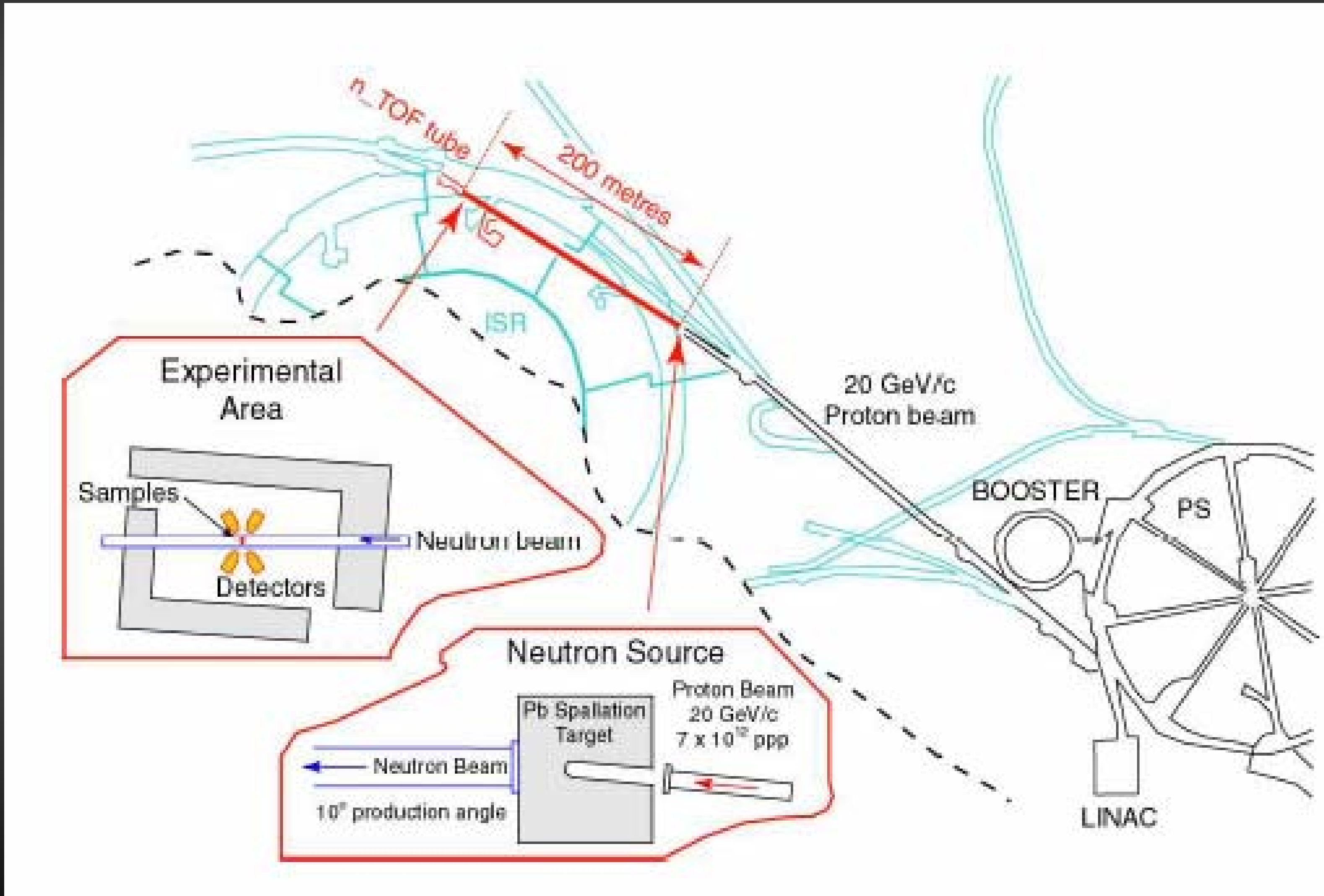
The Physics Programme at n_TOF (in 2007 and beyond)

Alberto Mengoni
IAEA , Vienna

- Yesterday
- Today
- Tomorrow (n_TOF-Phase 2)

The n_TOF facility at CERN



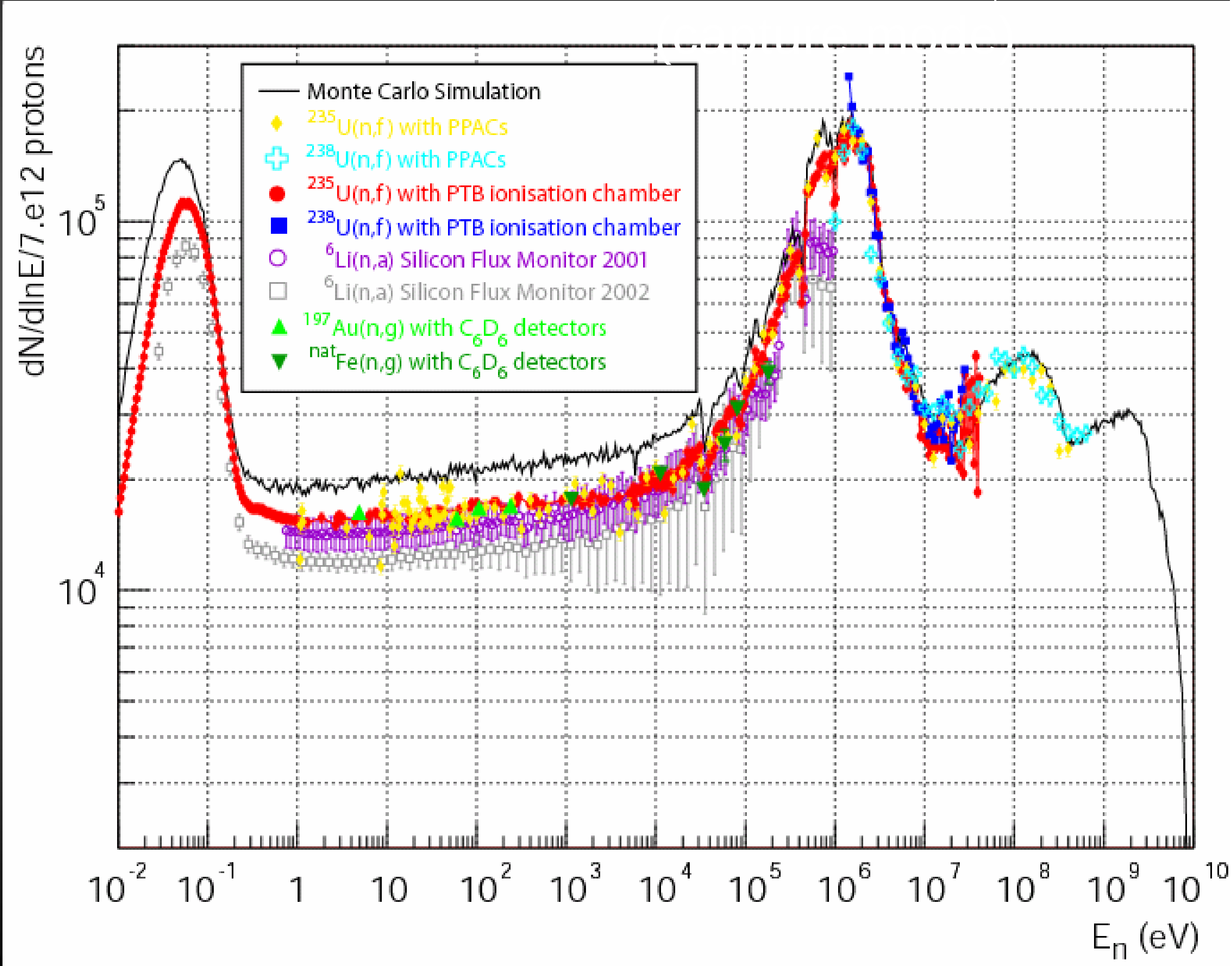
n_TOF basic parameters

proton beam momentum	20 GeV/c
intensity (dedicated mode)	7 x 10^{12} protons/pulse
repetition frequency	1 pulse/2.4s
pulse width	6 ns (rms)
n/p	300
lead target dimensions	80x80x60 cm^3
cooling & moderation material	H_2O
moderator thickness in the exit face	5 cm
neutron beam dimension in EAR-1 (capture mode)	2 cm (FWHM)

