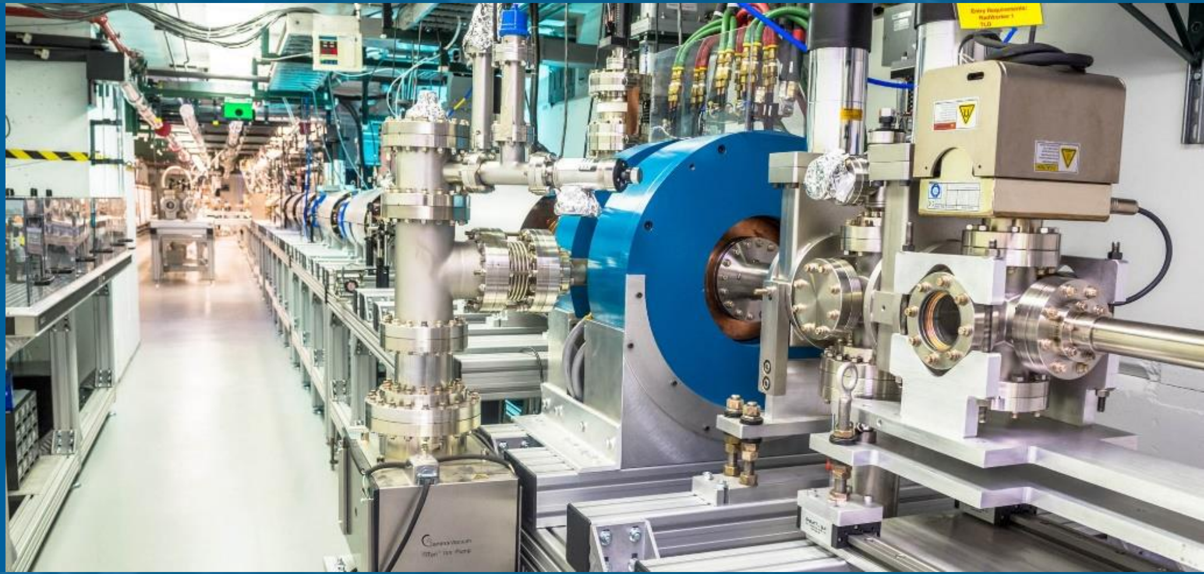
AUGUST 10, 2022

BENCHMARKING SIMULATION FOR AWA DRIVE LINAC AND EEX BEAMLINE USING GPT, OPAL, AND IMPACT-T



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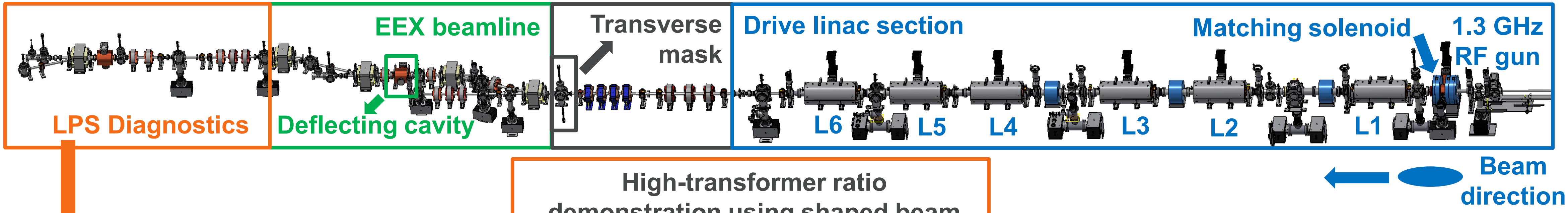
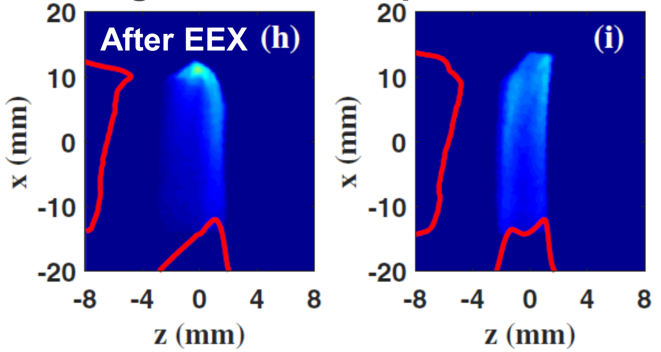
Argonne Wakefield Accelerator Facility

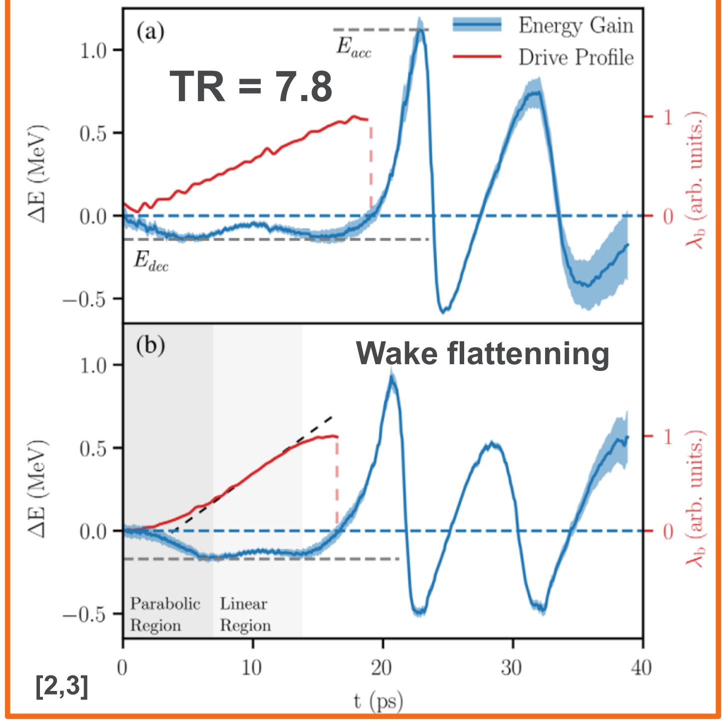
- R&D facility for novel beam manipulation and development of high-gradient, high-efficiency advanced accelerators



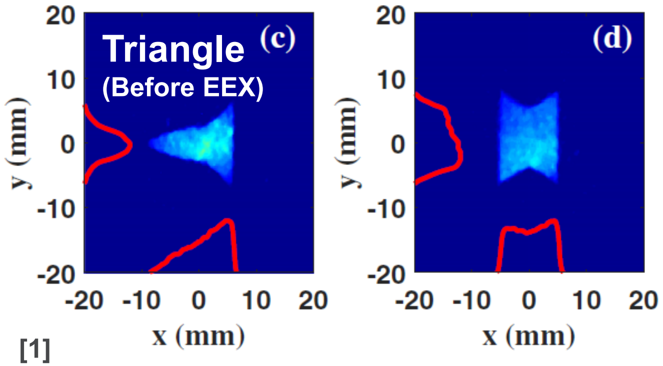
Exchange of transverse to longitudinal beam parameters



