The Second Meeting of
The Union for Compact Accelerator-Driven Neutron Sources

UCANS-II

A Photo-Neutron Source at the Dafne Beam Test Facility of the I.N.F.N National Laboratories in Frascati: Design anf first Experimental results

R. Bedogni[(1)], B. Buonomo[(1)], A. Esposito[(1)], M. De Giorgi[(1)] ,G. Mazzitelli[(1)], L. Quintieri[(1)], P. Valente[(2)], J.M. Gomez-Ros [(3)]

(1) INFN. Laboratori Nazionali di Frascati, Italy

(2) Università La Sapienza and INFN. Roma1, Roma, Italy

(3) CIEMAT, Madrid Spain

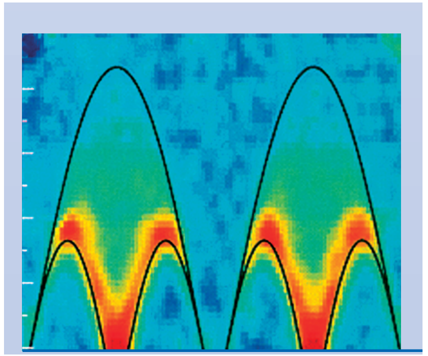
Indiana University, Bloomington

July 8, 2011

Summary

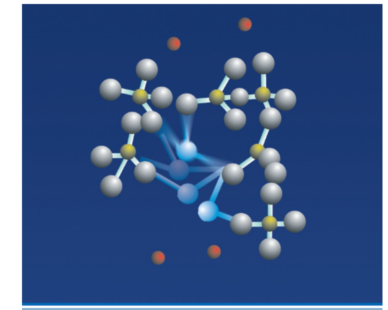
- Photoneutron source: Scientific motivation
- The electron/positron Facility: Beam Test Facility (BTF) of **Daφne** Collider
- Physics overview
- Overview of Photonuclear Physics implementation in MC codes: Fluka, Mcnpx, Geant4.
- Monte Carlo Predictions: simulation results by Fluka and Mcnpx (Geant4 still in progress)
- Experimental Measurements (feasibility test)
- Comparison between MC predictions and measurements
- Conclusion and Future plans

Scientific Motivation: research with neutrons (1/2)



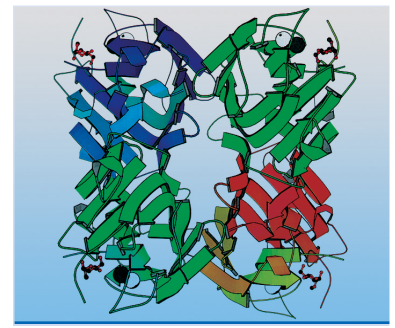
Solid State Physics:

Neutrons provide unique access to the magnetic structure and dynamics of solids.



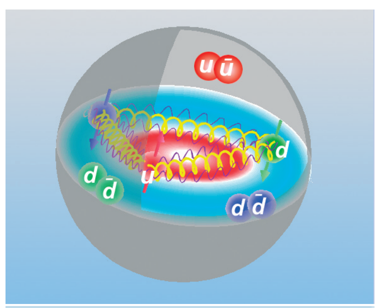
Neutron Scattering:

Neutron diffraction data is routinely used as the basis for structural models of crystals, glasses and liquids.



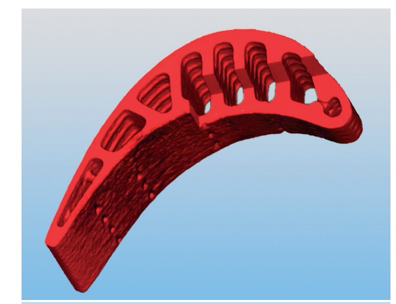
Biology and Biotecnology:

Neutrons are particularly sensitive to the dynamics of molecules and single atoms. .



Particle Physics

The neutron can be seen as a composite particle consisting of quarks, virtual pions and gluons. Its internal structure determines the decay process, the magnetic moment, and an anticipated electrical dipole moment that would indicate new physics beyond the Standard Model of particle physics. Related measurements can be performed using cold and ultra-cold neutrons. Essential contributions can be expected to the unification of fundamental forces in nature.



Material Science:

Neutron sensitive imaging will add a new dimension to real scale tomography and radiography.

Drug Discovery:

Knowledge of the three dimensional structures and dynamics of proteins and nucleic acids, as receptors for drug molecules, opens a structure based path to new drug discovery. For instance, major diseases in aging, such as Alzheimers, are caused by the formation of insoluble amyloid deposits of proteins in the brain and neurofibral tangles in the nerves. A combination of x-ray and neutron crystallographic studies, both of the enzymes that catalyse processing of the amyloid precursor proteins and of the proteins that associate with the plaques, could make an outstanding contribution to the design of therapeutic agents

Nuclear data Measurements:

Neutron Cross Section measurements (total, capture, fission, elastic, scattering gamma ray and neutron production) for supporting advanced Fuel cycle in New Generation Reactos

Scientific Motivation: research with neutrons (2/2)

General context:

- Increasing general interest of the scientific community for neutron facilities worldwide

Italian National Institute of Nuclear Physics mainly concerned with:

- Neutron Detector R&D for very precise Spectra Measurements in high energy electron accelerators
- Acquisition of know-how needed for next generation of high intensity neutron sources by photoproduction and as companion and complementary activities in the context of new powerful FEL (i.e. SparcX in Italy)
- Possibility to have a new european facility in ISO Standard for study and calibration of detectors and instrumentations with application in nuclear physics and radioprotection
- Investigate the feasibility of a cold neutron source (n energy less than 1eV). This kind of source has a great interest both in fundamental physics and for many other application fields (nano-technology, etc)
- Make available neutron facilities as a necessary support to relaunch the civil nuclear in Italy

Why the interest in photonuclear?

Emerging nuclear systems interest in photonuclear process is experienced for:

- Shielding of widely used medical (e.g bremsstrahlung radioterapy) and insutrial Linear electron accelerators,
- Need of new cost effective neutron sources,
- Trasmutation of nuclear waste either directly by photons or by neutrons created from photonuclear reactions (ADS applications),
- Lead cooled fast reactors (photoneutron concerns)
- Design of electron beam-dumps in intense electron beam accelerators

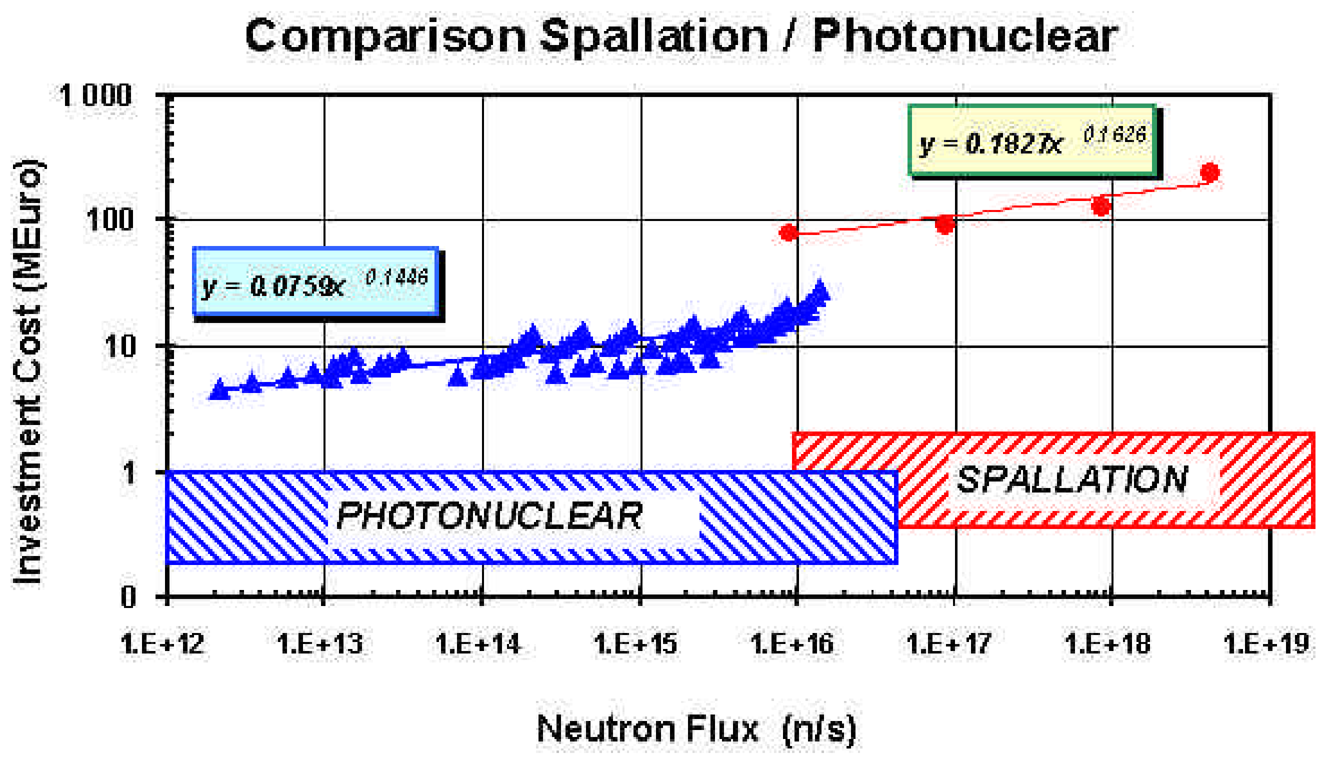
An accurate estimation of photoneutron production is necessary, that means that we need an adequate description of photonuclear physics

Computational issues of photonuclear physics in particle transport and interaction codes

- For a long time photonuclear processes were neglected mainly due to the lack of complete evaluated data for applications
- Photonuclear data are isotopic in nature, the cross sections showing irregular dependence on atomic number (Z) and atomic mass (A). Thus while photoatomic data are readily tabulated by element photonuclear data must be tabulated for each isotope of an element
- A relatively complete photonuclear data file in ENDF format for 164 isotopes became available only "recently", in 2000 (ENDF-6 formatted files containing complete interaction descriptions, i.e., double differential cross sections, suitable for use in transport calculations)

Spallation vs Photoneutron sources

- Spallation source are very effective in producing neutrons, but are large and expensive
- Electron drivers although are much less effective in neutron production are rather cheap and compact machine that might also bring advantages in terms of reliability



Above a given neutron flux the spallation will be preferred while for the lower fluxes, the photonuclear process will tend to be more convenient

To obtain very high neutron fluxes by photo-production, much higher electron beam intensity will be necessary. This will increase the electron accelerator complexity, resulting in a less convenient solution from an engineering and economical point of view (n>1.E+16 n/s).

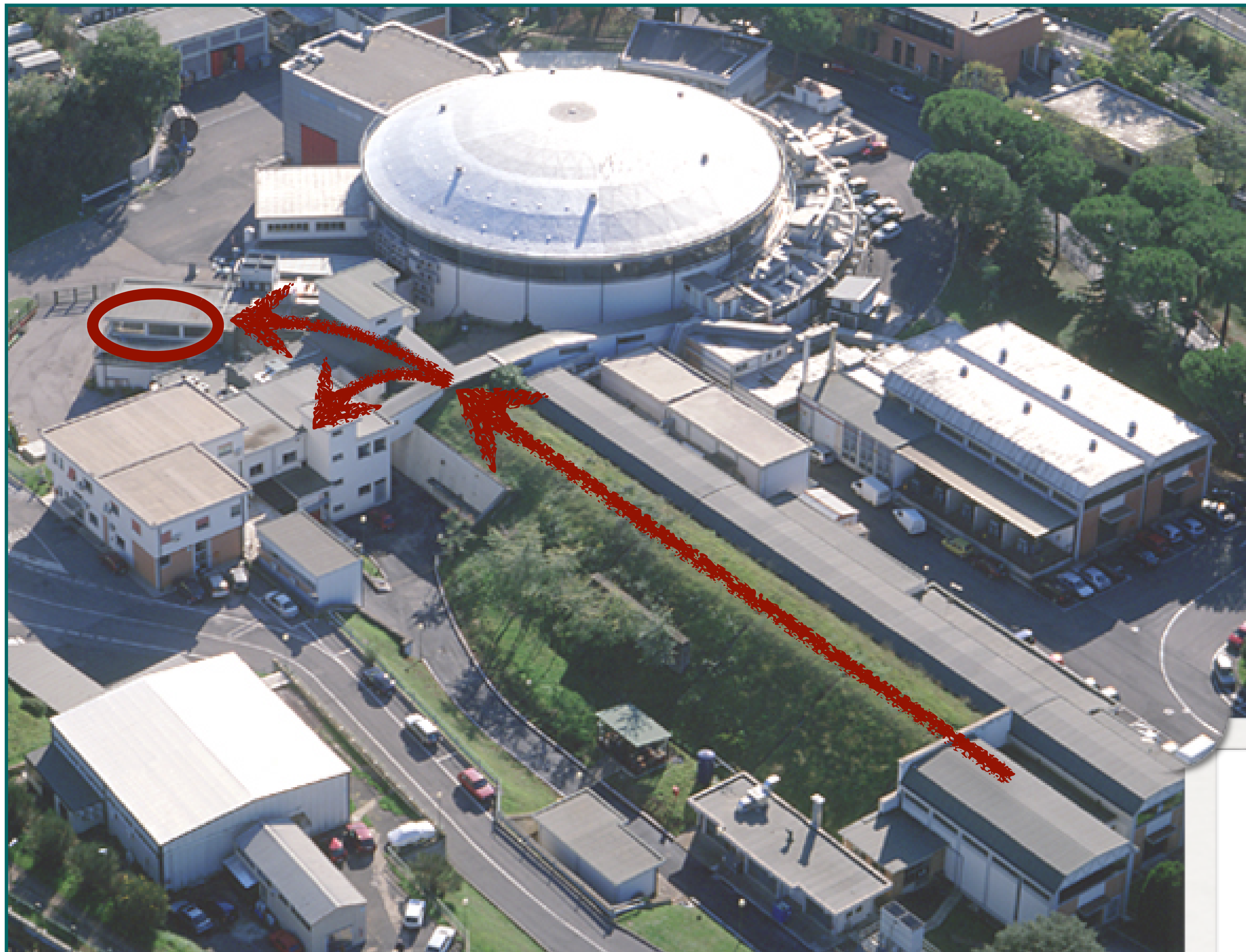
Plot reference:

Ref: D. Ridikas, H.Safa, M.L.Giacri – Conceptual Study of Neutron Irradiator Driven By Accelerator – *7th Information Exchange Meeting on Actinide and Fission Product P&T (NEA/OCDE), Jeju, Korea, 14-16 Oct. 2002*

THE WORKING CONTEXT

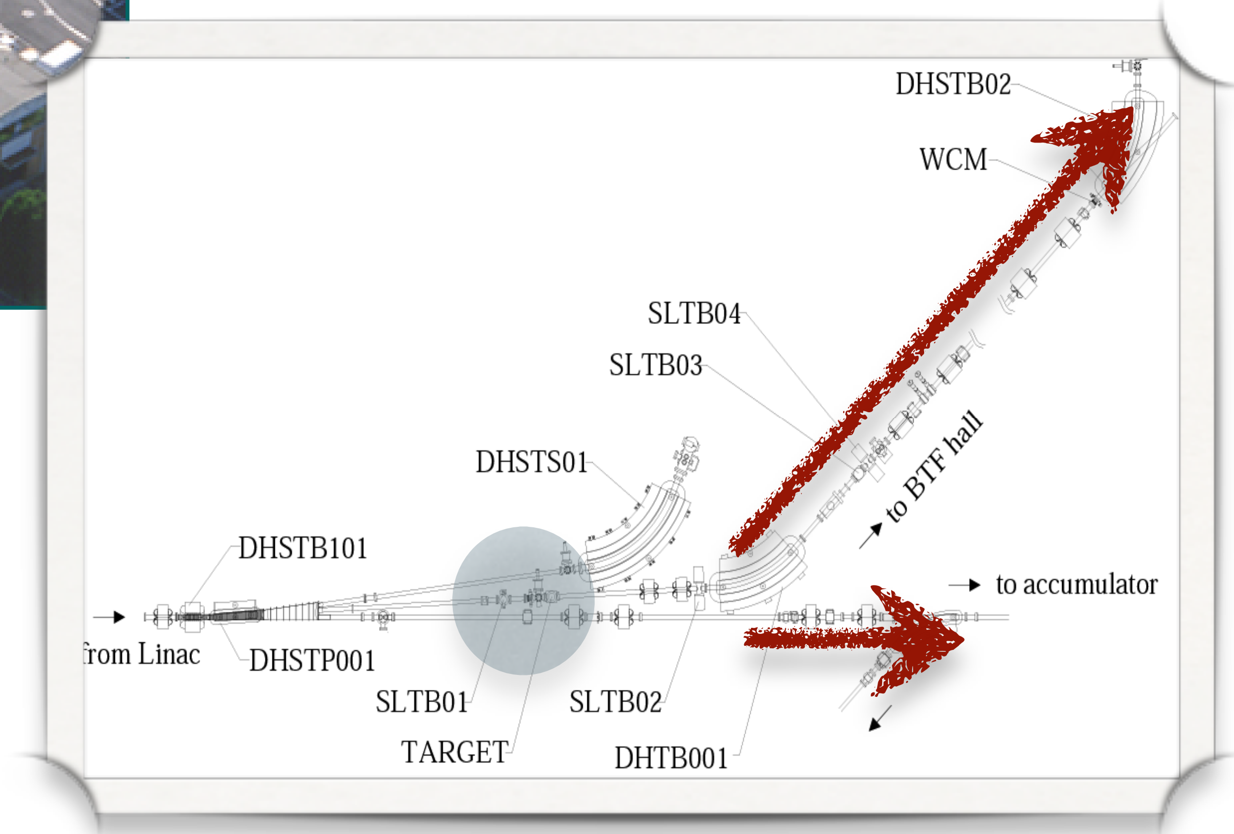
THE DAΦNE BTF

The DAΦNE Collider In Frascati



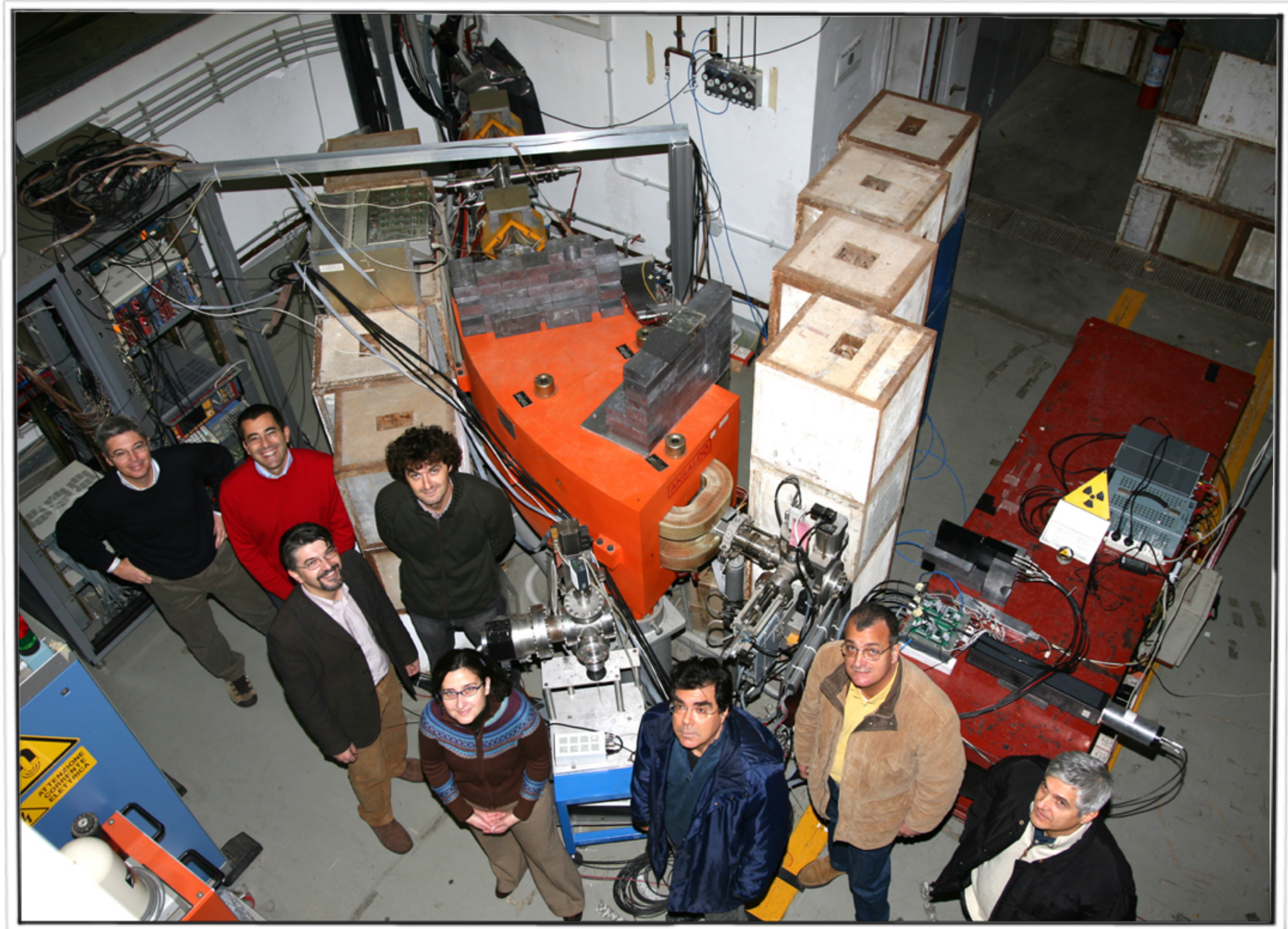
high current Linac:

- 1 – 500 mA e^- 200 mA e^+,
- 1 - 10 ns pulses, at least 10^7 particles



Energy Degrader: Need to attenuate the primary beam:

- Allows to tune the beam intensity
- Allows to tune the beam energy
- Single particle regime is ideal for detector testing purposes



