

Physics with neutron beams at the CERN n_TOF facility

Carlos GUERRERO (U. Sevilla)

(on behalf of the Spanish members of the CERN n_TOF Collaboration)

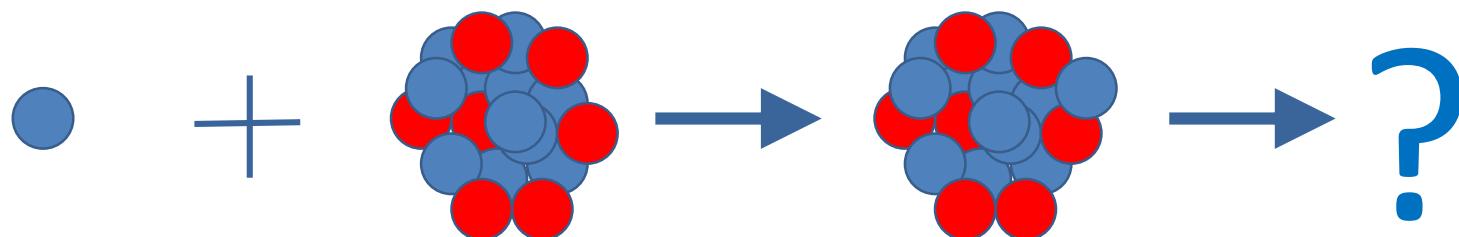
www.cern.ch/nTOF



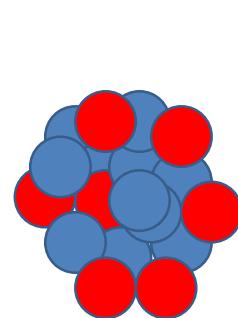
“In the early days of the Manhattan Project when an unknown neutron cross section was needed, the procedure for obtaining a value for it was simple. You went and asked Fermi. Invariably he would refuse to hazard a guess. The next step, so the story goes, was to recite slowly a long string of numbers, and if one of the numbers produced a gleam in Fermi's eye - that was the value to use!”

H. Goldstein (talk at Atomenergie, Sweden, September 1953)

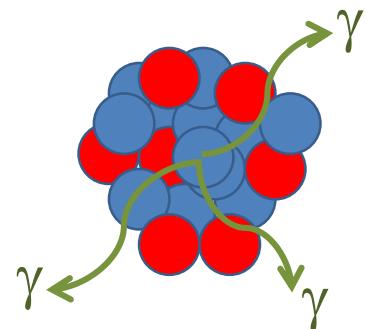
Neutron-Nucleus interactions?



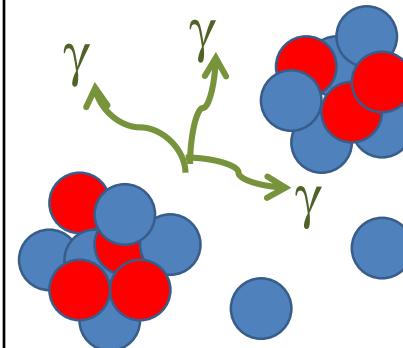
Elastic/Inelastic
scattering



Neutron radiative
capture

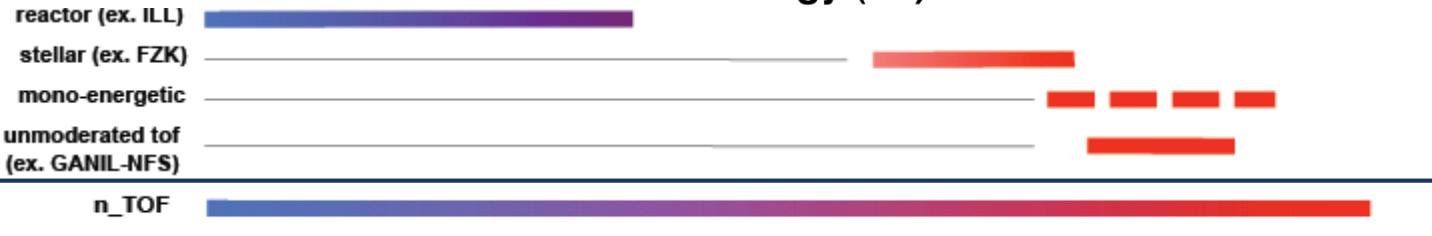
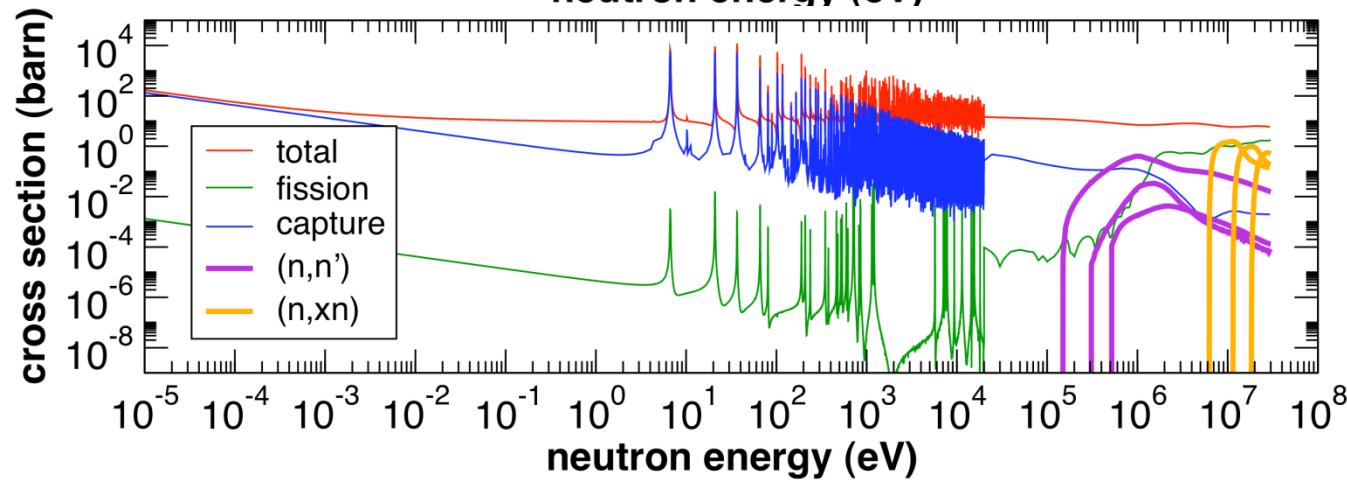
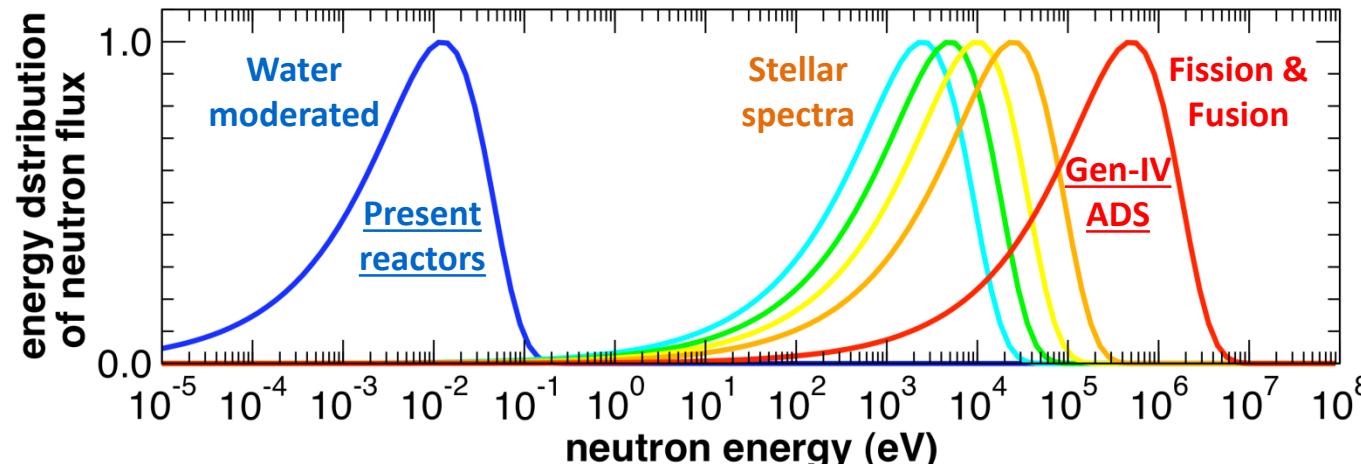


