Gas-dynamic density downramp injection in a beam-driven plasma wakefield accelerator

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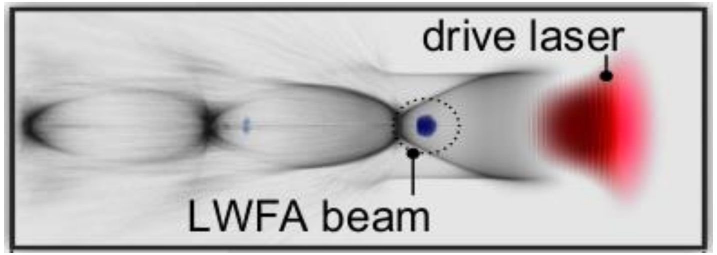
Hybrid Collaboration partners:

Plasma based electron acceleration

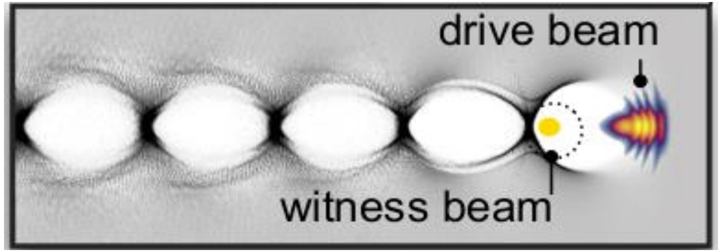
Laser Wakefield Acceleration (LWFA)



T. Kurz - Realization of a compact plasma accelerator for high quality electron beams – Phd Thesis

- Laser lab size
- **Lower phase velocity** due to the refractive index of the plasma
  - **Lower** trapping **threshold**
  - **Dephasing**
- Higher field strengths + **oscillating** field
  - **Hot** background **plasma**
  - → **No cold injection schemes**
- intrinsically short bunches (few fs)
  → **high (>10kA) peak current**

Plasma Wakefield Acceleration (PWFA)



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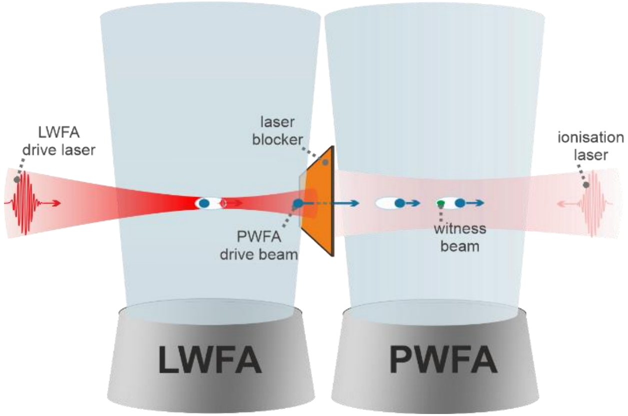
- Requires relativistic electron driver (e.g. LINAC)
- Electron driver propagate with approx. the **speed of light**
  - **Higher** trapping **threshold**
  - **No-dephasing**
- Lower field strength + **constant** field
  - **Cold** background **plasma**
  - → **Cold injection schemes** e.g. via ionization with an additional laser possible
  - → **Acceleration of high brightness witness beams**

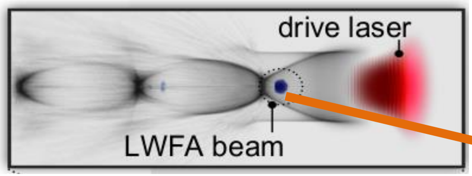
Hybrid LWFA-PWFA staging

Complementary features of LWFA and PWFA: Combination of both schemes by **driving PWFA** with **LWFA beam** with the **potential** to reach**:**

- **Higher brightness**
- **Enhanced stability**
- **Higher energy**



Laser Wakefield Acceleration (LWFA)



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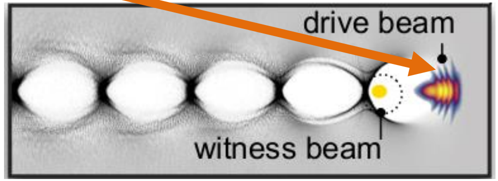
Plasma Wakefield Acceleration (PWFA)



