Optimization aspects of the new nELBE photo-neutron source

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A look at the research program at nELBE

- Fast neutron reactions relevant
  for Nuclear Trasmutation program
  and of interest for the GEN IV reactors

  - Neutron Inelastic scattering (n,n‘γ)
    for ^{56}Fe, Mo, Pb, Na and total neutron cross sections σ_{tot} (Ta, Au, Al, C, H)
  - MA fission cross sections **(radioactive Targets)**

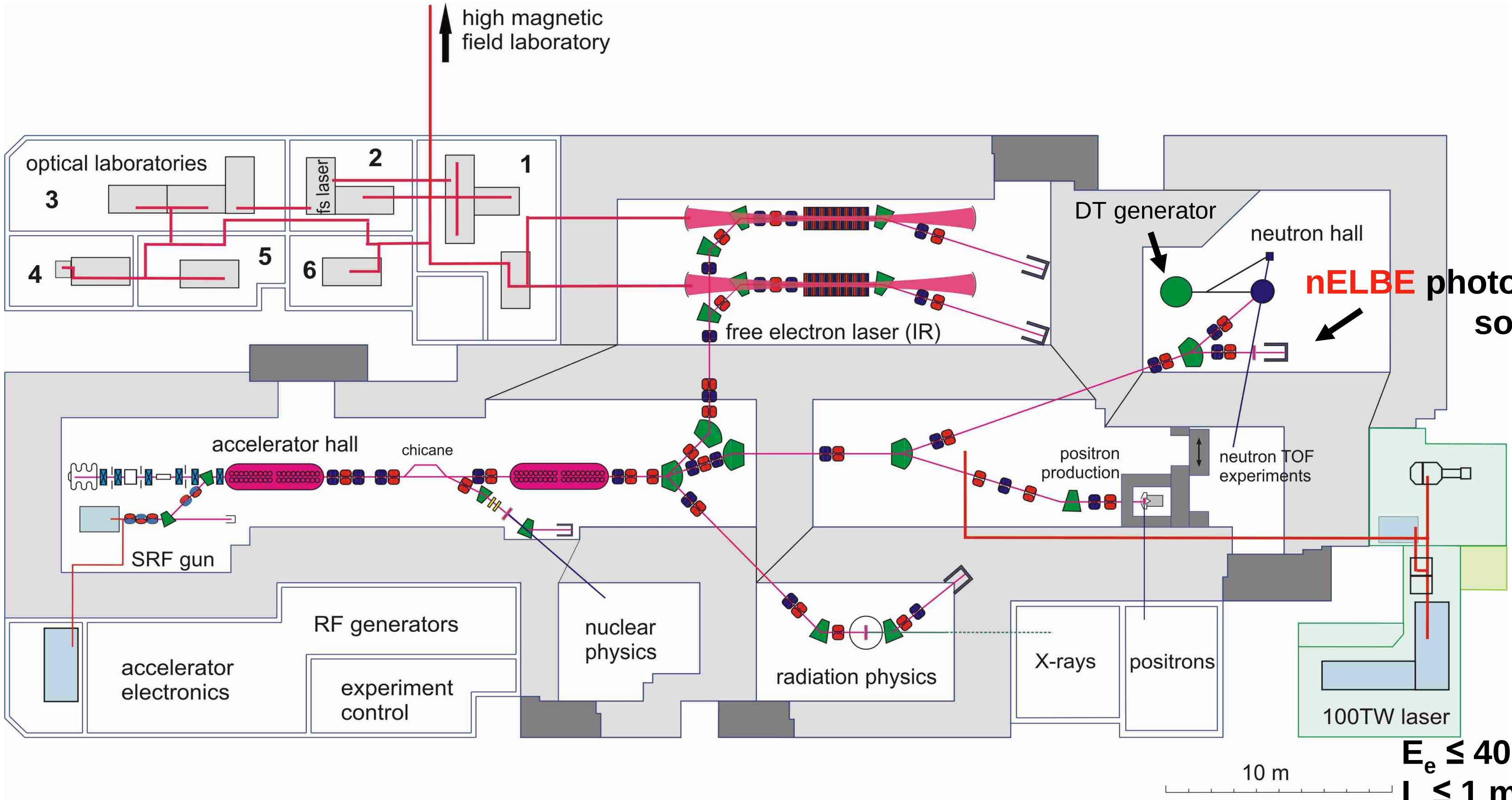
See talks of
A.Junghans and A.Matič

Based on the NEA high priority request list
and on the OECD Working Party
on Evaluation Co-operation (WPEC), subgroup 26

Co-ordinator: M. Salvatores, ANL, CEA
http://www.nea.fr/html/science/wpec/volume26/volume26.pdf

The ELBE accelerator complex

ELBE: **E**lectron **L**inear accelerator with high **B**rilliance and low **E**mittance



nELBE photoneutron source

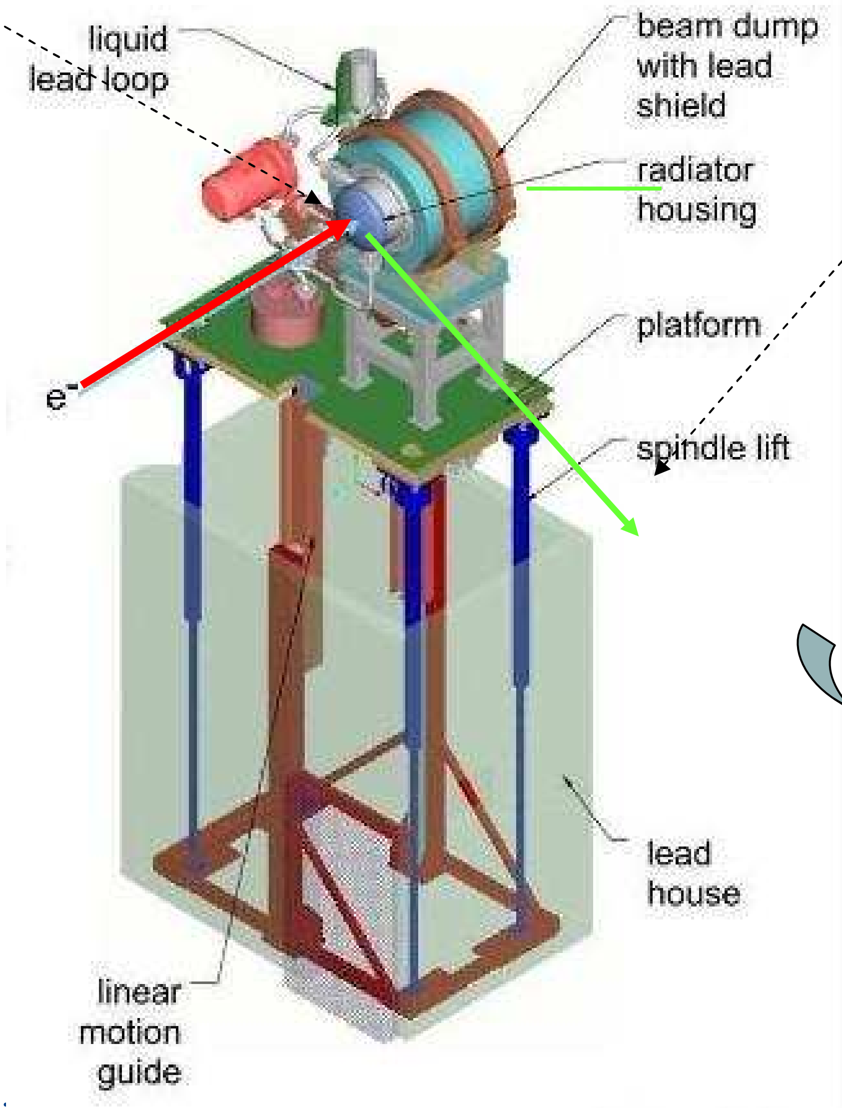
$E_e \leq 40$ MeV
$I_e \leq 1$ mA
Micropulse duration $\Delta t < 10$ ps
$f = 13$ MHz$/2^n$