Fission



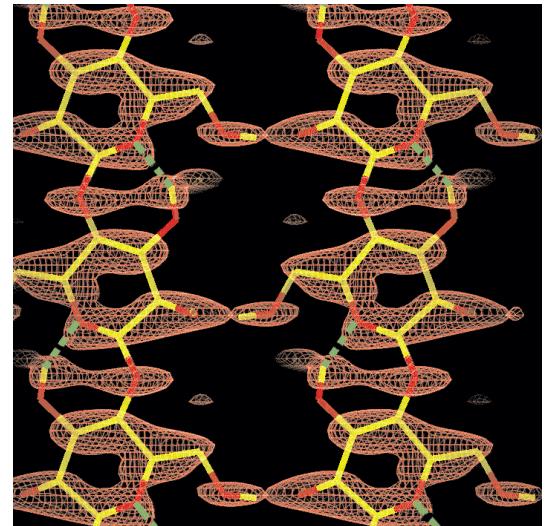
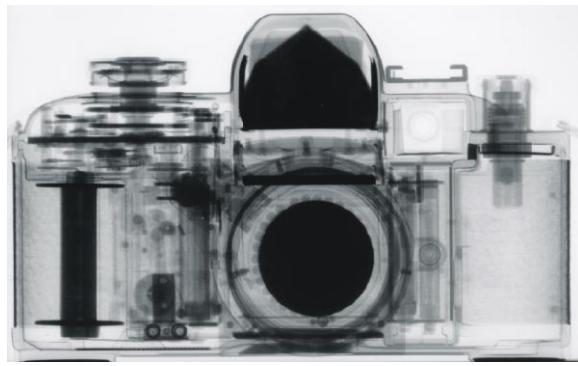
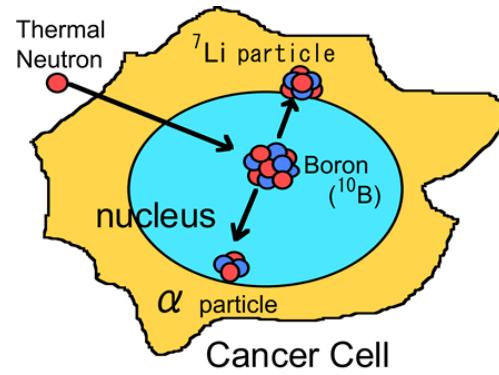
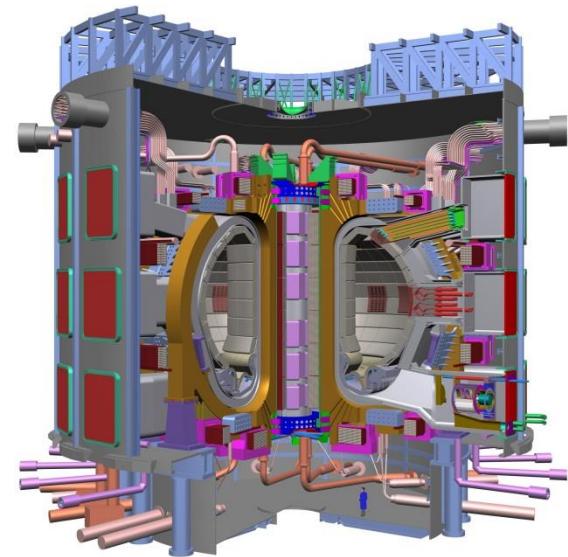
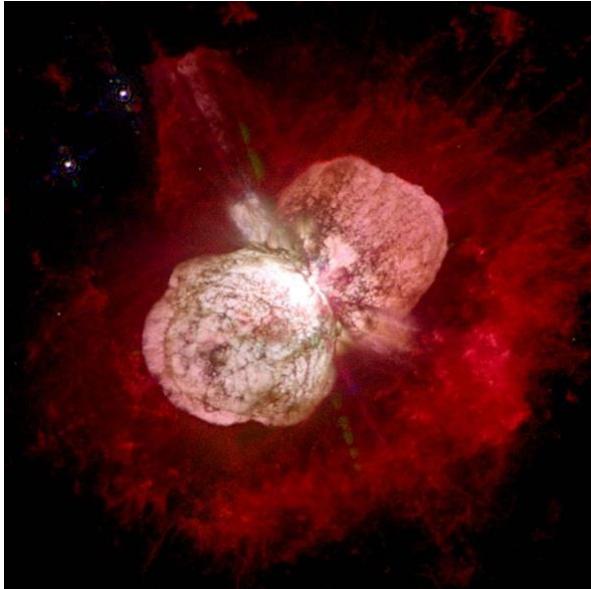
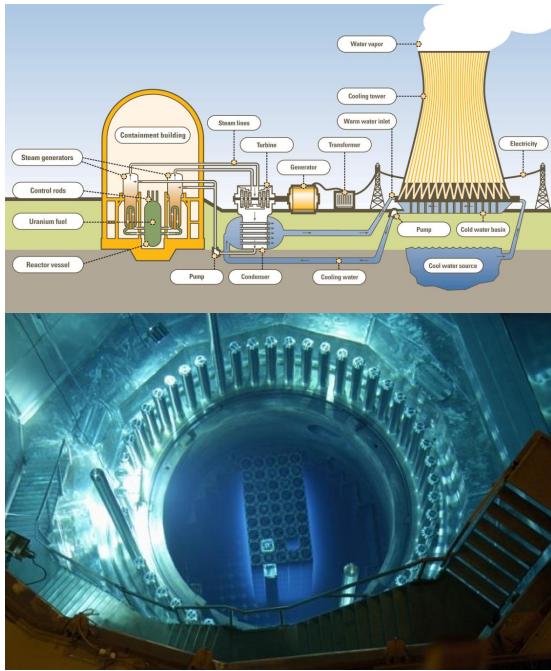
Many others:
 (n,p) , (n,α) ,
knock-out,
spallation
.....

Neutron energies and cross sections

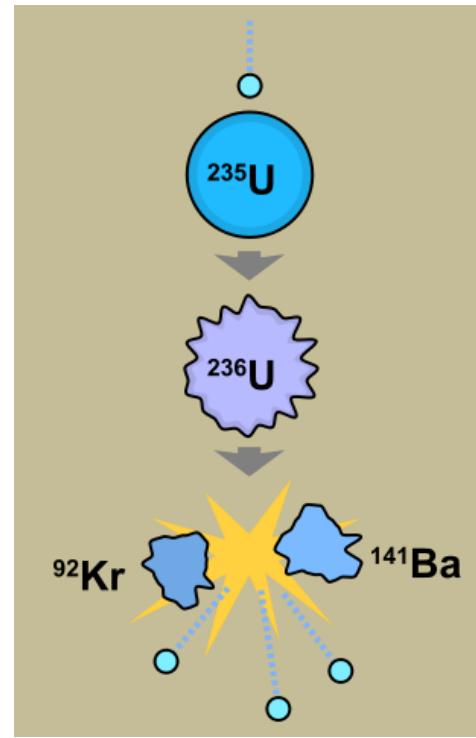
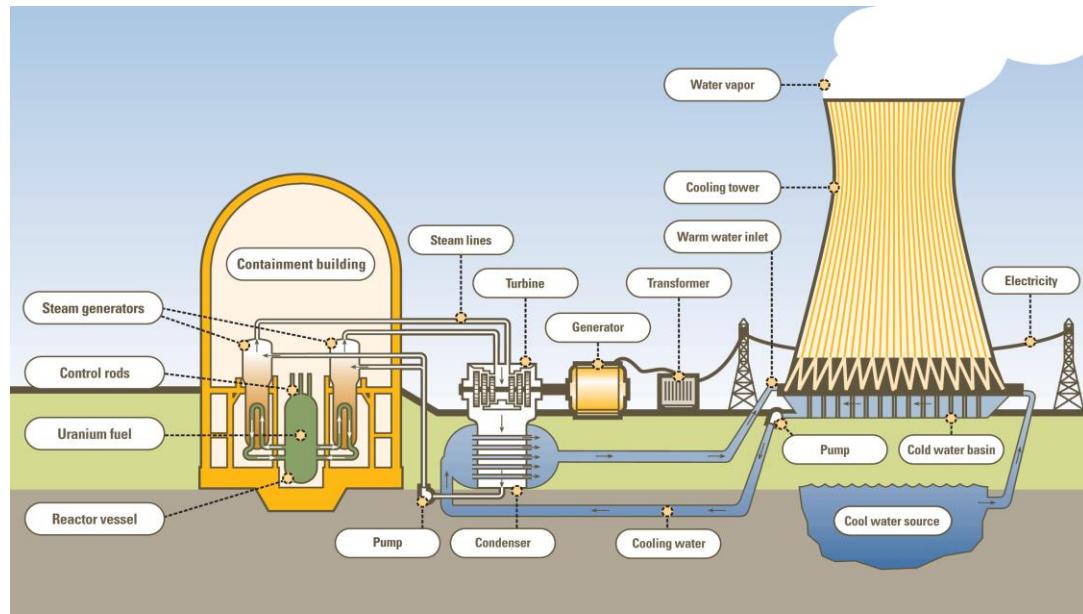


The importance of neutron induced reactions

Why are these important?



