present developments of the LMJ neutron diagnostics

DE LA RECHERCHE À L'INDUSTRIE

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OUTLINE

- LMJ laser facility and the French laser program present status
- LMJ neutron diagnostics
- Conclusions

LMJ and the French laser program
CEA experimental facilities

CEA LASER facilities

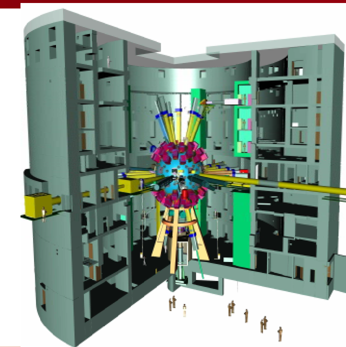
LIMEIL → CESTA

PHEBUS → **LIL**

3 kJ
@ 0.35 µm

30 kJ
@ 0.35 µm

LMJ
1.8 MJ
@ 0.35 µm



First shot

OMEGA /LLE - U. Rochester – NY- USA

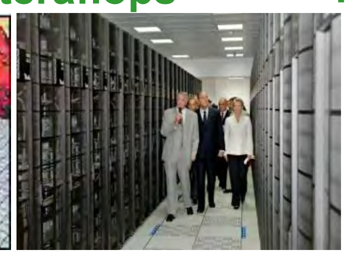
68 | 86 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | Dec. 14

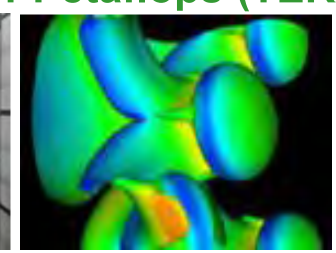
First DD Neutrons produced by laser at CEA/Limeil
Phys. Rev. A; 1, 821, 1969
Yn ~10^4 solid D2 ice

5 teraflops

50 teraflops

1 Petaflops (TERA 100)





TERA " family" computers

Numerical simulation facilities

MJ class laser facilities: LMJ (France) and NIF (USA)

<u>shared</u> R&D laser technology costs between France and US since 1994:

<u>Common characteristics</u>

Glass Neodymium laser (λ=1.06µm) & Multi pass laser amplification (x4)
Laser beam shape: square 40 x 40 cm^2
Frequency tripled λ=0.35 µm
Pulse duration: <1ns up to 17 ns (ignition pulse shaping – J. Nuckolls)
1 to 1.8 MJ laser energy on target & power 300 up to 800 TW

LMJ (in construction 2003 - 2014)

- I shaped laser building (2009)
- 176 (240) beams (42 to 60 quads)
- 2 (3) cones 33°-49°(59°) (½-½)
- Angular multi pass
- focusing by grating

(rejection of unconverted light)

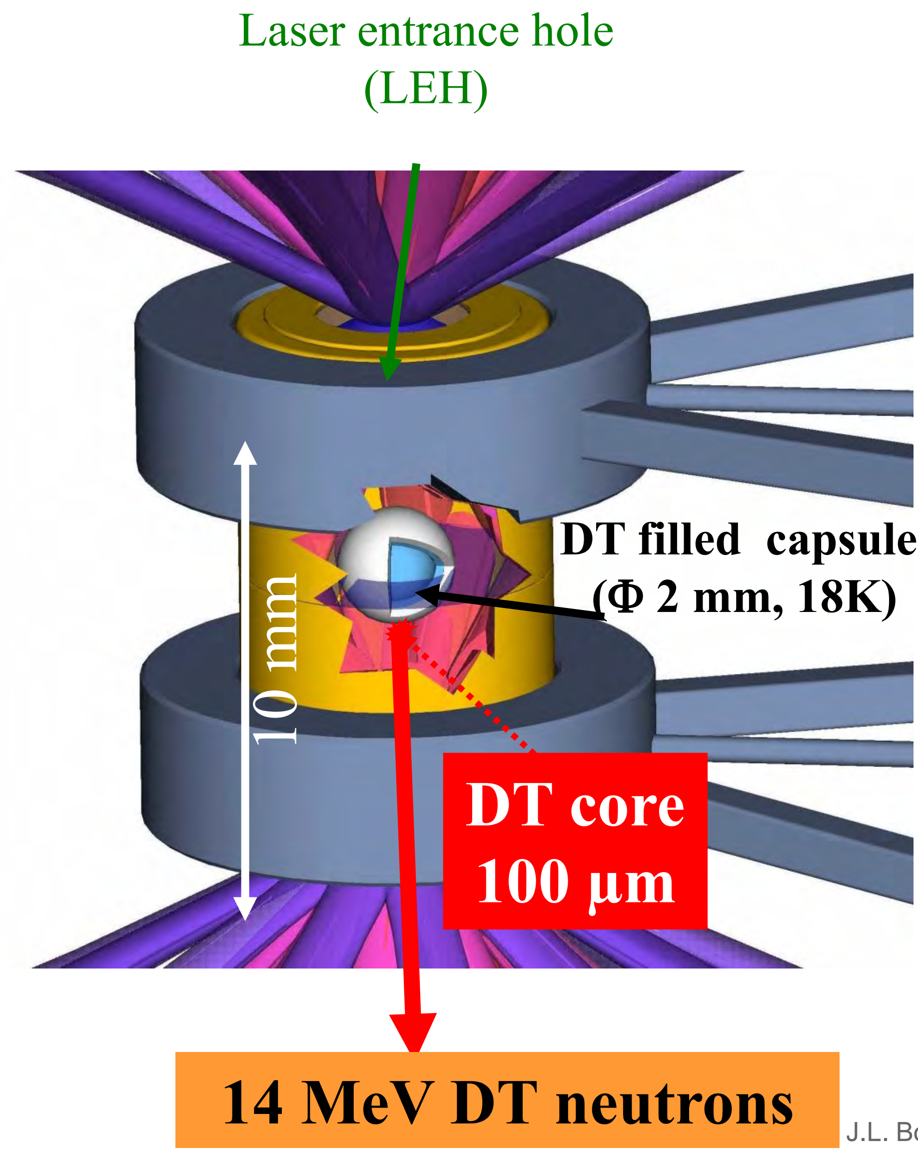
NIF (1997 – 2009 / operational)

- U shaped laser building (2002)
- 192 beams (48 quads)
- 2 (±1/2) cones (23/30°- 44/50°) ⅓– ⅔
- polarization multi pass
- Prismatic lens focusing

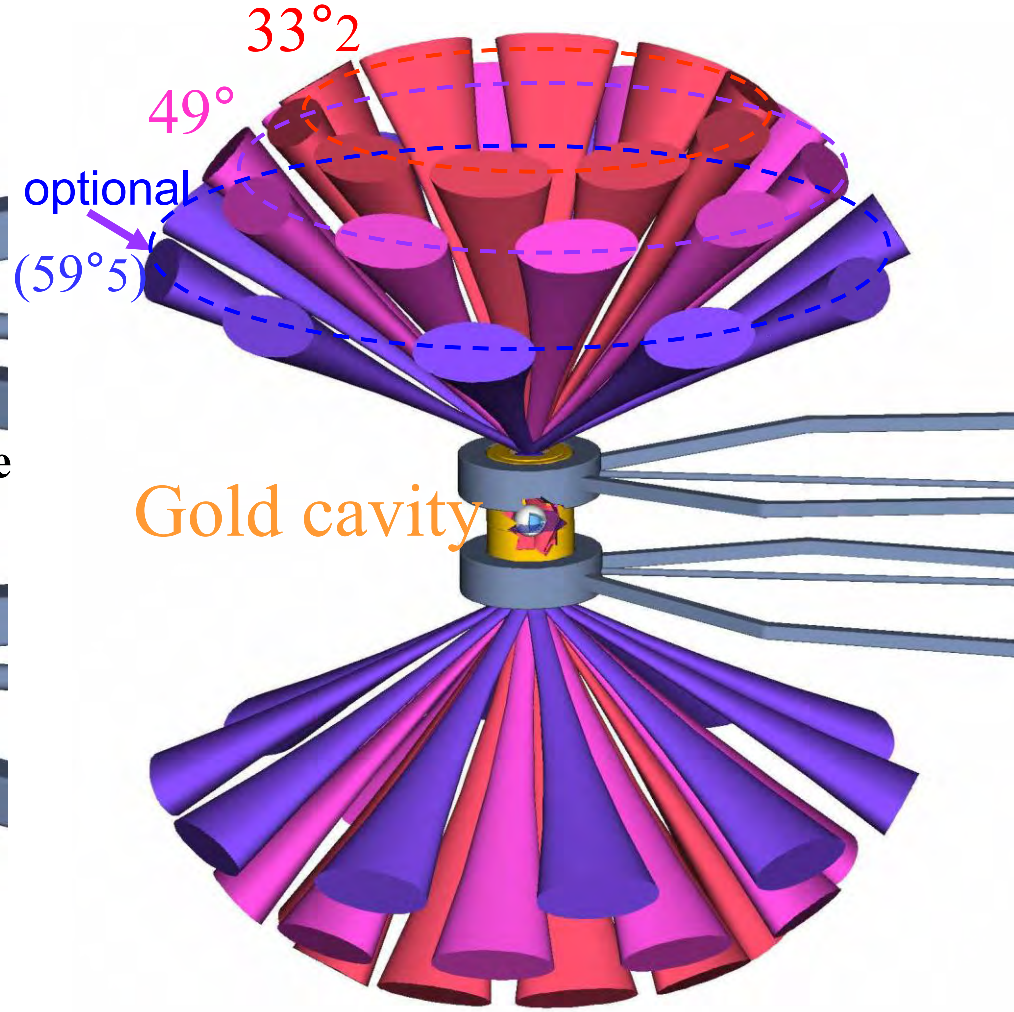
(deviation of the unconverted light)

