n_TOF Introduction

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n_TOF External Panel Review

CERN, 14/6/2007

FOR MORE INFO...

http://cern.ch/ntof

Outline

- Introduction
- Facility and Collaboration
- Experimental Infrastructure & Phase I program
- Spallation Target

Need for neutron cross sections

- Nuclear Waste Transmutation
- Medical Isotopes Production and Therapy
- Cleaner Energy Production
- Boron Neutron Capture Therapy [BNCT]
- Astrophysics:
  - Stellar evolution
  - Cosmochronometer
- ...

⇨ **Require the complete and precise knowledge of neutron cross sections**

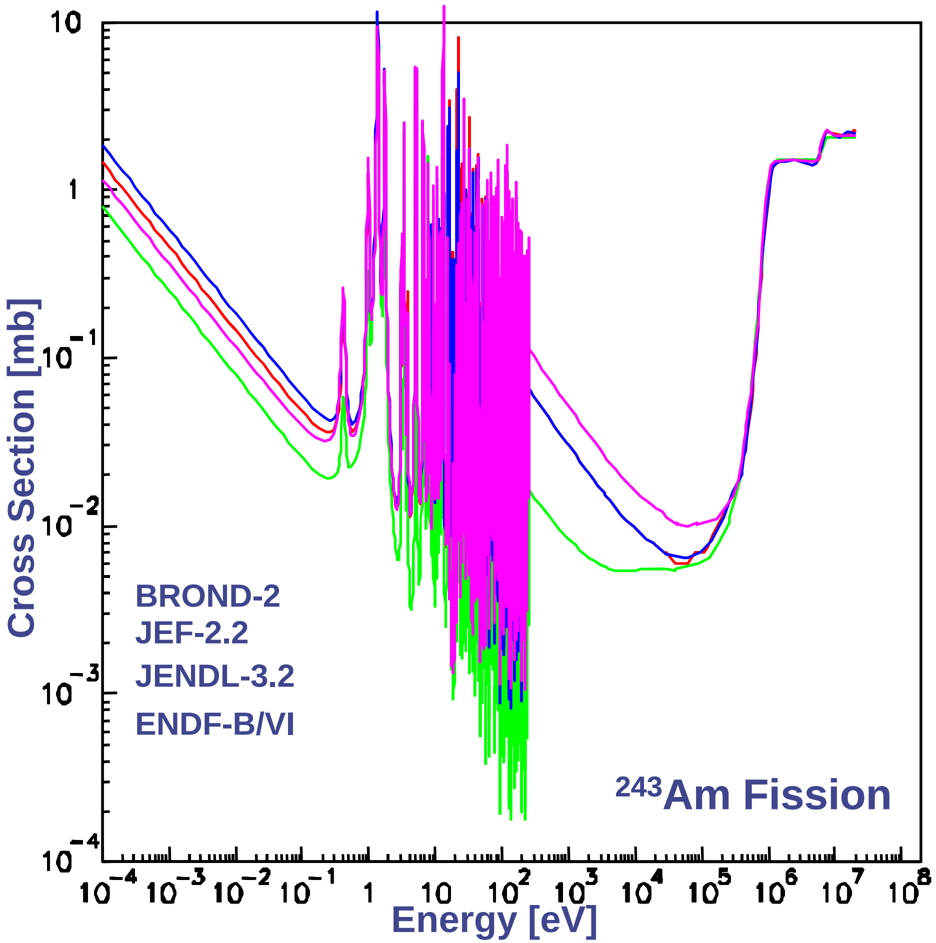
Neutron Cross section Libraries

Publicly Available Databases

- ENDF-B/VI
- JENDL
- JEF
- BROND-2

Problems:

- Limited to 20 MeV
- Differences
- Isotopes Missing
- ...



Concept of n_TOF

1. Knowledge acquired from TARC (PS-211)
2. PS of CERN [26 GeV/c, 3 10^{13} pr / pulse]
3. Spallation target Pb, to produce neutrons
   [1 proton 24 GeV/c ⇒ ~700 neutrons on infinite target]
4. Long flight path ~200 m

Results:

- Wide energy range [thermal to GeV]
  - high energy proton induced spallation process (20 GeV/c proton beam)
- high instantaneous neutron flux [~ 7×10^5 n/cm^2/7×10^{12}p]
  - high neutron yield/incident particle
- high resolution [$\Delta\lambda$=1.8 cm @ low E_n]
  - due to short proton pulse (6 ns RMS) and long flight path
- large suppression for flash and ambient background [0.1 γ/n & 0.2 c/n]
  - reduced γ-ray production, low repetion frequency
- favorable duty cycle for measurements of cross sections of radioactive samples [1/1.2 s^{-1}]

History

- 1997 - Concept by C.Rubbia validated by TARC exp. [CERN/EET/Int. Note 97-19]
- May ’98 - Further development of the initial idea towards a working facility [CERN/LHC/98-02+Add]
- Aug ’98 - CERN-GELINA joint Letter of Intent [CERN/SPSC/98-15, I220]
- 1999 – Construction started
- Oct 2000 – First proton on the spallation target

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 Phase-1 (2001-2004)

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 Phase-2 (> 2006)

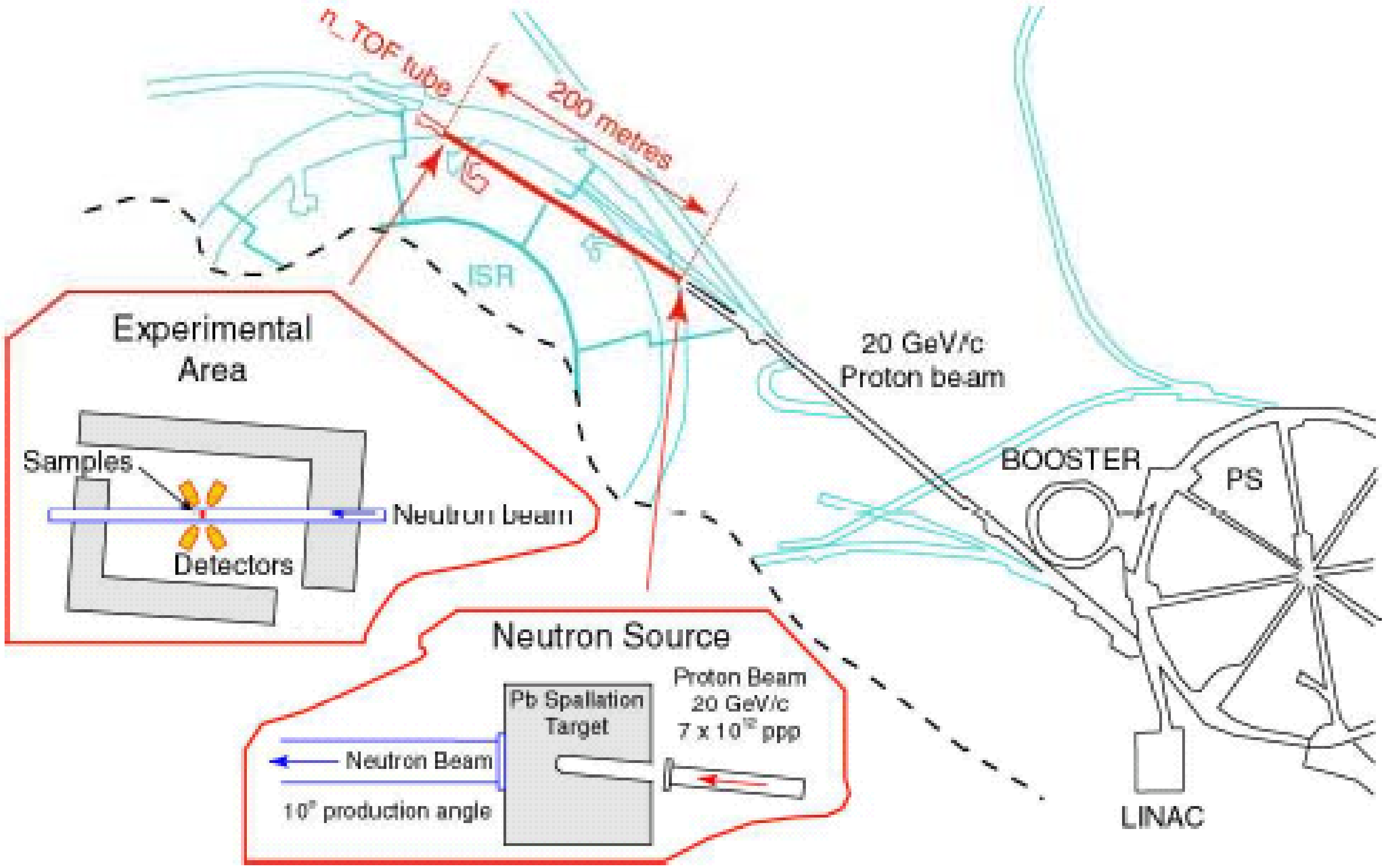
- n_TOF Collaboration Board
  Chairman & Spokesperson

