NORTHERN ILLINOIS CENTER FOR ACCELERATOR AND DETECTOR DEVELOPMENT

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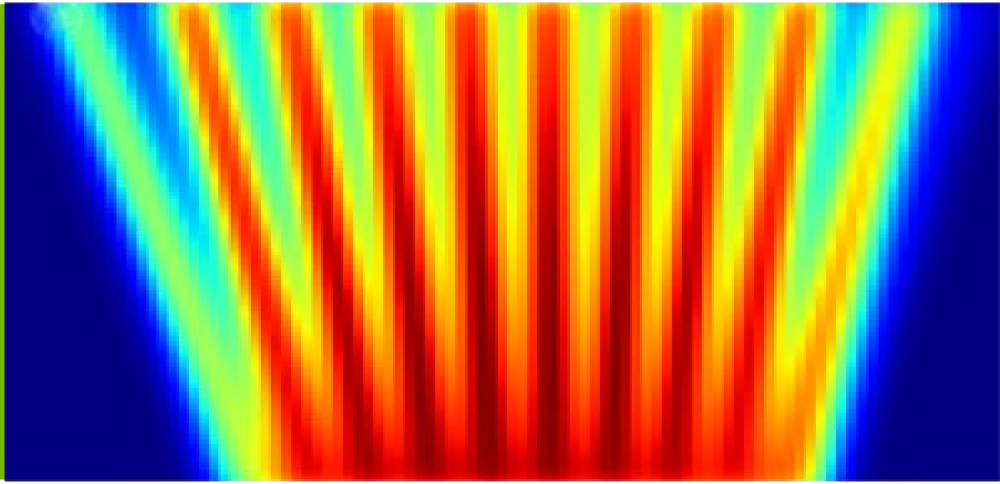
LOW-ENERGY PASSIVE BEAM-BUNCHING ON THE WITNESS-BEAM LINE: A PROPOSAL



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Credits: This work was initiated with Francois Lemery (now at DESY) during his graduate studies at NIU and is also based on a submitted proposal by P. Piot and J. Power

U.S. DEPARTMENT OF ENERGY | Office of Science

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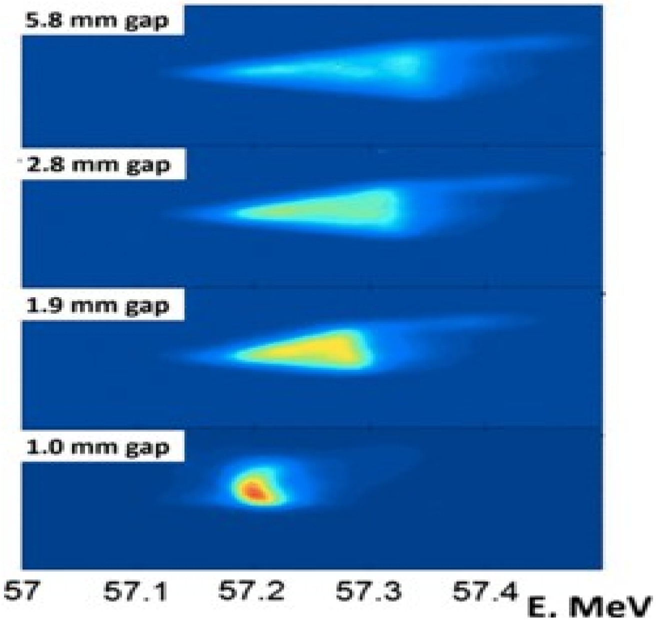
INTRODUCTION & MOTIVATION

- Passive longitudinal phase space manipulation is appealing owing to its simplicity.
- The wakefield provides large (local) correlation in the longitudinal phase space (LPS)
- Use includes:
  - Energy “silencer” or dechirper,
  - Control of nonlinear correlation in the LPS:
    - Linearization
    - Nonlinear correlation for beam shaping
  - Generation of microbunch
  - Streaking (using dipole-mode wakefield)



[Antipov, PRL **112, 114801** (2014)]