LMJ indirect drive design

LMJ indirect drive scheme: laser beams don't hit directly the microballoon but heats a hohlraum/cavity and the x-rays produced inside implode the microballon



LMJ: 2 cones first / 3 cones



LMJ

Experimental hall

(protection against 14 MeV fusion neutron thread)

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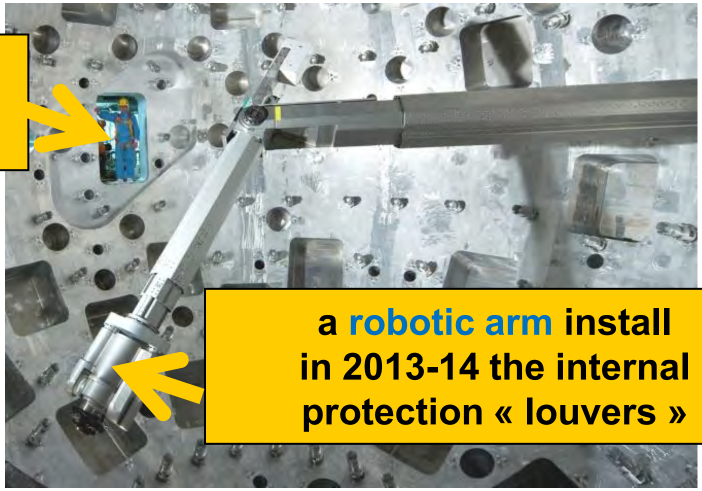
LMJ TARGET CHAMBER

- Target chamber inner diameter: 10 m
- Thickness: 100 mm
- Weight: 140 tons
- 80 laser holes out of 260
- Material: aluminium alloy 5083

(low level high A impurities – low neutron residual activation)

protection « louvers » (on the entire target chamber internal surface)

Man hatch (equatorial plane)



a robotic arm install in 2013-14 the internal protection « louvers »

Borated concrete layer on LMJ target chamber wall was sprayed for neutron shielding

Target chamber neutron shielding:

- **<u>concrete thickness 400 mm</u>**

(initial CDR tradeoff: transmission equal leak induced by laser ports w/o Boron)

- **Now concrete with Boron**

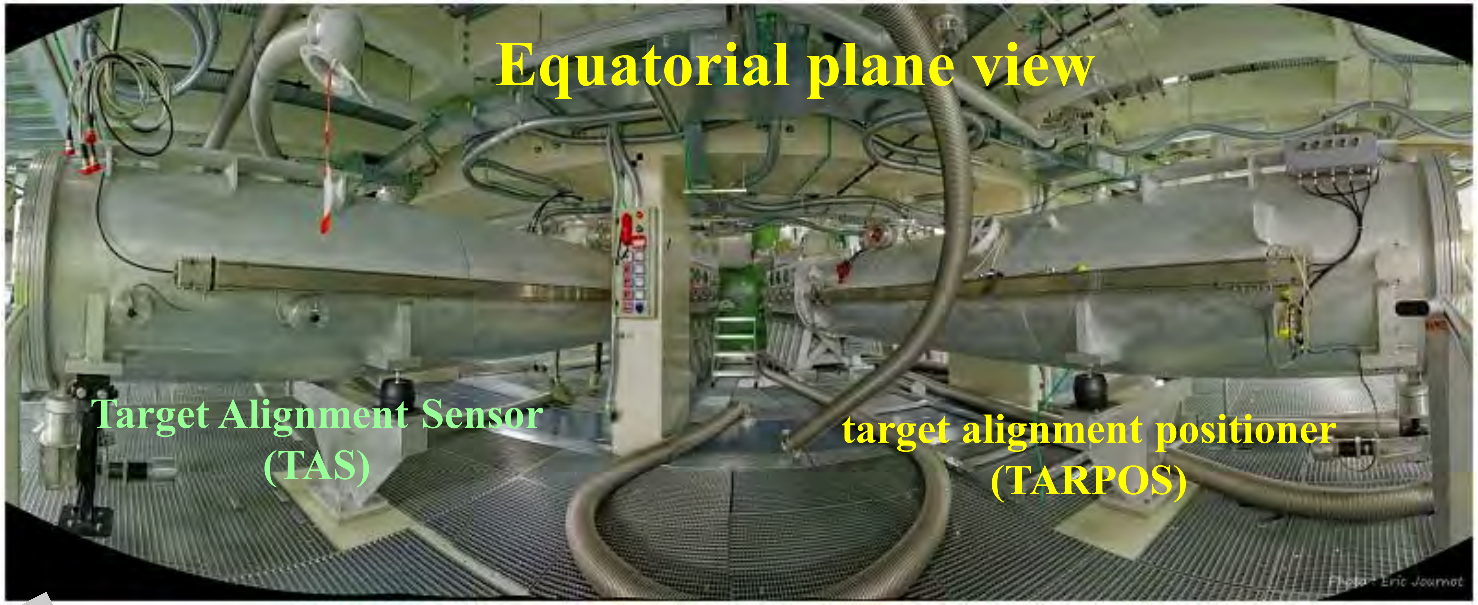
(1 % bore content)⇒ only 8% escaping neutrons through this protective layer

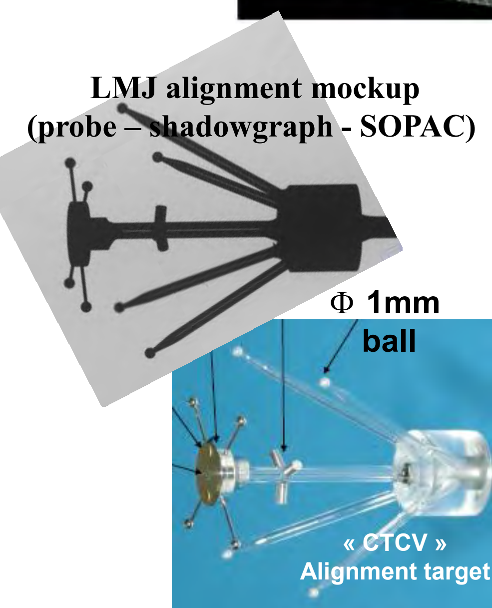
**With this shield
only 28% of the
14MeV DT fusion neutrons
are escaping outside
the target chamber.
Mainly (20%) by unshielded laser ports**