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

- Common M&O budget

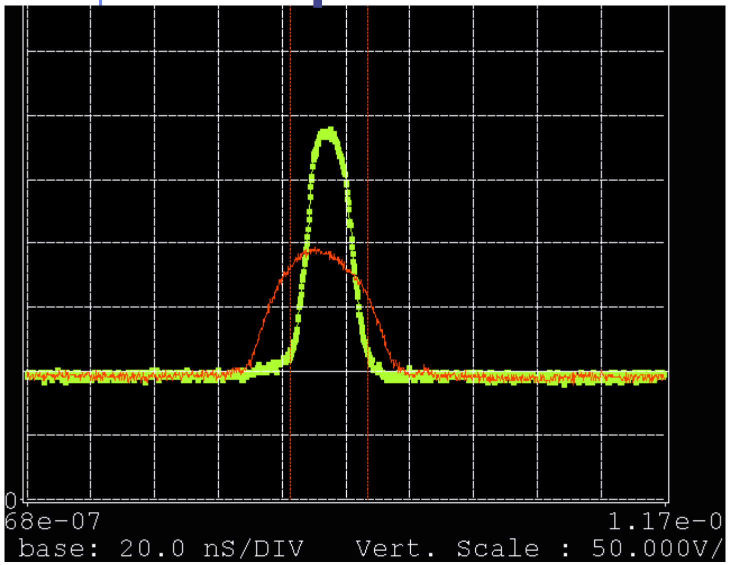
- Some team involved in EC/FP6 projects (EFNUDAT, EUROTRANS)

The n_TOF facility at CERN



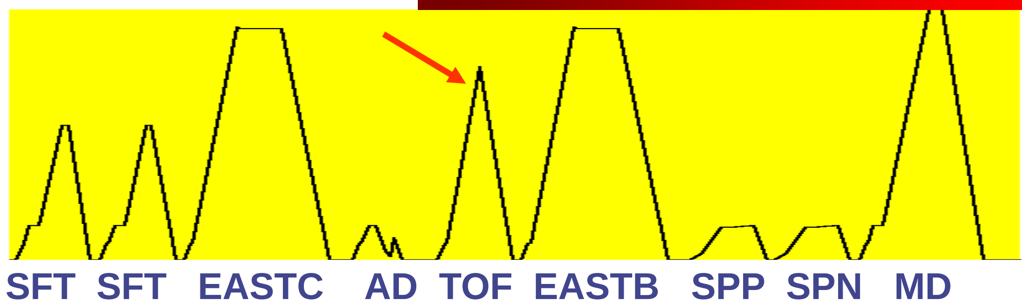
Proton Bunch

Before and After Compression



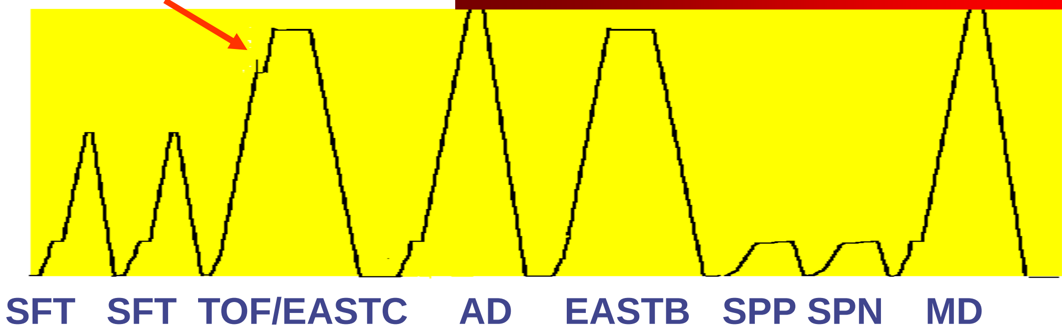
7×10^{12} pr/c @ 20 GeV/c
RMS $\leq$ 7 ns

Dedicated Mode



$I_p = 7\times10^{12}$ p, ΔT_{min}=1.2s

Parasitic Mode



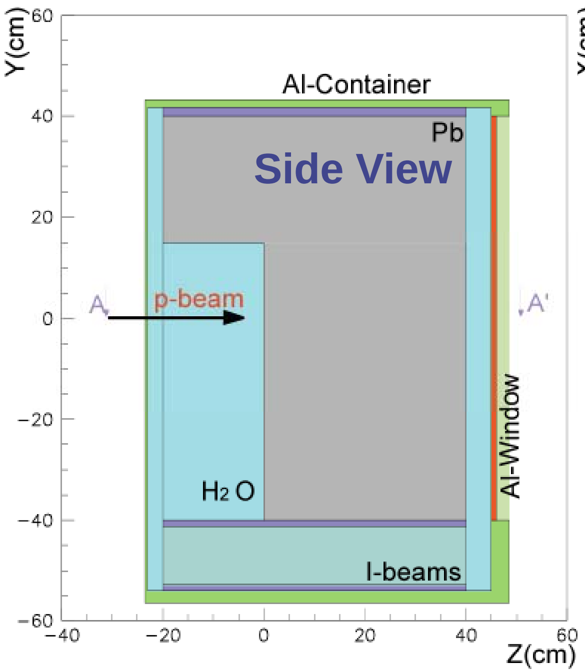
$I_p = 4\times10^{12}$ p, ΔT_{min}=2.4s

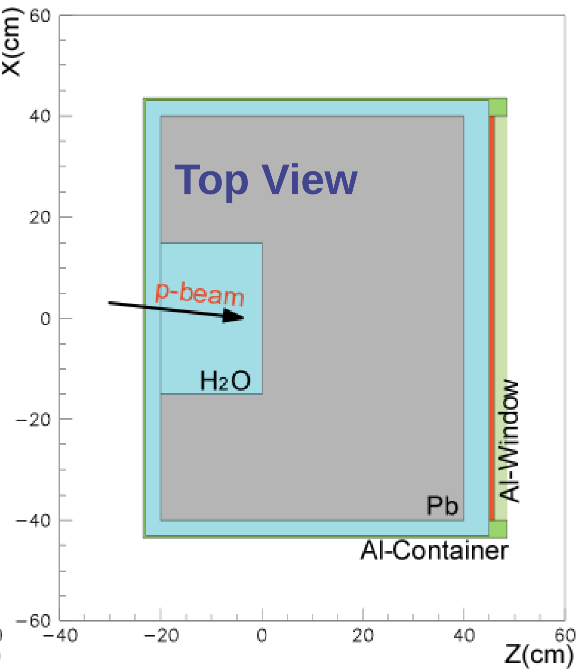
FOR MORE INFO...

http://accelconf.web.cern.ch/AccelConf/e00/PAPERS/THP1B10.pdf

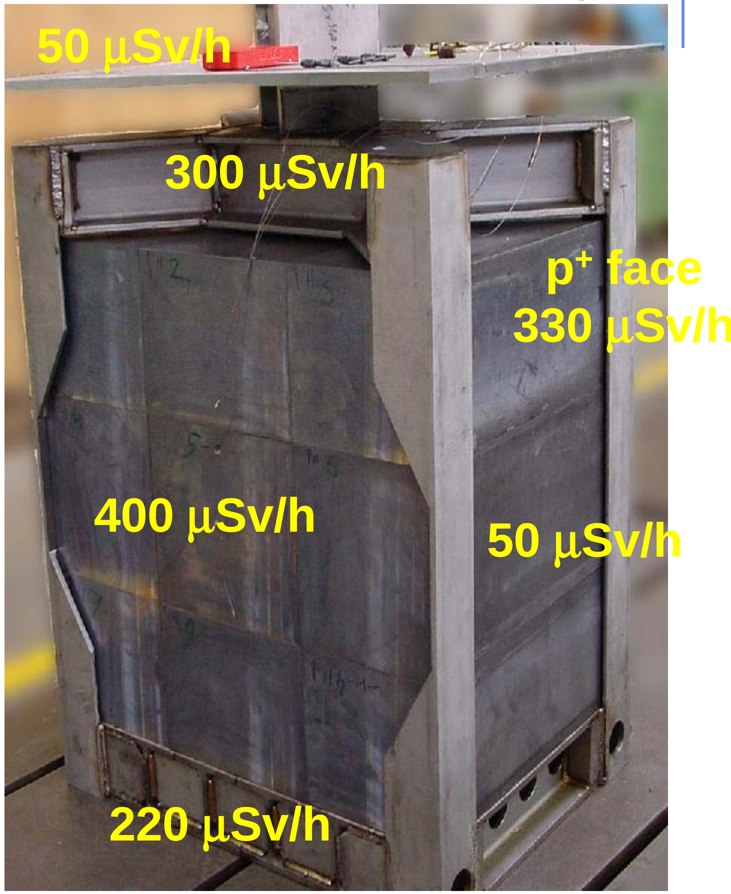
Lead Target

- Dimensions: 80 × 80 × 60 cm^3
- Pure Lead: 4 t
- H_2O moderator: 5 cm
- Al-window: 1.6 mm
- Al-container: 140 ℓ

