Magnetized and flat beam generation at FAST in 2017

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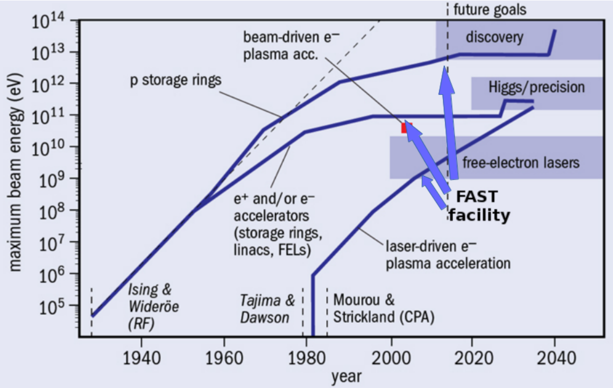
Motivation



Livingston plot - Image courtesy of CERN

Magnetized and flat beam research at FAST facility directly contributes to the **ILC** and **JLEIC** beam dynamics.

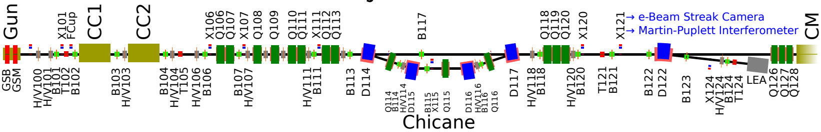
Additional applications

1. Conventional application - electron cooling (Derbenev, Ya., UM-HE-98-04-A)
2. Emittance partitioning via flat beams (interest of AWA group)
3. Flat beams in plasma acceleration (interest of UCLA/AWA)
4. Flat beams in DLWA (interest of PEGASUS facility)
5. Supressing microbunching instabilities in IOTA (collaboration with R. Li, JLab)
6. Several possible radiation experiments (dielectric structures, microundulators, channeling, etc.) can be done at FAST

CAM beams production at FAST is a stepping stone

Experimental opportunities

FAST injector beamline



- Capable of magnetized/flat beam production
- Magnetic bunch compressor (chicane)
- Flat beam acceleration in cryomodule
- High-charge flat beams
- Possible radiation generation experiments

Very nice test bed for flat beam research!

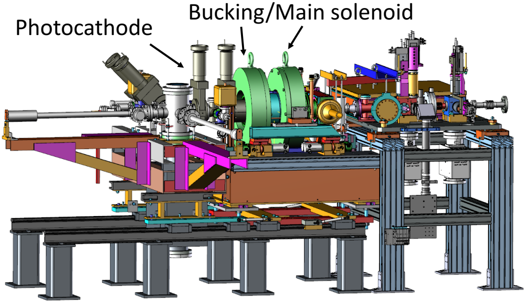
Busch's theorem

Total canonical angular momentum
of a charged particle in symmetric magnetic field is conserved

$$L = \gamma m r^2 \dot{\theta} + \frac{1}{2} e B_z(z) r^2, \qquad \mathcal{L} = L/2p_z$$

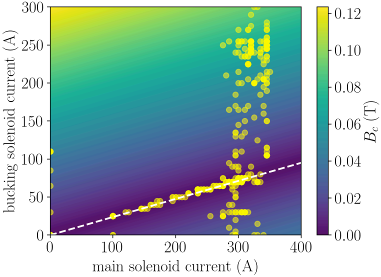
Eigenemittances:

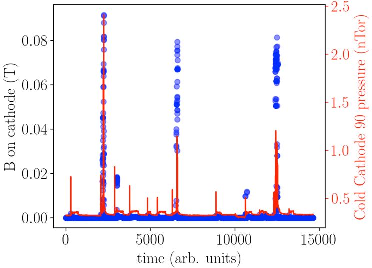
$$\epsilon_{\pm} = \sqrt{\epsilon_u^2 + \mathcal{L}^2} \pm \mathcal{L} \rightarrow \quad \epsilon_+ \approx 2\mathcal{L}; \quad \epsilon_- \approx \frac{\epsilon_u^2}{2\mathcal{L}}$$



RF-Gun conditioning

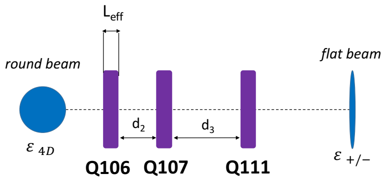
- Vacuum activity with increasing Bucking solenoid current
- Activity decreases with time (conditioning)
- FAST RF-gun is able to run with $I_B < 300$A



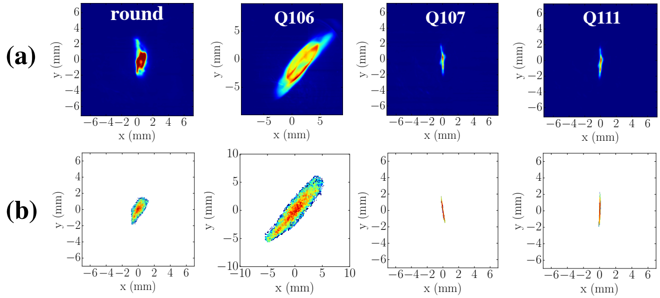


- On 11/17/2017 no vacuum activity at I_B=250A

Round-to-flat transformation

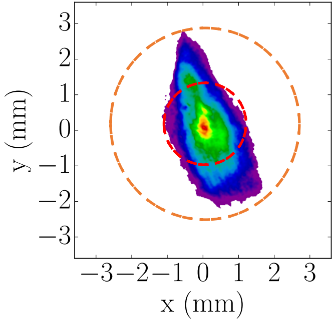


- Q106,Q107,Q111 - skew-quadrupoles
- (a) - Experimental, (b) - Simulations in Impact-T



Good agreement!

