Polarized Positron Beam Perspectives for DIS Studies

e+ @ EIC

Yulia Furletova[1], Joe Grames[1], Sonny Mantry[2], Eric Voutier[3]

on behalf of the JLab Positron Working Group

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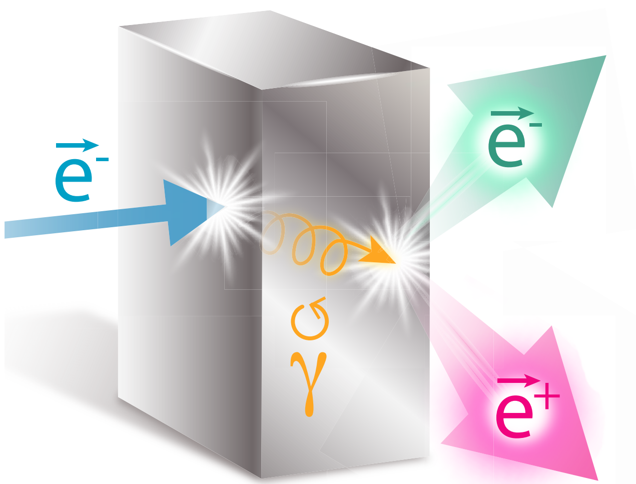
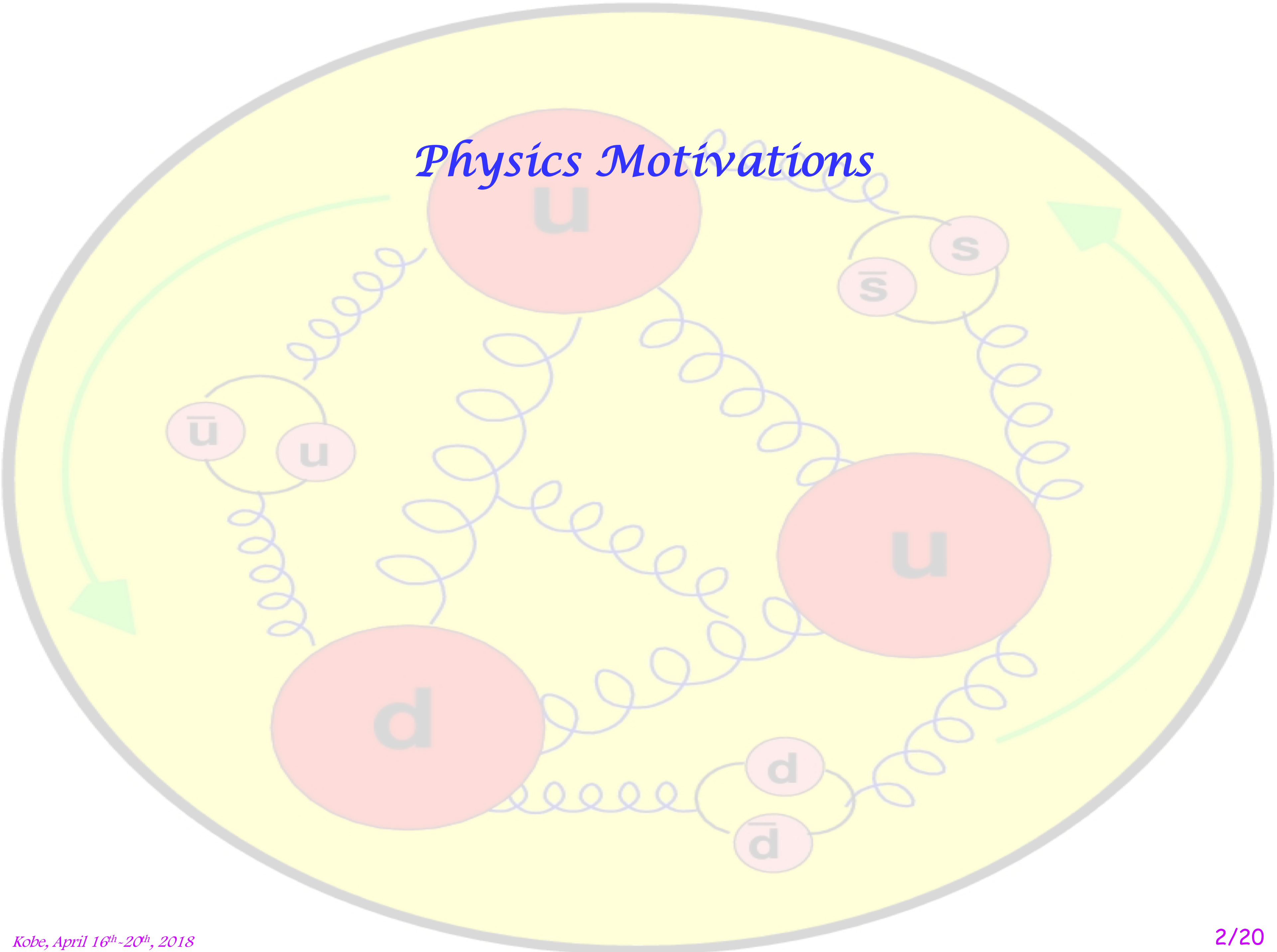


Physics Motivations



Physics Motivations

Interference Physics

- Two-photon physics
- Generalized parton distributions

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Structure Functions

- Neutral and charged DIS
- Charm production
- Pion and kaon structure

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Standard Model Tests
- Charge conjugation violation
- Dark photon
- Right-handed W-bosons
- Leptoquarks, leptogluons

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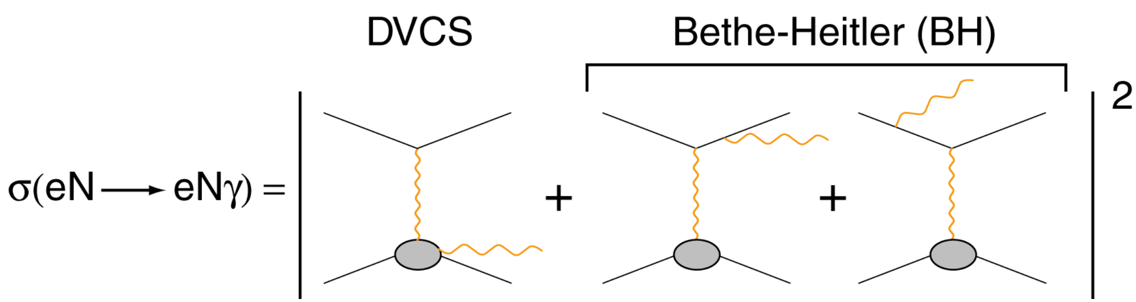
N(e,e'γN) Differential Cross Section

M. Diehl, CLAS12 European Workshop, Genova (2009)



$$\sigma^{e}_{P0} = \sigma_{BH} + \sigma_{DVCS} + P_l\,\tilde{\sigma}_{DVCS} + e_l\left(\sigma_{INT} + P_l\,\tilde{\sigma}_{INT}\right)$$