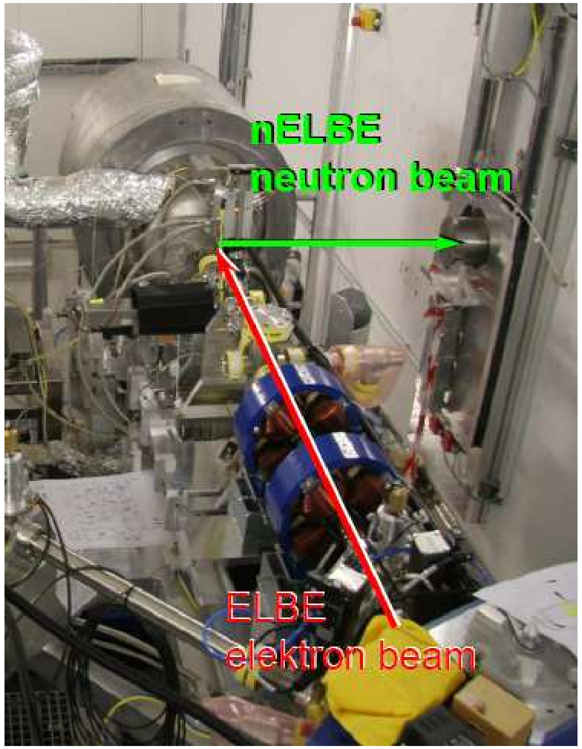
1: Diagnostic station, IR-imaging and biological IR experiment
2: Femtosecond laser, THz-spectroscopy, IR pump-probe experiment
3: Time-resolved semiconductor spectroscopy, THz-spectroscopy
4: FTIR, biological IR experiment
5: Near-field and pump-probe IR experiment
6: Radiochemistry and sum frequency generation experiment, photothermal deflection spectroscopy

The nELBE photo-neutron source

Radiator: 1.12 cm lead

Actual selected neutron direction: 95.5°





Main improvements of the new neutron beam-line

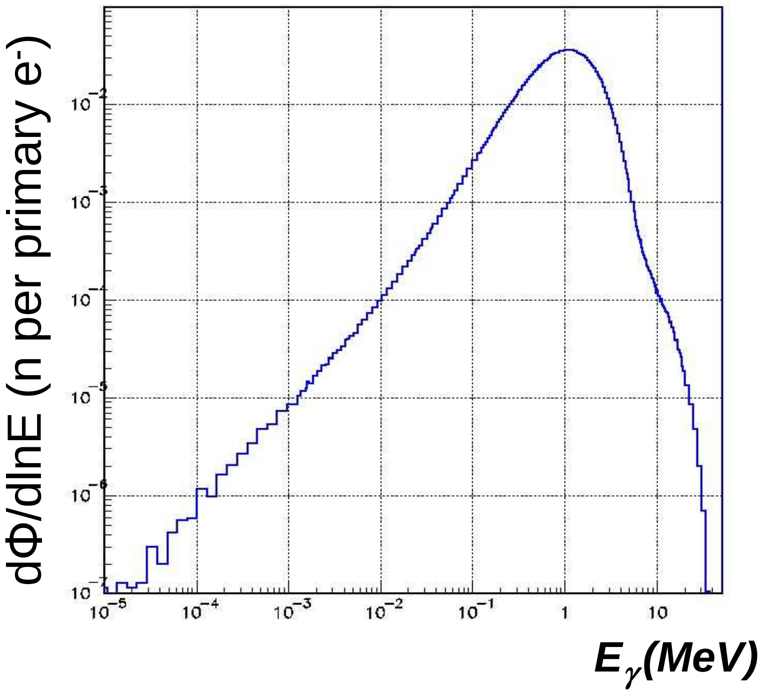
- Enhanced energy of the electron beam (up to 50 MeV)

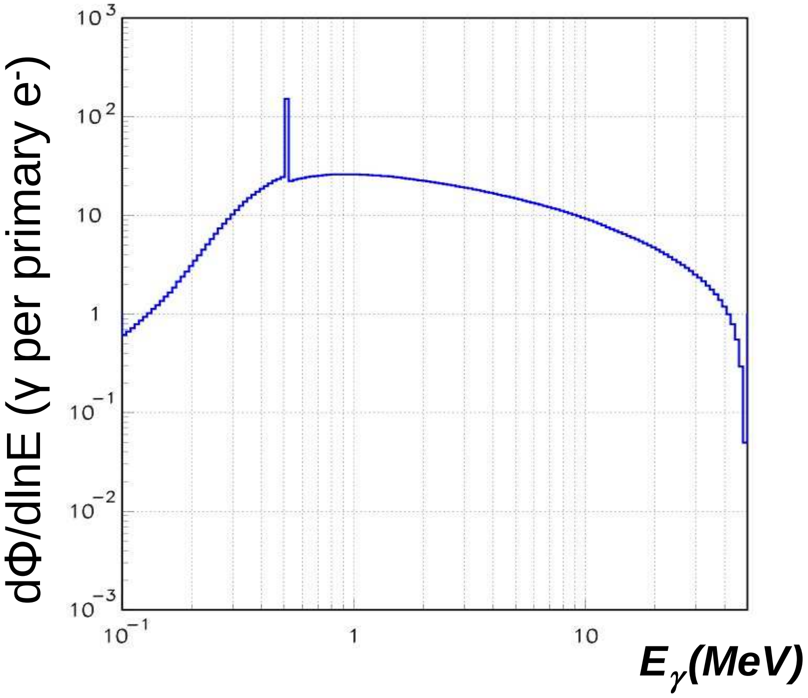
- Larger dimensions of the experimental room
  and better experimental conditions

- Optimized neutron beam-line
  with respect to the neutron/photon ratio

Strength of the improved source

Neutron and photon total yields at E_{e^-} = 50 MeV





n_{yield} (tot) = 5.67 10^{-3} n/e-

γ_{yield}(tot)= 6.68 γ/e

At the entrance of the collimator:

n_{yield} = 4.34 10^{-8} n per cm^2 per primary e-

A deeper look at the photoproduction simulation

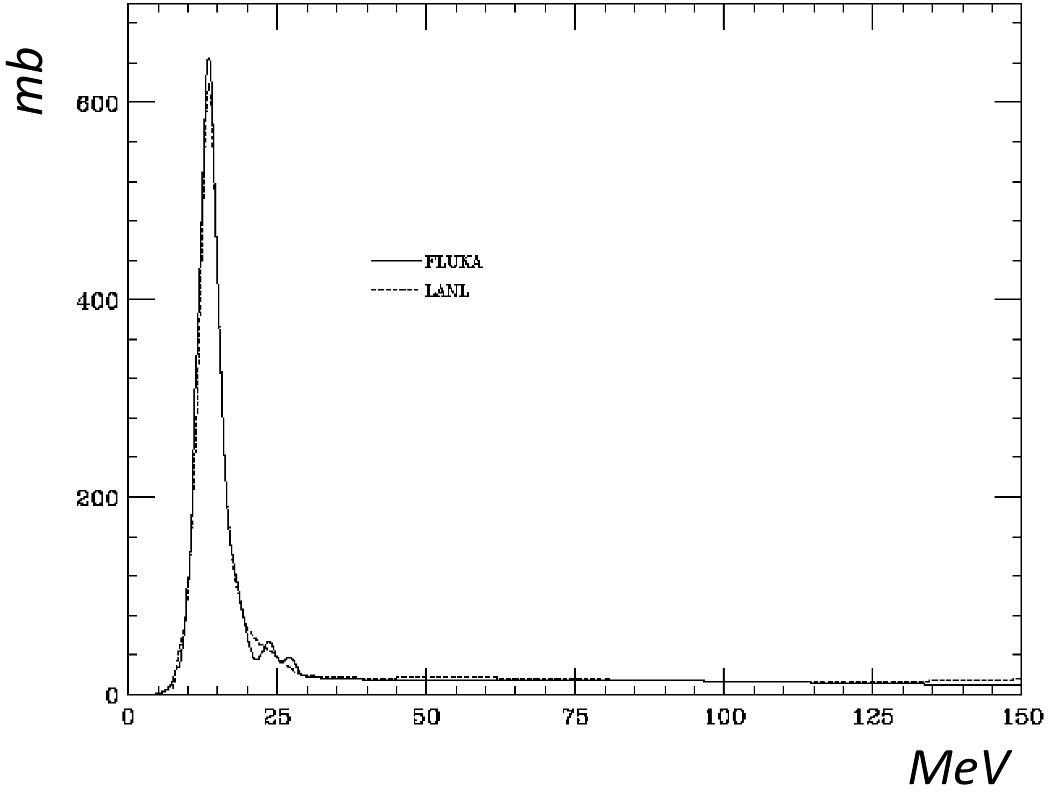
Comparison of the total cross sections in FLUKA and in the MCNP code

