



High-Yield and High Energy Protons in $p^{11}\text{B}$ reactions with pitcher–catcher configuration

Nanosecond Laser systems

Farmesk Abubaker, PhD

Istituto Nazionale Di Fisica Nucleare Laboratori Nazionali Del Sud (Italia)

abubaker@lns.infn.it

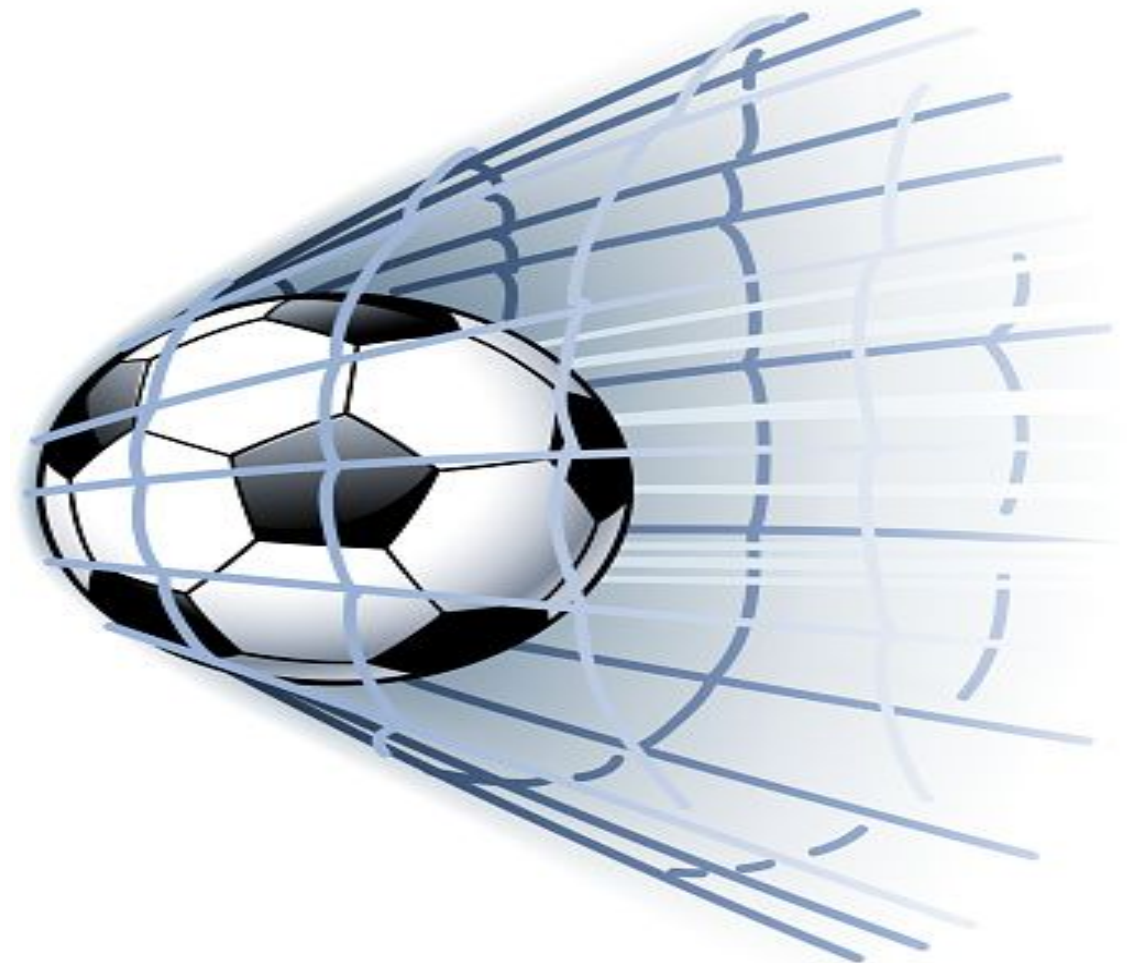
Outline

- ❖ Objective of the Experiments
- ❖ Experimental Set-Up
 - In-target configuration
 - Pitcher-Catcher configuration
- ❖ Maximum Proton energy and high Fusion yield recorded by
 - Thomson Parabola Spectrometers (TP)
 - Time Of Flight Detectors (TOF)
 - CR-39 Detectors
 - Electron Spectrometers
- ❖ Result and Conclusion



Main Goals of this work

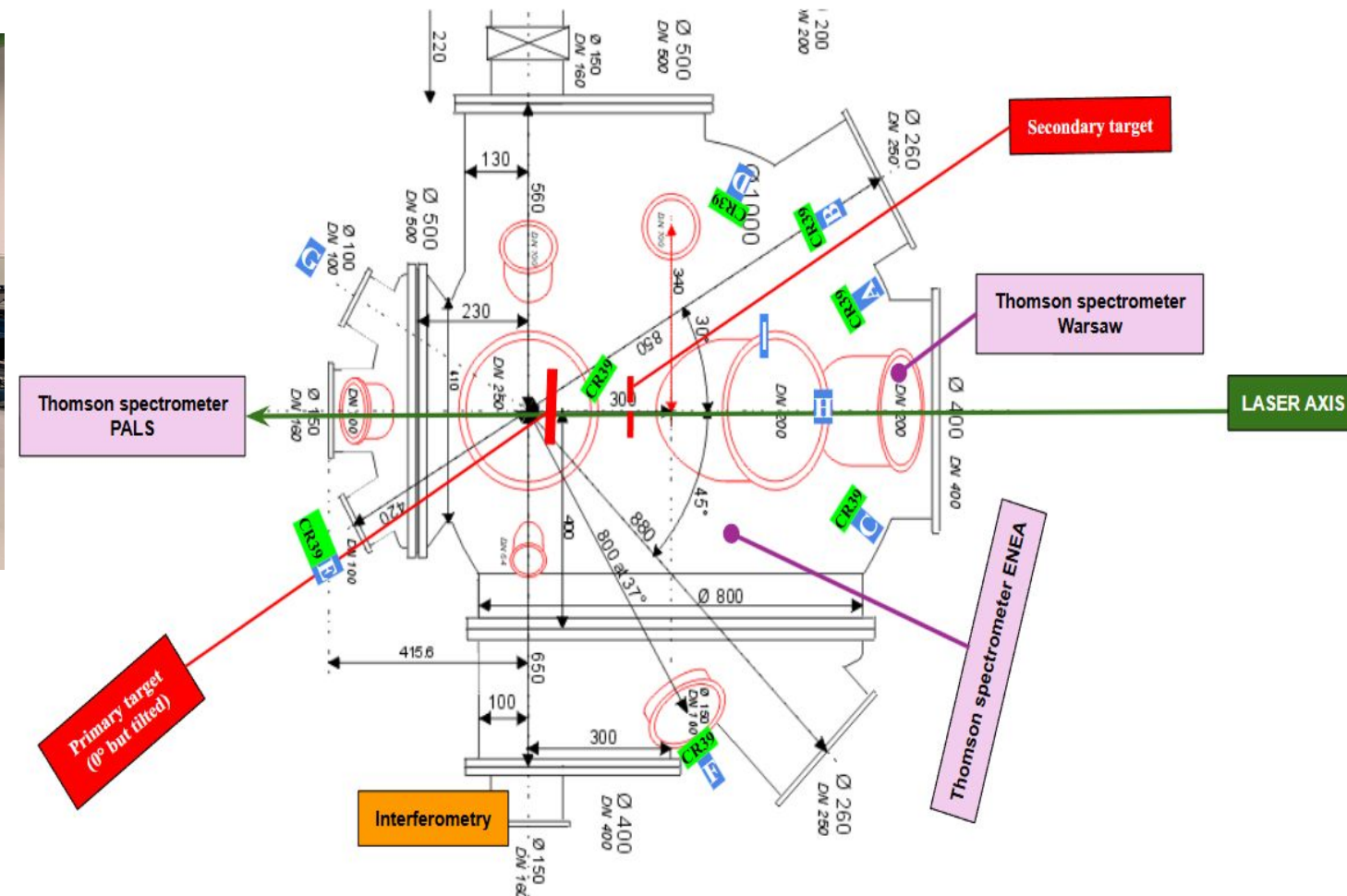
- ❖ The main goals of this work are to measure high fusion yield and the maximum energy of protons accelerated by high-intensity laser pulses and to test how consistent this acceleration is across different targets and experimental conditions.
- ❖ We used multiple diagnostics to ensure reliable measurements. In our experiments, the maximum proton energy reached **5.7 MeV** and was confirmed by all detectors. Even across 13 shots, the lowest maximum energy was still 4 MeV, showing that the acceleration mechanism is robust.



