ATF User Meeting
Proposal ID: UED-308079
Collaborator: BNL

Ultrafast Electron Microscopy with Flux Concentrator Objective Lens

9 Dec 2020

Euclid Techlabs LLC

SBIR Phase II PI: Sergey Antipov
UED-308079 PI: Eric Montgomery

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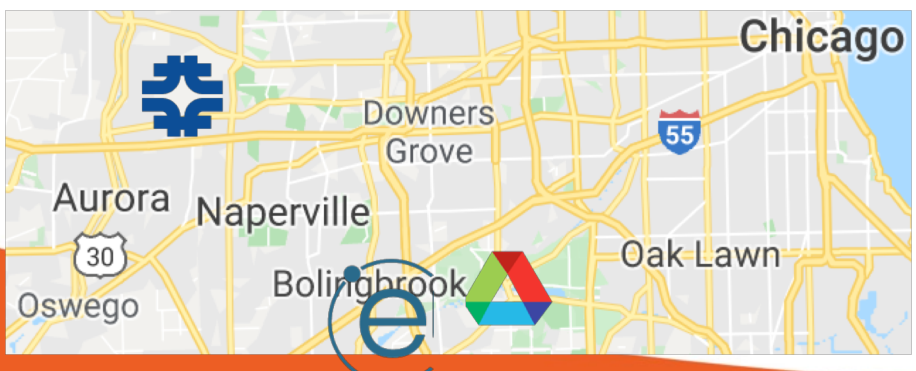
Who is Euclid?

Euclid Techlabs, LLC in Bolingbrook, IL, specializes in linear particle accelerators, ultrafast electron microscopy, and advanced material technologies for energy, defense, and medical applications.

20+ researchers • engineers • technicians
10,000 ft^2 research space, and growing

- time-resolved ultra-fast electron microscopy
- ultra-compact linear accelerators
- electron guns (thermionic, field, or photoemission)
- fast tuners for SRF cavities
- advanced dielectric materials
- HPHT and CVD diamond growth and applications
- thin-film applications in accelerator technologies



Current Collaborating Laboratories

- Brookhaven National Laboratory
- Jefferson Lab
- CERN
- Los Alamos National Laboratory, Est. 1943
- Fermilab
- NIST, National Institute of Standards and Technology, U.S. Department of Commerce
- Argonne National Laboratory
- SLAC
- Euclid Techlabs

Recent Euclid Achievements

New 100% Polarized Spintronics Candidate

“Chemical substitution induced half-metallicity in $CrMnSb_{(1-x)}P_x$”
O’Leary et al., J. Appl. Phys. 128, 113906 (2020)

R&D 100 Award: Laser-Free Stroboscopic TEM Pulser

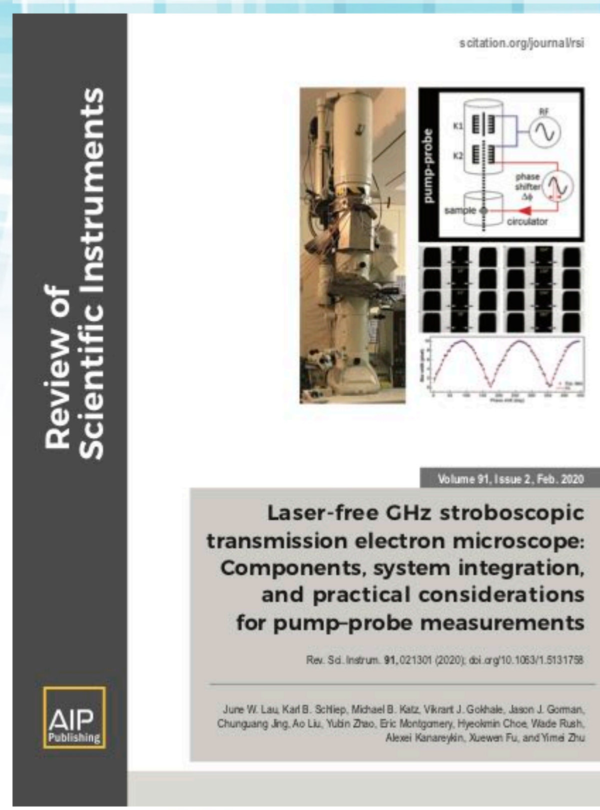
Science Advances: Ultrafast Imaging of GHz Fields in TEM

“Direct visualization of electromagnetic wave dynamics by laser-free ultrafast electron microscopy.” Fu et al., Sci. Adv. 6(40), eabc3456 (2020).

M&M 2020 Innovation Award

Microscopy & Microanalysis Conference

Cover of RSI, Feb 2020



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Current & Prior Collaborations with BNL

BROOKHAVEN NATIONAL LABORATORY | euclid TECHLABS

	Project Lead	PI + Project Lead
UNCD Photocathodes (BNL, ANL)	E. Wang	A. Kanareykin + E. Montgomery
Ultrafast TEM Pulser (BNL, NIST)	Y. Zhu	C. Jing + E. Montgomery
SRF Photogun (BNL)	Y. Zhu, M. Palmer	C. Jing + R. Kostin
Flux Concentrator (BNL)	T. Shaftan, + Y. Zhu, L. Doom	S. Antipov, +C. Jing, E. Montgomery
Encapsulated Photocathodes (BNL)	E. Wang	A. Liu

Prior Euclid has a long history with ATF (M. Palmer) and Brookhaven broadly. Past experiments at ATF include THz generation and a wakefield dechirper. These collaborations have generated near 10 publications including PRL, APL, etc.

