DE LA RECHERCHE À L’INDUSTRIE

ICF Indirect-drive experiments on the LMJ facility

2023, June 08

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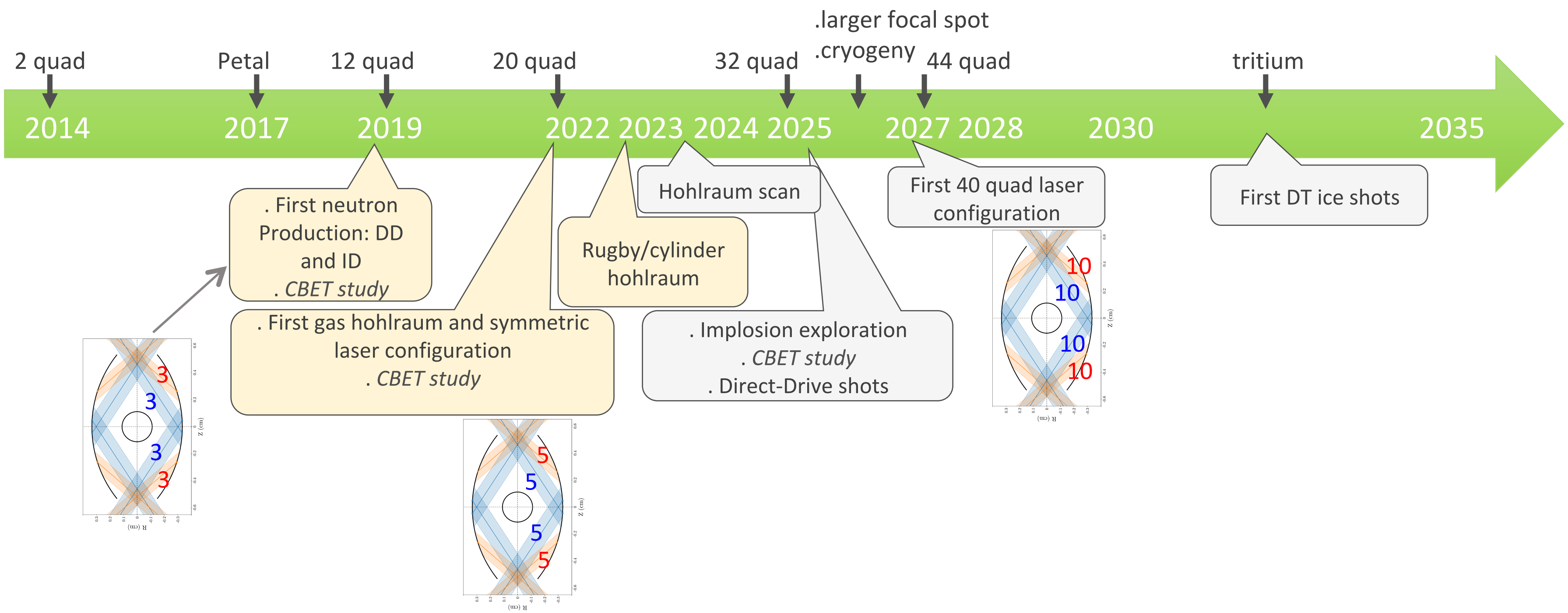
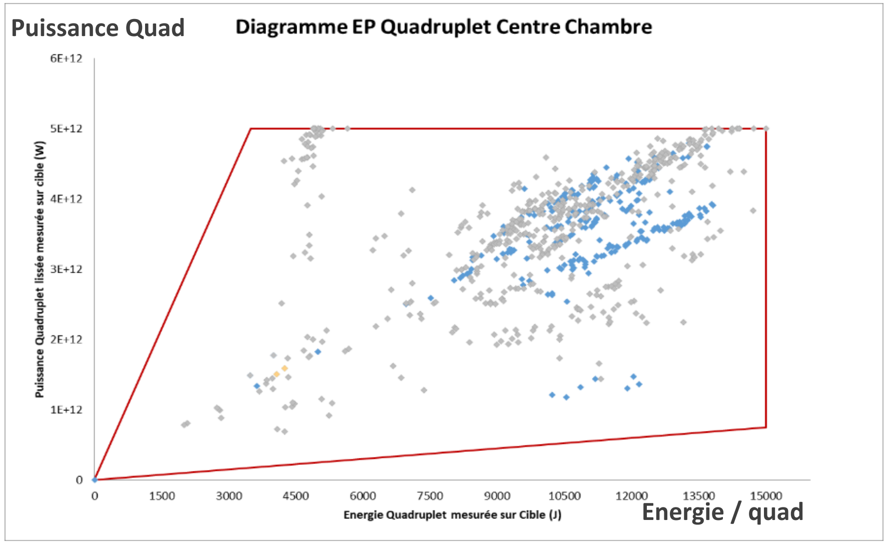
Outline and summary

- **LMJ facility presentation**
  - Today, 300 kJ and 100 TW are available (20*4 beams)
  - The LMJ performances and capabilities are still in a increasing phase
- **The ICF program on LMJ**
  - Some differences with another famous ICF program: rugby configuration, focal spot size, …
  - Since 2019, about 35 ICF shots were carried out on the LMJ
  - These shots prove our capability to control the implosion symmetry
- **Scope on the LPI issue**
  - But the coupling is not great: LPI turns out to be one of our main issues
  - Several ways to reduce the backscattering: design, drooping pulse, focal spot increase, defocus, quad-splitting, gold-Boron Wall

Since the beginning, about 35 ICF shots (indirect or direct drive + CBET studies) have been carried out on LMJ



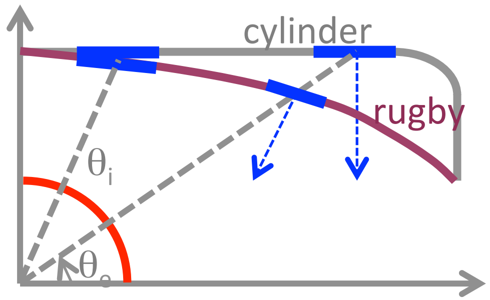
So far, the laser power is restricted (15 kJ, 5 TW / quad) in order to limit the optical damages



From 2028, the laser power upper limits are going to increase progressively until 30 kJ, 10 TW / quad

Why rugby on the LMJ facility ?

