DE LA RECHERCHE À L'INDUSTRIE

# EMP control and mitigation at LMJ-PETAL facility

30 septembre 2021

Stéphane COUDERT, Matthieu BARDON and Bertrand ETCHESSAHAR

# Outline

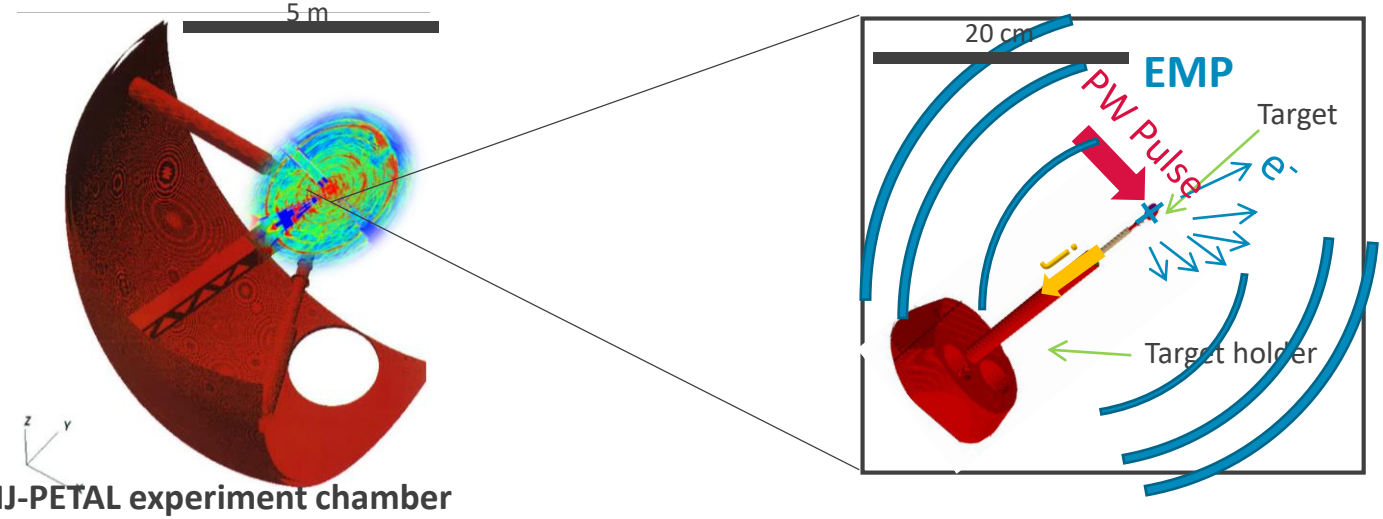
I) **EMP: motivation, phenomenology and modeling**

II) **Design and guarantee of EMP mitigation at LMJ-PETAL facility**

III) **Design of a new Current diagnostic for LMJ-PETAL facility**

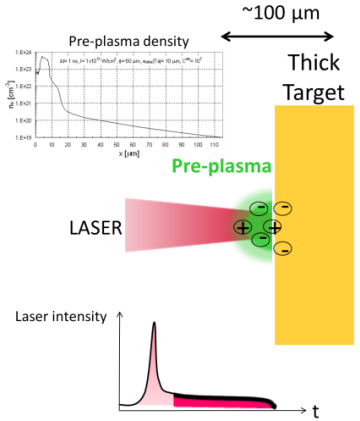
# EMP at LMJ-PETAL facility: phenomenology

