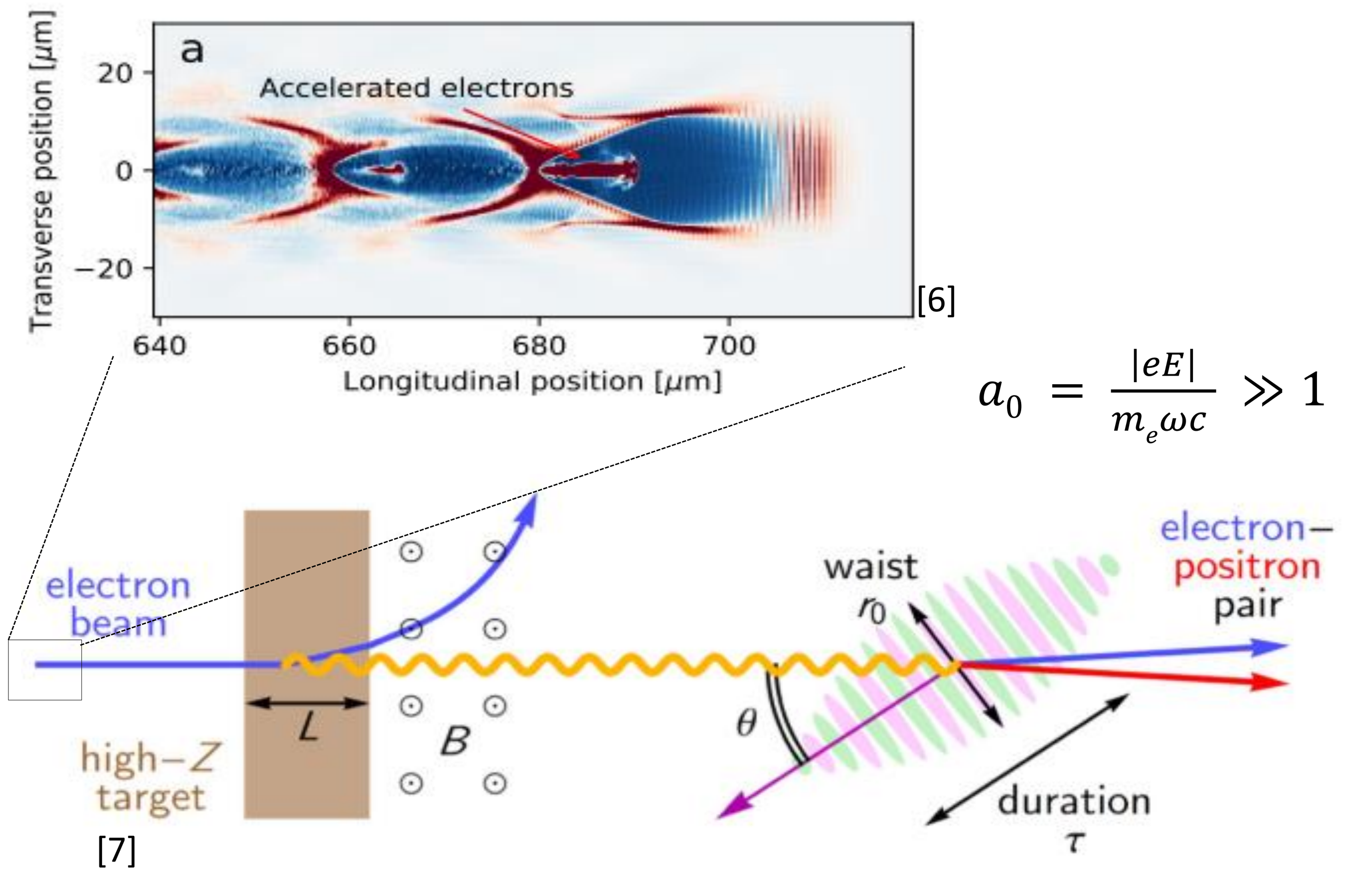
Laser Wakefield Acceleration to GeV Electron Energies

K. v. Grafenstein, F.C. Salgado, F.M. Foerster, F. Haberstroh, D. Campbell, A. Döpp, F. Irshad, A. Schletter, E. Travac, N. Weiße, M. Zepf and S. Karsch

