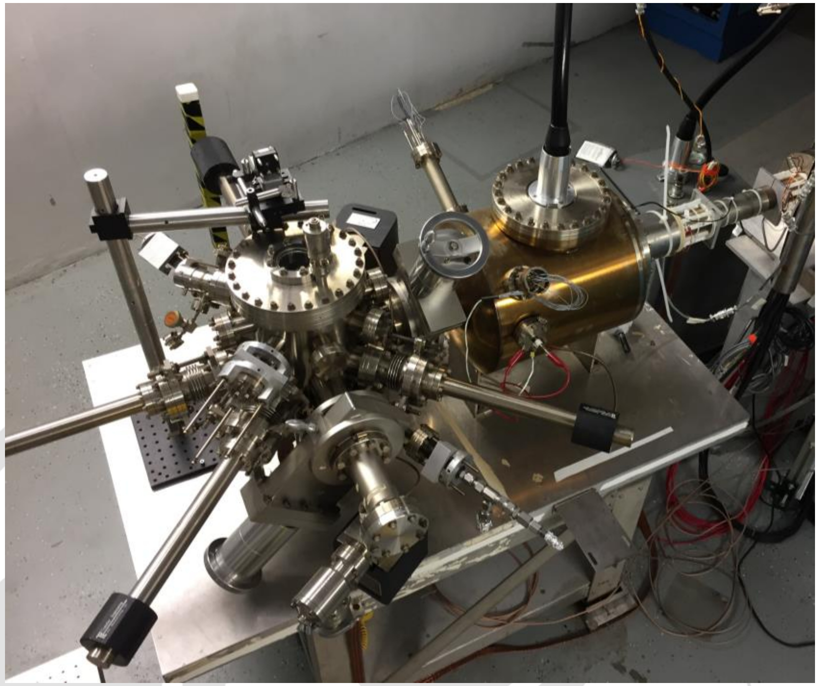
Polarized Electrons for Polarized Positron Beams

CEBAF Polarized Electron Source



- **P**olarized **E**lectrons for **P**olarized **Po**sitrons (PEPPo)
- Positron beam R&D @ JLab
- Example for a 3 GeV e- linac

Joseph Grames, Jefferson Laboratory
on behalf of the Ce^{+}BAF Working Group

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

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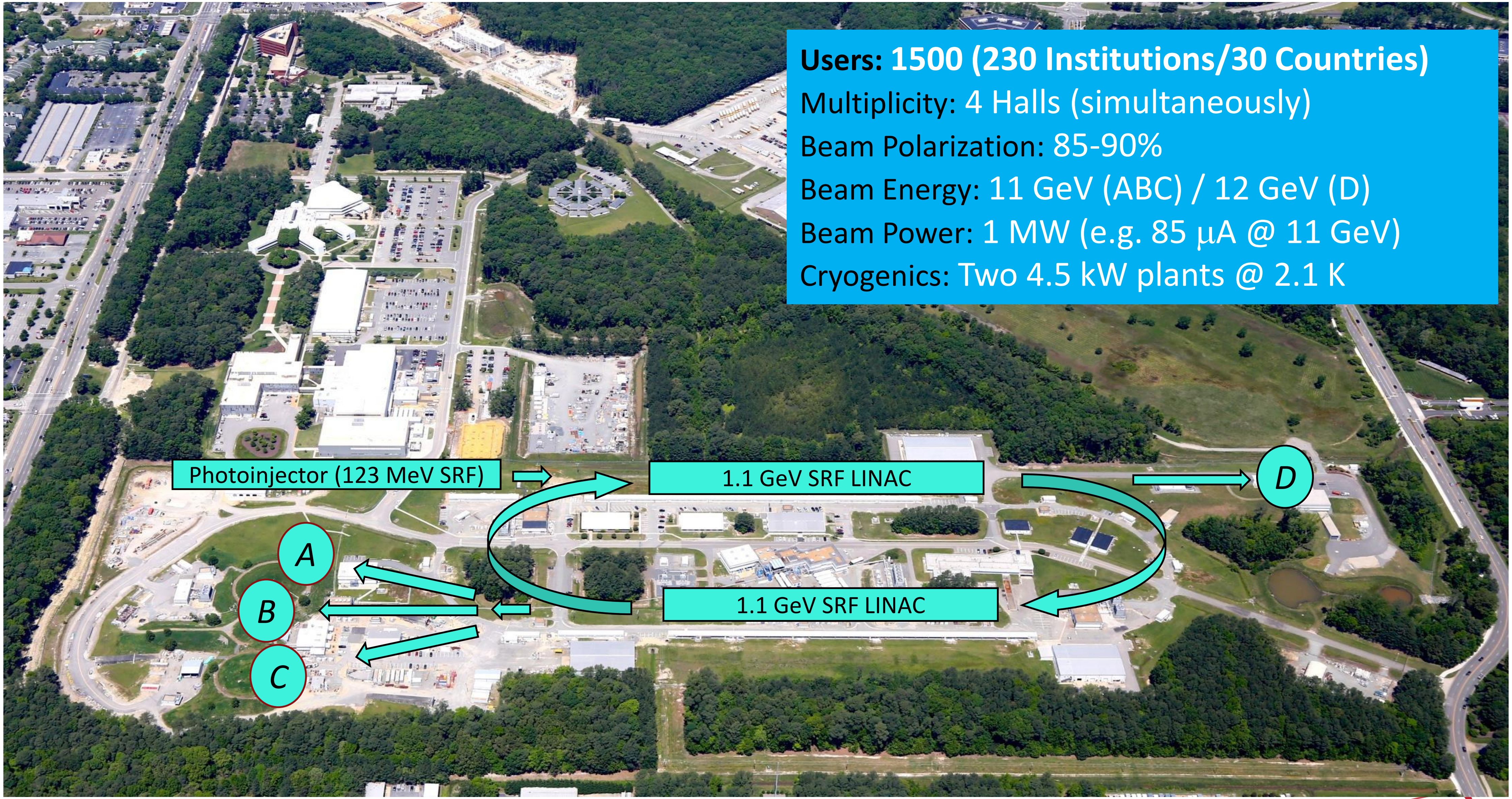
Future Circular Collider Week

June 10-14, 2024

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Jefferson Lab in Newport News, Va : CEBAF @ 12 GeV



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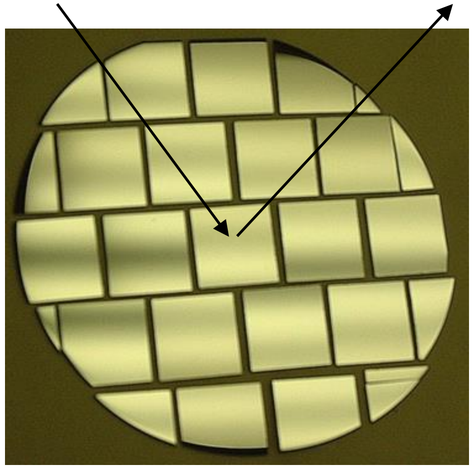
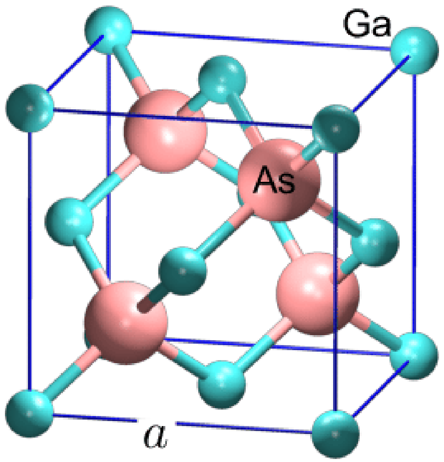
Spin polarized photoemission from GaAs