Experimental Setup



- Wavelength (1315 nm)
- 600 J on target (maximal energy)
- Pulse duration: 300 ps



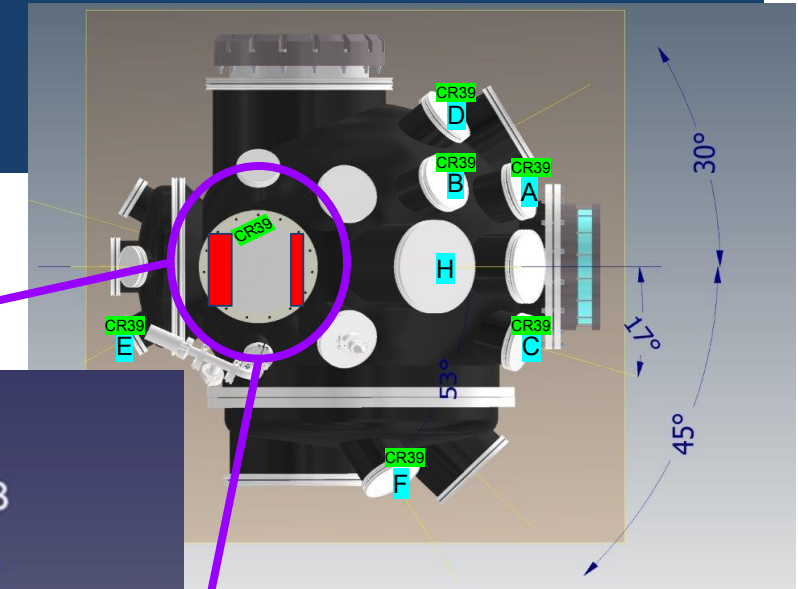
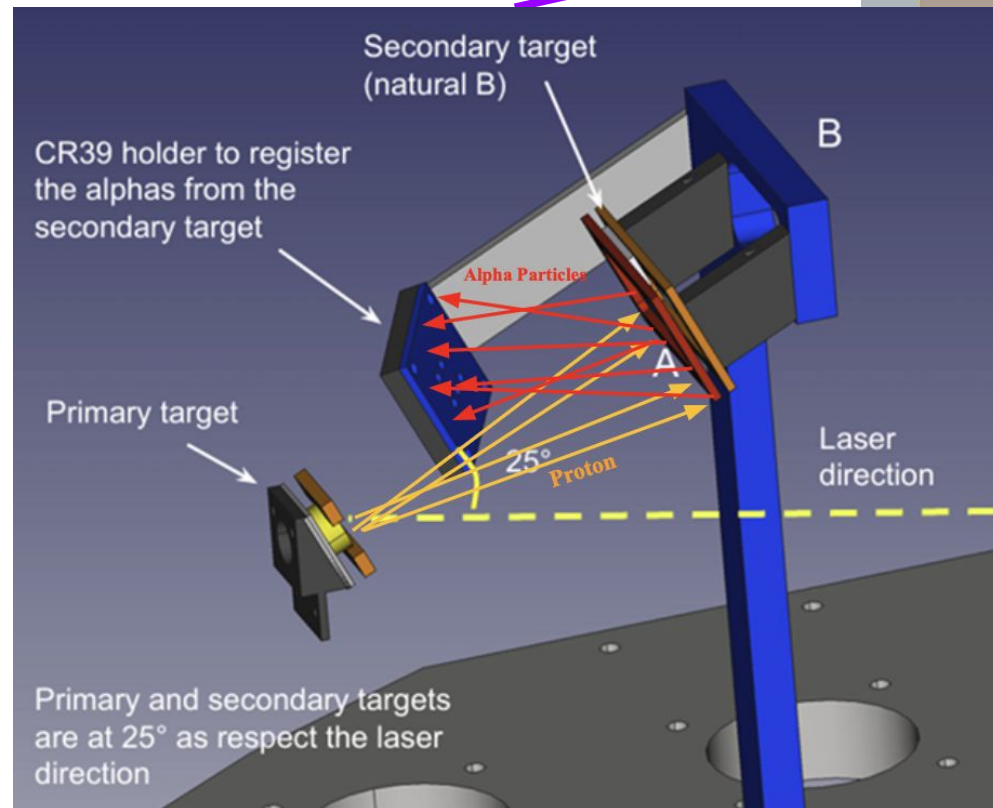
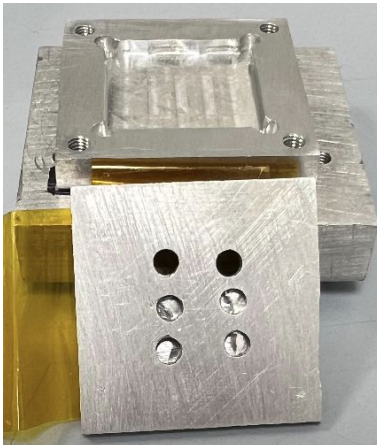
Primary Targets

Target List	Description	Details and more information	Thickness
Lecce	Consist of several layers of polymeric fibres (PMMA, PS) containing the boron precursor at different concentrations.	Fiber diameter (PMMA, PS) about 10 microns; Thickness range from 20-200 microns	200 microns
Trento/ Roma	Substrate: SiHB with foam deposited on top by means of synthesis chemistry;	Substrate thickness Yes 500 microns; Annealing in N2/H2 atmosphere + boron doping at higher concentration $>10^{22}$ at/cm ³ ; Density: 2.1 g/cm ³ ; Dimensions: 0.5 cm x 3 cm; Target thickness: hundreds of microns; Target density: a few mg/cm ³ ; Area: a few mm ²	700 micron
Trento/ Milano	SiHB substrate with deposited layers of Boron nano foam on top through PLD;	Substrate thickness Yes 500 microns; Annealing in N2/H2 atmosphere + boron doping at higher concentration $>10^{22}$ at/cm ³ ; Density: 2.1 g/cm ³ ; Dimensions: 0.5 cm x 3 cm; Target thickness about 100 microns of the deposited structures; Density from 1 g/cm ³ to 15 mg/cm ³ ; Area: 1 cm x 1 cm;	600 micron
Catania	Boric acid or compressed Boron tablets made more compact from acrylic resin (containing hydrogen, C and O)	Boron/polymer ratio: 10-20-50% wt; H3BO3/polymer ratio: 10-20-50% wt;	3+/-0.05 mm;
ELI-LNS	Boron substrate with a thickness of CH deposited on top	Boron target thickness 1.5 microns: Density 2.46 g/cm ³ Size: 2x2 cm ² Polymer thickness: 0.2-2 microns Density: between 0.6 and 1.6 g/cm ³	between 1.5 and 3.5 microns

1. Pitcher-Catcher Configuration

- A two-stage setup: primary target (pitcher) followed by a secondary target (catcher).
- **CR-39 detectors** were used.
- **Activation** Measurements allow the evaluation of the total alphas produced at the secondary target and we can have a comparison with CR39 measure.
- For the backscattering particles evaluation **Monte Carlo simulations** are needed

- The CR-39 was divided into six regions, **Aluminum filter** of increasing thickness: 0, 3, 6, 15, 20, and 35 μm .

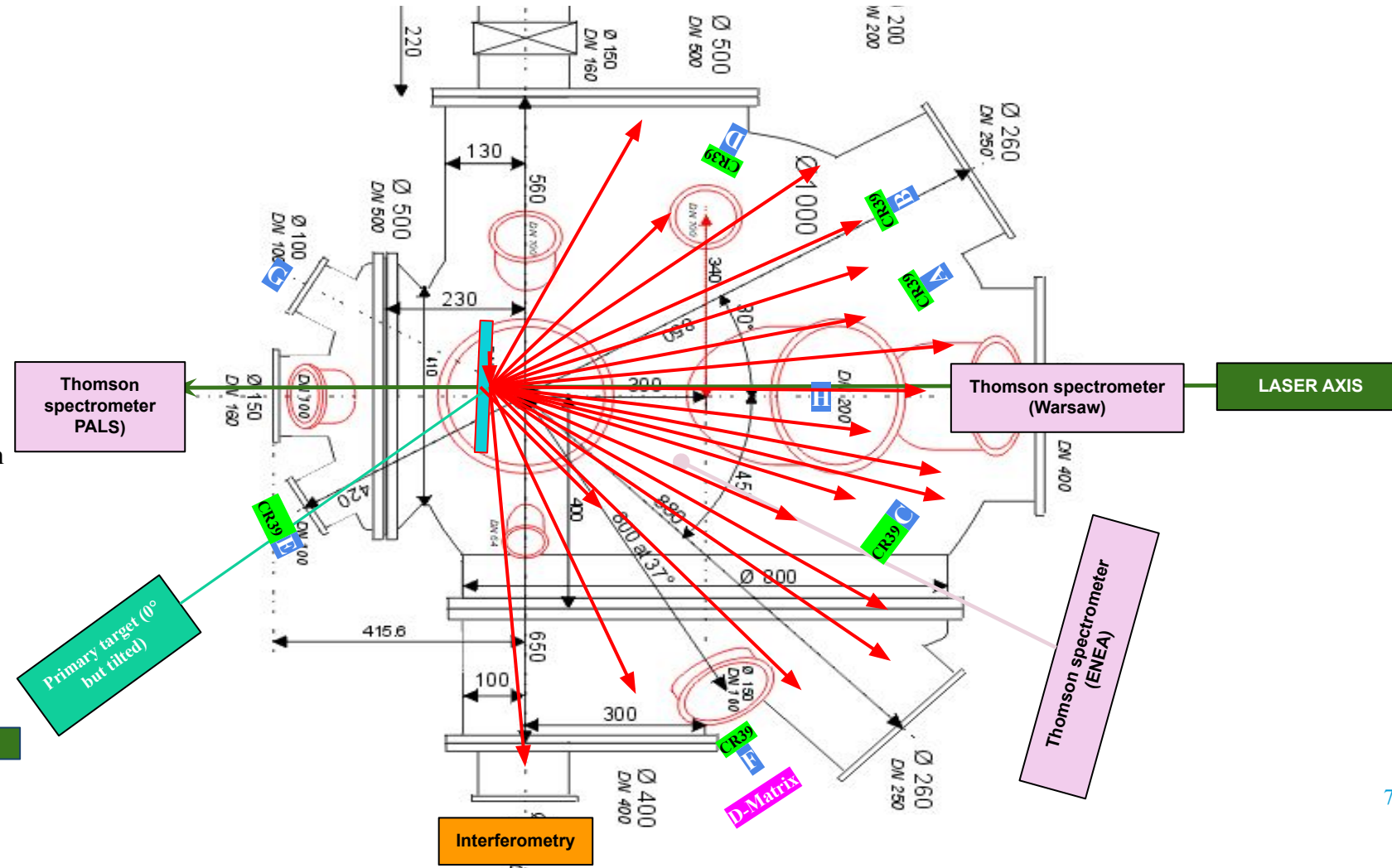
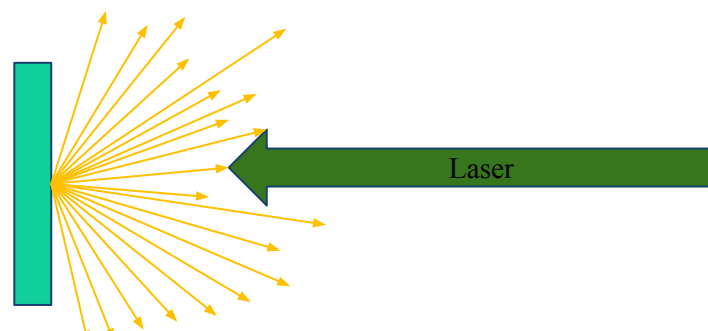


