Status of the Ce+BAF project

Motivation

Timeline

Expected beam properties

LERF layout for e+ facility

R&D activities

Conclusion

Yves R. Roblin and the Ce+BAF working group

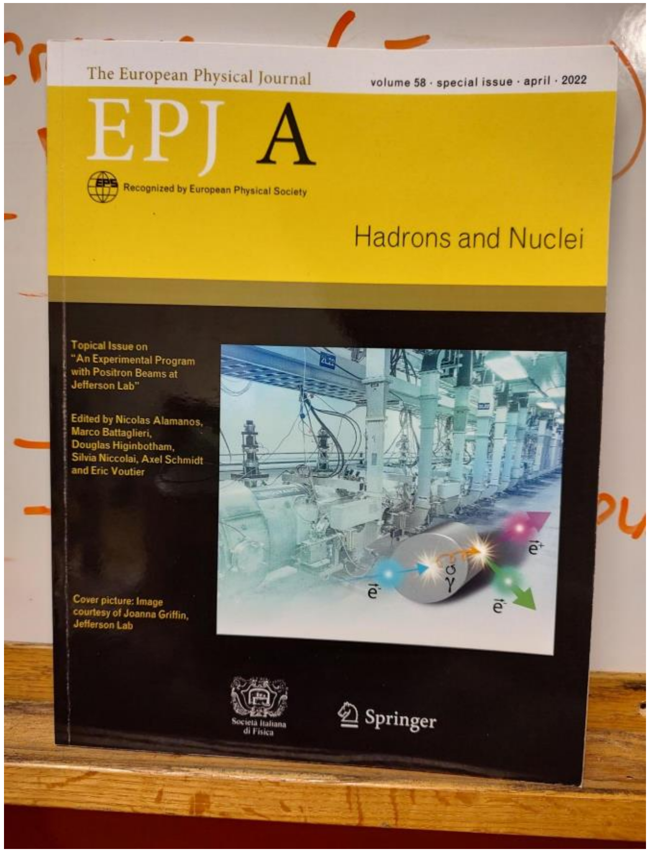
U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

Physics Motivation

Jefferson Lab Positron Working Group

Jefferson Lab Users have made a strong case for ***positron beams at CEBAF 12 GeV***

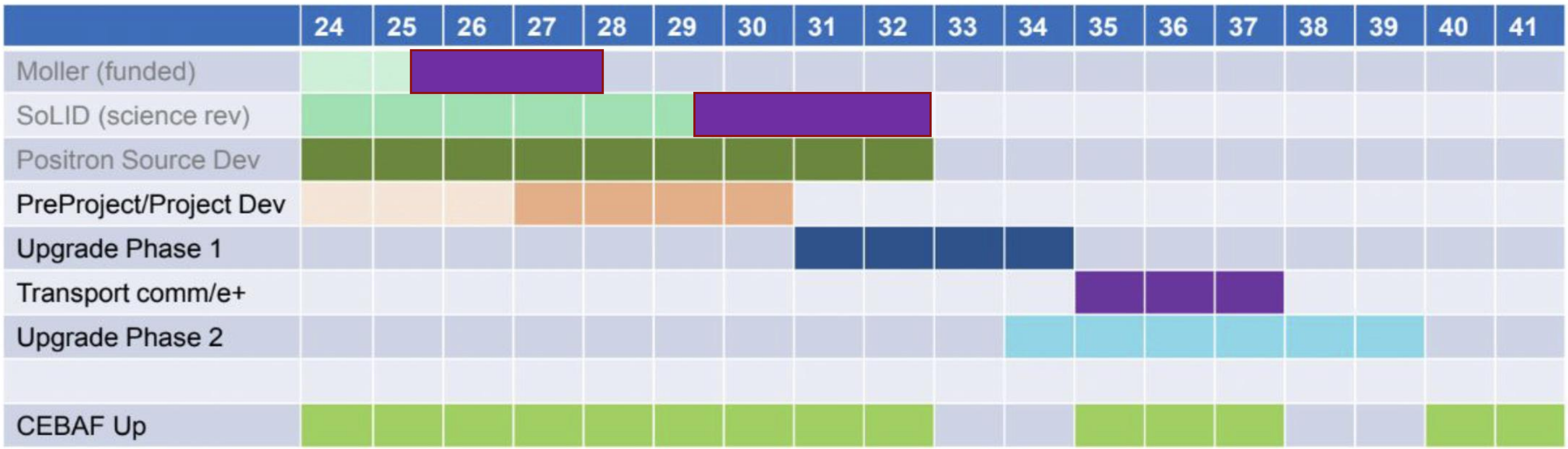
- Complementary **charge** and **spin** of **e^+** would provide a new probe at Jefferson Lab
  - 2018 – 7 letters of intent to PAC
  - 2020 – 2 conditionally approved PAC proposals
    - Hall B ~ **100 nA** polarized (>60%)
    - Hall C ~ **3 μA** unpolarized
- **2023 6 new proposals and 5 new letters of intent**



See Talk by D. Higinbotham

Proposed Timeline

Gantt chart to give a rough idea when these project could become a reality.



Phase 1 includes building the positron source and the tunnel & beamline connecting the source to main machine.
Phase 2 includes the new permanent magnets to allow 22 GeV within current CEBAF footprint.

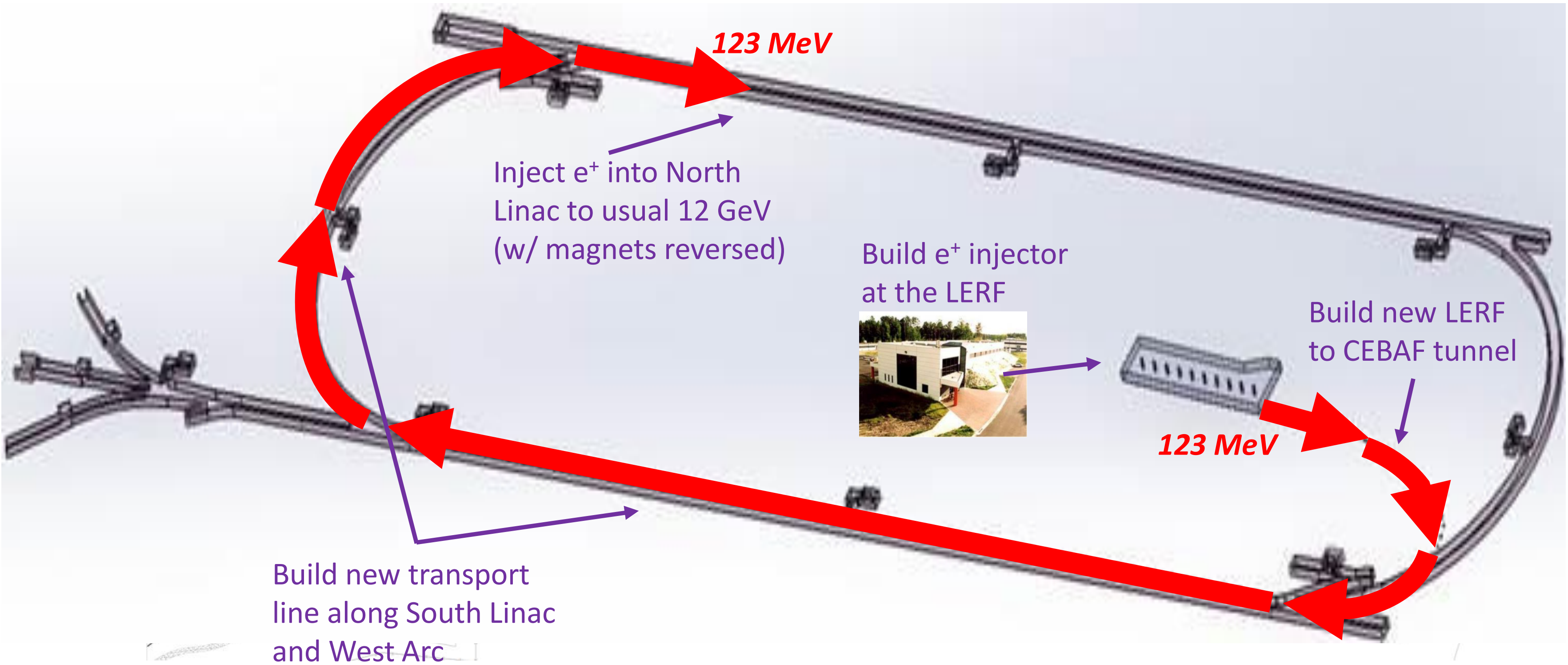
NOTE: Plan was formulated so that these projects are ramping up as the EIC project cost is ramping down.

