PETAL-UPgrade

Emmanuel HUGONNOT – CEA Cesta

The PETAL UPgrade project

Petal-UPgrade

- *aims to improve performances of* Petal PETAWATT AQUITAINE LASER
- *is co-funded by* Région Nouvelle-Aquitaine
- *has been launched in* ***07/2021***

The goal is to improve PETAL laser performances

- ***adjustable temporal contrast***
- ***1 kJ pulse energy***
- ***two beams delivery on target***

Wishes of the community gathered at the 1st LMJ-PETAL user meeting (2018)

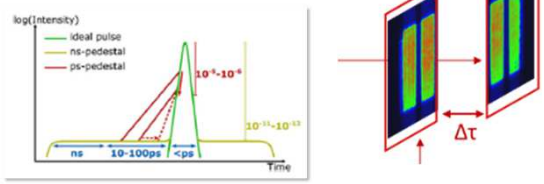
Association Lasers et Plasmas

and to ***possibly*** *add a* ***B-field capability*** *on the LMJ-PETAL experiment subsystem*

Four axis

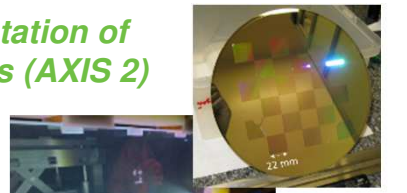
AXIS 1: Control of temporal contrast on target

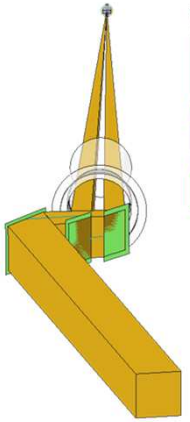
New front-end with adjustable temporal contrast (AXIS 1) and beam splitting with delay lines (AXIS 3)



AXIS 2: Increase of energy on target

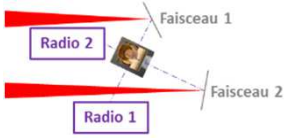
Implementation of new mirrors (AXIS 2)

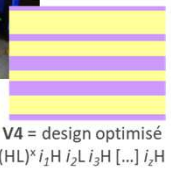




Segmentation of the last delivery mirror (AXIS 3)

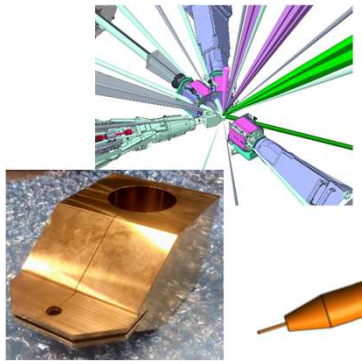
AXIS 3: Adaptation to the production of two beams



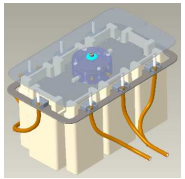


V4 = design optimisé
$(HL)^x i_1H\, i_2L\, i_3H\, [...]\, i_zH$

AXIS 4: Implementation of experiments in the presence of a strong magnetic field

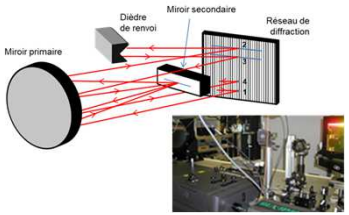


Target integrated coil hold by the cryogenic target inserter (AXIS 4)

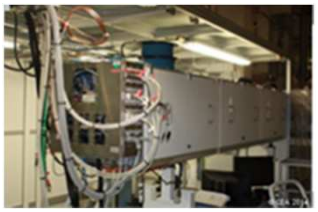


A new front-end (AXIS 1+2+3)

- PETAL front-end V1 is based on OPCPA (CPA + ns OPA)



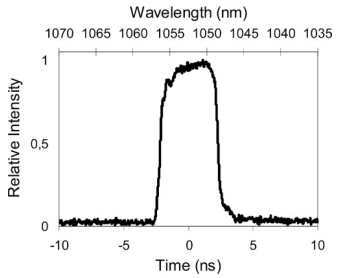
Öffner stretcher

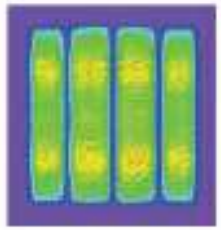


PETAL PAM

Chirped pulse
8 nm, 4.5 ns
150 mJ
1 shot/3 min.

*E. Hugonnot et al, Appl. Opt., **46**, 8181 (2007)*





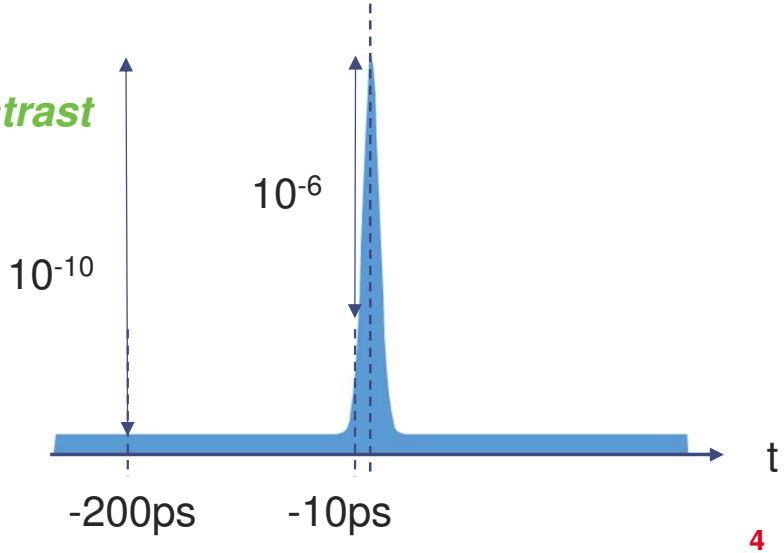
- PETAL front-end V2 will be based on OPCPA (CPA + fast OPA + ns OPA)

Laser specifications

Front-end V1 specs plus

- Contrast requirements: 10^{-10}@-200ps
  10^{-6}@-10ps
- Nanosecond monochromatic pedestal
- 2 Hz repetition rate
- Dispersion management (up to 7 ps/nm)
- Delay lines (up to 16,7 ns)

High temporal contrast front-end



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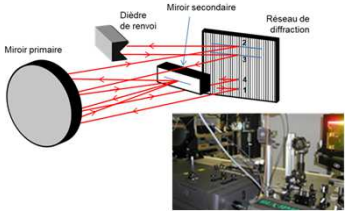

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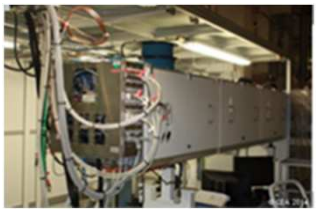

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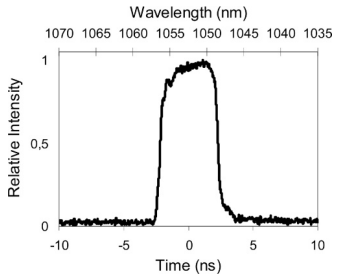

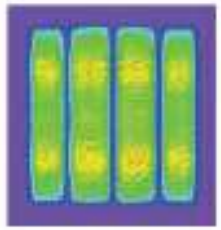

- PETAL front-end V2 will be based on OPCPA (CPA + fast OPA + ns OPA)

