Laser-driven ion acceleration and applications at IN2P3

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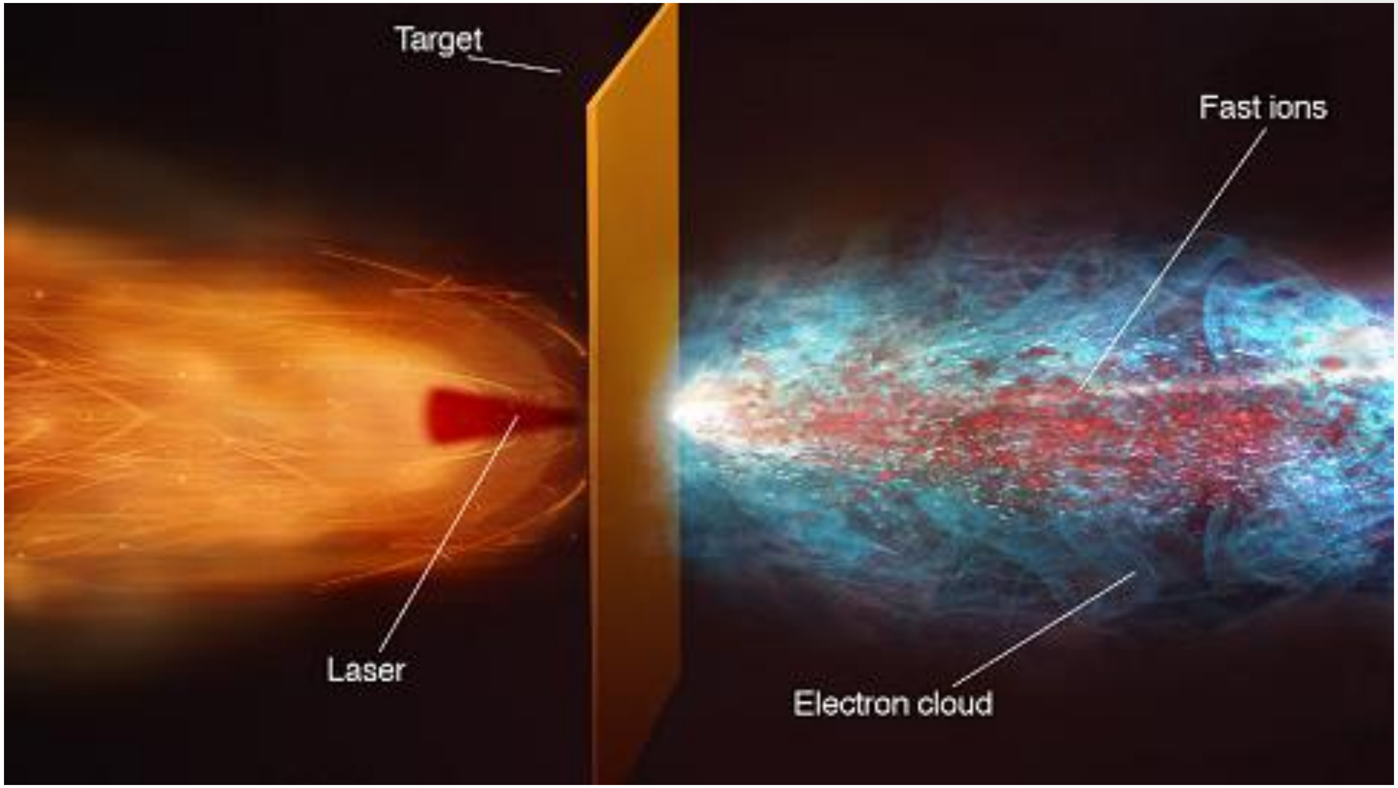
Laser driven ion source with solid targets

