Summary of flat-beam studies at FAST during FALL17 run

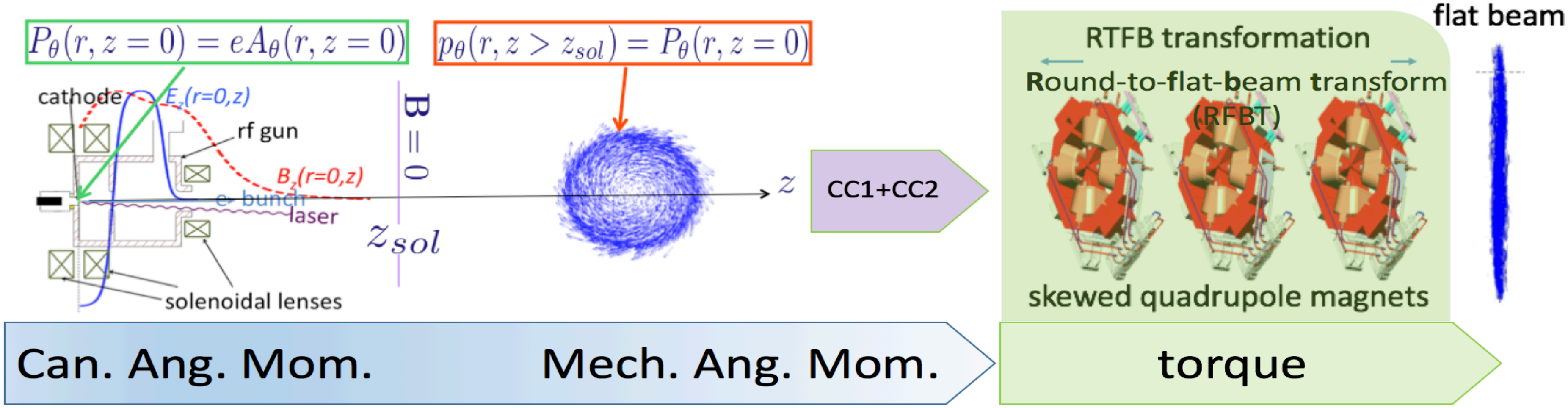
A. Halavanau*, work by all the FAST team.

Presented by P. Piot

Fermilab FAST/IOTA retreat 12/21/2017

Introduction

- Flat process:
  1. Magnetized beam
  2. Torque from skew quadrupole channel



$$\mathcal{L} = \frac{eB_0}{2mc}\sigma_c^2$$

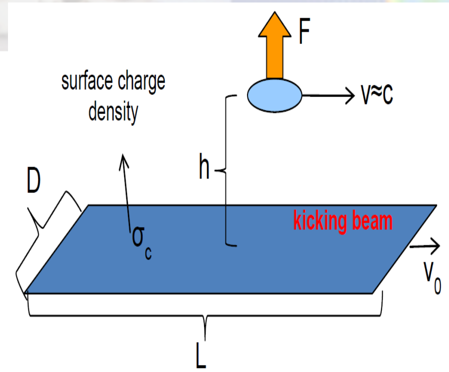
$$\varepsilon_\pm = \varepsilon \pm \mathcal{L}.$$ eigenemittances

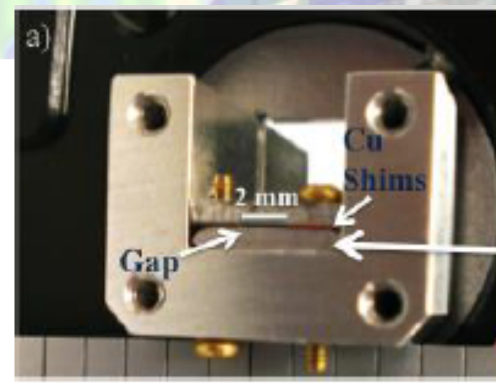
$$\varepsilon^2 = \mathcal{L}^2 + {\varepsilon_u}^2$$

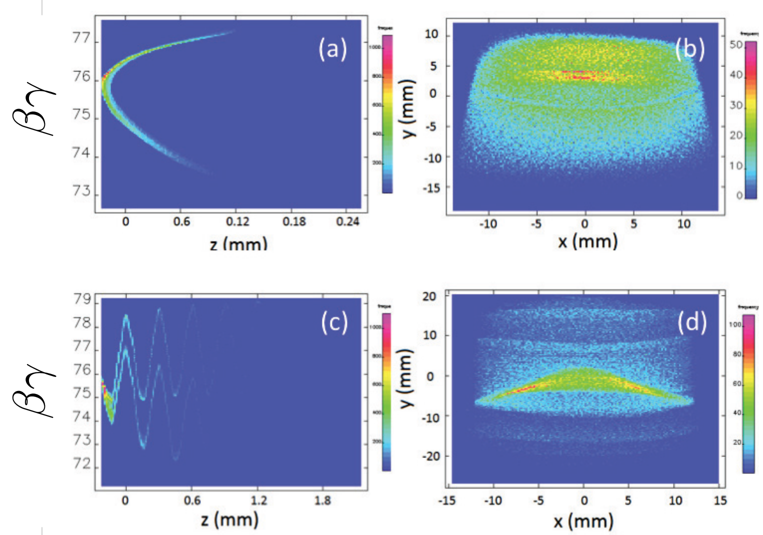
ε_- → ε_x, ε_+ → ε_y

Why flat beams?

- Physics of flat beam:
  - Transfer of eigen-emittances to conventional emittances
  - Compression of flat beams
  - Flatness limit (linear colliders)
  - Application as a phase-space diagnostics
- Applications:
  - Beam manipulation/acceleration in asymmetric structures (prop. w. radiabeam)
  - Micro-undulator (U. Florida), Smith Purcell…
  - Beam-beam kicker (idea by V. Shiltsev)
  - **Intermediary stage for transport of magnetized beam (e-cooling at JLEIC)**

