Neutron sources based on medical Linac

Marco Costa
INFN Sezione di Torino and Universita' di Torino

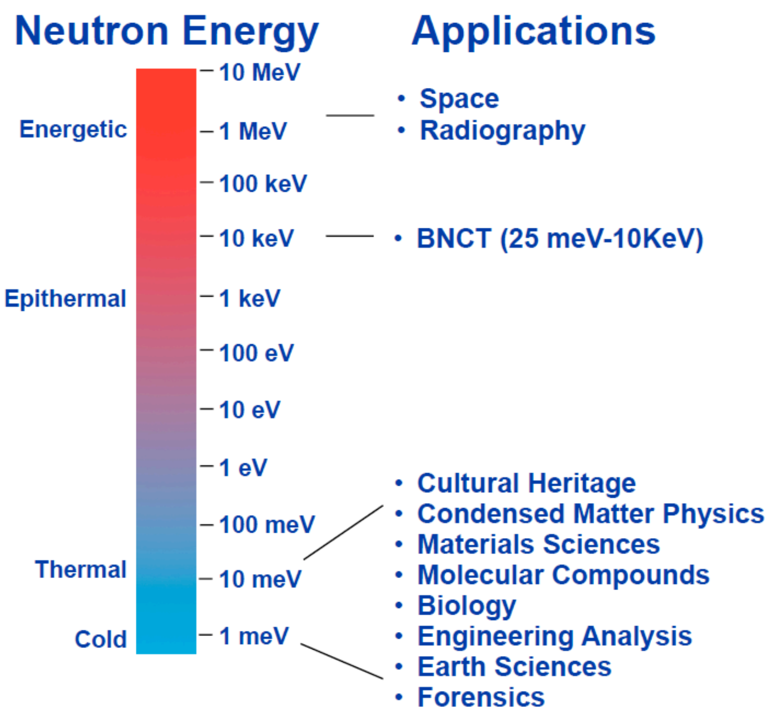
On behalf of INFN e-LiBaNS Collaboration
(INFN-LNF, Torino, Trieste)

UCANS V - 5th International Meeting Union for Compact Accelerator- Driven Neutron Source

The project goal

- **To setup a facility based on commercial Linac to provide qualified neutron sources differentiated in energy Thermal, EpiThermal (0.4 eV- 10 keV) and Fast >100 KeV) .**
- ➔ Bio-medical app, Cultural Heritage, Space, Neutron Diagnostic

In a medium intense field ($\Phi_n > 10^8\ cm^{-2}\ s^{-1}$) easily accessible, reproducible and relatively cheap



we are just at the beginng…
In the following I will speak only on Thermal neutron source

The contest…

- **INFN-PhoNeS** : In the past years the Photo Neutron Source project, funded by INFN and MIUR, demonstrated the possibility of producing a relatively intense thermal neutron self-shielded source cavity by coupling a dedicated photo-neutron converter to a commercial Linac
- **ELEKTA spa:** An agreement has been found with the company that is being providing us a 18 MV LINAC as those used in radiotherapy units, that will be 100% to research (summer 2015).
- **INFN & University of Torino**: Agreed to install the LINAC in a 150 m^2 existing bunker in Turin Physics Department that in the past was used for a 100MeV electron sincrotron.

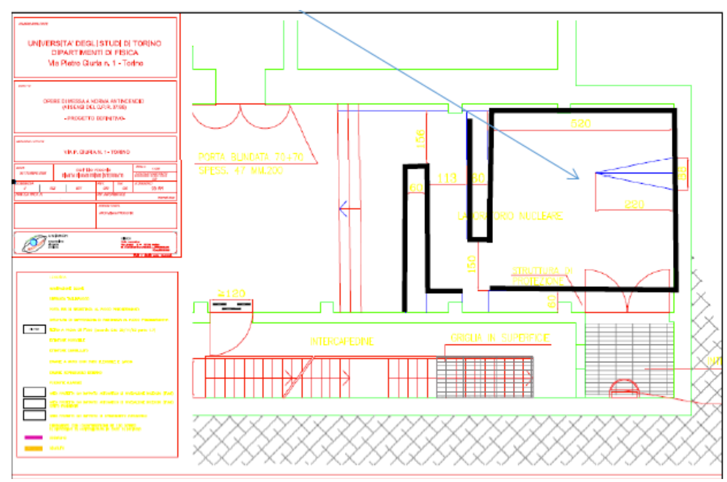


Photo-neutron production @ LINAC

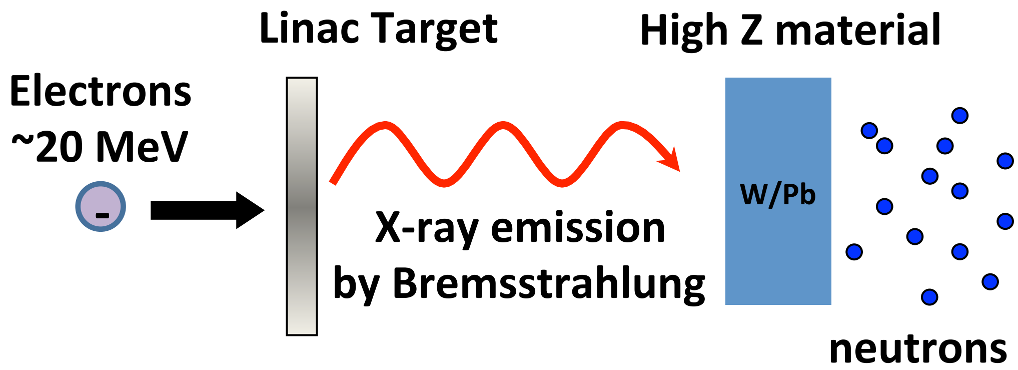
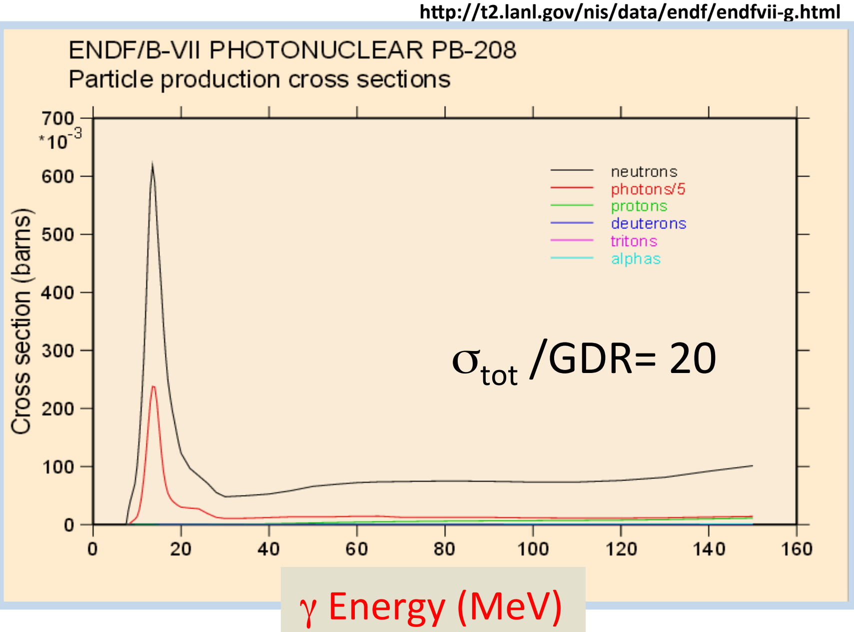


