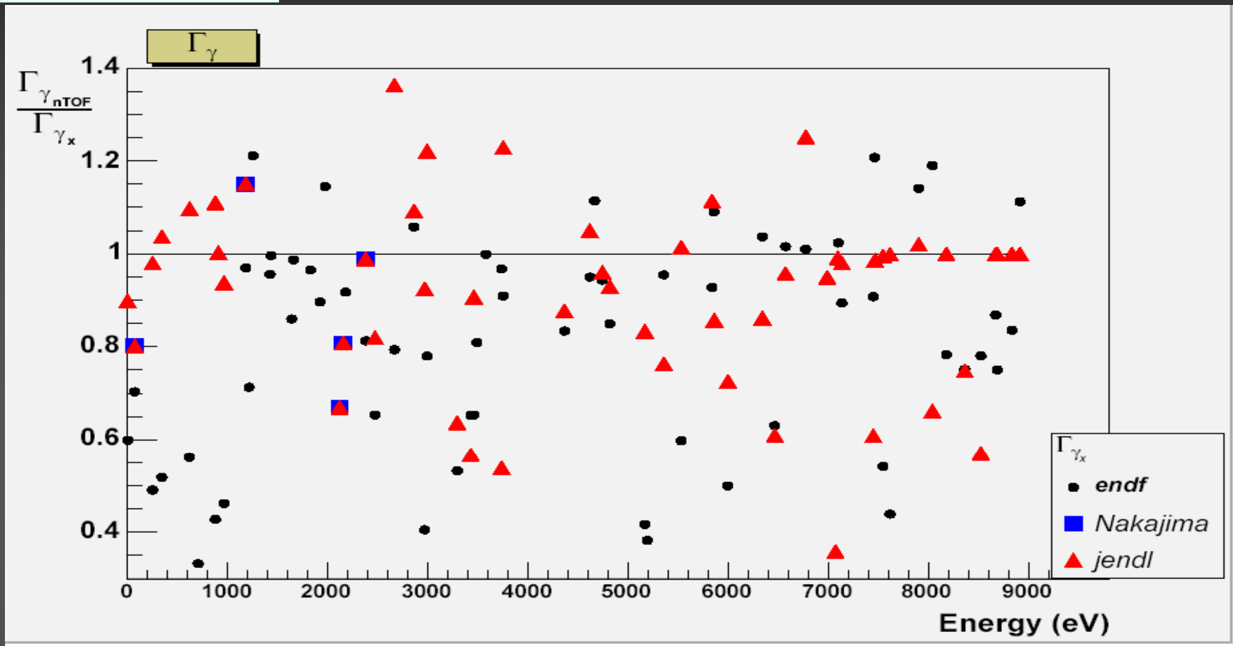
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{139}La(n,\gamma)$



Remarkable energy resolution and background conditions have allowed to determine the resonance parameters up to 9 keV

RI = 10.8 ± 1.0 barn
average γ-widths:
s-waves = 50.7 ± 5.4 meV
p-waves = 33.6 ± 6.9 meV
$\langle D_0 \rangle$ = 252 ± 22 eV
$S_0 = (0.82 \pm 0.05)\times10^{-4}$ $S_1 = (0.55 \pm 0.04)\times10^{-4}$

The n_TOF Collaboration

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

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Fission

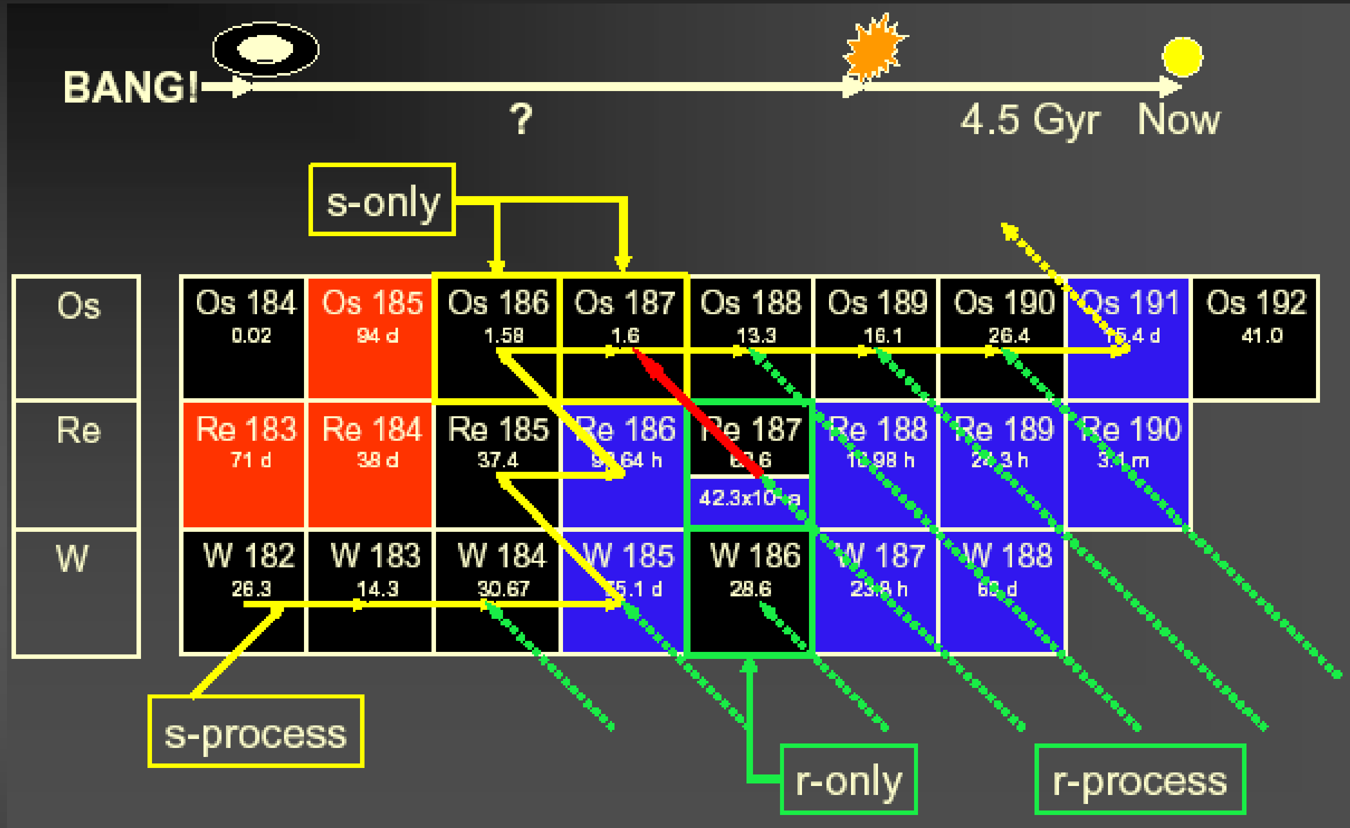
$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm



Re/Os clock

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

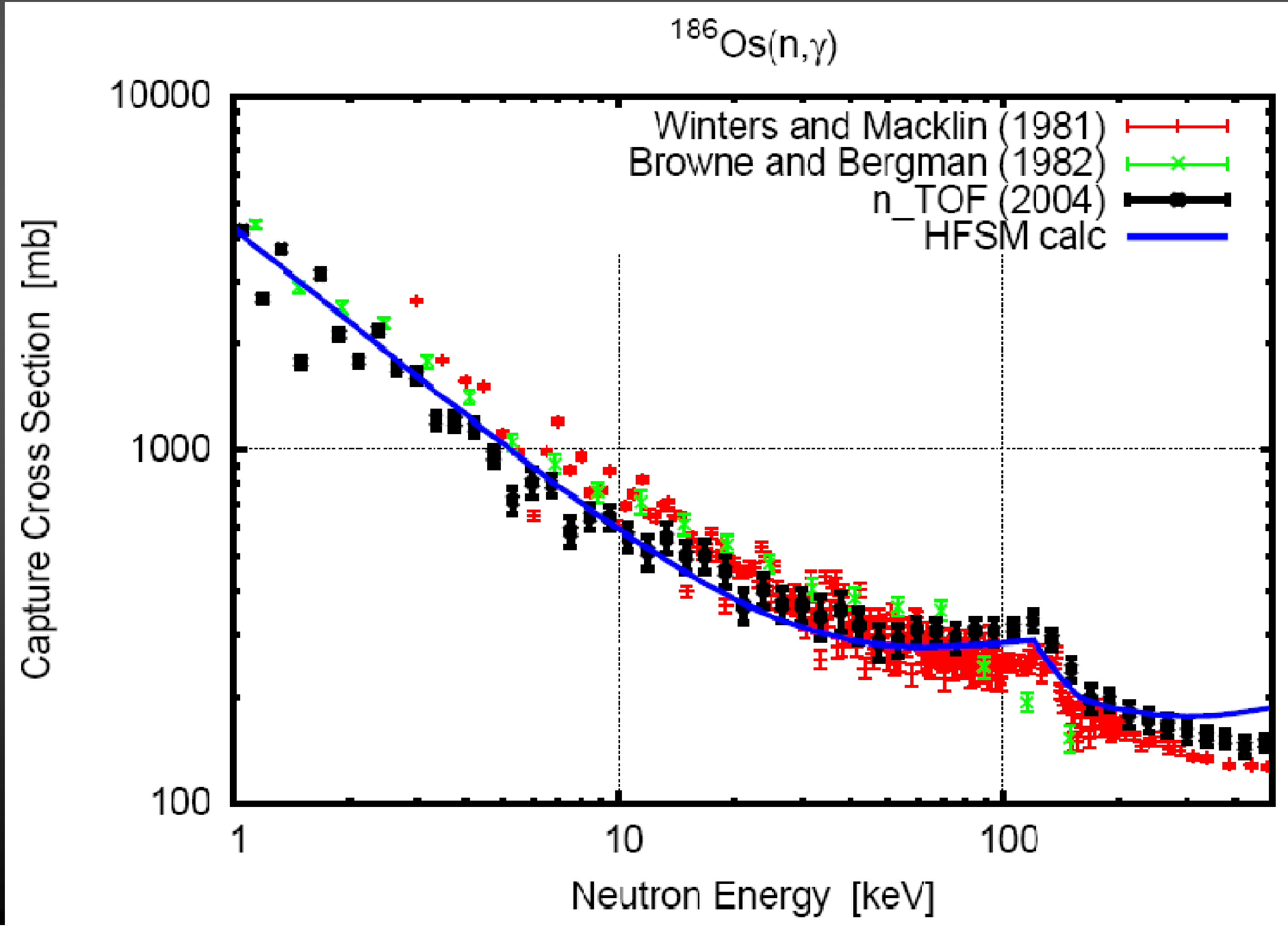
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

M Mosconi, *et al.* – (The n_TOF Collaboration)
NIC-IX, CERN, Geneva – June 2006
analysis completed - paper in preparation

MACS-30	
BrB81	438 ± 30 mb
WiM82	418 ± 16 mb
n_TOF	409 ± 17 mb



n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

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Fission

$^{233,234,235,236,238}U$

^{232}Th

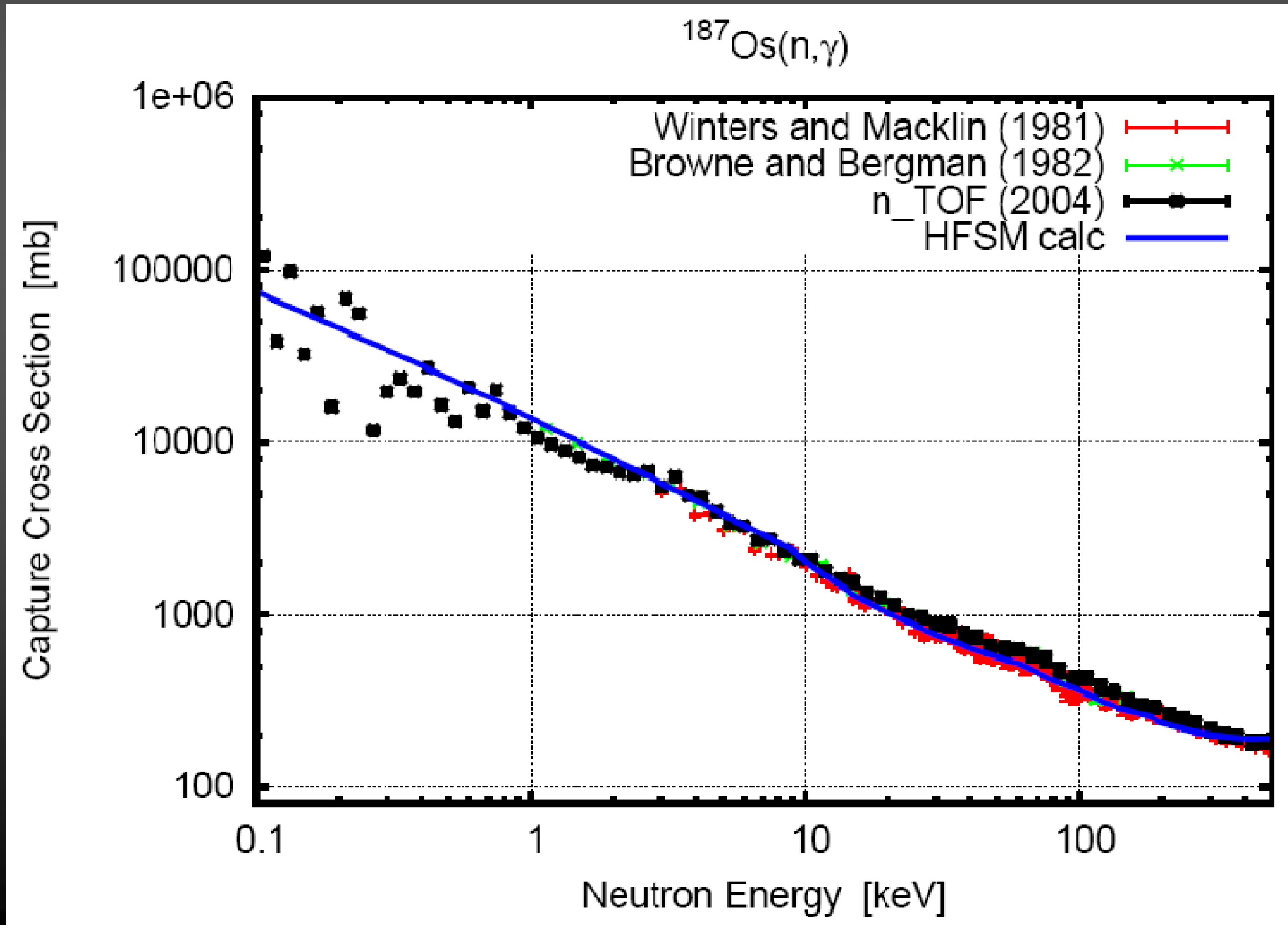
^{209}Bi

^{237}Np

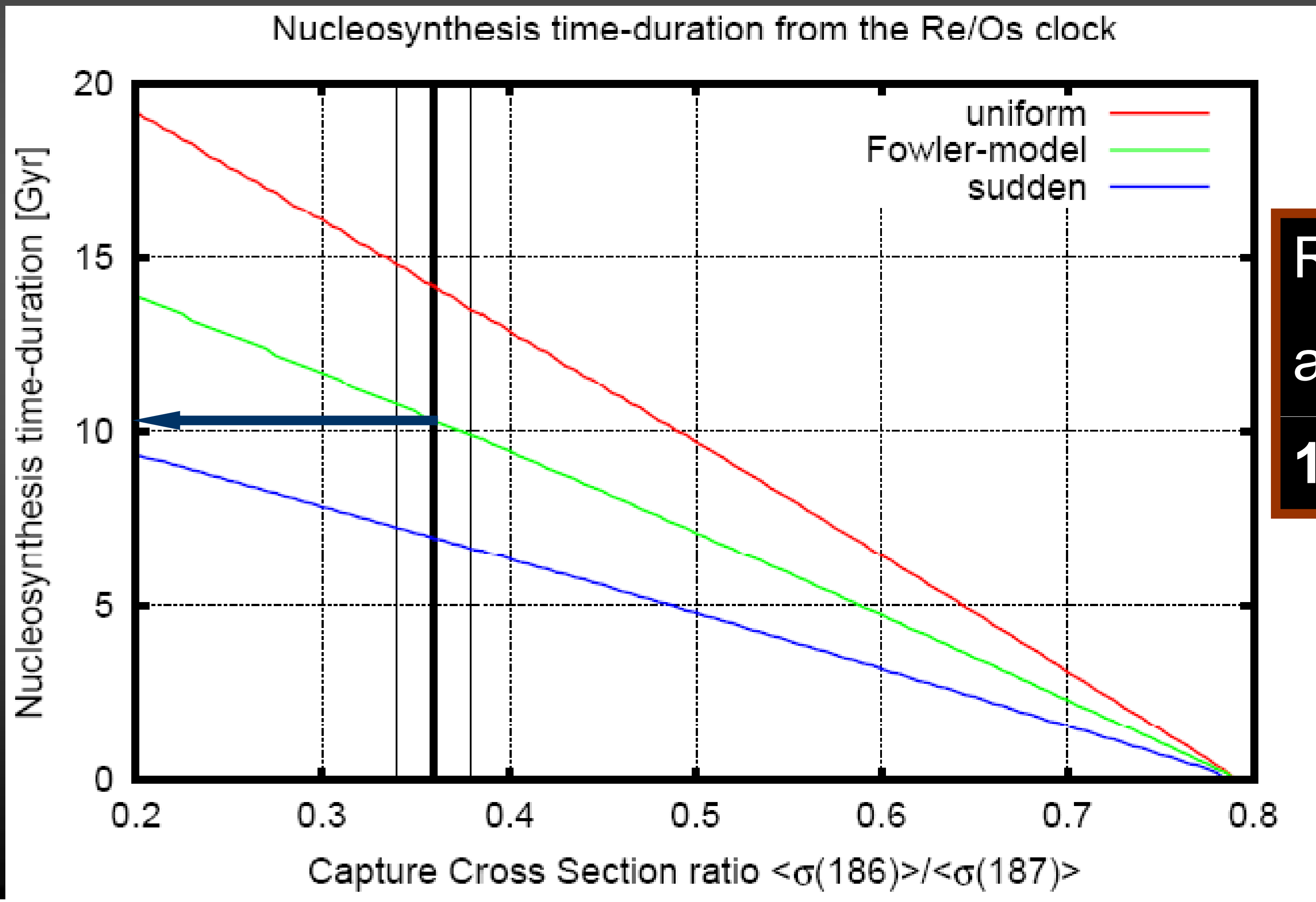
$^{241,243}Am$, ^{245}Cm

M Mosconi, *et al.* – (The n_TOF Collaboration)
NIC-IX, CERN, Geneva – June 2006
analysis completed - paper in preparation

MACS-30	
BrB81	919 ± 43 mb
WiM82	874 ± 28 mb
n_TOF	968 ± 18 mb



Stellar cross sections & the clock



$R^*_\sigma = 0.36 \pm 0.02$

age:

10.3+4.6=14.9 Gyr

uncertainty due to x-sections:

0.5 Gyr

<<

n_TOF experiments

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{139}La

^{186,187,188}Os

^{233,234}U

^{237}Np, ^{240}Pu, ^{243}Am

Fission

^{233,234,235,236,238}U

^{232}Th

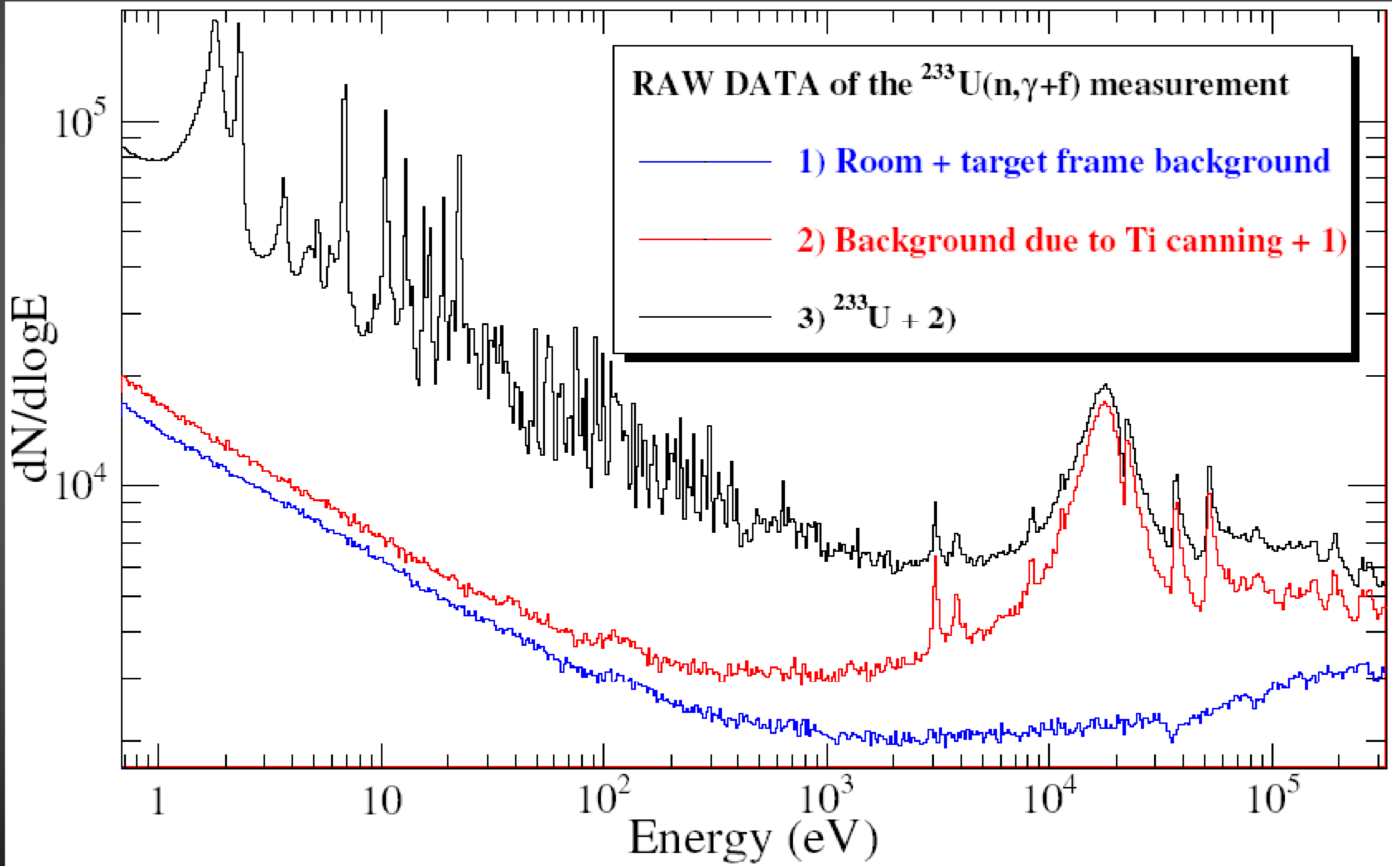
^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm

^{233}U(n,γ)

W Dridi, E Berthoumieux, *et al.*, (Dec. 2004)



n_TOF TAC in operation

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

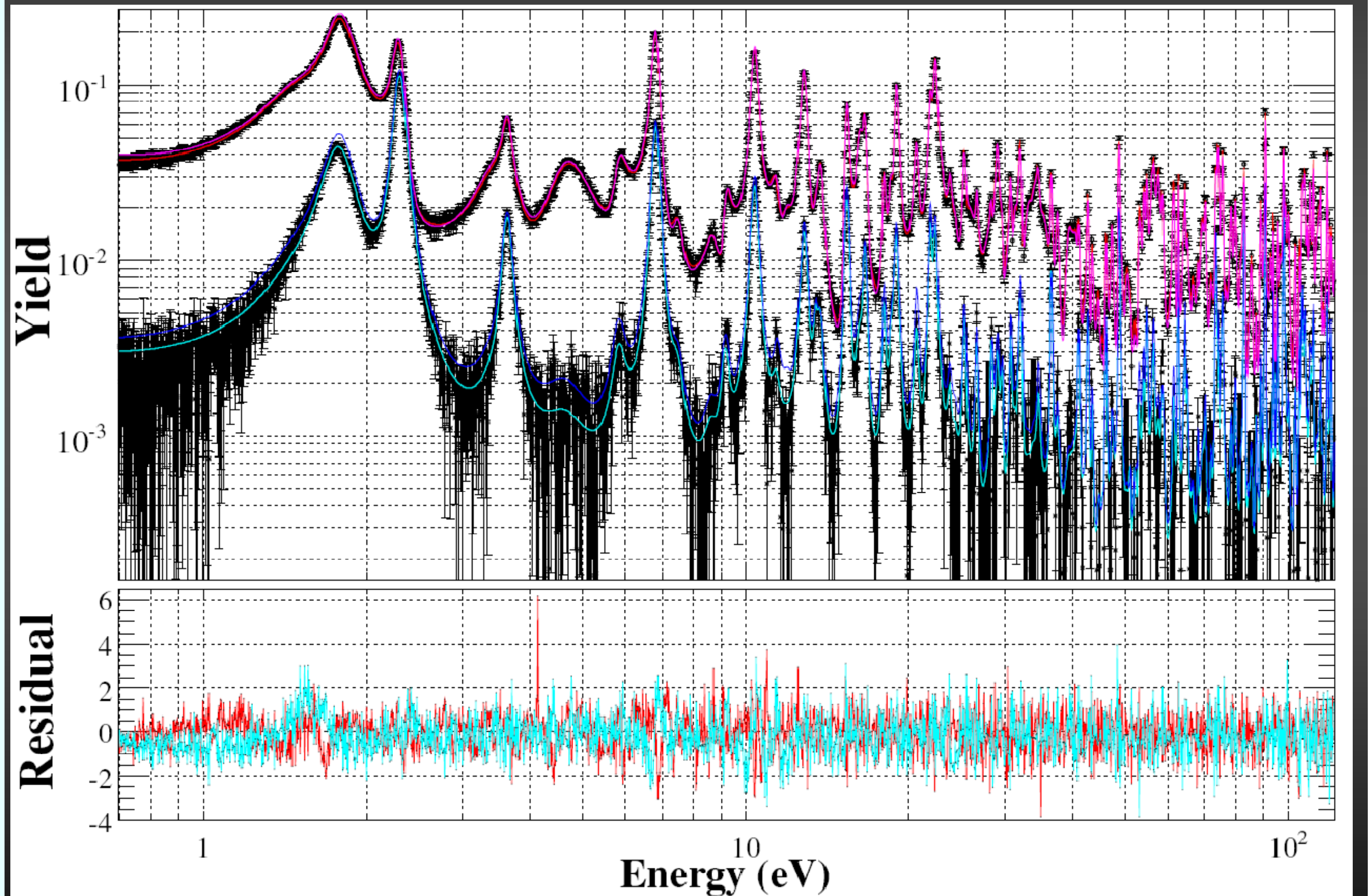
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{233}U(n,\gamma)$