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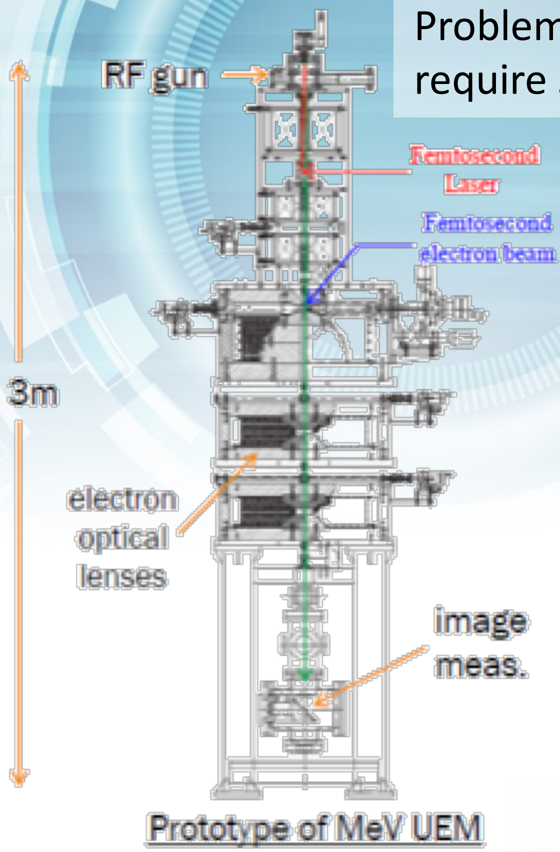
Motivation: MeV UEM

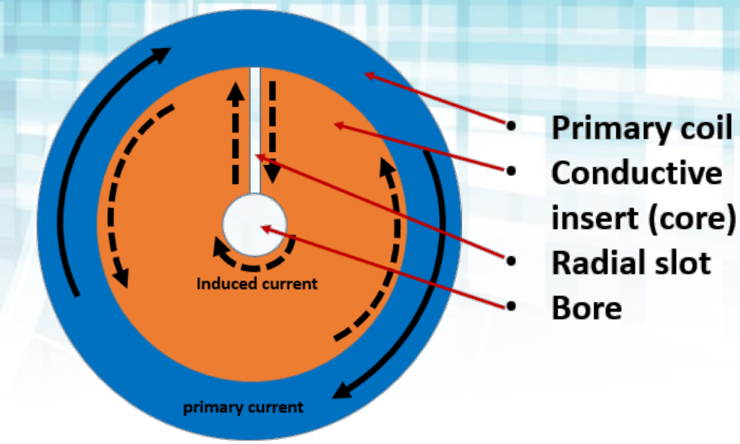
Problem: UEM (3-4MeV) electrons require strong solenoids to focus

Solution: pulsed solenoids with flux concentration

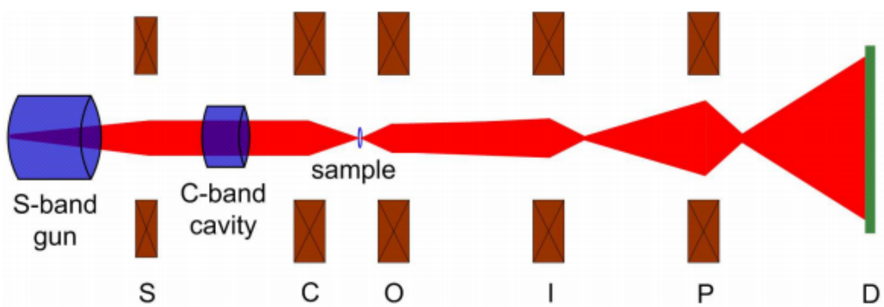


J. Yang, Workshop on ultrafast electron sources for diffraction and microscopy applications 2012

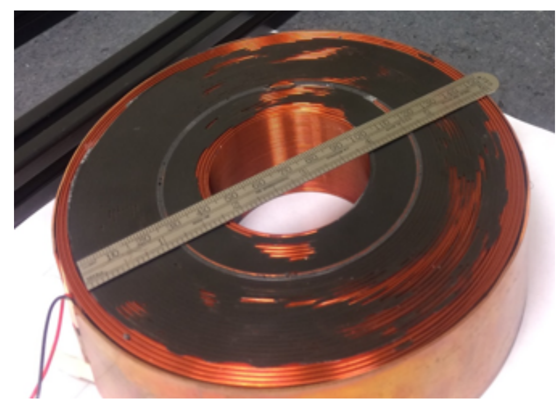
2 ton Obj. Lens (DC)



