UE111: Test of a Flux Concentrator for Electron Microscopy

PI: Eric Montgomery
Presented by C. Jing
Euclid Techlabs LLC
Collaborators: Yimei Zhu, Timur Shaftan, Mark Palmer (BNL)
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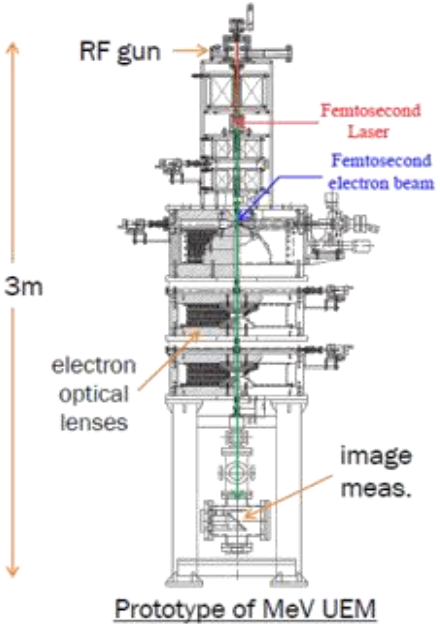
3/1/2023 for ATF User Meeting

Motivation

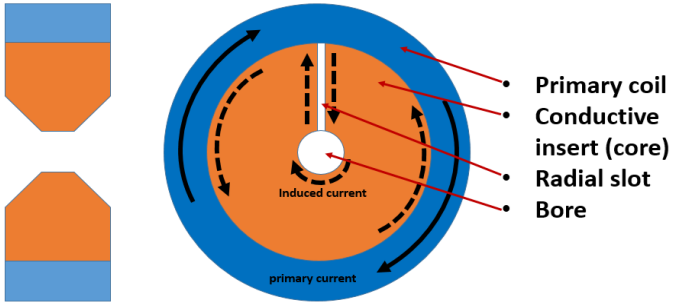


J. Yang, Workshop on ultrafast electron sources for diffraction and microscopy applications 2012

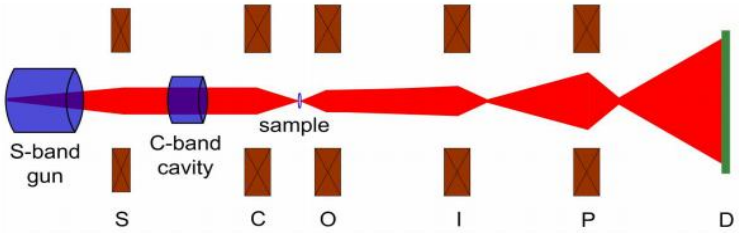
Problem: UEM (3-4MeV) electrons require strong solenoids to focus

2 ton Obj. Lens (DC)

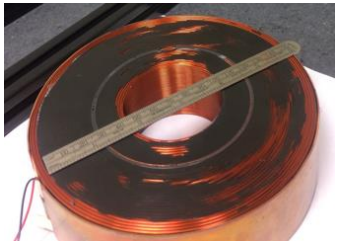
Solution: pulsed solenoids with flux concentration



Idea from ILC positron target solenoid design: 5 Tesla / 1 ms

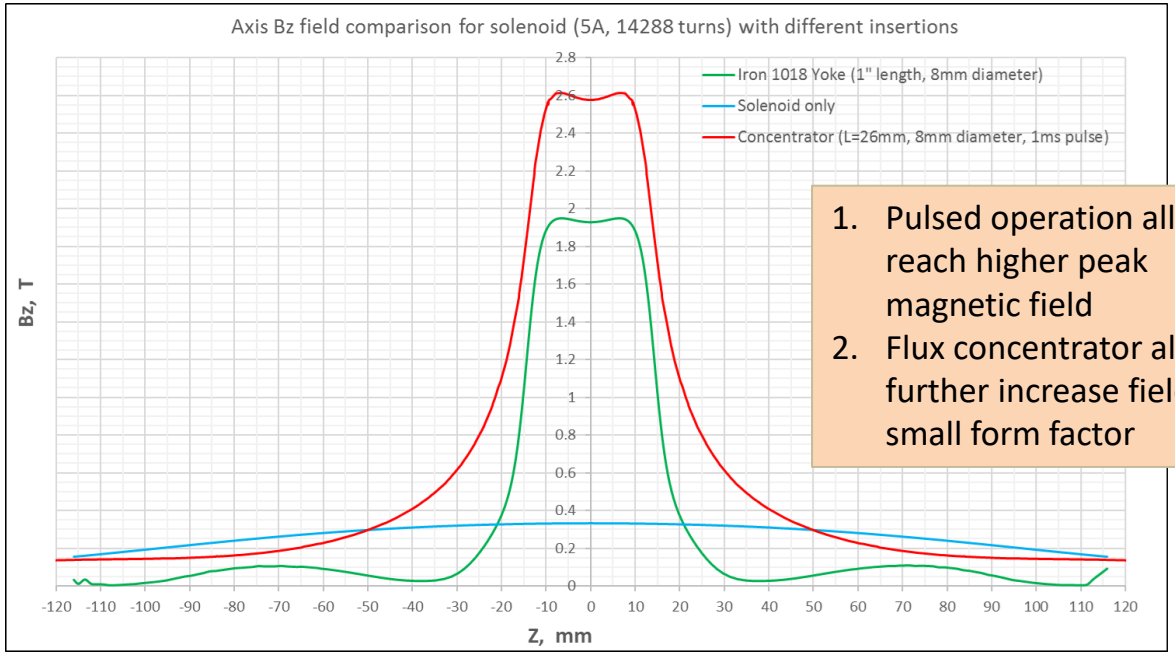


Dao Xiang, MeV Ultrafast Electron Diffraction and Microscopy Development at SJTU., FEIS-2015

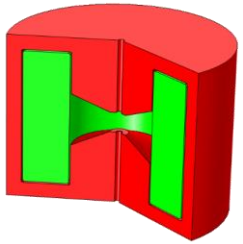


Standard TEM coil – want similar size

Comparison of steady state Iron Yoke and pulse magnetic field Concentrators

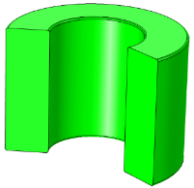


1. Pulsed operation allows to reach higher peak magnetic field
2. Flux concentrator allows to further increase field in a small form factor

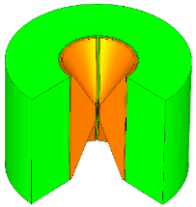


Solenoid with Iron yoke

Thermally not possible



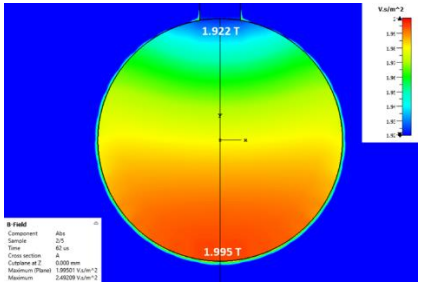
Solenoid



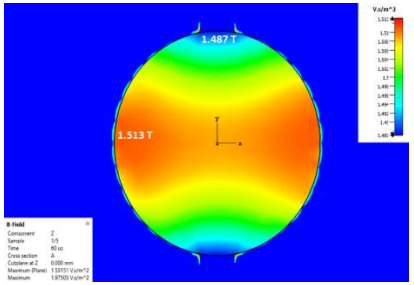
Solenoid with Copper concentrator 26mm

Uniformity of the field

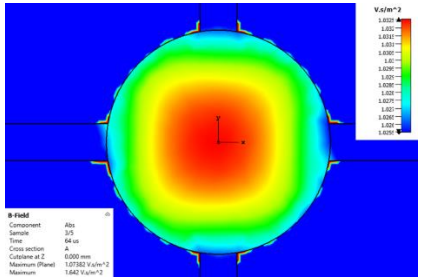
Optimized number of slits in concentrator



One slit



Two slits

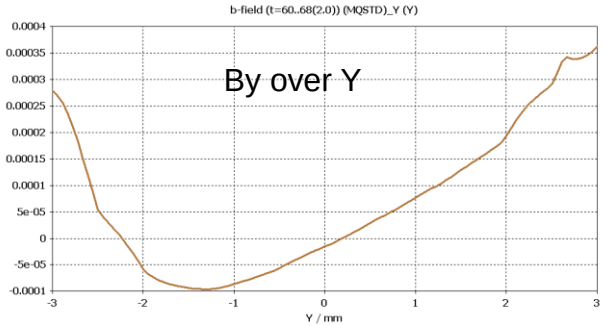


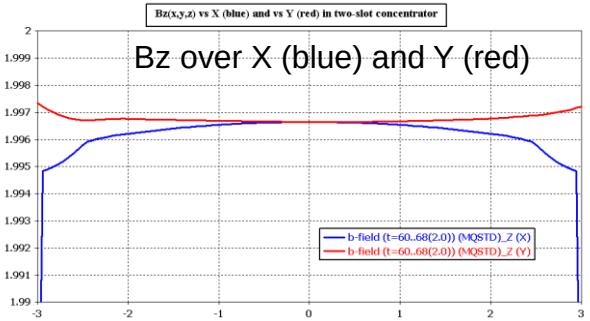
Four slits

More slits improve field uniformity at cost of field strength, for the same drive current.

