The Jefferson Lab Positron Physics Program

e⁺@JLab

Eric Voutier and the **Jefferson Lab Positron Working Group**

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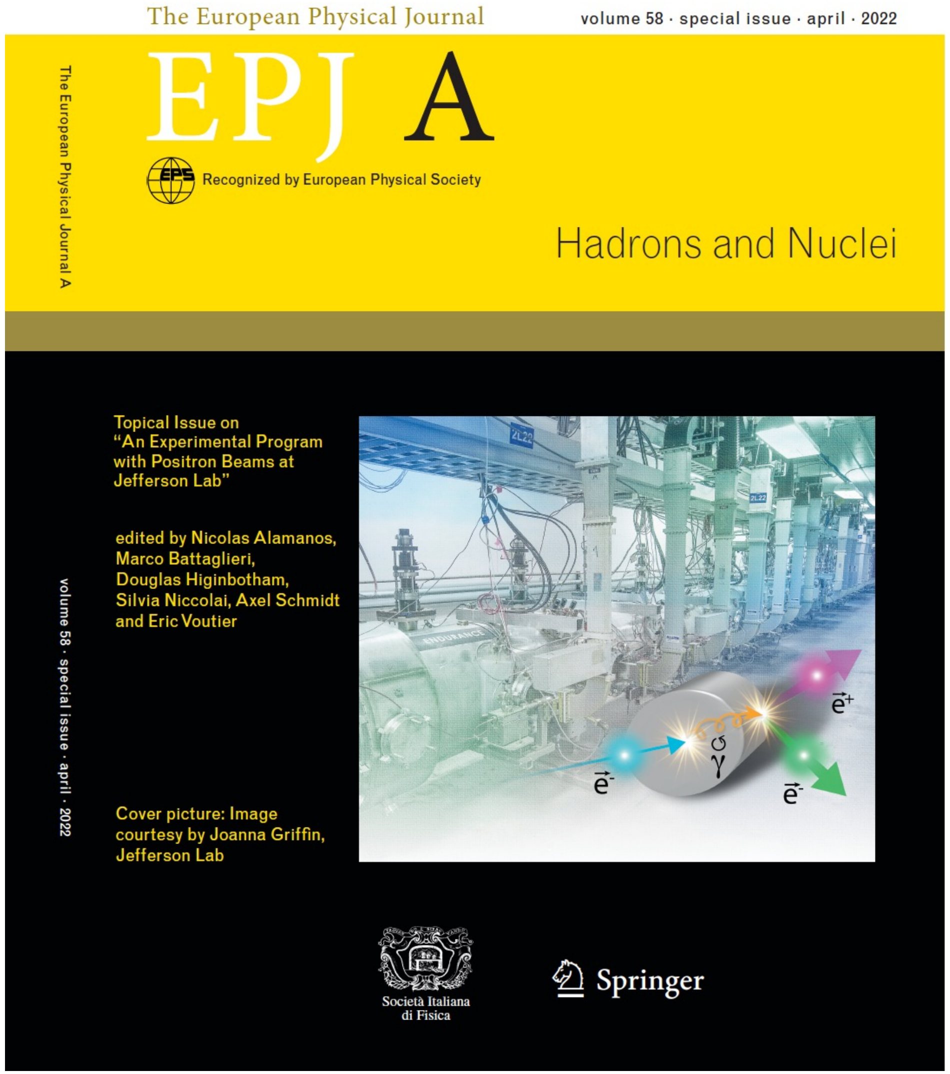
(i) Positron Working Group
(ii) Two photon exchange
(iii) Nuclear structure
(iv) Beyond the standard model
(v) Ce^+BAF

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement Nº 824093.



- The **JLab Positron Working Group** (PWG) developed the perspectives of an experimental program with **positron beams at CEBAF** in a topical EPJ A issue.

- This document constitutes the final **JLab Positron White Paper**, gathering 19 single contributions and a summary article, all peer-reviewed.

JLab PWG = ~**250** Physicists
from **75** Institutions and **16** countries

(Jefferson Lab Positron Working Group) A. Accardi *et al.* EPJ A 57 (2021) 261

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Positron Partial Program Summary

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

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

- **TPE Physics** in elastic scattering globally asks for low beam energies.
- **Nucleon Structure Physics** and **Beyond the Standard Model Physics** ask for high beam energies.

➢ There exists strong opportunities for **polarized target experiments**, which have not been yet explored.

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Jefferson Lab PAC51

- The Positron Experimental Program at JLab has formally started with the C1 approval of 5 positron proposals at the PAC meeting of Juy 2023, constituting 3 calendar years of single hall running.

NUMBER	TITLE	PHYSICS THEME	CONTACT PERSON	HALL	DAYS AWARDED	SCIENTIFIC RATING	PAC DECISION
PR12+23-002	Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the Proton at CLAS12	GPDs	Eric Voutier	B	100	**A-**	**C1**
PR12+23-003	Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of Coulomb Corrections in DIS	TPE	Dave Gaskell	C	9.3	**A-**	**C1**
PR12+23-006	Deeply Virtual Compton Scattering using a positron beam in Hall C	GPDs	Carlos Muñoz Camacho	C	137	**A-**	**C1**
PR12+23-008	A Direct Measurement of Hard Two-Photon Exchange with Electrons and Positrons at CLAS12	TPE	Axel Schmidt	B	55	**A**	**C1**
PR12+23-012	A measurement of two-photon exchange in unpolarized elastic positron–proton and electron–proton scattering	TPE	Michael Nycz	C	56	**A-**	**C1**

C1 = Conditionally Approved with Technical Review by the Lab

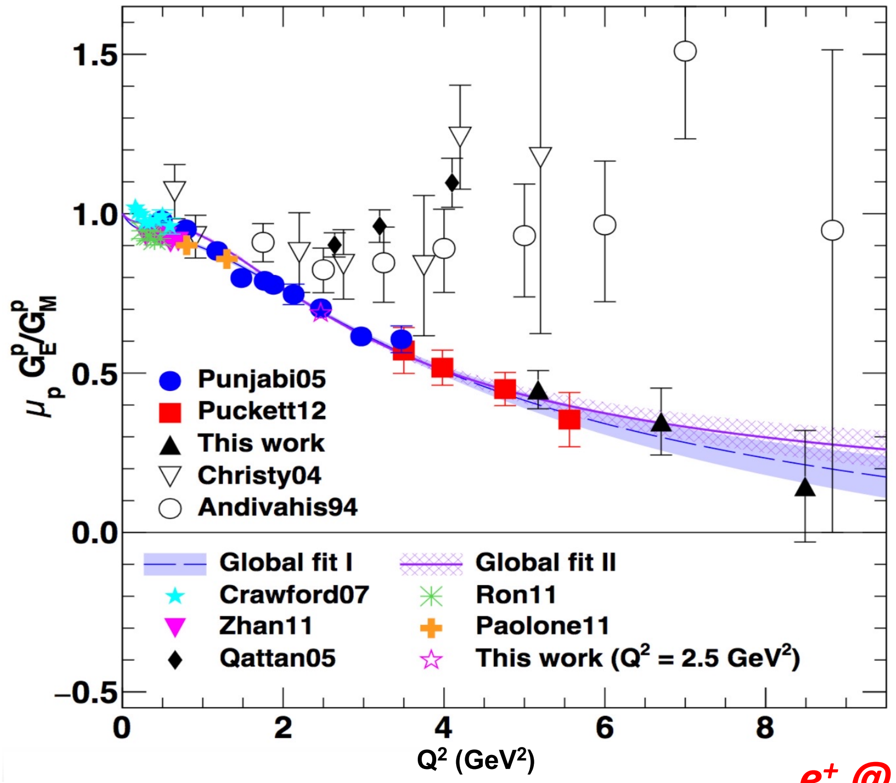
E. Voutier
IJCLab Irène Joliot-Curie

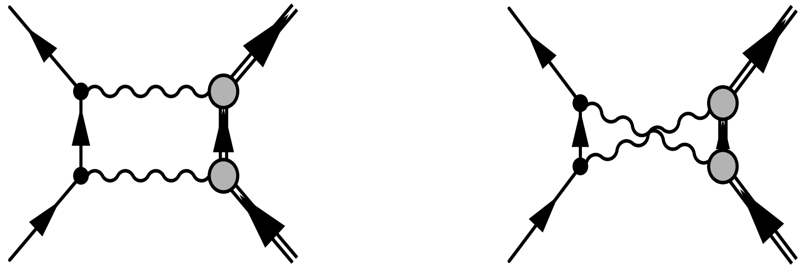
The Dilemma

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** (OPE) of the electromagnetic interaction.

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





Hard two-photon exchange (TPE) may be the cause of the form factor discrepancy at high Q^2.

- If TPE, the electromagnetic structure of the nucleon would be parameterized by **3 generalized form factors** i.e. **8 unknow quantities**.
- TPE can only be calculated within model-dependent approaches.

*e^+ @ JLab have the unique opportunity to bring a **definitive answer** about TPE.*

E. Voutier

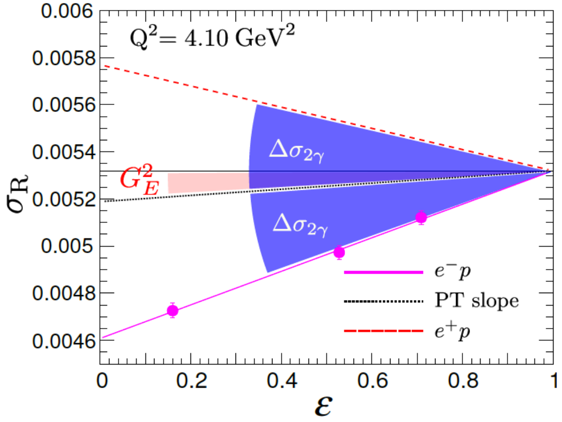
Experimental Observables

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

- The ratio of the positron and electron induced elastic cross sections measures TPE effects.

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

- The direct comparison of positron and electron Super-Rosenbluth separations doubles the sensitivity to a TPE signal, and test radiative correction hypotheses.