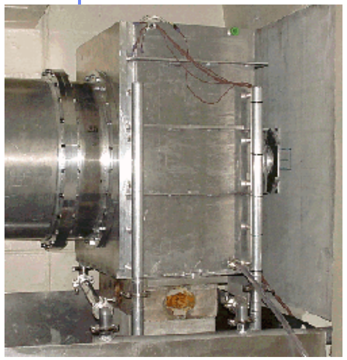




1 month irradiation
2 months of Cooling



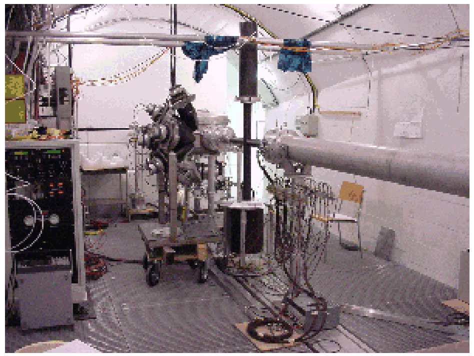
n_TOF Virtual Tour



Lead Container

Sweeping Magnet

2nd Collimator

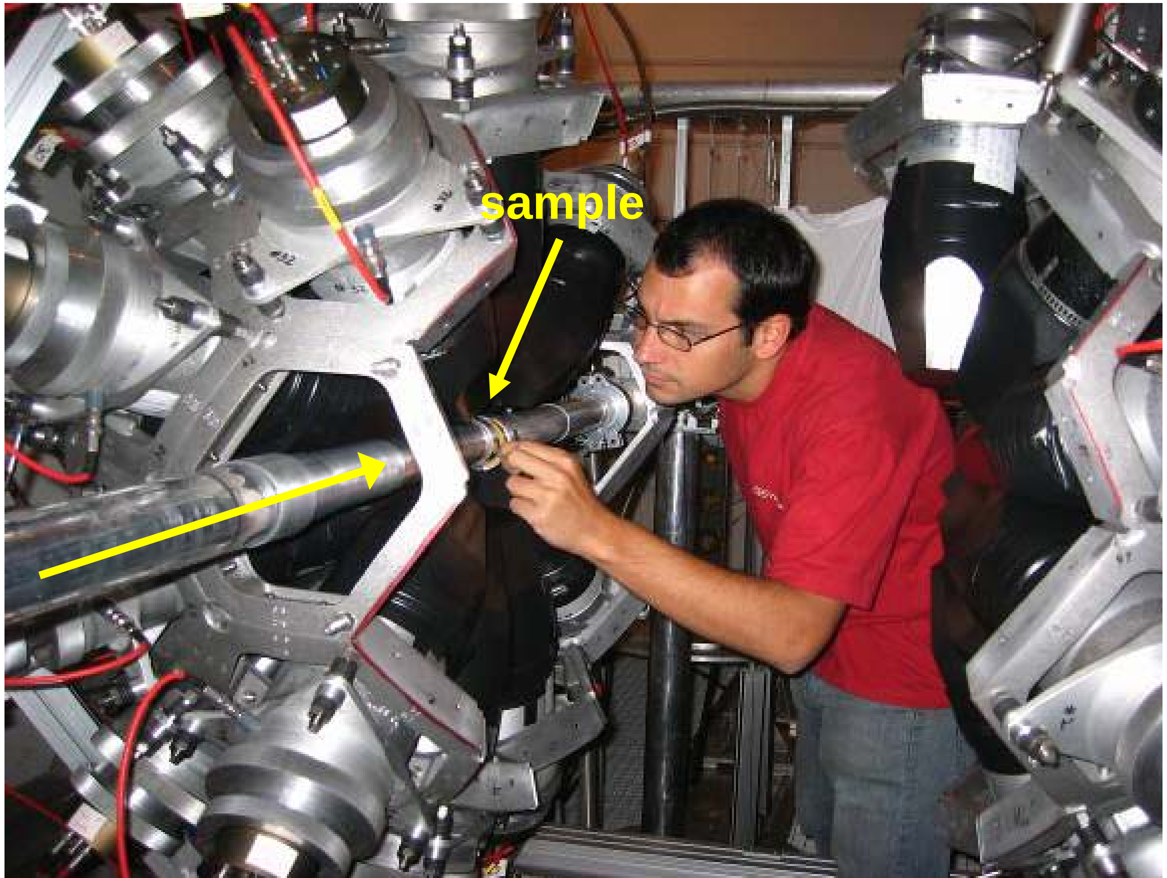


Exp. Area

n_TOF TAC for (n,γ) measurements

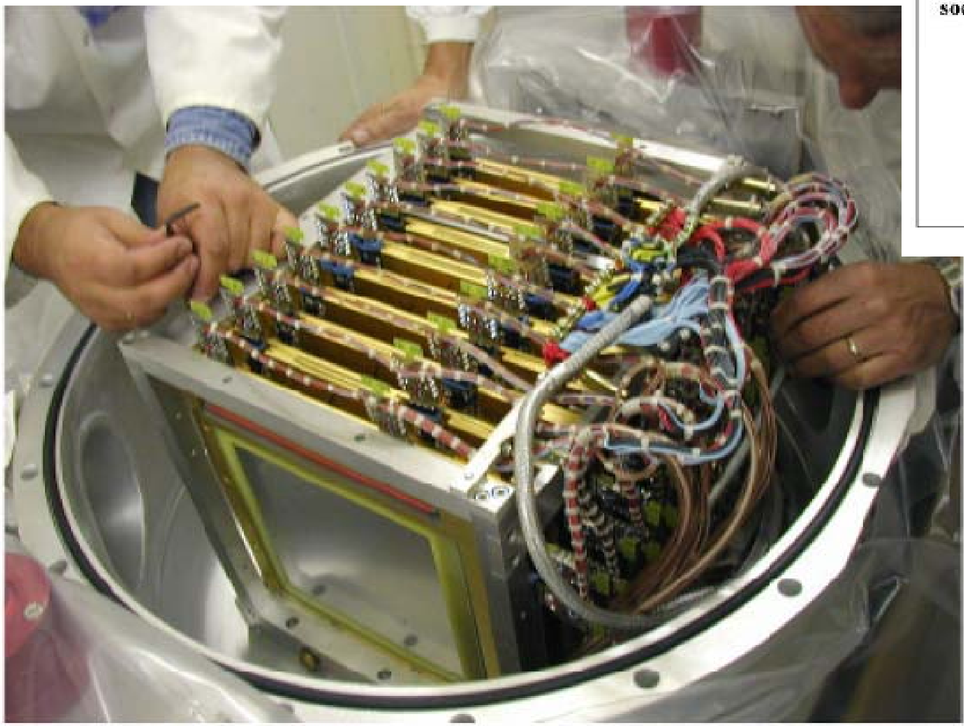
- Structure mounted in April-04
- 4π geometry: end of May-04
- 1.5 month commissioning
- Au(n,γ) & other standards

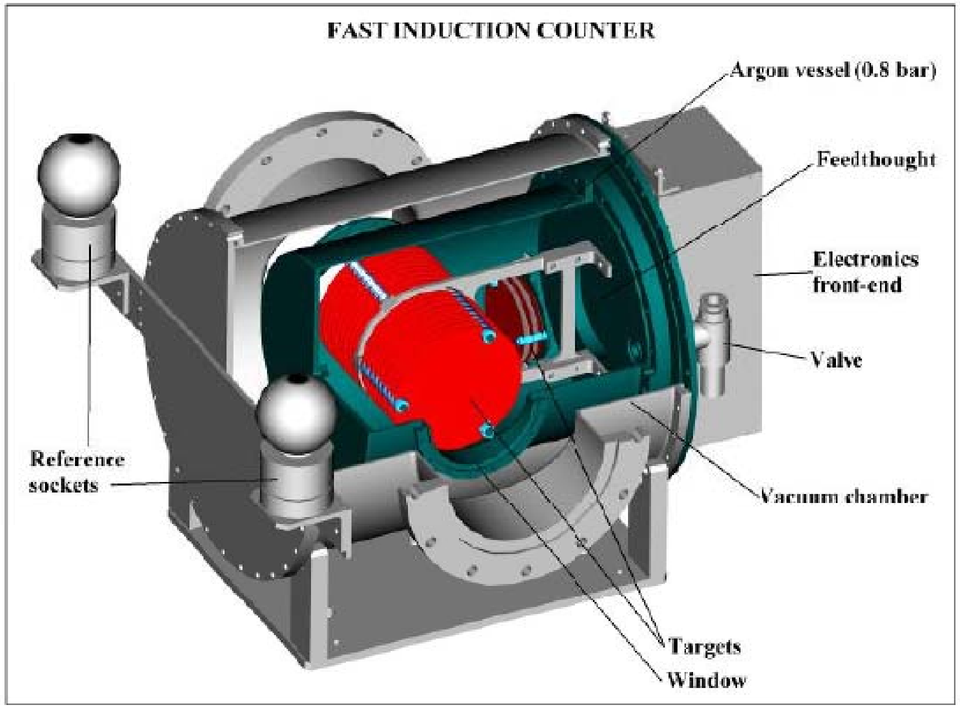
First measurement with a radioactive sample started in August 2004
^{237}Np(n,γ)



n_TOF fission detectors

- 20x20 cm^2
- Isobutane gas 7 mbar
- HV 500-600 V
- 3 mm between electrodes
- 1 anode (a few ns signal width)
- Electrode thickness: 1.5 μm (Mylar+Al)
- Deposit thickness : 100-300 μg/cm^2
- Backing thickness : 0.1 μm (Al)
- : 1.5 μm (Mylar)
- Fission event identification: T2 in coincidence with T1





- Gas: Ar (90%) CF_4 (10%)
- Gas pressure : 720 mbar
- Electric field : 600 V/cm
- Gap pitch : 5 mm
- Electrode diameter : 12 cm
- Electrode thickness : 15 μm (Al)
- Deposit thickness : 125 μm/cm^2
- Backing thickness : 100 μm (Al)
- Window thickness : 125 μm

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

n_TOF experiments 2002-4

- data analysis completed, results published
- data analysis completed, paper in preparation
- data analysis in progress

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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- $^{186,187,188}Os$
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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

Spallation Target

Characteristic Parameters

- Neutron Flux *Φ* ***[n/cm²/s]***
  - Irradiation time
  - Sample size & mass
  - Radioactive isotopes
  - Longer flight paths
- Effective Neutron Path *$\lambda \pm \Delta\lambda$* ***[cm]***
  - Resolution
  - Evaluation process
  - Limit of unresolved resonances

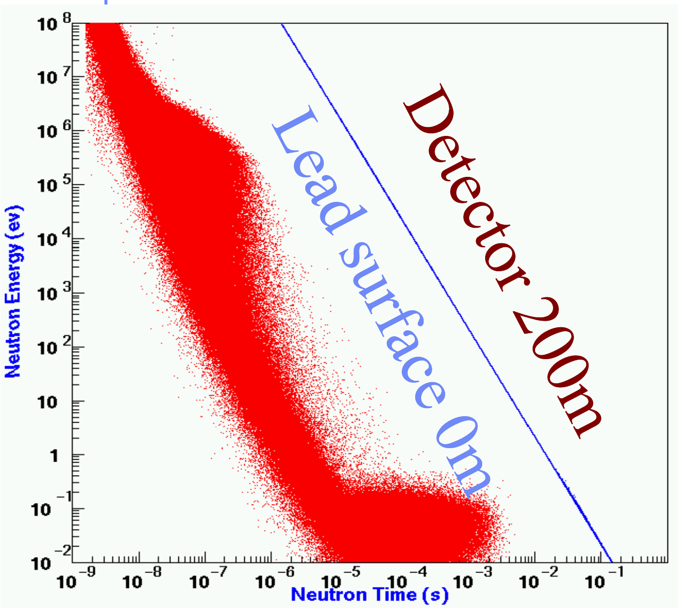
FOR MORE INFO...

