L/T and flavor separation in π^0 electro-production (Hall A@Jlab)

J. Roche (Ohio U.)

DVCS2

- M. Mazouz *et al.*, "Rosenbluth separation of the π^0 electro-production off the neutron", PRL, Feb `17.
- M. Defurne, M. Mazouz *et al.*, "Rosenbluth separation of the π^0 electro-production", PRL, Aug `16.

DVCS1

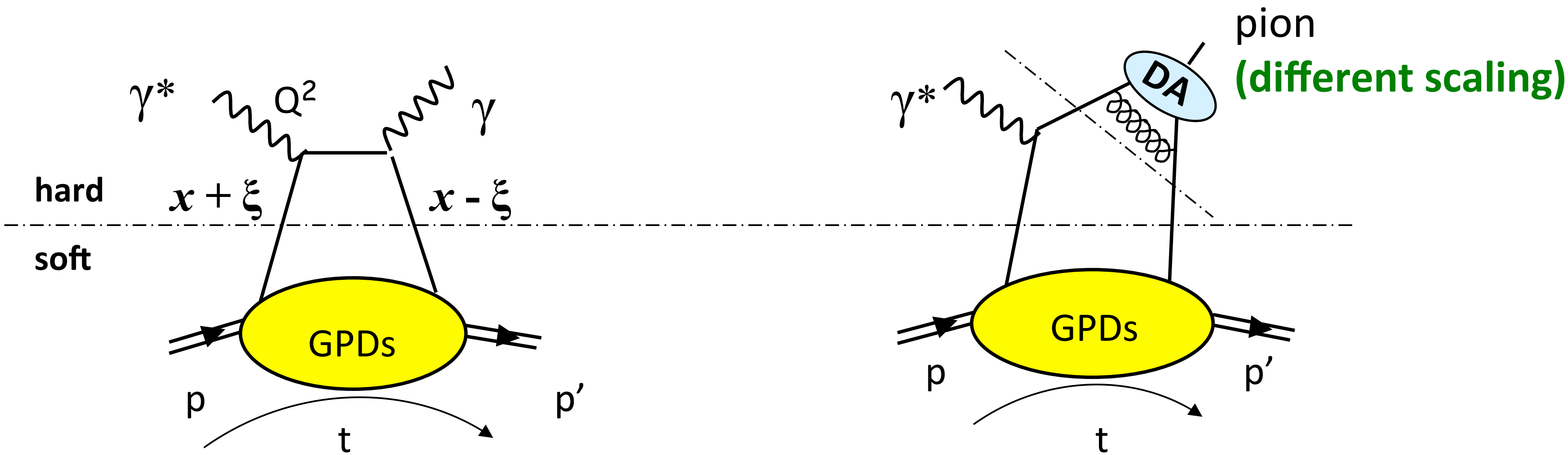
- E. Fuchey *et al.*, "Exclusive neutral pion electro-production in the Deeply Virtual Regime", PRC, Mar `10.

Thesis:

- M. Defurne, U of Paris IV, Jun `15.
- E. Fuchey, Clermont U, Apr `11.

Award #1614479

γ/π^0 Production : same GPDs??



	Nucleon Helicity conserving	Nucleon Helicity non-conserving
unpolarized GPD	H	E
polarized GPD	$\tilde{H}$	$\tilde{E}$

Chiral even GPDs:
helicity of the parton is conserved

Chiral even GPDs
+
Chiral-odd GPDs
(helicity of the parton can flip
in the top part of the process)

Different scaling and additional GPDs

Hall A/C DVCS is part of a worldwide program

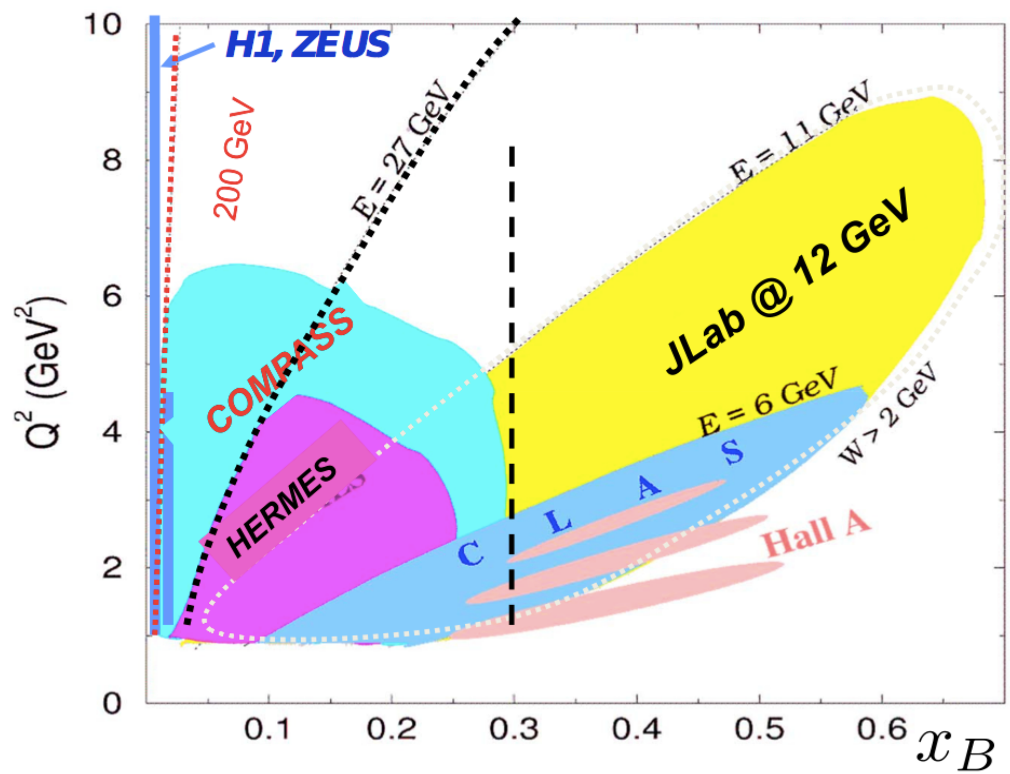
Timeline

- Pioneering results from non-dedicated experiments (Hall B and Hermes): ~2001
- First round of dedicated experiments (Hall A/B and Hermes): ~ 2005 ← **DVCS1**
- Second round of dedicated experiments (Halls A/B): ~2010 ← **DVCS2**
- Compelling DVCS program at JLab-12 GeV and Compass: 2014 and later ← **DVCS3**

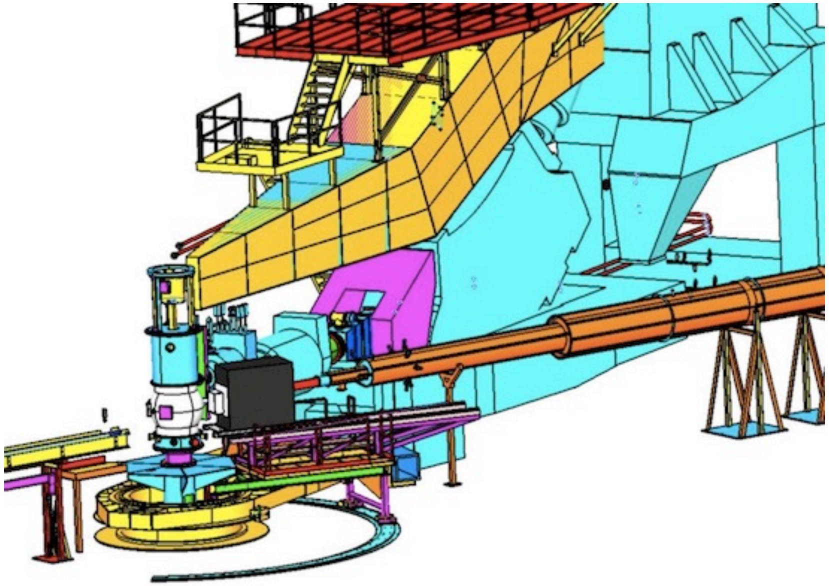
In the valence region (JLab)

