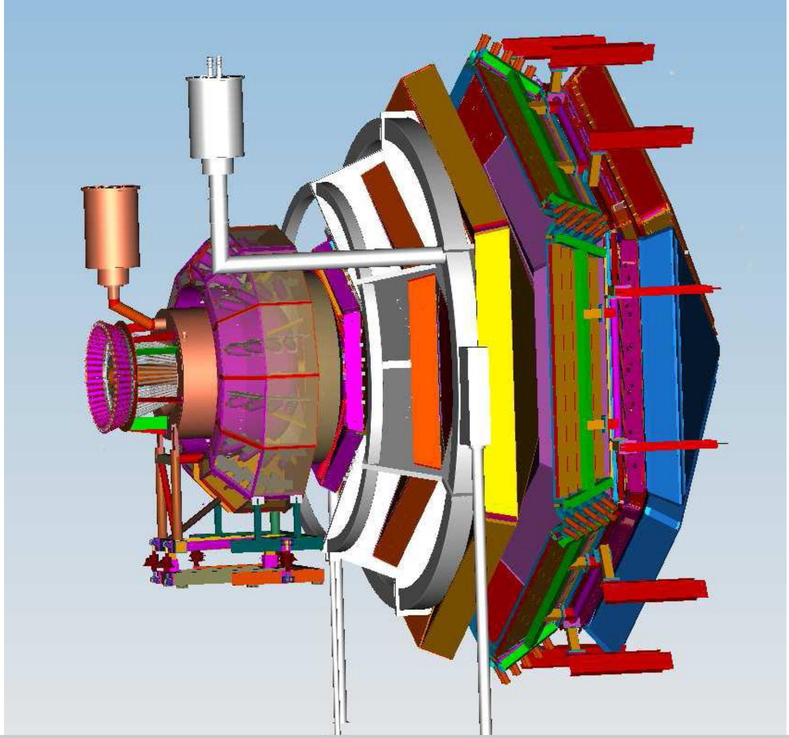
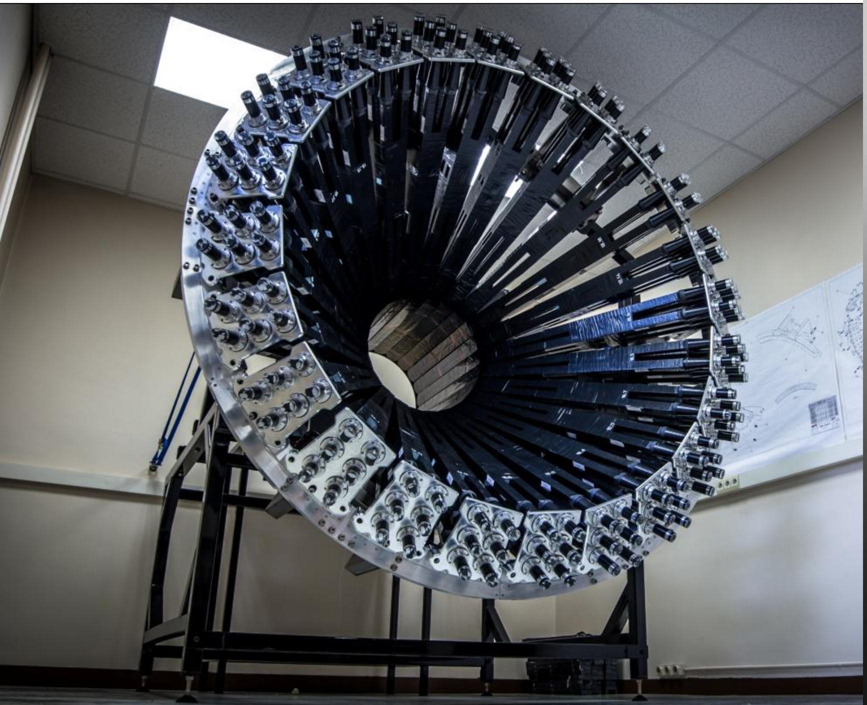
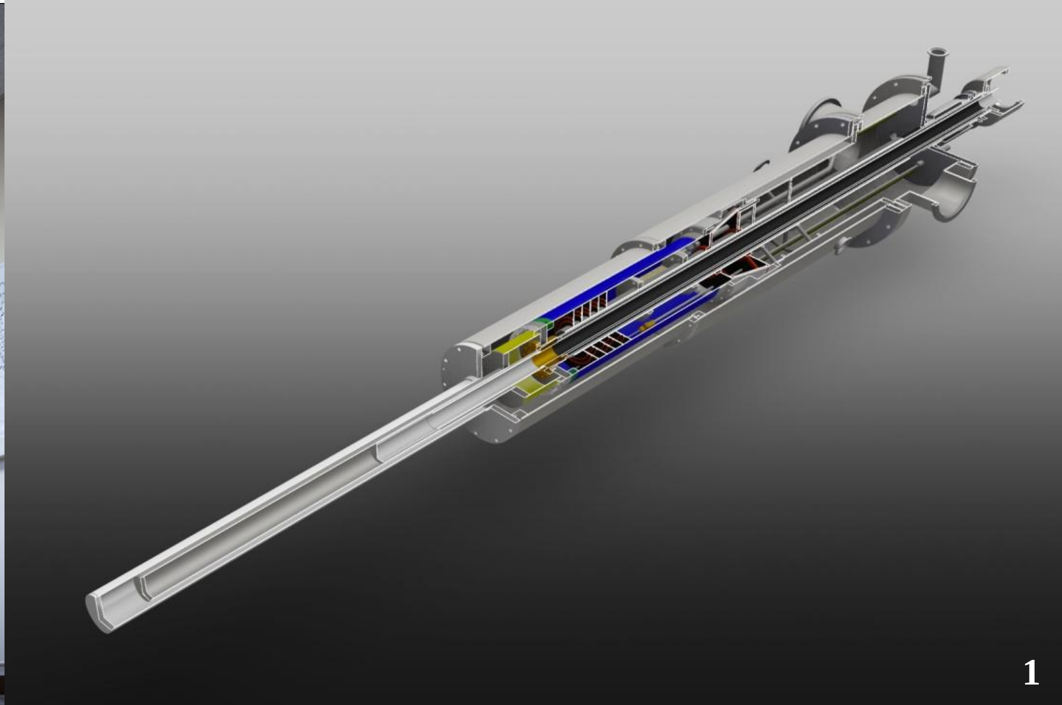
C12-15-004:
DVCS, DIS, and SIDIS
with a longitudinally polarized deuterium target



Silvia Niccolai IPN ORSAY

PAC44, JLab, 7/26/2016





C12-15-004:
DVCS, DIS, and SIDIS with a longitudinally polarized deuterium target

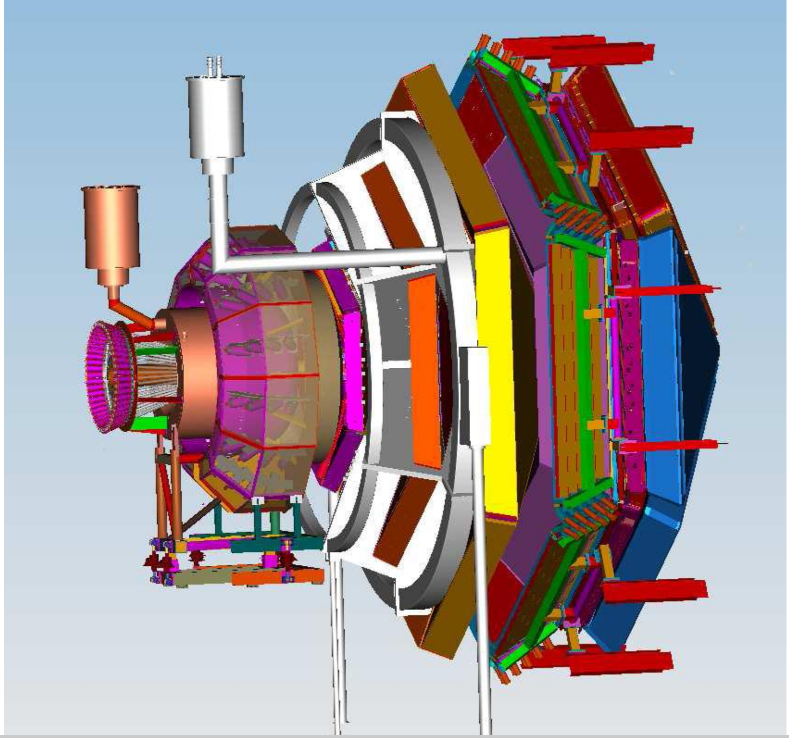
Co-spokespersons:
A. Biselli (Fairfield U),
C. Keith (JLab),
S. Kuhn (ODU)
S. Niccolai (IPN Orsay),
S. Pisano (INFN Frascati),
D. Sokhan (Glasgow U)

Silvia Niccolai IPN ORSAY

PAC44, JLab, 7/26/2016

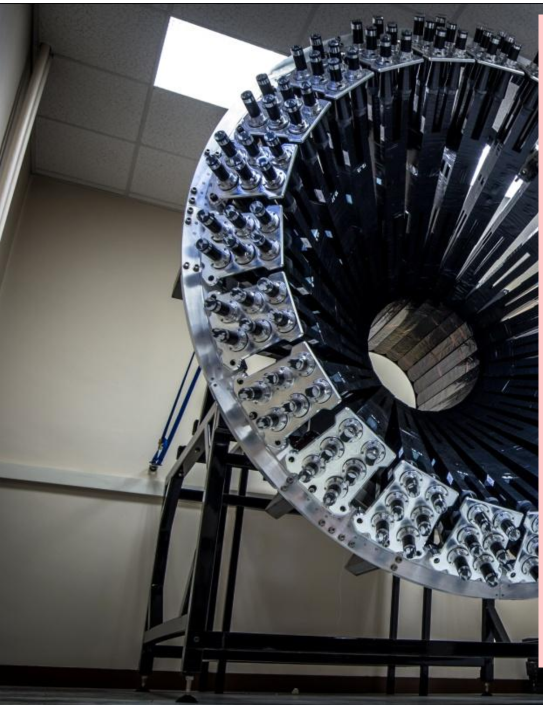
A CLAS collaboration proposal

C12-15-004:
DVCS, DIS, and SIDIS with a longitudinally polarized deuterium target



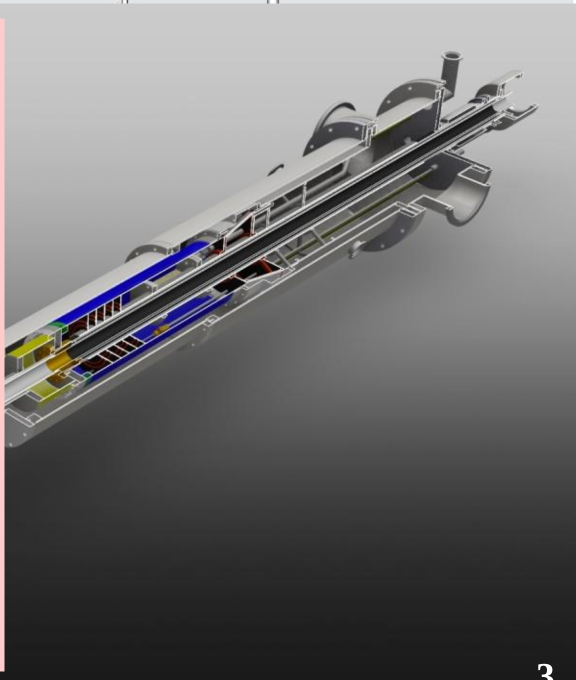
Silvia Niccolai IPN ORSAY

PAC44, JLab, 7/26/2016

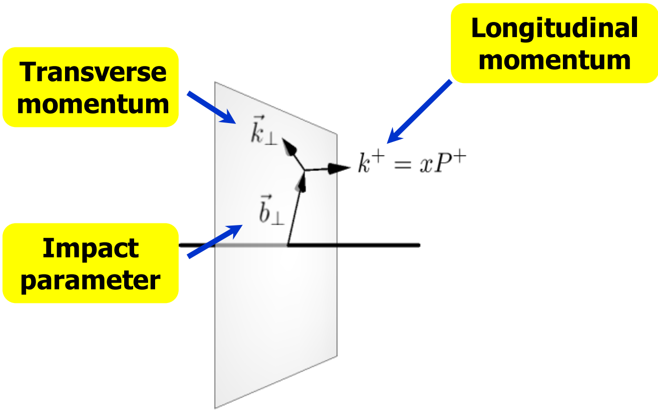


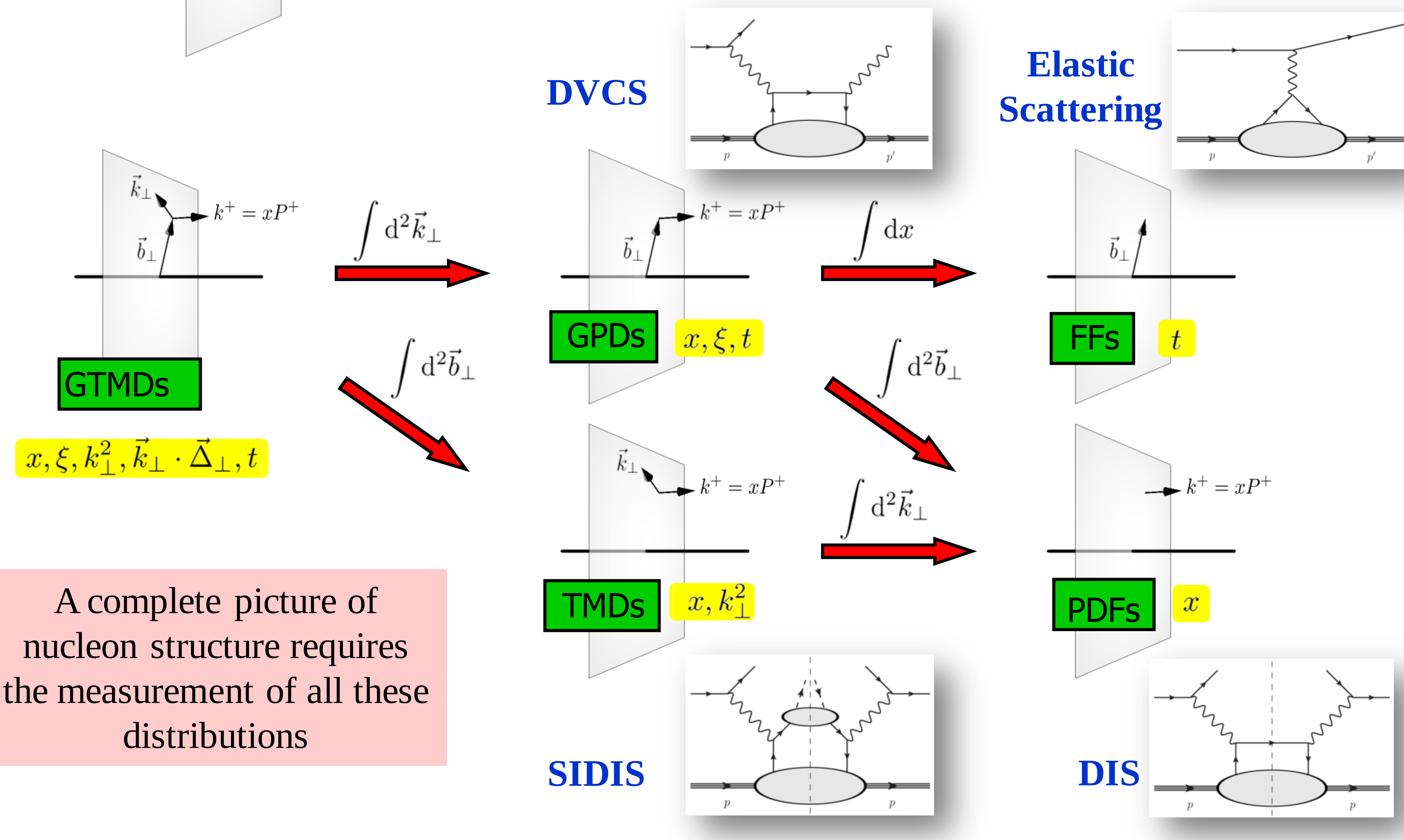
Outline:

- Multi-dimensional mapping of the nucleon
- Flavor separation of parton distributions
- Polarized target experiments with CLAS12
- Run group M: beam time request
- Experimental setup
- Physics cases:
  - ✓ Polarized nDVCS
  - ✓ SIDIS
  - ✓ DIS
  - ✓ Additional physics topics
- Conclusions/summary



Multi-dimensional mapping of the nucleon





A complete picture of nucleon structure requires the measurement of all these distributions

Flavor decomposition of parton distributions

• Proton and neutron have **different flavor compositions** → observables on these two target types are linked to different mixtures of **quark structure functions**

$$A_1^{p,n}(x) = \frac{\sum e_i^2 \Delta q_i(x,Q^2)}{\sum e_i^2 q_i(x,Q^2)}$$

Virtual-photon asymmetry from DIS

$$A_p^{\pi^+-\pi^-}(x) = \frac{4\Delta u_V(x) - \Delta d_V(x)}{4u_V(x) - d_V(x)} \qquad A_d^{\pi^+-\pi^-}(x) = \frac{\Delta u_V(x) + \Delta d_V(x)}{u_V(x) - d_V(x)}$$

SIDIS pion asymmetry
(integrated over k_T)

$$\sigma_{KM}^{K^+}(p) = 4h_{1L}^{\perp u} H_1^{\perp(1/2)u/K^+} + h_{1L}^{\perp d} H_1^{\perp(1/2)d/K^+} + h_1^{\perp \bar{s}} H_1^{\perp(1/2)\bar{s}/K^+}$$

$$\sigma_{KM}^{K^+}(n) = 4h_{1L}^{\perp d} H_1^{\perp(1/2)u/K^+} + h_{1L}^{\perp u} H_1^{\perp(1/2)d/K^+} + h_1^{\perp \bar{s}} H_1^{\perp(1/2)\bar{s}/K^+}$$

SIDIS $A_{UL}^{\sin 2\phi}$ for K^+

$$\mathcal{H}_p(\xi,t) = \frac{4}{9}\mathcal{H}_u(\xi,t) + \frac{1}{9}\mathcal{H}_d(\xi,t) \qquad \mathcal{H}_n(\xi,t) = \frac{1}{9}\mathcal{H}_u(\xi,t) + \frac{4}{9}\mathcal{H}_d(\xi,t)$$

Compton form factors
from DVCS

• Experiments on **proton and deuterium targets** must be performed to extract the flavor dependence of the various kinds of parton distributions
• **Longitudinally polarized observables**: nuclear targets, such as **NH_3** and **ND_3** are used
• ND_3 typically has **½ the polarization** of NH_3 (~40%)

ND_3 experiments with CLAS12: history

- E12-06-109 (Polarized DIS): **30 days on NH_3** (+overhead), **50 days on ND_3** (+overhead) **(run group C)**
- E12-06-119b (DVCS on longitudinally polarized protons): **120 days on NH_3 (run group C)**
- E12-07-107 (SIDIS with long. pol. target), E12-09-007b, E12-09-009 (K-SIDIS with long. pol. target)

→ **beam time for ND_3 ~40% of that for NH_3**

PR12-15-004 (« Deeply virtual Compton scattering on a longitudinally polarized deuterium target »), requesting **100 days** + overhead on **ND_3** was **conditionally approved** (**C2**) by **PAC 43**

*"…To obtain full approval, the collaboration needs to fulfill two conditions. One would be the **submission of a Run Group proposal**, connected to RG-C, that has been fully vetted according to standard procedures in the CLAS12 collaboration. The second would be the **submission of a new proposal, defining a new run group**, for the extended running time, **optimized for this measurement** (for example with increased neutron detection efficiency), and possibly **incorporating other experiments**. The PAC encourages the collaboration to consider the opportunities, and looks forward to understanding the full physics potential of a new run group."*

✓ PR12-06-109a, polarized nDVCS using the **existing 50 days of Run group Cb**; submitted to PAC44, after CLAS review and approval

✓ **C12-15-004: New run group M: three experiments, inclusion of FT to optimize nDVCS**

CLAS12 Run group M

Production data taking at $10^{35}cm^{-2}s^{-1}$ on ND_3 (10 nA)	**50 days**
Production data taking at $0.5\cdot10^{35}cm^{-2}s^{-1}$ on ND_3 (5 nA)	**10 days – with Forward Tagger**
Target work	4 days
Production data taking on C_{12} target	5 days
Moeller polarimeter runs	1 day
Configuration change	3 days
Total beam time request	**73 days**

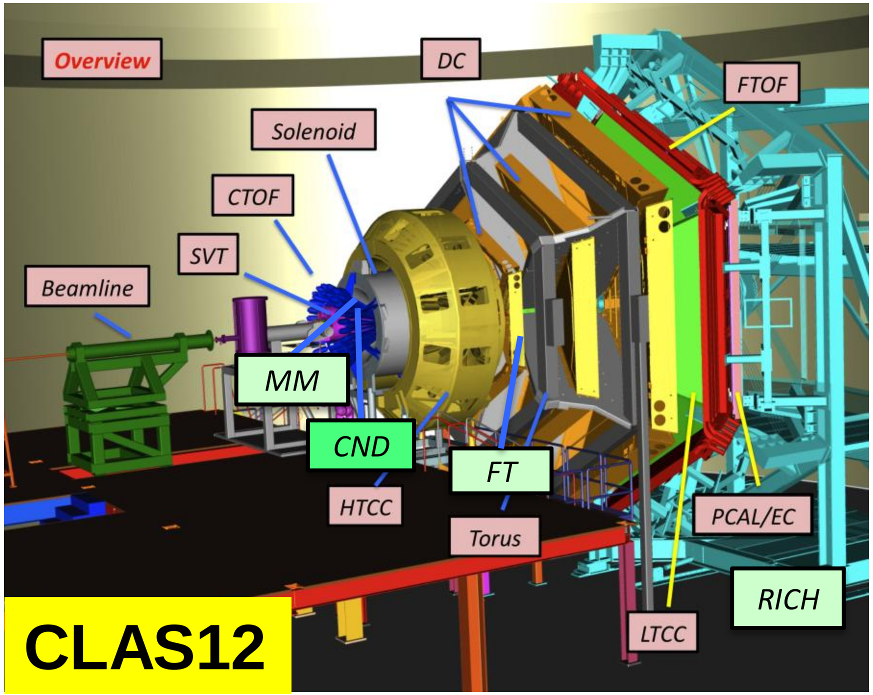
Beam energy: 11 GeV - Beam polarization: 85%

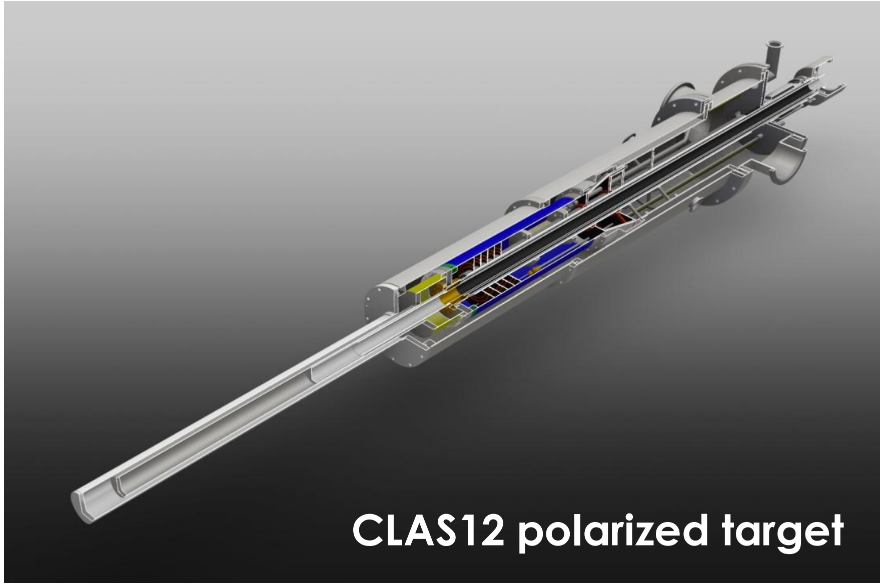
Assuming a total of 60 days (50 on ND_3 + 10 of overhead) for RG Cb
→ 133 days of beam time for polarized deuterium (110 on ND_3 + 23 of overhead)

Physics topics:

- **Polarized nDVCS (GPDs)**
- **Polarized SIDIS (TMDs)**
- **Polarized DIS (polarized PDFs)**
- **Additional topics: polarized nTCS, polarized nDVMP, di-hadron SIDIS**

Experimental setup of Run-group M





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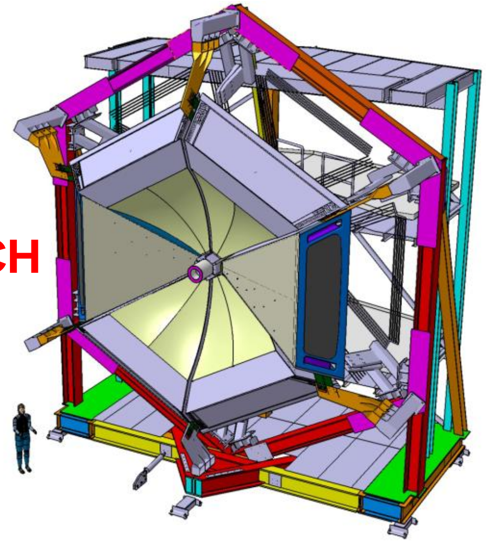
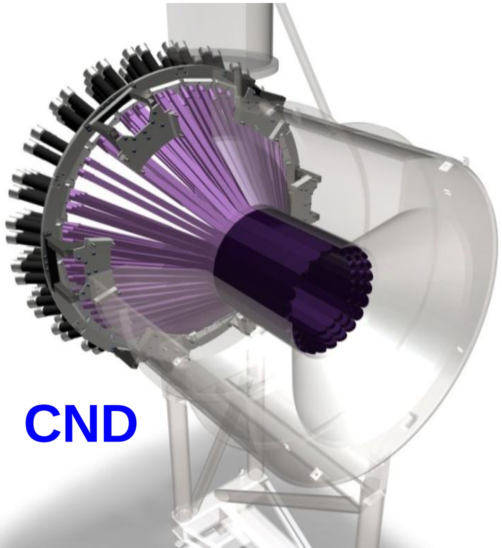
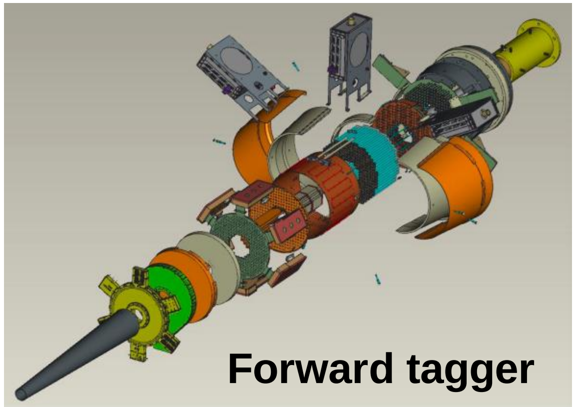




