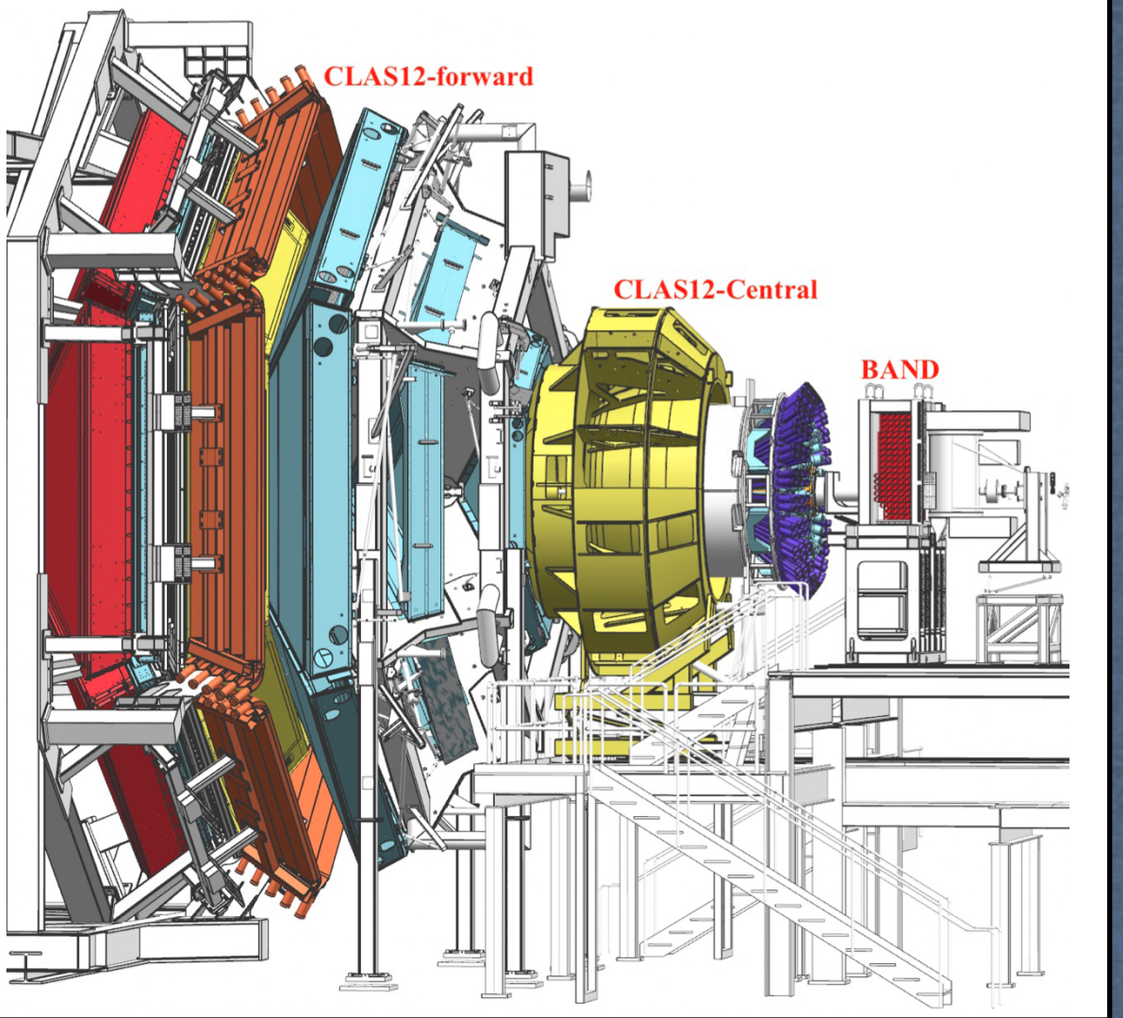
XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects

12-16 April 2021
Stony Brook, NY

Present and future of JLab CLAS12 physics program

M.Battaglieri
Jefferson Lab / INFN



Jefferson Lab

- ✳ Primary Beam: Electrons
- ✳ Beam Energy: 12 GeV
  - 10 > λ > 0.1 fm
    nucleon → quark transition
    baryon and meson excited states
- ✳100% Duty Factor (cw) Beam
  - coincidence experiments
  - Four simultaneous Beams with
  - Independently Variable Energy and Intensity
  - complementary, long experiments
- ✳ Polarization (beam and reaction products)
  - spin degrees of freedom
  - weak neutral currents

L > 10^7 - 10^8 x SLAC at the time of the original DIS experiments!

The CLAS12 detector

Forward Detector:

-TORUS magnet

- HT Cherenkov Counter

- Drift chamber system

- LT Cherenkov Counter

- Forward ToF System

- Preshower calorimeter

- E.M. calorimeter (EC)

Central Detector:

- SOLENOID magnet

- Barrel Silicon Tracker

- Central Time-of-Flight

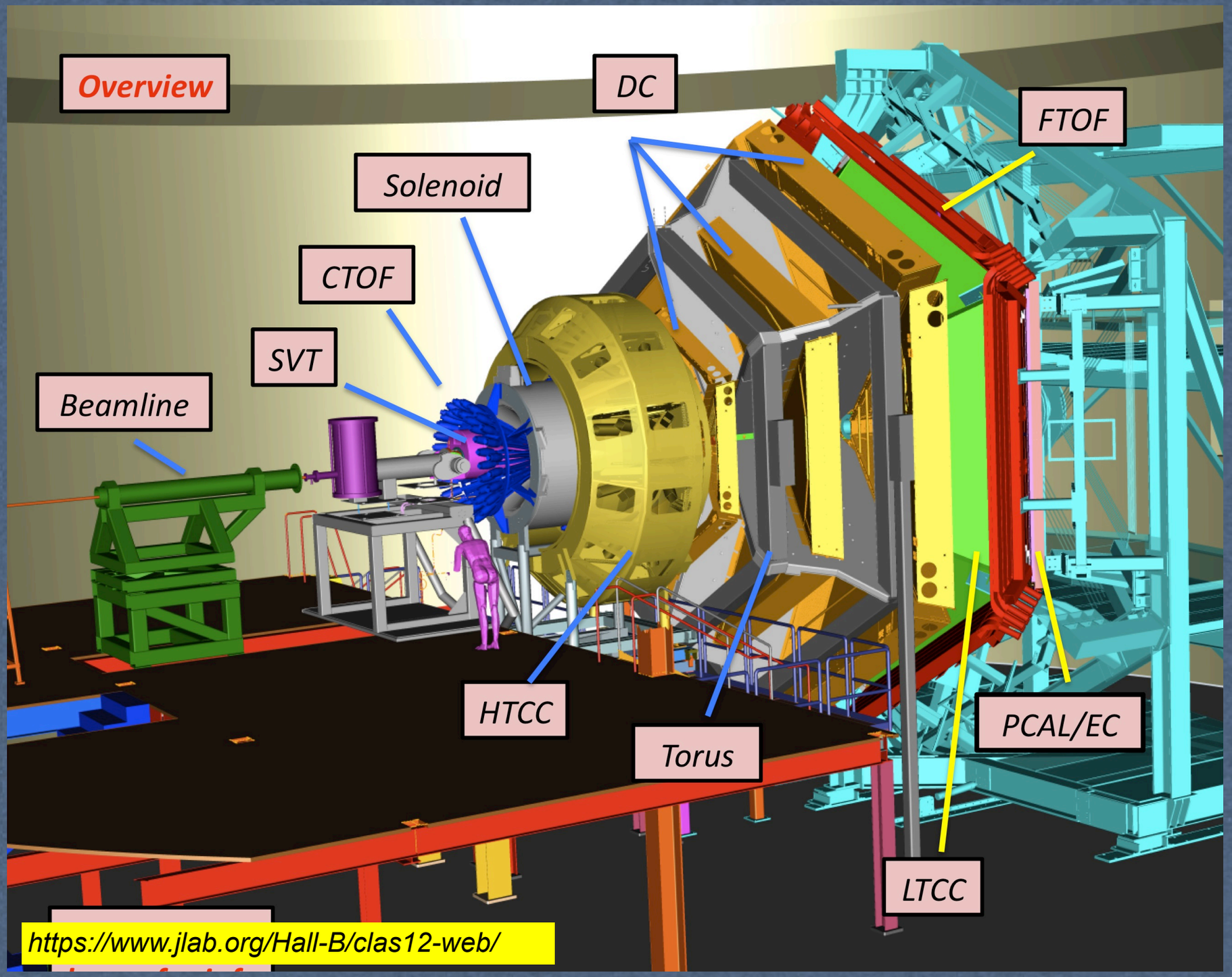
Upgrades:

- Micromegas (CD)

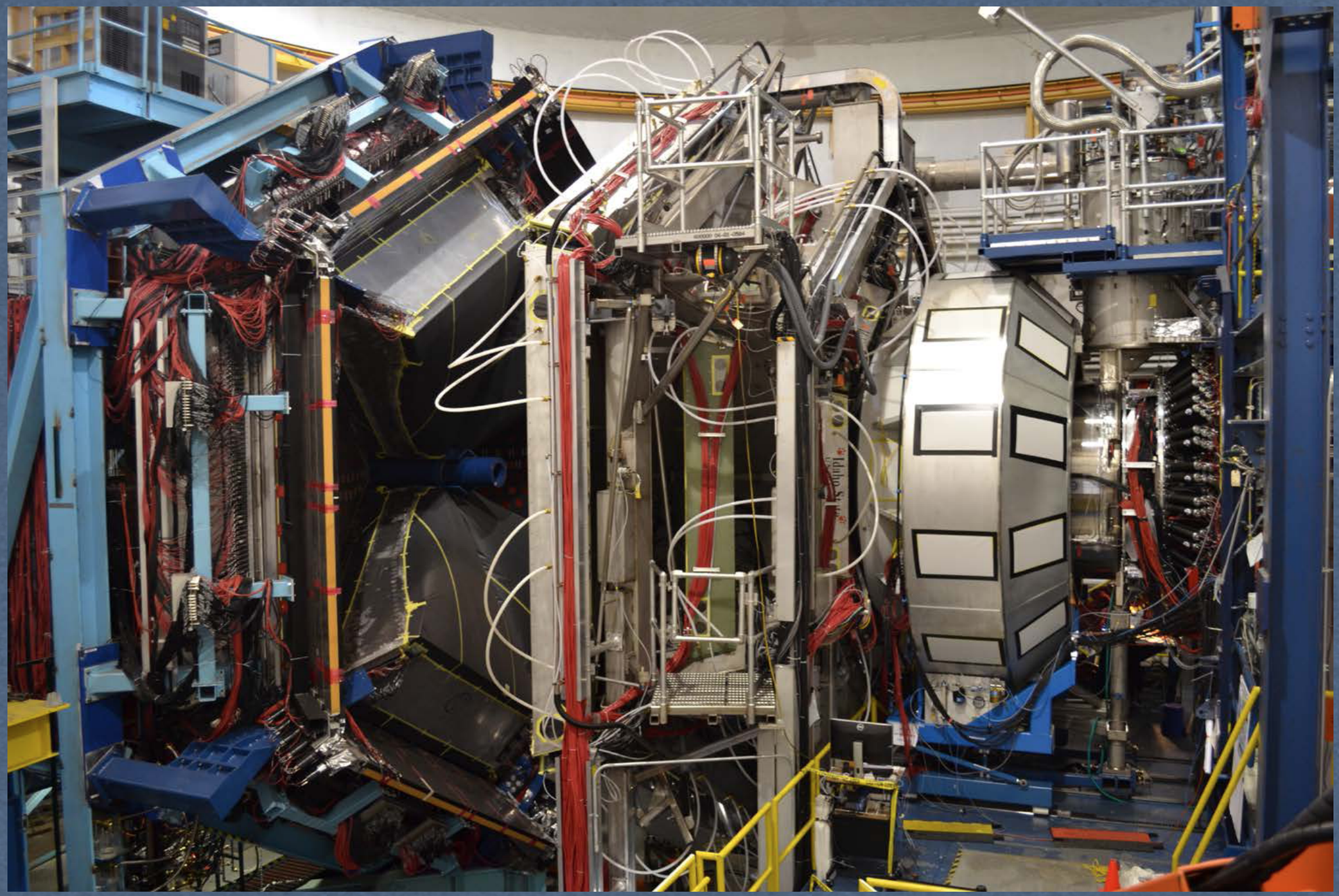
- Neutron detector (CD)

- RICH detector (FD)

