ION ACCELERATION FROM OPTICALLY SHAPED GAS JETS

PI : Medhi Tarisien / co-PI : Jean Raphael Marques
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Jean Raphael Marques

Antoine Maitrallain, Kristal Bontemps, Arnaud Huber, Fazia Hannachi, Medhi Tarisien

Johannes Hornung, Bernhard Zielbauer, Vincent Bagnoud

Thomas Carrière, Didier Raffestin, João Santos, Philippe Nicolaï

Pascal Loiseau

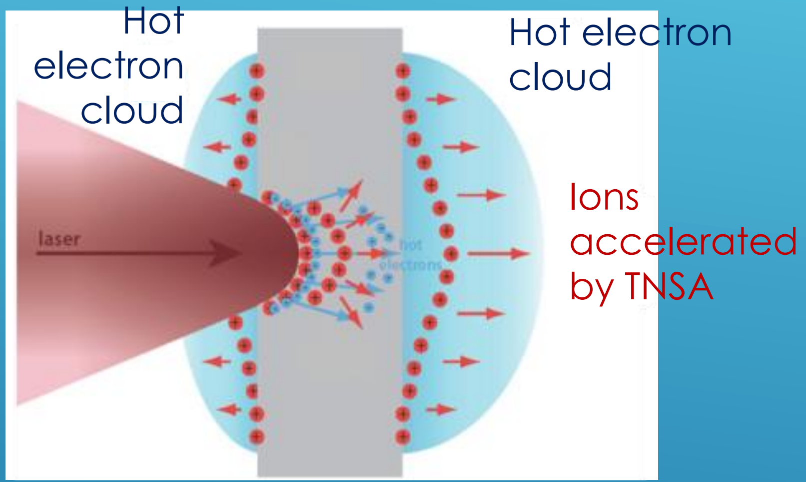
Jose Luis Henares

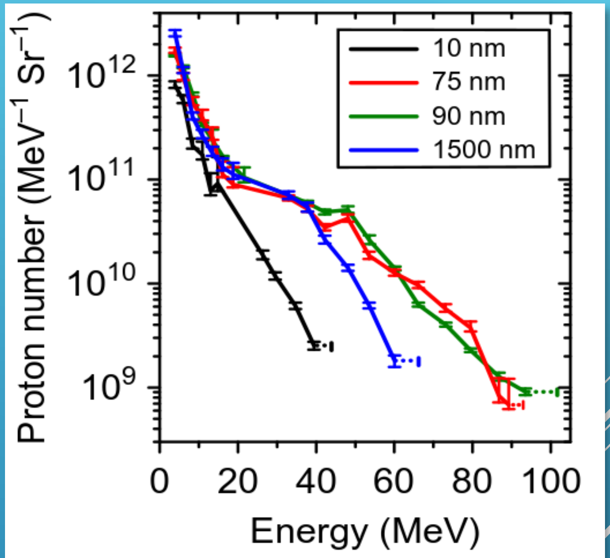
II. Identification of the collaboration

Title of the collaboration	ion acceleration from the interaction of high power lasers with optical shaped gas jets
Number of the collaboration	22-89
IN2P3 spokesperson	F. HANNACHI, M. TARISIEN
GSI spokesperson	V. BAGNOUD
Scientific Domain	Accelerators Detectors and Technologies

LASER DRIVEN ION ACCELERATION

- Solid targets: TNSA (“Target Normal Sheath Acceleration”)





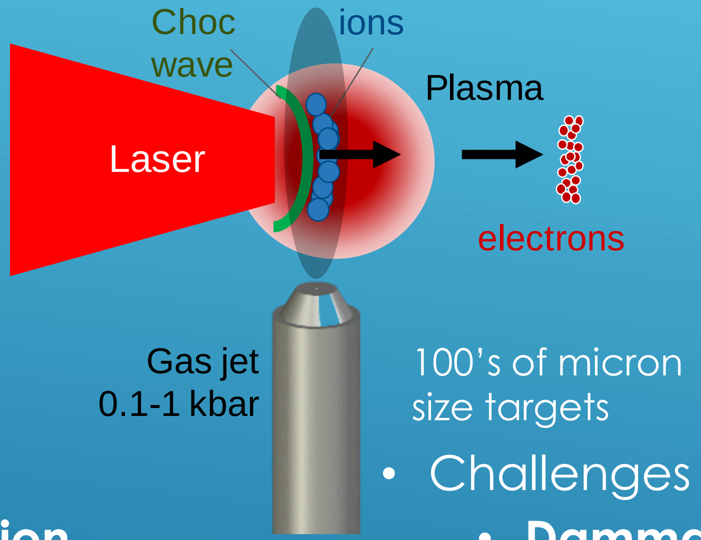
- Pros :
  - Shot to shot **reproducibility**
  - **Number** of accelerated **ions** (≈ 10^{12} / shot)
  - **Simplicity**
- Cons :
  - **Refreshing target after every shot**
  - **Debris** on surrounding optics
  - **Continuous energy** distribution
  - **Difficult** to **control** the **accelerated species** (target + contaminants)
  - ***Target*** *fabrication* ***cost***

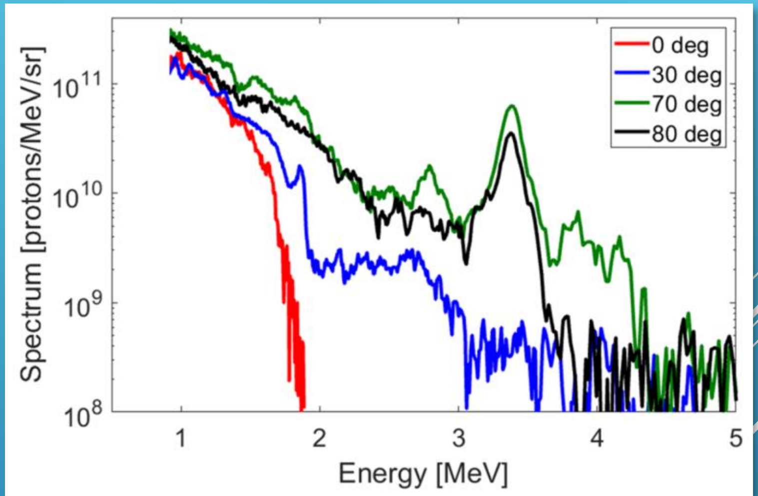
P. G. Thirolf, The Euroschool on Exotic Beams - Vol. 5, p.272, Springer (2021)

Higginson, A., et. al. Nat Commun 9, 724 (2018)

GAS TARGETS AND ION ACCELERATION

- High density gas targets (> 10^{21} e/cm^3, critical density) : CSA ("Collisionless Shock Acceleration")





- Pros :
  - Improve **energie distribution**
  - **Control** on accelerated ion **species**
  - Single **alignement**
  - **Decrease** debris

➢**High rep rate** (≈ Hz)