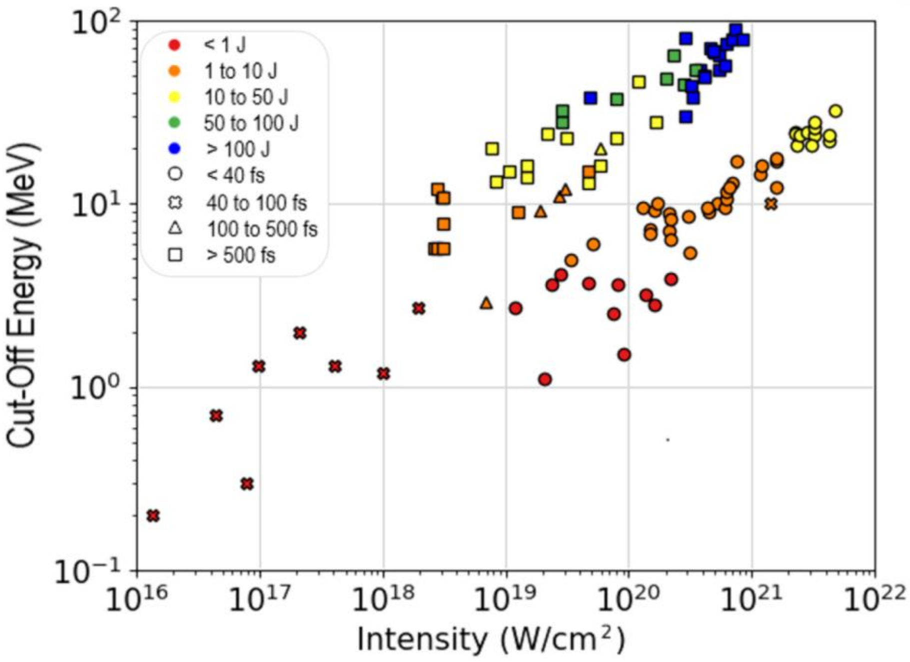


Target Normal Sheath Acceleration (TNSA)

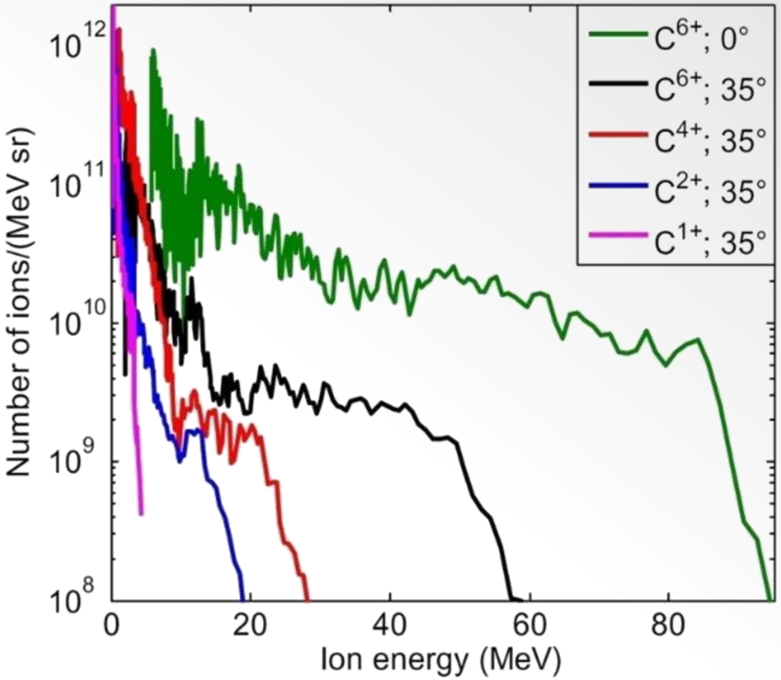
M. ROTH et al., Ion Acceleration—Target Normal Sheath Acceleration. CERN Yellow Reports, [S.l.], v. 1, p. 231, feb. 2016.

Laser driven ion source with solid targets

Laser accelerated protons overview



M. Zimmer et al., Phys. Rev. E 104, 045210 (2021)



Carroll, D. C et al.,New Journal of Physics **12** (2010) 045020 (15pp)

Astra-Gemini Laser : 115 TW ; 6 J ; 50 fs
=>7×10^{20}Wcm^{-2}

- peak intensity > kA of protons in a ~ps bunch duration
- TNSA well known, reliable, suitable energies BUT not compatible with new generation of lasers

Laser driven ion source with gas jet targets

Because of high-repetition rate lasers (0,01-10 Hz) :

Commercial lasers : 100's of TW @ few Hz :

THALES

Amplitude

Research facilities :