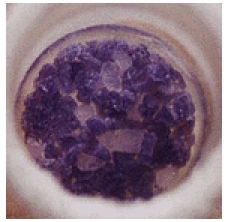
CND



Added to optimize nDVCS measurement

The CLAS12 longitudinally polarized target

Irradiated deuterated ammonia (ND_3)

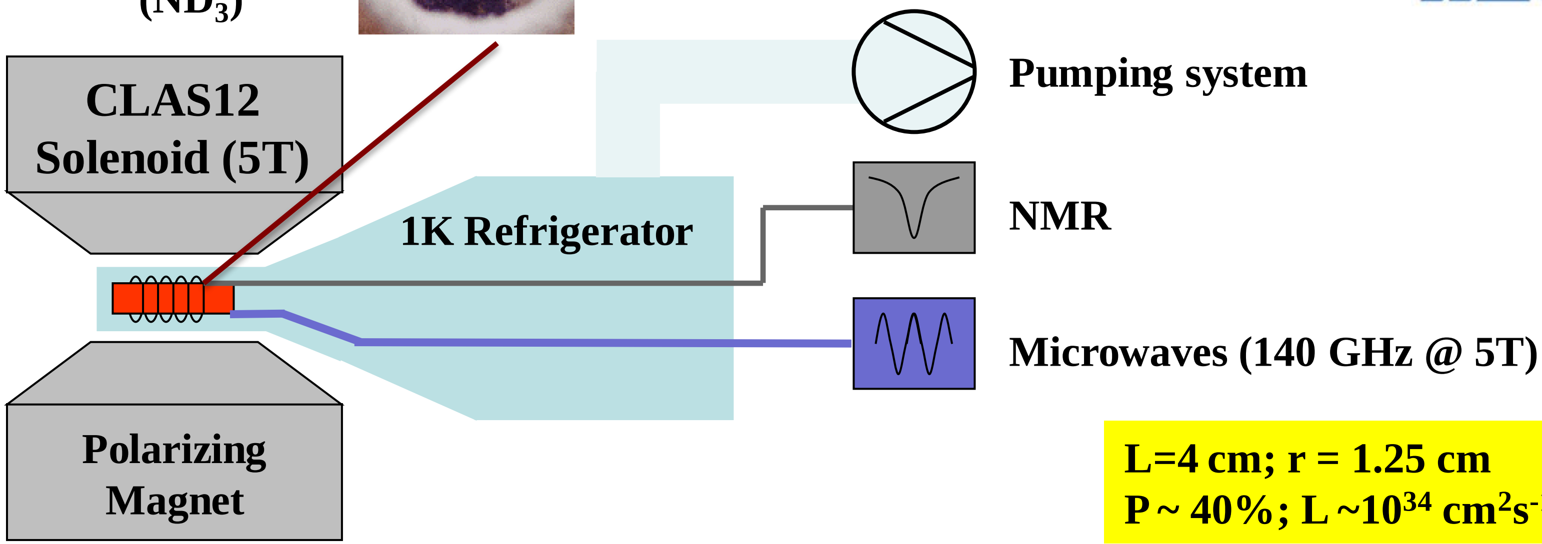


Jefferson Lab
Thomas Jefferson National Accelerator Facility

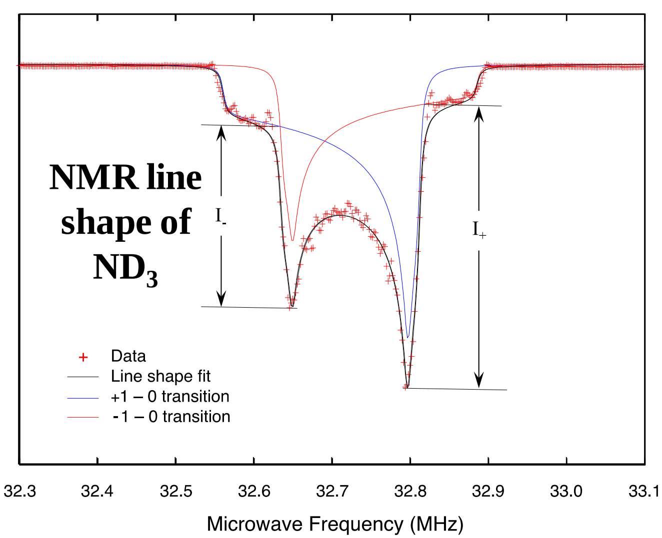
OLD DOMINION UNIVERSITY
IDEA FUSION

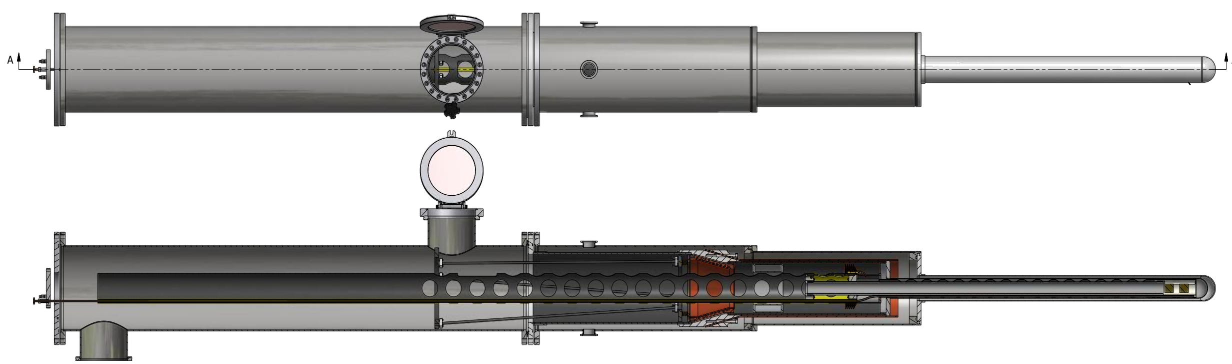
UNIVERSITY of VIRGINIA

CHRISTOPHER NEWPORT UNIVERSITY



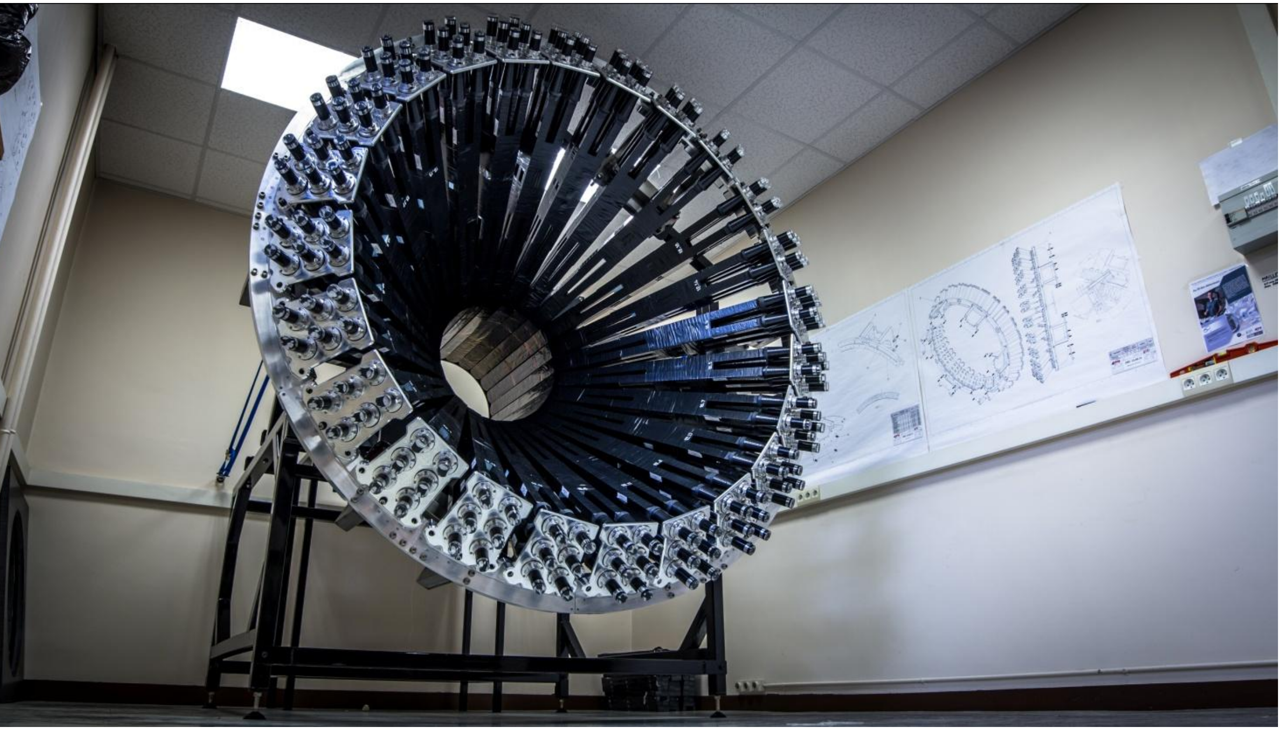
L=4 cm; r = 1.25 cm
P ~ 40%; L ~10^{34} cm^2s^{-1} /nA





Central Neutron Detector (CND)

Main physics goal: detect the **recoiling neutron in nDVCS**
Requirements/performances:
- good **neutron/photon separation** for **$0.2<p_n<1$ GeV/c → ~150 ps time resolution**
- momentum resolution **$\delta p/p < 10\%$**
- **neutron detection efficiency ~10%**



Project status:
- **Construction completed**
- Detector shipped to JLab in June 2015
- **Cosmic data analysis:**
σ_t ~150 ps for all blocks, confirmed with tests at JLab
- **Readiness Review** passed in June

→CND included in CLAS12 baseline equipment

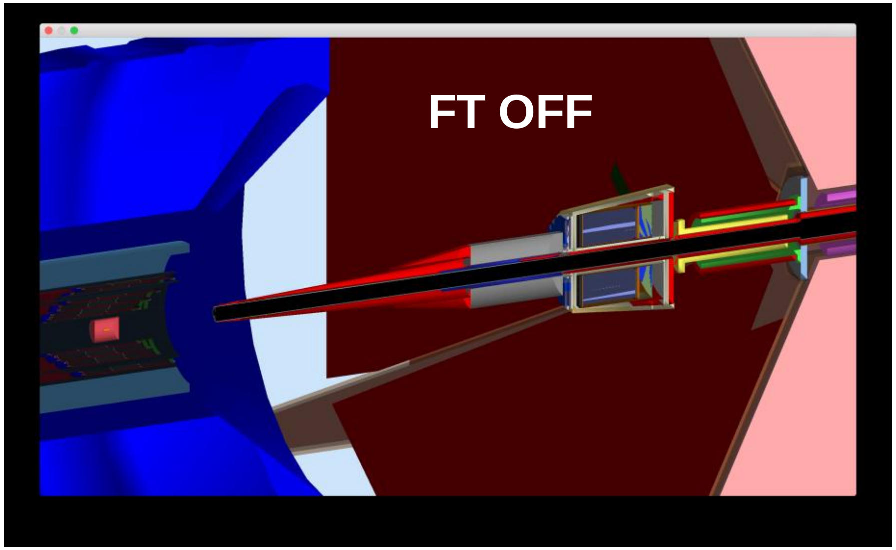
IPN ORSAY

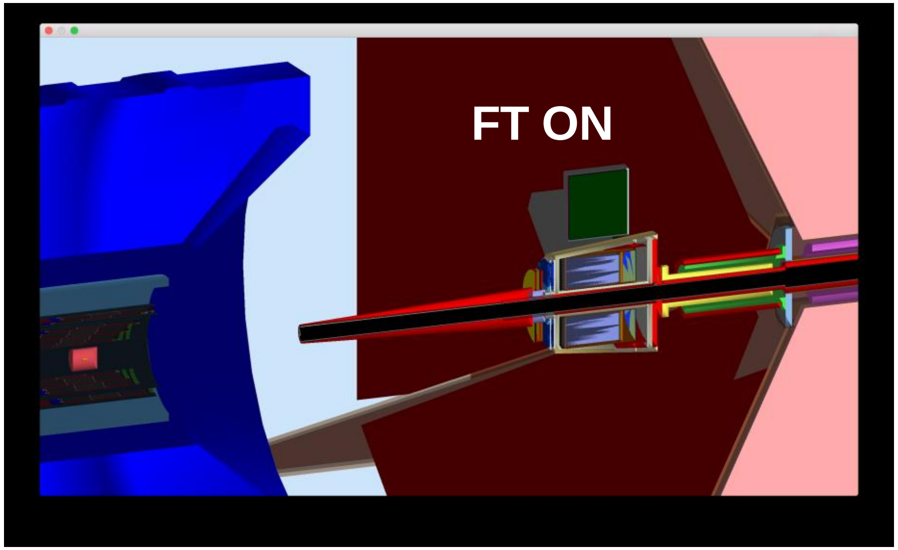
University of Glasgow

CND design: **scintillator barrel** - 3 radial layers, 48 bars per layer **coupled two-by-two** downstream by a **"u-turn" lightguide,** 144 long light guides with **PMTs** upstream

Forward tagger

• FT (**calorimeter + hodoscope** + tracker): polar angles between **2.5° and 4.5°**
→ Important for **DVCS**, low-angle **photons**, covering holes at **ϕ ~ 0°-360°**
• GEMC simulations on **ND_3** target, **rastered beam**, including **background**
• With the current design of the shielding, **high occupancy** (5%) in DC-R1 at **10 nA**
→ FT on for only a **subset** of the experiment (**10 days**), with **lower current (5 nA)**

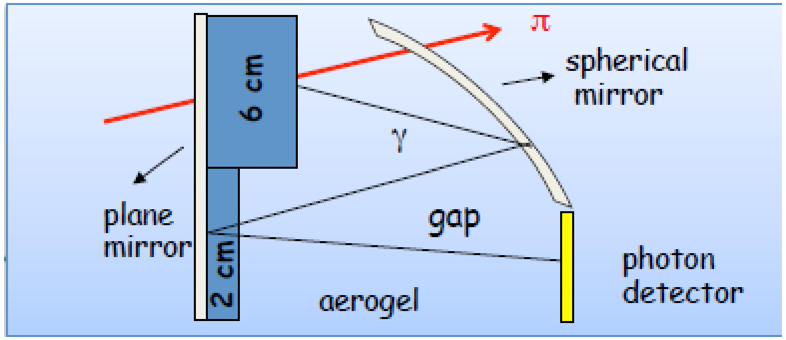


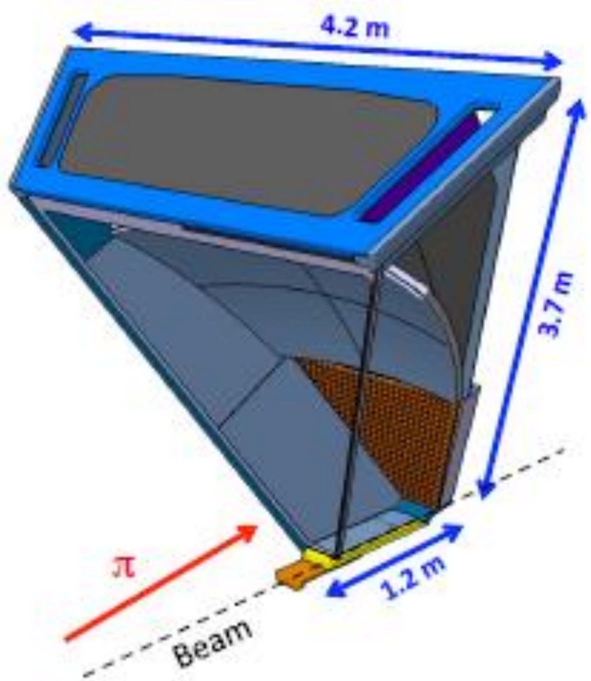


Configuration change (from Bob Miller and Chris Keith)**: 3 PAC days**
• 1 (calendar) day to move the SVT/solenoid/HTCC upstream
• 1 day to remove the Moller shielding
• 1 day to install the lead shield, Moller shield, outer shielding cone, and nose cone
• 1 day to move back the SVT/solenoid/HTCC into position
• 2 days to reinstall the polarized target and recover the polarization

CLAS12 RICH

Design goals:
- $\pi/K/p$ identification from 3 up to 8 GeV/c and 25°
- ~4σ pion-kaon separation
- pion rejection factor ~ 1:500
- will cover 1 sector (2 afterwards) of CLAS12, replacing LTCC





Project overview:

2010: Concept of Design and Technology
2011: Tests of components and small prototype
2012: Tests of large scale prototype
2013: June: RICH Technical Review
September: Project Review with DOE
→ **Start Construction Phase**
2014: RICH Mechanical Review
2015: June: RICH Internal Review
October: Project Mid-term Review DOE
2016: **RICH Readiness Review**
2017: September: **Ready for Installation** (1 sector)

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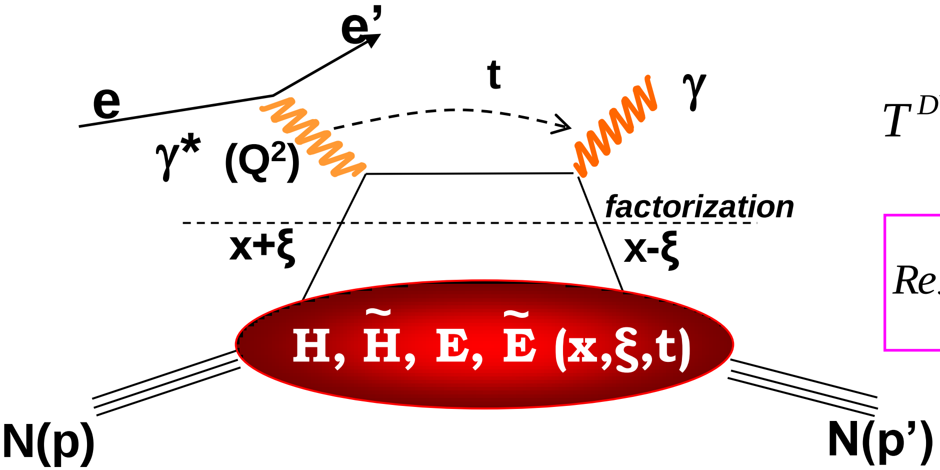
Jefferson Lab
Thomas Jefferson National Accelerator Facility
University of Glasgow
UNIVERSIDAD TECNICA FEDERICO SANTA MARIA
University of Connecticut
Argonne NATIONAL LABORATORY
DUQUESNE UNIVERSITY
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Deeply-virtual Compton scattering on the neutron with a longitudinally polarized deuteron target

A. Biselli (Fairfield U), C. Keith (JLab), S. Niccolai (IPN Orsay) (contact person), S. Pisano (INFN Frascati), D. Sokhan (Glasgow U)

Deeply Virtual Compton Scattering and GPDs



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

$$Re\mathcal{H}_q = e_q^2 P\int_0^{+1}\left(H^q(x,\xi,t)-H^q(-x,\xi,t)\right)\left[\frac{1}{\xi-x}+\frac{1}{\xi+x}\right]dx$$

$$Im\mathcal{H}_q = \pi e_q^2\left[H^q(\xi,\xi,t)-H^q(-\xi,\xi,t)\right]$$

At LO QCD, twist 2, chiral-even, quark sector → **4 GPDs for each quark flavor**

conserve nucleon spin	**Vector: H (x,ξ,t)**	**Axial-Vector: H̃ (x,ξ,t)**
flip nucleon spin	**Tensor: E (x,ξ,t)**	**Pseudoscalar: Ẽ (x,ξ,t)**

Nucleon tomography

$$q(x,b_\perp)=\int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2}e^{i\Delta_\perp b_\perp}H(x,0,-\Delta_\perp^2)$$

$$\Delta q(x,b_\perp)=\int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2}e^{i\Delta_\perp b_\perp}\tilde{H}(x,0,-\Delta_\perp^2)$$

M. Burkardt, PRD 62, 71503 (2000)

Quark angular momentum (Ji's sum rule)

$$\boxed{\frac{1}{2}\int_{-1}^{1}xdx(H_q(x,\xi,t=0)+E_q(x,\xi,t=0)) = J_q = \frac{1}{2}\Delta\Sigma+\Delta L}$$

X. Ji, Phy.Rev.Lett.78,610(1997)

DVCS observables and flavor separation of CFFs

Polarized **beam**, unpolarized target:

$\Delta\sigma_{LU} \sim \sin\phi\ \mathbf{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}$ ⇒ $Im\{\mathcal{H}_p, \mathcal{H}_p, \tilde{\mathcal{E}}_p\}$ / $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \tilde{\mathcal{E}}_n\}$

Proton
Neutron

Unpolarized beam, **longitudinal** target:

$\Delta\sigma_{UL} \sim \sin\phi\mathbf{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}} + \ldots\}$ ⇒ $Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ / $Im\{\mathcal{H}_n, \mathcal{E}_n\}$

Polarized **beam**, **longitudinal** target:

$\Delta\sigma_{LL} \sim (A+B\cos\phi)\mathbf{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E})\ldots\}$ ⇒ $Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ / $Re\{\mathcal{H}_n, \mathcal{E}_n\}$

Unpolarized beam, **transverse** target:

$\Delta\sigma_{UT} \sim \cos\phi\sin(\phi_s-\phi)\mathbf{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}$ ⇒ $Im\{\mathcal{H}_p, \mathcal{E}_p\}$ / $Im\{\mathcal{H}_n\}$

$\xi = x_B/(2-x_B)$
$k=-t/4M^2$

$$\mathcal{H}_p(\xi,t) = \frac{4}{9}\mathcal{H}_u(\xi,t) + \frac{1}{9}\mathcal{H}_d(\xi,t)$$
$$\mathcal{H}_n(\xi,t) = \frac{1}{9}\mathcal{H}_u(\xi,t) + \frac{4}{9}\mathcal{H}_d(\xi,t)$$

⇒

$$\boxed{\begin{aligned}\mathcal{H}_u(\xi,t) &= \frac{9}{15}\left(4\mathcal{H}_p(\xi,t) - \mathcal{H}_n(\xi,t)\right)\\ \mathcal{H}_d(\xi,t) &= \frac{9}{15}\left(4\mathcal{H}_n(\xi,t) - \mathcal{H}_p(\xi,t)\right)\end{aligned}}$$

Proton and neutron GPDs (and CFFs) **are linear combinations of quark GPDs**

A **combined analysis** of DVCS observables for **proton and neutron** targets is necessary to perform the **flavor separation** of the CFFs

What we learned from CLAS pDVCS asymmetries

Extraction of CFFs from combined analysis of CLAS data (TSA, BSA, DSA – eg1dvcs)
CFFs fitting code by M. Guidal
M. Guidal, Eur. Phys. J. A 37 (2008) 319, etc…

PROTON TOMOGRAPHY:

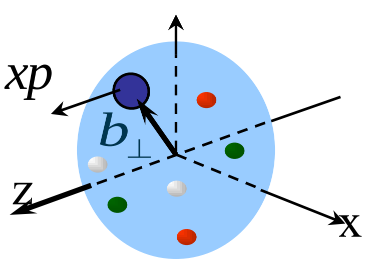
- **$Im\mathcal{H}$ has steeper t-slope than $Im\tilde{\mathcal{H}}$: axial charge more “concentrated” than the electric charge**

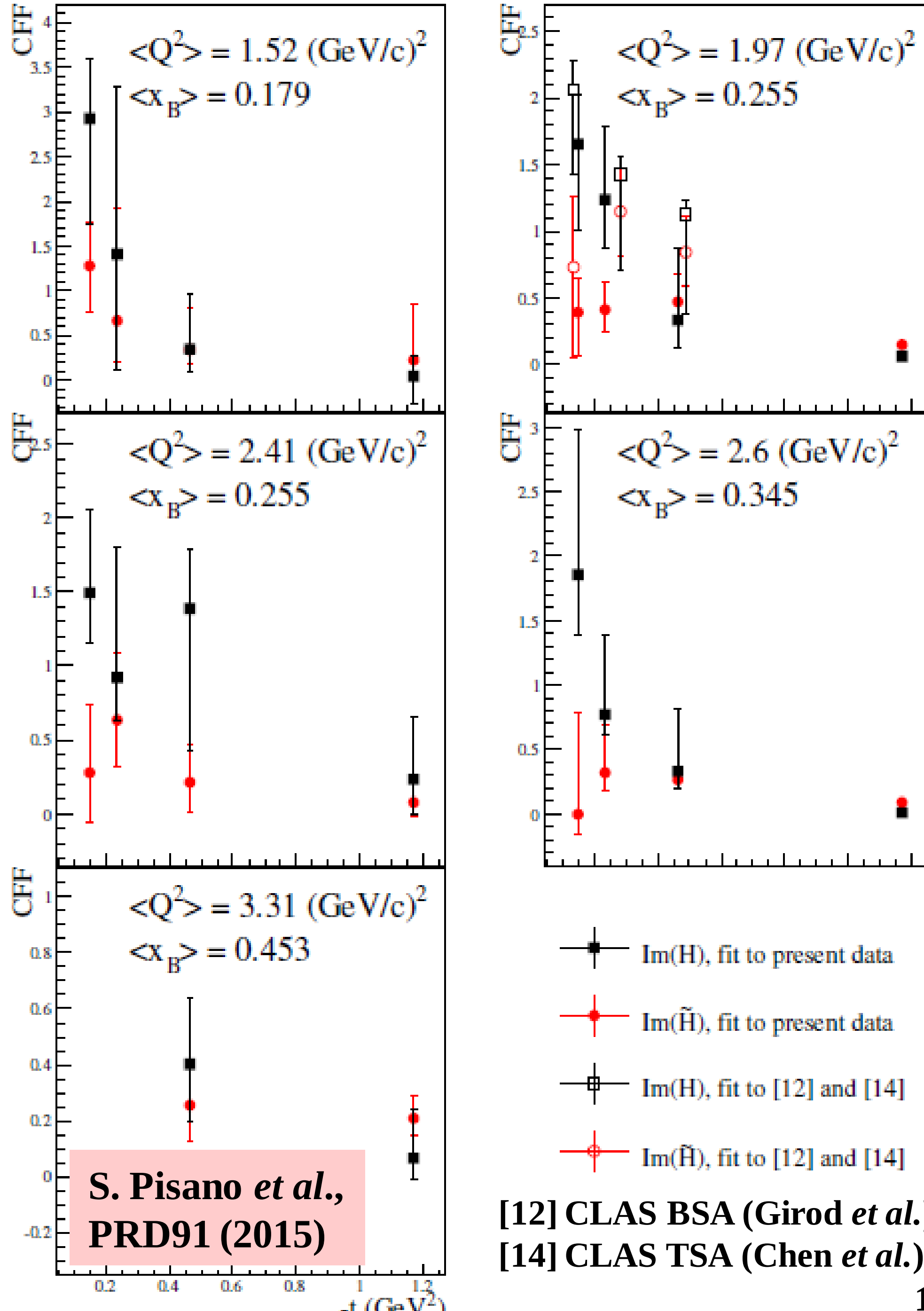
- **$Im\mathcal{H}$, flatter t-slope at high x_B: faster quarks (valence) at the core of the nucleon, slower quarks (sea) at its perifery**

$$\Delta q(x, b_\perp) = \int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} \tilde{H}(x,0,-\Delta_\perp^2)$$

$$\int H(x,\xi,t)dx = F_1(t)$$

$$\int \tilde{H}(x,\xi,t)dx = G_A(t)$$



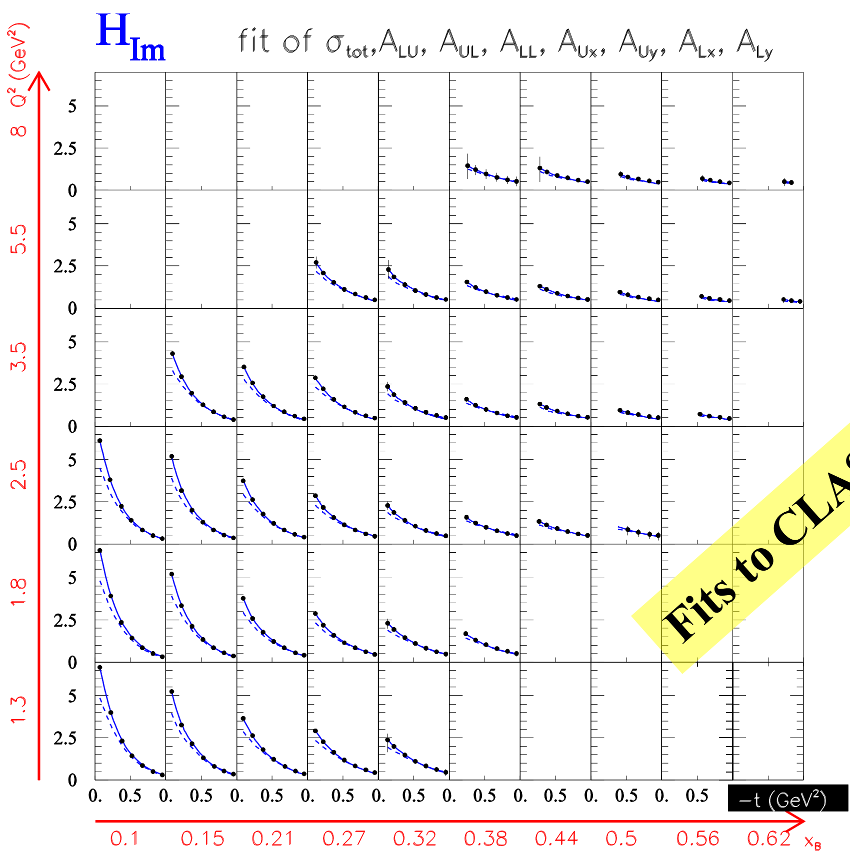


[12] CLAS BSA (Girod *et al.*)
[14] CLAS TSA (Chen *et al.*)