Laser specifications

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- Contrast requirements: 10^{-10}@-200ps
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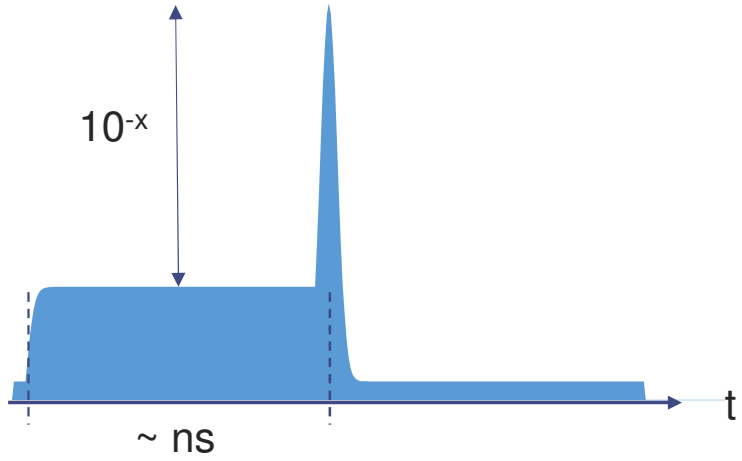
- 2 Hz repetition rate
- Dispersion management (up to 7 ps/nm)
- Delay lines (up to 16,7 ns)

Adjustable contrast



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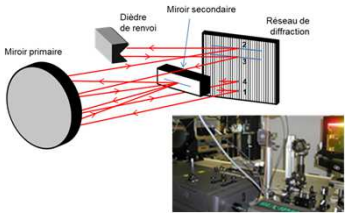

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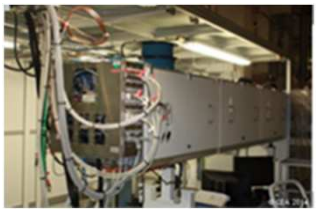

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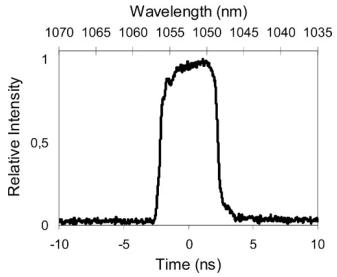

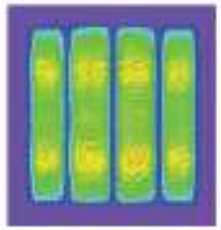

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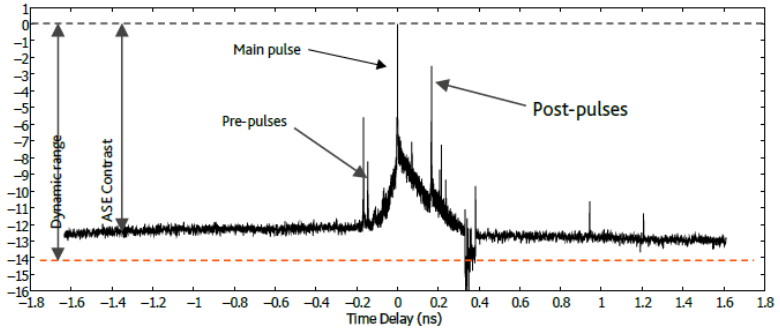
- Delay lines (Δt=0 to 16,7 ns)

will greatly simplify alignment, diagnostics (contrast measurement), …



Typical contrast measurement curve with Sequoia

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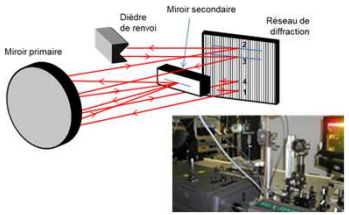

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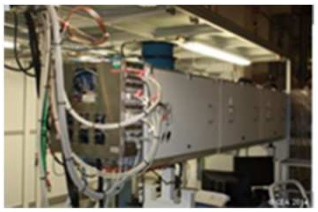

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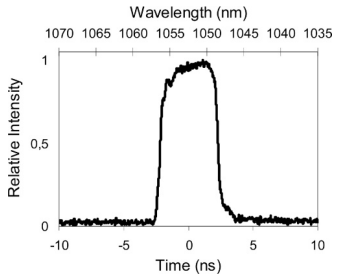

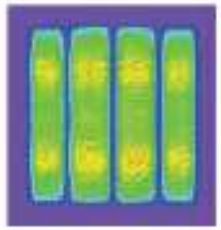

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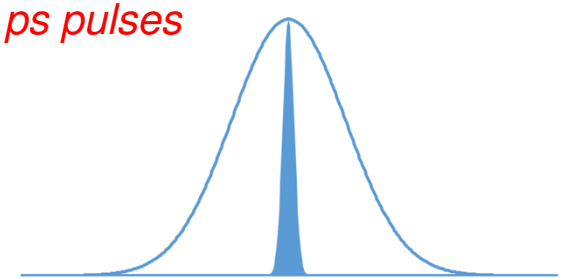
from Fourier transform pulses (500 fs) to 20 ps pulses



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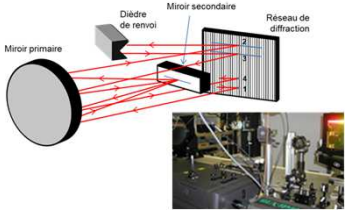

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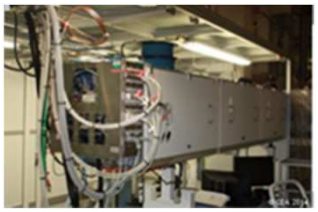

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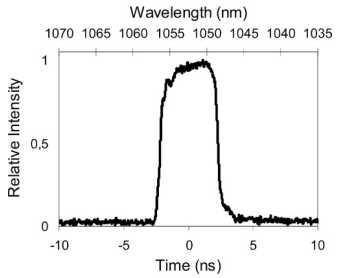

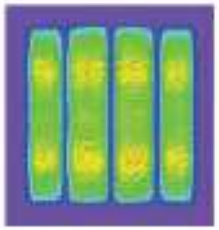

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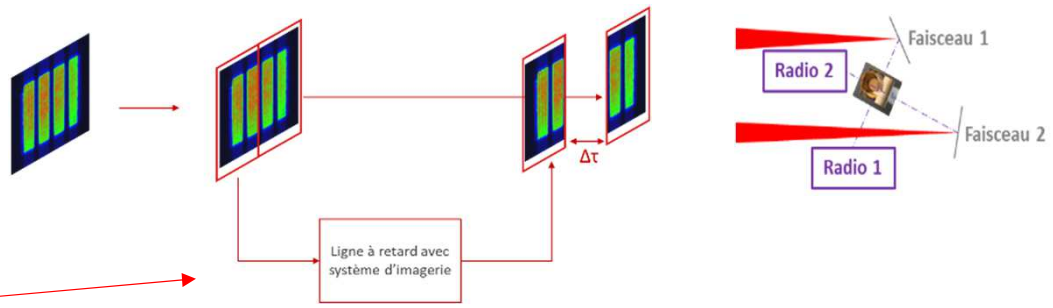

