Physics with neutron beams at the CERN n_TOF facility

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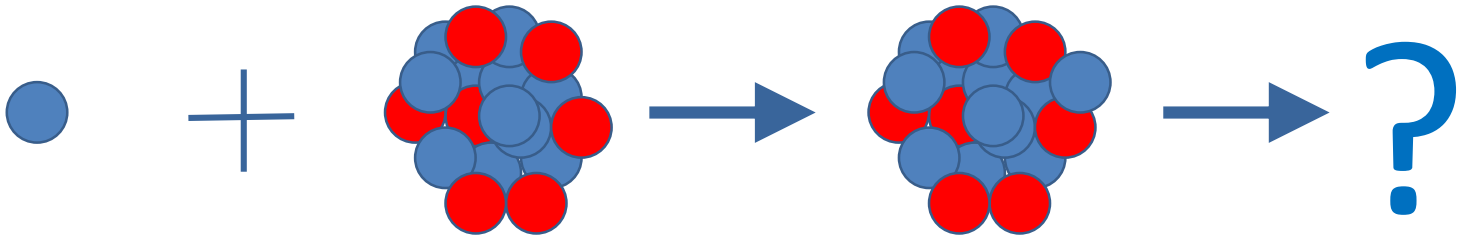
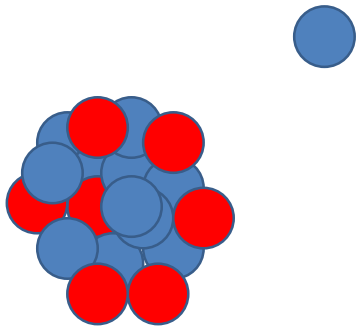
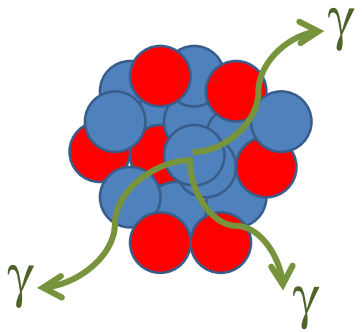
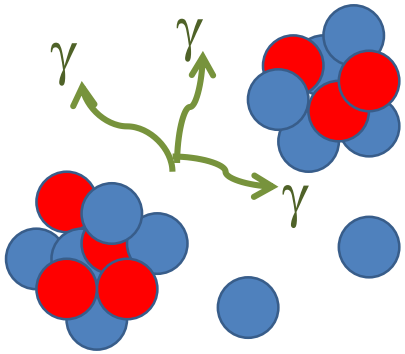
(on behalf of the Spanish members of the CERN n_TOF Collaboration)
www.cern.ch/nTOF

"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!"

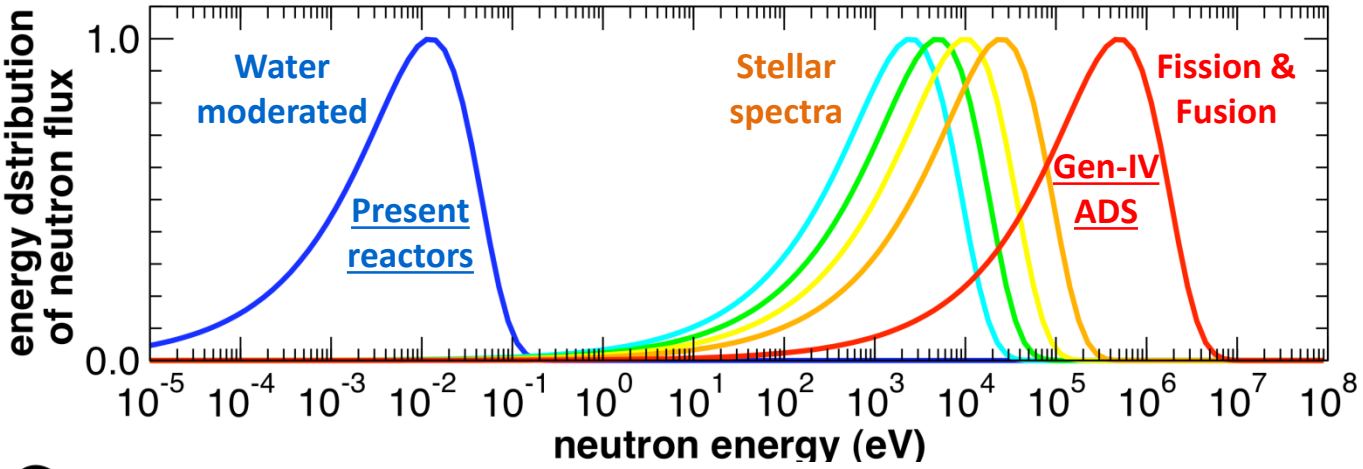
H. Goldstein (talk at Atomenergie, Sweden, September 1953)

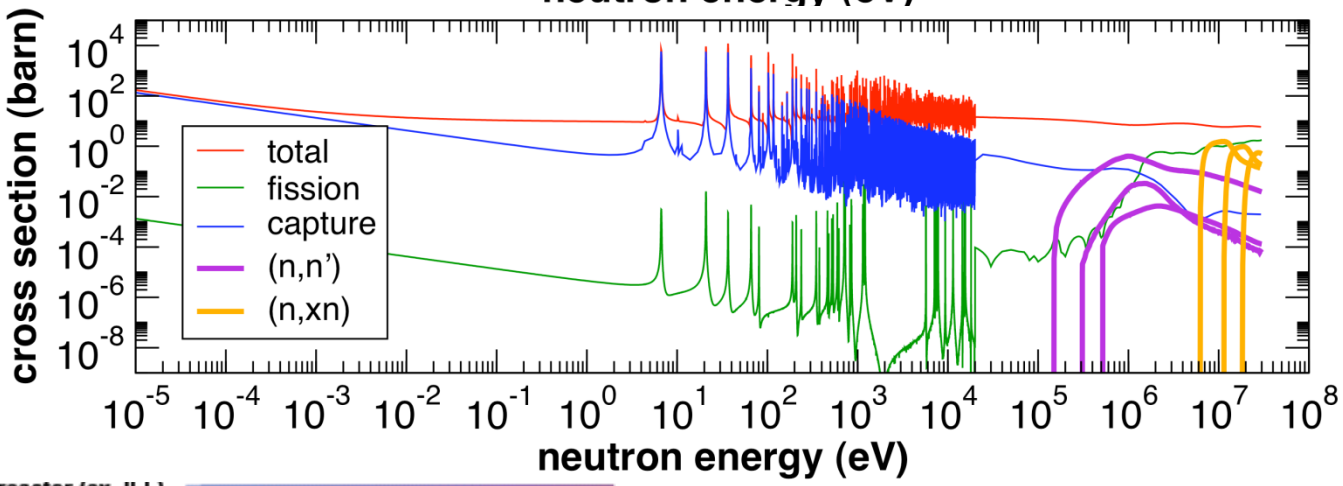
Neutron-Nucleus interactions?

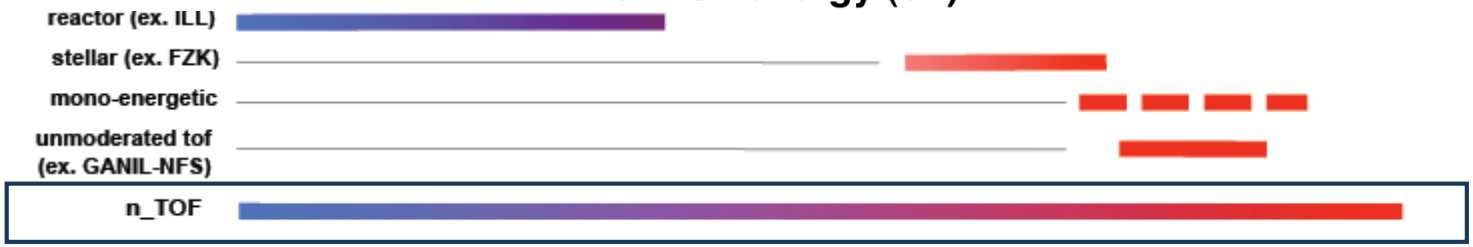


Elastic/Inelastic scattering	Neutron radiative capture	Fission	Many others: (n,p), (n,α), knock-out, spallation …..
			