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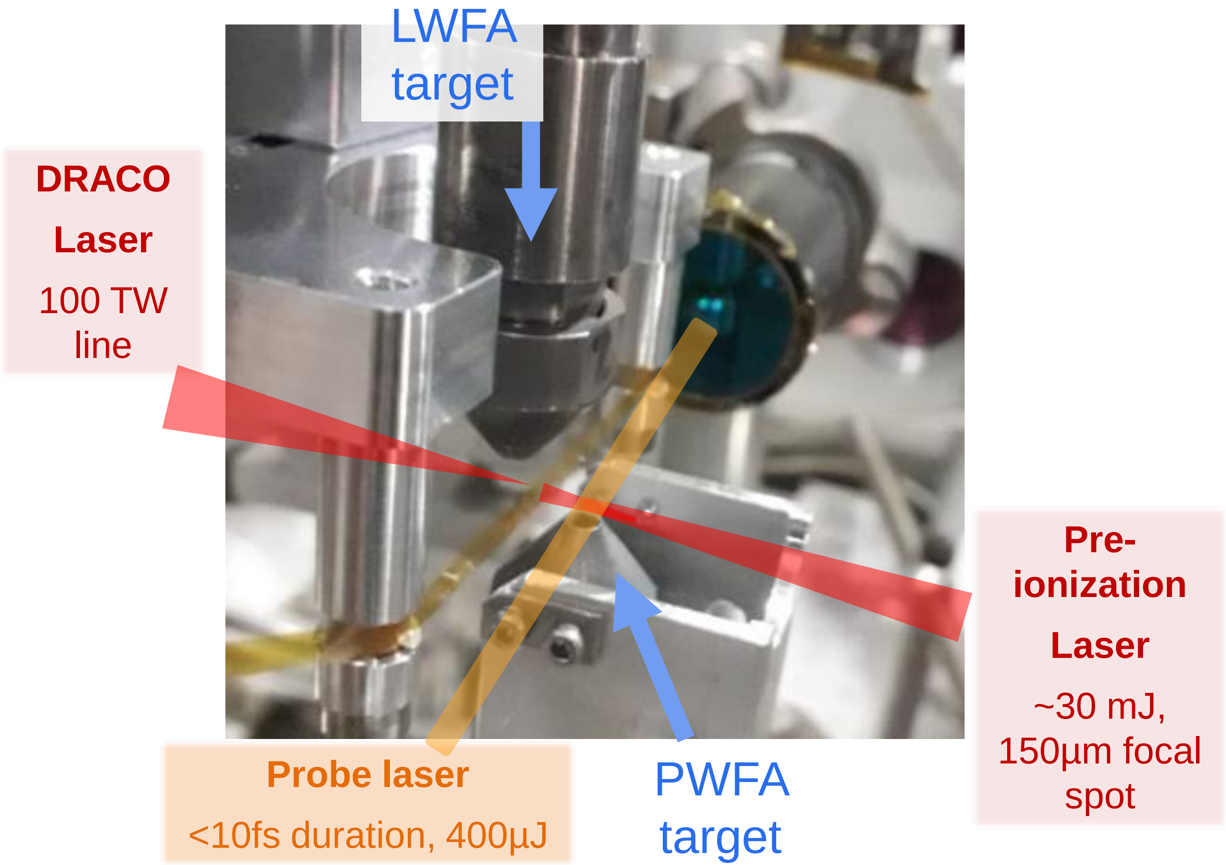
Foerster, M. et al. PRX 12, 041016 (2022)

Schöbel, S. et al. New J. Phys. 24 083034 (2022)

LPWFA general setup

- two similiar nozzles (3mm diameter, Mach10) used as LWFA and PWFA stage
- 1mm vacuum gap with the blocking foil in between
- **LWFA** generates PWFA driver via **STII**
- **Few-cycle optical probing** (shadowgraphy) in the PWFA stage



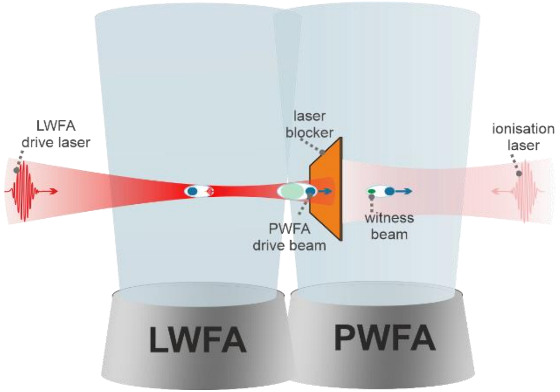
Influence of the blocking foil:
Raj, G. et al. Physical Review Research **2**, 023123 (2020)

