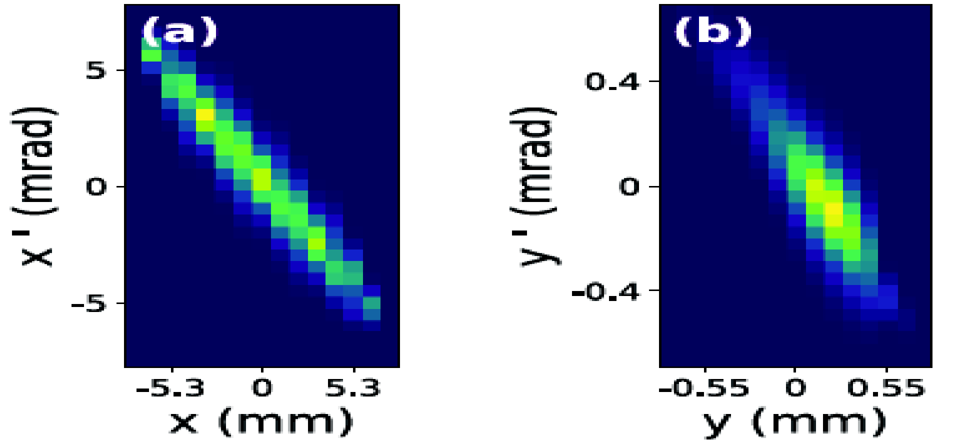
EMITTANCE REPARTITIONING FOR ADVANCED LINEAR COLLIDERS



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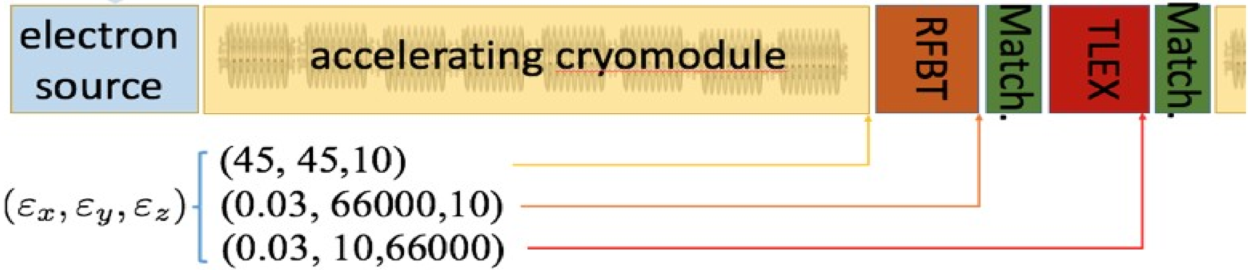
INTRODUCTION & MOTIVATION

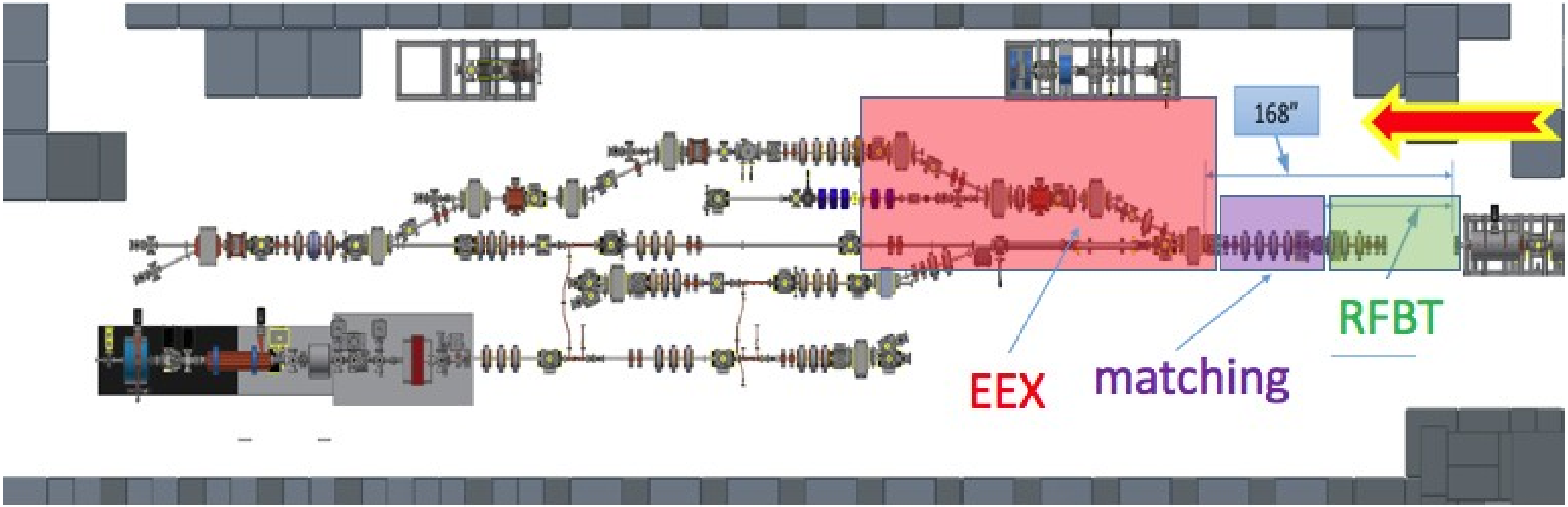
Parameters	ILC	CLIC	P/DWFA	LPA
Energy (TeV)	0.5	3	3	3
ε_x(µm)	10	0.66	10	50.10^{-3}
ε_y (µm)	35.10^{-3}	20.10^{-3}	35.10^{-3}	8.10^{-3}
bunch length(µm)	300	44	20	8
energy spread (%)	~0.1	0.35	~0.1	_
ε_z (µm)	3.10^6	92.10^4	12.10^4	_
ε_{6d} (µm)	101	23	35	_