Patrizia Rossi, HADRON 2023

12 GeV Ce+BAF e+ versus e-

Machine Parameter	Electrons	Positrons
Hall Multiplicity	4	**1 or 2**
Energy (ABC/D)	11/12 GeV	11/12 GeV
Beam Repetition	249.5/499 MHz	249.5/499 MHz
Duty Factor	100% cw	100% cw
Unpolarized Intensity	170 µA	**> 1 µA**
Polarized Intensity	170 µA	**> 50 nA**
Beam Polarization	> 85%	**> 60%**
Fast/Slow Helicity Reversal	1920 Hz/Yes	1920 Hz/Yes

Turning the LERF into a Positron Injector Facility



Machine parameters, several new options

Machine parameter table now more comprehensive

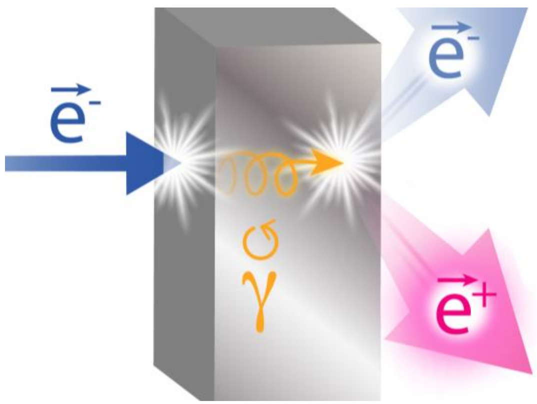
Machine Parameter	CEBAF e-	Ce+BAF		
		e+	Degraded e-	e-
Multiplicity	4	1 or 2		
Max. Energy (ABC/D)	11/12 GeV	11/12 GeV		
Beam Repetition	250/499 MHz	250/499 MHz		
Duty Factor	100% cw	100% cw		
Unpolarized Intensity	170 μA**	> 1 μA	>> 1 uA	170 μA**
Polarized Intensity	170 μA**	> 50 nA	>> 1uA	170 μA**
Beam Polarization	> 85%	> 60%	>85% ?	>85%

** Total beam power at Jefferson Lab is limited to 1.1 MW with a max. of 0.9 MW to individual high power dumps.

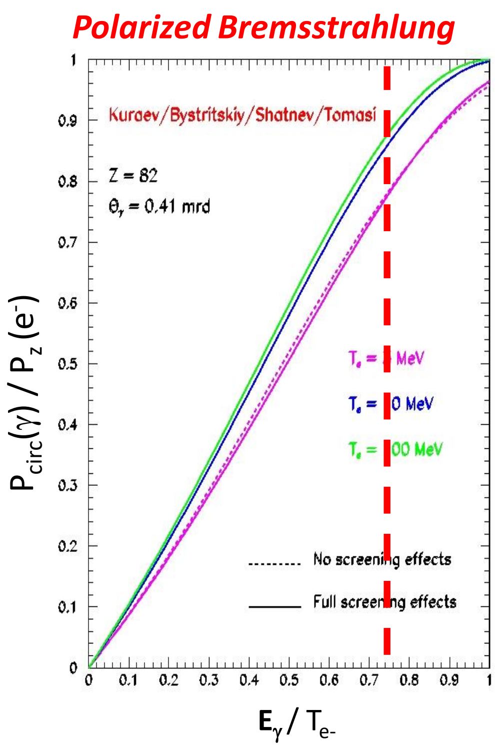
Exploit electron spin polarization to produce polarized positrons

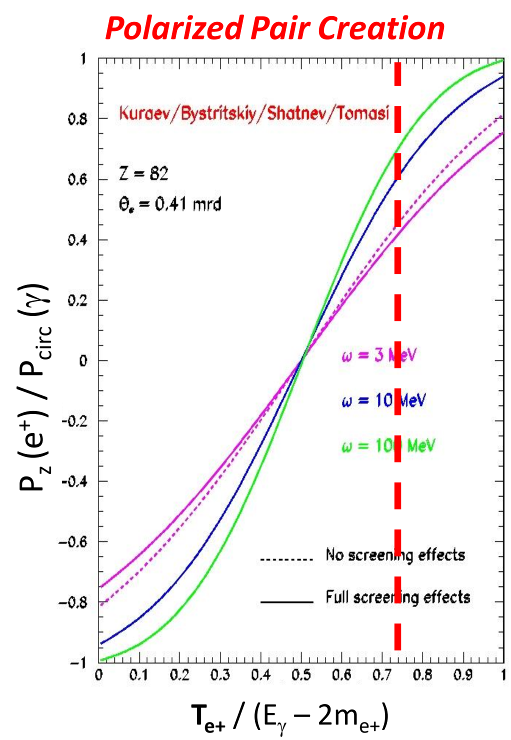
$$\vec{e}^- \rightarrow \overset{\circlearrowleft}{\gamma} \rightarrow \vec{e}^+ \; (+\, \vec{e}^-)$$

When a longitudinally polarized e^- beam strikes matter, e^+ produced in the shower carrying ***>50% of the e^- beam energy*** *are significantly longitudinally* ***spin polarized****…*



…so why not take advantage of this?