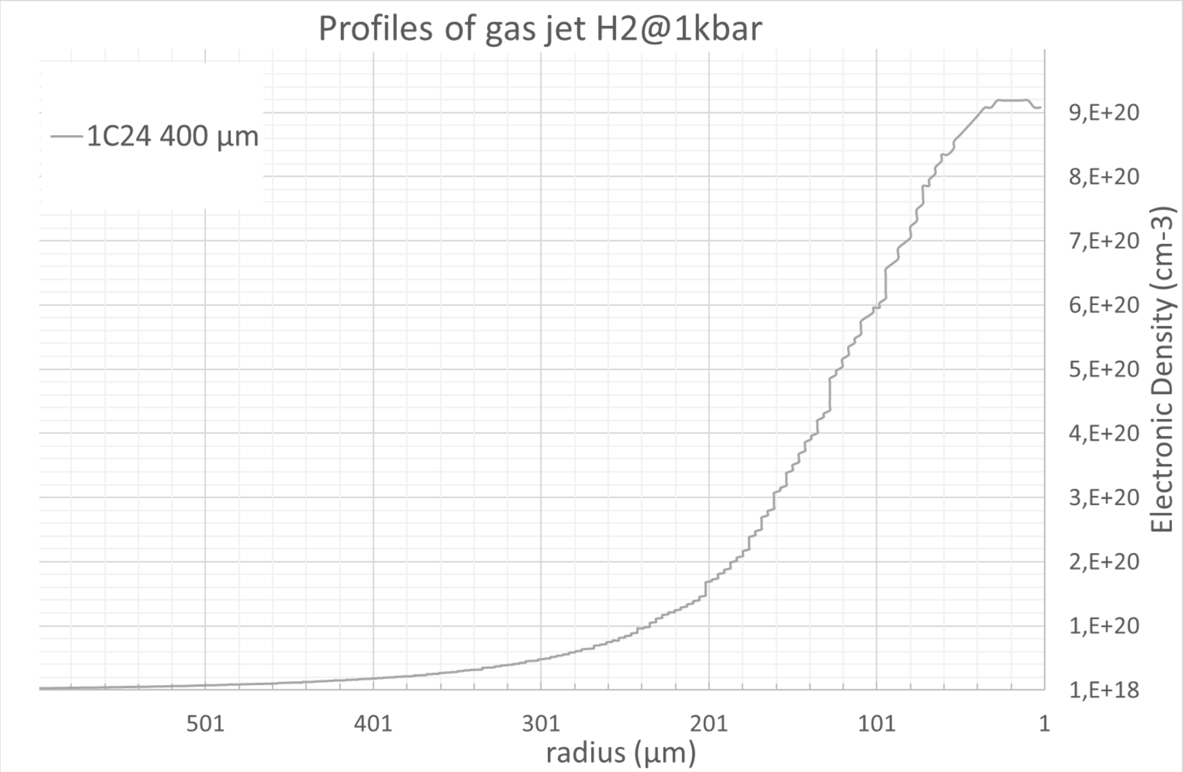
- Challenges :
  - **Dammaging** nozzle
  - Quantity gas released in target chamber under vacuum
  - **Manufacturing** targets showing a **sharp density gradient**

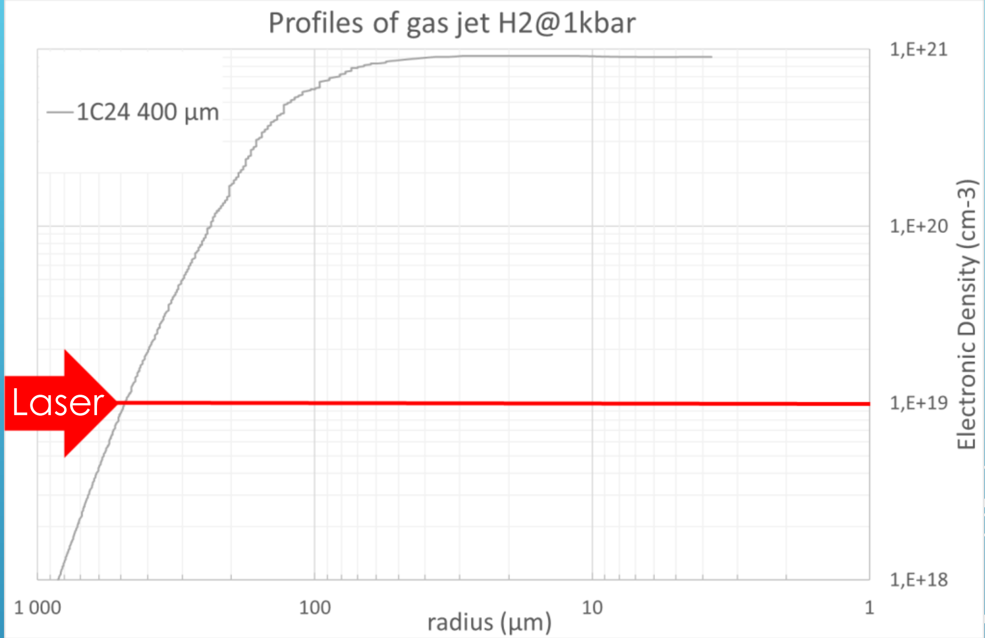
- **Promising results** obtained by the **ENL group**

P. Puyuelo-Valdes et al, Phys. Plasmas 26, 123109 (2019)

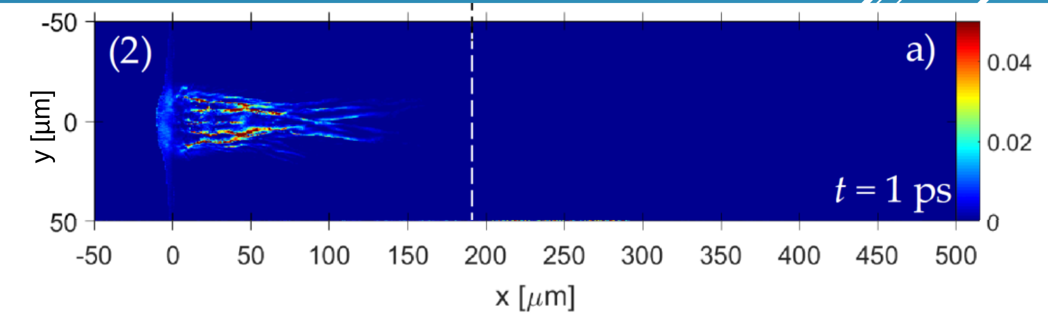
GAS TARGETS AND ION ACCELERATION

1 µm wavelength
→ Critical density : 10^{21} atom/cm^3





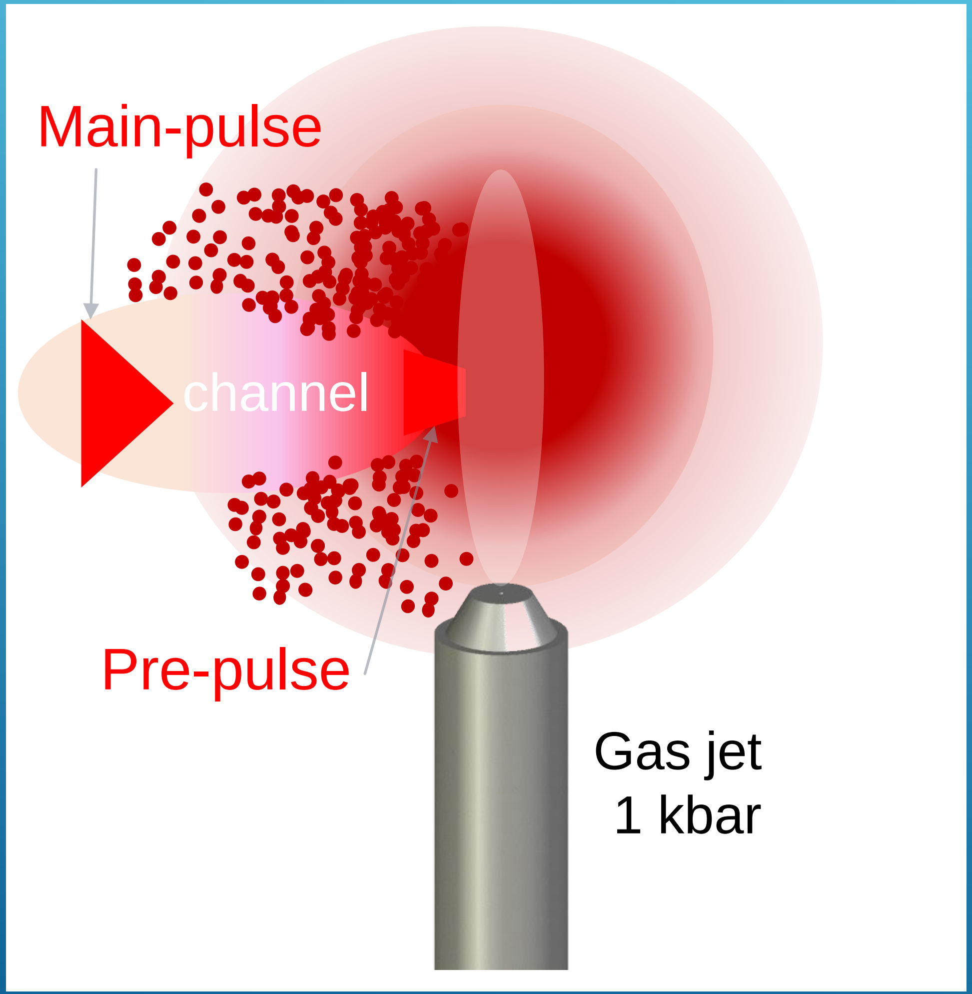
Interaction **100's of µm before** high density zone

