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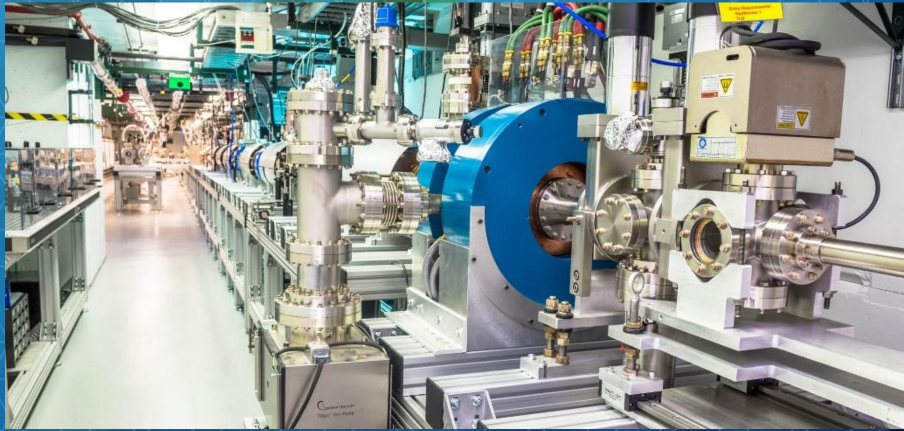
Progress Toward Experiments on an Integrated 10-MeV X-band Photoinjector Powered by a Two-Beam Acceleration Technique



EMILY FRAME
Graduate Student
Northern Illinois University

U.S. DEPARTMENT OF ENERGY
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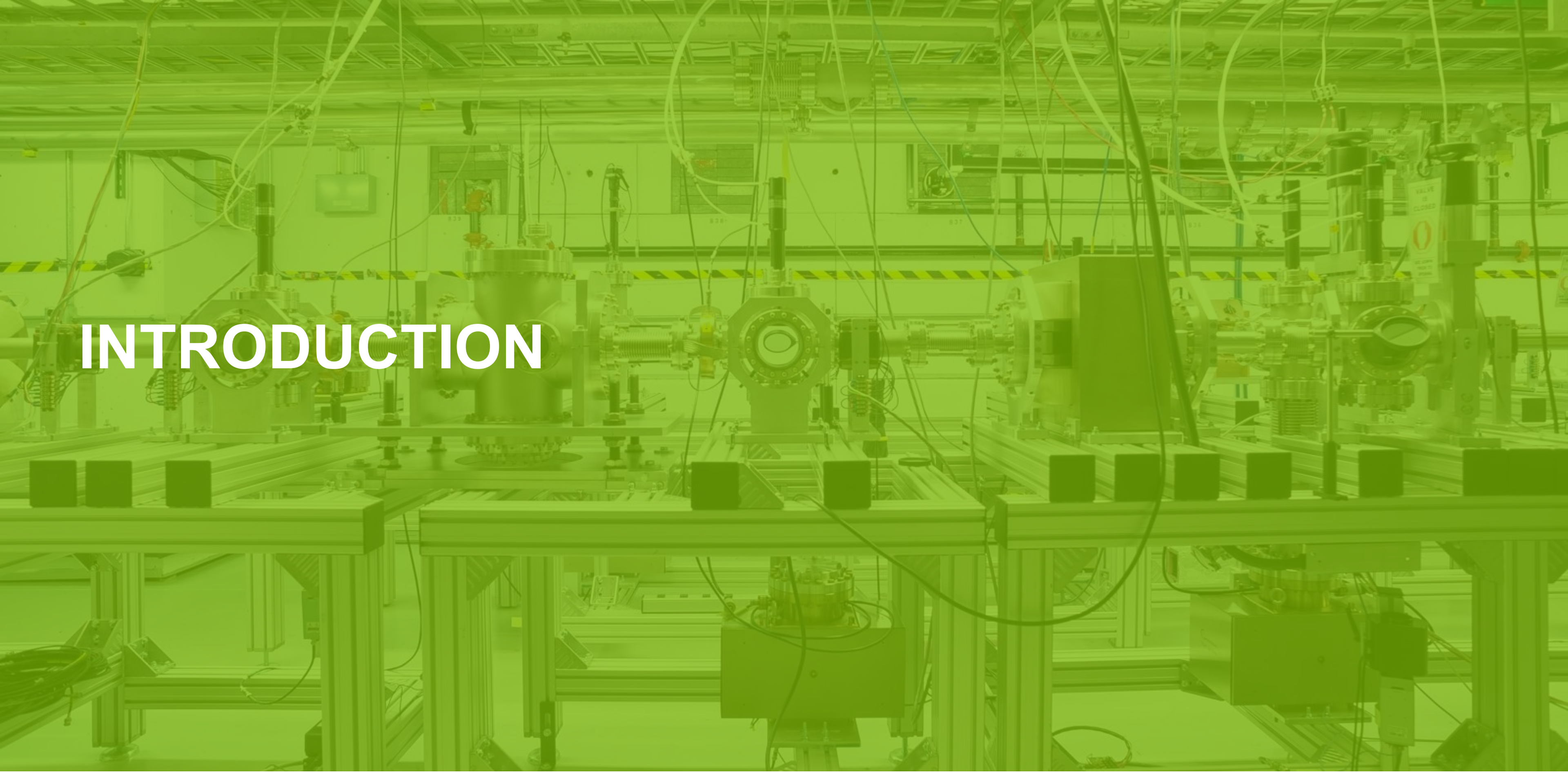
OVERVIEW

