A Positron Physics Program for the Jefferson Laboratory

e+ @ JLab 12 GeV   e+ @ JLEIC

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and the JLab Positron Working Group

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[2]Institut de Physique Nucléaire, Orsay, France
[3]Laboratory for Nuclear Science, Cambridge, MA, USA
[4]Istituto Nazionale di Fisica Nucleare, Genova, Italia
[5]Università di Genova, Genova, Italia
[6]Argonne National Laboratory, Argonne, IL, USA
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Outline

(i) Physics motivations

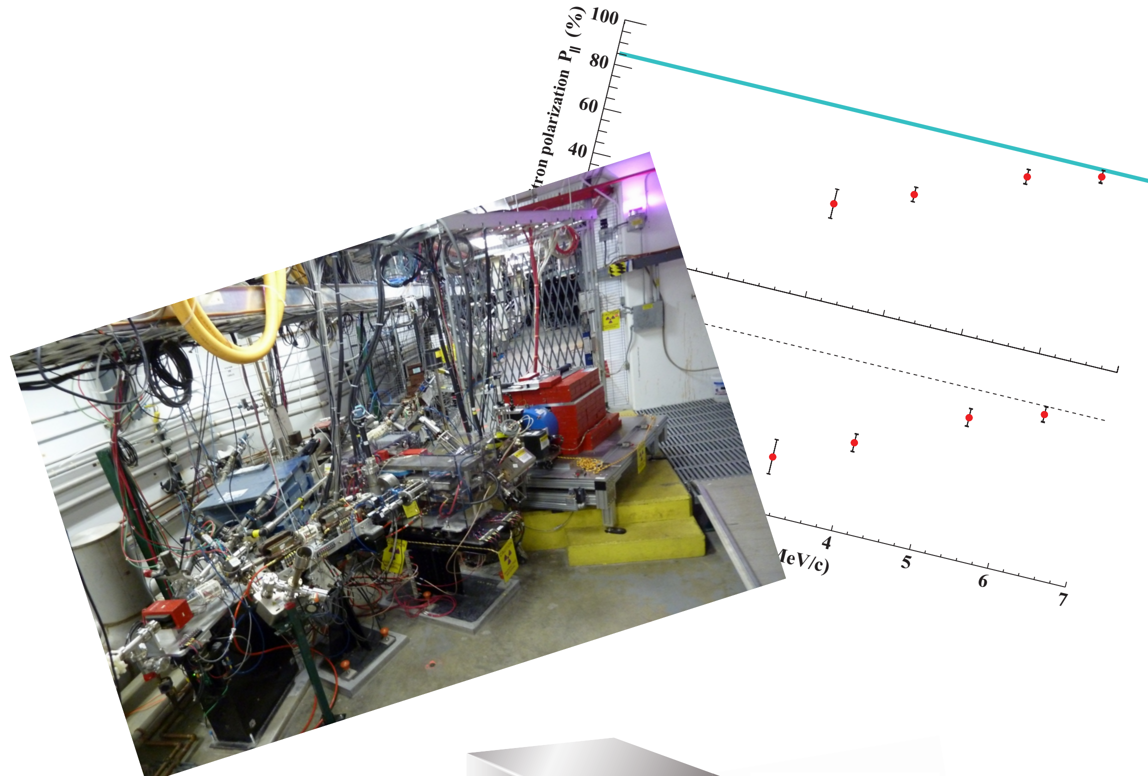
(ii) Interference physics

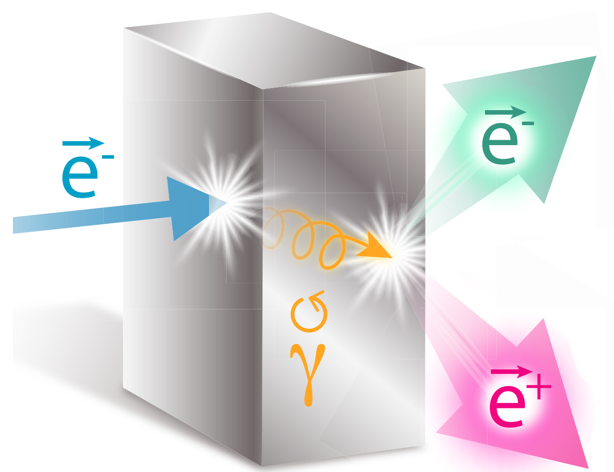
(iii) Structure functions

(iv) Sandard Model tests

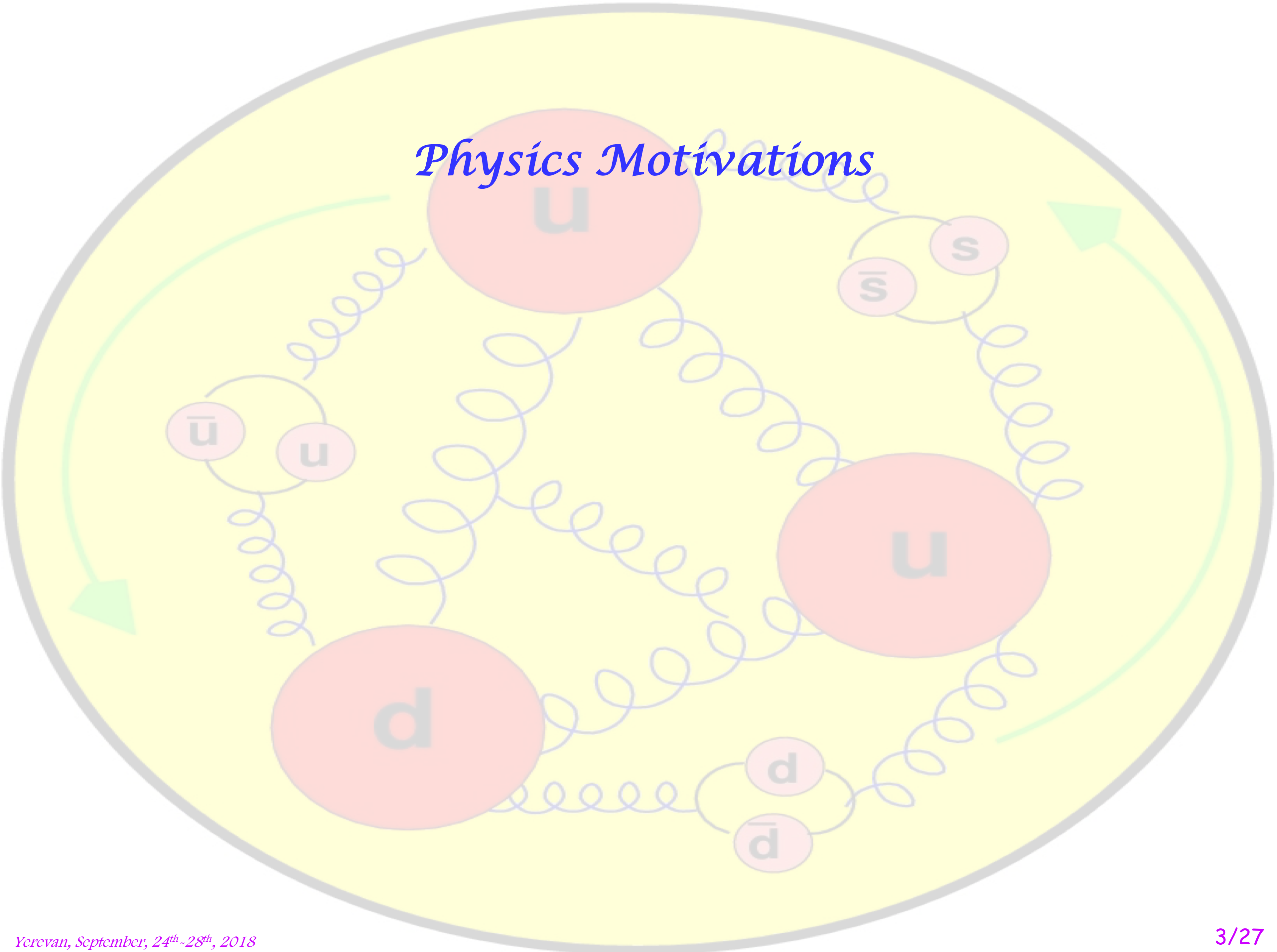
(v) Polarized positrons @ Jlab

(vi) Summary





Physics Motivations



Physics Motivations

Interference Physics

- Two-photon physics
- Generalized parton distributions

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

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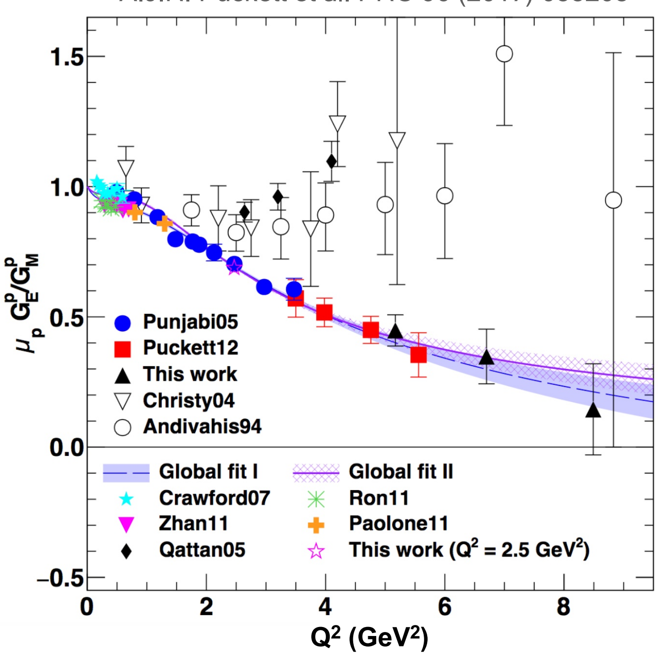
Electromagnetic Form Factors

P.A.M. Guichon, M. Vanderhaeghen, PRL 91 (2003) 142303   P.G. Blunden, W. Melnitchouk, J.A. Tjon, PRL 91 (2003) 142304

- Measurements of polarization transfer observables in electron elastic scattering off protons question the validity of the 1γ exchange approximation of the electromagnetic interaction.