Neutron-induced reactions in reactors



Neutron-induced reactions in reactors

	Cm 238 2,4 h	Cm 239 3 h	Cm 240 27 d	Cm 241 32,8 d	Cm 242 162,94 d	Cm 243 29,1 a	Cm 244 18,10 a	Cm 245 8500 a	Cm 246 2730 a
	α : 6,52 β^- : 188... γ : 9	α : 6,41 β^- : 188... γ : 9	α : 6,042 β^- : 280; 430; 474; 909... γ : 9	α : 5,94 β^- : 278; 289; 909... γ : 9	α : 5,291; 6,246... β^- : 431; 132... γ : 9	α : 5,113; 6,009... β^- : 9 γ : 144...; 6,0... σ : 20 η : 5	α : 5,785; 5,748... β^- : 9 γ : 276; 289; 210...; 9... ν : 130; m : 626	α : 5,805; 5,792... β^- : 9 γ : 143...; 6,0... σ : 15; η : 1,1	α : 5,361; 5,304... β^- : 9 γ : 175; 133... σ : 350; m : 2100
Am 236 ? 3,7 m	Am 237 73,0 m	Am 238 1,63 h	Am 239 11,9 h	Am 240 50,8 h	Am 241 432,2 a	Am 242 141 a - 16 h	Am 243 7370 a	Am 244 200 a	Am 245 10,1 h
α : 6,41 β^- : 188... γ : 9	α : 6,41 β^- : 188... γ : 9	α : 5,94 β^- : 280; 430; 474; 909... γ : 9	α : 5,774... β^- : 9 γ : 278; 289; 909... η : 9	α : 5,175... β^- : 9 γ : 988; 889... η : 9	α : 5,439... β^- : 9 γ : 145...; 6,0... σ : 50; 570; m : 2100	α : 5,405... β^- : 9 γ : 205...; 6,0... σ : 75 + 5 m : 2100	α : 5,875; 5,233... β^- : 9 γ : 143...; 142... σ : 75 + 5 m : 0,074	α : 5,361... β^- : 9 γ : 174...; 6,0... σ : 164... m : 200	α : 5,361... β^- : 9 γ : 250... σ : 241; 296... m : 9
Pu 235 25,3 m	Pu 236 2,858 a	Pu 237 45,2 d	Pu 238 87,74 a	Pu 239 2411 - 104 a	Pu 240 6563 a	Pu 241 4,35 a	Pu 242 3,750 - 105 a	Pu 243 4,956 h	Pu 244 8 - 107 a
α : 5,83 β^- : 1758; 34,1... γ : 180	α : 5,83 β^- : 1758; 34,1... γ : 180	α : 5,83 β^- : 1758; 34,1... γ : 180	α : 5,409; 5,408... β^- : 9 γ : 143; 100...; 6,0... η : 17	α : 5,159... β^- : 9 γ : 144...; 6,0... η : 17	α : 5,168; 5,124... β^- : 9 γ : 145...; 6,0... σ : 290; m : 0,048	α : 5,168... β^- : 9 γ : 145...; 6,0... σ : 370; m : 0,048	α : 4,901; 4,856... β^- : 9 γ : 145...; 6,0... σ : 370; m : 0,048	α : 4,901... β^- : 9 γ : 145...; 6,0... σ : 370; m : 0,048	α : 5,361... β^- : 9 γ : 250... σ : 241; 296... m : 9
Np 234 4,4 d	Np 235 396 d	Np 236 22,5 h	Np 237 154 - 103 a	Np 238 2,114 - 106 a	Np 239 2,117 d	Np 239 2,355 d	Np 240 7,22 m	Np 241 13,9 m	Np 242 2,2 m
α : 5,83... β^- : 1559; 1528... γ : 1802... σ : 900	α : 5,83... β^- : 1559; 1528... γ : 1802... σ : 900	α : 5,007... β^- : 1559; 1528... γ : 1802... σ : 900	α : 5,007... β^- : 1559; 1528... γ : 1802... σ : 900	α : 4,790; 4,794... β^- : 1,2... γ : 984; 1029; 1026; 924... σ : 2100	α : 5,12... β^- : 1,2... γ : 106; 277... σ : 228...; 6,0... η : 9 σ : 32 + 19; m : 0,02	α : 5,12... β^- : 1,2... γ : 106; 277... σ : 228...; 6,0... η : 9 σ : 32 + 19; m : 0,02	α : 5,12... β^- : 1,2... γ : 175; 175... σ : 601 m : 448...; 9	α : 5,12... β^- : 1,2... γ : 175; 175... σ : 601 m : 448...; 9	α : 5,12... β^- : 1,2... γ : 175; 175... σ : 601 m : 448...; 9
U 233 1,592 - 105 a	U 234 0,055	U 235 0,7200	U 236 120 - 2,342 - 107 a	U 237 75 d	U 238 99,2745	U 239 207 m	U 239 3,5 m	U 240 14,11 m	U 242 16,8 m
α : 4,824; 4,783... β^- : 42; 97...; σ : 47; m : 530	α : 4,824; 4,783... β^- : 42; 97...; σ : 47; m : 530	α : 4,824; 4,783... β^- : 42; 97...; σ : 47; m : 530	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006	α : 4,775; 4,773... β^- : 4338...; 6,0... γ : 145...; 6,0... σ : 47; m : 0,006
Pa 232 1,31 d	Pa 233 27,0 d	Pa 234 1,17 m	Pa 234 6,70 h	Pa 235 187 d	Pa 235 207 m	Pa 236 207 m	Pa 237 4,168 - 107 a	Pa 238 82 m	Pa 239 14,11 m
β^- : 0,3; 1,3...; ϵ : 150...; σ : 460; m : 700	β^- : 0,3; 0,6... γ : 312; 300... σ : 341...; 6,0... η : 20 + 19; m : < 0,1	β^- : 0,3; 0,6... γ : 312; 300... σ : 341...; 6,0... η : 20 + 19; m : < 0,1	β^- : 0,3; 0,6... γ : 312; 300... σ : 341...; 6,0... η : 20 + 19; m : < 0,1	β^- : 0,2... γ : 60; 208... η : 642	β^- : 0,2... γ : 60; 208... η : 642	β^- : 0,2... γ : 60; 208... η : 642	β^- : 0,2... γ : 60; 208... η : 642	β^- : 1,2; 1,3... γ : 75; 75... η : 75	β^- : 1,2; 1,3... γ : 75; 75... η : 75
Th 231 25,5 h	Th 232 100	Th 233 22,3 m	Th 233 22,3 m	Th 234 22,4 m	Th 235 22,4 m	Th 236 22,4 m	Th 237 22,4 m	Th 238 22,4 m	Th 239 22,4 m
β^- : 0,3; 0,4... γ : 28; 84... θ^-									

FF + Energy

These isotopes, today's nuclear waste, will be the **fuel of the next generation of nuclear reactors** (safer & cleaner):