W Dridi, E Berthoumieux, *et al.*, CEA/Saclay
Paper in preparation (October 2006)



n_TOF TAC in operation: capture & fission discrimination

The n_TOF Collaboration

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{139}La

^{186,187,188}Os

^{233,234}U

^{237}Np, ^{240}Pu, ^{243}Am

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^{233,234,235,236,238}U

^{232}Th

^{209}Bi

^{237}Np

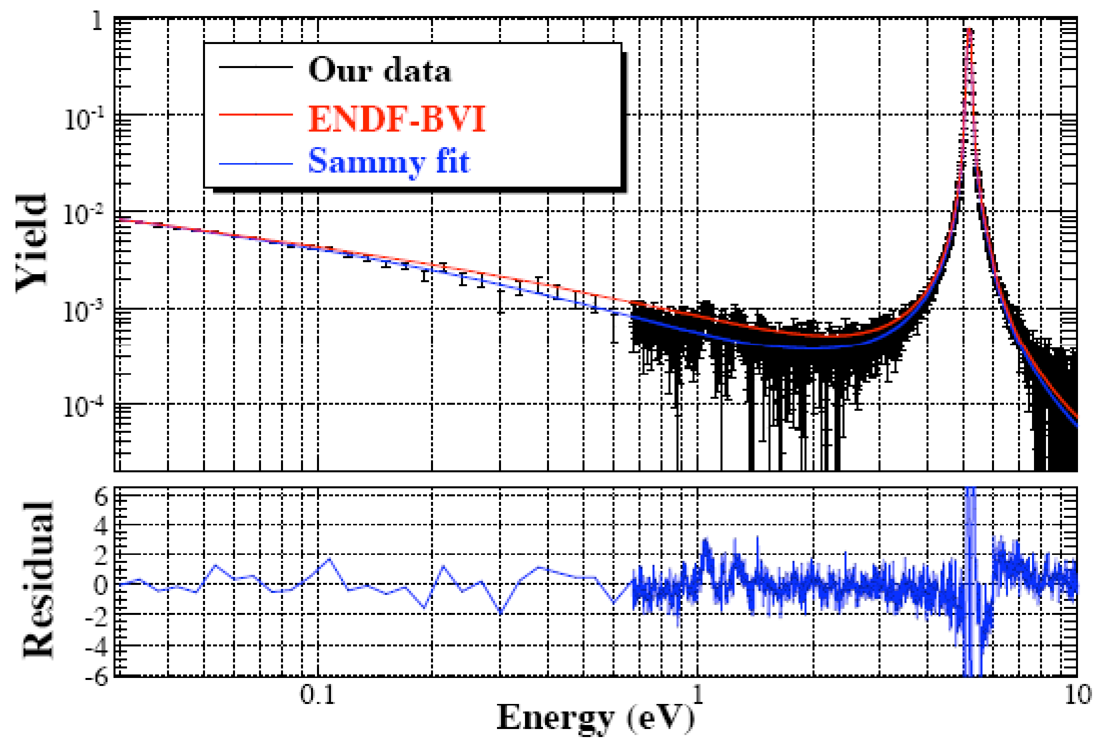
^{241,243}Am, ^{245}Cm

n_TOF experiments

W Dridi, E Berthoumieux, et al. (The n_TOF Collaboration)
PHYSOR-2006, Vancouver, September 2006
full paper in preparation

^{234}U(n,γ)

Figure 3: Neutron capture on ^{234}U yield in the thermal region and for the first resonance obtained in the present experiment.



n_TOF TAC in operation

n_TOF experiments

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{139}La

^{186,187,188}Os

^{233,234}U

^{237}Np, ^{240}Pu, ^{243}Am

Fission

^{233,234,235,236,238}U

^{232}Th

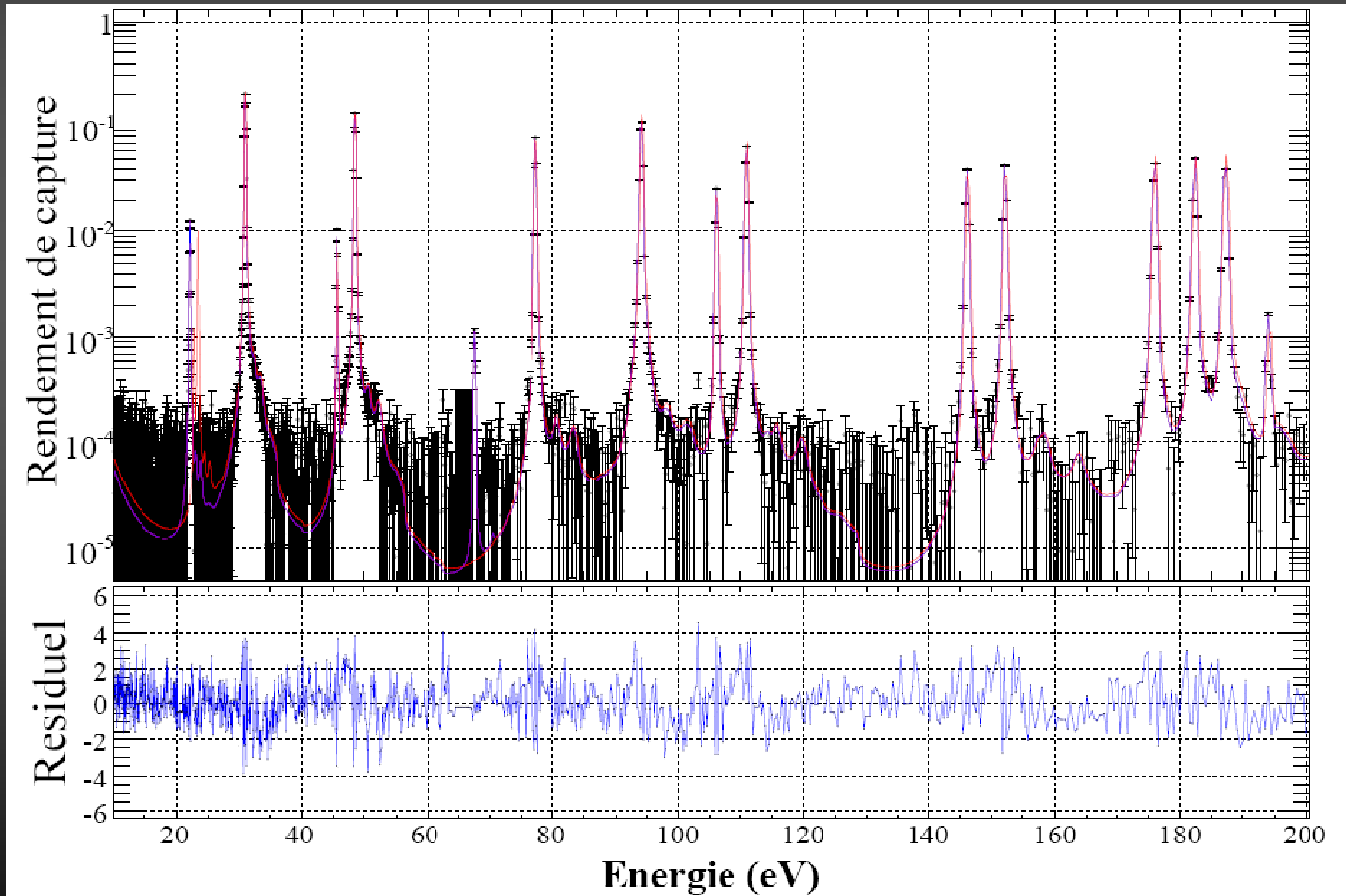
^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm

W Dridi, E Berthoumieux, et al. (The n_TOF Collaboration)
PHYSOR-2006, Vancouver, September 2006
full paper in preparation

^{234}U(n,γ)



n_TOF TAC in operation

n_TOF experiments

Capture

^{151}Sm

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^{232}Th

^{209}Bi

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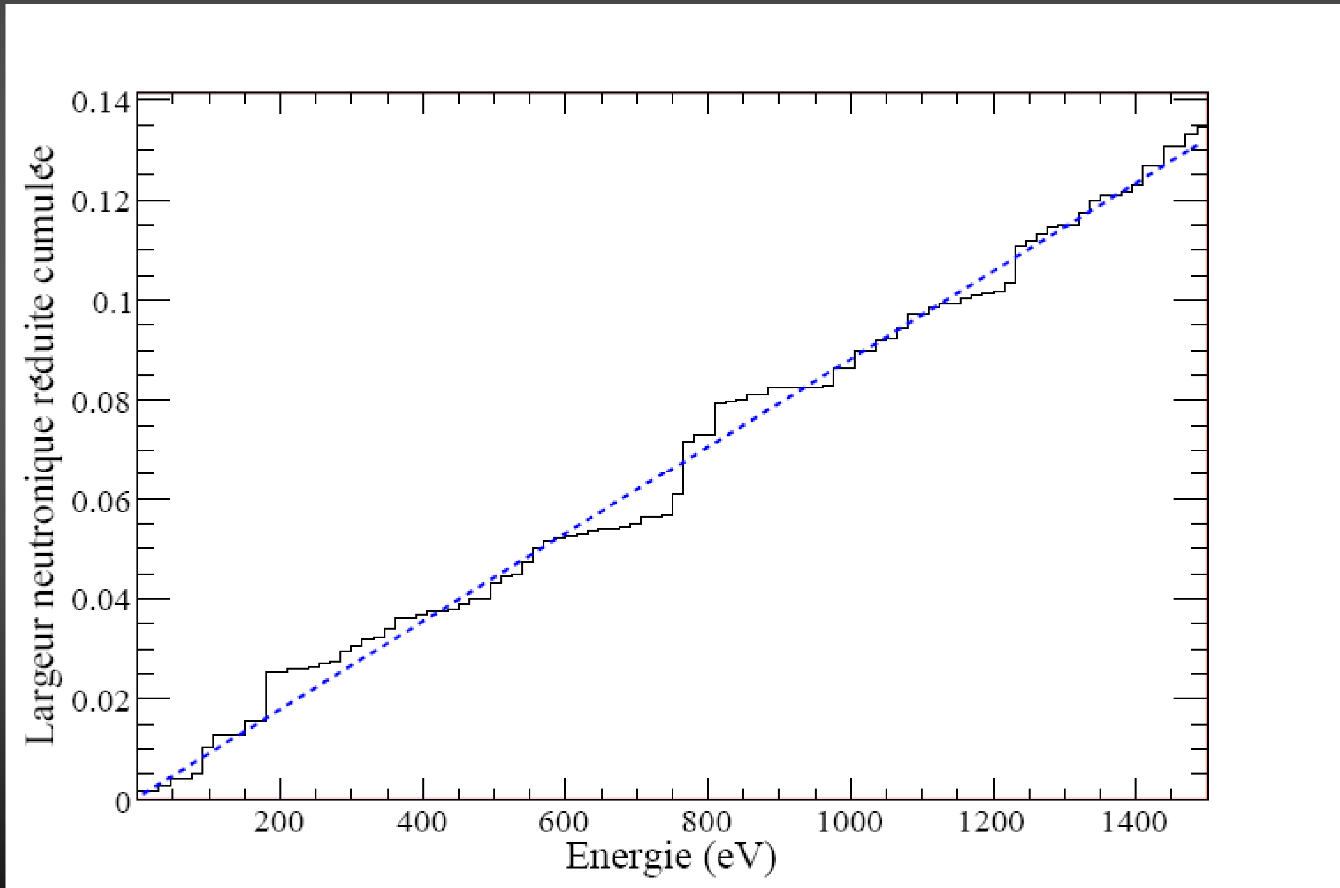
$^{241,243}Am$, ^{245}Cm

W Dridi, E Berthoumieux, et al. (The n_TOF Collaboration)
PHYSOR-2006, Vancouver, September 2006
full paper in preparation

$^{234}U(n,\gamma)$



n_TOF TAC in operation

Capture

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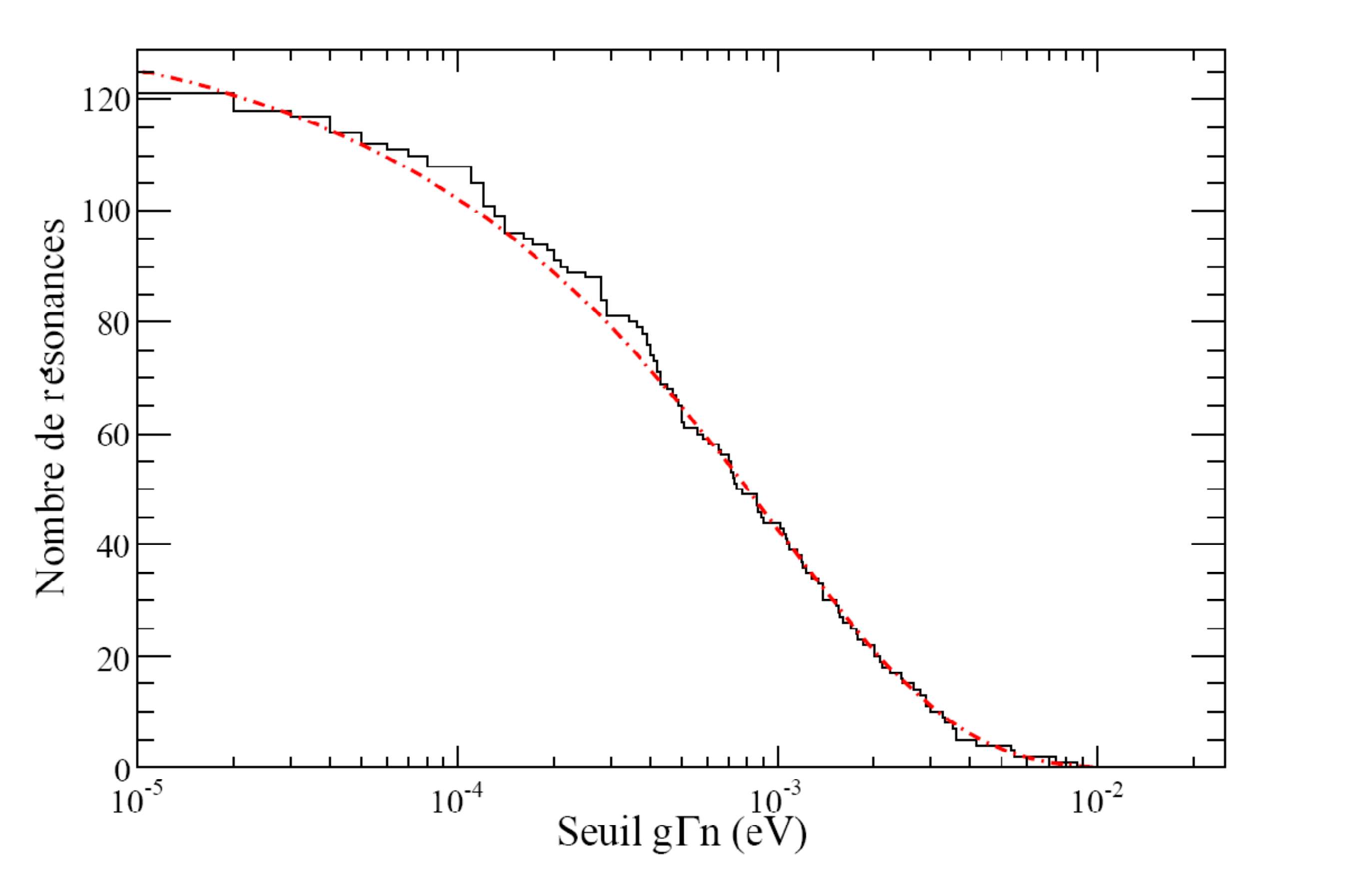
n_TOF experiments

W Dridi, E Berthoumieux, et al. (The n_TOF Collaboration)
PHYSOR-2006, Vancouver, September 2006
full paper in preparation

$^{234}U(n,\gamma)$



n_TOF TAC in operation

n_TOF experiments

Capture

^{151}Sm

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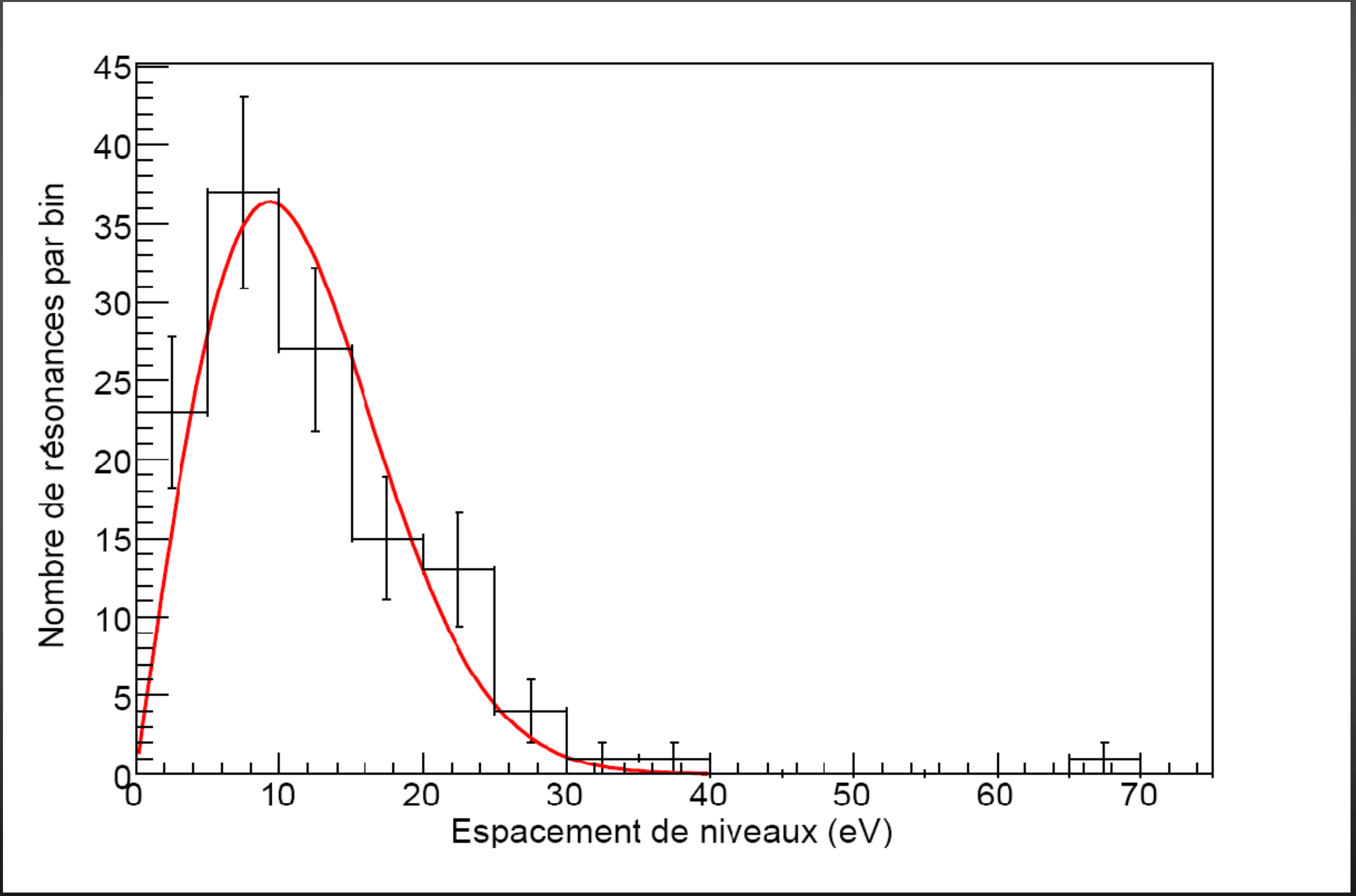
$^{241,243}Am$, ^{245}Cm

W Dridi, E Berthoumieux, et al. (The n_TOF Collaboration)
PHYSOR-2006, Vancouver, September 2006
full paper in preparation

$^{234}U(n,\gamma)$



n_TOF TAC in operation

n_TOF experiments

D Cano-Ott, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004

Capture

^{151}Sm

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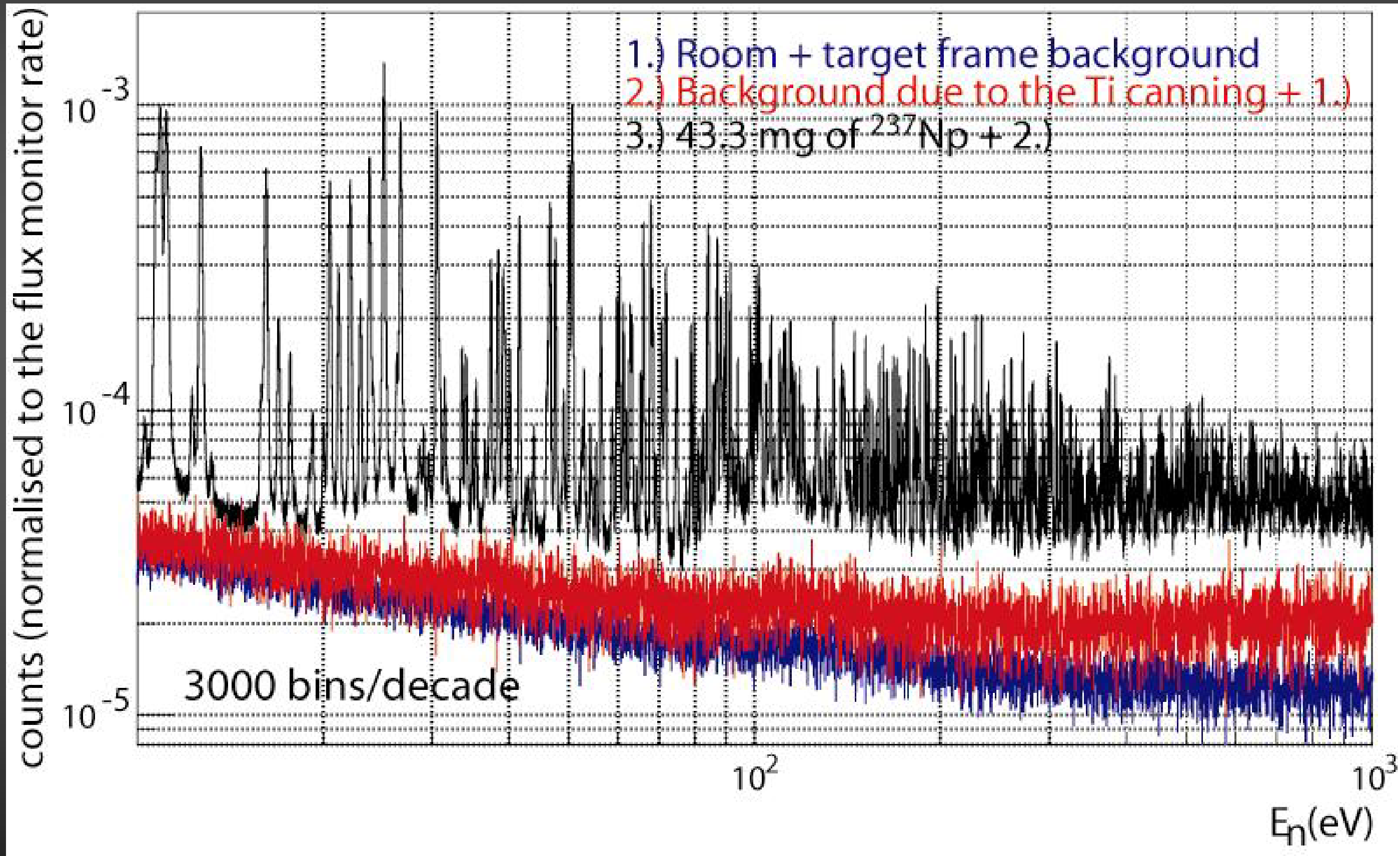

n_TOF TAC in operation

n_TOF experiments

C Guerero, D Cano-Ott, et al. - The n_TOF Collaboration
PHYSOR 2006, Vancouver, September 2006

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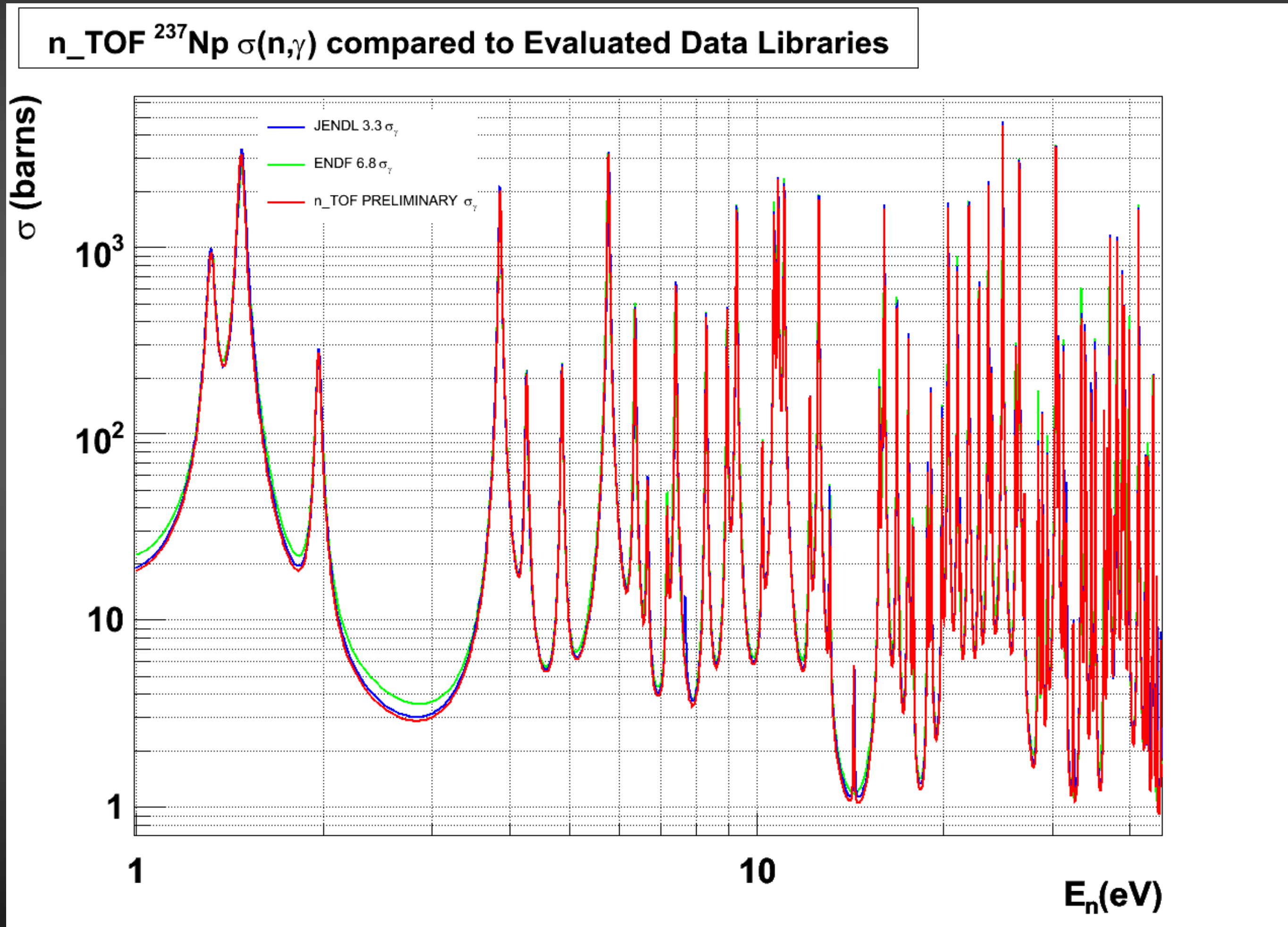

n_TOF TAC in operation

n_TOF experiments

C Guerero, D Cano-Ott, et al. - The n_TOF Collaboration
PHYSOR 2006, Vancouver, September 2006