A.J.R. Puckett et al. PRC 96 (2017) 055203



Within the 2γ exchange hypothesis, the electromagnetic structure of the nucleon may be parametrized by 3 generalized form factors, corresponding to 8 unknow quantities.

$$\widetilde{G}_M = G_M(Q^2) + e_1\,\delta\widetilde{G}_M(Q^2,\varepsilon)$$
$$\widetilde{G}_E = G_E(Q^2) + e_1\,\delta\widetilde{G}_E(Q^2,\varepsilon)$$
$$\widetilde{F}_3 = e_1\,\delta\widetilde{F}_3(Q^2,\varepsilon)$$

Experimental Observables

M.P. Rekalo, E. Tomasi Gustafsson, NPA 742 (2004) 322 C. Carlson, M. Vanderhaeghen, ARNPS 57 (2007) 171

➢ **Unpolarized $e^{\pm}$** elastic scattering and **polarization transfert observables** off the nucleon involve up to **5 unknown** quantities.

Cross Section

$$\sigma_R = G_M^2 + \frac{\varepsilon}{\tau} G_E^2 \pm 2 G_M \Re\left[f_0\left(\delta\widetilde{G}_M, \delta\widetilde{F}_3\right)\right] \pm 2\frac{\varepsilon}{\tau} G_E \Re\left[f_1\left(\delta\widetilde{G}_E, \delta\widetilde{F}_3\right)\right]$$

Polarization Transfert

$$\sigma_R P_t = -\sqrt{\frac{2\varepsilon(1-\varepsilon)}{\tau}} \left(G_E G_M \pm G_E \Re\left[\delta\widetilde{G}_M\right] \pm G_M \Re\left[f_1\left(\delta\widetilde{G}_E, \delta\widetilde{F}_3\right)\right]\right)$$

$$\sigma_R P_l = \sqrt{1-\varepsilon^2} \left(G_M^2 \pm 2 G_M \Re\left[f_2\left(\delta\widetilde{G}_M, \delta\widetilde{F}_3\right)\right]\right)$$

5 unknown contributions for 6 independent observables

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Polarization Transfert

5 unknown contributions for 6 independent observables

Combining **polarized electrons and positrons** allows a **model independent separation** of the electromagnetic form factors of the nucleon.

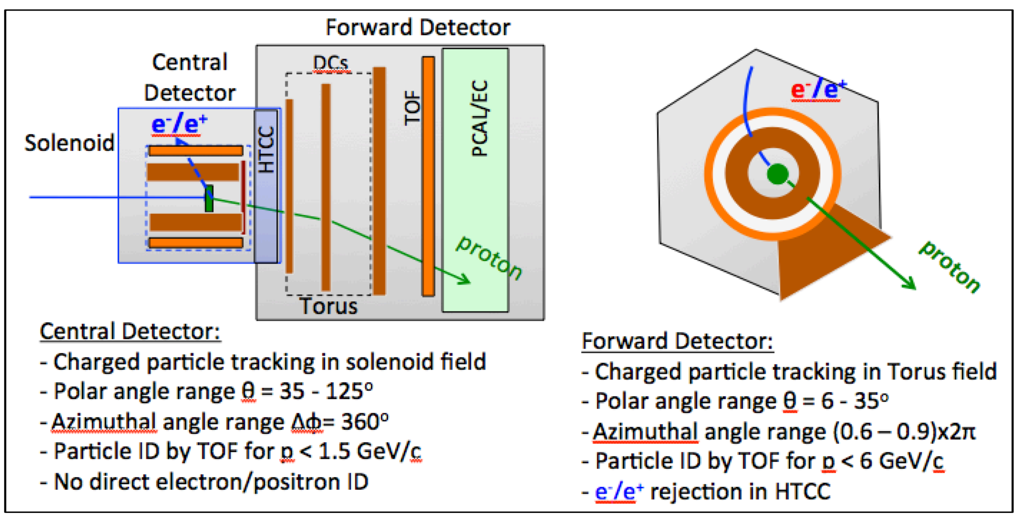
LOI12-18-004

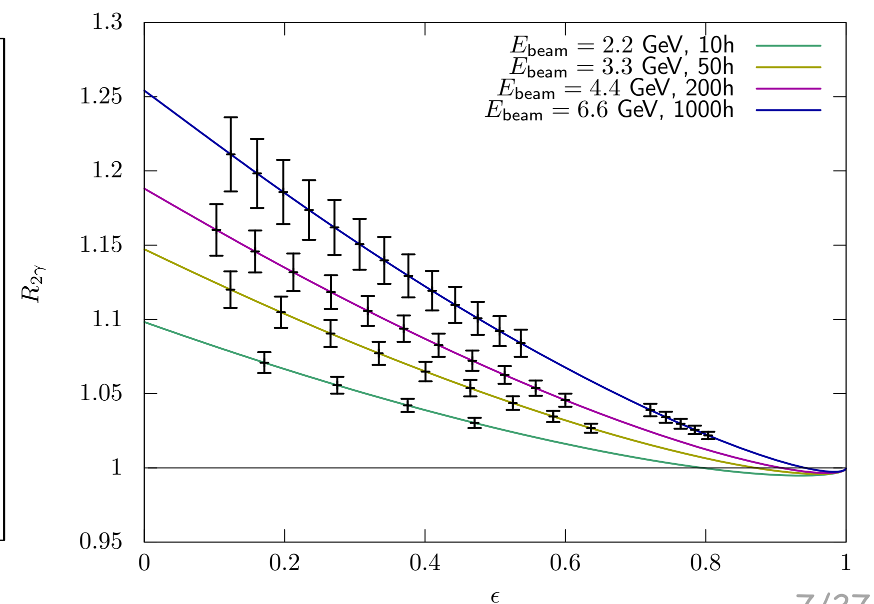
e+ @ JLab 12 GeV – J. Grames, E. Voutier et al.

J. Arrington, J. Bernauer, V. Burkert, A. Schmidt et al.

➢ A **modified CLAS12** hosting an electromagnetic calorimeter in place of the Central Neutron Detector would allow to **map out** the **2γ-effects** in the **(Q^2,ε)** space, providing a **conclusive answer about** the relevance of **2γ-effects**.

$$R_{2\gamma} = \frac{\sigma_{e^+}}{\sigma_{e^-}} \approx 1 + \delta_{2\gamma}$$



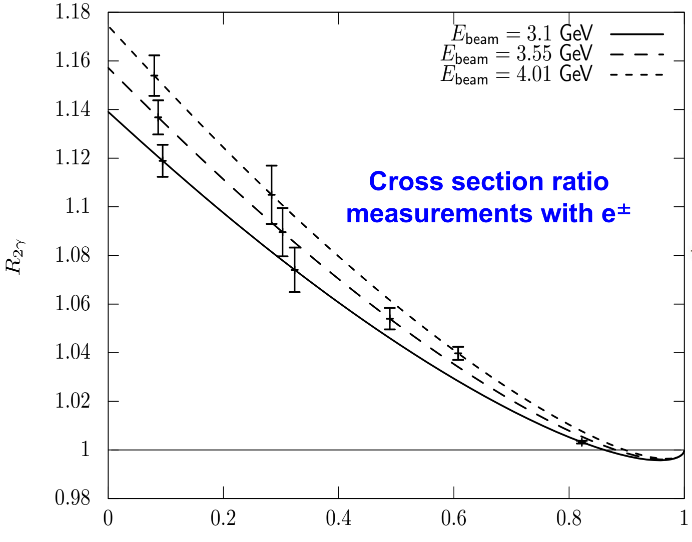


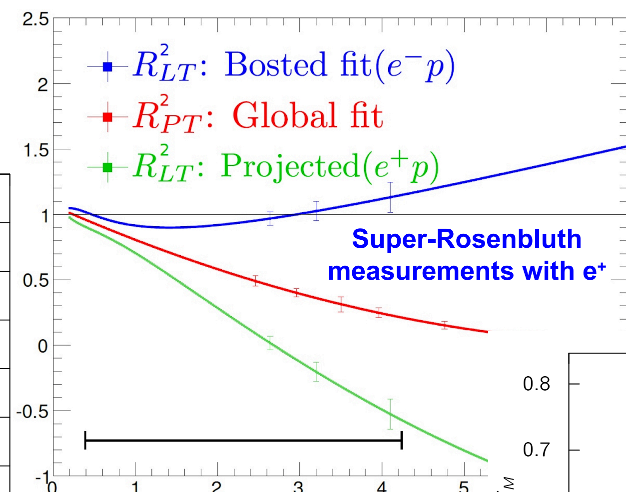
LOI12-18-004

e+ @ JLab 12 GeV – J. Grames, E. Voutier et al.

