Large phase space electron beams for machine acceptance studies at CEBAF

JLab LDRD project

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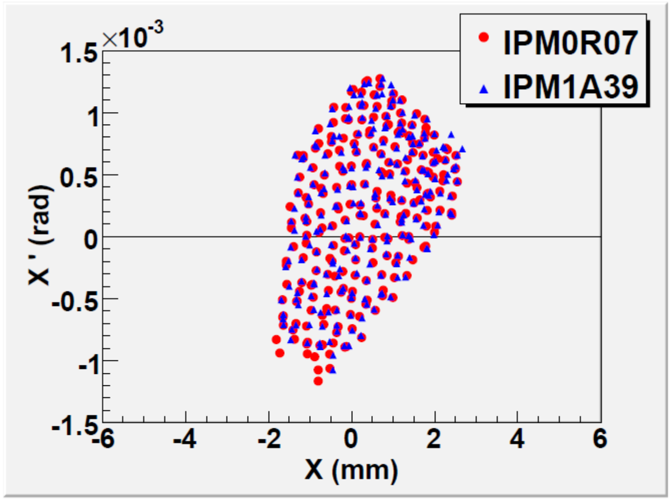
Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Why large phase space beams?

- Positron beams will be much larger in phase space than nominal electron beams at CEBAF
- We want to understand the transport of larger phase space beams in 12 GeV CEBAF
  - Do these larger beams fit in the machine?
  - How does the emittance evolve for higher number of passes?
  - Limits on positron phase space?



Horizontal admittance data from two different IPMs in 6 GeV CEBAF
S. Golge Ph.D. thesis

Table 1: Simulated Emittances in CEBAF [4], [5]

	Electrons			Positrons		
Area	$\delta p/p[\times 10^{-3}]$	$\varepsilon_x[nm]$	$\varepsilon_y[nm]$	$\delta p/p[\times 10^{-3}]$	$\varepsilon_x[nm]$	$\varepsilon_y[nm]$
Chicane	0.5	4.00	4.00	10	500	500
ARC1	0.05	0.41	0.41	1	50	50
ARC2	0.03	0.26	0.23	0.53	26.8	26.6
ARC3	0.035	0.22	0.21	0.36	19	18.6
ARC4	0.044	0.21	0.24	0.27	14.5	13.8
ARC5	0.060	0.33	0.25	0.22	12	11.2
ARC6	0.090	0.58	0.31	0.19	10	9.5
ARC7	0.104	0.79	0.44	0.17	8.9	8.35
ARC8	0.133	1.21	0.57	0.16	8.36	7.38
ARC9	0.167	2.09	0.64	0.16	8.4	6.8
MYAAT01	–	–	–	0.18	9.13	6.19
ARC10	0.194	2.97	0.95	–	–	–
Hall D	0.18	2.70	1.03	–	–	–

Simulated emittance evolution in CEBAF for electron and positron beams
Y. Roblin JLAB-TN-21-043

Approach: design, build, install a device to degrade beams

- Funded 2 year JLab LDRD project proposed 3 objectives:
  - Design and build a beamline to make electron beams “look like” positron beams
  - Measure machine acceptance and emittance evolution in CEBAF
  - Transport positrons through parts of the CEBAF injector

FY 2023 LDRD Proposal

FY 2023 LDRD Proposal

Program: DRD

Proposal Title: Assessing CEBAF using degraded beams for the Ce+BAF positron upgrade

Principal Investigator, Division: Amy Sy, Accelerator Division

Co-Investigator, Division:

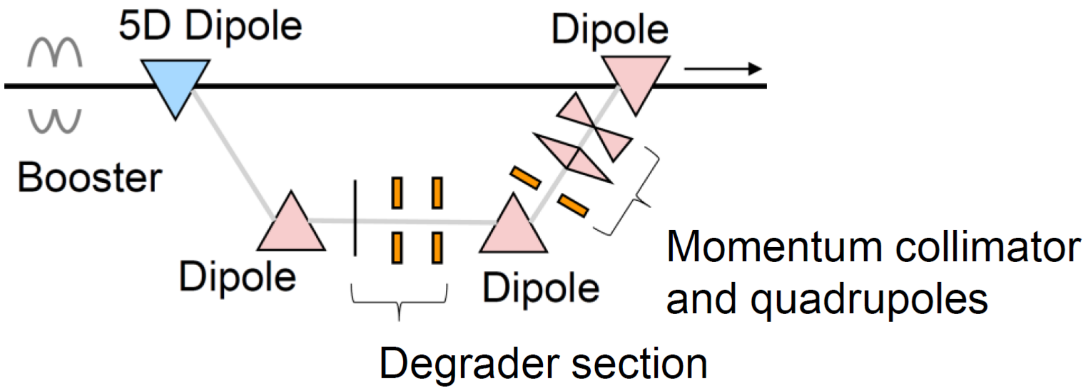
Contributors, Division: Dennis Turner, Accelerator Division; Yves Roblin, Accelerator Division
Victor Lizarraga-Rubio, Gary Hays, Shaun Gregory, Marcy Stutzman
Joe Grames, Carlos Hernandez-Garcia, Cristhian Valerio Lizarraga

Budget	Total	FY23	FY24	FY25
($K)	376.4	237.7	138.7	--

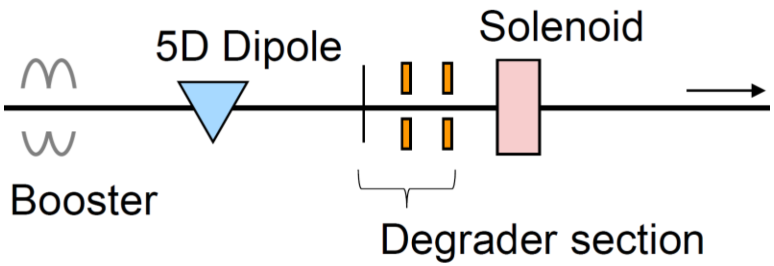
Year 1 focused on design

- Major components include the degrader target and apertures to collimate very large angle particles
- Many ways to implement

Original Design
More flexible
More complicated
and expensive



Final Design
Compact
Easier to implement
Less flexible



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Target materials and thicknesses simulated

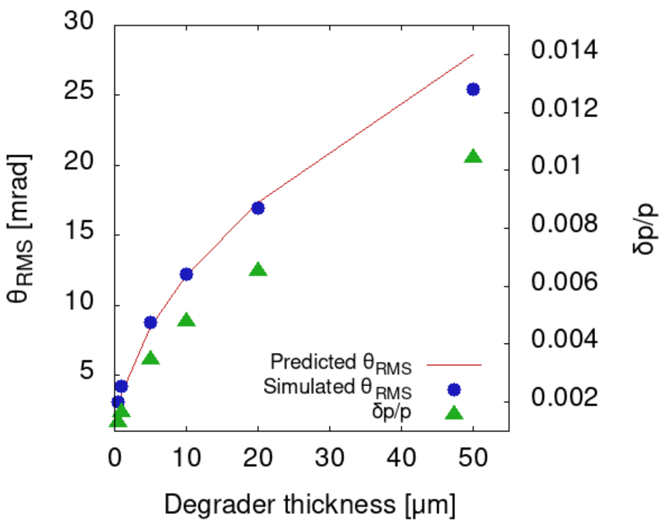
- Started with high-Z materials, like W for PEPPo
- Higher fraction of radiation length increases induced angular and energy spread
- Balance with losses due to collimation
- Choice of straight-ahead degrader implementation motivated shift to low-Z target material: Carbon, 1-10 μm thick

$$\theta_{rms} = \frac{13.6}{E[\mathrm{MeV}]}\sqrt{\frac{w}{X_0}}\left(1+0.038\ln\frac{w}{X_0}\right)$$

w: target thickness

X_0: material radiation length

RMS polar angle due to multiple scattering



RMS polar angle and energy spread in Carbon targets

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Two apertures to act as an emittance filter