Few-cycle probing results:
Schöbel, S. et al. New J. Phys. 24 083034 (2022)

First results of Hybrid LWFA-PWFA staging

First steps @ HZDR and LMU:

- **Observation** of **beam driven plasma waves**: LWFA beam is capable to drive a wake in a subsequent stage
- **Acceleration** of **witness beams** via recapturing downramp (HZDR) or second bucket injection (LMU) from LWFA
- **Different acceleration gradients** in **pre- vs. self-ionized** regime



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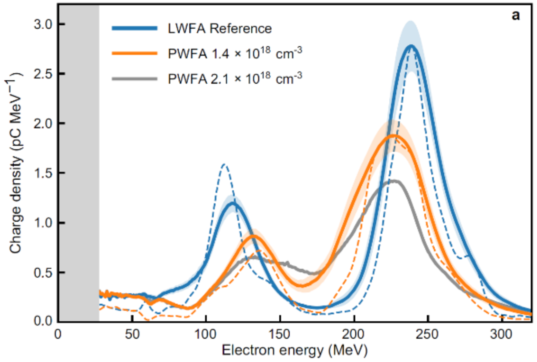

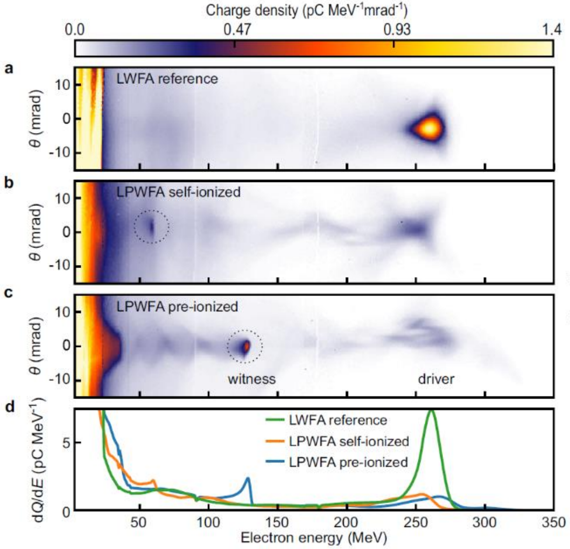

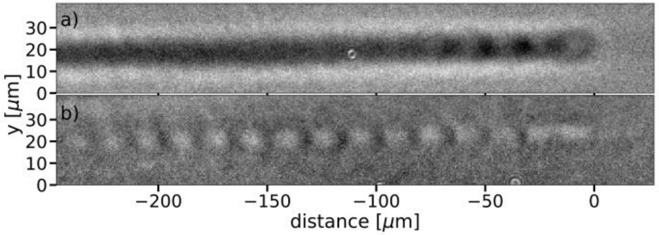

LPWFA Setup for density downramp injection

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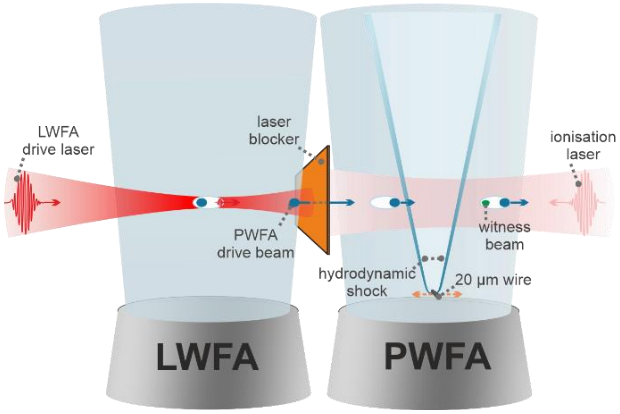
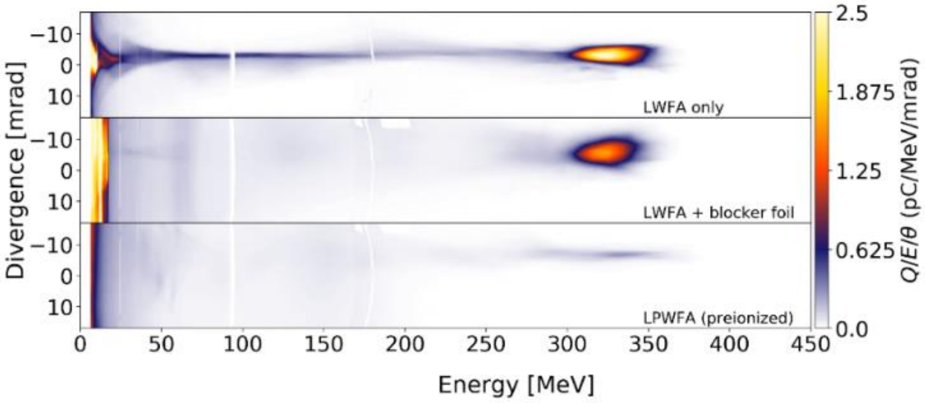