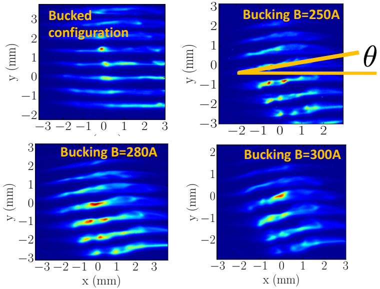
What if beam is not round?

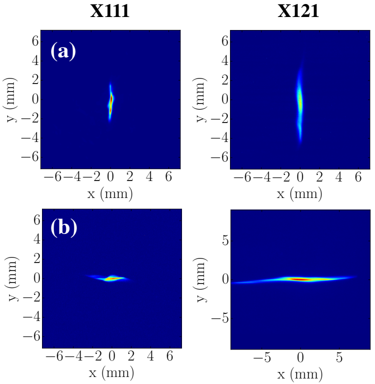


FAST laser cathode distribution
$\sigma_x = 520\mu$m, $\sigma_y = 920\mu$m
First flat beam with *asymmetric* laser!

1. Assume very low charge (20 pC) $\rightarrow$ no space charge. RTFB solutions do not depend on $\mathcal{L}$. White areas will be not present in the final phase space.
2. When space charge is included, the problem requires 4 skew quadrupoles in RTFB setup
3. FAST Run 2017 used 3 magnets, will add additional in the future

Magnetized and flat beam



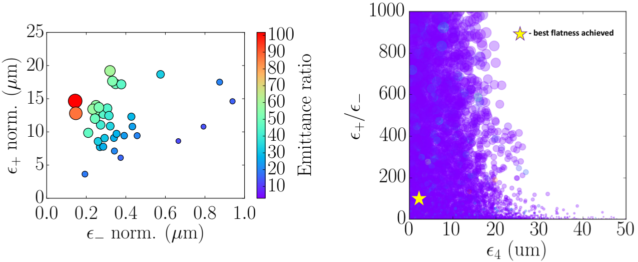


- Measured CAM with slits
- Value corresponds to Poisson simulation of FAST solenoids (good!)

- First demonstration of horizontal/vertical flat beam with a quadrupole sign flip! ϵ_+/ϵ_-=14 μm / 0.15 μm

FAST flat beam parameter space

(*left*) Experimental flat beam realizations at FAST. Size/color of circles defines aspect ratio. First automatic RTFB transformation!



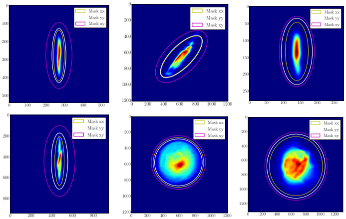
(*right*) 100,000 realizations of genetic optimization algorithm (MOGA). Optimizing flatness using: gun phase, gun gradient, CAV1/CAV2 parameters, spot size and solenoidal fields as variables (path to AI phase-space manipulation w/ Auralee Edelen).

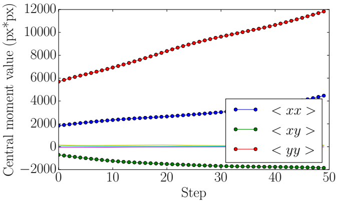
Image analysis: estima

Extended statistical image analysis - estima;
based on previous development at DESY (Löhl,2006), NIU, A0

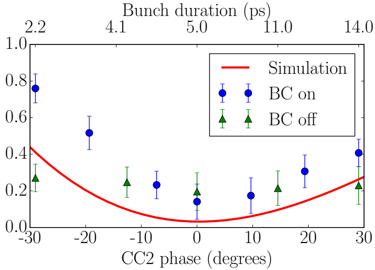
Requirements (we like fast things at FAST):

- Statistical central moments $(< xx >, < xy >, < yy >)$
- Applicable to any kind of beam image (coupled, noisy, etc.)
- Used in quadscan emittance measurements
- Available on Github soon (python based)

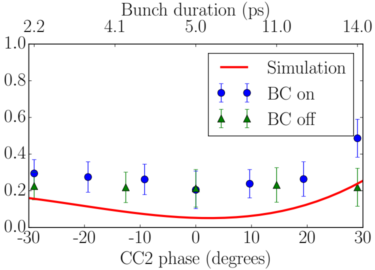




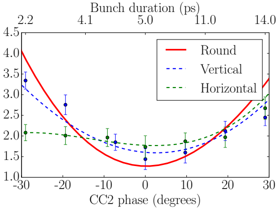
First compressed flat beams!



Compressed vertical flat beam - significant emittance growth at maximum compression



Horizontal flat beam - small emittance in the same plane as chicane CSR, slight growth (Zhu, 2014)



- Horizontal flat beam emittance is largely unaffected by chicane CSR
- Total $(\epsilon_x \epsilon_y)$ preserved better

Conclusions

1. Generated CAM/flat beam from asymmetric laser (**NEW**)
2. Automatic horiz./vert. flat beam transformation (**NEW**)
3. Lowest emittance 0.1 μm (below thermal) (**NEW**)
4. Compressed flat beams, helps with beam transport (**NEW**)
5. AI phase-space manipulations (**NEW, in progress**)
6. Start-to-end full FAST injector model
7. New comprehensive image analysis tool

Future of flat beams at FAST:

1. High-charge flat beams (with J. Rosenzweig)
2. Additional diagnostics $\rightarrow$ improve emittance ratio
3. Radiation generation at FAST (channeling, dielectric)

Thank you for your attention!

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