Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

NORTHERN ILLINOIS CENTER FOR ACCELERATOR AND DETECTOR DEVELOPMENT

NIU

High-Charged Magnetized Beams at FAST-IOTA

Northern Illinois University: A. Fetterman*, C. Marshall*, P. Piot$
Fermilab: D. Crawford, C. Edstrom, J. Ruan

Collaborators at JLab: S. Benson, J. Gubeli,
F. Hannon, S. Wang

* Graduate students (MS)
$ also FermiLab

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.

Note on emittances & Magnetization

- Effective emittance of a magnetized beam

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

uncorrelated emittance

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

Laser-spot size on cathode

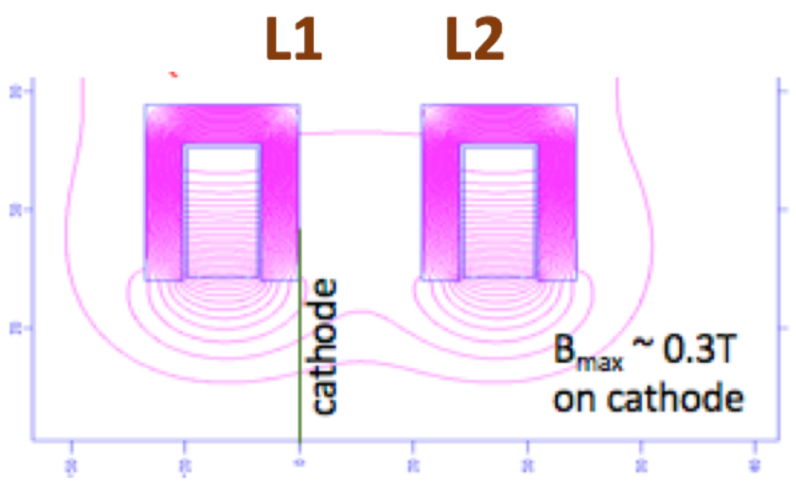
B field on cathode

- Eigen emittances

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

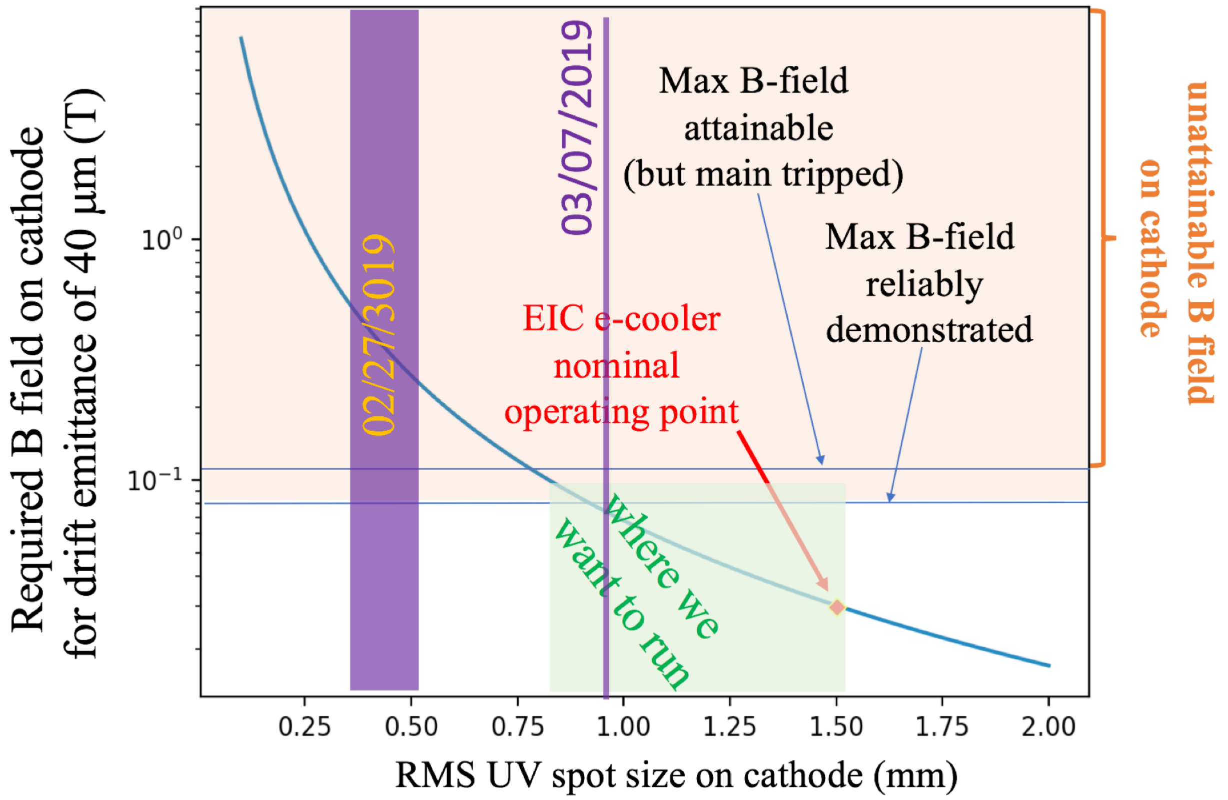
$$\begin{cases} \varepsilon_{n,+} = 2\gamma\mathcal{L} \equiv \varepsilon_{n,d} & \text{“drift” emittance} \\ \varepsilon_{n,-} = \dfrac{\varepsilon_{n,u}^2}{2\gamma\mathcal{L}} \equiv \varepsilon_{n,c} & \text{“cyclotron” emittance} \end{cases}$$

