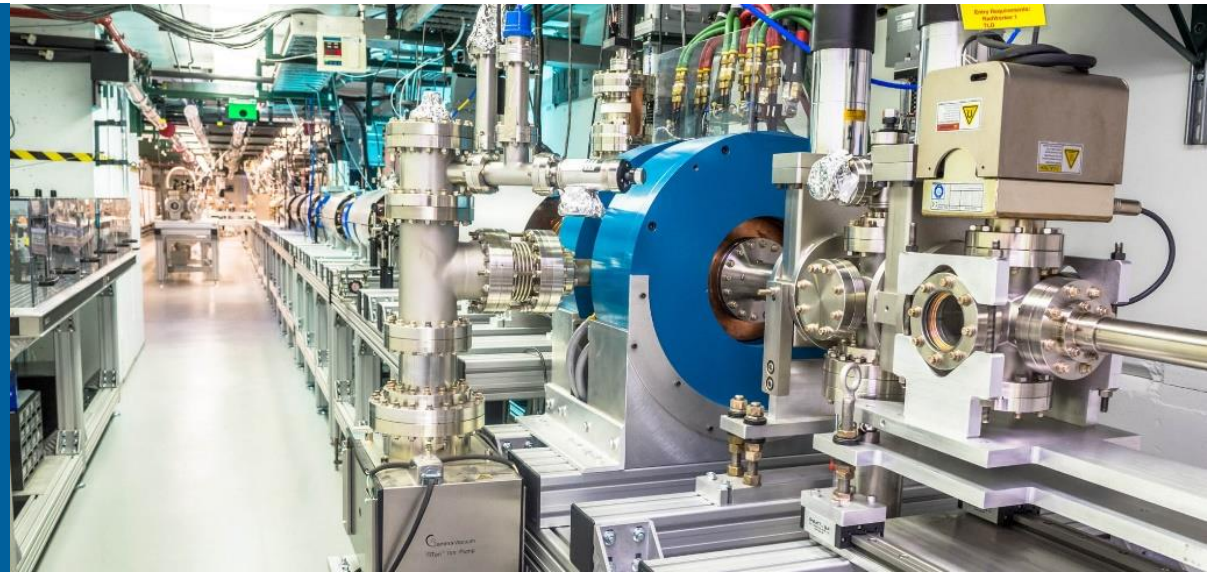
NOVEMBER 8, 2022

Argonne NATIONAL LABORATORY

LONGITUDINAL BUNCH SHAPING USING RF TRANSVERSE DEFLECTING CAVITIES at Argonne Wakefield Accelerator Facility



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U.S. DEPARTMENT OF ENERGY
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AAC'22 Advanced Accelerator Concepts Workshop
November 6 - 11, 2022
Hyatt Regency Long Island, NY

euclid TECHLABS

NIU Northern Illinois University

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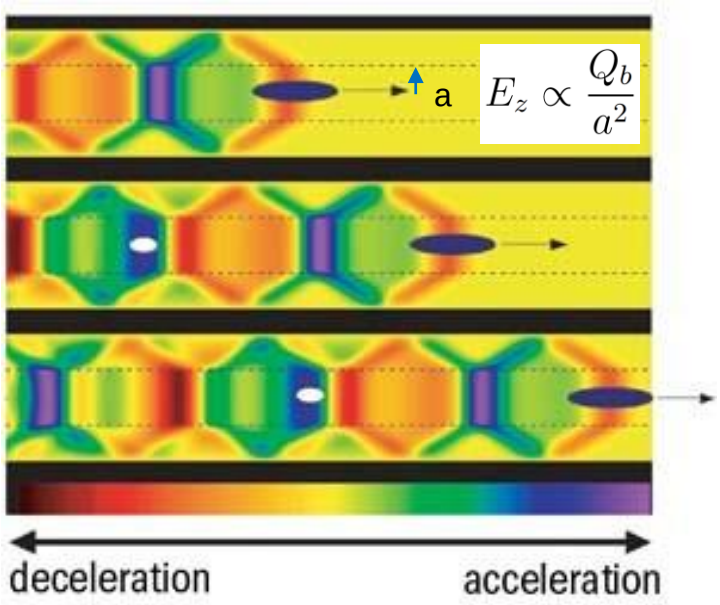
- ❖ Motivation
- ❖ Bunch shaping method using transverse deflecting cavity
- ❖ Particle tracking simulation results
- ❖ Conclusion, future works

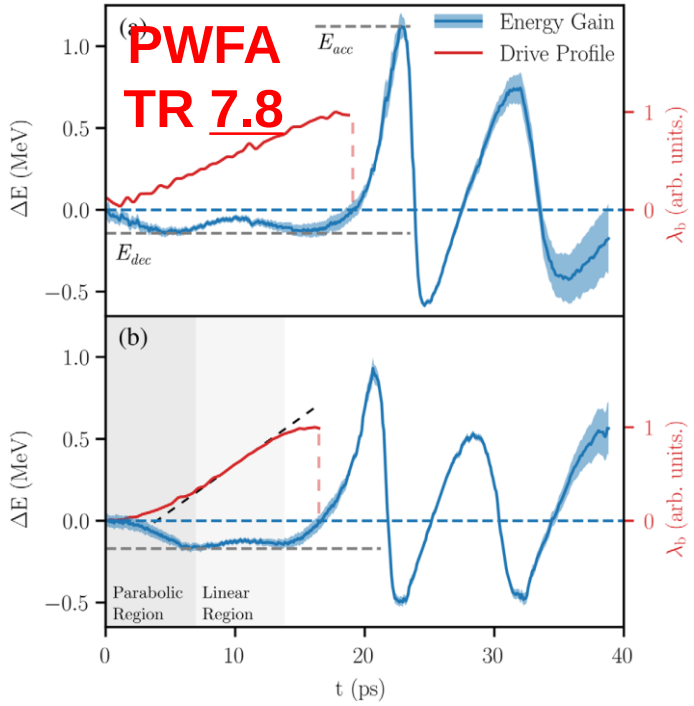
Motivation: high-charge bunch shaping

EM field in the dielectric wakefield structure

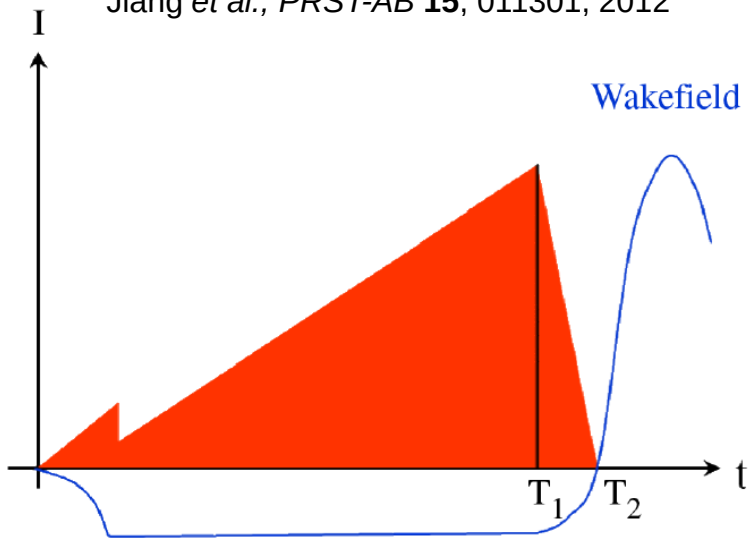


High-gradient wakefield accelerators (SWFA/PWFA)

