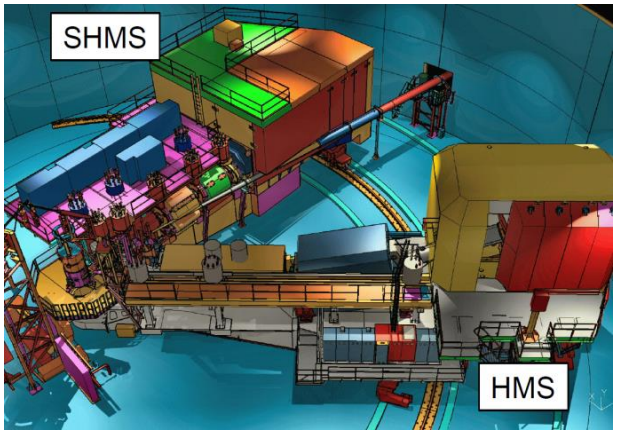
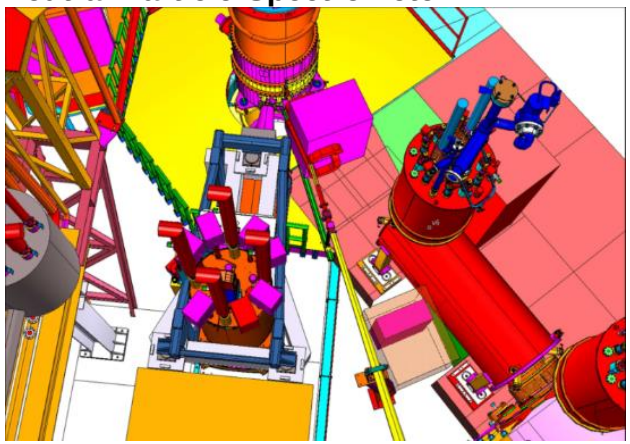
Flavour Decomposition with Precision Pion and Kaon Cross Sections

Hall C focusing spectrometers



Neutral Particle Spectrometer



Tanja Horn

The Catholic University of America

Jefferson Lab
Thomas Jefferson National Accelerator Facility

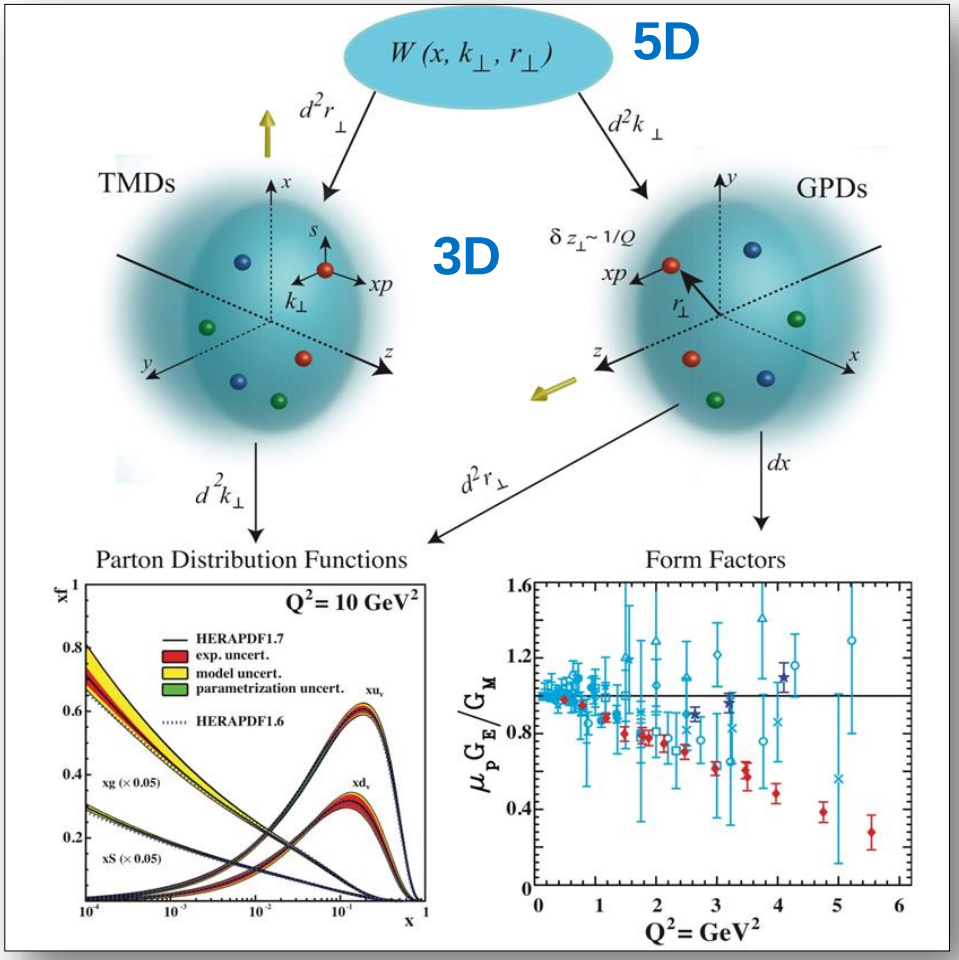
25th International Workshop on Deep Inelastic Scattering and Related Topics

3-7 April 2017, Birmingham, UK

The 3D Nucleon Structure

See also WG6 talks by D. Sokhan (GPDs) and A. Puckett, K. Allada, E. Kinney (TMDs)

Generalized Parton and Transverse Momentum Distributions are essential for our understanding of internal hadron structure and the dynamics that bind the most basic elements of Nuclear Physics