Electron observables

$$\sigma^{-}_{00} = \sigma_{BH} + \sigma_{DVCS} - \sigma_{INT}$$

$$\sigma^{-}_{+0} - \sigma^{-}_{-0} = 2\,\tilde{\sigma}_{DVCS} - 2\,\tilde{\sigma}_{INT}$$

Electron & positron observables

$$\sigma^{+}_{00} - \sigma^{-}_{00} = 2\,\sigma_{INT}$$

$$\left[\sigma^{+}_{+0} - \sigma^{+}_{-0}\right] - \left[\sigma^{-}_{+0} - \sigma^{-}_{-0}\right] = \left[\sigma^{+}_{+0} - \sigma^{-}_{+0}\right] - \left[\sigma^{+}_{-0} - \sigma^{-}_{-0}\right] = 4\,\tilde{\sigma}_{INT}$$

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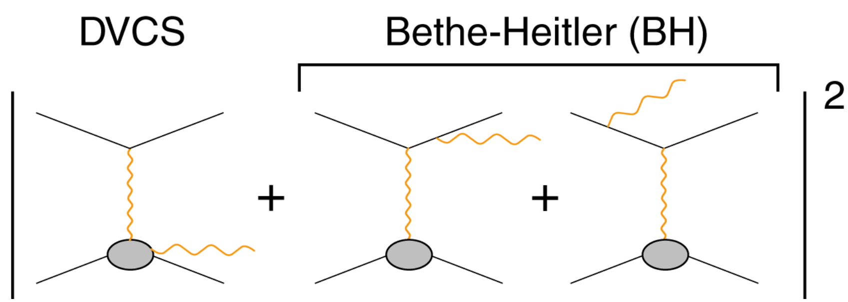
$\sigma(eN \longrightarrow eN\gamma) =$



$$\sigma^{e}_{PS} = \sigma^{e}_{P0} + S\left[P_l\, \Delta\sigma_{BH} + \left(\Delta\tilde{\sigma}_{DVCS} + P_l\, \Delta\sigma_{DVCS}\right) + e_l\left(\Delta\tilde{\sigma}_{INT} + P_l\, \Delta\sigma_{INT}\right)\right]$$

Additional observables

$$\sigma^{\pm}_{0+} - \sigma^{\pm}_{0-} = 2\Delta\tilde{\sigma}_{DVCS} \pm 2\Delta\tilde{\sigma}_{INT}$$

$$\left[\sigma^{\pm}_{++} - \sigma^{\pm}_{+-}\right] - \left[\sigma^{\pm}_{-+} - \sigma^{\pm}_{--}\right] = 4\,\Delta\sigma_{BH} + 4\,\Delta\sigma_{DVCS} \pm 4\,\Delta\sigma_{INT}$$

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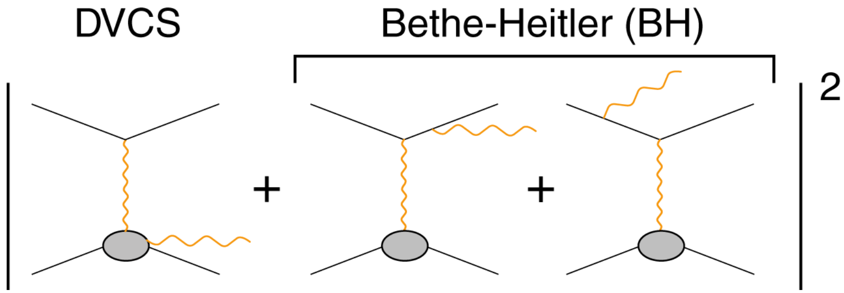

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Polarized electrons and positrons allow to **separate** the **unknown amplitudes** of the cross section for electro-production of photons.

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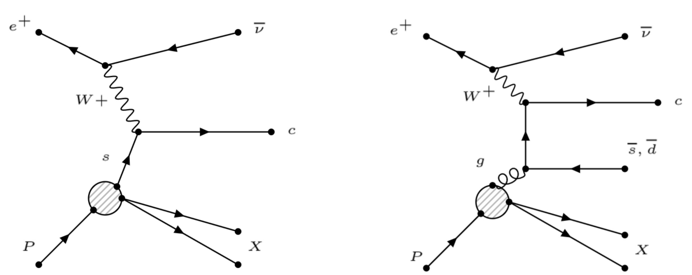
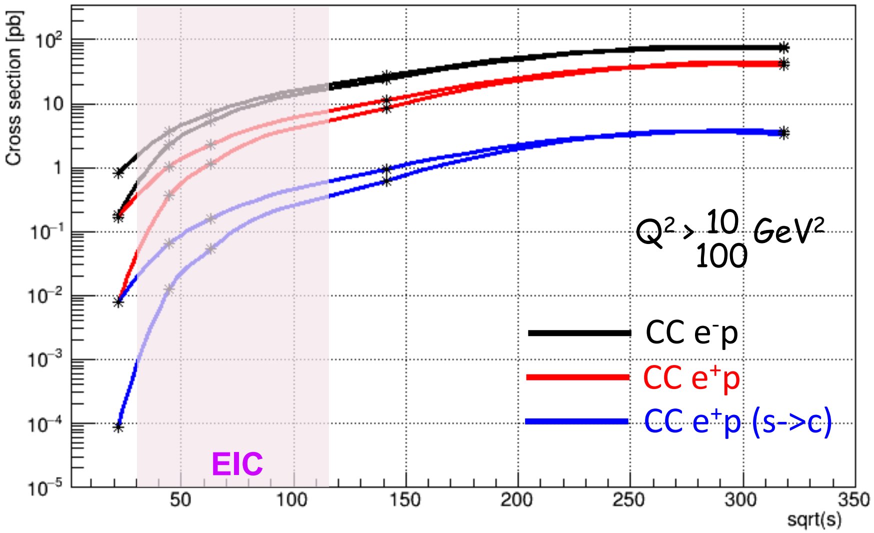
Strangeness Tagging

- The **modest center-of-mass energy** at the EIC can be **compensated** by the **high luminosity** and **polarization degree** of the lepton beam, to help for **precise measurements** of the small **charge current cross section**.



- **Charm production** via **charge current** exchange preferentially couples to the **strange content** of the nucleon.
- The boson-gluon-fusion mechanism is a source of **background**, **manageable** with good **PID** and **vertex reconstruction**.



$$e^+ + \mathrm{p} \rightarrow \bar{\upsilon}_e + c + X$$
$$e^- + \mathrm{p} \rightarrow \upsilon_e + \bar{c} + X$$

An integrated luminosity of 10 fb^{-1}/year would provide ~**1500 events/year**.

