Diagnostic Systems for Laser-Accelerated Ion Beams

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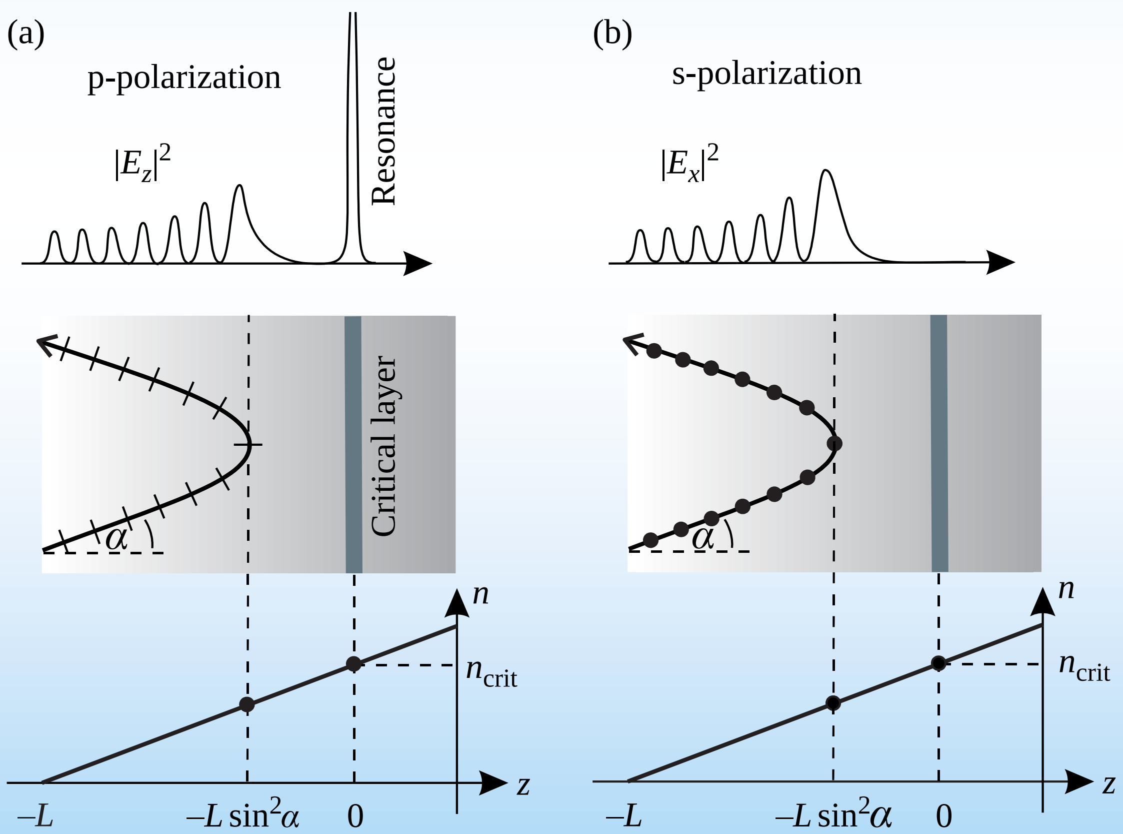
Acceleration Mechanism

Laser Absorption in Plasmas Relevant to TNSA

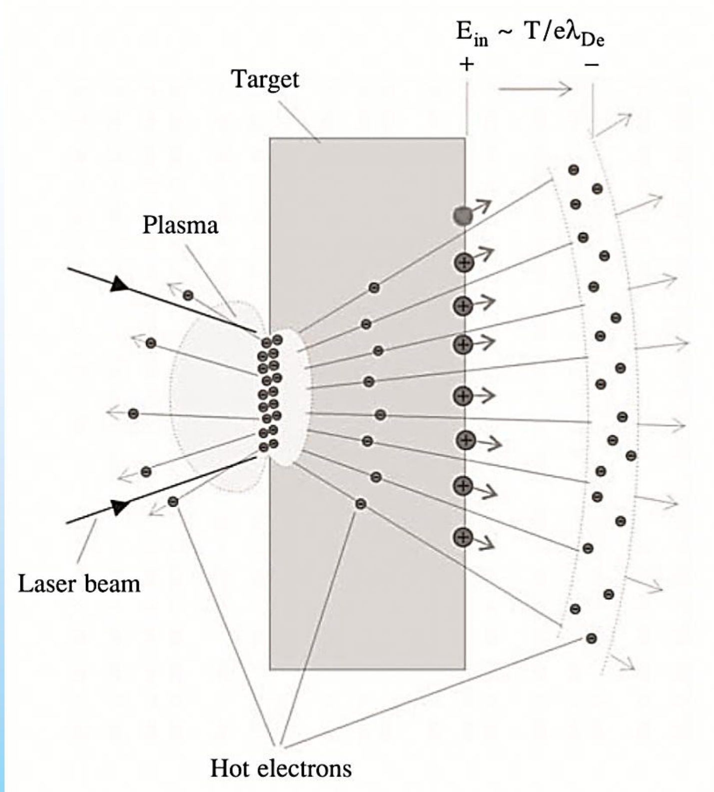
- Target ionization by laser pre-pulse
- Inverse Bremsstrahlung (collisional absorption)
- Resonance absorption
- Stimulated Raman scattering

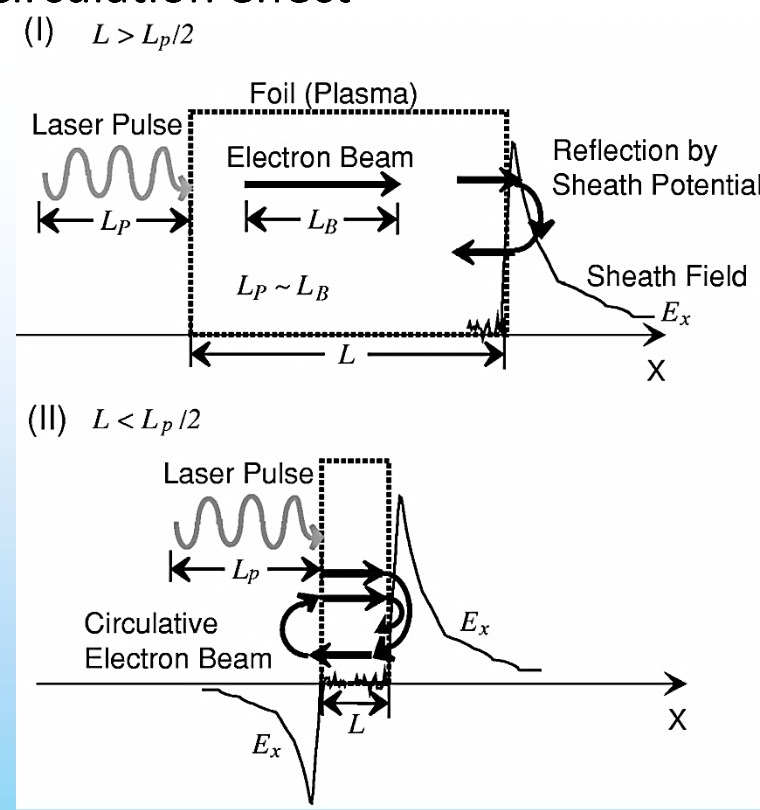


Acceleration Mechanism

TNSA Acceleration Mechanism

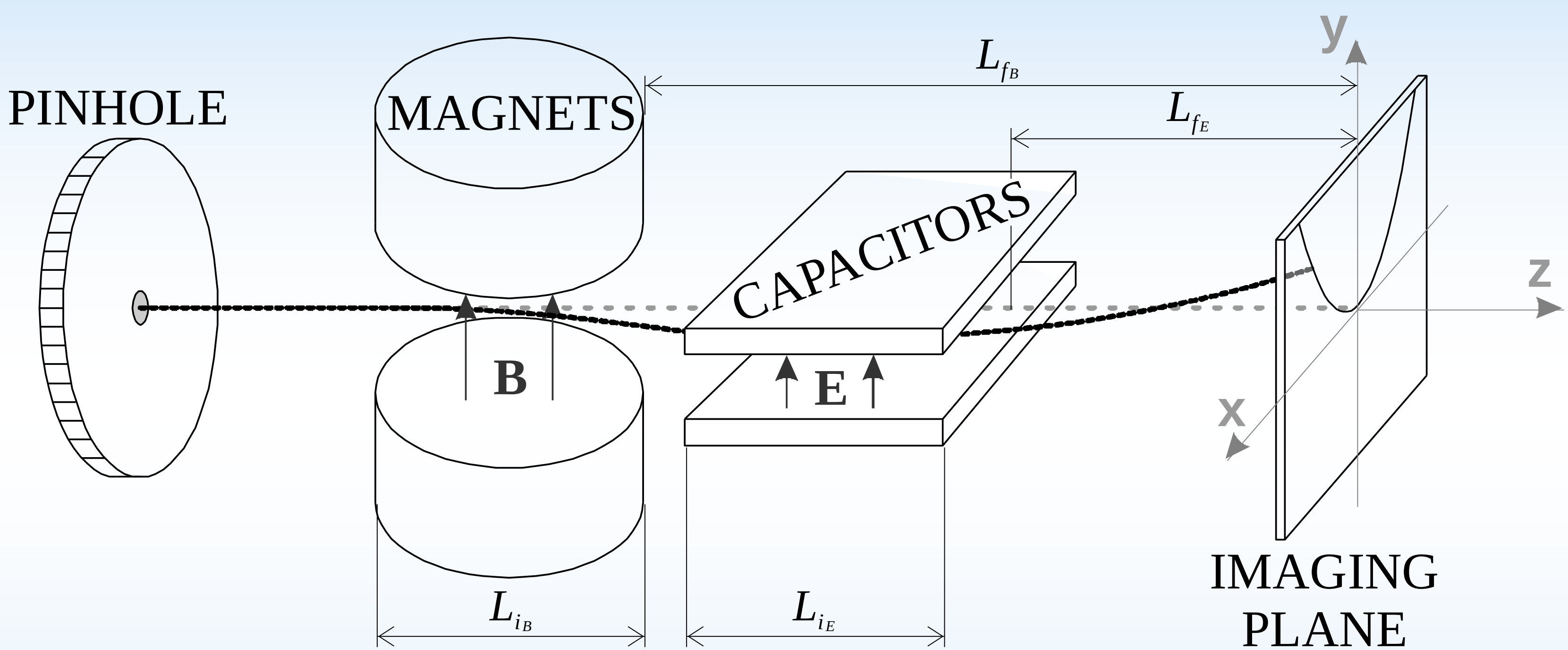
- Target Normal Sheath Acceleration
- Generation of hot electrons from braking the high amplitude plasma waves
- Ionization of the target rear side and creation of Debye sheath
- Ion acceleration along the normal of the target rear surface
- Acceleration enhancement by electron recirculation effect