High-transformer ratio demonstration using shaped beam



Transverse beam shaping with mask



[1] G. Ha *et al., Phys. Rev. Lett.* **118**, 104801, 2017
[2] Q. Gao *et al., Phys. Rev. Lett.* **120**, 114801, 2018
[3] R. Roussel *et al., Phys. Rev. Lett.* **124**, 044802, 2020

Motivation

For precise beam manipulation:

- ➢ Accurate estimation of the beam parameters from the tracking simulation [4]

Space charge force dominated regime:

- ➢ At low energy regime (near the photocathode)
- ➢ High-charge beam case

Coherent Synchrotron Radiation dominated regime:

- ➢ Emittance exchange (EEX) beamline; two dog-leg sections

Benchmarking simulations were performed using OPAL [5], GPT [6], and Impact-T [7] for i) space charge-dominated regime and ii) CSR-dominated regime

[4] N. Neveu *et al., In. Proc. NAPAC2016*, THPOA46, 2016

[5] A. Adelmann *et al., arXiv:1905.06654v1*, 2019

[6] S. Van der Geer et al., *In. Proc. ICAP2002*, 2002

[7] J. Qiang *et al., Phys. Rev. ST Accel. Beams* **9**, 044204, 2006

OPAL convergence check

➢ **Space charge-dominated regime: AWA drive linac case**

Global parameters range for convergence check

- ➢ Space-charge dominated regime; AWA drive linac was used

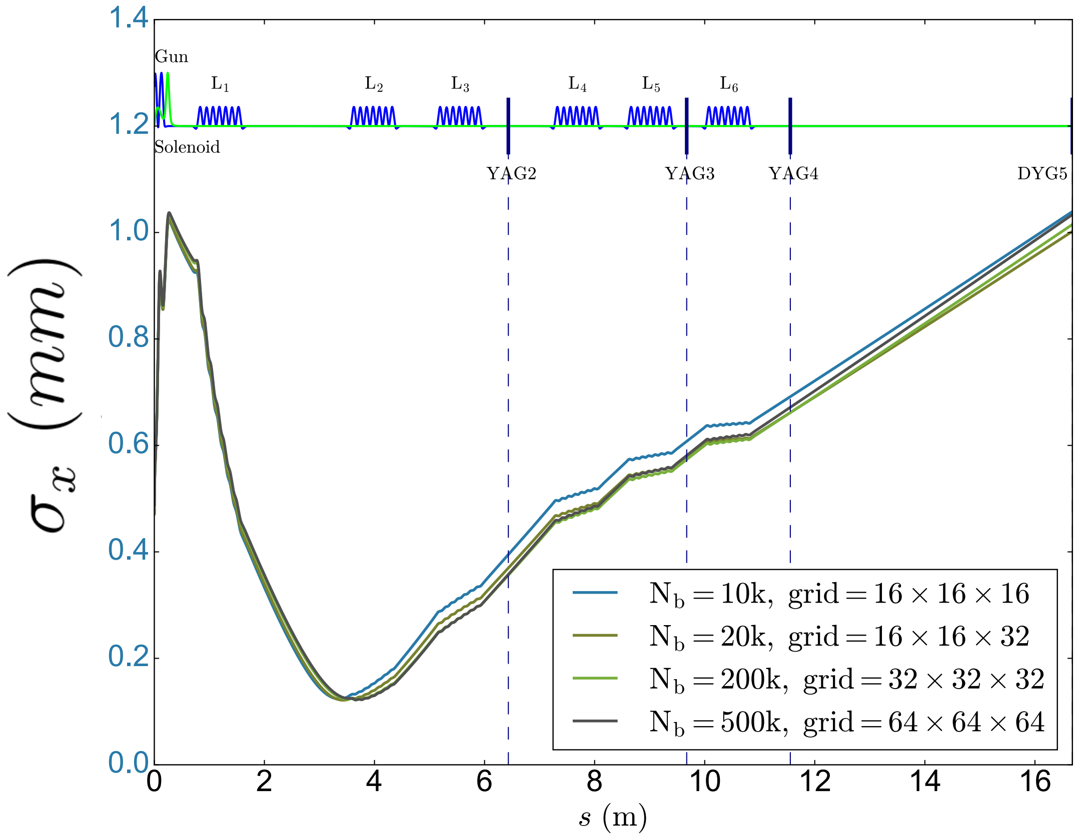
Parameter	Value					
Number of particles	10k	20k	50k	100k	200k	500k
Number of energy bins	**1**	5	10	50	100	
Time step (cavity / drift)	1.0 / 10.0 ps			0.1 / 1.0 ps		
Emission step	100	150	200	**500**	1000	1500
Grid points (x,y,z)	16x16x16	16x16x32	32x32x32	32x32x64	64x64x64	

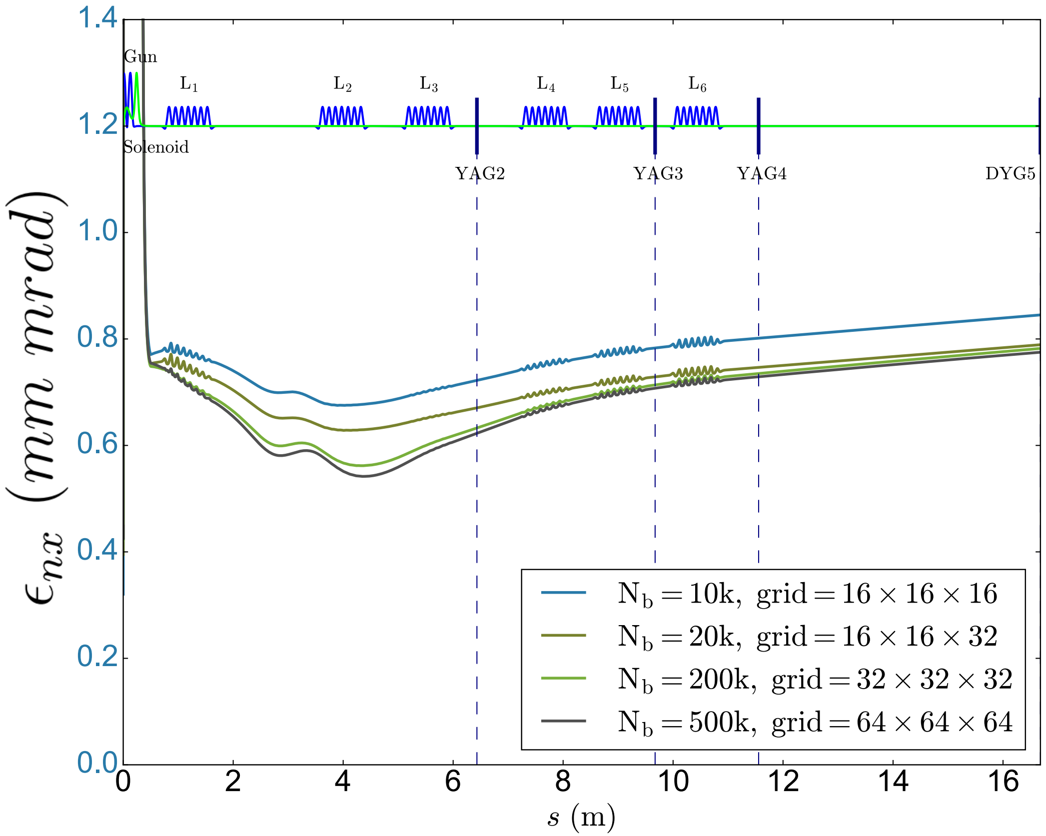
- ➢ Gun and linac cavity phases are set to optimal (maximum energy gain)
- ➢ Number of energy bin: 1 is still valid for RMS beam parameters convergence for short UV pulse
- ➢ Emission step: larger than 500 is valid for RMS beam parameters convergence