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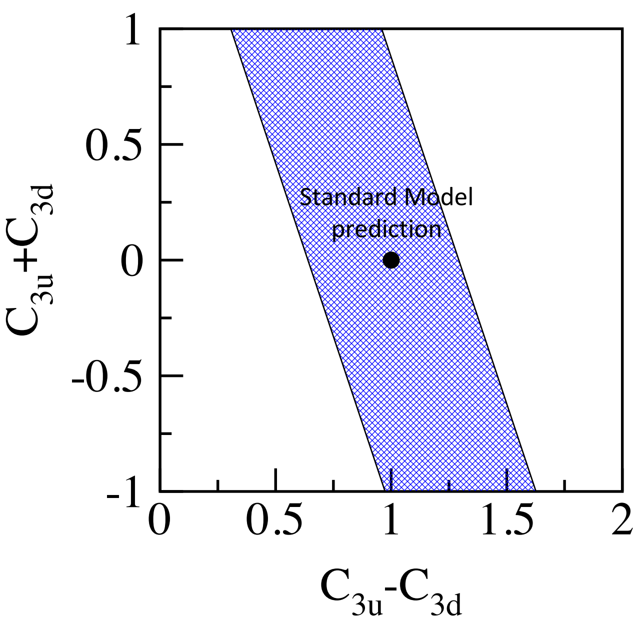
Weak Neutral Current Couplings

S.M. Berman, J.R. Primack , Phys. Rev. D 9 (1974) 2171   X. Zheng, JPos09, Newport News (2009)

- The comparison of **polarized electron** an **polarized positon** scatterings provides access to the **charge conjugation-violation** coupling C_{3q} from the interference between the weak neutral and electromagnetic currents.

$$\mathcal{L} = \frac{G_F}{\sqrt{2}} \sum_q \left[C_{1q}\, \bar{\ell}\gamma^\mu\gamma_5\ell\bar{q}\gamma_\mu q + C_{2q}\, \bar{\ell}\gamma^\mu\ell\bar{q}\gamma_\mu\gamma_5 q + C_{3q}\, \bar{\ell}\gamma^\mu\gamma_5\ell\bar{q}\gamma_\mu\gamma_5 q \right]$$

C_{3q} ← $g_A^e g_A^q$



The combination of C_{3q} couplings is **poorly known**; have only been measured at CERN using **muon** and **anti-muon** beams on a carbon target.

$$0.81\,(2C_{2u}-C_{2d}) + 2C_{3u}-C_{3d} = 1.53 \pm 0.45$$

D. Wang et al. Phys. Rev. C 91 (2015) 045506

$$2C_{3u} - C_{3d} = 1.65 \pm 0.45$$

C_{3q} are known only within 30%

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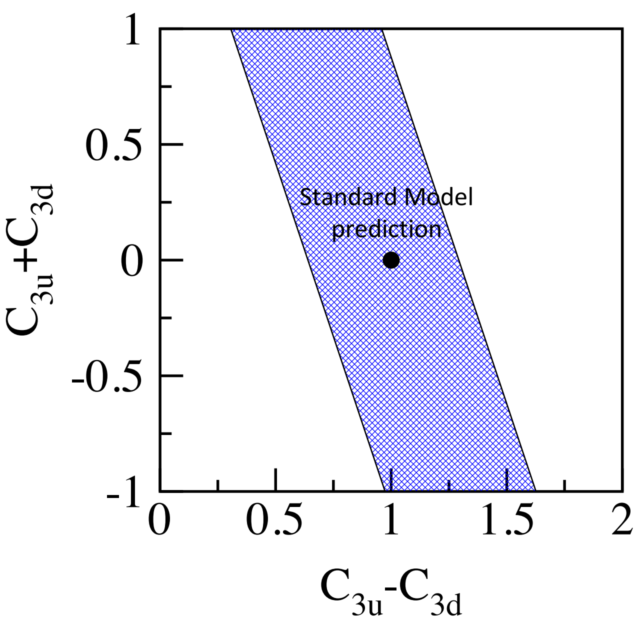
$C_{3q} \to g_A^e g_A^q$



$$A^{e_L^- - e_R^+} = \frac{d\sigma(e_L^- N) - d\sigma(e_R^+ N)}{d\sigma(e_L^- N) + d\sigma(e_R^+ N)}$$

$$A_p^{e_L^- - e_R^+} = \left(\frac{3G_F Q^2}{2\pi\alpha\sqrt{2}}\right) \frac{y(2-y)}{2} \frac{2C_{2u}u_V - C_{2d}d_V + 2C_{3u}u_V - C_{3d}d_V}{4u+d}$$

$$A_d^{e_L^- - e_R^+} = \left(\frac{3G_F Q^2}{2\pi\alpha\sqrt{2}}\right) \frac{y(2-y)}{2} \frac{2C_{2u} - C_{2d} + 2C_{3u} - C_{3d}}{5} \frac{u_V + d_V}{u + \bar{u} + d + \bar{d}}$$

$$A_d^{e_L^- - e_R^+} \approx 108\, \frac{y(2-y)}{2}\, (2C_{3u} - C_{3d})\, Q^2 \text{ ppm}$$

There exists a unique opportunity for a polarized electron and positron beam at EIC to improve the C_{3q} knowledge.

Polarized Charge Current Cross Section

Y. Furletova, S. Mantry

- The **polarization dependence** of the charge current cross section can be measured to potentially reveal *deviations from the Standard Model prediction*.

$$\frac{d^2\sigma_{SM}^{e^+p}}{dx\,dQ^2} = (1+P_e)\,\frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[\bar{u}+\bar{c}+(1-y^2)(d+s)\right]$$

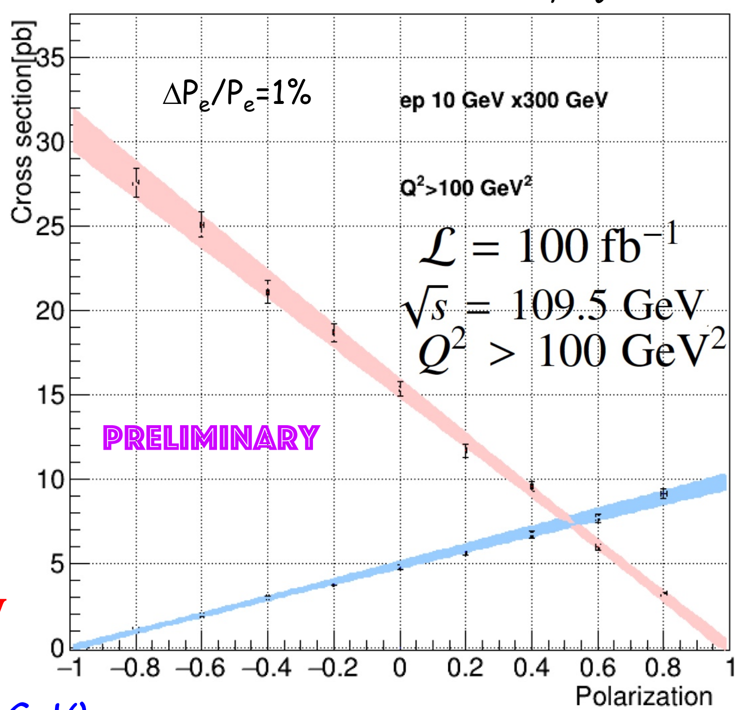
$$\frac{d^2\sigma_{SM}^{e^-p}}{dx\,dQ^2} = (1-P_e)\,\frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[u+c+(1-y^2)(\bar{d}+\bar{s})\right]$$

$$\sigma^{e^\pm p}\,(P_e=\mp 1)\neq 0\ \rightarrow$$ Limit on the mass of right-handed W-boson

