Deep Processes Working Group Report

CLAS Collaboration Meeting
Jefferson Lab, 15th November 2018

Publications:

CLAS 2017-09
Measurement of Unpolarized Cross Sections and Polarized Cross Section Differences for Deeply Virtual Compton Scattering (DVCS) on the proton at the Jefferson Laboratory with CLAS, at $0.1 < x_B < 0.58$, $1.0 < Q2 < 4.8\ GeV^2$, and $0.09 < -t < 2.0\ GeV^2$,
H. Saylor, published on Phys. Rev. C

CLAS 2017-13
Measurement of the Q^2 dependence of the deuteron spin structure function g_1 at its moments at $0.02 < Q2 < 0.7$ GeV2 with CLAS,
K.P.Adhikari, published on Phys. Rev. Lett.

CLAS 2018-5
Measurement of the beam spin asymmetry of the $ep \rightarrow e'p\eta$ in the deep-inelastic regime with CLAS,
B.Zhao, submitted to Phys. Lett. B

Ad Hoc Reviews

Analysis	Data	Lead Author	In progress
Exploring the structure of the proton via semi-inclusive pion electroproduction	**e1f**	**N. Harrison** **K. Joo**	1st round done on Sep 18

Analysis Reviews

Analysis	Data	Author	In progress
First Observations of Beam Spin Asymmetries for K+	**e1f**	**D. Riser**	1st round done on Sep 18
Extraction of $A_{LU}^{\sin\phi}$ moments from hard exclusive π^+ off the unpolarized hydrogen target in a wide range of kinematics	**e1f**	**S. Diehl**	Ongoing
Beam asymmetries in exclusive π^+ electro production for W> 1.7 GeV from e16	**e16**	**P. Bosted** **K. Park**	Analysis under revision

Analysis Reviews

Analysis	Data	Author	In progress
Exclusive electro-production of the f0(980) and f2(1270) on the proton with CLAS	**e1f**	**B. Garillon** **S. Niccolai**	Brice busy with other project
Di-hadron beam spin asymmetry in SIDIS electro production	**eg1-dvcs**	**S. Pisano**	Silvia busy with other project
Deep-virtual production of the ρ^+ meson off the proton	**e1-dvcs**	**A. Fradi**	Ahmed busy with other projects. Slow progress
Semi-inclusive pion production	**e16**	**M. Osipenko**	Working on a better alignment
Time-like Compton scattering	**g12**	**I. Abayrak**	Last record 2015

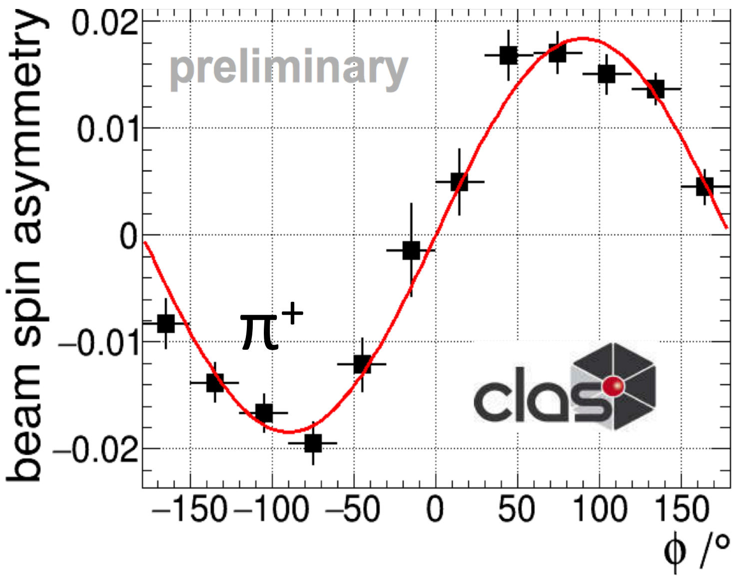
CAA Reviews

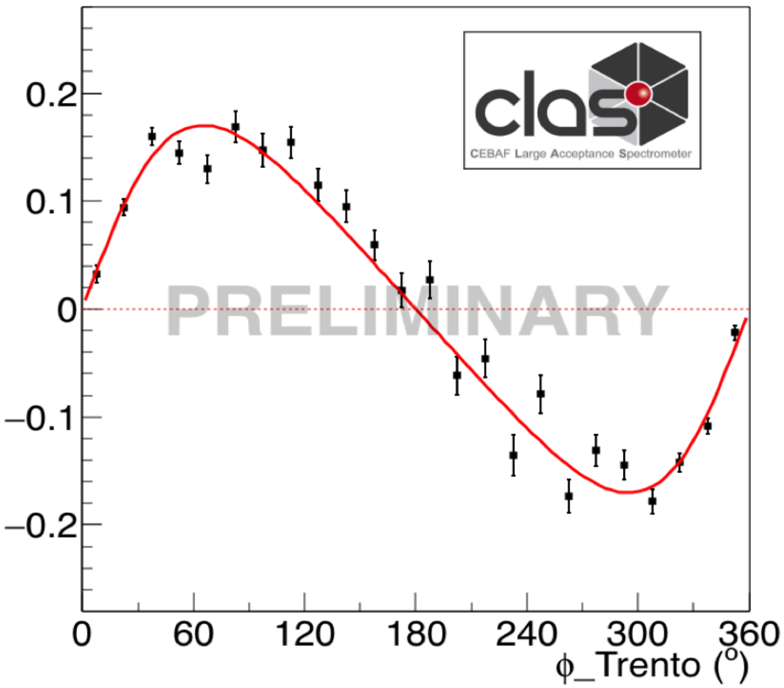
Analysis	Data	Author	In progress
Observation of transverse polarization of Lambda hyperons in the current frgamentation from unpolarized targets	**RGA**	**A. Vossen**	1st round done on Oct 18
Boer-Mulders effect and helicity dependent fragmentation functions in hadron pair production off unpolarized targets	**RGA**	**A. Vossen**	1st round done on Oct 18

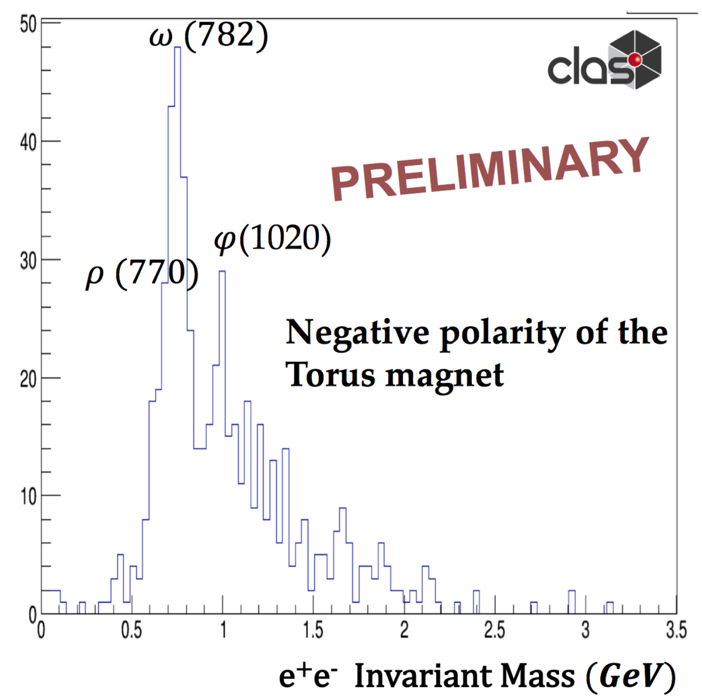
DNP Conference:

Good representation of DPWG studies and CLAS12 potentiality

Thanks to the DNP analyzers and DPWG for the successful effort







Thursday, 15 November 2018

Deep Processes Working Group - I

Remote connection: https://bluejeans.com/579906649

Convener: Mr. Marco Contalbrigo (INFN Ferrara)

Location: F113

08:30 **DPWG Business** *10'*

Speaker: Mr. Marco Contalbrigo (INFN Ferrara)

Material: **Slides**

08:40 **Alignment of CLAS6 DCs** *30'*

Speaker: Mikhail Osipenko (INFN Genova)

Material: **Slides**

09:10 **Q2-dependence of SIDIS observables** *30'*

Speaker: Dr. Harut Avagyan (Jefferson Lab)

Material: **Slides**

09:40 **Machine Learning techniques for CLAS12 data analysis** *20'*

Speaker: Noelie Cherrier (Saclay)

Material: **Slides**

Deep Processes Working Group - II

Remote connection: https://bluejeans.com/579906649

Convener: Mr. Marco Contalbrigo (INFN Ferrara)

Location: F113

10:30 **pi0 and eta electroproductiion measurements** *25'*

Speaker: Paul stoler (Rensselaer Polytechnic Institute and UCONN)

Material: **Slides**

10:55 **MC Business** *5'*

Speaker: Mr. Marco Contalbrigo (INFN Ferrara)

11:00 **MC Generators for SIDIS and Exclusive Channels** *30'*

Speaker: Dr. Harut Avagyan (Jefferson Lab)

Material: **Slides**

11:30 **TMD-Gen Package** *20'*

Speaker: Timothy Hayward (William and Mary)

Material: **Slides**

11:50 **RADGEN** *20'*

Speaker: Dr. Aram Movsisyan (INFN-Ferrara)

Material: **Slides**

12:10 **Open Discussion** *30'*

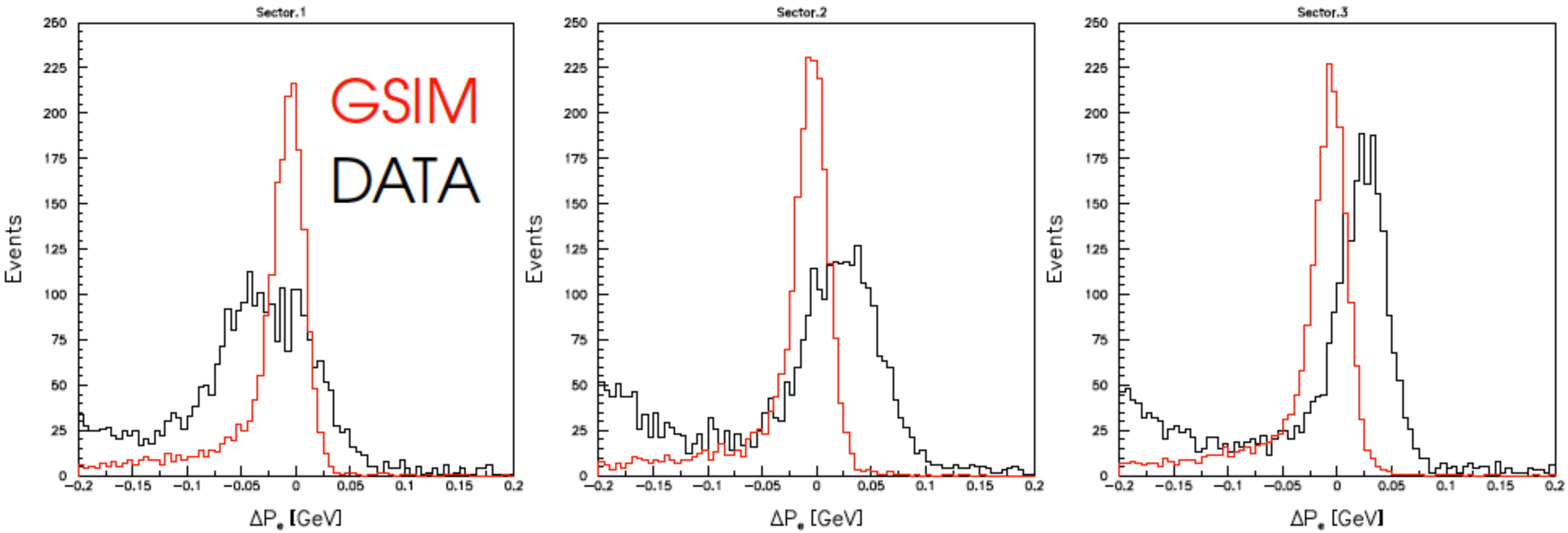
Speaker: Mr. Marco Contalbrigo (INFN Ferrara)