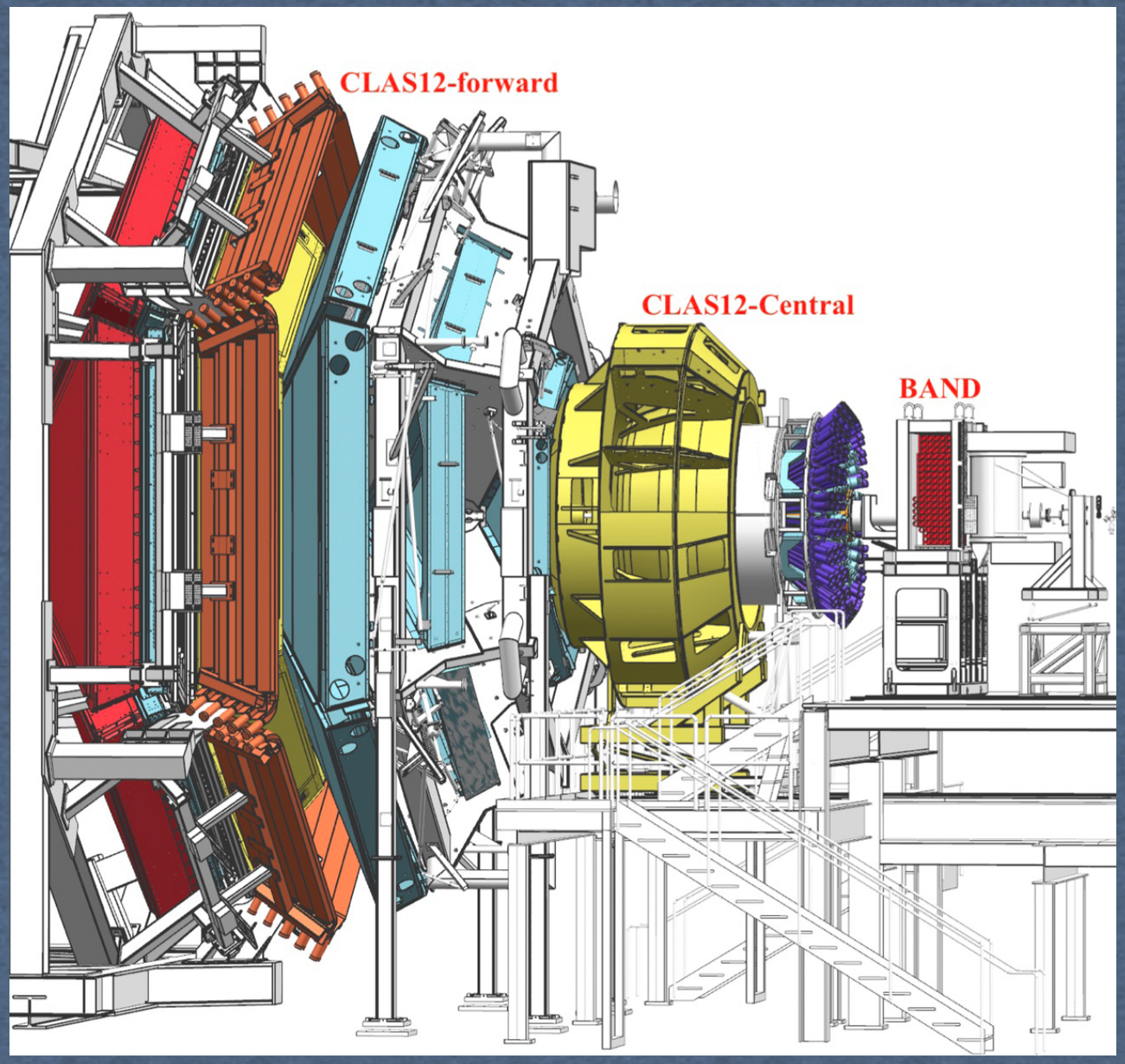
- Forward Tagger (FD)



The CLAS12 detector fully operational!



CLAS12 performance



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The CLAS12 Spectrometer at Jefferson Laboratory

V.D. Burkert [40,*], I. Elouadrhiri [40], K.P. Adhikari [28], S. Adhikari [12], M.J. Amaryan [33], D. Anderson [40], G. Angelini [13], M. Antonioli [40], H. Atac [39], S. Aune [4], H. Avakian [40], C. Ayerbe Gayoso [47,28], N. Baltzell [40], L. Barion [15], M. Battaglieri [17,40], V. Baturin [40], I. Bedlinskiy [29], F. Benmokhtar [8], A. Bianconi [43,20], A.S. Biselli [10], P. Bonneau [40], F. Bossù [4], S. Boyarinov [40], W.J. Briscoe [13], W.K. Brooks [41], K. Bruhwel [40], D.S. Carman [40], A. Celentano [17], G. Charles [21,33], P. Chatagnon [21], T. Chetry [28,32], G. Christiaens [44,4], S. Christo [40], G. Ciullo [15,11], B.A. Clary [6], P.L. Cole [25,14], M. Contalbrigo [15], M. Cook [40], V. Crede [27], R. Cruz-Torres [36], C. Cuevas [40], A. D'Angelo [18,36], N. Dashyan [48], M. Defurne [4], A. Deur [40], R. De Vita [17], S. Diehl [6], C. Djalali [32,38], G. Dodge [33], R. Dupre [21], M. Ehrhart [1,21], L. El Fassi [28], B. Eng [40], T. Ewing [40], R. Fair [40], G. Fedotov [32], A. Filippi [19], T.A. Forest [14], M. Garçon [4], G. Gavalian [40], P. Ghoshal [40], G.P. Gilfoyle [35], K. Giovanetti [23], F.X. Girod [40], D.I. Glazier [44], E. Golovatch [37], R.W. Gothe [38], Y. Gotra [40], K.A. Griffioen [47], M. Guidal [21], V. Gyurjyan [40], K. Hafidi [1], H. Hakobyan [41,48], C. Hanretty [40], N. Harrison [40], M. Hattawy [33,1], F. Hauenstein [28], T.B. Hayward [47], D. Heddle [5,40], P. Hemler [40], O.A. Hen [26], K. Hicks [32], A. Hobart [21], J. Hogan [40], M. Holtrop [30], Y. Ilieva [38], I. Illari [13], D. Insley [40], D.G. Ireland [44], B.S. Ishkhanov [37], E.L. Isupov [37], G. Jacobs [40], H.S. Jo [24], R. Johnston [26], K. Joo [6], S. Joosten [1,29], T. Kageya [40], D. Kashy [40], C. Keith [40], D. Keller [46], M. Khachatryan [33], A. Khanal [12], A. Kim [6], C.W. Kim [13], W. Kim [24], V. Kubarovsky [40], S.E. Kuhn [33], L. Lanza [18], M. Leffel [40], V. Lucherini [16], A. Lung [40], M.L. Kabir [28], M. Leali [43,20], S. Lee [26], P. Lenisa [15], K. Livingston [44], M. Lowry [40], I.J.D. MacGregor [44], I. Mandjavidze [4], D. Marchand [21], N. Markov [6], V. Mascagna [42,20,43], B. McKinnon [44], M. McMullen [40], C. Mealer [40], M.D. Mestayer [40], Z.E. Meziani [1,29], R. Miller [40], R.G. Milner [26], T. Mineeva [41], M. Mirazita [16], V. Mokeev [40], P. Moran [26], A. Movsisyan [15], C. Munoz Camacho [21], P. Naidoo [44], S. Nanda [28], J. Newton [33], S. Niccolai [21], G. Niculescu [23], M. Osipenko [17], M. Paolone [39], L.L. Pappalardo [15], R. Paremuzyan [39], O. Pastor [40], E. Pasyuk [40], W. Phelps [9,13], O. Pogoreliko [29], J. Poudel [33], J.W. Price [2], K. Price [31], S. Procureur [4], Y. Prok [39], D. Protopopescu [44], R. Rajput-Ghoshal [40], B.A. Raue [12,40], B. Raydo [40], M. Ripani [17], J. Ritman [22], A. Rizzo [18,36], G. Rosner [44], P. Rossi [40], J. Rowley [32], B.J. Roy [27], F. Sabatié [4], C. Salgado [31], S. Schadmand [22], A. Schmidt [29,13], E.P. Segarra [26], V. Sergeyeva [21], Y.G. Sharabian [40], U. Shrestha [32], Iu. Skorodumina [38,27], G.D. Smith [9], L.C. Smith [44,49], D. Sokhan [44], O. Soto [16,41], N.Sparveris [39], S. Stepanyan [40], P. Stoler [34], S. Strauch [38], J.A. Tan [24], M. Taylor [40], D. Tilles [40], M. Turisini [16], N. Tyler [38], M. Ungaro [40], L. Venturelli [43,20], H. Voskanyan [48], E. Voutier [21], D. Watts [45], X. Wei [40], L.B. Weinstein [33], C. Wiggins [40], M. Wiseman [40], M.H. Wood [3], A. Yegneswaran [40], G. Young [40], N. Zachariou [45], M. Zarecky [40], J. Zhang [46], Z.W. Zhao [7,33], V. Ziegler [40]

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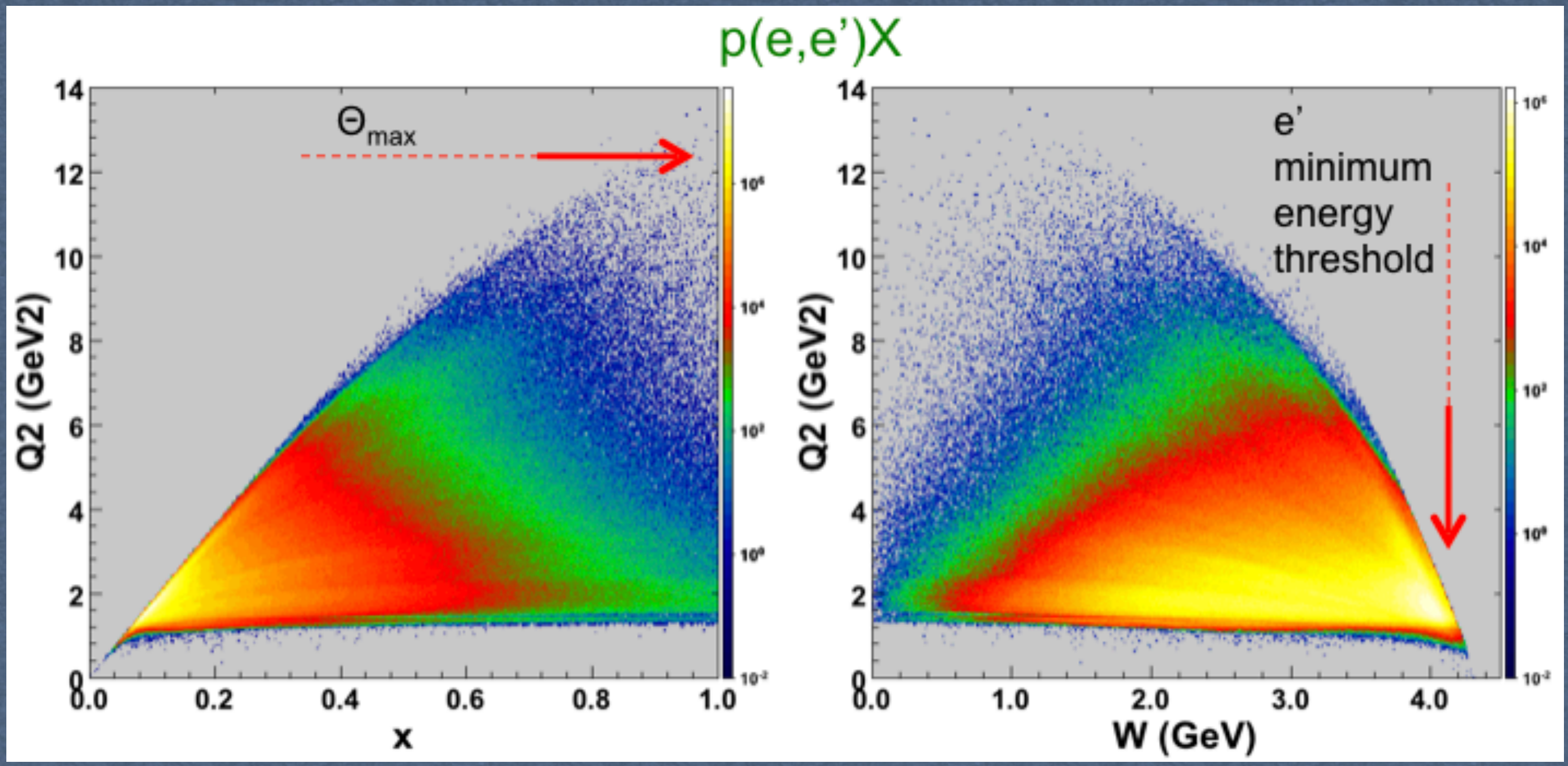
System	Reference/Status
SVT	M.A. Antonioli *et al.*, Nucl. Inst. and Meth. A 962, 163701 (2020)
MVT	A. Acker *et al.*, Nucl. Inst. and Meth. A 957, 163423 (2020)
CTOF	D.S. Carman *et al.*, Nucl. Inst. and Meth. A 960, 163626 (2020)
CND	P. Chatagnon *et al.*, Nucl. Inst. and Meth. A, 959, 163441 (2020)
HTCC	Y.G. Sharabian *et al.*, @ proof stage
DC	M.D. Mestayer *et al.*, Nucl. Inst. and Meth. A 959, 163518 (2020)
LTCC	M. Ungaro *et al.*, Nucl. Inst. and Meth. A 957, 163420 (2020)
RICH	M. Contalbrigo *et al.*, Nucl. Inst. and Meth. A 964, 163791 (2020)
FTOF	D.S. Carman *et al.*, Nucl. Inst. and Meth. A 960, 163629 (2020)
ECAL	G. Asryan *et al.*, Nucl. Inst. and Meth. A 959, 163425 (2020)
FT	A. Acker *et al.*, Nucl. Inst. and Meth. A 959, 163475 (2020)
Beamline	N. Baltzell *et al.*, Nucl. Inst. and Meth. A 957, 163421 (2020)
DAQ	S. Boyarinov *et al.*, Nucl. Inst. and Meth. A, in press
Trigger	B. Raydo *et al.*, Nucl. Inst. and Meth. A 960, 163529 (2020
Sim	M. Ungaro *et al.*, Nucl. Inst. and Meth. A 959, 163422 (2020)
Recon	V. Ziegler *et al.*, Nucl. Inst. and Meth. A 959, 163472 (2020)
Magnets	R. Fair *et al.*, Nucl. Inst. and Meth. A 962, 163578 (2020).
Overview	V.D. Burkert *et al. (CLAS Collaboration)*, Nucl. Inst. and Meth. A 959, 163419 (2020)

CLAS12 Kinematic reach

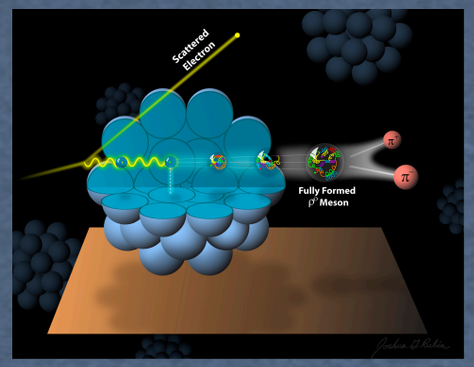
Beam energy at 10.6 GeV Torus current 3770 A, electrons in-bending, Solenoid magnet at 2416 A.



