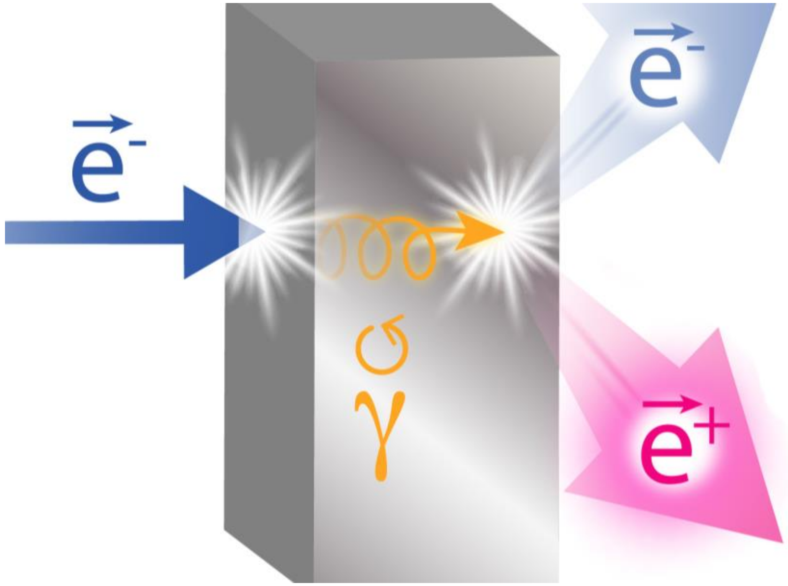
Update on Ce$^+$BAF Positron Activities

- Concept of Ce$^+$BAF injector
- Current Ce$^+$BAF projects/proposals
- Simulations of positron capture and acceleration



Andriy Ushakov (*Jefferson Lab*)

on behalf of the Ce$^+$BAF Working Group

International Workshop on Future Linear Colliders (LCWS2024),
July 8-11, 2024, University of Tokyo, Japan

Work supported by the U.S. Department of Energy Office of Nuclear Physics under contract DE-AC05-06OR23177 and Office of High Energy Physics US-Japan Science & Technology Cooperative Program

12 GeV Ce+BAF : Polarized Electron or Polarized Positron Beams

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

Program Advisory Committee Positron Experiments (July 2023)

NUMBER	TITLE	CONTACT PERSON	HALL	DAYS REQUESTED	DAYS AWARDED	SCIENTIFIC RATING	PAC DECISION
PR12+23-002	Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the Proton at CLAS12	Eric Voutier	B	100	100	**A-**	C1
PR12+23-003	Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of Coulomb Corrections in DIS	Dave Gaskell	C	9.3	9.3	**A-**	C1
PR12+23-005	A Dark Photon Search with a JLab positron beam	Bogdan Wojtsekhowski	B	60			Deferred
PR12+23-006	Deeply Virtual Compton Scattering using a positron beam in Hall C	Carlos Munoz Camacho	C	137	137	**A-**	C1
PR12+23-008	A Direct Measurement of Hard Two-Photon Exchange with Electrons and Positrons at CLAS12	Axel Schmidt	B	55	55	A	C1
PR12+23-012	A measurement of two-photon exchange in unpolarized elastic positron–proton and electron–proton scattering	Michael Nycz	C	56	56	**A-**	C1

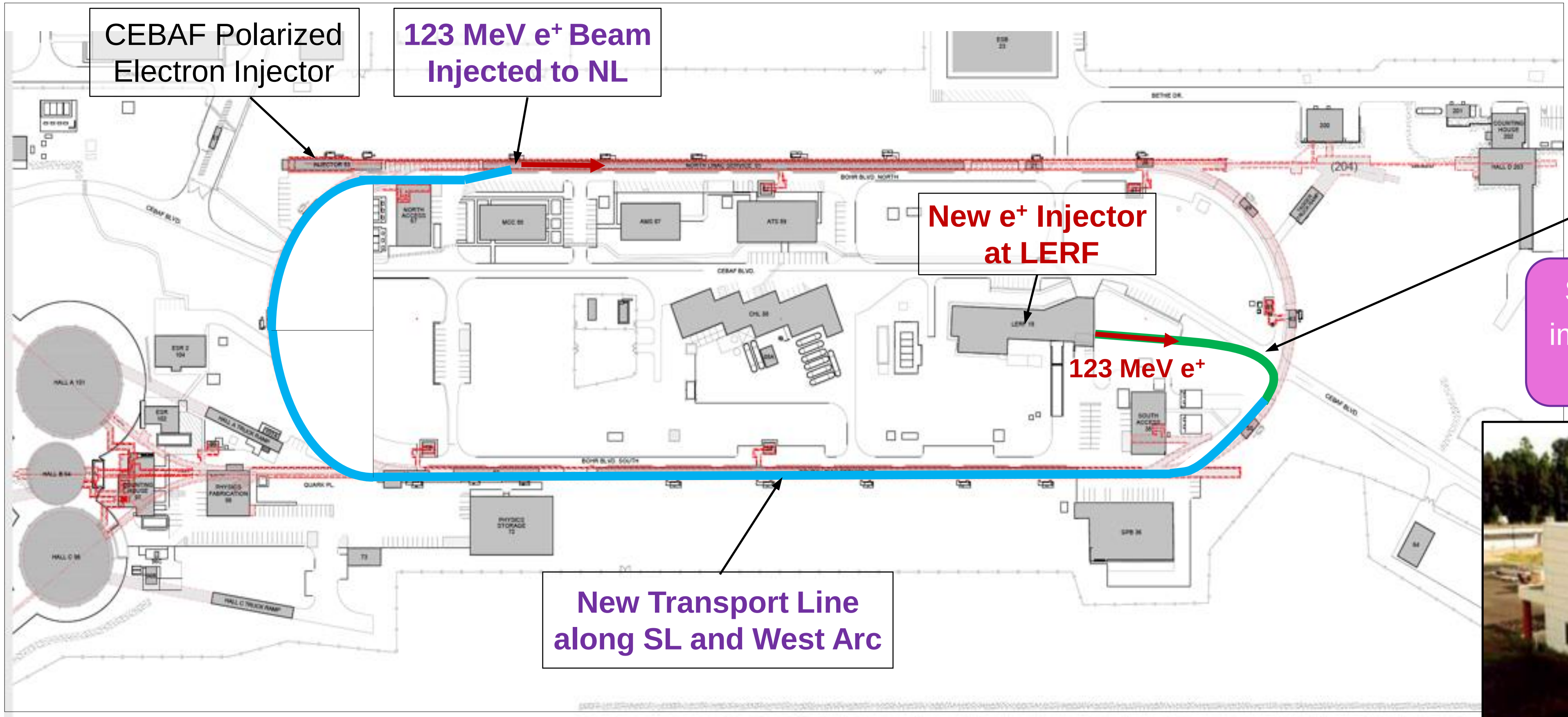
C1 = Conditionally Approved w/Technical Review by the Lab

Approved 155 days Hall B & 202 days in Hall C for 357 total PAC days

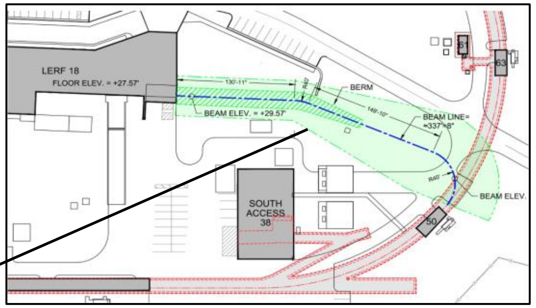
Three years of running at 34 weeks per year

(PAC day = two calendar day)

Turning the LERF into a Positron Injector Facility



New Beamline to CEBAF Tunnel



Strategic decision was taken to imagine using former FEL facility, starting with an R&D test bed

LERF – Low Energy Recirculation Facility

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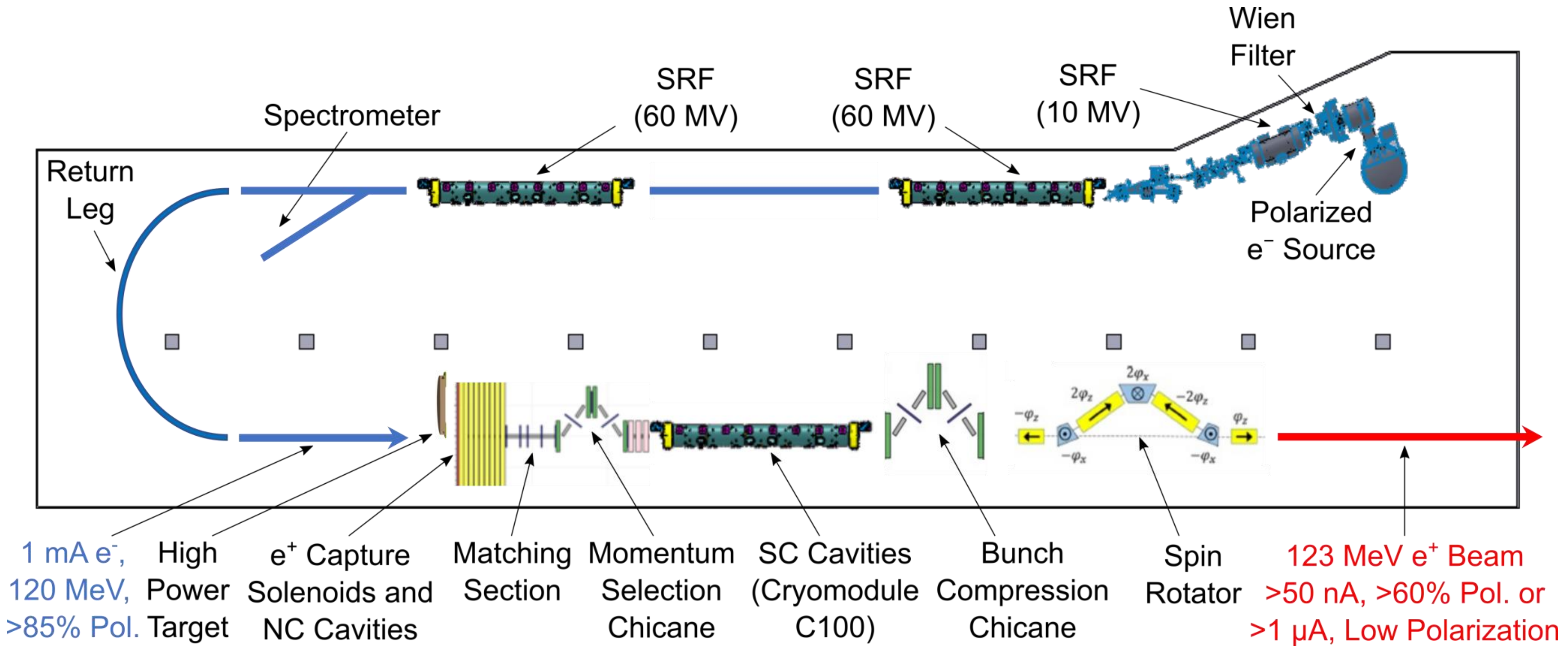
LERF Polarized Positron Injector Concept

Conceptual Development

- Improve design of positron injector
- Develop pCDR

Address Critical Risk Areas

- mA polarized e^- source
- High power target
- CW capture cavity



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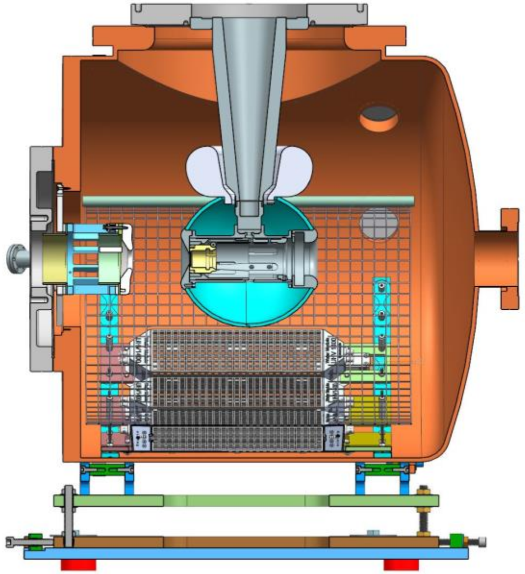
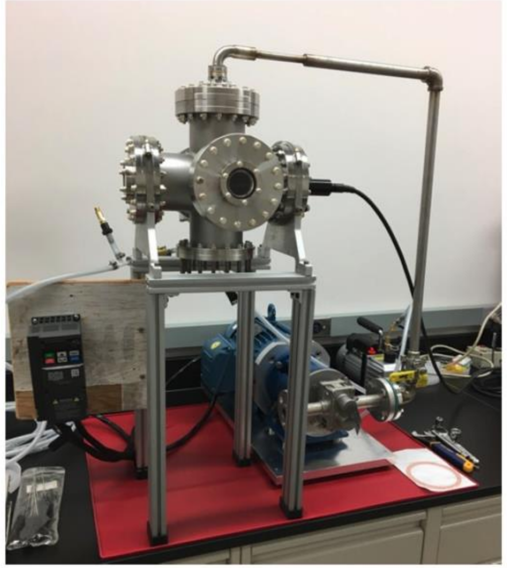
$Ce^{+}BAF$ Positron Activities