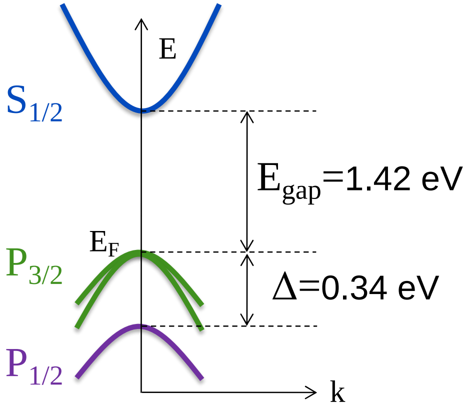
Photons IN # Electrons Out

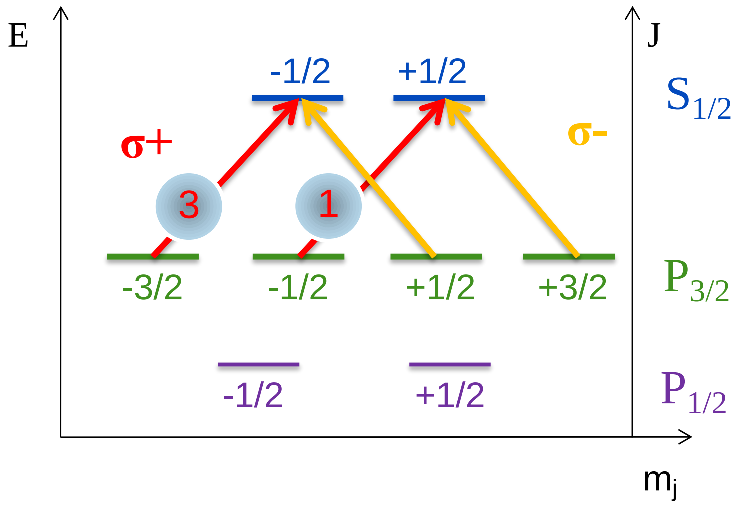
GaAs





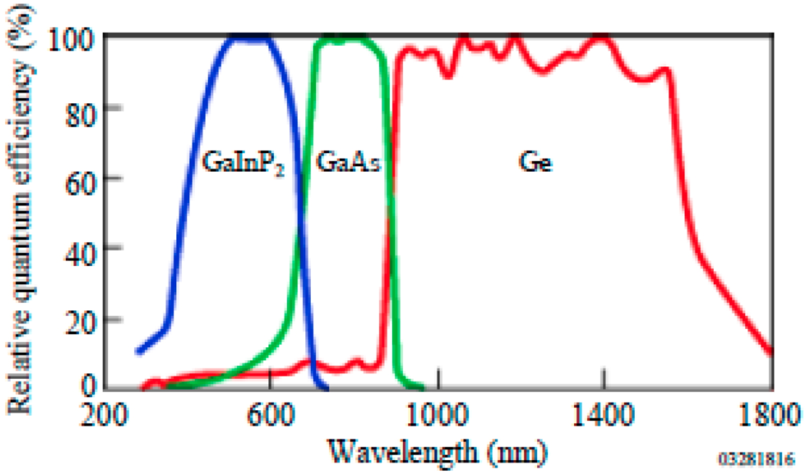
Zinc-blende bcc





$$\mathrm{QE} = \frac{hc}{e}\frac{I}{\lambda P}$$

$$\mathrm{QE}(\%) = \frac{124 * I\,(\mathrm{mA})}{\lambda\,(\mathrm{nm})\,P\,(W)}$$



Al-Naser, Qusay & Hilou, Hassan & Abdulkader, Abbas. (2009). The last development in III-V multi-junction solar cells. 1. 10.1109/CCCM.2009.5268104.

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Enabling Technology : CEBAF Polarized Electron Sources based on GaAs

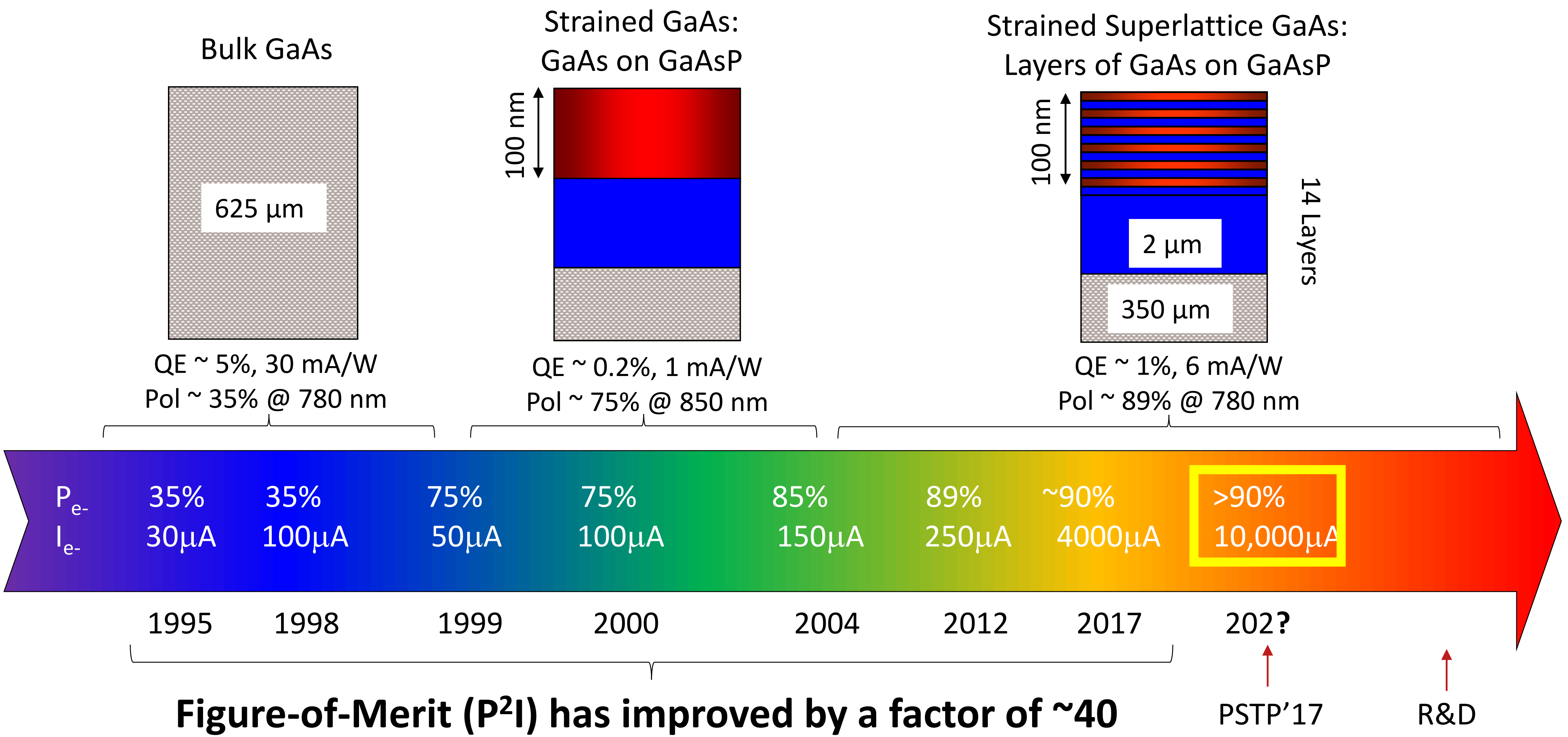


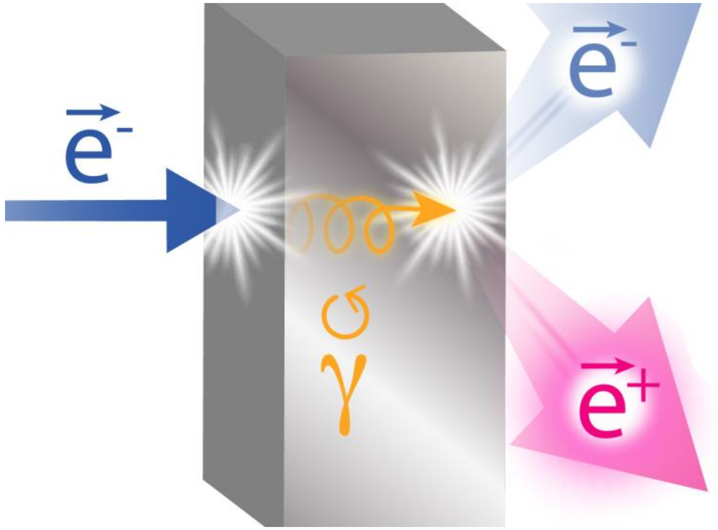
Figure-of-Merit (P^2I) has improved by a factor of ~40 over the span of the CEBAF lifetime

Intensity and Polarization requirements for positrons at CEBAF

Parameter	CEBAF 12 GeV Electron Beam	Proposed 12 GeV Positron Beam
Experiment Intensity	10 nA - 170 μA	**> 50 nA (pol)** **> 1 μA (unpol)**
Duty Factor	100% (cw)	same
Bunch Frequency	249.5/499 MHz	same
Spin Polarization	>85%	**>60%**
Rapid Spin Reversal	30 – 2000 Hz (Pockels cell)	same