PRINCIPLE

- Wakefield structure introduces an energy modulation

$$\Delta\mathcal{E}(\zeta) = 2\kappa QL \int_0^{\zeta} d\zeta_0 \cos[k(\zeta-\zeta_0)]\Lambda(\zeta_0)$$

- Downstream longitudinally-dispersive section generates the required R56
  - In a photoinjector $\gamma \sim \mathcal{O}(10)$ a drift yields

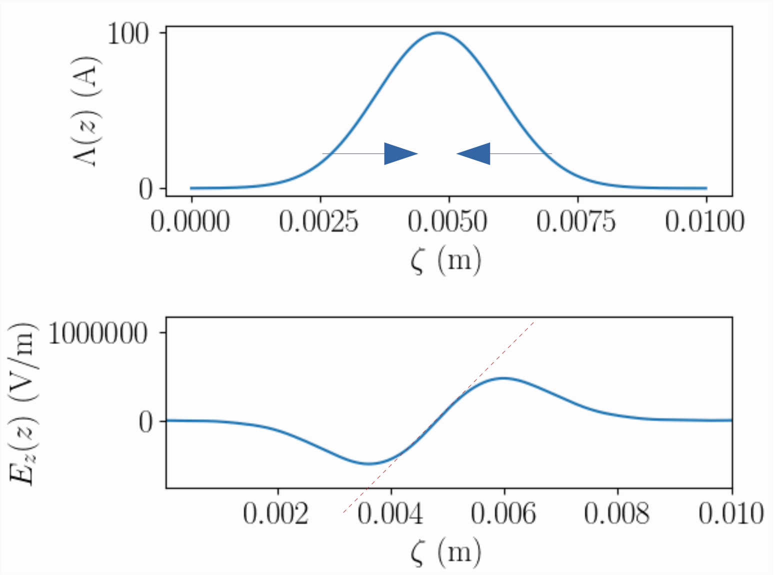
$$R_{56}(s) = \frac{s}{\gamma^2}$$

  - Likewise acceleration in a linac gives

$$R_{56}(s) = \frac{s}{\gamma_i \gamma_f}$$

- Note that the smallest longitudinal feature attainable is

$$\tau_\zeta \simeq R_{56}\sigma_\delta^u$$

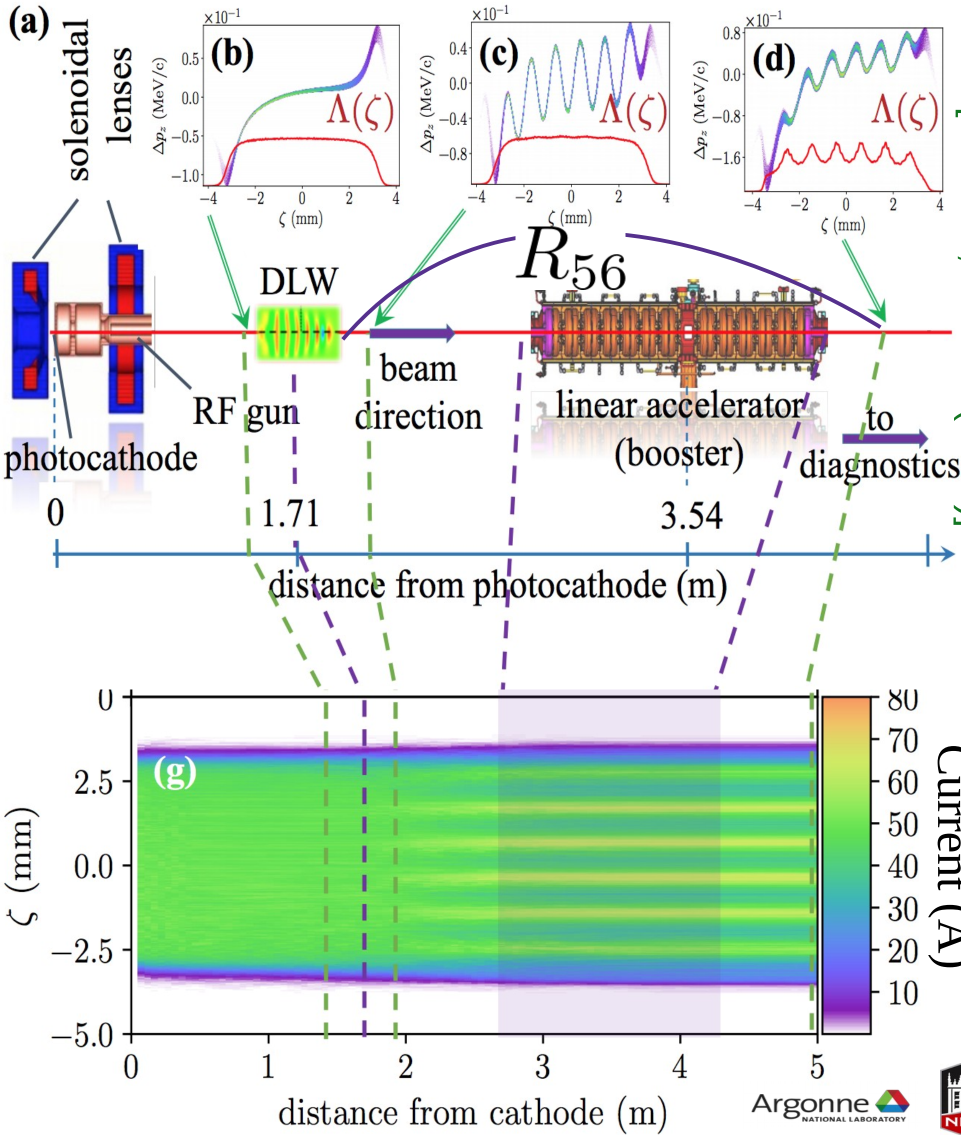


s is the drift/linac length
