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U.S. DEPARTMENT OF ENERGY | Office of Science

NORTHERN ILLINOIS CENTER FOR ACCELERATOR AND DETECTOR DEVELOPMENT

High-Charged Magnetized Beams at FAST-IOTA

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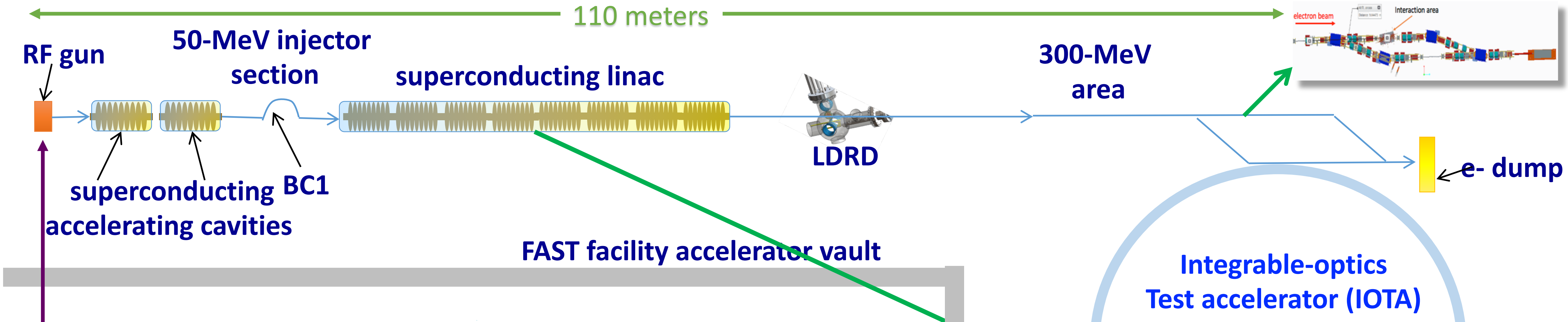
Introduction/Motivation

- High-charge magnetized beam:
  - Production of high-charge (3.2 nC) magnetized beam
  - characterization of magnetization
  - Transport + manipulation over long beamline including use of locally non-symmetric optics
- High-current magnetized beams → understanding halo
  - Explore halo formation in magnetized beam using a long-dynamical range diagnostics (LDRD)
- New merger concept:
  - Tests of merger concept combining RF deflector and magnetic coil proposed by A. Hutton -- augmenting recent test at Cornell.

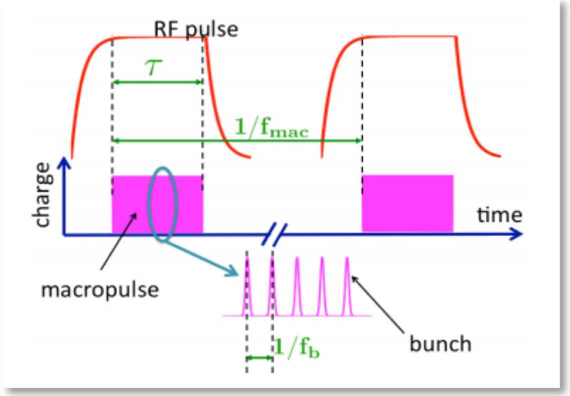
The FAST facility infrastructure

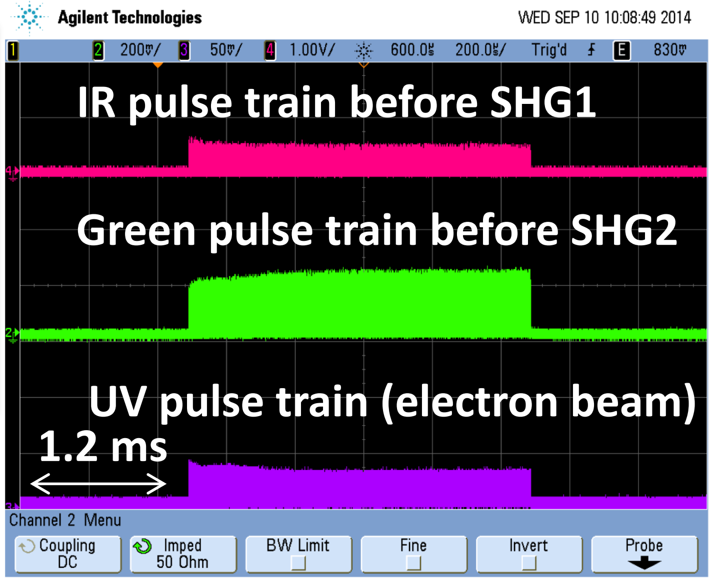


SHG2

SHG1

FAST photocathode laser system





IR pulse train before SHG1

Green pulse train before SHG2

UV pulse train (electron beam)

1.2 ms

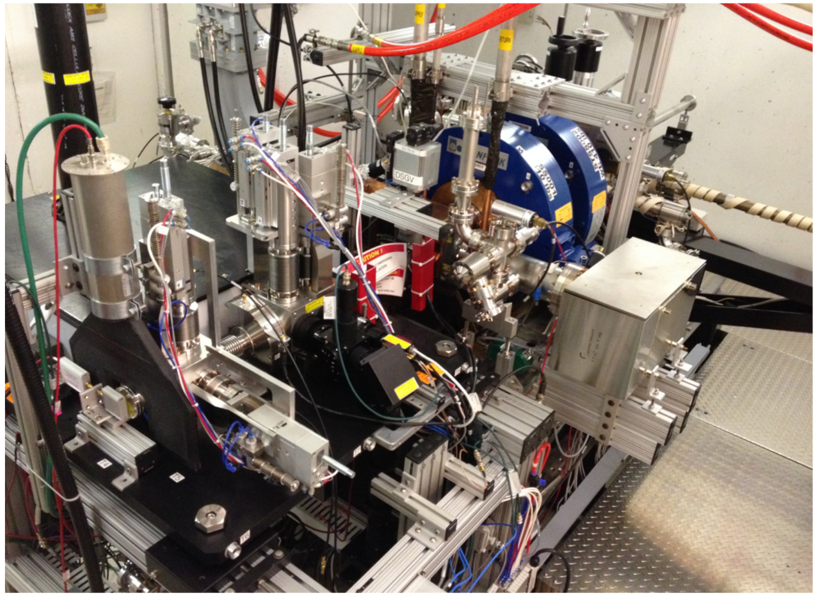
Magnetized beams in the FAST injector

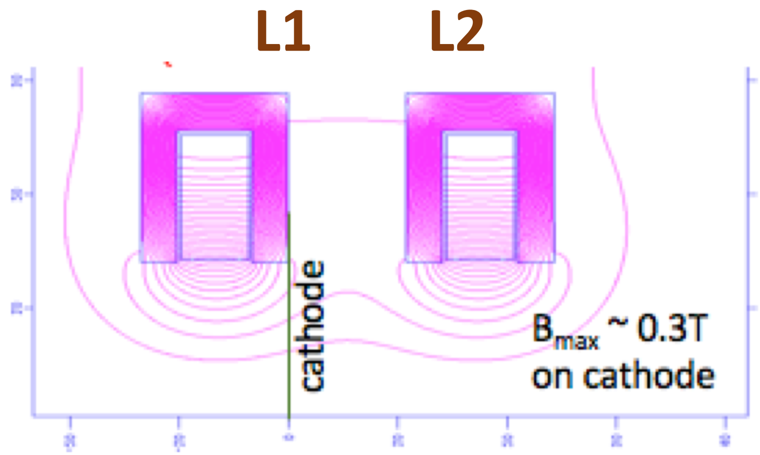
- The FAST injector includes
  - 1+1/2 RF gun
  - High quantum efficiency Cs_2Te photocathode
  - A symmetrical solenoid configuration can provides substantial field on cathode up to 0.15 T
- Magnetized beam is characterized by the *magnetization* parameter

