Generalized Parton Distributions programs at SoLID

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*speaker

OUTLINE

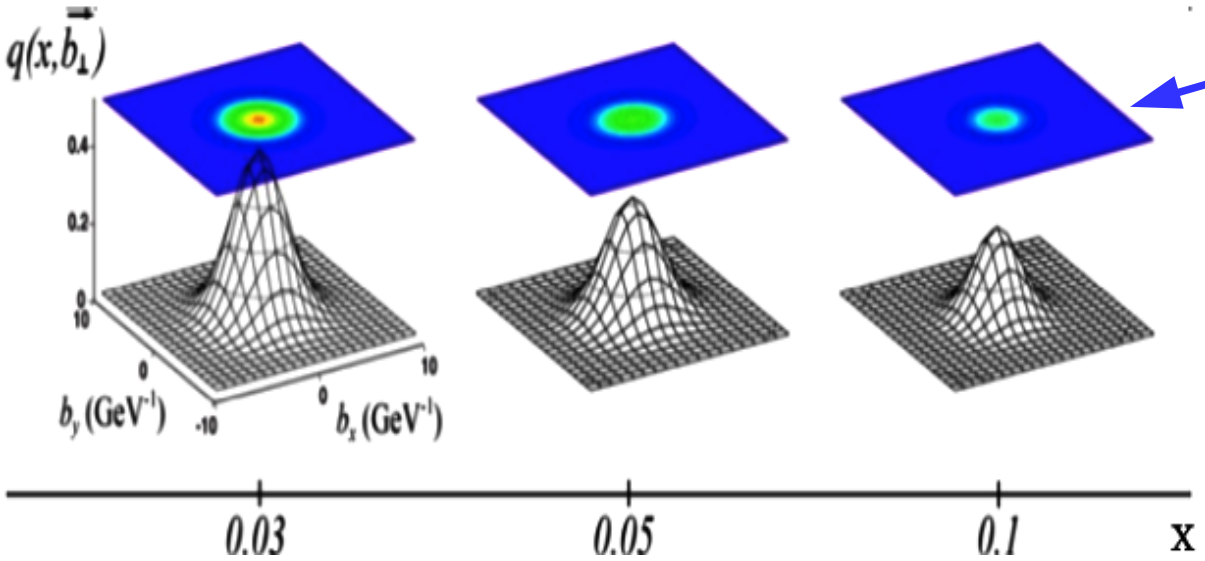
- GPD physics
  - reactions
  - fits of Compton Form Factors
- GPD projects for SoLID
  - DVCS
  - TCS
  - DDVCS
- Technical requirements for these programs

Generalized Parton Distributions of the nucleon

Goal: **A 2+1 dimensional picture of the nucleon**

GPD contain the correlation between transverse distribution of partons in nucleon and their longitudinal momenta → momentum dependent transverse distributions in position, spin...

Momentum dependent impact parameter distribution:

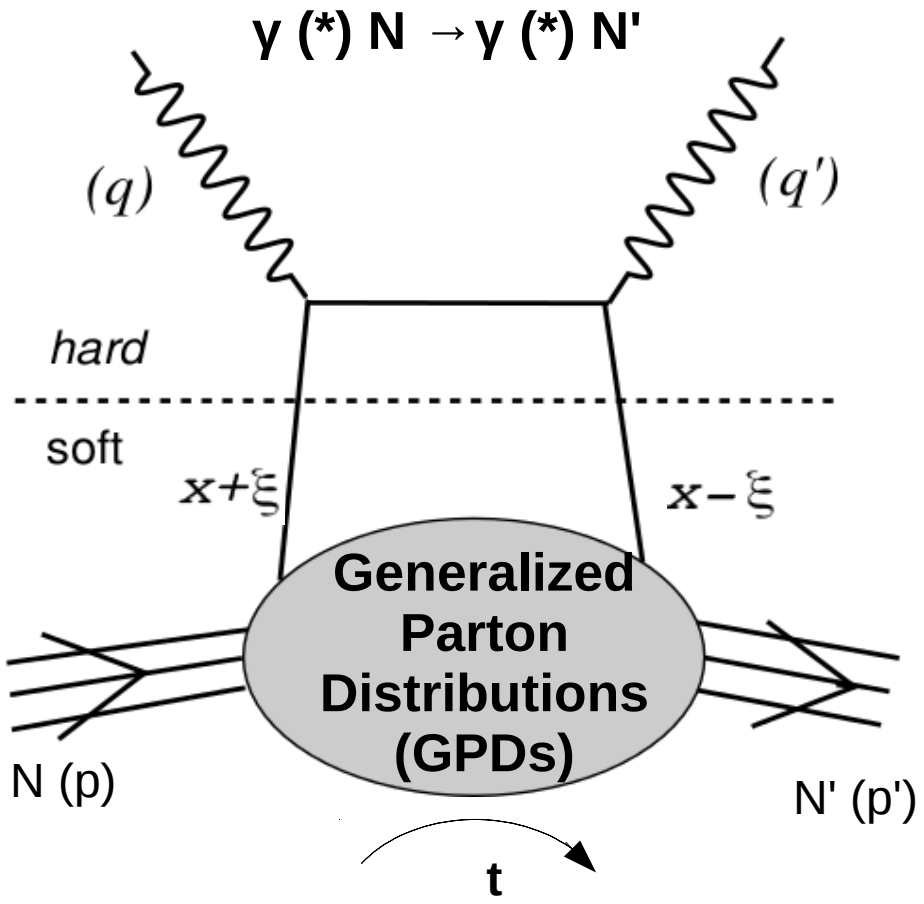


transverse momentum distributions
from momentum transfer² t-dependence
→ form factors = first momenta of GPDs

longitudinal momentum fraction
x-dependent parton densities
→ pdf = limits of GPDs at t=0

How could SoLID be involved in the measurement of the GPD ?

Exclusive Deeply Virtual Compton processes



x : longitudinal momentum fraction of the struck quark
ξ : longitudinal momentum transfer
t : momentum transfer squared
$Q^2 = -q^2$; $Q'^2 = +q^2$: hard scale

Different exclusive processes involving photons, same GPDs :

- outgoing photon is real: **DVCS**
(spacelike) Deeply Virtual Compton Scattering: e N → e' γ N'

- incoming photon is real: **TCS**
Timelike Compton Scattering:
γ N → l^+l^- N'

- both photons are virtual: **DDVCS**
Double Deeply Virtual Compton Scattering: e N → e' l^+l^- N'

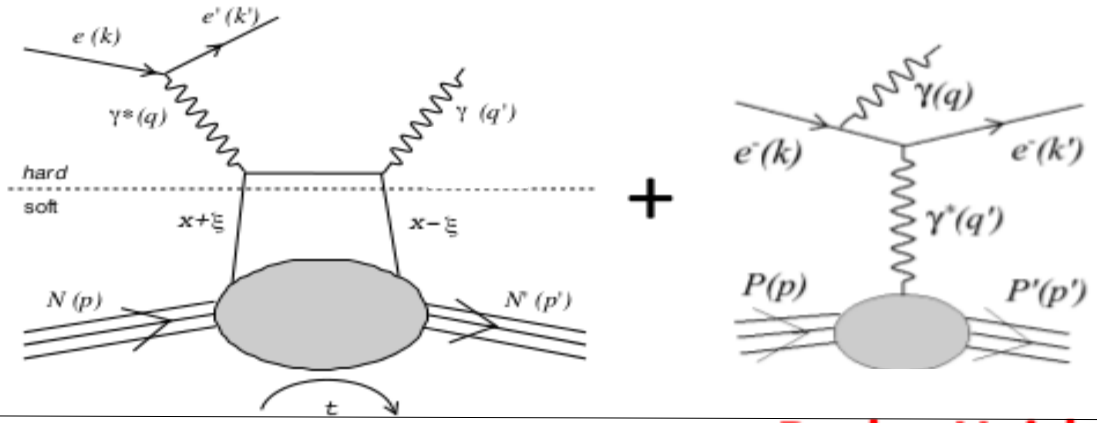
(l stands for any lepton,
beam could also be another lepton)