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



Relevance of FAST injector to JLEIC e- cooling

- Similar beam parameters except for a higher peak current

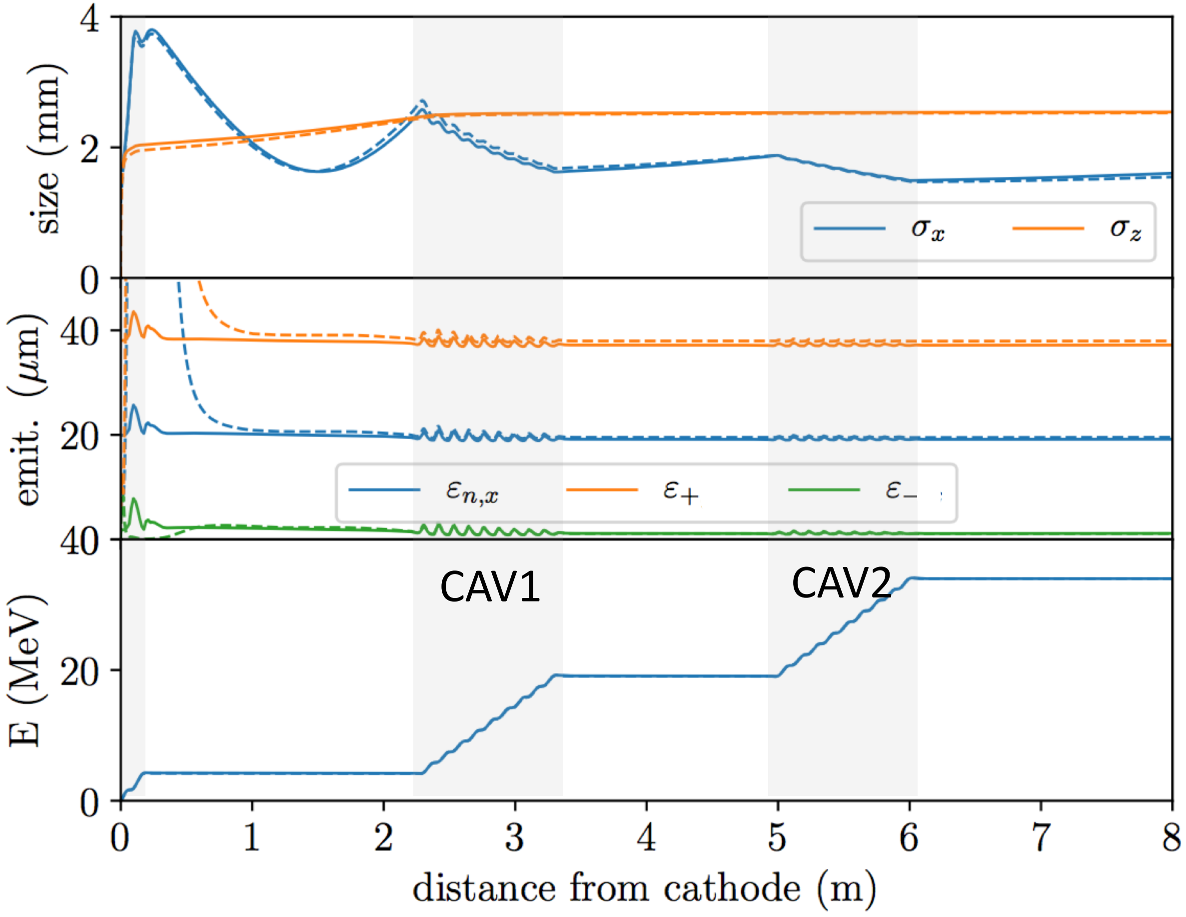


		JLEIC strong cooling	FAST
parameter	unit	value	value
beam energy	MeV	[20,55]	44[a]
bunch charge	nC	3.2 (1.6)	3.2[b]
cathode spot size[c]	mm	1.55	1
B field on cathode	T	0.05	< 0.09 [d]
cyclotron emit.	μm	≤ 19	< 5
drift emit.	μm	36	37
$\delta p/p$ (uncor.)	–	3.10^{-4}	$< 4.10^{-4}$
$\delta p/p$ (pk-to-pk.)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

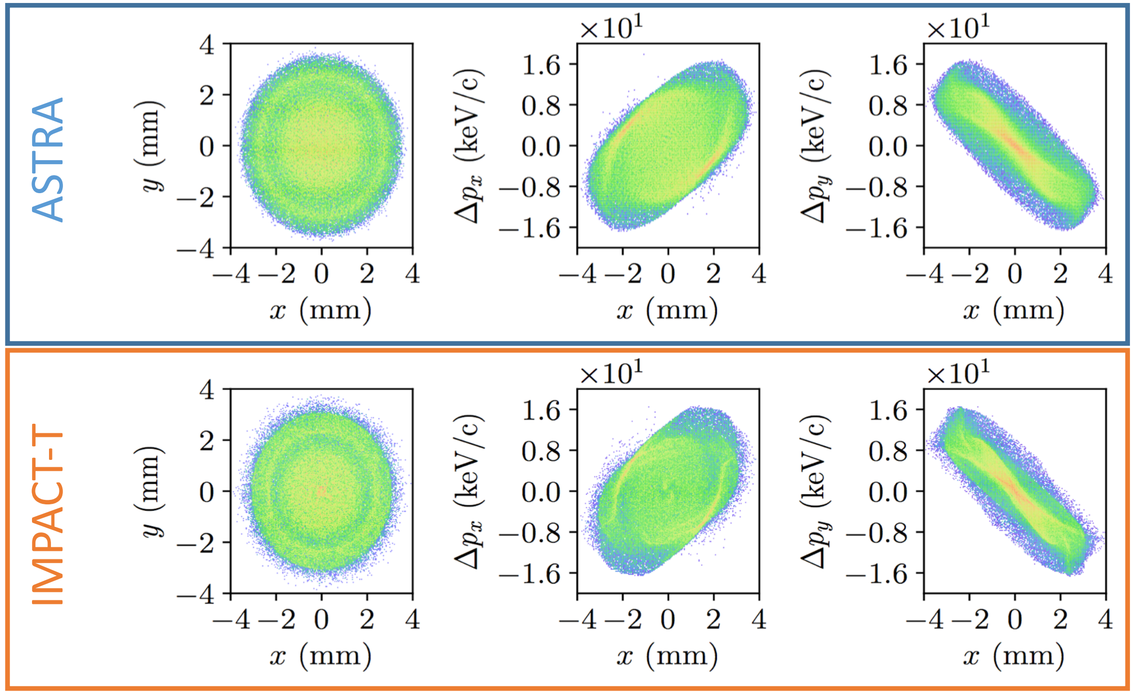
[a] energies in the range [20,45] MeV are easily achievable at FAST.
[b] [redacted]
[c] JLEIC requirements give the cathode radius r_c so that RMS values are taken to be $\sigma_{x,y} = r_c/2$, i.e. assuming a *uniform* emission source
[d] values experimentally achieved.
[e] this value corresponds to the *slice* fractional momentum spread.
[f] nominal value, longer values achievable with bunch decompression