Alignment of CLAS-6 DCs using tracks with constrained vertex

E1-6 run period, years 2001-2002

M. Osipenko[1]

[1]INFN Genova



DC Region 1 Survey: X,Y

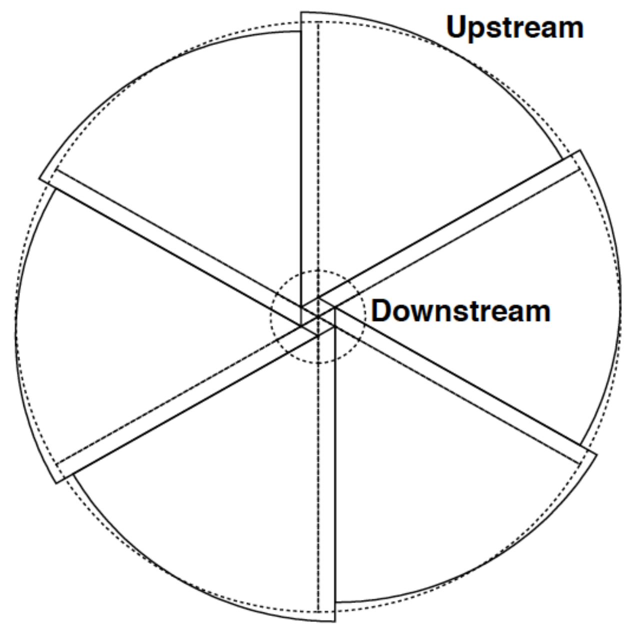
- DC Region 1 was surveyed in CLAS-Note-98-001,
- wrong indexing of X, Y-rotations in Geometry Table (used by all experiments): $S2 \leftrightarrow S6$, $S3 \leftrightarrow S5$,

Bugs in DC(dc_geom.c line.330)

```
/* actually, these (above) are the points on the wire in
 * the center of the chamber. To get the points in the
 * Sector midplane, we have to move along the wire to
 * where y=0 (definition of the Sector midplane).
 * Adjust the wire lengths as well.
 */
```

sectors are not rotated, but shifted in Y_{sector}

$$\Delta Y_{up} = -1.2 \pm 0.13 \times 10^{-3} * 510 = -0.61 \pm 0.07 mm,$$
$$\Delta Y_{down} = -7.1 \pm 0.8 \times 10^{-3} * 79.4 = -0.56 \pm 0.06 mm,$$



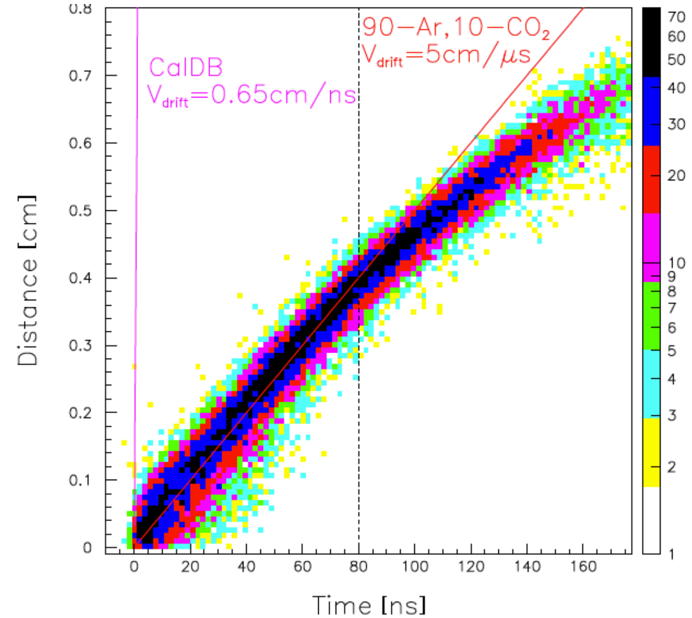
Alignment Data

Run Number	Run Period	Beam Energy (GeV)	Beam Current (nA)	Mini-Torus Current (A)	EC_{lo} Thresh. (mV)	Number of Events
8935	E1b	1.645	2.4*	6000	200	1138856
30909	E1-6	5.770	35*	6000	597	250573
30910	E1-6	5.770	35*	2000	597	1029523
31486	E1-6	5.770	35*	2000	600	358410
33006	E2b	4.470	1	2000	200	1566364
33683	E2b	0.984	1	2000	200	5733284
36654	E1e	5.015	1.5	2000	100	5032463
40905	Eg2a	4.023	20	0	172	360150
41709	Eg2a	5.015	2	2000	172	1011892
47447	DVCS	5.776	10	S 0 ?	168	14669929
50226	Bonus	5.268	21	S200	260	1114847
58609	DVCS2	5.911	16	S150	148	5426033
58612	DVCS2	5.911	30	S40	148	3215225
60110	EG1DVCS	5.979	5*	S40%	148	2009289
60111	EG1DVCS	5.979	5*	S80%	148	1270141
60649	EG1DVCS	5.777	5*	S?%	148	5059546

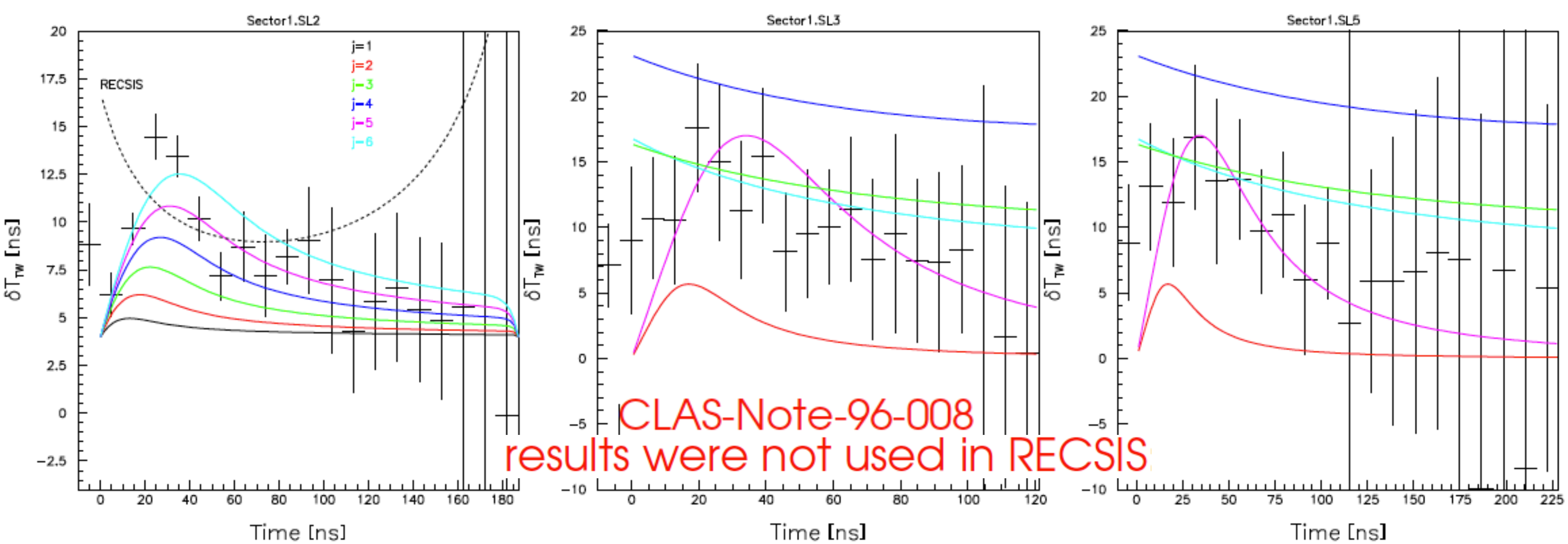
D vs. T Calibrations

$$d = p_1 t + \frac{d_{max} - p_1 t_{max}}{1 - p_2} \left\{ \left(\frac{t}{t_{max}} \right)^{p_3} - p_2 \left(\frac{t}{t_{max}} \right)^{p_4} \right\}$$