New fuel composition + New/Higher neutron energy ranges

Very substantial need of new/accurate ($n, *$) cross sections

Neutron-induced reactions in the stars

Main s-process $90 < A < 210$

TP-AGB stars $1-3 M_{\odot}$

shell H-burning

$0.9 \cdot 10^8$ K

$kT=8$ keV

10^7-10^8 cm $^{-3}$

He-flash

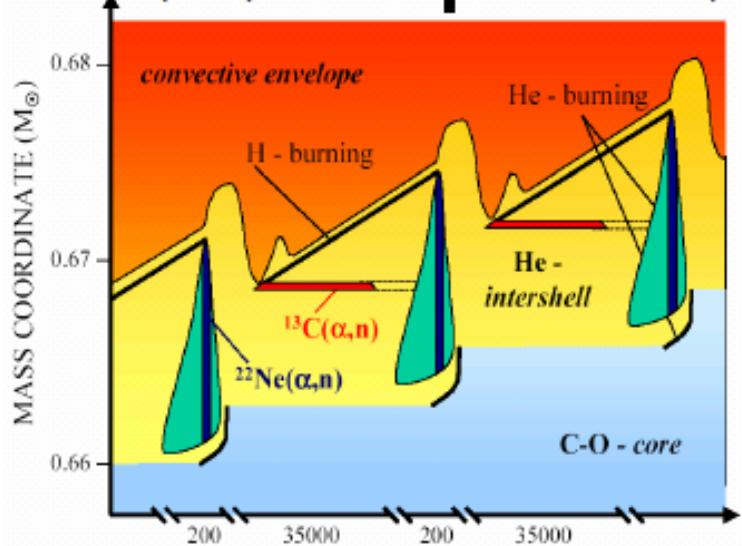
$3-3.5 \cdot 10^8$ K

$kT=25$ keV

$10^{10}-10^{11}$ cm $^{-3}$

$^{13}\text{C}(\alpha, n)$

$^{22}\text{Ne}(\alpha, n)$



Weak s-process $A < 90$

massive stars $> 8 M_{\odot}$

core He-burning

$3-3.5 \cdot 10^8$ K

$kT=25$ keV

10^6 cm $^{-3}$

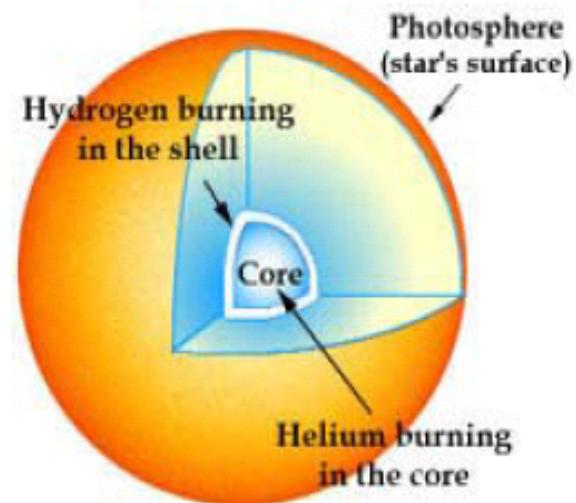
shell C-burning

$\sim 1 \cdot 10^9$ K

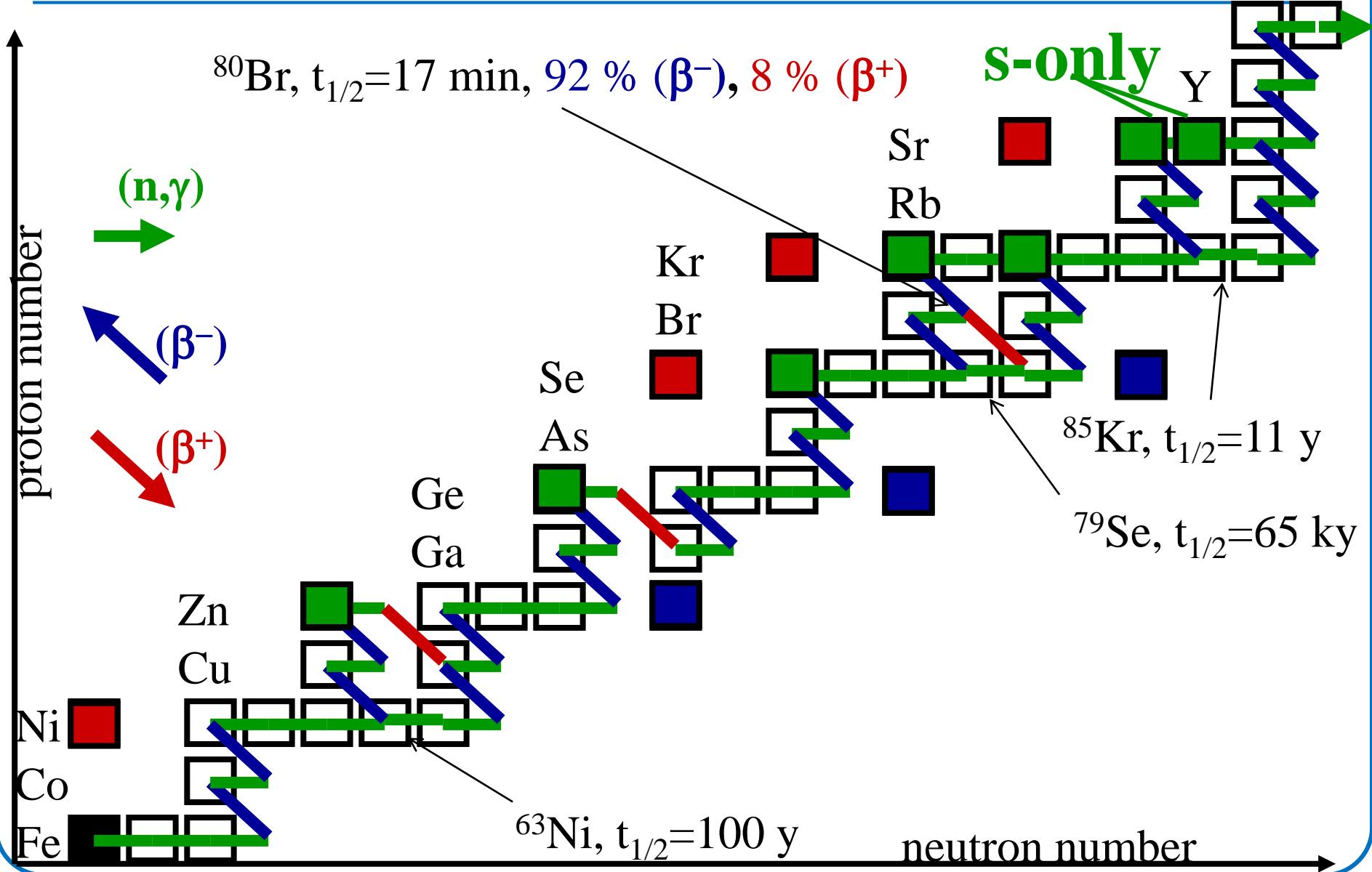
$kT=90$ keV

$10^{11}-10^{12}$ cm $^{-3}$

$^{22}\text{Ne}(\alpha, n)$

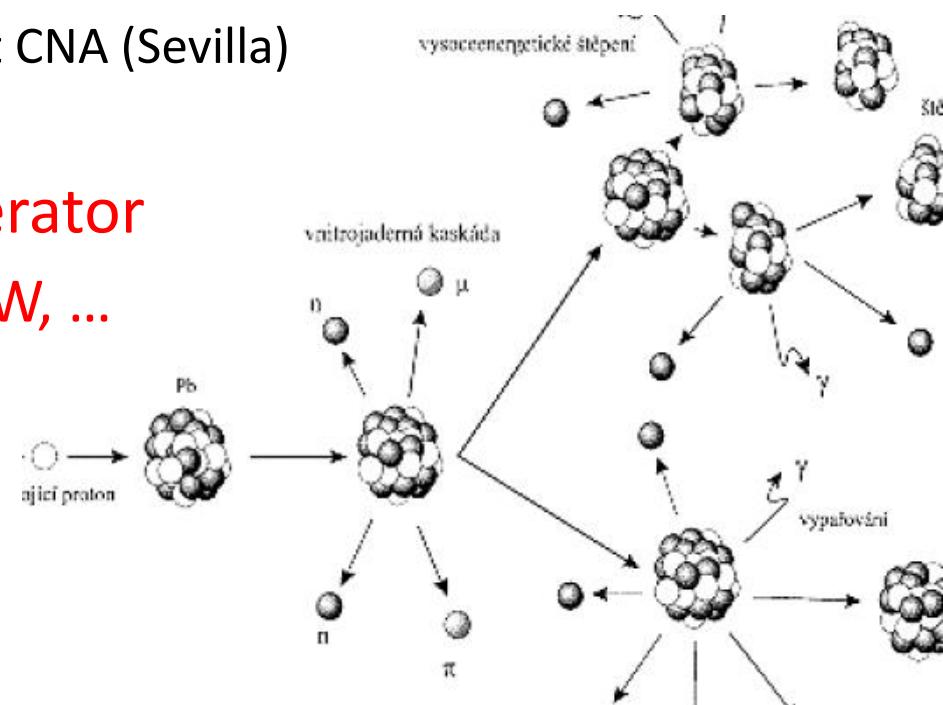


Neutron-induced reactions in the stars



Production of neutron beams

- Nuclear reactors
- Electron LINACs
 - $e + U \rightarrow$ Bremsstrahlung \rightarrow photofission
- “Low energy” proton (and D) accelerators
 - $p(^7\text{Li},n)^7\text{Be}$
 - $p(^9\text{Be},n)^9\text{B}$
 - Fusion reactions (D-D or D-T)
- “High energy” proton accelerator
 - Spallation reactions on Pb, W, ...



The n_TOF facility @ CERN

The n_T TOF Collaboration

The n_T TOF Collaboration

*33 Research Institutions from Europe, Asia and USA.
130 researchers*

NUCLEAR ASTROPHYSICS: stellar nucleosynthesis and cosmo-chronology

NUCLEAR TECHNOLOGIES: ADS, Gen-IV and Th/U fuel cycle

BASIC NUCLEAR PHYSICS: levels densities, γ -ray strength functions, ..

