Motivations	Experimental setup and data set	Analysis	Results
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# First-time observation of Timelike Compton Scattering, with the CLAS12 detector

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## Kickoff meeting - GDR-QCD / WG1 : Simple and Multiple Interactions between Partons

21-23 juin 2021 Fuseau horaire Europe/Paris



Experimental setup and data set

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## **Timelike Compton Scattering**





TCS (factorization regime)

**Bethe-Heitler** 

• BH cross section only depends on electromagnetic FFs

 $\sigma_{BH} >> \sigma_{TCS}$  at JLab energies

• Unpolarized interference cross section

$$\frac{d^4\sigma_{INT}}{dQ'^2dtd\Omega}\propto \frac{L_0}{L}\left[\cos(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)}\operatorname{Re}\tilde{M}^{--}+\ldots\right]$$

• Polarized interference cross section

$$\frac{d^{4}\sigma_{INT}}{dQ'^{2}dtd\Omega} = \frac{d^{4}\sigma_{INT}\mid_{\text{unpol.}}}{dQ'^{2}dtd\Omega} - \nu \cdot A \frac{L_{0}}{L} \left[ \sin(\phi) \frac{1+\cos^{2}(\theta)}{\sin(\theta)} \operatorname{Im}\tilde{M}^{--} + \dots \right]$$
$$\rightarrow \tilde{M}^{--} = \frac{2\sqrt{t_{0}-t}}{M} \frac{1-\xi}{1+\xi} \left[ F_{1}\mathcal{H} - \xi(F_{1}+F_{2})\tilde{\mathcal{H}} - \frac{t}{4M^{2}}F_{2}\mathcal{E} \right]$$
(hatagoon) Both Im $\mathcal{H}$  and Re $\mathcal{H}$  can be accessed in TCS

TCS with CLAS12 (P. Chatagnon)

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## Motivations to measure TCS

### Test of universality of GPDs

- TCS is parametrized by GPDs
- Comparison between DVCS and TCS results allows to test the universality of GPDs
- $\bullet~$  TCS does not involve Distribution Amplitudes unlike Deeply Virtual Meson Production  $\rightarrow$  direct comparison between DVCS and TCS

#### Real part of CFFs and nucleon D-term

- $\bullet$  As for DVCS, TCS unpolarized cross section is sensitive to  ${\rm Re}{\cal H},$  which is still not well constrained by existing data.
- The CFFs dispersion relation at leading order and leading twist :

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

• D(t) can be related to the mechanical properties of the nucleon.

Review in Polyakov, Schweitzer, International Journal of Modern Physics A, 2018

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## **Experimental setup**

## CLAS12



## Data set used in this work

## • Forward Detector (6 sectors)

- Torus magnet
- Drift Chambers
- Forward Time-of-Flight
- Calorimeters (EC and PCAL)
- Cherenkov counters

## Central Detector

- Solenoid magnet
- Central Vertex Tracker (Silicon and micromegas)
- Central Time-of-Flight
- Central Neutron Detector

Figure in Burkert et al., NIM A, 2020

- Fall 2018 run period
- LH<sub>2</sub> target / 10.6 GeV beam / RG-A
- Inbending torus magnetic field
- Accumulated charge:  $\sim$  150 mC ( $\sim$  200 fb^{-1})

TCS with CLAS12 (P. Chatagnon)



TCS with CLAS12 (P. Chatagnon)





Analysis

## **Positron identification**



Analysis

## Data/Simulation comparison

• Vector mesons peaks are visible in data:  $\omega$  (770 MeV),  $\rho$  (782 MeV),  $\Phi$  (1020 MeV) and  $J/\psi$  (3096 MeV)



• Data/BH comparison in the high mass region, no evident high mass vector meson production ( $\rho$  (1450 MeV, 1700 MeV))

## Phase space of interest

- 1.5 GeV  $< M_{e^+e^-} < 3$  GeV
- 0.15 GeV<sup>2</sup> < -t < 0.8 GeV<sup>2</sup>  $-t/M_{e^+e^-}^2 < 1 \rightarrow$  Factorization regime

• 4 GeV 
$$< E_{\gamma} < 10.6$$
 GeV.



Data/simulation are matching at 15 % level, up to normalization factor



#### Multidimensional binning of the acceptance

4 bins in -t, 3 bins in  $E_{\gamma}$  and  $Q'^2$ ,  $10^{\circ} \times 10^{\circ}$  bins in the  $\phi/\theta$  plane. Bins with  $\frac{\Delta Acc}{Acc} > 0.5$  and Acc < 0.05 are discarded ( $\Delta Acc$  is statistical error).





