EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

FIZINIŲ IR TECHNOLOGIJOS MOKSLŲ CENTRAS

EuPRAXIA Preparatory Phase

Enhanced Betatron X-ray Beams from Dual Stage Plasma Targets

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Funded by the European Union

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Outlook of the Presentation

Funded by the European Union

- Introduction
- Simulation of flux and critical energy of Laser driven hard X-ray/Gamma ray source from dual gas targets using CFD Fluent, FBPIC for LWFA, Synchrad and Geant for Secondary X-ray radiation
- Experimental results of electron acceleration, dependence of electron charge, energy and secondary X-ray radiation on backing pressure using single and dual gas targets at L3 ELI Beams Gammatron line
- Summary

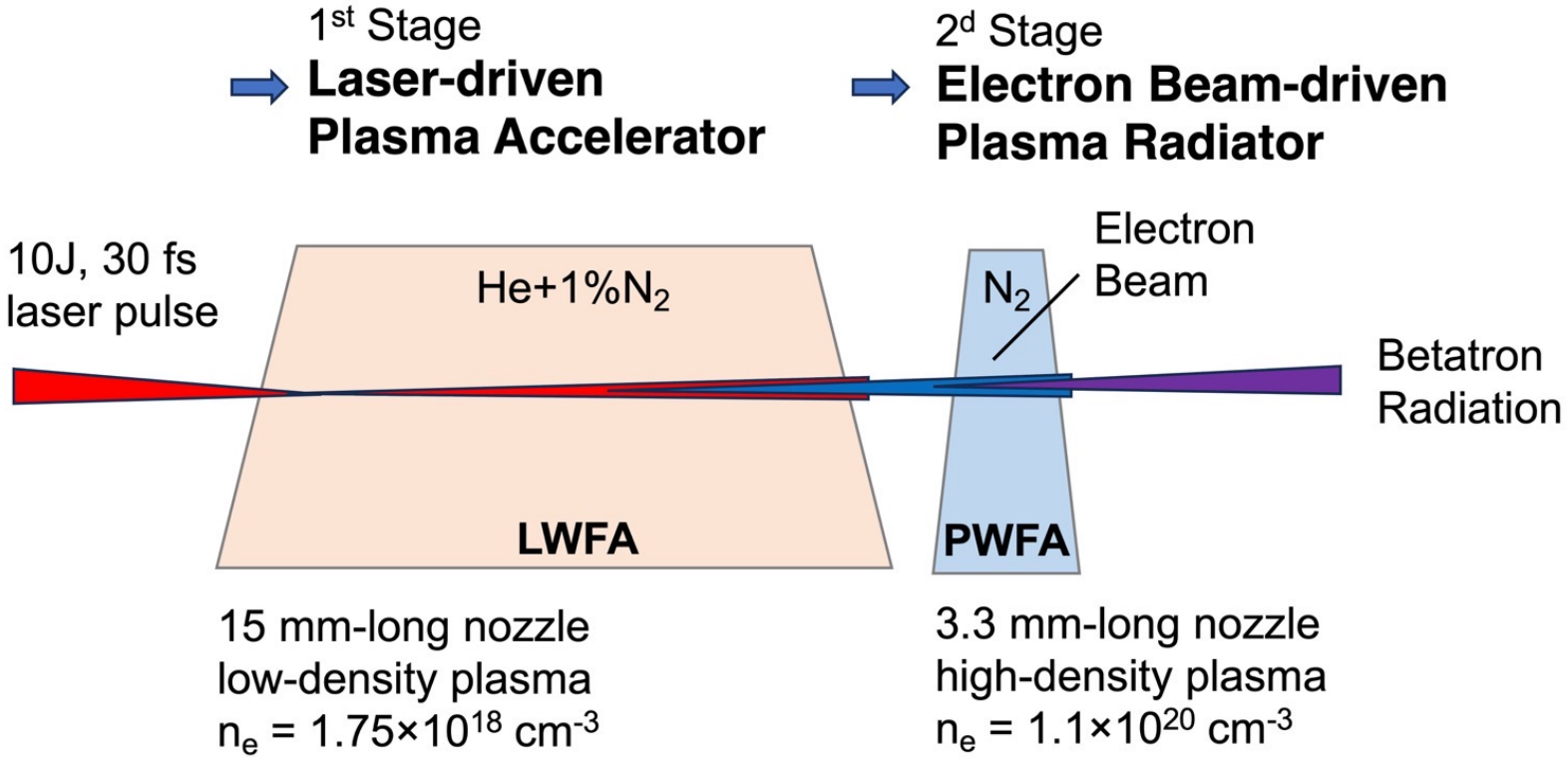
Funded by the European Union

ELIUPM5-005 ELI ALPS 5th User call, Enhanced Betatron Source for Time-Resolved Imaging of Dense Matter (ENBESO), 2026 - ELI BEAMS L3 Gammatron Line

Research objective

- Increase strongly the photon critical energy, flux and efficiency of Betatron radiation to enable the use of such sources for probing dense matter as well as industrial and scientific imaging
  - Demonstrate the dual stage laser plasma accelerator scheme for an intense hard X-ray beam
  - Characterise both the electron and X-rays pulses (energy, spectrum, charge/flux, pointing, divergence)

Dual Gas Jet Target



10 J
(~ 3 J on target)
30 fs
3 Hz

J. Ferri et al., Phys. Rev. Let.. 120, 254802 (2018)
X.Z Zhu et al., Sci. Adv. 6, 22, (2020)
M. Kozlova et al., Phys. Rev. X 10, 011061 (2020)
J.B. Svensson et al., Nat. Phys. 17, 639-645 (2021)
D. Čap et al., Proc. of SPIE Vol. 13537 1353707-1, (2026)
H. T. Kim et al., APLS 2026, (2026)
R. Lahaye et al., arXiv:2508.00145v1, (2026)

Dual Gas Targets for L3 at ELI Beams

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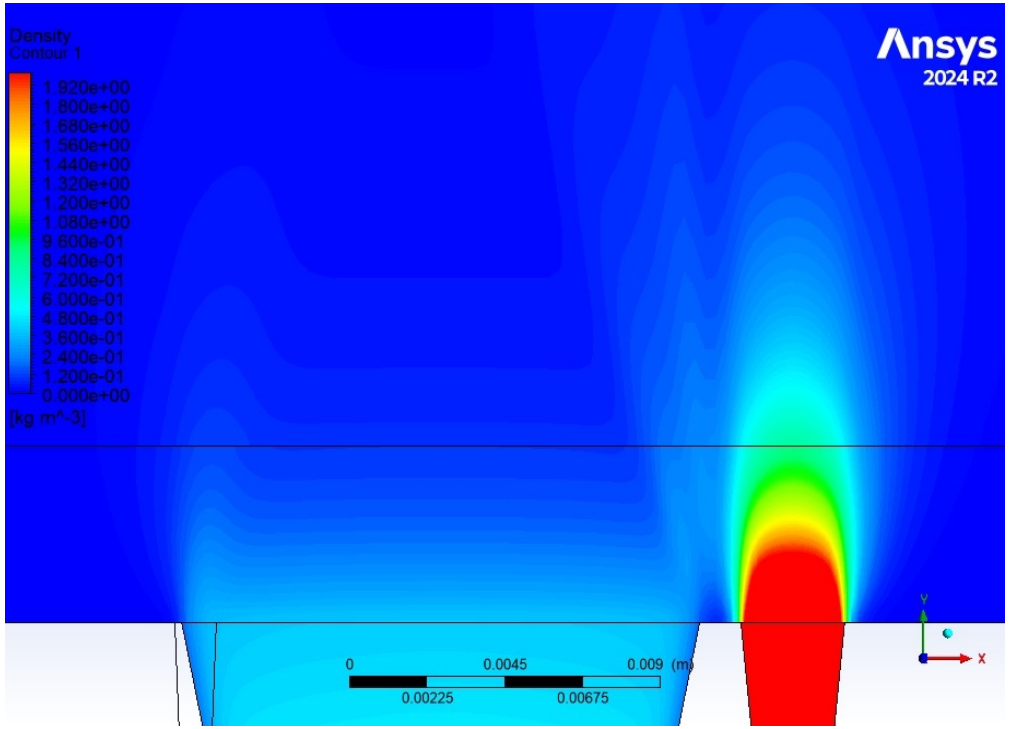
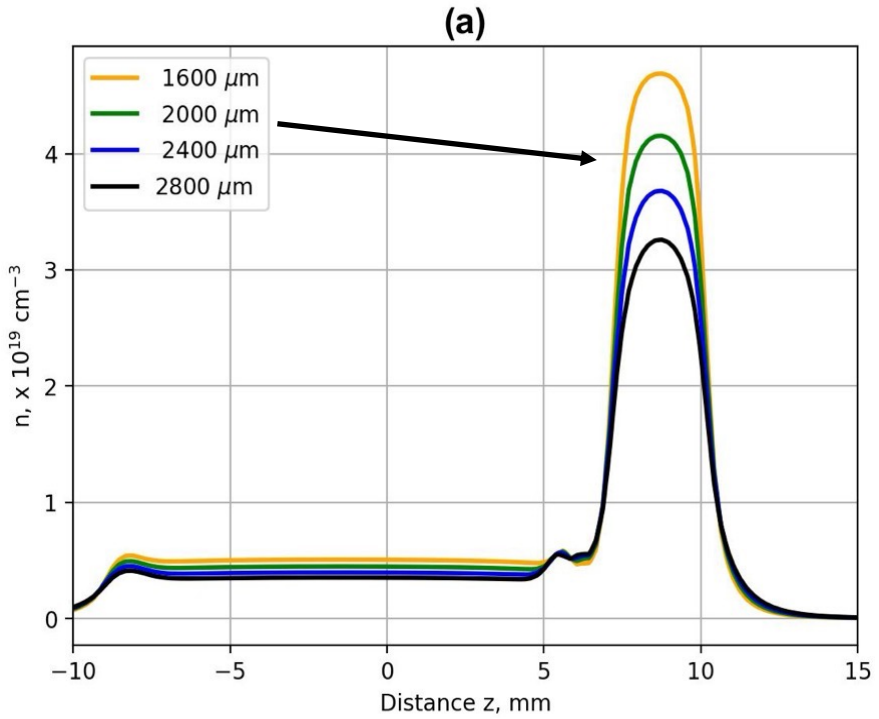
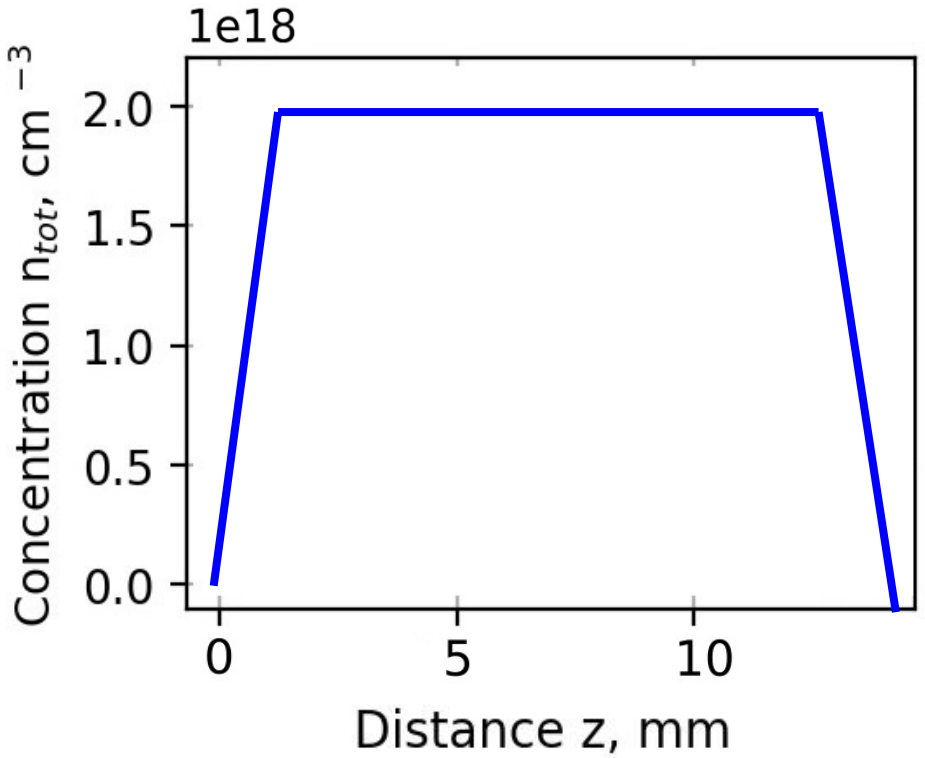