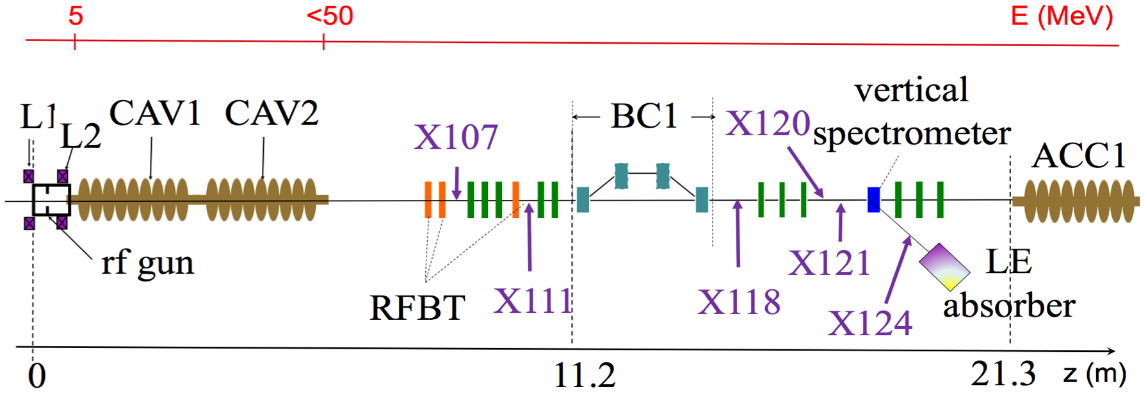
Example of optimization for 3.2 nC (simulations)

- Excellent agreement between ASTRA and IMPACT-T codes



Distributions at z=8 m from photocathode





How can we measure the eigen emittances?

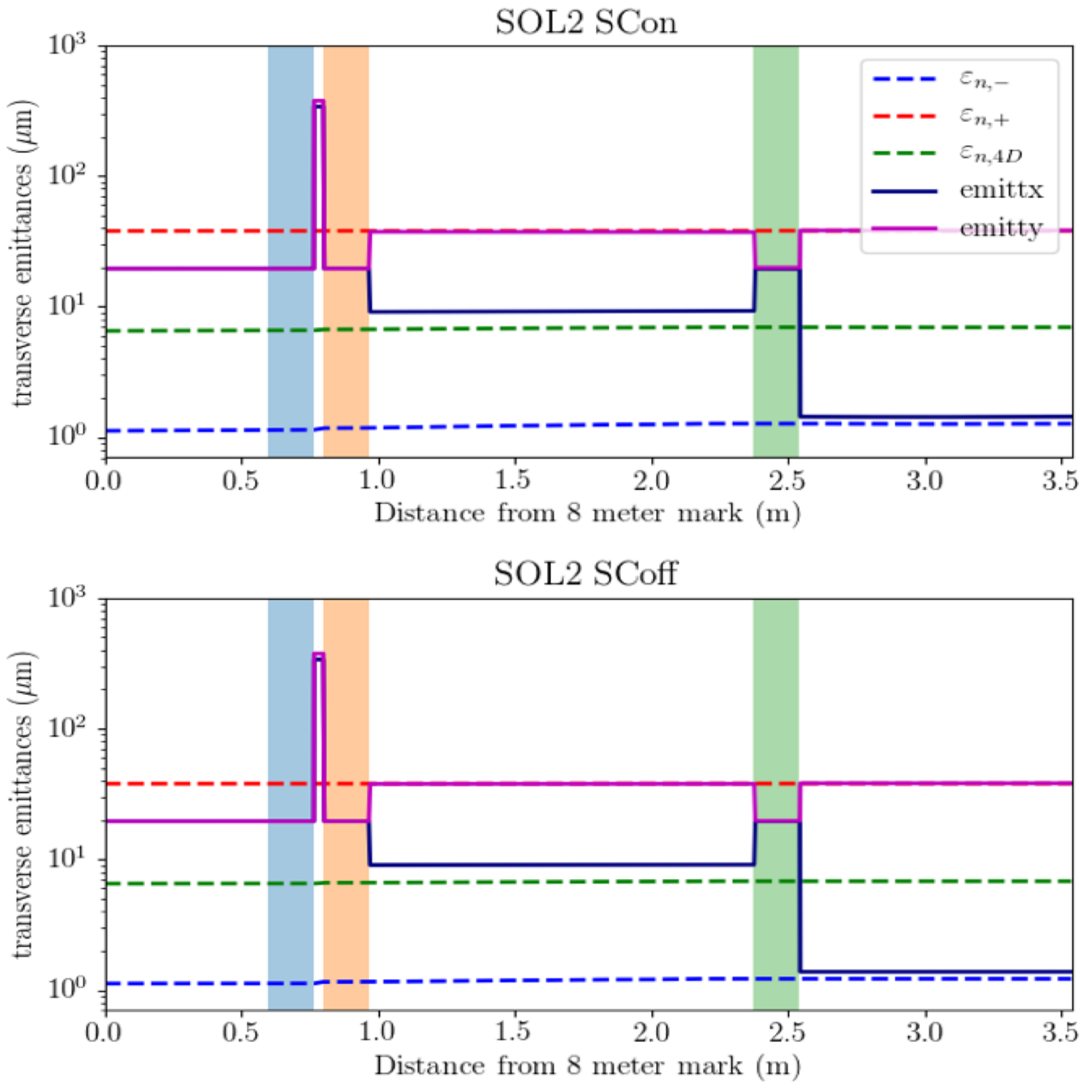
- map the eigen emittances into conventional emittance using a round-to-flat-beam converter:

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

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

(when beam is CAM-dominated)

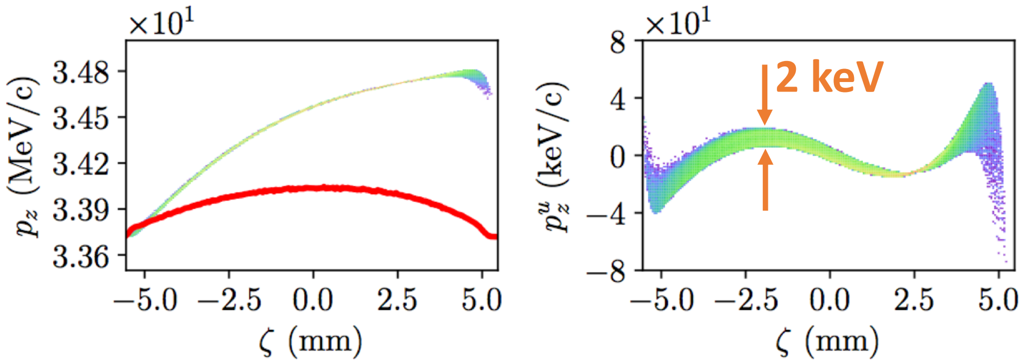
- mapping is excellent (<5%) even in presence of space charge (Q=3.2 nC and K~40 MeV)