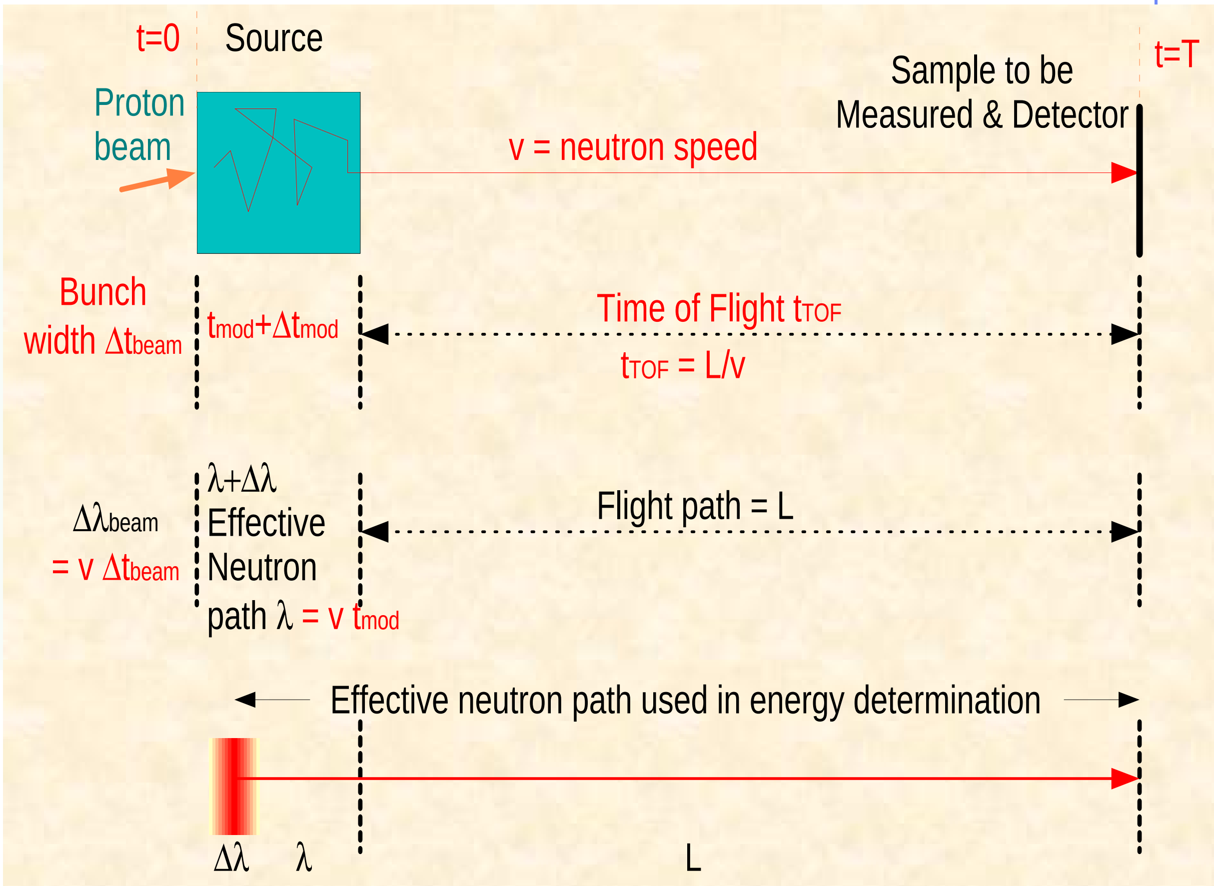
N_TOF Int. Note 1998-02/BEAM

Spallation Target Material Properties

Material	Lead	Tantalum	Tungsten
Symbol	Pb	Ta	W
Z / A	82 / 208	73 / 181	74 / 183
Density ρ(g/cm^3)	11.35	16.65	19.3
Melting Point (C)	327	3017	3422
Specific Heat C_p @293K (J/kg/K)	129	140	132
Thermal Conductivity (W/m/K)	35.3	57.5	174
20 GeV/c p^+ Inelastic Interaction Length λ(cm)	16.2	10.6	9.2
Capture Resonance Integral (n,γ) (En < 20MeV)	0.0061	656.5	333
Thermal Integral (n,γ)	0.00056	23.7	11.6
Inelastic integral (n,n')	2.59	10	11
(n,2n)	1.385	1.387	1.8
n/p/GeV	30	29	29
Cost (indicative)	$1/kg	$70/kg	$110/kg

