Status of Polarized Electron & Positron Source R&D at Jefferson Lab

ILC-IDT Working Group 2 (WG2)

Joe Grames

July 18, 2022

Jefferson Lab Polarized Source R&D Topics (2021 – 2022)

Polarized e-

High Polarization Photocathodes
- Molecular Beam Epitaxy (MBE)
- Molecular Organic Vapor Deposition (MOCVD)
- Chemical Beam Epitaxy (CBE)

Ion Damage Experiments
- Biased anode mitigation
- Robust chemistry
- Gun voltage dependence

High Voltage Devices
- 200 – 300 kV Wien filters
- 500 kV inverted insulator
- 300 kV polarized 1 mA photogun

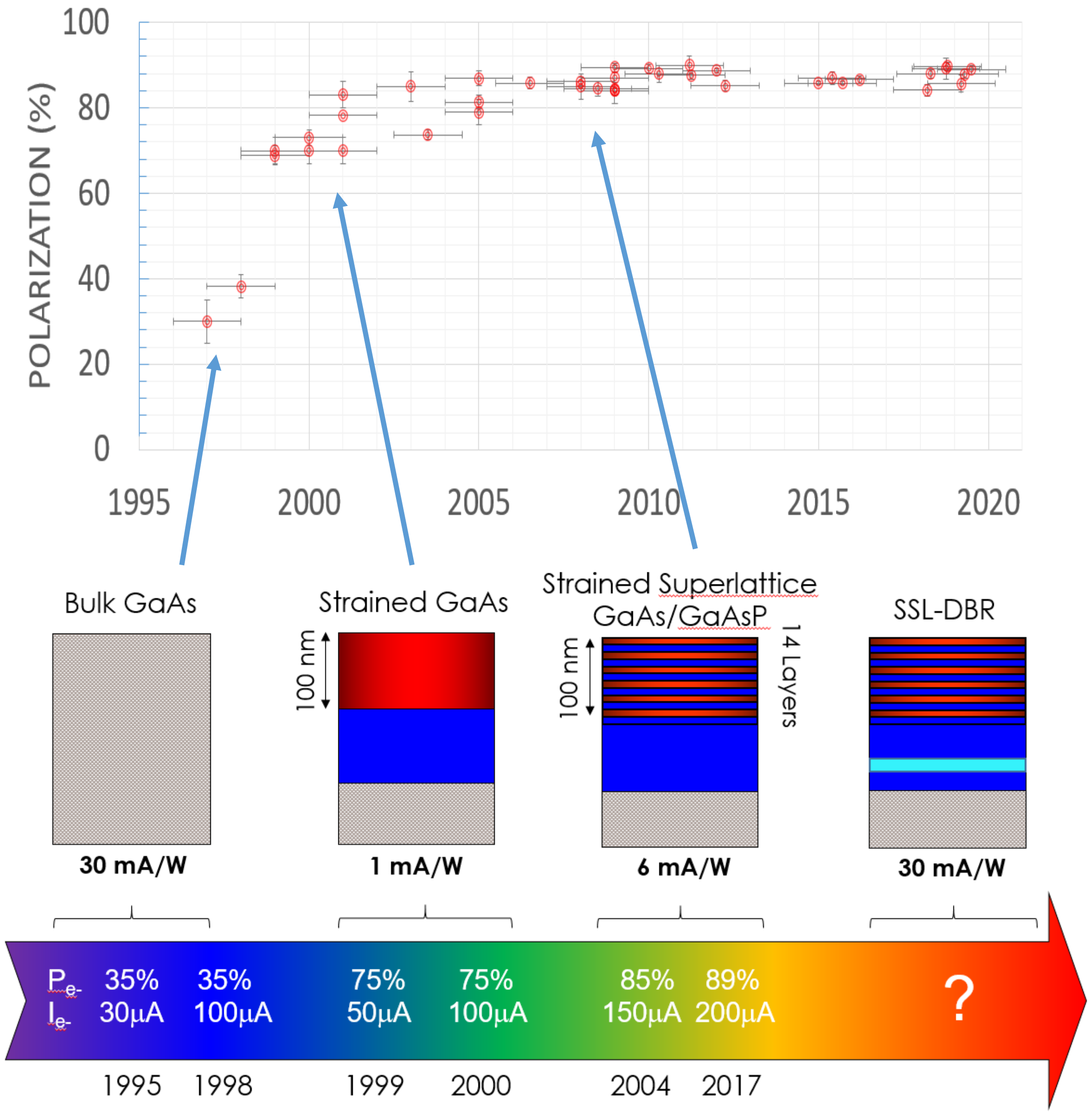
Simulation & Modeling
- GPT ion generation & spin tracking
- Lifetime evolution model
- Spot size evolution model

Polarized e+

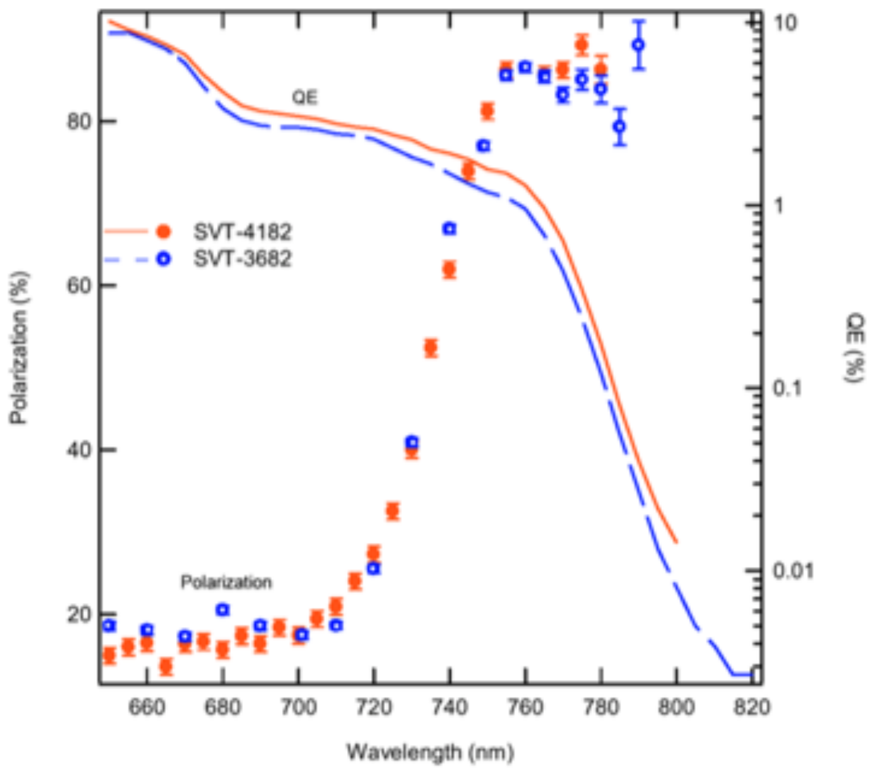
- Positron physics scope (today)
- CEBAF after 12 GeV e-
- Positron beams concept

High Polarization Photocathodes

- High polarization GaAs/GaAsP photocathodes fabricated by SVT Assoc. using MBE have been used at JLab for many years (QE~1%, P>85%)
- SVT no longer provides these for >5 years. PI has relocated to China and new business Aachen Optoelectronics.
- JLab is purchasing material at new fabrication facility for evaluation by end of 2022



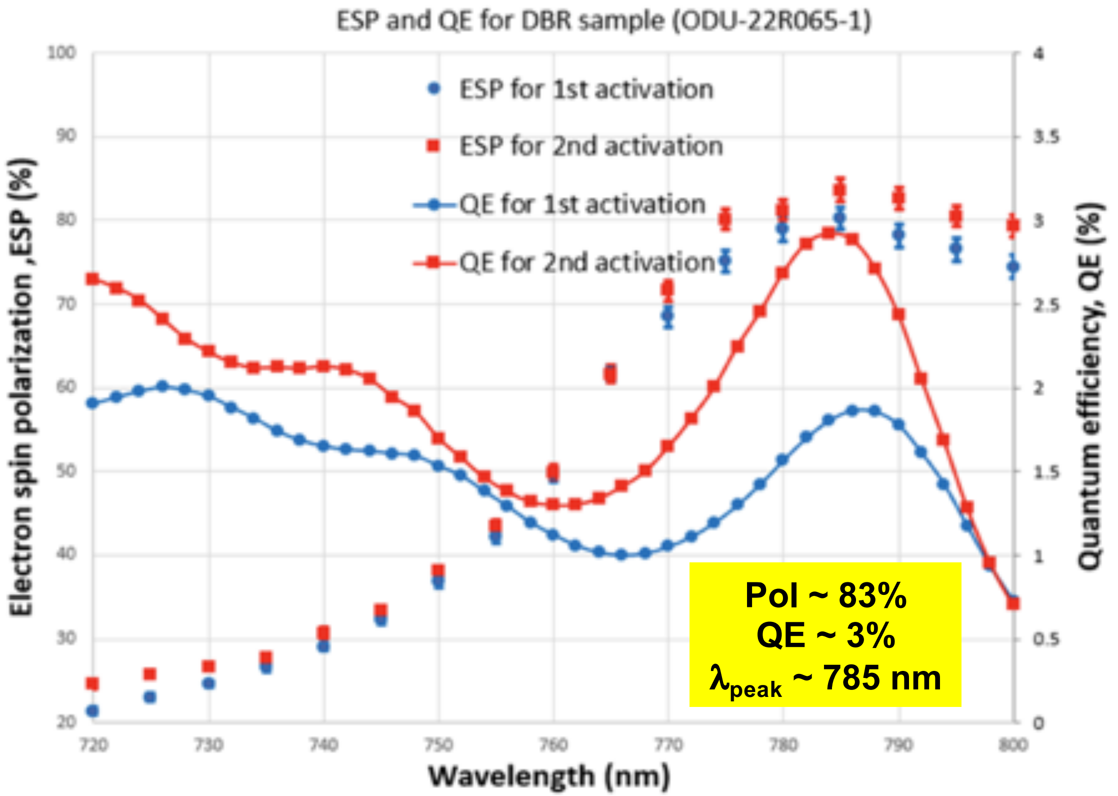
Strained Superlattice Photocathode
Aaron Moy, SVT Assoc and SLAC, PESP2002



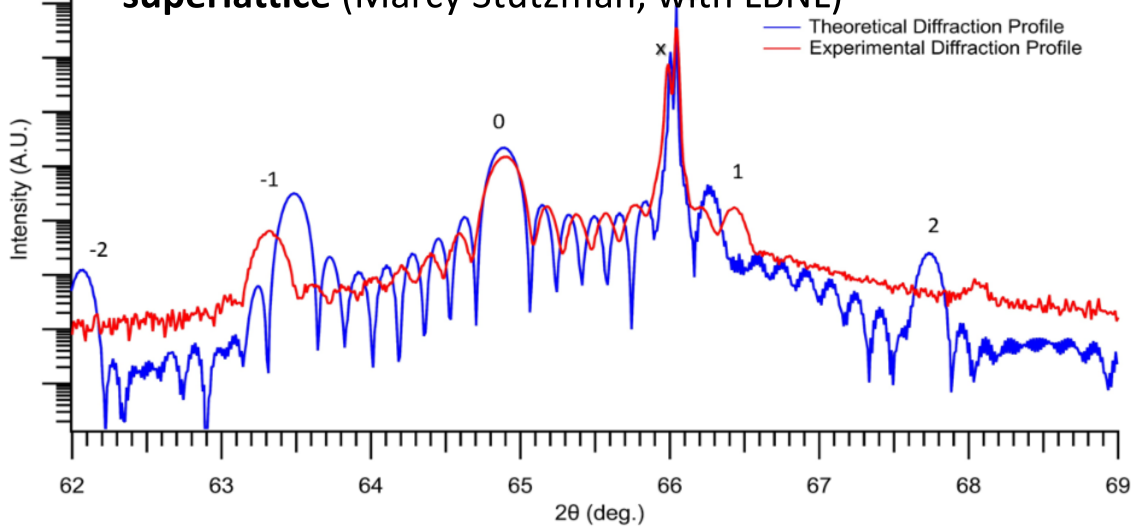
High Polarization Photocathodes

- US DOE supporting development of photocathode fabrication methods to address US supply chain
- Jefferson Lab has two funded projects
  - **Molecular Organic Chemical Vapor Deposition** of SSL/DBR-SSL (JLab, ODU, BNL)
  - **Chemical Beam Epitaxy** growth of GaAs/GaAsP Superlattice Photocathodes (JLab & UCSB)
- Additional proposal “Photocathodes For High Average Current Applications” (Sandia, BNL, JLab)

Molecular Organic Chemical Vapor Deposition **growth of DBR GaAs/GaAsP Superlattice Photocathodes** (Matt Poelker, with Old Dominion University and BNL)