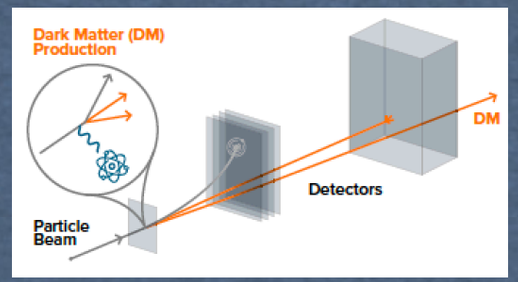
Plots based on 200 min. of data taking

Hall-B physics program

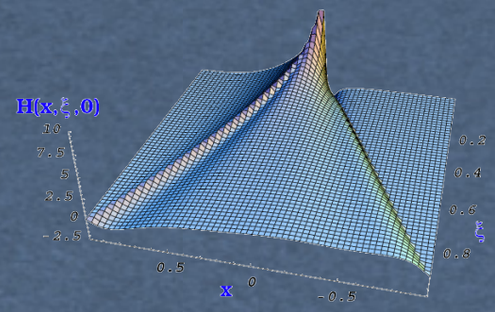
- The strong interaction in nuclei – evolution of quark hadronization, nuclear transparency of hadrons



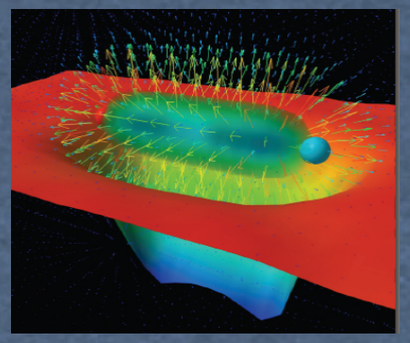
- BSM physics: search for light dark matter



- The 3D structure of the nucleon – from form factors and PDFs to GPDs and TMDs



- Quark confinement and the role of the glue in meson and baryon spectroscopy



Hall-B physics program organised in 'Run Groups'

- CLAS12
  - RG-A/K: LH_2 target, 3D structure functions, MesonEx
  - RG-B: Ld_2 target, as RG-A on n
  - RG-C: NH3/ND3 pol target, L p & n polarized structure functions
  - RG-D/E/M/L: nuclear target, hadroniz., color transparency, SRC, ν
  - RG-F: BONUS detector, n structure functions
  - RG-H: transverse pol target, T p & n polarized structure functions
  - RG-N : 3He polarized target for neutron DIS and TMD program
- HPS
  - RG-I: nuclear target, HPS detector A' search (LDM)
- PRAD/PRAD-II
  - RG-J: H_2 gas, Primex detector, proton radius

Proposal	Physics	Contact	Rating	Days	Group	Equipment	Energy	Run Group	Target
E12-06-108	Hard exclusive electro-production of π^0, η	Stoler	B	80	139	RICH (1 sector) Forward tagger	11	A F. Sabatié	liquid H_2
E12-06-108A	Exclusive N*->KY Studies with CLAS12	Carman		(60)					
E12-06-108B	Transition Form Factor of the η' Meson with CLAS12	Kunkel		(80)					
E12-06-112	Proton's quark dynamics in SIDIS pion production	Avakian	A	60					
E12-06-112A	SIDIS Λ productiuon in target fragmentation region	Mirazita		(60)					
E12-06-112B	Colinear nucleon structure at twist-3	Pisano		(60)					
E12-06-119(a)	Deeply Virtual Compton Scattering	Sabatie	A	80					
E12-09-003	Excitation of nucleon resonances at high Q^2	Gothe	B+	40					
E12-11-005	Hadron spectroscopy with forward tagger	Battaglieri	A-	119					
E12-11-005A	Photoproduction of the very strangest baryon	Guo		(120)					
E12-12-001	Timelike Compton Scatt. & J/ψ production in e+e	Nadel-Turonski	A-	120					
E12-12-001A	J/ψ Photoproduction & study of LHCb pentaquarks	Stepanyan		(120)					
E12-12-007	Exclusive φ meson electroproduction with CLAS12	Girod	B+	60					
E12-07-104	Neutron magnetic form factor	Gilfoyle	A-	30	90	Neutron detector RICH (1 sector) Forward tagger	11	B K. Hafidi	liquid D_2 target
E12-09-007(a)	Study of partonic distributions in SIDIS kaon production	Hafidi	A-	30					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	Contalbrigo	A-	56					
E12-09-008A	Hadron production in target fragmentation region	Mirazita		(60)					
E12-09-008B	Colinear nucleon structure at twist-3	Pisano		(60)					
E12-11-003	DVCS on neutron target	Niccolai	A	90					
E12-11-003A	In medium structure functions, SRC, and the EMC effect	Hen		(90)					
E12-11-003B	J/Psi production on deuterium	Ilieva	N/A	(80)					
Beam time partial sum				**765 (1555)**	**229**				

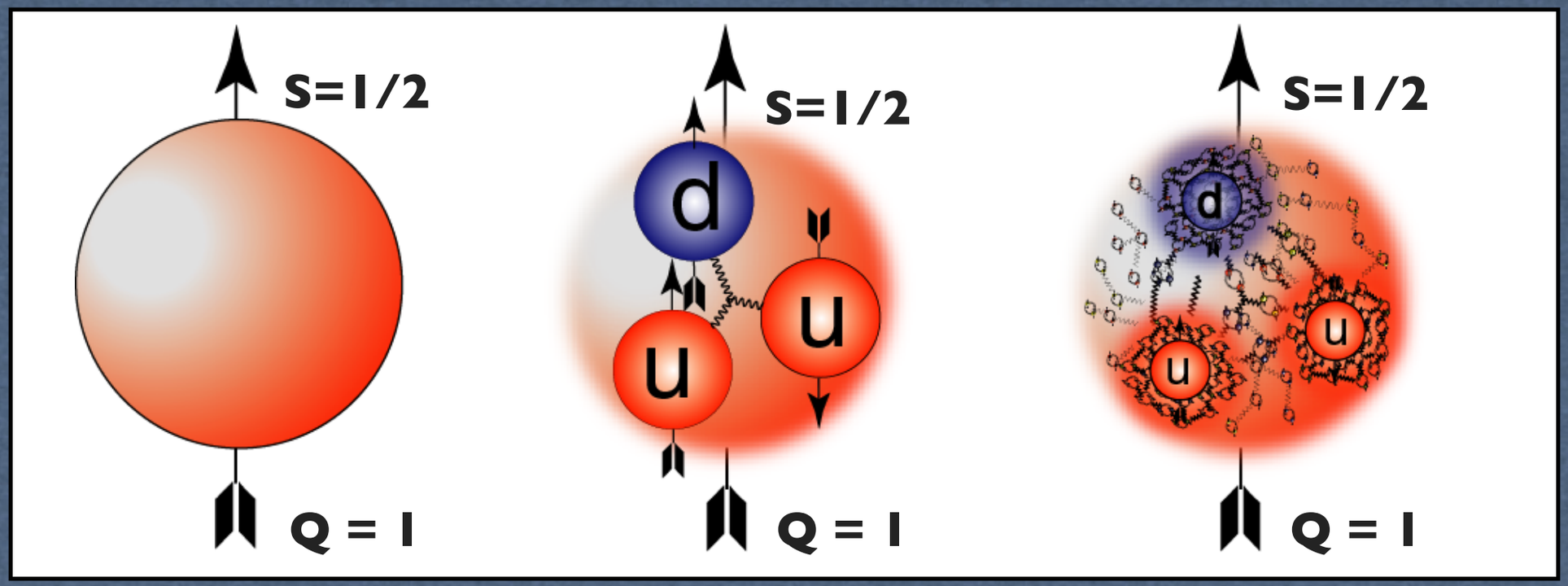
Proposal Count	Experiment Days	Run Groups	RG days
43	3288	13	1136

NUCLEON STRUCTURE
from elastic form factors to GPDs

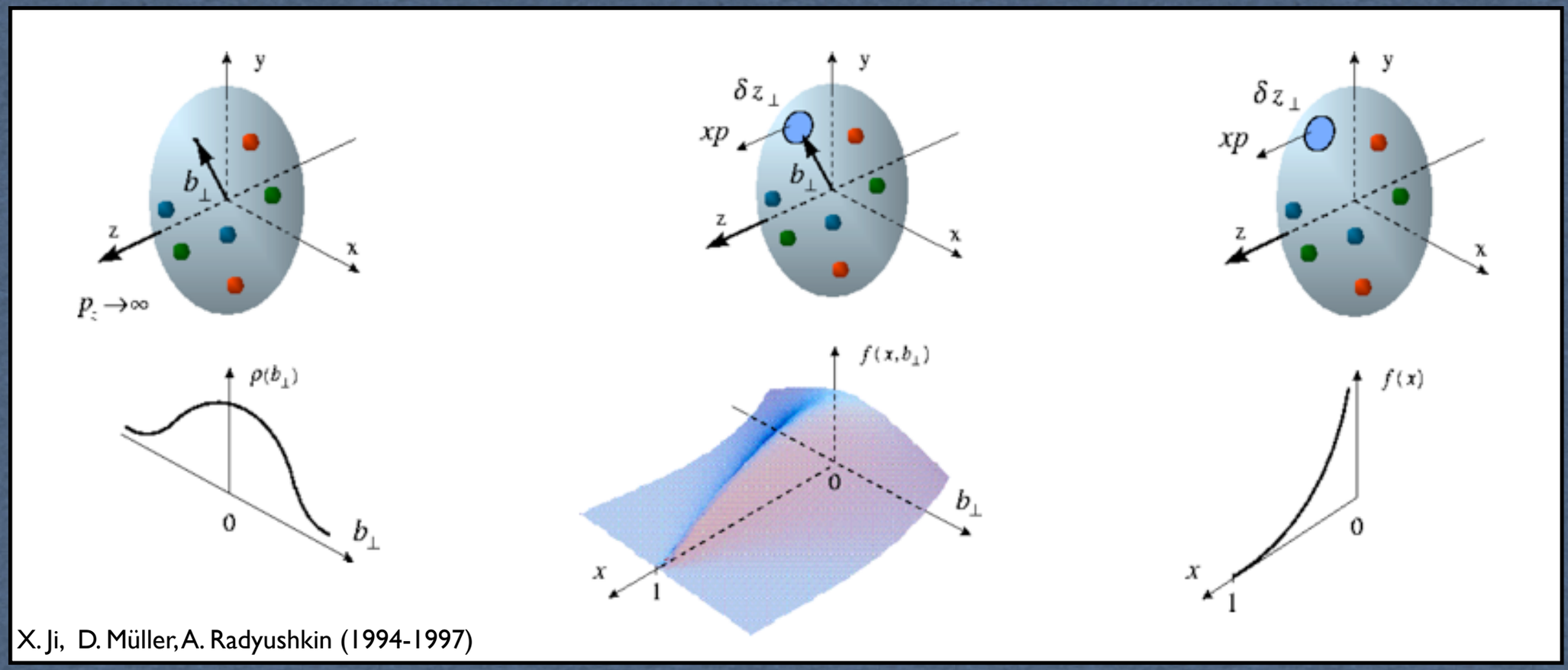
The Proton and Neutron are the "Hydrogen Atoms" of QCD

What we "see" changes with spatial resolution

>1 fm	0.1 — 1 fm	< 0.1 fm
Nucleons	Constituent quarks and glue	"bare" quarks and glue