Laser-spot size on cathode

$$\mathcal{L} = \frac{eB_c}{2mc}\sigma_c^2 \simeq 294 B_c[T]\sigma_c^2[m]$$

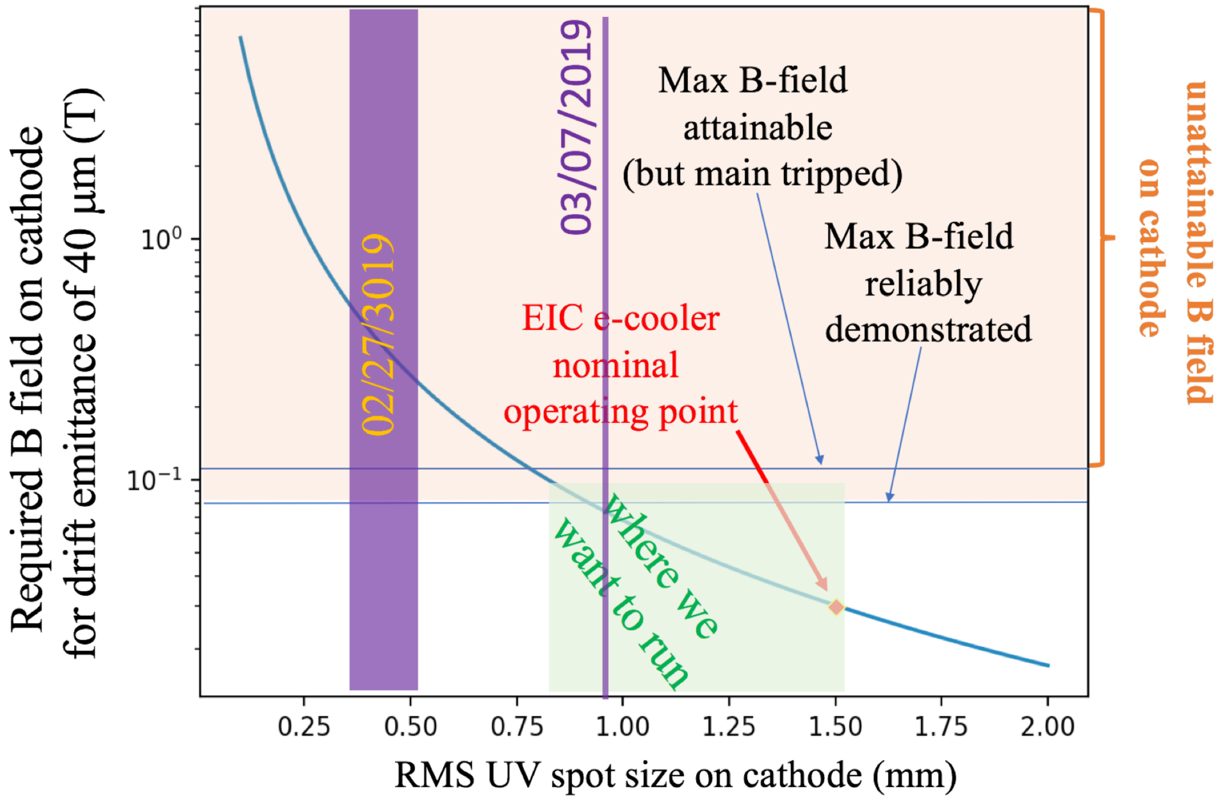
B field on cathode

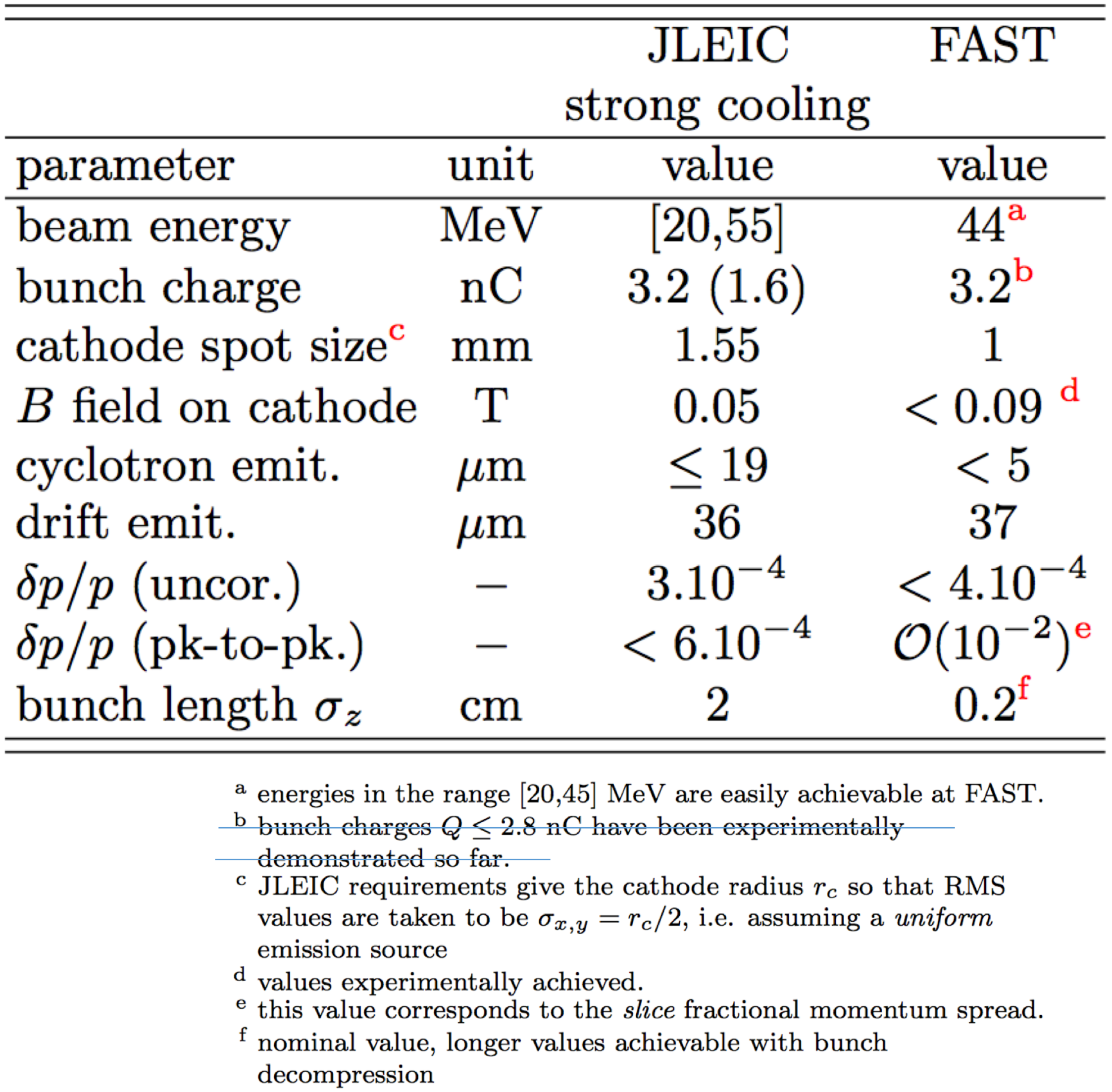




Relevance of FAST injector to EIC e- cooling

- Similar beam parameters except for a higher peak current





		JLEIC strong cooling	FAST
parameter	unit	value	value
beam energy	MeV	[20,55]	44[a]
bunch charge	nC	3.2 (1.6)	3.2[b]
cathode spot size[c]	mm	1.55	1
B field on cathode	T	0.05	< 0.09 [d]
cyclotron emit.	μm	≤ 19	< 5
drift emit.	μm	36	37
$\delta p/p$ (uncor.)	–	3.10^{-4}	$< 4.10^{-4}$
$\delta p/p$ (pk-to-pk.)	–	$< 6.10^{-4}$	$\mathcal{O}(10^{-2})$[e]
bunch length σ_z	cm	2	0.2[f]

[a] energies in the range [20,45] MeV are easily achievable at FAST.