- ➢ Transverse beam distribution is set to uniform

Convergence check: 0.1 nC beam charge

➢ **UV pulse length of 0.3 ps** (FWMH), Gaussian longitudinal distribution, B/F solenoid 550 A, Matching solenoid 240 A



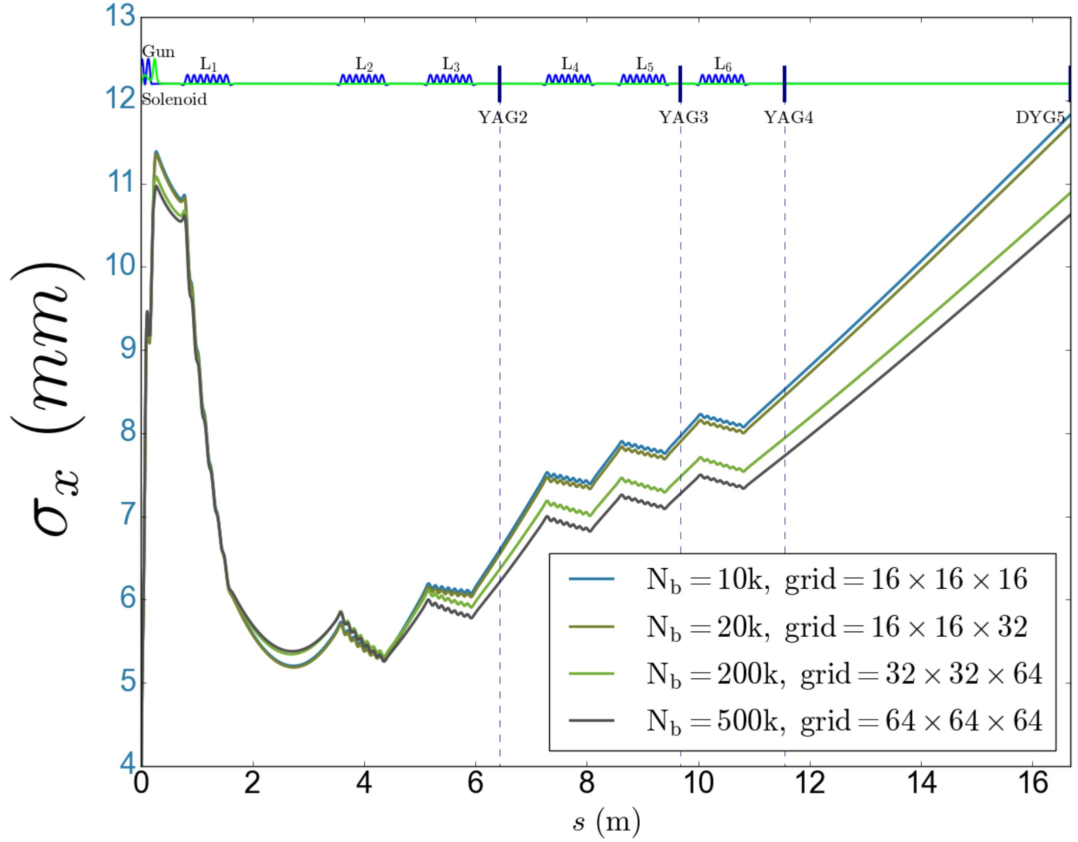


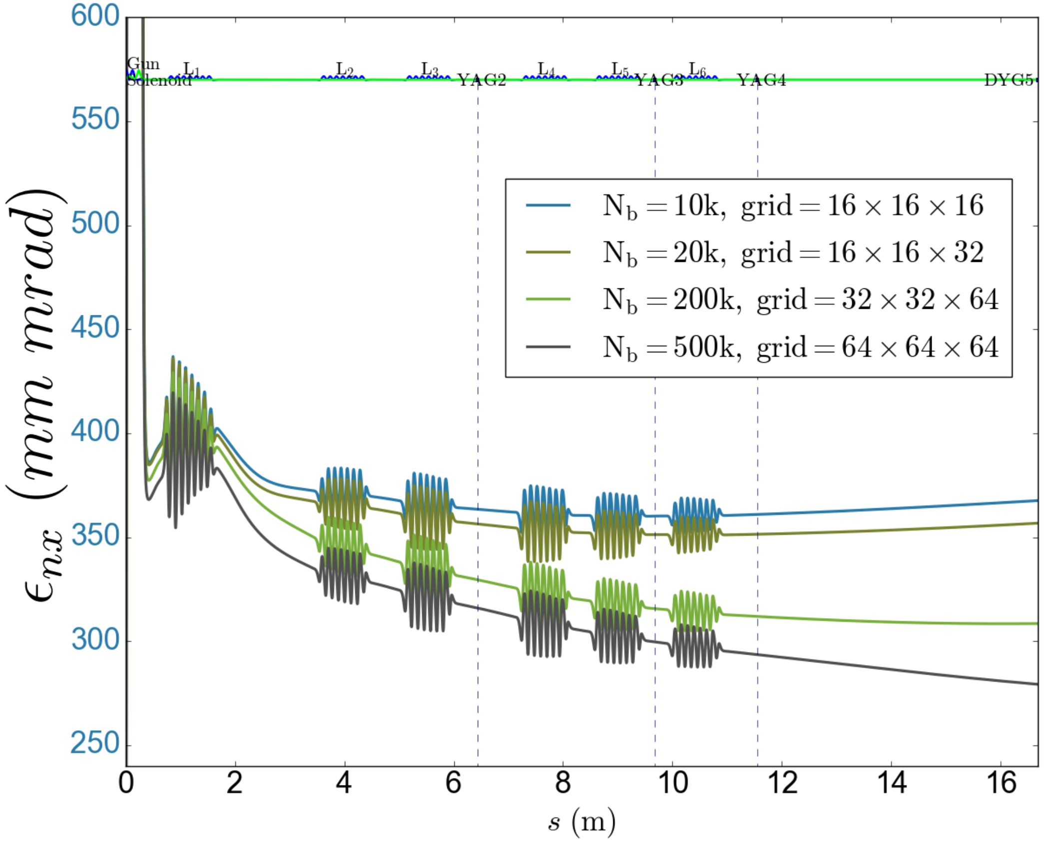
For parameter scan purpose **to check the trend** ➡ **10k** particles and **small grid points** are enough