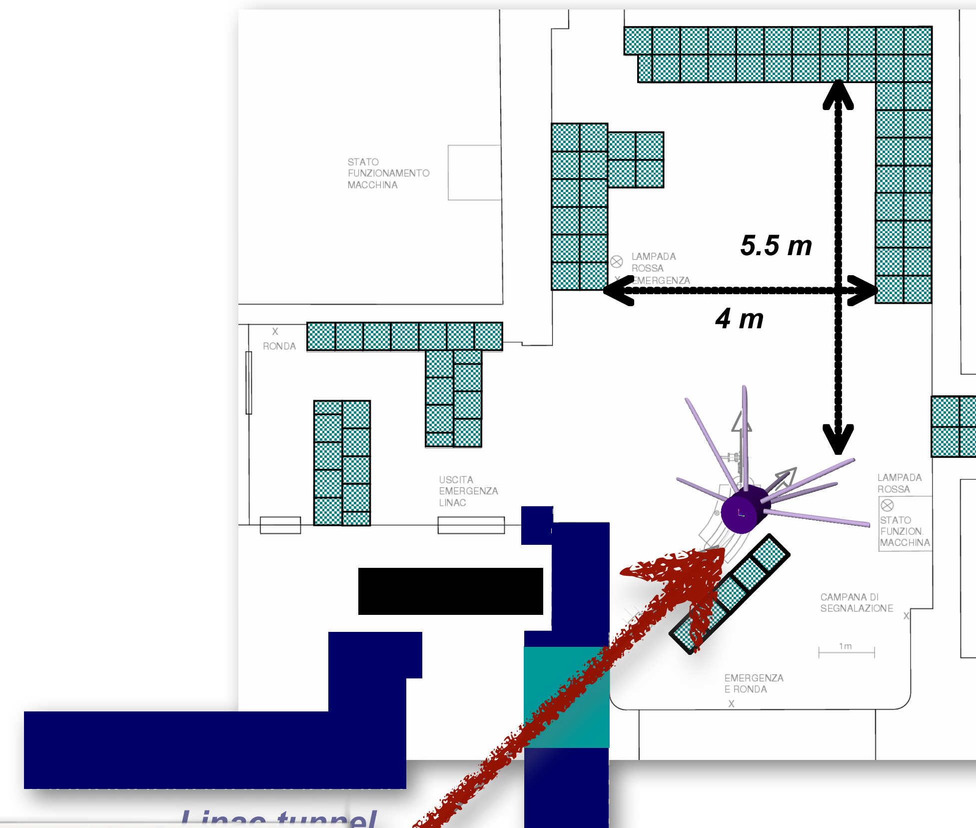
THE DAΦNE BTF

Beam in the Experimental Hall

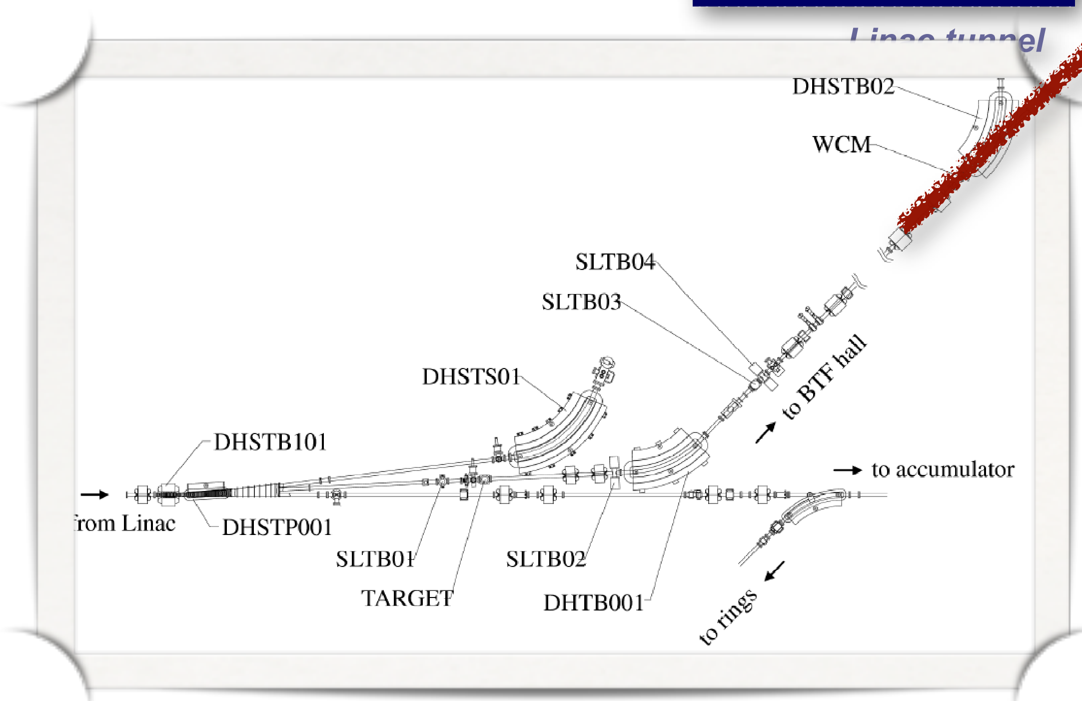
BTF main e- beam parameters

Parameter	Value
Energy Range	25-750 MeV (e-) 25-510 MeV (e+)
Transverse emittance @ 510MeV (both planes)	1mm mrad (e-) 10 mm mrad (e+)
Energy Spread @ 510 MeV	1% (e-) 2 % (e+)
Repetition Rate	1-50 Hz
Number of particles per pulse	1-10^10
Macro Bunch duration	1 or10 ns
Spot size (mm)	2mm (single particle) 2 cm (high multiplicity)

BTF Experimental Hall



BTF Transfer Line



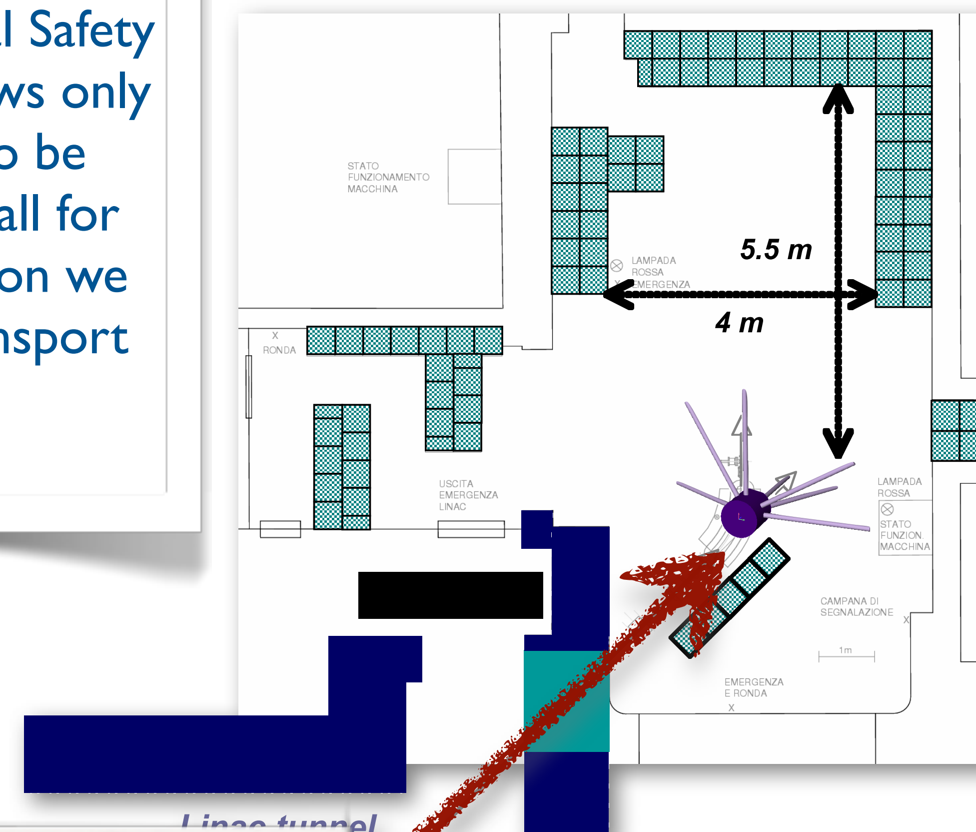
Beam in the Experimental Hall

BTF main e- beam parameters

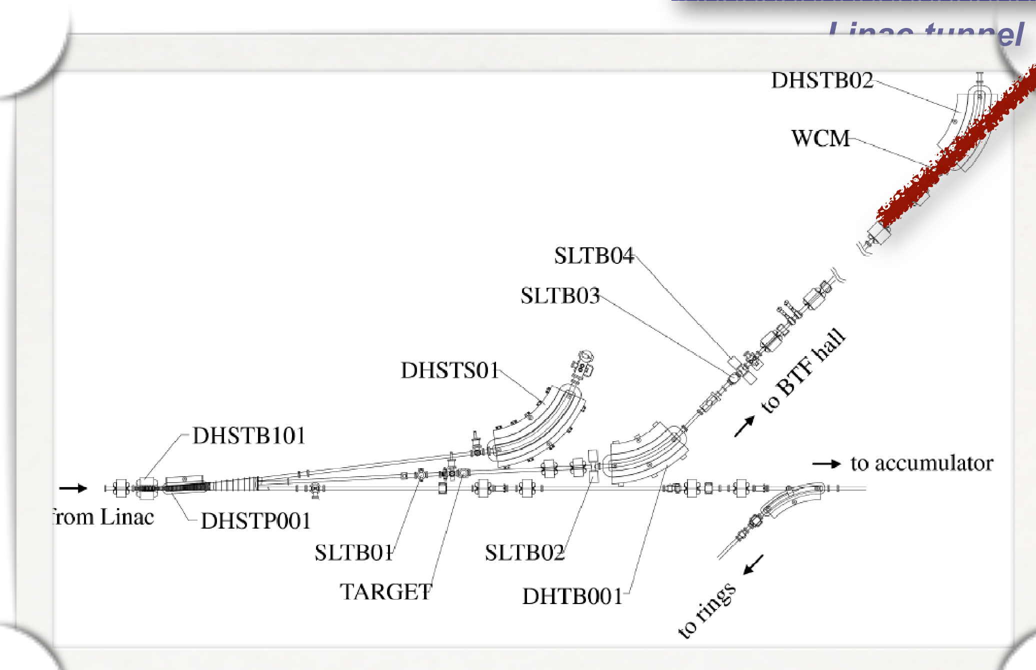
Parameter	Value
Energy Range	25-750 MeV (e-) 25-510 MeV (e+)
Transverse emittance @ 510MeV (both planes)	1mm mrad (e-) 10 mm mrad (e+)
Energy Spread @ 510 MeV	1% (e-) 2 % (e+)
Repetition Rate	1-50 Hz
Number of particles per pulse	1-10^10
Macro Bunch duration	1 or10 ns
Spot size (mm)	2mm (single particle) 2 cm (high multiplicity)

At present time the National Safety Regulatory commission allows only few tens of W (~50 W) to be released in experimental hall for producing neutrons, but soon we could be authorized to transport all the beam power: several tens of kW

BTF Experimental Hall

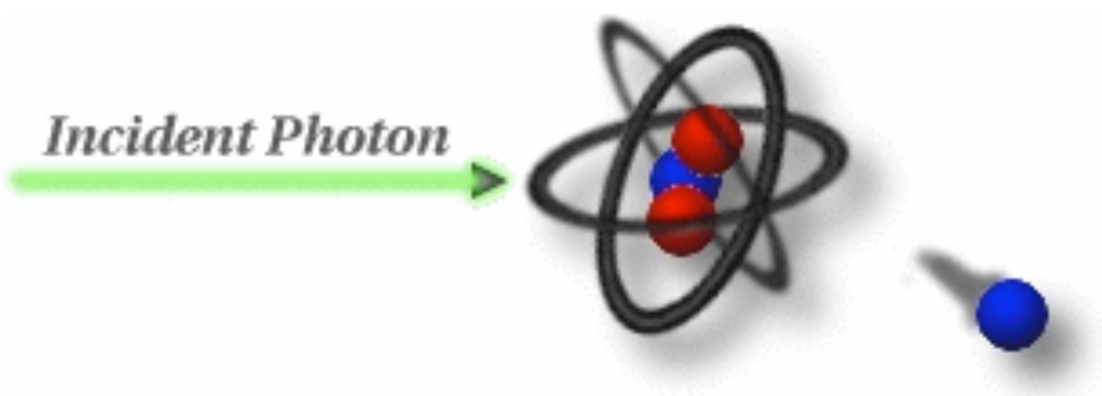


BTF Transfer Line



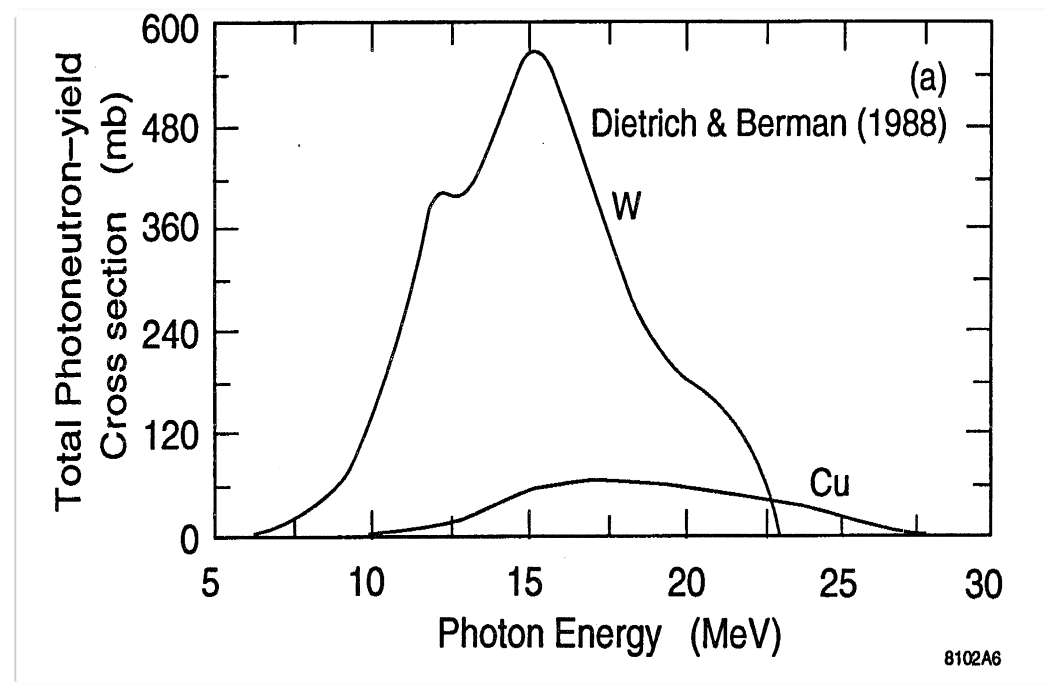
PHYSICS OVERVIEW
&
MONTE CARLO CODE CHOICE

The Physics: Neutron Photo-Production by Electron Interactions with a Target



More than 80% of electron interaction in the target produces Bremsstrahlung with continuos spectrum from 0 to E_e. The number of photon in a given energy interval is inversely proportional to the photon Energy

Typical Photoneutron cross section behaviour for medium (Cu) and high Z material (W)

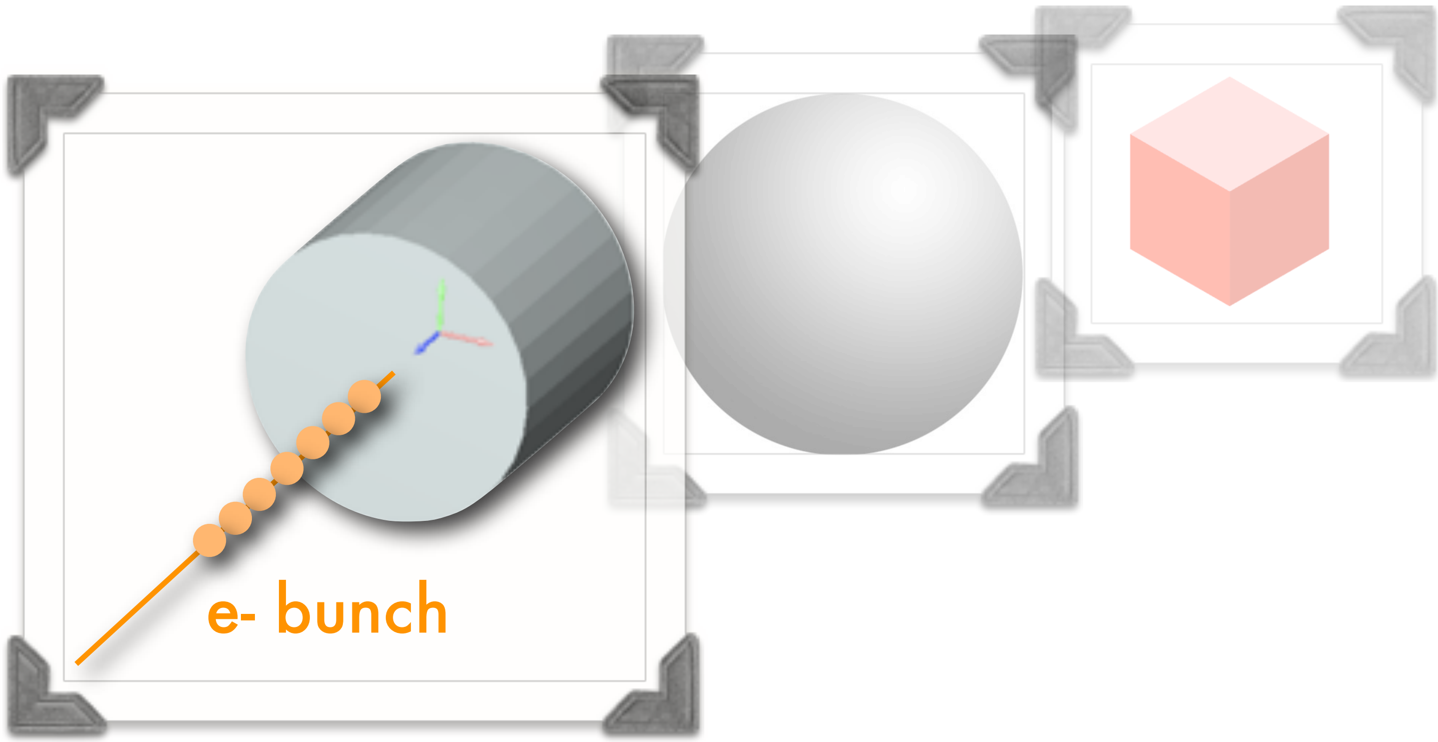


- Bremsstrahlung photons are generated when high energy electrons impinge on target
- These photons interact with the target nuclei, that are excited. These excited nuclei can emit neutron to come back to the fundamental status
- It is a threshold reaction: energy greater than binding energy (5-15 MeV) is needed to release a neutron. Photoneutron physics is dominated by a giant resonance phenomena (GDR) in the enrgy range from few MeV up to few tens MeV
- Protons could be also emitted but the presence of large Coulomb barrier strongly represses this channel in heavy nuclei . Below Z=20 the proton yield is in general larger than the neutron yield, while the reverse is true in heavier elements

Source Term: High Energy Electron (Daφne Linac)

Target : High Z material (optimal geometry and material)

Design strategy: activities performed



- Choice of MC codes: particle transport codes with implemented photonuclear physics (Fluka, Mcnpx,Geant4)
- Starting point for MC simulations: Fluka (general purpose MC code developed by INFN and CERN collaboration) http://www.fluka.org/
- FLUKA predictions validated by means of Swanson semiempirical correlations on thick target geometry
- Design of the experimental final apparatus (shield + extraction lines): neutron and photon fluences expected along the extractions lines
- MCNPX for benchmarking (done)
- Geant4 Simulations in progress

Fluka: Photonuclear implementation

Fluka is a single integrated code which can treat in a same run complete hadronics cascade (generation and transport of about 60 different particles) over an energy range spanning more than 14 orders of magnitude (up to 100 TeV). It is developed by INFN and CERN.

Photonuclear reactions have been implemented in 1994 opening the way toward a more accurate electron shielding design.

Fluka code deals with photonuclear reaction on the whole energy range.

Photon reactions with nuclei show features which are strongly changing with energy, in correspondence with very different interactions mechanism at the nuclear level. For modelling purpose 4 regions are distinguishable:

Giant Resonance
7<E<30 MeV

For medium and heavy nuclei, cross sections have been taken from the Atlas of Dietrich and Berman, Atomic Data and Nuclear Data Tables 38, 199 (1988), which provides cross section for neutron emission rather than total cross section: for heavy nuclei the two cross section are approximately equal

Quasi Deuteron Resonance
30<E<200MeV

Levinger absorption mechanism has been implemented

$$\sigma_{QD}(E_\gamma) = L\frac{NZ}{A}\sigma_D(E_\gamma)f(E_\gamma)$$

L is the Levinger constant given as function of A

Delta Resonance
E>140 MeV

Above the energy threshold per pion production, photonuclear interaction are characterized by excitation of Delta Resonance

High Energy Range
E>720 MeV

Above the delta resonance the Vector Meson Dominance model is used. The total cross section is obtained as :

$$\sigma_T = N\sigma_n + Z\sigma_p,$$

Photonuclear Cross Sections in Fluka

Taking advantage from:

- the new IAEA Photonuclear Data Library for 164 isotopes (2000)
- other evaluated data from various Laboratories (ORNL, LANL, CNDC, JAERI, KAERI, MSU)
- many experimental data made available via the EXFOR database

Un Important upgrade for the photonuclear physics was done in 2005: the Fluka Library was updated and completed:

At present a total cross section data for 190 nuclides have been inserted

190 nuclides data are tabulated :

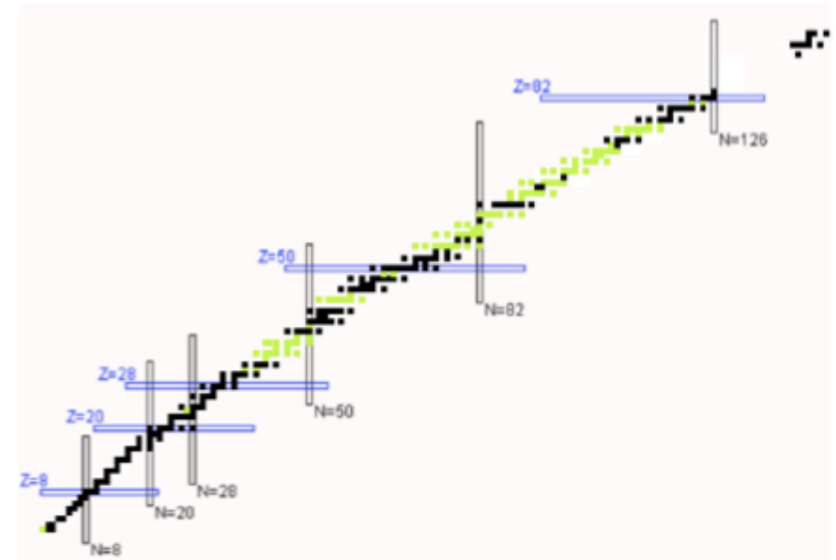


FIGURE 12. The 190 nuclides of the FLUKA GDR total cross section library (black squares). The grey squares indicate the stable nuclides not included in the library

If experimental cross sections are not available then Lorentz fits of the existing data are used:

- If Z>29 then Lorentz parametrization is used (with published Lorentz parameters as peak energy, peak height, width) if they exist. They are all those reported in the Atlas of Dietrich and Berman Atomic Data and Nuclear Data Tables 38, 199 (1988), except Pr, Au and Pb, for which we have used the parameters published in Berman et al., Phys. Rev. C36, 1286 (1987). otherwise
- Lorentz parametrization with parametrized Lorentz parameters. (it sounds funny, but Berman and Fultz (Rev. Mod. Phys. 47, 713 (1975) have published some general formulas giving the 3 Lorentz parameters as a function of A and Z.)