Capture

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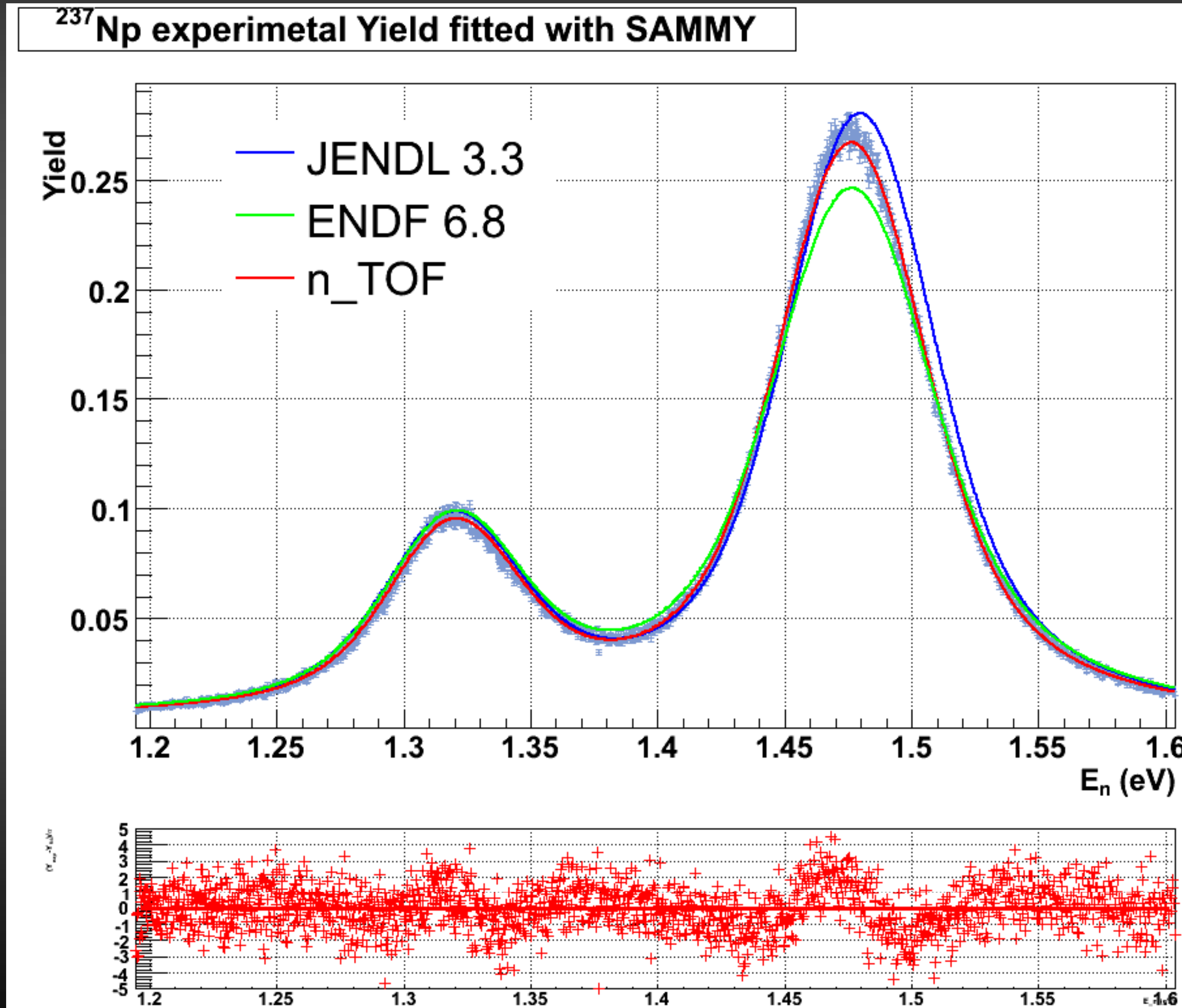

n_TOF experiments

Capture

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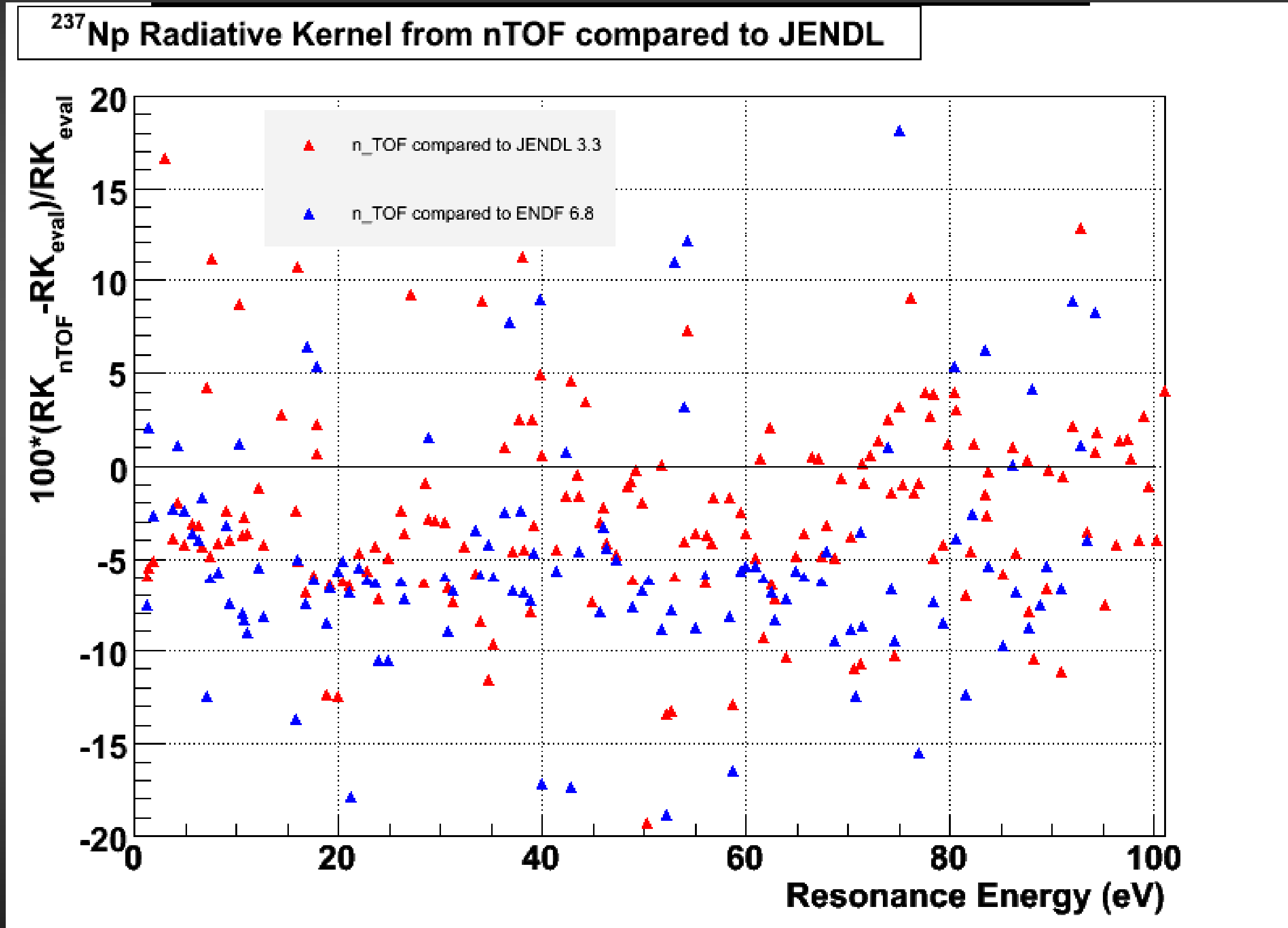
C Guerero, D Cano-Ott, et al. - The n_TOF Collaboration
PHYSOR 2006, Vancouver, September 2006



RK_{n_TOF} on average 3% below the RK_{JENDL} and 6% below the RK_{ENDF}

n_TOF experiments

D Cano-Ott, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

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$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

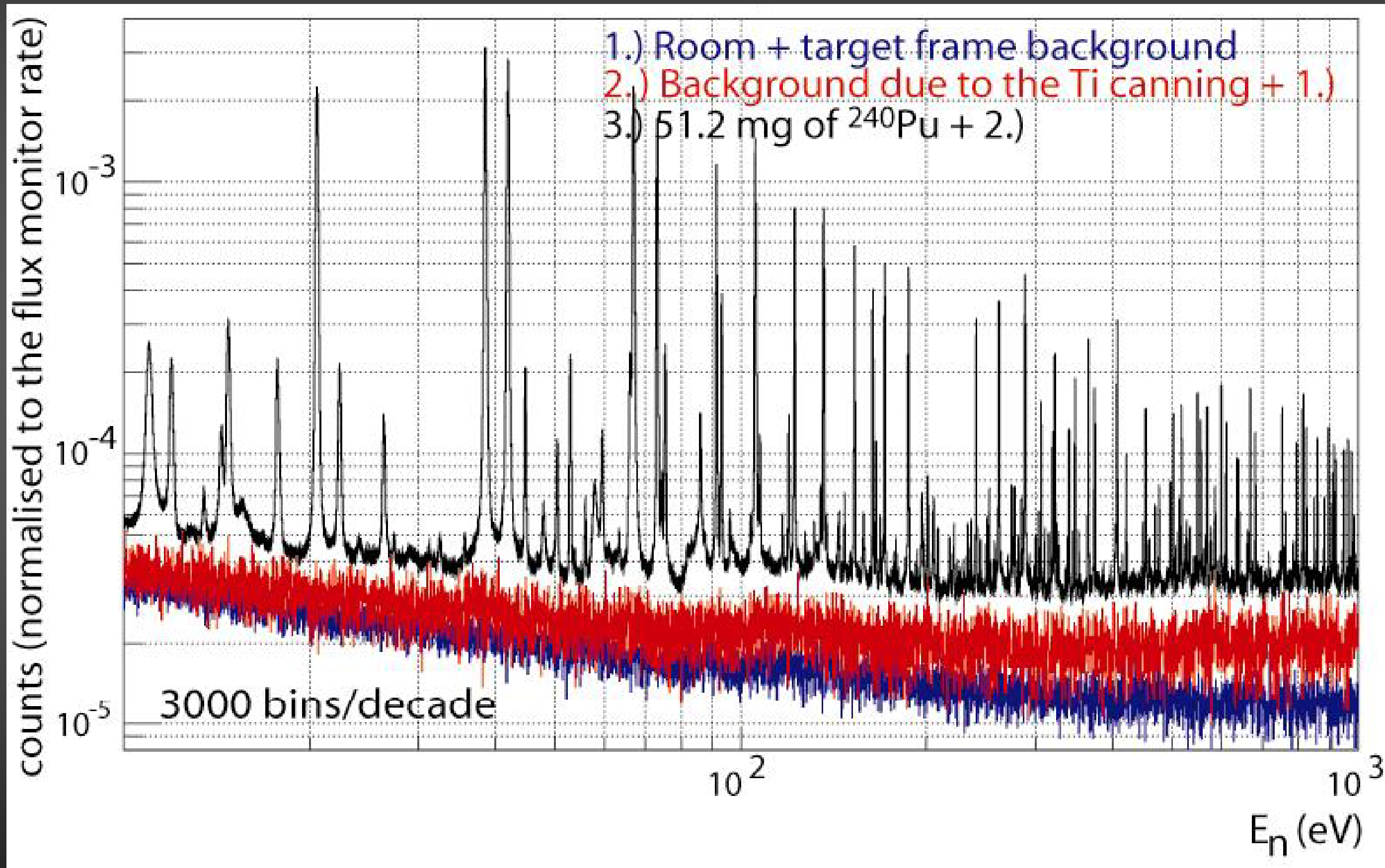
$^{233,234,235,236,238}U$

^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm



n_TOF TAC in operation

n_TOF experiments

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

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^{233,234}U

^{237}Np, ^{240}Pu, ^{243}Am

Fission

^{233,234,235,236,238}U

^{232}Th

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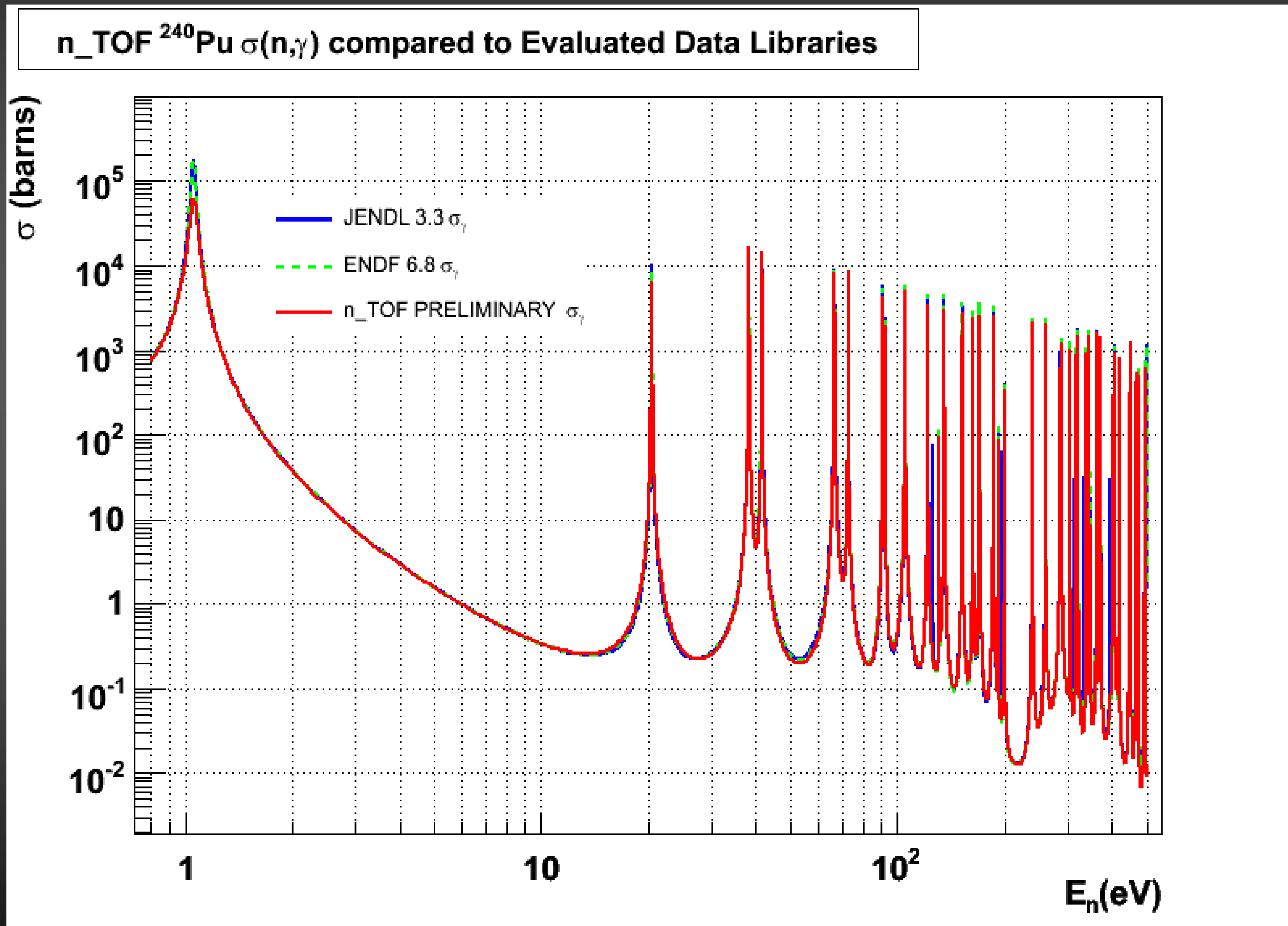
^{237}Np

^{241,243}Am, ^{245}Cm

C Guerero, D Cano-Ott, et al. - The n_TOF Collaboration
PHYSOR 2006, Vancouver, September 2006



n_TOF TAC in operation

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

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^{237}Np, ^{240}Pu, ^{243}Am

Fission

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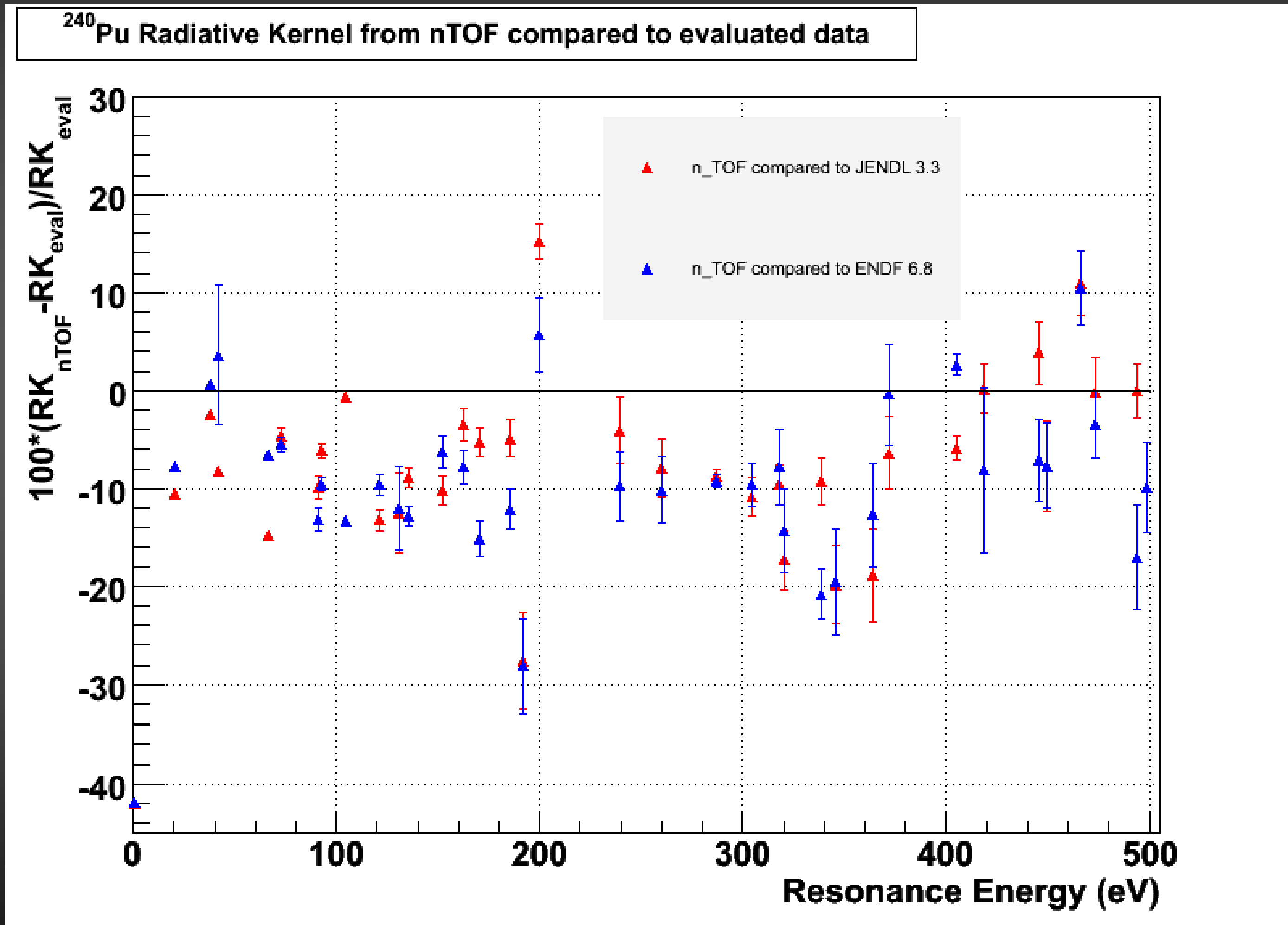
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

C Guerero, D Cano-Ott, et al. - The n_TOF Collaboration
PHYSOR 2006, Vancouver, September 2006



RK_{n_TOF} is on average 9% smaller than RK_{JENDL} and 7% smaller than RK_{ENDF}.

n_TOF experiments

D Cano-Ott, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

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Fission

^{233,234,235,236,238}U

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^{209}Bi

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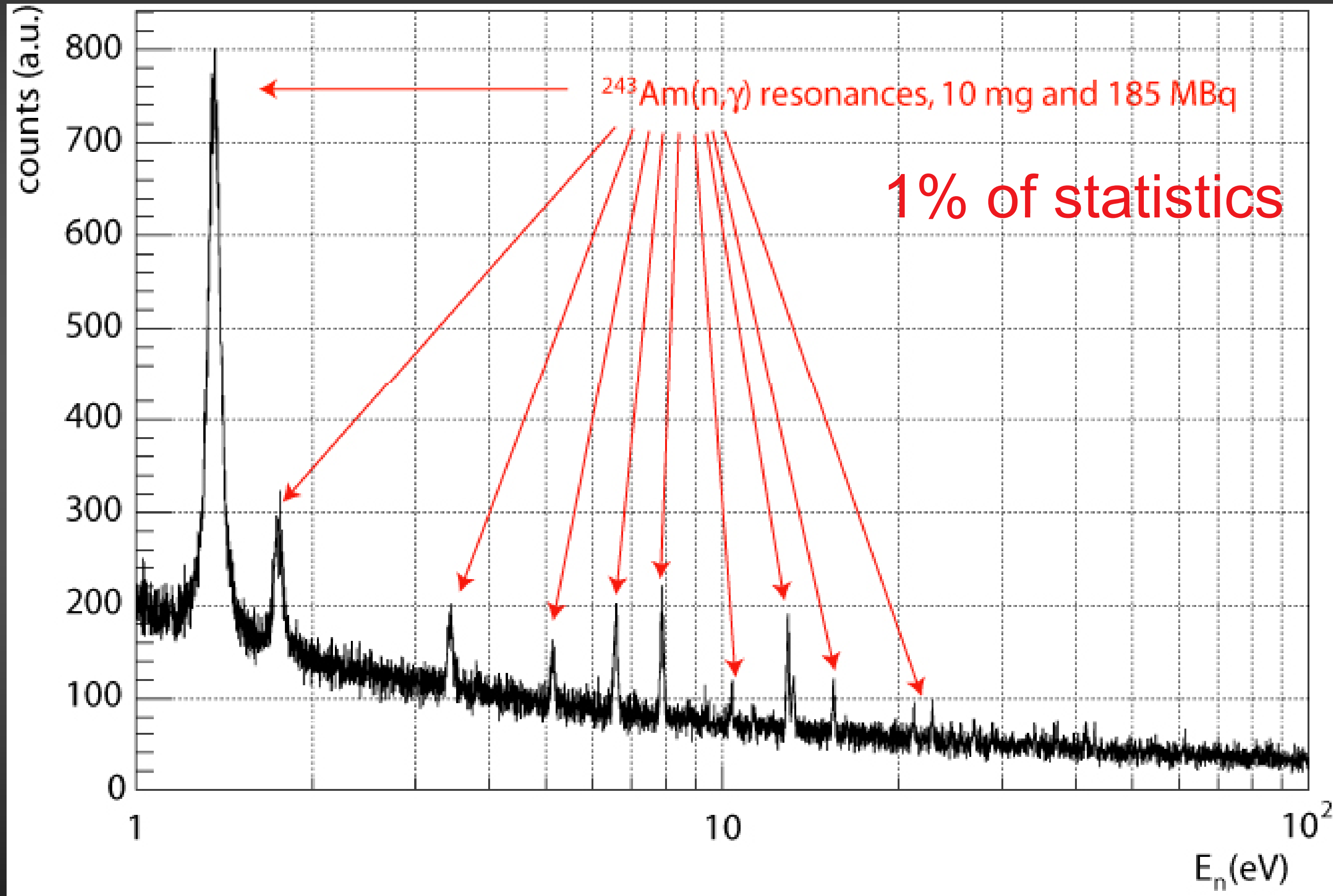

n_TOF TAC in operation

n_TOF experiments

Capture

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$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

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Fission

$^{233,234,235,236,238}U$

^{232}Th

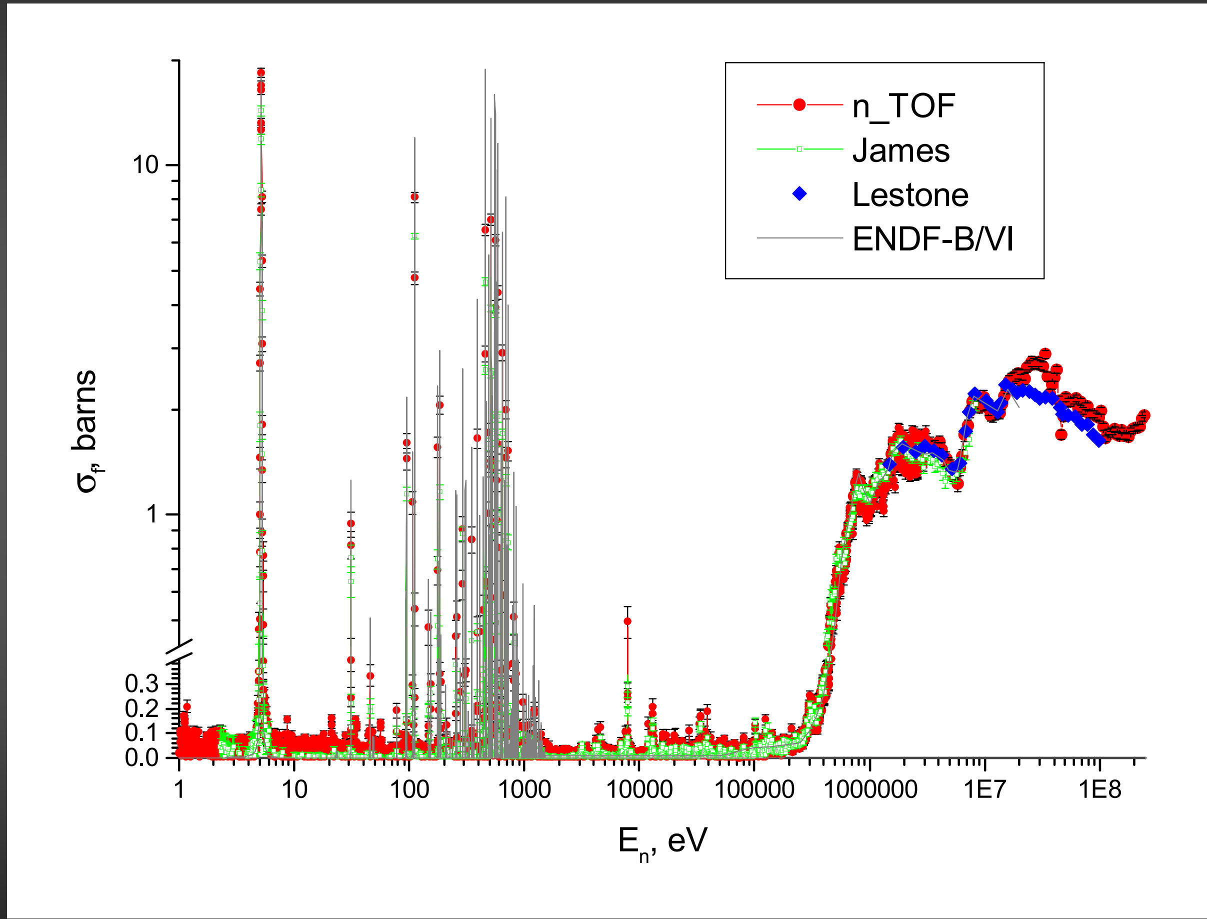
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{234}U(n,f)$

PPACs & FIC-0 (2003)



An unprecedent wide energy range can be explored at n_TOF in a single experiment

n_TOF experiments

PPACs & FIC-0 (2003)

