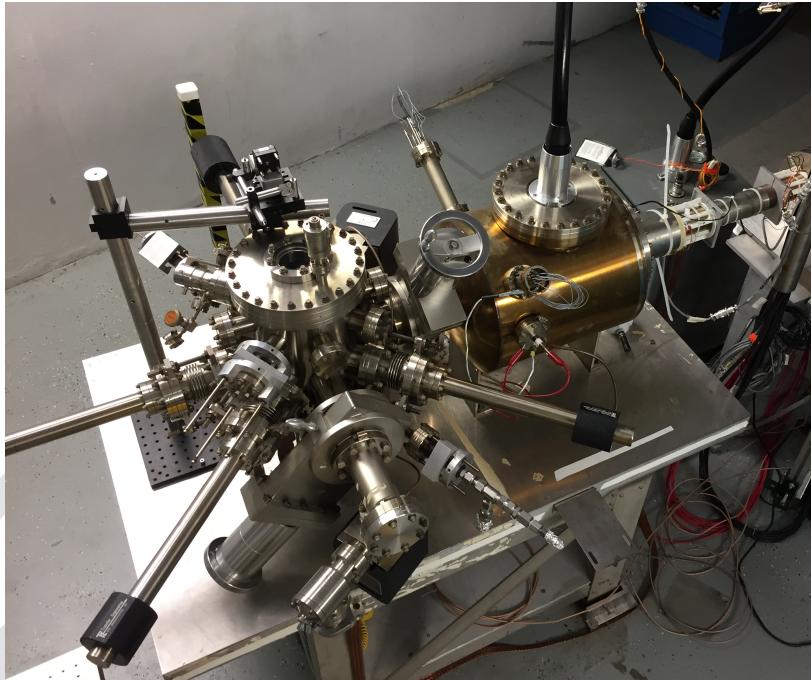


# Polarized Electrons for Polarized Positron Beams



- **Polarized Electrons for Polarized Positrons (PEPPo)**
- **Positrons at CEBAF**
  - Low Energy Concept
  - High Energy Concept
- **Positrons for JLab Electron Ion Collider (JLEIC)**
- **Why not PEPPo for the ILC ?**
- **Polarized Electron Source R&D**

Joseph Grames, Jefferson Laboratory, USA

Malek Mazouz, University of Monastir, Tunisia

Eric Voutier, IPN-Orsay, France

International Workshop on Future Linear Colliders (LCWS 2018)

October 22-26, 2018

# Jefferson Lab : CEBAF @ 12 GeV



Users: 1500 (230 Institutions/30 Countries)  
Multiplicity: 4 Halls (simultaneously)  
Beam Polarization: >85% (90%)  
Beam Energy: 11 GeV (ABC) / 12 GeV (D)  
Beam Power: 1 MW (85  $\mu$ A @ 11 GeV)  
Cryogenics: Two 4.5 kW plants @ 2.1 K

# Why Polarized Positrons at Jefferson Lab?

Parameter	CEBAF 12 GeV Electron Beam	Proposed 12 GeV Positron Beam
Beam Intensity	85 $\mu$ A	> 100 nA (pol) > 1 $\mu$ A (unpol)
Duty Factor	100% (cw)	100% (cw)
Bunch Frequency	249.5/499 MHz	249.5/499 MHz
Spin Polarization	>85%	>50%
Helicity Reversal	30 – 2000 Hz (Pockels cell)	30 – 2000 Hz (Pockels cell)

# Letter of Intent to PAC46 (LOI-12-18-004)

Letter-of-Intent to PAC46

## Physics with Positron Beams at Jefferson Lab 12 GeV

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- Jefferson Lab Positron Working Group (JLAB-PWG) formed in 2016
  - 120 members** (>90% are Users), and growing
  - 39 institutions**
- Letter of Intent "Physics Program with Positron Beams at CEBAF 12 GeV" submitted to PAC46 (July 2018), highlighting 7 mini-LOI's
- Summary:** *"These measurements all have significant physics interest. The proposers should carefully evaluate feasibility and present the best case possible in a future proposal."*

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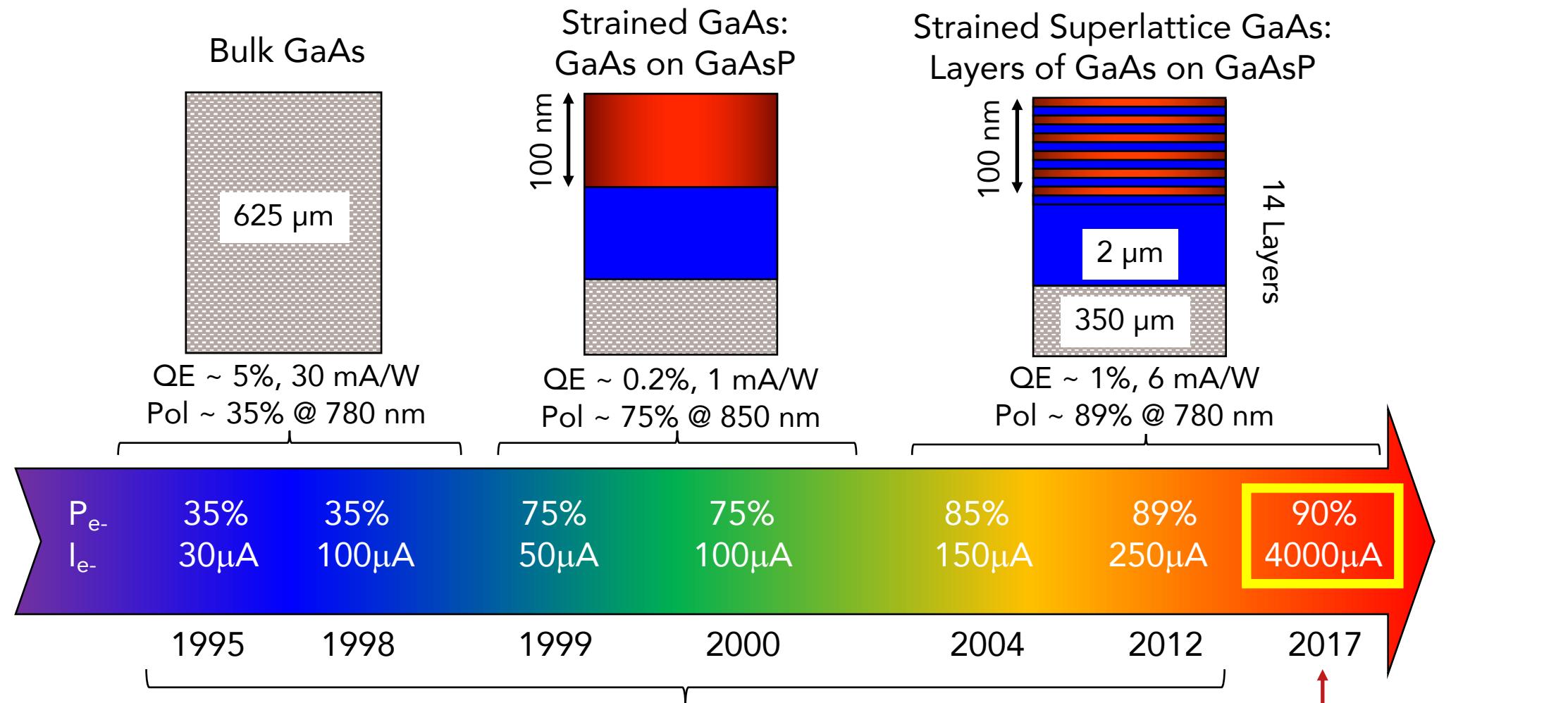
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3 June 2018  
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	I (nA) $e^-$	I (nA) $e^+$	Beam Polarization	Time (d)
<i>Two-photon exchange</i>				
TPE @ CLAS12	60	60	No	53
TPE @ SupRos	-	1000	No	18
TPE @ SBS	40000	100	Yes	55
<i>Generalized Parton Distributions</i>				
p-DVCS @ CLAS12	75	15	Yes	83
n-DVCS @ CLAS12	60	60	Yes	80
p-DVCS @ Hall C	-	5000	No	56
<i>Test of the Standard Model</i>				
$A'$ search	-	10-100	No	180
<b>Total Data Taking Time</b>				<b>525</b>

Table 1. Characteristics of a positron experimental program at Jlab.

# Enabling Technology : CEBAF Polarized Electron Sources based on GaAs



**Figure-of-Merit ( $P^2I$ ) has improved by a factor of 43 over the span of the CEBAF "6 GeV era"**

High Current Lifetime Studies at CEBAF

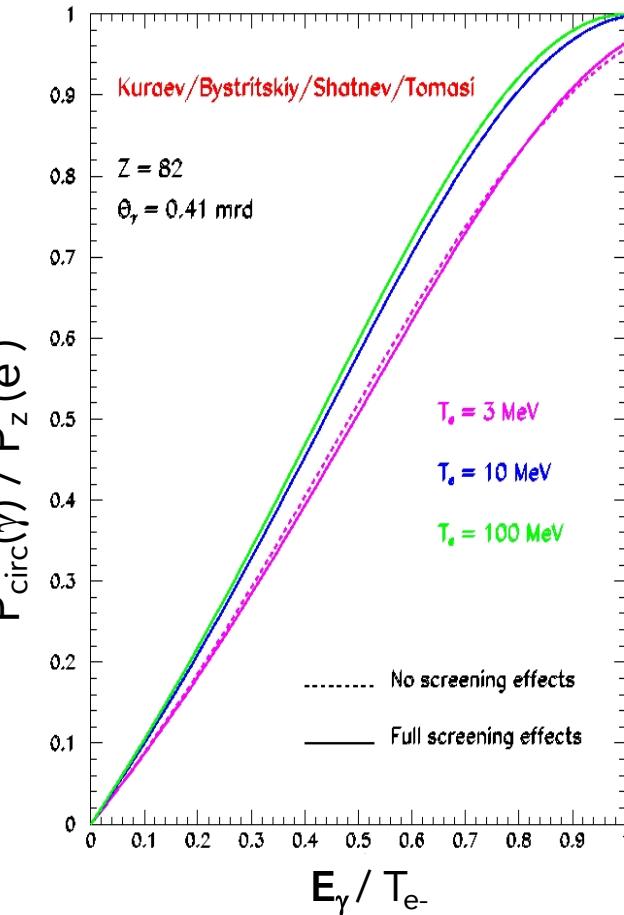
# New Method : Exploit Electron Beam Spin Polarization