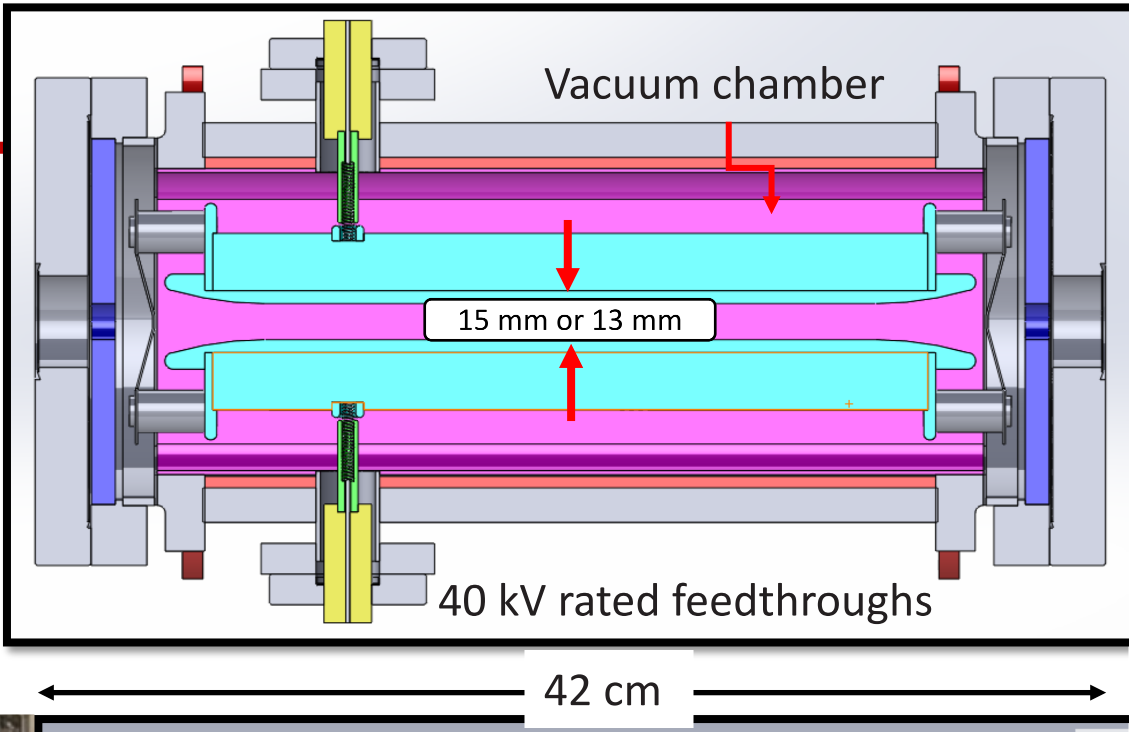


Chemical Beam Epitaxy **growth of first AlInGaAs/AlGaAs superlattice** (Marcy Stutzman, with LBNL)

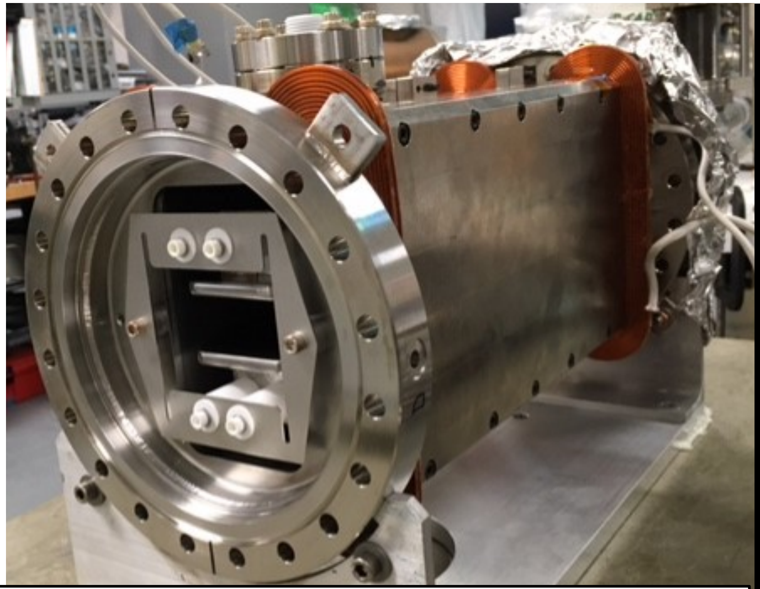


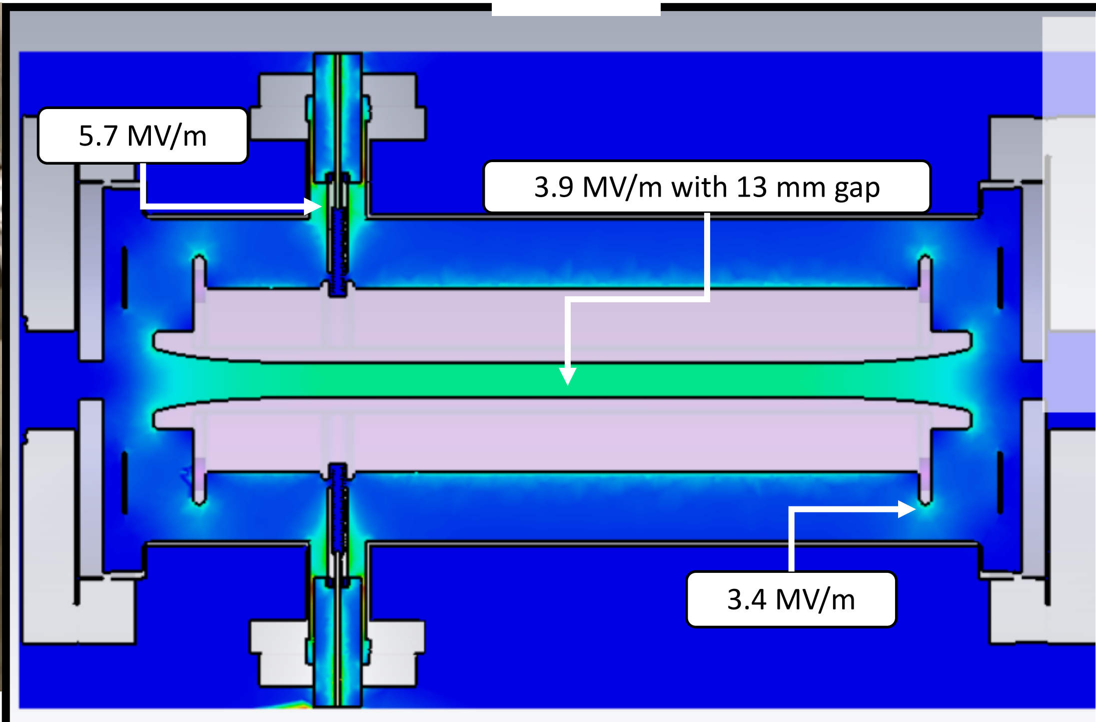
High gradient Wien Filters

- The original vertical and horizontal CEBAF Wien filters were upgraded for higher voltage operation to be compatible with 200 keV beam
- Both Wiens have been tested to 22 kV per electrode for 100 deg spin rotation angle with 15 mm gap for 200 keV beam
- A third Wien filter was built for UITF with reduced electrode gap and has been tested to 22 kV per electrode for 90 deg spin rotation for 300 keV beam
- The CEBAF Wiens are operational with 130 keV beam awaiting operations with 200 keV beam



- The UITF Wien will be tested with 180 keV in the coming days, awaiting opportunities to test with 300 keV beam later on
- A patent has been filed for incorporating active pumping in a Wien filter using the Penning cell concept and getter plates, emulating an ion pump during Wien operations.

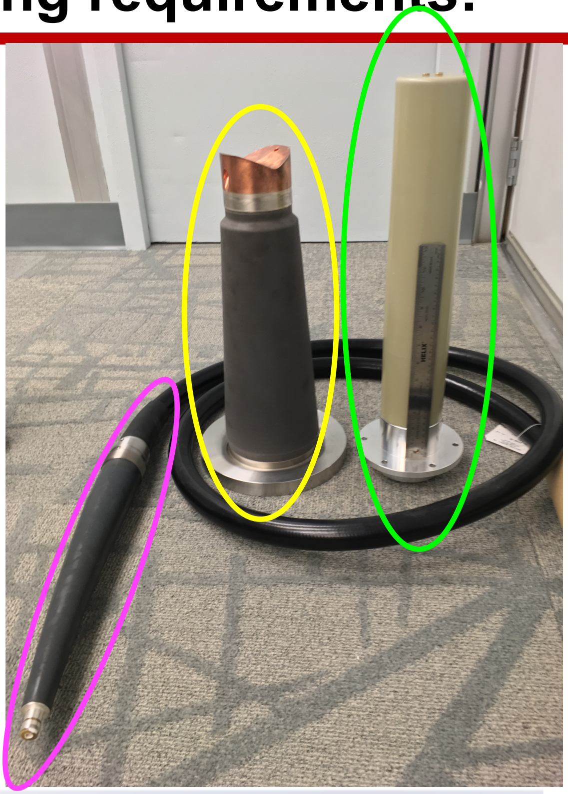




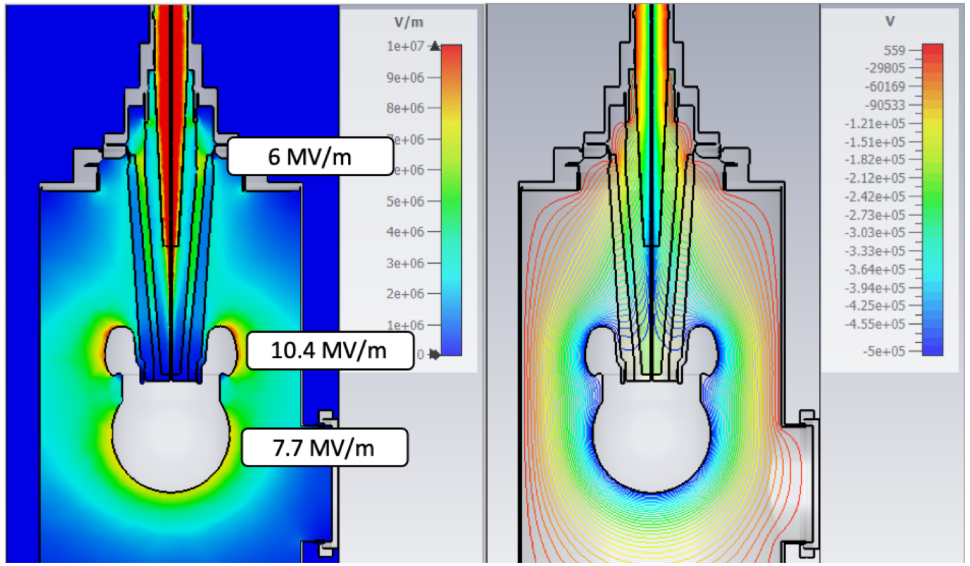
G. Palacios-Serrano, et al., "High voltage design and evaluation of Wien filters for the CEBAF 200 keV injector upgrade", 12th. Int. Particle Acc. Conf., IPAC2021, Campinas, SP, Brazil, doi:10.18429/JACoW-IPAC2021-M0PAB324.

500 kV cable-insulator concept* *with intervening SF_6 layer* has been designed with the intent to power a future 300 kV DC polarized photogun with the following requirements:

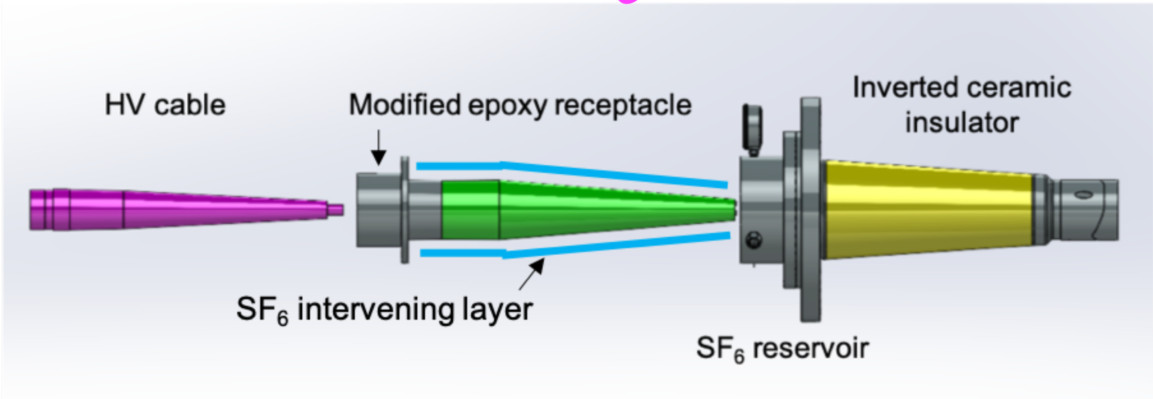
- Project Goals
  - Interface capable of 500 kV
  - Full beam transmission at 10 mA CW
  - $1x10^{-12}$ Torr dynamic vacuum at full current
  - No detectable field emission at 350 kV (requires capability of 500 kV reach for high voltage conditioning)



Gradients and potential at 500 kV



C. Hernandez-Garcia et al., "Inverted Geometry Ceramic Insulators in High Voltage DC Electron Guns for Accelerators", in proceedings of the 2021 IEEE Conference on Electrical Insulation and Dielectric Phenomena-Vancouver-Canada

