

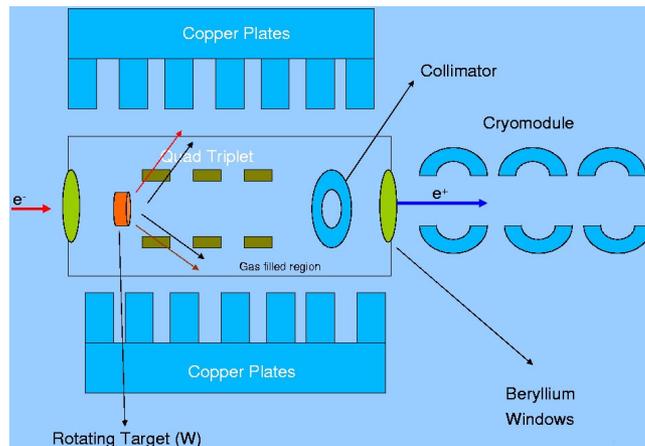
Polarized Electrons for Polarized Positrons

GPDs @ JLab⁺

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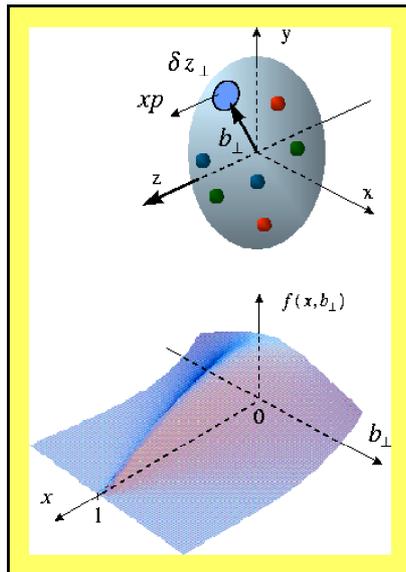
^{*} *Thomas Jefferson National Accelerator Facility
Newport News, Virginia, USA*



- (i) Physics motivations
- (ii) CHIPS @ JLab
- (iii) Technical challenges
- (iv) Polarization calculations
- (v) GEANT4 simulations
- (vi) Demonstration experiment
- (vii) Positron annihilation spectroscopy
- (viii) Conclusions

Parton Imaging

➤ **Generalized Parton Distributions** (GPDs) are the **appropriate** framework to deal with the **partonic structure** of hadrons and offer the **unprecedented** possibility to access the **spatial distribution** of partons.



❖ **GPDs** = $GPDs(Q^2, x, \xi, t)$ whose perpendicular component of the momentum transfer to the nucleon is **Fourier conjugate** to the **transverse position** of partons.

❖ The **GPDs** encode the **correlations between partons** and contain then information about the dynamics of the system like the **angular momentum** or the **distribution of the strong forces** experienced by quarks and gluons inside nucleons and nuclei.

X. Ji, PRL 78 (1997) 610 M. Polyakov, PL B555 (2003) 57

M. Burkardt, PRD 62 (2000) 071503 M. Diehl, EPJC 25 (2002) 223

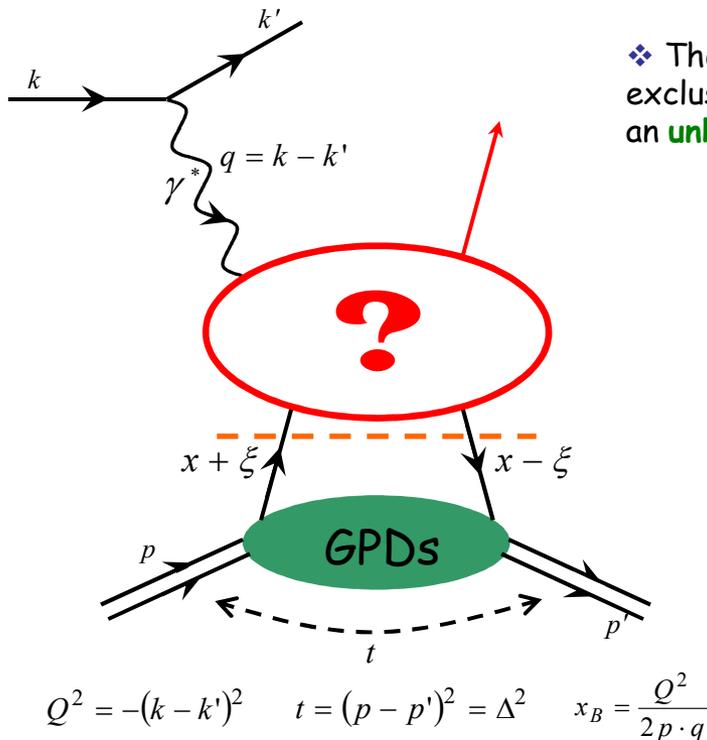
GPDs can be interpreted as $1/Q$ resolution **distributions** in the **transverse plane** of partons with **longitudinal momentum** x

A new light on the nuclear structure

Deep Exclusive Scattering

J.C. Collins, L. Frankfurt, M. Strikman, PRD56 (1997) 2982 X. Ji, J. Osborne, PRD 58 (1998) 094018 J.C. Collins, A. Freund, PRD 59 (1999) 074009

GPDs can be accessed via **exclusive reactions** in the **Bjorken kinematic regime**.

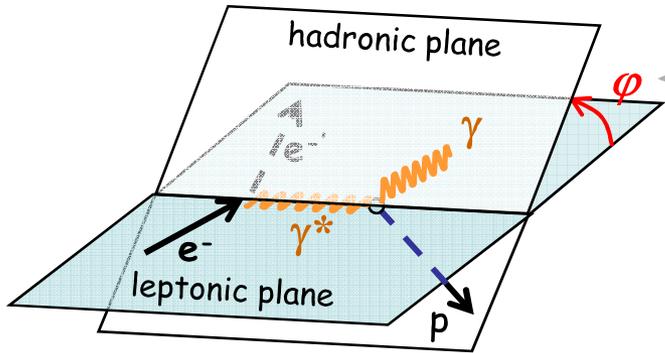


❖ The factorization theorem allows to express the cross section for deep exclusive processes as a **convolution** of a **known hard scattering kernel** with an **unknown soft matrix element** related to the nucleon structure (**GPDs**).

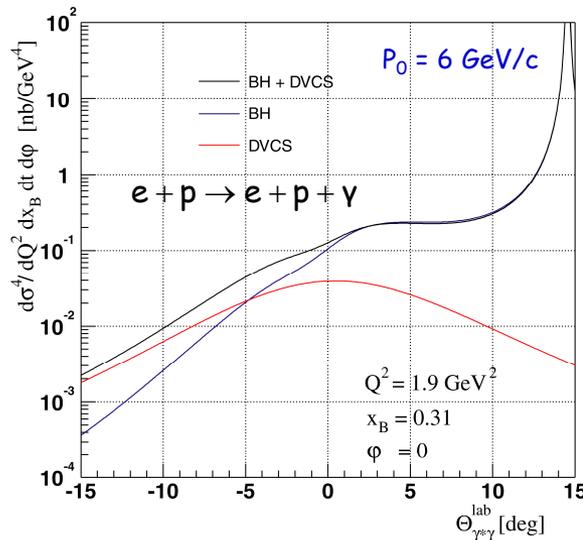
Factorization
 Interaction with elementary partons ($Q^2 \gg M^2$)
 Separation of perturbative and non-perturbative scales ($-t \ll Q^2$)
Hardness

GPD(Q^2, x, ξ, t)
 Probe tagging (ξ)
 Production of one additional particle (Δ_{\perp})
Final state identification
Exclusivity

Photon Electroproduction



Out-of-plane angle entering the harmonic development of the reaction amplitude
 A.V. Belitsky, D. Müller, A. Kirchner, NPB 629 (2002) 323



$\sigma(eN \rightarrow eN\gamma) = \left| \begin{array}{c} \text{DVCS} \\ + \\ \text{Bethe-Heitler (BH)} \end{array} \right|^2$

- ❖ The **Bethe-Heitler** (BH) process where the real photon is emitted either by the incoming or outgoing electron **interferes** with DVCS.
- ❖ **DVCS** & **BH** are **indistinguishable** but the **BH** amplitude is exactly calculable and **known** at **low t**.
- ❖ The **relative importance** of each process is beam energy and **kinematics dependent**.

Polarization observables help to single-out the DVCS amplitude.