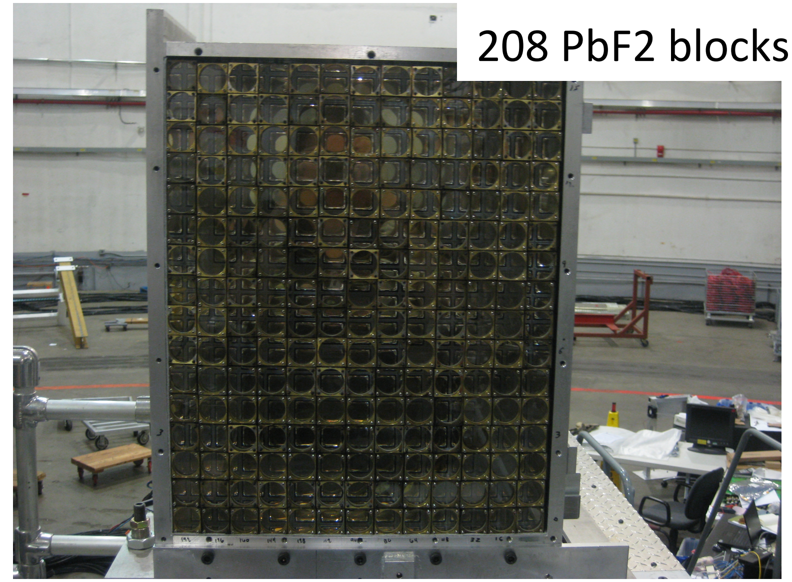
Partially complimentary, overlapping

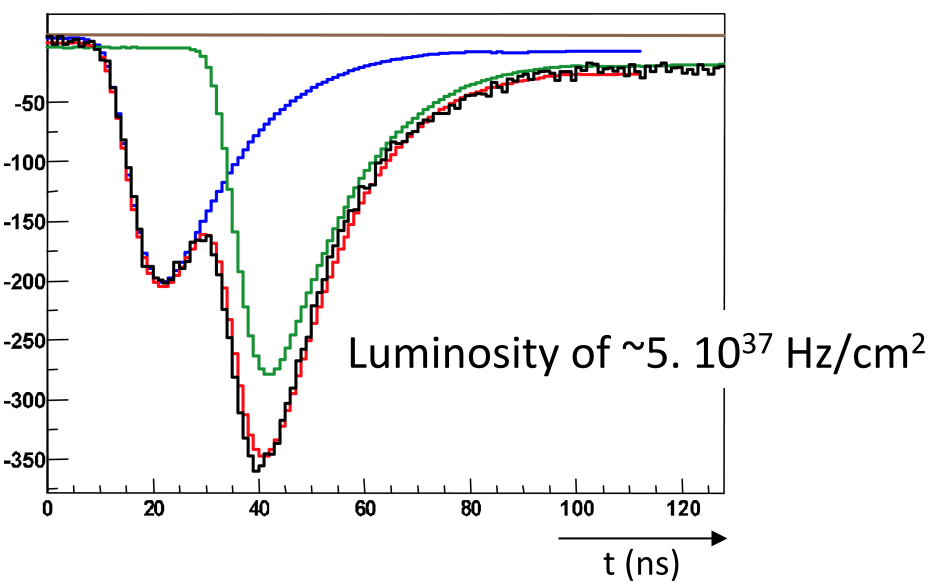
- Hall A: high accuracy (~5%)
  : limited kinematic
- Hall B: wide kinematic range
  : limited accuracy (15+%)

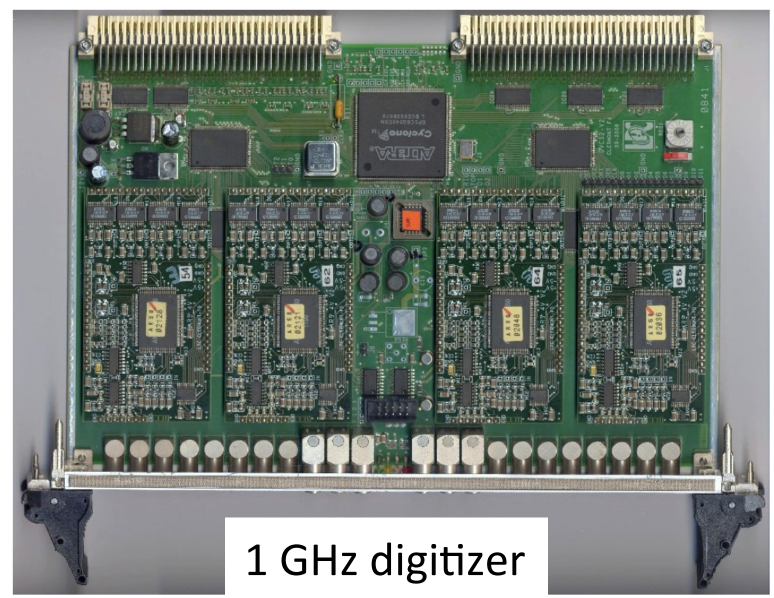


The Hall A detector scheme

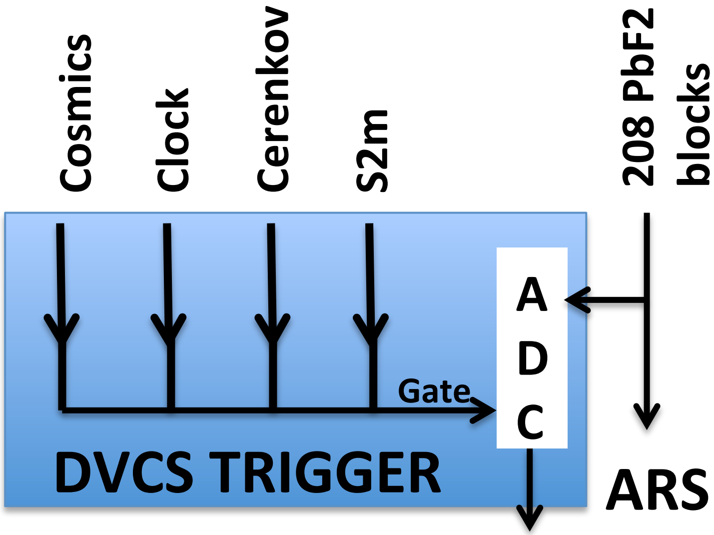








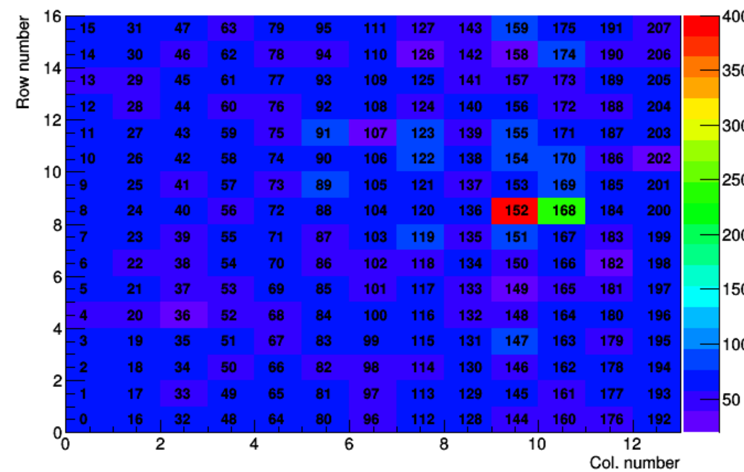
Trigger with *at least one* cluster in the calo.