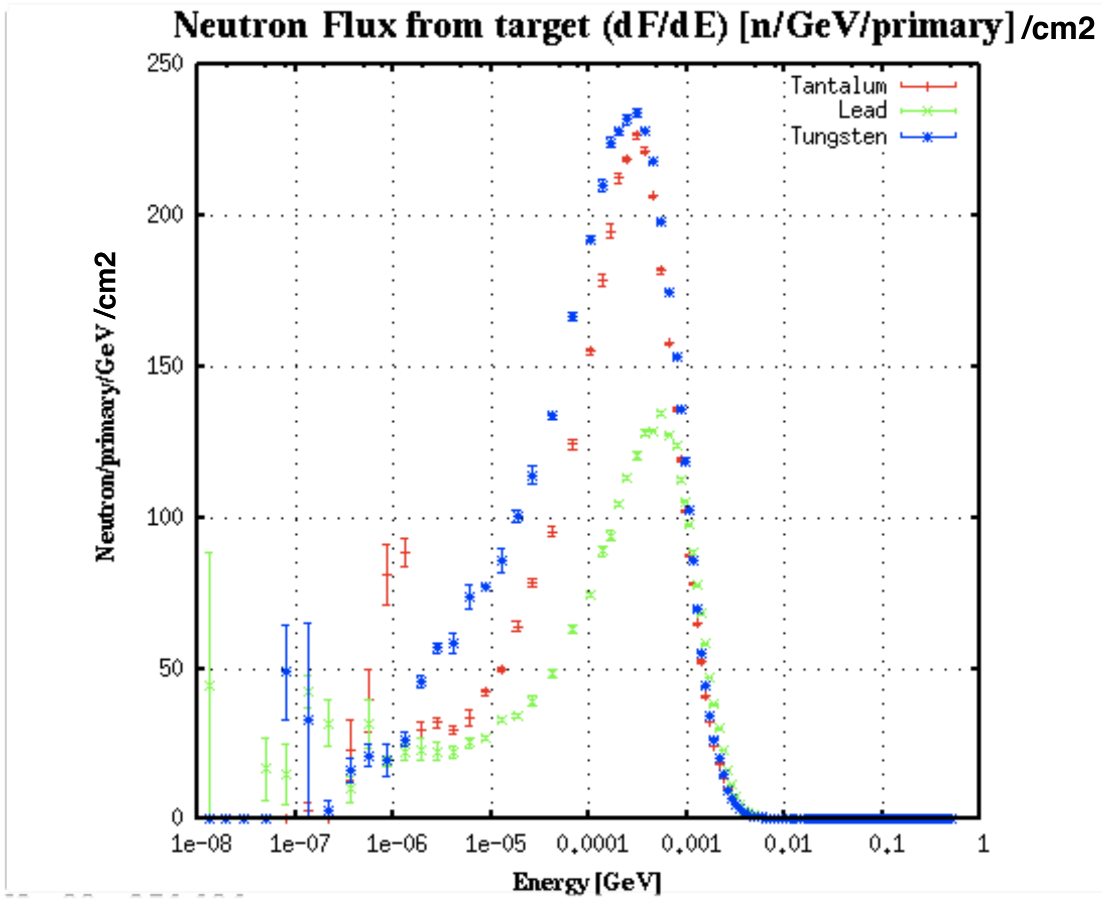
REFERENCE:

A. Fassò, A. Ferrari, P.R. Sala – Photonuclear Reactions in FLUKA: Cross Sections and Interaction Models – *AIP Conf. Proc. 769 (2005) pp.1303-1306*

OPTIMIZED TARGET
&
EXPERIMENTAL APPARATUS

Source term validation

Electron beam @ 500 MeV; Cylindrical Target



consequent study of material

Material	Swanson** [n/kW s] *E+12	Fluka* [n/kW s] E+12
Tantalum	2.13	2.37
Lead	1.98	2.06
Tungsten	2.42	2.67

Rate[n/E_dep]=(n/pr)*Ne/(Ne*(510*1.6E-19))=n/P[W]/s

Ne=e-/s

Validation of Fluka predictions against Swanson semi-empirical correlation**

The values of Swanson refer to thick targets and Ee=500 MeV

* Fluka version 2008.3b.0

**Reference: slac-pub-2042 (77)

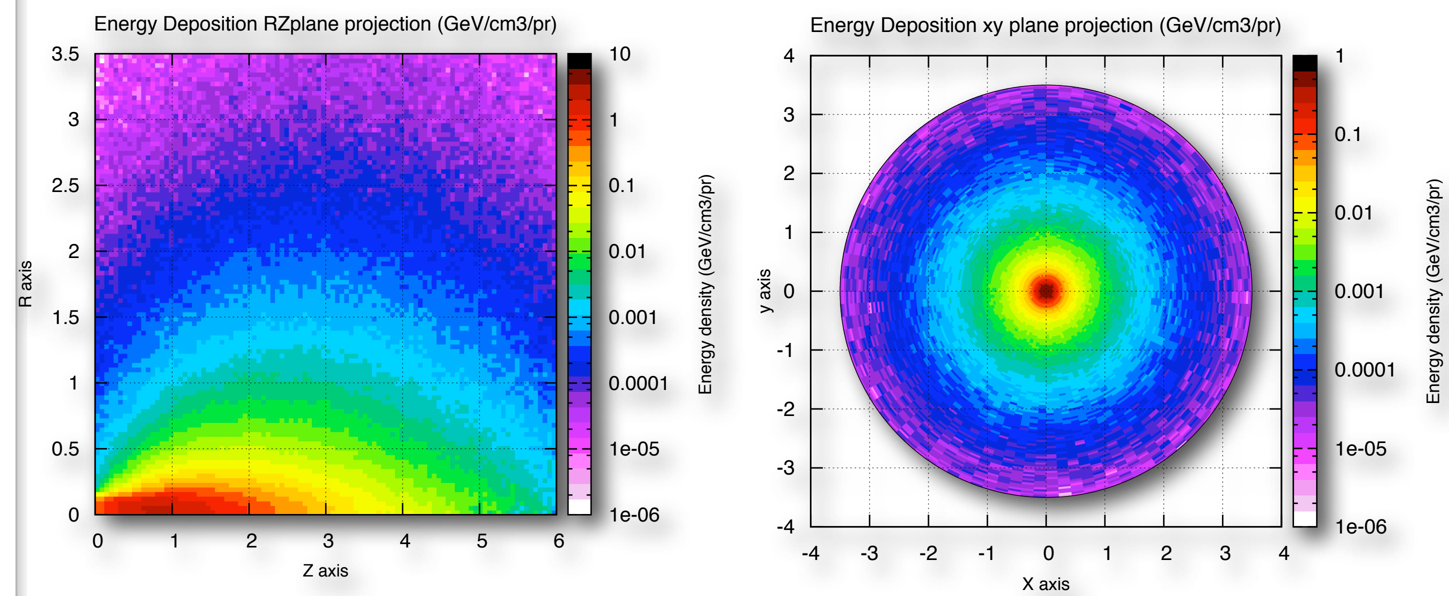
The agreement is very good (difference less than ~10 %): this makes us confident in the goodness of MC neutron source estimation

Tungsten vs Tantalum

Nuclear and thermo-mechanical properties

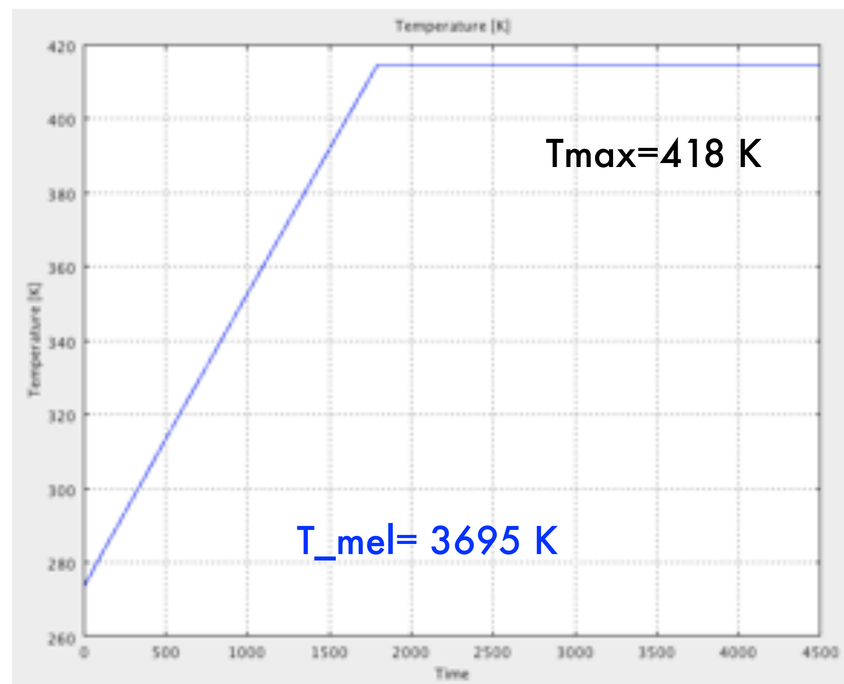
Properties	Ta	W
Density(g/cm3)	16.69	19.25
Z	73	74
P.M (g mol-1)	180.95	183.84
Moliere radius [cm]	1.073	0.9327
Rad Length [cm]	0.4094	0.3504
K (thermal cond)[W/mK]	57.5	173
E(young) [GPa]	186	411
Poisson Ratio	0.34	0.28
alpha µm/m*K	6.3	4.5
T(melting point) [k]	3290	3695
Specific Heat capacity [J/kg K]	25.36	24.27

Thermal Diffusivity
k/(ρ C)
in W ≃ 3 times larger than in Ta



Energy Deposition profile in zr and xy plane

Energy deposited by primary in the target=**493.06 MeV +3%**



Temperature plot refers to calculation with these assumptions :

- Adiabatic conditions on surface.
- Maximum power deposited in 0.5 h

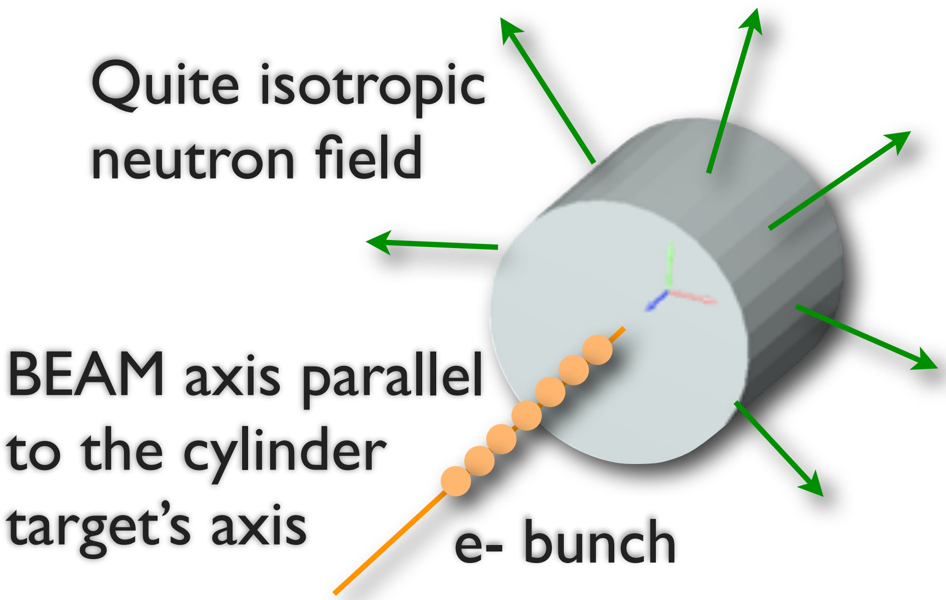
It is not necessary to provide cooling because of the low power deposited on the target (<100 W) and thanks to the high thermal conductivity (high gradient temperature) and high melting temperature of Tungsten

The Optimized Target

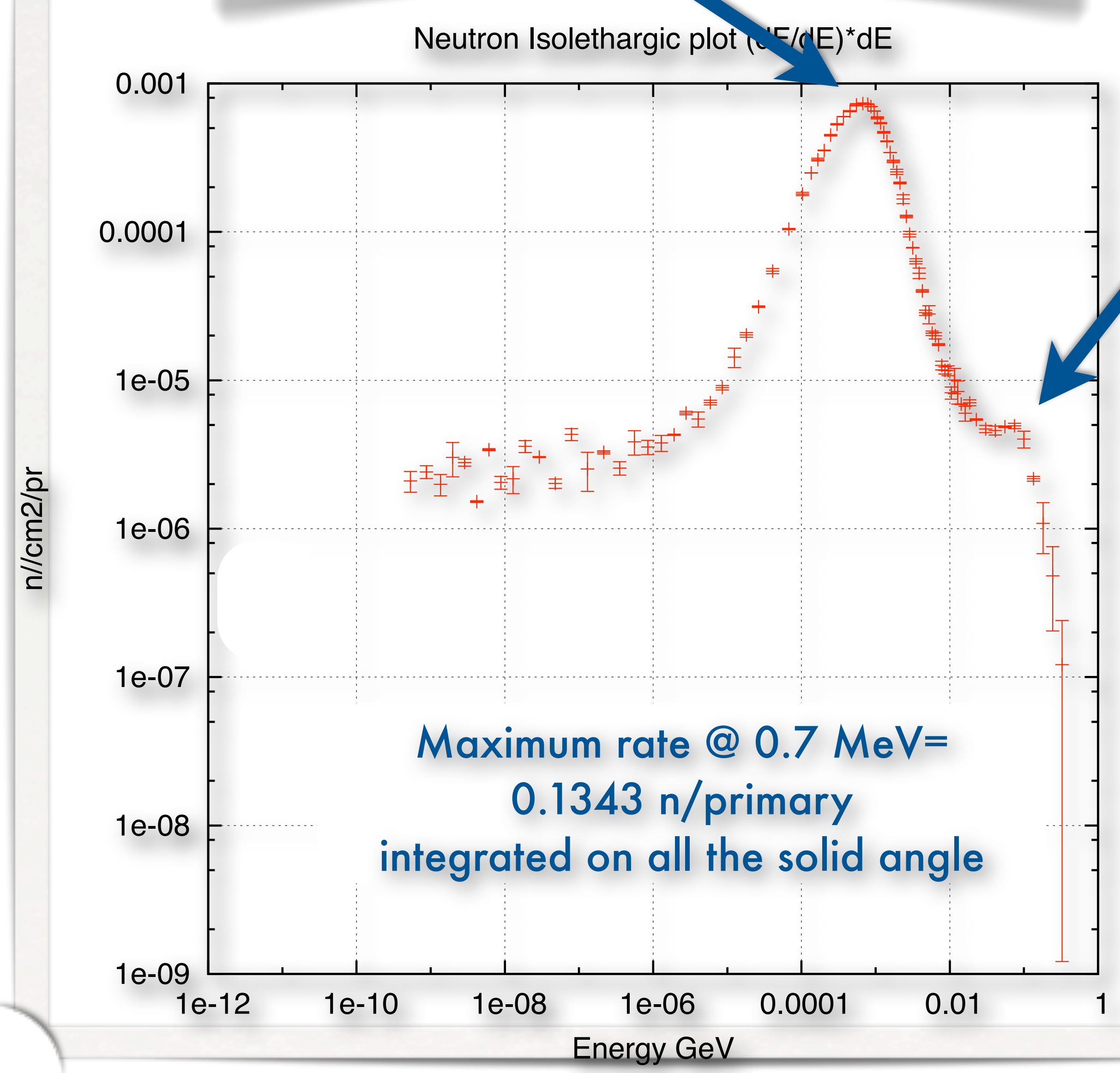
Optimization criterion: recursive process on calculating neutron fluences leaving the target, increasing linear dimensions (Rand L)
Best solution: the one for which, a new step would have affected only marginally the photoneutron yield (gain of only few %).
L from 15 to 20X0 gain less than 3% (so final choice 17X0 on the plateau); Same considerations: R final choice 10 X0.

W cylinder R=35 mm L =60 mm

(Z=74; ϱ=19 g/cm3; X0=0.35 cm; MR=0.9 cm)



Up to 100 MeV the spectrum is described as a Maxwellian distribution with average around 1 MeV



Approaching the higher energies the Quasi-Deuteron Effects adds a tail of high-energy neutrons to the Giant resonance spectrum. The slope becomes stepper as the incident electron energy is approached

n_yield= 2.12E-01 neutron/primary integrated on all the spectrum and solid angle escaping from the target

Neutron absorbed in the target= 3%
NEU-BAL=0.212451
n-produced=0.21809

Since the maximum electron beam spot size on the target is enclosed in a circle of 1.cm radius and the accuracy by which we can set the beam position is better of few mm, we can be confident that all the energy of the primary electrons wil be ever deposited in the target

The Optimized Target

Optimization criterion: recursive process on calculating neutron fluences leaving the target, increasing linear dimensions (Rand L)
Best solution: the one for which, a new step would have affected only marginally the photoneutron yield (gain of only few %).
L from 15 to 20X0 gain less than 3% (so final choice 17X0 on the plateau); Same considerations: R final choice 10 X0.

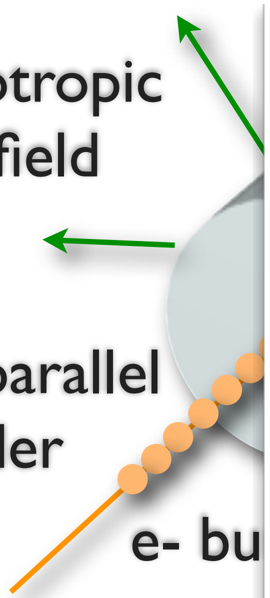
W cylinder R=35 mm L =60 mm

(Z=74; ϱ=19 g/cm3; X0=0.35 cm; MR=0.9 cm)

Up to 100 MeV the spectrum is described as a Maxwellian distribution with average

Quite isotropic neutron field

BEAM axis parallel to the cylinder target's axis



n_yield= 2.12E
neutron/prim
integrated on all the
and solid ang
escaping from the

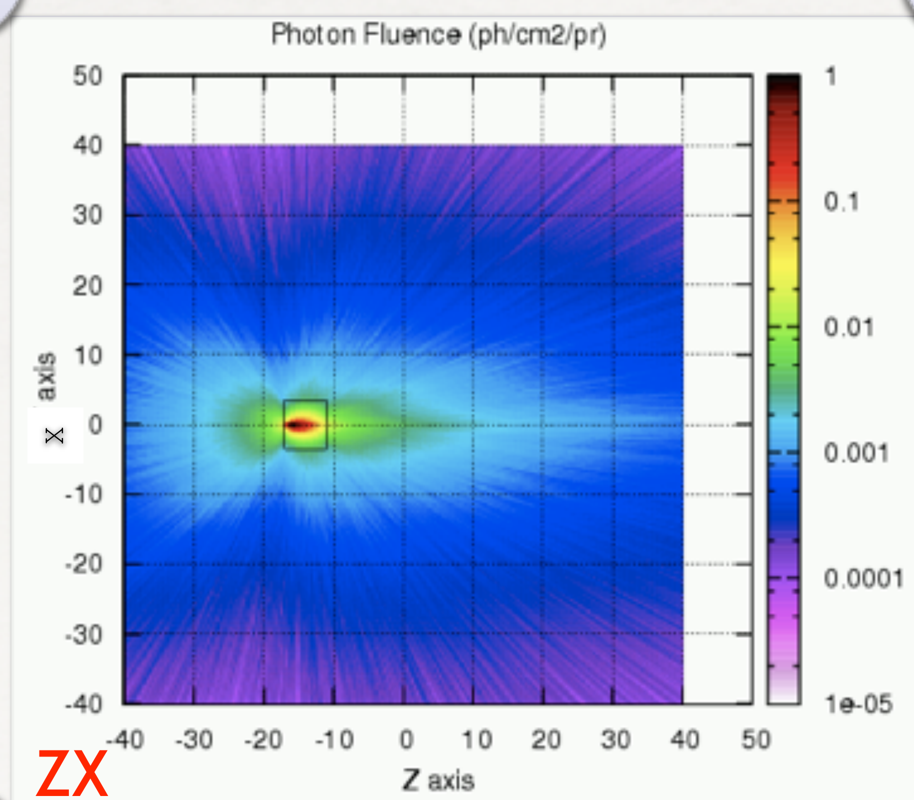
Neutron absorbed in the
NEU-BAL=0.212
n-produced=0.21

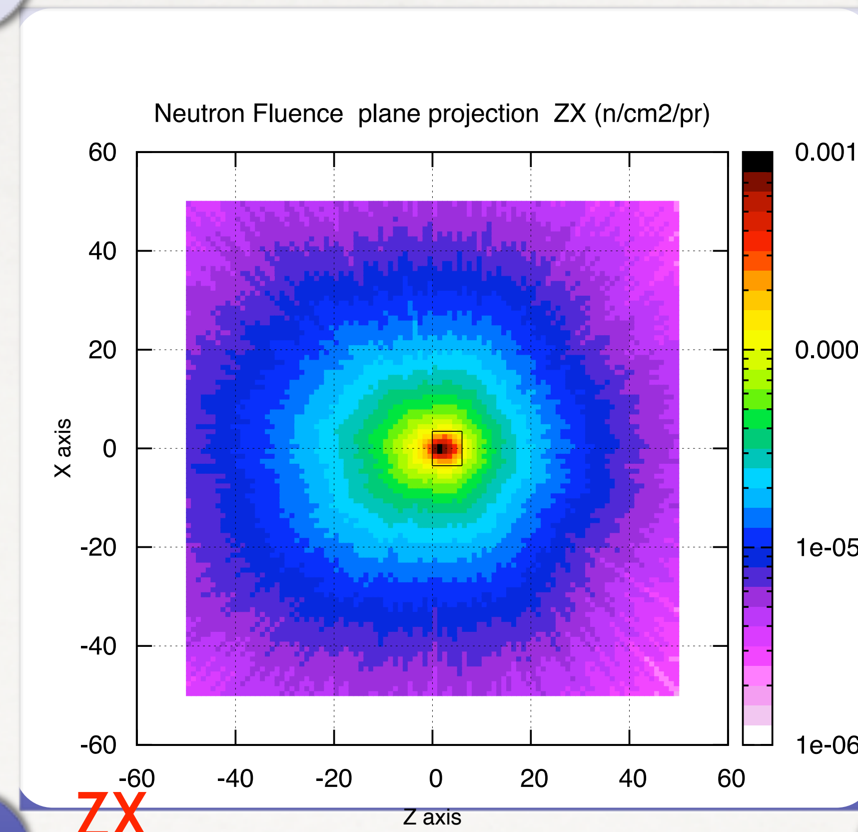
pproaching the
gher energies the
uasi-Deuteron
ects adds a tail of
gh-energy neutrons
the Giant
sonance spectrum.
e slope becomes
epper as the
cident electron
ergy is approached

Since the maximum electron beam spot size on the target is enclosed in a circle of 1.cm radius and the accuracy by which we can set the beam position is better of few mm, we can be confident that all the energy of the primary electrons wil be ever deposited in the target

Expected Neutrons and Photons:
(target in vacuum)

Spatial distribution





Higher intensity and hardest Gammas in forward direction. More than 2 order of magnitudes of difference in photon fluxes @ 90° and 0 ° wrt beam direction

Quite well isotropic

The photon and neutron fluxes have been calculated by the USRYIELD card for each direction

Expected Neutrons and Photons:
(target in vacuum)

Neutron and Photon Flux (Target and air around).