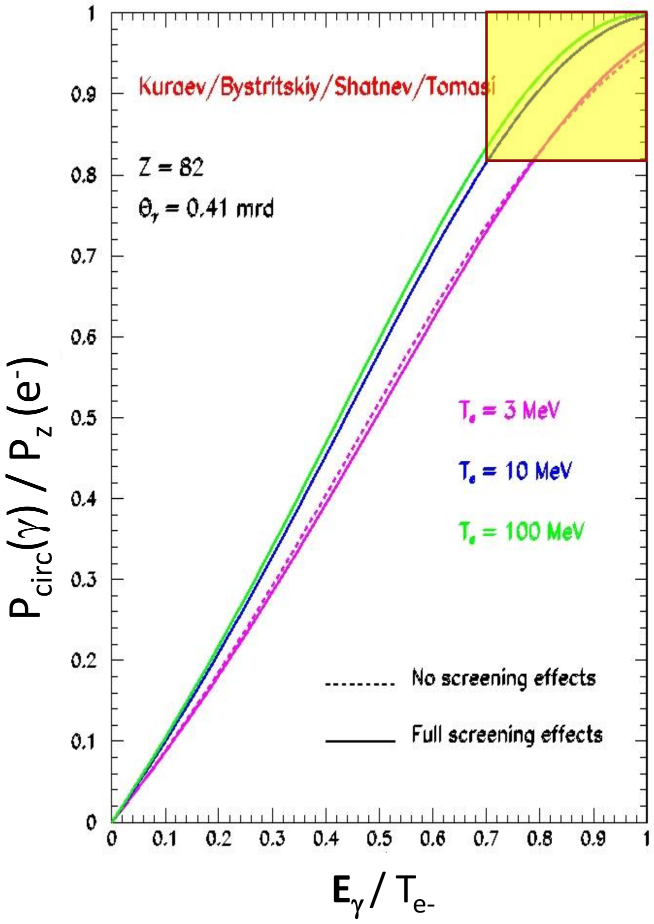
New Method : Exploit Electron Beam Spin Polarization

$$\vec{e}^- \to \vec{\gamma} \to \vec{e}^+ \; (+ \; \vec{e}^-)$$

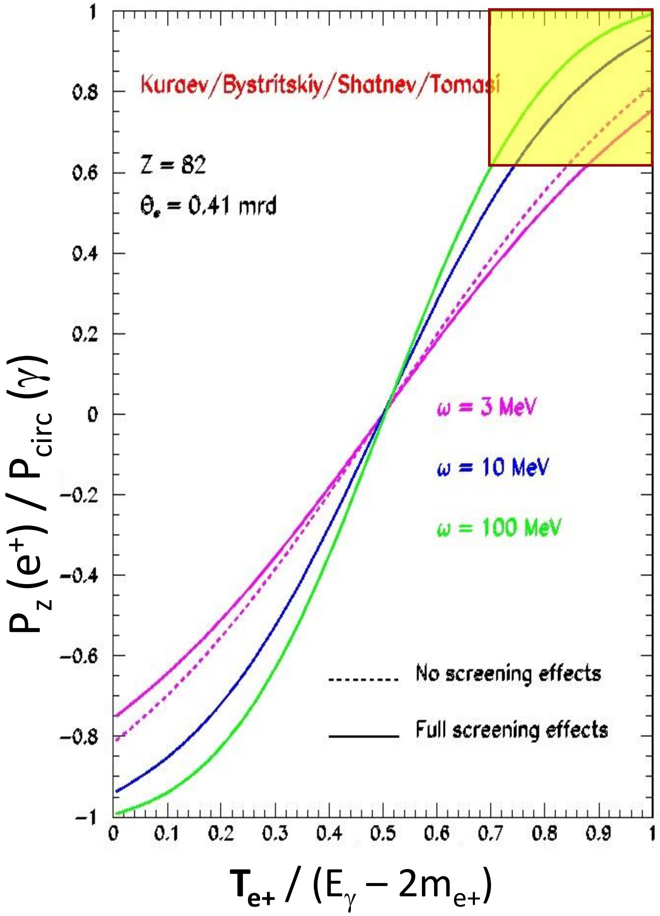


When a longitudinally polarized e^- beam strikes matter, e^+ produced in the shower carrying >50% of the e^- beam energy are significantly longitudinally spin polarized…

Polarized Bremsstrahlung



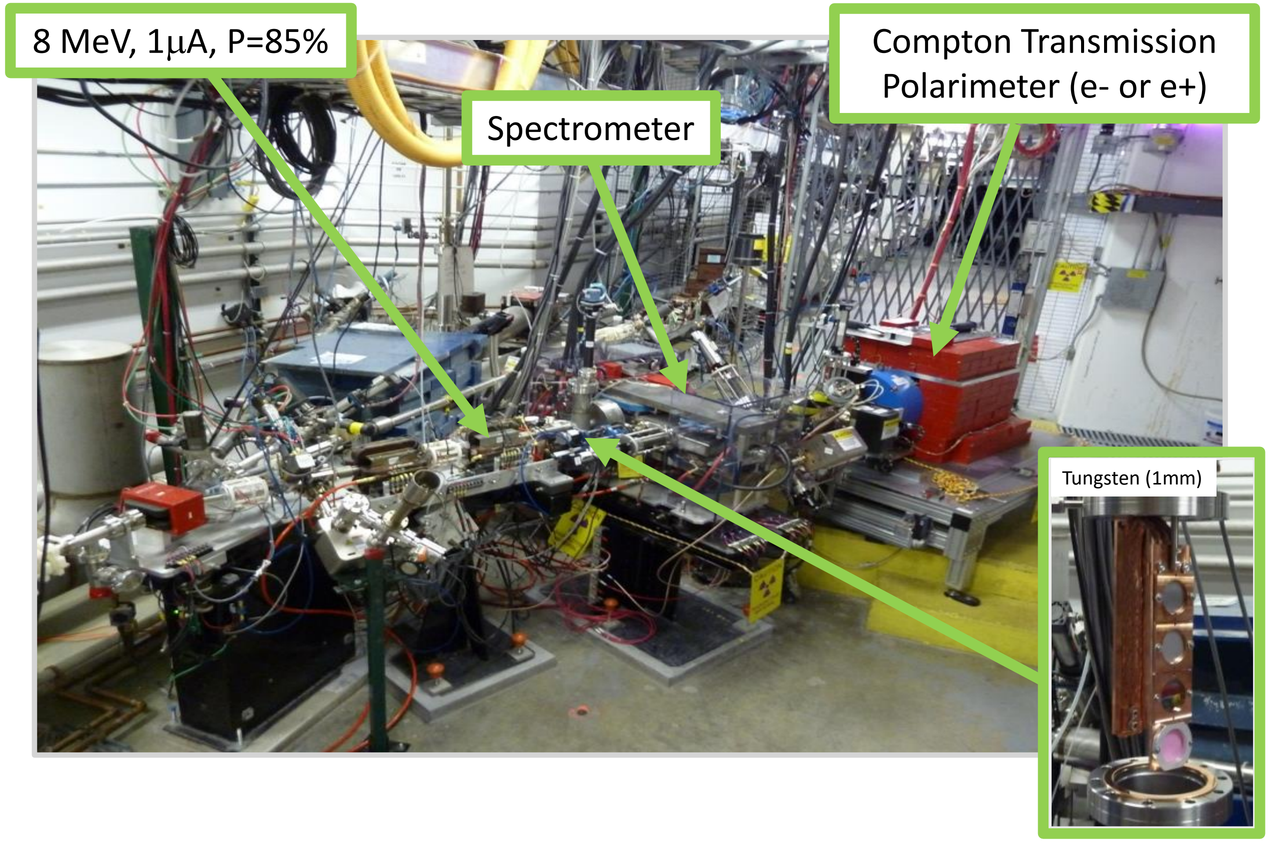
Polarized Pair Creation



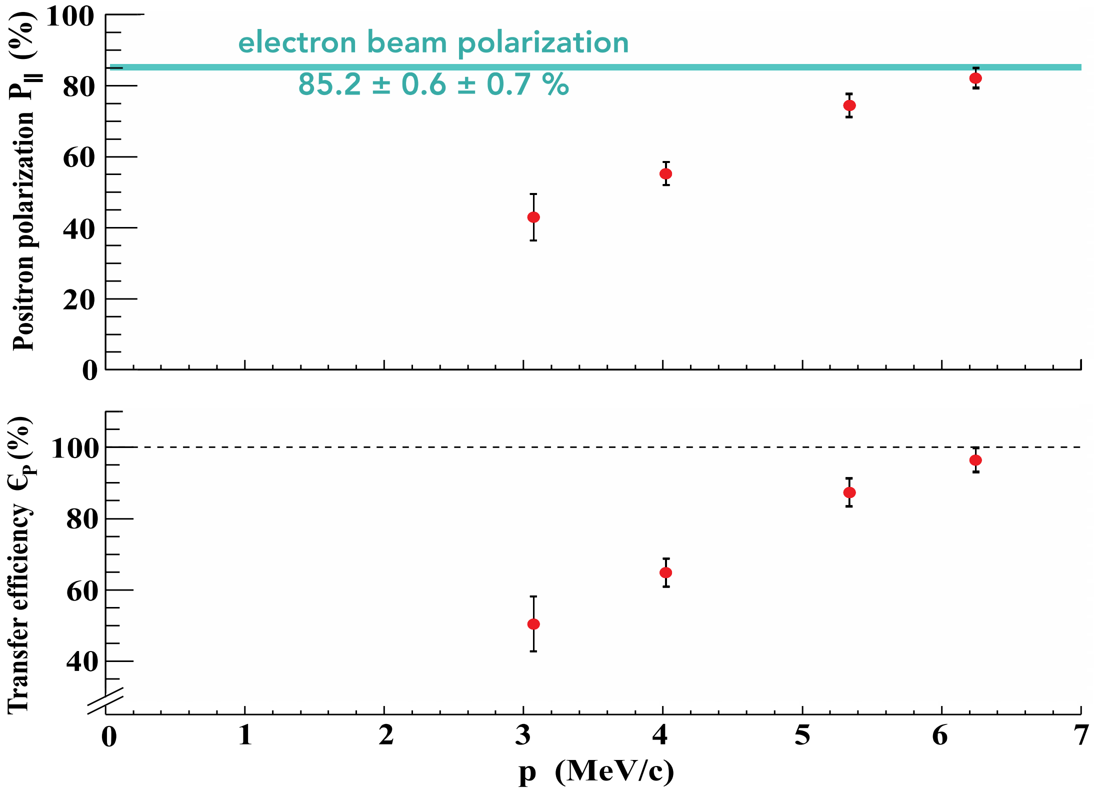
E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208