Breit-Wheeler Experiment



$$a_0 = \frac{|eE|}{m_e \omega c} \gg 1$$

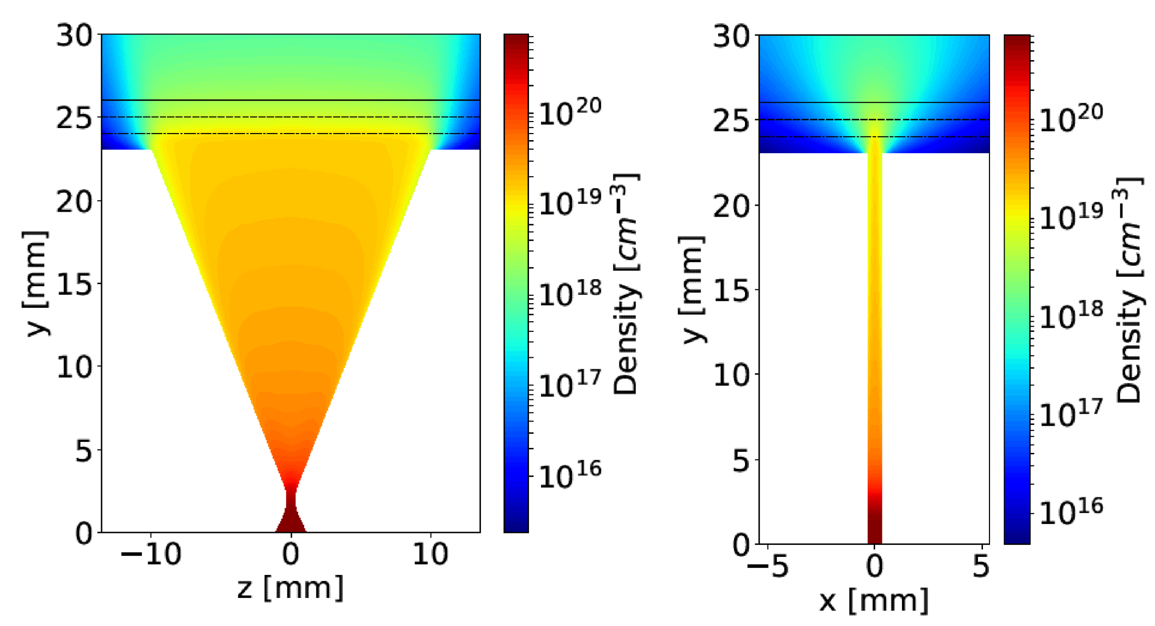
For the creation of matter-antimatter pairs from the quantum vacuum via the Breit-Wheeler mechanism [1], energetic γ-rays and an intense laser need to interact with each other. The Breit-Wheeler experiment in the perturbative regime has been accomplished at the Stanford Linear Accelerator Center in 1997 [2] but was never implemented in the non-perturbative regime, where the laser strength parameter $a_0 \gg 1$ and pair production occurs when an electron from the negative energy Dirac-sea tunnels to positive energy levels. At the moment, this experiment is in preparation in a fully laser-driven set-up using Laser Wakefield Acceleration (LWFA) with the ATLAS3000 laser at the Centre for Advanced Laser Applications [3]. In the experiment an initial high energy electron beam will be sent onto a Bremsstrahlung converter to generate γ-rays that are to interact with the intense laser.

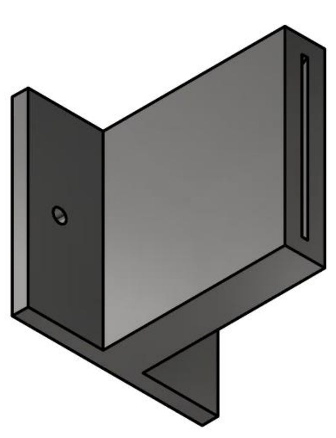
The goal for this experiment is an electron beam of around 2.5 GeV. Since several years LWFA has been improved to reach multi-GeV electron energies [4],[5]. However, building a reliable and stable source with low divergence and low pointing jitter with quasi-monoenergetic bunches over 2 GeV, as is needed for the Breit-Wheeler experiment, still holds challenges.