- Introduction & Motivation:
  - the x-band high-gradient photoinjector
- Methods:
  - numerical simulation tools
- Results
- Conclusion and Outlook

INTRODUCTION



High-Brightness Beams: why high gradients?

- High-brightness electron beams have been critical to recent accelerator developments
  - X-FELs
  - UED and UEM
- Bright beams combined with high-gradient acceleration and short-period undulators could enable the next-generation of compact X-ray FELs
- In photoemission electron sources, the brightness scales as

field experienced at emission

4D beam brightness (ideally invariant)

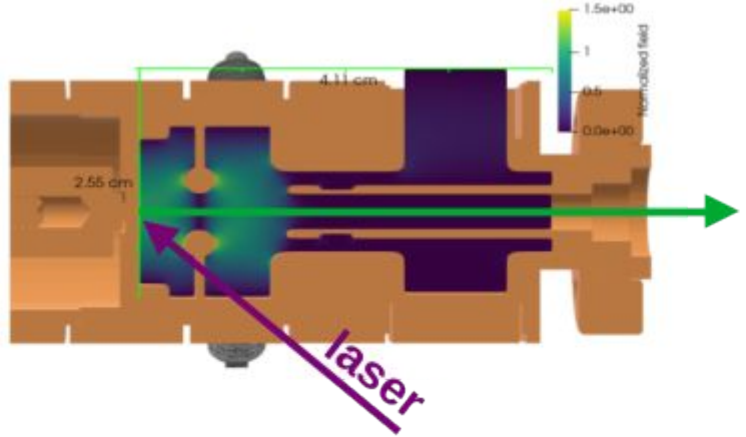
$$\mathcal{B} \propto \frac{E_0^{\nu}}{\mathrm{MTE}}$$

depends on initial aspect ratio of the beam

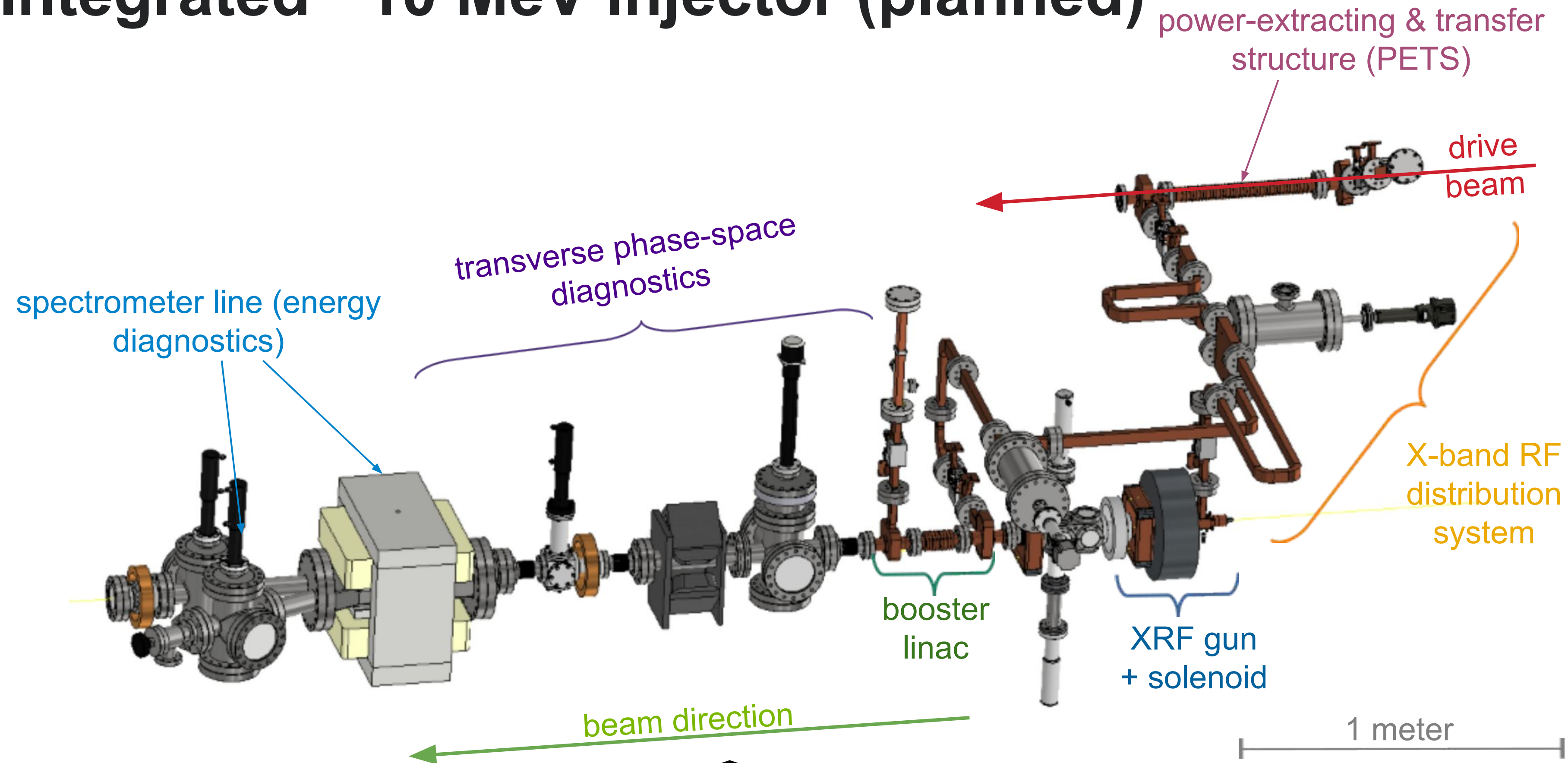
mean-transverse energy (a property of the photocathode)