2. In-Target Configuration

The laser used delivered high-intensity pulses focused onto these targets. Two configurations were explored:

1. Targets were directly irradiated by the laser.
2. Detectors placed at multiple angles around the target:
 - **CR-39** passive track detectors
 - **Thomson Parabola (TP)** spectrometers
 - **Time-of-Flight (ToF)** detectors
 - **Electron spectrometer** not in all shots
 - **Interferometry** (pico or femto-second resolution) for the plasma density evolution

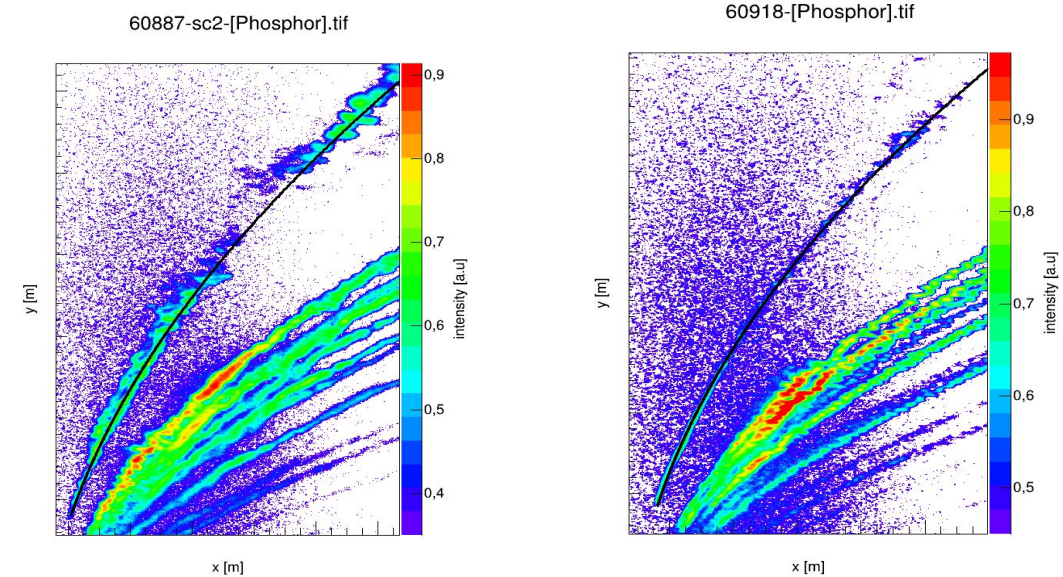
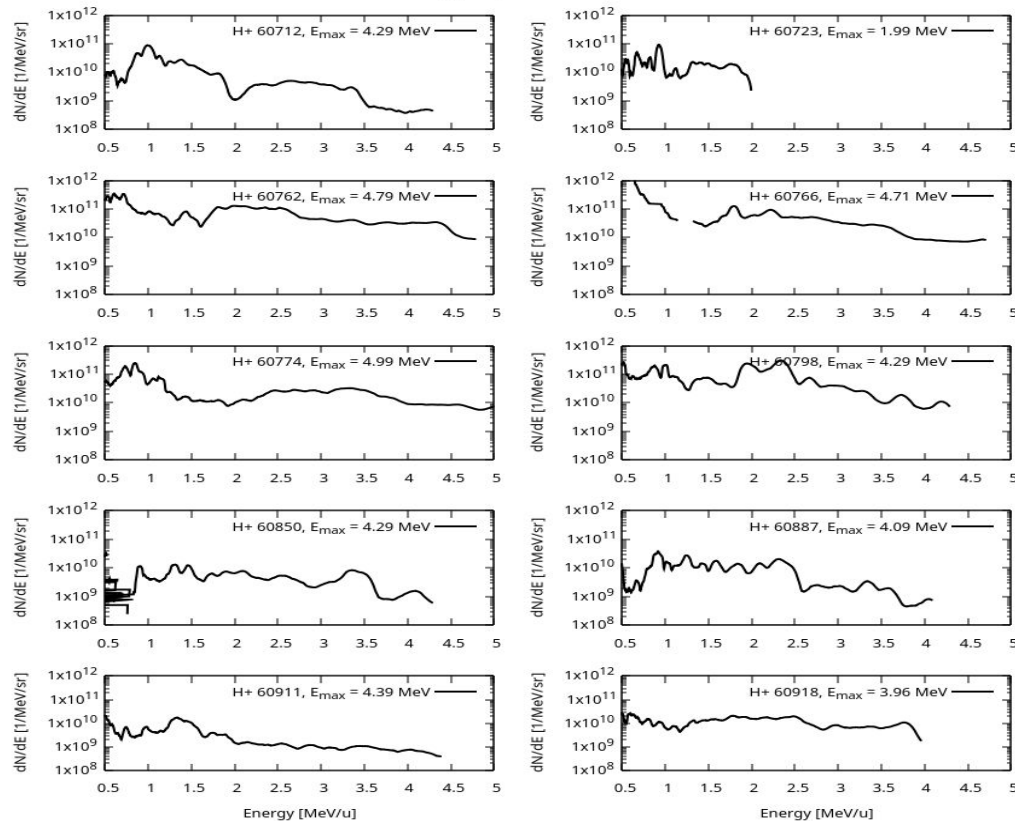
Primary (Pitcher) target



Proton Maximum Energy recorded by TP

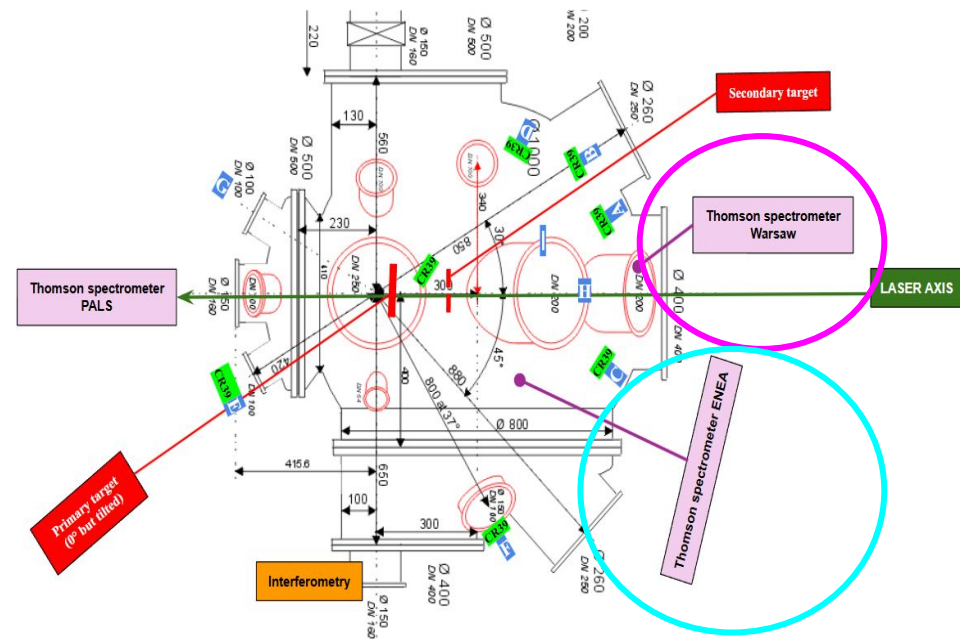
- TP spectrometers used to measure proton energy spectrum
- Clear parabolic traces of protons identified and reconstructed
- Proton energy (MeV) is detected for each shots