(Calculation with 25000 primaries)

Angle wrt beam direction	Photons[ph/cm2/pr] @0.5 m	Neutron [n/cm2/pr] @0.5 m
0°	1.16559E-02 +/- 1.207616 %	5.78188E-06 +/- 0.5680834 %
-30°	3.18765E-04 +/- 2.074163 %	7.32548E-06 +/- 1.397449 %
30°	2.00091E-03 +/- 0.6900502 %	6.98712E-06 +/- 0.2340965 %
-45°	2.55639E-04 +/- 1.500333 %	6.73067E-06 +/- 1.536476 %
45	9.85524E-04 +/- 0.7157903 %	6.37311E-06 +/- 0.8208705 %
-60	1.80074 E-04 +/- 3.305821 %	5.84105E-06 +/- 1.092179 %
60°	4.76631E-04 +/- 1.785744 %	5.35342E-06 +/- 1.501851 %
90°	9.61925E-05 +/- 4.184312 %	4.37955E-06 +/- 1.058816 %

Photon and Neutron Flux integrated on all the solid angle.
They are inversely proportional to the square of distance

	Photons[ph/cm2/pr]	Neutron [n/cm2/pr]
@ 0.5 m	6.2910217E-04 +/- 0.3605311 %	5.8066257E-06 +/- 0.5866572 %
@ 1.0 m	.5729200E-04 +/- 0.3733959 %	1.4539921E-06 +/- 0.5513448 %

The photon and neutron fluxes have been calculated by the USRYIELD card for each direction

Expected Neutrons and Photons:
(target in vacuum)

Neutron and Photon Flux (Target and air around).

(Calculation with 25000 primaries)

Angle wrt beam direction	Photons[ph/cm2/pr] @0.5 m	Neutron [n/cm2/pr] @0.5 m
0°	1.16559E-02 +/- 1.207616 %	5.78188E-06 +/- 0.5680834 %
-30°	3.18765E-04 +/- 2.074163 %	7.32548E-06 +/- 1.397449 %
30°	2.00091E-03 +/- 0.6900502 %	6.98712E-06 +/- 0.2340965 %
-45°	2.55639E-04 +/- 1.500333 %	6.73067E-06 +/- 1.536476 %
45	9.85524E-04 +/- 0.7157903 %	6.37311E-06 +/- 0.8208705 %
-60	1.80074 E-04 +/- 3.305821 %	5.84105E-06 +/- 1.092179 %
60°	4.76631E-04 +/- 1.785744 %	5.35342E-06 +/- 1.501851 %
90°	9.61925E-05 +/- 4.184312 %	4.37955E-06 +/- 1.058816 %

Photon and Neutron Flux integrated on all the solid angle.
They are inversely proportional to the square of distance

	Photons[ph/cm2/pr]	Neutron [n/cm2/pr]
@ 0.5 m	6.2910217E-04 +/- 0.3605311 %	5.8066257E-06 +/- 0.5866572 %
@ 1.0 m	.5729200E-04 +/- 0.3733959 %	1.4539921E-06 +/- 0.5513448 %

The photon and neutron fluxes have been calculated by the USRYIELD card for each direction

Expected Neutrons and Photons:
(target in vacuum)

Neutron and Photon Flux (Target and air around).

(Calculation with 25000 primaries)

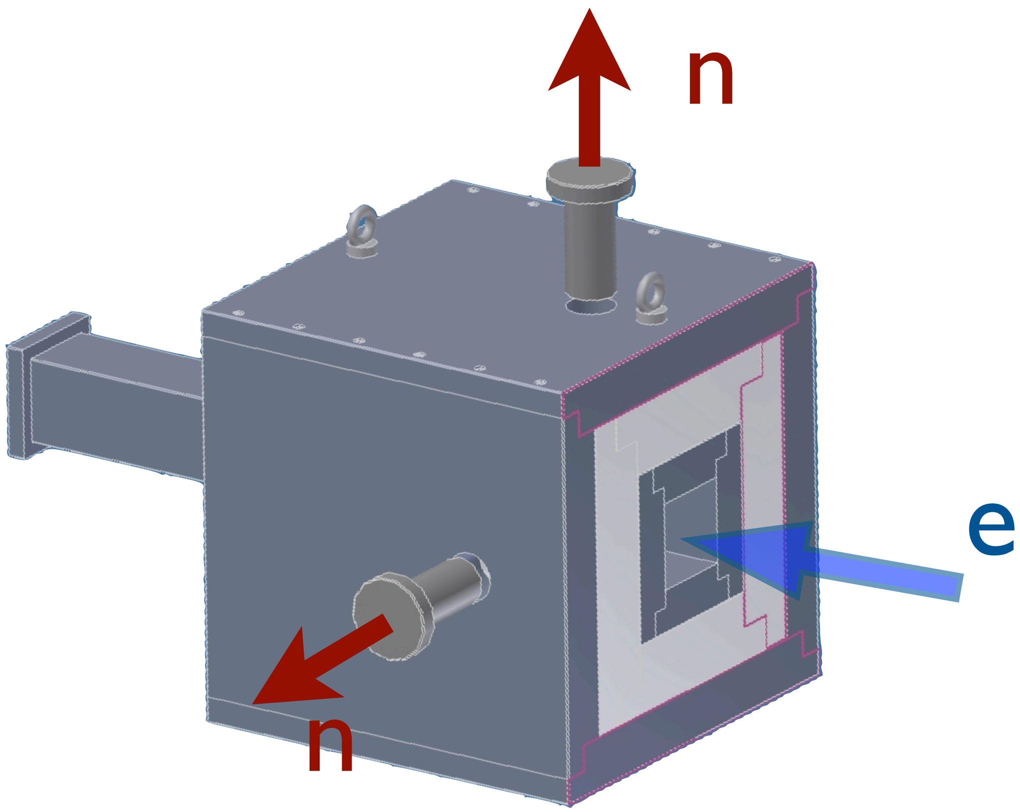
Angle wrt beam direction	Photons[ph/cm2/pr] @0.5 m	Neutron [n/cm2/pr] @0.5 m
0°	1.16559E-02 +/- 1.207616 %	5.78188E-06 +/- 0.5680834 %
-30°	3.18765E-04 +/- 2.074163 %	7.32548E-06 +/- 1.397449 %
30°	2.00091E-03 +/- 0.6900502 %	6.98712E-06 +/- 0.2340965 %
-45°	2.55639E-04 +/- 1.500333 %	6.73067E-06 +/- 1.536476 %
45	9.85524E-04 +/- 0.7157903 %	6.37311E-06 +/- 0.8208705 %
-60	1.80074 E-04 +/- 3.305821 %	5.84105E-06 +/- 1.092179 %
60°	4.76631E-04 +/- 1.785744 %	5.35342E-06 +/- 1.501851 %
90°	9.61925E-05 +/- 4.184312 %	4.37955E-06 +/- 1.058816 %

Photon and Neutron Flux integrated on all the solid angle.
They are inversely proportional to the square of distance

	Photons[ph/cm2/pr]	Neutron [n/cm2/pr]
@ 0.5 m	6.2910217E-04 +/- 0.3605311 %	5.8066257E-06 +/- 0.5866572 %
@ 1.0 m	.5729200E-04 +/- 0.3733959 %	1.4539921E-06 +/- 0.5513448 %

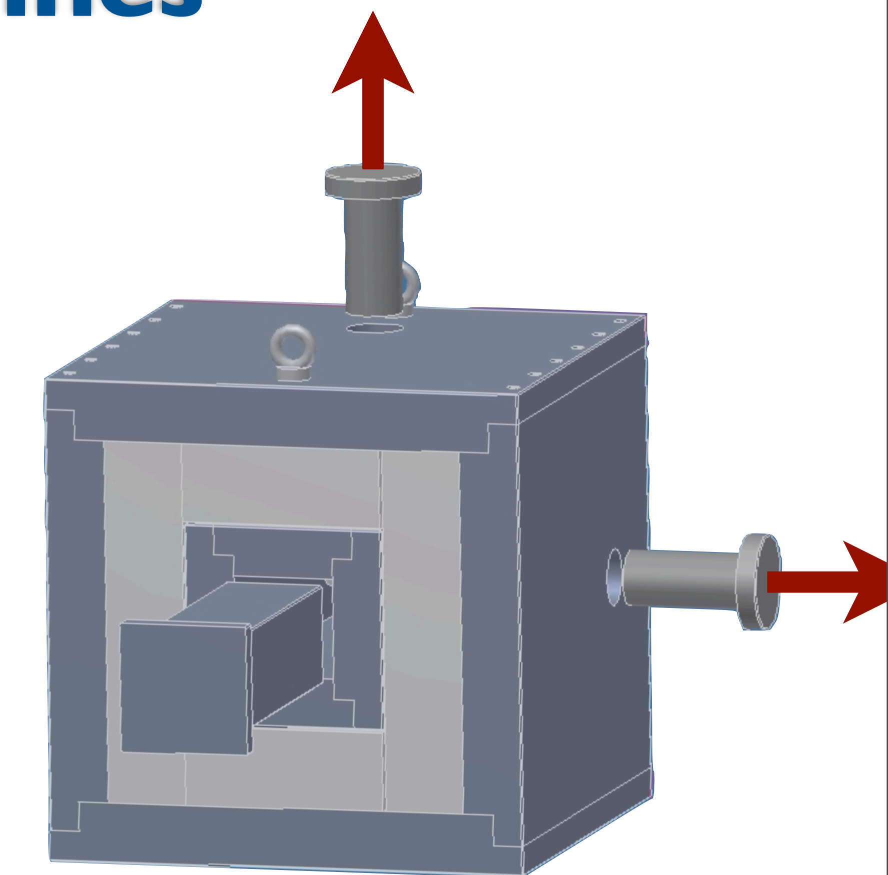
The photon and neutron fluxes have been calculated by the USRYIELD card for each direction

Shield and Extraction lines

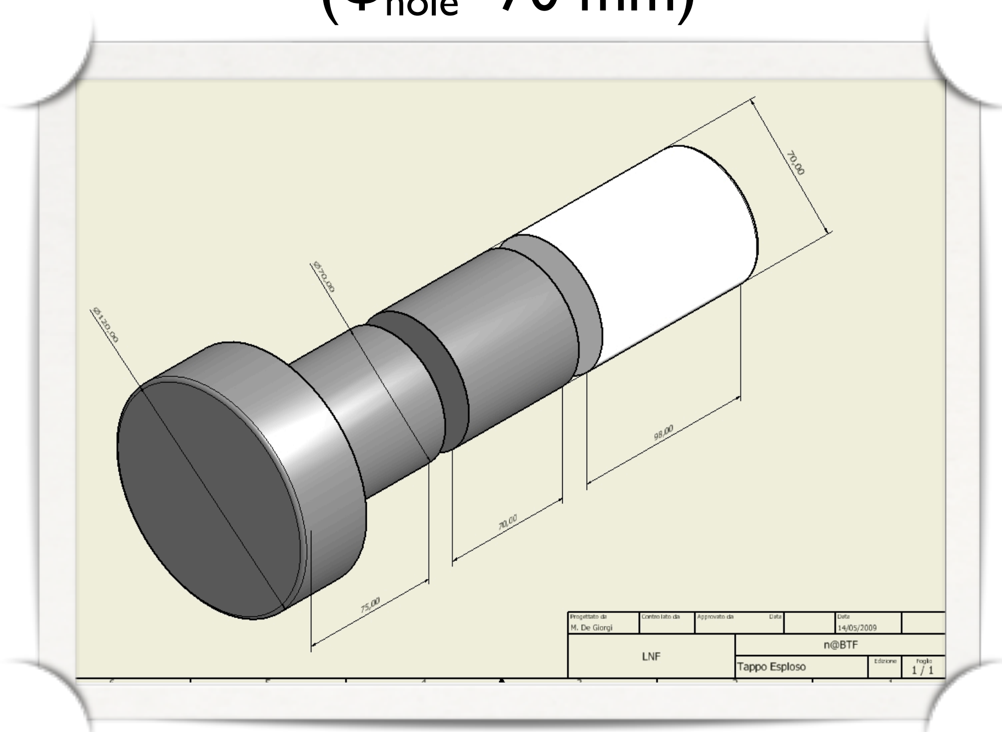


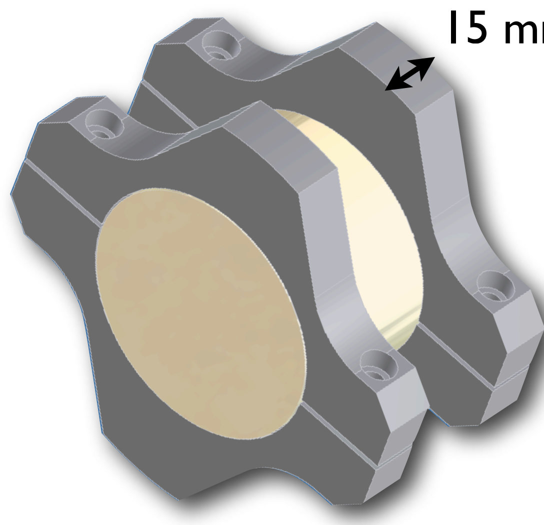
Maximum
dimensions:
600x600 mm

-15 cm of lead (11g/cm^3)
-25 cm in the front dump
-10 cm of polyethylene (0.95g/cm^3)



2 Extraction Lines **@ 90°**
wrt the beam direction
(Φ_{hole}=70 mm)





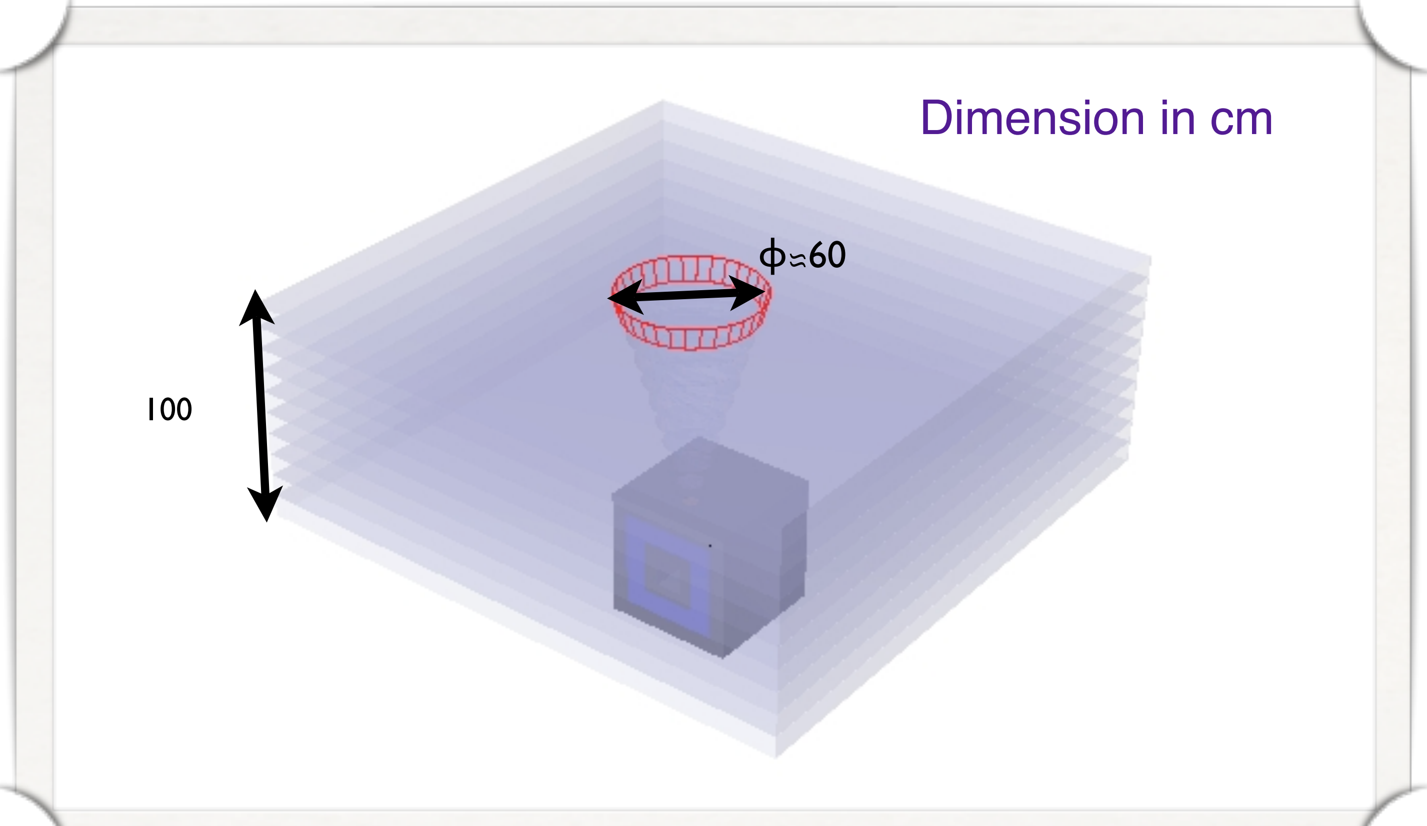
Two Stainless Steel rings for supporting
and centering the target

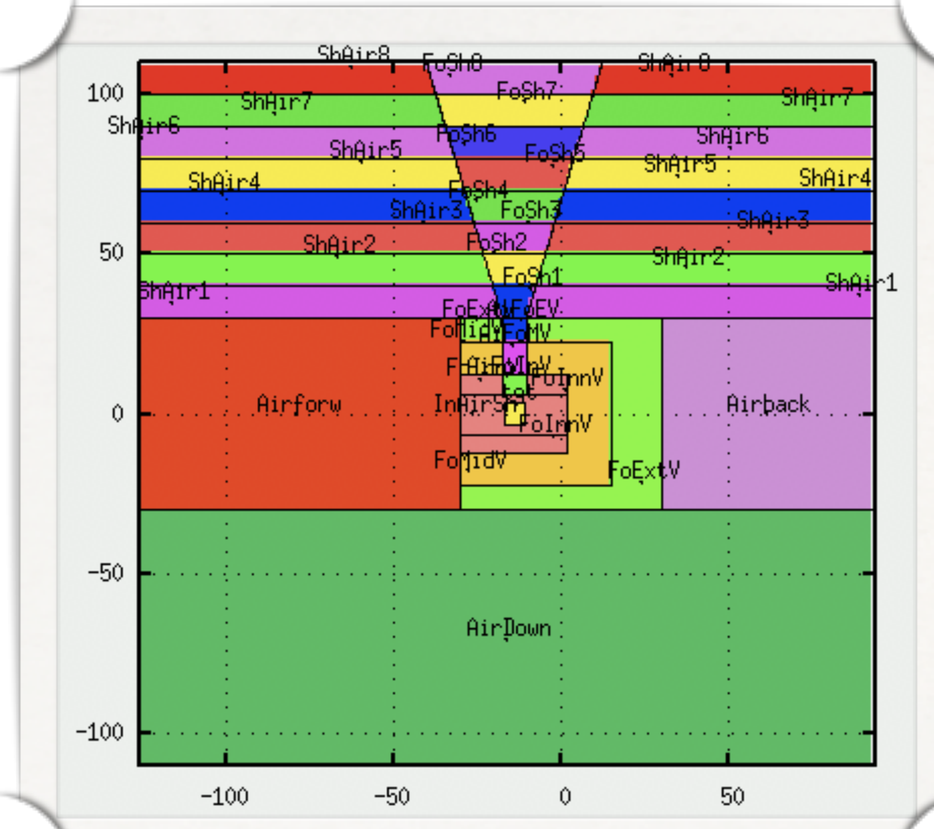
To enhance the **n-signal/ph-background** ratio along the extraction lines, several cap configurations have been foreseen and studied and other solutions are in progress.