- **Hydrodynamic shock** created by a **wire** of **20µm** diameter acting as an obstacle in the PWFA stage
- GOAL: **controlled witness beam injection at** the density **downramp** behind the shock

Influence of the blocking foil:
Raj, G. et al. Physical Review Research **2**, 023123 (2020)



LWFA Electron beam parameters	
Peak energy:	328 ± 29 MeV
Energy spread:	44 ± 18 MeV
FWHM bunch charge:	318 ± 71 pC
Divergence (rms):	1.81 ± 0.17 mrad
FWHM duration:	14.8 ± 1.6 fs

Downramp injection at a Hydrodynamic Shock

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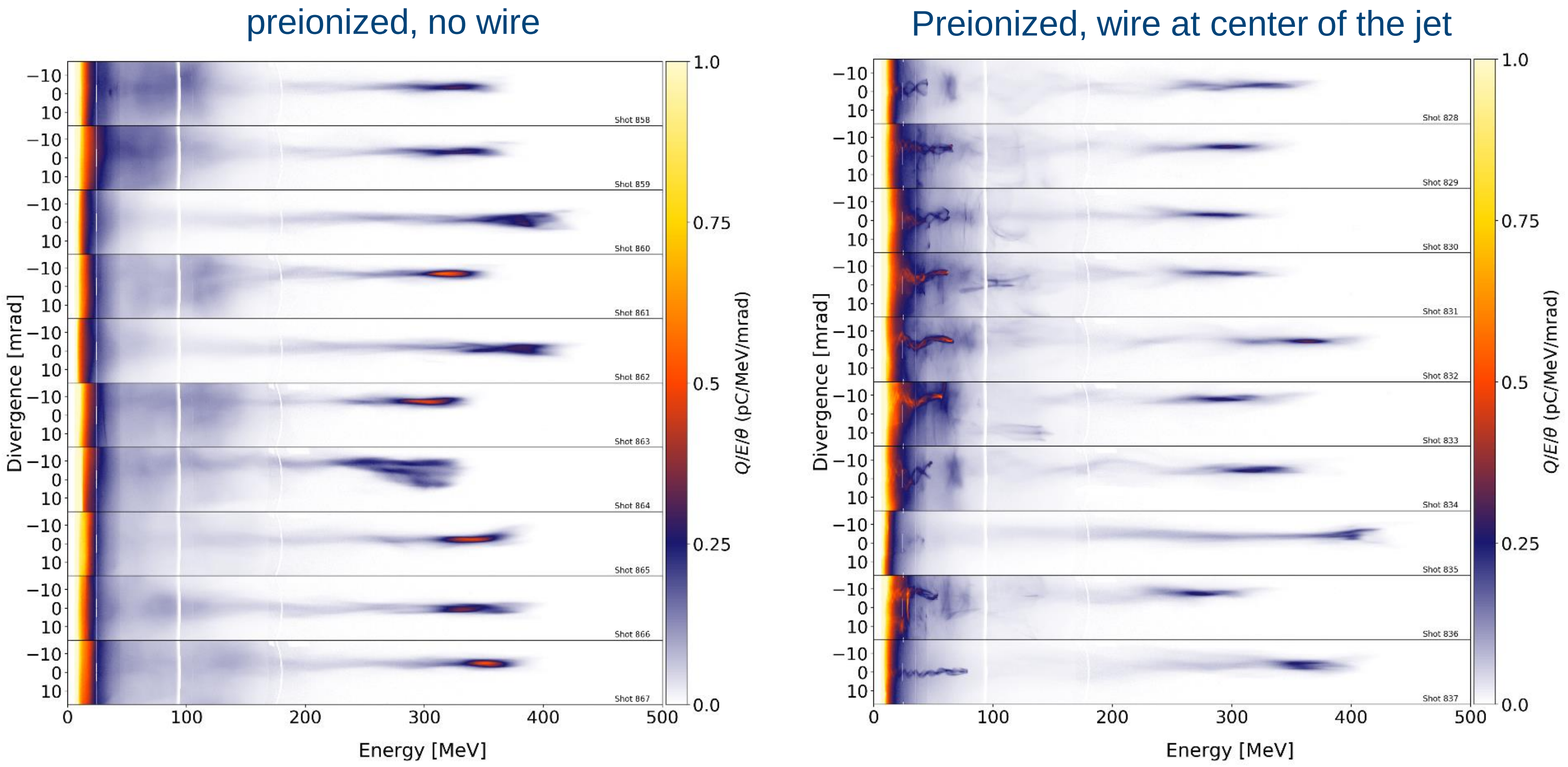