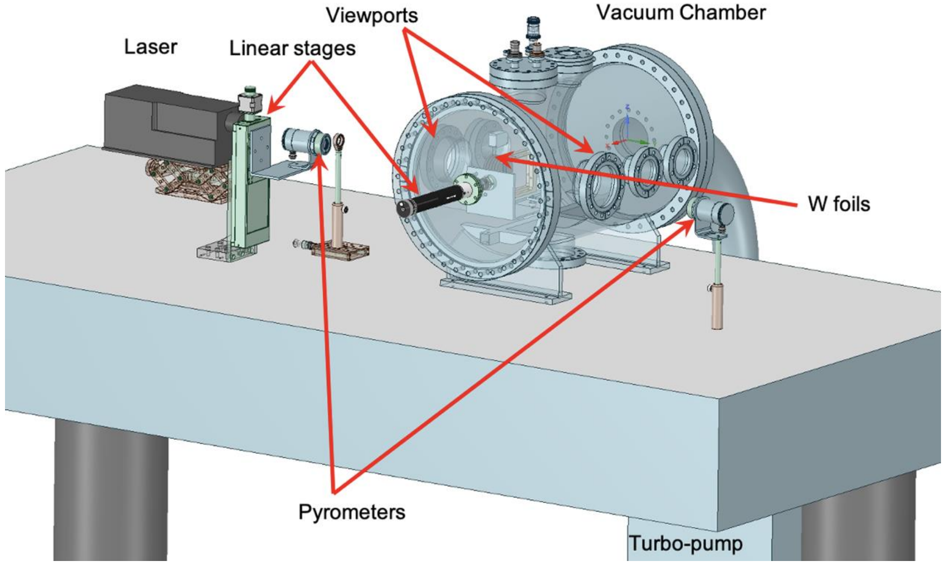
JLab LDRD Proposal
demonstrate mA e^{-} source



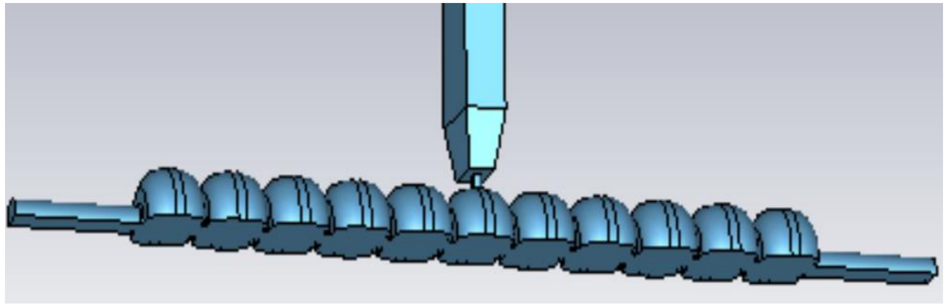
DOE SBIR Phase2
test GaInSn jet target



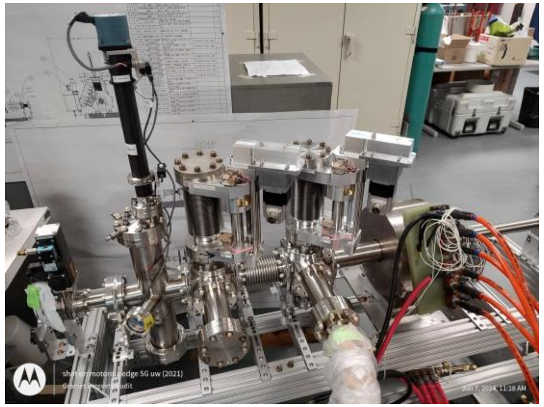
DOE NP Proposal
test prototype W target



DOE HEP Proposal
prototype capture cavity



JLab LDRD
measure CEBAF acceptance



- Silviu Covrig Dusa
  "CFD simulations of high power positron converter targets",
  Session: Sources,
  Jul 10, 2024, 9:20 AM
- Shaoheng Wang et al.
  "Capture cavities for the CW polarized positron source $Ce^{+}BAF$",
  Session: Normal conducting RF,
  Jul 10, 2024, 9:00 AM

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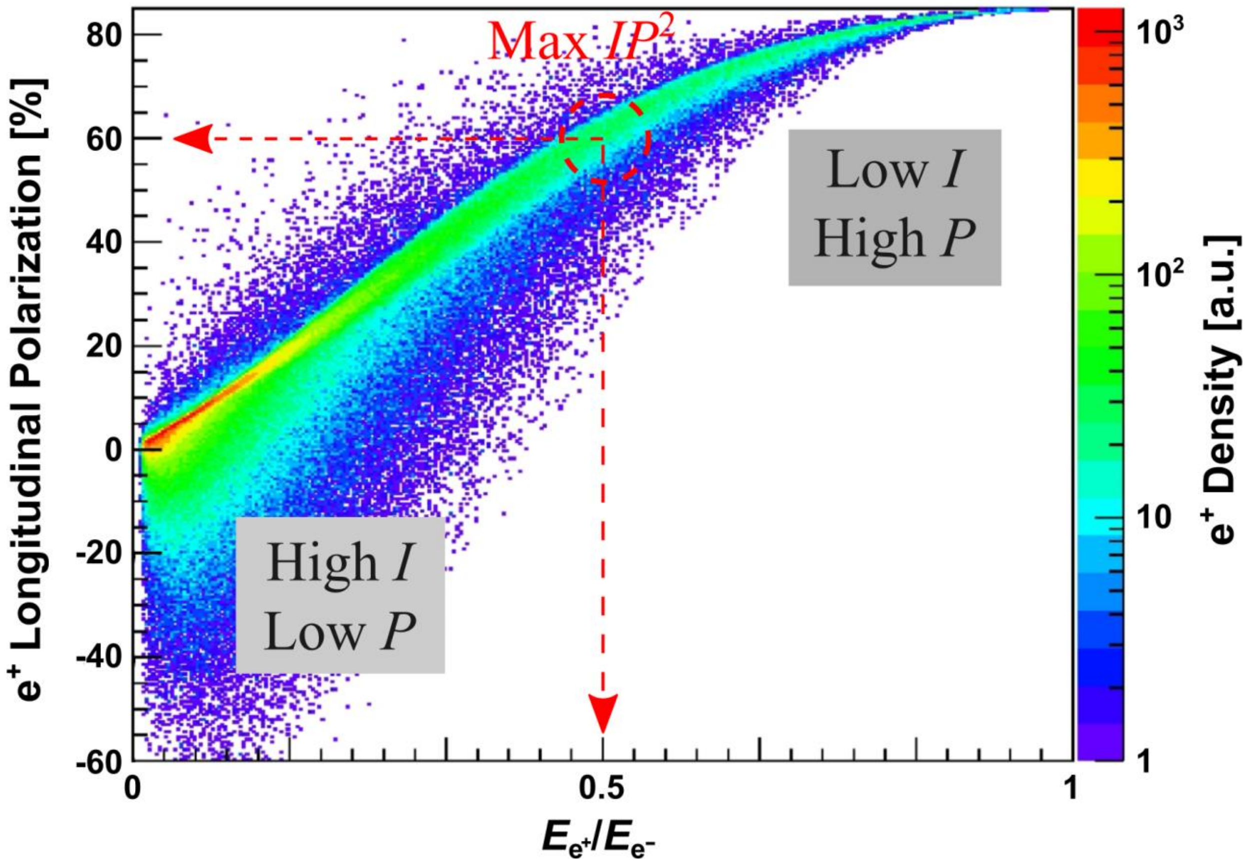
Selection of e^+ Energy at Target Exit and Thickness of Tungsten Target

e^+ Polarization vs Energy at Target Exit



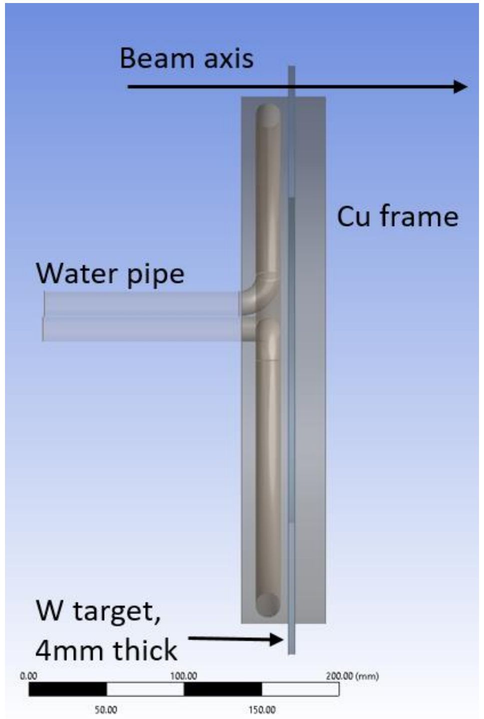
For max Figure-of-Merit ($FoM = IP^2$, where I is e^+ current and P is e^+ polarization):

- Optimal e^+ energy at target exit is about half of e^- drive beam energy.
- e^+ polarization at half of e^- energy is ~60%.
- 4 mm is an optimal thickness of W target for 120 MeV e^- beam

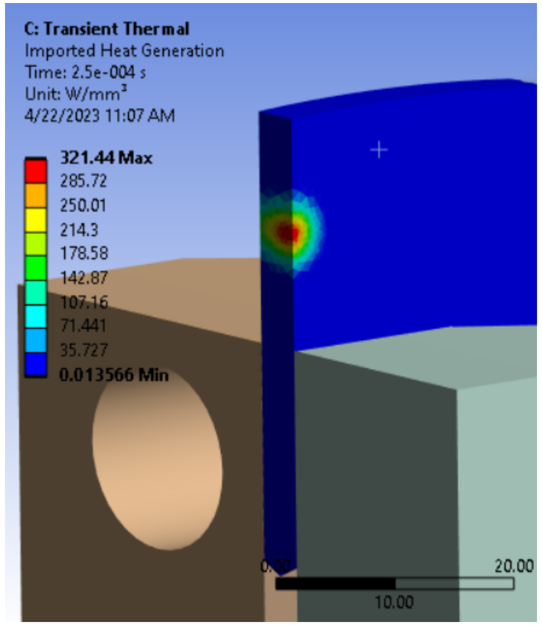
S. Habet et al., “Characterization and optimization of polarized and unpolarized positron production”, Tech. Rep. JLAB-ACC-23-3794, Feb. 2023. doi:10.48550/arXiv.2401.04484

Concept and Challenges of High-Power Target

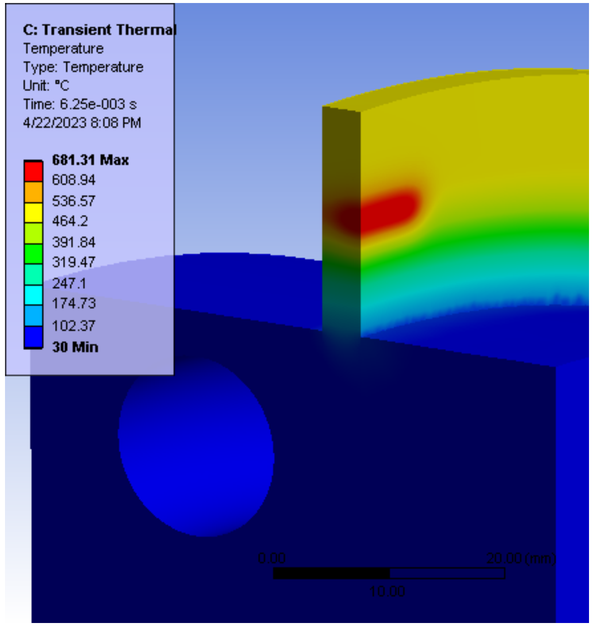
Target Concept (Side View)