PEPPo Experiment : Feasibility Demonstration at the CEBAF Injector (2012)

J. Grames, E. Voutier et al.,
JLab Experiment E12-11-105 (2011)



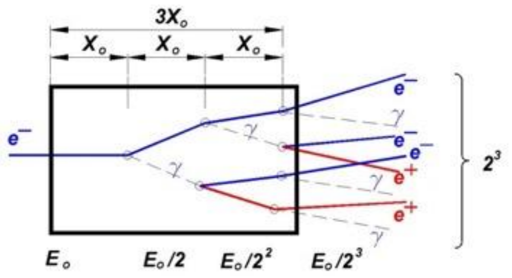
(PEPPo Collaboration) D. Abbott et al., Phys. Rev. Lett. ***116*** *(2016) 214801*



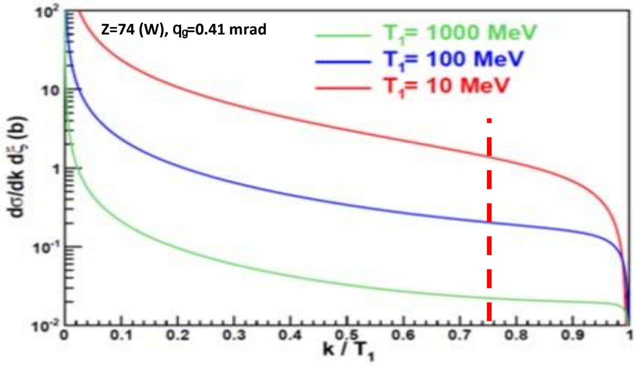
PEPPo possible due to support from ***SLAC*** *E166,* ***DESY, Princeton, Cornell, International Linear Collider Project*** *and the* ***Jefferson Science Associates***

PEPPo : Polarization and Intensity Trade Off

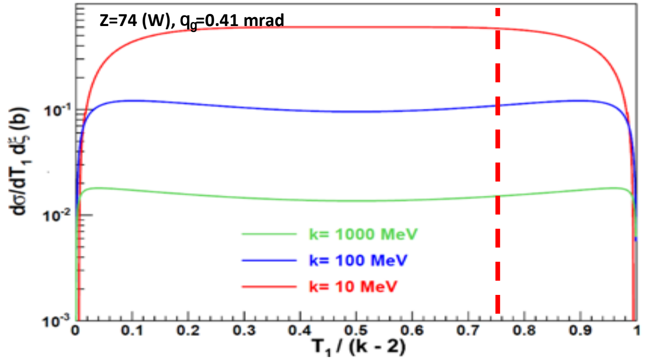
A realistic PEPPo source requires a convolution of repeated bremsstrahlung and pair-creation in a finite length target.

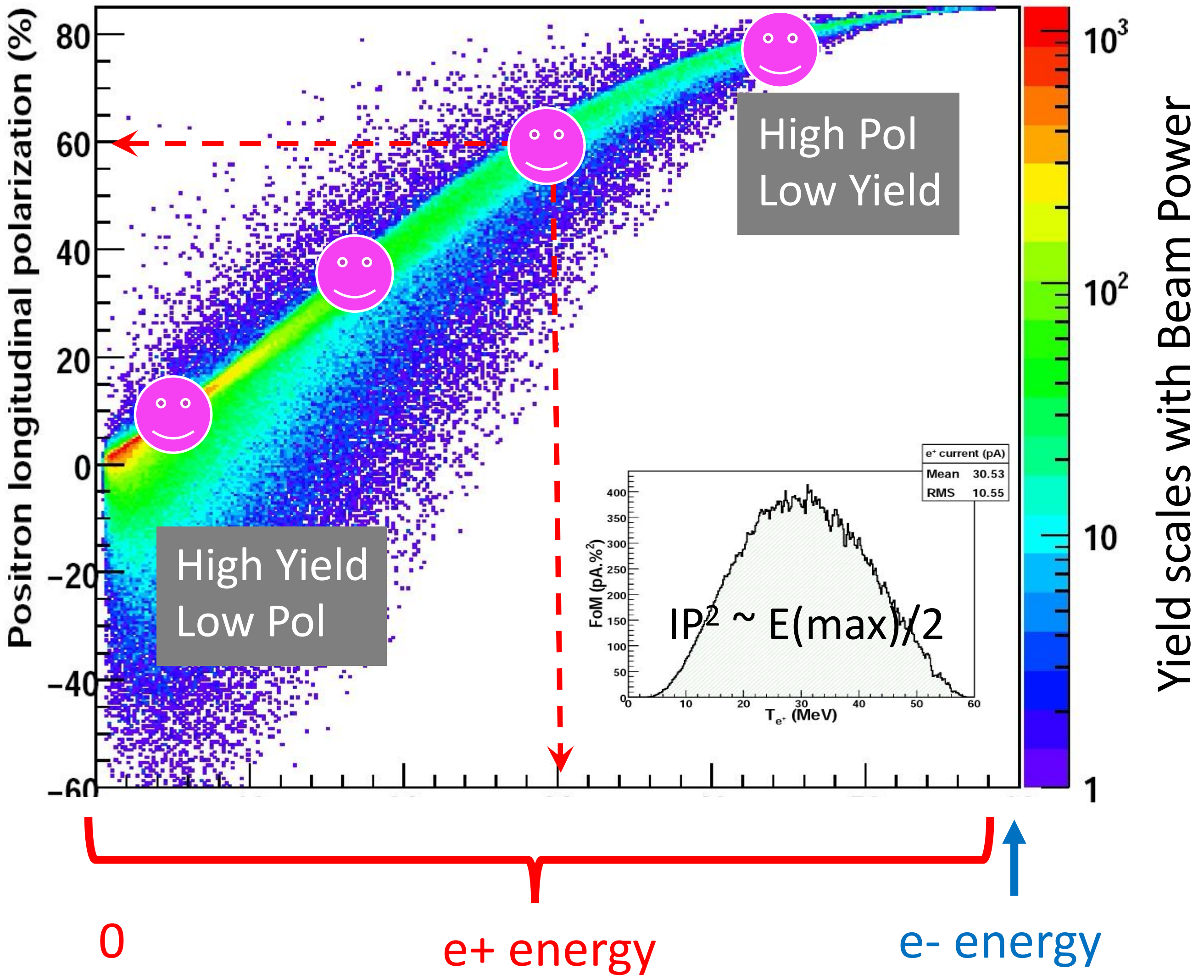


Bremsstrahlung



Pair Creation

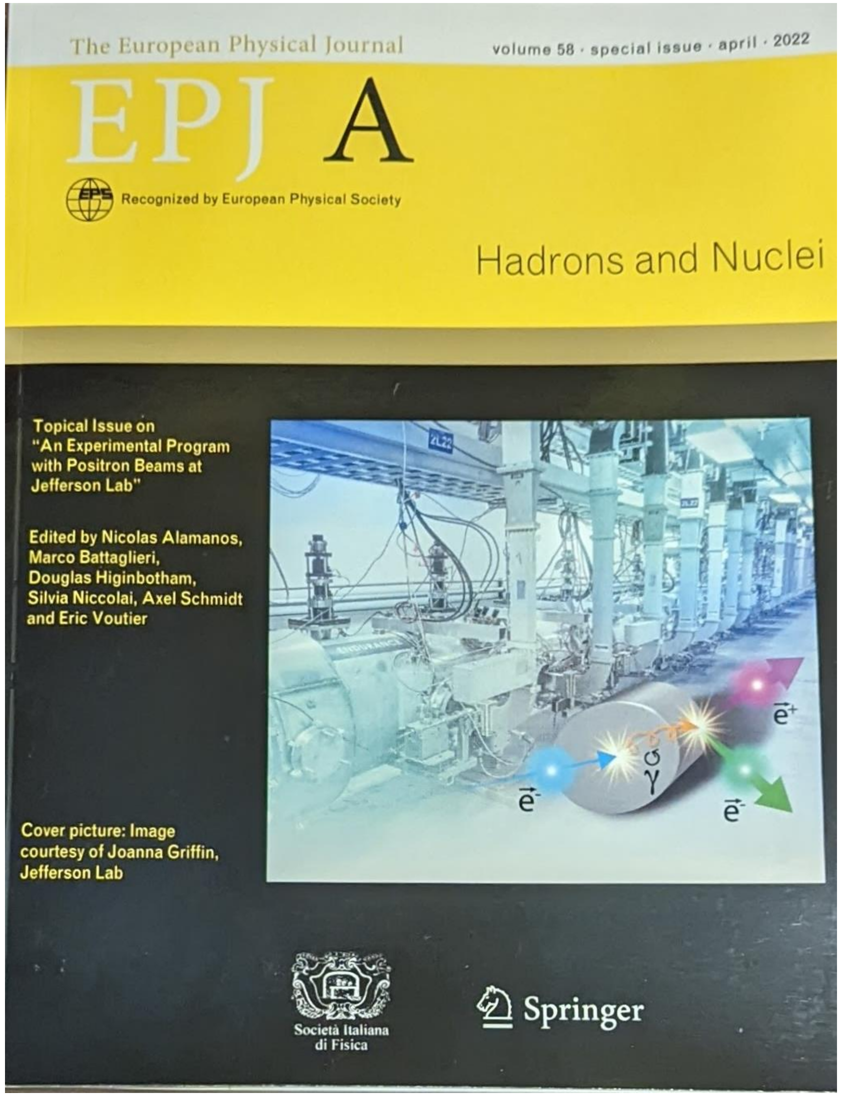




Positron Program White Paper Published 2022

Experiment Label (EPJ A)	Short Name	Hall	Detector	Target	Polarity	p (GeV/c)	P (%)	I (μA)	Time (d)
				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
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
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
57:253	LDM	B	PADME	C	+	11.0	0	0.100	180
			ECAL/HCAL	$PbWO_4$					120
57:315	CLFV	A	SoLID$^\mu$	H_2	+	11.0			
							Total (d)		**1121**