➤ From M. Diehl (DESY) @ CLAS12 European Workshop, Genova, February 25-28, 2009

Two photon exchange oooooooo	DVCS oooooo●o	Conclusions o
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Structure of differential cross section (unpolarized target)

$$\sigma_{ep \rightarrow e\gamma p} = \sigma_{\text{BH}} + e_\ell \sigma_{\text{INT}} + P_\ell e_\ell \tilde{\sigma}_{\text{INT}} + \sigma_{\text{VCS}} + P_\ell \tilde{\sigma}_{\text{VCS}}$$

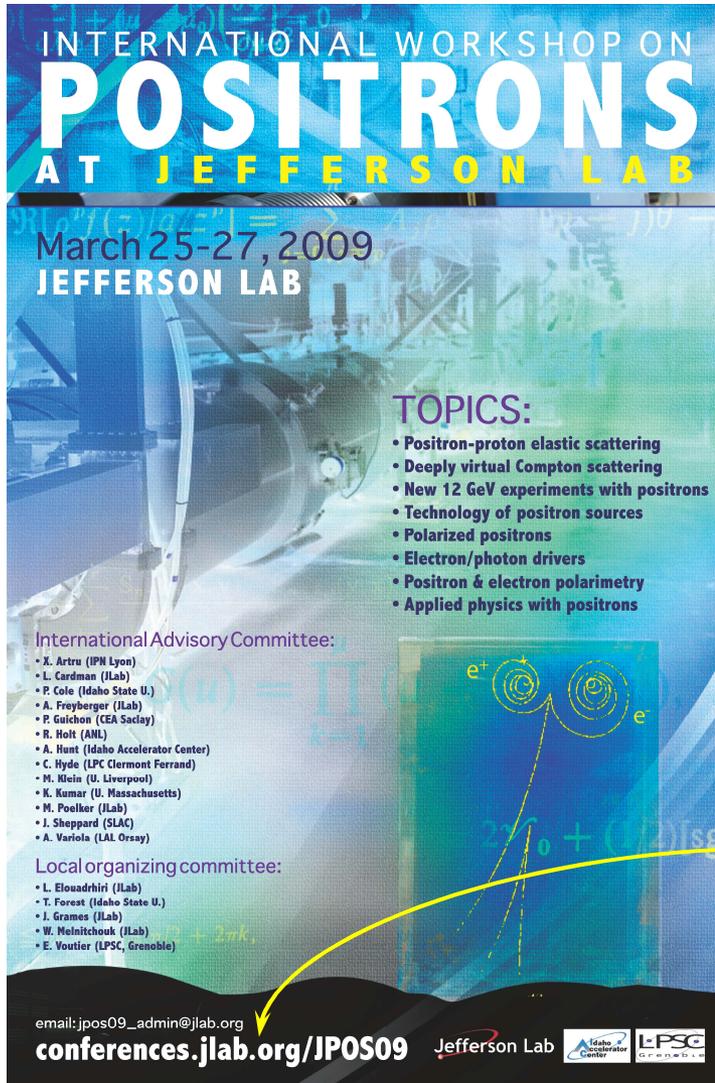
where σ even in ϕ $\sigma_{\text{INT}} \propto \text{Re } \mathcal{A}_{\gamma^* N \rightarrow \gamma N}$
 $\tilde{\sigma}$ odd in ϕ $\tilde{\sigma}_{\text{INT}} \propto \text{Im } \mathcal{A}_{\gamma^* N \rightarrow \gamma N}$

beam charge	beam pol.	combination
e^-	difference	$-\tilde{\sigma}_{\text{INT}} + \tilde{\sigma}_{\text{VCS}}$
difference	none	σ_{INT}
difference	fixed	$P_\ell \tilde{\sigma}_{\text{INT}} + \sigma_{\text{INT}}$

so that with

only pol. e^-	need Rosenbluth to separate $\tilde{\sigma}_{\text{INT}}$ from $\tilde{\sigma}_{\text{VCS}}$ (different y at same x_B and Q^2)
unpol. e^- and e^+	get σ_{INT}
pol. e^- and pol. e^+	get σ_{INT} and separate $\tilde{\sigma}_{\text{INT}}$ from $\tilde{\sigma}_{\text{VCS}}$

M. Diehl	Physics with positron beams	23
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**INTERNATIONAL WORKSHOP ON
POSITRONS
AT JEFFERSON LAB**

March 25-27, 2009
JEFFERSON LAB

TOPICS:

- Positron-proton elastic scattering
- Deeply virtual Compton scattering
- New 12 GeV experiments with positrons
- Technology of positron sources
- Polarized positrons
- Electron/photon drivers
- Positron & electron polarimetry
- Applied physics with positrons

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- W. Melnitchouk (JLab)
- E. Voutier (LPSC, Grenoble)

email: jpos09_admin@jlab.org
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Jefferson Lab  

- ❖ Generalized Parton Distributions
- ❖ Investigation of 2γ exchange in elastic scattering
- ❖ Study of Coulomb distortion in the inelastic regime
- ❖ Search for a light dark matter gauge U-boson
- ❖ Measurement of the C_{3q} neutral weak coupling
- ❖ Positron Annihilation Spectroscopy

*Program and talks posted
on the conference web site*

CEBAF High Intensity Positron Source

*J. Dumas, C. Hyde, W.J. Kossler, T. Forest, A. Freyberger, S. Golge,
J. Grames, R. Kazimi, E. Voutier*

➤ The **CHIPS** community develops concepts and ideas for the construction of a **high intensity polarized positron source** at JLab for **fixed target experiments** to take place in the **12 GeV** era.

Goals

- ❖ **e⁺** beam current > **100 nA** in **CW** mode (CEBAF @ 1497 MHz)
- ❖ As **large** as possible **e⁺** beam **polarization**

Challenges

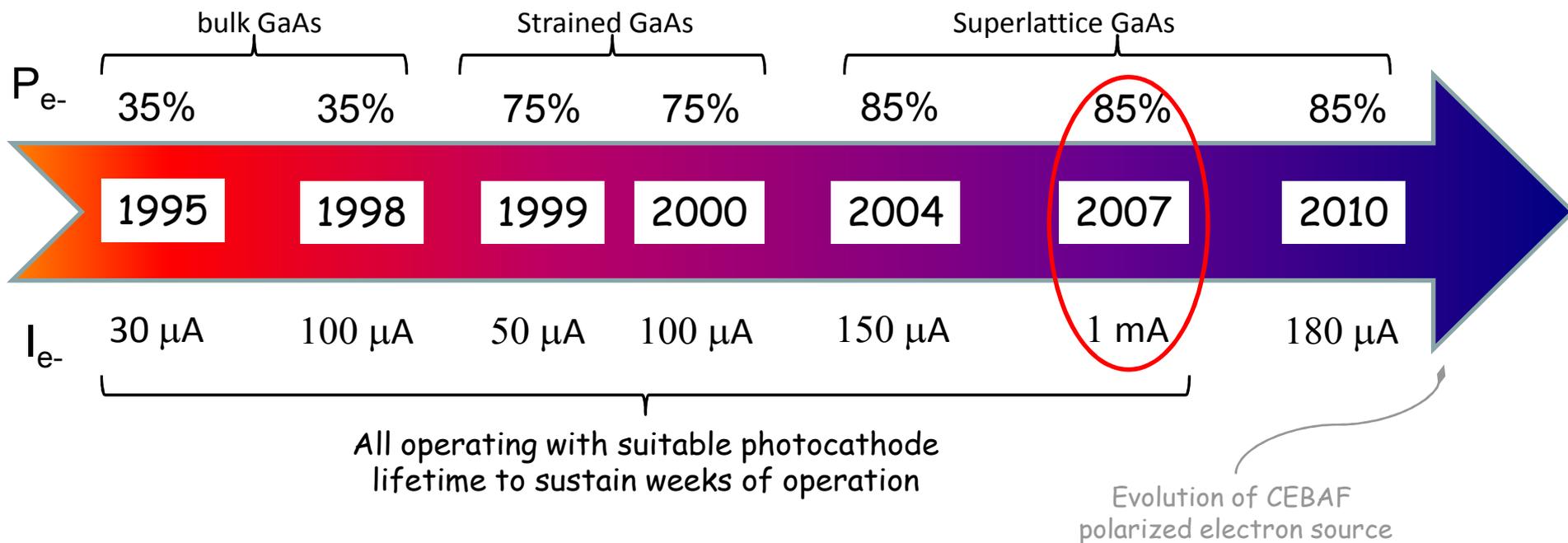
- ❖ High **e⁻** beam intensity **1-10 mA** together with high beam polarization \geq **85%**
- ❖ **High power** **e⁻** target (~1 MW beam driver @ 10-100 MeV)
- ❖ Efficient **e⁺** **capture**



Polarized Bremsstrahlung

E.G. Bessonov, A.A. Mikhailichenko, EPAC (1996) A.P. Potylitsin, NIM A398 (1997) 395