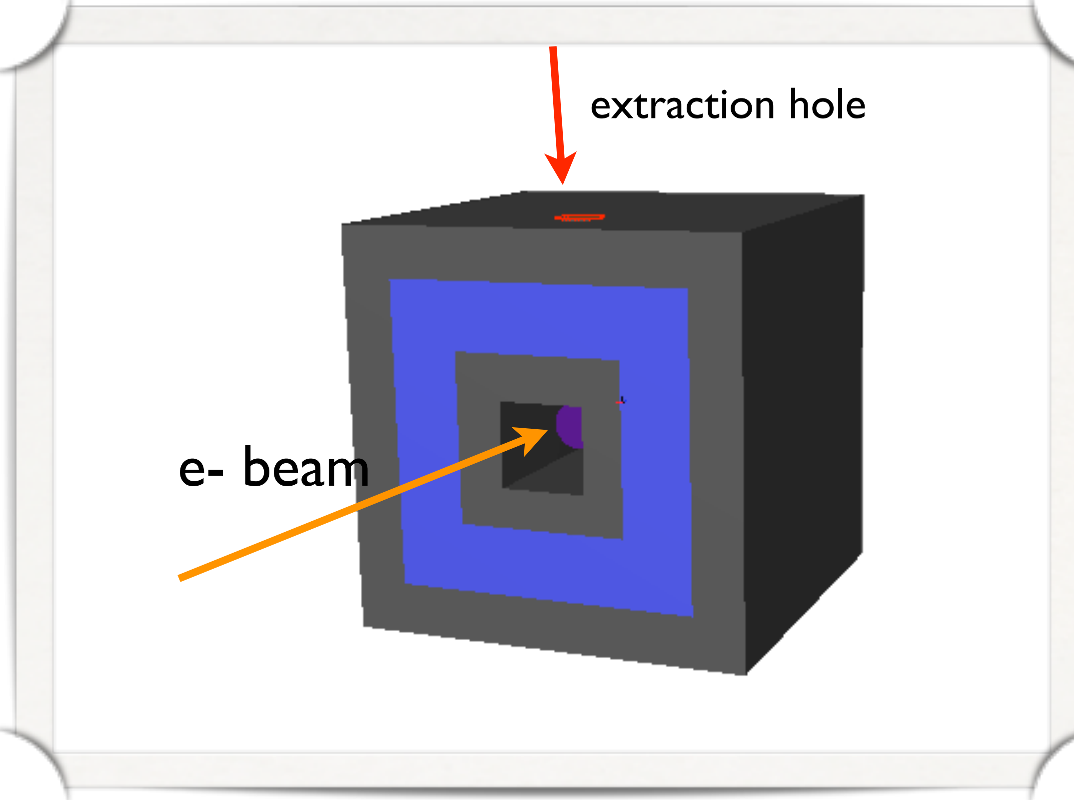
PREDICTED NEUTRON AND PHOTON FIELDS IN THE FINAL APPARATUS

Fluka Model:

Target+ Inner Air+ Layered Shield +External Air

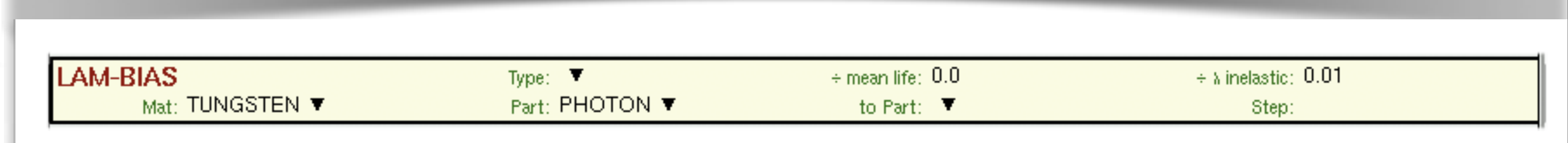






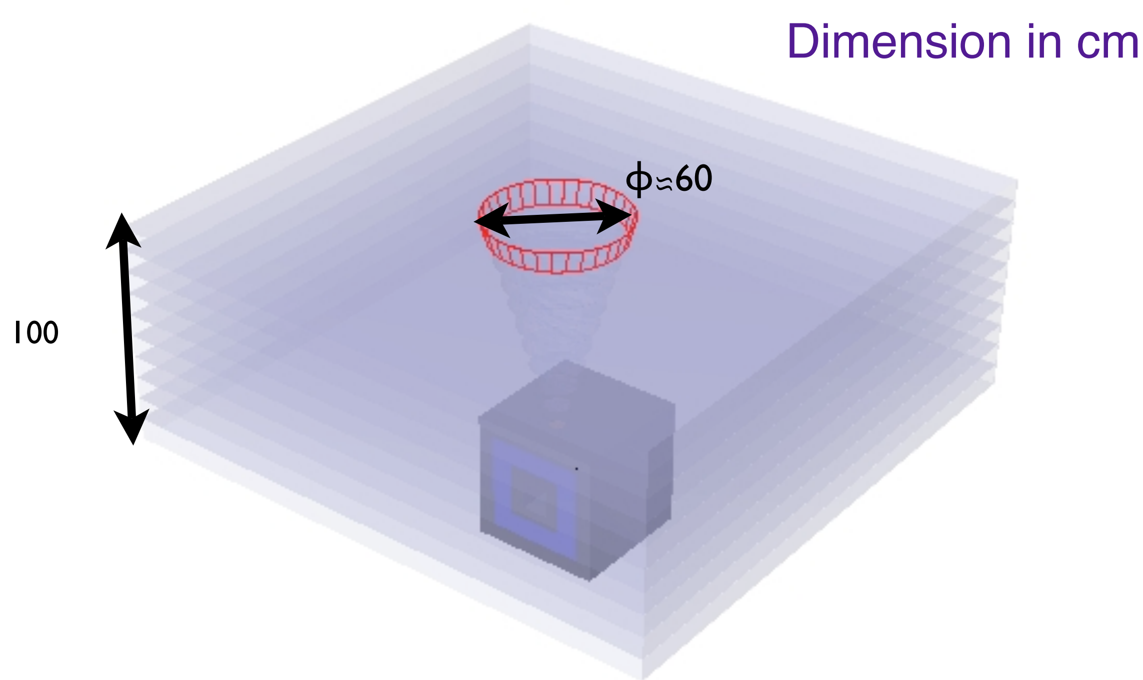
In the simulations an air volume of 260x260x260 cm3 has been introduced around the target.

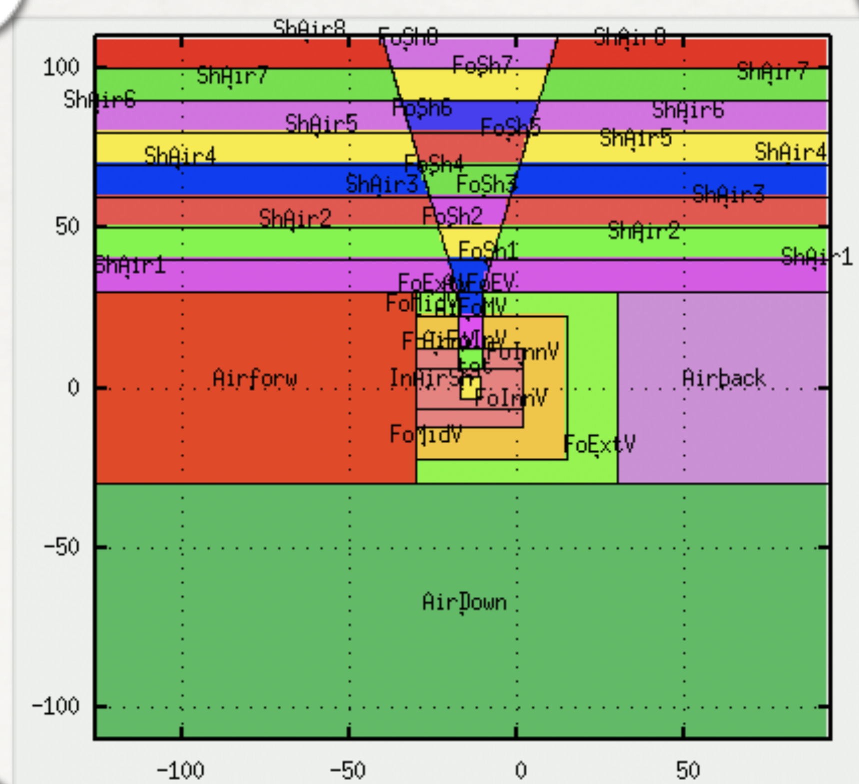
Physic:Activation of gamma interaction with high Z nuclei at all energies

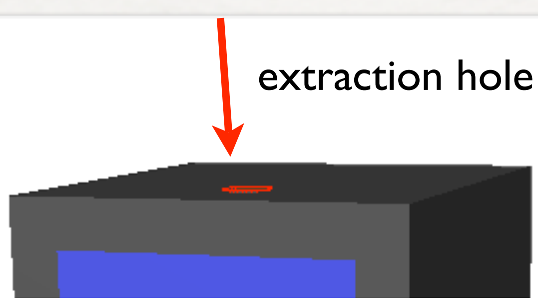


Fluka Model:

Target+ Inner Air+ Layered Shield +External Air







In the simulations an air volume of
260x260x260 cm3 has been introduced around the target.

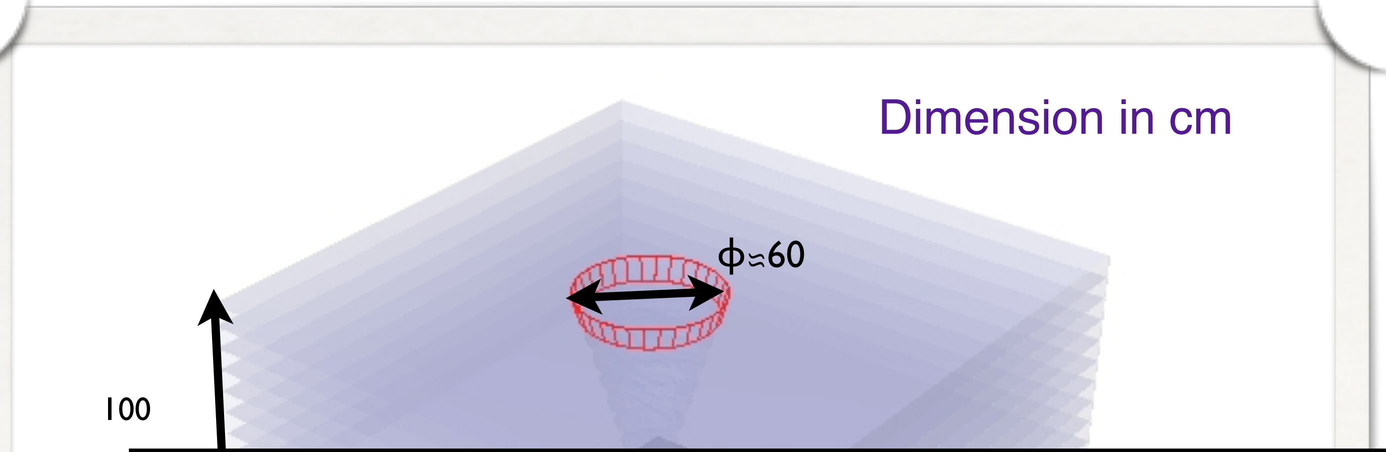
Physic:Activation of gamma interaction

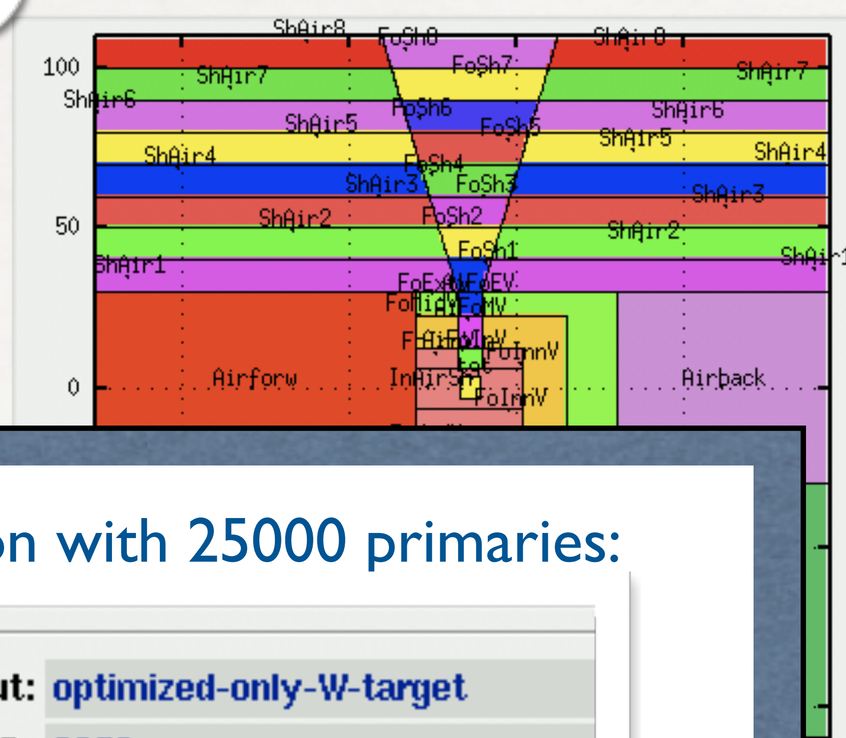
PHOTONUC Type: ▼ All E: off ▼
E>0.7GeV On ▼ Δ resonance On ▼ Quasi D On ▼ Giant Dipole On ▼
Mat: LEAD ▼ to Mat: TUNGSTEN ▼ Step: 6.0

LAM-BIAS Type: ▼ ÷ mean life: 0.0 ÷ λ inelastic: 0.01
Mat: TUNGSTEN ▼ Part: PHOTON ▼ to Part: ▼ Step:

Fluka Model:

Target+ Inner Air+ Layered Shield +External Air





Details of computation: Results refer to calculation with 25000 primaries:

Apple Mac Book
Linux Virtual Machine
Intel core duo
2 GHz

Input:	optimized-only-W-target
PID:	3350
Primaries:	1 out of 25000 (0.004%)
Remaining:	1d 15h 25m 3s
Time/prim:	5.67635 s

arget.

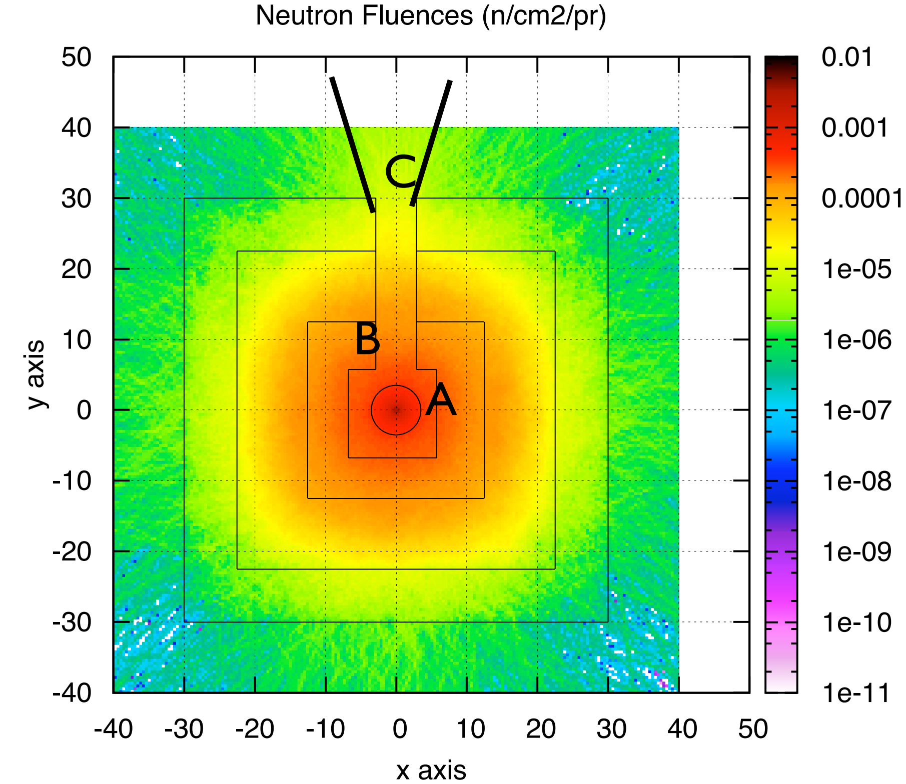
Physic:Activation of gamma interaction

PHOTONUC Type: ▼ All E: off ▼
E>0.7GeV On ▼ Δ resonance On ▼ Quasi D On ▼ Giant Dipole On ▼
Mat: LEAD ▼ to Mat: TUNGSTEN ▼ Step: 6.0

LAM-BIAS Type: ▼ ÷ mean life: 0.0 ÷ λ inelastic: 0.01
Mat: TUNGSTEN ▼ Part: PHOTON ▼ to Part: ▼ Step:

Fluka estimated neutron fluences (final setup)

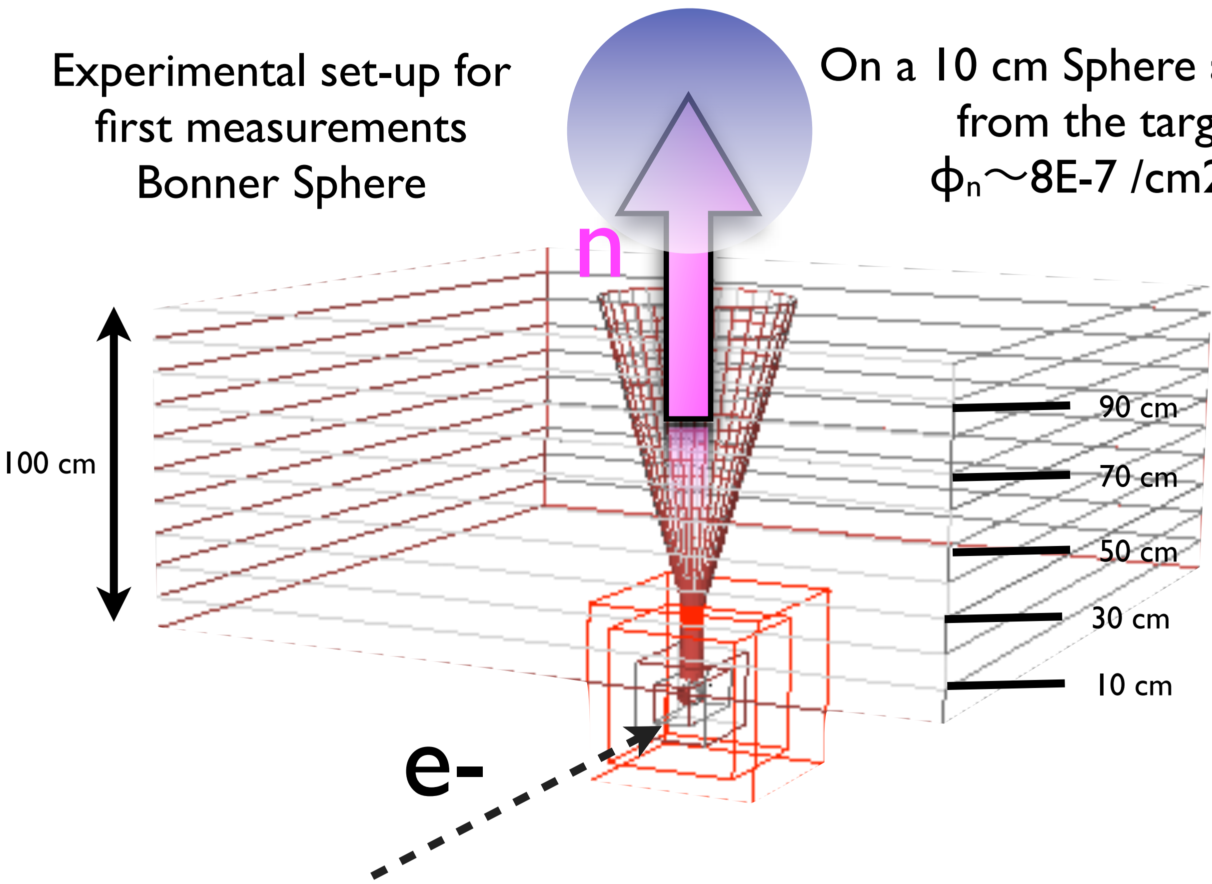
n@BTF	Fluence [n/cm2/pr] (on all spectrum)	FLUX n/cm2/s (all spectrum
exiting the target=$\phi 1$ (A)	1.8E-03 ±4%	8.80E+08
entering the shield=$\phi 2$ (B)	4.1E-04 ±4%	2.30E+08
leaving the shield=$\phi 3$ (C)	4.9E-05 ±4%	2.50E+07
1.5 m from shield=$\phi 4$ (D)	8.1E-07 ±4%	3.90E+05



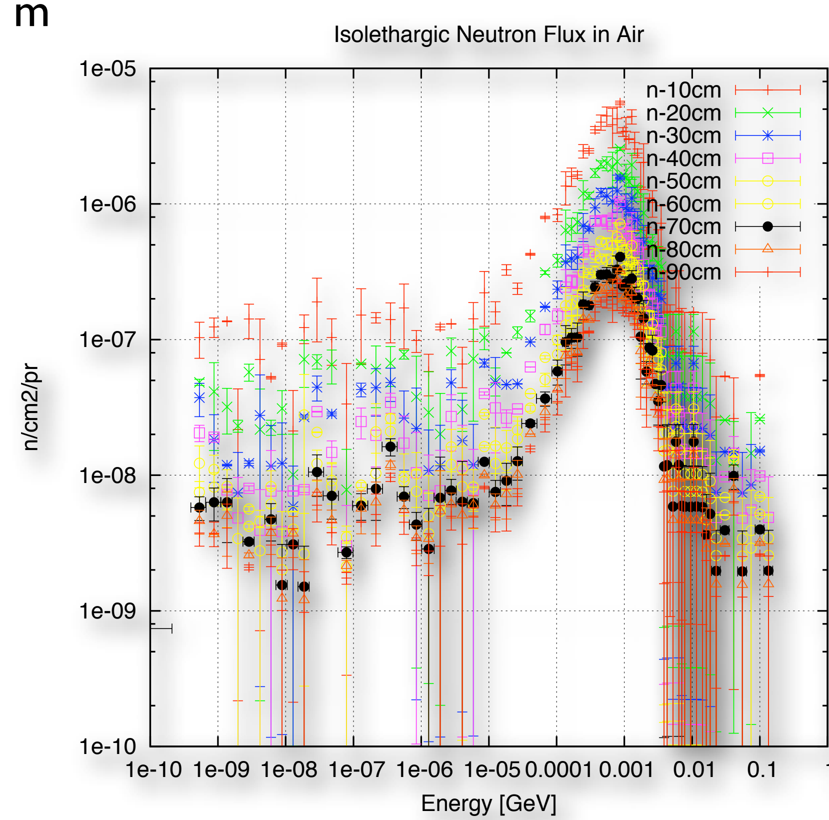
USRBDX card used to estimate the flux values. Current I_n crossing the considered area is stored