Neutron energies and cross sections

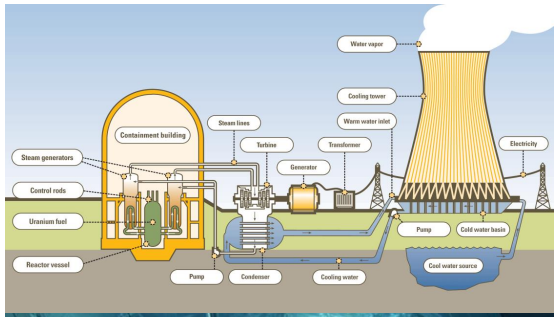


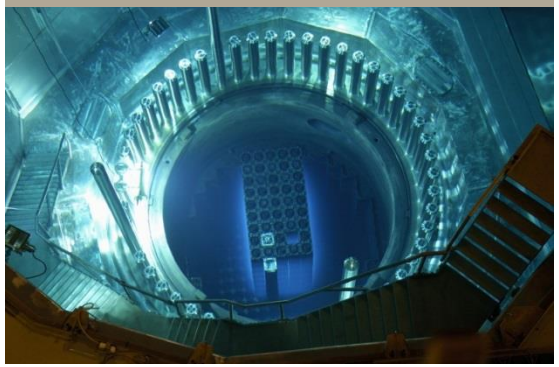


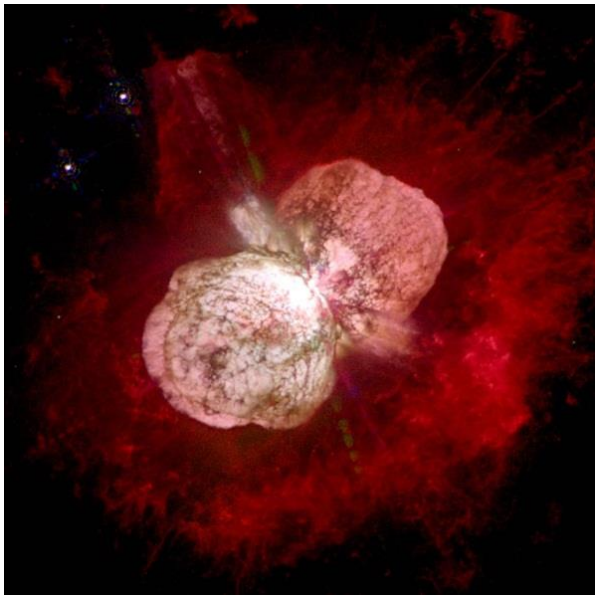


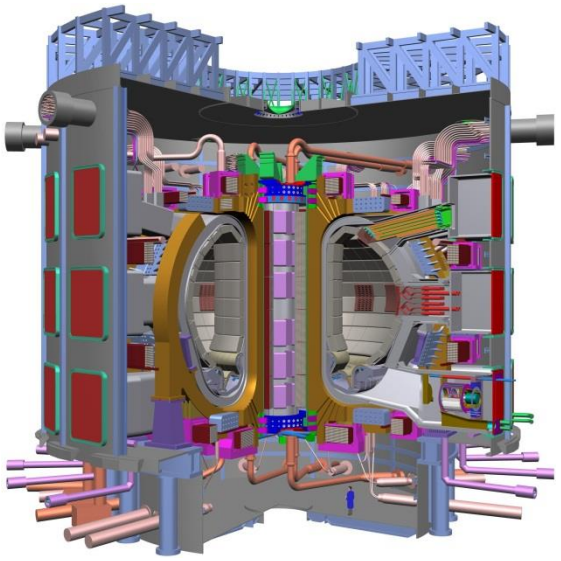
The importance of neutron induced reactions

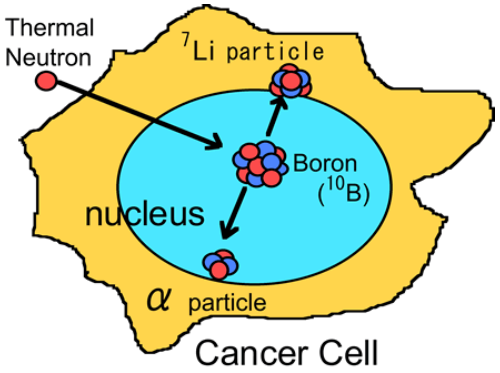
Why are these important?