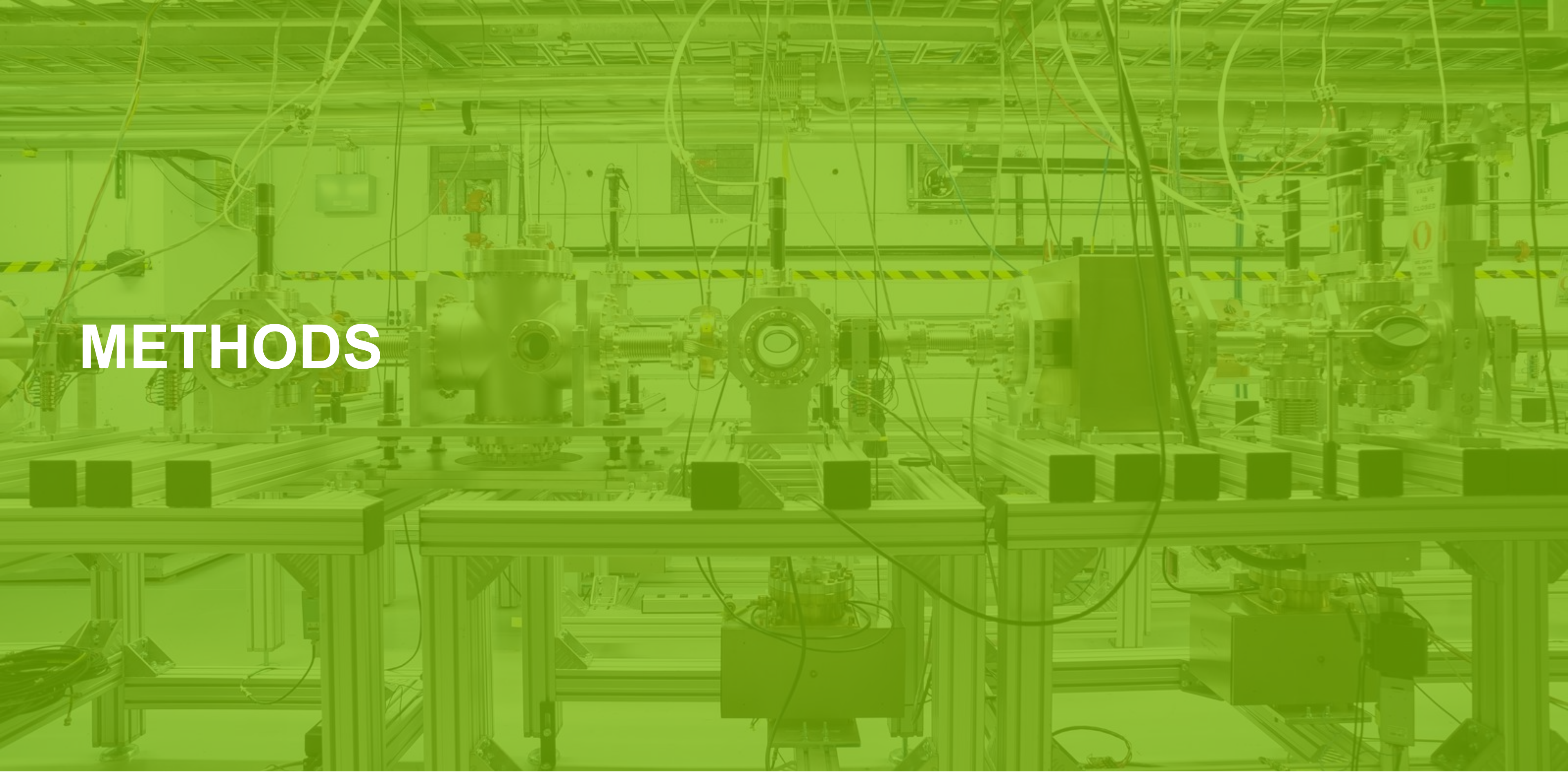
The x-band high-gradient photoinjector

- Collaboration between AWA, Euclid Techlabs, and NIU to develop an X-band photoinjector that operates at sub-GV/m gradients
- Xgun: 11.7 GHz, 1 + ½ cell gun with high-power, short RF pulses (~9 ns) supplied by AWA’s drive-beam linac
  - driven by UV laser
- The gun was successfully operated:
  - supports cathode E-field ~0.4 GV/m
  - enabled exploration of photoemission in the high-field regime
- Next phase is to accelerate the beam in using a short booster linac using the current hardware



Integrated ~10 MeV injector (planned)





METHODS

Particle Tracking in Astra

- Astra represents the beam as a collection of macroparticles, each representing many electrons, and integrates these equations of motion in (r, p):