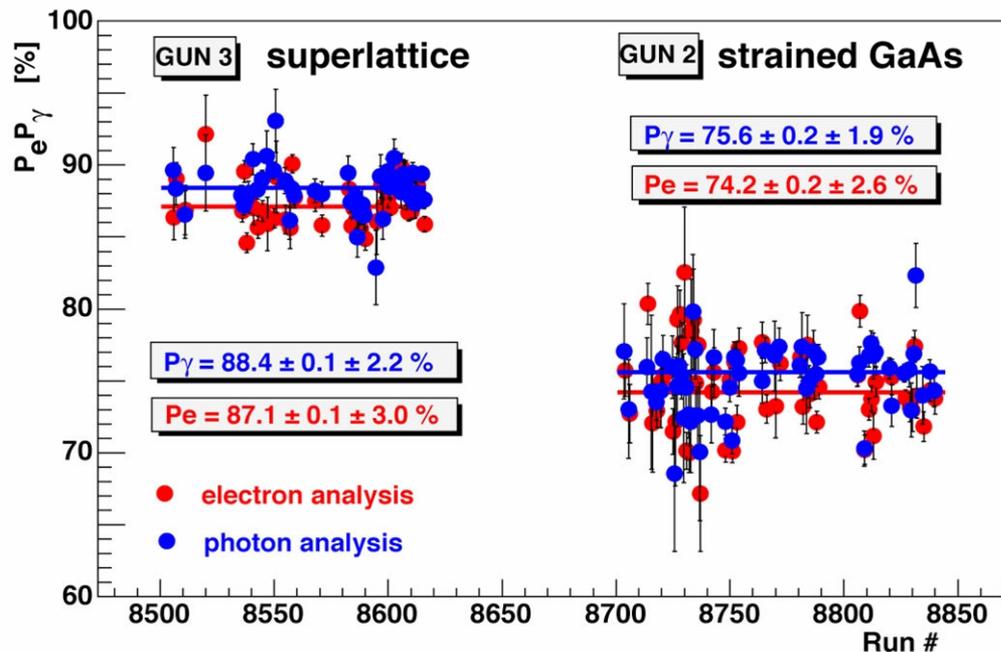
- Within a high Z target, **longitudinally polarized e⁻s** radiate **circularly polarized γ's**.
- Within the same/different target, **circularly polarized γ's** create **longitudinally polarized e⁺s**.



Polarized e^- @ JLab

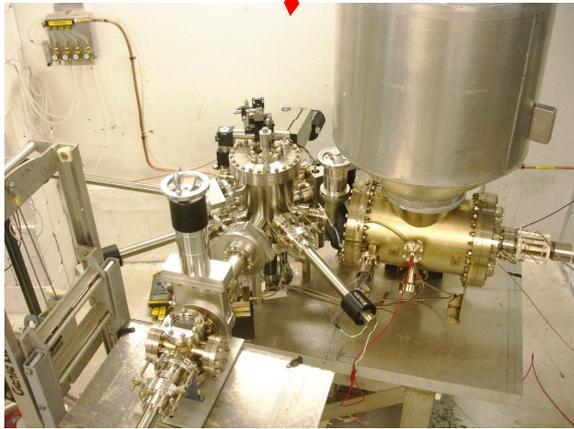
State of the Art @ JLab

HAPPEX-II 2004 run Compton Polarimetry



- ❖ **Strained** single-layer and multi-layer (superlattice) GaAs are used to achieve polarization greater than **50%**.
- ❖ Strained superlattice photocathodes provide the largest polarization ($P \sim 85\%$).
- ❖ They operate at JLab since 09/2005 delivering a **constant polarization** over photocathode charge lifetime.

The determinant elements for the achievement of a **high intensity high polarization e⁻** beam are: a performant **electron gun**, a very good **photocathode**, and a powerful **laser**.



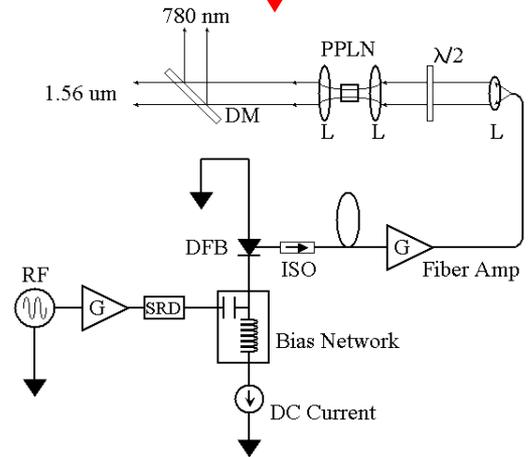
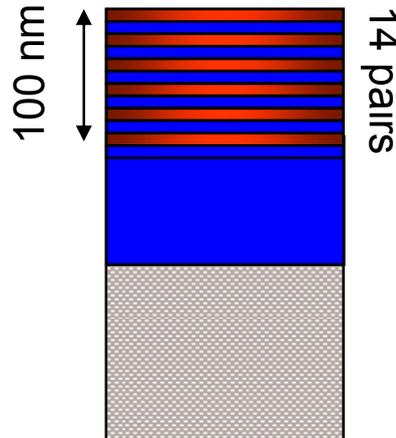
Load-lock gun