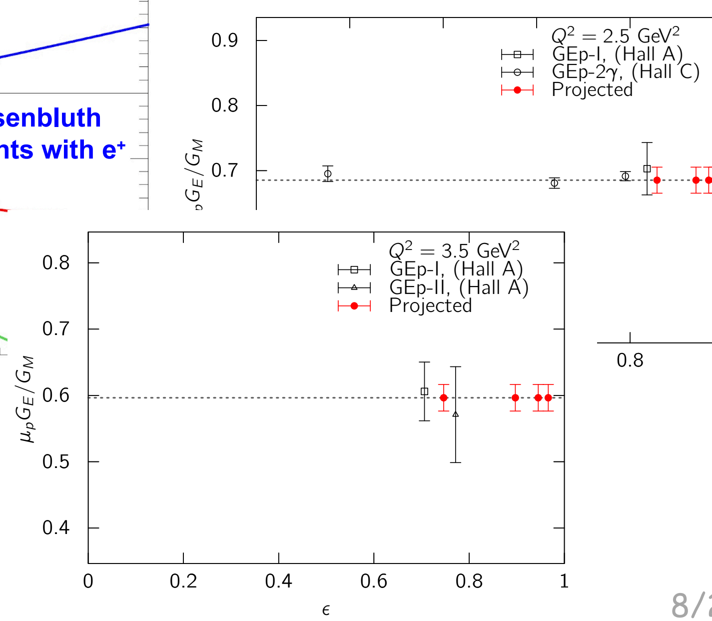
J. Arrington, J. Bernauer, A. Puckett, A. Schmidt et al.

➢ **High impact** measurements are also feasible in **Hall A & C** to **sign the existence** of 2γ-effects, better **control systematics** with the Super-Rosenbluth technique, and to **provide** unique **polarization transfer** data.





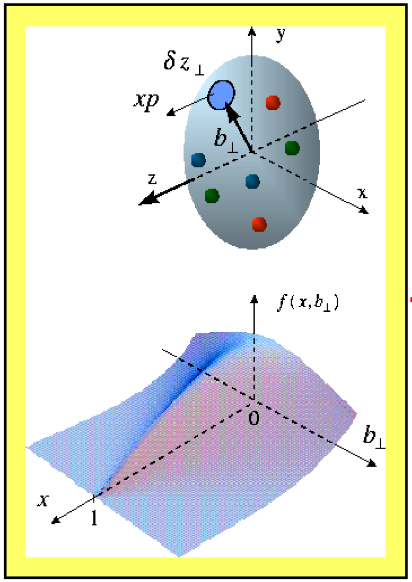
e± polarization transfer measurements with SBS



Parton Imaging

D. Müller, D. Robaschik, B. Geyer, F.M. Dittes, J. Horejsi, FP 42 (1994) 101 X. Ji, PRD 55 (1997) 7114 A. Radyushkin, PRD 56 (1997) 5524

- GPDs parameterize the partonic structure of hadrons and offer the unprecedented possibility to access the spatial distribution of partons.



GPDs encode the correlations between partons and contain information about the dynamics of the system like the angular momentum or the distribution of the strong forces experienced by quarks and gluons inside hadrons.

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

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

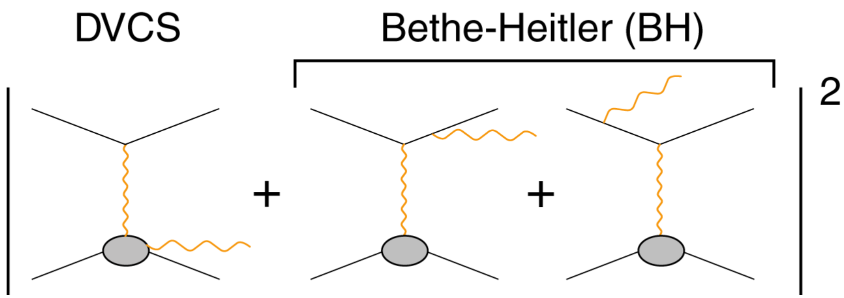
GPDs can be interpreted as a distribution in the transverse plane of partons carrying some fraction of the longitudinal momentum of the nucleon.

A new light on hadron structure

N(e,e'γN) Differential Cross Section

M. Diehl at the CLAS12 European Workshop, Genova, February 25-28, 2009

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



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

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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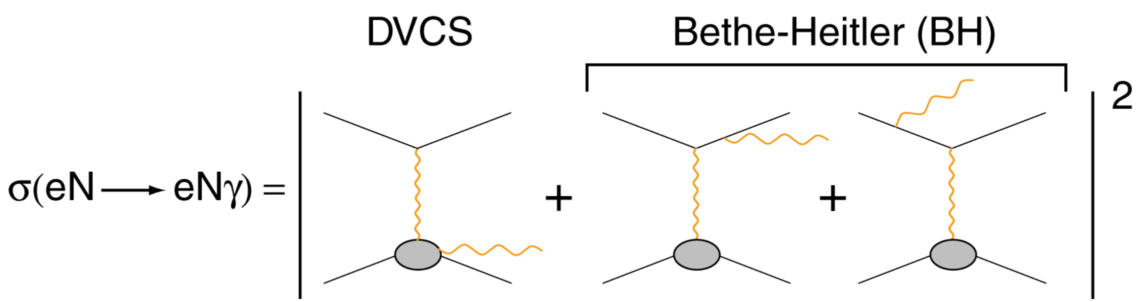

$$\sigma^{e}_{PS} = \sigma^{e}_{P0} + S\left[P_l\,\Delta\sigma_{BH} + \left(\Delta\tilde{\sigma}_{DVCS} + P_l\,\Delta\sigma_{DVCS}\right) + e_l\left(\Delta\tilde{\sigma}_{INT} + P_l\,\Delta\sigma_{INT}\right)\right]$$

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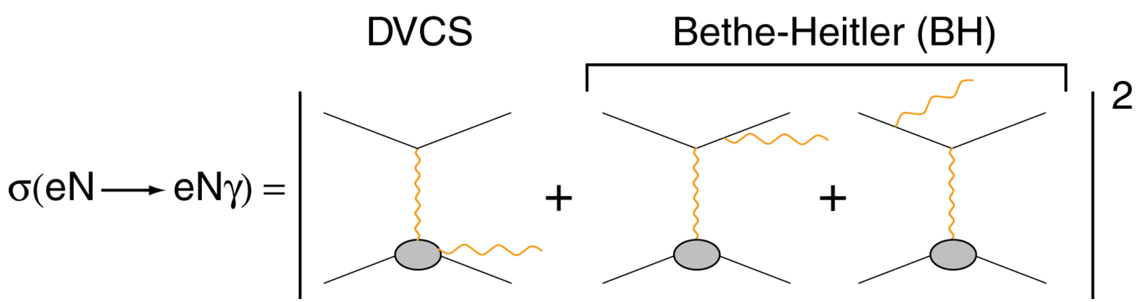

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Additional observables

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

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

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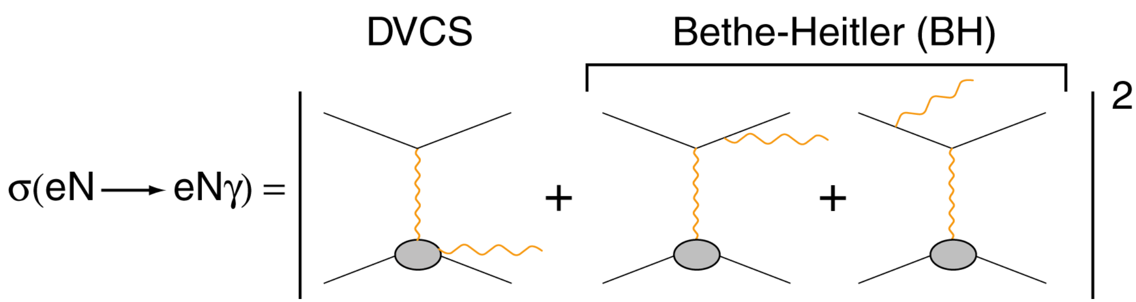

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Polarized electrons and positrons allow to separate the unknown amplitudes of the cross section for electro-production of photons.

Nucleon Internal Pressure

V. Burkert, L. Elouadrhiri, F.-X. Girod, Nature 557 (2018) 396 M.V. Polyakov, P. Schweitzer, Int. J. Mod. Phys. A33 (2018) 1830025

$$\int_{-1}^{1} x\, H(x,\xi,t)\, dx = M_2(t) + \frac{4}{5}\xi^2 d_1(t)$$

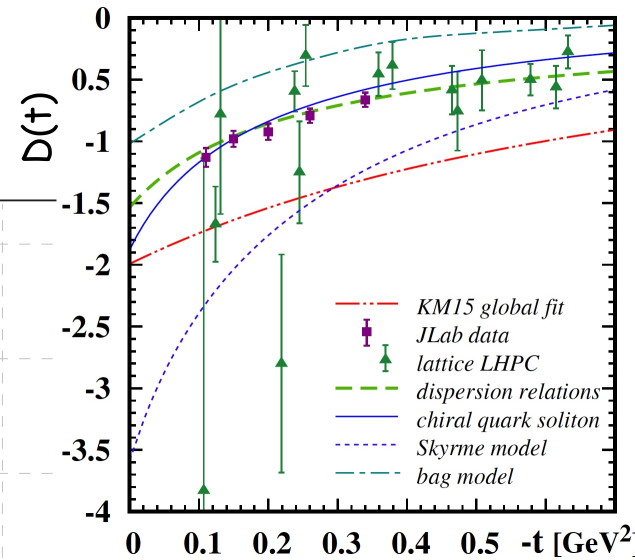
The 2nd order **Mellin moment** of GPDs allow to access the pressure distribution inside hadrons through the **skewness dependency** of GPDs… **DDVCS**.

