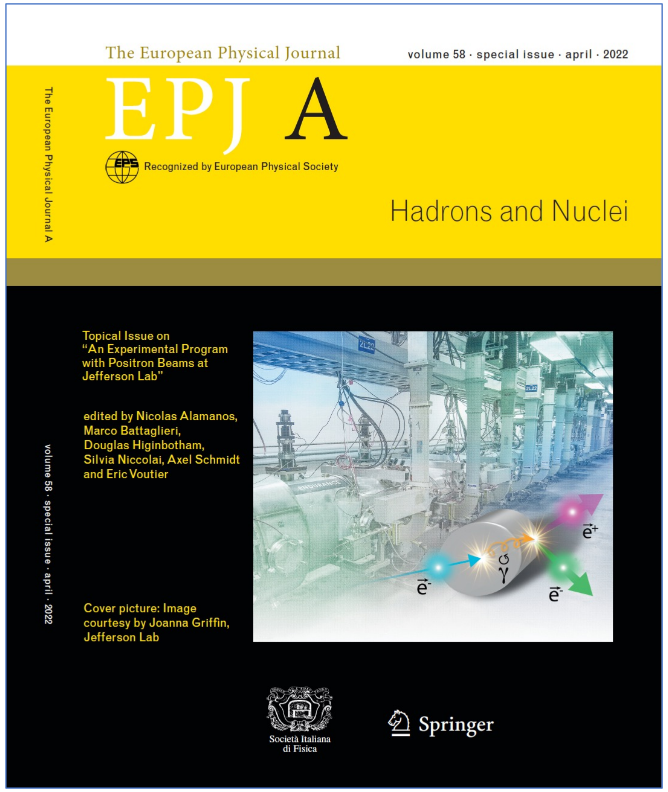
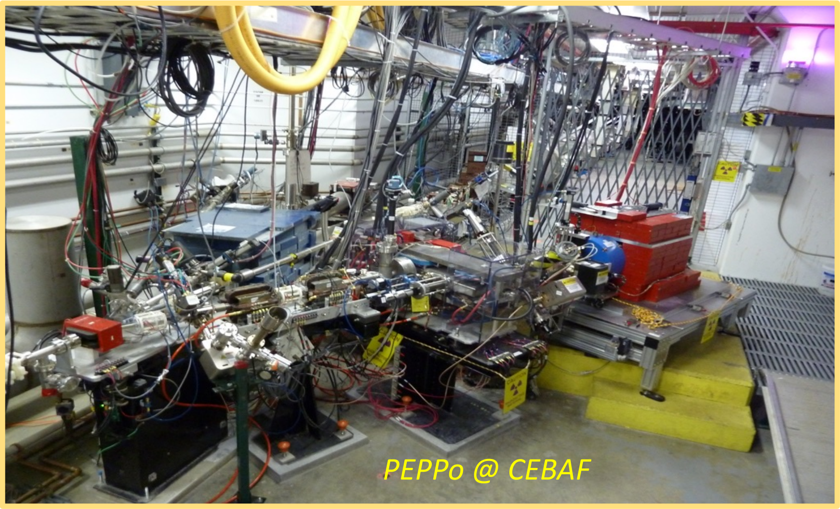
JLab Positron Beam Upgrade

Ce⁺BAF

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

Université Paris-Saclay, CNRS/IN2P3/IJCLab, Orsay, France





(i) Positron Working Group
(ii) Two photon exchange
(iii) Nuclear structure
(iv) Test of 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.

PAC51 Proposals

- 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

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PAC51 Letters-of-Intent

- p-GPs – LOI12+23-001
  Measurement of the generalized polarizabilities of the proton with positron and polarized electron beams
  N. Sparveris
- Axial form factor – LOI12+23-002
  The axial form factor of the nucleon from weak capture of positrons
  D. Dutta
- Dark Bhabha – LOI12+23-005
  A hopefully amplitude-level search for a Dark Photon in Bhabha scattering
  D. Mack
- TPE in polarization transfer – LOI12+23-008
  Polarization transfer in positron-proton elastic scattering
  A. Puckett, J.C. Bernauer, A. Schmidt
- Dispersive effects in DIS – LOI12+23-015
  Energy dependence of dispersive effects in unpolarized inclusive elastic electron/positron-nucleus scattering the impact of Coulomb correct
  P. Gueye, J. Arrington, P. Giuliani, D. Higinbotham

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Jefferson Lab PAC52

- New **experiments** have been submitted to the Jefferson Lab **PAC52** evaluation.

  - Dark photon search – Proposal (previously deferred at PAC51)

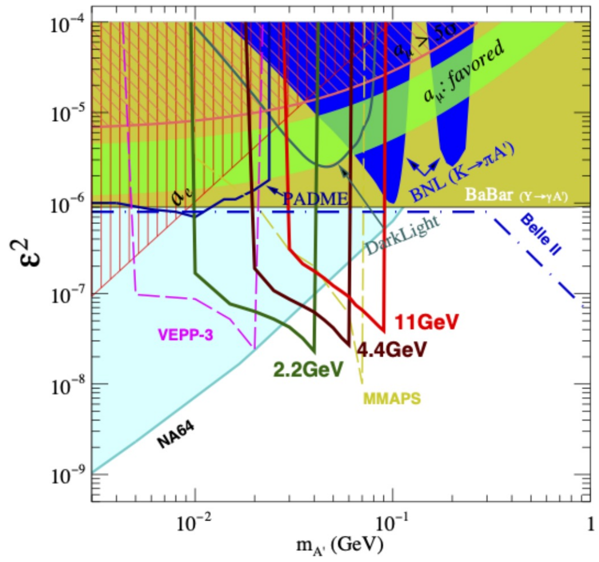
    A dark photon search with a JLab positron beam

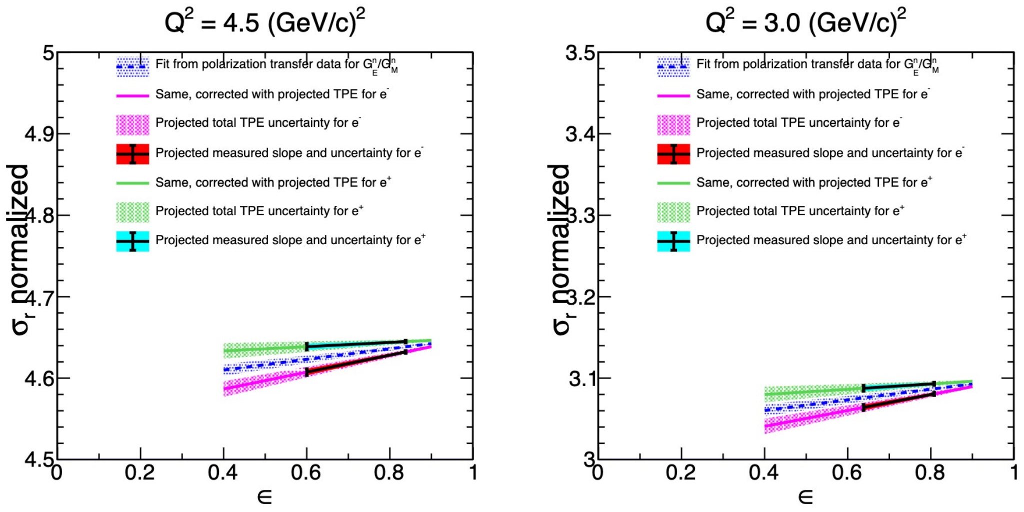
    B. Wojtsekhowski

  - TPE on the neutron – Letter-of-Intent

    Measurement of the two-photon exchange contribution to the positron-neutron elastic scattering cross section

    E. Fuchey





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E. Voutier
IJCLab Irène Joliot-Curie

Positron Physics Opportunities

U = Unpolarized
P = Polarized

Interference Physics
- Two-photon physics (U,P)
- Generalized parton distributions (U,P)

Charged Current Physics
- Deep inelastic scattering (U,P)
- Charm production (P)

Test of the Standard Model
- Search for a U-boson coupling to dark matter (U,P)
- Electroweak neutral coupling C_{3q} (U,P)
- Lepton flavor violation (U,P)

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Slow Positron Applications
- Positron annihilation spectroscopy (U,P)
- Spintronics (P)
- Positronium spectroscopy (U,P)
- Antimatter & energy production

Technological impact of Ce^{+}BAF

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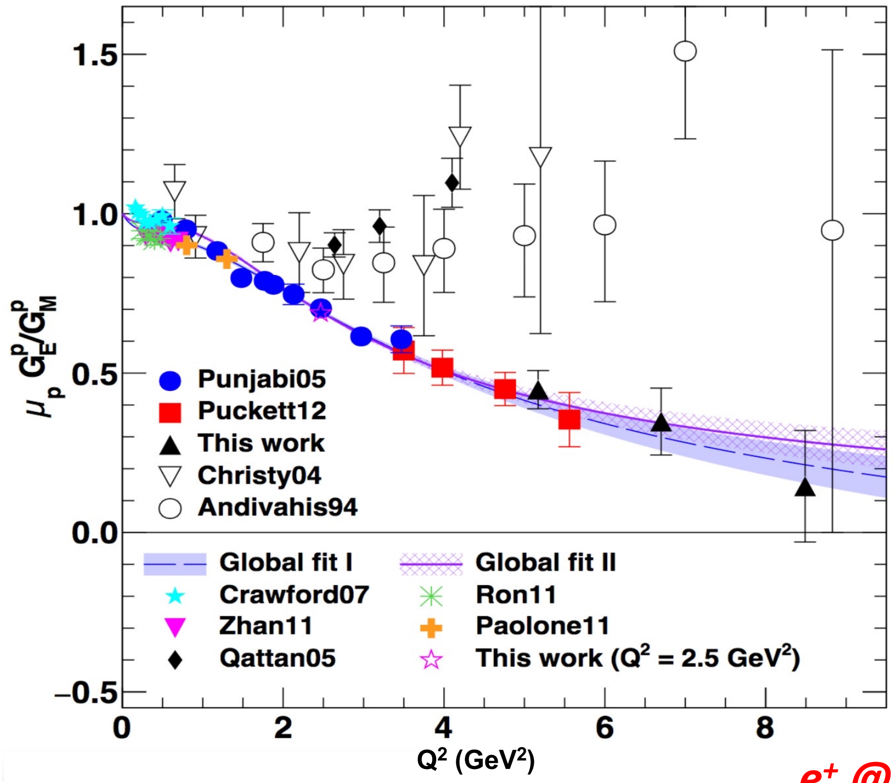
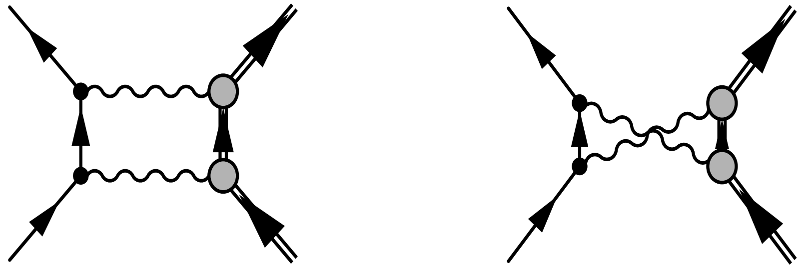
The Dilemma