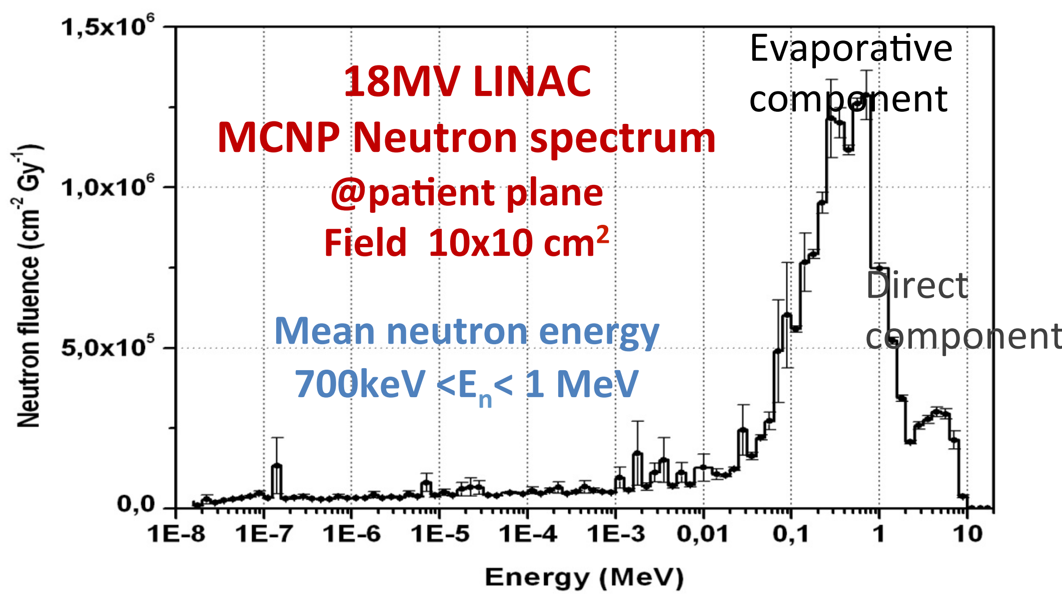
photo-nuclear σ by Levinger and Bethe :

$$\int_0^\infty \sigma(E)dE = \frac{2\pi^2 e^2 \hbar}{Mc}\frac{NZ}{A} = 60NZ/A$$

Neutrons are produced by (γ,n) reaction (photodisintegration) mainly on high Z material when Eγ > reaction energy threshold (W: 7.42MeV, Fe: 10.9MeV, Pb: 7.41 MeV)

http://t2.lanl.gov/nis/data/endf/endfvii-g.html





Photoconverter design

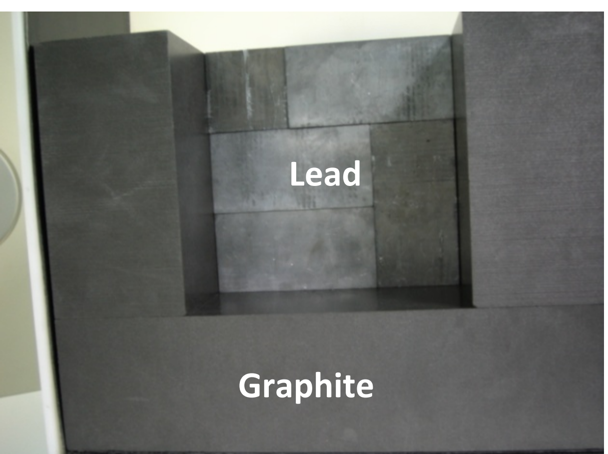
The study of the photoconverter materials and geometries has been carried in order to:

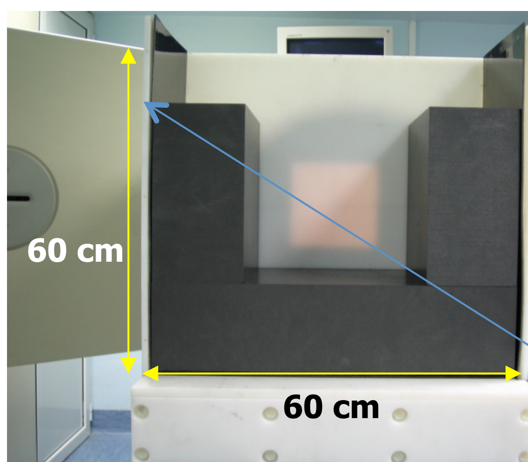
- **increase** the photoneutron production;
- **maximize** the hyperthermal neutron component of the beam (E < 10 keV);
- **minimize** the fast neutron component and γ undesired dose.

The main components of the photonconverter are:

Core
Increase (γ,n) production
(High Z elements: Pb, W)

Moderator:
Slow down neutron energy up to thermal/epithermal range, minimizing fast neutron component
(Graphite, D_2O, Polyethylene)



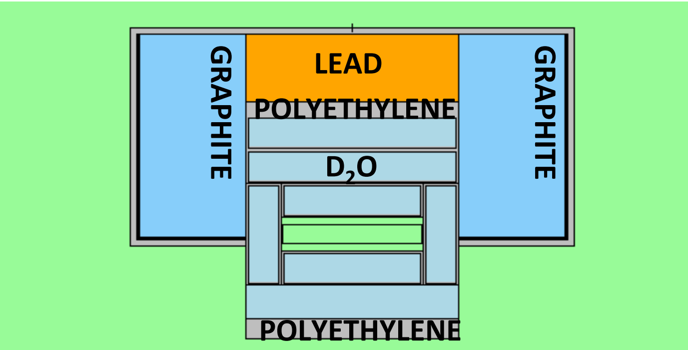


Neutron reflector
increase neutron flux
(Graphite, Pb)

Gamma shielding
minimize gamma (Pb e Bi)

Polyethylene, B_4C, Lead

Summary of previous results



PhoNeS "Bianco"prototype

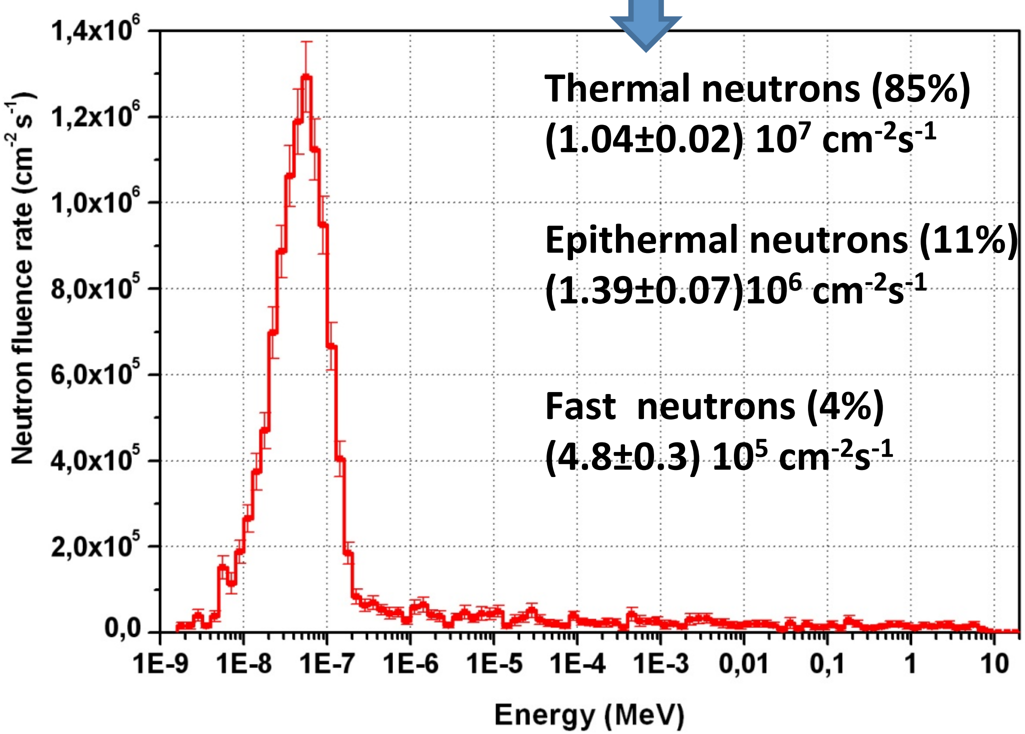
First in-hospital neutron source for BNCT trials