For precise value from the simulation ➡ **200k** particles with **increased grid points** are required

Convergence check: 50.0 nC beam charge

➢ **UV pulse length of 0.3 ps** (FWMH), Gaussian longitudinal distribution, B/F solenoid 550 A, Matching solenoid 240 A





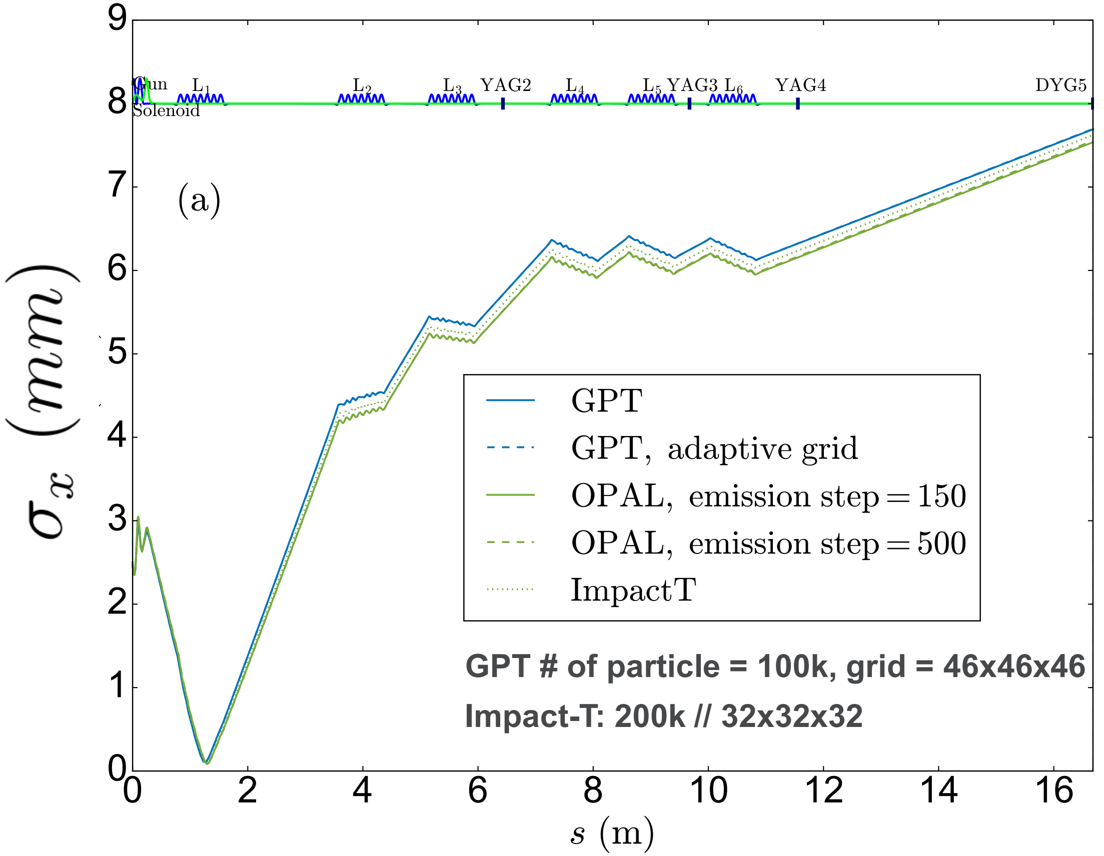
In case where the beam charge is very large ➡ more convergence check with **increased number of particles in each cell** is needed

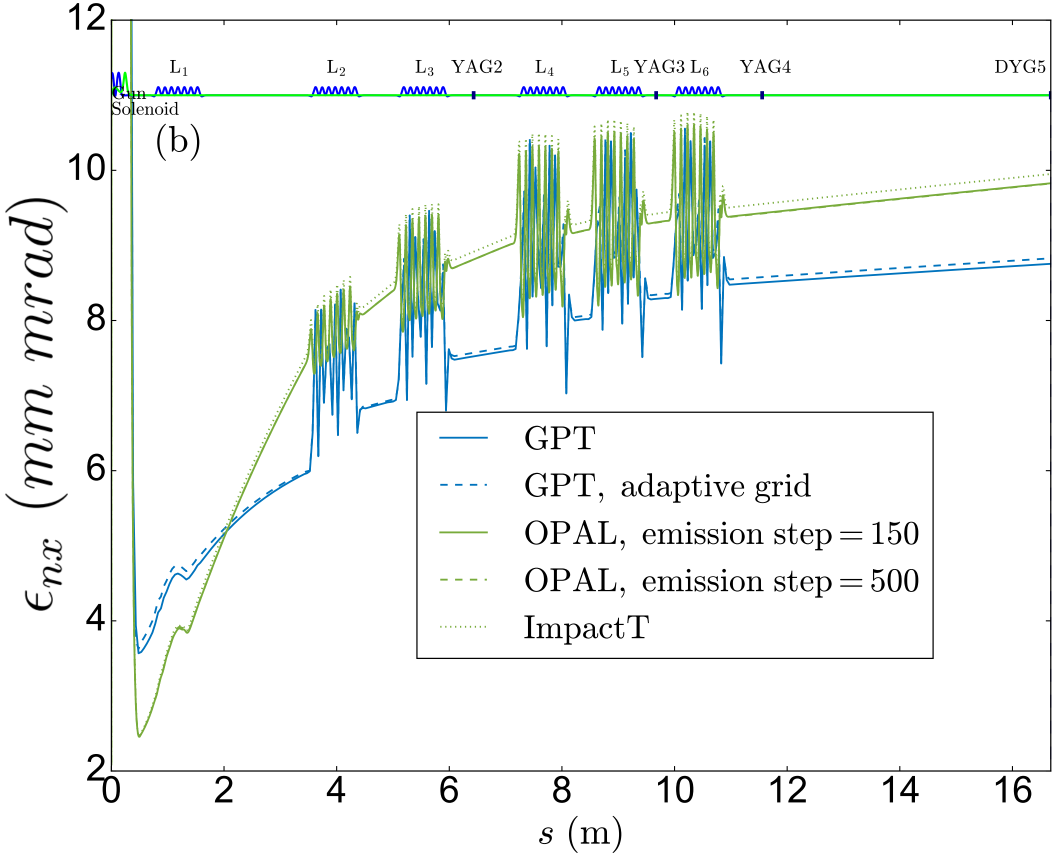
OPAL / GPT / Impact-T comparison

➢ **Space charge-dominated regime: AWA drive linac case**

Case 1: 0.1 nC beam charge, UV radius=5.0 mm

➢ **UV pulse length: 0.3 ps (FWHM), Gaussian longitudinal distribution**, B/F solenoid: 550 A, matching solenoid: 240 A