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.*

Two photon exchange

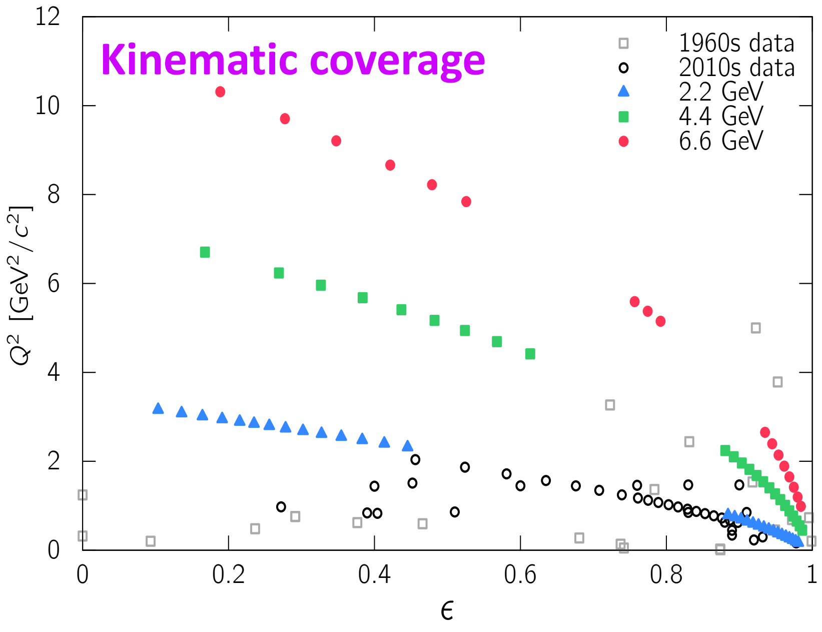
PR12+23-008

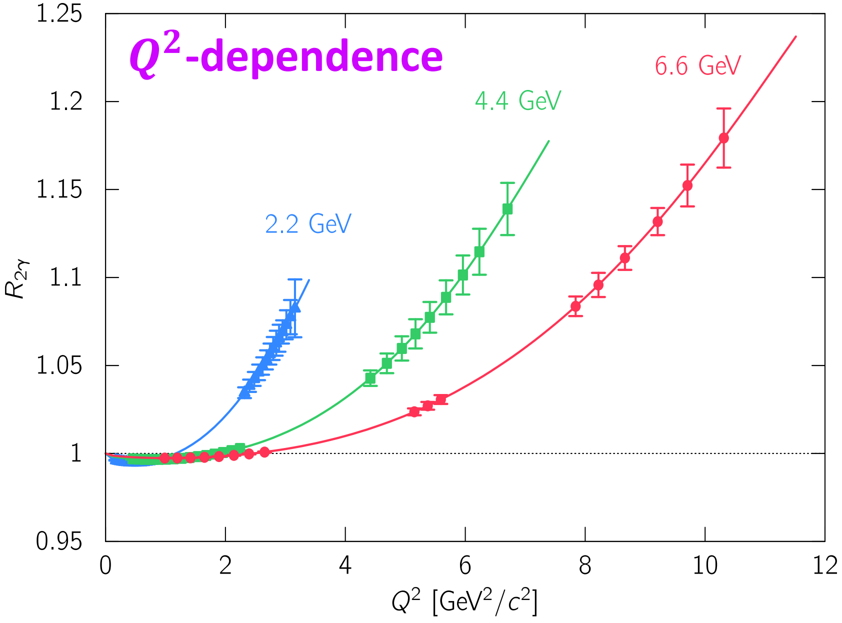
A. Schmidt, J. C. Bernauer, V. Burkert, E. Cline, I. Korover, T. Kutz, S. N. Santiesteban et al.

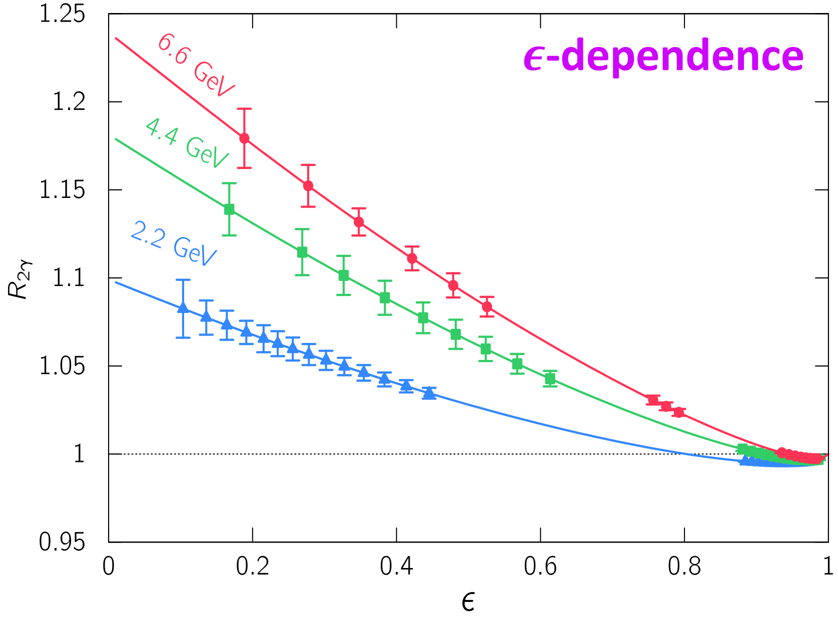
J.C. Bernauer et al. EPJ A 57 (2021) 144

- 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**, detecting leptons in the Central Detector and **protons** in the **Forward Detector**.

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







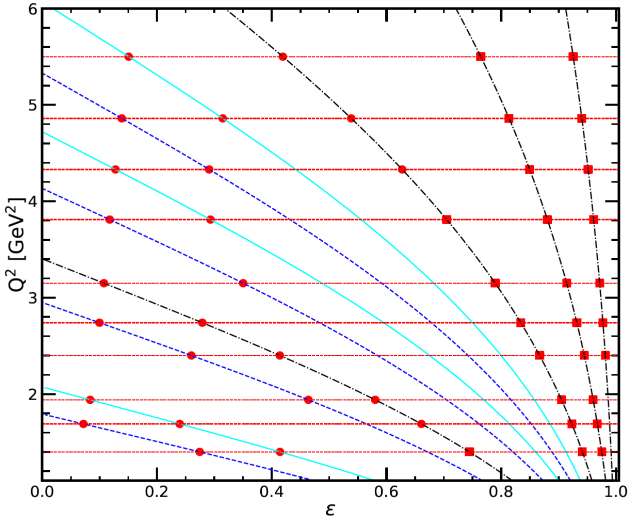
PR12+23-012

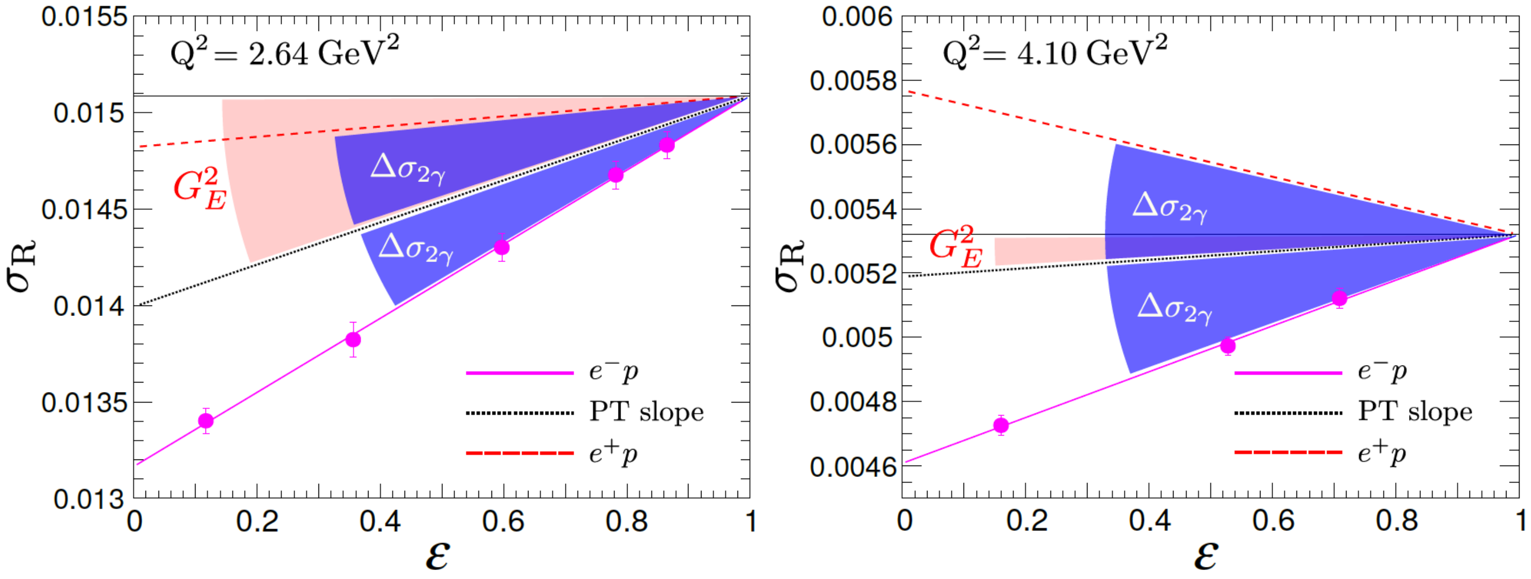
M. Nycz, J.R. Arrington, S.N. Santieseban, M. Yurov et al.

J.R. Arrington, M. Yurov EPJ A 57 (2021) 319

- The direct comparison of positron and electron Super-Rosenbluth separations doubles the sensitivity to a TPE signal.
- The positron and electron average data cancels TPE effects and allow to test the existence of additional effects from the comparison to polarization transfer data.