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

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^{209}Bi

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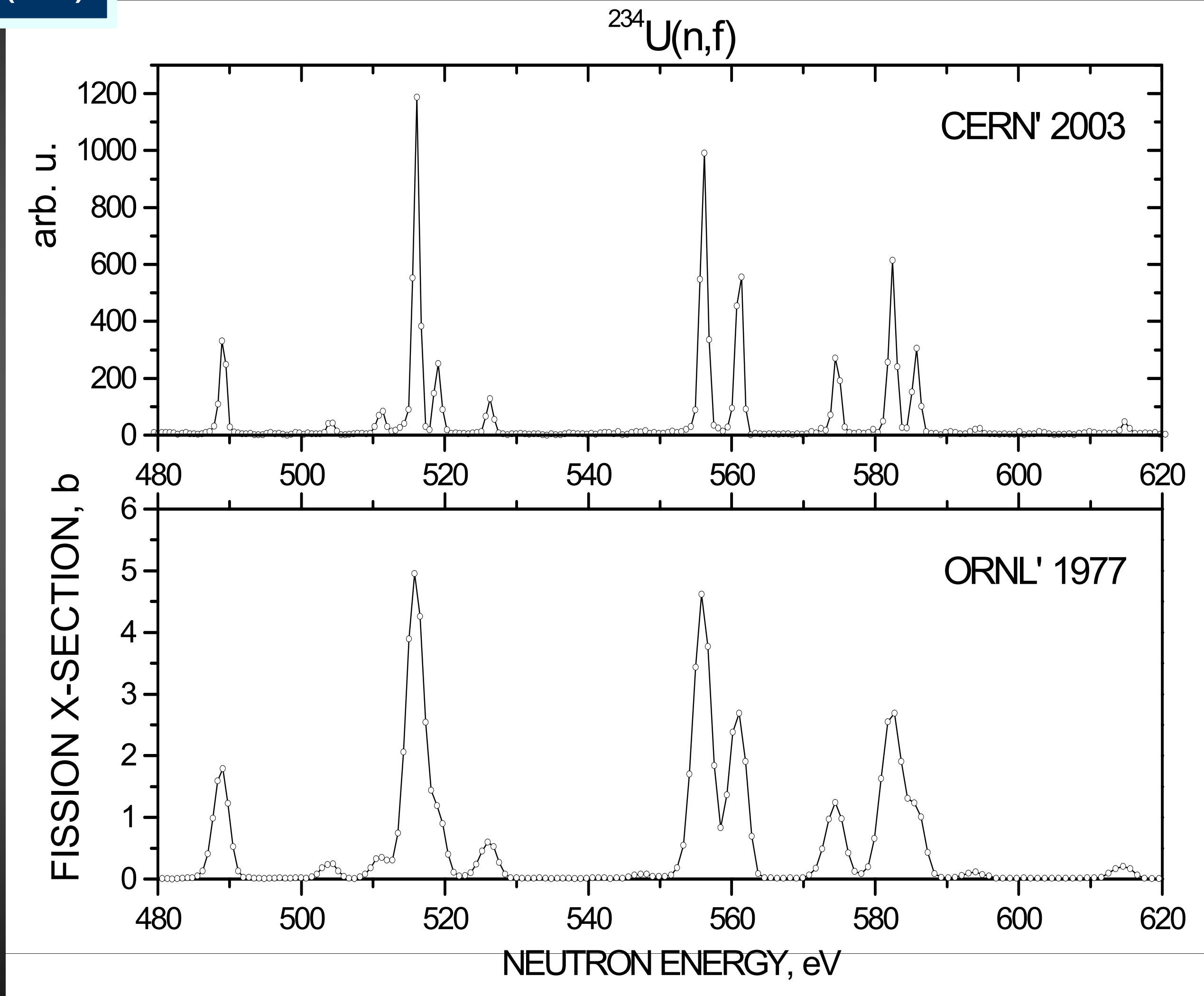
$^{241,243}Am$, ^{245}Cm

$^{234}U(n,f)$



High-resolution data up to high(er) energies

n_TOF experiments

PPACs & FIC-0 (2003)

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

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$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

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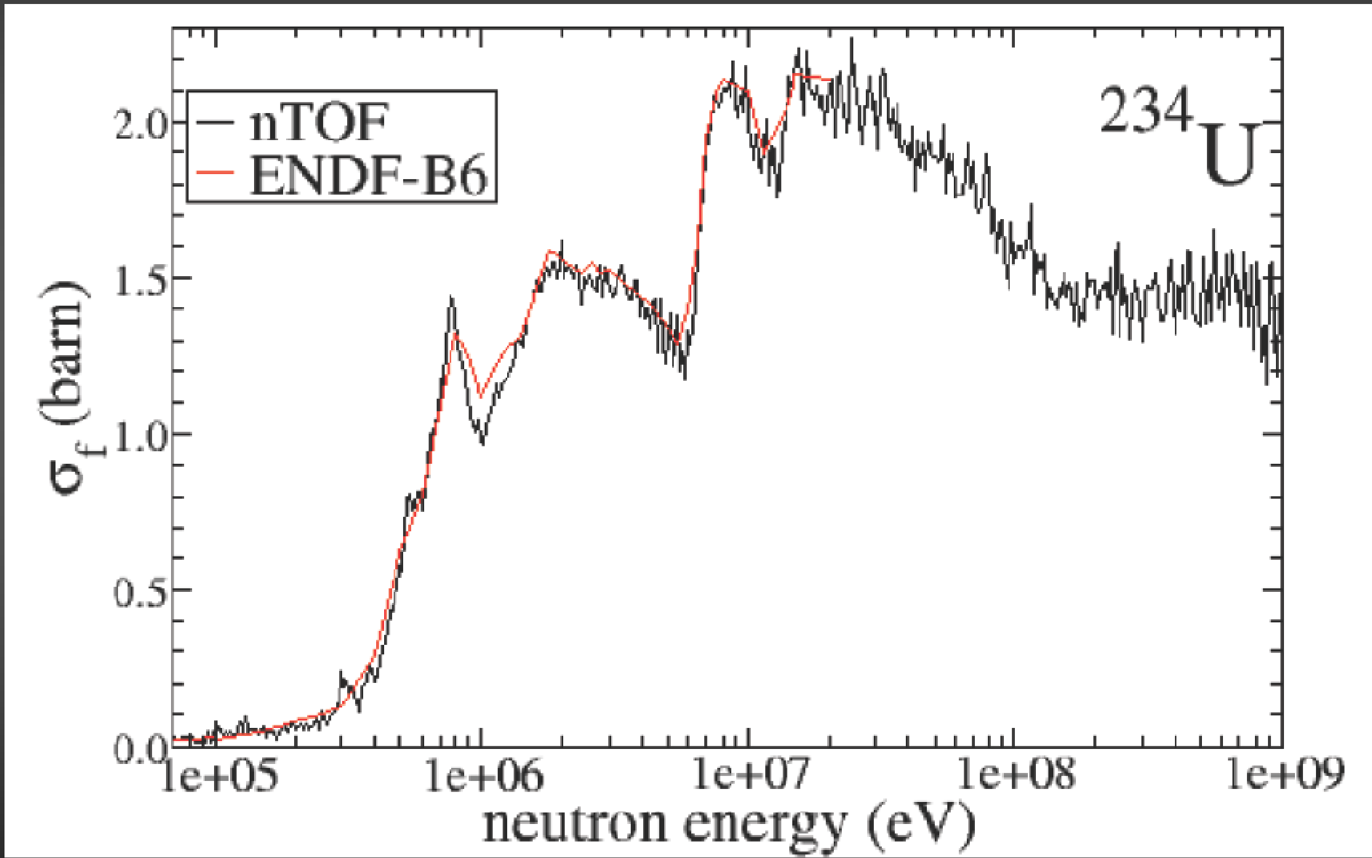
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{234}U(n,f)$



High-resolution data up to high(er) energies

n_TOF experiments

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{139}La

^{186,187,188}Os

^{233,234}U

^{237}Np,^{240}Pu,^{243}Am

Fission

^{233,234,235,236,238}U

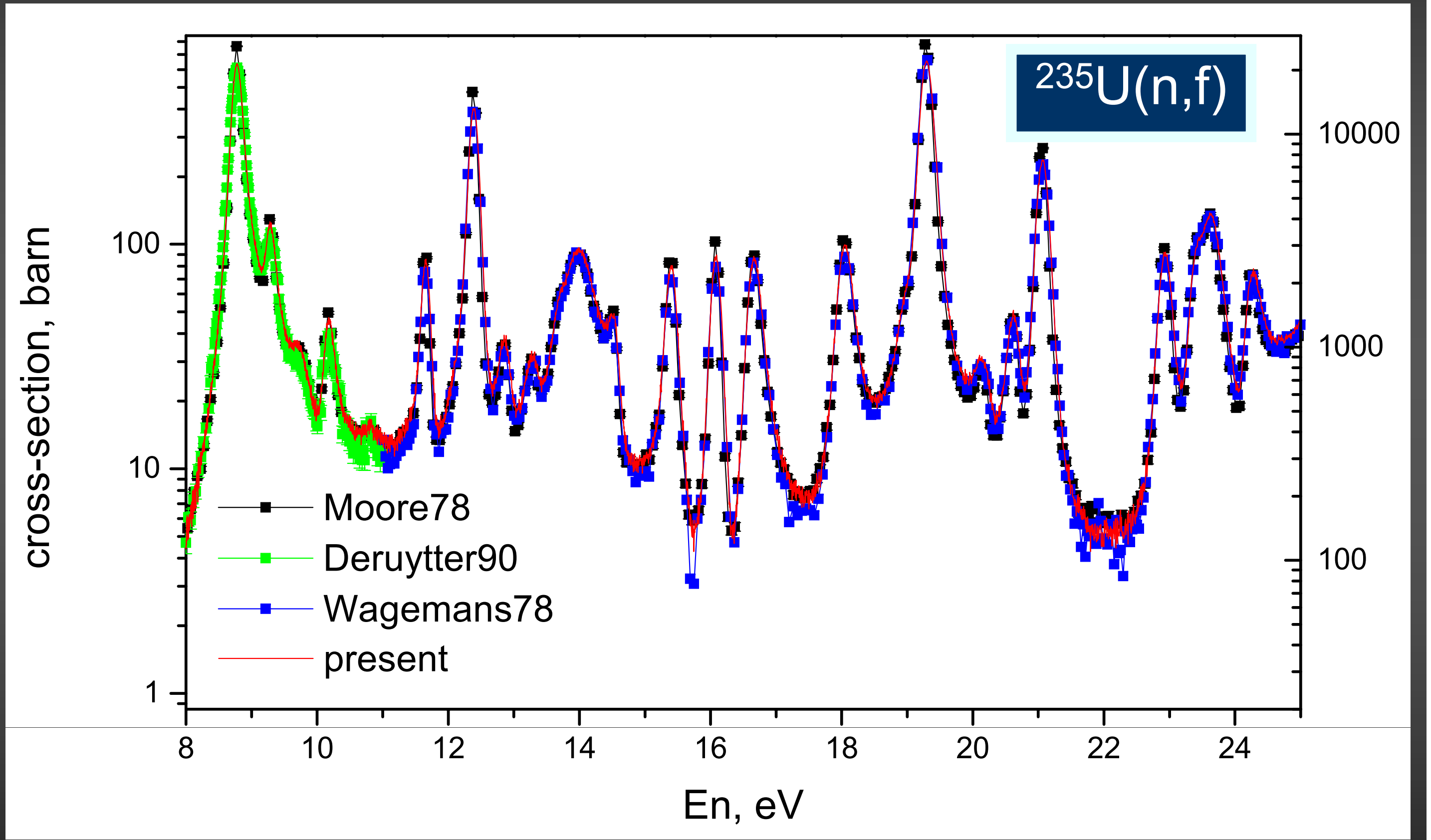
^{232}Th

^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm

FIC-0 (2003)



An unprecedent wide energy range can be explored at n_TOF in a single experiment

n_TOF experiments

FIC-1 (2003)

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{232}Th

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{139}La

^{186,187,188}Os

^{233,234}U

^{237}Np,^{240}Pu,^{243}Am

Fission

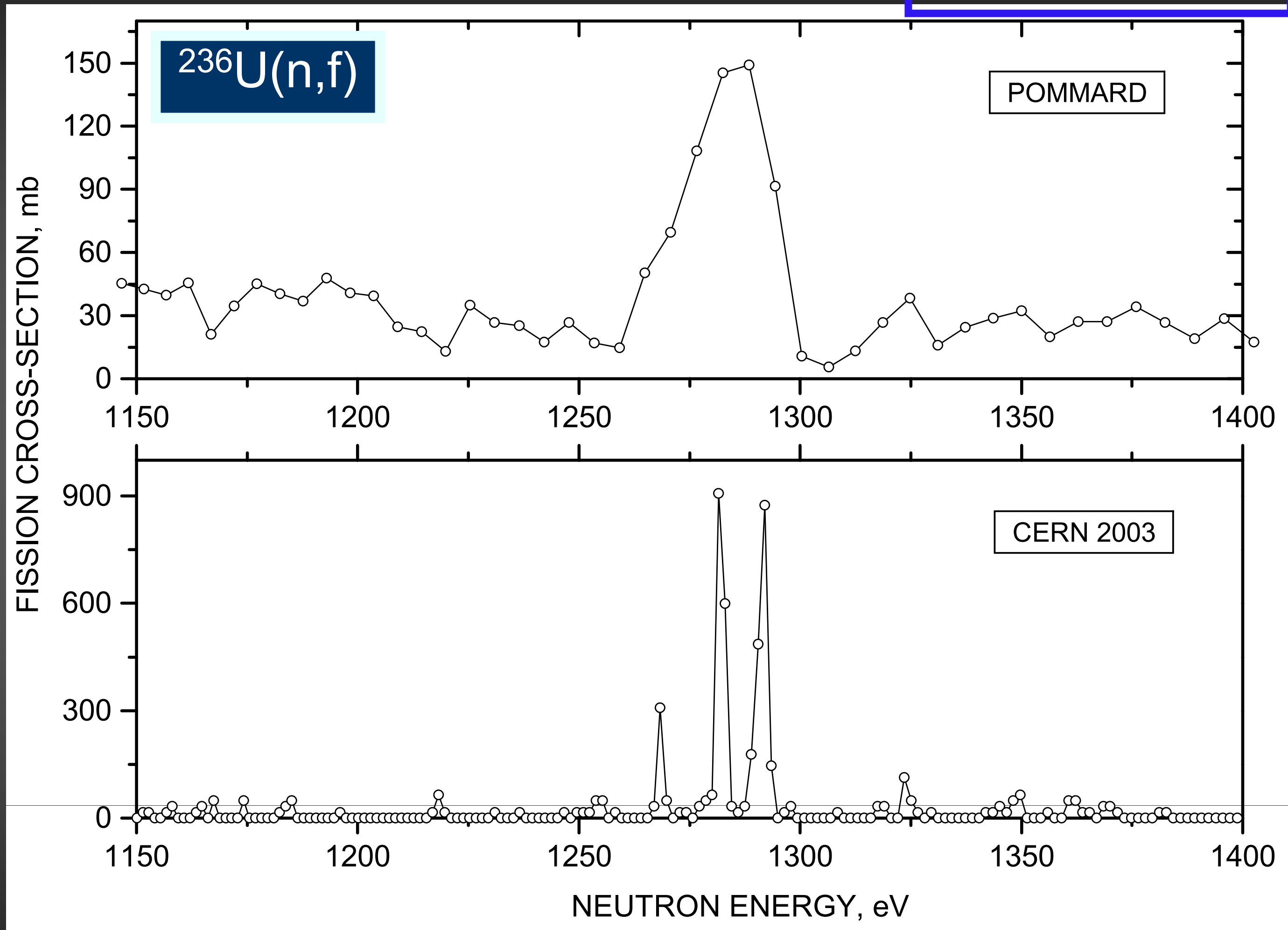
^{233,234,235,236,238}U

^{232}Th

^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm



An unprecedent wide energy range can be explored at n_TOF in a single experiment

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

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$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th

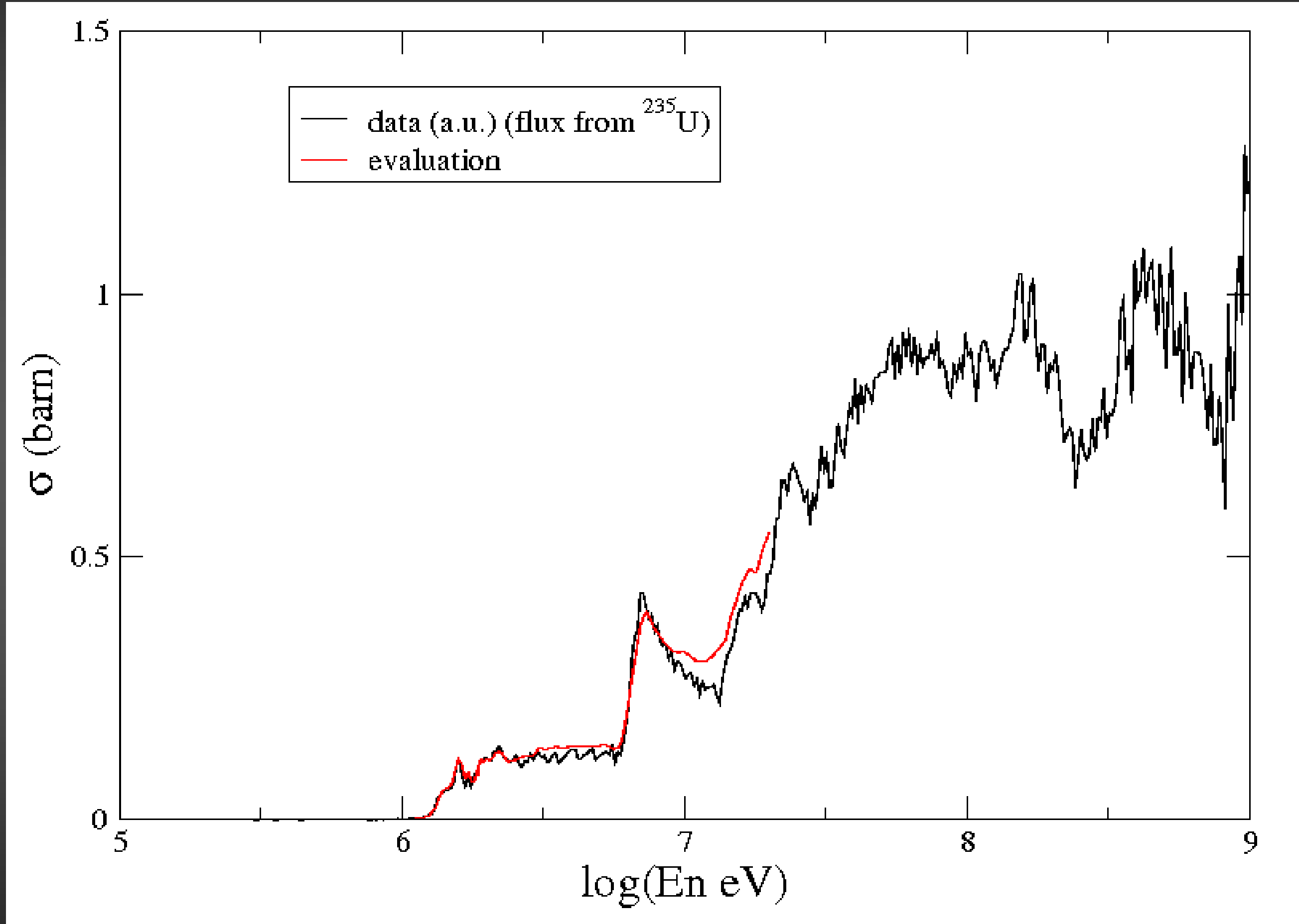
^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{232}Th(n,f)$

PPAC detectors



An unprecedent wide energy range can be explored at n_TOF in a single experiment

The n_TOF Collaboration

n_TOF experiments

FIC-0 (2003)

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

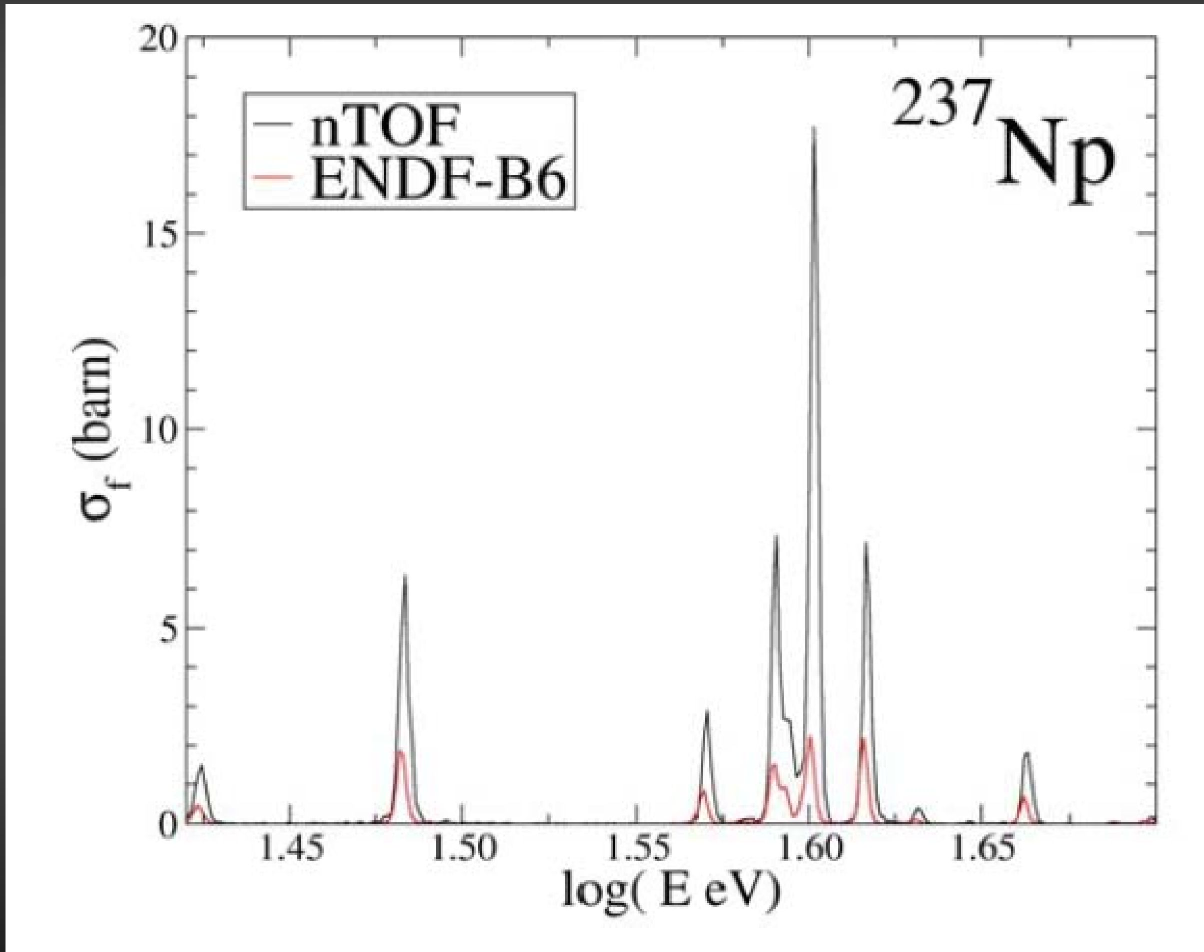
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{237}Np(n,f)$



Higher fission x-section in the sub-threshold region

n_TOF experiments

PPACs (2003)

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

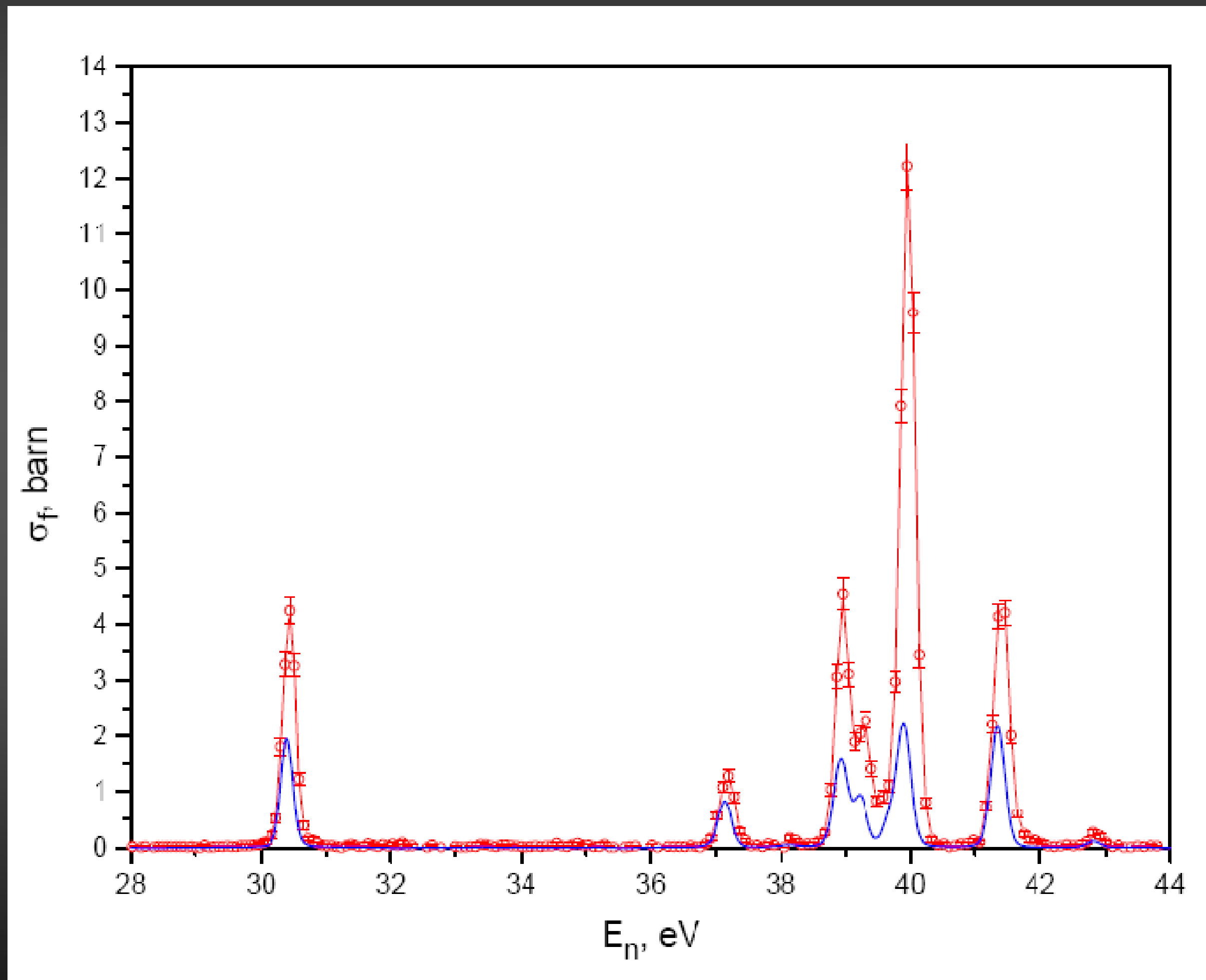
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{237}Np(n,f)$