Cilex Apollon — 10 PW every minute

CLPU Centro de Láseres Pulsados — 1 PW every second

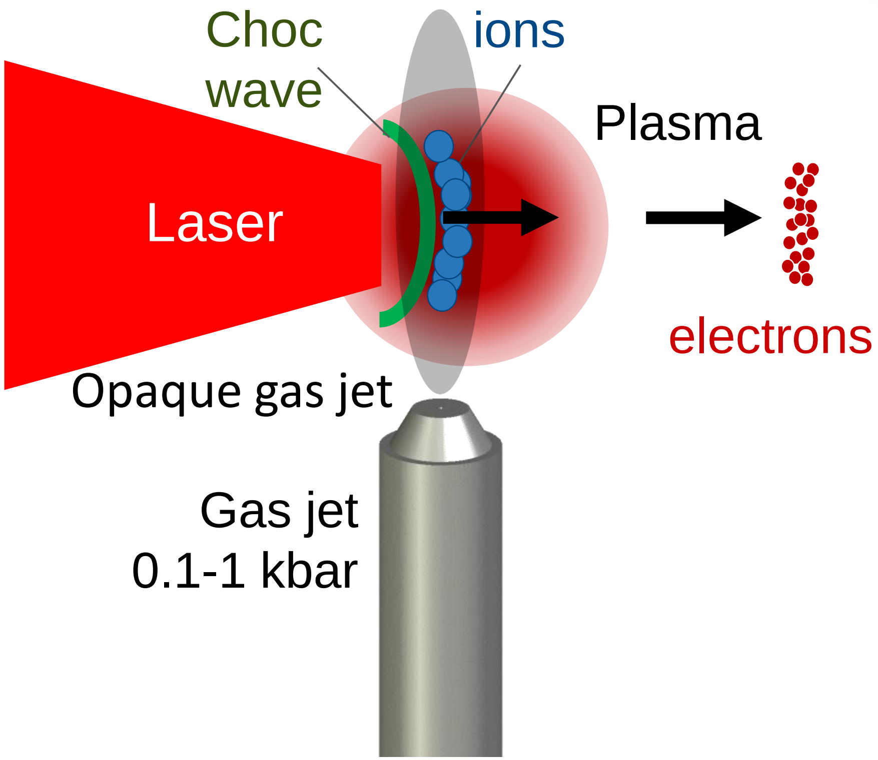
eli extreme light infrastructure — 1 PW every 0.1 second

Advantages of gaseous targets

- ✓ Target regeneration and alignment
- ✓ Less debris production (25 weeks of GSI/PHELIX≈ 2 min ELI-BL HAPLS@10Hz)
- ✓ Easy access to different ions
- ✓ Promote acceleration processes for high energies, high flux of ions and no Boltzmann energy distribution

Laser driven ion source with gas jet targets

Collisionless Shock Acceleration (CSA)



Observed on CO_2 laser (10 µm wavelength)

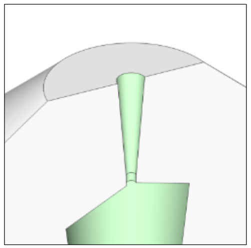
Dan Haberberger et al., Nature Physics, vol8, 95-99 (2012)

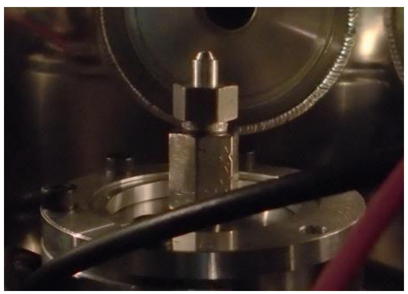
High Repetition Rate lasers are 1 µm wavelength

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

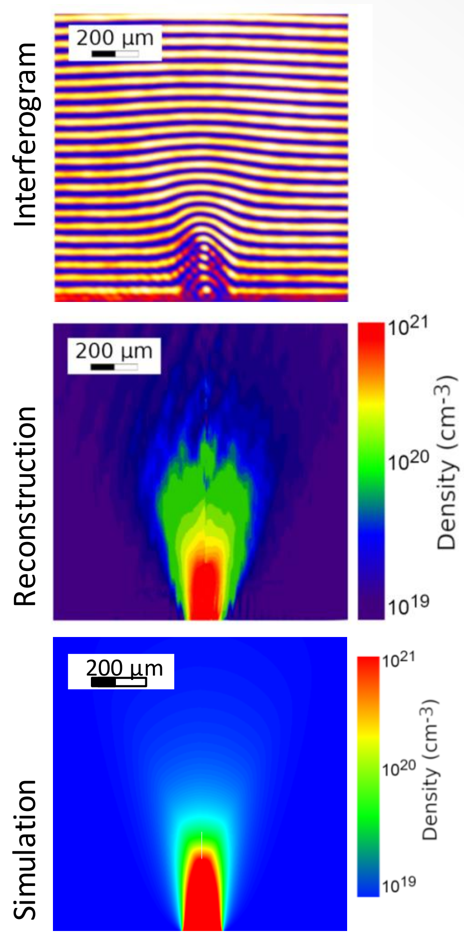
Laser driven ion source with gas jet targets