➢ The measurement of the polarization transfer of positrons to protons in the elastic scattering process is mandatory to establish its expected insensitivity to TPE.

$$\frac{P_t}{P_l} \approx -\sqrt{\frac{2\epsilon}{(1+\epsilon)\tau}}\frac{G_E}{G_M}\left(1 \pm \left\{\frac{\Re e\left[\delta \tilde{G}_M\right]}{G_M} + \frac{\Re e\left[f_1\left(\delta \tilde{G}_E, \delta \tilde{F}_3\right)\right]}{G_E} - 2\frac{\Re e\left[f_2\left(\delta \tilde{G}_M, \delta \tilde{F}_3\right)\right]}{G_M}\right\}\right)$$

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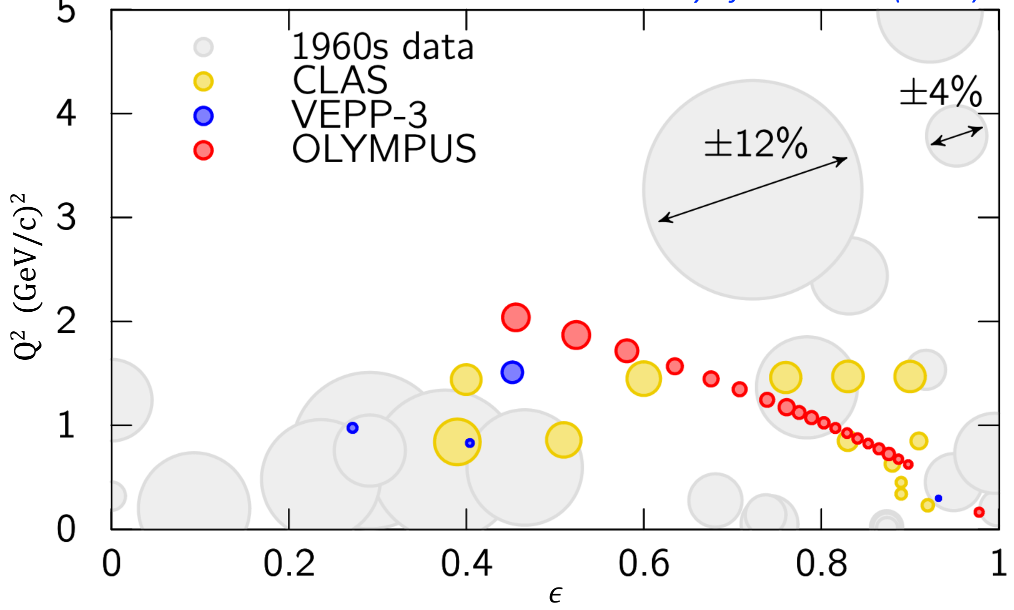
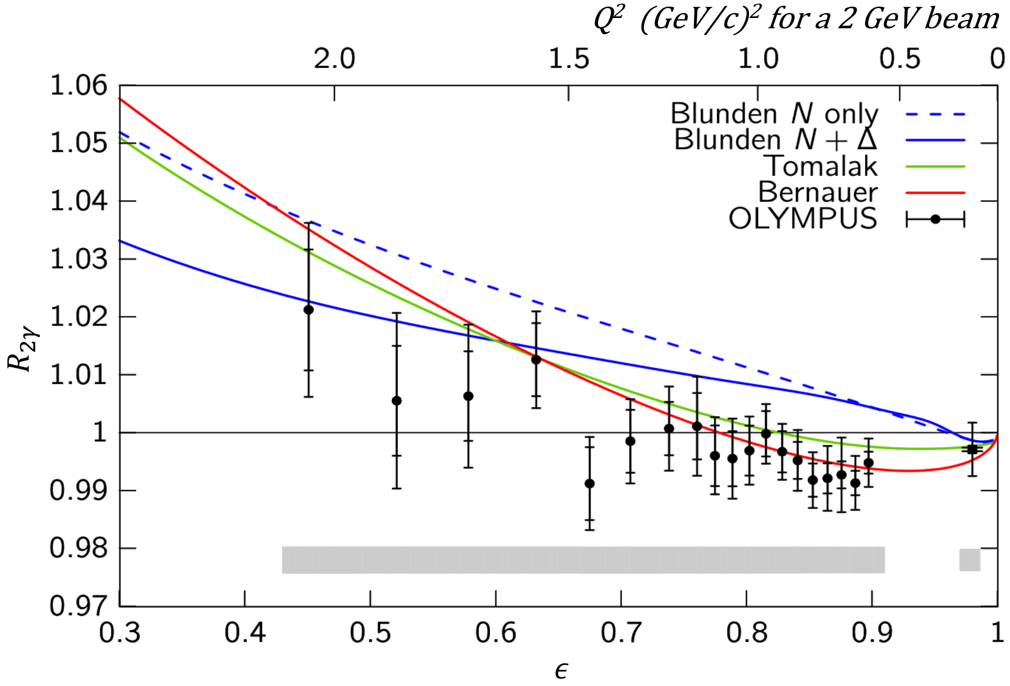
Current Knowledge

- Three experiments (CLAS,VEPP-3,OLYMPUS) recently attempted to measure TPE effects, but lacked the kinematical reach to draw meaningfull conclusions.
- OLYMPUS seems to observe a small effect, barely consistent with expectations.

Courtesy of A. Schmidt (GWU)





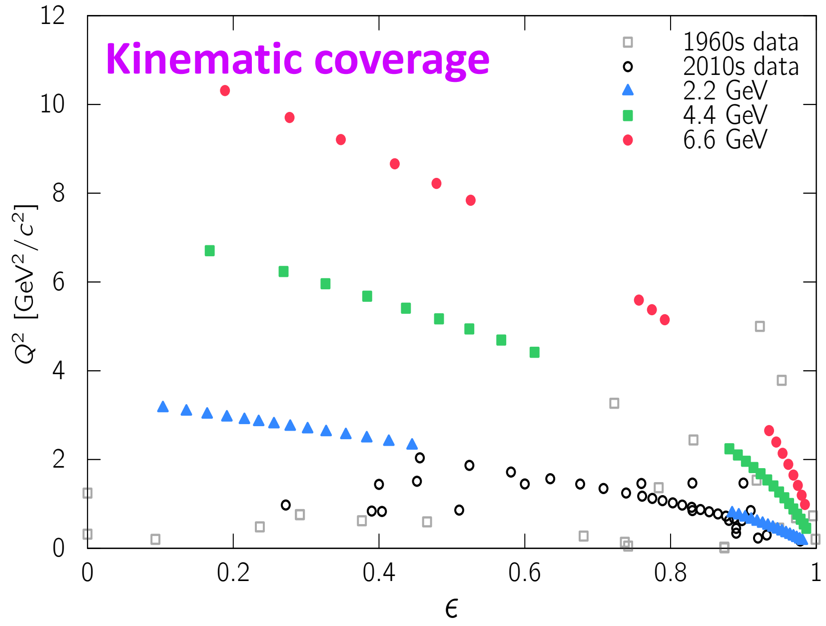
(CLAS Collaboration) D. Adikaram et al. PRL 114 (2015) 062003   I.A. Rachek et al. PRL 114 (2015) 062005   (OLYMPUS Collaboration) B. Henderson et al. PRL 118 (2017) 092501

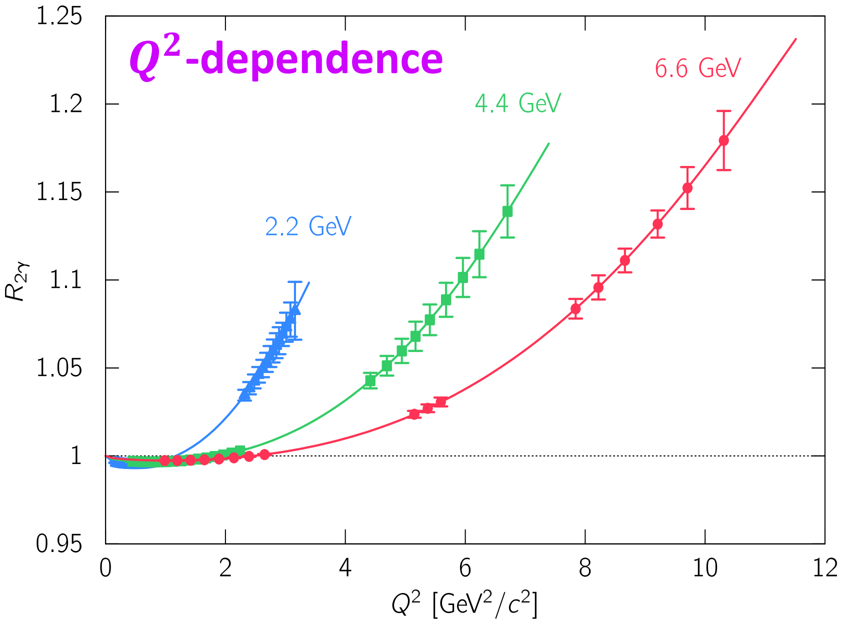
PR12+23-008

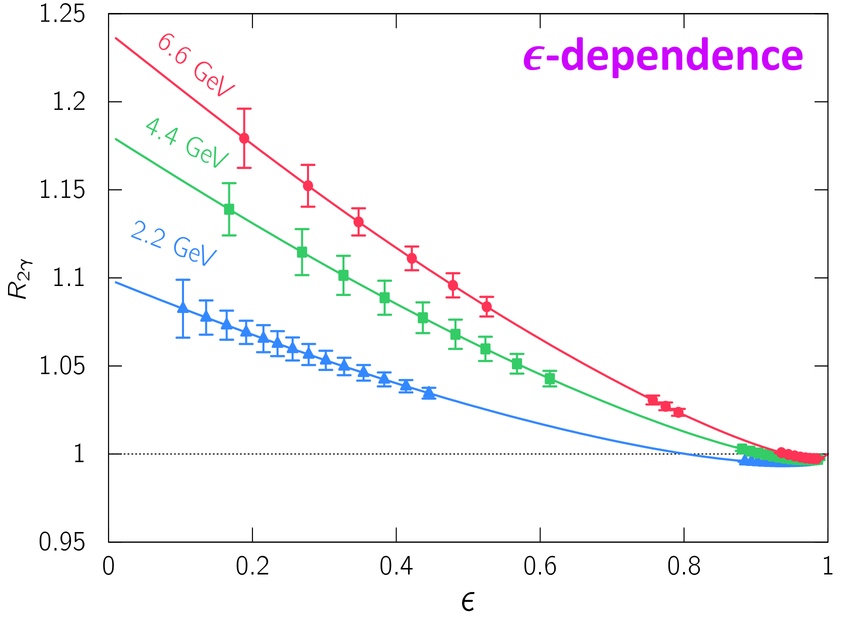
A. Schmidt, J. C. Bernauer, V. Burkert, E. Cline, I. Korover, T. Kutz, S. N. Santiesteban et al.

J.C. Bernauer et al. EPJ A 57 (2021) 144

- Over a run of **55 days**, alternating e^- and e^+ at 2.2-4.4-6.6 GeV and an intensity of 50 nA, the TPE@CLAS12 experiment proposes to map-out TPE effects.
- The CLAS12 trigger will be modified to allow lepton detection in the Central Detector while protons will be detected in the Forward Detector.







And Beyond...

- The perspective of **positron beams** at JLab **nourishes further reflexions** about the importance of **multi-photon effects** in other reaction mechanisms.

T. Kutz, A. Schmidt EPJ A 58 (2022) 36
A. Afanasev at the Positron Working Group Workshop, Charlottesville (2023)
D. Gaskell et al. JLab Proposal PR12+23-003
P. Gueye et al. JLab Letter-of-Intent LOI12+23-015

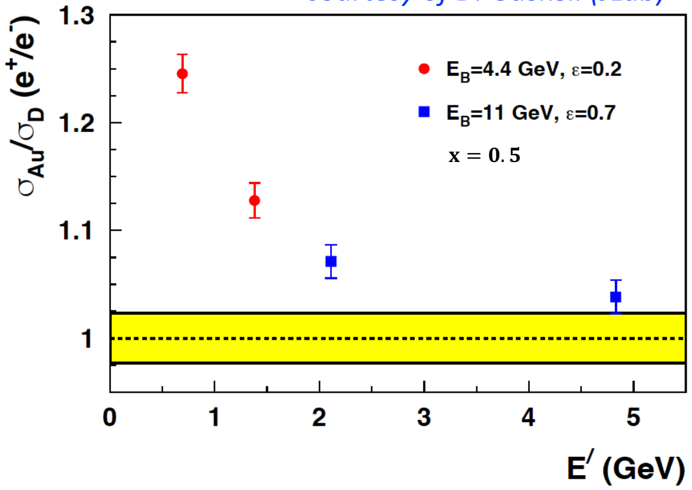
TPE and multi-photon effects in $e^{\pm}N$ interactions

- TPE in elastic scattering off nuclei
- Dispersive effects in A(e,e') inclusive scattering
- ...

TPE effects in Deep Inelastic Scattering (DIS)

- Magnitude of TPE effects in DIS experiments ?
- Magnitude of TPE and photon radiation by the hadrons in SIDIS ?
- Description of Coulomb corrections in the DIS regime
- ...