$\gamma_i,\ \gamma_f$ are the initial and final energies

In a photoinjector $\sigma_\delta^u \simeq 1$ keV and taking a meter-scale drive results in $\tau_\zeta \simeq 10\ \mu m$
(this is 30 fs!)

PRINCIPLE

- Tuning knobs include:
  - Wakefield amplitude and modulation wavelength (choice of structure geometry for a given set of beam parameters)
  - Incoming beam energy
  - R_{56} parameter
    - Drift length (non-ultra-rel. case)
    - Chicane/beamline configuration
    - Linac
- The method is compatible with emittance compensation (if needed + with some work).



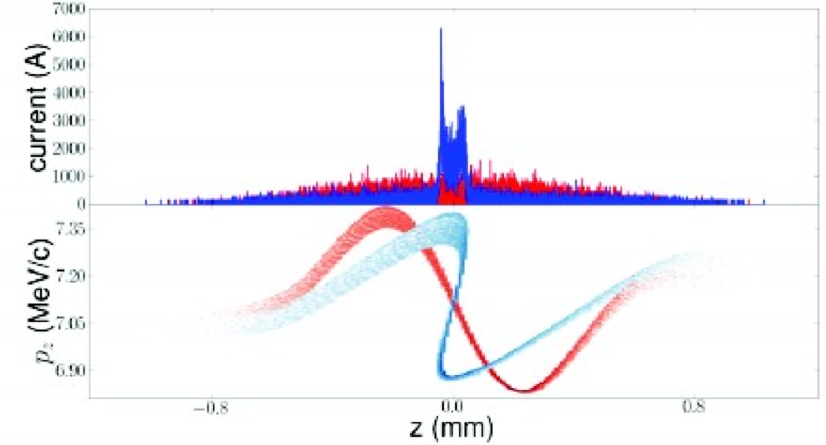
[PRL **122**, 044801 (2019)]