Access 4 chiral even nucleon's quark GPD (scattering off a nucleon): H, E, $\tilde{H}$, $\tilde{E}$
→ unpolarized and polarized distributions of quarks u and d in the nucleon
→ flavor separation by comparison of proton and neutron GPD
$H^p = 4/9\ H^u + 1/9\ H^d$ $H^n = 1/9\ H^u + 4/9\ H^d$

Compton processes + Bethe-Heitler

DVCS + BH

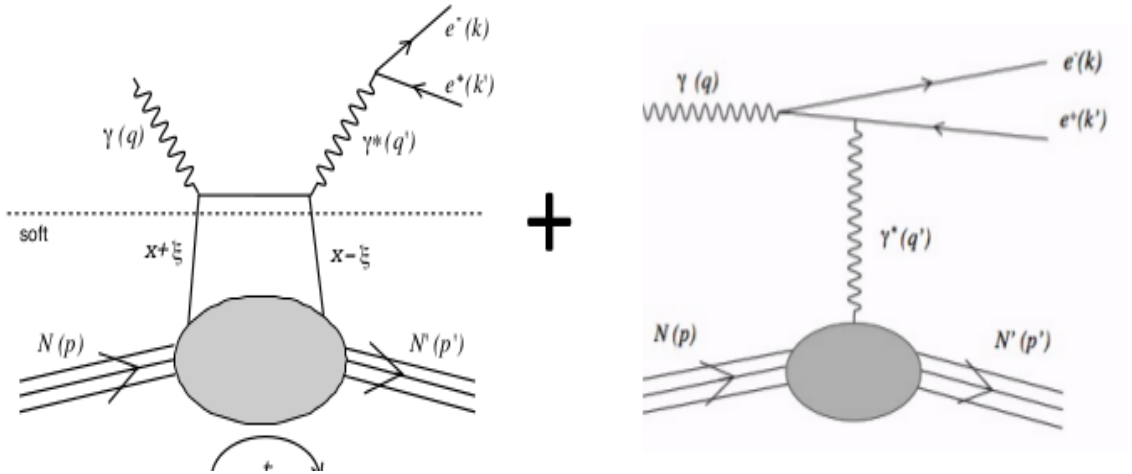
eN → e'γN'=



- interference with BH
- BH sensitive to Form Factors
- deconvolution : angular analysis, spin/charge asym...

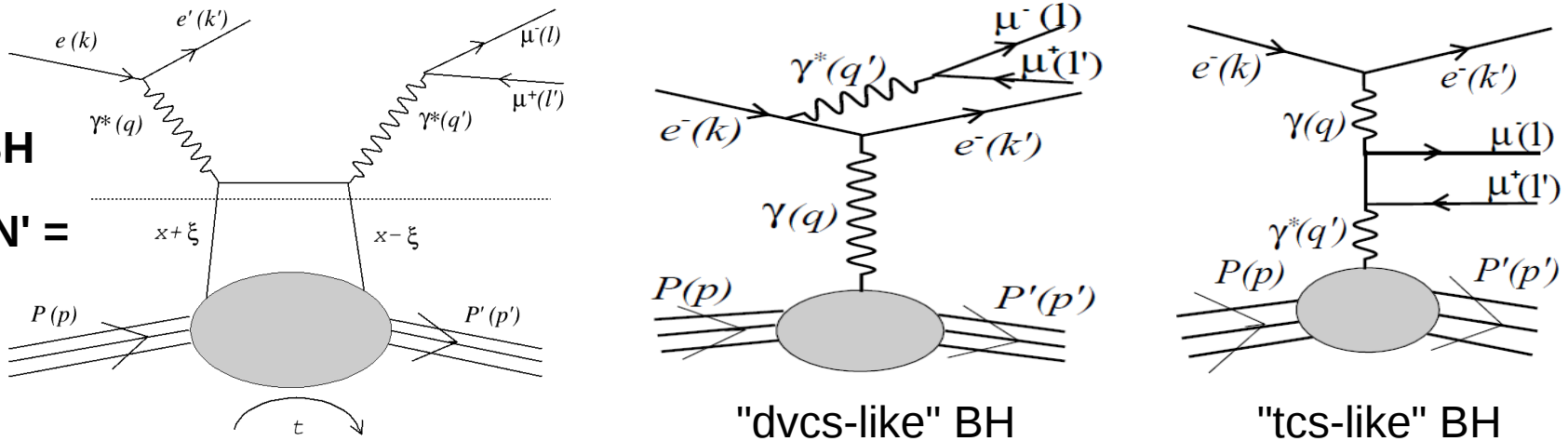
TCS + BH

γN → e⁺e⁻N=

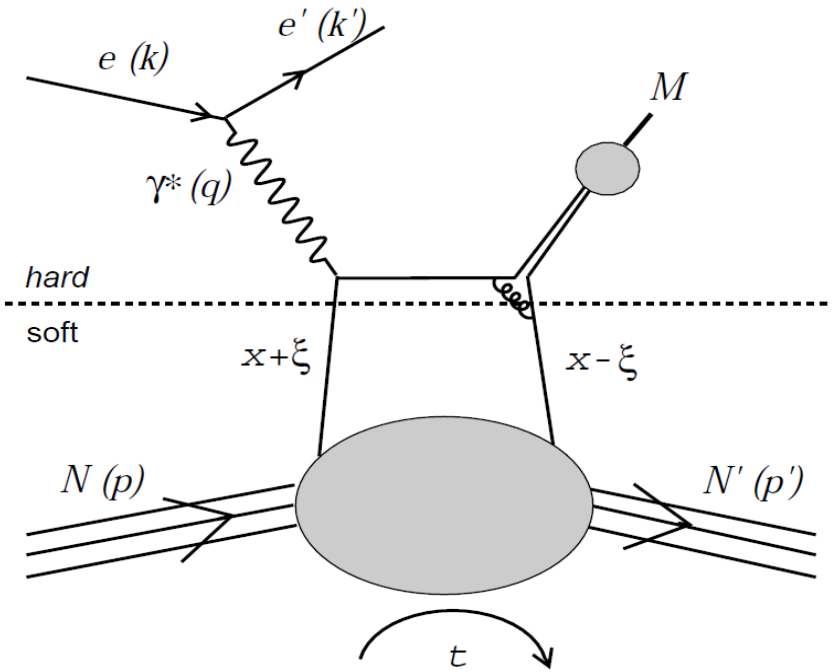


DDVCS + BH

e N → e' l⁺l⁻ N' =



Other processes: Deeply Virtual Meson Production



Selection of different combinations of GPD depending on meson spin-parity and flavor content

→ flavor separation, gluons

→ easier access to some GPDs compared to virtual Compton processes

- but additional non perturbative part, interpretation (scaling...), need phenomenological models to fit data...