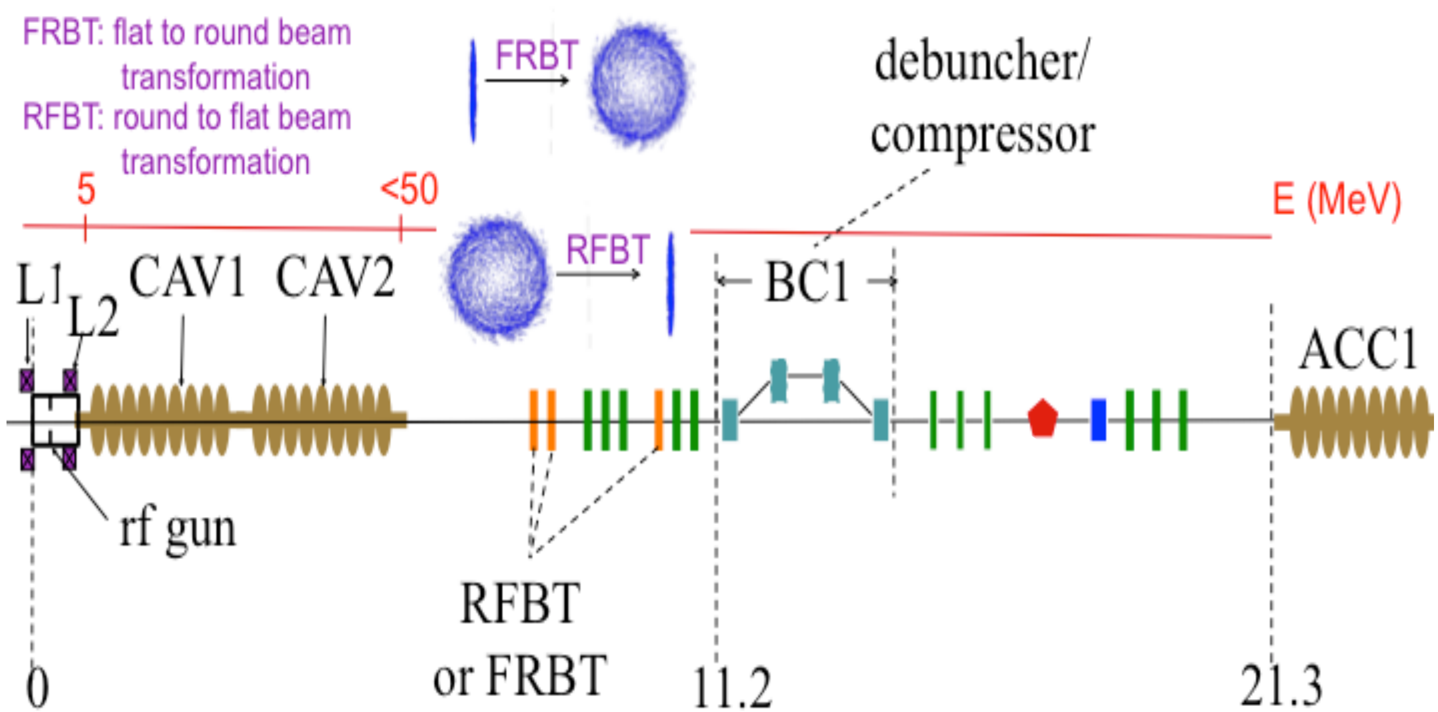






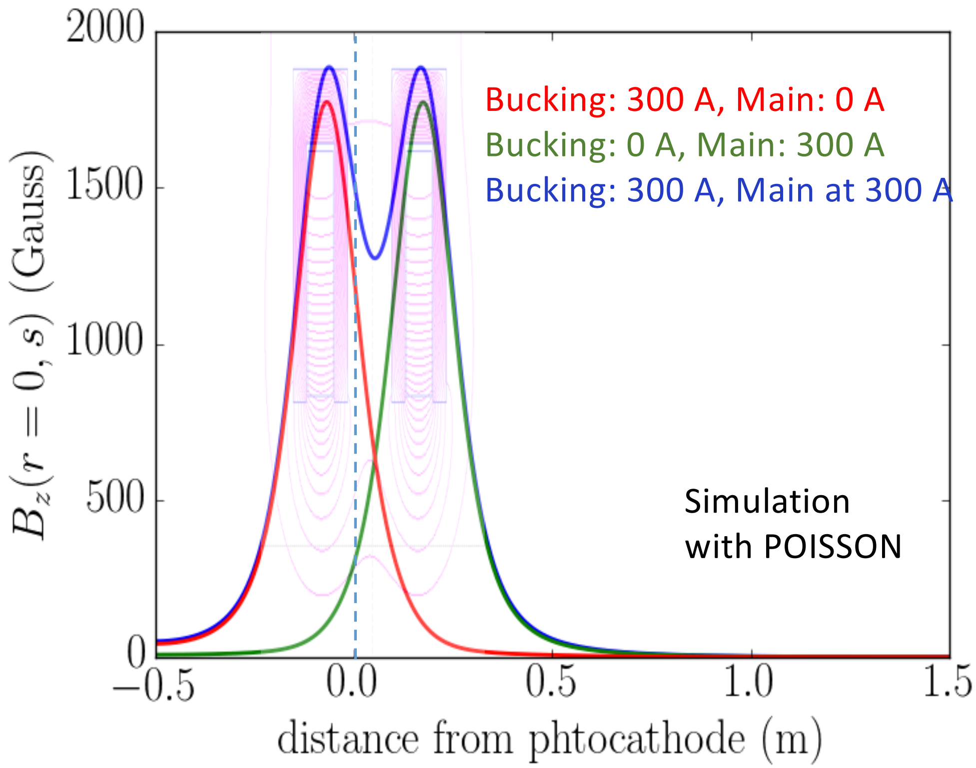
Hardware + Setup

- **Axial B field on photocathode**
- **Skew quads:**
  - **Q106, Q107, Q111** skewed
- **Diagnostics:**
  - Slits at X107 (incoming beam parameters) + magnetization
  - Slits at X118 would make experiment easier



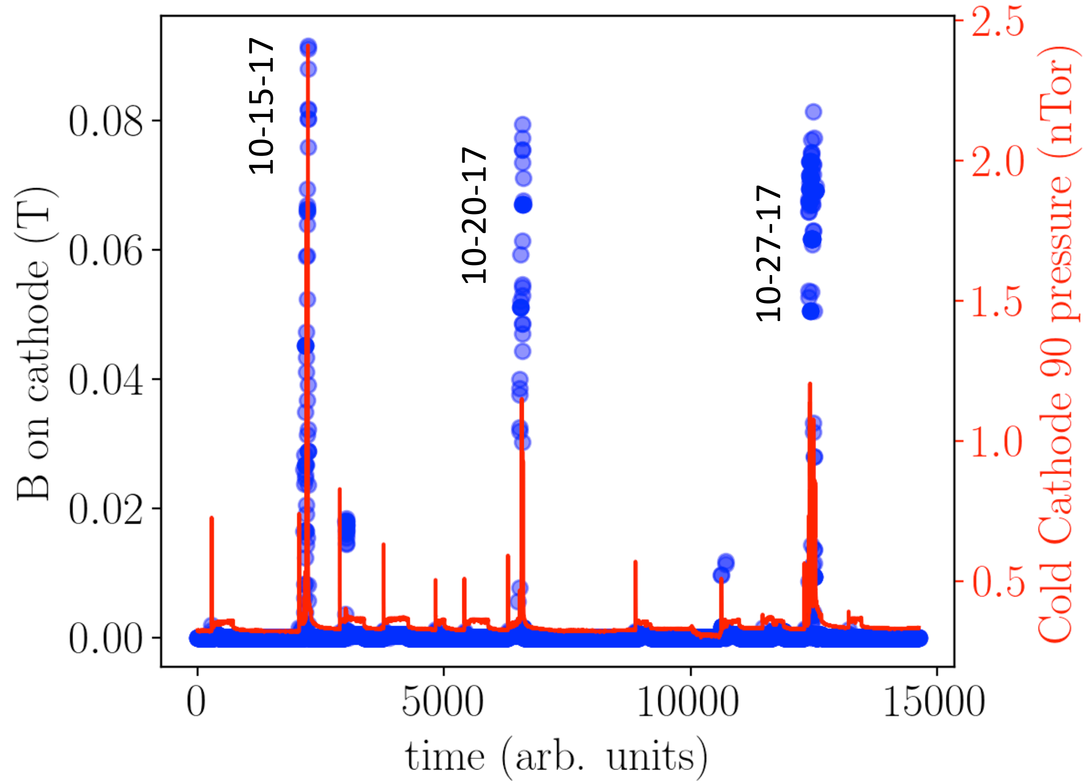
Anticipated improvements over past experiments

- **At A0PI experiment was limited:**
  - B-field on cath. <900 G
  - RFBT transformation at 15 MeV (SC + aberration limited the achievable emittance ratio)
- **At FAST**
  - B-field on cath. >~1200 G
  - RFBT transformation at >~40 MeV
  - Manipulation after RFBT:
    - Compression of flat beam
    - Acceleration in a cryomodule
    - “Re-magnetization”