Roussel *et al.*, *PRL* **124**, 044802, 2020



Jiang *et al.*, *PRST-AB* **15**, 011301, 2012



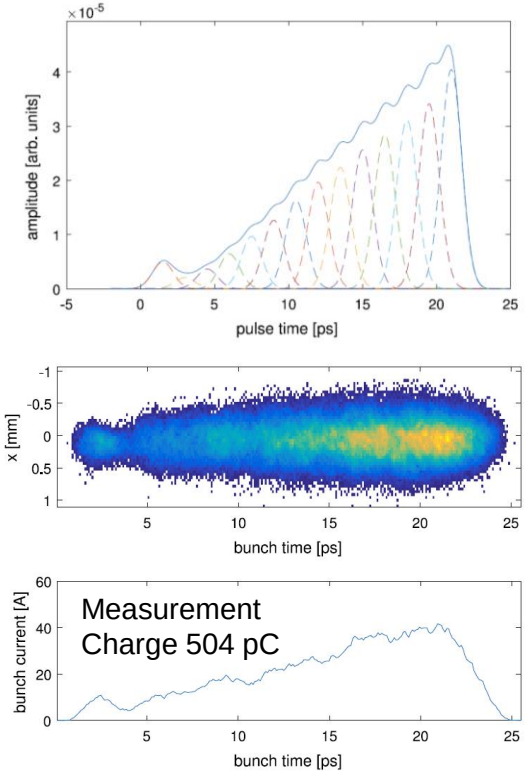
High-transformer ratio

High-gradient, high-transformer ratio wakefield accelerators:

➡ **High charge bunch shaping**

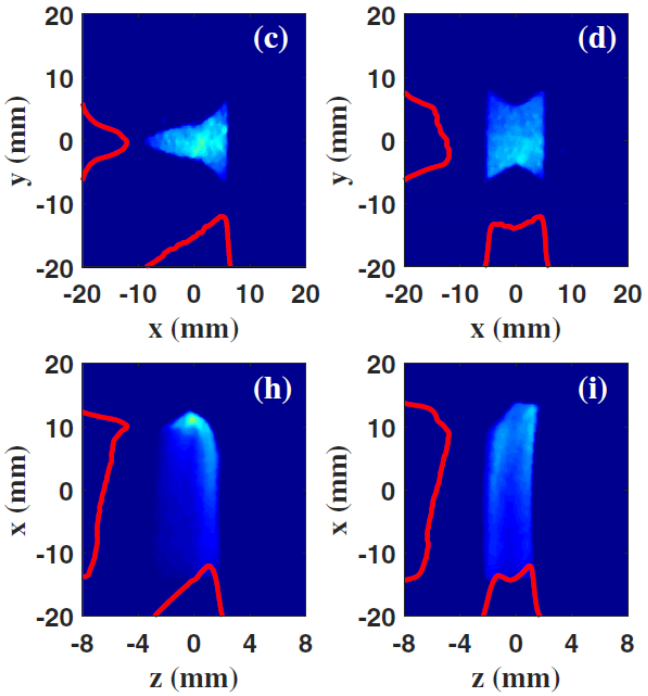
Motivation: high-charge bunch shaping

Loisch *et al., NIMA* **909**, 2018.



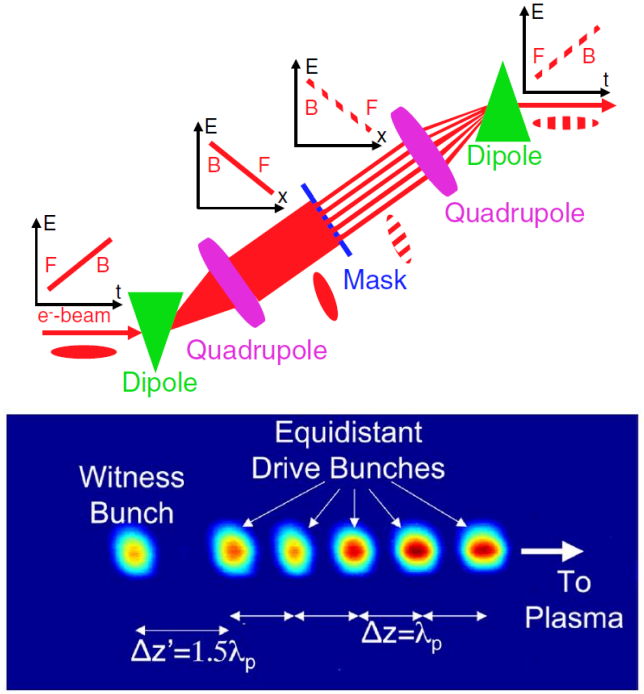
IR/UV laser shaping

Ha *et al., PRL.* **118**, 104801, 2017



Emittance Exchange beamline

P. Muggli *et al., PRL* **101**, 054801, 2008.
Muggli *et al., PRST-AB* **13**, 052803, 2010.



Correlation-based shaping

High quality bunch shaping for high charge beam:

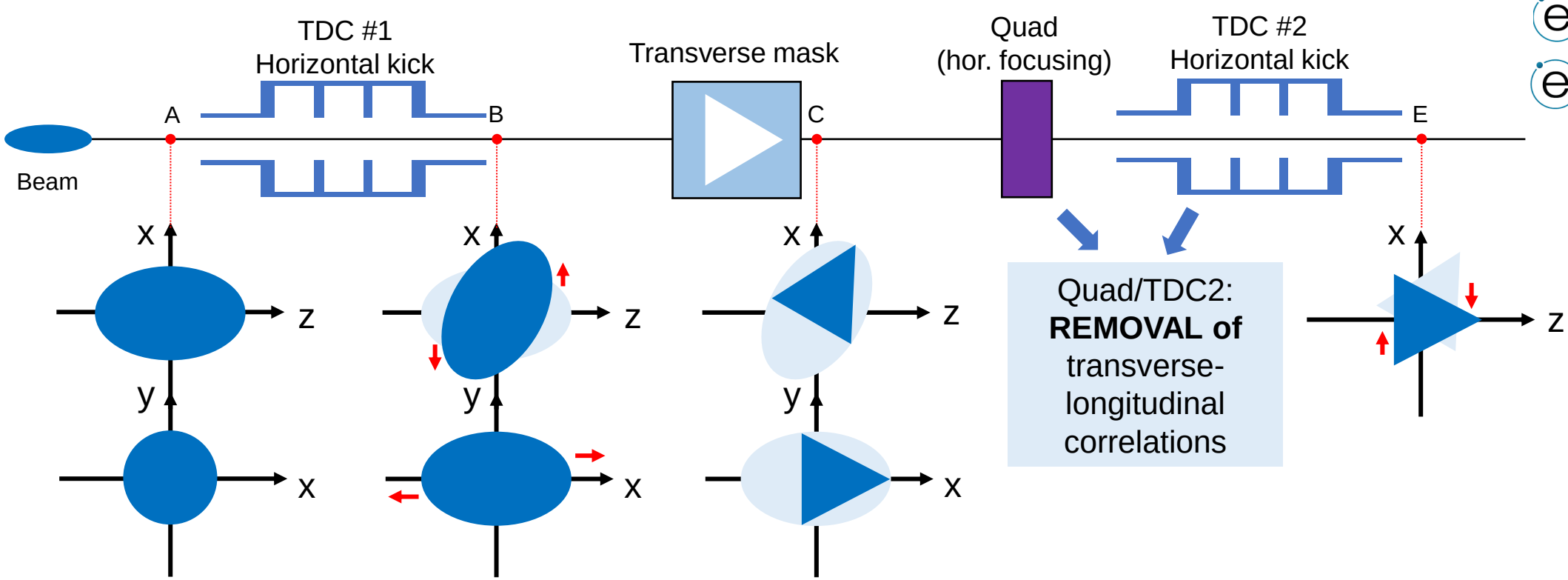
➡ Mitigation of collective effects (space charge, CSR)

Transverse deflecting cavity-based (TDC) Bunch shaping method

A solution to high-Q shaping: TDC-based bunch shaping

- **TDC: Transverse deflecting cavity**

- Originally suggested in: Kur *et al.,* Rep. No. LBNL-2670E, 2009.
- Extended study reported in: Ha *et al., PRAB* **23**, 072803, 2020.
- X-band TDC shaping: Kim *et al., In. Proc.* IPAC'22 (WEZOSP1), 2022: **Euclid SBIR project**



No dipole magnet is used: CSR-free

Ultra-relativistic beam is shaped: space-charge less considered

Particle tracking simulation results

- with AWA drive linac accelerator

Introduction to AWA facility

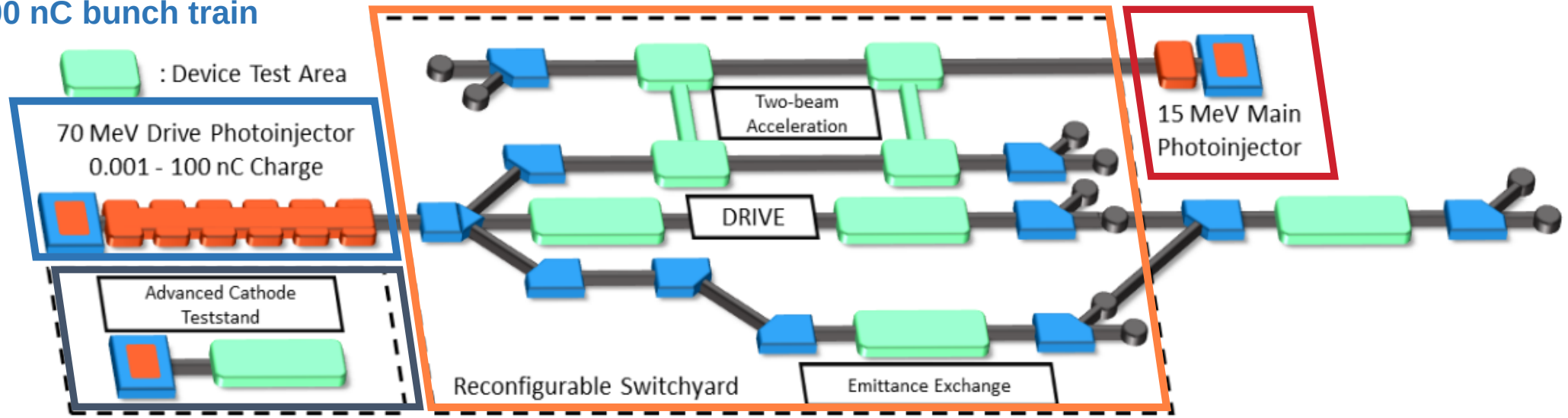
- **Multipurpose R&D test facility for high-gradient, beam-driven wakefield accelerator**

Drive RF photoinjector (6 – 65 MeV)

- **0.1 – 100 nC single bunch**
- **600 nC bunch train**

Witness RF photoinjector (15 MeV)

- Provides two-beam capability
- Bright beams



Argonne Cathode Test Stand – ACT (2 – 4 MeV)

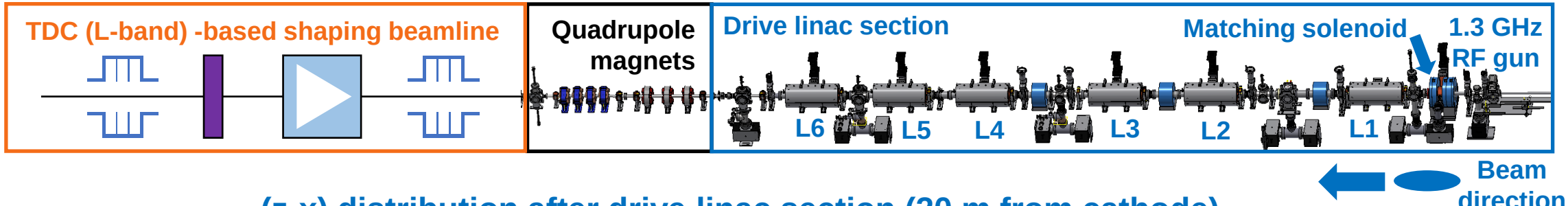
- Cathode research and diagnostics
- Physics of high-gradient breakdown