Energy-Time Relation





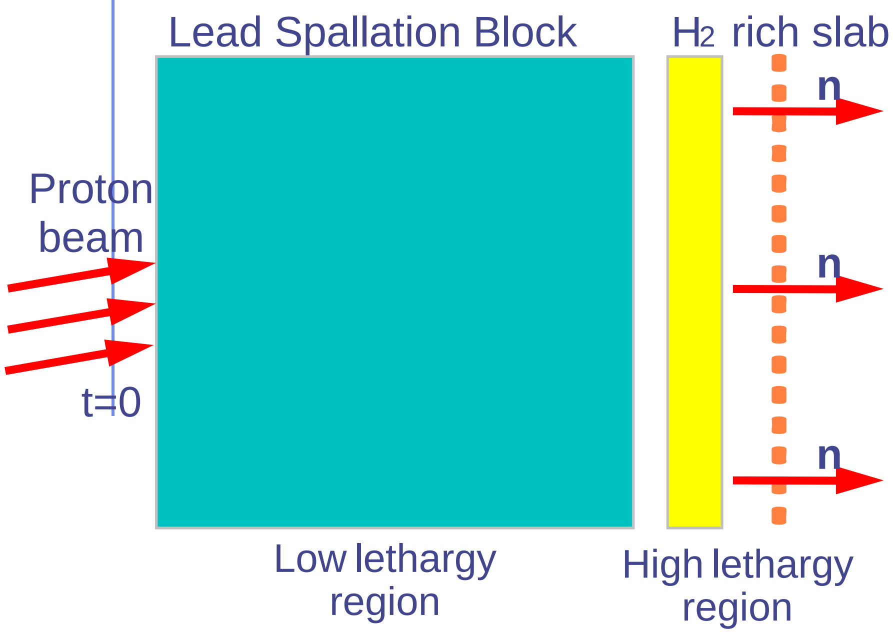
Moderation $$E = \frac{K}{(t+t_o)^2}$$

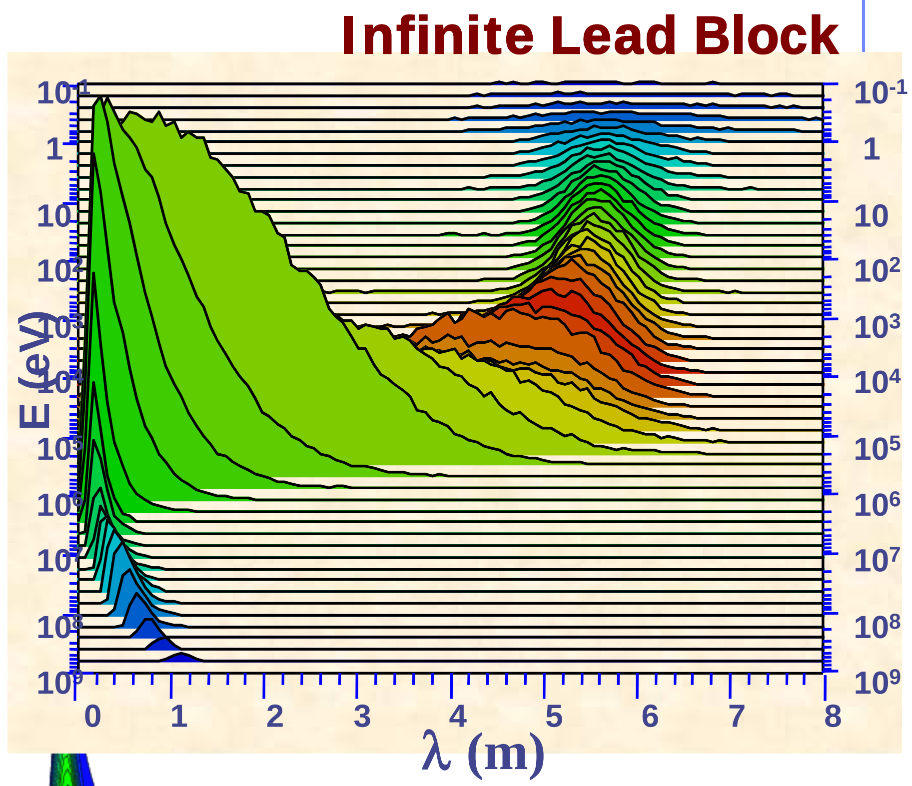
Flight $$E = \frac{m\,L^2}{2\,t^2}$$

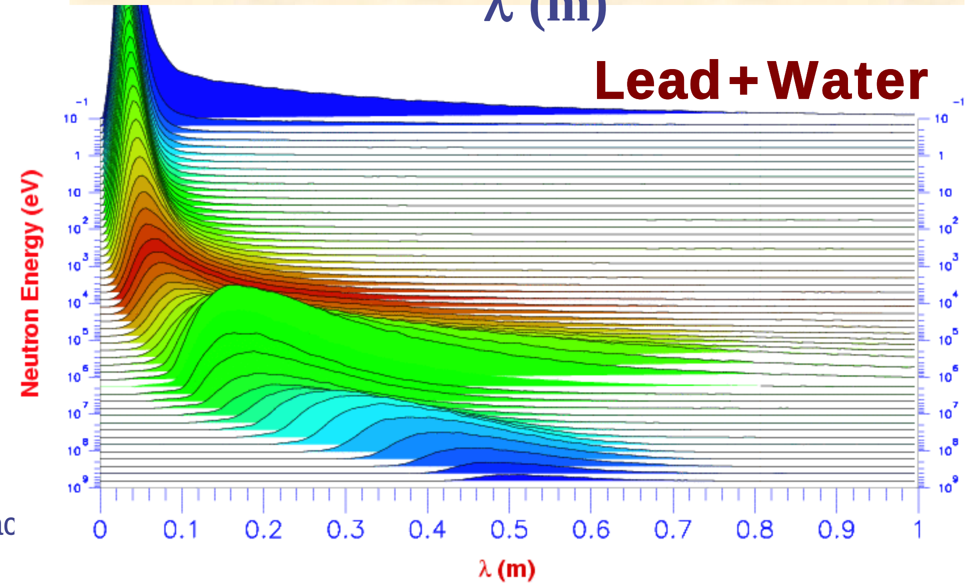
Uncertainty $$\frac{\Delta E}{E} = \frac{-2\Delta t}{t_{TOF}} = \frac{2\Delta\lambda}{\lambda + L}$$

The neutron velocity v is derived from the "effective neutron path" $v=(\lambda+L)/t$ with an uncertainty $\Delta v = \Delta\lambda/t$

Water moderator



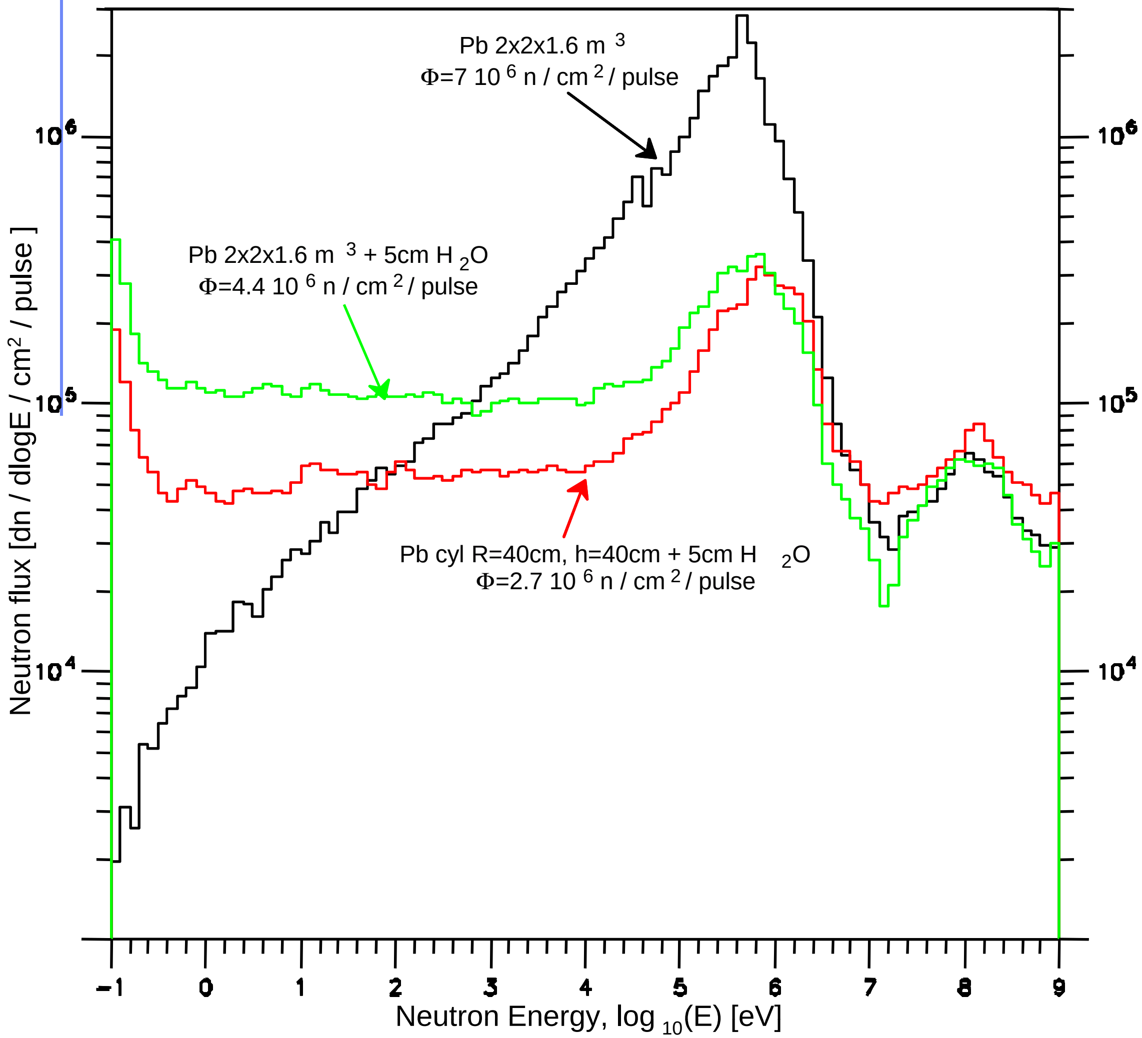




The spallation target is followed by *a thin (5 cm) Hydrogen rich moderator*

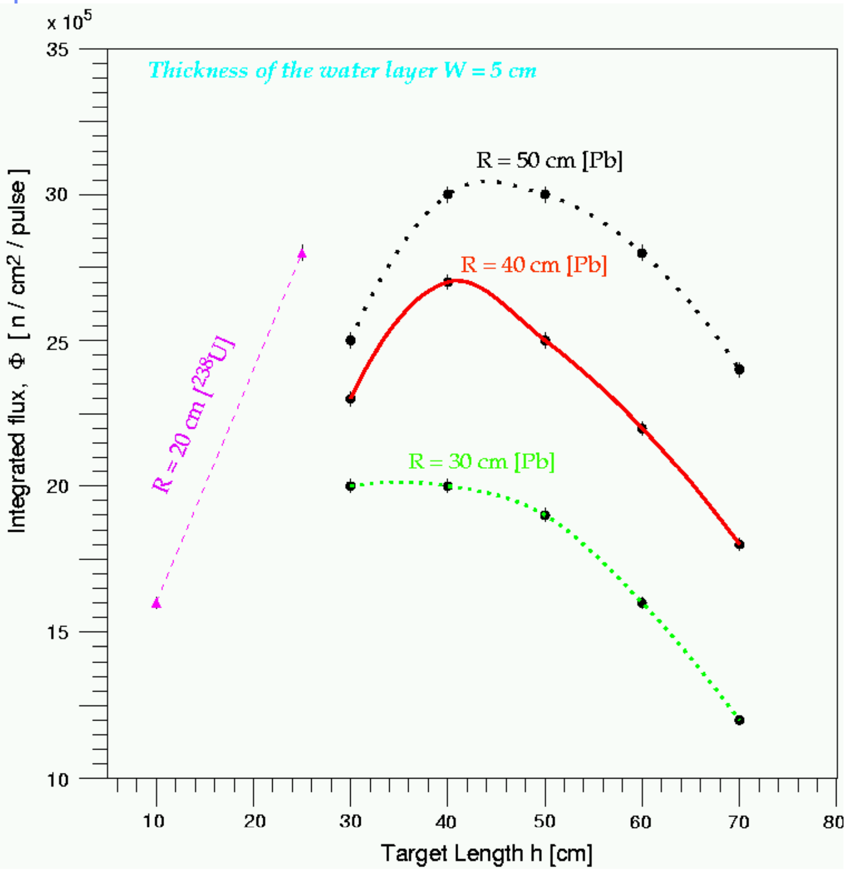
The neutron speed *v* is abruptly reduced while the time *Δt* remains essentially unchanged

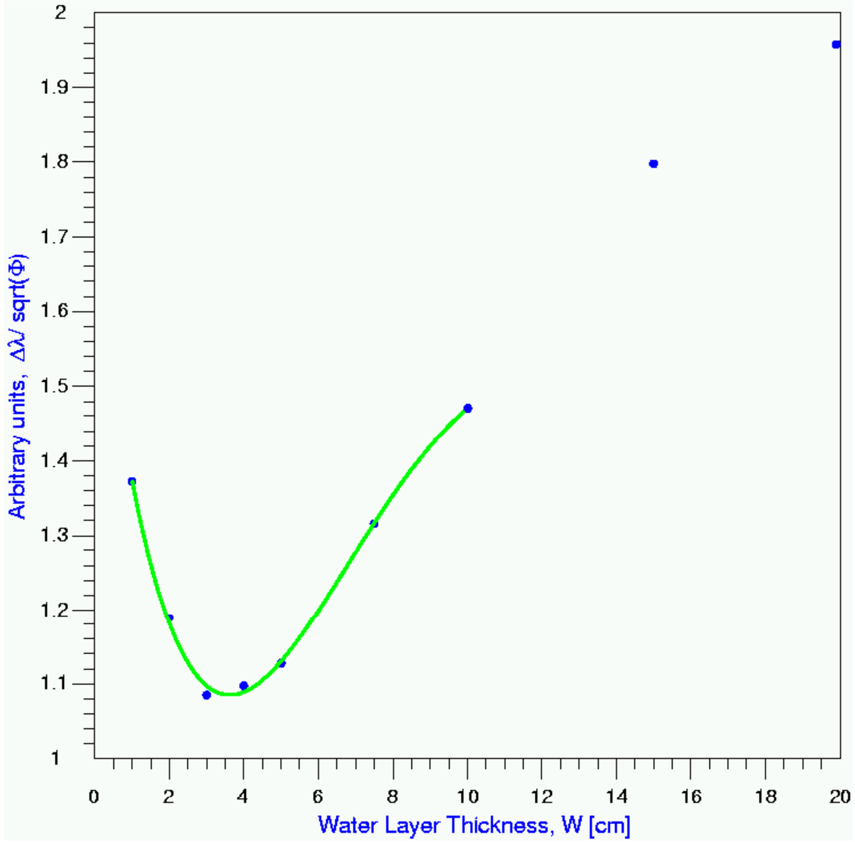
Water moderator: Effect on neutron flux



- Black Optimized lead target for maximum production of neutrons. Dimensions 2x2x1.6 m^3. Strong component from evaporation but no thermal neutrons
- Green Lead target as above with 5cm water layer. Moderation of neutrons is evident reducing the evaporation component and pushing neutrons to lower energies very quickly
- Red Ideal cylindrical target where neutron production and resolution are optimized.