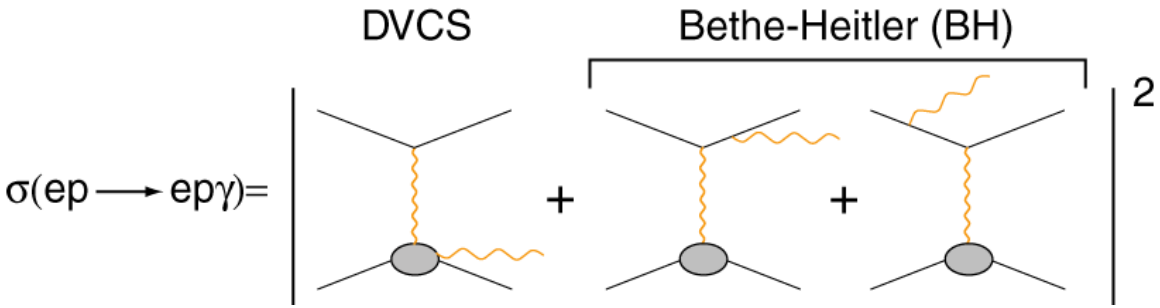
- TMDs
  - Confined motion in a nucleon (semi-inclusive DIS)
- GPDs
  - Spatial imaging (exclusive DIS)
- Requires
  - High luminosity
  - Polarised beams and targets

Major new capability with JLab12

Experimental Access to GPDs: DVCS

Deep Virtual Compton Scattering (DVCS)

See also talk by C. Munoz-Camacho



DVCS is the cleanest way to probe GPDs

- As the DVCS process interferes with BH one can access the DVCS amplitudes

At leading twist:

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\left(T^{BH}\cdot T^{DVCS}\right)$$

$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\left(T^{BH}\cdot T^{DVCS}\right) + |DVCS|^2$$

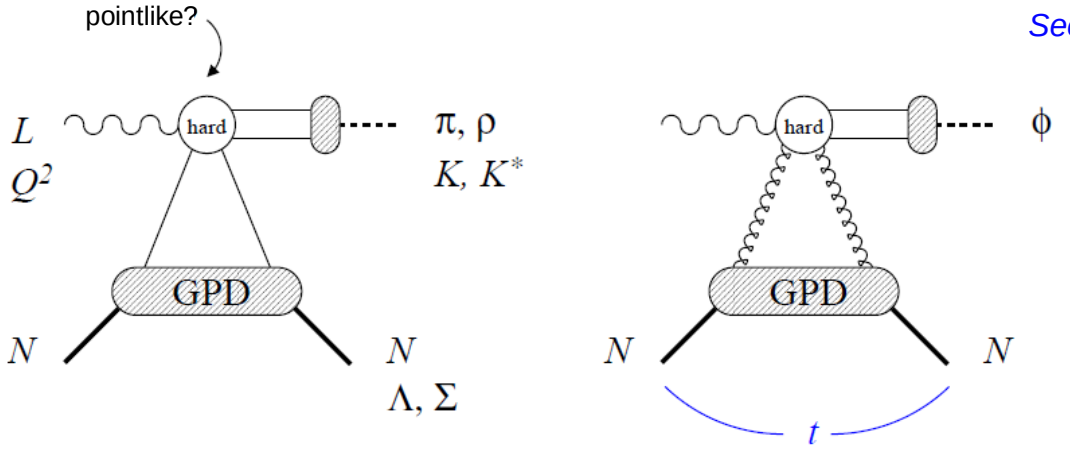
$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots =$$

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}}_{\text{Access in helicity-independent cross section}} - \underbrace{i\pi\, H(x=\xi,\xi,t)}_{\text{Access in helicity-dependent cross-section}} + \ldots$$

Towards spin-flavor separation: DVMP

Deep Virtual Meson Production (DVMP)

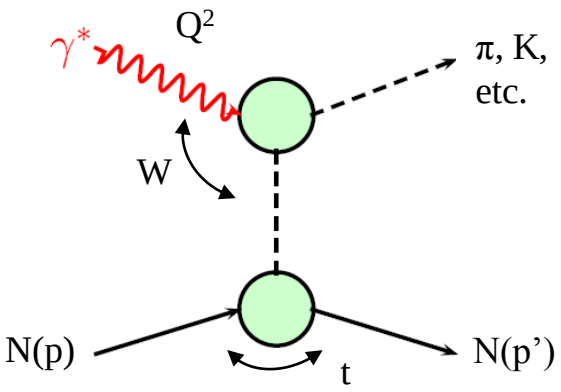
Exclusive Reactions: $\gamma^* N \rightarrow M + B$



See also talk by C. van Hulse

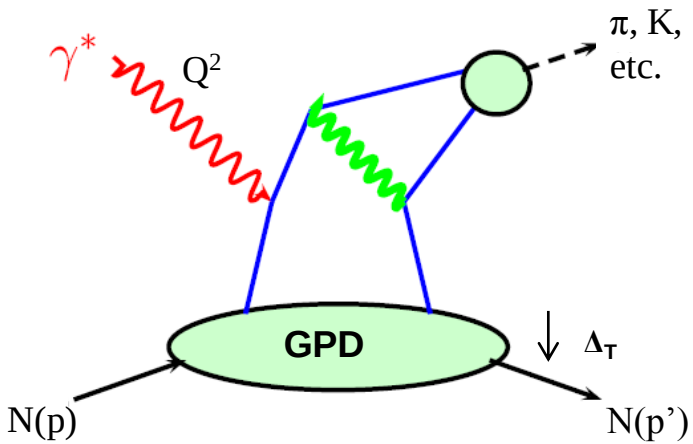
- Nucleon structure described by 4 (helicity non-flip) GPDs:
  - *H, E* (unpolarized), $\tilde{H}, \tilde{E}$ (polarized)
- Quantum numbers in DVMP probe individual GPD components selectively
  - Vector : $\rho^o/\rho+/K^*$ select *H, E*
  - Pseudoscalar: π,η,K select the polarized GPDs, $\tilde{H}$ and $\tilde{E}$
- Need good understanding of reaction mechanism
  - QCD factorisation for mesons
  - Can be verified experimentally through L/T separated cross sections

QCD Factorisation in DVMP



t-channel process

- In the limit of small –*t*, meson production can be described by the *t*-channel meson exchange (pole term)
  - Spatial distribution described by form factor