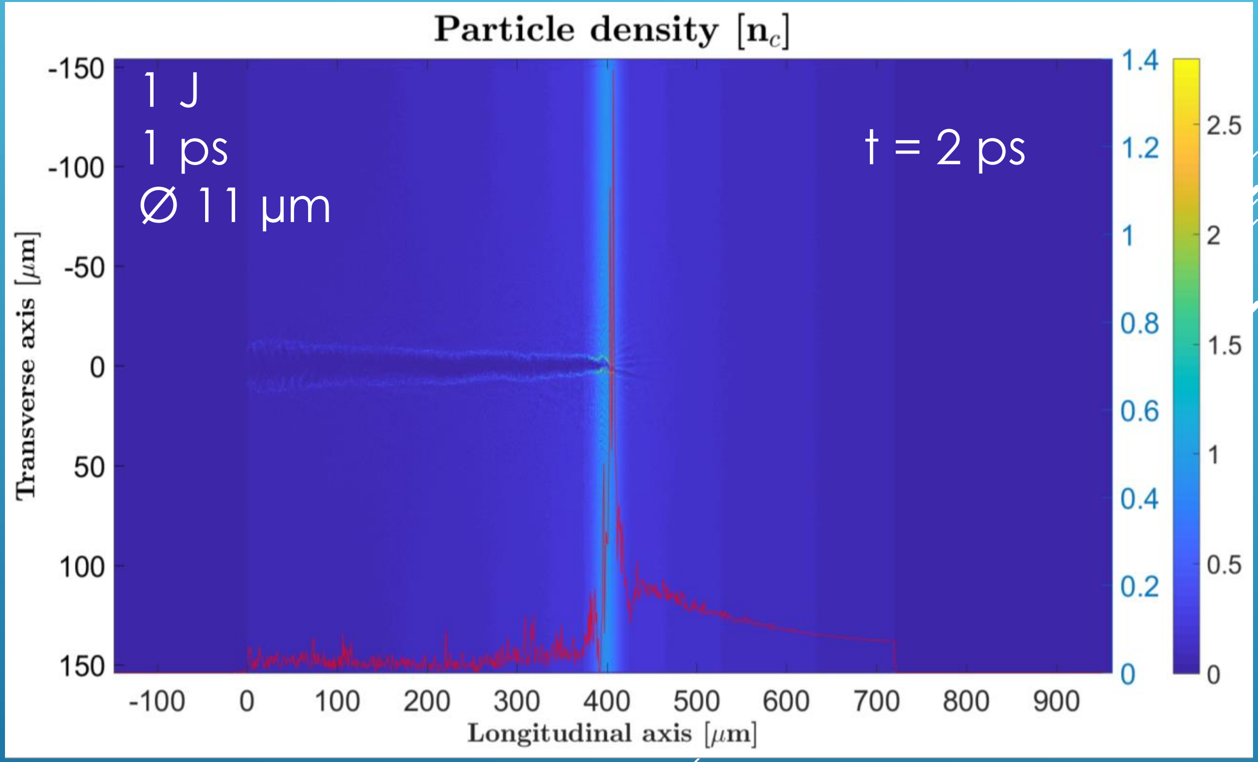


P. Puyuelo-Valdes et al, Phys. Plasmas 26, 123109 (2019)

Laser-driven ion acceleration with optically shaped gas jet targets

P-21-00004: **1st experiment with a pre-pulse** to shape the gas target





PICLS simulations

SIMPLIFIED EXPERIMENTAL SET UP

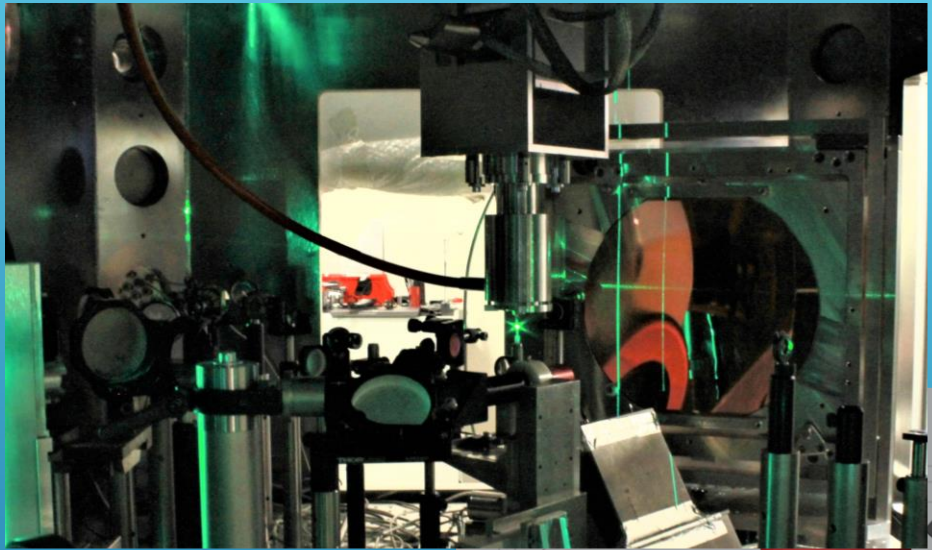
$E_m = 1 - 100$ J
$E_p = 0{,}1 - 50$ J
$\lambda_m = \lambda_p = 1054$ nm
$\Delta t_{m\text{-}p} = 10 – 1000$ ps
$\varnothing_0 = 2{,}3$ µm FWHM
$\tau_m = \tau_p = 500$ fs