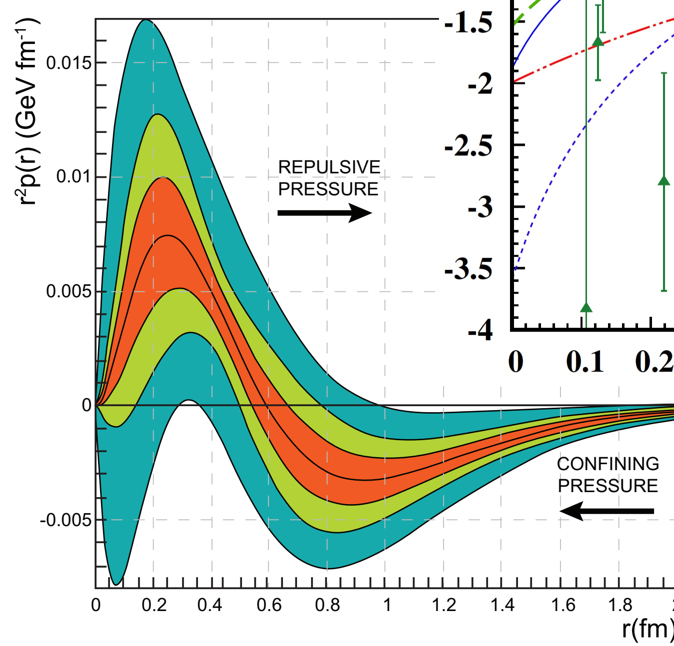
CFF
$$\mathcal{H}(\xi,t) = \int_{-1}^{1}\left[\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right] H(x,\xi,t)\, dx$$

$$\mathfrak{Re}[\mathcal{H}(\xi,t)] \overset{LO}{=} D(t) + \mathcal{P}\left\{\int_{-1}^{1}\left[\frac{1}{\xi - x} - \frac{1}{\xi + x}\right]\mathfrak{Im}[\mathcal{H}(x,t)]\, dx\right\}$$

$$D(t) = \frac{1}{2}\int_{-1}^{1}\frac{D(z,t)}{1-z}\, dz$$

$$D(z,t) = (1-z^2)\left[d_1(t)\, C_1^{3/2}(z) + \;\ldots\right]$$





Eric Voutier
IPN ORSAY

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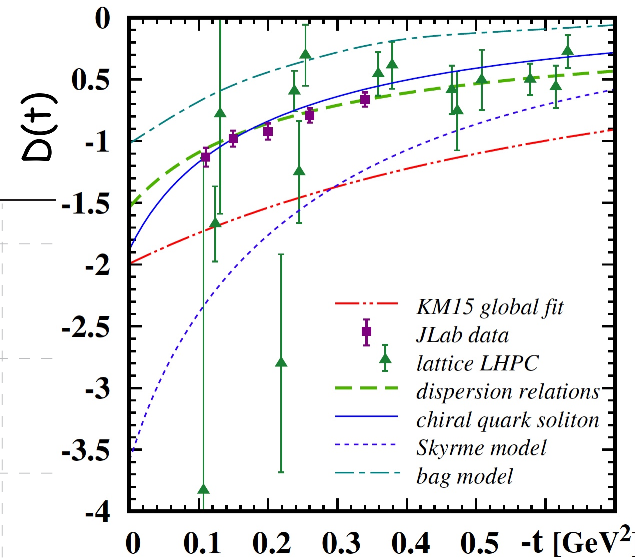
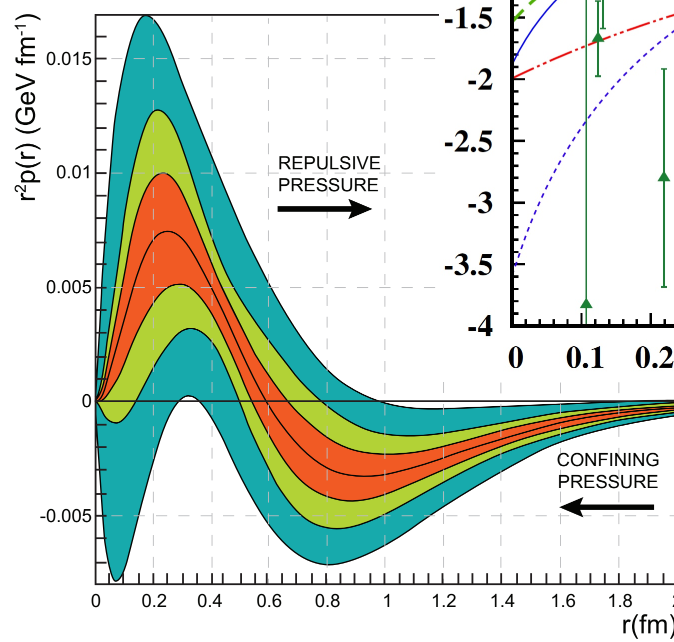
Real part of Compton form factors.





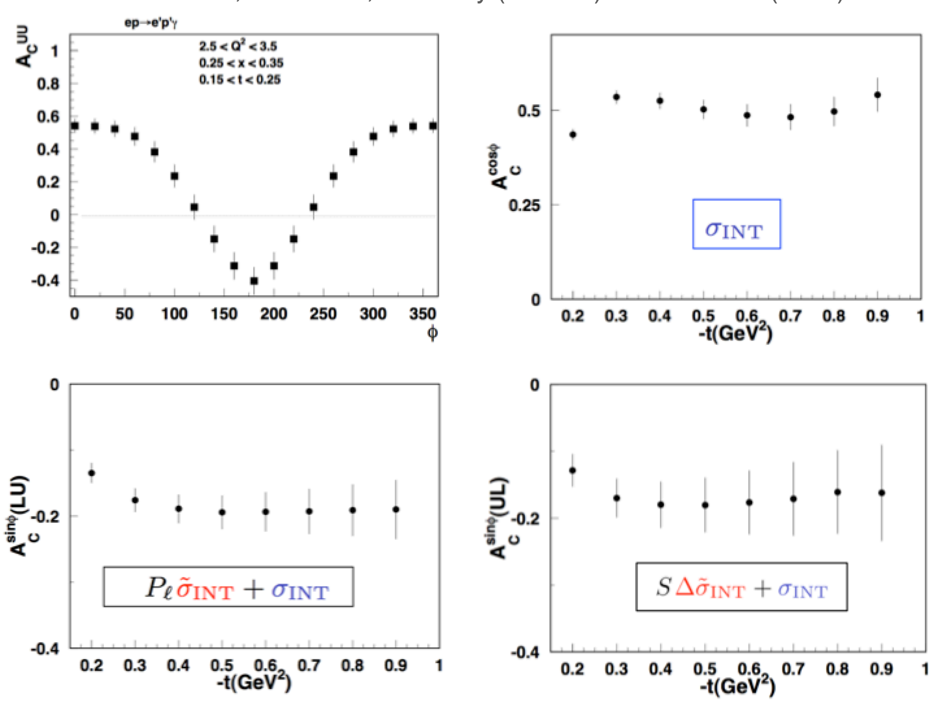
LOI12-18-004

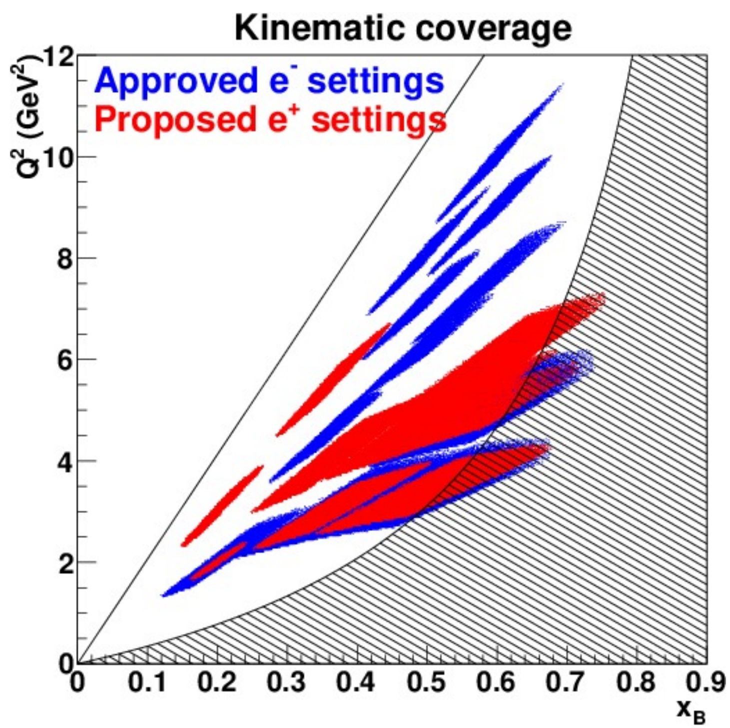
e+ @ JLab 12 GeV – J. Grames, E. Voutier et al.