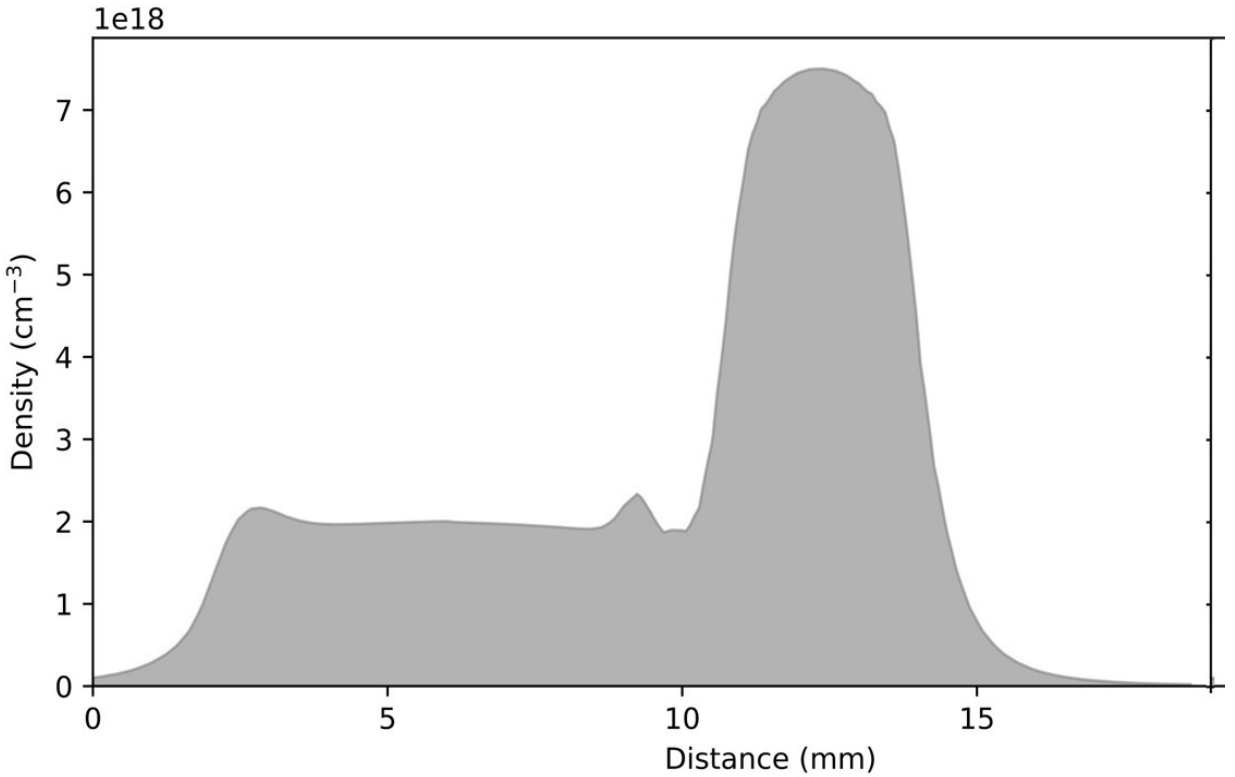


Dual slit nozzle – Density N_2 , 80 bar

15 mm x 1.2 mm + 3a mm x 1.2 mm. Gap 1 mm. Slit width defines the required gas concentration at laser beam – nozzle distance of ~ 2 mm

FBIC LWFA Simulation Using Concentration Profile of the Designed Gas Jet



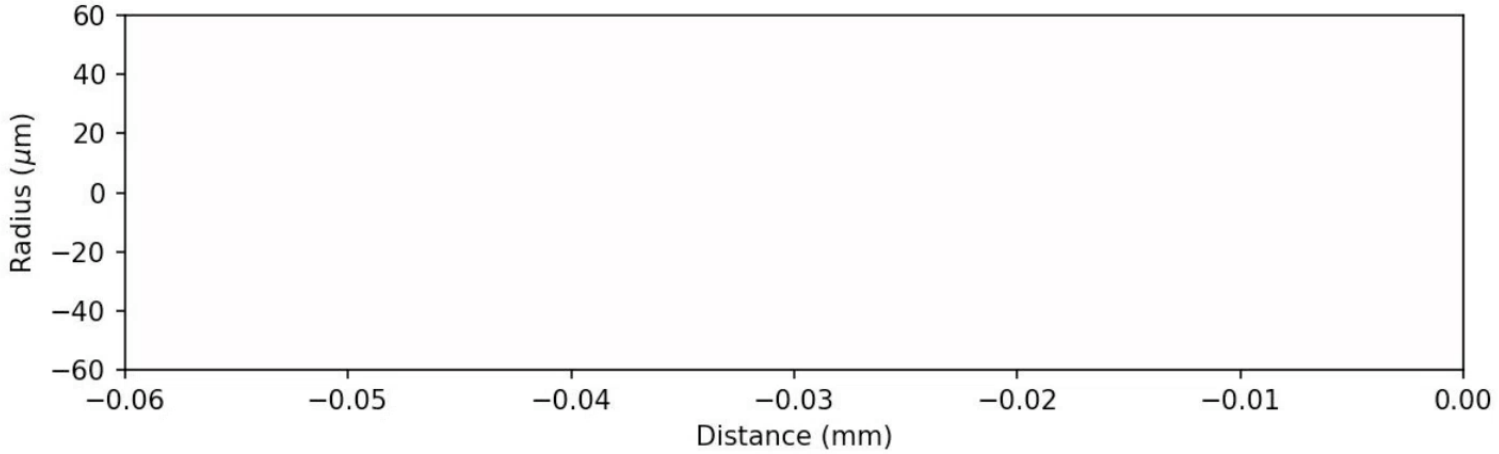


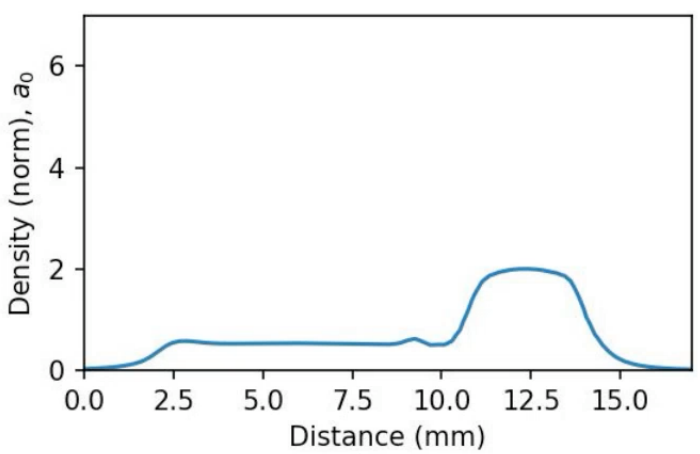
I. Andriyash, LOA

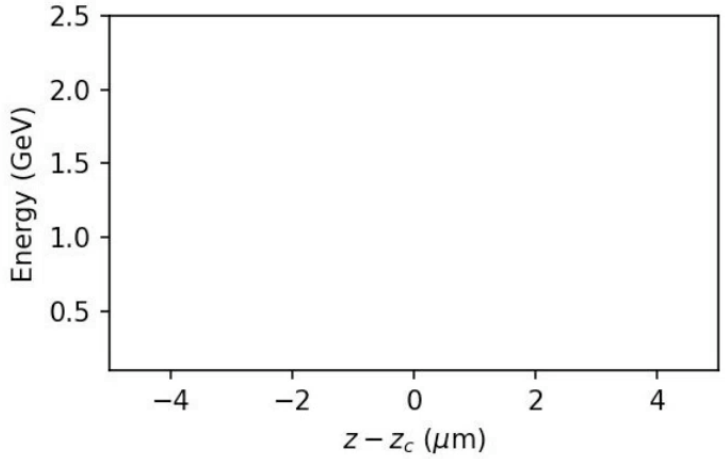
1. Slit nozzle – Density 2e18 cm^{-3}, 15 mm x 1.2 mm
2. Slit nozzle – Density 7.5e18 cm^{-3}, 5 mm x 1.2 mm slit.

Gap 1 mm

Evolution of the Spectrum of Electron Energy



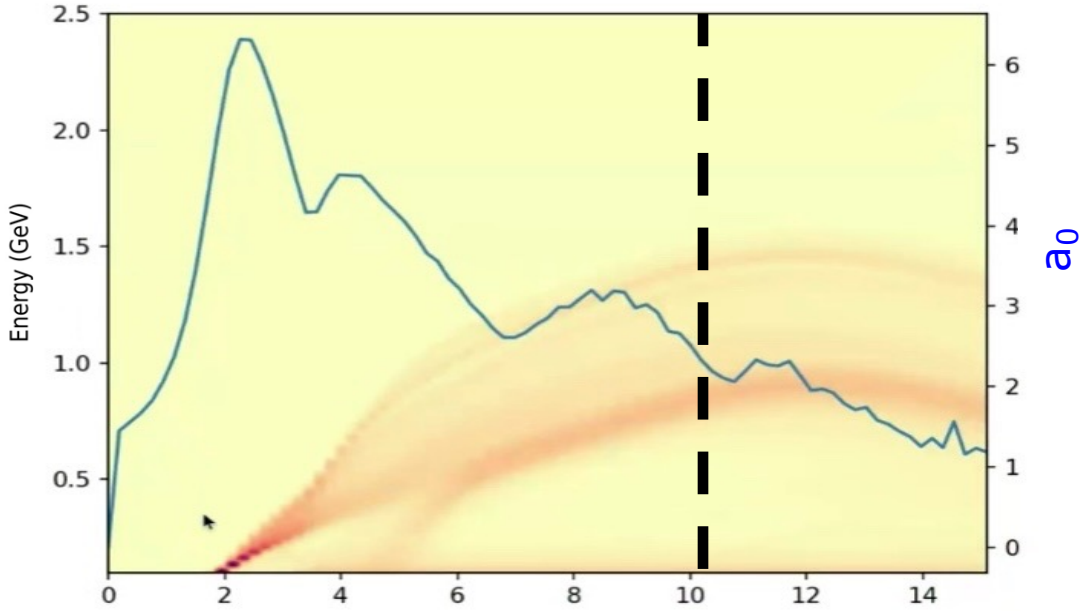




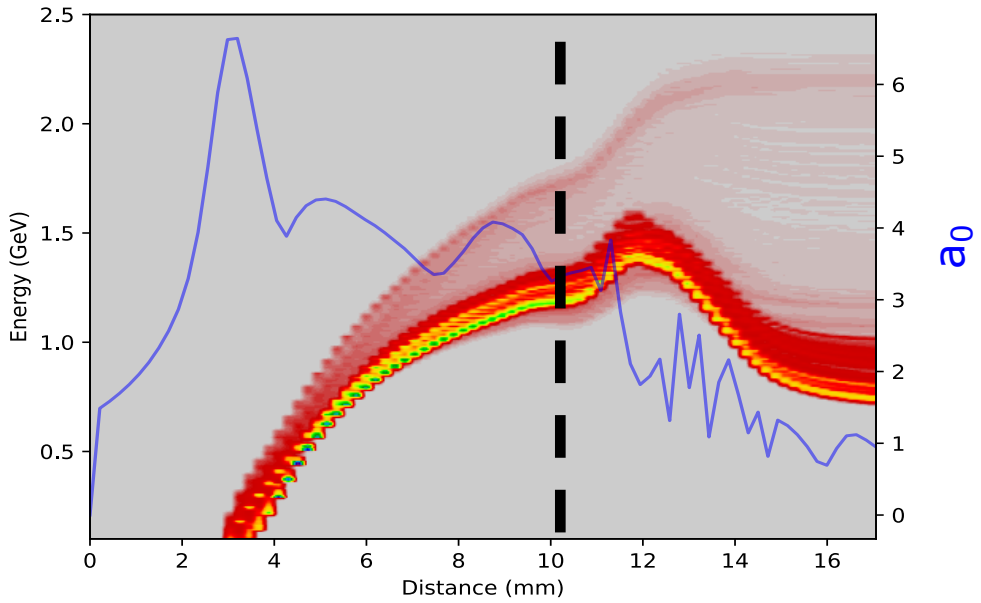
Optimization of Electron Acceleration and Betatron Radiation using FBPIC