Experimental Switchyard

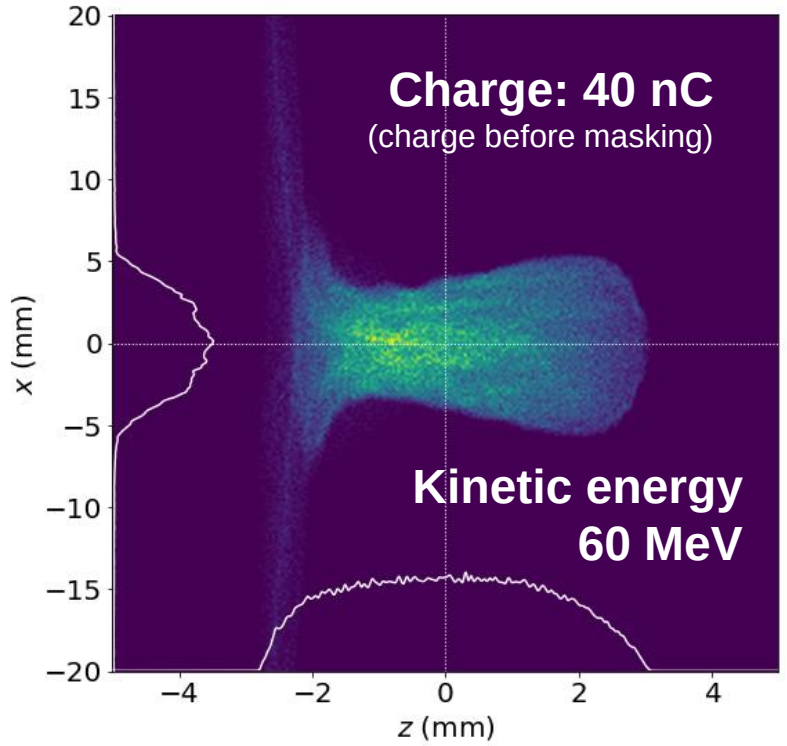
- **Highly reconfigurable beamline**
- **6D beam phase space manipulation**

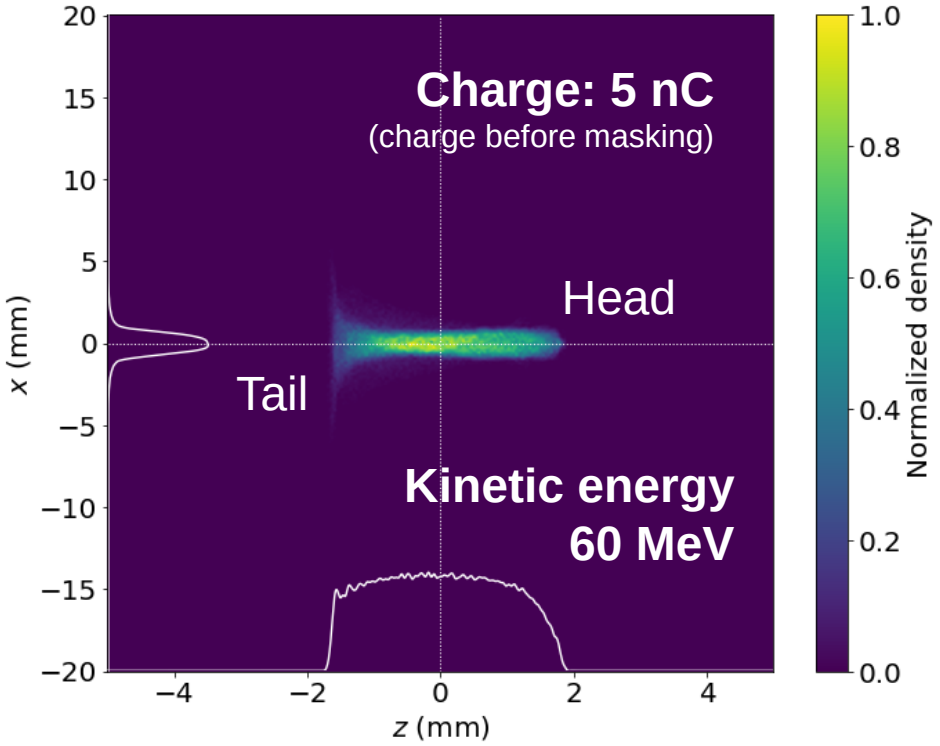
OPAL tracking simulation with AWA drive linac

- OPAL: Adelmann *et al.*, arXiv:1905.06654v1 (2018), https://gitlab.psi.ch/OPAL/src/-/wikis/home

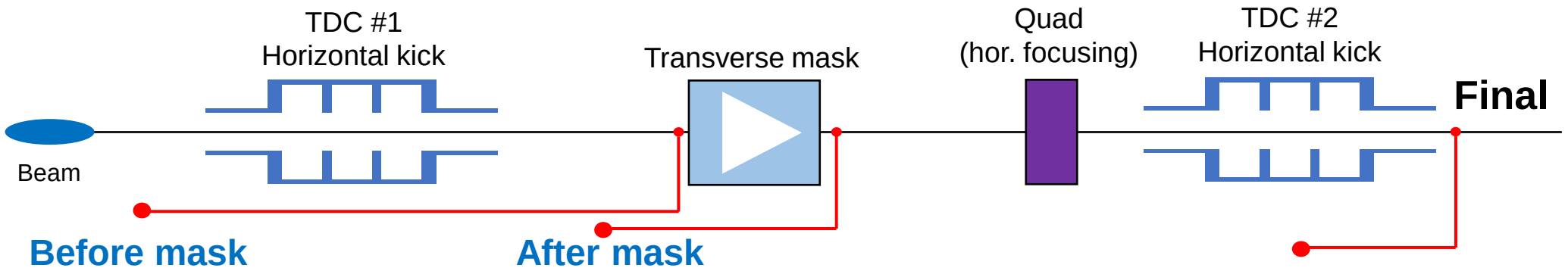


(z-x) distribution after drive linac section (20 m from cathode)