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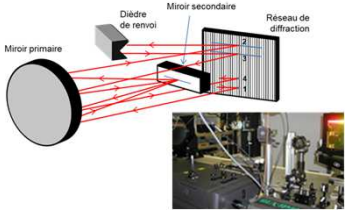
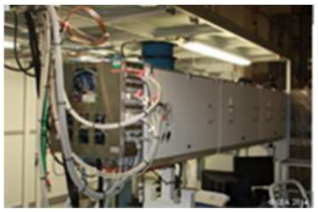


Öffner stretcher



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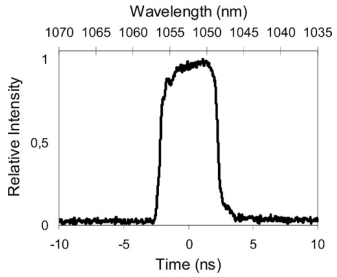

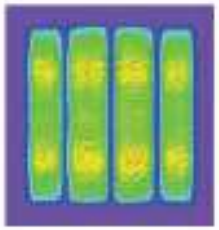

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Laser specifications

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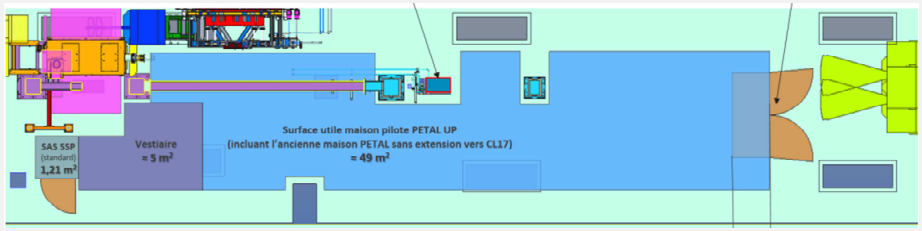
Reliability and easy-to-use requirements

Home-made front-end V1 ⇒ Factory-made front-end V2

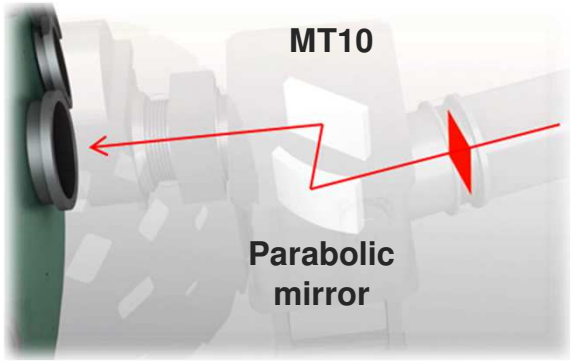
The front-end will be deployed in a dedicated lab

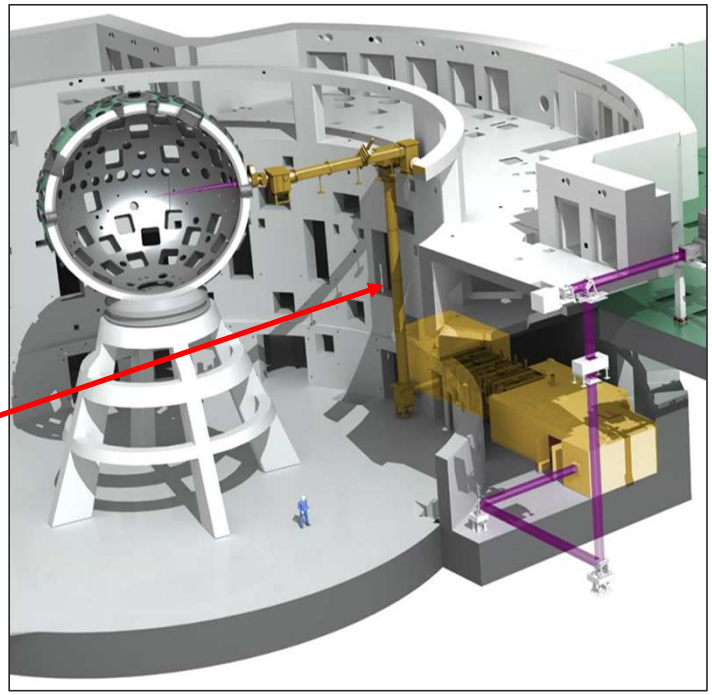


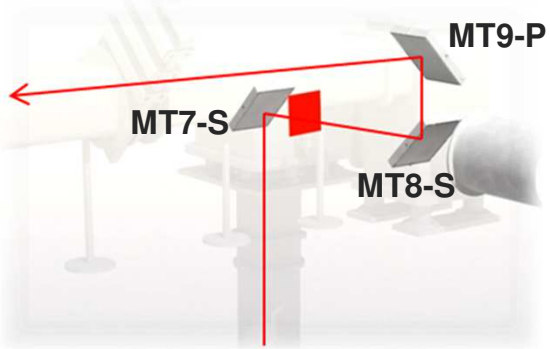
!! Call for tender is underway !!

Laser manufacturer will be chosen before end-2023

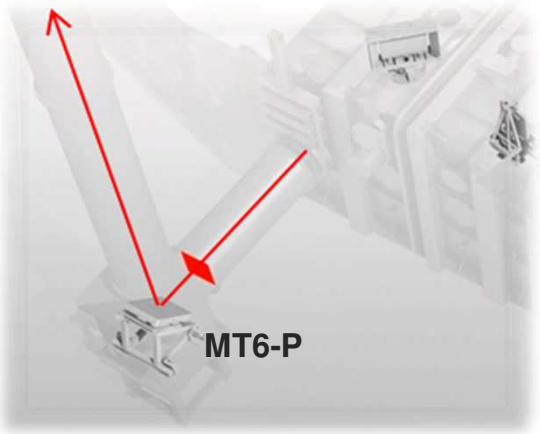
New final optics (AXIS 2)





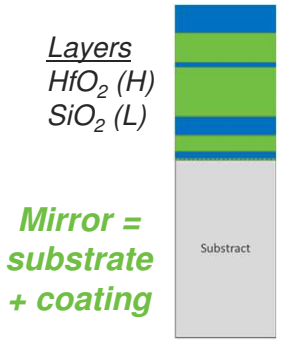


~60 meters after compression (PW range) with 6 mirrors (1 parabolic) and 4 vacuum chambers



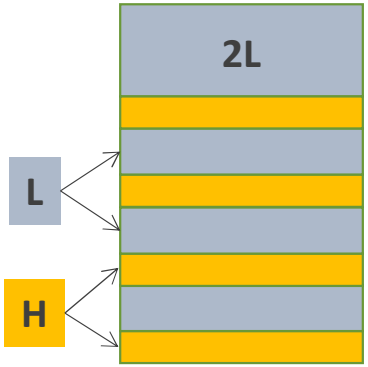
Damages on MT10 and parabolic mirror

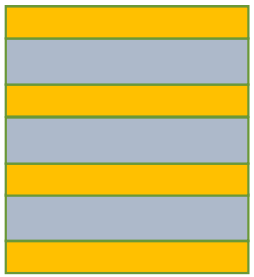
New final optics (AXIS 2)