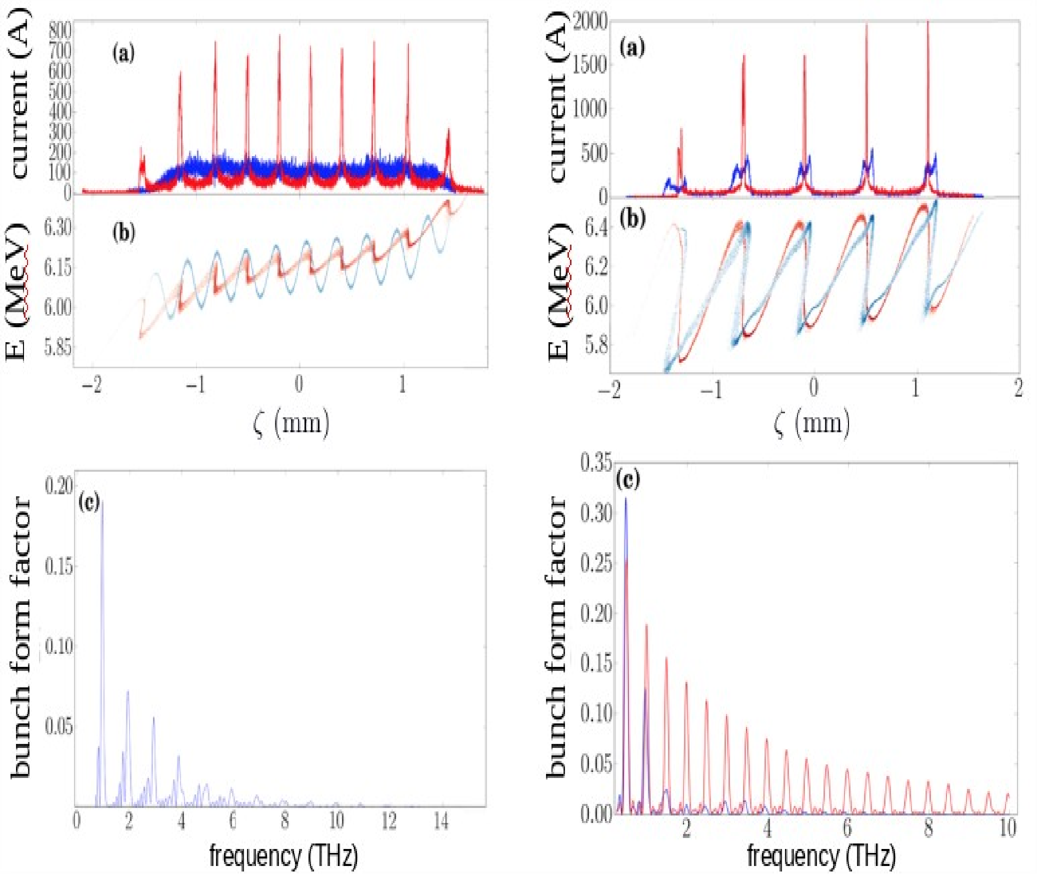
CAPABILITIES & APPLICATIONS

- **Features:**
  - This is a self-synchronized technique (no phase jitter)
  - Compatible with high-repetition rate (preliminary tests done with a long train ~200 bunches)
  - Work with any electron source (provided the structure's parameters are properly selected), could be a building block of a laser-free system
- **Possible applications:**
  - CW THz sources for pump-probe exp. at X-ray FELs (coupled to an SRF gun for high-repetition rate)
  - Bunch compression of field emitted bunches
  - Bunch shaping, drive/witness
  - Generation of spikes for injection in high-frequency accelerators

BUNCH COMPRESSION & TRAIN GENERATION

- Wavelength of the wakefield compared to the bunch length set the modulation versus overall bunching regimes
- In simulations very high-peak currents observed
- Associated bunch form factors have very high frequency content (up to 10 THz)