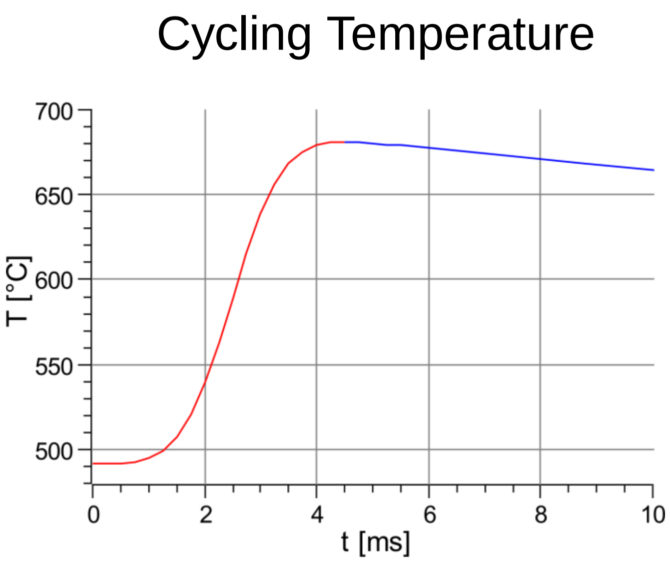
Heat by Beam



Temperature in Rot. Target



A. Ushakov et al., IPAC'23, WEPM120



- **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

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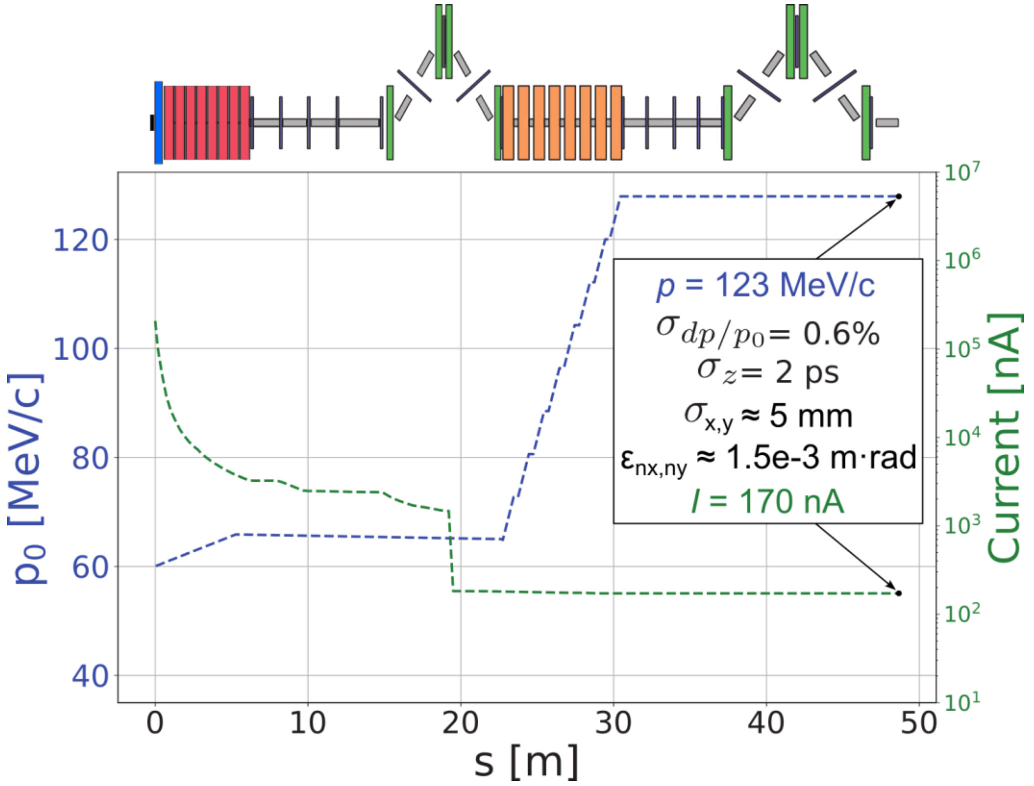
Simplified Model of Beam Line and e+ Beam Parameters in Polarized Mode

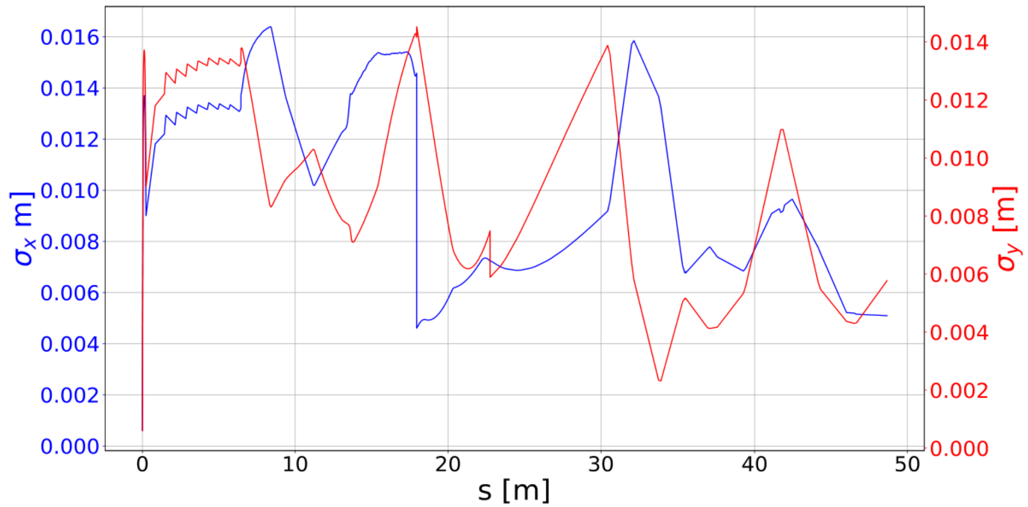
e^+ Current and Energy along Beam Line
(S. Habet, PhD Thesis, Dec. 2023)

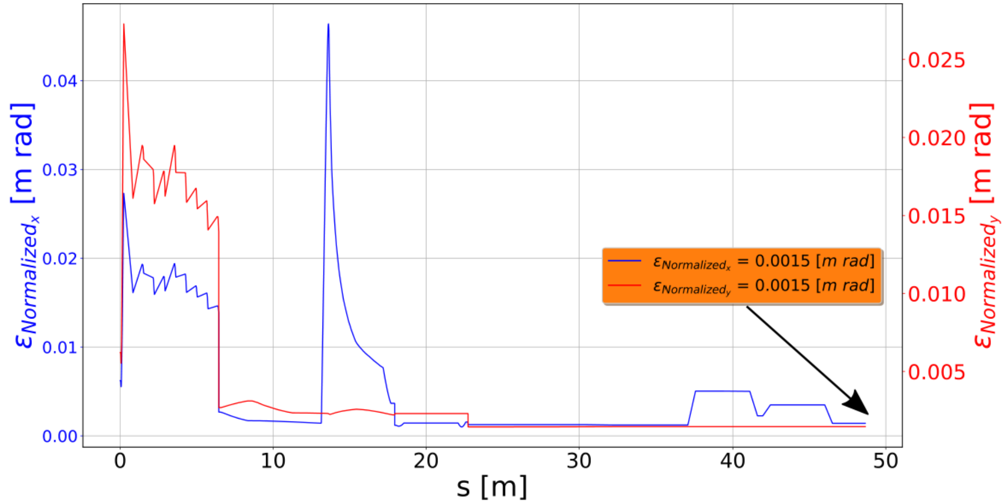


Quarter-Wave Transformer (QWT) – 2 solenoids

- ***Polarized mode***, 60 MeV @ target:
  B_1 = **2.5 T**, L_1 = **25 cm**, B_2 = 0.05 T, L_2 = 6 m
- ***Unpolarized mode***, 19 MeV @ target:
  B_1 = **1.3 T**, L_1 = **25 cm**, B_2 = 0.05 T, L_2 = 6 m

e^+ Bunch Size and Emittance along Beam Line
(S. Habet, PhD Thesis, Dec. 2023)





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Modeling Positron Injector in FLUKA and General Particle Tracer (GPT)

EM Fields

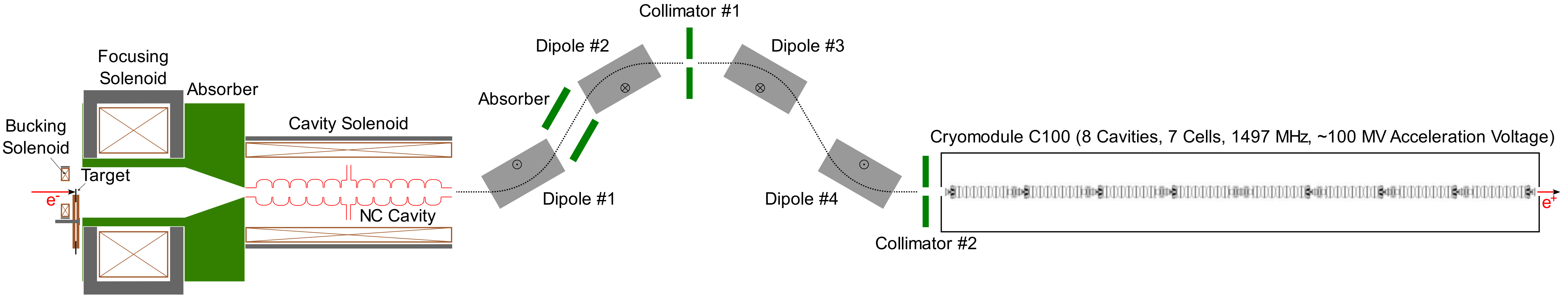
- 3D magnetic fields of solenoids - OPERA, CST
- NC SW Cavity - Advanced Computational Electromagnetics Code Suite (ACE3P)
- SC Cavities - CST

FLUKA

- Simulations of all particle in target, capture solenoid and NC cavity

GPT

- Positron production in 4 mm thick tungsten target by 1 mA @ 120 MeV e^- was calculated in Geant4 and imported to GPT at target exit
- Positrons are tracked up to end of C100 cryomodule