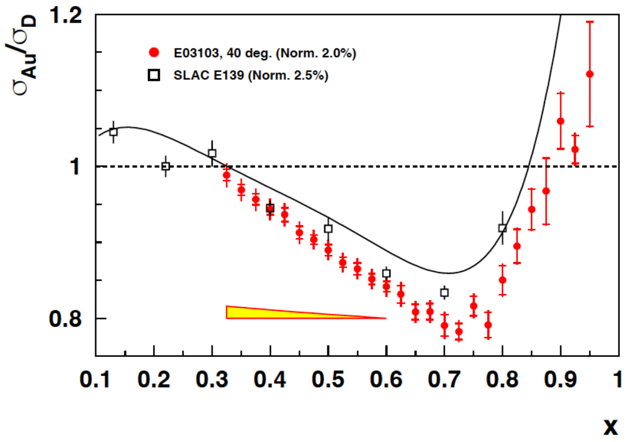
$$\sigma_R = G_M^2 + \frac{\varepsilon}{\tau} G_E^2 \pm 2\left\{ G_M \Re\mathrm{e}\left[f_0\left(\delta\tilde{G}_M, \delta\tilde{F}_3\right)\right] + \frac{\varepsilon}{\tau} G_E \Re\mathrm{e}\left[f_1\left(\delta\tilde{G}_E, \delta\tilde{F}_3\right)\right]\right\}$$

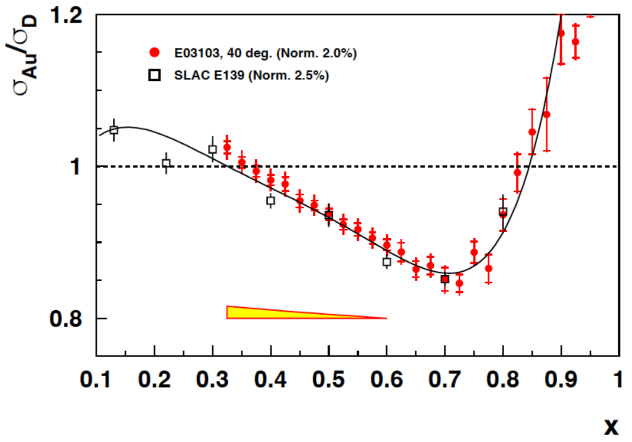




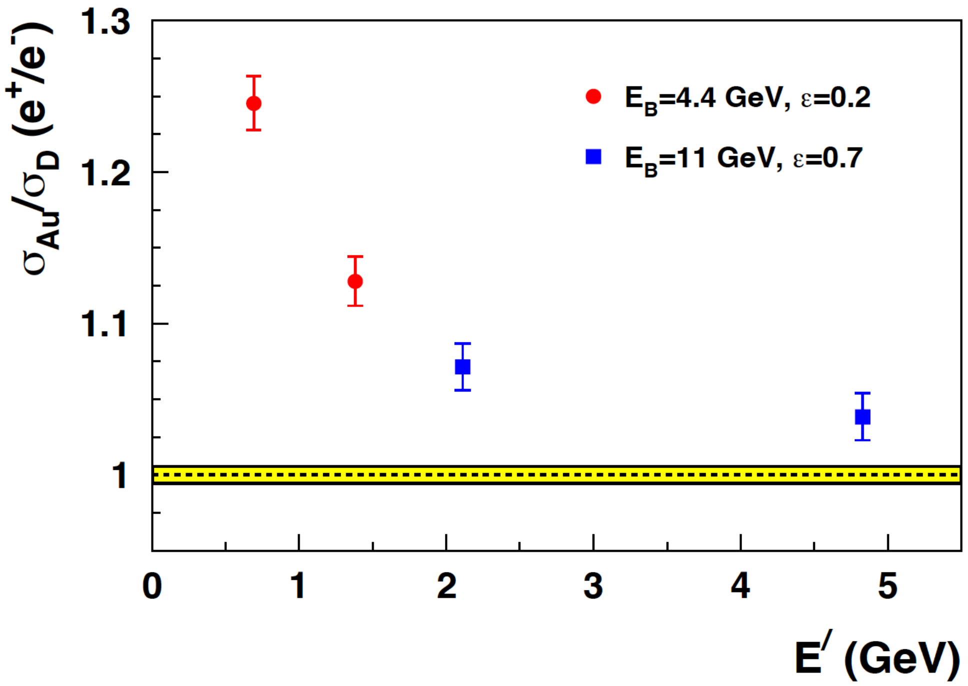
PR12+23-003
D. Gaskell, N. Fomin, W. Henry et al.

- The comparison of **positron** and **electron cross sections** in the DIS regime provides unambiguous information about the size of **Coulomb corrections**.
- The double ratio of Au/D DIS cross sections **tests** the **prescriptions** of Coulomb corrections, of particular importance for the understanding of the **EMC effect**.





Impact of Coulomb corrections on JLab Hall C EMC data, determined from the improved Effective Momentum Approximation.



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And Beyond...

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

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

❖ *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)*

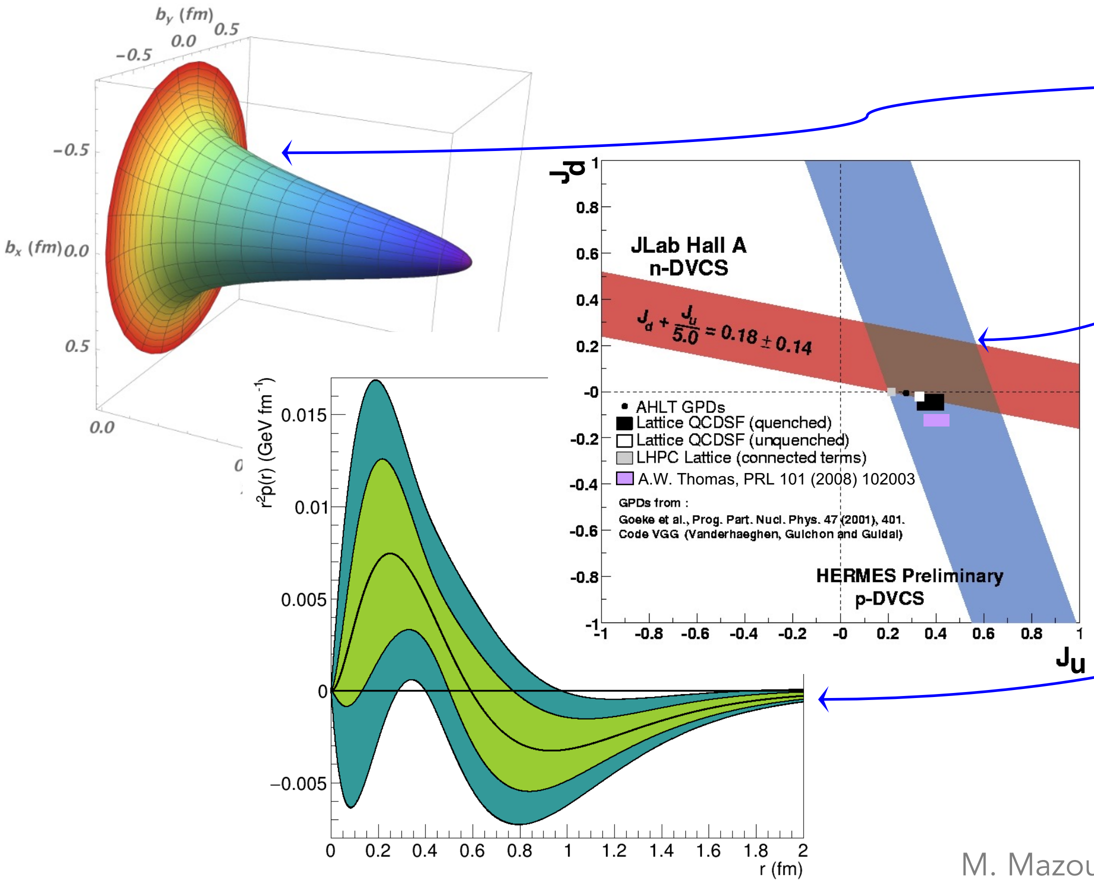
- Magnitude of TPE effects in DIS experiments ?
- Magnitude of TPE and photon radiation by the hadrons in SIDIS ?
- ...

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

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.



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

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

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

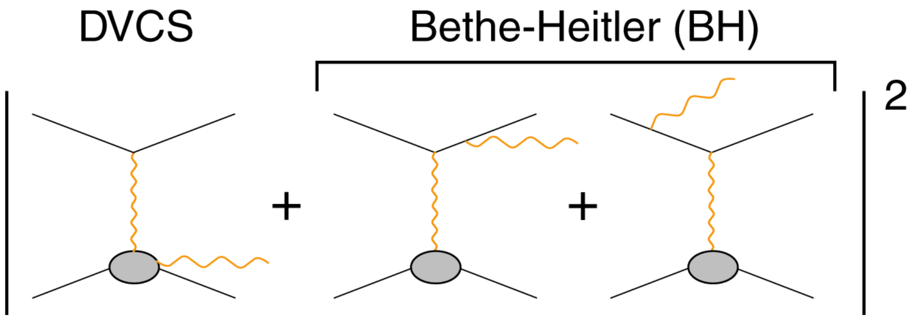
- **Unpolarized e^+ combined with unpolarized e^-** access the **real part** of the Compton Form Factors.
- **Polarized e^+ combined with polarized e^-** access the **imaginary part** of the Compton Form Factors (CFFs) and probe **higher twist effects**.