D. Cano-Ott et al.



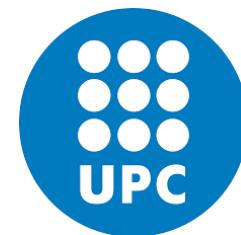
J.L. Tain et al.



I. Duran et al.



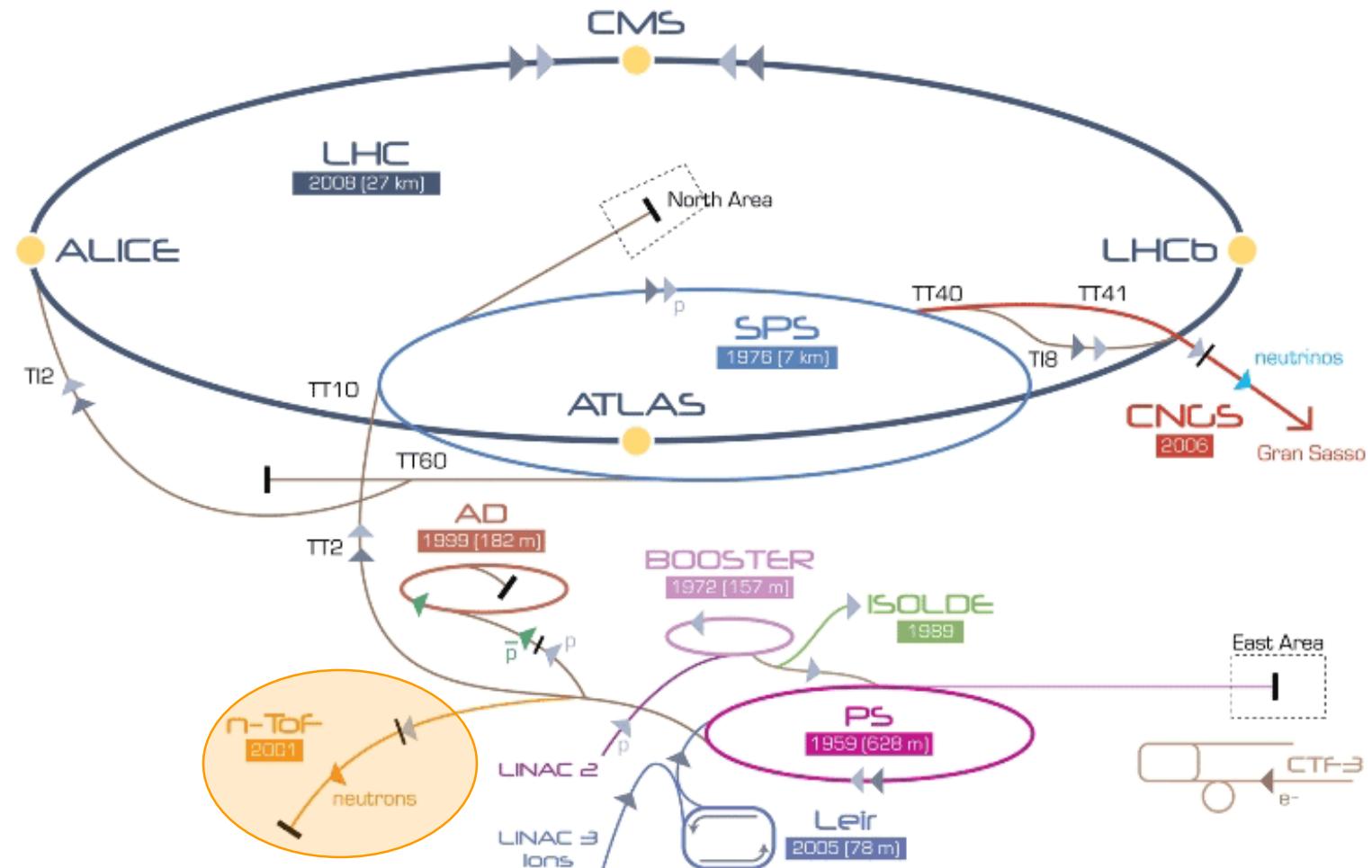
F. Calvino et al. J.M. Quesada et al.



"Physics with neutron beams at the CERN n_T TOF facility"

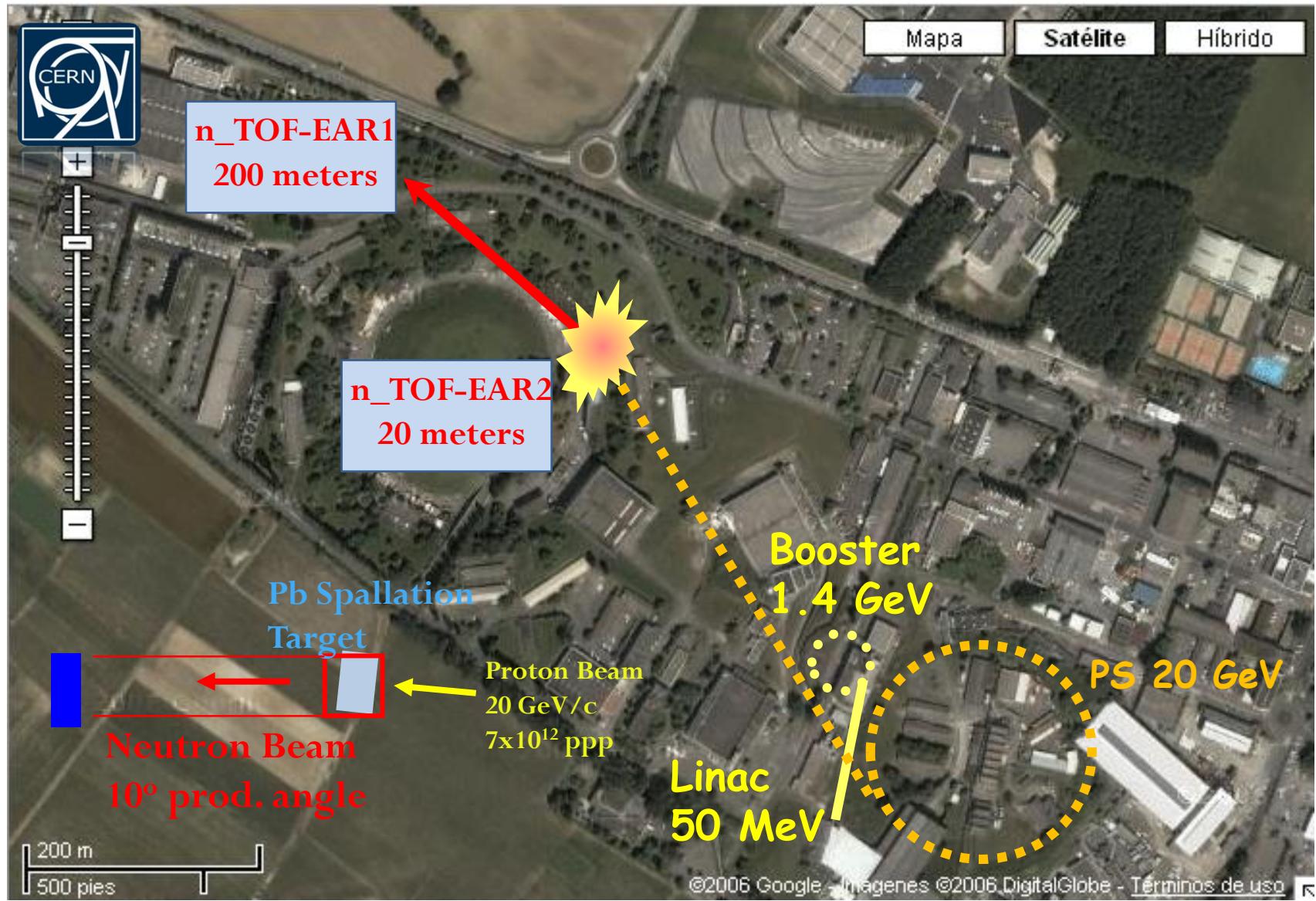
Carlos GUERRERO @ VI CPAN Days, Sevilla, October 21st 2014