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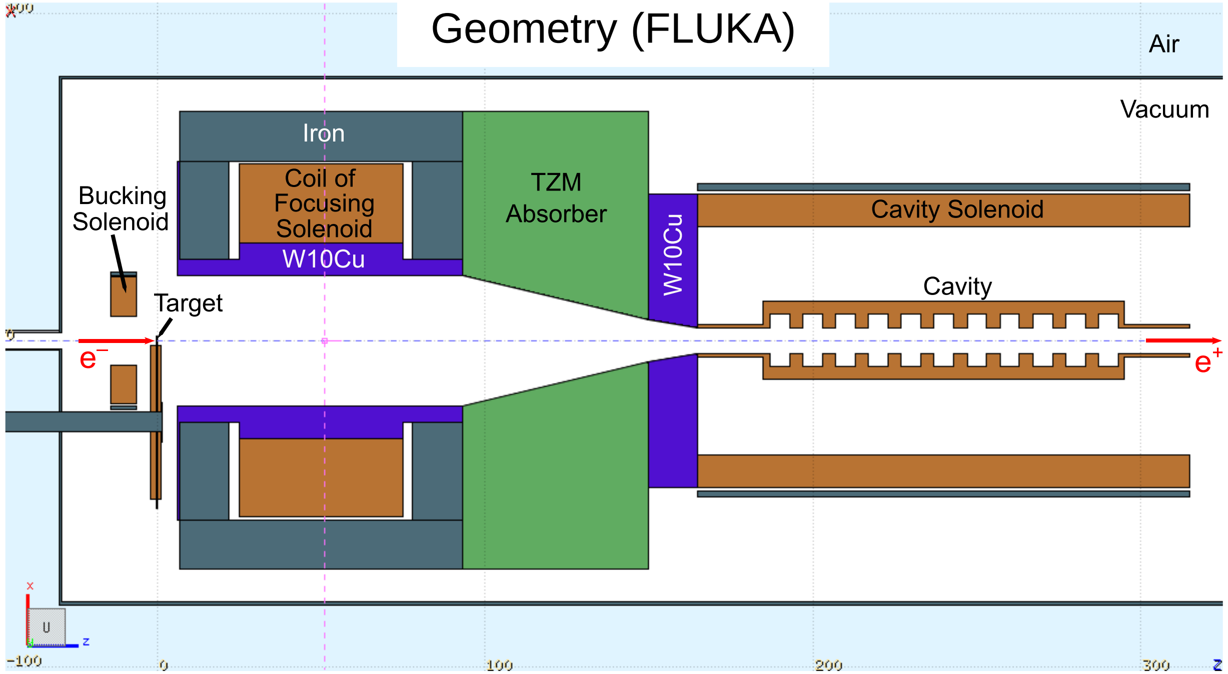
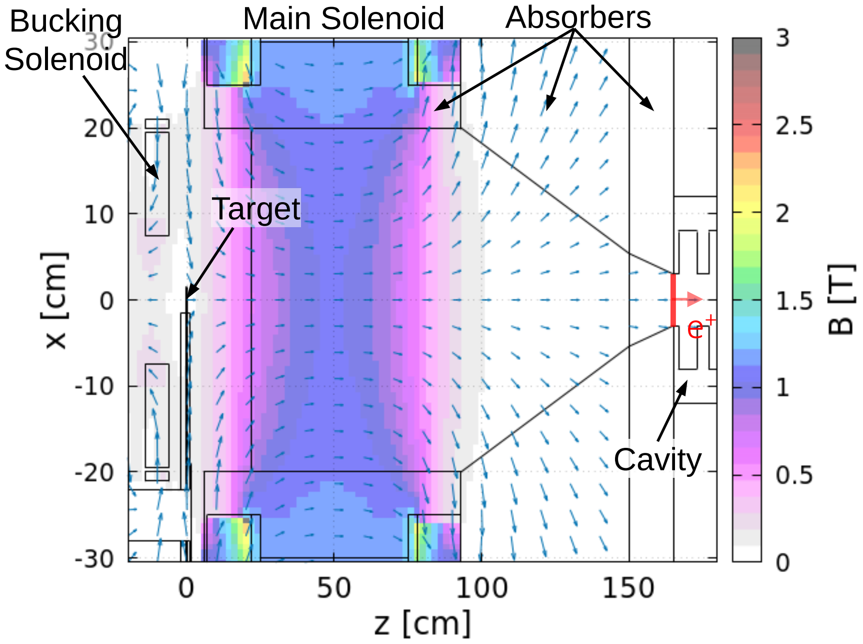
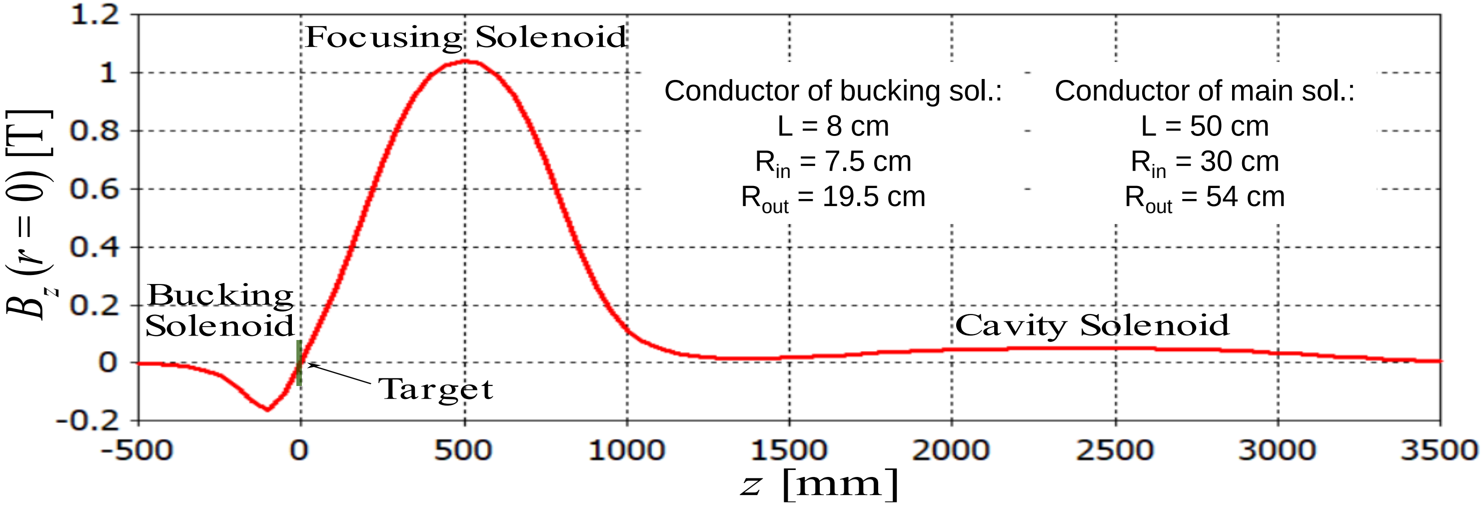
Model with Compensation Solenoid and Cavities







Conductor of bucking sol.:
L = 8 cm
R_{in} = 7.5 cm
R_{out} = 19.5 cm

Conductor of main sol.:
L = 50 cm
R_{in} = 30 cm
R_{out} = 54 cm

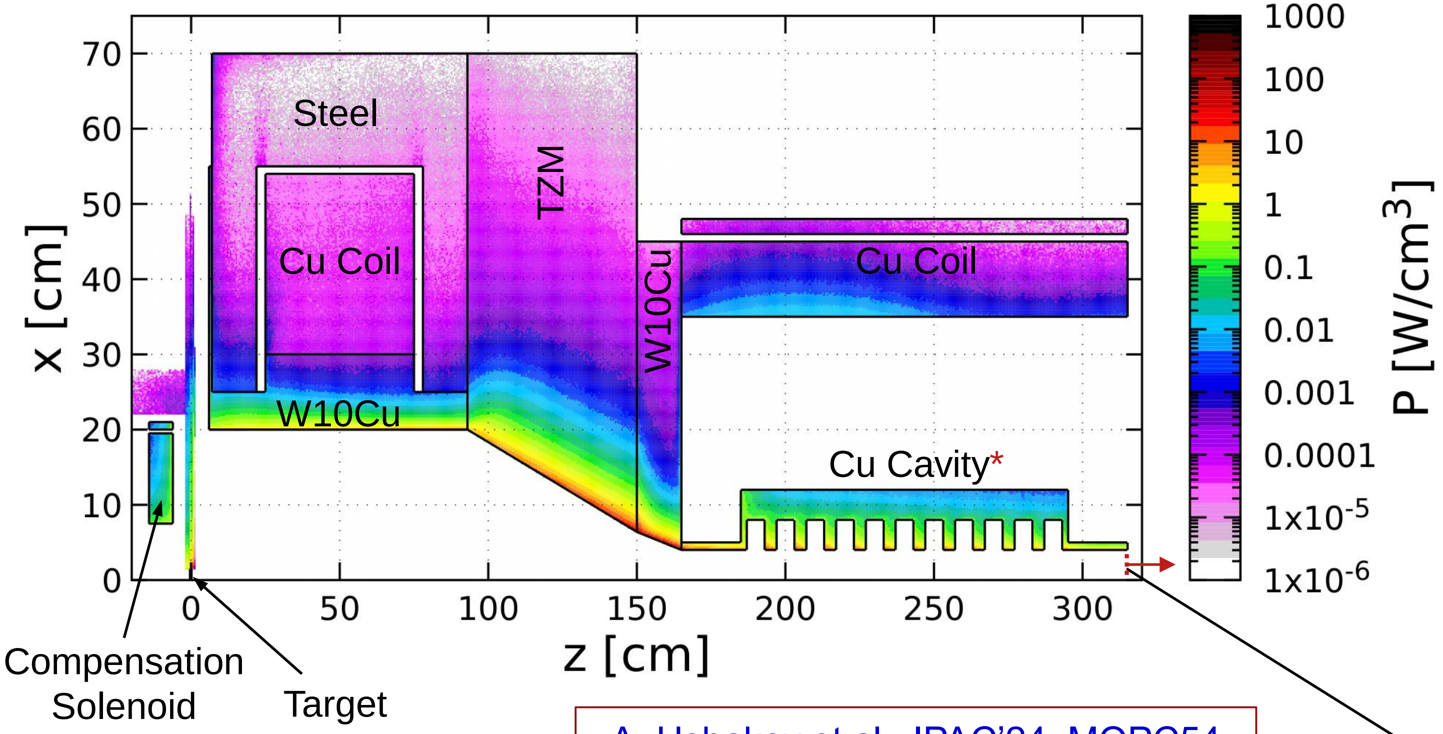
Same 14 mm square Cu conductor (15 mm square including insulator) with 11 mm hole for both main and bucking solenoids

$j \approx 446$ A/cm^2

$B_{max}(r = 0) = 1.03$ T

Water flow:
~500 cc/sec, 18 bar

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



A. Ushakov et al., IPAC'24, MOPC54

	Power [kW]
Target	18.32
Compensation Solenoid	0.74
Coil of Main Solenoid	0.02
Iron of Main Solenoid	0.07
W10Cu Absorber inside Main Solenoid	18.68
TZM Absorber (99.4% Mo, 0.5% Ti, 0.1% Zr)	54.96
W10Cu Absorber upstream Cavities	12.61
Solenoid around Cavity	0.62
Cu Cavities	6.50
Total Absorbed Power	**115.12 (96%)**

Power of γ, e⁻, e⁺ at z = 315 cm **4.29**

	Photons	Electrons	Positrons
Yield [N/e^-_{pr}]	0.152	0.040	0.008
Mean Energy [MeV]	13.06	50.54	33.78
Power [kW]	1.99	2.03	0.27
Fraction in Total Beam Power	46.4	47.3	6.3