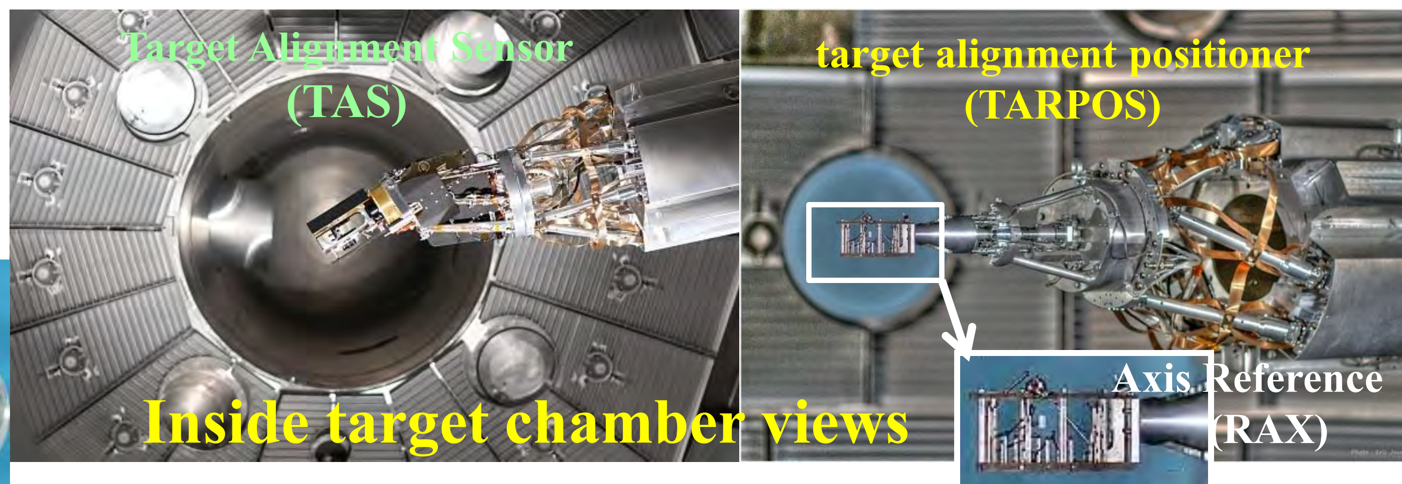
LMJ Experimental hall

THE LMJ EXPERIMENTAL HALL IS ALMOST READY FOR THE FIRST PHYSIC SHOT (Dec. 2014)

LMJ Experimental hall







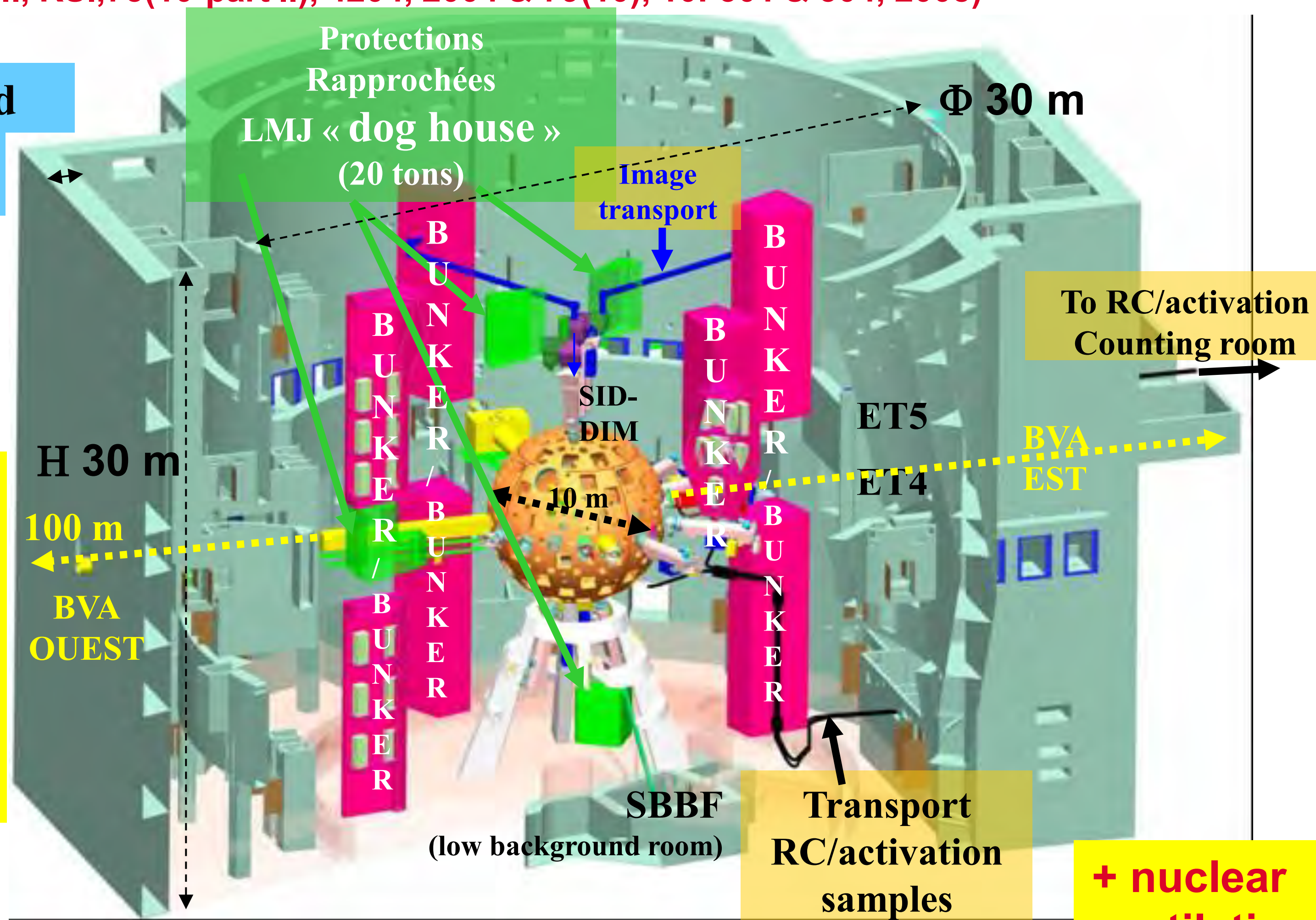
LMJ neutron diagnostics :

LMJ Experimental hall preparation vs harsh environment under neutron irradiation

LMJ target hall : nuclear harsh environment specific preparation

- LMJ target hall is designed to handle the neutron diagnostics

(J.L. Bourgade et al., RSI,75(10-part II), 4204, 2004 & 79(10), 10F301 & 304, 2008)



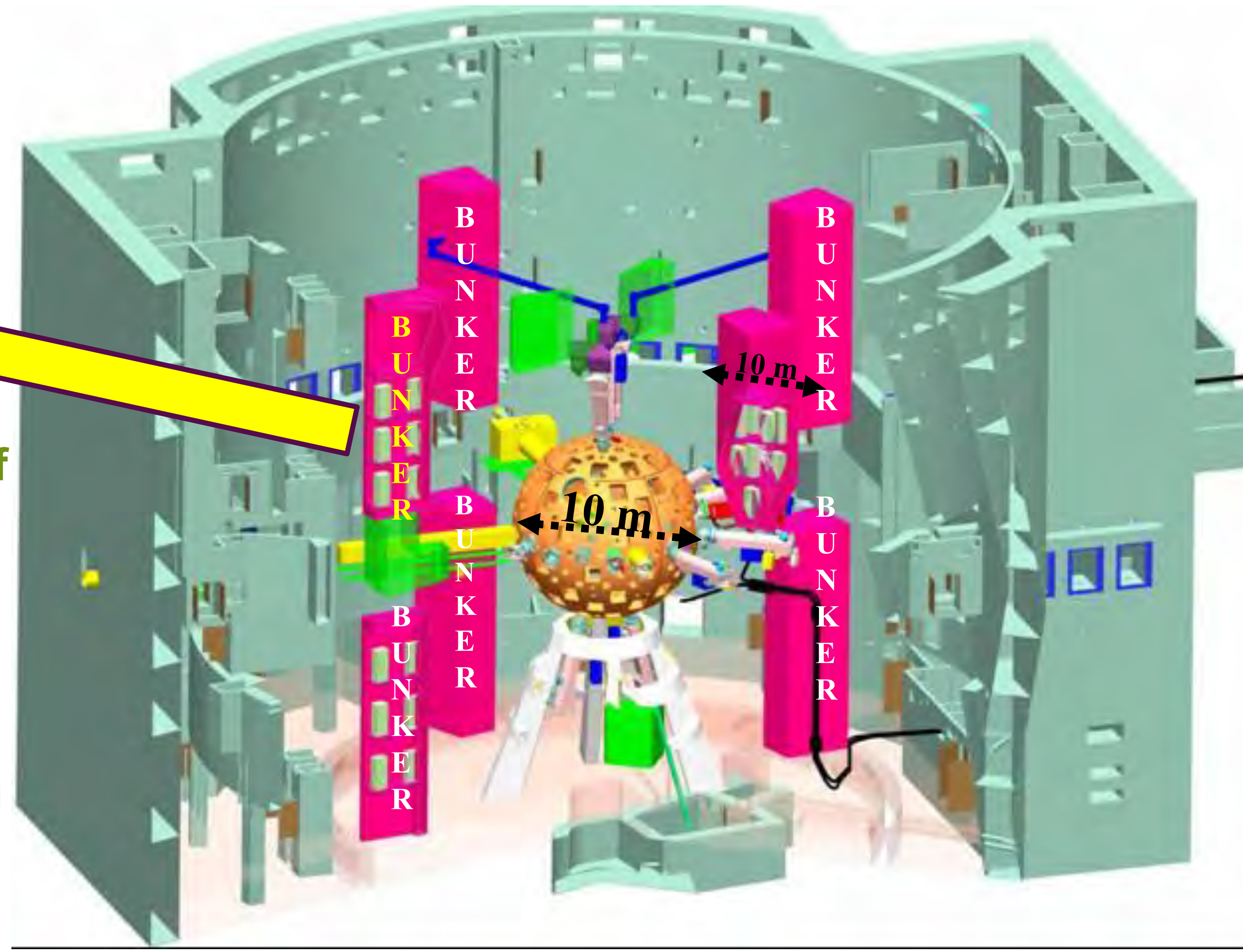
OUEST / WEST
Extended range LoS (~100 m)
Base de vol Allongée (BVA Est & Ouest)
For Nuclear Imaging (I.e. Neutron imaging) & other diagnostics