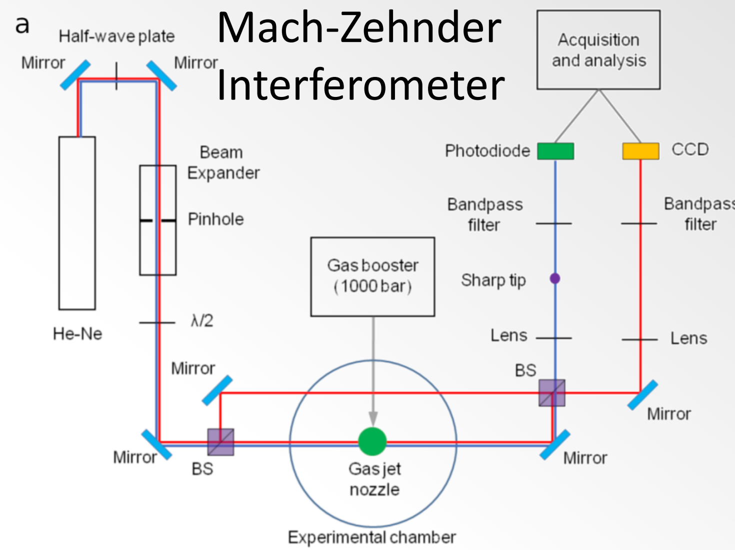
Our target

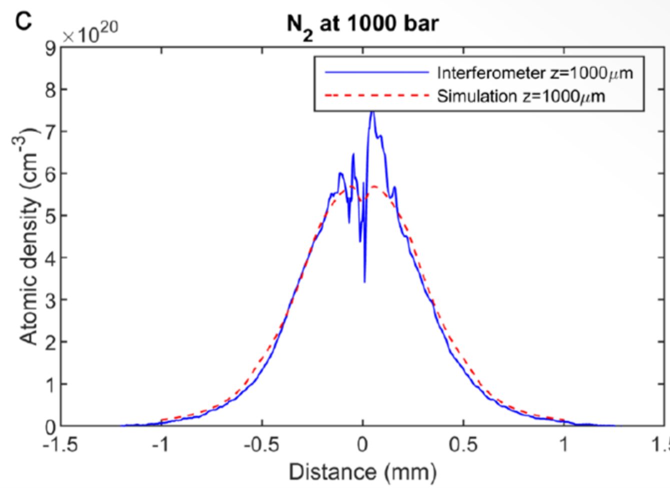




ANSYS FLUENT





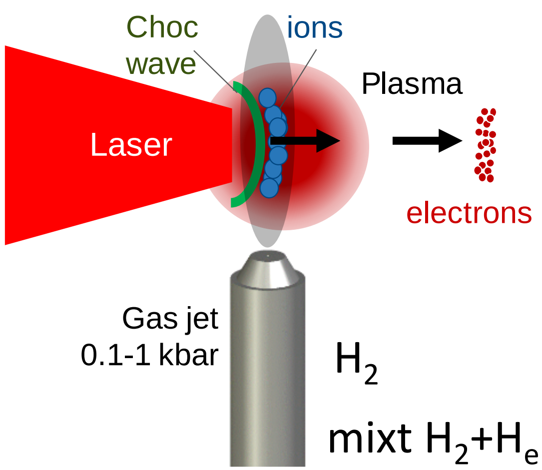


J.L. Henares, et al. Rev. Sci. Instrum. 90, 063302 (2019)
J L Henares, J. Phys. : Conf. Ser. 1079 012004 (2018)

Laser driven ion source with gas jet targets

Our first experiment

Laser	Energie (Joules)	Durée du pulse (ps)	Puissance (TW)	focal (µm)	Intensité (W/cm²)
PICO 2000	60	1	60	13	5E+19