Proton energy spectra - IPPLM TPS



Thomson parabola images of some shots

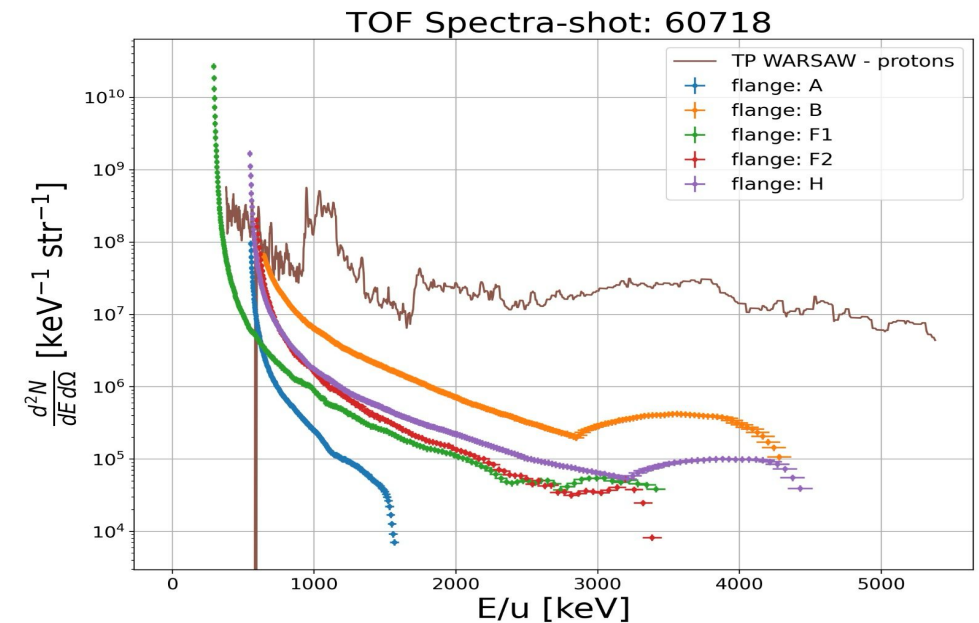
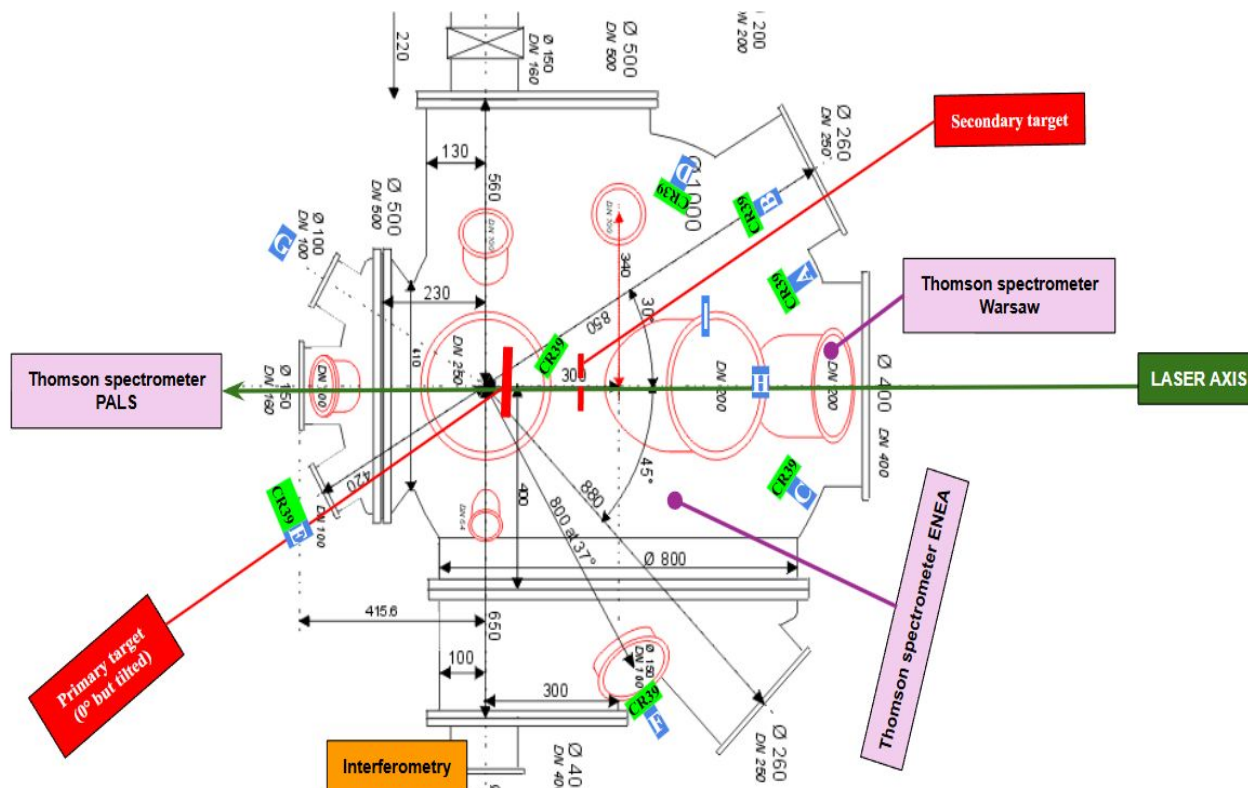
Proton Maximum Energy recorded by TP



Shots	Targets		Laser			TP (MeV)	
	primary targets	thickness (mm)	laser energy (J)	laser pulse (ps)	Intensity (10^{16} W/cm ²)	TP warsaw (MeV)	TP ENEA (MeV)
60760	ELI - BN+H (30w)	1.5	551	316.534	3.46	5.5	3.6
60718	Boron (Mirabella-B50)	3	493	237.101	4.14	5.4	3.5
60719		3	262	255.3	2.05	4.9	1.4
60774	Reference Target	3	451	303.9	2.94	5.1	3.6
60798		3	463	292.024	3.16	4.3	4.1
60712		3	406	255.436	3.16	4.3	2.5
60736		3	388	285.986	2.71	4	2.5
60911	Ammonia Borane	0.16	479	230.469	4.14	4.4	3.3
60918		0.160	493	371.592	2.64	4	2.5
60762	FBK	not given	572	291.501	3.90	4.8	3.5
60850		not given	468	303.742	3.06	4.3	2.6
60766	PALS Plastic		440	328.601	2.66	4.7	2.6
60887	Foam Target 50mg/cc Si-H	300+-1 um	455	279.886	3.24	4.1	2.75

Proton Maximum Energy recorded by TOF

- TOF detectors are placed in multiple angles around the target
- proton arrival time analyzed to extract energy spectra
- Maximum proton energy measured

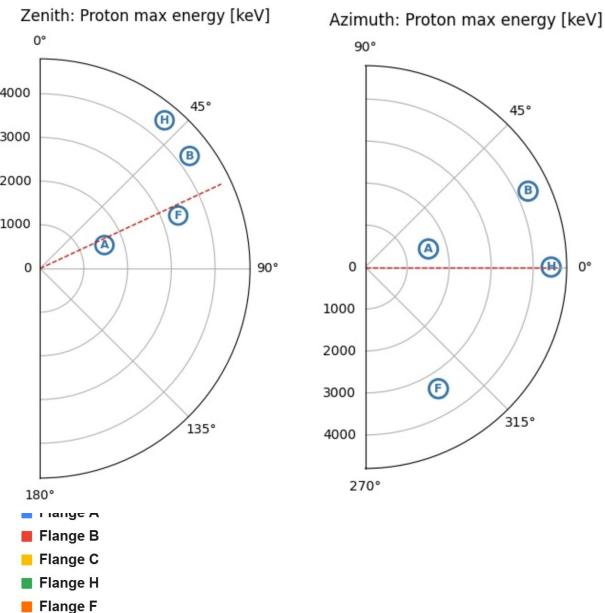
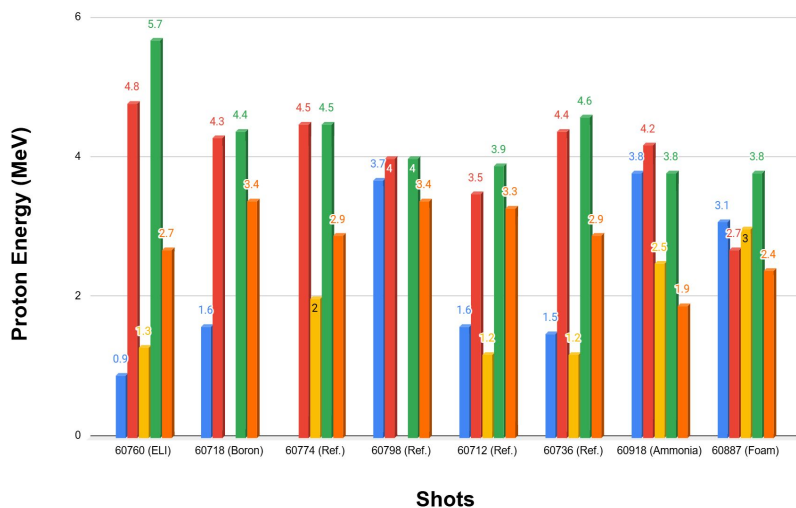


