



### Increasing the energy of high-quality electron bunches from a hybrid L-PWFA

# Moritz Foerster (LMU Munich, Karsch group)

on behalf of the Hybrid Collaboration:







[4] Couperus, Phys.Rev.Res. 2021 [5] Foerster, Phys.Rev.X, 2022 LPAW 2025

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[1] Götzfried, Phys.Rev.X, 2020

[2] Gilljohann, Phys.Rev.X, 2019

[3] Kurz, Nat.Comm. 2021

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[3] Kurz, Nat.Comm. 2021[4] Couperus, Phys.Rev.Res. 2021[5] Foerster, Phys.Rev.X, 2022

[1] Götzfried, Phys.Rev.X, 2020

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[1]

**LWFA** 

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[1] Götzfried, Phys.Rev.X, 2020
[2] Gilljohann, Phys.Rev.X, 2019
[3] Kurz, Nat.Comm. 2021
[4] Couperus, Phys.Rev.Res. 2021
[5] Foerster, Phys.Rev.X, 2022



**PWFA** 







**PWFA** [4,5] Energy [2,3]

CALA

Götzfried, Phys.Rev.X, 2020
Gilljohann, Phys.Rev.X, 2019
Kurz, Nat.Comm. 2021
Couperus, Phys.Rev.Res. 2021
Foerster, Phys.Rev.X, 2022

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# Hybrid L-PWFA



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	Be	eam quality	0.0	о  pC/(М	1. O IeV mra	- 1.5 d)	2.0		
[mrad]	3 -(a) 0 - –3 - LWFA alone								
ergence	3 - (b) Witness 0 - 0 - Q <sub>witness</sub> ~ 35pC no preionization of PWFA								
Div									
	г 0	) 100 20	0	300		400			

100 200 300 400 Energy [MeV]



	Beam quality	0.0 0.5 pC/(	н н о 5 MeV mrad)	2.0	
mrad]	3 -(a) 0 - 3 -	LWFA alc	one		
rgence [	3 -(b) Witness 0 - —3 - <i>Q<sub>witness</sub> ~</i> 35 <i>pC</i> r	o preionization of	PWFA		
Dive	3 -(c) 0 - _3 - <i>Q<sub>witness</sub> ~</i> 87 <i>pC</i> /b	ad' preionization c	of PWFA		





	Beam	quality	0.0	o ப ப pC/(MeV mrad		
mrad] I	3 -(a) 0 - 3 -		LW	FA alone		
rgence [ I	3 -(b) 0 - 3 -	Witnes Q <sub>witness</sub> ~ 35pC	s no preionizati	on of PWFA		
Dive	3 -(c) 0 - 3 -	Q <sub>witness</sub> ~ 87pC	bad' preioniza	ation of PWFA		
_	3 -(d) 0 - 3 -	Q <sub>witness</sub> ~ 144pC	homogeneou	s preionization	of PWFA	
	0	100 20 En	)0	800	400	



### 

# Beam quality

- Net gain in angular-spectral charge density<sup>[1]</sup>
  - Useful for applications





- Avoid mistakes
  - Here: non-ideal plasma density profile





- Avoid mistakes
  - Here: too long PWFA target
    - Depletion



Probing data: F. Haberstroh et al., to be submitted

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- Avoid mistakes
  - Here: too long PWFA target
    - Depletion





Plasma wave at the end of the PWFA target

Probing data: F. Haberstroh et al., to be submitted

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- Avoid mistakes
  - Here: too long PWFA target
    - Depletion





Plasma wave at the end of the PWFA target

### Driver depleted First bubble shrinks

Probing data: F. Haberstroh et al., to be submitted

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• Driver depletion also visible in PIC simulations





Witness still gains energy



• Driver depletion also visible in PIC simulations



Simulations provided by J. Zirkelbach

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# Increasing witness energy

Driver depletion also visible in PIC simulations



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Driver-generation:

- LWFA using ~10J, 30 fs laser
- Self-truncated ionization injection (STII) in a 15mm slit nozzle (H2 + 2% N2)







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- LWFA using ~10J, 30 fs laser
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PWFA target: 10mm slit nozzle (H2) wire-generated shock for injection

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From LWFA

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Ischia Island, Italy

















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· 3.0

- 2.5

- 2.0

Latest experiments



350 ·

300

250

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# Remaining limitations

- Drive beam determines wakefield
- Flatter field for longer drive beam
- Sets depletion length



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# Future plans

• Drive beam shaping



## Future plans

• Drive beam shaping



Typical LWFA beams are short <sup>[1,2]</sup>: ~5-15 fs/~2-5µm

Not ideal for our densities of  $\sim 2x10^{18}$  1/cm<sup>3</sup>

Experiments at higher density unsuccessful

-> Generate longer drive beams

[1] Heigoldt, Phys.Rev.A.B., 2014[2] LaBerge, Nat.Phot., 2024

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### Questions?

### High-quality beams,



accelerated to high energies,

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and still ideas to improve!