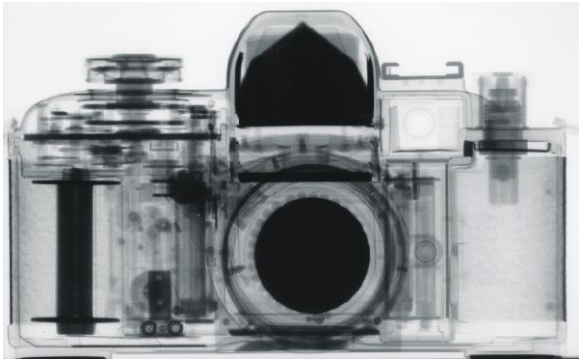


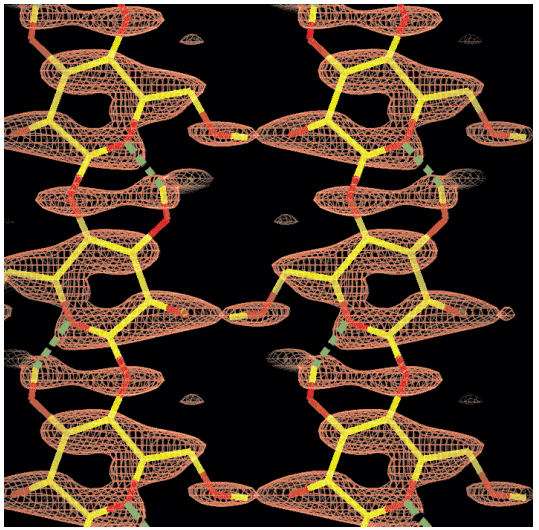




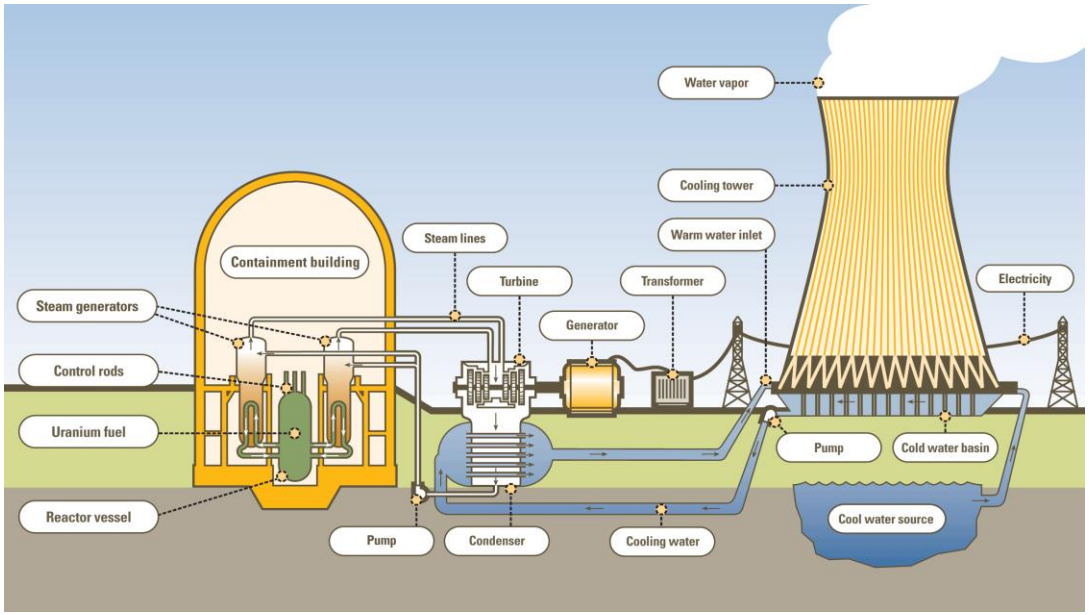


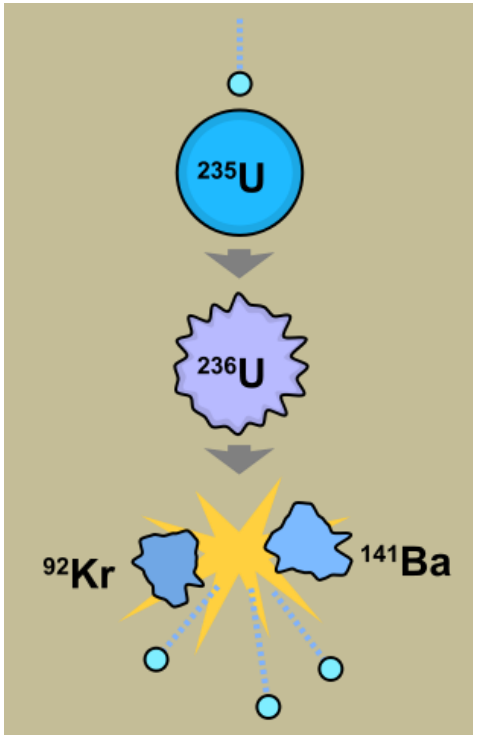




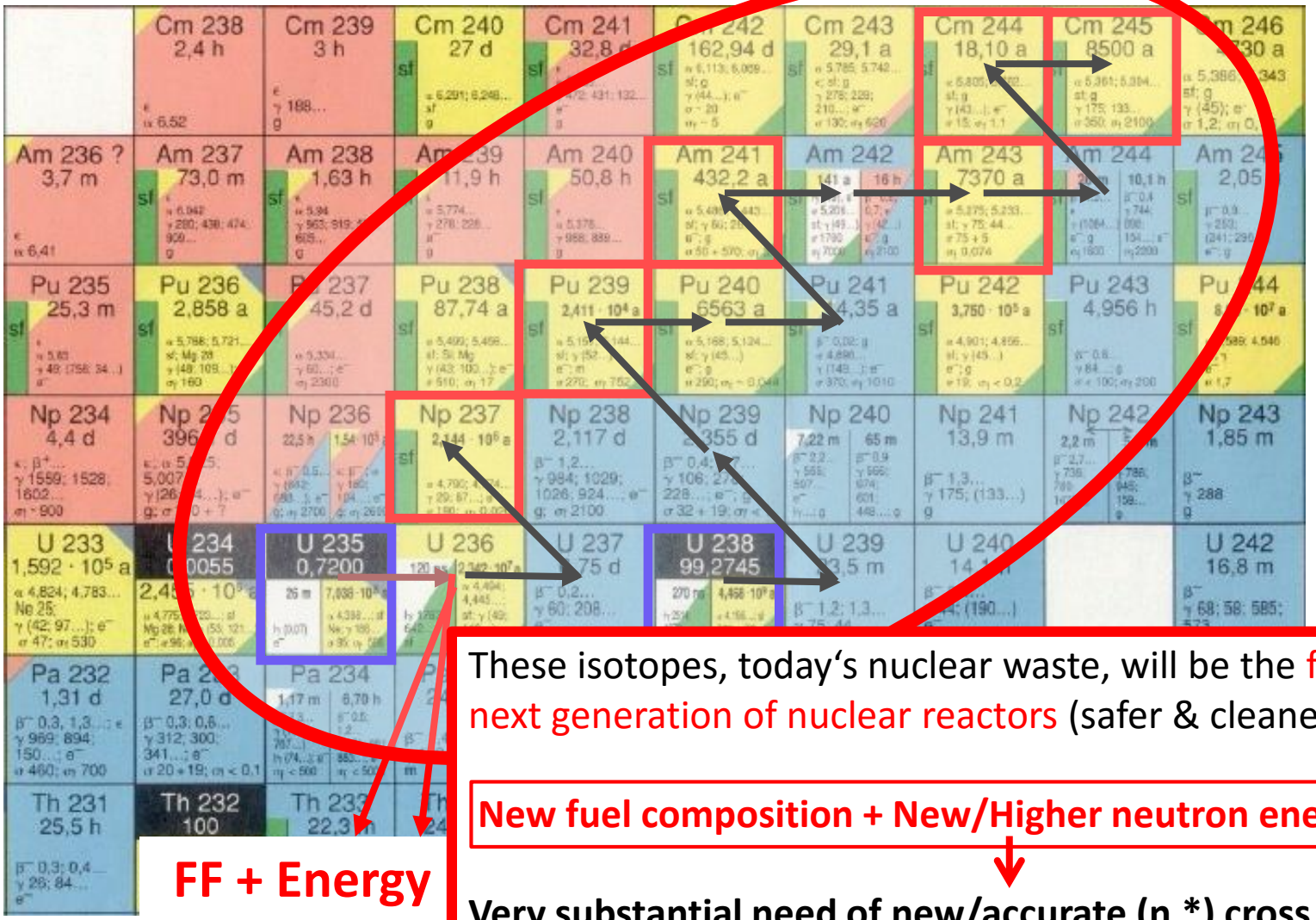


Neutron-induced reactions in reactors





Neutron-induced reactions in reactors



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

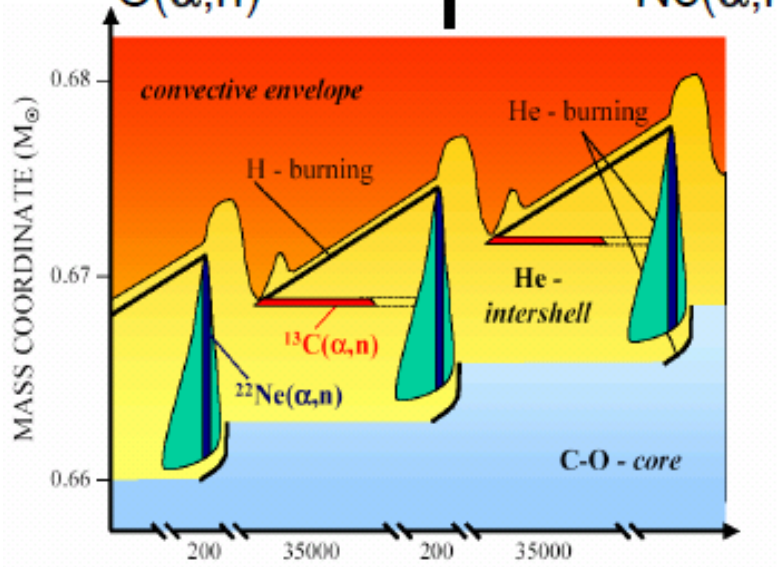
New fuel composition + New/Higher neutron energy ranges