Phones+Elekta precise 25MV

$\Phi_{th} = 1\ 10^7\ cm^{-2}s^{-1}\ \pm 20\%$

Transportable PhoNeS prototype closed cavity configuration

Cavity: 20 x 20 x 5 cm^3



Thermal neutron field of suitable intensity and energy spectral distribution for BNCT research and experiments on cells and biological samples

Irradiation time ~ 3hrs

$\Phi \sim 10^{11}\ cm^{-2}$

Work ongoing

Investigate possible modification of:

- **linac working parameters**
- **linac accelerator head components**

Monte Carlo approach to optimize the photoconverter geometry

- **MCNP4B–GN** (NEA-1733) http://www.oecd-nea.org/tools/abstract/detail/nea-1733/
- **MCNP 6**
- **GEANT 4**

Elekta Precise 18MV working parameters modification

Photon mode	25 MV	18 MV	15 MV	10 MV	6 MV	18 MV modified
Dose rate (MU/min)	400	400	400	400	400	**400**
Electron energy (MeV)	20	15.7	12.3	8.9	6	**20.39**
T (μs)	1.6	2.4	3.2	3.2	3.2	**2.8**
I (mA)	20	35	60	60	180	**50**
ν (Hz)	200	200	200	200	400	**200**
Power (W)	128	264	472	513	1328	**571**
K ($x10^{14}$ e^- s^{-1})	**0.4**	**1.05**	**2.4**	**3.6**	**14.4**	**1.74**

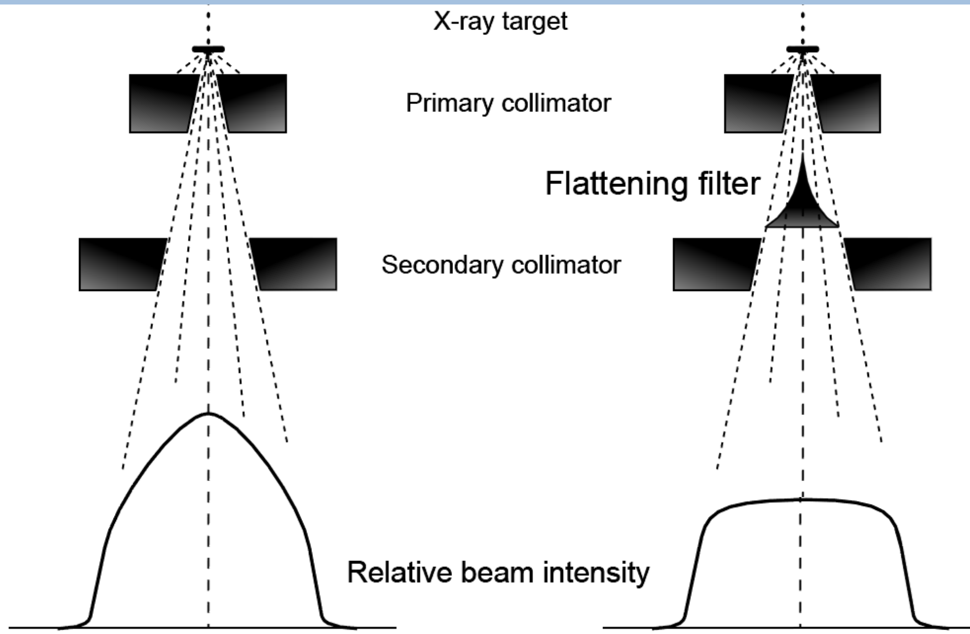
Elekta manufacturer provided

- MCNP : Average neutron fluence rate cross a surface (cm^2/e^-)
- Conversion factor cm^2/e^- ⟶ cm^2/s depends on LINAC duty cycle

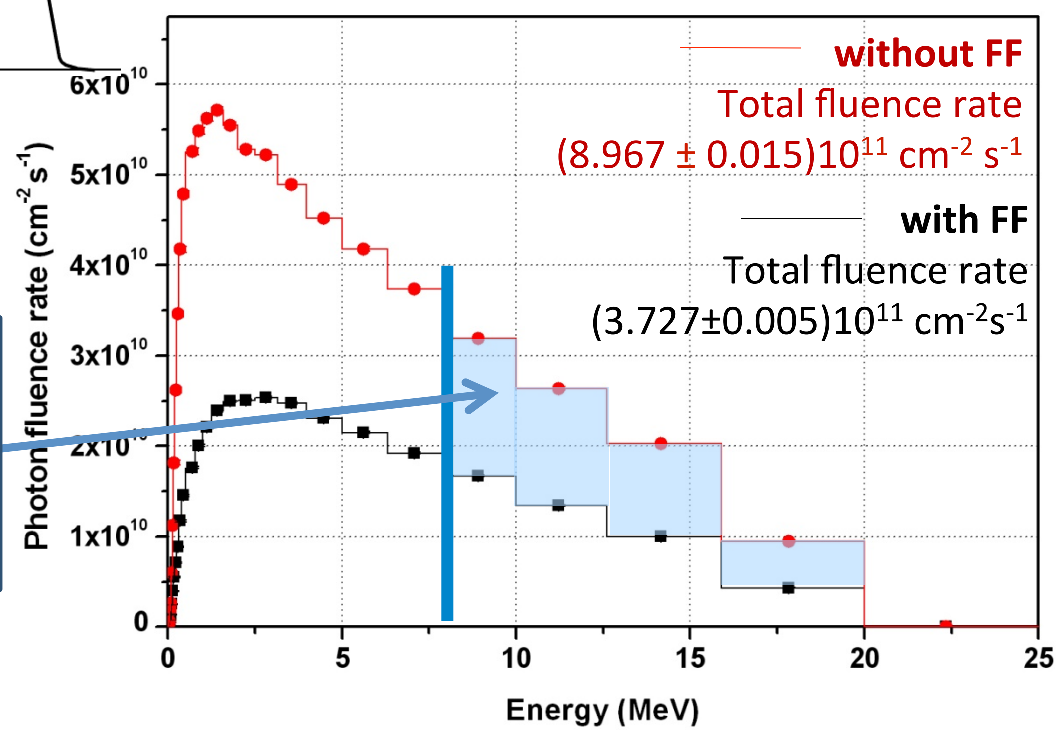
Elekta Precise 18 MV modified: I = 50 mA; ν = 200 Hz; T = 2.8 μs