Funded by the European Union

a



b

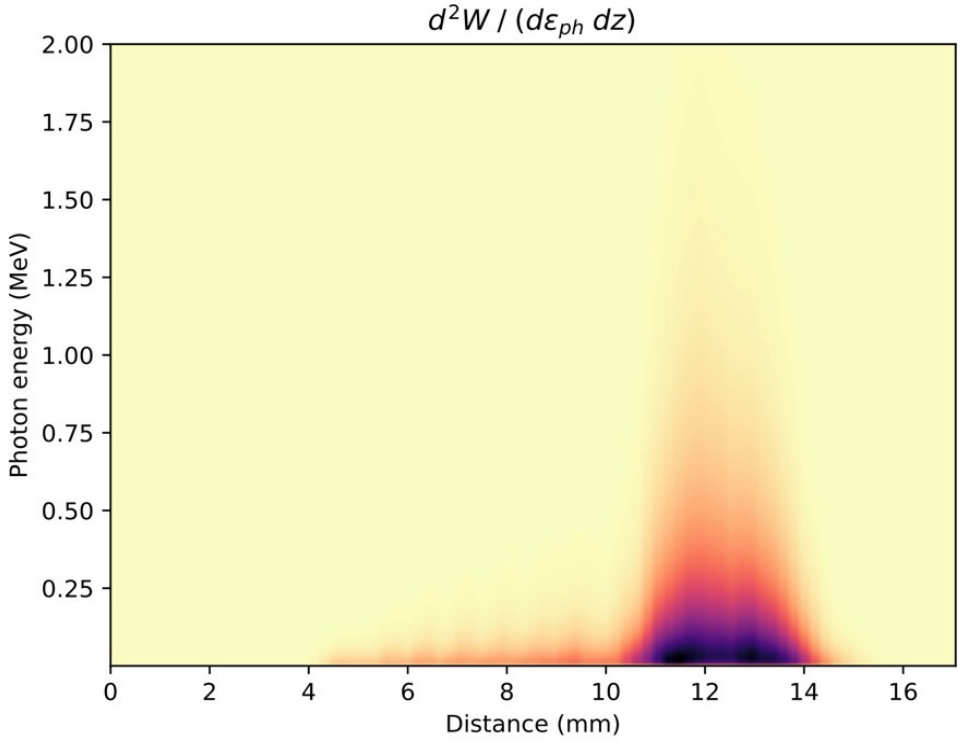


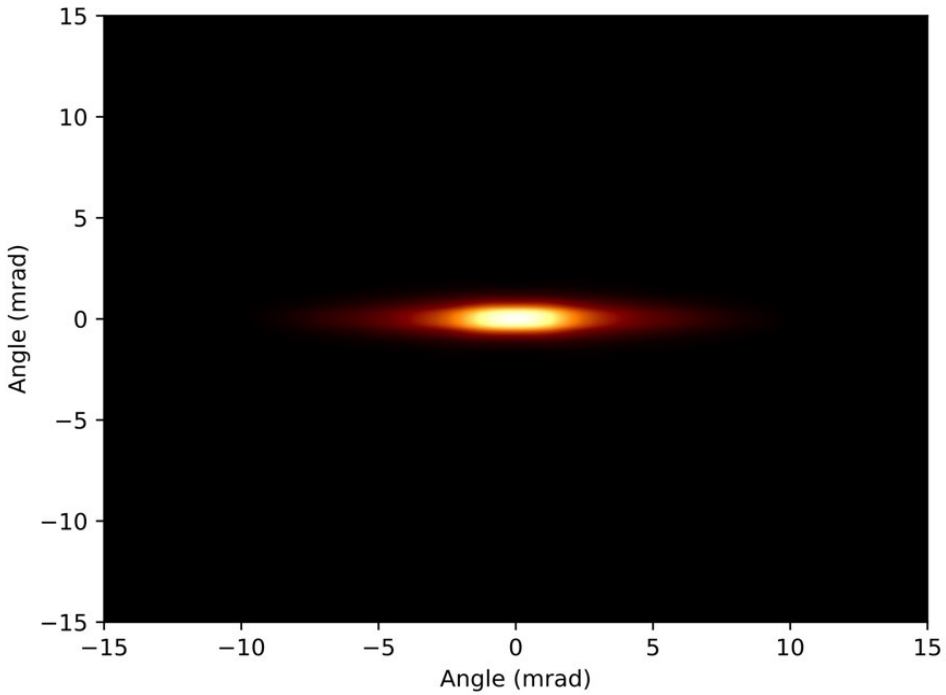
I. Andriyash, LOA

1. Slit nozzle – Density 2e18 cm^{-3}, 15 mm x 1.2 mm
2. Slit nozzle – Density 2-8e18 cm^{-3}, 5 mm x 1.2 mm slit. Gap 1 mm

- Rephasing, PWFA effects.
  To be re-iterated based on experimental results

Evolution of the Spectrum of Radiation



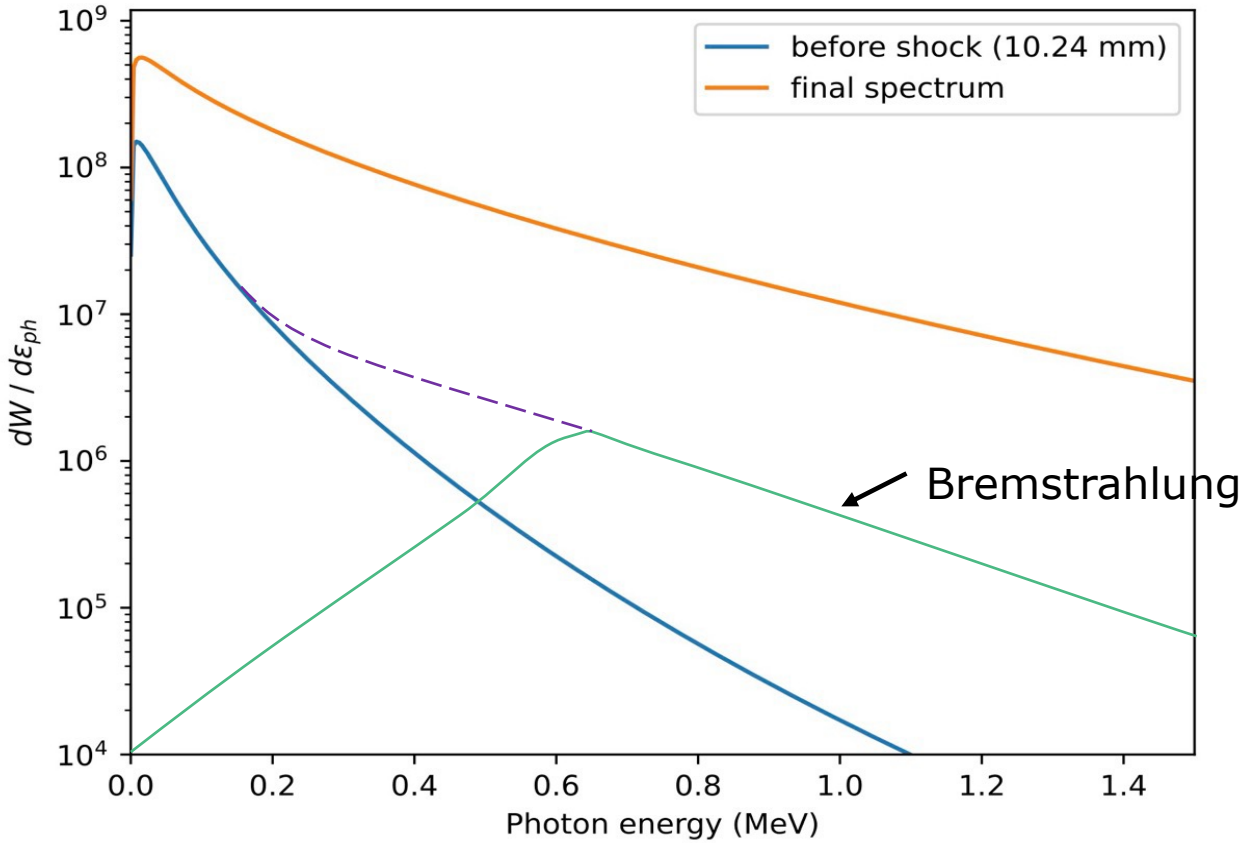


Dependence of radiation spectrum on acceleration distance and angular distribution of radiation.

I. Andriyash, LOA

Spectrum of the Secondary Radiation

- Comparison of Betatron FBPIC/Synchrad and Geant 4 using single and dual gas target

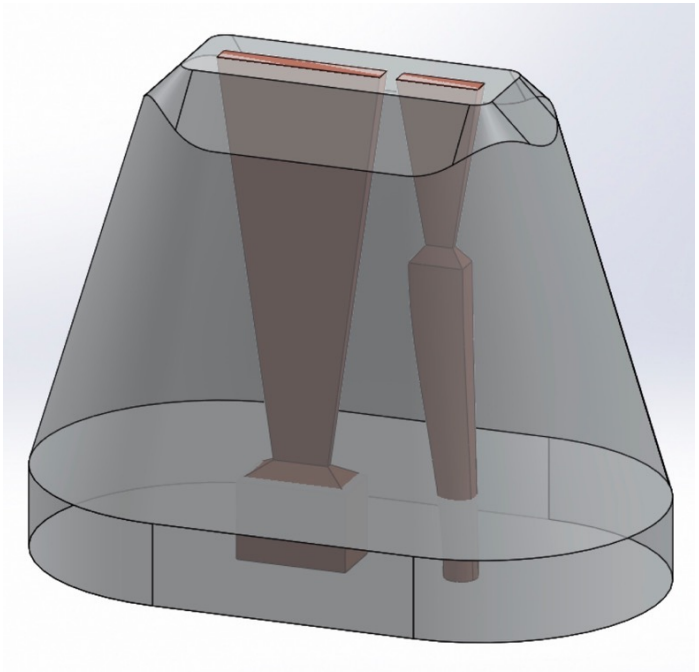


- Andriyash, Synchrad,
- Arunima Dev TV, Geant

- Maximal electron energy increases from 1.5 GeV to 2.3 GeV, the number of X-ray photons increases by 2.5 at low energy range and ~ 10^2 in the 500 keV - 1 MeV range.
- In the range of 0.5-1 MeV Bremsstrahlung contributes ~ 1e6 of of photons for 260 pC electron charge of 8×10^{18} cm^{-3} and dominates forward-directed emission in the cone of few degrees.