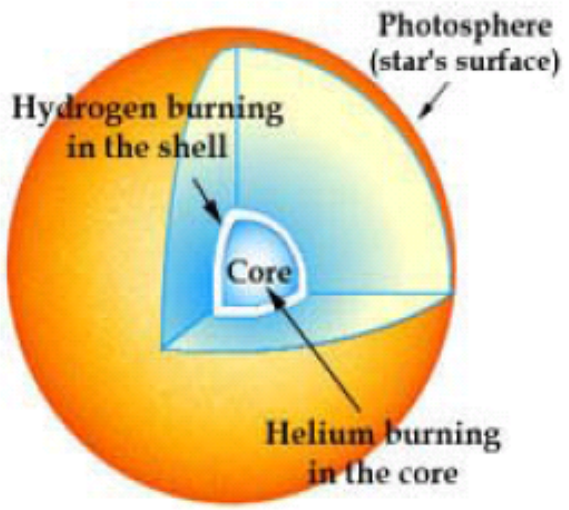
↓

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

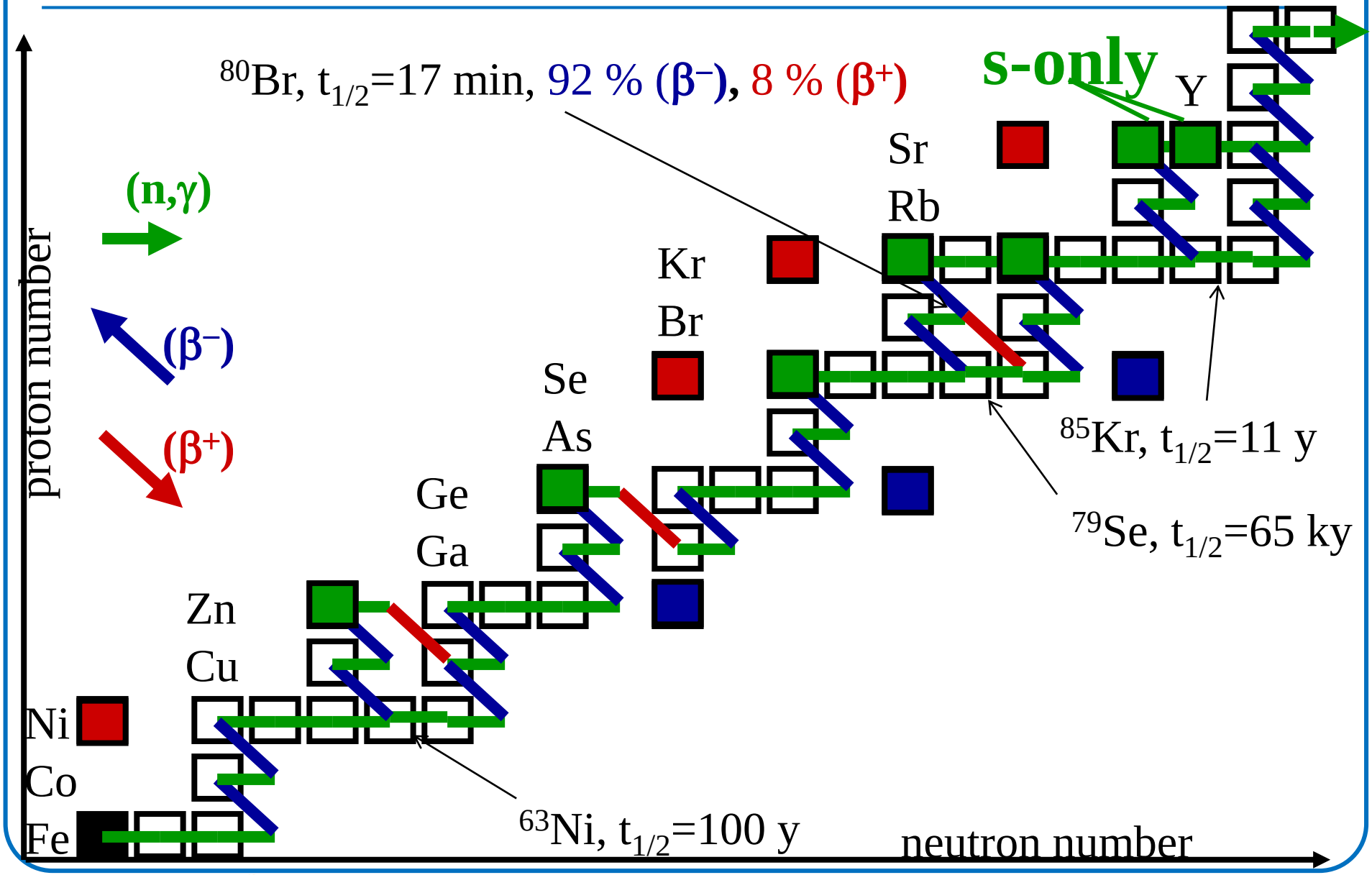
Neutron-induced reactions in the stars

Main s-process 90<A<210		Weak s-process A<90	
TP-AGB stars 1-3 $M_\odot$		massive stars > 8 $M_\odot$	
shell H-burning	He-flash	core He-burning	shell C-burning
$0.9 \cdot 10^8$ K	$3\text{-}3.5 \cdot 10^8$ K	$3\text{-}3.5 \cdot 10^8$ K	$\sim 1 \cdot 10^9$ K
kT=8 keV	kT=25 keV	kT=25 keV	kT=90 keV
$10^7\text{-}10^8$ cm^{-3}	$10^{10}\text{-}10^{11}$ cm^{-3}	10^6 cm^{-3}	$10^{11}\text{-}10^{12}$ cm^{-3}
$^{13}C(\alpha,n)$	$^{22}Ne(\alpha,n)$	$^{22}Ne(\alpha,n)$	





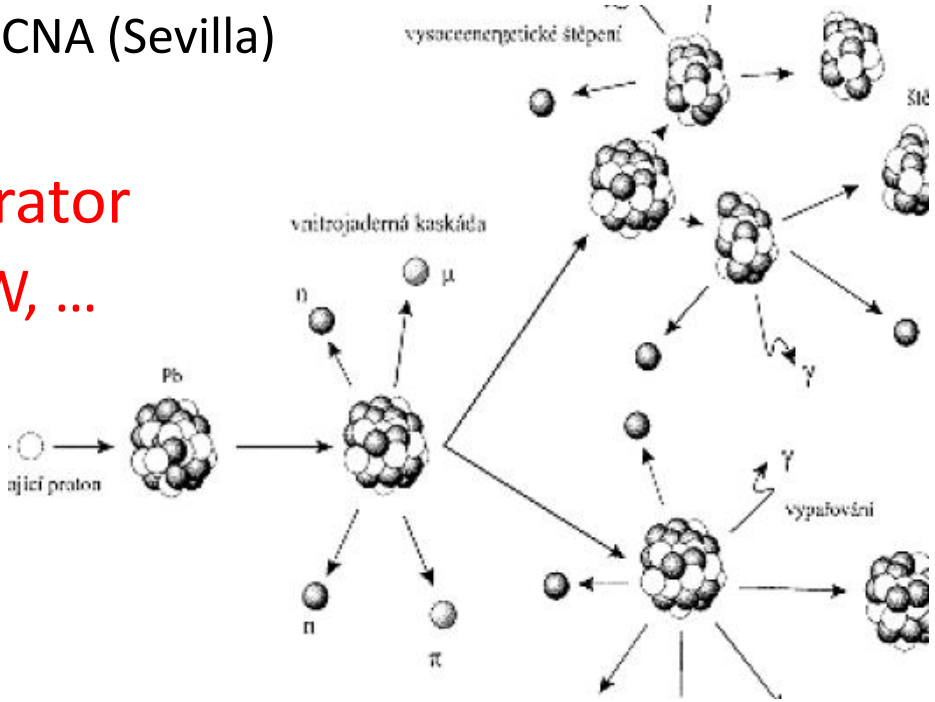
Neutron-induced reactions in the stars



Production of neutron beams

- Nuclear reactors
- Electron LINACs
  - e + U → Bremsstrahlung → photofission
- "Low energy" proton (and D) accelerators
  - $p(^{7}Li,n)^{7}Be$
  - $p(^{9}Be,n)^{9}B$
  - Fusion reactions (D-D or D-T)

  } At CNA (Sevilla)
- "High energy" proton accelerator
  - **Spallation reactions on Pb**, W, …



The n_TOF facility @ CERN

The n_TOF Collaboration

The n_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.

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J.L. Tain et al.

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I. Duran et al.

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F. Calvino et al.

UPC

J.M. Quesada et al.