Electrons rate = $1/1.602x10^{-19}$ x I x ν x T = 1.74 10^{14} e- s^{-1}

Elekta Precise 18MV filters' removal



Effect of the flattening filter on the photon beam intensity



Photon fluence rate increases ~2 times

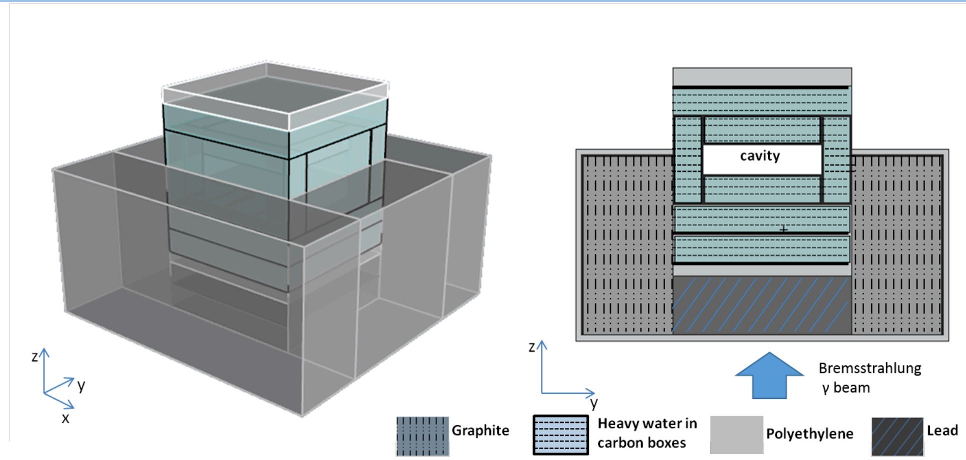
(from 4.4 10^{10} $cm^{-2}s^{-1}$ to 8.8 10^{10} $cm^{-2}s^{-1}$)

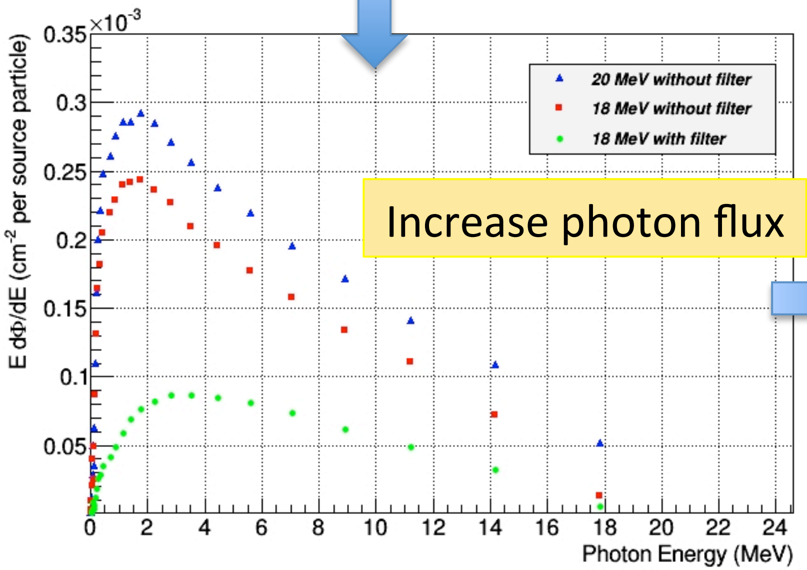
Effects on a "PhoNeS" geometry

To increase the neutron fluence rate in the cavity, with some modifications in the structure of the accelerator head and in its working parameters:

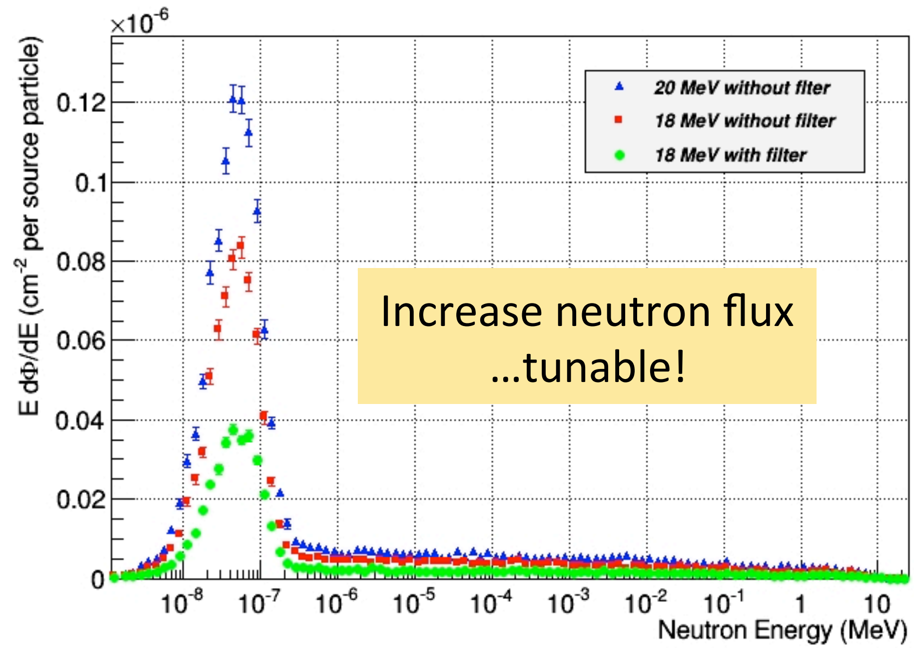
- removal of the flattening filter

- increase the electron energy up to 20 MeV





Photon spectra on a (20 x 20)cm² surface at 50 cm from the target



Work in progress (MCNP4B-GN, MCNP6)