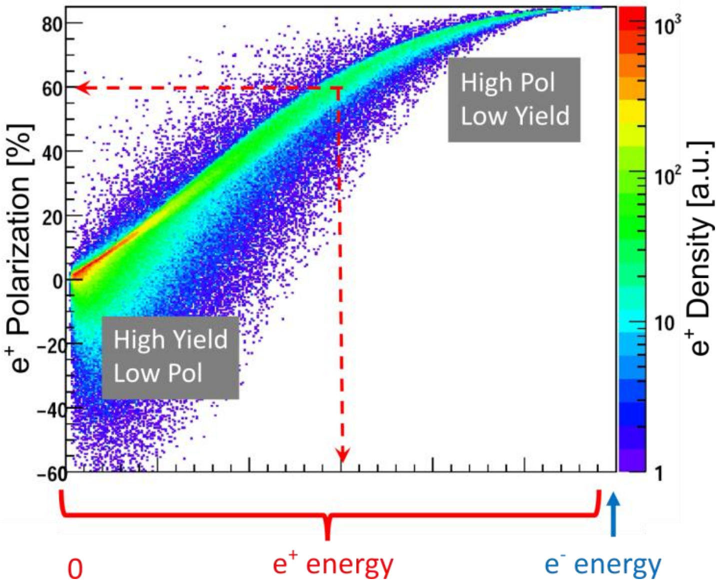




E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208

“Tunable” e^+ source

e+ Polarization vs Energy

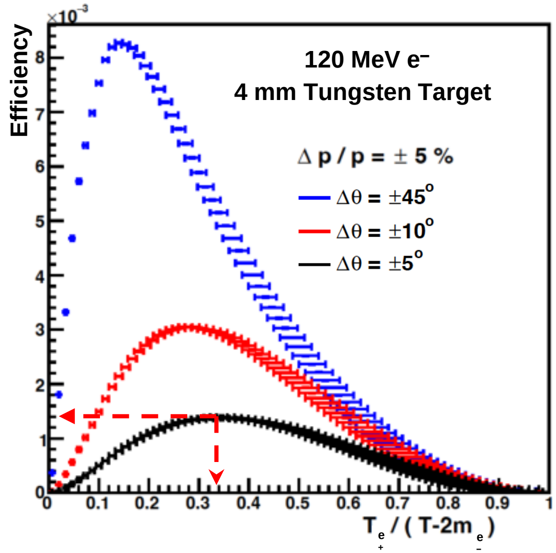


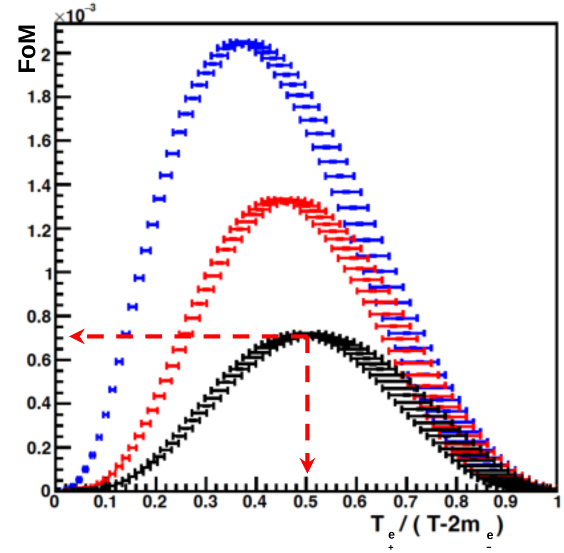
Unpolarized mode

Efficiency : $\epsilon = \frac{N_{e+}}{N_{e-}}$

Polarized mode

Figure-of-Merit $FoM = \epsilon P_{e+}^2$

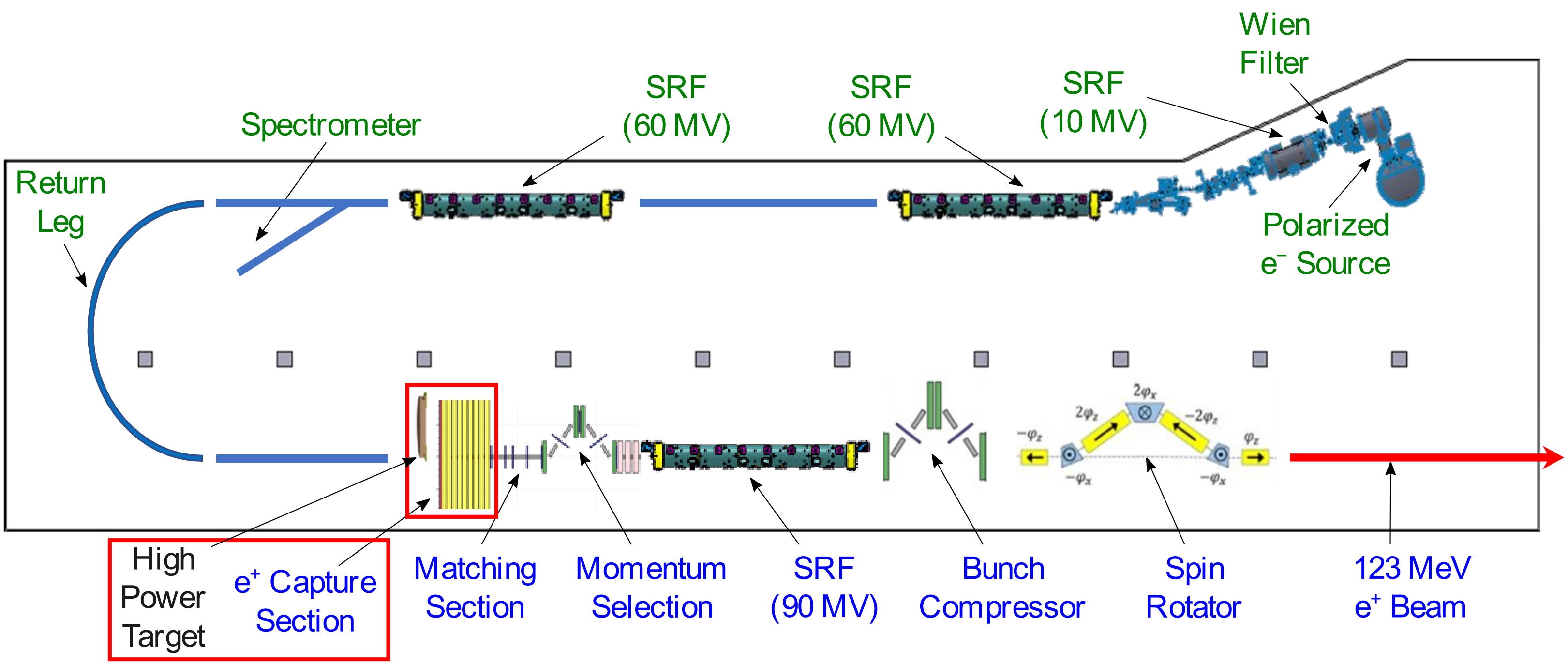




Positron beamline has to be designed
for efficient capture and transport of e^+ with different energies

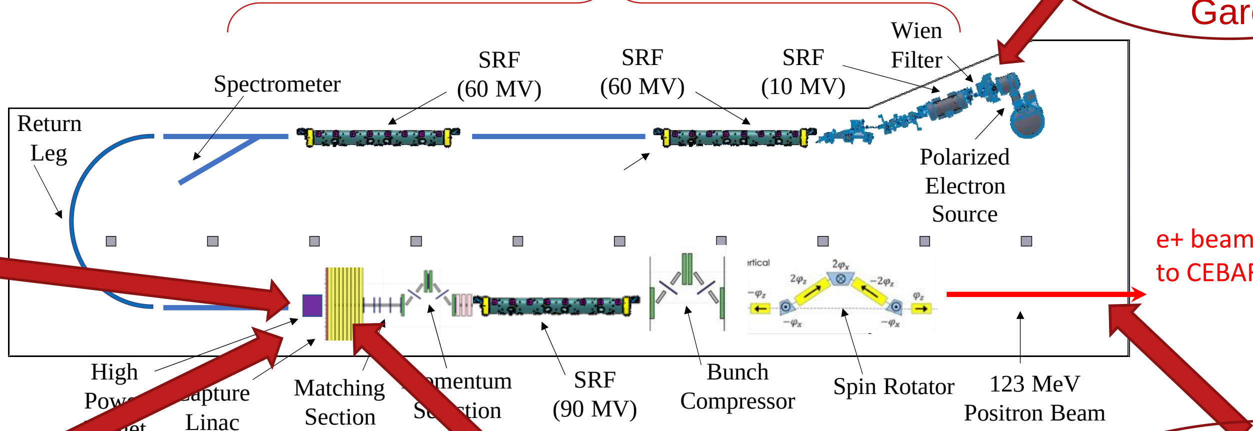
LERF Polarized Positron Injector Concept