95% confidence level upper bound

$$\sigma^{e^\pm p}\,(P_e=\mp 1) < 0.0776\ \text{pb}\ \rightarrow\ \boldsymbol{M_R \geq 285\ \text{GeV}}$$

EIC projections



(HERA limit in e^+p is 208 GeV)

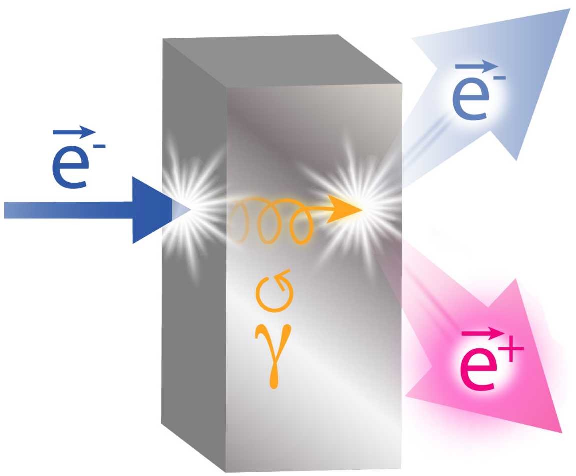
Polarized Positrons @ JLEIC

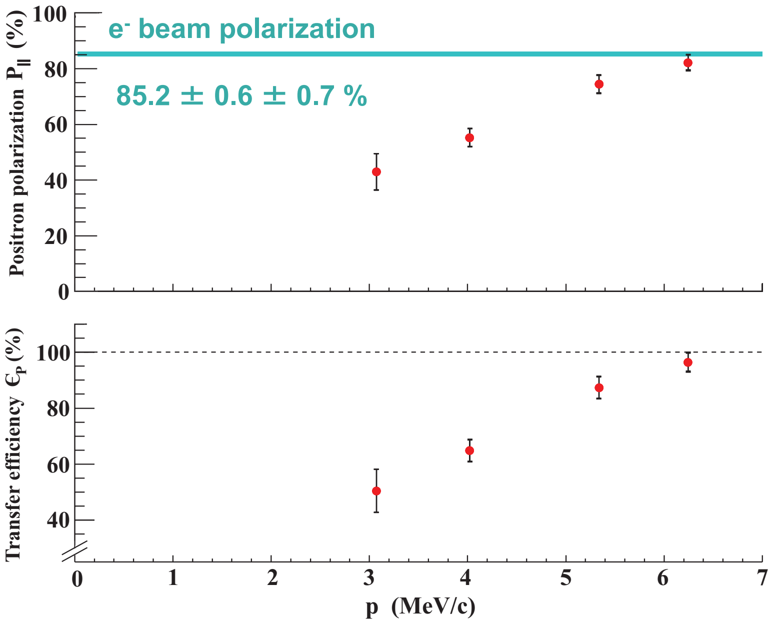
- Positron polarization
- Positron source concept

PEPPo Technique

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

- **PEPPo** demonstrated **efficient polarization transfer** from **8.2 MeV/*c*** **electrons to positrons**, expanding polarized positron capabilities **from GeV to MeV accelerators**.





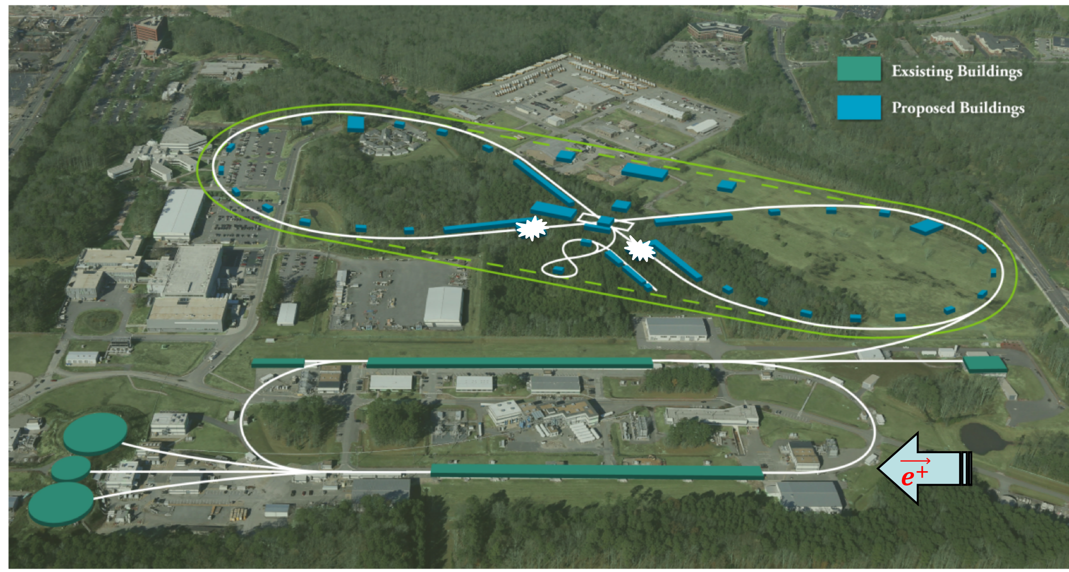
The **PEPPo** technique can optimaly achieve **75%** electron **polarization transfer**.

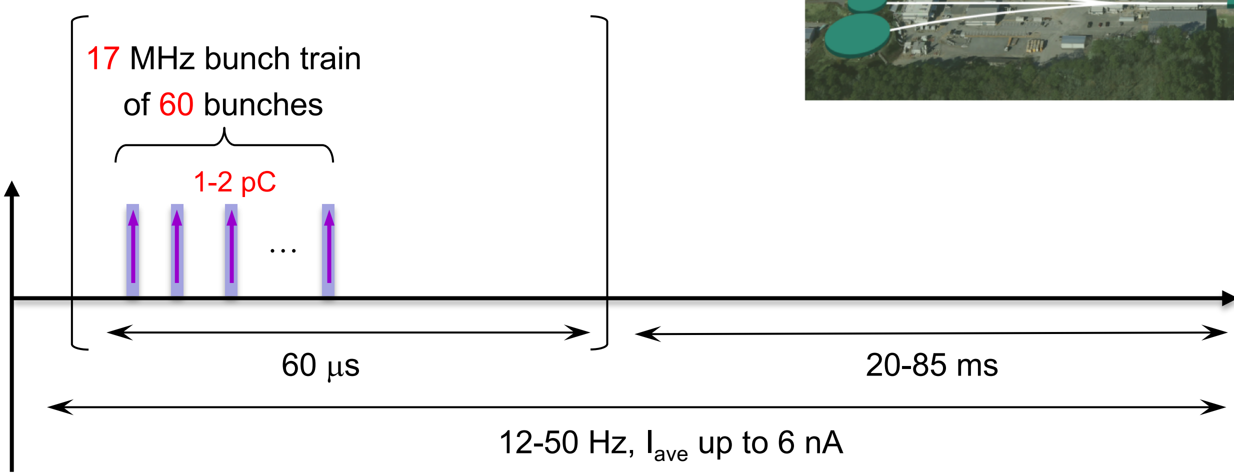
Design Constraints

F. Lin et al. JPos17, Newport News (2017)

- A possible design for a **Positron-Ion-Collider** (**PIC**) at **JLEIC** would involve a dedicated low energy polarized positron injector with specific pulse structure.