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

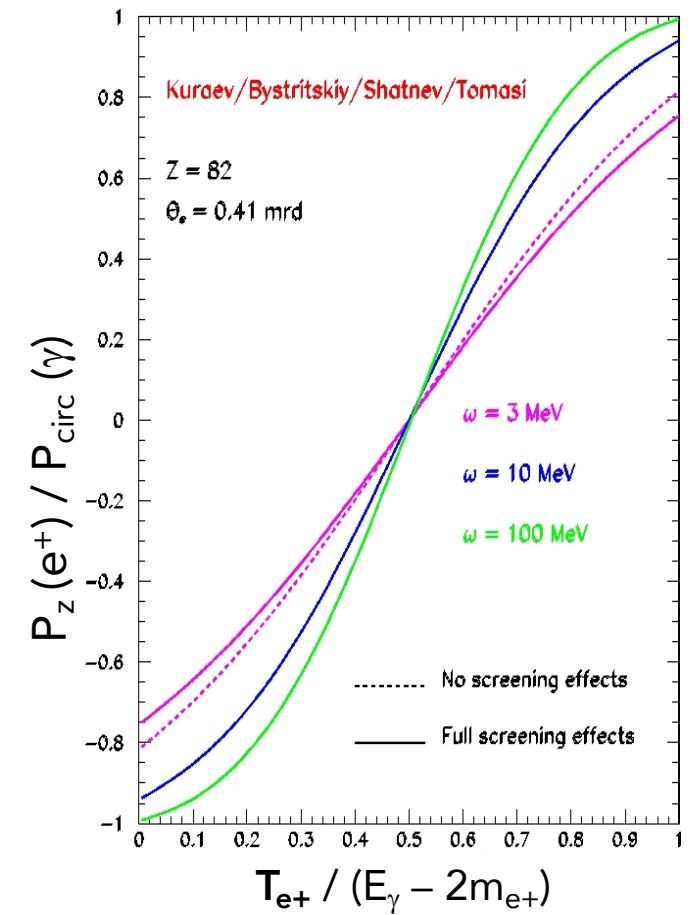


Longitudinal spin polarization passes from incident electrons to outgoing pair-produced positrons in the electromagnetic shower, when incident on a target, e.g. high-Z material useful.

### Polarized Bremsstrahlung



### Polarized Pair Creation



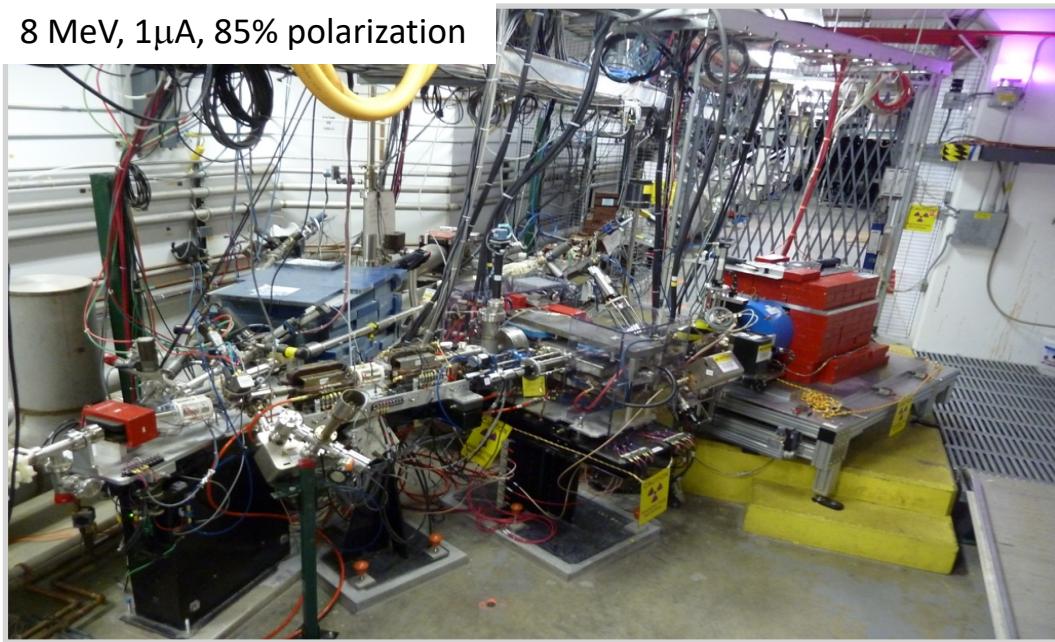
E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208

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

PEPPo (Polarized Electrons for Polarized Positrons) => **demonstrate feasibility** of using bremsstrahlung radiation of **MeV energy Polarized Electrons** for production of **Polarized Positrons**.

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

8 MeV, 1 $\mu$ A, 85% polarization



Tungsten (1mm)

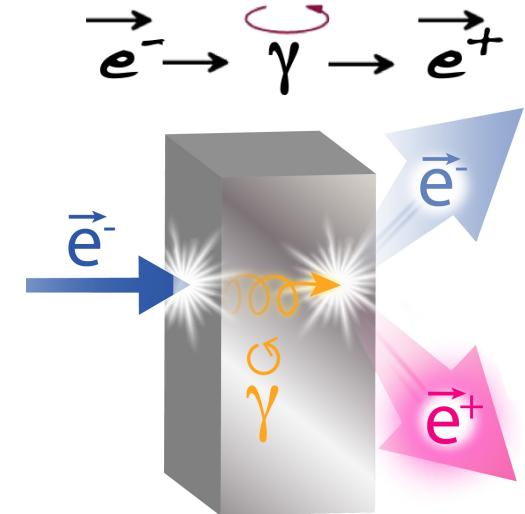
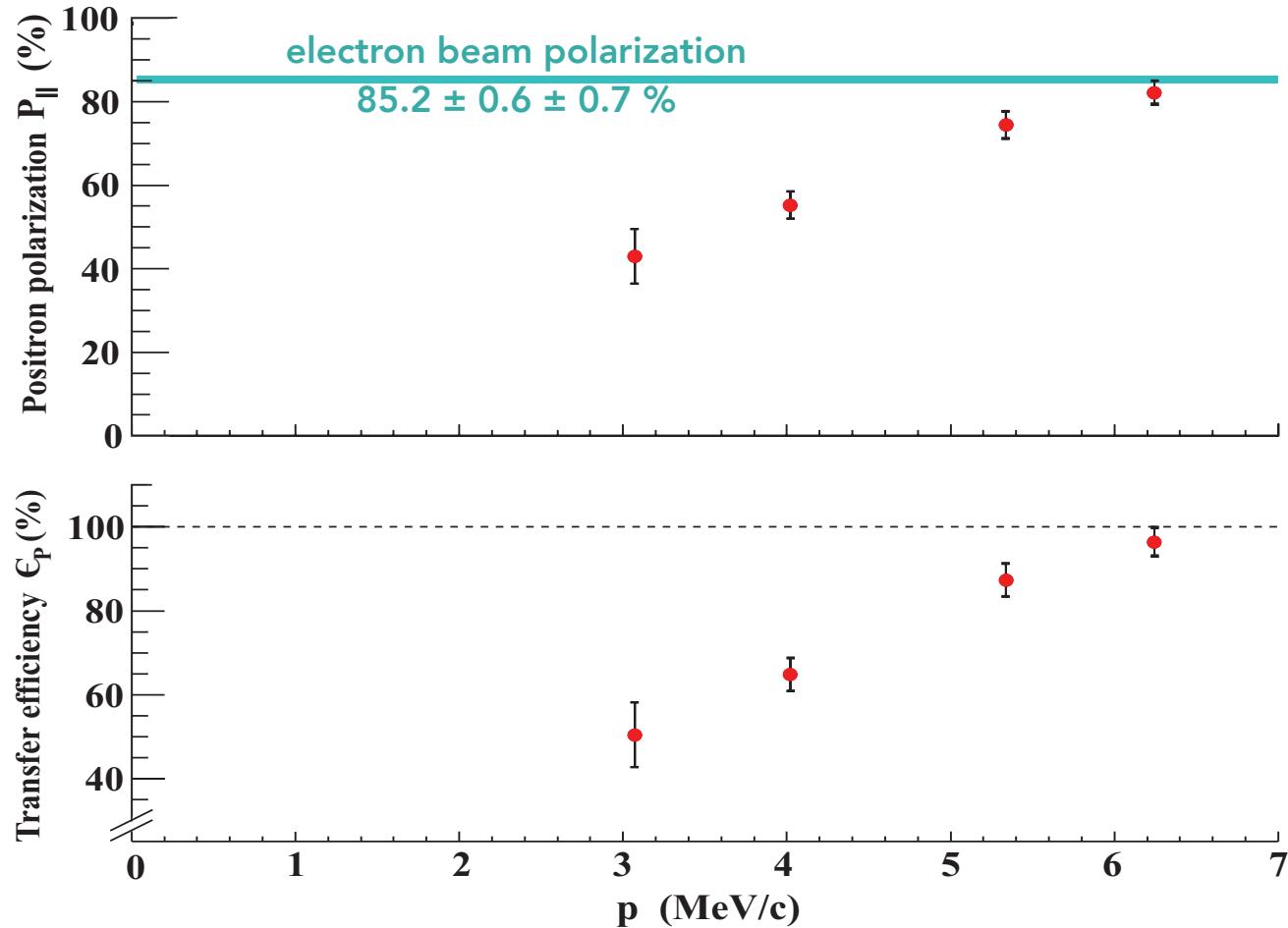


PEPPo possible due to support from **SLAC E166, DESY, Princeton, Cornell, International Linear Collider Project** and the **Jefferson Science Associates**

# PEPPo : Polarized Positron Production

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

PEPPo demonstrated efficient polarization transfer of 8.2 MeV/c polarized electrons to positrons, expanding polarized positron production using MeV electron beam energies.