$$\dot{\mathbf{r}} = \frac{\mathbf{p}}{m\gamma}$$

$$\dot{\mathbf{p}} = q(\mathbf{E} + \frac{\mathbf{p}}{m\gamma} \times \mathbf{B})$$

where E and B are fields composed of the external accelerating and focusing fields and the self-fields due to space-charge.

Particle Tracking in Astra

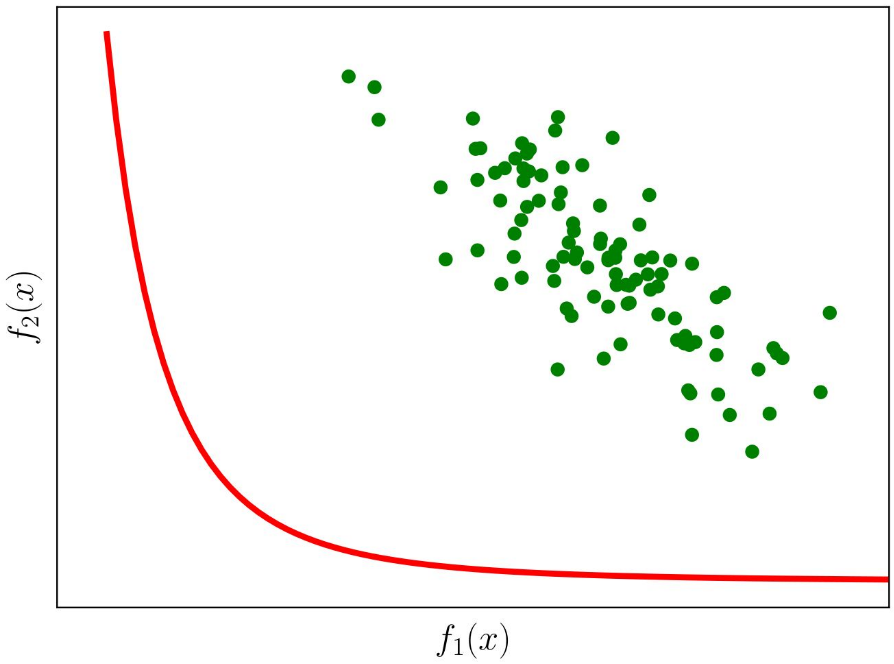
- Fields in Astra are described by their on-axis component and then expanded assuming cylindrical symmetry
- Time-dependent fields are represented by

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E}(\mathbf{r}) cos(\omega t + \phi)$$
$$\mathbf{B}(\mathbf{r}, t) = \mathbf{B}(\mathbf{r}) sin(\omega t + \phi)$$

- Astra tracks the beam through a user-specified beamline and computes the moments of the distributions and beam emittances at each time-step.