→ First **demonstration** of **internal injection** in a LWFA driven PWFA

Downramp injection at a Hydrodynamic Shock - Setup

- **Few-cycle optical probing** to determine the **shock conditions**

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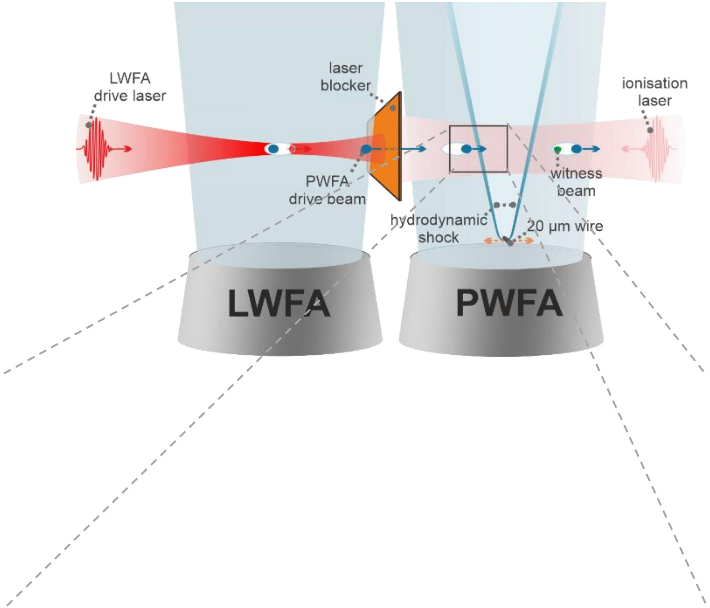

- Shock region around **20-40µm** FWHM, position jitter: **< +/- 10µm**
- rough estimation of **shock height: ~ 3-4 times plateau density**
- rough reconstruction of density profile using laser driven plasma waves

Downramp injection at a Hydrodynamic Shock - Setup

- Simulation with PIConGPU
- **Confirmes acceleration** of a **witness bunch** possible
- Only **electrons injected** at the **second shock** will be accelerated until the end of the PWFA stage

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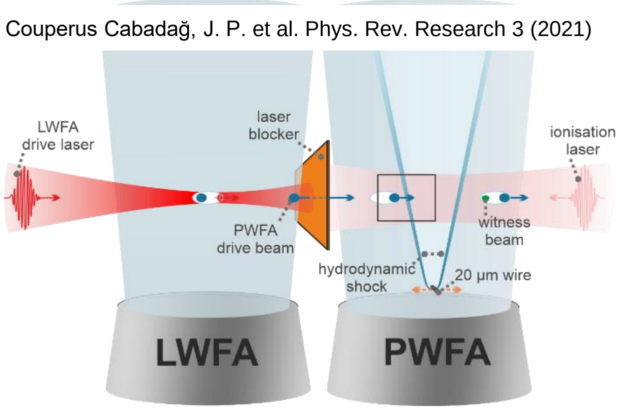