CLAS12$^+$ ≡ CLAS12 implemented with an Electromagnetic Calorimeter in the Central Detector
SoLID$^\mu$ ≡ SoLID complemented with a muon detector
+ Secondary positron beam
$-_s$ Secondary electron beam
$-_p$ Primary electron beam
(30) Do not require polarization but would take advantage if available at the required beam intensity



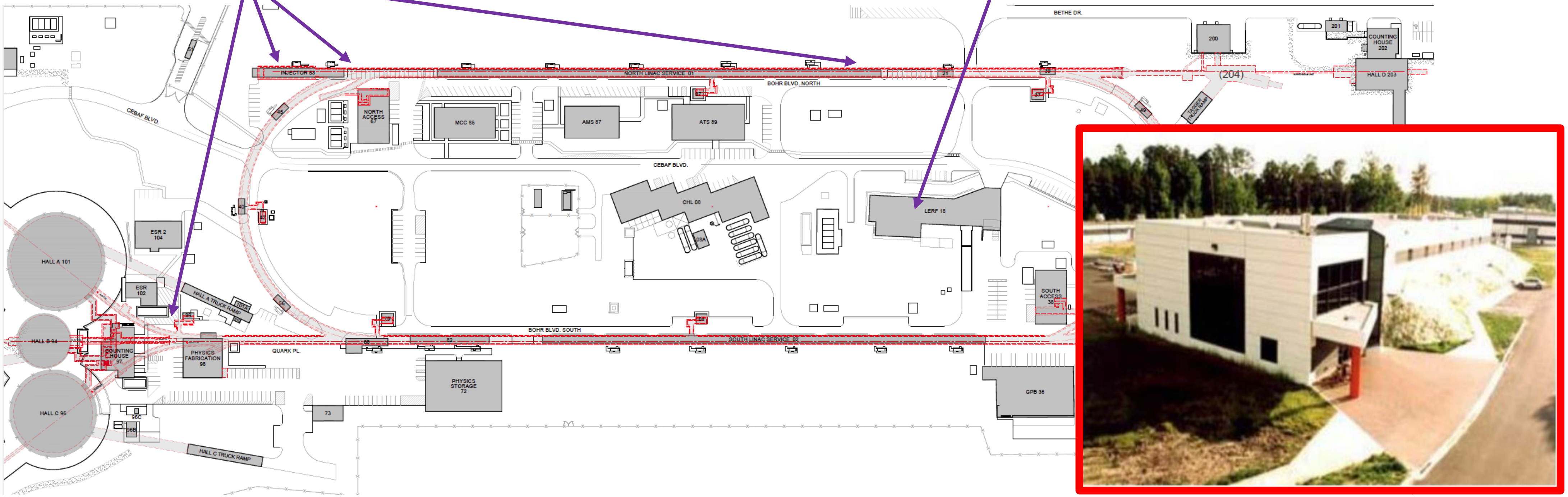
https://doi.org/10.1140/epja/s10050-022-00699-6

Options are good, but too many can be overwhelming…

During the pandemic a Lab Directed R&D project was funded to evaluate the e⁺ concept

We explored e⁺ production at 10, 100, 1000, 10000 MeV supported by a LDRD…

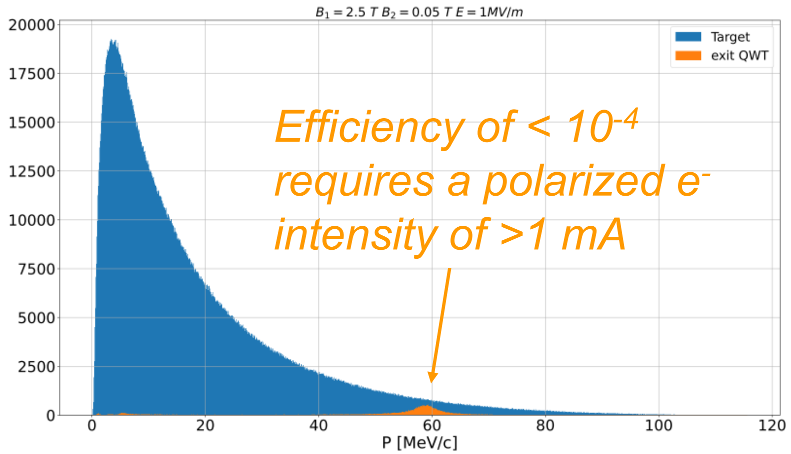
Strategic decision was taken to imagine using former FEL facility, starting with an R&D test bed

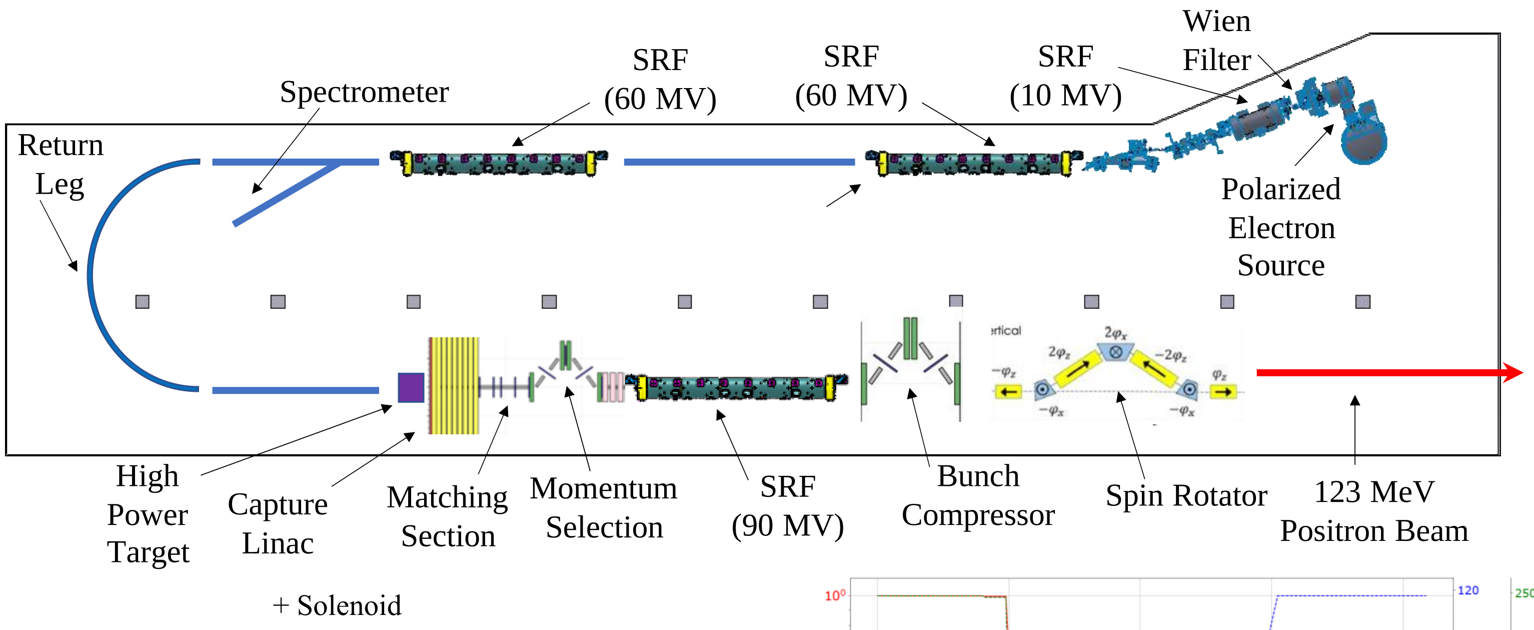


Design two new injectors (e^- and e^+)

Two challenging injectors have to be built

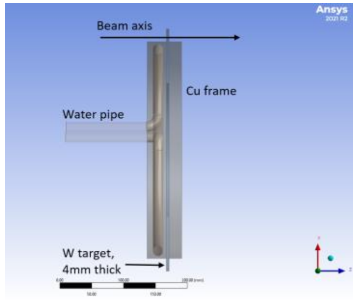
- >1 mA polarized e- injector >150 MeV
- >100 kW target & cw-collection beam line