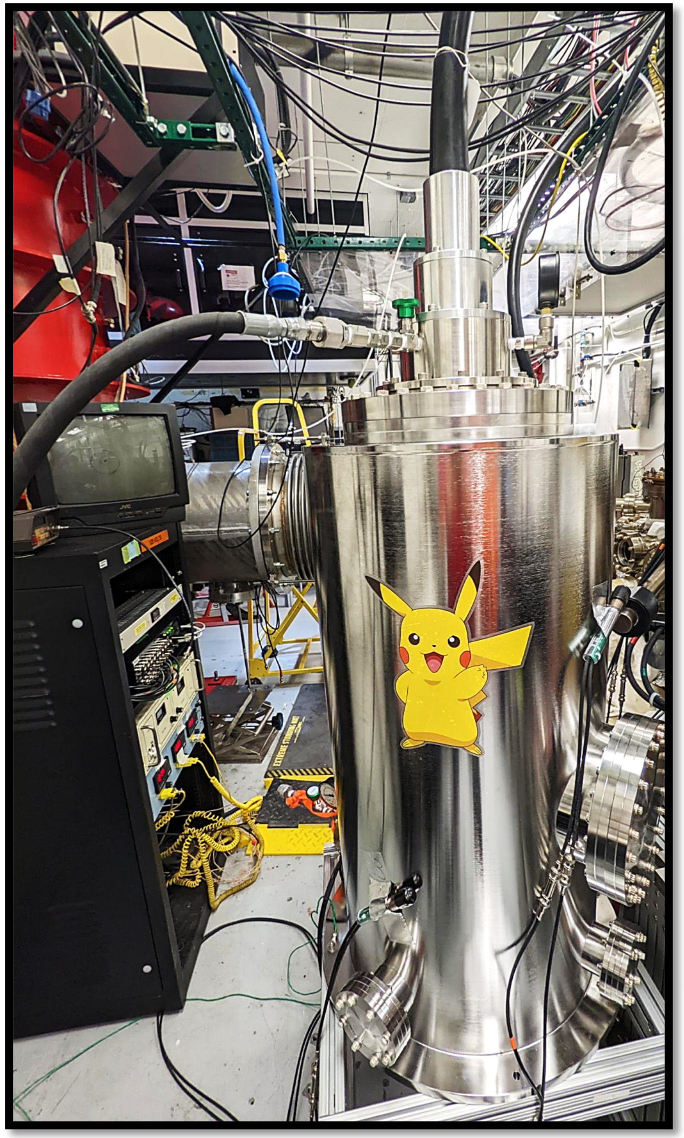


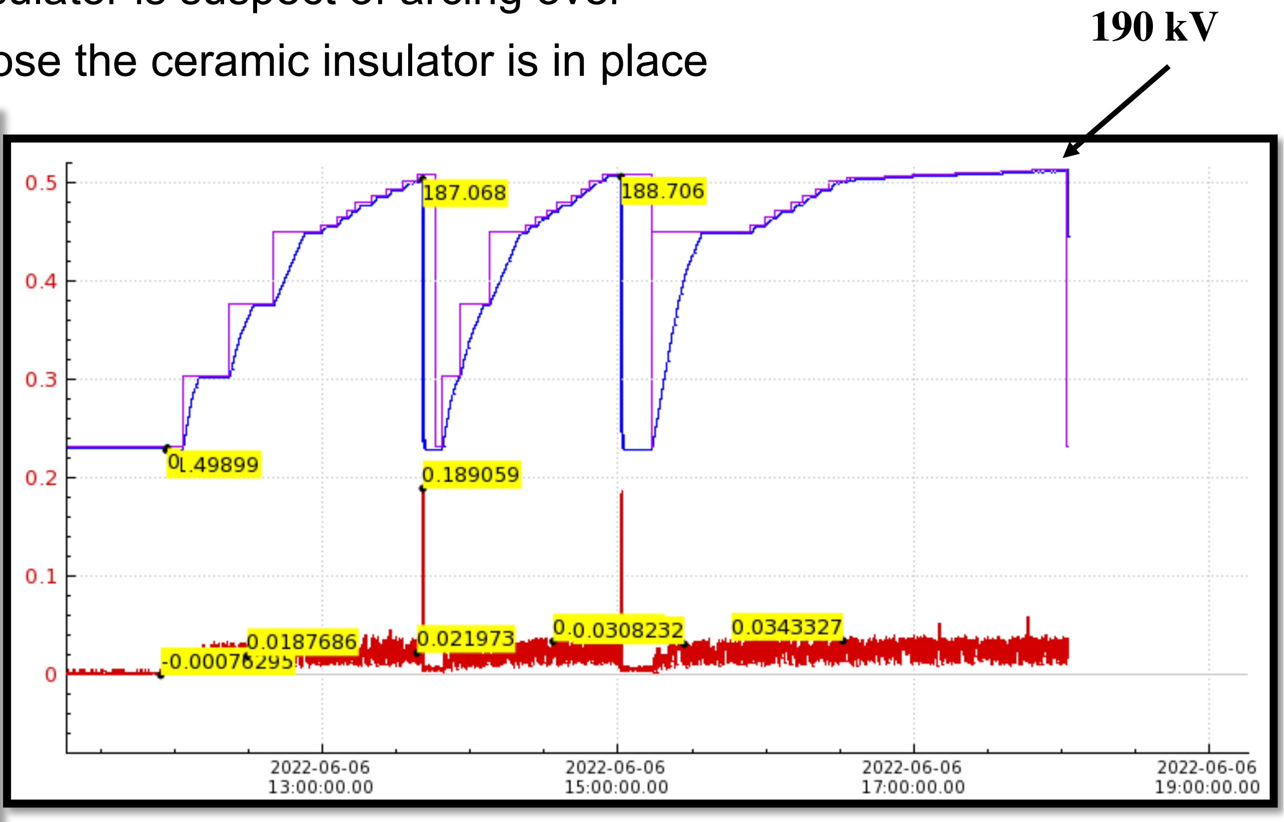
*Funding from DOE NP Office of Science, FOA 2020

Simulations and model by G. Palacios-Serrano, JLab

The cable-plug concept* is currently under testing in the Gun Test Stand (GTS)

- The assembly reached 190 kV during initial testing
- Higher voltage has been hampered by over-current events
- The cable-plug assembly has been tested on its own and appears to be fine
- The ceramic insulator is suspect of arcing over
- A plan to diagnose the ceramic insulator is in place





*Funding from DOE NP Office of Science, FOA 2020

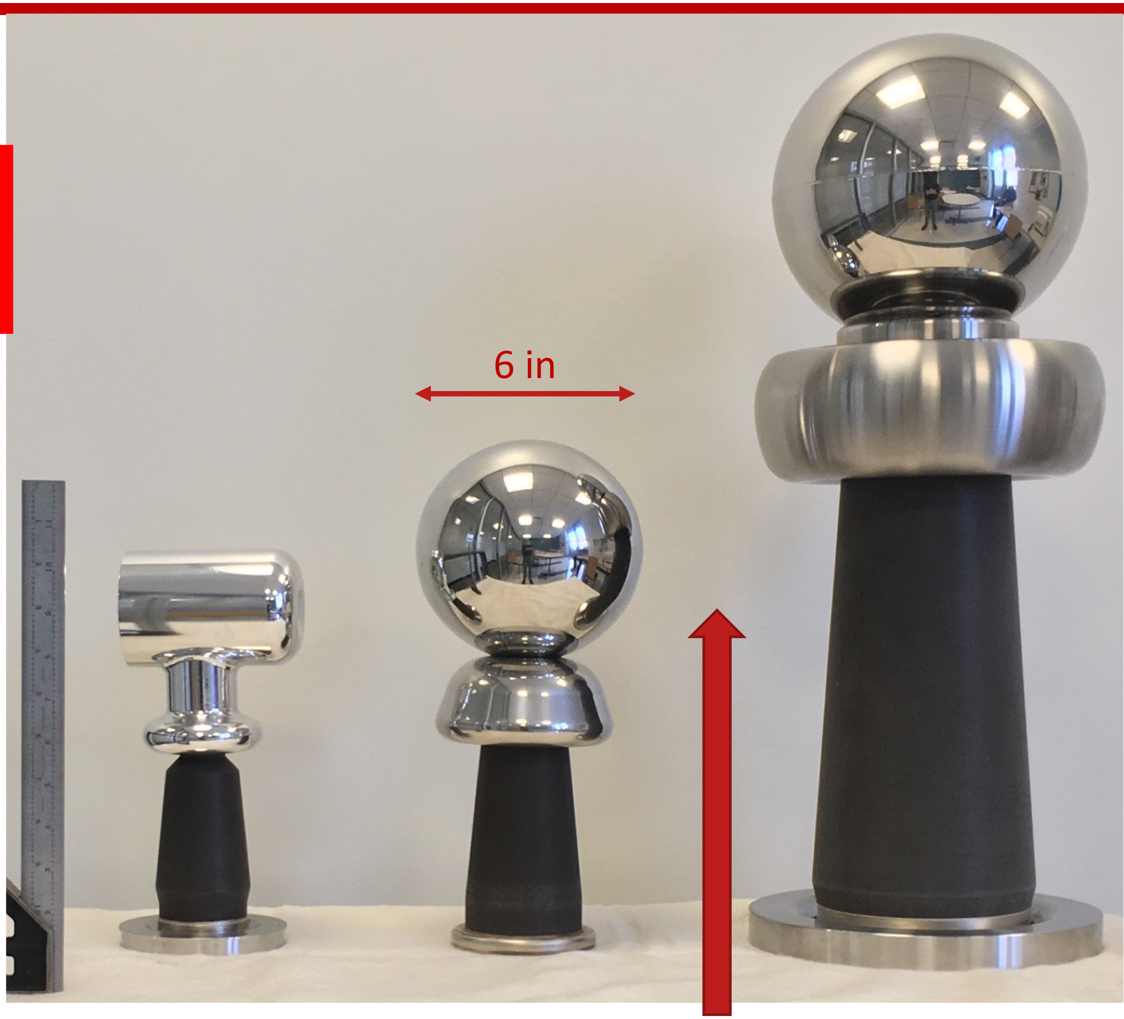
An FOA proposal was submitted to develop a 300 kV DC gun for generating > 1 mA CW spin-polarized *electron beam* as *driver for positron beam* production

The photogun will be designed to meet the following performance requirements:

- Beam polarization > 85 %
- Beam current > 1 mA CW
- Charge lifetime > 1000 Coulombs

Technical challenges:

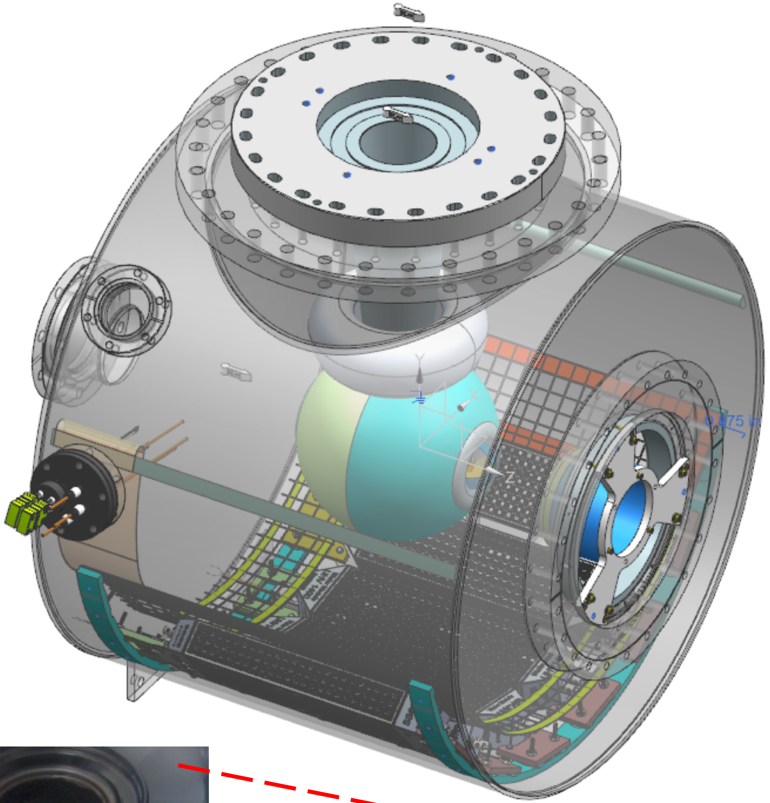
- **Competing design factors play important roles in:**
  - Increasing present charge lifetime observed in CEBAF from ~ 200 C at 0.2 mA CW, to ~1000 C at > 1 mA CW.
- **Vacuum conditions:**
  - Demonstrate < 1x10^{-12} Torr. Chamber materials choices for low outgassing, modeling to minimize surface area while keeping electrode gradient < 10 MV/m at 300 kV.
- **Mitigate QE degradation from ion-back bombardment:**
  - Large laser spot size on the photocathode (spread out damage)
  - Biased anode (repel ions)
  - High (> 250kV) operating voltage (decrease ionization yield)
- **300 kV operations without field emission** :
  - Field-emitted striking the vacuum chamber desorb gas that deteriorates QE
  - Keep max gradient < 10 MV/m at 350 kV