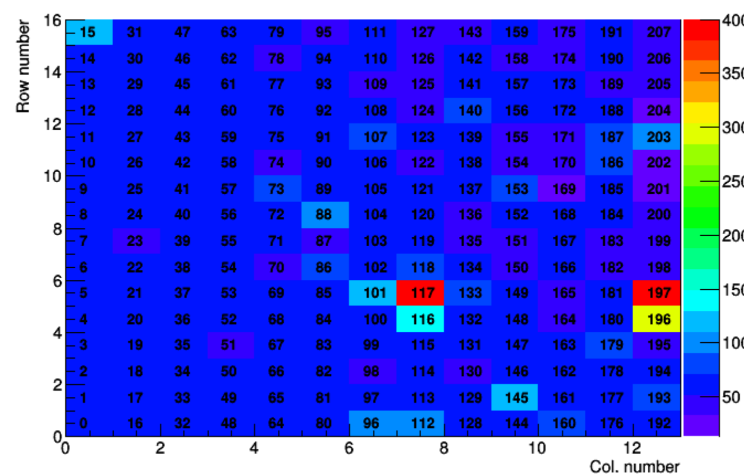


Triggers if a group of 2*2 blocks is above threshold

DVCS3- kin	1 cluster	2 clusters
36_1	100	23
36_2	100	27
36_3	100	26

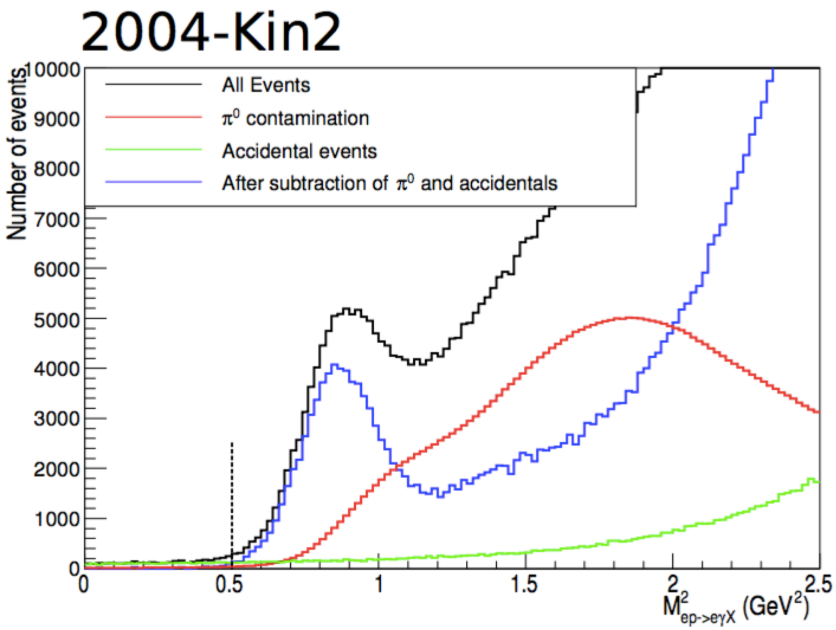
In some case, this trigger is by-passed



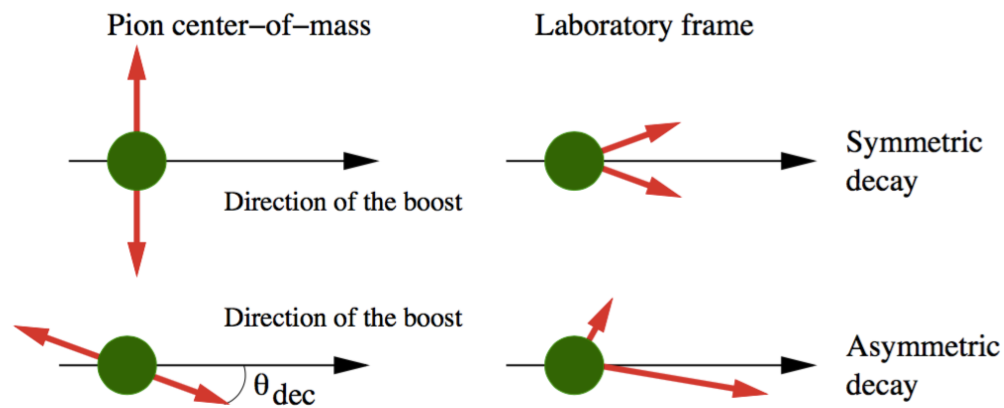


Target-Calorimeter distance such that 2γ from π^0 are separated by 3 blocks

2-clusters events used for DVCS analysis

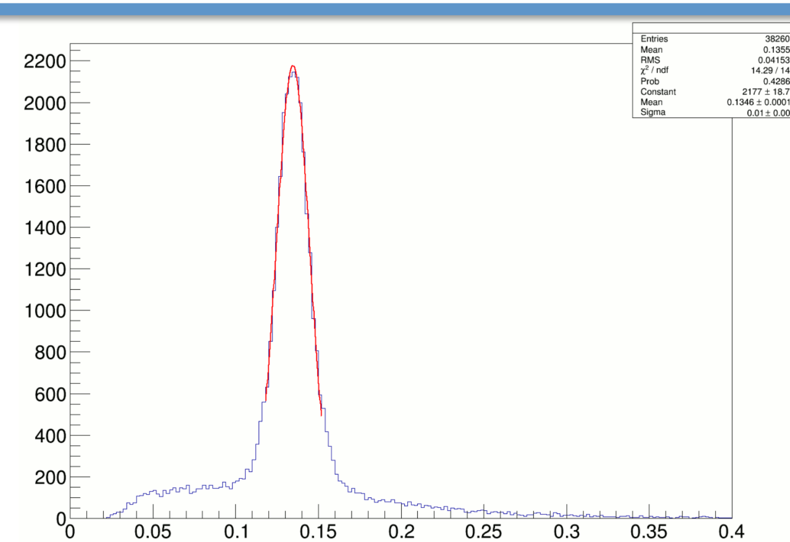


Evaluation of π^0 contamination to DVCS signal

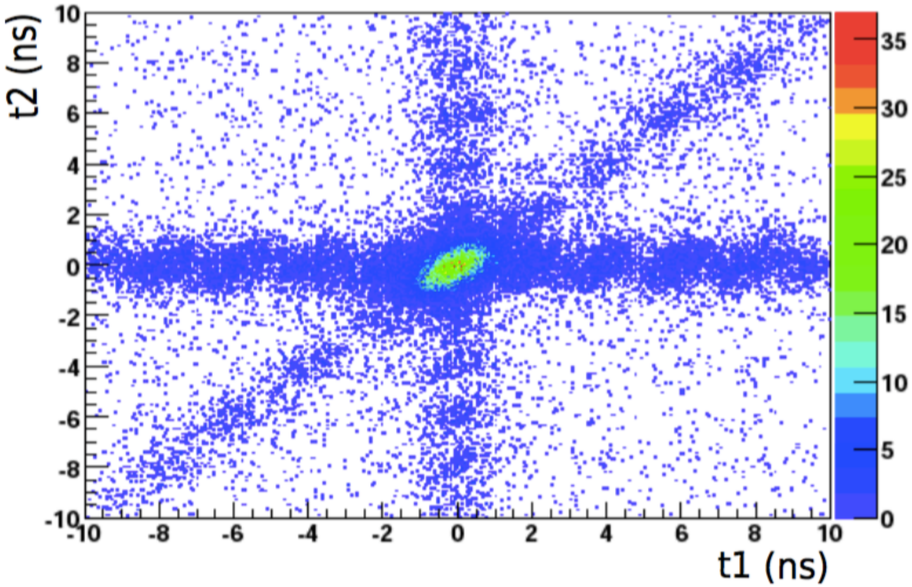


Monitoring and fine adjusting of energy calibration

- First pass: elastic calibration p(e,e'p'): invasive about every 4 weeks
- Second pass: π^0 calibration with about 1 day of data parasitic to DVCS data taking



Toward selecting $p(e,e'\pi^0)p'$ for physics

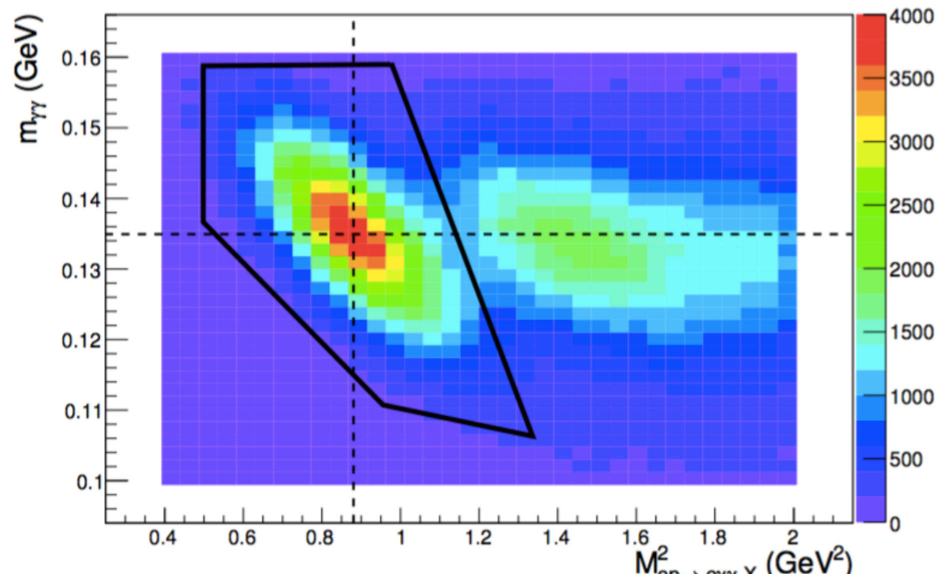


$$t_i = t(e') - t(\gamma_i)$$

- $e'\gamma_1\gamma_2$ all in coincidence
- $e'\gamma$ in coincidence but not with the other γ
- $\gamma_1\gamma_2$ in coincidence but not with e'
- $e'\gamma_1\gamma_2$ all in random coincidence.

- Software threshold of 500 MeV on each cluster

- Avoid the edge of the calorimeter to ensure full reconstruction of the EM shower.