NUCLEON STRUCTURE
from elastic form factors to GPDs



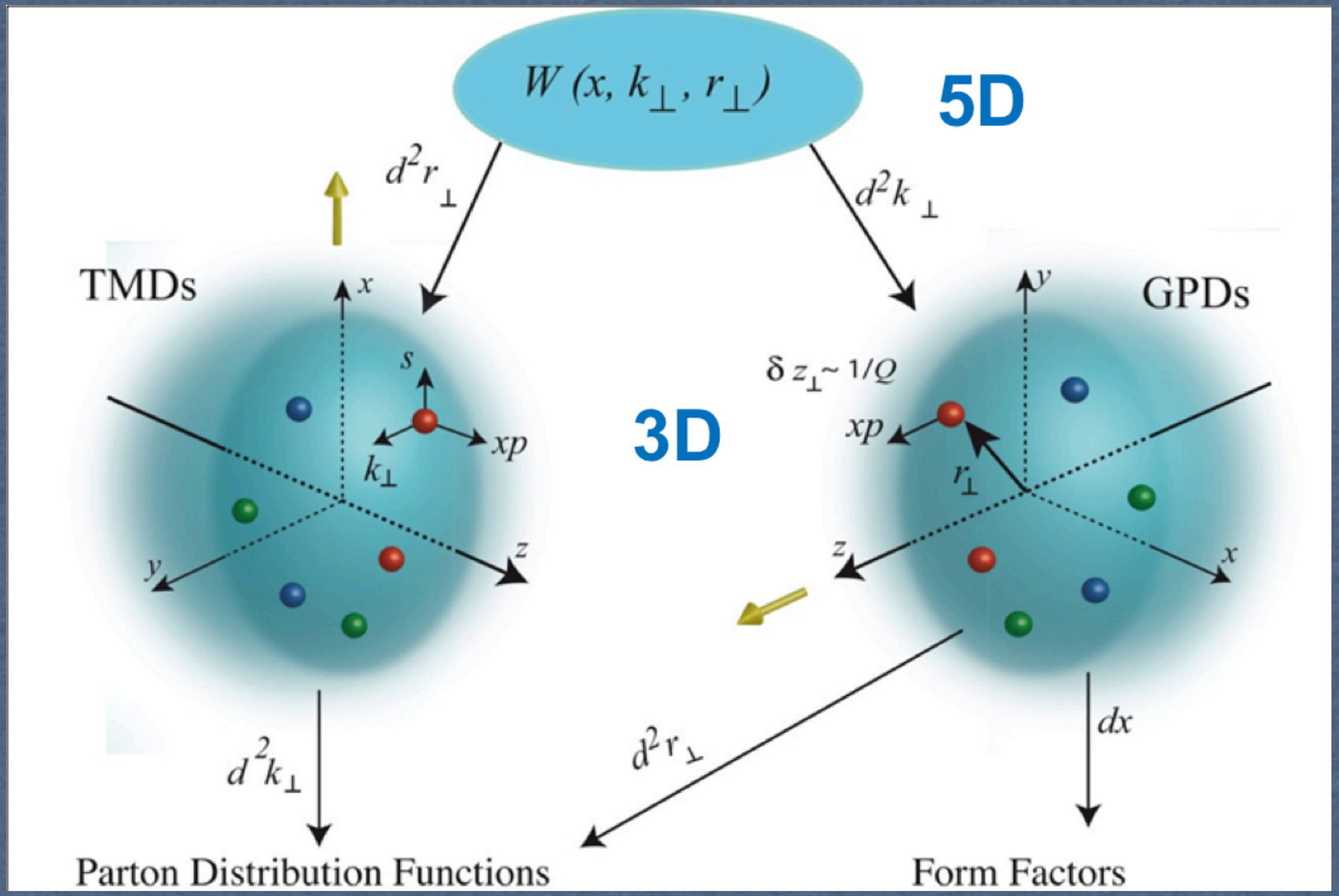
X. Ji, D. Müller, A. Radyushkin (1994-1997)

Elastic Scattering
transverse quark distribution in Coordinate space (charge and current densities)

Deep Exclusive Scattering
fully-correlated quark distribution in both coordinate and momentum space (**Generalized Parton Distributions**)

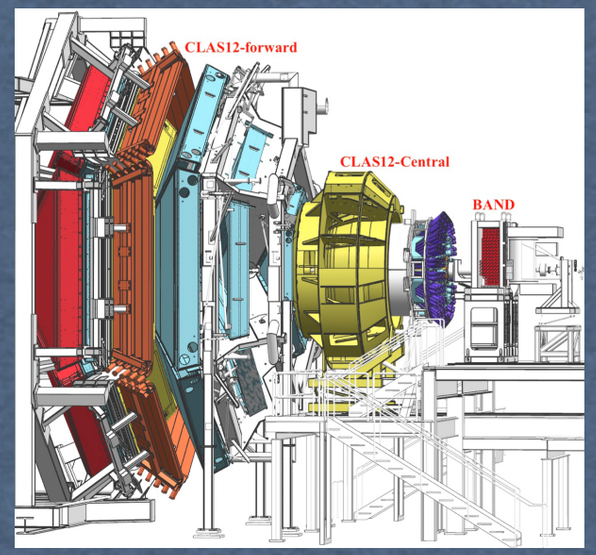
Deep Inelastic Scattering
longitudinal quark distribution in momentum space (momentum and helicity distributions)

NUCLEON STRUCTURE
Nuclear Femtography



Requires

- High luminosity
- Polarized beams and targets
- Sophisticated detector systems



Major new capability with CLAS12

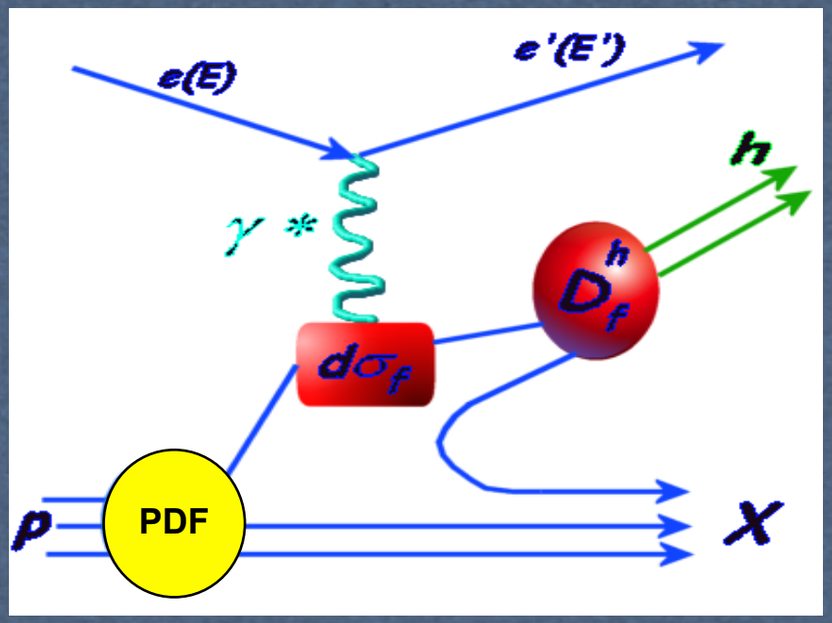
Transverse Momentum Dist. (TMD)

- Confined motion in a nucleon
- semi-inclusive DIS

Generalized Parton Dist. (GPD)

- Spatial imaging
- exclusive DVCS

Studying the Nucleon Structure: Transverse Momentum Distributions



Semi Inclusive Deep Inelastic Scattering

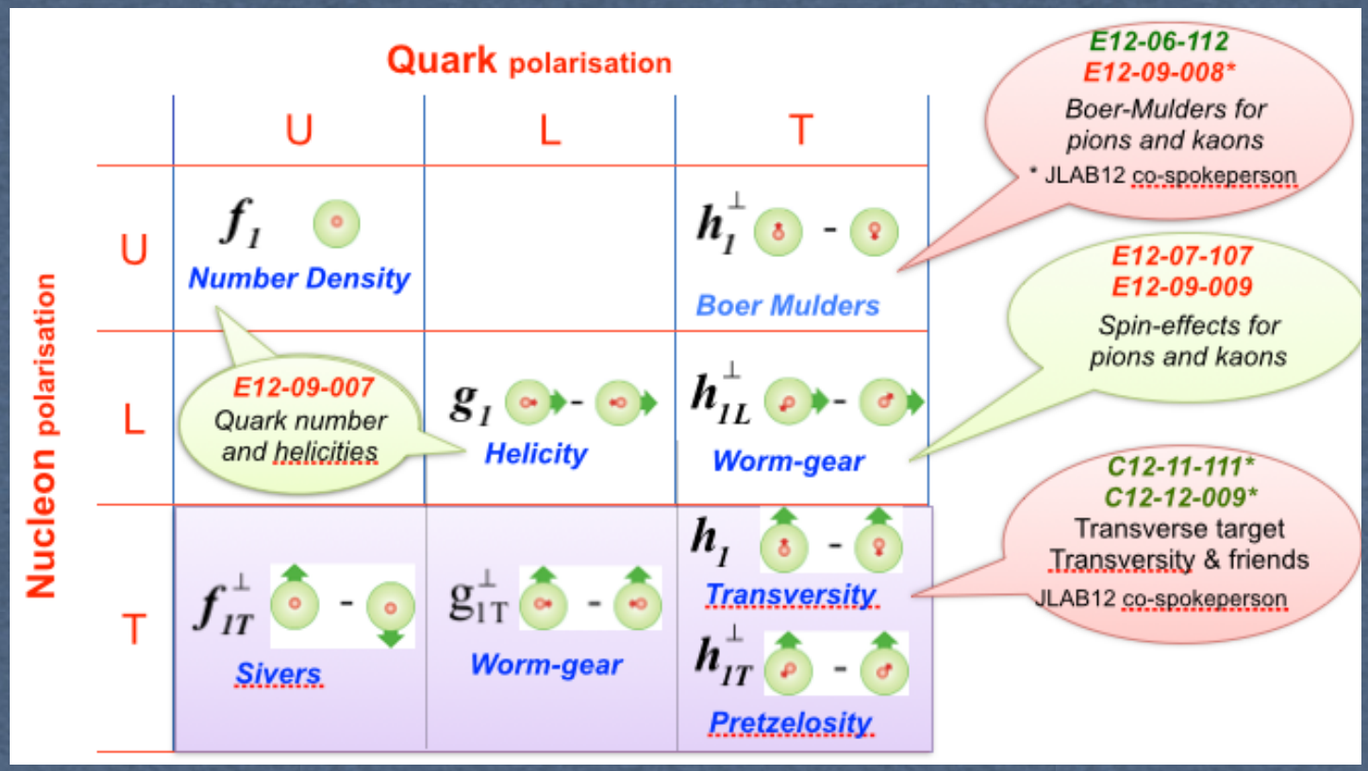
$$ep \rightarrow e'hX$$

$$d\sigma^h \propto \Sigma f^q(x, k_\perp) \otimes d\sigma^q(y) \otimes D^{(q\rightarrow h)}(z, p_\perp)$$

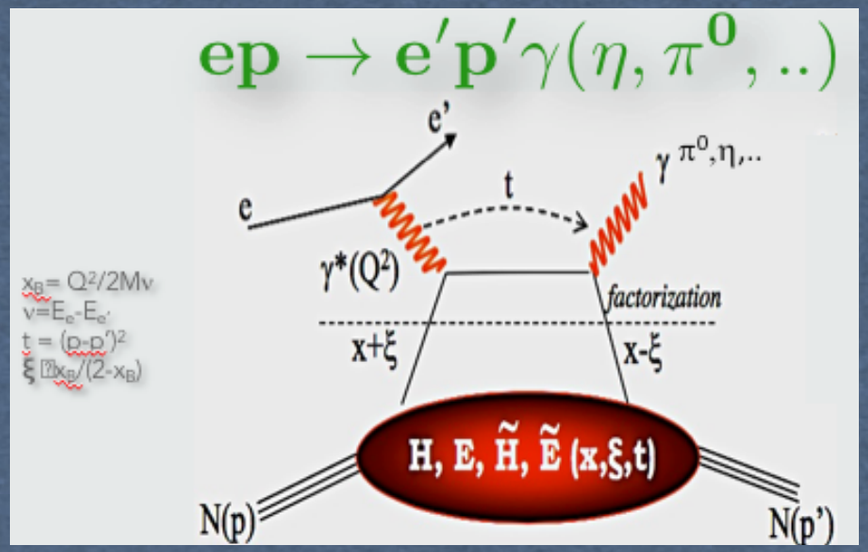
- ✳The nature of the spin of the nucleon
- ✳The nature of transverse motion of quarks and gluons
- ✳3D tomography of the nucleon by using TMDs

CLAS12 can access all of them through specific azimuthal modulations (φ, φ_S) of the cross-section thanks to the polarized beam and target

Probability to find a quark q in a nucleon P with a certain polarization

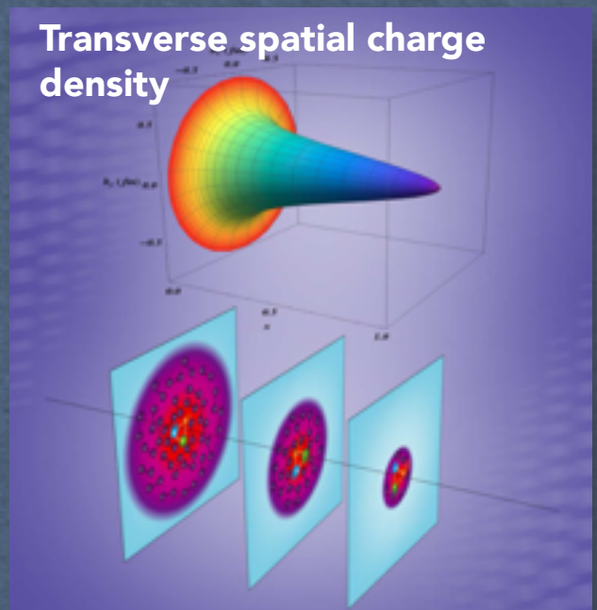


Studying the Nucleon Structure: Generalized Parton Distributions



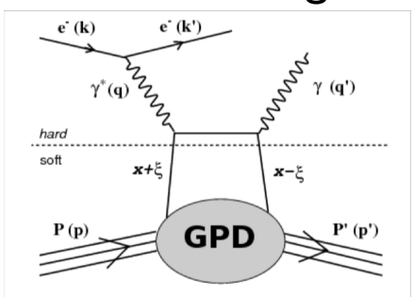
Exclusive
Deep Inelastic Scattering

General parton distributions: correlations of longitudinal momentum and transverse position. "Bidimensional version" of elastic form-factors

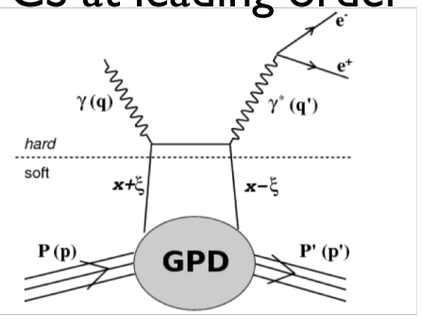


PHYSICAL REVIEW D 95, 011501(R) (2017)

DVCS at leading order



TCS at leading order



- Accessible via Deep Inelastic exclusive processes: DVCS and TCS

- DVCS: $e^- N \to e^- N \gamma$
- TCS: $\gamma N \to e^- N e^+ e^-$

GPDs appear in DVCS / TCS through the Compton Form Factor: the two processes are sensitive to different parts of it.