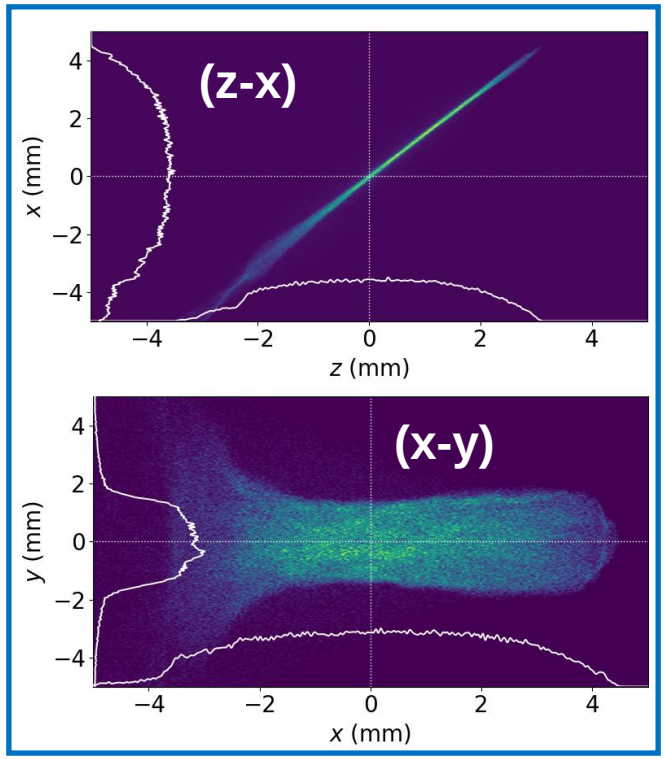




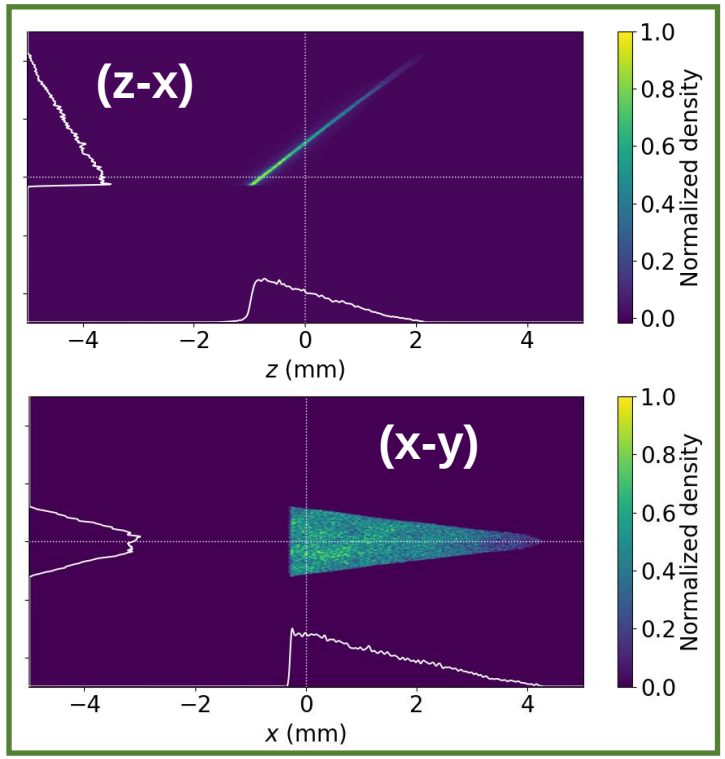
Shaping case 1: triangular distribution: 40 nC case