[b] ~~bunch charges $Q \leq 2.8$ nC have been experimentally demonstrated so far.~~

[c] JLEIC requirements give the cathode radius r_c so that RMS values are taken to be $\sigma_{x,y} = r_c/2$, i.e. assuming a *uniform* emission source

[d] values experimentally achieved.

[e] this value corresponds to the *slice* fractional momentum spread.

[f] nominal value, longer values achievable with bunch decompression

Note on emittances

- Effective emittance of a magnetized beam

$$\varepsilon_{n,\mathrm{eff}} = [(\gamma\mathcal{L})^2 + \varepsilon_{n,u}^2]^{1/2},$$

with magnetization given by $\gamma\mathcal{L} = \frac{eB_c}{2mc}\sigma_c^2$

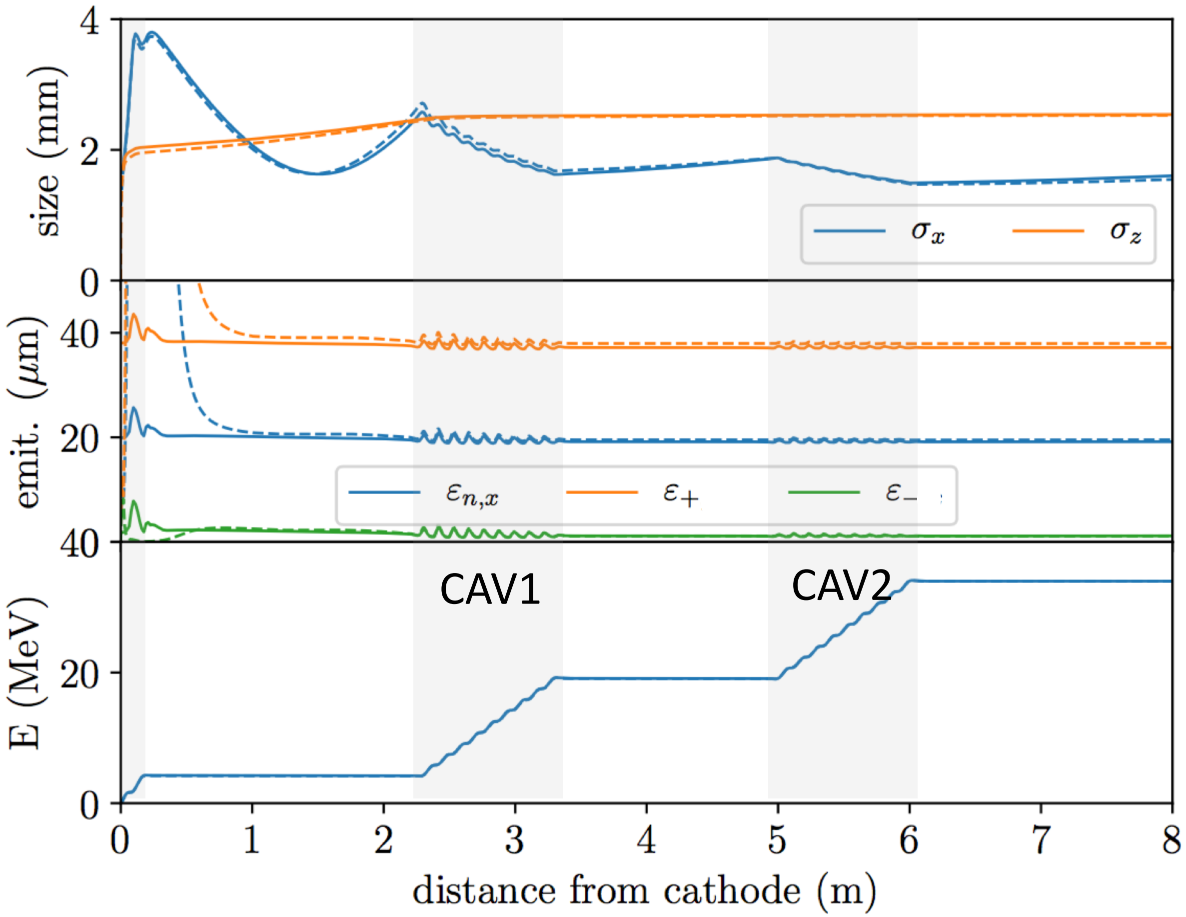
- Eigen emittances $\det[J\Sigma^{-1} - i\varepsilon_m I] = 0$

$$\begin{cases} \varepsilon_{n,+} = 2\gamma\mathcal{L} \equiv \varepsilon_{n,d} & \text{“drift” emittance} \\ \varepsilon_{n,-} = \dfrac{\varepsilon_{n,u}^2}{2\gamma\mathcal{L}} \equiv \varepsilon_{n,c} & \text{“cyclotron” emittance} \end{cases}$$

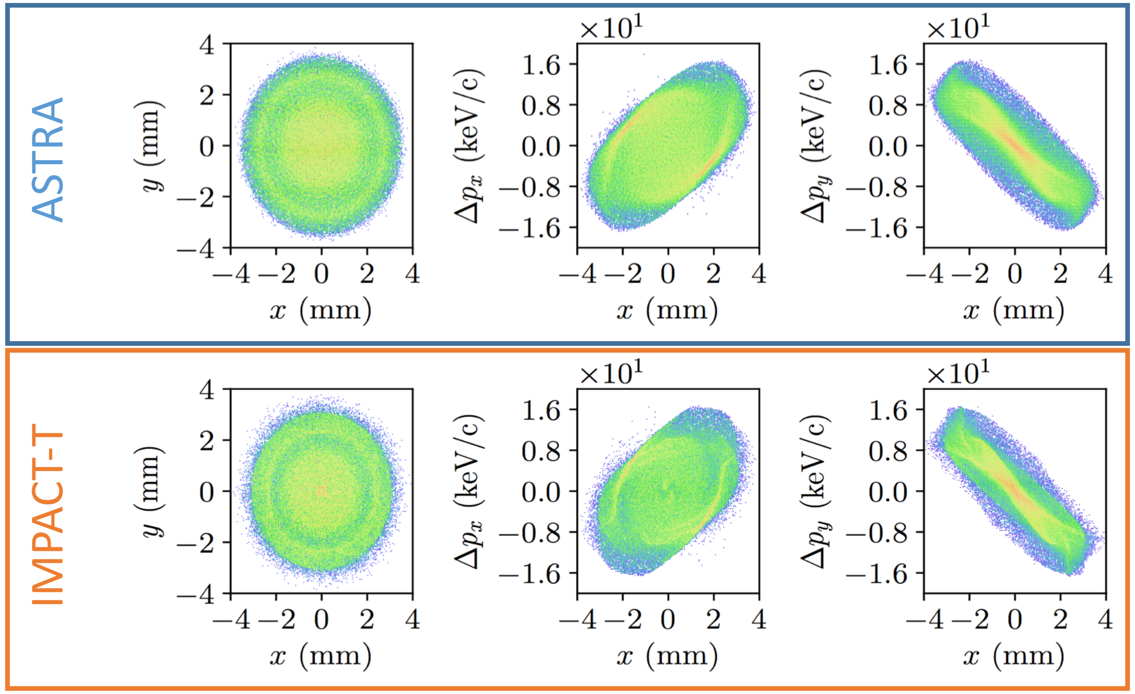
- 4-D emittance $\varepsilon_{n,4D} \equiv (\varepsilon_{n,d}\varepsilon_{n,c})^{1/2}$