- State-of-the-art electron sources are a key component of future linear collider.
  - Generally, the 6D phase space $\varepsilon_x\varepsilon_y\varepsilon_z$ volumes associated to the source and IP are comparable
  - The emittance partition between the three degrees of freedom is mismatched
- Explores beam transformations capable of redistributing the beam phase space between the three degrees of freedoms with special emphasis on emittance repartitioning)
- Emittance repartitioning has been proposed for FEL [Kim, PRAB9 100702 (2006)]
- Simple solution consists of combining an transverse-to-longitudinal emittance exchanger with a round to flat beam transform



EXPERIMENTAL SETUP AT AWA

- Experiment combines:
  - Round to flat beam transformer (RFTB) to partition the beam transverse emittances
  - Emittance exchanger (EEX): the exchange the horizontal emittances with the longitudinal one



SETTING UP THE EIGEN EMITTANCES

- Transverse and longitudinal phase spaces are assumed to be decoupled (for now)
- The two transverse phase space are coupled by applying an axial magnetic field B_c on the cathode
- The beam is born with a canonical angular momentum (so called “magnetized” beam)

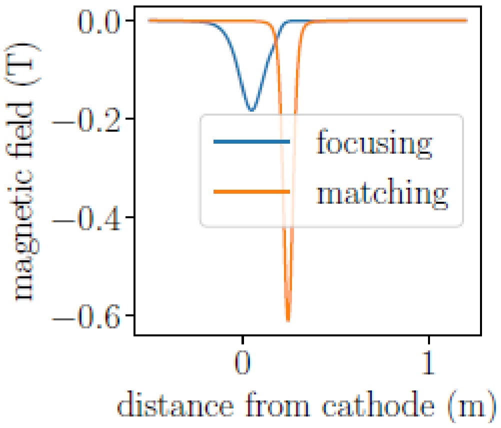
$$\mathcal{L} = \frac{ecB_c\sigma_c^2}{mc^2}$$

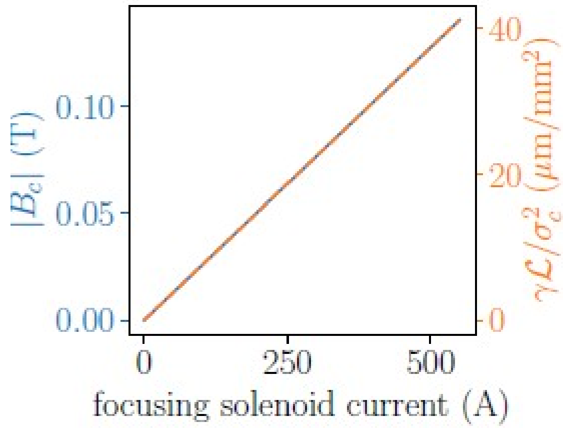
σ_c laser size on cathode

- The beam is fully coupled and its transverse eigenemittances (invariants) are $\varepsilon_\pm = \varepsilon_m \pm \mathcal{L}$ with the effective emittance given by