$\mathcal{L} \geqq 10^{33}\ cm^{-2}.s^{-1}$ $P \geqq 40\%$





A low average current is required for injection into **JLEIC** with a reasonably short injection time (mn) and a reasonable polarization.

PIC Expected Performances

F. Lin et al. JPos17, Newport News (2017)

	CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)		
			p	e±	p	e±	p	e±	
	Beam energy	GeV	**40**	**3**	**100**	**5**	**100**	**10**	
e⁻	Collision frequency	MHz	**476** **119**		**476** **119**		119		e⁺
	Particles per bunch	10^{10}	**1.0** **1.1**	**3.7** **1.1**	**1.0** **2.1**	**3.7** **1.1**	3.9	**3.7** **1.1**	
	Beam current	A	**0.8** **0.2**	**2.8** **0.2**	**0.8** **0.4**	**2.8** **0.2**	0.8	**0.7** **0.2**	
	Polarization	%	80	**80** **>40**	80	**80** **>40**	80	**75** **>40**	
	Luminosity/IP	10^{33} $cm^{-2}s^{-1}$	**2.5** **0.18**		**21.4** **2.9**		**5.9** **1.7**		

The **center-of-mass energy** reach can be extended to **115-140 GeV** (8.4-12 T) depending of the proton dipole magnets technology.

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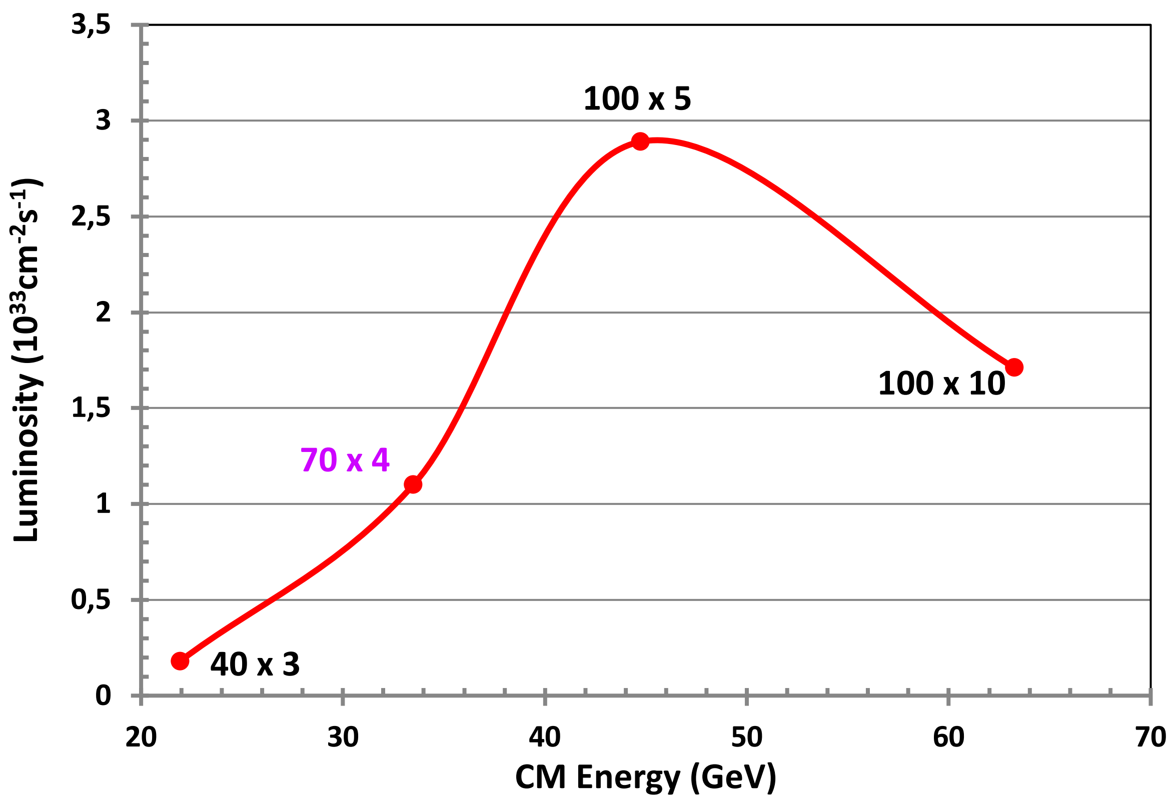
PIC Expected Performances

F. Lin et al. JPos17, Newport News (2017)



A polarized positron beam at JLEIC would access center-of-mass energies larger then **33 GeV** with a **luminosity ~10 times smaller than electron** luminosities.

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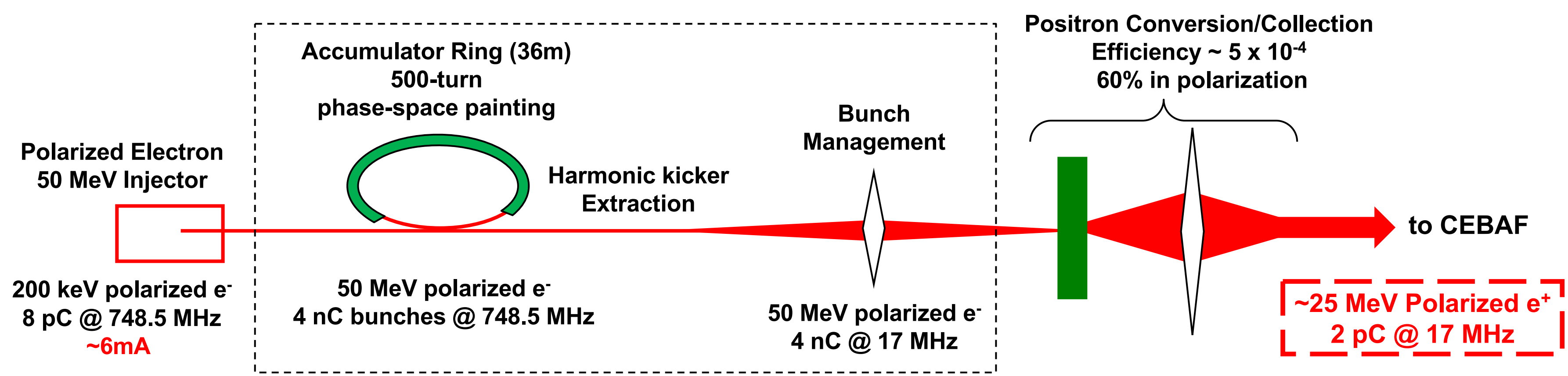
Positron Production Scheme

F. Lin et al. JPos17, Newport News (2017)



- High intensity **polarized electron** source
- **Management** of **beam power** and **material damage**
- Optimized **collection system**