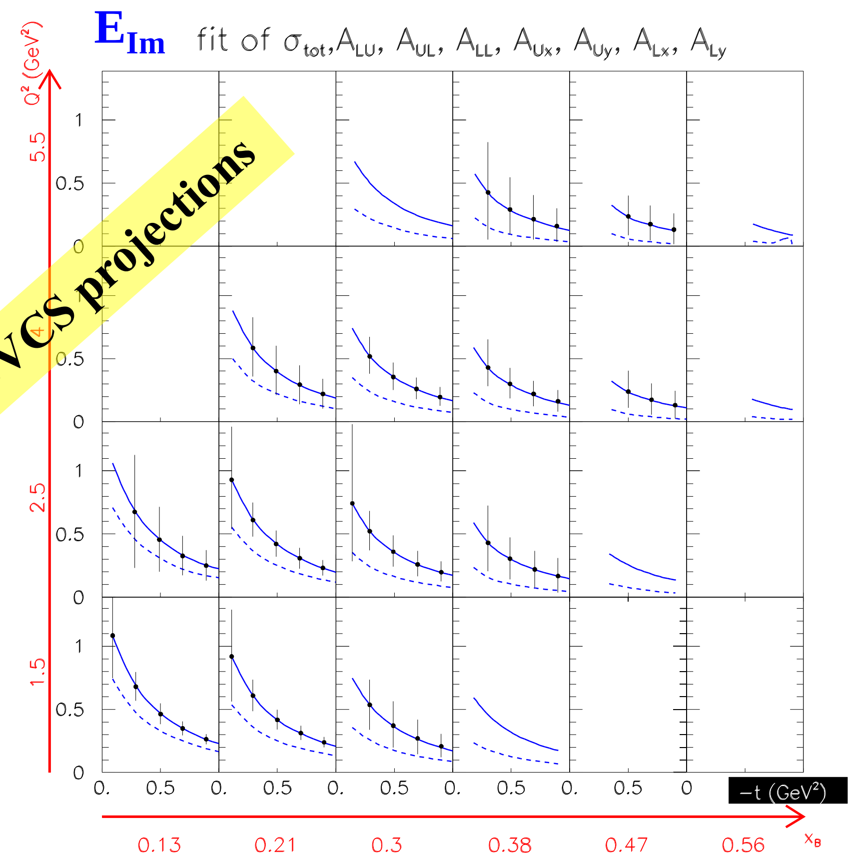
DVCS program for JLab12

Proton
Neutron

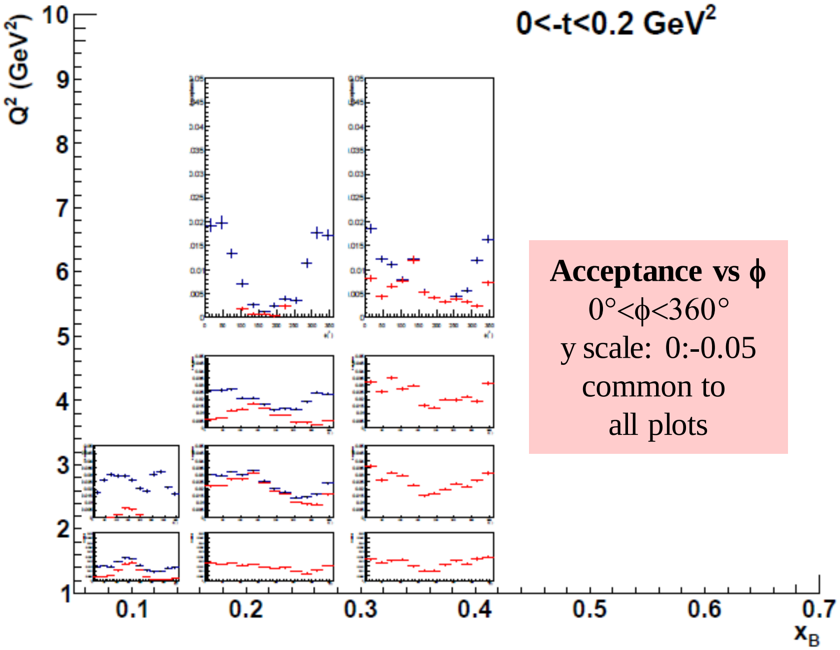
Observable (target)	Target	Sensitivity to CFFs	Completed experiments	12-GeV experiments
$\Delta\sigma_{beam}$(p)	Unpolarized hydrogen	$\Im m\mathcal{H}_p$	Hall A, CLAS	Hall A, CLAS12,Hall C
BSA(p)	Unpolarized hydrogen	$\Im m\mathcal{H}_p$	HERMES, CLAS	CLAS12
TSA(p)	Long. pol. NH3	$\Im m\tilde{\mathcal{H}}_p$, $\Im m\mathcal{H}_p$,	HERMES, CLAS	CLAS12
DSA(p)	Long. pol. NH3	$\Re e\mathcal{H}_p$, $\Re e\tilde{\mathcal{H}}_p$	HERMES, CLAS	CLAS12
tTSA(p)	Transv. pol. protons	$\Im m\mathcal{H}_p$, $\Im m\mathcal{E}_p$	HERMES	CLAS12
$\Delta\sigma_{beam}$(n)	Unpolarized deuterium	$\Im m\mathcal{E}_n$	Hall A	
BSA(n)	Unpolarized deuterium	$\Im m\mathcal{E}_n$		CLAS12
TSA(n)	**Long. pol. ND3**	$\Im m\mathcal{H}_n$		**C12-15-004**
DSA(n)	**Long. pol. ND3**	$\Re e\mathcal{H}_n$		



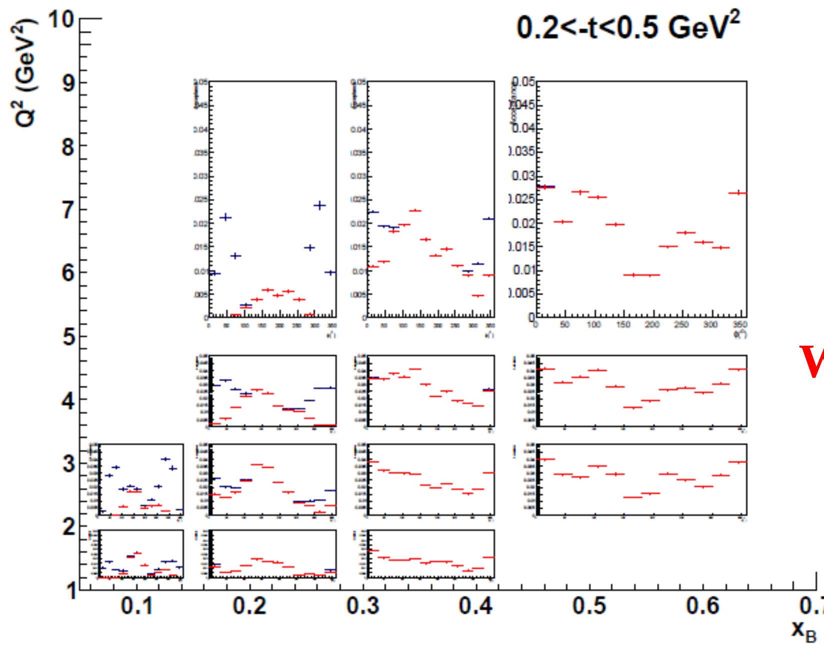
Fits to CLAS12 pDVCS projections



Effect of the Forward Tagger on the acceptance for nDVCS

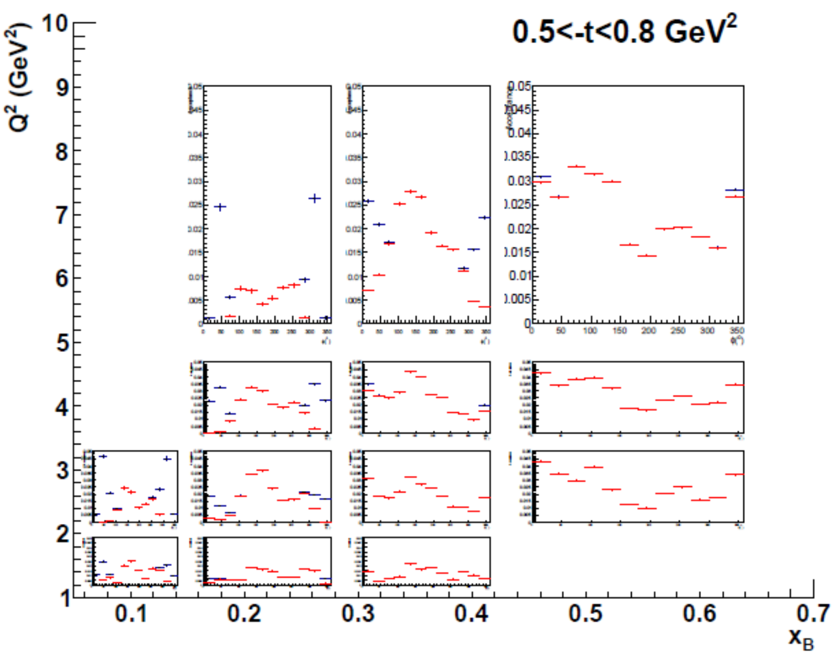


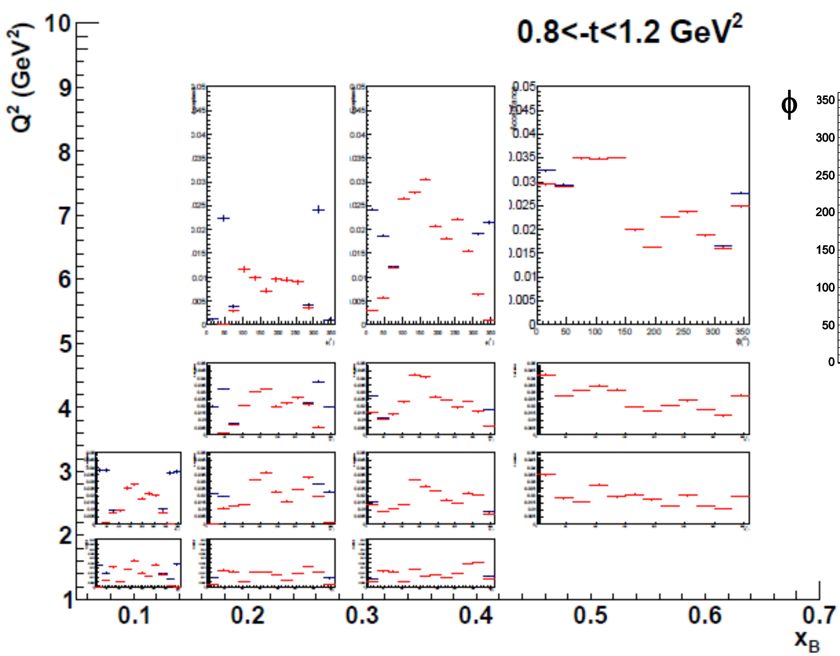
Acceptance vs ϕ
0°<ϕ<360°
y scale: 0:-0.05
common to
all plots

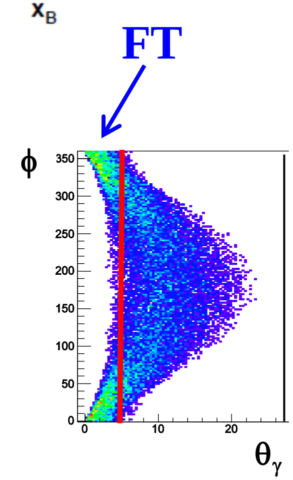


With FT

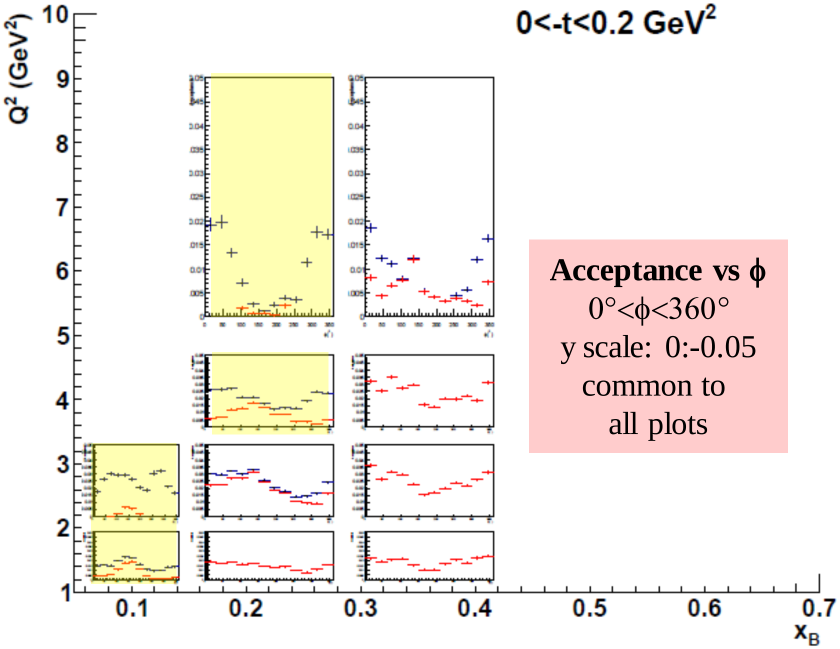
Without FT

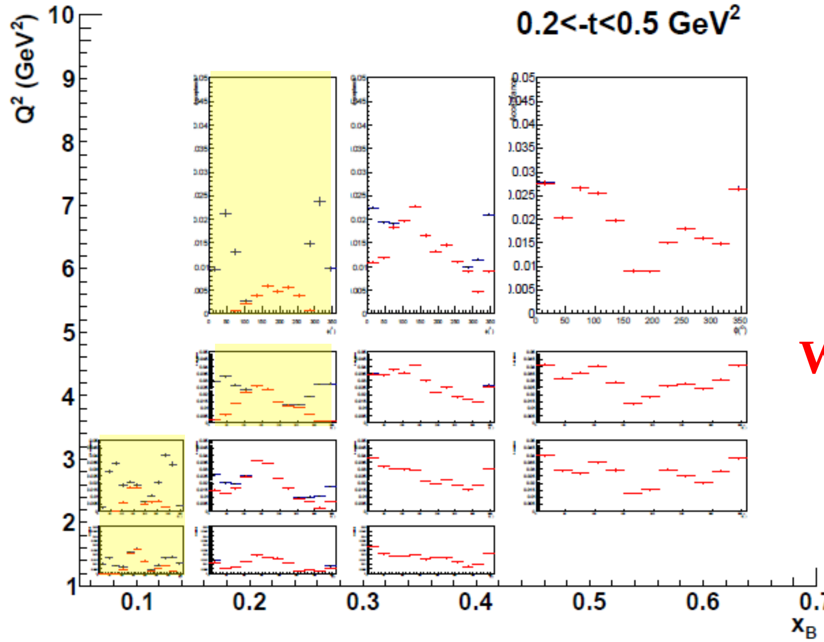






Effect of the Forward Tagger on the acceptance for nDVCS

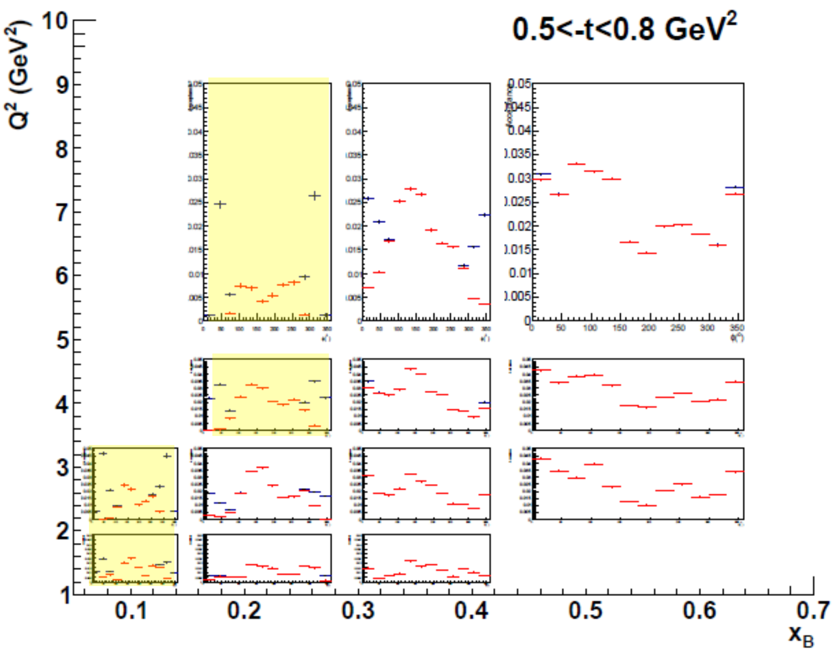


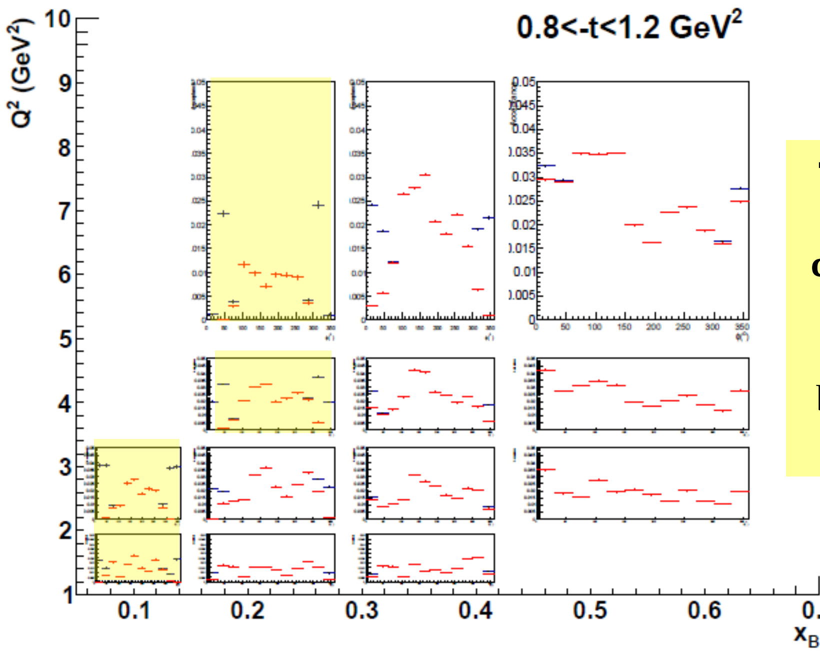


Acceptance vs ϕ
$0° < \phi < 360°$
y scale: 0:-0.05
common to
all plots

With FT

Without FT





The inclusion of the FT **completes the ϕ coverage,** affecting 16 bins out of 49 (**30%**),

Projected results: target-spin asymmetry

$$\sigma_A = \frac{1}{P_t} \cdot \frac{\sqrt{(1 - P_t \cdot A)^2}}{\sqrt{N}}$$

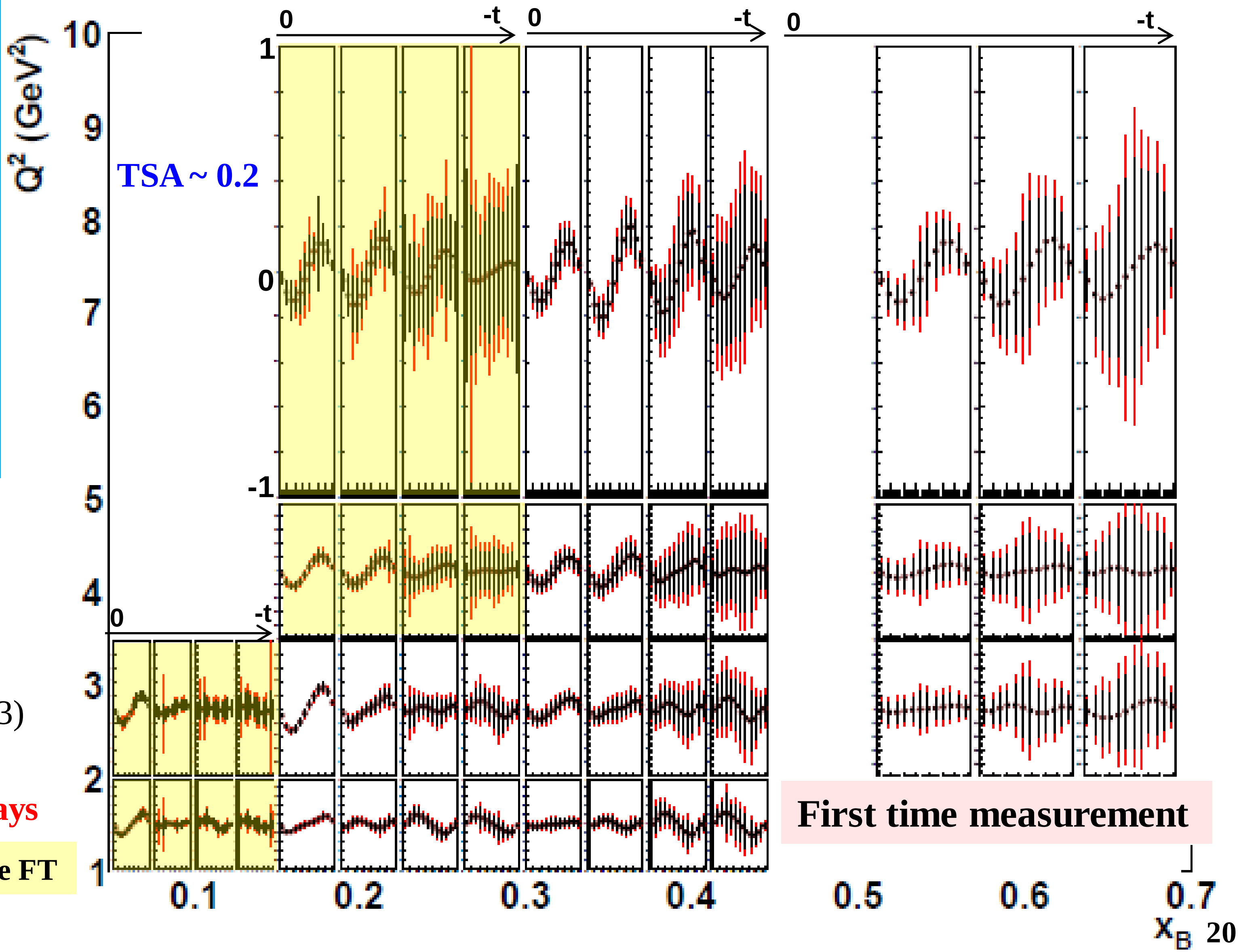
• L = **3/20·10^{35}cm^{-2}s^{-1}**, Time = **100 days@10 nA + 10 days@5 nA with Forward tagger,** P_t = **0.4**

✓Count rates computed with nDVCS+BH event generator + CLAS12 + FT acceptance from FastMC + CND efficiency from GEANT4 simulation
✓Asymmetries computed with VGG model

• 4 bins in Q^2
• 4 bins in $-t$
• 4 bins in x_B
• 12 bins in φ
(Same as E12-11-003)