- High current polarized electron injector (≳ 1 mA @ 10 MeV)
- High current 1-3 mA electron LINAC (two C75 CM)
- Positron conversion target (1 mA @ 120 MeV ⇒ 120 kW)
- Positron capture (≲ 100 μA @ ~60 MeV and ~20 MeV)
  - ~1T capture solenoid and nc standing wave cavity with 1497 MHz and ≳1 MV/m peak field
- e^+ compression and acceleration to 123 MeV



R&D activities for e- and e+ sources

Polarized e- injector



>mA e- source & photocathodes
C. Hernandez-Garcia

High power solid target
S. Covrig

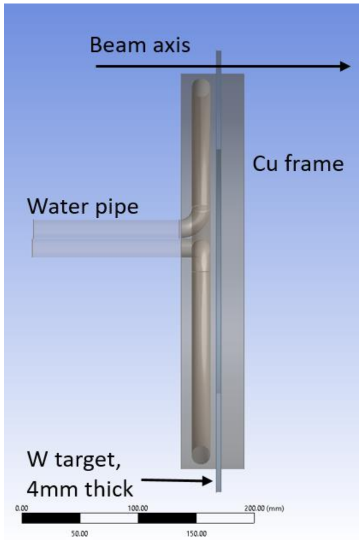
High power liquid target
V. Kolstrum

e+ collection system
A. Ushakov

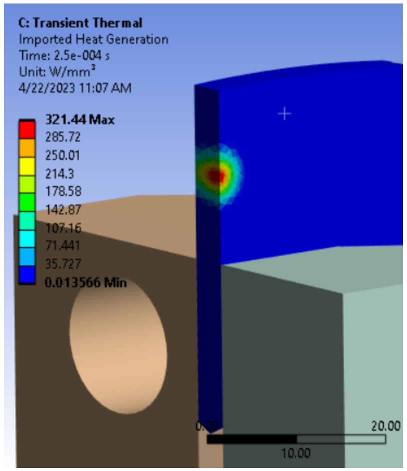
Transport large emittance e+ beams
A. Sy

Concept and Challenges of High-Power Tungsten Target

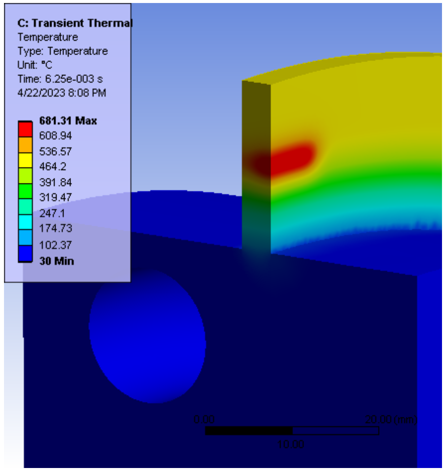
Target Concept (Side View)



Heat by Beam

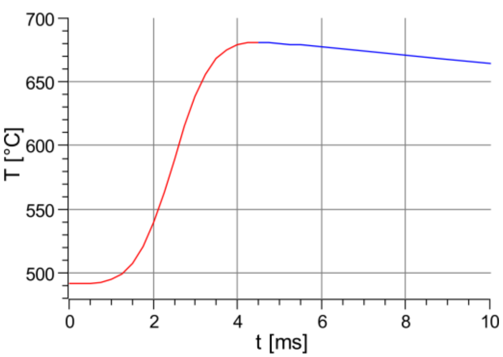


Temperature in Rot. Target



A. Ushakov et al, IPAC'23

Cycling Temperature



- **17 kW** deposited by 1 mA @ 120 MeV
- $\sigma_x = \sigma_y = 1.5$ mm

Some parameters of currently considered high-power e⁺ target:

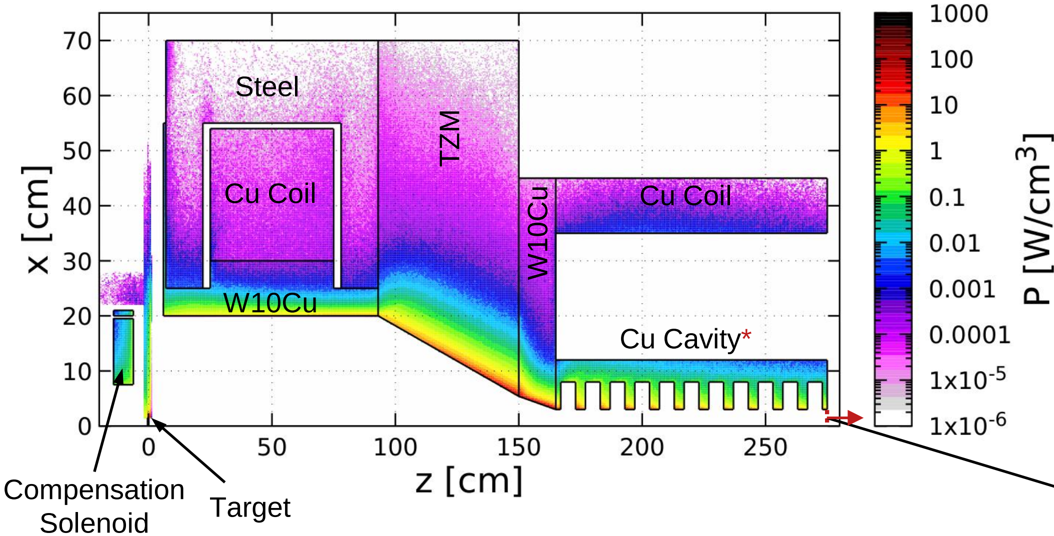
- ~40 cm target diameter
- 2 Hz rot. frequency
- 8 mm radius of water channel
- 0.3 kg/s water mass flow (1.5 m/s)

Target Challenges:

- **High power** deposited by beam → cool and rotate
- **Radiation damage** → rotate
- **Material fatigue** cause by cycling temperature → study material properties under realistic conditions

A. Ushakov

Distribution of Power Deposed by 1 mA @ 120 MeV e⁻ Beam (FLUKA)



	Power [kW]
Target	18.11
Compensation Solenoid	0.74
Coil of Main Solenoid	0.02
Iron of Main Solenoid	0.06
W10Cu Absorber inside Main Solenoid	18.88
TZM Absorber (99.4% Mo, 0.5% Ti, 0.1% Zr)	58.66
W10Cu Absorber upstream Cavities	12.50
Solenoid around Cavity	0.12
Cu Cavities	6.50
Total Absorbed Power	**115.56 (96.3%)**
Beam Power at z = 275 cm, r ≤ 3cm	**3.20**

	Photons	Electrons	Positrons
Yield per primary e^-	0.123	0.029	0.005
Mean Energy [MeV]	12.7	49.6	35.7
Power [kW]	1.57	1.44	0.19
Fraction in Total Beam Power	49.1	44.9	6.0