*only Compton processes in the following of this talk

Exclusive pion production at SoLID: talk GM Huber, SoLID meeting May 2015

Extraction of GPDs and Compton Form Factors

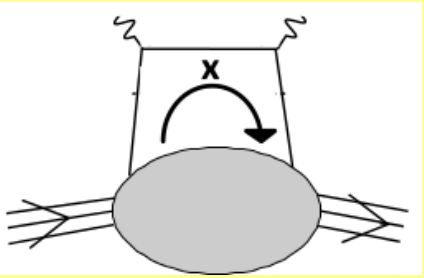
¤ Case of DVCS and TCS:

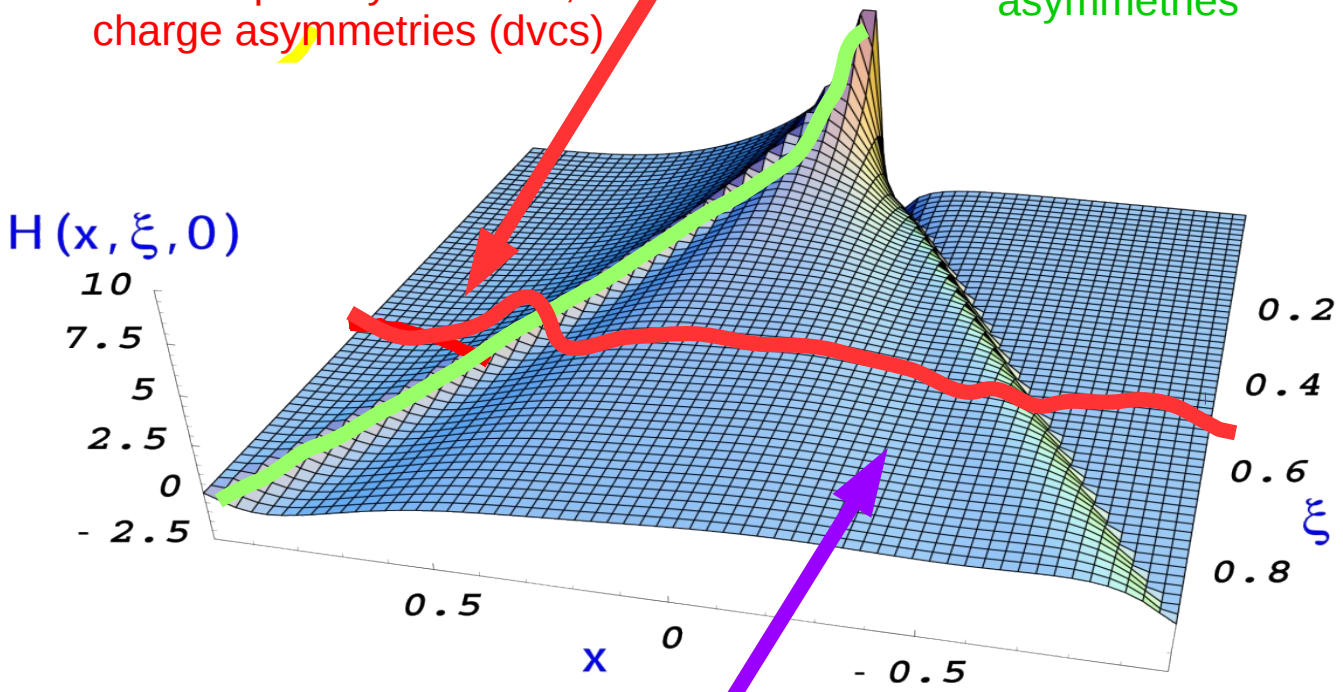
$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx - i\pi H(\pm\xi,\xi,t) + \ldots$$

cross sections,
double spin asymmetries,
charge asymmetries (dvcs)

single spin
asymmetries

ξ, t = measurable ; x = loop





¤ Case of DDVCS and
exclusive meson production:

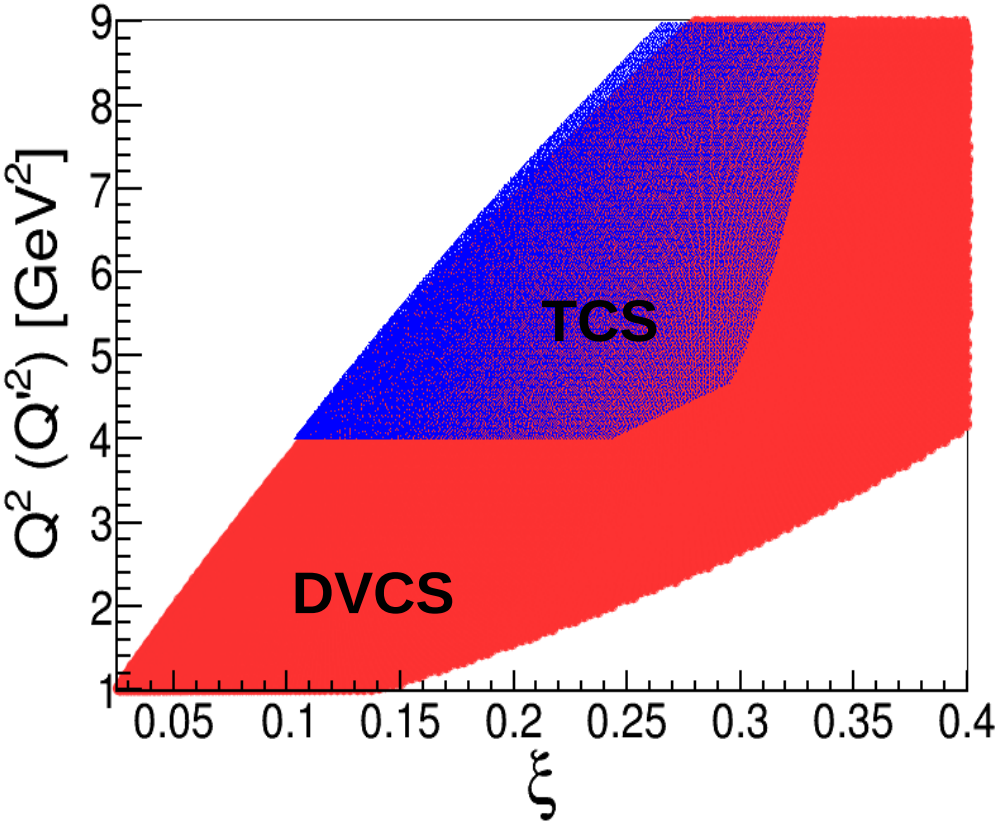
lever arm in Q'^2/Q^2 to access the
"out of diagonal" part of H(x, ξ, 0)