- For the irradiation symmetry, the best laser beam configuration in a cylinder is about (1/3, 2/3)
- But, on LMJ, the laser beam repartition is (1/2, 1/2): half of the quads for the inners, half for the outers
- Rugby: by moving the outer emission spot closer to the capsule and by bending the wall toward the capsule, the outer contribution is increased. The symmetry can be tuned.
- Also, because of a smaller wall area, a rugby configuration offers a better laser coupling to the capsule
- Consequently, on LMJ, our point design is a rugby hohlraum. So far.



This design has to be tested on LMJ

M. Vandenboomgaerde, PRL, 99, 065004 (2007)
F. Philippe, PRL, 104, 035004 (2010)
S. laffite, POP, 17, 102704 (2010)
P. E. Masson Laborde, POP, 23, 022703 (2016)

Main differences between our designs, LMJ and **NIF**

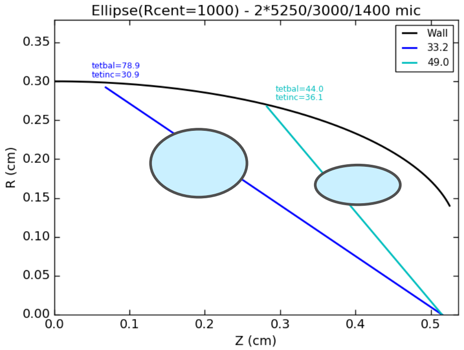
- Rugby <-> **cylinder**
- 2 laser cones, and a (1/2, 1/2) repartition <-> **4 laser cones and a (1/3, 2/3) repartition**
- The inner beams do not cross the equator <-> **They cross the equator**
- Small focal spots <-> **big focal spots**
- No Polarisation smoothing <-> **polarisation smoothing**

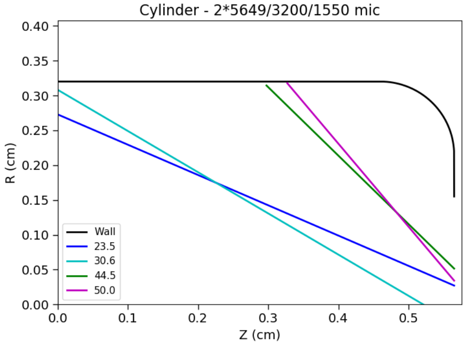
LMJ
750*1500 = 0.9 mm²

NIF – outer cone:
44.5°: 1060*1800 = 1.5 mm²
50°: 920*1600 = 1.2 mm²

NIF – inner cone:
23°: 1540*2160 = 2.6 mm²
30°: 1440*2020 = 2.3 mm²

1.2 MJ / 400 TW
CH ablator



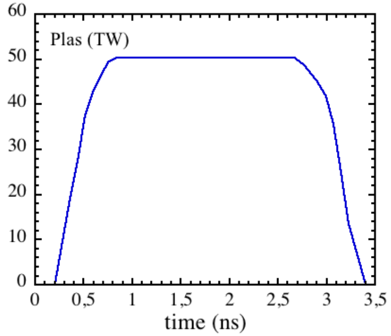


2.05 MJ / 500 TW
HDC ablator

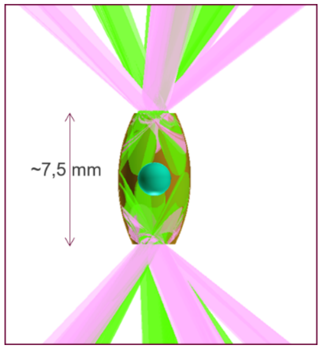
The first neutron production on LMJ took place in 2019 in a 3D configuration (12 quads)

2014 2017 **2019** 2022 2023 2024 2025 2027 2028 2030 2035

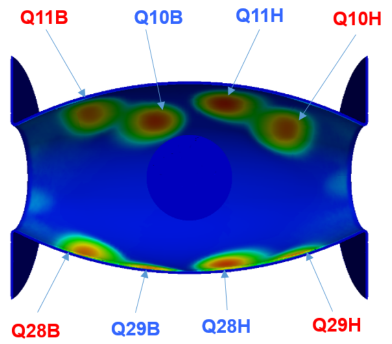
3ns square pulse
(Rc=4)

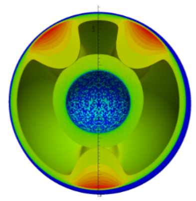


Empty hohlraum
(no gas fill)



3D configuration



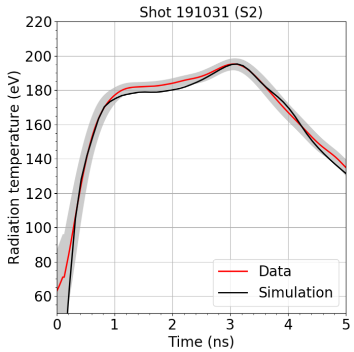


S. Liberatore, APS2022

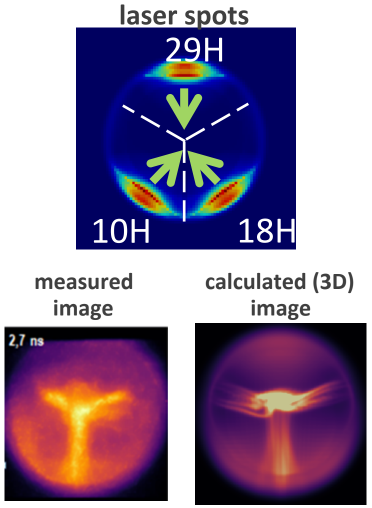
The 2019 fusion experiments have provided important data to benchmark 3D hydrodynamic codes

2014 2017 **2019** 2022 2023 2024 2025 2027 2028 2030 2035

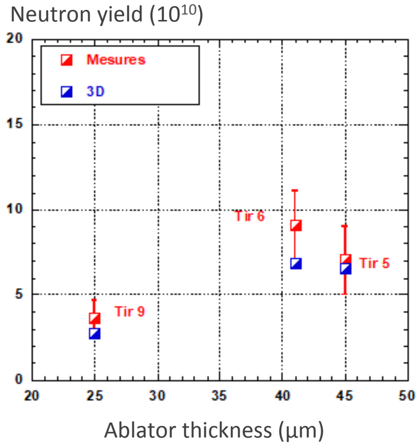
Hohlraum energetics (radiation temperature)