Multi-objective Optimization

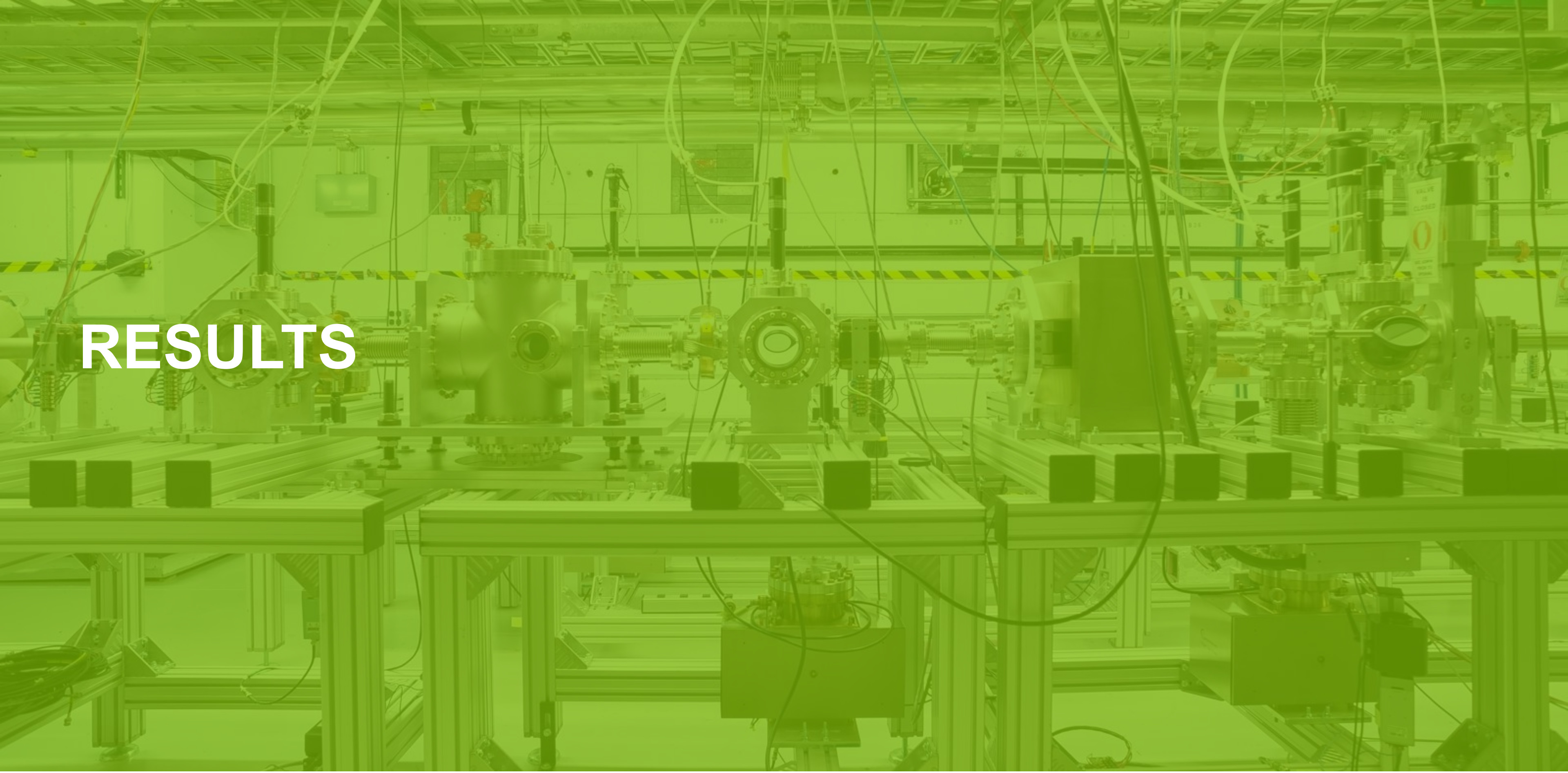
- This project used multi-objective optimization performed with Deap, which minimizes multiple objective functions $f_i\,(h)\ (i = 1,\,2,\,\ldots\,N)$ where h is a set of control parameters
- Deap produces a “hall of fame” set of points that contains settings for the control parameters that give non-dominated solutions, referred to as Pareto fronts.