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

σ(eN ⟶ eNγ) =



CFF = Compton Form Factors

∝ to the **real part** of a **CFF linear combination**

∝ to the **imaginary part** of a **CFF linear combination**

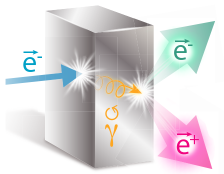
$$d^5\sigma^{e}_{P0} = d^5\sigma_{BH} + d^5\sigma_{DVCS} + P\, d^5\tilde{\sigma}_{DVCS} - e\,[d^5\sigma_{INT} + P\, d^5\tilde{\sigma}_{INT}]$$

∝ to the **real part** of a **CFF bilinear combination**

∝ to the **imaginary part** of a **CFF bilinear combination**

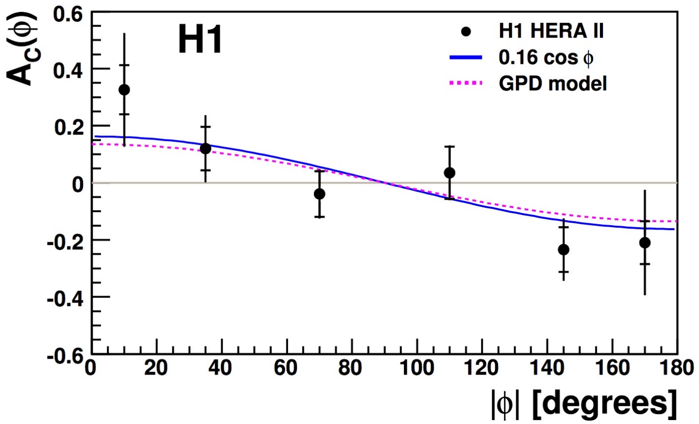
$$d^5\sigma^{e}_{PS} = d^5\sigma^{e}_{P0} + S\,[P\, d^5\Delta\sigma_{BH} + (P d^5\Delta\sigma_{DVCS} + d^5\Delta\tilde{\sigma}_{DVCS}) - e(P d^5\Delta\sigma_{INT} + d^5\Delta\tilde{\sigma}_{INT})\,]$$

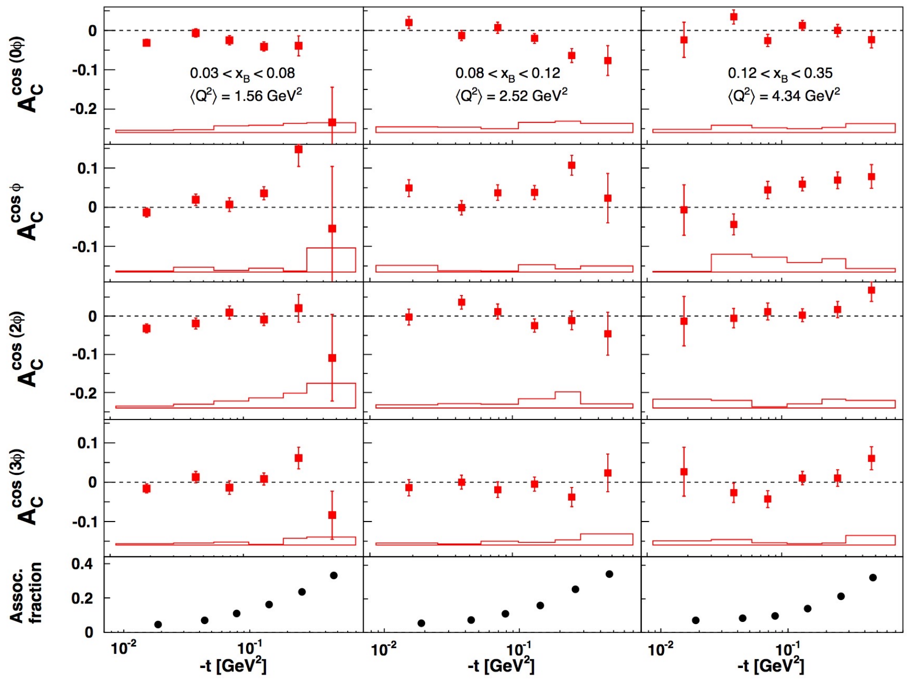
Polarized electrons and positrons allow to separate the unknown amplitudes of the cross section for electro-production of photons.



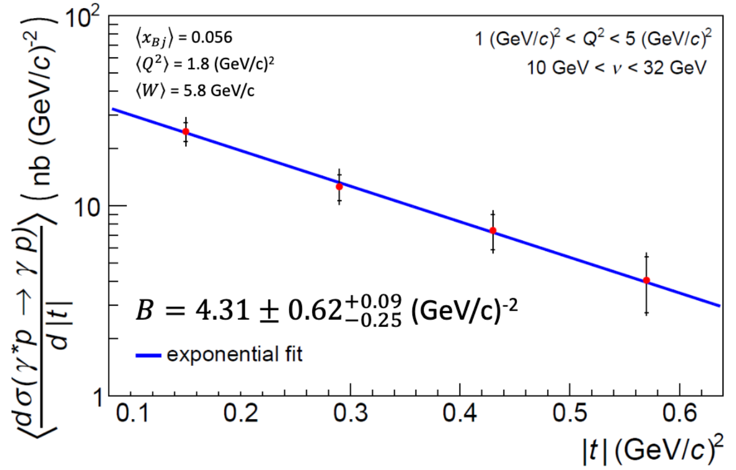
Current Knowledge

- 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

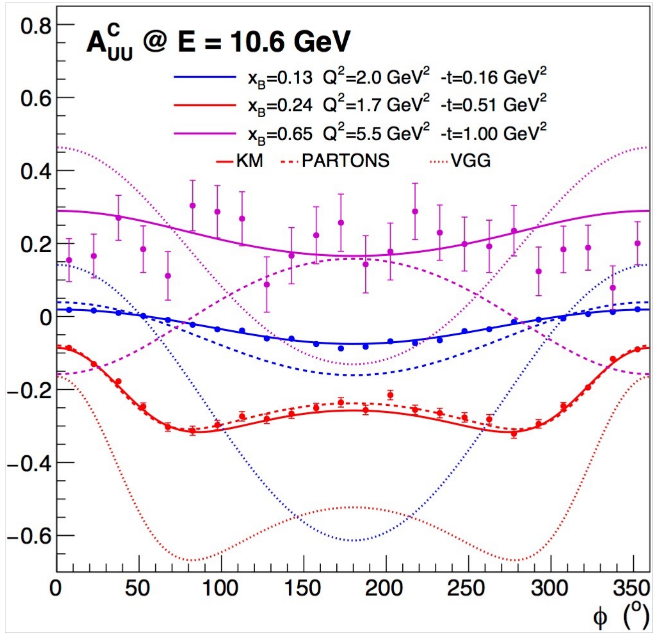
PR12+23-002

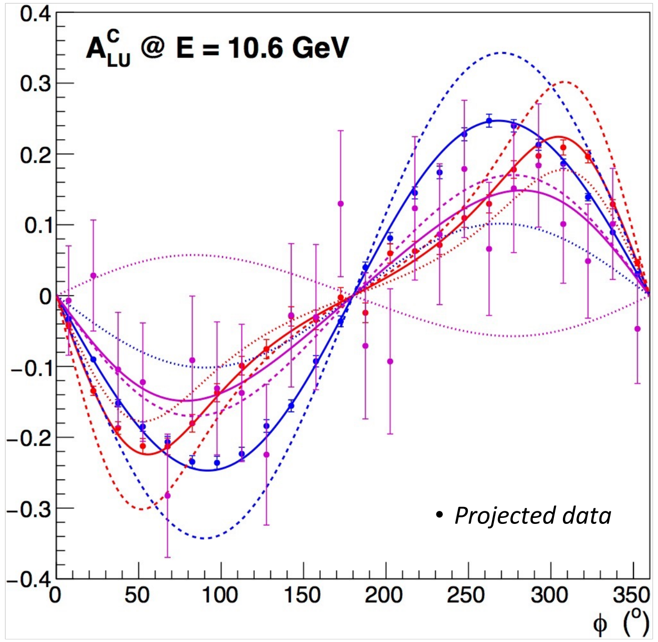
E. Voutier, V. Burkert, S. Niccolai, R. Paremuzyan et al.

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

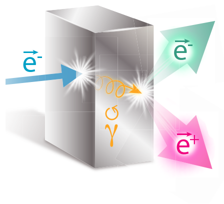
- Measurements of beam charge asymmetries with CLAS12 will provide a full set of new GPD observables:
  - the **unpolarized beam charge asymmetry** A^C_{UU}, sensitive to the **CFF real part**;
  - the **polarized beam charge asymmetry** A^C_{LU}, sensitive to the **CFF imaginary part**;
  - the **charge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