## ➢ Phenomenology: main mechanism



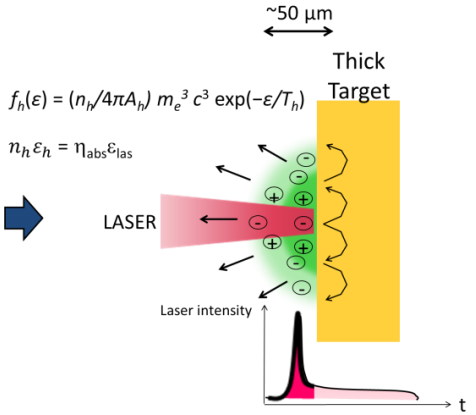

**1D ESTHER code [CEA]** — Hydrodynamic

Calculation of the plasma density profile
*scale ~ 100µm*



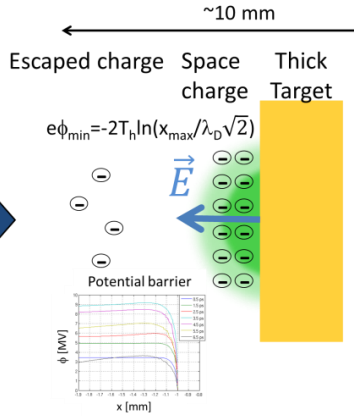

**3D CALDER code [CEA] + MCNP code** — Laser-plasma interaction + Particle transport

Electrons & protons emissivity calculation
*scale ~ 50 µm*

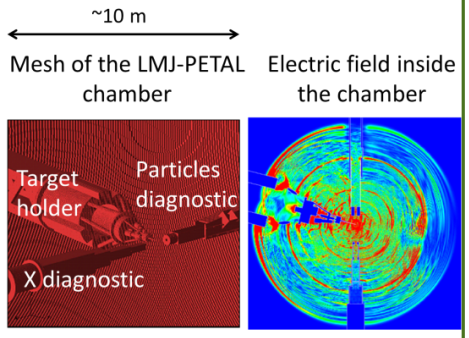



**3D SOPHIE code [CEA]** — Particles propagation in EM fields

Escaped charge calculation
*scale ~ 1 cm*




EM fields in the experimental chamber
*scale ~ 10 m*



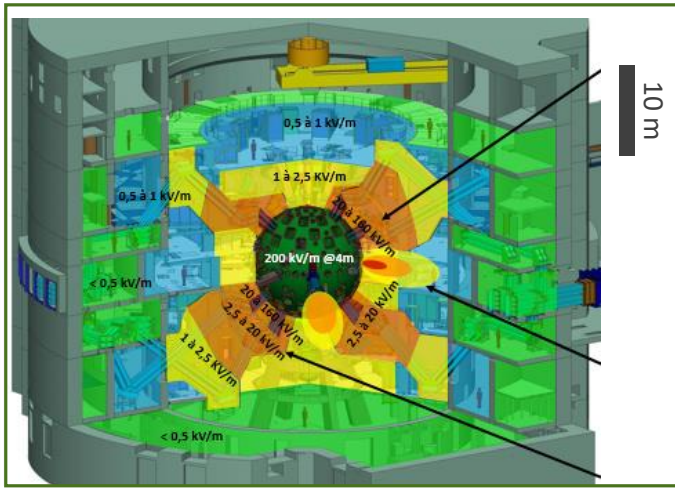

15 billions of cells
100 millions of particles

Target holder acts as an antenna

**Time**

# Motivation

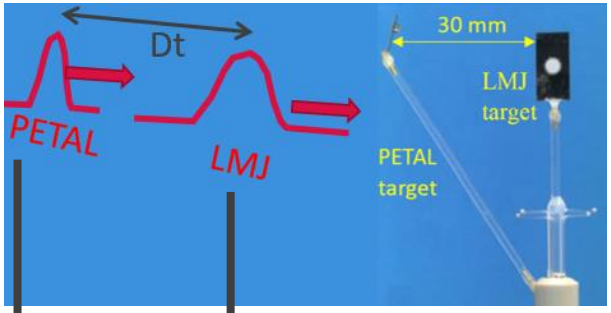
- **EMP amplitude PETAL 1 kJ**




**Petal 1kJ (future) :**
**Frequencies: 0.1-10 GHz**
**Current: 10 kA**
**EMP amplitude 40 cm from target: ~MV/m**

- **An electromagnetic pulse which can lead to equipments and diagnostics failures.**