The n_TOF facility at CERN

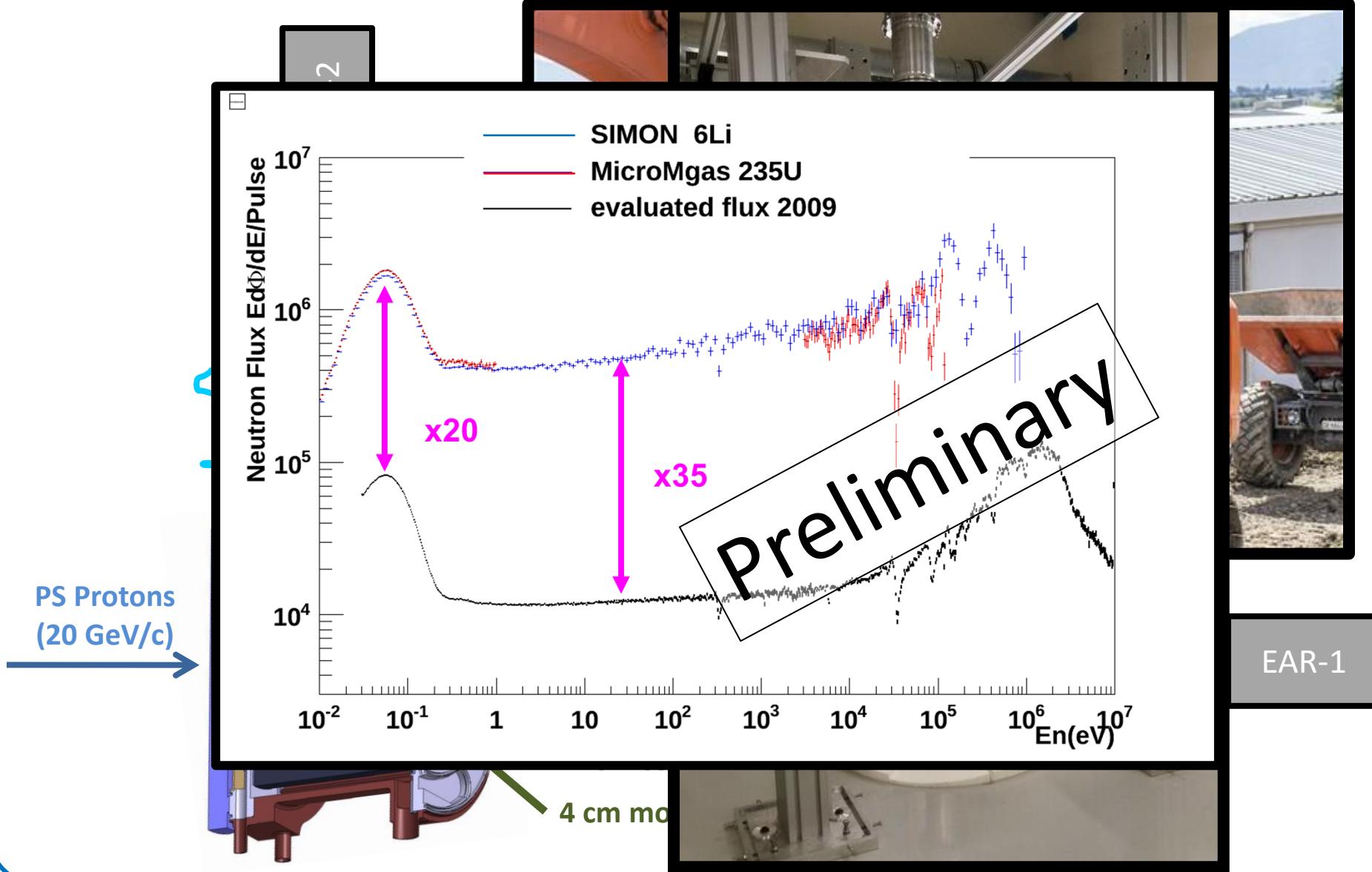


C. Rubbia et al., *A high resolution spallation driven facility at the CERN-PS to measure neutron cross sections in the interval from 1 eV to 250 MeV*, CERN/LHC/98-02(EET) 1998.

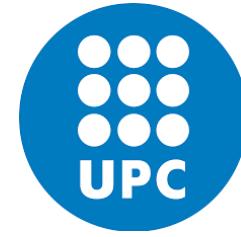
The n_TOF Facility at CERN: a Google™ view



The n_TOF lead spallation target



Physics program/experiments at n_TOF (a glimpse of the Spanish contributions)

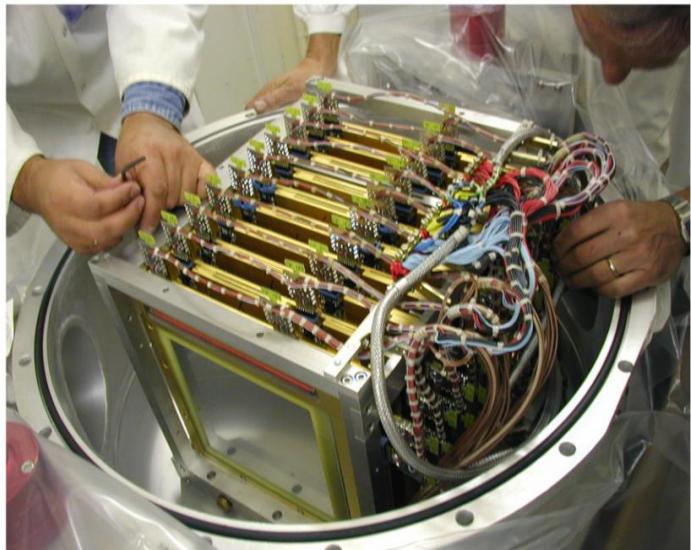


"Physics with neutron beams at the CERN n_TOF facility"

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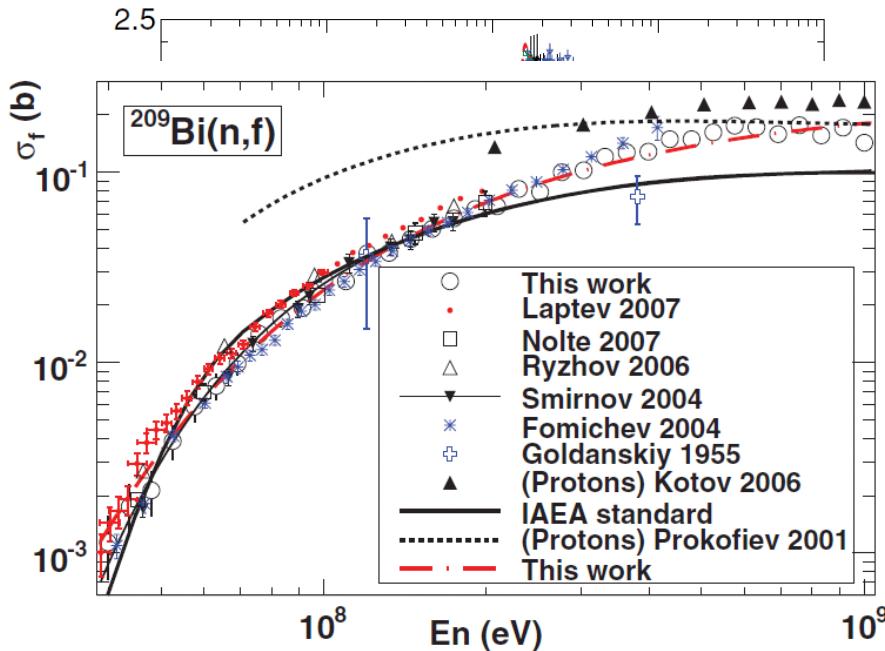
Fission reactions: pushing the high E_n limits!

PPAC: Parallel Plate Avalanche Chamber



Highlights:

- Time resolution <1 ns
- Thin (μm) backings \rightarrow both FF detected
- Transparent cathodes/anodes low γ -flash



• C. Paradela et al., PRC 82 (2010)