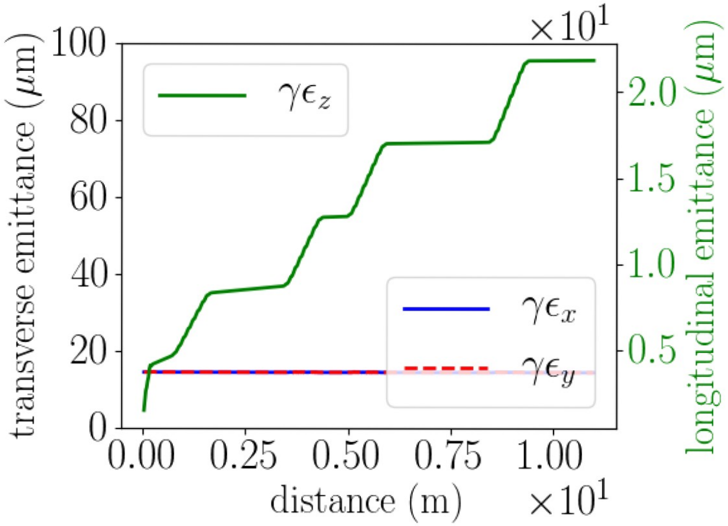
$$\varepsilon_m^2 = \epsilon_0^2 + \mathcal{L}^2$$

uncorrelated emittance





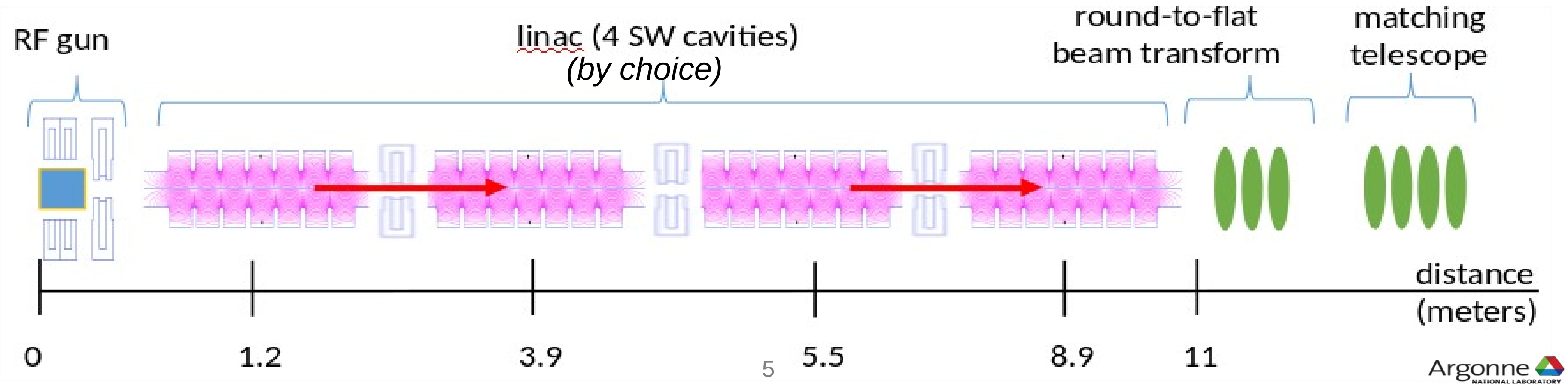
MAPPING TO CONVENTIONAL EMITTANCES



- A skew-quadrupole channel applied the torque necessary to decouple the beam in this process the eigen emittances are mapped to conventional emittances

$$\varepsilon_- \simeq \frac{\epsilon_0^2}{2\mathcal{L}} \qquad \varepsilon_+ \simeq 2\mathcal{L}$$

- With 4D emittance $\varepsilon_4 \equiv \sqrt{\varepsilon_- \varepsilon_+}$ being conserved



ROUND-TO-FLAT-BEAM CONVERSION (1)

$$C = \frac{\gamma \mathcal{L}}{\varepsilon_n}\begin{pmatrix}\alpha & \beta \\ -\frac{1+\alpha^2}{\beta} & -\alpha\end{pmatrix}$$