Higher fission x-section in the sub-threshold region

n_TOF experiments

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

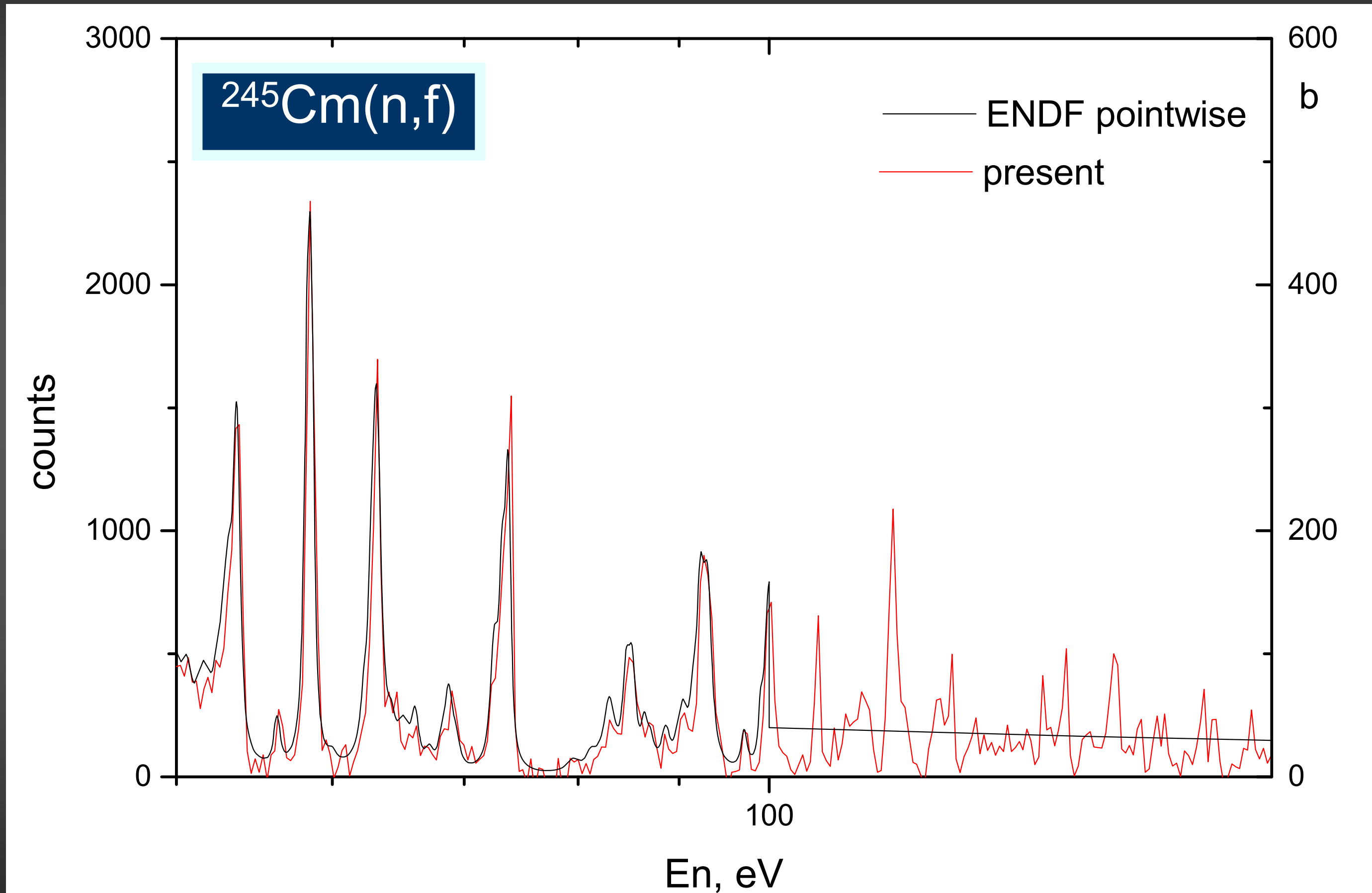
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

FIC-1 (2003)



High-resolution data up to high(er) energies

n_TOF experiments

FIC-0 (2003)

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

^{232}Th

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

^{139}La

$^{186,187,188}Os$

$^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

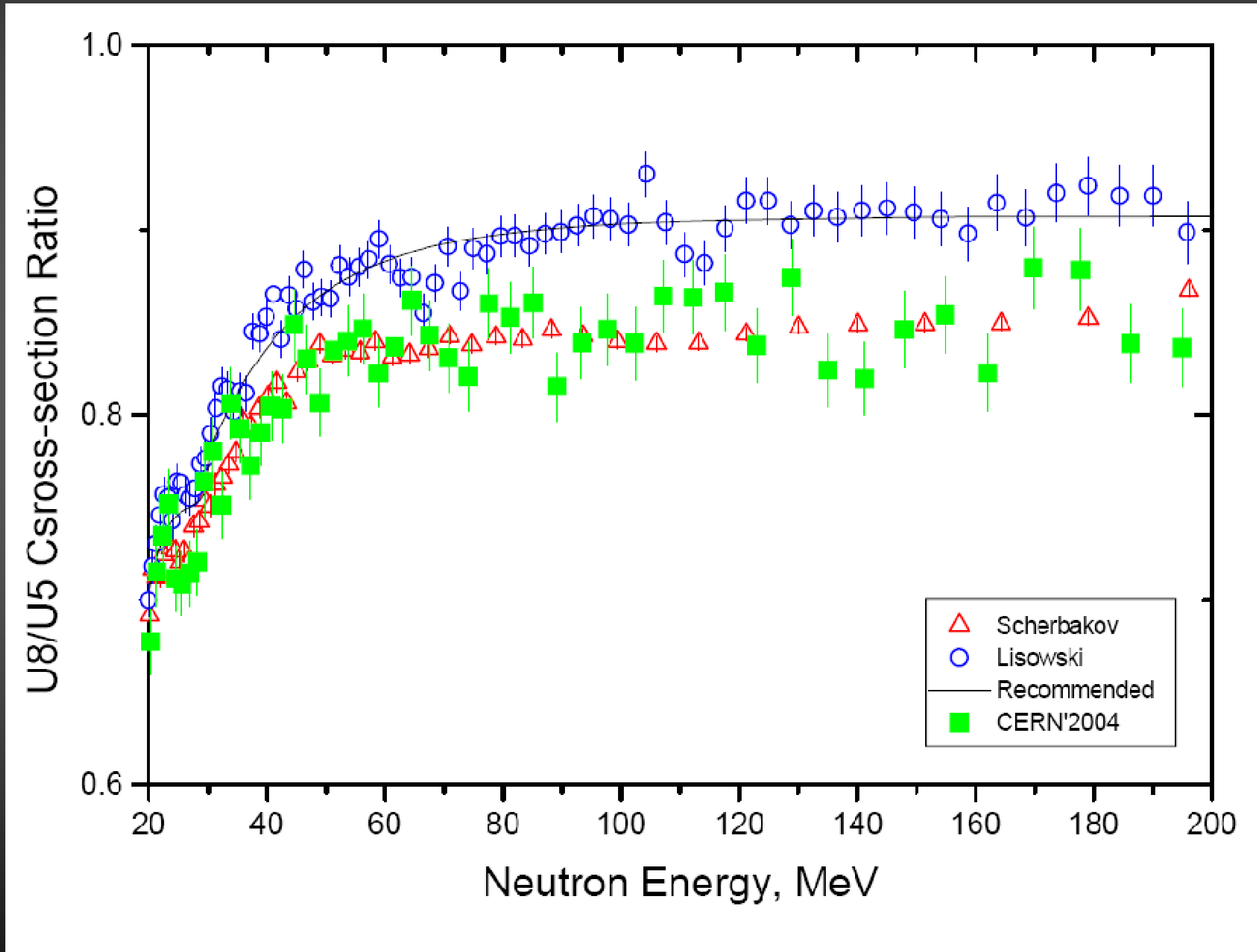
^{232}Th

^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

$^{238}U(n,f)/^{238}U(n,f)$

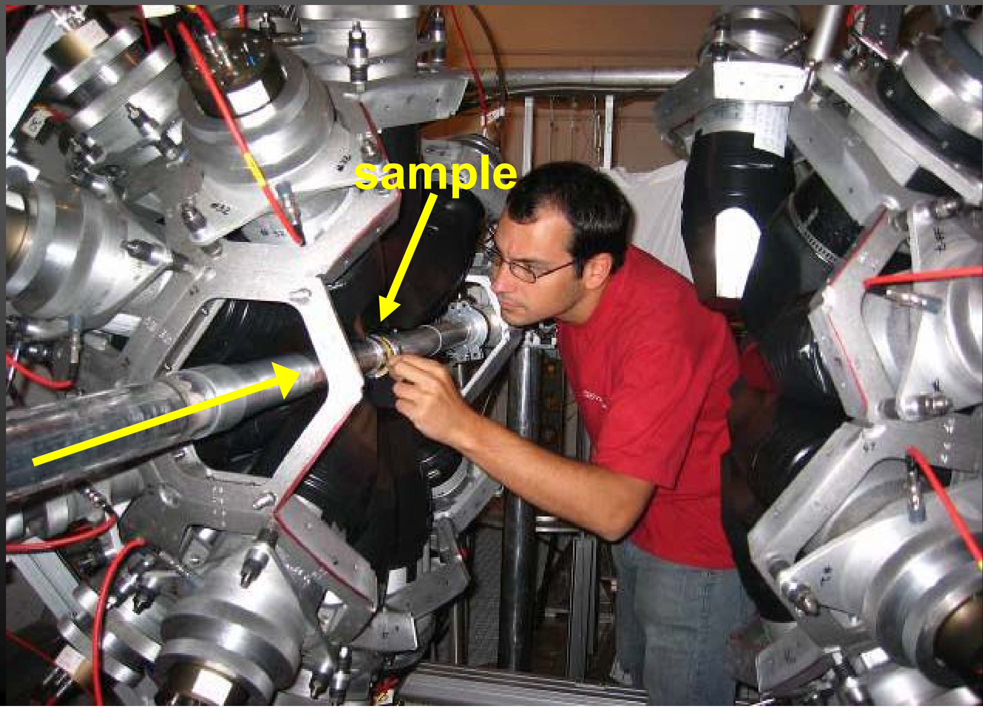


8% lower U8/U5 ratio at high energies

back

Capture samples

Sample	A	half-life yr	half-life s	Lambda 1/s	Mass mg	N	Activity Bq	Activity Ci	LA Bq	# of LA
Sm-151	151	9.30E+01	2.9E+09	2.36E-10	160	6.36E+20	1.5E+11	4.1E+00	-	-
U-233	233	1.59E+05	5.0E+12	1.38E-13	100	2.58E+20	3.6E+07	9.6E-04	700	50,755
U-234	234	2.46E+05	7.7E+12	8.95E-14	37	9.49E+19	8.5E+06	2.3E-04	700	12,126
U-236	236	2.34E+07	7.4E+14	9.38E-16	400	1.02E+21	9.5E+05	2.6E-05	800	1,192
Np-237	237	2.10E+06	6.6E+13	1.05E-14	50	1.27E+20	1.3E+06	3.6E-05	300	4,413
Pu-240	240	6564	2.1E+11	3.35E-12	50	1.25E+20	4.2E+08	1.1E-02	200	2,091,380
Pu-242	242	3.73E+05	1.2E+13	5.88E-14	20	4.96E+19	2.9E+06	7.9E-05	200	14,588
Am-241	241	432	1.4E+10	5.08E-11	400	9.96E+20	5.1E+10	1.4E+00	200	253,164,001
Am-243	243	7370	2.3E+11	2.98E-12	25	6.17E+19	1.8E+08	5.0E-03	200	919,833



Fission samples (FIC detectors)

Isotope	Diam. [mm]	Density [μg/cm2]	# of targets	Mass [mg]	T1/2 [yr]	A [Bq]	A[Ci]	N
U-234	50	150	6	35.3	2.46E+05	8.1E+06	2.2E-04	9.1E+19
U-235	50	200	2	15.7	7.04E+08	1.3E+03	3.4E-08	4.0E+19
U-236	80	100	2	20.1	2.34E+07	4.8E+04	1.3E-06	5.1E+19
U-238	80	300	2	60.3	4.47E+09	7.5E+02	2.0E-08	1.5E+20
Th-232	80	400	2	80.4	1.41E+10	3.2E+02	8.8E-09	2.1E+20
Np-237	80	150	1	15.1	2.10E+06	4.0E+05	1.1E-05	3.8E+19
Am-241	80	5	4	2.0	432.2	2.5E+08	6.9E-03	5.0E+18
Am-243	80	25	4	10.0	7370	7.4E+07	2.0E-03	2.5E+19
Cm-245	80	10	2	2.0	8500	1.3E+07	3.4E-04	4.9E+18

back

Capture studies

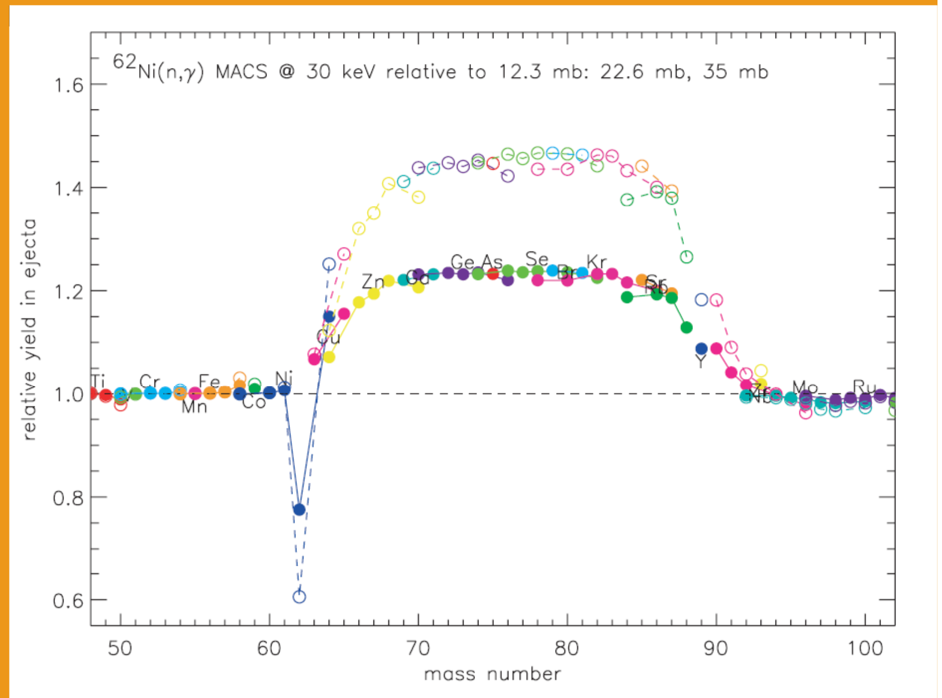
Capture studies: Fe, Ni, Zn & Se

<<

Motivations:

• Study of the weak s-process component (nucleosynthesis up to A ~ 90)

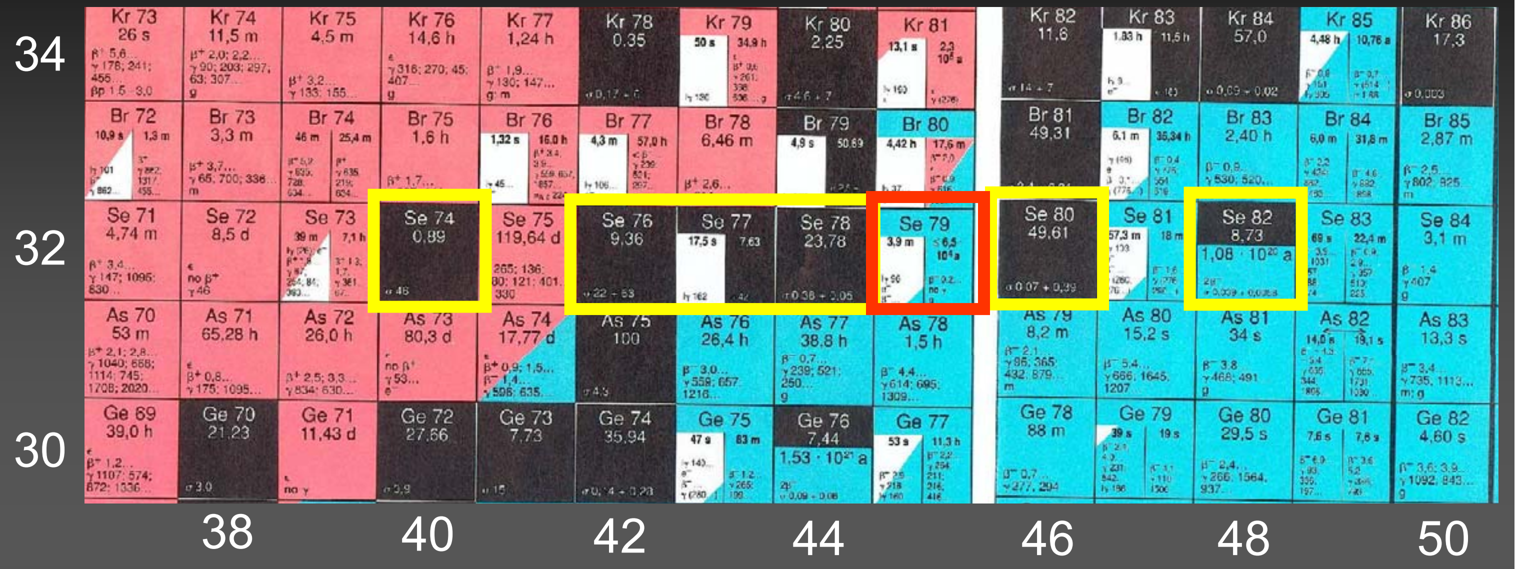
• Fe and Ni are the most important structural materials for nuclear technologies. Results of previous measurements at n_TOF show that capture rates for light and intermediate-mass isotopes need to be revised



• Contribution of massive stars (core He-burning phase) to the s-process nucleosynthesis
• s-process efficiency due to bottleneck cross sections (Example: ^{62}Ni)

Capture studies: Fe, Ni, Zn & Se

<<



The ^{79}Se case

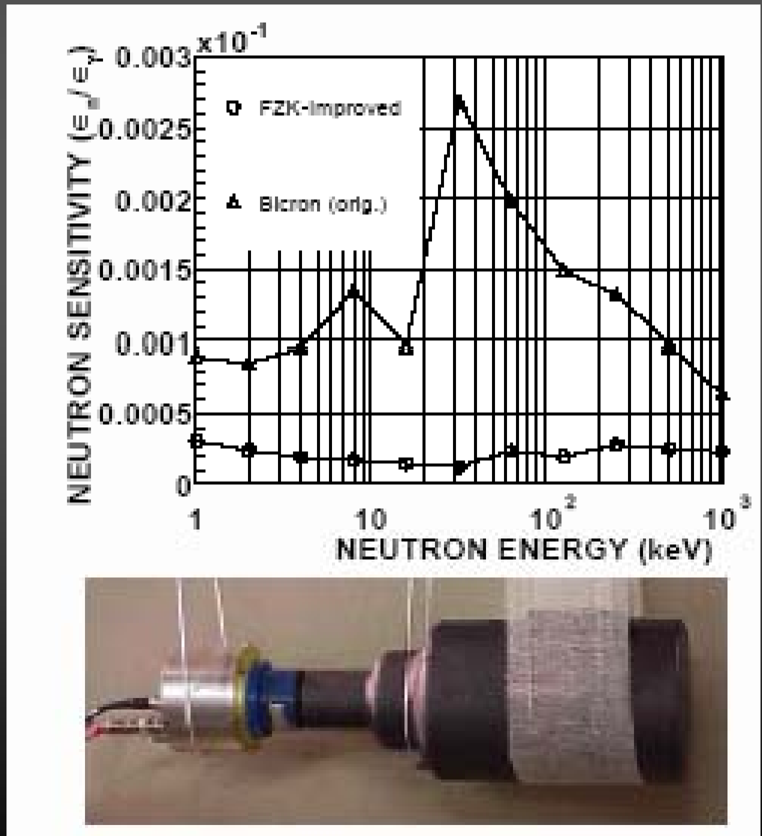
• s-process branching: neutron density & temperature conditions for the weak component

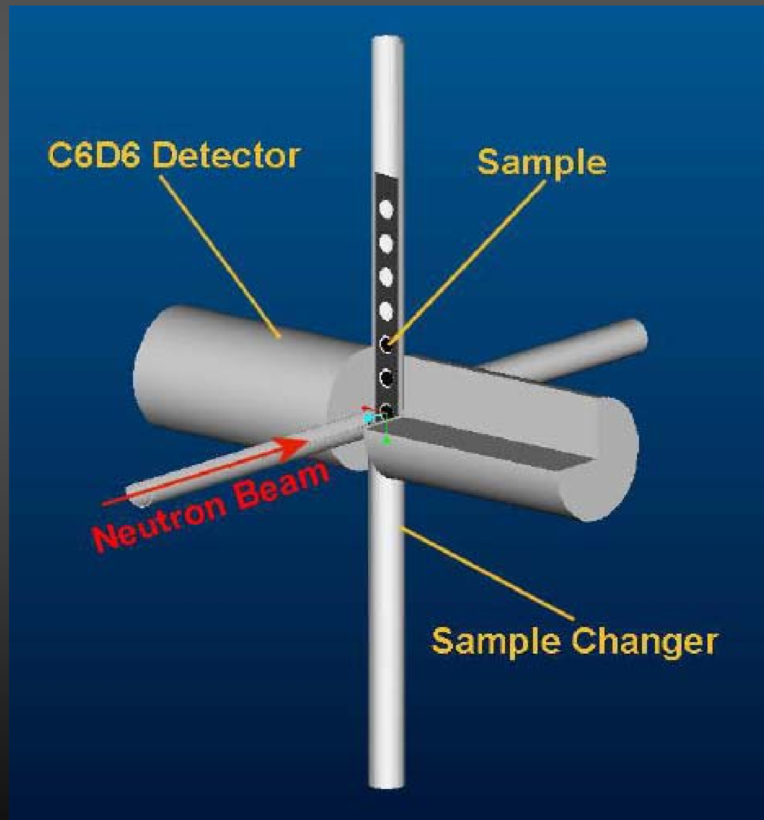
• $t_{1/2} < 6.5 \times 10^4$ yr

Capture studies: Fe, Ni, Zn & Se

<<

- Setup: C_6D_6 in EAR-1
- All samples are stable(*) and non-hazardous
- Metal samples preferable (oxides acceptable)





(*) except ^{79}Se

Capture studies: Mo, Ru & Pd

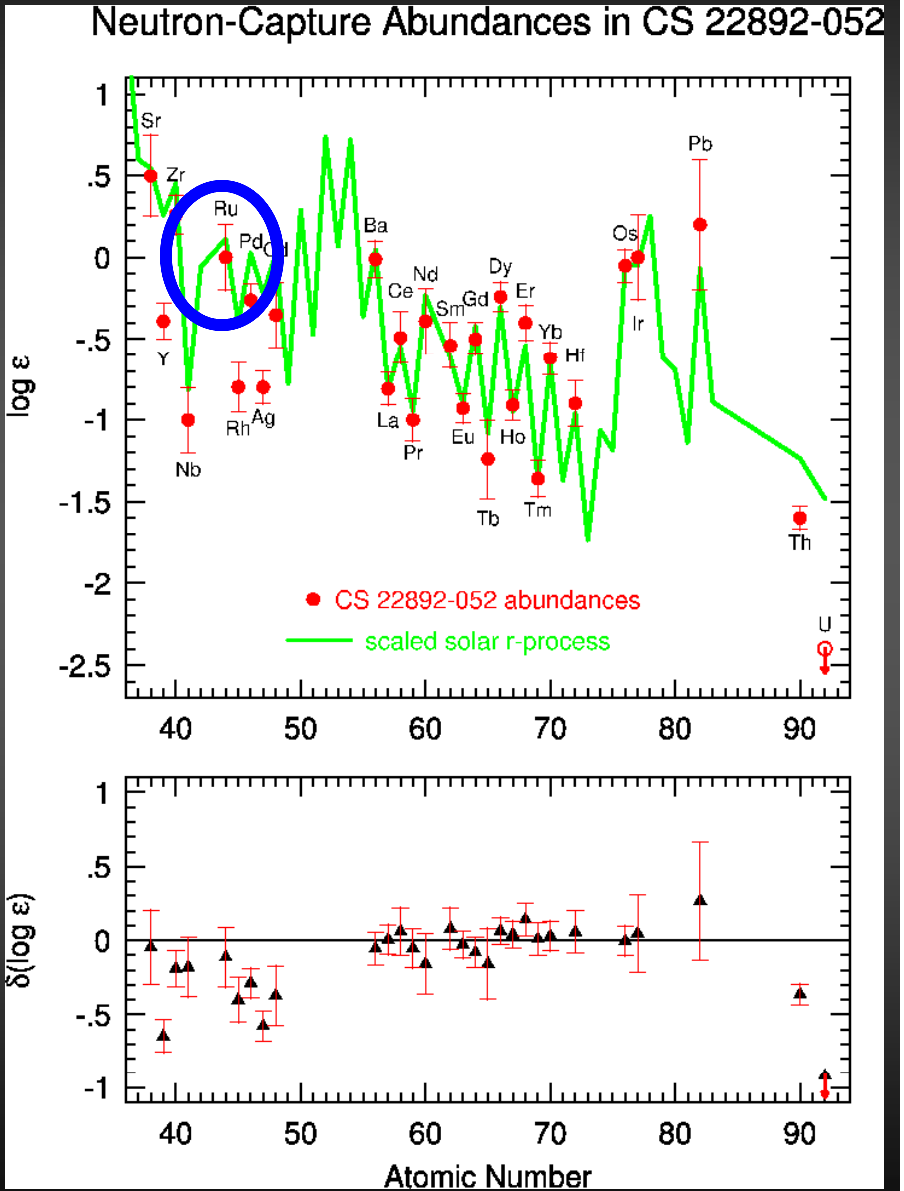
<<

Motivations:

- Accurate determination of the r-process abundances (r-process residuals) from observations

- SiC grains carry direct information on s-process efficiencies in individual AGB stars. Abundance ratios in SiC grains strongly depend on available capture cross sections data.