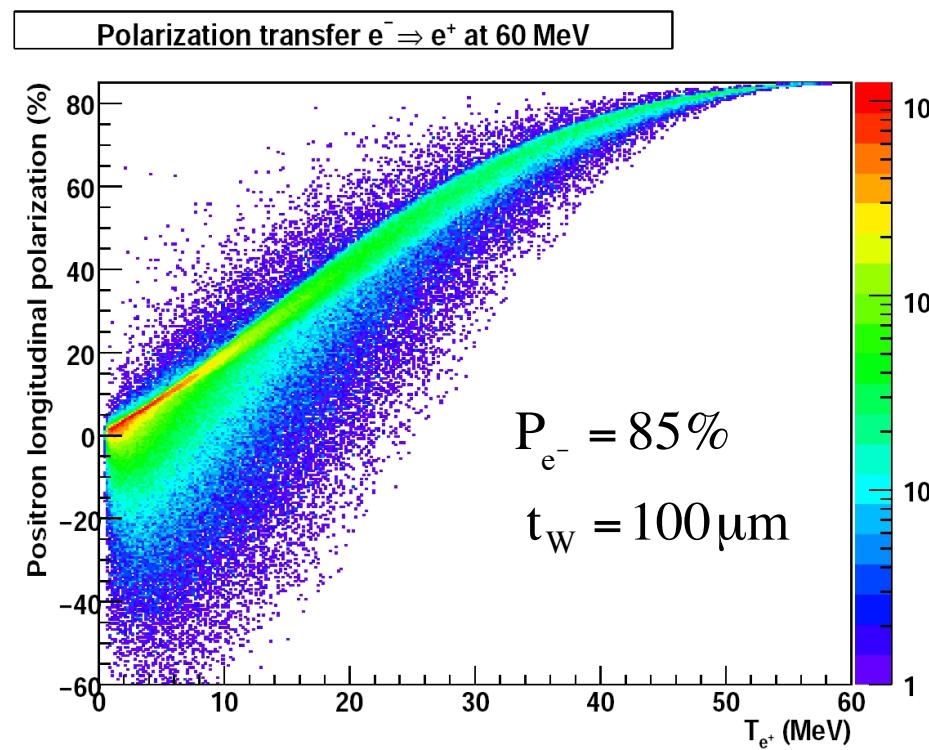


Whenever producing  $e^+$  from  $e^-$ , polarization is coming for free, if initial electrons are polarized.

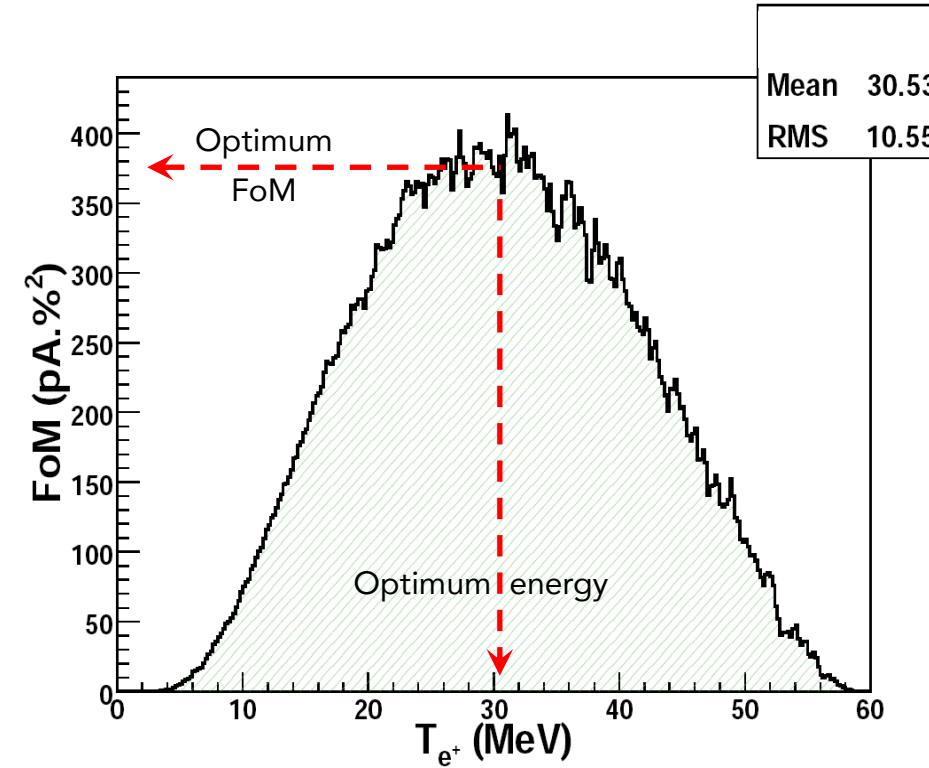
# Figure of Merit for Electron Energy 60 MeV (Injector Energy of 6 GeV CEBAF)

R. Dollan, K. Laihem, A. Schälicke, NIM A 559 (2006) 185,  
J. Dumas, J. Grames, E. Voutier, JPos09, AIP 1160 (2009) 120  
J. Dumas, Doctorate Thesis (2011)

The **polarization distribution** of generated positrons is dominated by **low-energy events**.

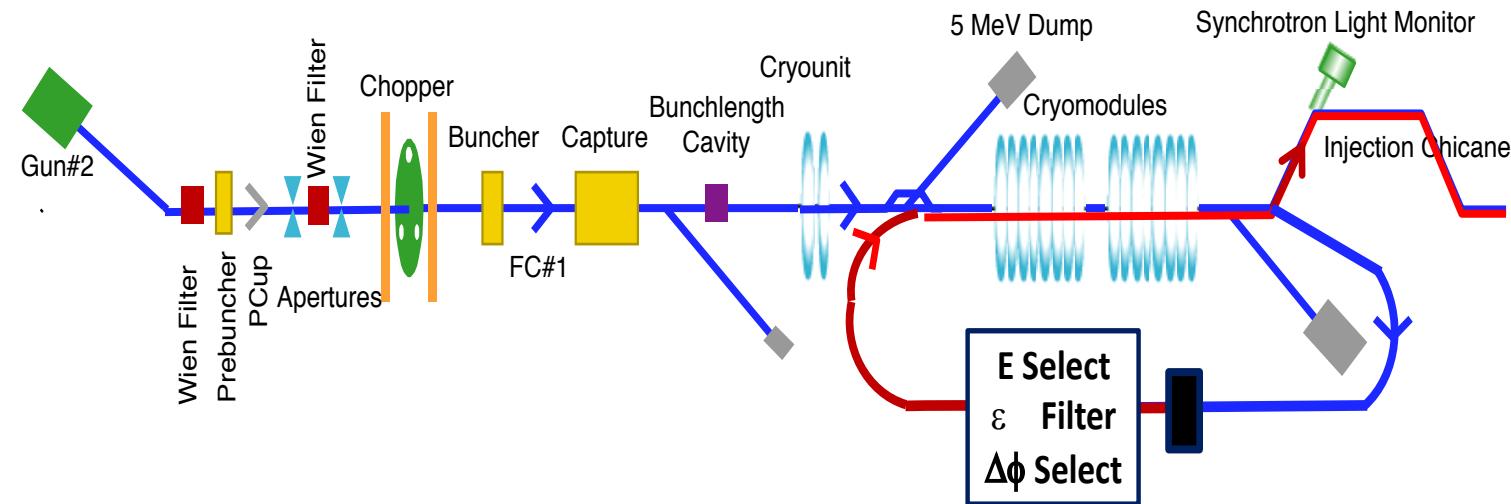


The **positron energy** at the optimum FoM ( $P^2I$ ) is about **half** of the **electron beam energy**.



# 12 GeV CEBAF: Low Energy (123 MeV) with High Current + Modest Bunch Charge

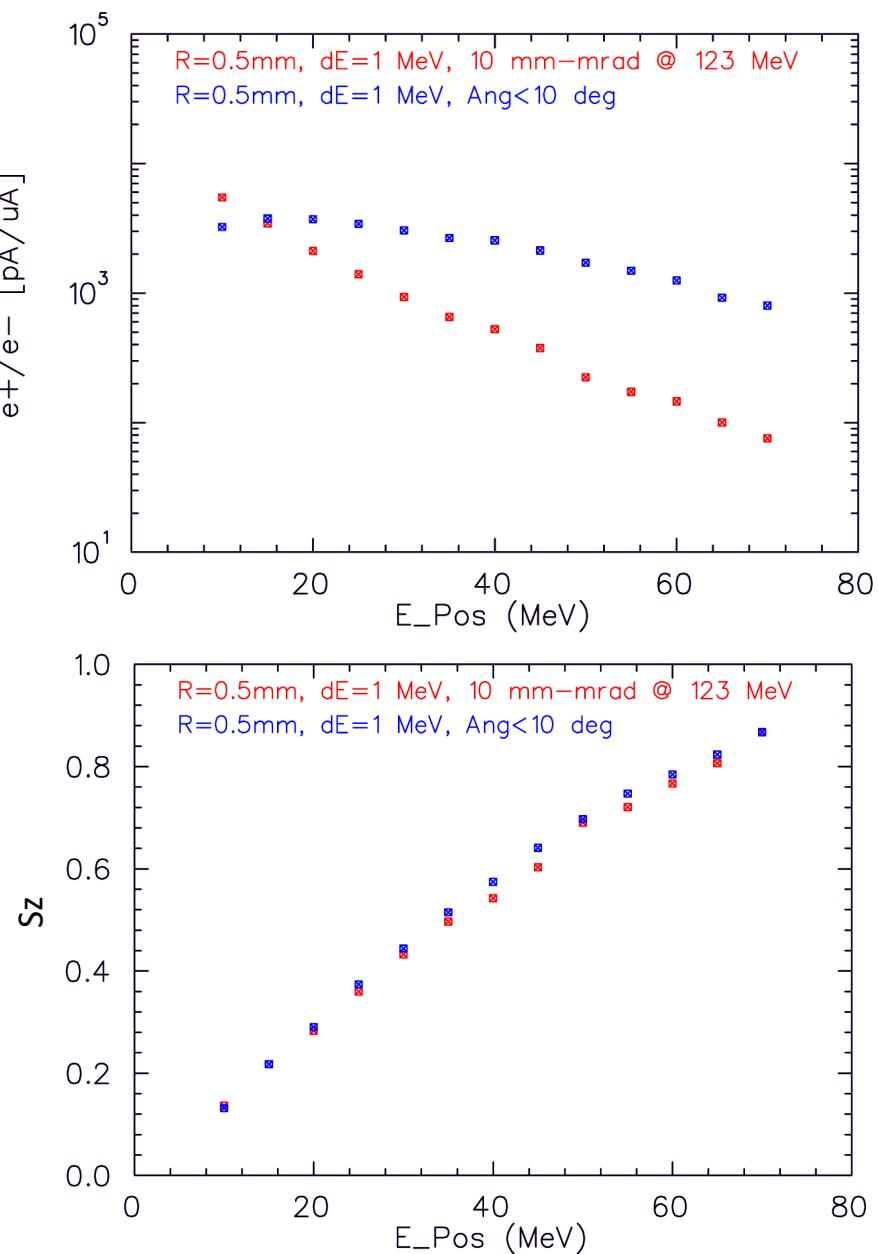
Positrons would be created at the CEBAF injector, using the **123 MeV** electron beam.