Nozzles tested

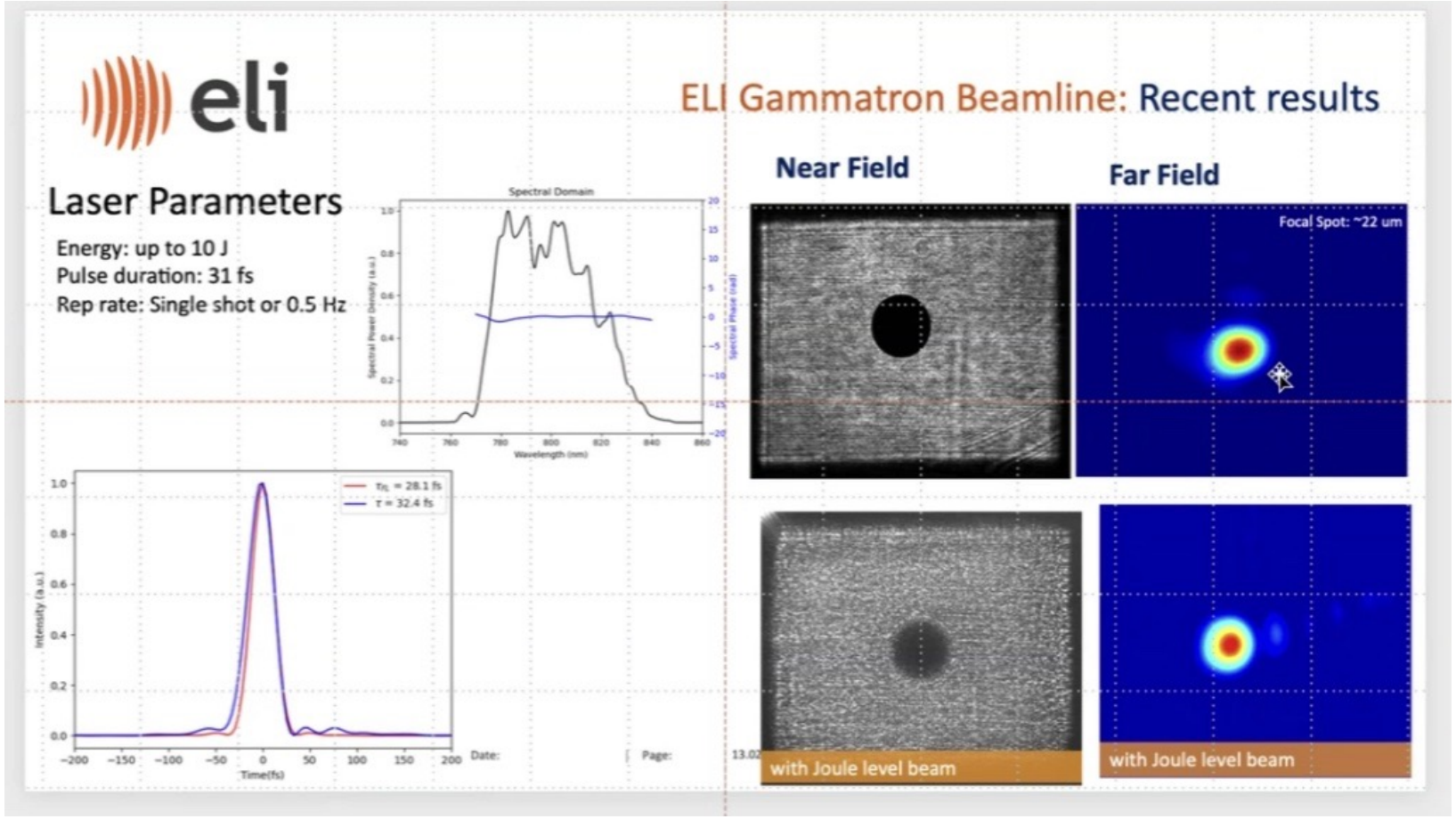
10 mm + 5 mm double jet with a gap of 1 mm manufactured from fused silica using 3D laser machining



M. Mackeviciute, J. Dudutis, P. Gecys, V. Tomkus, FTMC

L3 Laser parameters

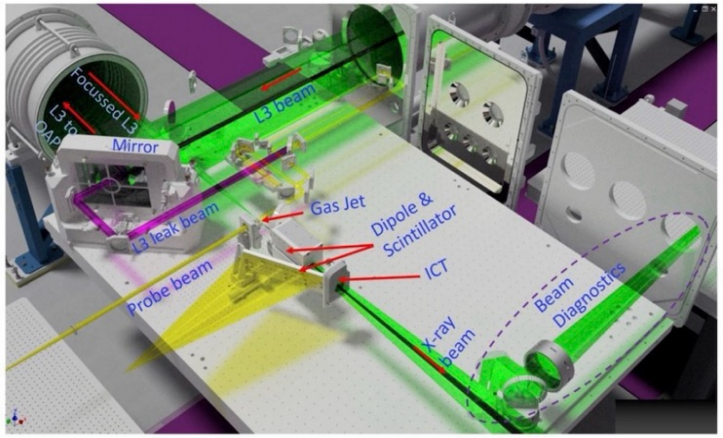
- Pulse energy (max) - 10 J
- Pulse energy (on the target) - 3J
- Pulse duration - 30 fs
- Repetition rate 0.25 - 3⅓ Hz
- Peak power - 0.37 PW
- Central wavelength - 810 nm
- Spectral bandwidth - 56 nm
- Pointing stability - 2.7 µrad RMS
- Polarization - linear
- Temporal contrast >10^{10}:1
- Beam size 214 x 214 mm
- f/20 parabolic mirror, spot 20 µm

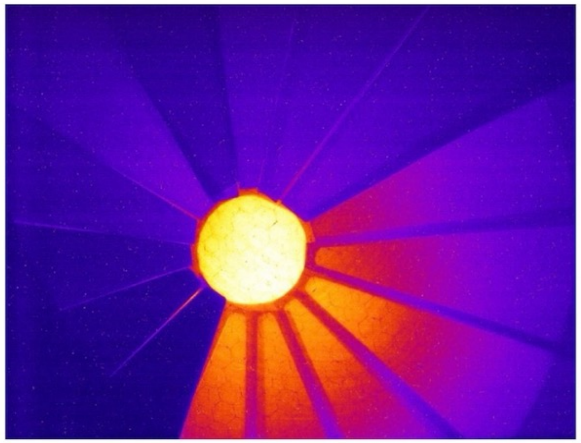


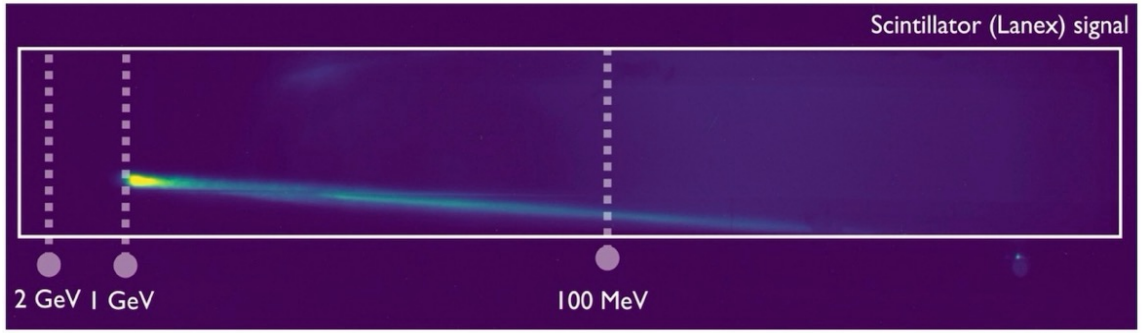
L3 Gammatron X-ray Experimental Station

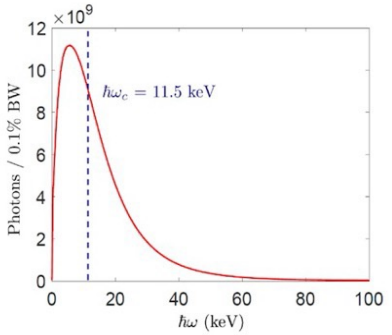
Funded by the European Union

2024 Commissioning Data







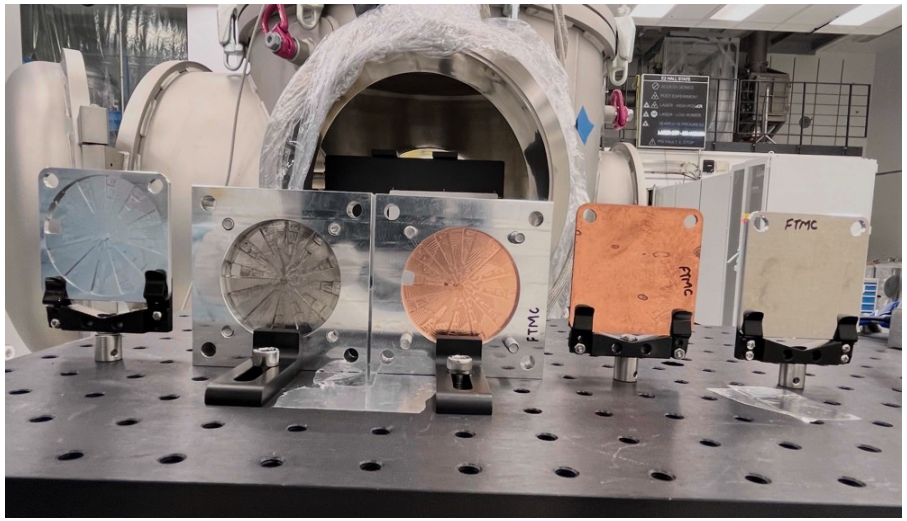


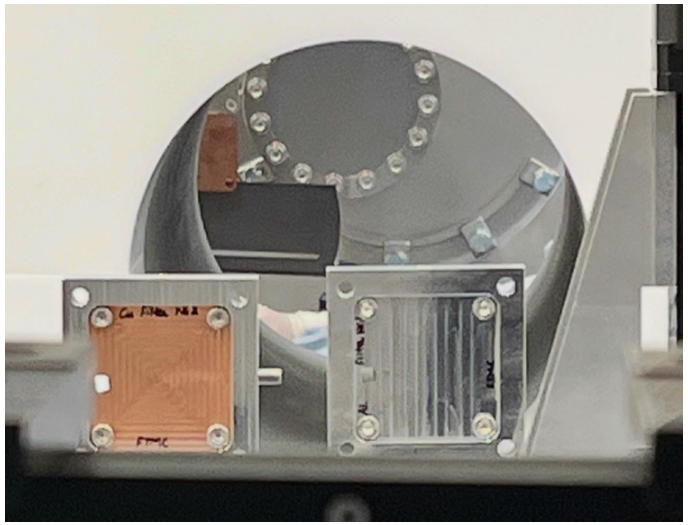
U. Chaulagain et al.,Photonics 9 (11), 853, (2022)

