GPR LIGHT
Grand Projet de Recherche

VALERIA

GdR APPEL
Accélérateurs Plasma PompÉs par Laser

Assemblée Générale

14.11.2023

Laser-plasma ion acceleration with a gas jet target

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- A. Huber
- F. Hannachi
- M. Tarisien

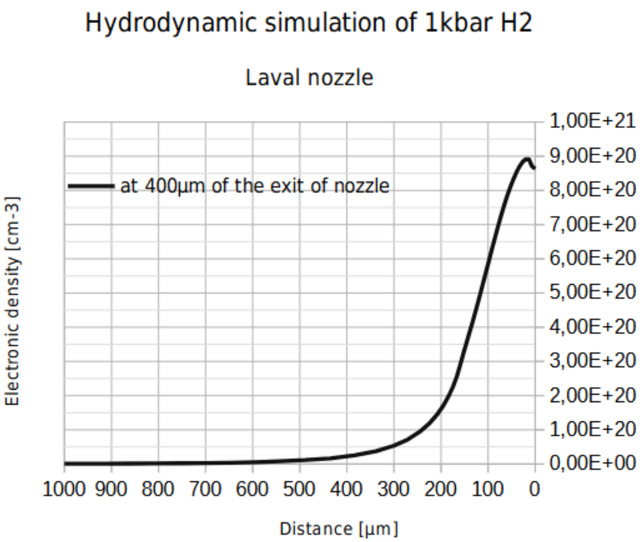
- P. Loiseau

- J. L. Henares

Motivations

Improve ASE using a high contrast laser and a prepulse to tailor the gas jet and to generate a clear shock.

BEFORE



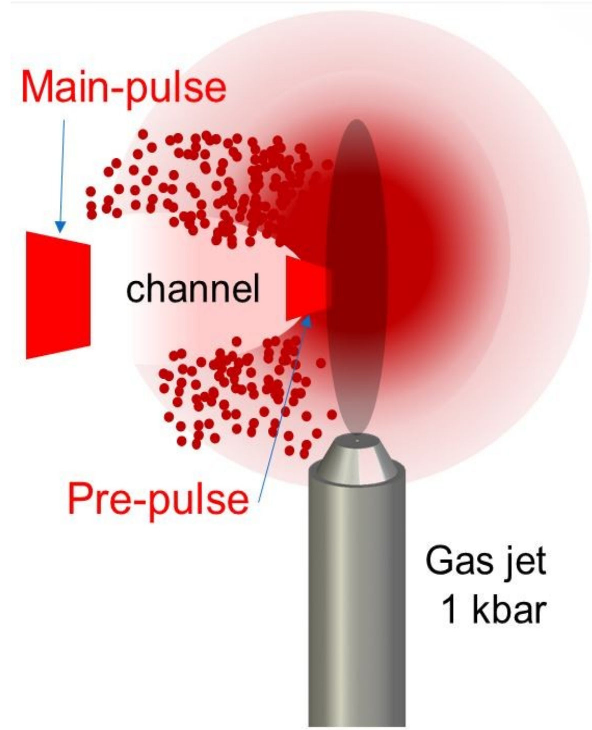


Figure : Optical shaping of the gas jet.

AFTER

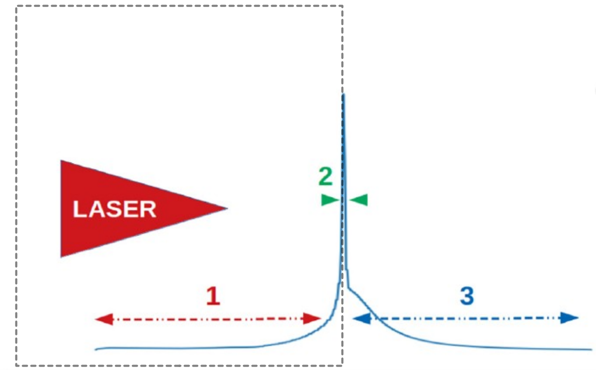


FIG. 1. Optimized gas density profile needed for efficient ion acceleration by laser-driven electrostatic shock: (1) A low density pedestal to avoid that the laser undergoes filamentation, self-focusing, and Raman scattering, and loses a large part of its energy. (2) A narrow high density region with the maximum density close to the relativistic critical density (γn_c) is used to produce a strong shock. (3) An upstream region crossed by the shock should present a smooth density profile to avoid TNSA competition. The typical widths of these three layers are of several tens of micrometers for layers (1) and (3) and thinner (several micrometers) for layer (2).

2021, Bonvalet et al
DOI:10.1063/5.0062503

OBJECTIVES

→ Reach high energy at high repetition rate along the direction of propagation of high energy main pulse.

→ Stable beam.

→ High amount of protons (10^{12}p+)

→ Medical, nuclear applications
 2007, Ute et al DOI: 10.1103/PhysRevSTAB.10.094801

→ This campaign : improve on LULI2019 setup with ASE using a high contrast laser and a prepulse.

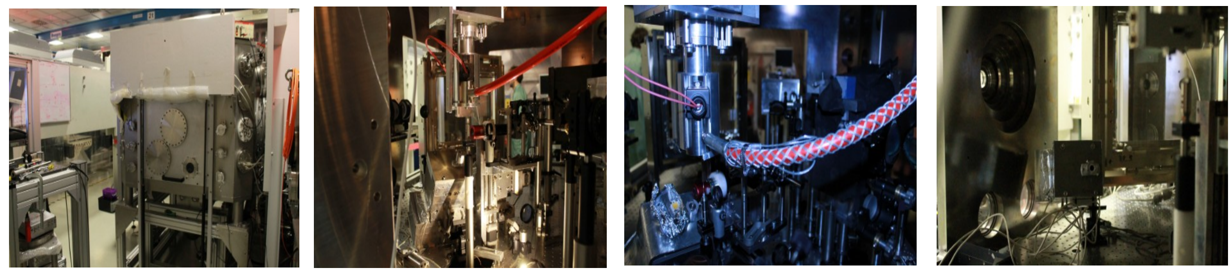
Outline

1. Experimental setup

1.1. Description

1.2. Thomson parabola

1.3. Shadowgraphy



Photos of P21-00004 experimental campaign on PHELIX GSI

2. Results

2.1. Effect of the prepulse at E_{main} = 5J on the interaction point.

2.2. Effect of the prepulse on ions spectra

2.2.1. Main at high energy (E_{main} = 100J) without prepulse

2.2.2. Case 1 : Main at high energy (E_{main} =100J) with a low energy prepulse (0,1J) and 2 differents delays: -100ps and -10ps

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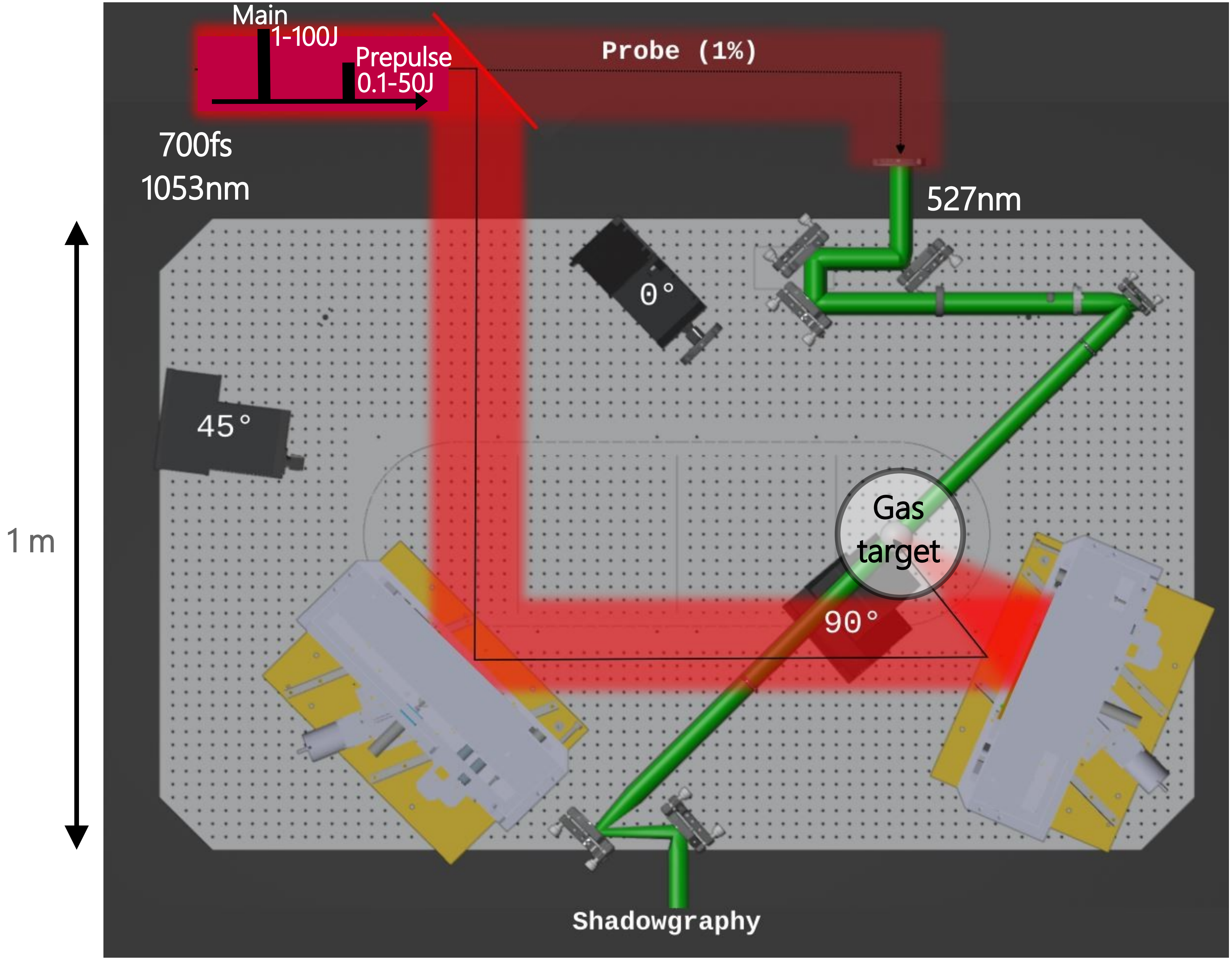

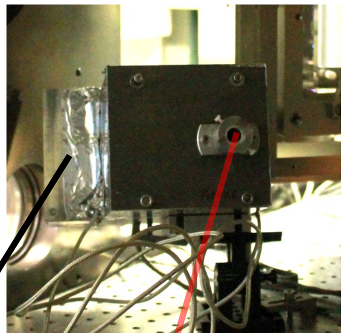

Figure: Photography of a magnetic spectrometer used on PHELIX experimental campaign.

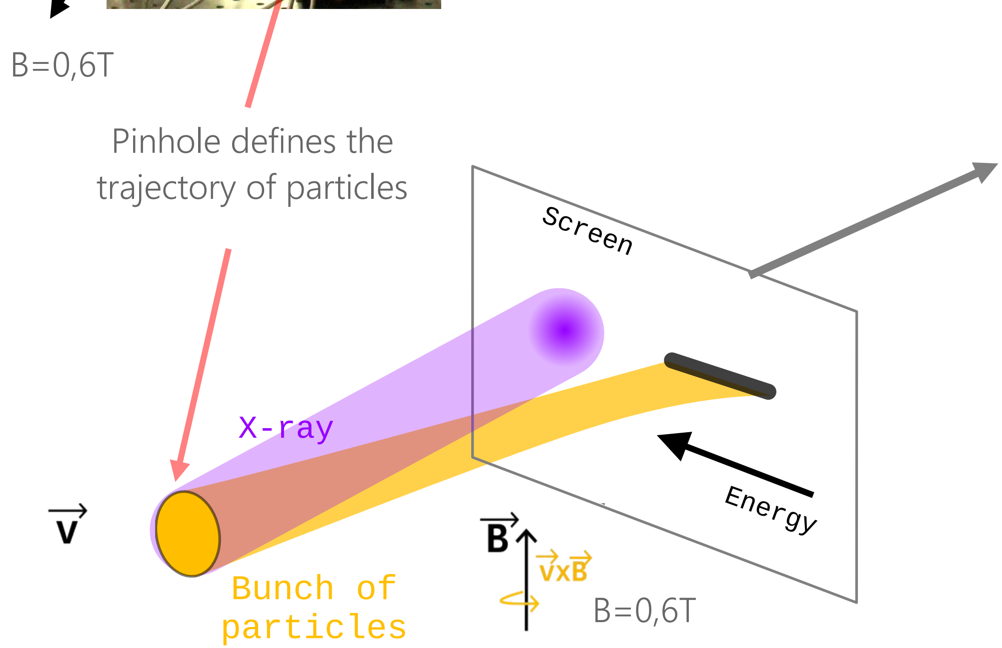

Figure : Scheme of the principle of a dispersive spectrometer. **B** deflects charged particles by the Lorentz force **F_L=qv x B** (by velocity).

Imagine plate or « IP »

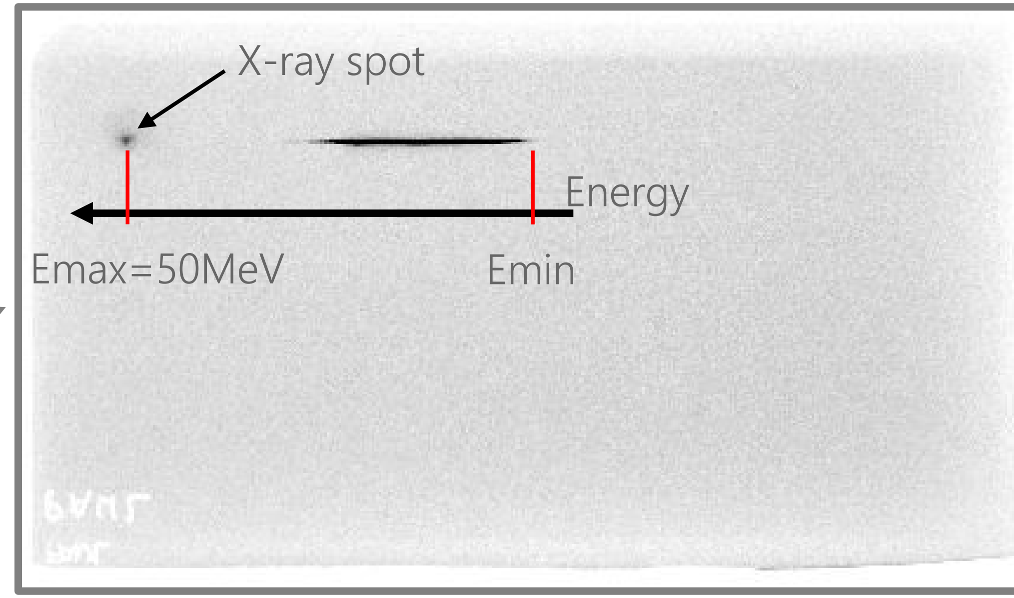

Figure : Image obtained from a magnetic spectrometer with a **H_2** target on this campain.

1. Experimental setup

1.3. Shadowgraphy : Imaging the spatial distribution of the plasma density.

How is the probe is affected by crossing the target near the optical axis ?

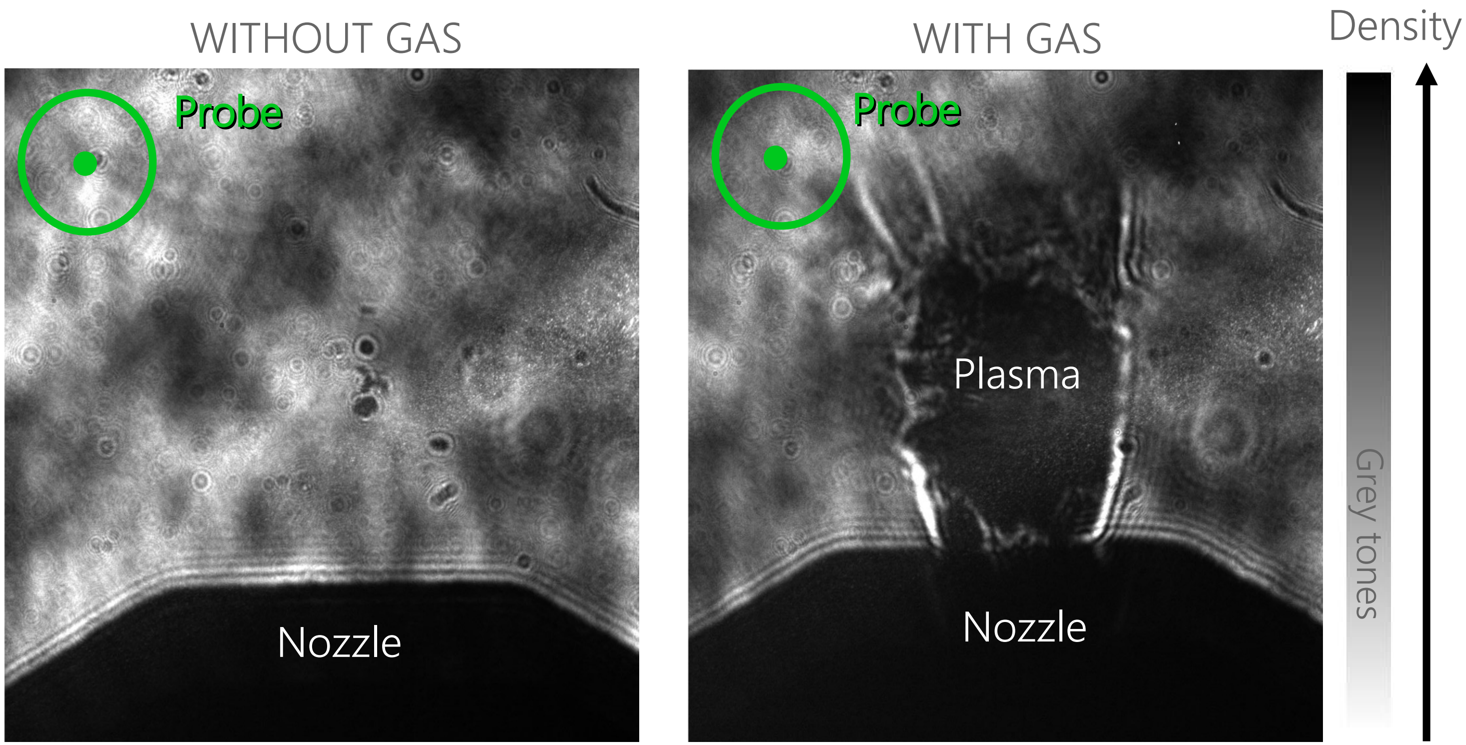

Figure : Shadowgraphy images from a shot from that experimental campaign.

Warning : In this diagnostic, the size of the plasma is bigger than in reality because plasma refract light like a lens. Some light rays don't reach the camera.

J-R Marques and al., 2023, doi :10.48550/arXiv.2309.16277

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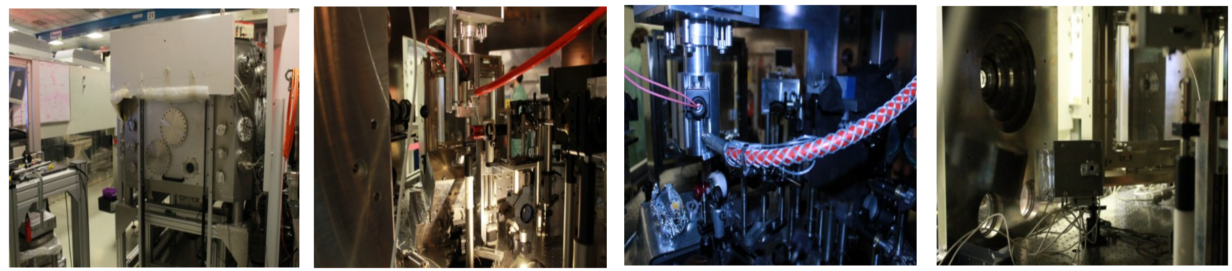

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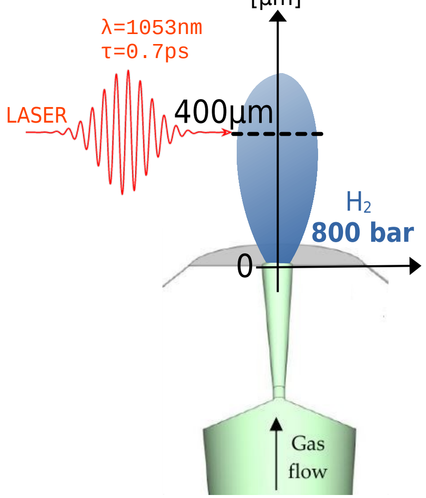
Seen on shadowgraphy with 2w generation displacement.