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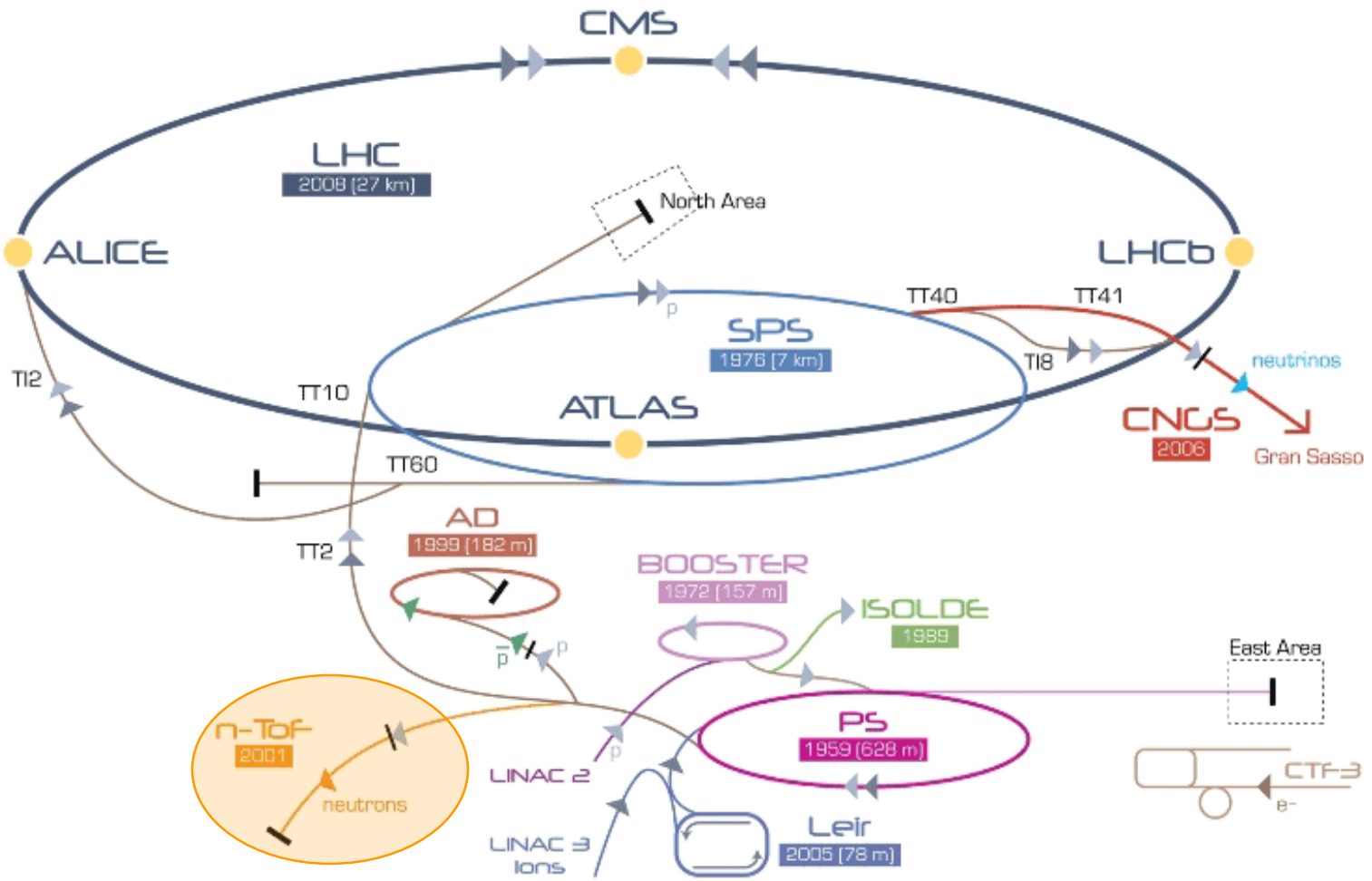
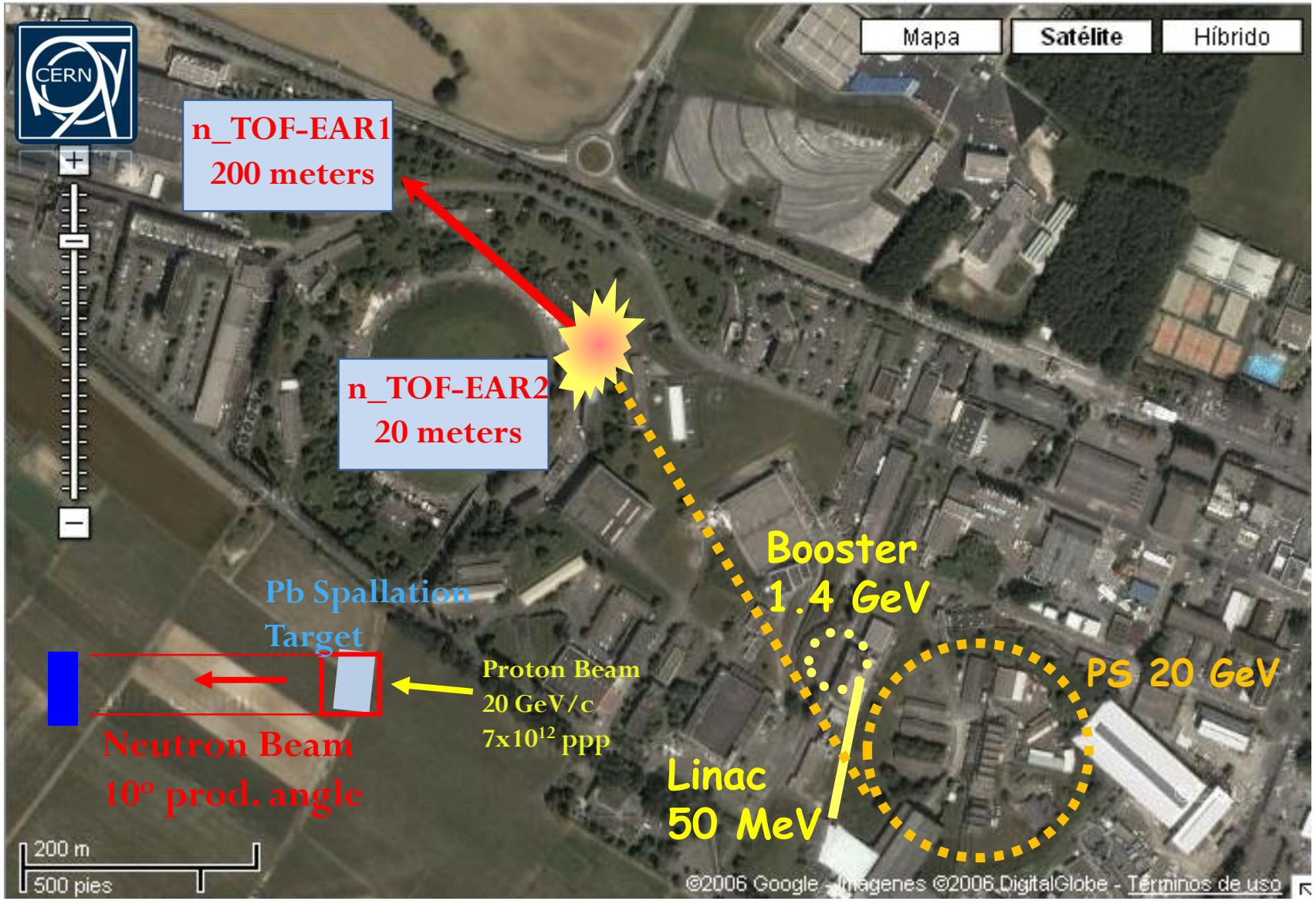
The n_TOF facility at CERN