Diagnostic Systems

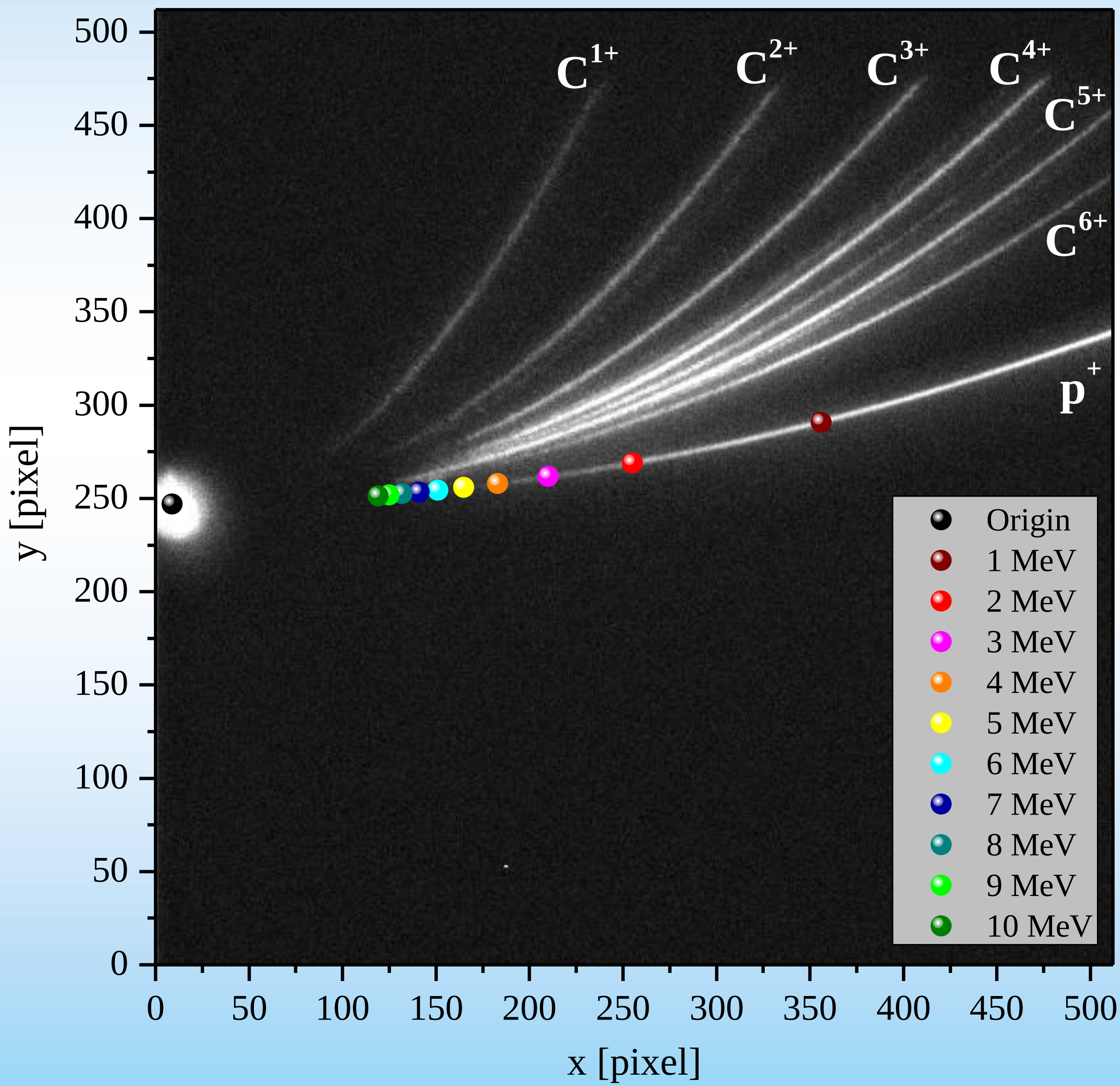
Thomson Parabola Spectrometer – I



$$y = \frac{q}{m} \cdot \frac{E L_{i_E} \left(\frac{L_{i_E}}{2} + L_{f_E} \right)}{B^2 L_{i_B}^2 \left(\frac{L_{i_B}}{2} + L_{f_B} \right)^2} \cdot x^2$$

Diagnostic Systems

Thomson Parabola Spectrometer – II



$$x = \frac{qBL_{i_B}}{mv}\left(\frac{L_{i_B}}{2} + L_{f_B}\right)$$

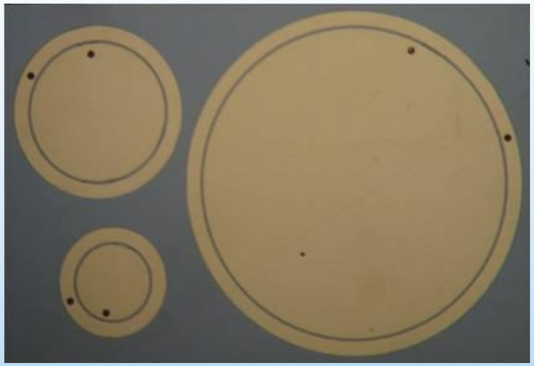
$$y = \frac{qEL_{i_E}}{mv^2}\left(\frac{L_{i_E}}{2} + L_{f_E}\right)$$

$$v = \frac{E}{B}\cdot\frac{x}{y}$$

Diagnostic Systems

SiC Detector

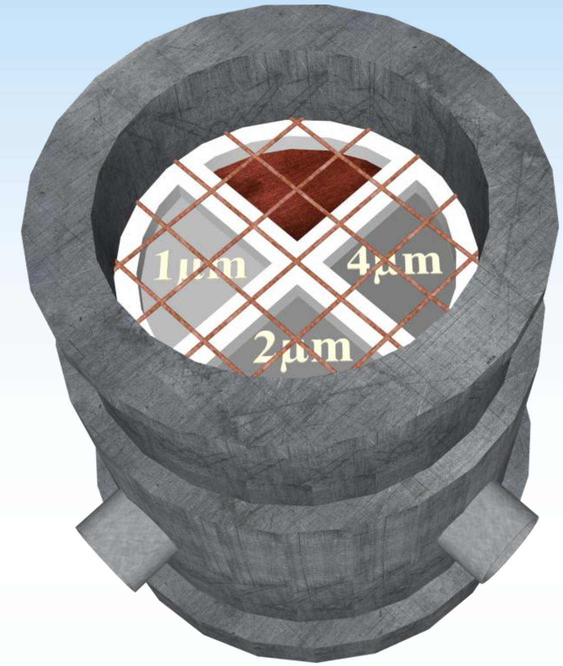
- Wide band gap
- High saturation velocities of the charge carriers
- High breakdown field
- High thermal conductivity