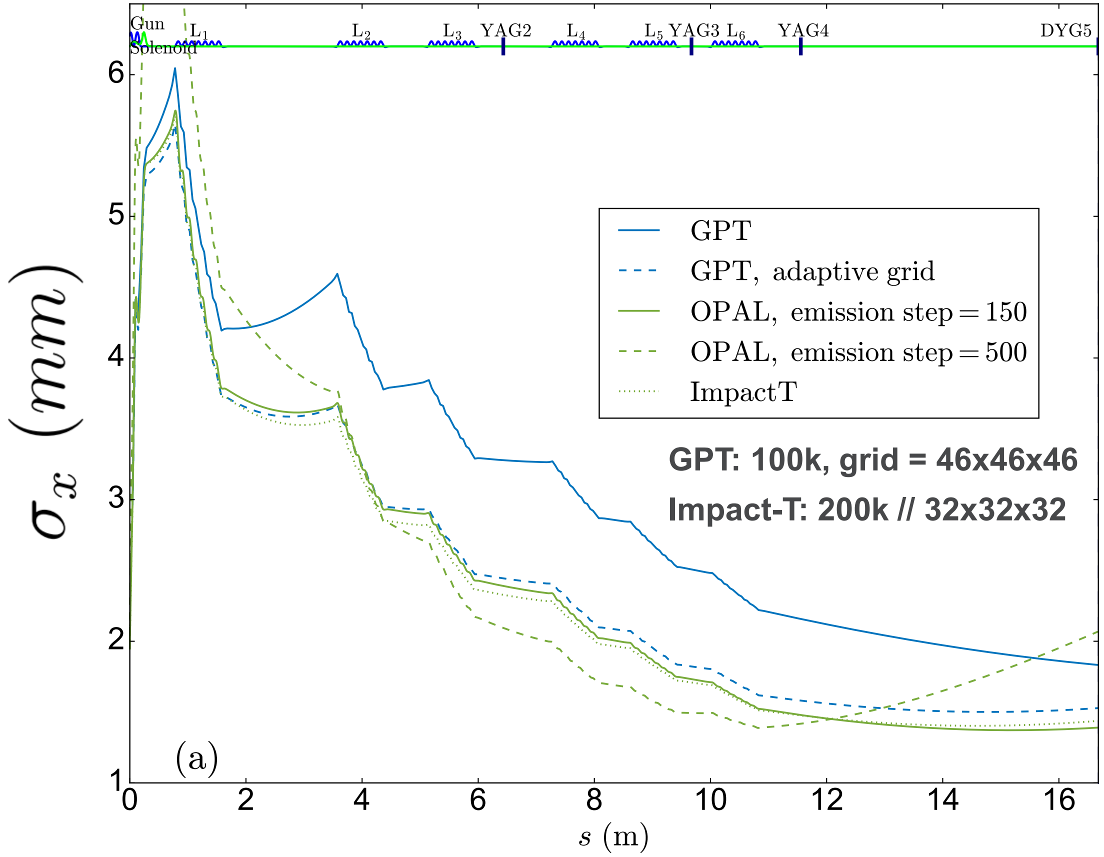


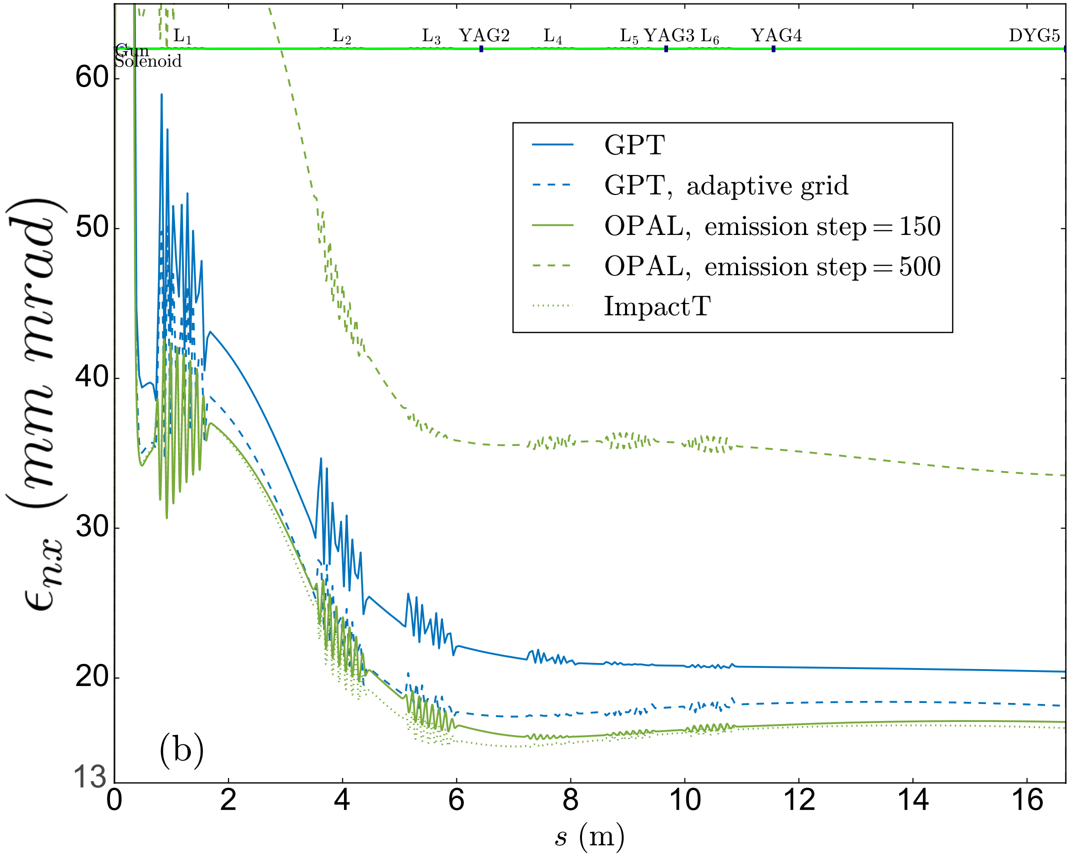
By using larger UV radius ➡ **Mitigation of space charge force** near cathode

Simulation results are reasonably agreed in terms of trend (except for the emittance after RF gun)

Case 2: 10.0 nC beam charge, UV radius=4.0 mm

➢ **UV pulse length: 0.3 ps (FWHM), Gaussian longitudinal distribution**, B/F solenoid: 550 A, matching solenoid: 240 A