n_TOF beam characteristics

- the neutron flux

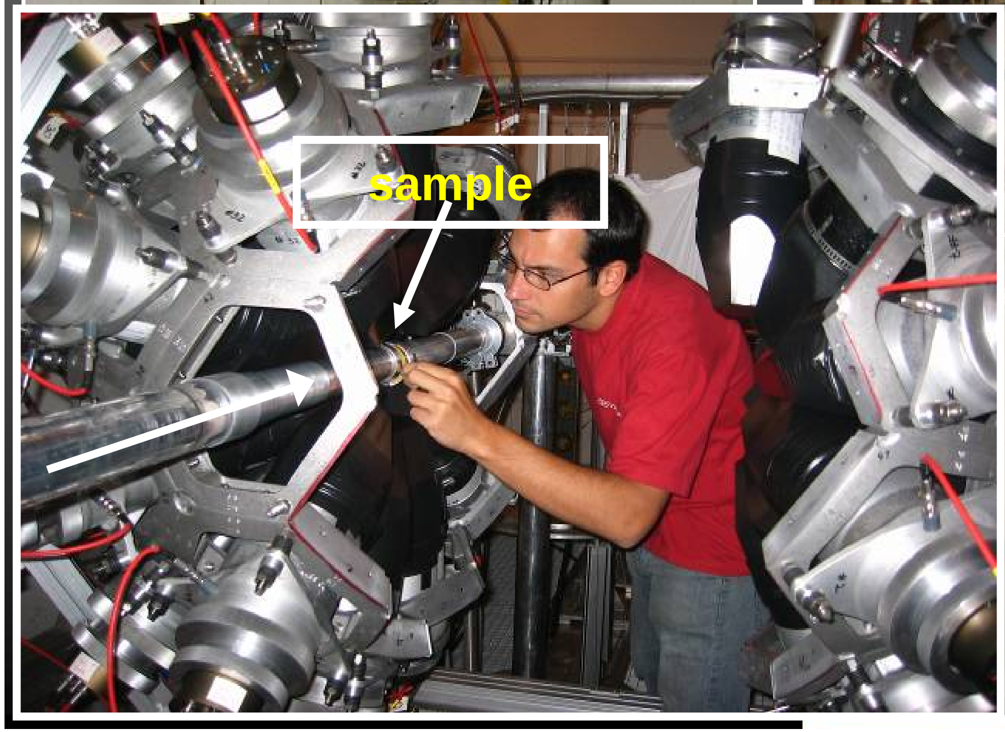
2^{nd} collimator ϕ=1.8 cm

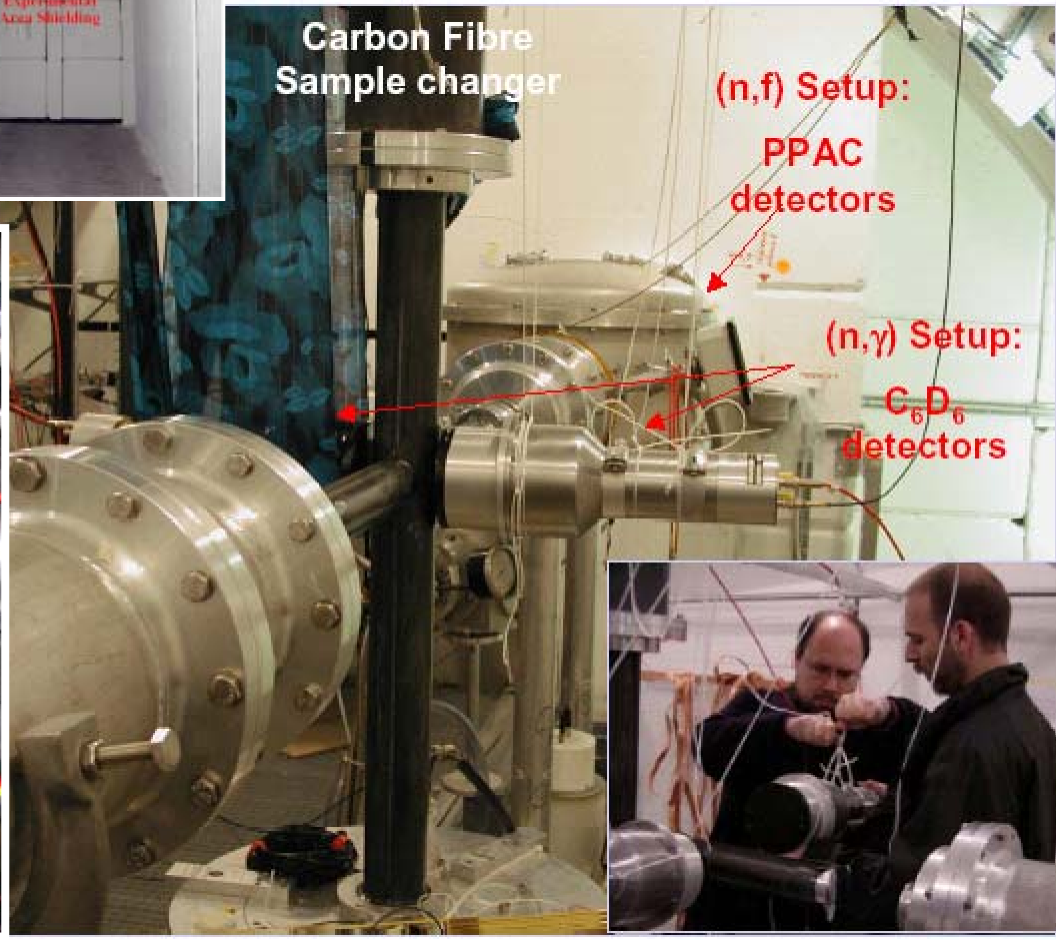


Performance Report
CERN-INTC-2002-037, January 2003
CERN-SL-2002-053 ECT

The real world

- n_TOF commissioned in 2001-2002





Objectives of the activity at n_TOF (n_TOF Phase-2, April 2005)

1. **C**ross sections relevant for Nuclear Astrophysics

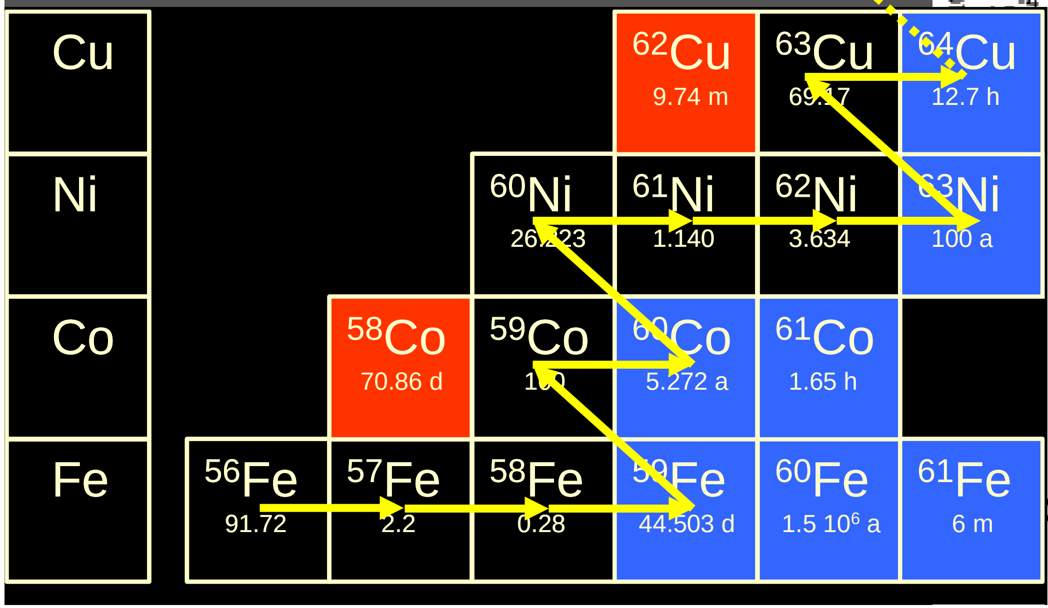
2. **M**easurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies

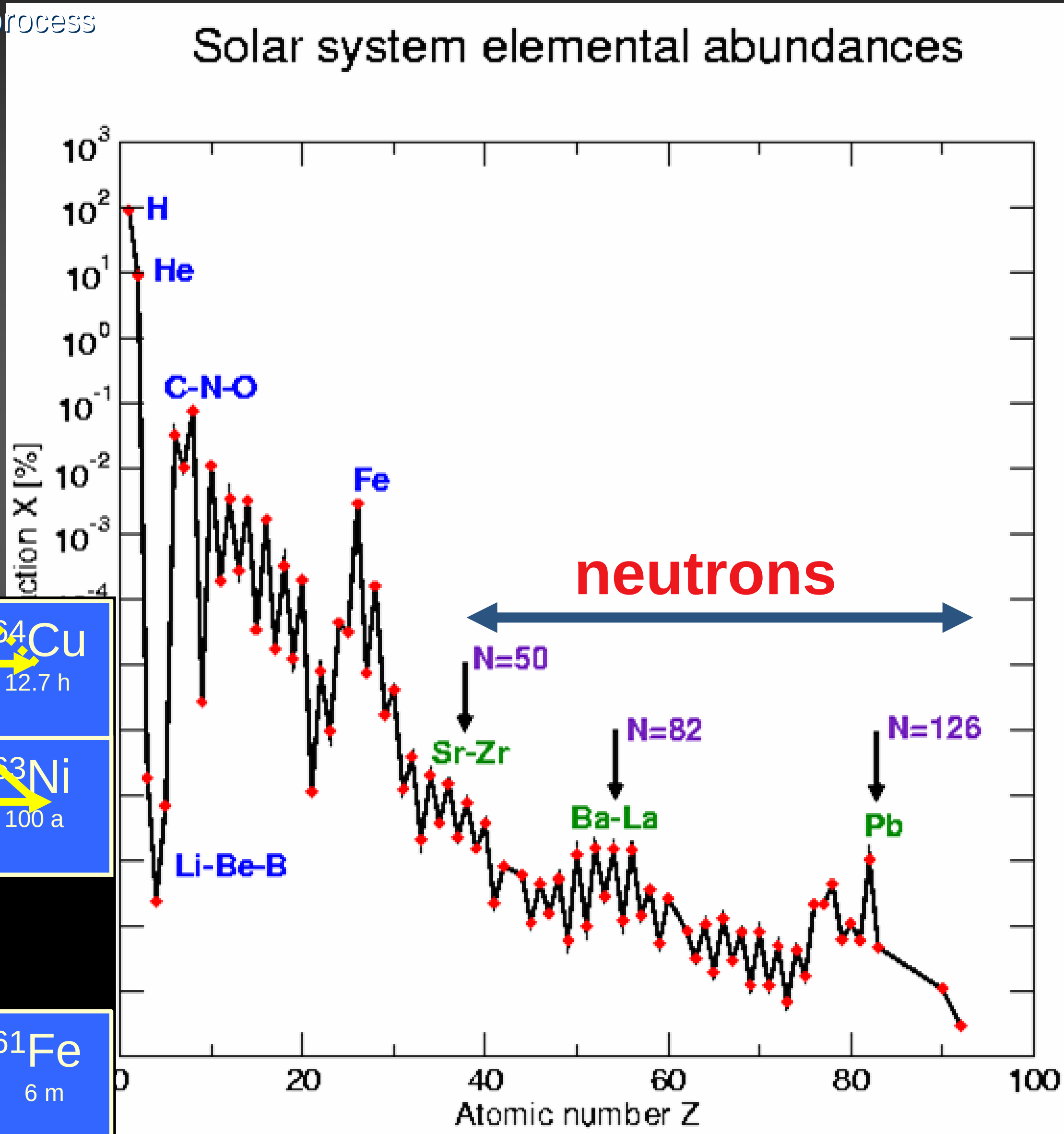
3. **N**eutrons as probes for fundamental Nuclear Physics & other applications

Nucleosynthesis: the s-process

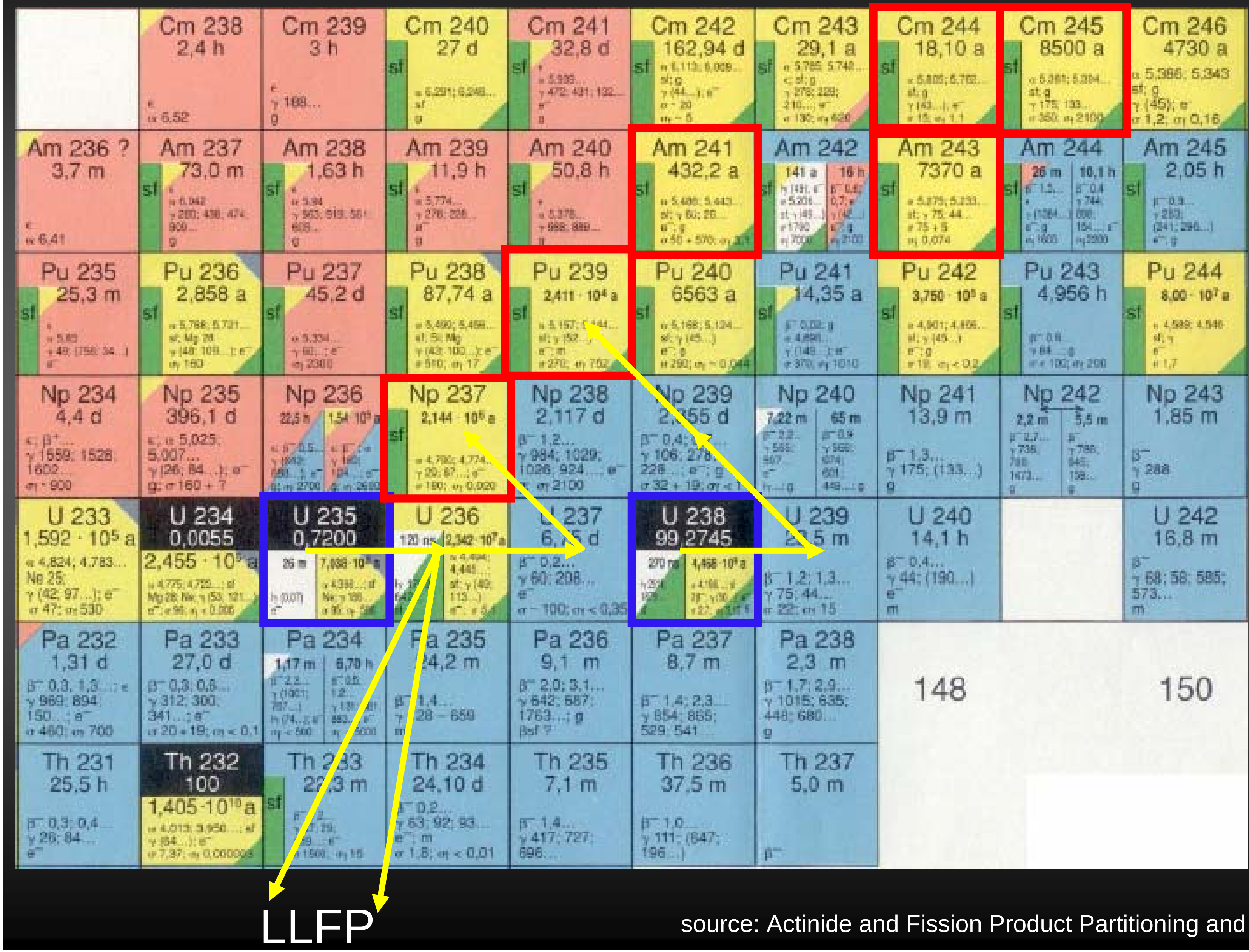
- ½ of the elements above Fe are produced by the s-process
- The astrophysical sites of the s-process are:
  - He burning in intermediate/massive stars
  - Low-mass AGB's
- There exists a direct correlation between the neutron capture cross section and the abundance ($\sigma(n,\gamma) \cdot N = const.$)
- The neutron capture cross sections are key ingredients for s-process nucleosynthesis

The canonical s-process





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)

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

10 groups of experiments endorsed by the INTC and approved by the RB:

- n_TOF-01: Facility proposal
- n_TOF-02: Commissioning
- n_TOF-03: Sm & Mg
- n_TOF-04: Os
- n_TOF-05: Pb & Bi
- n_TOF-06: Th-cycle fission
- n_TOF-08: Zr & La
- n_TOF-09: MA fission
- n_TOF-10: MA capture (TAC)

n_TOF experiments 2002-4

Capture

^{151}Sm

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

28 weeks/yr (average)

483 effective 8hr-shft/yr

1.3e19 protons/yr

Problems during Phase-1 runs:

- 2nd collimator alignment (minor)
- beam-requests (minor)
- end of 2004 run increased activity in the cooling (major, to be discussed later)

n_TOF experiments 2002-4

Capture

^{151}Sm

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

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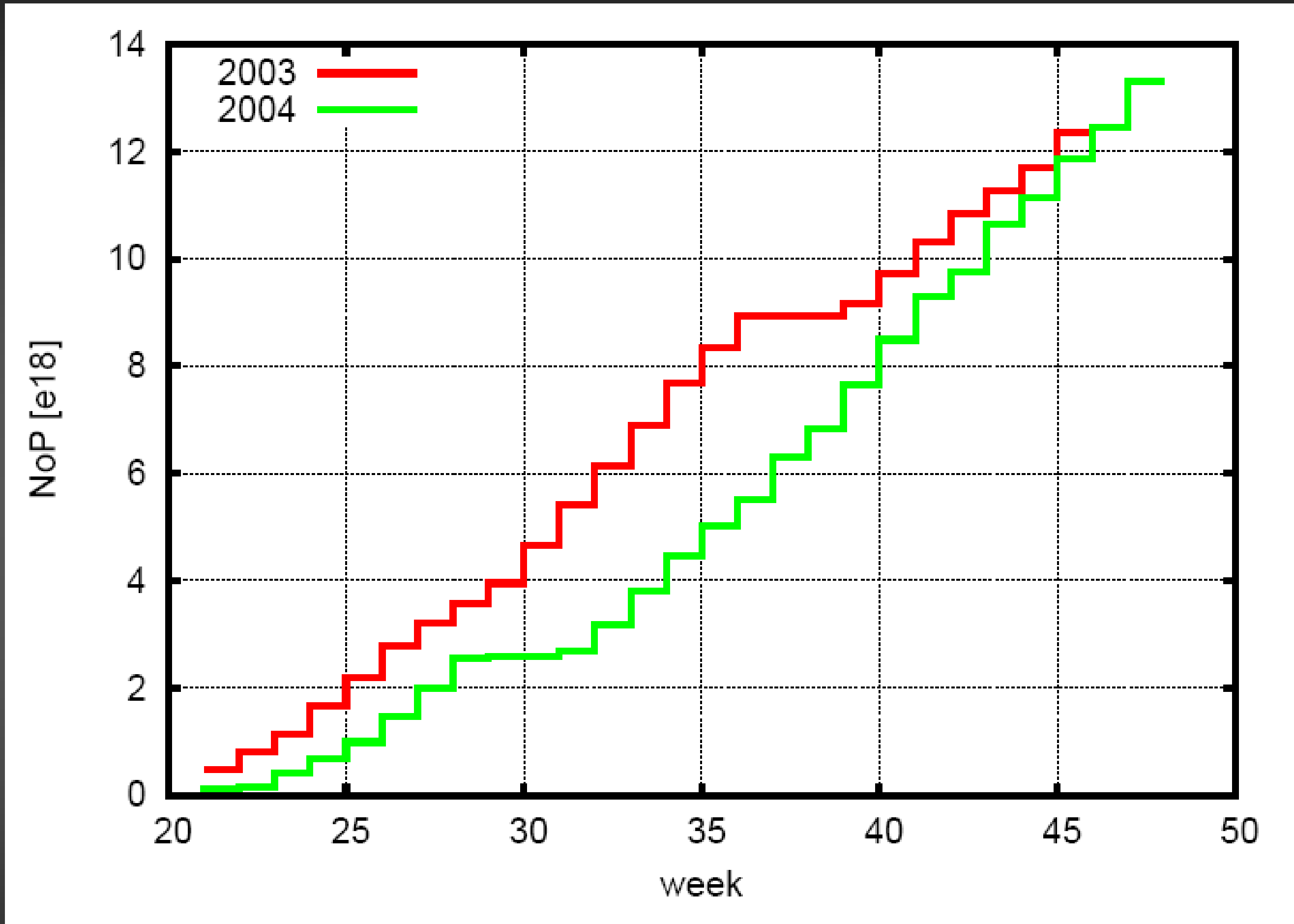


The n_TOF Collaboration

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 Institutions
120 researchers

n_TOF Collaboration structure & operation

n_TOF Collaboration Board
Chairman, Spokesperson

- 23 n_TOF teams
- all teams participates in the development, commissioning, and operation of detectors, daq, etc.
- all teams participated in all the experiments/measurements

- 16 partners in the n_TOF-ND-ADS EC Project (FP5)
  2.4 MEUR investment in equipments
  (6.3 MEUR total budget)
  run over the period 2001-2004
  (completed)

n_TOF Collaboration Board
Chairman & Spokesperson

- Teams involved in individual proposals/experiment (with individual spokesperson)
    - Fe, Ni, Zn & Se proposal
    - Fission measurements proposal
    - n-scattering proposal
    - ...

- Common M&O budget

- Some team involved in EC/FP6 projects (EFNUDAT, EUROTRANS)

The n_TOF-Ph2 experiments 2007 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 INTC, spokespersons: JL Tain (Valencia), M Heil (GSI, Darmstadt)

The n_TOF-Ph2 experiments 2007 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,α), ^{67}Zn(n,α), ^{99}Ru(n,α) ^{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

n_TOF: resume activities in 2007

All teams involved in Phase-1 expressed interest to continue the activities for n_TOF Phase-2

- LoI, January 2005
- Budget for M&O allocated by funding agencies
- new MoU, draft ready December 2006

2.5 years after last neutron beam delivered to EAR-1

New PhD students need data to work on(*)

EC I3 projects in FP6 (EFNUDAT, EUROTRANS) running

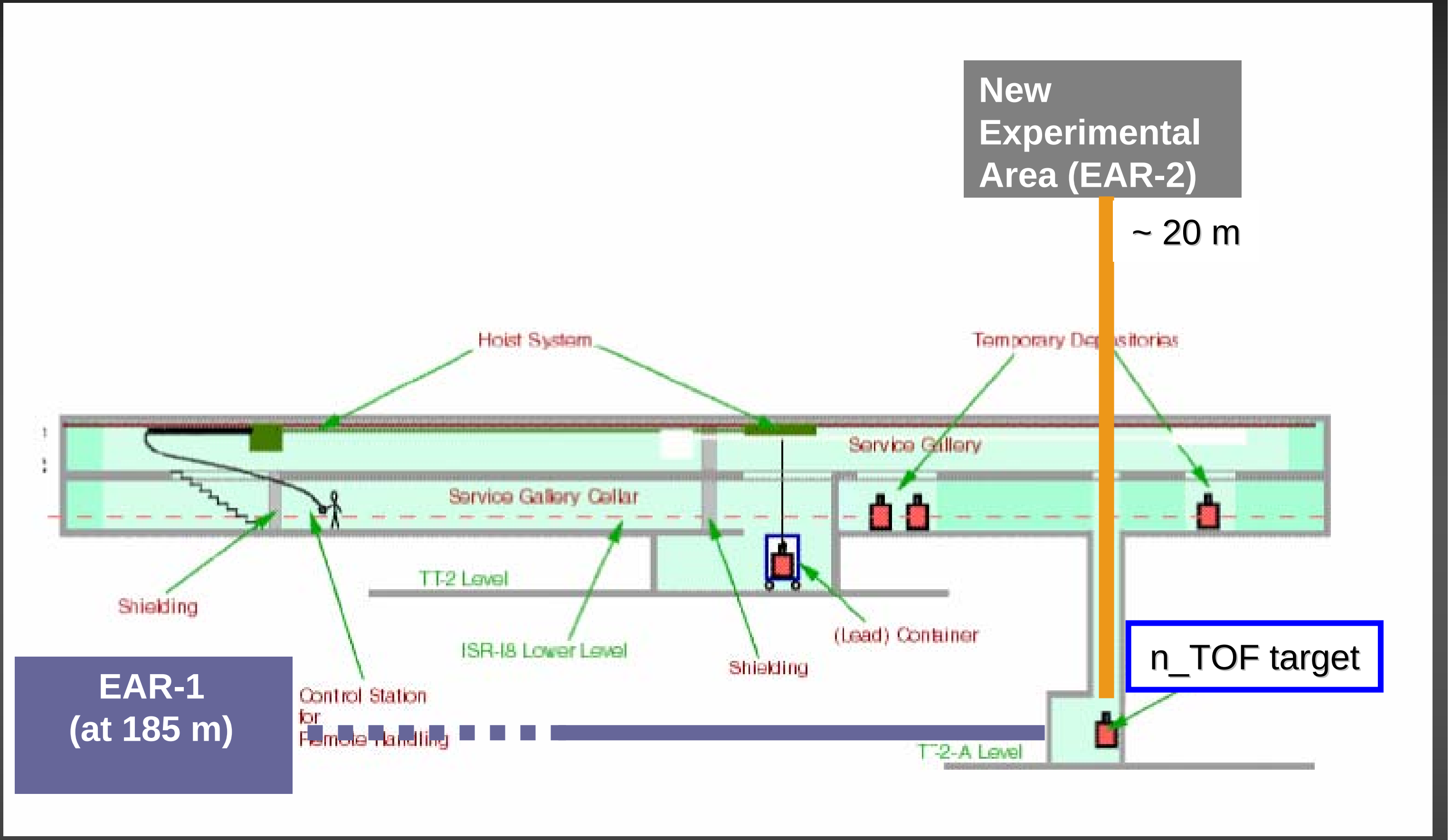
(*) so far: 13 PhD Thesis (completed), 6 in preparation (4 to be completed by 2007), 2 starting in 2007

n_TOF: resume activities in 2007!