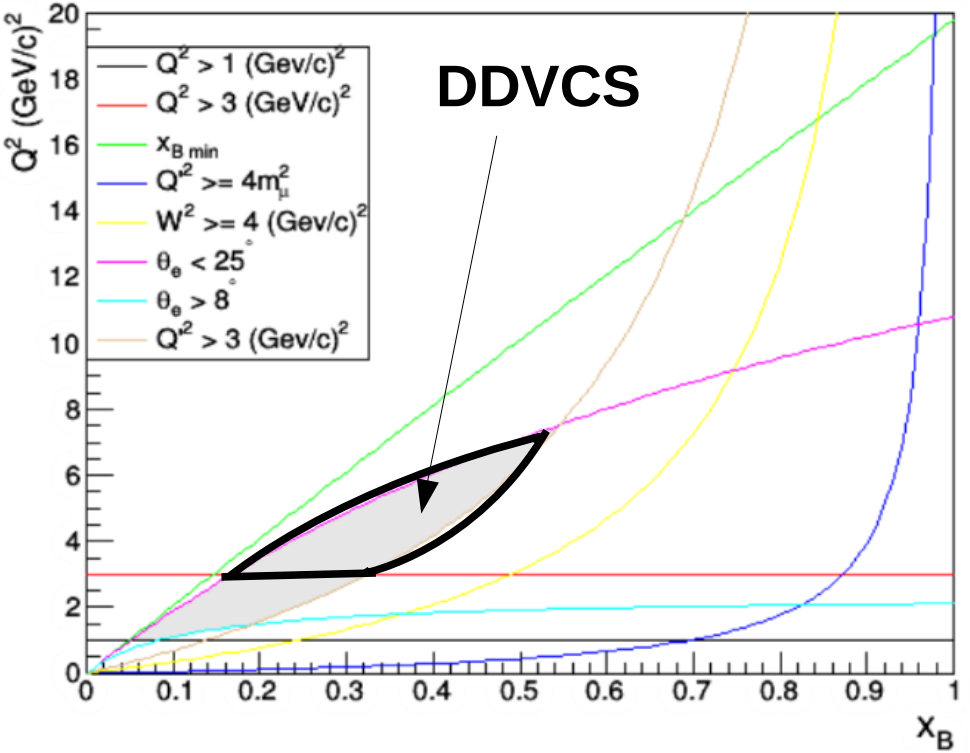
pole at $x = \pm \xi \frac{(1 - Q'^2/Q^2)}{(1+Q'^2/Q^2)}$

Unique way to access at GPD(x≠ξ), needed for deconvolution
of these 2 variables and for "3D" imaging at ξ=0.

Phase Space for these reactions (11 GeV electron)

[no acceptance considerations]





DVCS : already measured at 6 GeV, extension of the phase space

TCS: out of vector mesons resonance region
→ only at high Q'^2, need high luminosity

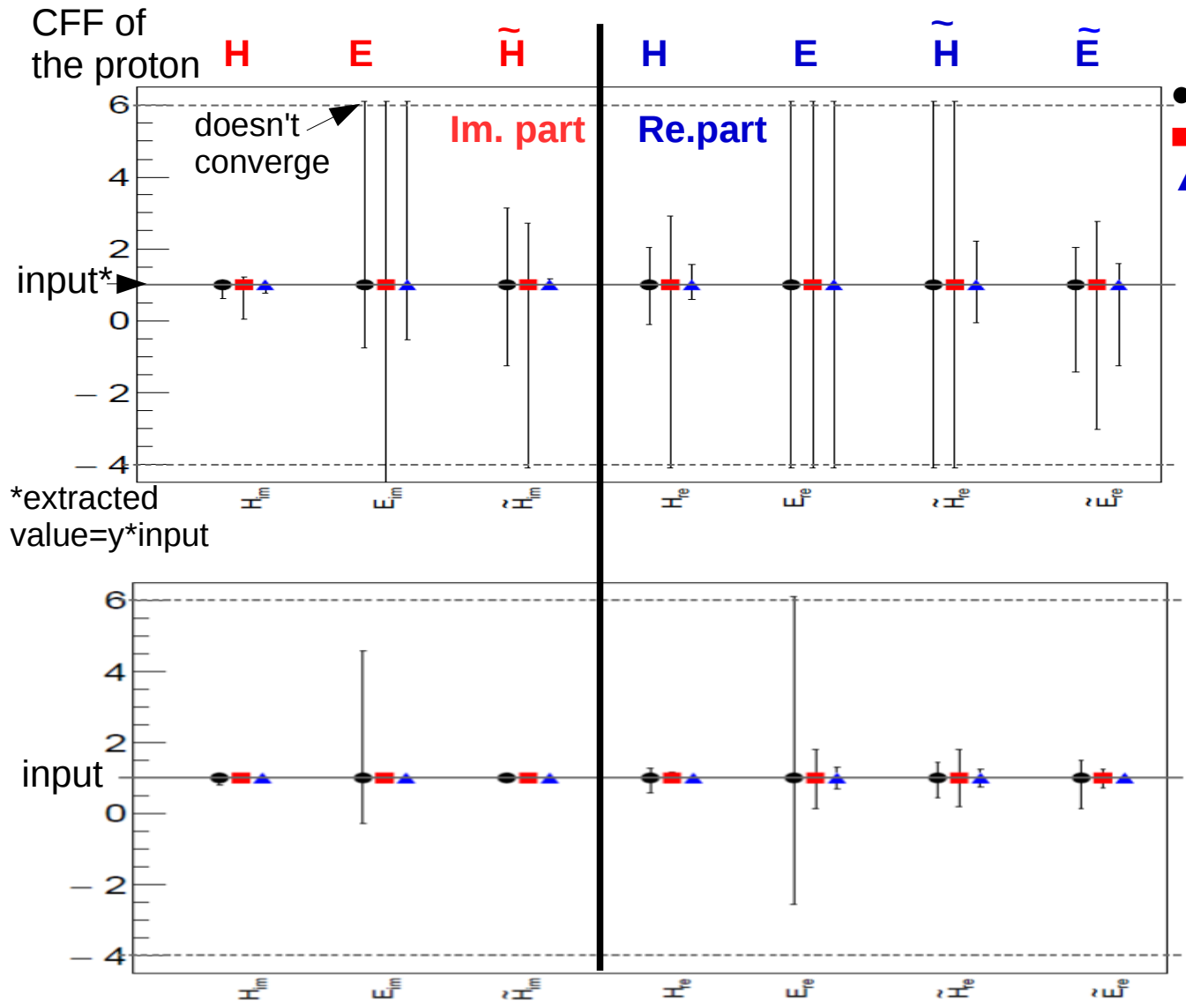
Common region: maybe used for comparison of measured Compton Form Factors and for combined CFFs fits of DVCS+TCS
(same CFF at first order)

DDVCS: very narrow phase space
(not all the cuts are represented)
→ only at high Q'^2 (like TCS)
→ need very high luminosity due to the multiple kinematical cuts and both high Q^2 and Q'^2

Complementarity on fits: what could we achieve with DVCS + TCS?

exercise with simulation: doesn't represent any realistic case / just comparative (relative statistics...) [in progress]

DVCS: observables already measured at JLab@6 GeV, TCS: proposed measurements



● DVCS $\sigma, \Delta\sigma_{LU}$
■ TCS $\sigma, \Delta\sigma_{\odot U}$
▲ **DVCS+TCS**

poorly constrained: 2 indep. observables for 7 free parameters

→ **Im. part better constrained**
→ **DVCS more sensitive to GPD than TCS**
→ **improvement with both reactions**
→ **Re(H), Im(H), Im($\widetilde{H}$)**

● DVCS $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{Uz}, \Delta\sigma_{Lz}$
■ TCS $\sigma, \Delta\sigma_{\odot U}, \Delta\sigma_{LU}, \Delta\sigma_{Ux}, \Delta\sigma_{Uy}$
▲ **DVCS+TCS**