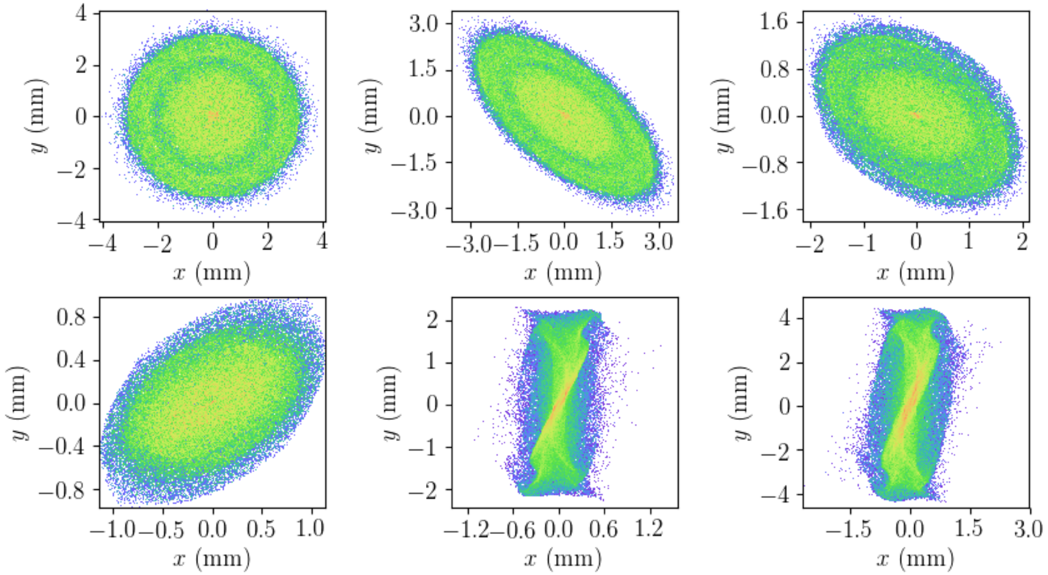


Mapping of eigen emittance to conventional emittances

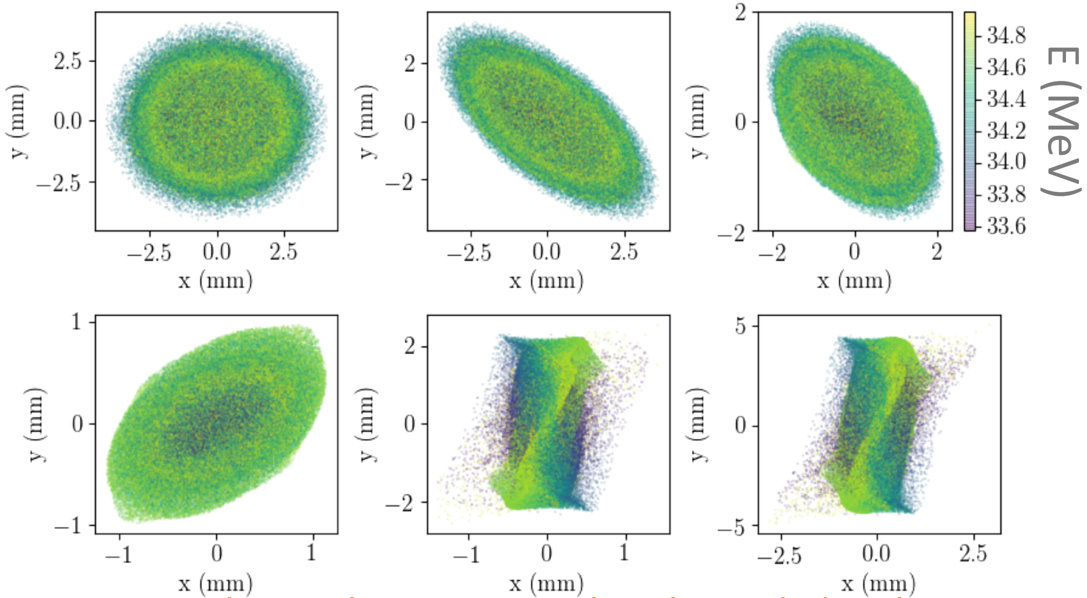
- Large total energy spread results in chromatic aberrations [uncorrelated energy spread $\mathcal{O}$(1 keV)]
- RMS matching to tune the RFTB is probably not the best approach

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





Development of round-to-flat beam transformation

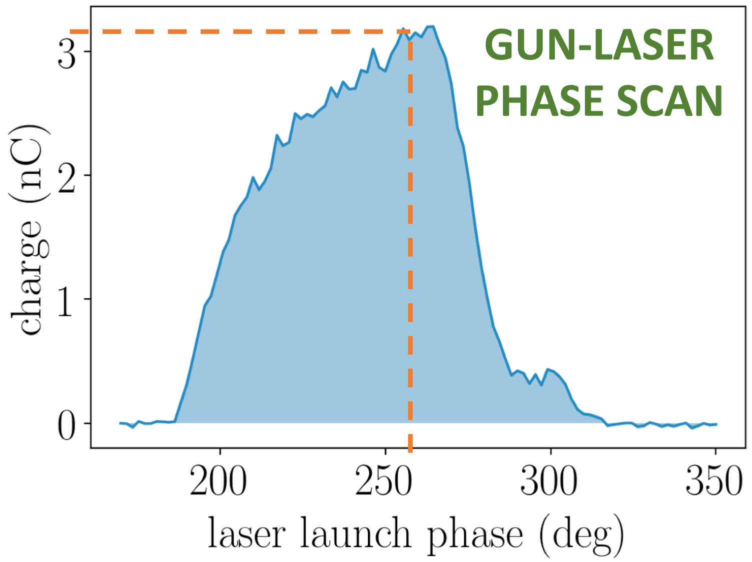


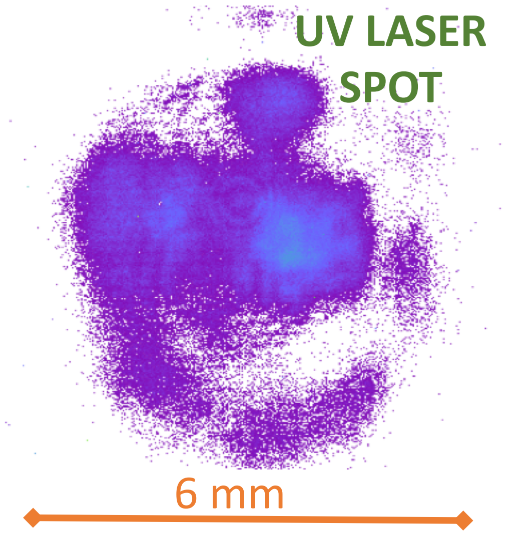
same but with macroparticle color-coded with energy

Experiment at FAST (March 2019)

- 6 shifts in march 2019:
  - Not all optimum parameters were attainable simultaneously (CAV1 field had to be lowered)
  - Laser distribution uniformity/control was a significant issue (required significant setup time)
  - Solenoid fields were varied while "locking" the B-field on cathode

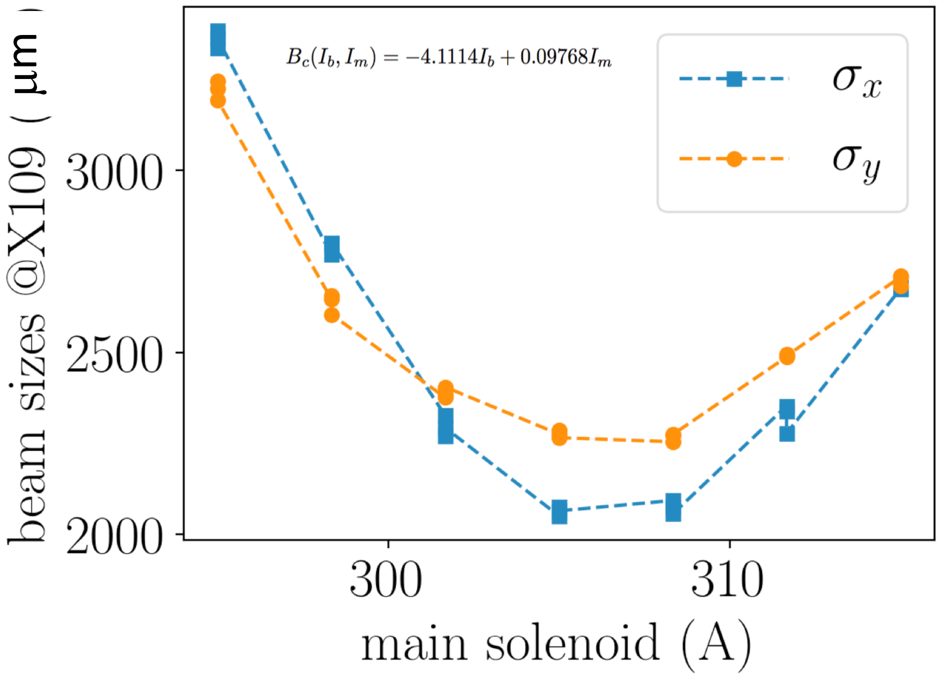
parameter	symbol	value	unit
laser rms duration	σ_t	3	ps
laser rms spot size	σ_c	1.15	mm
magnetic field on cathode	B_c	0.0468	T
bucking solenoid current	I_b	191.8	A
main solenoid current	I_m	321.5	A
laser/gun launch phase	φ_g	0[a]	deg
E field on cathode	E_g	40	MV/m
SRF cavity 1 phase	φ_1	0	deg
SRF cavity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