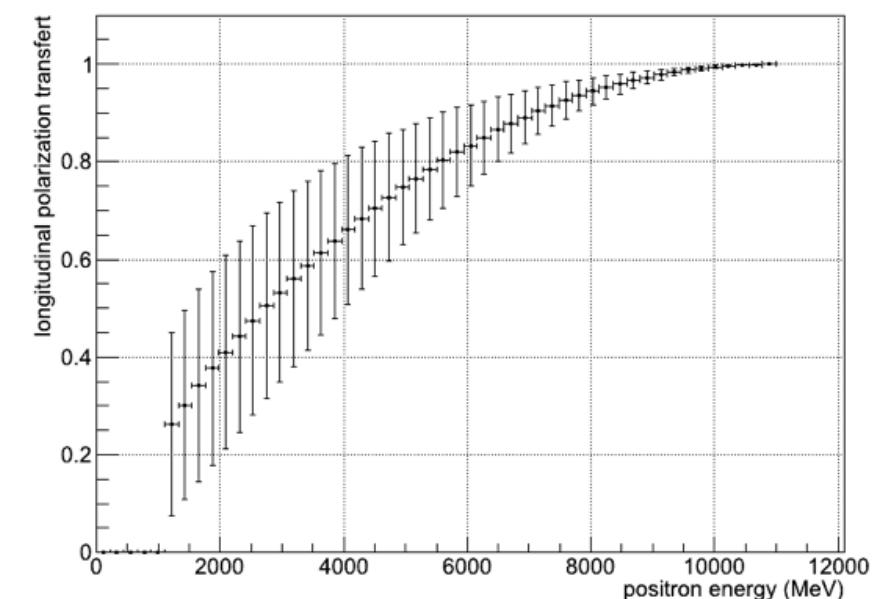
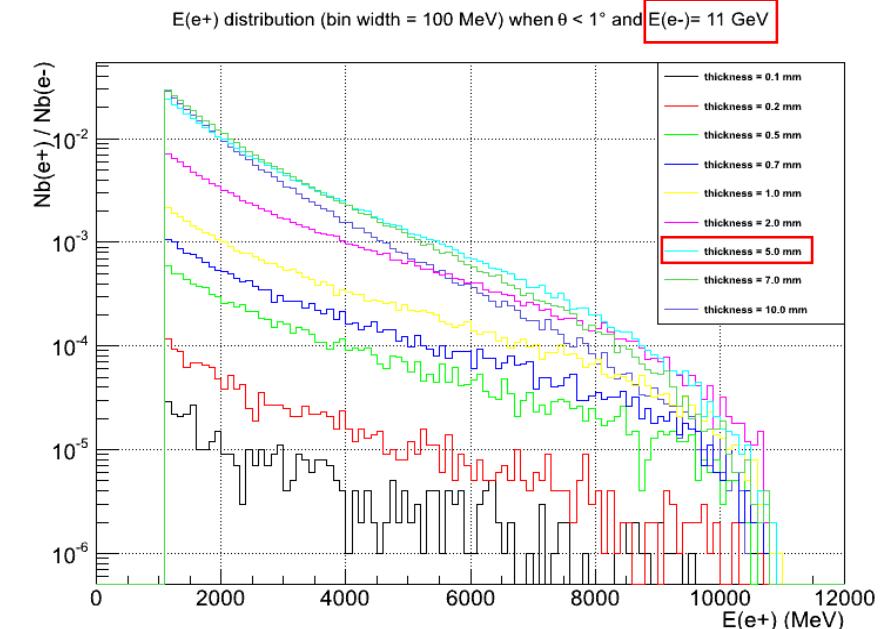
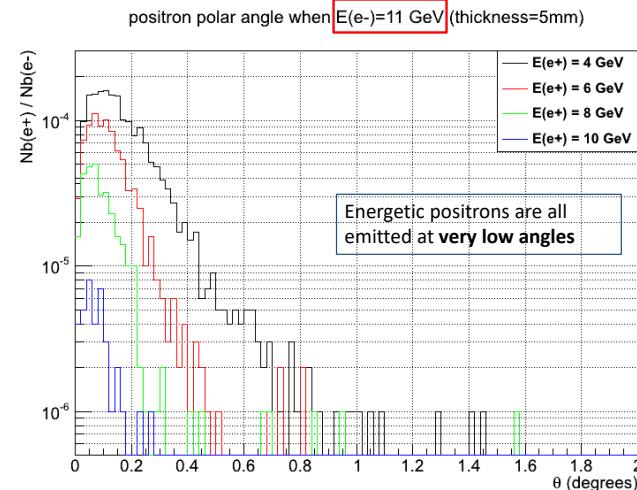
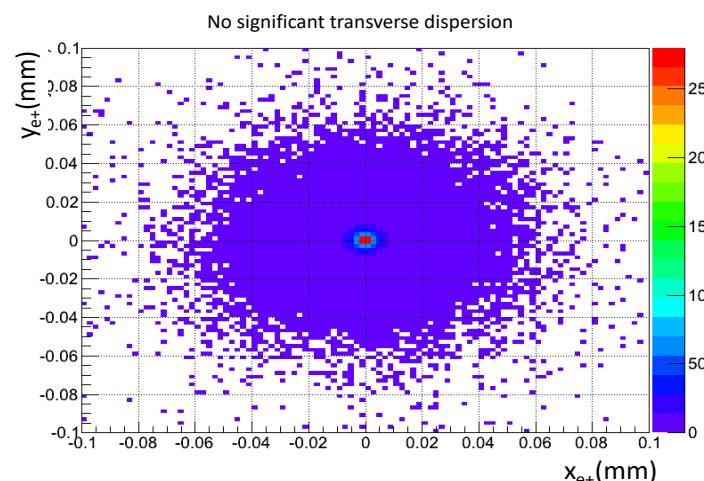
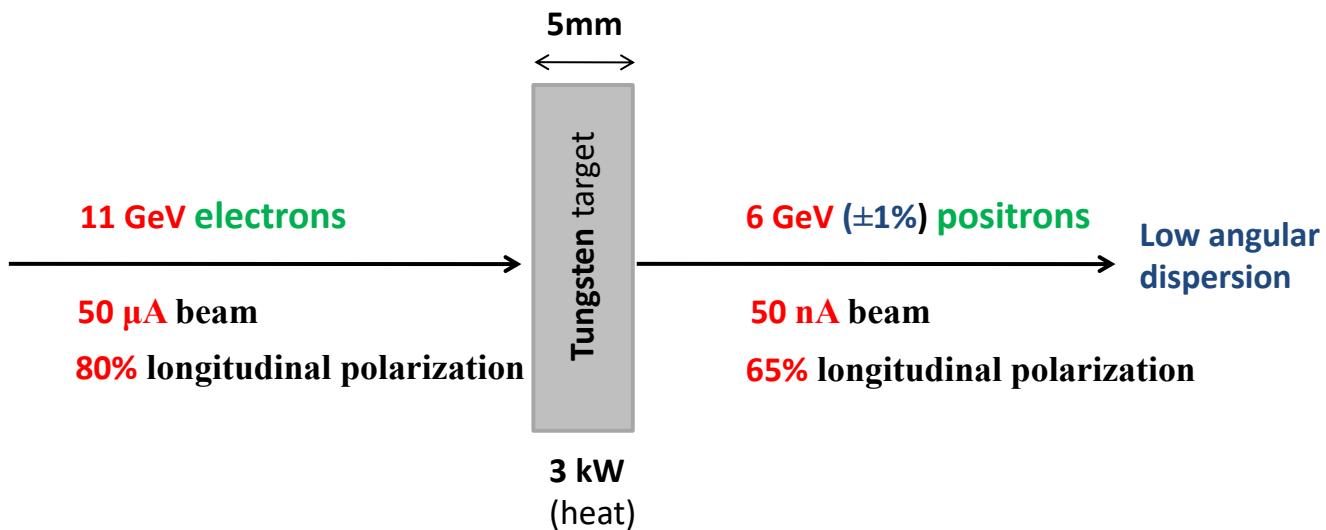
Selecting **60 MeV** positrons maximizes the FoM (**60%, 100 nA**).

Selecting **6 MeV** positrons maximizes the flux (**> 1 μA**).

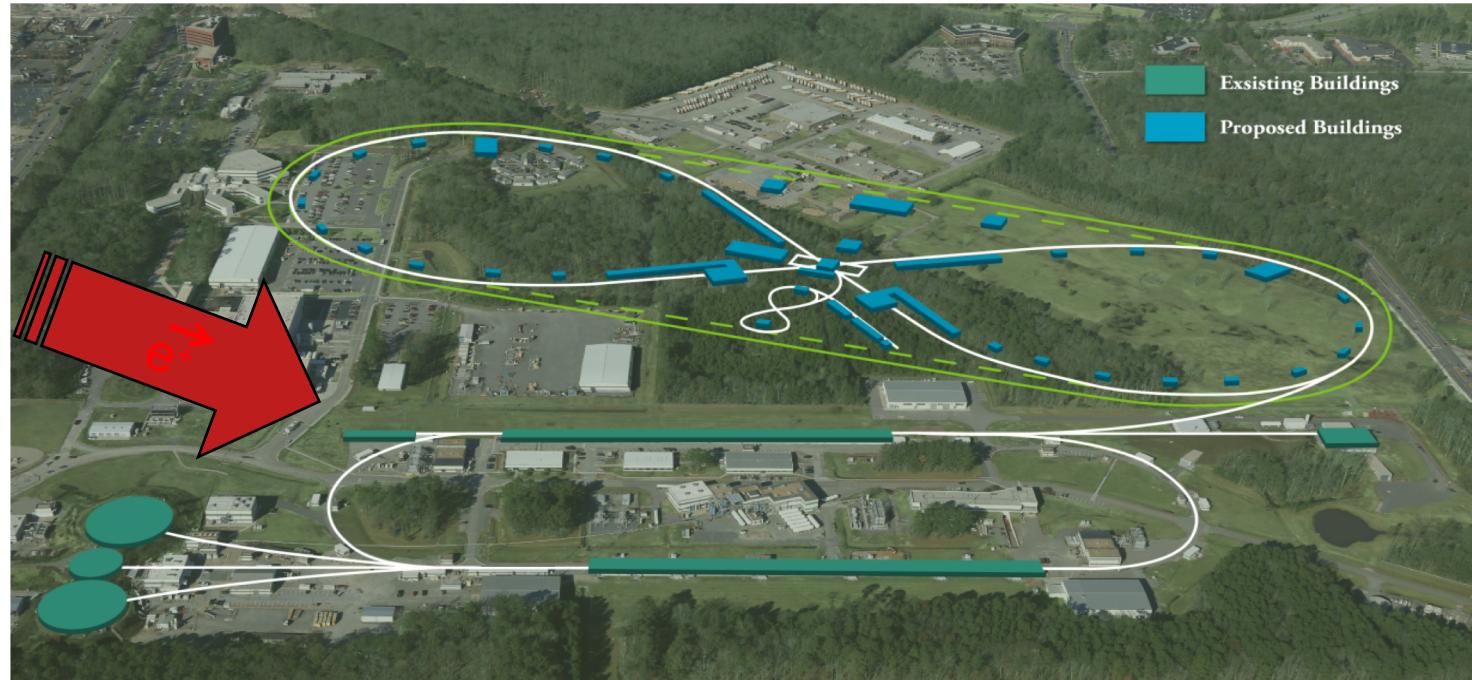
Positron source should have tunability to optimize for Intensity or Polarization