Hohlraum wall hydrodynamics and on-axis stagnation



Neutron yield

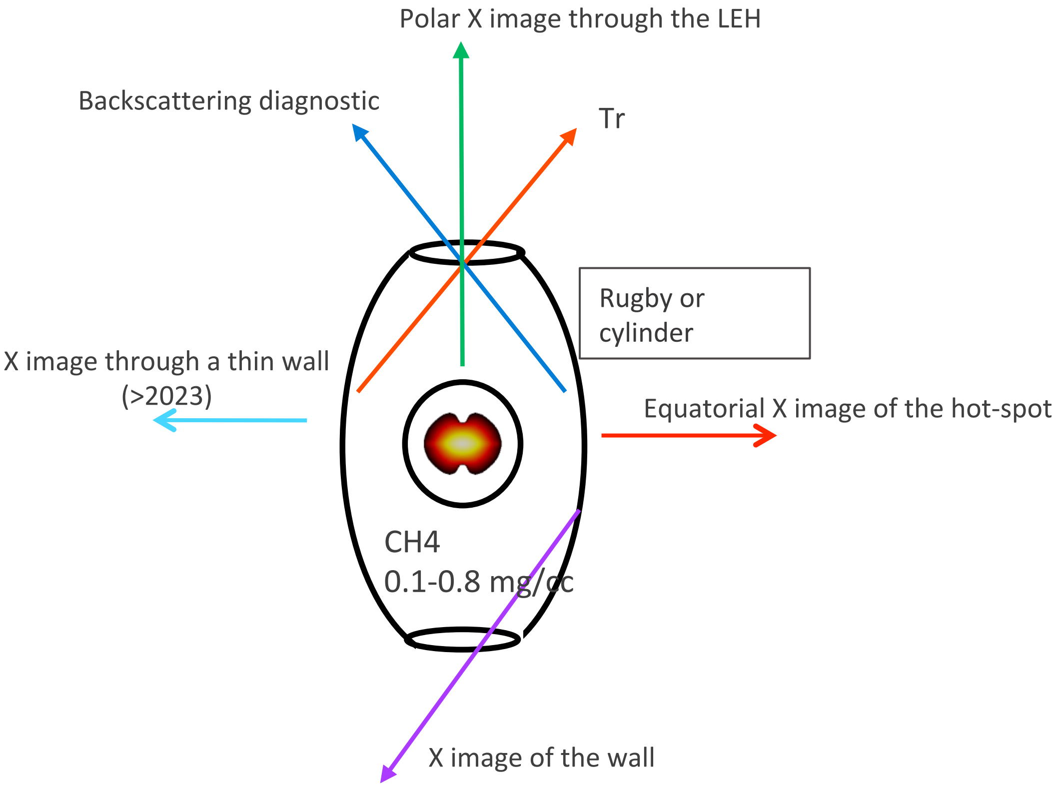


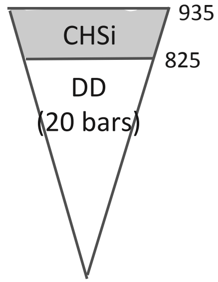
After these low-convergence shots, the objective, for the following campaigns was to explore more ablative implosion:(in gas filled hohlraum + symmetric laser configuration)

S. Liberatore, APS2022

The experimental set-up will be about the same for the 2022-2025 Indirect-Drive campaigns: symmetric laser configuration (20 quads) + gas fill + shaped pulse

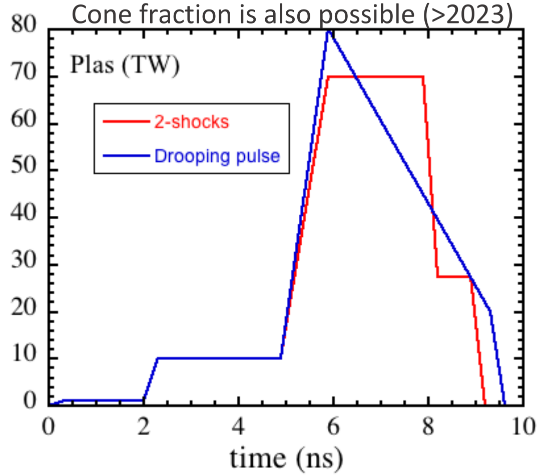
2014 2017 2019 **2022 2023 2024 2025** 2027 2028 2030 2035





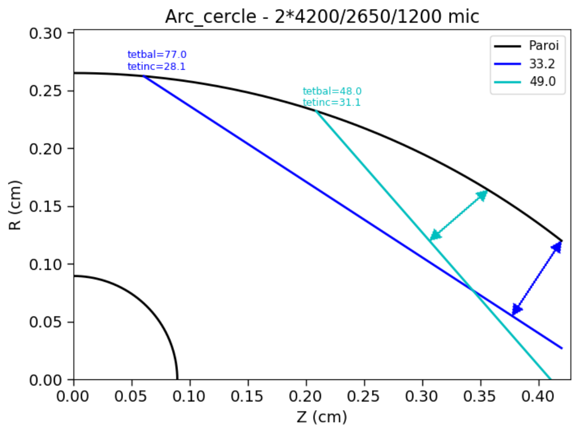
Variations of the dopant concentration (1-2 %) and of the ablator thickness (>2023)

Variations of the peak power is planned
Cone fraction is also possible (>2023)

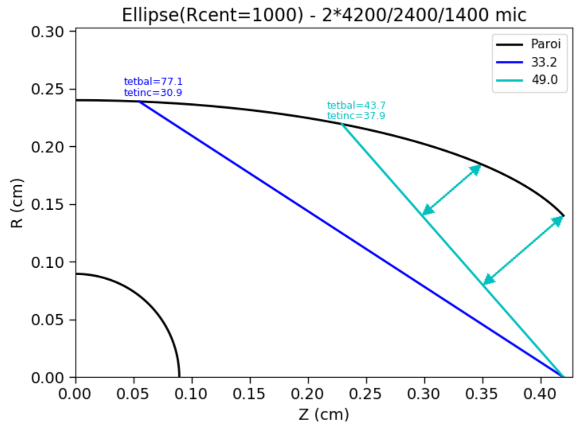


The 2022-2025 ICF campaigns are intended to find out the best hohlraum shape: best laser coupling for a symmetric ablative implosion

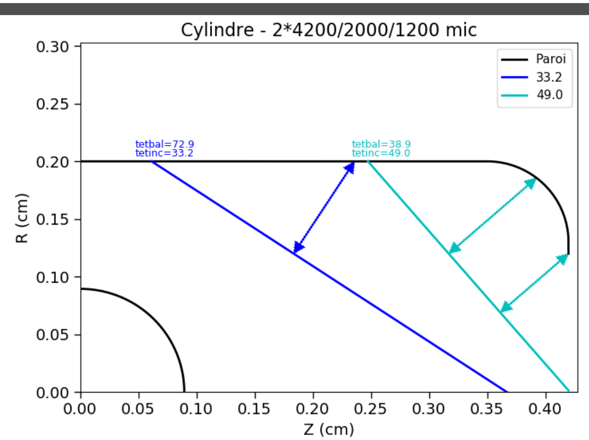
Four different hohlraum shapes are going to be addressed