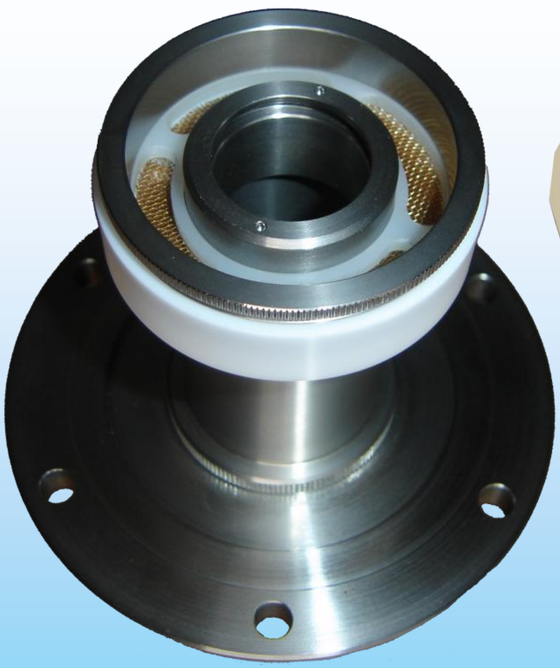


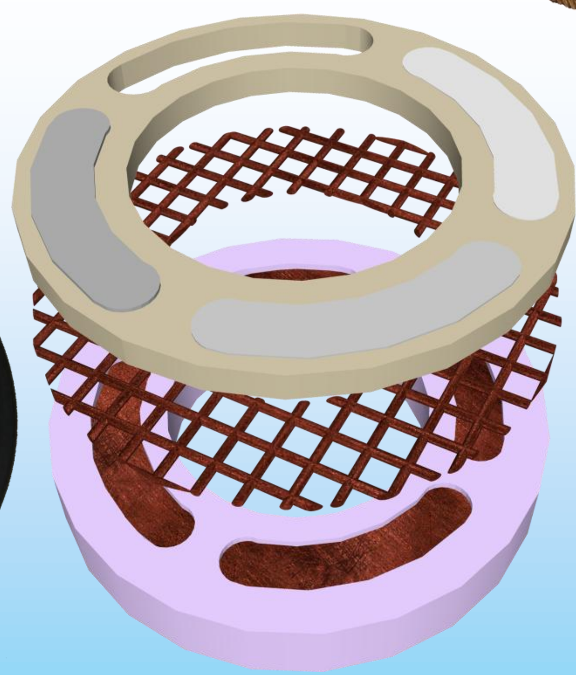
Diagnostic Systems

Ion Collector

Flat configuration



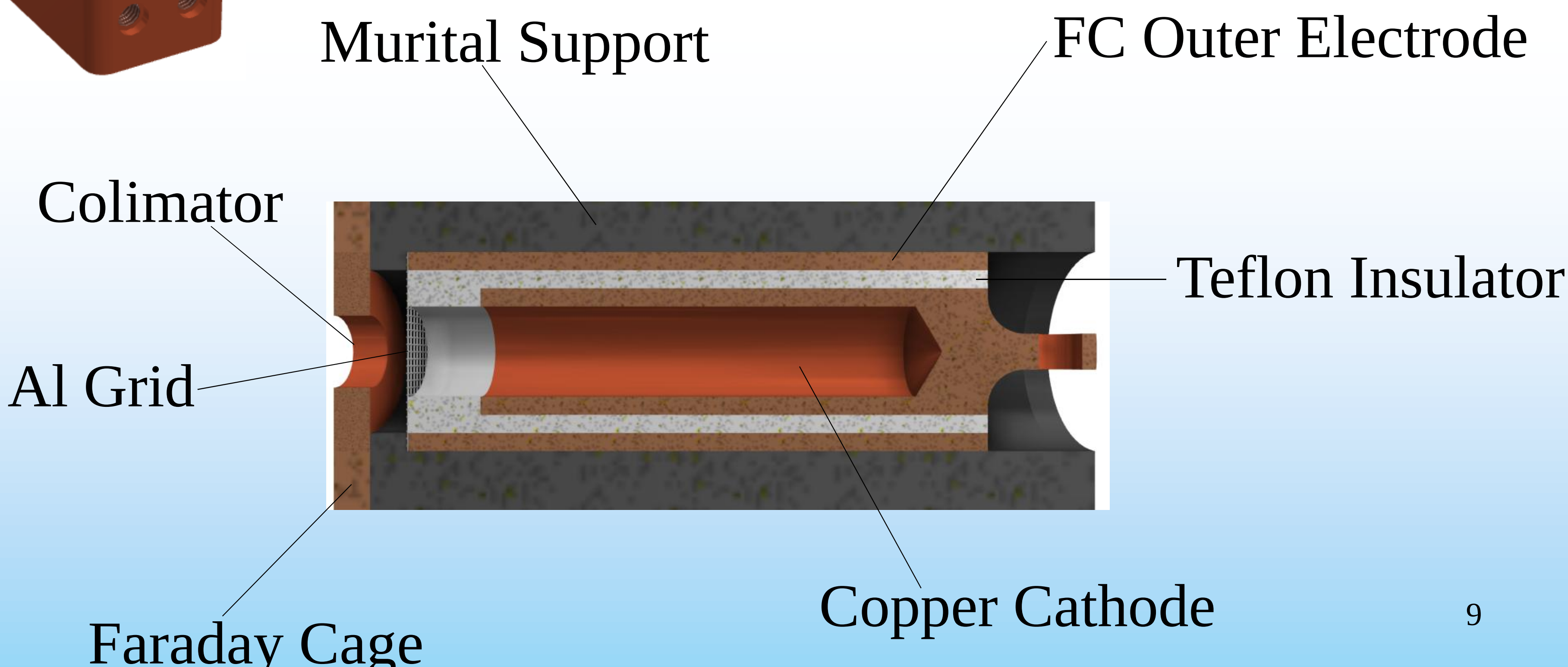




Ring configuration

Diagnostic Systems

New Developed Ion Collector System - I

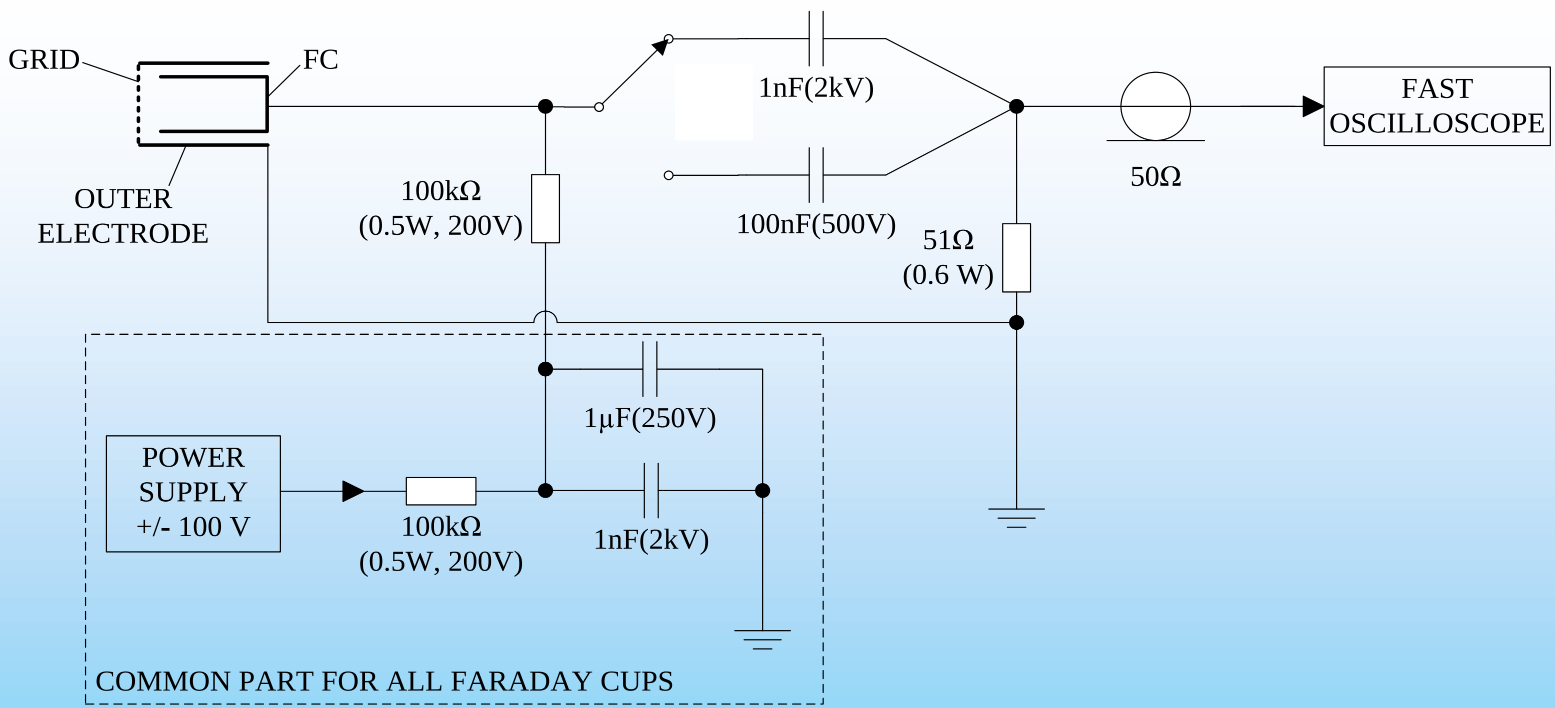


Diagnostic Systems

New Developed Ion Collector System - II

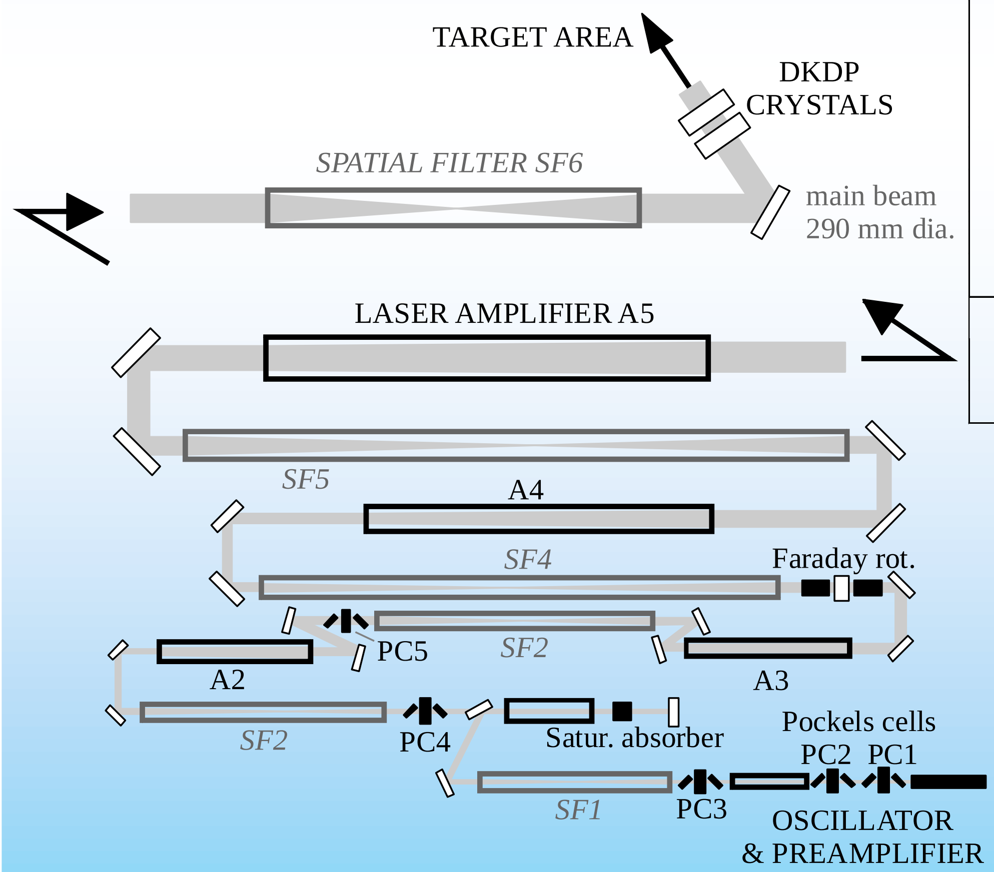
New Developed Ion Collector System – III

Faraday Cup Properties	Inner Electrode Diameter	3.50 mm
	Outer Electrode Diameter	4.50 mm
	95% Cutoff Frequency	15.87 GHz
	Inductance	5.03×10^{-8} H/m
	Capacitance	4.52×10^{-10} F/m
	Resistance	$1.68 \times 10^{-5}\sqrt{\omega}$ Ω/m
	Conductance	0 S/m
	Impedance	10.55 Ω