p_1 is drift velocity,
90% Ar+10% CO_2
has 5 cm/μs,

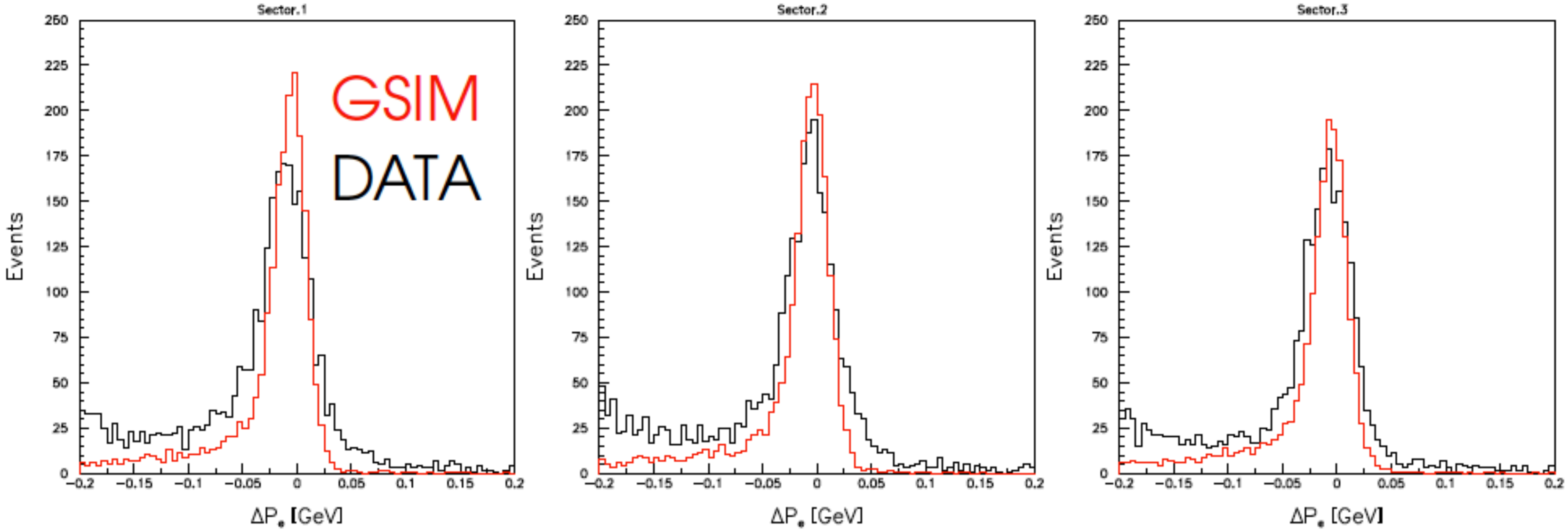


Time-Walk in DC

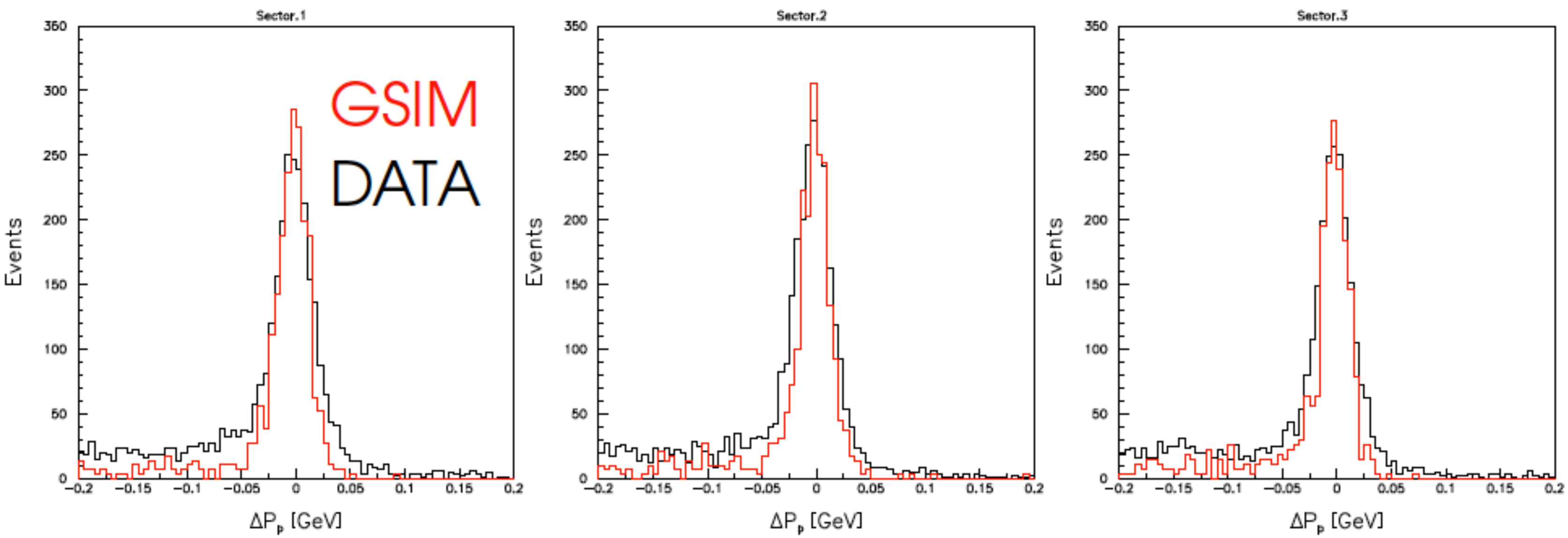


CLAS-Note-96-008
results were not used in RECSIS

elastic e'



elastic p'



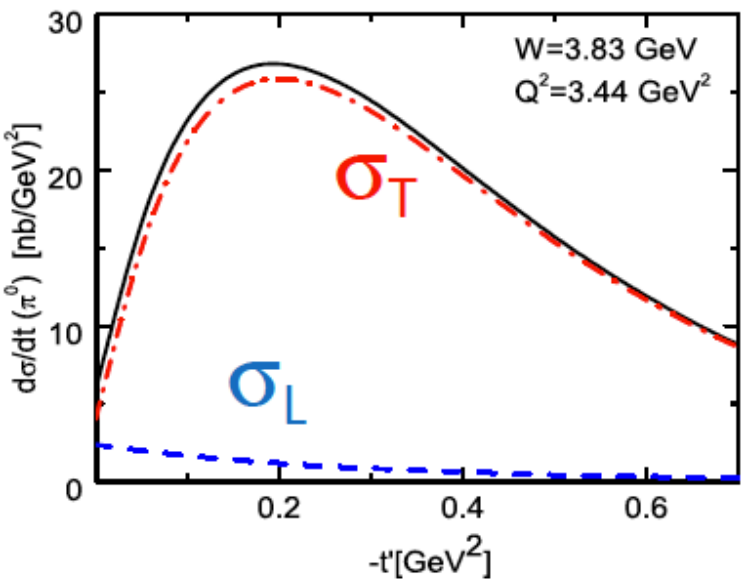
Measurement of **quark transverse polarization** at CLAS via π^0 and η exclusive electroproduction

Paul Stoler

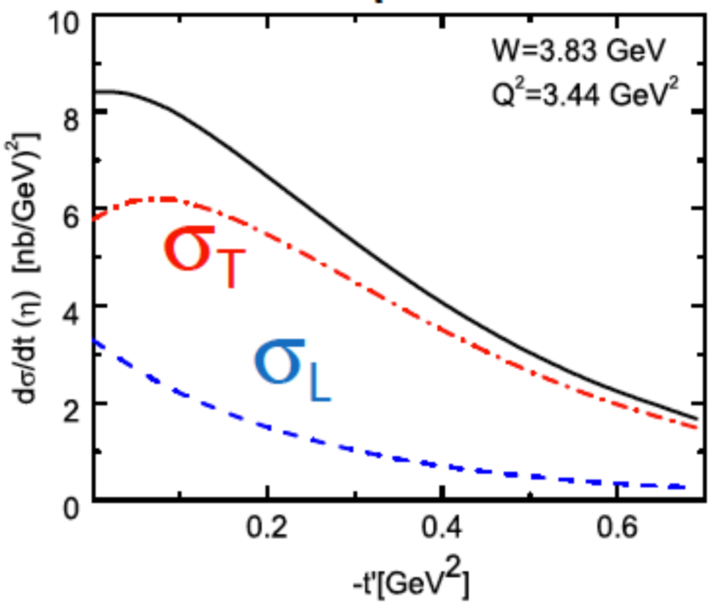
$$\frac{d^4\sigma}{dQ^2dx_Bdtd\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}(\sigma_T + \epsilon\sigma_L + \epsilon\cos 2\phi_\pi\sigma_{TT} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi\sigma_{LT})$$

Goloskokov-Kroll-1106.4897

π^0



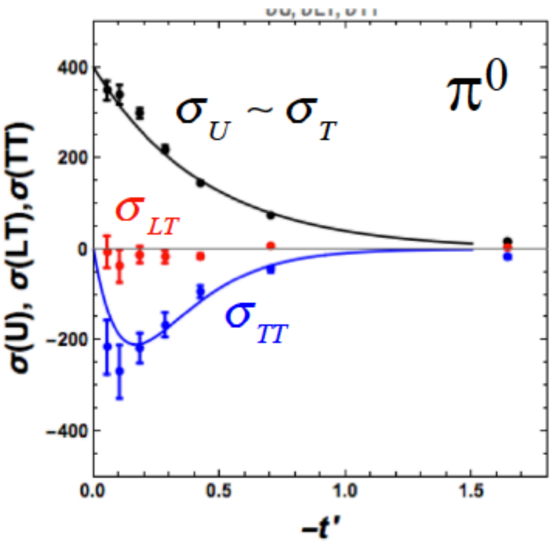
η

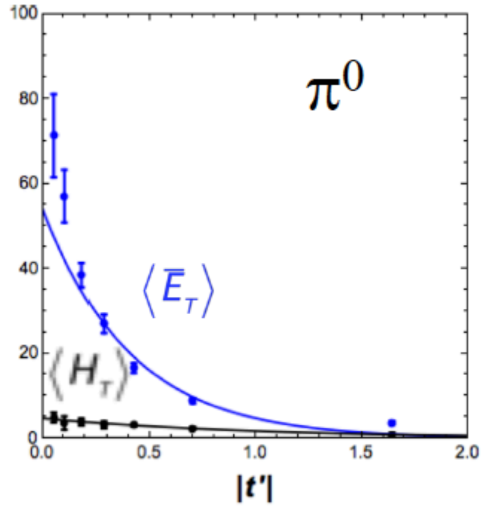


H_T and E_T - quark helicity flip

H_T nucleon helicity flip

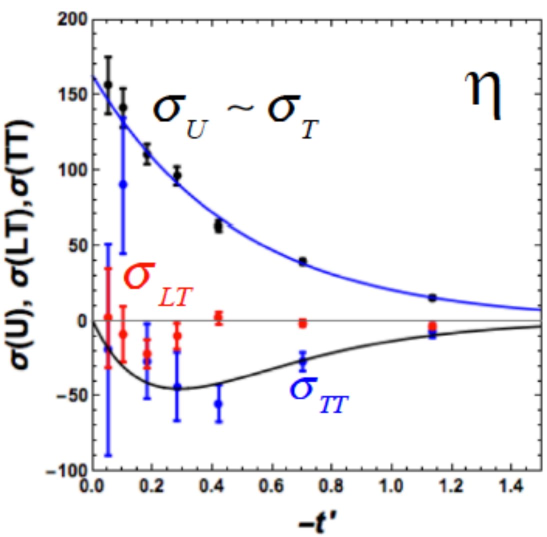
E_T nucleon helicity non-flip

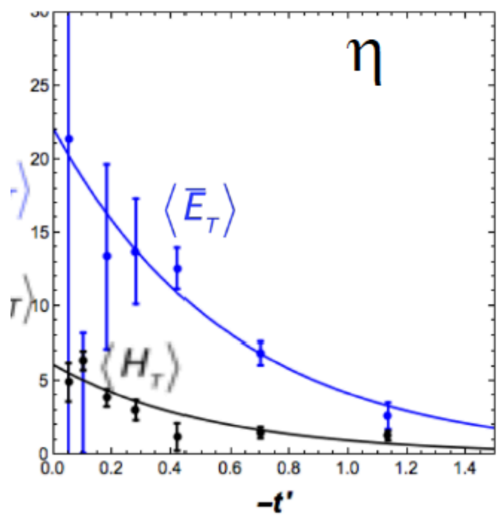




$$\frac{d\sigma_T}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\left\{\left(1-\xi^2\right)\left|\langle H_T\rangle\right|^2 - \frac{t'}{8m^2}\left|\langle E_T\rangle\right|^2\right\}$$

$$\frac{d\sigma_{TT}}{dt} = \frac{4\pi\alpha}{k'}\frac{\mu_\pi^2}{Q^8}\frac{t'}{16m^2}\left|\langle E_T\rangle\right|^2$$





$$\bar{E}_T^{\pi^0} \approx \frac{1}{\sqrt{2}}\left(e_u \bar{E}_T^u - e_d \bar{E}_T^d\right)$$

$$\bar{E}_T^{\eta} \approx \frac{1}{\sqrt{6}}\left(e_u \bar{E}_T^u + e_d \bar{E}_T^d\right)$$

$$\mathcal{H}(x,b) = \frac{1}{4\pi}\frac{h(x)}{f_H(x)} e^{-\frac{b^2}{4 f_H(x)}}$$