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

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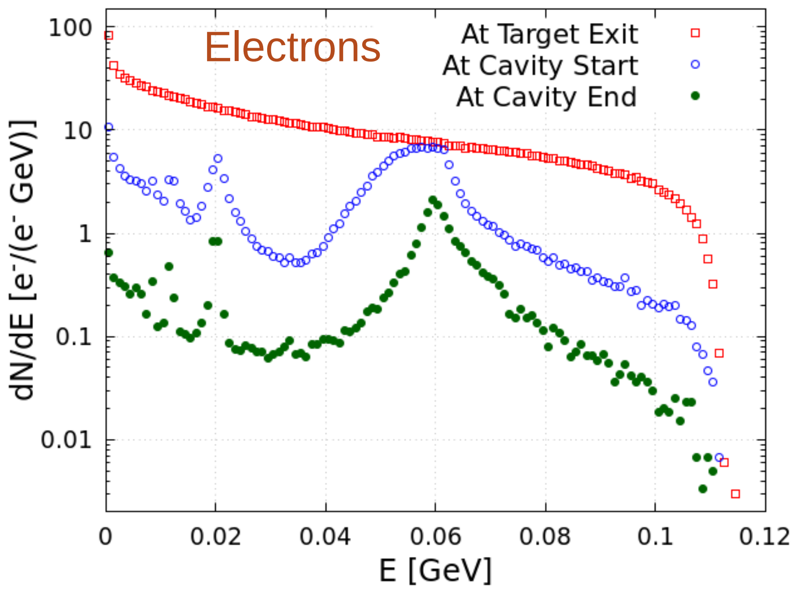
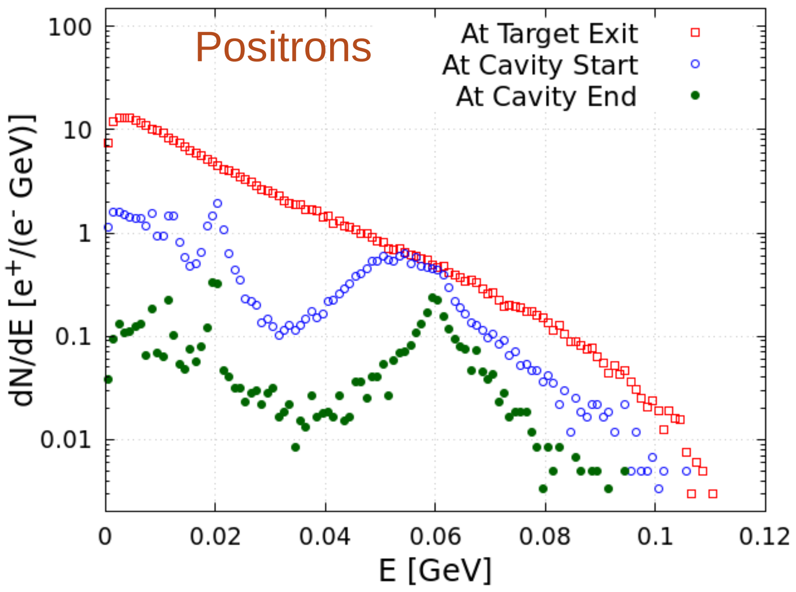
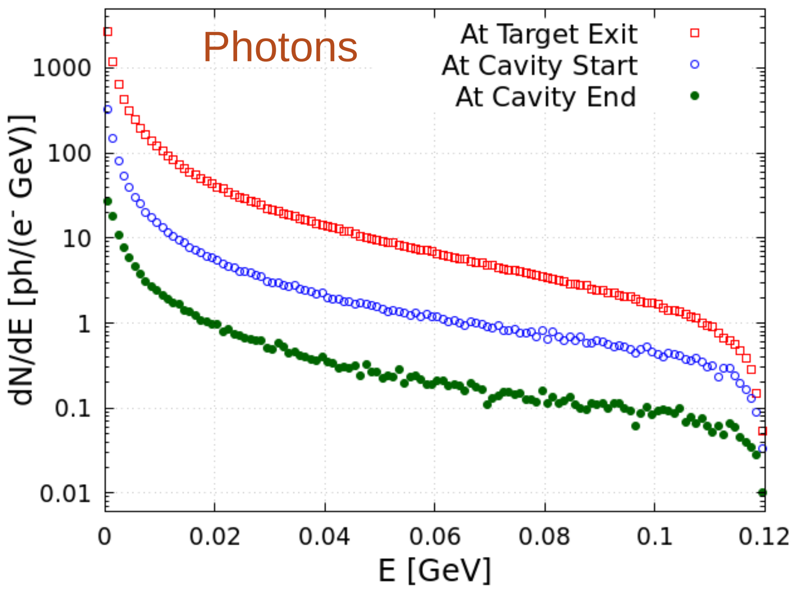
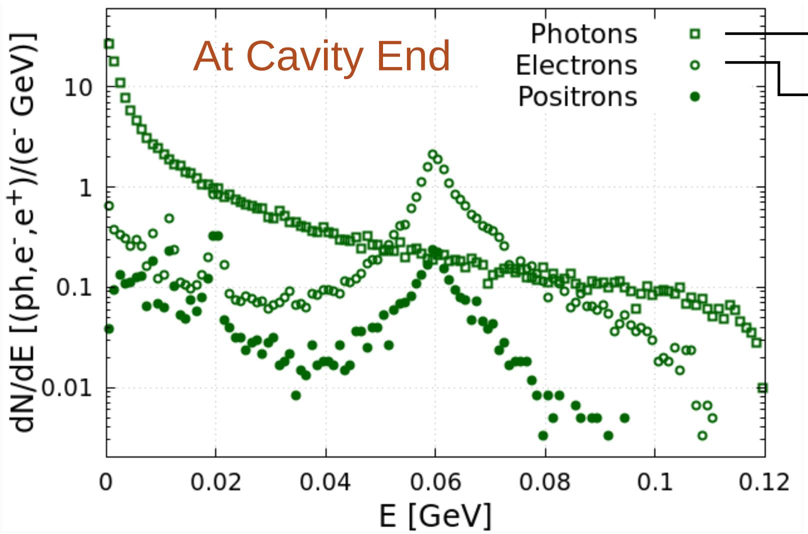
Energy Distributions of e⁻, e⁺ and γ at Different Z-Positions (FLUKA)









will be removed by forward dump

will be deflected by dipole and dumped

e^+ Yield at Cavity End:

- All energies:

  Y_{e+} = $5.5 \cdot 10^{-3}\ e^+/e^-_{pr} \longrightarrow 5.5\ \mu A$

- 60 MeV ± 5%:

  $Y_{60MeV\ e+}$ = $1.0 \cdot 10^{-3}\ e^+/e^-_{pr} \longrightarrow$ **1.0 μA**

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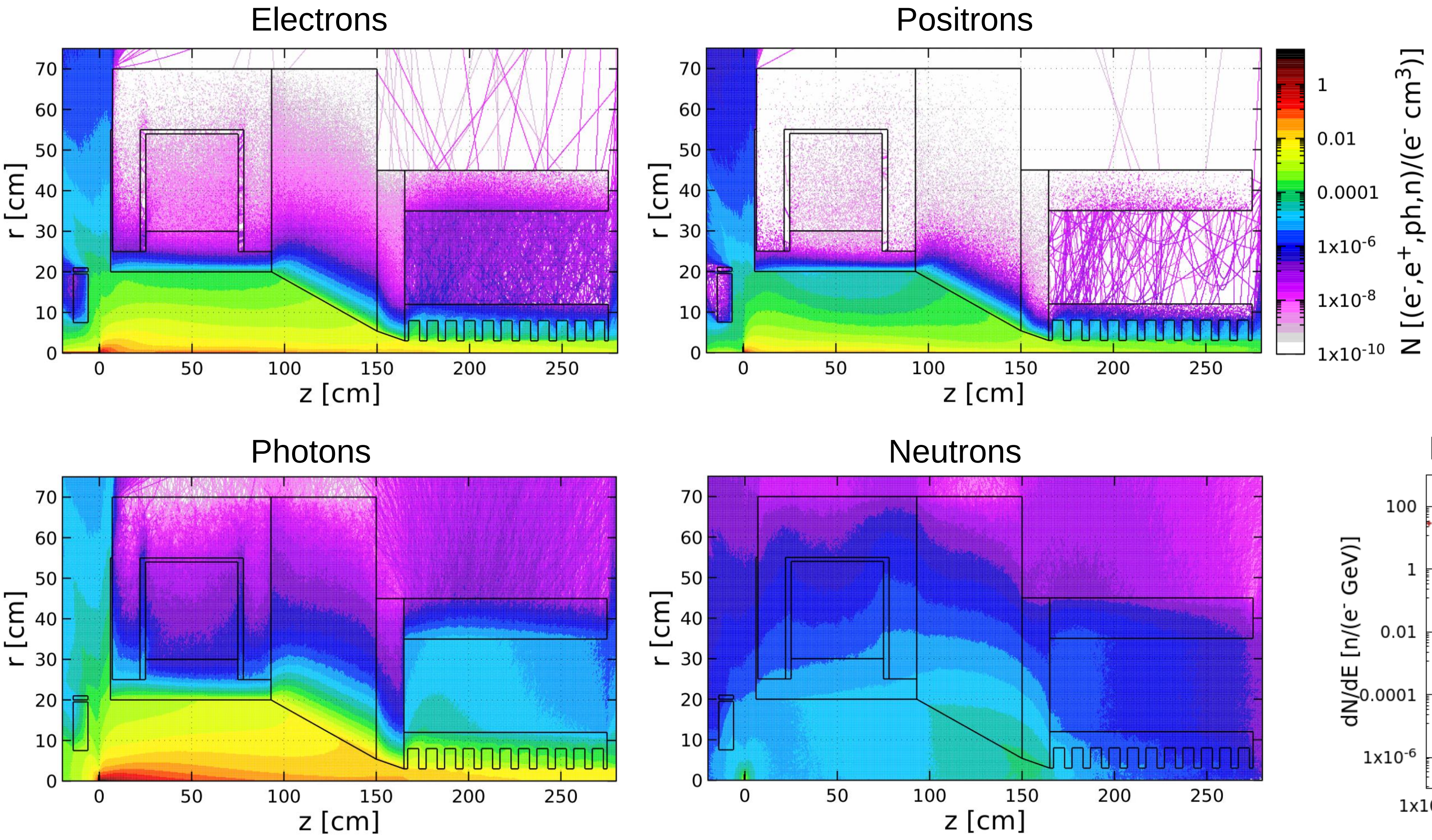
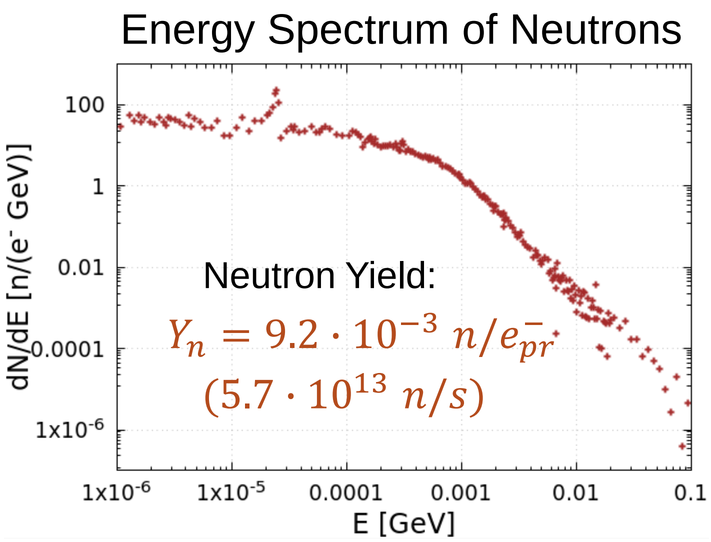
Spatial Distributions of e⁻, e⁺, γ and n. Neutron Energy and Yield (FLUKA)



We have begun working with the Radiation Control Department on radiation shielding

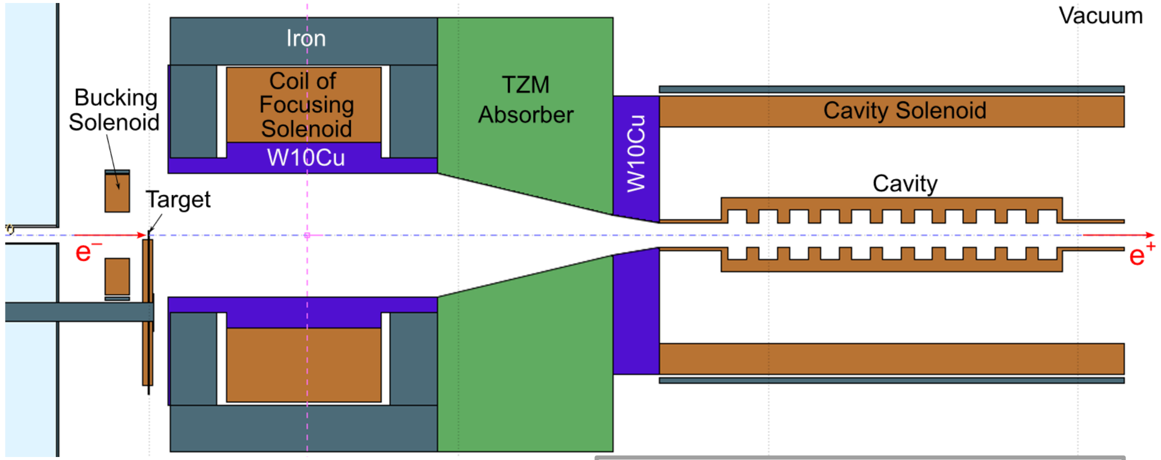


Standing Wave Capture Cavity (Shaoheng Wang)

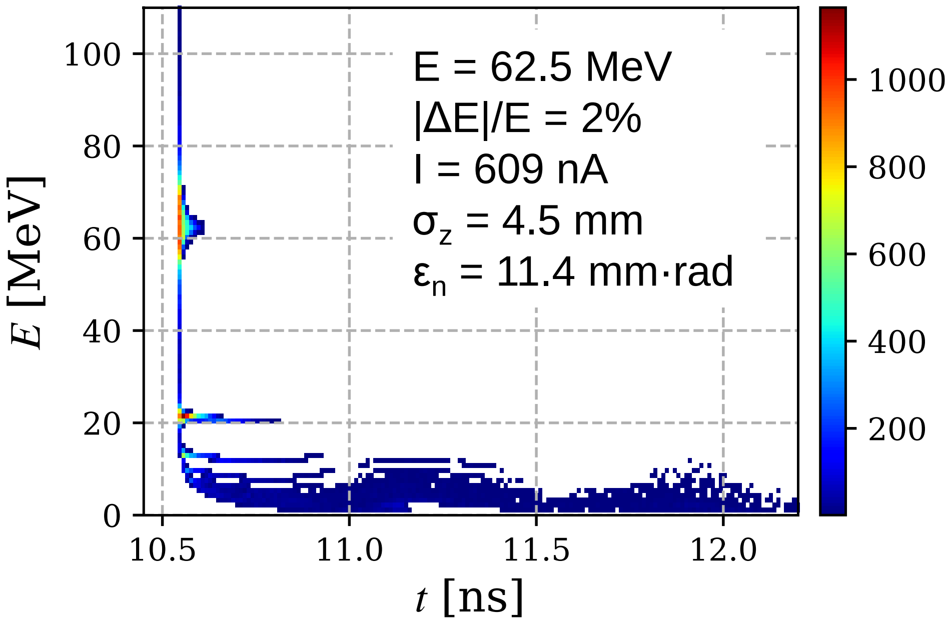
Work on development of CW capture cavity has been started