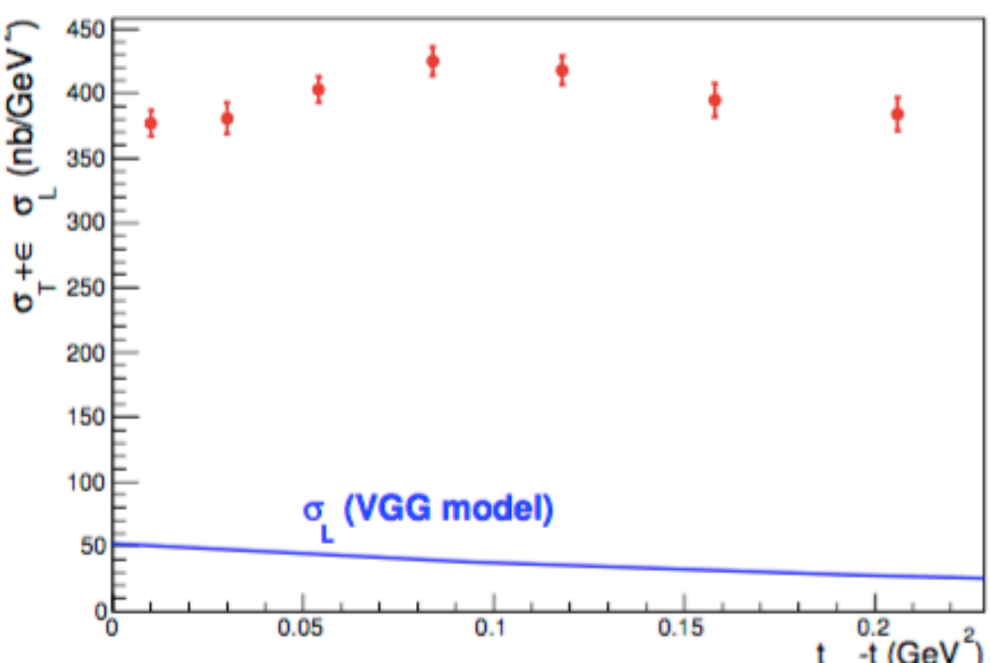
Hard Exclusive Meson cross-section

$$\frac{d^4\sigma}{dt\,d\phi\,dQ^2\,dx_B} = \frac{1}{2\pi}\Gamma_{\gamma^*}(Q^2, x_B, E_e)\left[\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{TL}}{dt}\cos(\phi) + \epsilon\frac{d\sigma_{TT}}{dt}\cos(2\phi)\right]$$

At first thought, if QCD factorization applies:

σ_L expected to dominate with σ_T suppressed by 1/Q.

But:



DVCS1 results

Fuchey et al. Phys Rev C 83.025201 (2011)

Q^2= 2.3 GeV^2

x_B=0.36

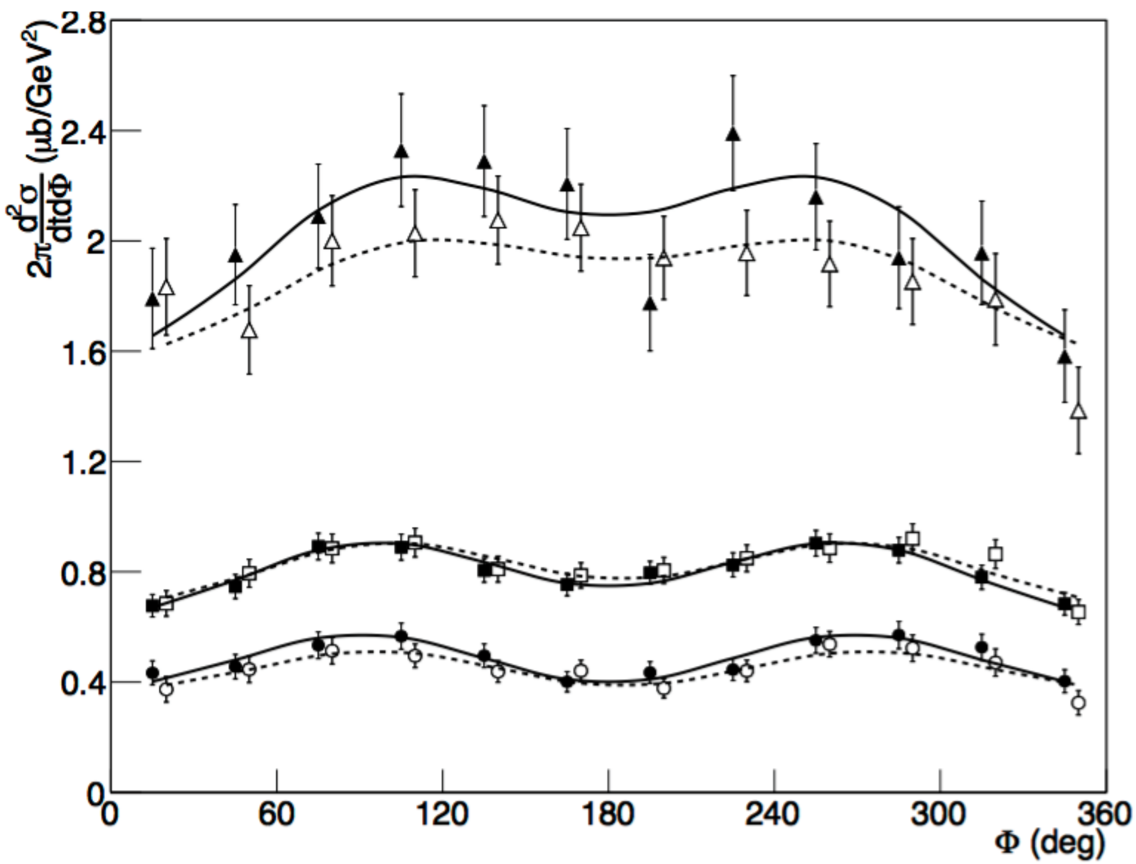
ε=0.61

Similar results at:

- CLAS with $\pi 0$
- HERMES & Hall C with π+

$$\frac{d^4\sigma}{dt\,d\phi\,dQ^2\,dx_B} = \frac{1}{2\pi}\Gamma_{\gamma^*}(Q^2, x_B, E_e)\left[\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{TL}}{dt}cos(\phi) + \epsilon\frac{d\sigma_{TT}}{dt}cos(2\phi)\right]$$

Setting	E (GeV)	Q^2 (GeV^2)	x_B	ϵ		
2010-Kin1	(3.355 ; 5.55)	1.5	0.36	(0.52 ; 0.84)	△	▲
2010-Kin2	(4.455 ; 5.55)	1.75	0.36	(0.65 ; 0.79)	□	■
2010-Kin3	(4.455 ; 5.55)	2	0.36	(0.53 ; 0.72)	○	●



DVCS2 results

M. Defurne et al.
PRL 117, 26 (2015)

x_B=0.36
$t\text{-}t_{min}$=0.025 GeV^2

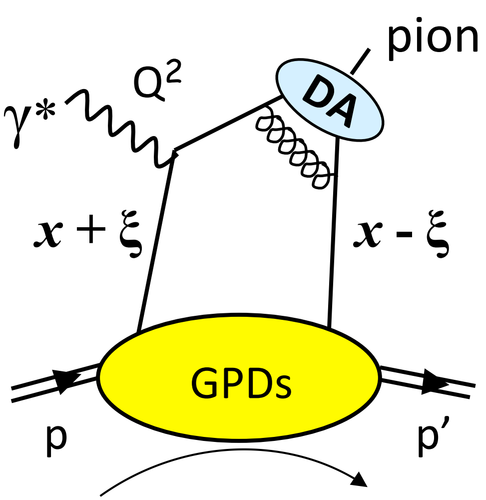
Why such a large dσ_T contribution?

Modified factorization approach proposed by

- Ahmad, Golstein and Liuti (Phys.Rev.D79, 054014 (2009))
- Goloskokov and Kroll (Eur.Phys.J A47, 112(2011))

In these models:

- Factorization is possible because of the specific make up of the mesons (singularities cancellations),
- Twist-3 Distribution amplitudes couple with transversity GPDs.