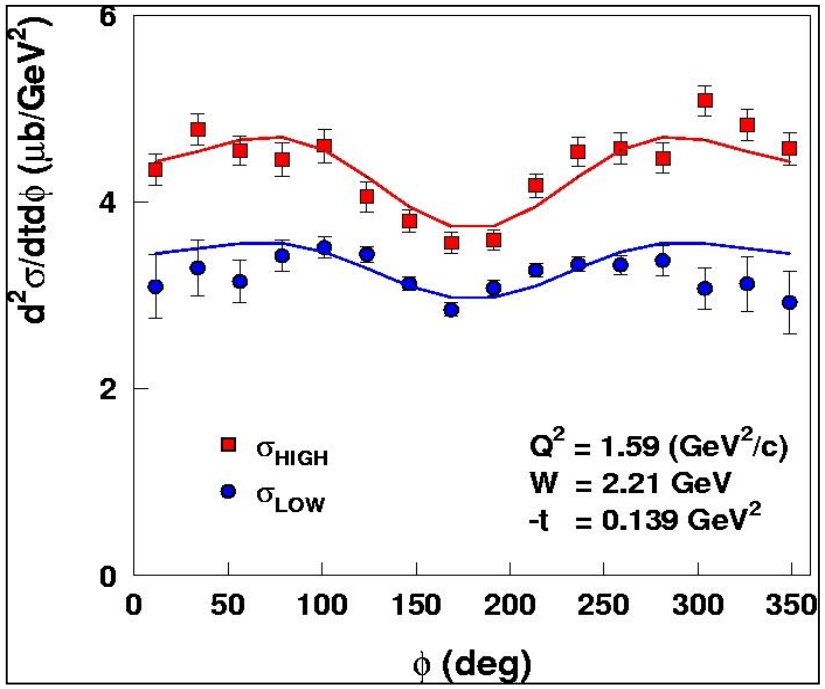


Handbag diagram

- At sufficiently high Q^2, the process should be understandable in terms of the "handbag" diagram – can be verified experimentally
  - The non-perturbative (soft) physics is represented by the GPDs
    - Shown to factorise from QCD perturbative processes for longitudinal photons *[Collins, Frankfurt, Strikman, 1997]*
  - Factorisation theorem predicts σ_L scales in this regime as Q^{-6}

Cross Section L/T Separation Example

- σ_L is isolated using the Rosenbluth separation technique
  - Measure the cross section at two beam energies and fixed W, Q^2, -t
  - Simultaneous fit using the measured azimuthal angle (ϕ_π) allows for extracting L, T, LT, and TT
- Careful evaluation of the systematic uncertainties is important due to the $1/\varepsilon$ amplification in the σ_L extraction
  - Spectrometer acceptance, kinematics, and efficiencies
- Magnetic spectrometers a must for such precision cross section measurements
  - This is only possible in Hall C at JLab



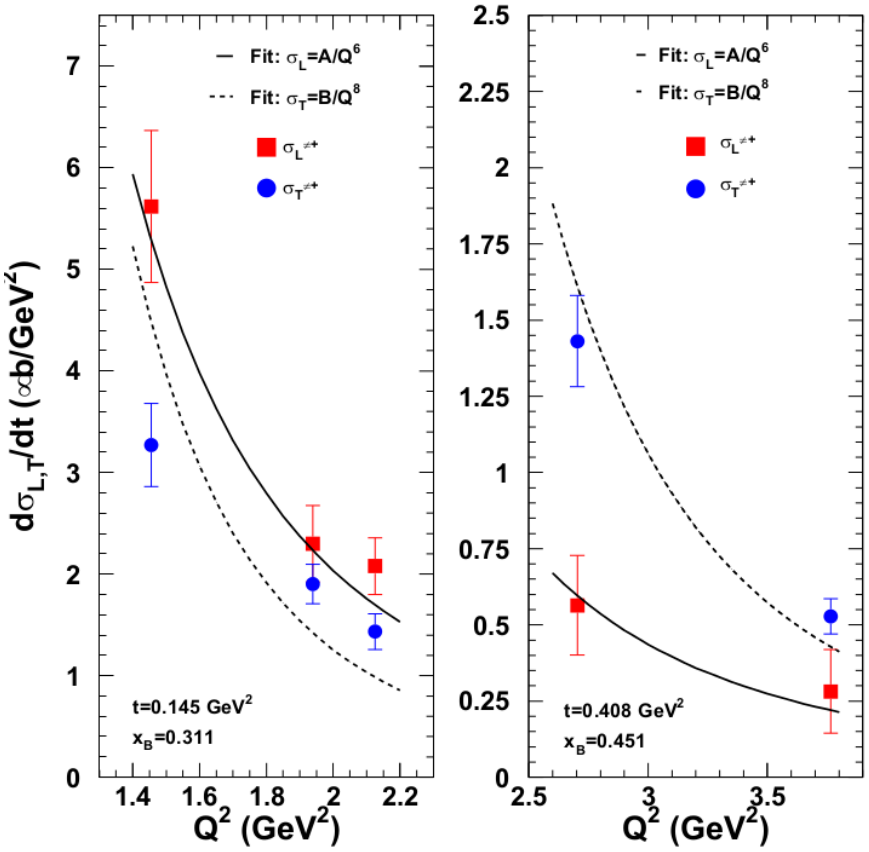
$$2\pi\frac{d^2\sigma}{dtd\phi} = \varepsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

σ_L for testing QCD factorisation

Relative L/T contribution to the meson cross section

Important for nucleon structure studies

π^+ data from 6 GeV JLab



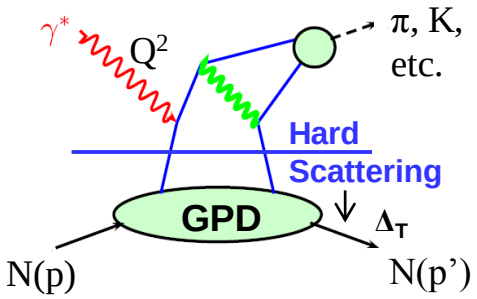
[Favart, Guidal, Horn, Kroll , EPJA (2016)]