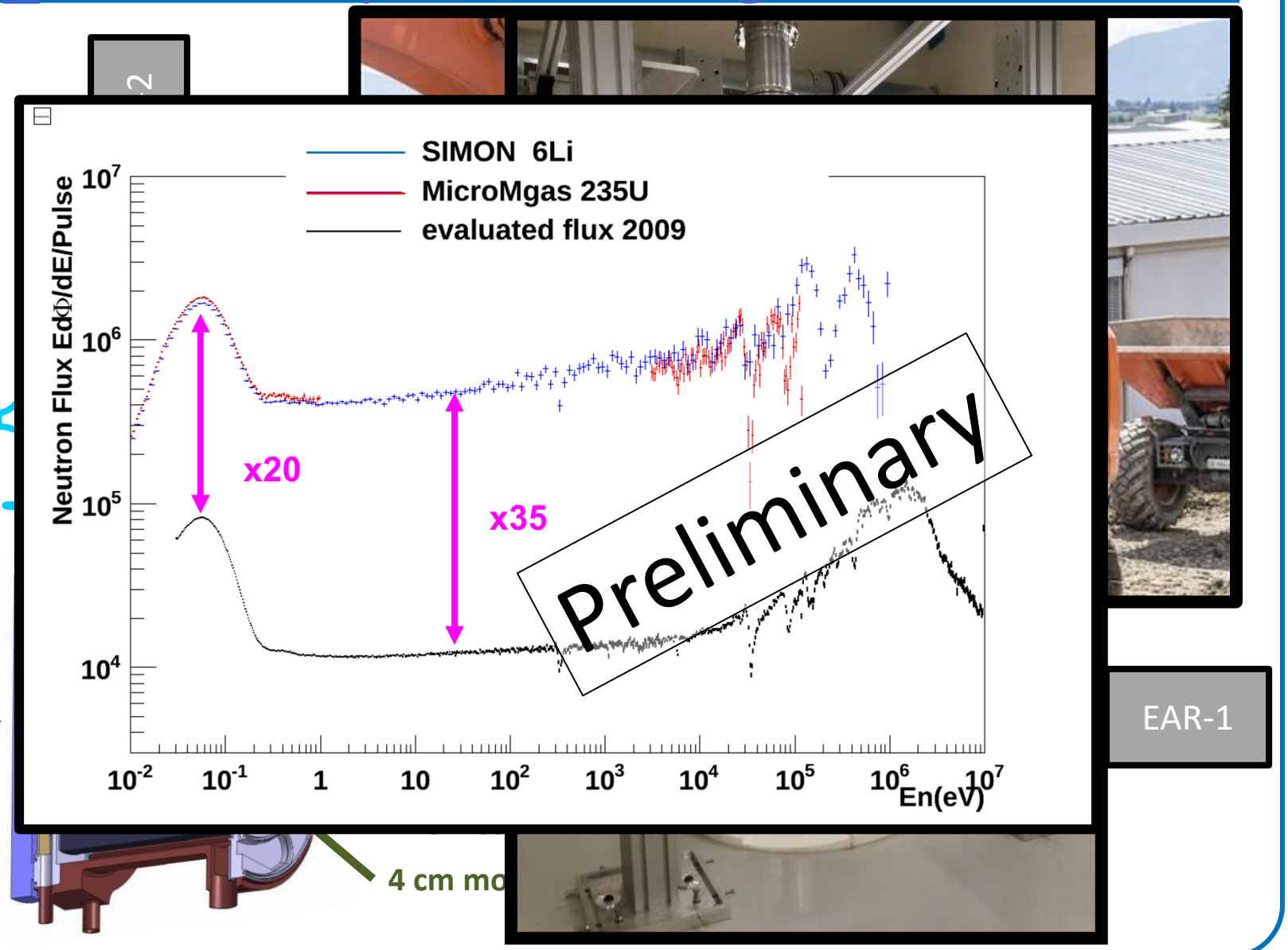


C. Rubbia et al., ***A high resolution spallation driven facility at the CERN-PS to measure neutron cross sections in the interval from 1 eV to 250 MeV***, CERN/LHC/98-02(EET) 1998.

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)

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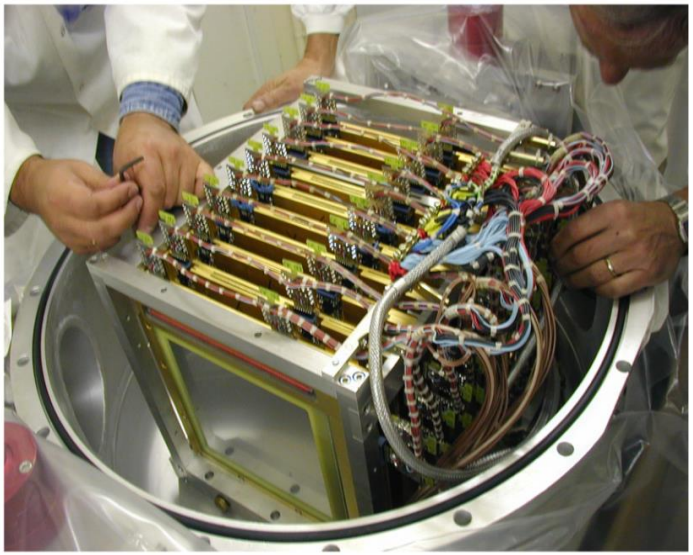
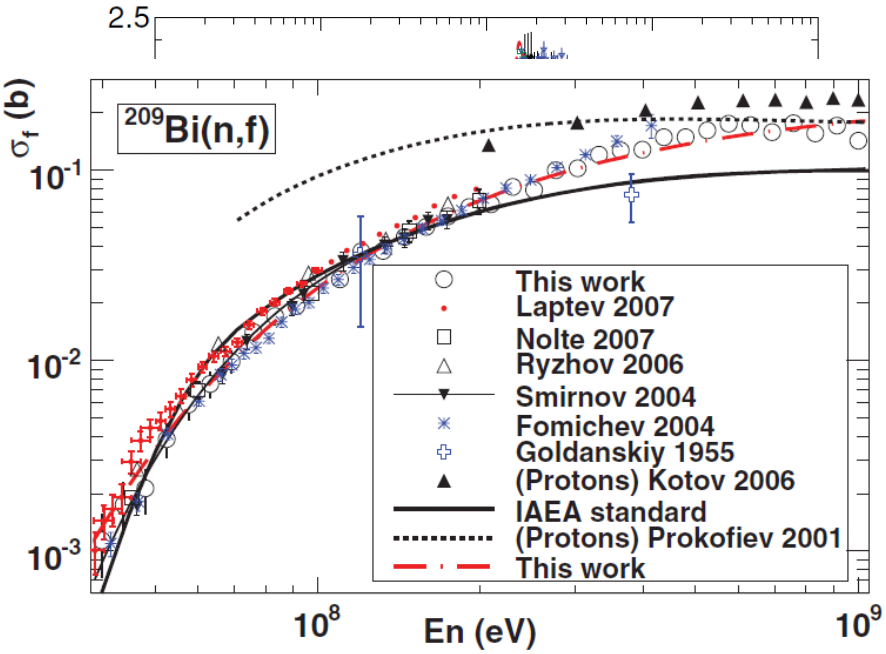
Fission reactions: pushing the high E_n limits!