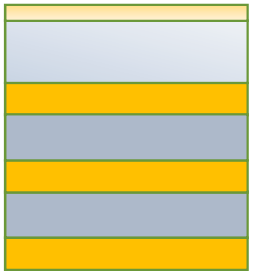


Generations of Petal mirrors

changing the stack design reduces the electrical field in the first layers of the coating







V1 = LMJ

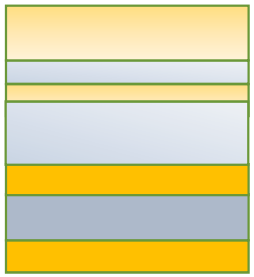
V2 = LMJ-2L

V3

Damages threshold ~ 550 J (±100 J)

Damages threshold ~750 J (±100 J)

Most recent generation = V4



Design @CEA and processing@LLE

M. Chorel et al., SPIE Laser Damage (2021)
*S. Diop et al., Optics Letters, **47**, 6177 (2022)*
*S. Diop et al, Applied Optics, **62**, B126 (2023)*

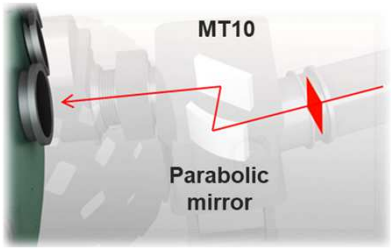
Experimental damage studies

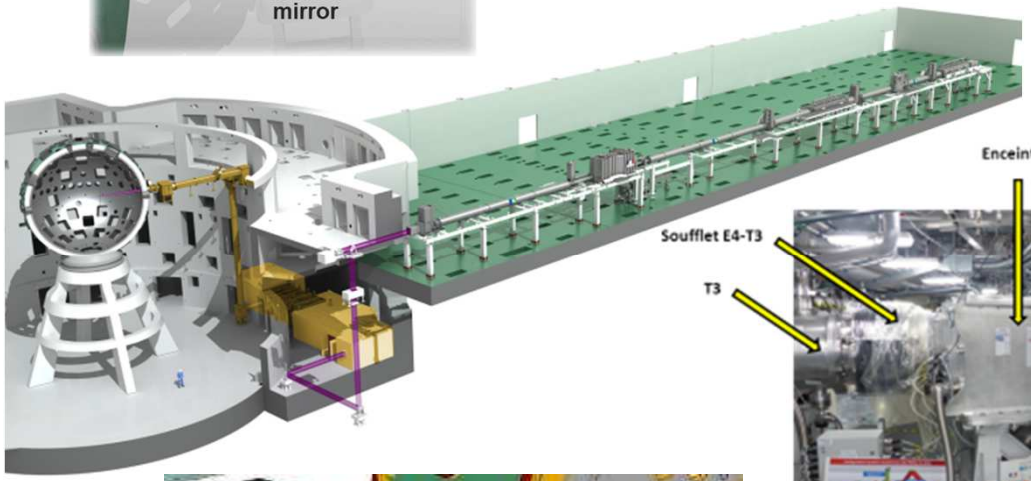
Type de miroir & Polarisation de test		LIDT estimé sous vide [J/cm²]	Réflectivité mesurée à LLE [%]	LIDT mesuré à LLE [J/cm²] (45deg, vide)
Miroir classique V2	P-pol	1.41	99.8%	
	S-pol	2.13	100%	+ 65 %
Miroir optimisé V4-P	P-pol	2.31	99.2%	2.33 +/- 0.033
	S-pol	3.17	99.9%	3.18 +/- 0.036

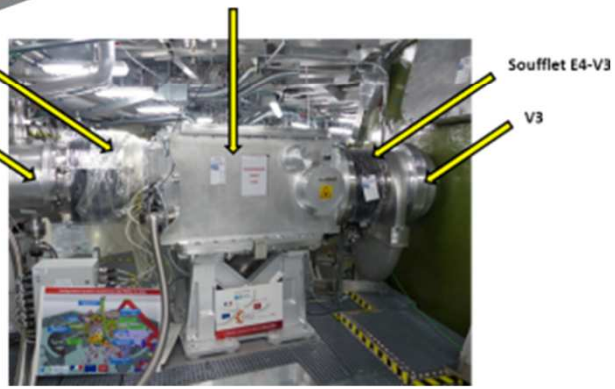
V4 OK for kJ level

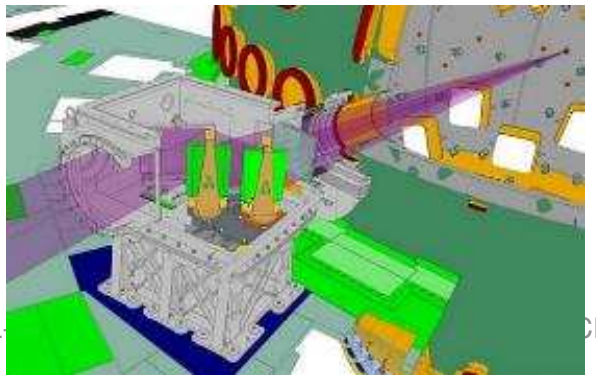
PETAL mirrors will be replaced by V4 generation in the next few years (the first V4 mirror has been realized this year)

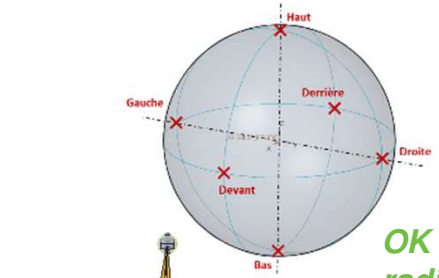
Two beams delivery (AXIS 3)





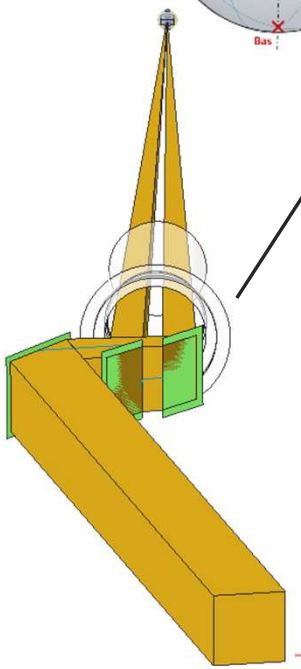




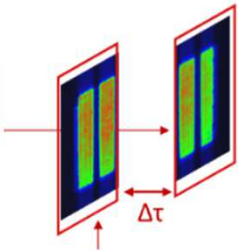


OK on a 50mm radius sphere

Aperture limited exploration ?