Experimental Results

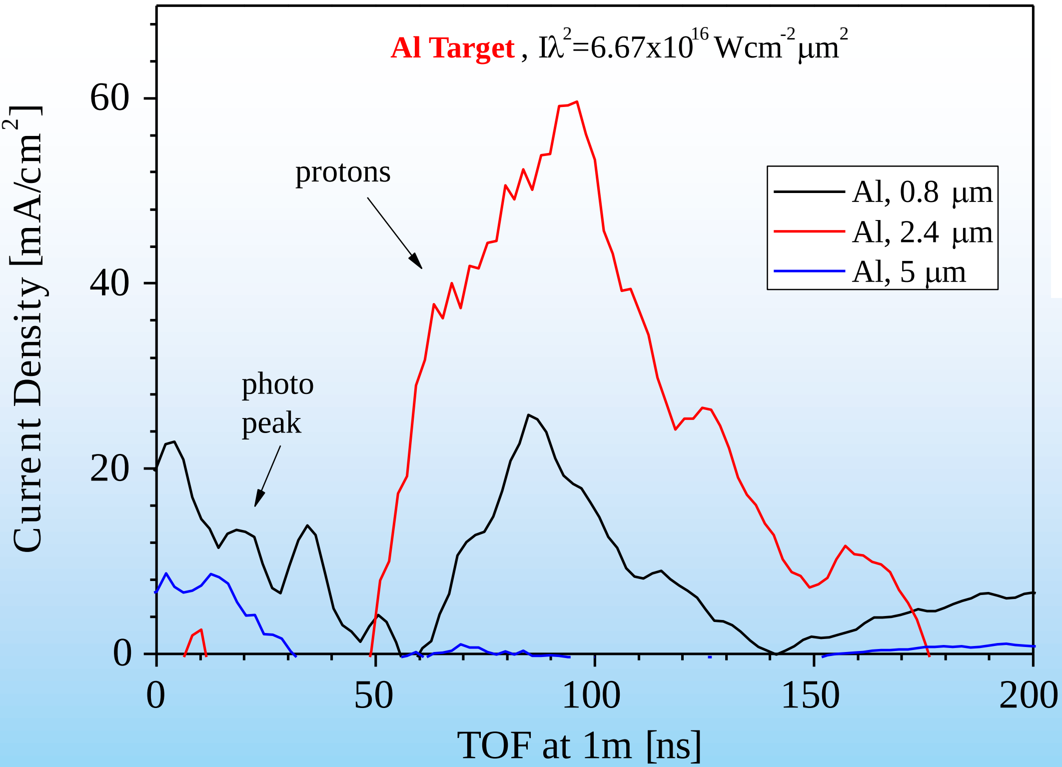
kJ Laser Beamline at PALS – Parameters

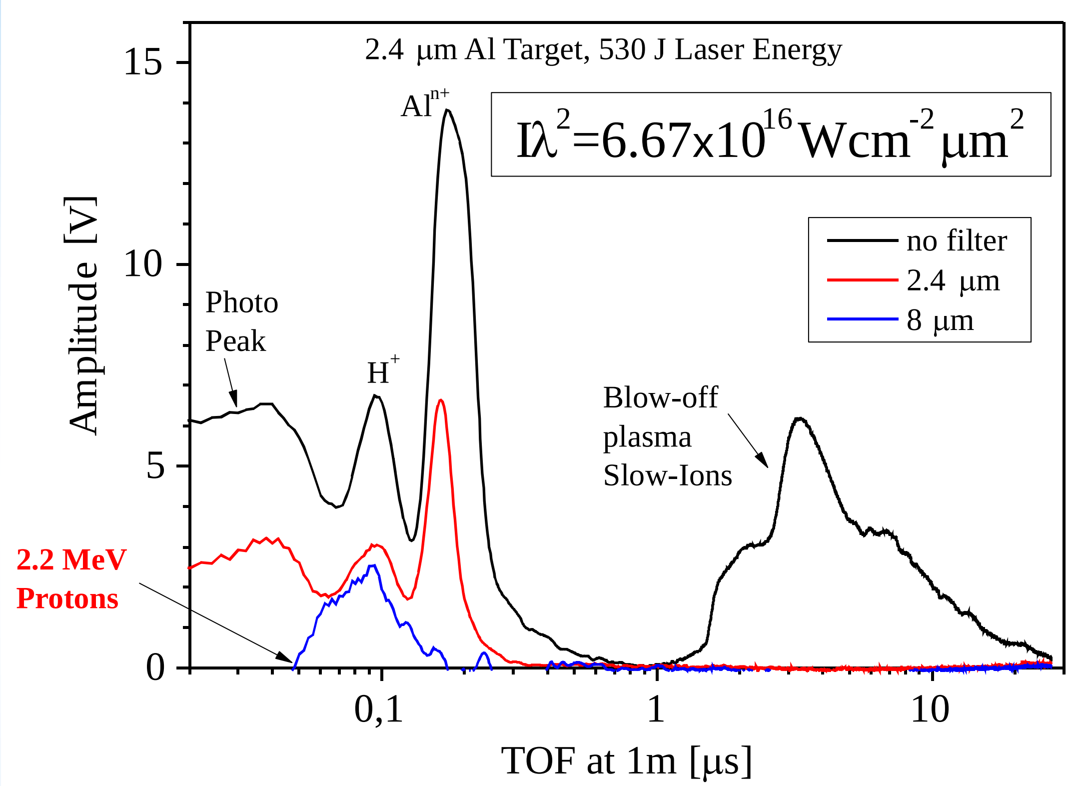


General	Fundamental wavelength	1.315 μm
	Pulse duration	200 ps to 350 ps
	Pulse contrast (pre-pulses & ASE)	~70 dB
	Repetition shot rate	25 min
	Output energy stability (over 10 shots)	< ±1.5 %
Main beam	Nominal pulse energy at 350 ps	1 kJ
	Nominal pulse power at 350 ps	3 TW
	Diameter	290 mm
	Conversion efficiency to 3ω	55 %
	Laser energy on target	~600 J
	Focal spot size at exp(-2)	~100 μm
	Peak intensity in focus	4.37×10^{16} W/cm^2
	$I\lambda^2$ in focus	7.55×10^{16} W.μm^2/cm^2
Auxiliary beam	Pulse energy at 350 ps	100 J
	Diameter	148 mm
	Conversion efficiency to 3ω	30 %

Experimental Results

kJ Laser Beamline at PALS – Results

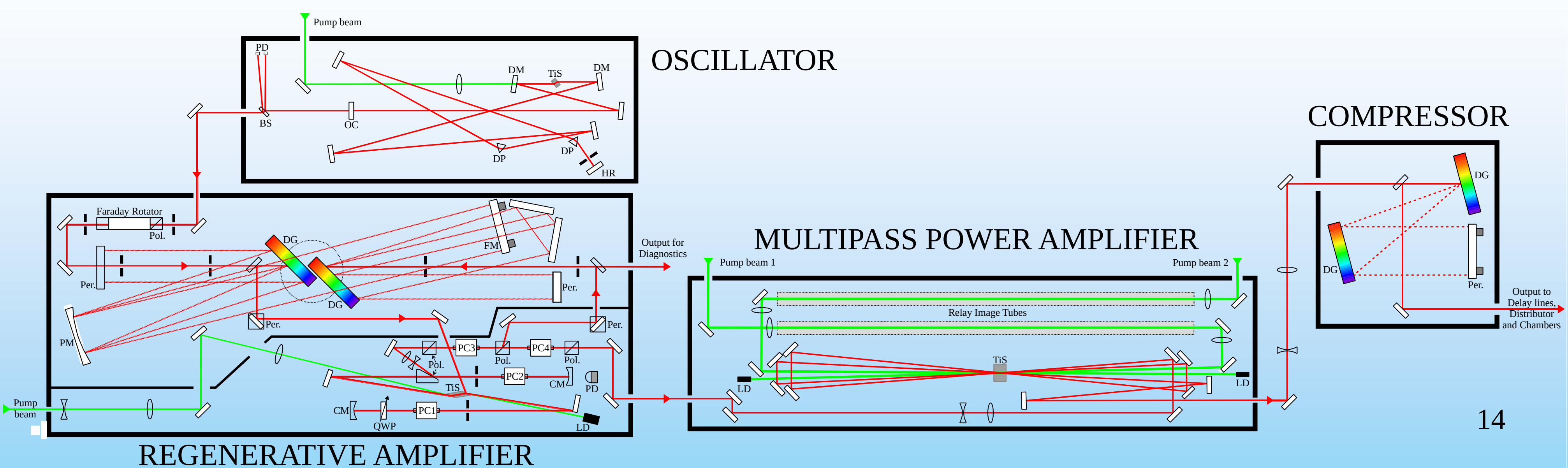




Experimental Results

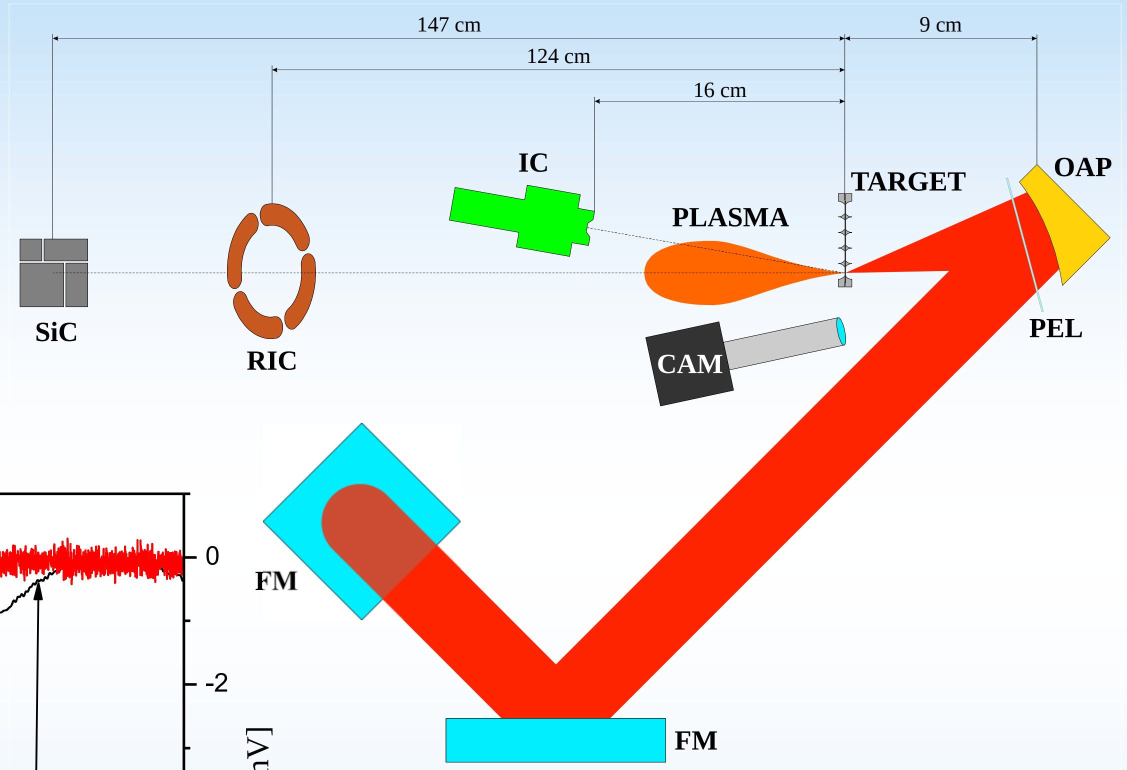
TW-class Ti:Sapphire Laser System at PALS – Parameters

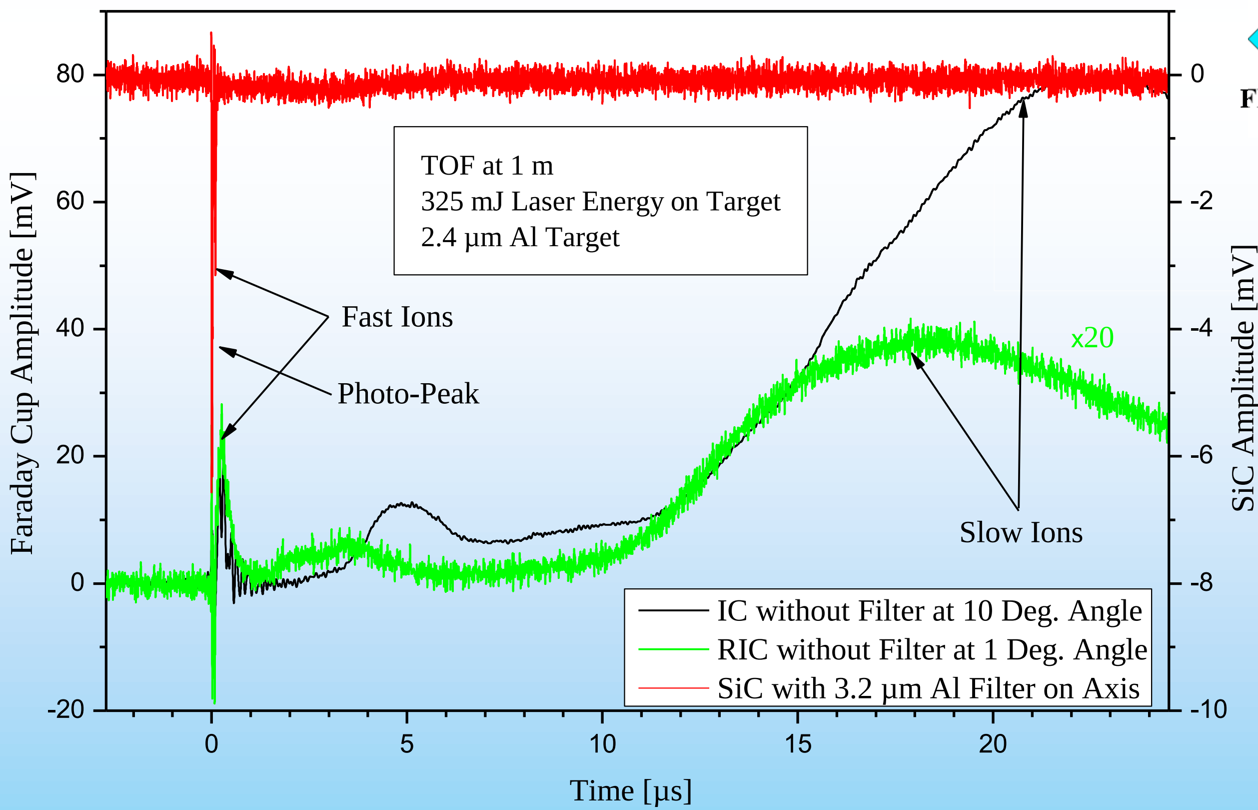
Maximum laser energy (before compressor)	800 mJ
Central wavelength	808 nm
Laser pulse length	45 fs
Laser energy on target	~520 mJ
Focal spot size at Exp(-2)	12.5 µm
Peak intensity in focus	1.88×10^{19} W/cm^2
$I\lambda^2$ in focus	1.23×10^{19} W/cm^2.µm^2
Laser contrast	70 dB
Polarization	Linear
Repetition rate	10 Hz