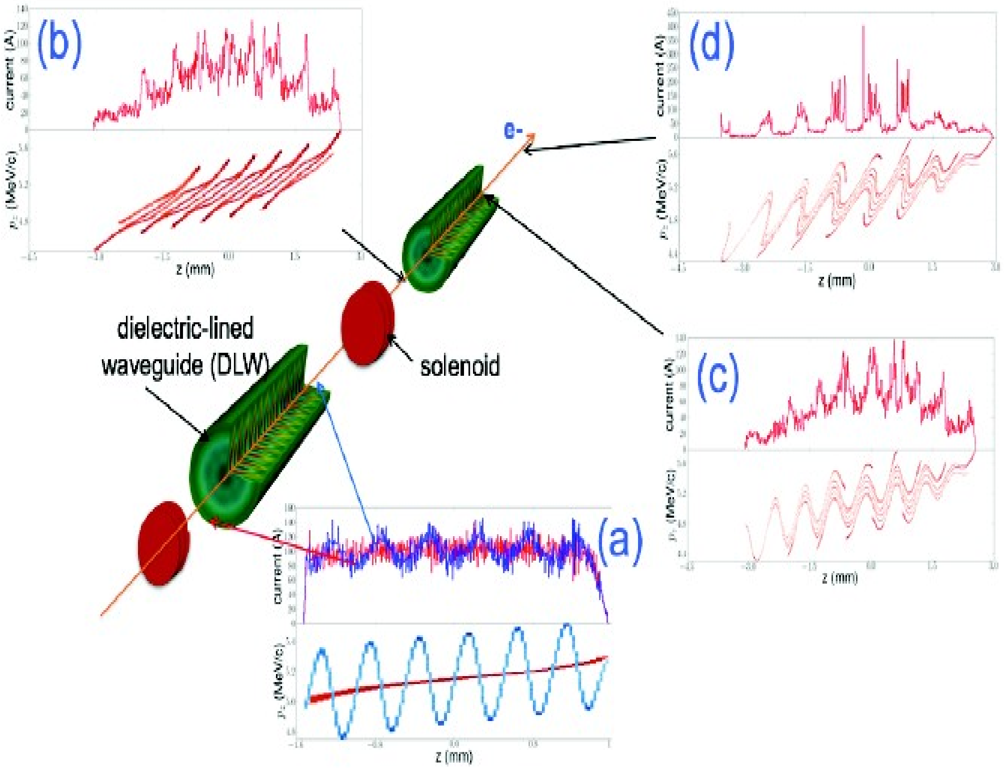




[PRAB**17**, 112804 (2014)]

COMBINING MULTIPLE STRUCTURES

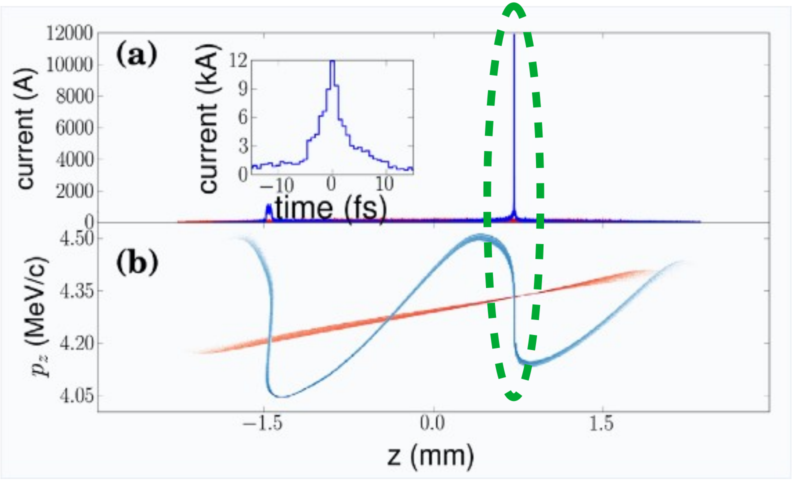
- Multiple structures can be used to
  - form fine structures on the bunch similarly to echo-enabled harmonic generation
  - Tailor the shape of the current profile (by selecting wavelengths of the different structures)
- Transport becomes challenging due to the required beam focusing over the successive structures.
- Quadrupole wiggler discussed in Sasha Zholent's talk could alleviate such a problem