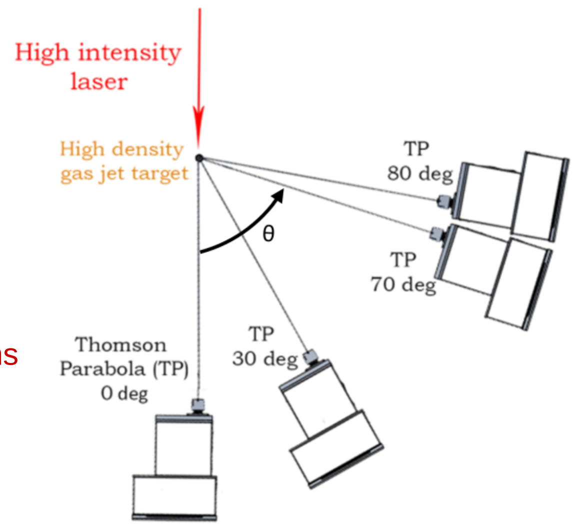


H_2

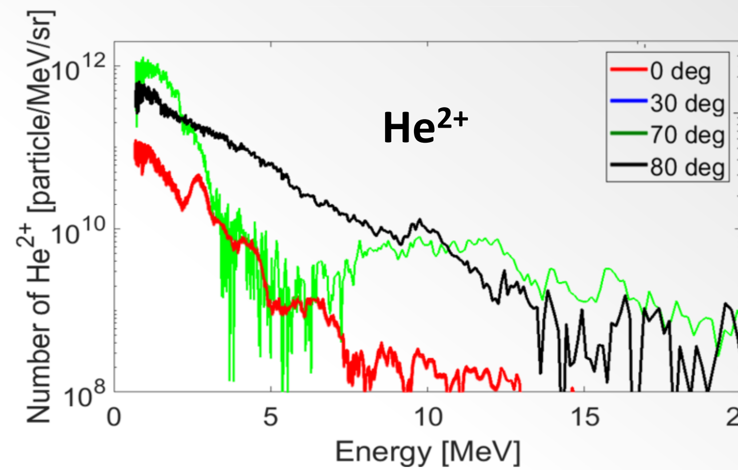
mixt H_2+H_e

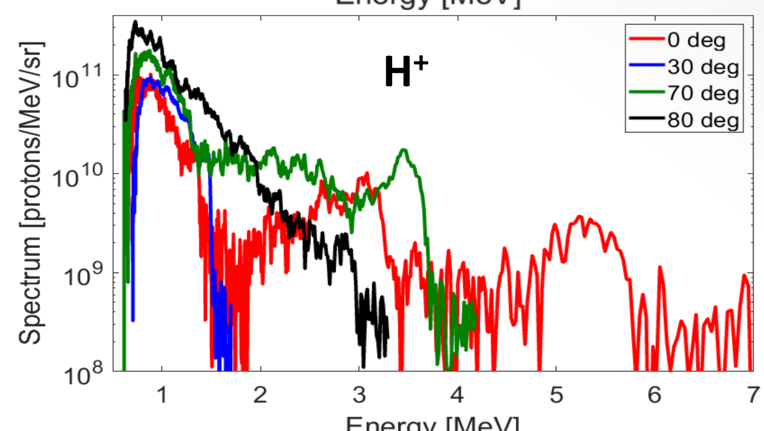
CSA :

Collisionless Shock Acceleration



(Project to use CMOS detectors)