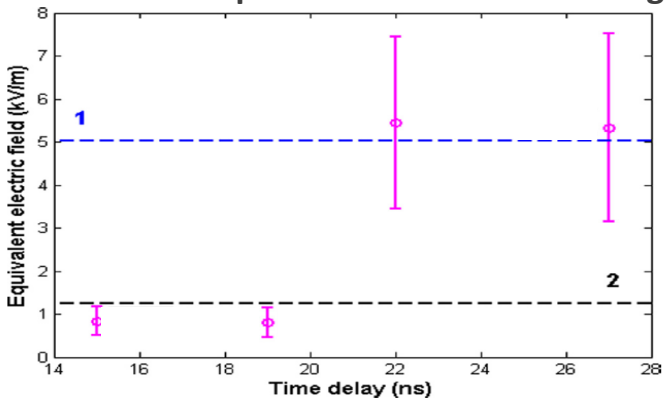
- **GREGORI experiment**




350 J
0,6 ps pulse

10-50 kJ
5 ns pulse
$\approx 10^{14}$ W/cm$^2$

**Electric field amplitude at 4 m from the target**



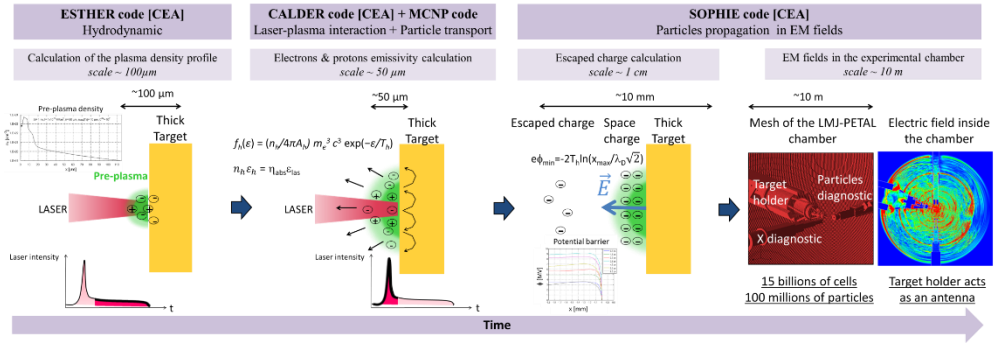

- **Dt>20 ns, PETAL EMPs are generated.**
- **Dt<20 ns, PETAL EMPs are NOT generated.**

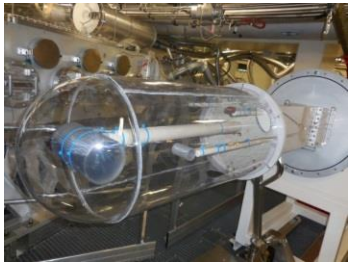
*M. Bardon et al 2020, Phys. Rev. Research, 2.*

*F. Consoli et al. 2020, High Power Laser Science and Engineering 8*

# Strategy

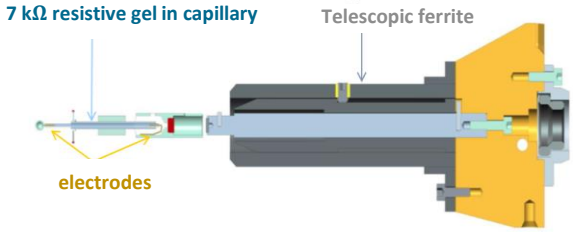
- EMP modeling and measurements



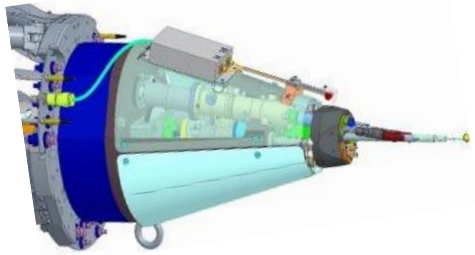



**H far field measurement**
(LMJ-PETAL experiment chamber)

- Design of an EMP mitigation device




- Design of a current and charge diagnostic for LMJ-PETAL facility



# Outline

## I) EMP: motivation, phenomenology and modeling

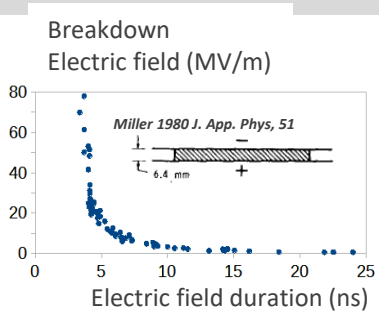
- *A process almost completely understood: far field measurements consistent with simulation chain results*
- *A phenomena which can lead to damage in kJ/ps laser facilities*

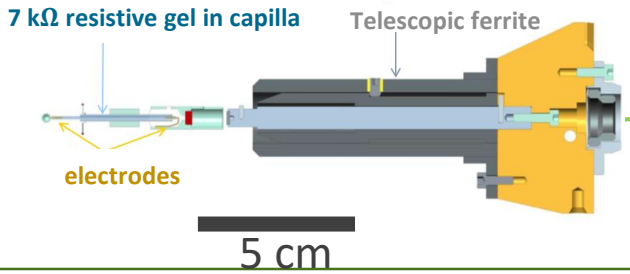
## I) Design and guarantee of EMP mitigation at LMJ-PETAL facility

## II) Design of a new current diagnostic for LMJ-PETAL facility

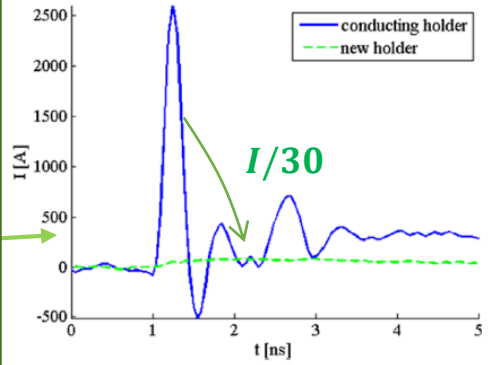
# Design of a new holder robust to breakdown: study at LULI facility