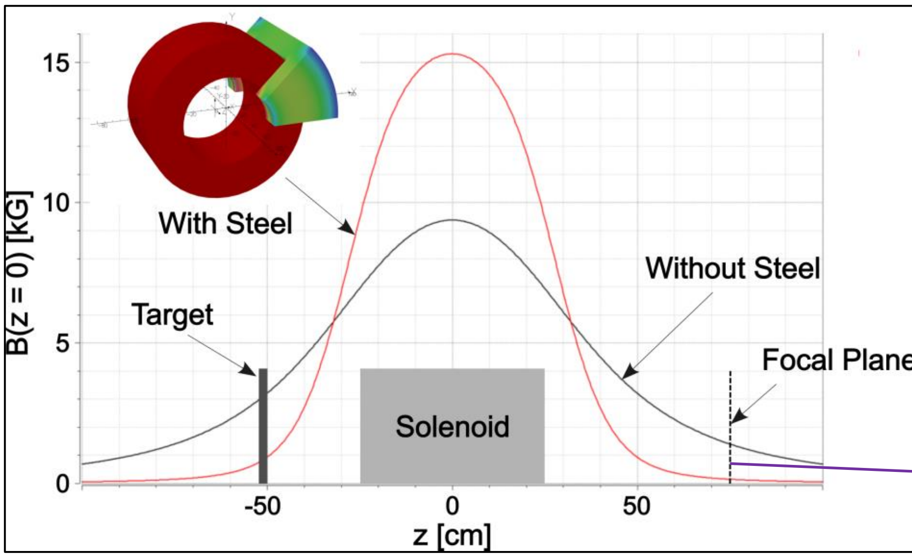
Mechanical design and simulations of temperature, thermal stress, radiation damage and optimization of whole e^+ capture system have to be done / will be continued

* FLUKA model does not have E-field in cavity

A. Ushakov

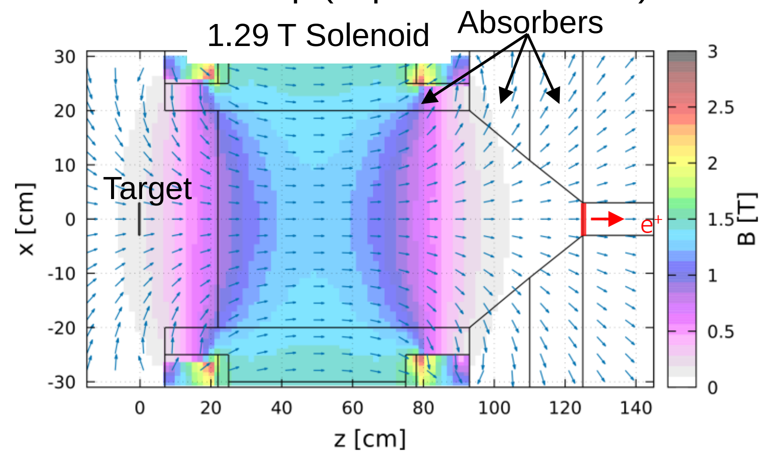
Capture using a high field solenoid in a QWT configuration

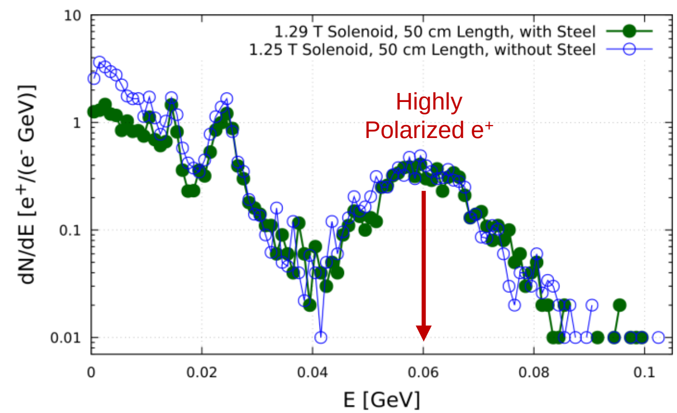
Solenoids with and without Steel
(calculated by J. Benesch)



15 cm thick good magnet steel with inner radius of 25 cm allows significant reduction of current density and reduces field in rotated target

Field Map (imported in FLUKA)



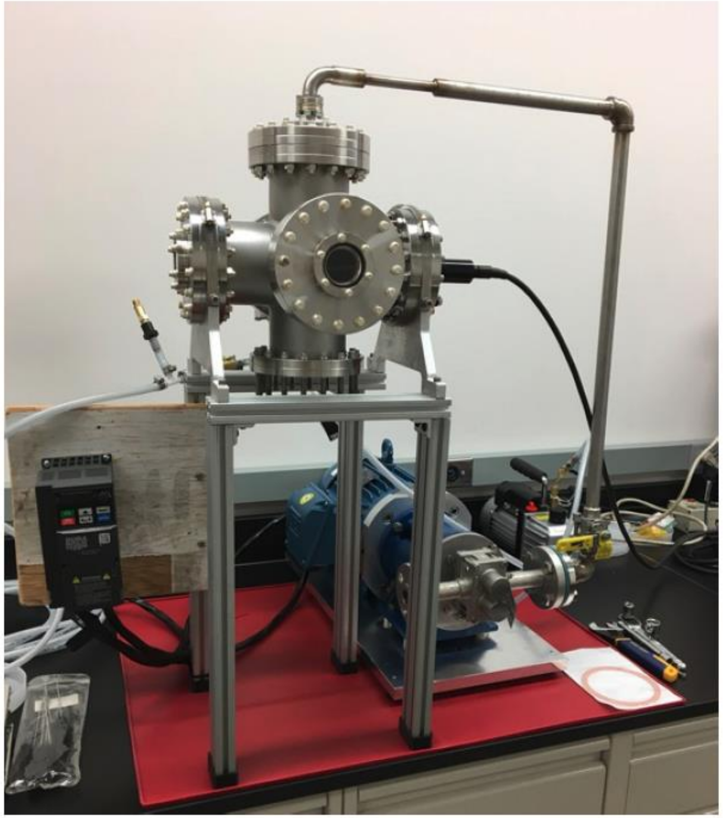


A. Ushakov

GaInSn prototype test stand

A free surface GaInSn liquid metal test stand was constructed from 304 SS.

The GaInSn is pumped by a Liquiflo Model H7F Mag-Drive gear pump with speed controlled by a constant-torque VFD.



Example GaInSn jet with speed ~ 8 m/s.

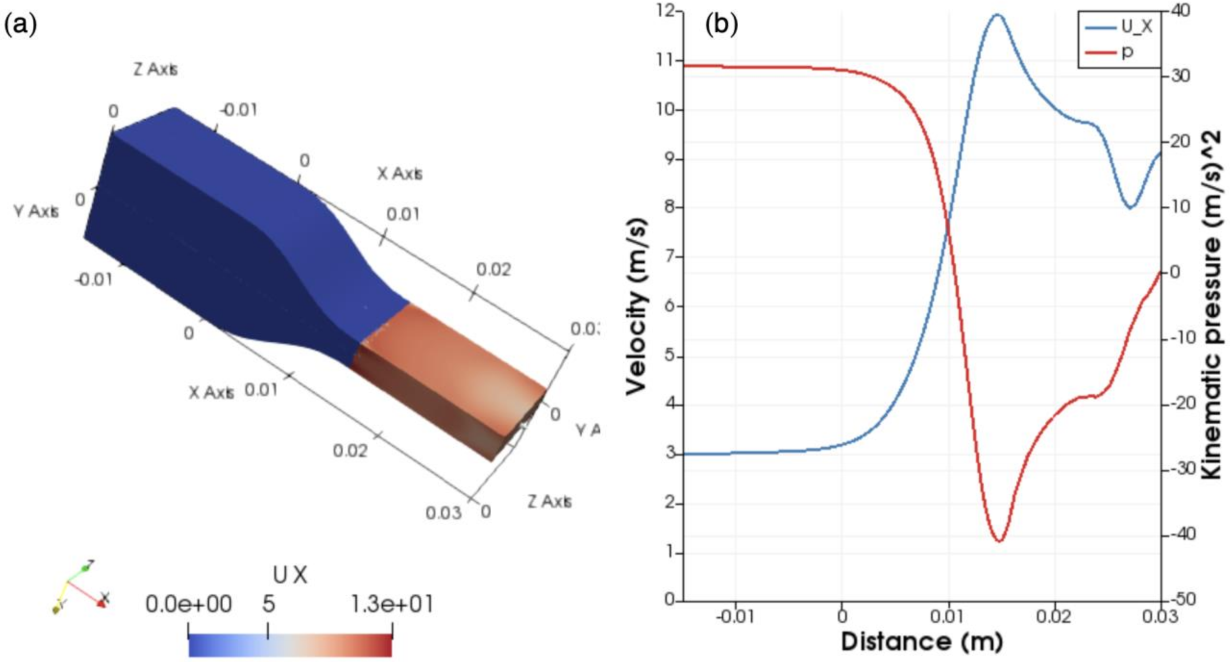
V. Kolstrum

XELERA

Nozzle for GaInSn target investigated using OpenFOAM.