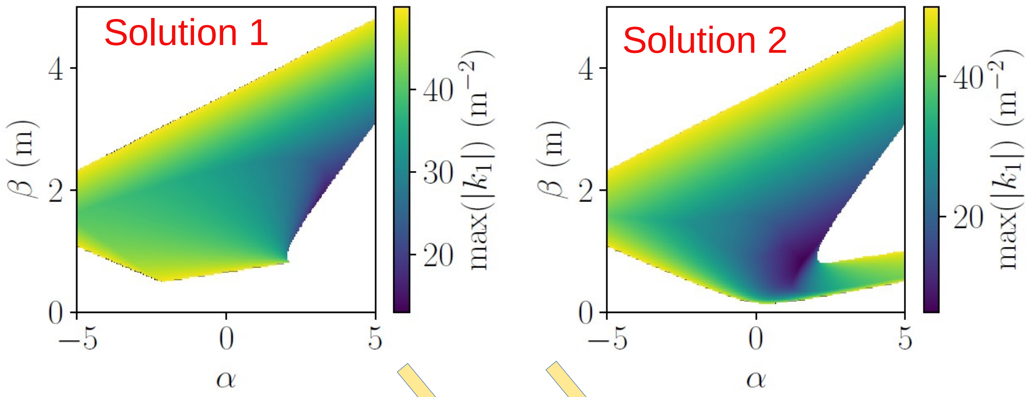
- RFTB do a mapping on a magnetized beam does the mapping

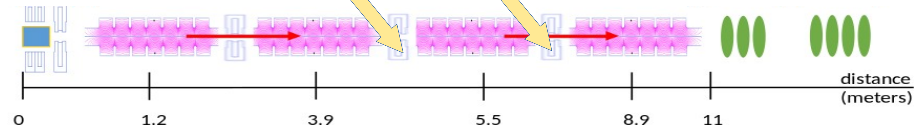
$$(x_c, x_c') \rightarrow (x, y) = (a x_c + b x_c', c x_c + d x_c')$$

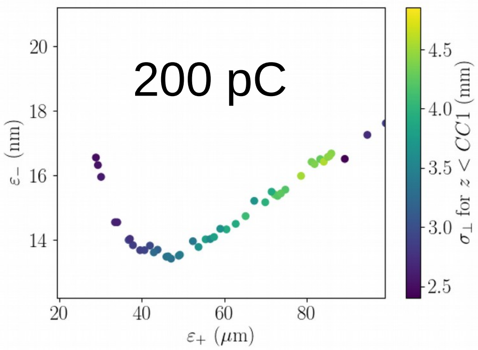
$$(y_c, y_c') \rightarrow (x', y') = (\tilde{a} y_c + \tilde{b} y_c', \tilde{c} y_c + \tilde{d} y_c')$$

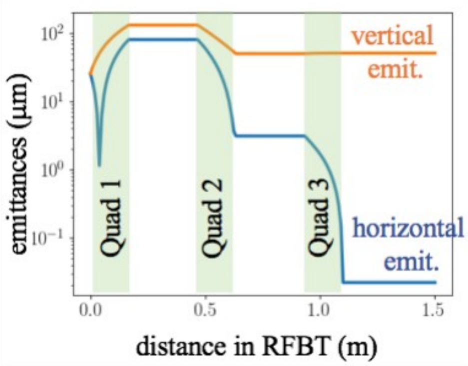
- In most of the setup to date there is no tuability (oly one set of transfer map is used). At AWA the solenoids available in the linac allow for flexibility
- This could also provide a way to change the transverse-emittance partition on the flight without altering the skew-quadrupole settings