Laval (1c24) steel

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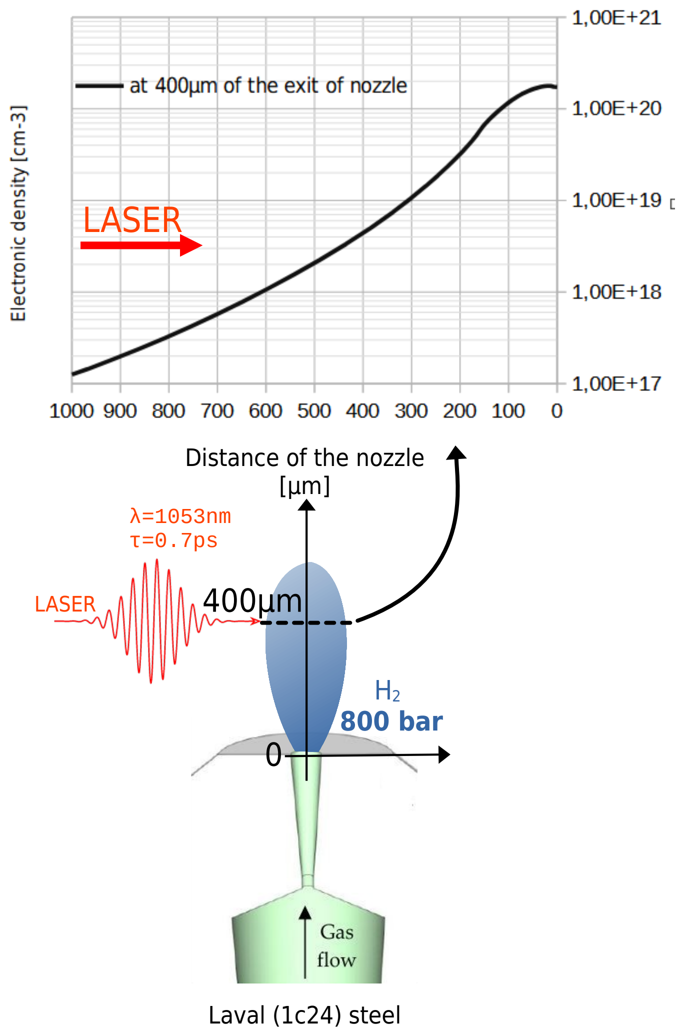

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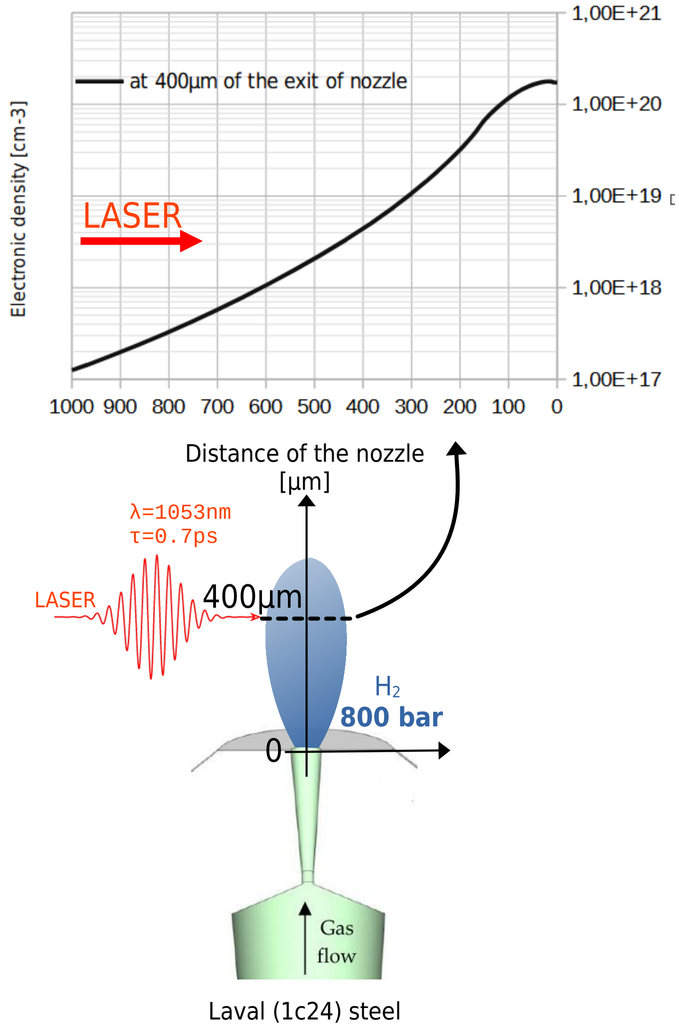

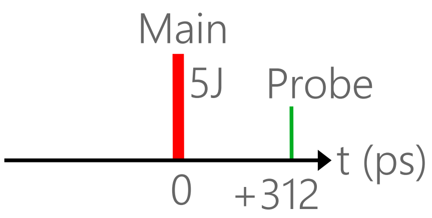

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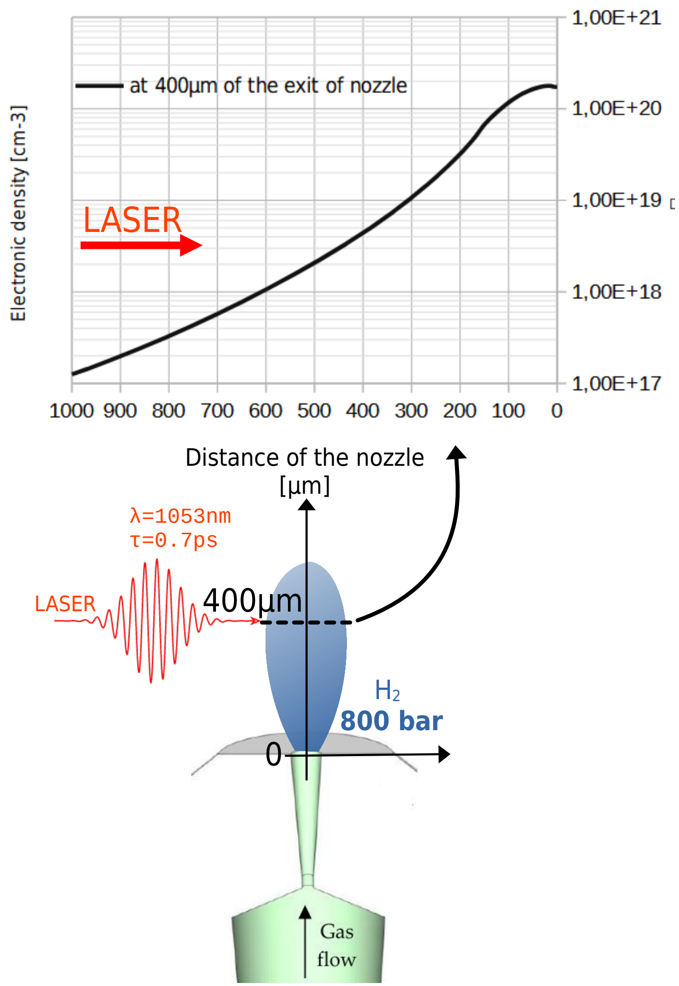

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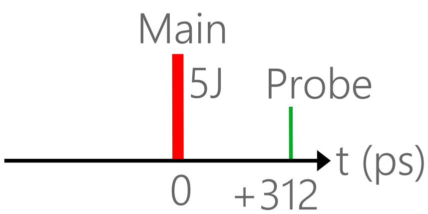

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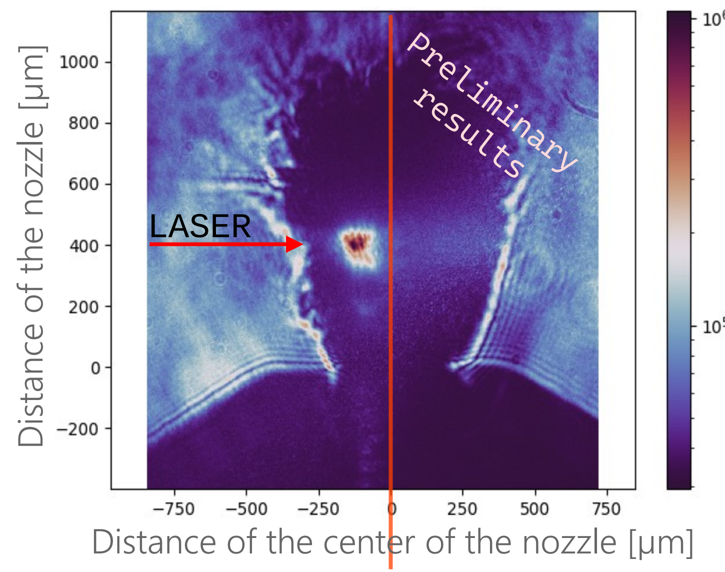

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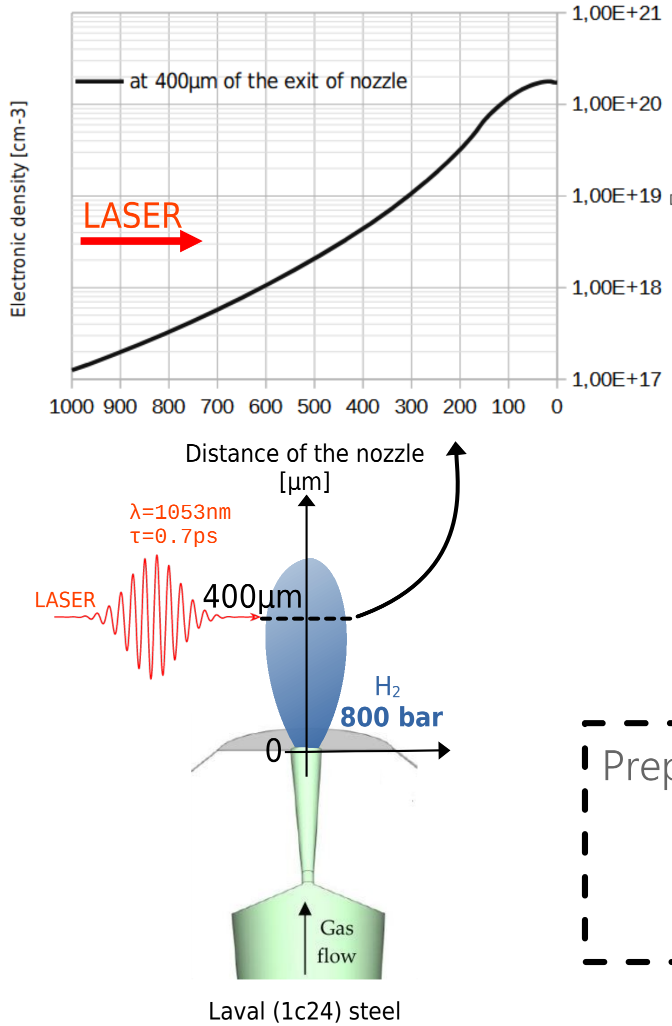

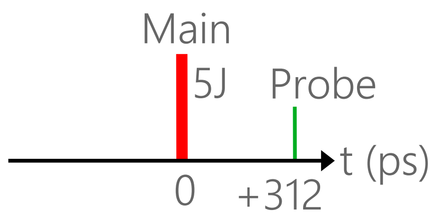

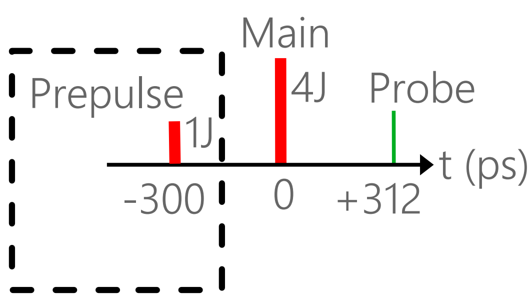

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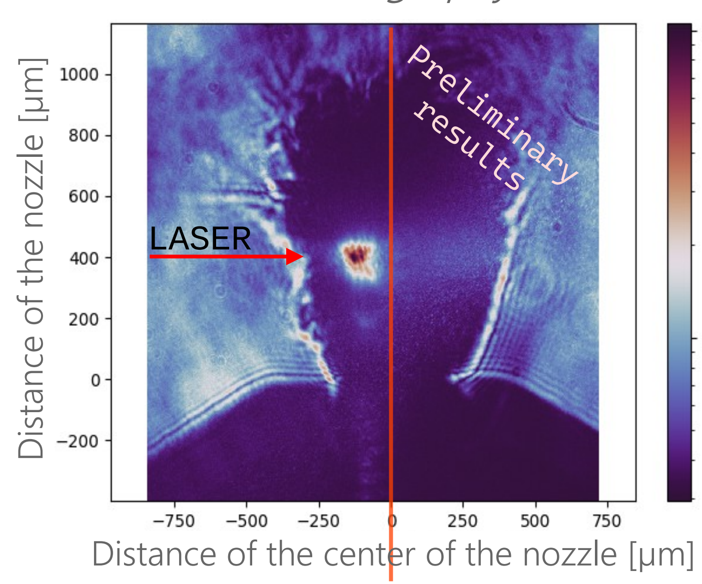

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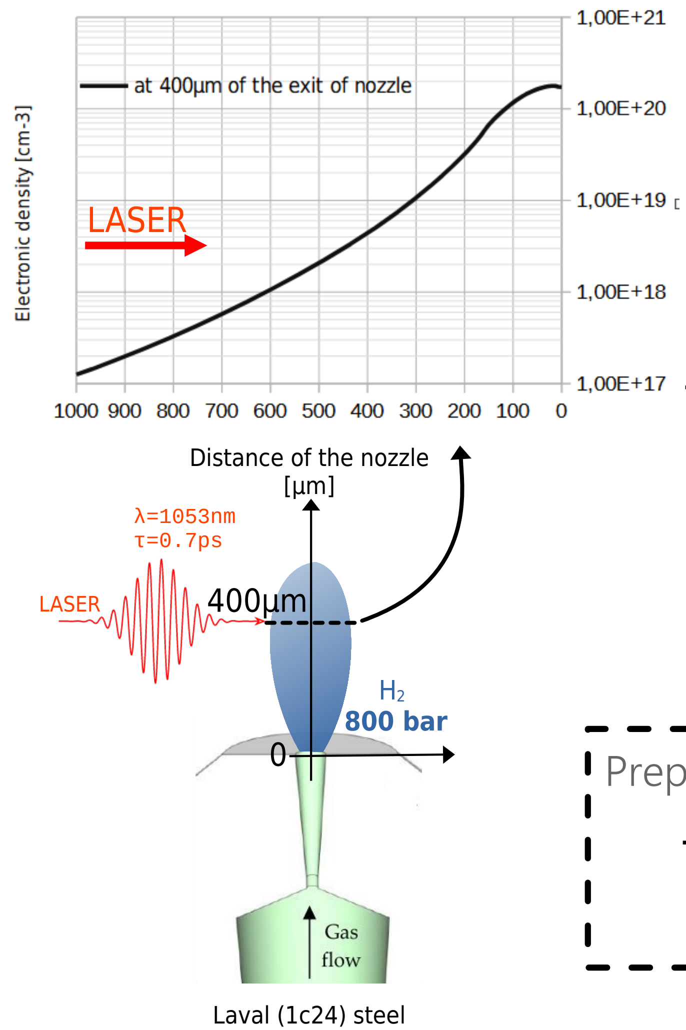

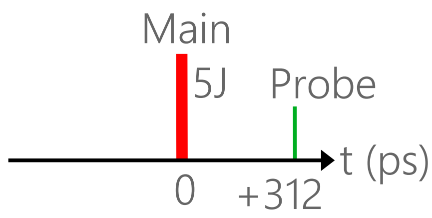

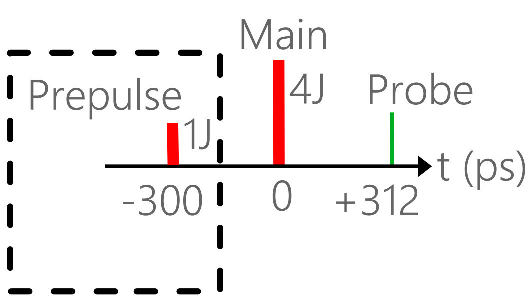

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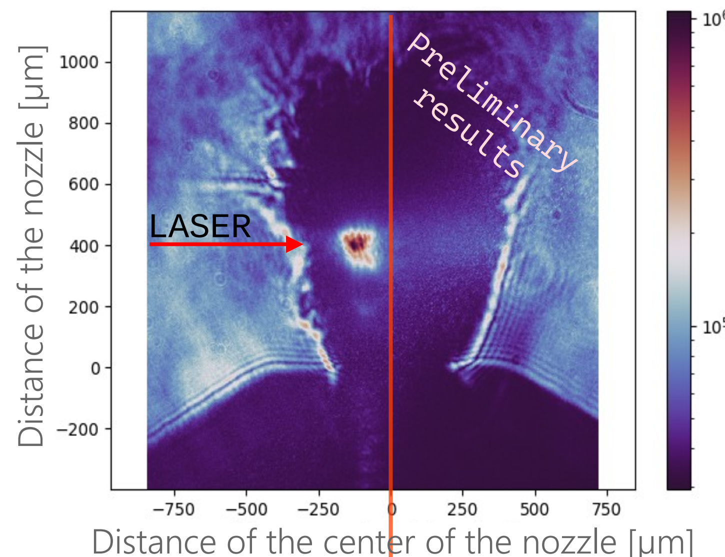

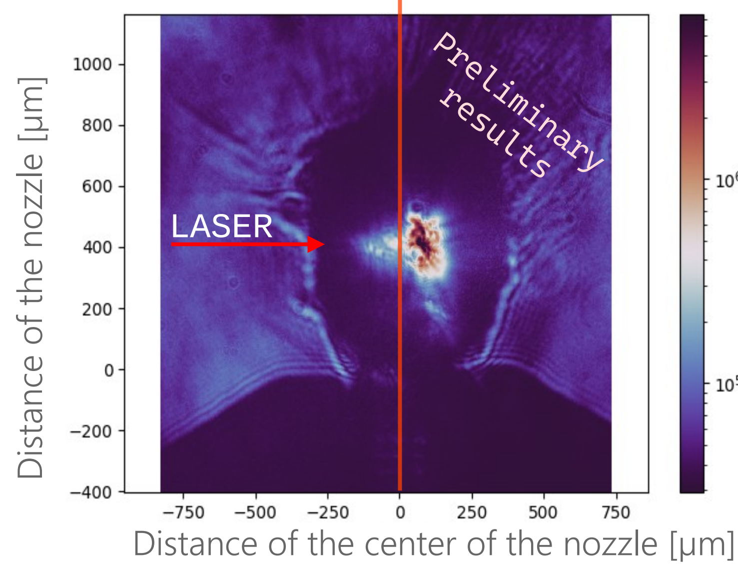

Prepulse allows the main pulse to interact with the **core** of the target : a **sharp gradient** and a **high electronic density**.

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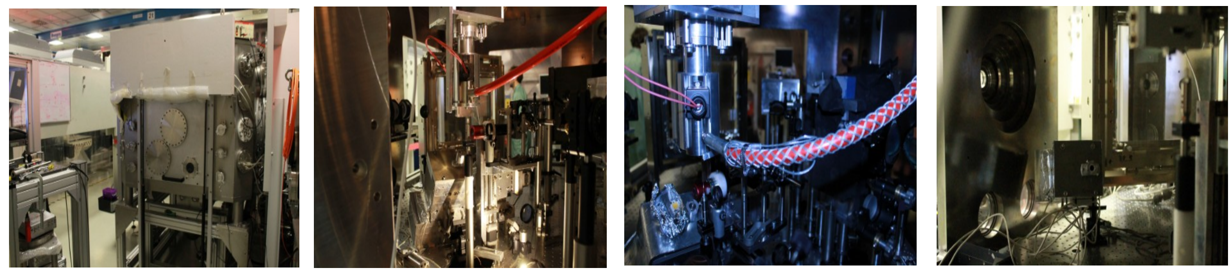

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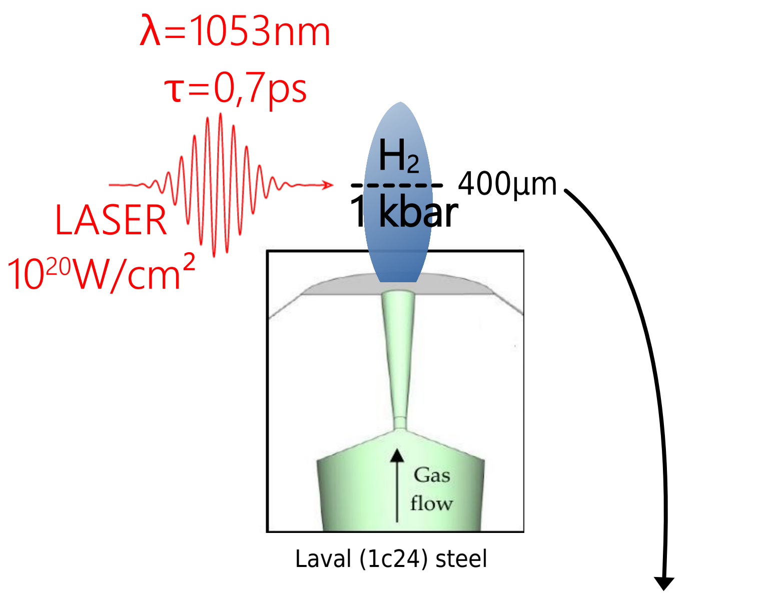

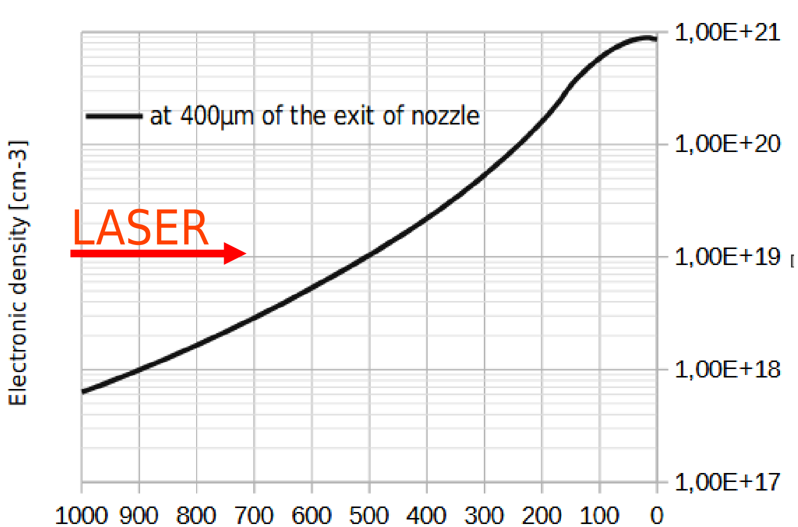

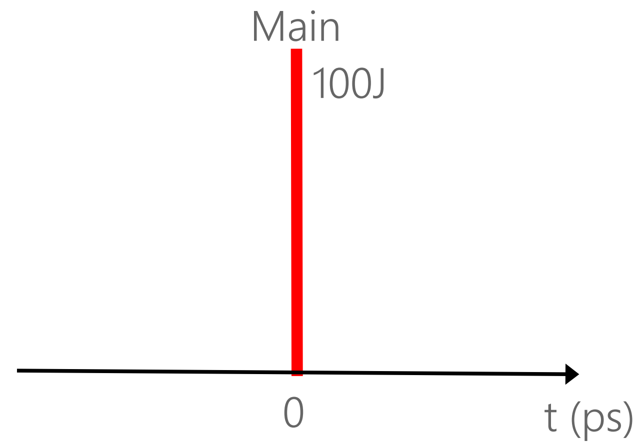

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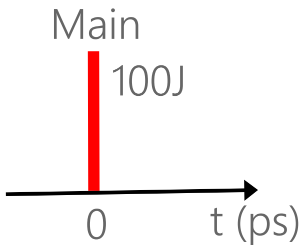
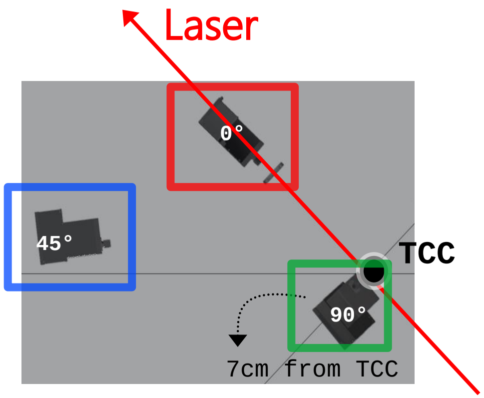
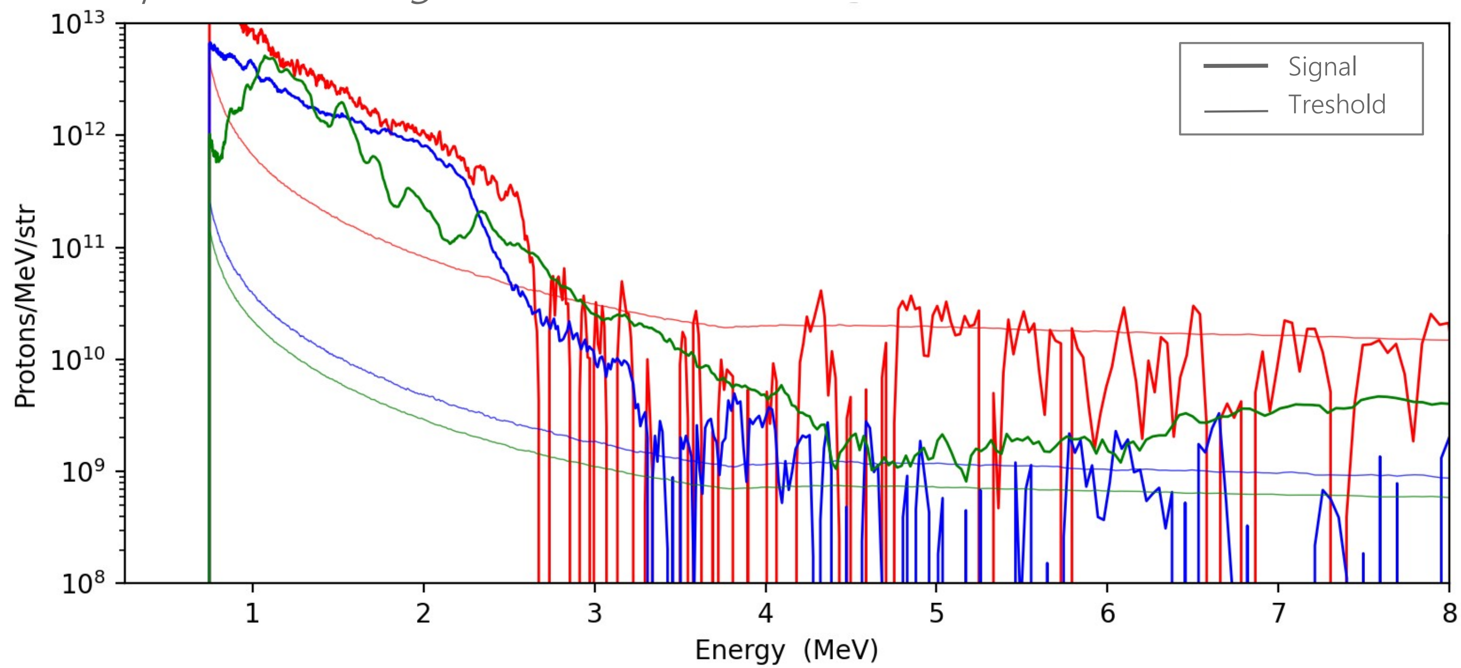




Spectra at all angles



- Different tresholds (X-ray coming from e^- at 0deg)
- Similar spectra at all angles
  - Same maximal number of protons at low energy.
  - Decrease of proton number by energy.
    - 0° : Cutoff energy at 2,5MeV.