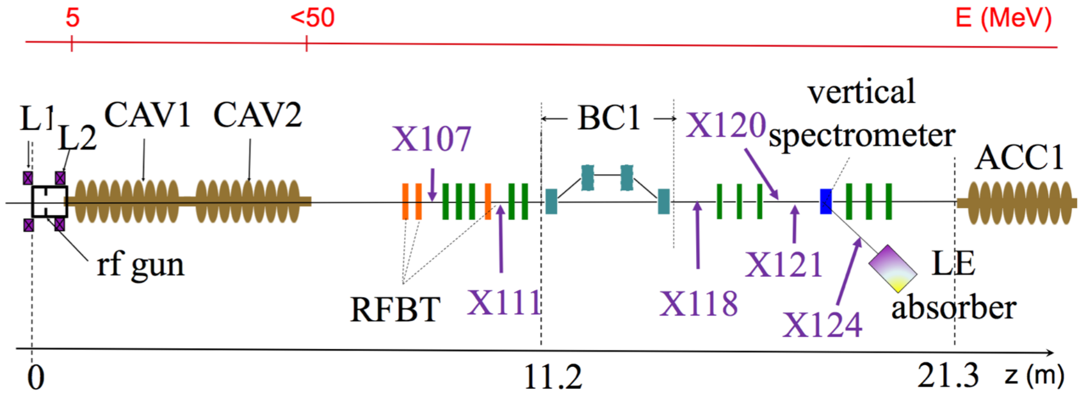
Example of optimization for 3.2 nC (simulations)

- Excellent agreement between ASTRA and IMPACT-T codes



Distributions at z=8 m from photocathode





How can we measure the eigen emittances?

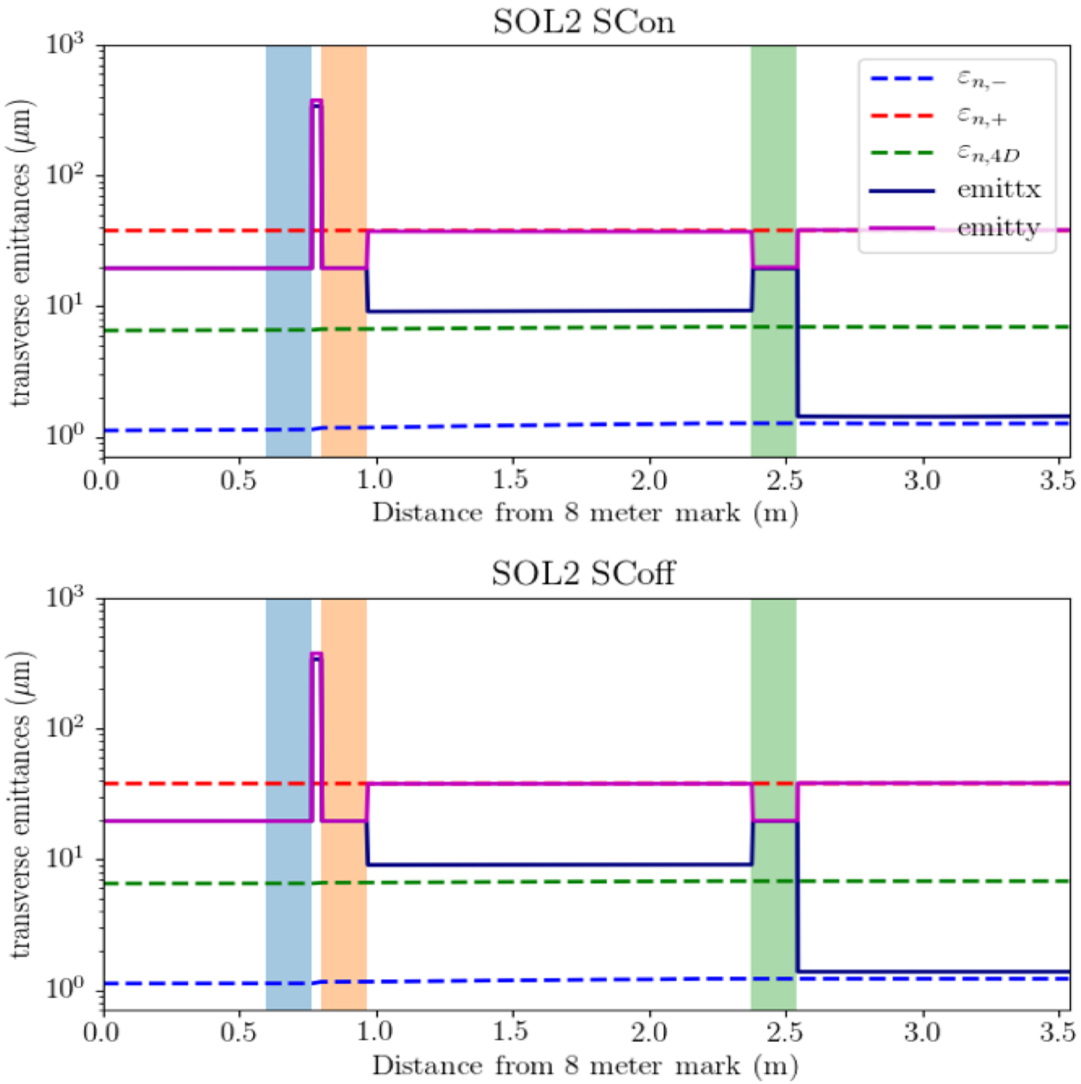
- map the eigen emittances into conventional emittance using a round-to-flat-beam converter:

$$\varepsilon_{n,\pm} = \sqrt{(\varepsilon_{n,u})^2 + (\gamma\mathcal{L})^2} \pm \gamma\mathcal{L}$$

$$\begin{cases} \varepsilon_{n,+} = 2\gamma\mathcal{L} \\ \varepsilon_{n,-} = \dfrac{(\varepsilon_{n,u})^2}{2\gamma\mathcal{L}} \end{cases}$$

(when beam is CAM-dominated)