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



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

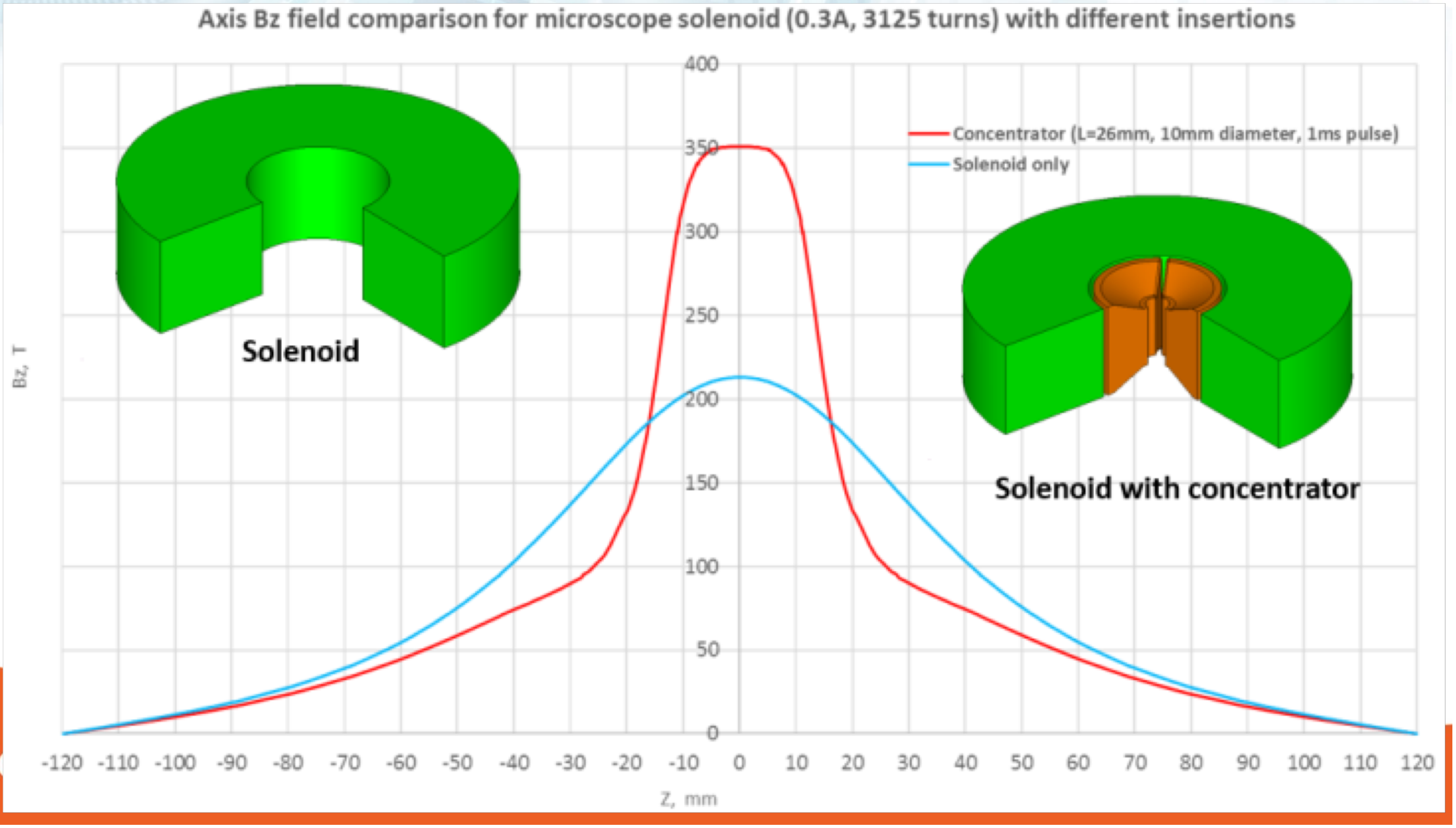


Standard TEM coil – want similar size

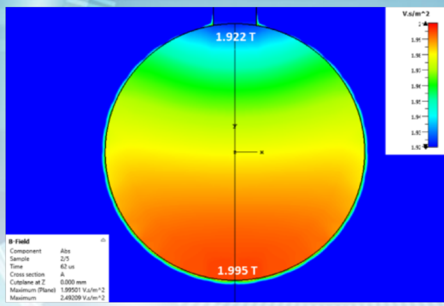
Progress in Phase II SBIR

1. Simulations and design concluded for flux concentrator
2. Beamline simulations and v1.1 bench tests (stability, efficiency)
3. Final v2.0 hardware fabrication – concentrator, ferrite
4. In progress: coil winding, duplicate sample chamber

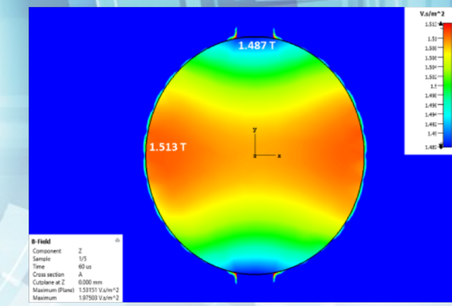
Flux concentrator can significantly enhance the solenoid field (right) for the same peak current



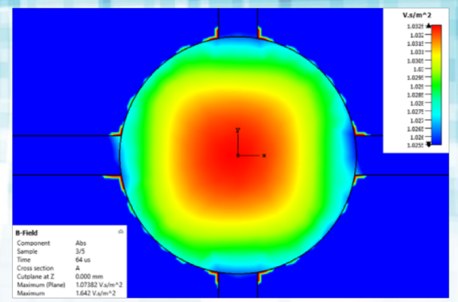
Optimized number of slits in concentrator



One slit



Two slit



Four slit

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.