Flange	φ	θ	Distance (cm)
Flange H	0	25	95
Flange A	-17	-6	127
Flange B	-25		128
Flange C	+17	-6	112
Flange F	+53	-4	107

Results and Conclusion: Proton Maximum Energy

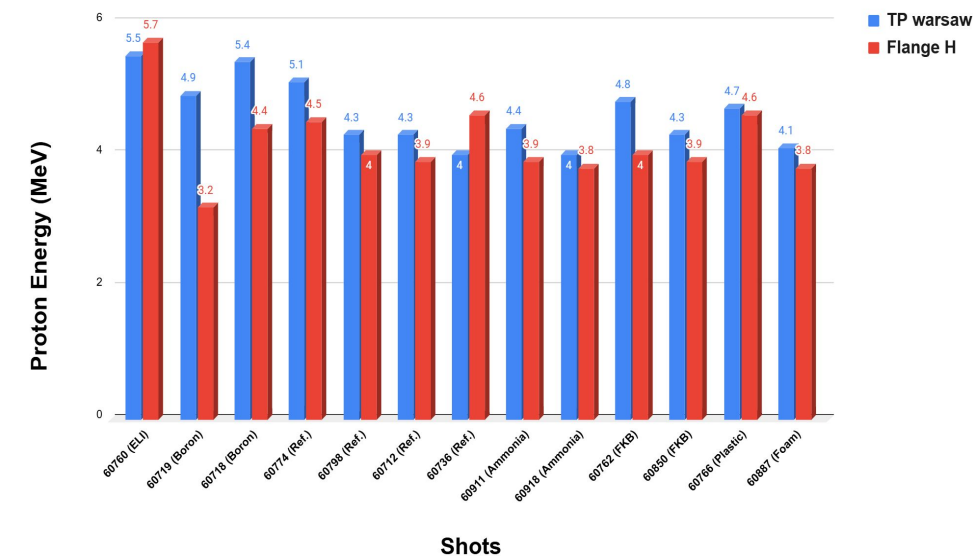
- Proton energies recorded by TOF detectors at different flanges and positions.
- Flange H (0°, 95 cm) shows the highest energies (up to 5.7 MeV), indicating strong forward-directed emission.
- Other flanges, located at larger angles, record lower proton energies, reflecting the angular distribution of accelerated protons

Proton energy recorded by TOF detectors (Flanges)



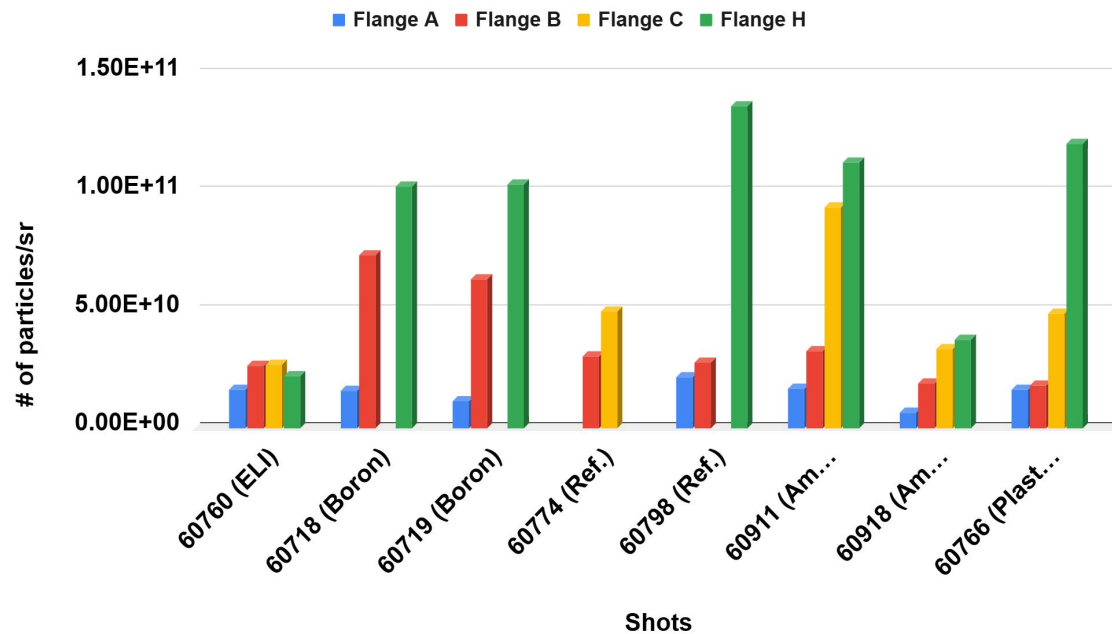
- Comparison of proton energies recorded by TP-Warsaw (blue) and TOF Flange H (red) at 0°.
- Results show good agreement between diagnostics across different targets, with measured proton energies ranging from ~3.8 to 5.7 MeV.
- The observed differences are within expected calibration and detection uncertainties, confirming the reproducibility of proton acceleration under various experimental conditions.