Optimization Lead Spallation target





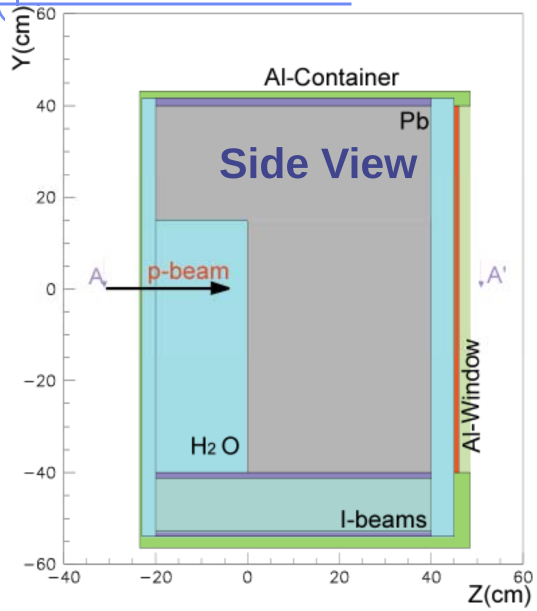
Important Parameters: $\Phi \sim \Phi_o / L^2$

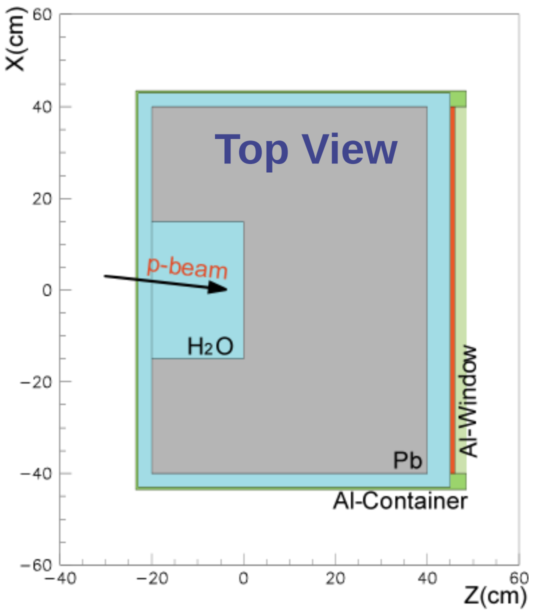
$\Delta E/E \sim 2\, \Delta\lambda / L$

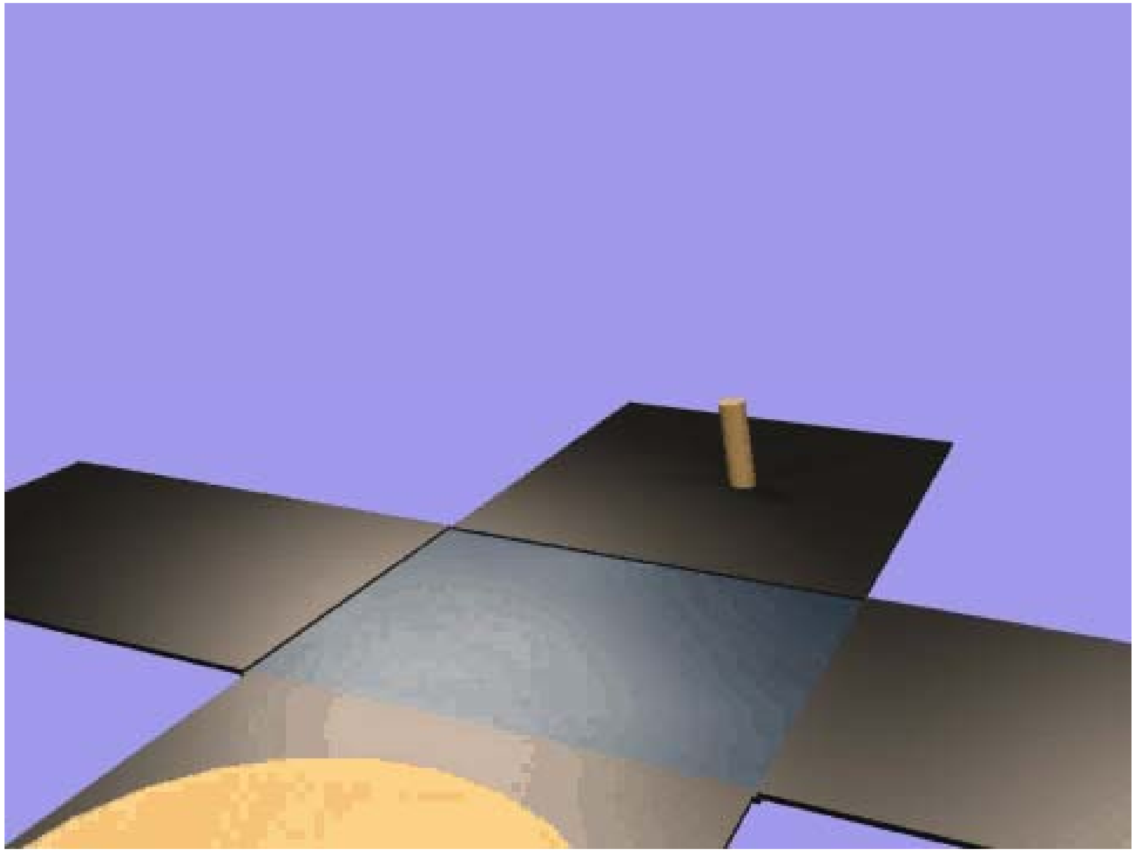
Figure of Merit $\Delta\lambda / \sqrt{\Phi}$

For more info: CERN/INTC/2000-04

Lead Target Design







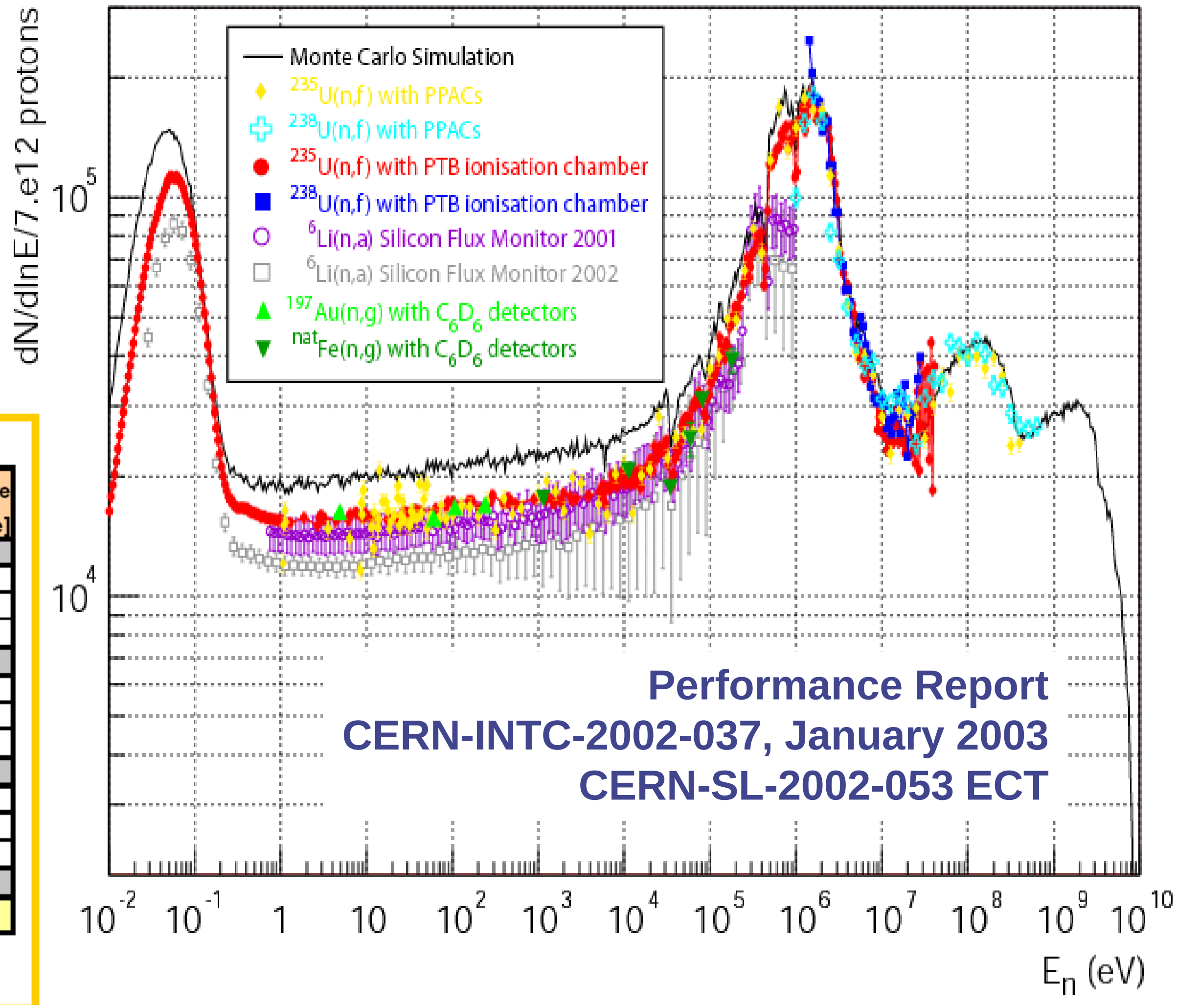
n_TOF basic parameters

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
(capture mode)