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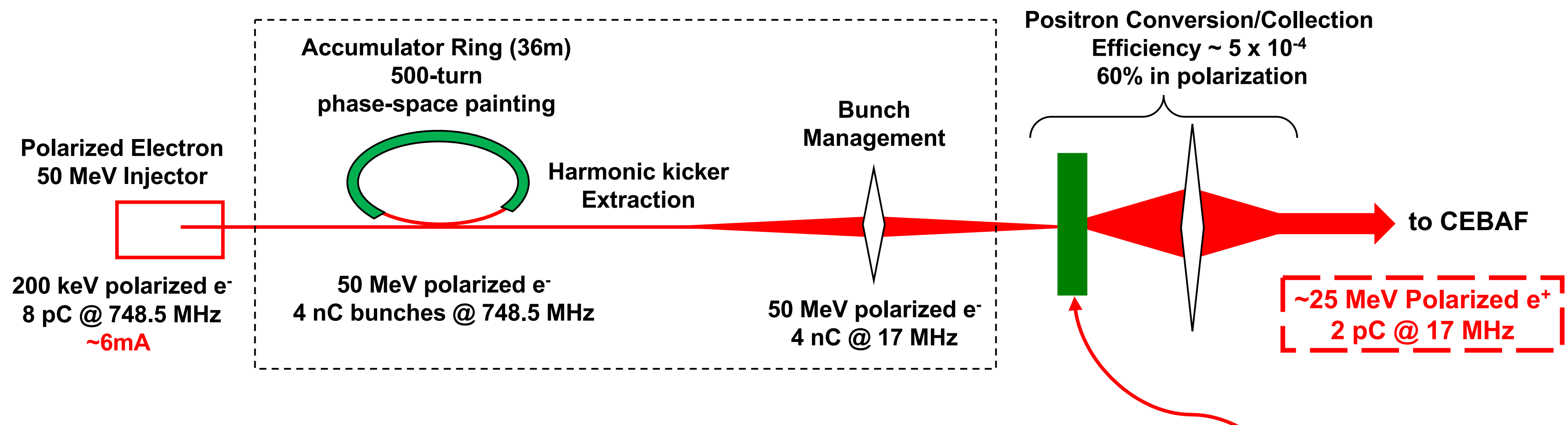
F. Lin et al. JPos17, Newport News (2017)



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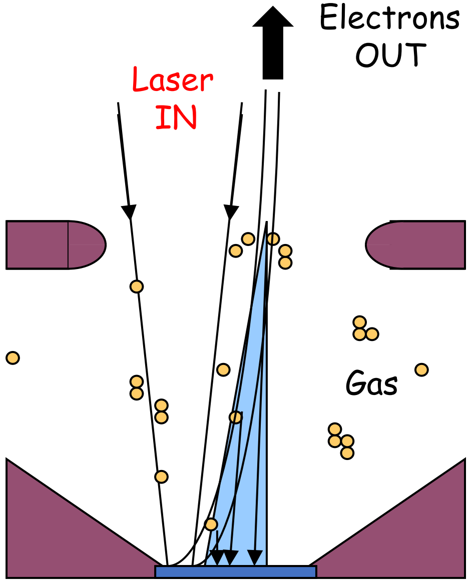
Power on target
3.4 MW peak power
0.6 kW average

Tecnological Challenges

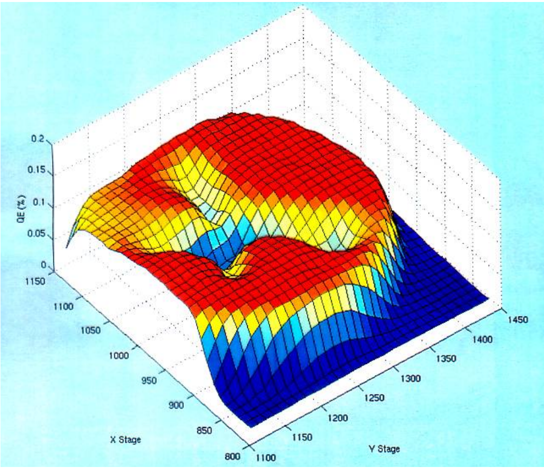
- Polarized electron source
- Accumulator ring
- Positron production
- Positron capture
- P3E initiative

Photocathode R&D

- The actual challenge of today's spin polarized GaAs photoelectron guns technology is the **extension** of the **charge lifetime** from **hundreds** to **thousands** of **Coulomb** for uninterrupted operation at **milli-Ampère beam current**.



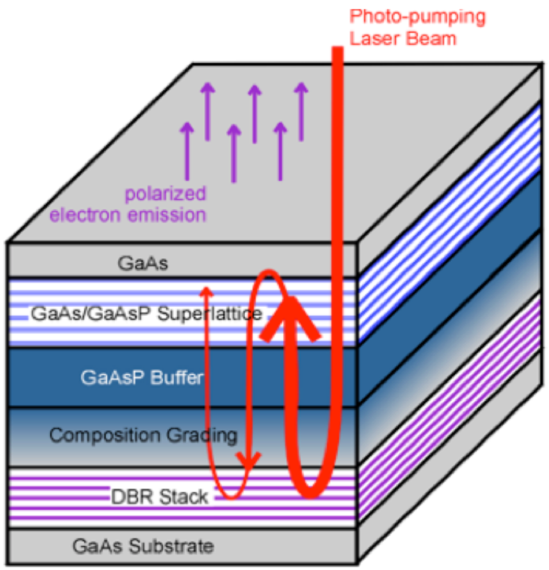
Ions create QE trough to electrostatic center



- **Minimizing ion production** rate (higher photo-gun voltage, increased quantum efficiency…)
- **Minimizing ion damage** effects (improved vacuum quality, larger spot size…)

Quantum Efficiency

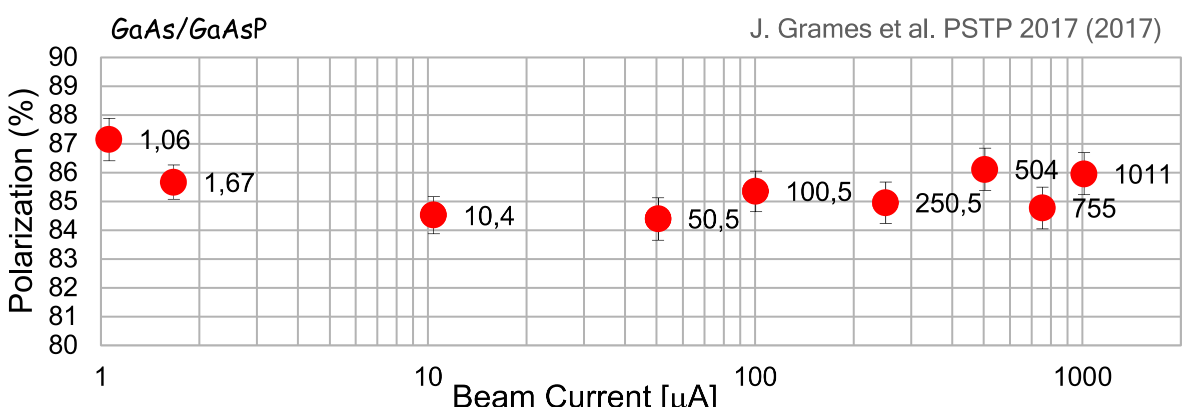
- Current GaAs/GaAsP **superlattice photocathodes** in operation at CEBAF demonstrated **high intensity** together with **high polarization**.
- Photocathode equiped with a **Distributed Bragg Reflector** demonstrated the ever measured the **highest QE & FoM**.