Experimental Results

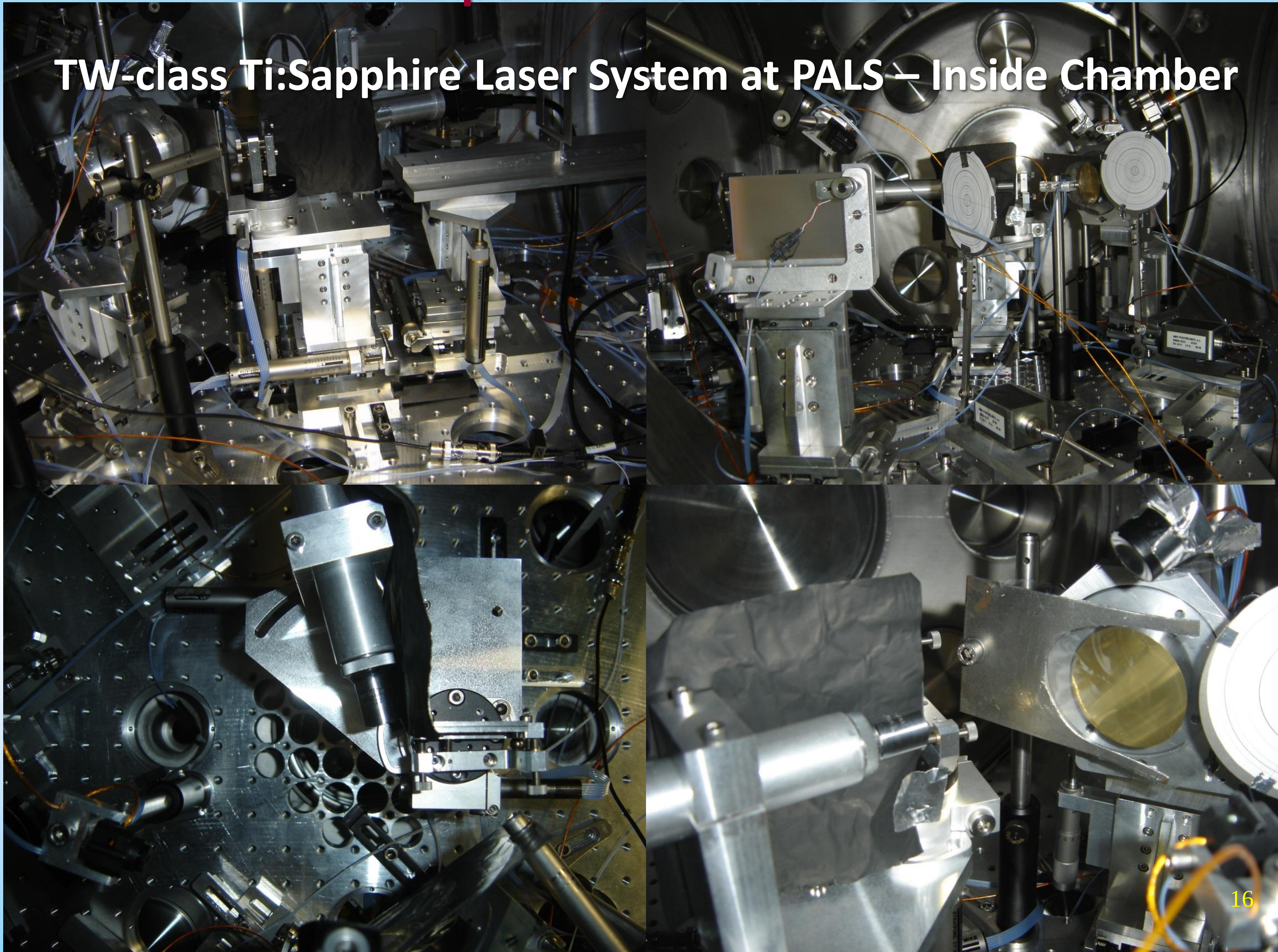
TW-class Ti:Sapphire Laser System at PALS – Setup





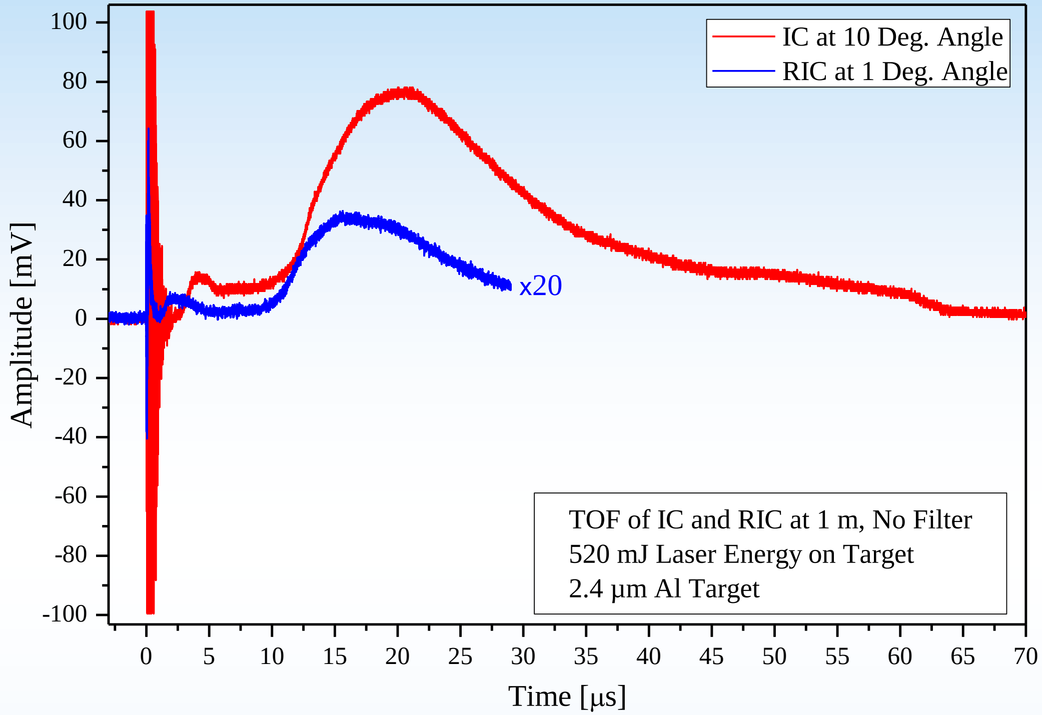
Experimental Results

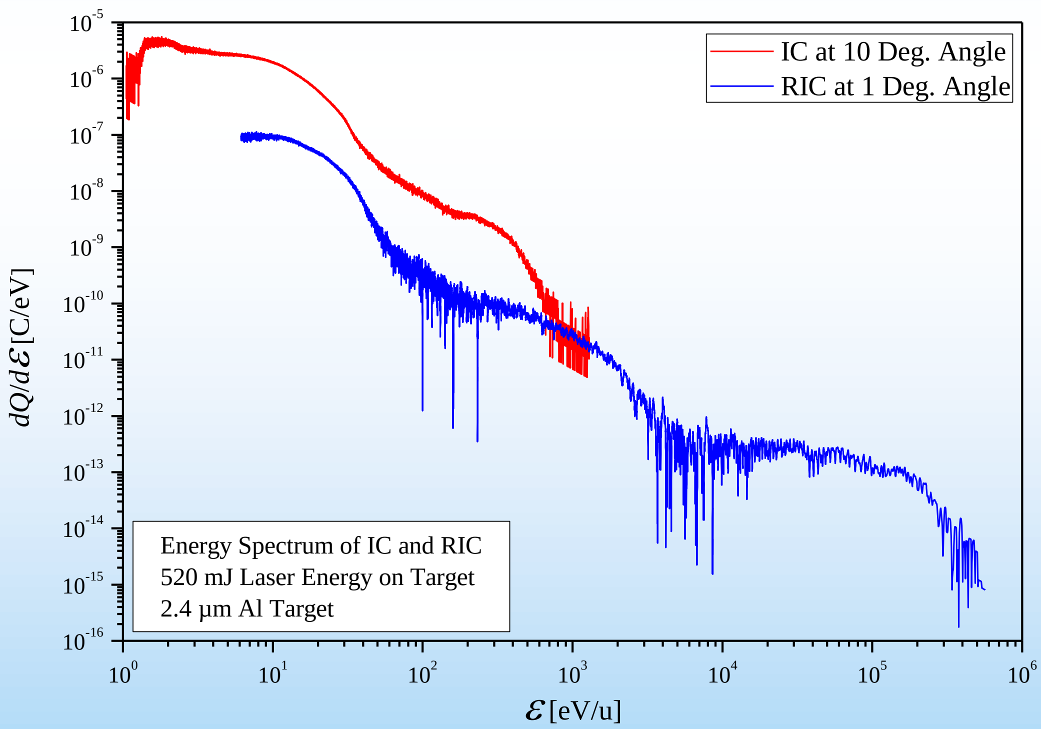
TW-class Ti:Sapphire Laser System at PALS – Inside Chamber



Experimental Results

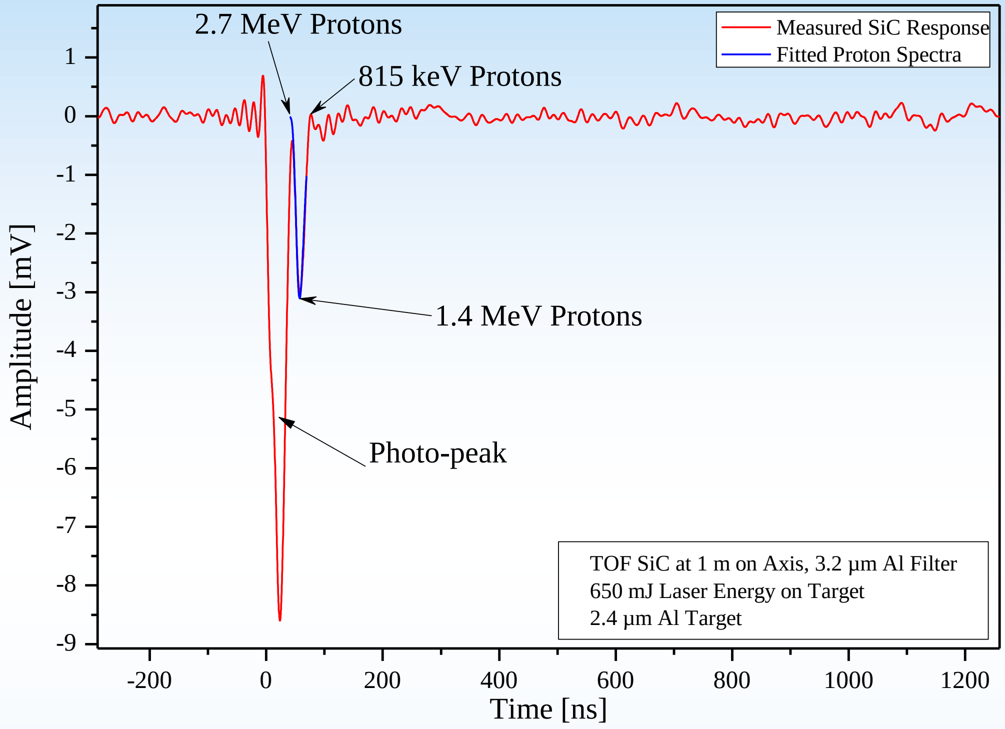
TW-class Ti:Sapphire Laser System at PALS – IC Results