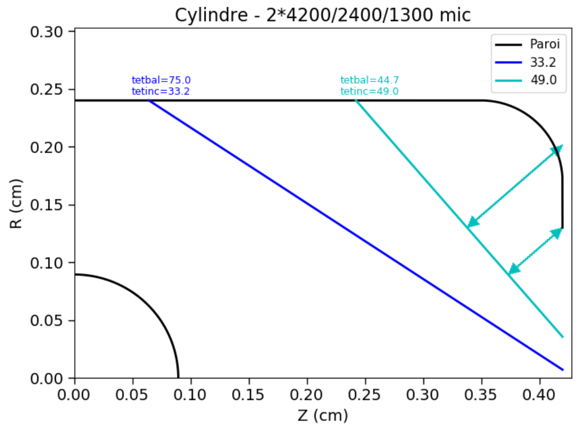
2022



2024, 2025



2023

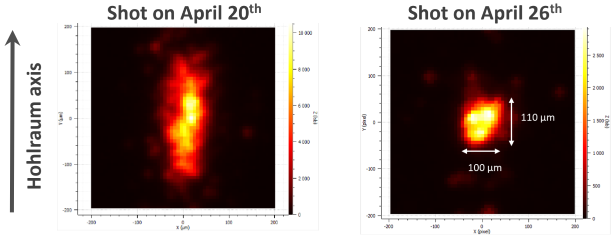


2024, 2025

2022: first hot-spot X-rays emissions have been measured on LMJ for low gas-filled hohlraum experiments

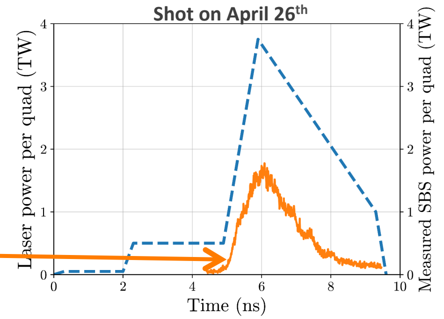
2014 2017 2019 **2022** 2023 2024 2025 2027 2028 2030 2035

- **Warm implosions in low gas-filled hohlraums have been fielded on LMJ for the first time in 2022**



- **Beam pointing variation was used to tune the hot-spot symmetry (+ 200 µm for the inner beams, + 100 µm for the outer beams)**

- **Drooping pulses were used to decrease the SBS power (by about a factor of 2) during the main drive, while maintaining the capsule compression**



- **But, still, high levels of Brillouin backscattering (>13 %) were observed**

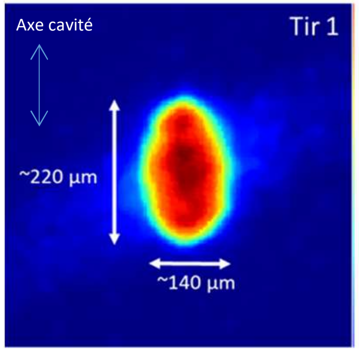
The SBS backscattering levels turn out to be our main concern

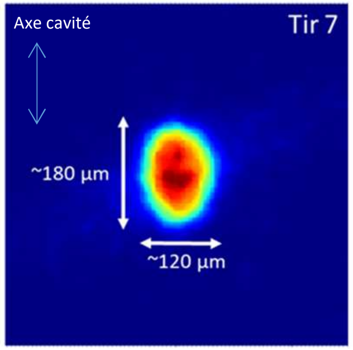
M. Lafon, S. Depierreux, R. Riquier, V. Tassin

In 2023 again, we showed our capability to control the implosion symmetry, varying the beam pointing (here, in the rugby configuration)

2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035

+ 150 μm inner beam pointing
(toward the LEH):



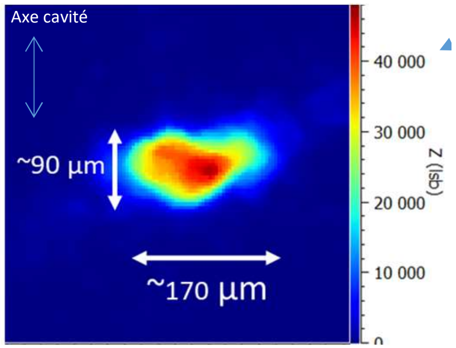


R. Riquier, V. Tassin, M. Lafon, S. Depierreux

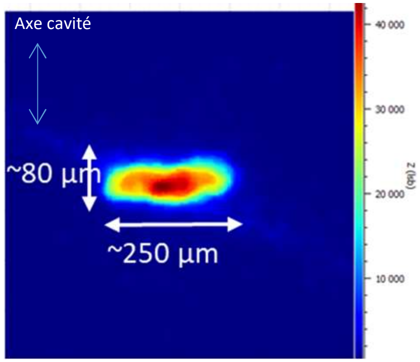
First cylinder on LMJ: as predicted, it helps to substantially reduce LPI. On the other hand, it also leads to a symmetry which is more difficult to control.

2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035

Drooping pulse

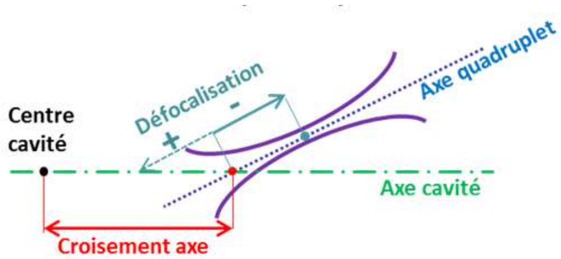


2 shock pulse



SBS (%)	2shock	drooping
Rugby	20 %	
Cylinder	2.1 %	0.6 %

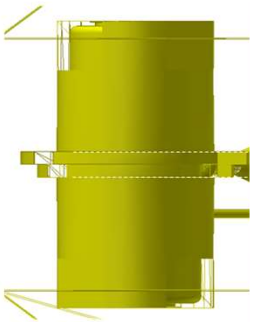
A "quad-defocus" (4 mm, here) helps also in the SBS reduction:

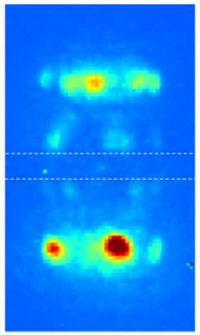


R. Riquier, V. Tassin, M. Lafon, S. Depierreux

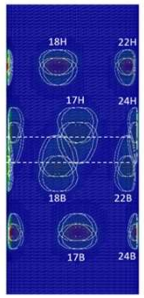
For the first time, we were able to measure the laser imprint through a thin hohlraum wall (6 μm)

2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035





t = 7 ns



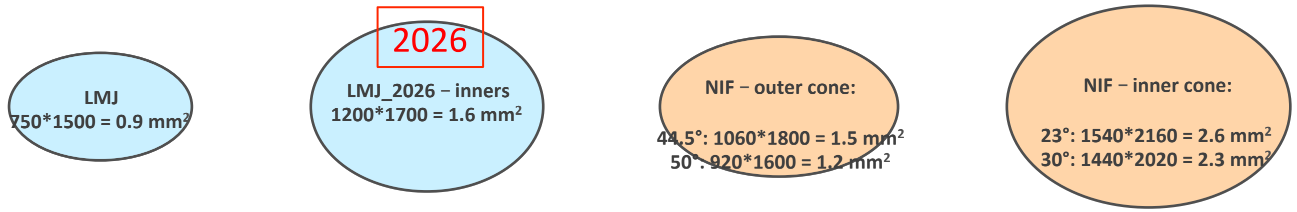
Vue Visrad t = 0 ns

Analysis in progress …

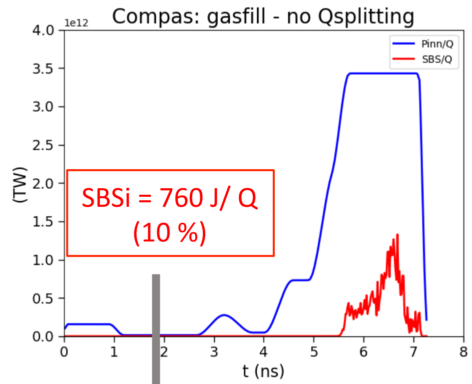
R. Riquier, V. Tassin, M. Lafon, S. Depierreux

Several ways exist to reduce the SBS levels, as SBS appears to be our main concern

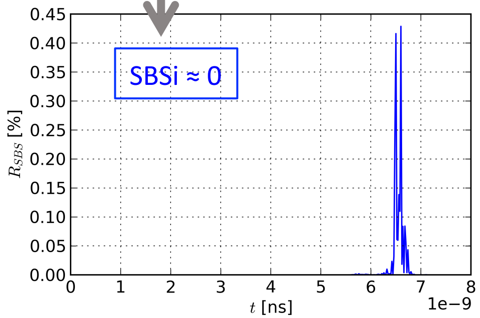
- Pulse shape: a drooping pulse instead of a 2-shocks pulse -> tested in 2022: OK !
- Quad-defocus: in order to reduce the laser intensity, thus the backscattering -> tested in 2023: OK !
- Quad-splitting: in order to reduce the laser intensity, thus the backscattering -> tested in 2023: OK !
- Design: the idea is to reduce the matter quantity that the beams propagate through -> cylinder in 2023: OK !
  -> 2 more designs tested in 2024 and 2025
- Gold-Boron mix in the wall to increase the Landau damping -> tested as soon a possible
- Larger focal spot: in order to reduce the laser intensity, thus the backscattering -> larger inner focal spots



Several ways exist to reduce the SBS levels, as SBS appears to be our main concern: quad-splitting and a gold-Boron mix

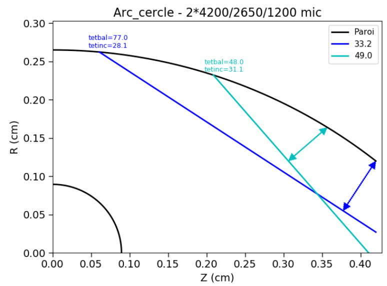


with 350 mic Quad-splitting



For this configuration tested in 2023, the quad-splitting has significantly reduced the SBS backscattering, between a factor of 5 and totally.

LMJ_20Q	Au	Au-B
Einn (kJ)	112	112
Eout (kJ)	119	119
SBS_inn (%)	16	7
SBS_out (%)	11	5

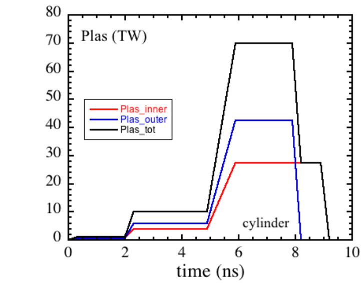


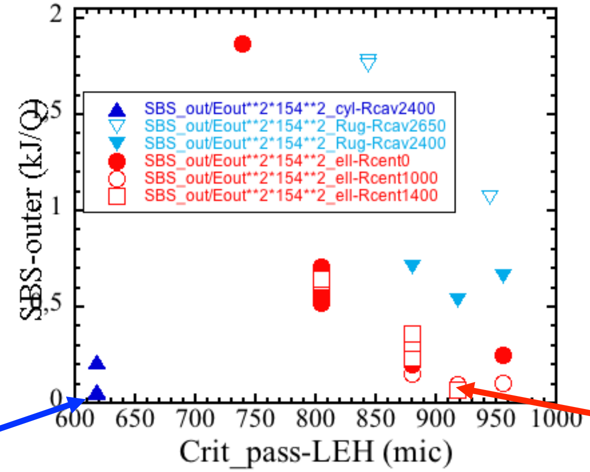
AU-B in the wall is planned to be tested in a "SBS generator" configuration

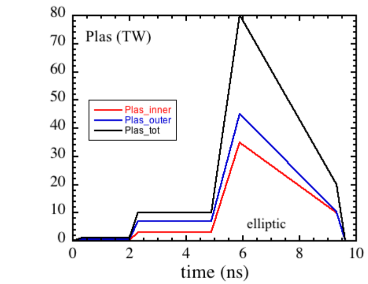
In 2024 and 2025, two other hohlraum shapes will be tested. Cone fraction will be used.