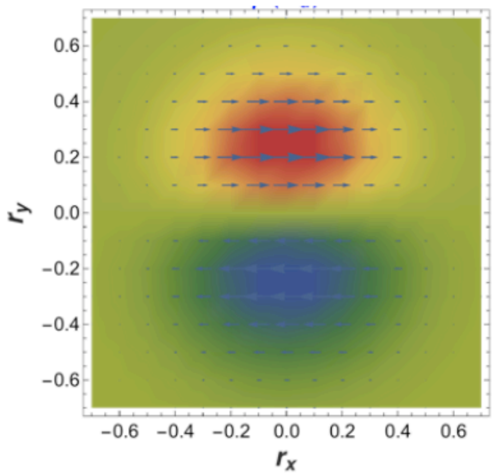
$$\bar{\mathcal{E}}_T(x,b) = \frac{1}{4\pi}\frac{e(x)}{f_E(x)} e^{-\frac{b^2}{4 f_E(x)}}$$

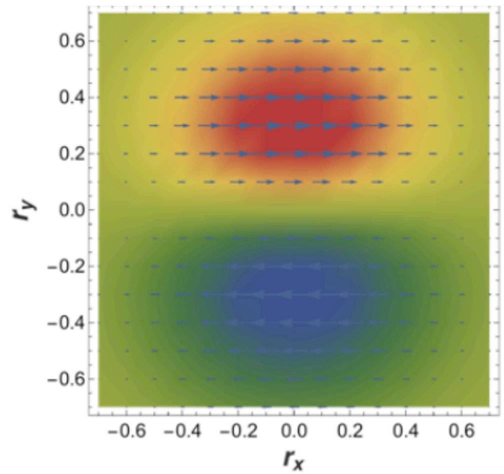
x=0.2
Parameters from π0, η Hall-B data
Goloskokov & Kroll

$$q_T(x,b^x) \equiv \frac{1}{2} b^y \frac{1}{m}\frac{\partial}{\partial b^2}\bar{\mathcal{E}}_T$$

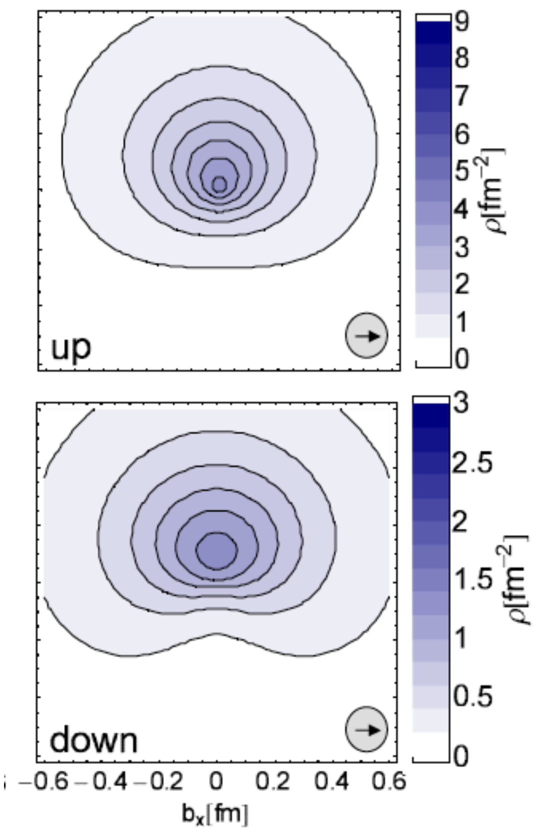
$q(\bar{\mathcal{E}}_T u)$

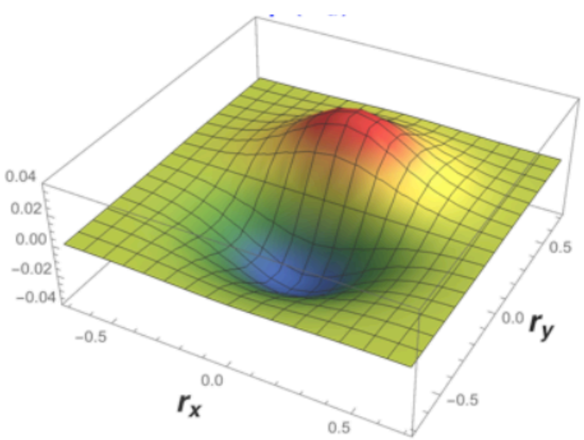
$q(\bar{\mathcal{E}}_T d)$

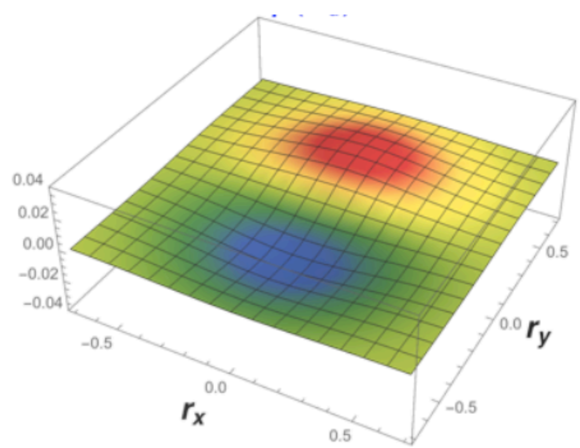




arXiv: hep-lat/0612032

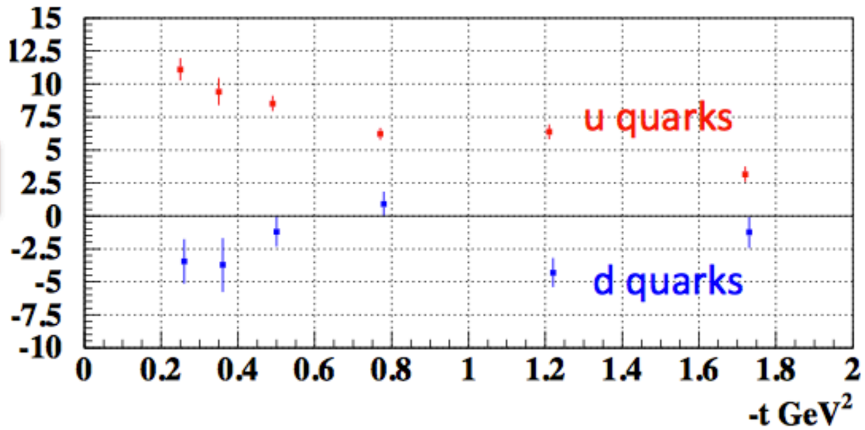




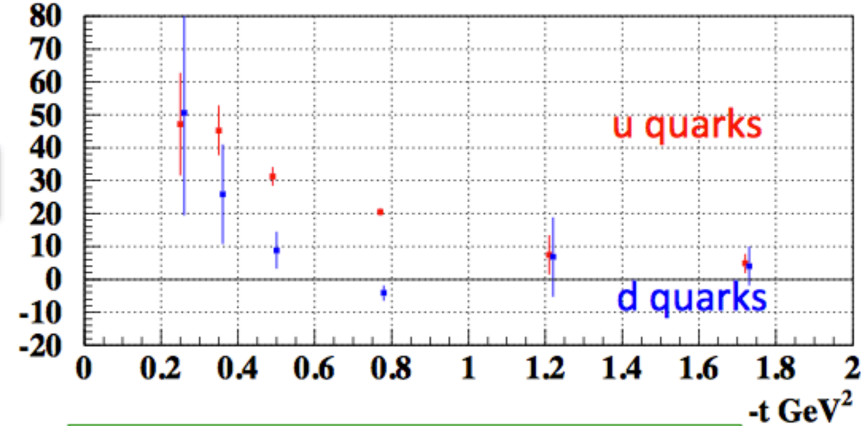


Extracting GFFs for individual quark flavors.