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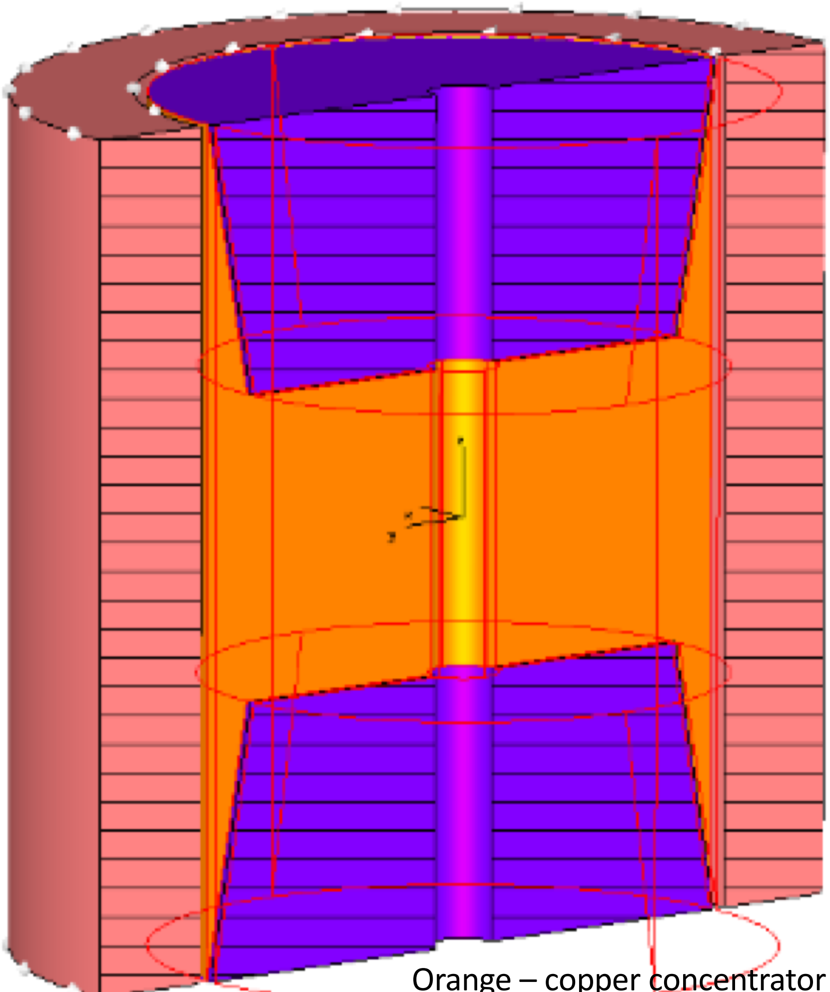
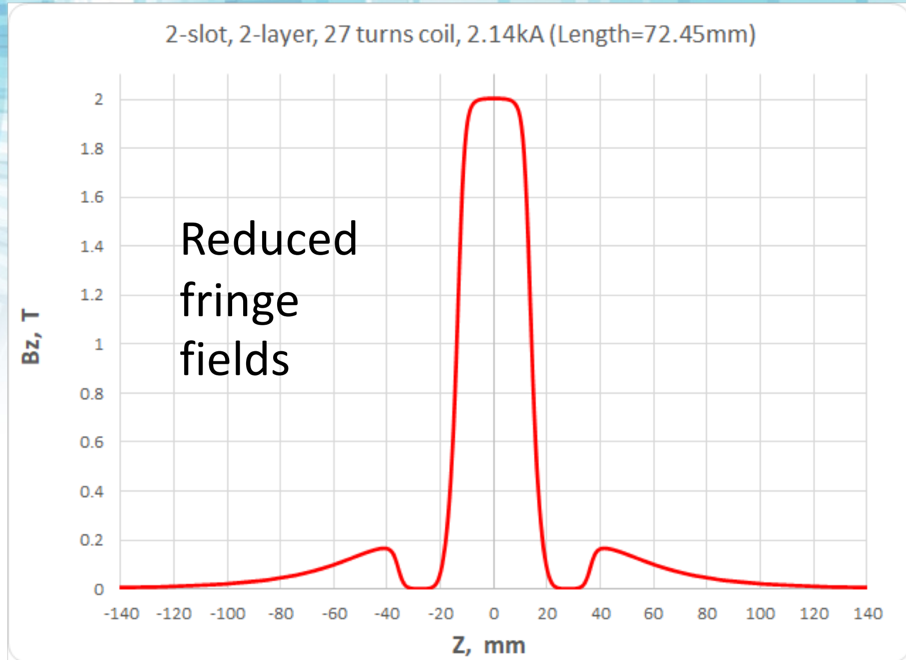
1 ms pulse simulation

Use of Ferrite – Final Design

Ferrite reduces fringe fields (near zero in ferrite), and drive current (down by 19%)



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

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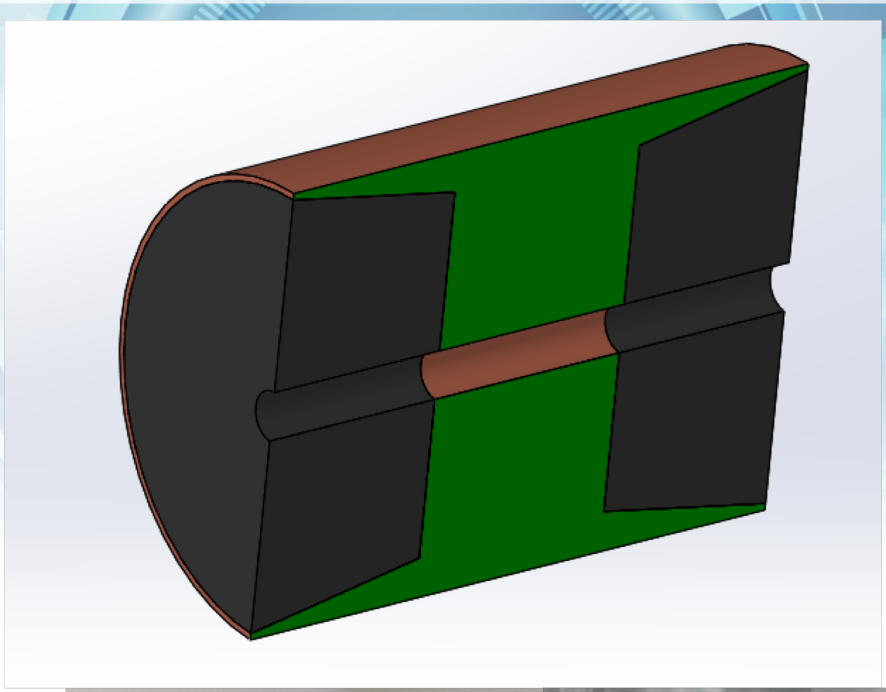
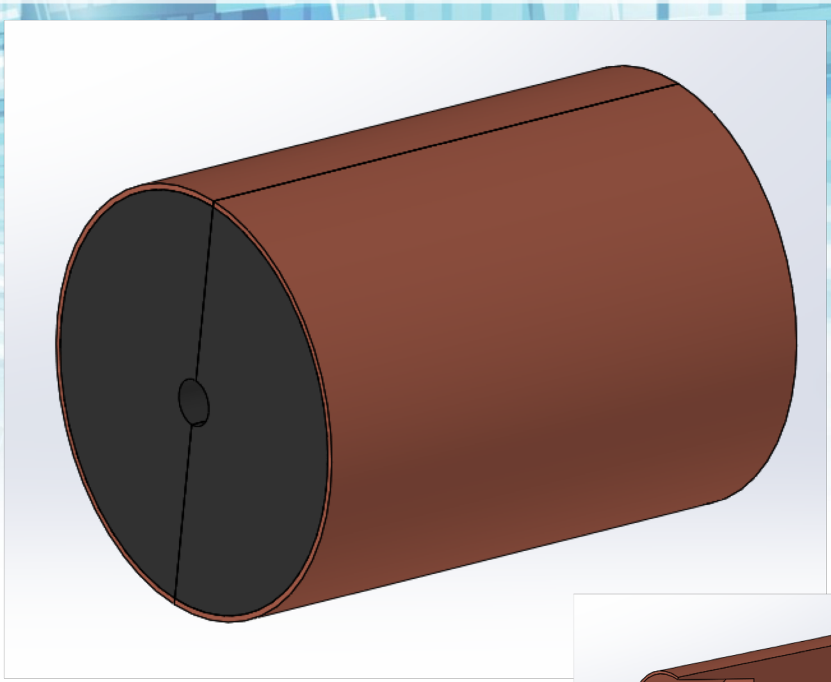
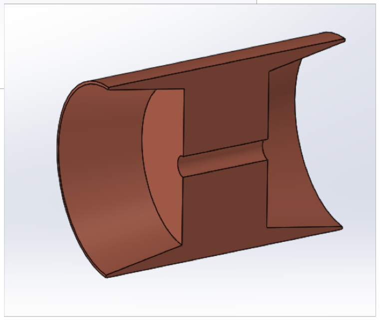
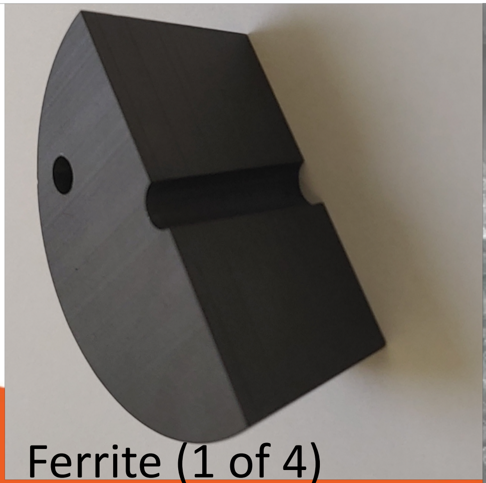
Concentrator/Ferrite Assembly for BNL