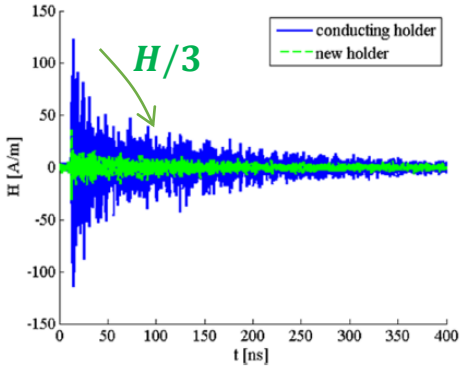
## Design of a resistive holder



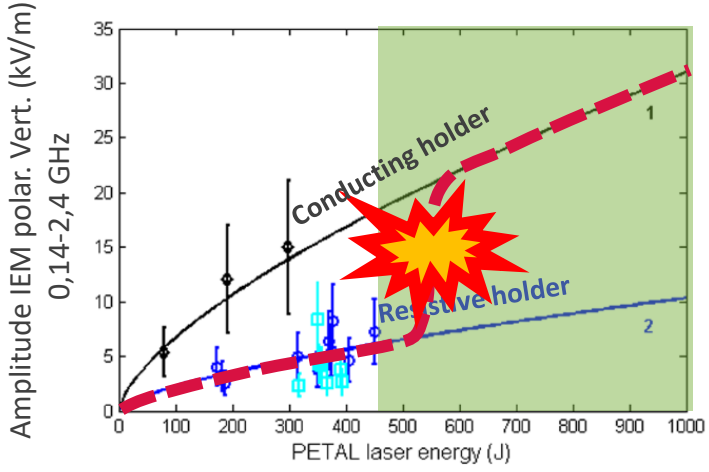




## Measurement at 80 J LULI facility




## EMP measurement at PETAL facility




*M. Bardon et al 2020, Phys. Rev. Research, 2.*

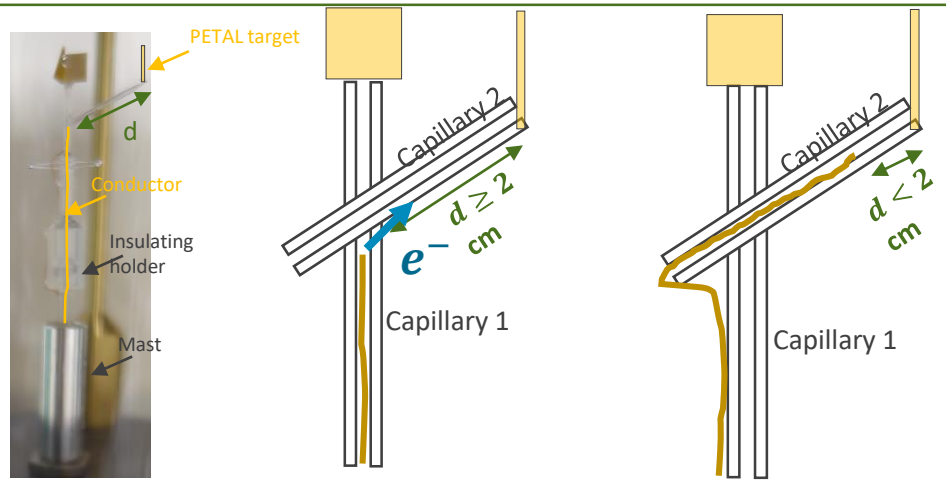
- **EMP amplitude divided by a factor 3**
- **Performance of resistive holder comparable with isolating holder**
- **Robustness of mitigation device to higher energies up to 1.2 kJ must be demonstrated**

*F. Consoli et al. 2020, High Power Laser Science and Engineering 8*

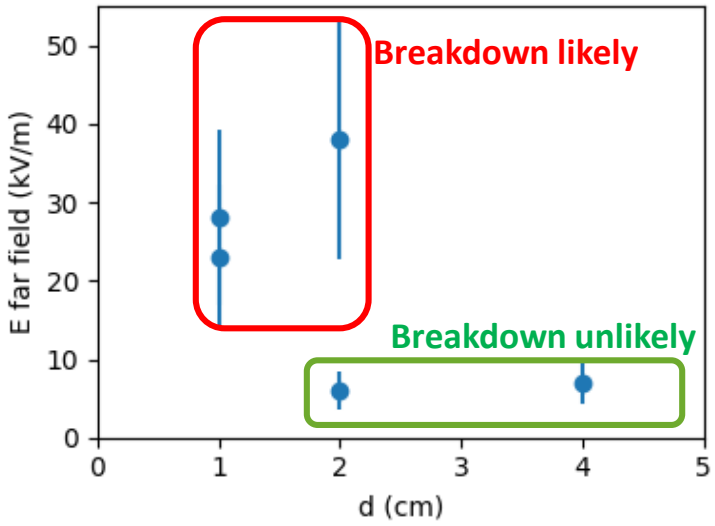
# Study of laser induced electrical breakdown