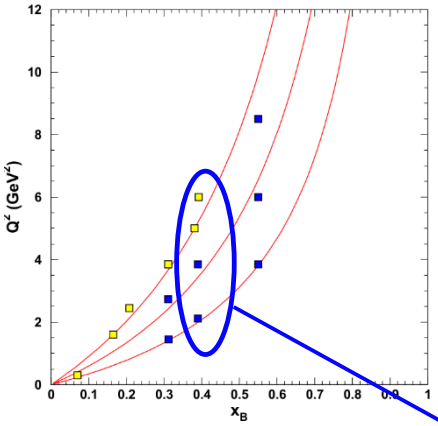
- Data from JLab 6 GeV demonstrated the technique of measuring the Q^2 dependence of L/T separated cross sections at fixed x and t

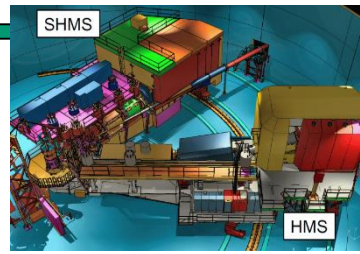
  *[T. Horn et al., Phys. Rev. C **78**, 058201 **(2008)**]*

- For interpretation of the JLab GPD program need to know:
  - Relative contribution of σ_L and σ_T
  - t/Q^2 dependence of σ_L and σ_T

JLab12: confirming potential for nucleon structure studies with pion production





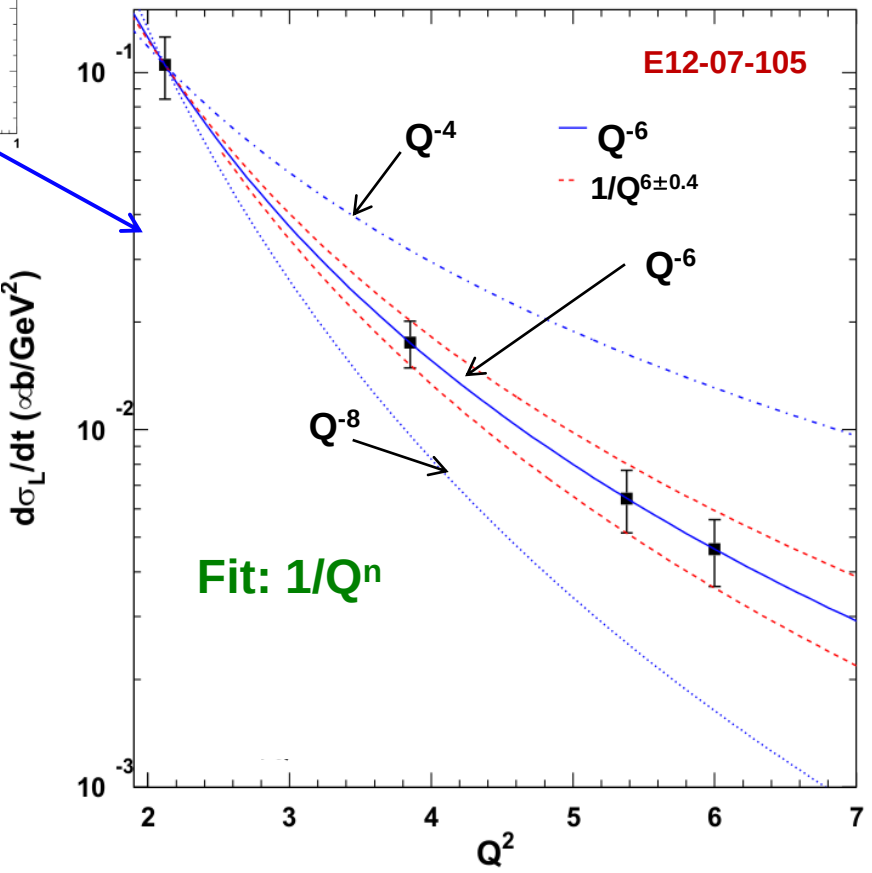


*E12-**07**-105 spokespersons: T. Horn, G. Huber*

- **E12-07-105 (P12):** Measure the Q^2 dependence of the π electro production cross section at fixed x and -t
  - Factorisation theorem predicts σ_L scales to leading order as Q^{-6}

x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.3	1.5-2.7	2.0-2.6	0.1
0.4	2.1-6.0	2.0-3.2	0.2
0.5	3.9-8.5	2.0-2.8	0.5

Considered for running **in 2019**



Transverse Contributions in pion production

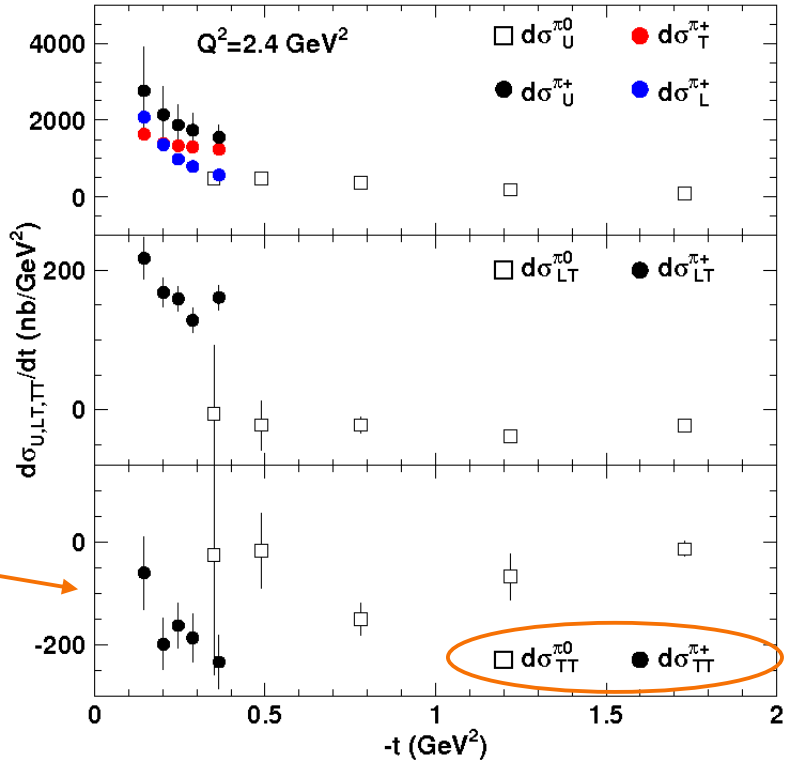
*[Favart, Guidal, Horn, Kroll , EPJA (**2016**)]*