PPAC: Parallel Plate Avalanche Chamber



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



- **C. Paradela et al., PRC 82 (2010)**

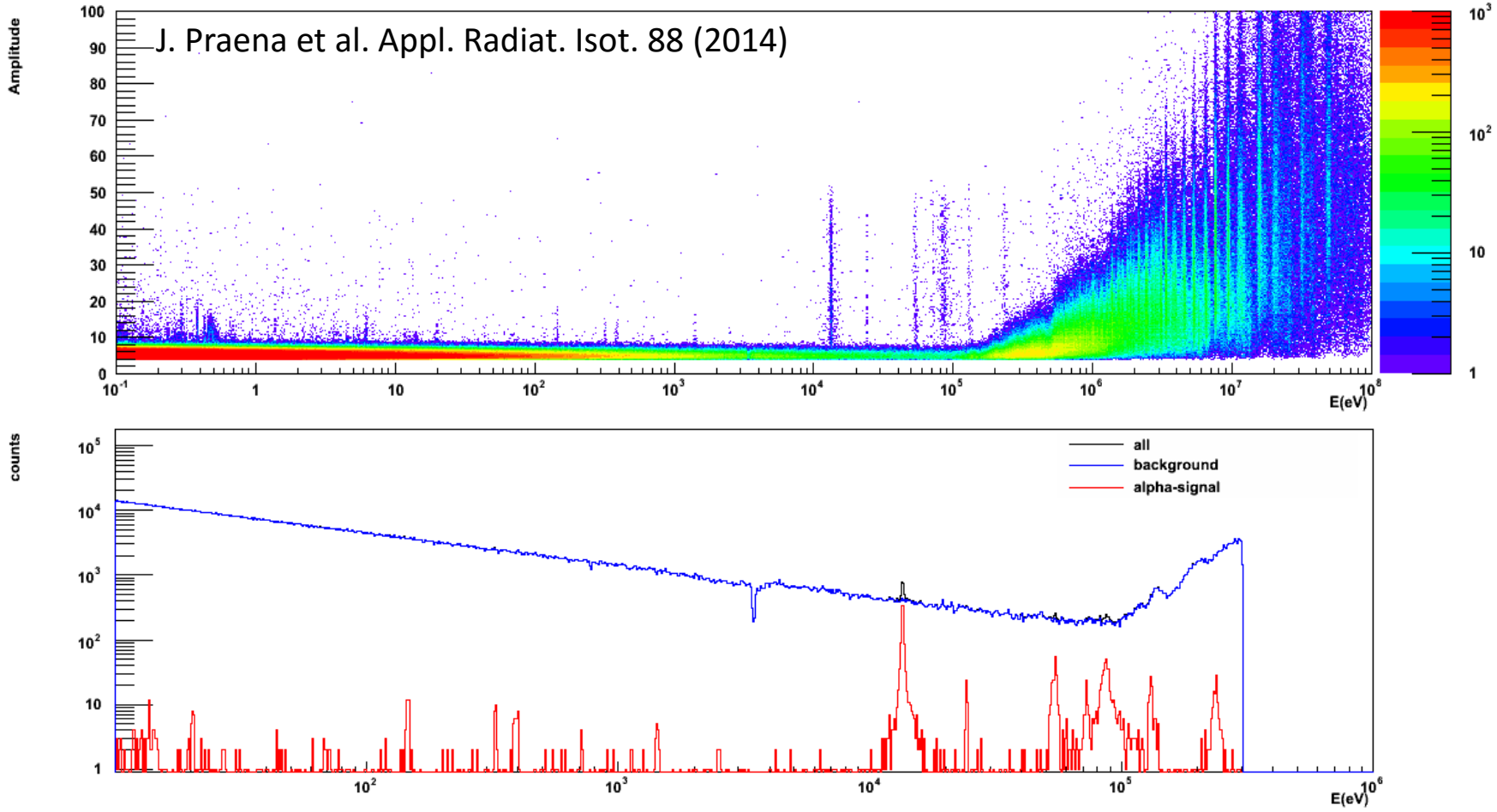
"Neutron-induced fission cross section of ^{234}U and ^{237}Np measured at the CERN …"

- **D. Tarrio et al., PRC 83 (2011)**

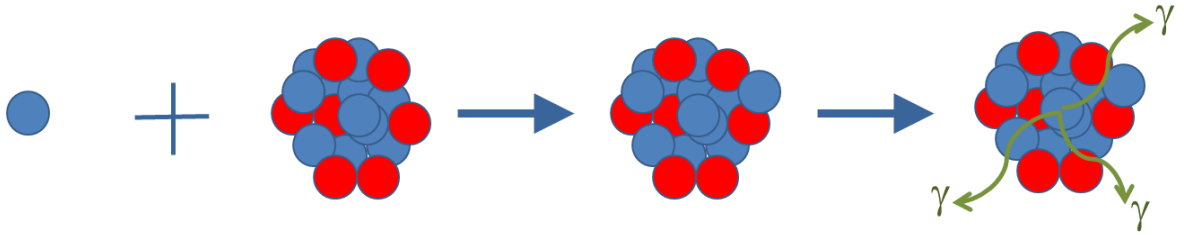
"Neutron-induced fission cross section of ^{nat}Pb and ^{209}Bi from threshold to 1 GeV"

(n,α) reactions for medical physics

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

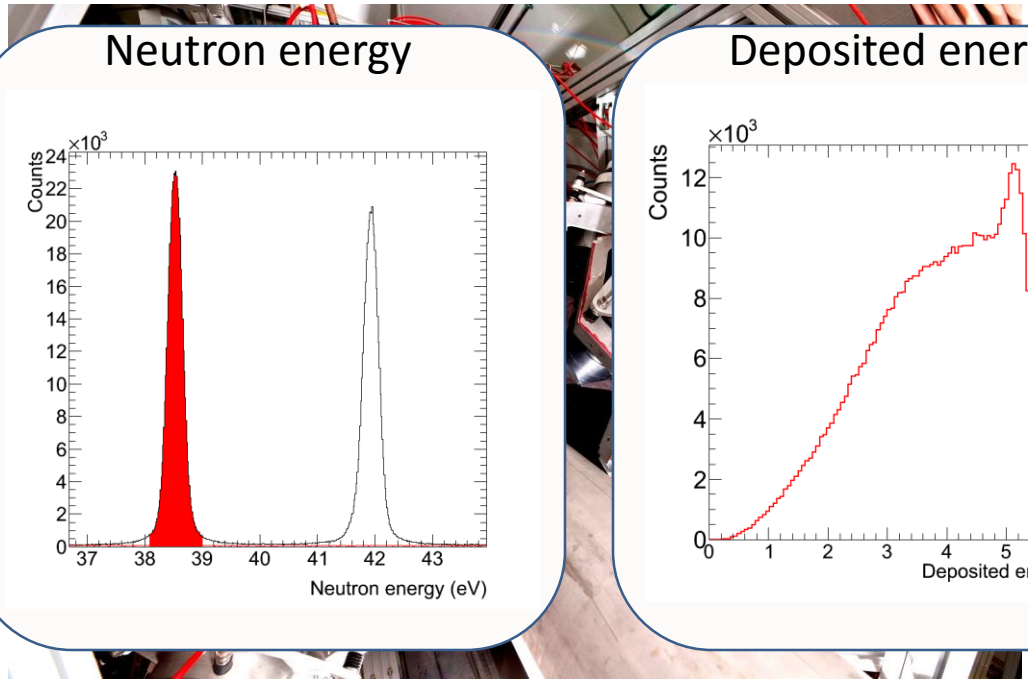


Neutron capture reactions for nuclear tech.



The n_TOF Total Absorption Calorimeter (TAC)

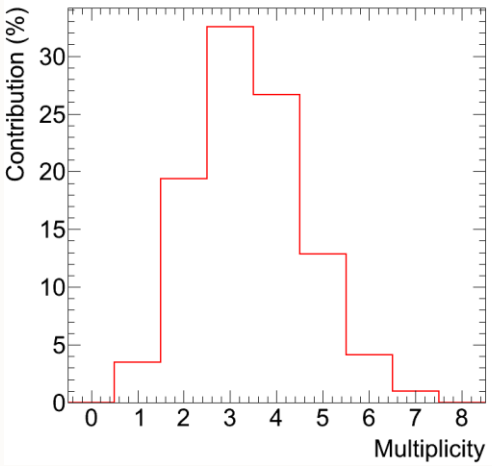
40 BaF_2 scintillator crystals → 95% solid angle coverage