# CEBAF: High Energy (11 GeV) with Low Current + Low Bunch Charge

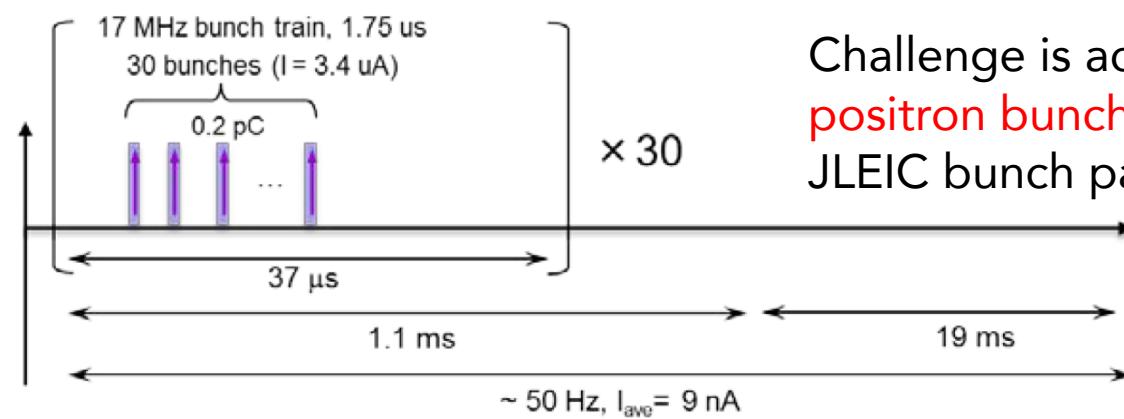


# Polarized Positrons at the Jefferson Lab Electron Ion Collider



A **polarized positron injector** suitable for the Jefferson Lab Electron Ion Collider (JLEIC) has also been considered.

$$\begin{aligned} \mathcal{L} &\geq 10^{33} \text{ cm}^{-2} \text{s}^{-1} & P_{e+} &\geq 40\% \\ I_{\text{ave}} &> 10 \text{ nA } (\sim 10^{10} e+/s) \\ I_{\text{peak}} &> 4 \mu\text{A } (\sim 10^{13} e+/s) \end{aligned}$$



Challenge is accumulating **positron bunch charge** with JLEIC bunch pattern.

# JLEIC: Low Energy (50 MeV) with Low Current + High Bunch Charge

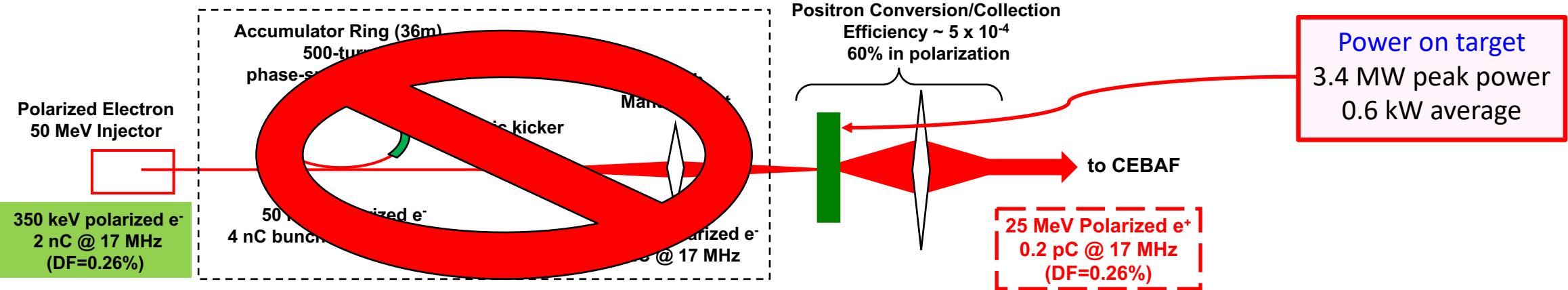


Table 1. Beam parameters at each stage of the polarized positron injection scheme for both JLEIC and CEBAF physics programs.

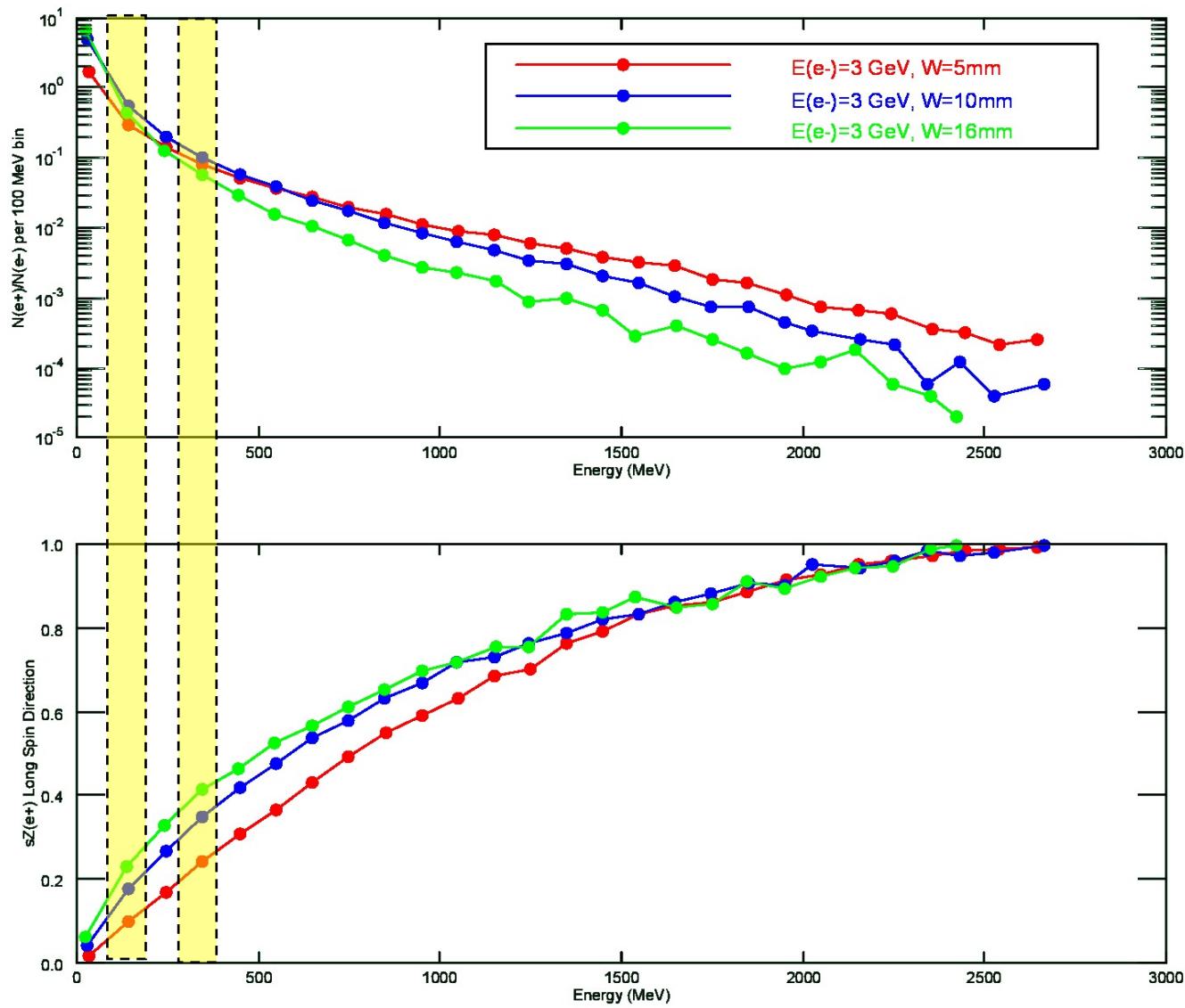
	Polarized Electron Source	Accumulator Ring	Electrons at Converter	Polarized Positron Source
JLEIC	4 pC @ 748.5 MHz 3 mA w/ DF = 5 %	8 pC @ 748.5 MHz 1 mA w/ DF = 5 %	2 nC @ 17 MHz 34 mA w/ DF = 0.26%	0.2 pC @ 17 MHz 3.4 $\mu$ A w/ DF = 0.26%
CEBAF	4-40 pC @ 250 MHz 1-10 mA (cw)	Not necessary	4-40 pC @ 250 MHz 1-10 mA (cw)	0.4-4 fC @ 250 MHz 100 nA – 1 mA

# ILC : Spin Polarized Electron Driven Source ?

What is expected (w/o any cuts) for a 3 GeV spin polarized electron beam over range of target thickness (5mm – 16 mm)

- Thicker targets improve yield of lowest energy positrons, and provide a degree of spin filtering.
- Thinner targets conversely improve yield of highest energy positrons, and with less impact by spin filtering.

