LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

CENTRE FOR ADVANCED LASER APPLICATIONS

CALA

Advancing Hybrid Laser- and Beam-Driven Plasma Accelerators: High-Energy and High-Quality Witness Beams

Moritz Foerster (LMU Munich)

on behalf of the
Hybrid Collaboration:

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

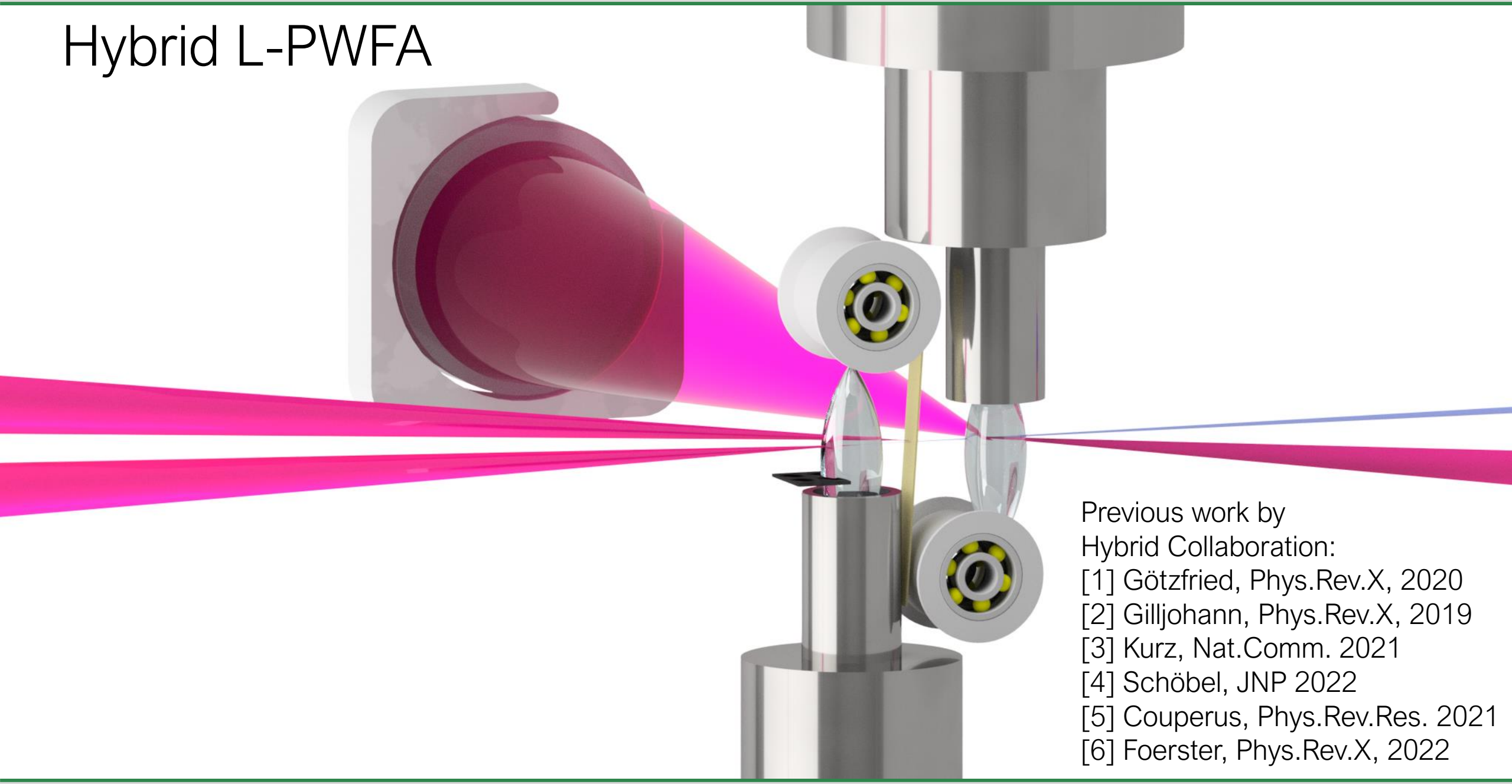
loa

DESY.

hhu

EAAC2025 7th European Advanced Accelerator Conference

Hybrid L-PWFA



Previous work by
Hybrid Collaboration:

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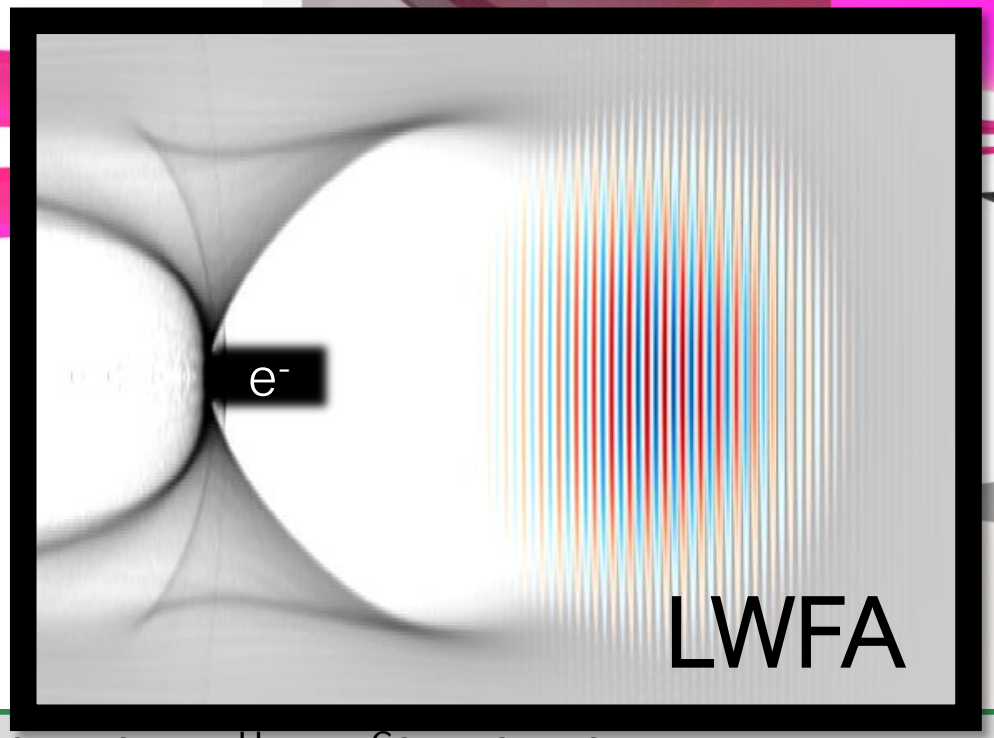

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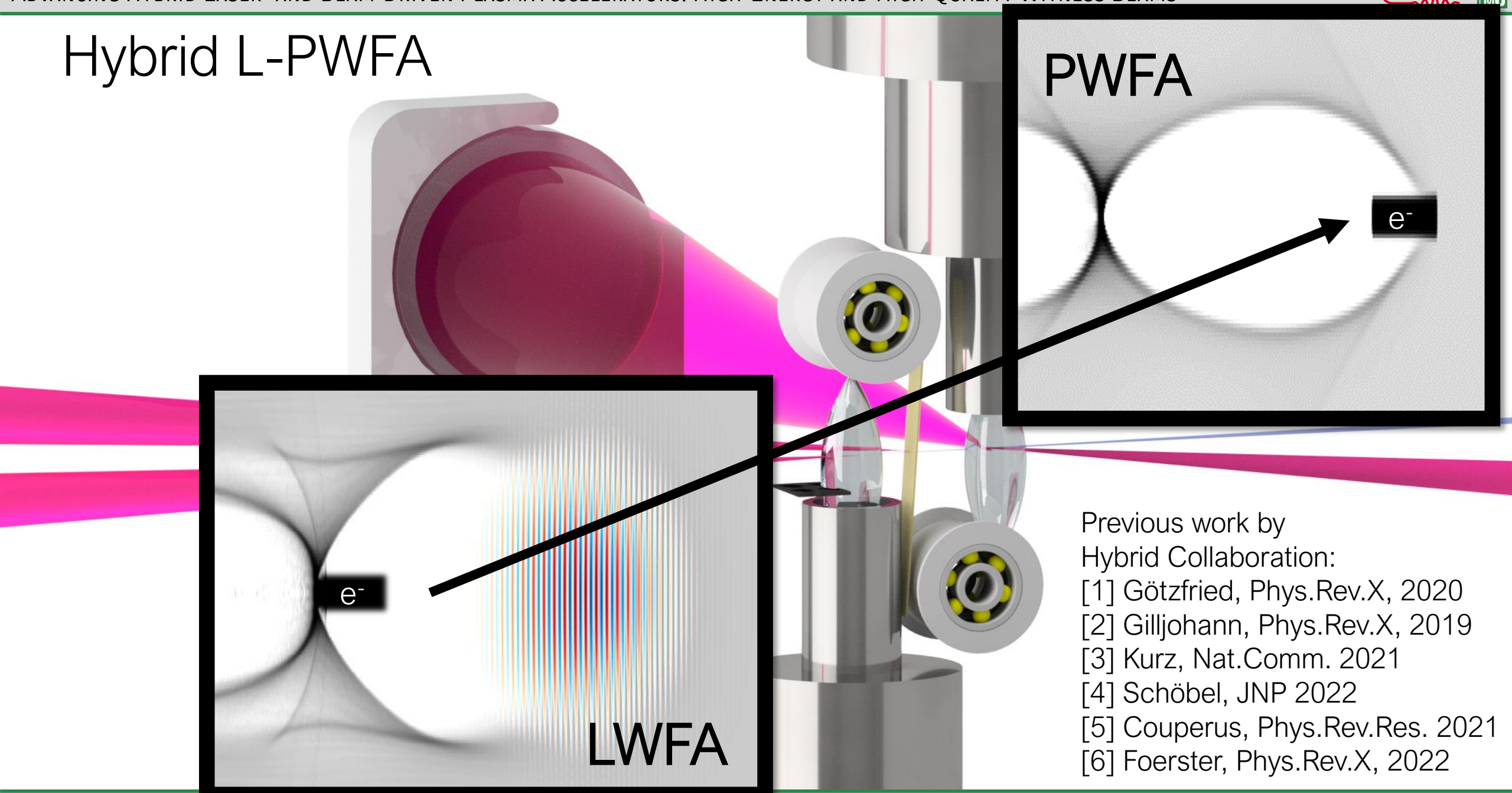

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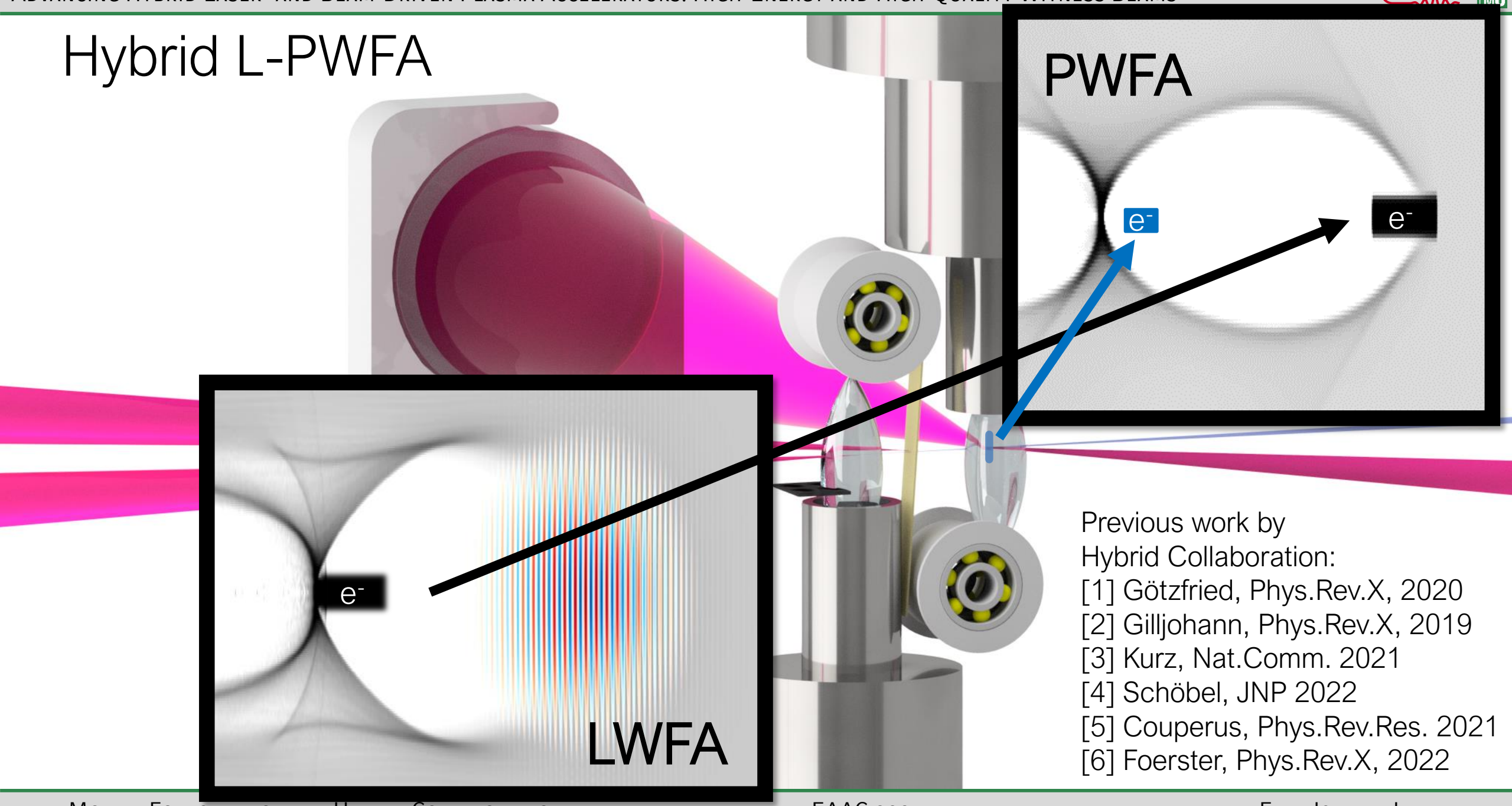

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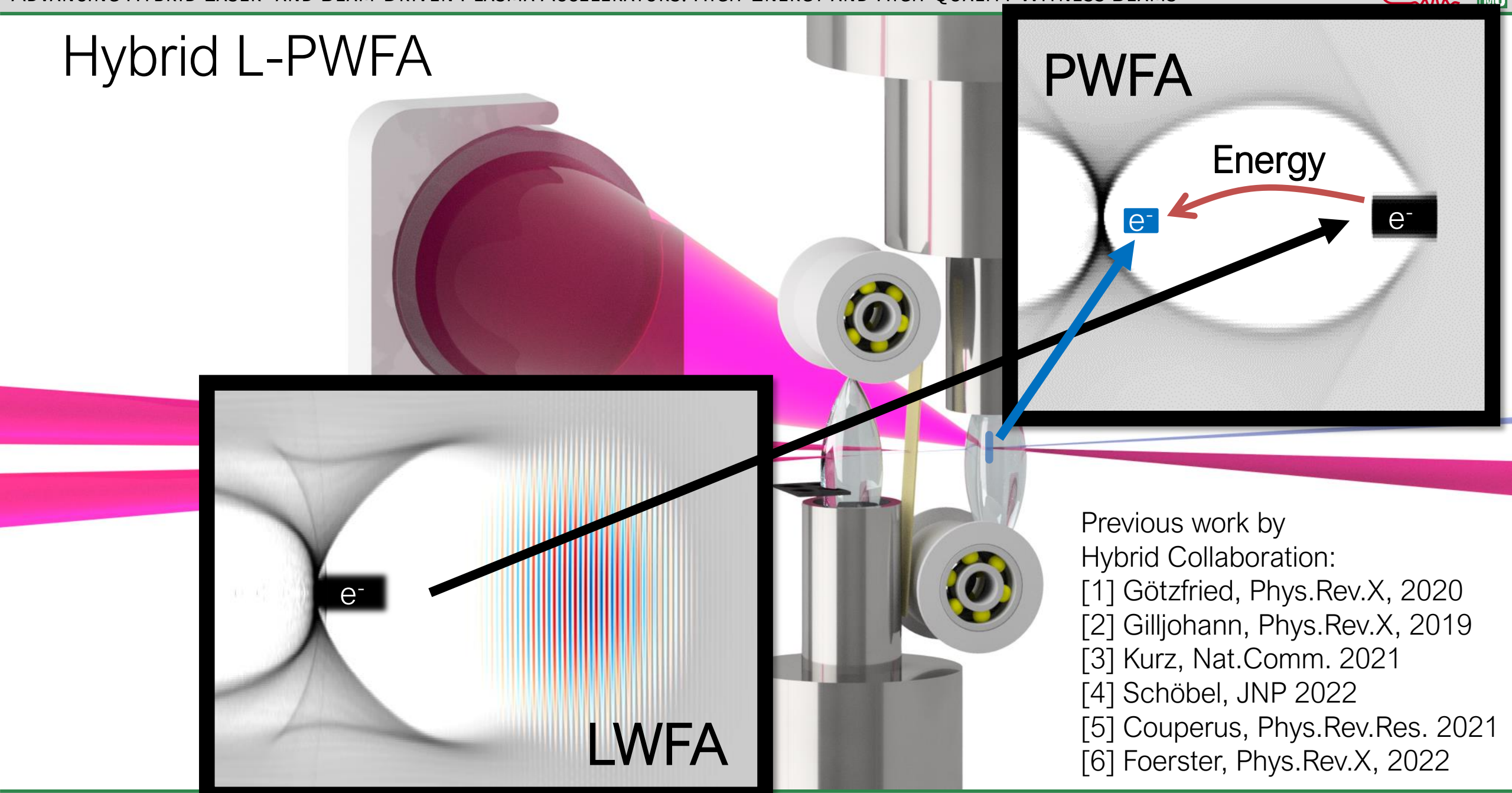