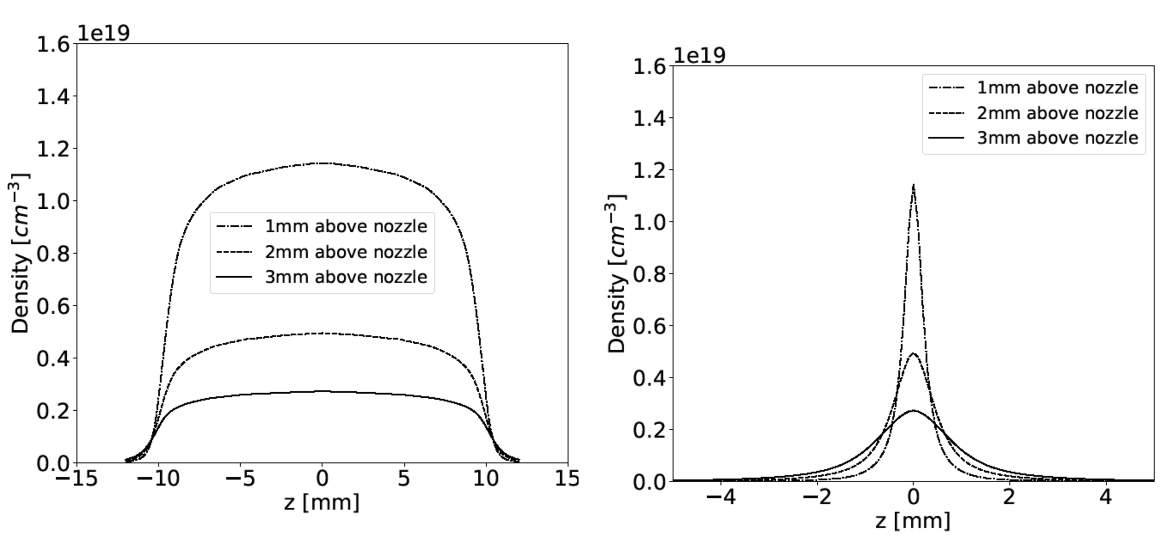
Design of multi-cm long Slit Nozzles

CFD simulations (ANSYS Fluent) to design and build cm-long slit nozzles:

- Long acceleration length (20mm) along longitudinal direction
- Small extend in transverse direction minimizing gas flow
- Convergent-divergent shape in longitudinal direction producing supersonic gas flow for sharp density gradients and enabling obstacle induced shock-front injection [8]