Improved electron gun with ultra-high vacuum

J. Grames et al., AIP CP 915 (2007) 1037

QE ~ 1% & P ~ 85% @ 780nm

Strained Superlattice GaAs

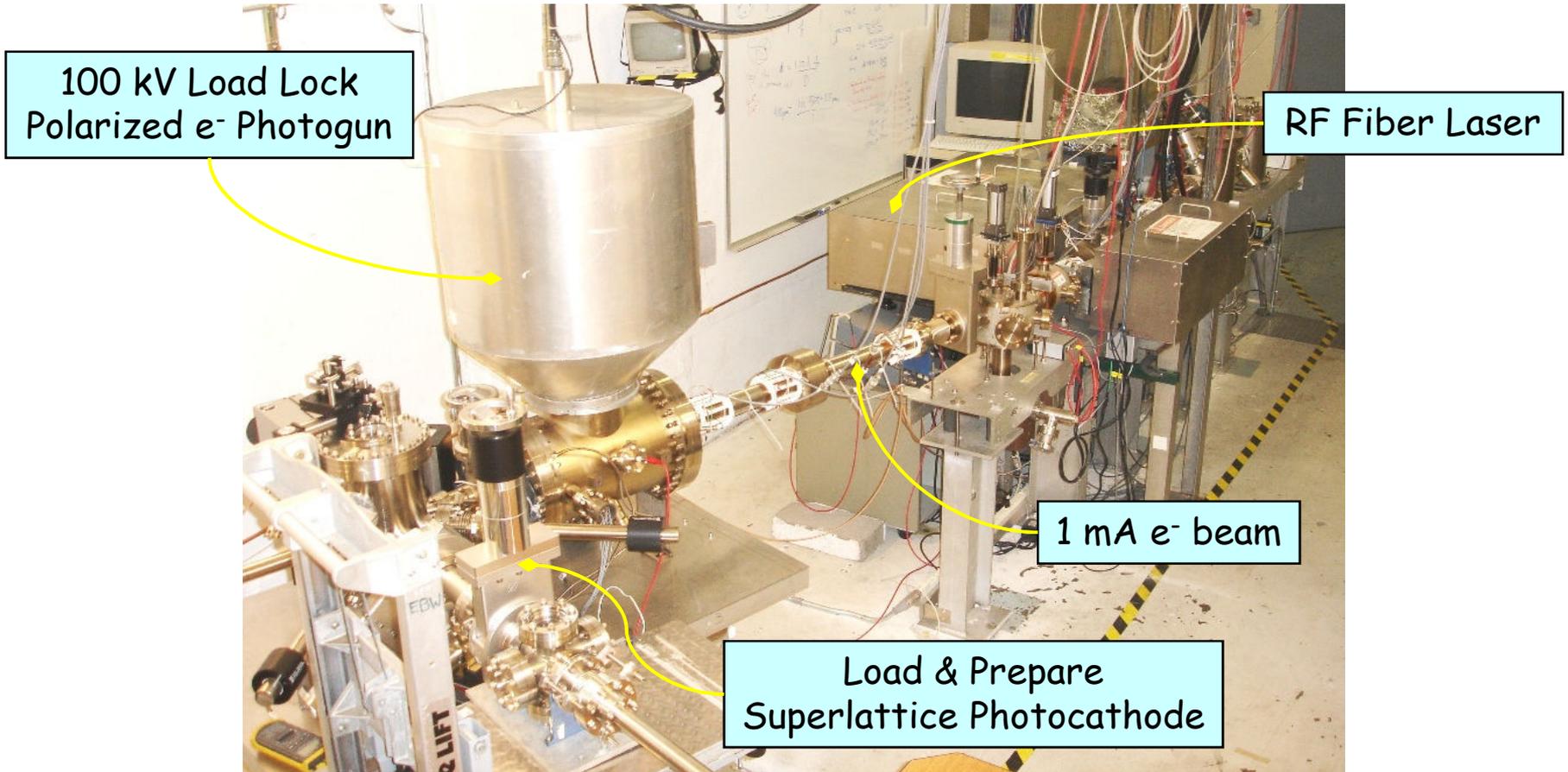


Fiber-based laser system

$P_w \sim 2W @ 780 \text{ nm}$ & $\delta t \sim 40 \text{ ps} @ 499 \text{ MHz}$

J. Hansknecht, M. Poelker, PRST-AB 9 (2006) 063501

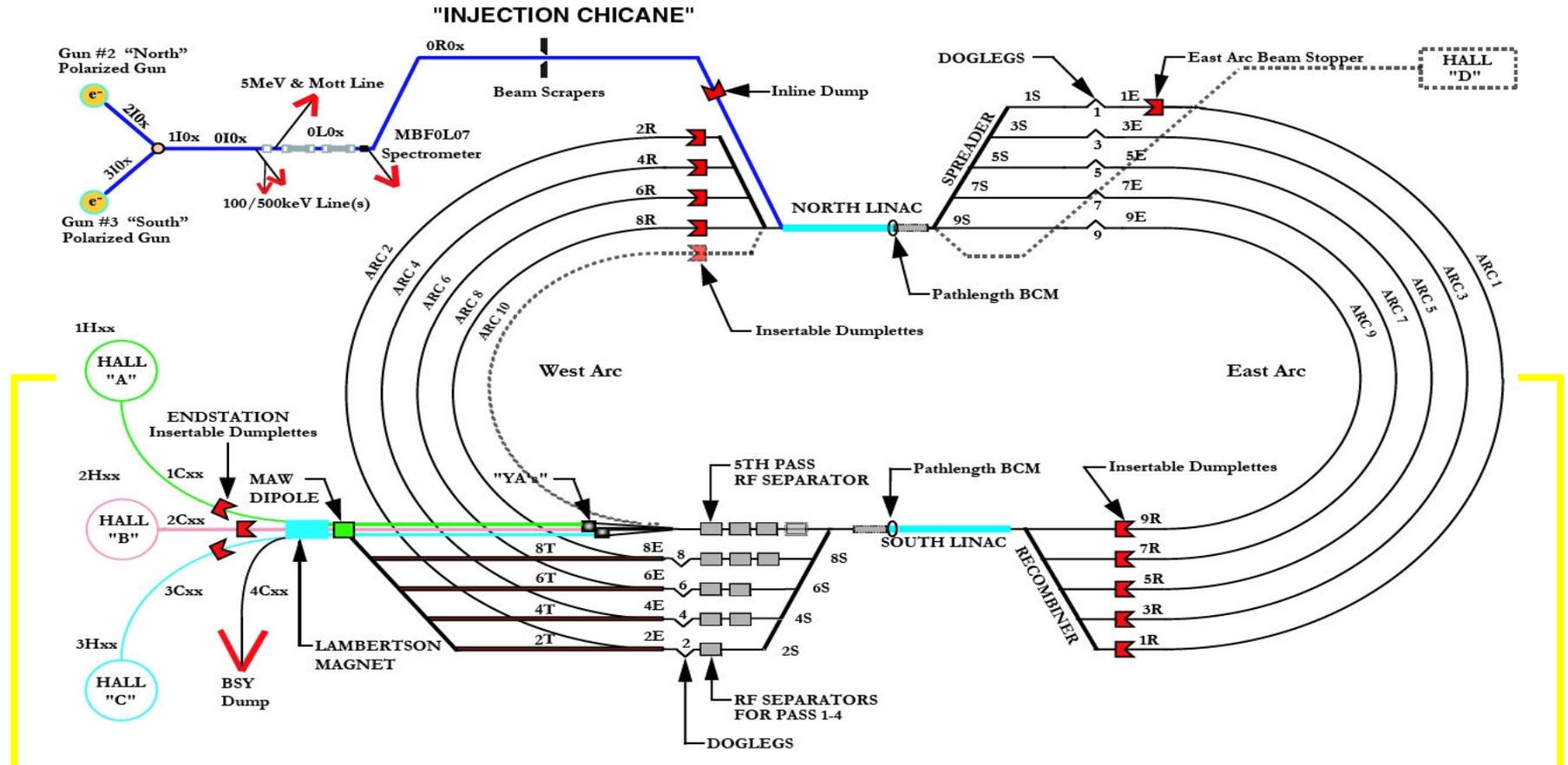
J. Grames et al., Proc. of XXIInd Particle Accelerator Conference, Albuquerque (NM, USA), June 25-29, 2007



An accelerator quality beam of **1 mA** with a charge lifetime of **~200 C** was demonstrated with a **superlattice** photocathode.

Beam polarization was not measured

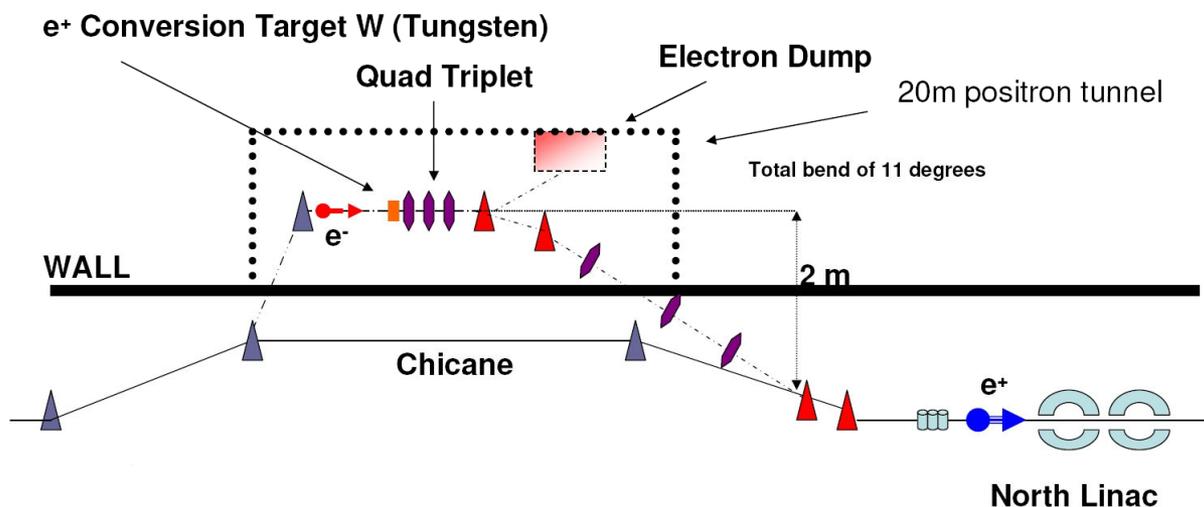
e⁺ Beam Concept



Geometric Emittance < 5 mm-mrad Absolute Energy Spread < 1 MeV
 Beam Current > 50 nA Bunch Length < 2 ps
 Duty Factor = 100 % Frequency = 1497 MHz

S. Golge et al., Proc. of the International Workshop on Positrons at Jefferson Lab, Newport News (VA, USA), March 25-27, 2009

- A **possible concept** involves the construction of a **dedicated e^+ tunnel** at the end of the injector and parallel to the north linac.
- Positrons would be produced with **120 MeV e^-** (JLab 12 GeV) incident on a tungsten target.
 - e^- 's are **selected** with a **quadrupole triplet** and **transported** to the accelerator section.

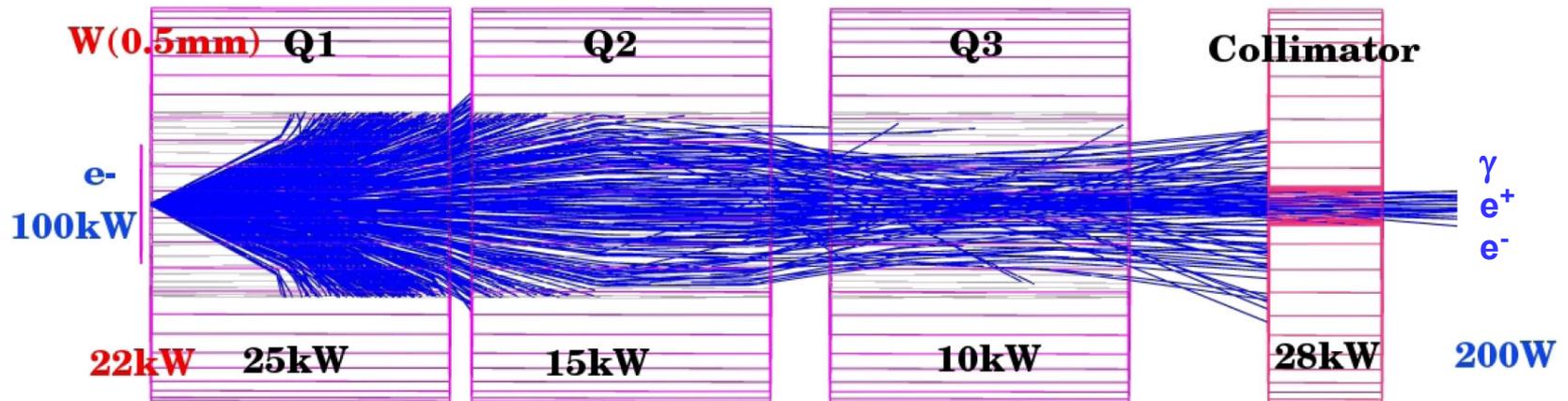


G4beamline simulations indicate a global efficiency of $10^{-5} e^+/e^-$ for 120 MeV e^- off a 3 mm W target.

$$10 \text{ mA } e^- \rightarrow 100 \text{ nA } e^+$$

S. Golge et al., Proc. of XXIInd Particle Accelerator Conference, Albuquerque (NM, USA), June 25-29, 2007

- Previous studies of the collection system (10 MeV e^- beam) indicate that a **large fraction** of the **beam power deposits** in the conversion target.