Red points = 50 days

Bins completed by the FT

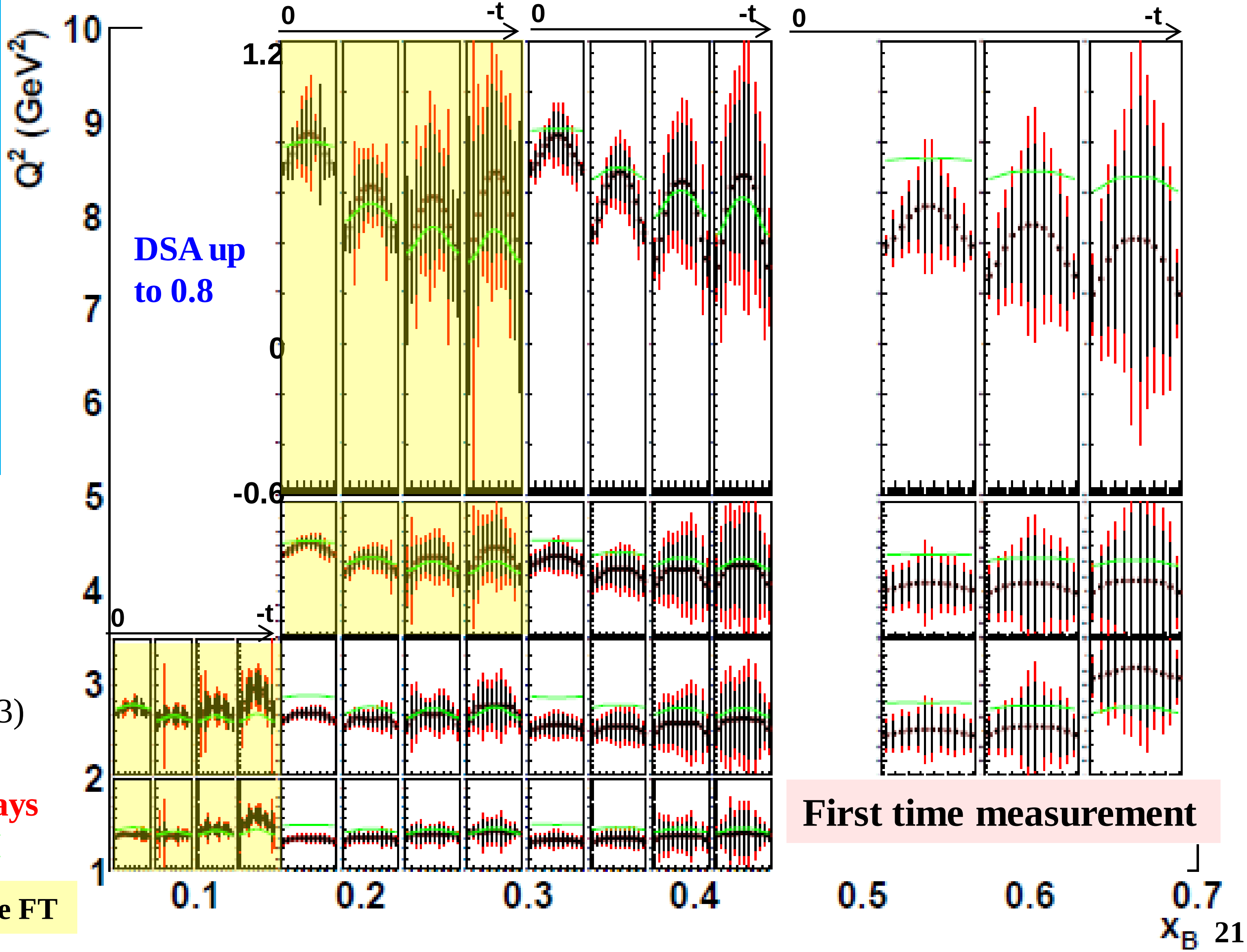


Projected results: double spin asymmetry

✓Count rates computed with nDVCS+BH event generator + CLAS12 + FT acceptance from FastMC + CND efficiency from GEANT4 simulation
✓Asymmetries computed with VGG model

$$\sigma_A = \frac{1}{P_b P_t} \cdot \frac{\sqrt{(1 - P_b P_t \cdot A)^2}}{\sqrt{N}}$$

- L = **3/20·10^{35}cm^{-2}s^{-1}**, Time = **100 days@10 nA + 10 days@5 nA with Forward tagger**, P_t = **0.4**, P_b = **0.85**



- 4 bins in Q^2
- 4 bins in $-t$
- 4 bins in x_B
- 12 bins in φ

(Same as E12-11-003)

Red points = 50 days
Green curves: BH

Bins completed by the FT

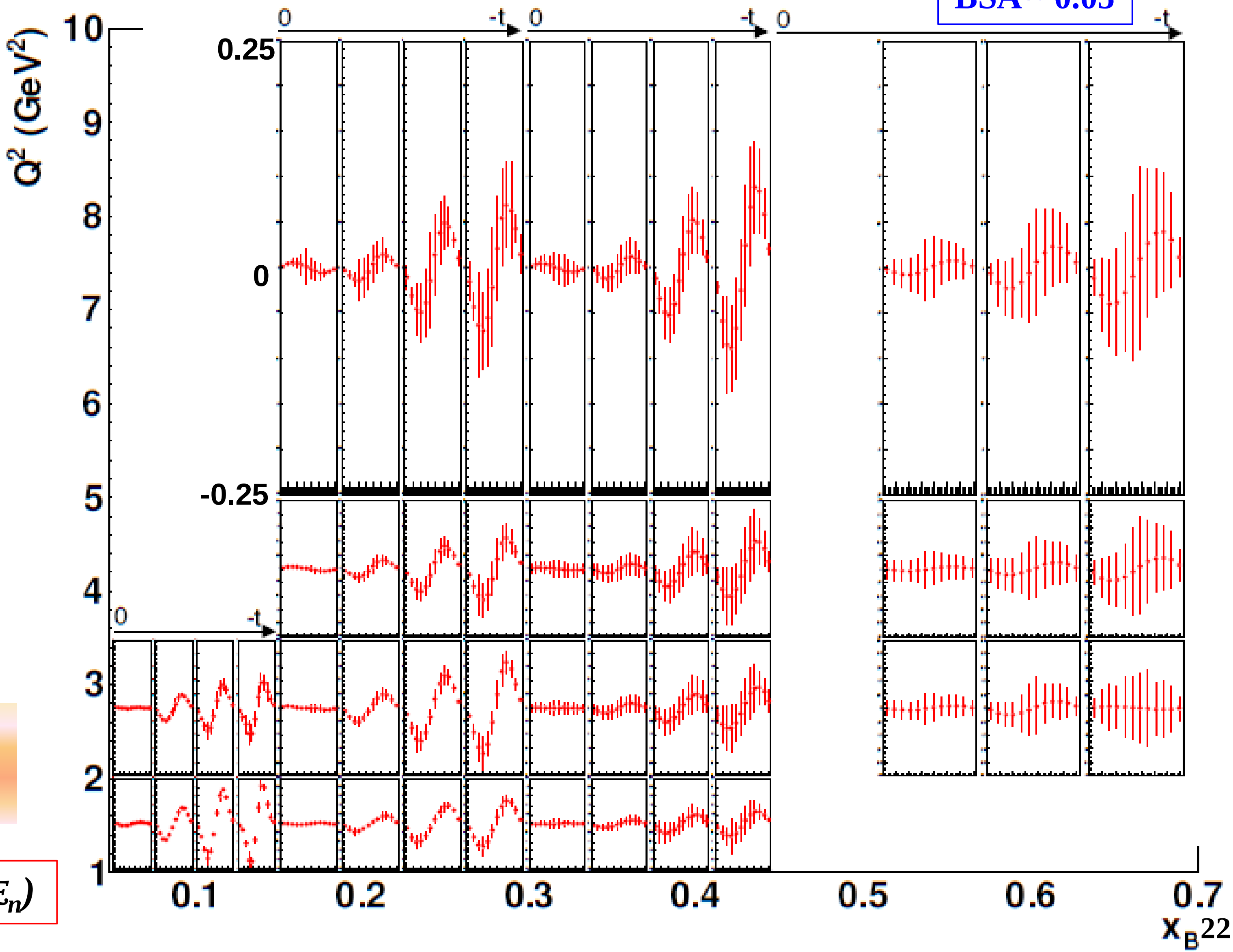
Projected beam spin asymmetry from C12-11-003

✓Count rates computed with nDVCS+BH event generator + CLAS12 + FT acceptance from FastMC + CND efficiency from GEANT4 simulation
✓Asymmetries computed with VGG model

$$\sigma_A = \frac{1}{P_b}\cdot\frac{\sqrt{(1-P_b\cdot A)^2}}{\sqrt{N}}$$

• L = **10^{35}cm^{-2}s^{-1}** for LD, Time = **80 days**; P_b = 0.85

BSA ~ 0.05



- 4 bins in Q^2
- 4 bins in $-t$
- 4 bins in x_B
- 12 bins in φ

High-impact experiment

Sensitive to *Im($\mathcal{E}_n$)*

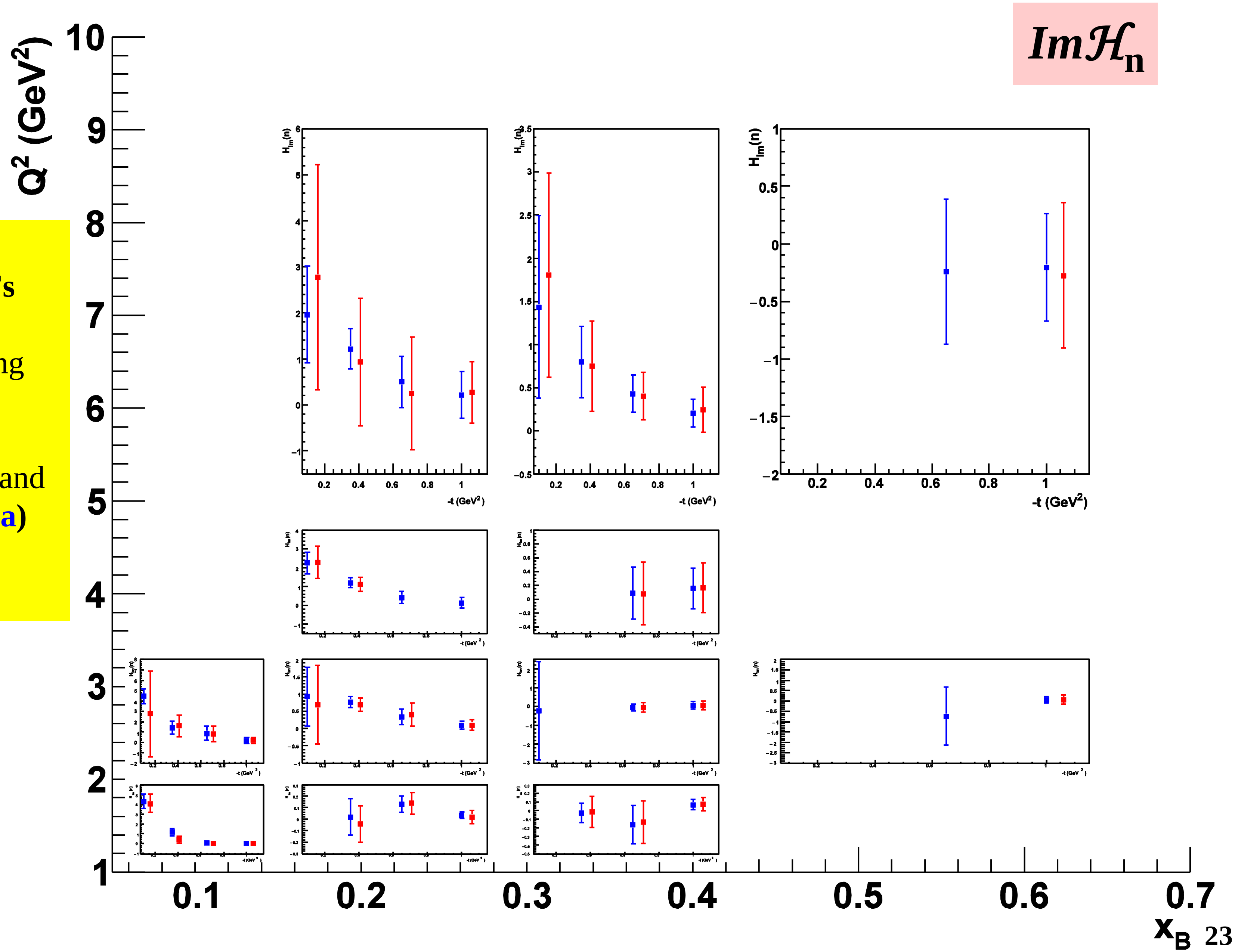
Combined analysis of C12-15-004 and E12-11-003

110 days
50 days

Extraction of **neutron CFFs** using **M. Guidal**'s fitting code. Fit of **TSA, DSA** (C12-15-004 and PR12-06-109a) and **BSA** (E12-11-003)

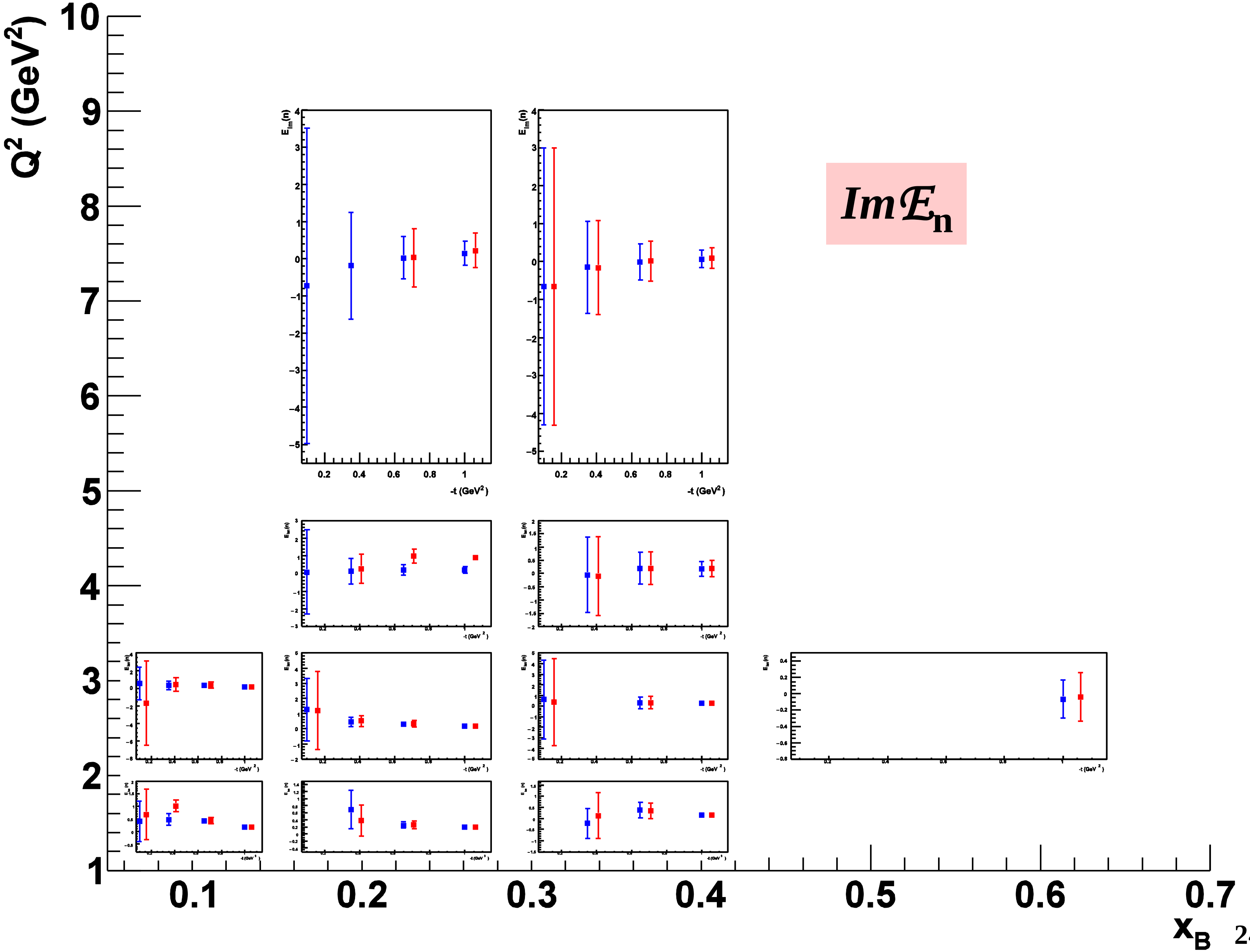
7 CFFs as free fit parameters

$\mathrm{Im}\tilde{\mathcal{E}} = 0$



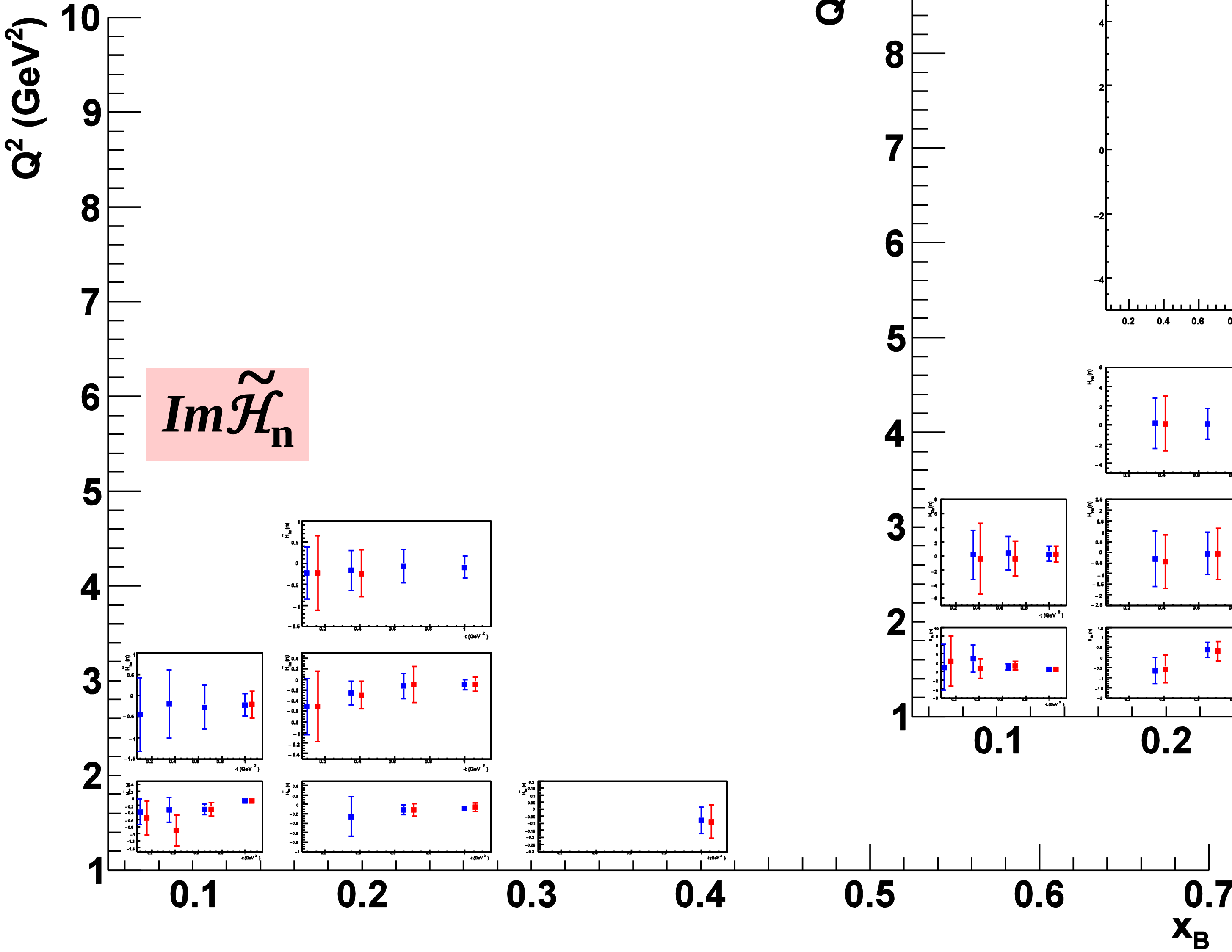
Combined analysis of C12-15-004 and E12-11-003