+ nuclear ventilation

LMJ target hall : bunkers (1/2)

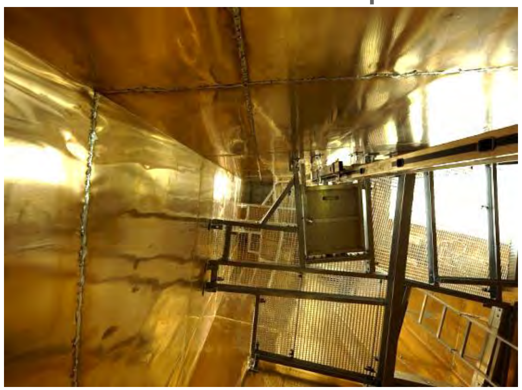
- **LMJ target hall have been designed w/ dedicated shielded area**
  - 8 bunkers created to protect sensitive electronics/recording devices **up to 10^{16} neutrons**

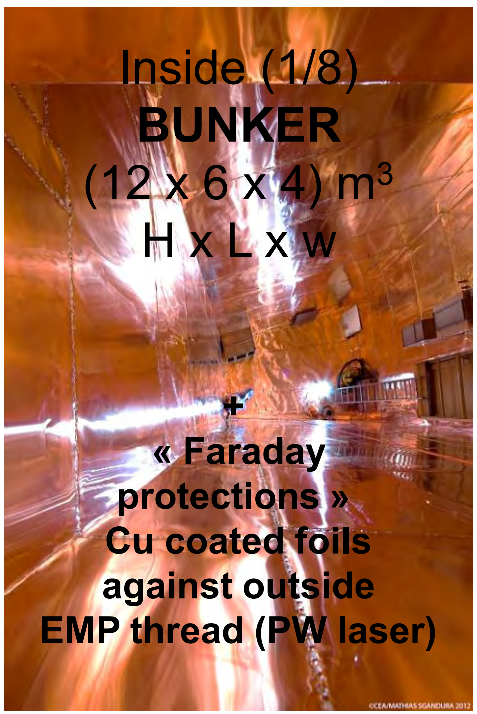
4 levels of space frame available for 11 recording cabinets (standard 19" units)

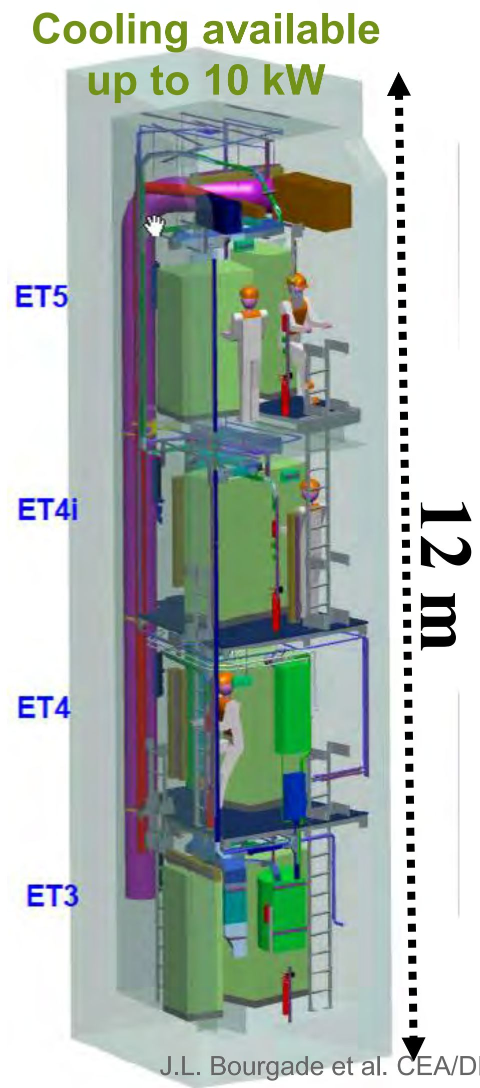


LMJ target hall : bunkers (2/2)

- **LMJ target hall have been designed w/ dedicated shielded area**
  - 8 bunkers created to protect sensitive electronics/recording devices **up to 10^{16} neutrons**



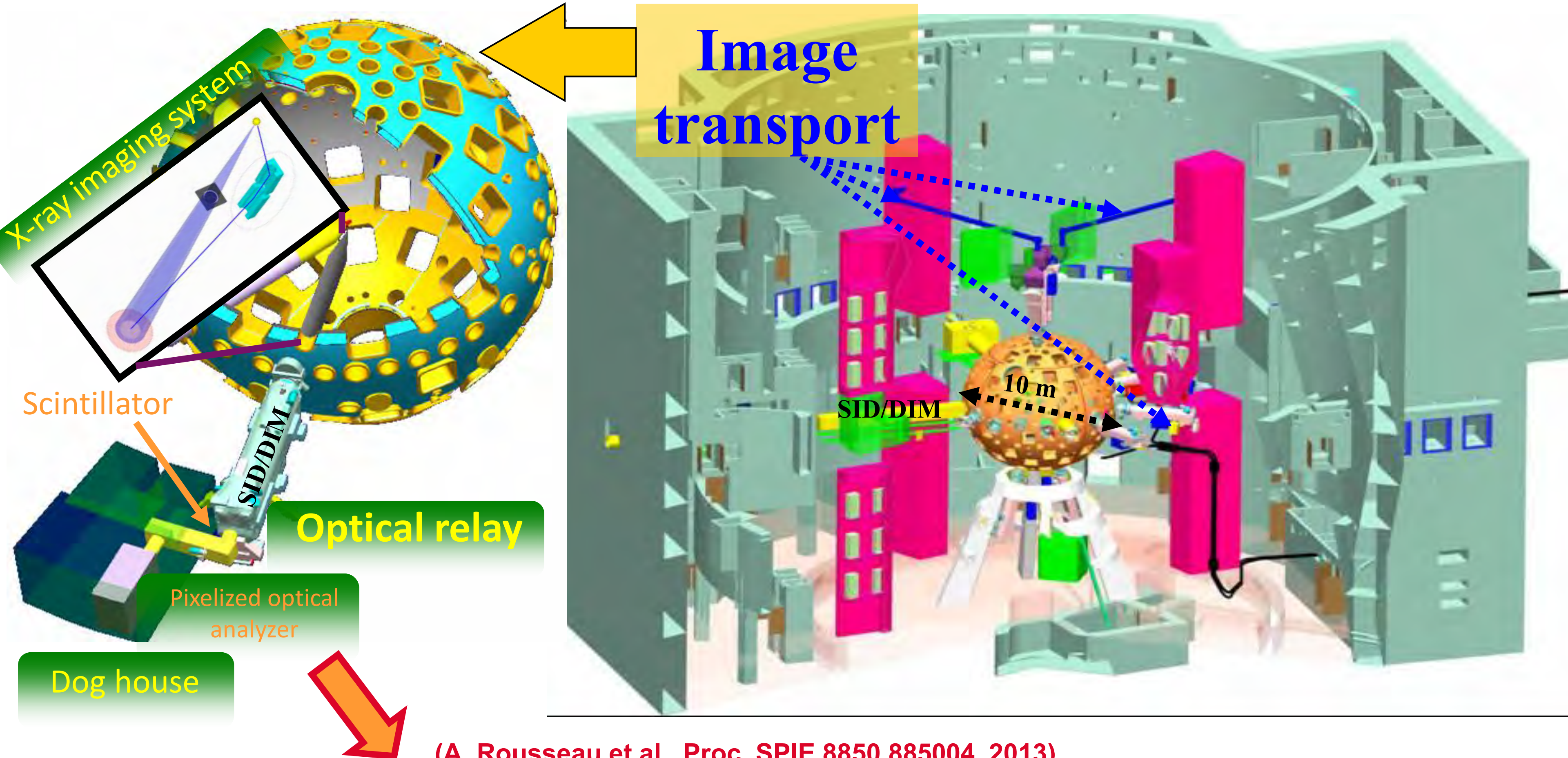




4 levels of space frame available for 11 recording cabinets (standard 19" units)