Experimental set-up for first measurements Bonner Sphere

On a 10 cm Sphere at 1.49 m from the target $\phi_n \sim 8E\text{-}7$ /cm2/pr



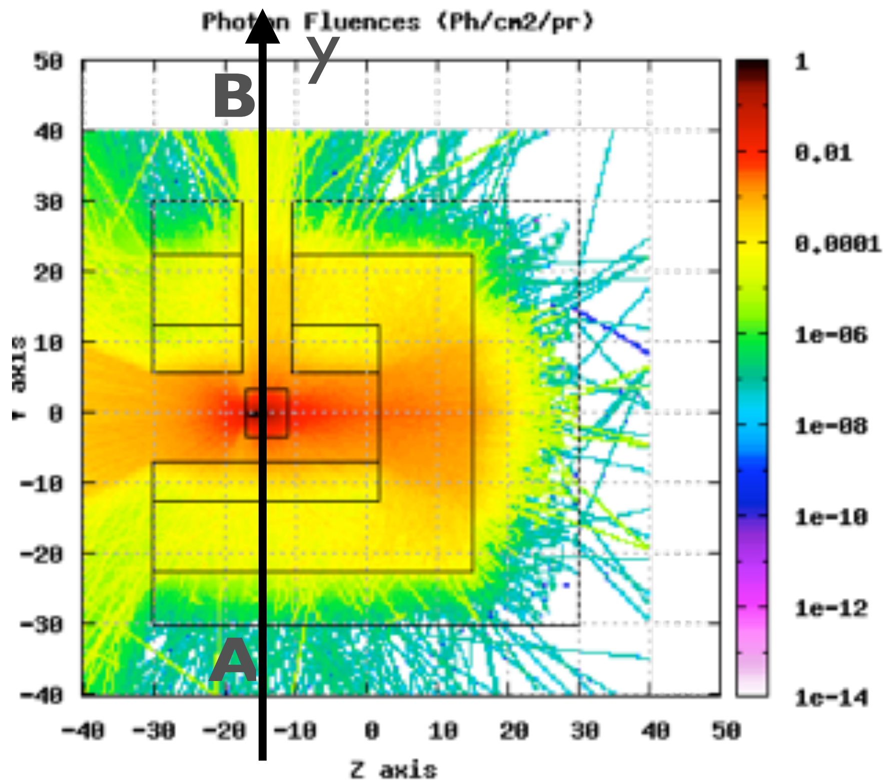
that means:
Average Integrated neutron rate for BTF = ~4.E+5 n/cm2/s (about 43 mSv/h Eq.Dose)

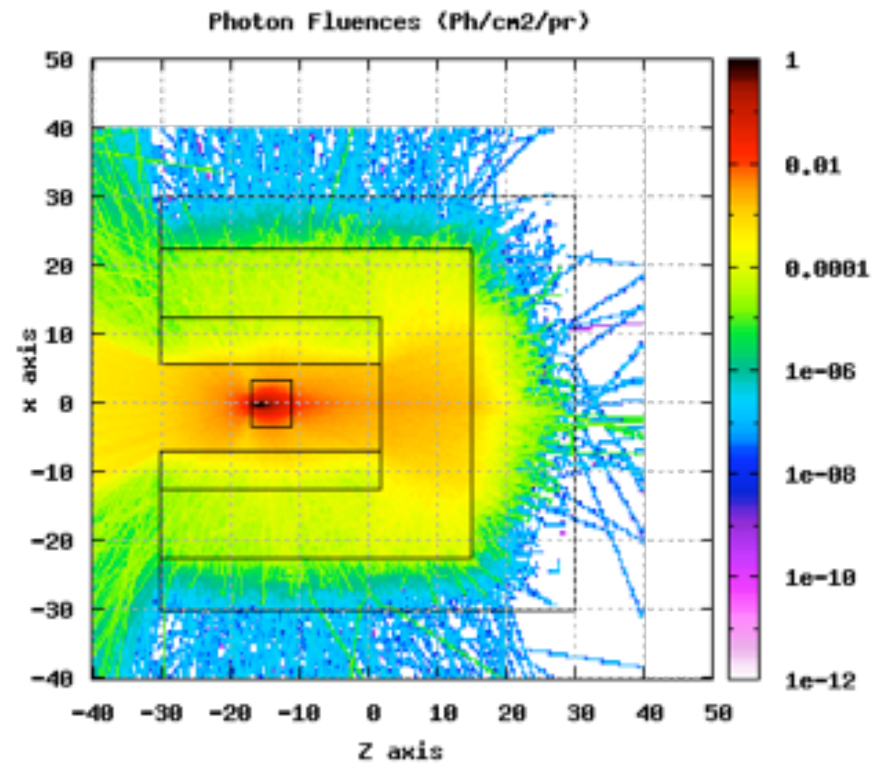


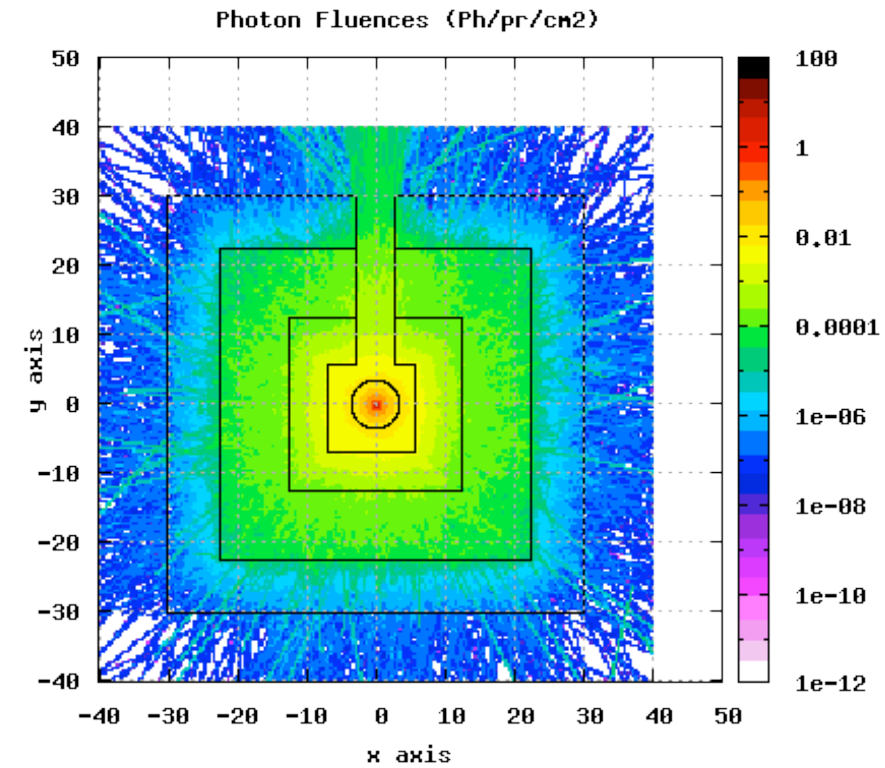
Neutron Energy spectra at different distances along the extraction line

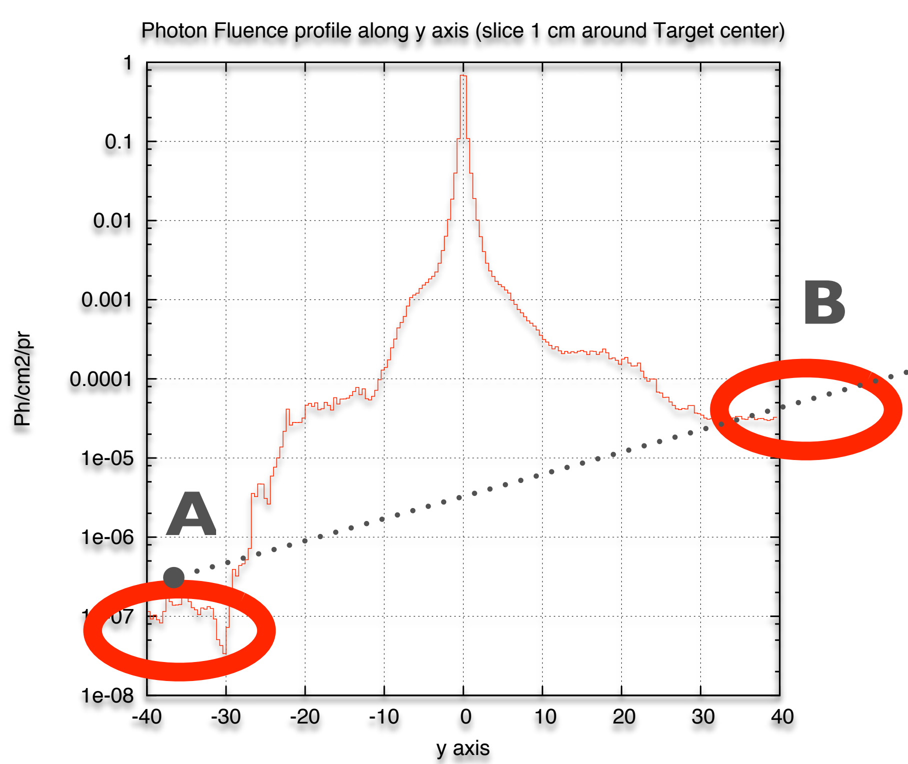
As expected for, the neutron spectrum shape along the extraction line in air remains essentially unmodified whereas, the intensity of fluxes decreases according the inverse of square distance from the neutron source

Summary of Results: the Photon field







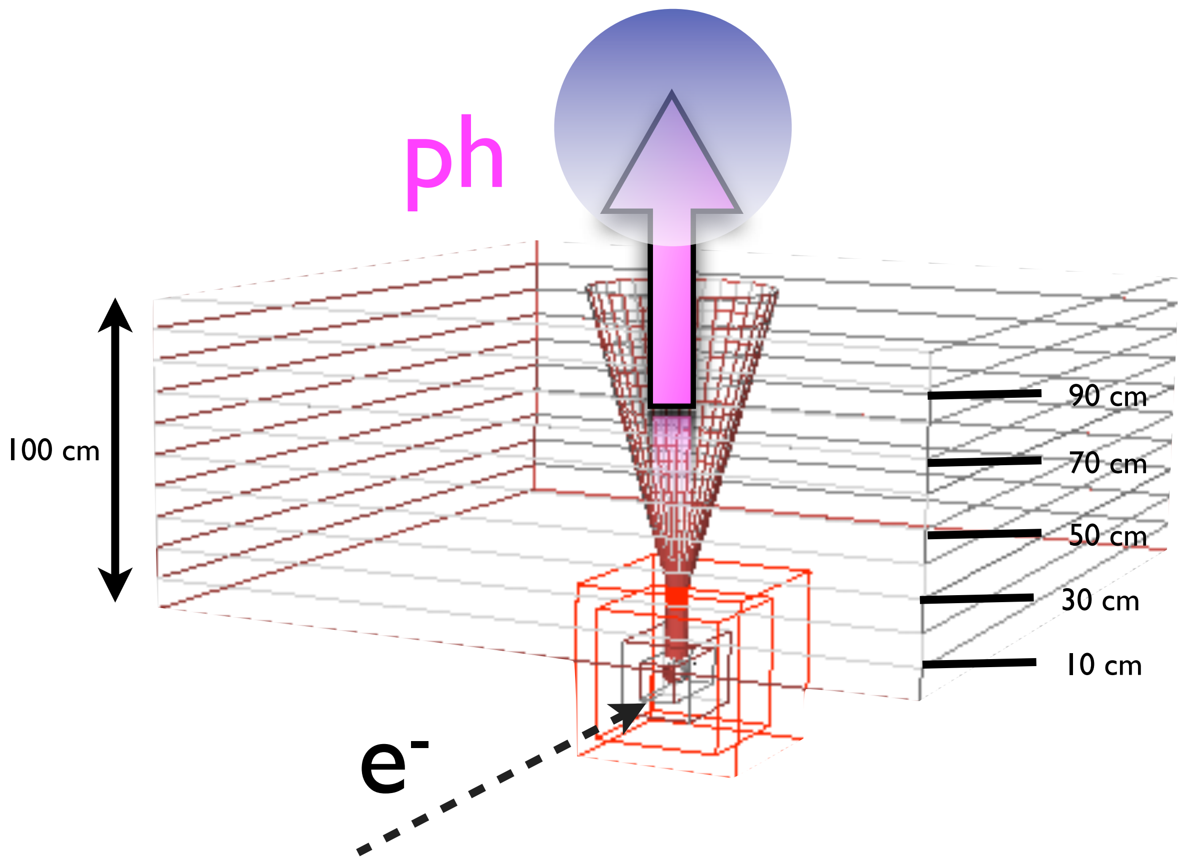


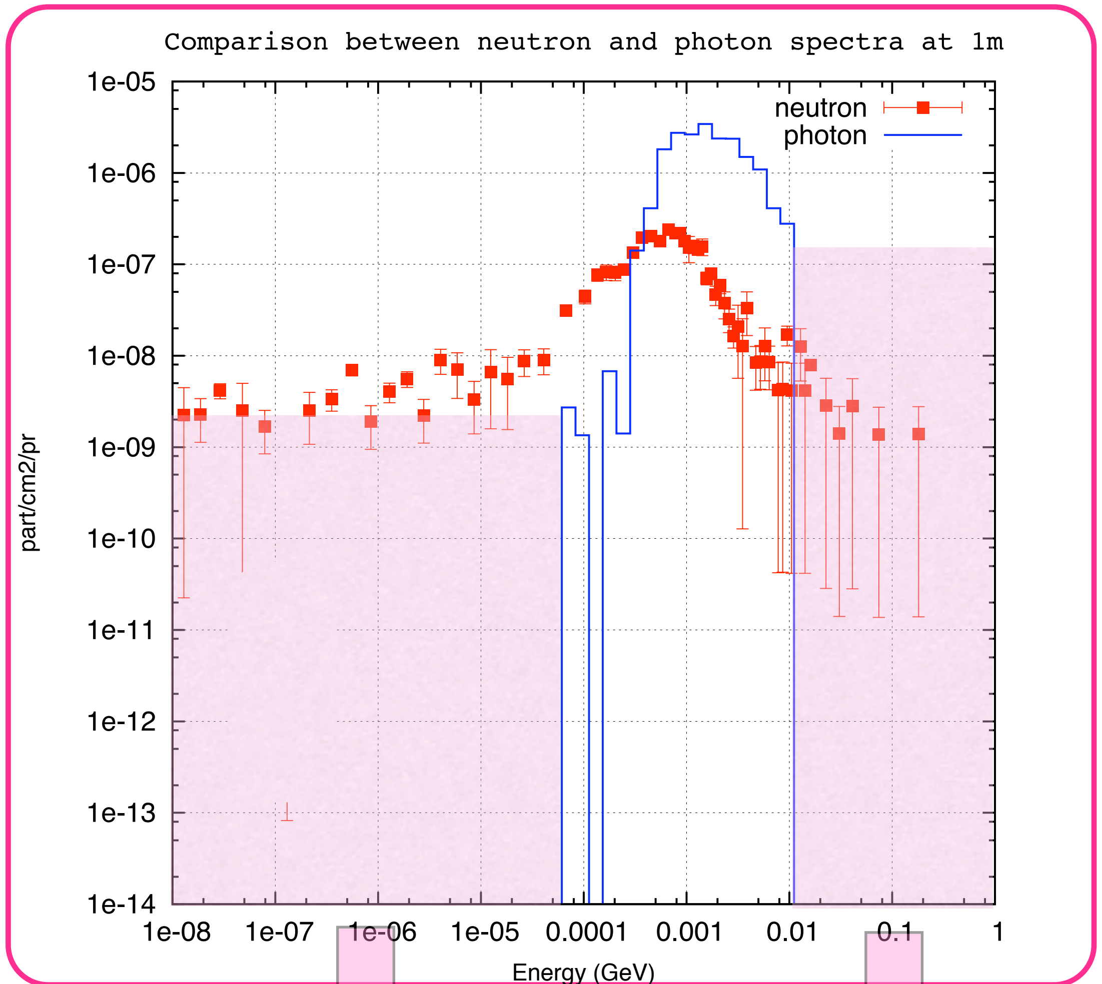
Photon along y axis

(averaged on the other two directions)

Effectiveness of shield at least: a factor 3E+2

Photon Spectra along extraction line in air





soft component suppressed by shield

hard component collimated along the primary beam

Photon at ~1.5m from shield entering the Bonner sphere:

Rate of photons (integrated on all the spectrum and solid angle) expected to enter the spherical detector of 10 cm Diameter with center 1.49 m apart from the upper face of the shield:

Fluence on 10 cm Detector = 1.4E-5 ph/cm2/pr ± 10%

⇓

Average Integrated Photon rate for BTF = 7.E+6 ph/cm2/s

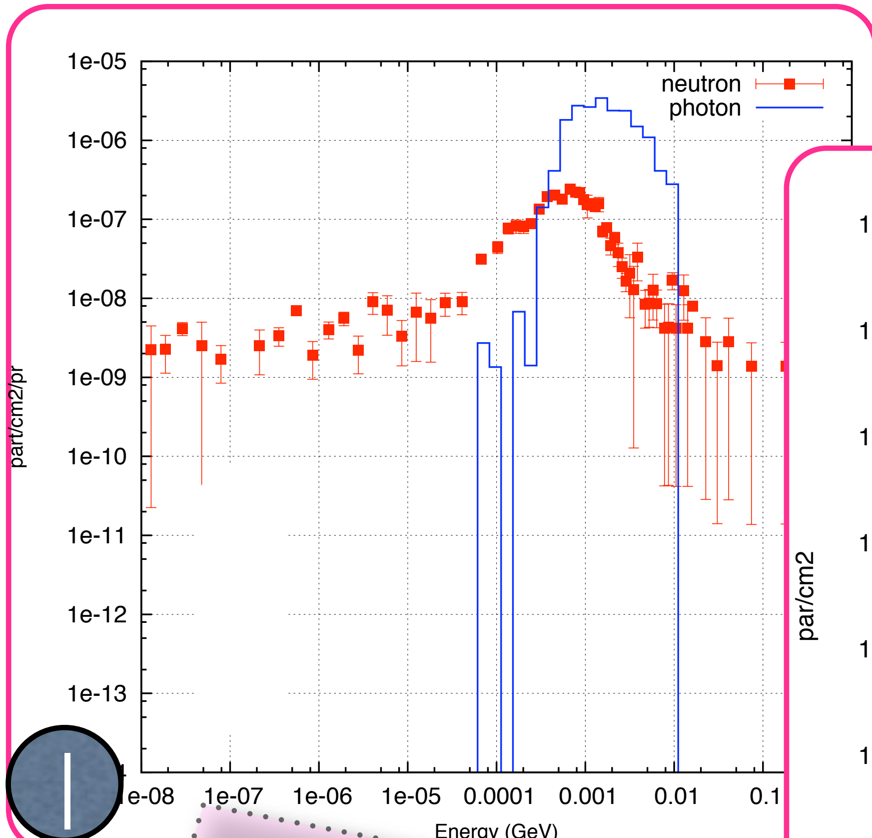
Ph and n spectra for 3 different extraction lines

$SNR = (R_n/R_{ph}) = (\phi_n * A / \phi_{ph} * A)$ where A= accep_detector

These tests are preliminary results
(low statistic: only 3000 primaries)

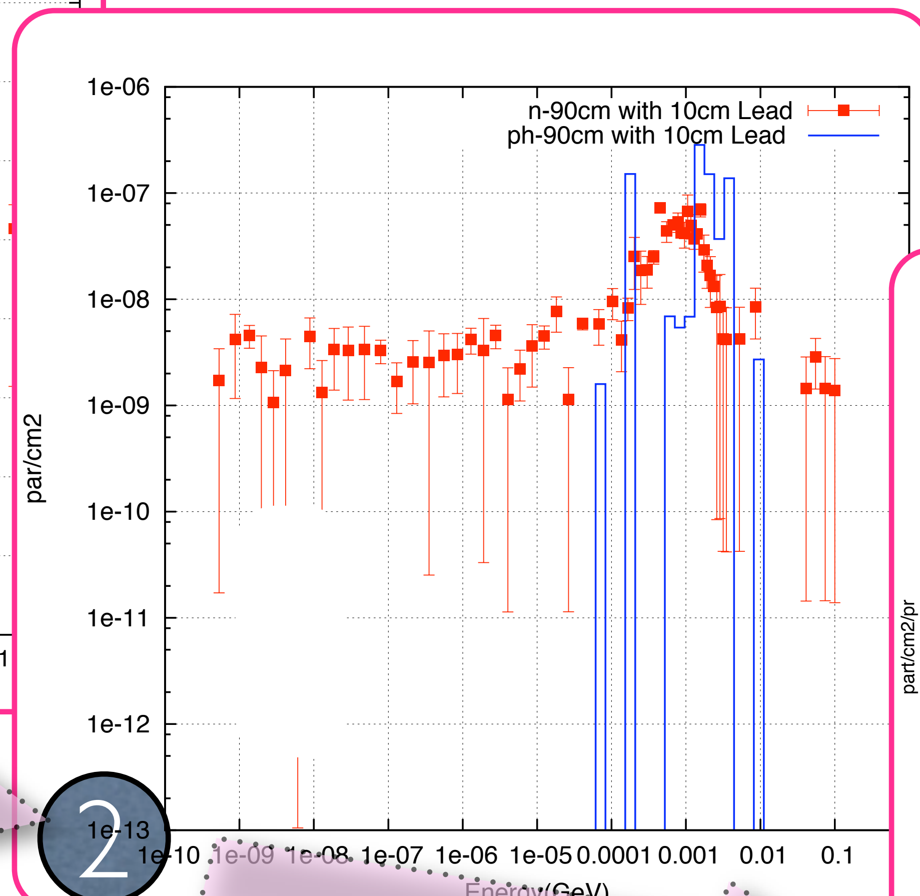
case 1: hole in air

$$SNR = \frac{1.6319249 \cdot 10^{-3}}{1.5751485 \cdot 10^{-2}} = 0.104$$



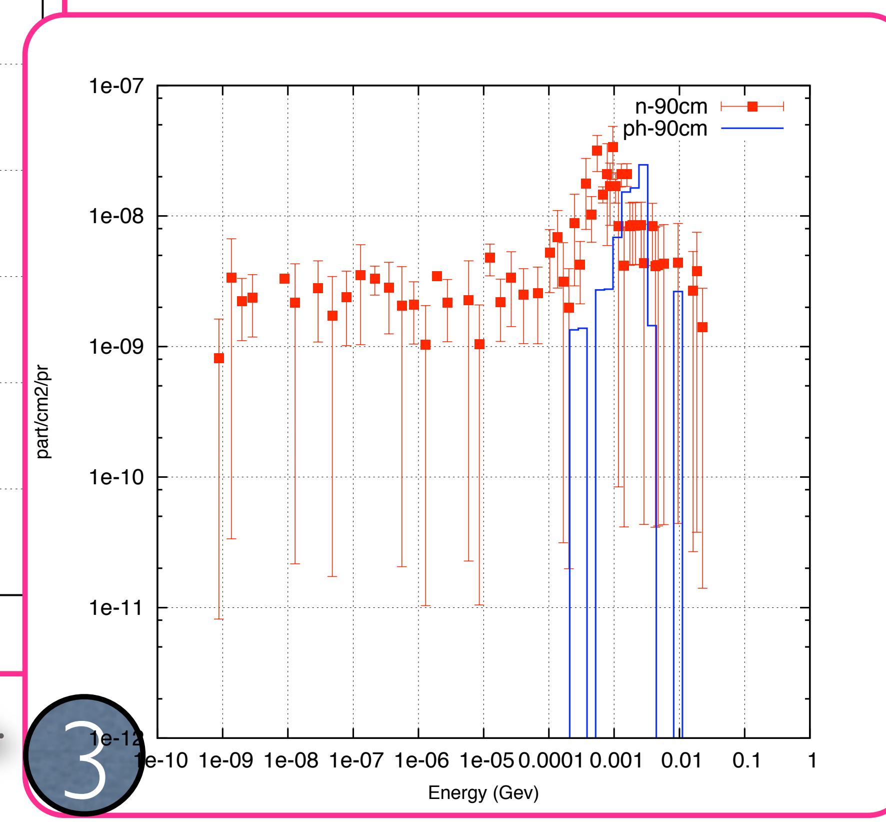
case 2: hole cover (10 cm Pb)