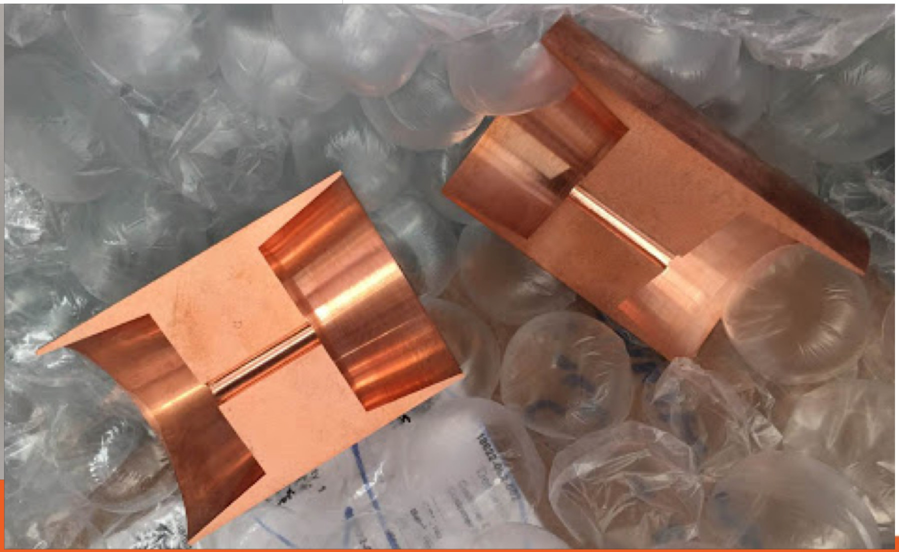








Ferrite (1 of 4)