$\langle H_T \rangle$

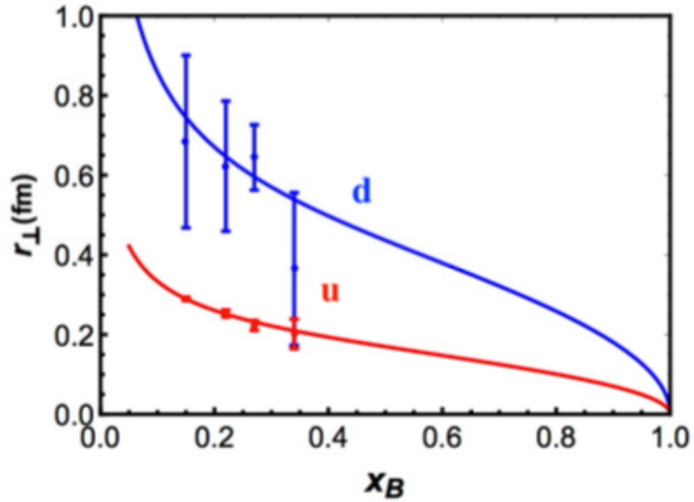


$\langle \bar{E}_T \rangle$

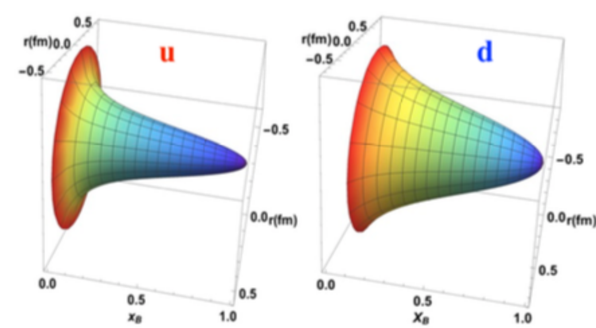


VK arXiv: 1601.04367 [hep-ex] 2016

Radius vs x_B



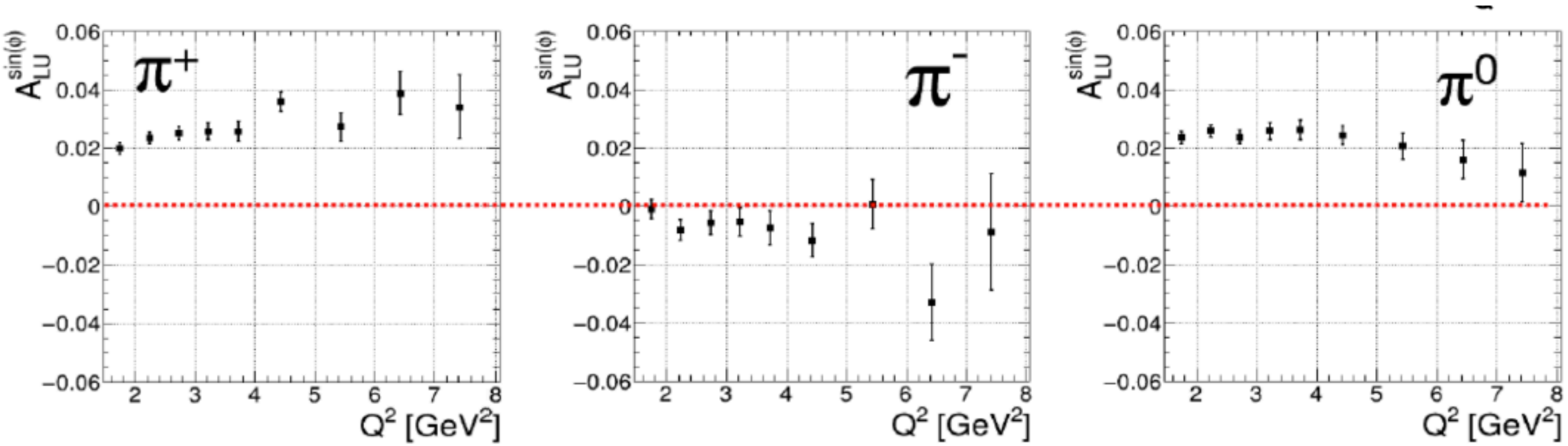
3D image



Q^2-dependence of SIDIS observables

Harut Avakian (JLab)

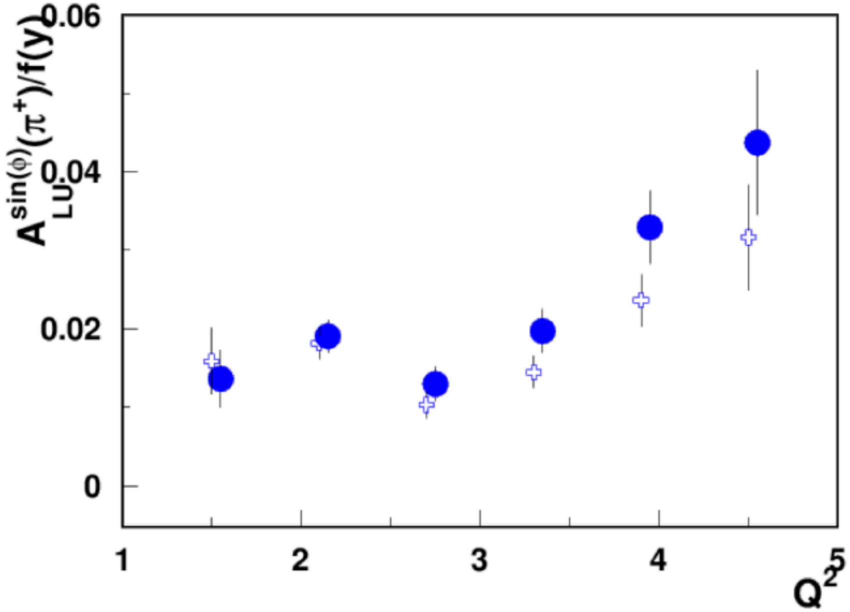
TMD means Transverse Momentum Dependent PDF with most important dependences making it different from other PDFs its dependence on transverse momentum and Q^2(evolution)!!!

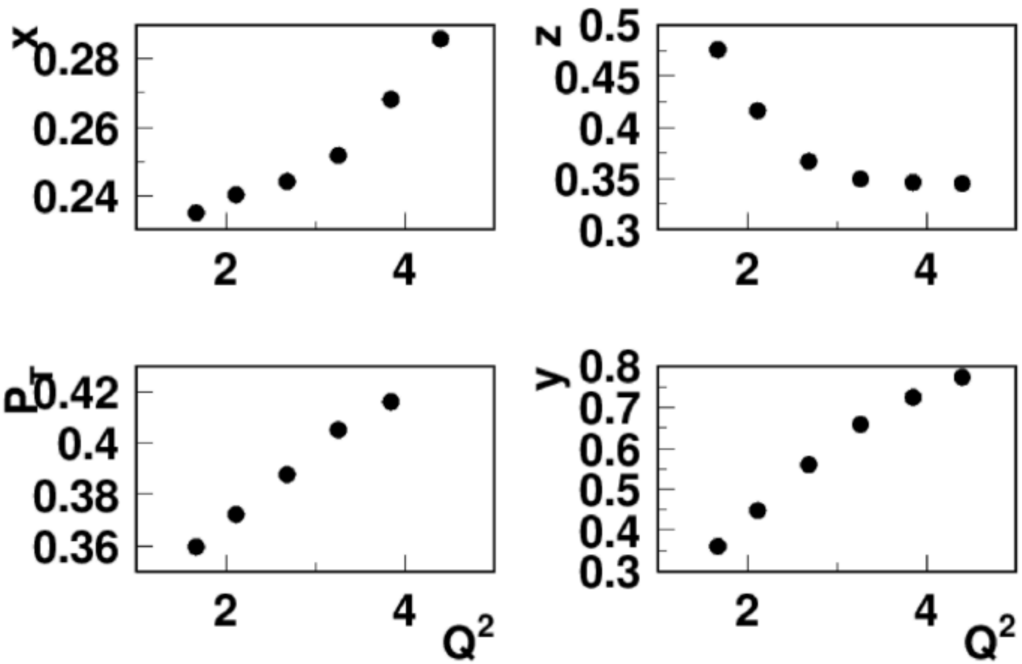


f(y)= $(2-y)\sqrt{1-y-\frac{1}{4}\gamma^2 y^2}$

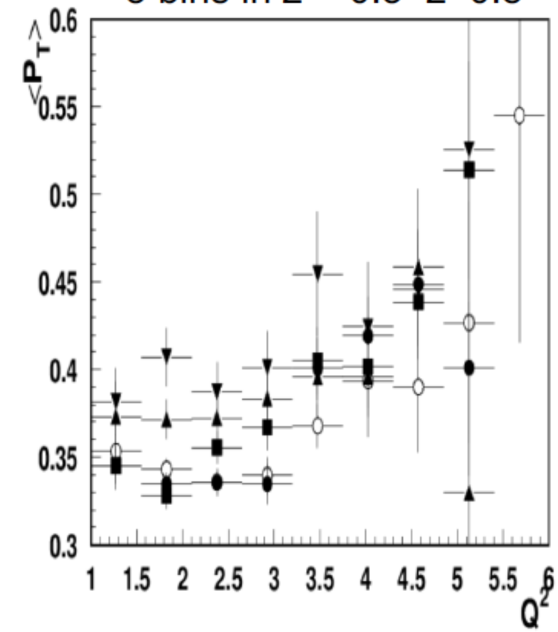
θ_e>8
Eπ>1.2

0.2<x<0.3
0.3<z<0.8
1.1<M_X
2<W<4
0.05<y<0.8

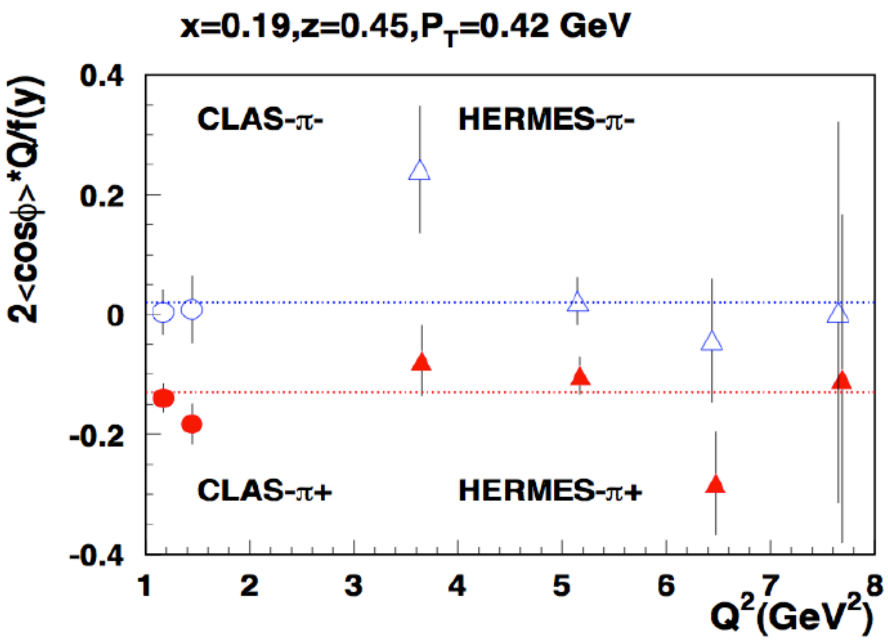




5 bins in z ->0.3<z<0.8

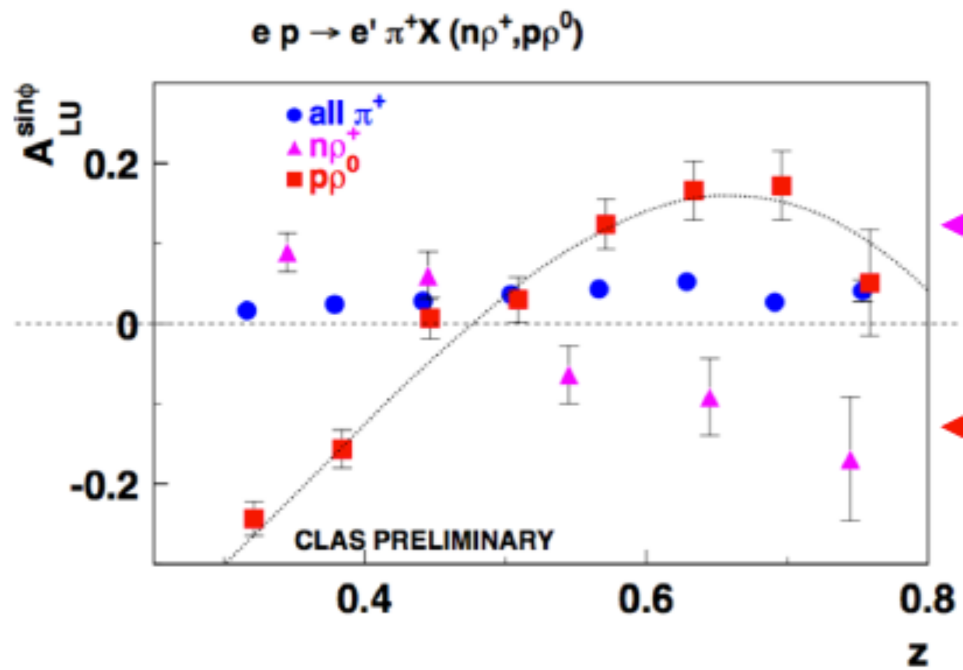


$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xh\,H_1^{\perp} + \frac{M_h}{M}\,f_1\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xf^{\perp}D_1 + \frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{H}}{z}\right)\right]$$