Courtesy of D. Gaskell (JLab)



*This **list** is not exhaustive but only **indicative** of the **current reflexions**.*

Virtual Compton Scattering

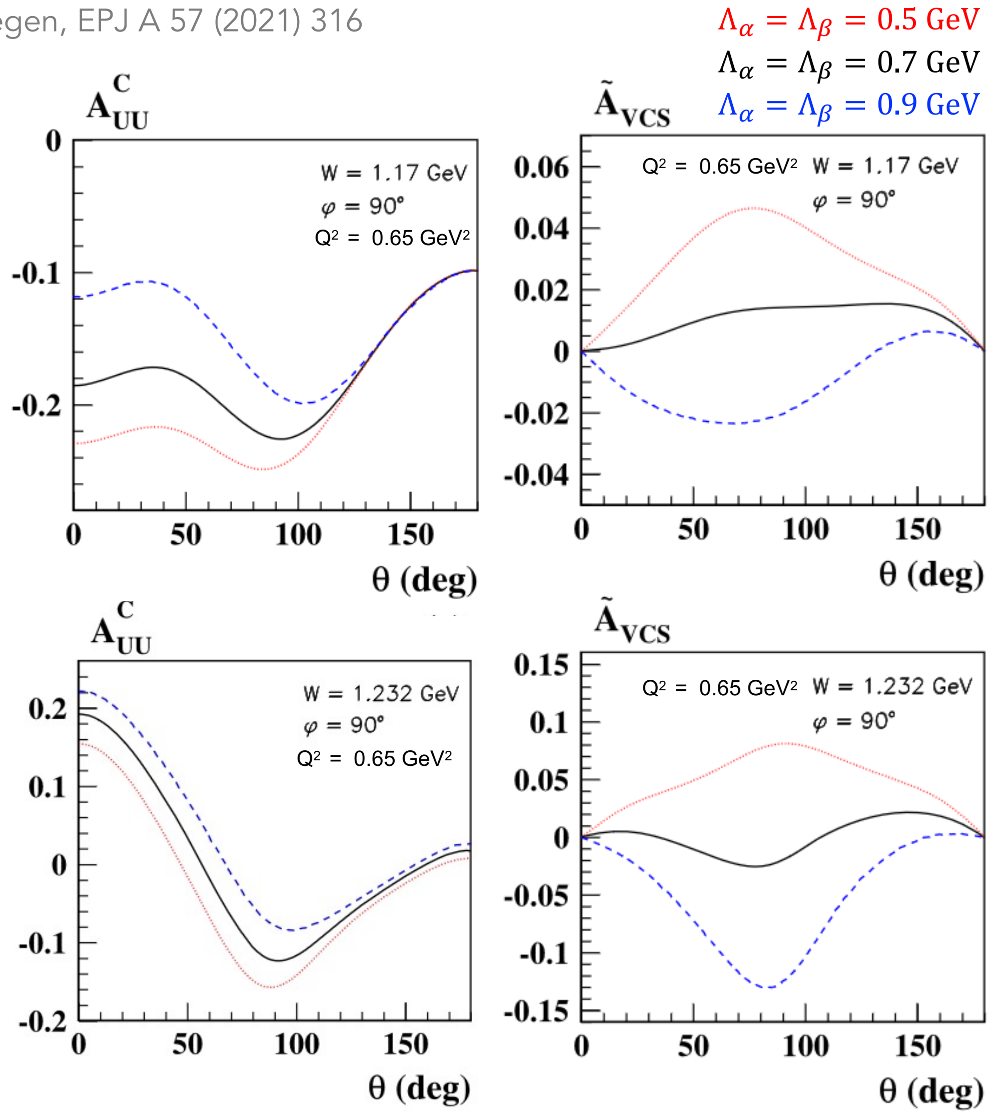
B. Pasquini, M. Vanderhaegen, EPJ A 57 (2021) 316

- The **comparison** of unpolarized/polarized electrons and positrons provides an **independent path** to access **Generalized Polarizabilities** (GPs).

$$d\sigma_P^e = d\sigma_{BH} + d\sigma_{VCS} + P d\tilde{\sigma}_{VCS} + e\,[d\sigma_{INT} + P d\tilde{\sigma}_{INT}]$$

$$A_{UU}^C = \frac{d\sigma_{INT}}{d\sigma_{BH} + d\sigma_{VCS}} \qquad \tilde{A}_{VCS} = \frac{2\, d\tilde{\sigma}_{VCS}}{d\sigma_{BH} + d\sigma_{VCS}}$$

- These new observables show **sizeable sensitivity** to GPs.
- $\tilde{A}_{VCS}$ is particularly sensitive to the **electric dipole** GP.



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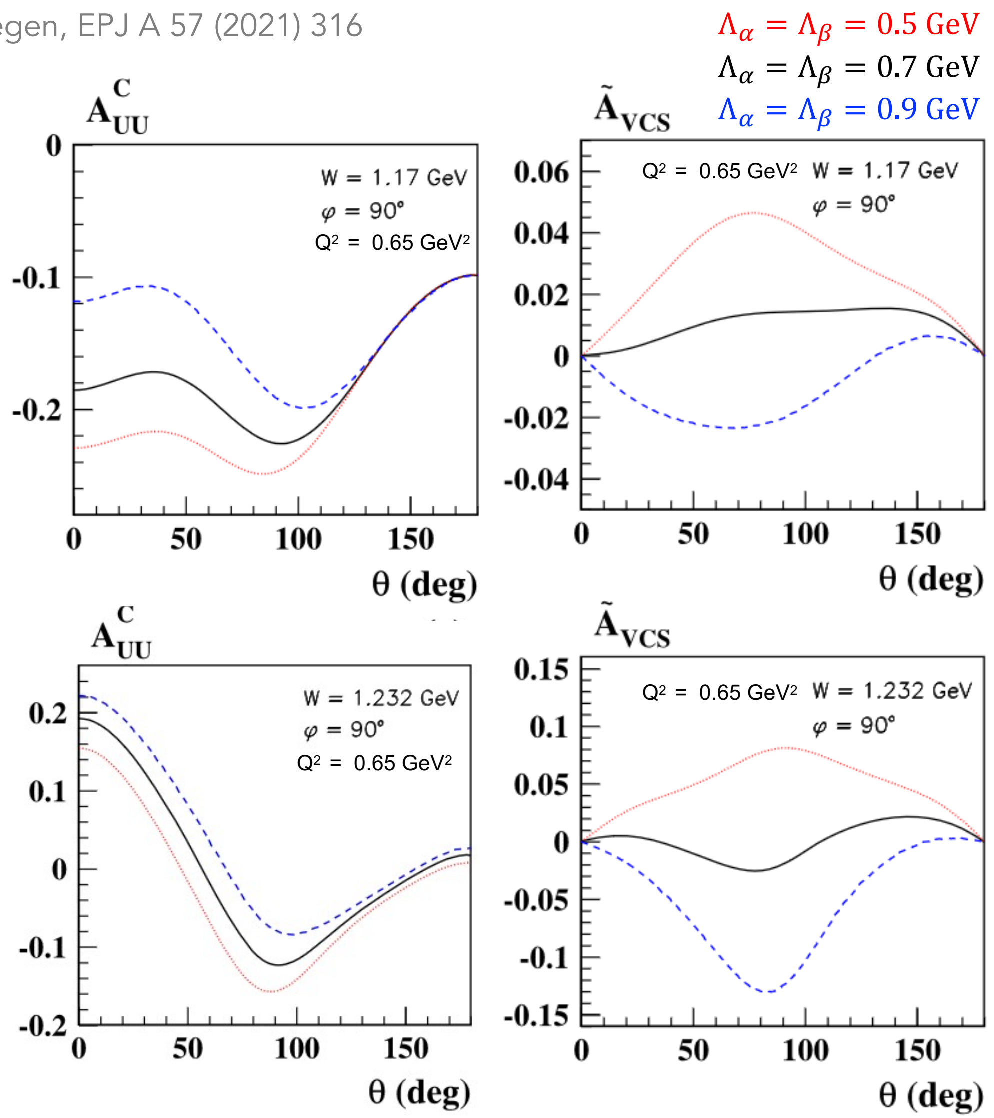
B. Pasquini, M. Vanderhaegen, EPJ A 57 (2021) 316



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- These new observables show **sizeable sensitivity** to GPs.
- $\tilde{A}_{VCS}$ is particularly sensitive to the **electric dipole** GP.

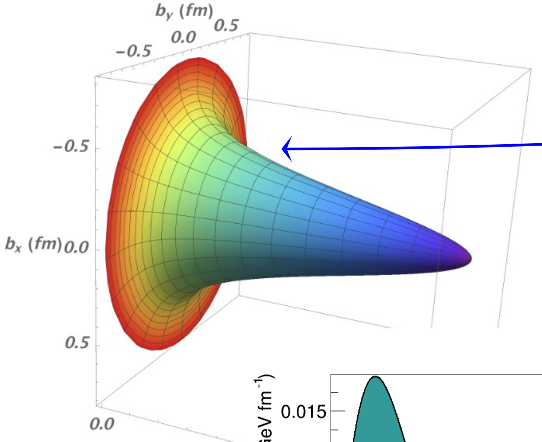
An experimental scenario is under study.

LOI12+23-001 N. Sparveris et al.

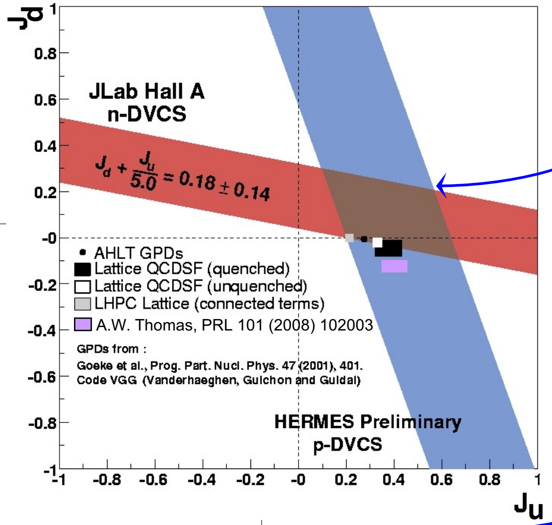
Generalized Parton Distributions

X. Ji, PRL 78 (1997) 610 M. Polyakov, PLB 555 (2003) 57
M.V. Polyakov, P. Schweitzer, IJMP A 33 (2018) 1830025

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

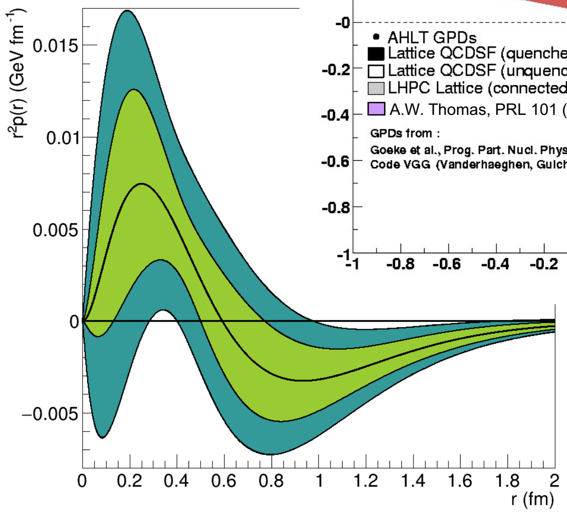


$$\rho_H^q(x,\boldsymbol{b}_\perp) = \int \frac{d^2\boldsymbol{\Delta}_\perp}{(2\pi)^2}\, e^{i\boldsymbol{b}_\perp\cdot\boldsymbol{\Delta}_\perp}\,[H^q(x,0,-\Delta_\perp^2) + H^q(-x,0,-\Delta_\perp^2)]$$



$$\lim_{t\to 0}\int_{-1}^{1} x\,[H^q(x,\xi,t) + E^q(x,\xi,t)]\,dx = J^q$$

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



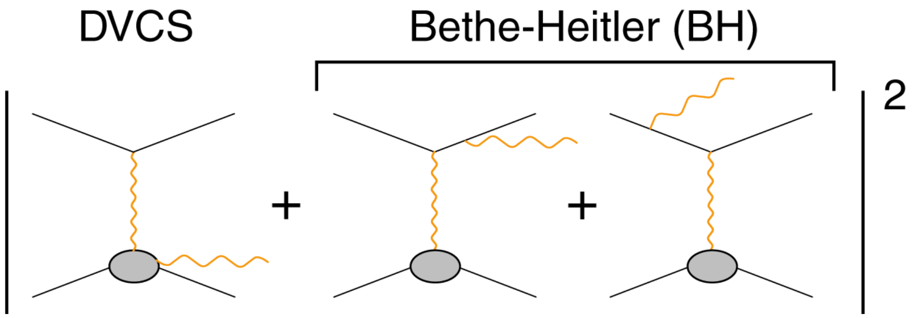
- **Unpolarized e$^+$ combined with unpolarized e$^-$** access the **real part** of the Compton Form Factors.
- **Polarized e$^+$ combined with polarized e$^-$** access the **imaginary part** of the Compton Form Factors (CFFs) and probe **higher twist effects**.