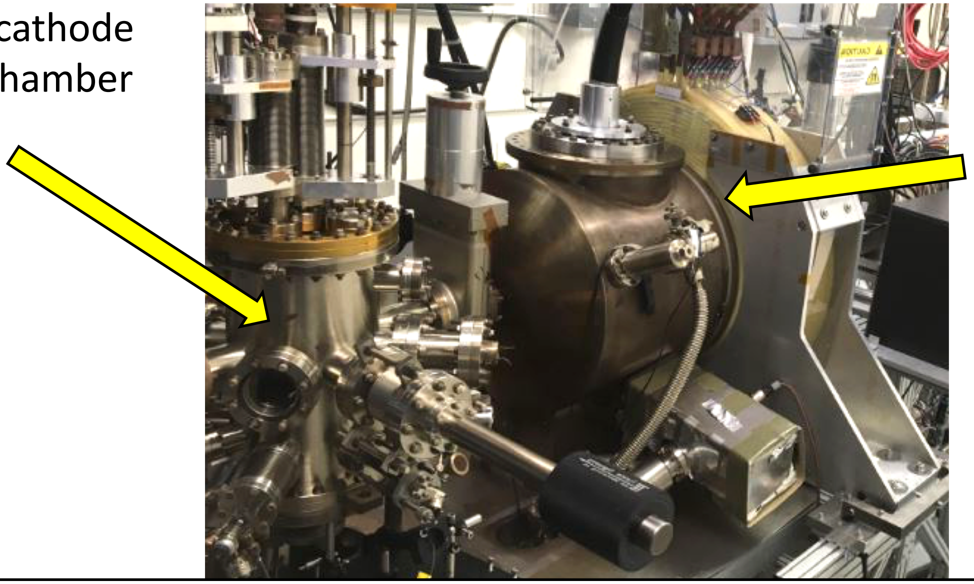
	CEBAF	GTS	Positrons	Test
	130 kV	300 kV	300 kV	500 kV
Field emission onset:	190 kV	300 kV	? > 320 kV	

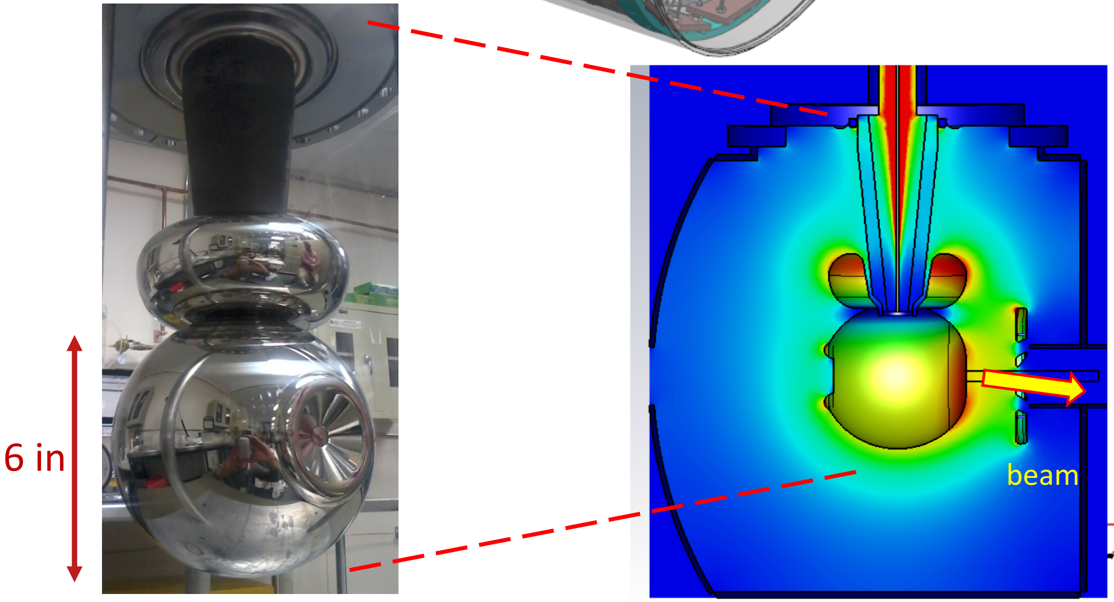
The high current electron gun for positron beam generation is envisioned to be based on the GTS gun design + improvements

- Larger electrode to accommodate larger laser spot size and to reduce gradient
- Larger vacuum chamber to accommodate larger electrode
- Biased and tilted anode to repel ions and compensate beam vertical kick
- Improved NEG system using ZAO 1400 l/s SAES new modules



The GTS gun uses alkali-based photocathodes to generate up to 5 mA CW 300 keV un-polarized electron beams

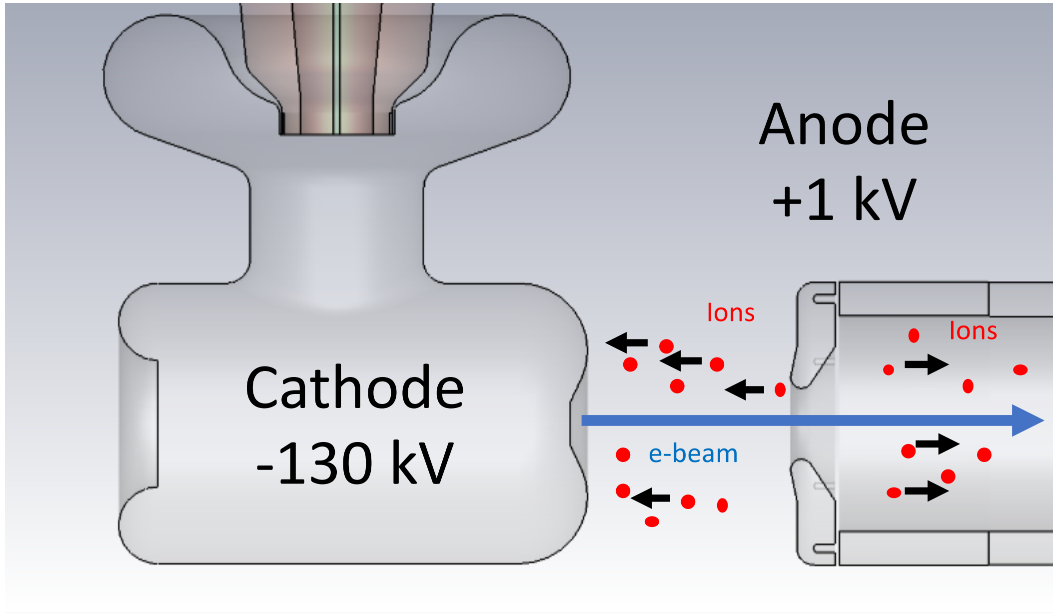


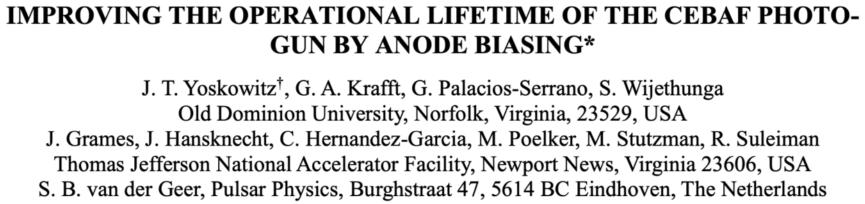


C. Hernandez-Garcia et al., “Compact – 300 kV dc inverted insulator photogun with biased anode and alkali-antimonide photocathode”, PRAB **22**, 113401 (2019)

Ion Damage Experiment at CEBAF

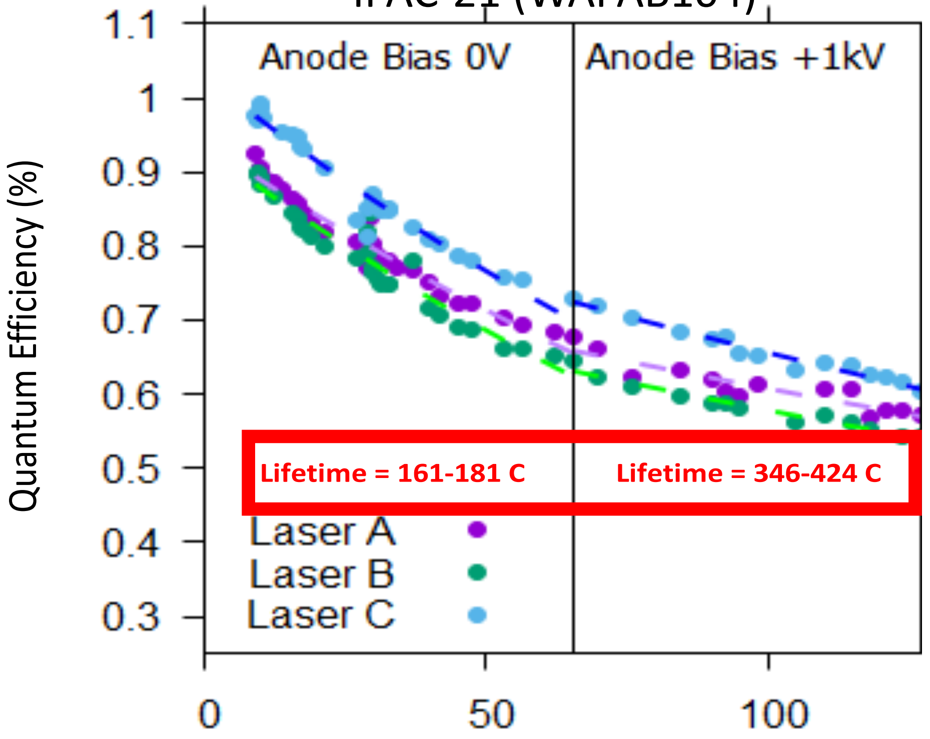
- Many factors contribute to reduction of photocathode lifetime (contamination, bad chemistry, poor vacuum, laser heating, field emission, …)
- In "best technology" gun mitigating ion bombardment remains opportunity for improvement
- At CEBAF tested efficacy of biasing gun anode to repel downstream ions from reaching photocathode




IMPROVING THE OPERATIONAL LIFETIME OF THE CEBAF PHOTO-GUN BY ANODE BIASING*

J. T. Yoskowitz†, G. A. Krafft, G. Palacios-Serrano, S. Wijethunga
Old Dominion University, Norfolk, Virginia, 23529, USA
J. Grames, J. Hansknecht, C. Hernandez-Garcia, M. Poelker, M. Stutzman, R. Suleiman
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
S. B. van der Geer, Pulsar Physics, Burghstraat 47, 5614 BC Eindhoven, The Netherlands

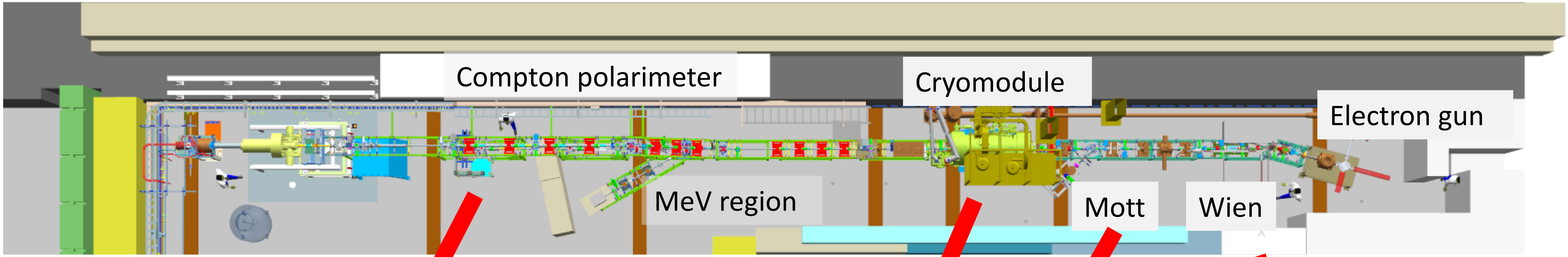
IPAC'21 (WAPAB104)

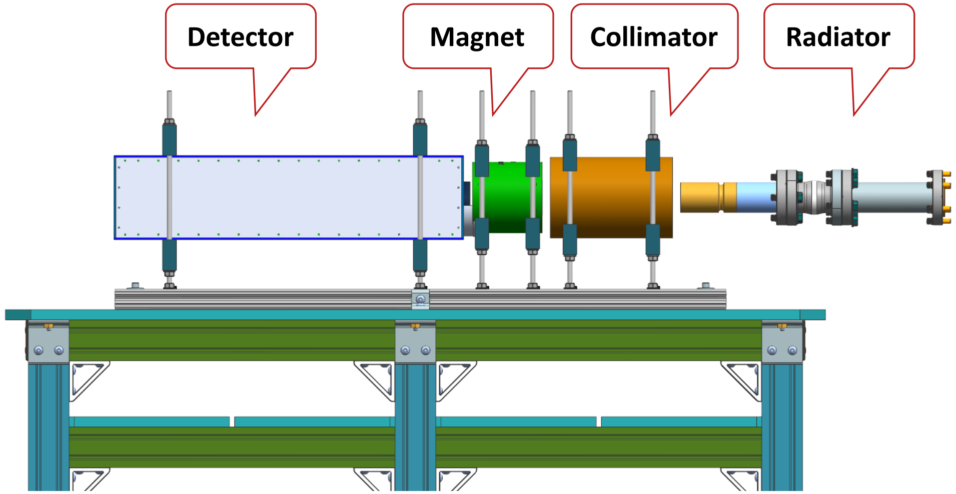


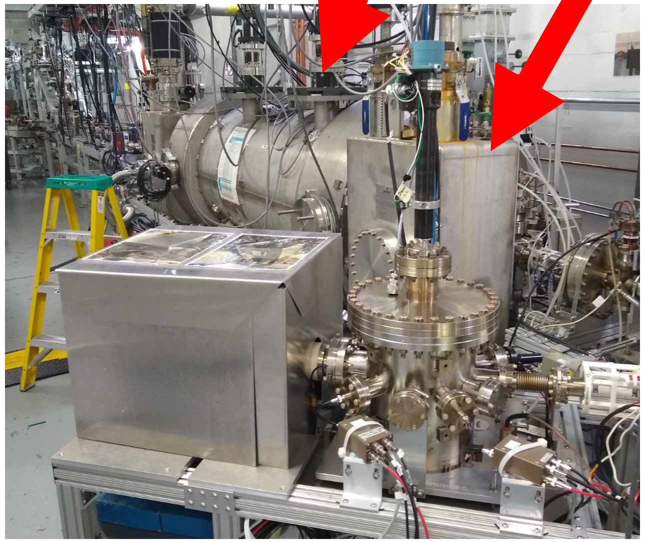
Photocathode lifetime increased by >50% when biasing the photogun anode to repel downstream ions
PhD Thesis work of Josh Yoskowitz, manuscript in preparation for Phys. Rev Accel. and Beams