! 5 independent obs. TCS, 4 DVCS

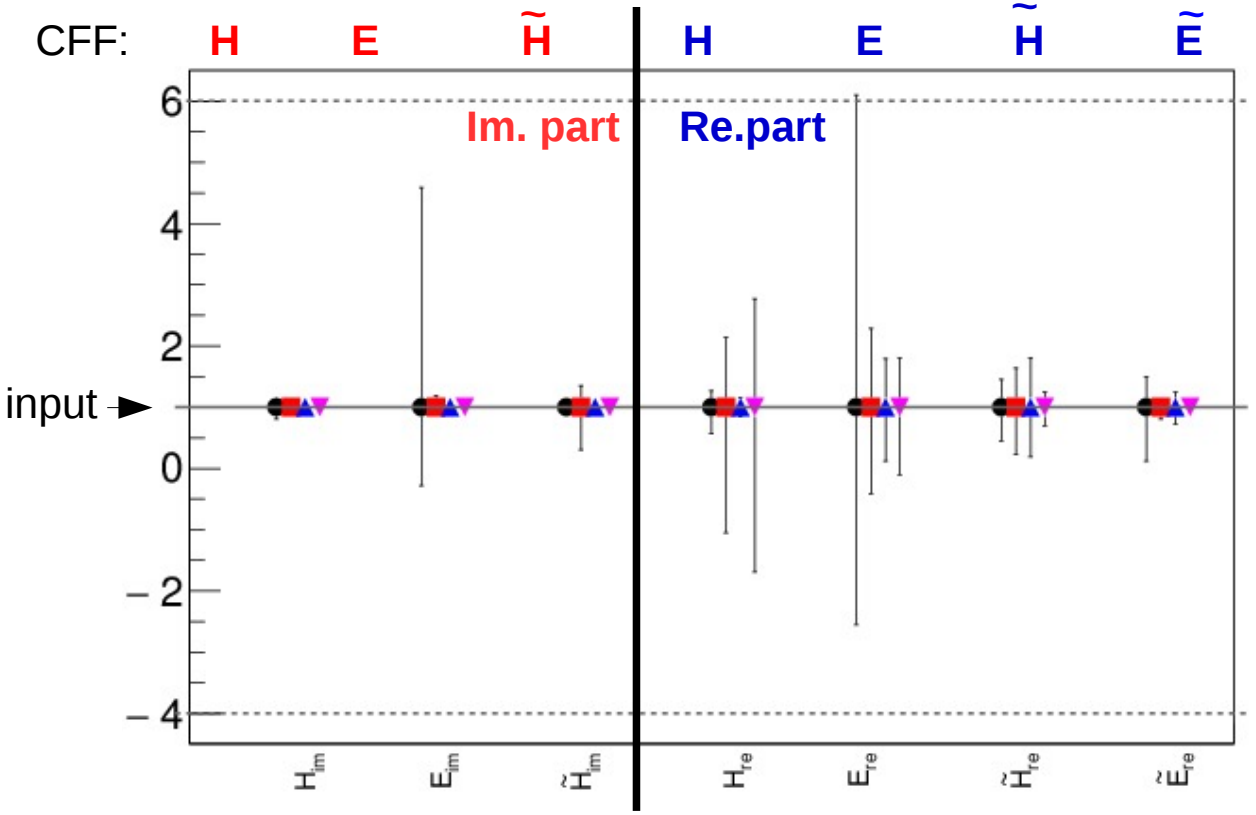
→ **extraction of E with combination**
→ **constraint Re. Part of CFF**
→ **7 independent obs. for 7 CFF with combined fits: extraction of all of them**

- Complementarity: DVCS+TCS observables for fits, assuming same CFF for DVCS and TCS (LO/twist)
- Comparison of GPD H with DVCS or TCS (high precision required): check universality => for SoLID.
- Equivalent results with transversally polarized target DVCS... this example is not exclusive

Comparison: fits of proton and neutron CFF with DVCS and TCS

exercise with simulation: doesn't represent any realistic case / just comparative (relative statistics...) [in progress]

DVCS: observables already measured at JLab@6 GeV, TCS: proposed measurements



- DVCS p
- DVCS n

$\sigma, \Delta\sigma_{LU}, \Delta\sigma_{Uz}, \Delta\sigma_{Lz}$

- TCS p
- TCS n

$\sigma, \Delta\sigma_{\odot U}, \Delta\sigma_{LU}, \Delta\sigma_{Ux}, \Delta\sigma_{Uy}$

! 5 independent obs. TCS, 4 DVCS,
Not same set of observables (as previous slide)

→ **Im. part better constrained for p and n**

- both proton and neutron are needed to separate u and d quark GPD
- similar results for DVCS p compared to n and TCS p compared to n

- Re(H) poorly constrained with neutron compared to proton
- "n" more sensitive to GPD E than "p", "p" more sensitive to GPD H compared to "n".

e P → e' y P

DVCS @ SoLID

Goal: measurement of DVCS off (polarized) proton or neutron with polarized e⁻

→ measurement of all combinations of beam and/or target spin asymmetries, polarized cross-sections

→ other experiment in Hall A, B, C have already published results or accepted proposals, no DVCS@SoLID yet

→ transversally polarized neutron would be new if proposed for SoLID => GPD E, spin...

→ high luminosity and large acceptance of SoLID are a plus for this purpose / systematics are to be studied

→ work in progress (Z. Ye...):

need background simulations, clarify what are the resolutions especially for the neutron detection, studies on what are the needs for the experimental setup: recoil detector?... manpower welcome!

➢ DVCS with polarized electron beam and targets: Z. Ye, May 2015

Polarization	Asymmetries	CFFs
Longitudinal Beam	A_{LU}	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_p, \mathcal{E}_n\}$
Longitudinal Target	A_{UL}	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
Long. Beam + Long. Target	A_{LL}	$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
Transverse Target	A_{UT}	$Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n\}$
Long. Beam +Trans.Targt	A_{LT}	$Re\{\mathcal{H}_p, \mathcal{E}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n\}$

NH3: Transversely polarized (proton)

He3: Transversely & Longitudinally polarized (neutron)

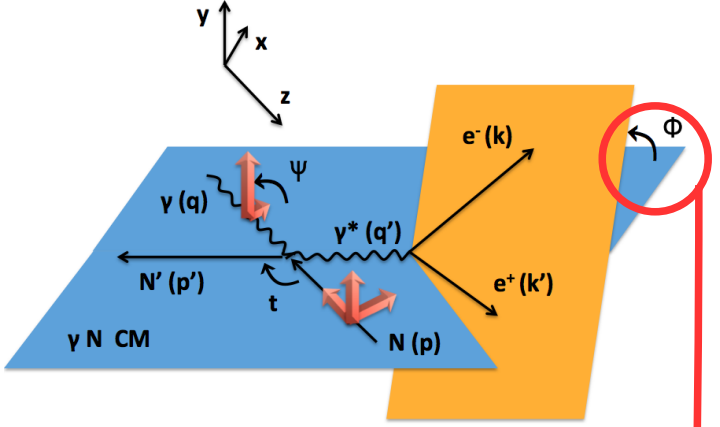
Suppressed at t→0 where $F_1^n \to 0$ but should be sensitive at large t

TCS @ SoLID

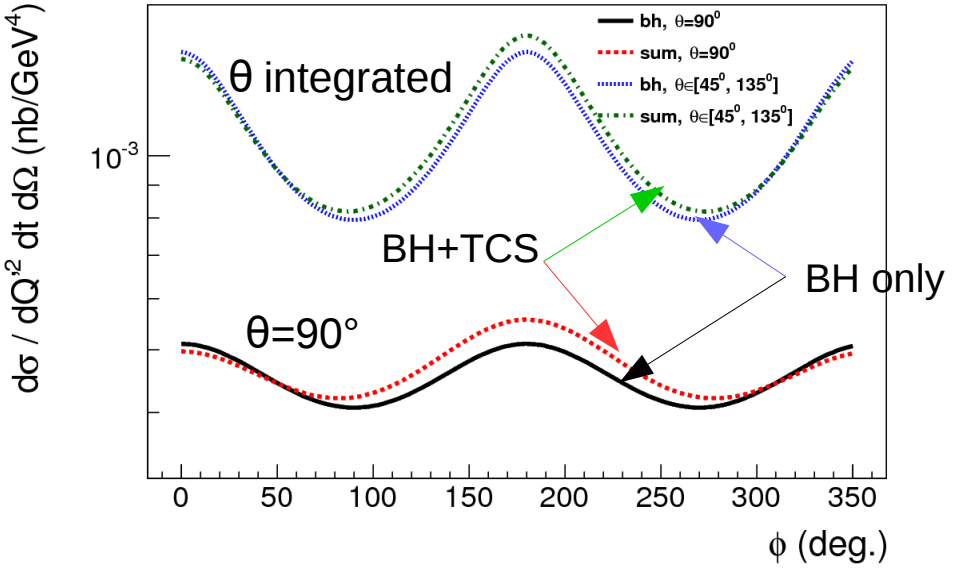
e P → (e') γ P → (e') P' e^+e^-

[quasi-real photon beam, circularly polarized 50% → 85%]

run group proposal E12-12-006A (2015)