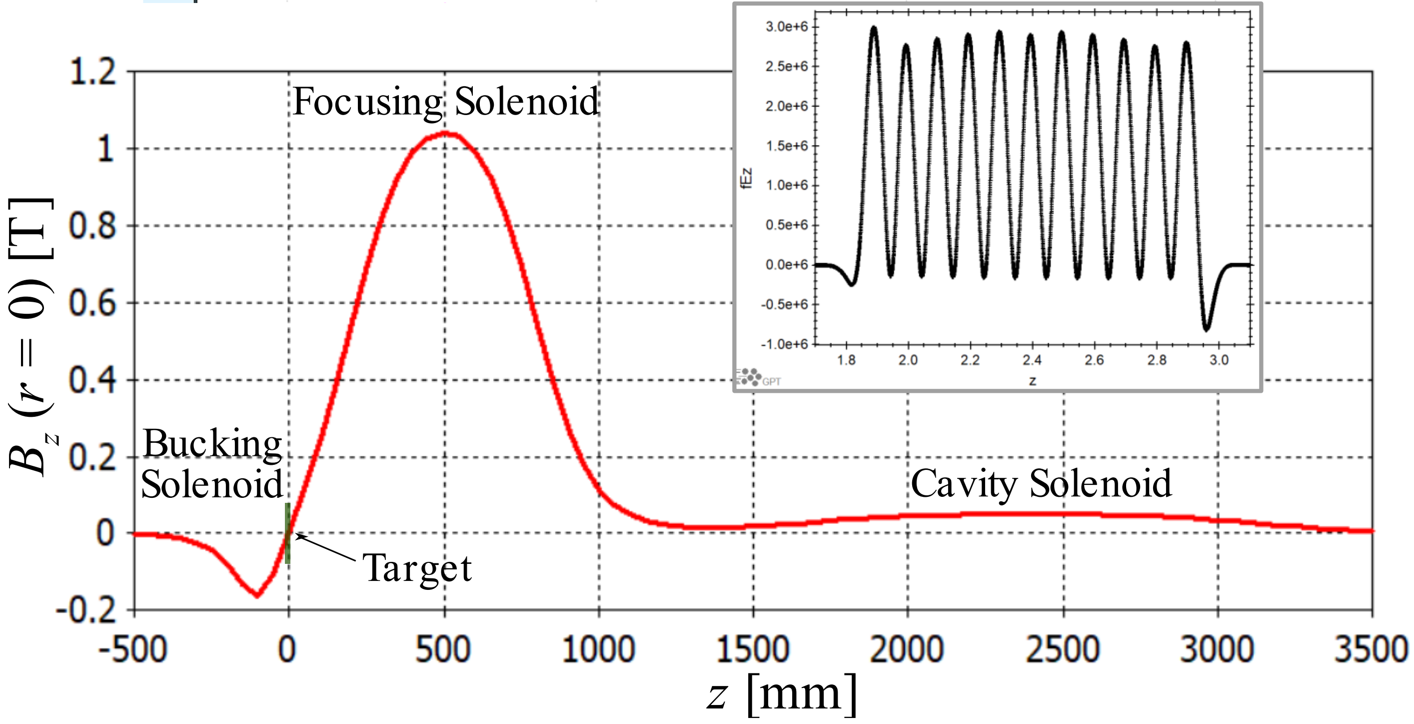
Cavity with a large iris radius:

- 11 cells standing wave normal conducting cavity
- Frequency = 1496.982 MHz
- E_{max} = 3 MV/m
- Aperture radius = 4 cm



Time-Energy Phase Space at Cavity Exit (GPT)





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Energy Selection Chicane and SRF Cryomodule C100

Dipoles

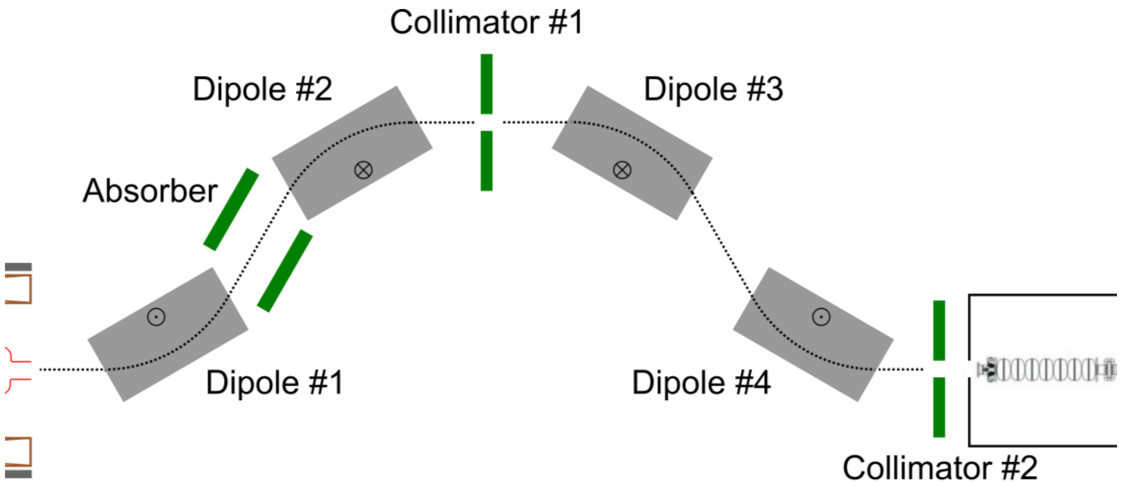
- Field = 0.34 T
- Bending angle = 20°
- Angle of entrance/exit pole face = 10°
- Gap = 9 cm
- First coefficient of fringe fields Enge function (2/Gap) = 22 m^{-1}
- e^+ Energy = 62.34 MeV (γ = 122)
- Bending radius = 61.16 cm

Absorber/Collimators

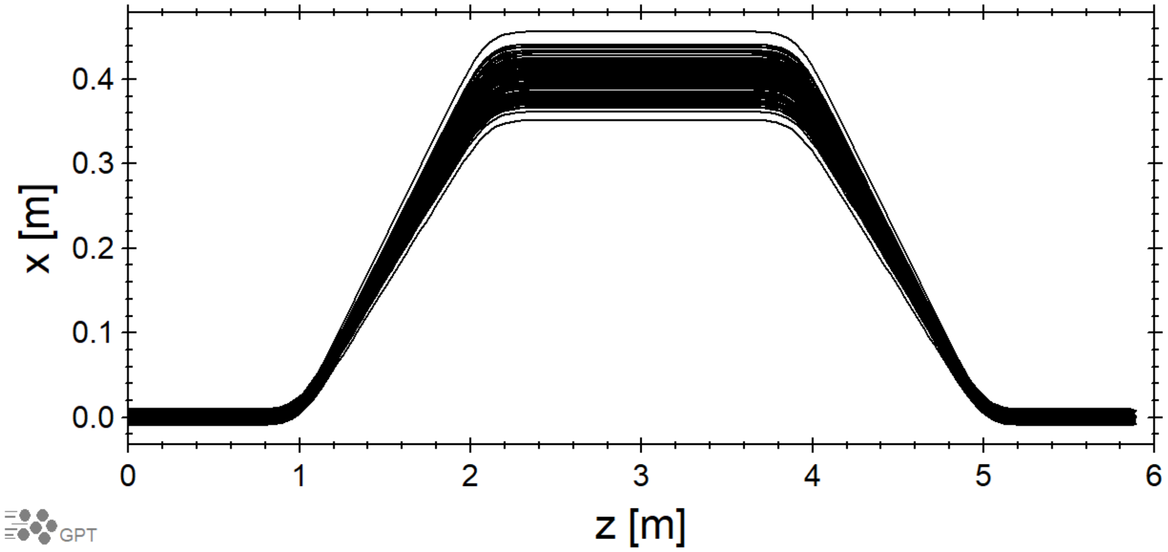
- $\Delta x_{absorber}$ = 25 cm, length = 1 m
- Δx_{col1} = 2.2 cm, length = 10 cm
- r_{col2} = 2.0 cm, length = 10 cm

SRF Cryomodule (C100) at the end of chicane

- 8 cavities, 7 cells, 1497 MHz
- Total accelerator length of 8 m
- Field adjusted to accelerate e^+ from ~62 MeV to 123 MeV