V. Burkert, L. Elouadrhiri, F.-X. Girod, C. Muñoz Camacho et al.

- It is proposed to measure **polarized** and **unpolarized** beam **charge asymmetries** off **protons** and **neutrons** (CLAS12), and **unpolarized p-DVCS cross section** with positrons (HMS+NPS).

H. Avakian, V. Burkert, V. Guzey (JPos09) AIP CP 1160 (2009) 43



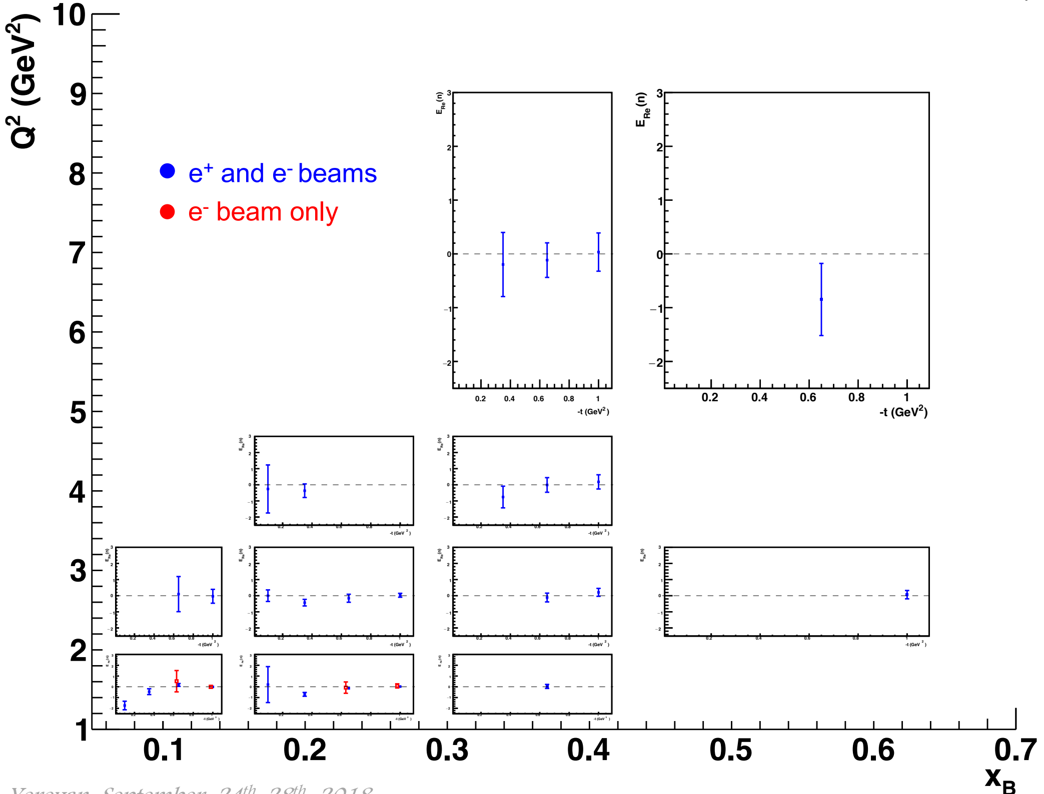


LOI12-18-004

e+ @ JLab 12 GeV – J. Grames, E. Voutier et al.

S. Niccolai, E. Voutier et al.

$$A_C(\phi) \propto \frac{1}{F_2} \Re e \left[\xi \widetilde{H}_n - \frac{t}{4M^2} E_n \right]$$



- The BCA on the neutron accesses the **real part** of the CFF **E**, and is sensitive to $\tilde{H}$ at some kinematics.

$$\Delta^C_{LU} = \frac{(d^4\sigma^+_{+0} - d^4\sigma^+_{-0}) - (d^4\sigma^-_{+0} - d^4\sigma^-_{-0})}{d^4\sigma^+_{+0} + d^4\sigma^+_{-0} + d^4\sigma^-_{+0} + d^4\sigma^-_{-0}}$$

$$\Sigma^C_{LU} = \frac{(d^4\sigma^+_{+0} - d^4\sigma^+_{-0}) + (d^4\sigma^-_{+0} - d^4\sigma^-_{-0})}{d^4\sigma^+_{+0} + d^4\sigma^+_{-0} + d^4\sigma^-_{+0} + d^4\sigma^-_{-0}}$$

$$A_{LU} = \frac{\Sigma^C_{LU}}{1 - A_C} - \frac{\Delta^C_{LU}}{1 - A_C}$$

Polarized positron beams provide a different **access** to the **imaginary part**, and **probe** the importance of **higher twists**.

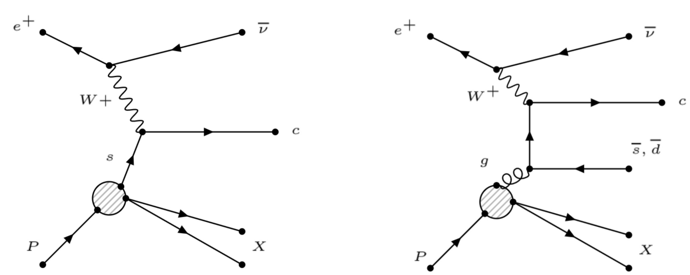
Structure Functions

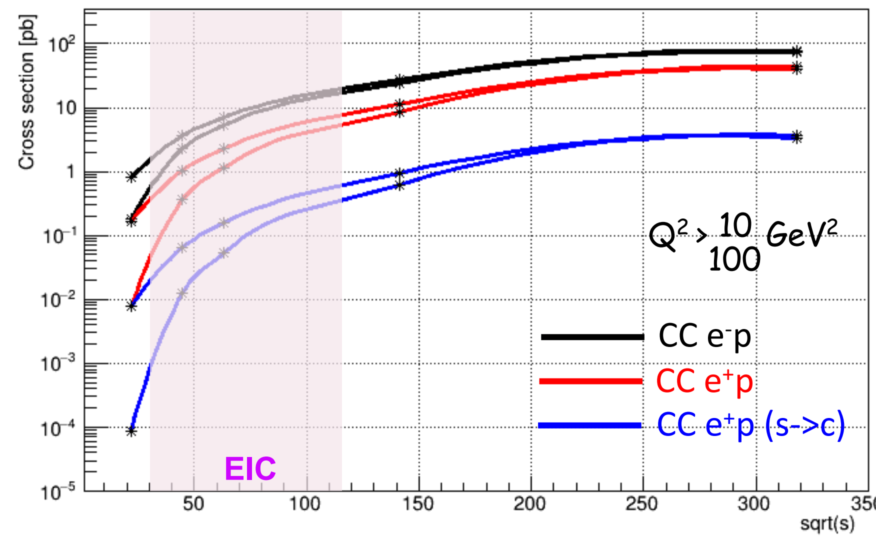
- Neutral and charged DIS
- **Charm production**
- Pion and kaon structure

Eric Voutier
IPN ORSAY

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**.