M. Mazouz et. al. PRL 9 (2007) 242501
A. Airapetian et al. JHEP 06 (2008) 066 R. Dupré, M. Guidal, M. Vanderhaeghen, PRD 95 (2017) 011501 V. Burkert, L. Elouadrhiri, F.-X. Girod, Nat. 557 (2018) 396

Deeply Virtual Compton Scattering

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

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



CFF = Compton Form Factors

$\propto$ to the **real part** of a **CFF linear combination**

$\propto$ to the **imaginary part** of a **CFF linear combination**

$$d^5\sigma^e_{P0} = d^5\sigma_{BH} + d^5\sigma_{DVCS} + P\, d^5\tilde{\sigma}_{DVCS} - e\,[d^5\sigma_{INT} + P\, d^5\tilde{\sigma}_{INT}]$$

$\propto$ to the **real part** of a **CFF bilinear combination**

$\propto$ to the **imaginary part** of a **CFF bilinear combination**

$$d^5\sigma^e_{PS} = d^5\sigma^e_{P0} + S\,[P\, d^5\Delta\sigma_{BH} + (P d^5\Delta\sigma_{DVCS} + d^5\,\Delta\tilde{\sigma}_{DVCS}) - e(P d^5\Delta\sigma_{INT} + d^5\Delta\tilde{\sigma}_{INT})\,]$$

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

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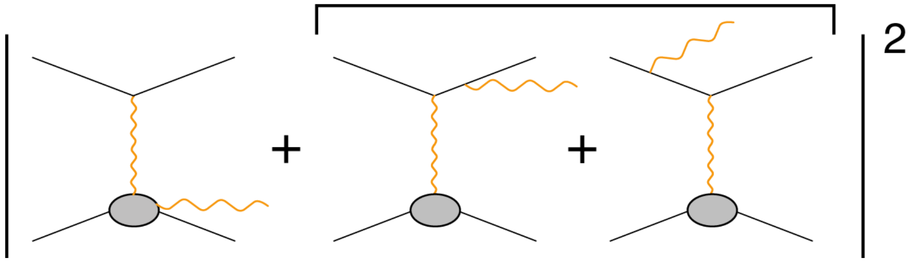
Deeply Virtual Compton Scattering

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

DVCS | Bethe-Heitler (BH)

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



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$\propto$ to the **imaginary part** of a **CFF bilinear combination**

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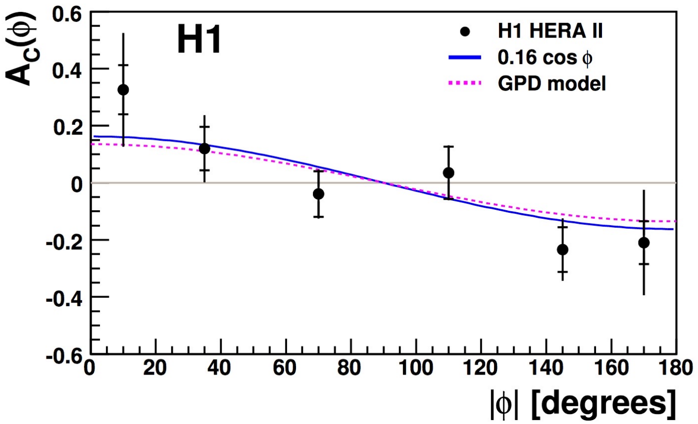
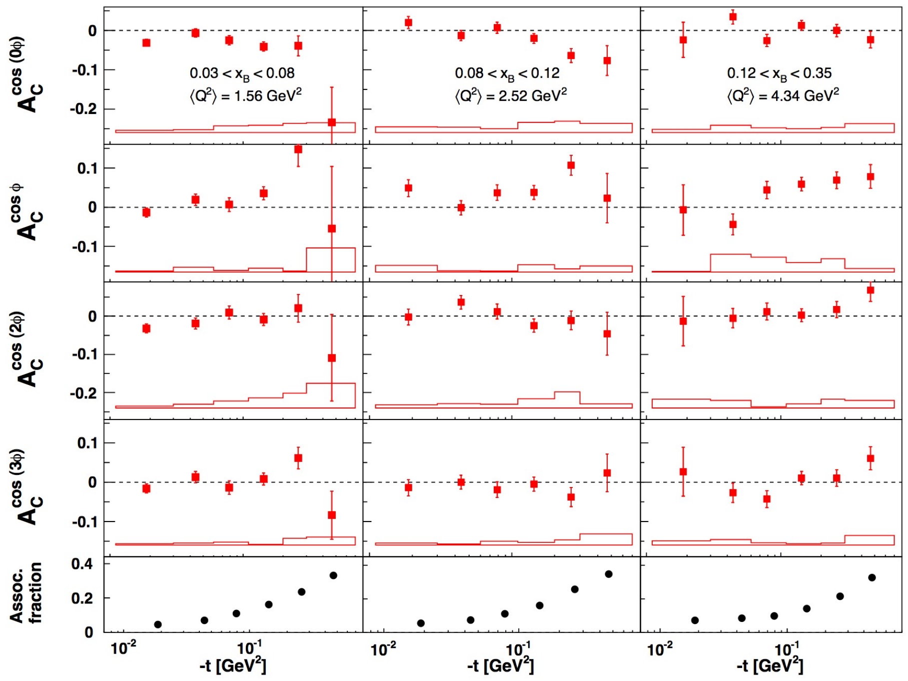
Polarized electrons and positrons allow to **separate** the unknown amplitudes of the cross section for electro-production of photons.

Current Knowledge

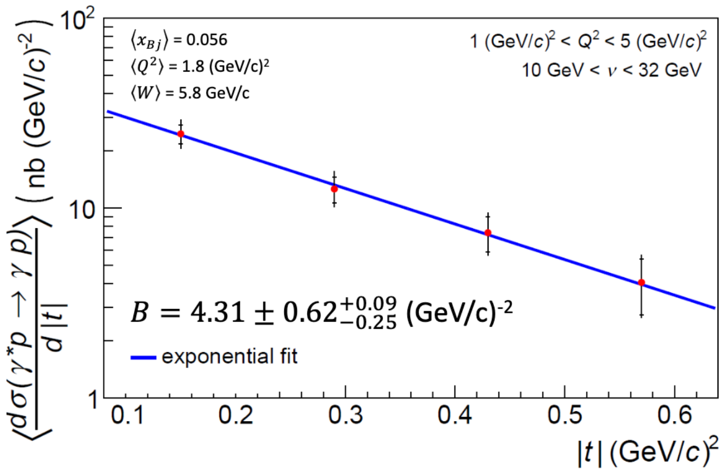
- Pioneering comparisons of DVCS with **electron** and **positron** beams at **HERA** and **HERMES demonstrated** the existence of a **BCA-signal**.

- Because of the $\overleftrightarrow{\mu}^{\pm}$ beam nature, the **COMPASS** experiment cannot combine beam charge and polarization independently.





$$\Sigma\sigma_{\mp P}^{\pm} = 2(d^5\sigma_{BH} + d^5\sigma_{DVCS} - Pd^5\tilde{\sigma}_{INT})$$



(H1 Collaboration) F.D. Aaron et al. PLB 681 (2009) 391 (HERMES Collaboration) A. Airapetian et al. JHEP 06 (2008) 066 – 11 (2009) 083 – 07 (2012) 032
(COMPASS Collaboration) R. Akhunzyanov et al. PLB 793 (2019) 188

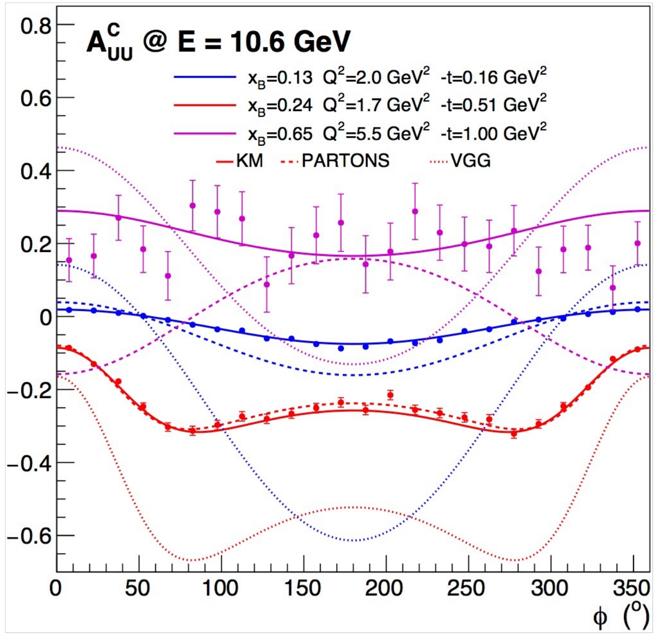
PR12+23-002

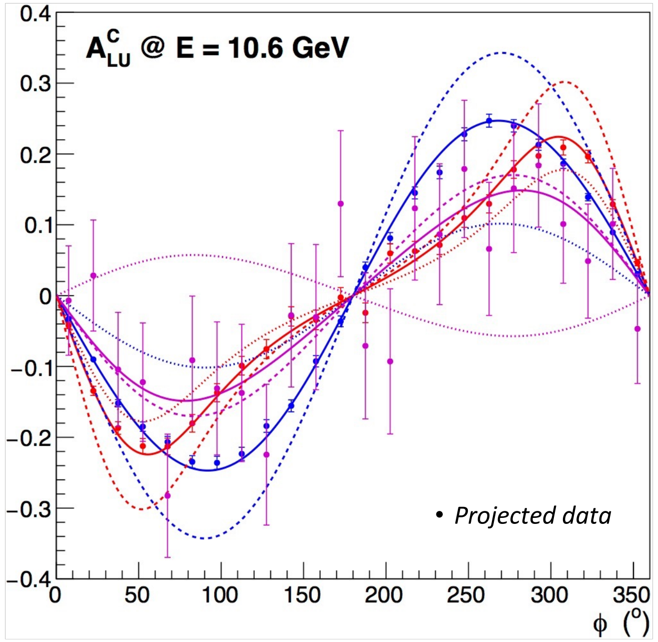
E. Voutier, V. Burkert, S. Niccolai, R. Paremuzyan et al.