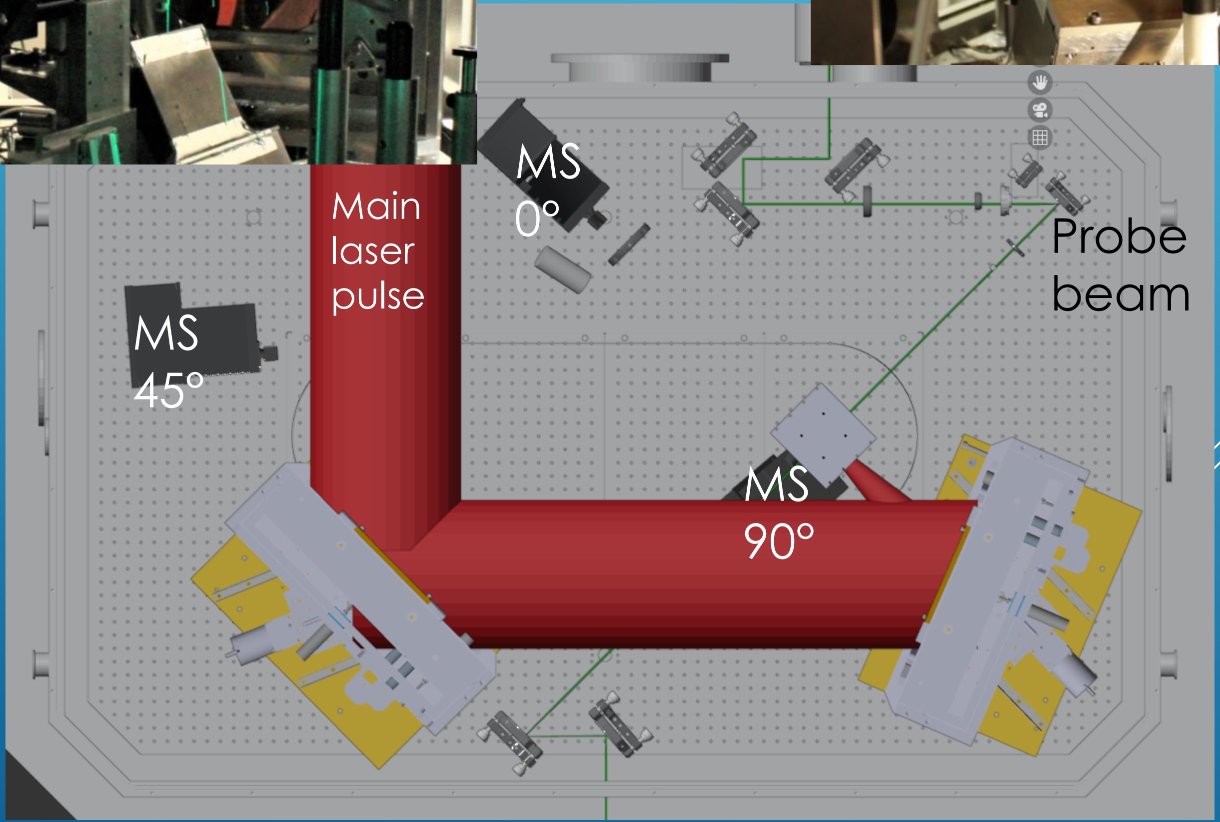
$\Rightarrow I_m < 5 \times 10^{20}$ W/cm²
$\Rightarrow I_p < 5 \times 10^{18}$ W/cm²

$\tau_{probe} \approx 500$ fs
$-25 < \delta t_{probe} < 300$ ps
$\lambda_{probe} = 526$ nm

P = 0,1-1 kbar

Repetition rate: 1 shot every 90 min if $E_m > 5$ J

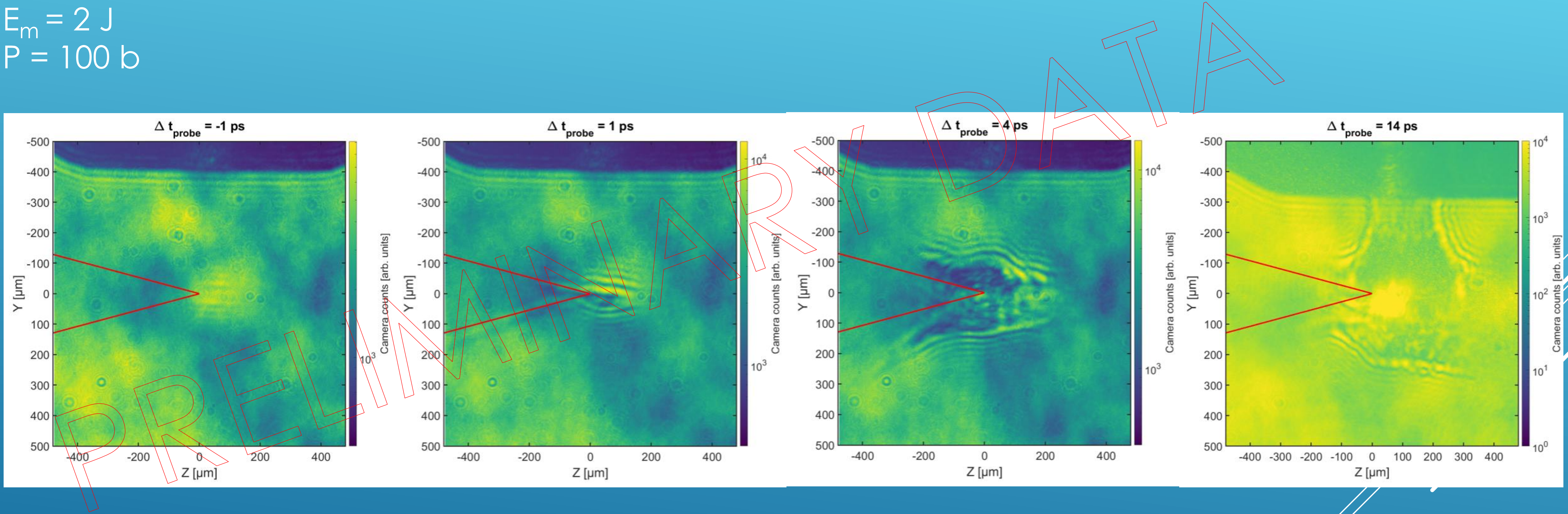




Shadowgraphy
Particle diagnostics (magnetic spectrometers)