Multi-objective Optimization

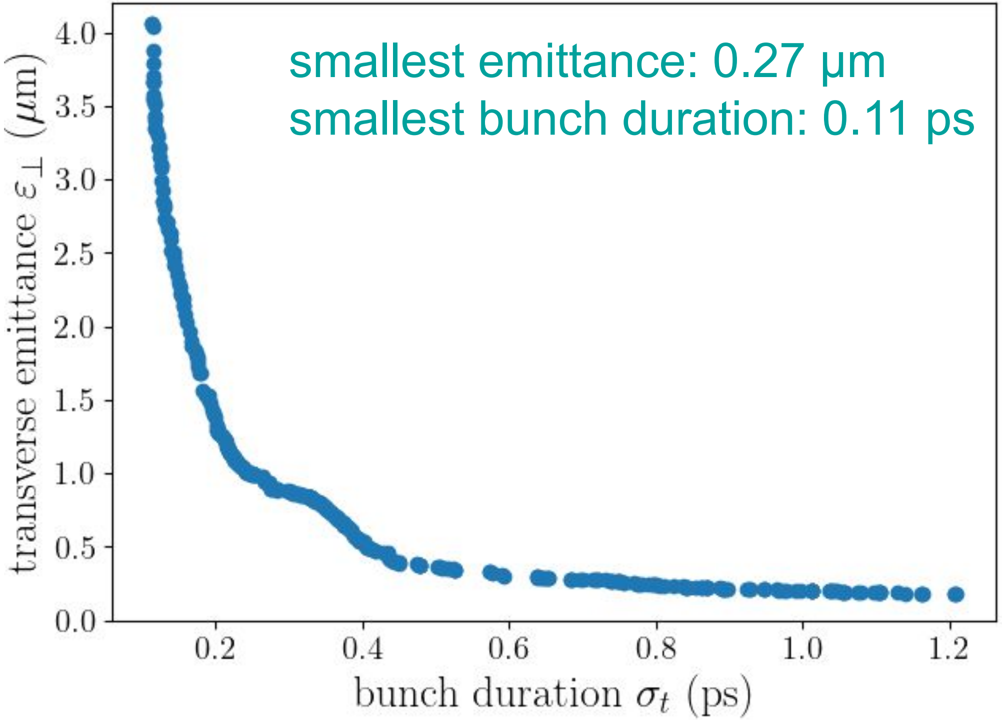
- Goal:
  - perform a multi-objective optimization to minimize transverse emittance and bunch duration
  - generate a 100-pC particle bunch that is accelerated to ~10 MeV

Parameter	Range of values
Xgun phase	(-50, 50)°
linac phase	(-50, 50)°
linac peak field	(100, 250) MV/m
linac position	(0.13, 0.5) m
Laser spot-size	(0.1, 0.5) mm
Laser pulse duration	(1e-3, 6e-3) ns
Solenoid peak field	(0.1, 0.5) T



RESULTS

Pareto front

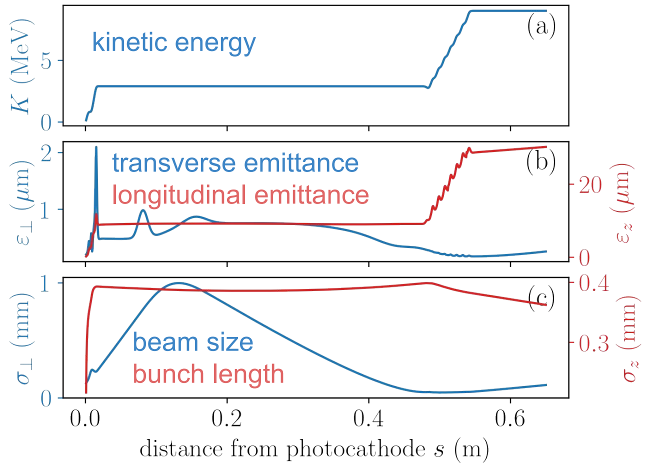


optimal configuration point: low emittance

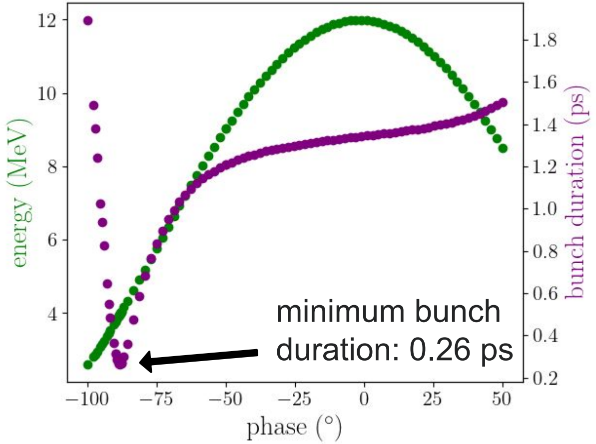
Parameter	Value
Xgun phase	-4.2°
linac phase	-50°
linac peak field	205 MV/m
linac position	0.5 m
Laser spot-size	0.12 mm
Laser pulse duration	4.2 ps
Solenoid peak field	0.32 T
Beam size	0.11 mm
Bunch duration	1.2 ps
Transverse emittance	0.27 µm
Energy	9.03 MeV