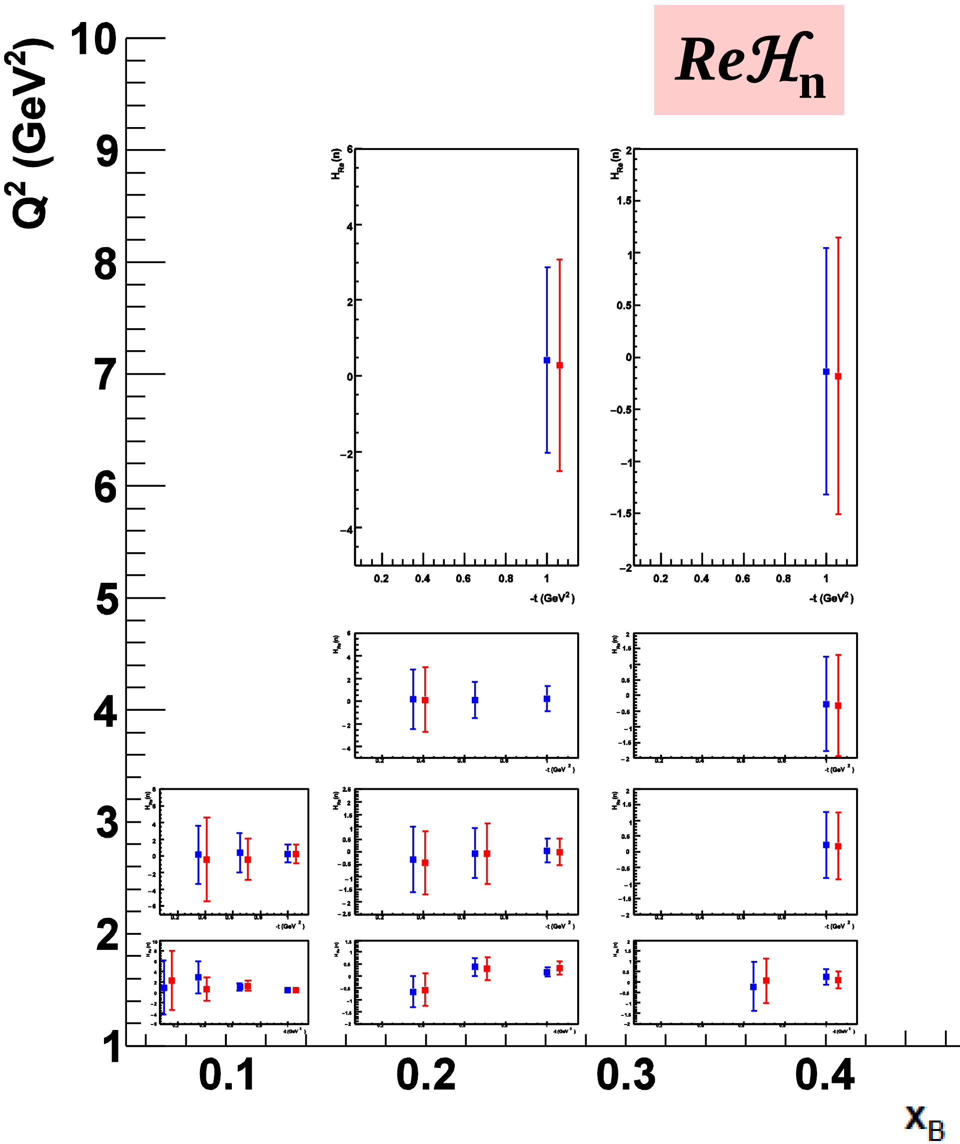
110 days
50 days



Combined analysis of C12-15-004 and E12-11-003

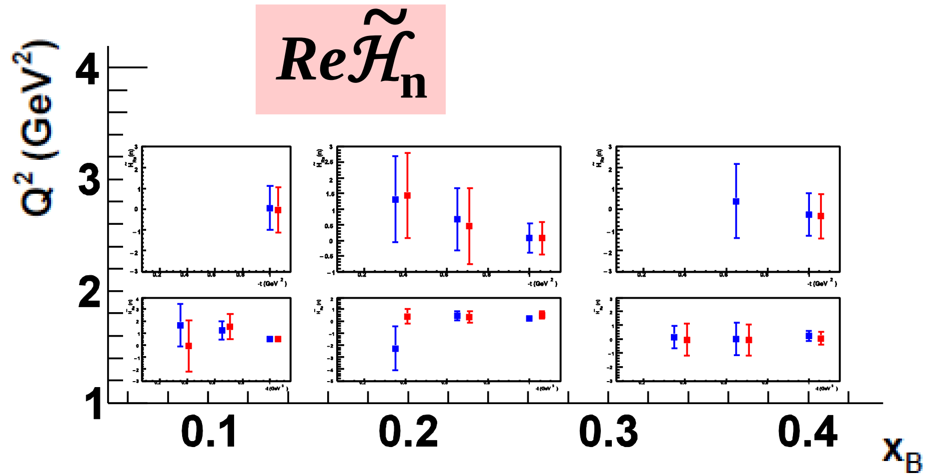
110 days
50 days

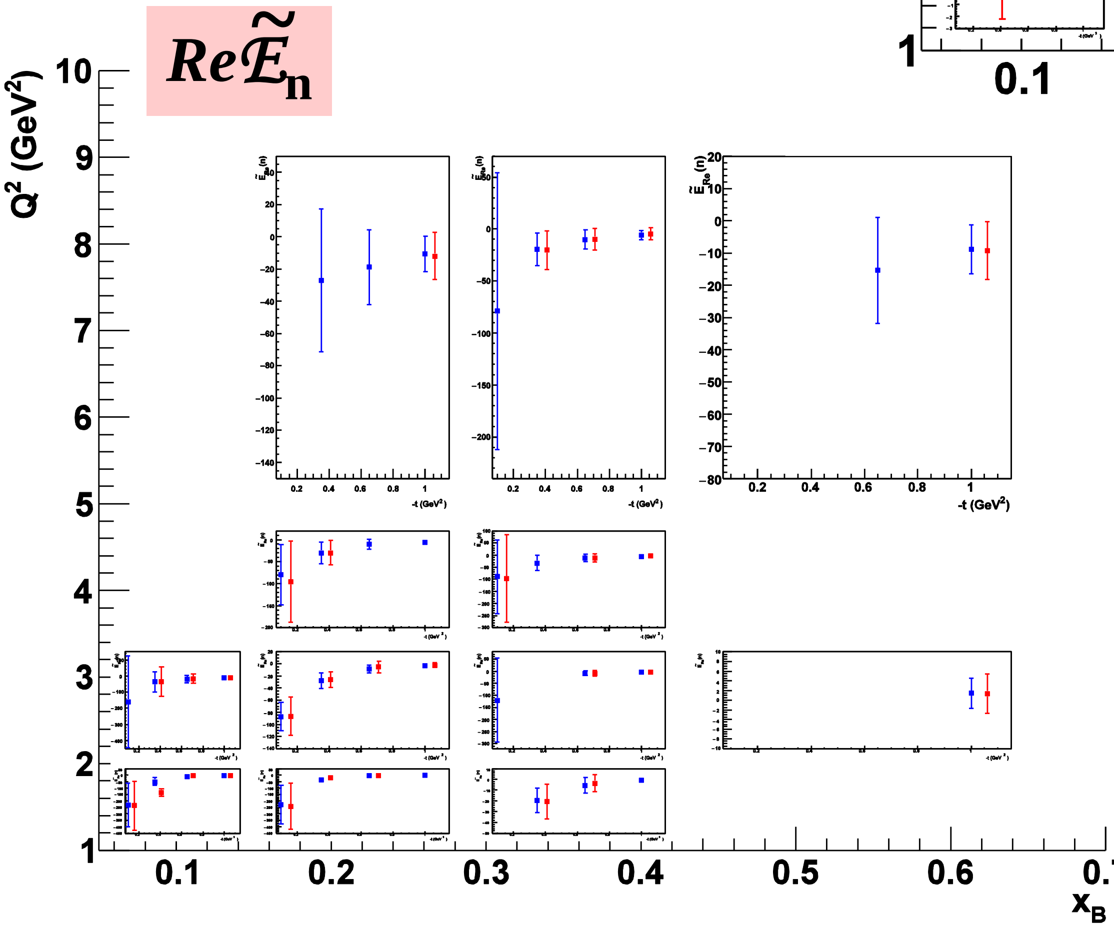


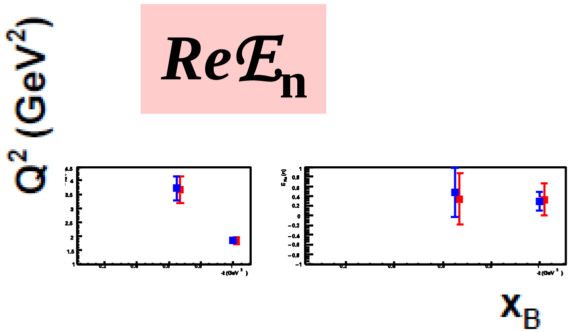


Combined analysis of C12-15-004 and E12-11-003

110 days
50 days





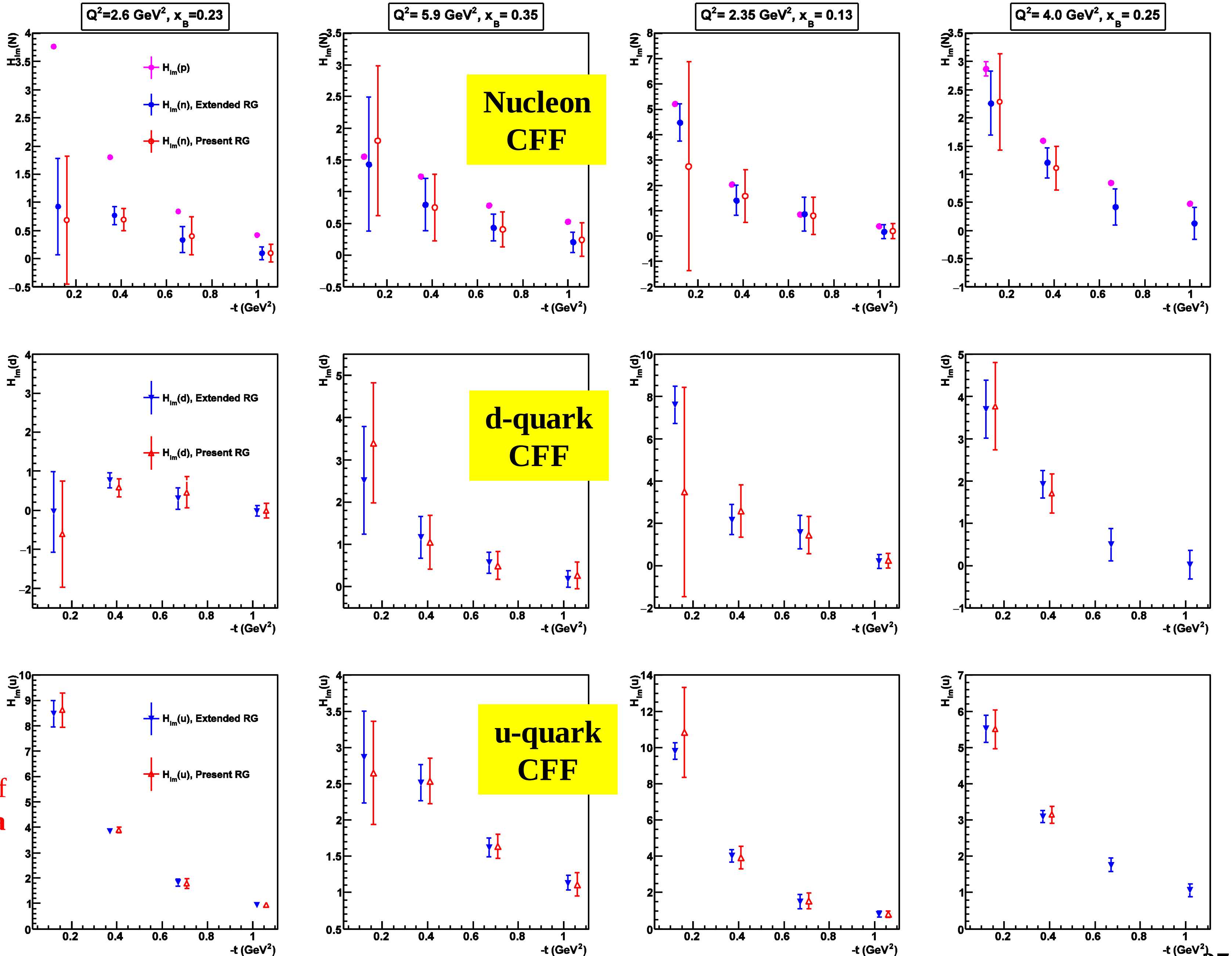


Projections for flavor separation ($Im\mathcal{H}$)

Fit using all the projected **pDVCS** asymmetries of the CLAS12 program

Fit using the projected **nDVCS** asymmetries of **C12-15-004** and E12-11-003 **(110 days)**

Fit using the projected **nDVCS** asymmetries of **PR12-06-109a** and E12-11-003 **(50 days)**

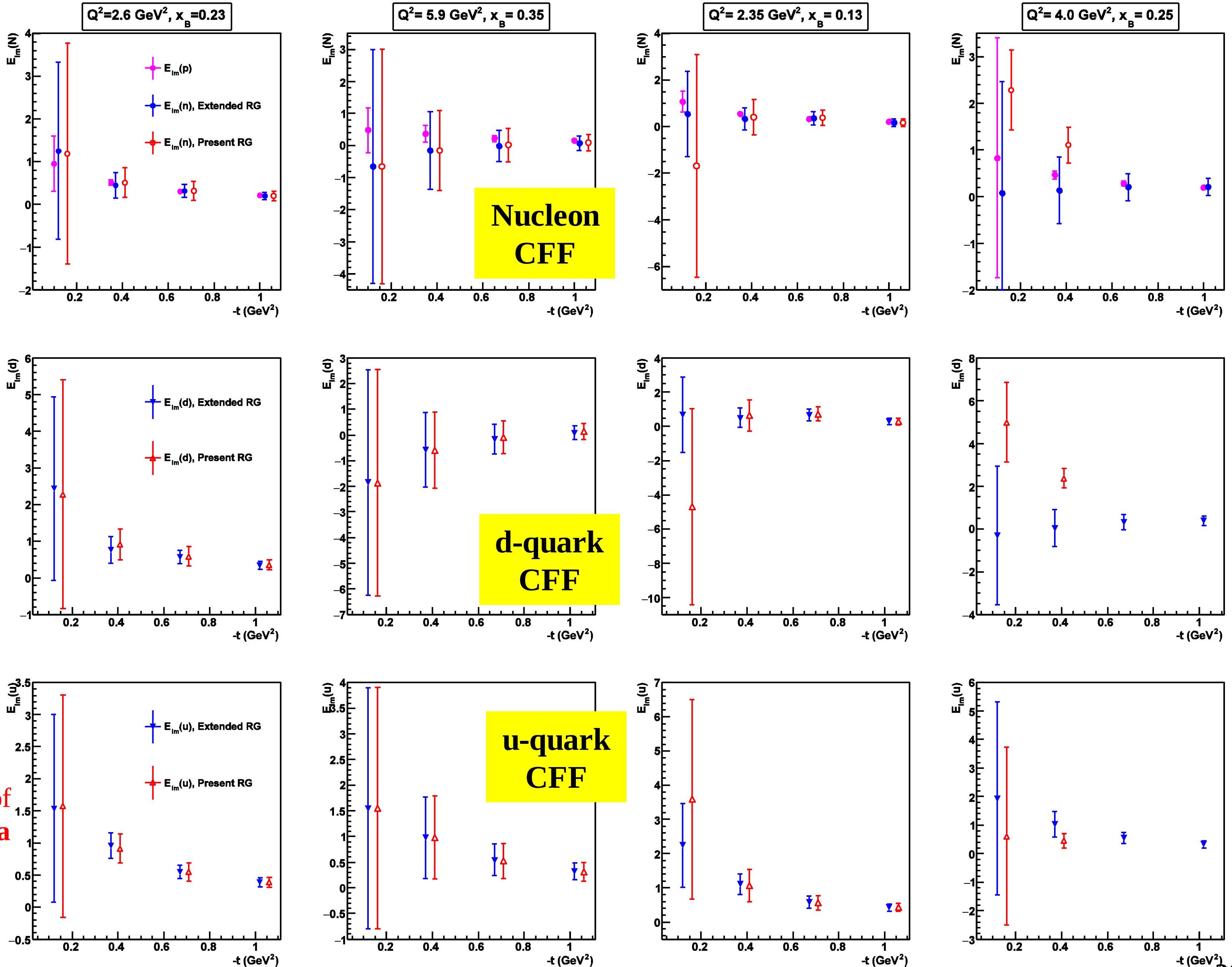


Projections for flavor separation (*ImE*)

Fit using all the projected **pDVCS** asymmetries of the CLAS12 program

Fit using the projected **nDVCS** asymmetries of **C12-15-004** and E12-11-003 **(110 days)**

Fit using the projected **nDVCS** asymmetries of **PR12-06-109a** and E12-11-003 **(50 days)**



Final-state interactions for nDVCS on the deuteron

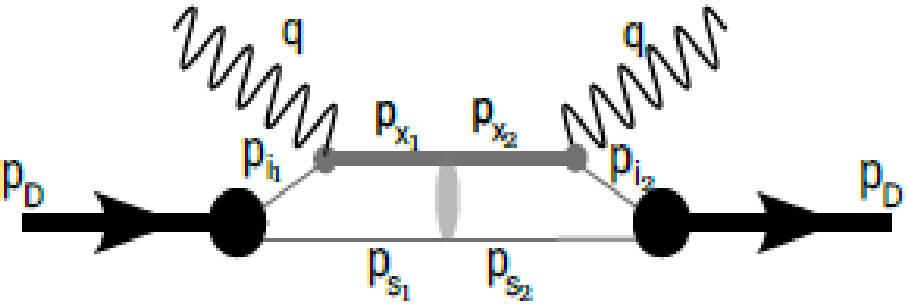
Detected in forward CLAS12

Not detected

ed→e'**n**γ(p)

Detected in CND, EC

Detected in EC, FT



FSI effects without charge exchange (**pn→pn**) will be estimated empirically measuring **enγ and epγ on deuteron** in this same experiment and comparing with **proton data**

The effect of **charge-exchange FSI** can be **calculated** and corrected for.

M. Sargsian estimated this effect for the extraction of the **neutron form factor in polarized electron scattering from polarized He^3** (**S.Riordan *et al.*, PRL 105, 262302 (2010), W. Cosyn *et al.*, PRC89, 014612 (2014)):**

- **pn→ np** interaction is due to **pion exchange** → amplitude has a **1/√s suppression factor** as compared to non-charge exchange pn→pn scattering (**W. R. Gibbs and B. Loiseau, PRC 50, 2742 (1994)**)
- 10% at the **cross-section level**
- **negligible impact on asymmetry, as pion-exchange is a spin-independent effect**
- pn→np has a **larger slope factor** in the amplitude → it decreases faster with t than pn→np

A measurement of **fully exclusive nDVCS**, using **BoNus** for the spectator proton and the **CND** for the active neutron could also be done, even if it will have limited statistics: experimental check of FSI calculations, possibility to select kinematics minimizing FSI effects

Semi-Inclusive Deep Inelastic Scattering (SIDIS) on deuterium: The case for doubling the statistics

Silvia Pisano, INFN Frascati, contact person

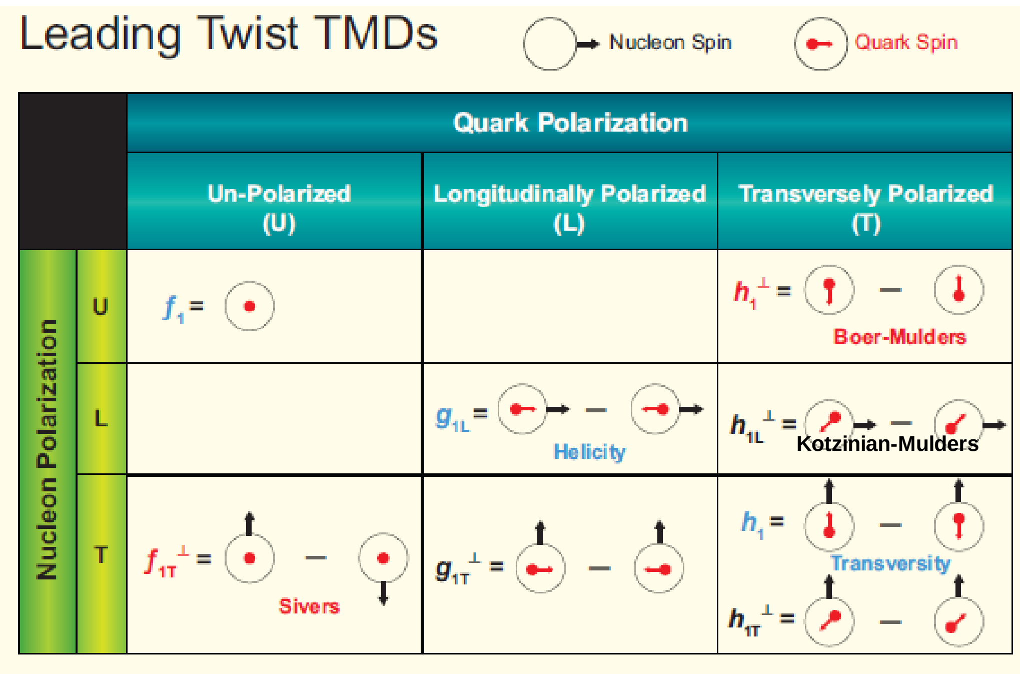
Transverse Momentum Dependent PDFs&FFs

8 leading-twist TMDs

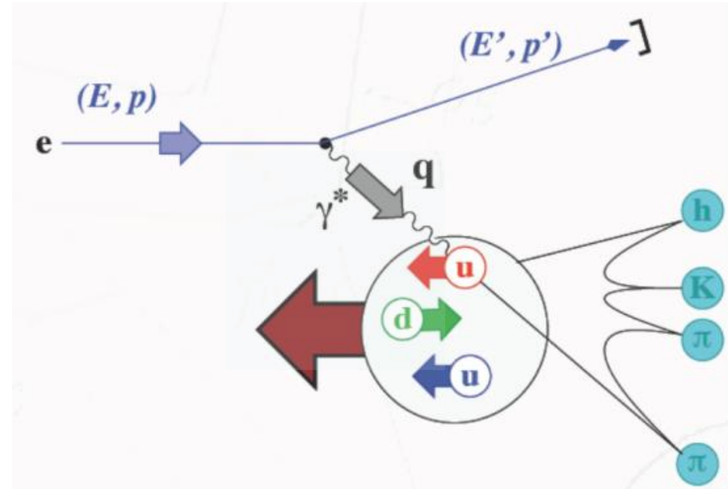
- They depend on the parton **longitudinal momentum fraction** ***x*** and on its **transverse momentum** $\boldsymbol{k_T}$

→ **3D dynamics of the nucleon**

- Diagonal elements: **PDFs**
- **Off-diagonal elements require OAM**



Approved **CLAS12 SIDIS experiments**, with 50 days on longitudinally polarized ND_3:
E12-07-107 (**pion SIDIS**) , E12-09-009 (**kaon SIDIS**)



Fragmentation Functions

Hadronization of the active quark→ transition from **partonic to hadronic** degrees of freedom

q/H	U	L	T
U	$\boldsymbol{D_1}$		$H_1^\perp$
L		$\boldsymbol{G_{1L}}$	$H_{1L}^\perp$
T	$H_1^\perp$	G_{1T}	$\boldsymbol{H_1}$, $H_{1T}^\perp$

Single-hadron SIDIS cross-section

Depending on the polarizations of beam and target, different TMD and FF can be accessed:

$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

Unpolarized target

$$\Big\{ \left[F_{\mathrm{UU,T}} + \epsilon F_{\mathrm{UU,L}} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi)F_{\mathrm{UU}}^{\cos(\phi)} + \epsilon\cos(2\phi)F_{\mathrm{UU}}^{\cos(2\phi)}\right]$$

$$+ \lambda_l \left[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi)F_{\mathrm{LU}}^{\sin(\phi)}\right]$$

Longitudinally pol. target

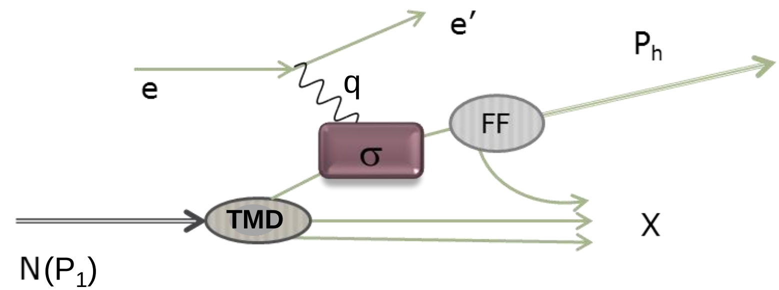
$$+ S_L \left[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi)F_{\mathrm{UL}}^{\sin(\phi)} + \epsilon\sin(2\phi)F_{\mathrm{UL}}^{\sin(2\phi)}\right]$$

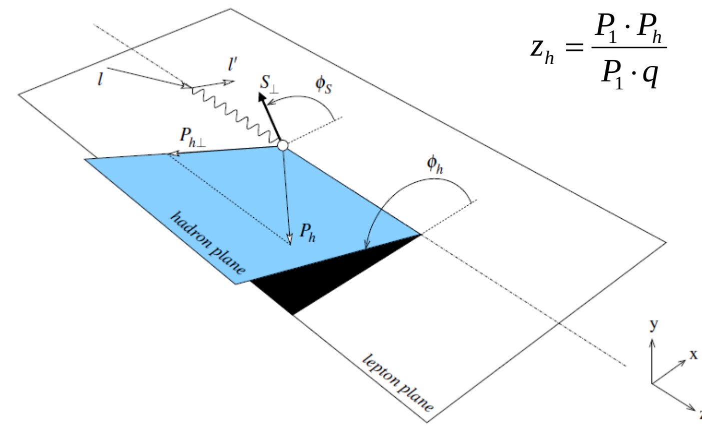
$$+ S_L\,\lambda_l \left[\sqrt{1-\epsilon^2}F_{\mathrm{LL}} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi)F_{\mathrm{LL}}^{\cos(\phi)}\right]$$

Tranversely pol. target

$$+ S_T \Big[\sin(\phi-\phi_S)\left(F_{\mathrm{UT,T}}^{\sin(\phi-\phi_S)} + \epsilon F_{\mathrm{UT,L}}^{\sin(\phi-\phi_S)}\right) + \epsilon\sin(\phi+\phi_S)F_{\mathrm{UT}}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{\mathrm{UT}}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{\mathrm{UT}}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S)F_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T\,\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{\mathrm{LT}}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F_{\mathrm{LT}}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{\mathrm{LT}}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$





$$z_h = \frac{P_1 \cdot P_h}{P_1 \cdot q}$$

$$F_{ij,k} \propto TMD(x, k_T) \otimes FF(z_h, p_\perp)$$

Depending on the produced hadron and on the **target type**, different **flavor combinations** of TMDs and FFs can be singled out

SIDIS on polarized ND_3: single target spin asymmetry

N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

h.t. $\qquad h_{1L}^\perp \otimes H_1^\perp$

$$\frac{d\sigma}{dx dy d\phi_S d\phi_h dP_{h\perp}^2} \propto S_L \left[\sqrt{2\epsilon(1+\epsilon)} sin\phi_h F_{UL}^{sin\phi_h} + \epsilon sin(2\phi_h) F_{UL}^{sin(2\phi_h)} \right]$$
$$+ S_L \lambda_e \left[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)} cos(\phi_h) F_{LL}^{cos(\phi_h)} \right]$$

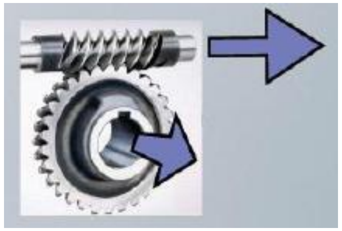
$g_{1L} \otimes D_1 \qquad$ h.t.

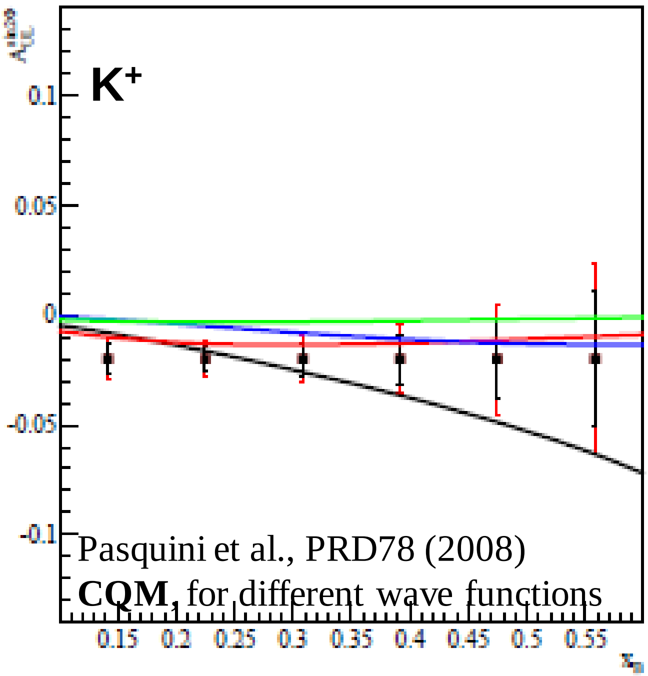
A_{UL}: sin2ϕ is the only **twist-2** term
- Kotzinian-Mulders function (worm gear)

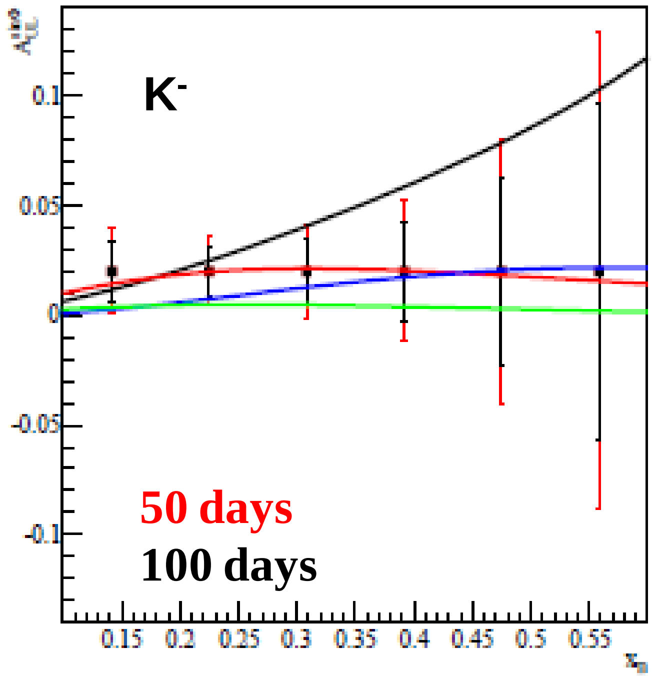
→ transversely polarized quark in a longitudinally polarized proton

→ quark spin-orbit correlations

- provides independent information on **Collins function $H_1^\perp$**





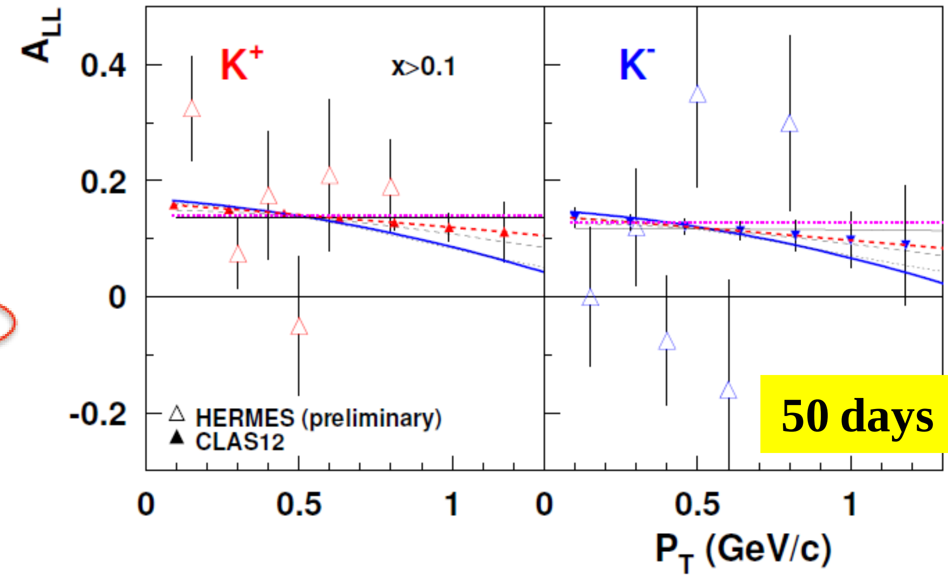


Doubling the statistics helps at high x_B, where models differ the most, and it is crucial for the K^- channel, which has lower statistics

SIDIS on polarized ND_3: double spin asymmetry

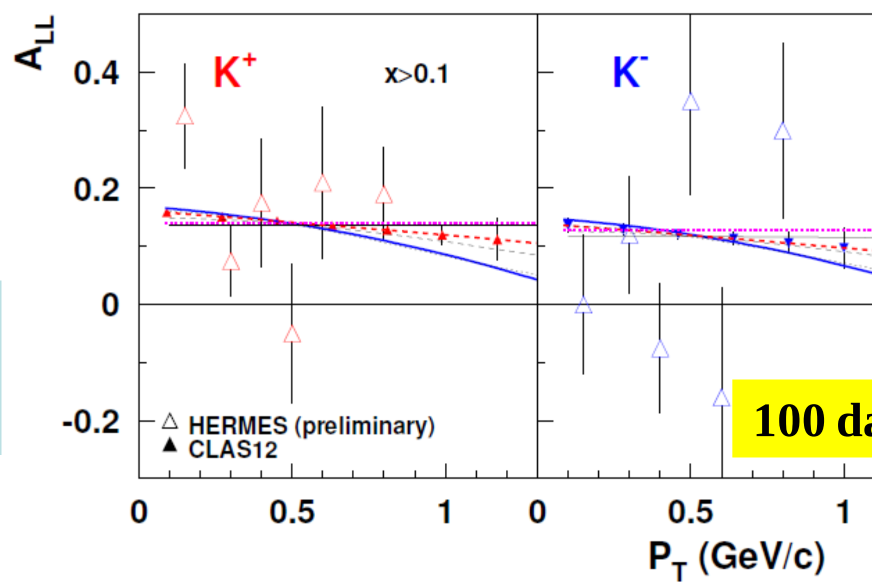
N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

$$\frac{d\sigma}{dx\,dy\,d\phi_S\,d\phi_h\,dP_{h\perp}^2} \propto S_L\left[\overbrace{\sqrt{2\epsilon(1+\epsilon)}sin\phi_h F_{UL}^{sin\phi_h}}^{\text{h.t.}} + \overbrace{\epsilon sin(2\phi_h) F_{UL}^{sin(2\phi_h)}}^{h_{1L}^\perp \otimes H_1^\perp}\right]$$
$$+S_L\lambda_e\left[\underbrace{\sqrt{1-\epsilon^2}F_{LL}}_{g_{1L}\otimes D_1} + \underbrace{\sqrt{2\epsilon(1-\epsilon)}cos(\phi_h)F_{LL}^{cos(\phi_h)}}_{\text{h.t.}}\right]$$