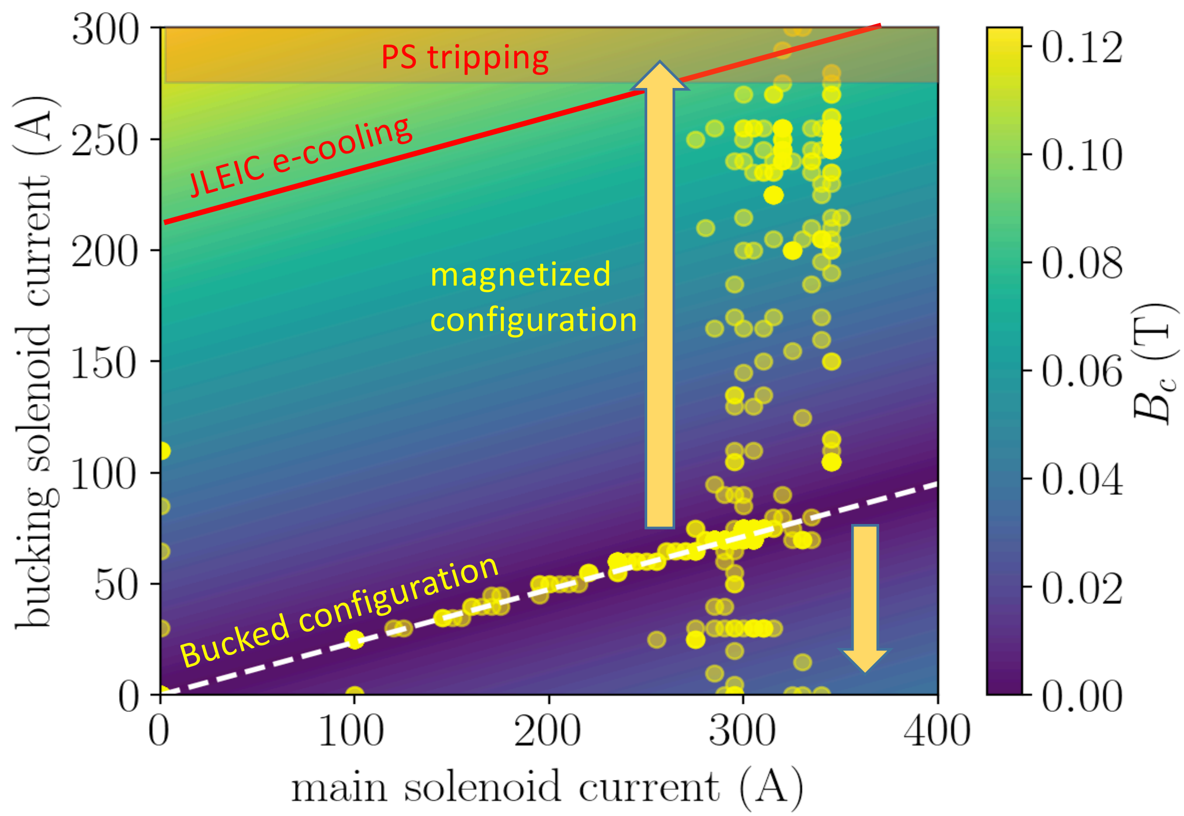
Solenoid field on cathode (I)

- Changing the B field leads to vacuum activity
- But this was seemingly conditioned by gradually increasing the field over a few shifts
- We were not able to go over 300 A due to other issue



Solenoid field on cathode (II)

- Ultimately, the limitation that prevented higher field came from the bucking-solenoid power supply (**to my knowledge the root cause has not been investigated**)



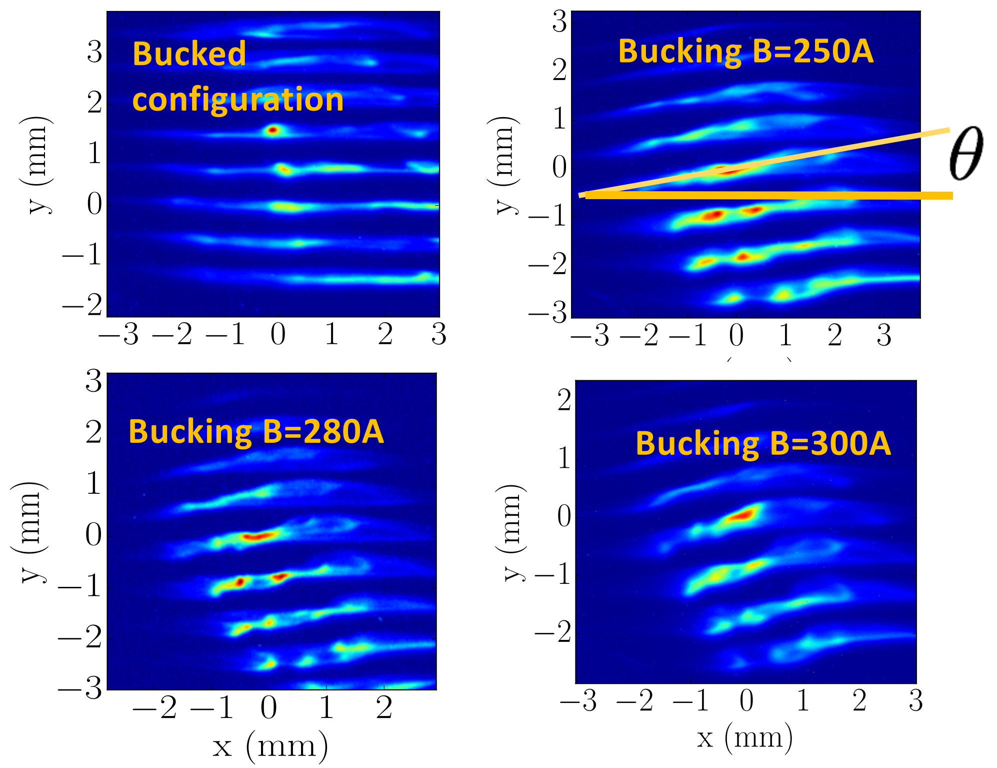
Magnetization (I)

- The beam magnetization was measured using X107 slits + X111 viewer

$$\mathcal{L} = 2\frac{p_z}{mc}\frac{\sigma_{107}\sigma_{111}\sin\theta}{D}$$

- Later we used the improved setup with X107 CCD

Bucking current, A	Rotation angle, (deg)	<L >, μm
250A	8	18.3
280A	14	19.8
300A	17	25.3



Magnetization (II)