- Imaginary part: DVCS spin asymmetries
- Real part: DVCS cross-section / TCS angular distribution

$$\mathcal{H} = \sum_q e_q^2 \left\{ \mathcal{P} \int_{-1}^{1} dx H^q(x,\xi,t) \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] + i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right] \right\}$$

CLAS12 data taking

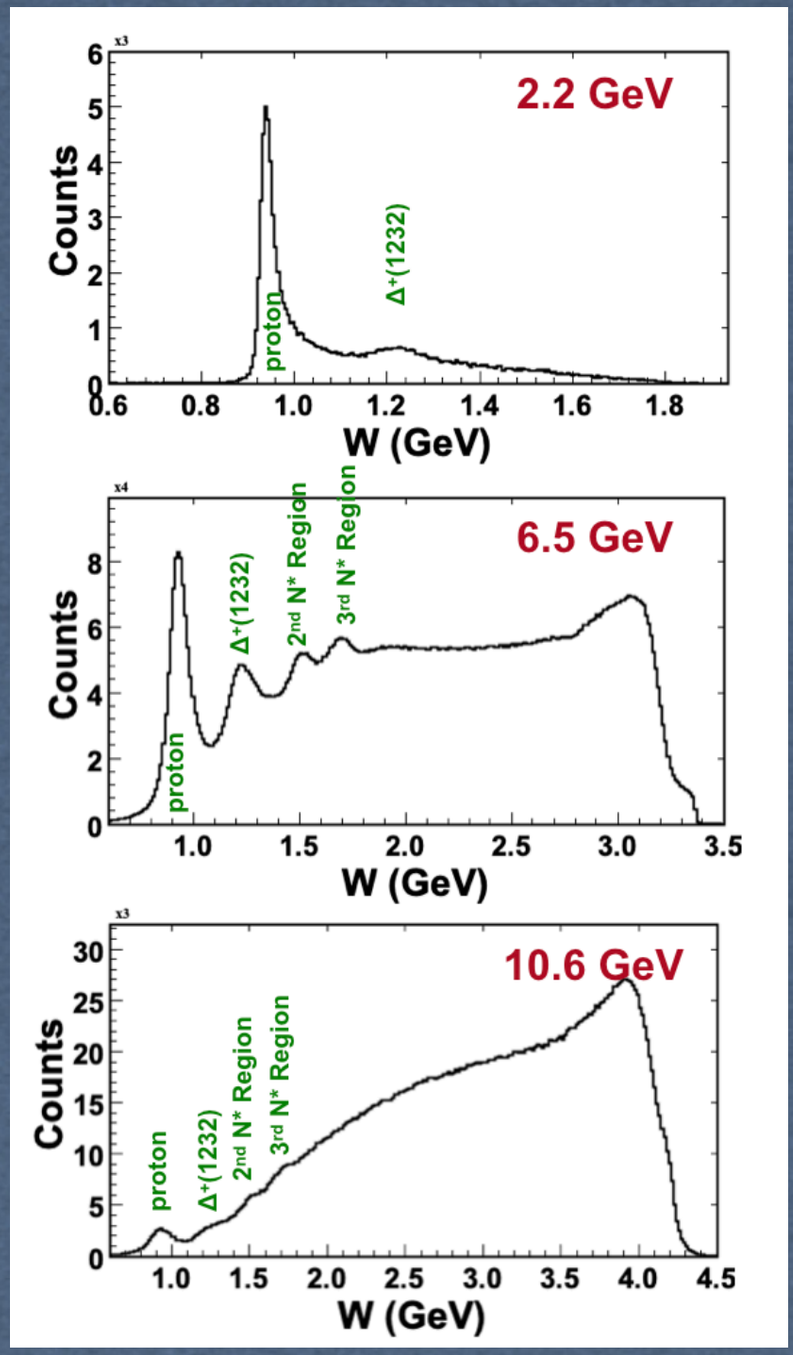
- **CLAS12 data taking**
- from Feb 2017 (KPP) to Spring 2019 (physics runs)

  – **Run Group A**:
    - 13 experiments
    - 10.2-10.6 GeV polarized electrons
    - Liquid-hydrogen target
    - ~300 mC, ~50% of approved beam time

  – **Run Group K**:
    - 3 experiments
    - 6.5, 7.5 GeV polarized electrons
    - Liquid-hydrogen target
    - ~45 mC, ~12% of approved beam time

  – **Run Group B**:
    - 7 experiments
    - 10.2-10.5 GeV polarized electrons
    - Liquid-deuterium target
    - ~155 mC, ~43% of approved beam time

  – **Run Group F (BONUS)**:
    - 1 experiments
    - 10.2 GeV polarized electrons (+2.2 GeV for calibration)
    - Gas-deuterium target + BONUS RTPC
    - ~92% of approved beam time (Run concluded!)



Run Group A experiments (LH_2)

Comprises 13 different experiments

- TMDs
- GPDs
- Fracture functions
- Form Factors
- hard exclusive meson production
- baryon and meson spectroscopy
- nucleon resonances
- strange baryons
- J/psi
- exotics

Proposal	Physics
E12-06-108	Hard exclusive electro-production of π^0, η
E12-06-108A	Exclusive N*->KY Studies with CLAS12
E12-06-108B	Transition Form Factor of the η' Meson with CLAS12
E12-06-112	Proton's quark dynamics in SIDIS pion production
E12-06-112A	SIDIS Λ productiuon in target fragmentation region
E12-06-112B	Colinear nucleon structure at twist-3
E12-06-119(a)	Deeply Virtual Compton Scattering
E12-09-003	Excitation of nucleon resonances at high Q^2
E12-11-005	Hadron spectroscopy with forward tagger
E12-11-005A	Photoproduction of the very strangest baryon
E12-12-001	Timelike Compton Scatt. & J/ψ production in e+e
E12-12-001A	J/ψ Photoproduction & study of LHCb pentaquarks
E12-12-007	Exclusive φ meson electroproduction with CLAS12

- Different experiments have different patterns in CLAS12

  Trigger decision based on PMT detectors and DC, configured for 3 sets of experiments: "electrons", "MesonEx", "muons"
- Original DAQ requirements: 10kHz event rate, 100MB/sec data rate, LT= 0.9
- Production rates at 50nA beam, FT=ON: 12kHz event rate, 550MB/sec data rate, LT=0.94%

  Electron trigger 5kHz (40%), muon trigger 2.7kHz (20%), MesoEx trigger 4.5kHz (40%)
- Data Reconstruction: 342 of the accumulated statistics ready for physics analyses (*cooked data)*

  60G triggers, 1.2 PB raw data → 160TB DST → 100TB DST (16M core/hours processing time, 62.5M jobs processed)
- Preparing a better version of data cooking (*Pass2*) to recook the entire data set

  Pass1 data suffer from CD mis-alignment and other issues solved in the new cooking

CLAS12 first results

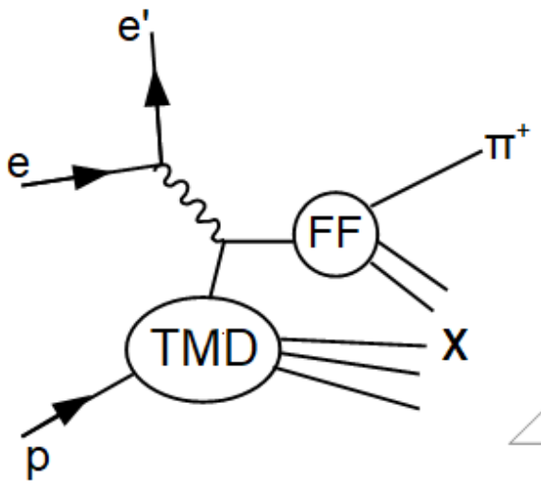
First multidimensional, high precision measurements of semi-inclusive π^+ beam single spin asymmetries from the proton over a wide range of kinematics

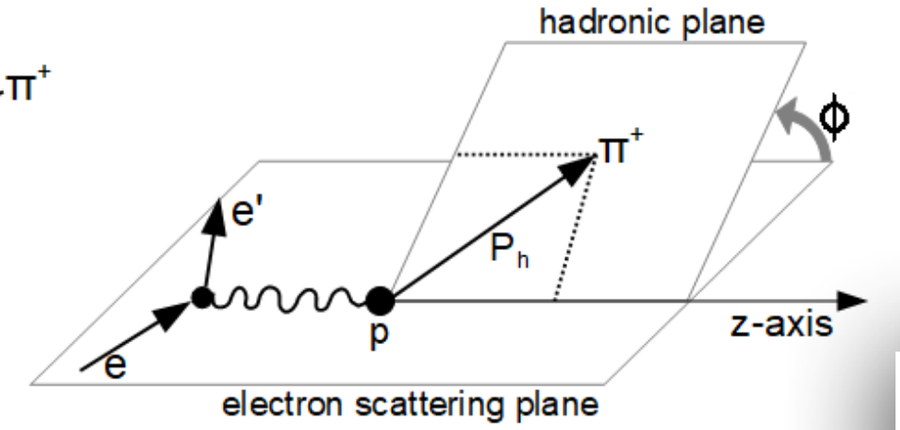

First multidimensional, high precision measurements of semi-inclusive π^+ beam singl spin asymmetries from the proton over a wide range of kinematics

I. Diehl,[34,4] A. Kim,[6] G. Angelini,[13] K. Joo,[6] S. Adhikari,[11] M. Amaryan,[29] M. Arratia,[9] H. Atac,[43] H. Avakian,[4] C. Ayerbe Gayoso,[31] N.A. Baltzell,[44] L. Barion,[15] S. Bastami,[5] M. Battaglieri,[44,17] I. Bedlinskiy,[28] F. Benmokhtar A. Bianconi,[47,20] A.S. Biselli,[9] M. Bondi,[17] F. Bossù,[3] S. Boiarinov,[44] K.-T. Brinkmann,[34] W.J. Briscoe,[13] W. Brooks,[6] D. Bulumulla,[29] V.D. Burkert,[44] D.S. Carman,[44] J.C. Carvajal,[11] A. Celentano,[17] P. Chatagnon,[21] T. Chetry,[27,32] G. Ciullo,[15,10] L. Clark,[48] B.A. Clary,[6] P.L. Cole,[25] M. Contalbrigo,[15] O. Cortes,[11] V. Crede,[12] A. D'Angelo,[18,37] N. Dashyan,[52] R. De Vita,[17] M. Defurne,[3] A. Deur,[44] S. Diehl,[6,25] C. Djalali,[32] M. Duggger,[3] R. Dupre,[21] M. Ehrhart,[1,21] A. El Alaoui,[6] L. El Fassi,[27] L. Elouadrhiri,[44] S. Fegan,[49] A. Filippi,[19] T. Forest,[14] G. Gavalian,[44] G.P. Gilfoyle,[36] F.X. Girod,[44] D.I. Glazier,[48] A.A. Golubenko,[41] R.W. Gothe,[42] Y. Gotra,[44] K.A. Griffioen,[51] M. Guidal,[21] K. Hafidi,[1] H. Hakobyan,[6] M. Hattawy,[29] T.B. Hayward,[51] D. Heddle,[5,44] K. Hicks,[32] A. Hobart,[21] M. Holtrop,[39] C. Hyde,[29] D.G. Ireland,[48] E.L. Isupov,[41] H.S. Jo,[24] R. Johnston,[28] S. Joosten,[1] D. Keller,[50] M. Khachatryan,[29] A. Khanal,[11] W. Kim,[24] A. Kripko,[34] V. Kubarovsky,[44] S.E. Kuhn,[29] L. Lanza,[19] M. Leali,[47,20] S. Lee,[26] P. Lenisa,[15,10] K. Livingston,[48] Z. Lu,[38] I.J.D. MacGregor,[48] D. Marchand,[21] N. Markov,[44,6] L. Marsicano,[17] V. Mascagna,[46,20] B. McKinnon,[48] Z.E. Meziani,[1,42] R.G. Milner,[26] T. Mineeva,[6] M. Mirazita,[16] V. Mokeev,[44] P. Moran,[25] A. Movsisyan,[15] C. Munoz Camacho,[21] P. Nadel-Turonski,[44] P. Naidoo,[48] K. Neupane,[42] S. Niccolai,[21] G. Niculescu,[23] T.R. O'Connell,[6] M. Osipenko,[17] M. Paolone,[30,43] L.L. Pappalardo,[15,10] R. Paremuzyan,[44,39] E. Pasyuk,[44] W. Phelps,[13] N. Pilleux,[21] Y. Prok,[33] A. Prokudin,[6] B.A. Raue,[11,44] M. Ripani,[17] J. Ritman,[22] A. Rizzo,[18,37] C.D. Ross,[25] P. Rossi,[44,16] J. Rowley,[32] F. Sabatié,[3] C. Salgado,[31] A. Schmidt,[13] E.P. Segarra,[26] Y.G. Sharabian,[44] U. Shrestha,[32] O. Soto,[16,40] N. Sparveris,[43] S. Stepanyan,[44] P. Stoler,[36] I.I. Strakovsky,[13] S. Strauch,[42] K. Tezgin,[6] A. Thornton,[48] N. Tyler,[42] R. Tyson,[48] M. Ungaro,[44] L. Venturelli,[47,20] H. Voskanyan,[52] A. Vossen,[7] E. Voutier,[21] D.P. Watts,[48] K. Wei,[6] X. Wei,[44] S.-S. Xu,[45] B. Yale,[51] N. Zachariou,[48] and J. Zhang[29]
(The CLAS Collaboration)