Possible solutions are a **rotating target** or a **liquid metal target** but have not yet been investigated in the JLab context.

Polarization Transfert

H. Olsen, L. Maximon, PR114 (1959) 887

- **Polarization transfert** in **polarized bremsstrahlung** and **pair creation** processes have been investigated by **O+M** within the **Born approximation**, for **relativistic particles** and **small scattering angles**.

$$\frac{d\sigma^0}{dk d\xi d\varphi} \propto \left[(\varepsilon_1^2 + \varepsilon_2^2)(3 + 2\Gamma) \pm 2\varepsilon_1\varepsilon_2(1 + 4\xi(1 - \xi)\Gamma) \right]$$

Unpolarized cross section
Coulomb correction

$$\Gamma = \ln\left(\frac{2\varepsilon_1\varepsilon_2}{k}\right) - 2 - f(Z) + \mathcal{F}(\Delta)$$

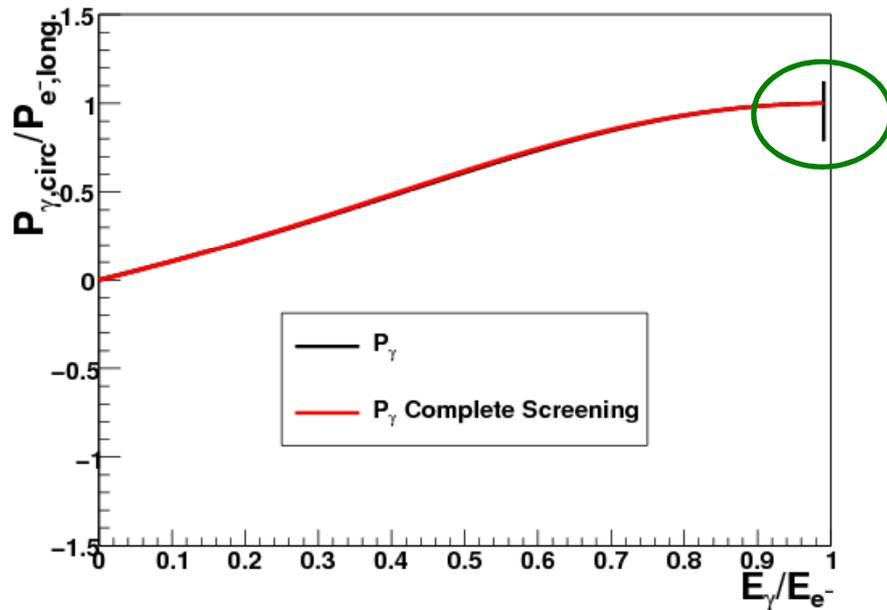
Screening correction

- Screening effects have been evaluated within the Molière model

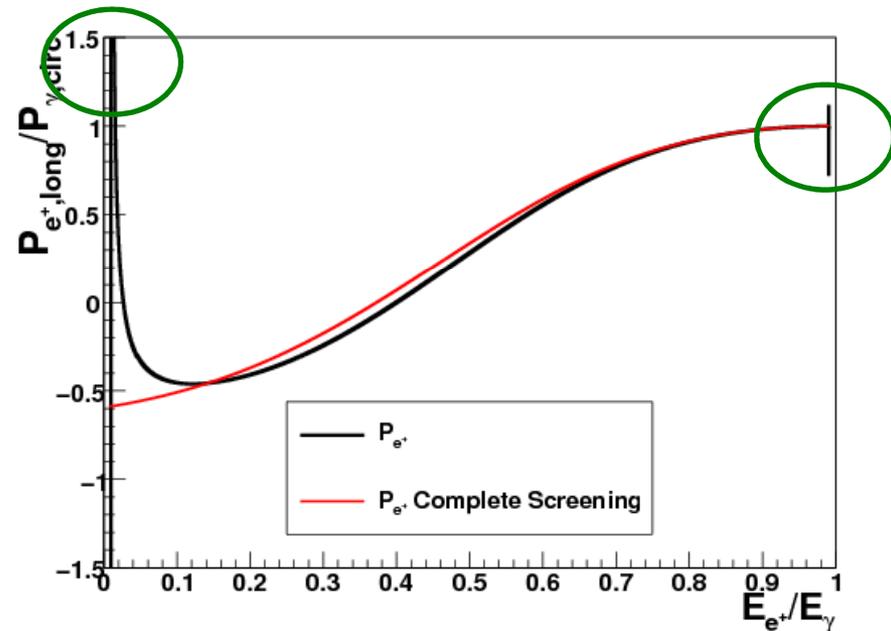
$$\Delta = \frac{Z^{1/3}}{121} \frac{12\varepsilon_1\varepsilon_2}{k} \xi \quad \longrightarrow \quad \begin{array}{l} \Delta < 0.5 \rightarrow \text{No screening} \\ 0.5 \leq \Delta < 120 \rightarrow \text{Intermediate screening} \\ 120 \leq \Delta \rightarrow \text{Complete screening} \end{array}$$

➤ Calculations at a **60 MeV** incident energy and a **0.41 mrd** scattering angle

BREMSSTRAHLUNG



PAIR CREATION

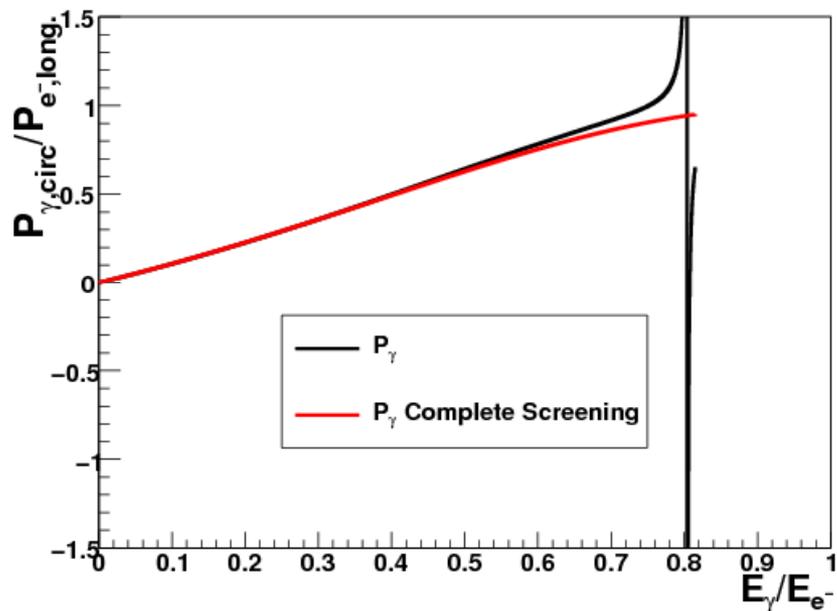


Singularities originating from a nul cross section (tip region problem)