CLAS data consistent with HERMES (27.5 GeV)

What is the role of vector meson decay contribution ?



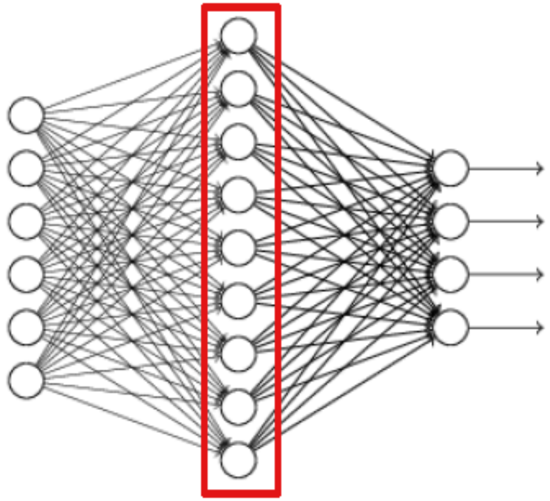
Interpretable machine learning algorithms for DVCS analysis in CLAS12 data

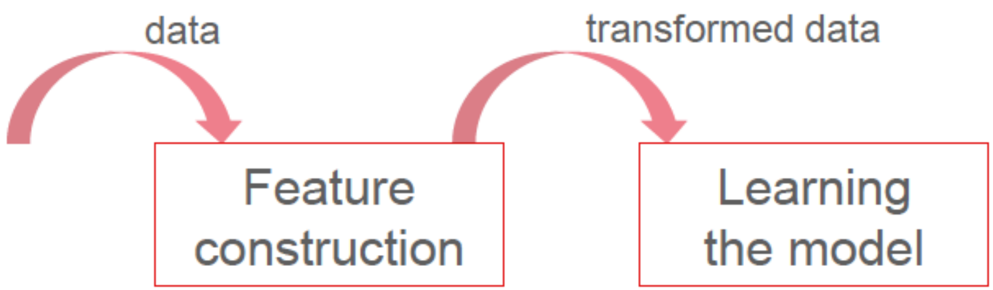
Noëlie Cherrier (CEA Saclay)

Discriminate between DVCS (signal) events and background events in CLAS12 data

- **Idea: build automatically new variables to improve the score of a machine learning classifier**

  → **Feature construction**





- **Use interpretable models**

APPLICATION TO CLAS12 DATA

- **MC data: uniform generation of DVCS and π^0 production events**

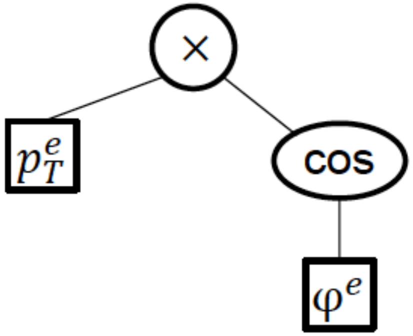
- **Base features: one electron, one proton, three photons**

  Selection: at least 2 of these particles including an electron

  $E > 2\ GeV$
  $Q^2 > 1.5\ GeV^2$
  $W^2 > 4\ GeV^2$

- **3-momentum for each particle**

- **Tree-like individuals are generated following the grammar and transition probabilities**



- **Base score with XGBoost: 64% of correctly classified MC events**

- **Examples of high-level features that can be used for cuts:**

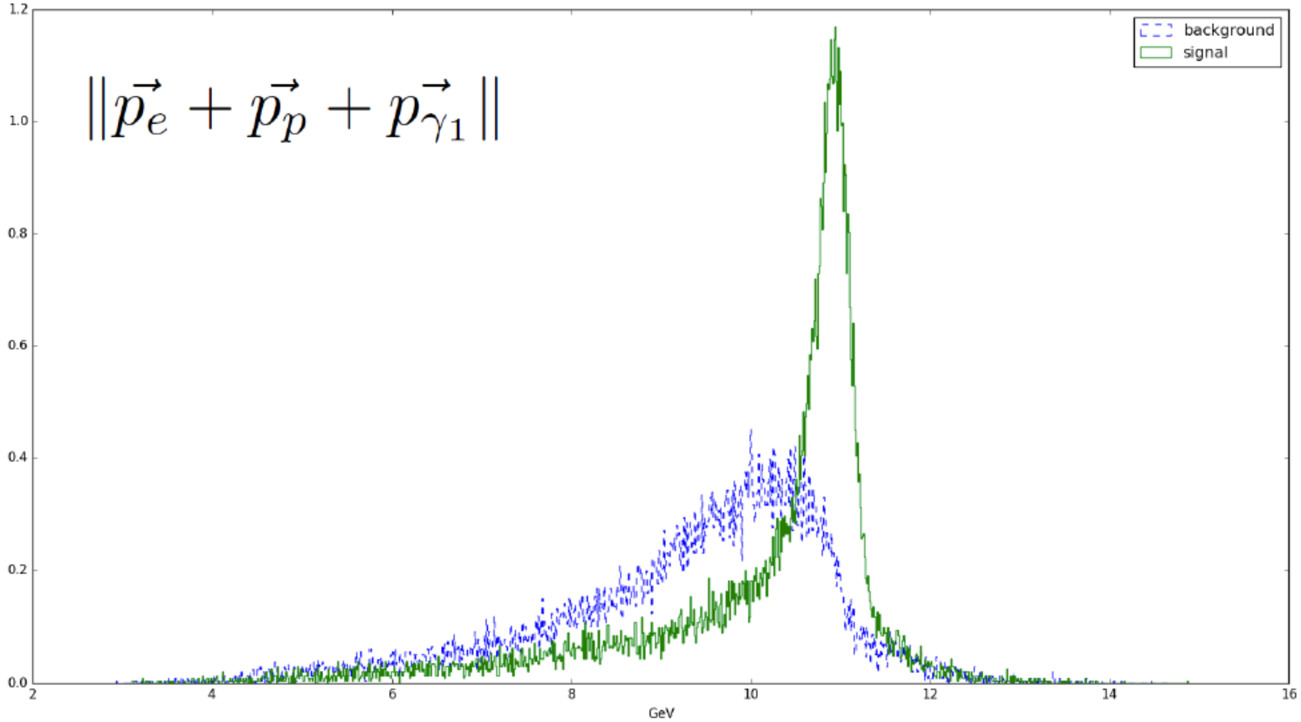
→ M[ep→epγ]	+0.77%
→ M[ep→epX]	+0.23%
→ Photon energy	+0.23%
→ Cone angle	+1.69%
→ Photon energy + cone angle	+1.75%
→ All at once	+2.04%

- **2 examples of feature built by the feature construction algorithm (from 2 independent runs, vectorial representation with operators such as norm, angle, dot product, ...):**

$$M_p + (\vec{p_e} + \vec{p_p} + \vec{p_{\gamma_1}})_z$$

$$||\vec{p_e} + \vec{p_p} + \vec{p_{\gamma_1}}||$$

Both add **2%** to the score, which is big compared to the examples above!



- **Automatic feature construction may greatly improve the classification score, while keeping the interpretability/readability of newly built features**

MC Generators for SIDIS and Exclusive Channels

Harut Avakian (JLab)

- To get a proper account of radiative corrections the full set of relevant azimuthal moments should be accounted (Bastami et al arXiv:1807.10606)
- Simultaneous extraction of all moments is important also because of correlations!

a) **Full event generators trying a comprehensive description of a reaction**

Applications: attempt to reproduce the raw data
understand background conditions
estimating rates of certain types of events
planning and optimizing detector performances,...

b) **Specific event generators (single- and di-hadron, DVCS, DVMP) where only the final state of interest is generated**

Applications: develop and validate analysis
flexible integration of different models
cross-section weighting
easier implementation of radiative corrections

Event generators for DIS/SIDIS/HEP studies

https://github.com/JeffersonLab/clasdis-nocernlib
https://github.com/JeffersonLab/inclusive-dis-rad
https://github.com/JeffersonLab/dvcsgen

Event generators in github:

Ex.Readme.md

inclusive DIS generator, taking as input Bosted and CJ15 parametrizations with radiative corrections, can generate and work with grids

- Need to define some common standards for MC generators, including
  - storage (github), compilation, command line options
  - their capability to run with docker for remote processing
  - flexible input for different involved input non-perturbative functions, integration with some TMD/GPD libraries
  - capability to use grids for input structure functions and output
  - capability to run with both modes (x-section, weights)
  - ……

radiative corrections ?

TMDGen for SIDIS

Timothy B. Hayward

Models

- Many distribution and fragmentation function models are already included.
- Full packaged within TMDGen.