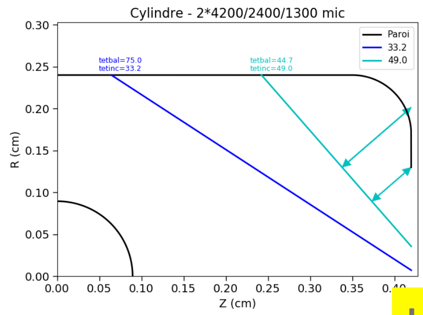
2014 2017 2019 2022 2023 **2024 2025** 2027 2028 2030 2035

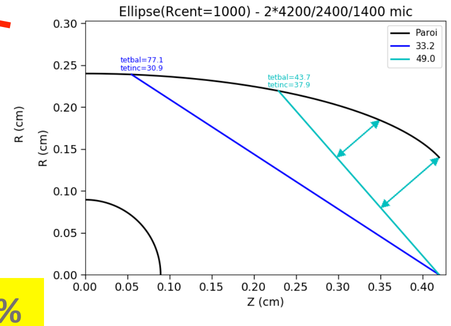
The target/laser pulse were designed to figure out the higher possible backscattering level reduction







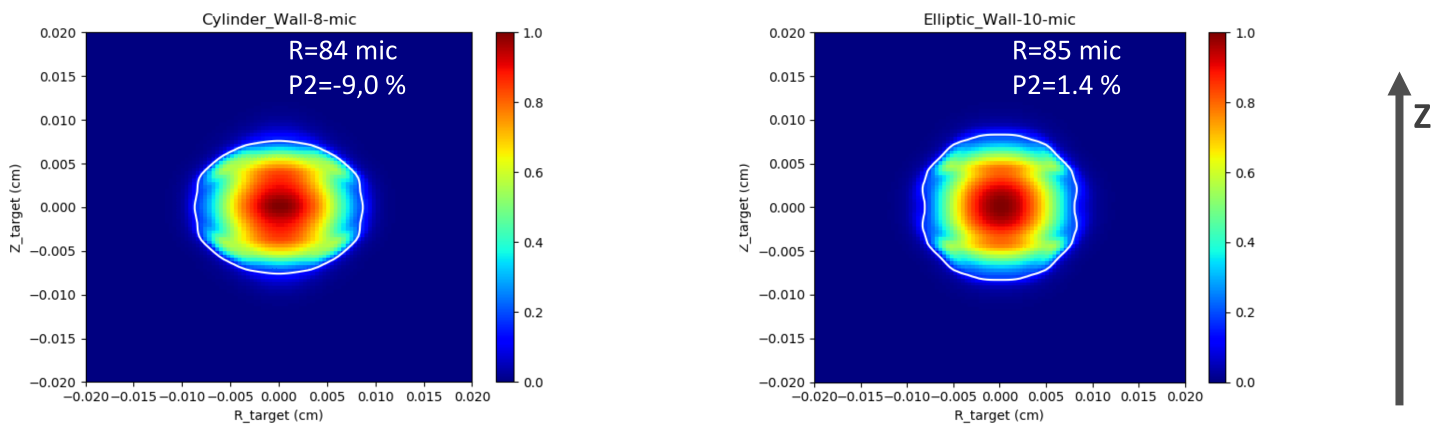




Low levels of backscattering are predicted: < 1 %

The implosion symmetry, with a P2 < 10 % according to the calculations, will be tuned during the campaigns with beam pointing and cone fraction.

2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035



	El (kJ)	SBS (%)	Ecap/Elas	Tr (eV)	Vimp	Comp	Mremain	neut
Cylinder	250	0,4	10 %	205	335	10	7 %	8e11
Rugby	250	0,5	11 %	210	340	10	6 %	9e11

Conclusion

- **LMJ facility presentation**
  - Today, 300 kJ and 100 TW are available (20*4 beams)
  - The LMJ performances and capabilities are still in a increasing phase

- **The ICF program on LMJ**
  - Some differences with another famous ICF program: rugby configuration, focal spot size, …
  - Since 2019, about 35 ICF shots were carried out on the LMJ
  - First shots prove our capability to control the implosion symmetry

- **Scope on the LPI issue**
  - But the coupling is not great: LPI turns out to be one of our main issues
  - Several ways to reduce the backscattering: design, droopy pulse, focal spot increase, defocus, quad-splitting, gold-Boron Wall

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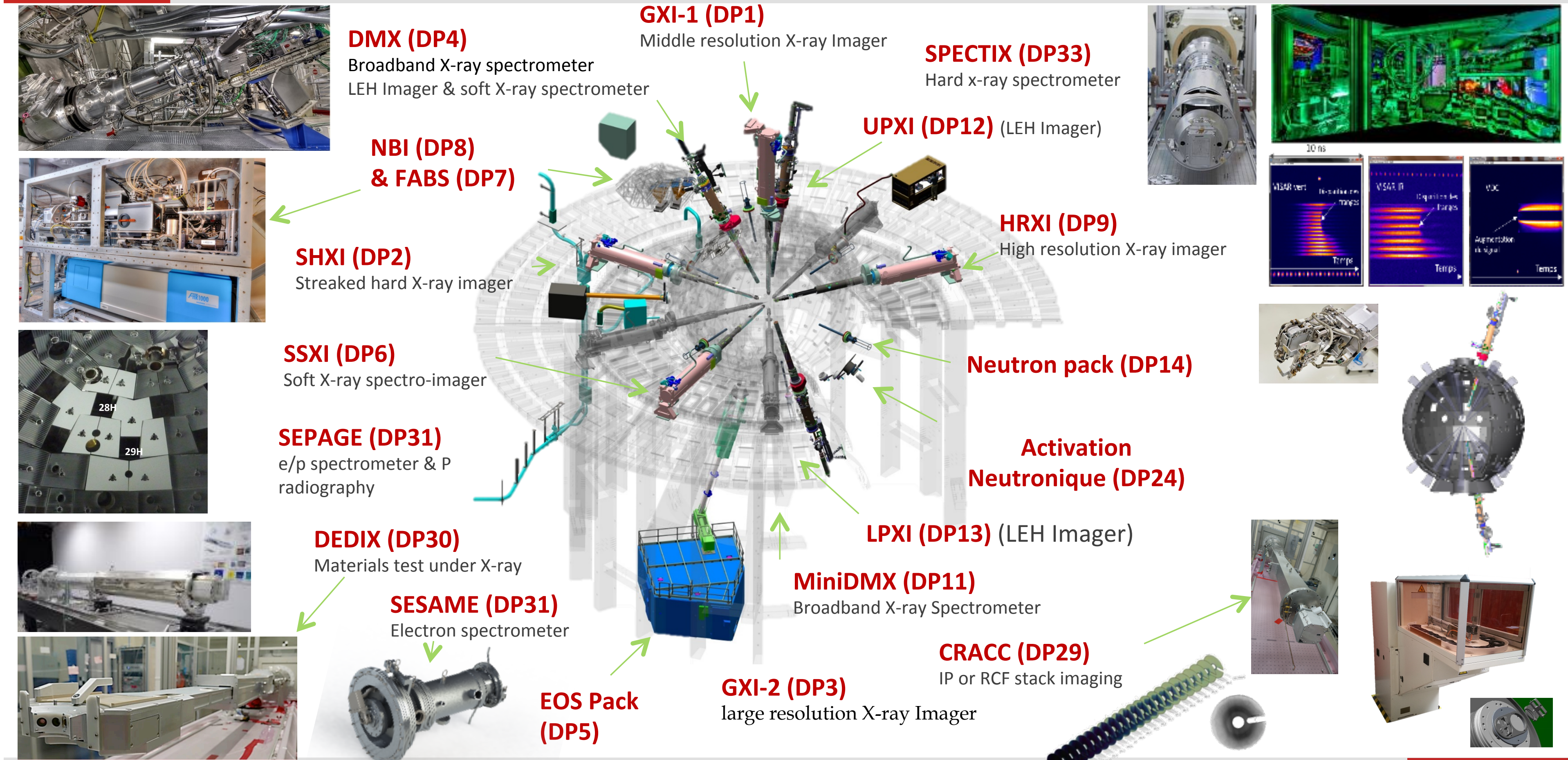
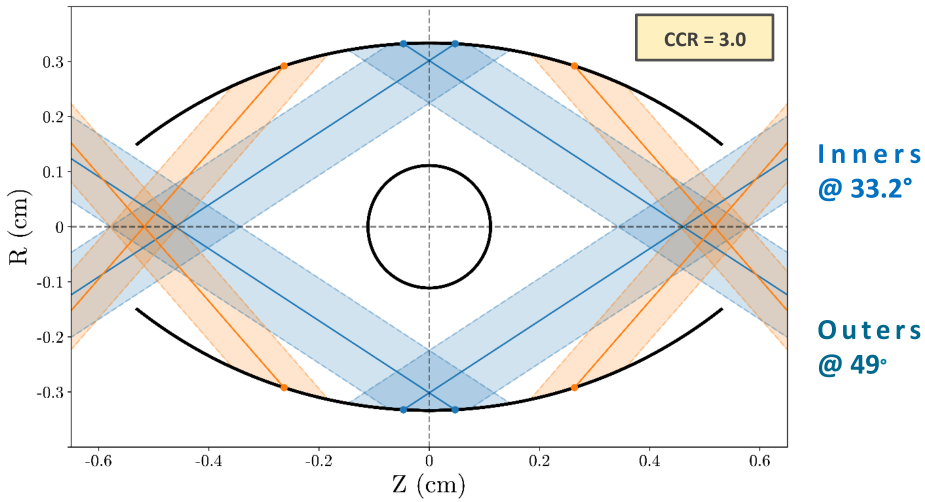
Backup