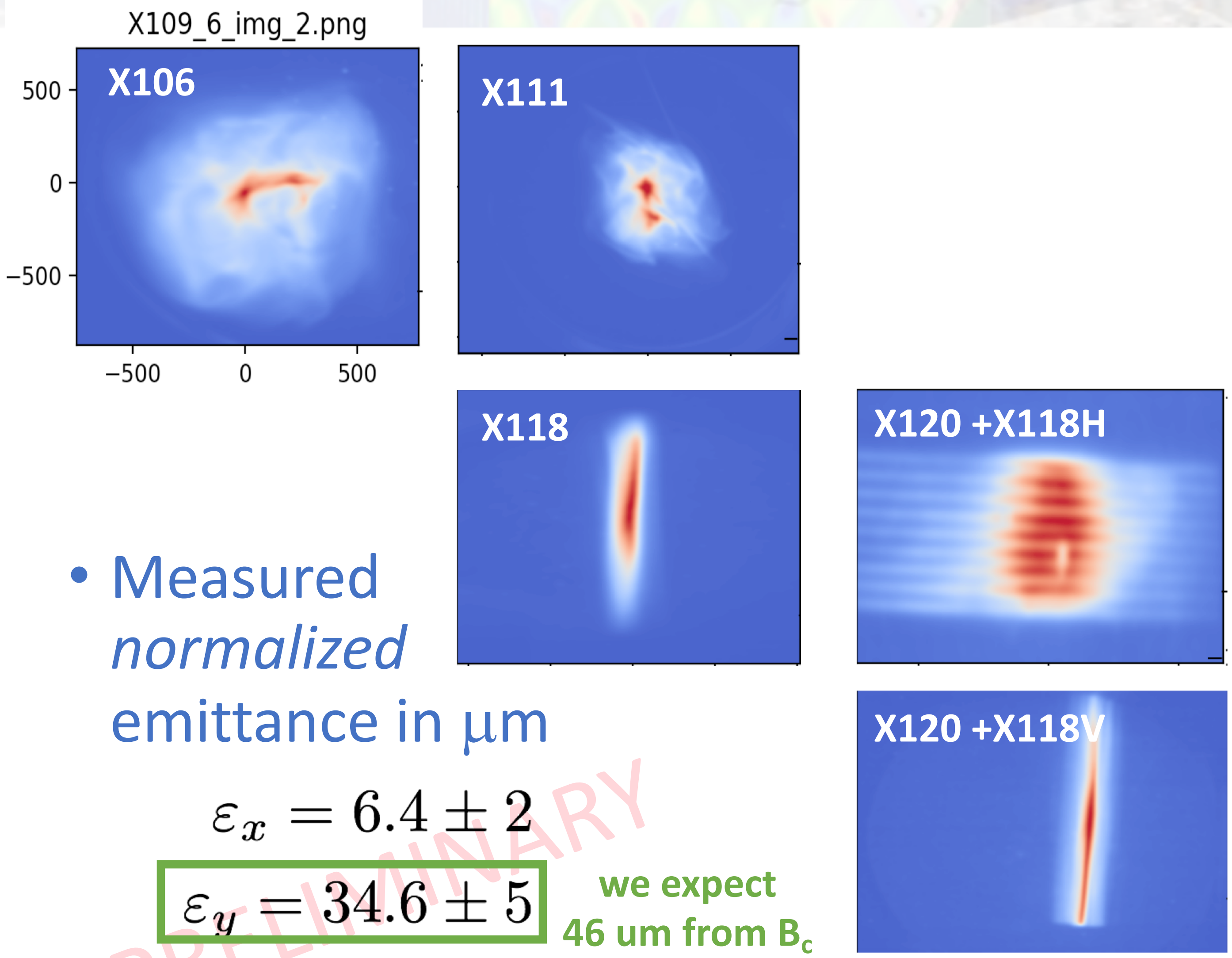




Preliminary Analysis of one case (3/14 data)