An important difference:

- **MCNP** works with differential cross sections, for each reaction channel

- **FLUKA** uses the total cross sections to determine where the interaction occurs, then proceeds with the models (evaporation, PEANUT)

$^{208}Pb(\gamma, tot)$ **- FLUKA and LANL**



FLUKA vs MCNP

Calculation of the total yields (Source Strength)

Electron Energy (MeV)	Neutron Yield (n/e$^-$)	Neutron Source Strength at the radiator (n/s)	
	FLUKA	MCNP (*)	FLUKA
20	1.205 10^{-3}	7.9 10^{12}	7.52 10^{12}
30	3.108 10^{-3}	1.9 10^{13}	1.94 10^{13}
40	4.51 10^{-3}	2.7 10^{13}	2.81 10^{13}
50	5.67 10^{-3}		3.54 10^{13}

Hyp: 1 mA current → 6.24 10^{15} e$^-$/s

(*) nELBE published results:
Ann. of Nucl. En. 34 (2007) 36-50

FLUKA statistical accuracy: < 1%

→ *MCNP and FLUKA agree at the level of few percent in the yield calculation*

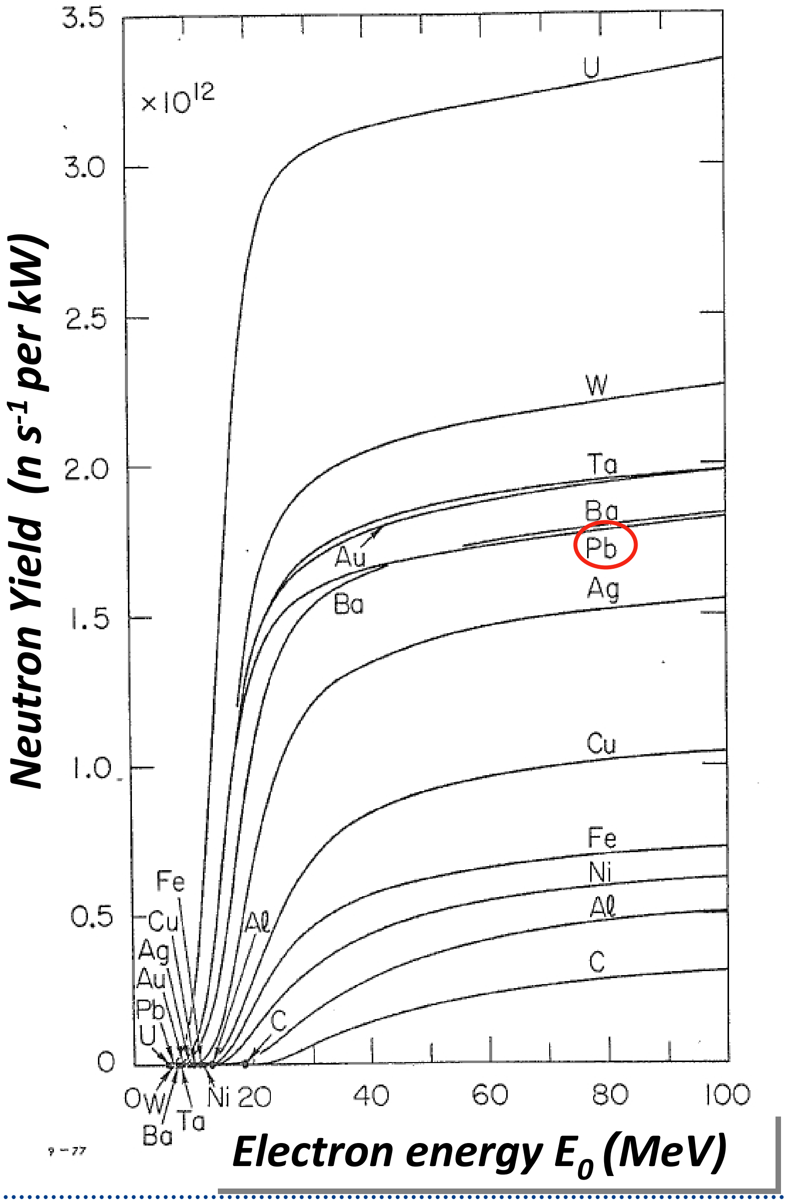
An additional check: the comparison with the Swanson evaluations

Swanson (SLAC-PUB-2042, 1978)
calculated the neutron yields from semiinfinite slabs of materials by folding the published photoneutron cross sections with the numerical integration of the photon track length distributions (derived from the analytical theory of the showers)

$$9.3 \cdot 10^{10}\, Z^{(0.73 \pm 0.05)} \text{ neutrons } s^{-1}\, kW^{-1}$$

The formula gives, for the asymptote of the curve of the lead: $2.32 \cdot 10^{12}$ n s^{-1} kW^{-1}

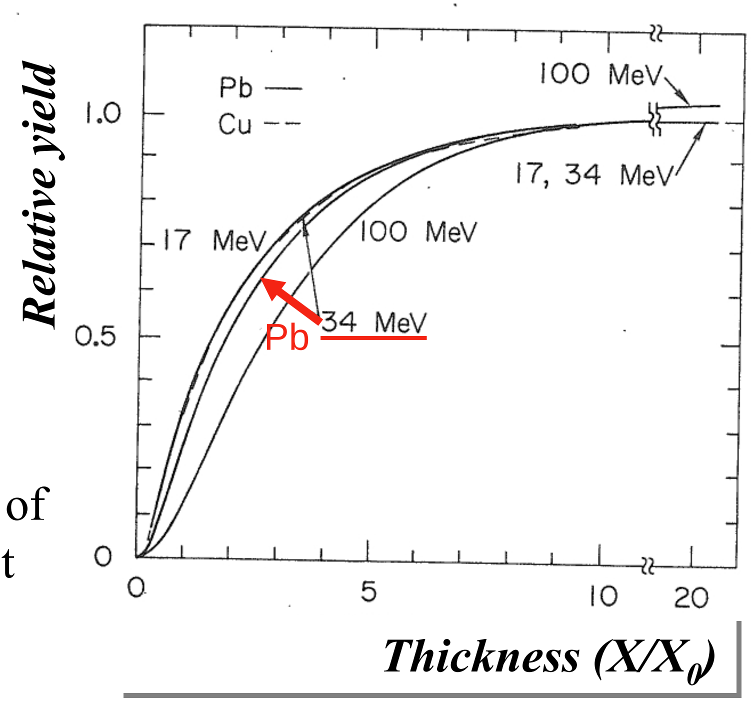
This value is valid for semiinfinite slabs and at high energies: we have to correct in real cases.