- Recent data suggest that transversely polarized photons play an important role in charged and neutral pion electroproduction
  - π^+: σ_T magnitude is large even at Q^2=2.5 GeV^2
  - π^o: σ_T is large even at Q^2=2 Gev^2

    *[M. Defurne et al, PRL **117 (2016)** no.26, 262001]*

    See also talk by F. Sabatie
  - substantial fraction of σ_{TT} in the *unseparated* cross section for t > 0.2 GeV^2

    *[*Bedlinskiy et al, PRL**109**, **(2012)** *109; arXiv:1405.0988* ***(2014)****]*



Measurements of relative σ_L and σ_T contributions to the π cross section to higher Q^2 planned for JLab 12 may shed light on this

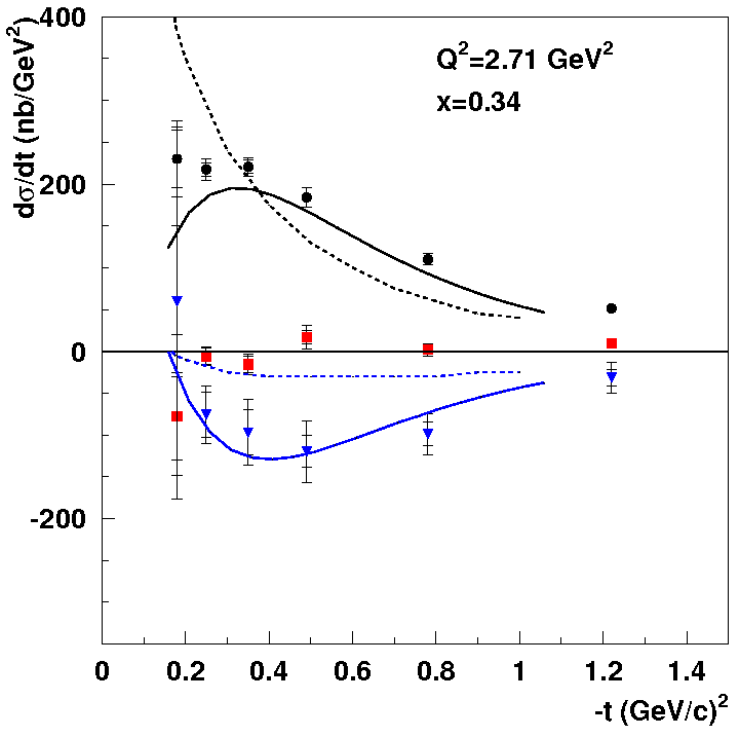
- Exclusive π^o data may also be helpful for constraining non-pole contributions in F_π extraction

*E12-**07**-105 spokespersons: T. Horn, G. Huber*

*E12-**13**-010 spokespersons: C. Munoz-Camacho, T. Horn, C. Hyde, R. Paremuzyan, J. Roche; E12-**06**-101: K. Joo et al.*

Transverse Contributions may allow for probing a new set of GPDs

*[Favart, Guidal, Horn, Kroll , EPJA (**2016**)]*



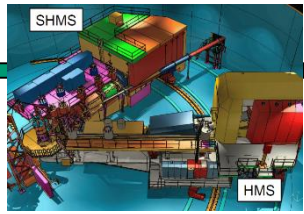
*Goloskokov, Kroll, EPJ C65, 137 (2010); EPJ A45, 112 (**2011**)*

*[Ahmad, Goldstein, Liuti, PRD **79 (2009)**]*

*[Goldstein, Gonzalez Hernandez, Liuti, J. Phys. G **39 (2012)** 115001]*

- To access transversity GPDs need transverse photons to dominate
  - Separated precision charged pion data confirmed a large contribution of transverse photons up to Q^2=2.45 GeV^2
  - Model predictions based on handbag in good agreement with data
- For pion and kaon production the relative contribution of longitudinal and transverse photons in JLab 12 GeV kinematics has to be verified
- A large transverse cross section in meson production may allow for accessing helicity flip GPDs

JLab12: confirming potential for nucleon structure studies with kaon production



- **E12-09-011**: Separated L/T/LT/TT cross section over a wide range of Q^2 and t