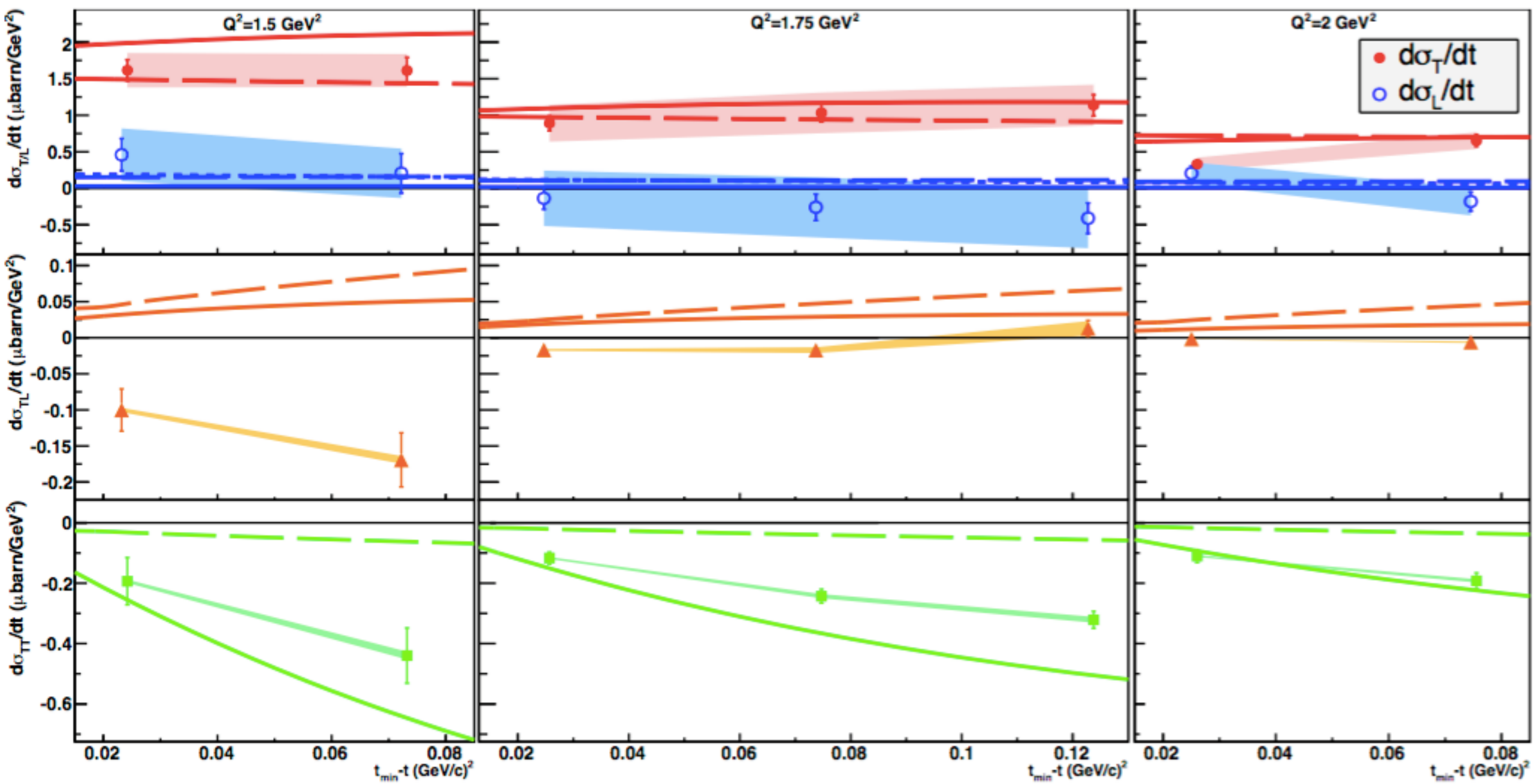


$$\frac{d\sigma_T}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\left[(1-\xi^2)|\mathcal{H}_T|^2 - \frac{t'}{8m^2}|2\widetilde{\mathcal{H}}_T + \mathcal{E}_T|^2\right]$$

$$\frac{d\sigma_{TT}}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\frac{t'}{16m^2}|2\widetilde{\mathcal{H}}_T + \mathcal{E}_T|^2,$$

$$\mu_\pi = \frac{m_\pi^2}{m_u + m_d} \simeq 2.5 \text{ GeV}$$ > experimental Q (less than 1.4)

DVCS2 results: fully separated contributions



G-H-L ('11)

G-K

Small $d\sigma_L$, large $d\sigma_T$: models ok on these

Wrong sign and Q dependence on $d\sigma_{TL}$ and $d\sigma_{TT}$

$d\sigma_{TL}$ sizeable => $d\sigma_L$ is small but not null

DVCS2 results neutron data

M. Mazouz PRL 118 (2017) 22, 222002

At Q^2=1.75 GeV^2 and x_B=0.36 , half of the data taken on a LD2 target.

Below the two pions threshold:

From LH2,
add Fermi smearing

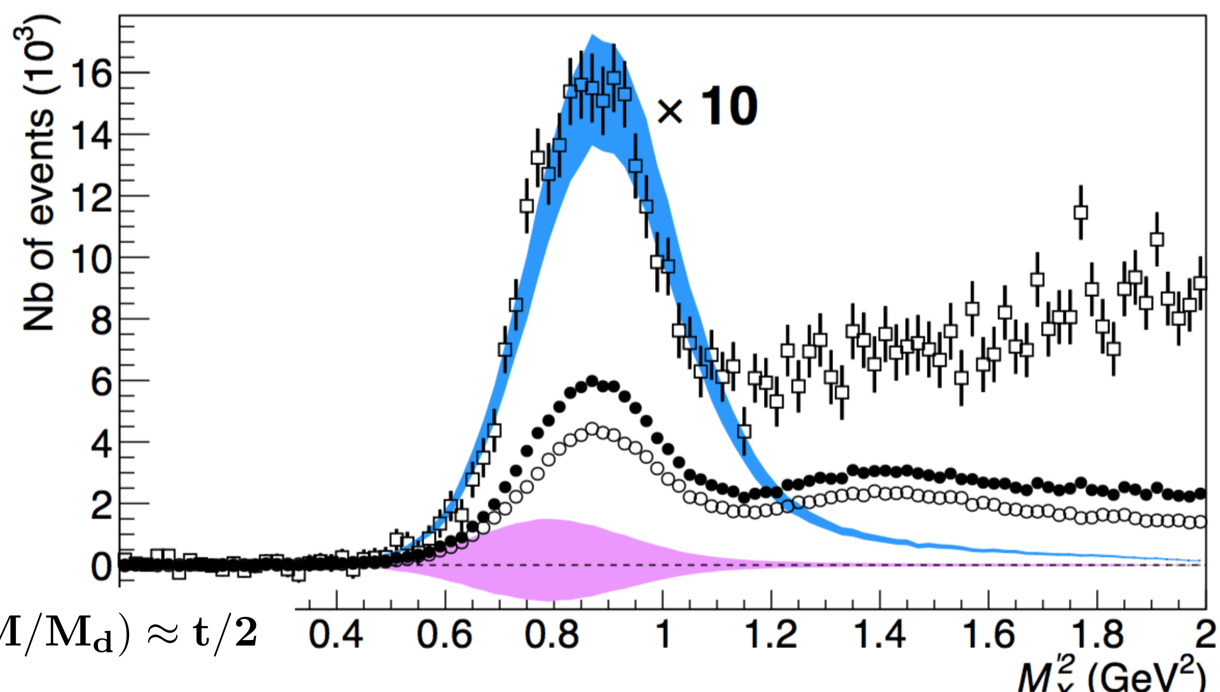
$$D(e,e'\pi^0)X = d(e,e'\pi^0)d + n(e,e'\pi^0)n + p(e,e'\pi^0)p.$$

- ● LD2
- ○ LH2
- □ LD2-LH2

- $d(e,e'\pi^0)d$
- $n(e,e'\pi^0)n$

separated by

$$\Delta M_X^2 = t(1 - M/M_d) \approx t/2$$



Computed for $n(e,e'\pi^0)X$

Events with missing mass squared below 0.95 GeV^2:

- are divided in 12 x 2 x 5 x 30 bins in ϕ, E, t and M_x^2

  ϕ, E allow for L, T, LT and TT separation

  M_x^2 allows for the n/d separation

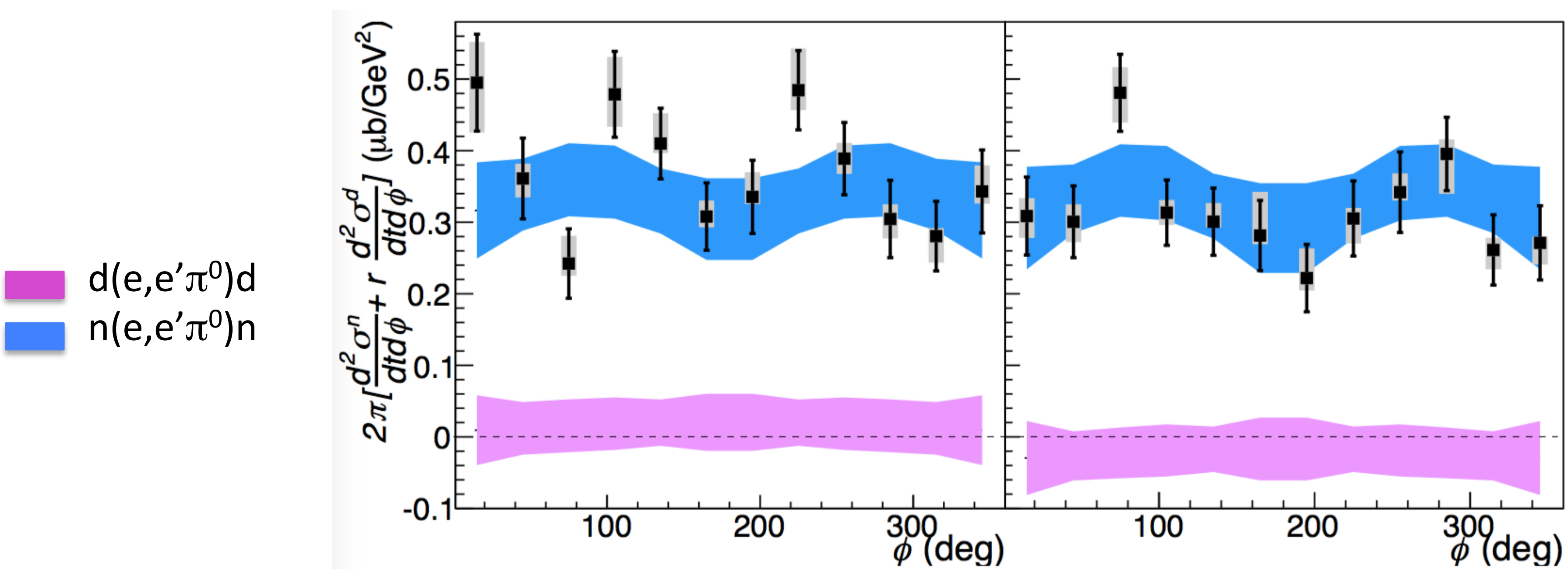
- fitted with eight cross-section function structure

$$\mathbf{d}\sigma^{\mathbf{n,d}}_{\mathbf{\Lambda}}(\mathbf{t}) \qquad \mathbf{\Lambda} = \mathrm{T,\ L,\ LT,\ TT}$$

Q^2=1.75 GeV^2 and x_B=0.36

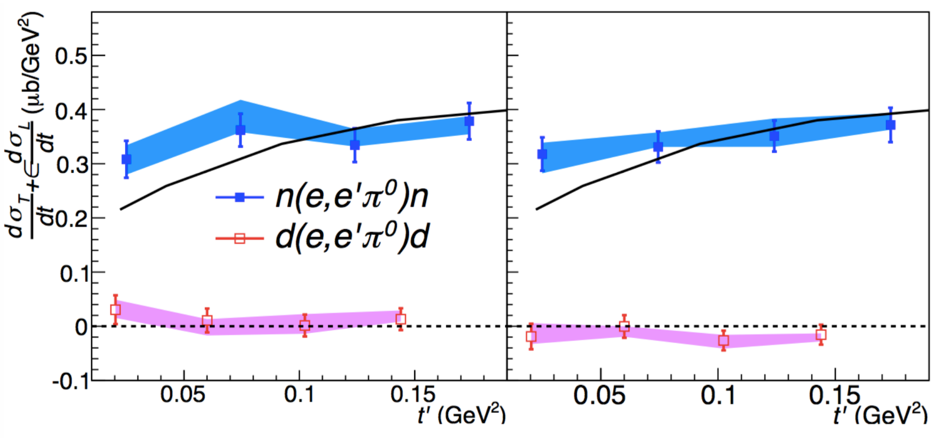
E=4.45 GeV
<t'>= 0.025 GeV^2

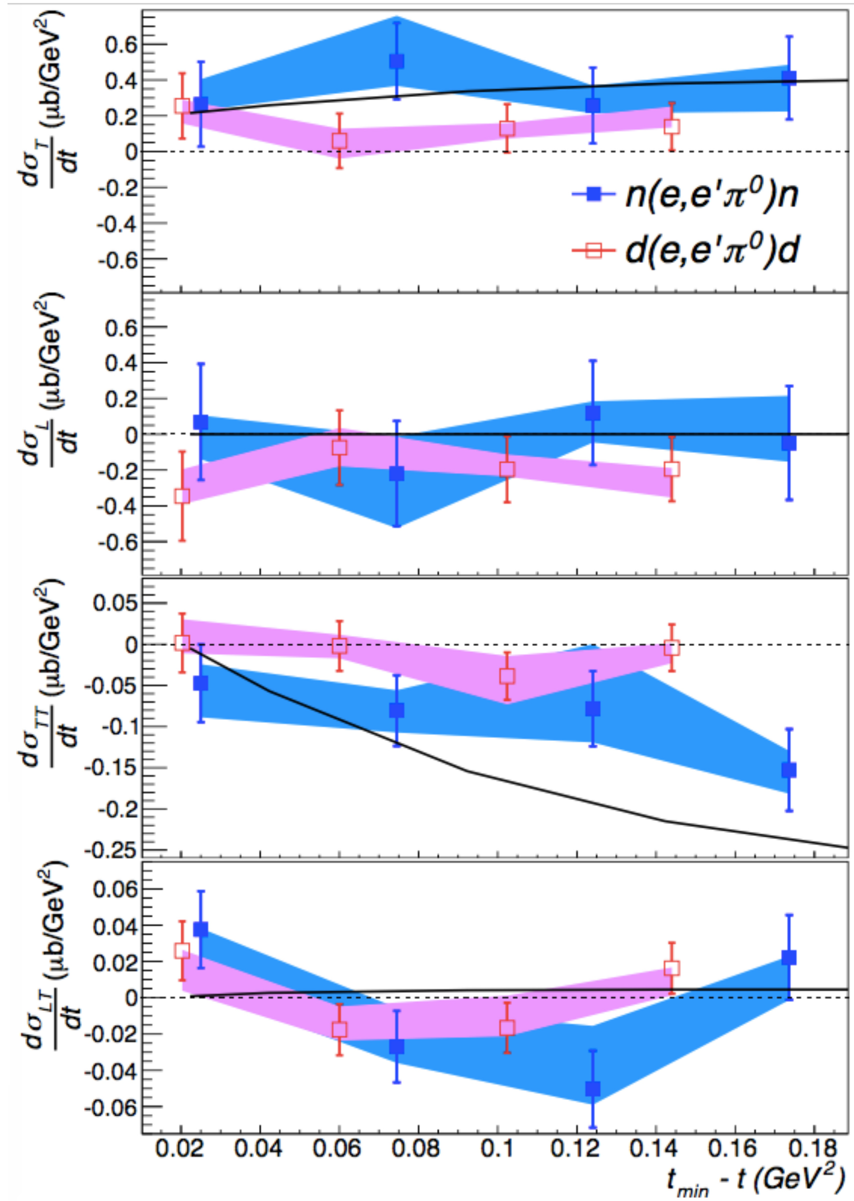
E=5.55 GeV
<t'>=0.021 GeV^2



DVCS2n results: fully separated contributions

Q^2=1.75 GeV^2 and x_B=0.36





— Goloskokov and Kroll
Eur Phys J A47 (2012)

$$\frac{d\sigma_T}{dt} = \Lambda \left[\left(1-\xi^2\right) \left|\langle H_T \rangle\right|^2 - \frac{t'}{8M^2} \left|\langle \bar{E}_T \rangle\right|^2 \right]$$

$$\frac{d\sigma_{TT}}{dt} = \Lambda \, \frac{t'}{8M^2} \left|\langle \bar{E}_T \rangle\right|^2 .$$