#### Efficiency corrections

- Data-driven correction for the proton detection efficiency derived using ep → e'π<sup>+</sup>π<sup>-</sup>(p') reaction
- Efficiency correction from **background merging** using random trigger events

Analysis

## **Observable 1:** Photon polarization asymmetry $(A_{\odot U})$

#### Access to the imaginary part of CFFs

$$A_{\odot U} = \frac{\sigma^{+} - \sigma^{-}}{\sigma^{+} + \sigma^{-}} = \frac{-\frac{\alpha_{em}^{2}}{4\pi s^{2}} \frac{1}{-t} \frac{m_{P}}{Q'} \frac{1}{\tau \sqrt{1 - \tau}} \frac{L_{0}}{L} \frac{\sin \phi}{\sin(\theta)} \frac{(1 + \cos^{2} \theta)}{\sin(\theta)} \frac{\mathrm{Im}\tilde{M}^{--}}{\mathrm{Im}\tilde{M}^{--}}}{d\sigma_{BH}}$$

#### **Experimental** measurement

- $A_{\odot U}(-t, E\gamma, M; \phi) = \frac{1}{P_B} \frac{N^+ N^-}{N^+ + N^-}$ where  $N^{\pm} = \sum \frac{1}{A_{cc}} Pol_{transf.}$
- Pol<sub>transf.</sub> is the transferred polarization from the electron to the photon
- *P<sub>B</sub>* is the polarization of the CEBAF electron beam (85%)
- The  $\phi\text{-distribution}$  is fitted with a sine function



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## **Systematics**



#### Method

• Calculated from generated BH events, and full-chain simulated events.

#### Proton

• Apply  $\chi^2$  cut for the proton identification

#### **Positron Identification**

 Vary the positron ID cut (0.5 ± 0.3; max. significance region)

#### Efficiency

• Calculate observable with/without data-driven proton efficiency

#### **Exclusivity cuts**

• Vary the values of the exclusivity cuts:  $| Pt/P | < 0.05 \pm 0.01, | M_X^2 | < 0.4 \pm 0.1 \text{ GeV}^2$ Fully integrated relative uncertainty

#### Acceptance

- Calculate observable with acceptance produced using BH-weighted events or unity weights
- Neighboring bins uncertainties are averaged
- Then added in quadrature

Motivations	Experimental setup and data set	Analysis	Results
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$A_{\odot II}$ results			

- First time measurement
- A sizeable asymmetry is measured (above the expected vanishing A<sub>⊙U</sub> of BH)
  - $\rightarrow$  signature of TCS
- Theoretical predictions were provided by M.Vanderhaeghen (using the VGG model) and P.Sznajder (using the GK model)
- Size of the asymmetry is well reproduced by VGG and GK models → model dependent hints for universality of GPDs

$$< M >=$$
 1.8 GeV;  $< E_{\gamma} >=$  7.29 GeV;  
 $< \theta >=$  92°



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## **Observable 2: Forward-Backward asymmetry**

- Concept explored for  $J/\Psi$  production (Gryniuk, Vanderhaeghen, *Phys. Rev. D*, 2016).
- Exploratory studies for TCS performed during my thesis.
- Very first predictions for TCS have been published very recently (Heller, Keil, Vanderhaeghen, *Phys. Rev. D*, 2021).
- Use the different parity of the TCS and BH amplitudes under the inversion of the leptons directions  $k \leftrightarrow k' \iff (\theta, \phi) \leftrightarrow (180^{\circ} \theta, 180^{\circ} + \phi)$



- Access to the real part of the CFFs with no integration over angles
- ${l \circ}\,$  Removes large dependencies on angular acceptance  $\rightarrow$  direct comparison with models
- $\bullet \ \ \mathsf{But \ smaller \ phase \ space} \to \mathsf{lower \ statistics}$

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## A<sub>FB</sub> selected results

- $A_{FB}$  measured in two mass regions:  $M \in [1.5 \text{ GeV}, 3 \text{ GeV}]$  and  $M \in [2 \text{ GeV}, 3 \text{ GeV}]$
- The measured *A<sub>FB</sub>* is non-zero: evidence for signal beyond pure BH contribution
- Three model predictions
  - 1 VGG without D-term
  - 2 VGG with D-term
    - D-term in Pasquini et al., Physics Letters B, 2014
  - 3 GK without D-term
- Measured asymmetry is better reproduced by the VGG model including the D-term in both mass bins

$$< M >= 1.8 \text{ GeV}; < E_{\gamma} >= 7.24 \text{ GeV}$$



$$< M >=$$
 2.25 GeV;  $< E_{\gamma} >=$  8.13 GeV



#### Motivations

Experimental setup and data set

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## Conclusions

- TCS observables were measured for the first time
- Sizeable  $A_{\odot U}$  (sensitive to ImH) and  $A_{FB}$  (sensitive to ReH) are clear signatures of TCS
- The results obtained allow to draw physical conclusions:
  - the A<sub>⊙U</sub> is well reproduced by models that reproduce existing DVCS data → hints for universality of GPDs
  - the Forward/Backward asymmetry appears to be better reproduced by model with a D-term

 $\rightarrow$  promising path to the measurement of the mechanical properties of the proton

• The analysis was reviewed by the CLAS collaboration and the article is currently under ad-hoc review (intended to submit to PRL).

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Opportunities ahead to measure TCS: EIC, Ultra-peripheral collisions (LHC), CLAS12 high lumi. upgrade