2023, June 08

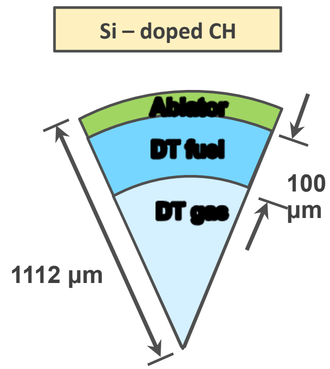
Backup: today, about 20 diagnostics are available on LMJ



The baseline ignition design on LMJ uses a rugby shaped hohlraum

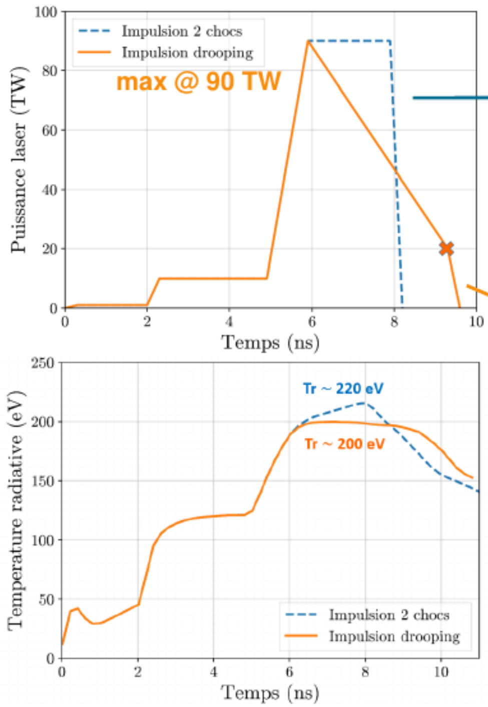


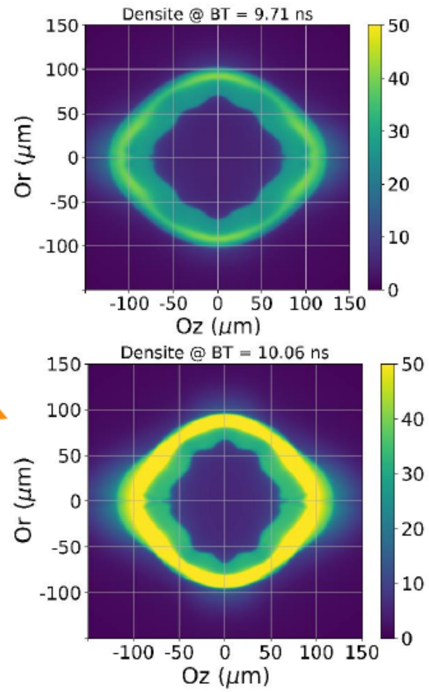
- E_L = 1.2 MJ
- P_L = 400 TW
- Pulse length = 11.2 ns
- He Gas @ 0.6 mg/cc
- T_{rad} = 290 eV