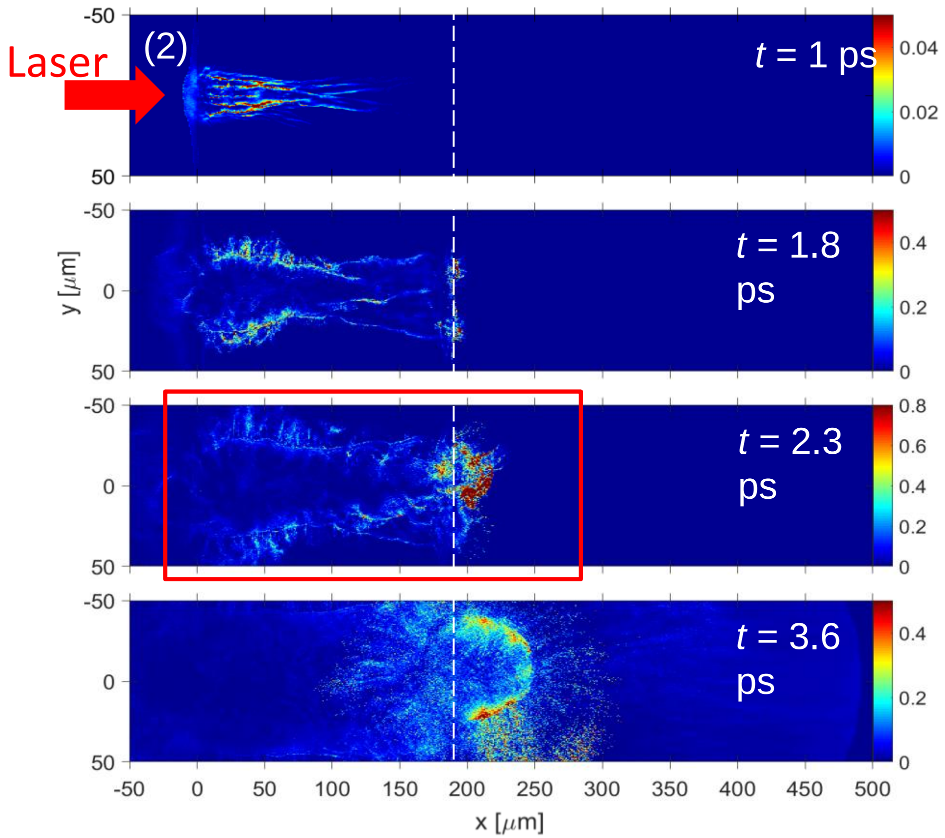


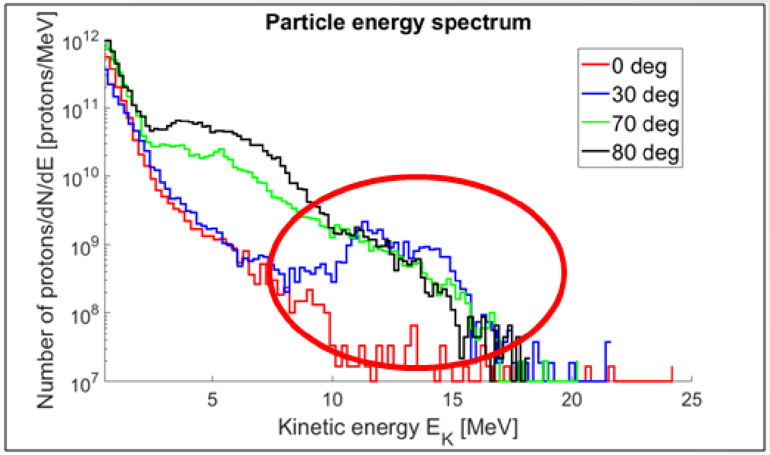
Puyuelo-Valdes, Proc. SPIE 11037, Laser Acceleration of Electrons, Protons, and Ions V, 110370B (2019)
Puyuelo-Valdes *et al.*, Phys Plasma, 26, 123109 (2019)

Laser driven ion source with gas jet targets

Our simulations

Particle In Cell simulations : PICLS





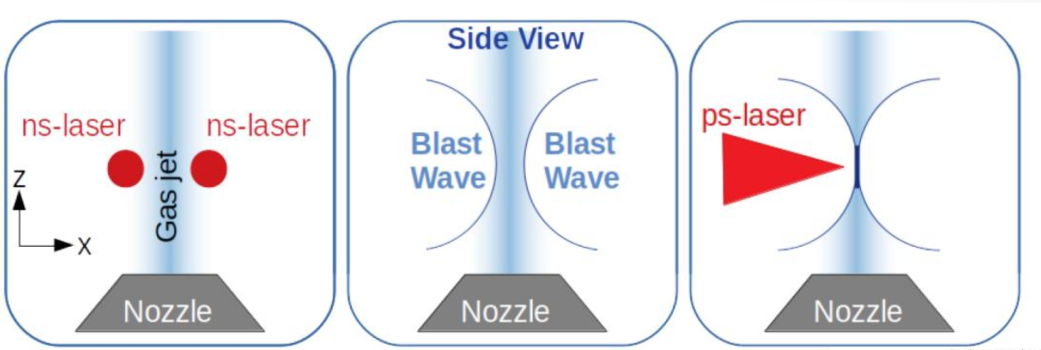
Structure formation in the energy spectra in forward direction

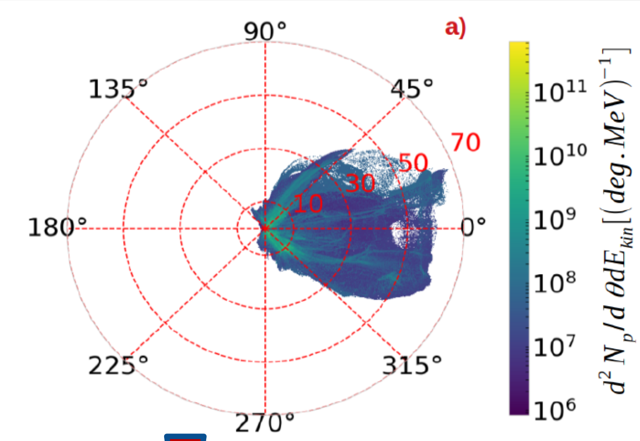
Laser interacts in low density part of gas jet target