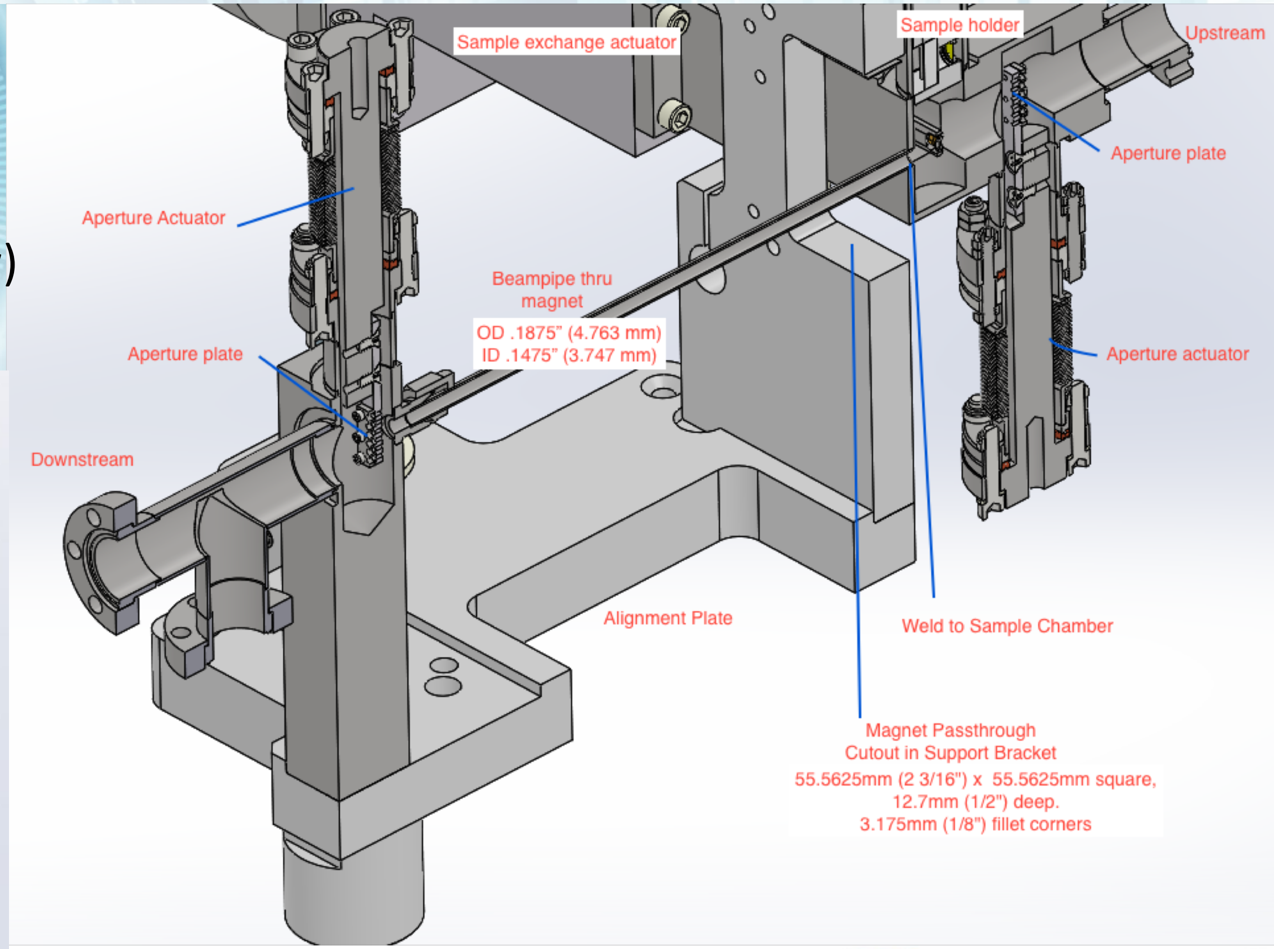


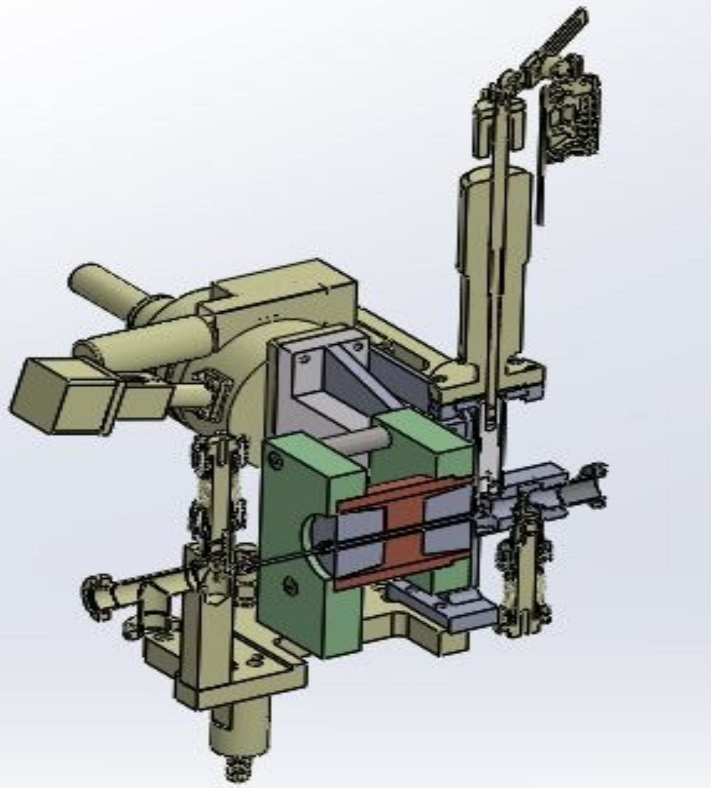
Concentrator (2 pieces)

Drop-In Compatibility with UEM Beamline

BNL UEM Objective Lens location (right)

Cutaway for Euclid System (below)





Vibration concerns? Flux concentrator damps 20 us after pulse, fully compatible with ~10 kHz or less rep rate