LMJ target hall: image transports

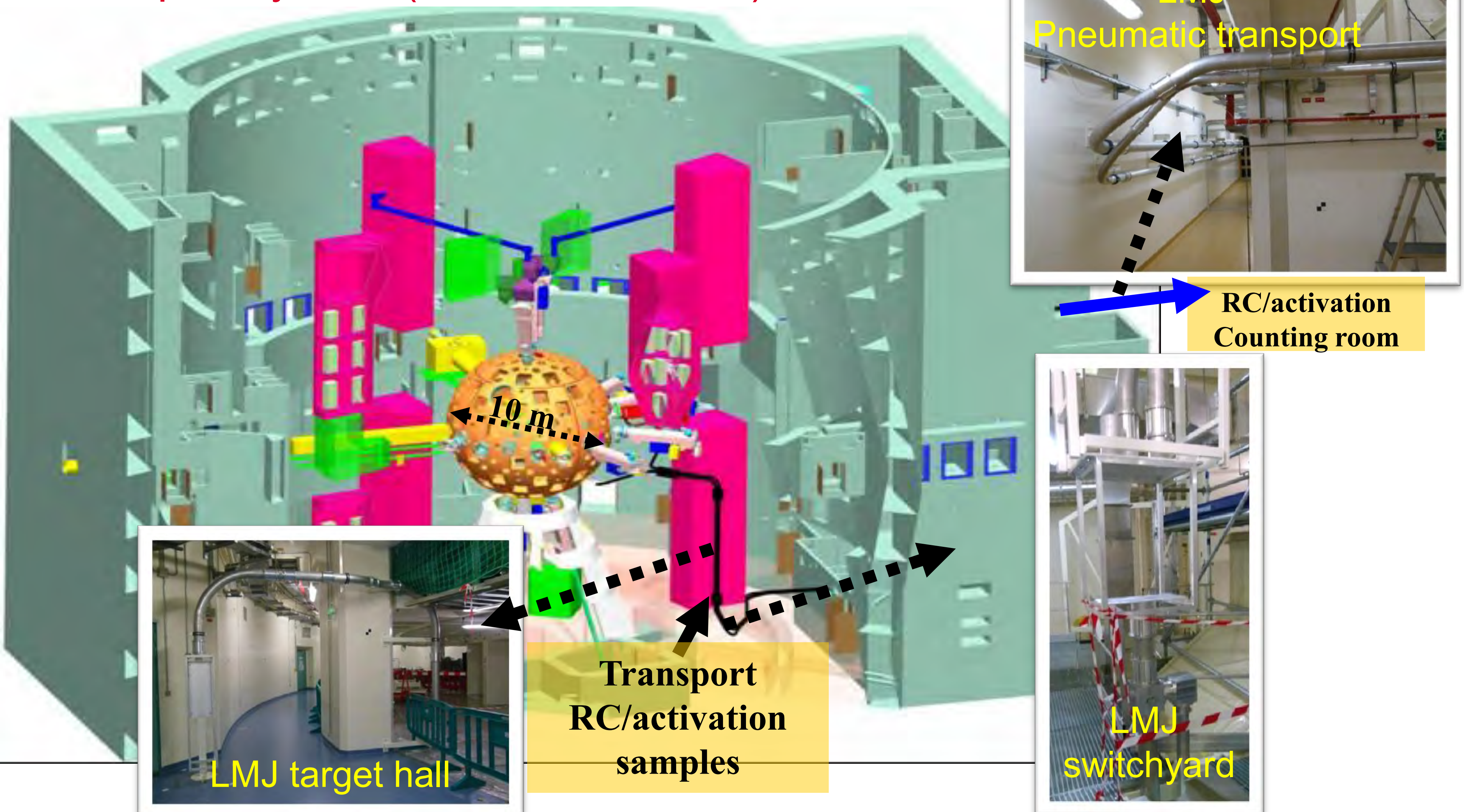
- LMJ target hall have been designed w/ few image transports for nuclear imaging diagnostics (hard x-rays / Gamma or neutron)



(A. Rousseau et al., Proc. SPIE 8850,885004, 2013)

LMJ target hall: radioactive samples transports

- LMJ target hall have been designed w/ pneumatic radioactive sample transport system (AREVA - France)



LMJ Neutron diagnostics :

1. Neutron yield
   a) Activation
   b) CVD diamond
2. Ti & neutron bang time
3. Neutron imaging
4. Neutron spectra

Neutron yield: activation diagnostics

Activation sample are one of the best internationally cross calibrated neutron yield measurements

Yn range for LMJ

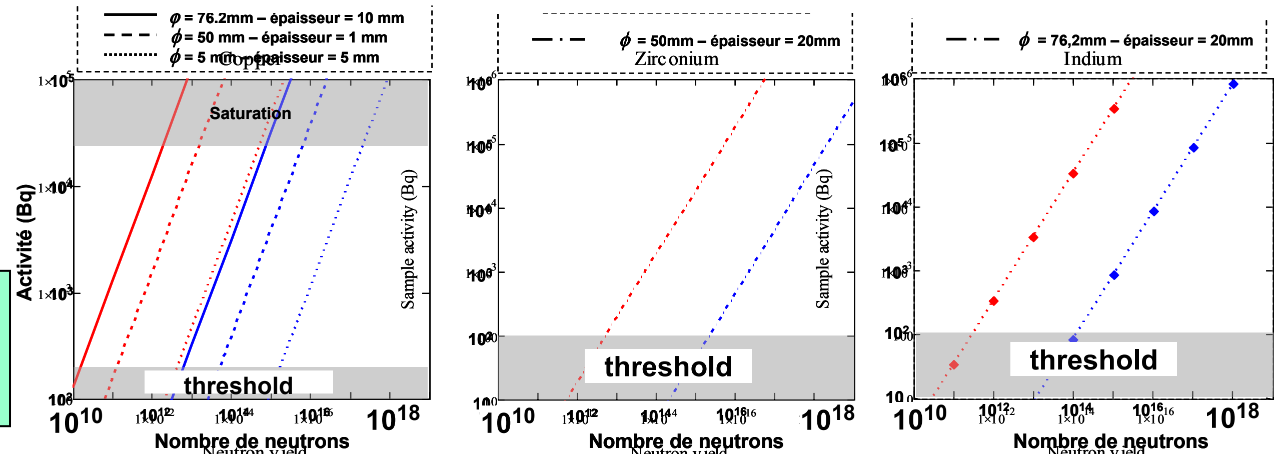
10^9 à 5.10^{18} DT neutrons

10^{10} à 10^{15} DD neutrons

To cover this entire yield range

- **Differents material**
- **2 distances from source**

Cu 10^{10} to 10^{17} | **Zr 10^{13} to 10^{19}** | **In 5 10^{11} to 10^{15}**



1m /source @TCC **20m /source @TCC**

<u>Independent cross calibration</u>

between

<u>LLE nToF</u>

and

<u>CEA Cu activation</u>

neutron yield measurements

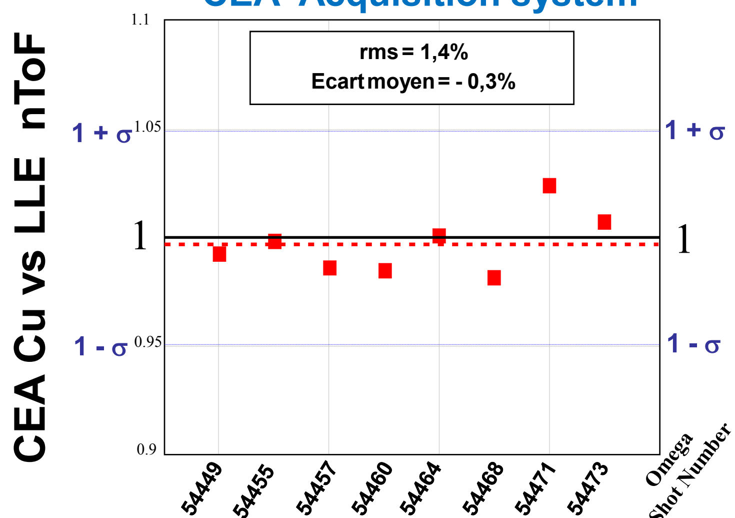
<u>on same Omega shots</u>

Difference < 0.3%

(less than errors)