3 Questions:

1. **New target design, construction & installation**
2. **Use of radioactive samples in EAR-1**
3. **Perspectives for further developments & optimizations of the facility outlined (EAR-2)**

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

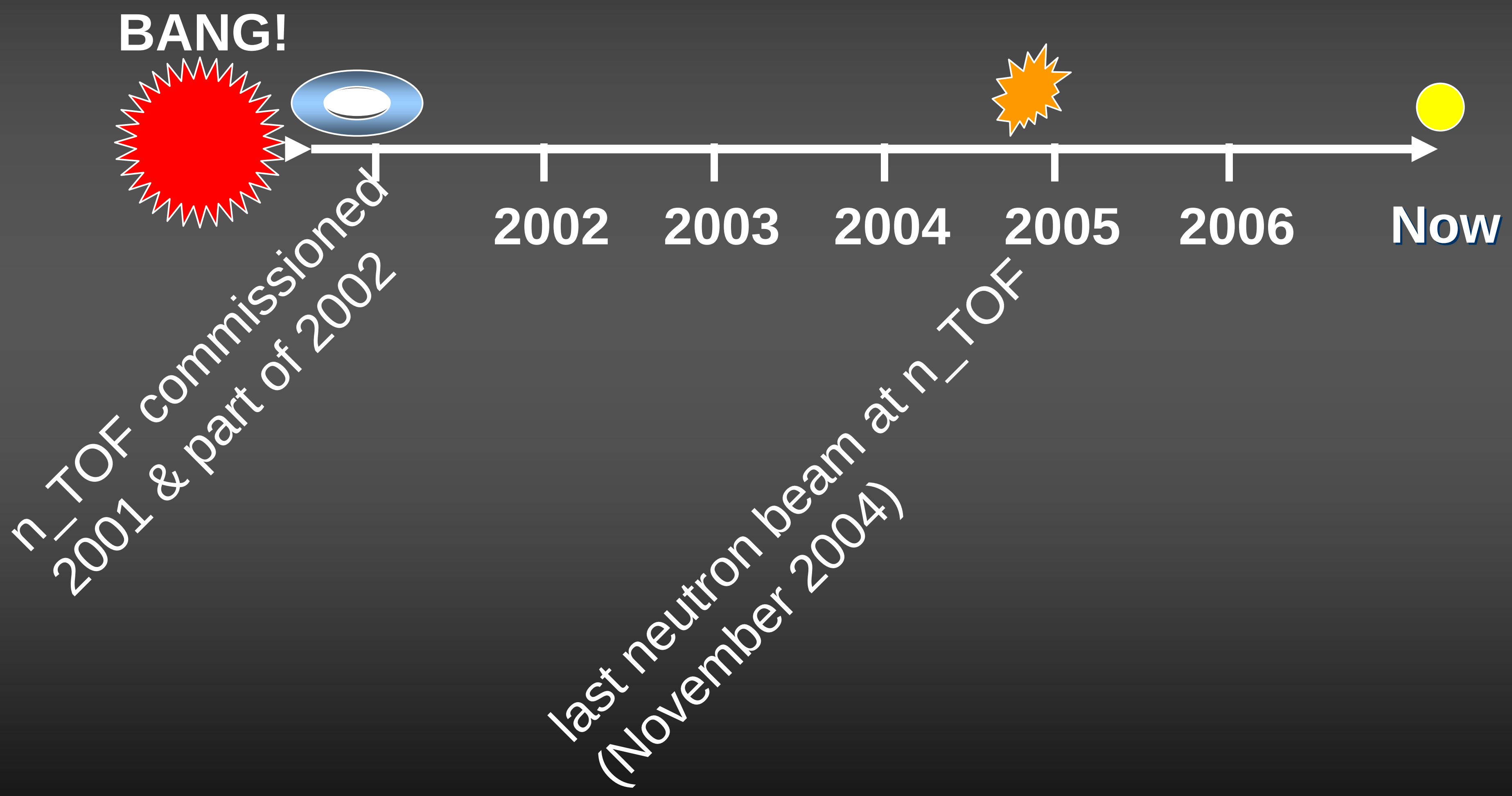
EAR-2: Optimized sensitivity

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

Time at n_TOF


BANG!
2002
2003
2004
2005
2006
Now
n_TOF commissioned
2001 & part of 2002
last neutron beam at n_TOF
(November 2004)

The End

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

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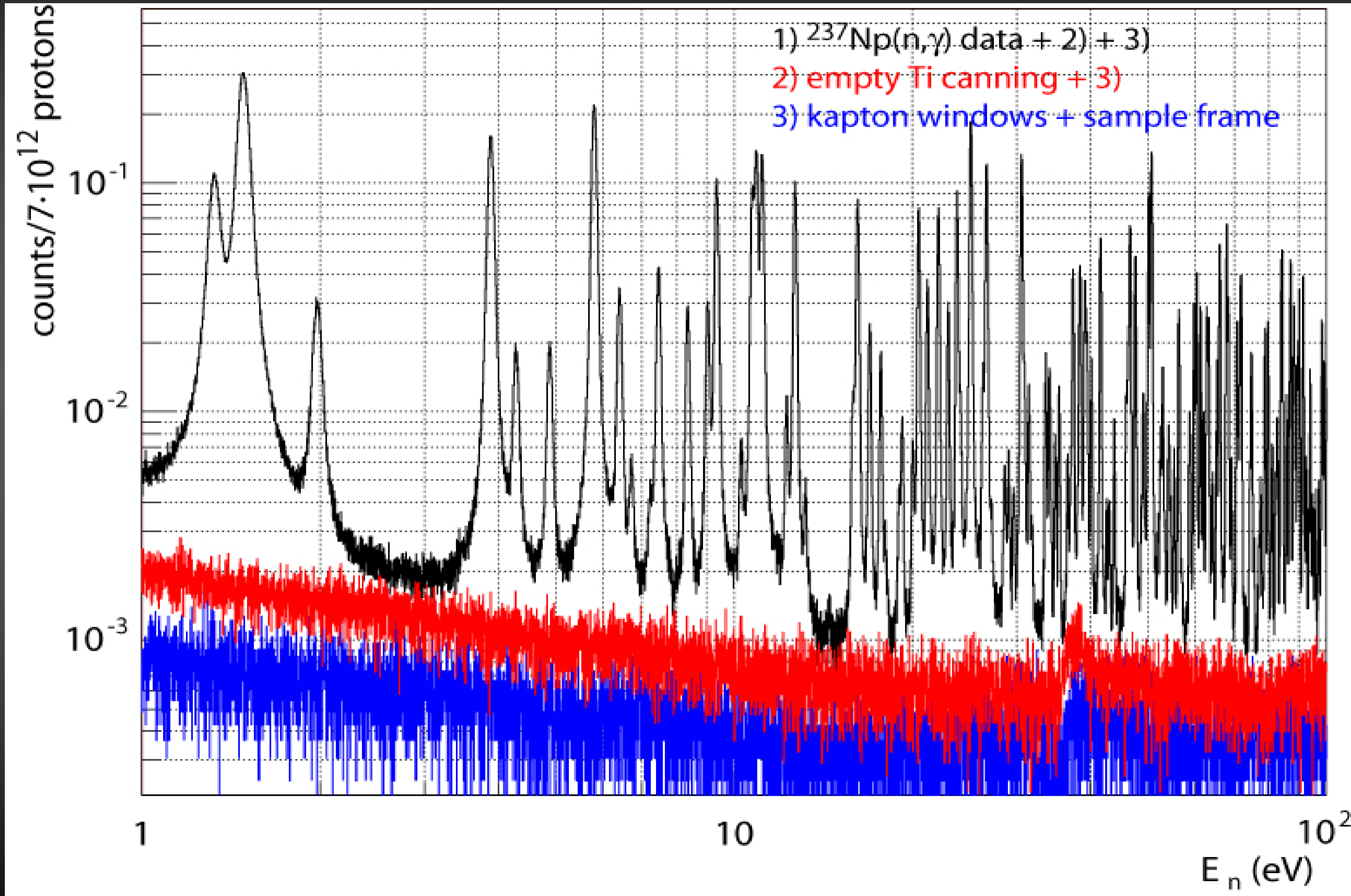