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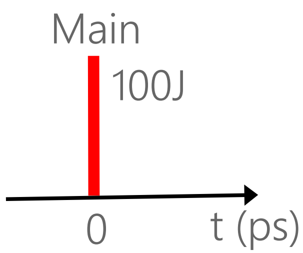

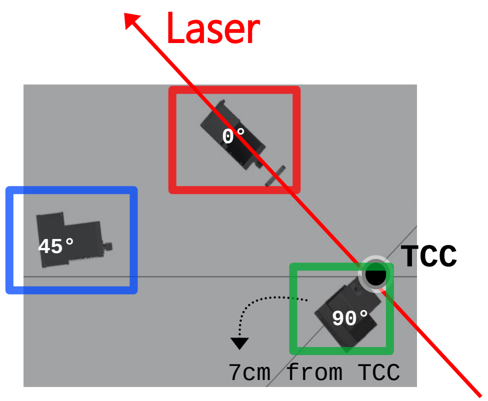

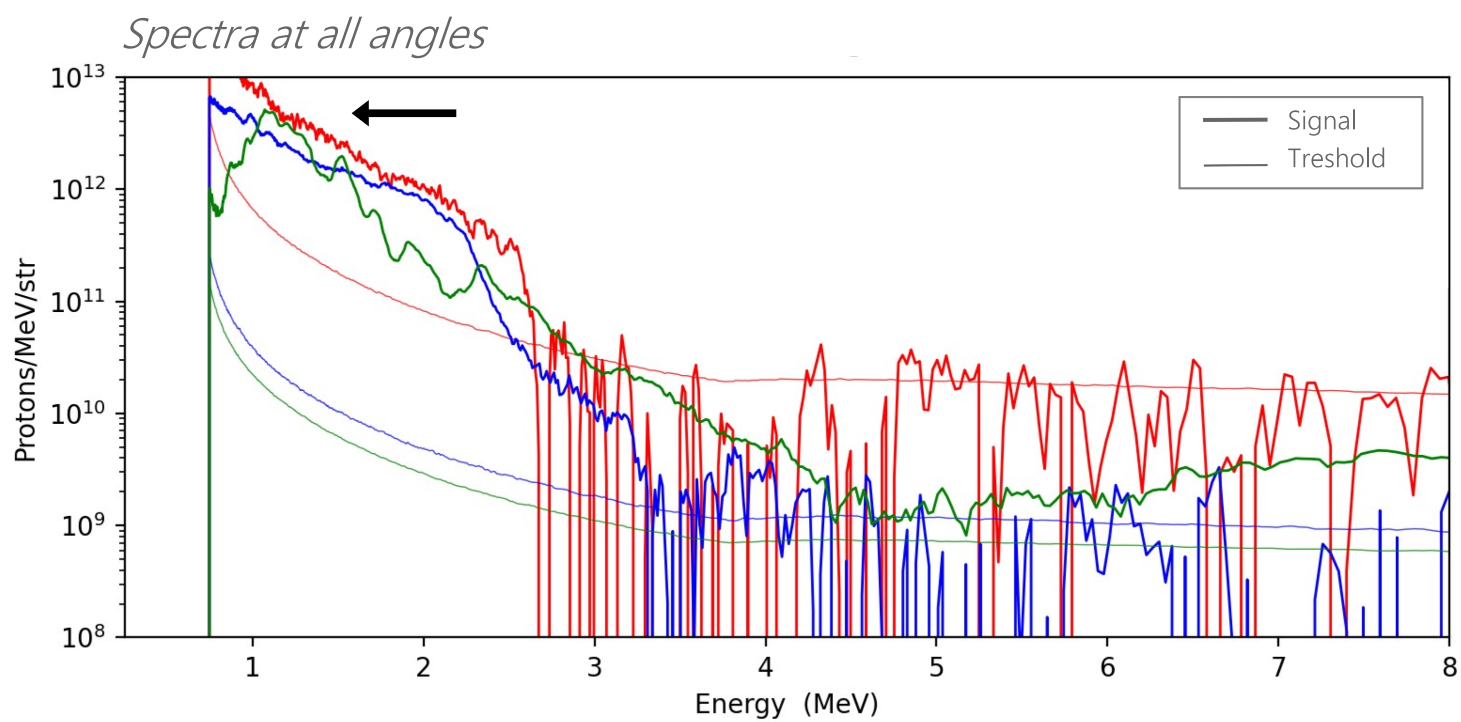

- Different tresholds (X-ray coming from e⁻ at 0deg)
- Similar spectra at all angles
  - Same maximal number of protons at low energy.
  - Soft decrease of proton number by energy.

Coulomb explosion

- 0° : Cutoff energy at 2,5MeV.

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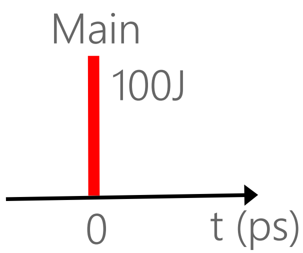

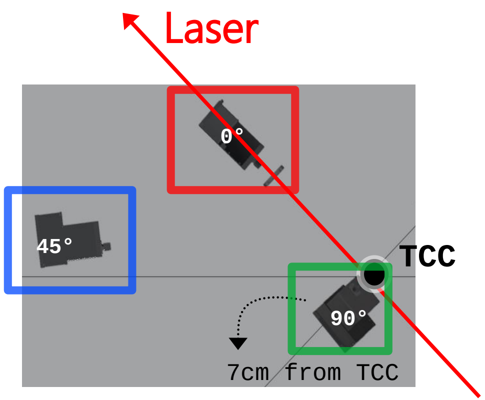

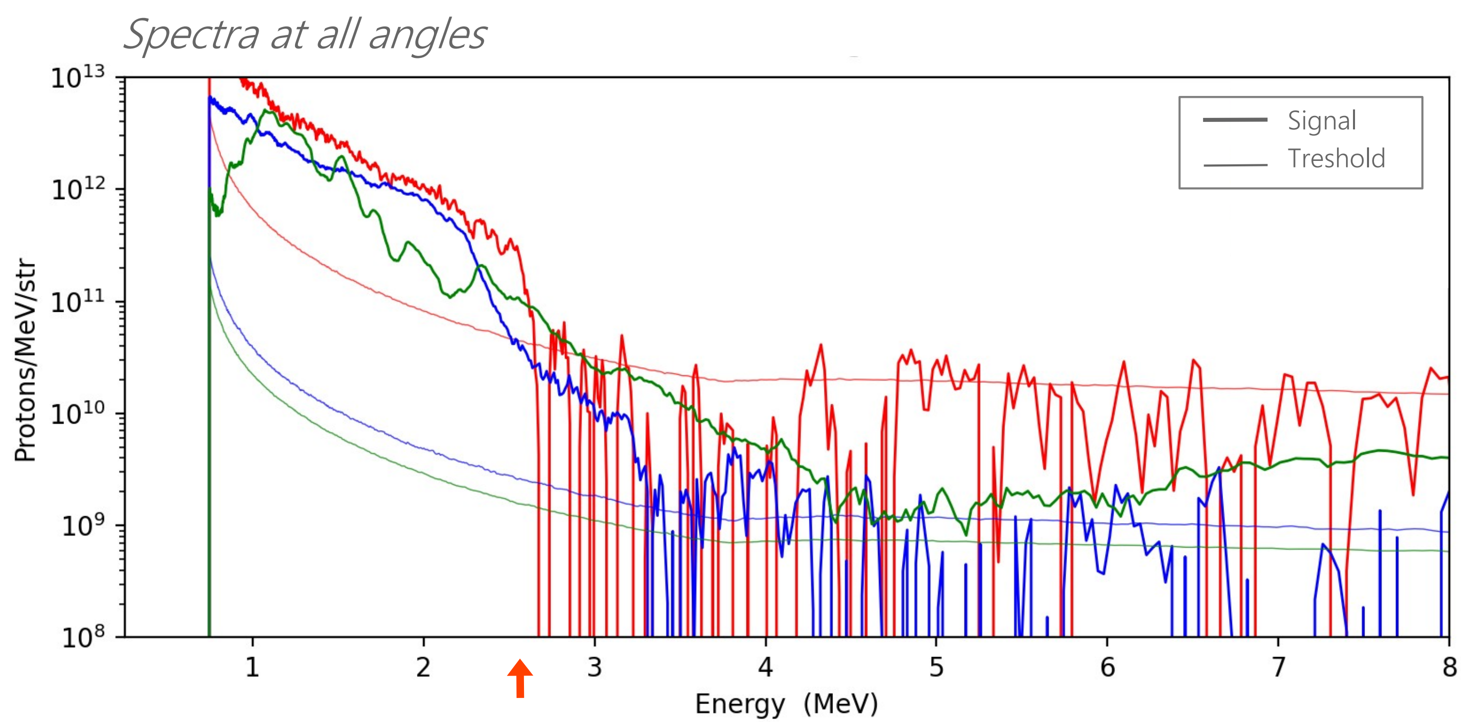

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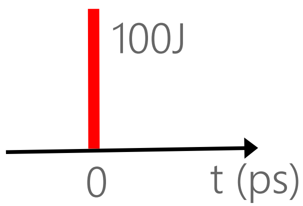

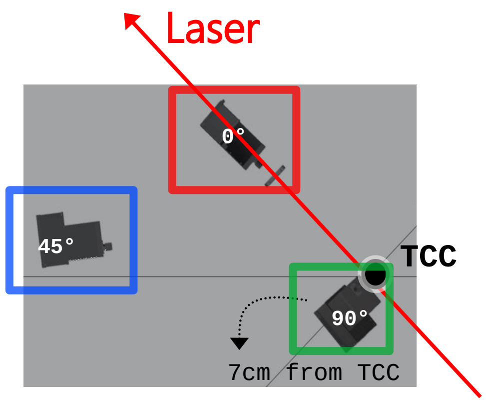

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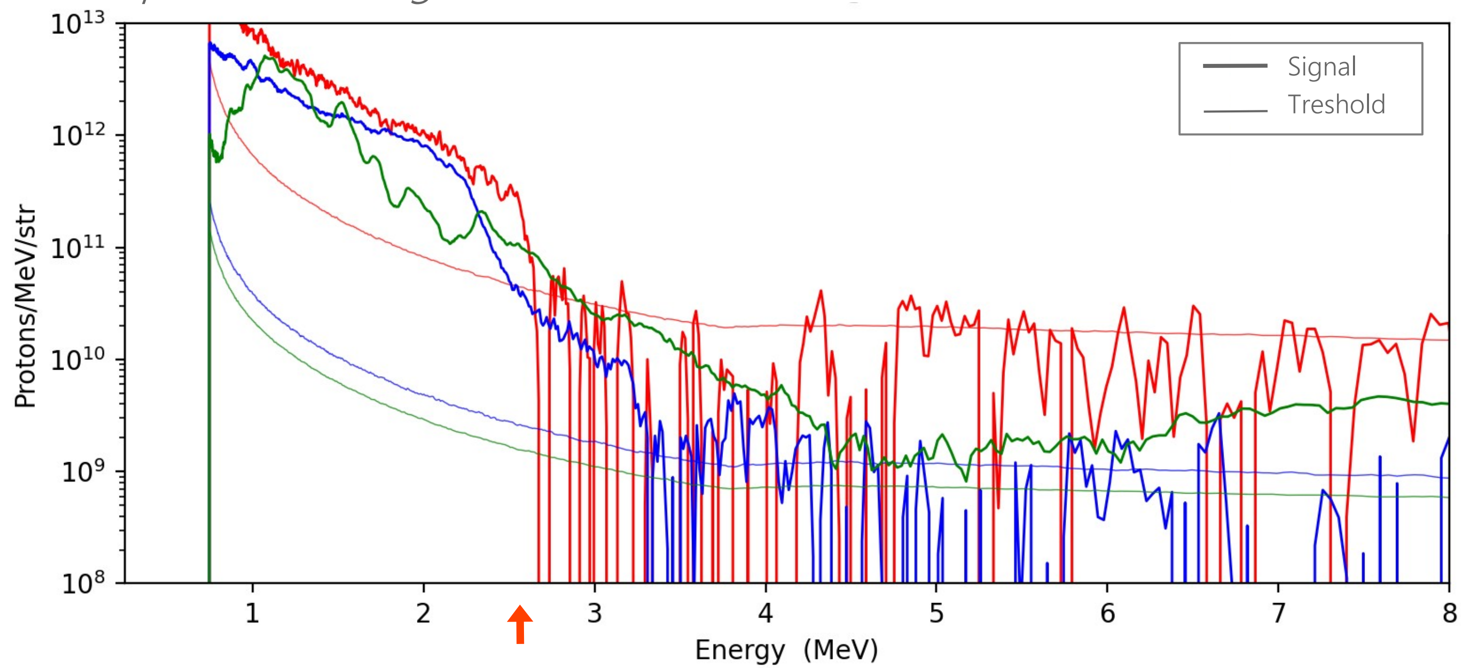

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- 0° : Cutoff energy at 2,5MeV.

No privileged direction of acceleration (isotropic).

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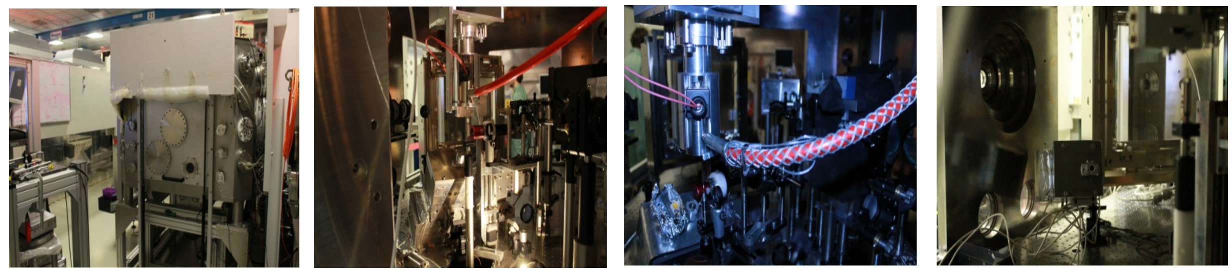

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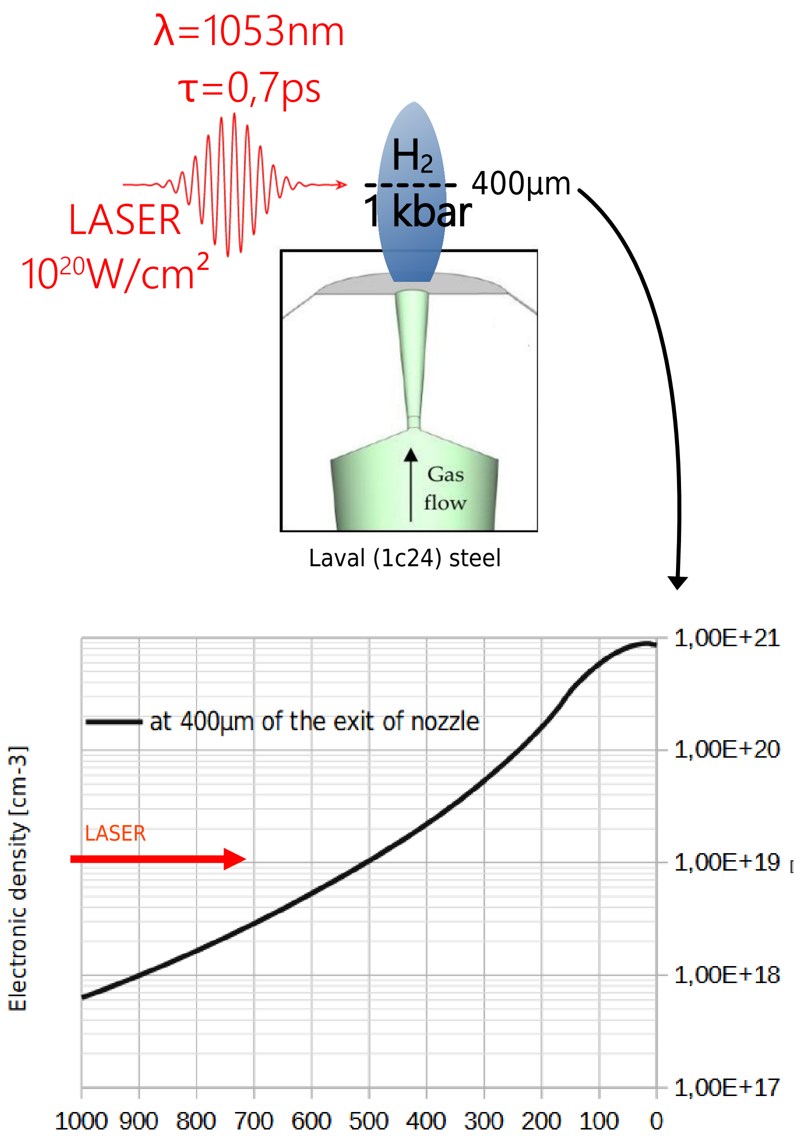

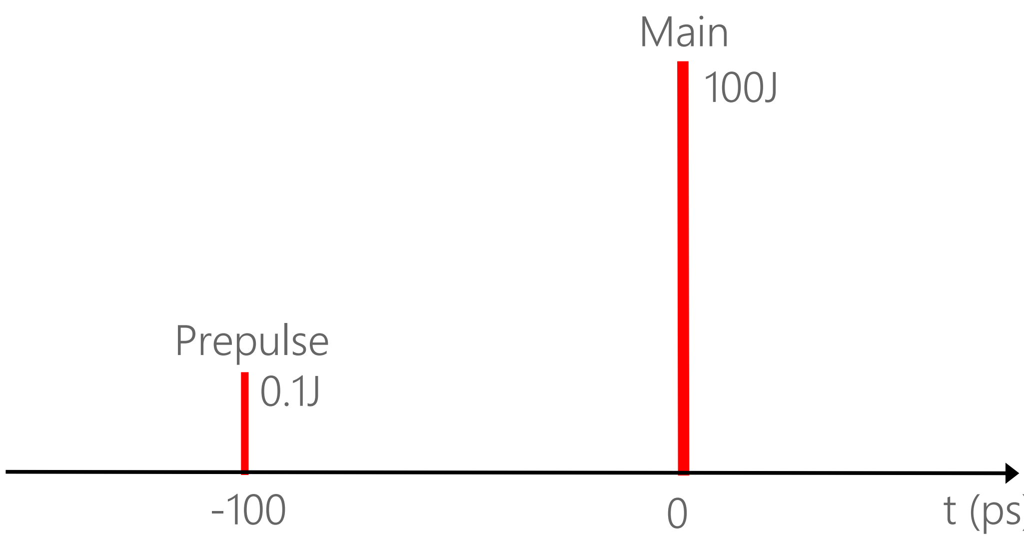

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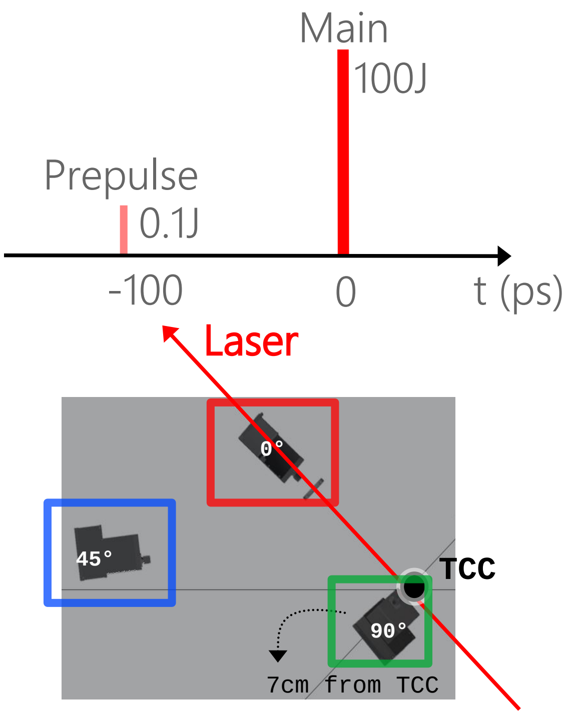