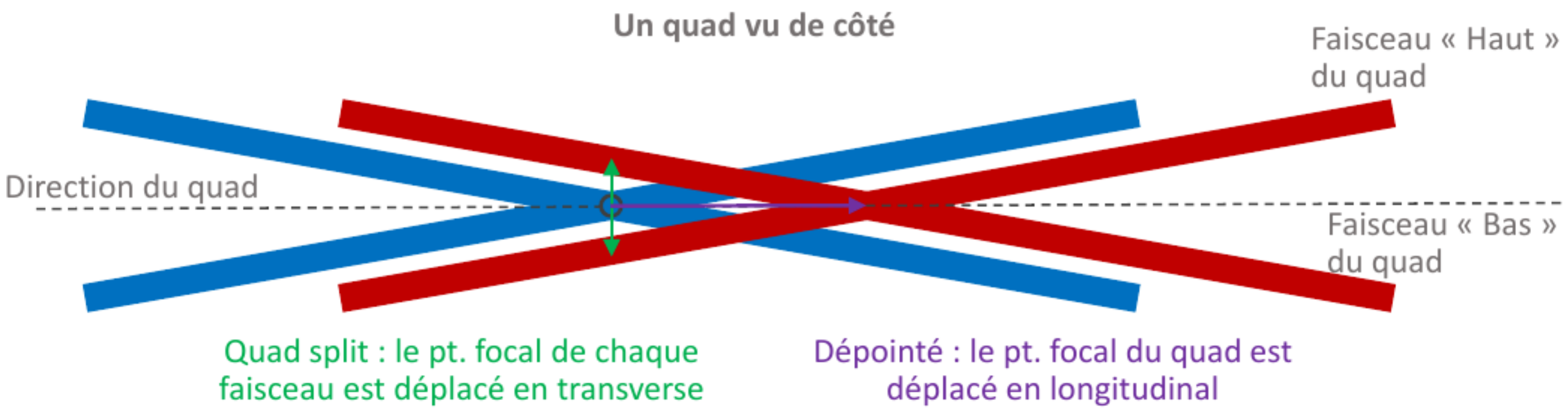
M. Lafon, APS2021

Backup: at first, the drooping pulse was chosen in order to increase the compression at stagnation



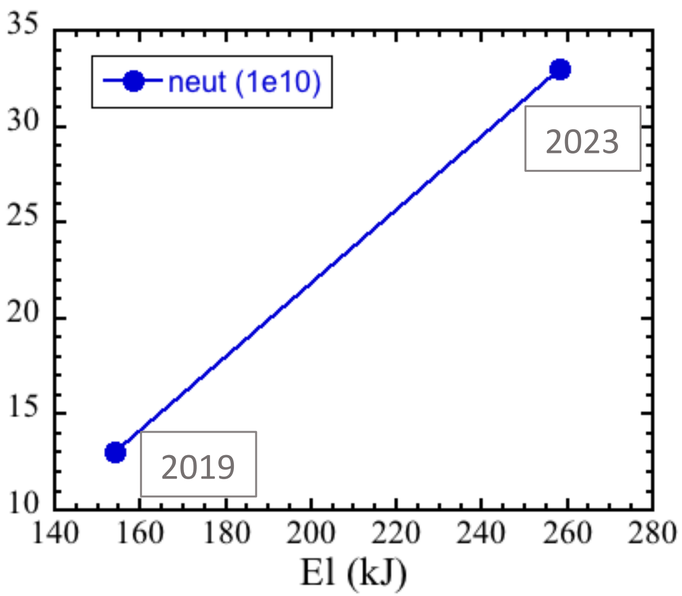


Backup: a quad-defocus was carried out on LMJ, in 2023



Without surprise, the neutrons increased with the laser energy

2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035

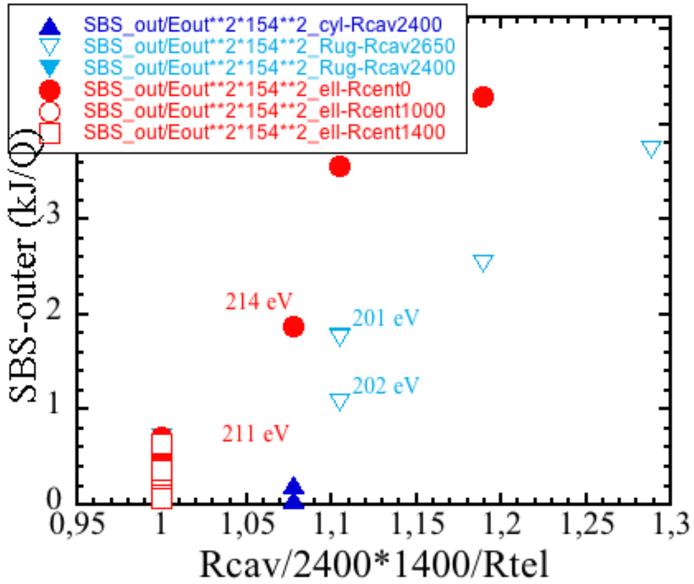


R. Riquier, V. Tassin, M. Lafon, S. Depierreux

Backup: the outer backscattering level is reduced by lowering the hohlraum size or by increasing the LEH size

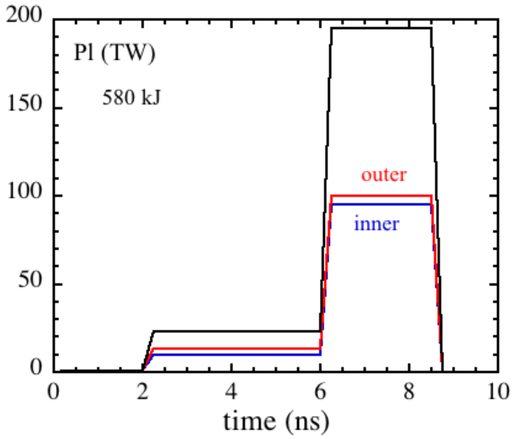
2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035

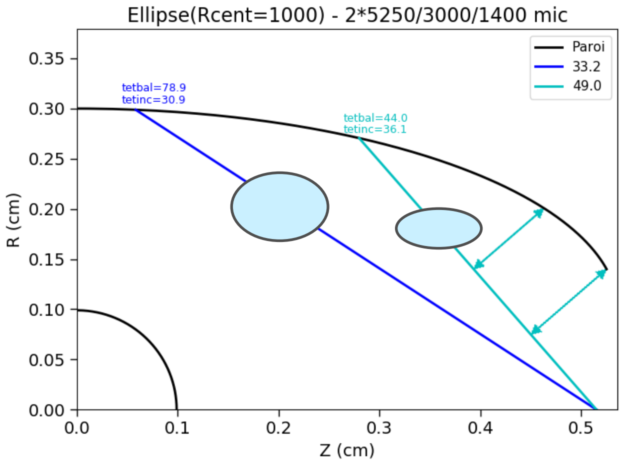
We expect very low level of Raman (0) and Brillouin (<1 %) backscattering



Backup: after these campaigns, the laser configuration will be upgraded to 40 quads. A bigger laser spot for the inner quads should allows to keep at acceptable levels the backscattering

2014 2017 2019 2022 2023 2024 2025 2027 2028 2030 2035





	580 kJ
SBS (inn+out)	10 %
Tr	260 eV
Ecap/Elas	13 %
neut	8e12
Rc	13
M_remain	9 %