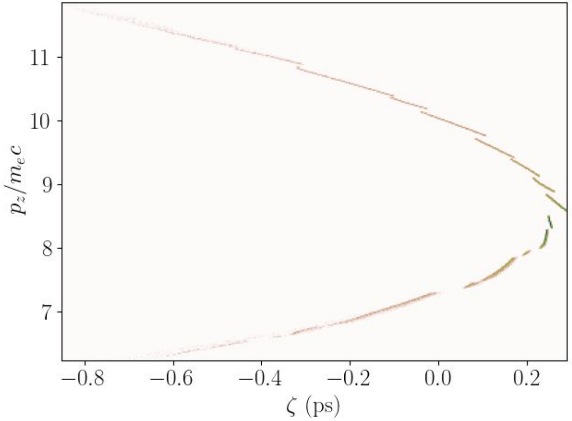
Booster Linac Simulations

- Investigate the lowest emittance case:
  - Beam dynamics evolution
  - Transverse phase space

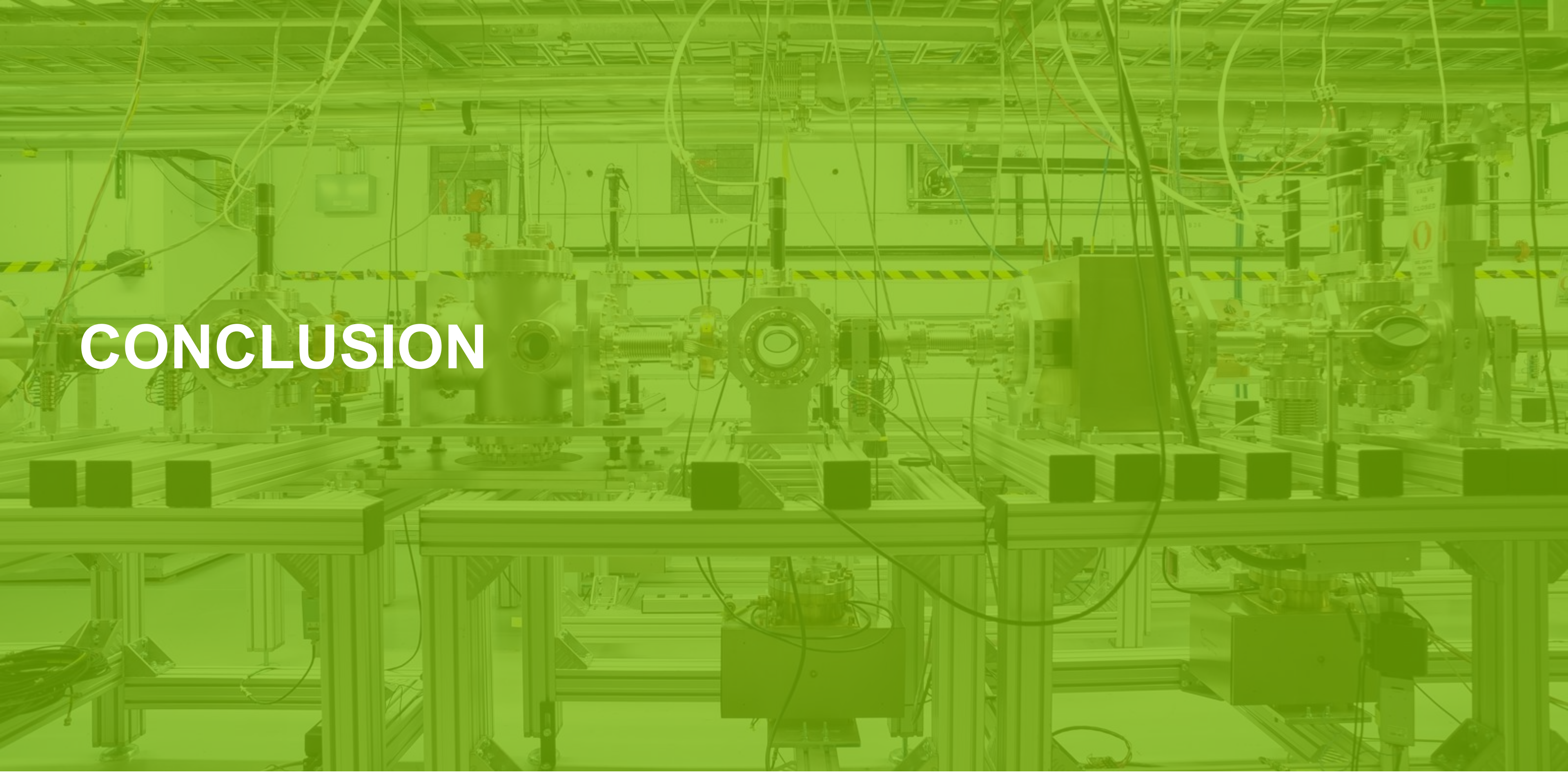


- Phase scan for energy and bunch duration





CONCLUSION



Summary and Outlook

- Over the last 2 years significant progress has been made on operating RF structure with surface field close to GV/m
- Short (< 10-ns) RF-pulses naturally produced in two-beam accelerators (TBA) are critical to GW peak-power generation at X-band frequencies
- An X-band RF photoemission electron source powered by short pulses was recently commissioned at AWA. It demonstrated (i) ~400 MV/m on photocathode, (ii) did not produce observable dark current and (iii) had no significant breakdown.