E(e-)=3 GeV W=16mm	E(e+)	N(e+)/N(e-)	$\langle S_z \rangle$	P (%)
	150 MeV	0.436	0.23	21
	350 MeV	0.056	0.41	37



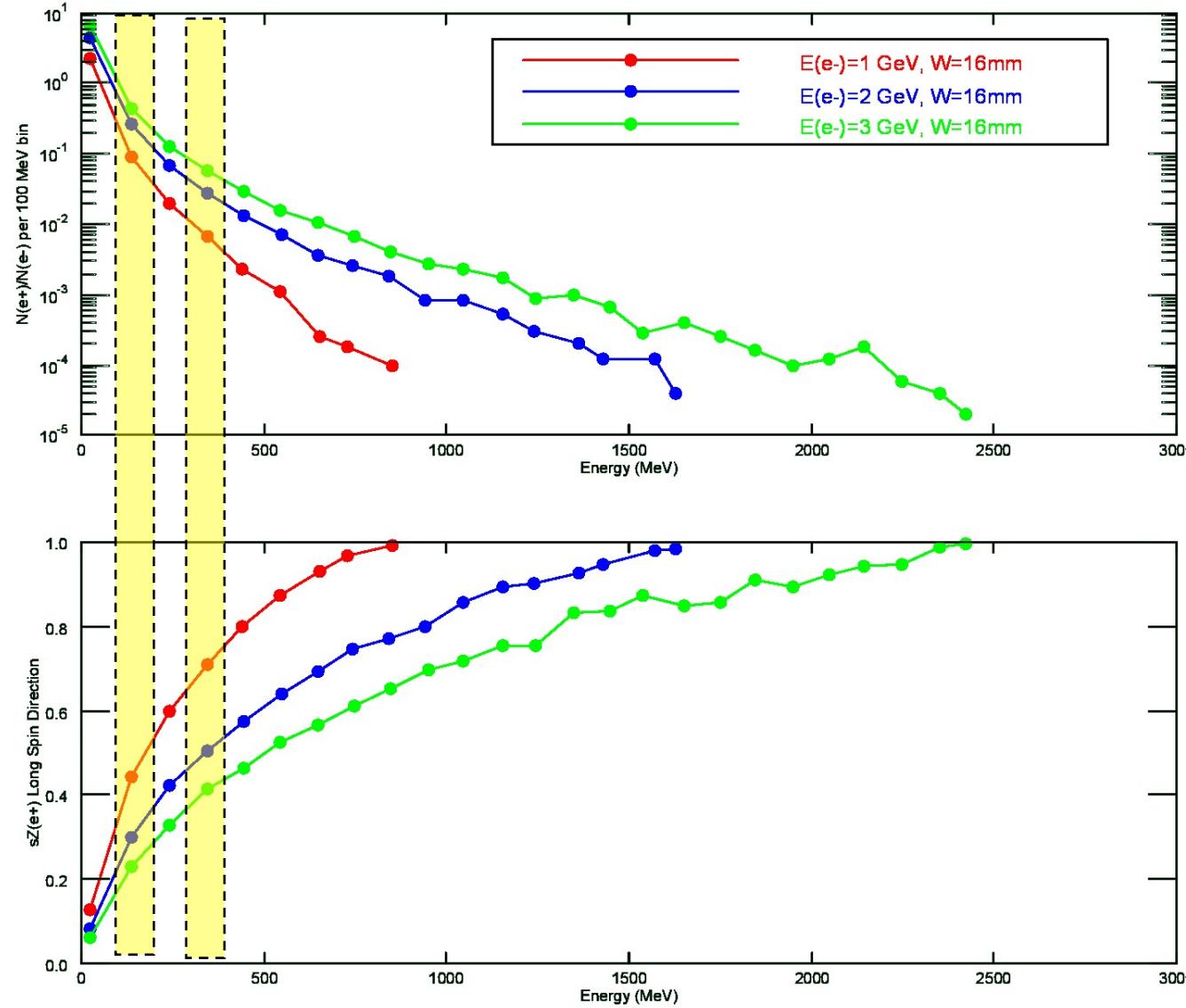
# ILC : Spin Polarized Electron Driven Source ?

What is expected (w/o any cuts) if the electron beam energy were lowered, for the same target thickness (16mm).

- Lower electron beam energy results in lower yield, expectedly, preferentially at low positron energy.
- Lower electron beam energy results in high spin polarization at same positron energy

	E (e-)	N(e+)/N(e-)	$\langle S_z \rangle$	P (%)
E(e+)=150 MeV W=16mm	3 GeV	0.436	0.23	21
	1 GeV	0.091	0.44	40

	E (e-)	N(e+)/N(e-)	$\langle S_z \rangle$	P (%)
E(e+)=350 MeV W=16mm	3 GeV	0.056	0.41	37
	1 GeV	0.007	0.71	64



# ILC : Spin Polarized Electron Driven Source ?

What is expected (w/o any cuts) if the electron beam energy were 1 GeV, and target thickness reduced.

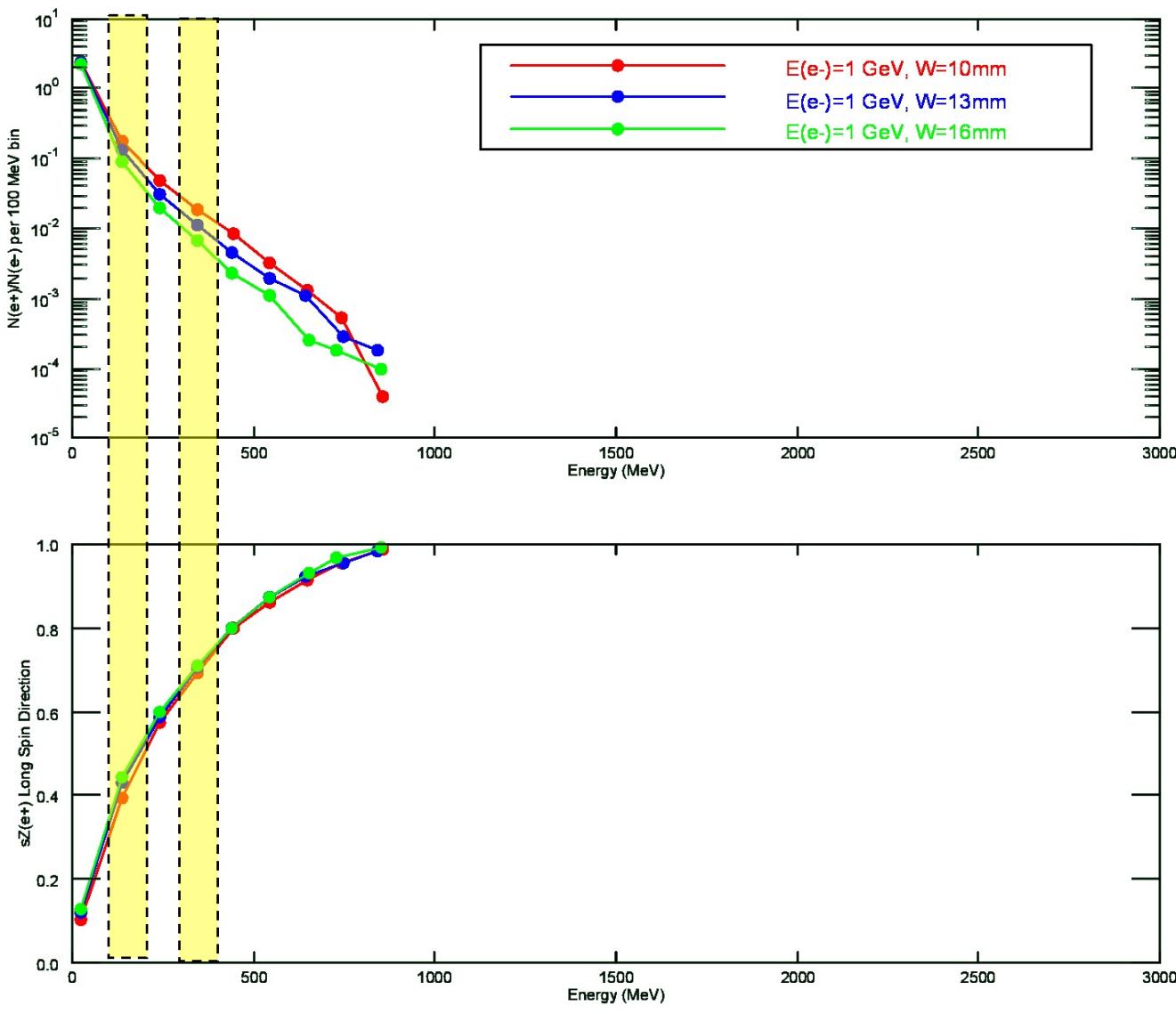
- Small reduction in target thickness has the effect of increasing yield (at this lower electron beam energy).
- Target thickness has less impact when positron energy large fraction of electron energy.

E (e-)	Target	N(e+)/N(e-)	$\langle S_z \rangle$	P (%)
3 GeV	16 mm	0.436	0.23	21
1 GeV	10 mm	0.178	0.39	35

E(e+)=150 MeV

E (e-)	Target	N(e+)/N(e-)	$\langle S_z \rangle$	P (%)
3 GeV	16 mm	0.056	0.41	37
1 GeV	10 mm	0.018	0.69	62

E(e+)=350 MeV



# GaAs Polarized Electron Source Parameters

Parameter \ Machine =>	CEBAF	SLC	JLab/FEL	Cornell ERL	LHeC	eRHIC	CLIC	ILC	JLEIC(e+)	CEBAF (e+)
Polarization	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Number electrons/microbunch	$2.5 \times 10^6$	$1 \times 10^{11}$	$8.3 \times 10^8$	$4.8 \times 10^8$	$1 \times 10^9$	$2.2 \times 10^{10}$	$6 \times 10^9$	$3 \times 10^{10}$	$1.2 \times 10^{10}$	$2.5 \times 10^8$
Number of microbunches	CW	2	CW	CW	CW	CW	312	3000	900	CW
Width of microbunch	50 ps	2 ns	35 ps	2 ps	100 ps	$\sim 100$ ps	$\sim 100$ ps	$\sim 1$ ns	100 ps	50 ps
Time between microbunches	2 ns	61.6 ns	13 ns	0.77 ns	25 ns	71.4 ns	0.5002 ns	337 ns	1.33 ns	4 ns
Microbunch rep rate	499 MHz	16 MHz	75 MHz	1300 MHz	40MHz	14MHz	1999 MHz	3 MHz	750 MHz	250 MHz
Width of macropulse	-	64 ns	-	-	-	-	156 ns	1 ms	1.1 ms	-
Macropulse repetition rate	-	120 Hz	-	-	-	-	50 Hz	5 Hz	50 Hz	-
Charge per micropulse	0.4 pC	16 nC	133 pC	77 pC	500 pC	3.6 nC	0.96 nC	4.8 nC	2 nC	40 pC
Charge per macropulse	-	32 nC	-	-	-	-	300 nC	14420 nC	1800 nC	-
Average current from gun	200 uA	2 uA	10 mA	100 mA	20 mA	50 mA	15 uA	72 uA	88 uA	10 mA
Average current in macropulse	-	0.064 A	-	-	-	-	1.9 A	0.0144 A	0.034 A	-
Duty Factor	$2.5 \times 10^{-2}$	$2.8 \times 10^{-7}$	$2.6 \times 10^{-3}$	$2.6 \times 10^{-3}$	$4 \times 10^{-3}$	$1.4 \times 10^{-3}$	0.2	$3 \times 10^{-3}$	$2.6 \times 10^{-3}$	$1.2 \times 10^{-2}$
Peak current of micropulse	8 mA	8 A	3.8 A	38.5 A	5 A	35.7 A	9.6 A	4.8 A	20 A	0.8 A
Current density*	$4 \text{ A/cm}^2$	$10 \text{ A/cm}^2$	$19 \text{ A/cm}^2$	$500 \text{ A/cm}^2$	$100 \text{ A/cm}^2$	$182 \text{ A/cm}^2$	$12 \text{ A/cm}^2$	$6 \text{ A/cm}^2$	$20 \text{ A/cm}^2$	$16 \text{ A/cm}^2$
Laser Spot Size*	0.05 cm	1 cm	0.5 cm	0.3 cm	0.5 cm	0.5 cm	1 cm	1 cm	1 cm	0.10 cm