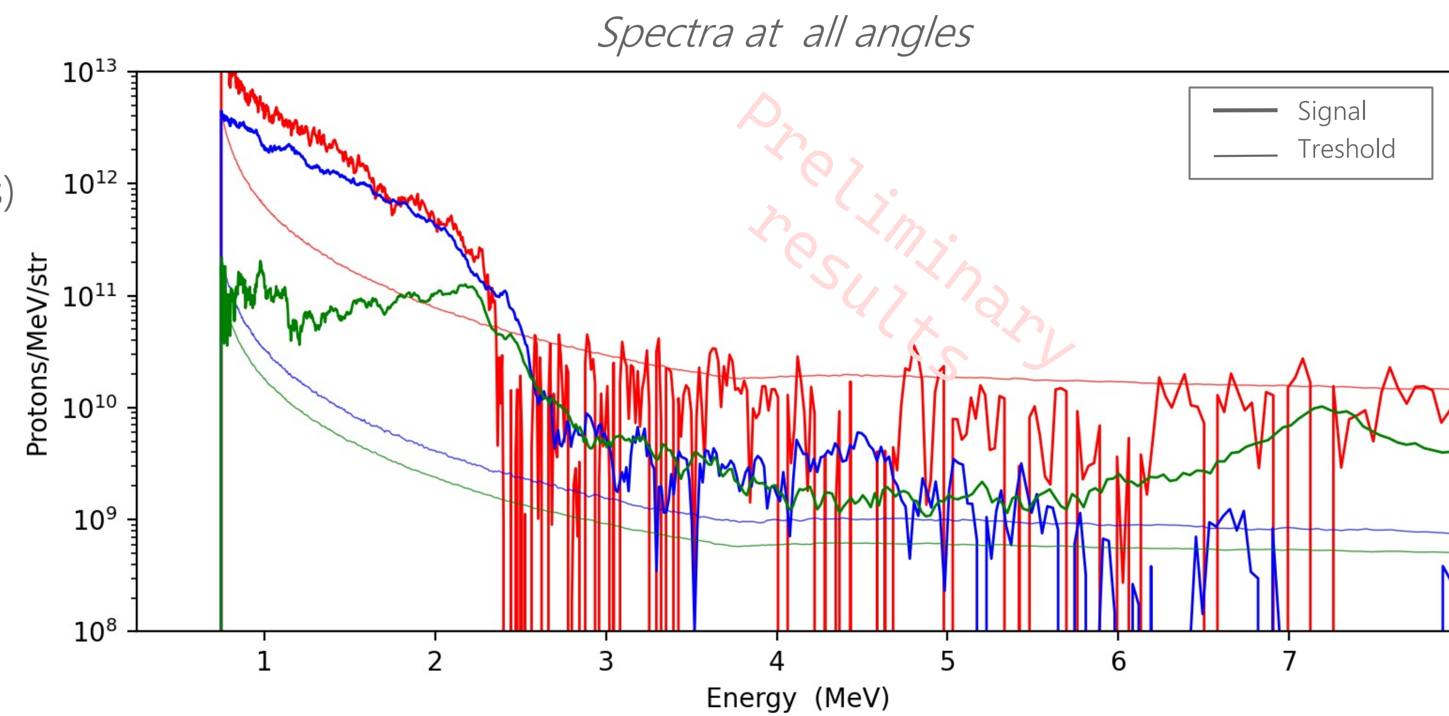

- Adding a prepulse change spectrum at 90° from laser axis :
  - Transverse acceleration more structured
  - There is less protons at low energy → directional
  - x1 structure at 7MeV

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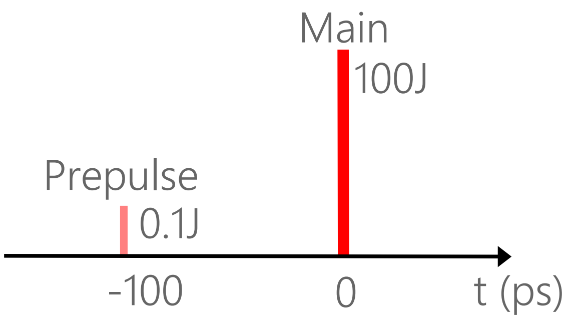

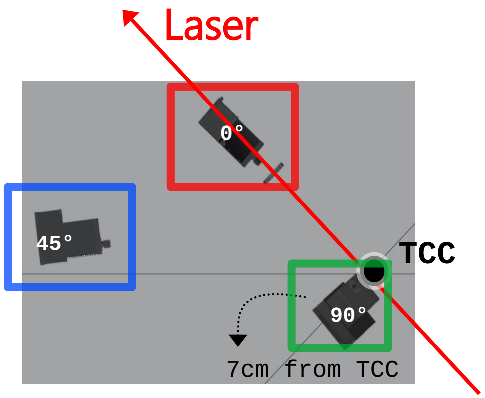

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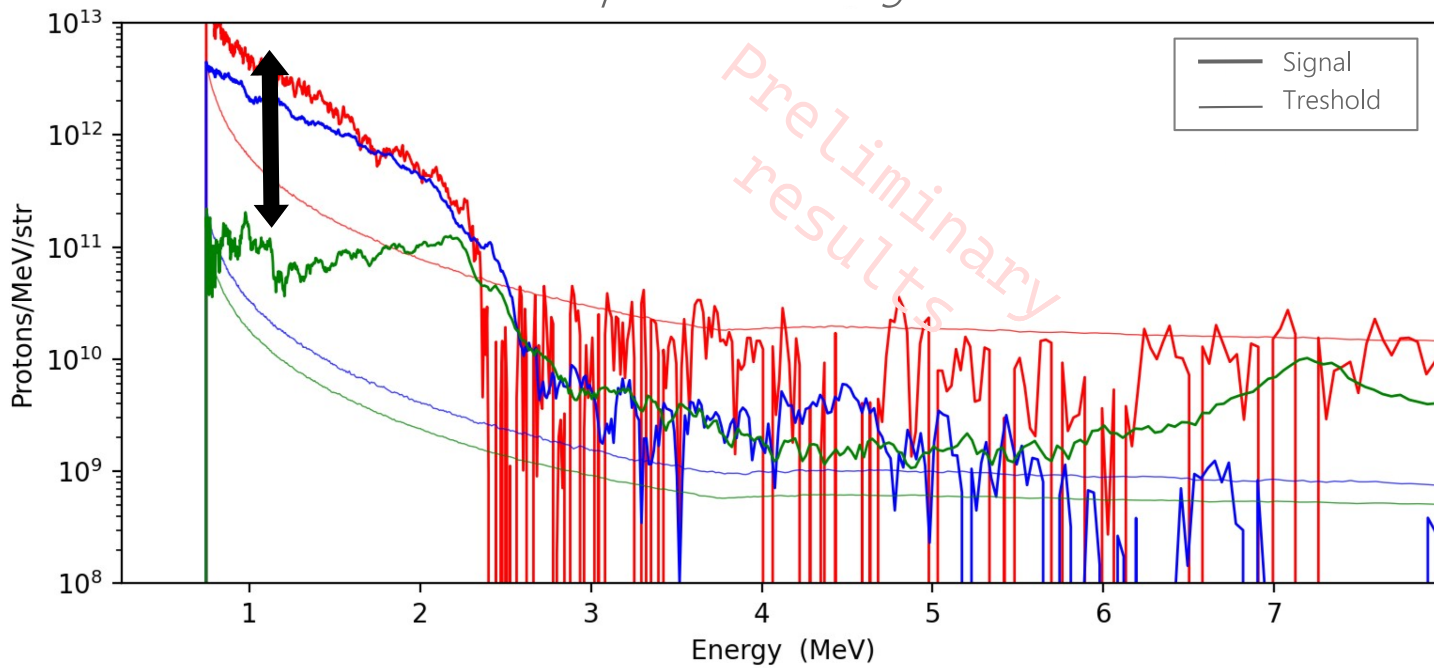

- Adding a prepulse change spectrum at 90° from laser axis :
  - Transverse acceleration is more structured
  - There is less protons at low energy → directional
  - x1 structure at 7MeV

Less coulomb explosion

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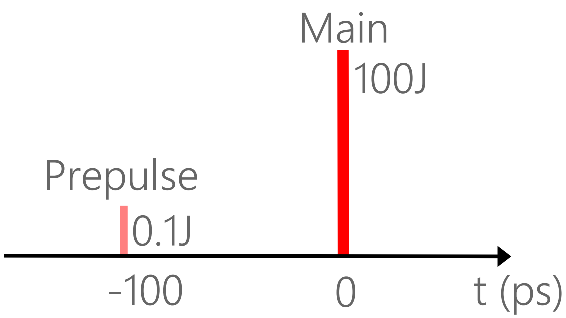
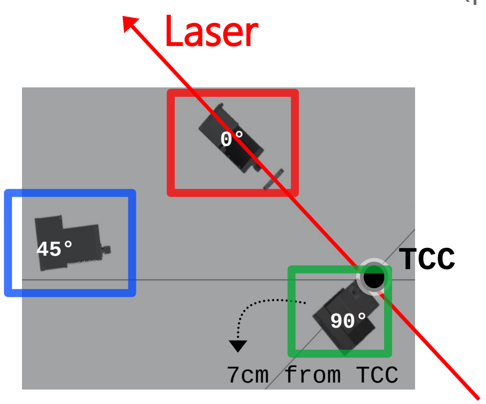
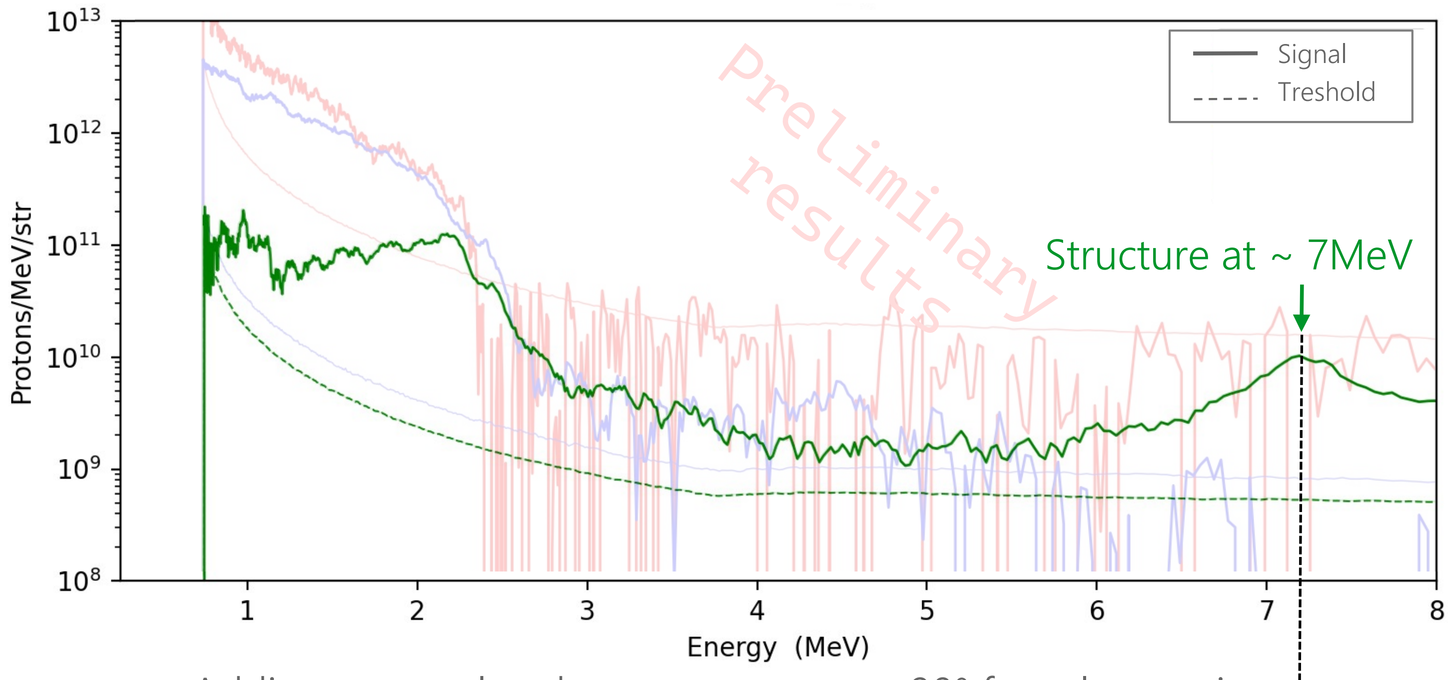




*Spectra at **90°** from the main laser direction*



- Adding a prepulse change spectrum at 90° from laser axis :
  - Transverse acceleration is more structured

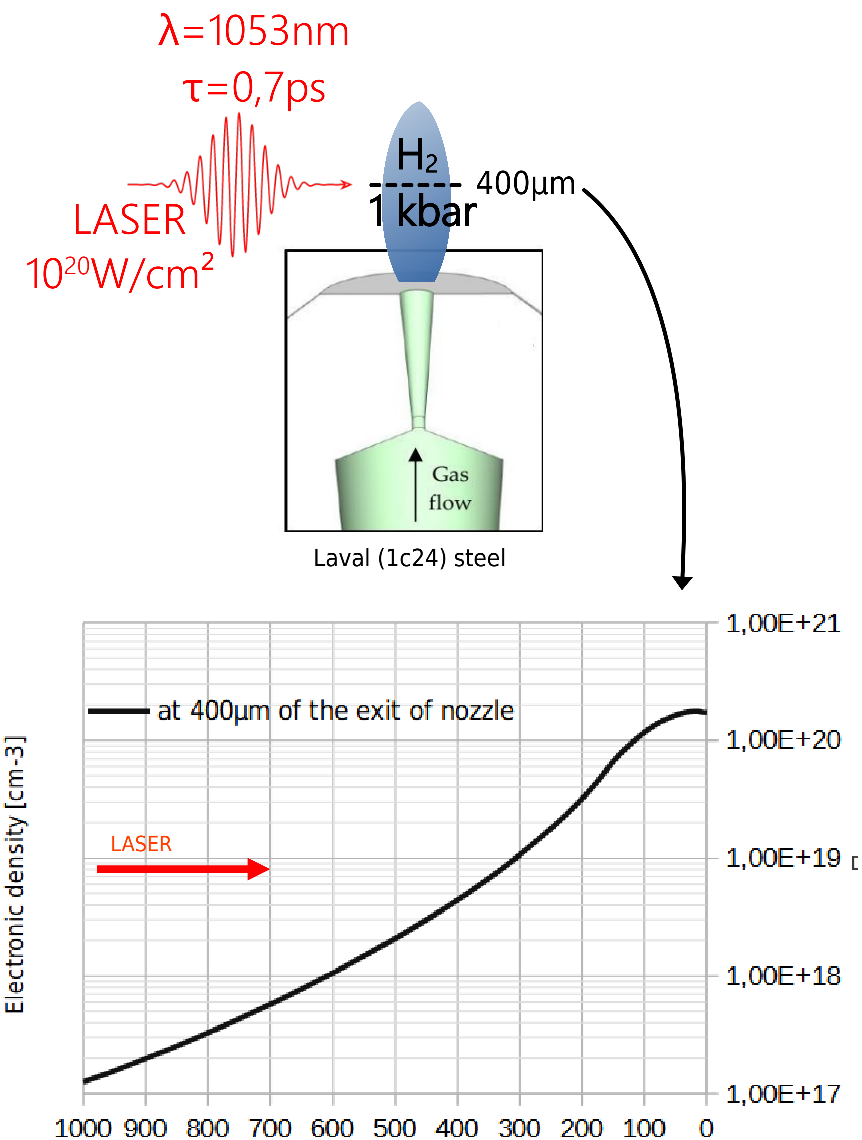
Less coulomb explosion ←
  - There is less protons at low energy → directional

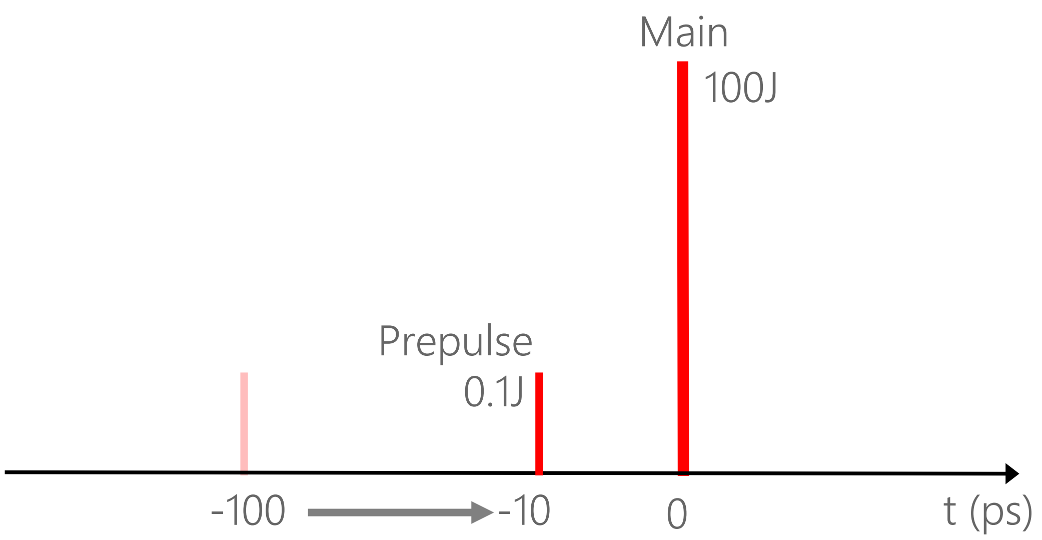
HBA + CSA ←
  - x1 structure at 7MeV

2. Results

2.2. Effect of the prepulse on ions spectra

2.2.2. Main at high energy (100J) with a low energy prepulse (0,1J) and 2 differents delays: {100;**10**}ps





2. Results

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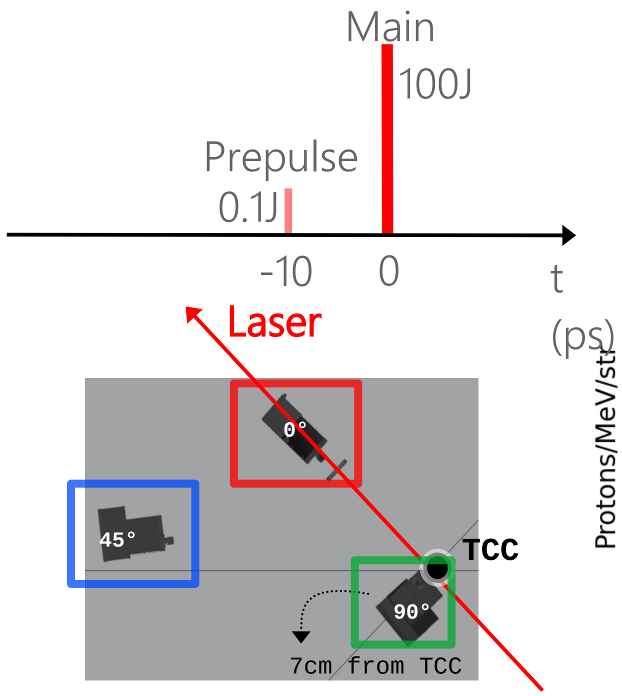
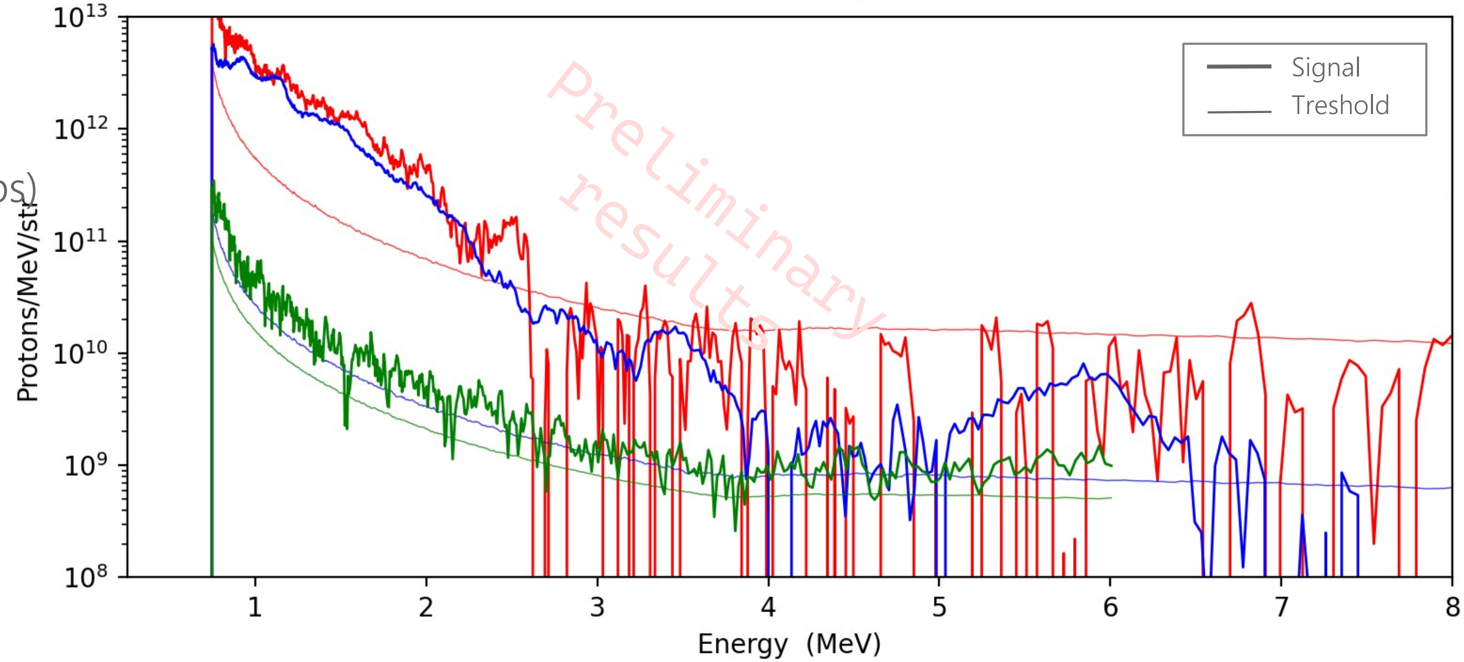


Spectra at all angles



2. Results

2.2. Effect of the prepulse on ions spectra

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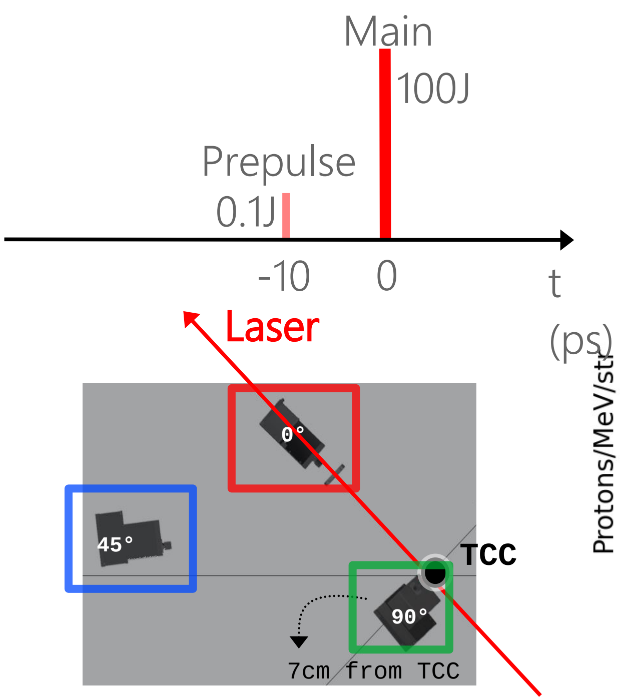