Models: Anselmino et al., PRD74 (2006)
Different k_T widths for helicity distributions

- p_T dependence of **constant term of A_{LL}** (LT term): access to $\mathbf{g_{1L}}$ → **helicity dependence of k_T distributions of quarks**
- p & d data for p_T-dependent flavor decomposition



Doubling the statistics helps at high p_T, where models differ the most, and it is crucial for the K^- channel, which has lower statistics

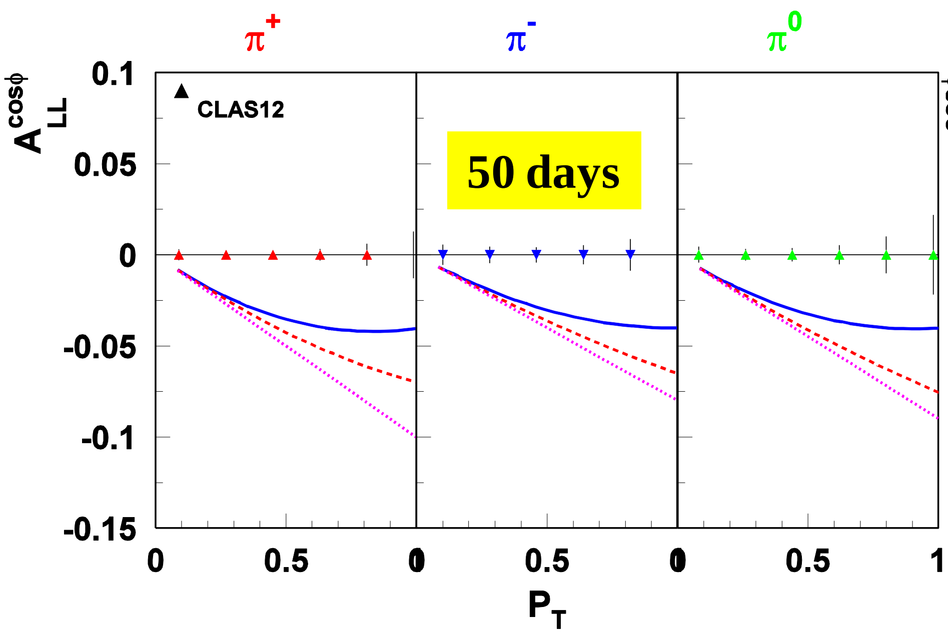
SIDIS on polarized ND_3: double spin asymmetry

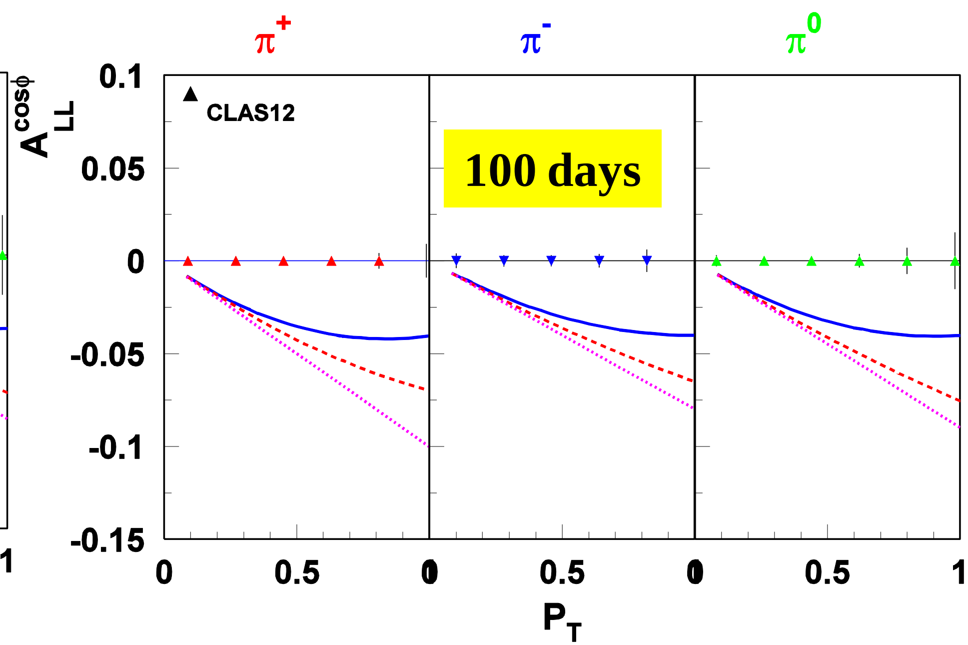
$$\frac{d\sigma}{dx\,dy\,d\phi_S\,d\phi_h\,dP_{h\perp}^2} \propto S_L\left[\overbrace{\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h}}^{\text{h.t.}} + \overbrace{\epsilon \sin(2\phi_h) F_{UL}^{\sin(2\phi_h)}}^{h_{1L}^{\perp}\otimes H_1^{\perp}}\right]$$
$$+ S_L\lambda_e\left[\underbrace{\sqrt{1-\epsilon^2}F_{LL}}_{g_{1L}\otimes D_1} + \underbrace{\sqrt{2\epsilon(1-\epsilon)}\cos(\phi_h)F_{LL}^{\cos(\phi_h)}}_{\text{h.t.}}\right]$$

cosϕ term of A_{LL} is linked to higher-twist TMDs

Higher-twist TMDs

N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h,e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	f_T, $f_T^{\perp}$	g_T, $g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$





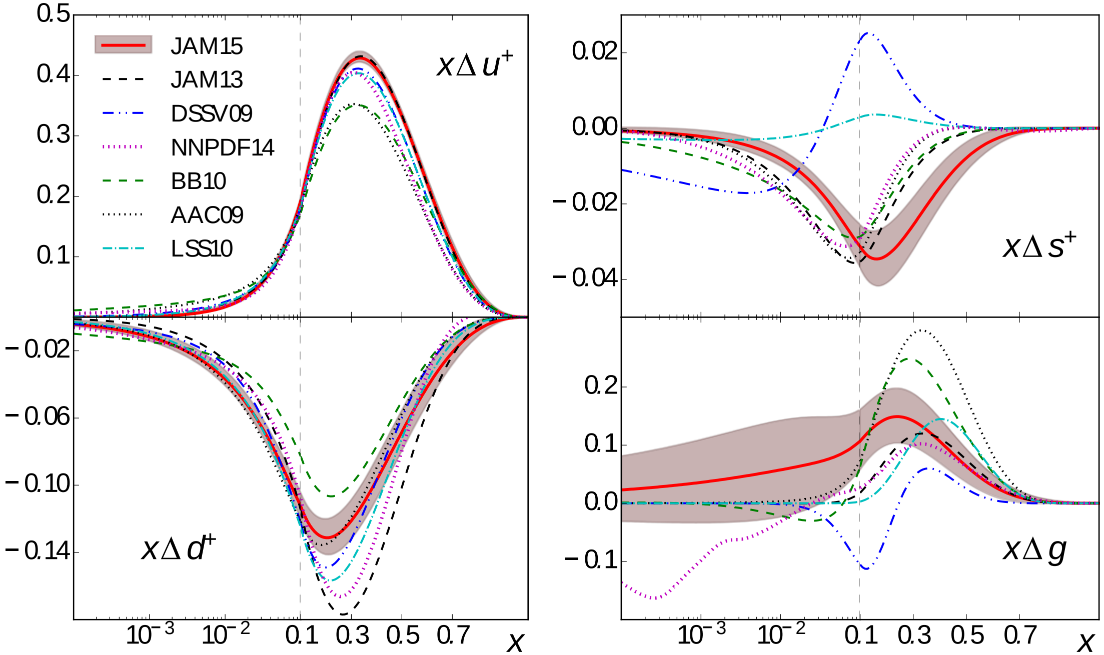
Models: Anselmino et al., PRD74 (2006)
Different k_T widths for helicity distributions

Also for pions, doubling the statistics helps at high p_T, where models differ the most

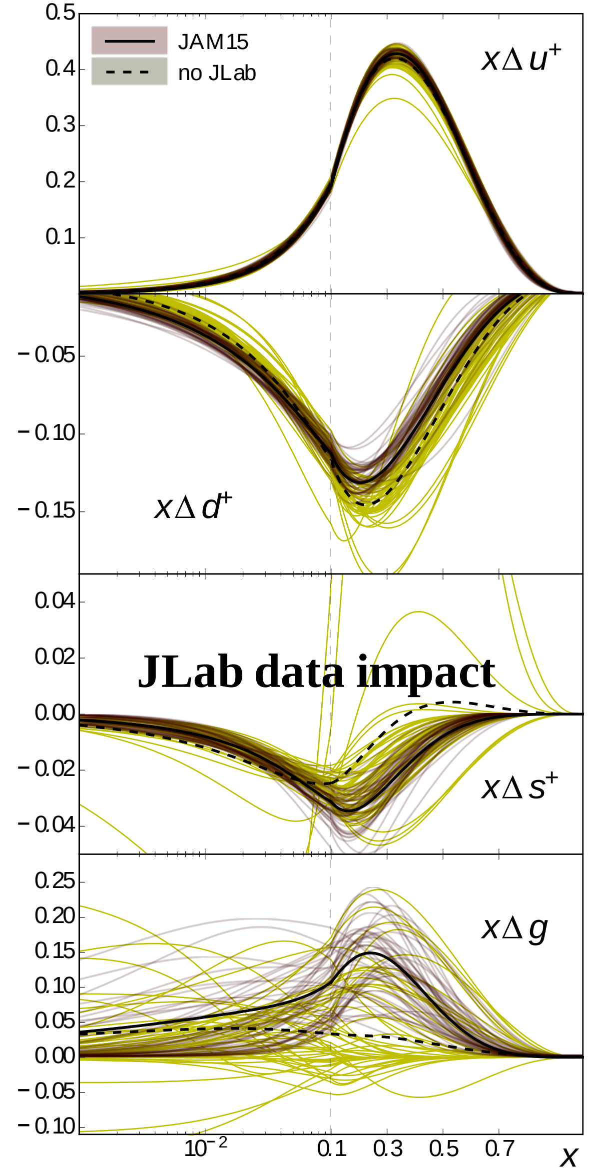
Deep Inclusive Scattering (DIS) on Deuterium: The case for doubling the statistics

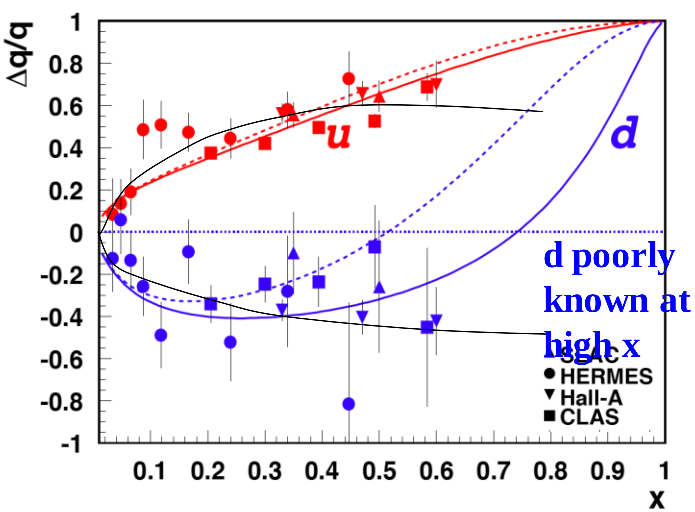
Sebastian Kuhn, ODU, contact person

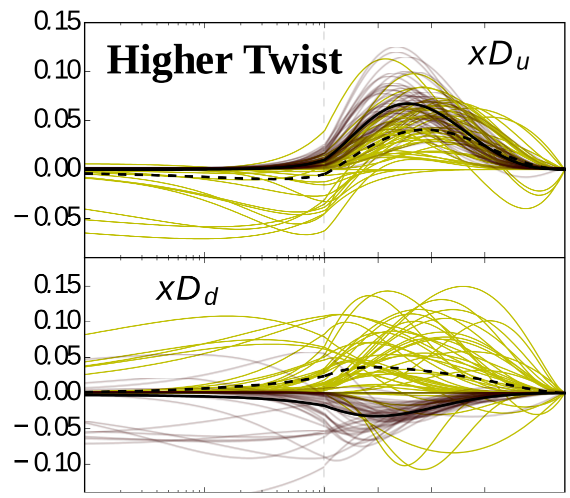
Present Status: What do we know about polarized PDFs?



JAM
Fit

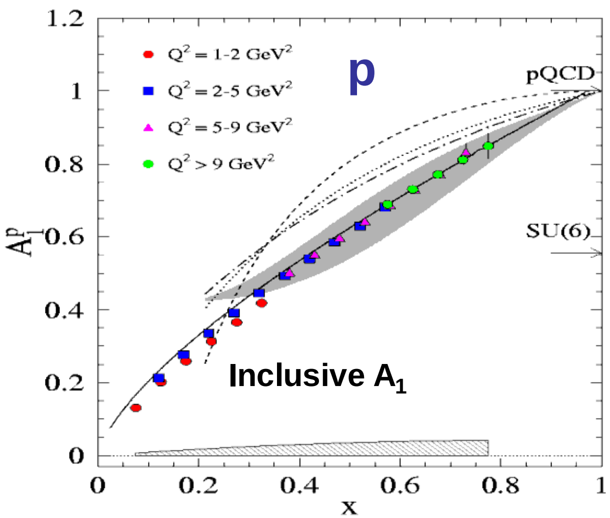


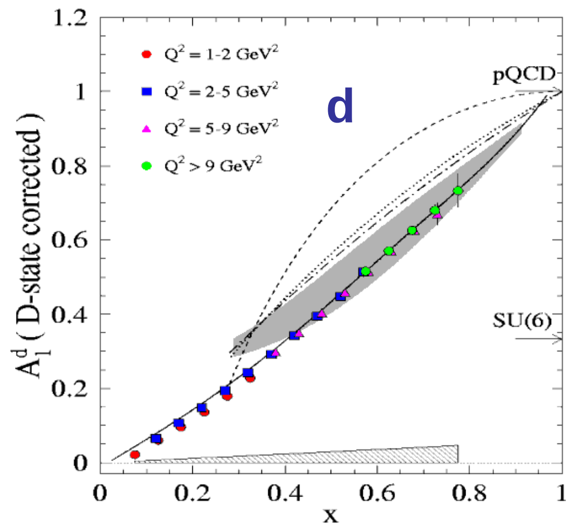


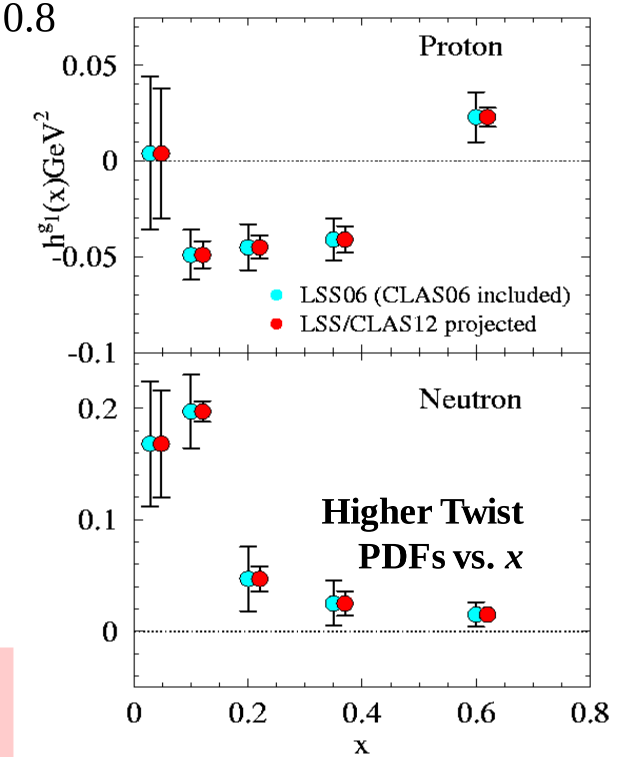


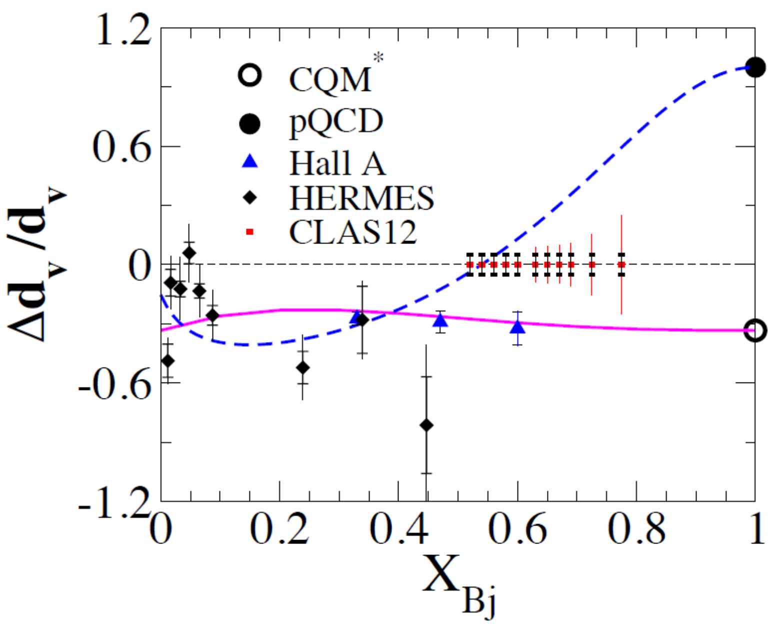
CLAS12 Approved (RG C: 30 days p, 50 days d)

- Goal of E12-06-109: **x-dependence of each PDF** (q or g) for 0.06< x< 0.8
- Measurement of **DIS and SIDIS** (no p_T dependence)



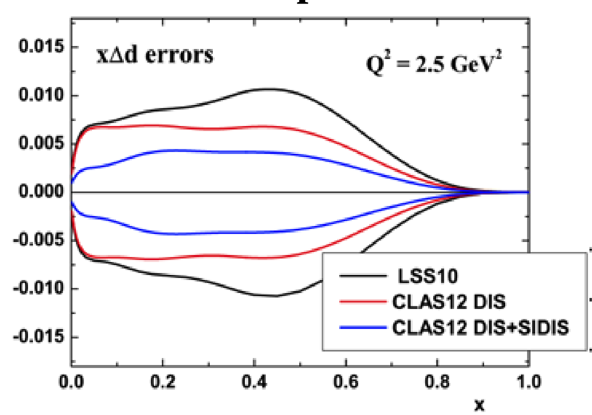


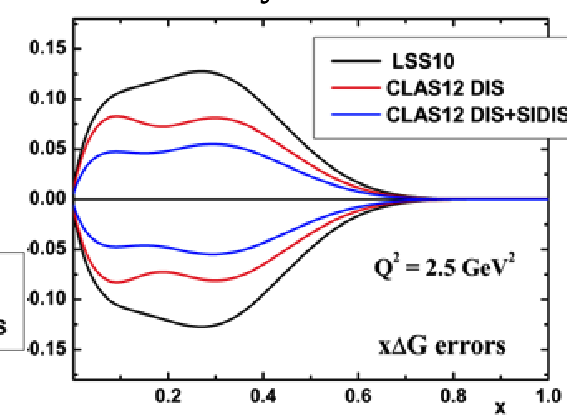




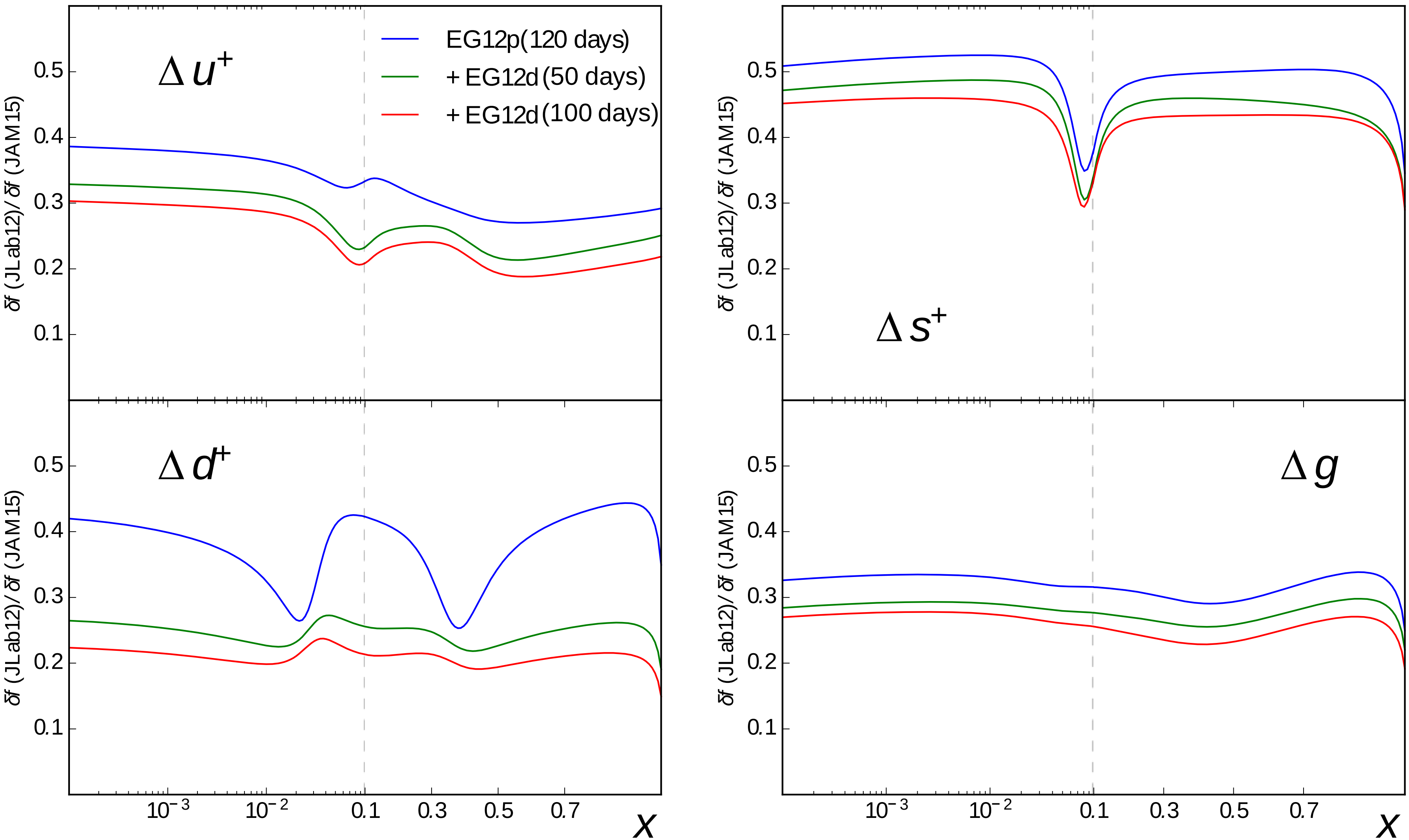
Additional information on Δq from SIDIS

Improved PDFs from NLO analyses



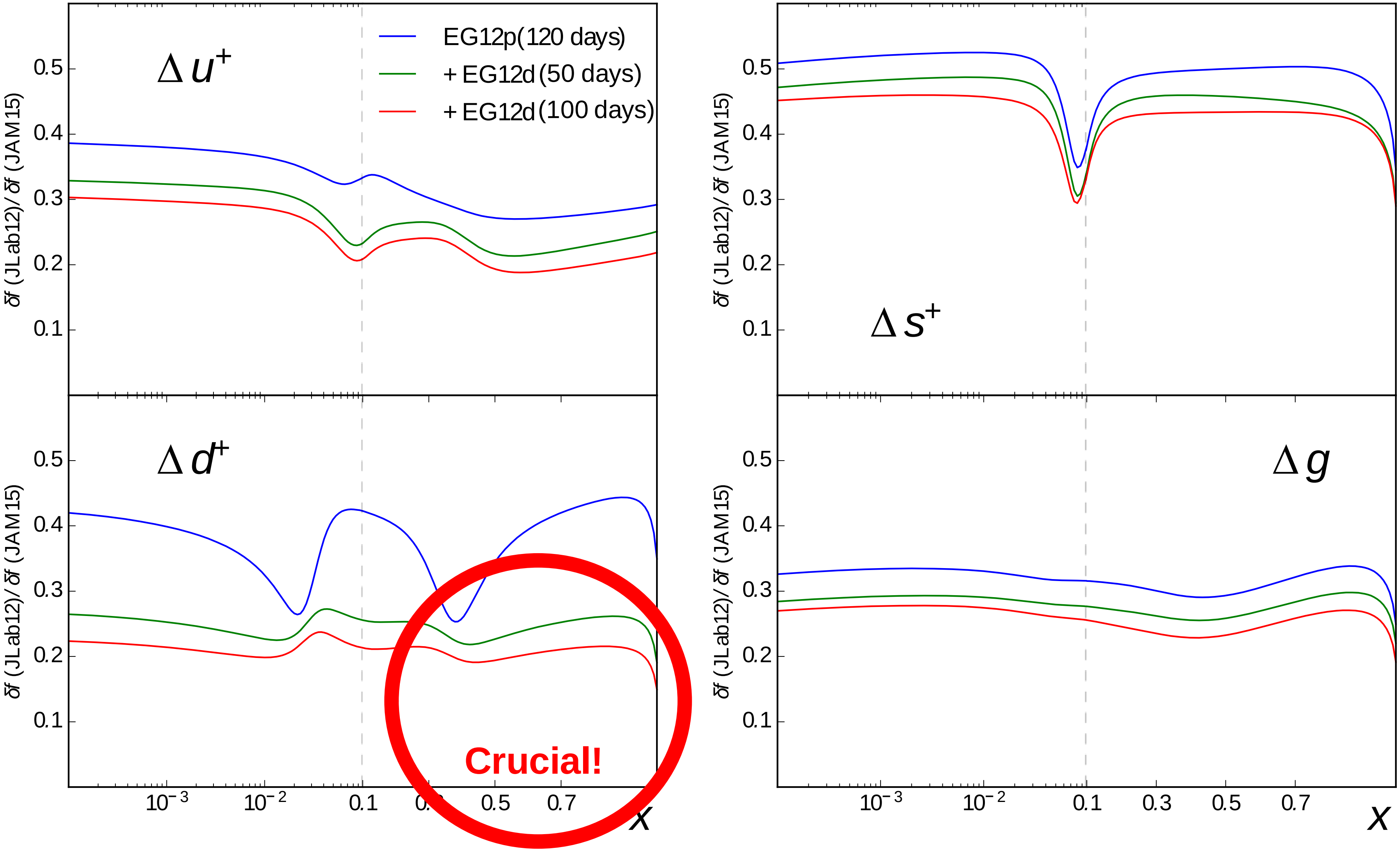


What will 50 more days on D bring us?