Submitted to PRL

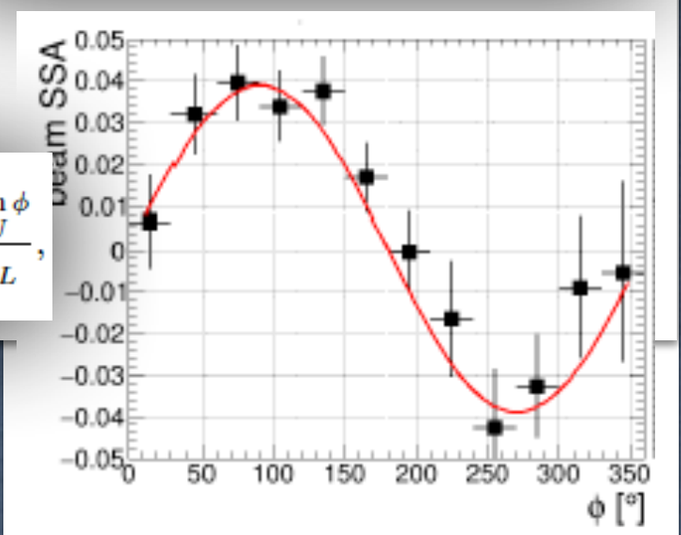
- So far, good mapping of 1D PDF (longitudinal momentum dependence)
- Are the q carrying an orbital angular momentum? how is it connected to the spin of the nucleon? q correlations?
- 3-D structure accessed trough Transverse Momentum dep. Distributions (TMDs)
- Semi Inclusive DIS (SIDIS) to study the transverse structure of the nucleon
- Single Spin Asymmetries (SSA) sensitive to TMDs and Fragmentation Functions (FF)
- Beam SSA: twist-3, subleading, O(M/Q), accessible in fixed target, medium energy (~10 GeV) experiments



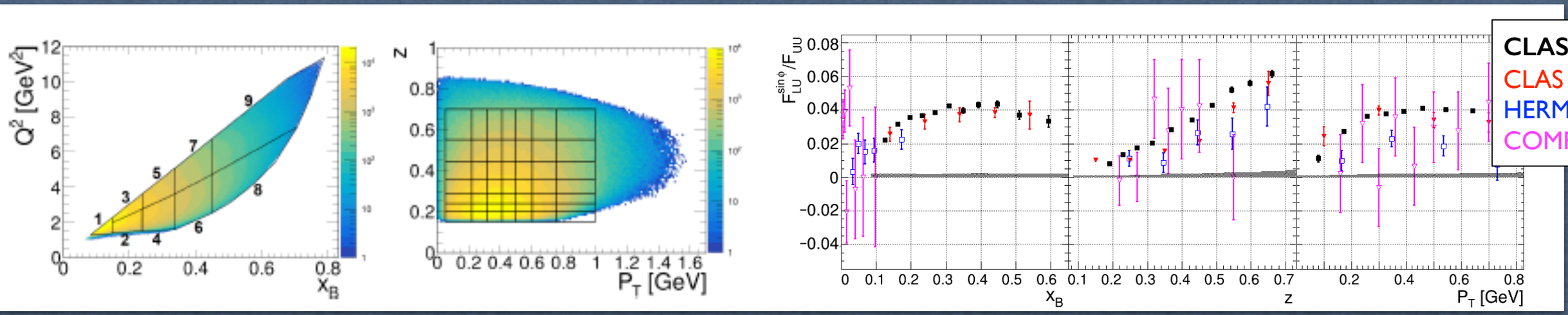


$$SSA(z, P_T, \phi, x_B, Q^2) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{\sin\phi} \sin\phi}{1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi},$$

$$A_{LU}^{\sin\phi} = \frac{\sqrt{2\epsilon(1-\epsilon)}\, F_{LU}^{\sin\phi}}{F_{UU,T} + \epsilon F_{UU,L}},$$



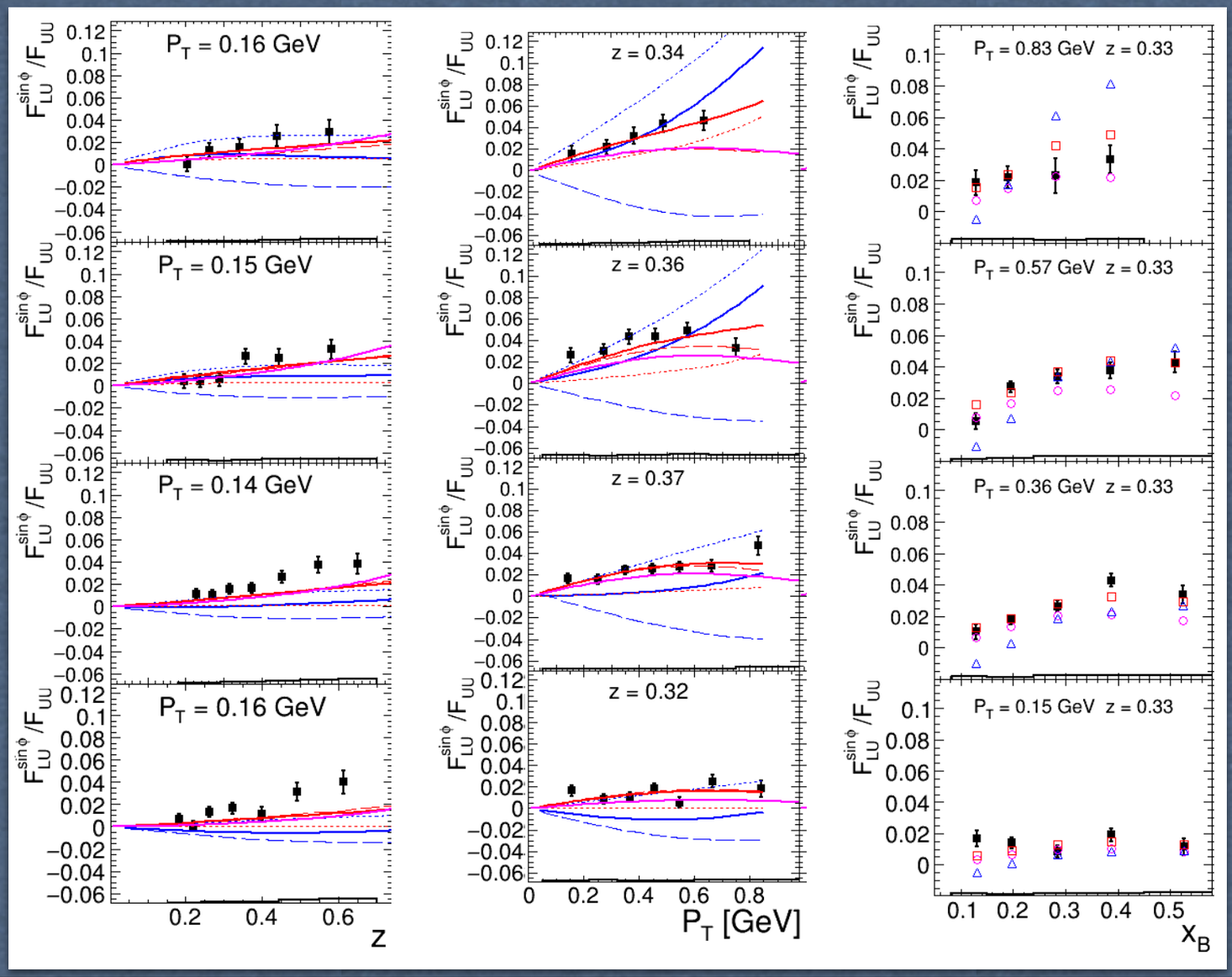
- x_B= proton momentum fraction carried by the struck q
- z = γ_v energy fraction carried by π
- PT = π transverse momentum
- F_{LU} = q-g correlation (genuine tw-3) = Convolution {Collins, Boers-Mulders, tw-3 TMD pol and unpol FF}



- Good kinematic coverage necessary for multi-D mapping
- Existing data are sparse and limited in kinematics
- CLAS12: Ee=10.6 GeV, Pe~86% δA_{LU}~6%
- Models:
  1) active q + spectator di-q (scalar)
  2) active q + spectator di-q (ax-vector) (best fit)
  3) H (parametrized) + e (chiral soliton)
- Model-dep extraction of Collins (dashed) and TMD tw-3 (dotted)

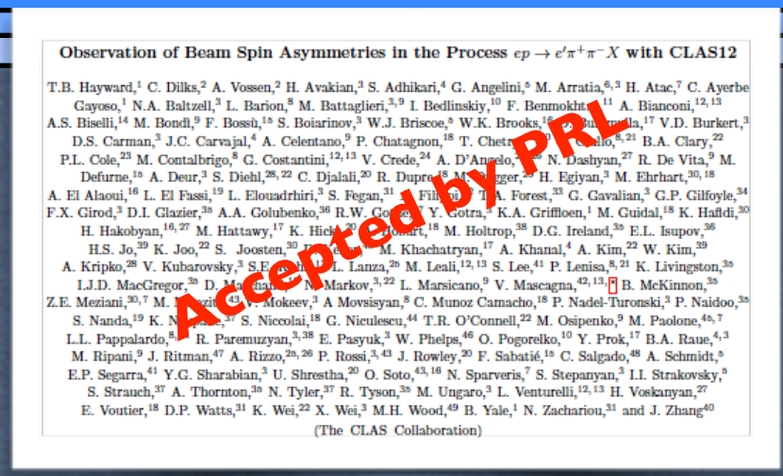
★ First multi-D measurement over a wide kinematic range

★ Extraction of Collins and TMD functions



CLAS12 first results

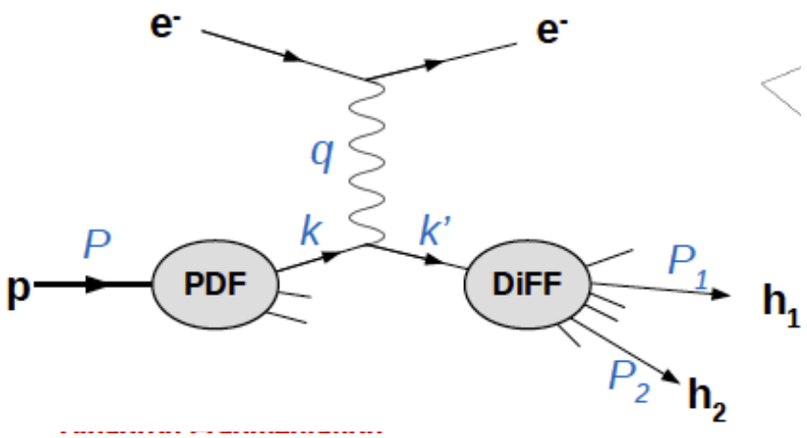
First Observation of Beam Spin Asymmetries in the Process e p → e' π⁺ π⁻ X with CLAS12