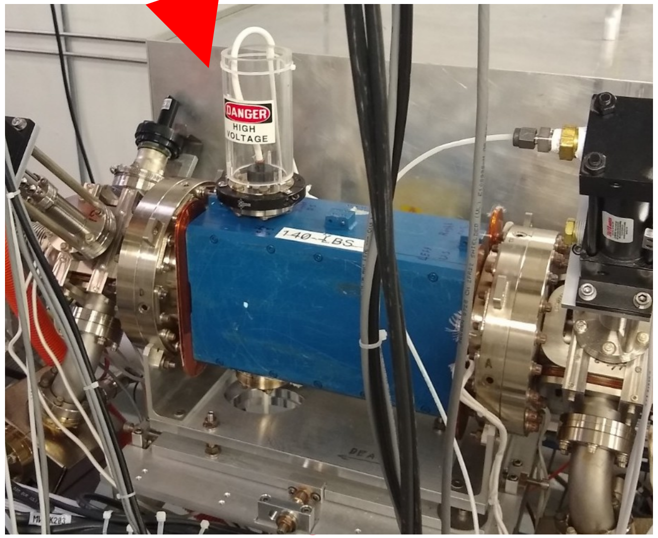
UITF 10 MeV Polarized Electron Accelerator

- UITF 10MeV beam irradiation of water with 1,4-dioxane contamination
  - Polarized photogun, Wien filter an Mott scattering polarimeter for photocathode and lifetime studies
  - Compton polarimeter for SRF polarized gun test at BNL









Ion Damage Experiments at the UITF

Using UITF to probe photocathode lifetime

- JLab scientist Max Bruker is testing hypothesis that higher gun voltage is expected to lead to higher charge lifetime

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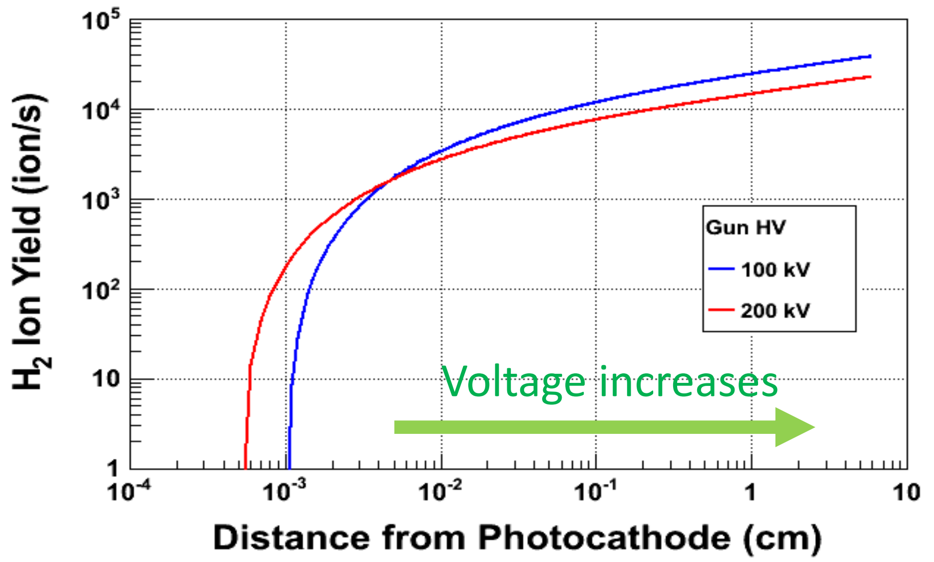
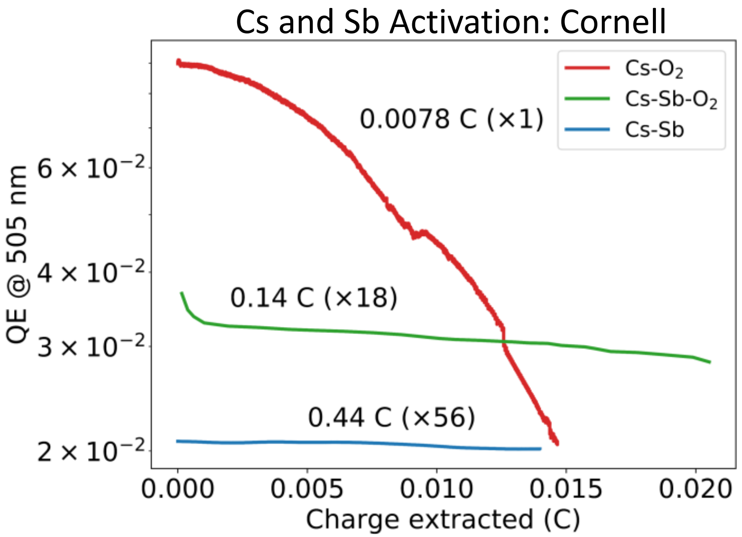
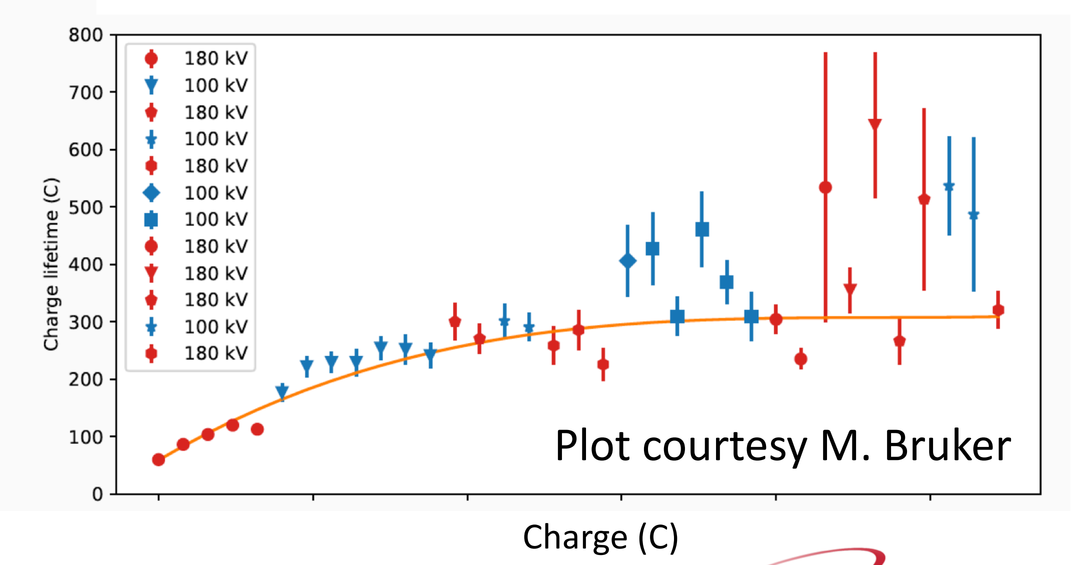
- Testing whether the Cornell NEA activation leads to a more robust chemically stable barrier to ion damage a photogun.



J. Bae *et al*, *J. Appl. Phys* **127**, 124901 (2020)





Pulsar Physics General Particle Tracer (GPT) development at JLab

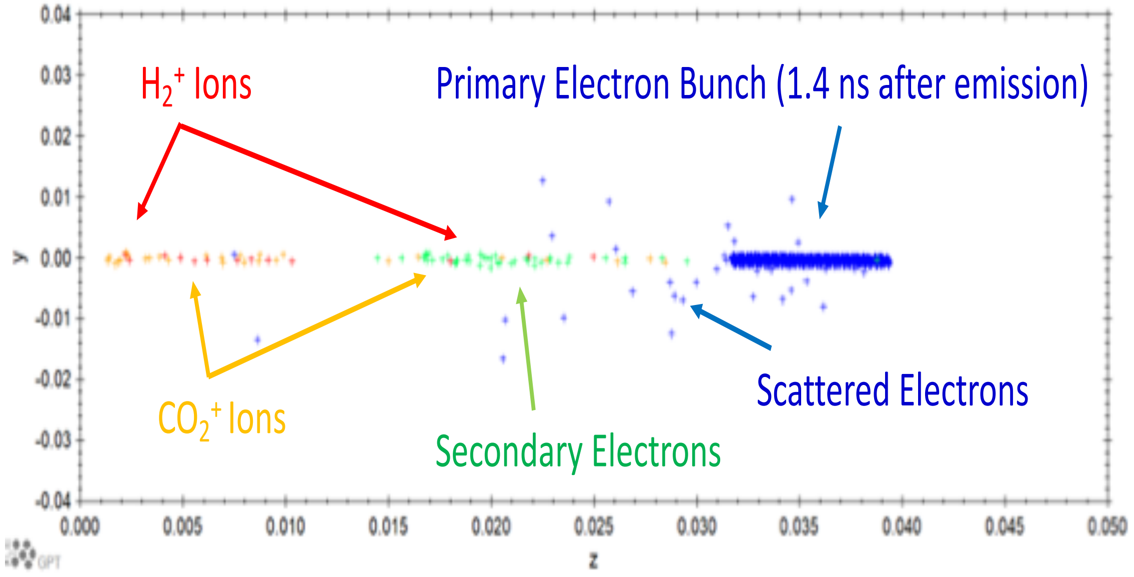
Development of GPT code for injector applications, working closely with Bas van der Geer

- GPT –Ions includes realistic electron impact ionization cross-sections and tracking
- GPT –Spin new version of code which incorporates spin tracking (e-, e+, p, etc.)

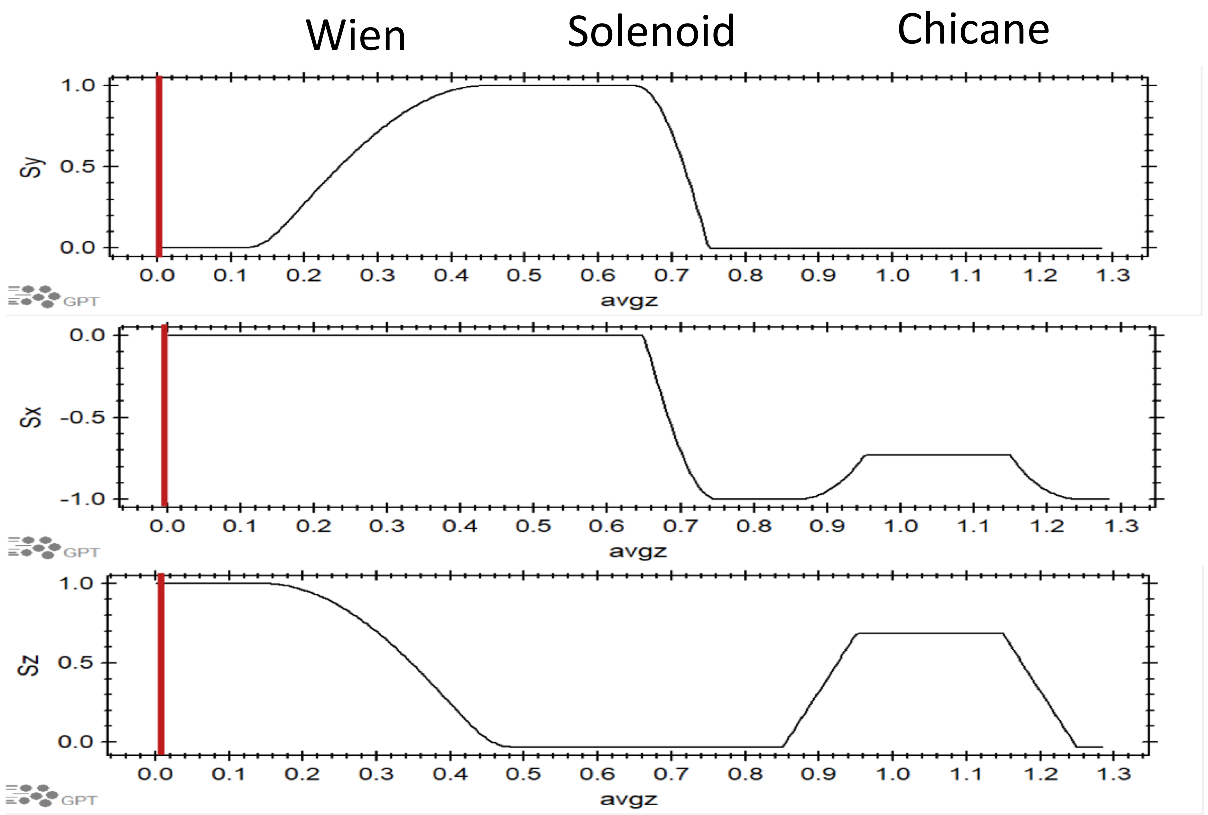
SIMULATING ELECTRON IMPACT IONIZATION USING A GENERAL PARTICLE TRACER (GPT) CUSTOM ELEMENT*