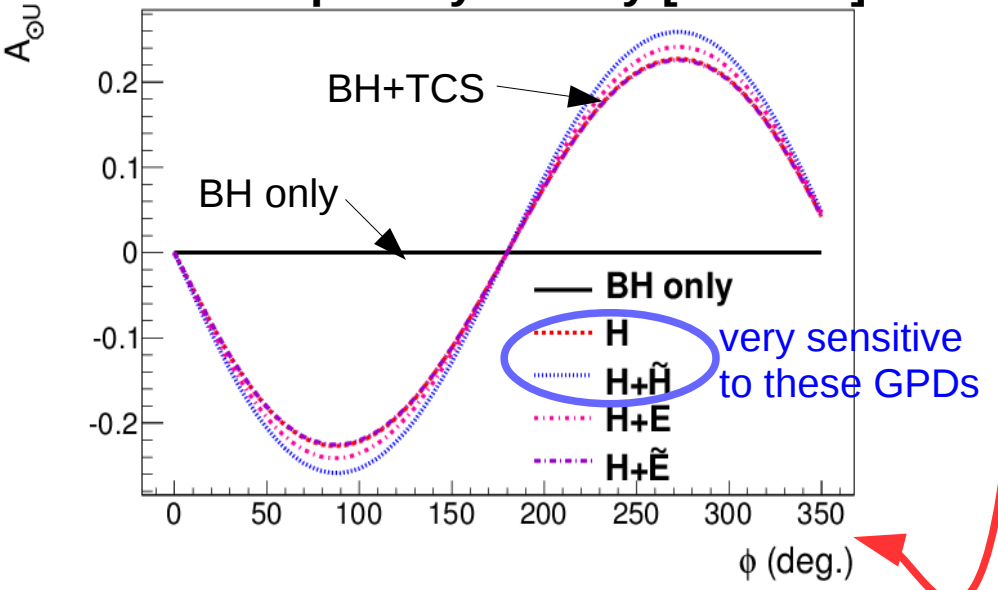
cross section



- highly dominated by BH (at any kinematic):
  high precision required to distinguish TCS signal

sensitive to Real and Im. part of amplitudes

beam spin asymmetry [circular]



- comes from interference term

sensitive to Im. part of TCS amplitude

distinction between different GPD's parametrizations

- High luminosity and resolution of SoLID, large acceptance is a plus for this measurement.

- Complementary with future experiments/LOI: Hall B: E12-12-01 (2012) ; Hall C: LOI12-15-005 (2015)

Hall B: same observables but lower luminosity ; Hall C: transversally polarized target.

- Could also be measured in muon pair [cf DDVCS].

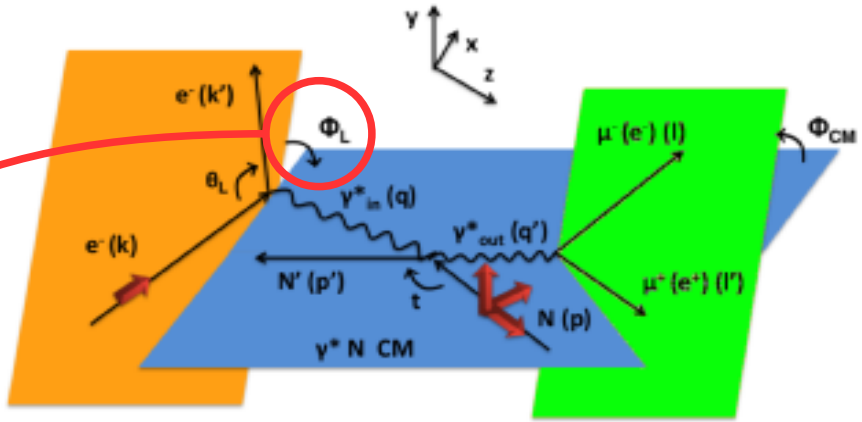
DDVCS @ SoLID

$e\,P \rightarrow e'\,P'\,\mu^+\,\mu^-$

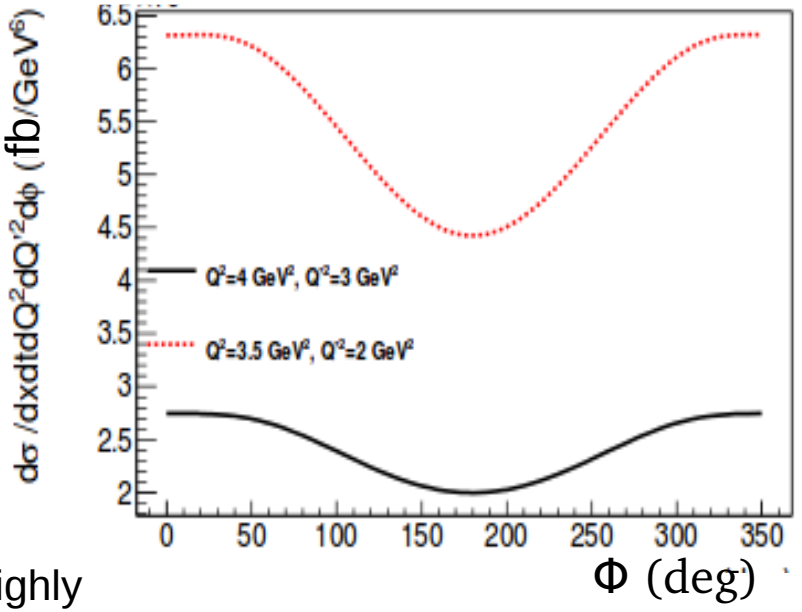
Interest : GPD extracted at $x \neq \xi$

How : lever arm with Q^2/Q'^2 ratio

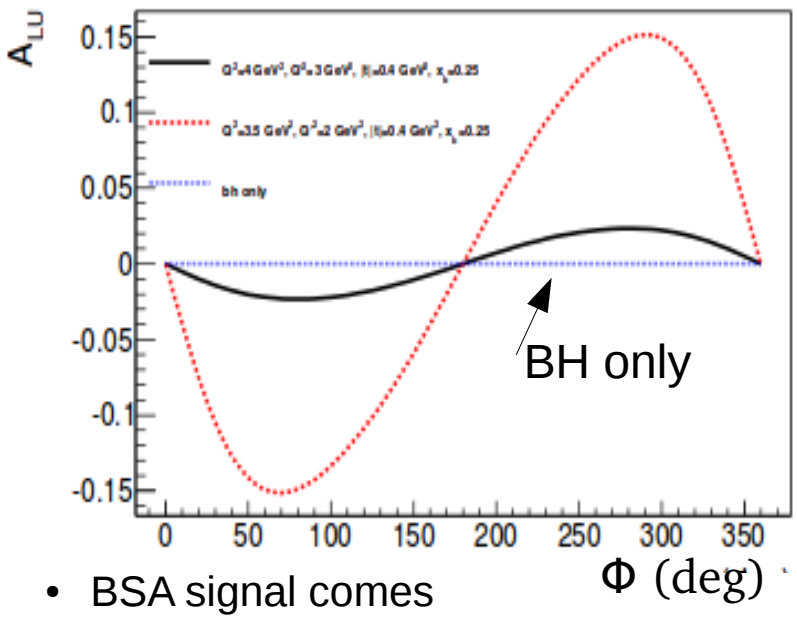
LOI12-15-005 (2015)



cross section and beam spin asymmetry for 2 kinematics vs phi (DVCS-like angle)