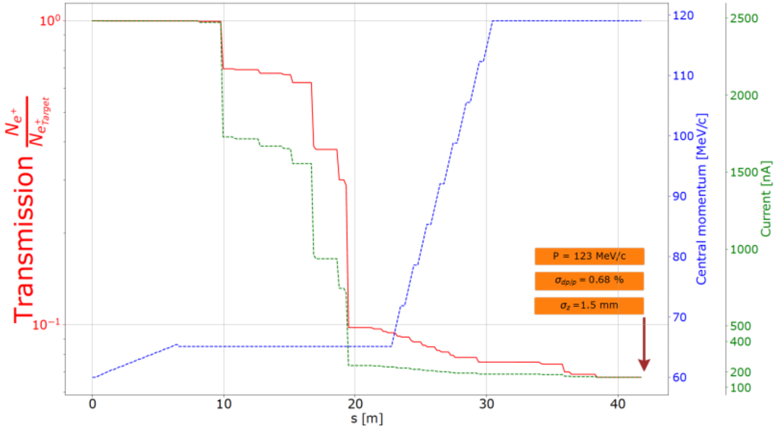


Ce$^+$BAF Parameter	Status	Goal
p_0 [MeV/c]	60	60
$\sigma_{\delta p/p_0}$ [%]	0.68	±1
σ_z [ps]	3	≤ 4
Normalized ϵ_n [mm mrad]	140	≤ 40
p_f [MeV/c]	123	123
$I_{e^+}(P > 60\%)$ [nA]	170	> 50

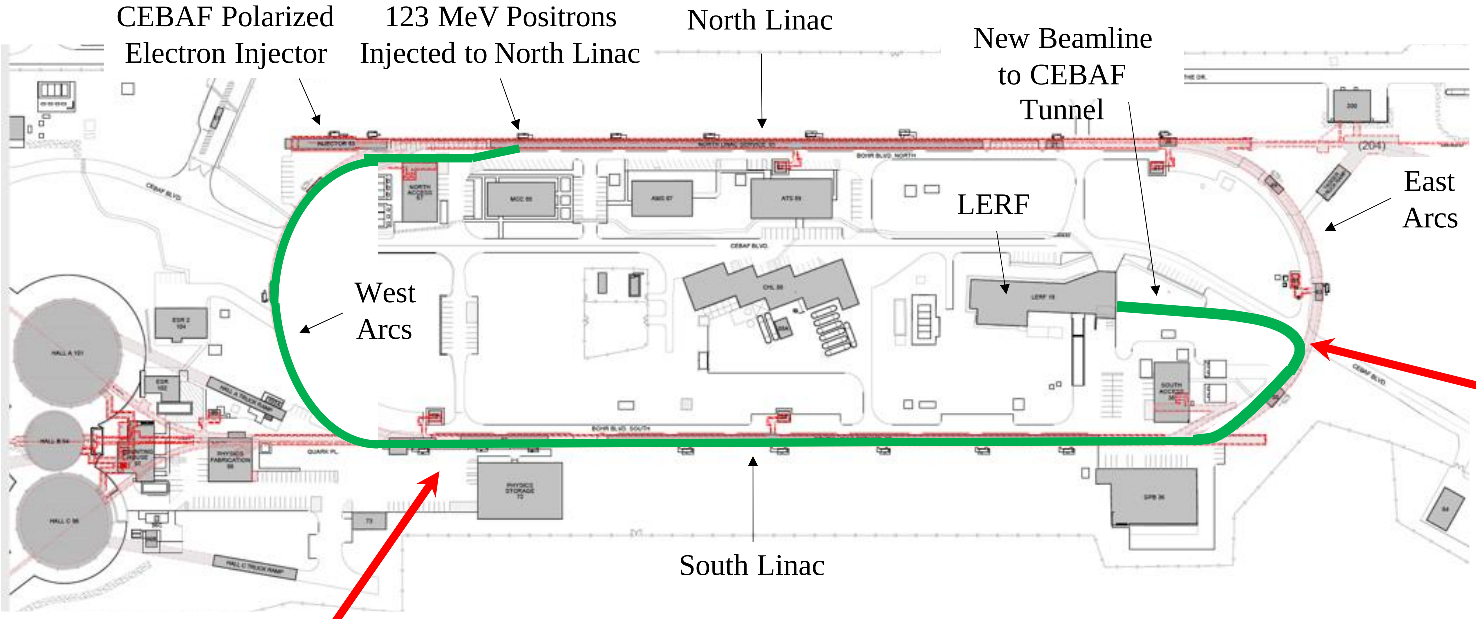
PhD thesis work of Sami Habet



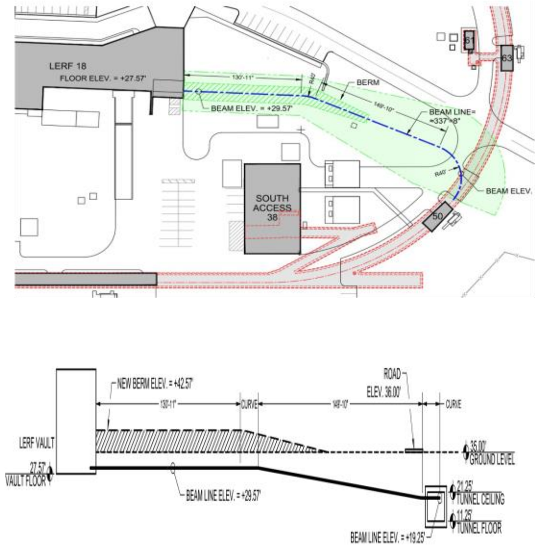
120 kW e^- beam irradiates water cooled spinning tungsten target (**17 kW deposit**)



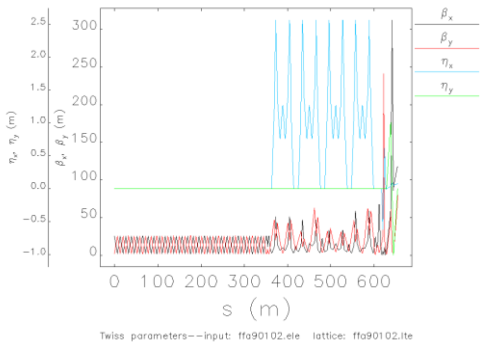
Injecting e+ to CEBAF 12 GeV



Once e+ source is ready, civil construction connects the LERF by a new tunnel to CEBAF. The transport line will maintain the e+ polarization in plane.

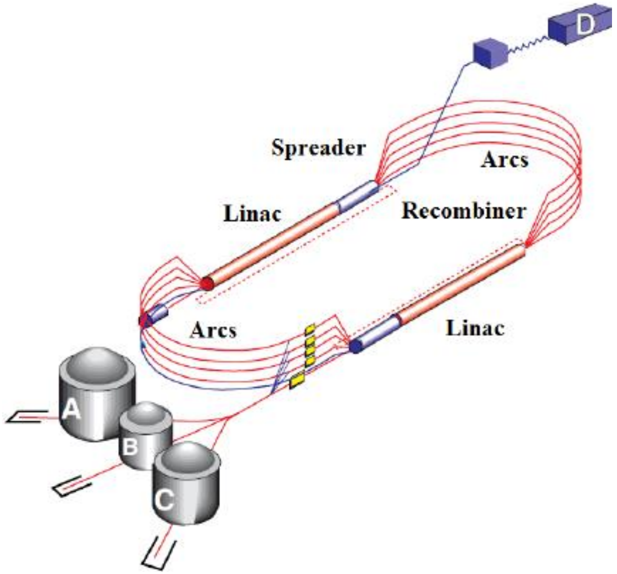


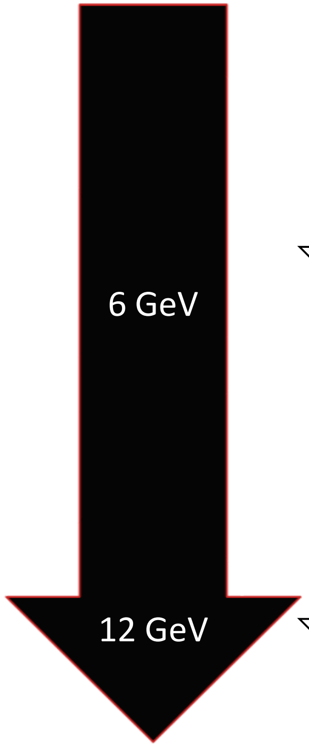
e+ transported in new beamline and injected to CEBAF for 12 GeV, with magnet polarities reversed