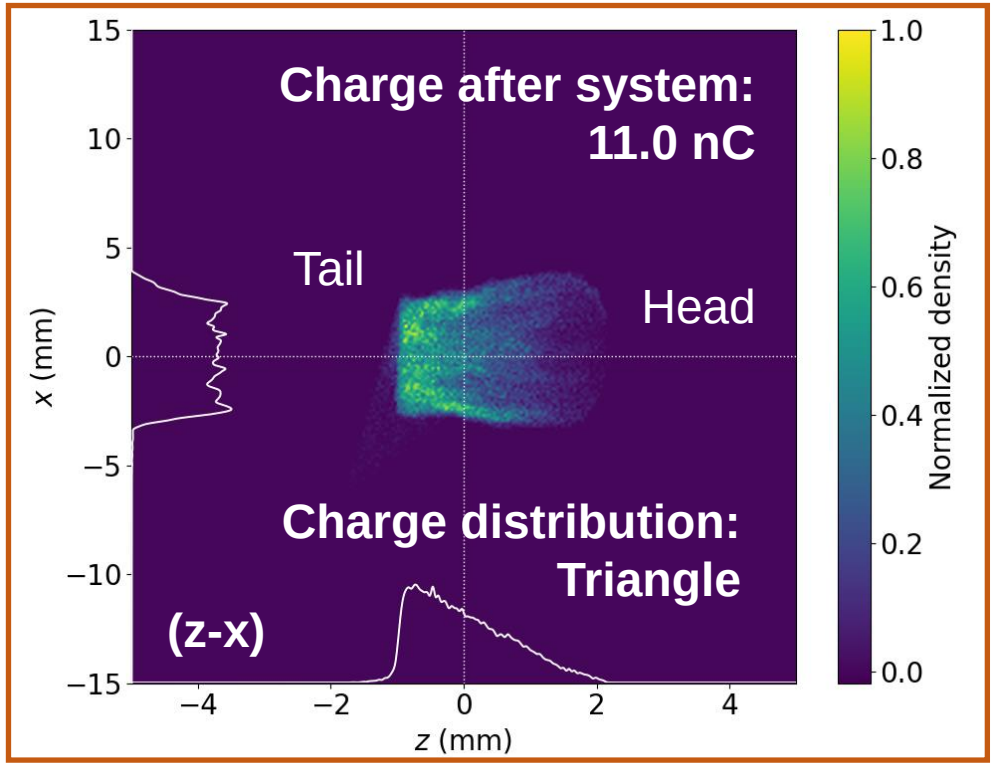


Before mask



After mask

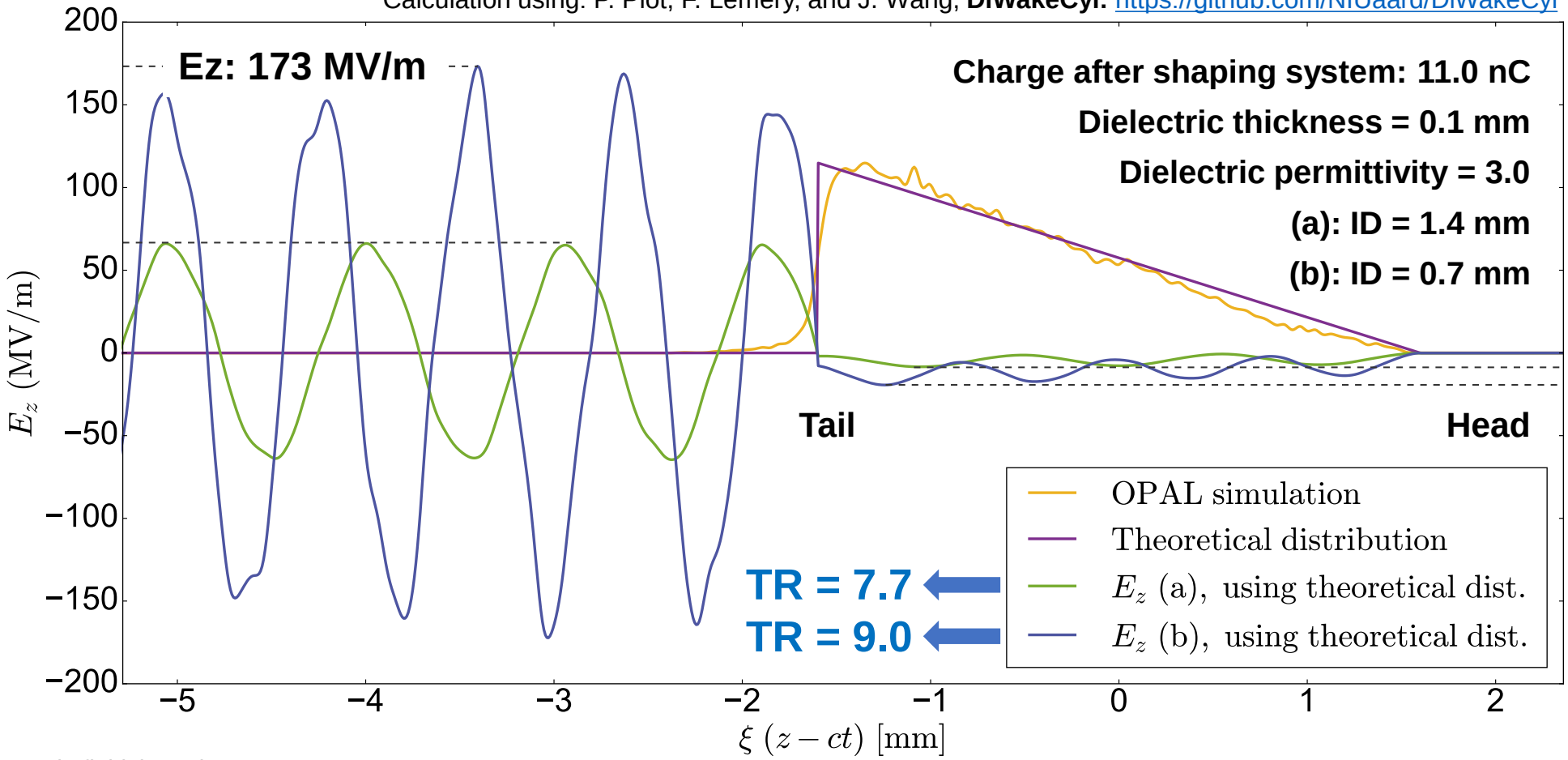




Shaping case 1: triangular distribution: 40 nC case

Calculation using: P. Piot, F. Lemery, and J. Wang, **DiWakeCyl:** https://github.com/NIUaard/DiWakeCyl