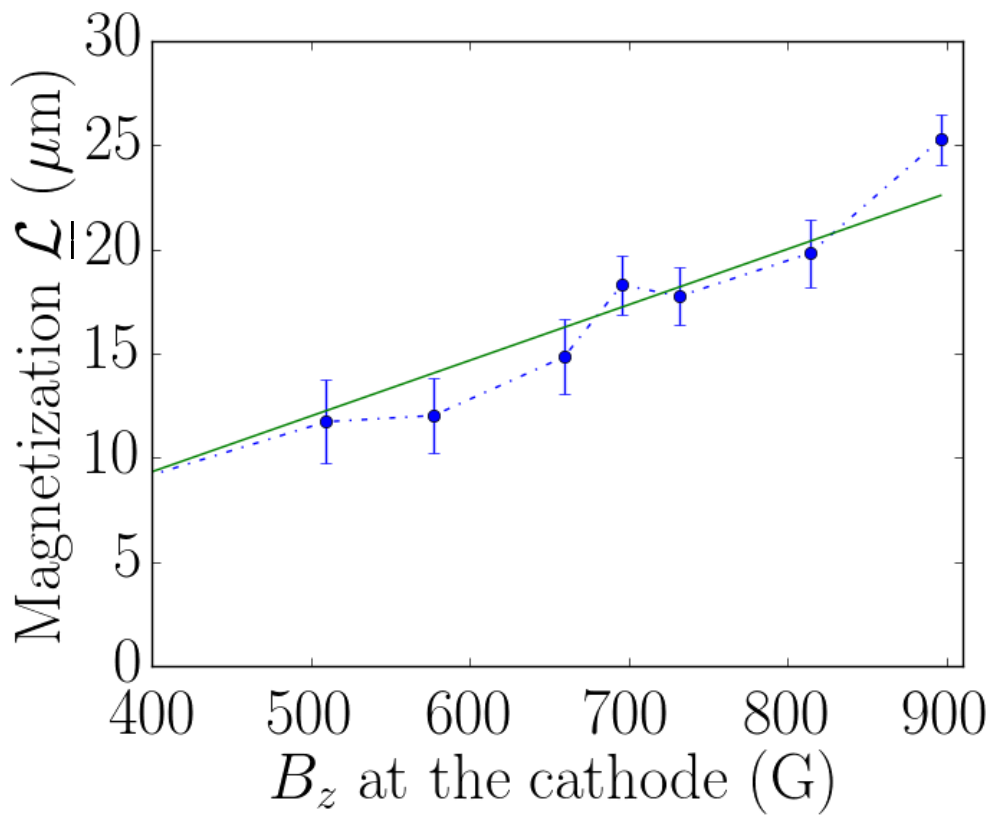
- Magnetization:

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

field on cathode

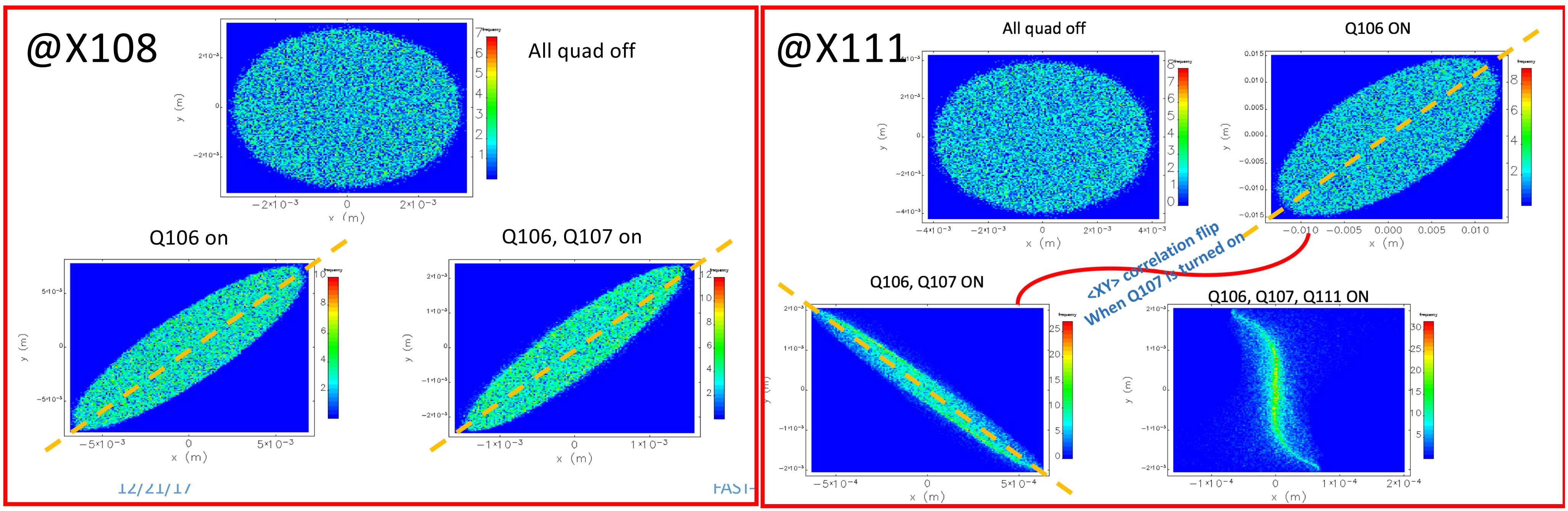
Laser spot size

- Linear scaling vs applied field on cathode is observed
- Due to bucking-solenoid over heating, maximum of 260A was used, magnetization around 20 um
- A different (quad scan method was also used but analysis not yet finalized)



Decorrelation with skew quadrupoles

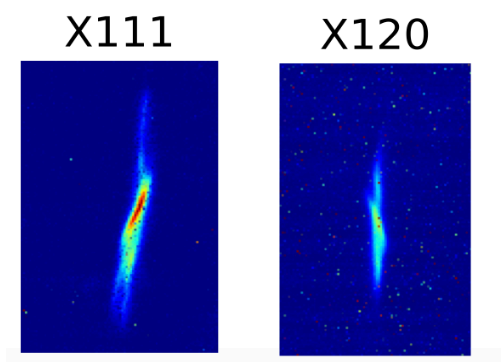
- Given the CAM-dominated beam a set of skew quadrupole magnet can be used to apply a torque
- In the process the CAM is removed and beam becomes asymmetric



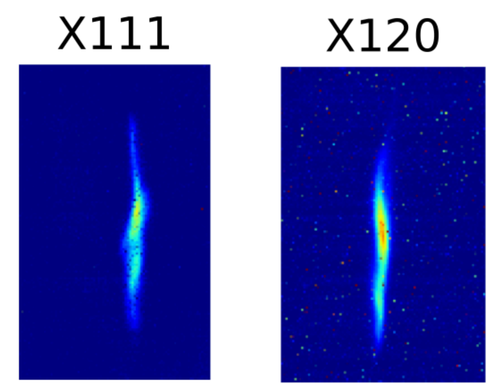
On-line optimization of skew quadrupole

- Because of lack of understanding of our initial condition and time constrains simulations settings were not producing a flat beam
- Used the pyACNET high-level software (python) combined with python-based optimization to optimize skew quad settings
- Procedure:
  - let the optimizer make a flat beam at X111 and check iterate with X120 back and forth
  - Could be improved by directly using X118 slits eventually

Dialing settings from Simulations (at the time no idea of the laser distribution)

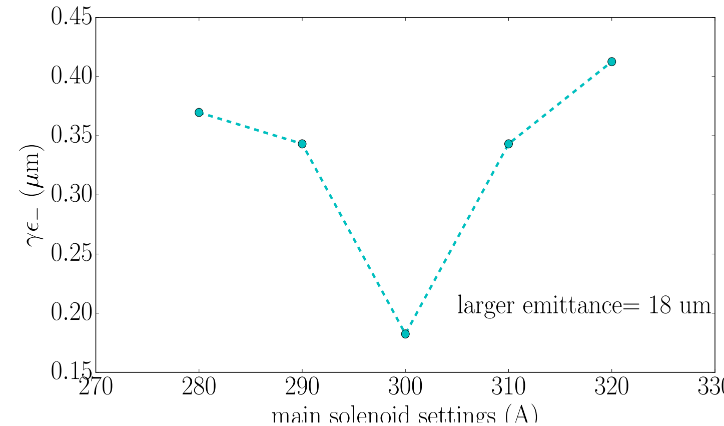


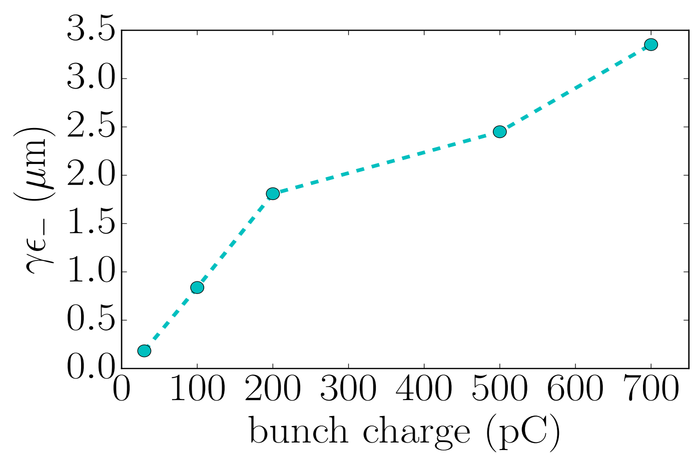
Letting the PYTHON optimizer work (with help from a skilled operator…)