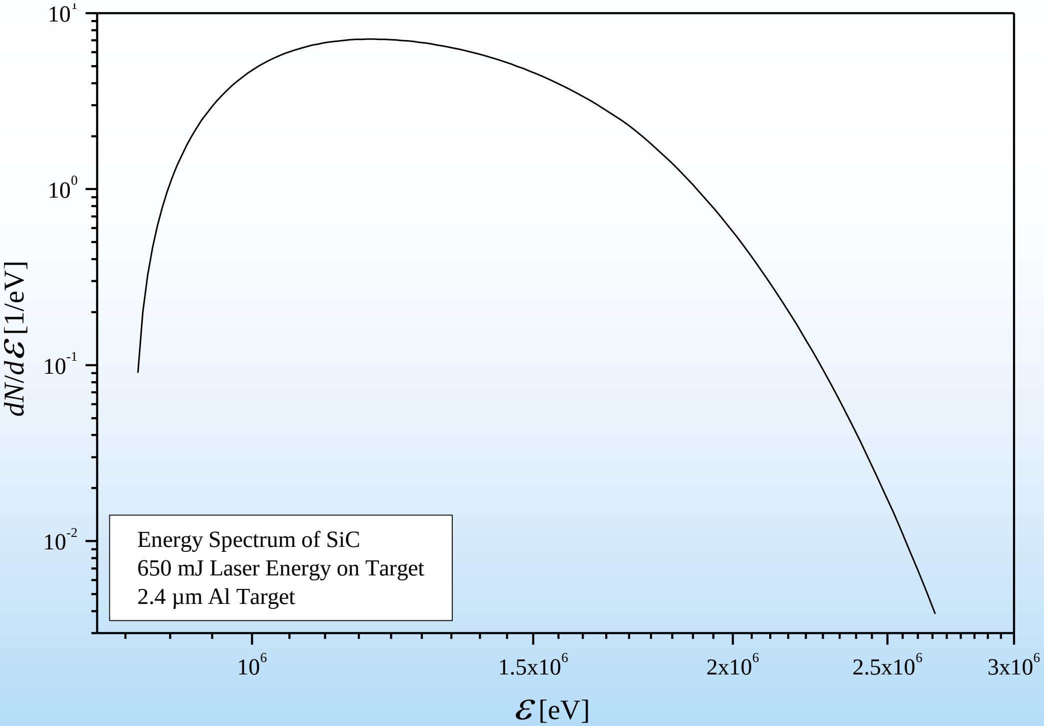




Experimental Results

TW-class Ti:Sapphire Laser System at PALS – SiC Results





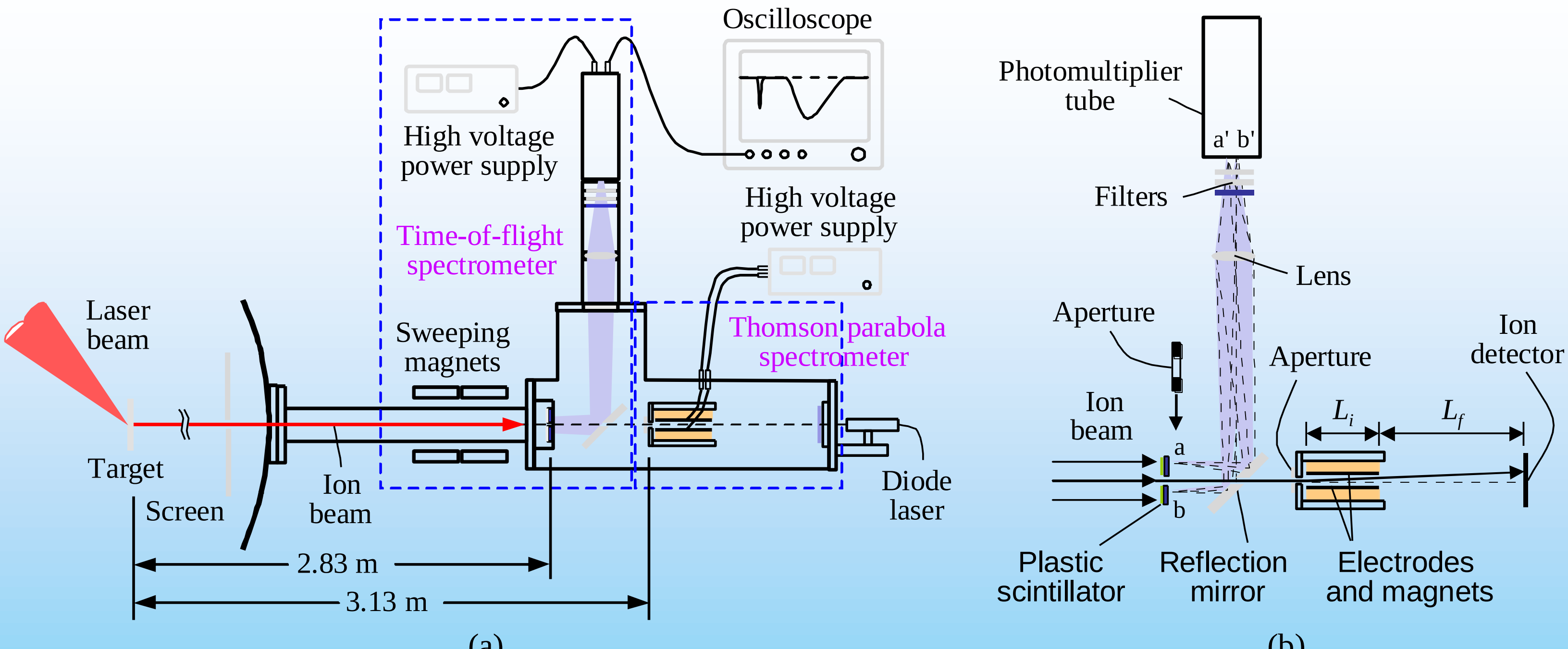
Boltzmann-like TOF:

$$U(t) = \frac{AL}{Rt^5} \mathrm{Exp}\left[-\frac{m_i}{2k_B T}\left(\frac{L}{t} - V\right)^2\right]$$

Experimental Results

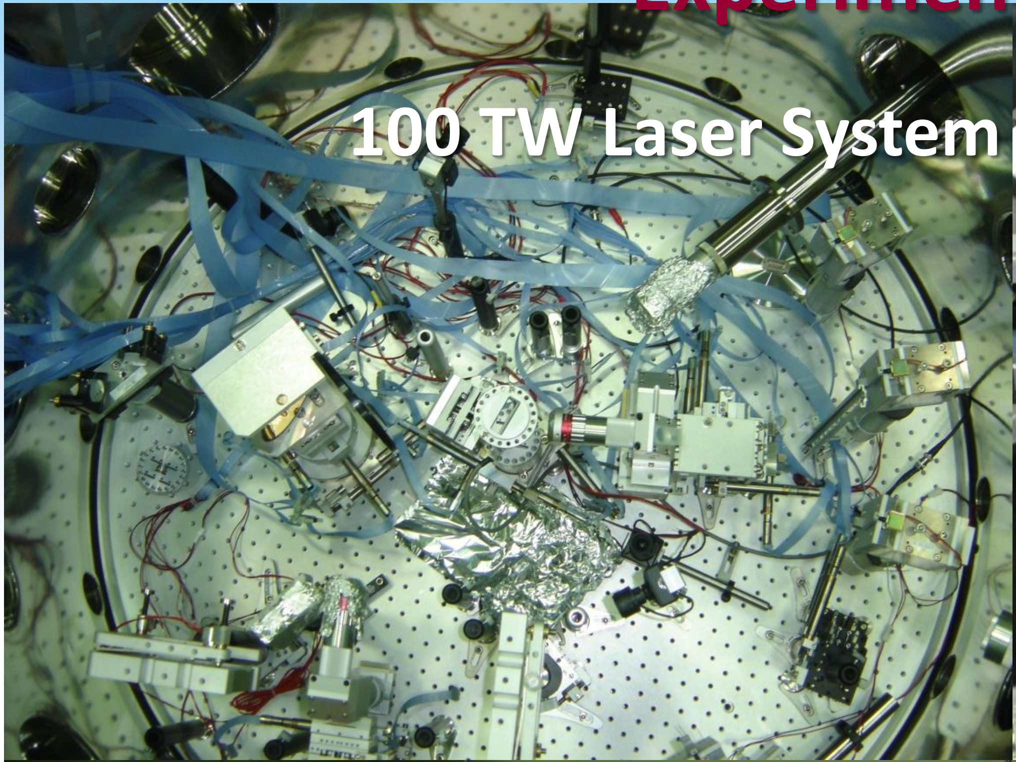
100 TW Laser System at APRI-GIST – Parameters

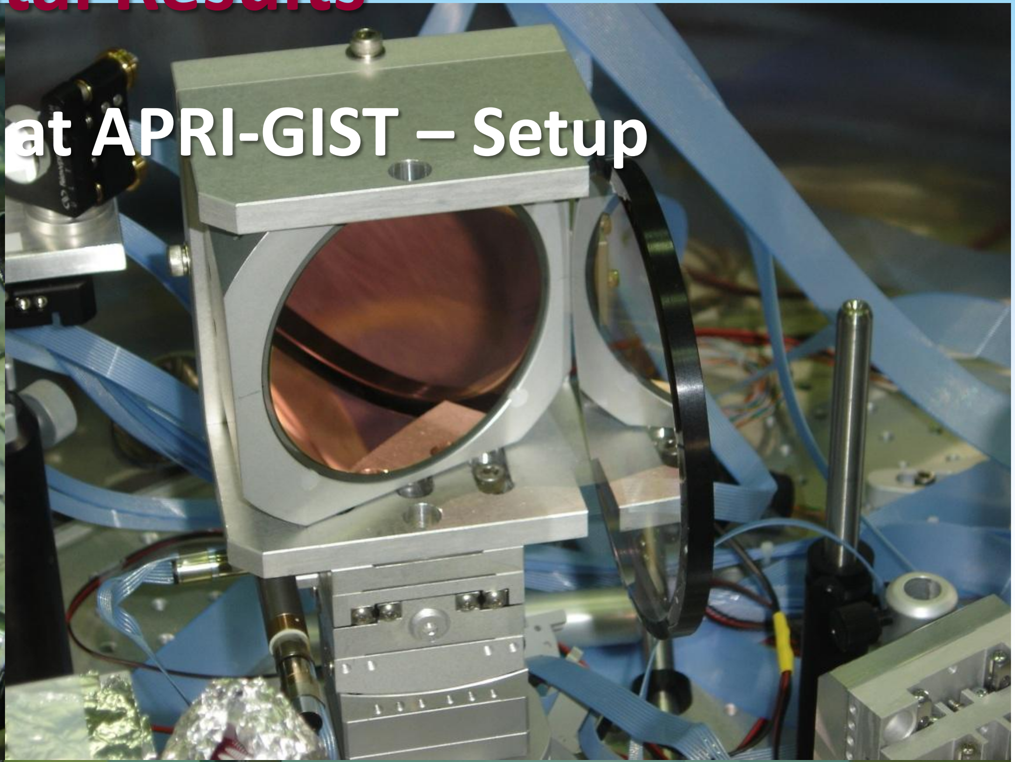
Maximum laser power (before compressor)	100 TW
Laser energy (after compressor)	4 J
Central wavelength	800 nm
Laser pulse length	~30 fs
Laser energy on target	1.92 J
Focal spot size at Exp(-2)	8.7 µm
Peak intensity in focus	2.15×10^{20} W/cm^2
$I\lambda^2$ in focus	1.38×10^{20} W/cm^2.µm^2
Laser contrast	110 dB
Polarization	Linear
Repetition Rate	10 Hz