Check at 30 MeV

a) The correction for the energy comes from the previous curve: at 30 MeV the yield is ~ $1.6\ 10^{12}\ n\ s^{-1}\ kW^{-1}$

b) The correction for the target thickness can be taken from the curve at 34 MeV in this page, with $X/X_0 = 2$



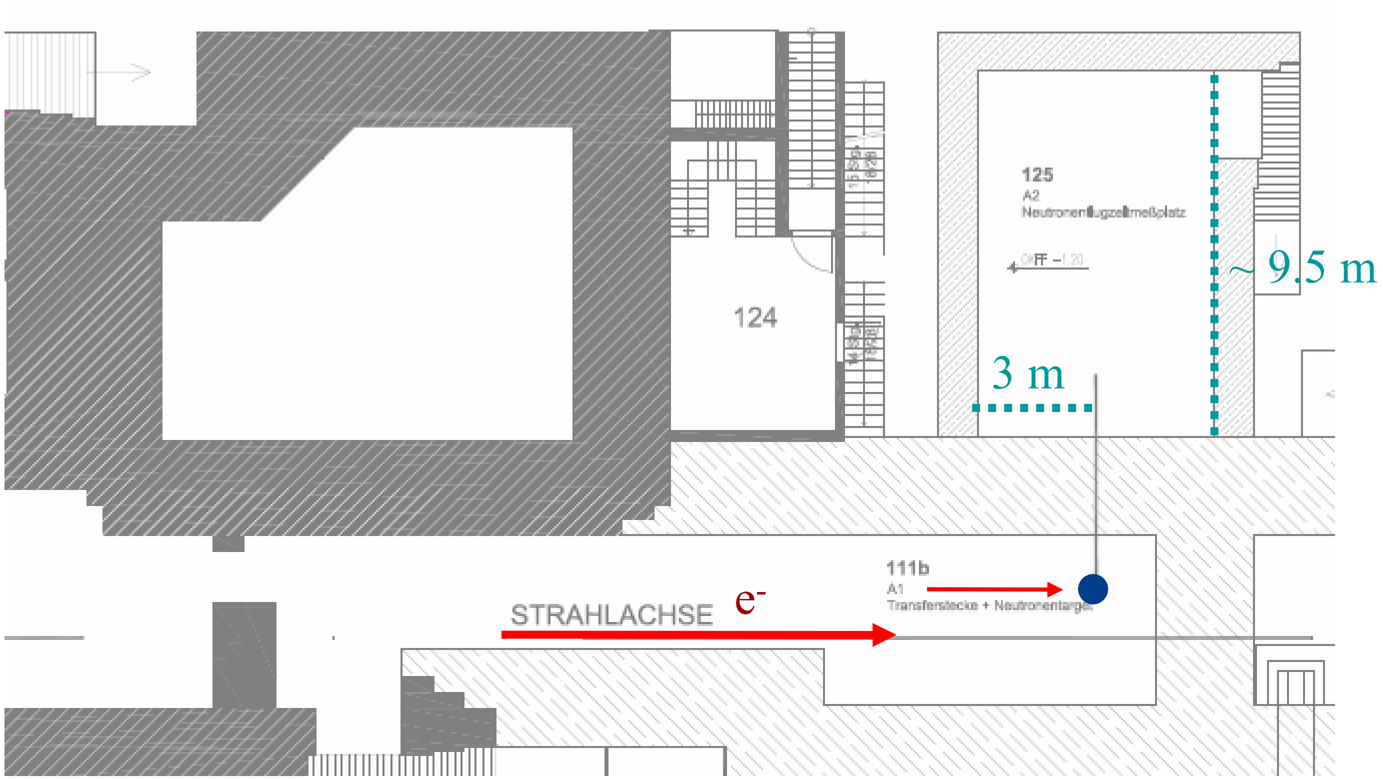
or, better:
we can calculate via Monte Carlo what is the portion of the yield in the first $2X_0$, compared with a thick target

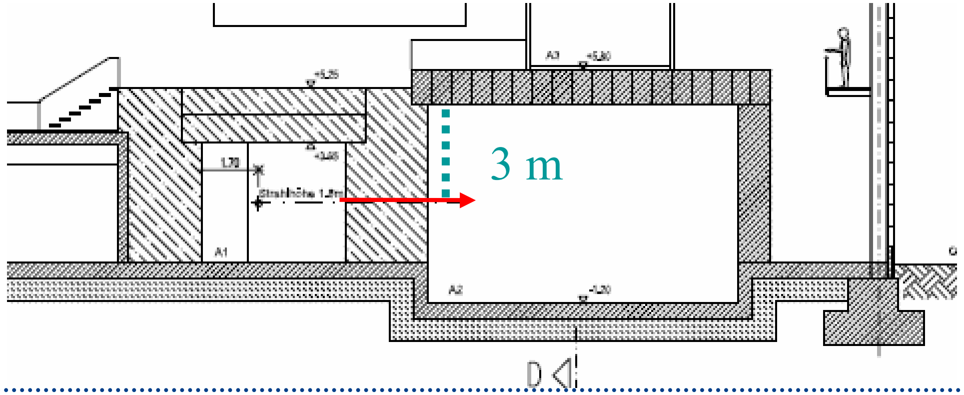
By calculating this value (40%) and by applying the correction we get:

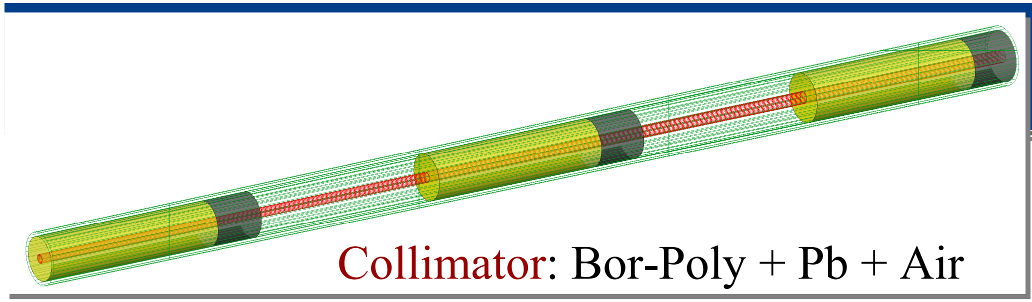
$1.92\ 10^{13}\ n\ s^{-1}$ @1mA

in perfect agreement with both MCNP and FLUKA

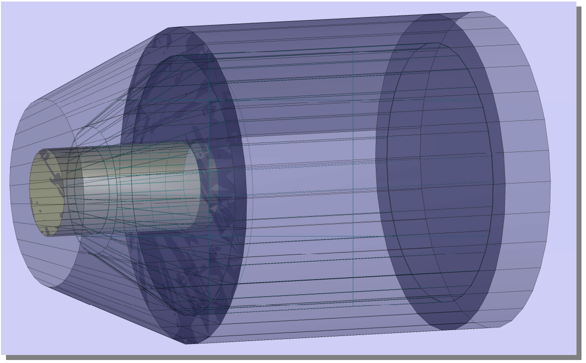
The new neutron experimental room

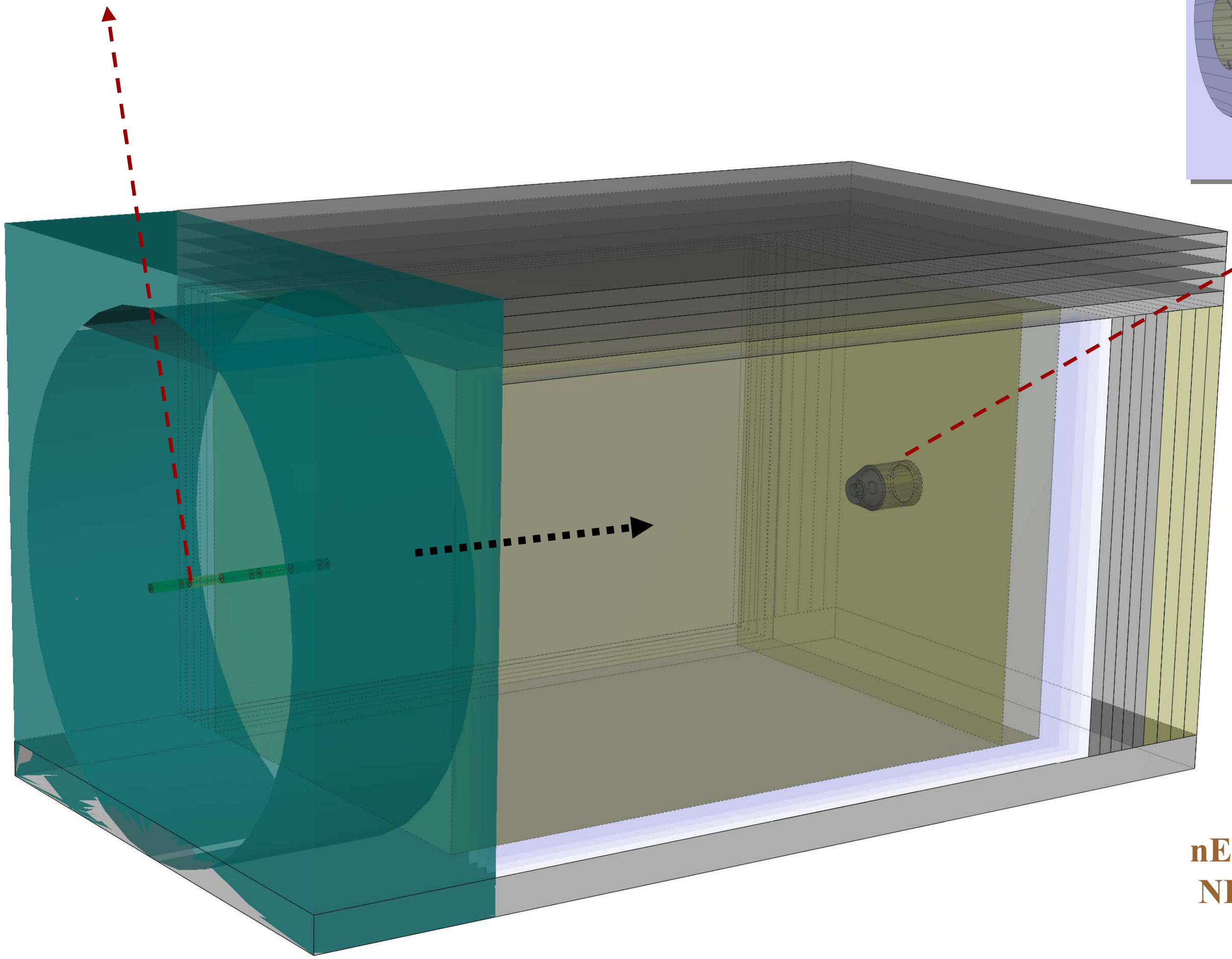






Collimator: Bor-Poly + Pb + Air

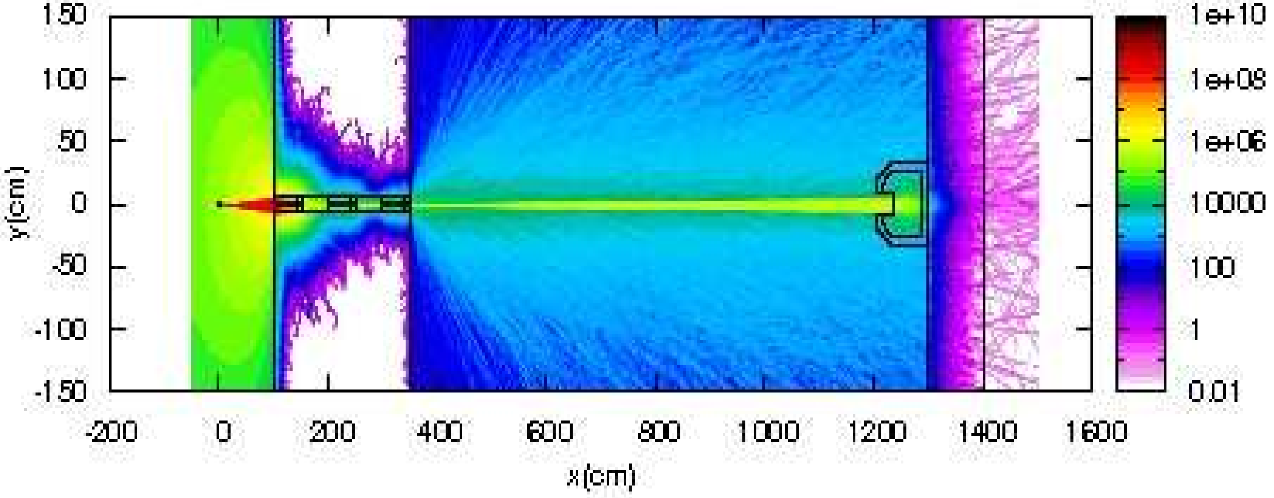


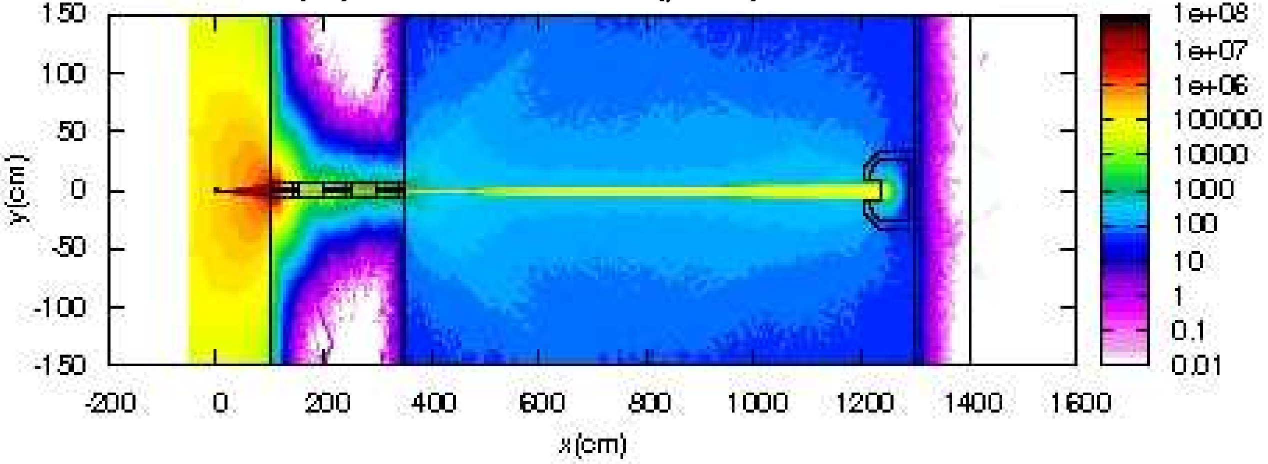


Beam Dump:
Bor-Poly +
Lead +
Cadmium foil

nELBE published paper:
NIM A 577 (2007) 641-653

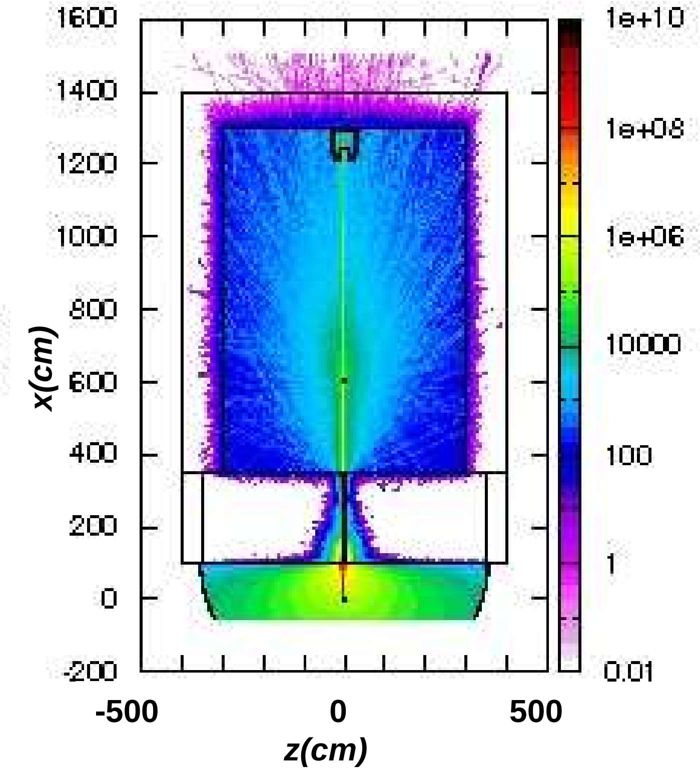