Distribution Functions	Model Identifier
f_1	CTEQ [74]
f_1	LHAPDF [75]
f_1	BCR08 [76]
f_1	GRV98 [77]
g_1	GRSV2000 [78]
f_{1T}, $h_{1T}^{\perp}$, h_1	Torino Group [79, 80, 81, 82, 83]
f_1, g_1, g_{1L}, g_{1T}, f_{1T}, h_1, $h_1^{\perp}$, $h_{1T}^{\perp}$	Pavia Spectator Model [31]

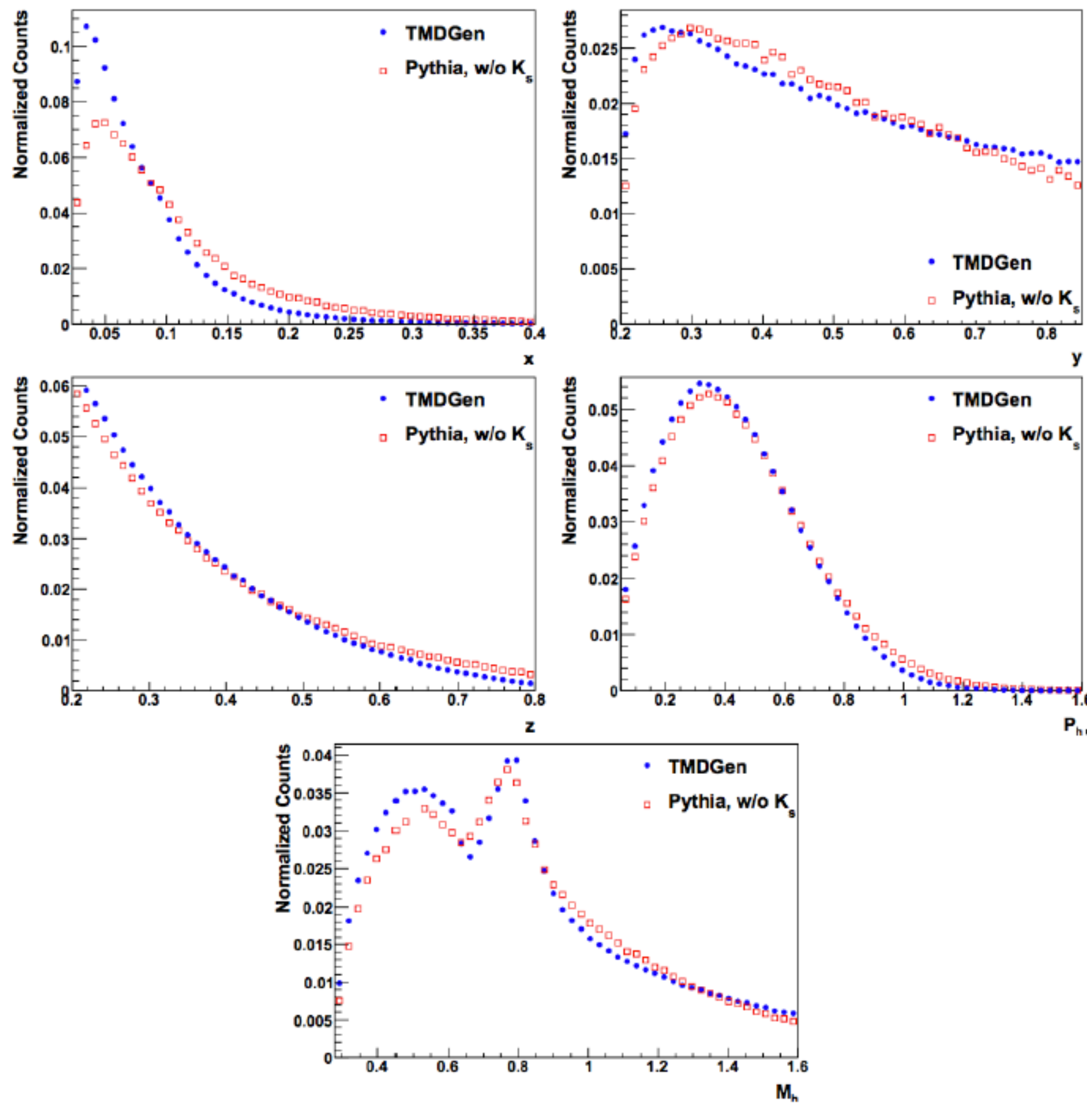
Table 3.1: Models of distribution function available in TMDGen.

Frag. Functions	Final State	Model Identifier
D_1	pseudo-scalar	fDSS [84, 85]
D_1	pseudo-scalar	Kretzer [86]
D_1, $H_1^{\perp}$	dihadron	Spectator Model (Section 2.4)
D_1, $H_1^{\perp}$	dihadron	Set given partial wave proportional to any other partial wave

Table 3.2: Models of fragmentation function available in TMDGen.

Pythia vs TMDGen

Gliske comparison between Pythia and TMDGen for e’π+π-X

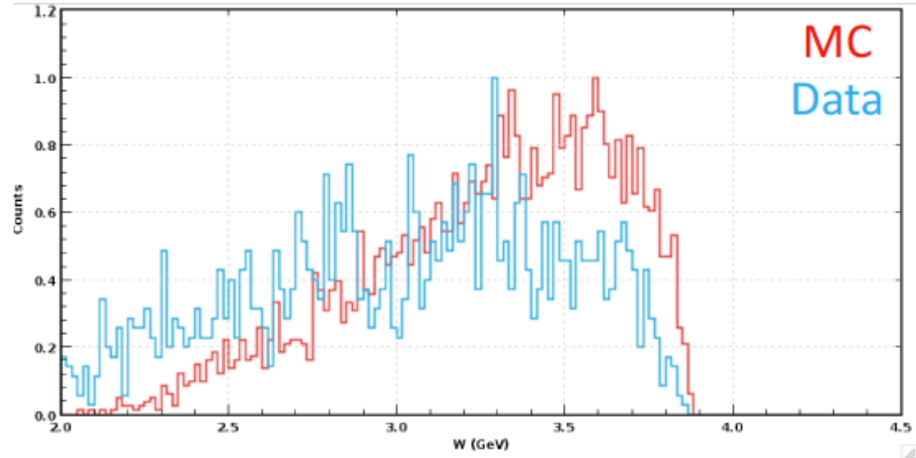


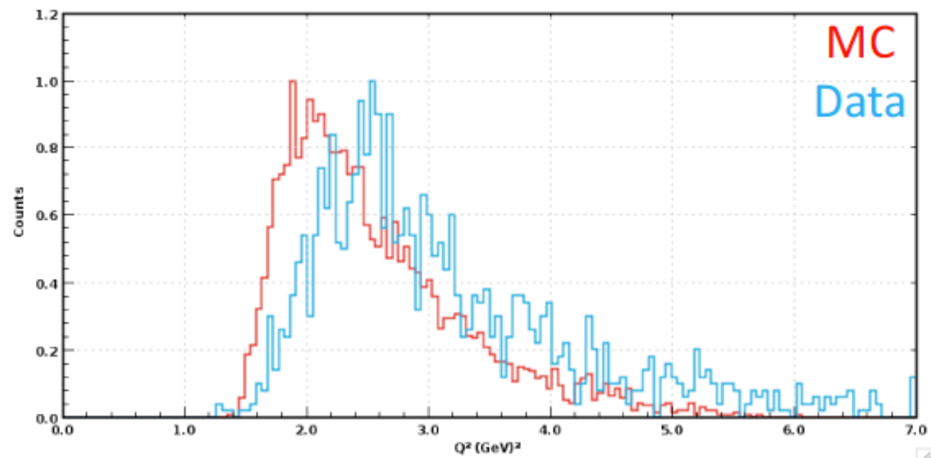
* Polarized beam and target cross sec
coded for single hadron case

* Only longitudinally polarized target
section coded for di-hadron

TMDGen vs CLAS12 DATA

- Pre-DNP results with updated PID
  - e' momentum > 2.25 GeV,
  - Q2 > 1 GeV2
  - W > 2 GeV
  - EC and DC fiducial cuts





Simulation of Radiative Effects for DVCS(BH)

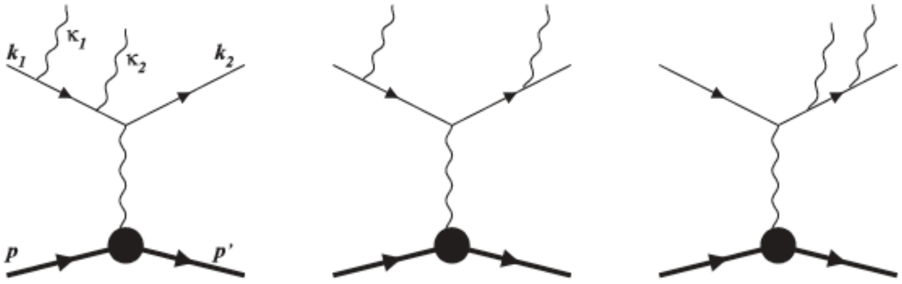
A. Movsisyan

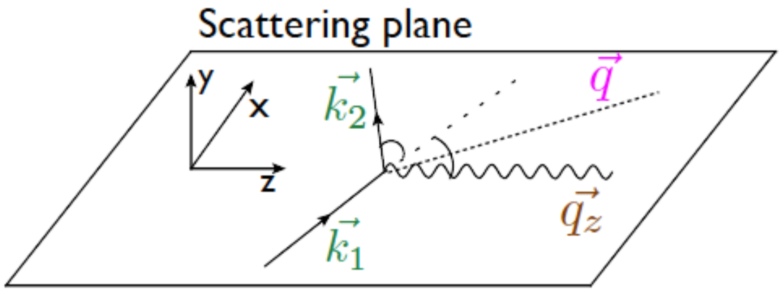
Our goal is to simulate radiative effects for DVCS (BH) in a common framework of CLAS12

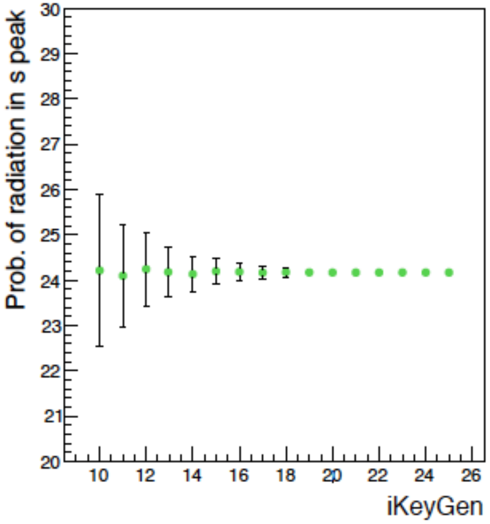
For the fixed kinematic point (Q^2, $x_{Bj.}$, $-t$, ϕ) the born and radiative cross sections together with the probabilities for two-photon emission were calculated by:

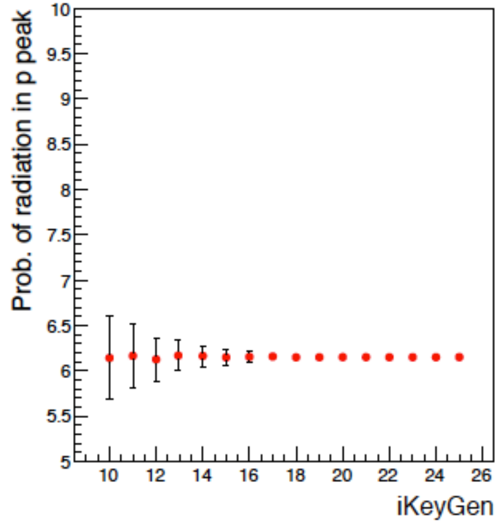
I. Akushivich, A. Ilyichev Phys. Rev. D85, 053008 (2012)