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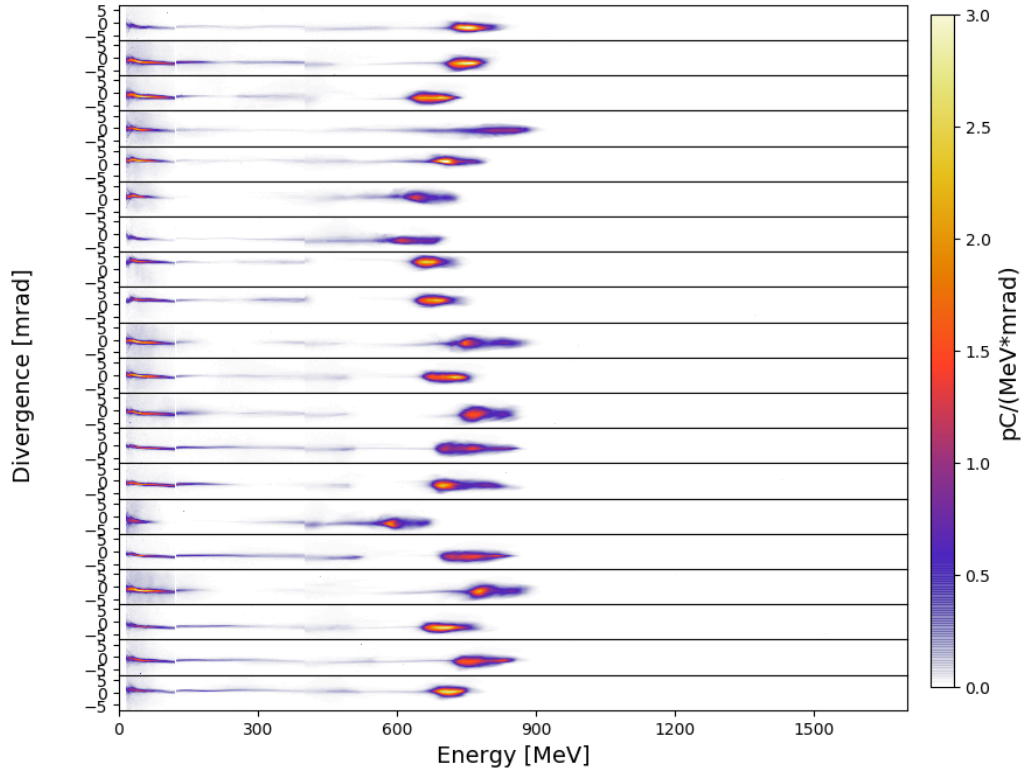
Latest experiments

LWFA-generated Driver:
via self-truncated ionization injection (STII)
in a 15mm slit nozzle (H2 + 2% N2)
- 750 MeV, 350 pC



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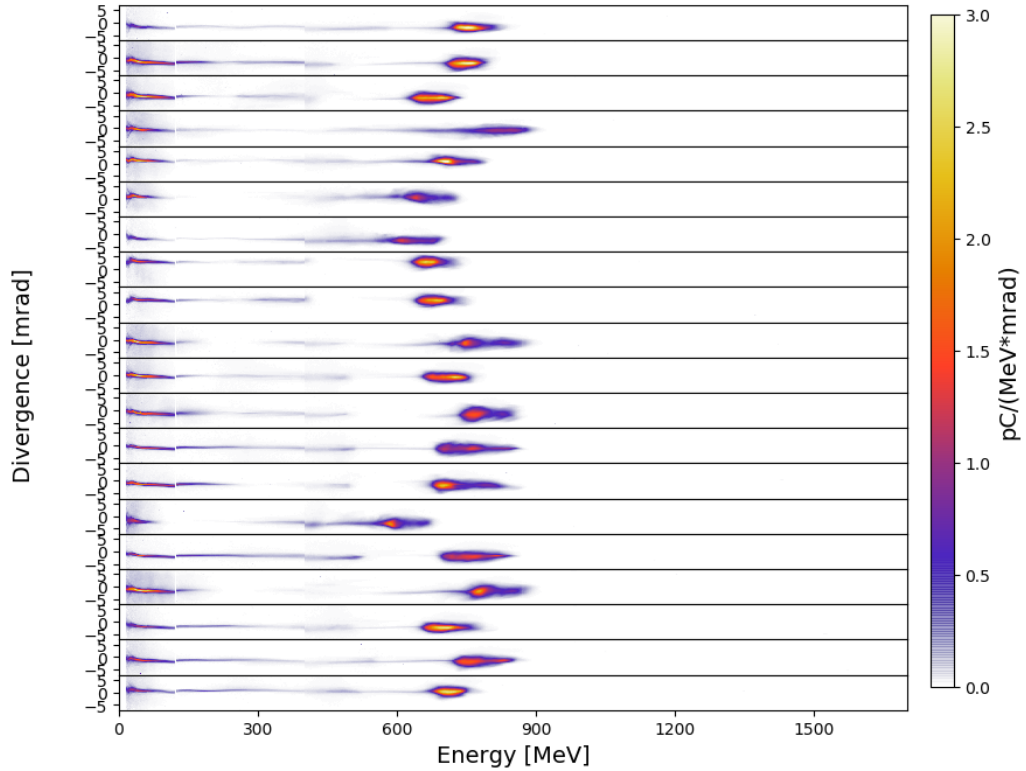
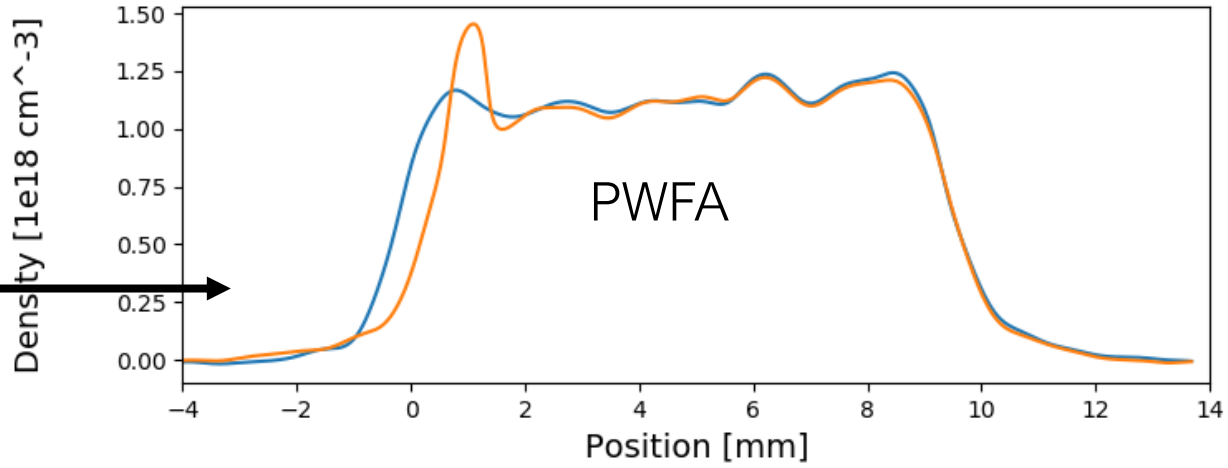


PWFA target:
10mm slit nozzle (H2)
wire-generated shock for injection

From LWFA



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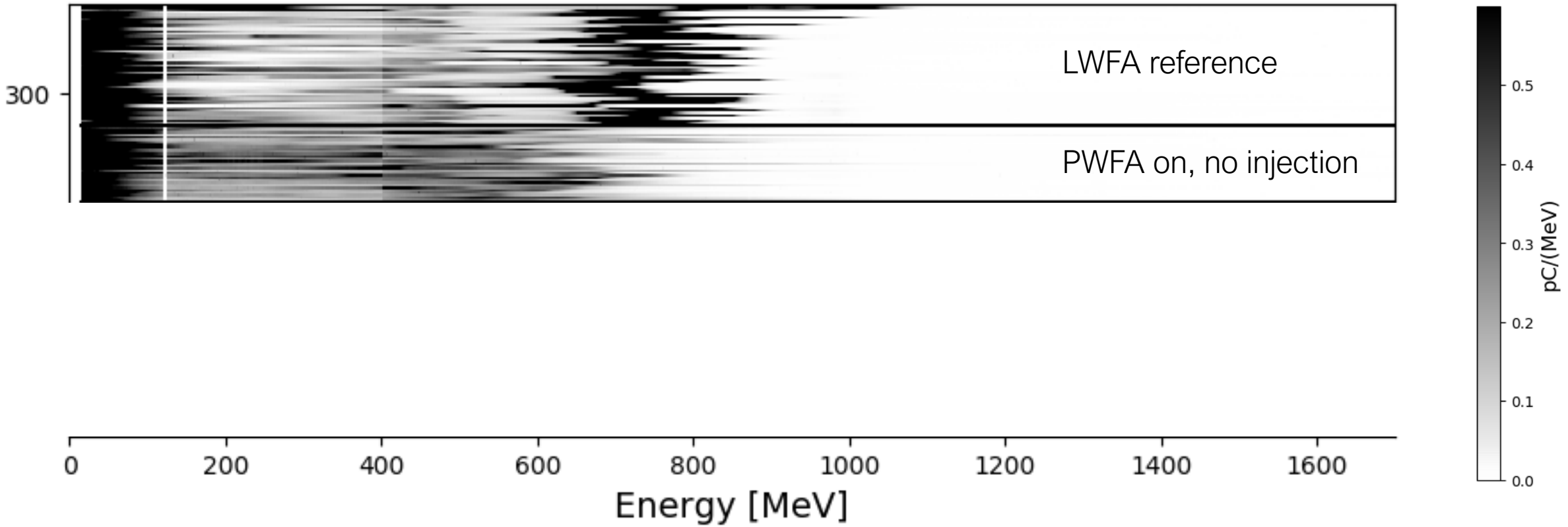

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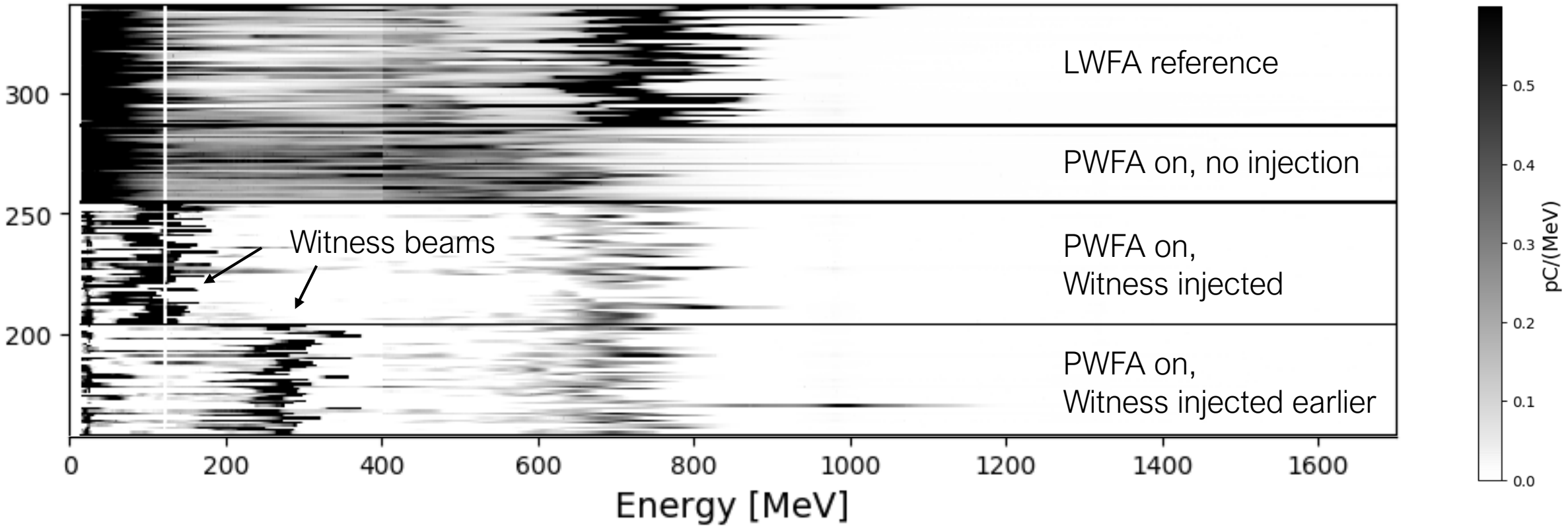

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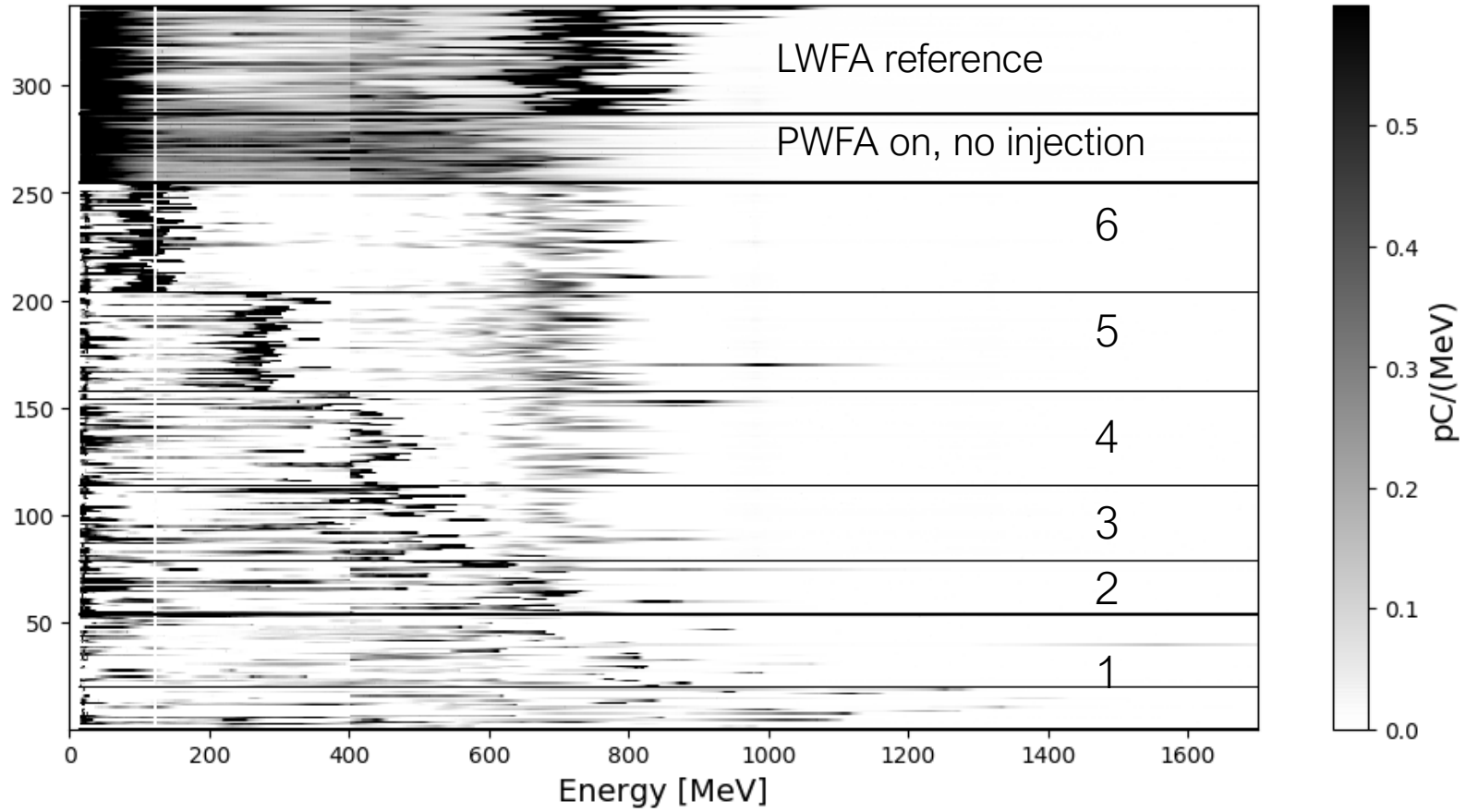