Energy of LWFA accelerated electrons and spectrum of the betatron radiation

U. Chaulagain et al., Proc. of SPIE Vol. 13537 1353707-1, (2026)

Experimental chamber

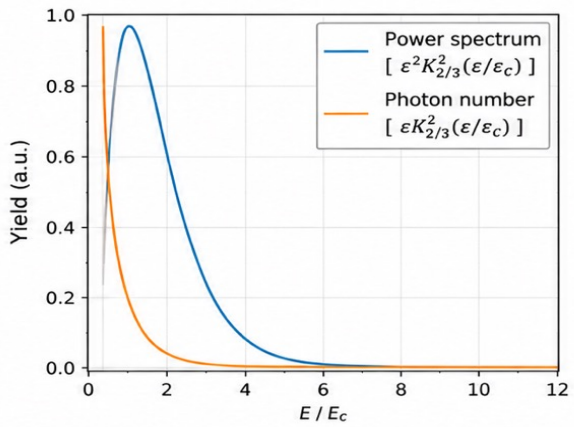




- Be window 500 um
- Electron dump
- Set of wedge filters
- X-ray - flat camera

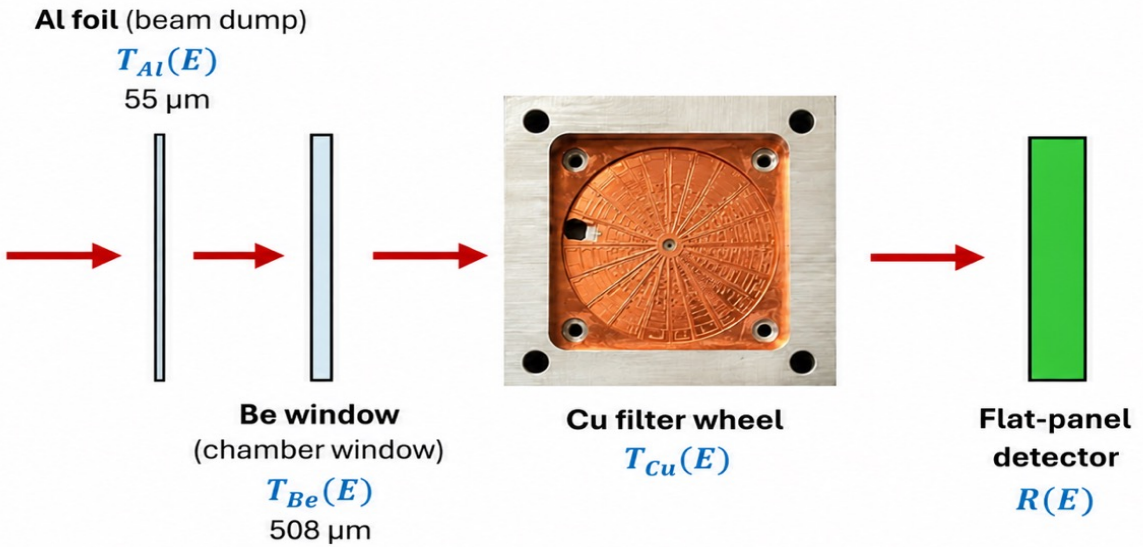
Set up of X-ray characterization

Assume a spectrum → simulate → compare → adjust



assumed spectrum

$f(E)$



$$S_i = \int f(E) T_i(E) R(E) dE$$

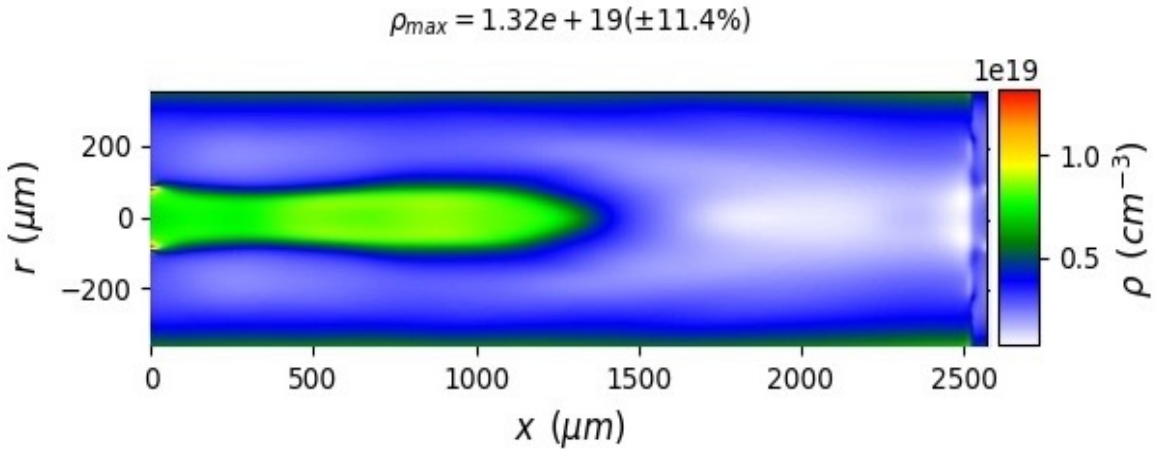
- S_i = signal
- $f(E)$= assumed spectrum
- $T_i(E)$= transmission for the filters
- $R(E)$= camera response

For Betatron:

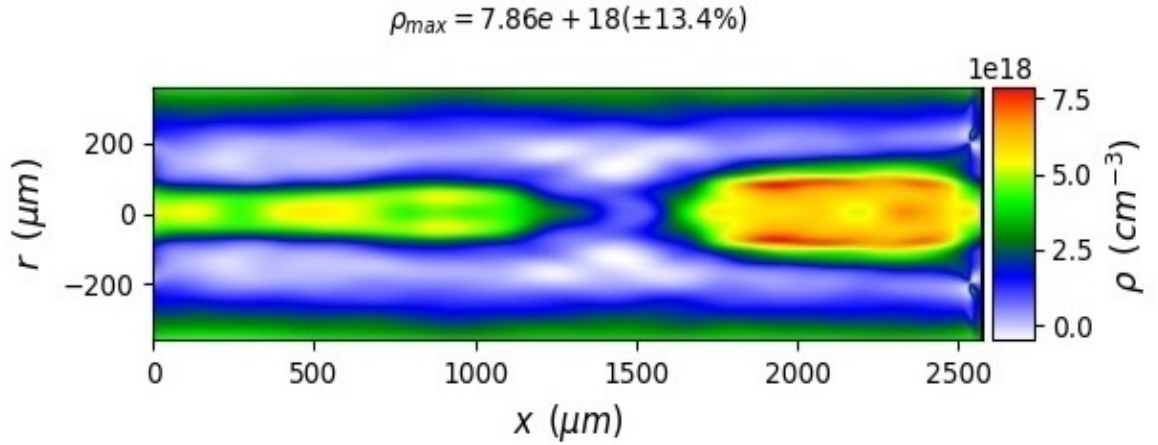
$$f(E) = A\left(\frac{E}{E_c}\right)^2 K_{2/3}^2\left(\frac{E}{E_c}\right)$$