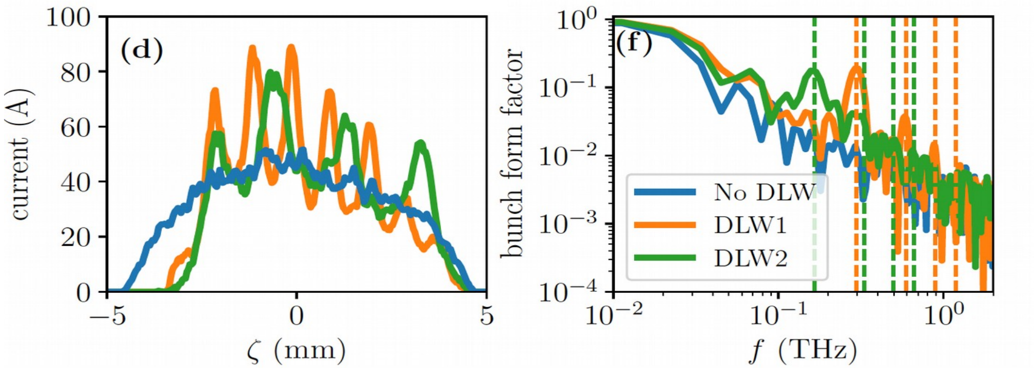
MOTIVATION FOR THE PRESENT WORK

- Initial proof-of-principle experiment performed at PITZ/DESY:
  - mm-period wakefield
  - modulation regime $\lambda < \sigma_z$
  - ~single-mode structure
  - Bunch train

[PRAB**17**, 112804 (2014)]



[experimental results PRL**122**, 044801 (2019)]

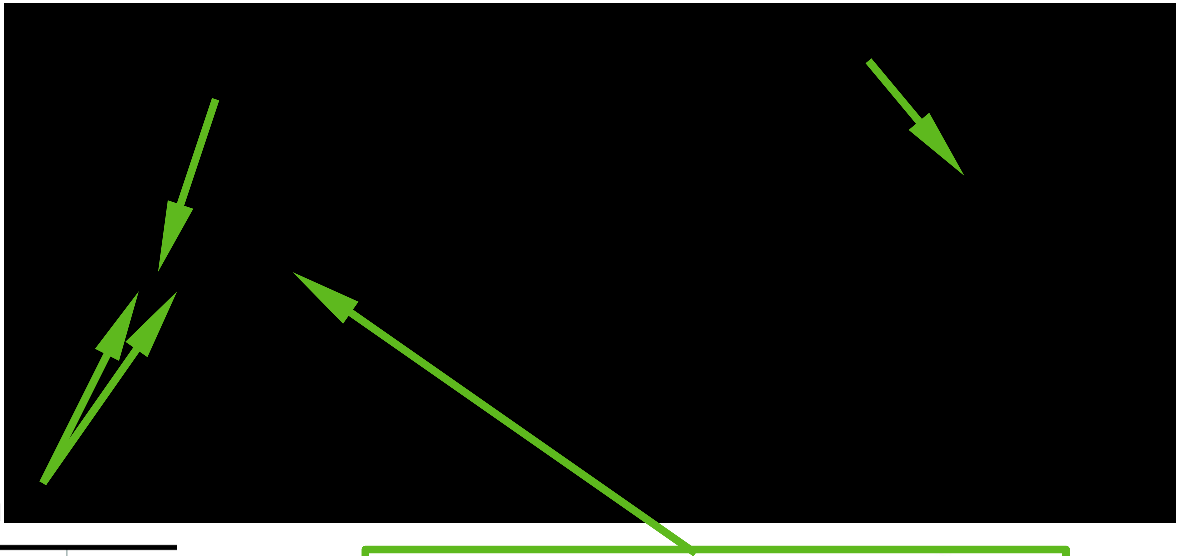


- Bunch compression $\lambda \sim \sigma_z$
  - Single spike, e.g. for injection in high-frequency structures
  - Whole-bunch compression
- Modulation $\lambda < \sigma_z$
  - Multi-mode structures, multiple structures, impact of bunch shape

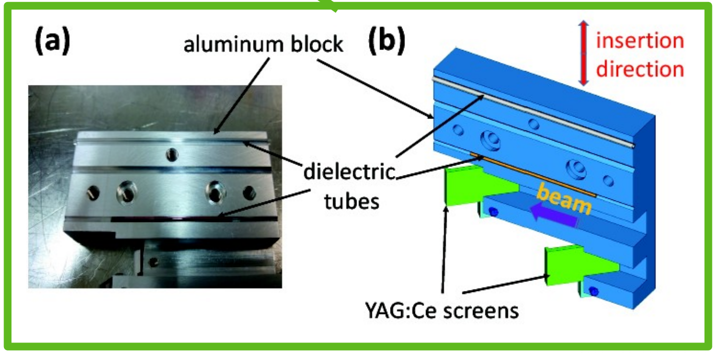
USE OF THE WITNESS-BEAM BEAMLINE

- Well suited for the present proposal:
  - Low energy (<15 MeV)
  - Available space after gun
  - Linac + space for possible THz radiator
- Diagnostics will require some development