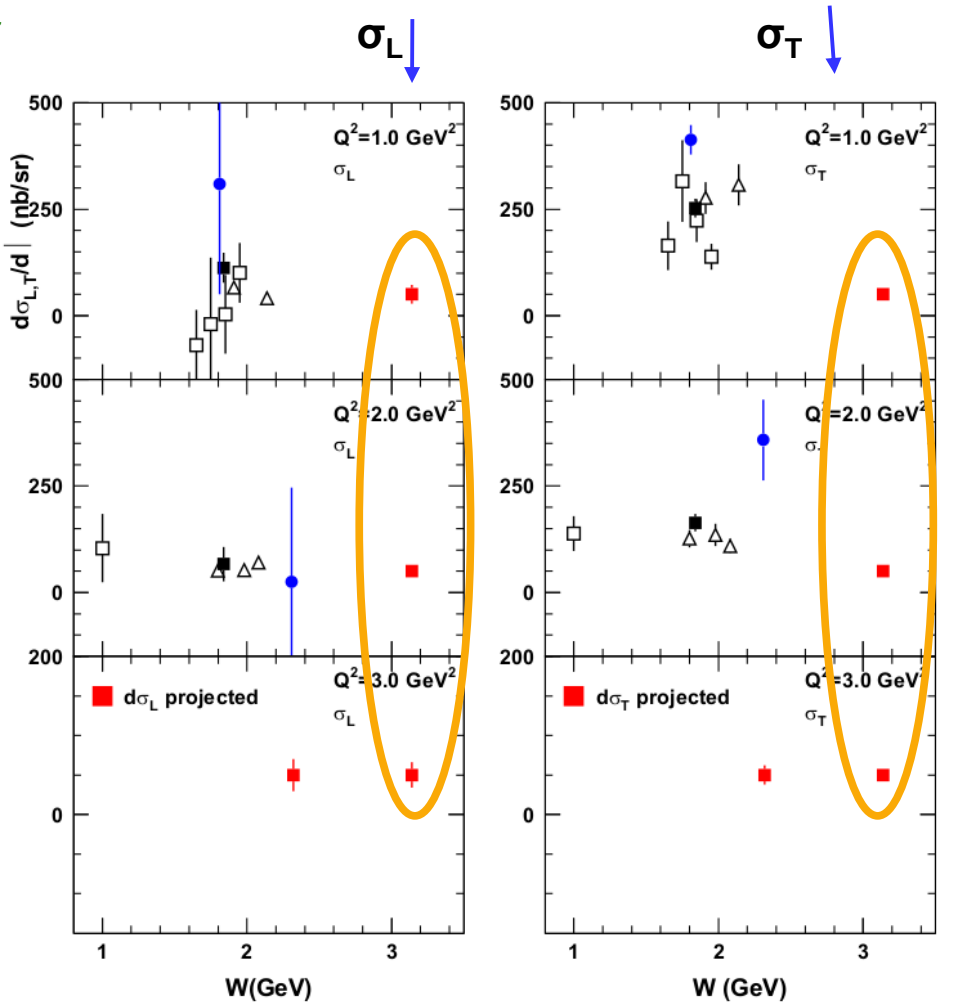
*E12-**09**-011spokespersons: T. Horn, G. Huber, P. Markowitz*

JLab 12 GeV Kaon Program features:

- First cross section data for Q^2 scaling tests with kaons
- Highest Q^2 for L/T separated kaon electroproduction cross section
- First separated kaon cross section measurement above W=2.2 GeV

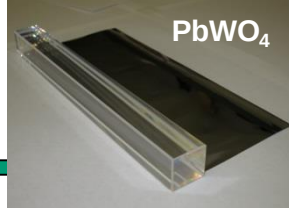
approved for 40 PAC days and **scheduled to run in 2017/18**

x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.1-0.2	0.4-3.0	2.5-3.1	0.06-0.2
0.25	1.7-3.5	2.5-3.4	0.2
0.40	3.0-5.5	2.3-3.0	0.5



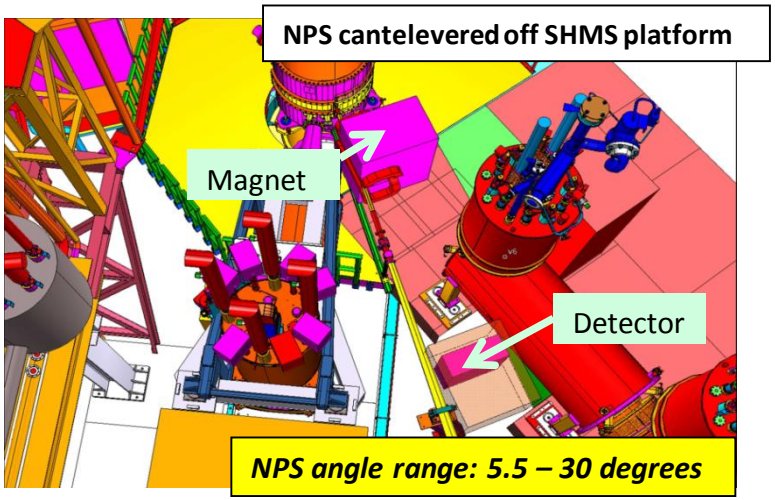
*[blue points from M. Carmignotto, PhD thesis **(2017)**]*

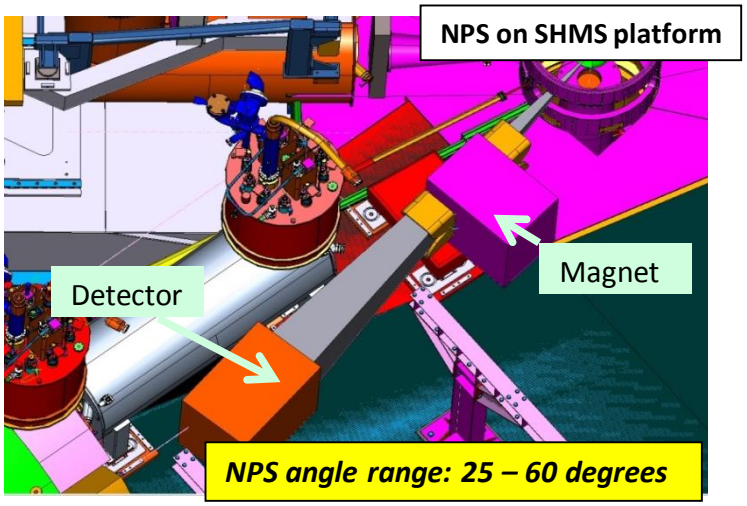
The Neutral-Particle Spectrometer



NSF MRI PHY-1530874

- The NPS is envisioned as a facility in Hall C, utilizing the well-understood HMS and the SHMS infrastructure, to allow for precision (coincidence) cross section measurements of neutral particles (γ and π^0).