J. T. Yoskowitz†, G. A. Krafft, Old Dominion University, Norfolk, Virginia, 23529, USA
S. B. van der Geer, Pulsar Physics, Burghstraat 47, 5614 BC Eindhoven, The Netherlands
J. Grames, Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
R. Montoya Soto, Departamento de Física, Universidad de Guanajuato, Leon, 37150 Mexico
C. A. Valerio Lizarraga
Facultad de Ciencias Físico-matemáticas Universidad Autónoma de Sinaloa, 80010 Mexico

IPAC'21 (WEPAB105)



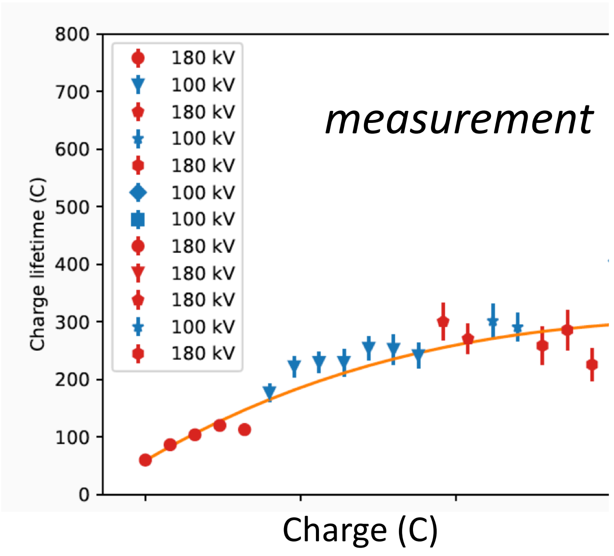
M. Stefani and B. van der Geer, **New Spin Tracking Software Developed For General Particle Tracer**, Proc. of SPIN 2021

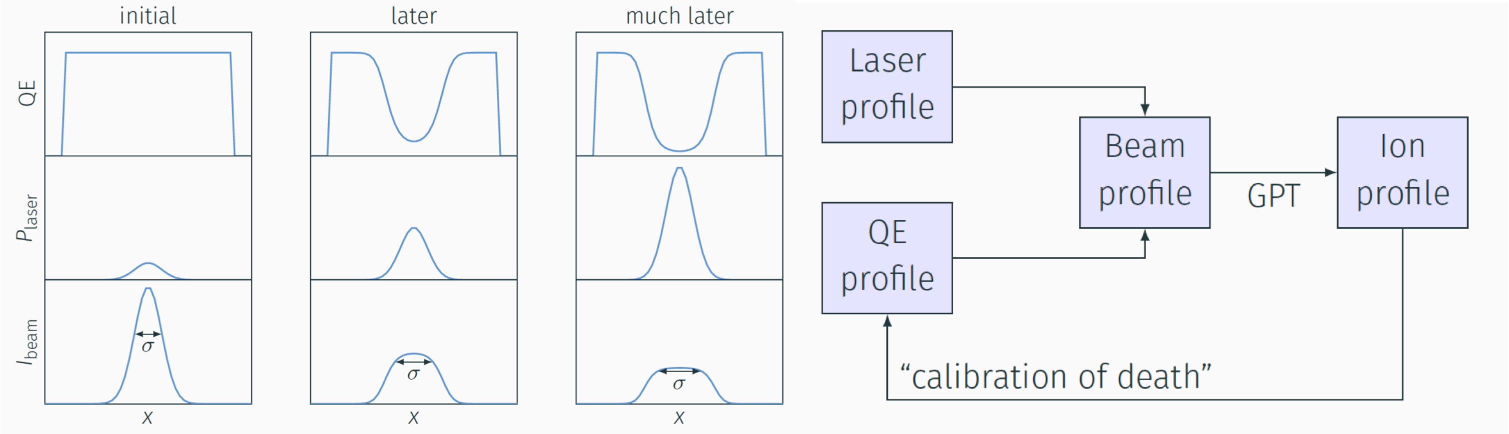


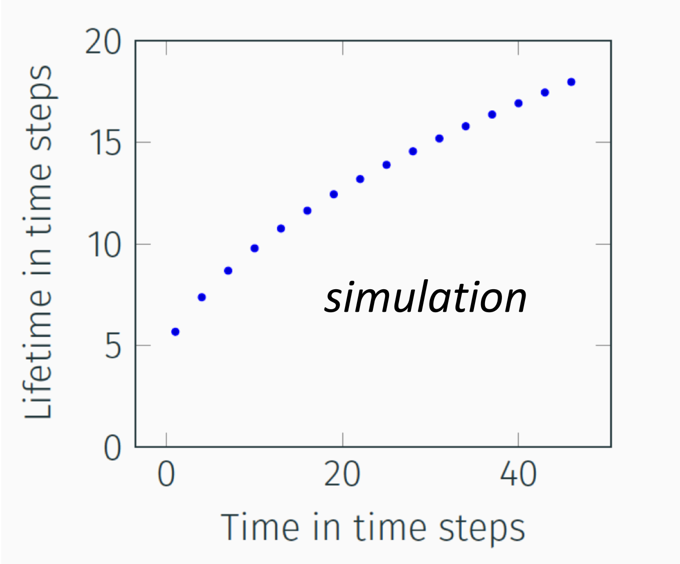
New Simulations using GPT –Ions

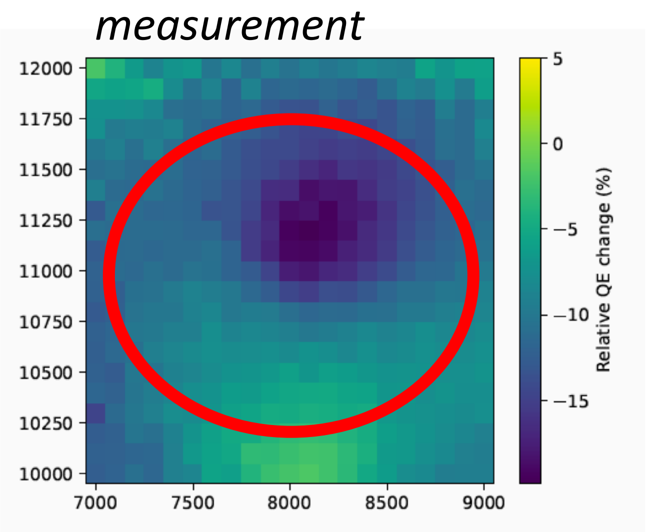
Work of Max Bruker, JLab

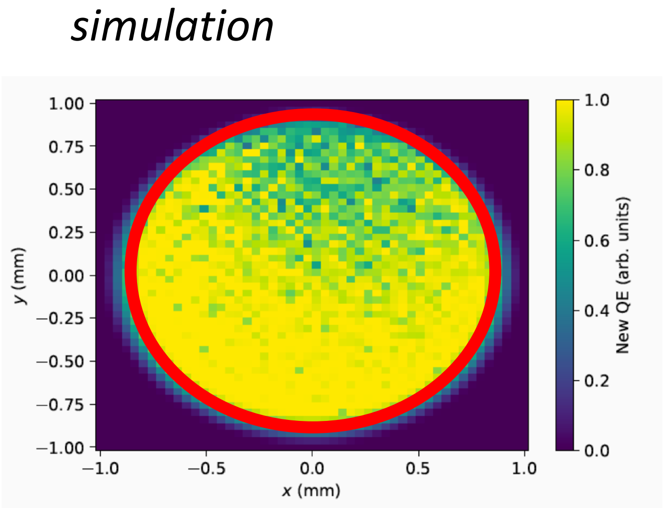
To dynamically explain and predict QE degradation, developing a dynamic mode which can be calibrated to reality.









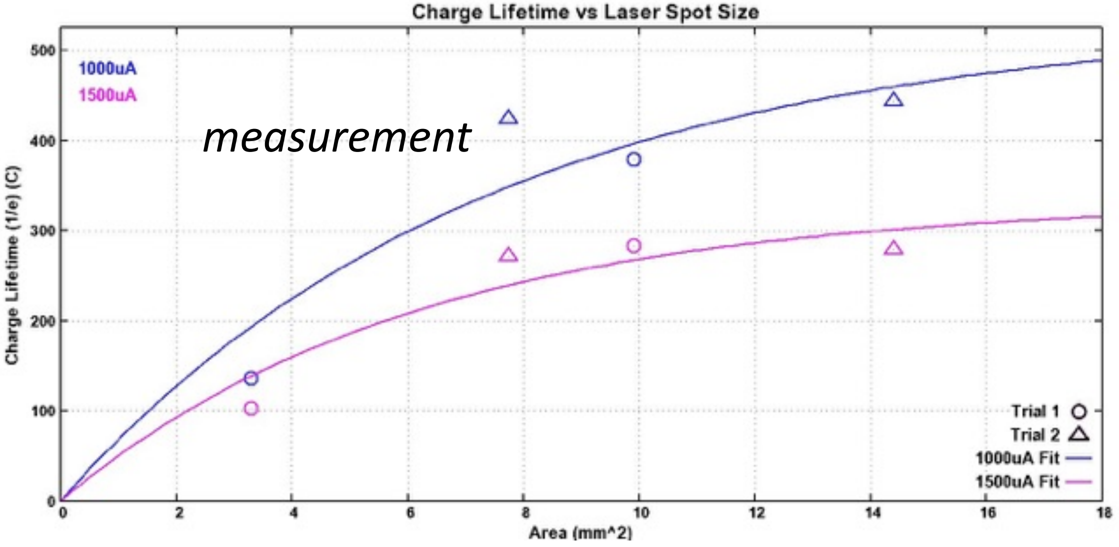


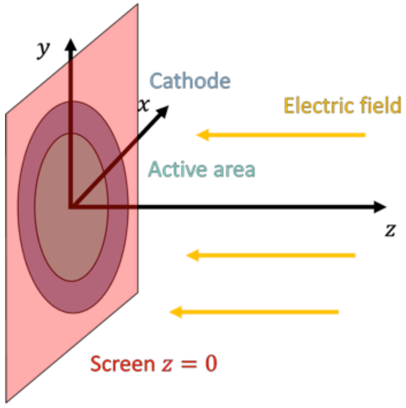
New Simulations using GPT –Ions

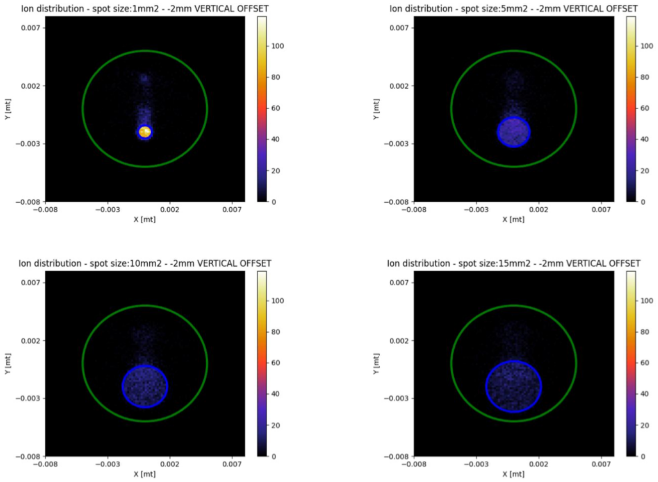
Work of Victor Manuel Lizarraga Rubio, Univ. Sinola Mexico

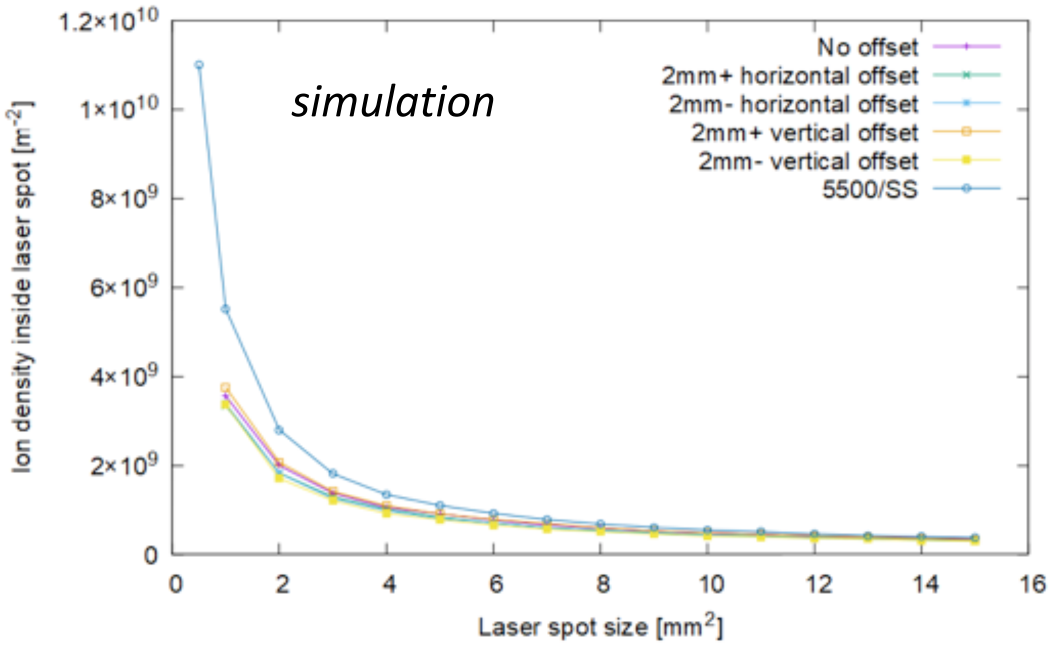
To predict the fraction of ions which return to the laser location as a function of laser position and laser size