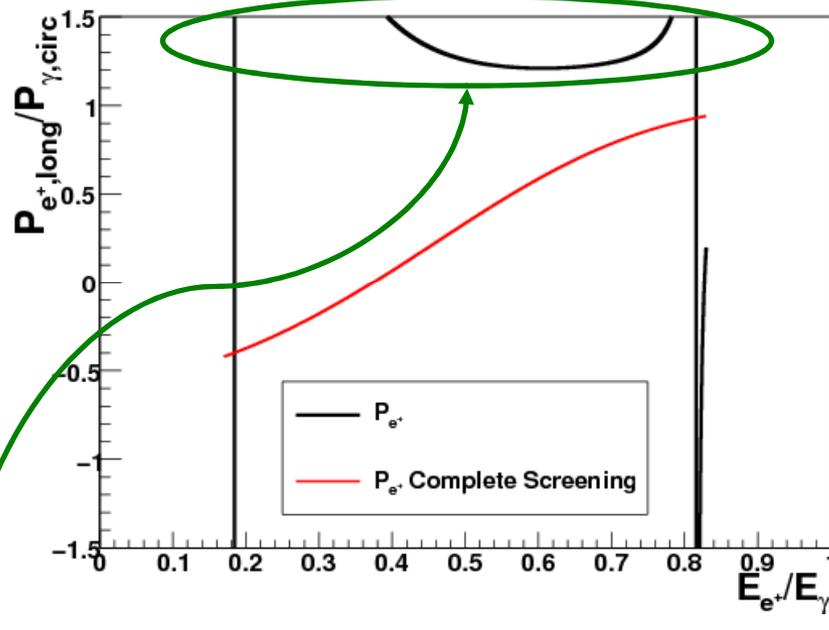
Selecting **complete screening** removes singularities

➤ Calculations at a **3 MeV** incident energy and a **0.41 mrd** scattering angle

BREMSSTRAHLUNG



PAIR CREATION



Unphysical results over the whole phase space

Some features of **O&M calculations** are **not valid**
Coulomb corrections ? Screening corrections ? Relativistic approximation ? ...

E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E. Tomasi Gustafsson are currently investigating this problem...

e⁺ Source Polarization

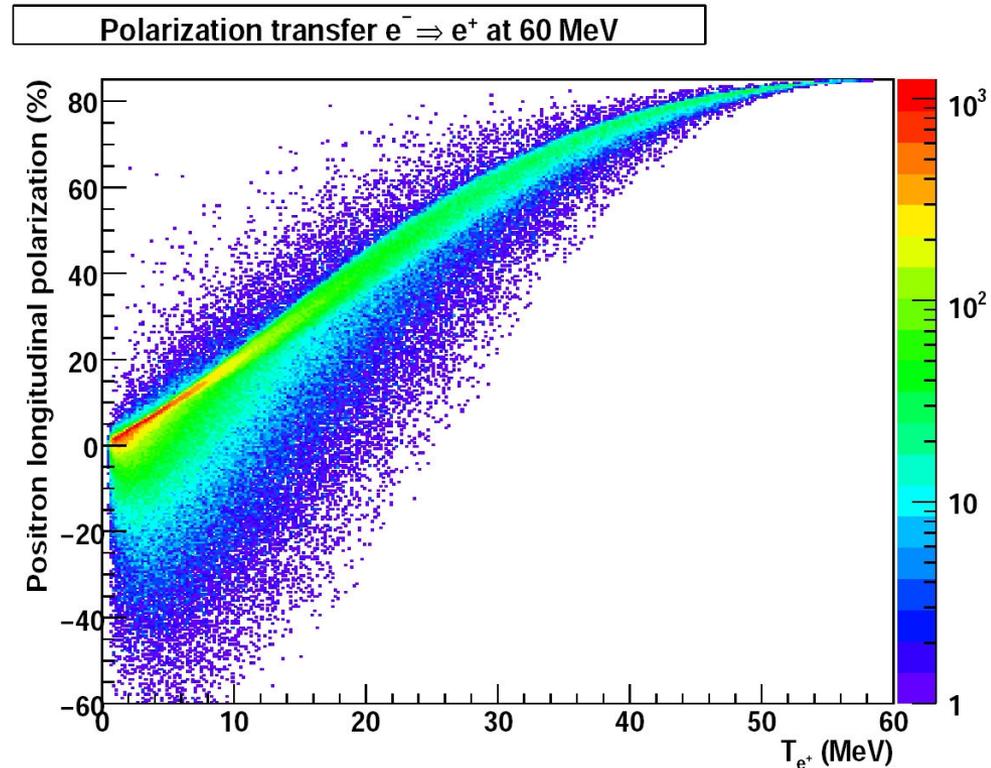
- Simulation are performed within the **GEANT4** framework, taking advantage of the **polarization capabilities** developed by the **E166 Collaboration**.

R. Dollan, K. Laihem, A. Schlicke, NIM A559 (2006) 185

- The **source** files are **modified** to select complete screening, independently of Δ .

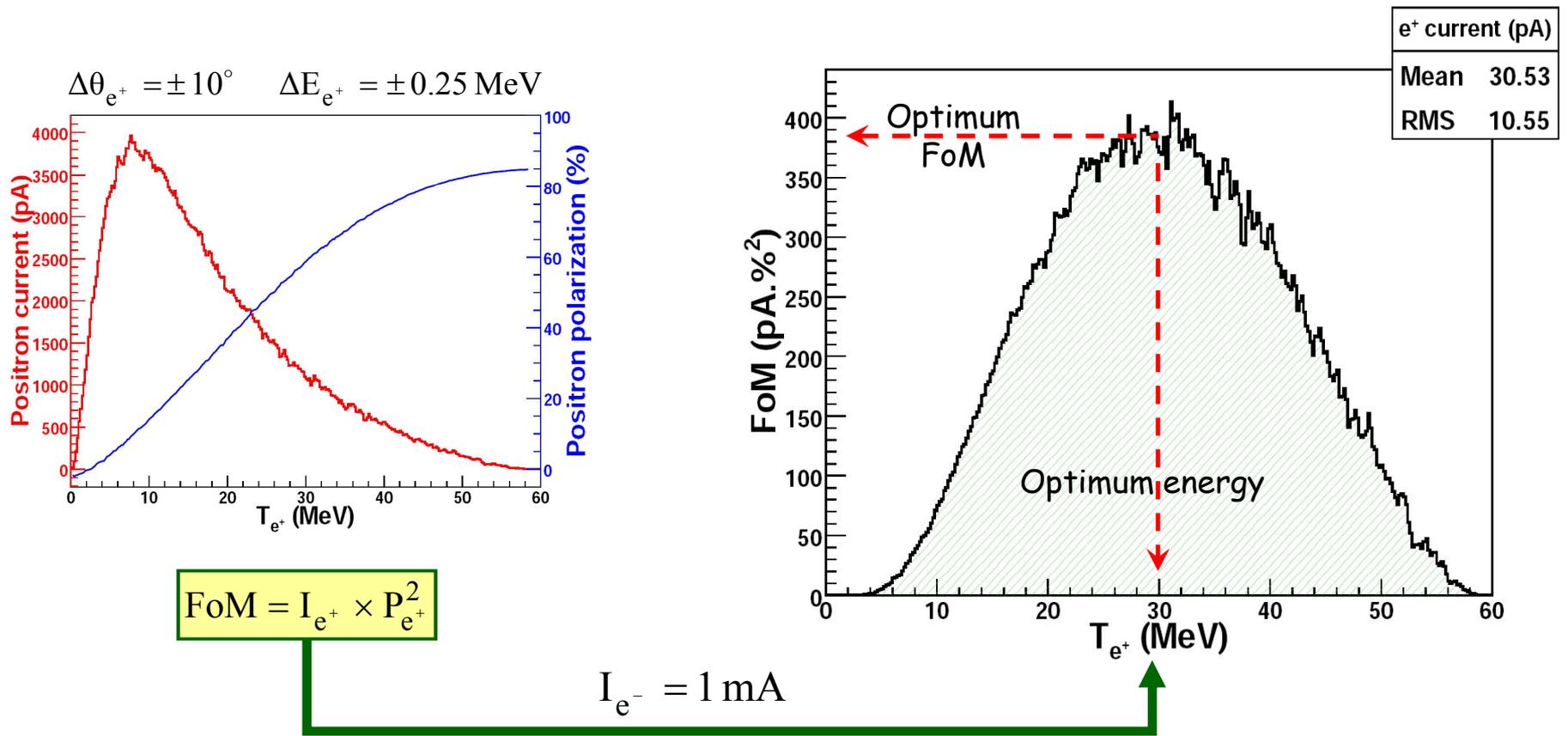
(a cooking recipe while waiting for a better calculation)