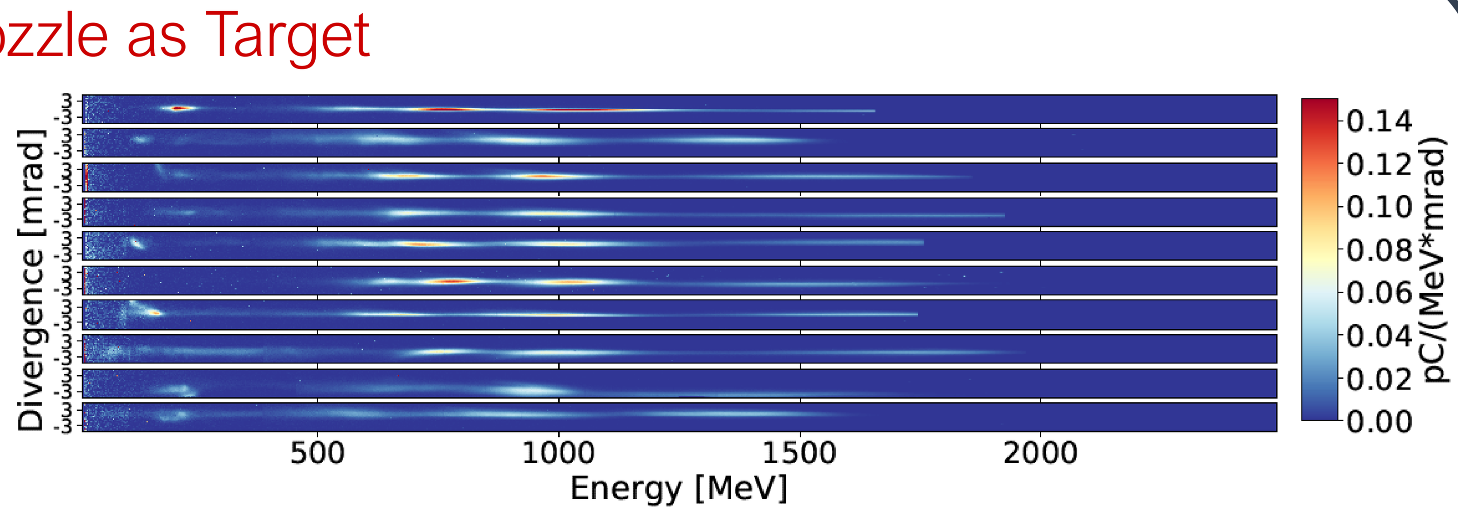




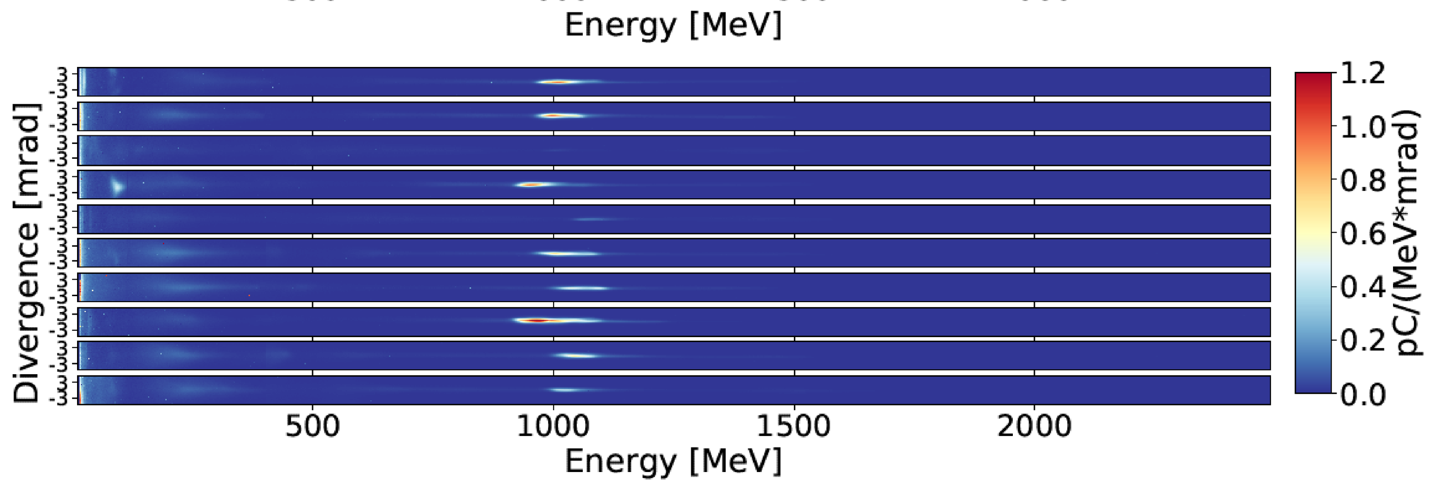
Density profiles along laser propagation direction (left) and in transverse direction (right) in different heights over the nozzle