Joe Grames et al., "Milliampere beam studies using high polarization photocathodes at the CEBAF Photoinjector", Proc. of PSTP 2017









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Ion Damage Experiments
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- Gun voltage dependence

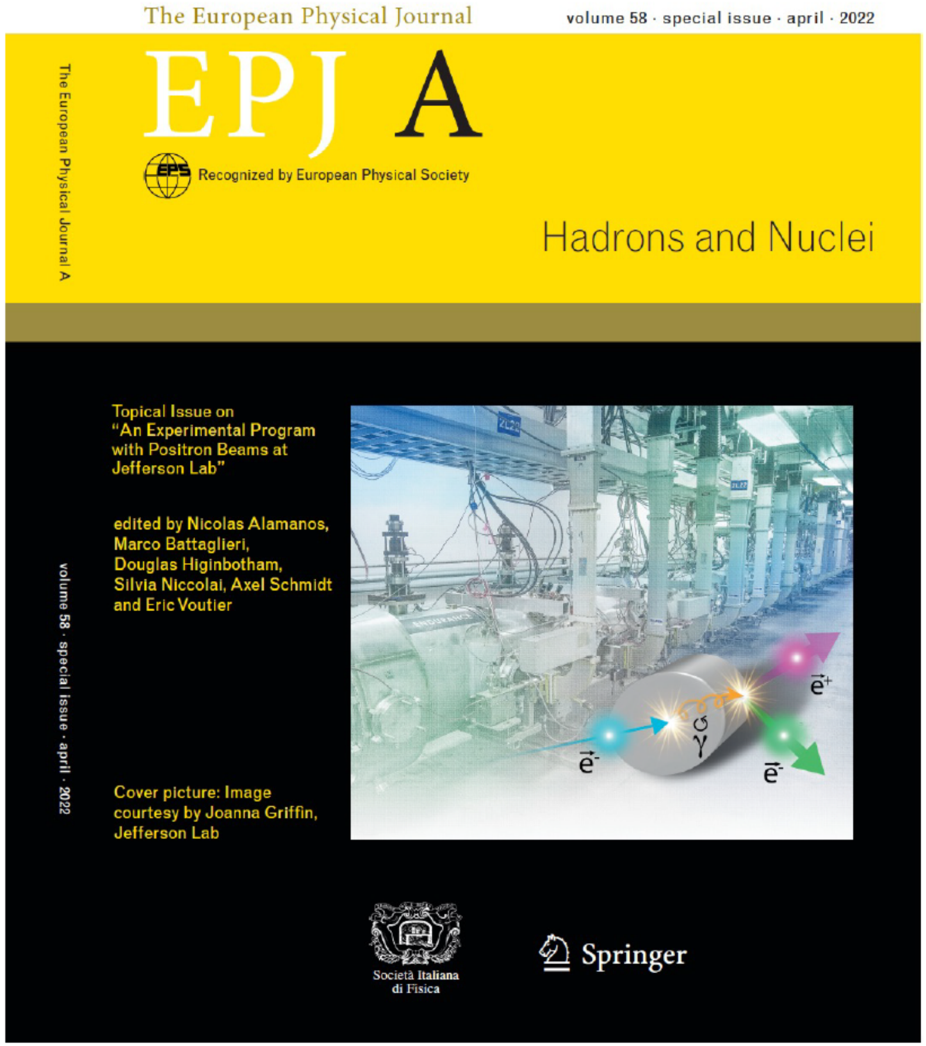
Simulation & Modeling
- GPT ion generation & spin tracking
- Lifetime evolution model
- Spot size evolution model

Polarized e+

Polarized positrons beams for CEBAF
- Physics scope
- CEBAF after 12 GeV e-
- Positron injector
- Technical workshop

Positron physics motivation

The EPJ A Topical Issue about an experimental positron program at CEBAF has been released



Positron Partial Program Summary

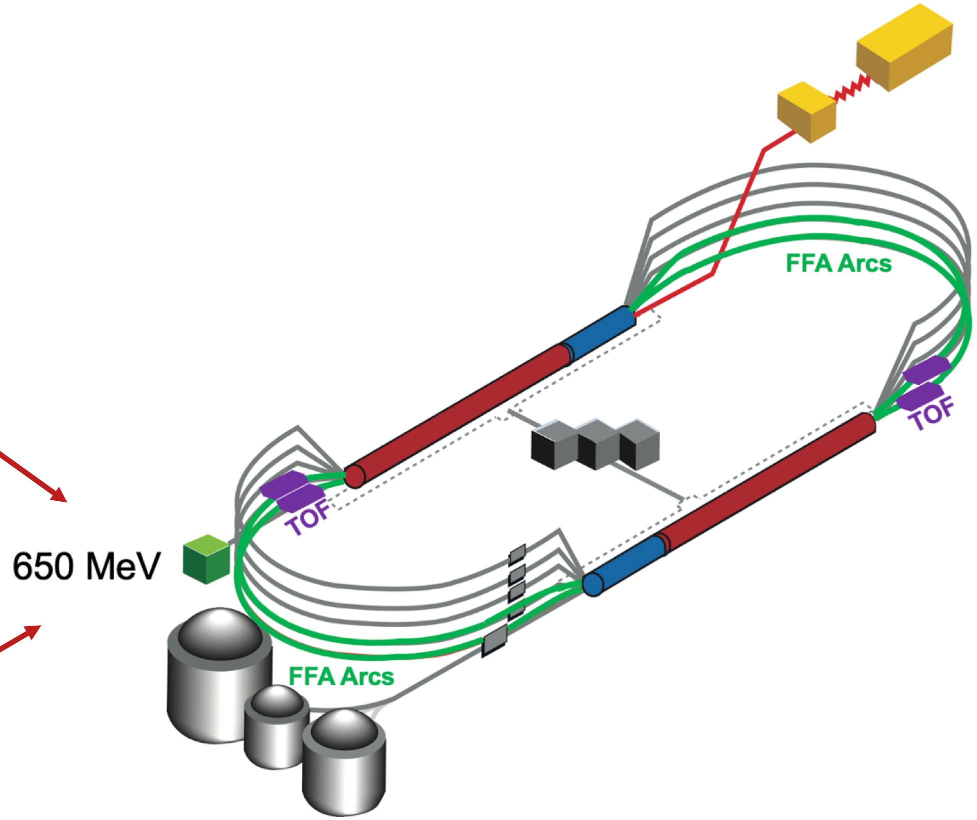
Experiment		Measurement Configuration			Beam Parameters					
Label (EPJ A)	Short Name	Hall	Detector	Target	Polarity	p (GeV/c)	P (%)	I (μA)	Time (d)	PAC Grade
Two Photon Exchange Physics										
57:144	$H(e,e'p)$	B	CLAS12$^+$	H_2	$+/-_s$	2.2/3.3/4.4/6.6	0	0.060	53	
57:188	$H(\vec{e},e'\vec{p})$	A	ECAL/SBS	H_2	$+/-_p$	2.2/4.4	60	0.200	121	
57:199	r_p	B	PRad-II	H_2	+	0.7/1.4/2.1	0	0.070	40	
	r_d			D_2		1.1/2.2		0.010	39	
57:213	$\vec{H}(e,e'p)$	A	BB/SBS	$N\vec{H}_3$	$+/-_s$	2.2/4.4/6.6	0	0.100	20	
57:290	$H(e,e'p)$	A	HRS/BB/SBS	H_2	$+/-_s$	2.2/4.4	0	1.000	14	
57:319	SupRos	A	HRS	H_2	$+/-_p$	0.6−11.0	0	2.000	35	
58:36	$A(e,e')A$	A	HRS	He	$+/-_p$	2.2	0	1.000	38	
Nuclear Structure Physics										
57:186	p-DVCS	B	CLAS12	H_2	$+/-_s$	2.2/10.6	60	0.045	100	C2
57:226	n-DVCS	B	CLAS12	D_2	$+/-_s$	11.0	60	0.060	80	
57:240	p-DDVCS	A	SoLID$^\mu$	H_2	$+/-_s$	11.0	(30)	3.000	100	
57:273	He-DVCS	B	CLAS12/ALERT	^{4}He	$+/-_s$	11.0	60			
57:300	p-DVCS	C	SHMS/NPS	H_2	+	6.6/8.8/11.0	0	5.000	77	C2
57:311	DIS	A/C	HRS/HMS/SHMS		$+/-_s$	11.0				
57:316	VCS	C	HMS/SHMS	H_2	$+/-_s$		60			
Beyond the Standard Model Physics										
57:173	C_{3q}	A	SoLID	D_2	$+/-_s$	6.6/11.0	(30)	3.000	104	D
57:253	LDM	B	PADME ECAL/HCAL	C $PbW0_4$	+	11.0	0	0.100	180 120	
57:315	CLFV	A	SoLID$^\mu$	H_2	+	11.0				
								Total (d)	**1121**	

CLAS12$^+$ ≡ CLAS12 … l Detector
SoLID$^\mu$ ≡ SoLID com…
+ Secondary positron …
$-_s$ Secondary electron …
$-_p$ Primary electron b…
(30) Do not require pc… beam intensity

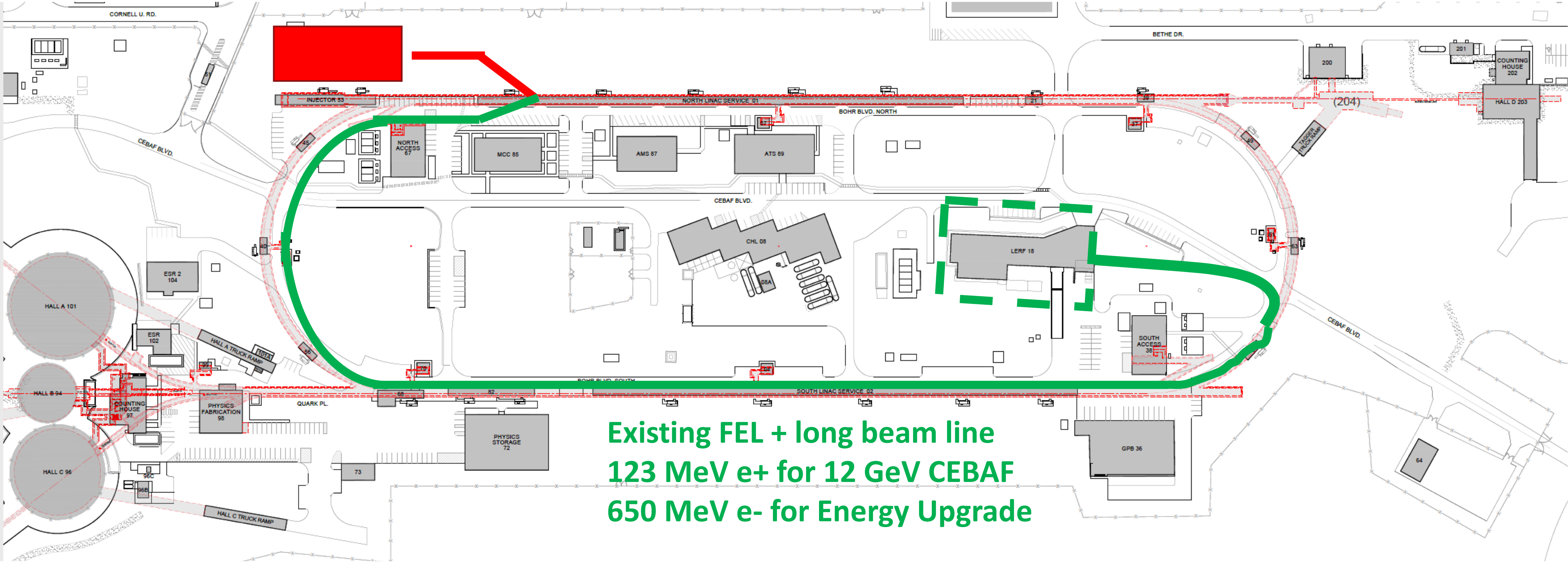
Assuming
36 weeks/year of beam and
50% accelerator efficiency, this is
4.8 years of running.