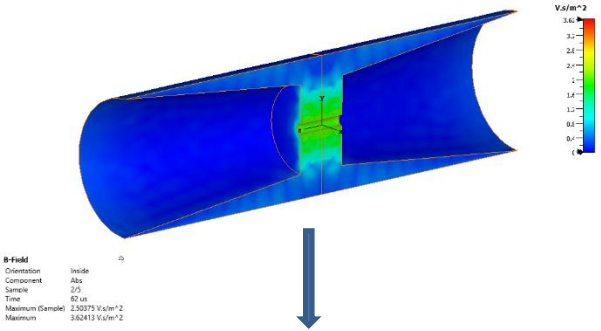
It helps that the beam into the objective lens is very small (depending on the focal strength of the upstream condenser lens and electron scattering after the sample).

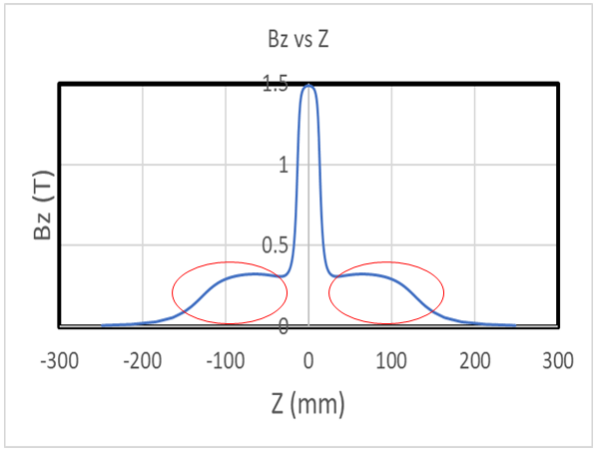
Optimization done for transverse field using 2-slit FC design as the final product.



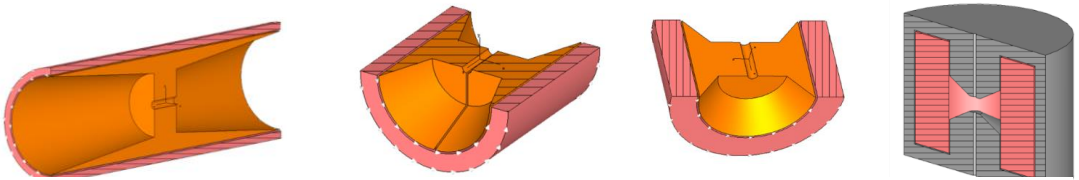


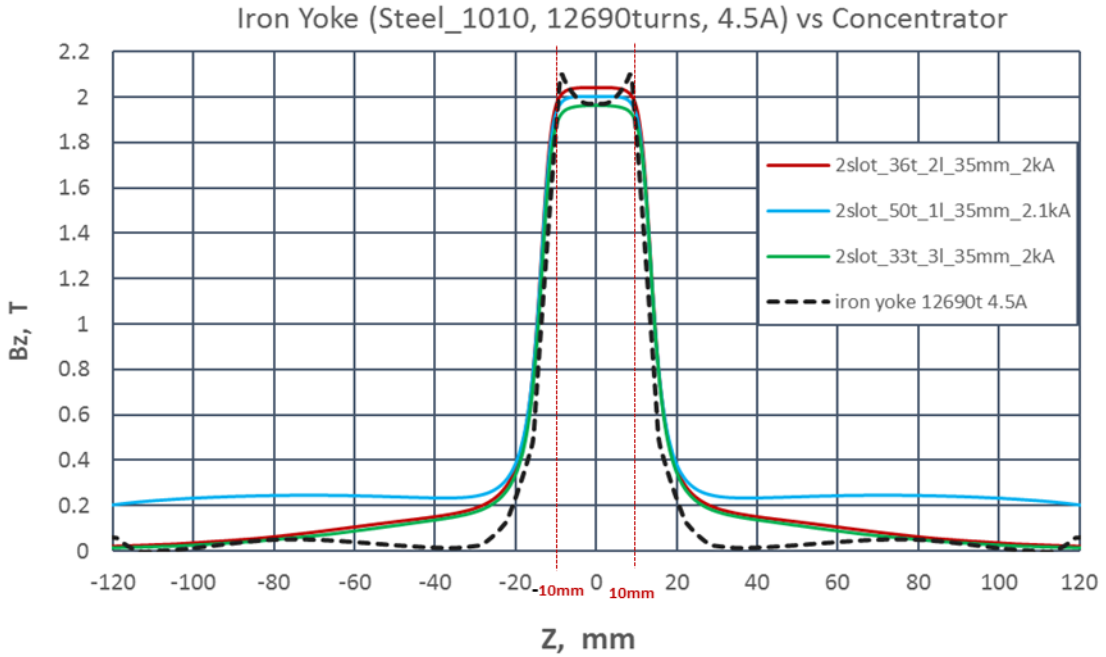
Fringe Field Suppression



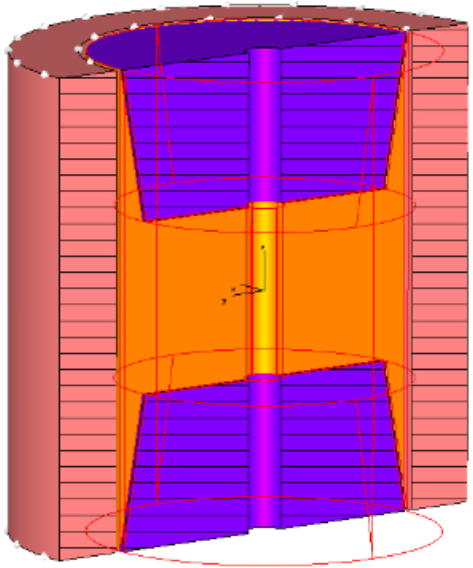


Conquer the Fringe field

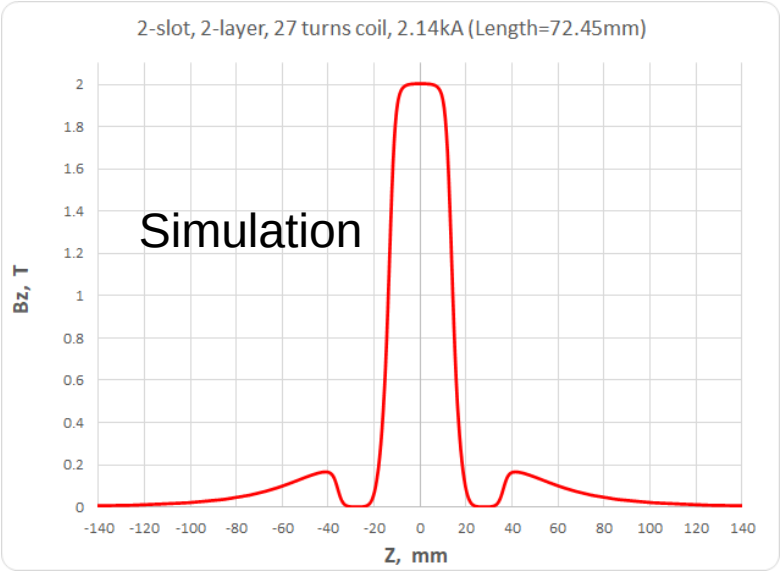




Final Design



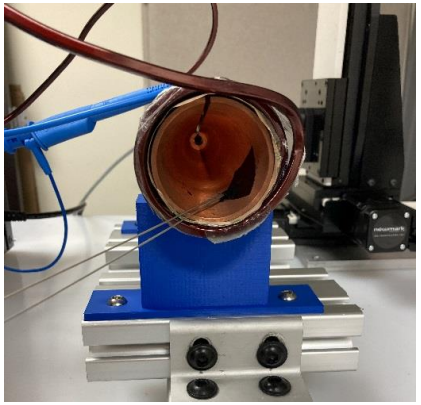
Orange – copper concentrator
Purple – ferrite insert
Red – water cooled coil