$$N_r = N_{solar} - N_s$$

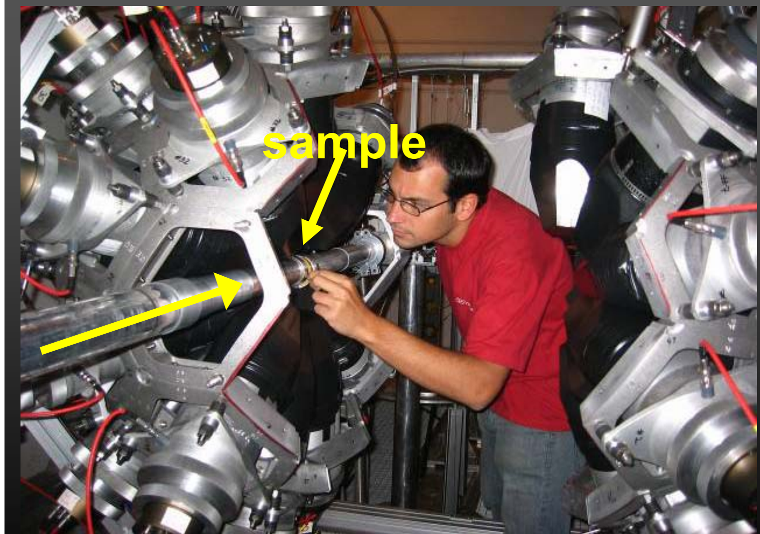


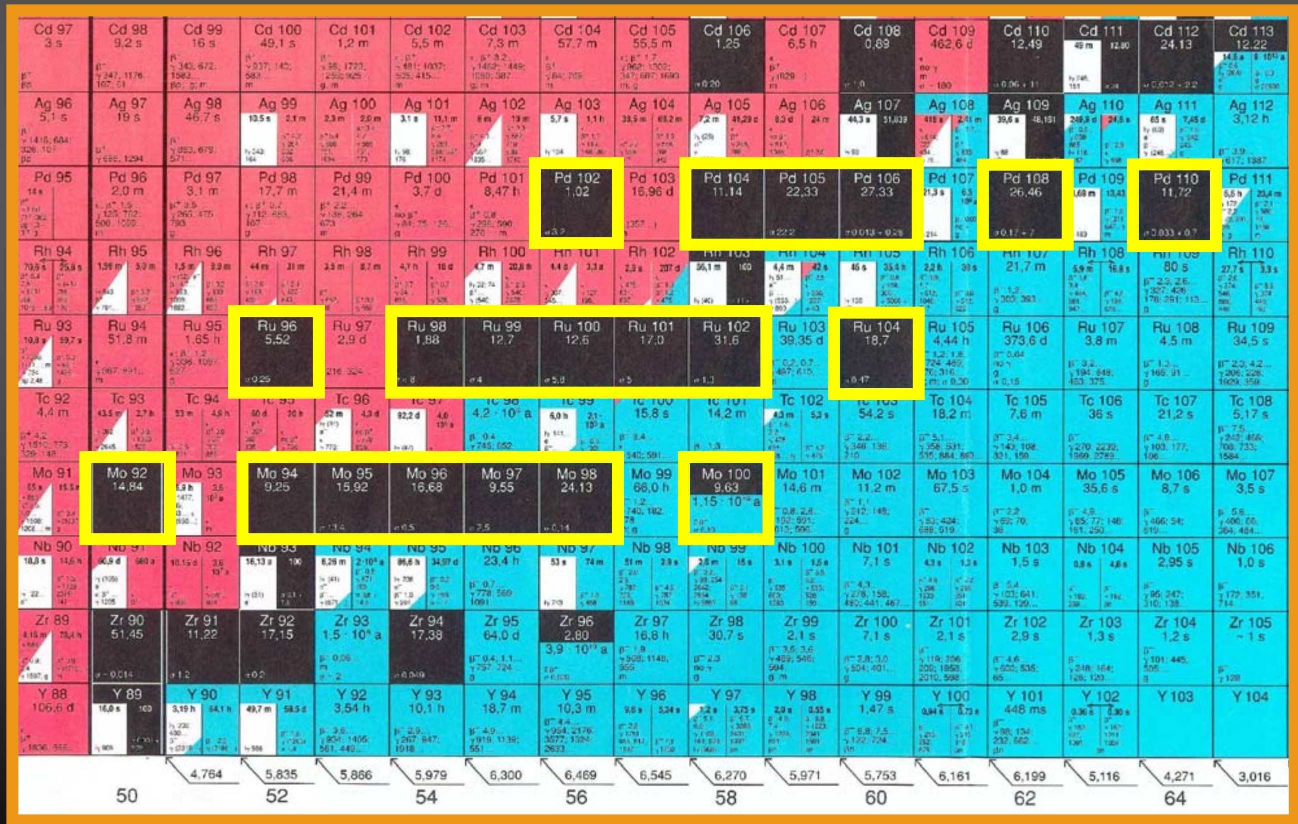
Capture studies: Mo, Ru & Pd

<<

- Setup: The n_TOF TAC in EAR-1
  (a few cases with C_6D_6 if larger neutron scattering)
- All samples are stable and non-hazardous
- Metal samples preferable (oxides acceptable)

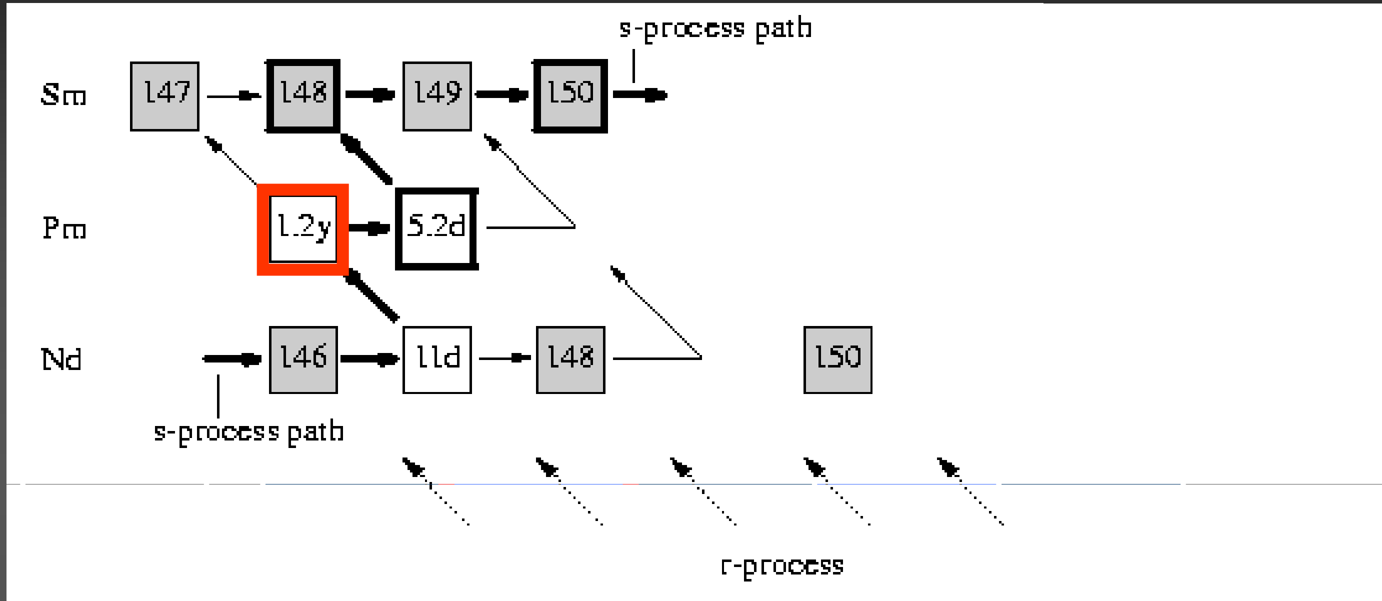
Estimated # of protons
20 x 5×10^{16} = **10^{18}**





Capture studies: A ≈ 150

<<



- EAR-2 required
- Sample from ISOLDE?

- branching isotope in the Sm-Eu-Gd region: test for low-mass TP-AGB
- branching ratio (capture/β-decay) provides infos on the thermodynamical conditions of the s-processing (if accurate capture rates are known!)

Capture studies: actinides

<<

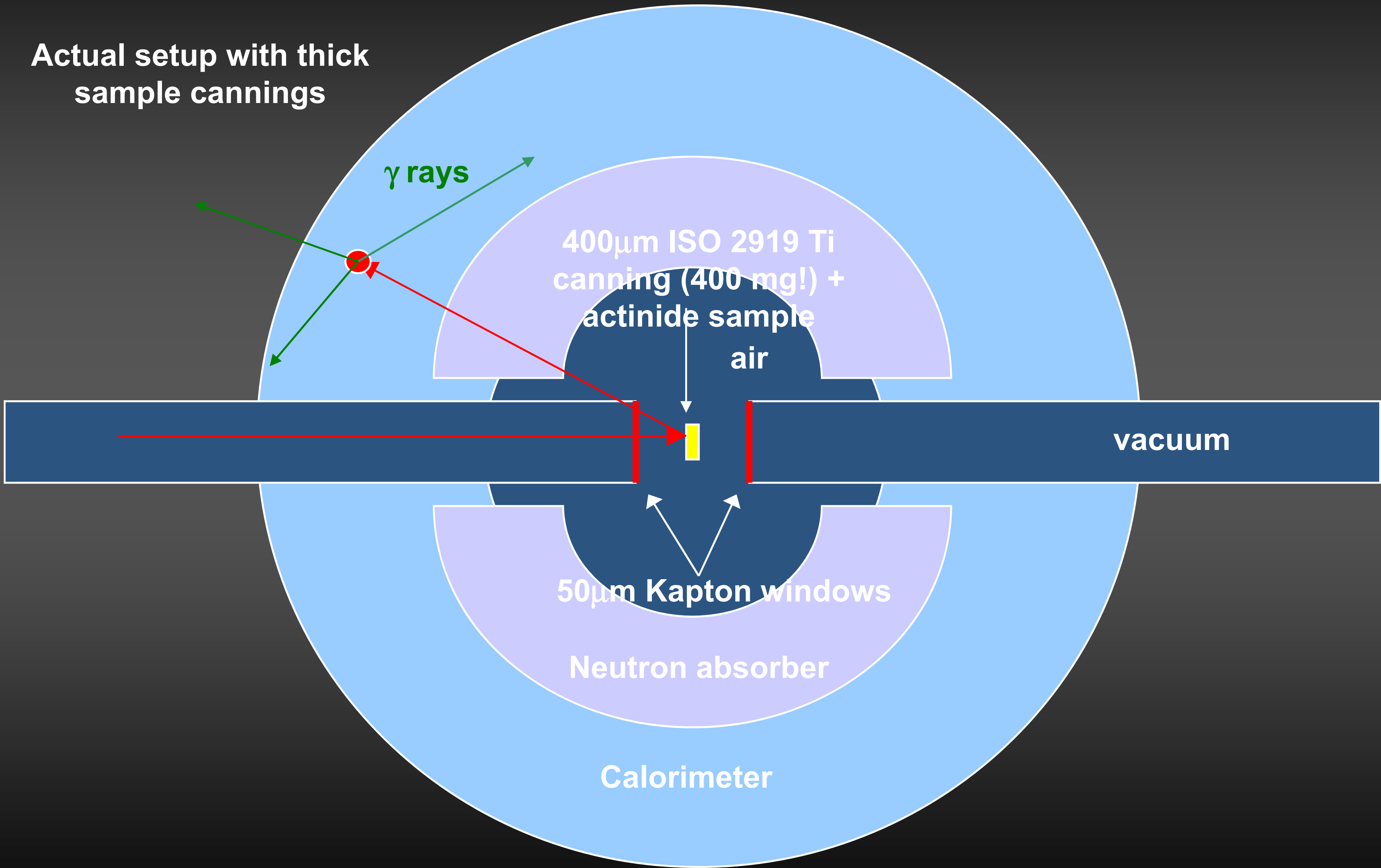
Neutron cross section measurements for nuclear waste transmutation and advanced nuclear technologies

$^{241,243}Am$	The most important neutron poison in the fuels proposed for transmutation scenarios. Build up of Cm isotopes.
$^{239,240,242}Pu$	(n,γ) and (n,f) with active canning. Build up of Am and Cm isotopes.
^{245}Cm	No data available.
$^{235,238}U$	Improvement of standard cross sections.
^{232}Th, $^{233,234}U$ $^{231,233}Pa$	Th/U advanced nuclear fuels. ^{233}U fission with active canning.

All measurements can be done in EAR-1 (except ^{241}Am and ^{233}Pa)

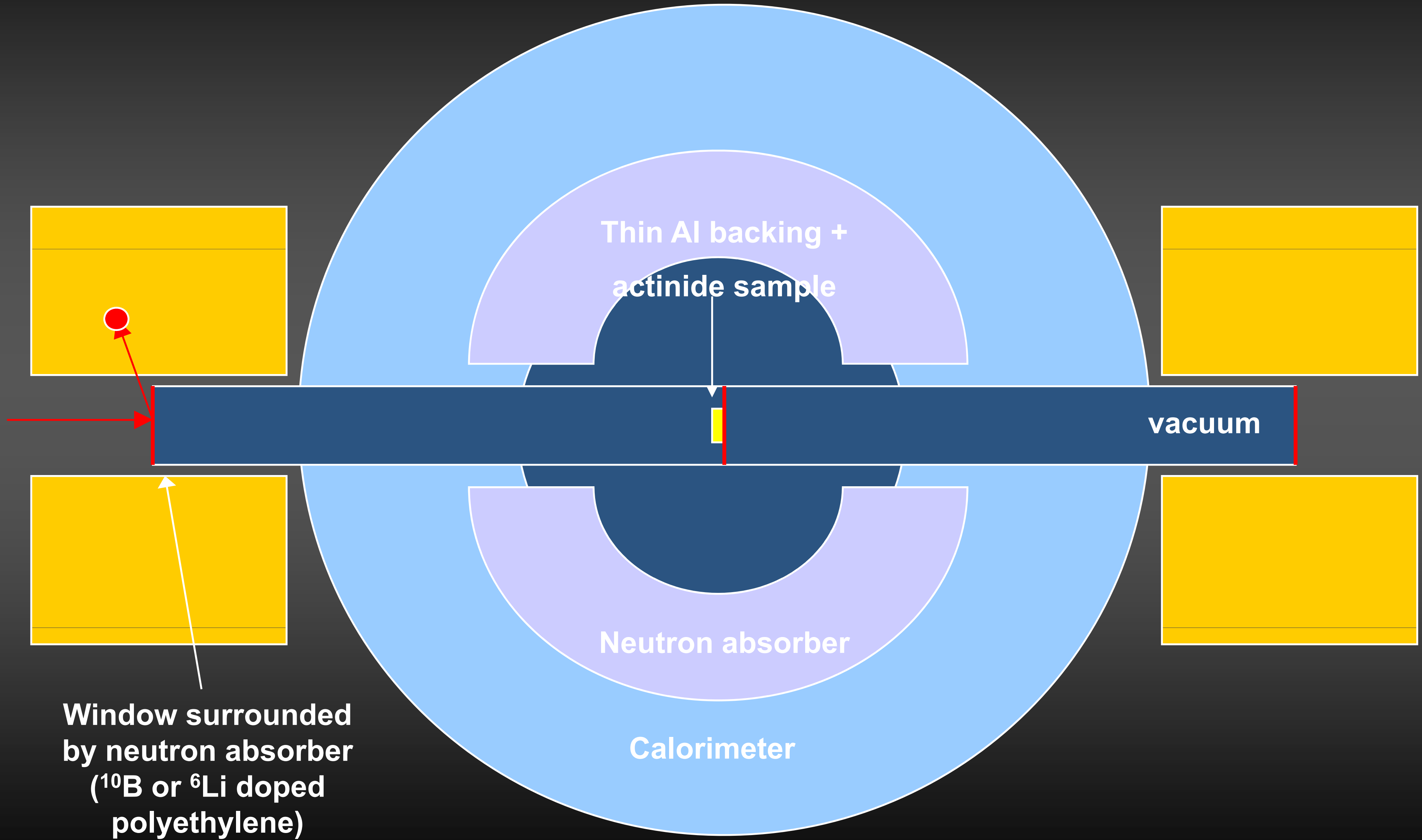
Capture studies: actual TAC setup

<<



TAC: Low neutron sensitivity setup

<<



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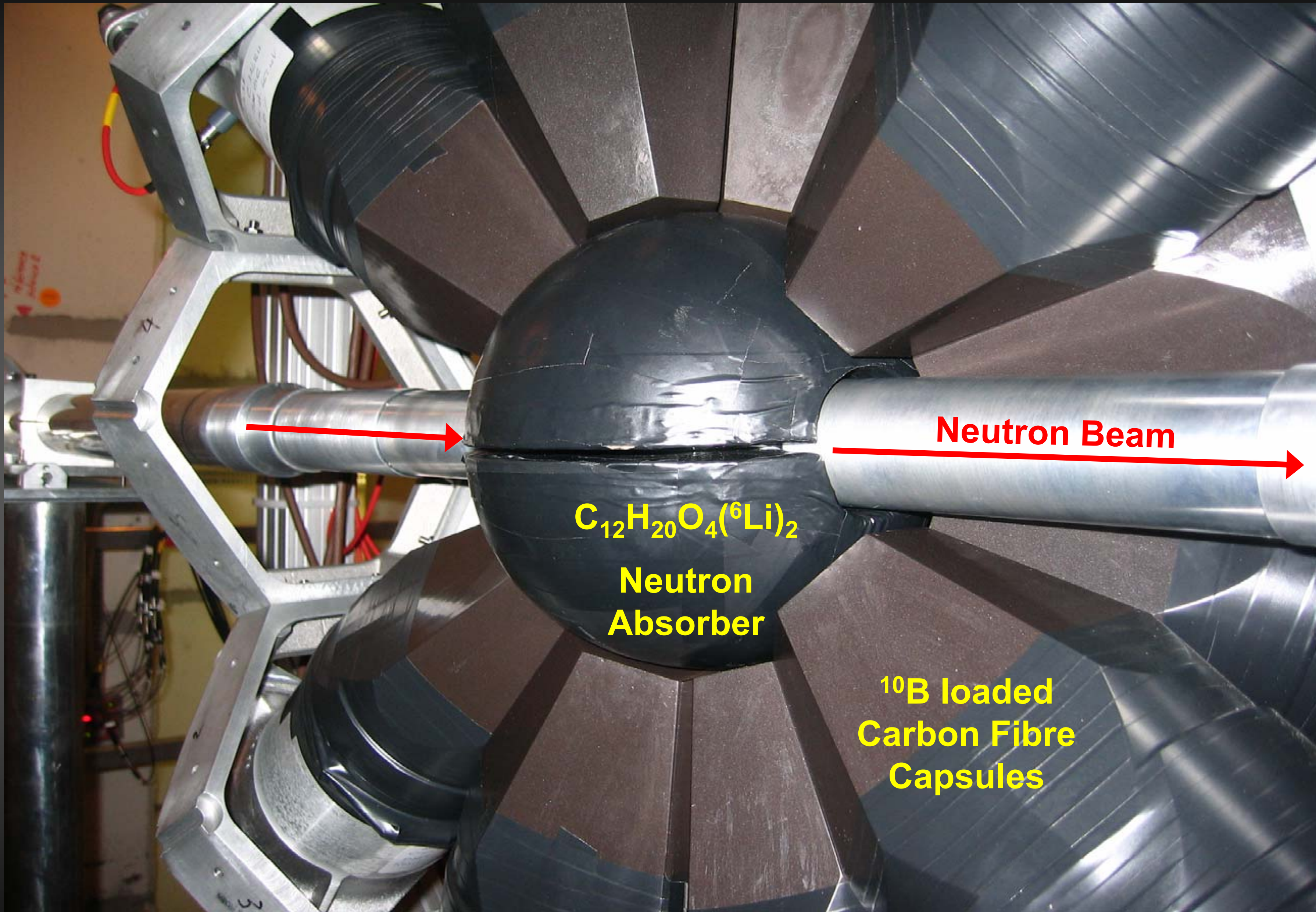
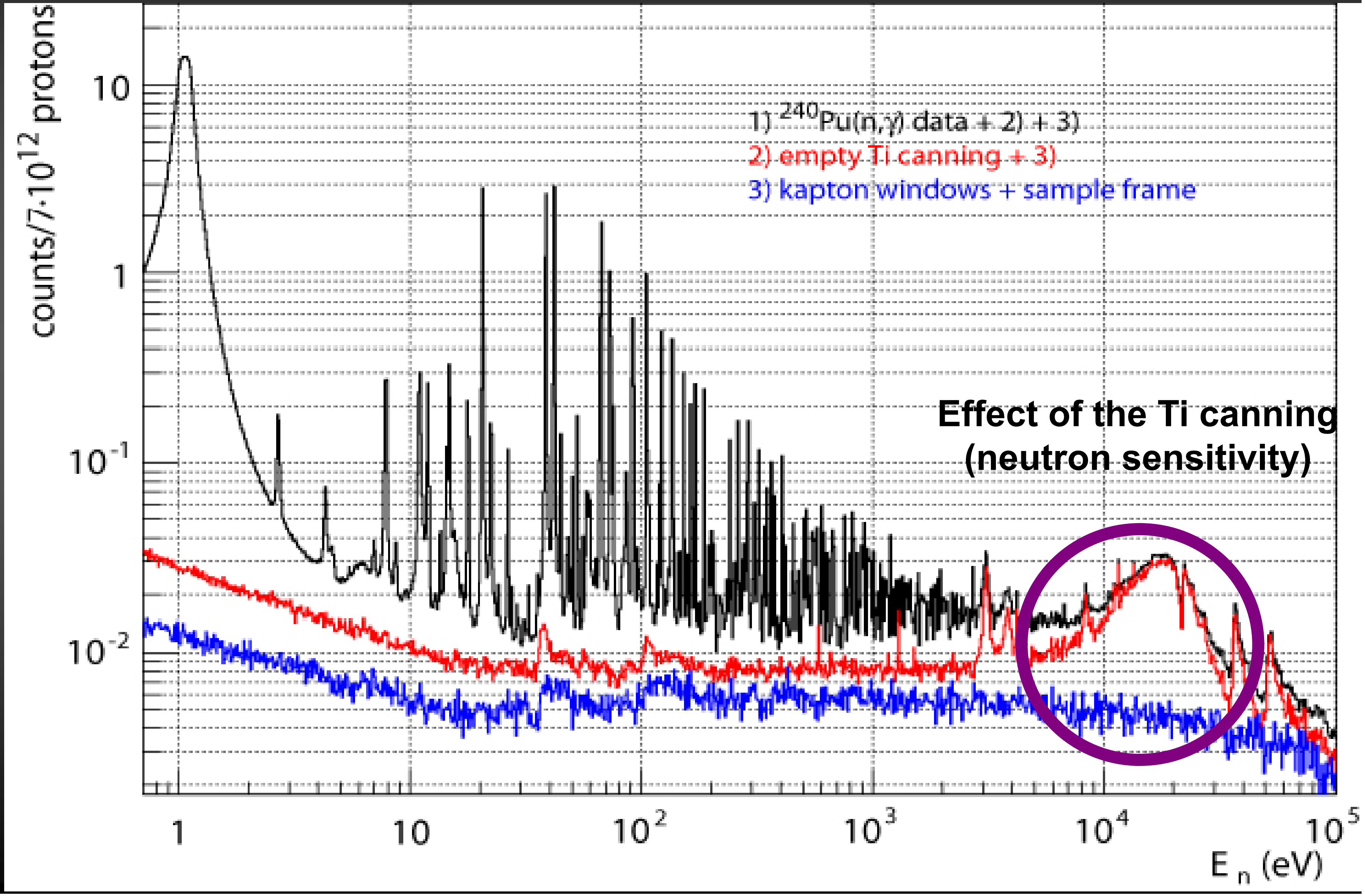
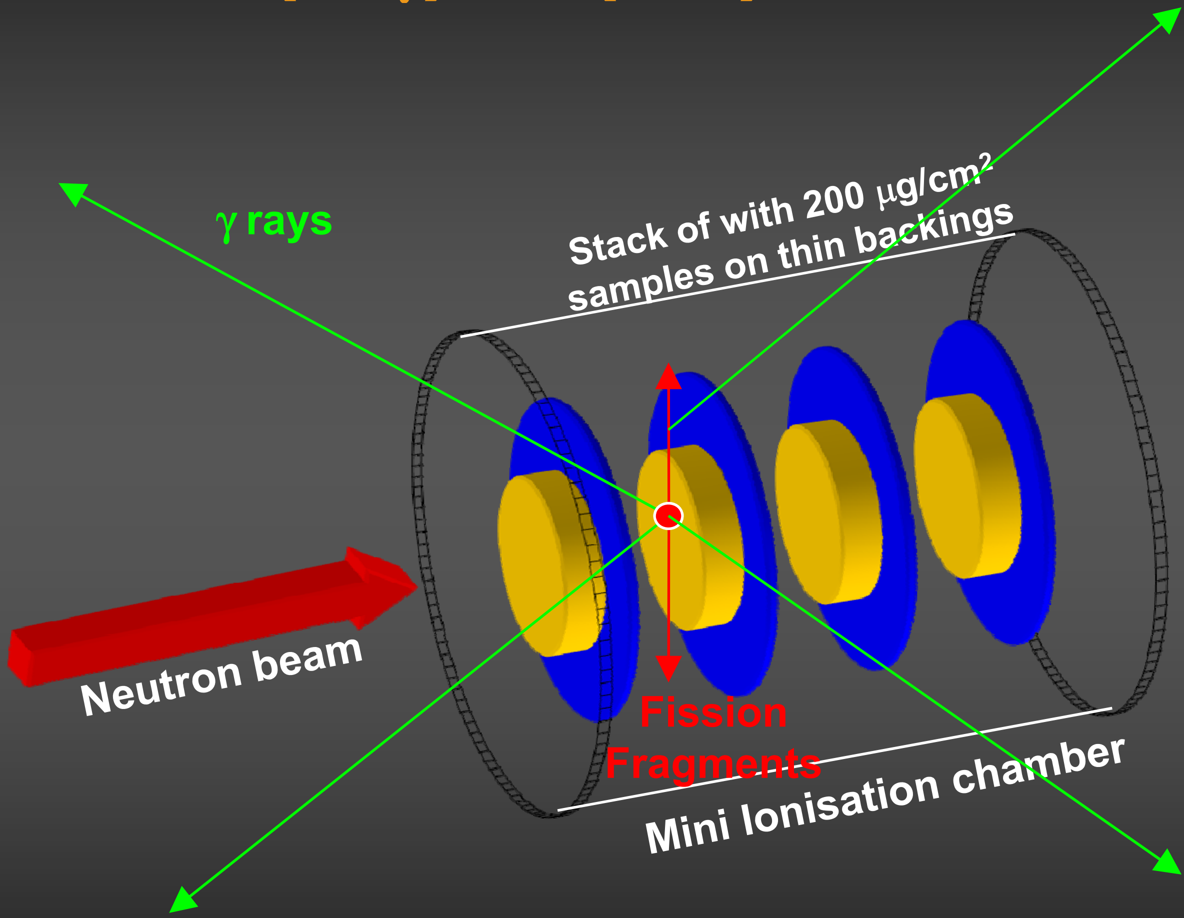

Neutron Beam
$C_{12}H_{20}O_4(^6Li)_2$
Neutron Absorber
^{10}B loaded Carbon Fibre Capsules

Capture studies: actual TAC setup



Capture studies: active canning for simultaneous (n,γ) & (n,f) measurements

<<



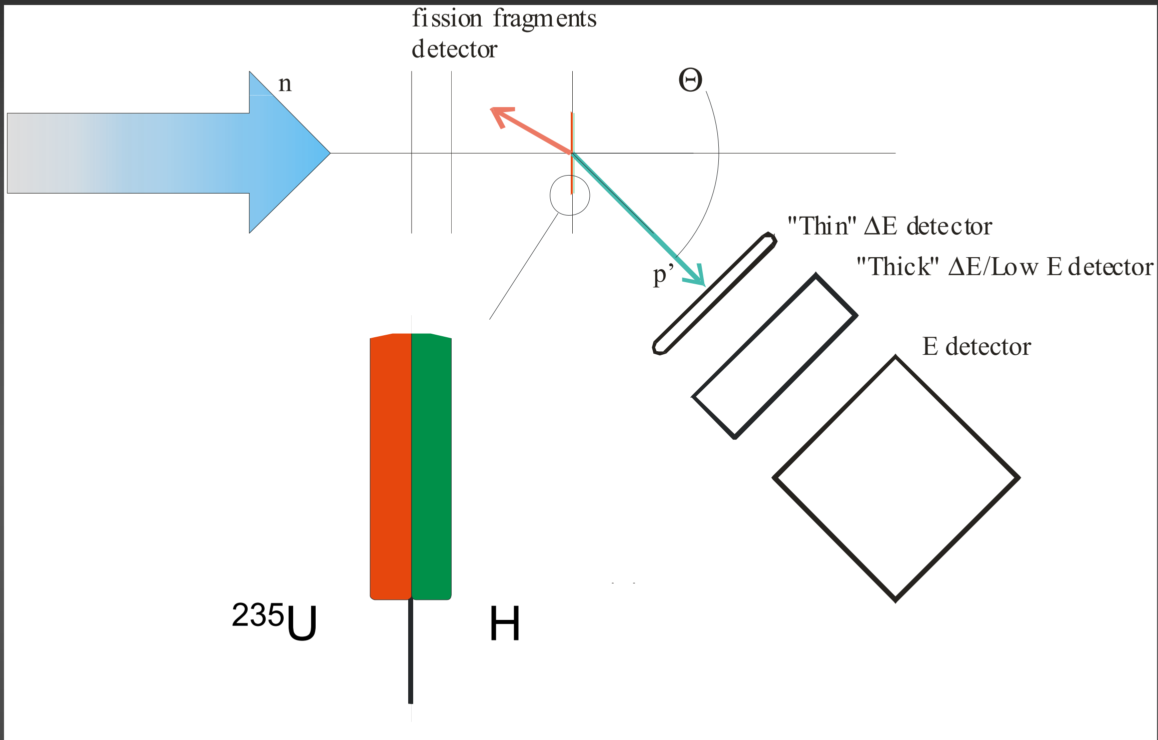
Measurement of capture cross sections of fissile materials (veto) and measurement of the (n,γ)/(n,f) ratio.