CEBAF 12 GeV : Transverse Emittance* and Energy Spread†

- Use n-bend acrobats and large aperture quads for 123 MeV injection line to CEBAF
- Modify low-energy CEBAF arcs to have smaller dispersion (beam size)
- SR radiation damping benefits e+ emittances more than e-





electron beam

Damping / SR

Area	dp/p [x10^{-3}]	e_x [nm]	e_y [nm]
Chicane	0.5	4.00	4.00
Arc 1	0.05	0.41	0.41
Arc 2	0.03	0.26	0.23
Arc 3	0.035	0.22	0.21
Arc 4	0.044	0.21	0.24
Arc 5	0.060	0.33	0.25
Arc 6	0.090	0.58	0.31
Arc 7	0.104	0.79	0.44
Arc 8	0.133	1.21	0.57
Arc 9	0.167	2.09	0.64
Arc 10	0.194	2.97	0.95
Hall D	0.18	2.70	1.03

positron beam

Damping / SR

Area	dp/p [x10^{-3}]	e_x [nm]	e_y [nm]
Chicane	10	500	500
Arc 1	1	50	50
Arc 2	0.53	26.8	26.6
Arc 3	0.36	19	18.6
Arc 4	0.27	14.5	13.8
Arc 5	0.22	12	11.2
Arc 6	0.19	10	9.5
Arc 7	0.17	8.9	8.35
Arc 8	0.16	8.36	7.38
Arc 9	0.16	8.4	6.8
MYAAT01	0.18	9.13	6.19

** Emittances are geometric, † Quantities are rms*

(an LDRD is exploring the transport of large emittance beams at CEBAF)

3 Year e^+ R&D Plan

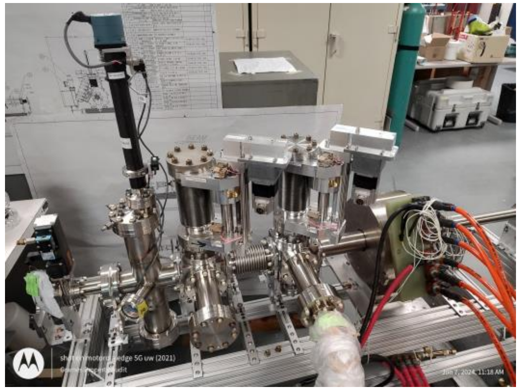
Conceptual Development
- *improve design*
- *develop pCDR*

Address Critical Risk Areas
- *mA polarized e- source*
- *high power target*
- *cw capture cavity*

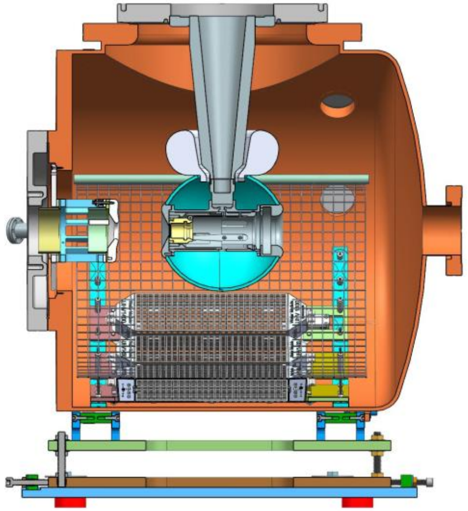
Concept to provide users e- or e+ on demand

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 ∝A**	> 1 ∝A	>> 1 uA	170 ∝A**
Polarized Intensity	170 ∝A**	> 50 nA	>> 1uA	170 ∝A**
Beam Polarization	> 85%	> 60%	>85% ?	>85%