SHADOWGRAPHY

$E_m = 2$ J
$P = 100$ b

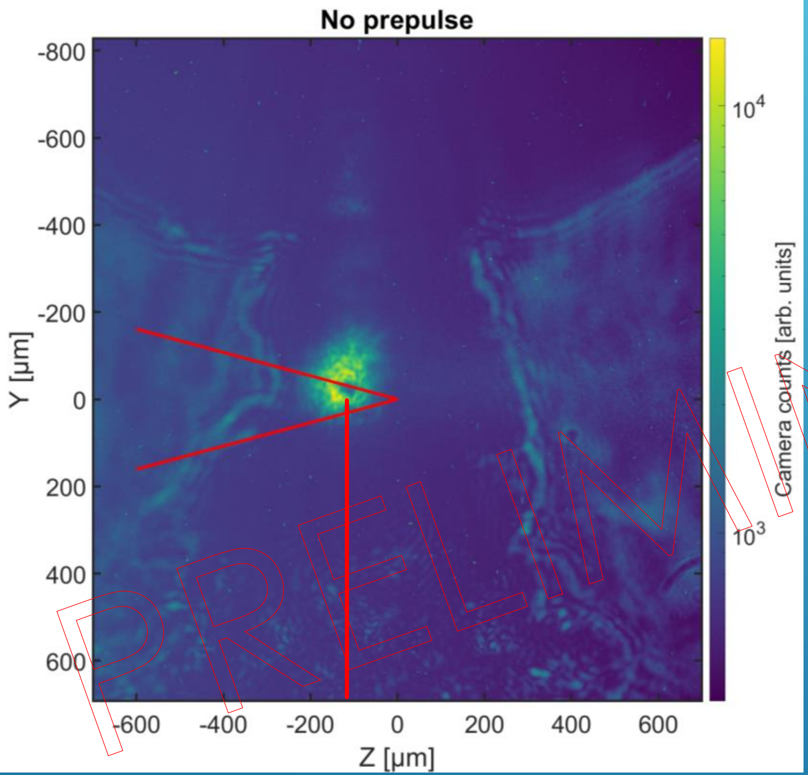


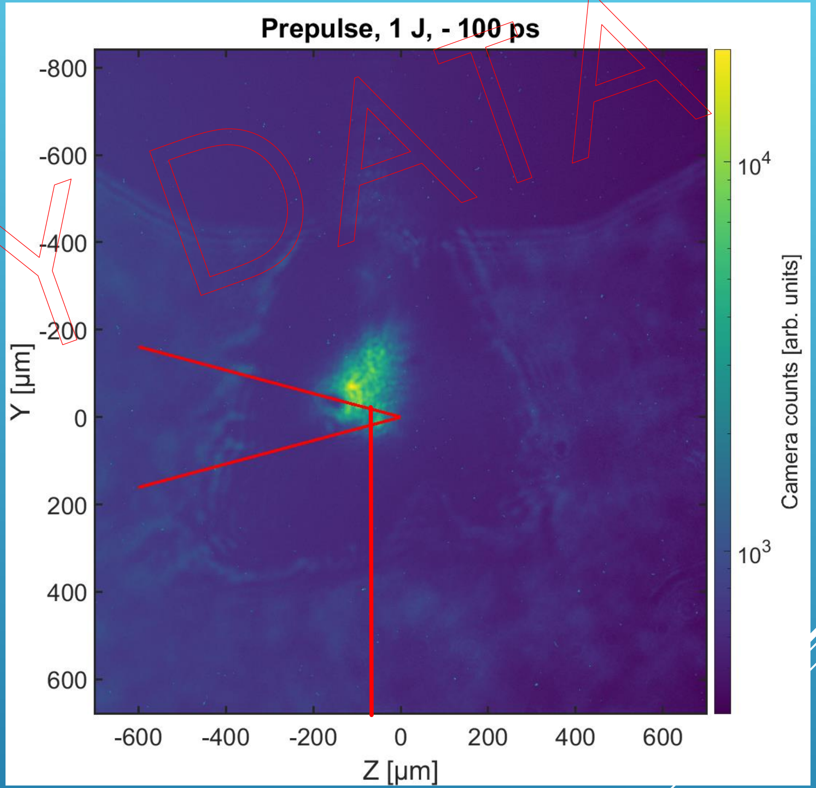
When **plasma** created, the medium becomes **opaque** to the probe wavelength hence a **dark region** is obtained on the images

SHADOWGRAPHY AT HIGH PRESSURE

When high intensity laser interacts with sharp gradients/high density medium: 2ω (526 nm) light emitted

P = 1 kb





E_m = 100 J
E_p = NA
Δt_{m-p} = NA

No prepulse

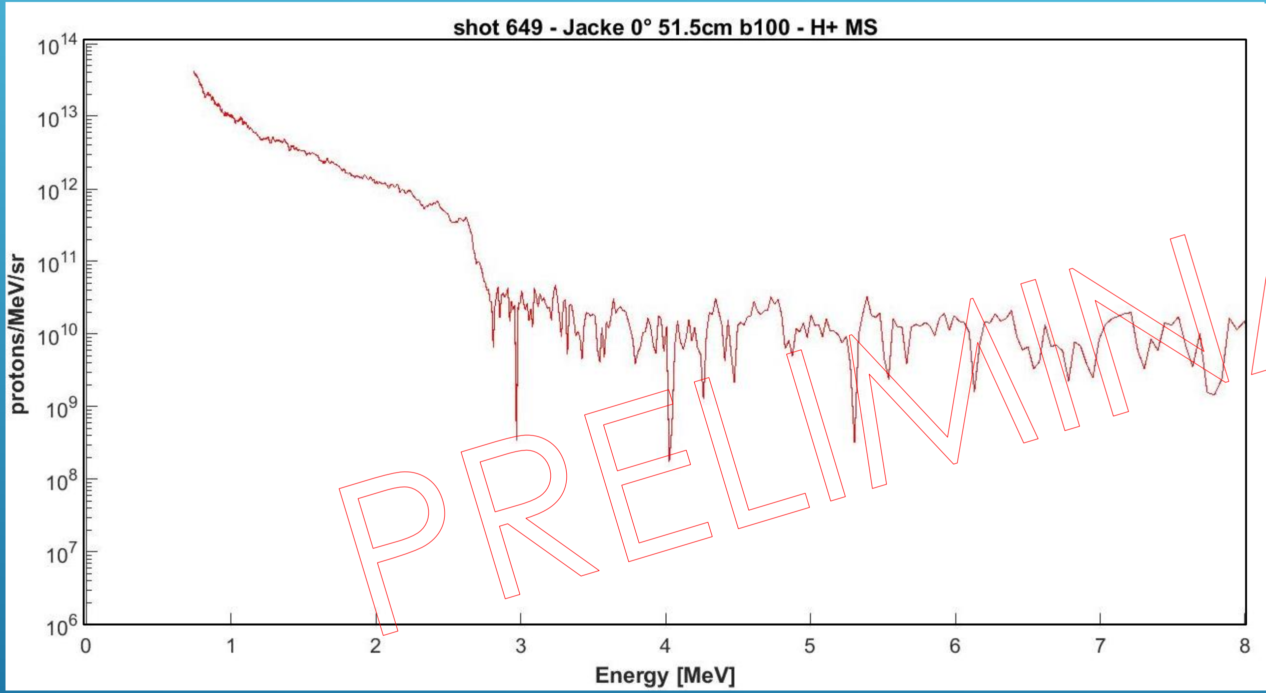
Prepulse

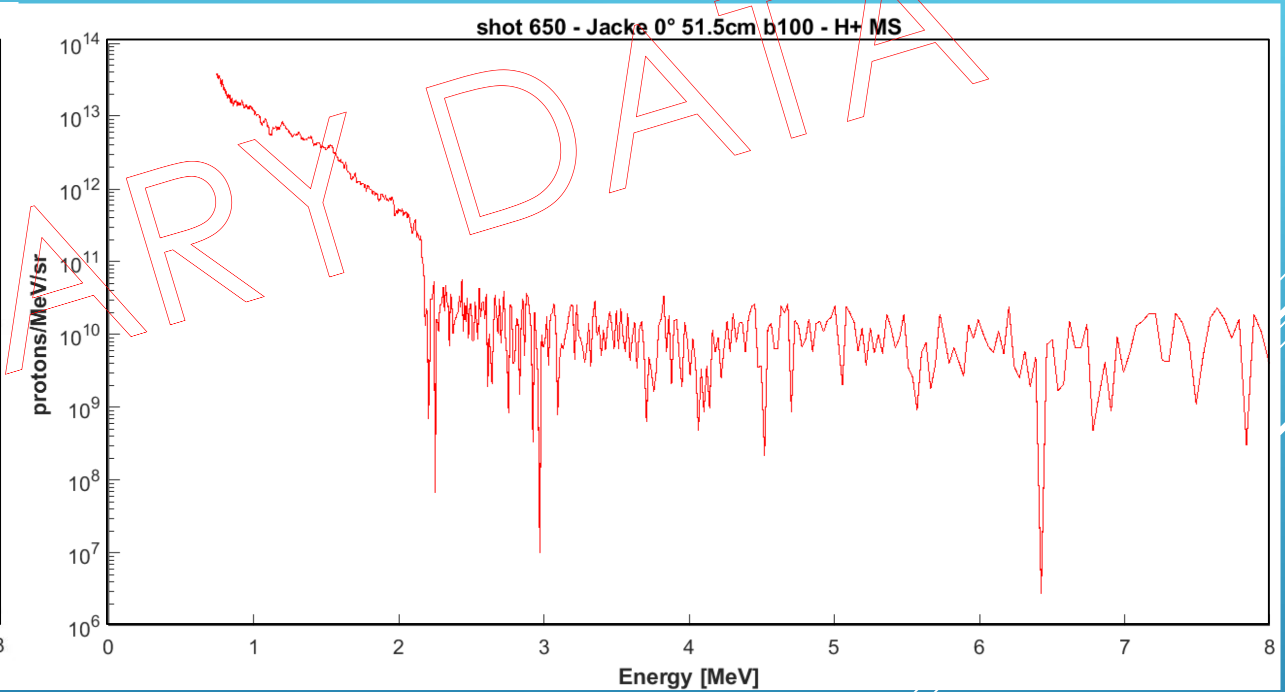
E_m = 100 J
E_p = 1 J
Δt_{m-p} = -100 ps

With a **prepulse**, the **2ω emission comes from further** in the gas jet
=> **points towards the right direction**