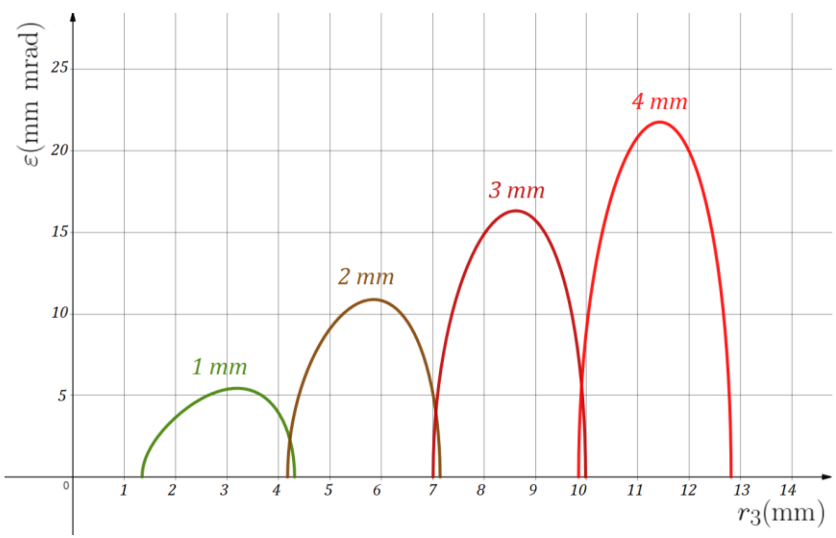
- Maximum transmitted emittance determined by aperture size and spacing to target location

$$\varepsilon^2 = \frac{\left[\frac{r_2^2\left(r_1^2 + r_3^2 - 2r_2^2\right)}{2} - \frac{\left(r_1^2 - r_3^2\right)^2}{16}\right]}{L^2}$$

r_1, r_2, r_3 are aperture radii, L is distance between apertures [JLAB-TN-89-191, JLAB-TN-90-261]

Generalized for arbitrary spacing [V. Lizarraga]

$$\varepsilon^2 = r_2^2 \frac{L_1\left(r_3^2 - r_2^2\right) + L_2\left(r_1^2 - r_2^2\right)}{L_1 L_2 (L_1 + L_2)} - \left(\frac{L_2^2\left(r_1^2 - r_2^2\right) - L_1^2\left(r_3^2 - r_2^2\right)}{2L_1 L_2 (L_1 + L_2)}\right)^2$$

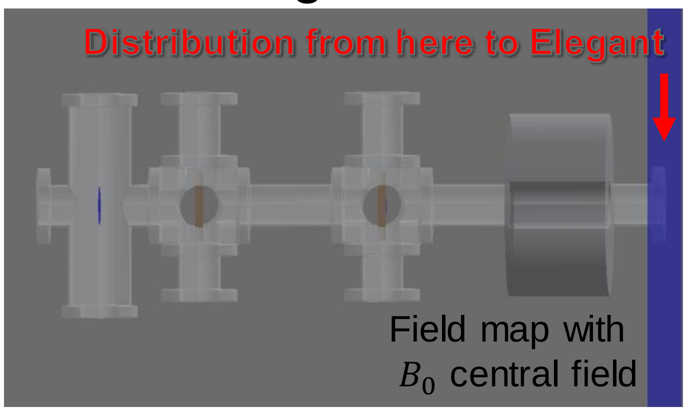


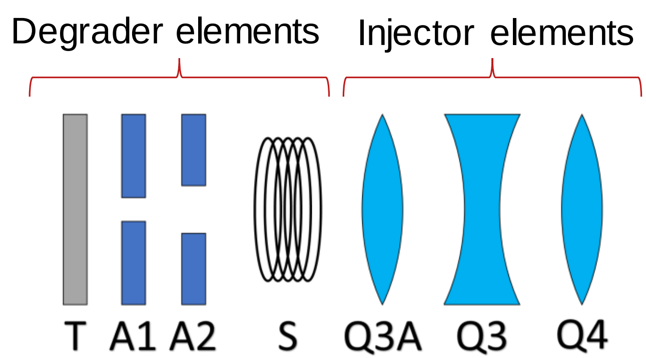
We will have two hole sizes per aperture assembly

Maximum transmitted emittance values are a few orders of magnitude larger than emittance near this location now

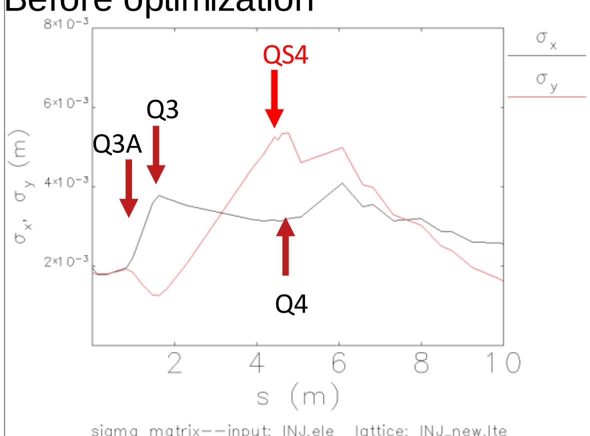
Optics optimization for maximizing transmission