Flat-beam parametric scans

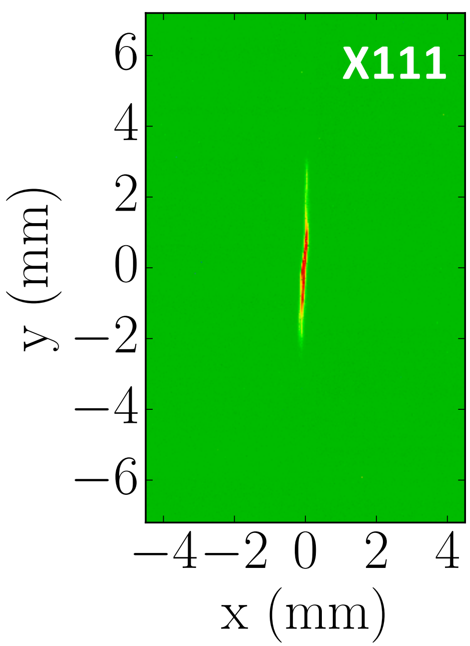
- For a given magnetization we expect emittance to be minimized for a give range of main-solenoid settings
  - Qualitatively observed
  - Will be compared with simulation
- Flat-beam emittance as function of charge:
  - As bunch charge increases the smaller-emittance value significantly increase
- Flat beam as a function of cavity phase (chromatic aberration in skew quadrupole)