acceptance of the AWA RFTB



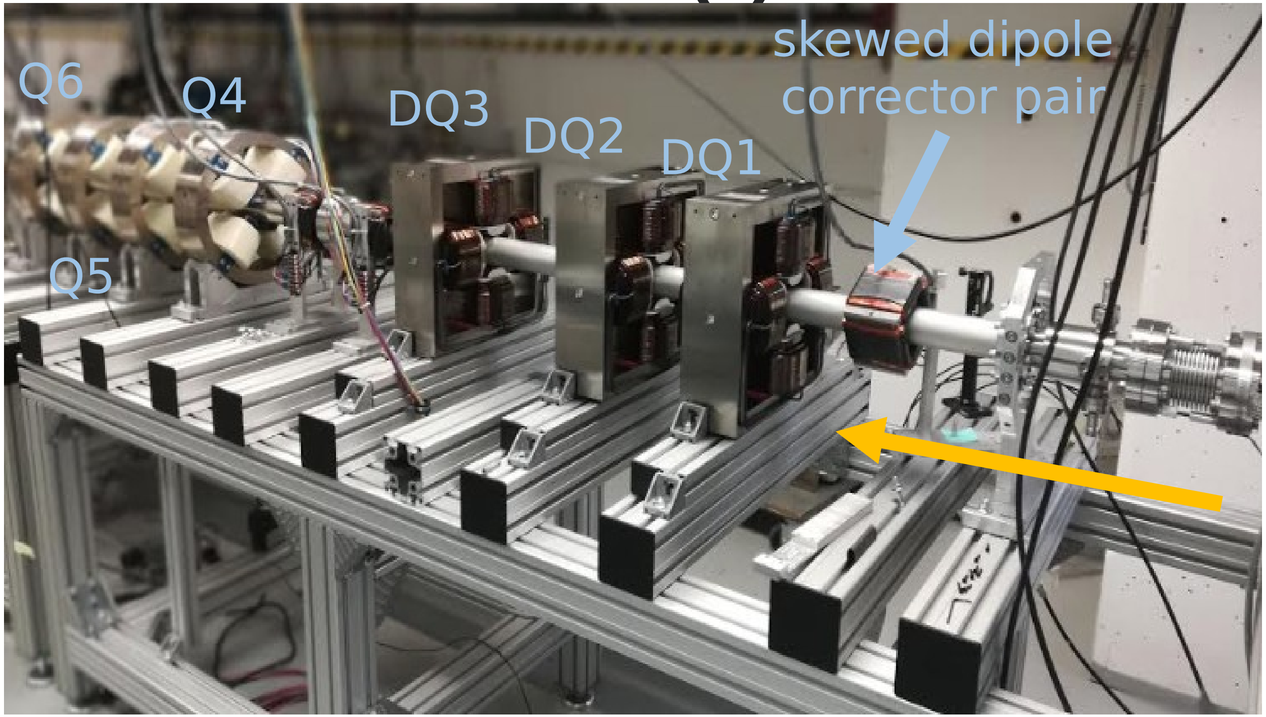






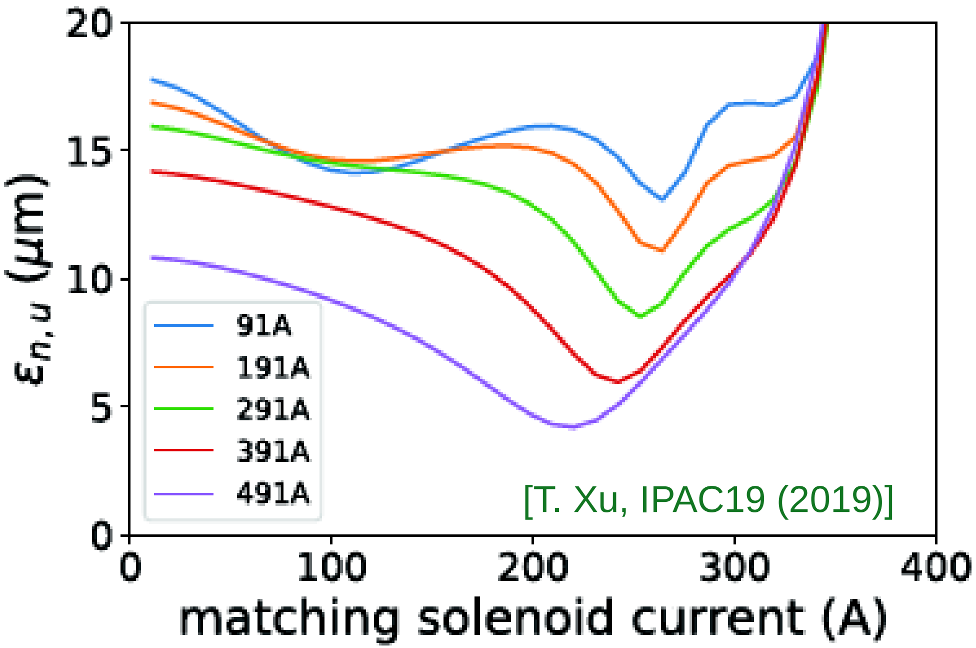
ROUND-TO-FLAT-BEAM CONVERSION (2)

- First RFTB installed during winter 2018, final quad installed late spring 2018
- Commissioned in summer 2018 and ran/studied when time allows
- Has transited from an”object of study” status to support new opportunities
  - D/PWFA (G. Andonian)
  - Dipole-mode in D/PFWA suppression in asymmetric structures (S. Baturin)
  - Other under consideration...