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





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

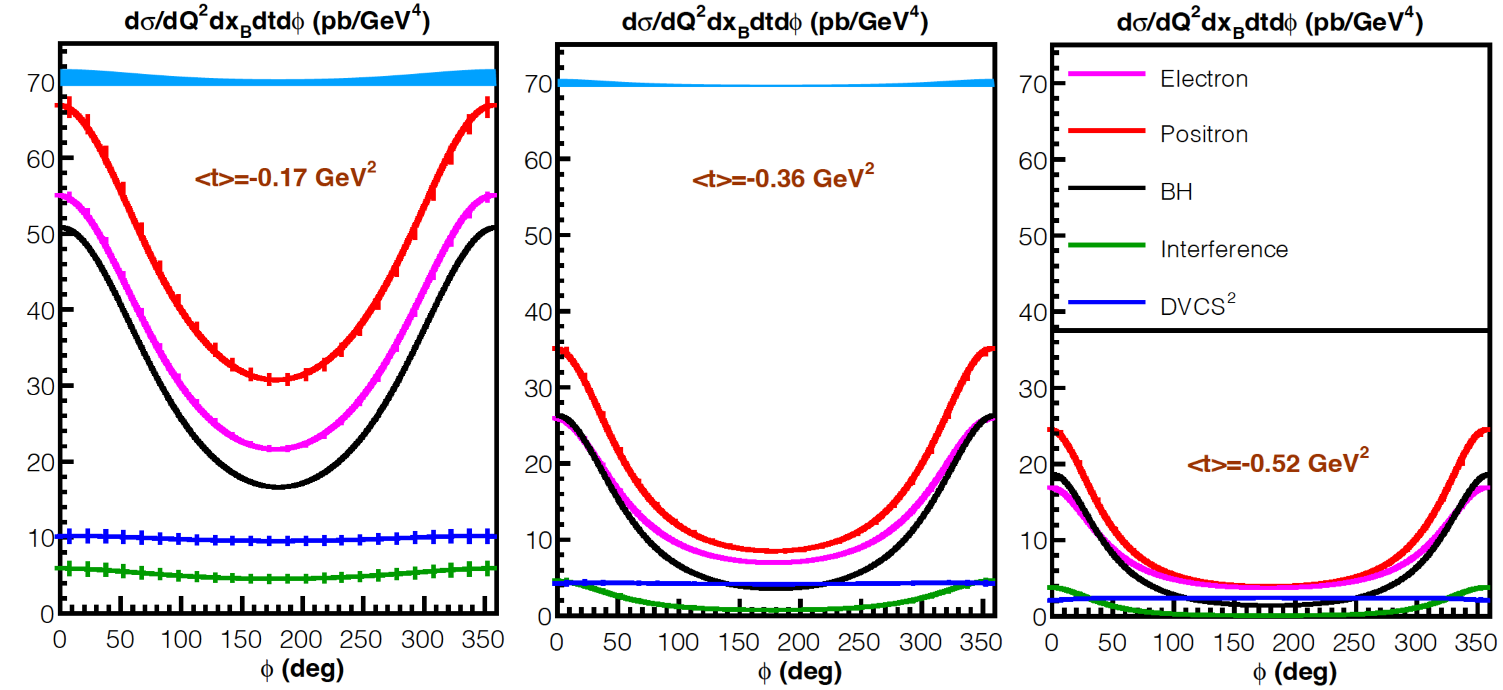


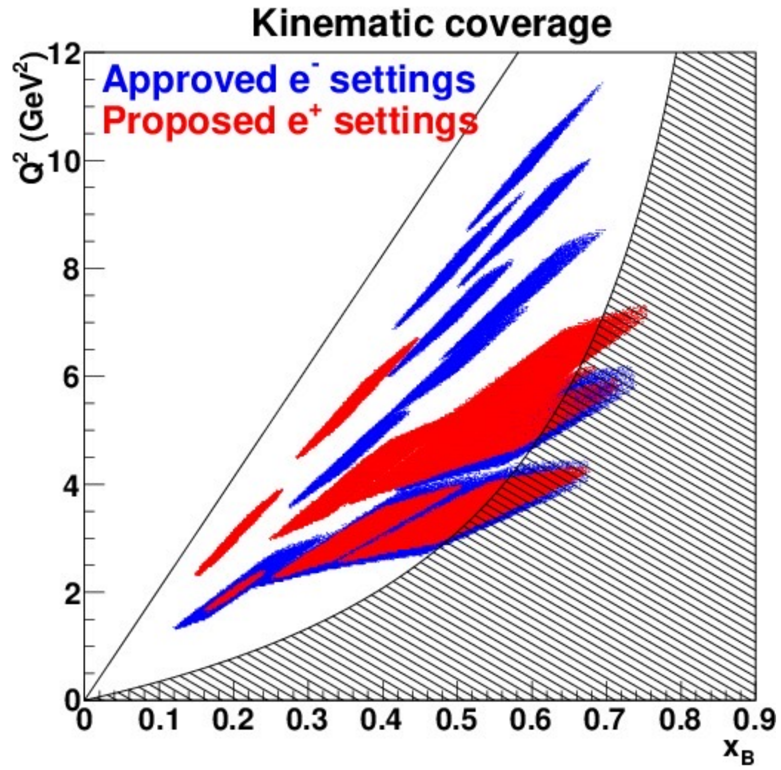
PR12+23-006
C. Muñoz Camacho, M. Mazouz et al.

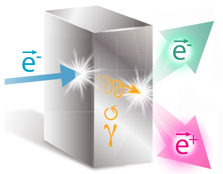
A. Afanasev et al. EPJ A 57 (2021) 300

- 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.

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



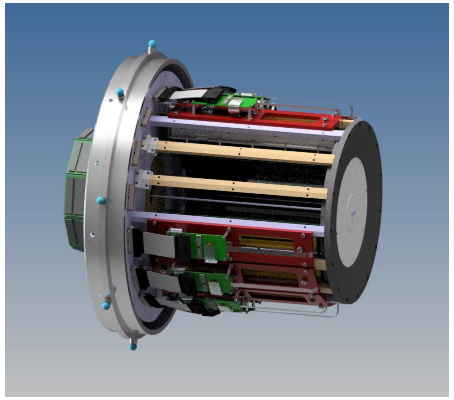




And Beyond…

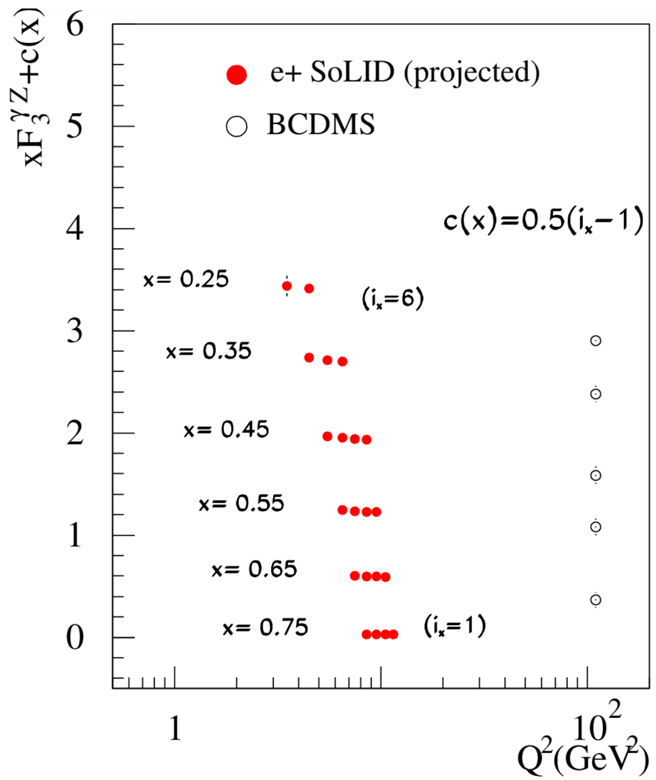
S. Niccolai, P. Chatagnon, M. Hoballah, D. Marchand, C. Muñoz Camacho, E. Voutier, EPJ A 57 (2021) 226
S. Fucini, M. Hattawy, M. Rinaldi, S. Scopetta, EPJ A 57 (2021) 273
S. Zhao et al. EPJ A 57 (2021) 240

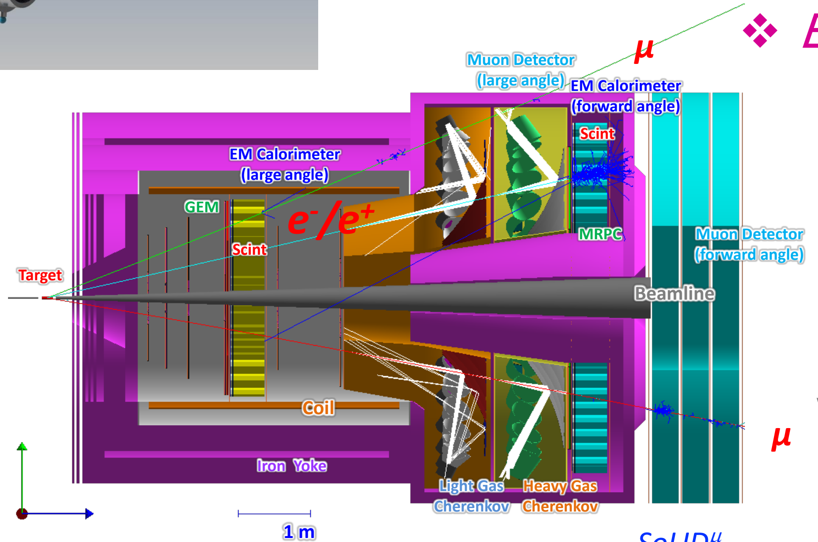
ALERT



❖ *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 ?
- …





SoLID^μ

❖ *Electroweak physics*

- Axial form factor of the proton
- Strangeness content of the nucleon ?
- Electroweak structure function $F_3^{\gamma Z}$
- …

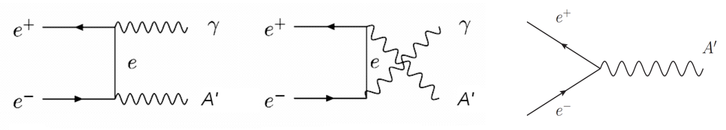
E. Aschenauer, T. Burton, T. Martin, H. Spiesberger, M. Stratman, PRD 88 (2013) 114025
W. Melnitchouk, J.F. Owens EPJ A 57 (2021) 311 X. Zheng et al. Jefferson Lab Proposal PR12-21-006 (2021)
D. Dutta et al. JLab Letter-of-Intent LOI12+23-002

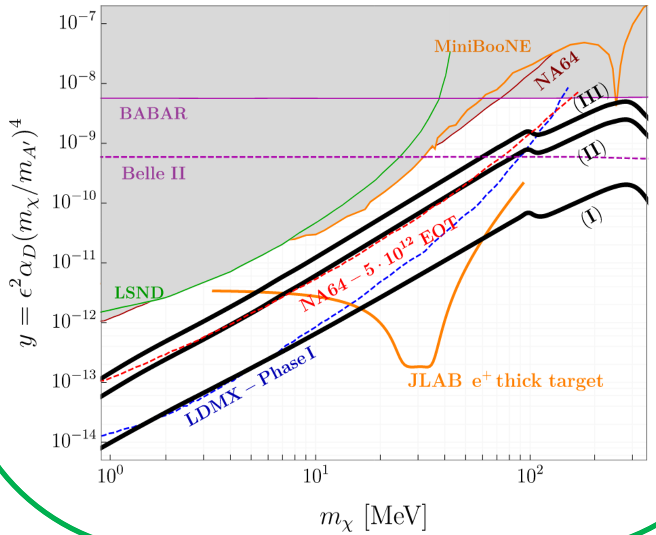
*This **list** is not exhaustive but only **indicative** of the **current reflexions**.*

Standard Model Violation

Dark photon search

M. Battaglieri et al. EPJ A 57 (2021) 253
B. Wojtsekhowski et al. PR12+23-005 (2023)
D. Mack LoI12+23-005 (2023)



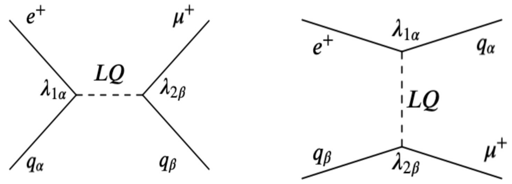


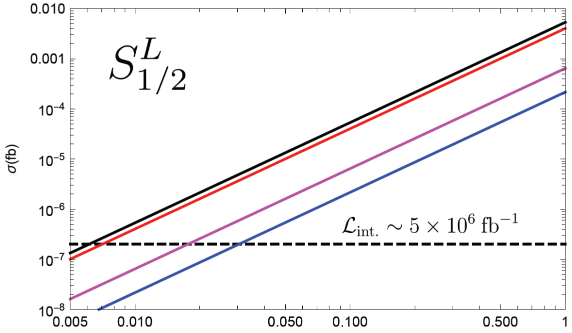
Lepton flavor violation

Y. Furletova, S. Mantry, EPJ A 57 (2021) 315

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

CEBAF/Ce$^+$BAF **luminosities** allow to explore lepto-quark (LQ) production in a mass region **beyond HERA mass limits**.