Relative uncertainties on polarized PDFs with various data sets (Courtesy N. Sato)

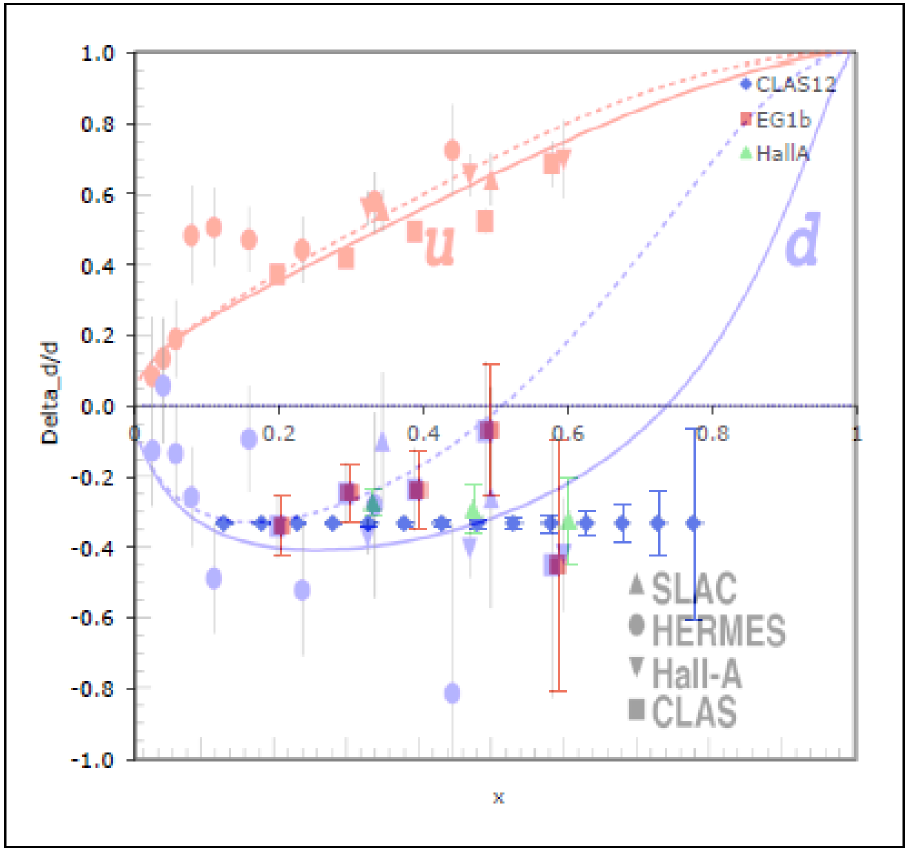
What will 50 more days on D bring us?

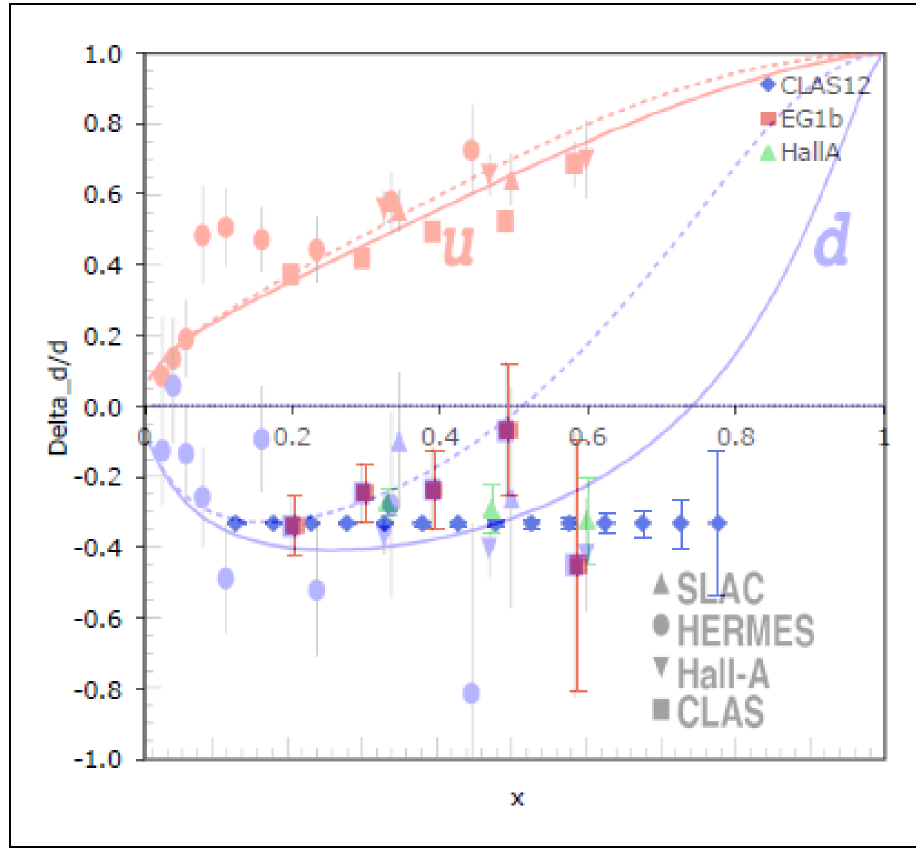


Relative uncertainties on polarized PDFs with various data sets (Courtesy N. Sato)

What will 50 more days on D bring us?

$\Delta d/d$ for $x \to 1$





Curves: pQCD without and with OAM effects (Brodsky et al. Nucl. Phys. B441 (1995) – Avakian et al. PRL99 (2007))

Projections: hyperfine perturbed model (N. Isgur et al., PRD59 (1999)

As approved

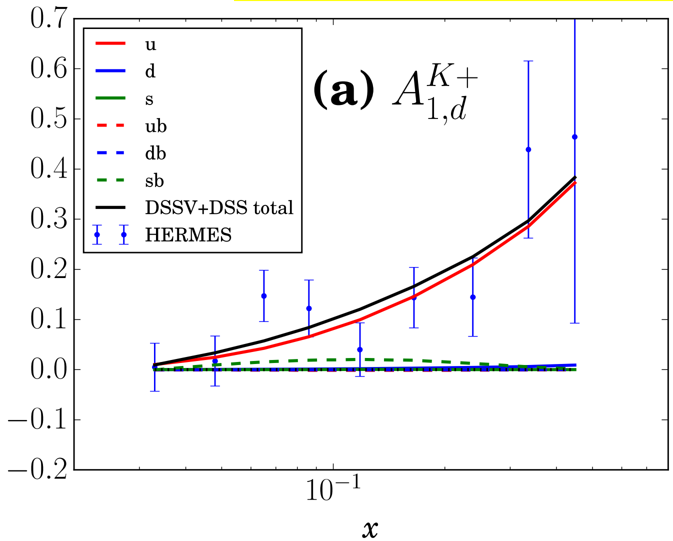
With "unlucky" statistical fluctuations, cannot exclude $\Delta d/d > 0$ at highest x (χ^2/dof=2.5, p=8%)

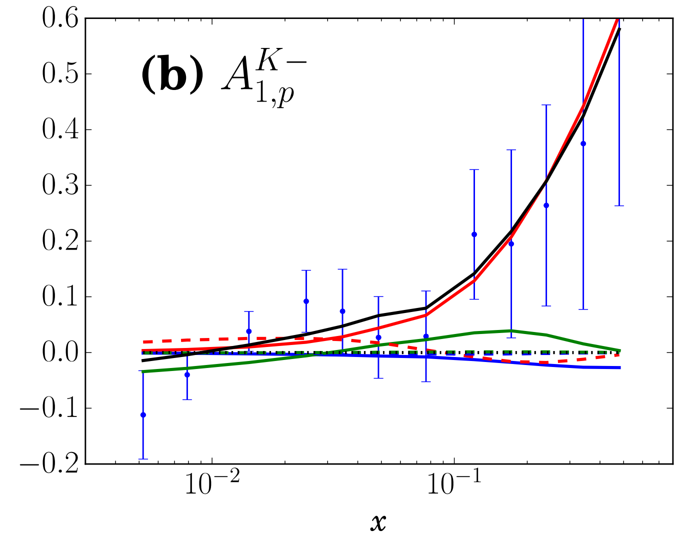
With doubled beam time

Even with "unlucky" statistical fluctuations, can exclude $\Delta d/d > 0$ at highest x (χ^2/dof=6.6, p=0.4%)

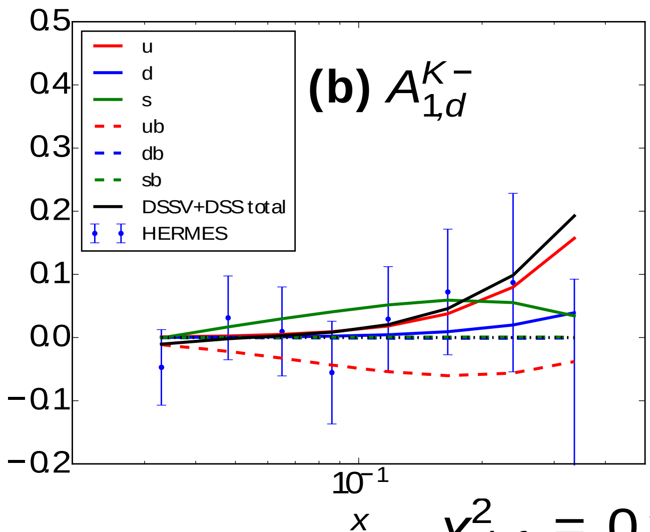
What will 50 more days on D bring us?

A_1 from SIDIS (kaon channels) – HERMES data



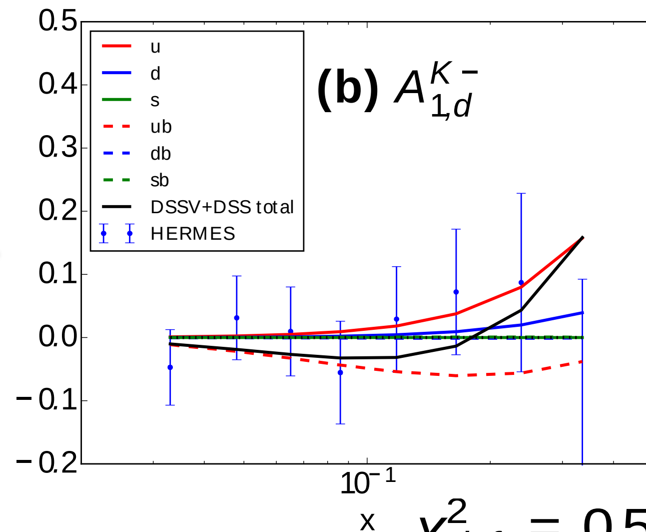


Only K^- production on D is uniquely sensitive to Δs (Δu and Δd largely cancel)



$\chi^2_{dof} = 0.38$

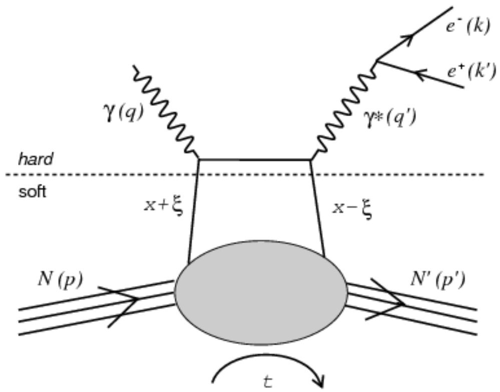
$\Delta s \rightarrow 0$

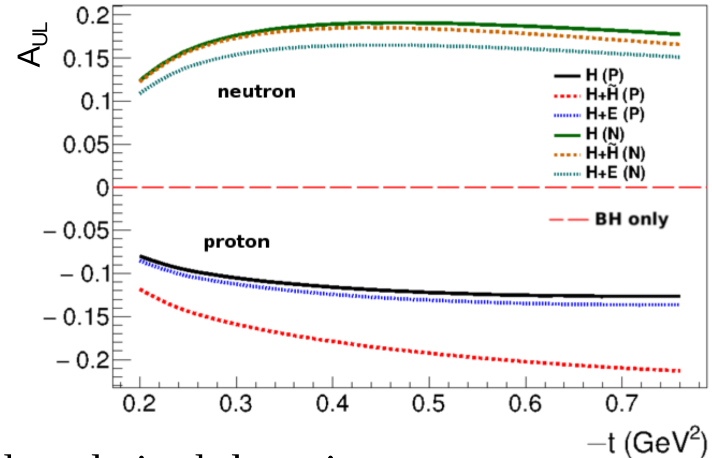


$\chi^2_{dof} = 0.51$

Additional topics

- First time measurement of **Timelike Compton scattering**, $\gamma n \to n e^+ e^-$, on longitudinally polarized neutron:
  - ✓ universality of GPDs
  - ✓ A_{UL} and A_{LL} have sensitivity to H_n and E_n
  - ✓ A_{UL} expected to be fairly big (0.15)
  - ✓ nTCS cross section only a factor of 2 less than the pTCS one
  - ✓ 120 days approved for pTCS with unpolarized target





- First-time measurement of **di-hadron SIDIS** on longitudinally polarized deuterium:
  - ✓ cleanest access to chiral-odd PDFs
  - ✓ promising preliminary results for A_{UL} on NH_3 with CLAS at 6 GeV
  - ✓ ND_3 needed for flavor dependence of the various PDFs and FFs, high stat for mapping

- **DVMP** on longitudinally polarized neutrons:
  - ✓ transversity neutron-GPDs in pseudoscalar channels (π^0, η, π^-)
  - ✓ link to transversity GPDs shown by 6-GeV CLAS results on π^0, η
  - ✓ A_{UL} proportional to LT interference term of the cross section $\to H_T$, E_T, $\bar{E}_T$

Conclusions/summary: CLAS12 Run group M

• The multi-dimensional structure of the nucleon is one of the primary goals of the 12-GeV upgrade of JLab, and it is the core of the CLAS12 program

• Parton distributions depend on quark flavors, measurements on proton and deuterium are necessary

• Current approved beam time on ND_3 for CLAS12 is ~40% of the NH_3 one

• We request 73 PAC days of new beam time (11 GeV, 85% polarization):
  - ➢ 60 of production running on ND_3, 13 of ancillary measurements/configuration change

• Setup: CLAS12 + ND_3 polarized target, CND, RICH, FT (for 10 days at 5 nA)

• The inclusion of the FT completes the ϕ coverage for nDVCS, improvement for CFF fits beyond statistical effects

• This will bring the total running time on ND_3 for CLAS12 to133 days – same as NH_3

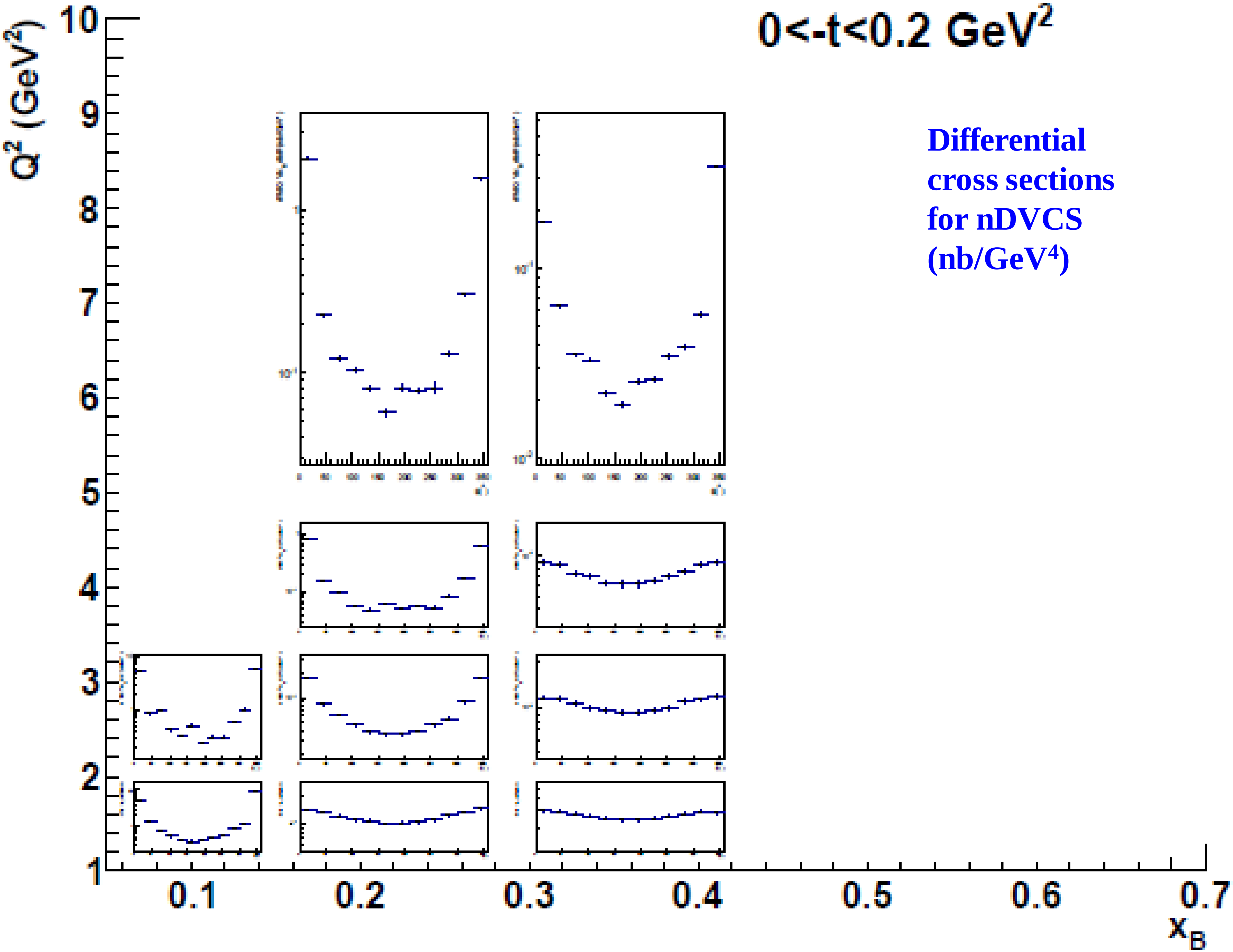
• First time measurement of polarized nDVCS

• Increased statistics for SIDIS, important especially for kaon channels at high x, p_T

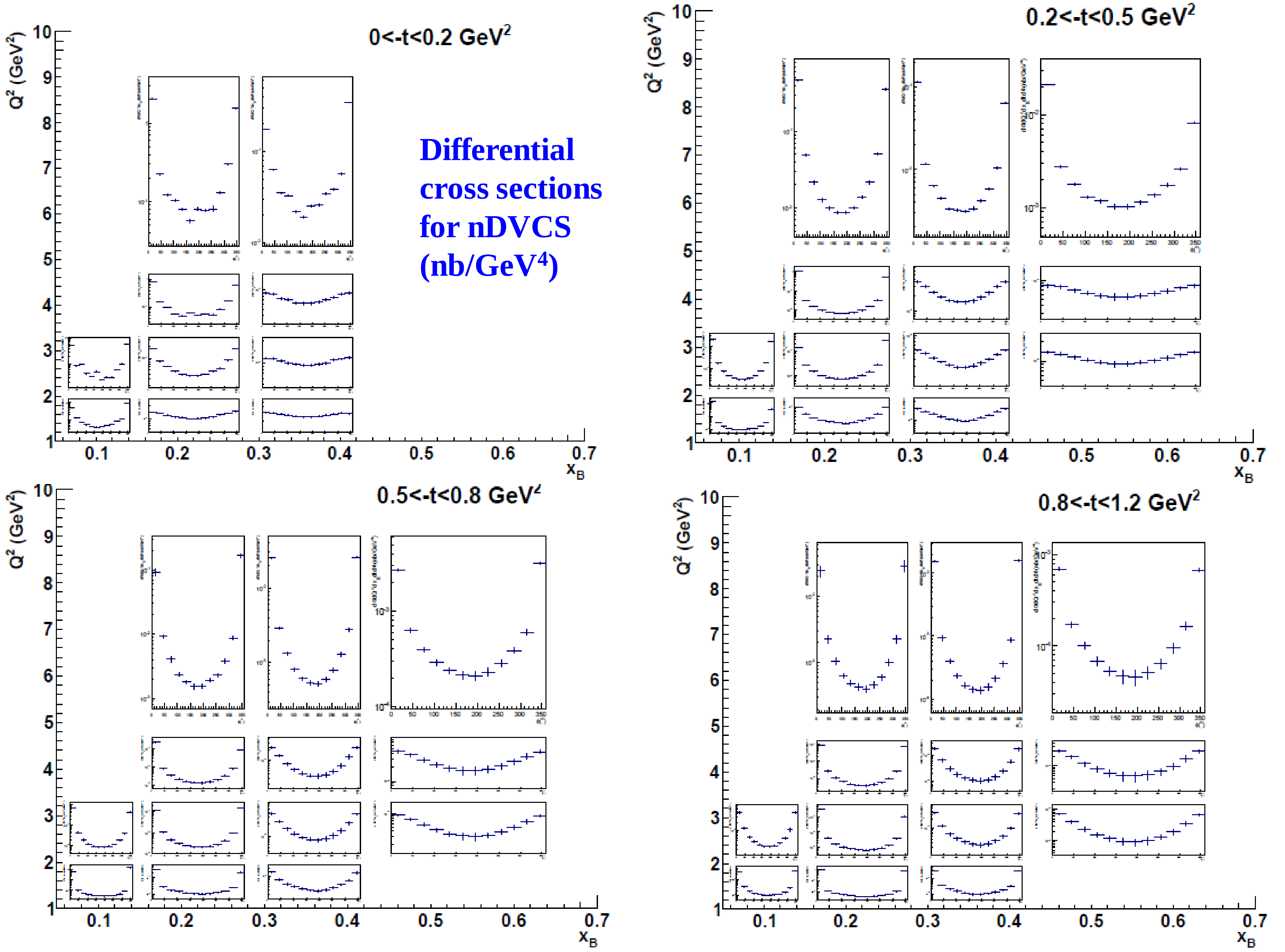
• High precision measurement of collinear structure functions

• Exploratory measurements of DVMP, nTCS, di-hadron SIDIS

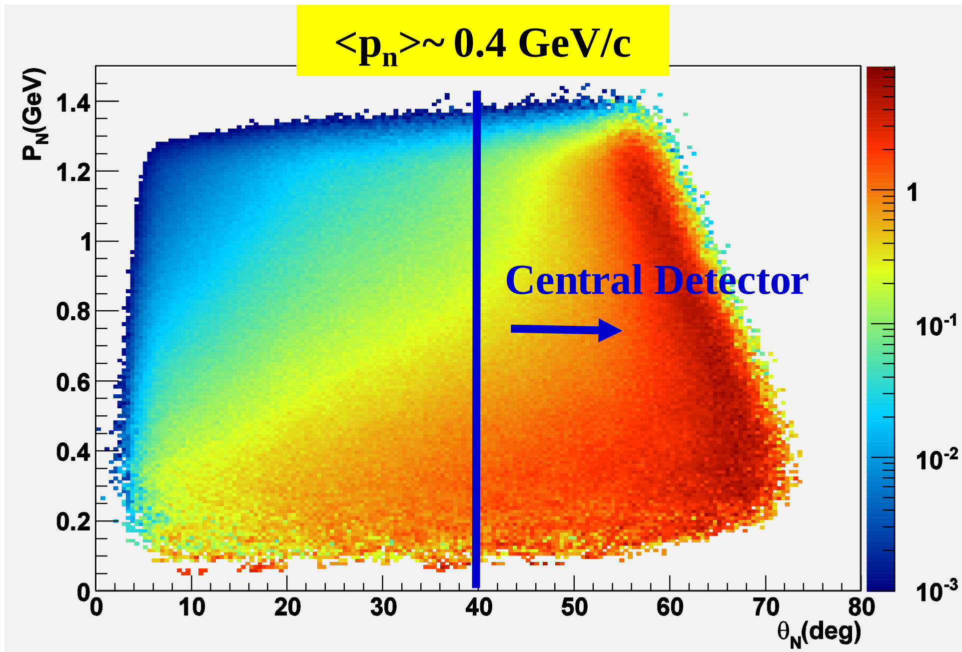
Back-up slides



0<-t<0.2 GeV²
Differential cross sections for nDVCS (nb/GeV⁴)
Q² (GeV²)
10
9
8
7
6
5
4
3
2
1
0.1
0.2
0.3
0.4
0.5
0.6
0.7
x_B


0<-t<0.2 GeV²
0.2<-t<0.5 GeV²
0.5<-t<0.8 GeV²
0.8<-t<1.2 GeV²
Differential cross sections for nDVCS (nb/GeV⁴)
Q² (GeV²)
x_B

CND: requirements



More than **80%** of the neutrons have **θ>40°**
→ **Neutron detector in the CD**

Detected in forward CLAS12

Not detected

$ed \rightarrow e'\mathbf{n}\gamma(p)$

Detected in CND

Detected in EC, FC

$$p^{\mu}_{e} + p^{\mu}_{n} + p^{\mu}_{p} = p^{\mu}_{e'} + p^{\mu}_{n'} + p^{\mu}_{p'} + p^{\mu}_{\gamma}$$

In the hypothesis of **absence of FSI**:

$p^{\mu}_{p} = p^{\mu}_{p'} \rightarrow$ **kinematics are complete**
detecting **e', n (p,θ,ϕ), γ**

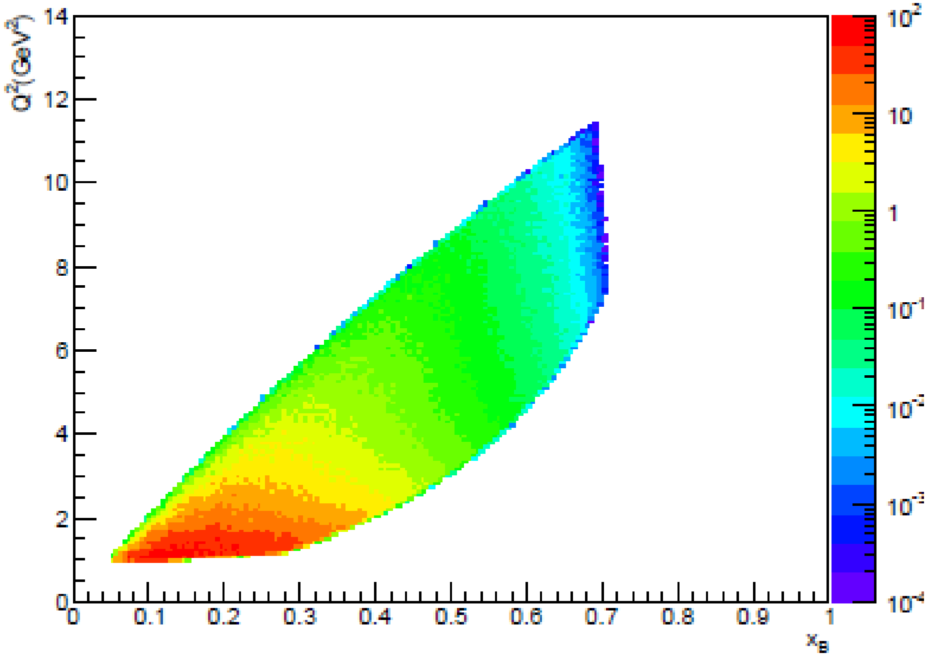
FSI effects will be estimated measuring
enγ, epγ, on deuteron
in this same experiment
and compare with free-proton data