(a) The red part shows a 3 mm × 10 mm jet. The nozzle extends from 0 to 0.015 m.

(b) Nozzle velocity (blue), for an input velocity of 3 m/s. The output velocity is ~12 m/s. The red curve is the kinematic pressure p/ρ.



V. Kolstrum

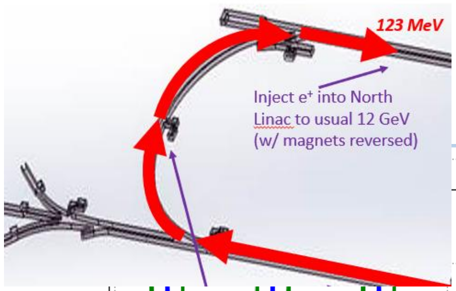
Transporting large e+ beam

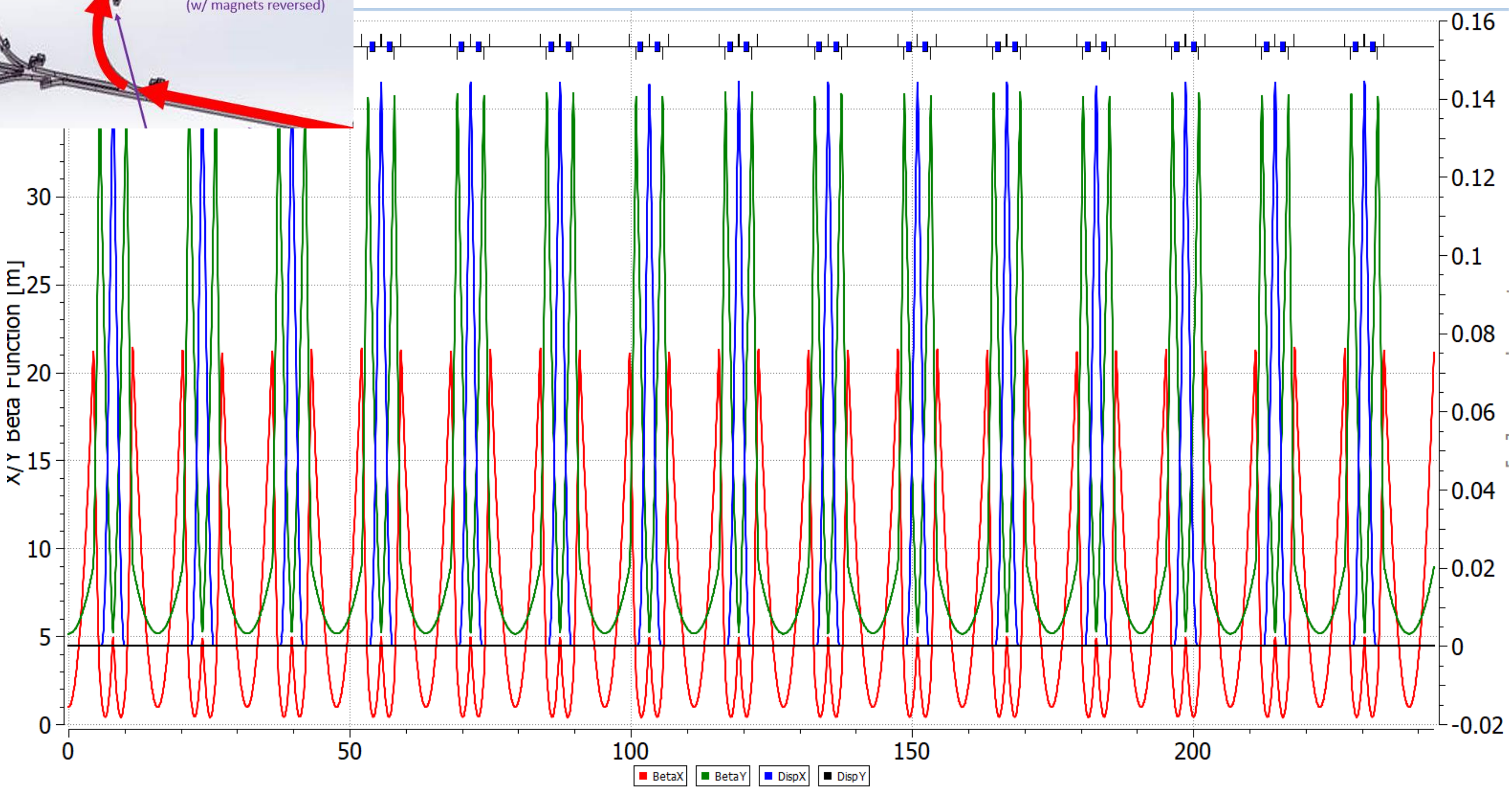
- Transverse emittance is many times that of CEBAF. Goal is to inject up to 40 mm.mrad (usual e- beam is 1mm.mrad) to the front of NL. This beam also has up to a percent of energy spread.

- Dedicated transport lines with large bore quads and low dispersion optics were designed

- LDRD (Amy Sy) aims at designing, installing and using a degraded e- beam in the existing CEBAF to confirm that one can transport 40mm.mrad.

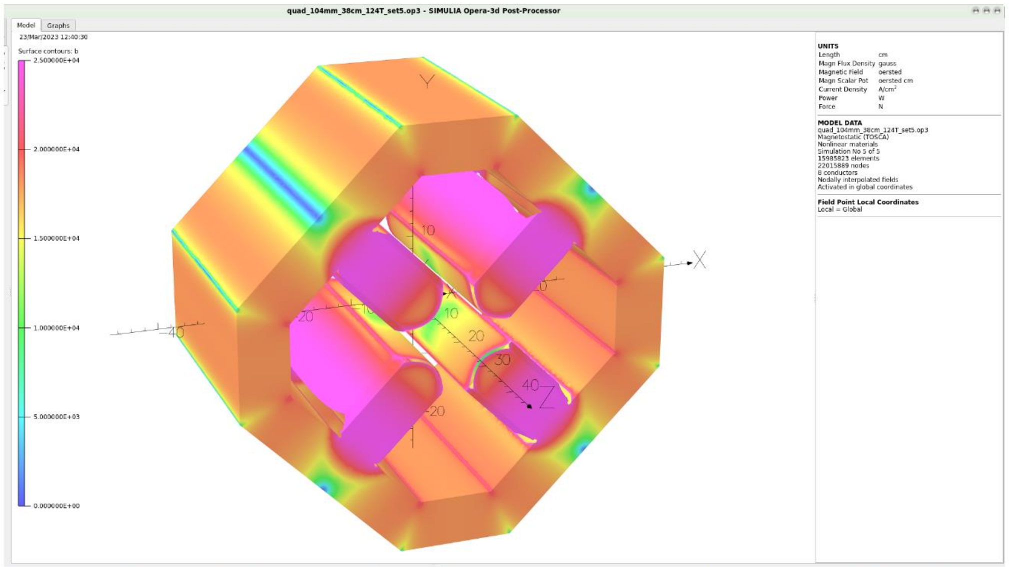
Recent development: Using a DBA structure