Reconstructed Plasma Density

He + 2% N_2
5.0 bar + 0 bar
~ 7e18 cm^{-3}



He + 2% N_2 / He
5.0 bar + 2 bar
~ 6e18 cm^{-3} /
~ 8e18 cm^{-3}



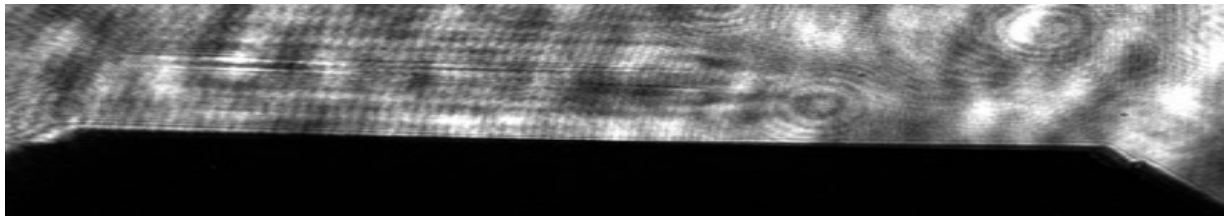
Reconstructed Electron Spectrum

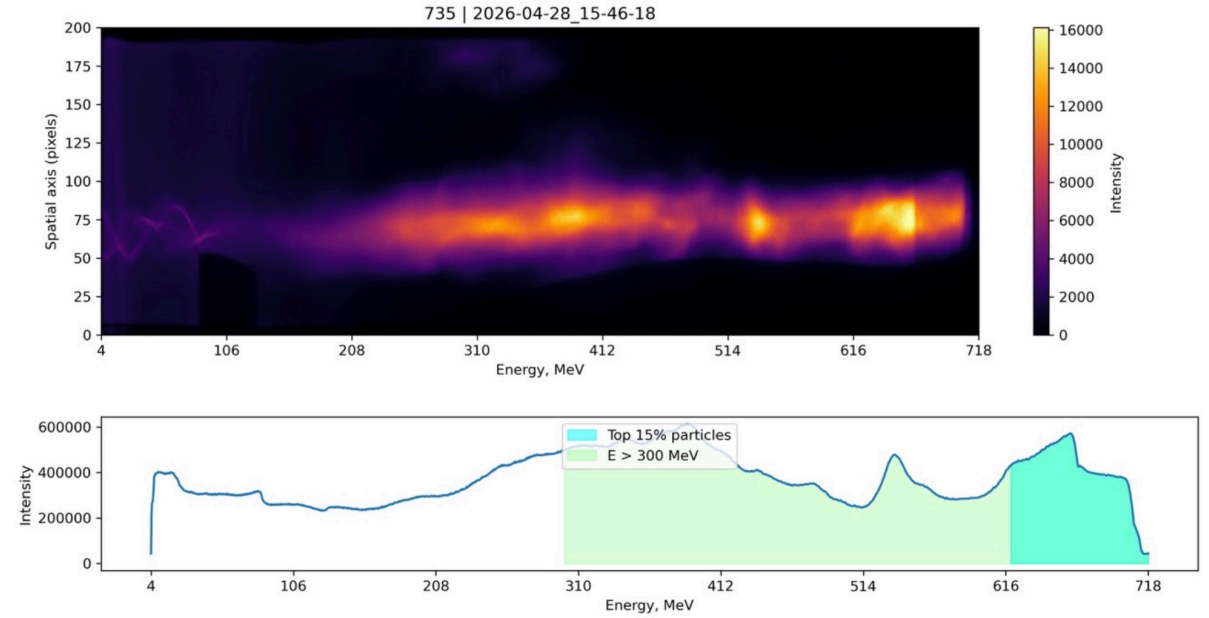
Single 10 mm nozzle

He + 2% N_2

5.0 bar + 0 bar

Qel ~ 0.68 nC
at > 300 MeV
1.3 nC Total





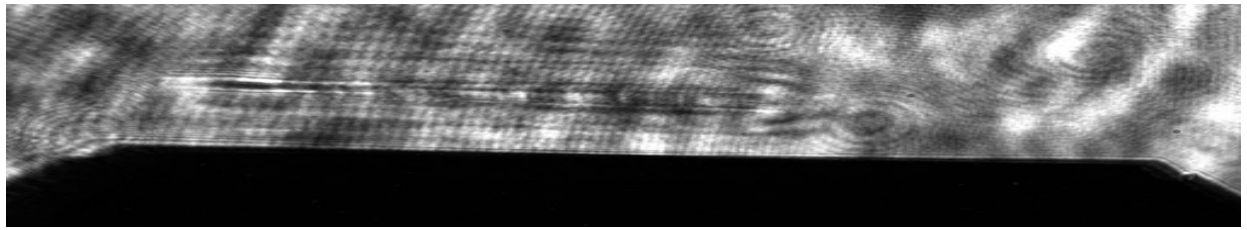
Reconstructed Electron Spectrum

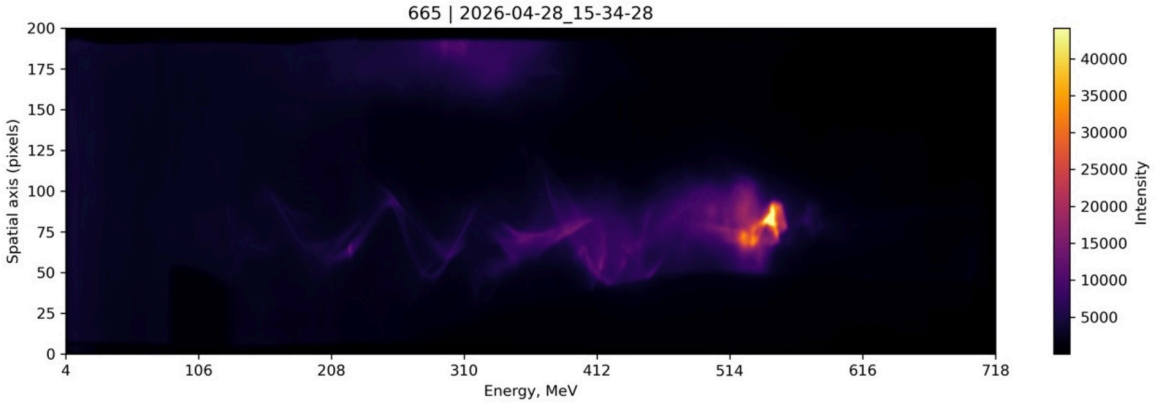
Single 10 mm nozzle

He + 2% N_2

8.0 bar + 0 bar

Qel ~ 1.36 nC
at > 300 MeV
2.0 nC Total





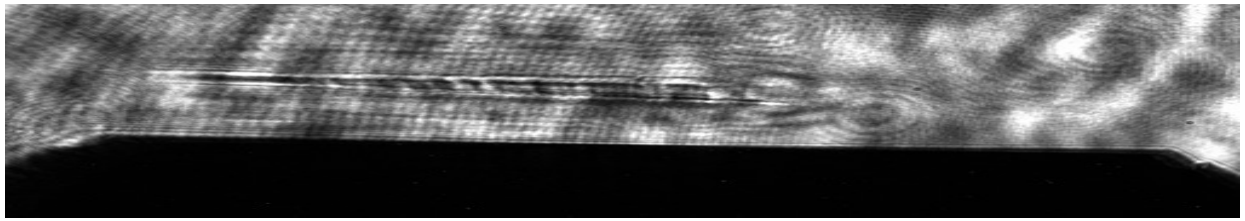
Reconstructed Electron Spectrum

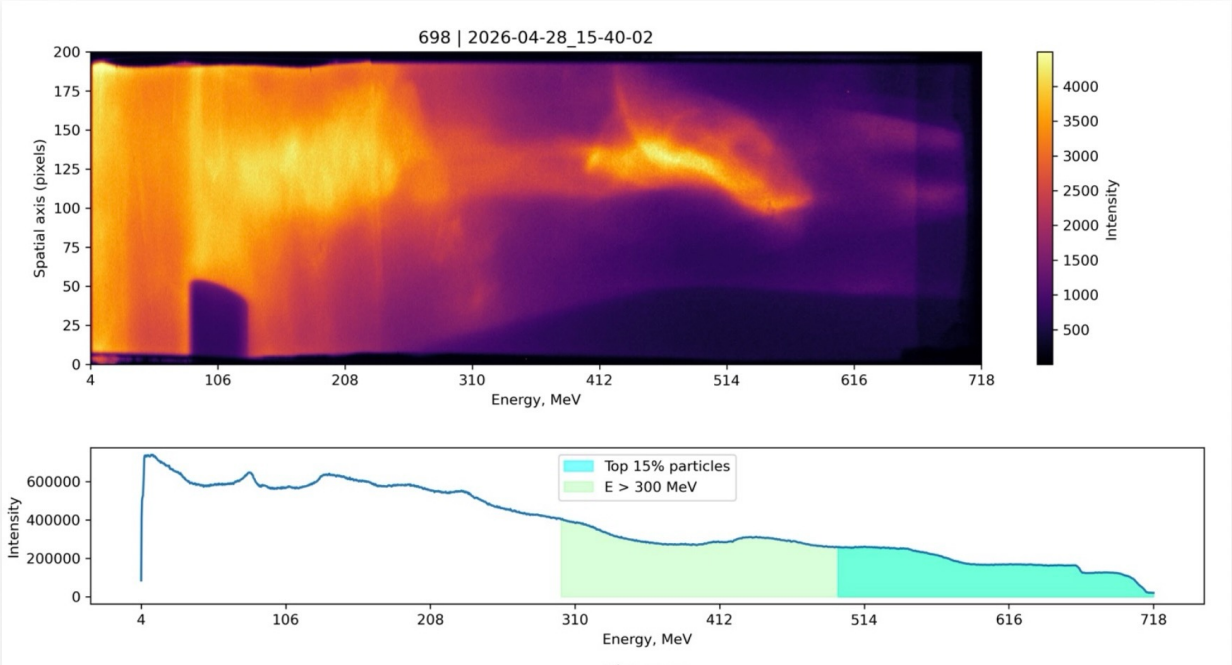
Single 10 mm nozzle

He + 2% N_2

11.0 bar + 0 bar

Qel ~ 0.75 nC
at > 300 MeV
2.2 nC Total





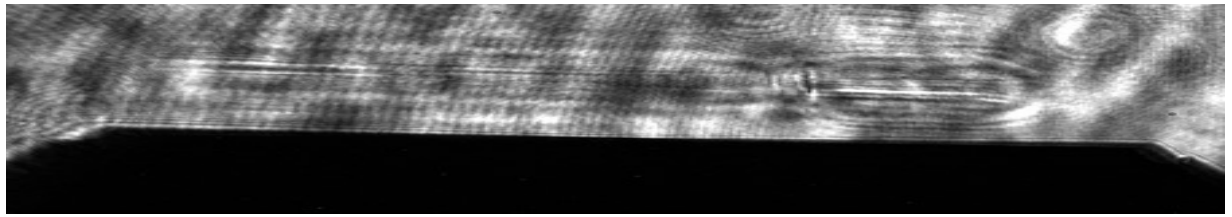
Reconstructed Electron Spectrum

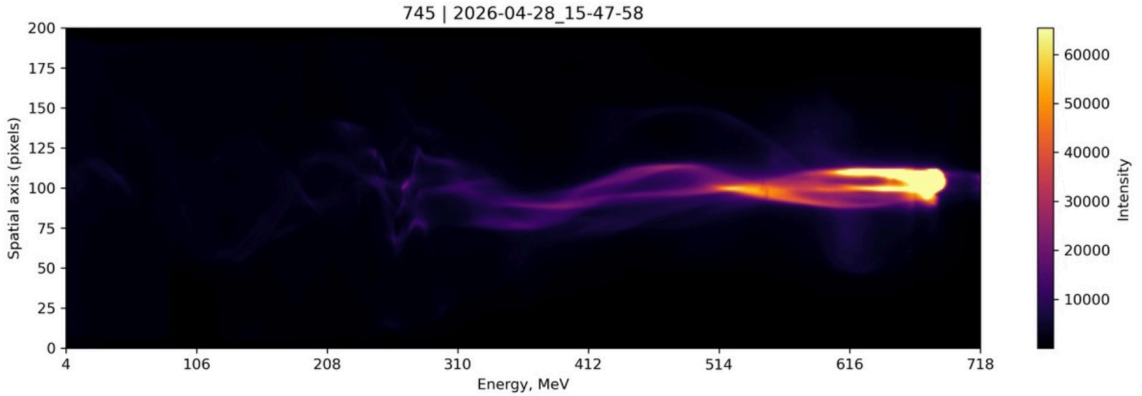
Double 10+5 mm nozzle

He + 2% N_2 / He

5.0 bar + 2 bar

Qel ~ 0.75 nC
at > 300 MeV
2.9 nC Total





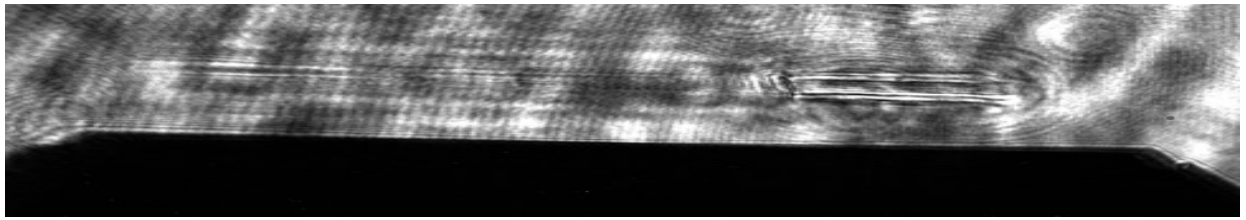
Reconstructed Electron Spectrum

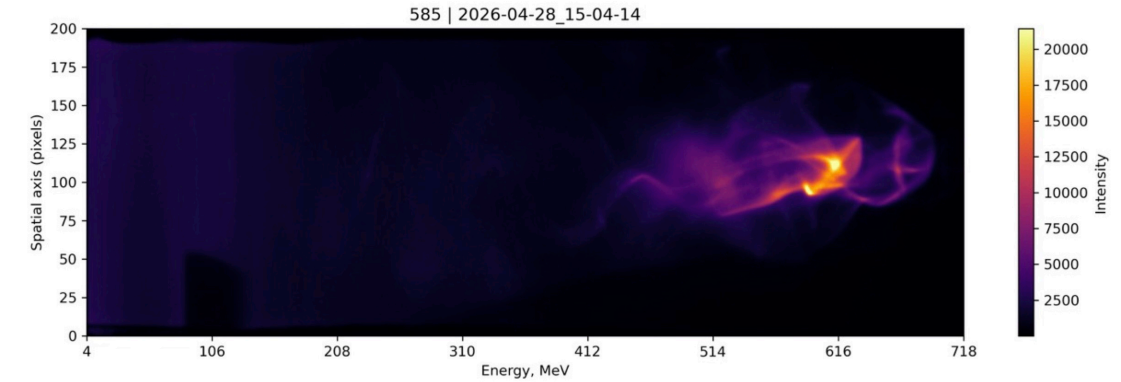
Double 10+5 mm nozzle

He + 2% N_2 / He

5.0 bar + 5 bar

Qel ~ 0.9 nC
at > 300 MeV
1.9 nC Total



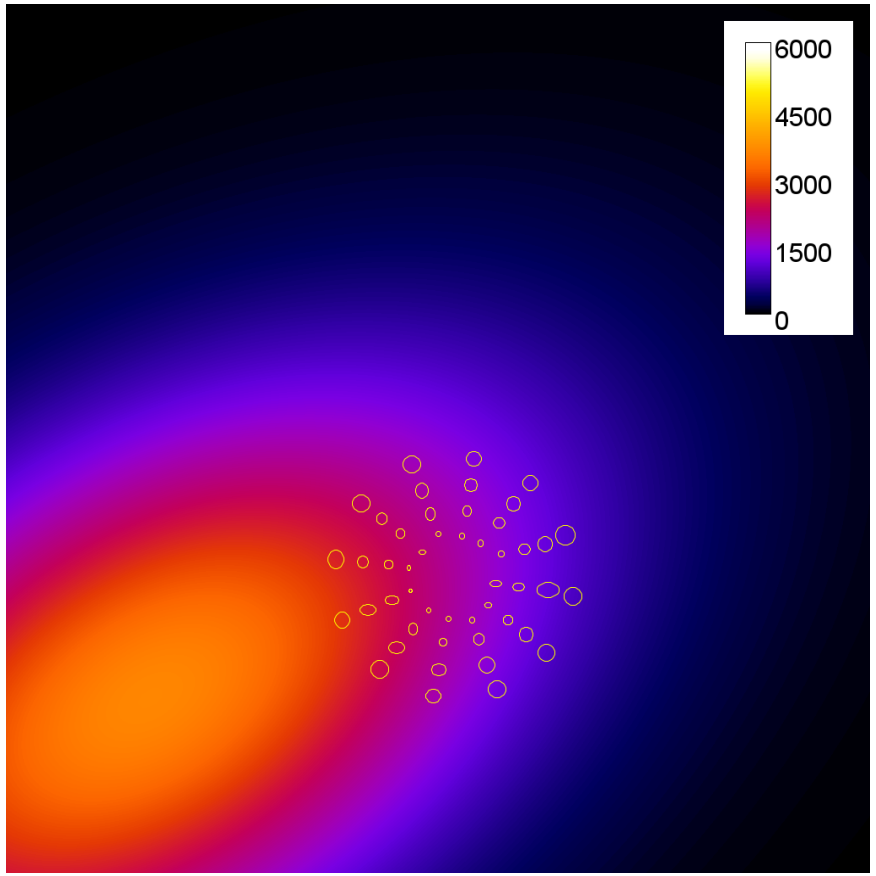