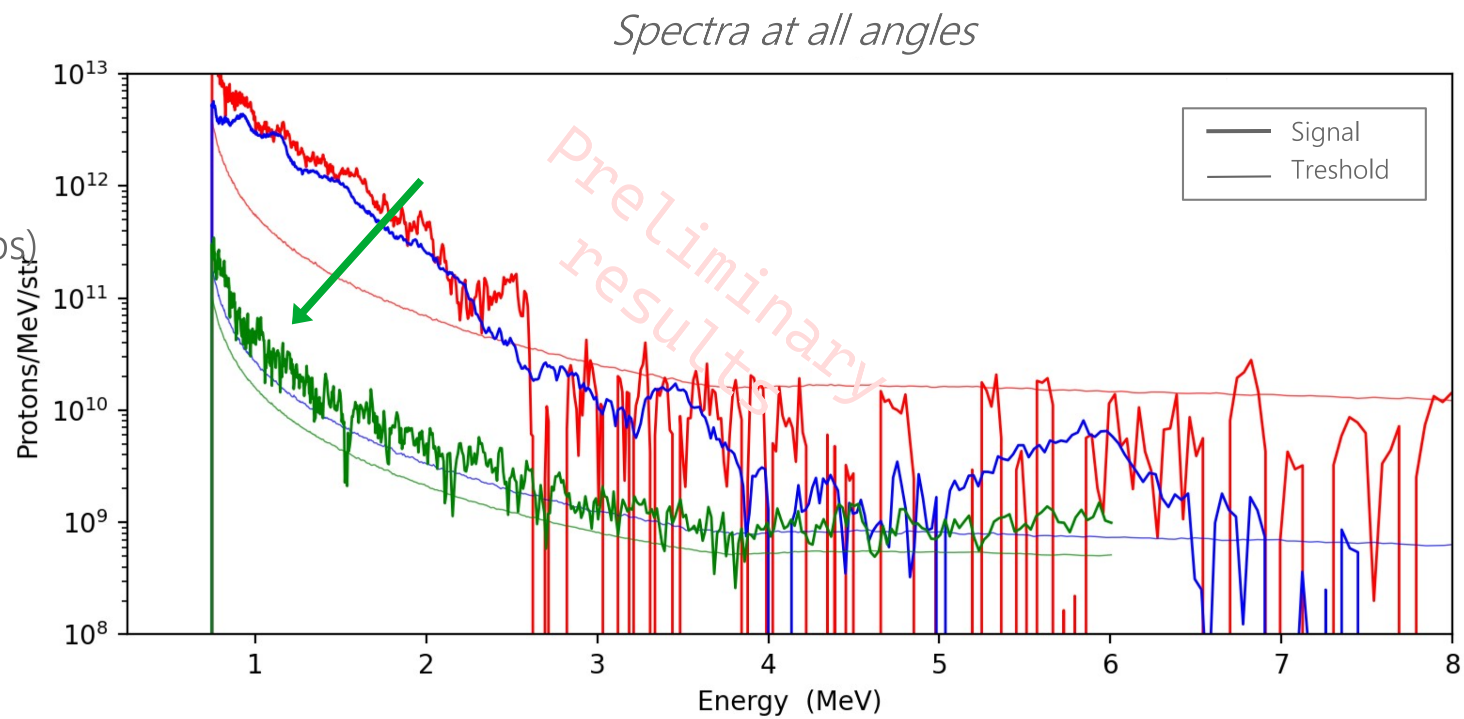

- No signal at 90°
- 0 & 45°
  - The maximum number of protons is almost identical
  - 45° : there are x2 structures

2. Results

2.2. Effect of the prepulse on ions spectra

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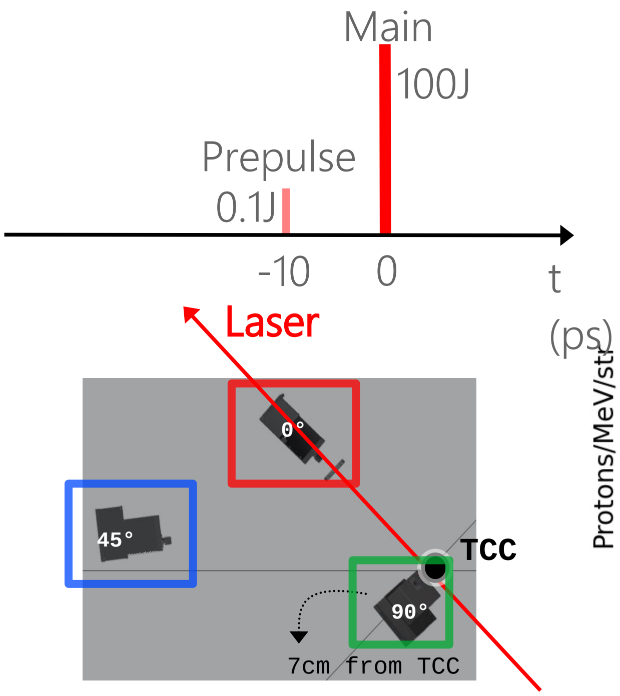

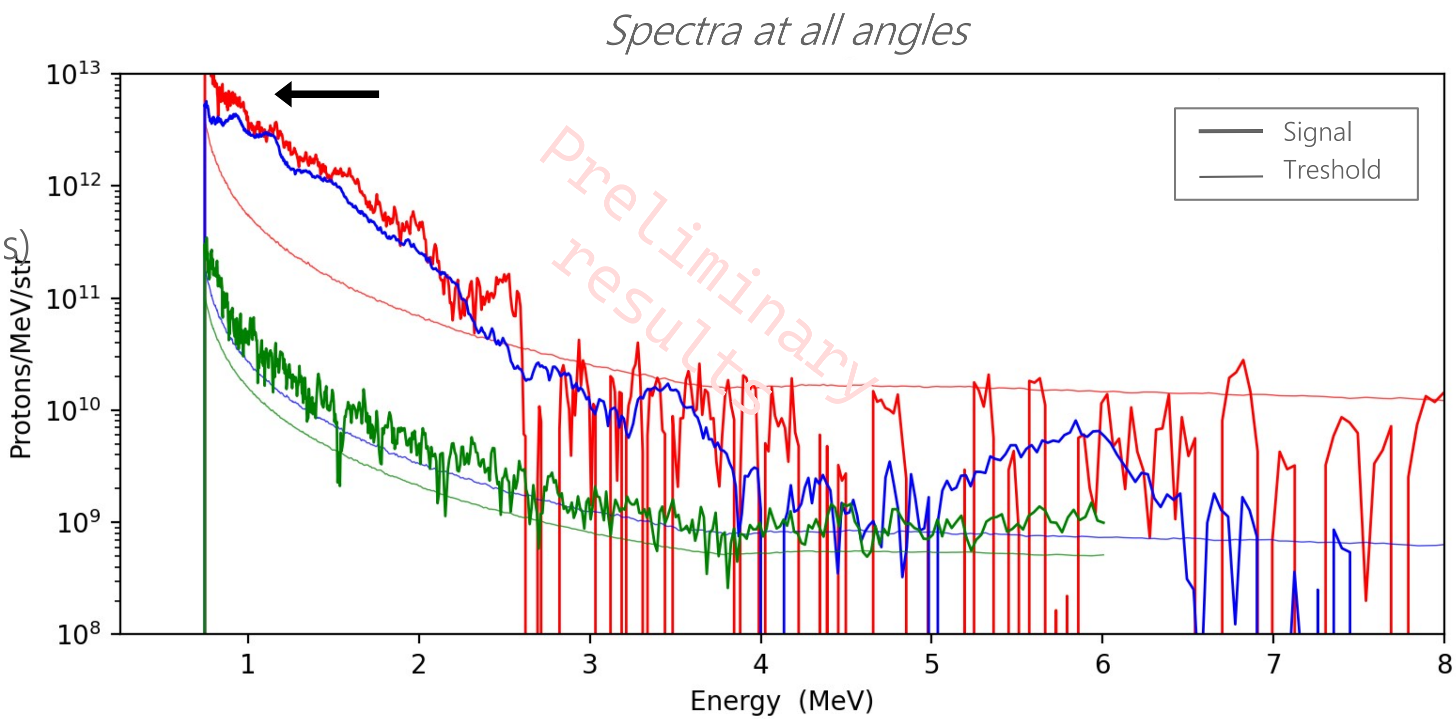

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Coulomb explosion

2. Results

2.2. Effect of the prepulse on ions spectra

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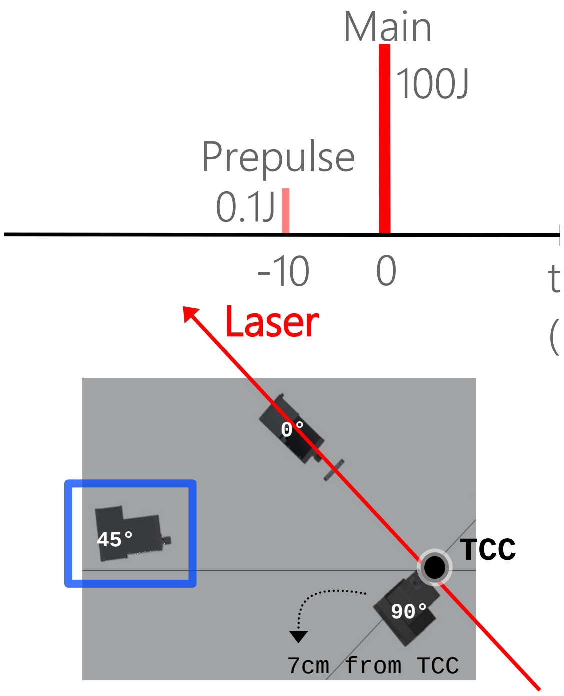
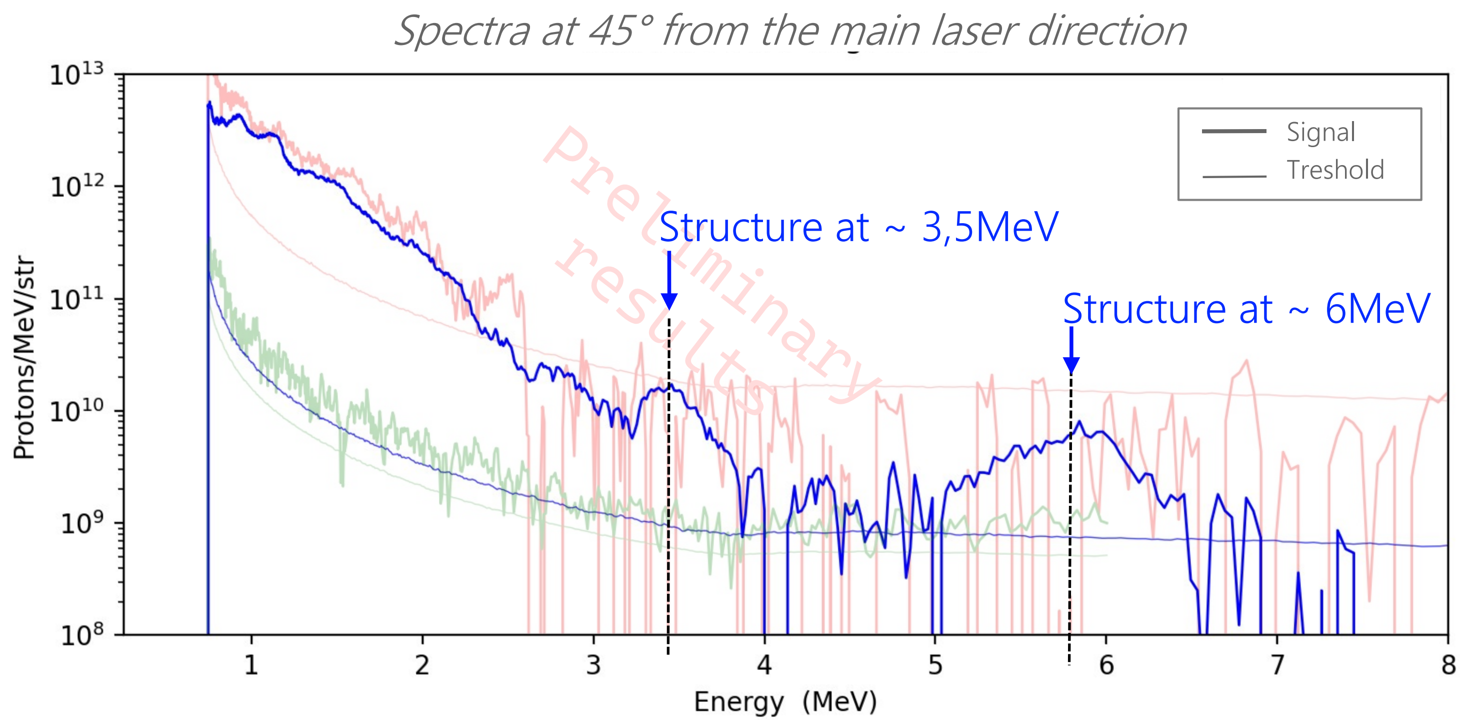




- No signal at 90°

- 0 & 45°
  - The maximum number of protons is almost identical
  - 45° : there are x2 structures

Coulomb explosion ← The maximum number of protons is almost identical

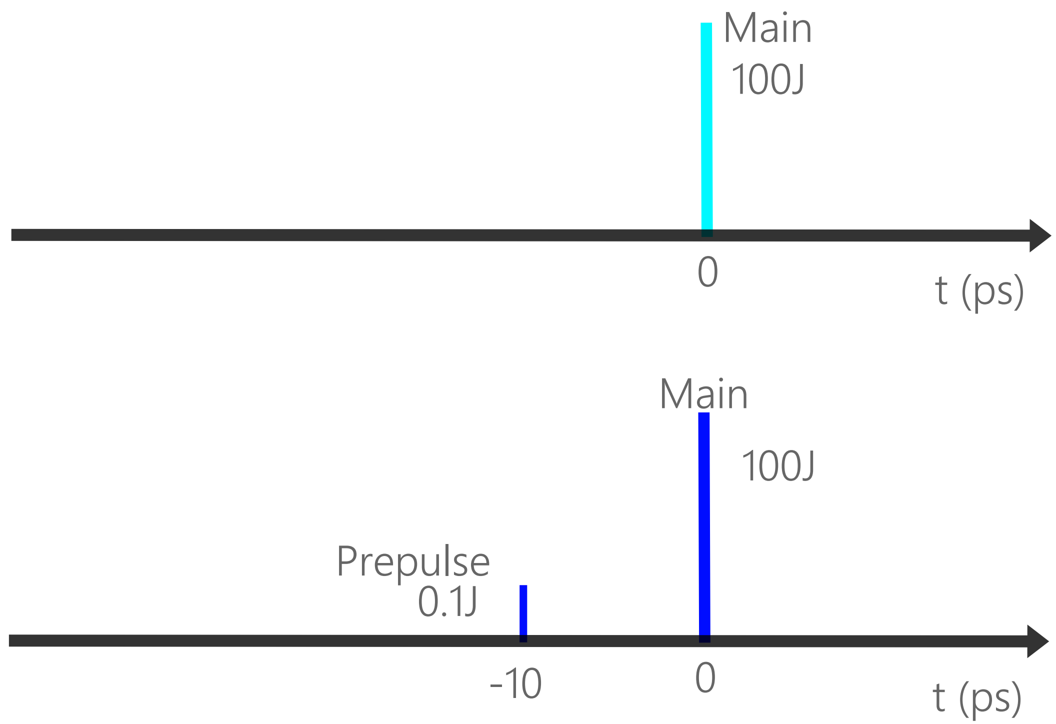
HBA + CSA ← 45° : there are x2 structures

2. Results

2.2. Effect of the prepulse on ions spectra

2.2.2. Main at high energy (100J) with a low energy prepulse (0,1J) and 2 differents delays: {100;**10**}ps

Comparing with the configuration of reference



2. Results

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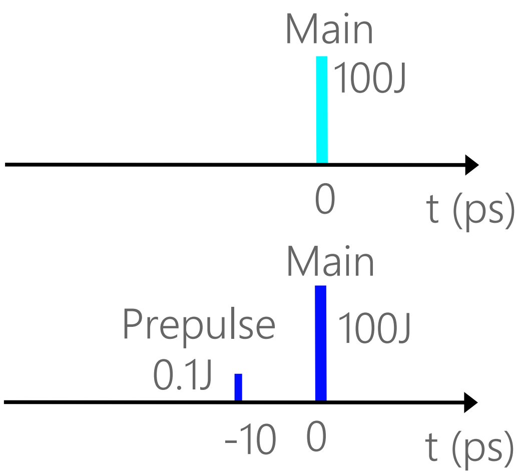
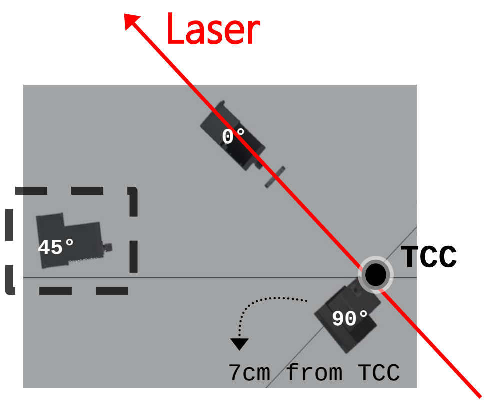
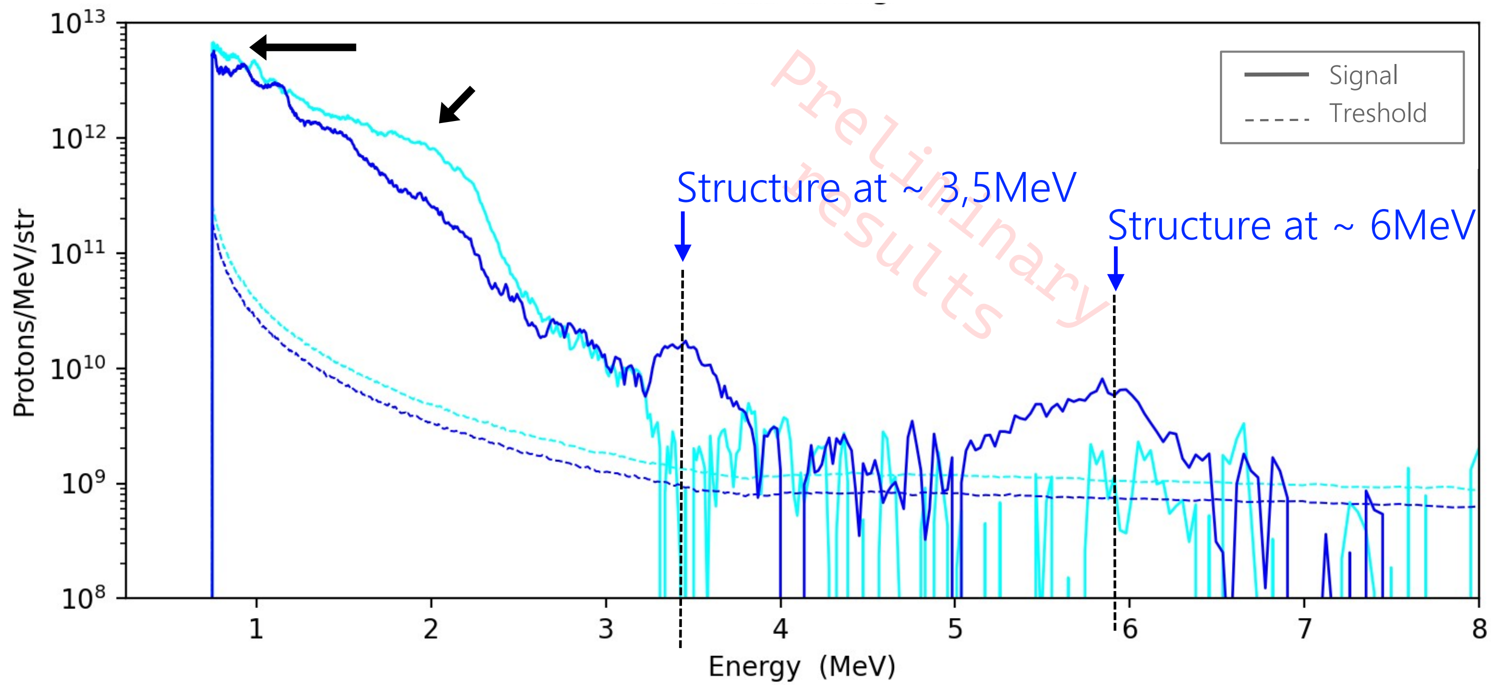




Spectra at 45° from the main laser propagation



Coulomb explosion

Other mecanisms ?

- Same maximal number of protons at low energy.
- Less proton at low energy (around 2 MeV)

Take-home message :

A prepulse change the shape of the energy spectra.