delay lines in the V2 front-end



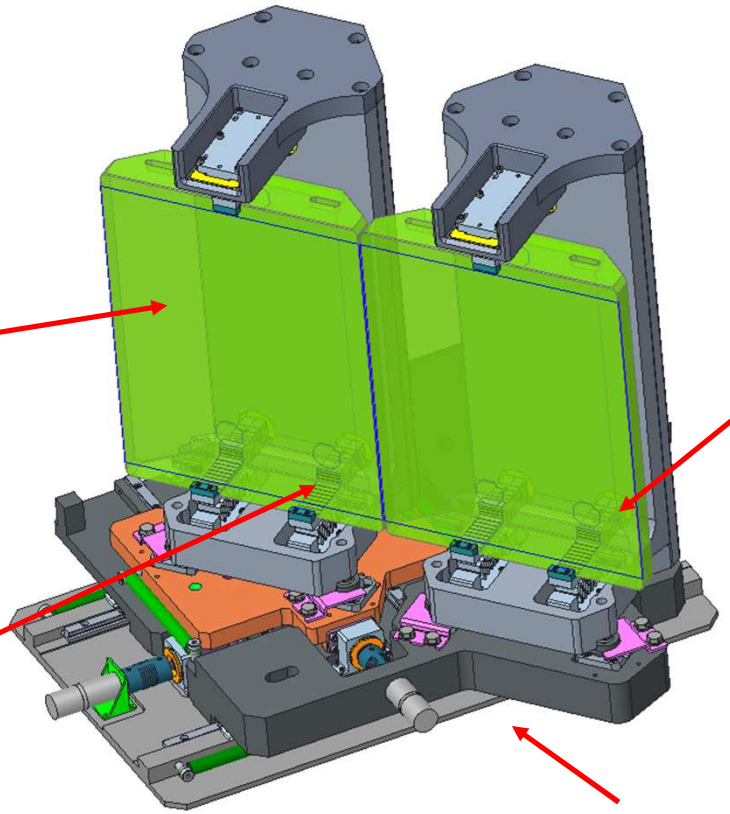
Mirror Segmentation (AXIS 3)

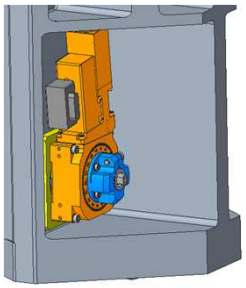
The main challenge is beam phasing (to recover one beam)

Specifications
Angular resolution = 25 nrad
Residual deformation with motion < 70 nm

Optical components
two BK7 mirrors
420mmx350mmx80mm
Power: PV< 170nm
Flatness PV< 160 nm
RMS slope < 1 µrad

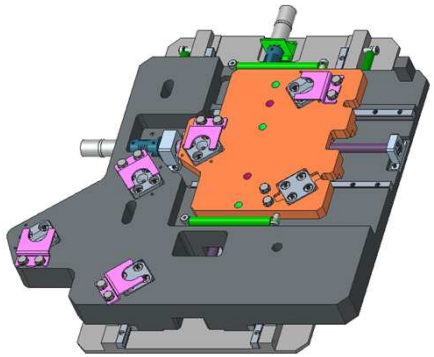
Elastic deformation maintaining systems
(will be patented)





Actuators
Resolution ~ 1 nm
Motion =± 4 mm

2-axis translation table



Fabrication 2nd semester 2023

B-field capability (AXIS 4)

2022	2023	2024	2025	2026	2027	2028
Feasibility			Specification	Fabrication	Qualification	Implementation

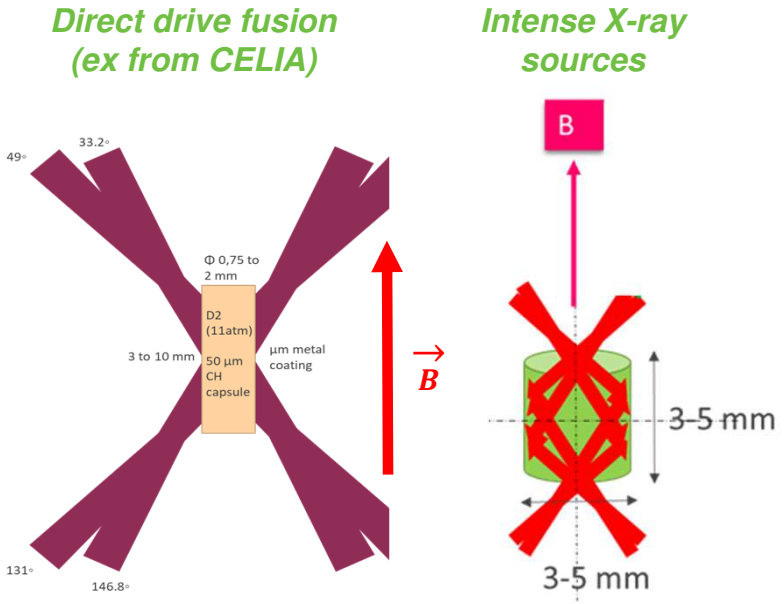
- **Feasibility study phase**

→ **end expected by late-2024: "GO / NO GO" decision**

- Sizing of the electromagnetic system
- Performances evaluation
- Identification of the interfaces and preparation for integration
- Evaluation of acquisition and operating costs

- **Specifications discussed with CELIA, LULI and CEA/DIF**
  - 30 T on a φ = 6 mm x h = 6 mm cylindrical volume
  - 5-10 % spatial homogeneity
  - 100 ns duration
  - 5 % temporal stability
  - Vertical direction

- **Typical experiments for first sizing**



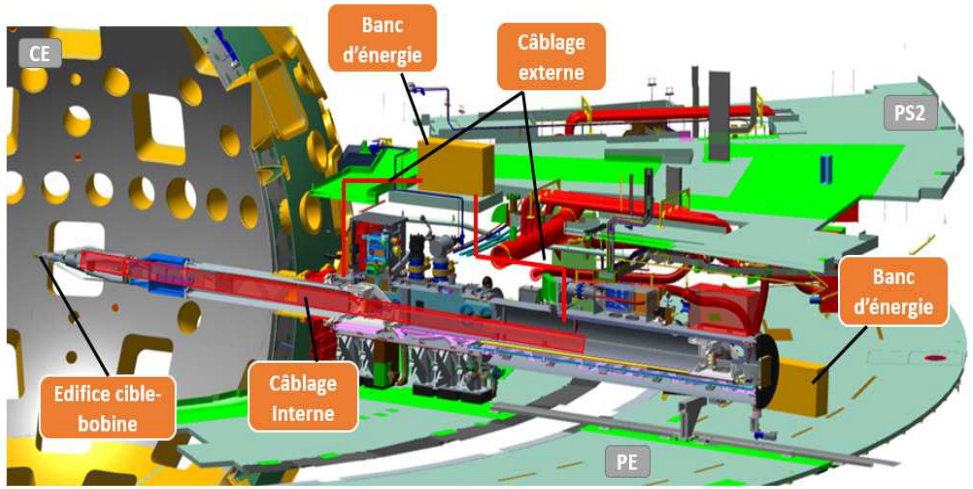
Integration on the cryogenic target inserter (AXIS 4)

- **Main choices of concepts**
  - Target integrated coil held by an inserter
  - Integration into the cryogenic positioner PCC (for future cryogenic compatibility)
  - Pulser in the experiment room (the options into the inserter are too complex for maintenance, integration with the cryogenic inserter)
  - Non destructive coil (mainly because of the risks of incomplete vaporization with destructive coil)

- **Integration on the cryogenic target positioner (PCC)**
  - Mutualizes the needs
  - 2 phases of employment envisaged
    - separate DT cryogenic / magnetic field experiments
    - with cryogeny and B-field together