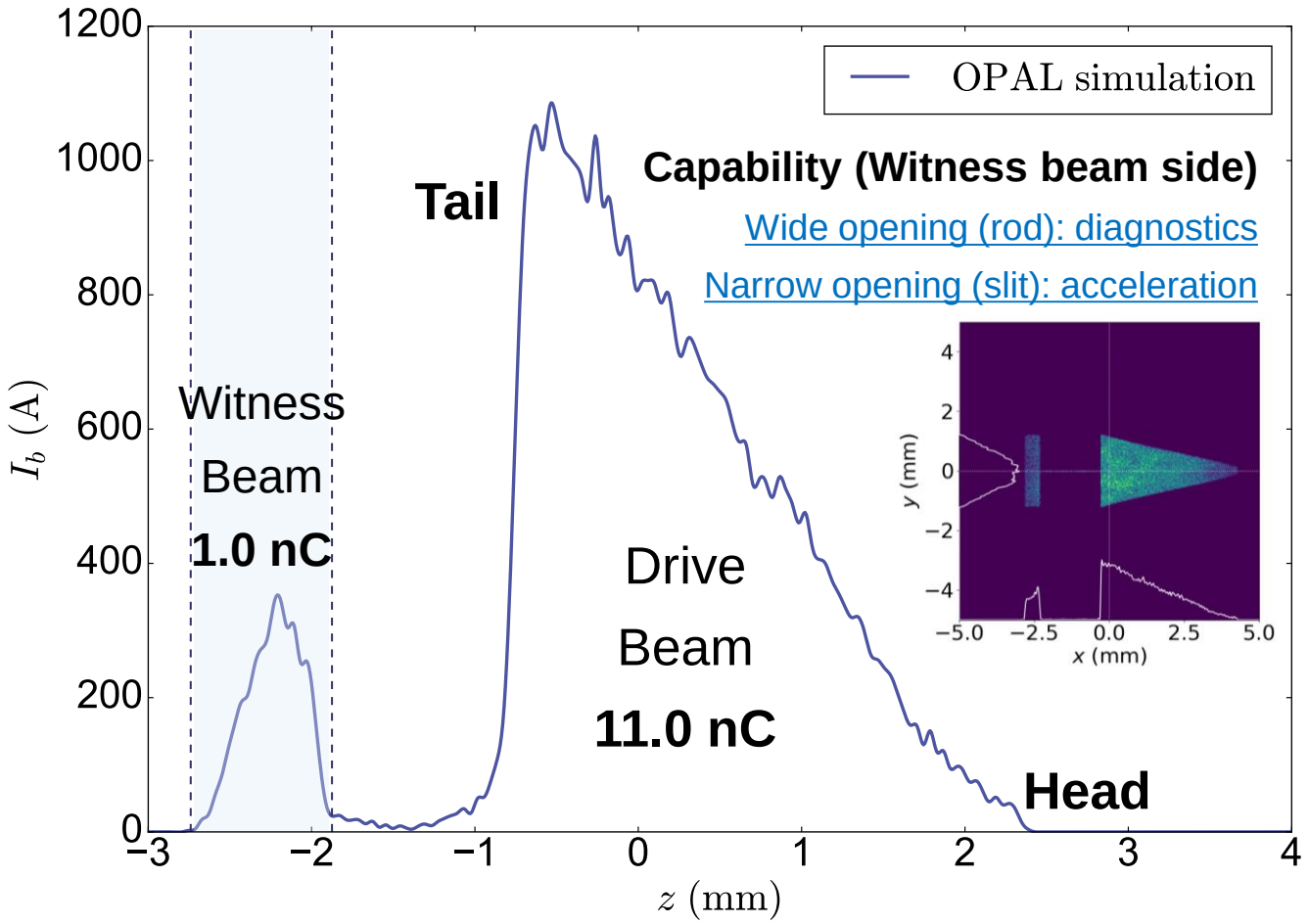
DWA



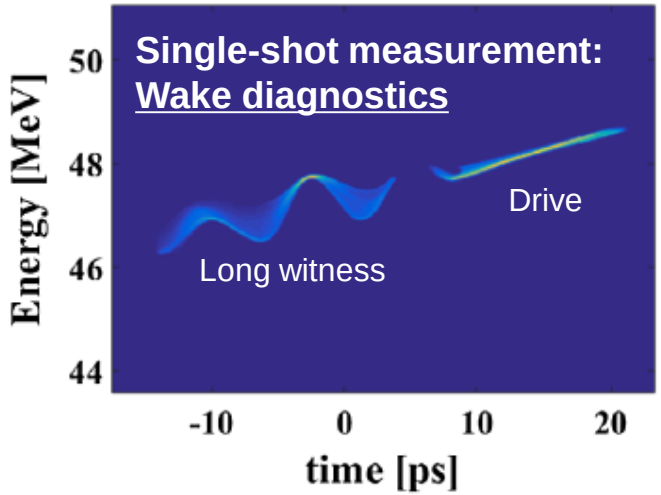
Calculation of the wakefield: based on

- K.-Y. Ng, *PRD* **42**, 1990
- M. Rosing, W. Gai, *PRD* **42**, 1990

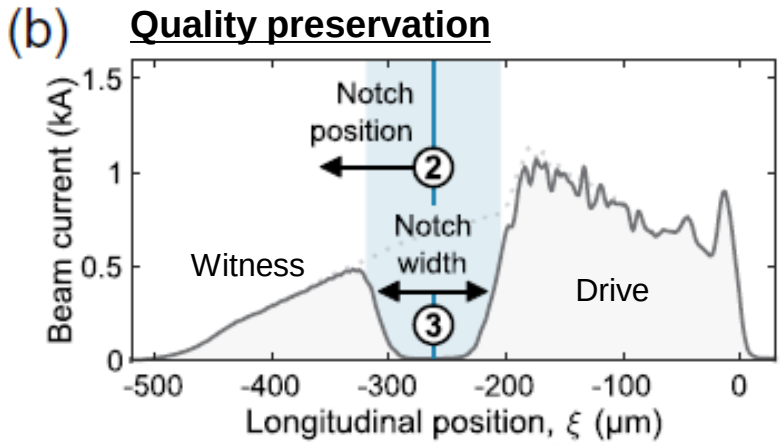
Shaping case 2: shaped drive + witness beam



Gao *et al.*, *PRAB* **21**, 062801, 2018



Witness beam acceleration:
Quality preservation



Lindstrom *et al.*, *PRL* **126**, 014801, 2021

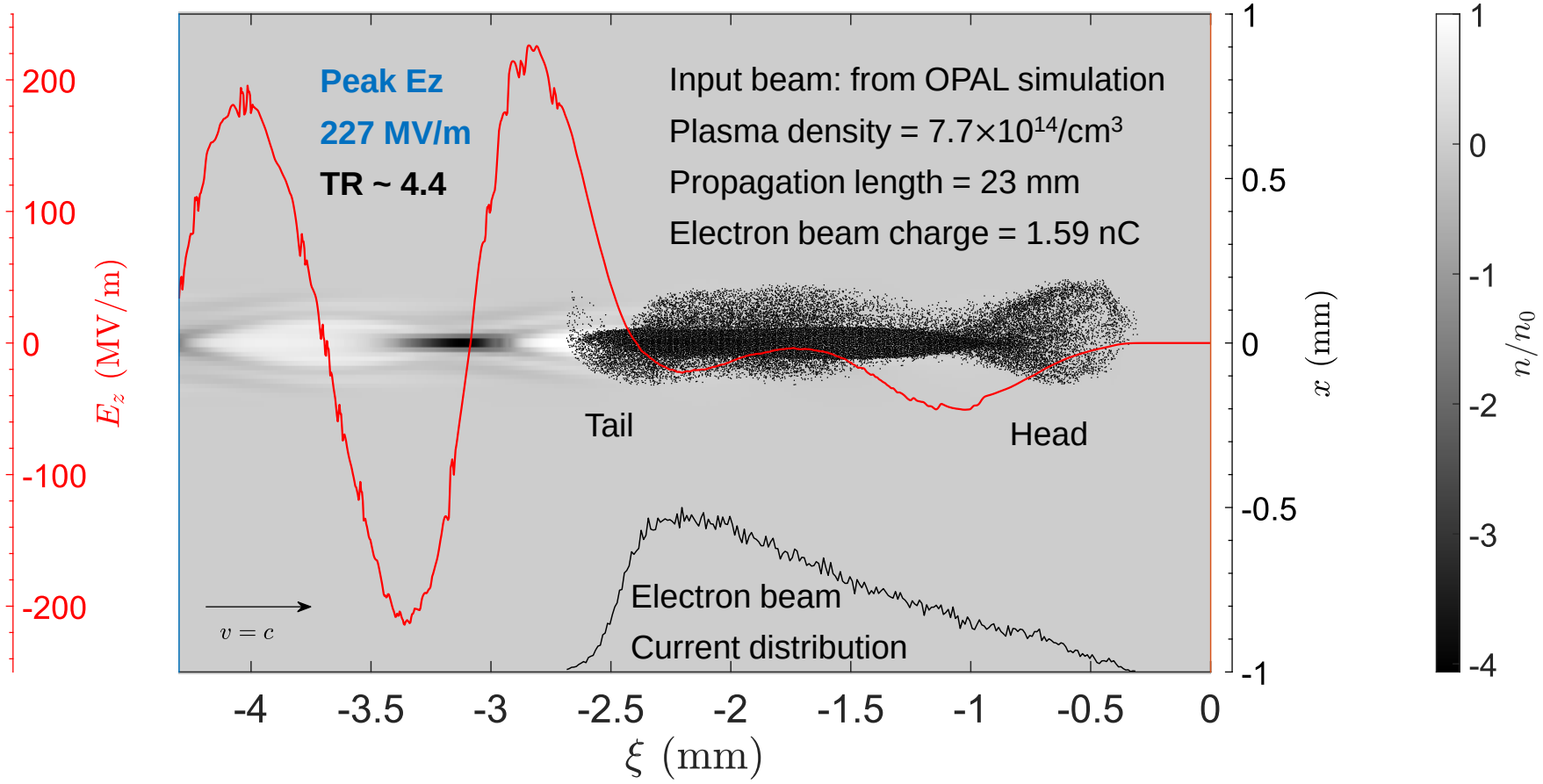
- For versatile, on-line bunch shaping: **multi-leaf collimator (MLC)**
- **Please refer to talk by N. Majernik (UCLA): WG5, Monday, 1:50 pm**