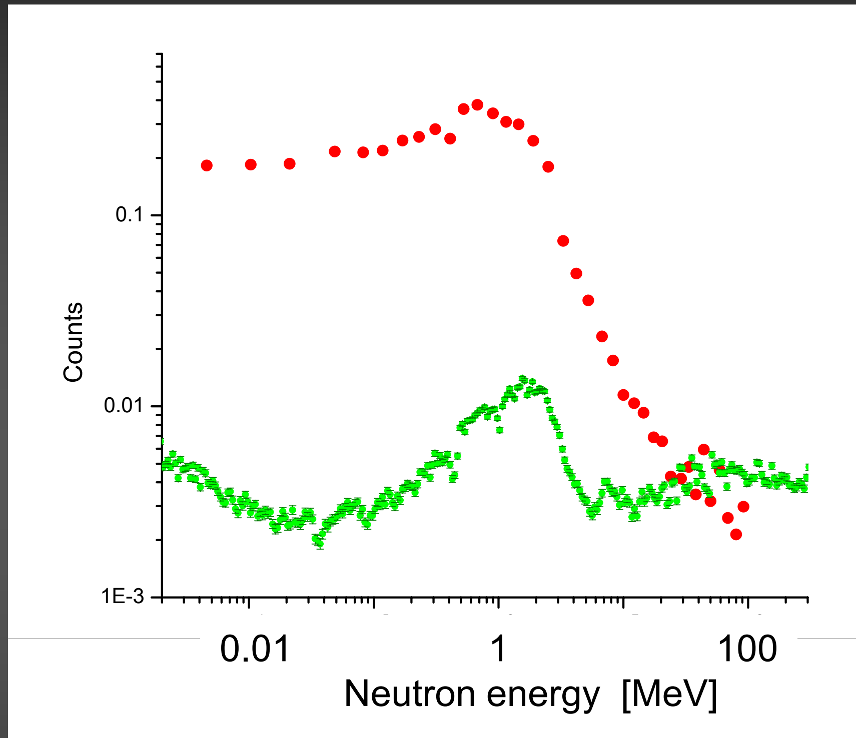
Fission studies

Fission studies

[<<]

absolute $^{235}U(n,f)$ cross section from (n,p) scattering





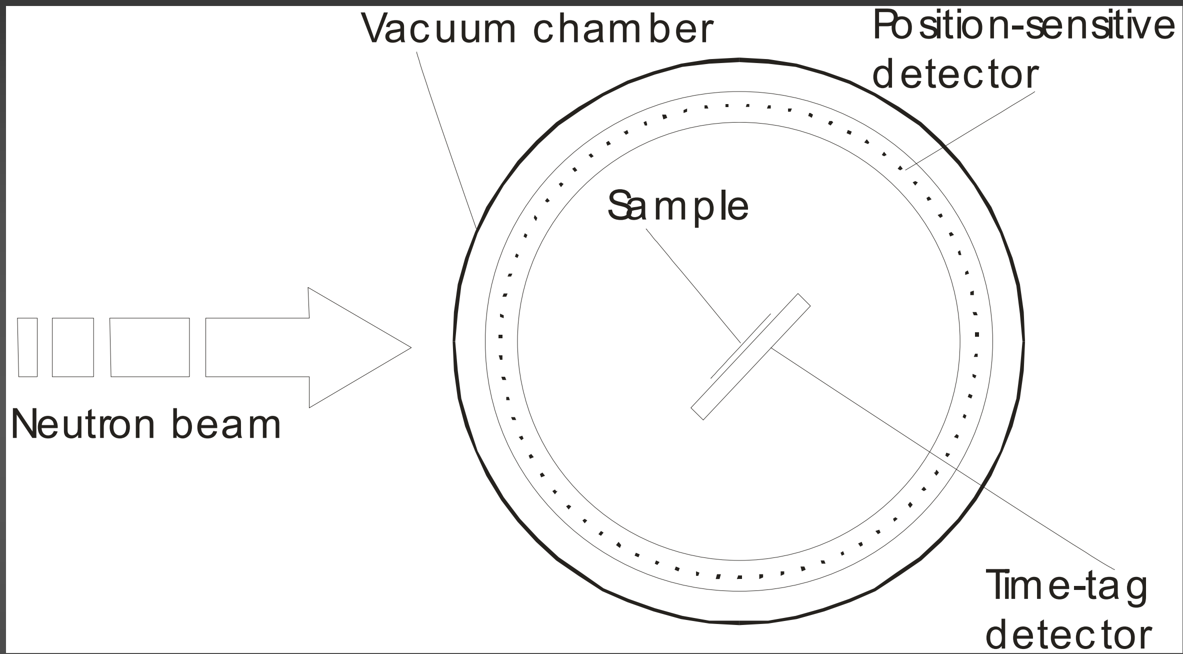
Beam	capture mode (2 mm Ø)
Scattering angle	30°
Target thickness	250 $\mu g/cm^2$
Detector radius	20 mm
Target-to-detector distance	250 mm

(n,p) larger or comparable up to 100 MeV

Fission studies

FF distributions in vibrational resonances

<<



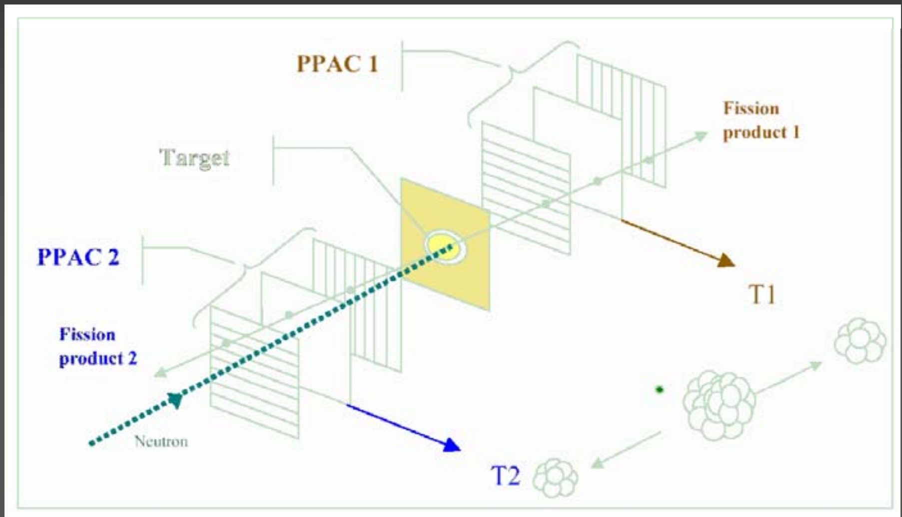
Principles:

- Time-tag detector for the "start" signal
- Masses (kinetic energies) of FF from position-sensitive detectors (MICROMEGAS or semiconductors)

Fission studies

<<

cross sections with PPAC detectors: present setup



Measurements:

- $^{231}Pa(n,f)$
- Fission fragments angular distributions (45° tilted targets) for ^{232}Th, ^{238}U and other low-activity actinides

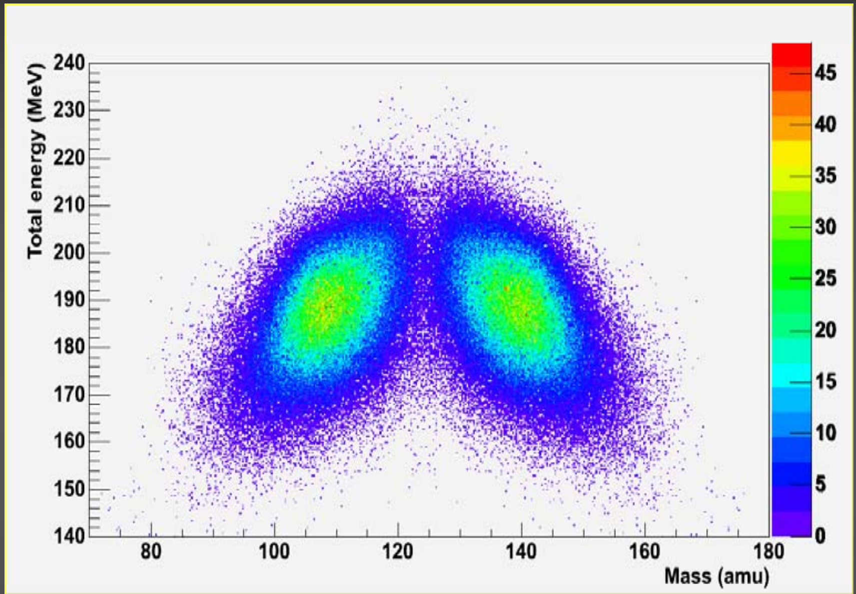
EAR-2 boost:

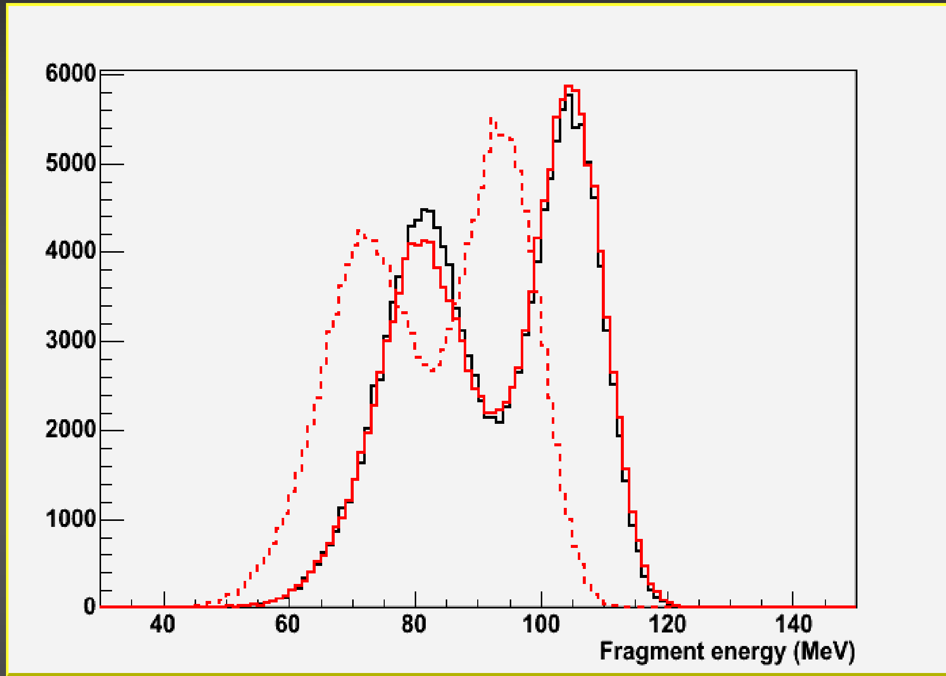
- measurements of $^{241,243}Am$ (in class-A lab)
- measurements of ^{241}Pu and ^{244}Cm (in class-A lab)

Fission studies

with twin ionization chamber

<<





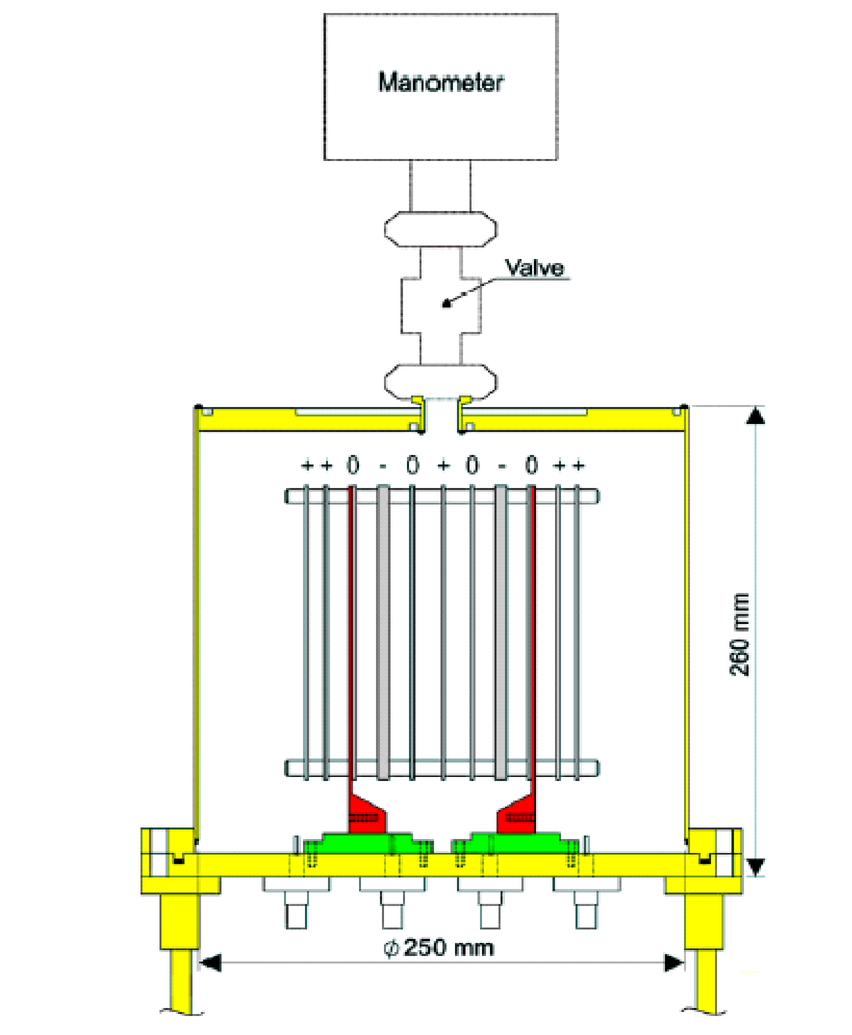
Twin ionization detector with measurement of both FF (PPAC principle)

Measurements:

- FF yields: mass & charge
- Test measurement with ^{235}U then measurements of other MA

(n,p), (n,α) & (n,lcp) measurements <u><<</u>

1. CIC: compensated ion chamber already tested at n_TOF



For n_TOF-Ph2:

- four chambers in the same volume for multi-sample measurements

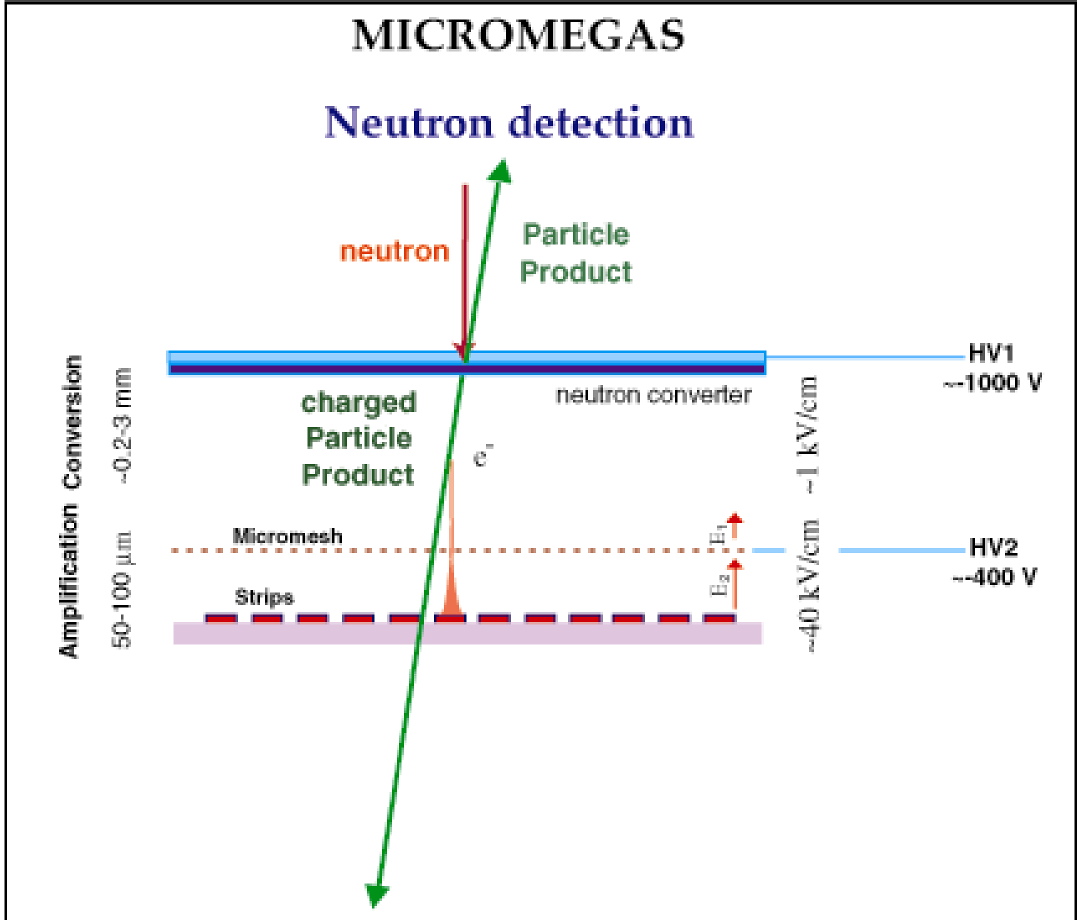
Measurements:

- $^{147}Sm(n,\alpha)$ (tune up experiment)
- ^{6}LiF target for calibration

EAR-2 boost:
- approx 100 times the ORELA count rate expected
- ^{67}Zn and ^{99}Ru (n,α) measurements

(n,p), (n,α) & (n,lcp) measurements <<

2. MICROMEGAS
already used for measurements of nuclear recoils at n_TOF

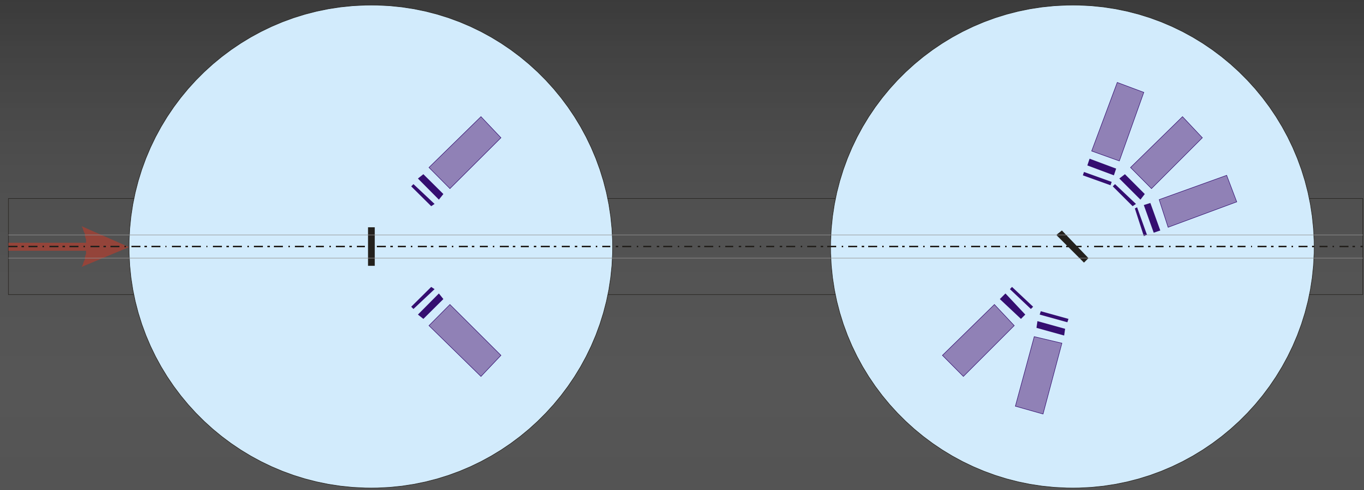


For n_TOF-Ph2:

- converter replaced by sample
- expected count rate: 1 reaction/pulse (σ=200 mb, Ø=5cm, 1μm thick)

(n,p), (n,α) & (n,lcp) measurements <<

3. Scattering chambers with ΔE-E or ΔE-ΔE-E telescopes



Setup: in parallel with fission detectors

✓ production cross sections $\sigma(E_n)$ for (n,xc)

✓ c = p, α, d

✓ differential cross sections $d\sigma/d\Omega$, $d\sigma/dE$

Measurements:

- ^{56}Fe and ^{208}Pb (tune up experiment)
- Al, V, Cr, Zr, Th, and ^{238}U
- a few x 10^{18} protons/sample in fission mode

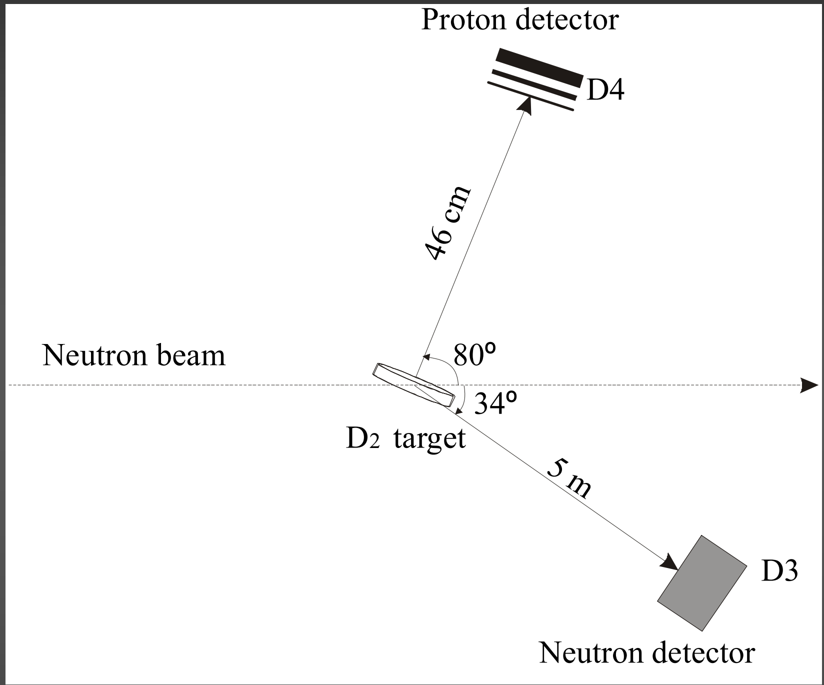
Neutron scattering reactions

<<

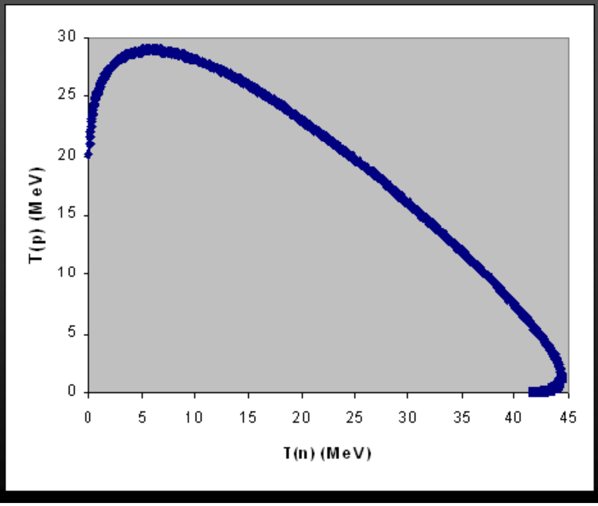
Direct n + n scattering experiment not feasible!

Alternatively, interaction of two neutrons in the final state of a nuclear reaction. Examples of such reactions are:

- $\pi^+ + {}^2H \rightarrow n + n + \gamma$
- $n + {}^2H \rightarrow n + n + p$



Neutron incident energy 30 – 75 MeV in 2.5 MeV bins



Kiematic locus of the $n + {}^2H \rightarrow n + p + n$ reaction for:
E_n = 50 MeV
$\Theta_n = 20^o$, $\Phi_n = 0^o$
$\Theta_p = 50^o$, $\Phi_p = 180^o$

<< back

$^{237}Np(n,\gamma)$ at n_TOF

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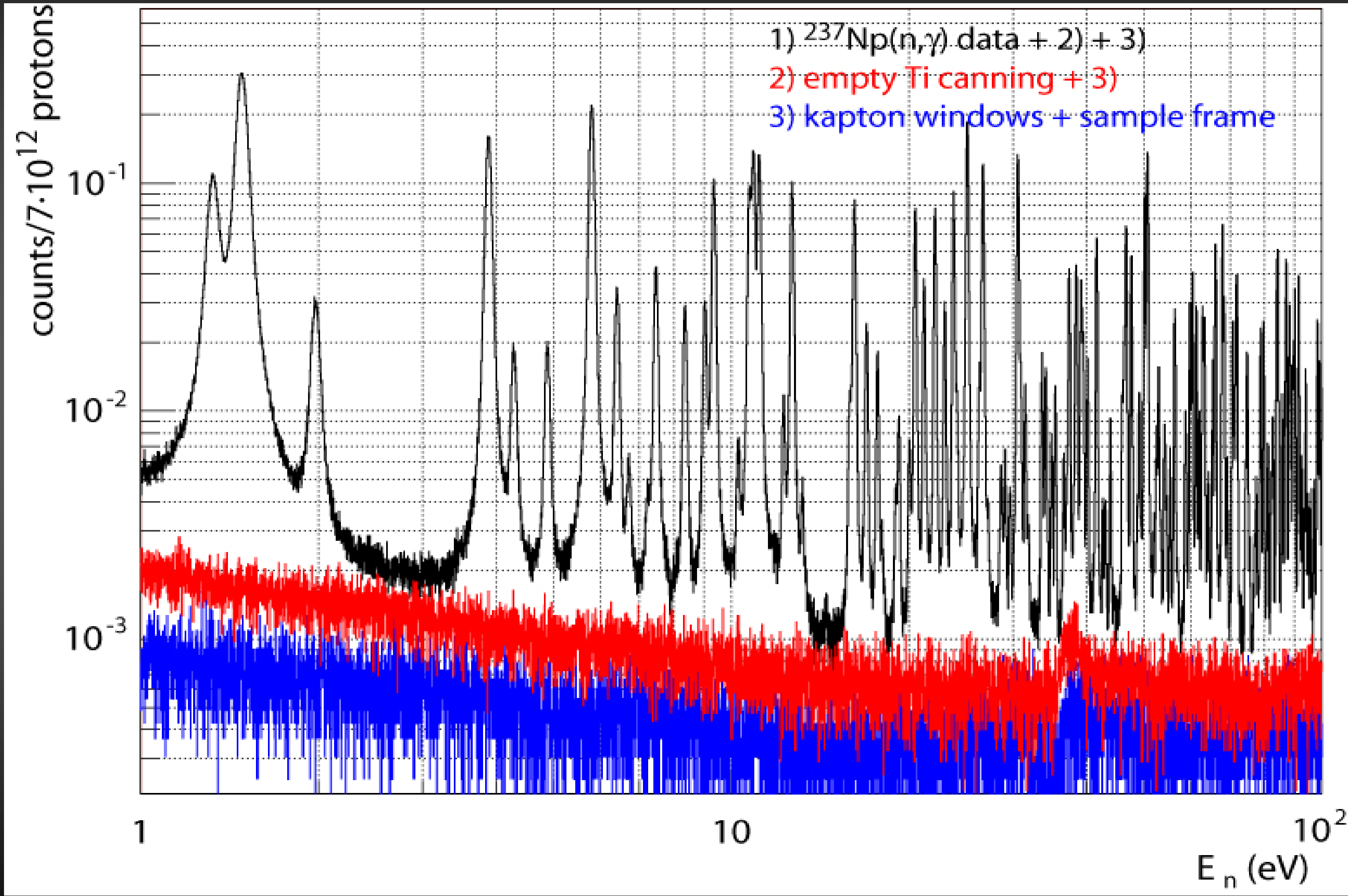