V. Burkert et al. EPJ A 57 (2021) 186

- Measurements of beam charge asymmetries with CLAS12 will provide a full set of new GPD observables:
  - the **unpolarized beam charge asymmetry** A^C_{UU}, sensitive to the **CFF real part**;
  - the **polarized beam charge asymmetry** A^C_{LU}, sensitive to the **CFF imaginary part**;
  - the **charge averaged beam spin asymmetry** A^0_{LU}, signature of **higher twist effects**.

$$A^C_{UU} = \frac{d^5\sigma_{INT}}{d^5\sigma_{BH} + d^5\sigma_{DVCS}}$$





$$A^C_{LU} = \frac{d^5\tilde{\sigma}_{INT}}{d^5\sigma_{BH} + d^5\,\sigma_{DVCS}}$$

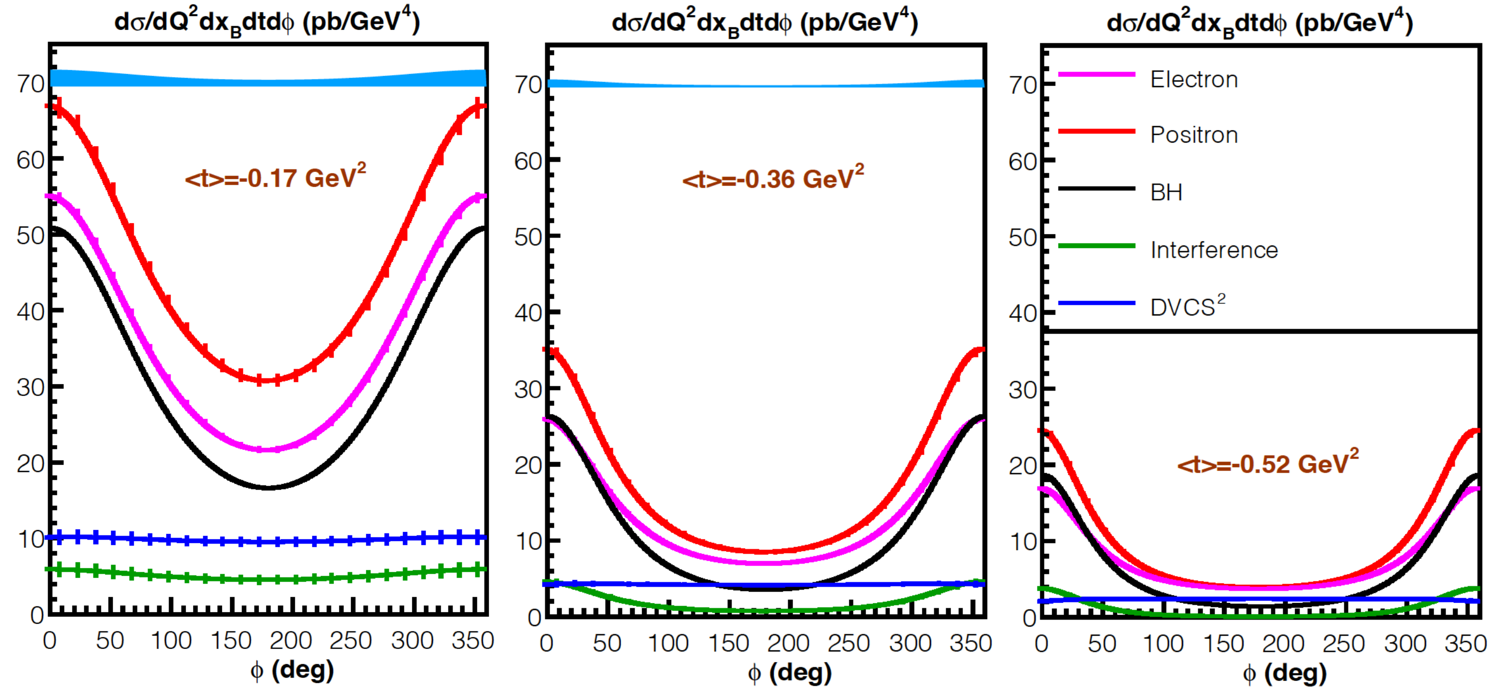
PR12+23-006

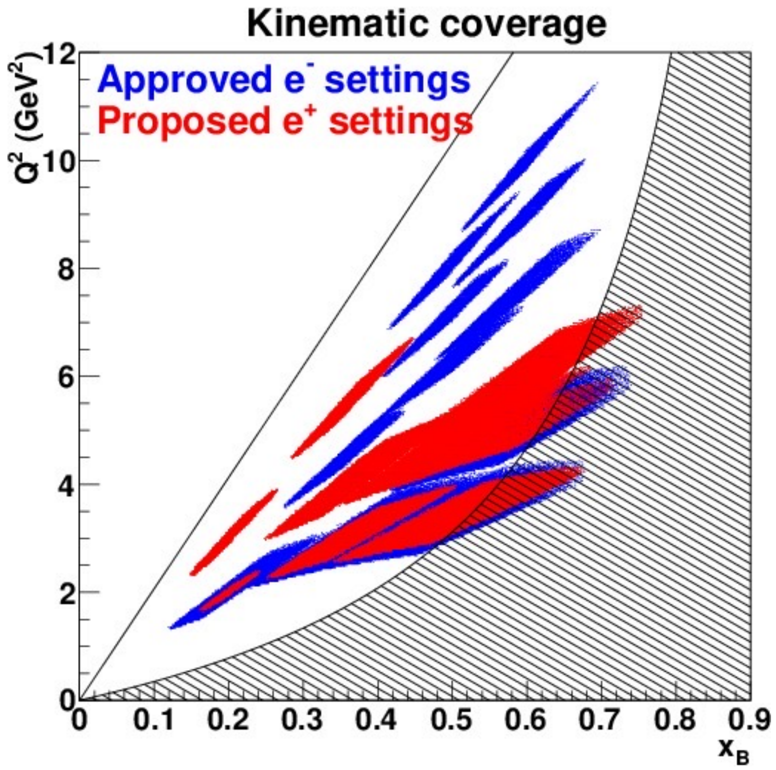
C. Muñoz Camacho, M. Mazouz et al.

A. Afanasev et al. EPJ A 57 (2021) 300

- Combining the HMS and the NPS spectrometers, precise cross section measurements with unpolarized positron beam are proposed at selected kinematics where electron beam data will soon be accumulated.

$x_B = 0.36 \quad Q^2 = 4.0\ GeV^2$

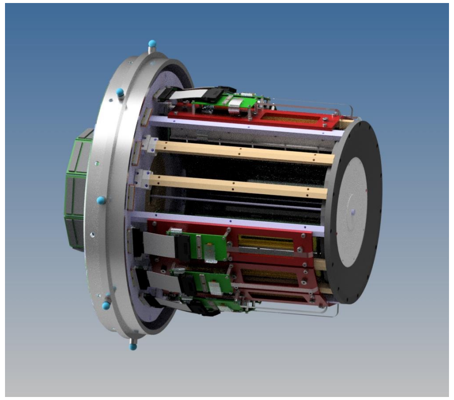




And Beyond…

S. Niccolai, P. Chatagnon, M. Hoballah, D. Marchand, C. Muñoz Camacho, E. Voutier, EPJ A 57 (2021) 226
S. Fucini, M. Hattawy, M. Rinaldi, S. Scopetta, EPJ A 57 (2021) 273
S. Zhao et al. EPJ A 57 (2021) 240

ALERT

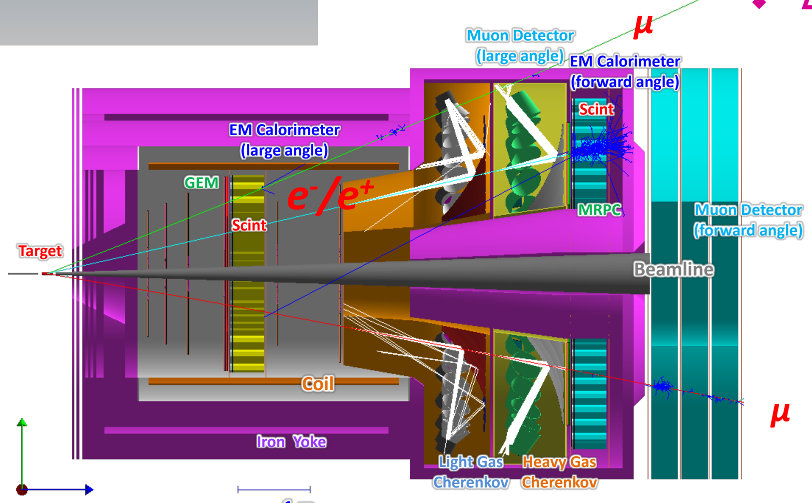


❖ Generalized parton distributions

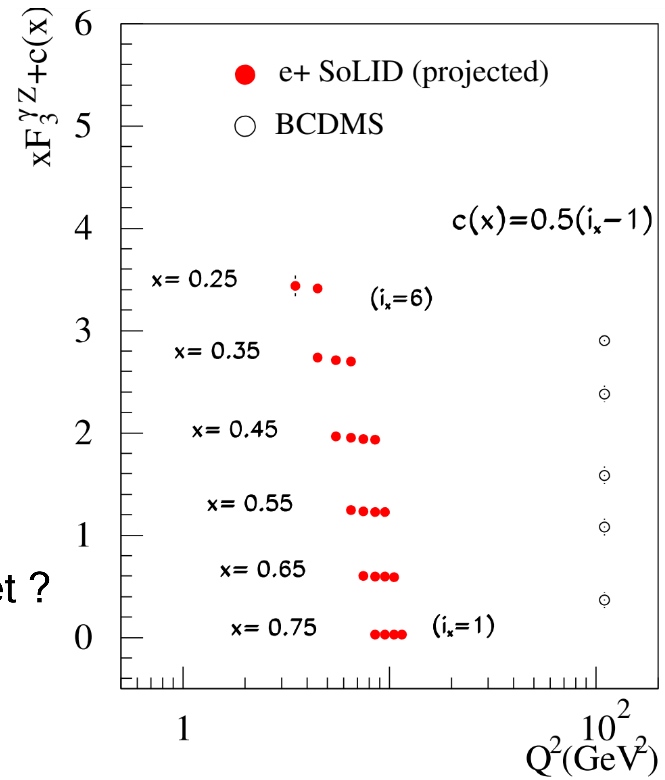
- DVCS off the neutron
- Coherent DVCS off the nucleus
- Incoherent DVCS off the nucleus
- Double DVCS off the proton
- DVCS off polarized targets ?
- ...

❖ Electroweak physics

- Axial form factor of the proton
- DIS on a longitudinally polarized target ?
- Strangeness content of the nucleon ?
- Electroweak structure function $F_3^{\gamma Z}$
- ...