(Beam shaping using an ultra-high vacuum multileaf collimator and emittance exchange beamline)

Shaping case 3: triangular distribution: 5 nC case

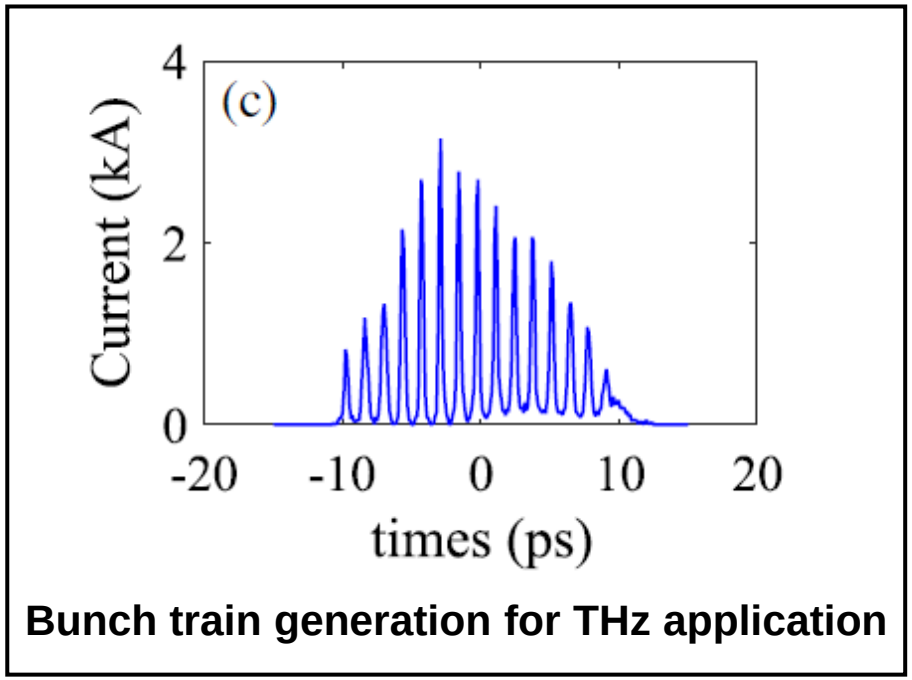
- **Preliminary FBPIC** simulation for beam-driven PWFA (https://github.com/fbpic/fbpic)

PWFA



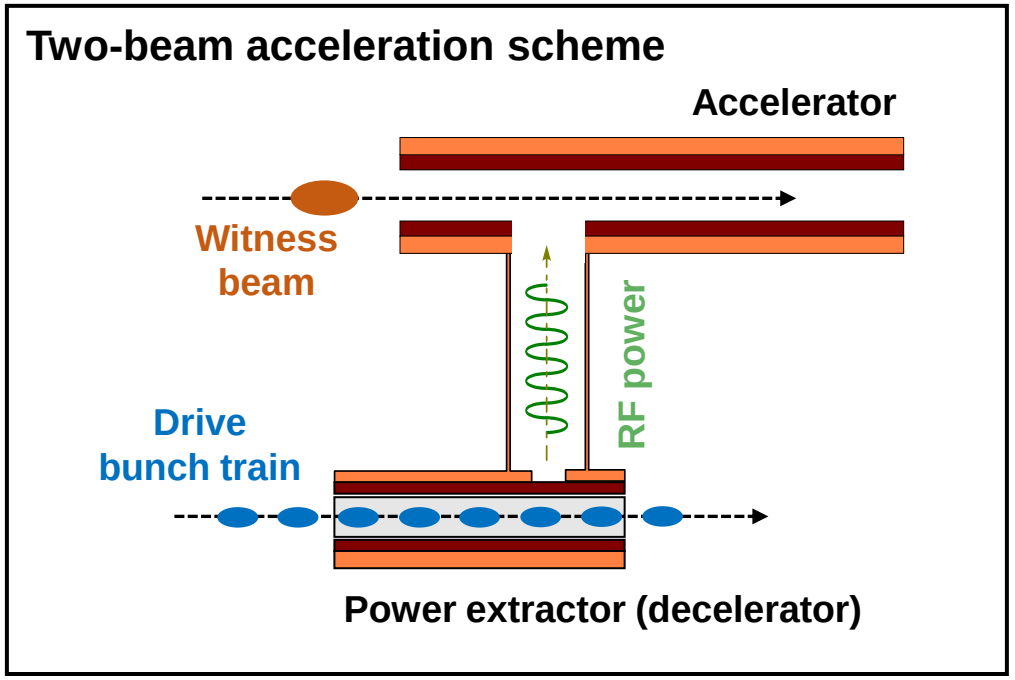
- High-transformer ratio with optimized beam parameters can be achieved:
- Roussel *et al., PRL* **124**, 044802, 2020 ➡ ***TR ~ 8***

Beam manipulation for two-beam acceleration (TBA)



Bunch train generation for THz application

Ha *et al., PRAB* **23**, 072803, 2020.



Experimental demonstration @ AWA:
Jing *et al., NIMA* **898**, 2018.

TDC-based bunch shaping method:
Versatile beam distributions for high-gradient CWA/TBA

Conclusion and future works

- **TDC-based bunch shaping:**
  - **CSR-free, space charge is less considered:** flexible beam manipulation against collective effects is made possible
- **Beam manipulation for high-gradient CWA and TBA**
  - High charge beam can be shaped: **high-gradient + high-transformer ratio**
- **Future plan: Experimental demonstration of bunch shaping using TDCs @ AWA**
  - **Bunch shaping** will be performed using L-band TDC existing in the AWA beamline
  - Experiments such as **high-transformer ratio + beam acceleration** will be carried out with collaborators (Euclid, NIU)
  - Also, **X-band TDC-based shaping driven by power extractor*** is under investigation

***** X-band TDC shaping: Kim *et al., In. Proc.* IPAC'22 (WEZOSP1): **Euclid SBIR project**

Acknowledgements

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Alexis Bibian

Ernest Knight

- **Northern Illinois University**

Philippe Piot

Northern Illinois University