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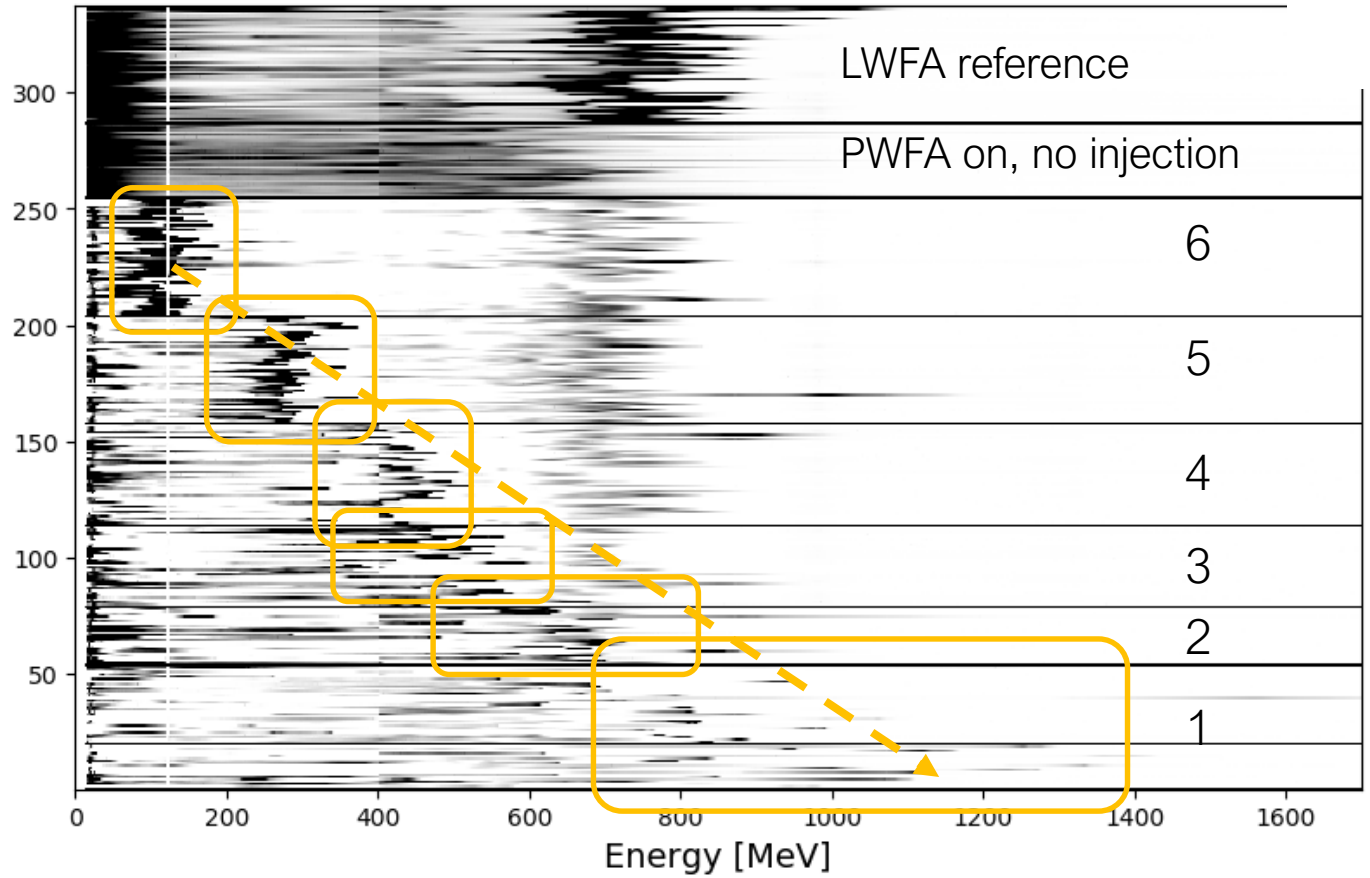

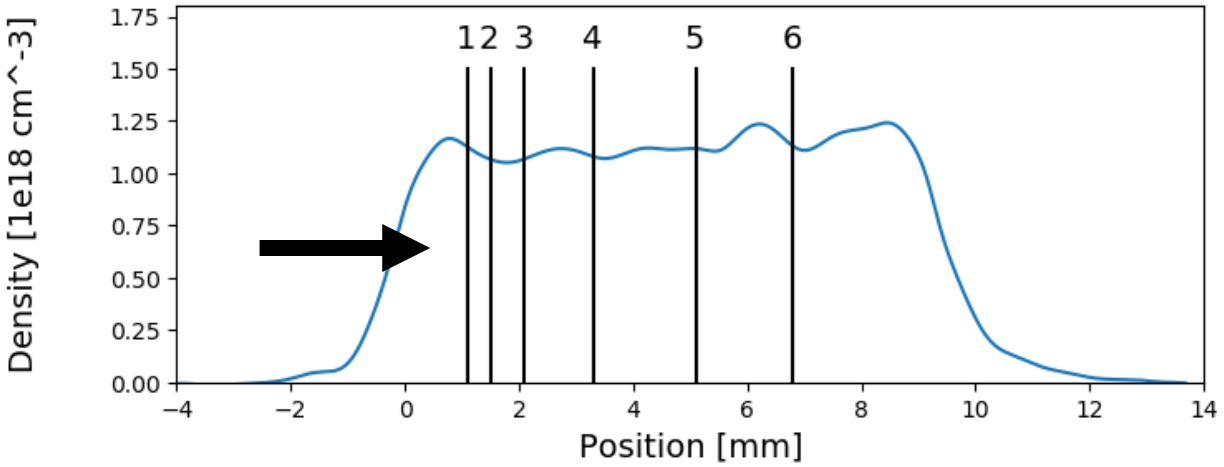

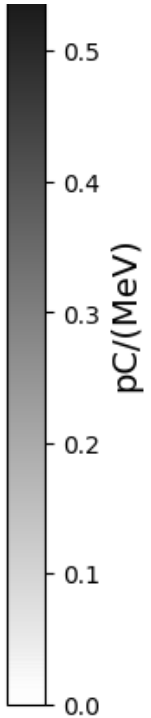

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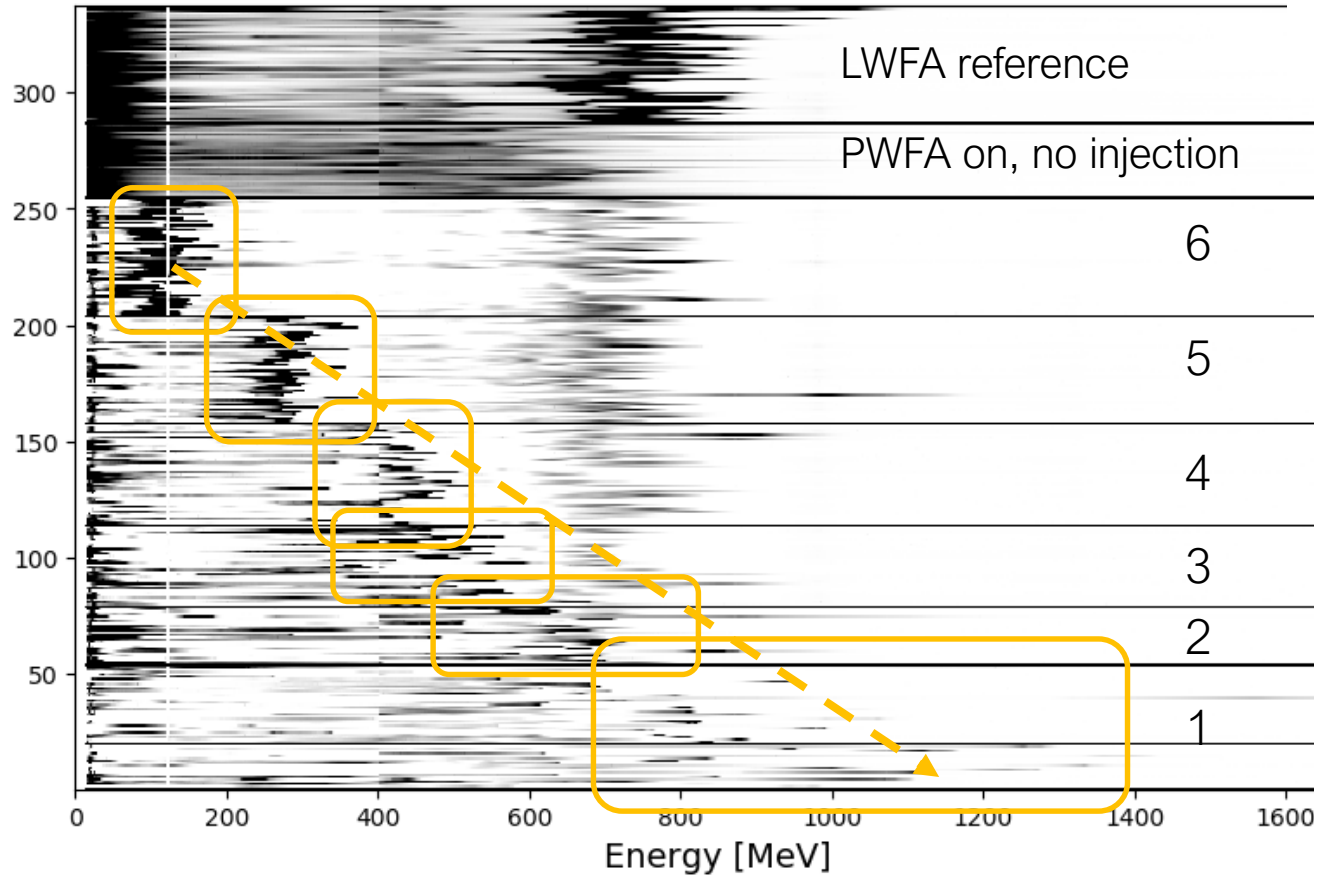