SoLID$^{\mu}$



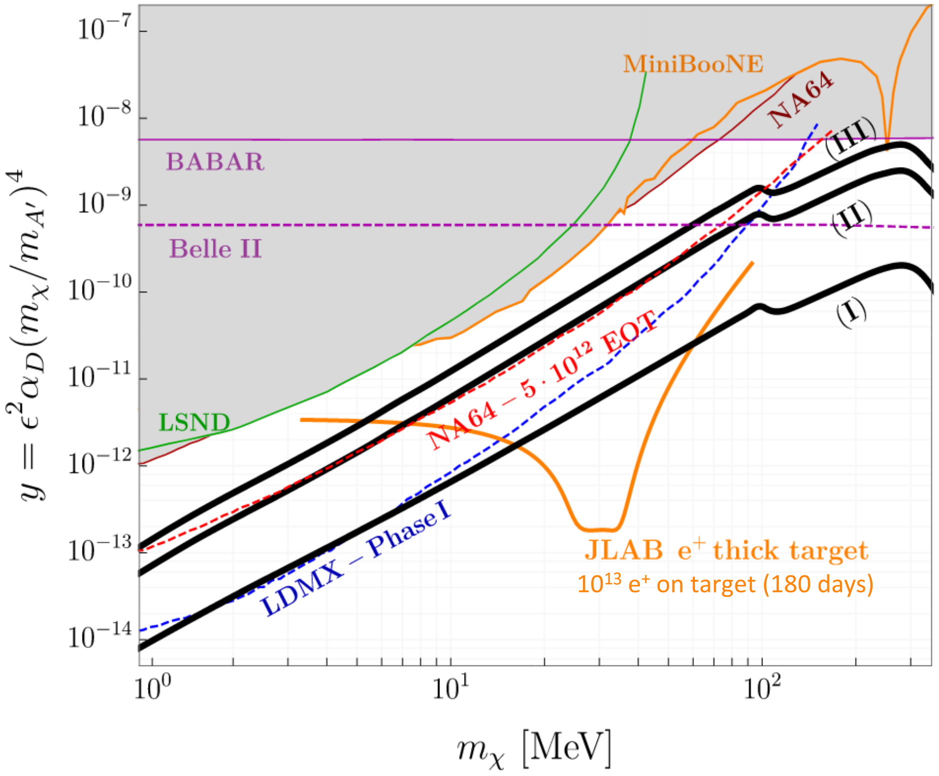
E. Aschenauer, T. Burton, T. Martin, H. Spiesberger, M. Stratman, PRD 88 (2013) 114025
W. Melnitchouk, J.F. Owens EPJ A 57 (2021) 311 X. Zheng et al. Jefferson Lab Proposal PR12-21-006 (2021)
D. Dutta et al. JLab Letter-of-Intent LOI12+23-002

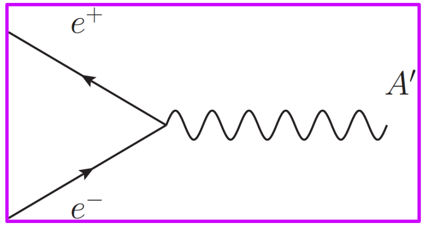
*This **list** is not exhaustive but only **indicative** of the **current reflexions**.*

Direct Dark Matter Production

M. Battaglieri et al. EPJ A 57 (2021) 253

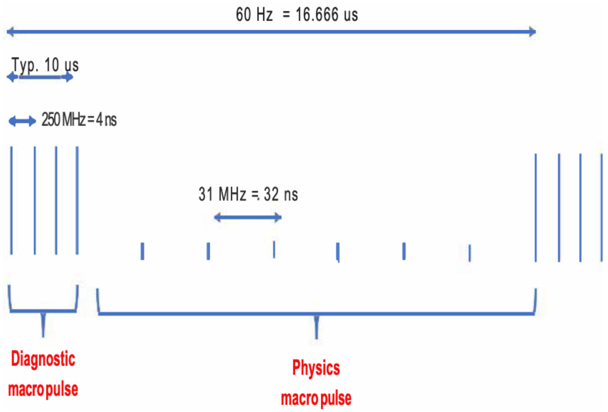
- A direct search of dark matter in the e^+e^- **annihilation** has been evaluted using a beam energy of **11 GeV** and a **180 days** data taking period.
- The measurement of an **energy deposit smaller** than the **e⁺ beam energy** signs the **production** of the *A'*.



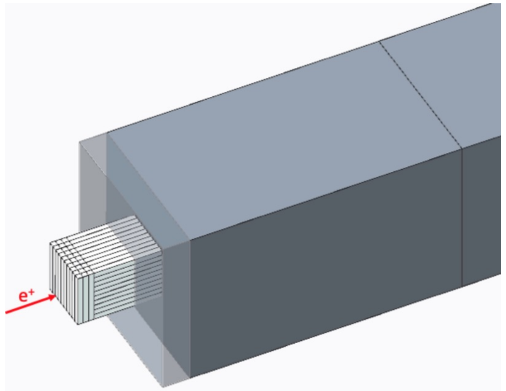


$$E_{miss} = E_{beam} - E_{CAL}$$

$$m_{A'} = \sqrt{2m_e E_{miss}}$$

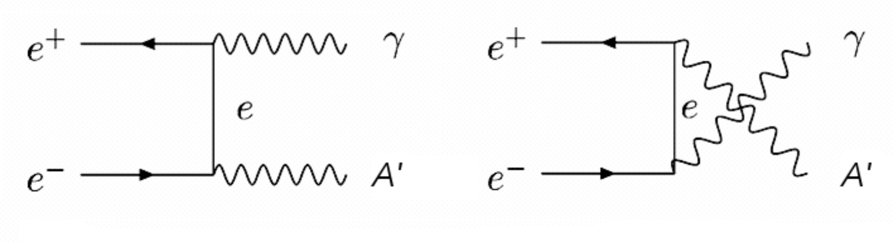


A specific time structure of the beam is required to avoid e⁺ beam pile-up in the detector.



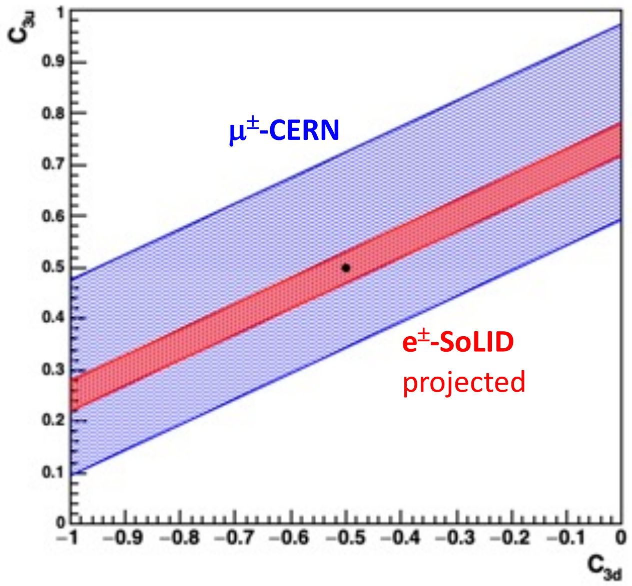
*An **active thick target** completed with an **hadronic calorimeter** constitute the experimental set-up.*

And Beyond…

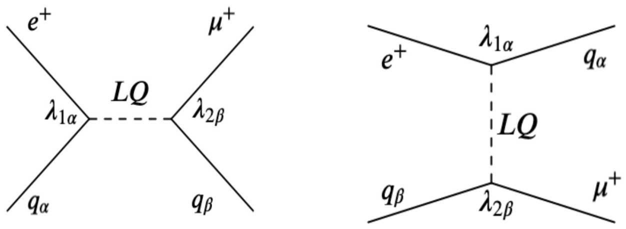


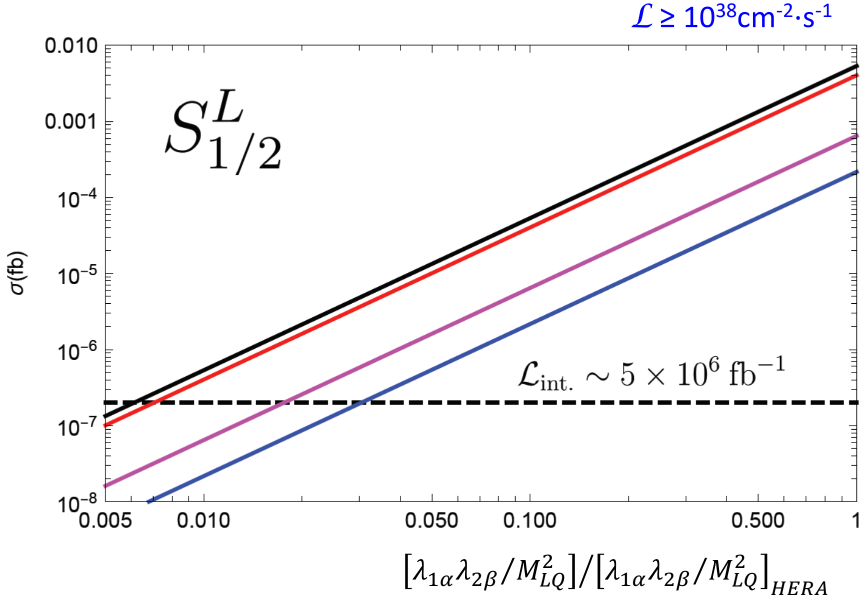
- *Testing standard model predictions*
  - Dark matter search
  - Axial-axial neutral current coupling
  - Charged lepton flavor violation ?
  - …

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



$$e^\pm + N \longrightarrow \mu^\pm + X$$





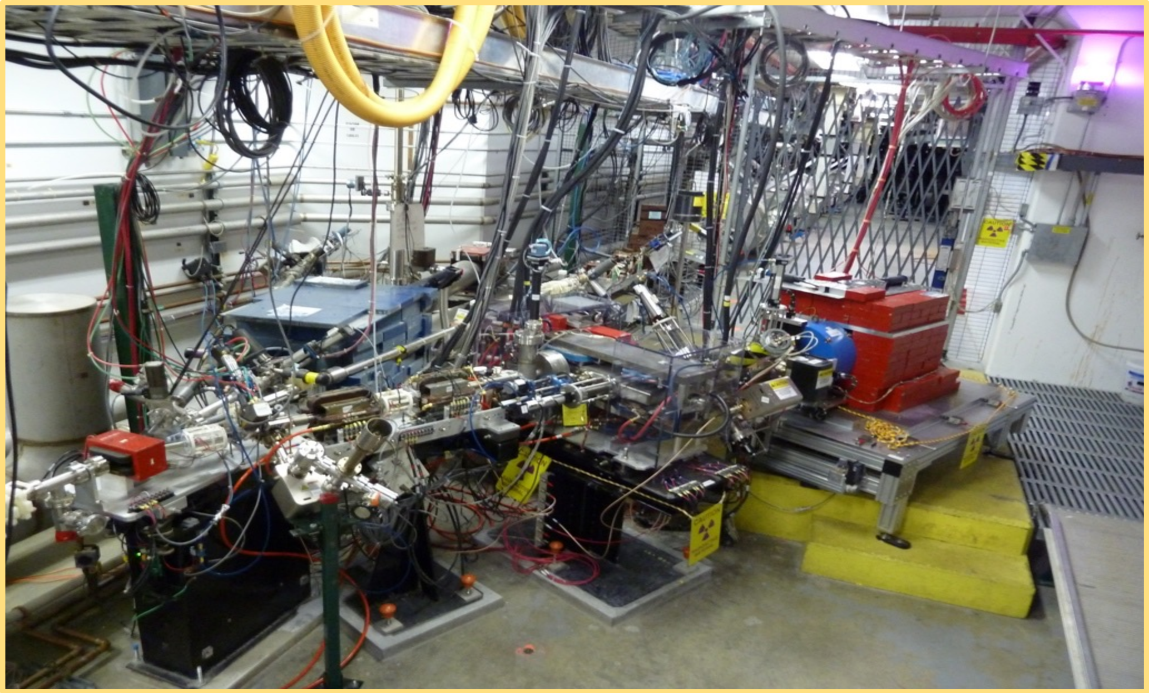
X. Zheng, J. Erler, Q. Liu, H. Spiesberger, EPJ A 57 (2021) 173 Y. Furletova, S. Mantry, EPJ A 57 (2021) 315
B. Wojtsekhowski et al. Jefferson Lab Proposal PR12+23-005 D. Mack Jefferson Letter-of-Intent PR12+23-005

*This **list** is not exhaustive but only **indicative** of the **current reflexions**.*

PEPPo

(PEPPo Collaboration) D. Abbott *et al.* PRL 116 (2016) 214801

- The JLab positron source builds on the PEPPo (Polarized Electrons for Polarized Positrons) experiment which demonstrated the feasibility of using bremsstrahlung radiation of **MeV Polarized Electrons** for producing **Polarized Positrons**.