New photo-converters study

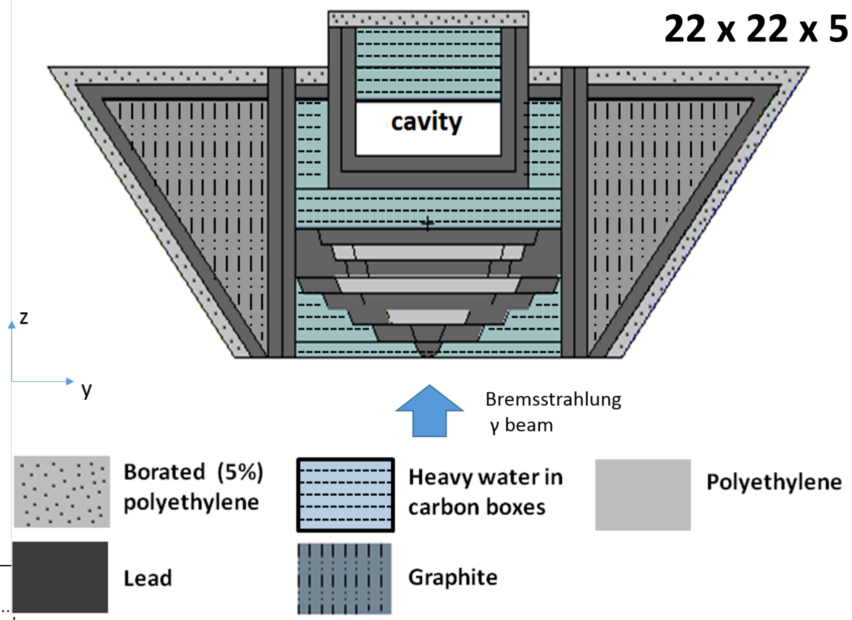
1- Thermal neutron source

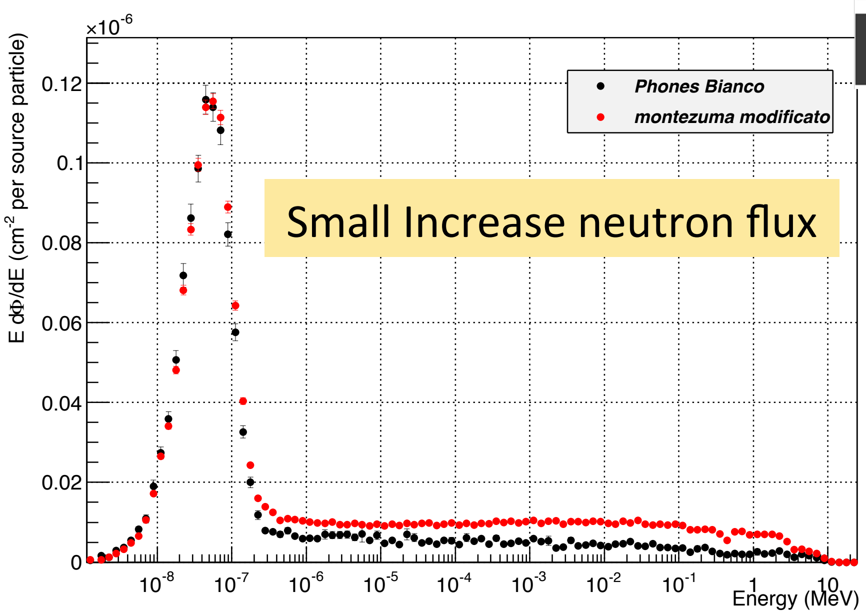
-Trying new geometries and assembly scheme

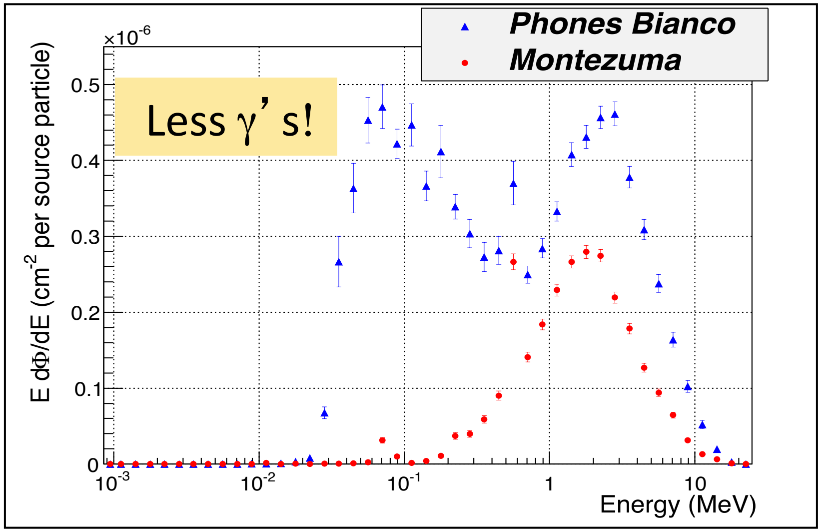
-next try alternative materials (work in progress..)

"Montezuma" scheme

Cavity: 22 x 22 x 5 cm^3







Summary table

Hyperthermal n means E <10keV

Elekta Precise with "Phones Bianco"	Hyperhermal neutron fluence per source particle (cm^{-2})	Electron rate N_e (s^{-1})	Hyperhermal neutron flux (cm^{-2} s^{-1})	Gamma contamination **$D_\gamma/\phi_{th/epith}$ (Gy cm^2)**	Fast neutron contamination **$D_f/\phi_{th/epith}$ (Gy cm^2)**
18 MeV with filter	$(9.35\pm 0.18)\ 10^{-8}$	$1.05\ 10^{14}$	$(9.83\pm 0.19)\ 10^{6}$	$(1.13\pm 0.03)\ 10^{-10}$	$(8.6\pm 0.5)\ 10^{-13}$
18 MeV without filter	$(1.99\pm 0.03)\ 10^{-7}$	$1.05\ 10^{14}$	$(2.09\pm 0.03)\ 10^{7}$	$(1.64\pm 0.03)\ 10^{-10}$	$(8.7\pm 0.3)\ 10^{-13}$
20 MeV without filter	$(2.96\pm 0.05)\ 10^{-7}$	$1.75\ 10^{14}$	$(5.19\pm 0.08)\ 10^{7}$	$(1.35\pm 0.02)\ 10^{-10}$	$(1.00\pm 0.04)\ 10^{-12}$
Elekta Precise with "Montezuma"					
20 MeV without filter	$(3.36\pm 0.03)\ 10^{-7}$	$1.75\ 10^{14}$	$(5.89\pm 0.05)\ 10^{7}$	$(5.07\pm 0.09)\ 10^{-11}$	$(3.2\pm 0.1)\ 10^{-12}$

Almost factor 6 better

A factor 2 better

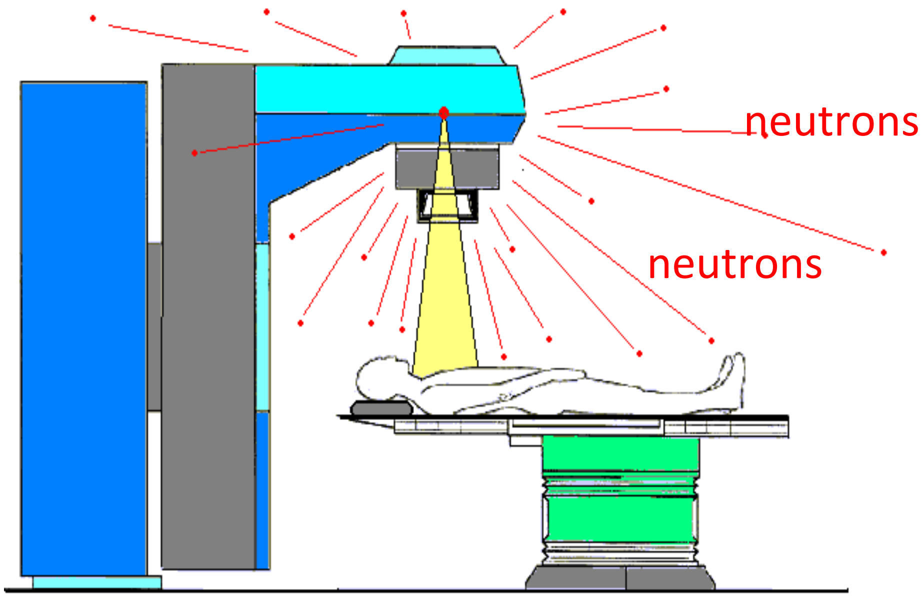
A factor 3 worse

Some promising results for hyperthermal neutrons and gamma's
More work is needed especially on fast neutron component