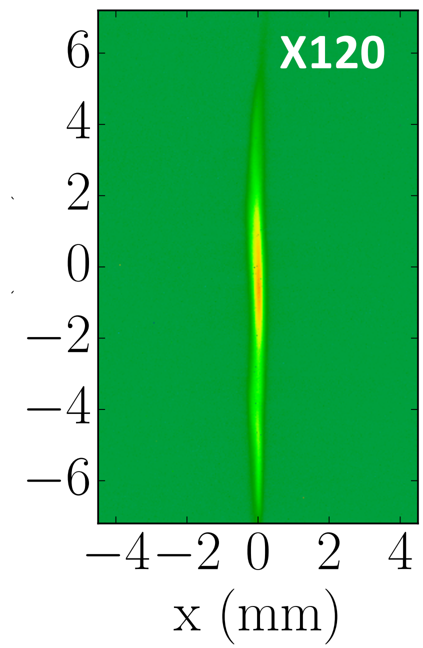


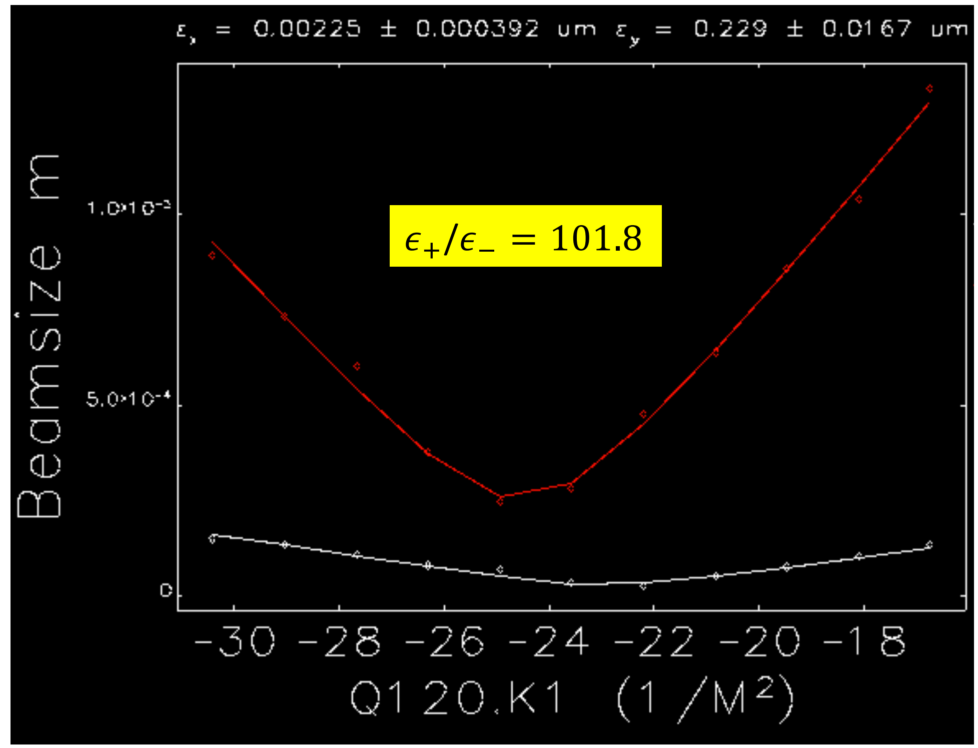


Best emittance ratio of ~100

- Archived for a vertical flat beam
- 30-pC bunch charge

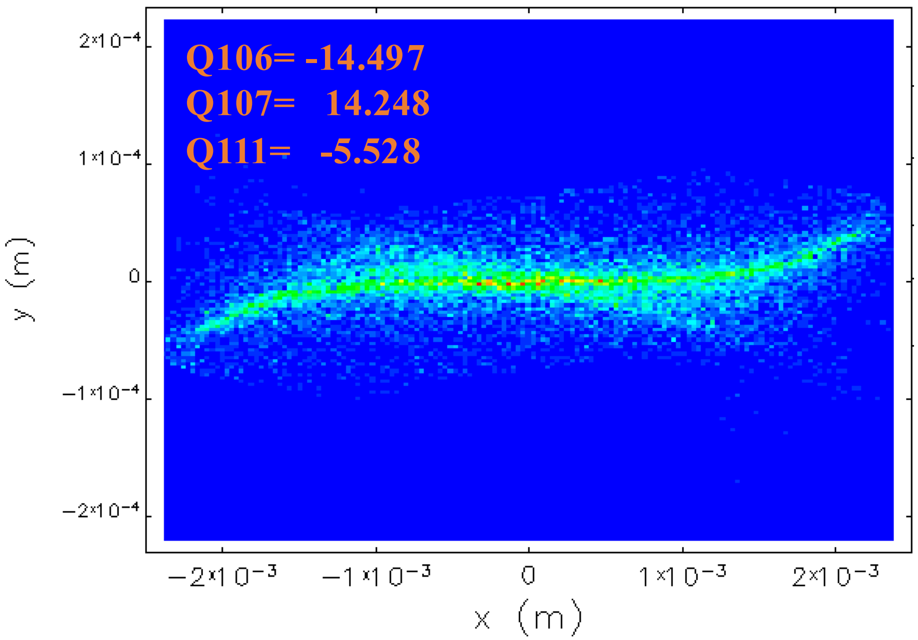


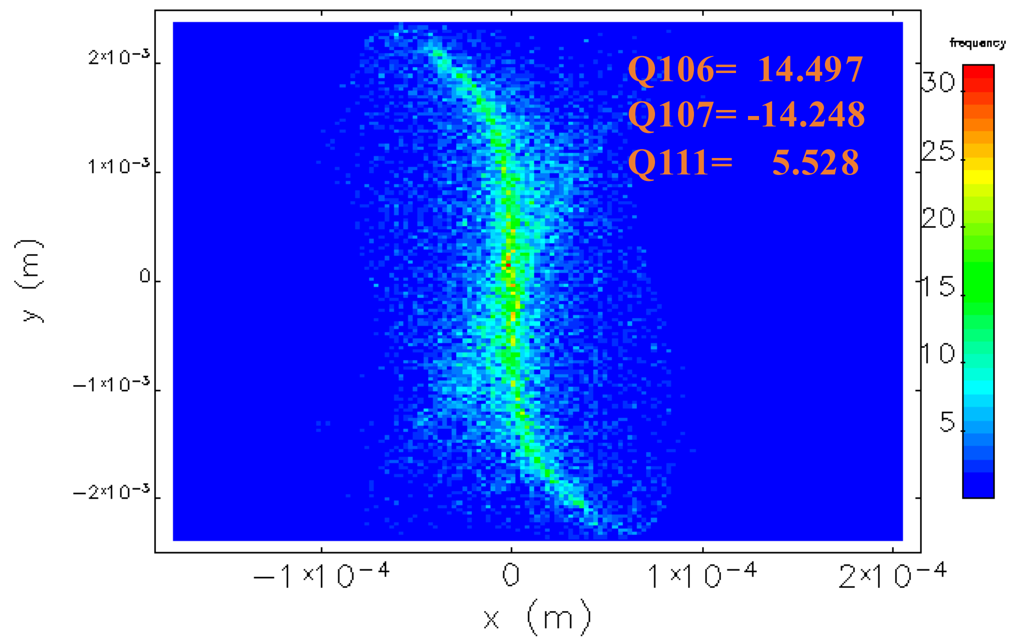




Horizontal or Vertical flat beams?

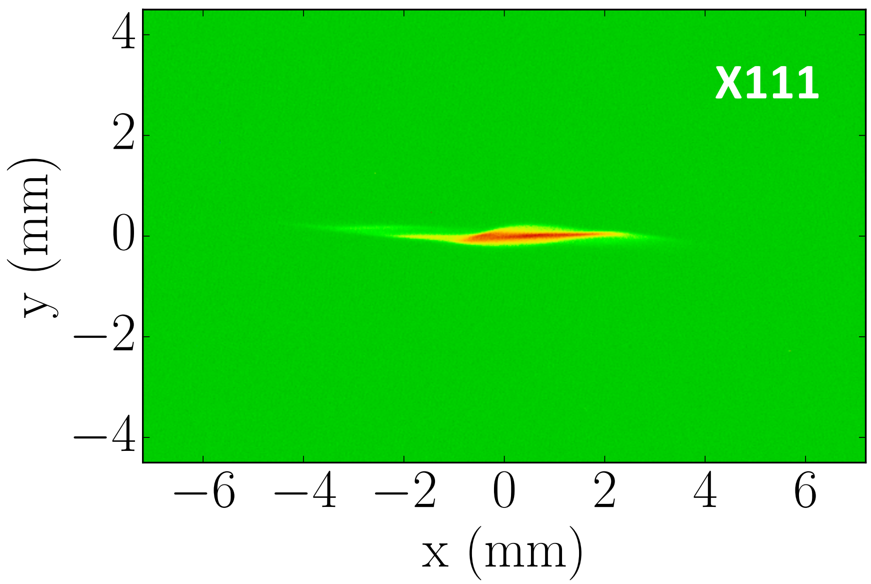
- For a given magnetization both type possible (quad polarity switch)
- Horizontal flat beams mitigate (in theory) 4D emittance growth in chicane during compression.

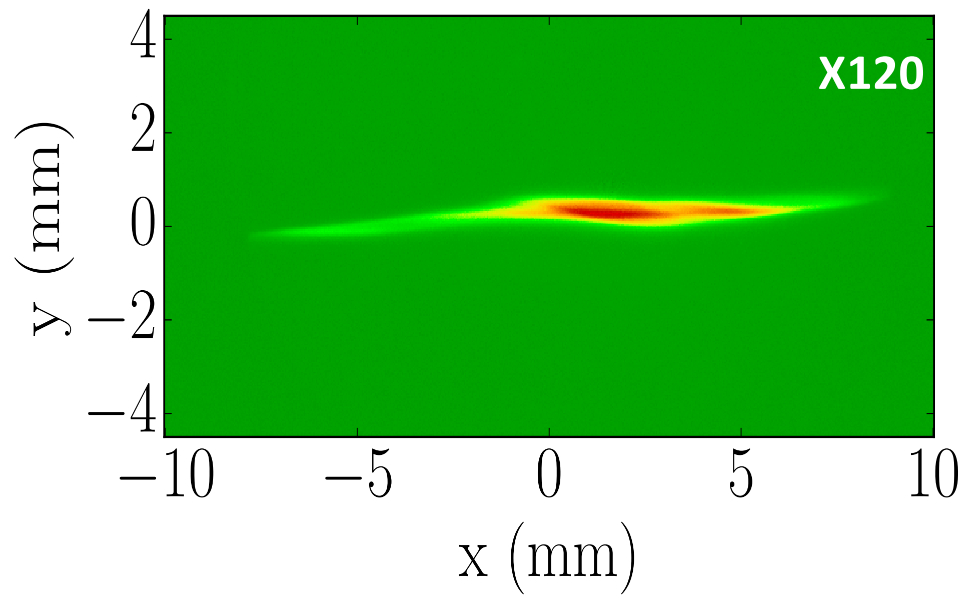




Horizontal flat beams also produced

- Flat horizontal beam were also produced
- Beam quality was not has good as vertical flat beam





Summary table (from Aleksei)

Round beam

- a

Charge	ϵ_x, um (norm.)	ϵ_y, um (norm.)	Notes
250 pC	0.77	1.28	Iris 10%
250 pC	0.4	0.37	Sasha R. values
30 pc	3.4	9.0	Iris 100%

Flat beam

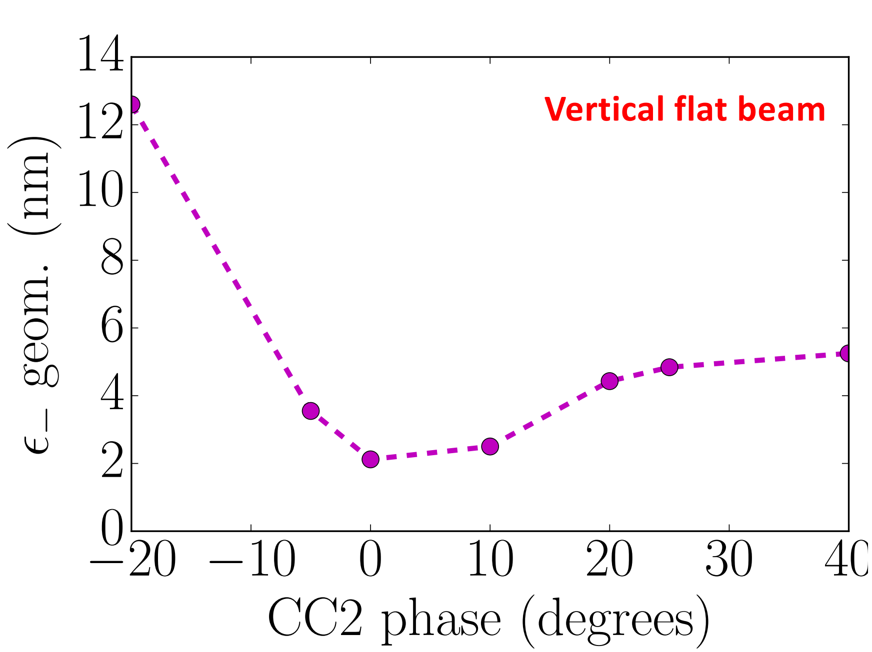
Charge	ϵ_+, um (norm.)	ϵ_-, um (norm.)	Notes
30 pC	14.66	0.144	Iris 100%, B=260A, VFB
30 pC	12.8	0.15	Iris 100%, B=260A, HFB
30 pC	19.2	0.32	Iris 100%, B=260A, VFB
30 pC	9.4	0.21	Iris 100%, B=260A, HFB