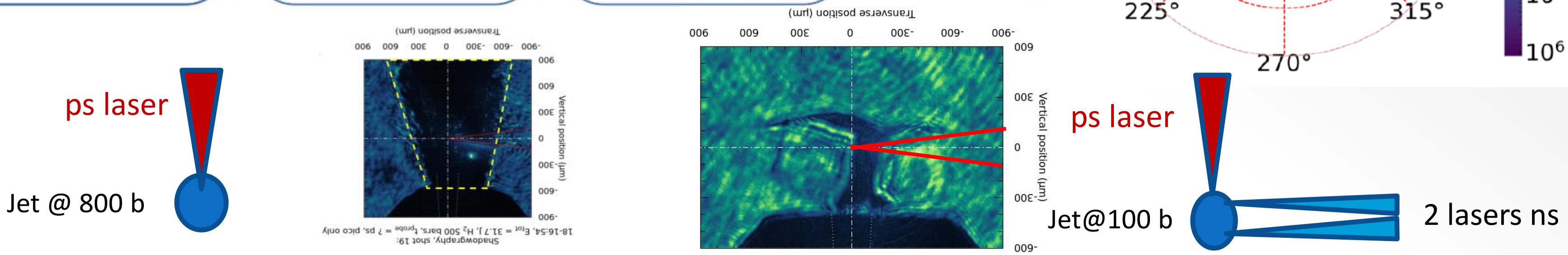
Puyuelo-Valdes *et al.*, Phys Plasma, 26, 123109 (2019)

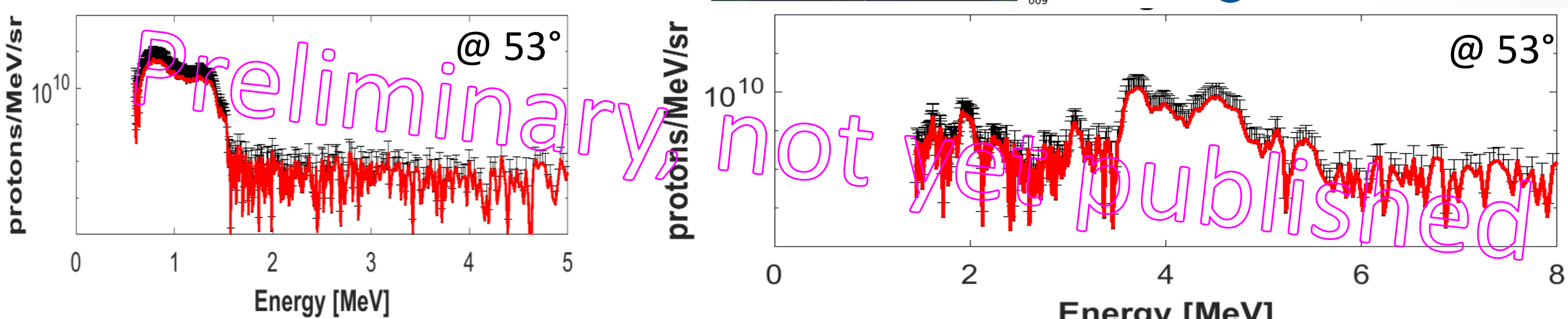
Laser driven ion source with gas jet targets