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





- Measured *normalized* emittance in μm

$$\varepsilon_x = 6.4 \pm 2$$

$$\varepsilon_y = 34.6 \pm 5$$

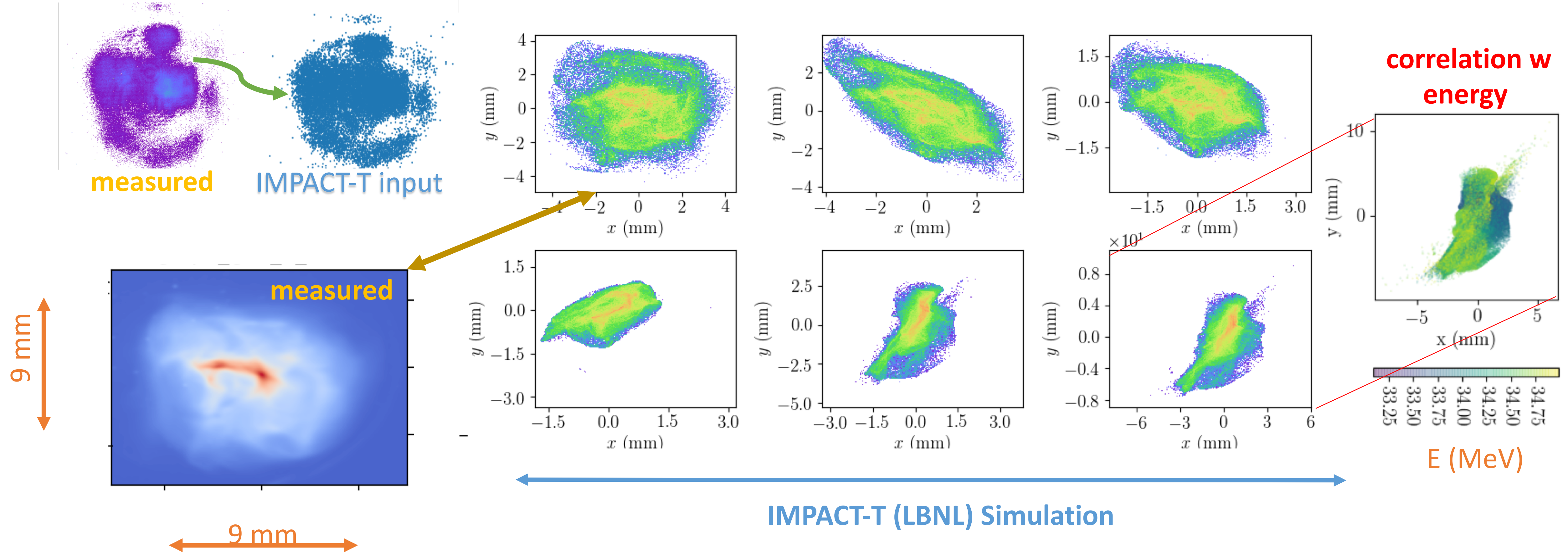
we expect 46 um from B_c

PRELIMINARY

FlatBeam2019/MagBeam_EIC/MAR-14-2019/SolScan_fixedBcath_20190315_003959

Simulations using realistic experimental conditions

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

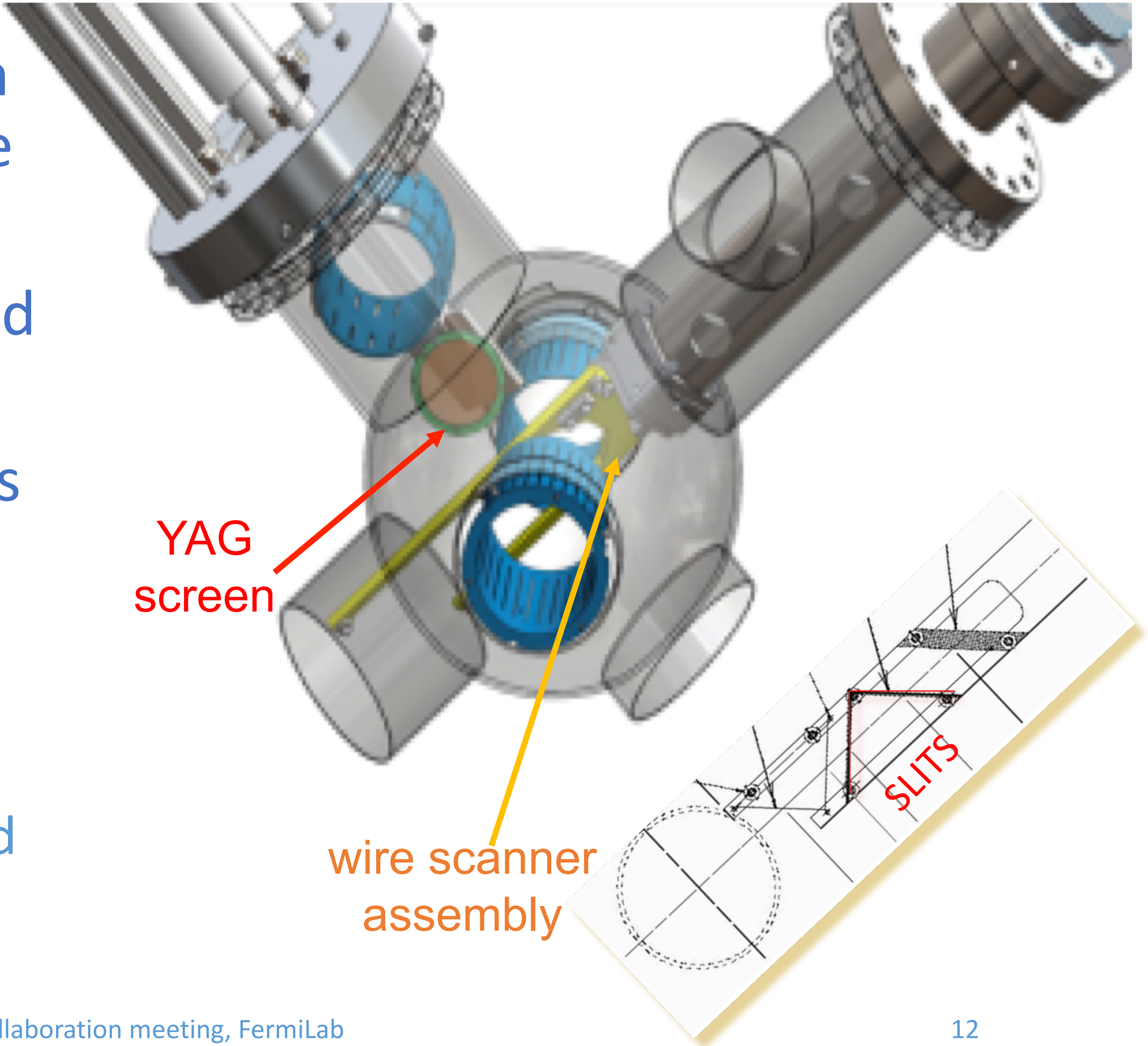


Conclusions on measurements

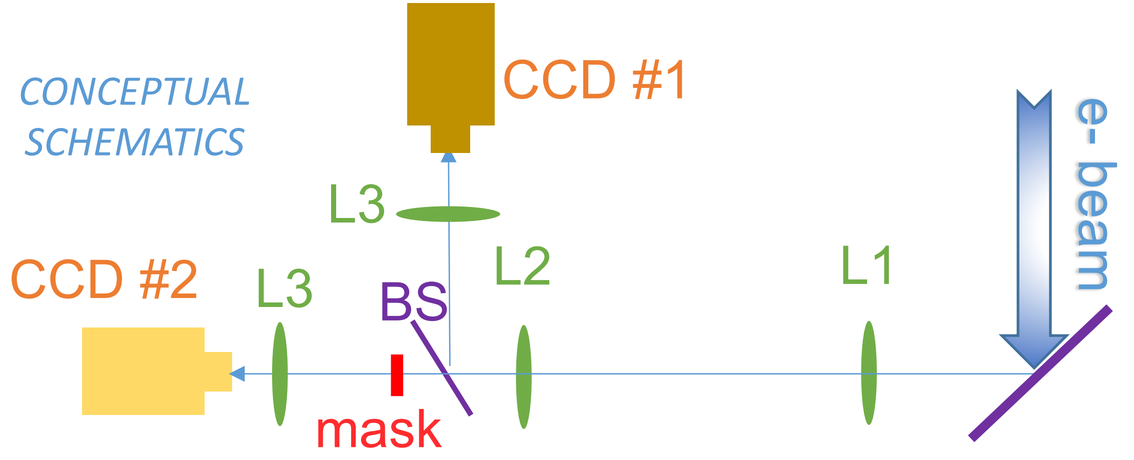
- Measurement technique tested based on mapping of eigen emittance to conventional emittances
- Data will be analyzed over the summer (A. Fetterman's thesis)
  - Better analysis based on RMS calculation
  - Compared measured eigen emittance with what expected from B field on cathode and understand discrepancies