More…

Radioprotection issue

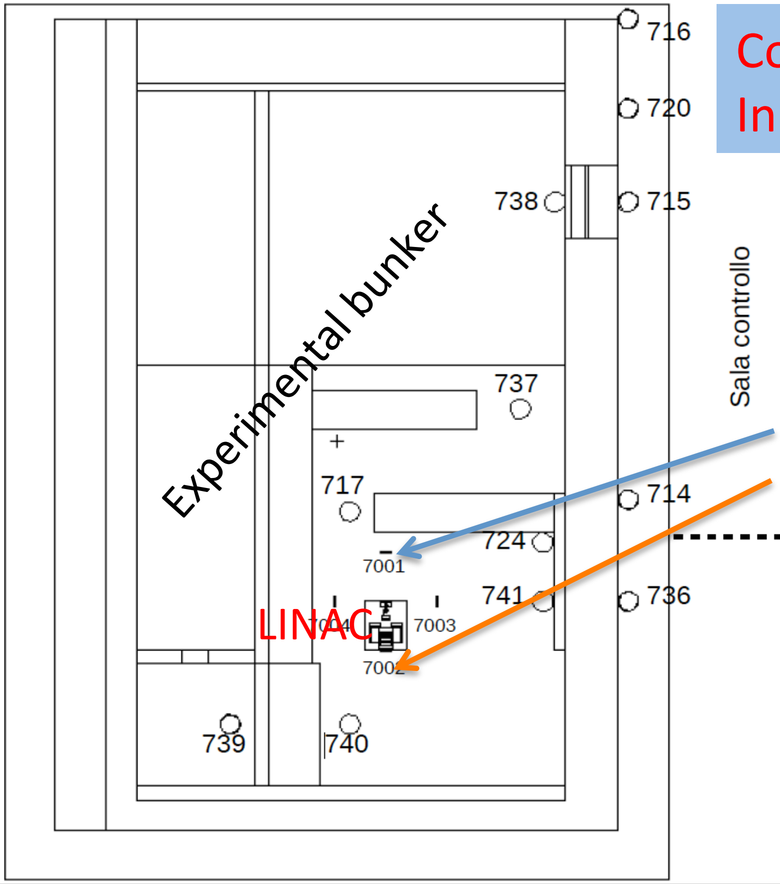
Collimators of a normal radiotherapy LINAC are made of Pb or W ➔ fast neutron are produced



A medical LINAC dedicated to research is interesting also to:

- to study and measure the undesired neutron dose
- As a facility to test new active diagnostics (see LATND-Neurapid project) at variable fluence and energy

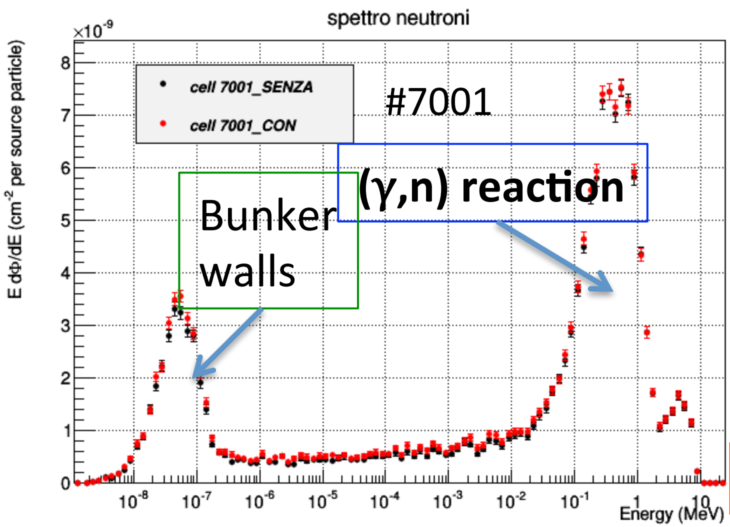
Correlated question: what does it change In the bunker with PhoNeS coupled to LINAC?

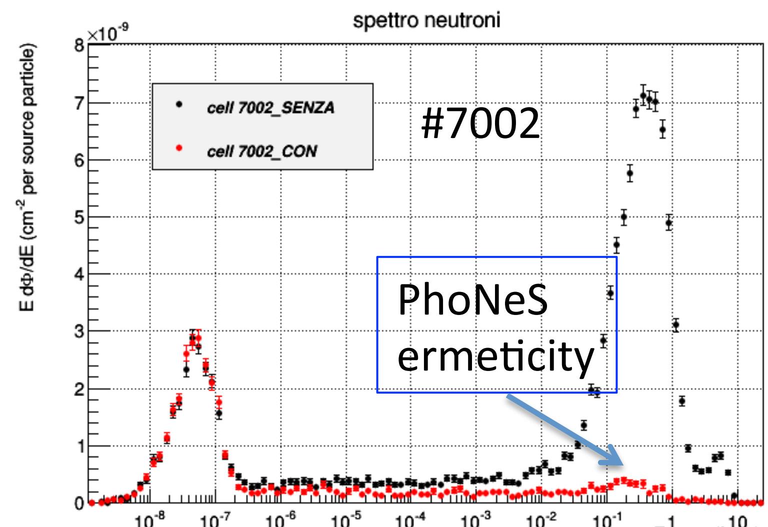


Torino bunker has been included in the simulation

Cell	(A) Neutron Fluence **with** photoconverter	(B) Neutron Fluence **without** photoconverter	Ratio A/B
	cm^{-2} per source particle	cm^{-2} per source particle	
7001	(3,52 ± 0,04)E-08	(3,41 ± 0,04)E-08	1,03 ± 0,02
7002	(0,87 ± 0,03)E-08	(2,76 ± 0,04)E-08	0,32 ± 0,01
7003	(3,31 ± 0,04)E-08	(3,12 ± 0,04)E-08	1,06 ± 0,02
7004	(3,64 ± 0,04)E-08	(3,48 ± 0,04)E-08	1,04 ± 0,02
7005	(4,61 ± 0,05)E-08	(4,30 ± 0,04)E-08	1,07 ± 0,02
7006	(2,44 ± 0,03)E-08	(2,37 ± 0,03)E-08	1,03 ± 0,02

Tab.1 Neutron fluence per source particle at 1 m from the target with and without photoconverter.





No significant change! , even better in the forward direction

Conclusions

- The study of a new facility in Torino (INFN&UNITO) based on a linear accelerator and a new photoconverter is being carried on. Results have been shown for thermal source

- A **dedicated facility** allows to modify LINAC working parameters and the accelerator head components in order to increase the photon production. **Simulations demonstrated that without flattening filter and rising the electron energy the photon fluence rate useful for (γ,n) reaction increases by a factor 6 and is "tunable".**

- Different photoconverters were simulated. The "Montezuma"configuration with closed cavity, provides a max neutron fluence rate (E < 10 keV) of **$(5.89 \pm 0.05) 10^{7}$ cm^{-2} s^{-1}**
- With the "Montezuma" geometry the gamma dose is much reduced, while the fast neutron component gets higher. Further work is needed

- With a medical Linac dedicated to research radioprotection issues can be addressed and new diagnostics can be tested

- The proposed photo converter coupled to the LINAC does not increase the neutron dose in the bunker. Side comment: it can be coupled to "any" LINAC

Backup

Declared endorsement/interest:

(Departments of biotecnology e Science del farmaco, Ospedali S.Luigi e S.Giovanni Vecchio –ThalesAlenia)

Dipartimento di Scienze del Farmaco
Università degli Studi del Piemonte Orientale "A.Avogadro"

Prof. Luigi Panza

Novara, 16/07/2014

Prof.ssa Alba Zanini
Via Pietro Giuria 1
10125 Torino
cc: Prof. Marco Costa, Universita' degli studi Torino

Gentile Dott.ssa Zanini
come gia' discusso a Helsinki, durante il recente congresso ICNCT 16 tenutosi dal 19 al 24 Giugno, confermo il mio interesse per il progetto dei nuovi fotoconvertitori e-Libans in grado di produrre fotoneutroni di energie termiche, epitermiche e veloci, accoppiati ad un acceleratore Elekta 18 MV installato presso il bunker del Dipartimento di Fisica di Torino. Dal momento che nella mia attivita' di ricerca continuo ad occuparmi della sintesi di prodotti boronati per applicazioni nella terapia a cattura neutronica, sono molto stimolato dalla notizia, in quanto prevedo di avere a breve dei prodotti boronati per la BNCT, per i quali non è sempre facile avere la possibilità di effettuare dei test, e credo che la facility che prevedete d
disponibili per questo tipo di misure . La prego
poter usufruire della apparecchiatura non appena

Grazie per l'attenzione e cordiali saluti.