Trajectories of e^+ with γ = 122 and σ_γ = 6



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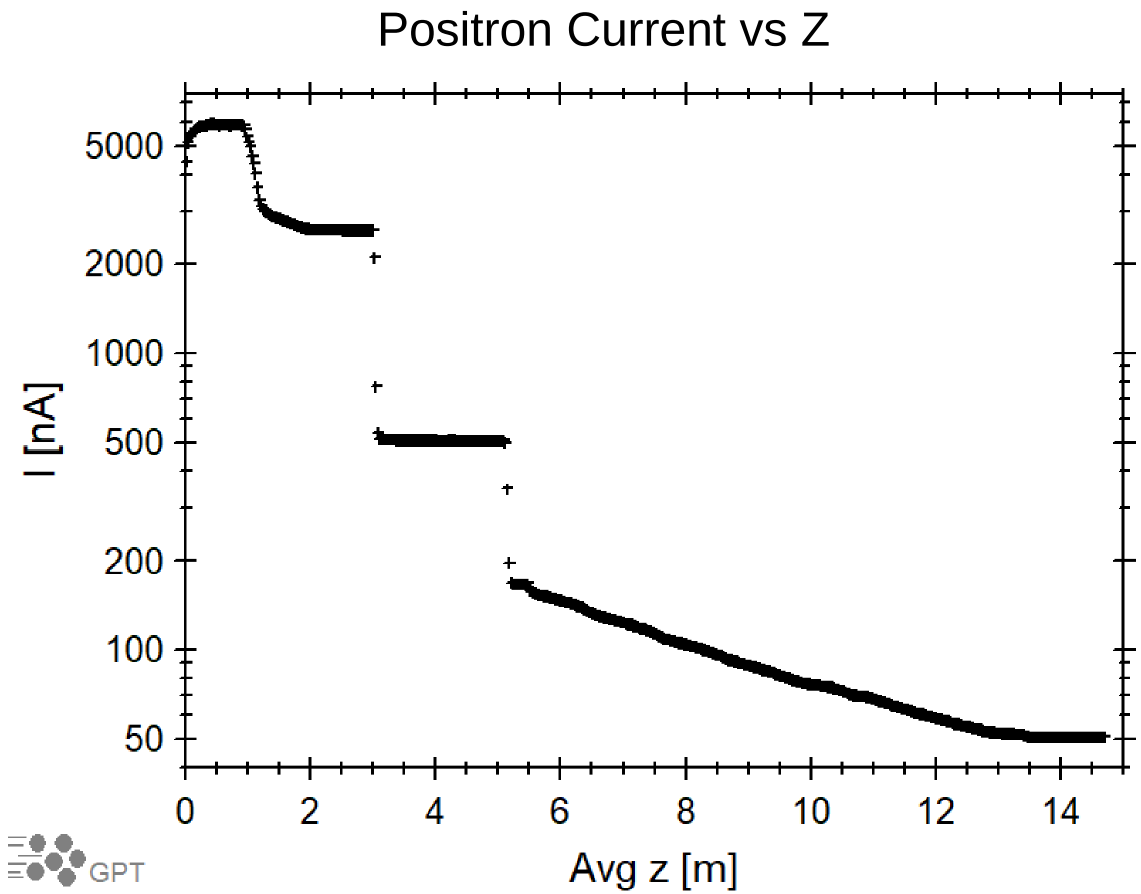
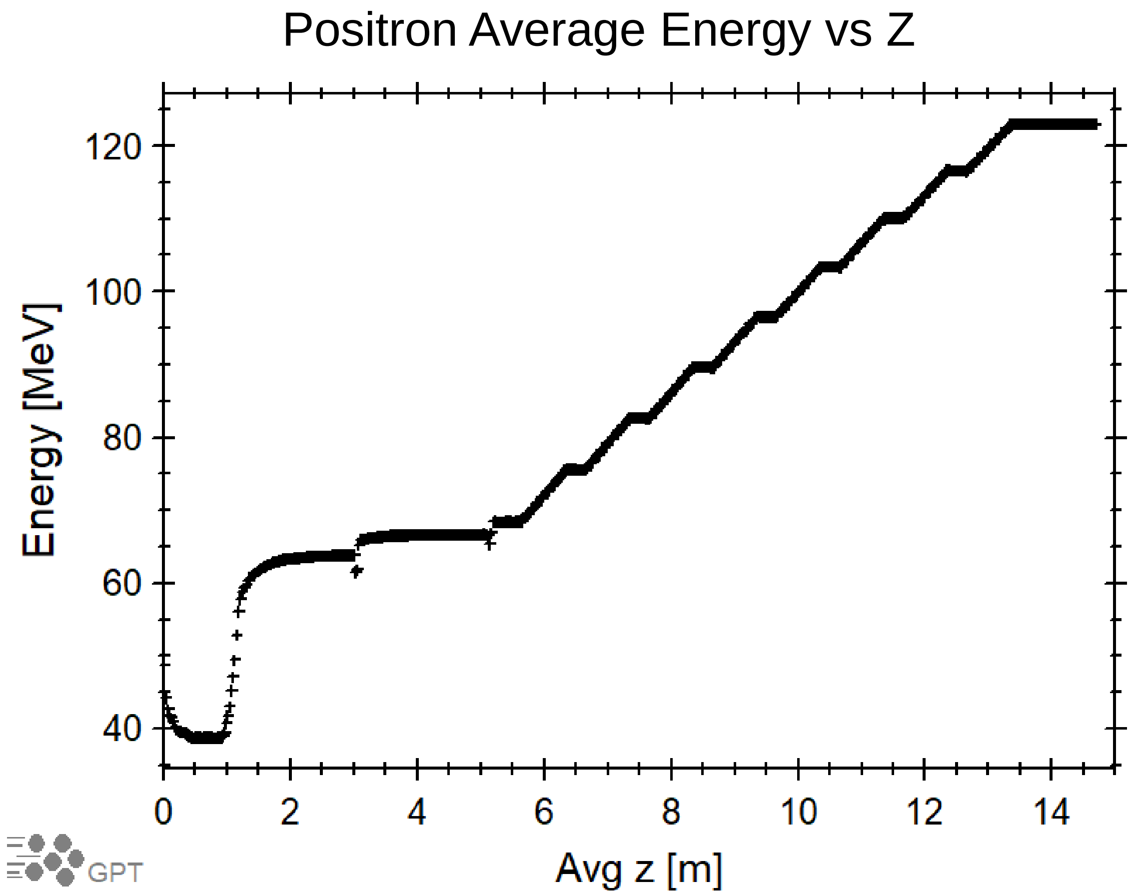
e⁺ Current and Energy vs Z in Chicane and Cryomodule (Preliminary Results)

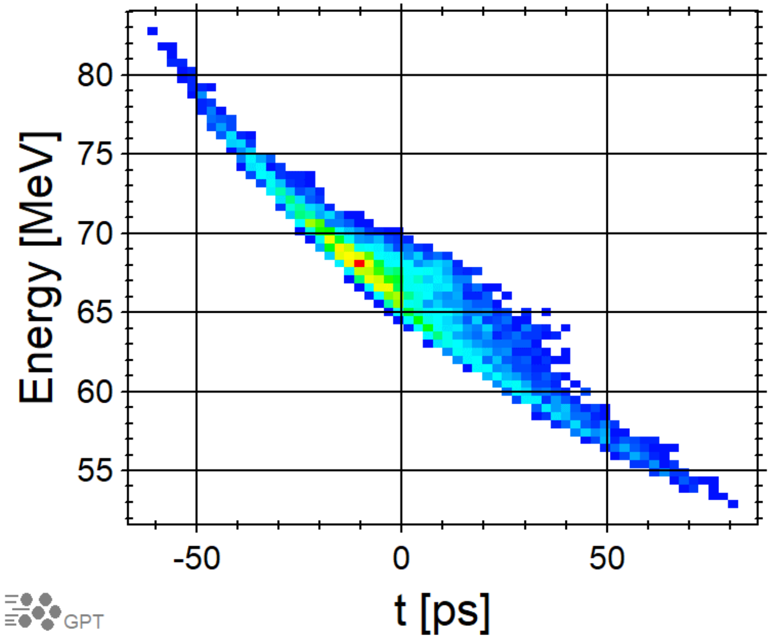




Avg z = 0 is at exit of NC capture cavity

Time-Energy Phase Space after Collimator #1 and before/after Cryomodule

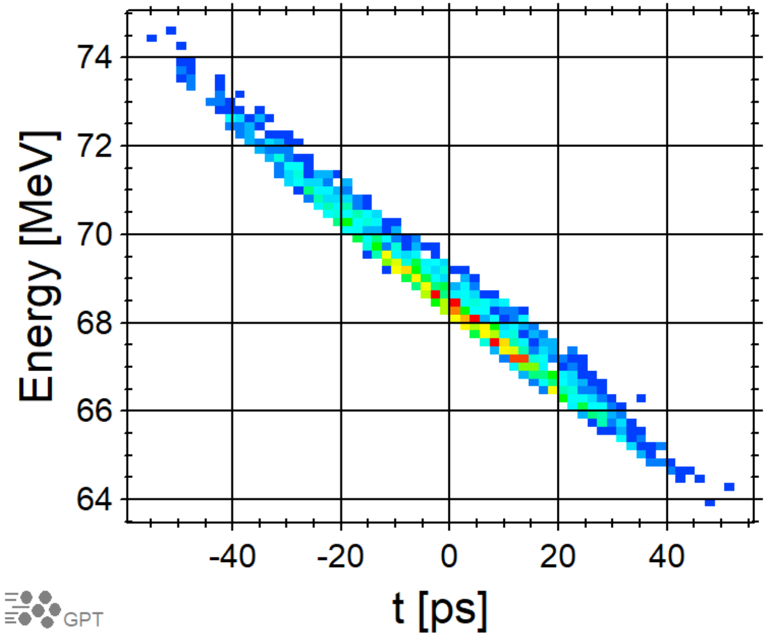
After Collimator #1



N(G) = 5167
Avg(G) = 130.54
Std(G) = 8.37996
Std(t) = 2.14096e-11

I = 516.7 nA
$\Delta E/E$ = 6.4%
σ_t = 21.4 ps

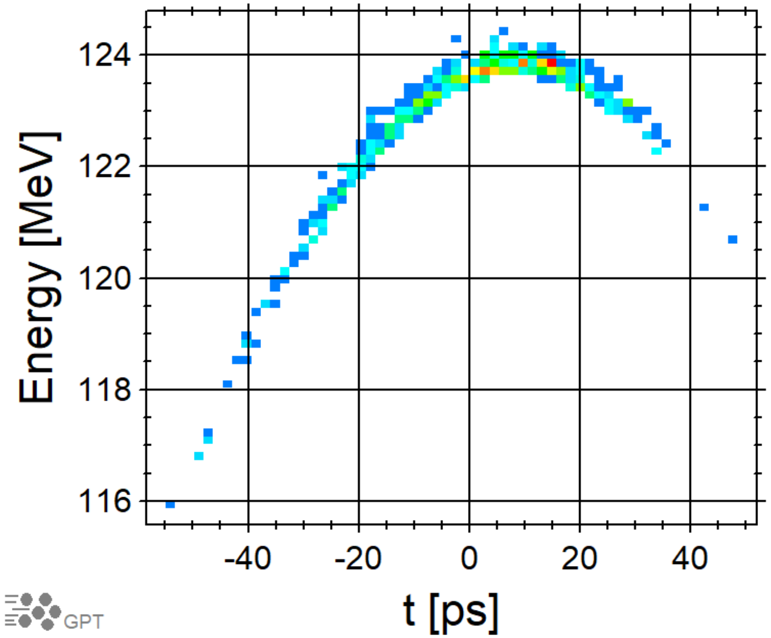
At Entrance of C100



N(G) = 1666
Avg(G) = 134.255
Std(G) = 3.43225
Std(t) = 1.77532e-11

I = 166.6 nA
$\Delta E/E$ = 2.6%
σ_t = 17.75 ps

At Exit of C100



N(G) = 508
Avg(G) = 240.697
Std(G) = 2.49027
Std(t) = 1.79318e-11

I = 50.8 nA
$\Delta E/E$ = 1.0%
σ_t = 17.9 ps

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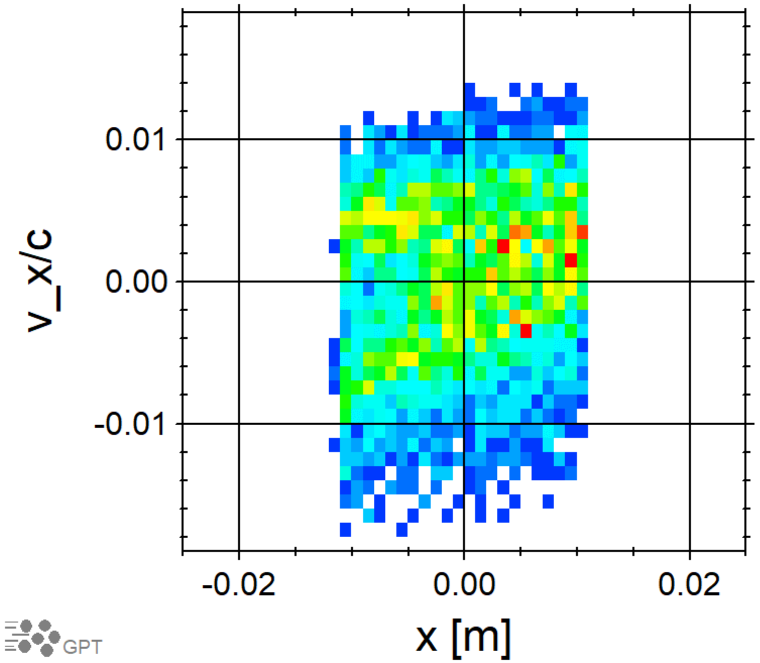
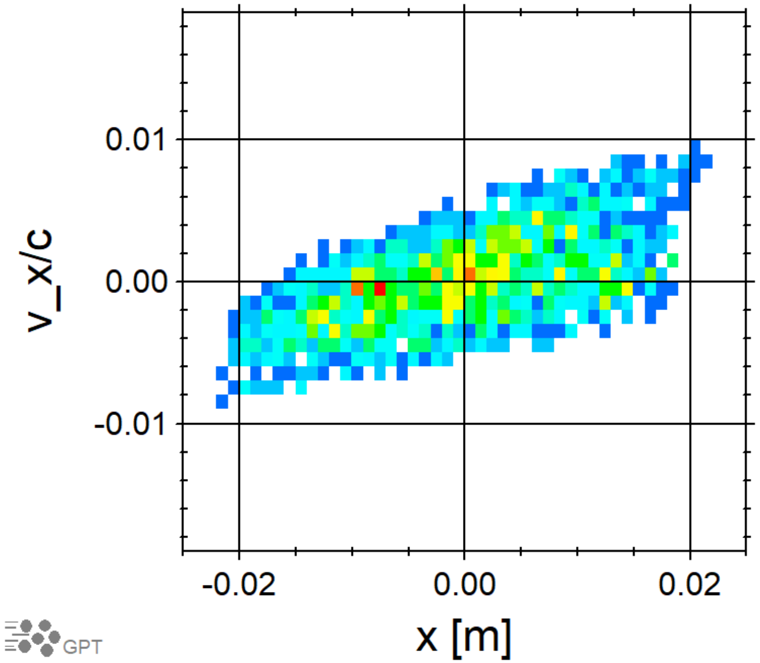
XX’ Phase Space after Collimator #1 and before/after Cryomodule