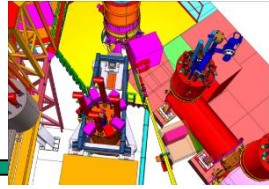


- Scientific program: 5 experiments approved by PAC to date

See also talk by E. Kinney

  - E12-13-007: Measurement of Semi-inclusive π^0 production as Validation of Factorization
  - E12-13-010 – Exclusive Deeply Virtual Compton and π^0 Cross Section Measurements in Hall C
  - E12-14-003 – Wide-angle Compton Scattering at 8 and 10 GeV Photon Energies
  - E12-14-005 – Wide Angle Exclusive Photoproduction of π^0 Mesons
  - E12-14-006 – Initial State Helicity Correlation in Wide-Angle Compton Scattering

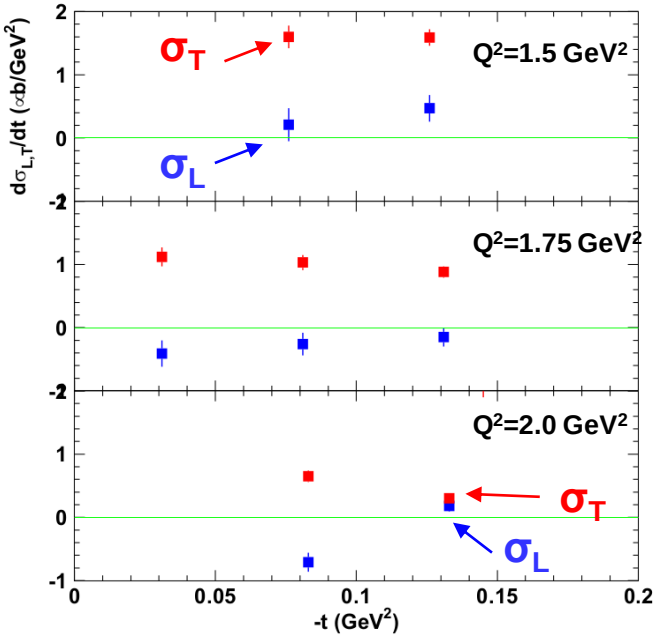
E12-13-010: exclusive π^0 cross section



- Relative L/T contribution to π^0 cross section important in probing transversity
  - If σ_T large: access to transversity GPDs
- Results from Hall A at 6 GeV Jlab suggest that the longitudinal cross section in π^0 production is non-zero up to Q^2=2GeV^2

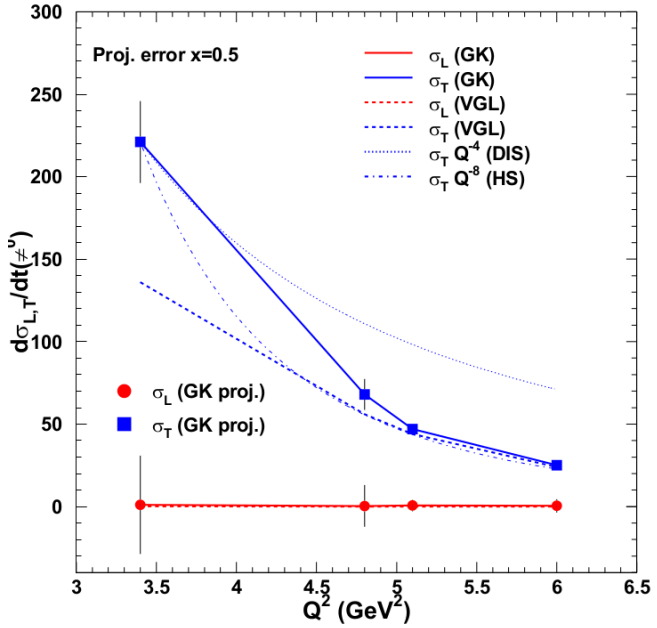
See also talk by F. Sabatie

- Need to understand Q^2/t dependence for final conclusion on dominance of σ_T



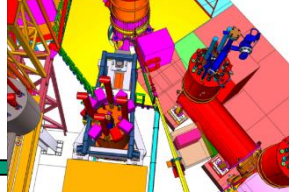
*M. Defurne et al, PRL **117** (**2016**) no.26, 262001*

E12-13-010 projections

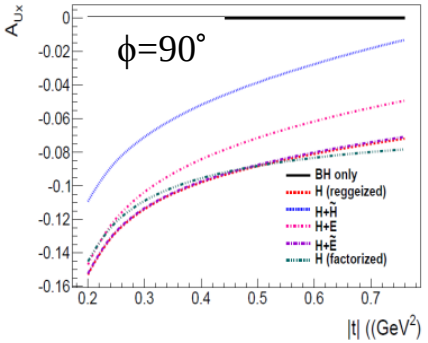


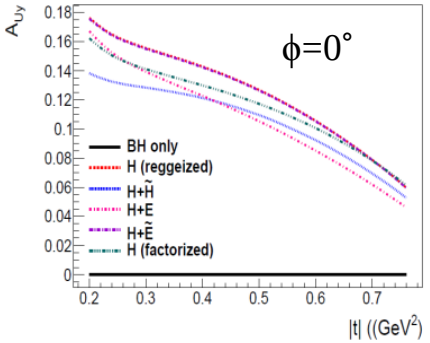
E12-13-010 will provide essential data on σ_T and σ_L at higher Q^2 for reliable interpretation of 12 GeV GPD data

LOI12-15-007: Timelike Compton Scattering with Transverse targets

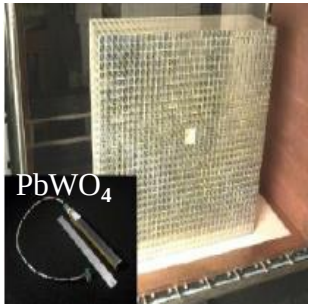


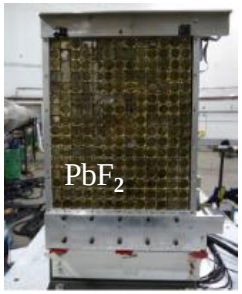
- Features of TCS measurements with transversely polarized target
  - Theoretical calculations show that transverse asymmetries are very sensitive to GPDs
    [M. Boer, M. Guidal, arXiv:1412.2036]
  - Asymmetries for the BH the main background for TCS is zero!
  - Predictions for asymmetries with different assumption of GPDs vary up to 20%