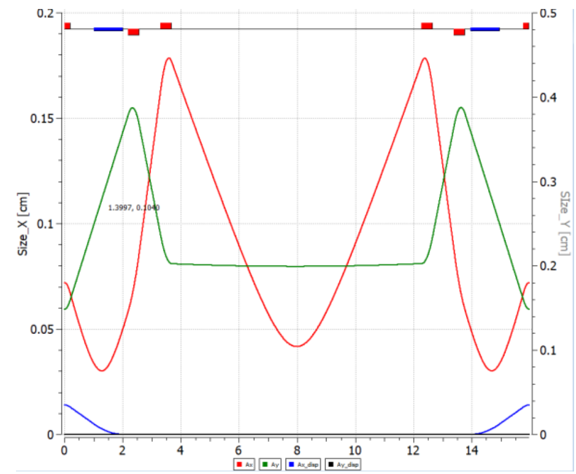


Large bore quadrupoles

- JLAB TN-06-029 (Benesch). Designed to accommodate the 60mm.mrad normalized emittance expected in 22 GeV hall lines



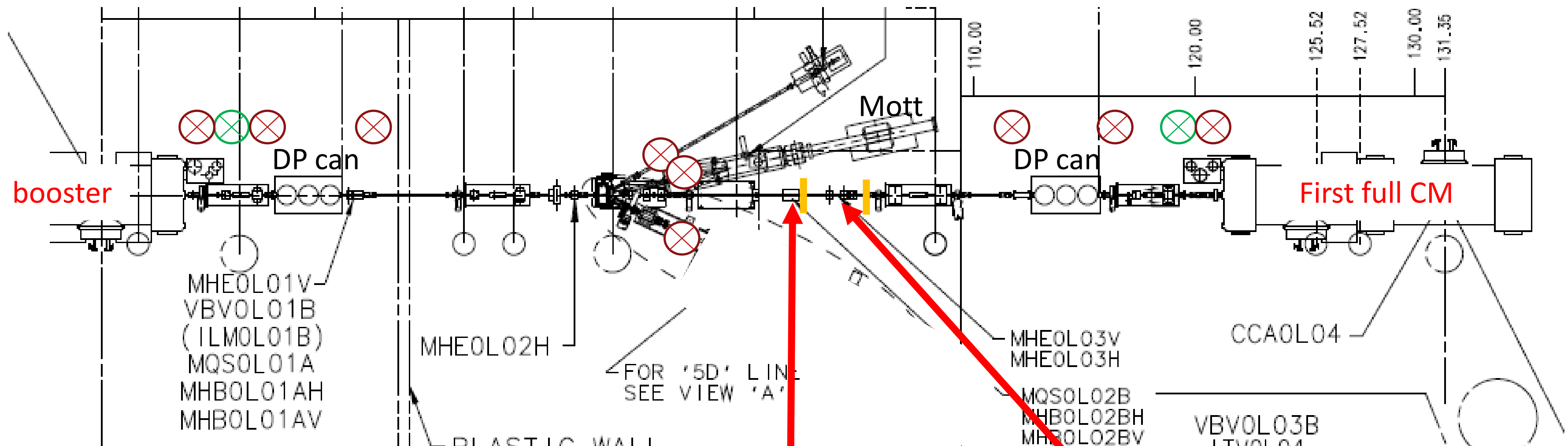
40 to 60 mm.mrad normalized is what we expect in the LERF to CEBAF transport.



104 mm ID. Can be made 35.56 cm or longer. More than enough field for our needs and eliminate considerations of chromatic effects.

Will need custom power supplies but it can be ganged together in the LERF->SL line

Degrader girder location in CEBAF



Beamline valves

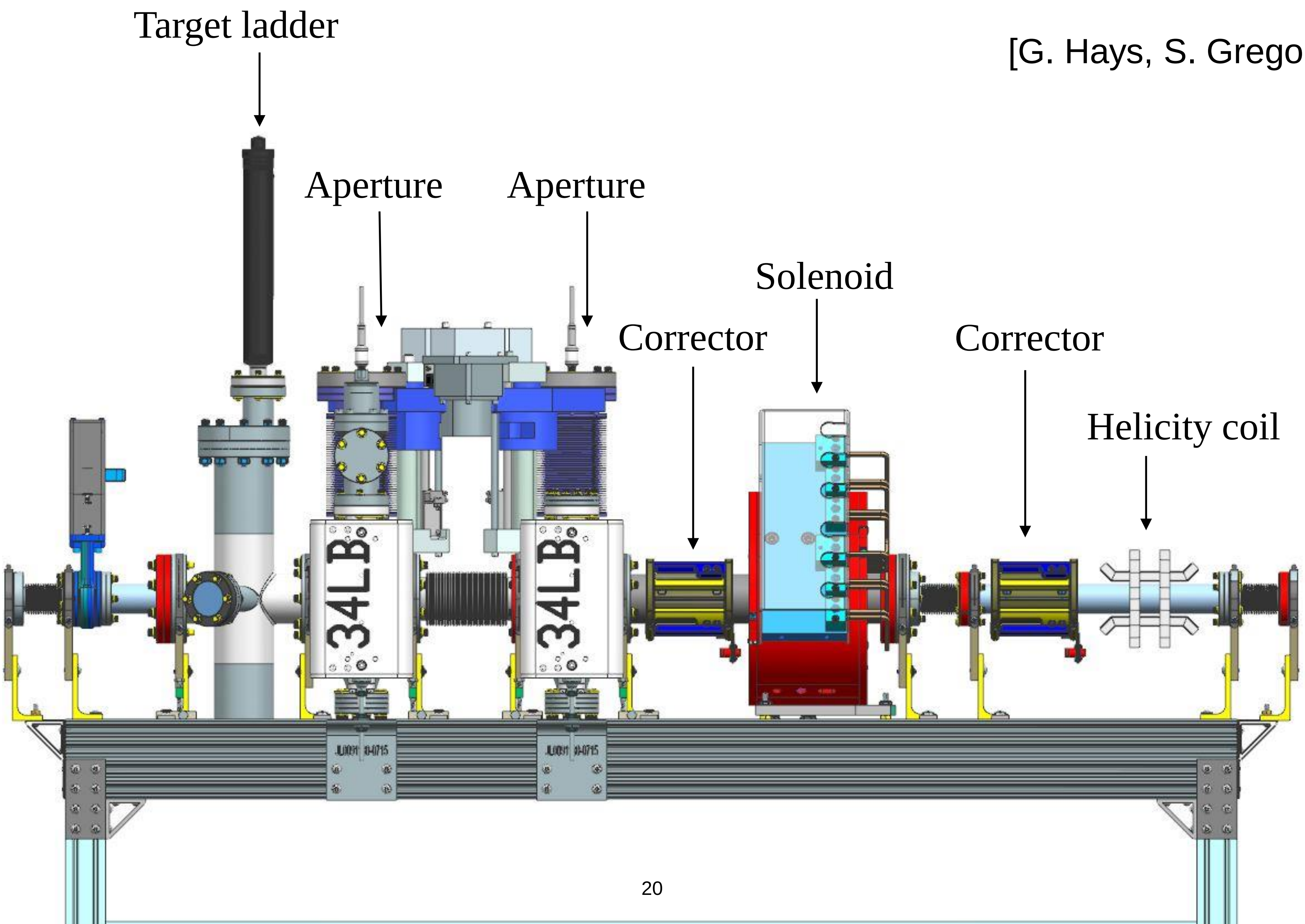
Fast valves

58 inch section
Break at yellow markers

Amy Sy

Moving towards reality: engineering design

[G. Hays, S. Gregory]



Reversing polarity in magnets, how fast can we go ?