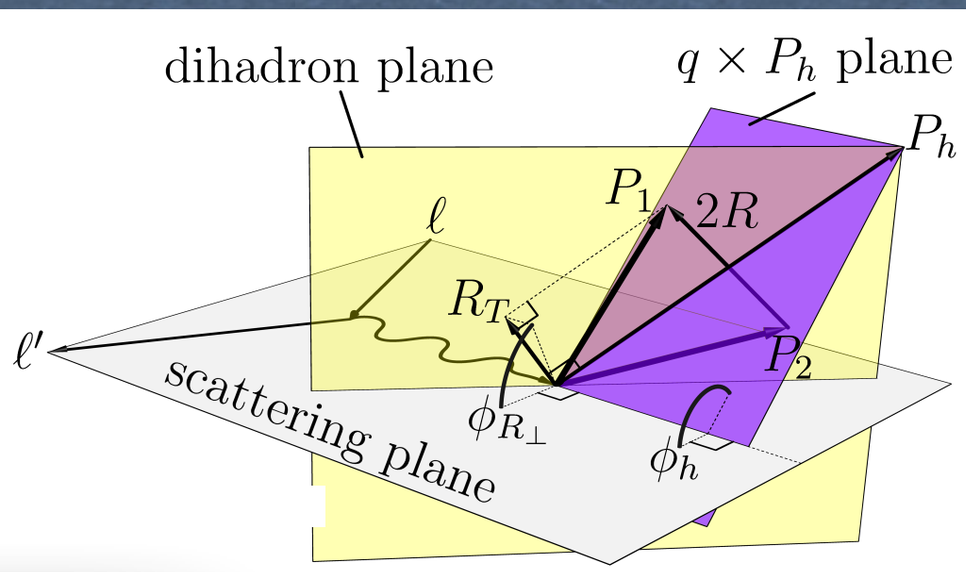

Observation of Beam Spin Asymmetries in the Process $ep \to e'\pi^+\pi^- X$ with CLAS12

T.B. Hayward,[1] C. Dilks,[2] A. Vossen,[2] H. Avakian,[3] S. Adhikari,[4] G. Angelini,[5] M. Arratia,[6,3] H. Atac,[7] C. Ayerbe Gayoso,[1] N.A. Baltzell,[3] L. Barion,[8] M. Battaglieri,[3,9] I. Bedlinskiy,[10] F. Benmokhtar,[11] A. Bianconi,[12,13] A.S. Biselli,[14] M. Bondì,[9] F. Bossù,[15] S. Boiarinov,[3] W.J. Briscoe,[5] W.K. Brooks,[16] [illegible],[17] V.D. Burkert,[3] D.S. Carman,[3] J.C. Carvajal,[4] A. Celentano,[9] P. Chatagnon,[18] T. Chetry,[19] [illegible],[8,21] B.A. Clary,[22] P.L. Cole,[23] M. Contalbrigo,[8] G. Costantini,[12,13] V. Crede,[24] A. D'Angelo,[25,26] N. Dashyan,[27] R. De Vita,[9] M. Defurne,[15] A. Deur,[3] S. Diehl,[28,22] C. Djalali,[20] R. Dupre,[18] M. Ehrhart,[29] H. Egiyan,[3] M. Ehrhart,[30,18] A. El Alaoui,[16] L. El Fassi,[19] L. Elouadrhiri,[3] S. Fegan,[31] [illegible],[32] T.A. Forest,[33] G. Gavalian,[3] G.P. Gilfoyle,[34] F.X. Girod,[3] D.I. Glazier,[35] A.A. Golubenko,[36] R.W. Gothe,[37] Y. Gotra,[3] K.A. Griffioen,[1] M. Guidal,[18] K. Hafidi,[30] H. Hakobyan,[16,27] M. Hattawy,[17] K. Hicks,[20] [illegible],[18] M. Holtrop,[38] D.G. Ireland,[35] E.L. Isupov,[36] H.S. Jo,[39] K. Joo,[22] S. Joosten,[30] [illegible] M. Khachatryan,[17] A. Khanal,[4] A. Kim,[22] W. Kim,[39] A. Kripko,[28] V. Kubarovsky,[3] S.E. [illegible] L. Lanza,[26] M. Leali,[12,13] S. Lee,[41] P. Lenisa,[8,21] K. Livingston,[35] I.J.D. MacGregor,[35] D. M[illegible]chan,[3] N. Markov,[3,22] L. Marsicano,[9] V. Mascagna,[42,13,*] B. McKinnon,[35] Z.E. Meziani,[30,7] M. [illegible]zitt[illegible],[43] V. Mokeev,[3] A Movsisyan,[8] C. Munoz Camacho,[18] P. Nadel-Turonski,[3] P. Naidoo,[35] S. Nanda,[19] K. N[illegible],[37] S. Niccolai,[18] G. Niculescu,[44] T.R. O'Connell,[22] M. Osipenko,[9] M. Paolone,[45,7] L.L. Pappalardo,[8,21] R. Paremuzyan,[3,38] E. Pasyuk,[3] W. Phelps,[46] O. Pogorelko,[10] Y. Prok,[17] B.A. Raue,[4,3] M. Ripani,[9] J. Ritman,[47] A. Rizzo,[25,26] P. Rossi,[3,43] J. Rowley,[20] F. Sabatié,[15] C. Salgado,[48] A. Schmidt,[5] E.P. Segarra,[41] Y.G. Sharabian,[3] U. Shrestha,[20] O. Soto,[43,16] N. Sparveris,[7] S. Stepanyan,[3] I.I. Strakovsky,[5] S. Strauch,[37] A. Thornton,[35] N. Tyler,[37] R. Tyson,[35] M. Ungaro,[3] L. Venturelli,[12,13] H. Voskanyan,[27] E. Voutier,[18] D.P. Watts,[31] K. Wei,[22] X. Wei,[3] M.H. Wood,[49] B. Yale,[1] N. Zachariou,[31] and J. Zhang[40]
(The CLAS Collaboration)

Accepted by PRL

- SIDIS ingredients: q in the nucleon (PDF), hadronization (Fragmentation Functions)
- Fragmentation in 2h is sensitive to *several* TMDs and Dihadron Fragmentation Functions (DiFFs)
- Spin-momentum correlations in hadronization
- Access to PDF e(x) (transv polarized q in a unp nucleon, tw-3) and Dihadron FF G1-perp (helicity of fragmenting q)
- Complement single-hadron SIDIS, with the advantage of another degree of freedom





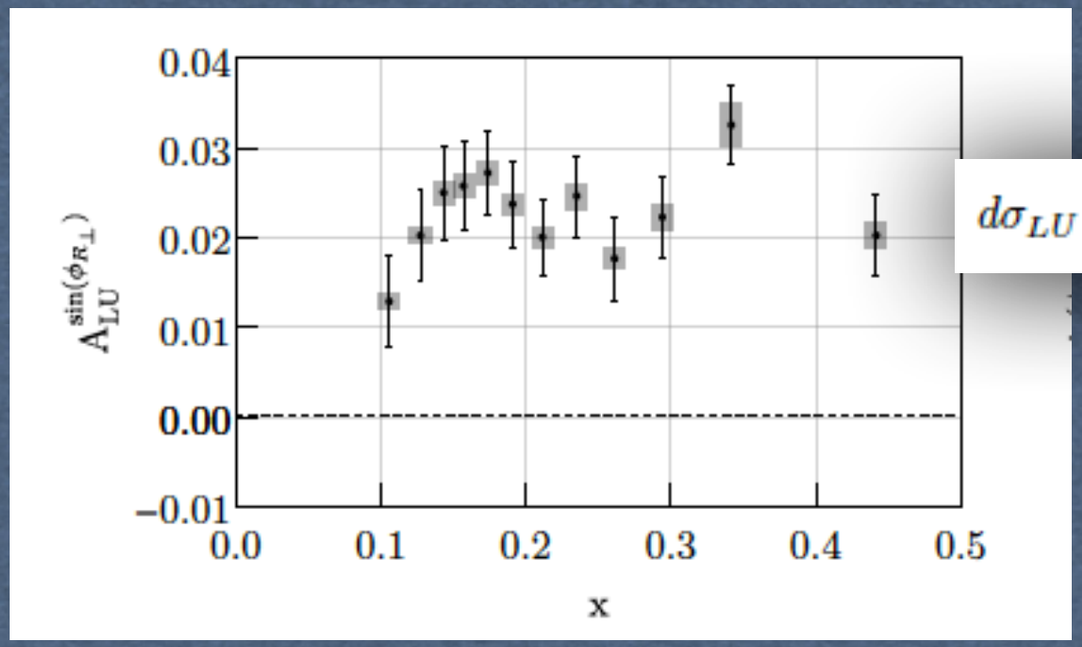
$$A_{LU} = \frac{1}{P_{\text{beam}}} \frac{N^+(\phi_h, \phi_{R_\perp}) - N^-(\phi_h, \phi_{R_\perp})}{N^+(\phi_h, \phi_{R_\perp}) + N^-(\phi_h, \phi_{R_\perp})} =$$
$$A_{LU}^{\sin(\phi_h - \phi_{R_\perp})} \sin(\phi_h - \phi_{R_\perp}) + A_{LU}^{\sin(\phi_{R_\perp})} \sin(\phi_{R_\perp}),$$

- Ph = P1 + P2 pions 3-mom
- RT is the component of R perpendicular to Ph

$$\boldsymbol{R_T} = \left(z_2 \boldsymbol{P_1^\perp} - z_1 \boldsymbol{P_2^\perp}\right)/z$$

- Φh = azimuthal angle of q × Ph plane
- ΦR⊥ = azimuthal angle of di-hadron plane

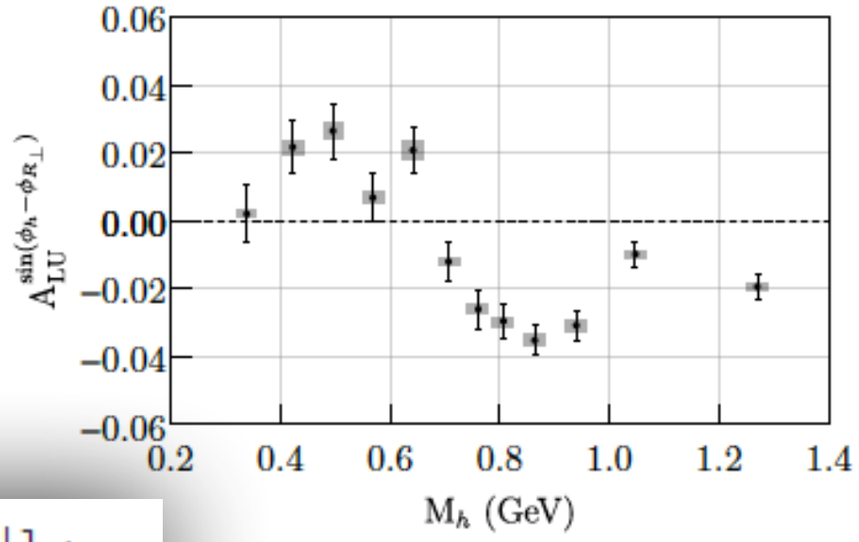
$$d\sigma_{LU} \propto \tag{4}$$
$$W\lambda_e \sin(\phi_{R_\perp}) \left(xe(x)H_1^{\sphericalangle}(z, M_h) + \frac{1}{z} f(x)\tilde{G}^{\sphericalangle}(z, M_h) \right)$$

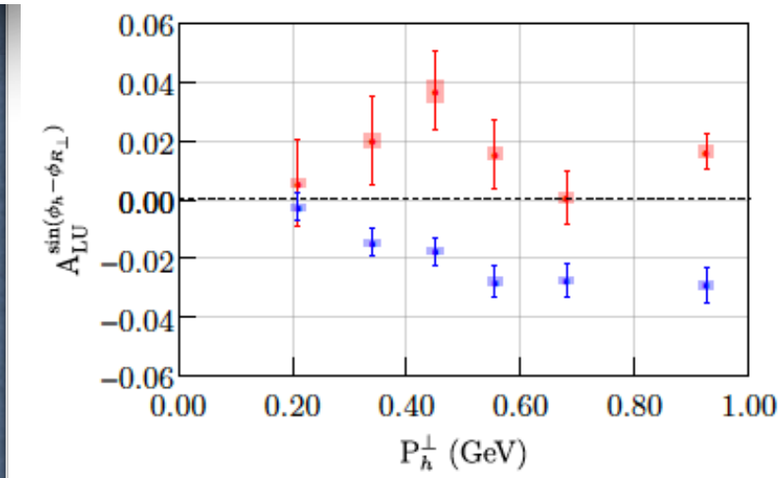


- e(x)≠ 0 in valence region
- From known H-function, e(x) can be extracted

$$d\sigma_{LU} \propto C\lambda_e \sin(\phi_h - \phi_{R_\perp}) \mathcal{I}\left[f_1 G_1^\perp\right] + \ldots$$