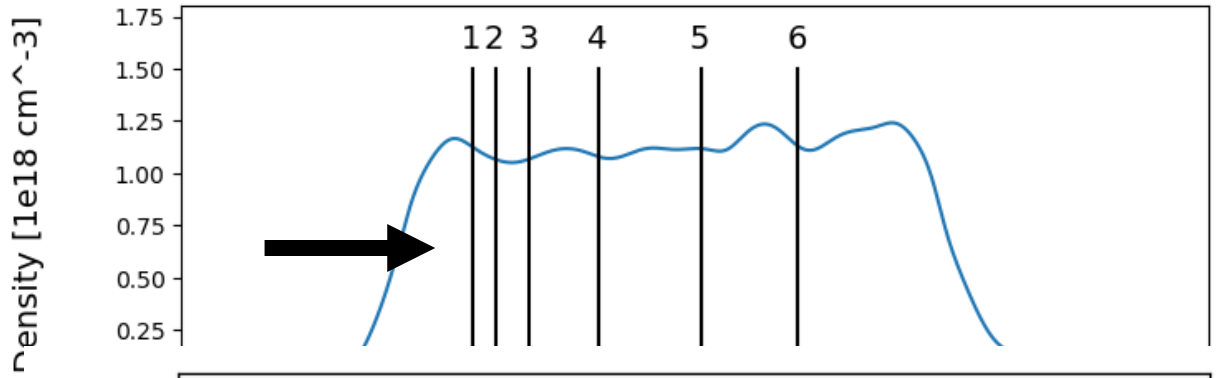

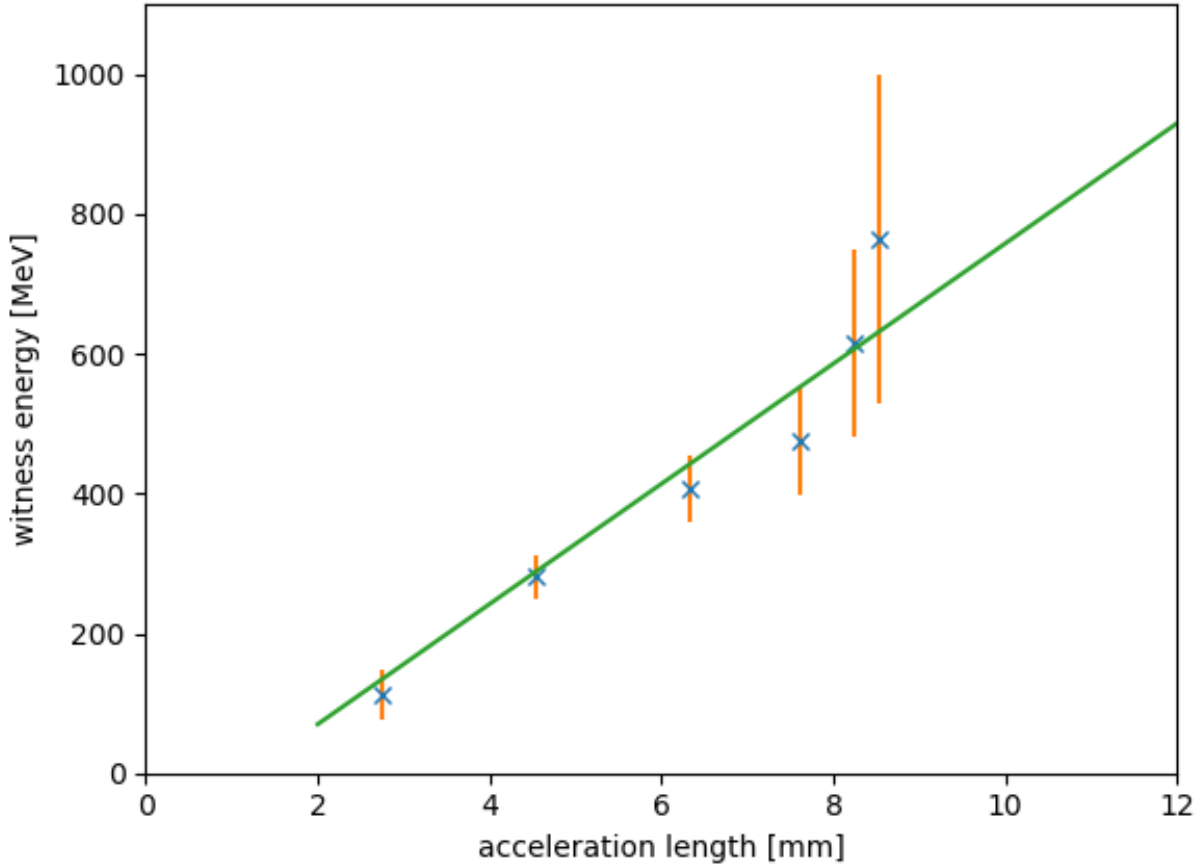

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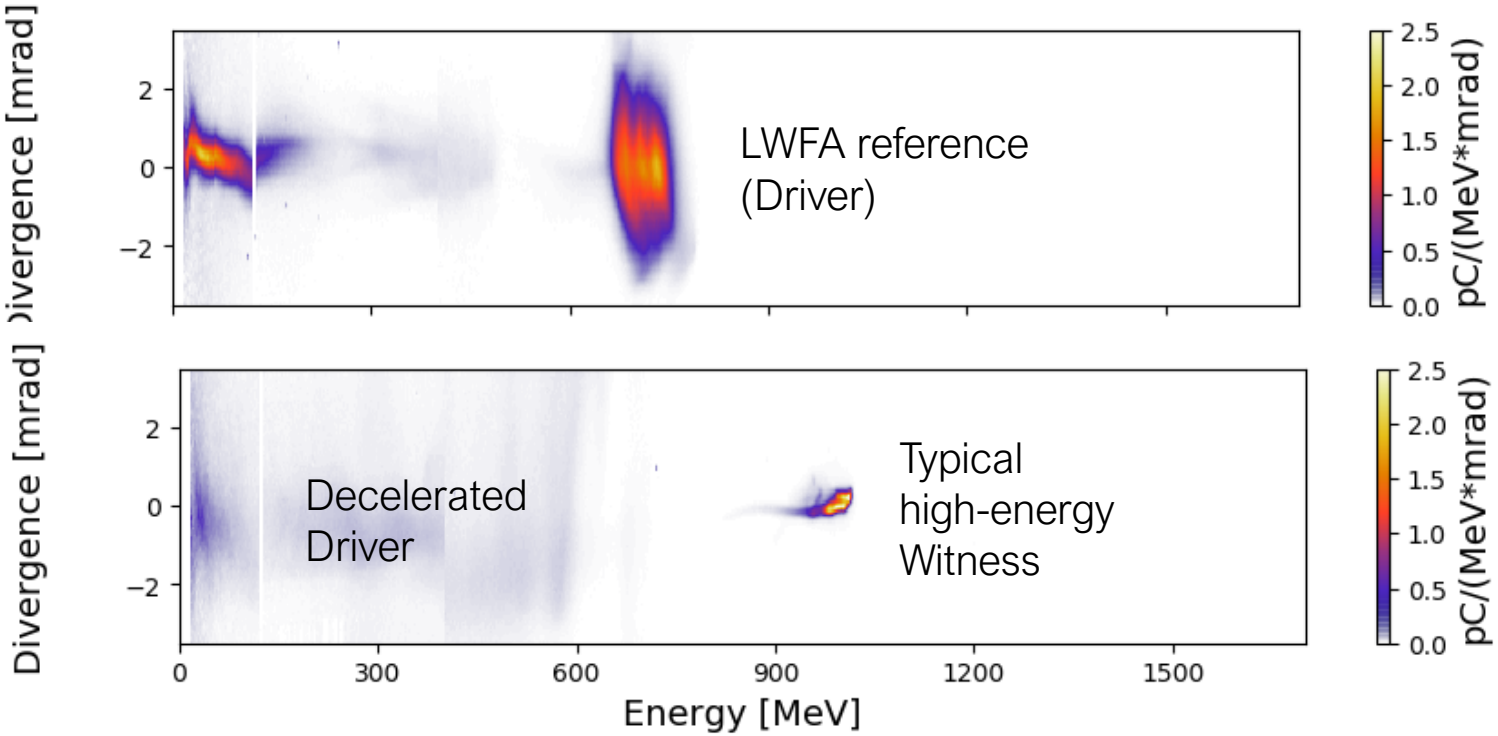
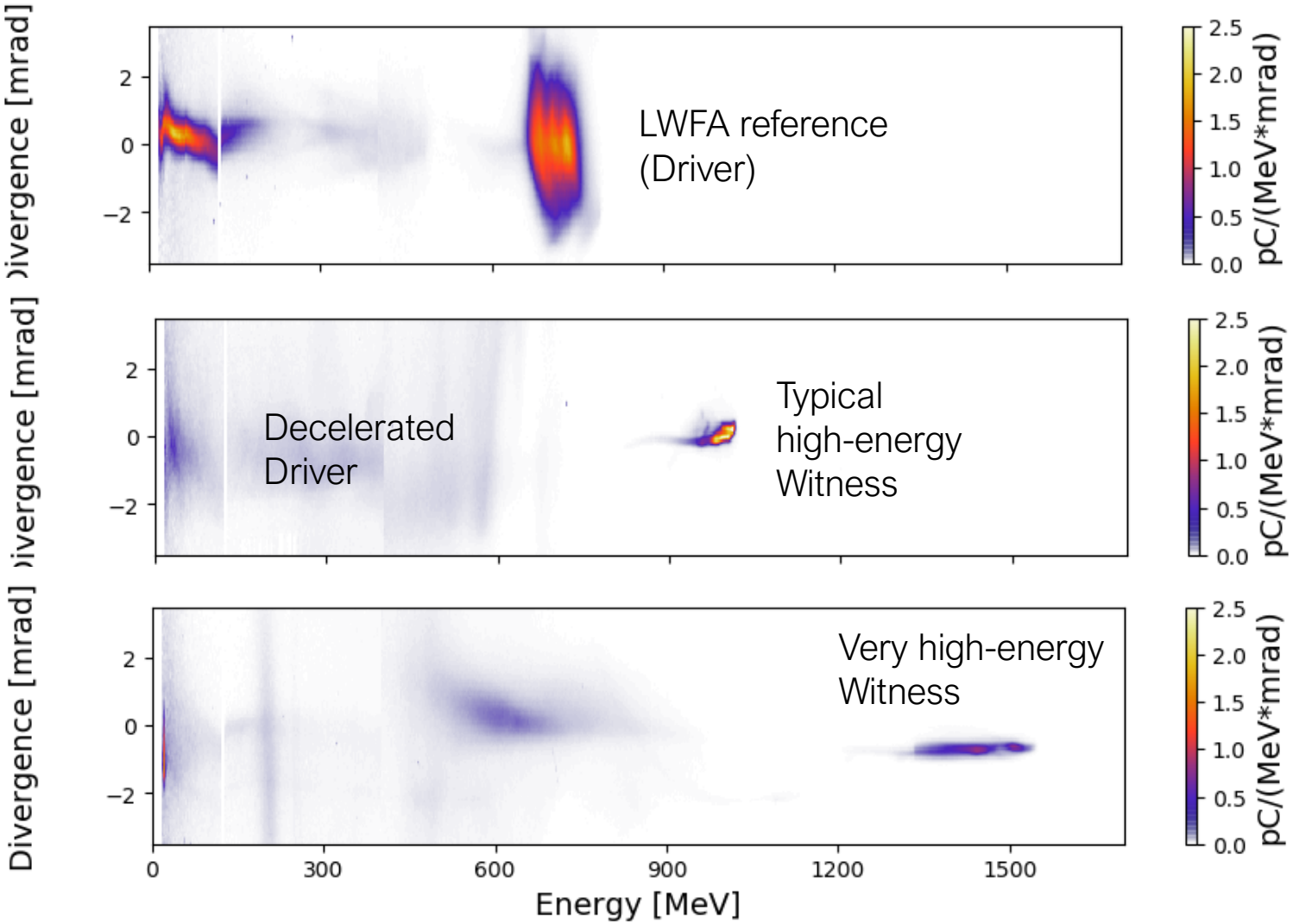


~50 pC Witness charge
0.14 mrad rms divergence
~1% rms energy spread
(resolution limited)

Latest experiments



~50 pC Witness charge
0.14 mrad rms divergence
O(1%) rms energy spread
(resolution limited)

Energy transformer ratio ~2

Understanding energy gain of witness - towards diagnostic-aided improvements

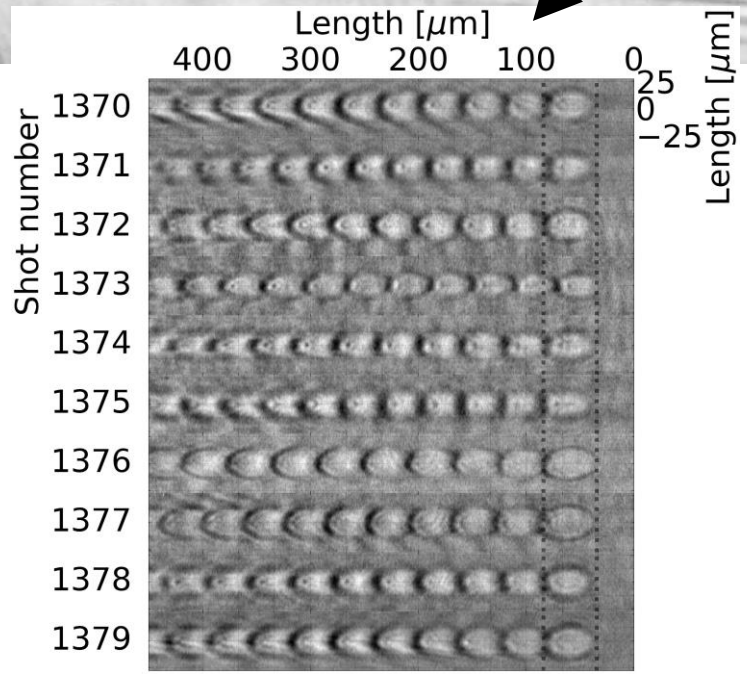
- Few-cycle shadowgraphy
  - Observe size and morphology of plasma wave
    - Work done by Florian Haberstroh
- Coherent transition radiation (CTR)
  - Retrieve current profile in particular bunch spacing
    - Work done by Bi Zewu

Few-cycle shadowgraphy of PWFA

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

e^- from LWFA

Down-ramp for injection



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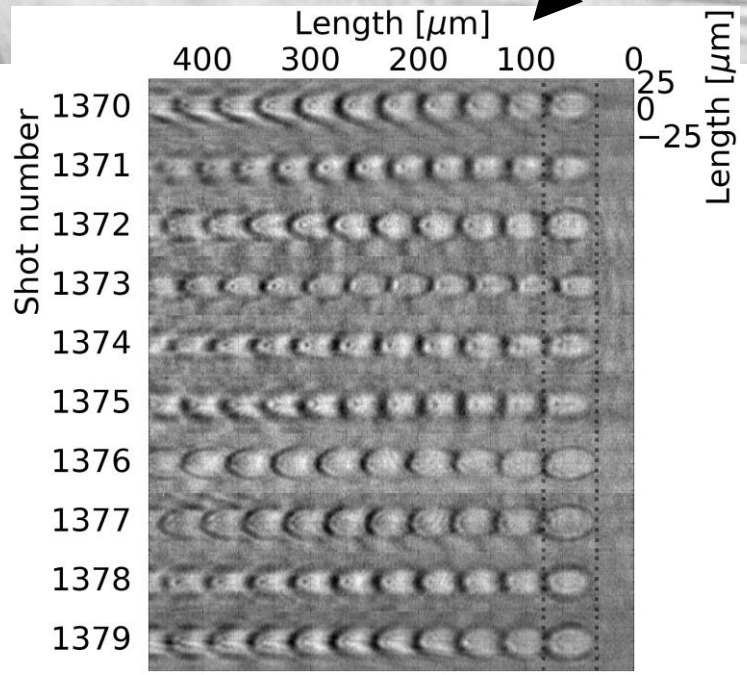

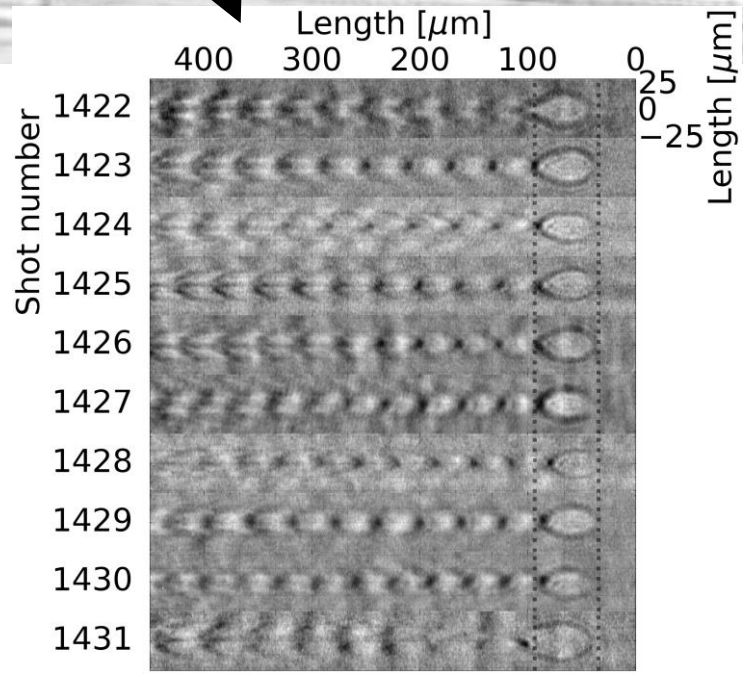

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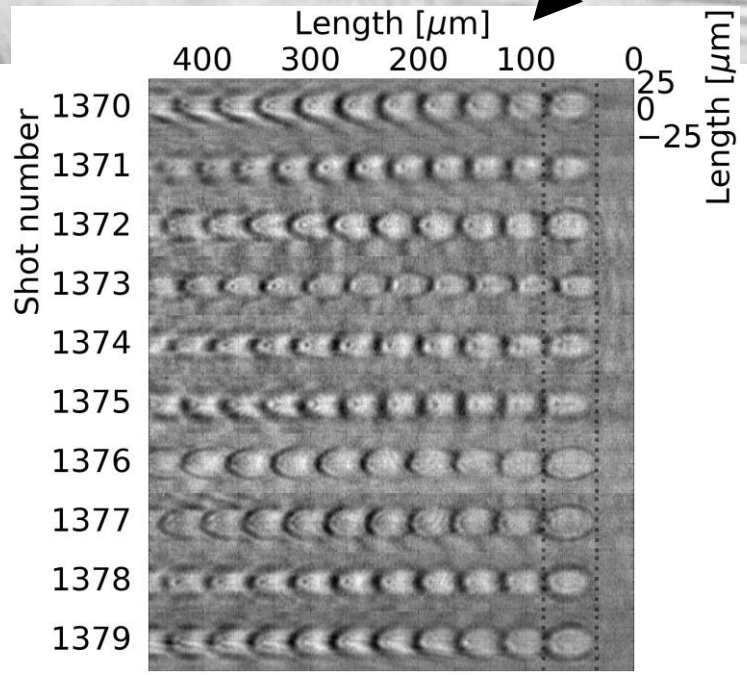
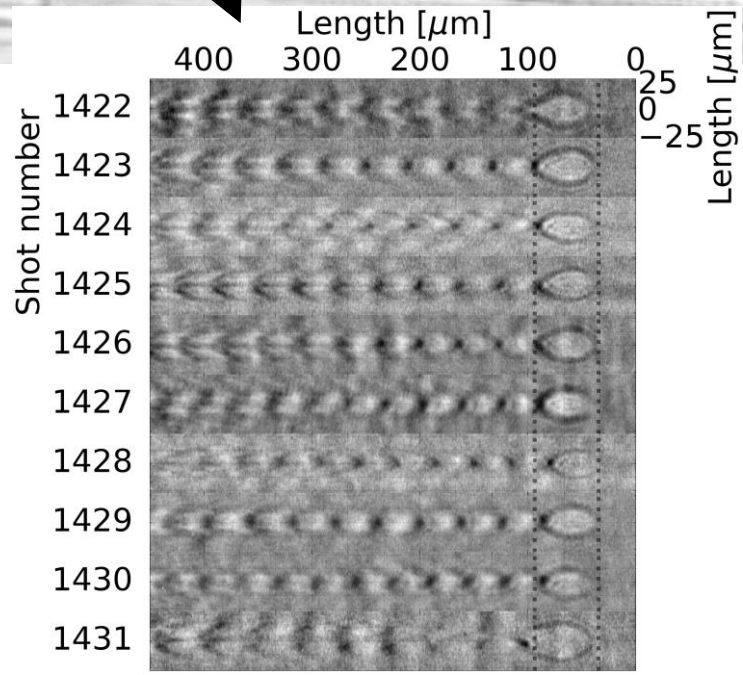
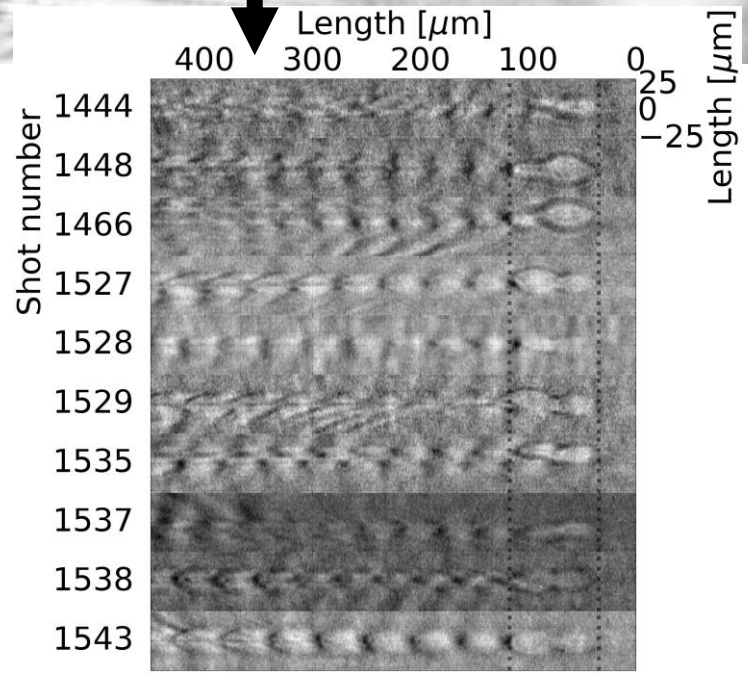
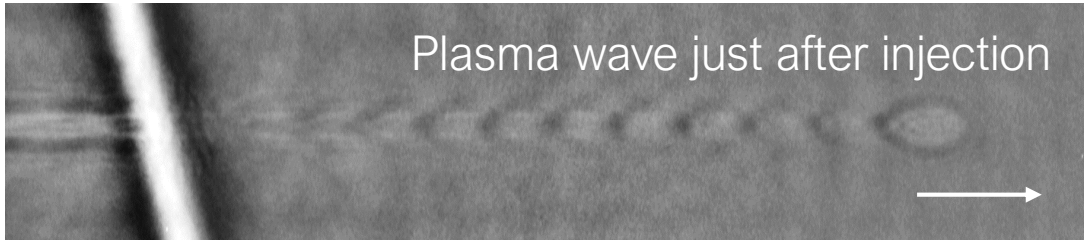