TJNAF

W. Liu et al. Appl. Phys. Lett. 109 (2016) 252104

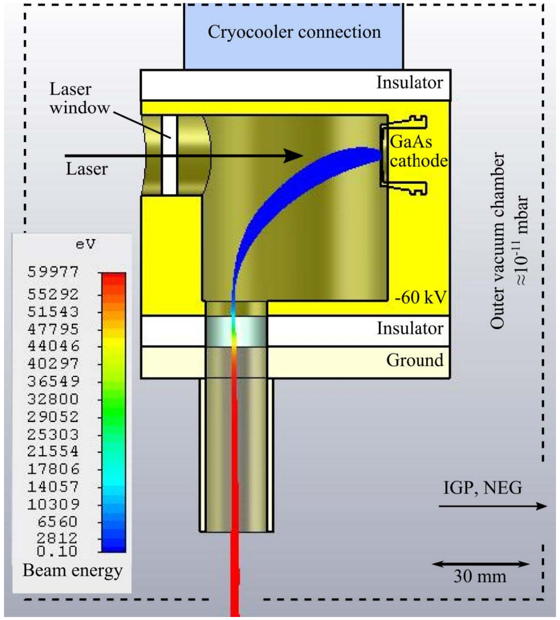
Cathode	Lab/Inc.	P (%)	QE (%)	FoM (P^2xQE)
GaAS-GaASP	SLAC/SVTA	86	1.20	0.89
AlInGaAs-AlGaAs	St. Petersburg	92	0.85	0.72
GaAs-GaAsP	Nagoya	92	1.60	1.35
GaAs-GaASP/DBR	JLab/SVTA		6.40	4.52



Vacuum Quality

S. Weih et al. JACoW IPAC (2017) TUPAB032

- A photocathode placed in a **cryogenic environment** is expected to sustain **higher laser power**, and to **much less** suffer **ion-back-bombardment** effects because of better local vacuum condition from cryopumping at the cold surfaces.



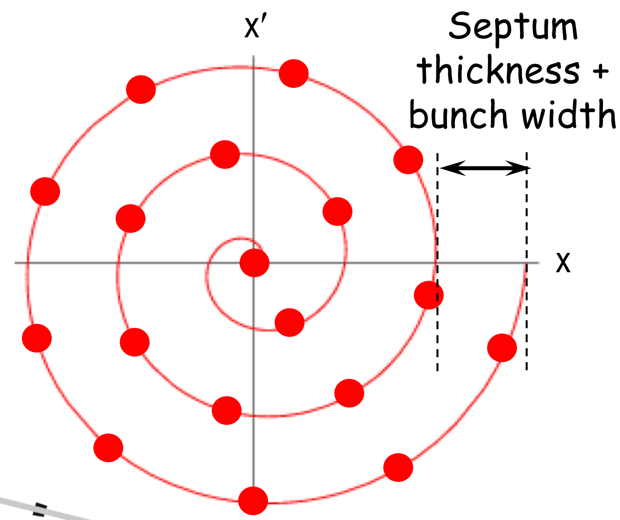
TUD

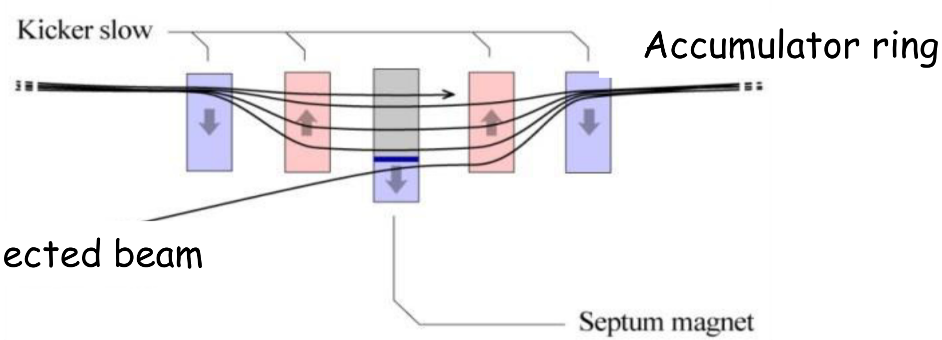
- A laser window **prevents** inner surfaces from outside **contamination**.
- A bending electric field **prevents ions** produced by the extracted beam from **traveling back** to the cathode.

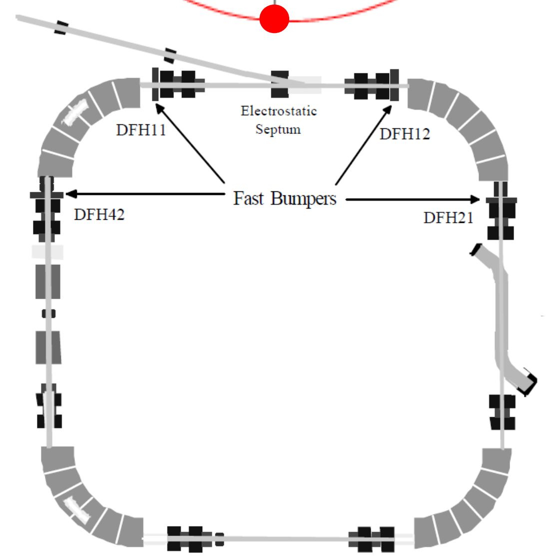
☛ *Would potentially provide 100 times higher beam currents.*

Multi-Turn Injection

- ➢ The concept consists in an orbit bump near a septum which is then slowly reduced as beam being injected (**phase-space painting**).
- ➢ The process can simultaneously occur in the longitudinal and vertical dimensions.
- ➢ CERN's LEIR has a design for **75-turn** injection of Pb^{54+}. The plan is to push this number to a **few hundred** to a **thousand** thanks to low electron emittance.



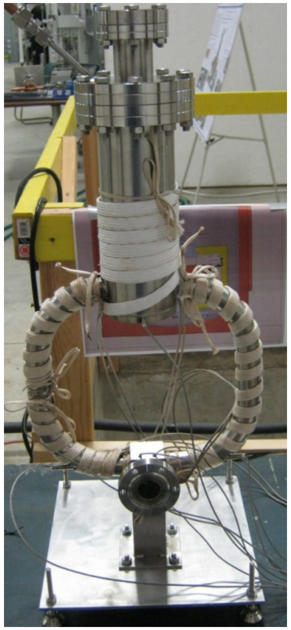




Courtesy of Vasiliy Morozov

High Power Target

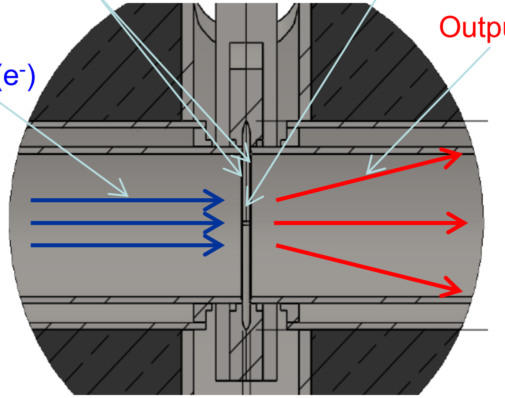
- Proposed high intensity polarized positron sources (ALTO, CEBAF, JLEIC, ILC…) represent challenging target issues with respect to **beam power deposition** and **degradation of material** through **radiation exposure**.