$$SNR = \frac{6.4360496 \cdot 10^{-4}}{6.4834551 \cdot 10^{-4}} = 1$$



case 3 hole cover (25 cm Pb)

$$SNR = \frac{3.8569755 \cdot 10^{-4}}{6.1961604 \cdot 10^{-5}} = 6.2$$



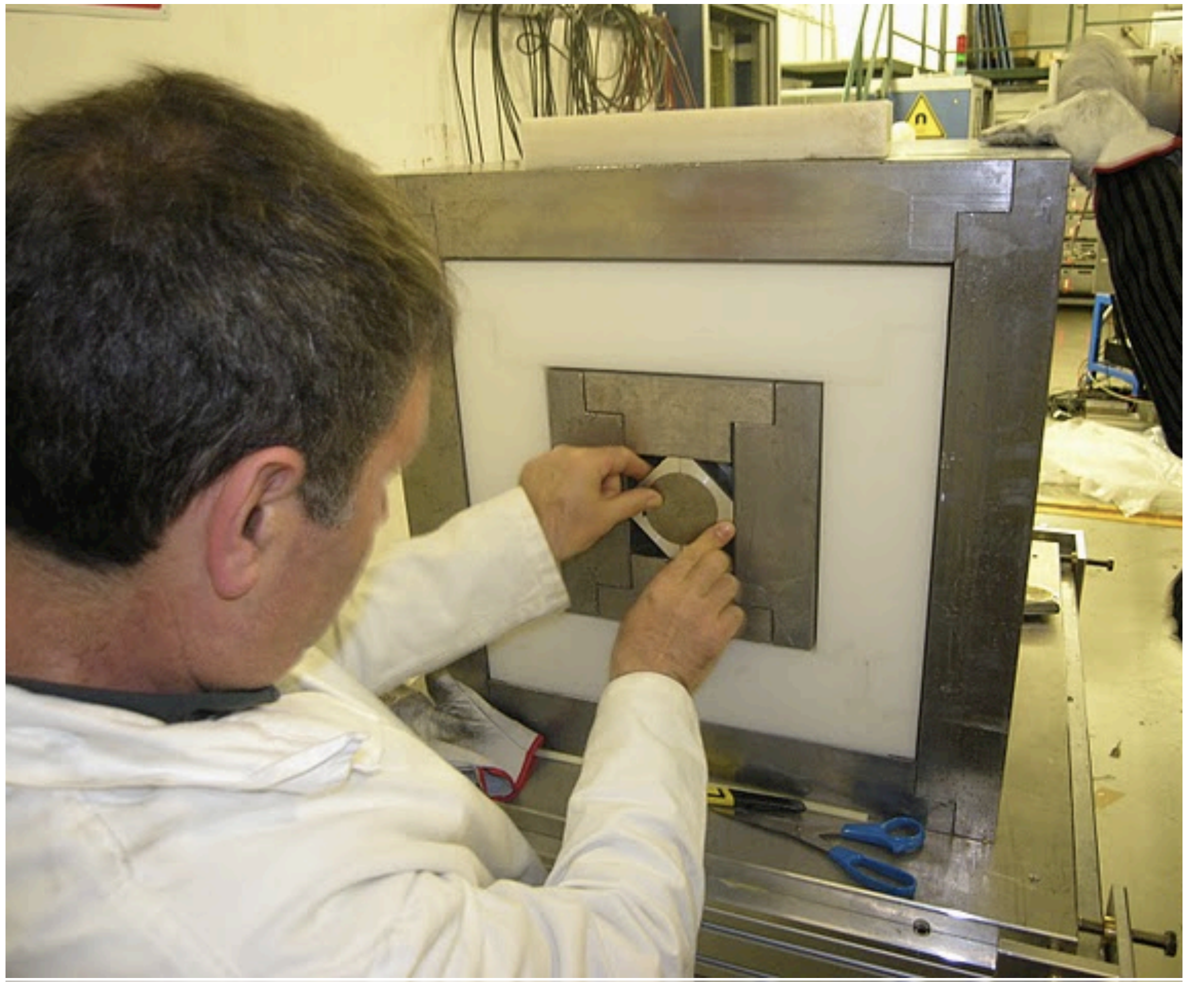
Signal to noise

ratio

enhancement

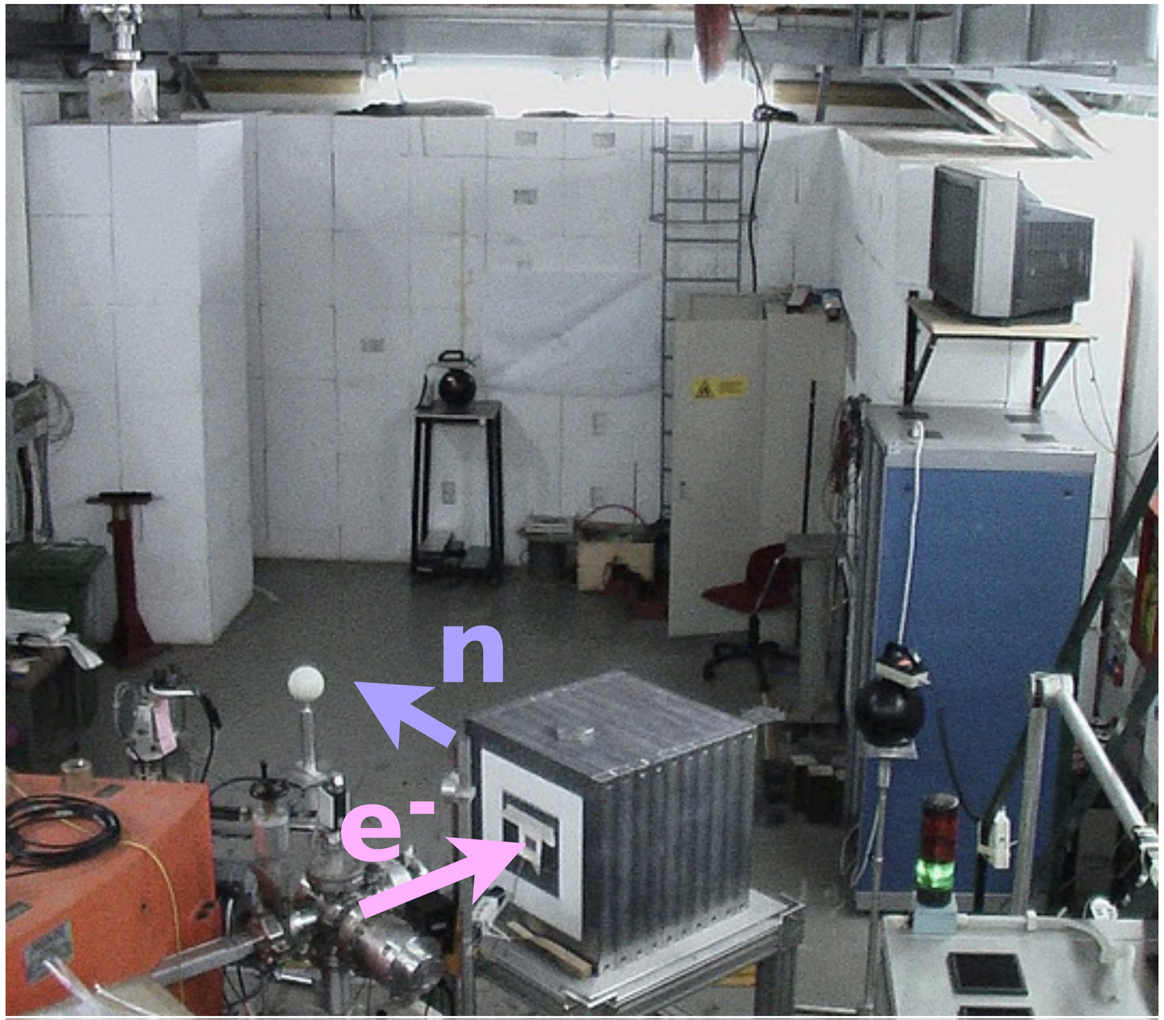
THE FEASIBILITY TEST

Final Experimental SET-UP

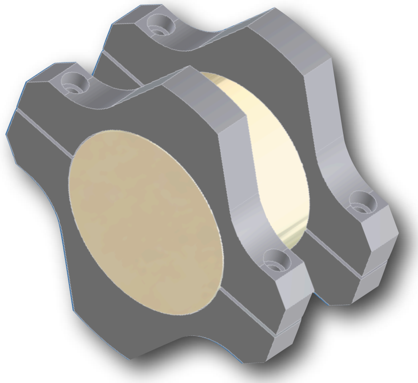


April 2010

First Measurements May 2010



Aluminum centering rings=
1.5 cm thickness



2 environmental detectors: response from thermal up to 20 MeV. The constance of ratio of their readings assure to have done measurements in a satisfactory repeatability or irradiation condition within ±1.5%

The Detector: Bonner Sphere Spectrometer

All spheres are designed to host the detector (for thermal neutron) in their centers.

The inner detector can be passive or active:

- Gold or Disprosium target (activation foil)
  (well suited in presence of high photonic background)
- ILi(Eu) Scintillator
- TLD

The LNF-ERBSS includes:

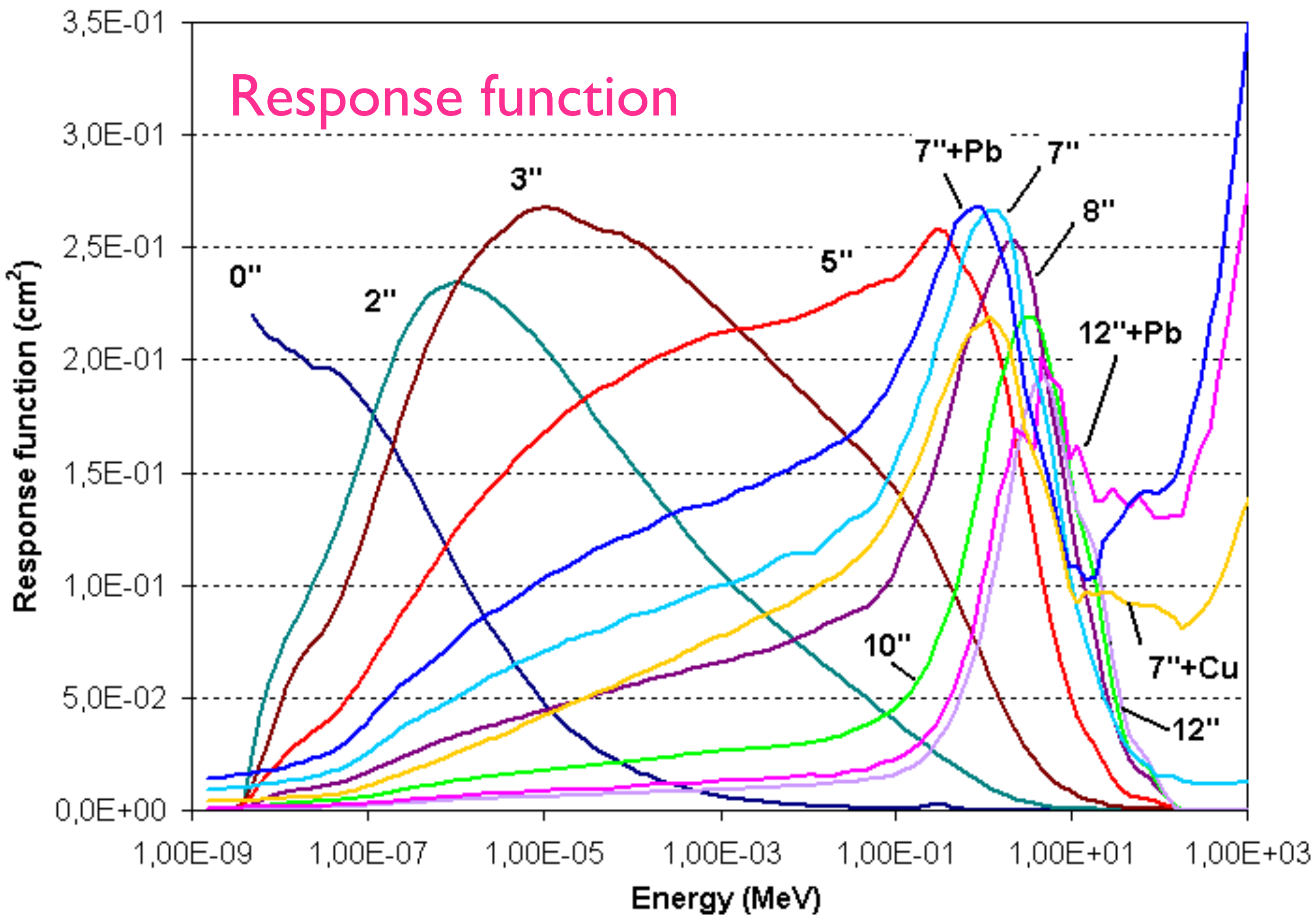
- 8 polyethylene spheres (density 0.95 g $\cdot$cm^{-3})
- 3 polyethylene spheres (density 0.95 g $\cdot$cm^{-3}) loaded with copper and lead
- a 4x4 ^{6}LiI(Eu) active scintillator

First Measurement: Raw Data Elaboration

- We worked in integration modality using the spheres in sequence (one after another).

- The exposition time was about 0.5 h for each sphere (depending on the primary electron beam intensity).

- All the responses of the detectors have been normalized with respect to the primary beam: this means to make available a reliable diagnostic instrumentation for the beam current monitoring (ICT).



Response functions of the ERBSS were calculated with MCNPX Monte Carlo transport code.

The response matrix of the ERBSS was validated in reference neutron fields and its overall uncertainty was estimated to be ±3%.

In order to obtain the neutron final spectra from the raw data of each sphere a special unfolding program has been developed at Frascati:

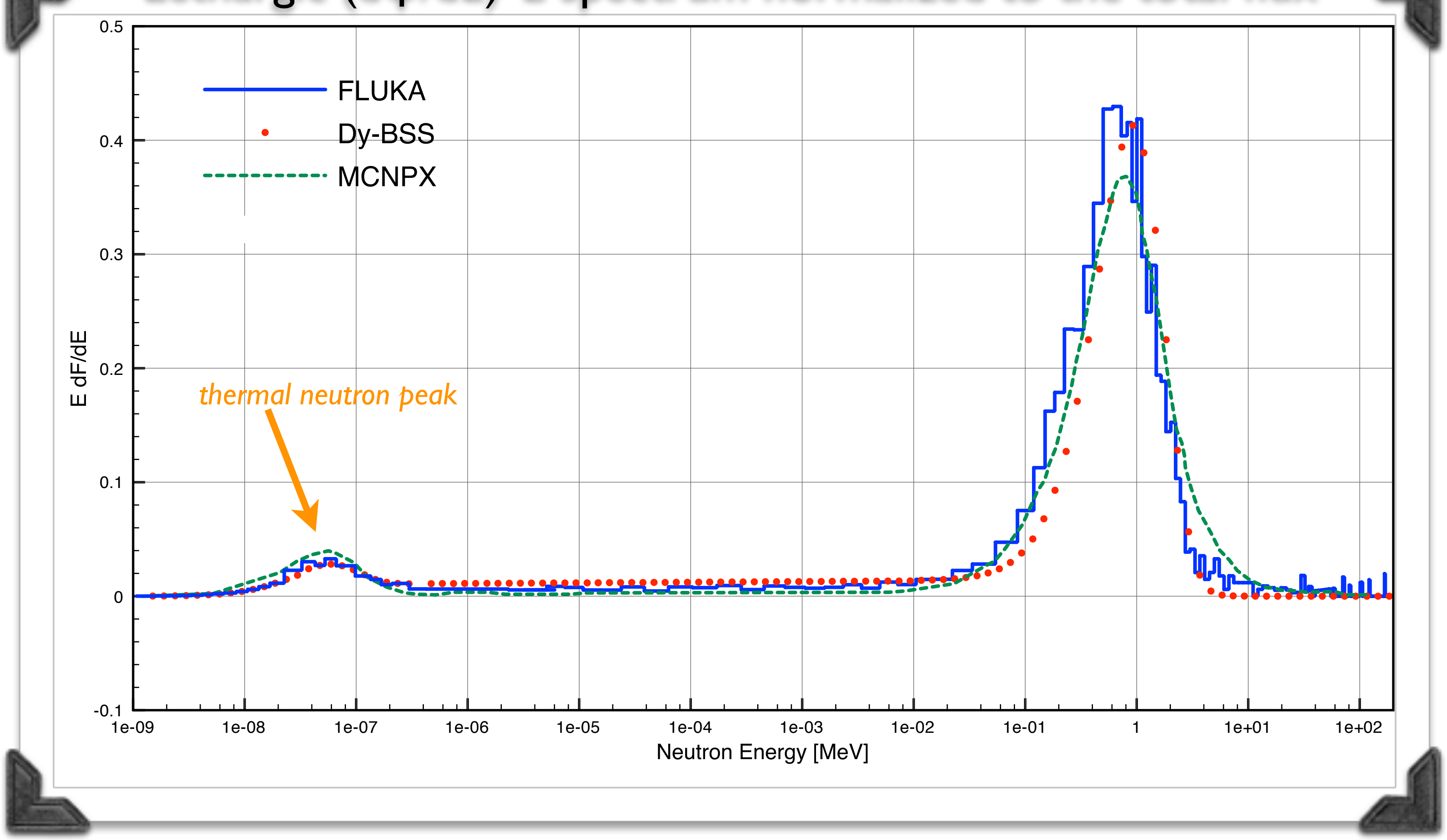
FRUIT**
(FRascati Unfolding Interactive Tool)

****Nuclear Instruments and Methods in Physics Research A 580 (2007) 1301-1309**

Experimental and Computational neutron Spectra

The point of test was at ~150 cm from the target and at 90° wr to the impinging electron beam line

Lethargic (dϕ/dE)*E spectrum normalized to the total flux



The flux above 10 keV is 6.53E-7 /cm2/pr

As expected, more than 80% is found around the Giant resonance (from 10 KeV up to 20 MeV)

Statistical uncertainty in the calculations less than 4%
meaure;ents less than 3%

Total Neutron Flux per primary particle		
Ex. Measurement	FLUKA	MCNPX
8.04E-7 ±3%	**8.10E-7 ±4%**	**8.02E-07 ±0.2%**

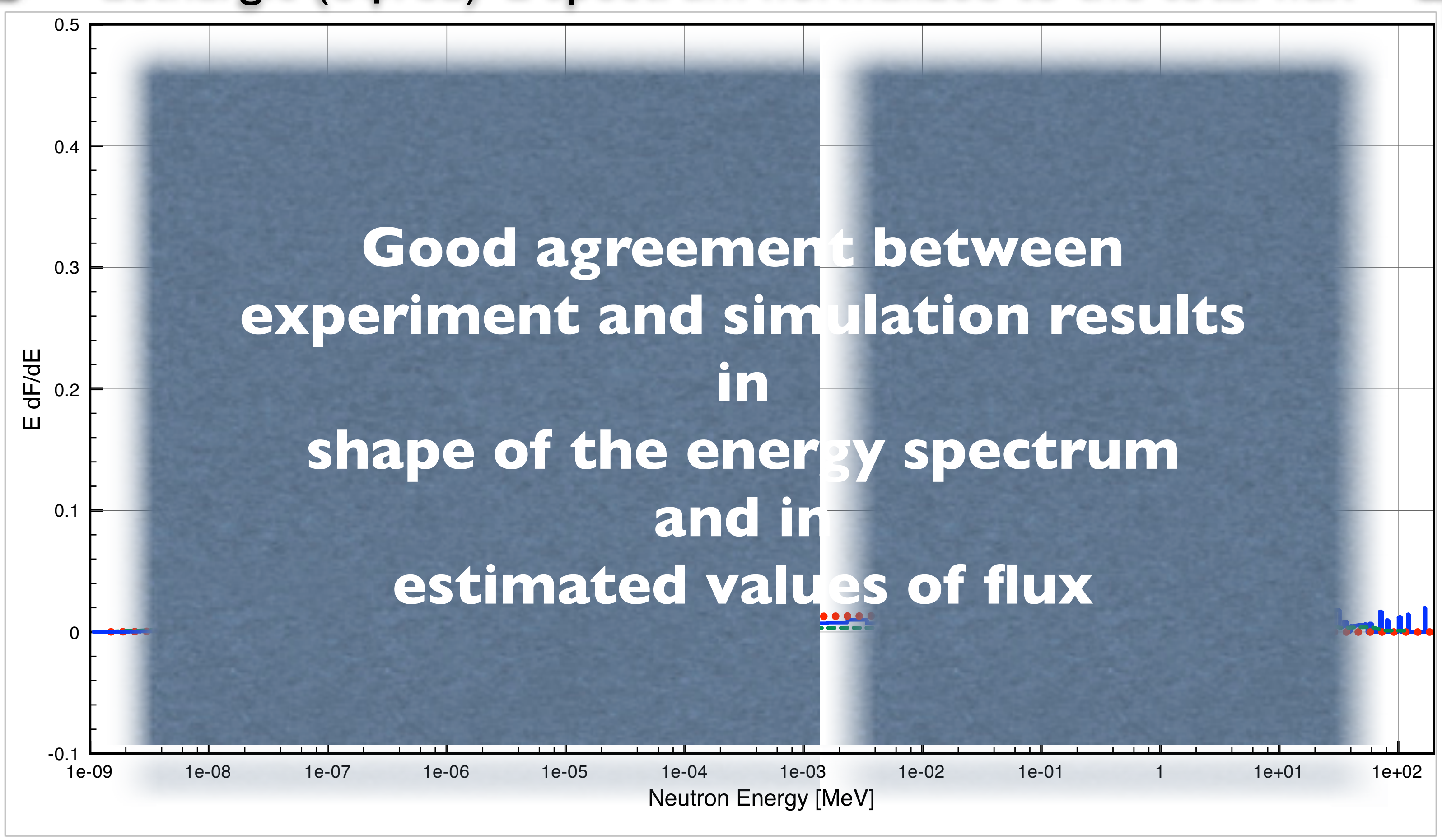
Max neutron Flux currently available in BTF