Proton energy (MeV) recorded by TP-Warsaw and TOF (Flange H) at 0 degree

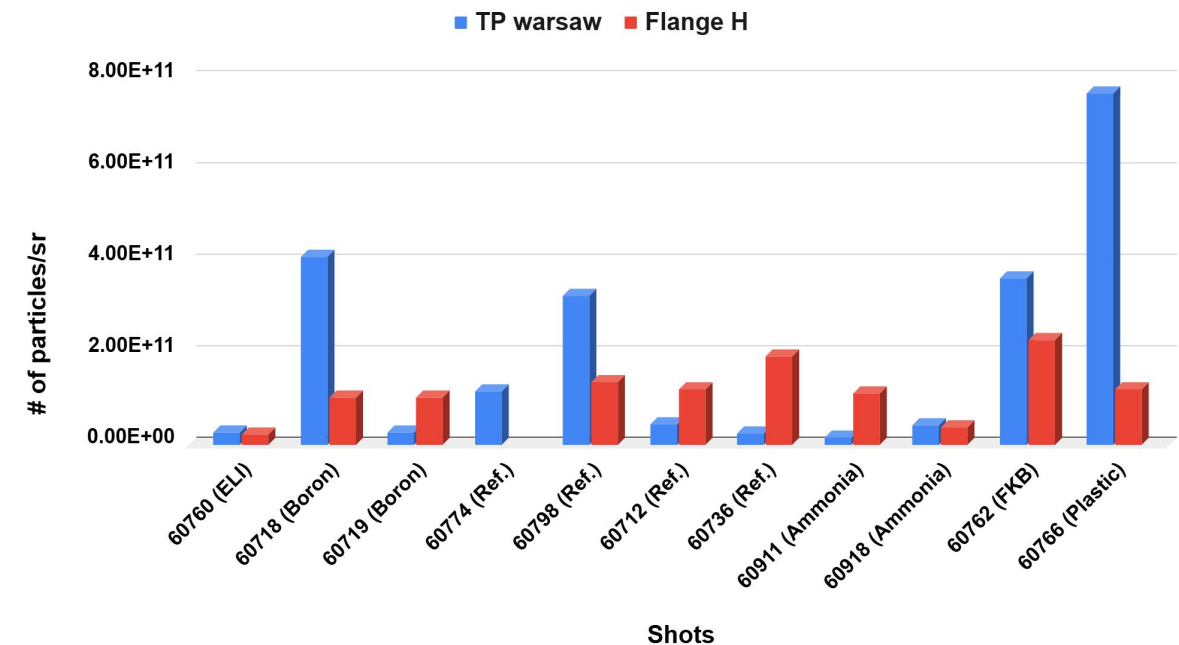


Results and Conclusion: High Fusion Yield

#particles/sr for each shots recorded by TOF (Flanges) detectors



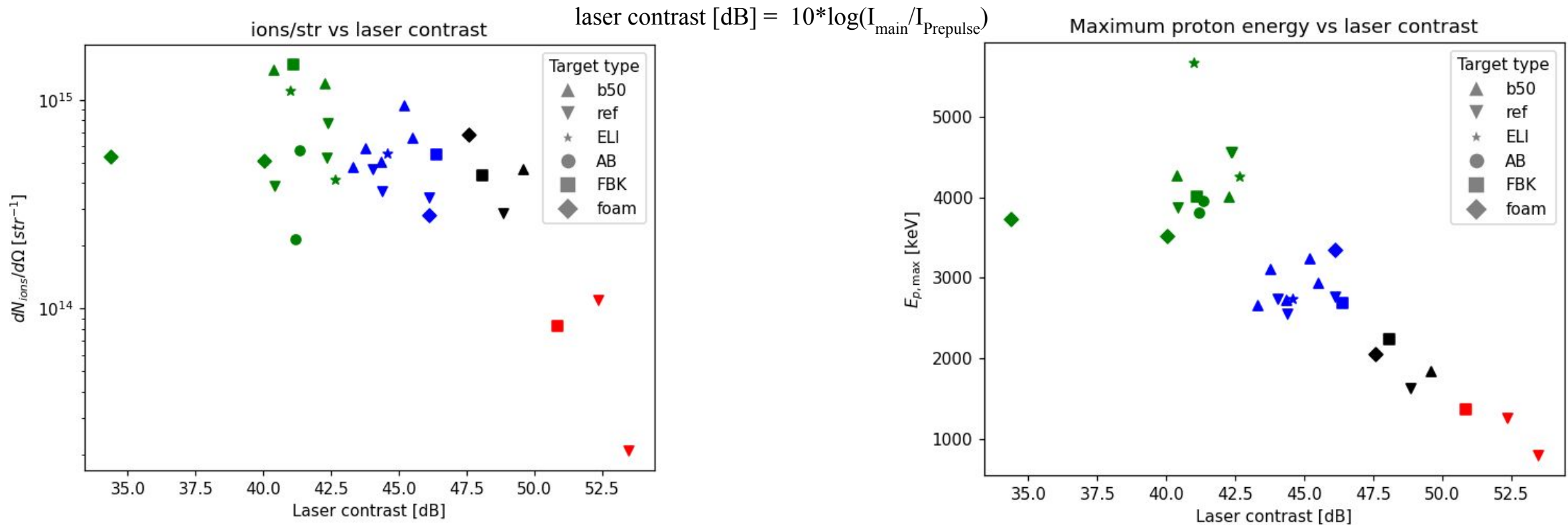
of Particles/sr recorded by TP-Warsaw and Flange H (TOF) detector for different shots



- Proton yield recorded by TOF detectors at different flanges. The highest number of particles per steradian is observed at Flange H (0°), confirming the forward-directed emission of protons.
- Boron-containing targets show higher yields than references, while the maximum yield reaches $\sim 1.5 \times 10^{11}$ protons/sr for shot 60911.

- Comparison of charged particle yields recorded by TP and TOF detectors.
- Both diagnostics show higher particle numbers for boron targets and forward emission (Flange H), reaching values up to $\sim 8 \times 10^{11}$ particles/sr.

Results and Conclusion: Laser Contrast



- **Ion yield and proton maximum energy** strongly depend on **laser contrast**.
- **Best performance** (highest yield & ~5 MeV protons) at **intermediate contrast (40–45 dB)**.
- At **very high contrast (>50 dB)**, both yield and energy decrease due to reduced pre-plasma.

Results and Conclusion: CR-39 Detectors

Flanges (ToF and Cr39 detectors): configuration

Configuration	Position	Filters	Dimension
TOF	A - B - C - D - E	20,25,30,35	1x1 cm ²
Flange F	F	(Matrix 1) 3,6,10,15	1x1 cm ²
		(Matrix 2) 20,25,30,35	1x1 cm ²

Al-thickness [um] = 20

Area 1

cut off energy protons [MeV]= 1.23
cut off energy alphas [MeV]= 4.7

Al-thickness [um] = 25

Area 2

cut off energy protons [MeV]= 1.43
cut off energy alphas [MeV]= 5.5

Al-thickness [um] = 35

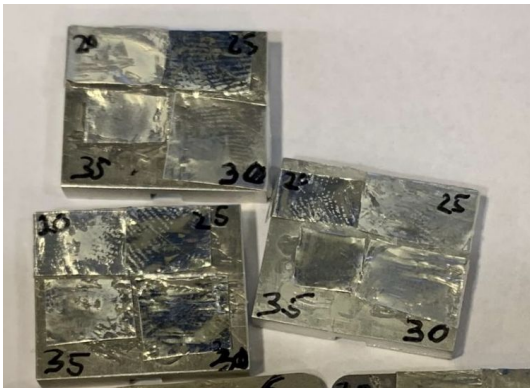
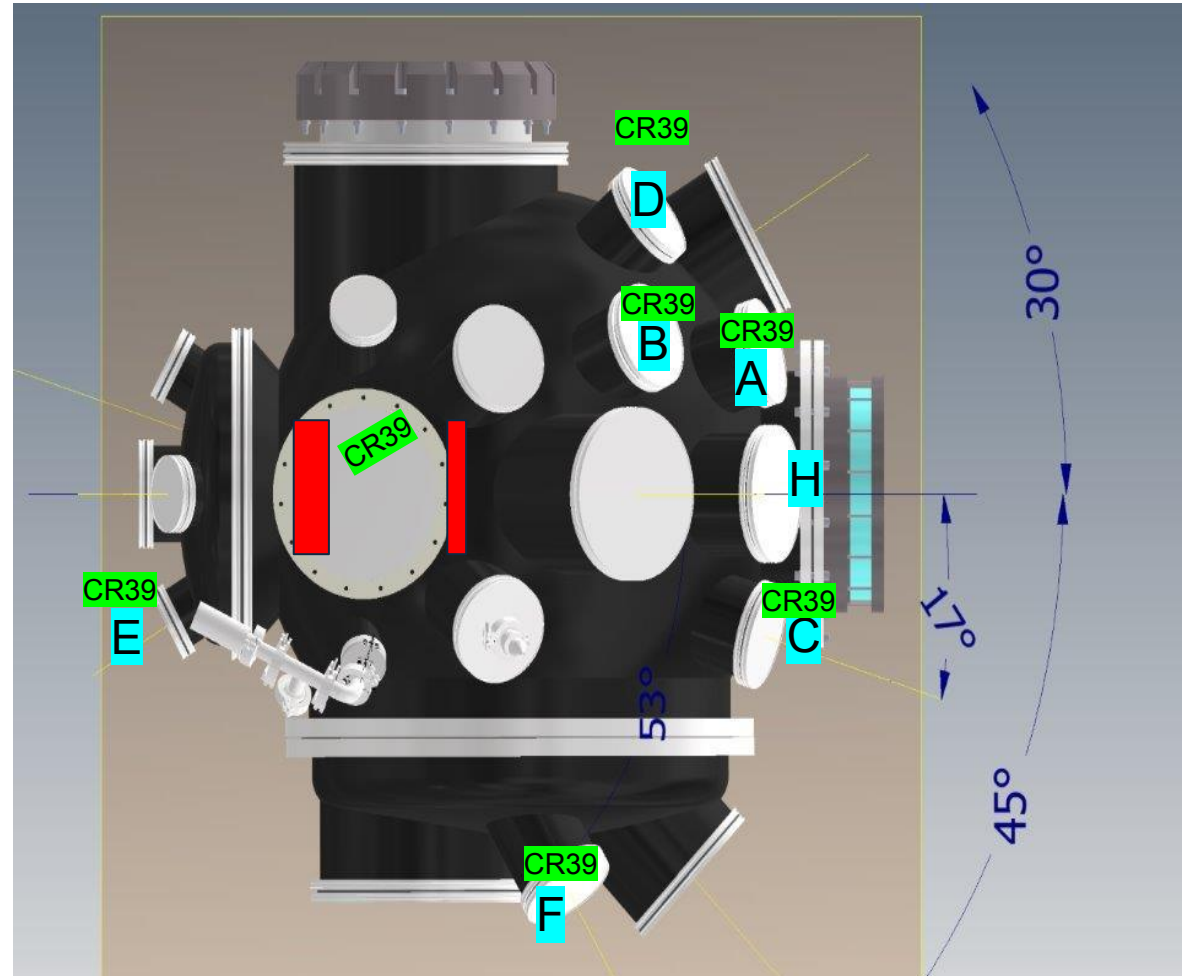
Area 3