- highly dominated by BH



- BSA signal comes from interference

- phenomenological efforts ongoing for interpretations and to lead the proposal

- plan to turn LOI of 2015 into a run group proposal in 2016 (with E12-12-006)

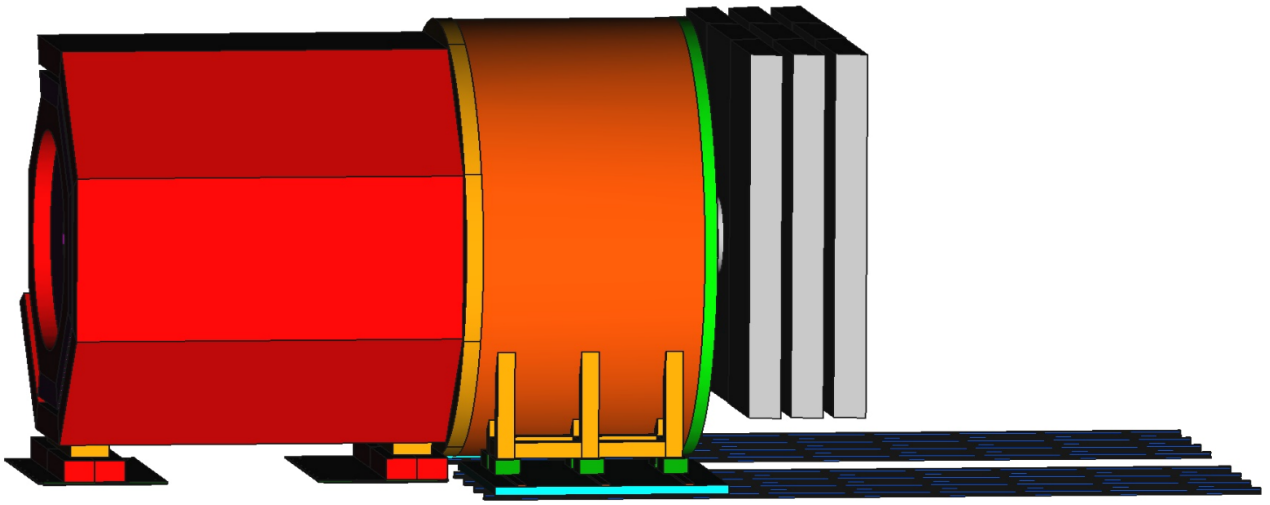
SoLID: first DDVCS LOI (Hall B LOI also in progress), very high luminosity and acceptance needed

Goal: run "parasitic" with another experiment to show feasibility, then dedicated experiment if possible

Muon detector for “parasitic” SoLID DDVCS (with J/ψ exp.)

- Muons detector: from CLEO
  - Forward
  - Reuse 2nd and 3rd layer iron
  - Muon chambers between iron

- Move chambers with magnet
- Test one chamber using Ar/Co2 maybe in Temple (N. Sparveri)

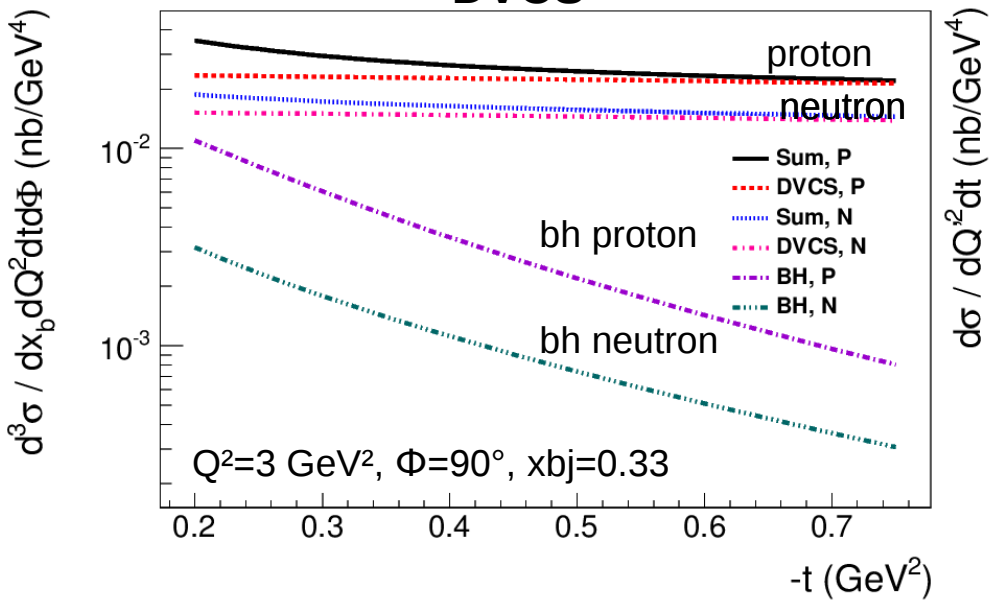


Luminosity requirements and other experiments @12 GeV

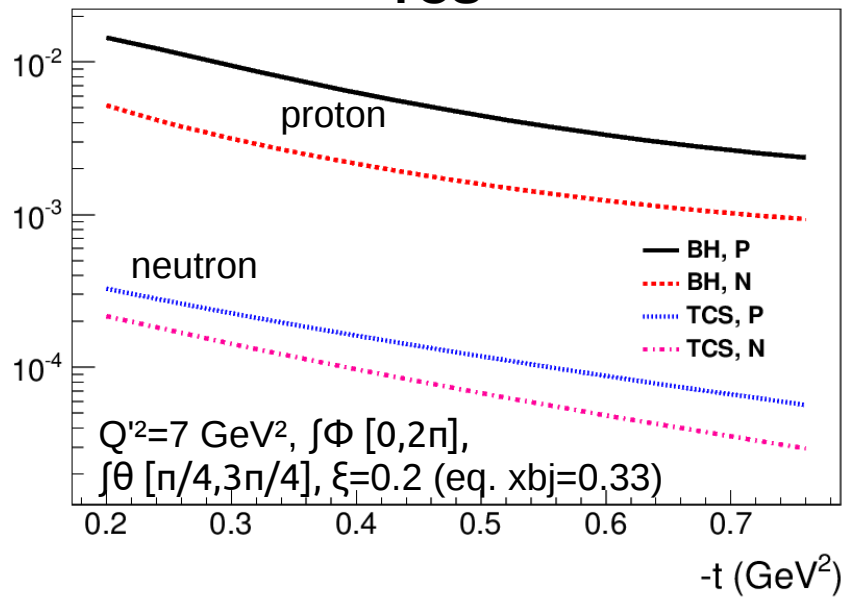
DVCS (only unpolarized target)	TCS	DDVCS (unpolarized target)
CLAS12: 10^35 $cm^{-2}s^{-1}$ NPS: 10^37 $cm^{-2}s^{-1}$ SoLID: 10^37 $cm^{-2}s^{-1}$ (*) (*)= feasibility to be demonstrated	CLAS12: 100+20 days, 10^35 $cm^{-2}s^{-1}$ (unpolarized target) NPS: 10^35 $cm^{-2}s^{-1}$ (*) (transversally polarized target) SoLID: 50 days, 10^37 $cm^{-2}s^{-1}$	CLAS12: 10^37 $cm^{-2}s^{-1}$ (*) SoLID: 10^38 $cm^{-2}s^{-1}$ (*)