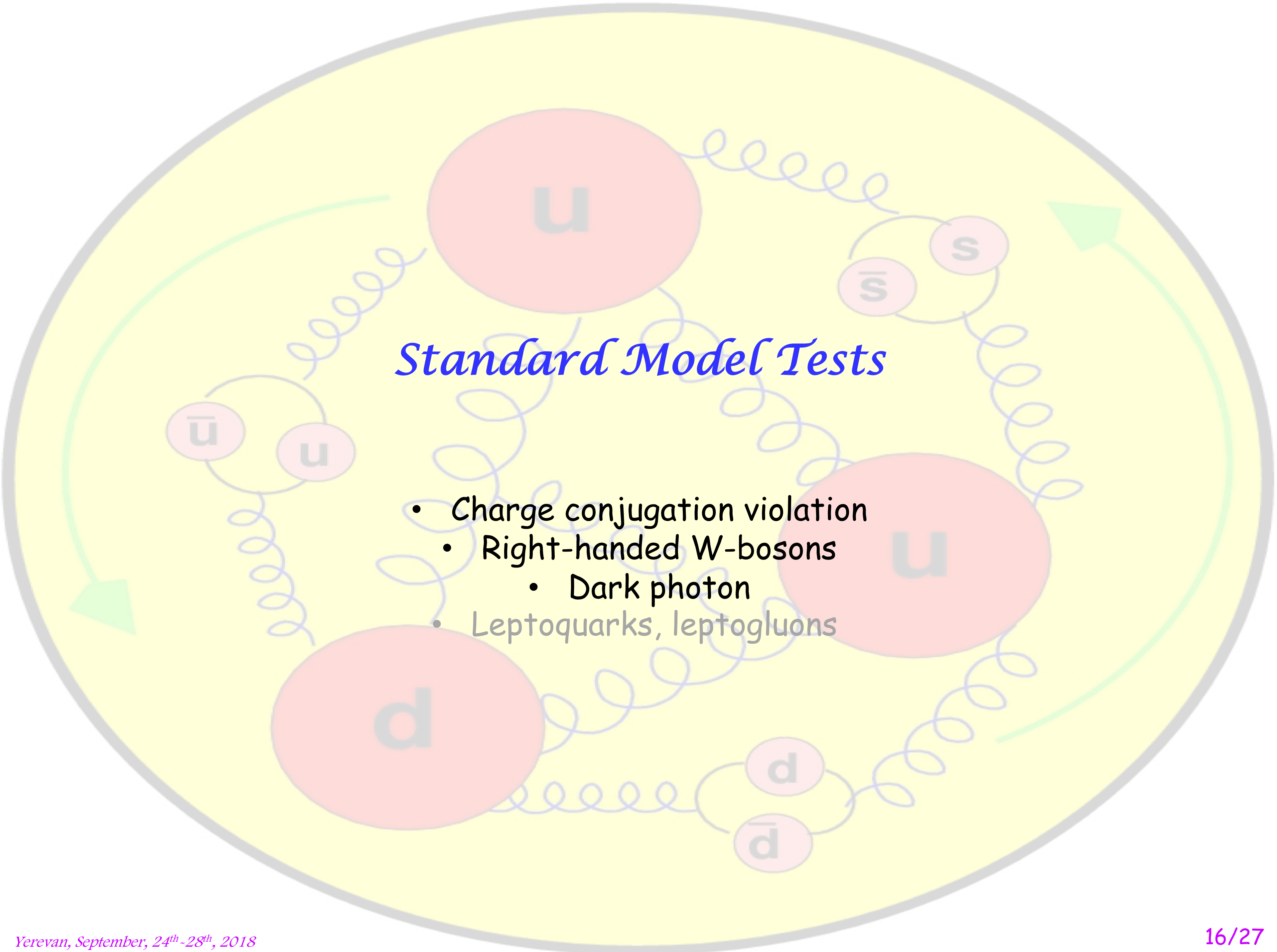




- **Charm production** via **charge current** exchange preferentially couples to the **strange content** of the nucleon.
- The boson-gluon-fusion mechanism is a source of **background**, **manageable** with good **PID** and **vertex reconstruction**.

$$e^+ + p \rightarrow \bar{\nu}_e + c + X$$
$$e^- + p \rightarrow \nu_e + \bar{c} + X$$

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



Standard Model Tests

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

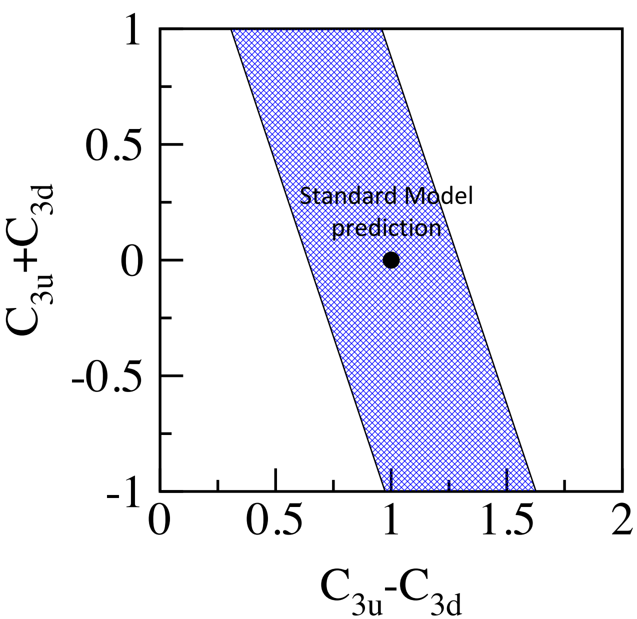
Weak Neutral Current Couplings

S.M. Berman, J.R. Primack , Phys. Rev. D 9 (1974) 2171 X. Zheng, (JPos09) AIP CP 1160 (2009) 160

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

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

$g_A^e g_A^q$



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%

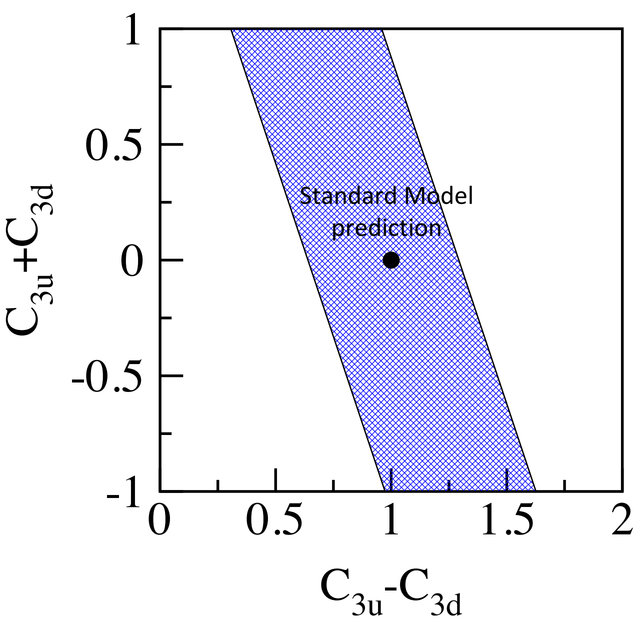
Weak Neutral Current Couplings

S.M. Berman, J.R. Primack , Phys. Rev. D 9 (1974) 2171 X. Zheng, (JPos09) AIP CP 1160 (2009) 160

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

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

$g_A^e g_A^q$



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

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

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

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

Polarized Charge Current Cross Section

Y. Furletova, S. Mantry, (JPos17) AIP CP 1970 (2018) 030005

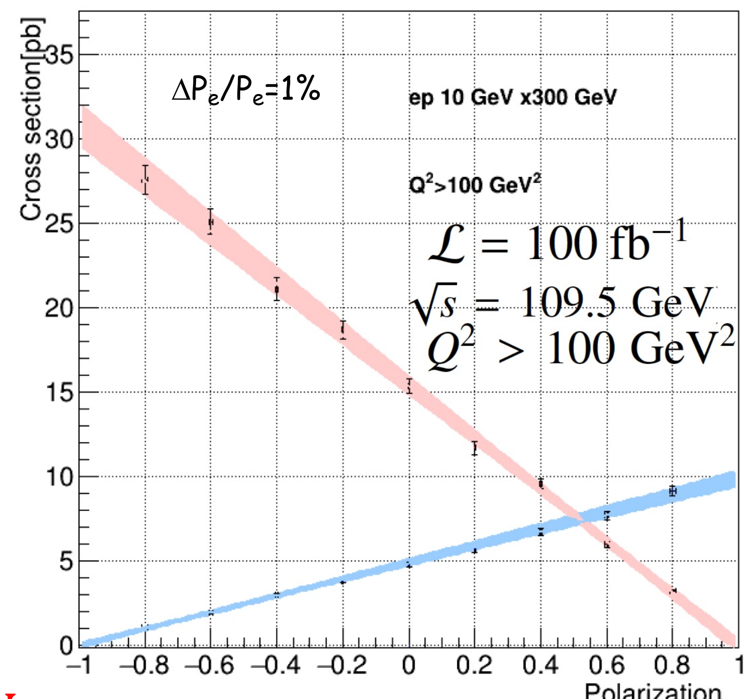
- The **polarization dependence** of the charge current cross section can be measured to potentially reveal *deviations from the Standard Model prediction*.

EIC projections

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

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

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

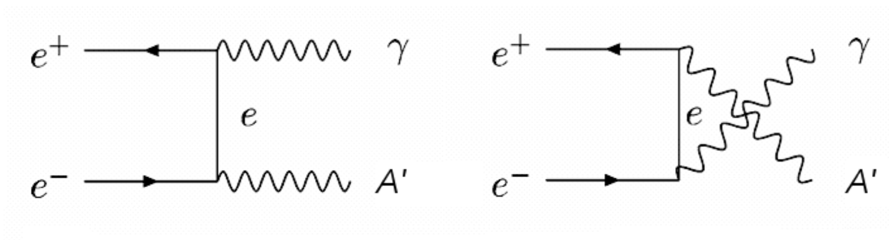


95% confidence level upper bound

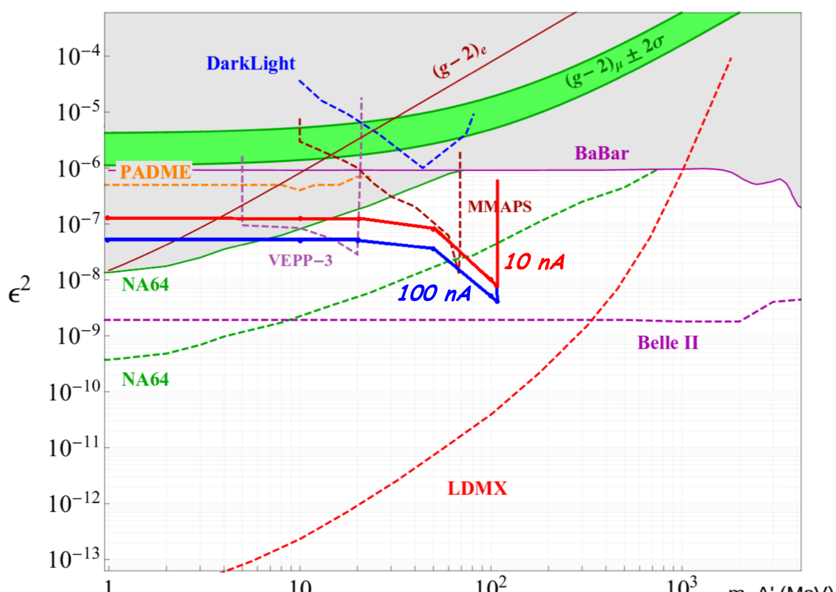
$$\sigma^{e^\pm p}\,(P_e=\mp 1) < 0.0776\ \mathrm{pb} \;\rightarrow\; \boldsymbol{M_R \geq 285\ \mathrm{GeV}}$$

LOI12-18-004
e+ @ JLab 12 GeV – J. Grames, E. Voutier et al.