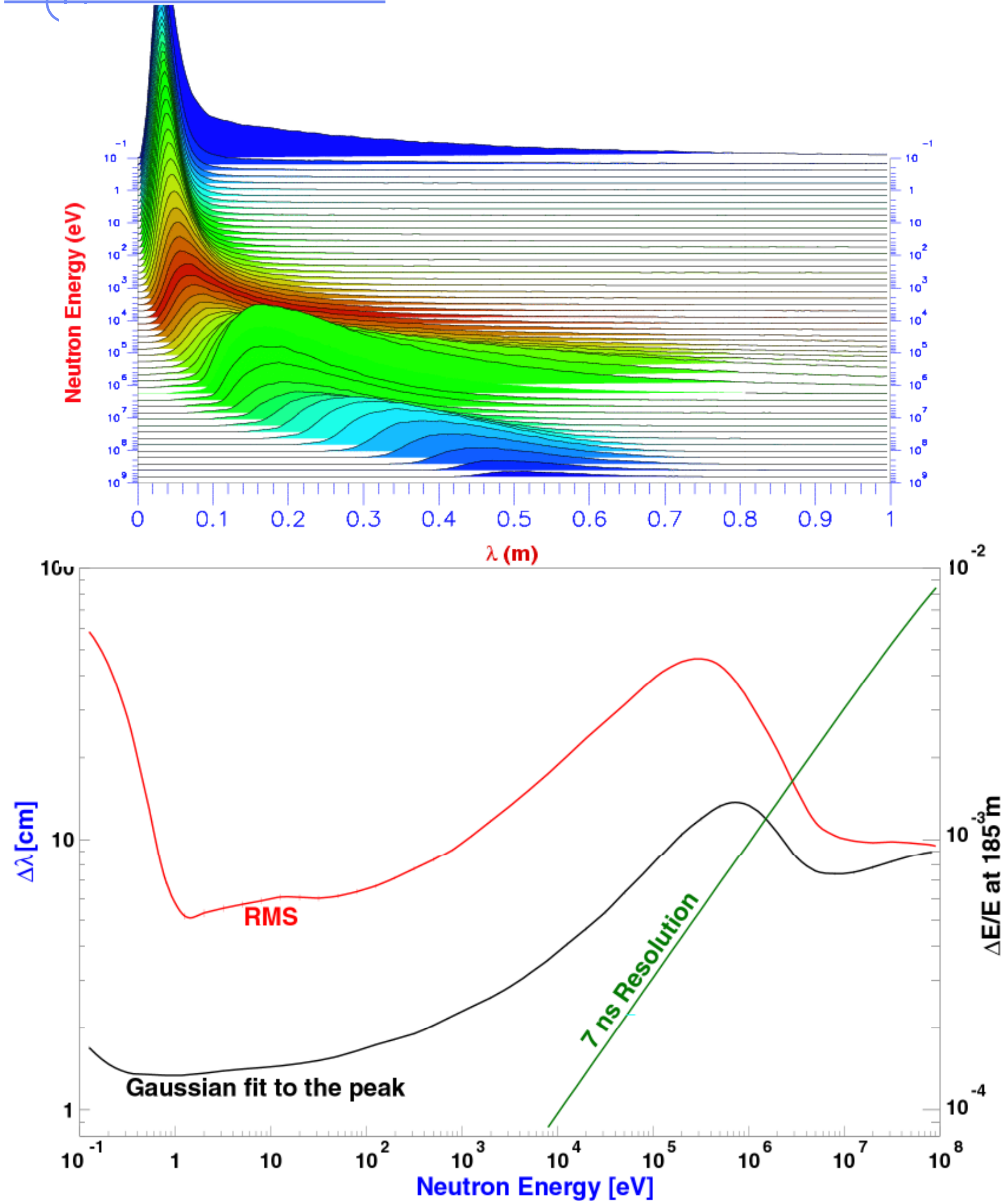


The neutron fluence in EAR-1

Energy range	Uncollimated [n/pulse/cm2]	Capture mode [n/pulse]	Fission mode [n/pulse]
< 1 eV	**2.0E+05**	**3.1E+05**	**2.0E+06**
1 eV - 10 eV	2.7E+04	4.5E+04	2.9E+05
10 eV - 100 eV	2.9E+04	4.7E+04	3.1E+05
100 eV - 1000 eV	3.0E+04	5.1E+04	3.3E+05
1 eV - 1 keV	**8.6E+04**	**1.4E+05**	**9.3E+05**
1 keV - 10 keV	3.2E+04	5.4E+04	3.6E+05
10 keV - 100 keV	3.9E+04	7.1E+04	4.7E+05
100 keV - 1000 keV	1.1E+05	2.3E+05	1.5E+06
1 keV - 1 MeV	**1.8E+05**	**3.5E+05**	**2.3E+06**
1 MeV - 10 MeV	8.3E+04	2.4E+05	1.7E+06
10 MeV - 100 MeV	2.8E+04	7.2E+04	5.1E+05
> 100 MeV	4.4E+04	1.2E+05	5.6E+05
1 MeV - > 100 MeV	**1.6E+05**	**4.4E+05**	**2.7E+06**
Total	**6.2E+05**	**1.2E+06**	**8.0E+06**

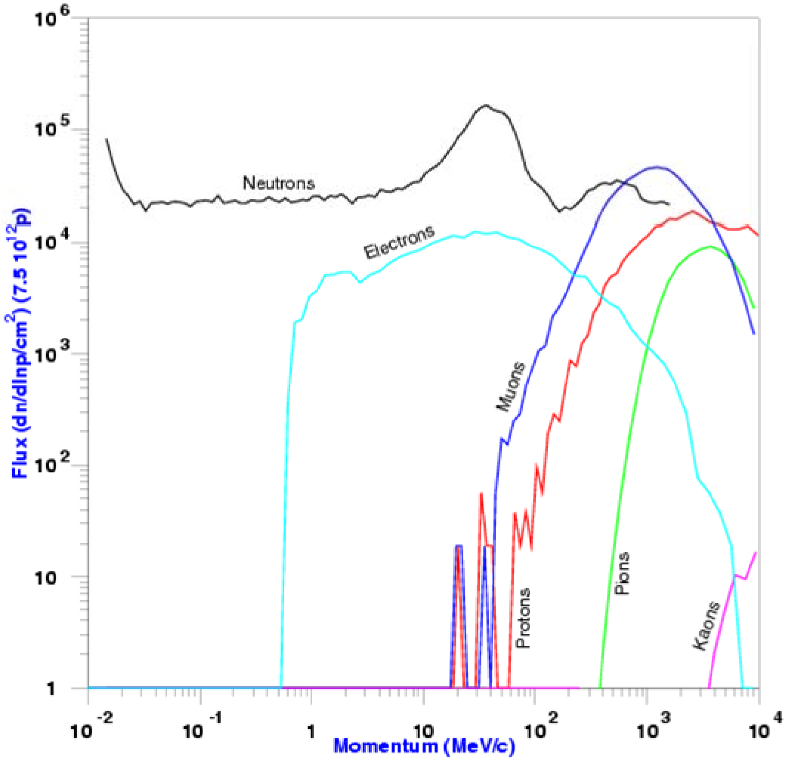
Note: 1 pulse is 7E+12 protons. Collimated fluence (fission and capture modes) is integrated over the beam surface.