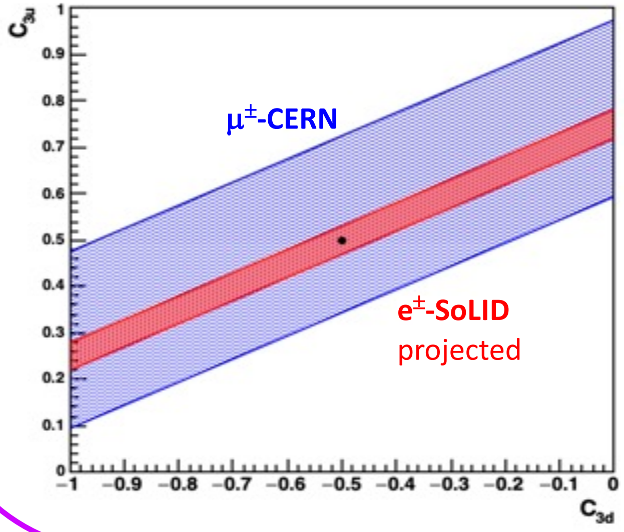
Electroweak coupling

X. Zheng et al. EPJ A 57 (2021) 173
X. Zheng et al. PR12-21-006 (2021)

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

$$A_d^{e^+e^-} \approx -108\, Y(y)\, R_q(x) (2C_{3u} - C_{3d})\, Q^2$$

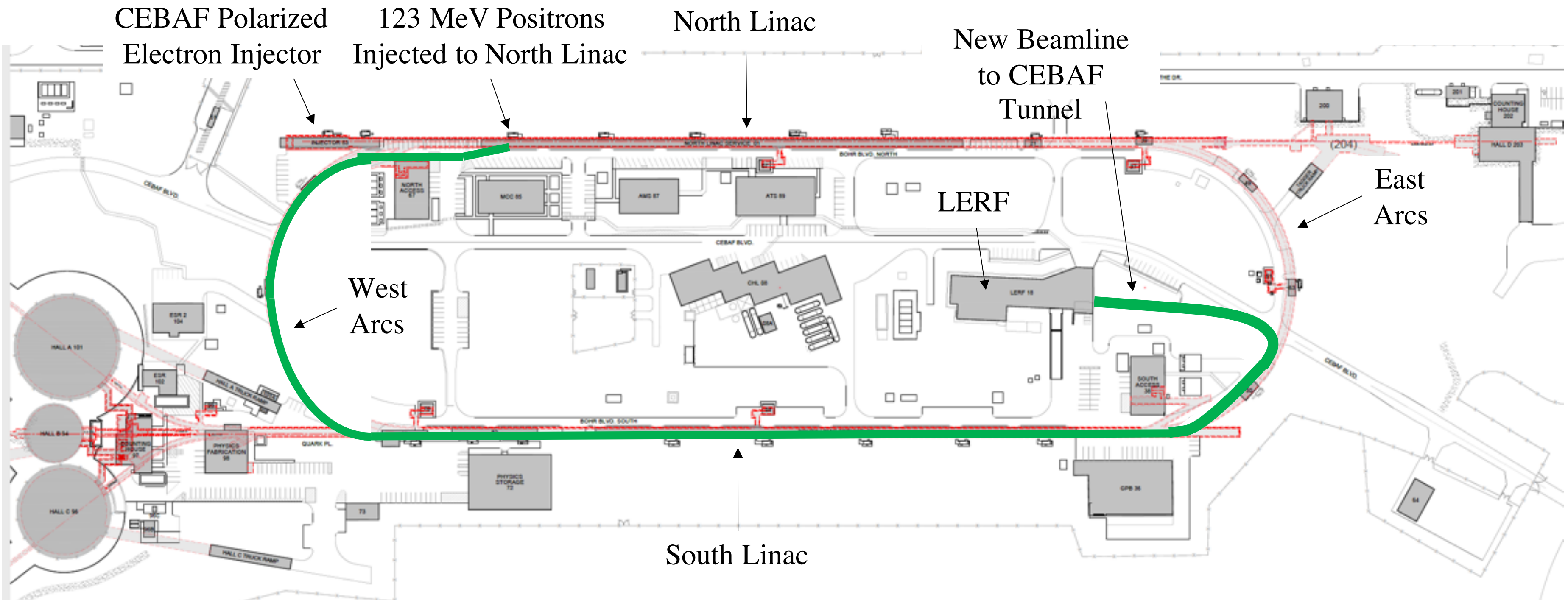
(in ppm/GeV²)



e+@CEBAF

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

- The CEBAF positron upgrade forsees **transforming** the **LERF** into a **123 MeV positron injector** which beam will be transported towards the **CEBAF injection point** through a **new transport line** attached to the ceiling of the existing accelerator tunnel.



New Capabilities

- $Ce^{+}BAF$ will offer **new experimental capabilities** not only in the **existing experimental halls** but also at **LERF** at beam **energies below the pion** production threshold.

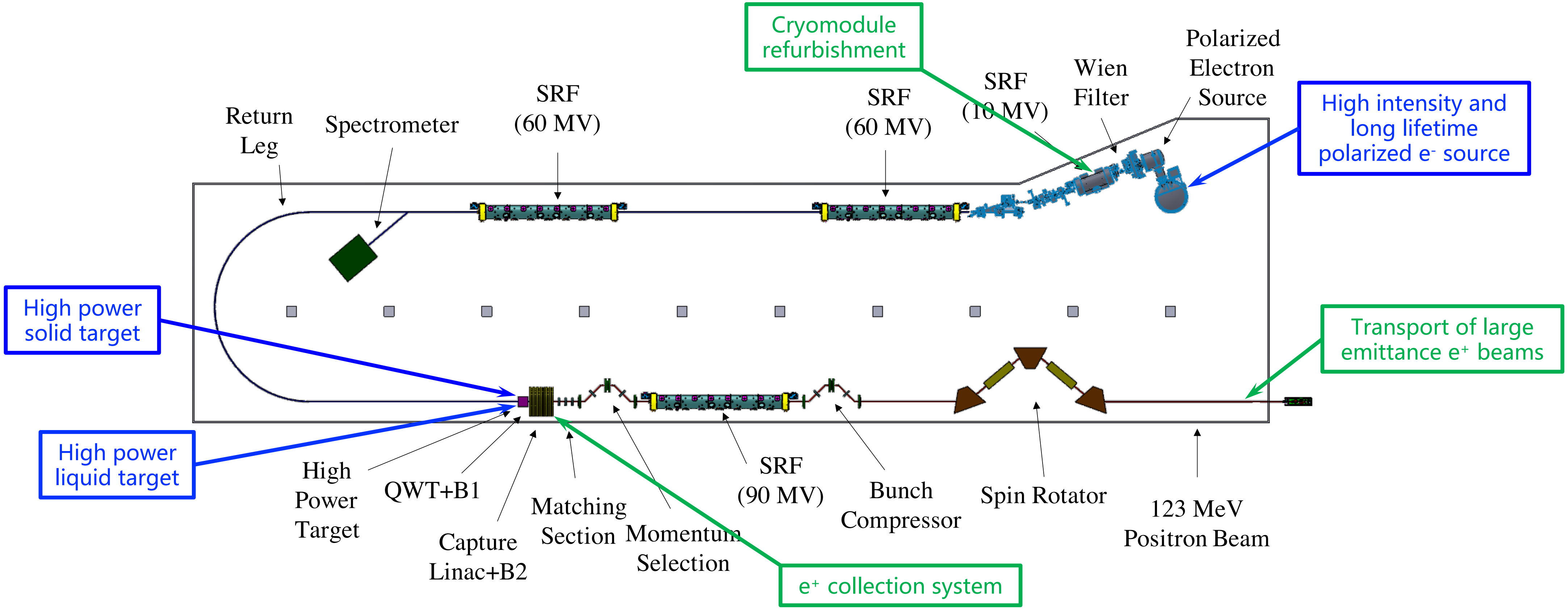
Machine Parameter	CEBAF e^-	$Ce^{+}BAF$			LERF		
		e^+	Degraded e^-	e^-	e^+	Degraded e^-	e^-
Multiplicity	4	1 or 2			1		
Max. Energy (ABC/D)	11/12 GeV	11/12 GeV			$\leq$ 123 MeV		
Beam Repetition	250/499 MHz	250/499 MHz			250/499 MHz		
Duty Factor	100% cw	100% cw			100% cw		
Unpolarized Intensity	170 μA	> 1 μA	>> 1 μA	170 μA	> 1 μA	> 1 mA	> 1 mA
Polarized Intensity	170 μA	> 50 nA	>> 1μA	170 μA	> 50 nA	> 1 mA	> 1 mA
Beam Polarization	> 85%	> 60%	> 85% ?	> 85%	> 60%	> 85% ?	> 85%

Possibilities for experiments at LERF will be available before the completion of $Ce^{+}BAF$.