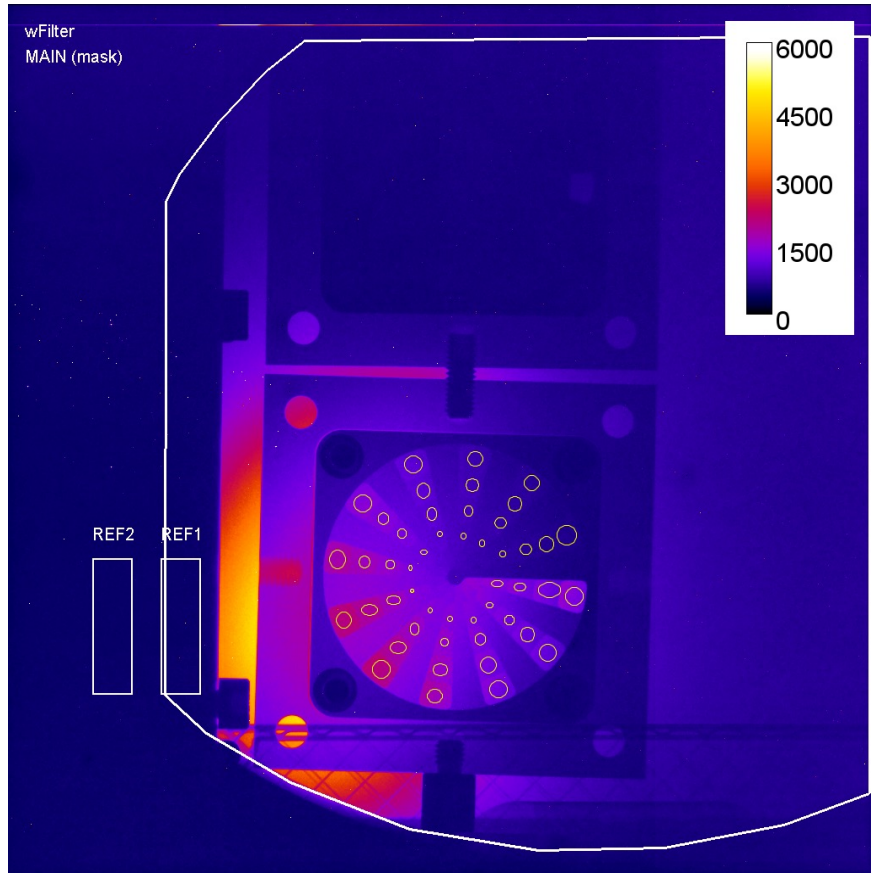
X-ray characterization

Single 10 mm nozzle

He + 2% N_2

5.0 bar + 0 bar



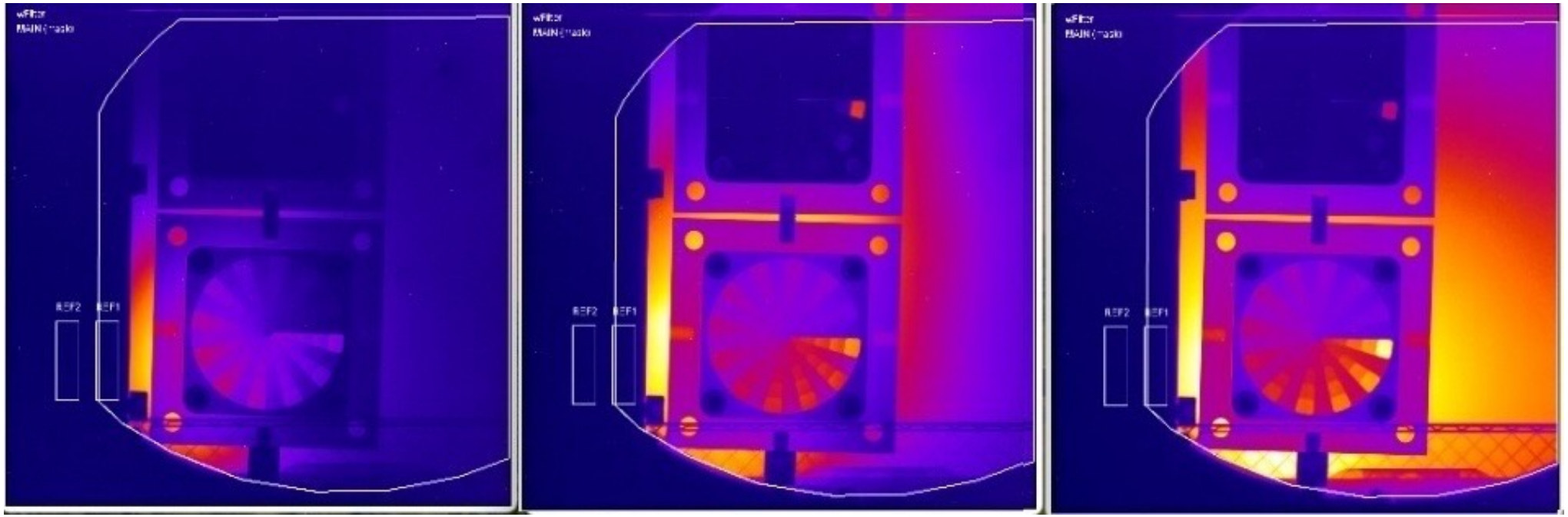


X-ray characterization

Single 10 mm nozzle

He + 2% N_2

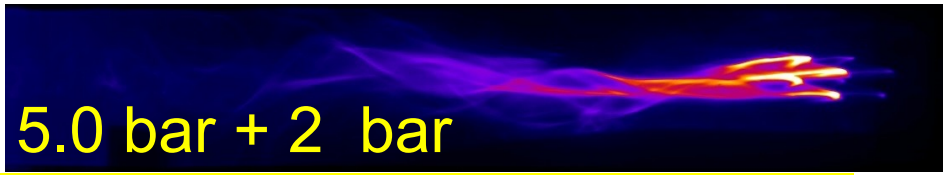
5.0 bar 8.0 bar 11.0 bar



X-ray characterization

Double 10 + 5 mm nozzle

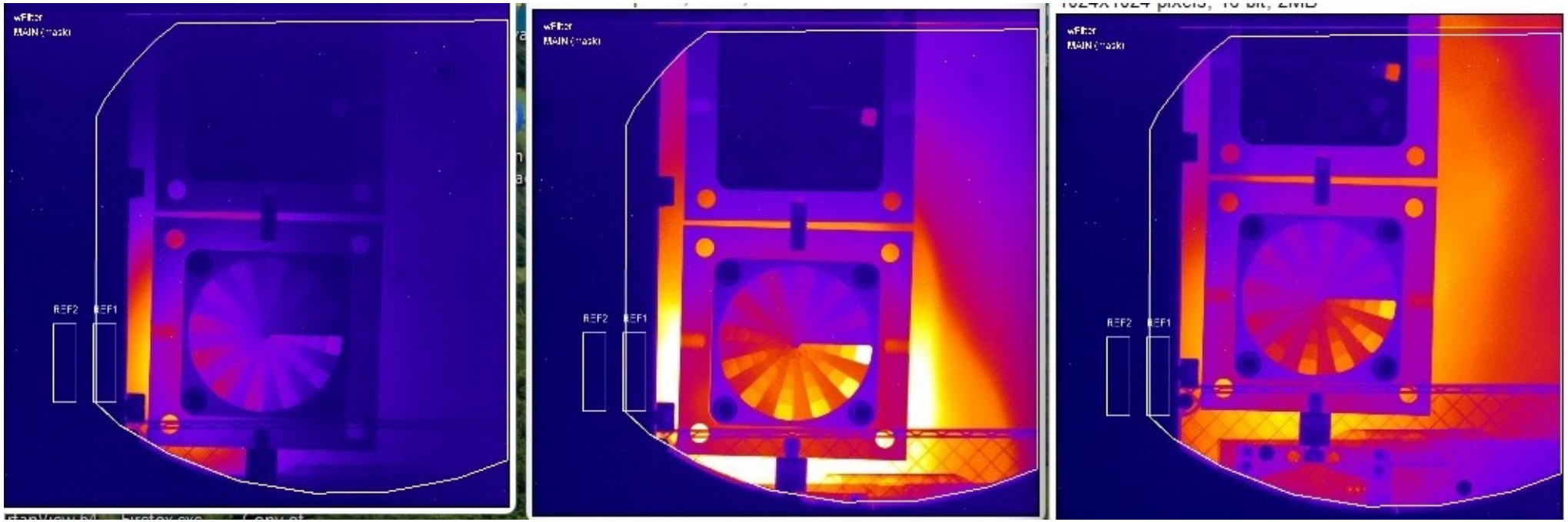
He + 2% N_2 / He



5.0 bar + 0 bar

5.0 bar + 2 bar

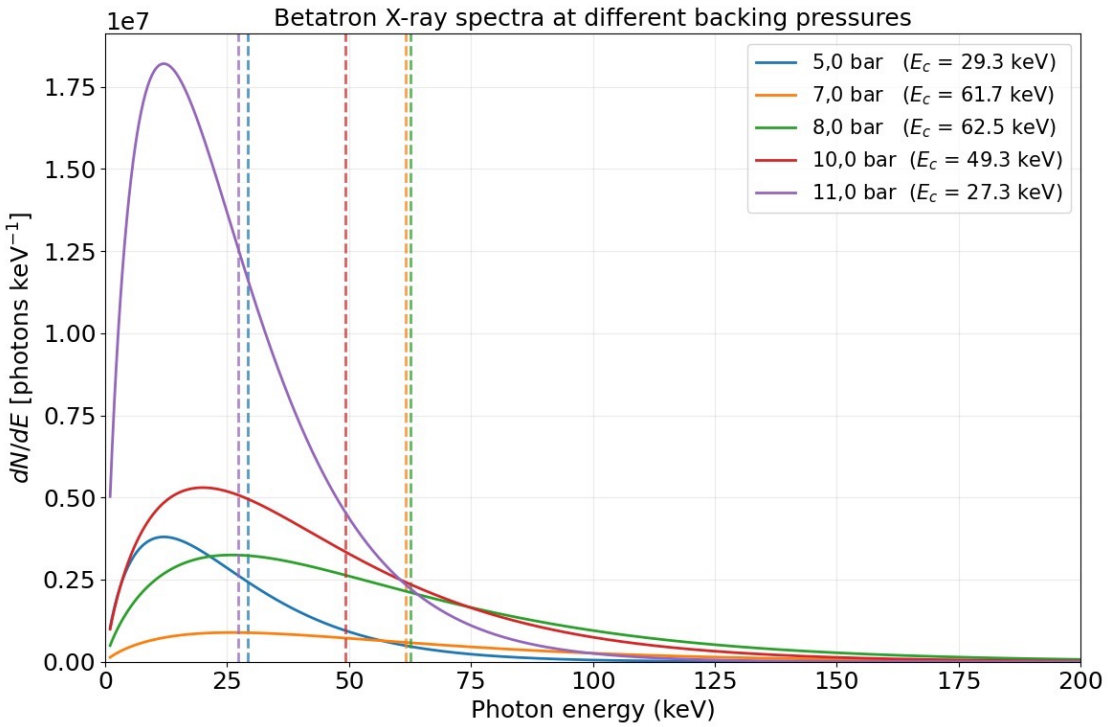
5.0 bar + 5 bar



Critical Energy of Betatron Radiation

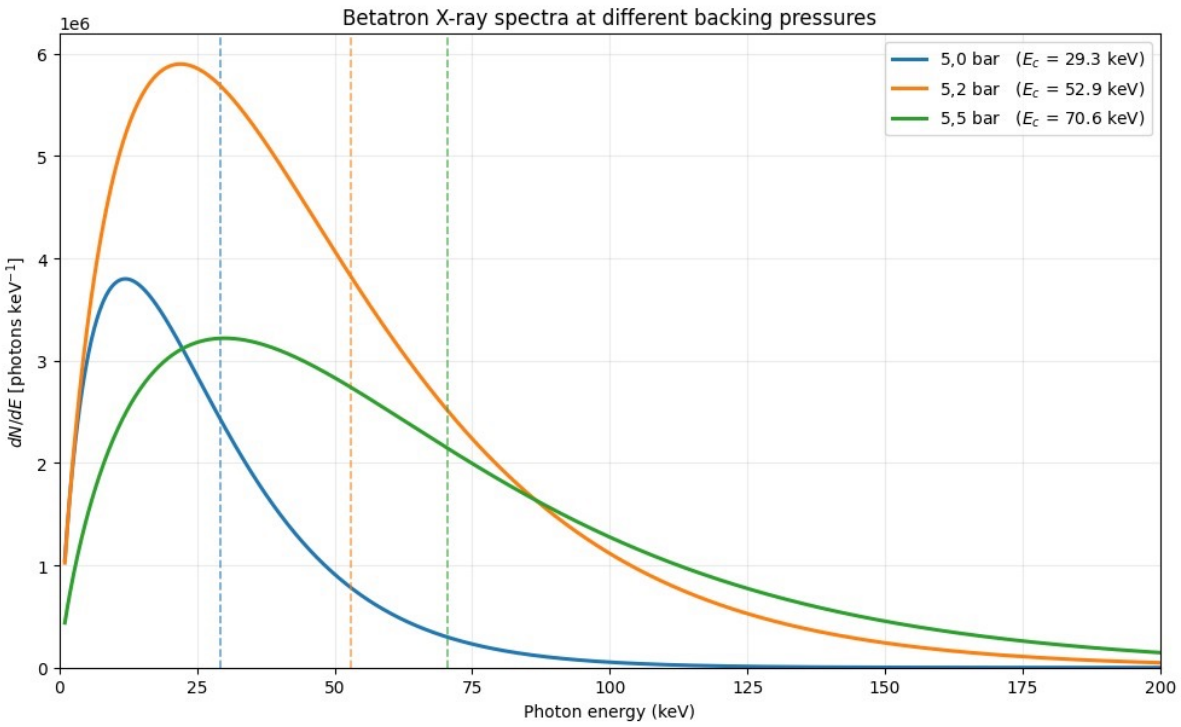
Single 10 mm nozzle

He + 2% N_2



Double 10 mm + 5 mm nozzle

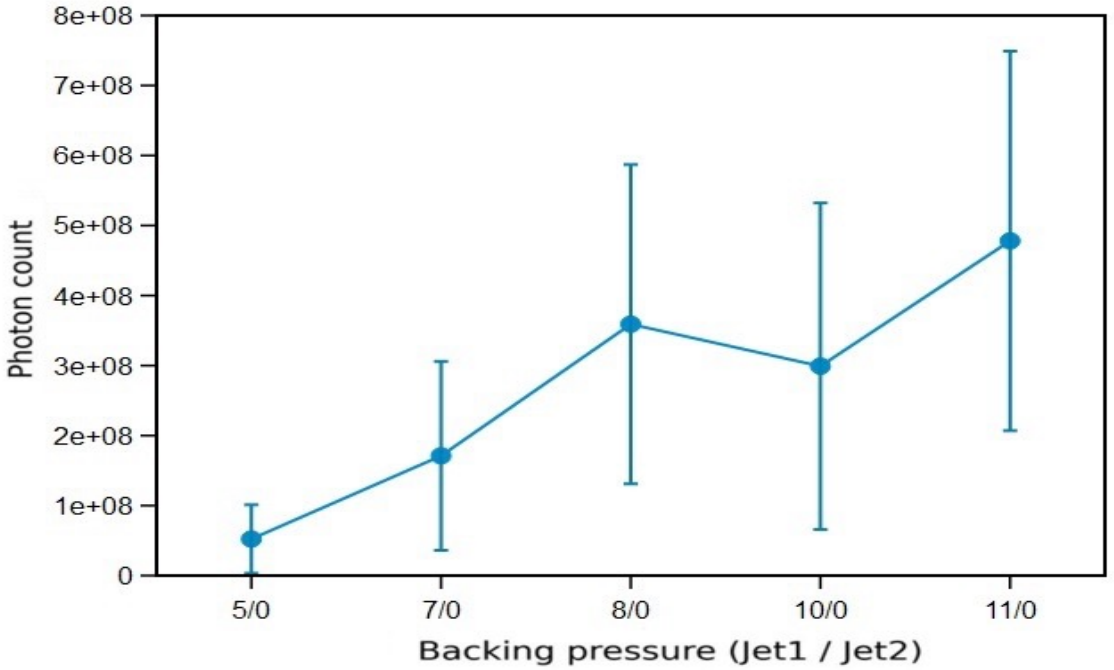
He + 2% N_2 / He



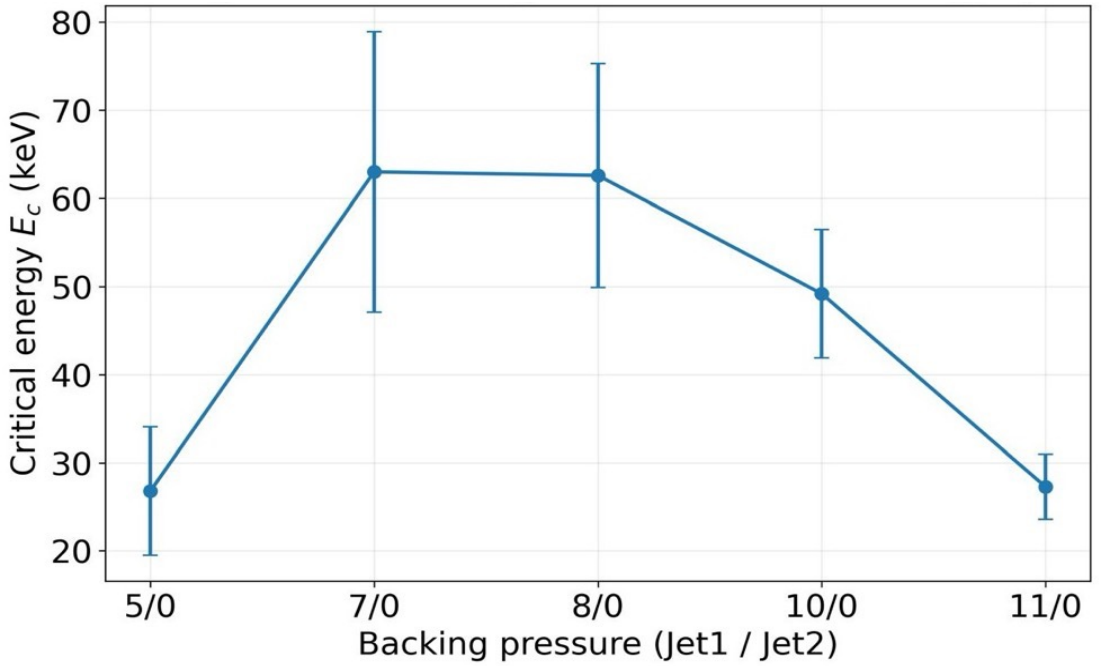
Photon Counts and Critical Energy vs Backing Pressure

Single 10 mm nozzle

He + 2% N_2



~ 7e18 cm^{-3} ~ 1.1e19 cm^{-3} ~1.5e19 cm^{-3}

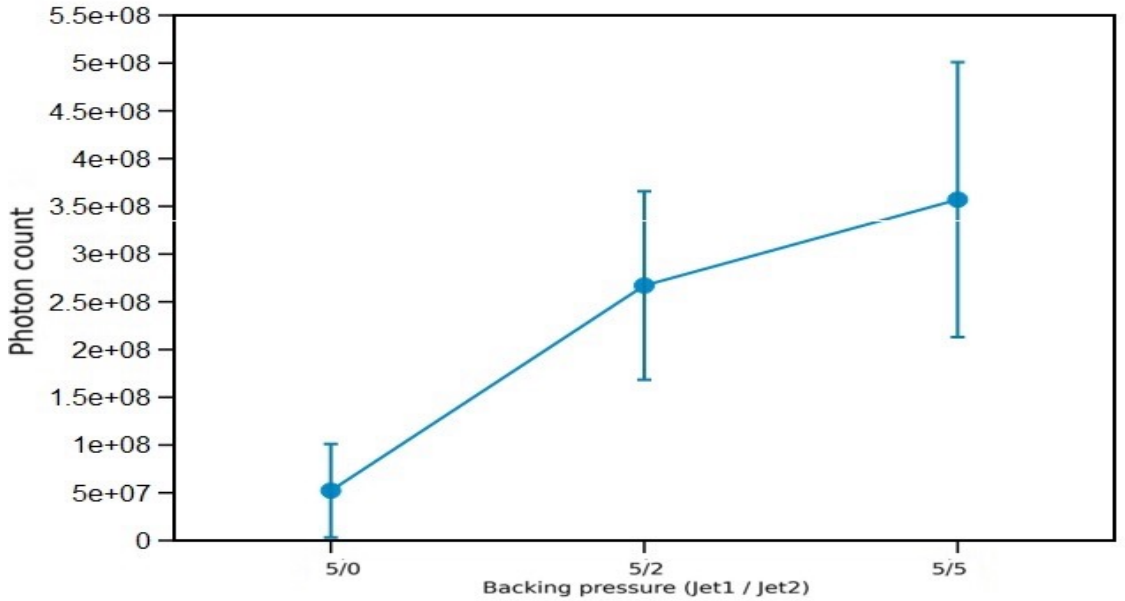


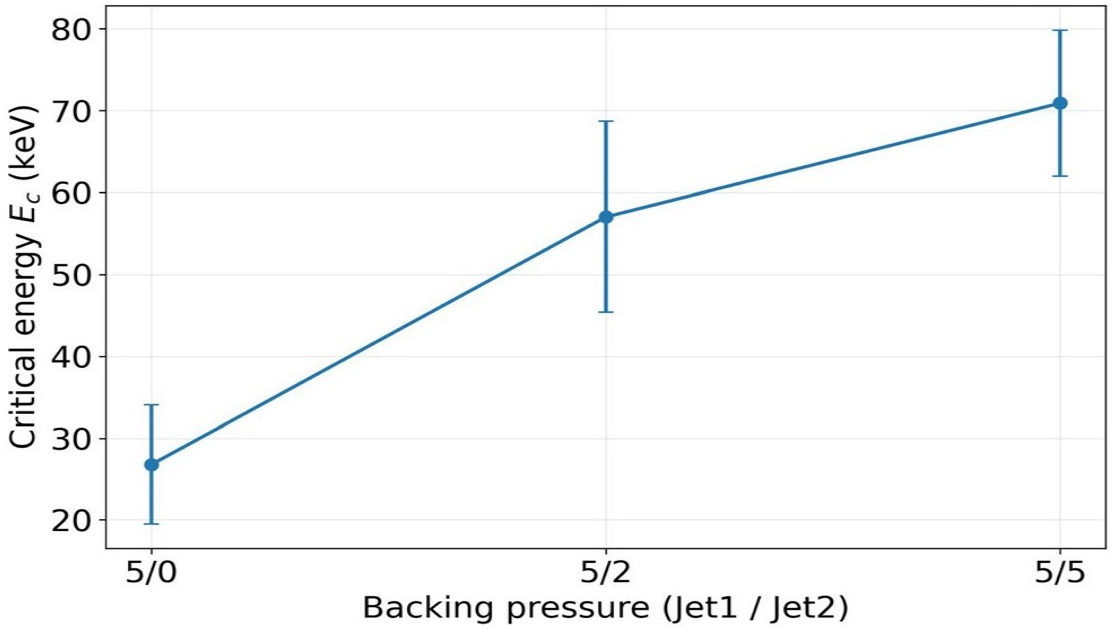
~ 7e18 cm^{-3} ~ 1.1e19 cm^{-3} ~1.5e19 cm^{-3}

Photon Counts and Critical Energy vs Backing Pressure in the Second Nozzle

Double 10 mm + 5 mm nozzle

He + 2% N_2 / He





~ 7e18 cm^{-3} ~ 6e18 cm^{-3} / ~ 8e18 cm^{-3} ~ 6e18 cm^{-3} / ~ 2e19 cm^{-3}