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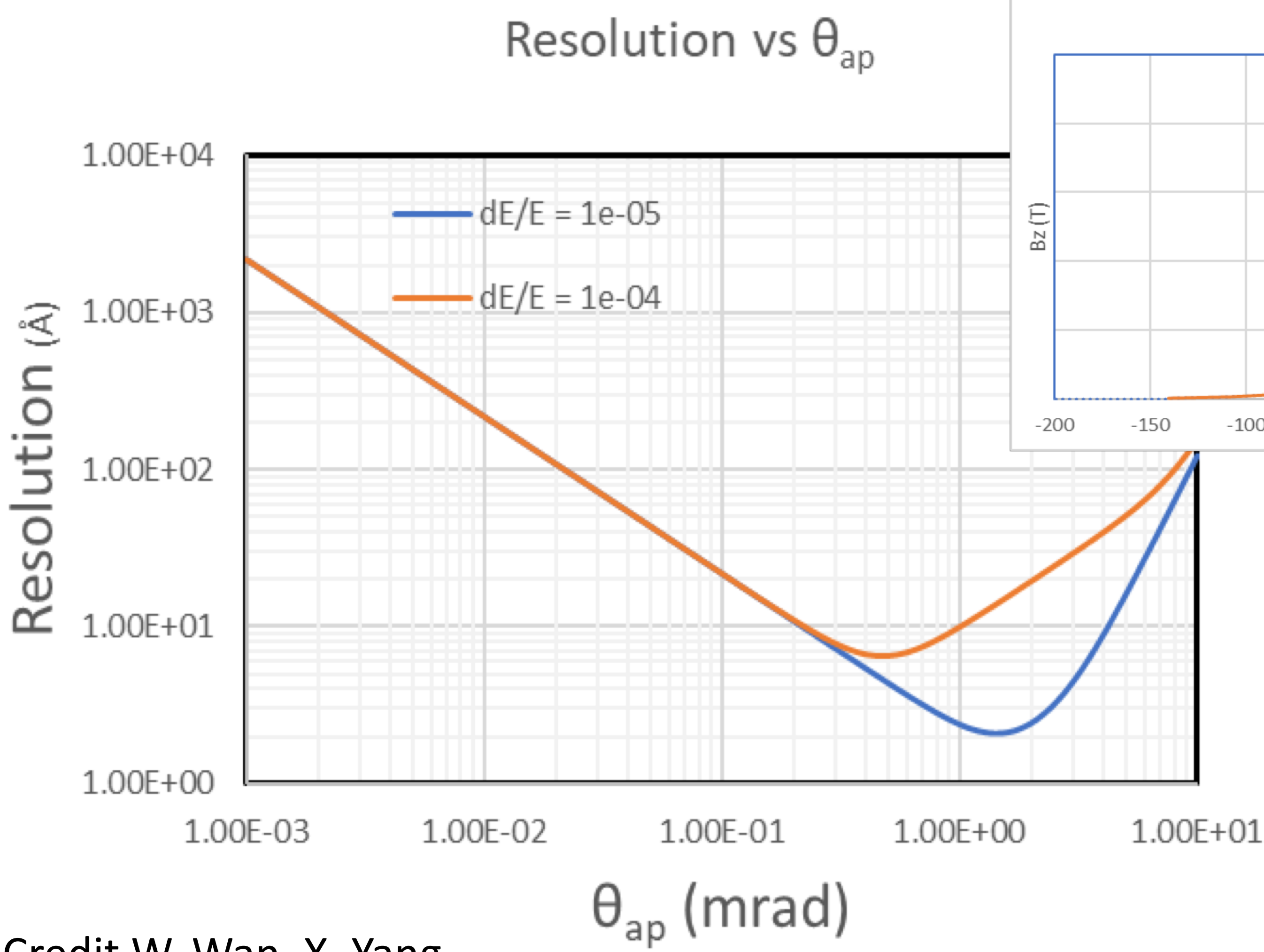
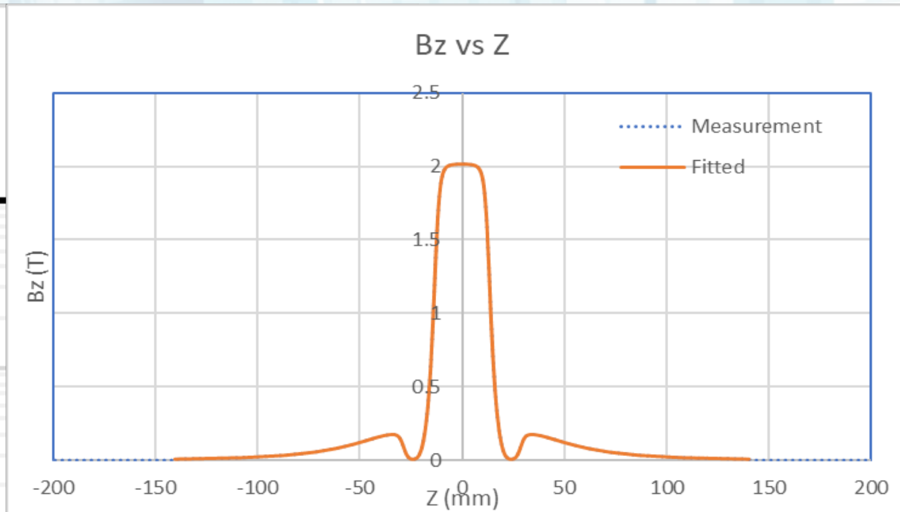
Modeling





Credit W. Wan, X. Yang

2 Tesla (above), CST

2.1 Å resolution (left), if sample is 18 mm from lens center (impossible w/present goniometer)

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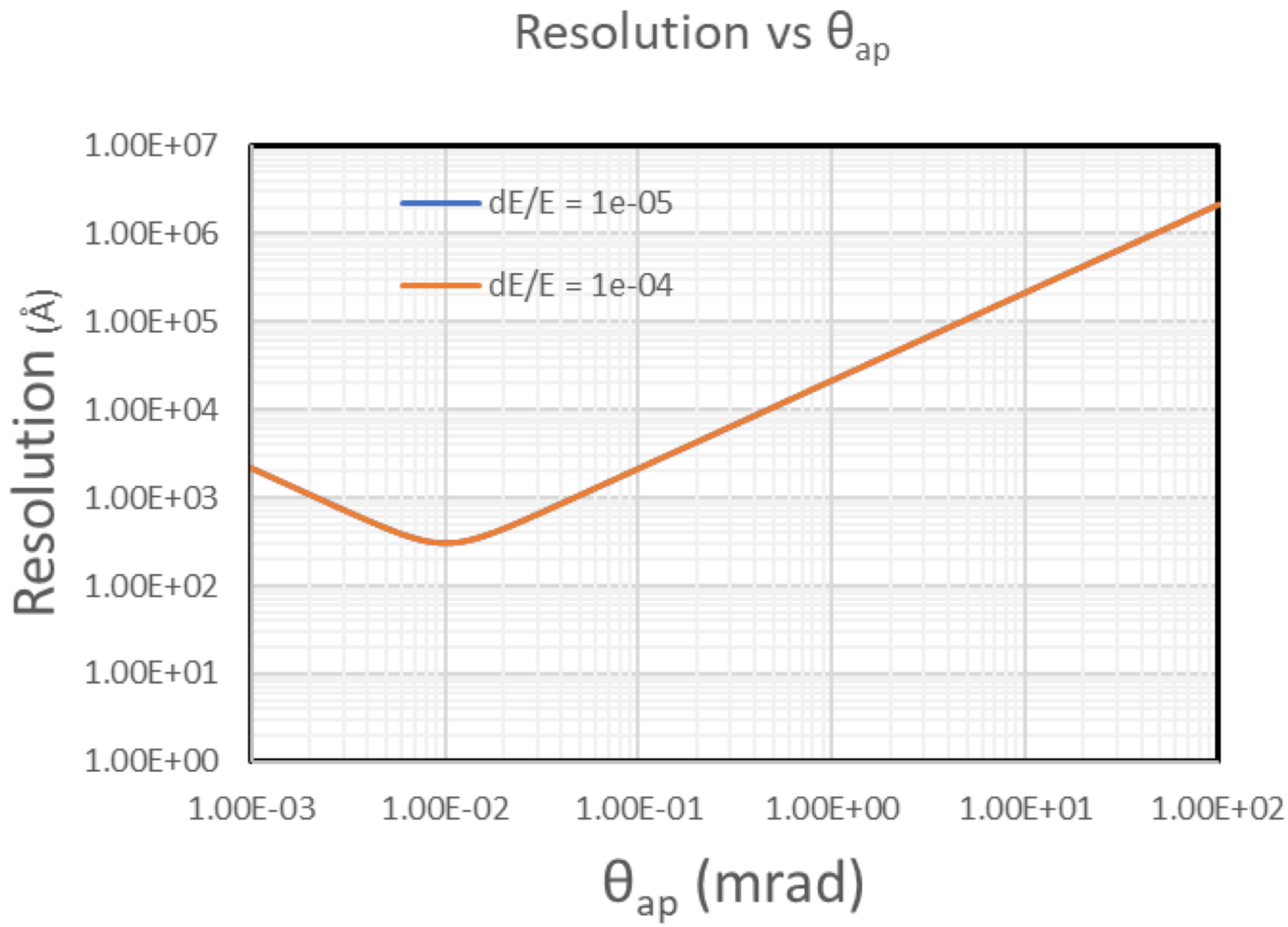
Modeling