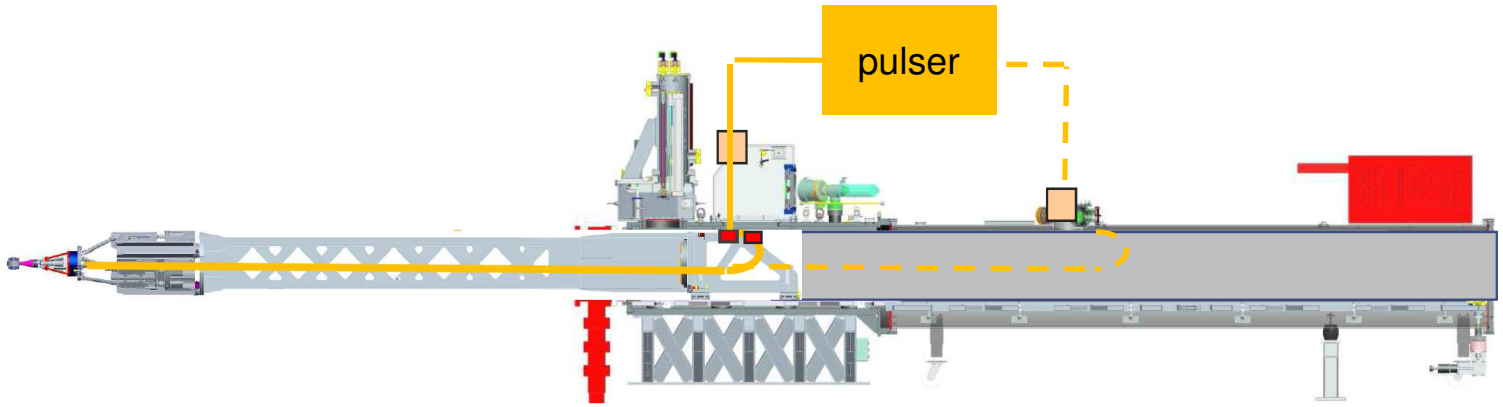
  PCC integration studies have been done

  → **feasibility now demonstrated**



Engineering issues and associated prototypes (AXIS 4)

- Some problems still need to be solved …

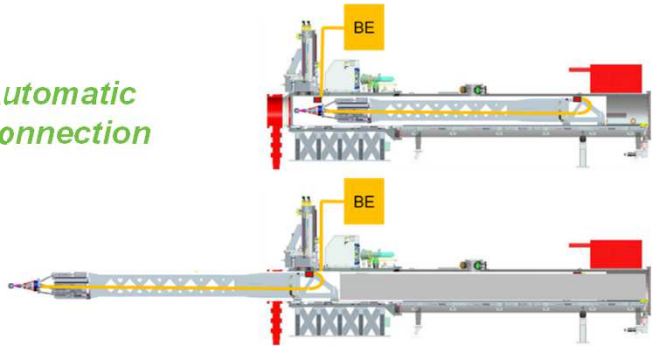


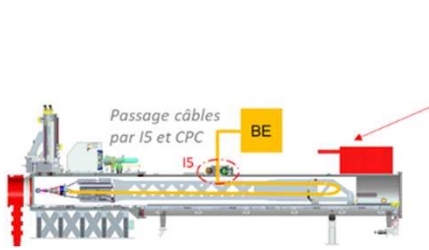
Engineering issues and associated prototypes (AXIS 4)

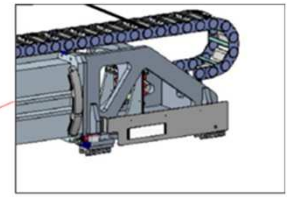
- Automatic connection or cable track ?

Cable track mechanical test bench

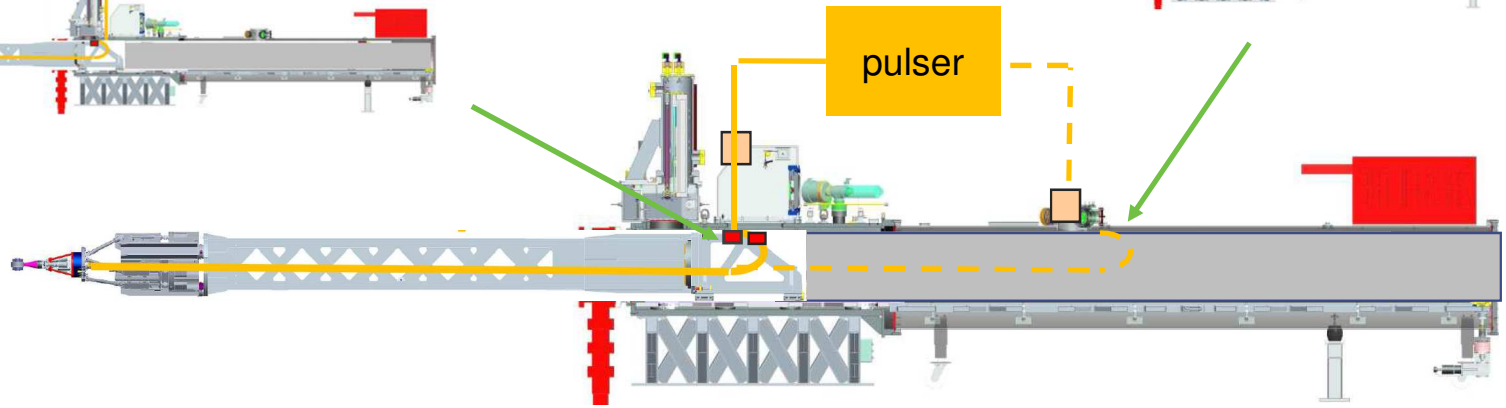
Automatic connection





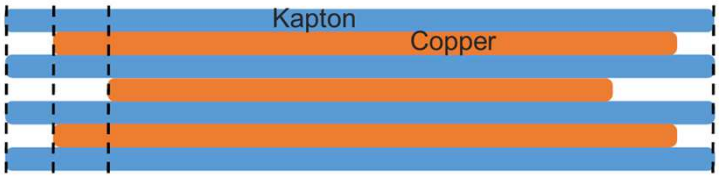


cable-track



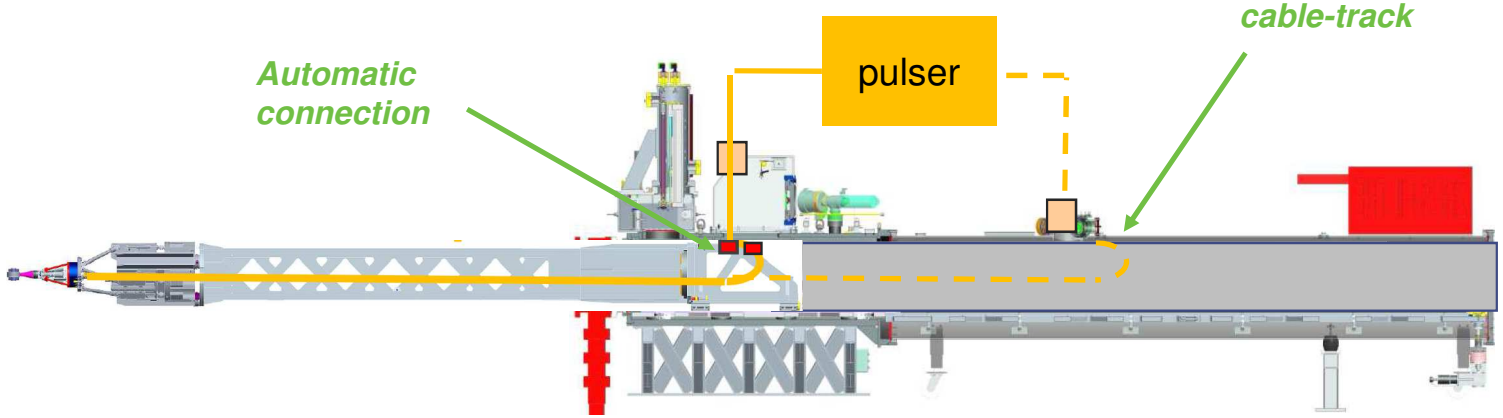
Engineering issues and associated prototypes (AXIS 4)

- Standard cables and/or strip-line ?