Strong space charge force near the cathode is expected

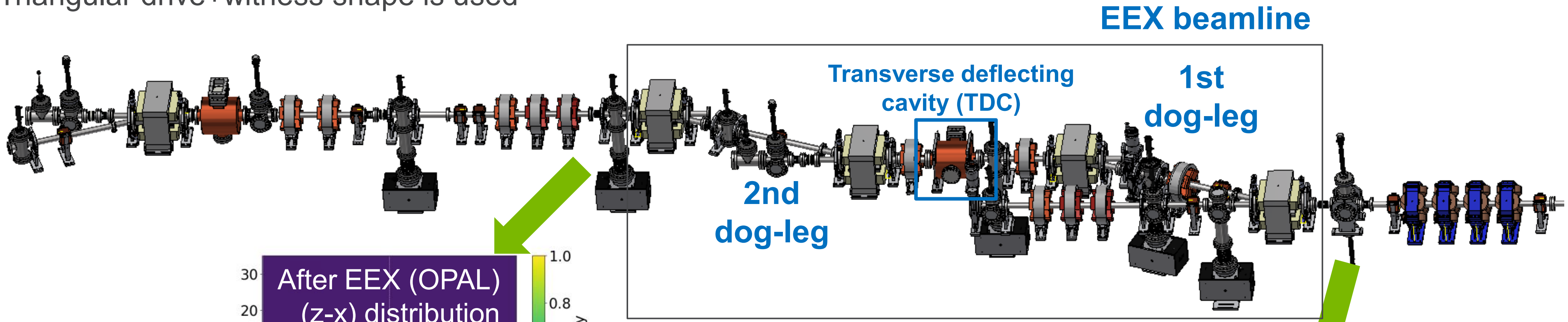
➡ **Less emission steps provides more reasonable results**

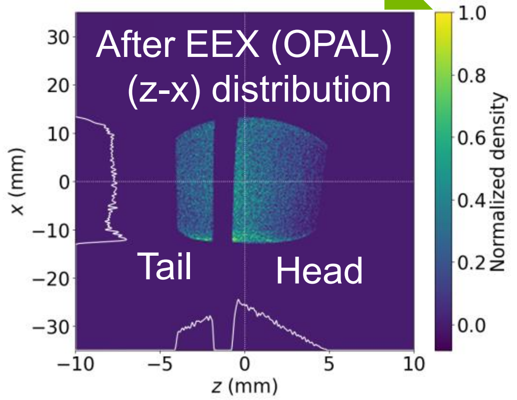
OPAL / Impact-T comparison

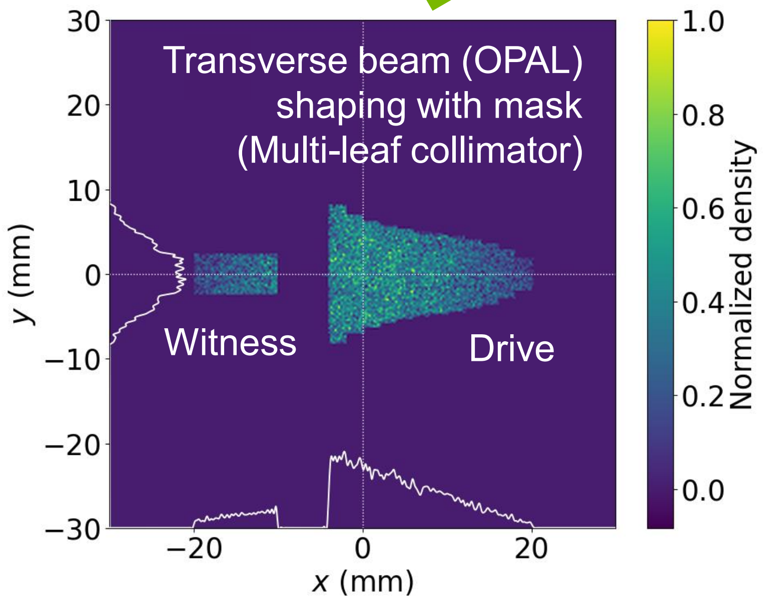
➢ CSR-dominated regime: EEX beamline case

EEX beamline comparison

- Triangular drive+witness shape is used



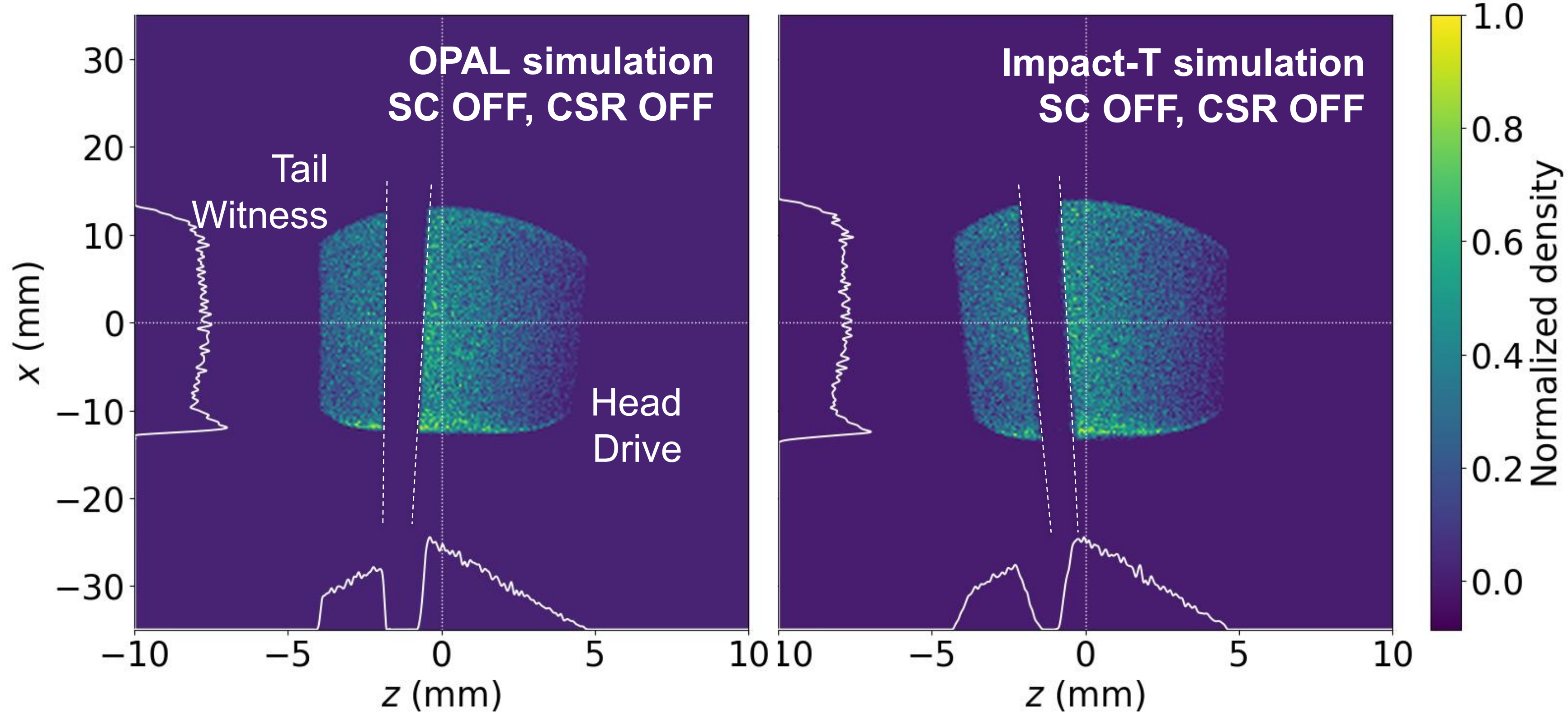




- **EEX beamline**: can be utilized for various bunch shaping such as triangular distribution for high-transformer ratio of wakefield [1-3]
- **Please see N. Majernik *et. al.*, TUPA85 paper for more details on EEX-based longitudinal bunch shaping using multi-leaf collimator**