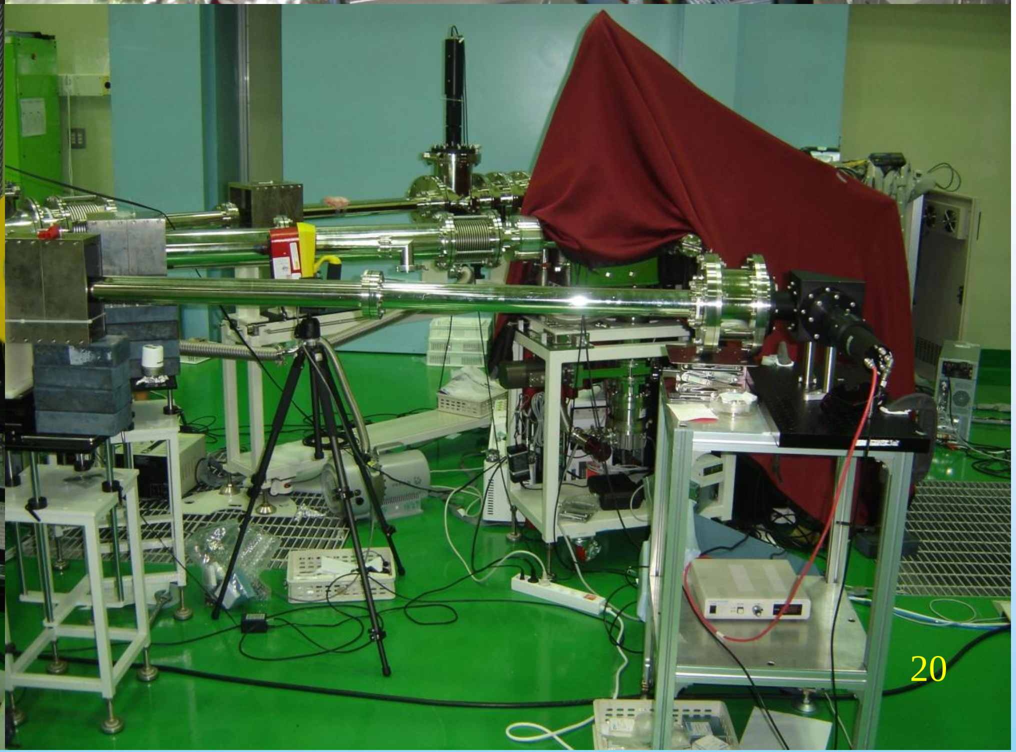


Experimental Results

100 TW Laser System at APRI-GIST – Setup

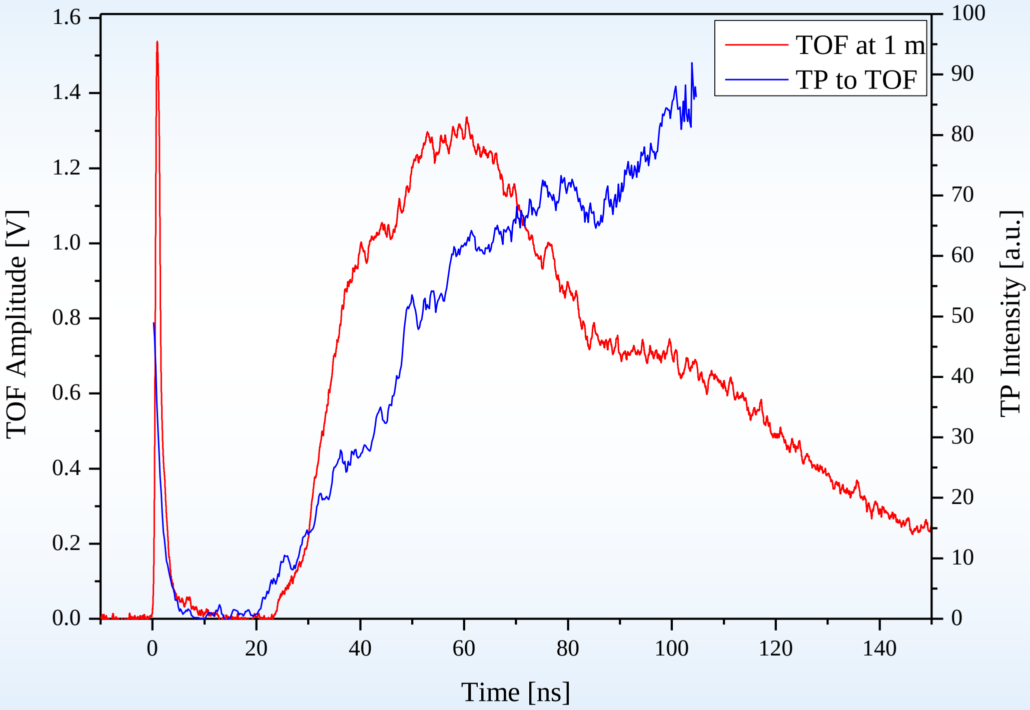


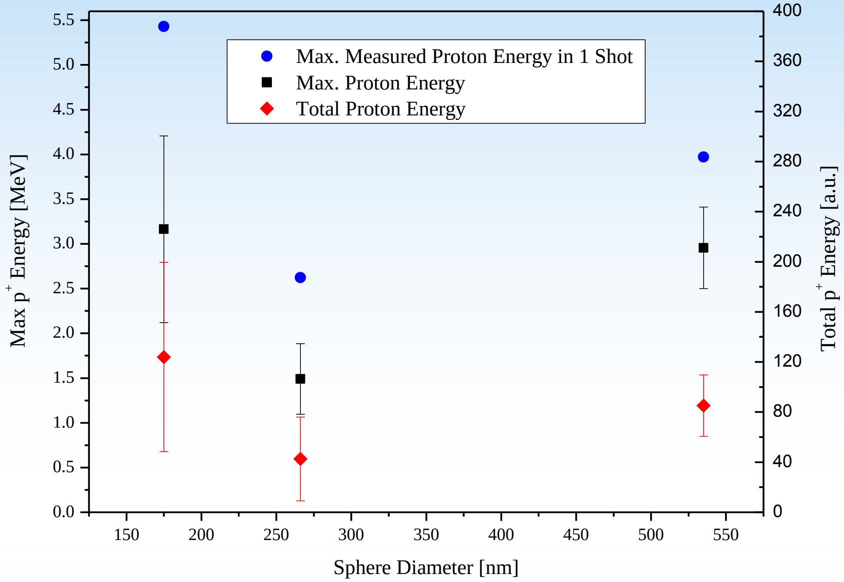


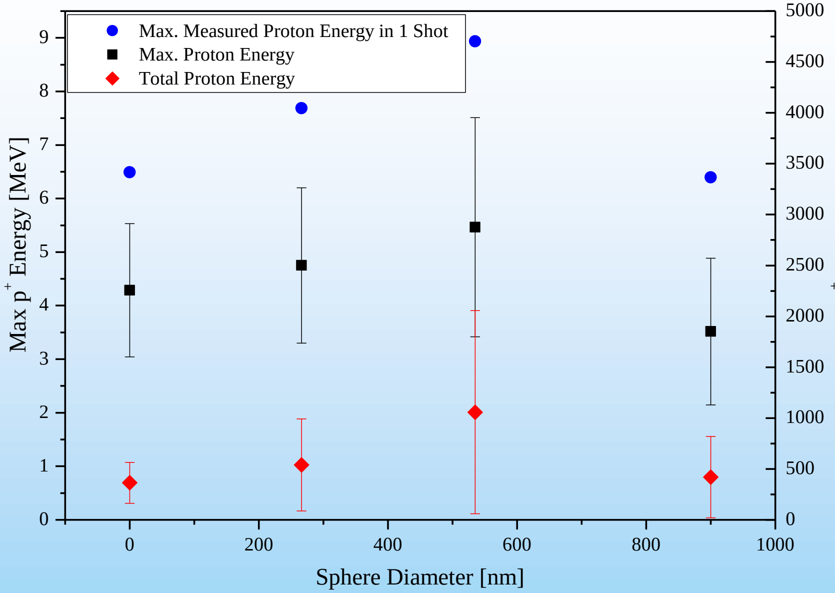


Experimental Results

100 TW Laser System at APRI-GIST – Results



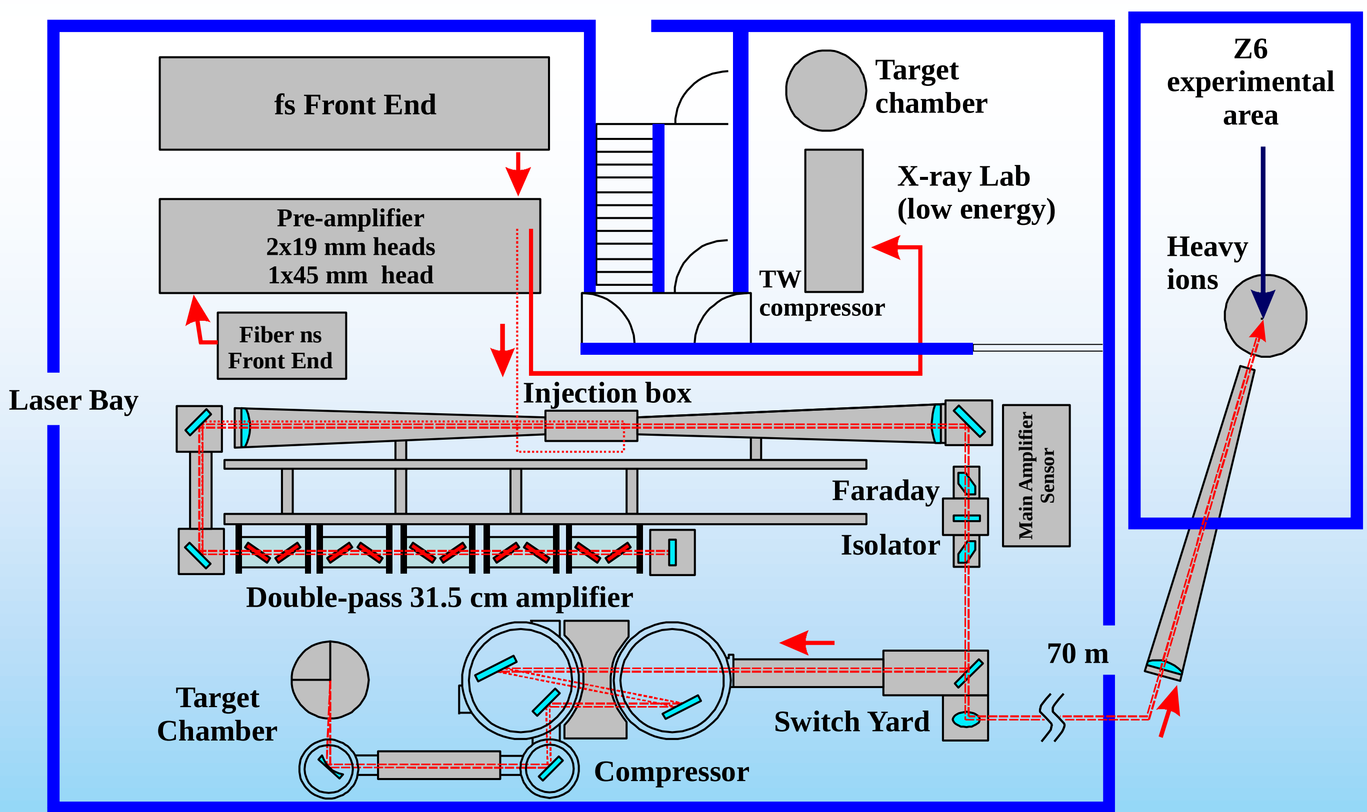




Experimental Results

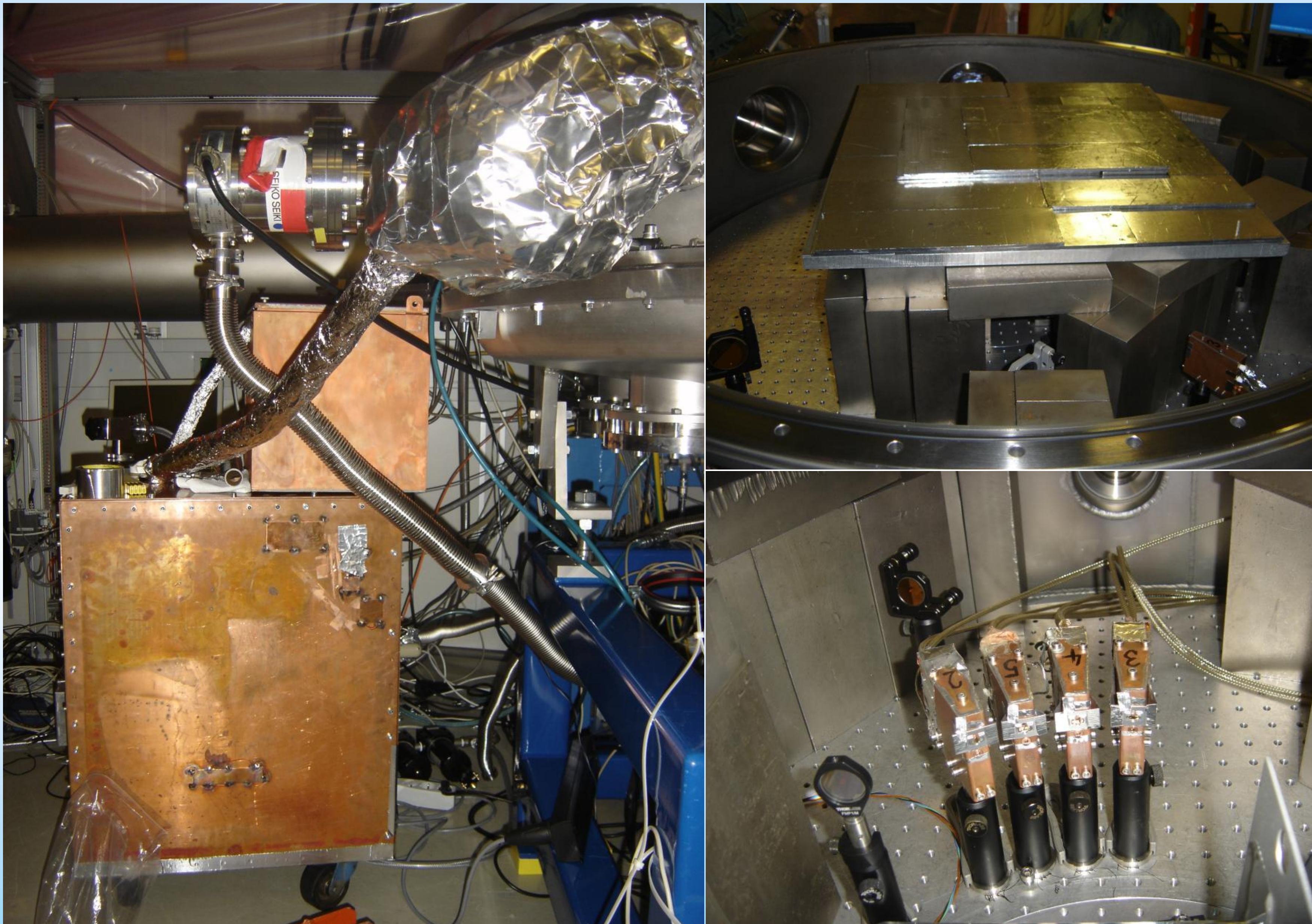
500 TW PHELIX Laser in GSI – Parameters

Maximum compressor output energy	140 J
Central wavelength	1053 nm
Laser pulse length	~500 fs
Focal spot size at Exp(-2)	Horizontal 130.3 µm; Vertical 38.6 µm
Peak intensity in focus	1.42×10^{19} W/cm^2
$I\lambda^2$ in focus	1.57×10^{19} W/cm^2.µm^2
Laser contrast	60 dB
Polarization	Linear
Repetition rate	1 shot per 1.5 hours