- From Elegant: p=6.74 MeV/c; σ_x=0.85 mm; dpp=1e-3
- Degraded beam distribution from GEANT4
- Back to Elegant for further beam transport

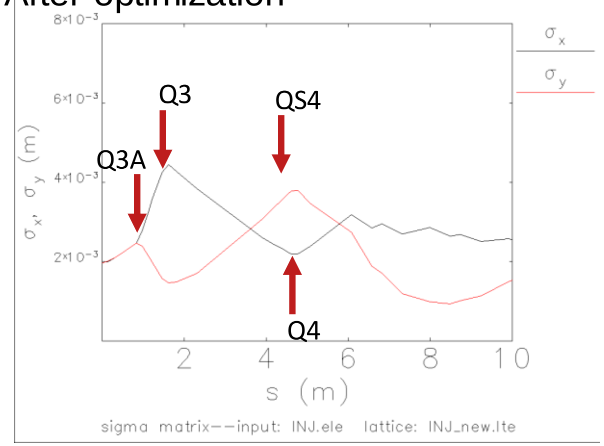




Before optimization



After optimization

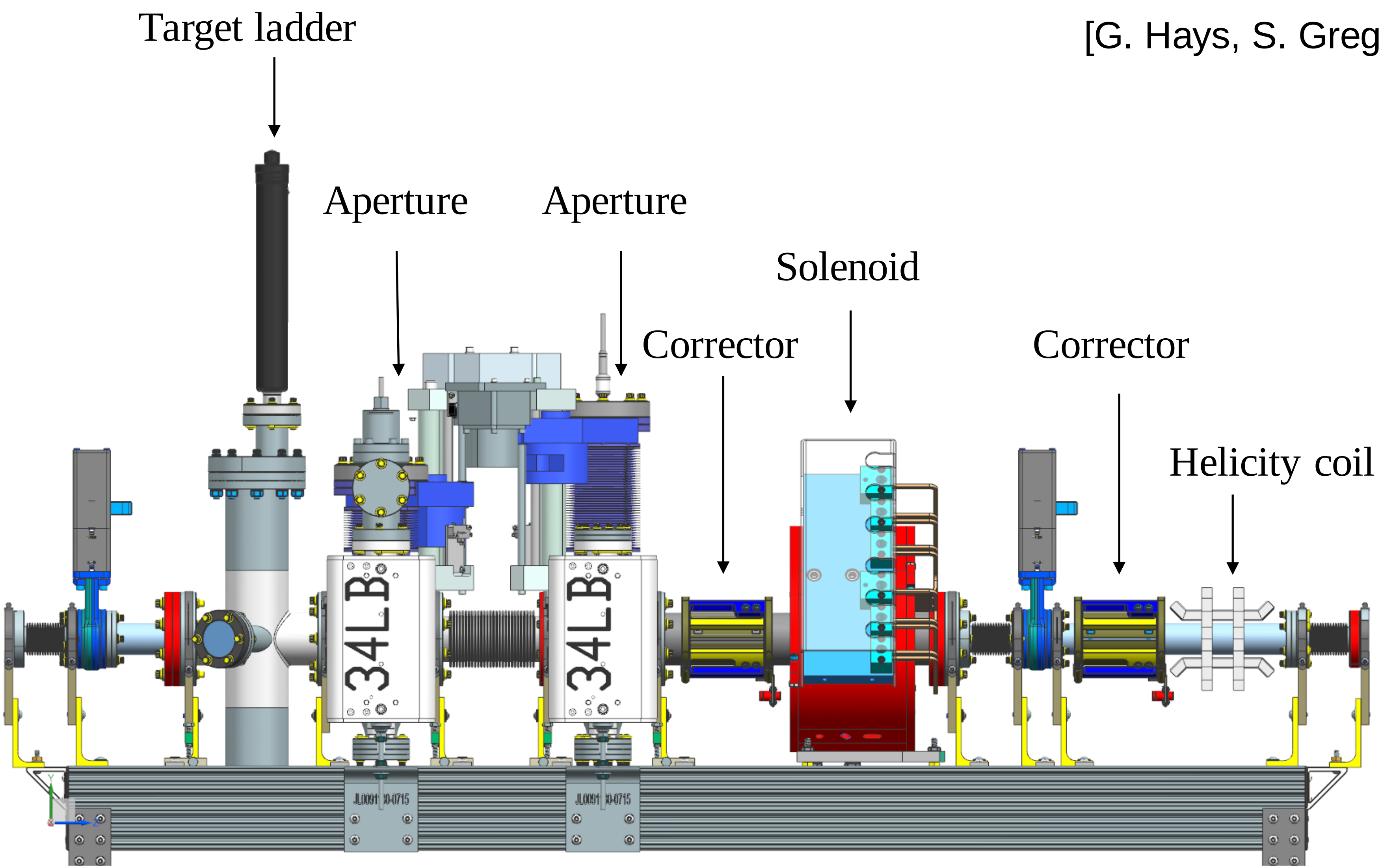


Estimated transmission for thinnest target > 95%

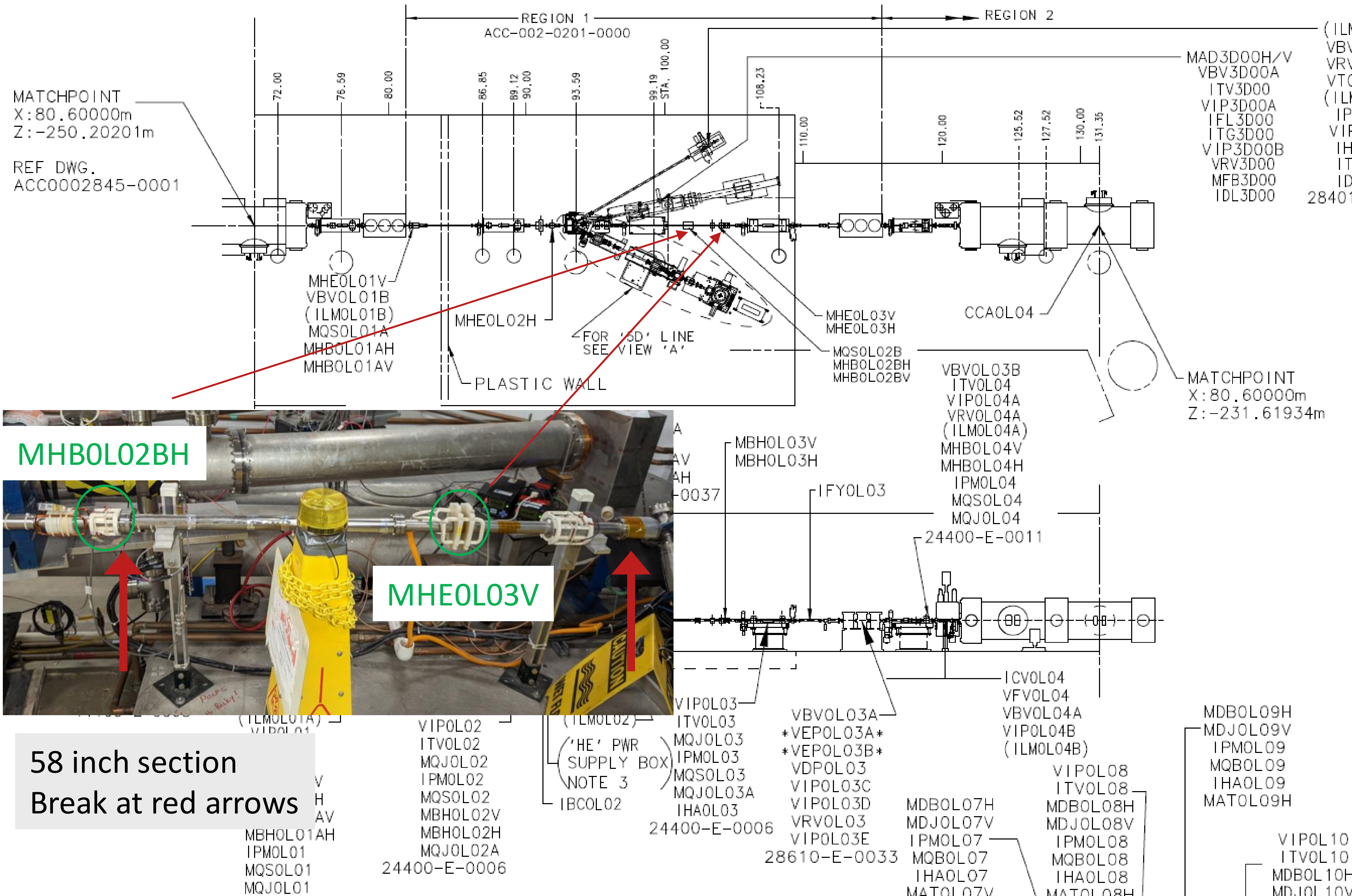
Estimated transmission for thickest target > 65%