Comparison: longitudinal emittance, final z-x distribution

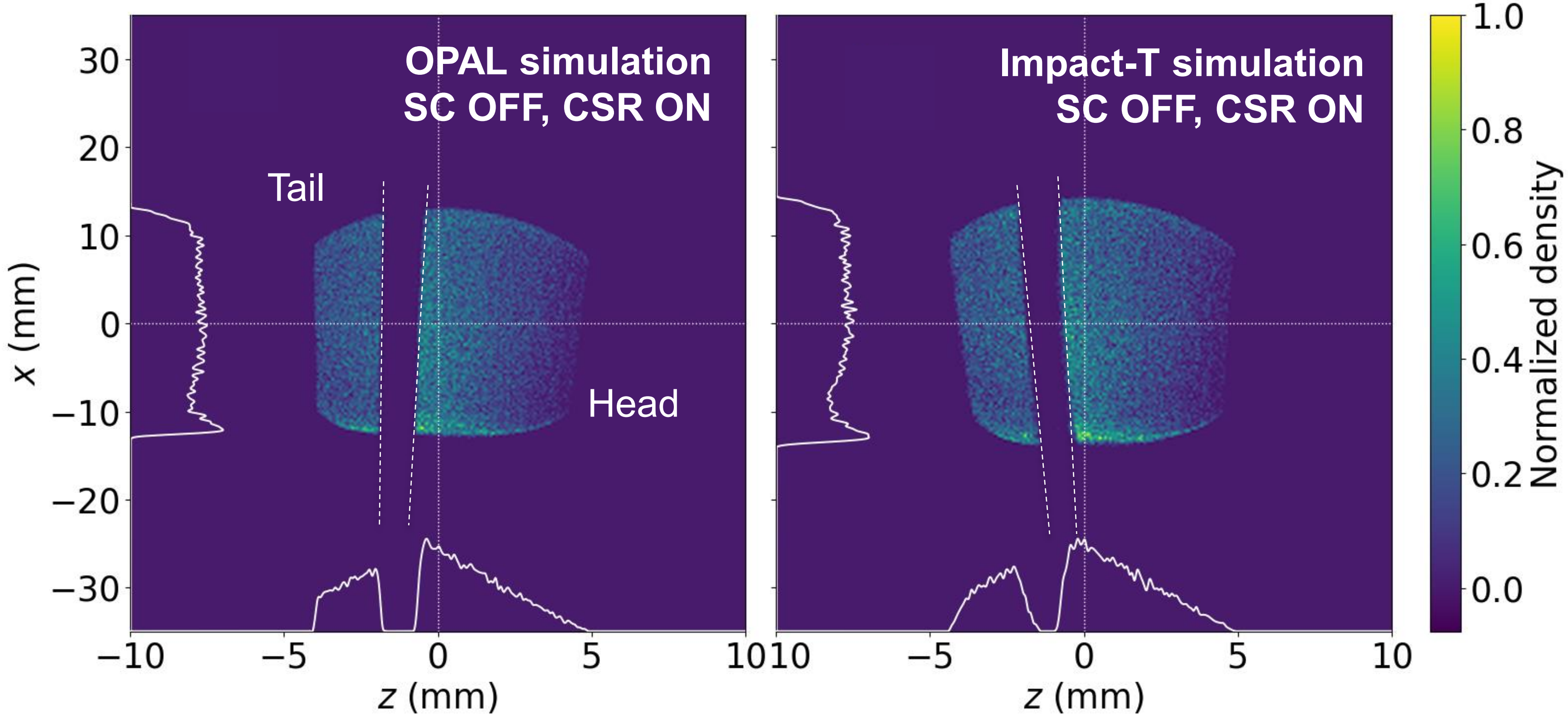
- OPAL // Impact-T simulation results: **After EEX beamline**



Without any collective effects ➡ distortion is expected to be due to slightly different TDC phase setting

Comparison: longitudinal emittance, final z-x distribution

- OPAL // Impact-T simulation results: **After EEX beamline**



Future works: analysis should be done using the case where the CSR effect is clearly shown

Conclusion and future works

- **Benchmarking simulation has been performed for studies on AWA's drive linac and EEX**
  - OPAL convergence check: **for high charge more than 10.0 nC, more convergence check** with increased number particles in each cell is needed