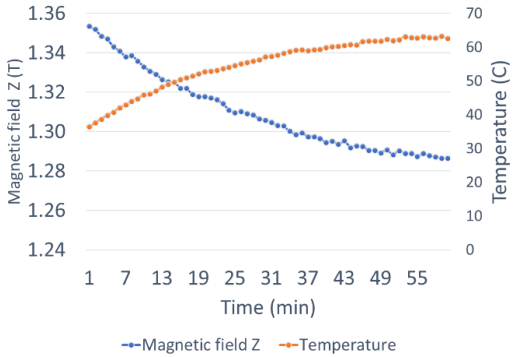


Peak Field	2 Tesla
Energy/pulse	31 Joules
Sample-center	51 mm
Total inductance	15 uH
Peak current	2.1 kA
Length	72.5 mm
Diameter, coil	64.4 mm
Aperture	6 mm

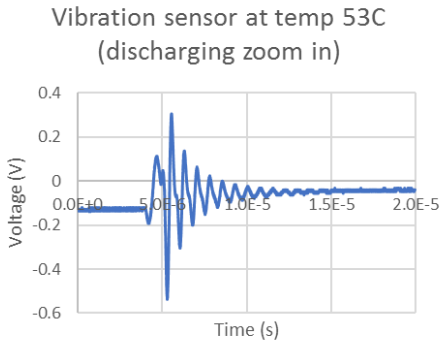
Performance Evaluation of the Prototype FC

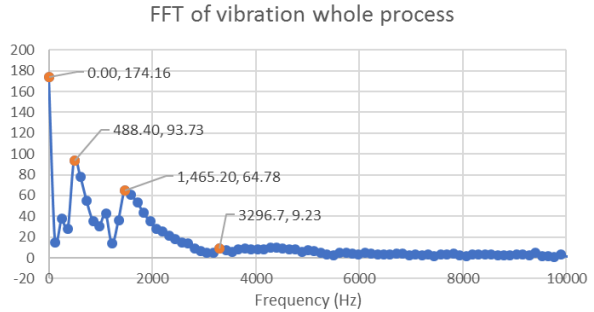
Thermal stability

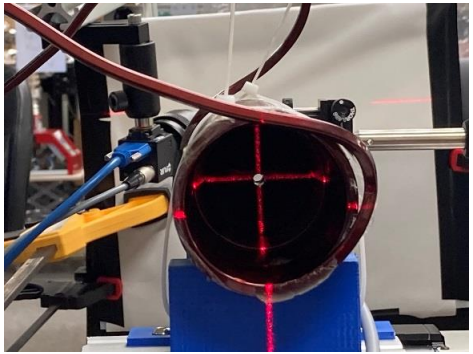


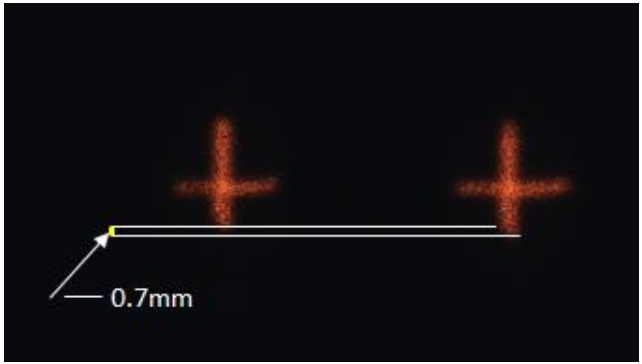


Mechanical stability



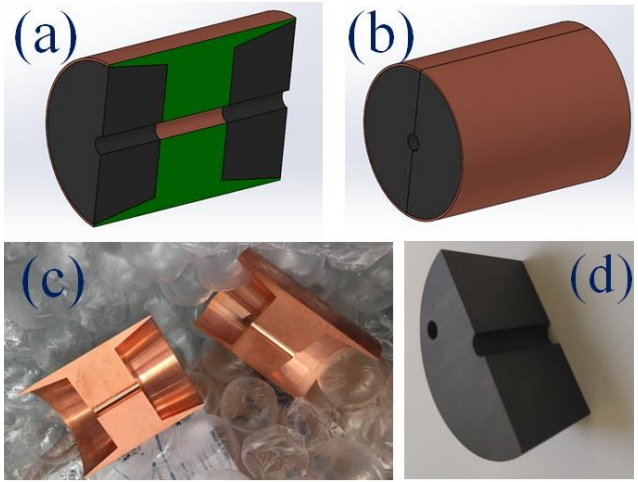


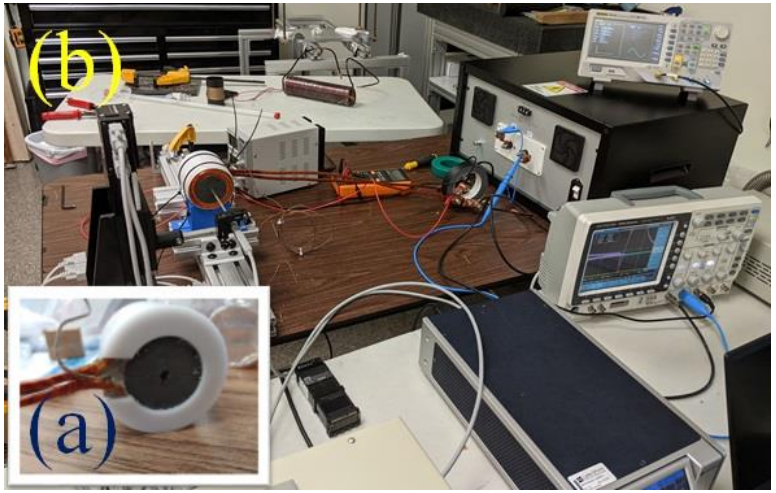


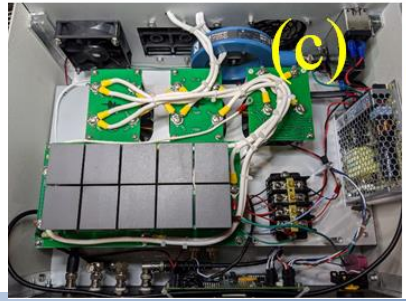


Improved Version

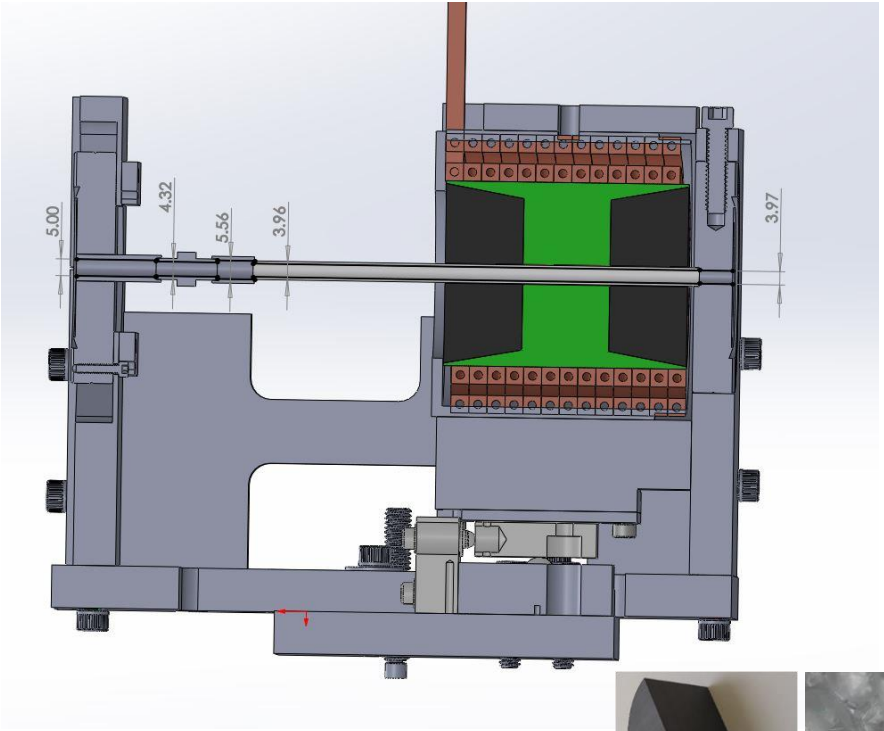
- Shorter coil for less inductance.
- with Ferrite to suppress the fringe field
- high stability power supply
- hollow wire for cooling
- Potted coil and case for stability