cut off energy protons [MeV]= 1.78
cut off energy alphas [MeV]= 6.95

Al-thickness [um] = 30

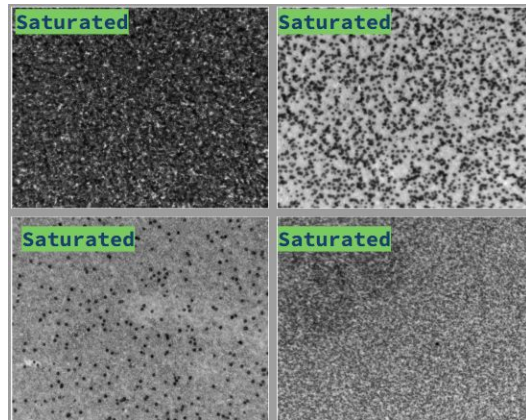
Area 4

cut off energy protons [MeV]= 1.61
cut off energy alphas [MeV]= 6.26

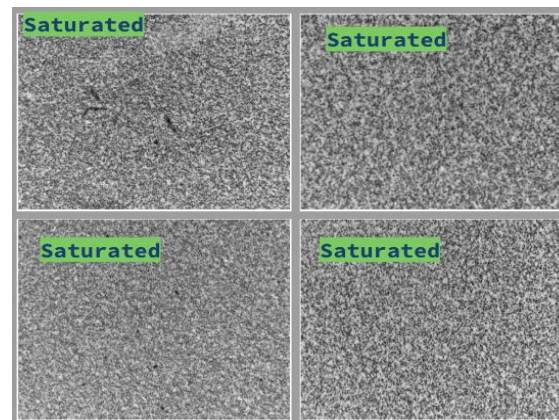


Results and Conclusion: CR-39 Detectors

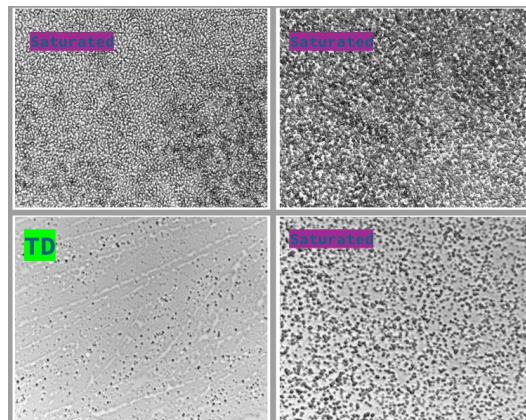
Shot 60774- CR 605- Matrix 1 -Etching Time: 30 Min



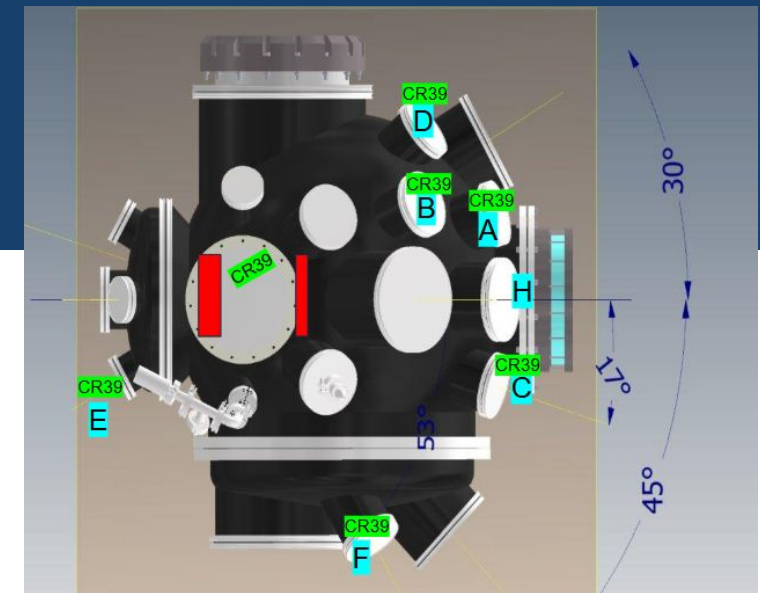
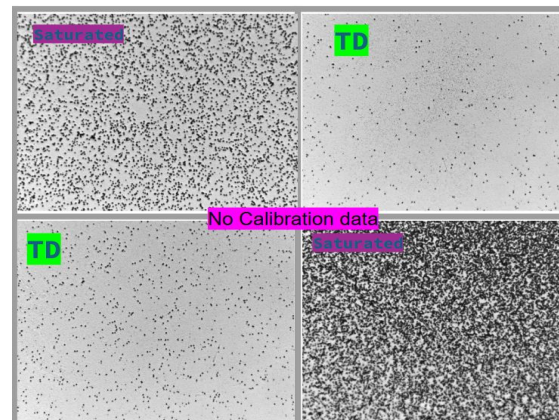
Shot 60774- CR 609- Flange B -Etching Time: 30 Min



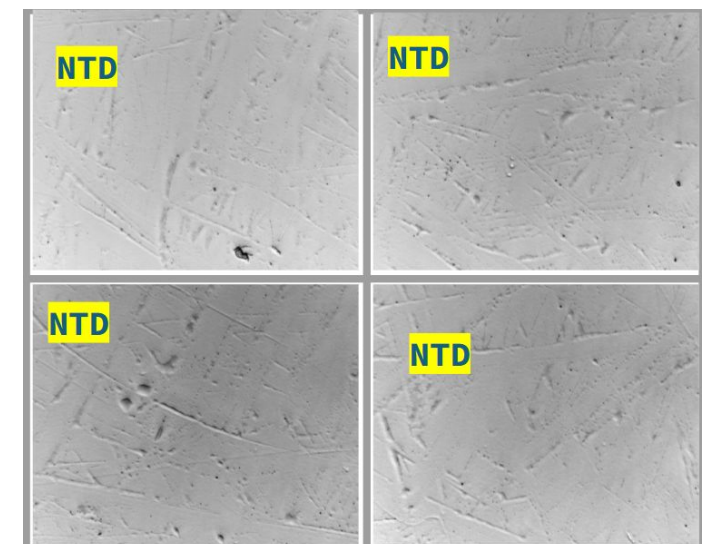
Shot 60718- CR 358- Matrix 2-Etching Time: 90 Min



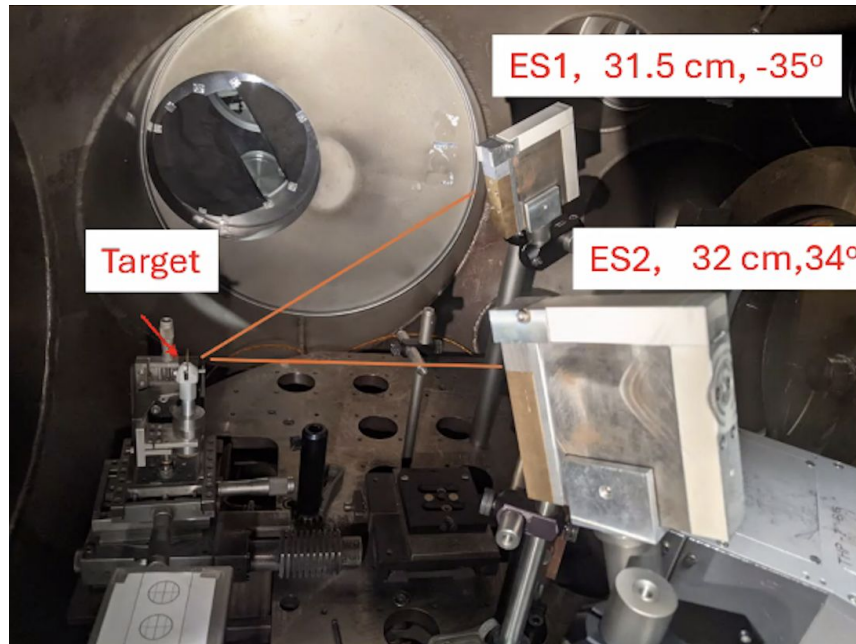
Shot 60718- CR 304- Flange B - Etching time: 30 min



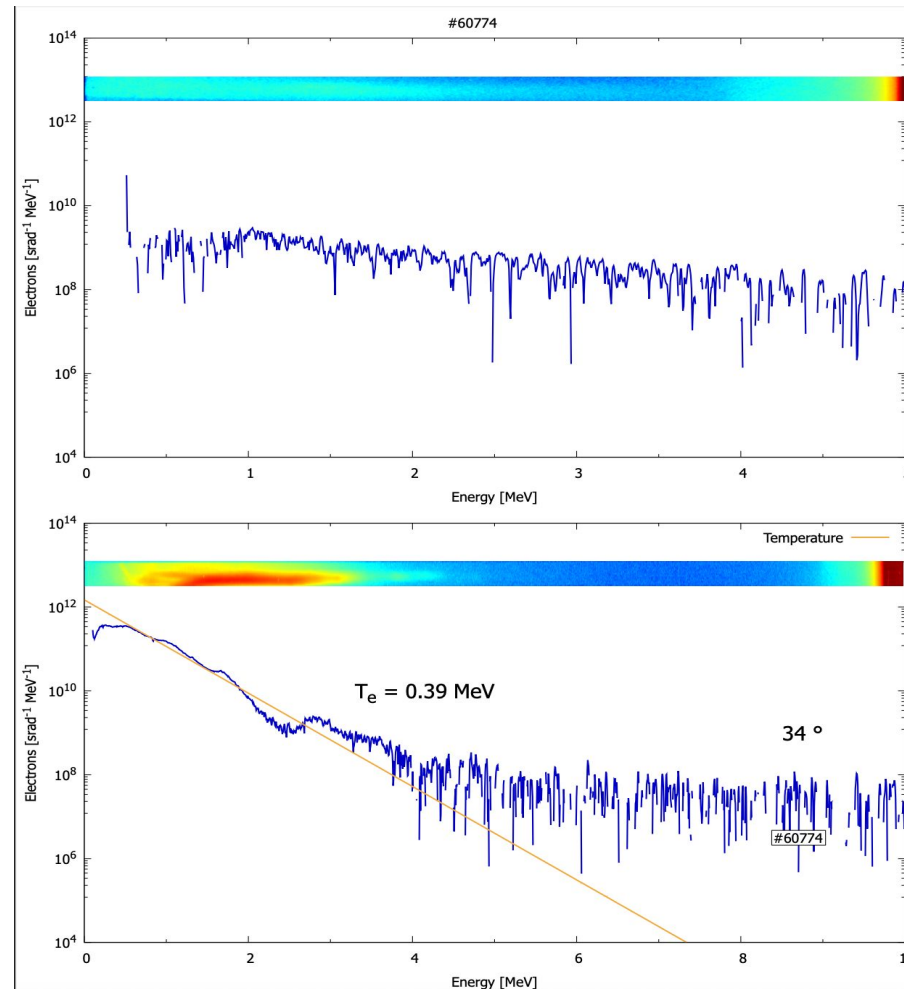
Shot 60718- CR 291- Flange E - Etching time: 60 min