Comparison of cross sections for the different processes (at xbj~0.33):
[remarks for the kinematic shown and for JLab kinematic only]

DVCS



TCS



dvcs and bh "cross sections" are comparable here: dvcs>bh (not the case in general)
cross sections order ~pb – nb

bh>>tcs (always about 2 order of magnitude)
cross sections order ~ pb

DDVCS: order of fb, very narrow phase space, bh>>ddvcs

Very high luminosity required for TCS and DDVCS

Summary / work ongoing

Thanks to its high luminosity and large acceptance SoLID could provide unique opportunities for GPD physics

- **DVCS: goal = LOI at next PAC**

  - simulations, background

  - experimental requirements: setup -recoil detector?, resolution...

  - counting rates

- **TCS: run group proposal accepted in 2015**

  - still some effort for TCS and background simulations

- **DDVCS: LOI in 2015, goal = run group proposal this year**

  - phenomenological effort: interpretation of the results, interferences with meson production, fits...

  - simulations of DDVCS and background (in progress)

  - experimental setup: muon detector...

  - counting rates

Need of manpower

=> join our workshop "ECT dileptons" at Trento, Oct. 24-28, 2016
infos: camsonne@jlab.org

Open questions

- Resolution
  - Exclusivity by missing mass only
    - Electron
    - calorimeter resolution (do we need improvement ?)
    - Optimize proton acceptance
- Cross sections measurement : Accuracy possible in SoLID
- Luminosity
  - Can we run more than 10^37 $cm^{-2}s^{-1}$ and measure cross sections ? (Tracking efficiency in background, PID)
- Evaluation of improved statistics impact on GPDs extraction
- Parallel experiments: trigger requirements

BACKUP SLIDES

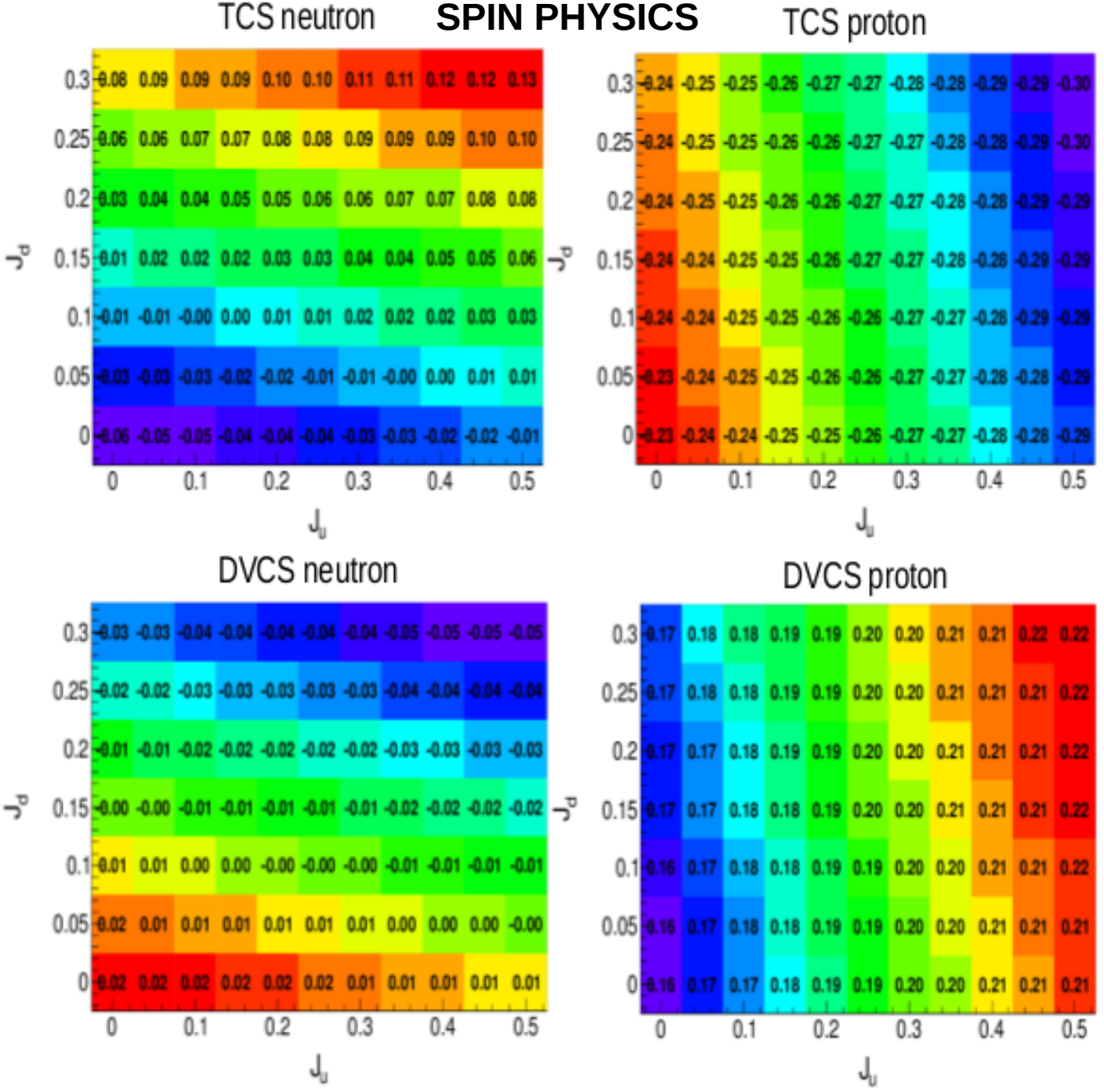


Figure 5: TCS $A_{\odot U}$ on the neutron (top left panel), TCS $A_{\odot U}$ on the proton (top right panel), DVCS A_{LU} on the neutron (bottom left panel), DVCS A_{LU} on the proton (bottom right panel) as a function of J^u and J^d. Calculations are done for $\phi = 90°$, $\xi = 0.2$, $Q'^2 = 7$ GeV^2, $-t = 0.4$ GeV^2 and θ integrated over $[\pi/4, 3\pi/4]$.

DVCS

target	observable	Other exp	Current luminosity		detector	Access CFF
H	asymmetry	CLAS12, NPS	10^35 10^37			Fit (Hp Htp)
H	Difference Crossection	CLAS12 NPS	10^35 10^37			Im Hp
D	asymmetry	CLAS12				Im En
D	Cross section	CLAS12				Im En
NH3	asymmetry		10^35			Im Ep
NH3	asymmetry		10^35			
He3	Beam spin asymmetry		10^36			Im Hp
He3	Target spin asymmetry		10^36			
HD			4.10^33			
He4						He4 GPD

dvmp

Target	Pion	Observable	Other exp	Lumi	Detector	Access
H	π	asymmetry	CLAS12, NPS			Im H
H		Crossection	CLAS12, NPS			
D		asymmetry	CLAS12			
D		Cross section	CLAS12			
NH3		asymmetry				
NH3		asymmetry				
He3		Beam spin asymmetry				
He3		Target spin asymmetry				
	He4					He4 GPD