ASSOCIATED ION SPECTRA AT 0°

P = 1 kb





E_m = 100 J
E_p = NA
Δt_{m-p} = NA

No prepulse

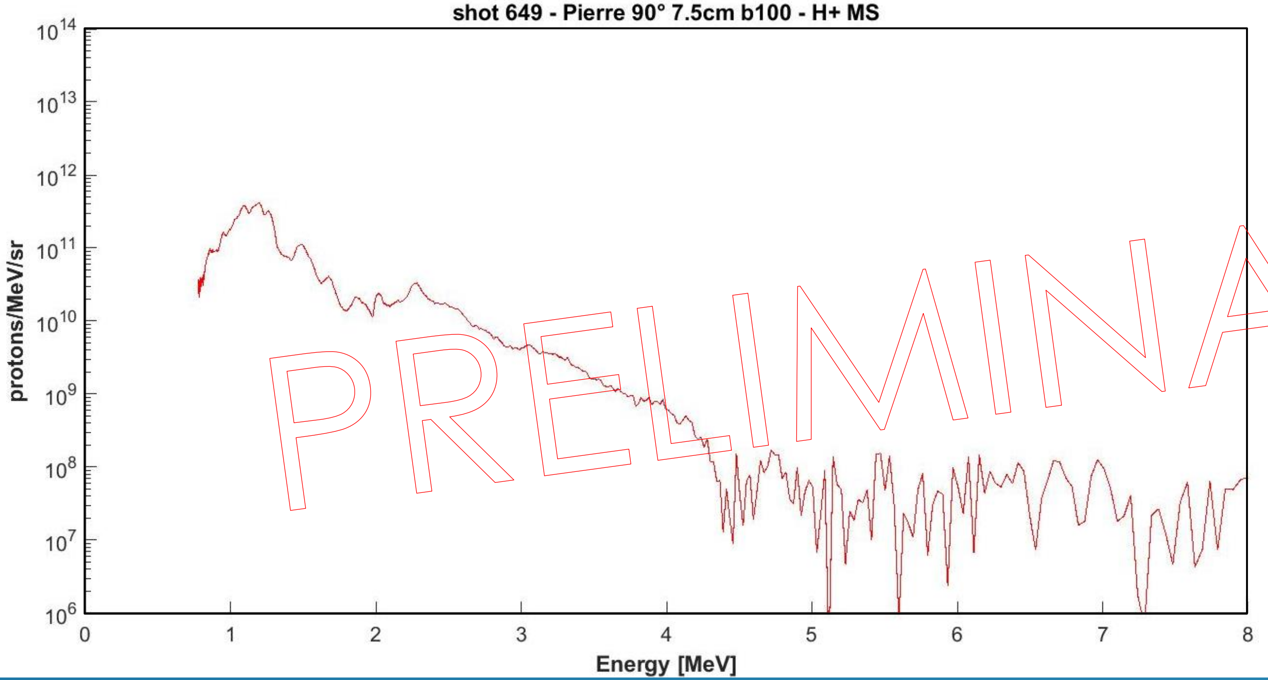
Prepulse

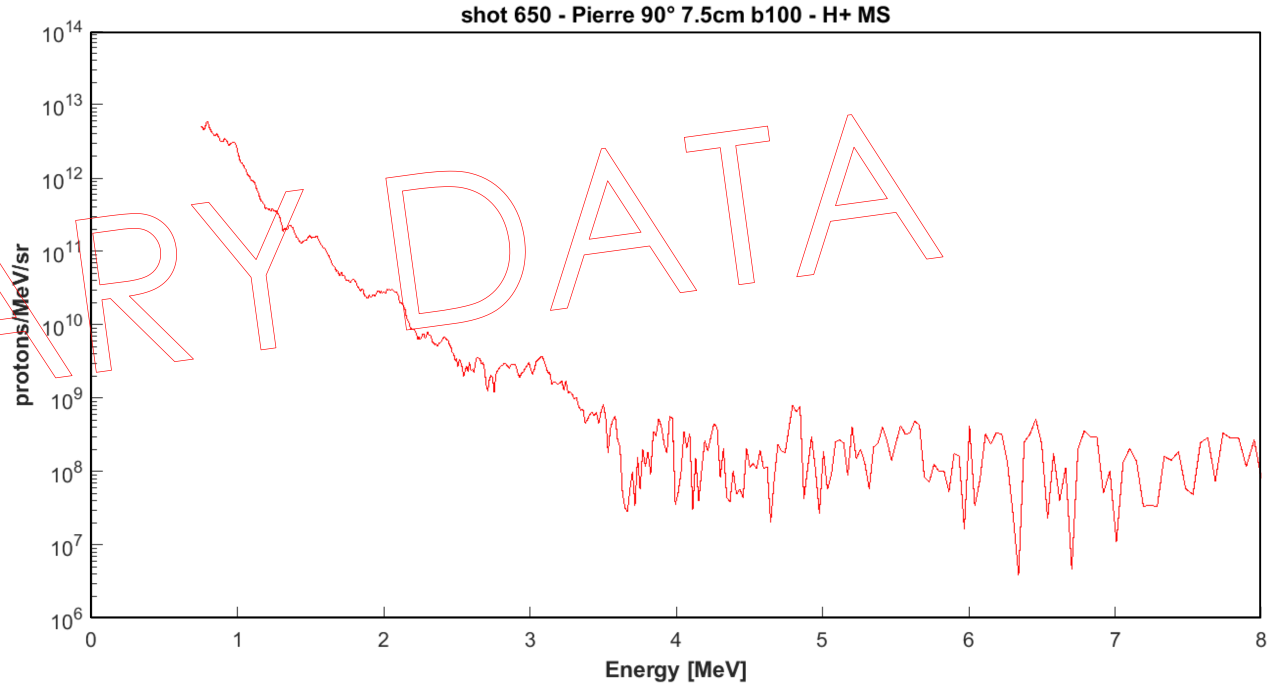
E_m = 100 J
E_p = 1 J
Δt_{m-p} = -100 ps

No improvement on the particle distribution (on single shot basis)

ASSOCIATED ION SPECTRA AT 90°

P = 1 kb





$E_m = 100$ J
E_p = NA
Δt_{m-p} = NA

No prepulse

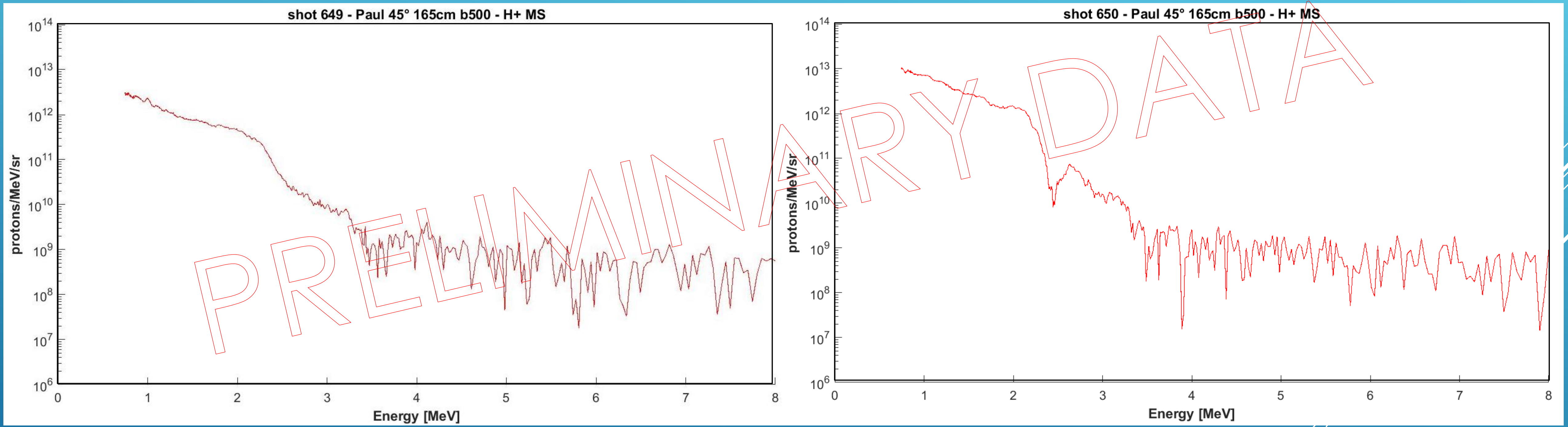
Prepulse

$E_m = 100$ J
$E_p = 1$ J
$\Delta t_{m-p} = -100$ ps

No improvement on the particle distribution (on single shot basis)