Technote JLAB-TN-23-043

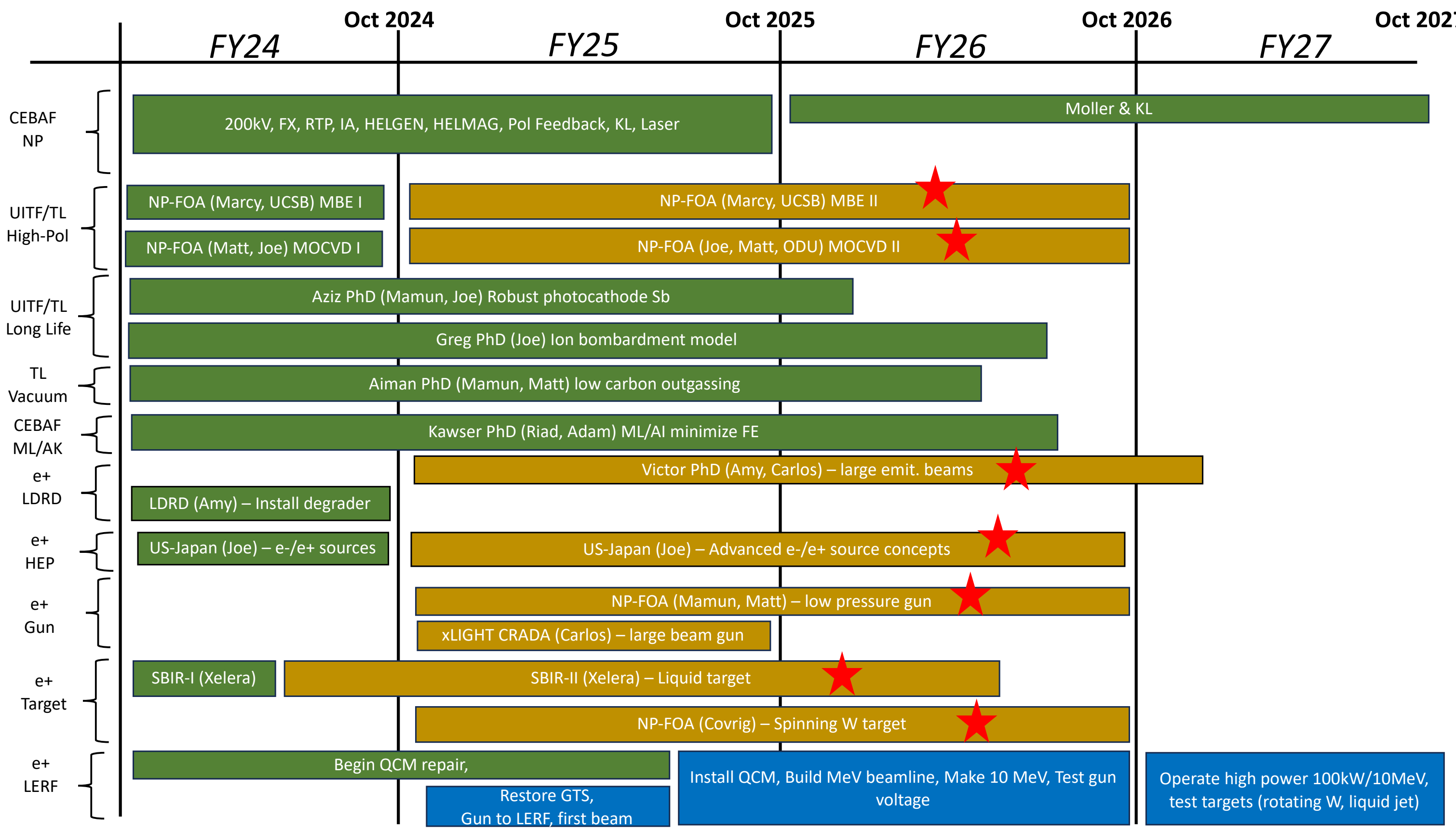
Reversing polarity of 2100 CEBAF magnets (S. Philip Head DC Power group)

- >1900 (correctors & quads) already bipolar operation
- 39 (recirculation/transport dipoles) will require engineered solution
  - 21 recirculation & dog-leg
  - 12 extraction units
  - 6 end-station transport/dump
- Hall D is only permanent magnet – would have to be rotated

Magnetic Field Integrity (M. Tiefenback CEBAF magnet systems integrator)

- Unipolar dipoles would need to be deliberately tested
  - demonstrate field restores after polarity inversion
  - quantify possible systematic effects
- Soft iron steel are expected to perform well under polarity reversal
- Two decades of operation suggest remnant fields <20 G tolerable
  - Sudden power supply trips introduce uncontrolled flux
  - Modifications to power supplies or field maps

3-Year R&D overview – aggressively pursuing FOA's



Recent publications, presentations

- Technote JLAB-TN-23-043, magnet polarization reversal
- Sep 24-29, SPIN2023 - https://indico.jlab.org/event/663/J. Grames, 'A positron beam at CEBAF”
- J. Grames et al., (poster) "Status of Ce+BAF: Polarized Positron Beam Capability at CEBAF 12 GeV“,IPAC2023
- R. Kazimi et al., "Polarized Electron Injector for Positron Capability at CEBAF 12 GeV“. IPAC2023
- A. Sy et al., "Degrader beamline design at the CEBAF injector for machine acceptance studies“,IPAC2023
- A. Ushakov et al, "Conceptual Design of a High-Power Target for Positron Production at CEBAF“,IPAC2023
- A. Ushakov, "Positron target design and fatigue studies“, UVA PWG meeting, Charlottesville
- D. Turner,"Delivering e+ beams from LERF through Ce+BAF”, UVA PWG meeting, Charlottesville
- S. Habet, “Concept of a polarized positron injector for CEBAF”, UVA PWG meeting, Charlottesville
- Y. Roblin, "Positron beam: technical aspects“, International workshop on CLAS12 Physics
- C. Hernandez-Garcia, "Building the next high voltage dc photogun polarized source for the ILC at JLab“, LCWS2023
- Snowmass 2022 White paper, Positron Sources for Future High Energy Physics Colliders https://arxiv.org/pdf/2204.13245
- A. Accardi et al., "e+@JLab White Paper: An Experimental Program with Positron Beams at Jefferson Lab", https://arxiv.org/abs/2007.15081 (2020)

Acknowledgments

I would like to acknowledge the **Ce$^+$BAF Working Group**, the **Jefferson Lab Positron Working Group** and all those who have been supportive to this progression of activity.

J. Benesch, A. Bogacz, L. Cardman, J. Conway, S. Covrig, P. Degtiarenko, S. Ghoshal, S. Gopinath, J. Gubeli, S. Habet, C. Hernandez-Garcia, D. Higinbotham, A. Hofler, R. Kazimi, M. Kostin, F. Lin, V. Kolstrum, V. Lizarraga-Rubio, S. Nagaitsev, M. Poelker, N. Raut, B. Rimmer, Y. Roblin, A. Seryi, K. Smolenski, M. Spata, R. Suleiman, A. Sy, D. Turner, A. Ushakov, C. Valerio-Lizaraga, E. Voutier, S. Zhang

Conclusion

- Significant R&D effort ongoing at Jefferson Lab and collaborating institutions

- Feedback and requests from user community for specific e+ capabilities welcome

- For further information, contact Joe Grames (grames@jlab.org)