Results and Conclusion: Electron Spectrometers



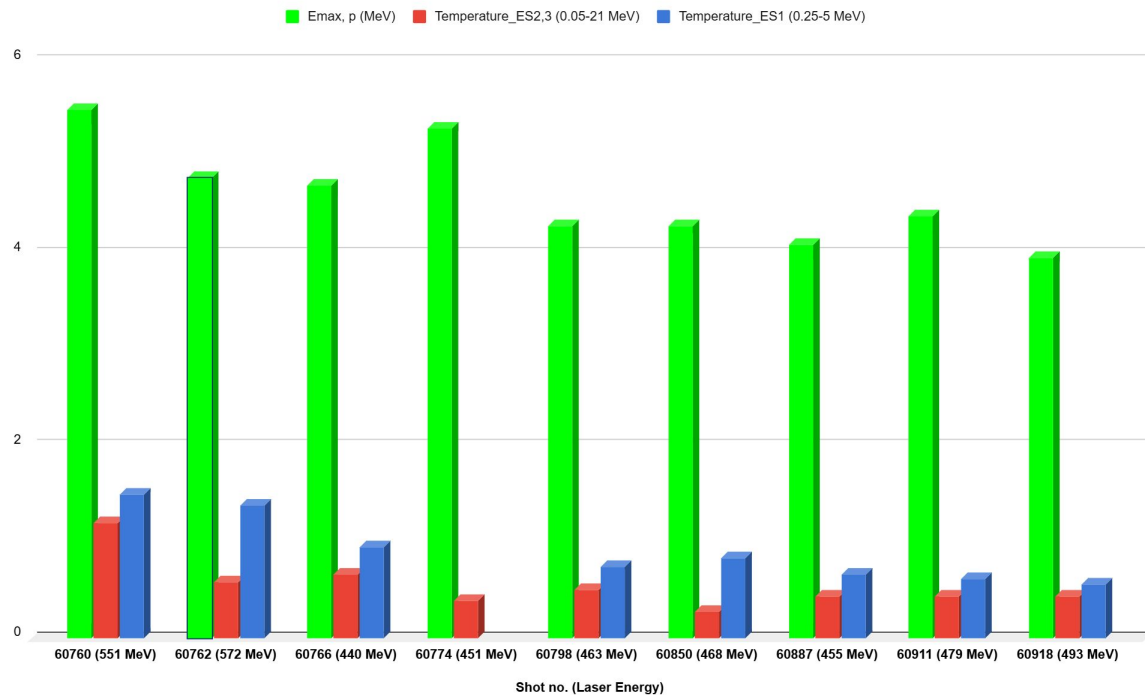
To measure the fast electrons generated in our experiment, we used electron spectrometers placed around the target at different angles. ES1 was placed at -35° and ES2 at $+34^\circ$, both about 32 cm from the target. These spectrometers measure the electron energy distribution.



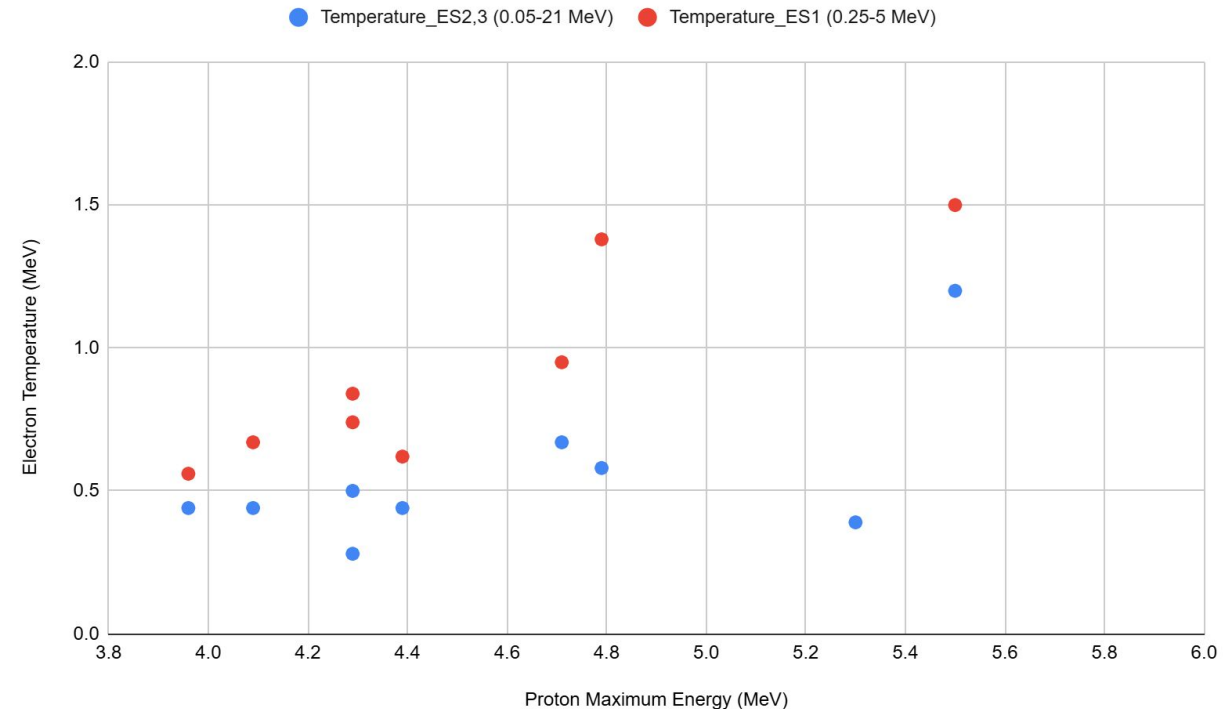
Electron Spectrometer	Energy range(MeV)	Distance from Target (mm)	Angle from Target Normal (°)
ES1	0.25-5	315	-35
ES2	0.05-2	320	34
ES3	0.05-21	312	34

- The spectra show that electrons are emitted with energies extending up to several MeV.
- By fitting the slope of the spectrum from ES2, we extracted a hot-electron temperature of about 0.39 MeV

Results and Conclusion: Electron Spectrometers



The graph shows electron temperature against proton maximum energy. We see a trend suggesting that higher electron temperatures correspond to higher proton energies, which supports the idea that hotter electrons produce stronger sheath fields for proton acceleration



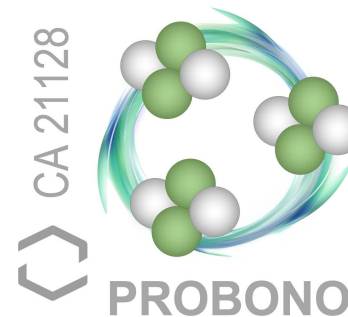
Summary

- ❖ This experiment was designed to measure the maximal energy of protons and the high fusion yield when they were released from the front side of various target materials which had been exposed to high-intensity laser pulses.
- ❖ In this work two schemes are employed: the In-Target and the Pitcher-Catcher configurations to characterise proton energy and fusion yield.
- ❖ Various target materials and geometries were used in both setups to explore the influence of target composition on the acceleration process and the yield.
- ❖ Remarkably, the highest proton energy, up to around 5.5 and 6 MeV, were reliably detected by the TP and TOF detectors orientated along the primary target normal (0°) respectively. All diagnostic results showed an outstanding level of agreement.
- ❖ It's interesting to note that the maximal proton energy measured was not significantly impacted by the target's boron content.
- ❖ Overall, the highest proton energy was successfully recorded for TOF and TP diagnostics across all target types .



Acknowledgement

- **COST**: This work has been carried out within the framework of the **COST** Action CA21128- PROBONO "PROton BORon Nuclear fusion: from energy production to medical applicatiOns", supported by COST (European Cooperation in Science and Technology - www.cost.eu).
- **INFN Committee V**: The authors wish to thanks INFN Committee V for the financial support of the "FUSION" project
- **PALS experiment** : The authors wish to thanks LASERLAB for the support given for the experiment "FUSION": Maximizing the $p(11\text{B}, \alpha)2\alpha$ reaction using in-plasma and pitcher target configurations and novel target design' (PID: 26286)





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Address

Via S. Sofia, 62, 95125 Catania CT



E-mail

abubaker@lns.infn.it