ASSOCIATED ION SPECTRA AT ≈ 45°

P = 1 kb



E_m = 100 J
E_p = NA
$\Delta t_{m\text{-}p}$ = NA

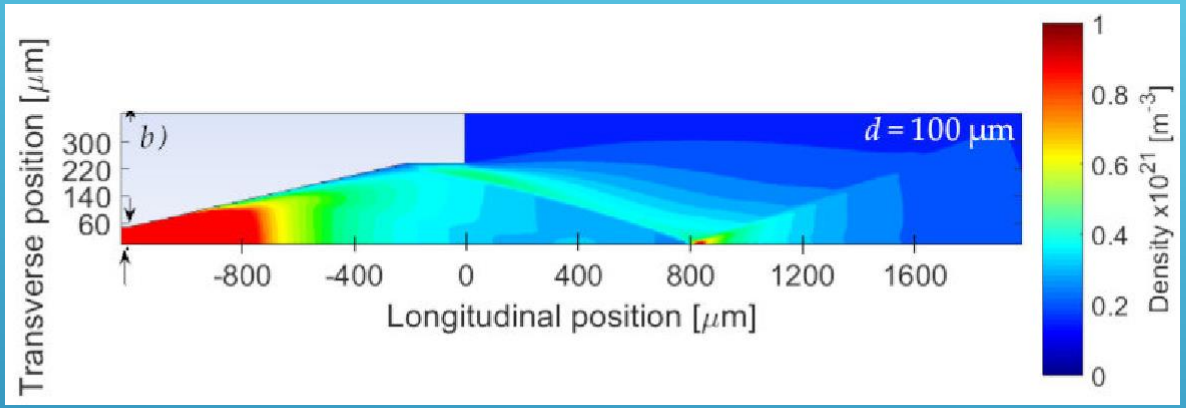
No prepulse

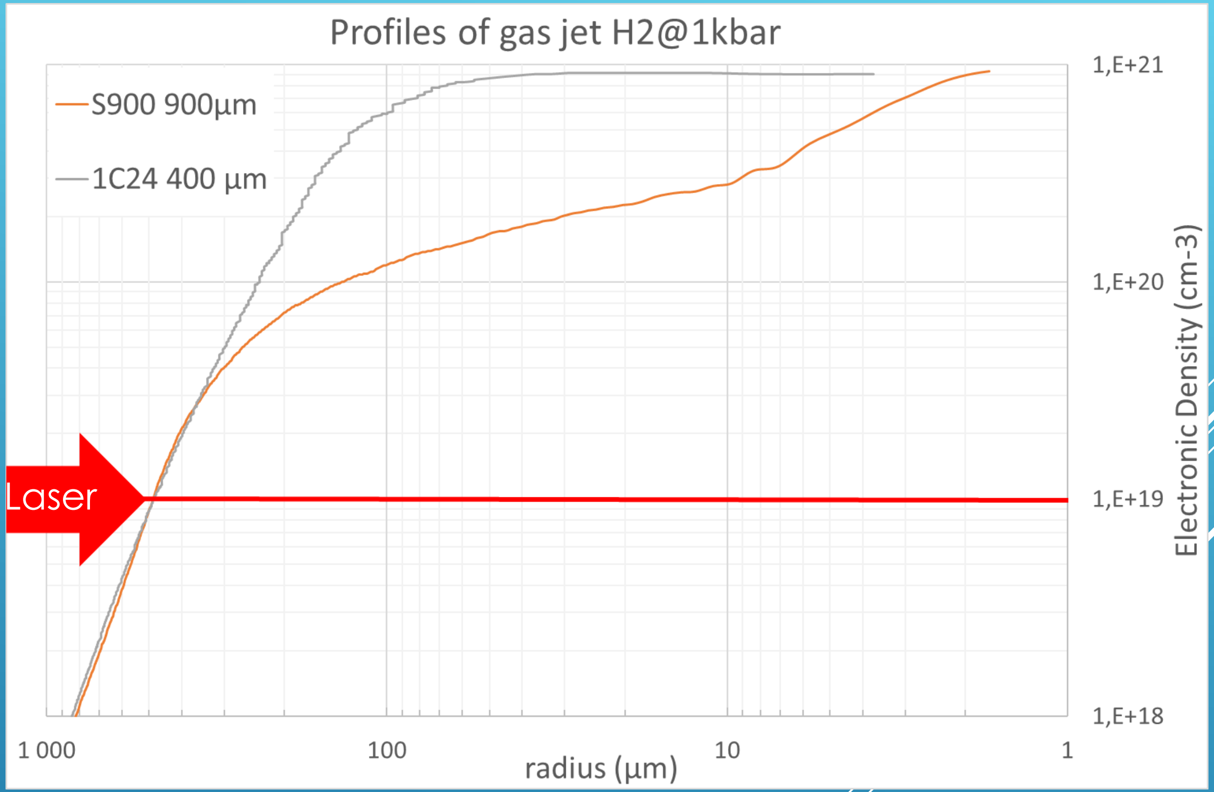
Prepulse

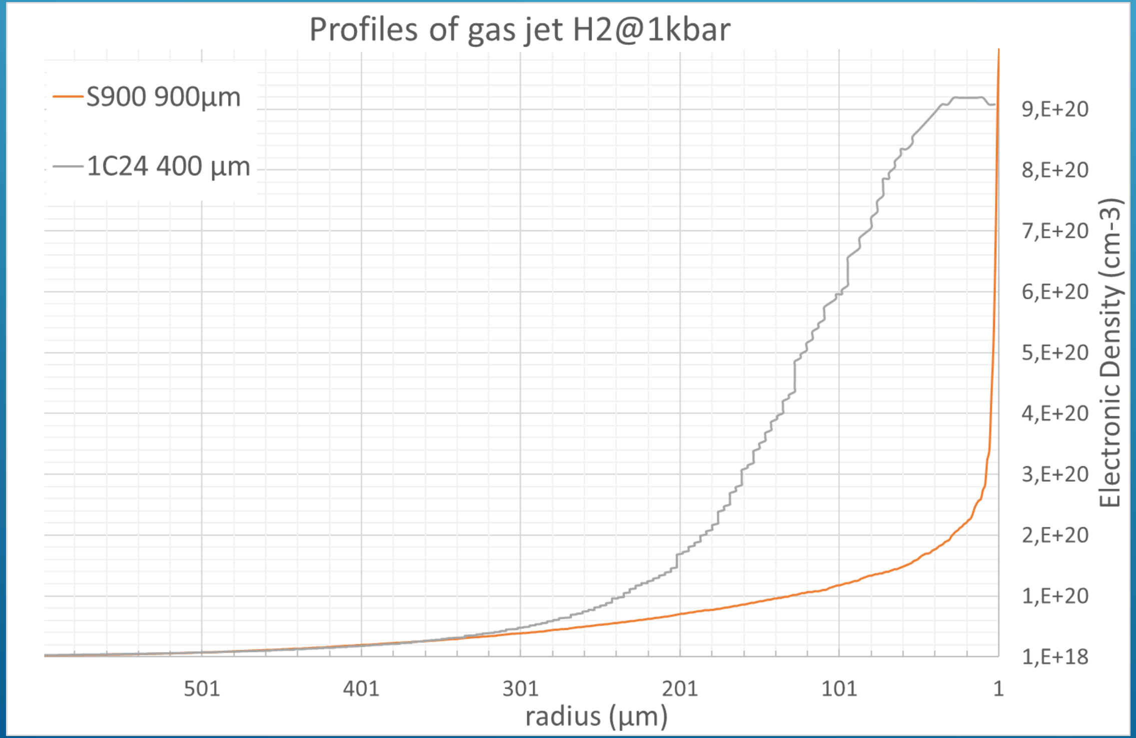
E_m = 100 J
E_p = 1 J
$\Delta t_{m\text{-}p}$ = -100 ps