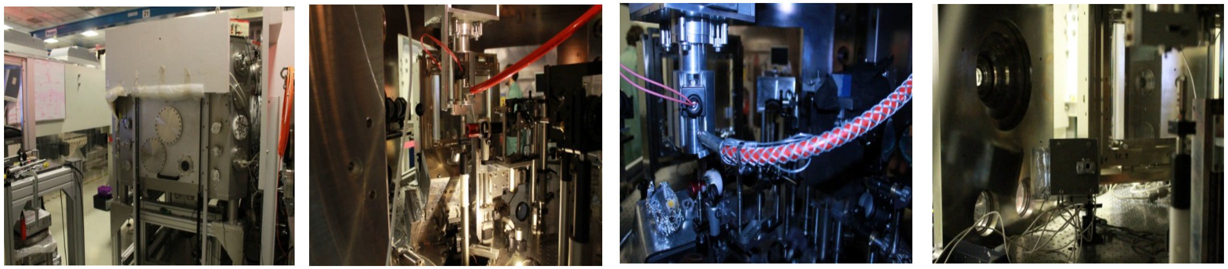
Outline

1. Experimental setup

1.1. Description

1.2. Thomson parabola

1.3. Shadowgraphy



Photos of P21-00004 experimental campaign on PHELIX GSI

2. Results

2.1. Effect of the prepulse at E_{main} = 5J on the interaction point.

2.2. Effect of the prepulse on ions spectra

2.2.1. Main at high energy (E_{main} = 100J) without prepulse

2.2.2. Case 1 : Main at high energy (E_{main} =100J) with a low energy prepulse (0,1J) and 2 differents delays: -100ps and -10ps

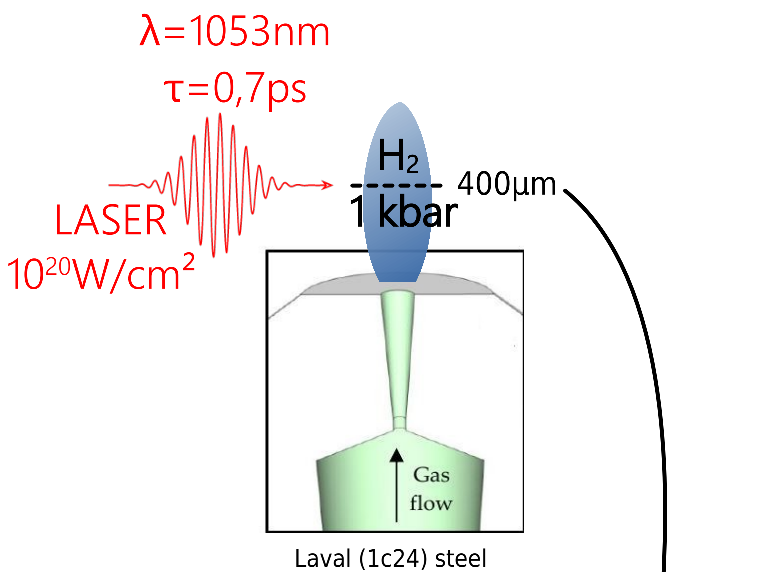
2.2.3. Case 2 & 3 : Delay scan and energy of the prepulse : 1J-100J & 50J-50J

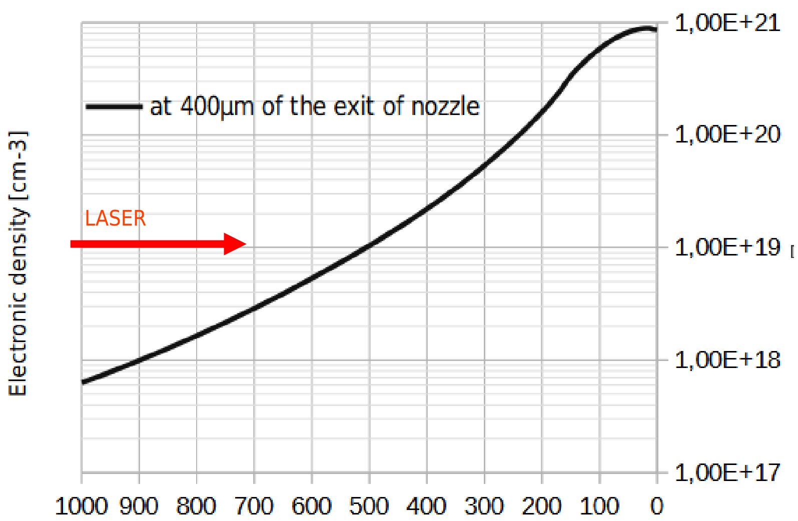
2.2.4. 3 cases comparison : energy scan at -100ps delay of the prepulse.

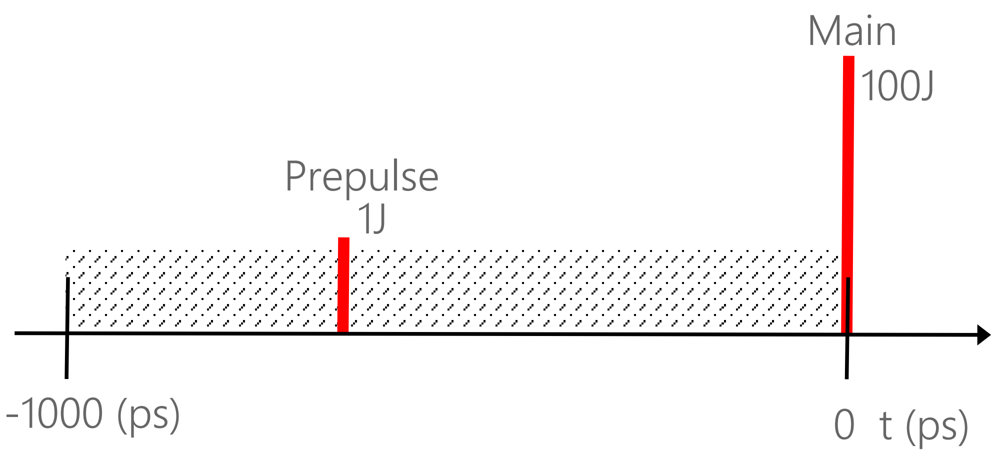
2. Results

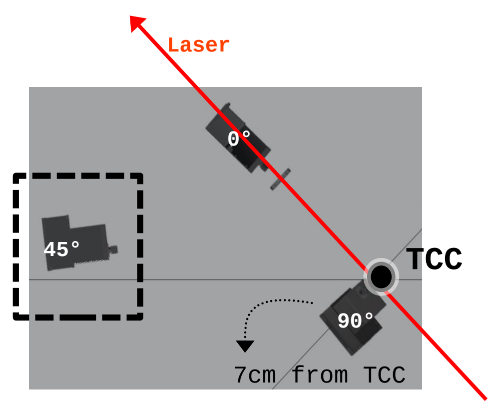
2.2. Effect of the prepulse on ions spectra

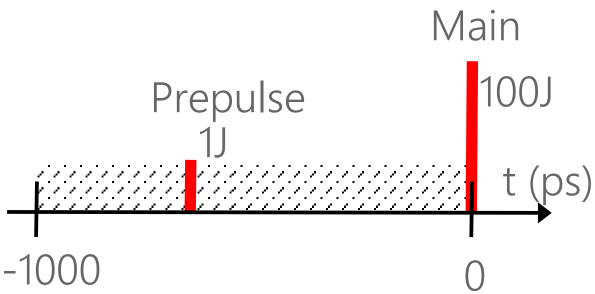
2.2.3. Delay scan and energy of the prepulse : **1J-100J** & 50J-50J

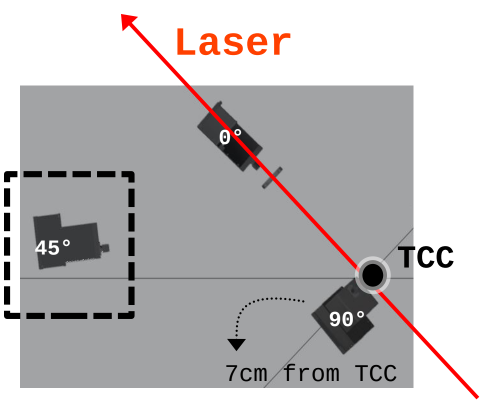


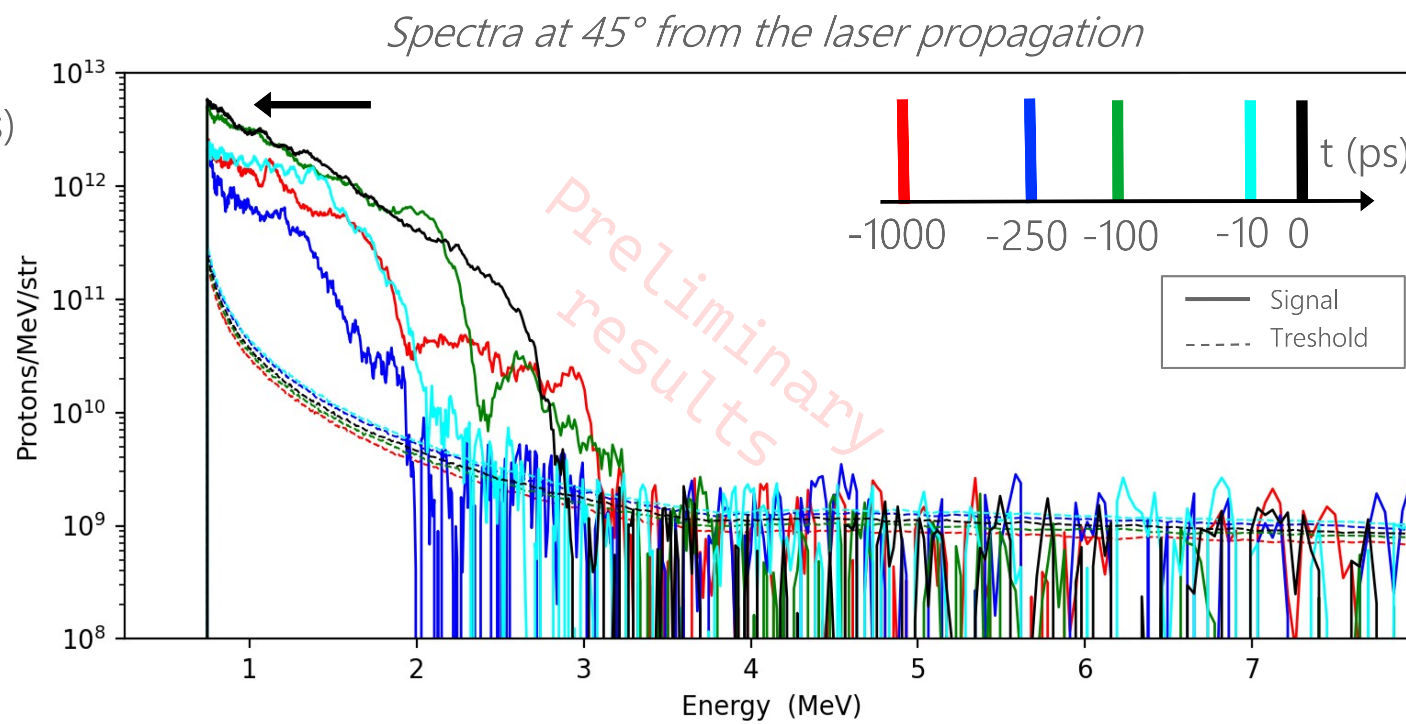












Coulomb explosion

- No clear relation between prepulse delays and maximum number of protons.

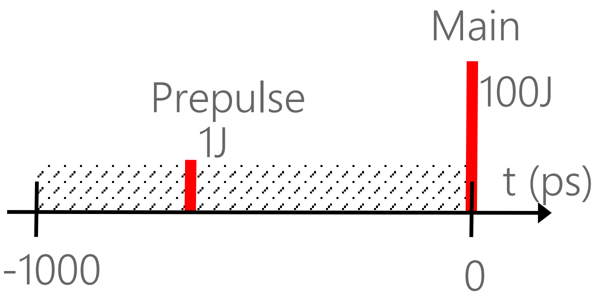
- -100ps delay reach the maximum of energy : 3 MeV.
- Loss of low energy protons

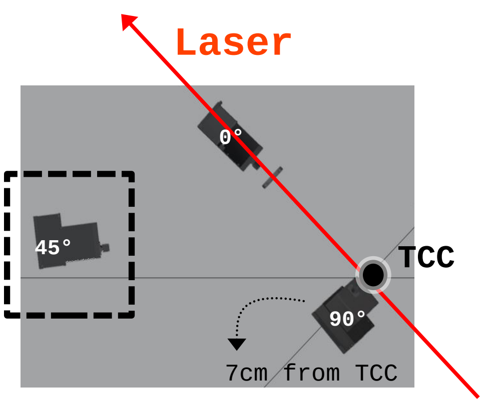
- The acceleration is directional for the -100ps delay

2. Results

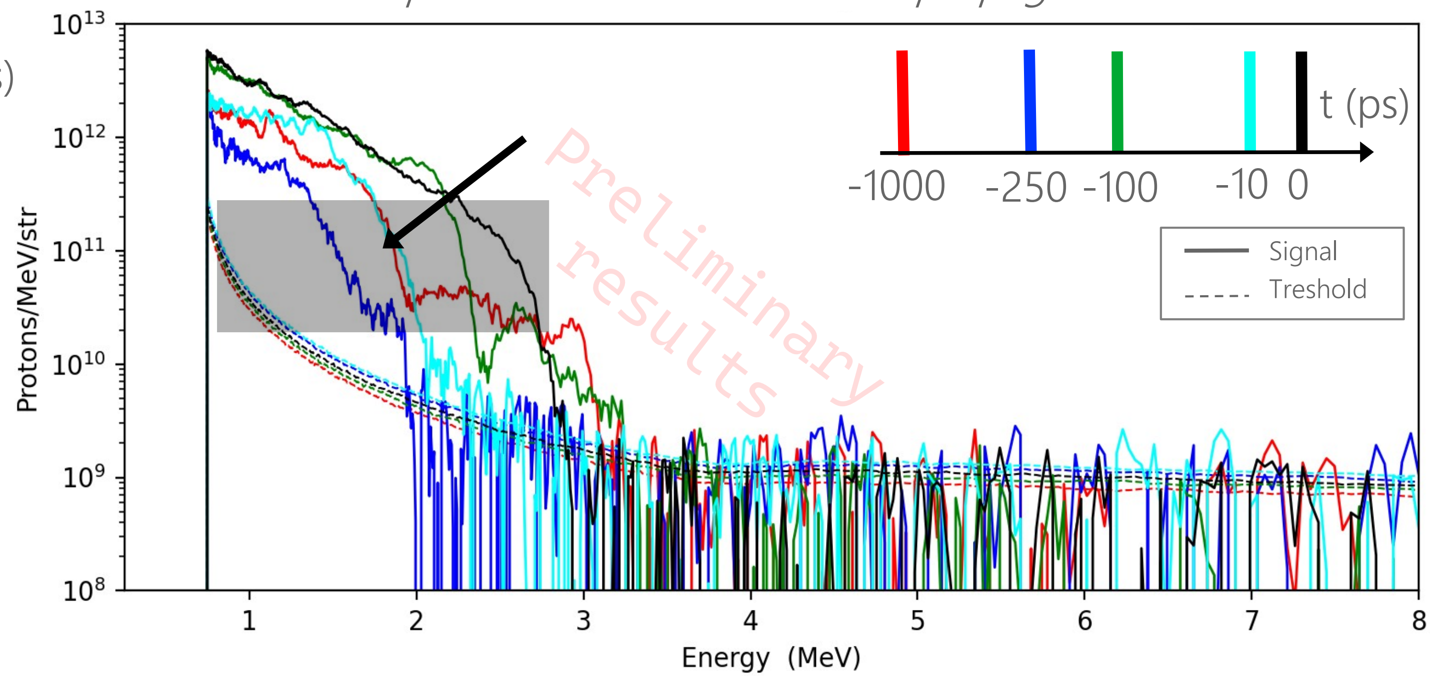
2.2. Effect of the prepulse on ions spectra

2.2.3. Delay scan and energy of the prepulse : **1J-100J** & 50J-50J





Spectra at 45° from the laser propagation



Coulomb explosion ← • No clear relation between prepulse delays and maximum number of protons.

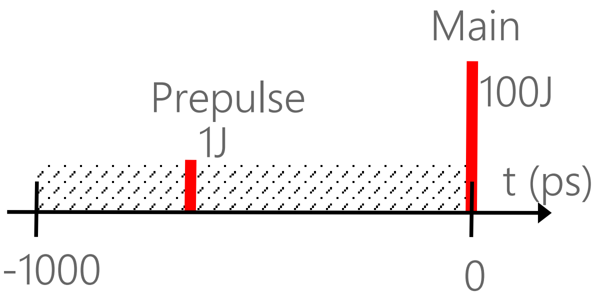
Less coulomb explosion ← • -100ps delay reach the maximum of energy : 3 MeV.
• Loss of low energy protons

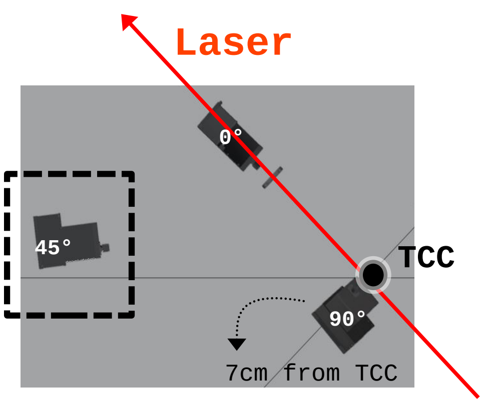
• The acceleration is directional for the -100ps delay

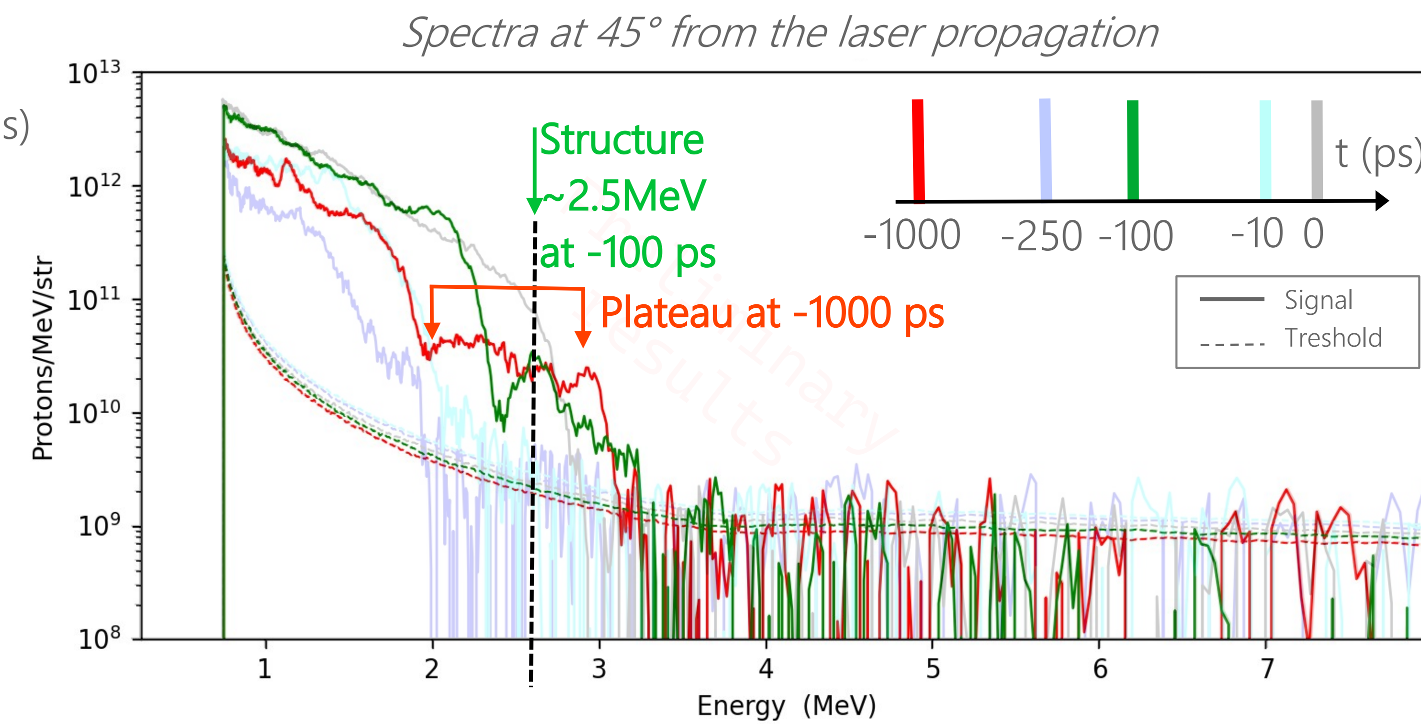
2. Results

2.2. Effect of the prepulse on ions spectra

2.2.3. Delay scan and energy of the prepulse : **1J-100J** & 50J-50J







Coulomb explosion ← • No clear relation between prepulse delays and maximum number of protons.

Less coulomb explosion ← • -100ps delay reach the maximum of energy : 3 MeV.
• Loss of low energy protons

HBA + CSA ← • The acceleration is directional for the **-100ps delay**

2. Results

2.2. Effect of the prepulse on ions spectra

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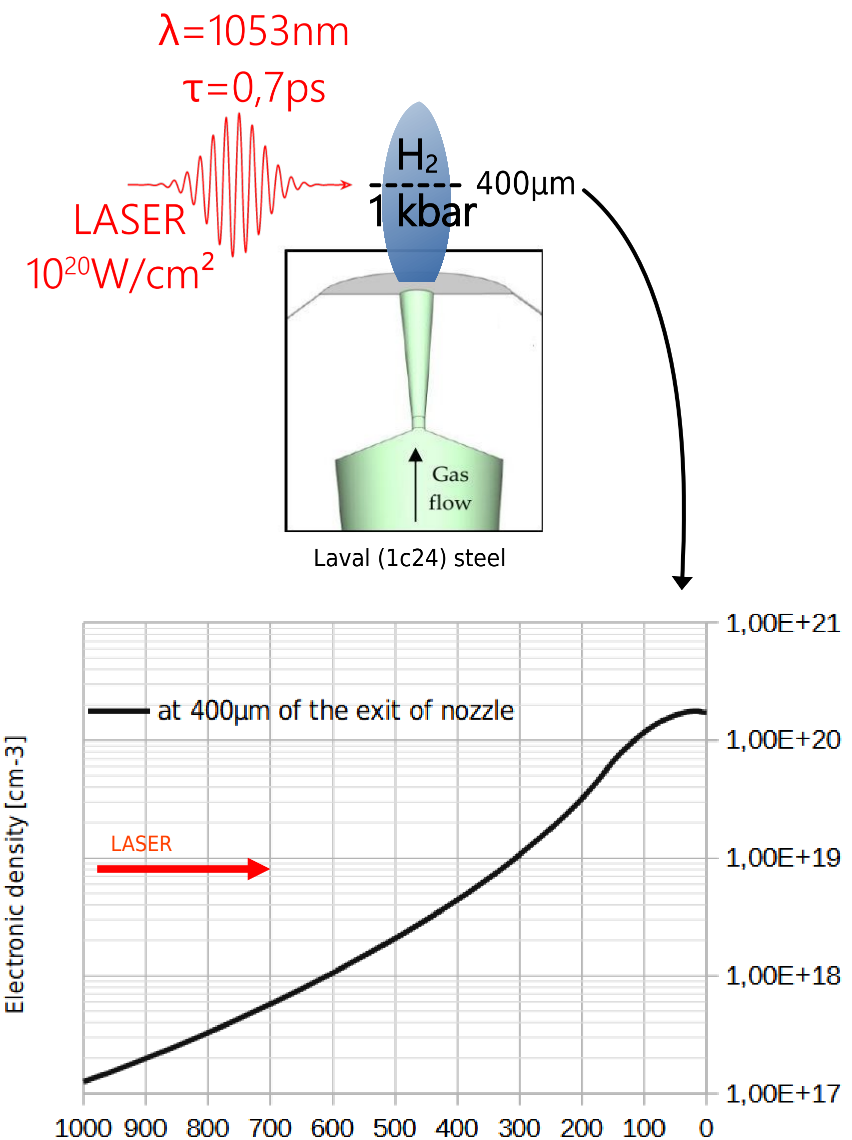