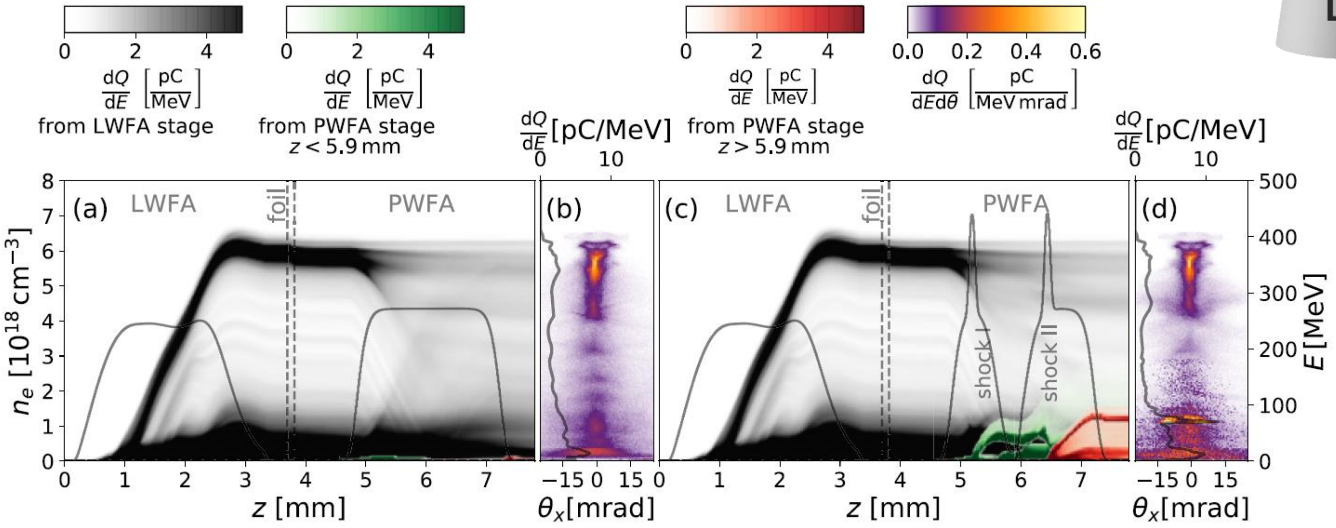

Downramp injection at a Hydrodynamic Shock – tunability

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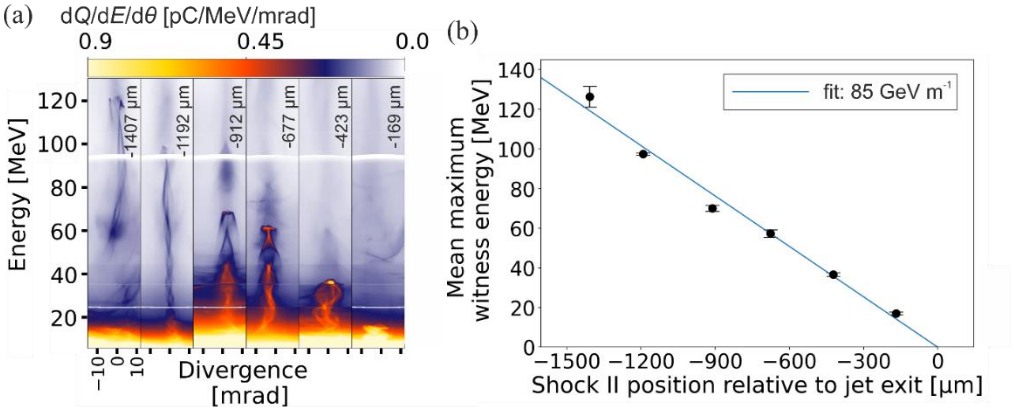
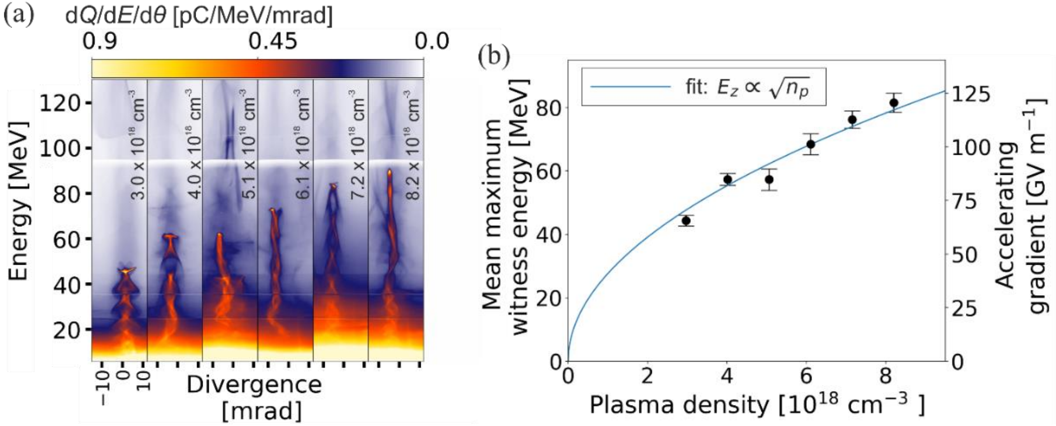
- Wire position = shock position scan
    - **Linear scaling** of the witness **bunch energy**
    - Estimation of the accelerating gradient: **85 GeV/m**
- density scan:
    - witness bunch **energy follows** the expected **scaling**
    - mechanism works for a **broad density range**