(O. Landoas et al.,RSI, 82, 073501, 2011)

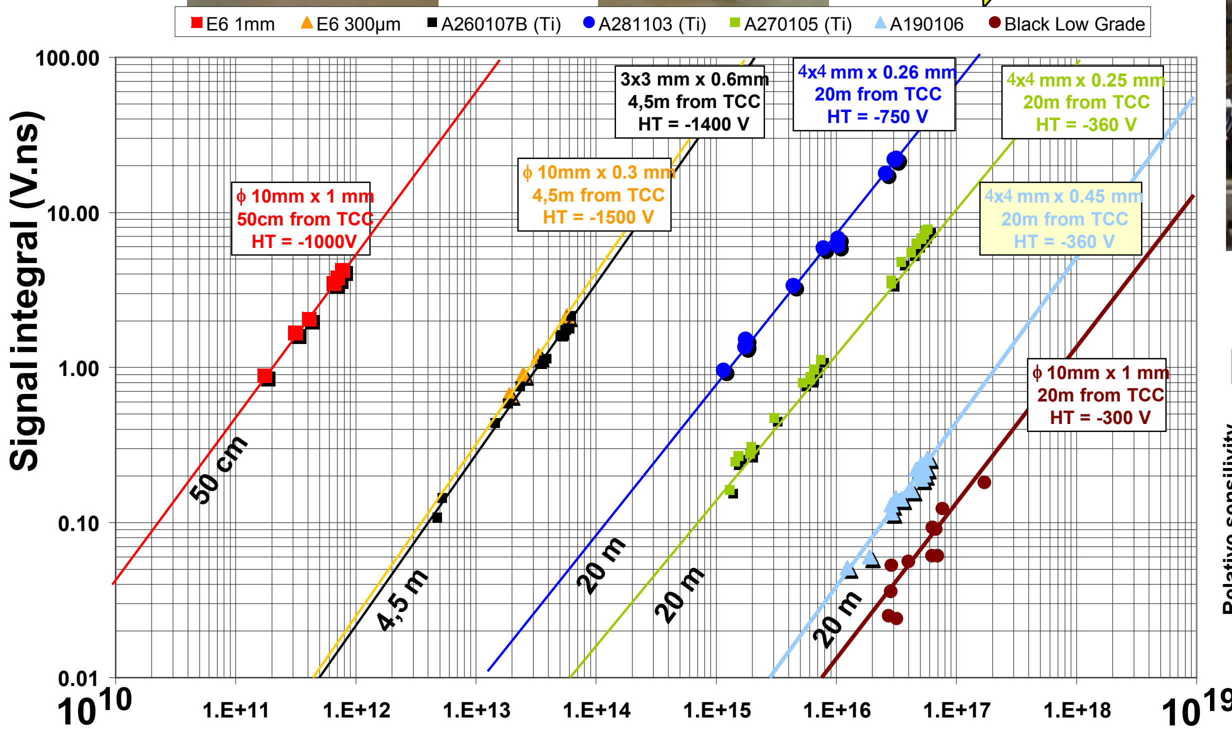
CEA Acquisition system



Neutron yield: CVD diamond detectors

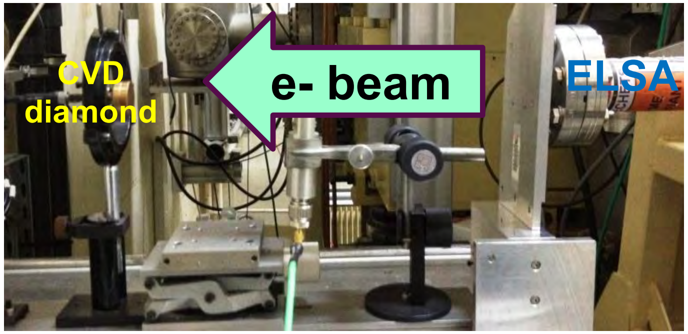
CVD diamond are good candidates for measuring neutron flux on LMJ:

- **tested/calibrated on high yield neutrons shots on Omega**

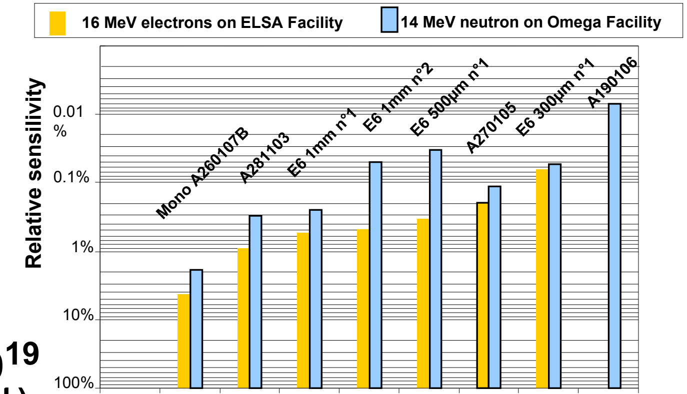


LLE annual report 112, 272, (2007)

- **measurement on a MeV electron pulsed source (20 ps) (ELSA e^- accelerator @16 MeV) to infer a crude sensitivity (e^- / n)**



Sensitivity comparison per volume unit for electrons and neutron irradiation

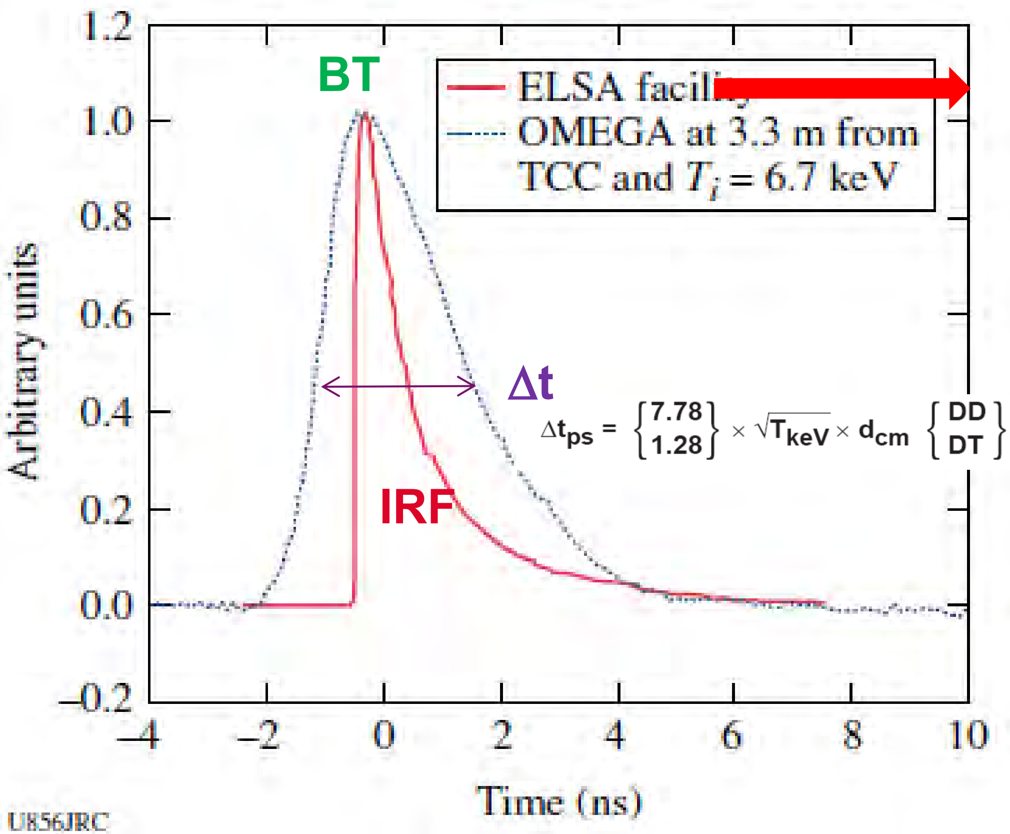


CVD diamond detectors: BT & Ti of the DT fuel measurement

• CVD diamond are also good candidates for measuring implosion Bang Time (BT) and fuel temperature (Ti) on LMJ:

❑ fuel ion temperature by Doppler broadening (**Δt**)

❑ implosion Bang time (**BT**)



• **IRF is fundamental to unfold CVD detectors time signals for Ti**

• CEA measure each CVD diamond detector's IRF on a MeV electron pulsed source **ELSA**

- **e^- accelerator @16 MeV**
- **Near in volume irradiation (n-like)**
- **emission duration ~20-40 ps**

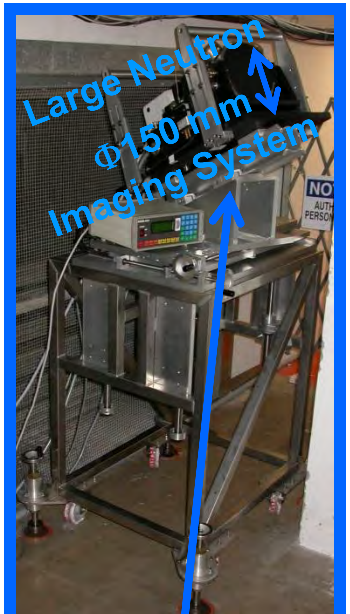
See LLE annual report 116, 256, (2008)

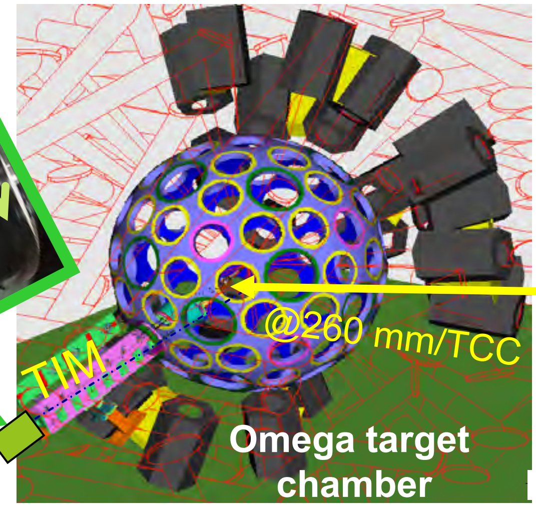
Neutron imaging (1/2)

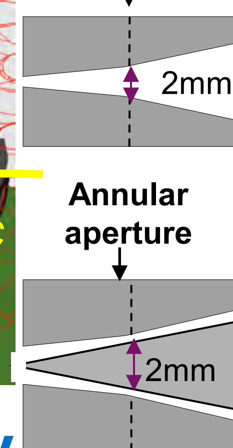
CEA neutron imaging systems (NIS) are developed since more than 10 years on Omega (L. Disdier et al.,RSI, 74(3), 1832, 2002; T. Caillaud et al., RSI, 83, 033502, 2011)

LMJ goal for neutron imaging :

5µm spatial resolution @ Yn> 5 10^{14}



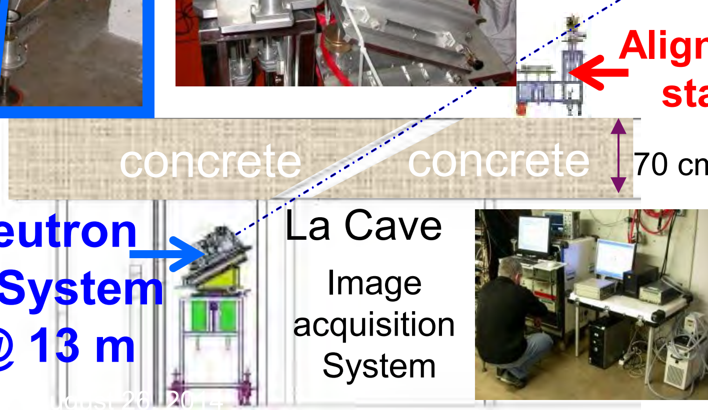




(SNIS) @ 4m

NIS LoS

Omega target bay



Large Neutron Imaging System (LNIS) @ 13 m

Penumbra & annular apertures can be exchanged as wished w/ alignment

One of the NIS main challenge (G~100 @ LMJ = alignment)

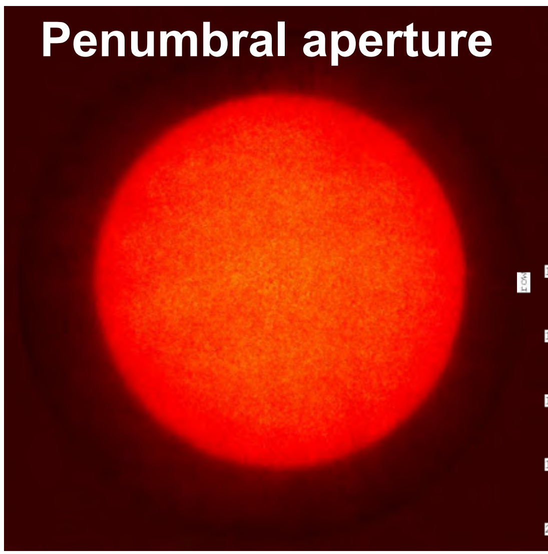
I. Thfoin & et al.,RSI, 81, 033503 2010

Neutron imaging (2/2)

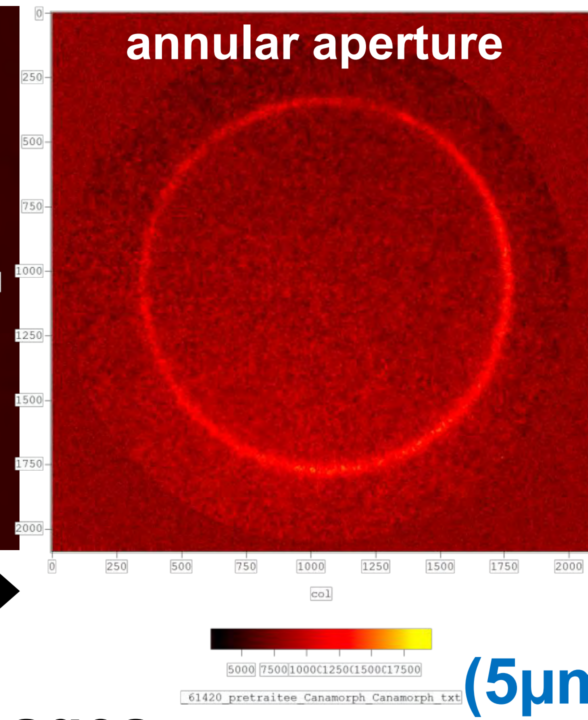
CEA neutron images are recorded since more than 10 years on Omega

w/ an original and robust unfolding method

(A. Rouyer RSI, 74, 1234, 2003)

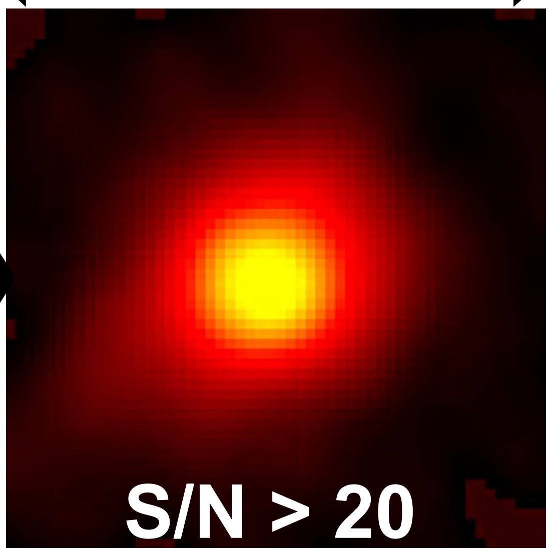


150 mm



Unfolding

200 µm



Raw coded images recorded on the large neutron camera (LNIS)

LMJ goal

(5µm spatial resolution)

seems feasible:

(13 µm already demonstrated on Omega)