Moving towards reality: engineering design

[G. Hays, S. Gregory]



Degrader girder location in CEBAF



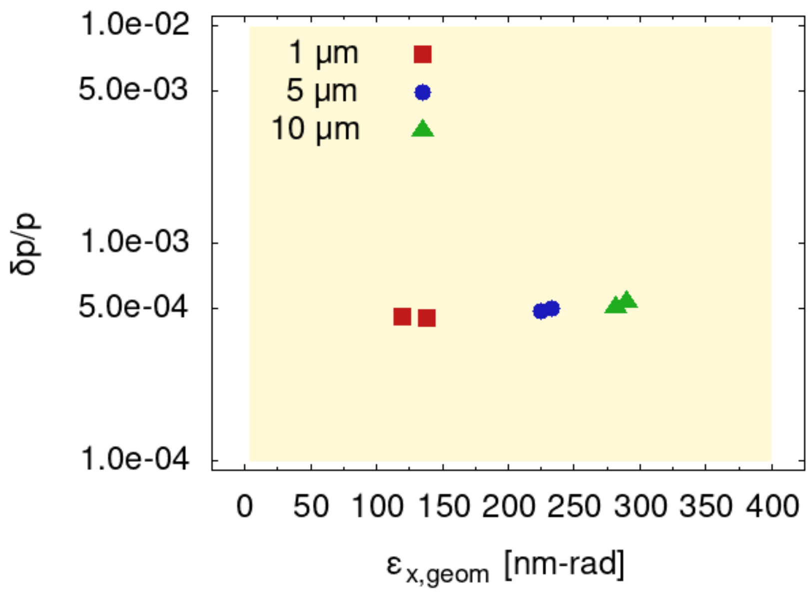
58 inch section
Break at red arrows

Degraded beam parameter space @ 123 MeV beam energy

- Trying to span the range between nominal electron parameters and potential positron parameters

	Electrons			Positrons		
Area	$\delta p/p[\times 10^{-3}]$	$\varepsilon_x[nm]$	$\varepsilon_y[nm]$	$\delta p/p[\times 10^{-3}]$	$\varepsilon_x[nm]$	$\varepsilon_y[nm]$
Chicane	0.5	4.00	4.00	10	500	500

- Maximum transverse geometric emittance injected at front of NL estimated to be 167-500 nm-rad [doi: 10.18429/JACoW-IPAC2023-MOPL152]



Current focus is on expanding the energy spread parameter space

Exploring variation of energy spread in beam before the degrader target and optics in the injector chicane

Objectives and milestones – as presented 8/4/2023

	FY2023				FY2024				Person
Task	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Beam transport simulations (1)	■	■							Sy
Target simulations (1)	■								Victor
Engineering design of beamline (1)			■						ENG
Beamline procurement (1)				■	■				ENG
Staging and component testing (1)					■				ENG
Accelerator readiness review (1)						■			Sy
Beamline installation (1) *							■		ENG
Beamline commissioning (1) *							■	■	Turner
First measurements in CEBAF (2) *								■	Turner

*This may change due to potential delay of 2024 SAD

Summary

- Because positron beams will be much larger in phase space than nominal electron beams, we want to understand the transport of large phase space beams in CEBAF
- We are building a device to generate large phase space beams through multiple scattering in thin carbon targets
- The degraded beam parameter space available from this device has substantial overlap with the parameter range of interest
- We are working towards being ready to install during the summer 2024 SAD