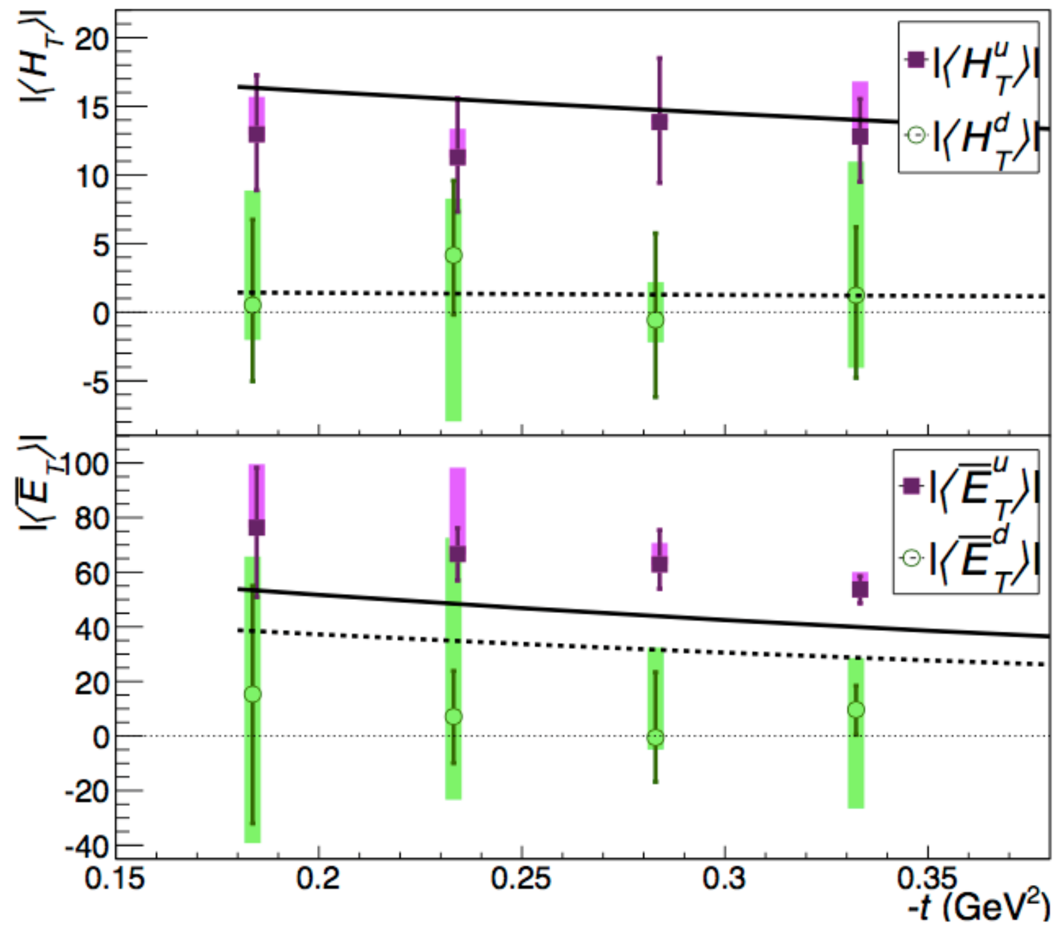
$$\bar{E}_T = 2\tilde{H}_T + E_T$$

DVCS2n results: flavor separation

$$|\langle H_T^{p,n}\rangle|^2 = \frac{1}{2}\left|\frac{2}{3}\left\langle H_T^{u,d}\right\rangle + \frac{1}{3}\left\langle H_T^{d,u}\right\rangle\right|^2$$

Q^2=1.75 GeV^2 , x_B=0.36

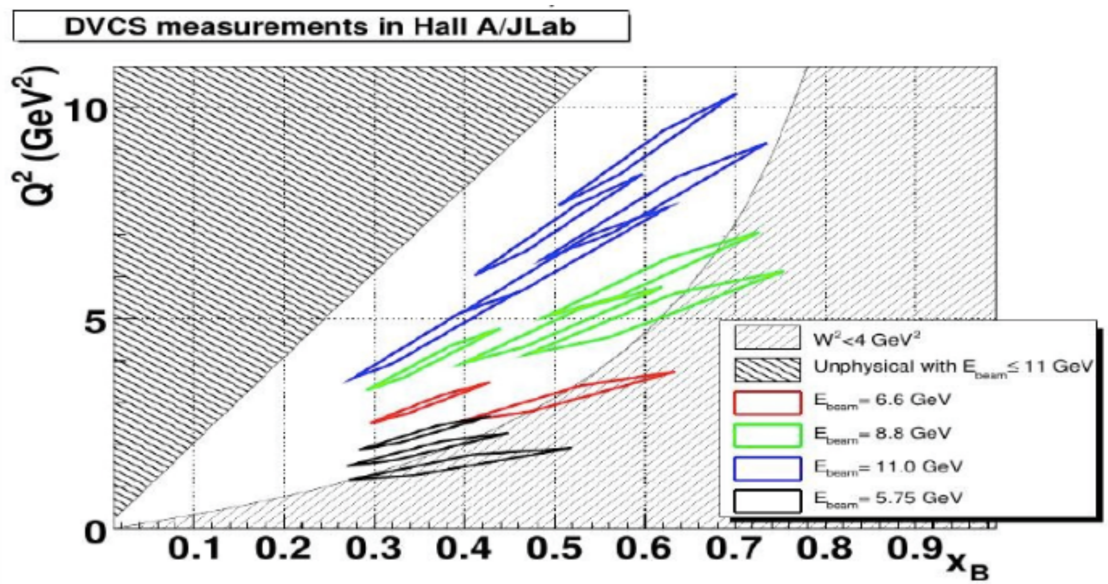
account for the unknown phase variation between u and the d amplitude $\gamma^*q \to q'\pi^0$ convoluted with $(H,E)_T$

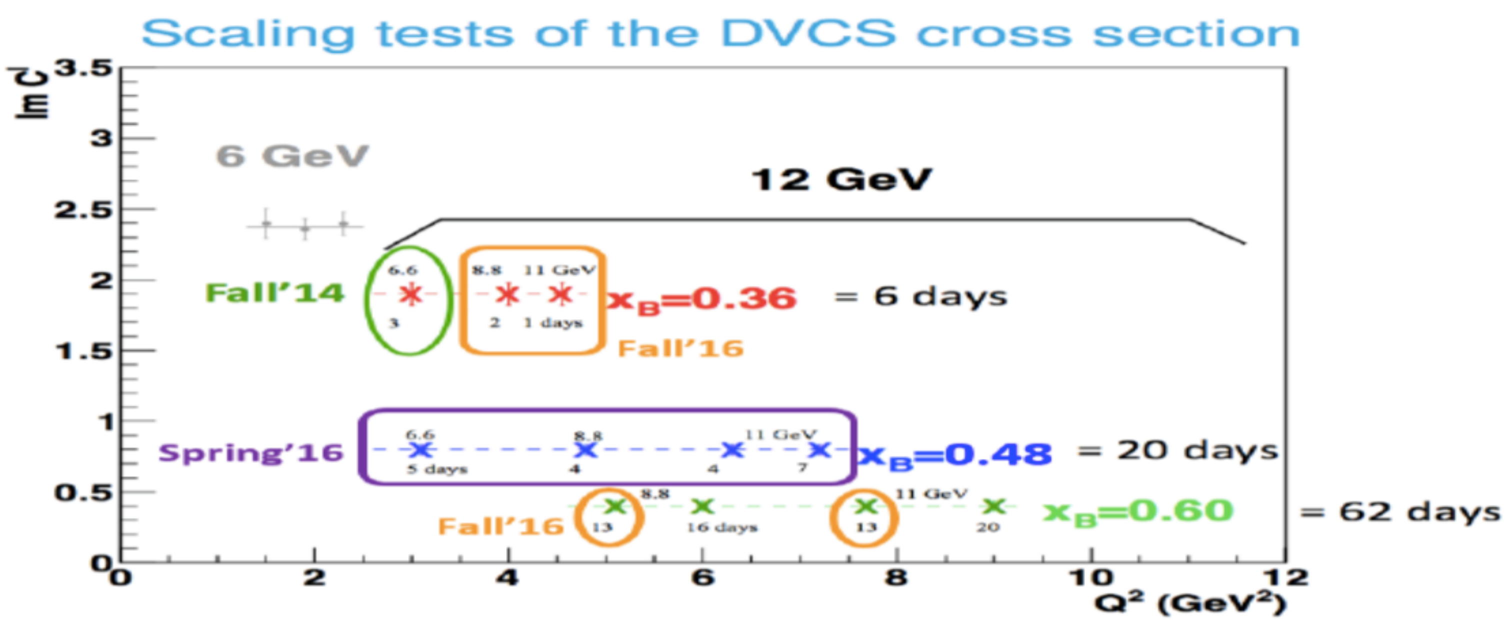


Goloskokov and Kroll
Eur Phys J A47 (2012)