Slit Nozzle as Target

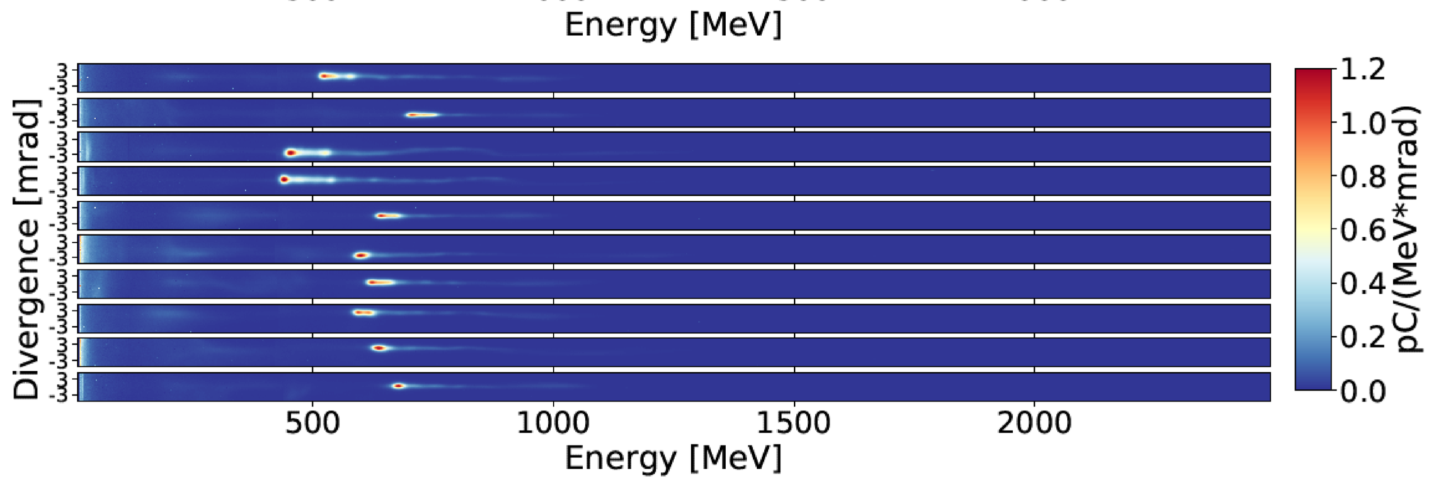
Self injection



shock-front injection

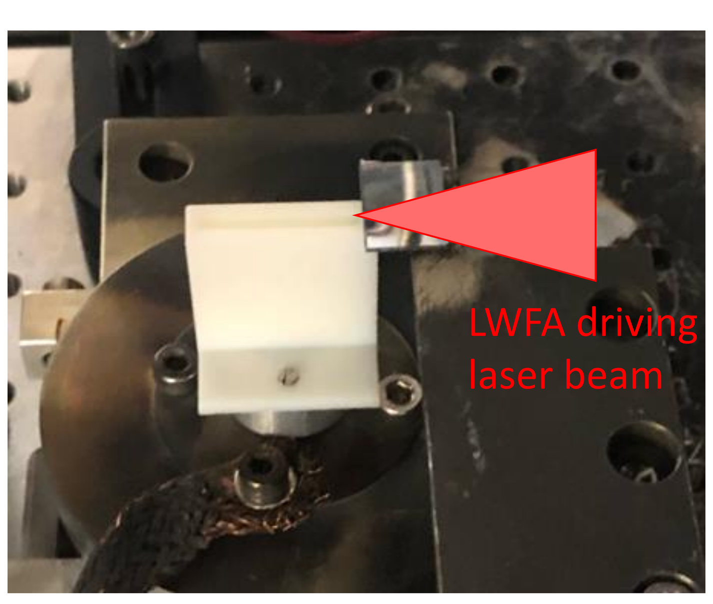


shock-front injection



Results:

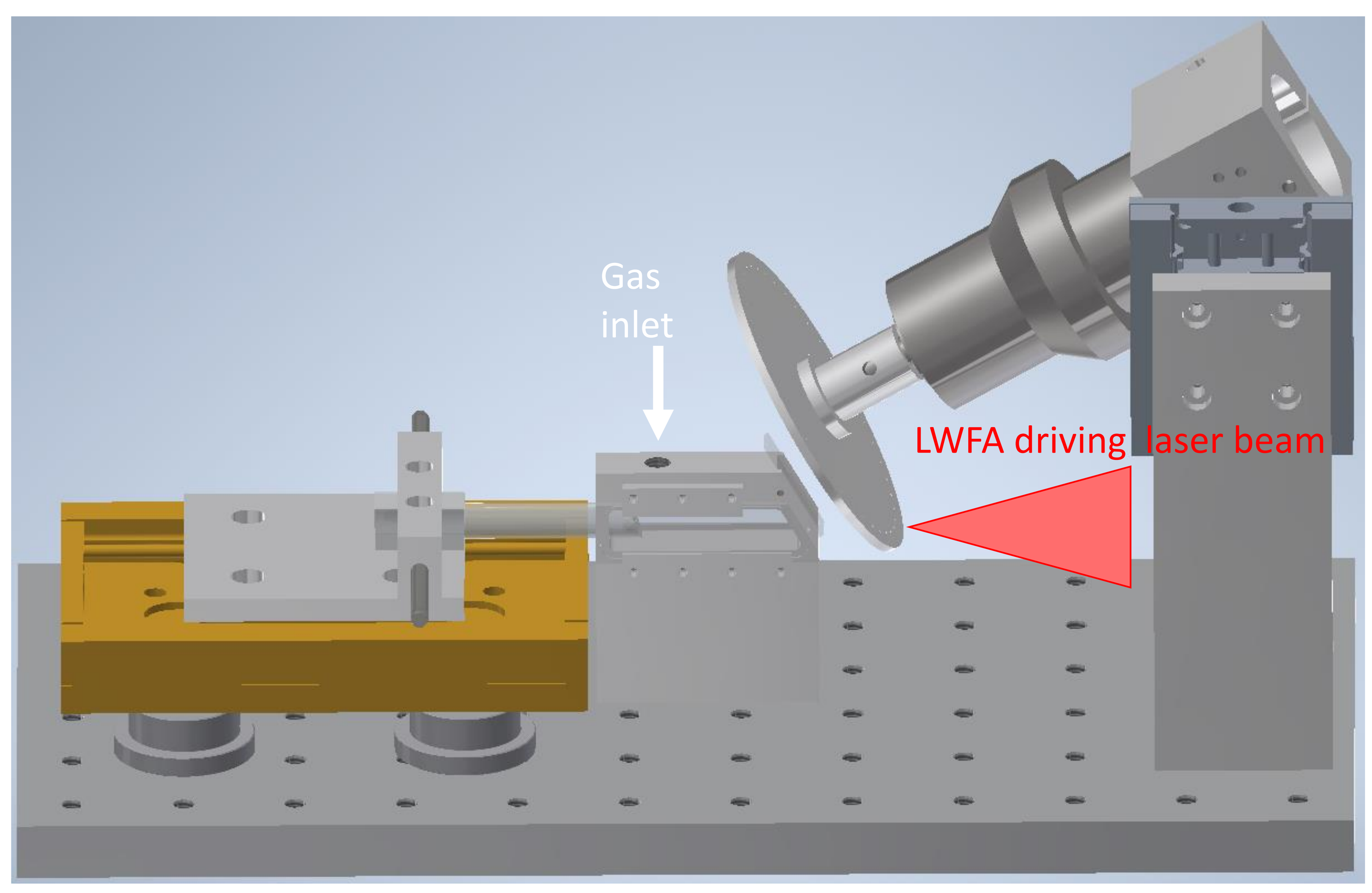
- Self injection: over 1.5 GeV with mean total charge ~ 8 pC (~32 pC over 1 GeV)
- shock-front injection: around 1 GeV with mean charge in peak (within 20% of peak spectral charge density) ~ 100 pC
- shock-front injection: around 600 MeV with mean charge in peak (within 20% of peak spectral charge density) ~ 93 pC

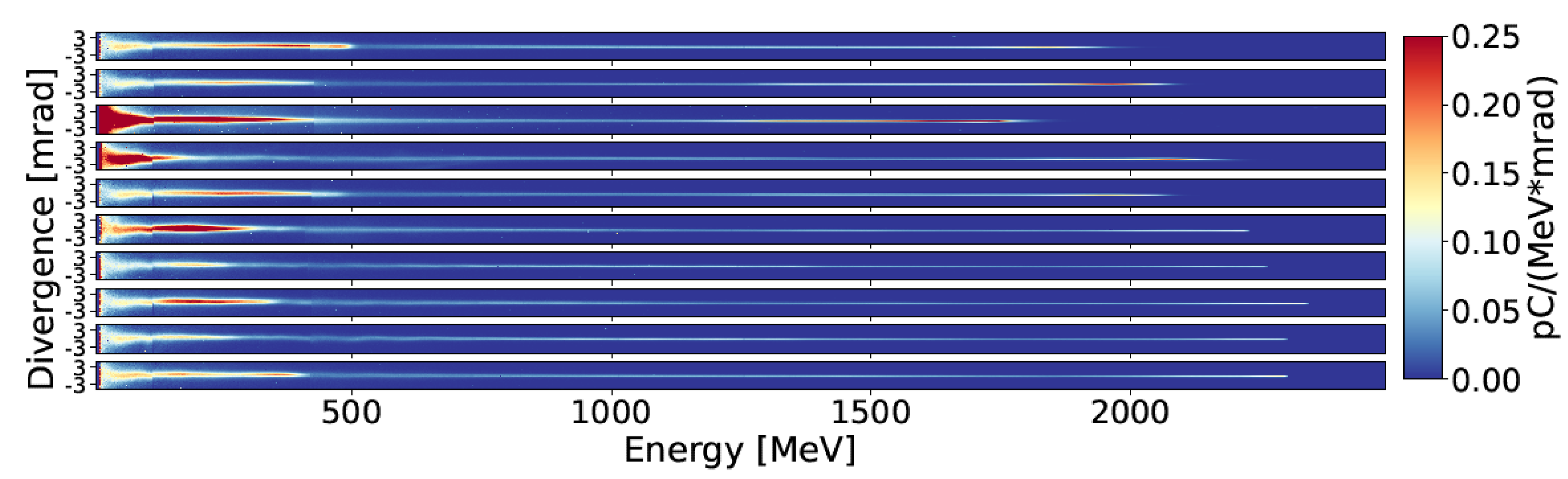


Variable Length Gas Cell as Target

Gas cell design was developed and tested:

- Variable length: 5 – 30 mm
- Glass windows on both sides enable optical probing
- Remotely exchangeable entrance pinhole ensures sharp density gradient [9]
- Transverse hole through gas cell for second laser beam to build density shock via field ionization, enabling shock-front injection

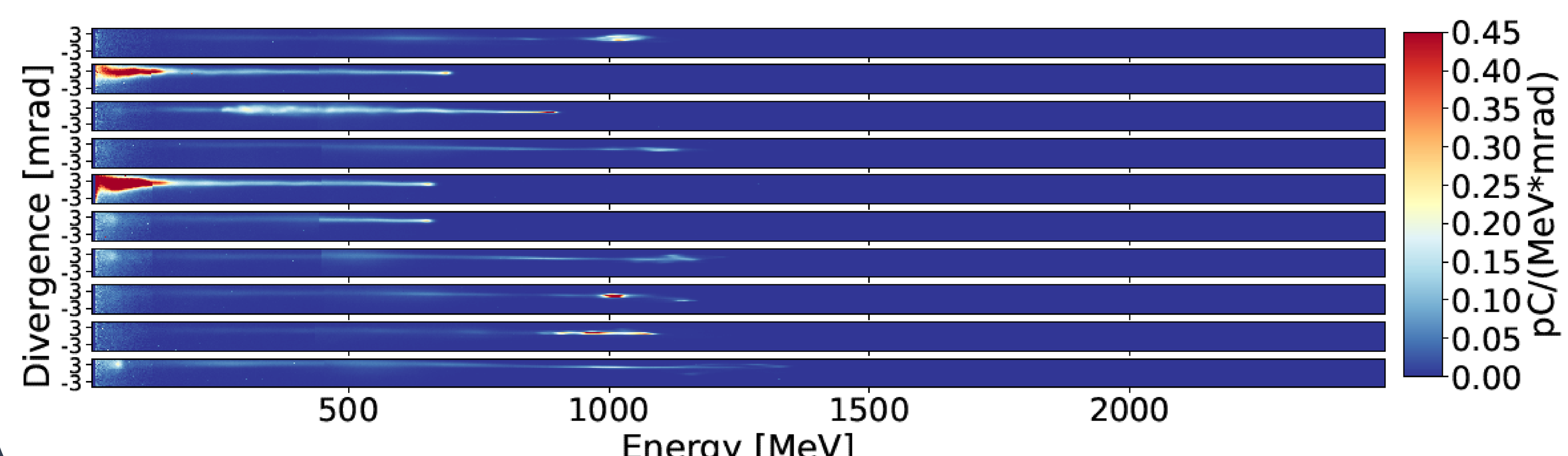




Results:

- Self injection: over 2 GeV with mean total charge ~ 10 pC (~38 pC over 1.5 GeV)

- shock-front injection: around 1 GeV with mean charge in peak (within 20% of peak spectral charge density) ~ 24 pC



References

1. G. Breit and J. A. Wheeler. Phys. Rev. 46 (12. Dec. 1934), pp. 1087-1091
2. C. Bula et al. Phys. Rev. Lett. 76 (17 Apr. 1996), pp. 3116-3119
3. F. C. Salgado et al. 2021 New J. Phys. 23 105002
4. X. Wang et al. Nat Commun. 4:1988 doi: 10.1038/ncomms2988 (2013)
5. A. J. Gonsalves et al. Phys. Rev. Lett. 122.8 (Feb. 2019)
6. S. Schindler et al. Proc. of SPIE 11037N-1 (2019)
7. G Blackburn, M Marklund 2018 Plasma Phys. Control. Fusion **60** 054009
8. K. Schmid et al. Phys. Rev. Special Topics – Accelerators and Beams 13.9 (Sept. 2010)
9. O. Kononenko et al. Nuclear Instruments & Methods in Physics Research A (2016)

EUROPEAN NETWORK FOR NOVEL ACCELERATORS

NPACT supported by EU via I-FAST

ACKNOWLEDGEMENT - This poster presentation has received support from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730.