M. Battaglieri, A. Celentano, L. Marsicano et al.



- The e^+e^--annihilation offers an alternative way to probe the existence of a dark photon by measuring the photon spectra in the A' invisible decay chanel.



P. Valente, J. Alexander, (JPos17) AIP CP 1970 (2018) 020007
L. Marsicano, (JPos17) AIP CP 1970 (2018) 020008

180 days data taking with a high energy positron beam would extend the A' mass reach up to 100 MeV and would improve by a factor 10 the coupling strength sensitivity.

Polarized Positrons @ JLab

- PEPPo concept
- Positron polarization
- e^+ @ JLab 12 GeV
- e^+ @ JLEIC
- P3E initiative

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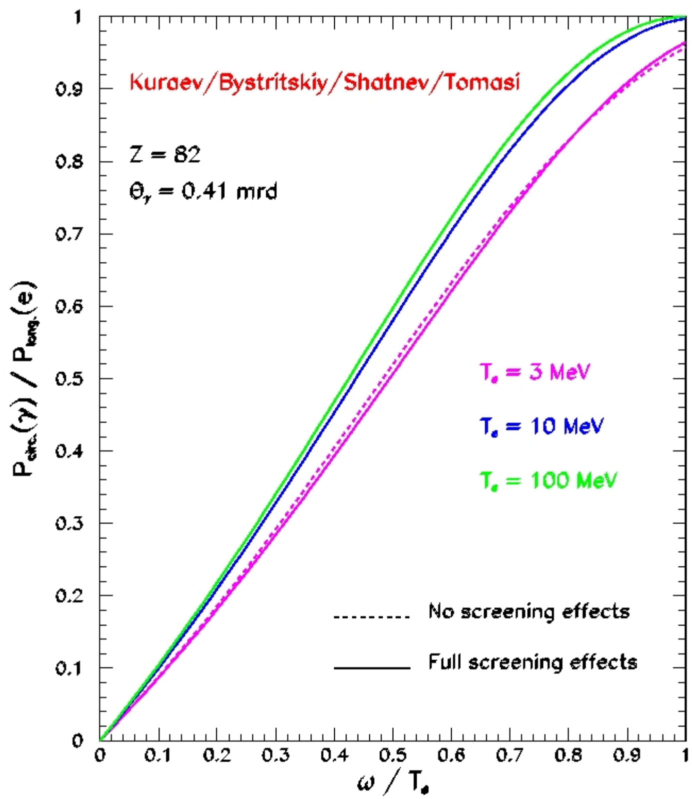
Bremsstrahlung and Pair Creation

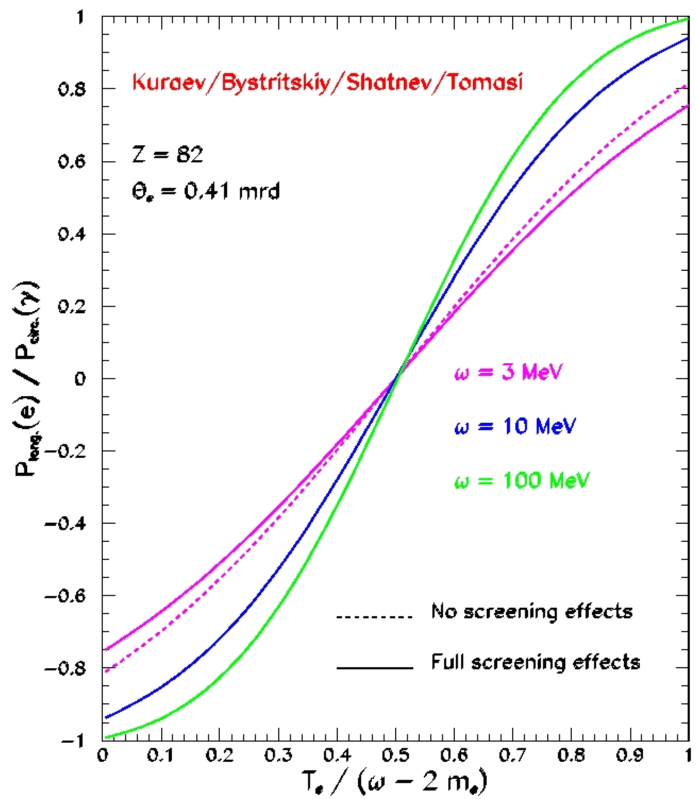
H. Olsen, L. Maximon, PR 114 (1959) 887   E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E. Tomasi-Gustafsson, PRC 81 (2010) 055208

- **Finite lepton mass** calculations of the bremsstrahlung and pair creation processes predict **very efficient polarization transfers**.

BREMSSTRAHLUNG



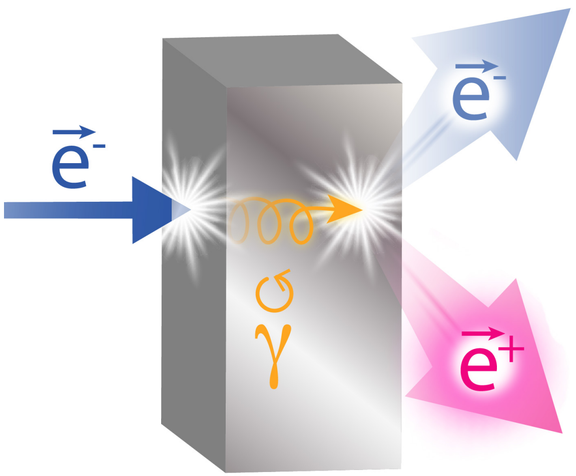
PAIR CREATION

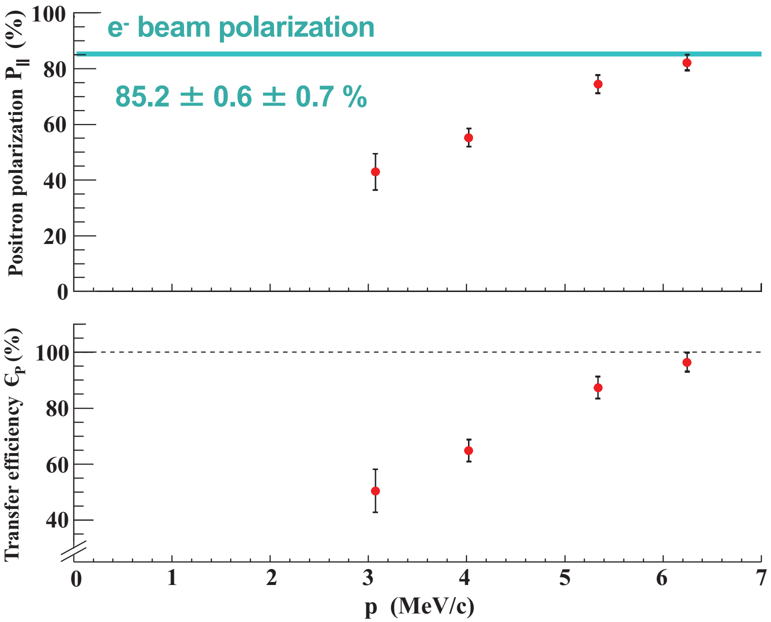


PEPPo Technique

(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**.





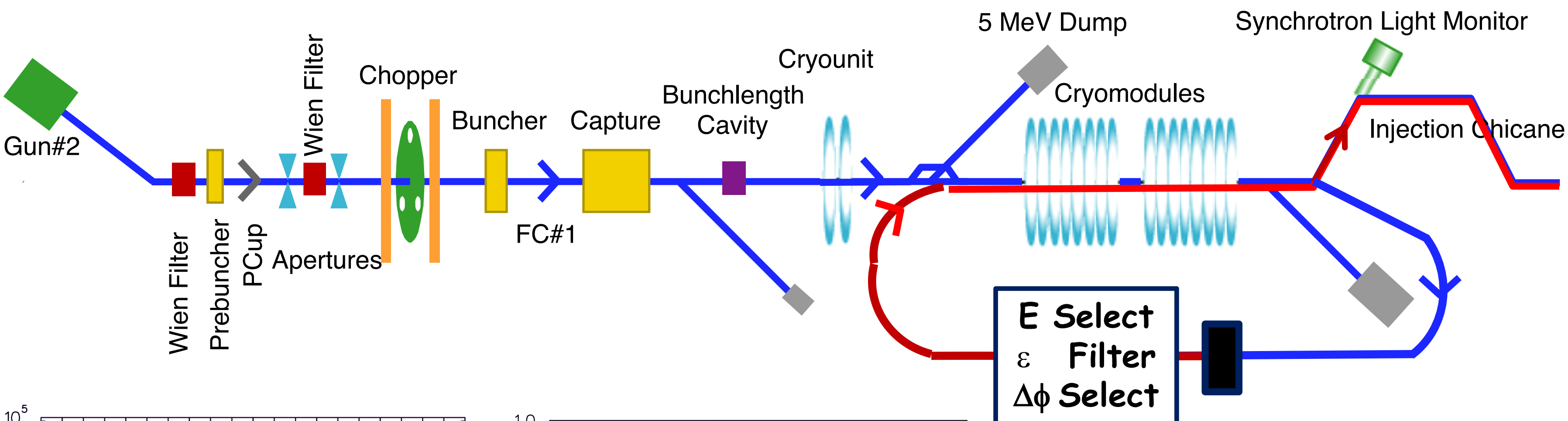
The **PEPPo** technique can achieve up to **100% transfer** of the electron.