Driver depletion

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



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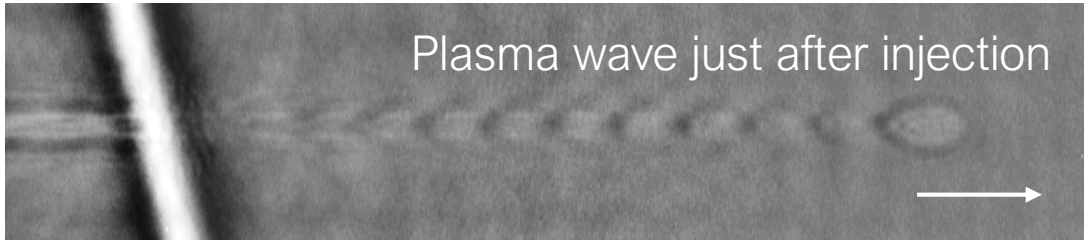

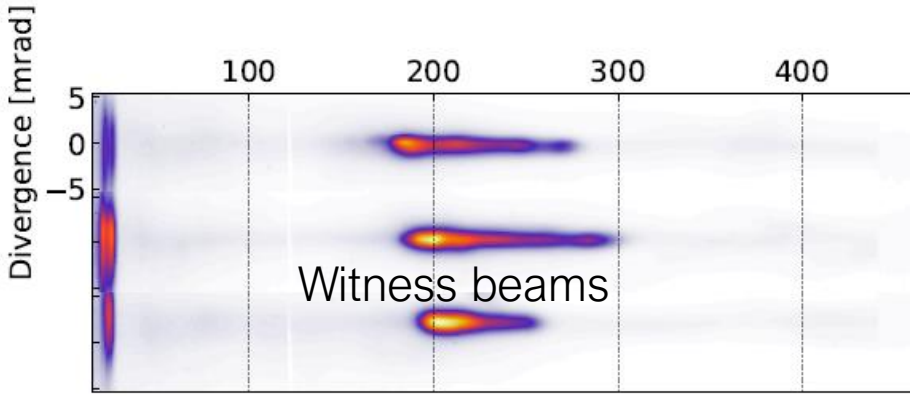

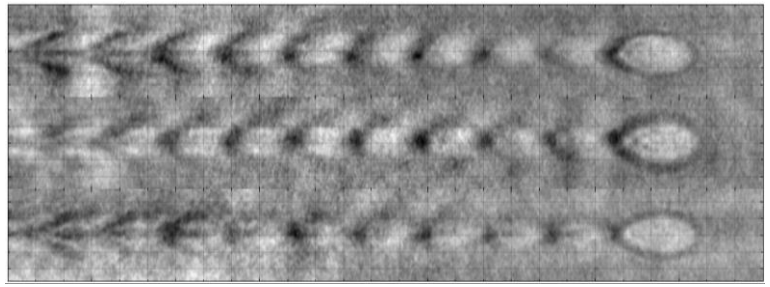

Plasma wave at the end of the PWFA target

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

Driver depletion

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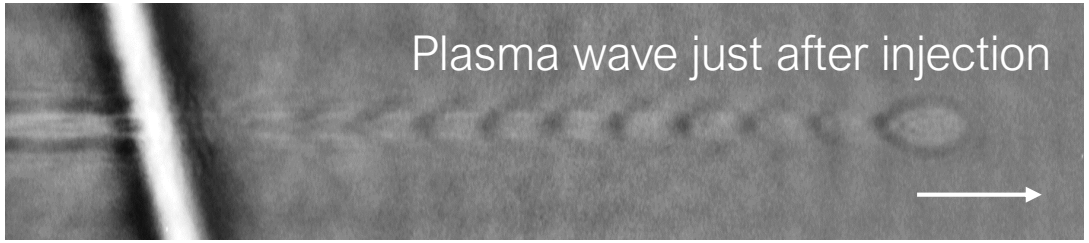

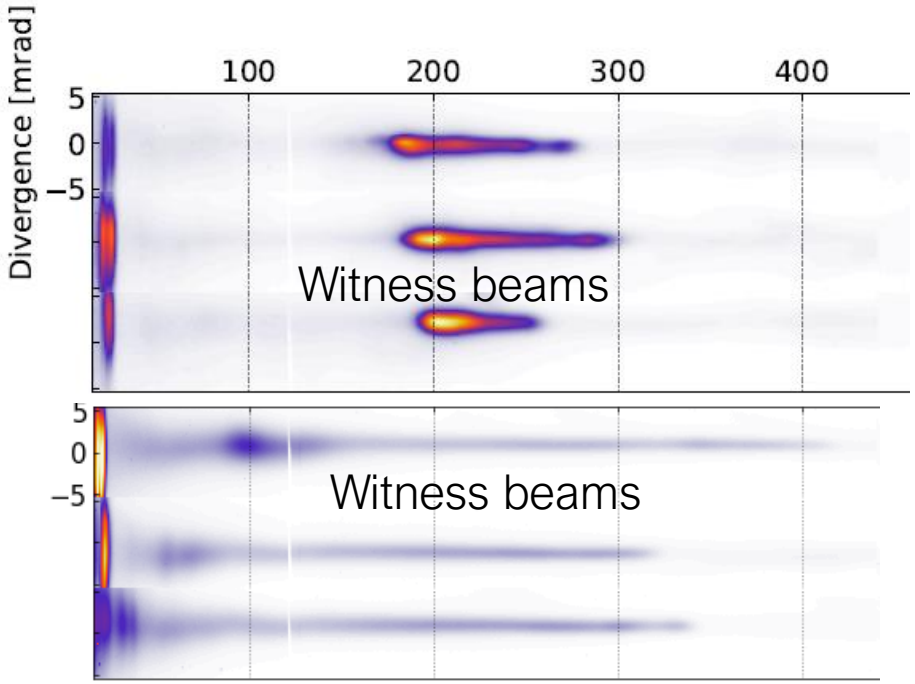

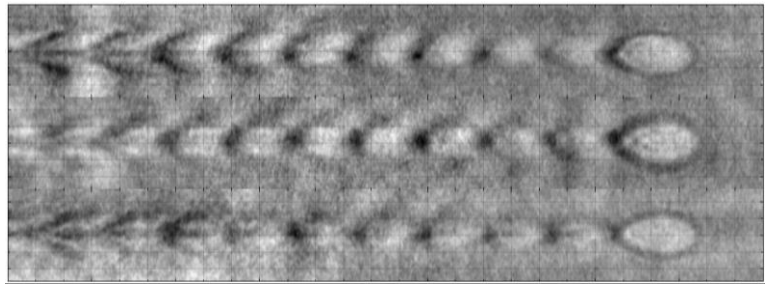

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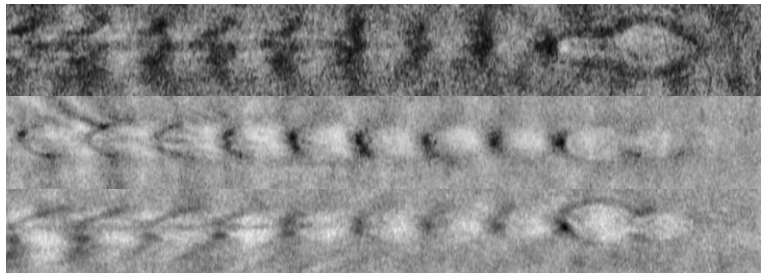
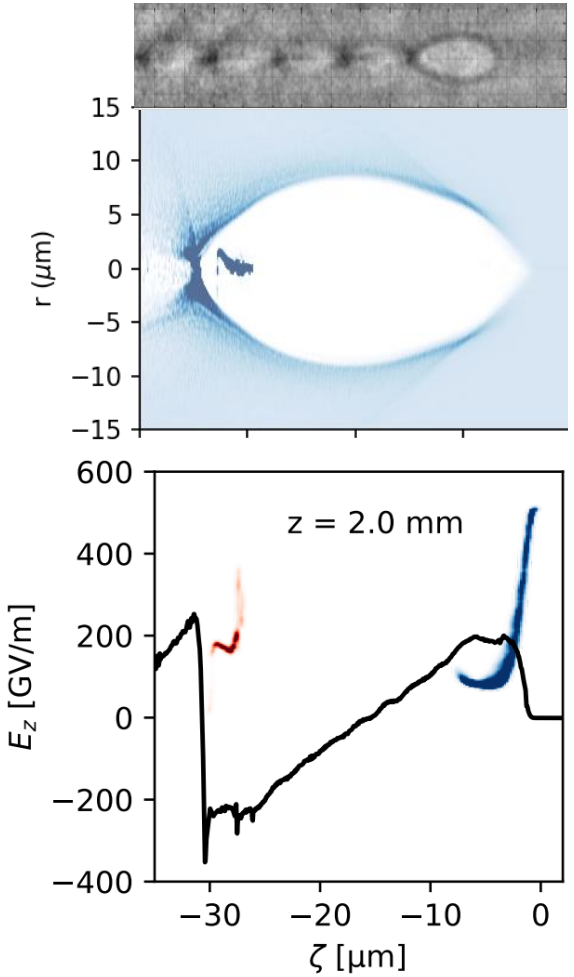