$$P_{e^-} = 85\% \quad t_W = 100 \mu\text{m}$$

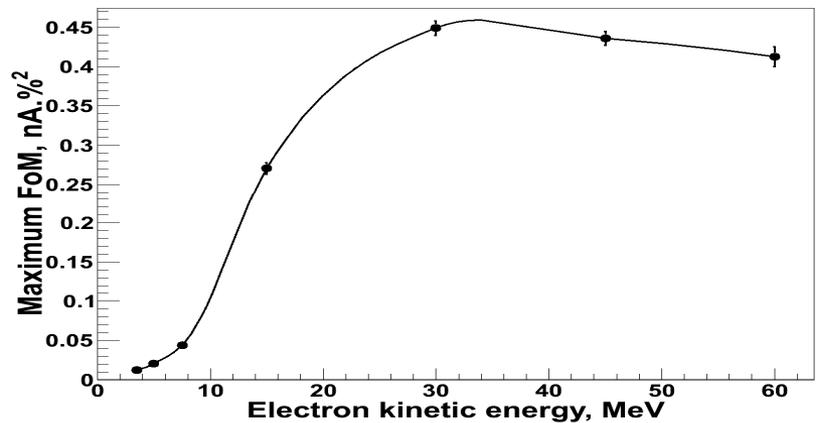
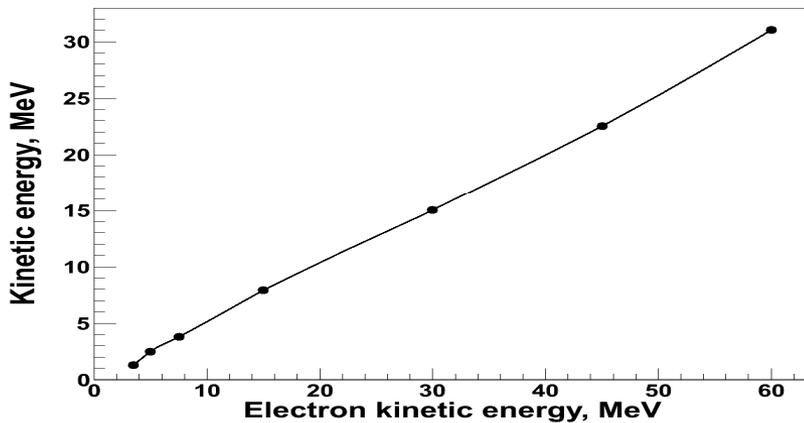
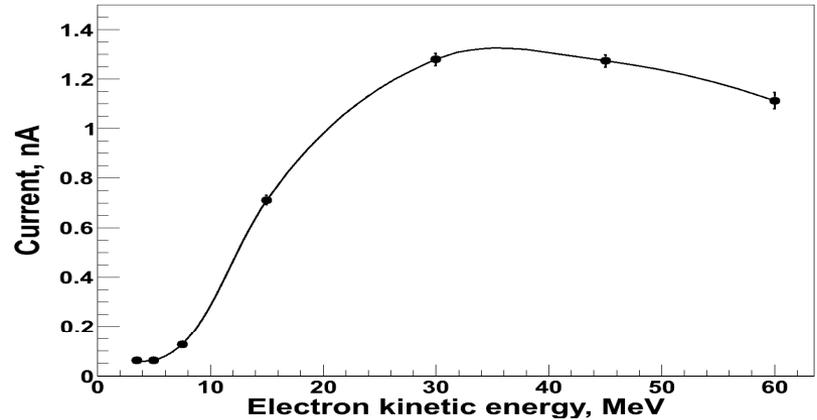
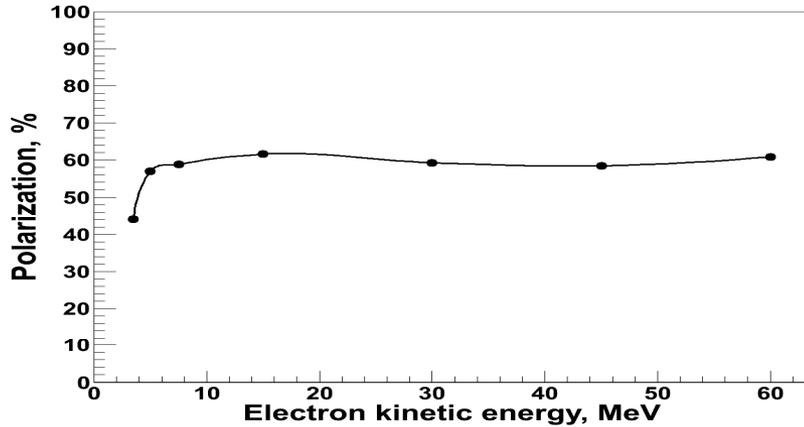


e⁺ Figure of Merit

- The **Figure of Merit** is the quantity of interest for the accuracy of a measurement which combines the **incident flux** of particles and its **polarisation**.



➤ *Simplistic* cuts are applied to mimic a *capture system* and the *accelerator acceptance*.



Thickness sensitivity is under study...

Conceptual Design

➤ An experiment to test the production of polarized positrons is currently designed.

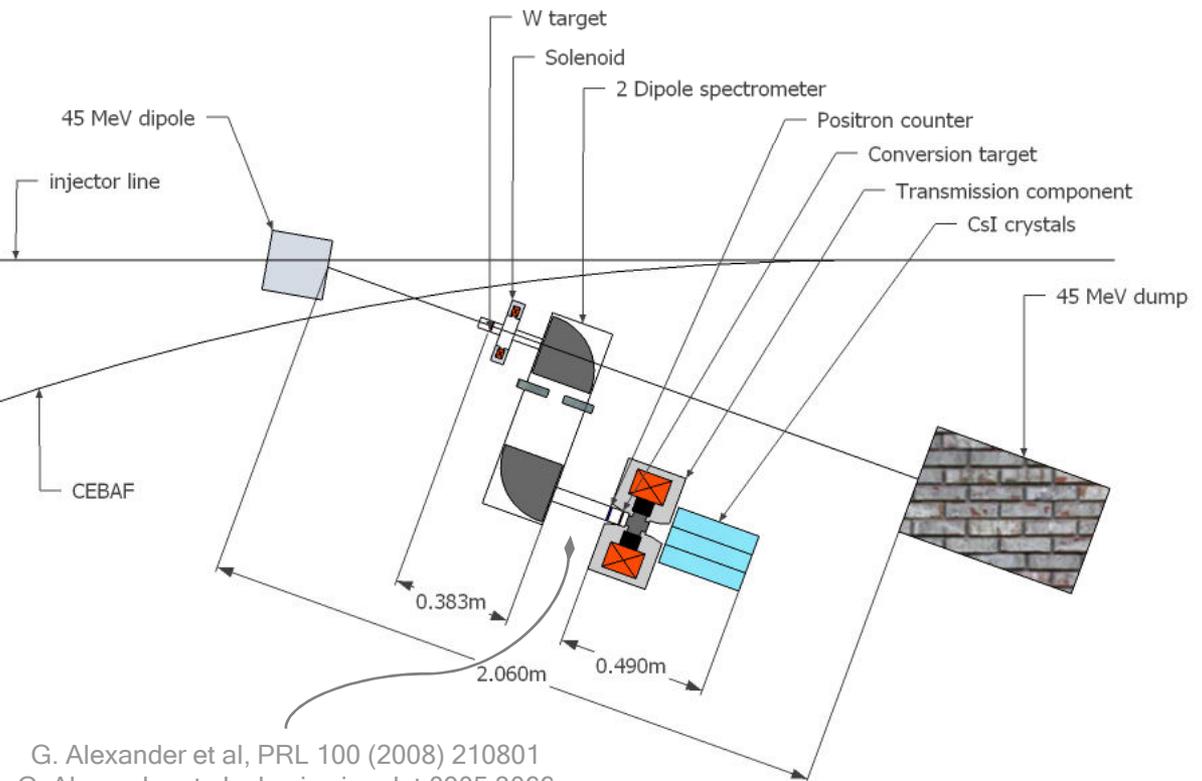
The **goals** are to measure the **yield** and **polarization distributions** as a function of the **beam energy**.

- The **E166** successful set-up serves as a **conceptual guidance** towards the final design.

- Polarimetry would consist of a **Compton transmission polarimeter**.

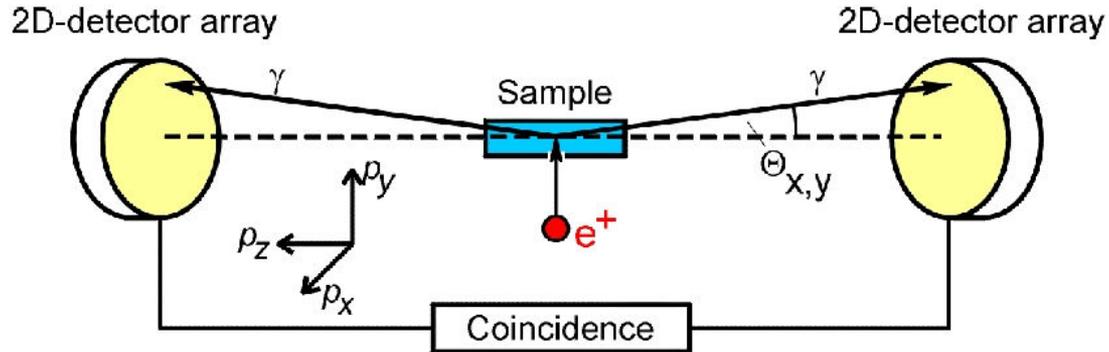
- **Calibration** and check of the analyzing power can be performed with the **polarized electron** beam.