✓ **Liquid Metal Target**
Lead-bismuth eutectic compound

- High Z = **82**, **83**
- Low melting point: **124° C**
- High boiling point: **1670° C**
- **Natural circulation** from density differential in warm/cold legs
- Possibility of **mechanical** and/or **electromagnetic pumping** to increase the flow

C. Boulware et al. JPos17 (2017)

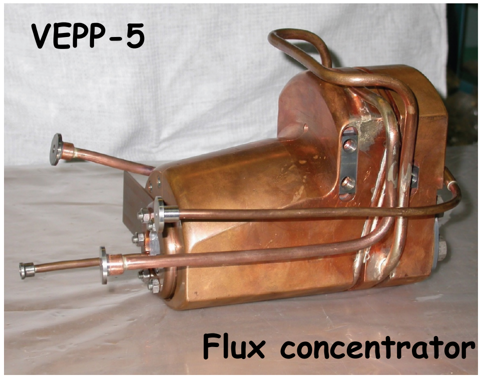


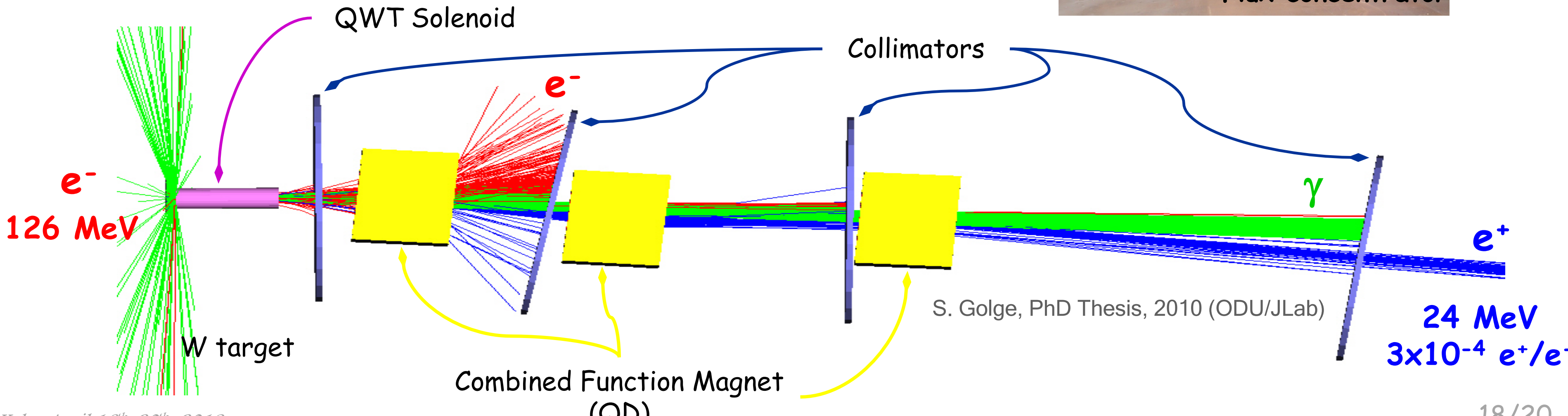
NIOWAVE www.niowaveinc.com

~**10 kW** power in **CW**

Positron Collection Concept

- In comparison to unpolarized positron sources, the **PEPPo** technique **requires** the selection of a **specific energy bite** of the positron momentum spectra in order to optimize the figure-of-merit (**P^2I**) of the beam.
- Due to large emission angles, positron must be captured in an **efficient matching system**: Quarter Wave Transformer (QWT), Adiabatic Matching Device (AMD), Lithium Lenses, Plasma Lenses…
- Additional **emittance filters** should also be considered to match CEBAF injection requirements.

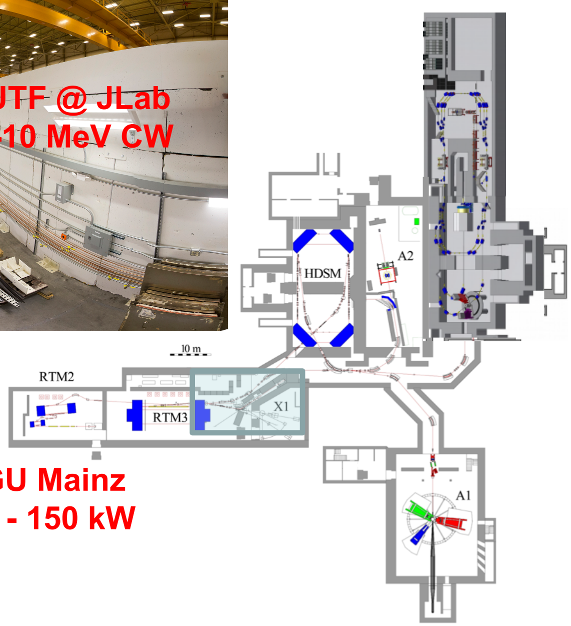




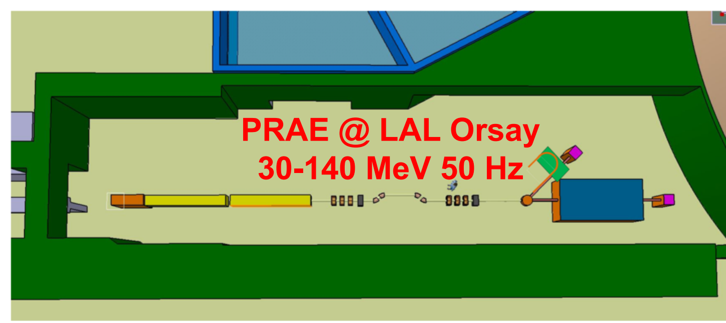
Technical Concept Validation

K. Aulenbacher, N. Berger, I. Chaivoska, J. Enders, J. Grames, G. Moortgat-Pick, S. Riemann, E. Voutier et al.

- **Technical solutions** for each component of the positron source must be **experimentally evaluated** and **optimized**.



MAMI @ JGU Mainz
1.6 GeV CW - 150 kW



The **P3E** (**Polarized Electrons, Positrons, and Polarimetry**) initiative, part of the **STRONG-2020** proposal (**H2020-INFRAIA-2018-2019** call), intends to address these issues .

Summary

Polarized and **unpolarized positron beams** provide a unique opportunity to achieve **precision physics measurements** and to **enhance** the **physics reach** of electron based facilities.

Interferences, neutral and charged currents, test of the Standard Model...

JLab12, EIC...

☛ Work is progressing to **assess** the **quantitative impact** of a polarized positron beam at **JLab12** and **EIC**.

❑ The **P3E european/US initiative** has been proposed to **evaluate** and **address** the **technical challenges** of **polarized positron beams driven by high intensity polarized electron beams.**

Stay tuned, subscribe to pwg@jlab.org...