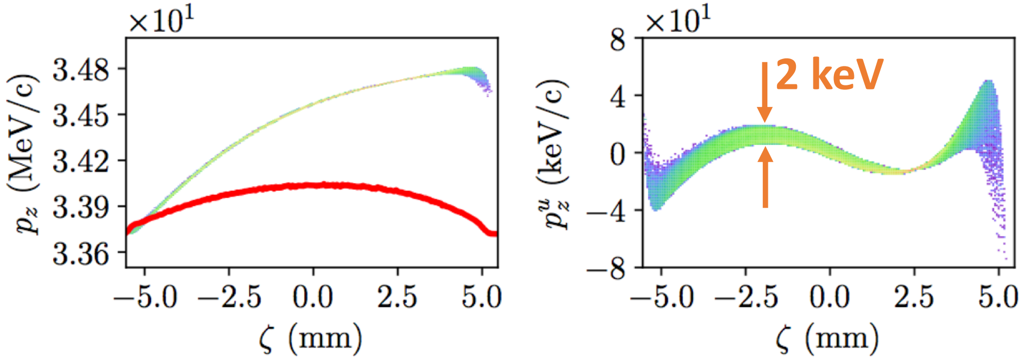
- mapping is excellent (<5%) even in presence of space charge (Q=3.2 nC and K~40 MeV)

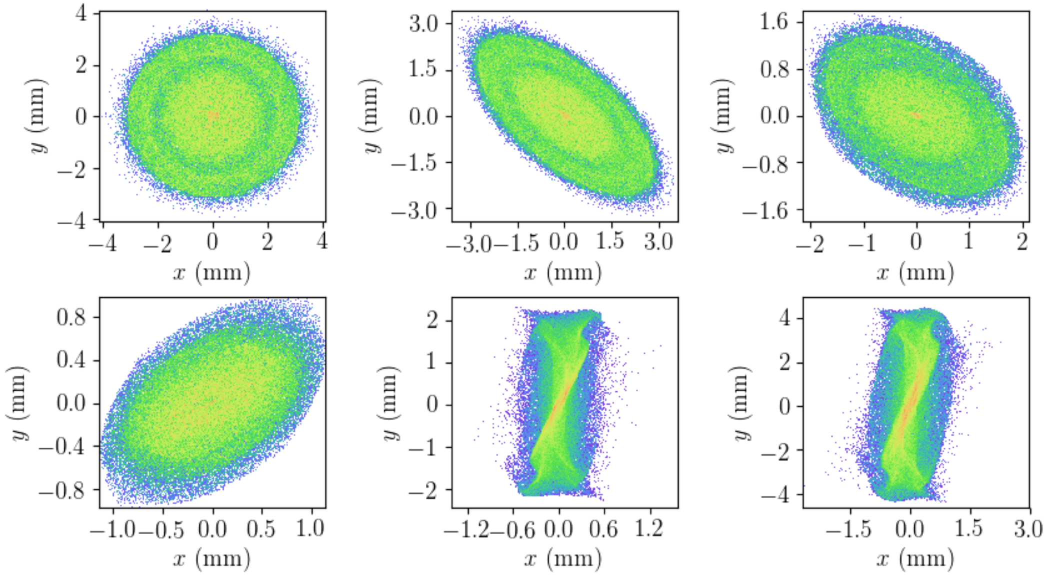


Mapping of eigen emittance to conventional emittances

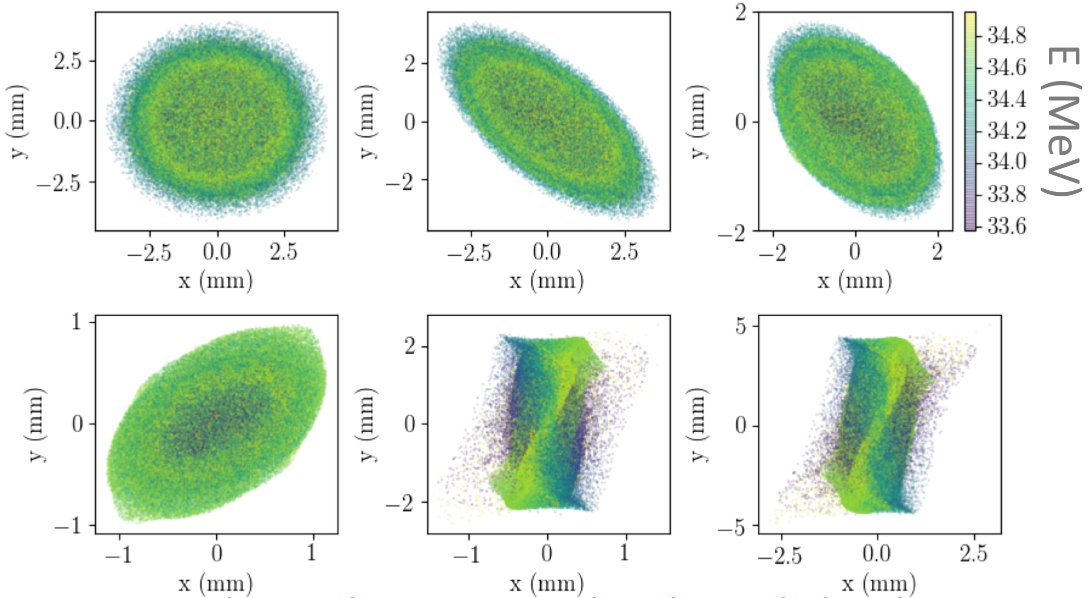
- Large total energy spread results in chromatic aberrations [uncorrelated energy spread O(1 keV)]
- RMS matching to tune the RFTB is probably not the best approach

Longitudinal phase space (left: 5th-order correlation removed)





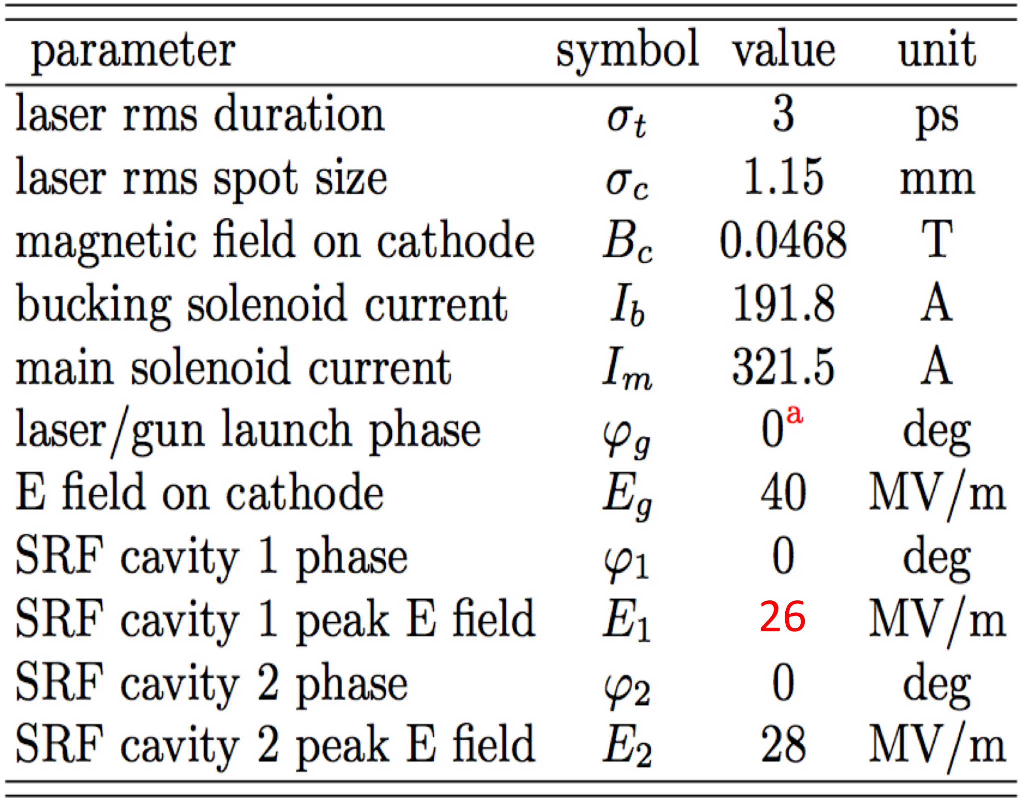
Development of round-to-flat beam transformation