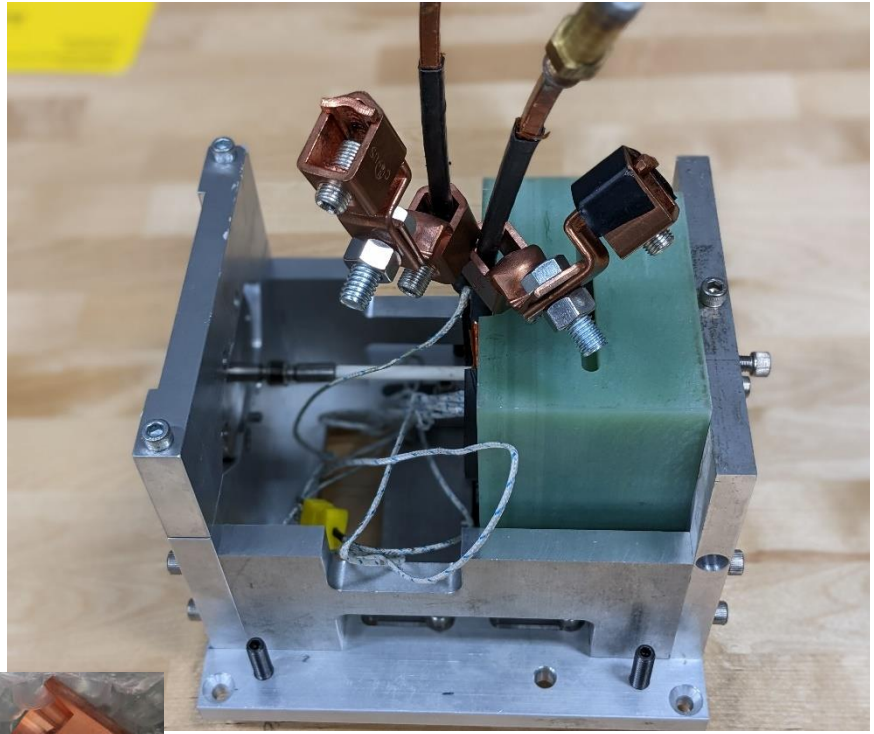


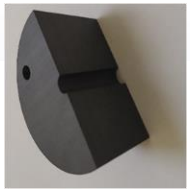




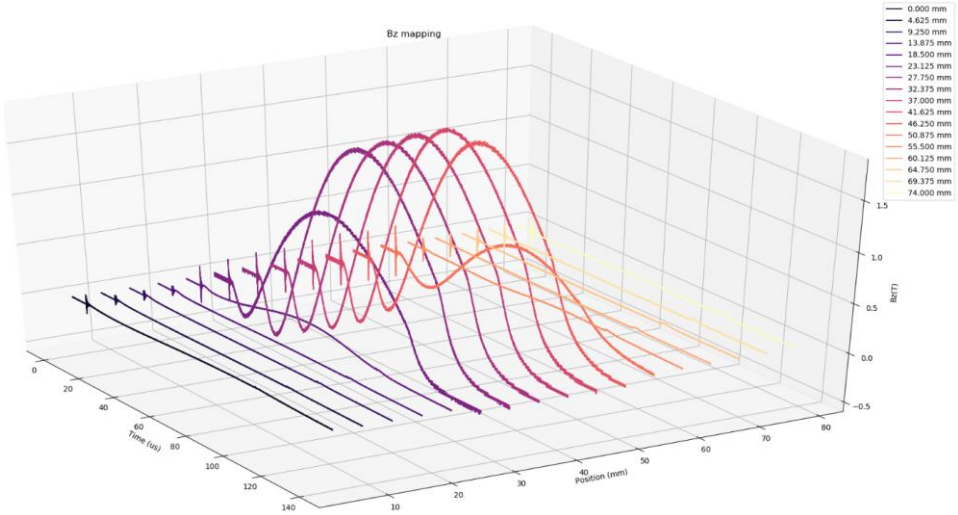
Implementation of the final FC lens

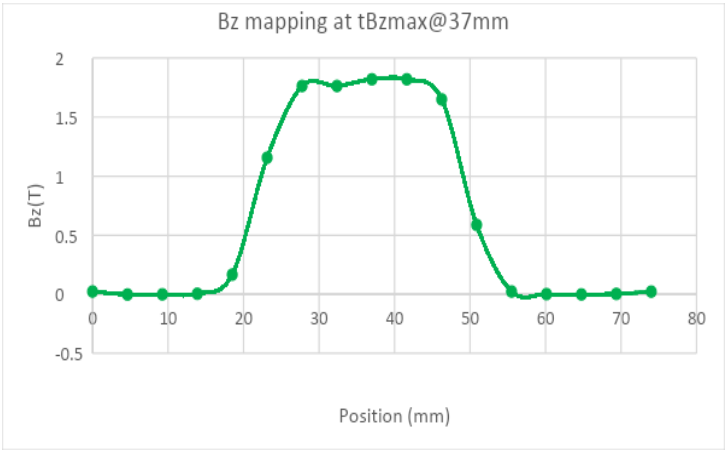


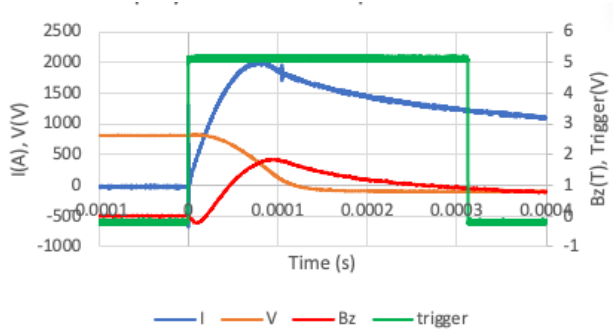


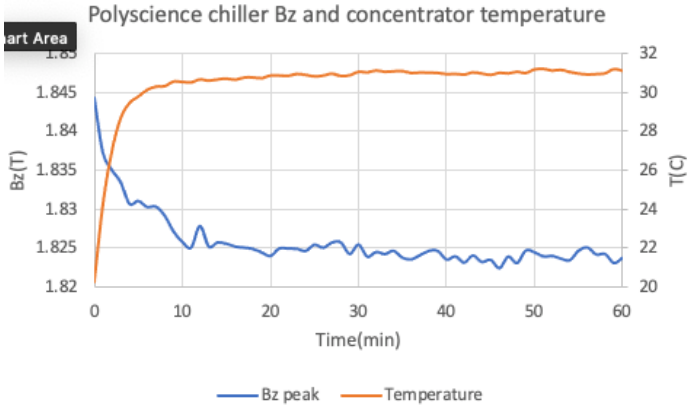


Bench Test

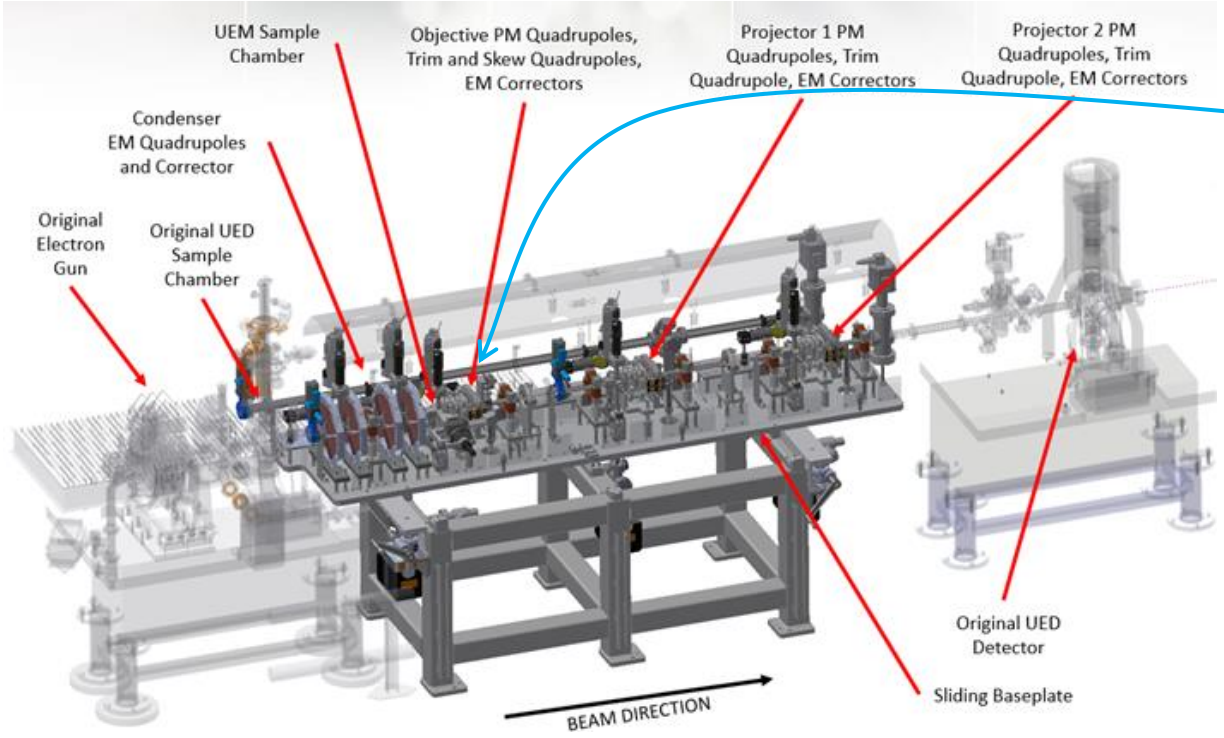

Bz mapping
0.000 mm
4.625 mm
9.250 mm
13.875 mm
18.500 mm
23.125 mm
27.750 mm
32.375 mm
37.000 mm
41.625 mm
46.250 mm
50.875 mm
55.500 mm
60.125 mm
64.750 mm
69.375 mm
74.000 mm
Time (us)