→ Witness energy **controllable** via shock position and density

→ Still **large energy bandwidth**

→ **Optically** generated **hydro-dynamic shock** for more control and stability

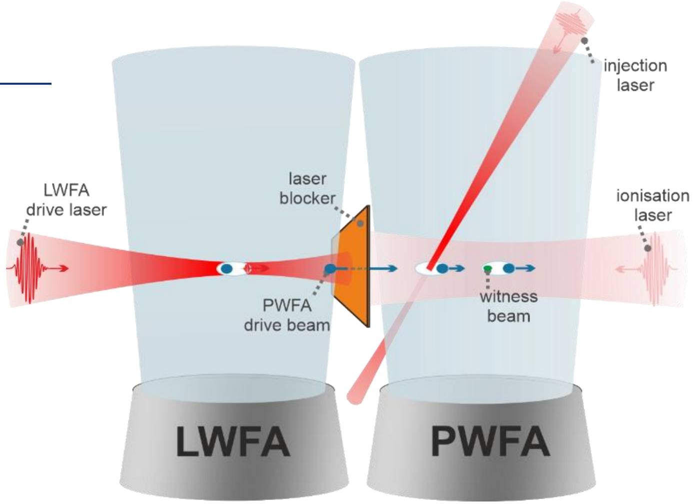




Foerster, M. et al. PRX 12, 041016 (2022)

Outlook: Trojan Horse injection

- Recent experiments: demonstration of Trojan Horse injection
- Additional, **inherently synchronized laser beam** ionizes additional species which is not ionized by electron beam or preionizer before
- **Tunable, controllable injection** regime with promissing beam parameters



mean energy:
142 MeV

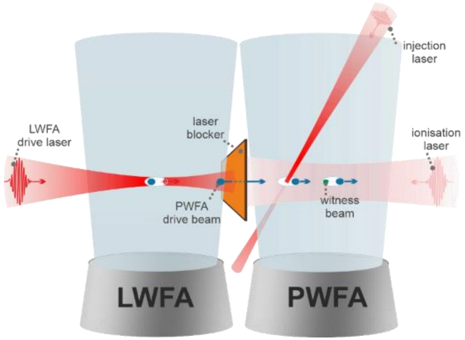
energy spread:
2 MeV

charge (FWHM):
7.8 pC

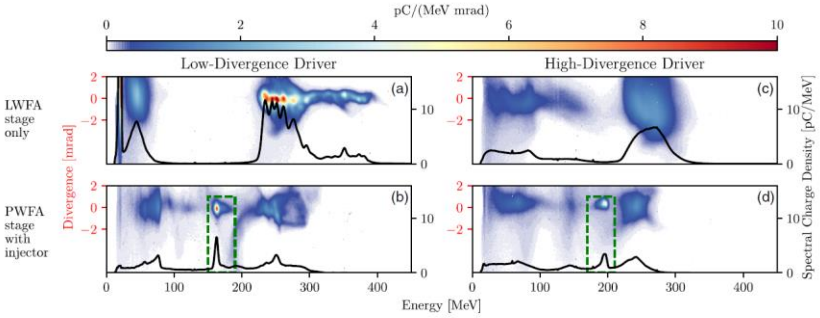
divergence (rms):
0.41 mrad

Summary and Outlook

- demonstration of **denstiy downramp injection** in a **PWFA** stage
- **energy** of witness beams **tunable** via **shock position** and **plasma density**
- measurement of shock properties via few-cycle shadowgraphy



- **Optical density downramp**: successful demonstration, more control and tunability → see Foerster, M. et al. PRX 12, 041016 (2022)
- Promising beam parameters from first results of **Trojan Horse injection**



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Thank you for your attention!