➢ **As passenger on 2021 PETAL experiment (equivalent 100 J for EMP)**

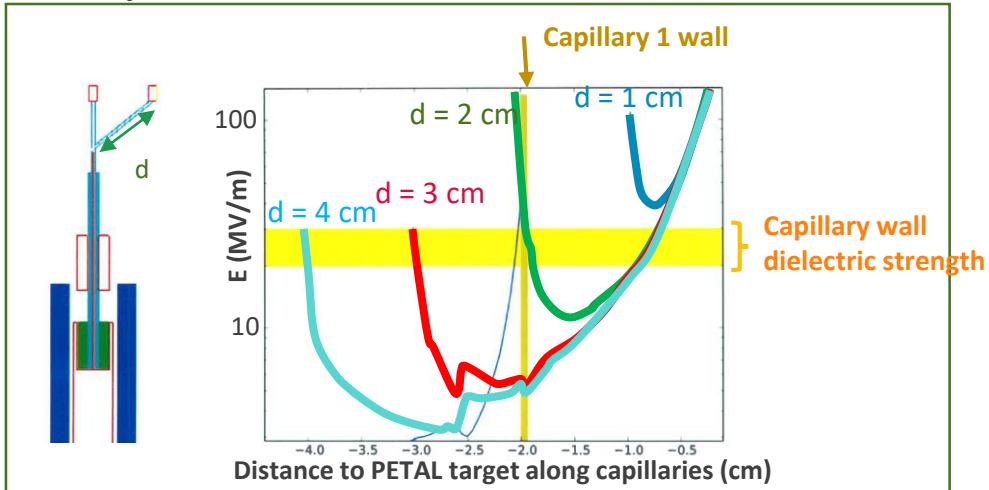
**Idea: increase artificially the electric field in the insulating capillary in order to generate point effect and electrical break down.**




**EMP far field measurement**




**EM Sophie Simulations**




***Numerical results consistent with far field experimental EMP amplitude***

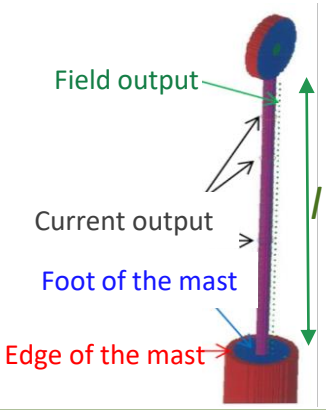
# Guarantee of mitigation device up to 1 kJ

## ➢ Next step (project for 2022):

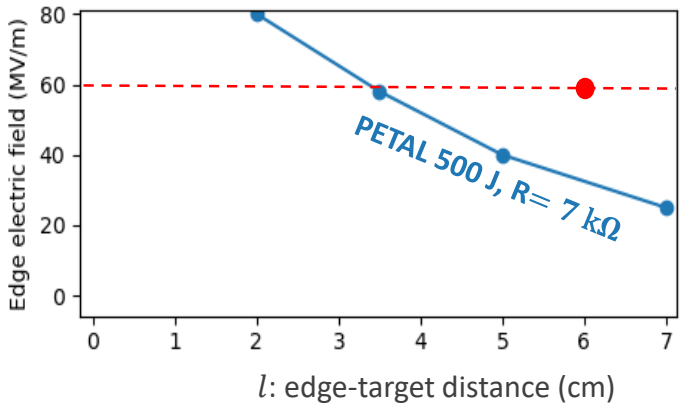
**Campaign on VULCAN and PETAL facilities:**

➢ **Goal: to guarantee the robustness of the resistive EMP mitigation device with respect to electrical breakdown at 1 kJ with 450 J energetic laser pulse.**