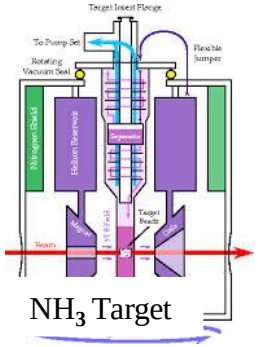


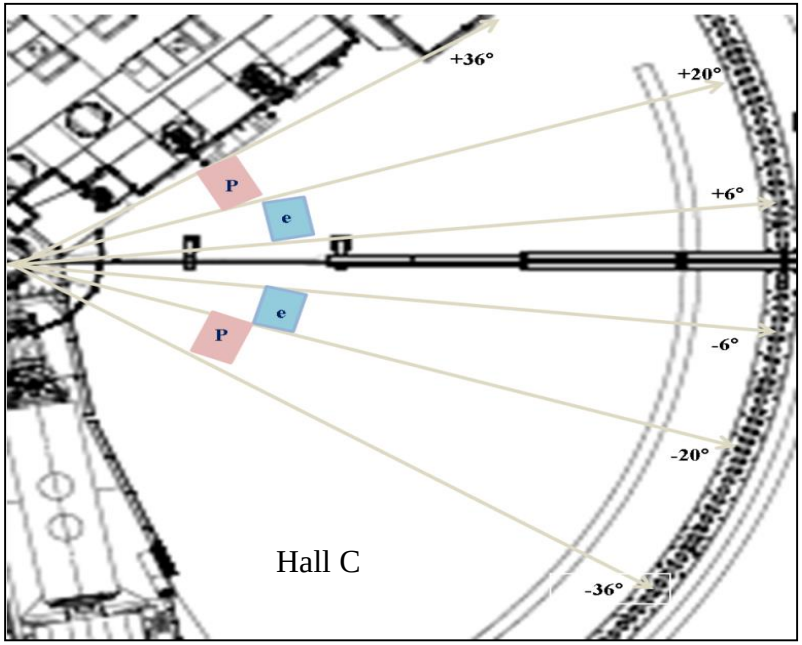


- TCS event detection with NPS
  - Lepton pair will be detected by pair of NPS
  - Recoil detection by combination of tracking and TOF







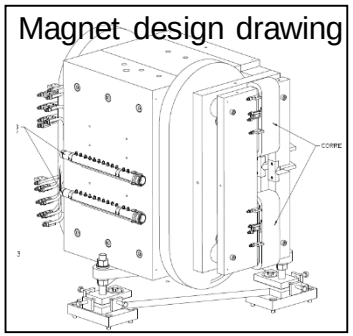


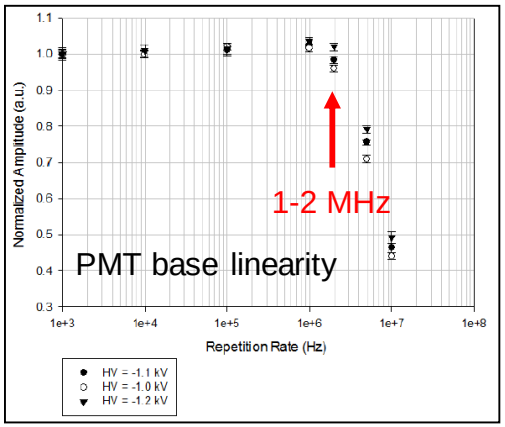
TCS measurements with transversally polarized target open interesting opportunities for probing GPD E

NPS Project Status

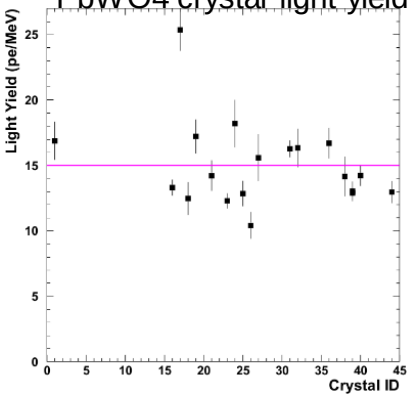
The Catholic University of America

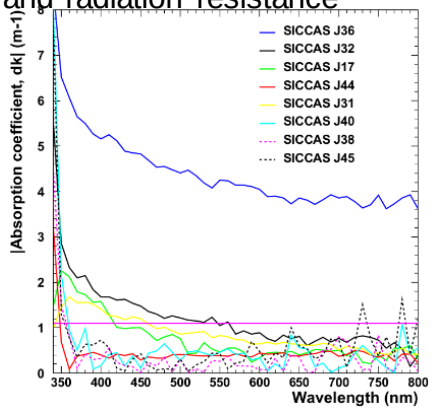
- Magnet: design drawings finalized, procurement of main and corrector coil awarded, yoke ongoing
- PMT and HV bases: design drawings final, vendor selection ongoing, linearity test complete, magnetic shielding concept selected
- Frame and integrated systems: initial design drawings completed, specifications for Light Monitoring System and curing system ongoing
- Crystals: characterization of systematic dependencies, irradiation studies, chemical analysis and crystal growing in collaboration with the Vitreous State Laboratory (VSL), synergy with EIC crystal calorimeter R&D





PbWO4 crystal light yield and radiation resistance





Summary and Outlook

- Precision cross section measurements are essential for the GPD program at 12 GeV JLab
  - Validate applicability of hard-soft factorization in exclusive processes required for accessing GPDs
- The neutral particle physics program in Hall C plays an important role in the GPD program
- The Neutral Particle Spectrometer gives unique opportunity for coincidence precision cross section measurements with neutral particles
  - Preparations for NPS design/construction underway