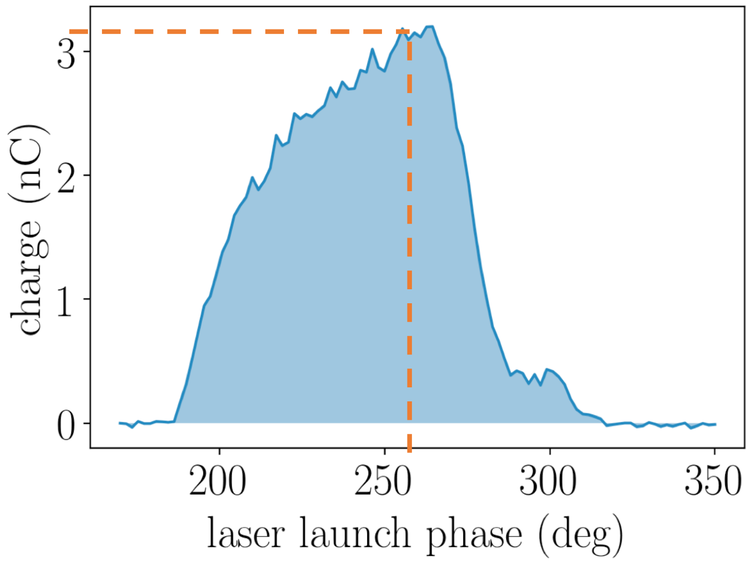
same but with macroparticle color-coded with energy

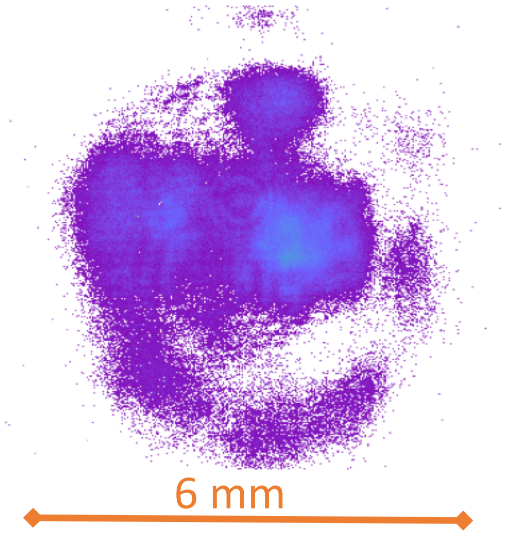
Experiment at FAST (March 2019)

- 6 shifts in march 2019:
  - Optimized parameters were not all simultaneously attainable (CAV1 field had to be lowered)
  - Laser distribution uniformity was an issue
  - Solenoid fields were varied while locking the B-field on cathode



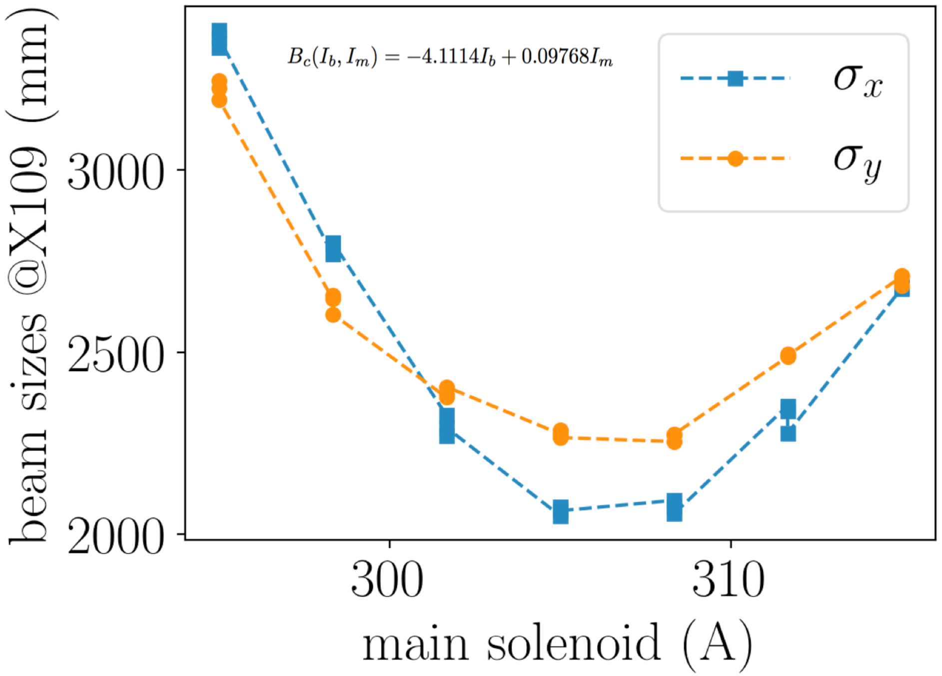
parameter	symbol	value	unit
laser rms duration	σ_t	3	ps
laser rms spot size	σ_c	1.15	mm
magnetic field on cathode	B_c	0.0468	T
bucking solenoid current	I_b	191.8	A
main solenoid current	I_m	321.5	A
laser/gun launch phase	φ_g	0^{a}	deg
E field on cathode	E_g	40	MV/m
SRF cavity 1 phase	φ_1	0	deg
SRF cavity 1 peak E field	E_1	26	MV/m
SRF cavity 2 phase	φ_2	0	deg
SRF cavity 2 peak E field	E_2	28	MV/m

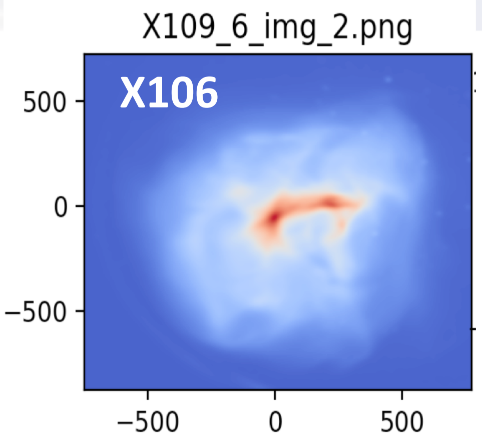


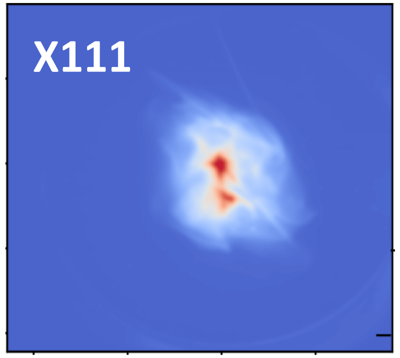


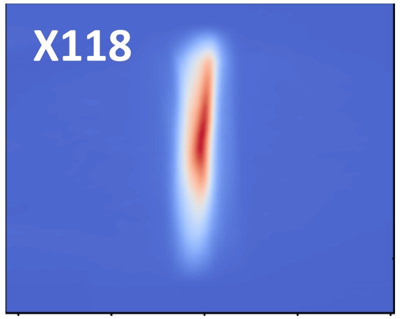
Preliminary Analysis of one case (3/14 data)