  - Use simulation to guide/understand data analysis
- We will use current downtime to:
  - Improve the laser transport + uniformity (~~considering using a UV DMD~~).
  - Check diagnostics (issue with charge measurement, focusing on X107, change stepping motors on X118 slits)
  - Install hardware related to future magnetized-beam work

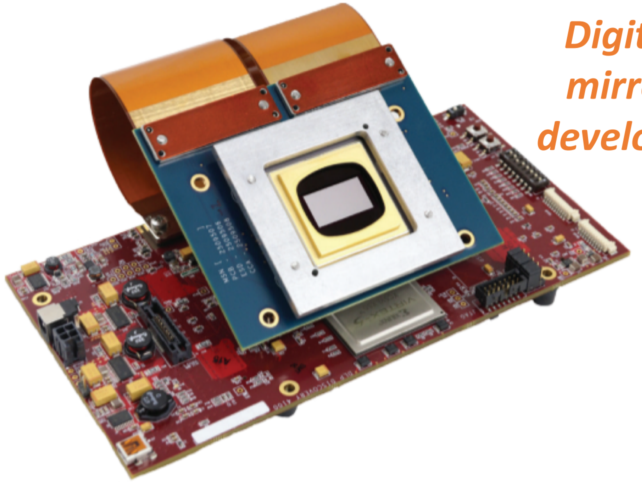
Halo formation in magnetized beams

- 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):
  - YaG:Ce screen with dual-sensor detection system.
  - Incorporate a moving horizontal and vertical slits



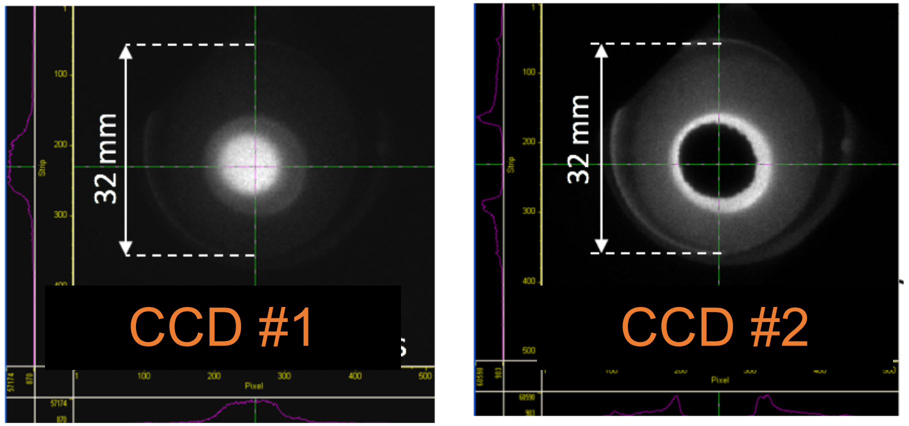
Measurement of halo at $\sim 10^{-6}$ fraction





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 will focus on parametric studies on magnetized beam and halo formation