CEBAF Upgrade(s) beyond 12 GeV e-

- Polarized positrons capability
  - Near term, ~5 years, 12 GeV, multi-hall
  - Imagine 100 – 300 MeV e- injector
- Energy upgrade experimental program
  - 22 GeV, a decade from now, multi-hall
    - Can have an intermediate stage of 17 GeV
  - Replace two arcs per side with new FFA permanent magnet arcs
    - (Single pair of arcs is considered too)
  - Requires ~600 MeV e- injector
    - This mean a shielded vault of ~70x10m



An electron/positron injector vault is required for both upgrades



Green option is presently more cost effective and provides options for staging positron and energy upgrade

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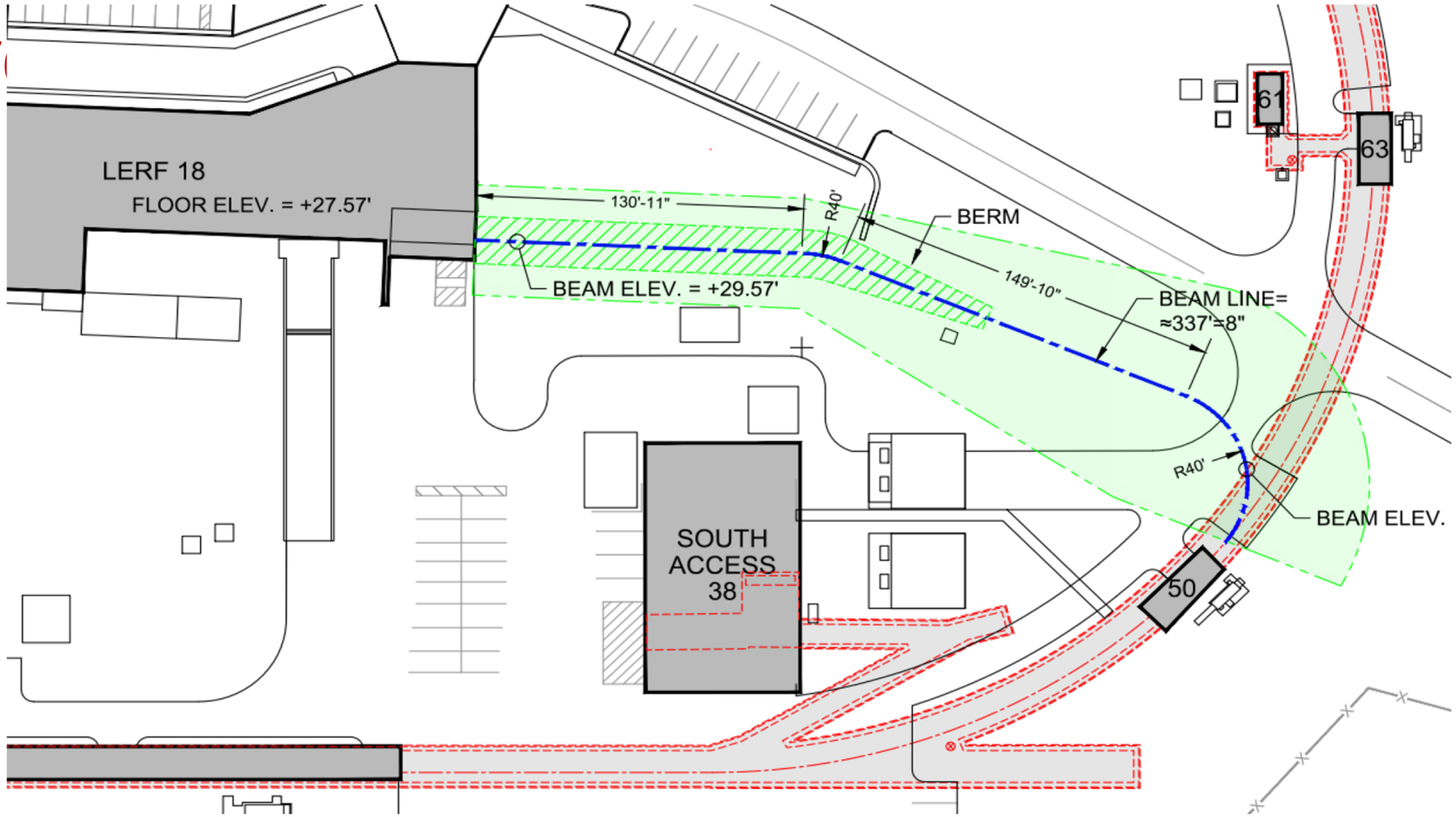
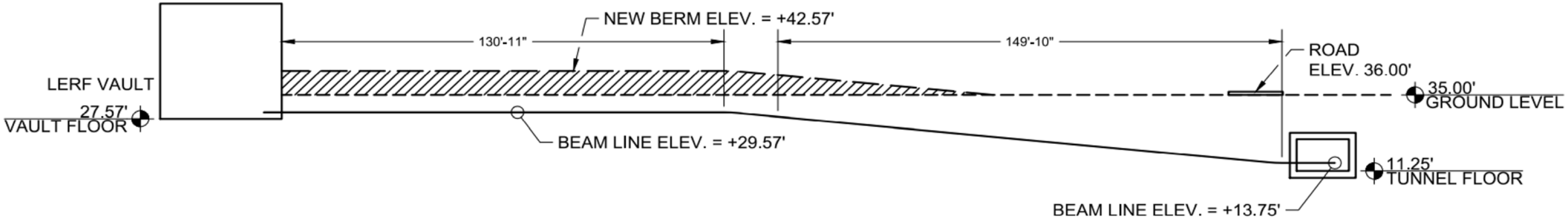
Tunnel to East Ar

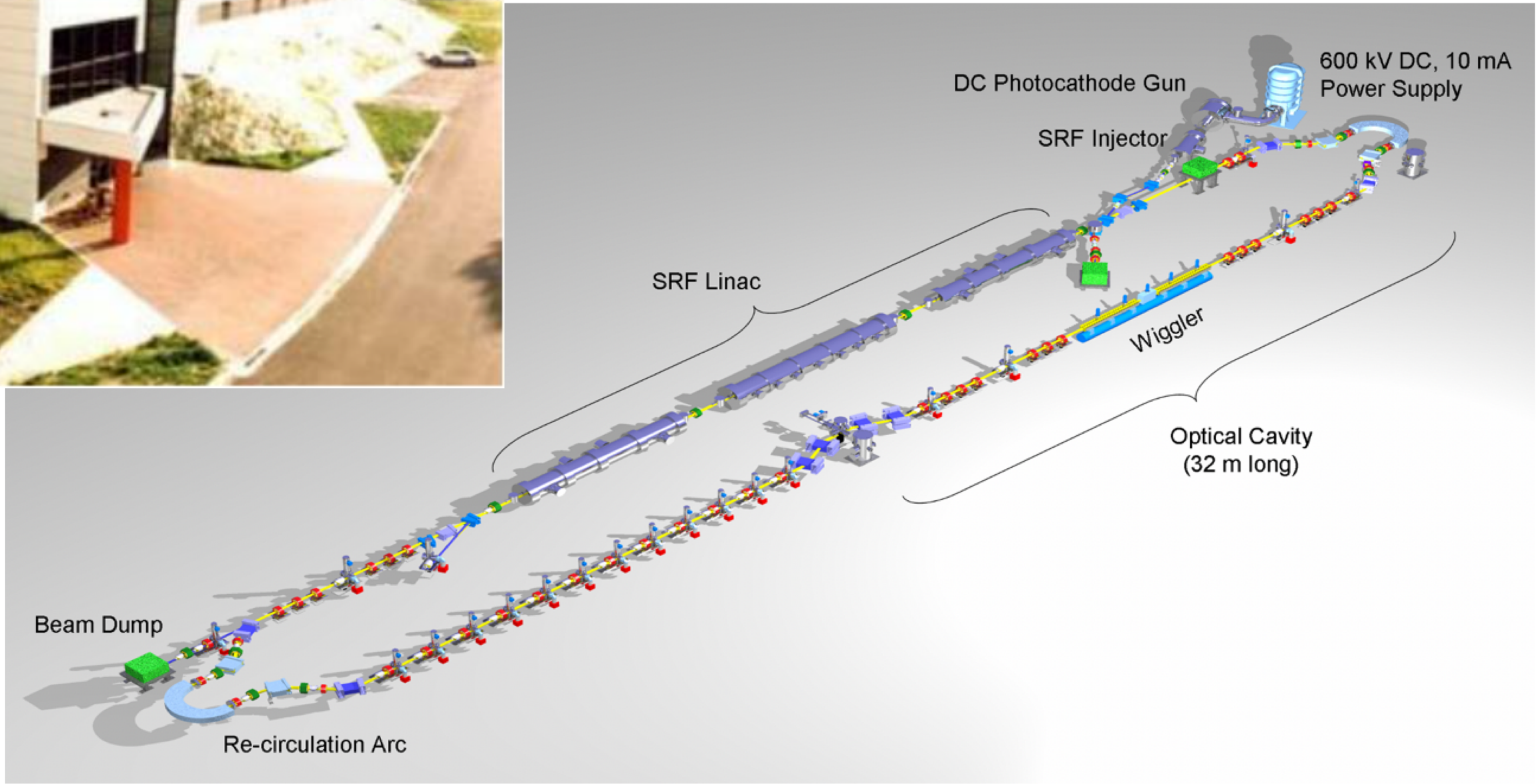
- Conventional Facilities construction experts assessment and design optimization
  - Options 2a and 2b assessed
  - Option 2c suggested and evaluated
  - Feasibility confirmed
- Rough cost estimates for hardware are in the process



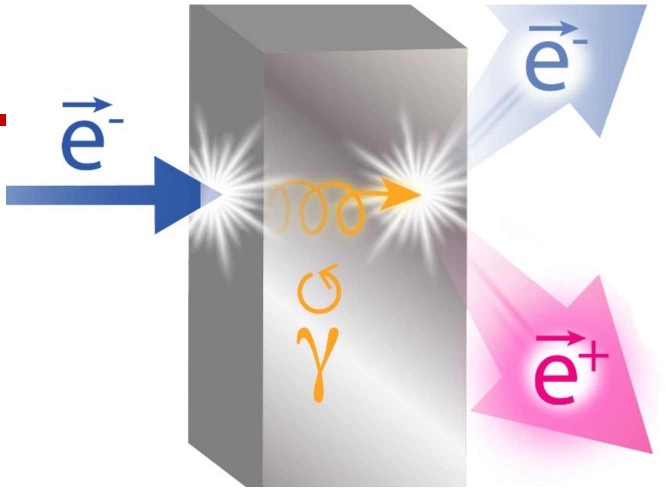


Drawings courtesy Joel Dolbeck

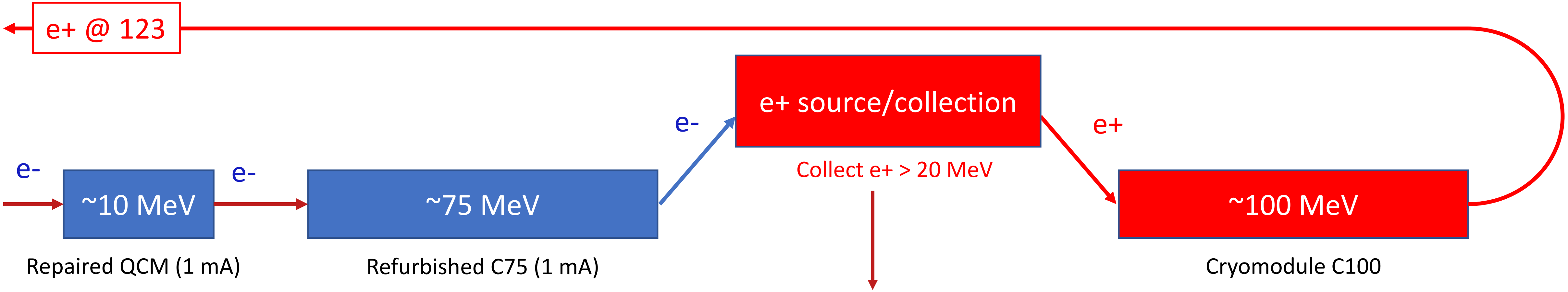
Staging electron/positron injector at the FEL



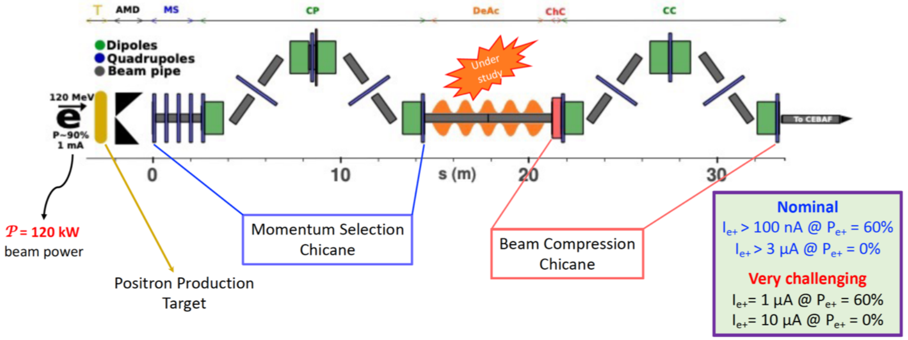
Polarized e+, big picture



- Hardware needed:
  - High current polarized e- source
  - A cryomodule to accelerate e-
  - An e+ target-source and collection system
  - A cryomodule to accelerate e+



Polarized positrons generation



Would like to organize a workshop at Jlab in the Late 2022 or Early 2023 to discuss technical collaboration.

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