Position (mm)
Bz(T)

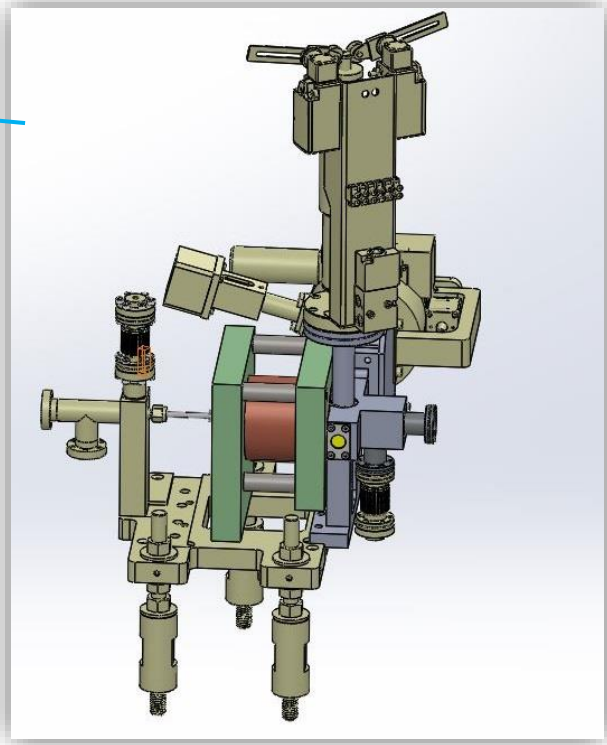

Bz mapping at tBzmax@37mm
Bz(T)
Position (mm)


I(A), V(V)
Bz(T), Trigger(V)
Time (s)
I
V
Bz
trigger

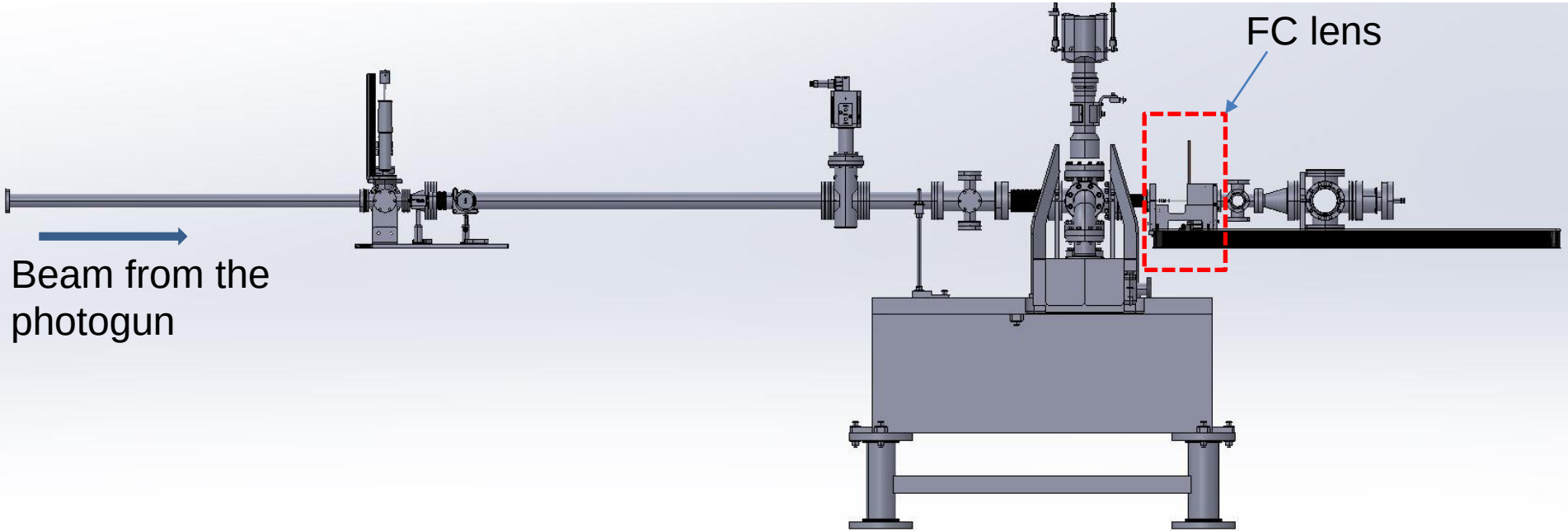

Polyscience chiller Bz and concentrator temperature
Bz(T)
T(C)
Time(min)
Bz peak
Temperature

Original plan of the test at BNL UEM Beamline





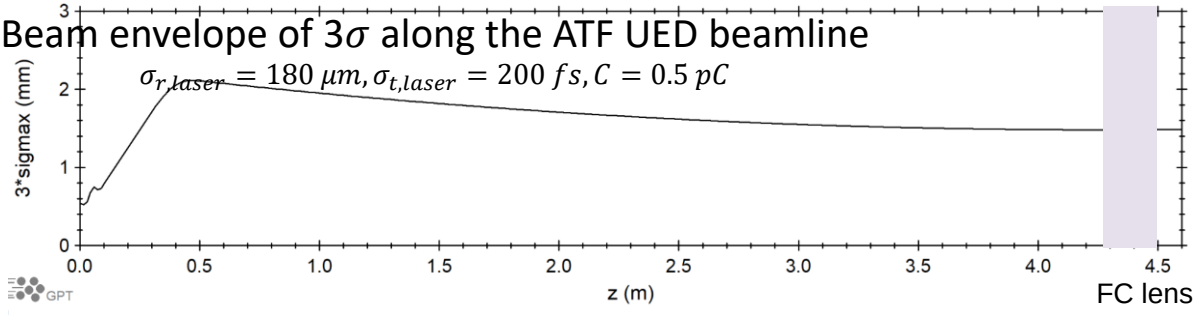
Beamline configuration for the test at BNL UED facility



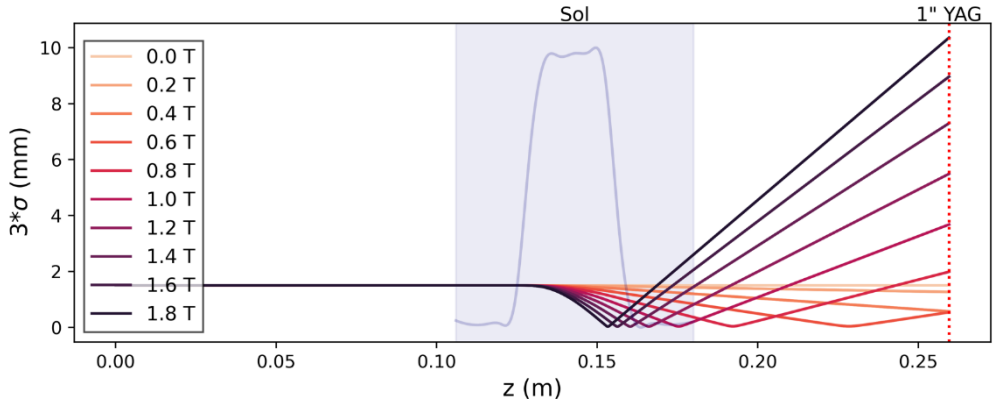
Beam Tracking before the Experiment at ATF