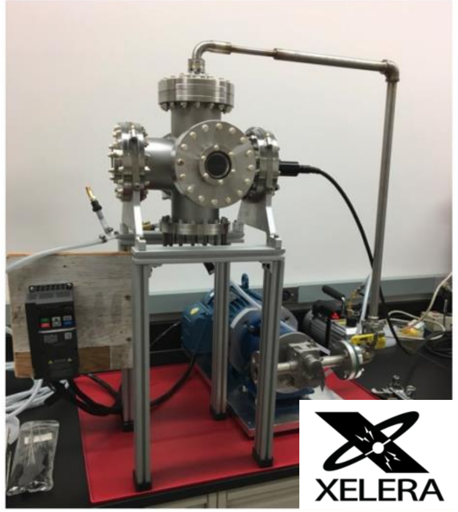
Measure CEBAF acceptance



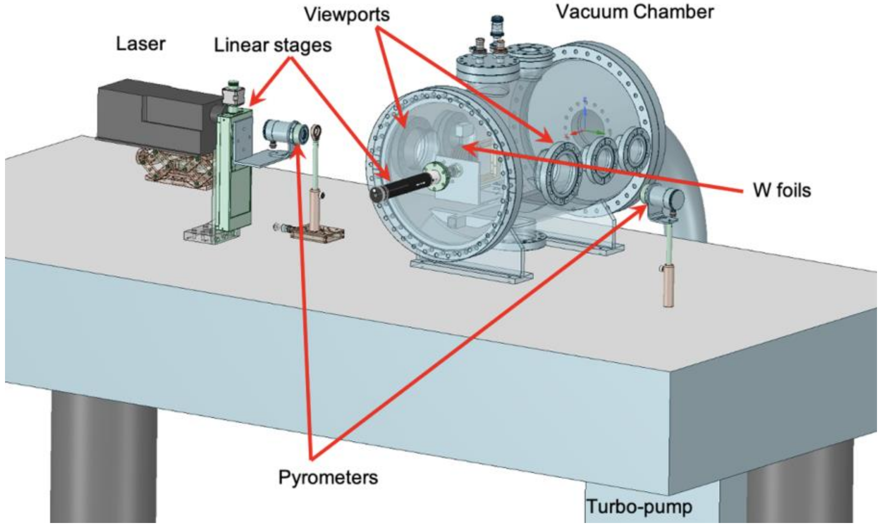
Proposal for mA e- source



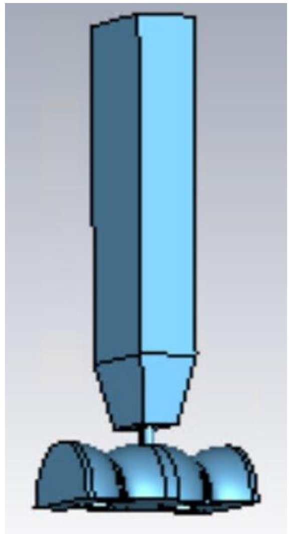
Test GaInSn Jet Target



Proposal to test prototype W Target

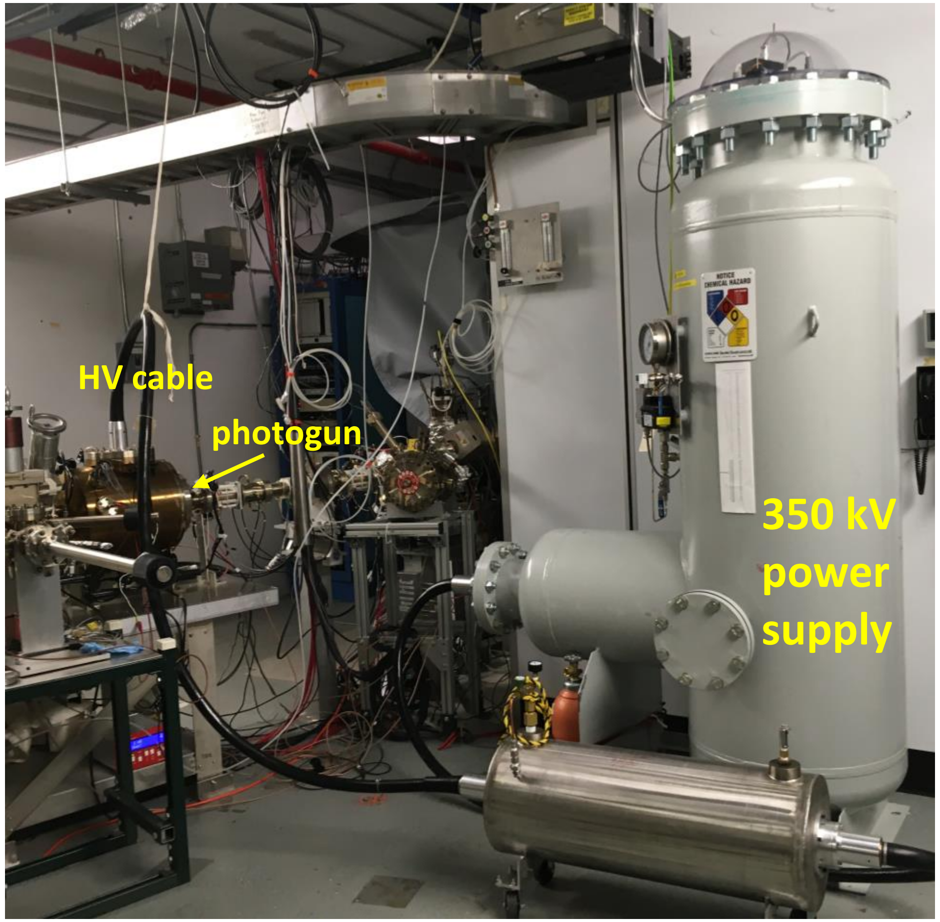


Proposal CW cell prototype

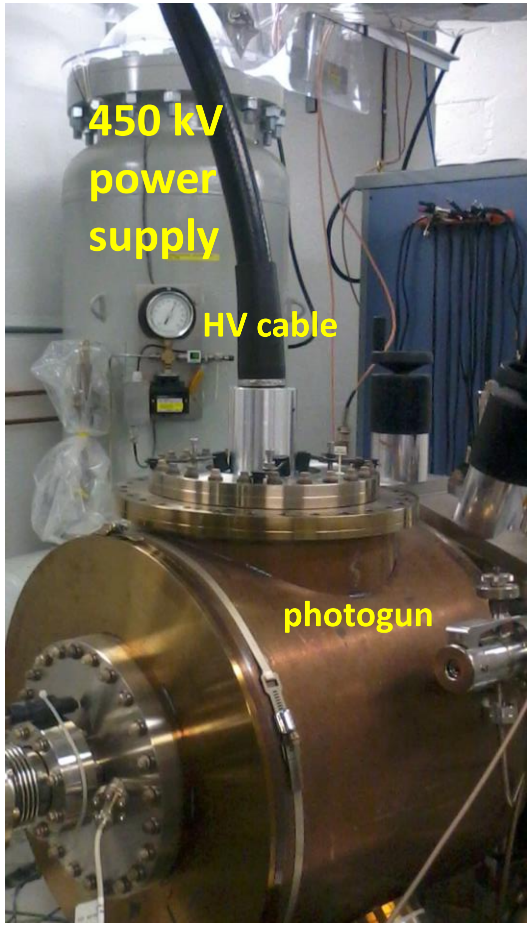


Build 100kW/10MeV e^-/e^+ test-bed at LERF

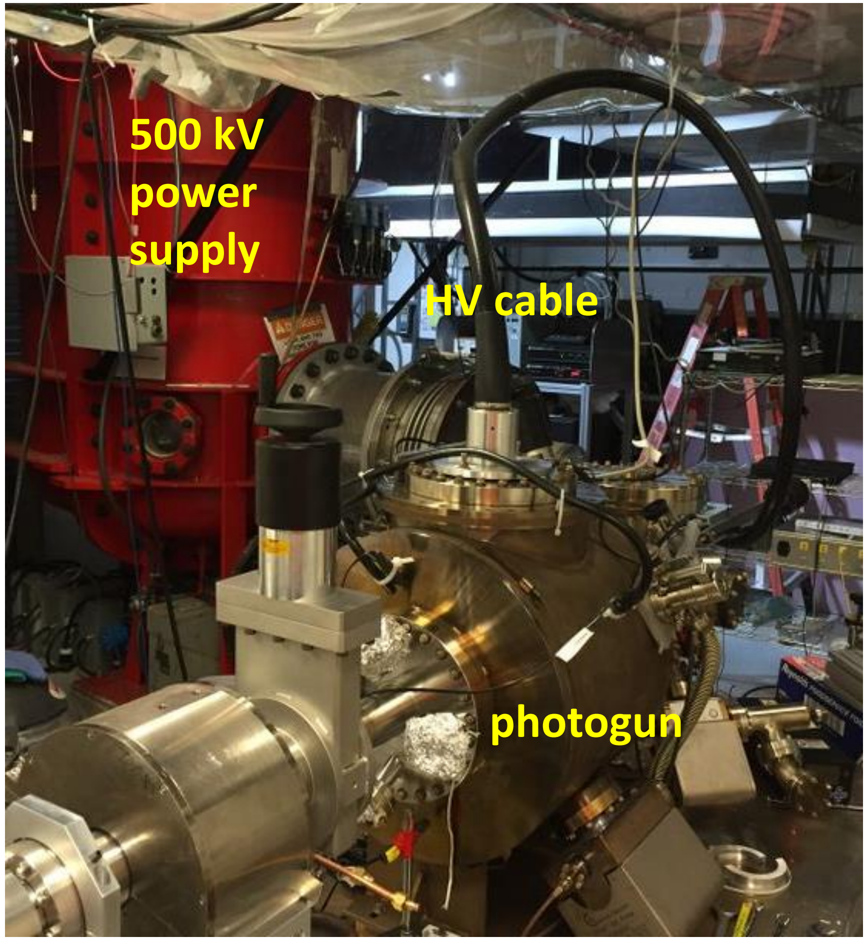
CEBAF : Nuclear Physics



UITF : MeV Test Facility



GTS : Advanced Gun Test Facility



Example – 3 GeV polarized e$^-$ beam

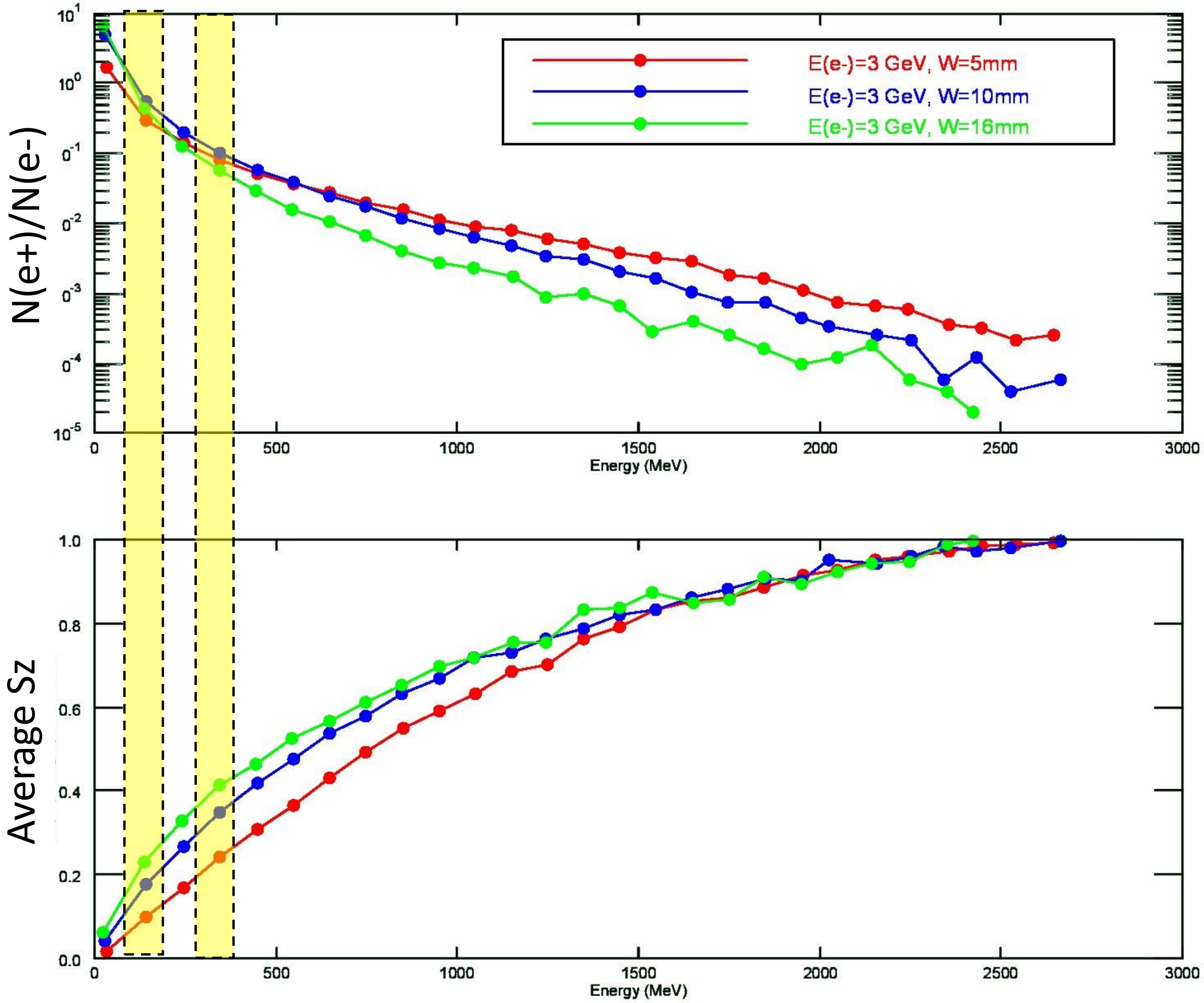
Geant4 simulation of e$^+$ generated from 3 GeV polarized e$^-$ beam (90%)

- 5, 10, 16 mm W
- 100 MeV bins

- Usual trade off between Yield and Pol

- Optimum target thickness depends also on polarization (spin filtering)

E(e+)	N(e+)/N(e-)	<Sz>	P (%)
150 MeV	0.436	0.23	21
350 MeV	0.056	0.41	37



Jefferson Lab

Conclusions

- **PEPPo demonstrated very high spin positron polarization from polarized electrons,** at low energy w/ small footprint, extensible to higher energies.

- Jefferson Lab Users are making the case for **positron beams at CEBAF 12 GeV**.

- PEPPo approach can **turn a "no polarization" scheme into a "polarization scheme"**, or for a later upgrade…

Invite you to join us at Jefferson Lab in September.

Thank you.

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.

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M. Poelker, N. Raut, B. Rimmer, Y. Roblin, A. Seryi, K. Smolenski, M. Spata, R. Suleiman,
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