- Change of sign around ρ mass
- First measurement of TMD fragmentation in 2π's

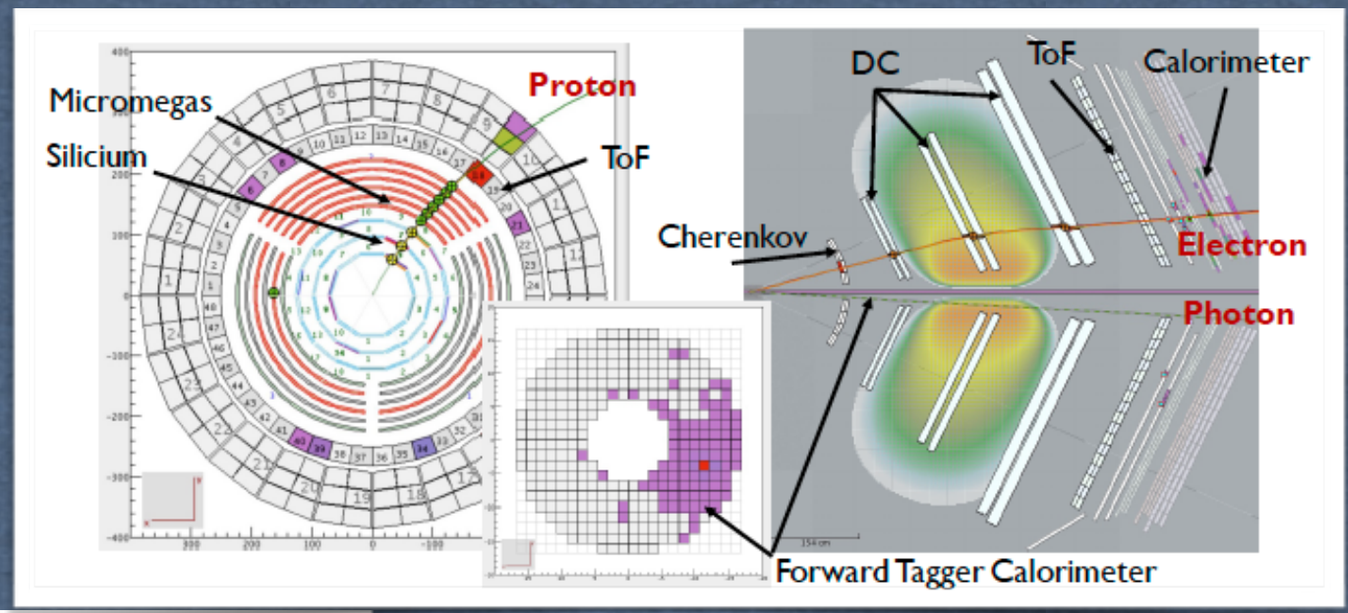




★ First measurement of BSA in di-h production
★ Sub-leading PDF e(x) different from 0
★ First helicity-deg FF $G_1^\perp$ observation

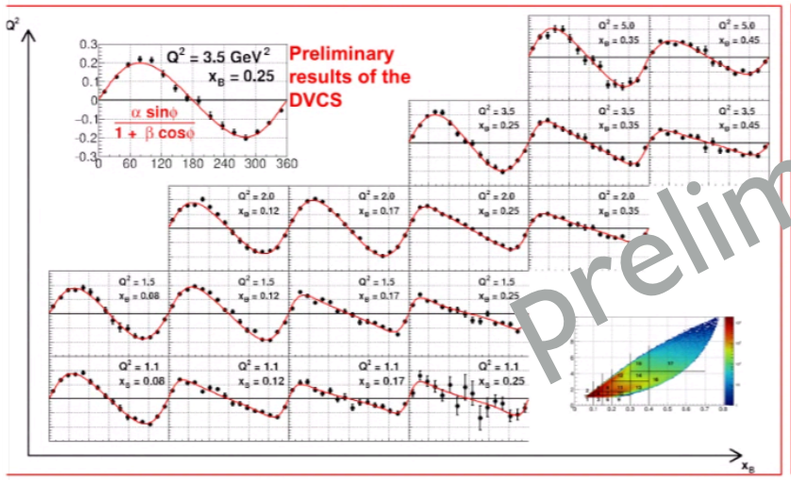
CLAS12 preliminary results

Typical DVCS event:
- Electron in the forward detector (torus, DC, ToF, Cherenkov, Calorimeter)
- Photon in the forward tagger (calorimeter)
- Proton in the central detector (solenoid, Silicium, Micromegas and ToF)

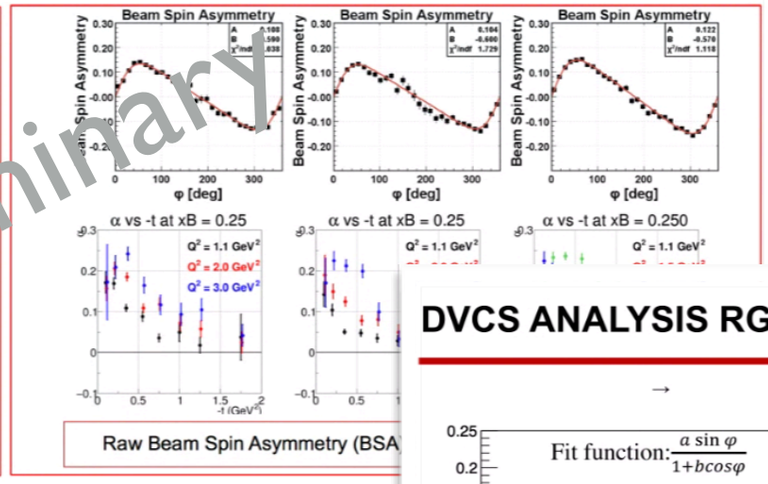


DEEPLY VIRTUAL COMPTON SCATTERING

RG-A



RG-K



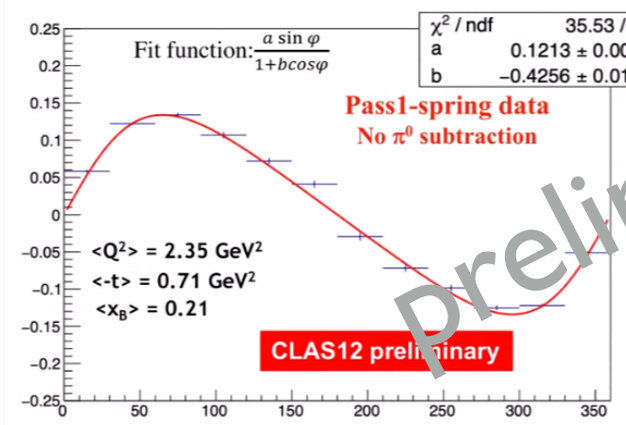
Raw Beam Spin Asymmetry (BSA)

Preliminary

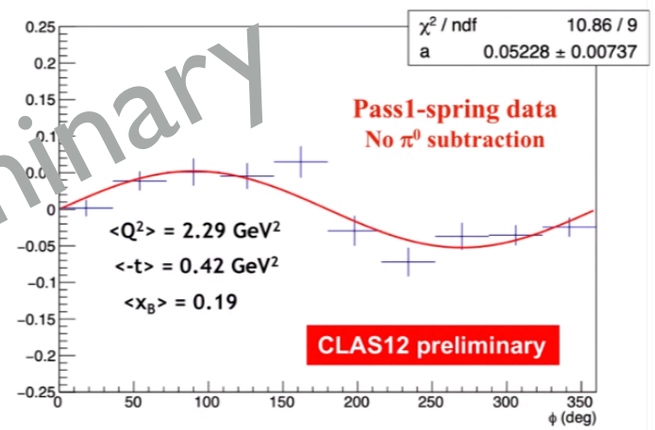
Requires understanding of the tracking/PID in Central tracking
Requires understanding the photon/pi0 reconstruction in the calorimeter
Requires understanding physics background in particular the pi0

Note: Common problems to all run groups (A, B and K) and the groups are worl

DVCS ANALYSIS RG-B



Incoherent pDVCS on deuterium



nDVCS with RGB data

Preliminary

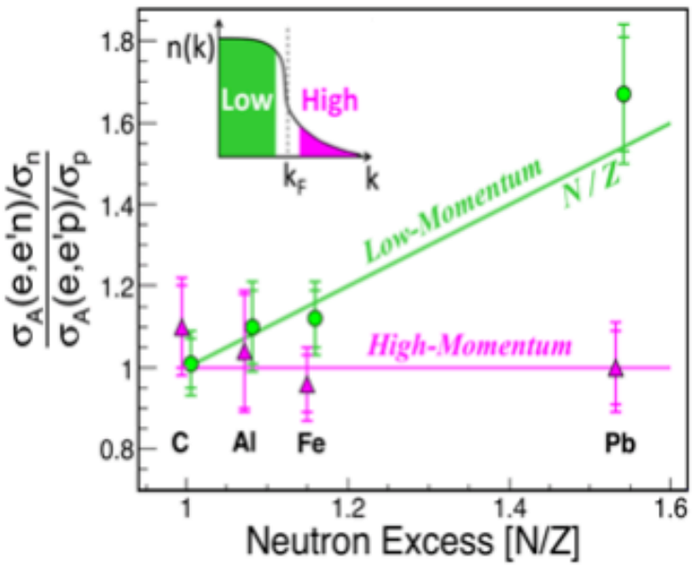
CLAS12 FY21 schedule

RG-M status

- Scheduled for 30 PAC days: October-December 2021
- D, 4He, C, [O,] 40Ar, 40Ca, 48Ca, Sn
  - Targets designed and under development
  - Standard liquid target cell
  - Short 0.5-cm Ar liquid target cell
  - Solid target C, Sn insertion mechanism
  - Special Ca target holders
- [1,] 2, 4, 6 GeV
  - Outbending at 2 GeV
- Standard CLAS12 plus BAND, no FT or LTCC
- Simulations underway to optimize
  - Trigger
  - Torus field

Short Range Correlations

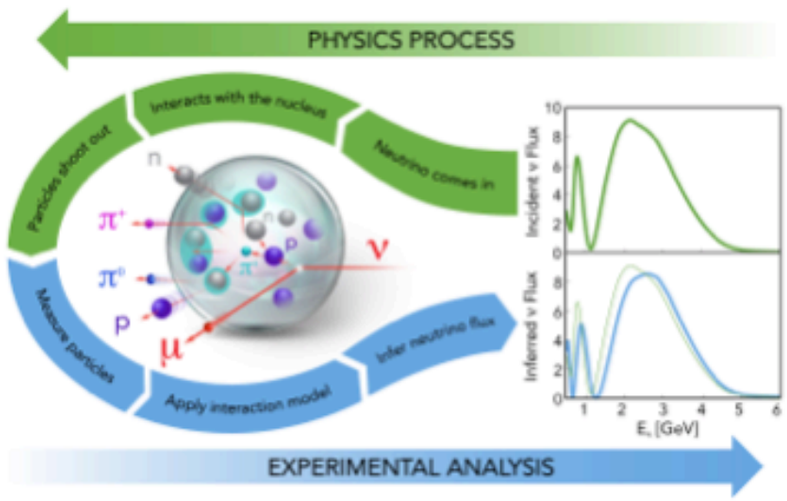
- Build on the tremendous success of the CLAS6 data mining SRC program (Science, several Nature, …)
- Take far more (e,e'pN) and (e,e'pNN) data on a wider range of nuclei
  - Three nucleon SRCs?
  - Constraining the NN interaction at short distances
  - Understanding factorized effective theories
  - SRC formation mechanisms
  - SRCs and the EMC Effec



Electrons for neutrinos

- Take (e,e'X) data to test vector-current part of neutrino-nucleus event generators
  - Energy reconstruction techniques
  - Event generators key to reconstructing

oscillation parameters



Conclusions

✳ A comprehensive hadron physics program just started with CLAS12 at JLab

✳ **Nucleon structure (GPD, TMD)**, light-quark meson spectroscopy (hybrids, exotics, penta-q), nuclear structure (correlated pairs)

✳ Reach and long (~10y!) physics program exploiting CLAS12 excellent resolution and particle ID paired to high luminosity e-/γ and beam/target polarization available in Hall-B

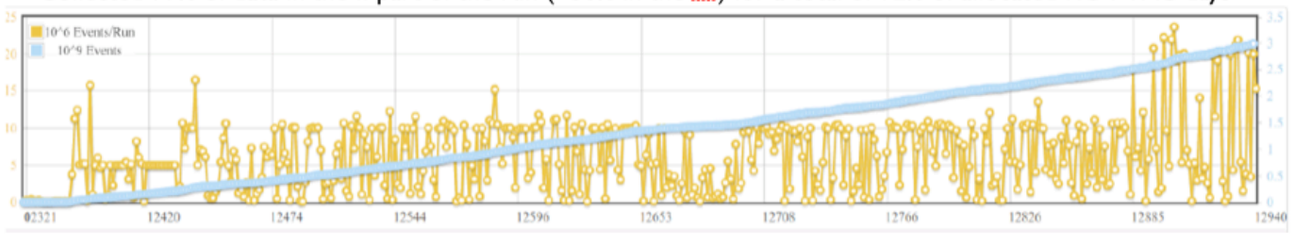
✳ A significant kinematic coverage assessing many final states will cover a parameter space that will be further investigated by future initiatives (EIC)

✳ The CLAS12 detector is performing well providing the first physics results

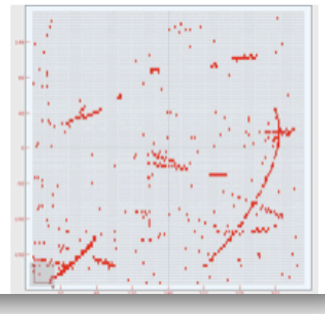
First CLAS12 results ready for publications, many more to come!

Hall-B operations

- Monday Sept 21st ended the RG-F physics run
- Generous effort of JLab staff members and local insts (ODU, HU, CNU, RichmndU) to cover shifts for a successful ru
- Good feedback by virtual shifts, plans to adopt them on regular base in the future
- Collected 77% of data in the II part of the run (+50% in the Ist) for a total of 92% of allocated RG-F PAC days



- Beside production runs on D2, regular calibration runs on different targets (empty, H2, He4) + Moeller measurement + dedicated run at low energy at the beginning of the run
- Dedicated equipment (BONUS RTPC)
- Decommissioning started, RTPC to EEL building (?), will be stored at ODU/HU



Despite COVID-19 CLAS12 accomplished the planned physics program