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

p_e = 8.2 MeV/c I_e = 1 μA t_W = 1 mm $\mathcal{P}$ < 10 W

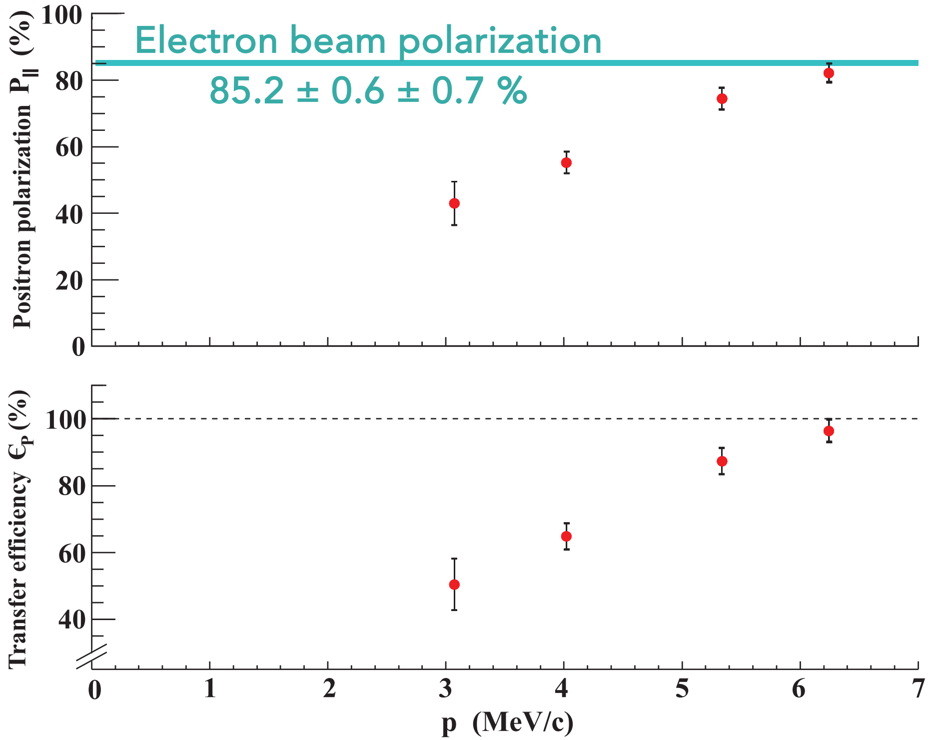
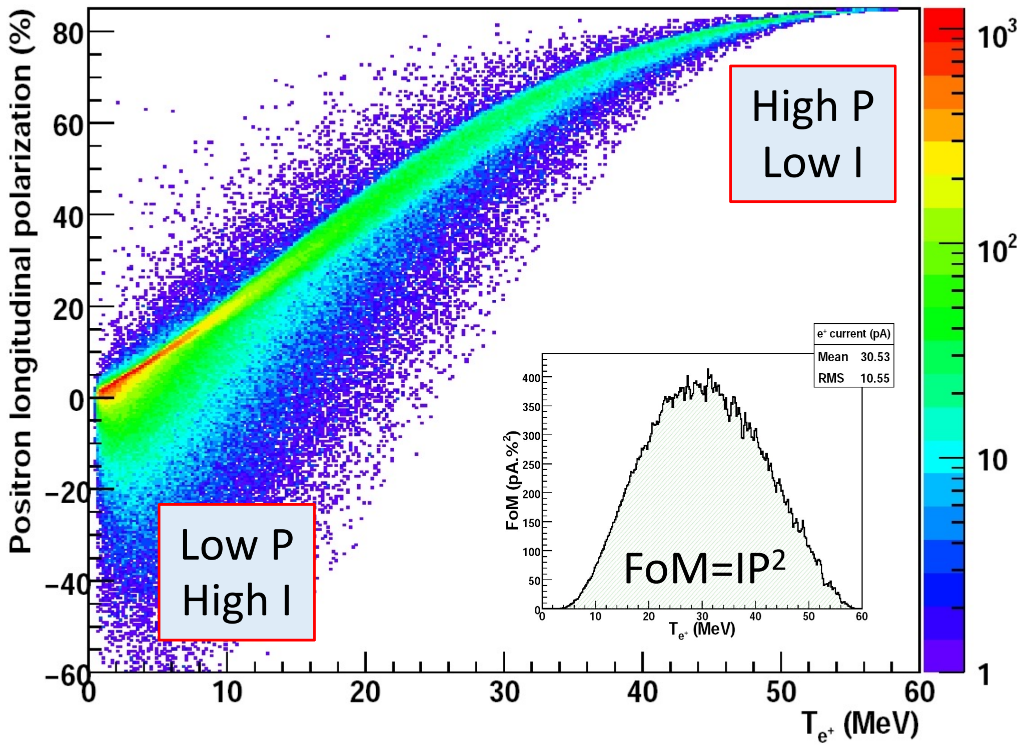


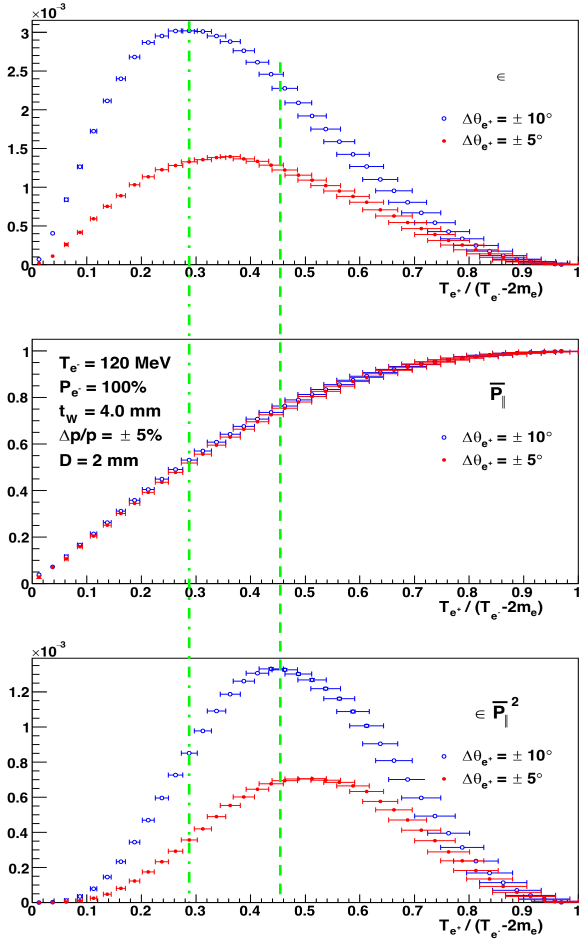
Figure-of-Merit

- The positron **yield** (e^+/e^-) scales with the beam power (**Beam Energy × Beam Intensity**) and depends on the thickness of the production target.
- It is **sensitive** to the **collection system** characteristics which can be mimic by an **angular** and a **momentum acceptance**.



- Selection of e^+ momentum allows to operate the source from low to highly polarized modes.

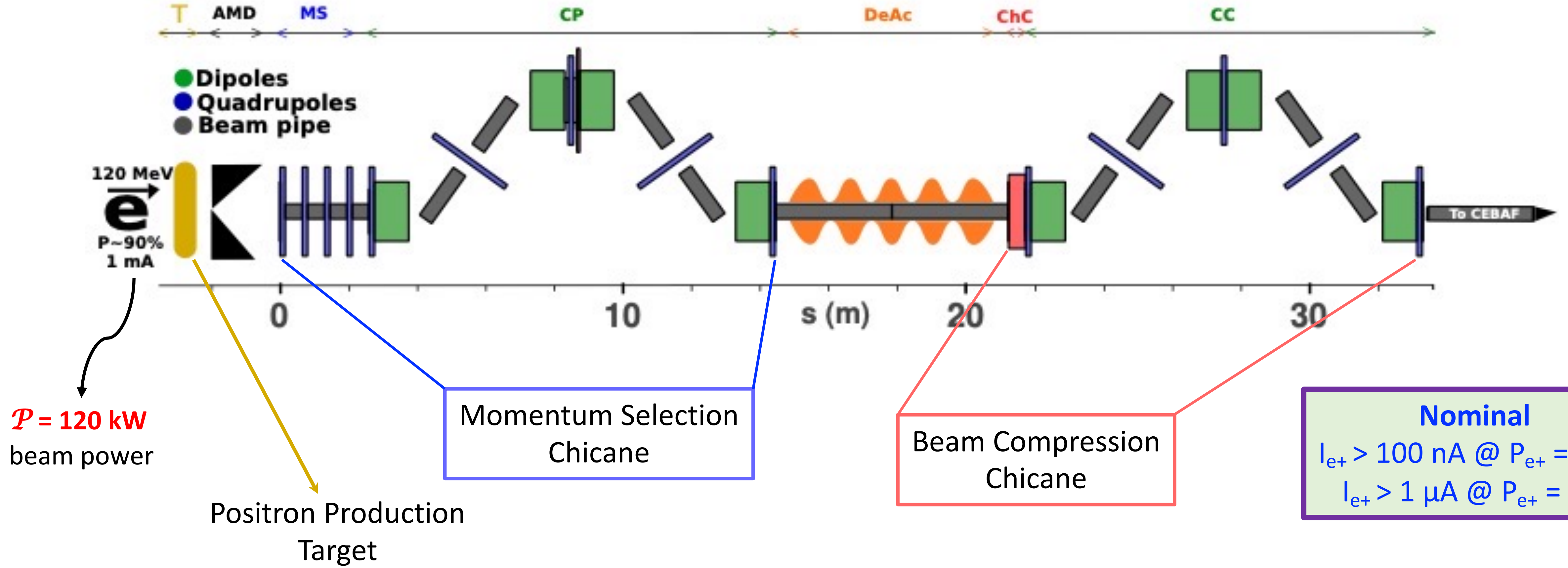
(Jefferson Lab Positron Working Group)
A. Accardi *et al.* EPJ A 57 (2021) 261



Positron Injector

S. Habet, Y. Roblin et al. JACoW IPAC (2022) 457 S. Habet, Doctorate, Université Paris-Saclay, 12/2023

- The design of the JLab positron source evolved towards the today's latest concept :