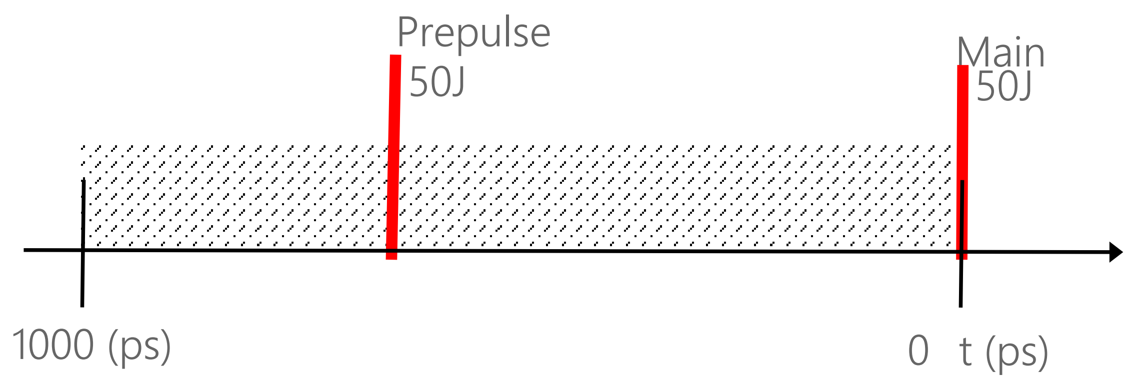

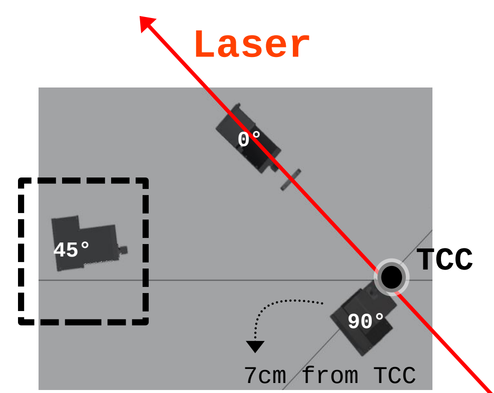

2. Results

2.2. Effect of the prepulse on ions spectra

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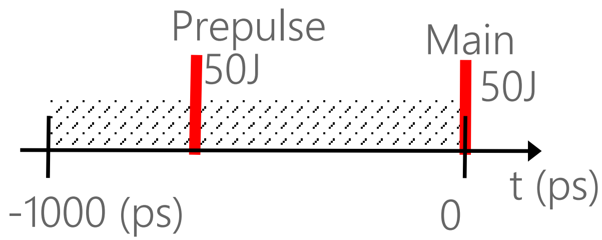
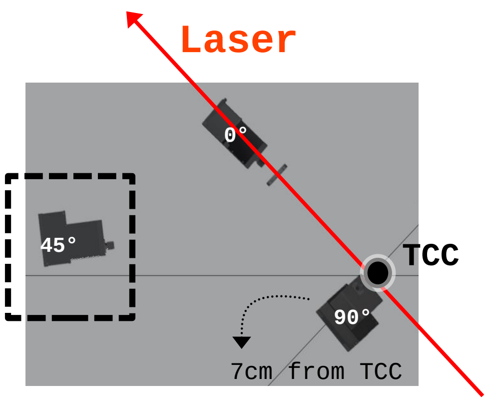
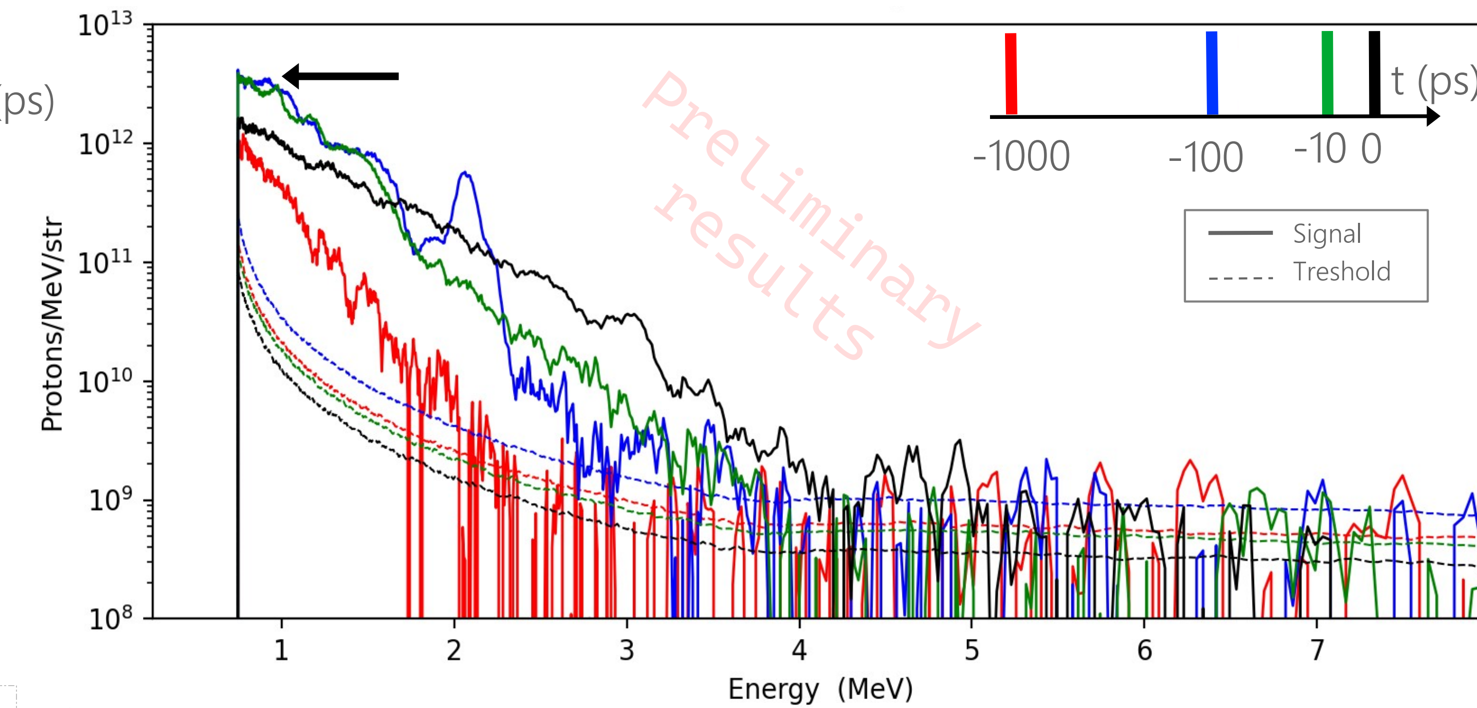






Coulomb explosion

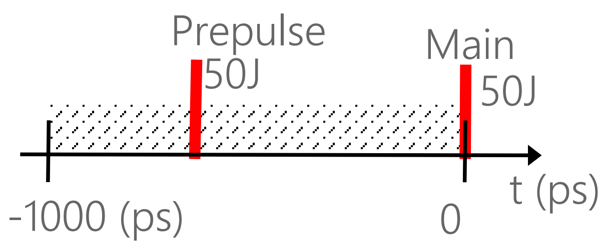
- No relation between prepulse delays and maximum number of protons is observed.

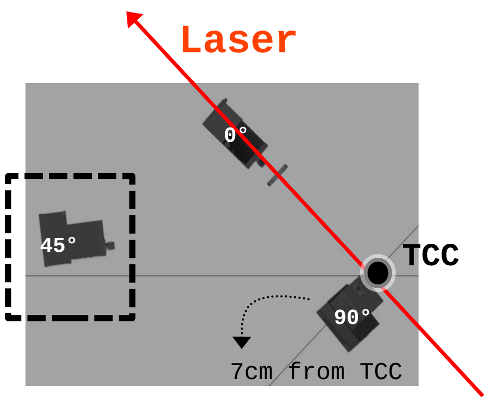
- Directional acceleration at 45° with high number of protons (10^{12})

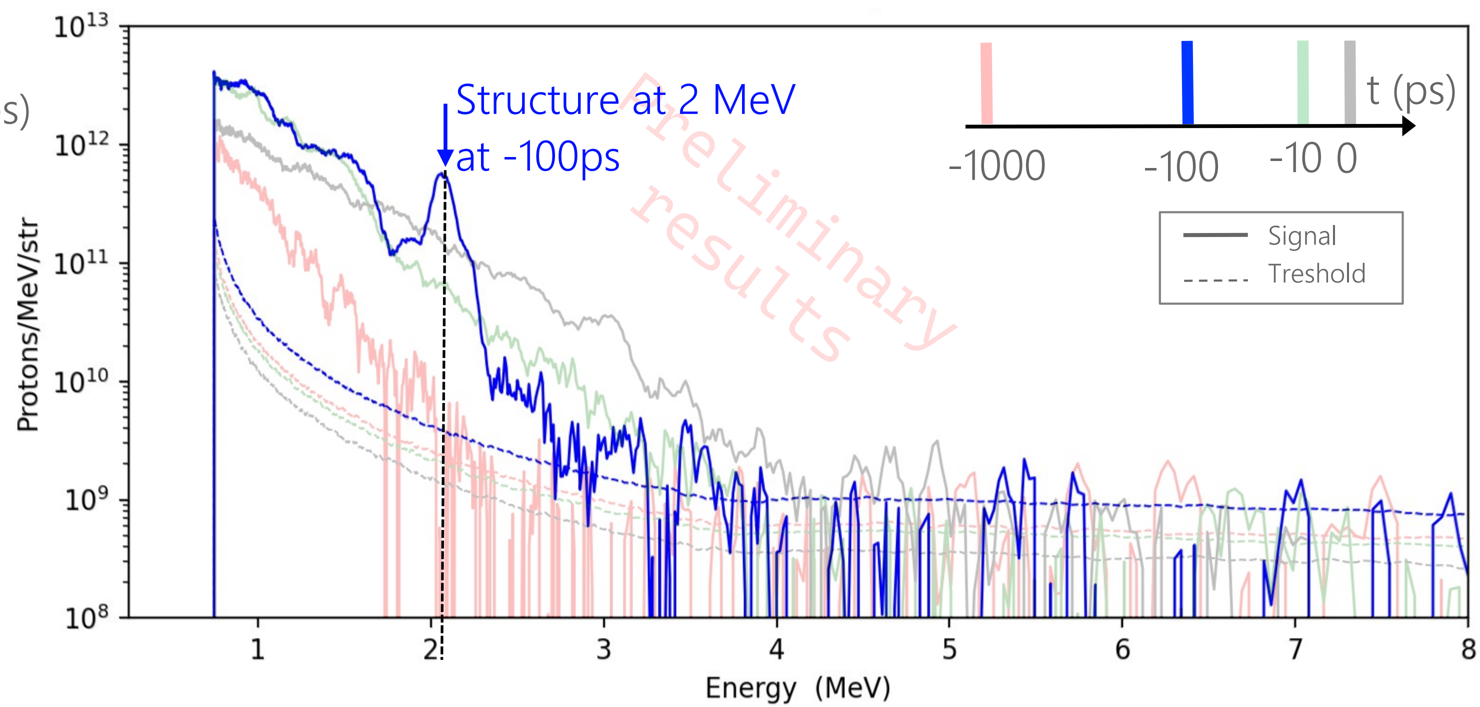
2. Results

2.2. Effect of the prepulse on ions spectra

2.2.3. Delay scan and energy of the prepulse: 1J-100J & **50J-50J**







Coulomb explosion ← • No relation between prepulse delays and maximum number of protons is observed.

CSA ← • Directional acceleration at 45° with high number of protons (10^{12})

For this 2 energy configurations (0,1J-100J & 50J-50J),
a prepulse with a delay of **-100ps** changes ions spectra.

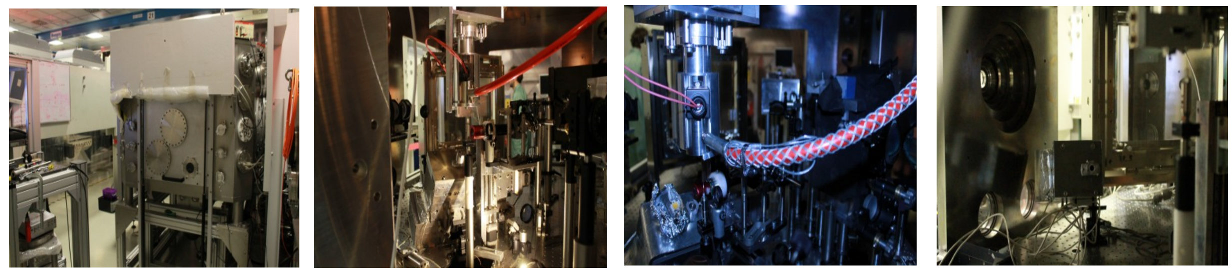
Outline

1. Experimental setup

1.1. Description

1.2. Thomson parabola

1.3. Shadowgraphy



Photos of P21-00004 experimental campaign on PHELIX GSI

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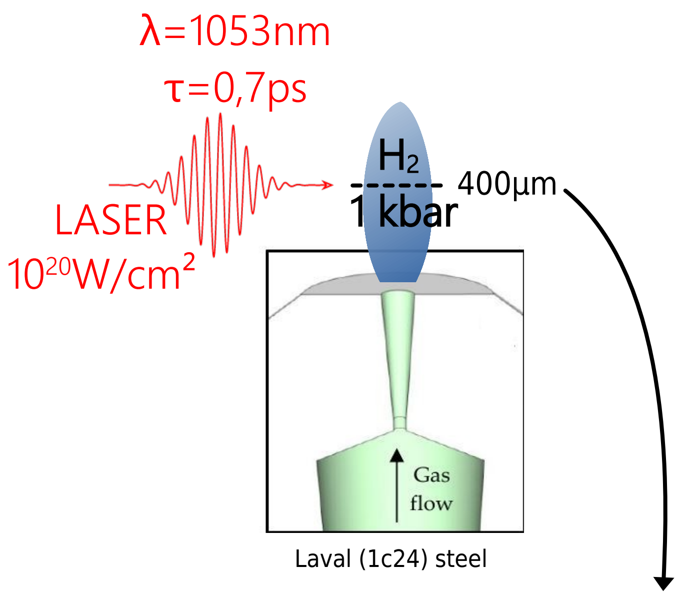
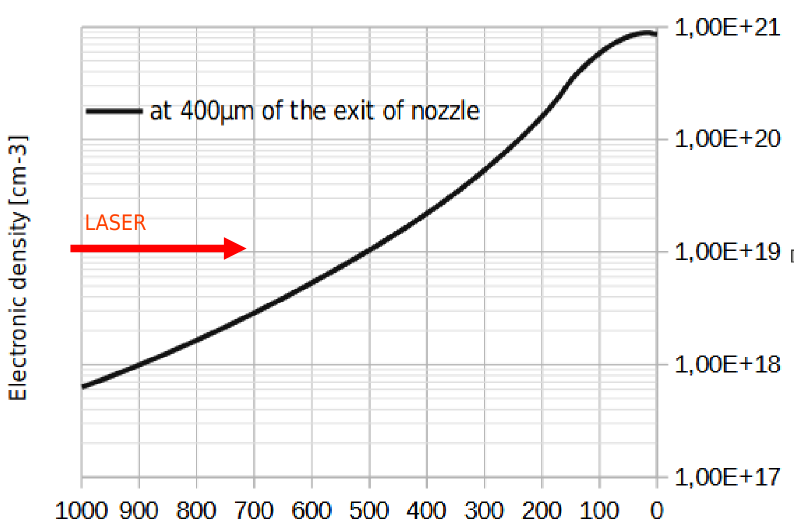
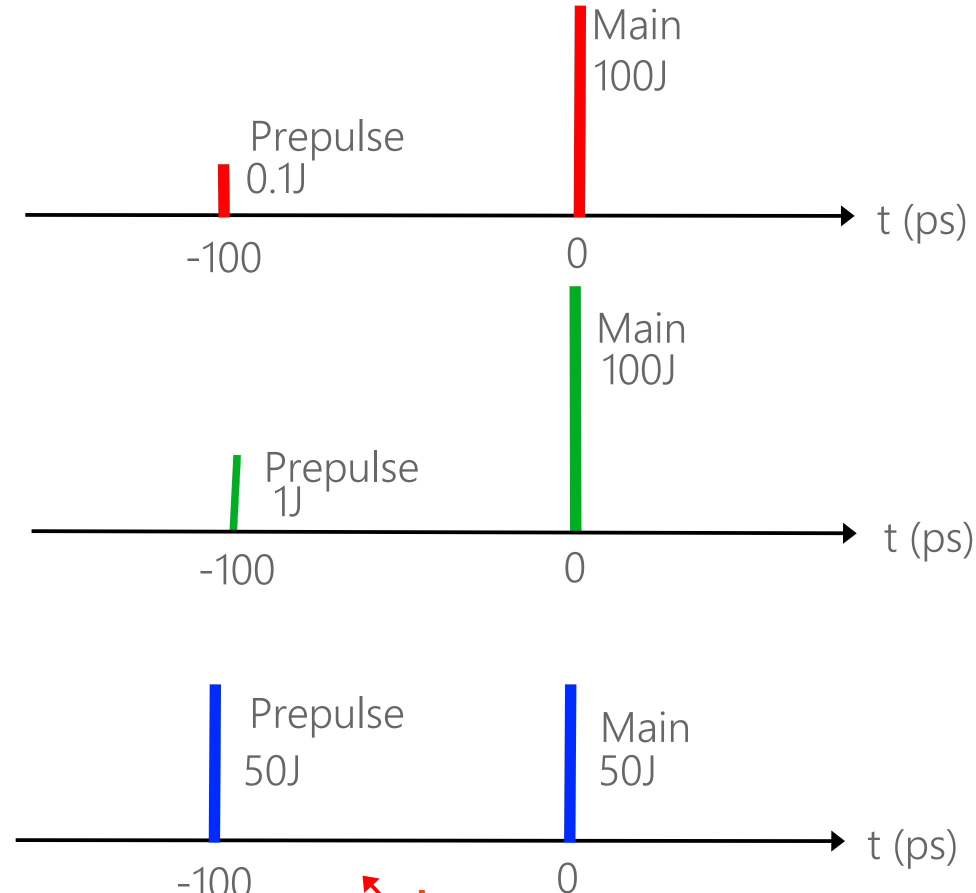
2. Results

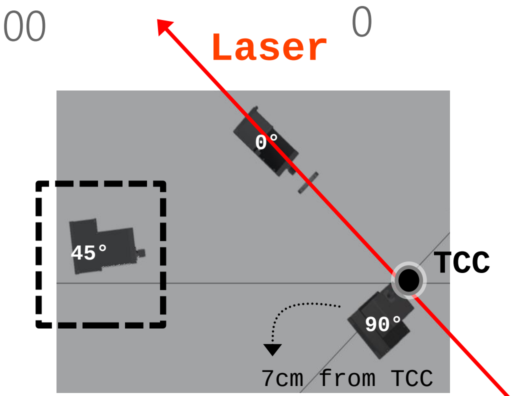
2.2. Effect of the prepulse on ions spectra

2.2.4. Energy scan at 100 ps delay of the prepulse.





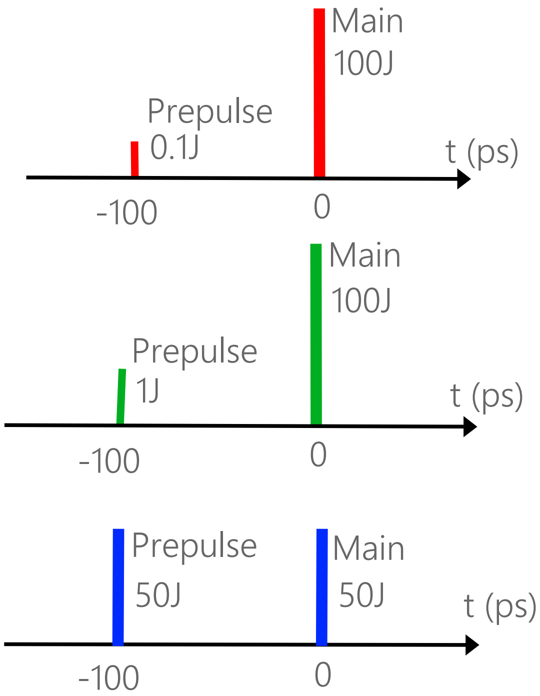


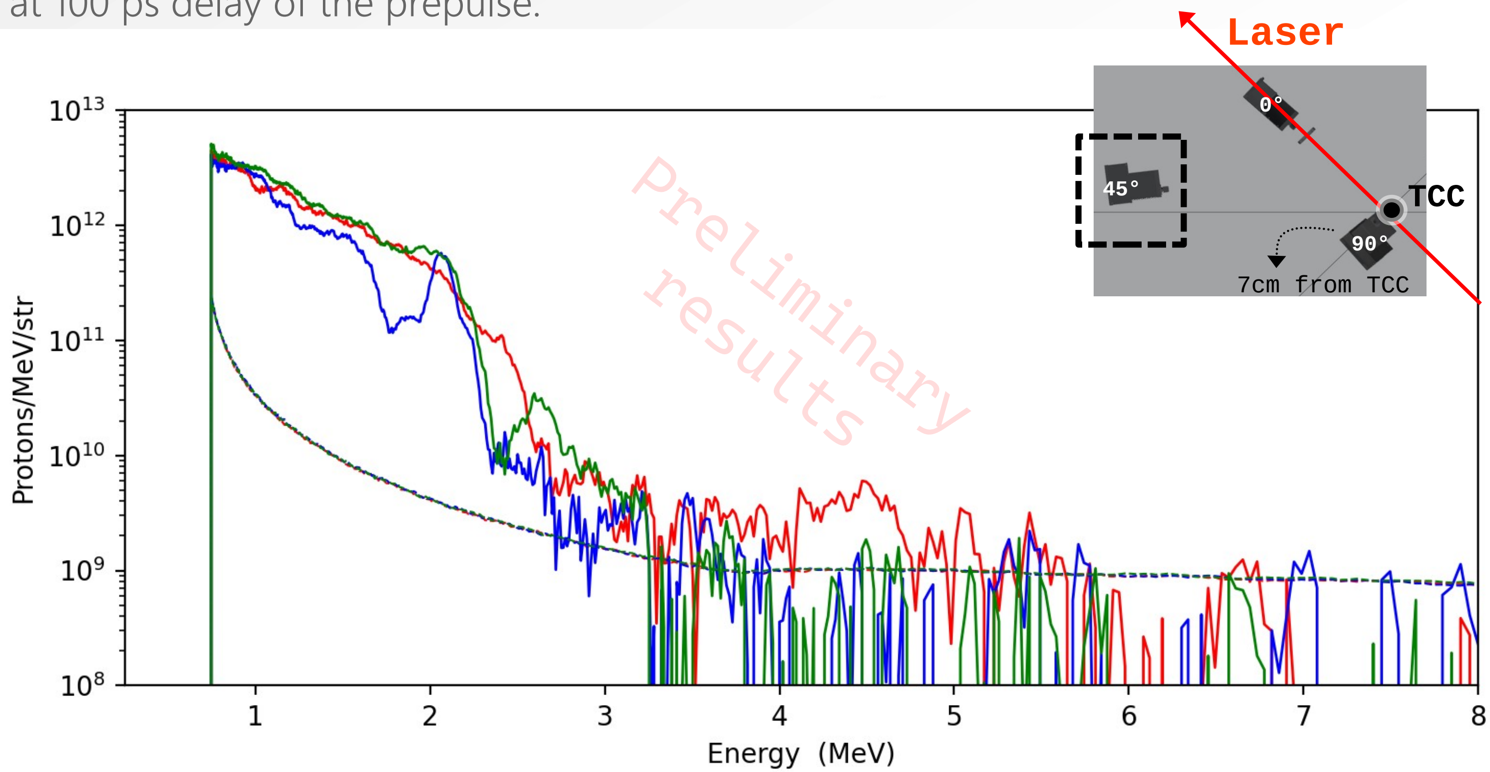


2. Results

2.2. Effect of the prepulse on ions spectra

2.2.4. Energy scan at 100 ps delay of the prepulse.





- Similarities :
  - Tendancies.
  - Maximum number of protons at low energy
  - Directionnal acceleration at 45° with different structures depending of the energy.