ThalesAlenia Space

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Torino, 16/7/2014
Prot. SFEH/14/CL/002
A: Prof. Marco Costa, Dipartimento di Fisica, Universita' di Torino

Subject: **Espressione d'interesse per il potenziale utilizzo di una sorgente di neutroni termici, epitermici e veloci da installare presso il Dipartimento di Fisica dell'Università di Torino**

Con questa lettera Thales Alenia Space Italia vuole esprimere il suo interesse per il potenziale utilizzo di una sorgente di radiazione basata su un acceleratore Elekta Precise 18 MV, installato presso il bunker del Dipartimento di Fisica di Torino che, oltre a fasci di elettroni e fotoni, tramite nuovi fotoconvertitori e-Libans, sara' in grado di produrre fotoneutroni di energie termiche, epitermiche e veloci.

Per le applicazioni spaziali in ambito industriale delle quali la nostra azienda è leader nel settore, lo studio del comportamento dei materiali e dei componenti elettronici esposti alla radiazione cosmica è cruciale. Inoltre, lo studio degli effetti della radiazione cosmica sull'uomo è fondamentale per la progettazione di futuri habitat per missioni interplanetarie.

L'utilizzo di una sorgente di neutroni termici e fotoni e` quindi di potenziale interesse di Thales Alenia Space Italia per studiare la perdita di prestazioni dei materiali (e.g. polimeri) esposti ad alte dosi di radiazioni e, in previsione dello sviluppo dei fotoconvertitori per neutroni ad alta
gia, anche nella ricerca riguardante gli effetti sui componenti elettronici.

nclusione, Thales Alenia Space Italia considera positivamente l'installazione della
china radiogena in oggetto presso il Dipartimento di Fisica della facoltà di scienze
dell'Università di Torino ed è interessata al suo potenziale utilizzo.

are Lobascio

d of Space Flight, Environment & Habitat,
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Date: 11th July 2014

Dr Roberto Bedogni
INFN – LNF, Via E. Fermi 40
Frascati (Rome)

Cc: Professor Marco Costa (Università degli Studi di Torino)

Dear Roberto,

We were extremely interested to hear about the project proposal for the development of e-LIBANS, an epithermal neutron field based upon a ^{241}Am-Be radionuclide neutron source. This is an extremely important energy region for many fields of science and it has been overlooked in terms of experimental facilities for too long.

Just as your new source-based thermal neutron field facility (ETHERNES) complements our accelerator-based thermal neutron field facility here at NPL, we envisage that your source-based epithermal neutron field facility will complement our accelerator-based epithermal / 1/E neutron field facility, which is due for completion by the end of 2014.

The NPL Neutron Metrology Group has followed the output from NESCOFI @ BTF with great interest and is following progress in the NEURAPID project just as closely. Given the degree of synergy between our research projects, we look forward to continuing our collaborative efforts to maximise the outcomes of our work.

We wish you every success with your proposal.

Best Regards,

Graeme Taylor
Principal Research Scientist
Neutron Metrology Group
NPL
Tel: +44 208 943 7087
Email: Graeme.taylor@npl.co.uk

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CNA — CENTRO NACIONAL DE ACELERADORES

(Universidad de Sevilla-Junta de Andalucía-CSIC)

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Seville, 30th of June 2014

Dear Ric. Roberto Bedogni:

We heard with interest about the INFN projects where you are involved, especially for the development of the single moderator multi-detector neutron spectrometer CYSP, able to measure in a single exposure the whole neutron spectrum along a given direction.

The Centro Nacional de Aceleradores (CNA) de Sevilla recently commissioned few well characterized neutron beam lines by means of the ^{7}Li(p,n) and D(d,n) reactions and plans to qualify them as reference radiation fields for the epithermal and fast neutron domains.

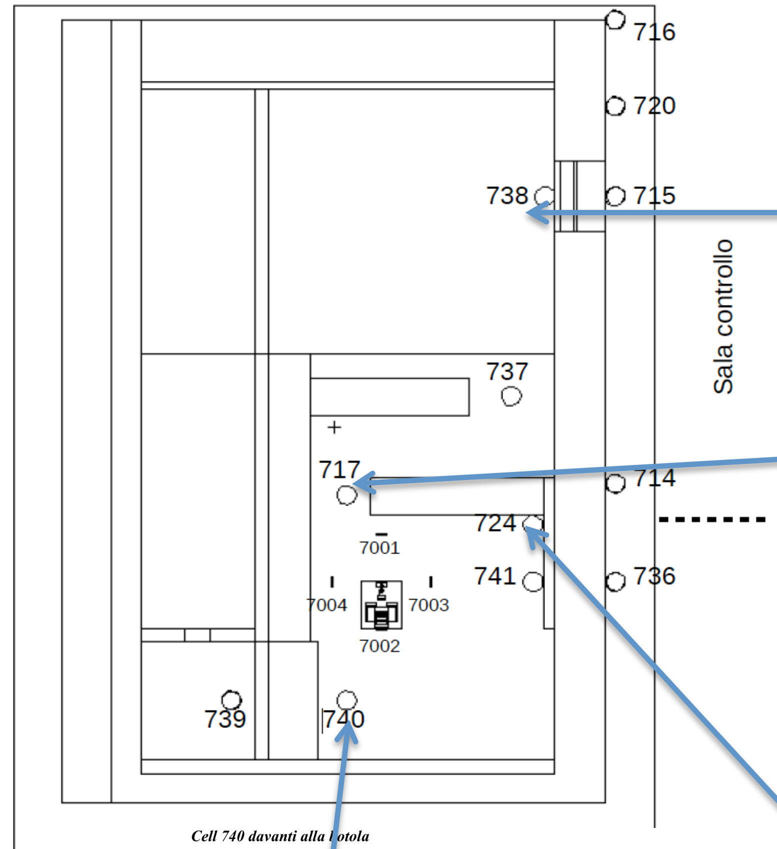
Given the degree of synergy between our researches, we agree with you to start a collaboration between our two groups. From our side, we offer access free of charge to our epithermal and fast neutron beams, subject to approval by CNA scientific committee, for testing the new diagnostics you are developing in NEURAPID and E-LIBANS projects. In exchange, you will contribute to characterize the neutron fields at CNA using your CYSP spectrometer.