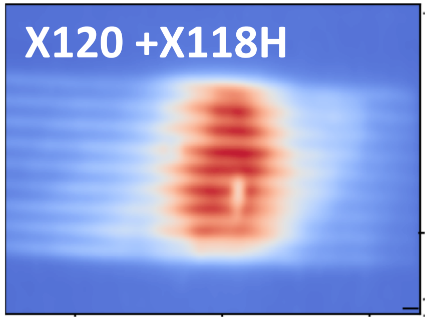
- Q=3.29+/-0.1 nC
- B_c=678 G
- Solenoid scan with fixed B field on cathode

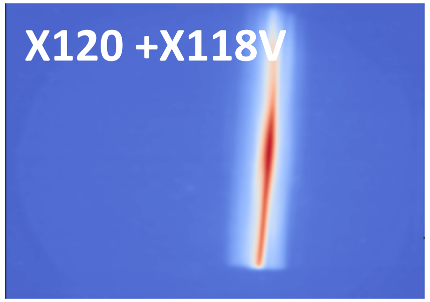












- Measured *normalized* emittance in μm

$$\varepsilon_x = 6.4 \pm 2$$

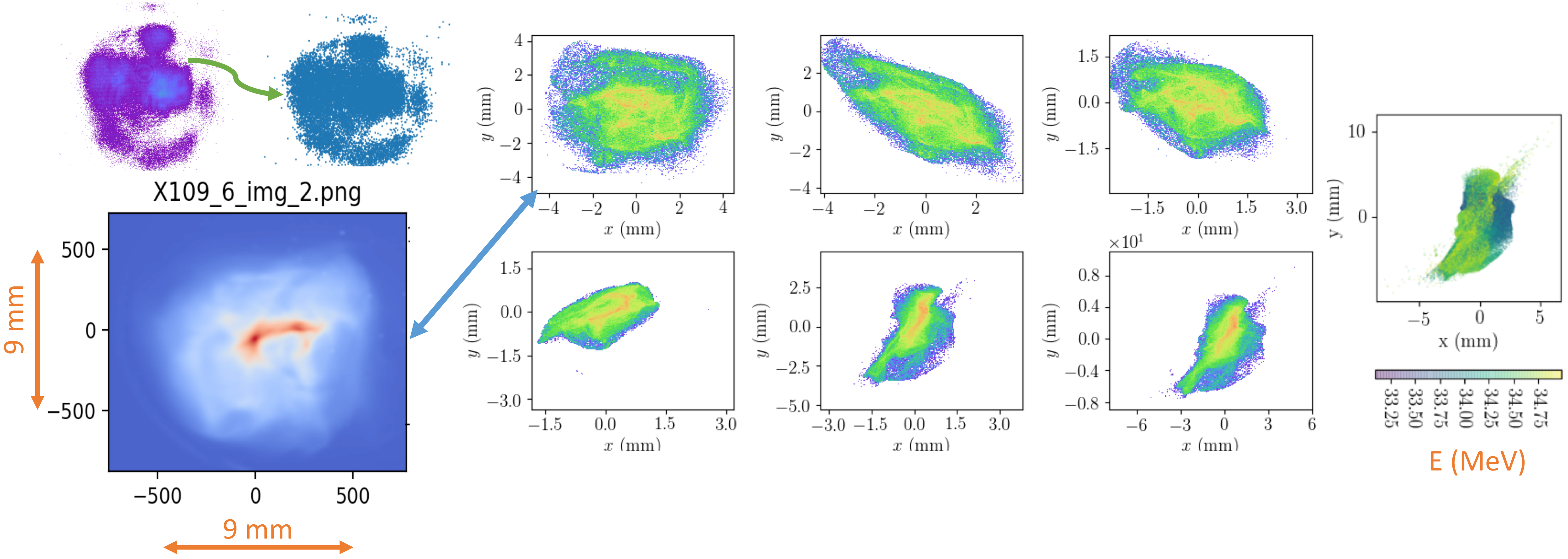
$$\boxed{\varepsilon_y = 34.6 \pm 5}$$

we expect 46 um from B_c

FlatBeam2019/MagBeam_EIC/MAR-14-2019/SolScan_fixedBcath_20190315_003959

Simulation using realistic experimental conditions

- Optimization done for idealized laser distribution
- Impact of non-ideal distribution is explored via simulation