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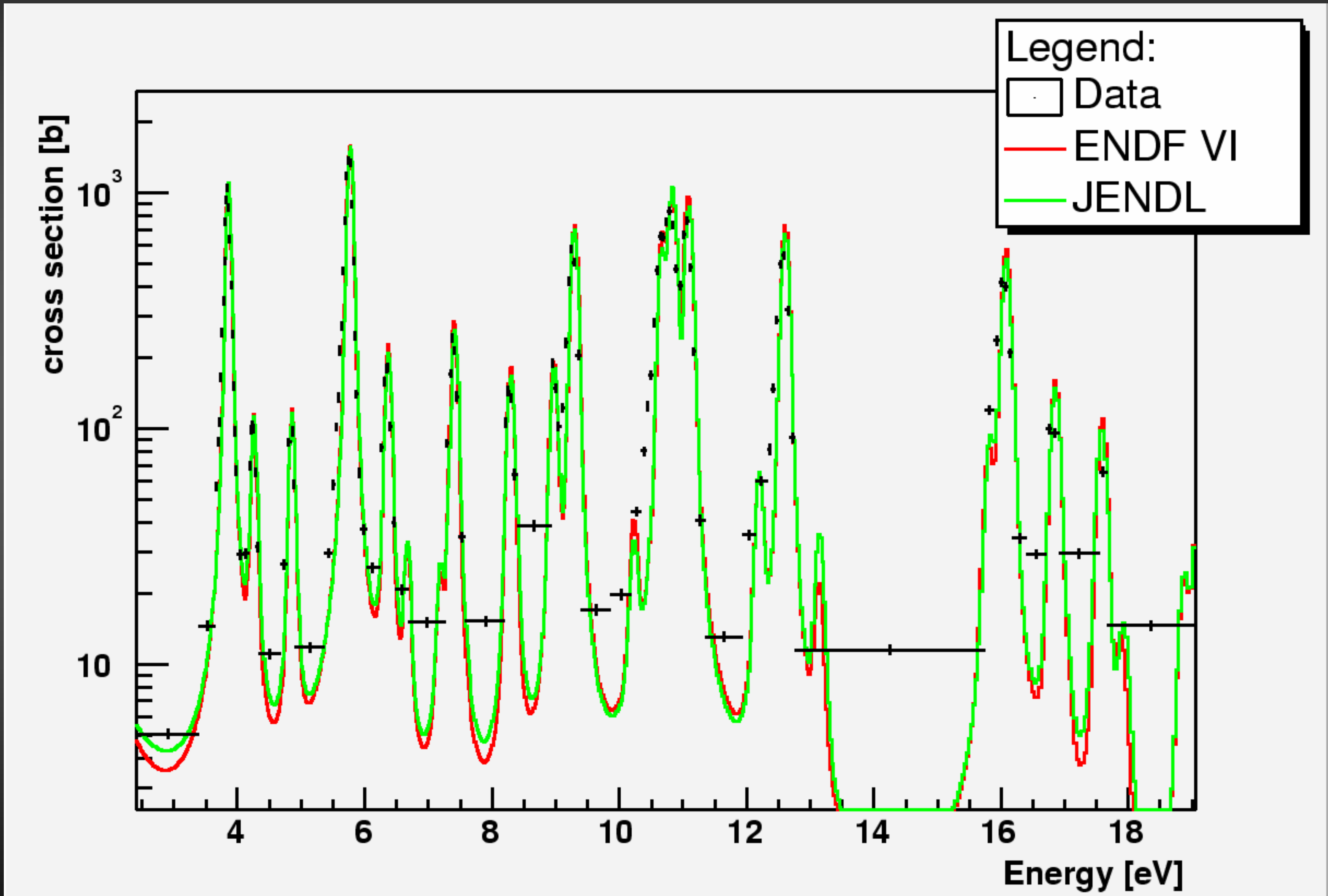
$^{237}Np(n,\gamma)$ at LANSCE



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

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

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

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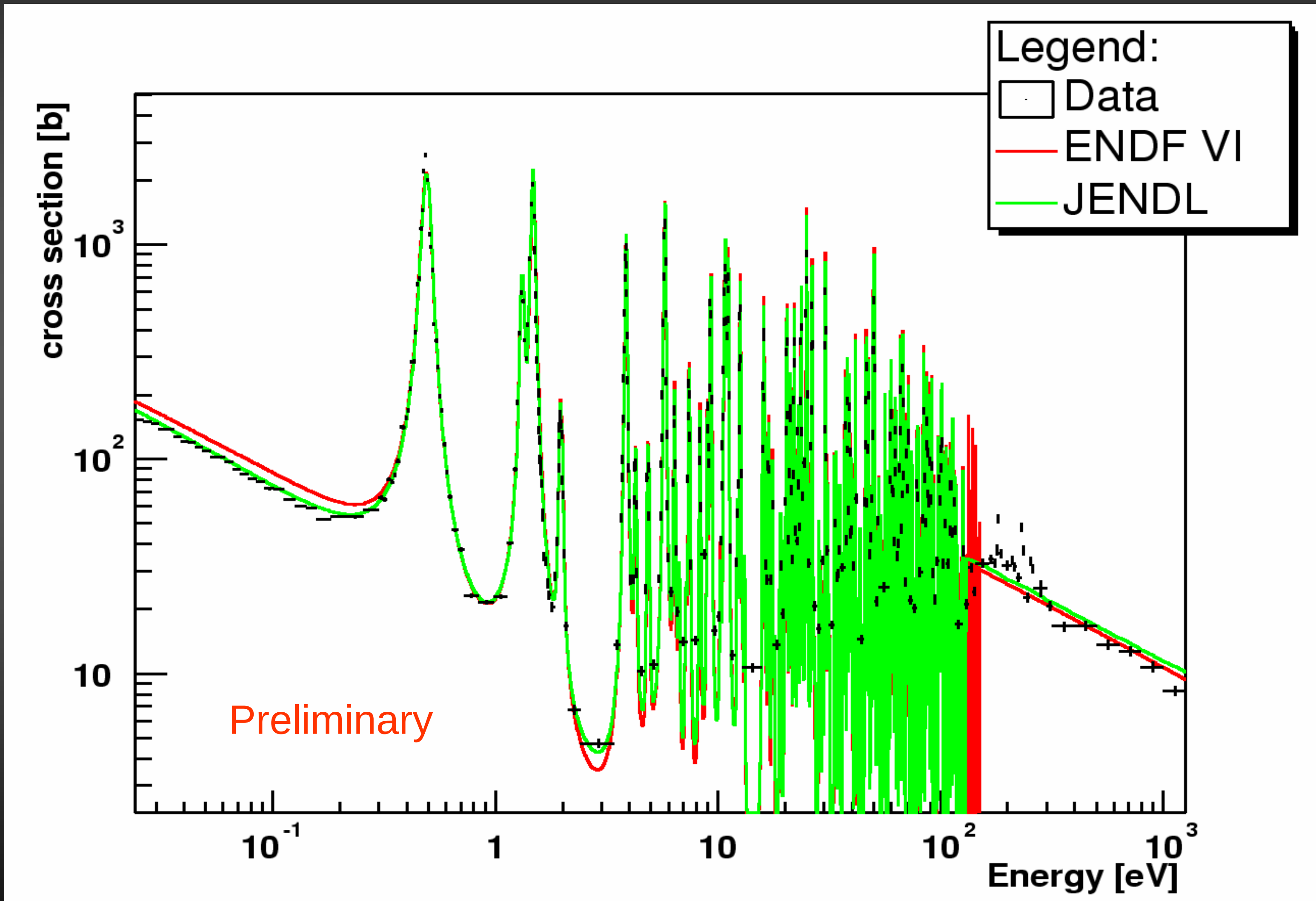

(Analysis by E.I. Esch and R. Reifarth)