Photon and neutron fluences inside the experimental room


H*(10) rate from photons (μSv/h)

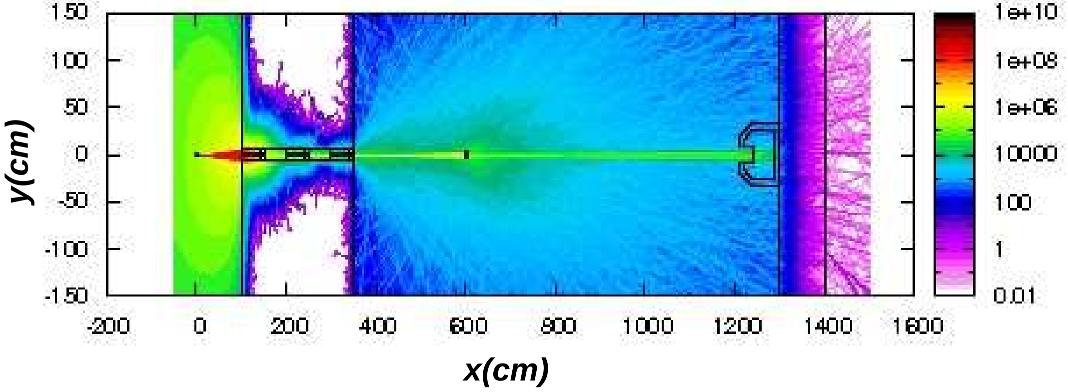

H*(10) rate from neutrons (μSv/h)

A more realistic case: photon fluence…

H*(10) rate from photons (μSv/h)

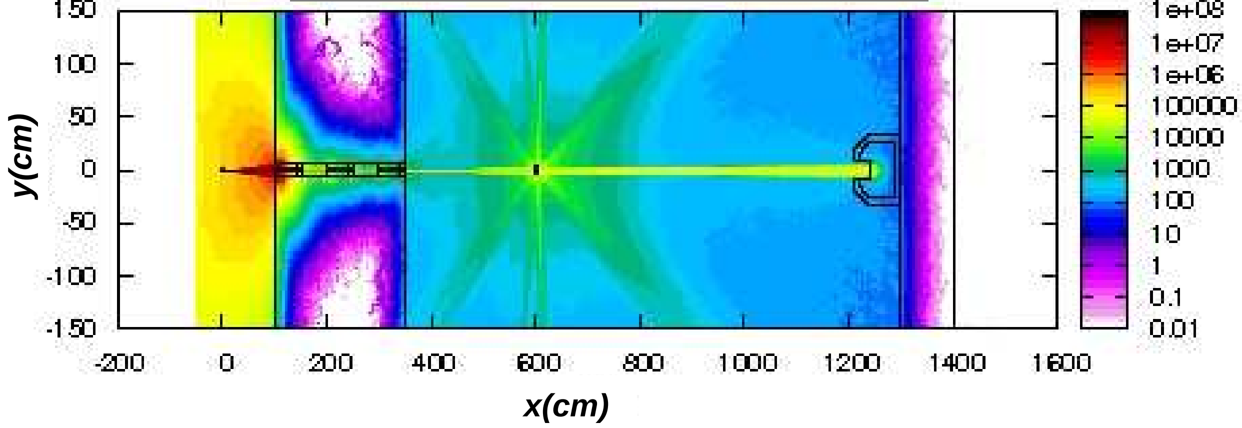


H*(10) rate from photons (μSv/h)

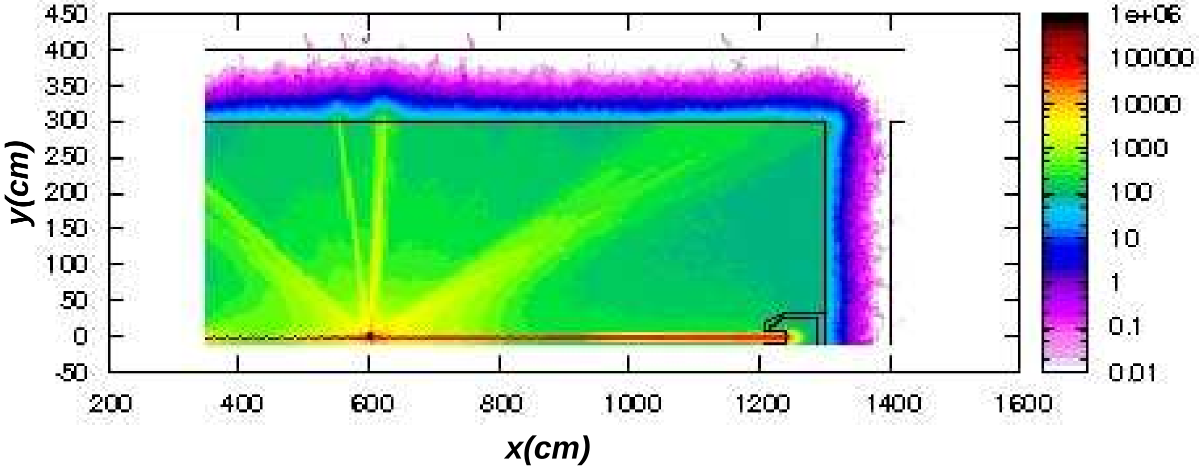


… and neutron fluence

H*(10) rate from neutrons (μSv(h)



H*(10) rate from neutrons (μSv(h)



Target:

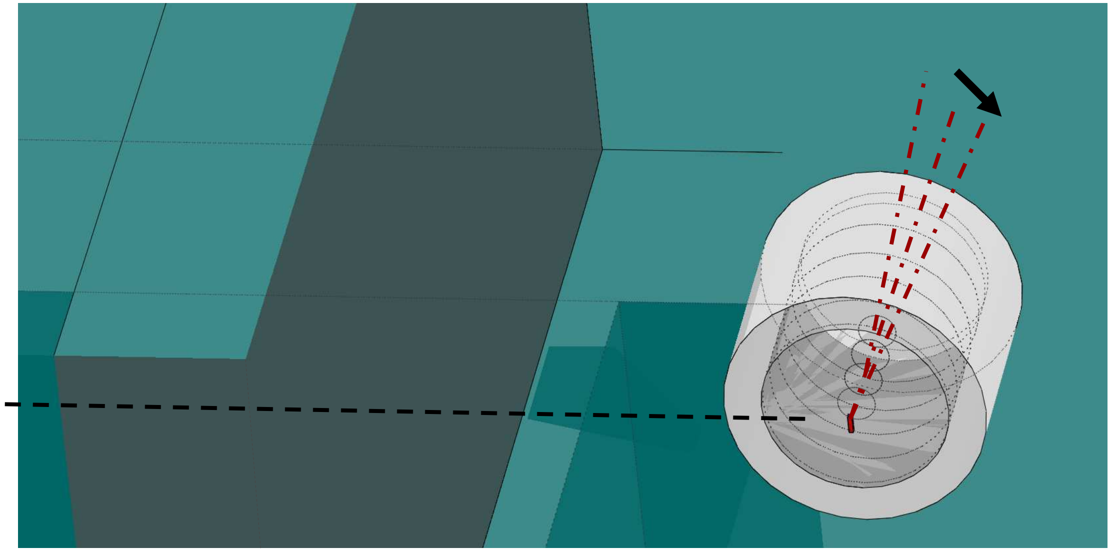
Pb slab 2 cm long,
5cm x 5cm large

Optimizing the direction of the neutron beam-line

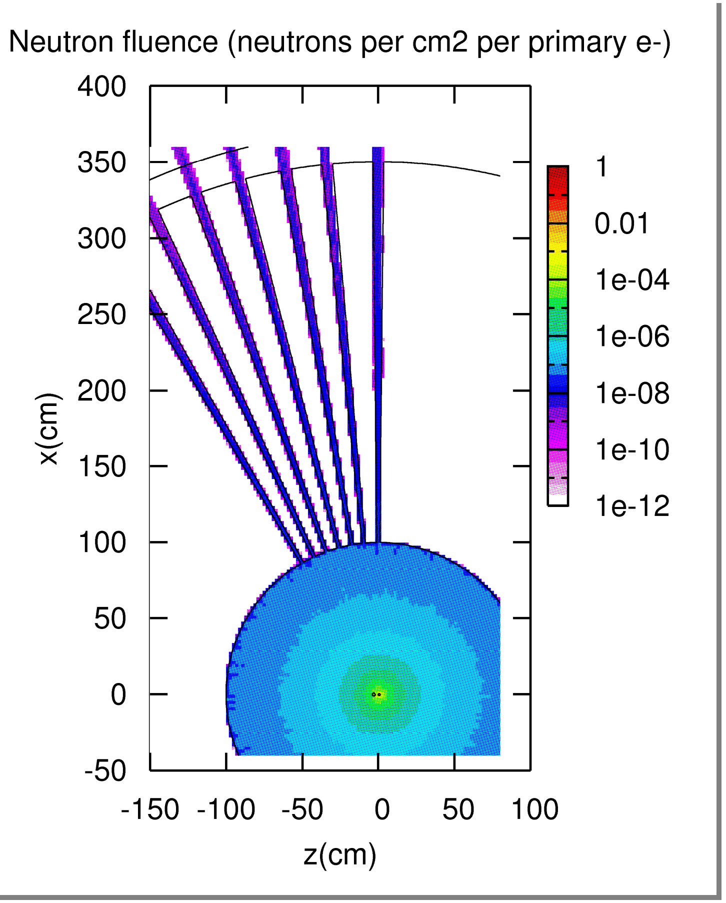
- Goal: choose a direction of the neutron beam-line
  that maximize the ratio n_{yield}/γ_{yield},
  taking into account the isotropy of the neutron
  production and the typical shape of the bremsstrahlung

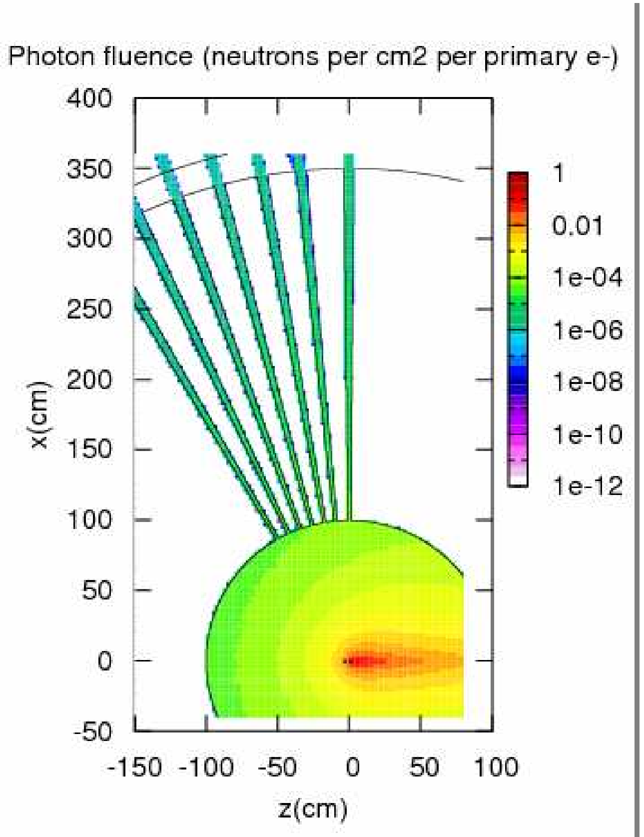
⬇

The optimized direction will be implemented in the new neutron beam-line by rotating the whole photo-neutron source (liquid lead target + dump)



The case of an ideal source (no dump)