Driver depleted
First bubble shrinks

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

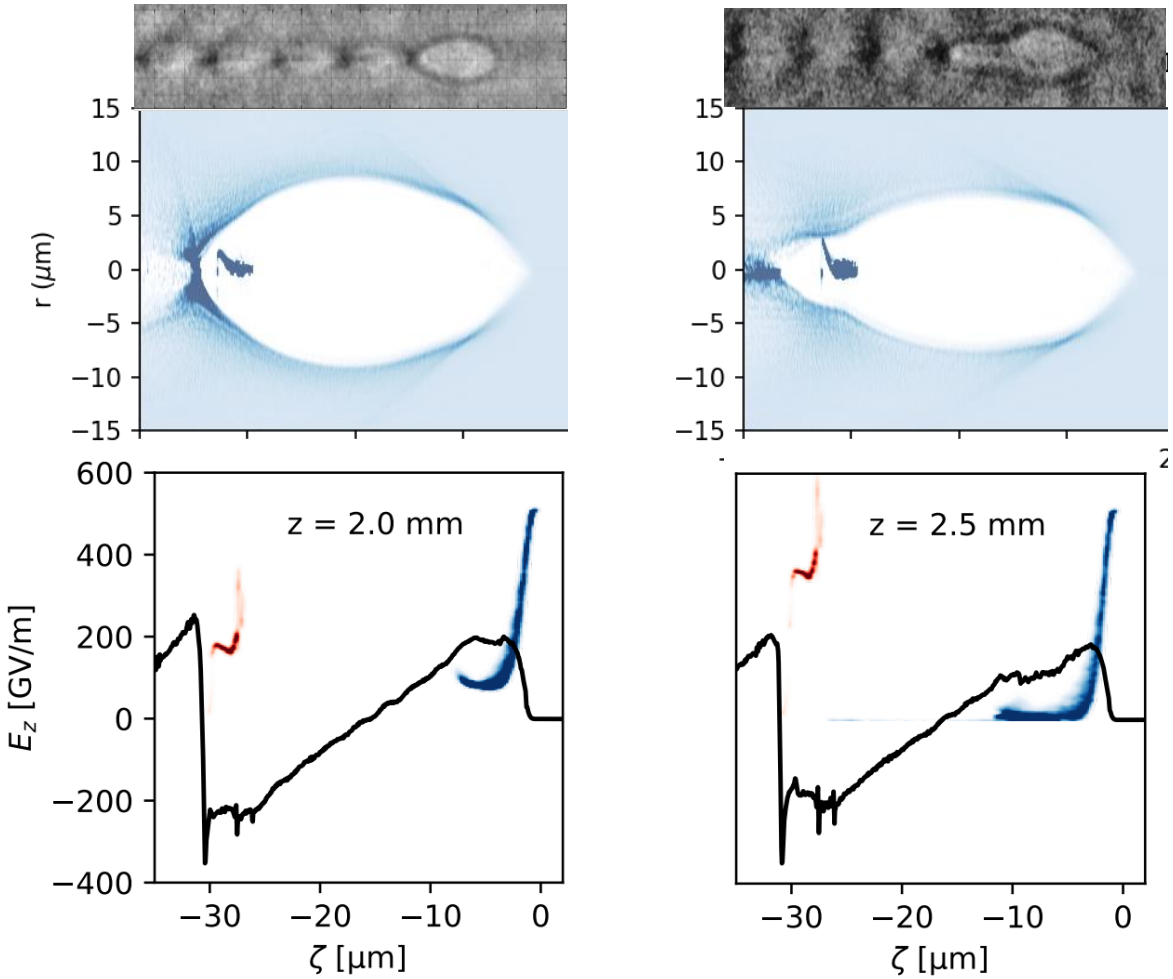
Driver depletion



Witness still gains energy

Simulations provided by
J. Zirkelbach

Driver depletion

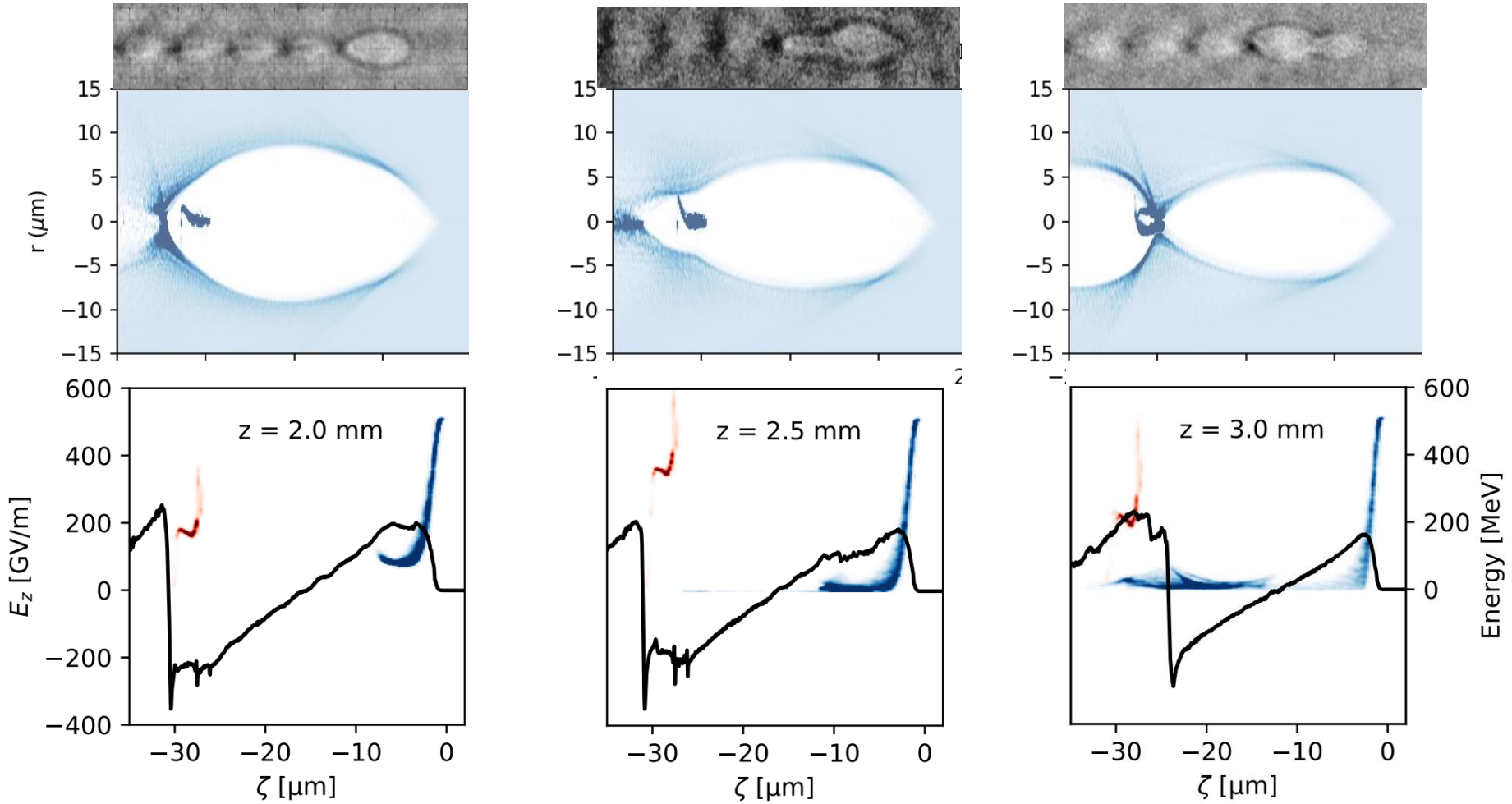


Witness still gains energy

Driver depletes

Simulations provided by J. Zirkelbach

Driver depletion

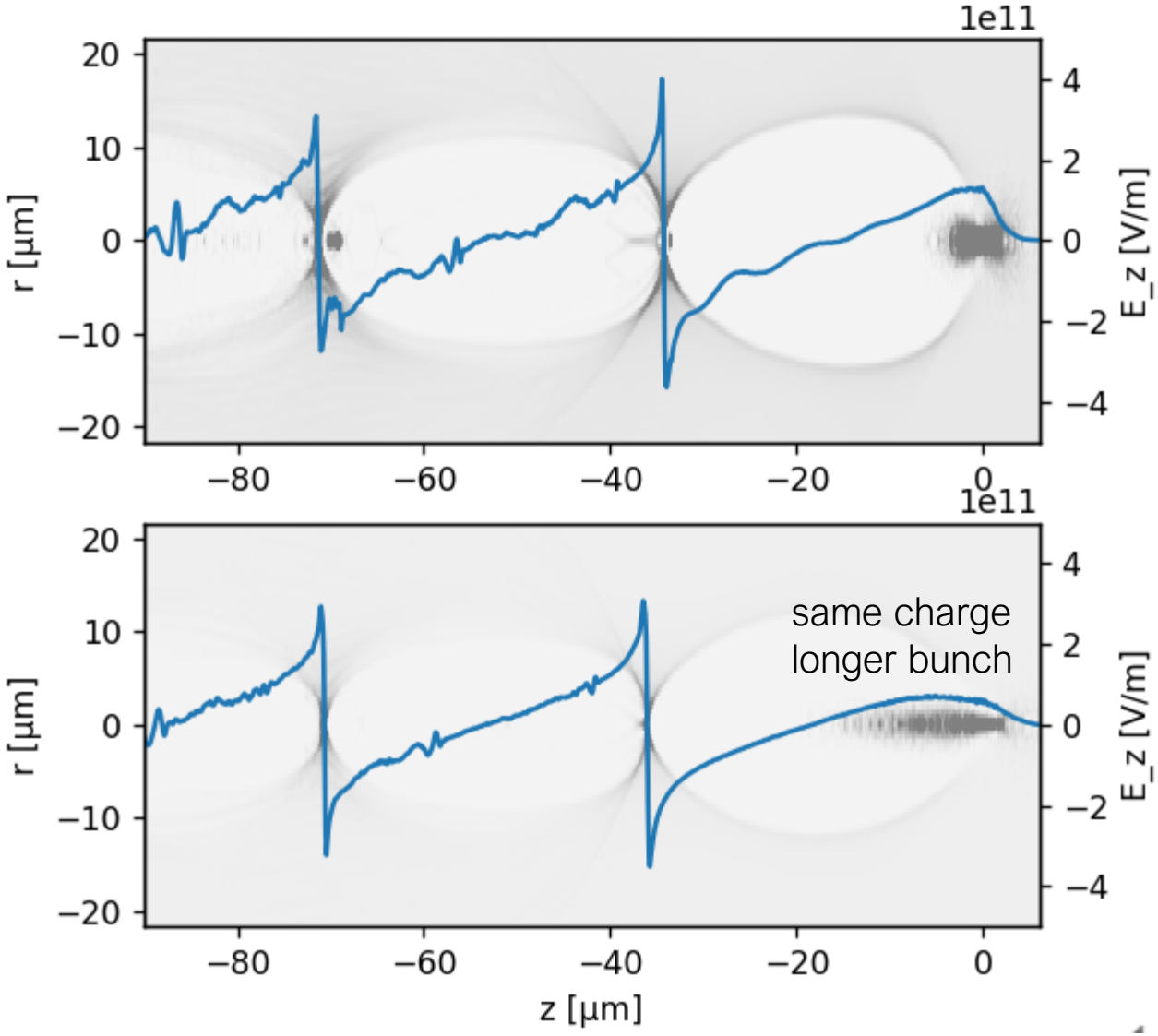


Witness still gains energy → Driver depletes → Witness looses energy

Simulations provided by J. Zirkelbach

How to fight early depletion?

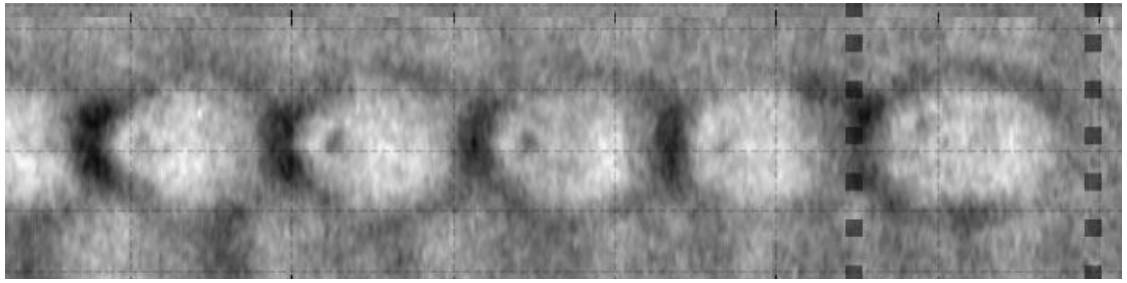
- Shape driver current
- More homogeneous field
- Higher transformer ratio
- But: Typical LWFA beams are short [1,2]:
  - ~5-15 fs/~2-5µm

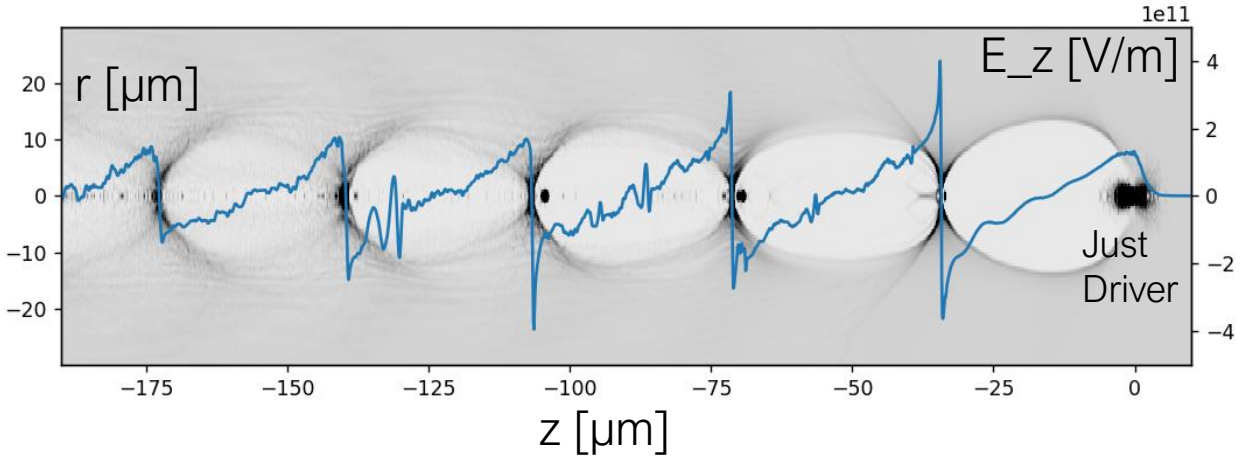


[1] Heigoldt, Phys.Rev.A.B., 2014
[2] LaBerge, Nat.Phot., 2024

Guess a current that matches bubble shape

Before witness injection (just driver)





Probing data: Florian Haberstroh

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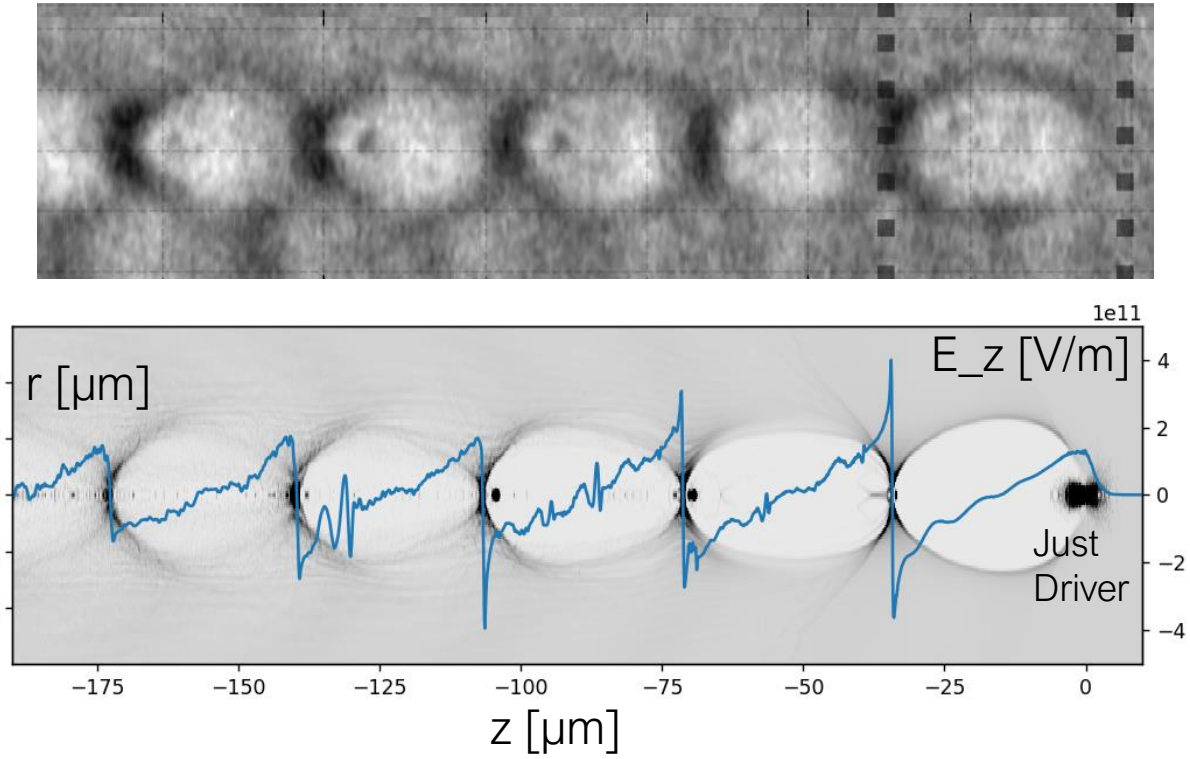
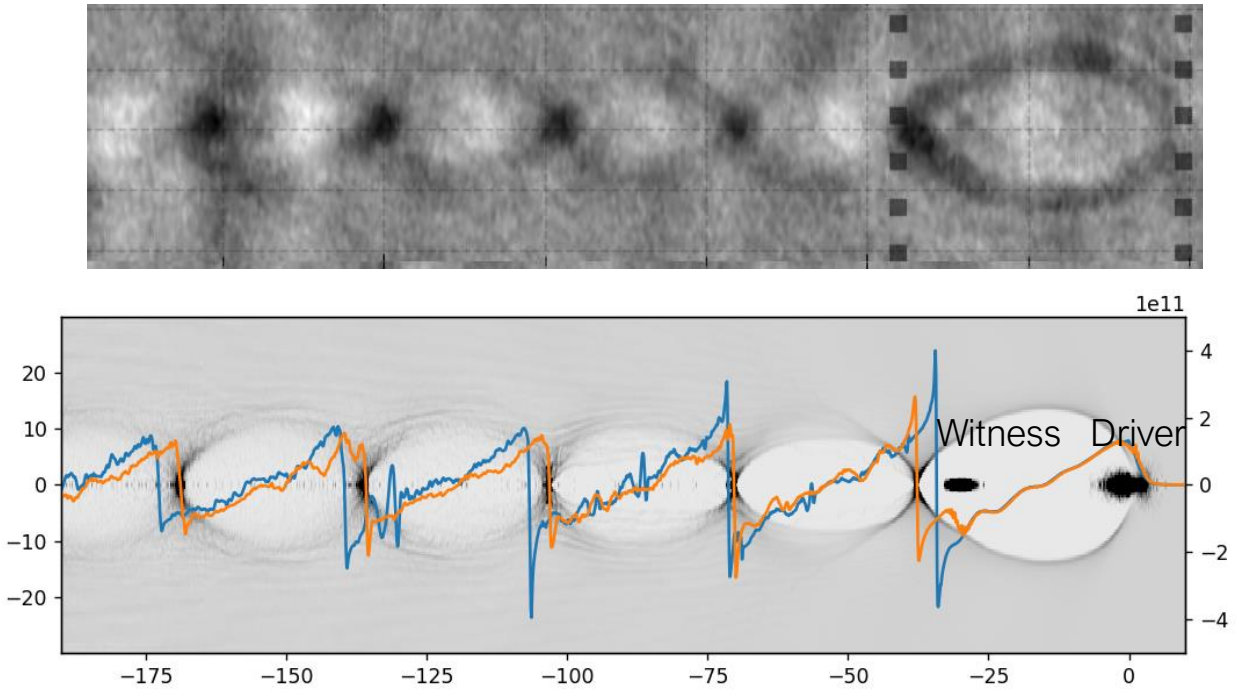


After witness injection



Longer first bubble
Reduced fields -> beam-loading

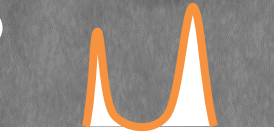
Probing data: Florian Haberstroh

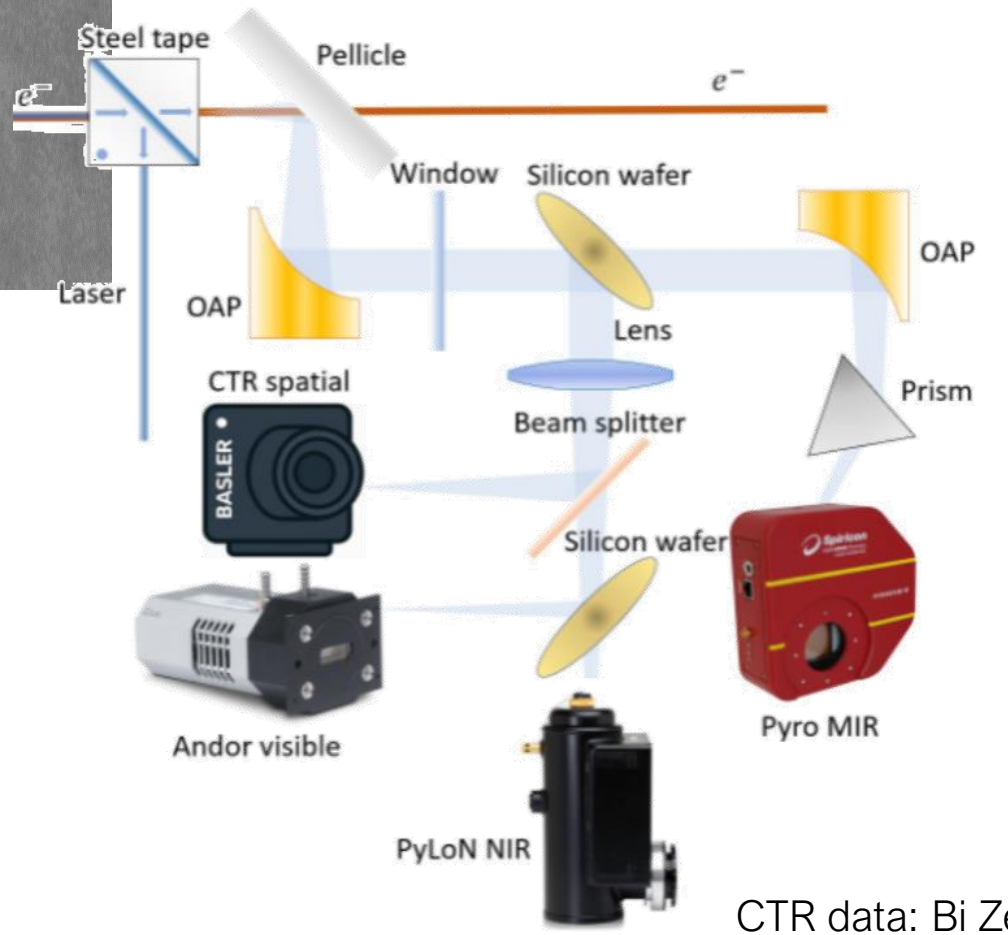
Where are the beams?

Where are the beams?