Beam envelope of 3σ along the ATF UED beamline

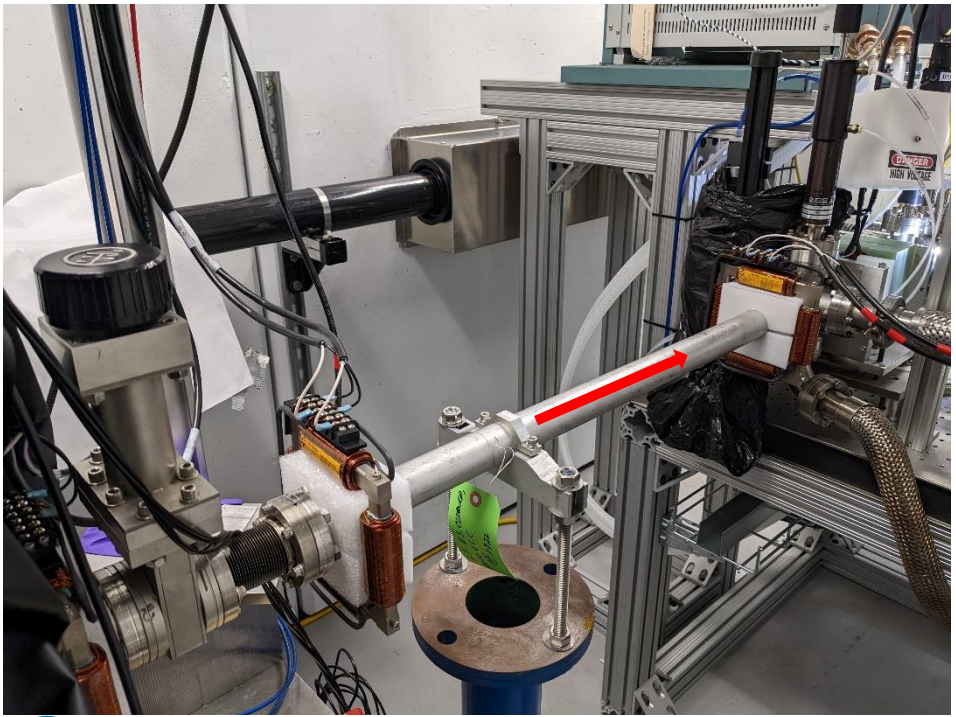
$\sigma_{r,laser} = 180\ \mu m, \sigma_{t,laser} = 200\ fs, C = 0.5\ pC$



Courtesy to Dr. Yang Xi

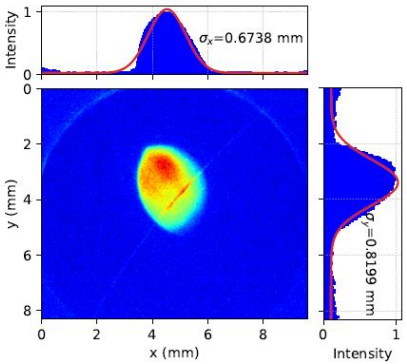


Experiment Setup at ATF (beam at 1.73MeV)

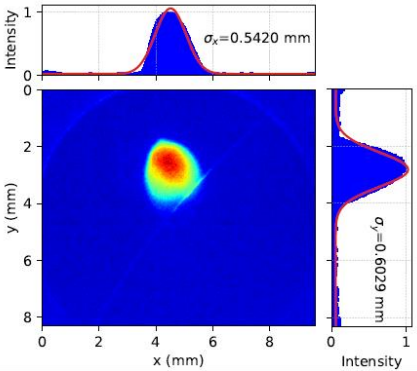


Experiment Results at ATF: beam profile at BMP-B

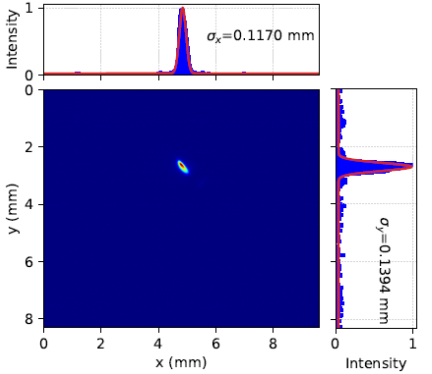
0kG



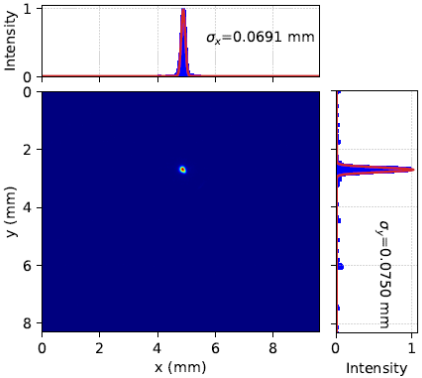
1.5kG



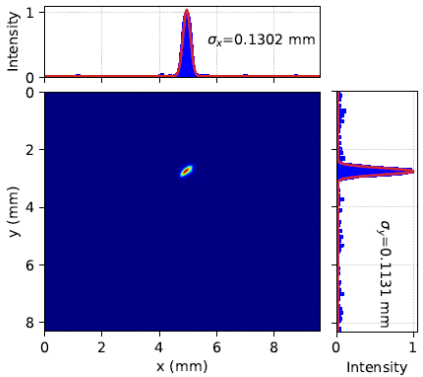
2.4kG



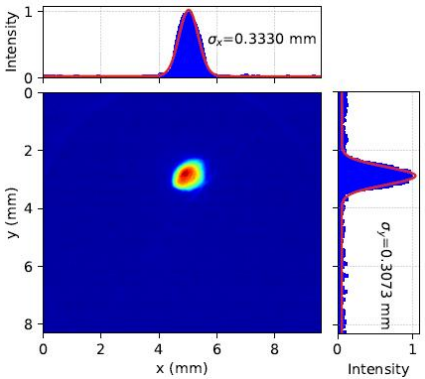
2.6kG



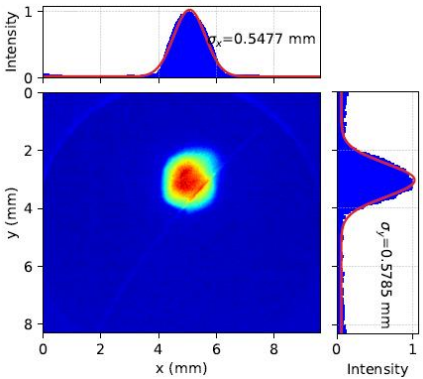
2.7kG



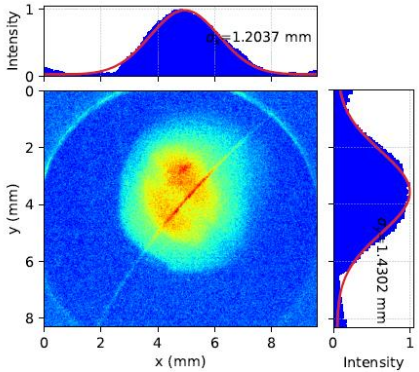
3.0kG



3.3kG

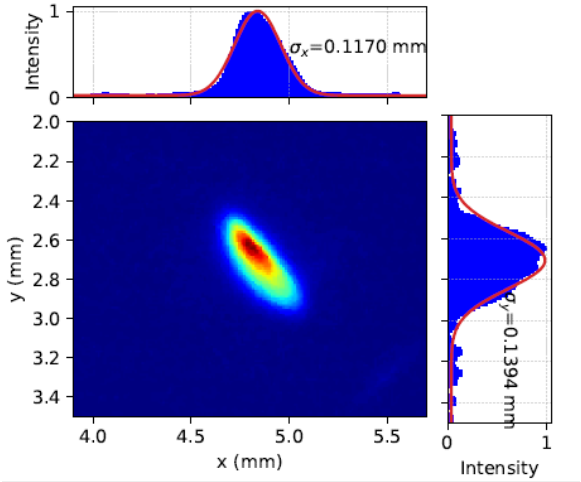


4.3kG

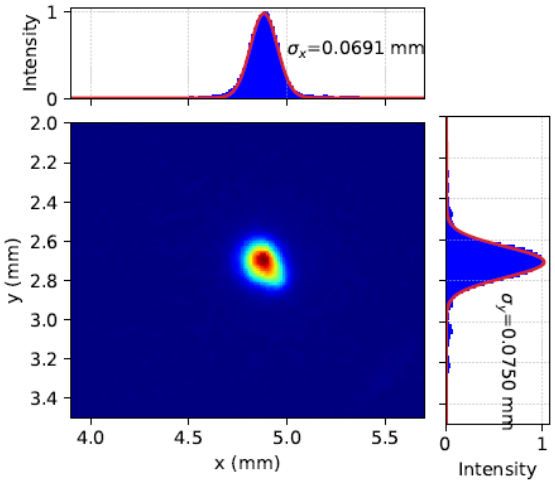


Astigmatism ?