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

$^{232}Th(n,\gamma)$: n_TOF & GELINA

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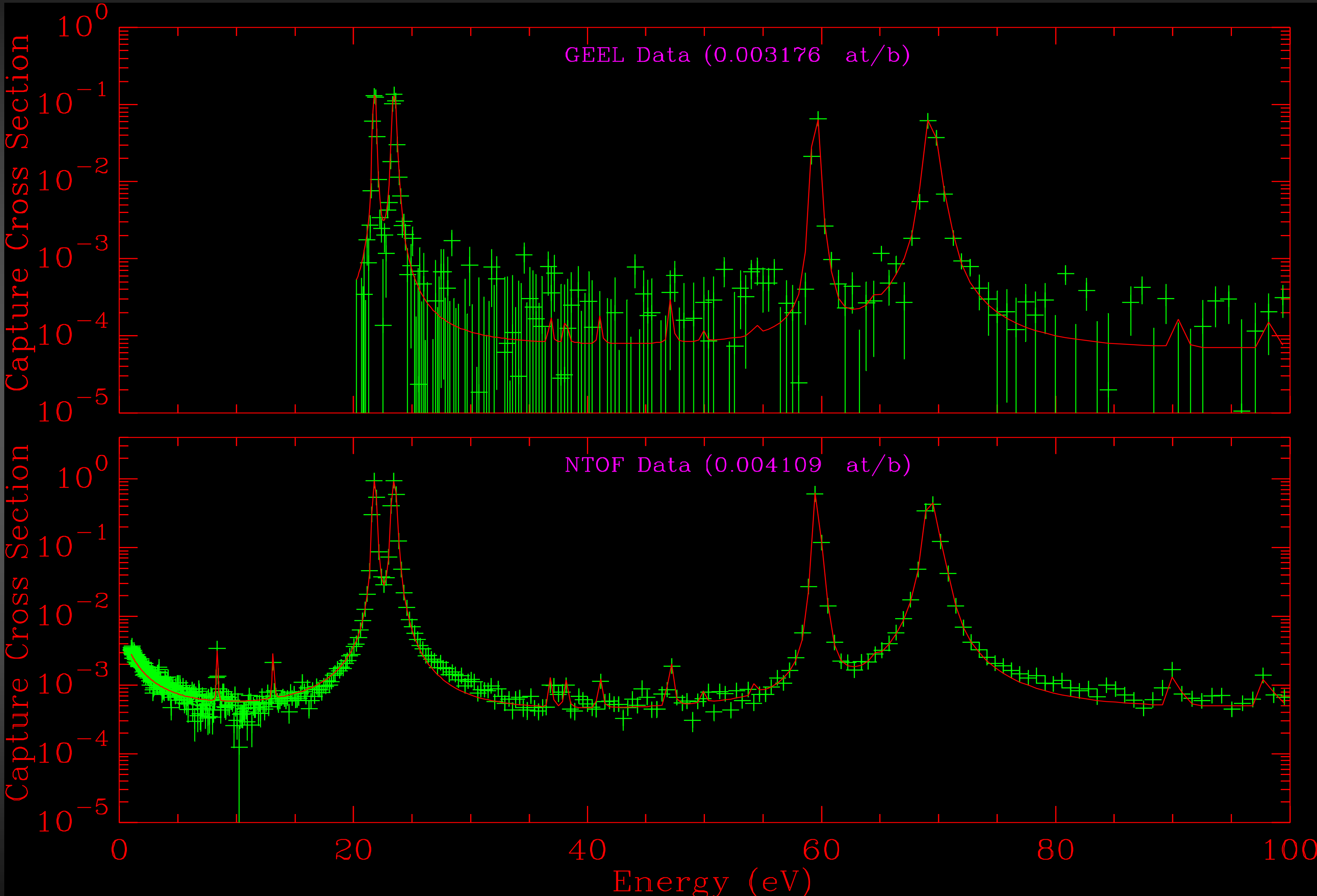

Source: L Leal, IAEA CRP meeting, December 2004

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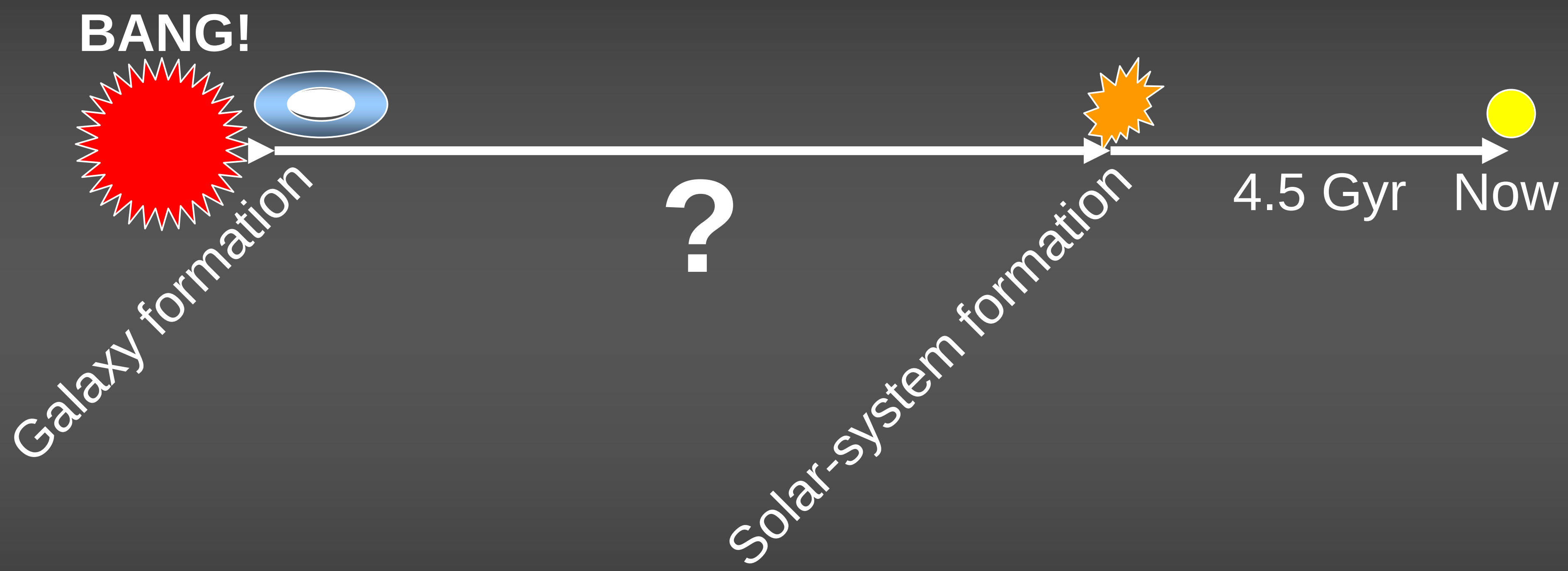
Time



Re/Os clock

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Os	Os 184 0.02	Os 185 94 d	Os 186 1.58	Os 187 1.6	Os 188 13.3	Os 189 16.1	Os 190 26.4	Os 191 15.4 d	Os 192 41.0
Re	Re 183 71 d	Re 184 38 d	Re 185 37.4	Re 186 90.64 h	Re 187 62.6 42.3×10^9 a	Re 188 16.98 h	Re 189 24.3 h	Re 190 3.1 m	
W	W 182 26.3	W 183 14.3	W 184 30.67	W 185 75.1 d	W 186 28.6	W 187 23.8 h	W 188 69 d		

The β-decay half-life of ^{187}Re is 42.3 Gy

Effect on the abundance of the decay daugther ^{187}Os

Summary

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- Cosmological way (WMAP observations)

13.7 ± 0.2 Gyr

- Astronomical way

14 ± 2 Gyr

- Nuclear way: Re/Os clock

14.9 ± 2 Gyr(*)

Th/U clock

$14.5 \pm ^{2.8}_{2.2}$ Gyr

Source: Dauphas, Nature **435** (2005) 1203

(*) 0.4 Gyr uncertainty due to x-sections

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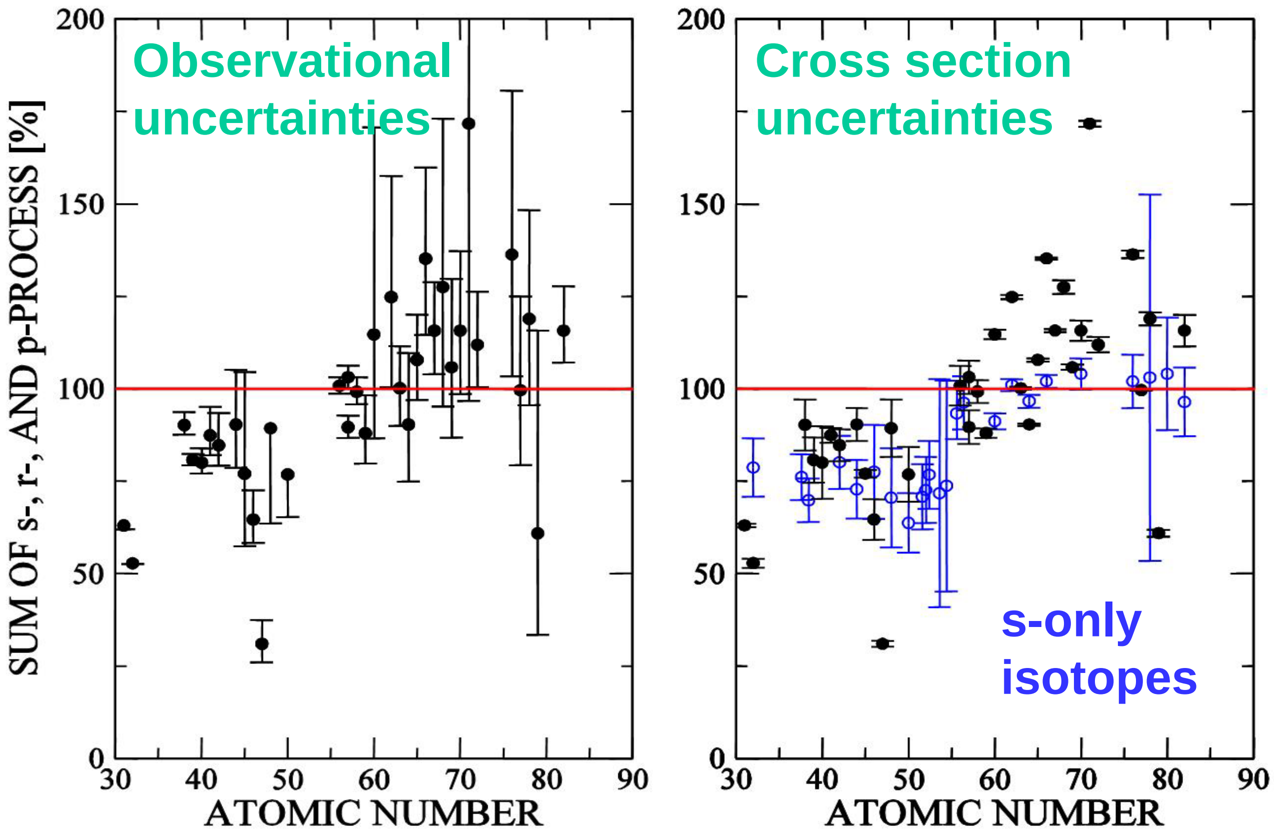
In general:

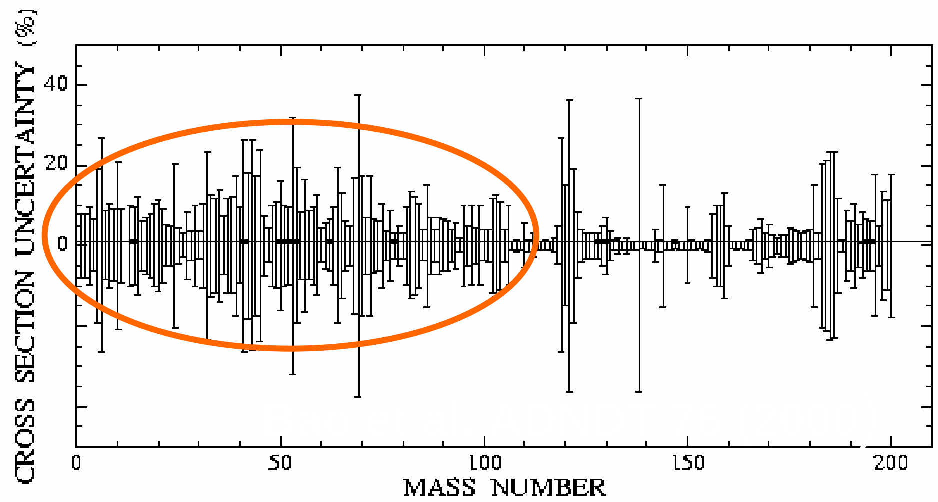
Stellar model
s-abundance
calculation

Tavaglio et al. APJ521 (1999)
Arlandini et al. APJ525 (1999)

+
CS22892-052
r-abundance



Need for more than one r-process or need for improved s- abundances (cross sections)?



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Capture studies: Fe, Ni, Zn, and Se

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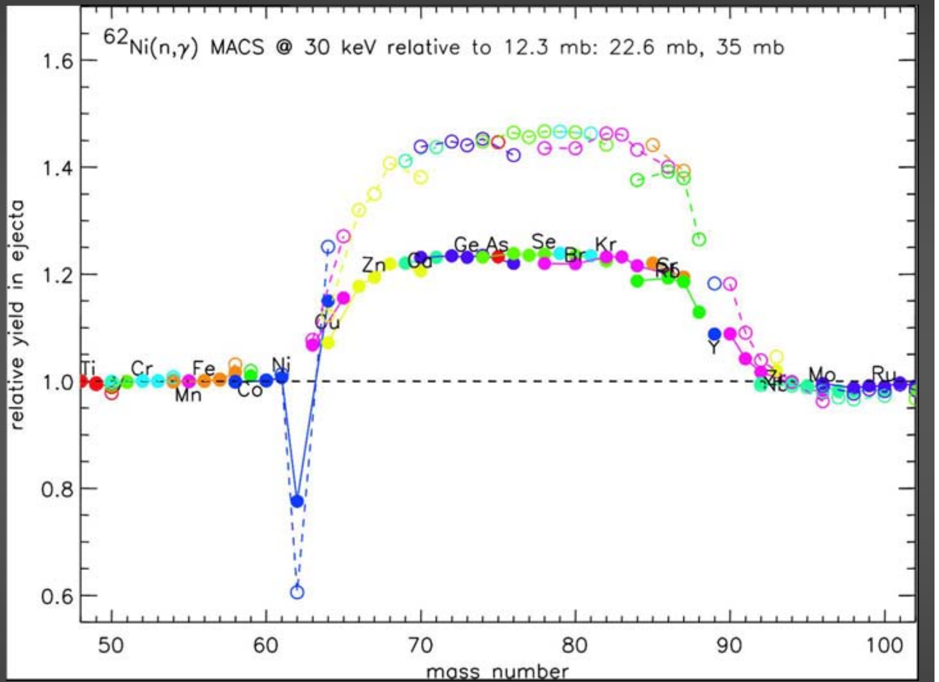
Motivations:

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

• Contribution of massive stars (core He-burning phase) to the s-process nucleosynthesis.

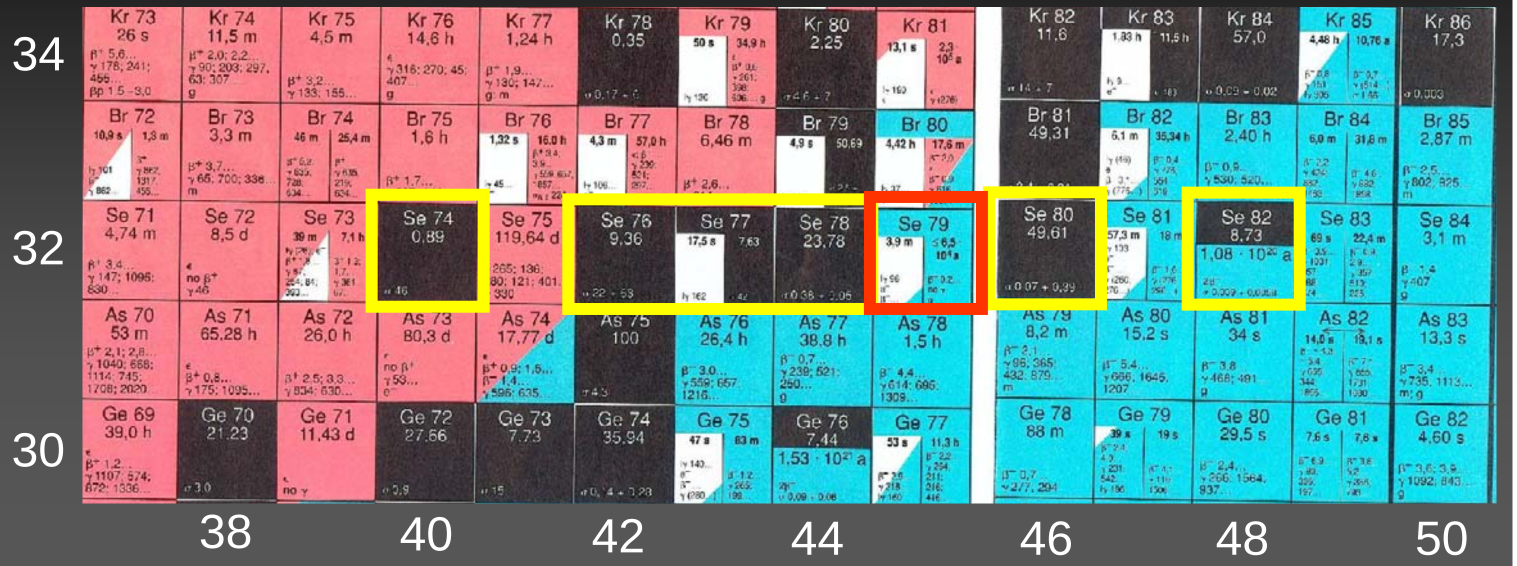
• s-process efficiency due to bottleneck cross sections (Example: ^{62}Ni)



In addition:

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.

Capture studies: Fe, Ni, Zn, and 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

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