e+@LERF

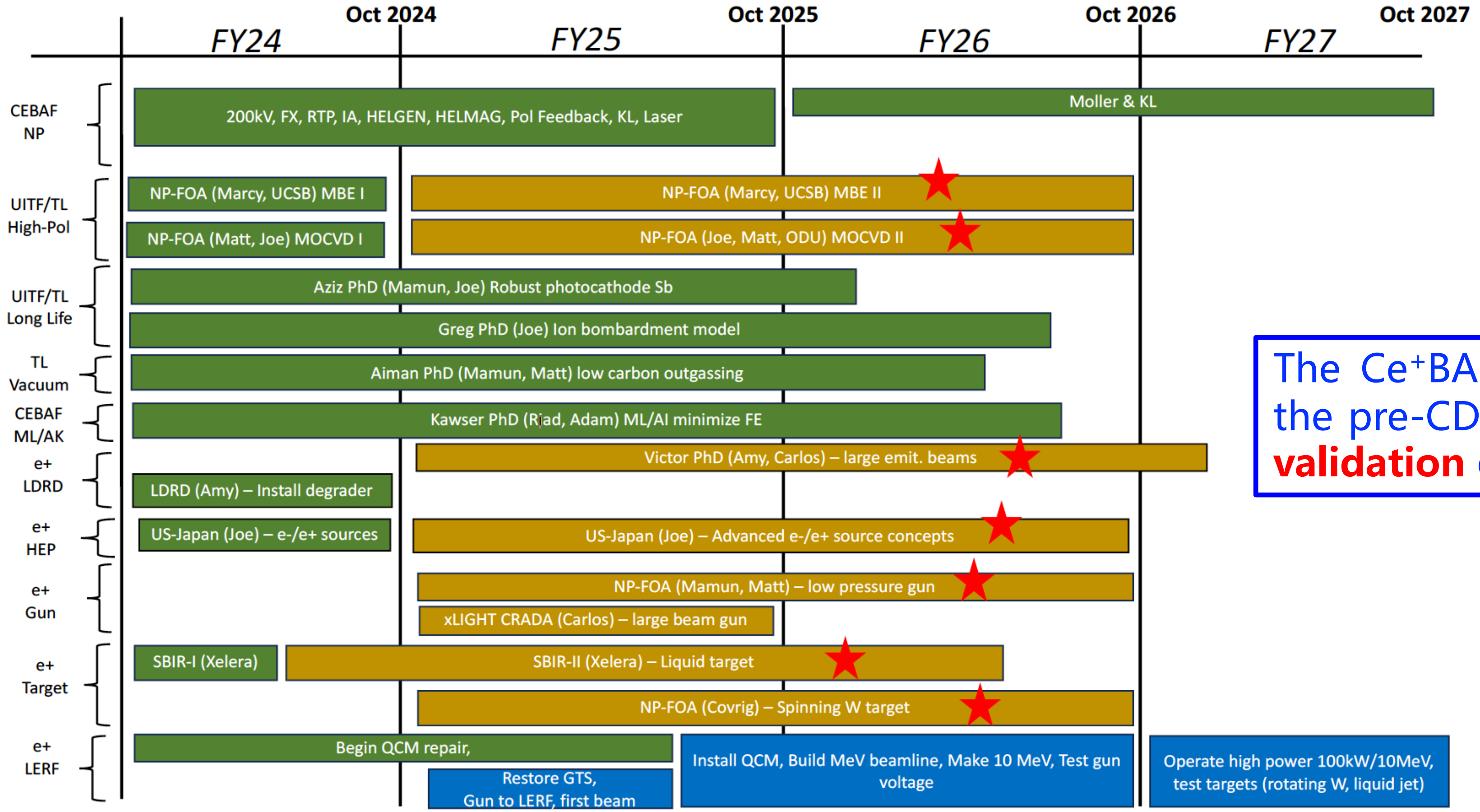
(Ce+BAF Working Group) J. Grames *et al.* JACoW IPAC2023 (2023) MOPL152; arXiv2309.15581

- The R&D activity around the **Ce+BAF** project entered a new phase aiming at the **testing of critical components** and an **elaborated design of the positron source** towards a **pre-CDR** by the end of **2026**.



R@D Overview

- A **3 years R&D plan** is progressing, agressively pursing funding support (FOA).

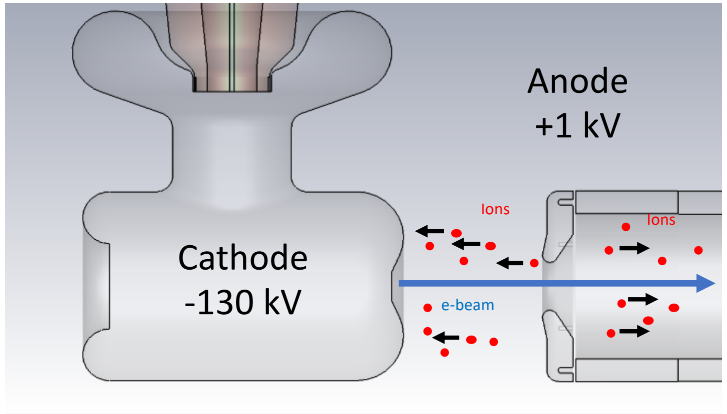


The Ce+BAF design and to a lesser extent the pre-CDR goal ask for the **experimental validation** of the **critical components**.

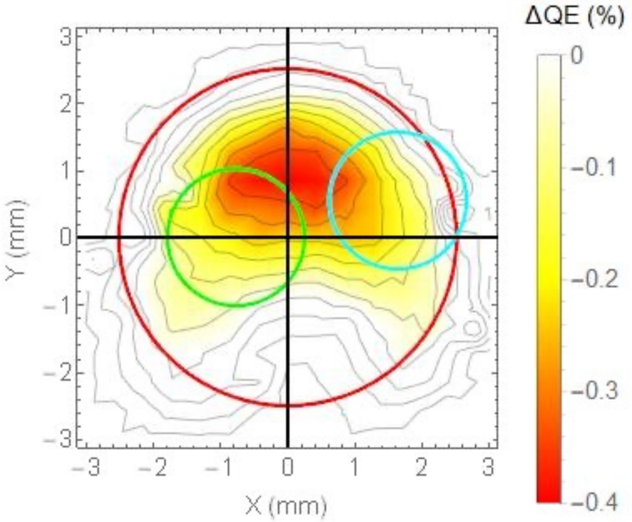
Polarized Electron Source

C. Hernandez-Garcia et al. PWG Workshop (2024) M. Bruker et al. IPAC 2024

- The Ce+BAF polarized electron source must be capable of **high current** (**1 mA**) over a **long lifetime** (**>1kC**), which is **5 times** better than the **state-of-the-art CEBAF** photogun.
  - Improvement of the **vacuum**
  - Increase of the gun **HV**
  - Enlargement of the **laser spot size**
  - Enlargement of the **photocathode**



The main limitation of photocathode lifetime is the **back-bombardment of ions** produced by the interaction of electrons with the **residual gas**.

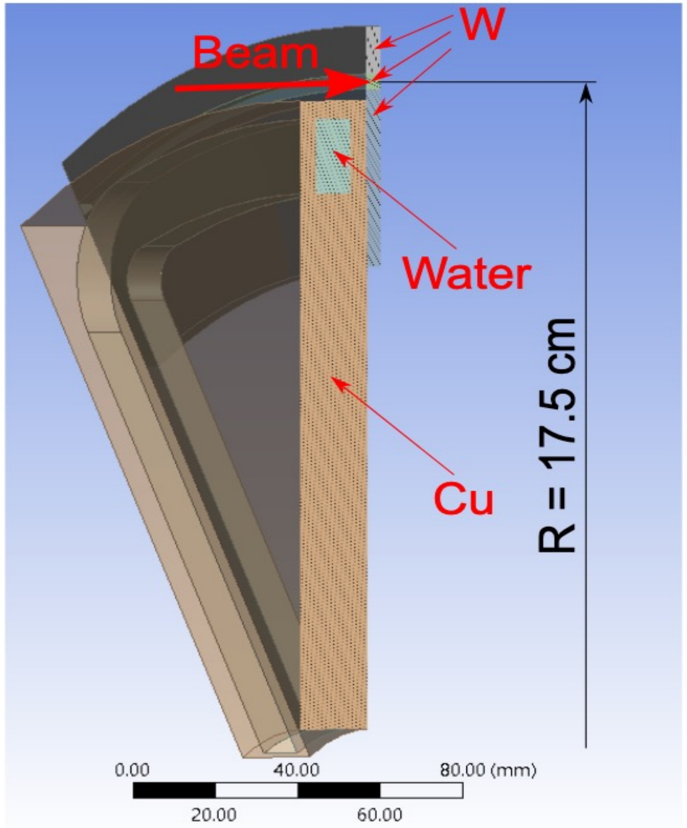


Red circle: Photocathode active area (5 mm diameter)
Green circle: 1st laser spot (2 mm FWHM)
Cyan circle: 2nd laser spot (2 mm FWHM)

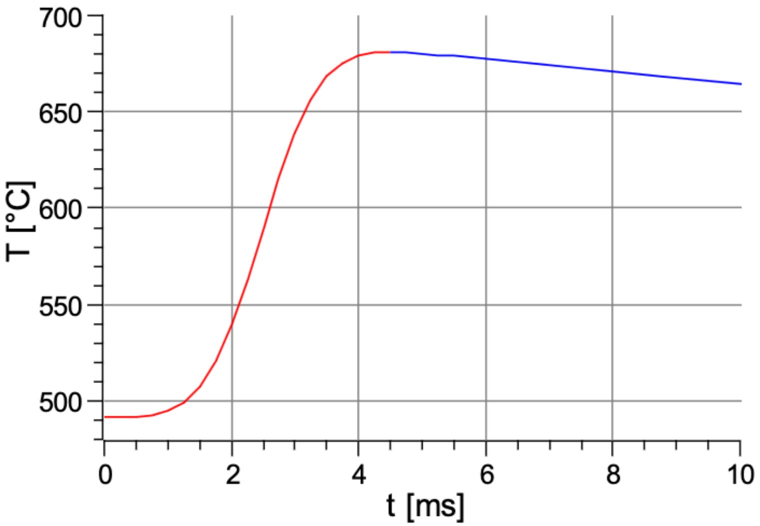
High Power Solid Target

A. Ushakov et al. JACoW IPAC (2023) WEPM120 S. Covrig et al. PWG Workshop (2024)

1/6 segment of the e^+ target



- The electron beam deposits a power of **17 kW** in the **4 mm** W rim.
- The water channel with turbulent water flows at a speed of **2 m/s** and a **22°C** inlet temperature.
- The beam spot RMS size is **1.5 mm**.
- The rotation speed of the target is **2.3 m/s**.



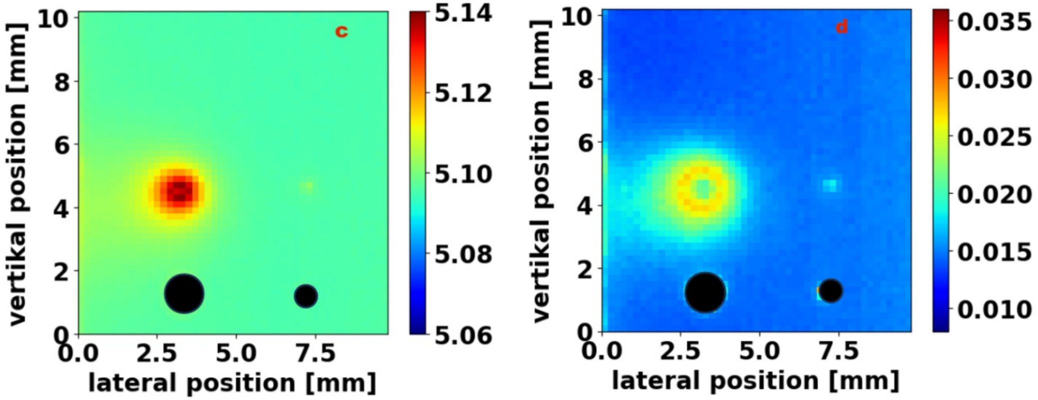
The tungsten target is expected to operate at an **average temperature** of **500°C** with a **peak temperature** at **680°C** at each rotation cycle (0.5 s).