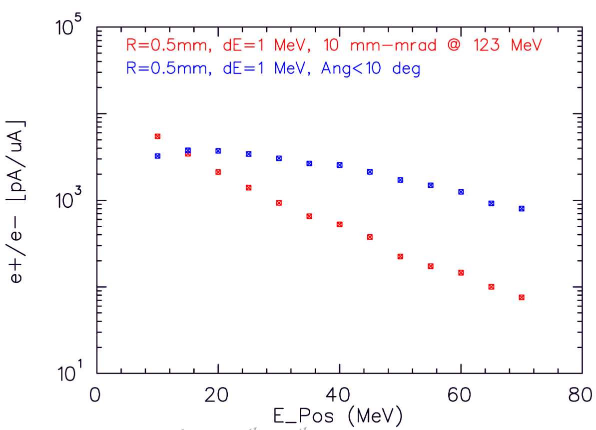
LOI12-18-004

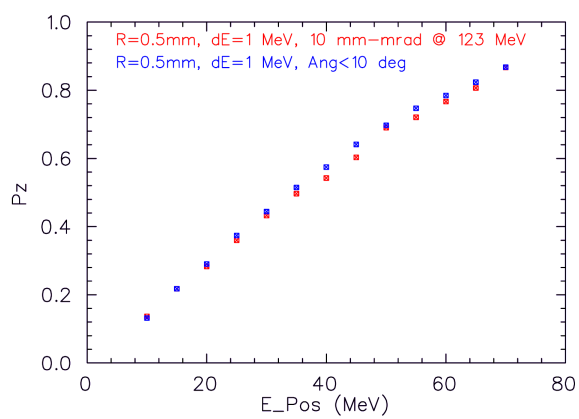
e+ @ JLab 12 GeV – J. Grames, E. Voutier et al.

L. Cardman et al. (JPos17) AIP CP 1970 (2018) 050001

- 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**).

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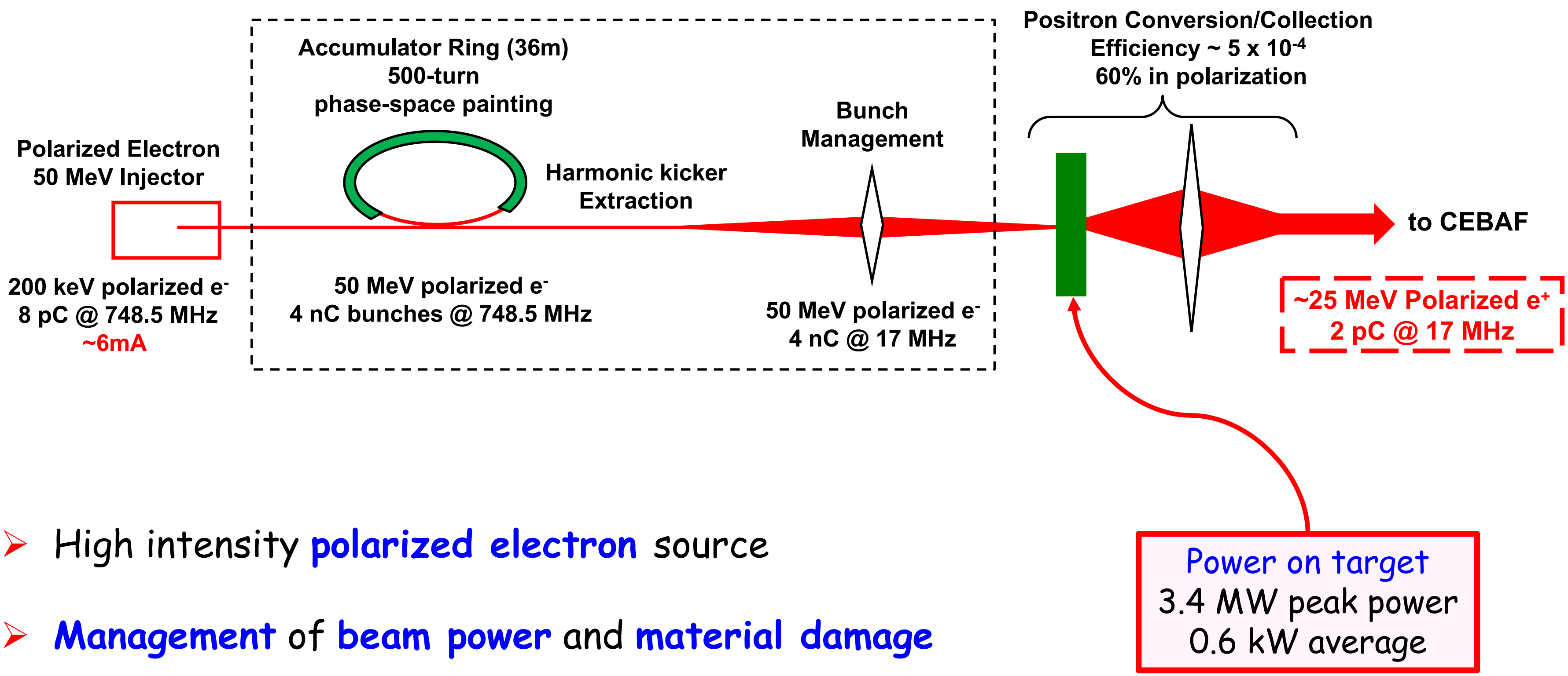
Positron Production Scheme

F. Lin, J. Grames, J. Guo, V. Morozov, Y. Zhang, (JPos17) AIP CP 1970 (2018) 050005

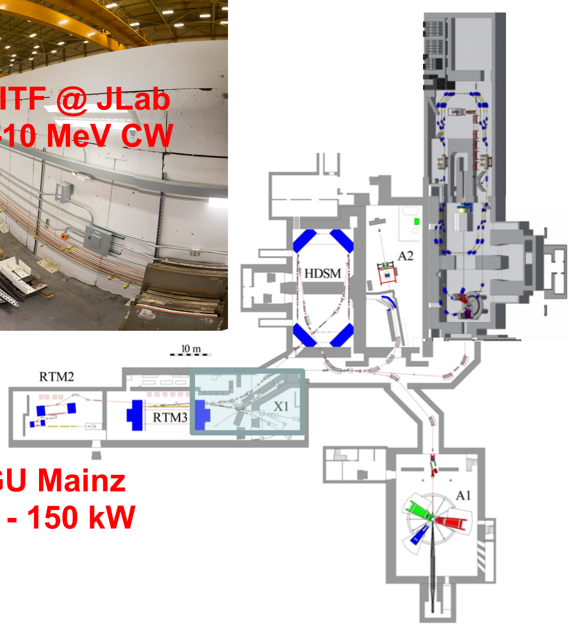


- High intensity **polarized electron** source
- **Management** of **beam power** and **material damage**
- Optimized **collection system**

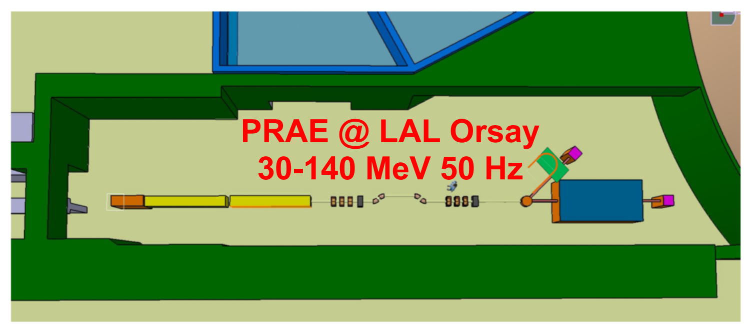
Technical Concept Validation

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** (**P**olarized **E**lectrons, **P**ositrons, and **P**olarimetry) initiative, part of the **STRONG-2020** proposal (**H2020-INFRAIA-2018-2019** call), intends to address these issues .

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e^+ @ JLab

Polarized and **unpolarized positron beams** provide a unique opportunity to **enhance** the **physics reach** of JLab and a future EIC.

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

JPos17 proceedings, AIP CP 1970 (2018)
https://aip.scitation.org/toc/apc/1970/1?size=all&expanded=1970

LOI12-18-004 to JLab PAC46

« ... These measurements all have significant physics interest. The proposers should carefully evaluate feasibility and present the best case possible in a future proposal. The justification must be very strong to enable the significant changes needed in the accelerator, both in equipment and in schedule... »

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

White Paper (planned 2019), Conceptual Design Report (goal 2020)

Eric Voutier
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Polarized e^+ @
ALTO, MAMI, MESA, JLab, EIC, ILC, CEPC...

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

- The P3E initiative will also **investigate** the **constraints/abilities** for the production of low energy polarized positron beams (Material Science...) particularly in the context of the upgrade of the **ALTO facility in Orsay**.

Polarized e^+ @
ALTO, MAMI, MESA, JLab, EIC, ILC, CEPC…

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Consider contributing to this adventure !!

voutier@ipno.in2p3.fr grames@jlab.org ***Subscribe to pwg@jlab.org***

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