$\Rightarrow$ l ↘ $\Rightarrow$ E ↗




**SOPHIE Simulations:**




Field nominal mitigation device PETAL 1kJ

➢ **For breakdown :**

**500 J, 7 kΩ, $l = 3.5$ cm ⇔ 1 kJ, 7 kΩ, l=6 cm**

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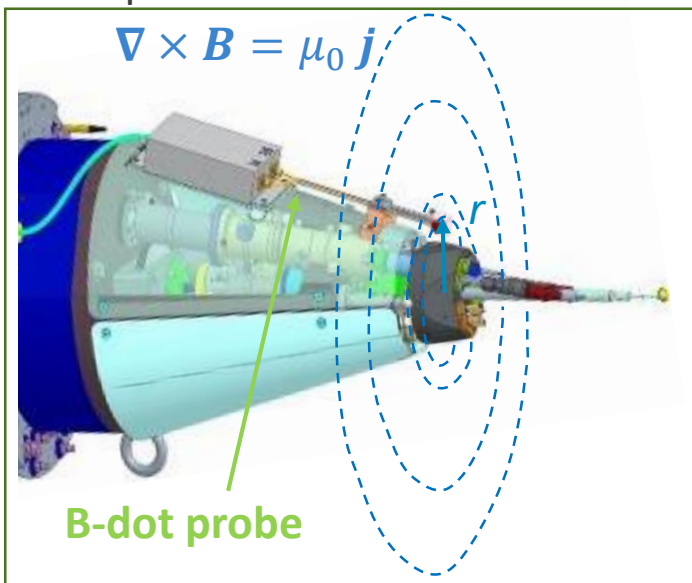
- *Development of mitigation device which reduces current and EMP amplitude*
- *Mitigation device which should be robust with respect to electrical breakdown*
- *Experimental observation of electrical breakdown generated by laser*
- *Understanding of electrical breakdown provided by EM simulations*
- *Experimental campaigns on PETAL and VULCAN facilities in 20221-2022*

## II) Design of a new current diagnostic for LMJ-PETAL facility

# Design of a new current diagnostic for LMJ-PETAL facility

➢ **Concept**




Near field $\Rightarrow \oint \boldsymbol{B}(\boldsymbol{r}) \cdot \boldsymbol{dl} = \mu_0 I$

Assuming axisymmetry of the magnetic field:

Maxwell-Ampère: $2\pi\, r\, B(r) = \mu_0 I$

Advantages:

- Broad band sensor (0.1=>10 GHz)
- Easy to implement on LMJ-PETAL facility

Requirements:

- Robust axisymmetry of magnetic field with respect to chamber geometry
- Robust to high voltages (up to 7 kV)

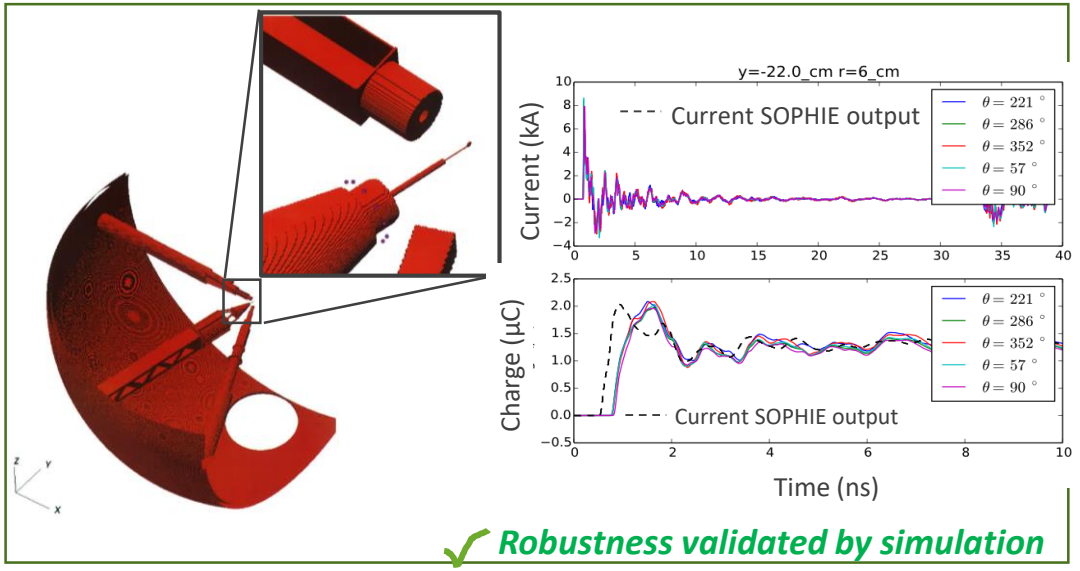
# Validation of the robustness with respect to geometry

➢ **Concept**

Comparison of current SOPHIE output (CIRC), with results obtained with several one-single point B-field measurements within various chamber geometry.