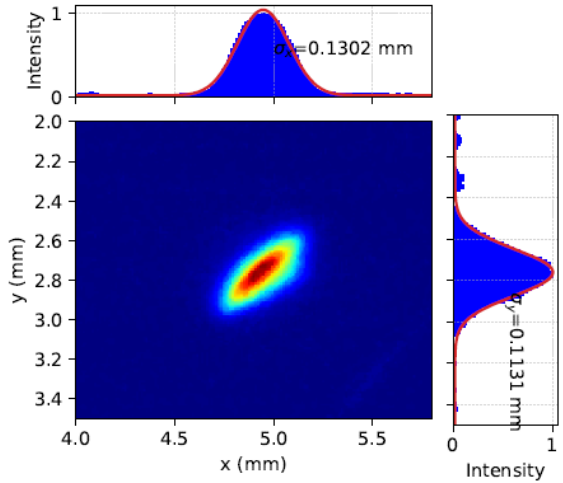
2.4kG (zoom in)



2.6kG (zoom in)

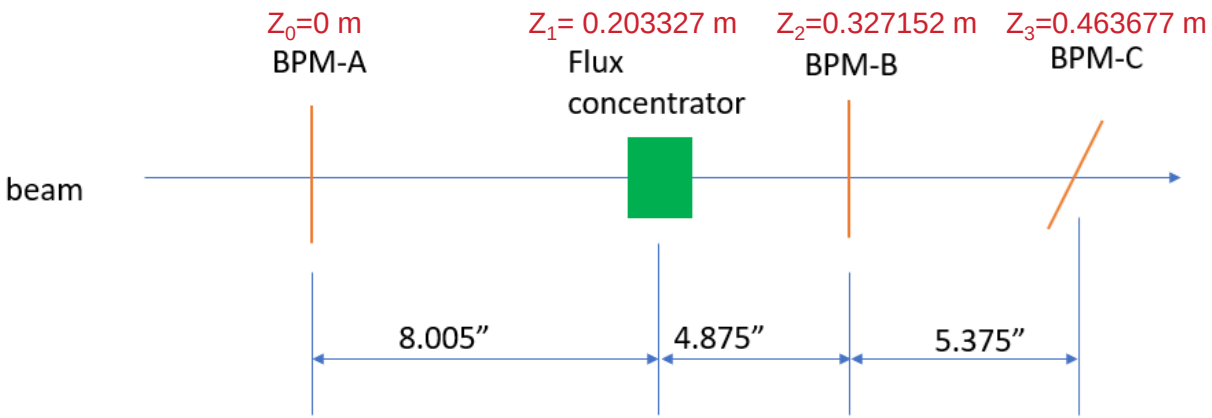


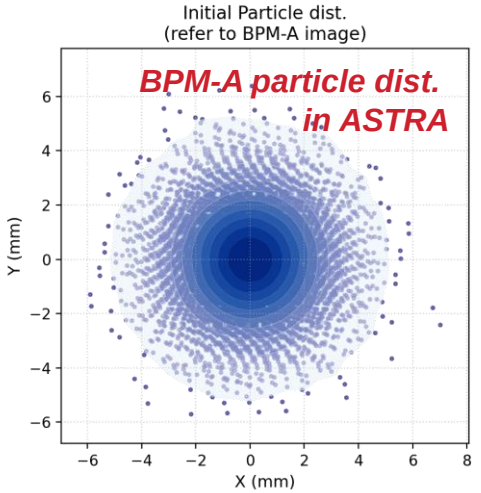
2.7kG (zoom in)

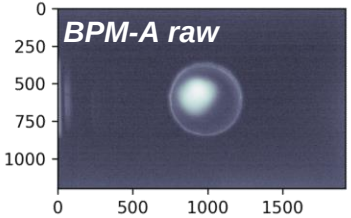


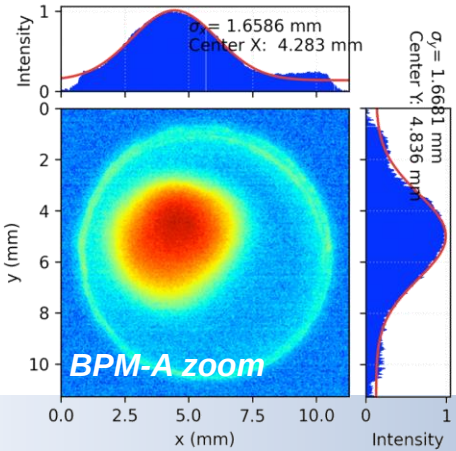
Beamline layout

BNL setup





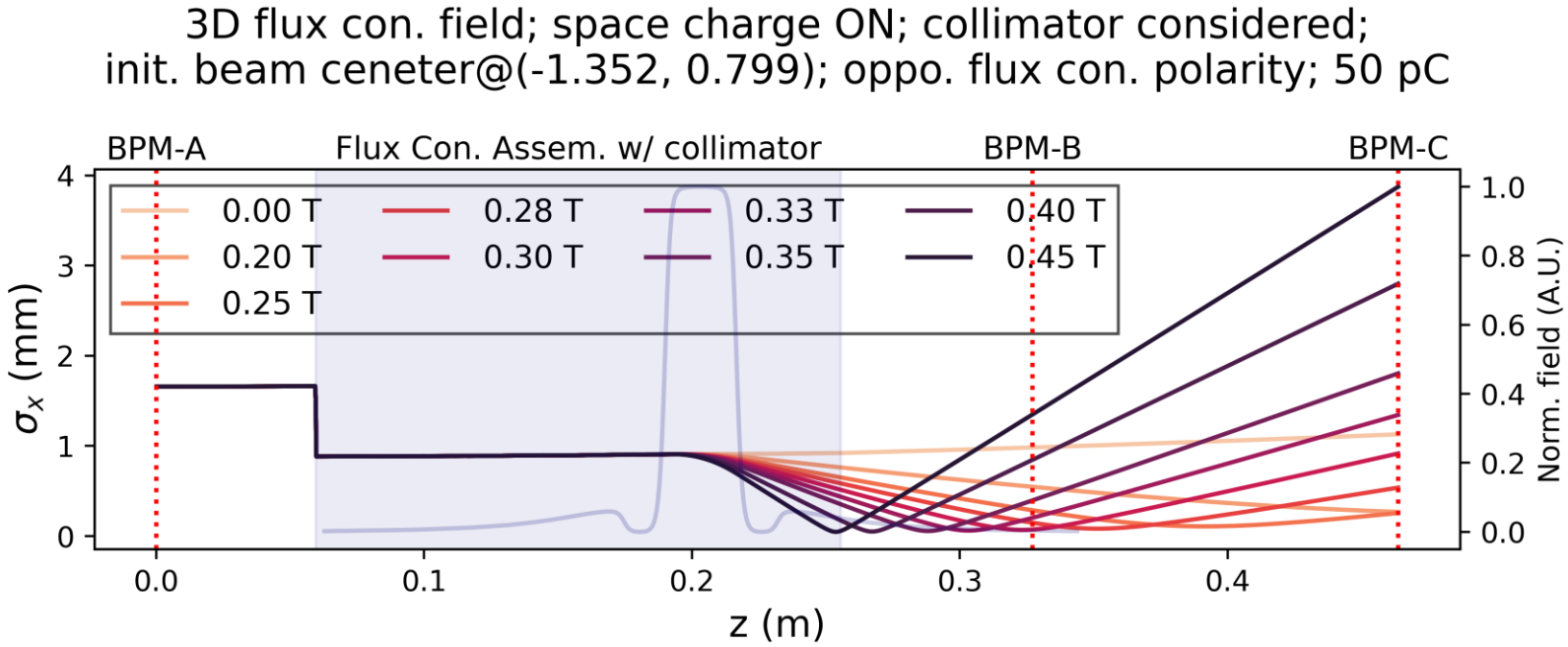




Basic simulation params.:

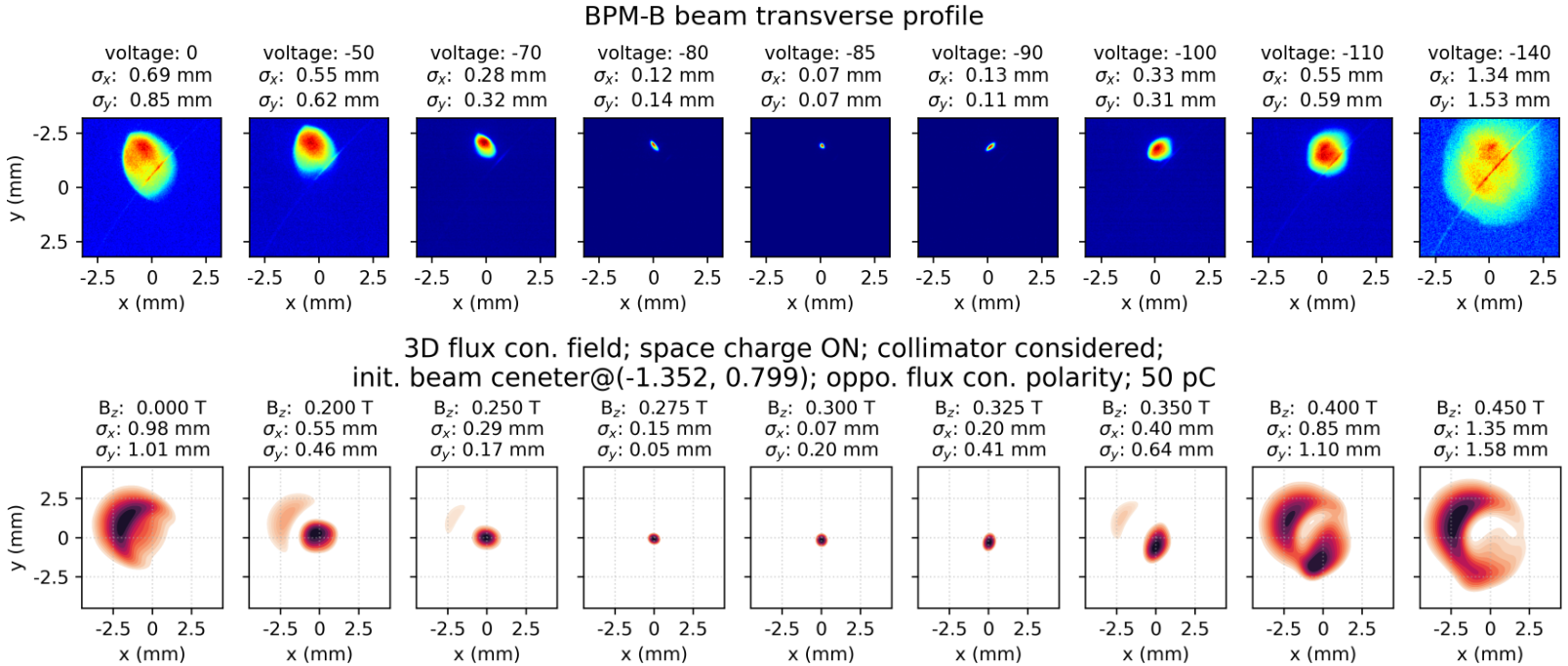
- Initial beam σ_x, σ_y: 1.6578 mm, 1.6801 mm
- Initial beam offset Δx, Δy: -1.352 mm, 0.799 mm
- Beam energy: 1.73 MeV
- Energy spread: 5e-3 (using 2.5 keV in ASTRA)
- Bunch charge:100 pC
- Bunch length (rms): 100 fs
- Emittance: 0.1 mm*mrad

BPM-B simulations using 3D field; init. beam@(-1.352, 0.799); oppo. polarity; 50 pC



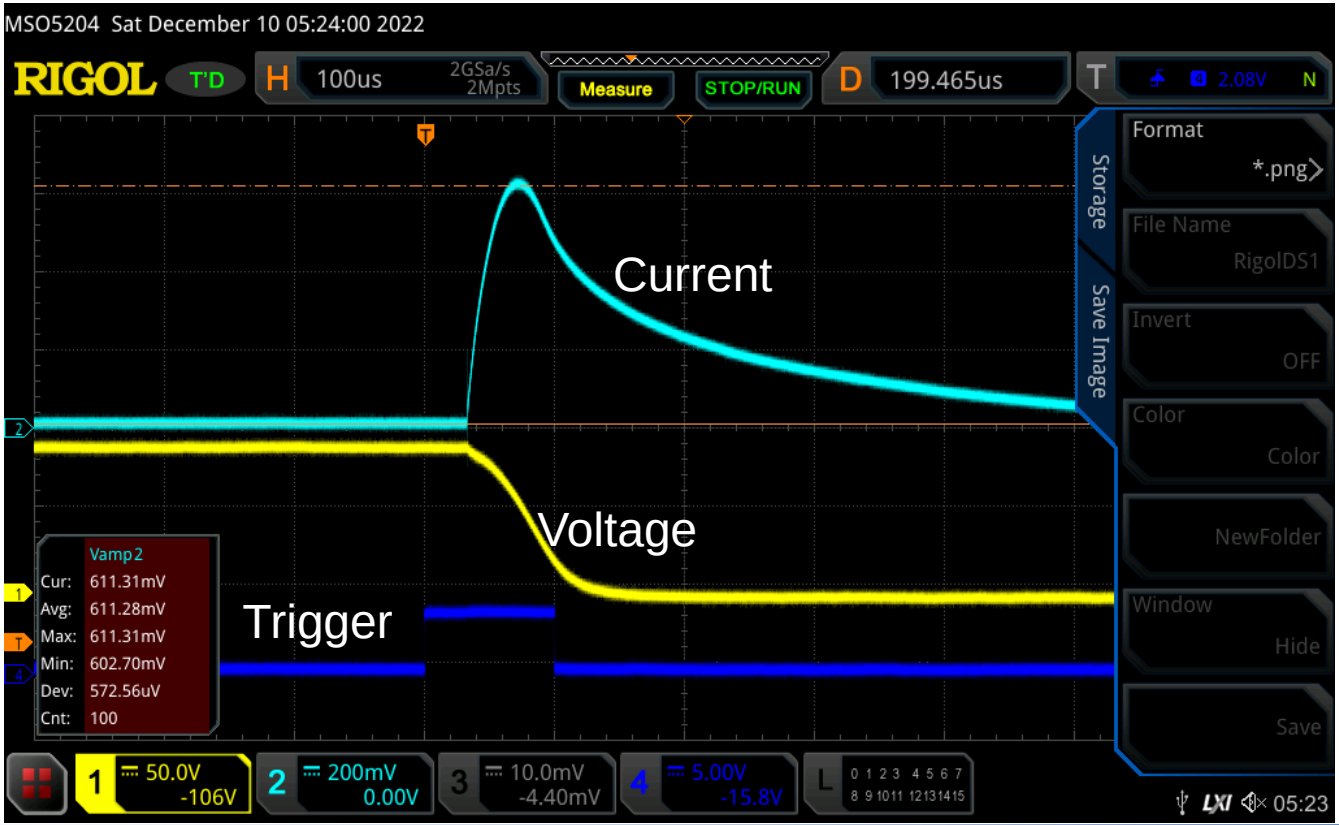
Courtesy to Dr. Gongxiaohui Chen

BPM-B simulations using 3D field; init. beam@(-1.352, 0.799); oppo. polarity; 50 pC



Courtesy to Dr. Gongxiaohui Chen

Pulsed Current Source



Thank ATF Team to make this test happened!

Questions?

CONTACT:

Euclid Techlabs LLC (R&D facility)
365 Remington Blvd
Bolingbrook, IL 60440 USA
Phone: (630)-313-6562
info@euclidtechlabs.com
www.euclidtechlabs.com

Thanks!

Activities & Impacts Associated with this Experiment – ***All Years*** (feel free to add pages as necessary)

Publications:

1. Pulsed Solenoid with Flux Concentrator for Ultrafast Electron Microscopy, Poster presentation IPAC19, May 2019.
2. Implementation of a Flux-Concentrator-Based Objective Lens for UED/UEM, Poster presentation, NAPAC2022, Aug. 2022.
3. Development of a Flux-Concentrator-Based 2-Tesla Solenoid as a Round Lens for Ultrafast Microscopy, Abstract submitted, IPAC23
4. A manuscript for a peer-reviewed journal is under preparation.

Commercialization activities:

The Relativistic Ultrafast Electron Diffraction and Imaging (RUEDI) Facility at UK bears strong interests in our flux concentrator lens. Collaborative design work is under negotiation.

COVID-19 Pandemic Impacts

- Please summarize any significant impacts from COVID-19 on your experiment and team through the course of your experiment
  - A certain delay of original experiment schedule.