\* Loose estimates

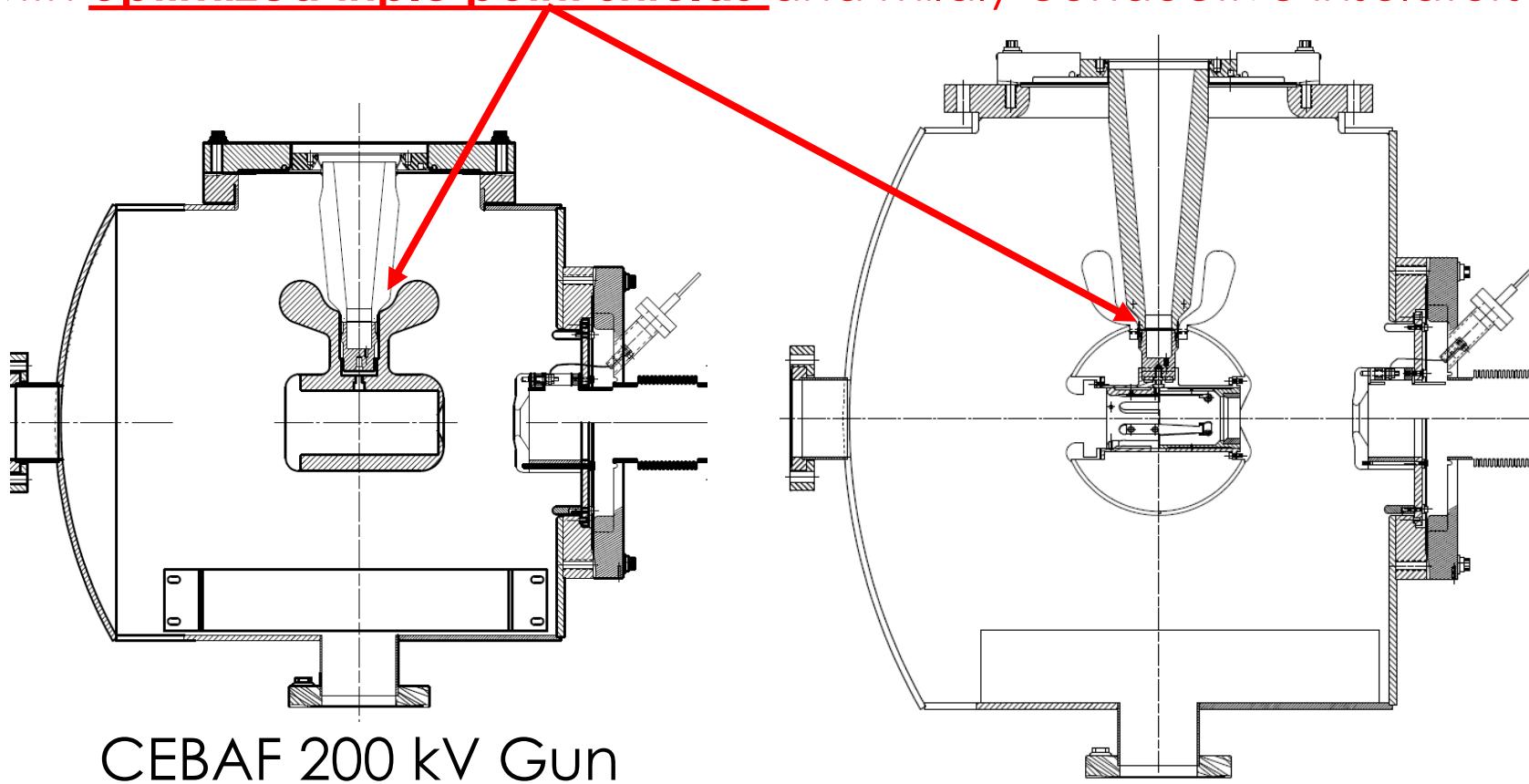
Demonstrated

Proposed (excuse outdated values)

My Speculations

# Jefferson Lab: Inverted Insulator Photogun

with optimized triple point shields and mildly conductive insulators



Both designs, maximum field strength < 10 MV/m

# Jefferson Lab: High Voltage (200-350 kV) Inverted Insulator Photo-guns



CEBAF 200 kV  
Installed June 2018  
(operates at 130kV until  
an upgrade in 2020)

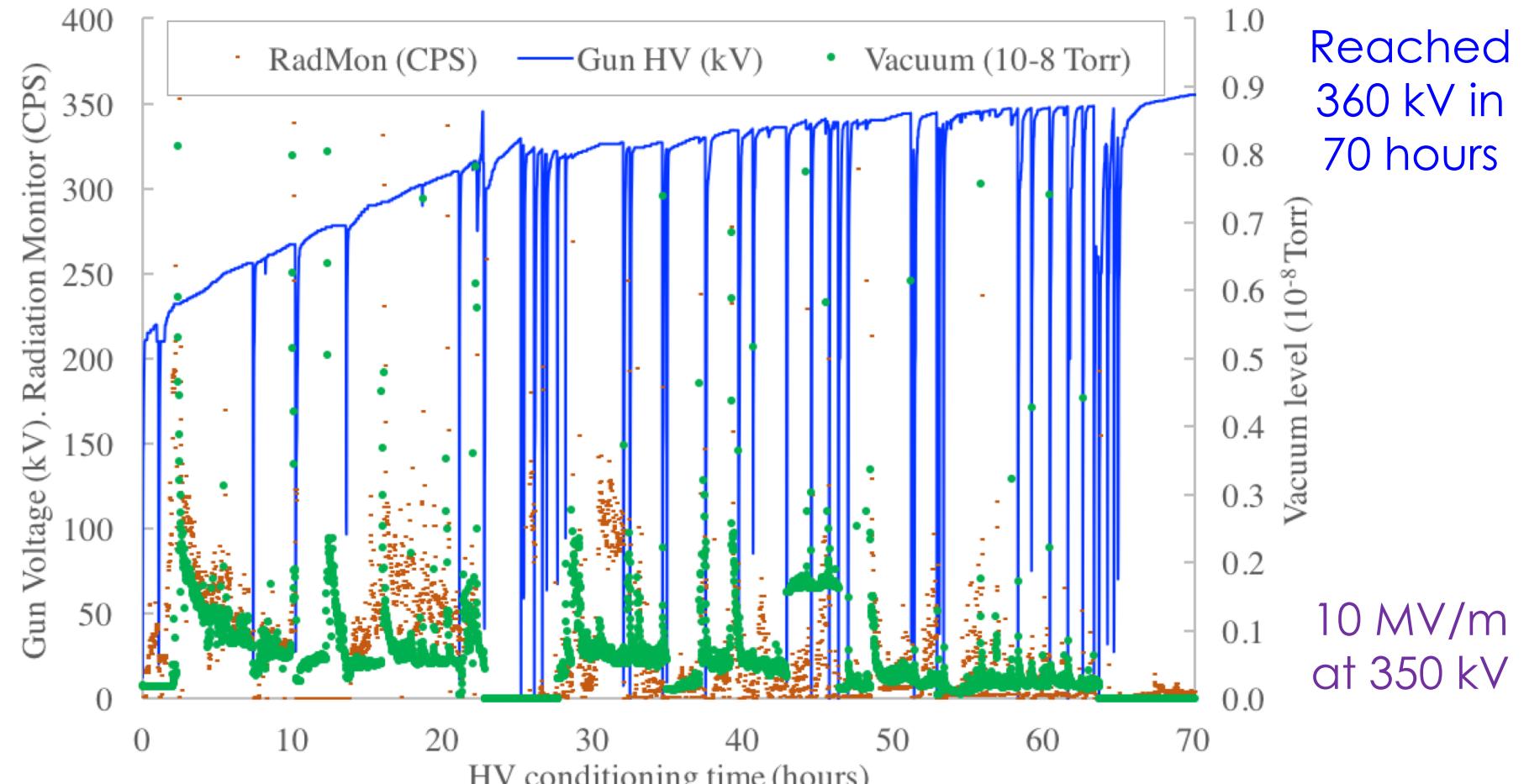


GTS 350 kV  
In operation since Nov 2016  
with CsK<sub>2</sub>Sb photocathode



UITF 350 kV  
Polarized Gun  
Under assembly

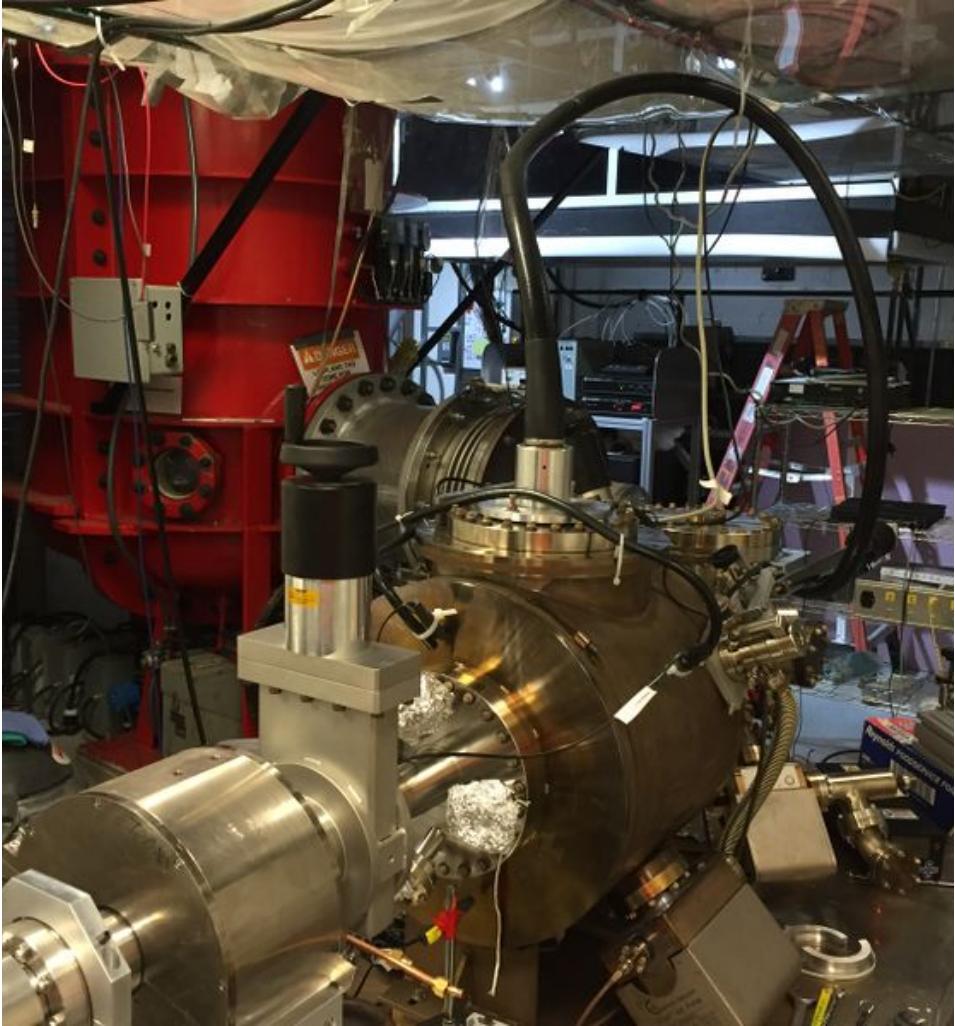
# Metric of Success: High Voltage without Field Emission