PWFA

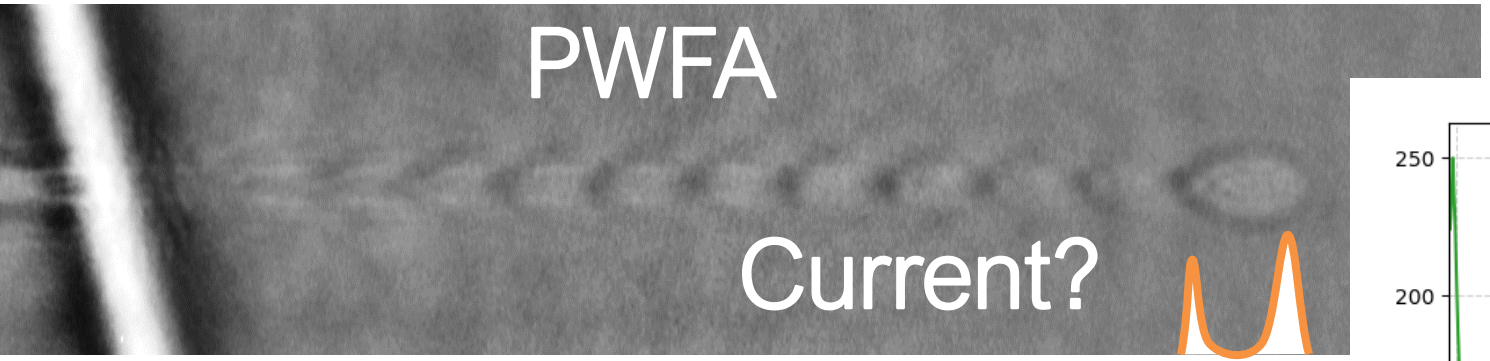
Current?

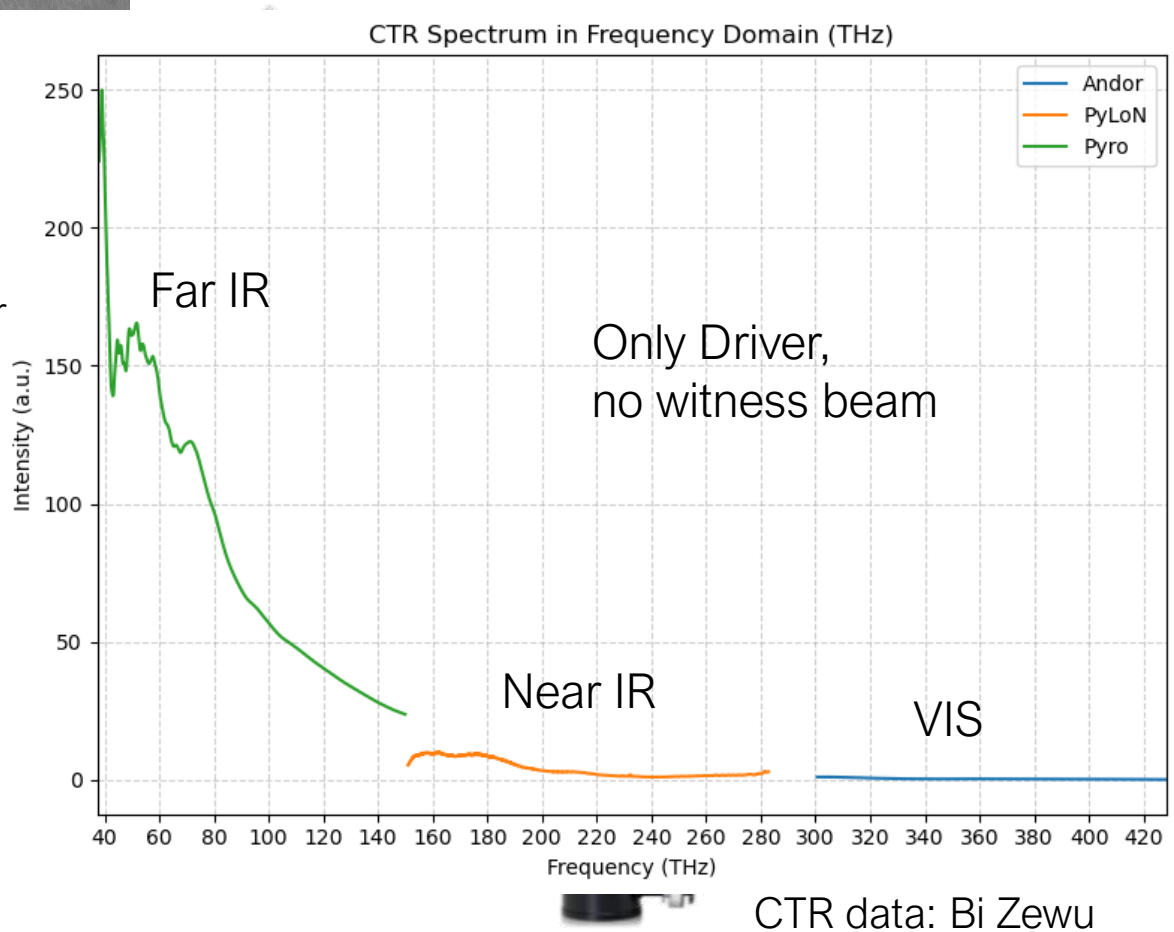




CTR data: Bi Zewu

Where are the beams?





CTR data: Bi Zewu

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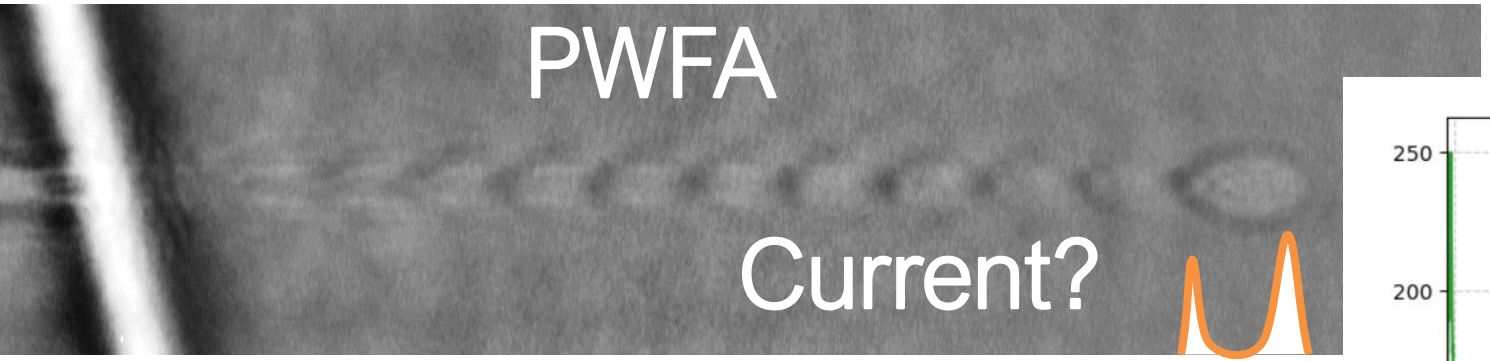
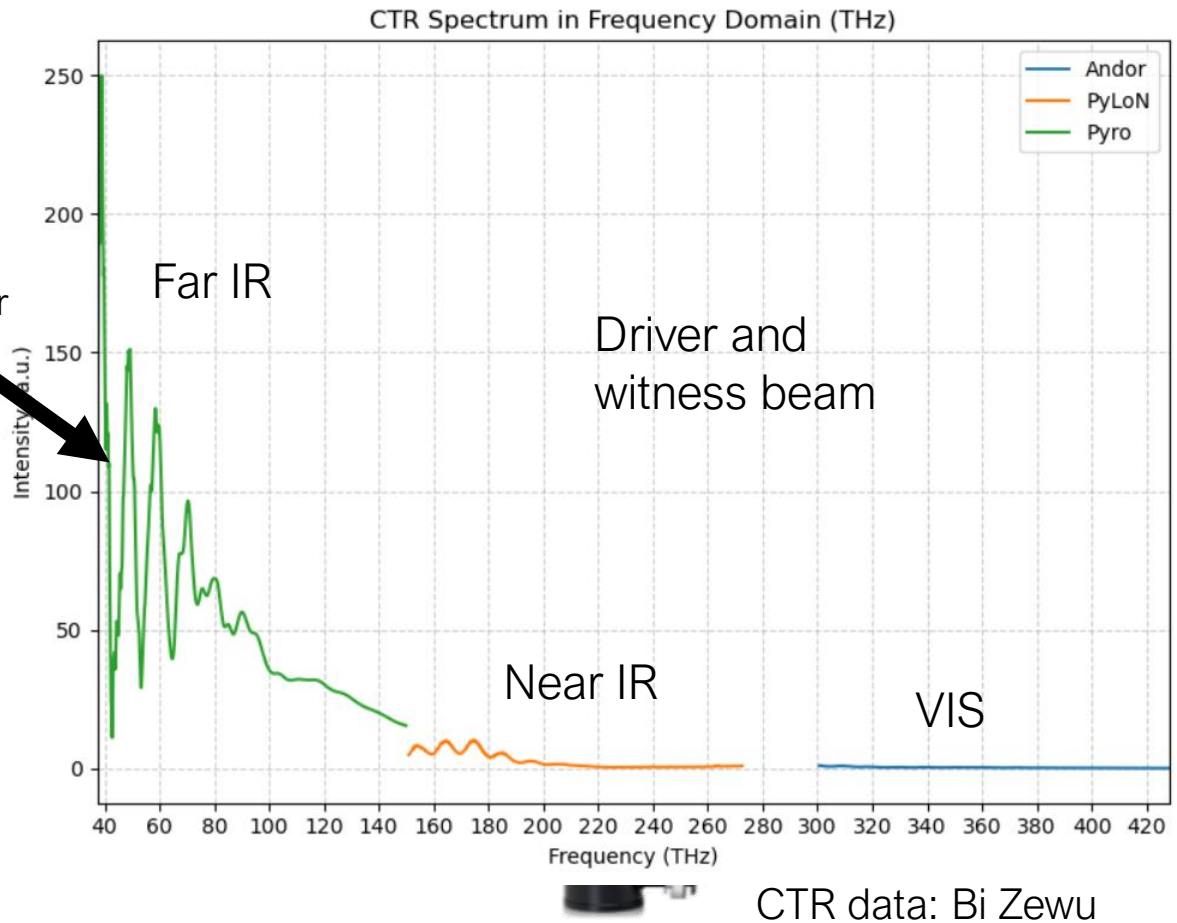
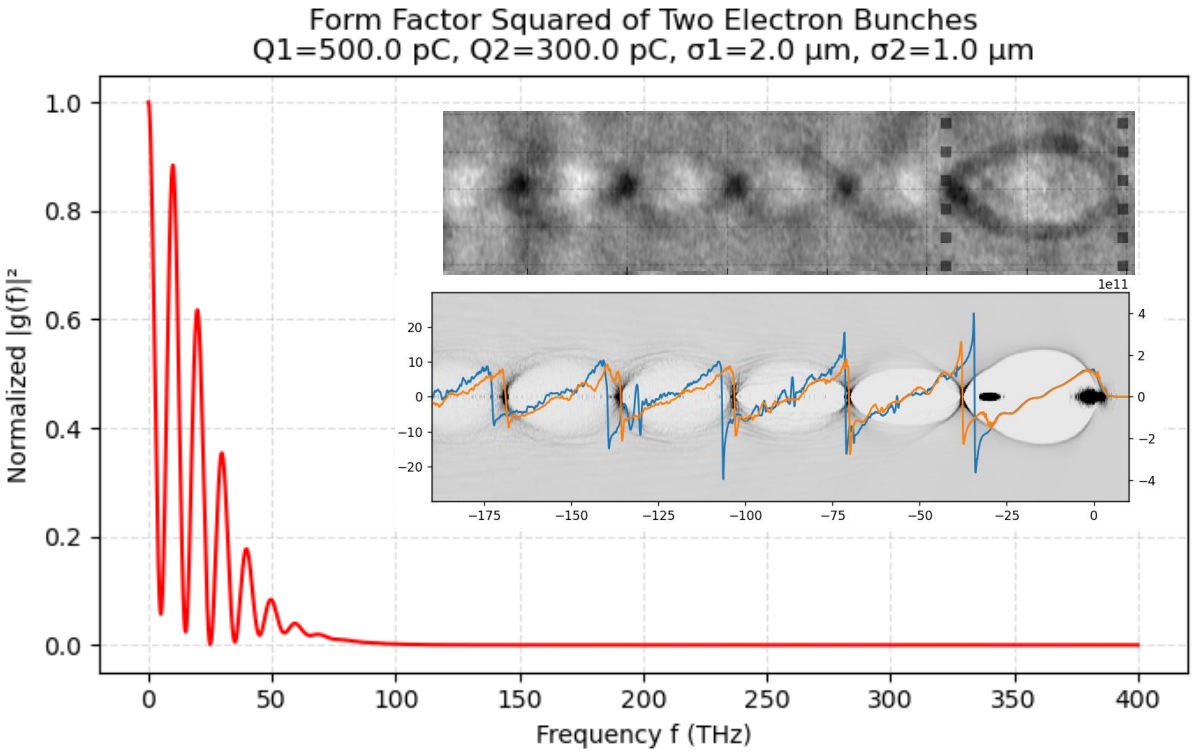