- Flat beam study partially done
- Some data taken on single-knob emittance partitioning

OPTIMIZATION



[T. Xu, IPAC19 (2019)]

- Predicted emittance partition for ideal case (axi-symmetric field) is

$$\varepsilon_+, \varepsilon_- = (180, 0.2)\,\mu\text{m}$$

- We find that large B-field on cathode surface results in a smaller 4D emittance (may be exploited to produce brighter beam?)
- Eigen emittance mapping to conventional emittance is excellent (~few percent degradation for smaller emittance)
- 3D effects in field map (due to coupler-induced asymmetry in RF gun and linac deteriorates the 4D emittance and lower flat-beam emittance
- However optimize value (axi-symmetric field) is higher than the canonical ~1 μm/nC

[T. Xu, IPAC19 (2019)]

EXPERIMENT ON FLAT BEAM GENERATION

- Direct measurement of phase spaces (scanning slit technique)
- Demonstrated variable emittance ratio [55, 164]
- Developed procedure to quickly tune the RFTB
- Ratio currently limited by small emittance

Parameter	Value	units
Laser pulse duration FWHM	8	ps
Laser spot radius	3.2	mm
Laser launch phase	50	deg
Magnetic field on cathode (B_c)	0.125	T
Beam energy	43	MeV
Magnetization ($\gamma\mathcal{L}$)	102	μm

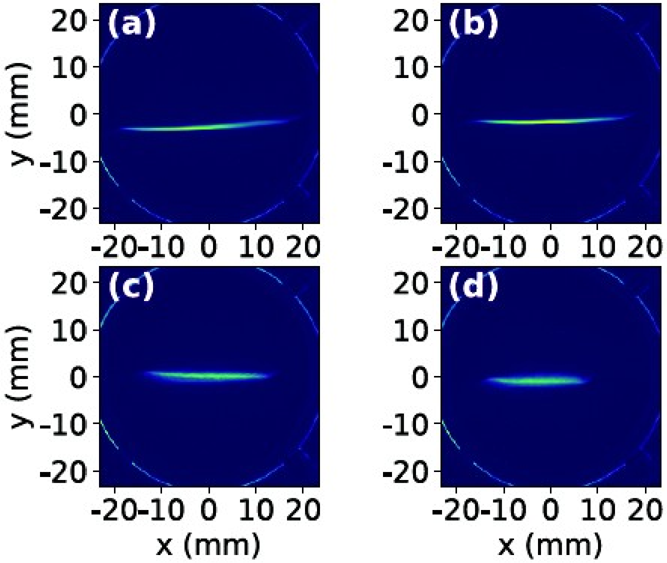
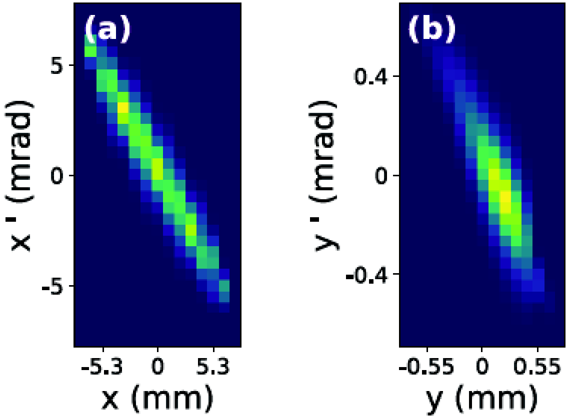