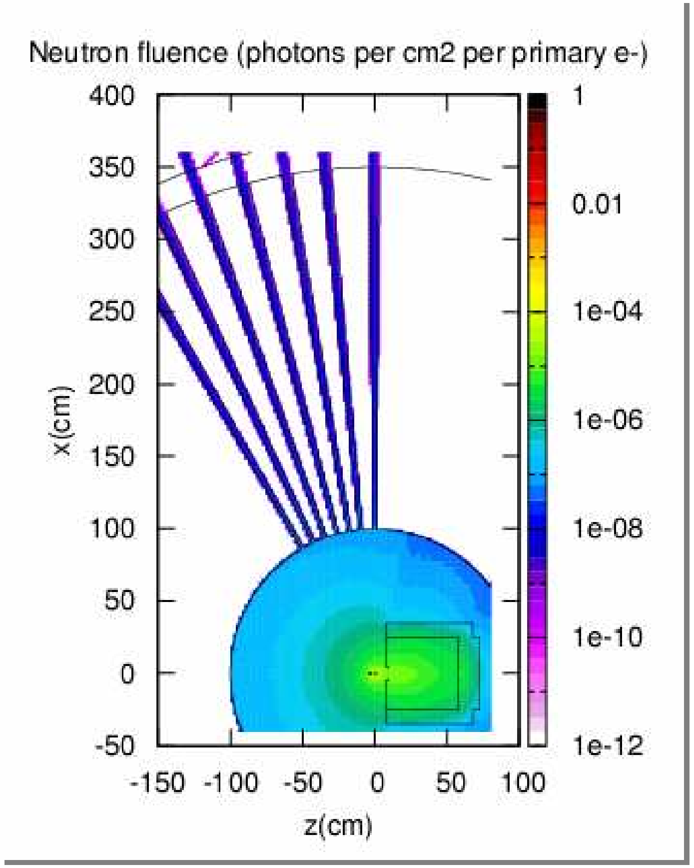


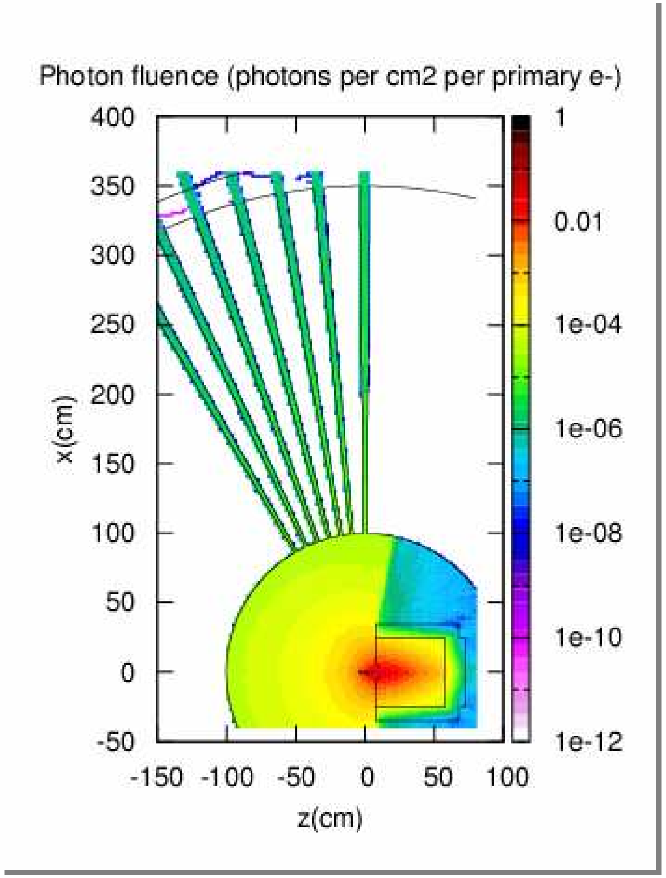


Statistical accuracy of the fluence simulation: $\leq 1\%$

	90°	95.5°	100°	105°	110°	115°
Ratio n_{yield}/g_{yield}	$2.20\ 10^{-3}$	$2.38\ 10^{-3}$	$2.52\ 10^{-3}$	$2.77\ 10^{-3}$	$2.88\ 10^{-3}$	$3.05\ 10^{-3}$

The realistic case





	90°	95.5°	100°	105°	110°	115°
Ratio n_{yield}/γ_{yield}	$2.17\ 10^{-3}$	$2.39\ 10^{-3}$	$2.53\ 10^{-3}$	$2.78\ 10^{-3}$	$2.92\ 10^{-3}$	$3.14\ 10^{-3}$

Summarizing:

	90°	**95.5°**	**100°**	**105°**	**110°**	**115°**
Ideal source **n_{yield}/γ_{yield}**	$2.20\ 10^{-3}$	$2.38\ 10^{-3}$	$2.52\ 10^{-3}$	$2.77\ 10^{-3}$	$2.88\ 10^{-3}$	$3.05\ 10^{-3}$
Real source **n_{yield}/γ_{yield}**	$2.17\ 10^{-3}$	$2.39\ 10^{-3}$	$2.53\ 10^{-3}$	$2.78\ 10^{-3}$	$2.92\ 10^{-3}$	$3.14\ 10^{-3}$

- We increase the source strength of ~ 40 % passing from 90° to 115°

  - the neutron contamination not coming from the photo-neutron source remain at the level of 2-3 % at 115°

- Passing from 95.5° to 105° we increase the source strength of ~ 16%

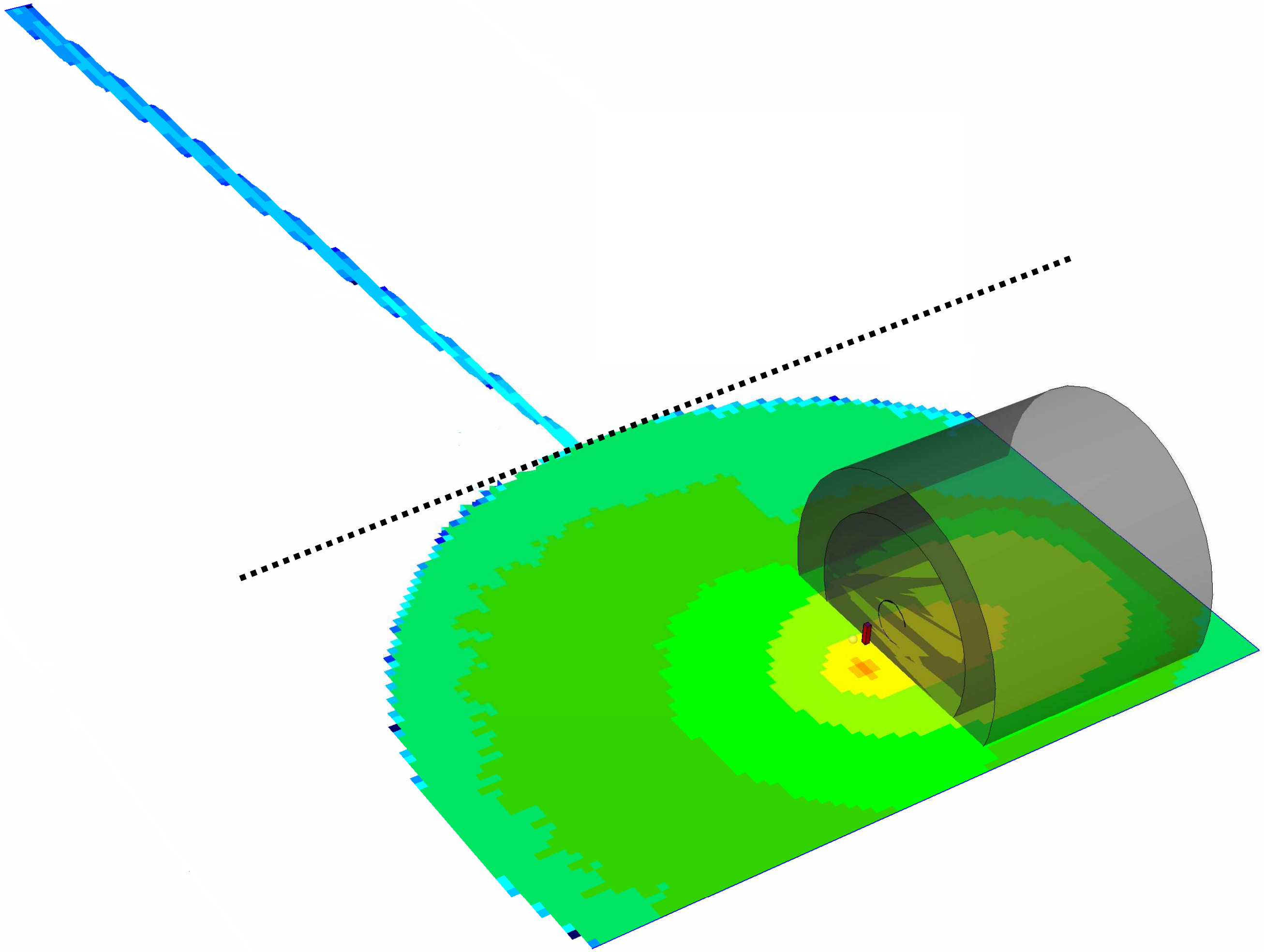
Conclusions

- A new neutron room dedicated to the experimental program of nELBE will be built at FZD in the next years

The larger dimensions and the better experimental conditions will allow us to perform measurements less affected by background

- Moving the orientation of the photo-neutron beam-line at an appropriate angle with respect to the electron beam-line would result in a sizeable enhancement of the ratio n_{yield}/γ_{yield}

Spares



Neutron spectra at the entrance of the collimator, where neutrons are considered in a very large angle around the axis of the collimator (phi=3.5°, to be compared with the angle of 0.112°, that allows a particle entering the collimator to exit without collisions)

The bins in the fig. are centered at the polar angles 95° (red), 105° (blue), 115° (light blue) and 120° (green) and have an opening angle (phi radius) of 3.5°.