	f (cm)	$C_{s,x}$ (cm)	$C_{s,y}$ (cm)	$C_{s,xy}$ (cm)	$C_{c,x}$ (cm)	$C_{c,y}$ (cm)
Round lens	1.36	3.36	3.36	3.36	2.22	2.22
Solenoid 2T	1.37	0.86	0.86	0.86	1.60	1.60



Credit W. Wan, X. Yang

Abberations (above)

31 nm resolution (left), if sample is 41.5 mm from lens center (using present goniometer)

Compare to 100 nm for PMQ (permanent magnet quadrupole)

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Proposal

1. Operate a 2 Tesla pulsed flux concentrator solenoid objective lens on the UEM beamline, single shot at 5-10 Hz.

2. Show pulsed power of the 2 Tesla lens is <1 kW average.

3. Characterize timing stability.

4. Show 3 MeV beam focusing.

5. Show spatial resolution better than 80 nm (new state of the art).
We see 30 nm from the modeling with the existing sample holder and goniometer, but if in the future the sample holder can be non-metallic inside the taper of the concentrator, closer to the hard edge of the magnet, we may achieve resolution better than 1 nm.

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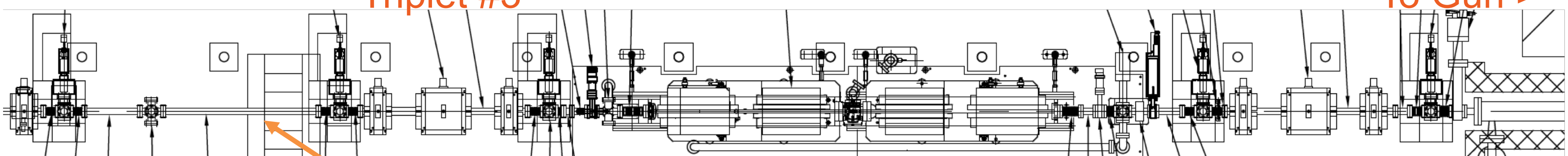
Synergies

Dr. Roman Kostin will present next on the SRF Photogun. A high gradient cryogenic source will produce low energy spread; Euclid's version is a "tabletop" design with a cryocooler instead of a liquid helium plant, made possible by a Nb3Sn coating. We hope to set up a new user capability in the old ATF-II bunker.

ATF itself is our proposed backup in case the UEM beamline is not ready. We would place the lens downstream of the third triplet and perform focusing and synchronization tests without imaging, at around 25 MeV.

ATF Beamline



Special Equipment Requirements and Hazards

- Experiment Requires UEM (LDRD configuration)
- User Sample and Setup
  - Special Equipment: Camera and screen, steering coils, UEM imaging lenses
- Pump Laser Requirements
  - No special requirements – standard photogun drive laser, 5-10 Hz
- Hazards & Special Installation Requirements
  - Large installation: Chamber & magnet <50 kg
  - New power supply and chiller provided by Euclid
  - Power supply to hang above beamline for shortest leads
  - Introducing new magnetic elements: replaces Objective lens & duplicates sample chamber
  - Introducing new materials into the beam path: alumina beampipe with carbon coating for charge dissipation
  - Any other foreseeable beam line modifications: None

Special Equipment Requirements and Hazards

Power requirements:
-Pulser: 110V, single phase, 3A.
-Power supply: 110V, single phase. 32A (rating), 18A (operational) (we will set 18A as internal limit).

Dimensions and weight:
-Pulser: 19" rack, 3U, depth 500mm, 15kg.
-Power supply: 19'' rack, 6U, depth 585mm, 25kg.
-Magnet assembly: ~80mm cube, ~25kg plus chamber, mount

Experimental Time Request

CY2021 Time Request

Capability	Setup Hours	Running Hours
UED Facility	48	112

Time Estimate for Remaining Years of Experiment (including CY2021)

Capability	Setup Hours	Running Hours
UED Facility	48 – nothing past CY2021	112 – nothing past CY2021