~ 7e18 cm^{-3} ~ 6e18 cm^{-3} / ~ 8e18 cm^{-3} ~ 6e18 cm^{-3} / ~ 2e19 cm^{-3}

Summary

- Simulation of flux and critical energy of Laser driven hard X-ray/Gamma ray source from dual gas targets using CFD Fluent, FBPIC for LWFA, Synchrad and Geant for Secondary X-ray radiation was carried out
- Experiments of electron acceleration, dependence of electron charge, energy and secondary X-ray radiation on backing pressure using single and dual gas targets were performed at L3 ELI Beams Gammatron line
- The mean energy of accelerated electrons reached 450-520 MeV, the charge - 0.7- 2.1 nC. Maximal electron energy up to 1.4 GeV was observed.
- The photon counts dN/dE of X-ray radiation for single target was in the range of 0.9 – 18e6 keV^{-1} at 5-11 bar. The critical energy had the maximum of 63 keV at 8 bar and dropped to 27 keV at highest backing pressure of 11 bar.
- Both the photon counts and critical energy of X-ray radiation increased with implementation of double target. The dN/dE increased from 4 to 6e6 keV^{-1} and E_c from 27 keV to 71 keV at 5 bar + 5 bar at the second nozzle correspondingly. In this region, the X-ray filaments and distortion of electron beam were observed.

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