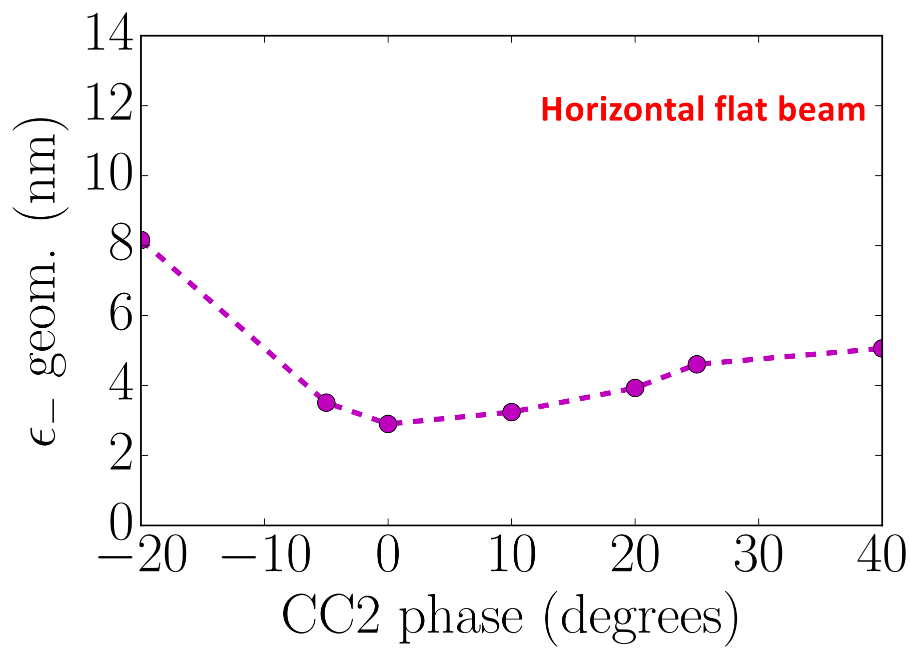
[yellow] - best values, difficult to reproduce

[green] - average values, easy to reproduce

Flat-beam compression

- Observation consistent (but need quantitative analysis) with expectations

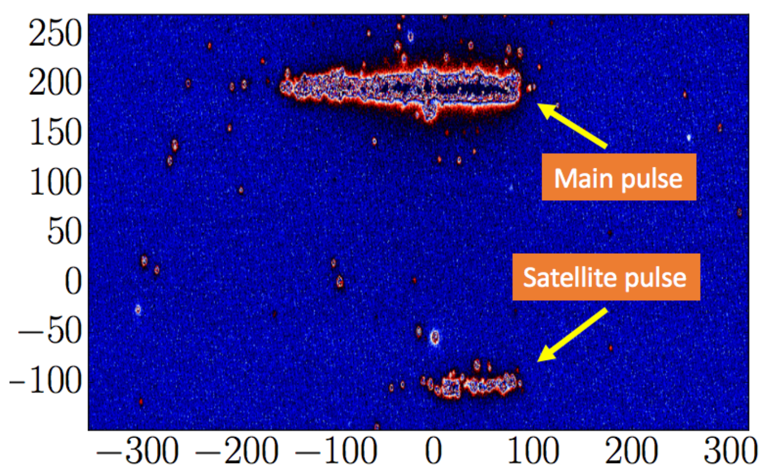


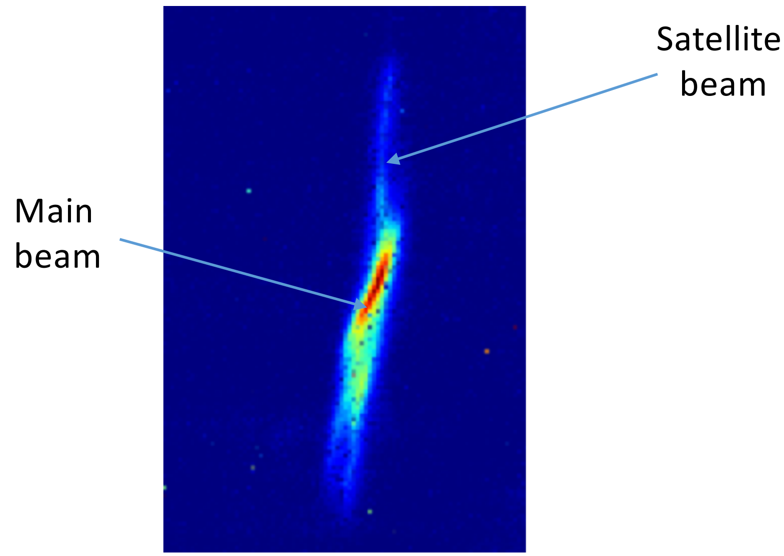


Double-beam?

- On several diagnostics
  - Slit images
  - Beam spot on screen
- We observed a double beam

Bunch time profile (uncalibrated)



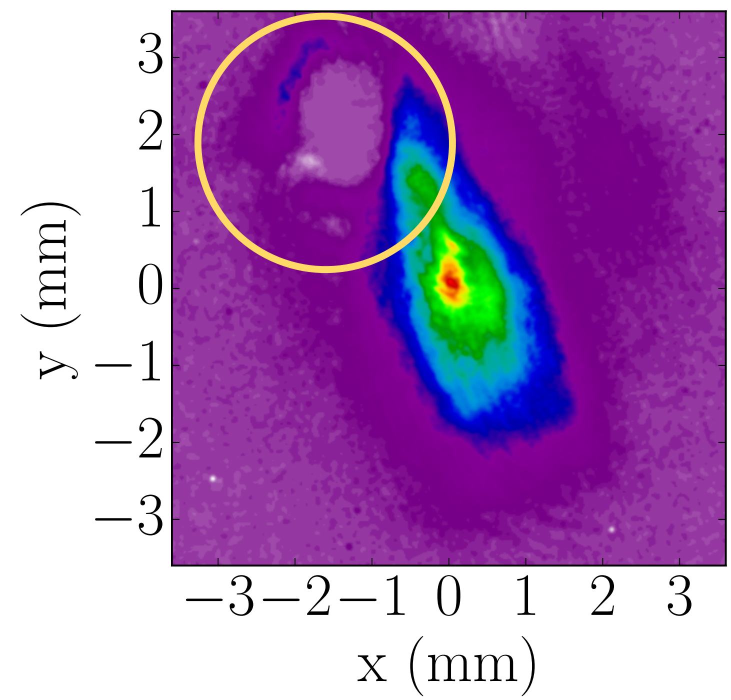


- Confirmed by streak camera
- Not yet sure how to process account for this anomaly (% emit?)