- Easy: bunch separation from modulation
- More difficult: exact current profile

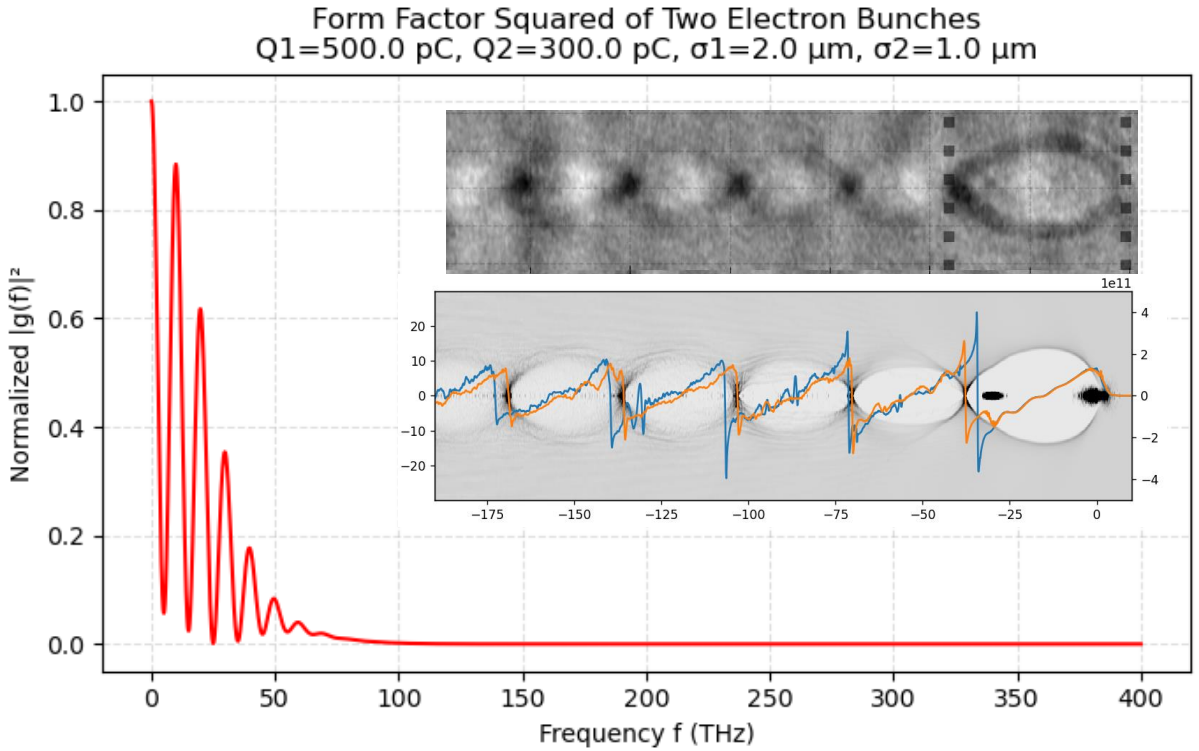


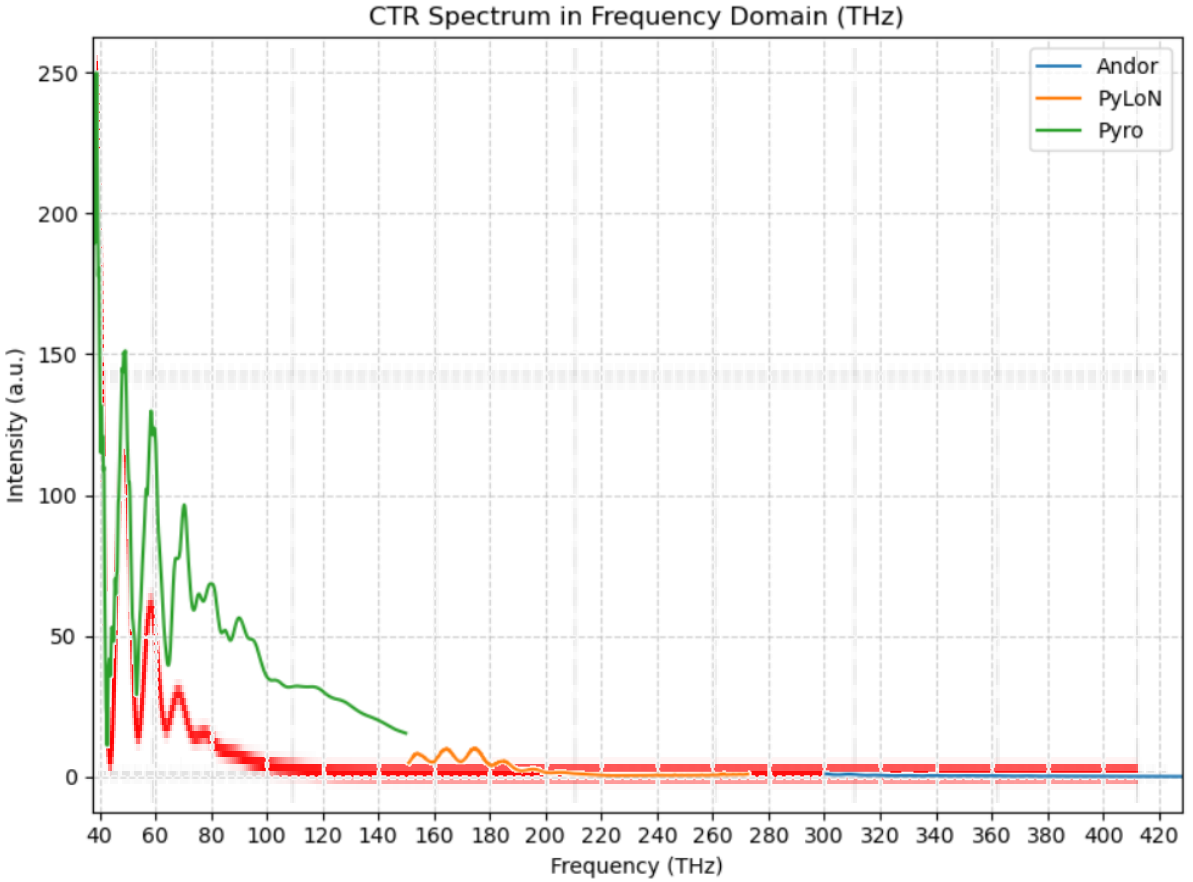
CTR data: Bi Zewu

Does this current produce the right CTR spectrum?



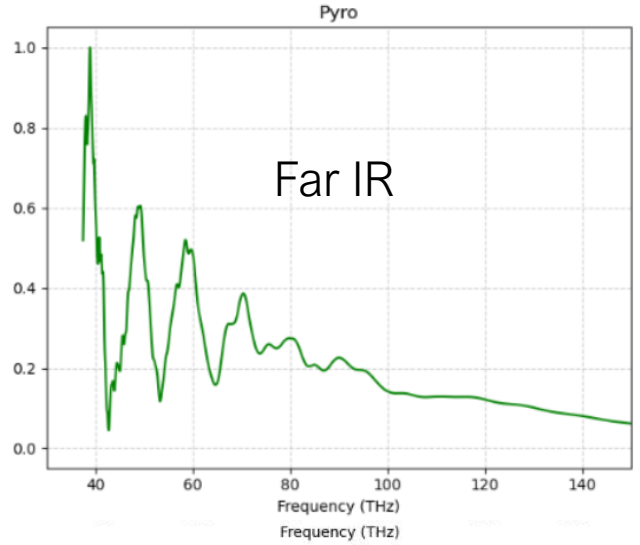
Does this current produce the right CTR spectrum?

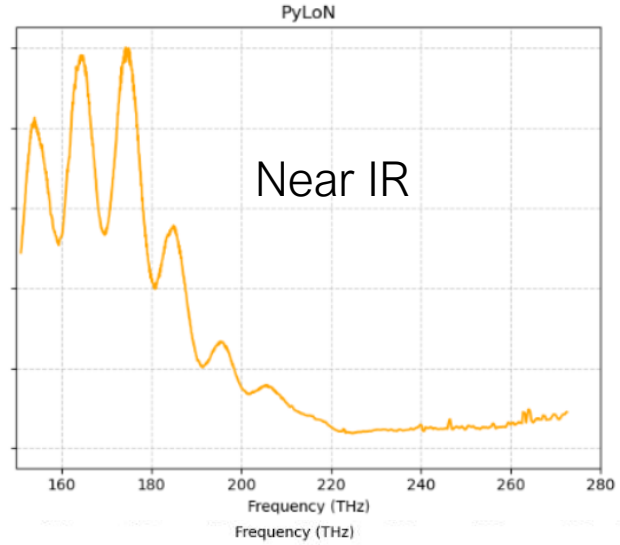


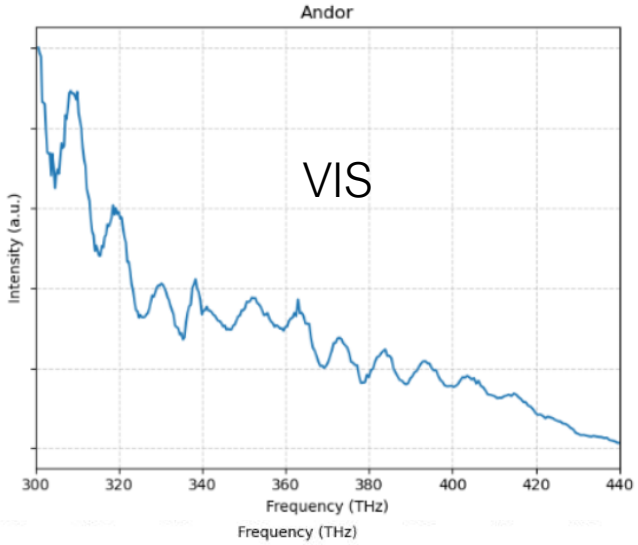


Guess current from CTR spectrum

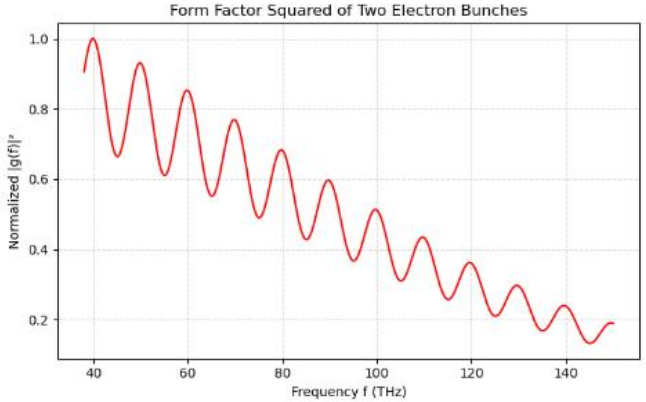
Measured

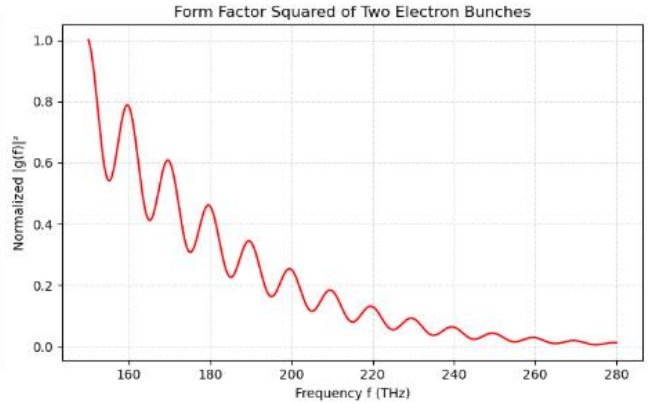


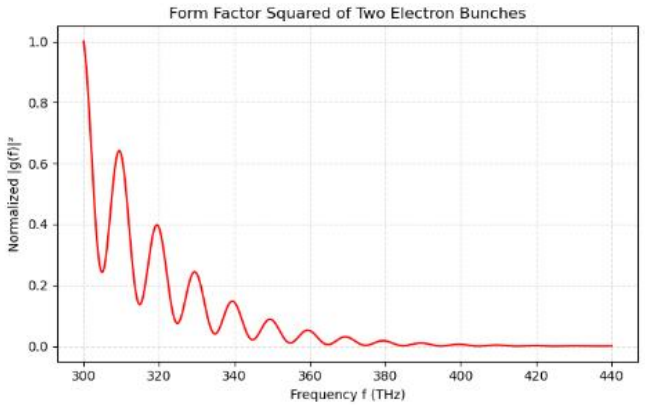




Guessed



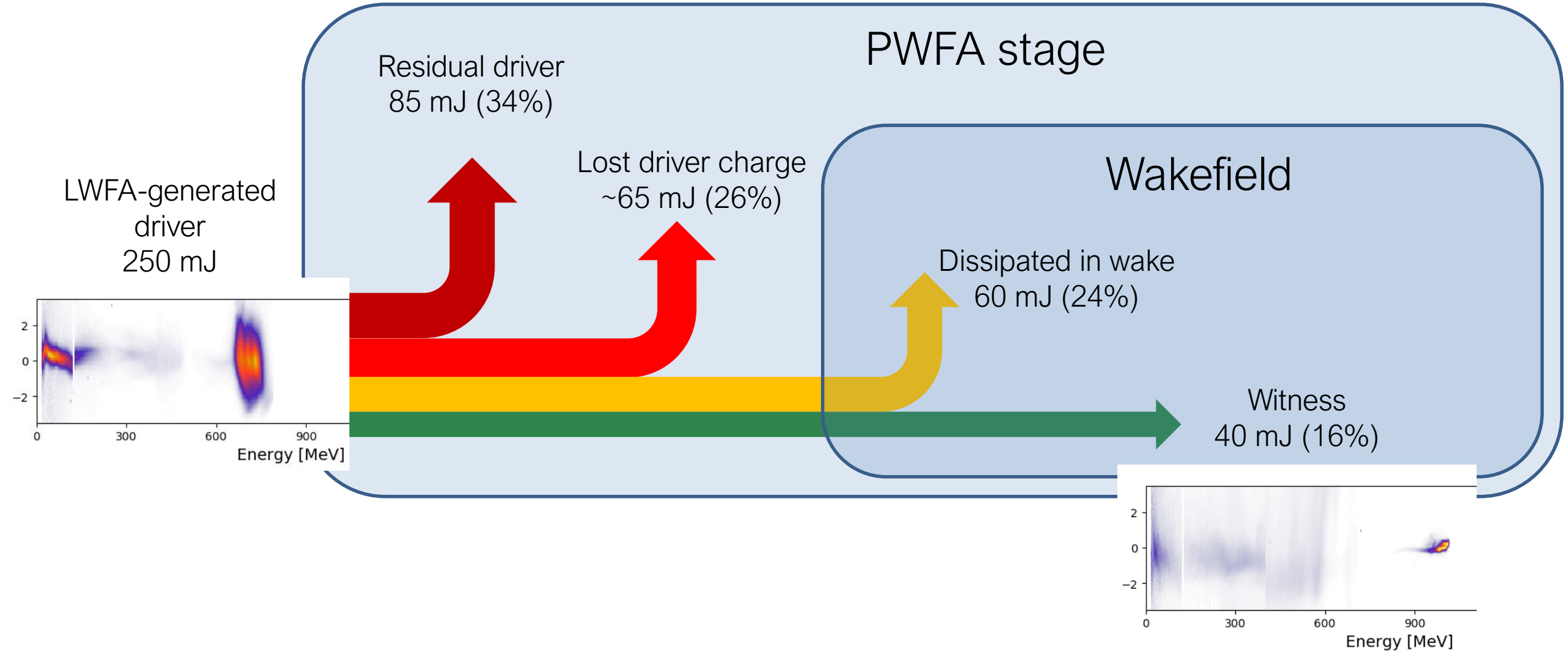




Project ongoing

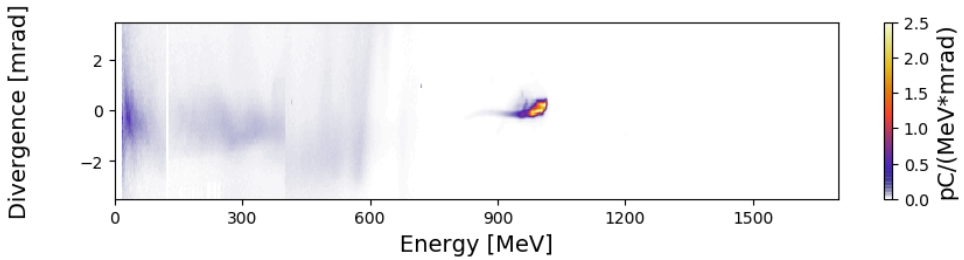
CTR data: Bi Zewu

Efficiency

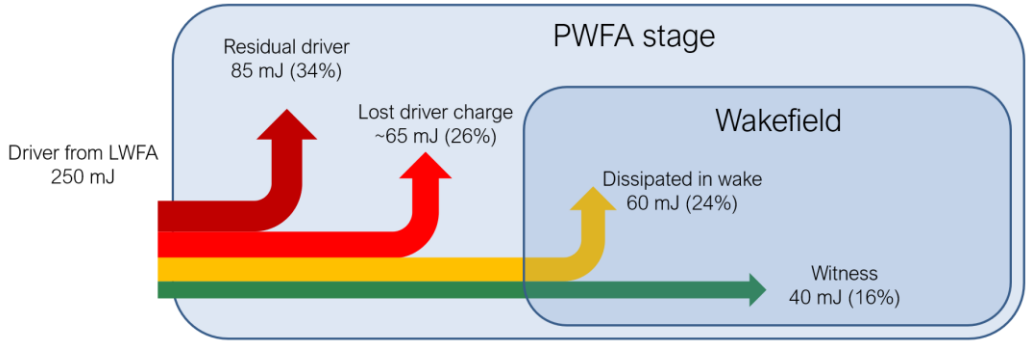

PWFA stage
Residual driver
85 mJ (34%)
Lost driver charge
~65 mJ (26%)
Wakefield
LWFA-generated
driver
250 mJ
Dissipated in wake
60 mJ (24%)
Witness
40 mJ (16%)
2
0
−2
0
300
600
900
Energy [MeV]
2
0
−2
0
300
600
900
Energy [MeV]

Questions?

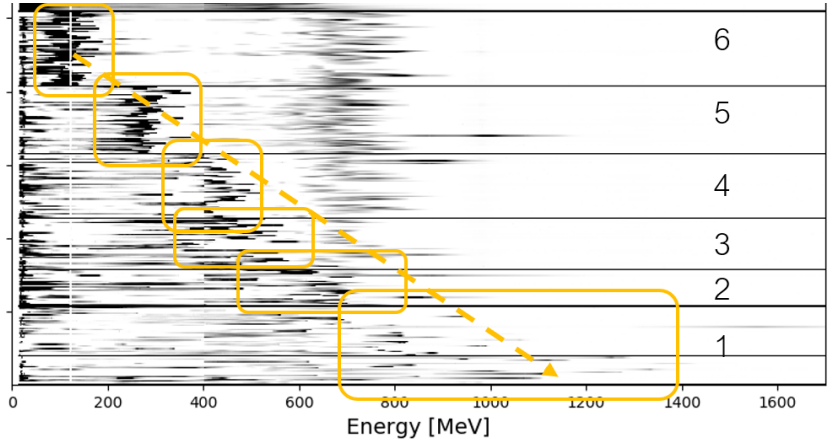
High-quality beams,



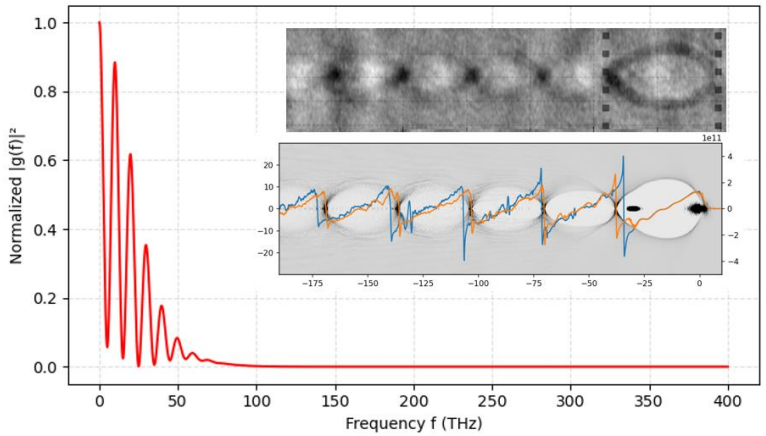
accelerated at very high efficiency,



to high energies,



and still ideas to improve!



Latest experiments