➢ **Robustness of the method with respect to global chamber geometry**

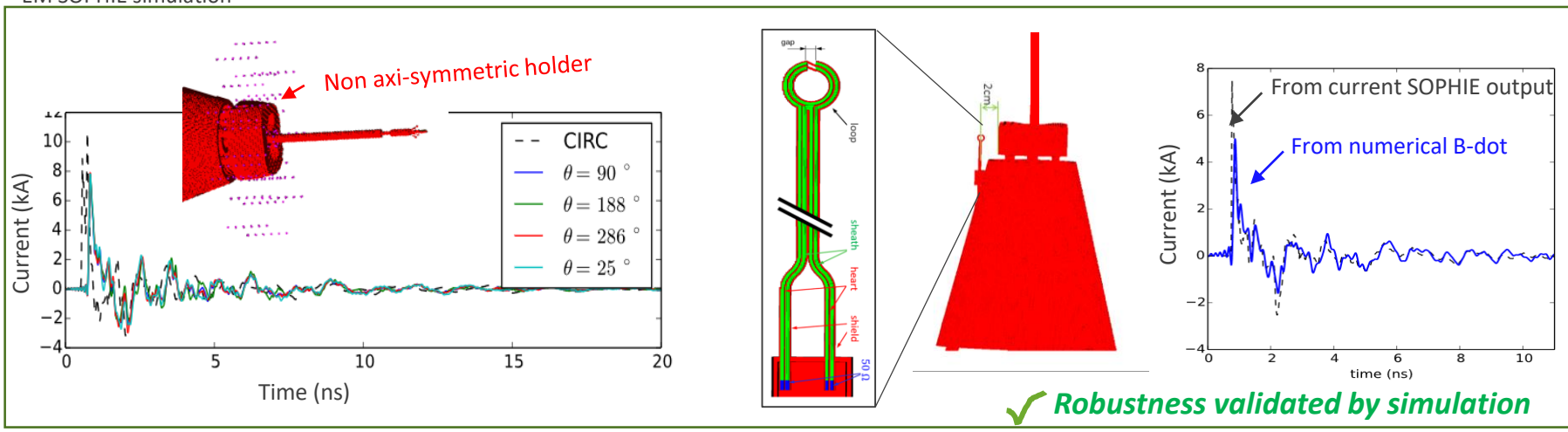
SOPHIE simulation




✓ ***Robustness validated by simulation***

➢ **Robustness of the method with respect to local geometry**

EM SOPHIE simulation

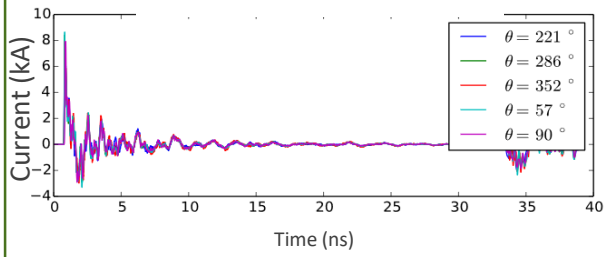



✓ ***Robustness validated by simulation***

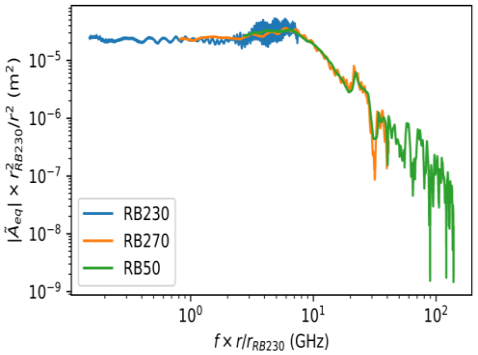
# Validation of the robustness with respect to voltage amplitude