- A near-term upgrade is to accelerate the beam to ~10 MeV using an available traveling-wave booster linac. This 10-MeV integrated injector provides local emittance-compensation below 300 nm [currently limited by the use of repurposed hardware (e.g. solenoid)].
- Simulations related to the booster linac system are continuing:
    - Investigate applications to inverse Compton scattering
    - Study impact of jitter from the drive beam
- Install booster linac next year and measure emittance

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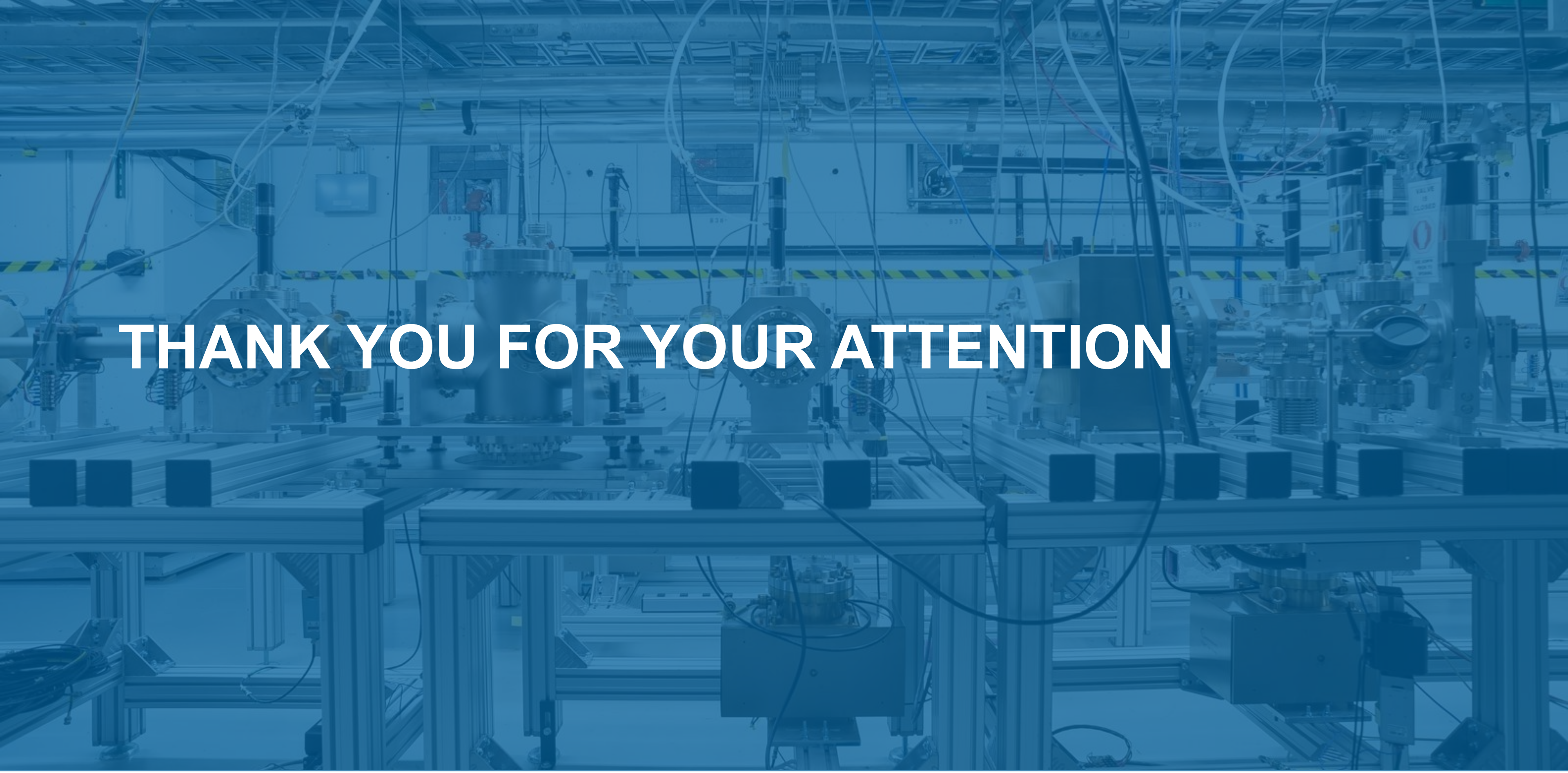

THANK YOU FOR YOUR ATTENTION