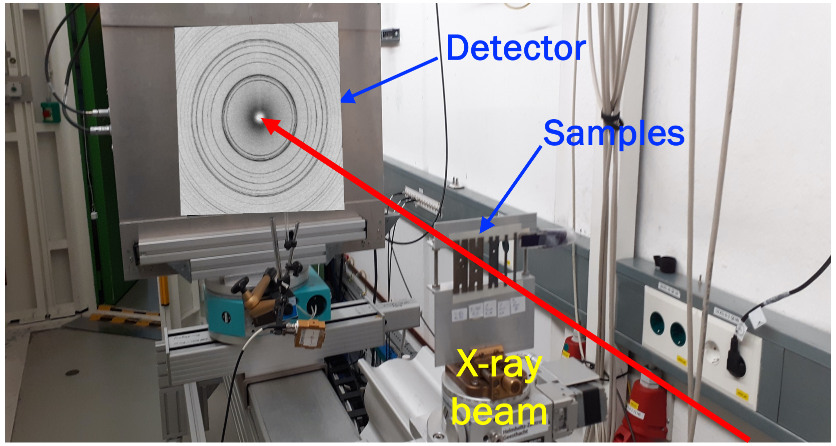
Radiation Damages Characterization

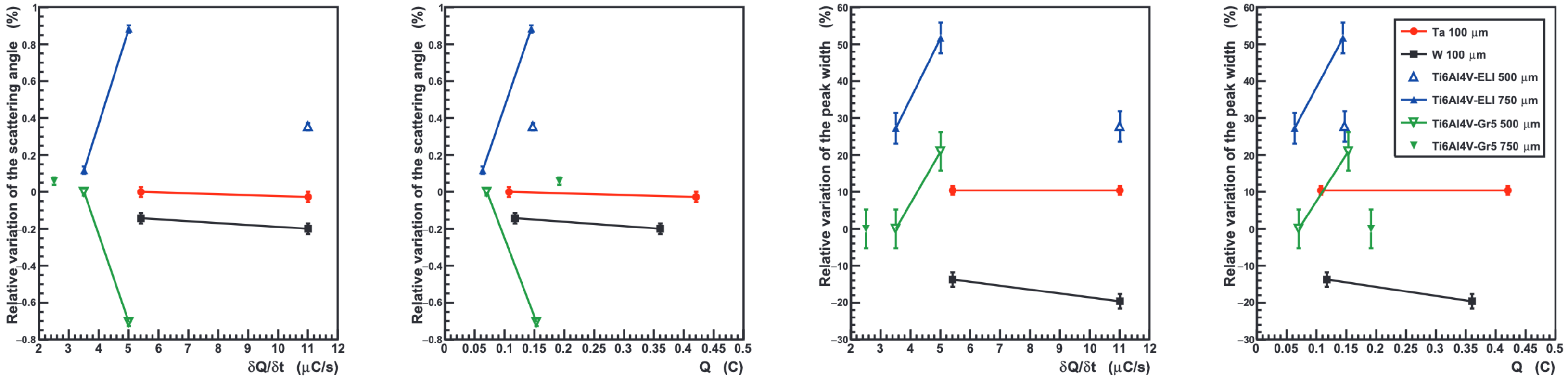
T. Lengler et al. JACoW IPAC (2024) TUPC81

- The damages to the structure of different materials exposed to the 3.5 MeV MAMI electron beam, are characterized at the PETRA III synchrotron facility.

- The change in the scattering angle of the transmitted X-rays and the width of the intensity peak are monitored with respect to a witness sample.





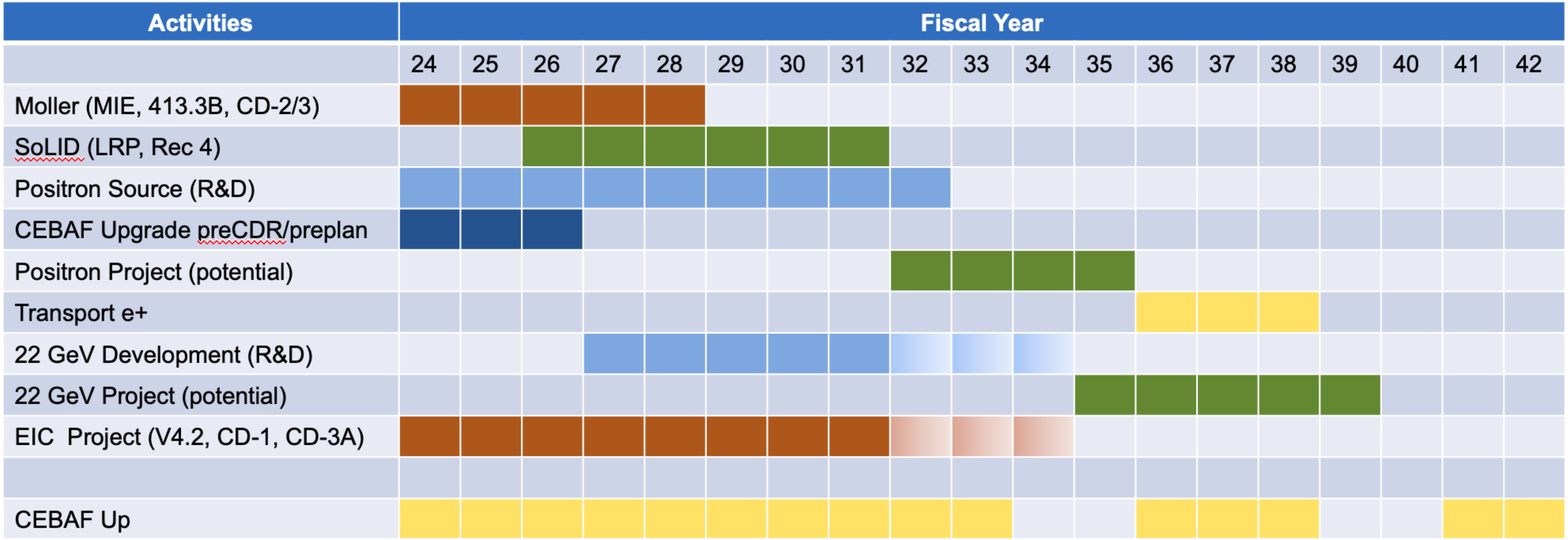


Unexpectedly, the Tantalum material does not show any particular radiation damage.

Timeline

D. Dean at the Annual Meeting of the Jefferson Lab User Organization, June 10-12, 2024

- A possible schedule based on a notional timing of the possibility of funds avalability (EIC ramp down) would put **Ce$^+$BAF** in the **early 2030's**.



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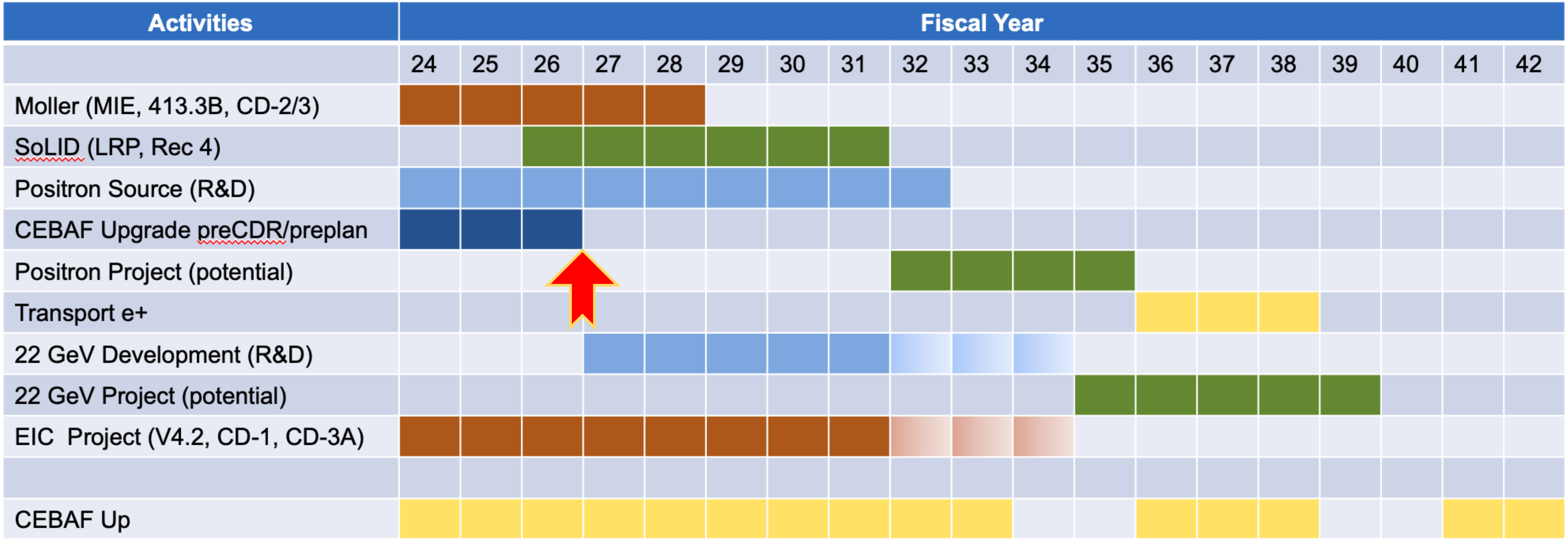

Ce^+BAF Working Group

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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

S. Wang et al. JACoW IPAC2024 (2024) MOPC51 M.W. Bruker et al. JACoW IPAC2024 (2024) MOPC52 A. Sy et al. JACoW IPAC2024 (2024) MOPC53 A. Ushakov et al. JACoW IPAC2024 (2024) MOPC54 T. Lengler et al. JACoW IPAC2024 (2024) TUPC81

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.

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

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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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.

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**.

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https://www.institut-pascal.universite-paris-saclay.fr/en https://indico.ijclab.in2p3.fr/event/10641/ (in work)

MDHS (organized by C. Mezrag): Multidimensional hadron structure at the dawn of the high-precision era.
JPhys++ (organized by E. Voutier): Physics opportunities with Jefferson Lab positron and energy upgrades.

2 weeks brainstorming (in-person) + 1 week workshop (hybrid)

October 21st – November 8th, 2024

JPhys++

- Form factors (D. Higinbotham)
- Multi-photon exchange (A. Afanasev)
- Generalized parton distributions (S. Niccolai / E. Voutier)
- Meson structure (M. Defurne)
- Hadron mass (C. Lorcé)
- Electroweak processes (M. Nycz / R. Trotta / X. Zheng)
- Tests of the standard model (M. Battaglieri)

Explore the benefits of Ce^{+}BAF positron beams, defining new direction of research and/or new experimental proposals.