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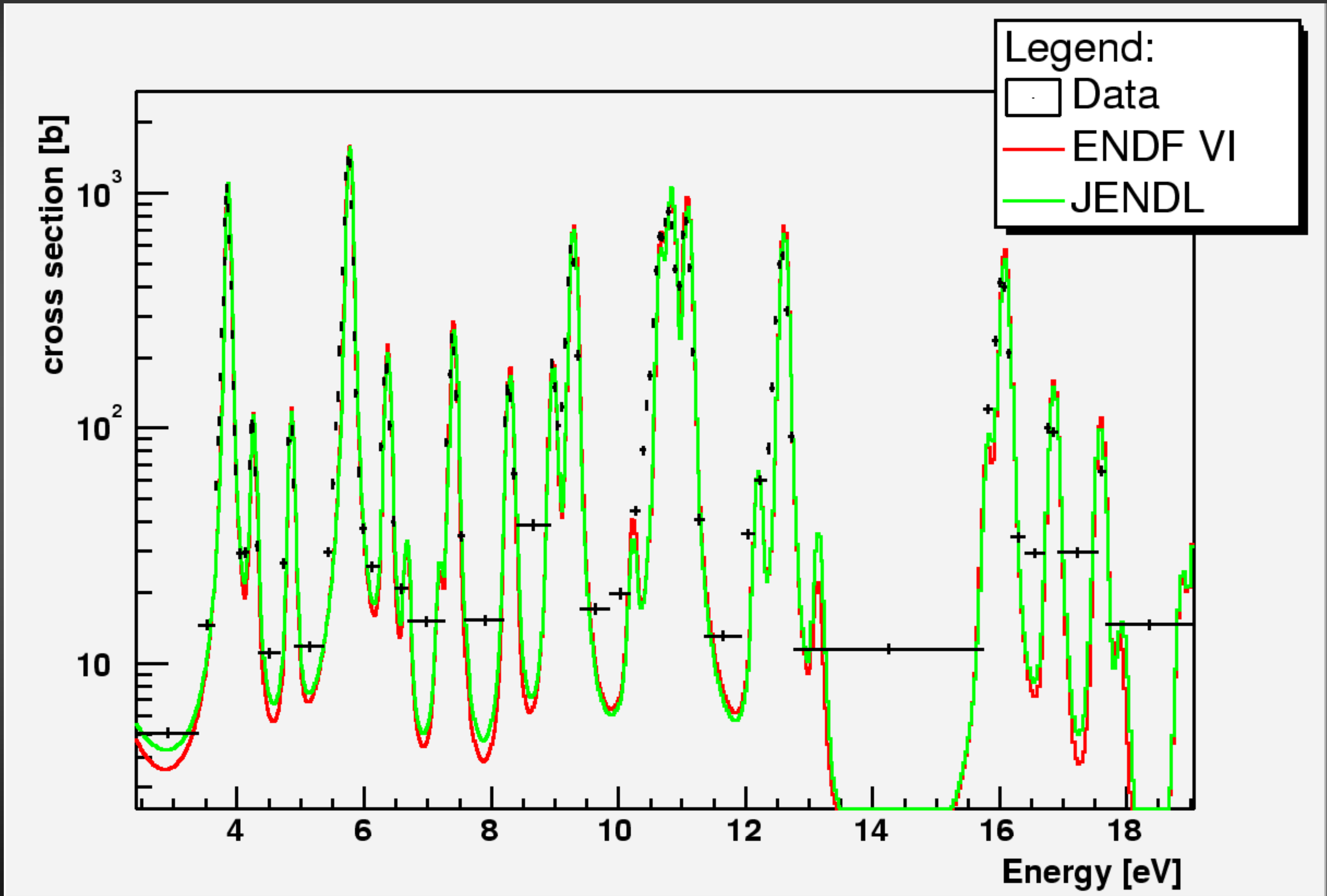
$^{237}Np(n,\gamma)$ at LANSCE



(Analysis by E.I. Esch and R. Reifarth)

Source: J Ullman, n_BANT workshop, CERN, March 2005

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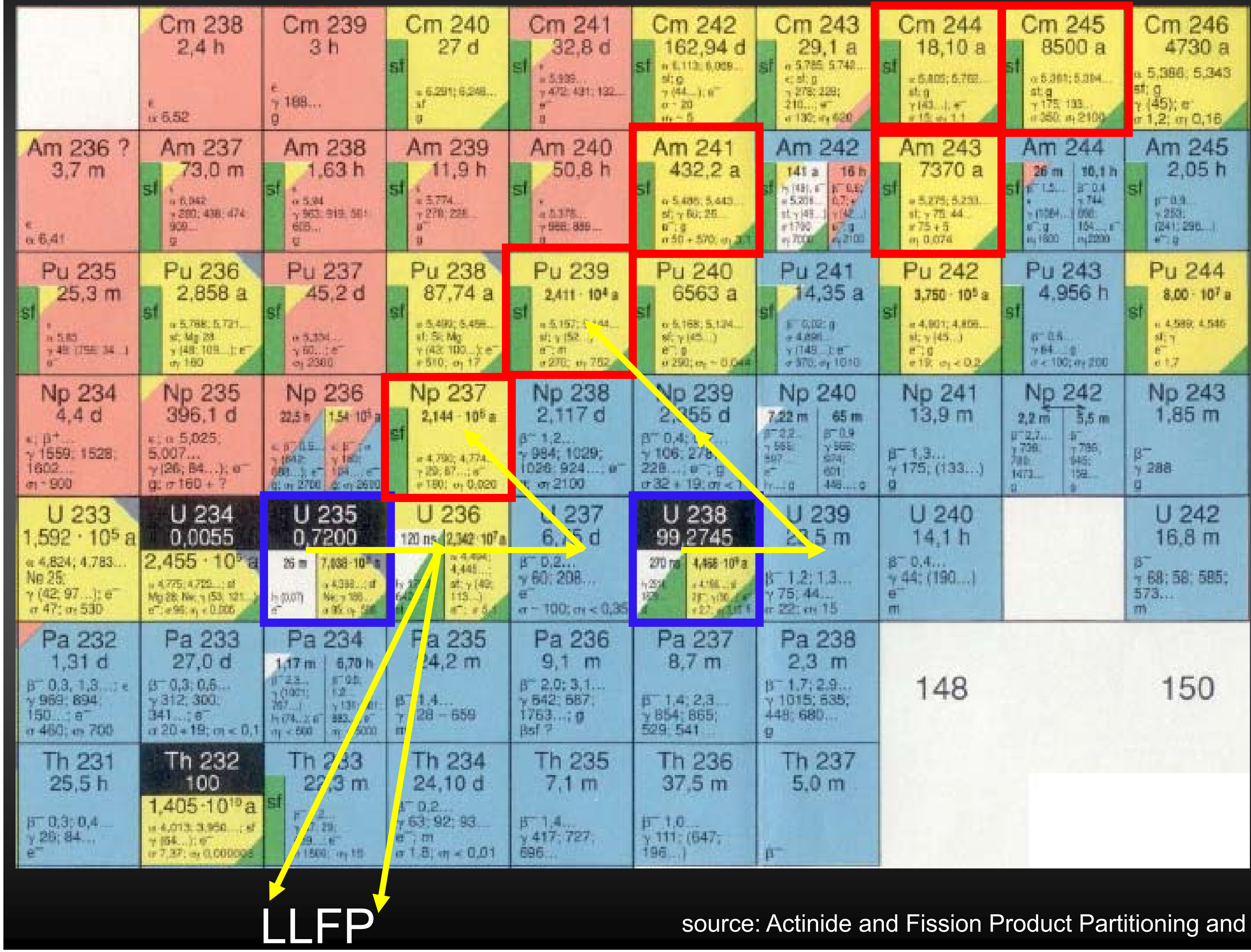
Nuclear waste: TRU (1000 MW_e LWR)



^{244}Cm
1.5 Kg/yr

^{241}Am: 11.6 Kg/yr
^{243}Am: 4.8 Kg/yr

^{239}Pu: 125 Kg/yr

^{237}Np: 16 Kg/yr

LLFP
76.2 Kg/yr

source: Actinide and Fission Product Partitioning and Transmutation – NEA (1999)

<< back

Fast neutrons!

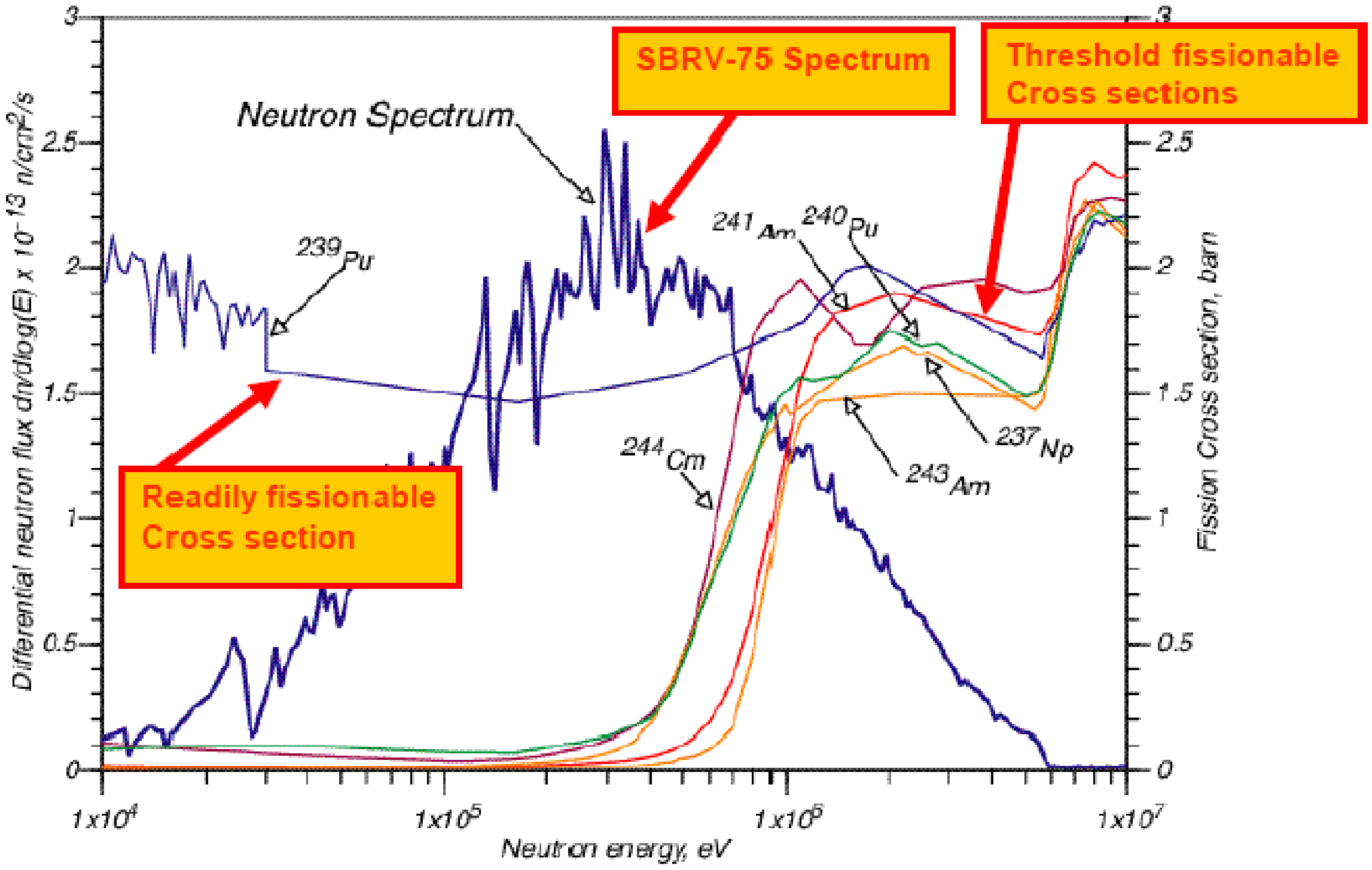


Figure 1: Simulation of the neutron spectrum in the SBRV-75 reactor [2], loaded with the Spiro MA fuel mixture (1/2 of ^{241}Am, 1/4 of ^{243}Am and 1/4 of equal amount of ^{244}Cm and ^{237}Np). The fission cross sections of several MA in consideration here are shown. The fission cross section of ^{239}Pu is also shown for a direct comparison with a non-threshold fission case.

source: C Rubbia (2002)

Neutron cross sections data are needed!

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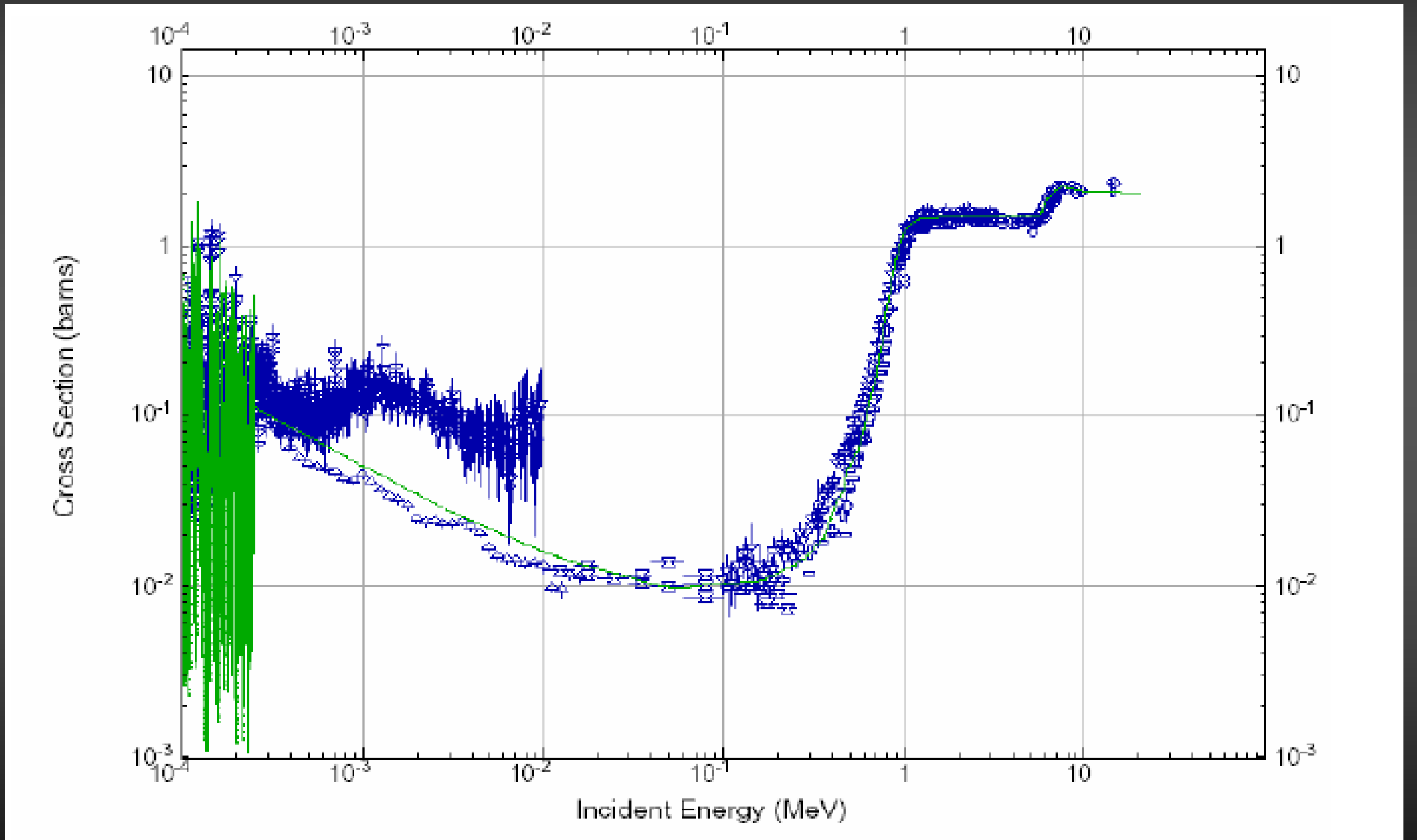
$^{243}Am(n,f)$



source: n_TOF Collaboration
(fission proposal)

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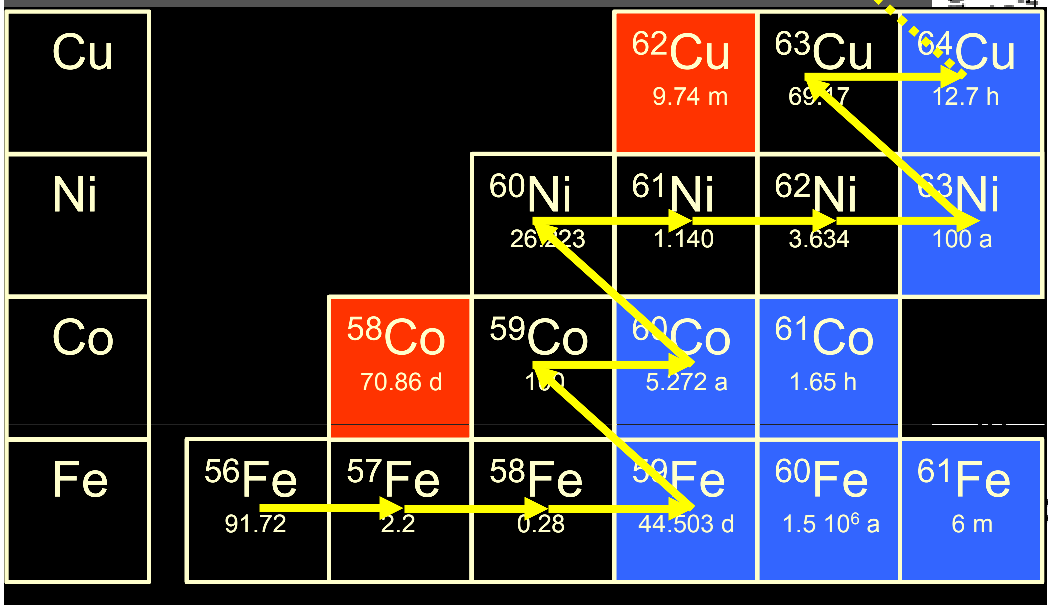
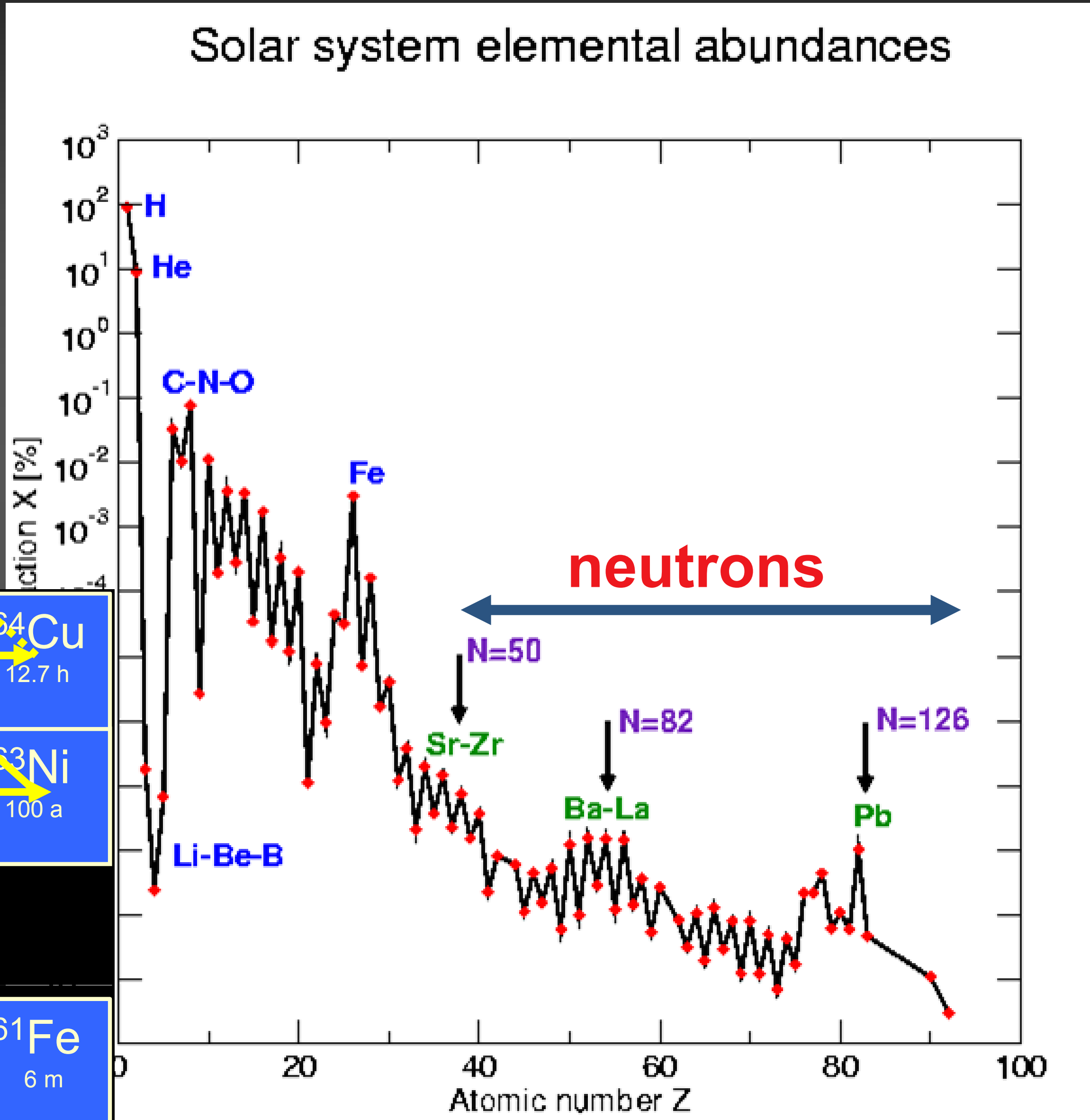
Nucleosynthesis: the s-process

direct correlation between neutron capture cross section and abundance:

$$\sigma(n,\gamma) \cdot N = const.$$

The canonical s-process



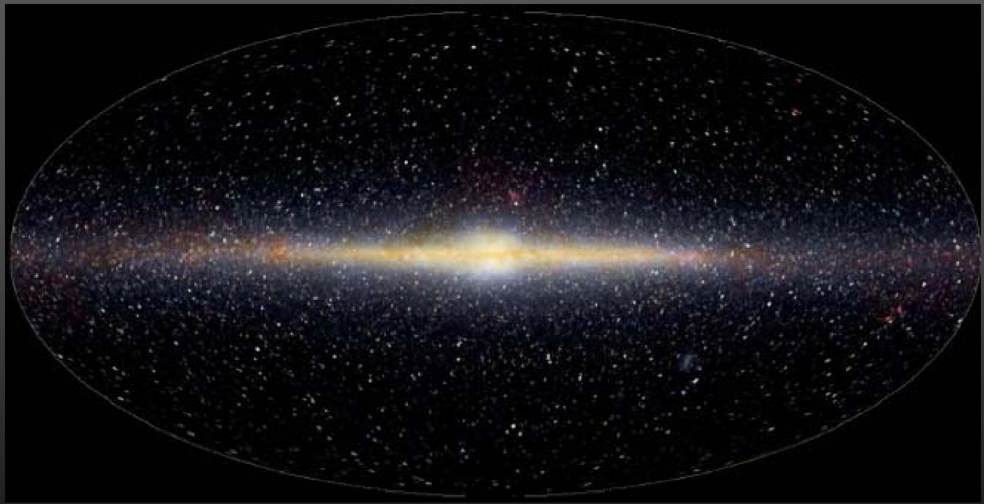


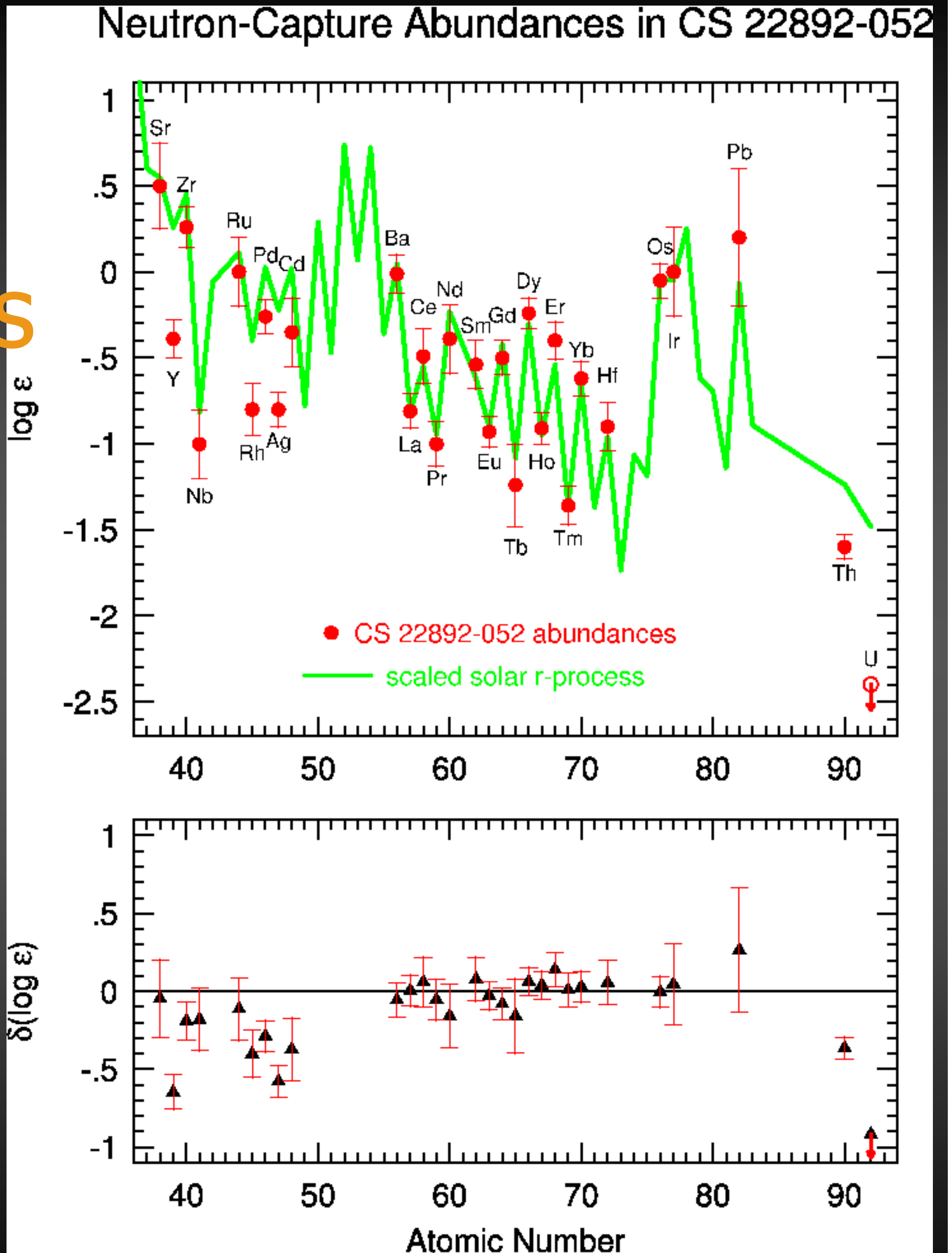
Nucleosynthesis:

the s-process &

the r-process residuals

$$N_r = N_{solar} - N_s$$





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