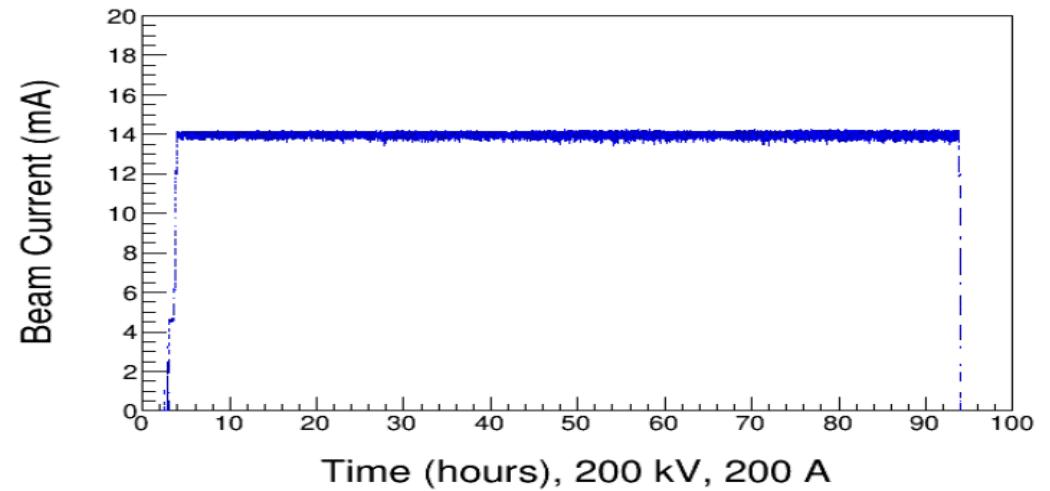
Vacuum and radiation levels indistinguishable from background at 350kV

# Magnetized Beam Photogun at the Gun Test Stand (GTS)

*Magnetized Beam LDRD, PI's: R. Suleiman and M. Poelker*

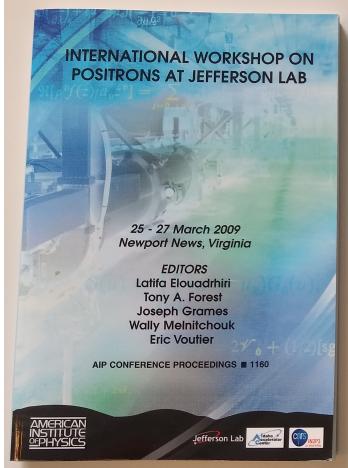


- Load-lock inverted insulator photo-gun (multiple photocathodes), **like CEBAF geometry**.
- **Cable connection** from HVPS to gun.
- Over **1000 hours operating >300kV**; HV conditioning about 1 week.
- Operating with CsKSb photocathodes at **>10 mA average current**, and **0.7nC bunch charge**.

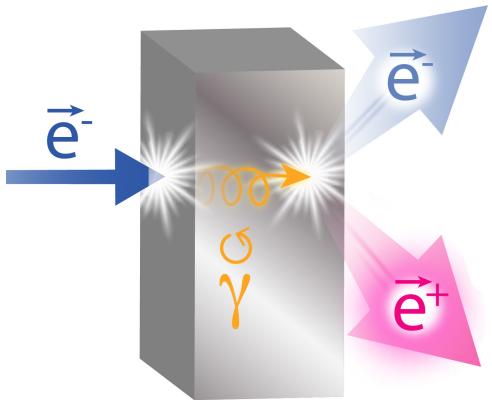


# Roadmap: Jefferson Lab

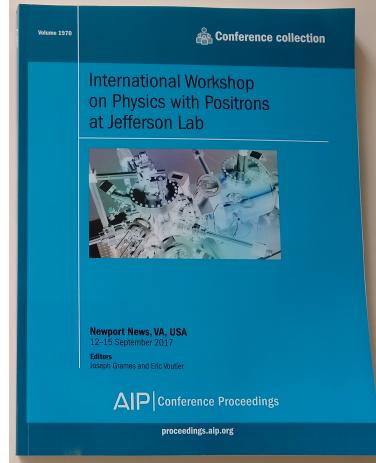
JPos'09  
(2009)



PEPPo  
(2012-2015)



JPos'17  
(2017)



LOI-12-18-004  
(2018)

Letter-of-Intent to PAC46

**Physics with Positron Beams at Jefferson Lab 12 GeV**

A long list of authors and their contributions to the Physics with Positron Beams at Jefferson Lab 12 GeV project, including Andrei Afanasev<sup>29</sup>, Ibrahim Albayrak<sup>9</sup>, Salina Al<sup>34</sup>, Moskov Amaryan<sup>34</sup>, Annalisa D'Angelo<sup>18,32</sup>, John Annand<sup>34</sup>, John Arrington<sup>6</sup>, Arshak Asaturyan<sup>9</sup>, Harut Avakian<sup>1</sup>, Todd Averett<sup>28</sup>, Luca Barion<sup>17</sup>, Marco Battaglieri<sup>1</sup>, Vincenzo Bellini<sup>16</sup>, Vladimir Berdnikov<sup>27</sup>, Jai Bernauer<sup>2</sup>, Angela Biselli<sup>12</sup>, Marie Boer<sup>27</sup>, Marangela Bondi<sup>10</sup>, Koen Thomas Brinkmann<sup>32</sup>, Bill Brisson<sup>2</sup>, Volker Burkert<sup>1</sup>, Alessandro Caccianiga<sup>1</sup>, Thomas Casper<sup>14</sup>, Lorraine Cernan<sup>1</sup>, Marco Carnignotto<sup>1</sup>, Lucien Caurier<sup>2</sup>, Andra Celentano<sup>4</sup>, Pierre Chatagnon<sup>2</sup>, Giuseppe Ciulli<sup>17,31</sup>, Marco Contalbrigo<sup>17</sup>, Donald Day<sup>37</sup>, Maxime Dufurie<sup>15</sup>, Stefan Dietz<sup>32</sup>, Bishoy Dongwi<sup>14</sup>, Raphaël Dupé<sup>2</sup>, Dipangkar Dutta<sup>21</sup>, Mathieu Ehrhart<sup>2</sup>, Latifa Elouadrhiri<sup>1</sup>, Rolf Ent<sup>1</sup>, Ishara Fernando<sup>14</sup>, Alessandra Filippi<sup>19</sup>, Yuli Furtetova<sup>1</sup>, Hayyan Gao<sup>10</sup>, Ashot Gasparian<sup>27</sup>, Dave Gaskell<sup>1</sup>, Frederick Graw<sup>1</sup>, Francisco-Xavier Gomez<sup>1</sup>, Jonathan Green<sup>1,\*</sup>, Chao Gu<sup>10</sup>, Michel Guidal<sup>2</sup>, David Hamilton<sup>1</sup>, Douglas Hasell<sup>3</sup>, Douglas Higinbotham<sup>1</sup>, Mostafa Hoballah<sup>2</sup>, Tanja Horwitz<sup>27</sup>, Charles Hyde<sup>24</sup>, Antonio Italiano<sup>16</sup>, Narbe Kalantarians<sup>29</sup>, Gregorze Kalicy<sup>27</sup>, Dustin Keller<sup>37</sup>, Cynthia Keppel<sup>1</sup>, Mitchell Kersev<sup>23</sup>, Paul King<sup>23</sup>, Edward Kinney<sup>33</sup>, Ho-San Ko<sup>2</sup>, Michael Kohl<sup>14</sup>, Valery Kubarovskiy<sup>1</sup>, Lucilla Lanza<sup>18,30</sup>, Paolo Lenisa<sup>17</sup>, Nilanga Liyanage<sup>27</sup>, Simonaetta Luti<sup>37</sup>, Juliette Mameti<sup>35</sup>, Dominique Marchand<sup>2</sup>, Peter Markowitz<sup>13</sup>, Luca Marsicano<sup>13</sup>, Malek Mazouzi<sup>21</sup>, Michael McCaughey<sup>1</sup>, Bryan McKinnon<sup>31</sup>, Mina Mihovilovic<sup>28</sup>, Richard Milner<sup>2</sup>, Arthur Mkrtchyan<sup>1</sup>, Hamlet Mkrtchyan<sup>1</sup>, Aram Movsisyan<sup>17</sup>.

- ❖ Based upon preliminary simulations that suggest a CW polarized positron source can be built to meet the CEBAF requirements, a **conceptual design study report is now essential** to inform a plausible scheme that is integrated into the CEBAF program.
- ❖ The next R&D priorities include **designing, building and testing a positron beam collection system** to define/optimize useful positron phase space (6D+spin) and **assessing the performance of CEBAF for new positron beam conditions (magnet reversal, low intensity, 6D acceptance)**.

## Summary

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- ❖ Jefferson Lab Users are making the physics case for both high energy **polarized and unpolarized positron beams at CEBAF 12 GeV.**
- ❖ **PEPPo demonstrated high positron polarization from polarized electrons at low energy w/ small footprint (cost, energy, radioactivity), extensible to high energy.**
- ❖ We are exploring concepts to produce **positron beams for both CEBAF (CW, pC, mA) and JLEIC (pulsed, nC,  $\mu$ A) with tunability on intensity and polarization.**
- ❖ Recent progress is promising to develop a **350 kV polarized source based on the inverted insulator geometry** necessary for  $>nC$  bunch charge.
- ❖ Can the PEPPo concept applied to the ILC electron driven positron source **turn a “no polarization” scheme into a “polarization scheme”**, even for a later upgrade?