Neutron Flux at 1.5m from shield = 4E+5 n/cm2/s corresponds to Equivalent Dose=45 mSv/h

Experimental and Computational neutron Spectra

The point of test was at ~150 cm from the target and at 90° wr to the impinging electron beam line

Lethargic (dϕ/dE)*E spectrum normalized to the total flux



The flux above 10 keV is 6.53E-7 /cm2/pr

As expected, more than 80% is found around the Giant resonance (from 10 KeV up to 20 MeV)

Statistical uncertainty in the calculations less than 4%
meaure;ents less than 3%

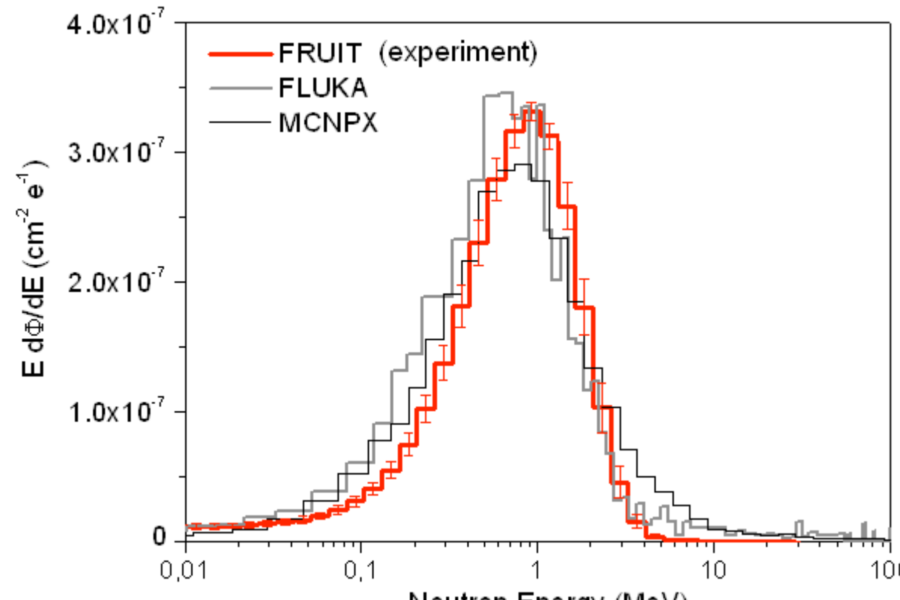
Max neutron Flux currently available in BTF

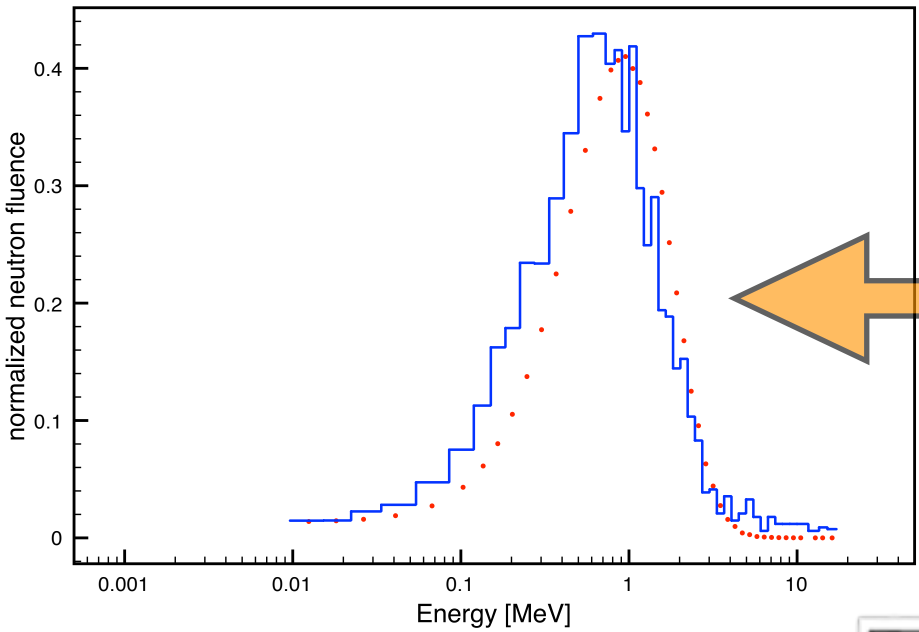
Neutron Flux at 1.5m from shield = 4E+5 n/cm2/s corresponds to Equivalent Dose=45 mSv/h

Total Neutron Flux per primary particle		
Ex. Measurement	FLUKA	MCNPX
8.04E-7 ±3%	**8.10E-7 ±4%**	**8.02E-07 ±0.2%**

MC Accuracy wrt Experimental Data

We performed GoF tests to asses quantitatively the accuracy around the GDR



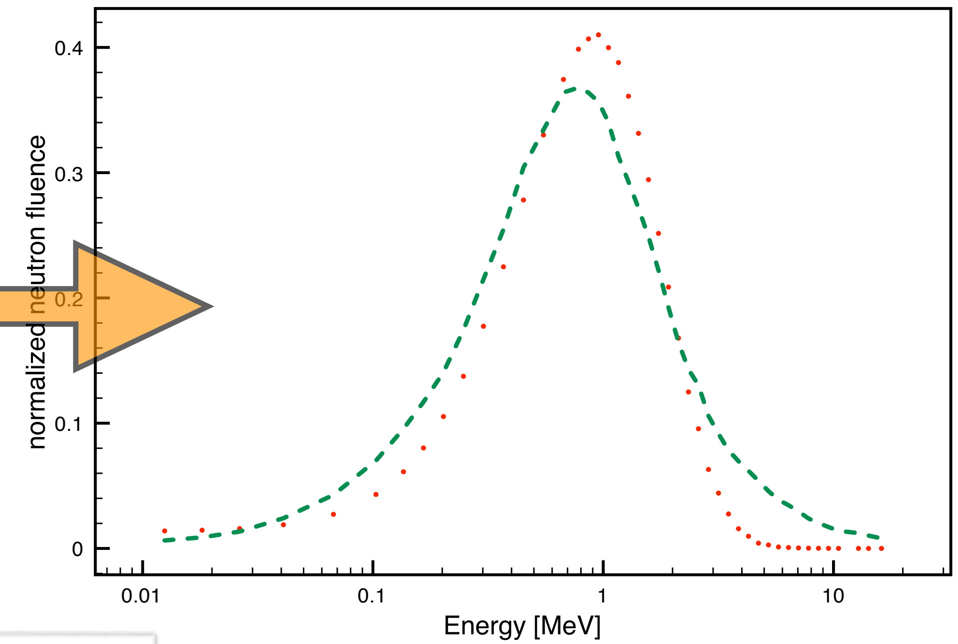


$\chi^2=(MC^2-Exp^2)/(\sigma^2_{MC} + \sigma^2_{Exp})$

n=Exp point

Σ=SUM χ^2 over n

p_value=CHIDIST(Σ,n)



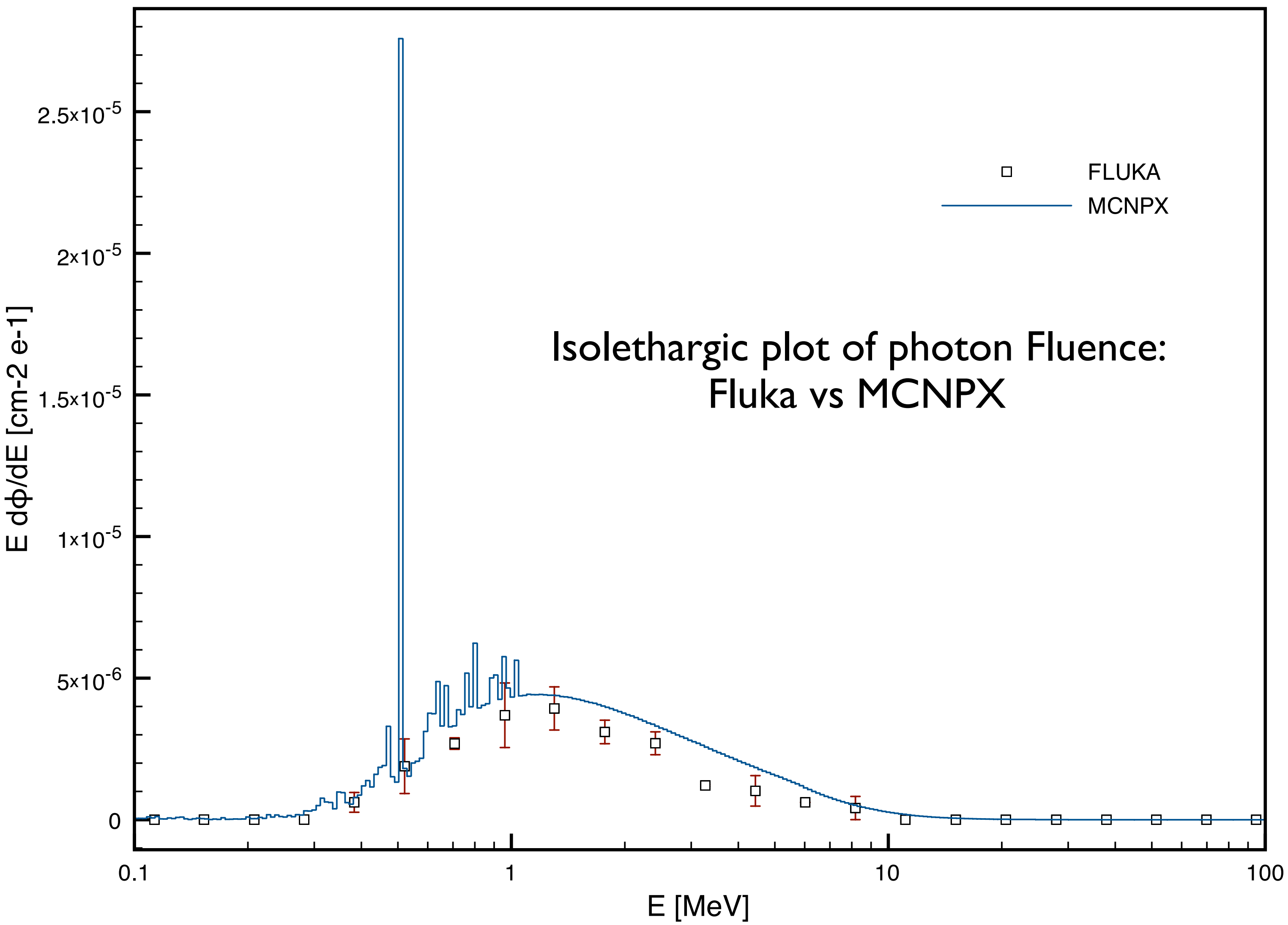
Fit Fluka-Exp
χ2 test: p value= 0.967

Both FLUKA and MCNPX provide an accurate reconstruction of the experimental resonance, both in energy position and amplitude

Fit MCNPX-Exp
χ2 test: p value=0.996

- MCNPX algorithm to estimate the neutron energy is based on continuos cross section.
- Fluka neutron trasport is performed by multigroup algorithm: 260 groups available below 20 MeV since 2008

Photon Spectra @ 1.49 m
Fluka vs MCNPX



Preliminary measurements
of the photon flux :
A YAP:Ce crystal detector has been used;
(6mmx6mmx25mm)
It has been located at the reference point

Measured photon fluence:
1.E-4 ph/cm2/pr +/-10 %

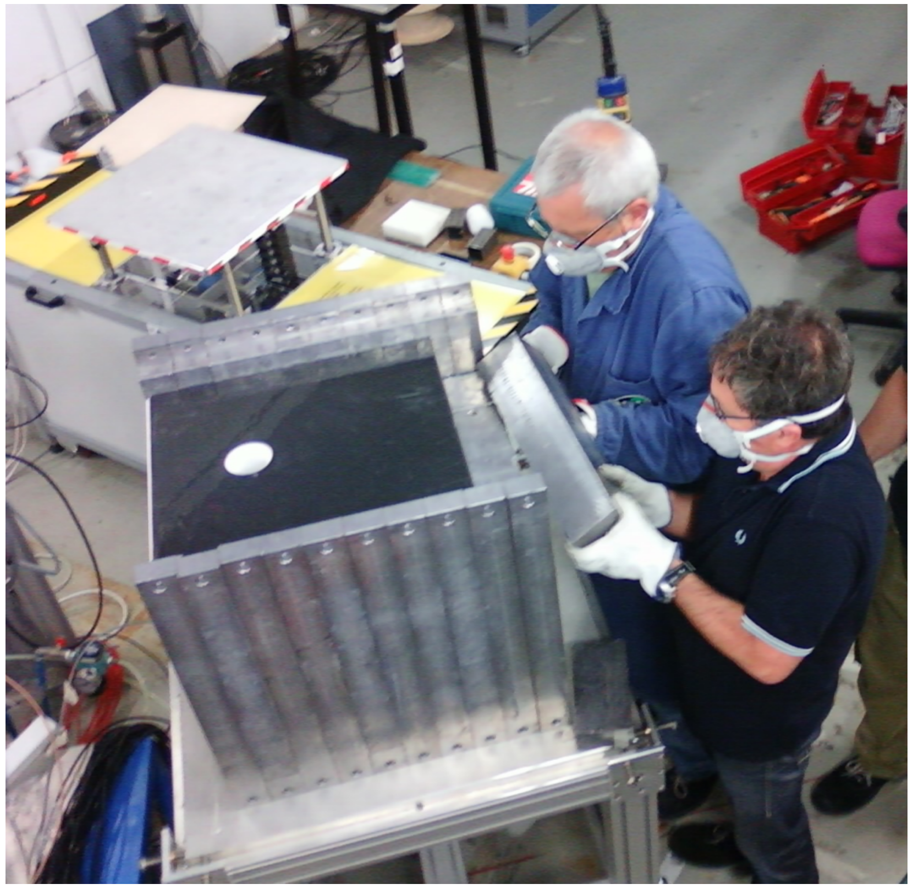
Total Fluence predicted:
1E-5 ph/cm2/primary
(MCNPX and Fluka agree within few percent)

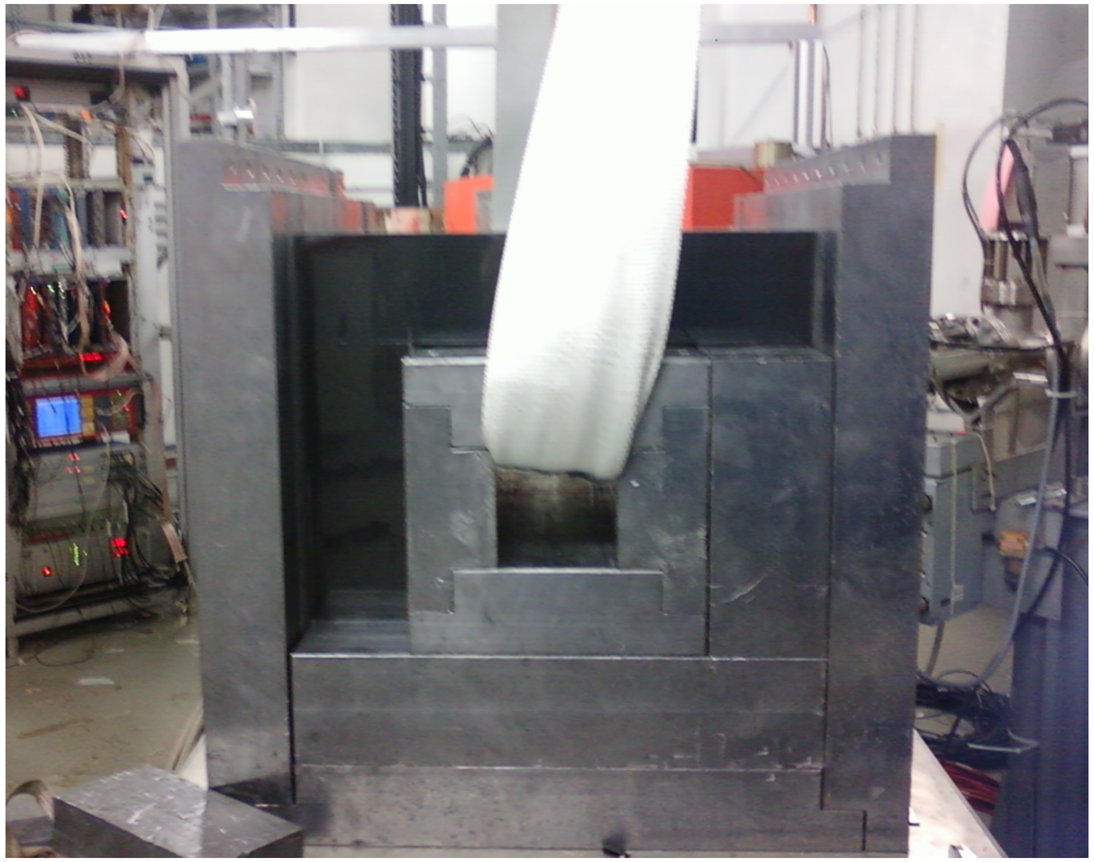
This discrepancy is due to the fact that the BTF experimental hall is not yet completely represented in the MC simulations

Recent Facility upgrade

In order to reduce the neutron fluxes in all the the directions around the shield, except along the extraction lines, we have mounted, at the end of June, Boron Carbide sheets.

- The sheets are 2 mm thick and are made of epossidic matrix charged with Boron at 75%
- The Boron-carbide sheets have been placed externally respect the polyethylene layer: the neutron flux is strongly reduced thanks to the high absorption cross section of the boron capture $^{10}B(n,\alpha)^{7}Li$, for thermal neutrons (σ=3835 barns)
- A reduction of the integrated flux of about an order of magnitude is expected





TOWARD A TRUE NEUTRON FACILITY

n@BTF Spinoff and complementary projects

The NESCOFI (NEutron Spectrometry in COmplex FIelds) project is aimed at developing active instruments for real-time spectrum measurements in neutron producing facilities (industrial, research and medical fields).

The innovative feature of the these devices is the energy range of the response, that is required to extend from thermal up to hundreds MeV neutrons (10 decades in energy).

NESCOFI@BTF is a three-years (2011-2013) project funded by the 5th Scientific Commission of INFN. Two are the main interests of developing this project using the neutron source of n@BTF:

- (1) n@BTF is an adequate facility for testing the realistic performance of the spectrometer, because (a) neutron energy extends from thermal to about 200 MeV, (b) sharply pulsed time structure, representative of many real installations, (c) presence of large photon background and (d) large variability of neutron fluence rate

- (2) the n@BTF facility will implement the new spectrometer as a routine spectrometric monitor able to evidence variations of the neutron beam with time and with different operating conditions.

courtesy of R. Bedogni (resp. NESCOFI)-LNF-INFN

n@BTF first user concerns

Researchers from University of Tor Vergata aimed at developing detector for neutron spectroscopy

With respect to their scopes, n@BTF is interesting for several reasons:

• Need to optimize the signal/background ratio in harsh photon background (severe testing conditions), for R&D of detectors for NRCA (Neutron Resonance Capture Analysis): detection of resonance radiative capture gamma-rays;

• Study of the performance of compact detector readout, e.g the silicon photomultipliers for neutron and/or gamma detectors where neutron and gamma are, respectively, signal and background (to assess discrimination strategies to use).

• Pre-test phase (at "home facility") for the development of thermal neutron detectors not based on 3He (3He replacement) e..g. thermal neutron radiative capture-based neutron counters (Cd coupled to scintillators).

Moreover the n flux available at n@BTF have useful characteristics (moderated beam configuration) for the following objective:

• NRCA (ToF based) measurements on metallic objects of cultural and artistic relevance to assess elemental composition (resonance identification) and relative or (hopefully) absolute atomic percentage Taking into account that at the present the max available distance from the neutron source is about 5 m, resonances in the range 1-20 eV may be effectively recognized (e.g. Au, Sb, Ag, Cu).

• Test of locally neutron beam monitors (diamond detectors) as diagnostic for n@BTF

courtesy of A. Pietropaolo-Unversity of Tor Vergata

Conclusions and Future Plans

Synthesis:

- Design of neutron photon source based on MC codes
- Neutron production (fluxes and spectra) well in agreement with MC predictions
- BTF can now deliver to the users not only leptonic or photon beams but also hadrons (neutrons)

Computational Tasks:

- Comparison of results with other MC codes (Geant4)
- Other solutions for extraction lines are under investigation for optimising the SNR (neutron converter materials and suitable reflector)
- study of U_nat as material for the target to enhance by an order of magnitude the neutron yield (higher photonuclear efficiency + photo-phissions). Compare the different code predictions in presence of photofissions
- Feasibility study of extension to cold neutrons

Milestones for the new facility:

- June 2011 complete characterization of the photon field + neutron field.
- First Users for neutrons by the end of September: NRCA with neutron flux picked around 1 eV
- NESCOFI project funded by CS5 of INFN
- Implementation of all the diagnostic devices for users by the end of December 2013 (NESCOFI)
- Design of moderated neutron extraction lines (study and optimization of material is in progress)
- Use of superfluid helium to test the possibility of producing cold neutrons too...(desirable objective...)

http://www.lnf.infn.it/acceleratori/btf/

http://www.lnf.infn.it/acceleratori/btf/

THANK YOU
FOR YOUR ATTENTION