—— u quark
------ d quark

E12-06-114: high impact experiment

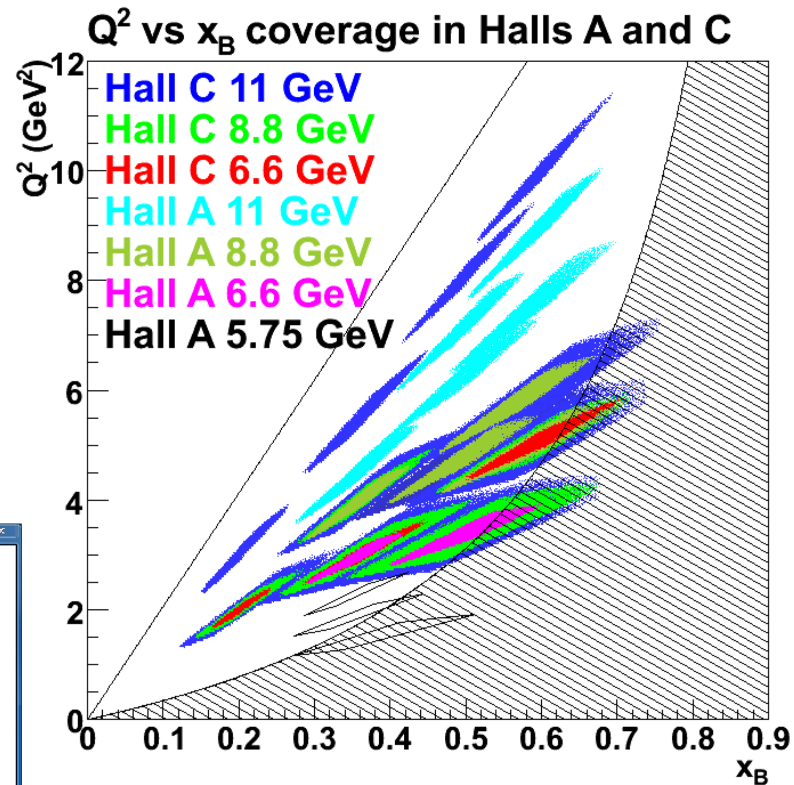




50 % of
PAC allocation
taken in between
2014 and 2016

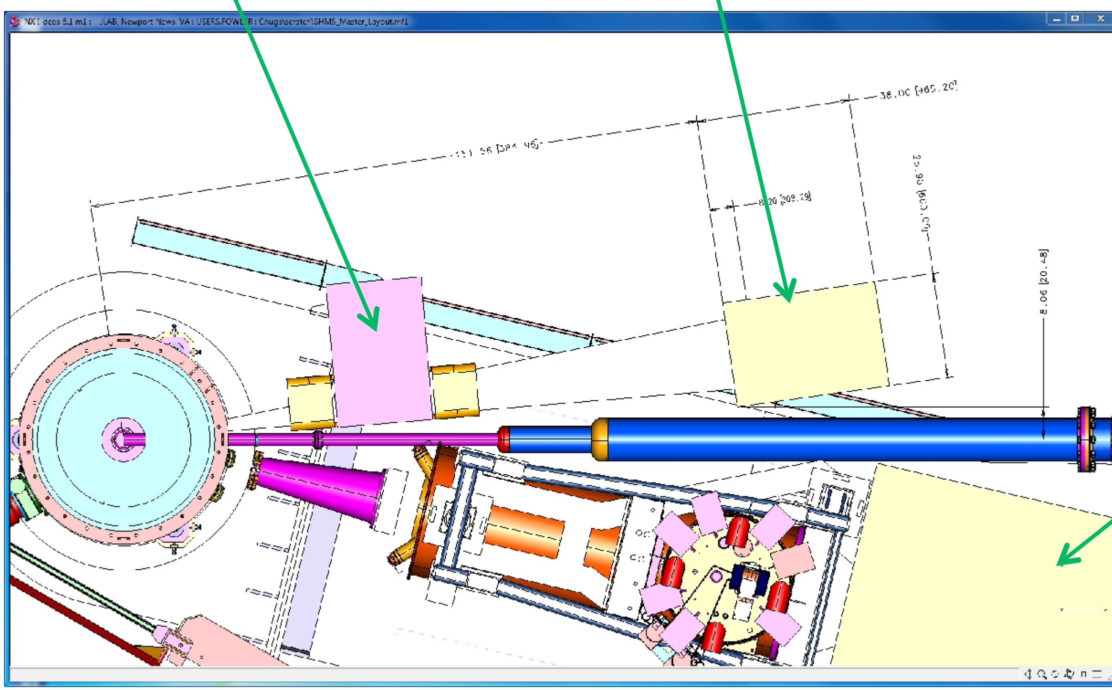
E12-13-010: "DVCS" at 11 GeV in Hall C

- Energy separation of the DVCS cross section
- Higher Q^2: measurement of higher twist contributions
- Low x_B extension (thanks to sweeping magnet)



Sweeping magnet

1116-block $PbWO_4$ calorimeter



Hall C HMS

Tentative running: ~ 2019-20 ??

E12-13-010: electro-production of π^0 in Hall C

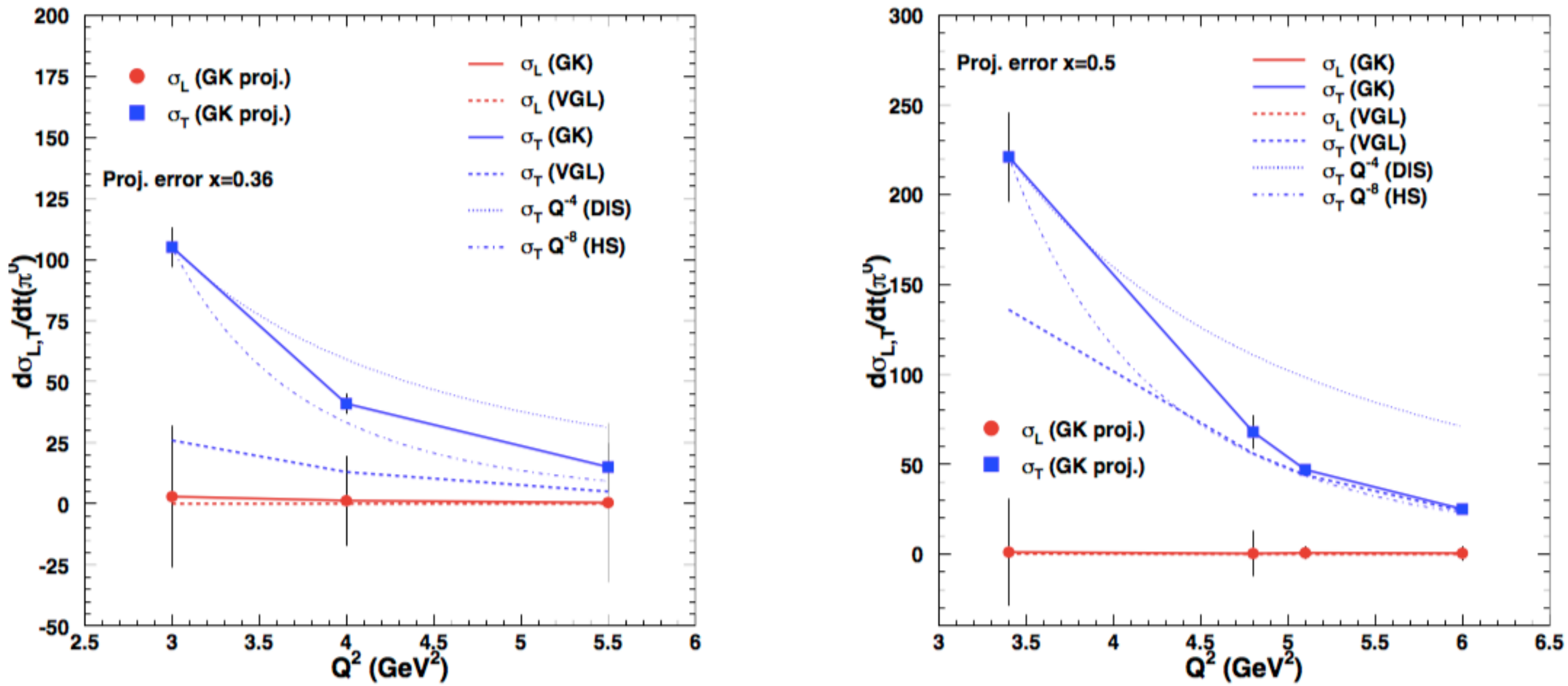


FIG. 3: Projected uncertainties for the Q^2 dependence of σ_L and σ_T at fixed x_B=0.36, 0.5. The points are plotted assuming the GK model predictions. Also shown are the hard scattering (HS, R=σ_L/σ_T $1/Q^{-2}$) and the DIS (DIS, R $1/Q^2$) expectation, and the model predictions of the VGL (Regge) model. The points at Q^2=5.1 and 6.0 GeV^2 in the right panel are scaled from the x_B=0.6 setting in Table III and include events from the Hall A DVCS experiment [28] for the low beam energy in the L/T separation where appropriate. The point at Q^2=5.5 GeV^2 also includes events from the Hall A experiment for the low beam energy in the L/T separation.

Outlook

- Our scheme is to measure electro-production of π^0 parasitically to DVCS.
  - We have published π^0 data on proton and neutron for all our 6GeV data.
  - We have data on tape at 12 GeV (one energy only).
  - We will take data at 12 GeV with NPS (multiple energies).

- Our data support the dominance of σ_T measured by HERMES and CLAS and explained by the modified factorization approach proposed by Liuti and by Kroll

  Can experiment provide data that would further "test" this modified factorization scheme?

- We have published a first flavor separation of the <HT> and <ET>. A limiting factor to the precision of this measurement is the relative phase between the u and d amplitudes. This could be mitigated by exclusive $p(\gamma^*,\eta p)$ data.

  Is this worth it?