To promote the CSA process … the **Plasma Tailoring**







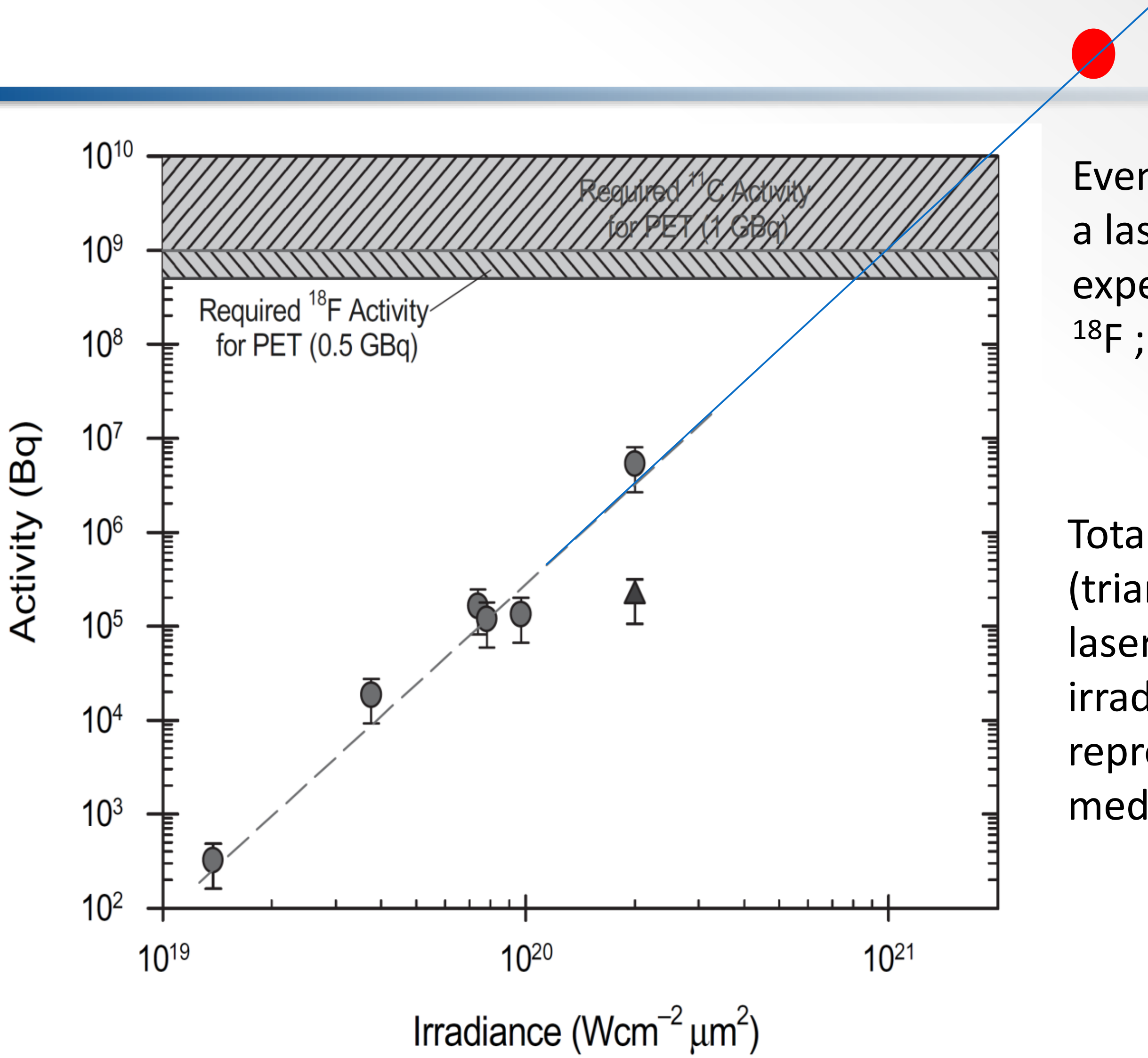


- Experiment at GSI in November 2020 : structures of energy distribution confirmed, but energy around 4 – 5 MeV

J.-R. Marques, et al. , Phys Plasma, 28, issue 2, (février 2021)

J.Bonalet et al., Phys Plasma, 28, 113102 (nov 2021)

Application : medical radioisotope production



Even without optimization, during a laser shot we produce in our experiments few kBq/shot of ^{11}C ; ^{18}F ; ^{13}N

Total activity of ^{11}C (circles) and ^{18}F (triangle) generated by one single laser shot as a function of its irradiance. The upper shaded area represents the activities used in medicine.

K.W.D. Ledingham and W. Galster, New Journal of Physics ***12,*** *045005* ***(2010)***

Conclusions

- New generation of high power lasers at High Repetition Rate (HRR) will give a new thrust to laser plasma acceleration
- Some issues need to be fixed before using the HHR capabilities of the lasers (knowledge on acceleration process, targets, diagnostics, …) : well-established laser facilities are mandatory (PHELIX/GSI)
- Gas jet targets are promising for HHR facilities, promoting interesting acceleration processes for energy and angular distribution
- A short-term application is the production of medical radioisotopes
- A medium-term application would be the production of short-lived radioisotopes for nuclear physics studies in transient astrophysical type plasmas created with high power lasers