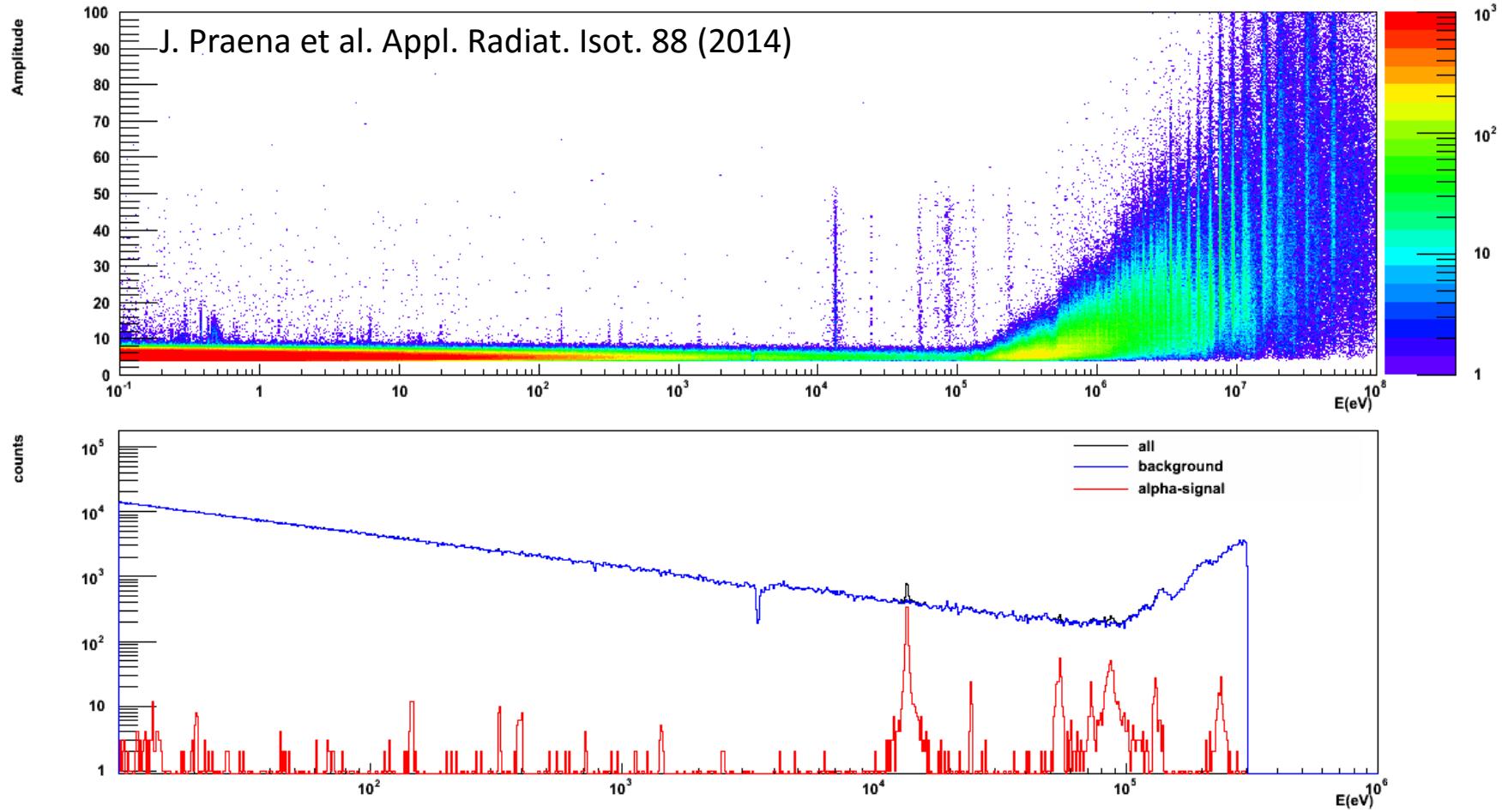
“Neutron-induced fission cross section of ^{234}U and ^{237}Np measured at the CERN ...”

• D. Tarrio et al., PRC 83 (2011)

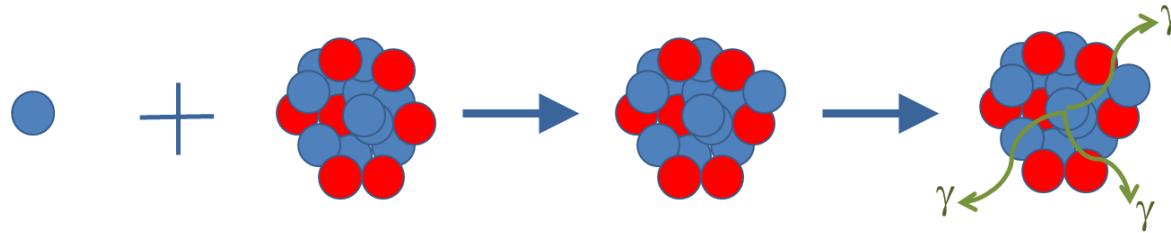
“Neutron-induced fission cross section of ^{nat}Pb and ^{209}Bi from threshold to 1 GeV”

(n,α) reactions for medical physics

- Measurement of $^{33}\text{S}(n,\alpha)$ as a complementary isotope for BNCT

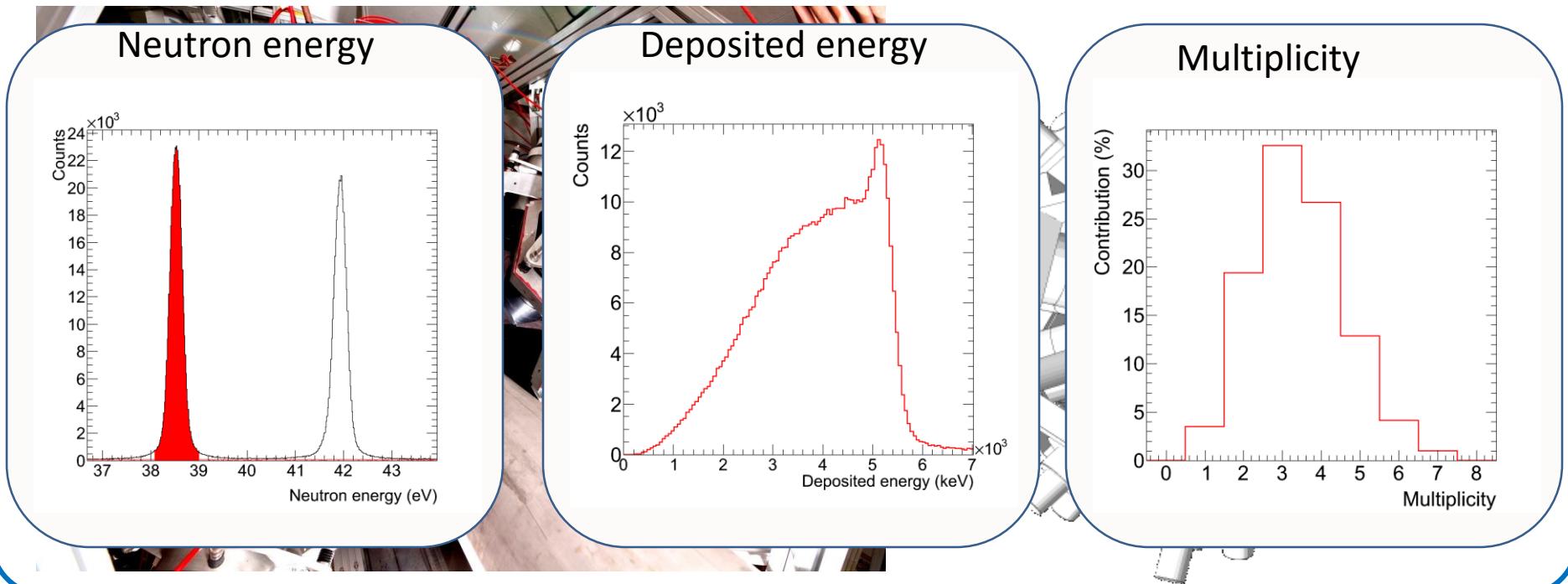


Neutron capture reactions for nuclear tech.



The n_TOF Total Absorption Calorimeter (TAC)