## ➢ Amplitude of the voltage inside the probe during experiment :

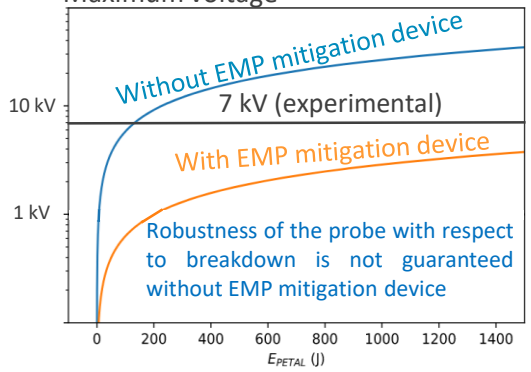
SOPHIE Simulated current




Experimental caracteristics of the probe

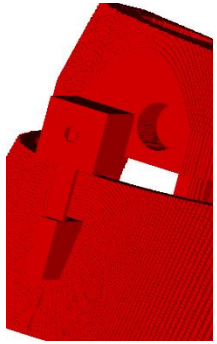


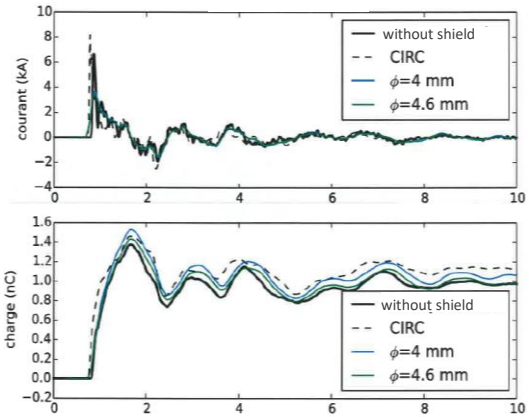

Maximum voltage



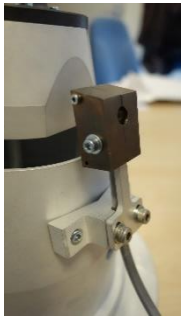

## ➢ Reduction of the voltage by the use of a shield with a hole

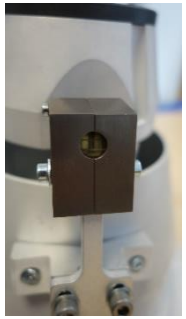
EM SOPHIE simulation



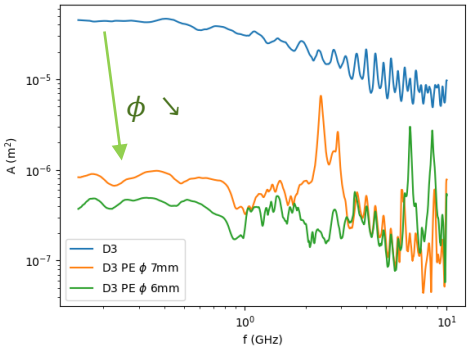



Experimental calibration untill 10 GHz



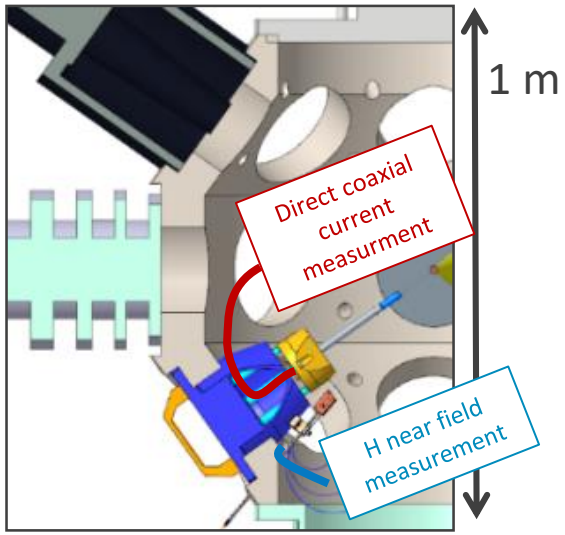


$\phi$ 7 mm hole => sensitivity /10

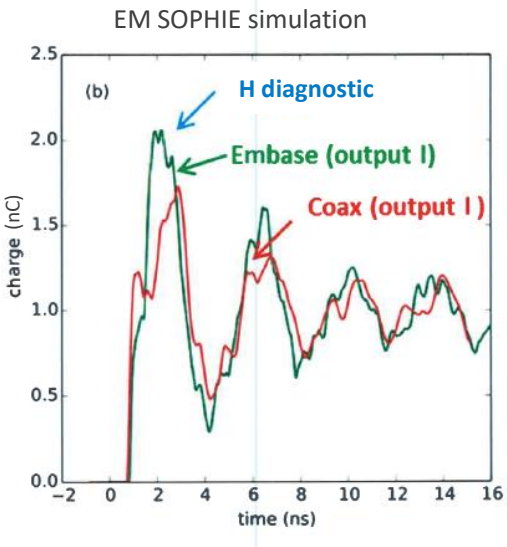


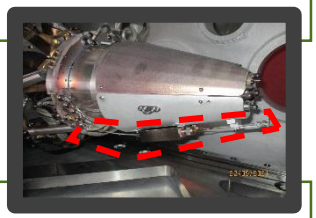
# Validation campaign at EQUINOX facility (100 mJ, CEA DIF)

## ➢ Experimental validation campaign at EQUINOX facility 100 mJ (CEA DIF) in 2021




EQUINOX CAD



## ➢ Finally:

- ➢ Diagnostic designed with SOPHIE simulations
- ➢ Robustness with respect to geometry validated
- ➢ Robustness to large field improved with specifically designed field atenuator
- ➢ Implemented on LMJ-PETAL facility
- ➢ Experimental validation of the concept in 2021 at EQUINOX facility
- ➢ First results on LMJ-PETAL facility: 2021-2022

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## II) Design of a new current diagnostic for LMJ-PETAL facility

- *Design and integration of a current diagnostic for LMJ-PETAL facility :*
  - *with ad hoc bandwidth*
  - *robust to various experimental chamber configurations*
  - *robust to high voltage*
- *Validation campaign of the concept in 2021*
- *First tests and results at LMJ-PETAL facility on 2021-2022*

***[1] F. Consoli et al. 2020, High Power Laser Science and Engineering 8***
***[2] Poyé et al. 2018, Phys. Rev. E, 3***
***[3] Poyé et al. 2015, Phys. Rev. E, 91***
***[4] M. Bardon et al 2020, Phys. Rev. Research, 2, 2020.***

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# Thank you for your attention

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