Nominal

$I_{e+} > 100$ nA @ $P_{e+} = 60\%$

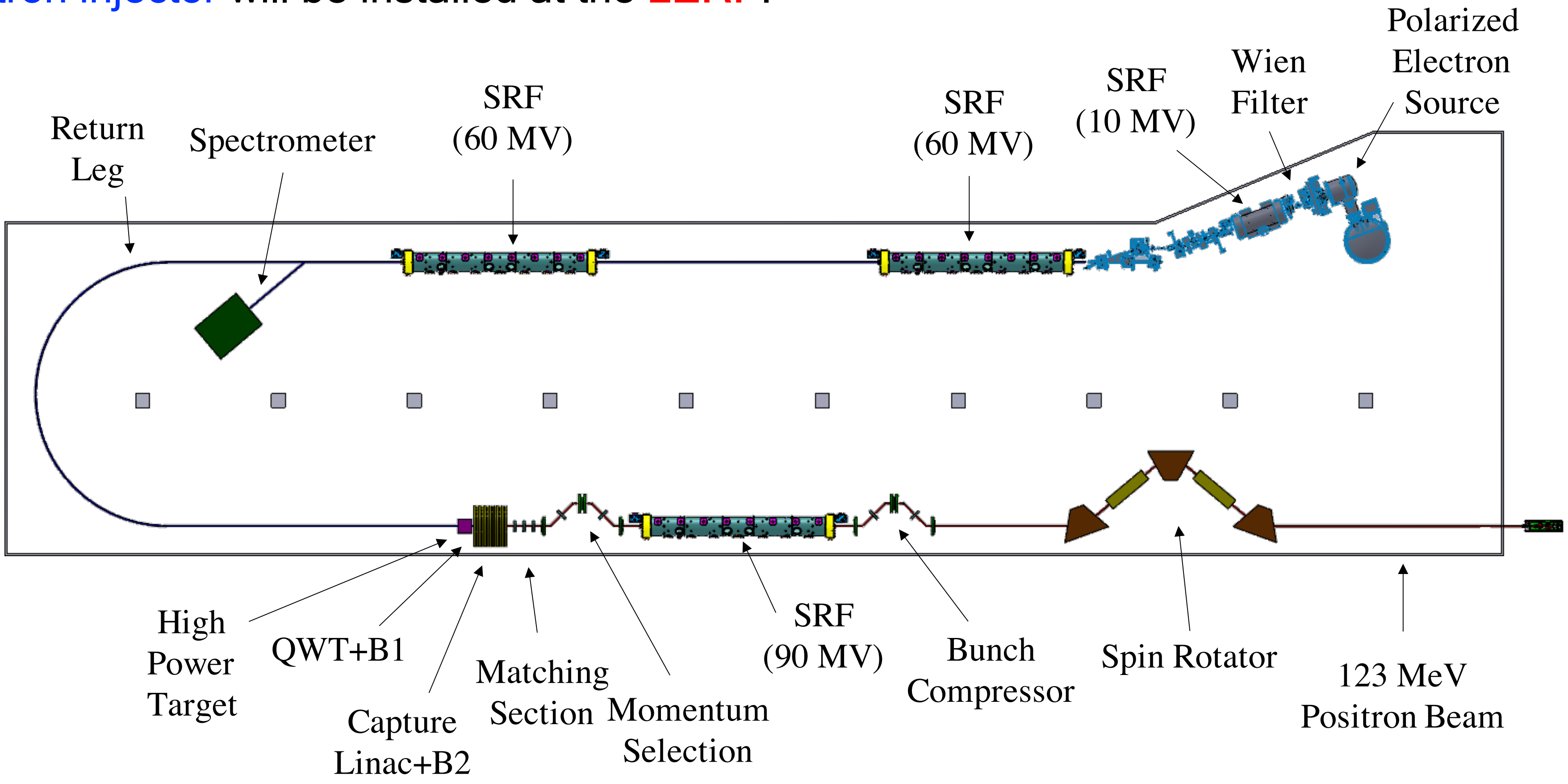
$I_{e+} > 1$ μA @ $P_{e+} = 0\%$

***High duty cycle, intensity**, and **polarization** distinguish JLab positron beam from any past or existing others.*

e+@LERF

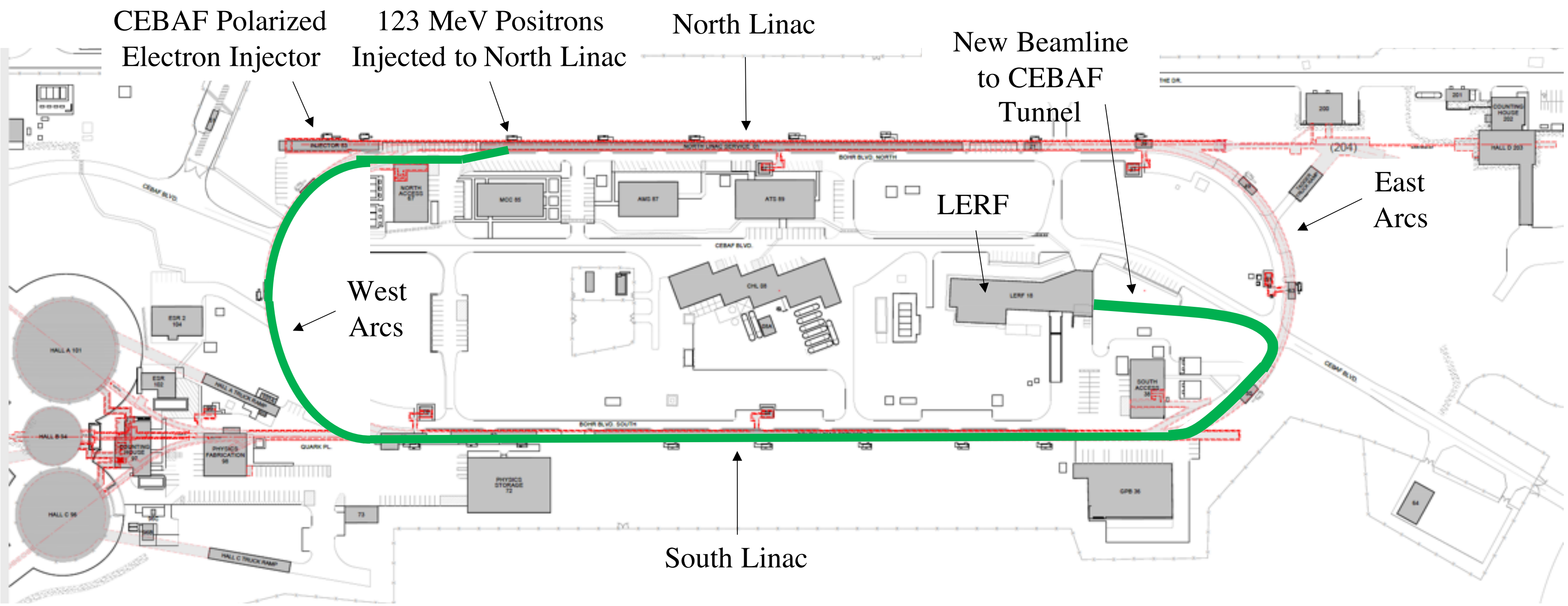
(Ce+BAF Working Group) J. Grames *et al.* JACoW IPAC2023 (2023) MOPL152; arXiv2309.15581

- Taking advantage of the existing infrastructure (electric and cryogenic power supplies, shielding…), the new positron injector will be installed at the LERF.



e+@CEBAF (Ce+BAF Working Group) J. Grames *et al.* JACoW IPAC2023 (2023) MOPL152; arXiv2309.15581

- A new beam transport line attached to the ceiling of the existing tunnel will guide the 123 MeV e+ beam till the injection point at the entrance of the North LinAc.



D. Turner and Y. Roblin (JLab)

Ce+BAF Working Group

J. Benesch, A. Bogacz, L. Cardman, J. Conway, S. Covrig, J. Grames, J. Gubeli, C. Gulliford, S. Habet, C. Hernandez-Garcia, D. Higinbotham, A. Hofler, R. Kazimi, V. Kostroun, F. Lin, V. Lizarraga-Rubio, M. Poelker, Y. Roblin, A. Seryi, K. Smolenski, M. Spata, R. Suleiman, A. Sy, D. Turner, A. Ushakov, C. Valerio, E. Voutier, S. Zhang, Y. Zhang

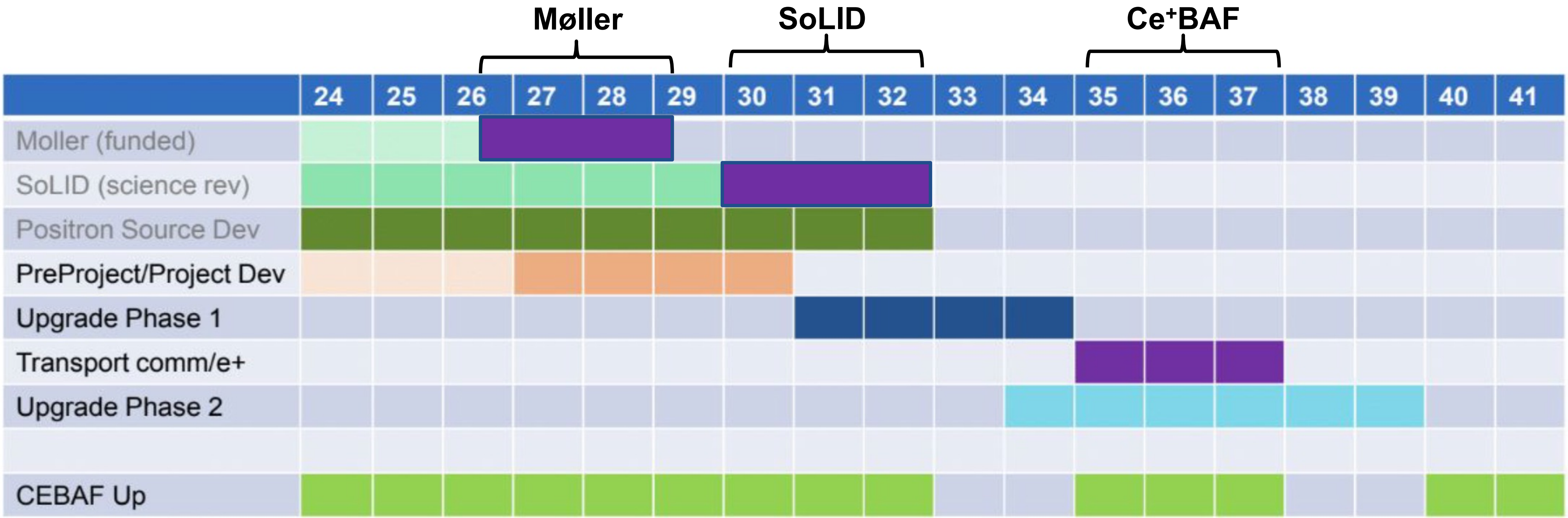
(Ce+BAF Working Group) J. Grames *et al.* JACoW IPAC2023 (2023) MOPL152

S. Habet *et al.* JACoW IPAC2022 (2022) 457 R. Kazimi *et al.* JACoW IPAC2023 (2023) WEPA035 A. Sy *et al.* JACoW IPAC2023 (2023) MOPM081
A. Ushakov *et al.* JACoW IPAC2023 (2023) WEPM120

Jefferson Lab · IJCLab Irène Joliot-Curie · Oak Ridge National Laboratory · Universidad Autónoma de Sinaloa · XELERA

Timeline

D. Dean at the International Workshop on CLAS12 Physics and Future Perspectives at JLab, Paris, March 21-24, 2023



- Phase 1 includes building a positron source and the tunnel & beamline connecting to CEBAF
- Phase 2 includes new permanent magnets to allow 22 GeV within current CEBAF footprint

Summary

- A **rich** and **high impact** experimental program asking for **intense CW polarized and unpolarized positron beams** at JLab has been elaborated, allowing us to measure **new observables** and to explore **new reaction channels**.

These beams will be a world « première ».

- A strong accelerator R&D **effort** is progressing towards the final design and implementation of polarized and unpolarized positron beams at Jefferson Lab.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement N° 824093.

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Experimental capabilities will concern
not only the **high energy Ce^{+}BAF** beam
but also **low energy** electron and positron beams to be available at **LERF**.

Subscribe *to the JLab Positron Working Group mailing list* ***pwg@jlab.org***

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LERF
$I_{e-} > 1$ mA @ $P_{e-} > 90\%$
$I_{e+} > 50$ nA @ $P_{e+} = 60\%$
$I_{e+} > 1$ µA @ $P_{e+} = 0\%$
$T_{e\pm} \leq 120$ MeV

Ce^{+}BAF
$I_{e+} > 50$ nA @ $P_{e+} = 60\%$
$I_{e+} > 1$ µA @ $P_{e+} = 0\%$
$T_{e^+} \leq 12$ GeV

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