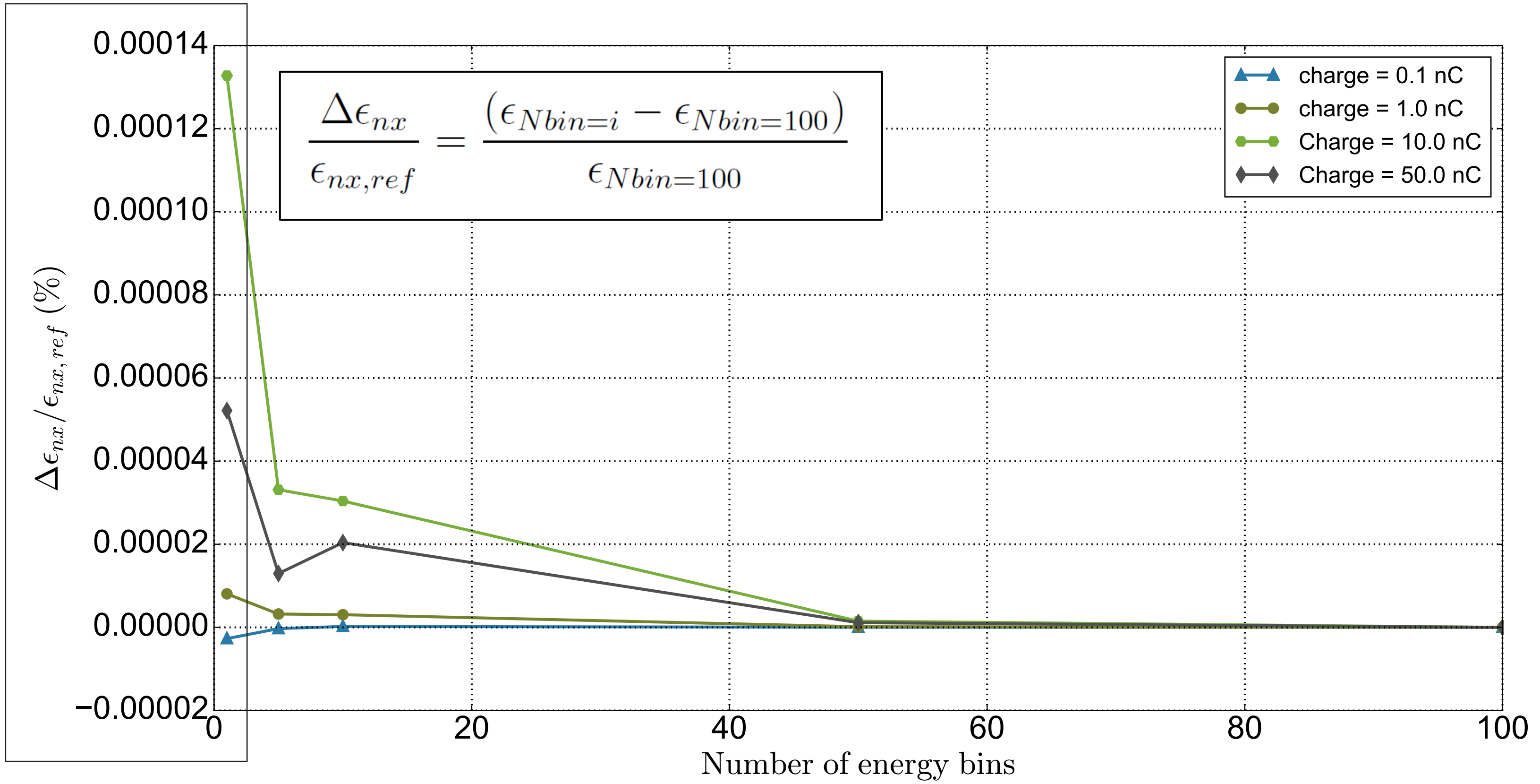
- **Drive linac benchmarking simulation provides an information about**
  - **For low charge and low space charge force:** OPAL/GPT/Impact-T simulation trends are in reasonable agreement
  - When **strong space charge force near the cathode** is expected:
    - **100~150 EMISSIONSTEPS in OPAL** gives reasonable results compared to GPT/Impact-T
    - **More analysis with 6D phase space will be carried out**

- **Emittance Exchange beamline simulation for CSR investigation**
  - Systematic comparison is needed with specific case where the CSR effects are clearly shown
    - **Analysis on 6D phase space** after dipole to check the **deviation induced by the CSR effect**

Back-up slides

Parameter scan: varying number of energy bins

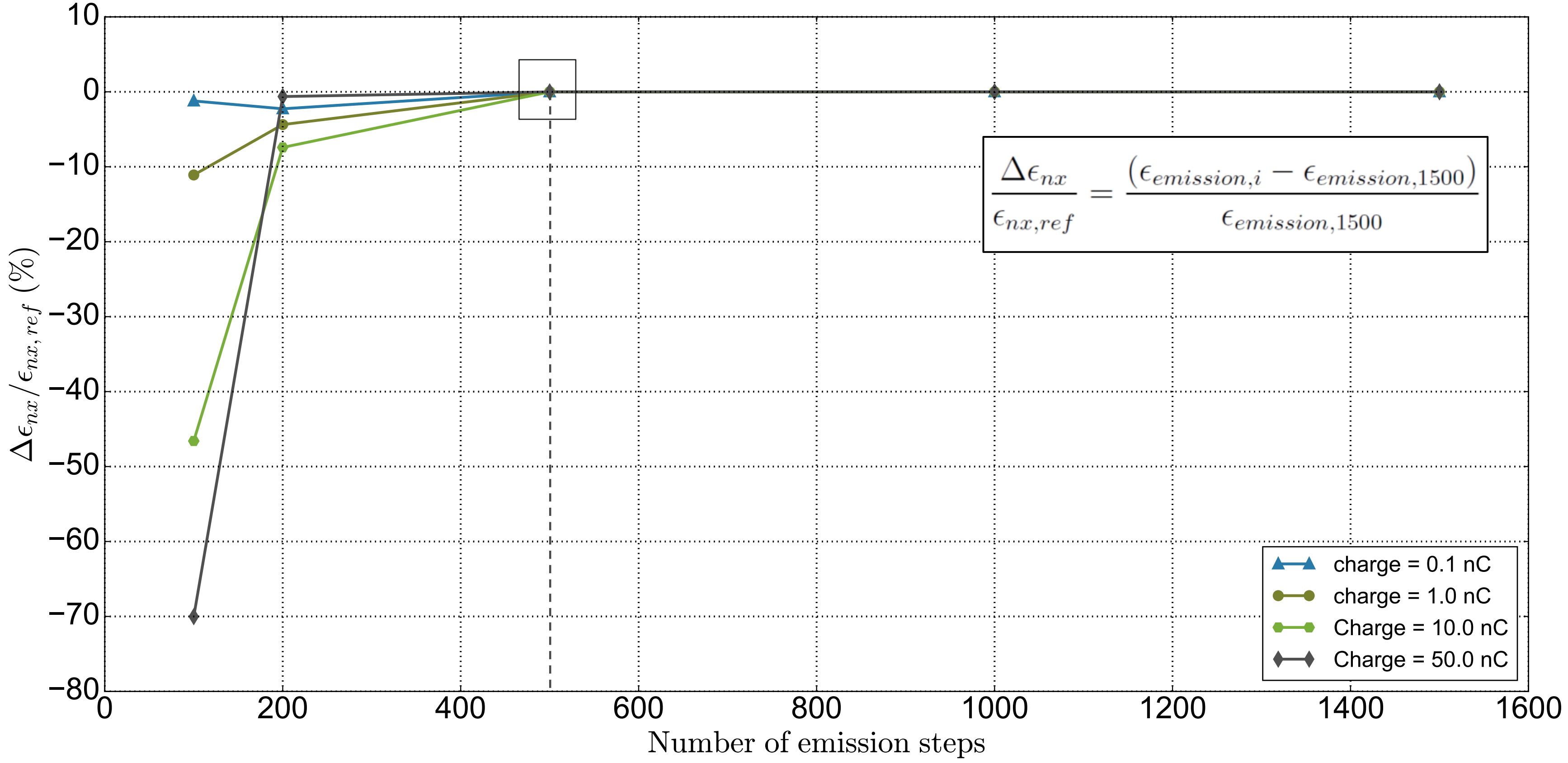
- Initial UV pulse length is 0.3 ps FWHM (short one)



Difference is very small → we do not need to consider using many number of energy bins for high-resolution for space charge with different fractional energy distribution along the bunch

Parameter scan: varying number of emission step

- Timestep at the gun is 1.0 ps, initial UV pulse length is 0.3 ps FWHM (short one)



Emittance difference is minimized and converged when the emission step becomes 500 or larger

→ Time step at the gun (near the cathode) becomes 2.0 fs