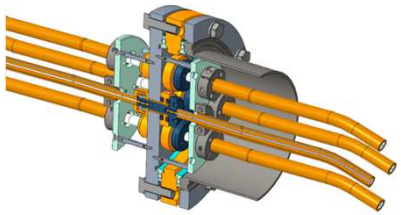
Benchmark and qualification of a first strip-line
Studies are on-going

Cable track mechanical test bench



Engineering issues and associated prototypes (AXIS 4)

- Connections ?



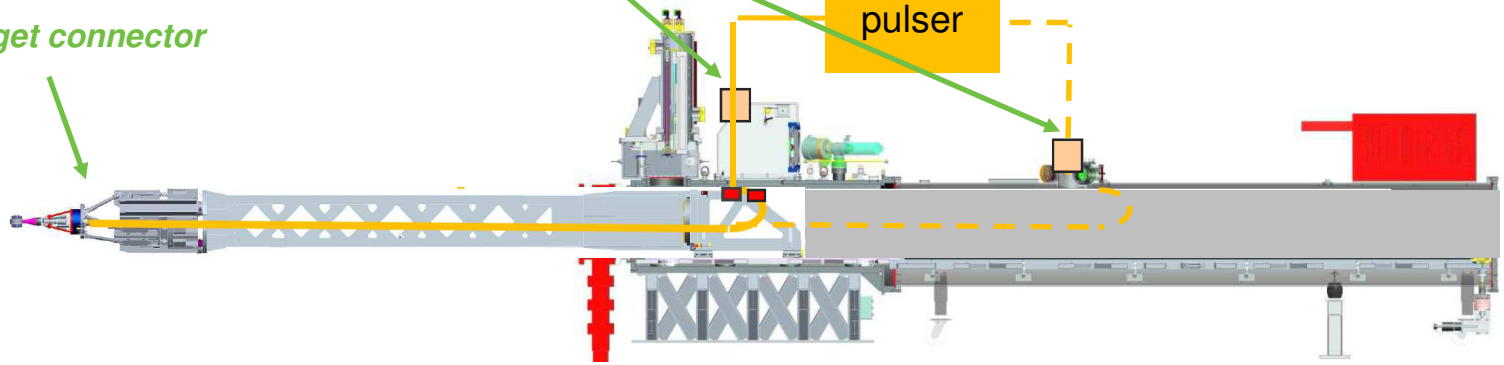
Vacuum /electrical prototype

Results
Vacuum 2.10^{-6} mbar
No breakdown up to 35 kV

Vacuum tight feedthrough

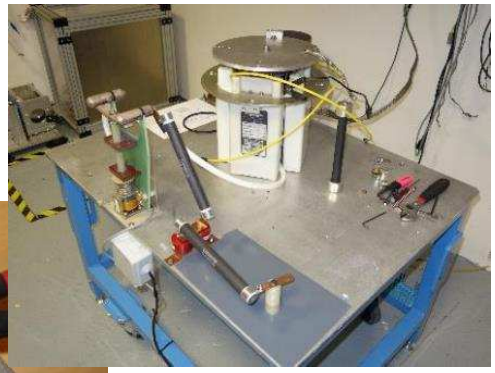
Target connector

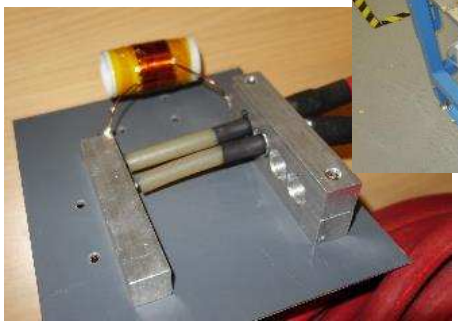
pulser



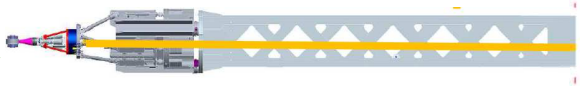
Engineering issues and associated prototypes (AXIS 4)

- *B-field performances ?*
- *Debris risks ?*
- *Remote effects ?*

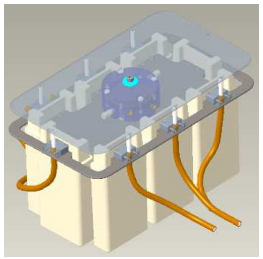




Electro-tech. prototype

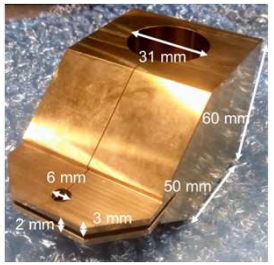


B field performances
Debris risks
Remote effects



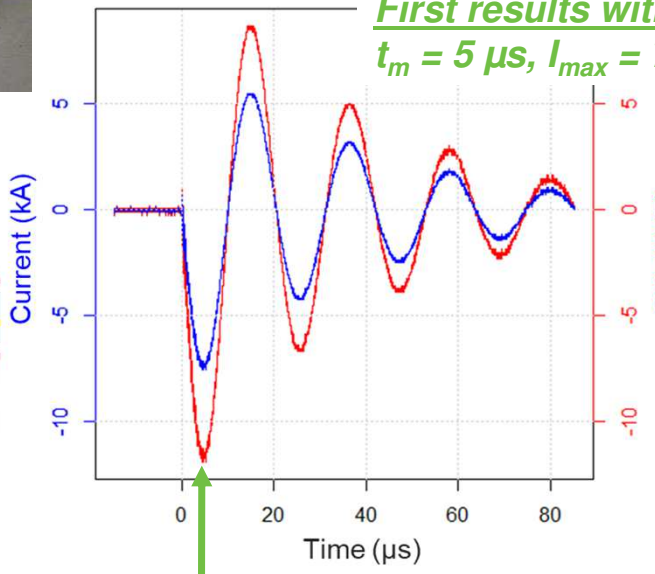
New 2 kJ pulser under construction

Target-coil prototype to be tested



First results with 1 kJ pulser

t_m = 5 µs, I_{max} = 7,4 kA, B_{max} > 10 T



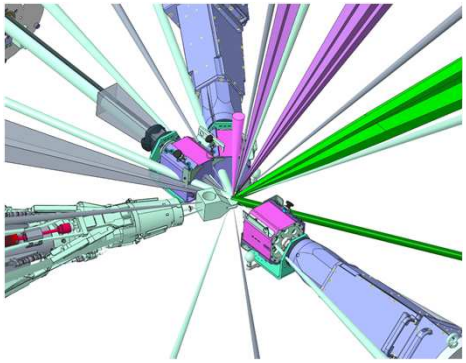
Laser shot will happen here

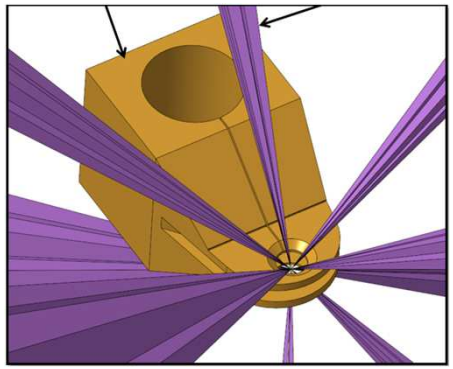
Home-made coil

Engineering issues and associated prototypes (AXIS 4)