- The **Compton asymmetry** would be measured by **reversing** the **beam** (up to 1 kHz frequency of random change) **and/or** the **target polarization**.

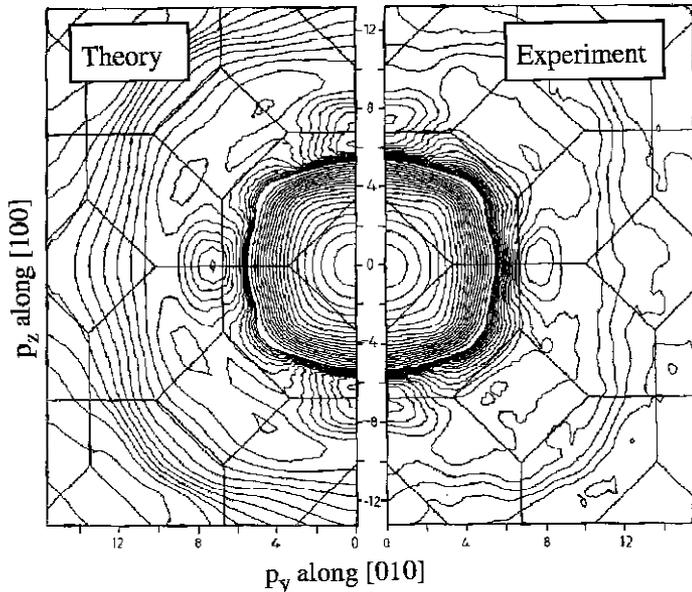


G. Alexander et al, PRL 100 (2008) 210801
 G. Alexander et al, physics.ins-det:0905.3066

2D/3D ACAR



The motion of atomic electrons results in a **Dopler distortion** of the energy of γ 's from e^+e^- annihilation, and an **angular deviation** breaking γ 's colinearity.



Surface and purity studies of semiconductors

Technological (production and thermalisation of e^+) and **instrumental** ($\sigma\Theta = 1$ mrd, $\sigma k \leq 1$ keV) **challenges**.

Summary

The possibilities of developing a **CW** « low cost » **polarized positron** source at JLab look promising.

Technical challenges concern the electron beam driver (**10 mA @ 85%**) and the **high power conversion target**

(optimum positron capture, accelerator acceptance, damping/accumulator ring ?...)

Calculations of O&M appear to be of **limited** application in the low energy domain.

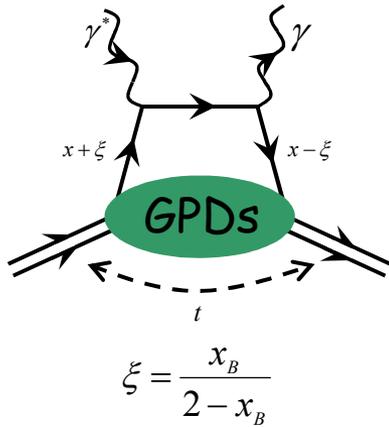
The **longitudinal polarization transfert** from electrons to positrons was **never experimentally investigated**.

Need for experimental data

Proposal expected by end of 2009 – Collaborators are welcome

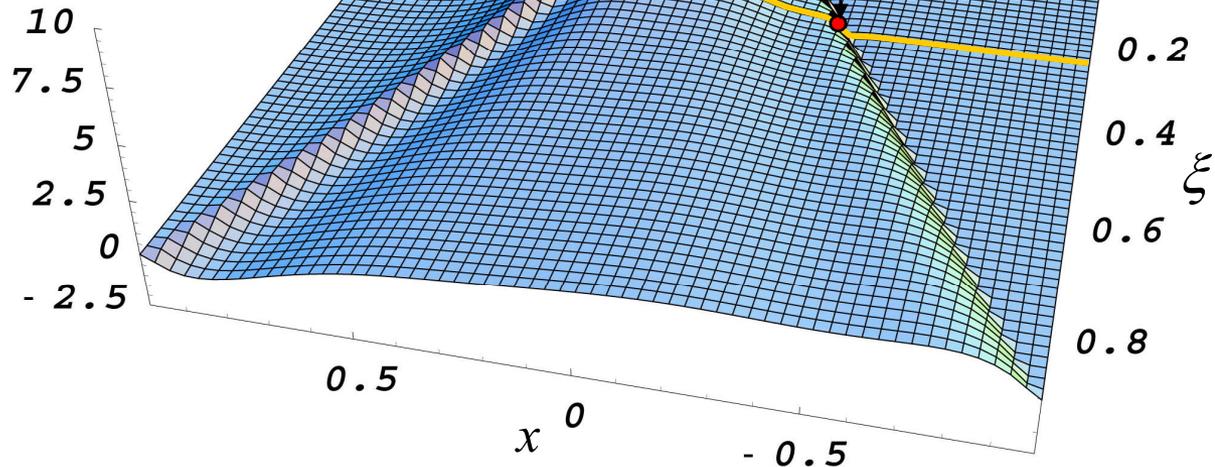
Such a new type of **polarized positron source** is of interest not only for **JLab** physics but also for the **Super B** project (A. Variola's talk) and would be a **breakthrough** for **solid state** physics.

GPDs enter the cross section of hard scattering processes via Compton form factors, that are integrals over the intermediate parton longitudinal momenta.



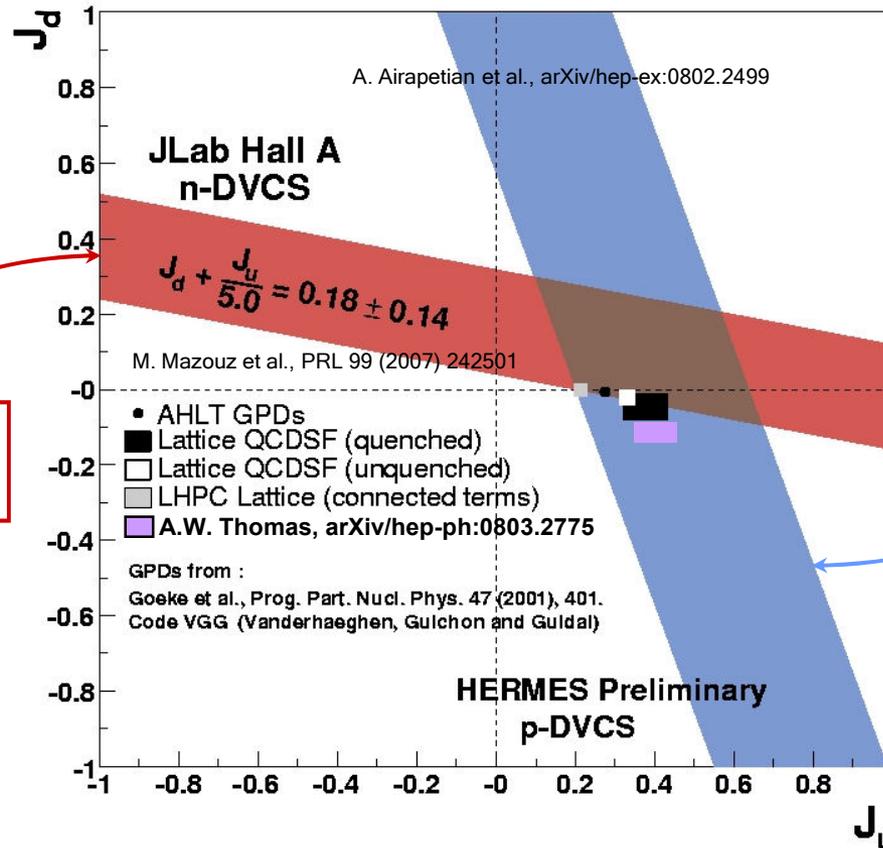
$$\sigma \propto \left| \int_{-1}^{+1} dx \frac{\text{GPD}(x, \xi, t)}{x \pm \xi \mp i\epsilon} \right|^2 = \left| \mathcal{P} \int_{-1}^{+1} dx \frac{\text{GPD}(x, \xi, t)}{x \pm \xi} \pm i\pi \text{GPD}(x = \pm \xi, \xi, t) \right|^2$$

$H(x, \xi, 0)$



$Q^2 \gg M^2 \quad -t \ll Q^2$

$E03-106 \rightarrow n\text{-DVCS}$
 P.Y. Bertin, C.E. Hyde, F. Sabatié, E. Voutier *et al.*



Measurements off **neutron** are sensitive to J_d (**u** quark in the **neutron**)

Measurements off **proton** are sensitive to J_u (**u** quark in the **proton**)

Neutrons are a **mandatory step** in the hunt for the **quark orbital momentum**.