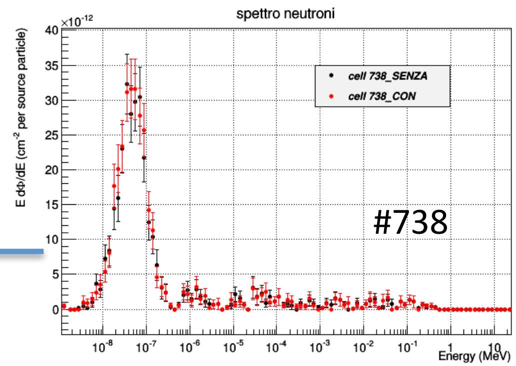
Wishing you every success,

Joaquín Gómez Camacho
Director
Centro Nacional de Aceleradores

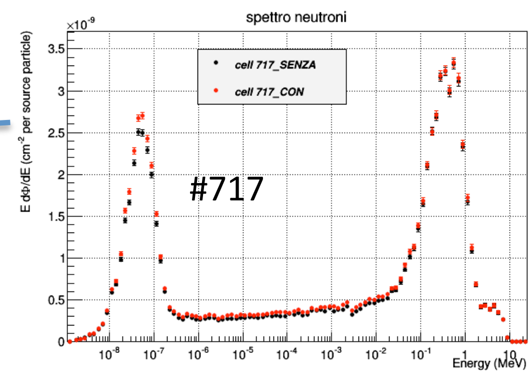
Javier Praena
Researcher in charge neutron beam lines
Centro Nacional de Aceleradores

Neutron Fluence in the bunker with/without photo-converter

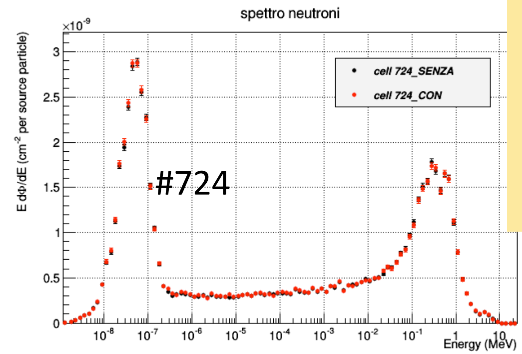


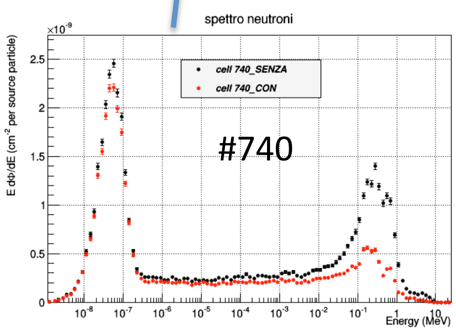


Neutron spectra in spheres of 20 cm radius with and without photoconverter

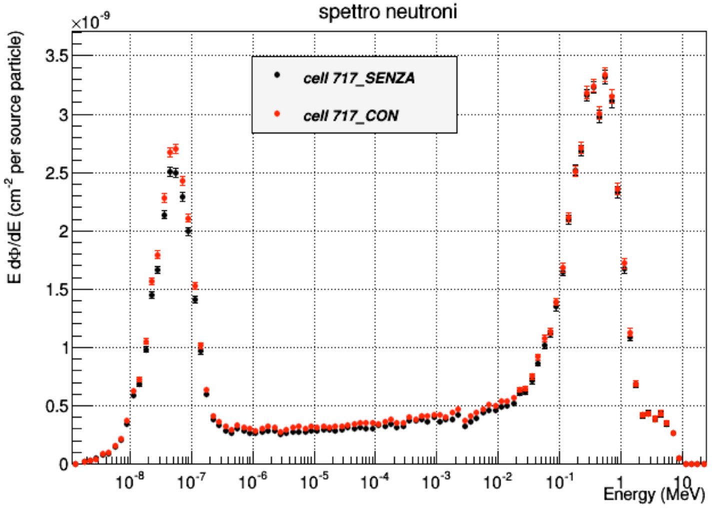


The photo-converter is either not increasing the neutron flux in the bunker or is also beneficial in the forward direction





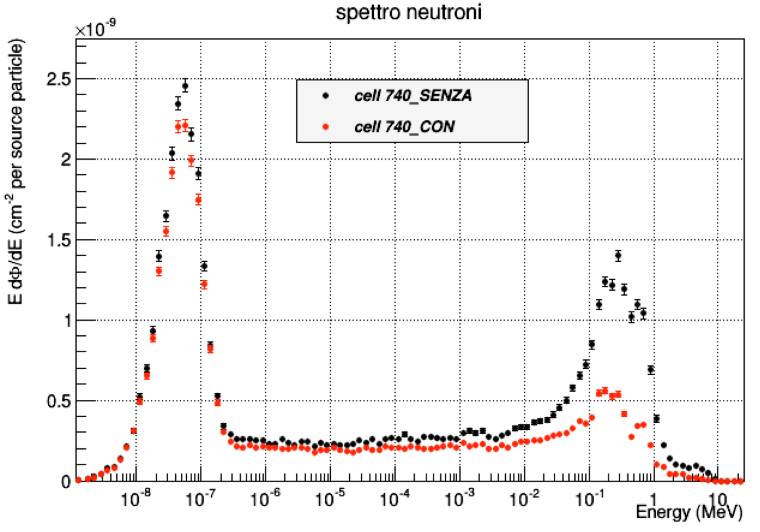
Neutron Dose in the bunker with/without photo-converter



Posizione	Dose neutroni (pSv per particella sorgente)	Dose neutroni per Gy di fascio gamma erogato Sv/Gy (400UM/min)	Dose neutroni per settimana di lavoro (150 Gy / settimana)	Rapporto A/B
(A) Cell 717 **con** fotoconvertitore	(2,36 ± 0,02)E-06	3,72 E-03	5,58 E-01	1,01 ± 0,01
(B) Cell 717 **senza** fotoconvertitore	(2,34 ± 0,02)E-06	3,69 E-03	5,53 E-01	

Fig 4 Spettro di neutroni e dose in una sfera di raggio 20 cm posta all'uscita della chicane di accesso alla sala di irraggiamento
Non si osservano apprezzabili differenze fra le configurazioni "con" e "senza" fotoconvertitore

Neutron Dose in the bunker with/without photo-converter



Posizione	Dose neutroni (pSv per particella sorgente)	Dose neutroni per Gy di fascio gamma erogato Sv/Gy (400UM/min)	Dose neutroni per settimana di lavoro (150 Gy / settimana)	Rapporto A/B
(A) Cell 740 **con** fotoconvertitore	(3,42 ± 0,06)E-07	0,54 E-03	0,81 E-01	0,40 ± 0,01
(B) Cell 740 **senza** fotoconvertitore	(8,55 ± 0,13)E-07	1,35 E-03	2,02 E-01	

Fig 7 Spettro di neutroni e dose in una sfera di raggio 20 cm posta di fronte alla botola di uscita verso il giardino
Nella configurazione "con" il fotoconvertitore si osserva un'apprezzabile riduzione del flusso neutronico, in particolare nella componente ad alta energia

…..next future

- **2- Epithermal neutron source**
- Linee guida: (esperienza pregressa per sorgente da fusione D-D)
- core per la produzione di neutroni (al vaglio Pb, W, Be);
- moderatore per il rallentamento dei neutroni fino all'energia desiderata (al vaglio trifluoruro di alluminio, floruro di magnesio o Fluental);
- riflettore/collimatore per incrementare il flusso di neutroni (al vaglio Pb e W). Eventuale linea di estrazione ;
- Rimozione componente γ indesiderata (al vaglio fluoruro di litio arricchito in ^{6}L .
- **3- Fast neutron**
- Prodotti da conversione dei gamma su un bersaglio di piombo : componente evaporativa con uno spettro di energia piccato a 700 keV e anche una componente diretta di minore intensita fra 2 e 7 MeV.
- Per massimizzare il flusso si prevede di circondare core di Pb con materiali riflettenti con valori di albedo > 0.8 (anche leghe particolari quali Densalloy o "Tungsten carbide ")