solen

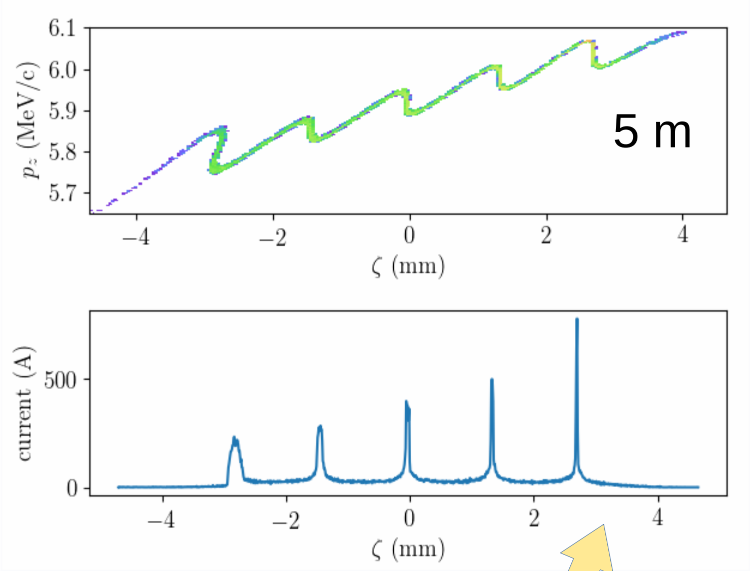


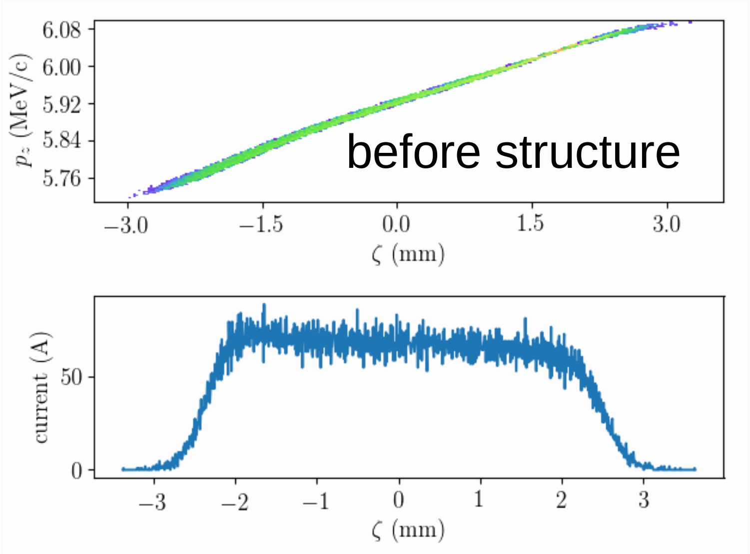
Parameter	*Required value*	*Range*	*Unit*
Beam energy	5-8	[=2-14]	MeV
Bunch charge	1	0.02-10	nC
Number of bunch per shot	1	2^n (n=0,5)	--
Train frequency	5	0.1-5	Hz
RMS normalized emittance	~2 (1 nC)	[1,200]	μm
RMS bunch duration	2-5 (1 nC)	.5-10	ps
Peak current	50	<200	A