Neutron energy

Deposited energy

Multiplicity

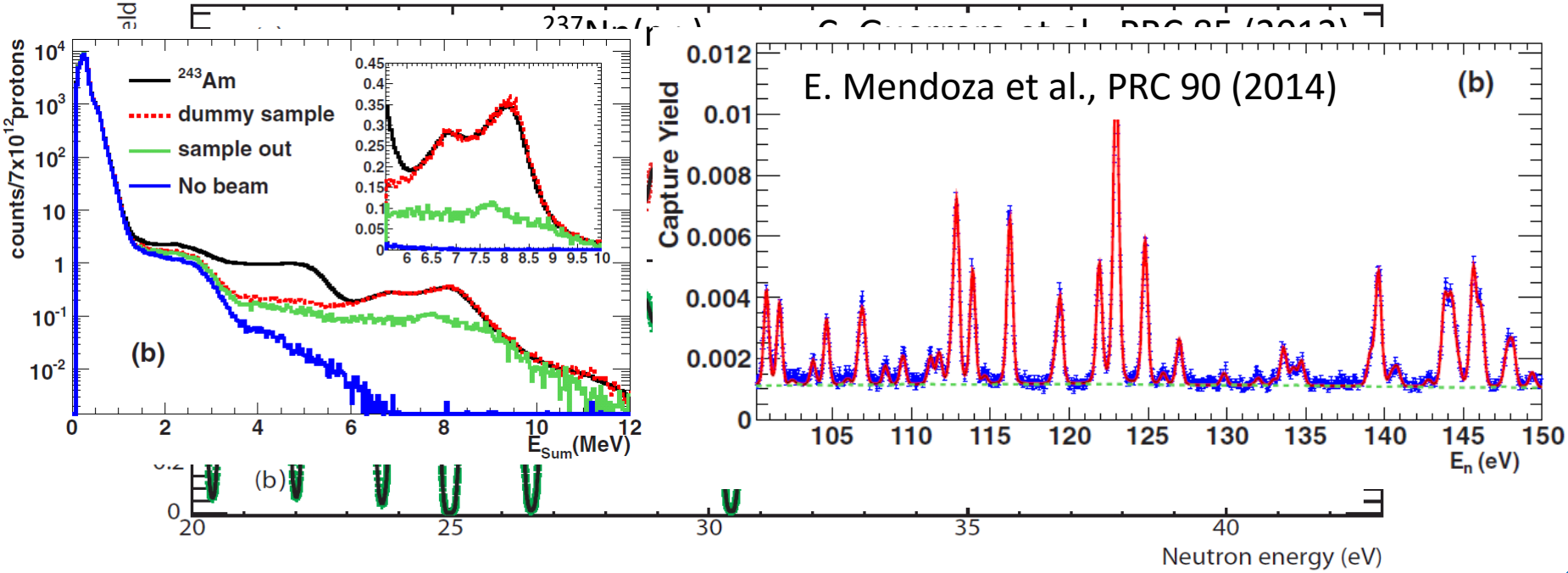


Neutron capture reactions for nuclear tech.

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

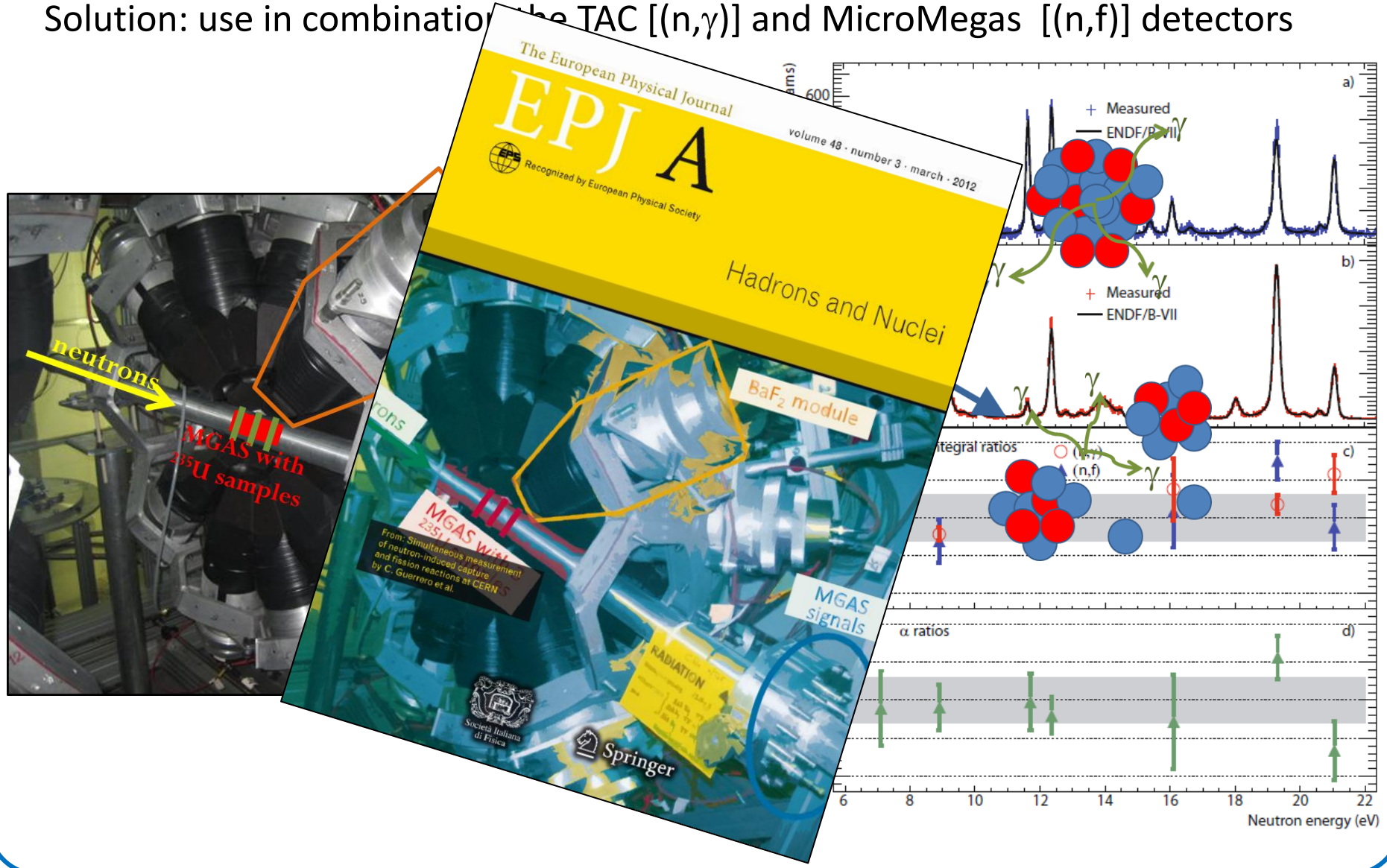
Low material available + high specific activities

This is what n_TOF + TAC are suited for



Neutron capture of fissile isotopes

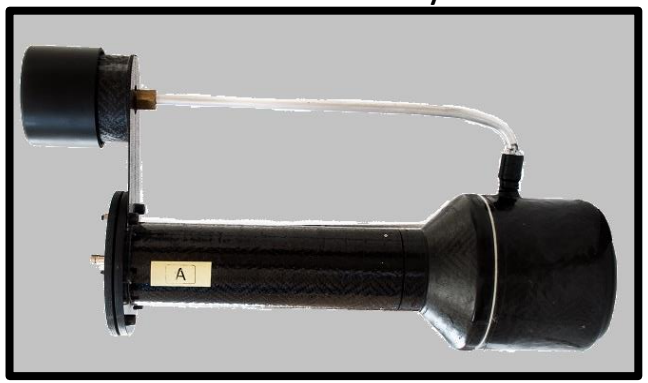
Solution: use in combinatio[illegible]e TAC [(n,γ)] and MicroMegas [(n,f)] detectors



Neutron capture reactions for astrophysics

Neutron scattering dominates (10^4) over neutron capture

VERY low neutron sensitivity scintillators (C_6D_6)



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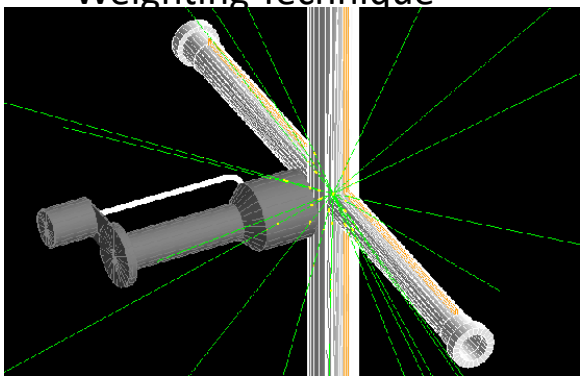
VERY detail MC simulation for the Pulse Height Weighting Technique



- 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 He_3 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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