40 BaF₂ scintillator crystals → 95% solid angle coverage

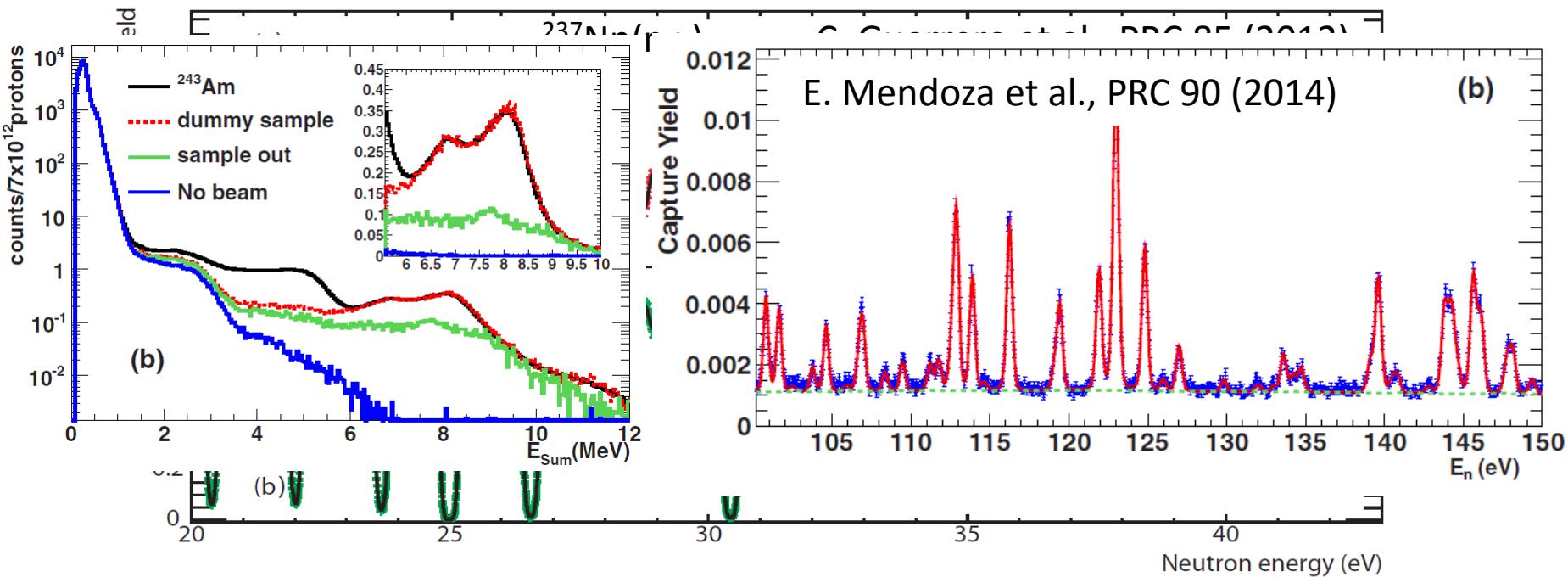


Neutron capture reactions for nuclear tech.

- Isotopes of interest: actinides Th, U, Np, Pu, Am, Cm

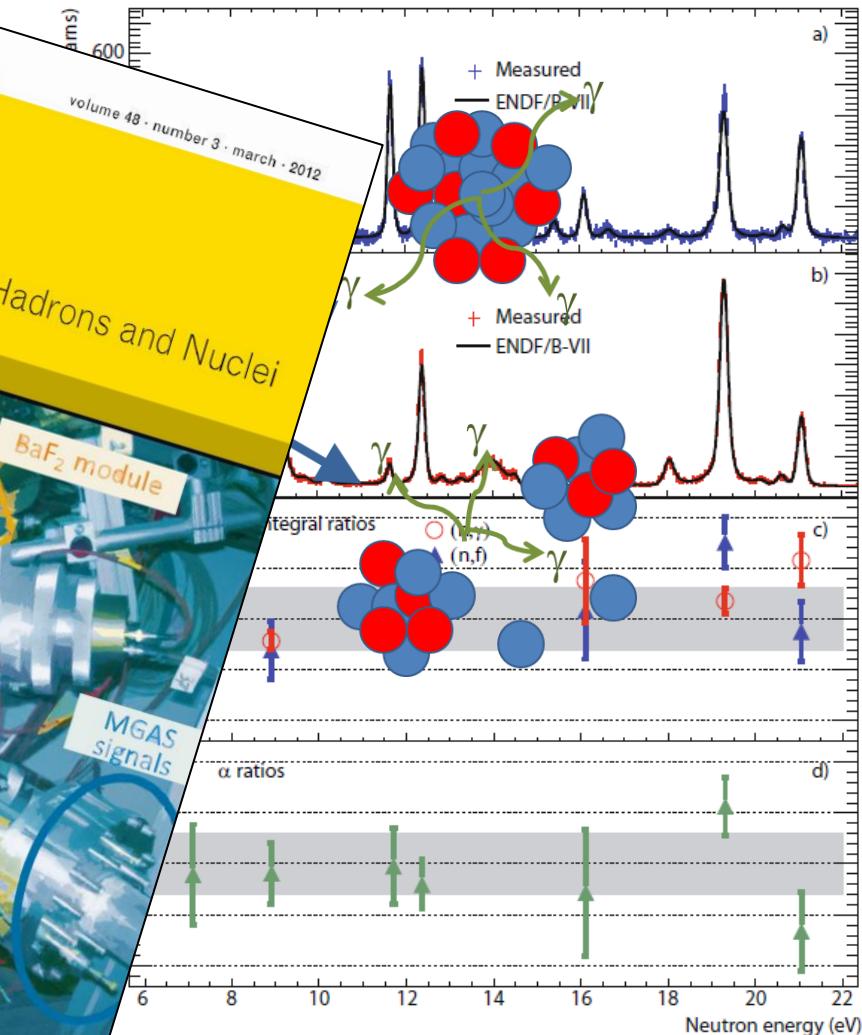
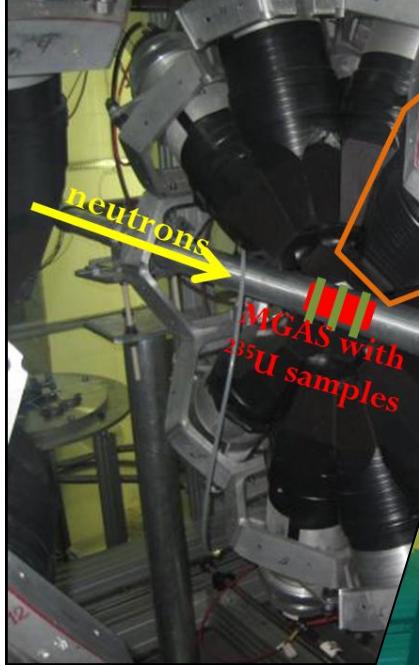
Low material available + high specific activities

This is what n_TOF + TAC are suited for



Neutron capture of fissile isotopes

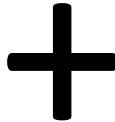
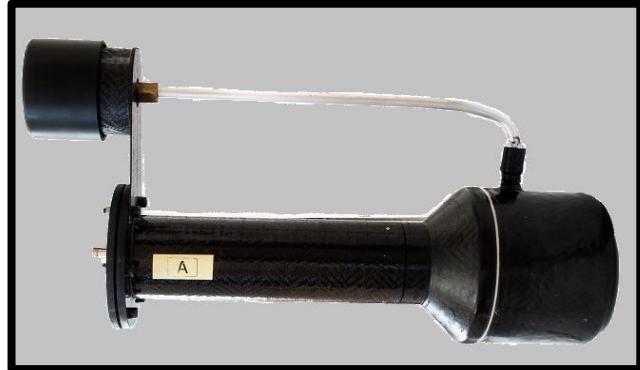
Solution: use in combination the TAC [(n, γ)] and MicroMegas [(n,f)] detectors



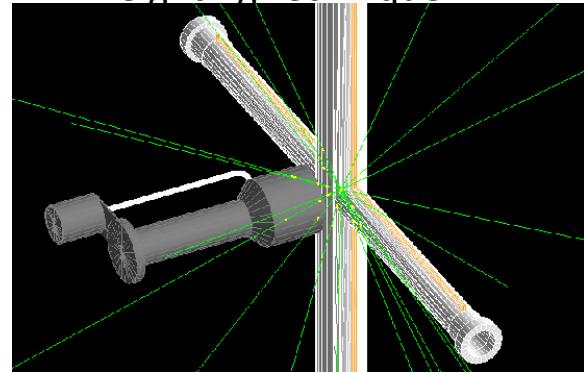
Neutron capture reactions for astrophysics

Neutron scattering dominates (10^4) over neutron capture

VERY low neutron sensitivity scintillators (C_6D_6)



VERY detail MC simulation for the Pulse Height Weighting Technique



- M. Mosconi et al., PPNP 59 (2007)
“*Neutron reactions and nuclear cosmo-chronology*”
- U. Abbondanno et al., PRL 93 (2004)
“*Neutron Capture Cross Section Measurement of ^{151}Sm ...*”
- C. Domingo-Pardo , PRC 74 (2006)
“*New measurement of neutron capture resonances in ^{209}Bi ”*
- [...]
- C. Guerrero et al., “*Hunting the s-process branching points ^{147}Pm , ^{171}Tm and ^{204}Tl at CERN*”, ongoing



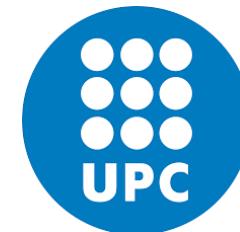
Physics with neutron beams at CERN

- The n_TOF facility at CERN is the worldwide leader in
 - Instantaneous neutron intensity
 - Scientific production (cross sections/year)

Experience in this and other nuclear physics projects over the past decade allows us today leading the design and construction of new innovative detection systems:

- USC: A new high counting rate neutron monitor based on fission detectors
- CIEMAT: Study of a new EM calorimeter suited for n_TOF EAR-2
- UPC: On the use of long He₃ counters for neutron background measurements
- IFIC-US: Imaging techniques for (n,γ) with low neutron sensitivity detectors

GOAL: fully exploit the new n_TOF-EAR2 vertical beam line



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