Resolution

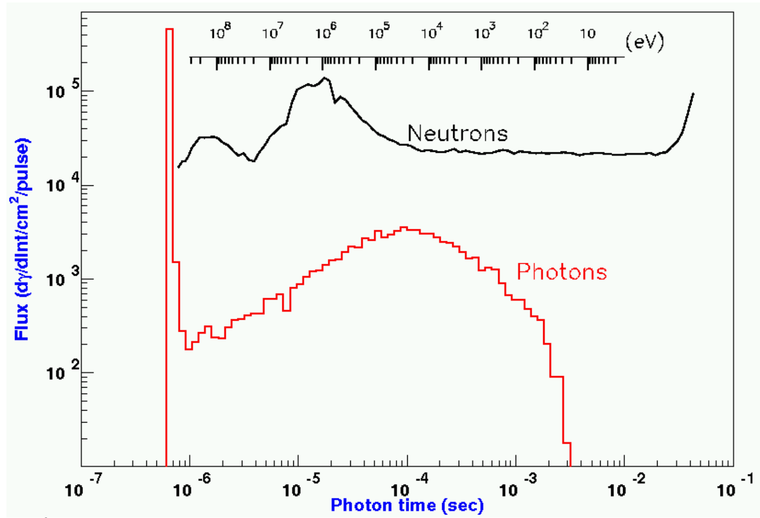


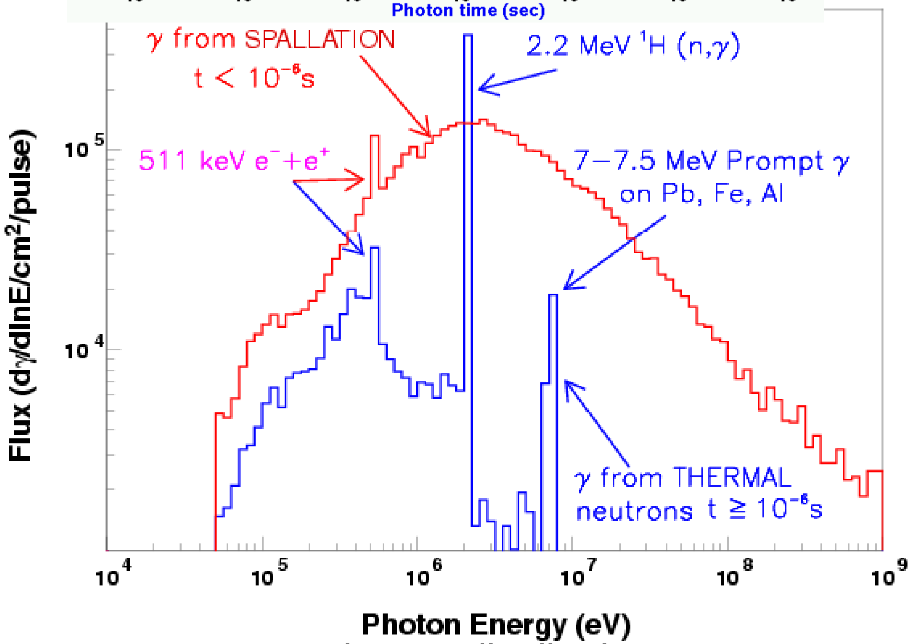
- The resolution experiences a peak + a tail due to the peculiarity of the moderation process of the lead + water moderator target
- Δλ was represented with 2 ways: (i) as the sigma obtained by a fit on the peak of a small energy interval (20 bpd), (ii) as the RMS of the λ distribution over the same energy interval

Charged Particles and Photons



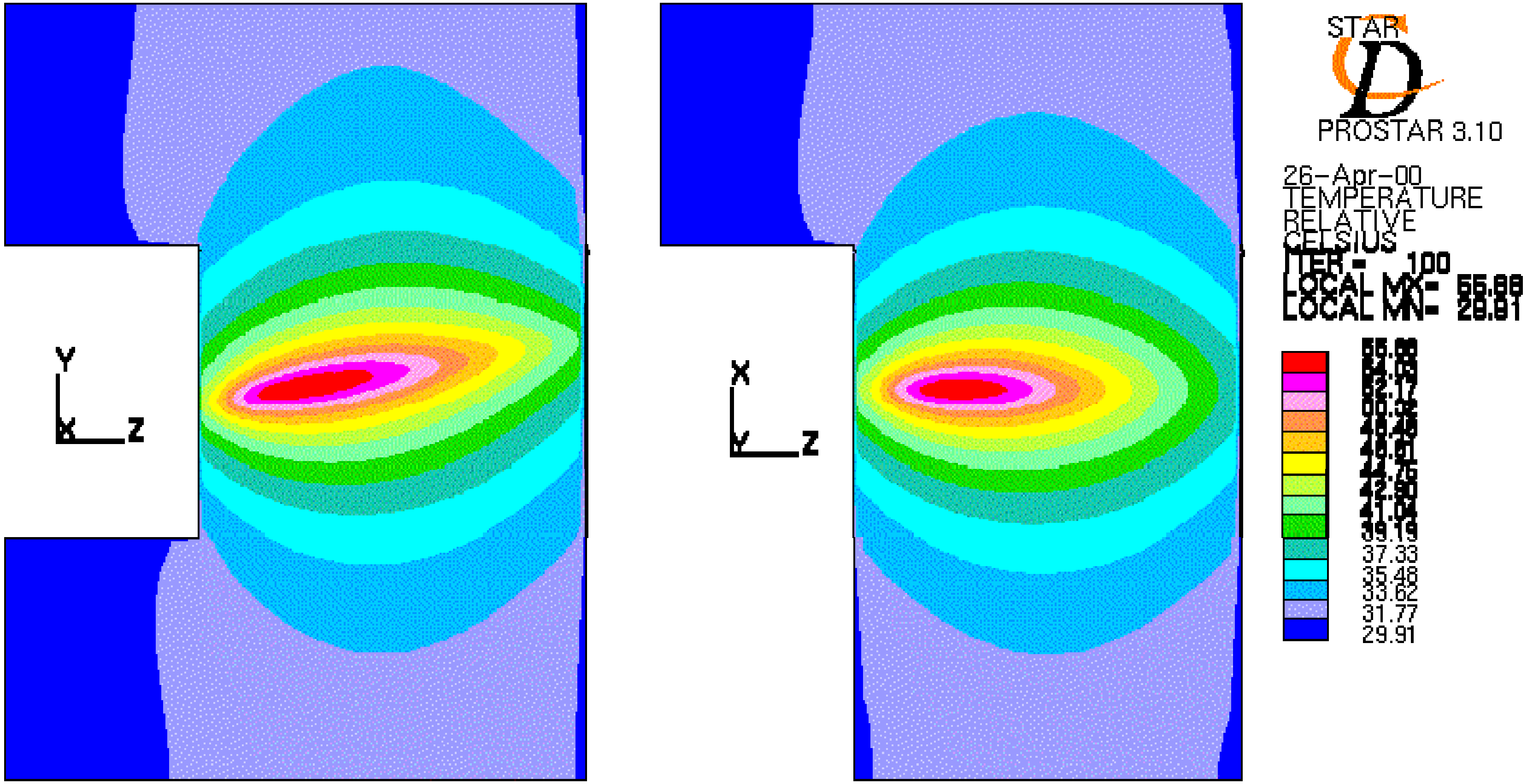
Fluxes of charged and neutral particles as a function of their momentum.





Prompt photons distribution at 200 m.

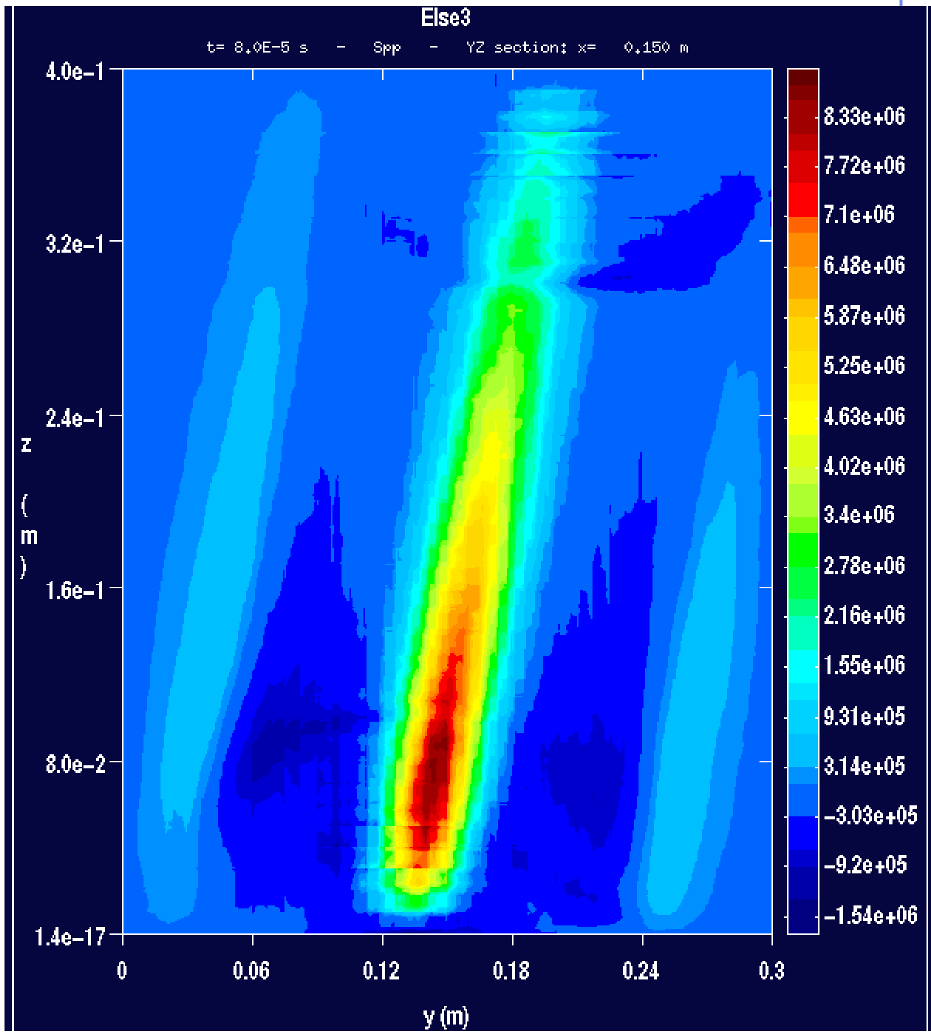
Temperature Map



Temperature map for one pulse of 7 10^{12} pr

Sound Waves Calculation

- FLUKA coupled with ELSE^3
- Rapid energy deposition → Adiabatic heat up
- Thermal expansion is immediate and not balanced inside the material → Stress & waves are generated
- 15% of elastic vibrations go to water
- Displacement 1mm/m^2 produce up to 75 dB noise



Resources

- Physics optimization of a possible conceptual design (~1 FTE month)
- Iteration with the engineering design (see Yacine talk)