After Collimator #1



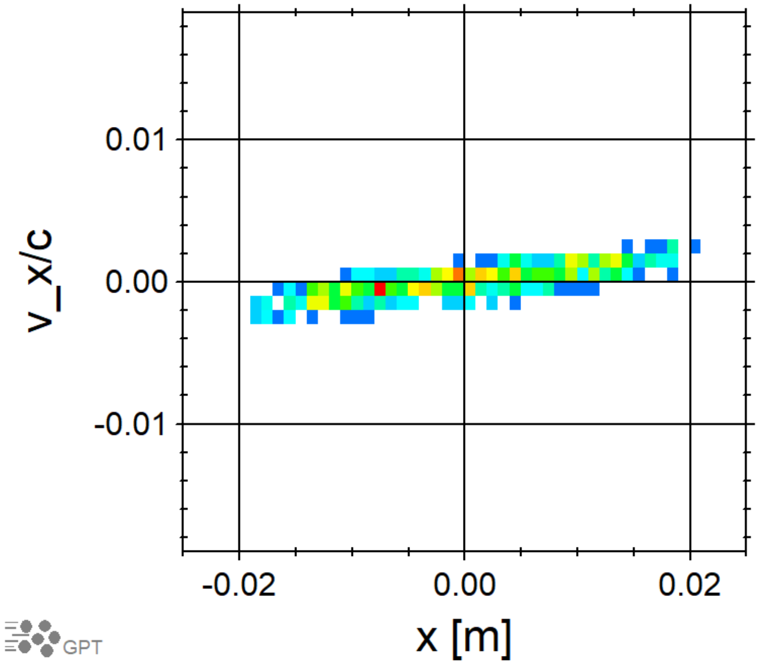
N(x) = 5167
Avg(x) = -0.0379708
Std(x) = 0.00619764
Std(Bx) = 0.00573795

At Entrance of C100



N(x) = 1666
Avg(x) = -0.000138683
Std(x) = 0.00958812
Std(Bx) = 0.00317531

At Exit of C100



N(x) = 508
Avg(x) = -0.000416875
Std(x) = 0.00939427
Std(Bx) = 0.00103766

ε_{nx} = 1.4 mm·rad
ε_{ny} = 1.8 mm·rad

Summary

- We are working on improving the design of the Ce^+BAF injector concept and critical risk areas:
  - mA polarized e^- source
  - High power target
  - CW capture cavity
- Current project/proposal:
  - Proposal for mA e^- source with >85% polarization
  - Test prototype tungsten target
  - Test liquid metal target (Xelera)
  - Development of normal conducting CW capture cavity
  - Measure CEBAF acceptance
- Improving simulation model by using more realistic geometries and fields of e^+ injector components

Acknowledgments

We would like to acknowledge members of the **Ce$^+$BAF Working Group**, the **Jefferson Lab Positron Working Group**, the **DOE industry partner Xelera**, members of the **DOE US-Japan HEP Collaboration,** and collaborators at **Universities and National Labs** which contribute to the positron R&D effort.

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

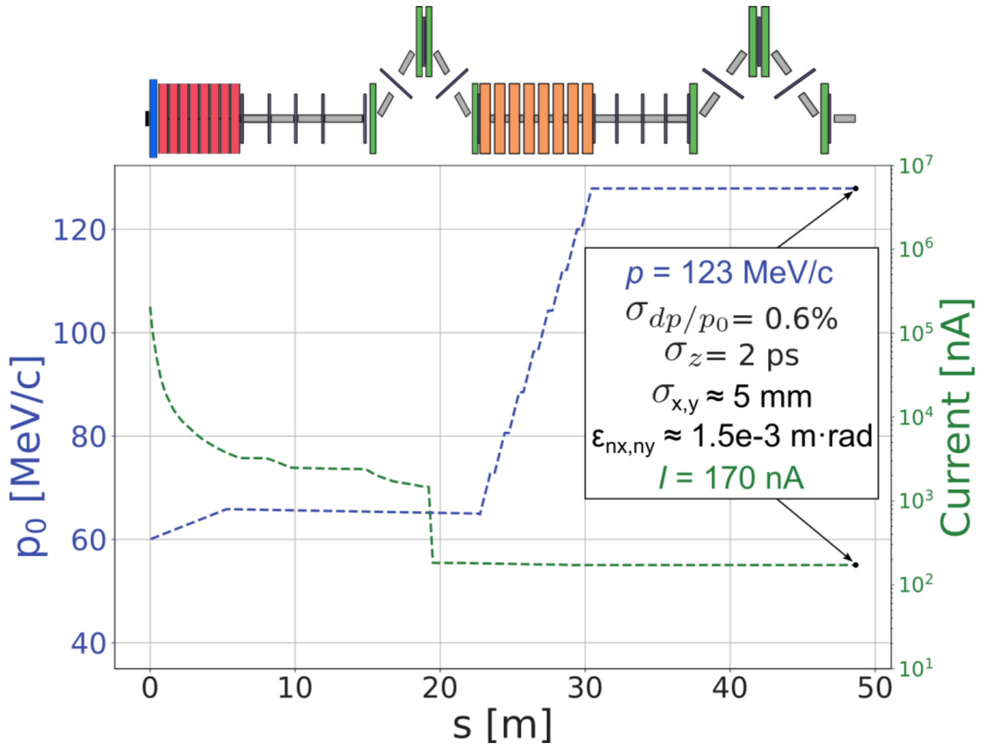
Invite you to join us at
Jefferson Lab in September.

Thank you.

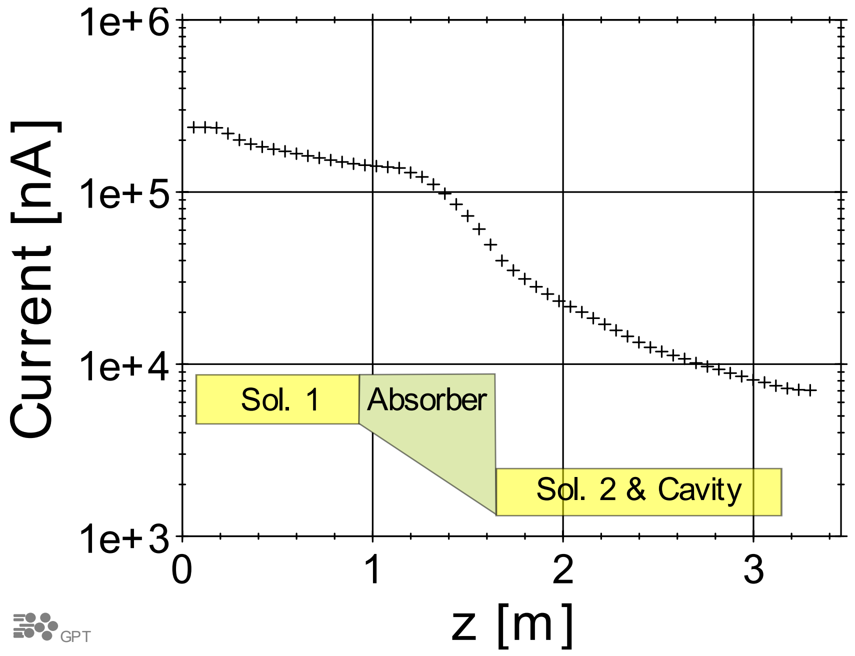
Backup Slides

e^+ Beam Current vs Z at Capture 1.03 T Solenoid and NC Capture Cavity

e^+ Current And Energy along Beam Line
(S. Habet, PhD Thesis, Dec. 2023)



e^+ Current vs Z at Capture Solenoid and 1st Cavity



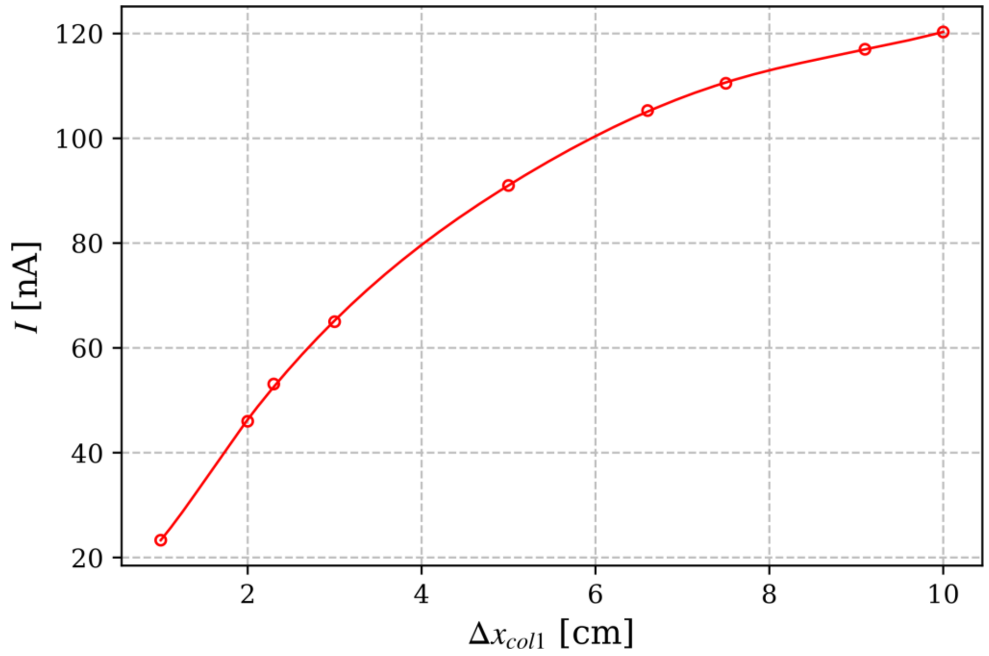
Current at the End of Capture Cavity:

- Elegant (Sami): I_{e^+} = 3 μA
- GPT (Andriy): I_{e^+} = 7 μA

Jefferson Lab

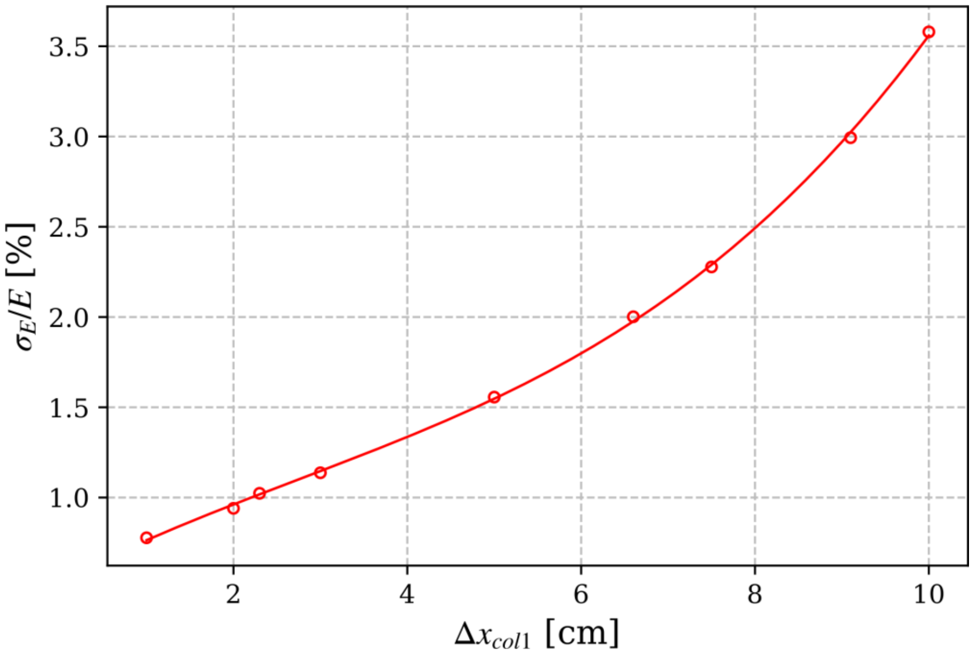
e^+ Current and Energy Spread at Exit of C100 vs Aperture Size of Collimator #1

e^+ Current vs Aperture Size (Δx) of Collimator #1



$I\ (\Delta x_{\mathrm{col1}} = 2.2\ \mathrm{cm}) = 50.8\ \mathrm{nA}$

Energy Spread vs Aperture Size (Δx) of Collimator #1



$\sigma_E/E\ (\Delta x_{\mathrm{col1}} = 2.2\ \mathrm{cm}) = 1\%$