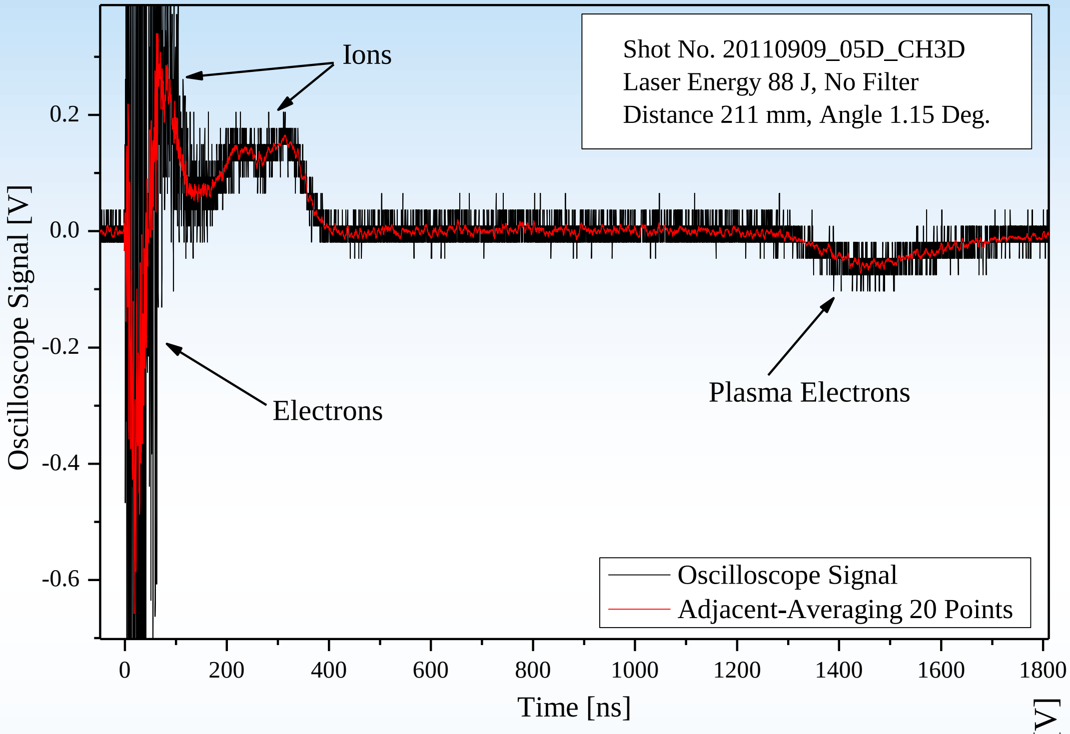
Experimental Results

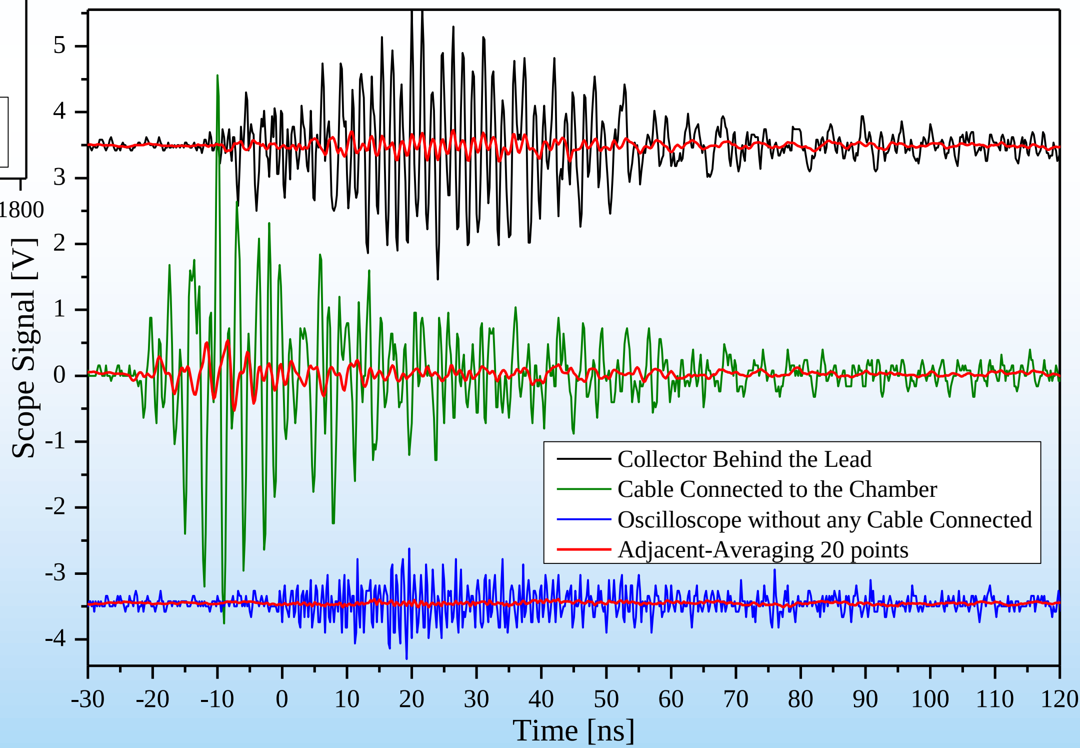
500 TW PHELIX Laser in GSI – Setup



Experimental Results

500 TW PHELIX Laser in GSI – Results





Conclusions and Perspectives

- Maximum proton energy of 2.2 MeV at kJ laser beam at PALS

- Maximum proton energy of 2.7 MeV at fs laser beam at PALS
- Use of energy spectrometers to confirm TOF results in future experimental campaign

- Experimental verification of PIC simulations at APRI-GIST
- Agreement of TP with TOF diagnostics

- Testing of developed ion collector system at GSI
- Further upgrade:
  - Geometry of Faraday cup
  - Assemblage of Faraday cup with signal cables
  - Higher sampling of the oscilloscope

Thank you for your attention!