Next Step (near term -- analysis)

- Re-Analyze all the data using different analysis [all the data (esp. emittance) are analyzed with an on-line software with limited capabilities (need to be fast)]
- Most likely will address the double population beam by quoting percentile emittance
- The fact we started with a coupled asym-metric laser spot and generated a flat beam is very interesting (and made us realize of a possible generalization of the flat-beam generation theory)

UV laser spot on cathode



Future plans (longer term)

- I compatible with nominal operation I would suggest we keep the skew quad setup for one more round of run
- I (PP) view this experiment as a stepping stone:
  - a good teaser but we need to iron issues especially with controlling the laser-beam distribution.
  - Quad scan works well but too slow (X118 would be very useful eventually)
  - I still hope we have a path to achieve higher flat-beam emittances than achieved during this running period. Higher charge and compression have important applications and could interest others
- Collaboration with JLab:
  - JLab/JLEIC staff were interested in participating in some aspects of our experiment but we never followed up as we felt this was not ready for prime time.
  - The parameter we have reached are very close to the nominal e- cooling parameters (now joining force on a DOE-NP proposal).

FAST and JLEIC electron cooling (DOE-NP proposal in preparation)

Weak Cooler Specifications (Electrons)

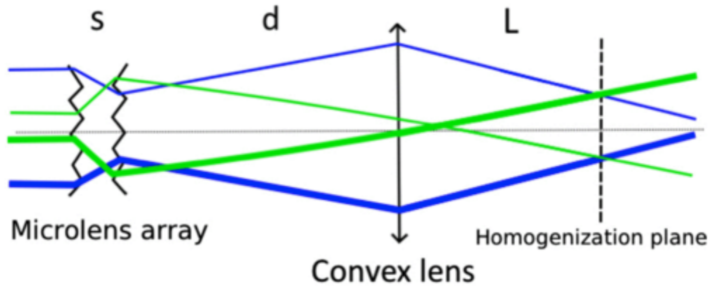
- Energy 20–55 MeV [1] Up to 47 MeV
- Charge 420 pC achieved
- Linac frequency 952.6 MHz
- Bunch length (tophat) 2 cm (23°)
- Thermal emittance <19 mm-mrad [2]
- Cathode spot radius 2.2 mm 0.5 but tunable
- Cathode field 0.1 T [3] 0.09 demonstrated
- Gun voltage 400 kV 20 but with 0.5 mm
- Normalized hor. drift emittance 36 mm-mrad
- *rms* Energy spread (uncorr.)* 3×10^{-4}
- Energy spread (p-p corr.)* $<6\times10^{-4}$

Strong Cooler Specifications (Electrons)

- Energy 20–55 MeV [1]
- Charge 2.0 nC
- CCR pulse frequency 476.3 MHz
- Gun frequency 23.82 MHz
- Bunch length (tophat) 2 cm (23°)
- Thermal emittance <19 mm-mrad [2]
- Cathode spot radius 2.2 mm
- Cathode field 0.1 T [3]
- Gun voltage 400 kV
- Normalized hor. drift emittance 36 mm-mrad

Note on laser homogenization

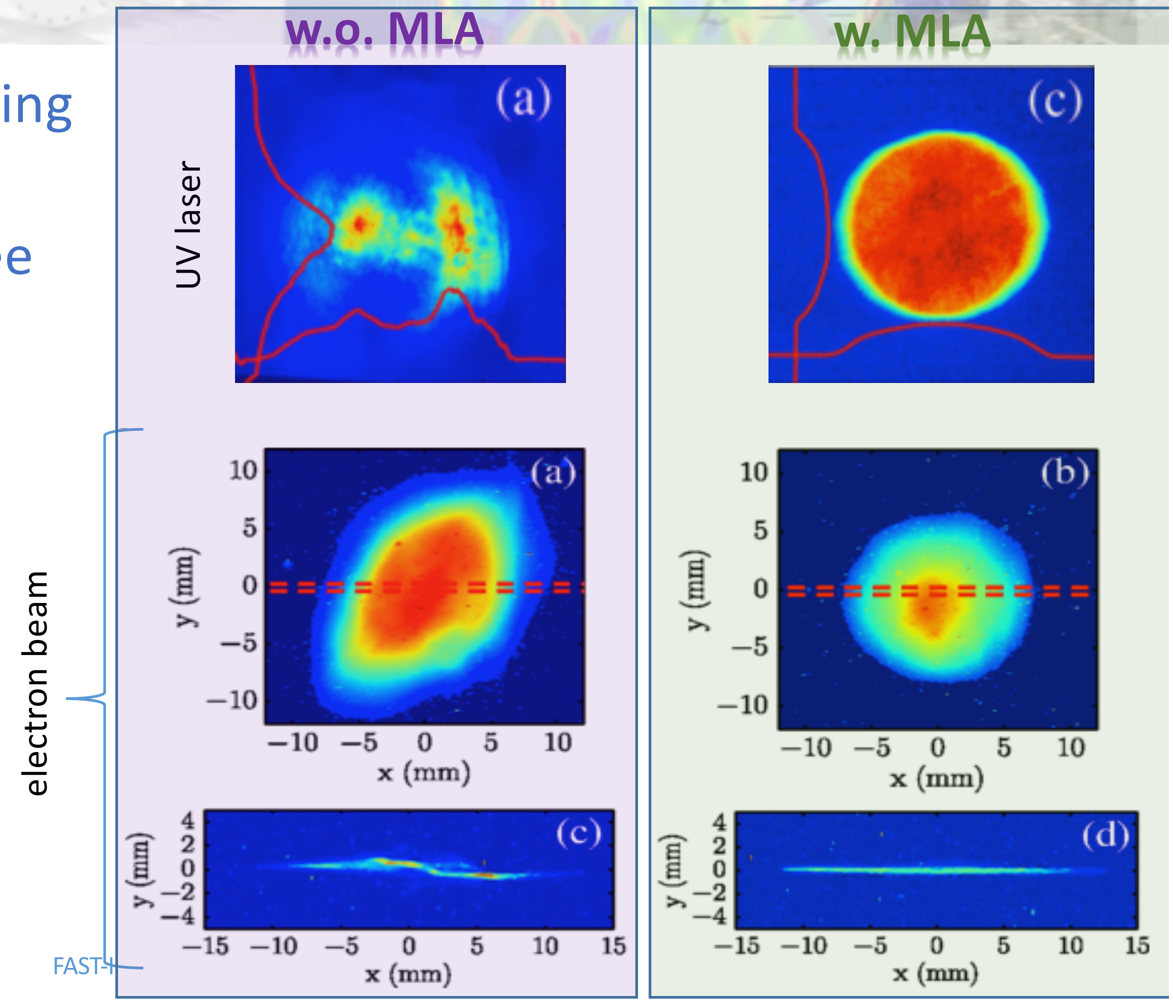
- We should **re**consider installing an MLA-based homogenizer
- Robust and maintenance-free
- ANL/AWA now routinely operates with one



PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 103404 (2017)

Spatial control of photoemitted electron beams using a microlens-array transverse-shaping technique

A. Halavanau,[1,2] G. Qiang,[3,4] G. Ha,[5] E. Wisniewski,[3] P. Piot,[1,2] J. G. Power,[3] and W. Gai[3]



Final words

- Overall I think it is amazing we pulled a decent experiment in such a short time using a not fully understood/commissioned accelerator
- Key elements:
  - VERY good support/people
  - ability to develop on-the-fly applications (e.g. flat-beam optimizer)
  - Very stable/reproducible accelerator settings
- The flat beam did not provide the expected results in term of achieved beam quality but several finding/results are very interesting and will provide impetus for some theoretical/numerical studies
  - This will be what Aleksei has to do in the final stretch of his dissertation work
  - These studies, supported by our experiments, will be of interest to the community
- **Thank you to all for the support!**