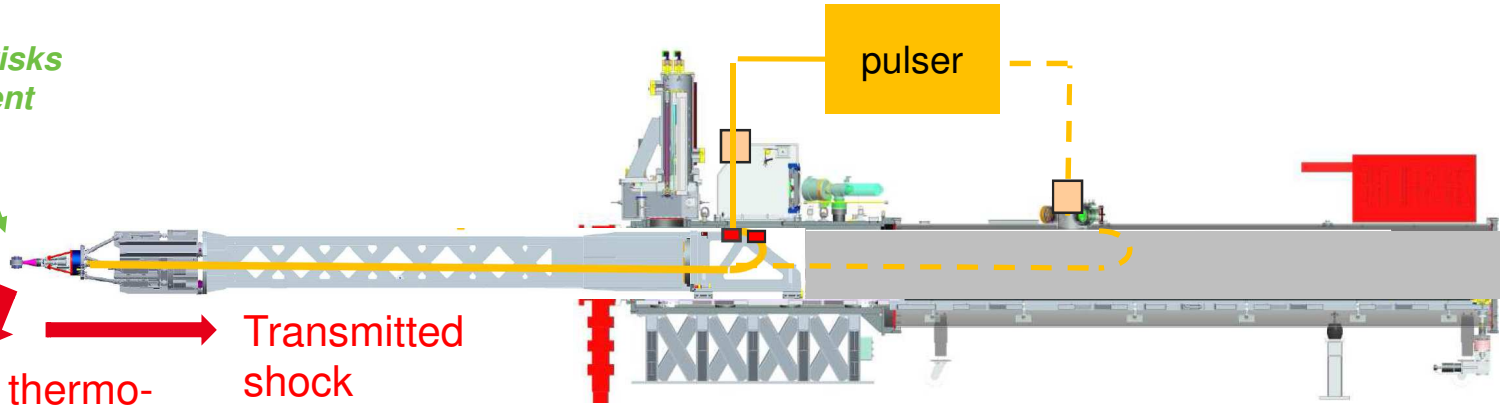
- ***Alignment ?***
- ***Shocks ?***

Integration / alignment studies are on-going





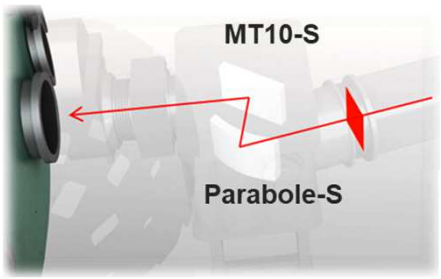
Debris risks
Alignment

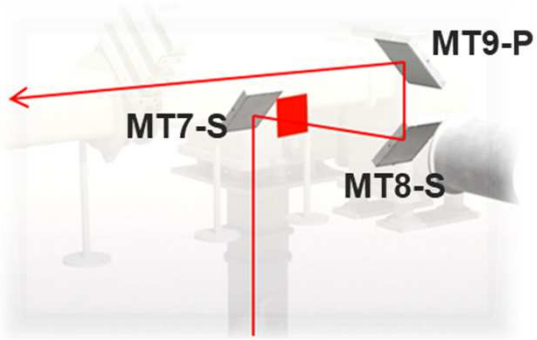


Numerical simulations in progress

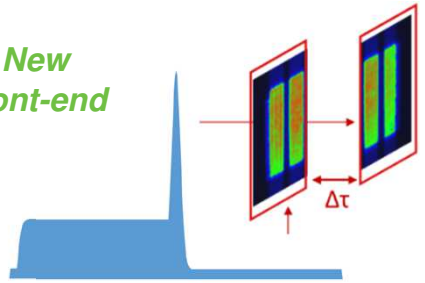
Conclusion

New final optics

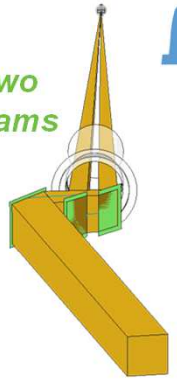


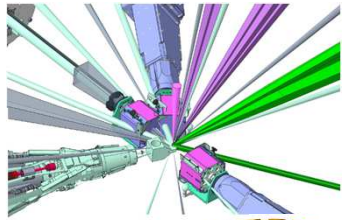


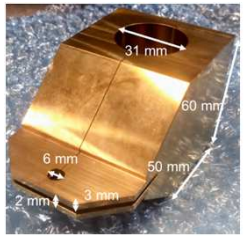
New front-end



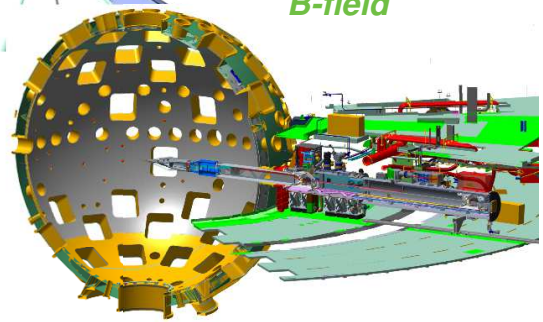
Two beams







B-field



Petal-UPgrade

MT10 + parabole V2
New front-end call of tender

MT8 + MT9 V4
GO/NO GO on B-field implementation

Segmented MT10 V4
+ Parabolic mirror V4

MT7 V4
New front-end installation

B-field implementation

2023 | 2024 | 2025 | 2026 | 2027 | 2028 and over

INCREASE IN ENERGY (AXIS 2)

650J | 800J | 900J | 1kJ

TWO BEAMS (AXIS 3)
CONTROL OF CONTRAST (AXIS 1)

B-FIELD (AXIS 4)

The PETAL UPgrade team

Laser Engineering : ***N. Blanchot, H. Coïc, X. Ribeyre, A. Le Camus, C. Rouyer***

Front-end: ***F. Scol, D. Hamon***

Opto-mechanic: ***F. Macias***

Optics: ***E. Lavastre, M. Chorel***

Magnetic System: ***E. Mainguy, B. Cassany, B. Etchessahar***

B-field inserter: ***L. Quebert, T. Bart, R. Ferbos, B. Etchessahar***

C/C: ***N. Santacreu, P. Bagur***

System Engineering: ***G. Balmigere, M. Baltazart (Technicatome)***
P-A. Gomez, K. Lapierre, L. Ho-Pin (Ametra)

Planning: ***M. Thibault (LGM)***

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Petal-UPgrade