Table 4: Flat-beam Parameters Measured for Different B_c

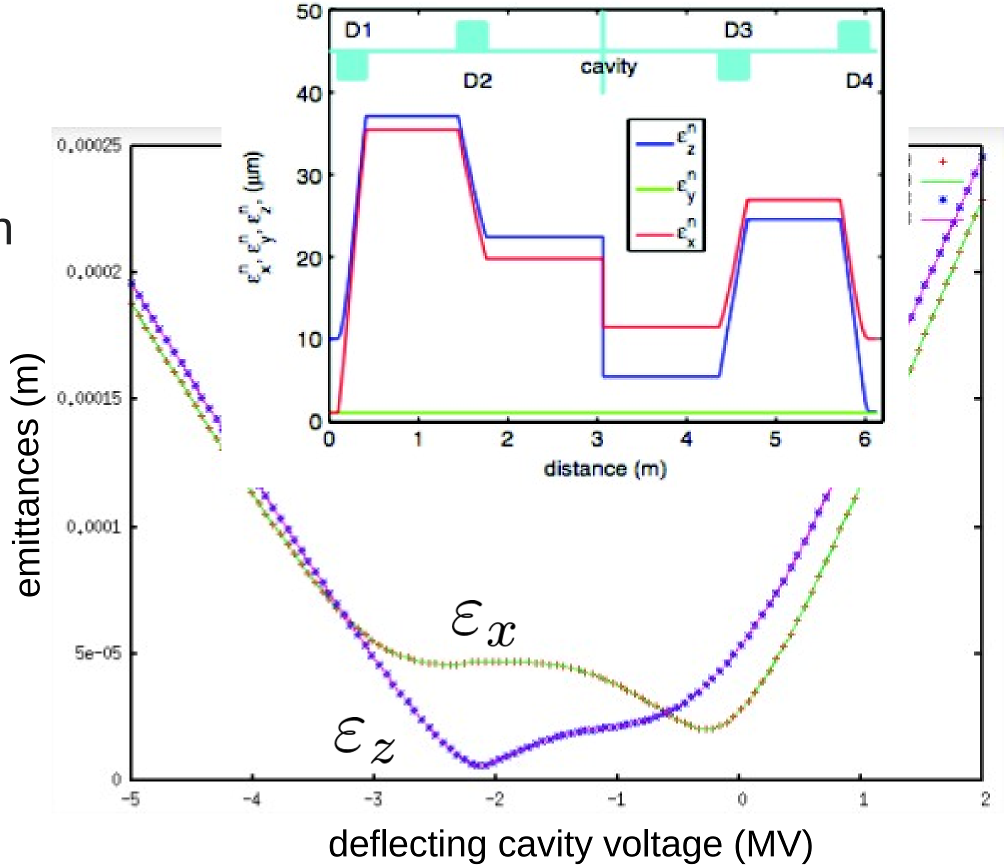
Current (A)	491	391	291	191
B_c(T)	0.125	0.1	0.074	0.049
Charge (nC)	0.63 ±0.05	0.63 ±0.06	0.74 ±0.14	0.5 ±0.1
ε_+ (μm)	215.6 ±32.3	175.2 ±26.2	136.4 ±20.4	77.3 ±11.5
ε_- (μm)	1.4 ±0.2	1.1 ±0.2	1.9 ±0.3	1.4 ±0.2
$\varepsilon_+\varepsilon_-$ (μm^2)	306.9	186.9	270.0	108.3
emittance ratio	152	164	69	55

1 nC



HORIZONTAL TO LONGITUDINAL EEX

- Longitudinal emittance is ~independent from the two transverse emittances
- At AWA is it essentially set by the laser/gun with some degradation along the linac due to curvature effects
- Upgraded laser could enable smaller longitudinal emittance (along with linearized transverse space charge) if shaped and/or operated in the blow-out regime (also ultimately we need $\varepsilon_x \gg \varepsilon_z$)
- Simulation of EEX setup but full start-to-end not yet done



SUMMARY AND FUTURE WORK

- First step of the program, generation of flat beam has been successful and open new opportunities (HEP & NP, e.g. EIC e-cooling).
- Next step (experiment) include parametric studies on transverse emittance repartitioning and demo of single-knob emittance tuning
- Generation of temporally-shaped (linear-ramp) flat beam under investigation (simulation and first-pass shaper this Fall?)
- Producing the right horizontal-longitudinal emittance partition is challenging and we will explore use of the blow-out regime (or laser shaping), the straight ahead deflecting cavity will be use to measure the longitudinal emittance).
- Emittance exchange is well established at AWA but probing the domain where ideal exchange occurs will provide
- Question on QE/dark-current emission with B field on cathode is an interesting/open question

QUESTIONS?