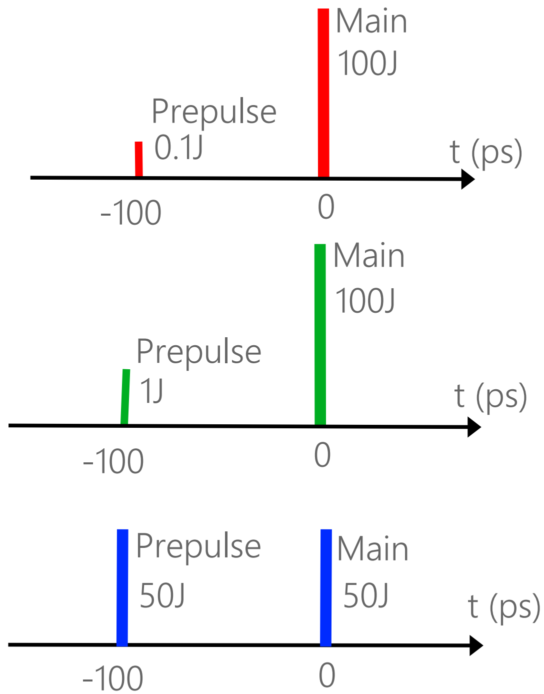
TNSA-Like

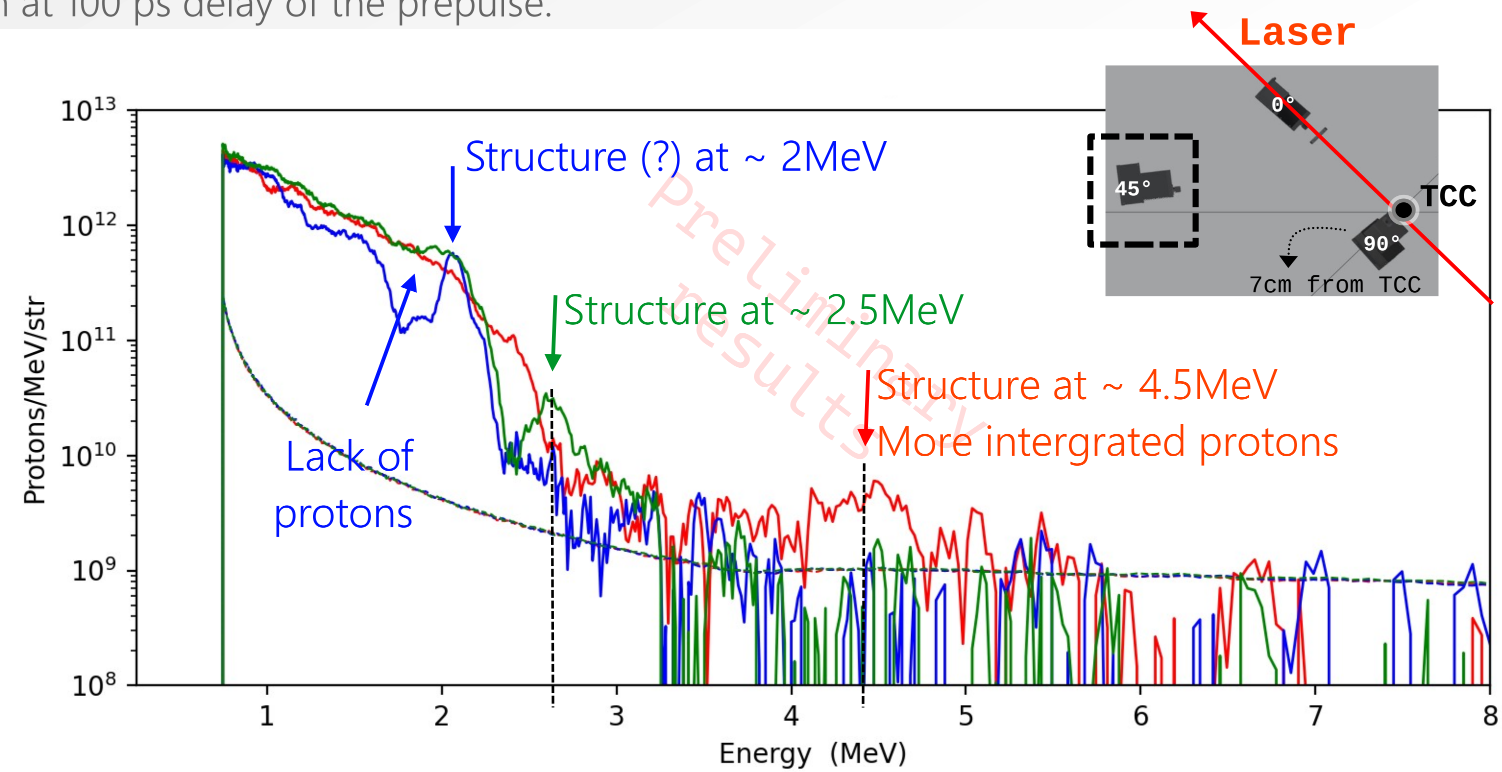
Coulomb explosion

2. Results

2.2. Effect of the prepulse on ions spectra

2.2.4. Energy scan at 100 ps delay of the prepulse.





TNSA-Like

Coulomb explosion

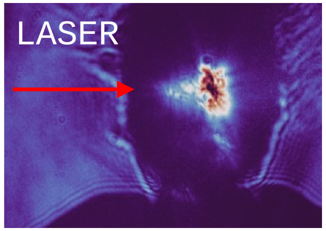
HBA + CSA

- Similarities :
  - Tendancies.
  - Maximum number of protons at low energy
  - Directionnal acceleration at 45° with different structures depending of the energy.

Delay and energy must be chosen together

The energy of the prepulse must be <1J to not completely alter the target.

Summary and perspectives



- A low energy prepulse interacting with a gaz jet formed by a laval nozzle allows the main pulse to reach the **core** of the target : high gradiant and high electronic density.

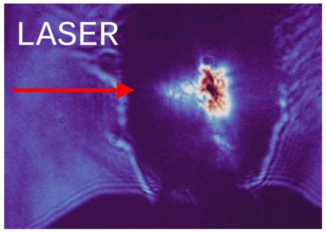
- It enables to **favour angle** of acceleration : Mainly situated at **45°** from propagation direction with energy up to **6MeV**. It can reach **7MeV at 90°** → **CSA ? We need reproductibility studies.**
- Prepulse **delay and energy** have to be determined **together**.
- Many other acceleration mecanisms than CSA (TNSA-Like, Coulomb explosion, HBA) → We need **simulations** to identify them.

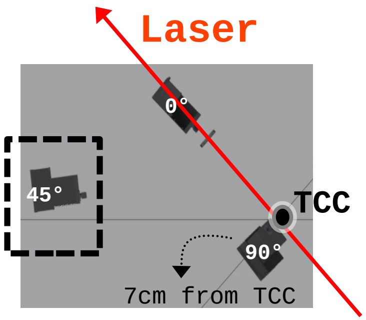
Smilei)

2D/3D simulations with several hydrodynamics input profiles wich will reproduce this experiment.

- Experimental campaigns at LP2IB : prepulse studies with differents shapes, at different probe delays on two type of target with a YAG Laser (Powerlite DLS 8000) 1J,8ns, FWHM ~50µm.
- Direct application on an ultra high intensity laser facility with a ns YAG laser.
- Study reproductibility.

Summary and perspectives





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Powerlite DLS 8000

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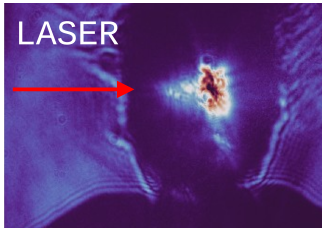
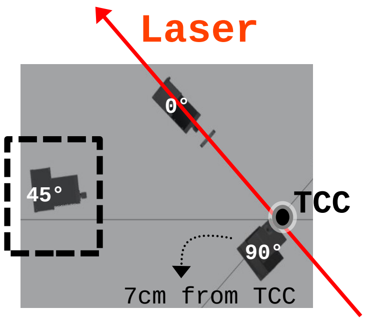
Summary and perspectives





- A low energy prepulse interacting with a gaz jet formed by a laval nozzle allows the main pulse to reach the **core** of the target : high gradiant and high electronic density.

- It enables to **favour angle** of acceleration : Mainly situated at **45°** from propagation direction with energy up to **6MeV**. It can reach **7MeV at 90° → CSA ? We need reproductibility studies.**
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Smilei)

2D/3D simulations with several hydrodynamics input profiles wich will reproduce this experiment.

Powerlite DLS 8000

- Experimental campaigns at LP2IB : prepulse studies with differents shapes, at different probe delays on two type of target with a YAG Laser (Powerlite DLS 8000) 1J,8ns, FWHM ~50µm.
- Direct application on an ultra high intensity laser facility with a ns YAG laser.
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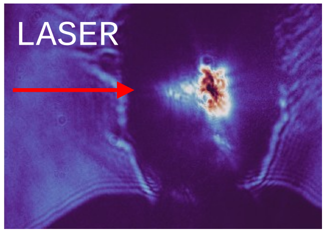
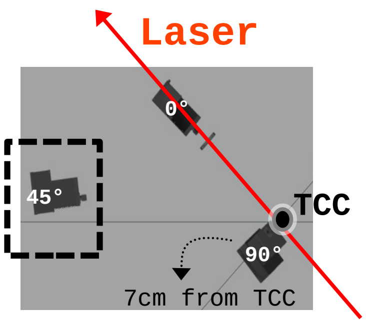
Summary and perspectives





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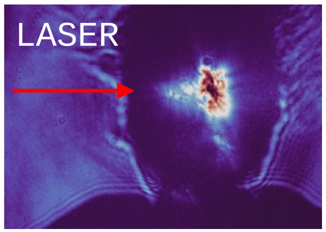

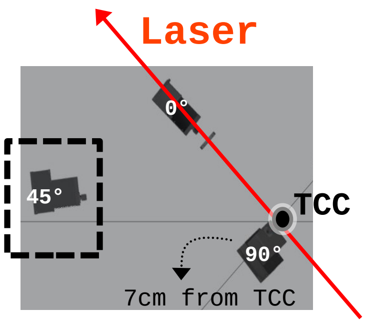

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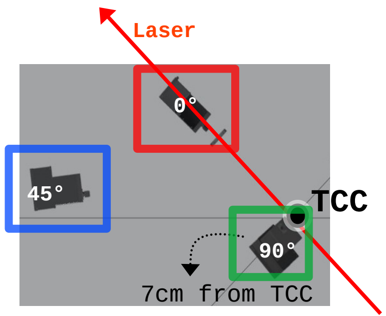
Thank you
for your attention.

Questions ?

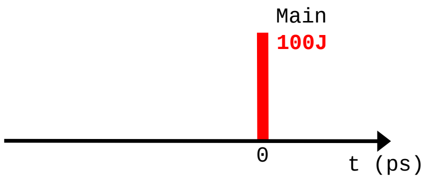
Backup

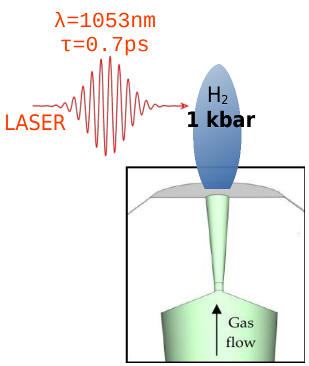
Results

Angular scan with a high energy main pulse (100J) without pre-pulse

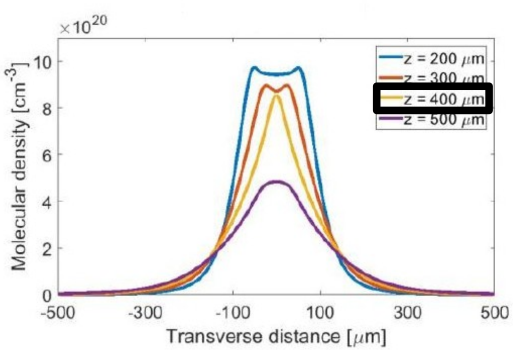


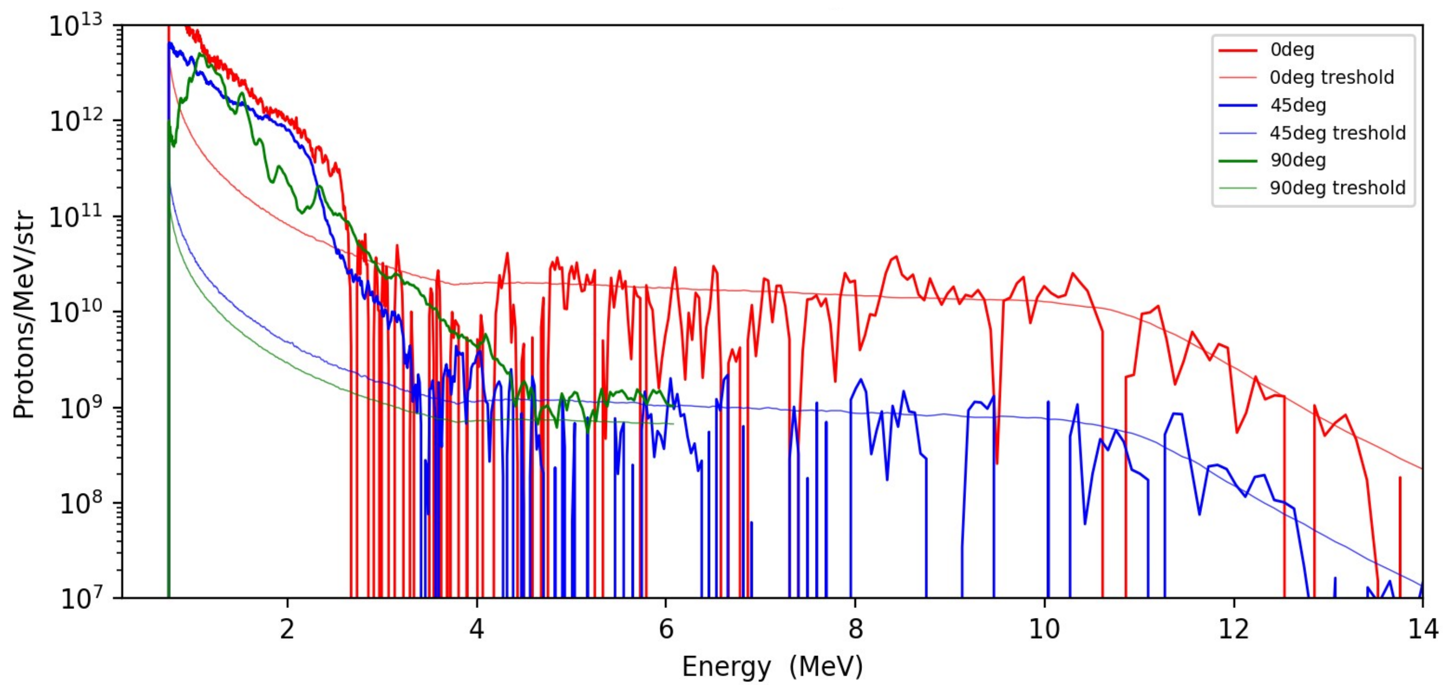
Configuration	Spectrum at 45°

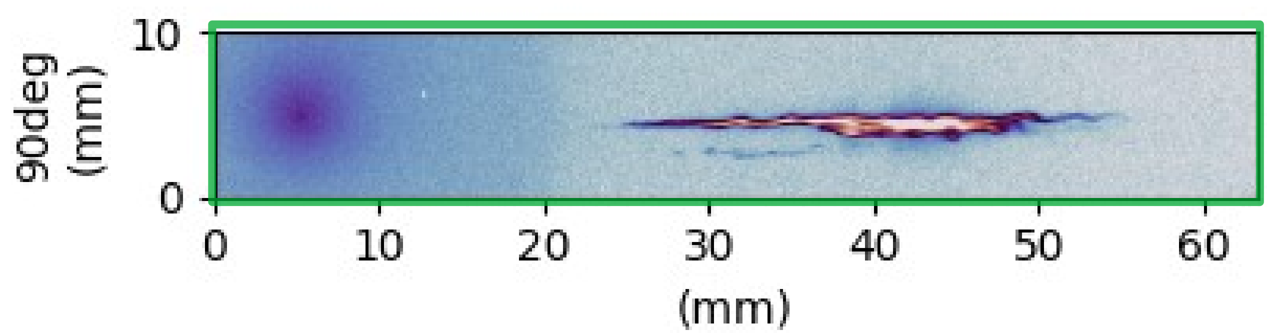




Laval (1c24) steel

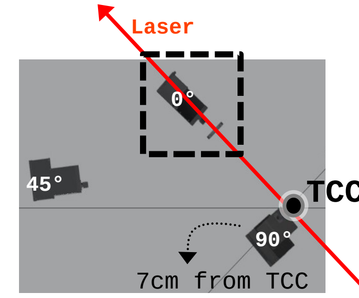




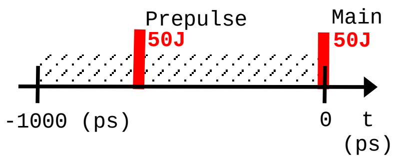


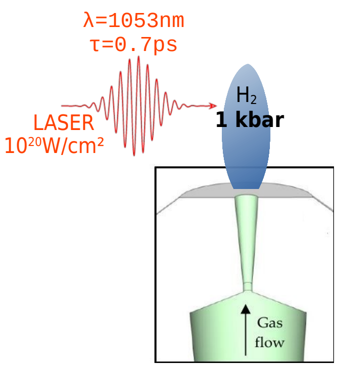
Results

Delay scan 50J-50J pre-main pulse energies.

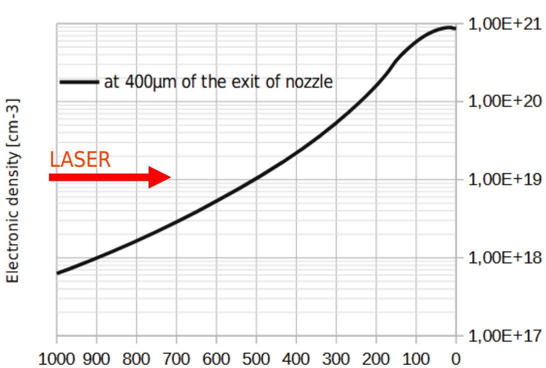


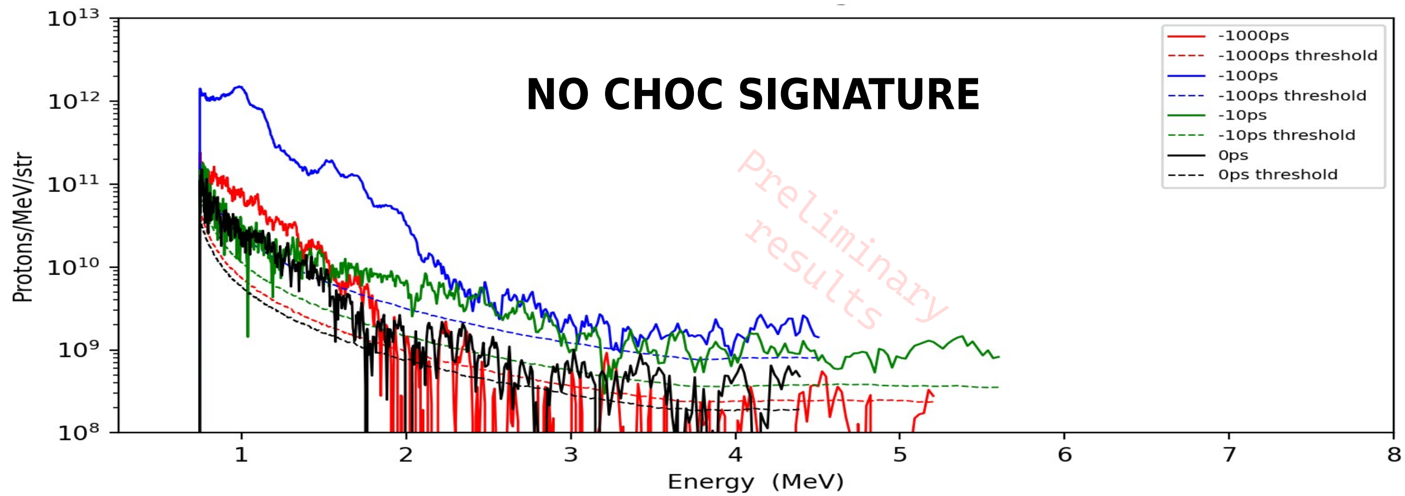
Configuration	Spectrum at 90°

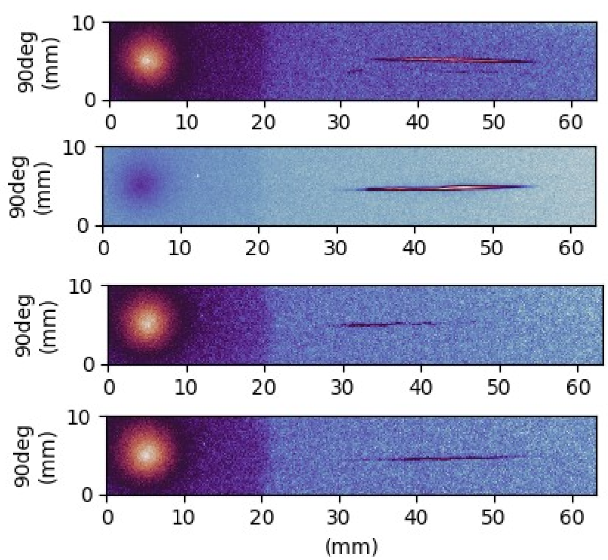




Laval (1c24) steel







-1000ps

-100ps

-10ps

0ps