Structure observed in spectrum (on single shot basis)

GAS TARGETS AND ION ACCELERATION: SHOCK NOZZLES



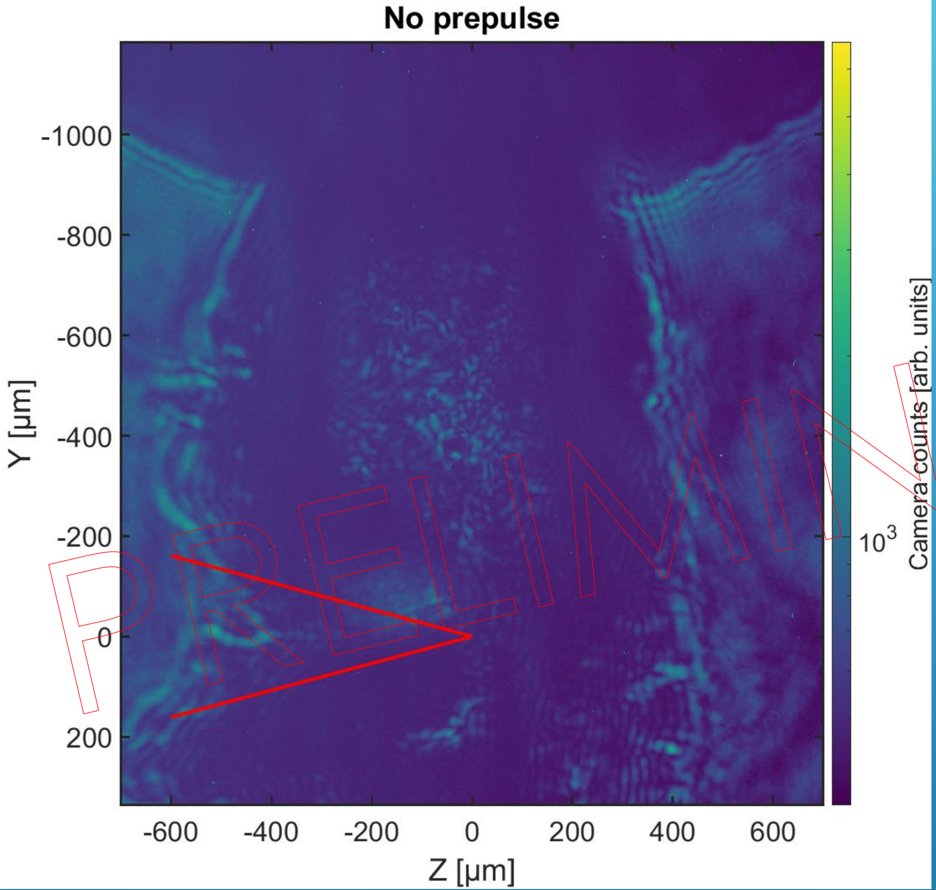


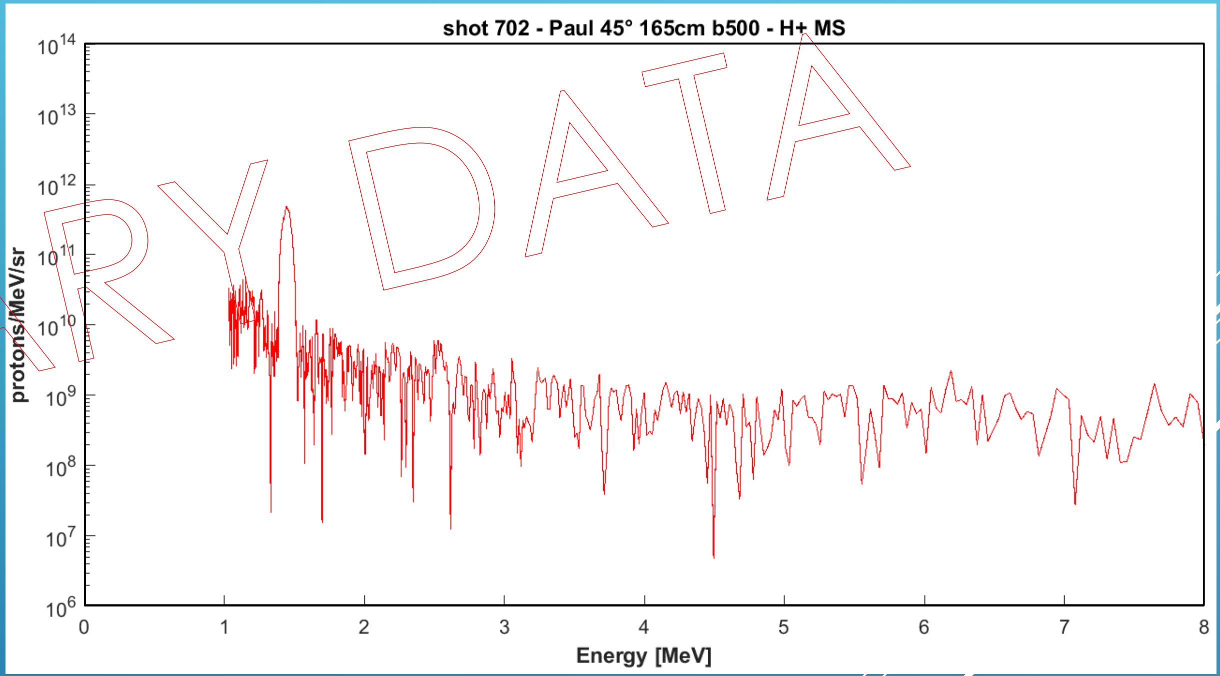


Reduces the low density wings of the density profile

RESULTS ON SHOCK NOZZLES

P = 1 kb





No prepulse

$E_m = 100$ J
$E_p =$ NA
$\Delta t_{m-p} =$ NA

Promising results, mono energetic beam

CONCLUSIONS & OUTLOOK

- **PRELIMINARY ANALYSIS**:
  - **Optical diagnostics** point towards indicating that **the laser energy is deposited further inside the density profile**, where the density is the highest. **As expected**.
  - **Particle diagnostics** seem to show there is **no improvement** on the energy distribution (except at 45°).

Needs to be understood

- Improvements:
  - Need for **higher repetition rate** laser facilities to conduct **parametric studies** for in depth understanding of the mechanisms at play during the interaction (2 weeks experimental campaign: 59 shots collected)
    - **Comparison** could be **biased** by **shot to shot** fluctuations
  - **Prepulse** which is **longer** (ns) and has **less energy** could be better suited for this type of studies (simulations)
  - Further studies with shock nozzles

REQUEST TO THE COLLABORATION

IV.2 Estimated duration for IN2P3 scientists in GSI		
Total time requested for 2022	84	
List of scientists	1. F.Hannachi (21 days) 2. M.Tarisien (21 days) 3. A.Maitrallain (21 days) 4. PhD student (21 days)	42 days granted, all used
IV.3 Estimated duration for GSI scientists in France		
Total time requested for 2022	8	
List of scientists	1. V.Bagnoud (4 days) 2. J.Hornung (4 days)	8 days obtaineded, none used yet

IV.2 Estimated duration for IN2P3 scientists in GSI		
Total time requested for 2023	18	
List of scientists	1. M Tarisien (6 days) 2. A Maitrallain (6 days) 3. new student (6 days)	Shared supervision of a PhD between LP2iB and GSI
IV.3 Estimated duration for GSI scientists in France		
Total time requested for 2023	6	
List of scientists	1. V.Bagnoud (3 days) 2. J Hormung (3 days)	

Need support for 3 weeks to collaborate on thesis and discuss future experiments on laser driven acceleration from **liquid targets**