I. Akushivich, A. Ilyichev, M. Shumenko Phys. Rev. D90, 033001 (2014)



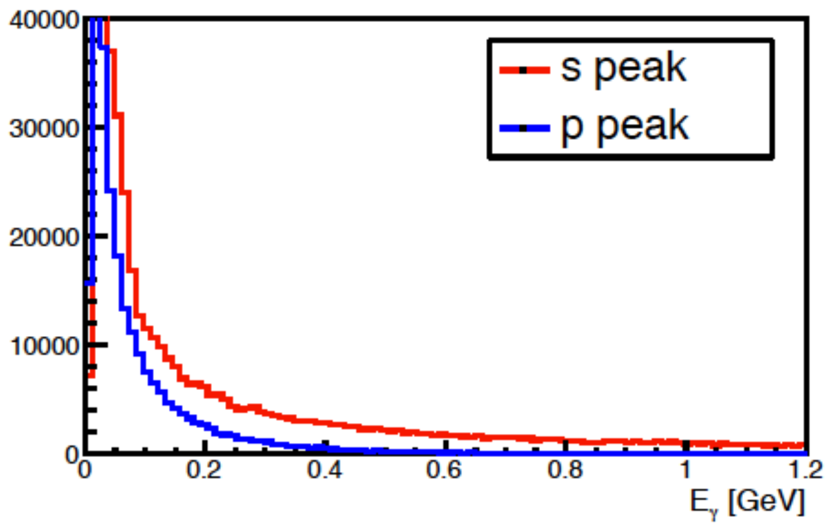




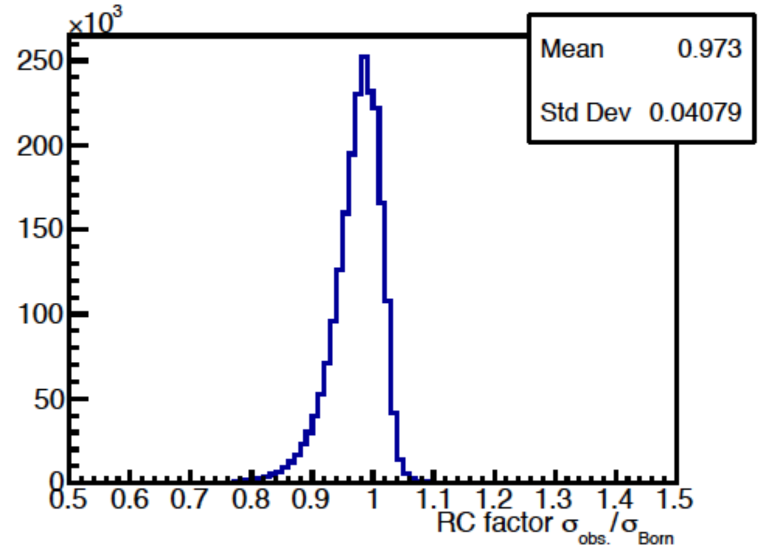


The size of the loop in MC integration: pow(2,iKeyGen)

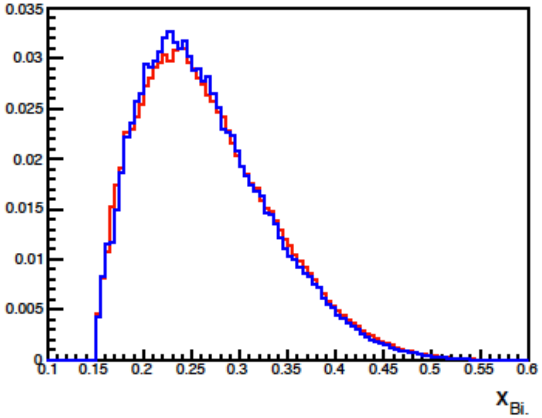
Energy distributions of generated photons

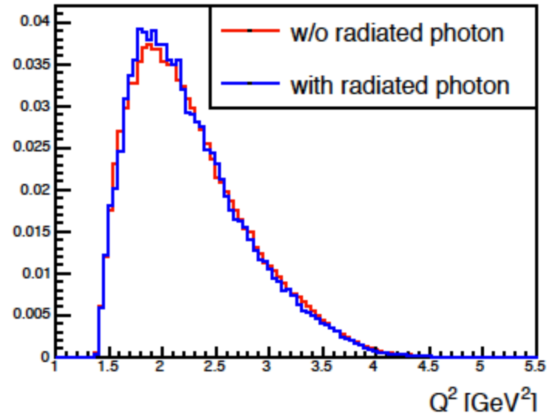


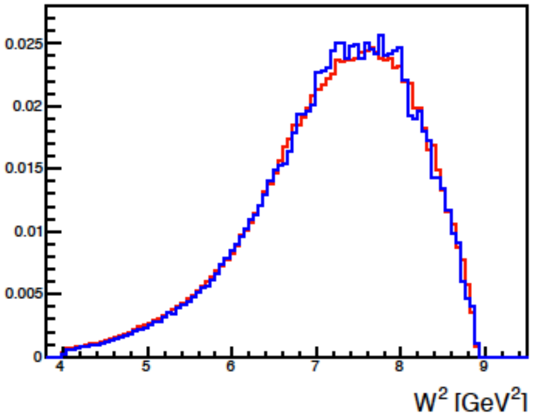
Distribution of RC factor for e16 geometry



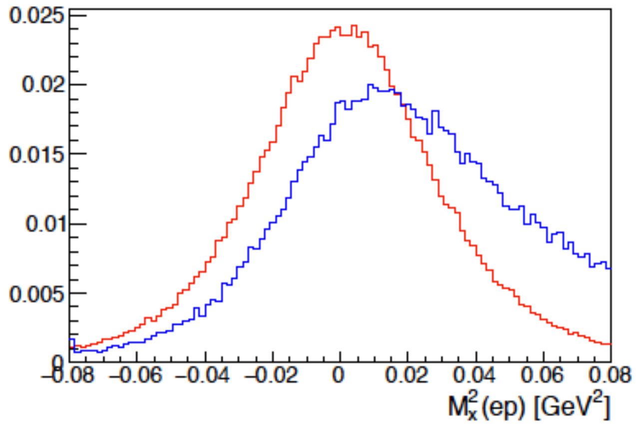
Comparison of the shapes of kinematic distributions for samples with and without radiated photon. Distributions are normalized to the area.

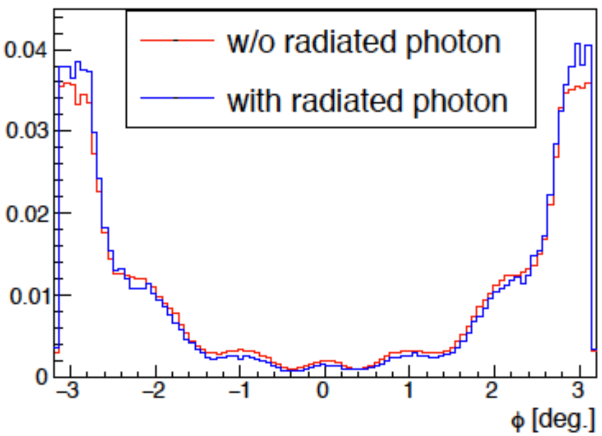




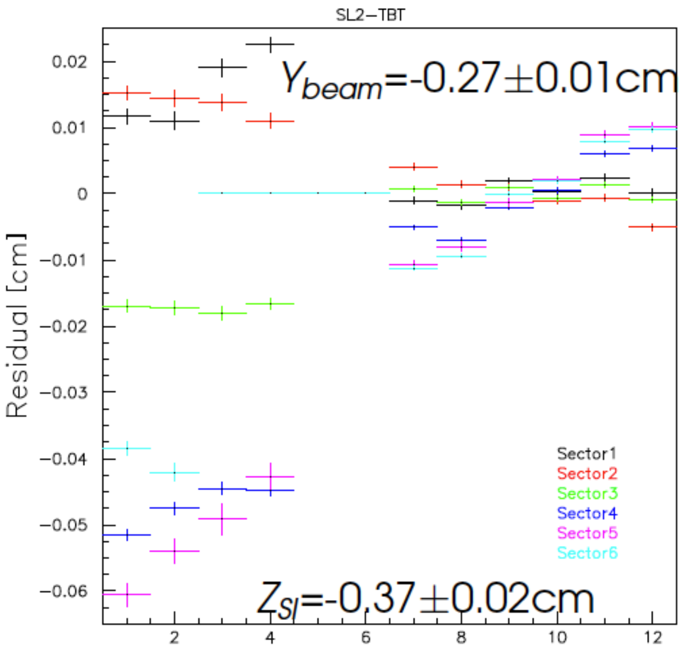


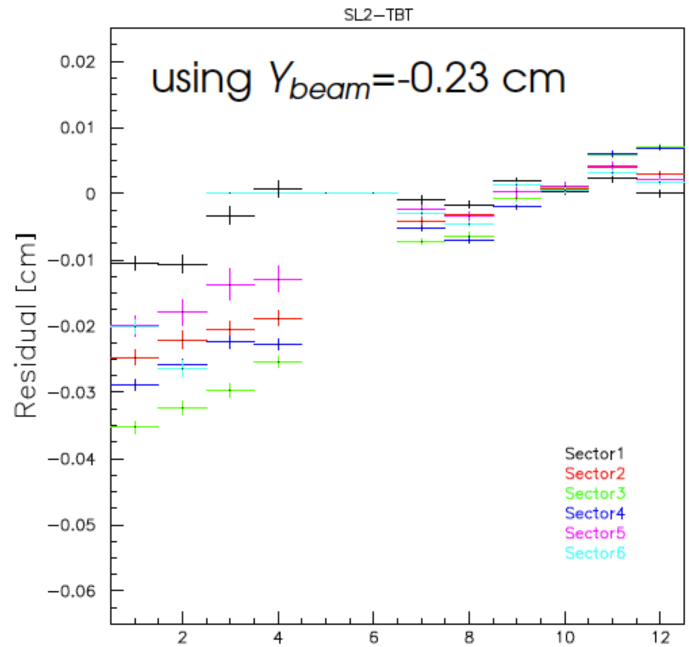
Comparison of the shapes of M_x^2 & ϕ distributions for samples with and without radiated photon. Distributions are normalized to the area.





SL1 Residuals (ϕ_{EC})





New Alignment