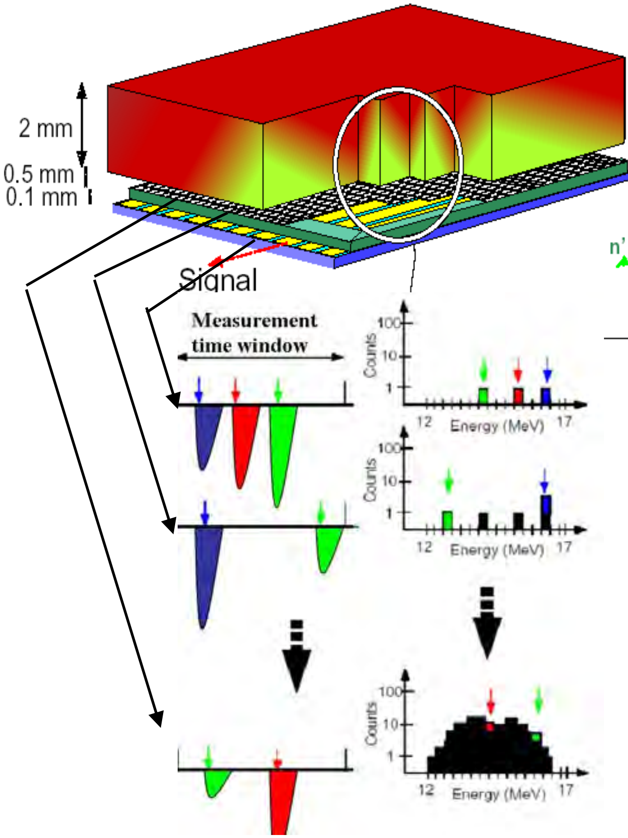
Neutron spectrometer: DEMIN

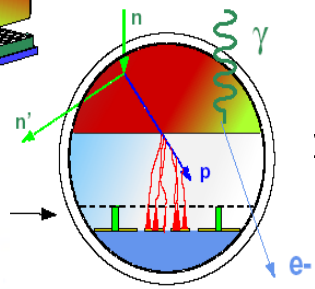
- **DEMIN** (**DE**tecteur **MI**cromégas* pour **N**eutrons) uses neutron time of flight technique (nToF) to measure neutron spectra on fusion target.

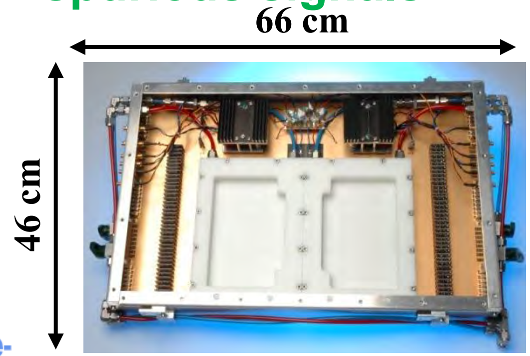
*Micromégas detector: patent deposited by CEA/DSM/DAPNIA - G. Charpak, I Giomataris

- It can be used to measure secondary or tertiary produced fusion neutrons (2005) and even TT and downscattered fusion neutrons (2013-14) on Omega facility

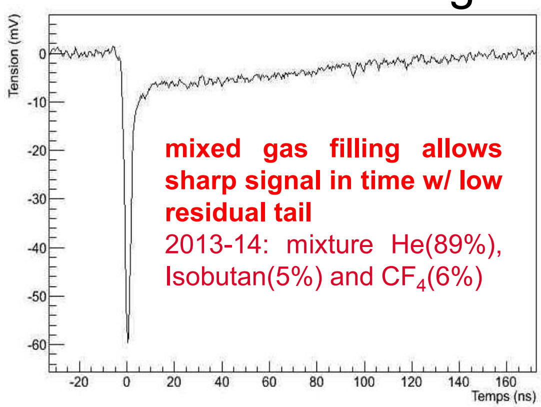
DEMIN have been designed to reject gamma ray induced spurious signals







DEMIN individual signal



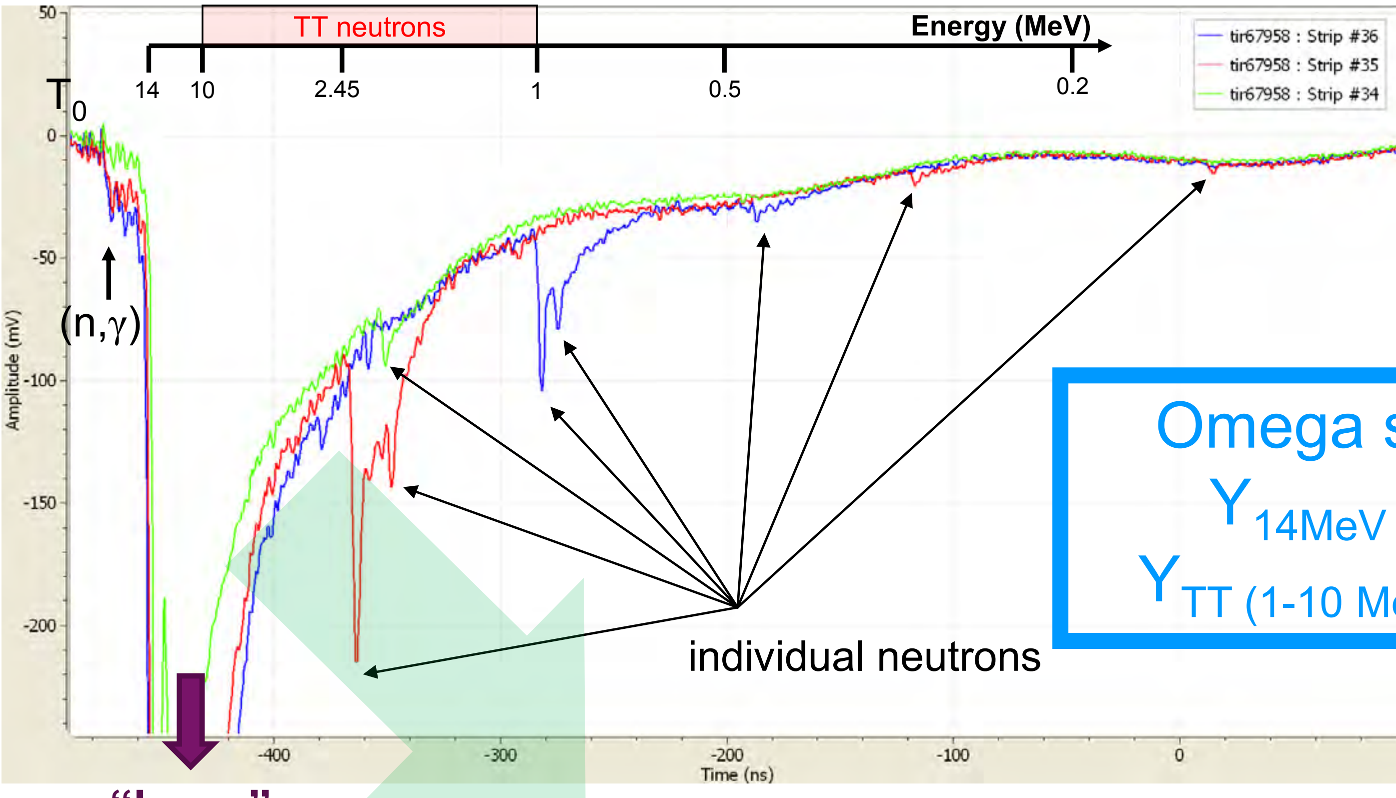
2005 Omega P9 port mount

(M. Houry et al., NIM A 557, 648, 2006)

Neutron spectrometer: DEMIN premiere on TT & downscattered neutrons

- **2013-14 first time ever TT and/or down scattered neutrons detected w/ DEMIN after DT "huge" pulse**

Recorded raw nToF signal and neutron equivalent energy



Omega shot #67958,
$Y_{14MeV} = 3.5 \times 10^{12}$
$Y_{TT\ (1\text{-}10\ MeV)} = 1.5 \times 10^{12}$

"huge" DT neutron peak

Very fast channel recovery after DT peak

LLE 2013 annual report, DOE/NA/1944-1149, p. 315, (01/2014)

Conclusion

CEA is developing since more than 10 years a complete set of nuclear diagnostics for his LMJ laser facility and is preparing its experimental hall to protect and secure these type of nuclear measurements.

- By dedicated heavily shielded areas inside the Experimental hall
- By designing main nuclear detectors and diagnostics able to accurately measure:
  - Neutron yield
  - Ti fuel & Bang Time
  - Neutron image of the nuclear emission areas
  - Neutron spectra by a new technique/detector (adapted from High Energy Physics @ CERN)
    - first time demonstrated on low energy TT and DS neutrons after a DT initial and usually blinding pulse on standard neutrons detectors.

THANK YOU FOR YOUR ATTENTION