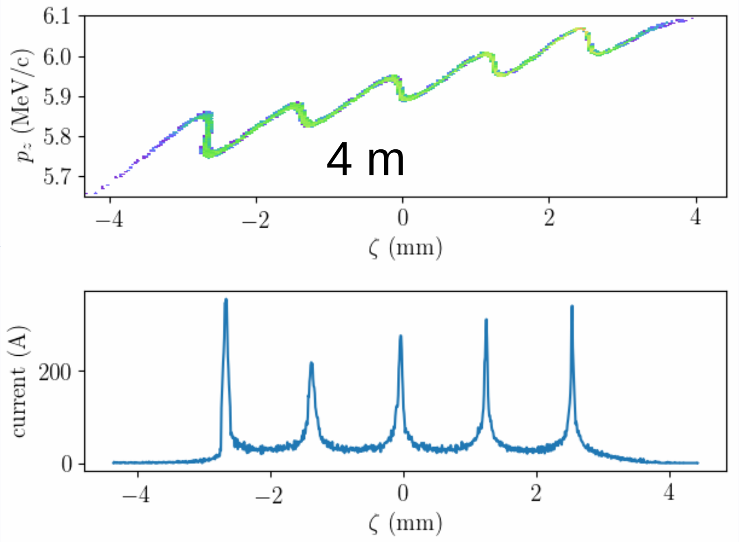


EXAMPLE (SANITY CHECK)

- Performed some first-pass simulation to check suitability of the witness-beam beamline
- Consider 1 nC, 12 ps plateau laser distribution, with 0.75 mm rms spot size on cathode with E=55 MV/m
- 5-cm long structure with fundamental mode 1.2 mm







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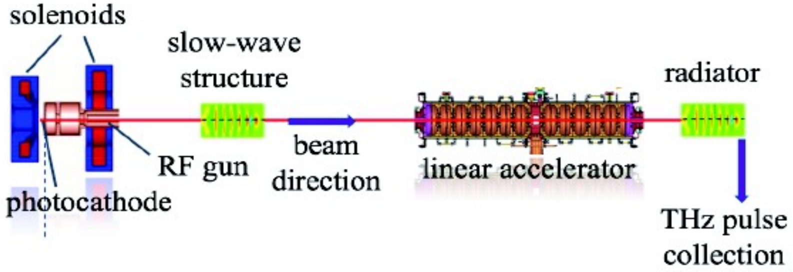
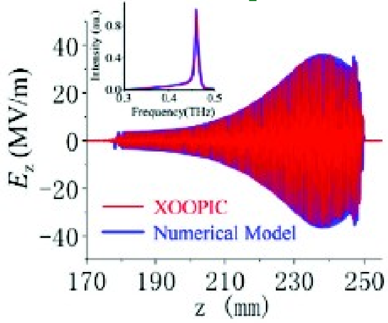
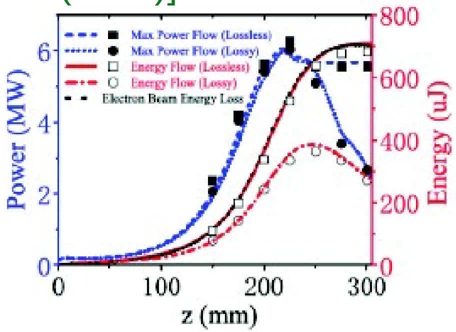
OPPORTUNITIES FOR FURTHER R&D

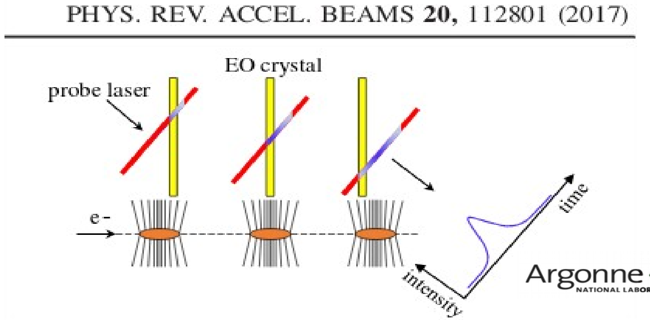
- So far we only consider dielectric-lined structure, optimization of structures could improve overall performance and versatility of the scheme.
- For prolongated interaction a feedback mecha-nism (similar to a single-pass FEL) can develop [see Stupakov, PRSTAB 18, 030709 (2015)]. This could generate sub-mJ THz pulses.
- Temporal diagnostic with required resolution (~50 fs) is challenging, exploring simple methods such as spatially encoded electro-optical imaging and/or self-streaking with (dipole) wakefield would be beneficial.



[Li, NIMA785, 75 (2019)]







QUESTION?