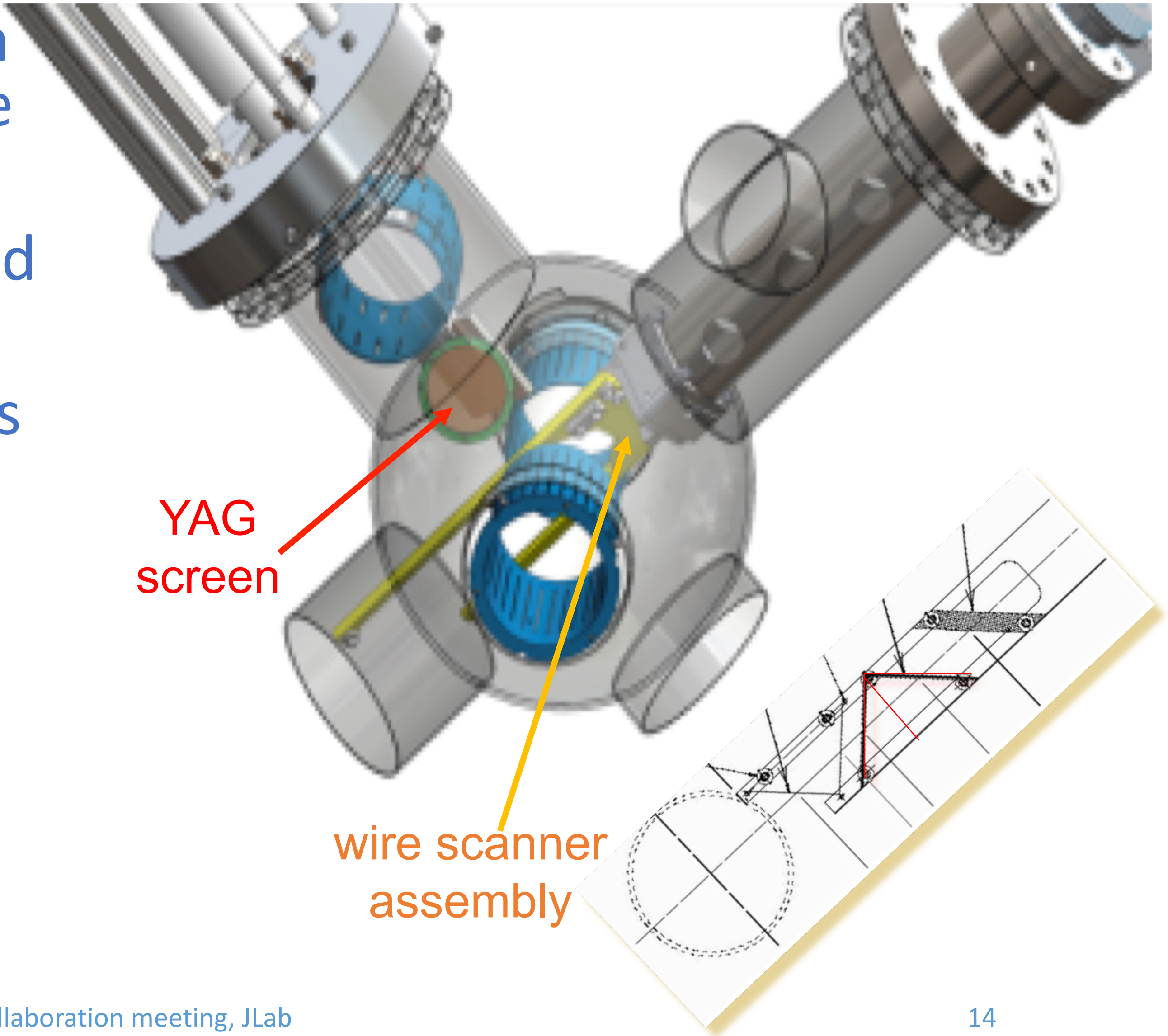


Conclusions on measurements

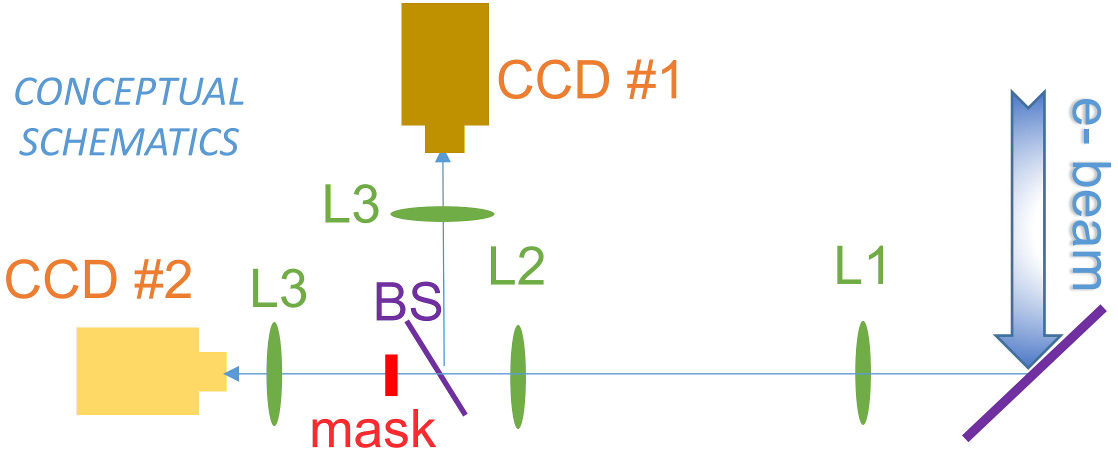
- Measurement technique tested based on mapping of eigen emittance to conventional emittance tested
- Data will be analyzed over the next few weeks
  - Better analysis based on RMS calculation
  - Compared measured eigen emittance with what expected from B field on cathode and understand discrepancies
  - Use simulation to guide/understand data analysis
- FAST-IOTA is currently in a “spring” shutdown to install H- source for IOTA. We will use this down time to:
  - Improve the laser transport + uniformity (considering using a UV DMD).
  - Check diagnostics
  - Install hardware related to future magnetized-beam work

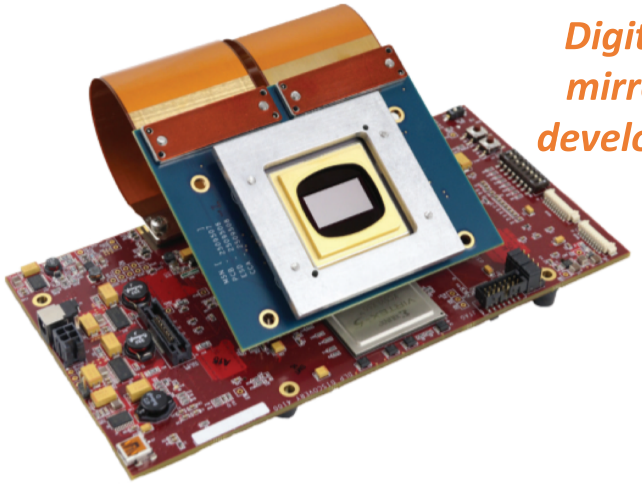
Halo formation in magnetized beams

- Halo could cause beam loss which would ultimately limit the average current of the ERL cooler
- Various source of halo (some could be mimicked with laser shaping)
- Large-dynamical-range diagnostics developed at Jlab (P. Evtushenko and J. Gubeli):
    - Wire scanner with high-dynamical range electronic or PMT (measured projections only)
    - YaG:Ce screen with dual-sensor detection system.



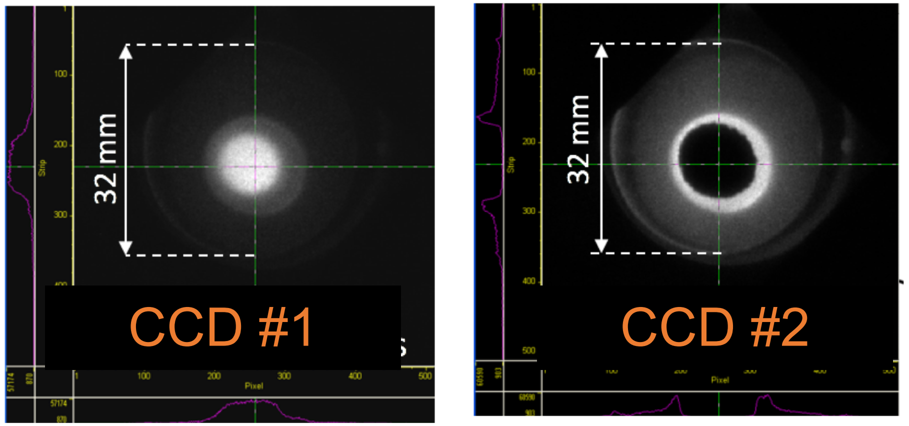
Measurement of halo at $\sim 10^{-6}$ fraction



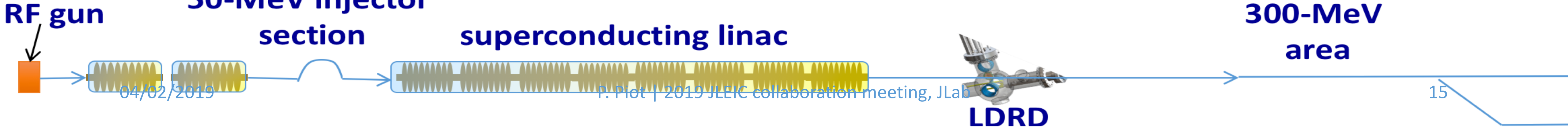


Digital-micro-mirror (DMD) development. kit

- LDRD optics will be tested soon (w. DMD)
- Optics simulation (SRW)
- Magnetized beam will be transported for 50-70 m and halo diagnosed -- already done (and injected in IOTA) operators error.



(adapted from R. Fiorito UMD)



Summary

1. High-charge magnetized beam:
   a. Simulation of 3.2 nC magnetized beam with parameters consistent with JLEIC mostly done; need to understand limiting effects associated with mapping into conventional emittances (flat-beam transform).
   b. Simulations of transport of magnetized beams started.
   c. Beam experiment on magnetized-beam; analysis + comparison with simulation just started.
2. High-current magnetized beams
   a. Possible locations for the LDRD identified,
   b. LDRD optics designed and to be tested soon
3. Next running period (August) will focus on parametric studies on magnetized beam and halo formation (we expect more shifts given that all the operation subtilties associated with switching IOTA to FAST linac are now worked out)