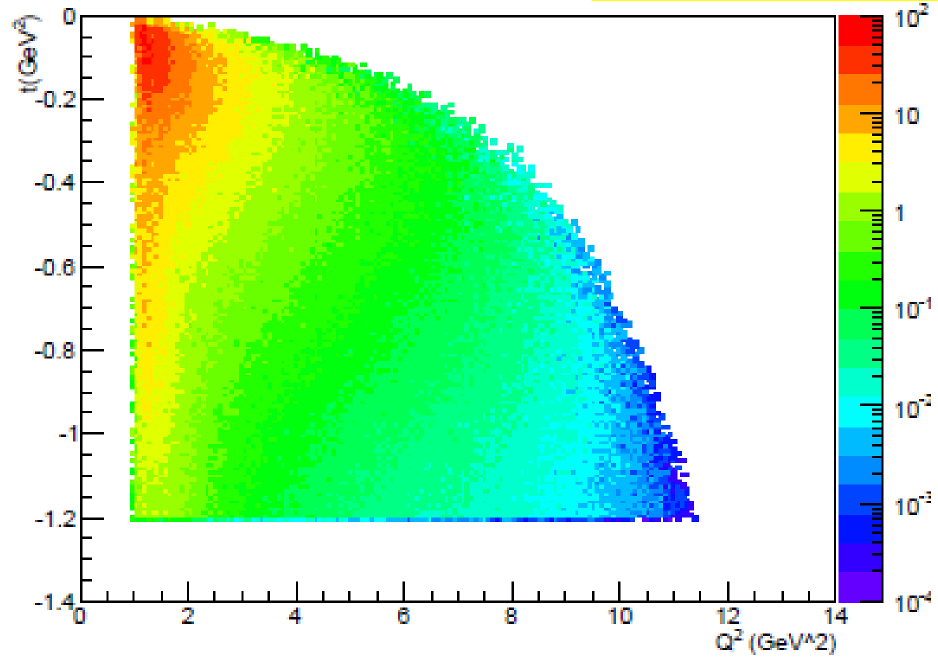
Resolution on **MM(enγ)** studied with nDVCS event generator + electron and photon resolutions obtained from CLAS12 FastMC
+ design specs for Forward Calorimeter
→ **dominated by photon resolutions**

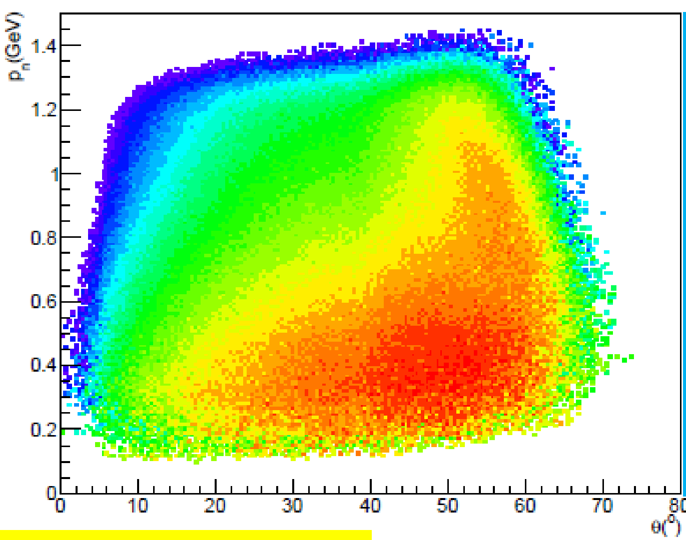
→ The CND must ensure:
- **good neutron identification** for $0.2<p_n\leq 1$ GeV/c
→ **σ(TOF) ~ 150 ps** for n/γ β−separation
- momentum resolution **up to 10%**
- no stringent requirements for angular resolutions

nDVCS@CLAS12: kinematics and acceptances

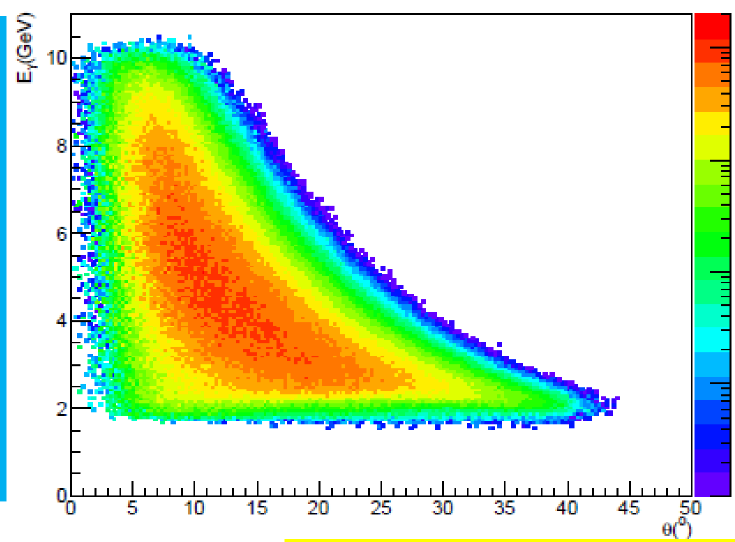
ed→e'nγ(p)







nDVCS+BH event generator on a FREE deuteron target + CLAS12 acceptance from FastMC (eγ) + CND efficiency from GEANT4 simulation

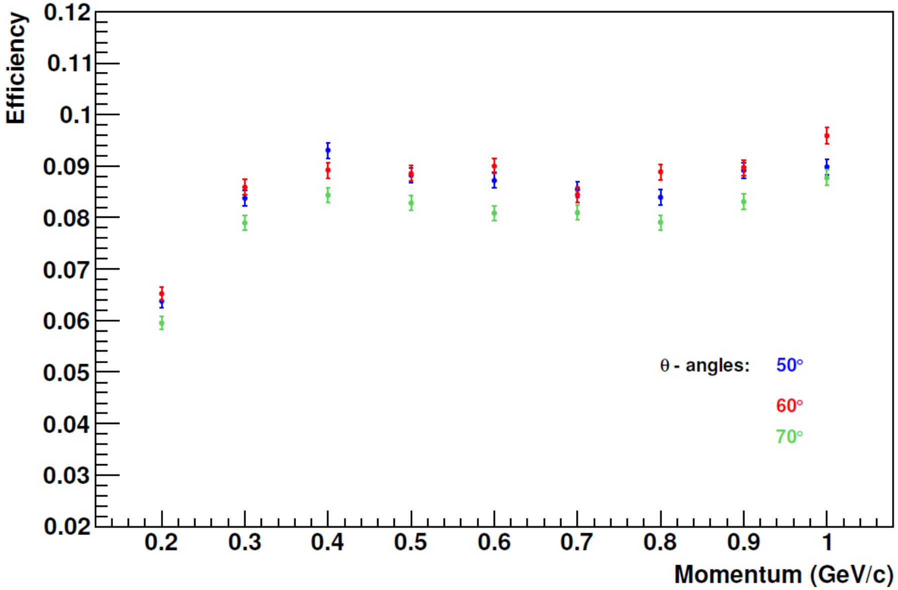


80% of neutrons in CND (θ>40°)

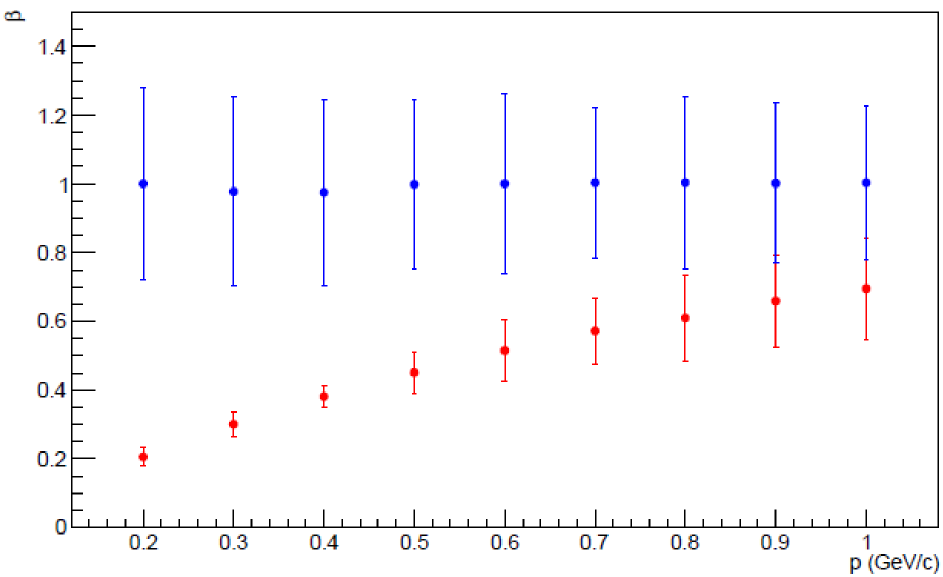
E_e = 11 GeV, Q^2>1 GeV^2, W>2 GeV^2, t<-1.2 GeV^2

nDVCS-BH photons have E>2 GeV

CND: expected performances (Monte Carlo)

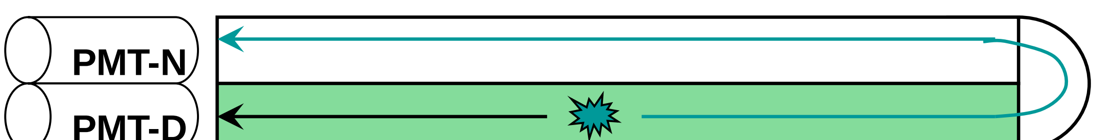


GEANT4 simulations used to evaluate:
- efficiency
- PID (neutron/photon separation)
- momentum and angular resolutions
- definition of reconstruction algorithms
- background studies



Measured σ_t and light loss due to u-turn implemented in the simulation

Efficiency ~ 8-9%
for a threshold of 3 MeV, TOF<8 ns and p_n = 0.2 - 1 GeV/c



Definitions of nDVCS observables

For each 4-D. bin in (Q^2, x_B, $-t$, ϕ)

$$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{D_f\left(P_t^-\left(N^{++} + N^{-+}\right) + P_t^+\left(N^{+-} + N^{--}\right)\right)}$$

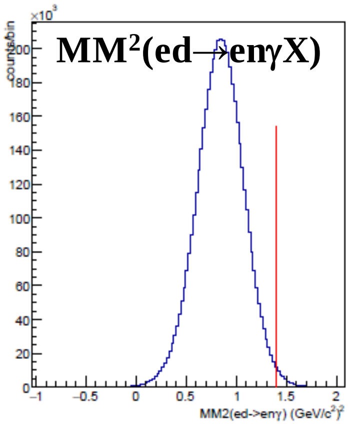
Target-spin asymmetry

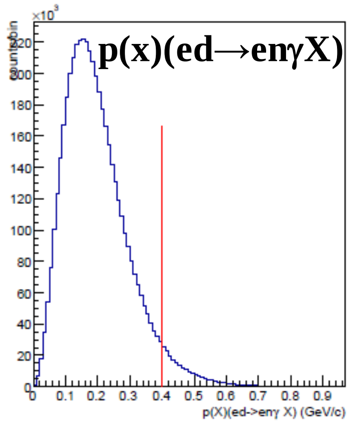
$Im\{\mathcal{H}_n, \mathcal{E}_n\}$

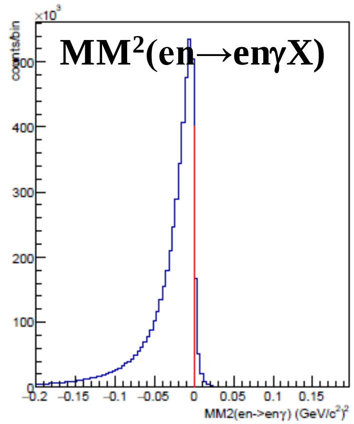
$$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{D_f P_b\left(P_t^-\left(N^{++} + N^{-+}\right) + P_t^+\left(N^{+-} + N^{--}\right)\right)}$$

Double spin asymmetry

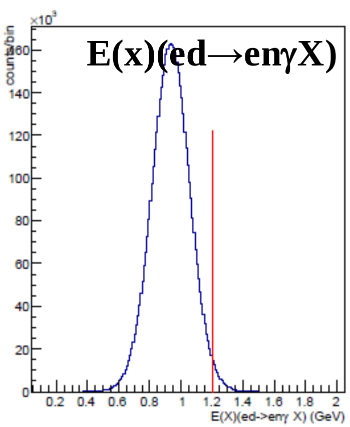
$Re\{\mathcal{H}_n, \mathcal{E}_n\}$

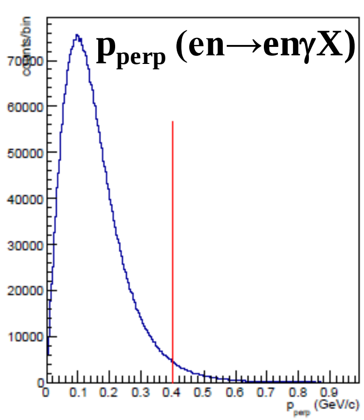






Yields extracted applying exclusivity cuts to enγX events





Exclusivity cuts suppress:

- **nuclear background (^{14}N)**
- **π^0 background**
- **accidentals in the CND**

Dilution factor (needs ^{12}C data)

$$D_f(en\gamma) = 1 - c\,\frac{N_{^{12}C}}{N_{ND_3}} \approx 0.7$$

Definitions of nDVCS observables

For each 4-D. bin in (Q^2, x_B, $-t$, ϕ)

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Target-spin asymmetry

$Im\{\mathcal{H}_n, \mathcal{E}_n\}$

$$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{D_f P_b\left(P_t^-\left(N^{++} + N^{-+}\right) + P_t^+\left(N^{+-} + N^{--}\right)\right)}$$

Double spin asymmetry

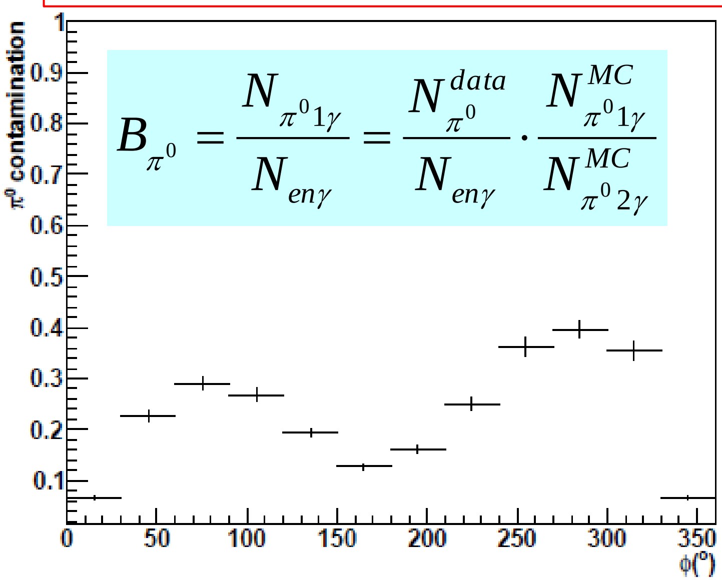
$Re\{\mathcal{H}_n, \mathcal{E}_n\}$

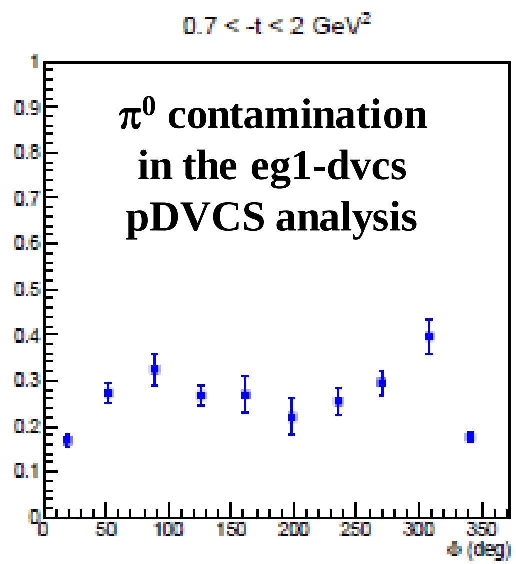
$$N^{bt} = (1 - B_{\pi^0}^{bt}) \cdot \frac{N_{en\gamma}^{bt}}{FC^{bt}}$$

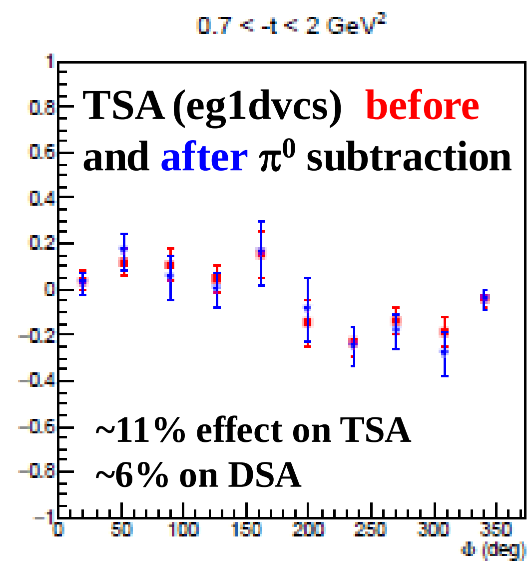
Charge-normalized DVCS/BH yield

b: **beam;** ***t***: **target**
FC^{bt}: **charge, (Faraday Cup)**
B_{π^0}: **π^0 contamination**
P_t: **target pol.;** P_b: **beam pol.**
D_f: **dilution factor**

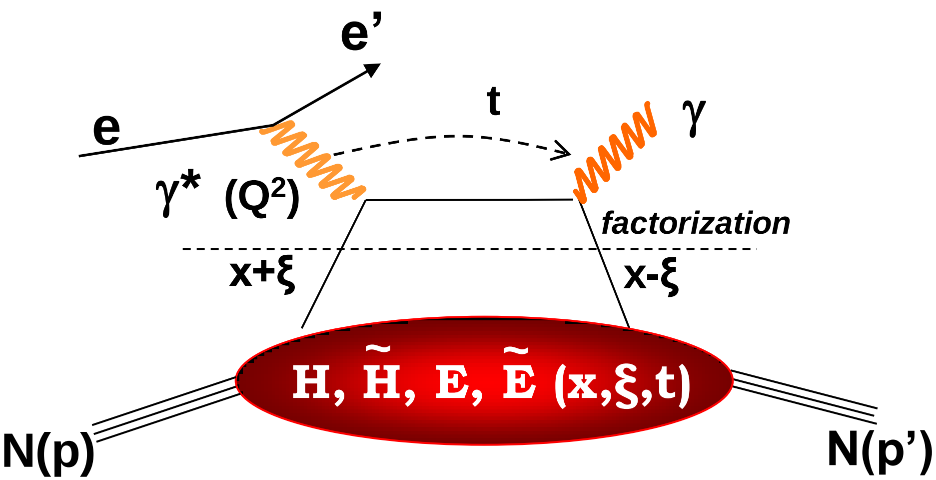
Projected π^0 contamination vs ϕ







Deeply Virtual Compton Scattering and GPDs



- $Q^2 = -(e-e')^2$
- $x_B = Q^2/2M\nu \quad \nu = E_e - E_{e'}$
- $x+\xi$, $x-\xi$ longitudinal momentum fractions
- $t = \Delta^2 = (p-p')^2$
- $x \cong x_B/(2-x_B)$

« Handbag » factorization valid in the Bjorken regime: high Q^2, ν (fixed x_B), $t \ll Q^2$

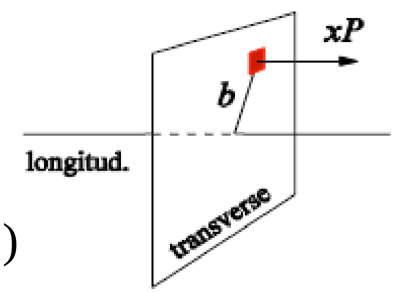
At LO QCD, twist 2, chiral-even, quark sector → 4 GPDs for each quark flavor

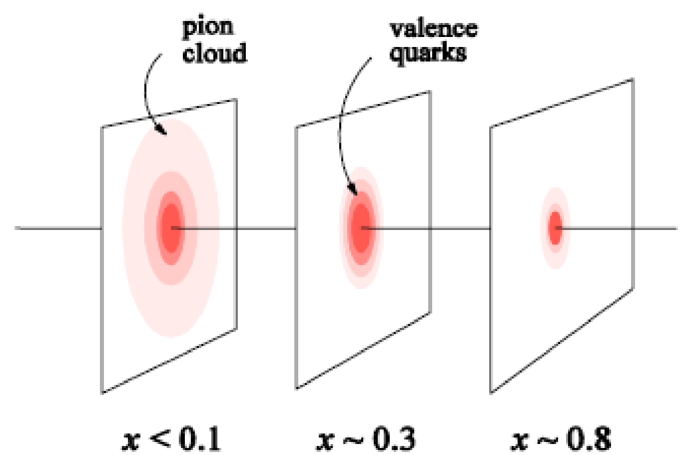
conserve nucleon spin	Vector: $H(x,\xi,t)$	Axial-Vector: $\tilde{H}(x,\xi,t)$
flip nucleon spin	Tensor: $E(x,\xi,t)$	Pseudoscalar: $\tilde{E}(x,\xi,t)$

Nucleon tomography

$$q(x, b_\perp) = \int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} H(x,0,-\Delta_\perp^2)$$

$$\Delta q(x, b_\perp) = \int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} \tilde{H}(x,0,-\Delta_\perp^2)$$





M. Burkardt, PRD 62, 71503 (2000)

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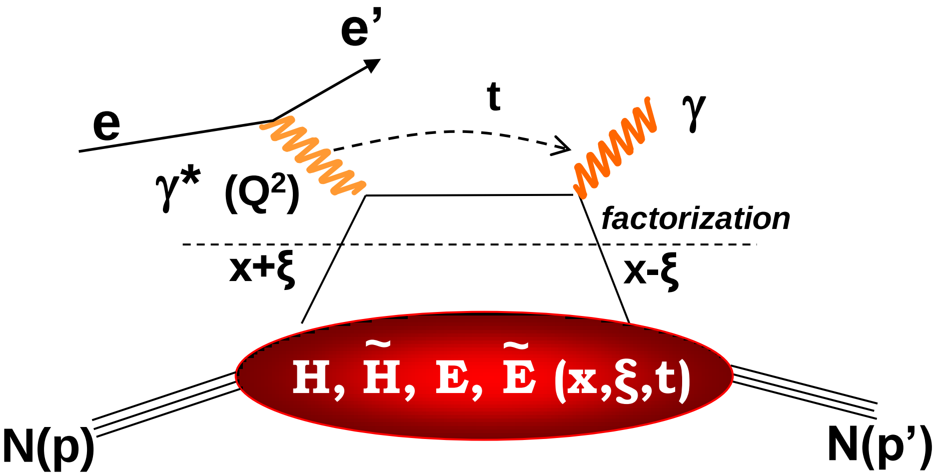

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M. Burkardt, PRD 62, 71503 (2000)

Quark angular momentum (Ji's sum rule)

$$\frac{1}{2}\int_{-1}^{1} x dx (H_q(x,\xi,t=0) + E_q(x,\xi,t=0)) = J_q = \frac{1}{2}\Delta\Sigma + \Delta L$$

X. Ji, Phy.Rev.Lett.78,610(1997)

Accessing GPDs through DVCS

DVCS allows access to 4 complex GPDs-related quantities: Compton Form Factors (ξ,t)

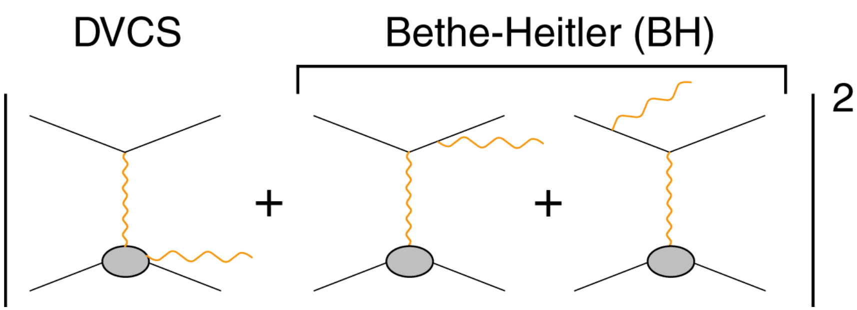
$$T^{DVCS} \sim P\int_{-1}^{+1} \frac{GPDs(x,\xi,t)}{x\pm\xi}dx \pm i\pi GPDs(\pm\xi,\xi,t) + \ldots$$

Only ξ and t are accessible experimentally

$$\boxed{Re\mathcal{H}_q = e_q^2 P\int_0^{+1}\left(H^q(x,\xi,t) - H^q(-x,\xi,t)\right)\left[\frac{1}{\xi - x} + \frac{1}{\xi + x}\right]dx}$$

$$Im\mathcal{H}_q = \pi e_q^2\left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right]$$

$\sigma(eN \longrightarrow eN\gamma) =$

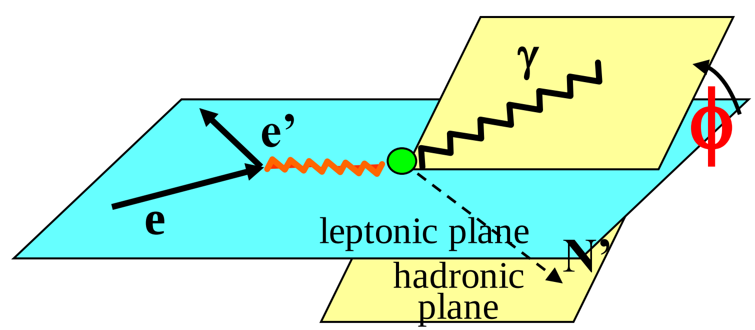


BH is calculable (electromagnetic FFs)

$$\sigma \sim \left|T^{DVCS} + T^{BH}\right|^2 \propto \mathrm{Re}(CFFs) \quad (also\, DSA)$$

$$\Delta\sigma = \sigma^+ - \sigma^- \propto I\left(DVCS \cdot BH\right) \propto \mathrm{Im}(CFFs)$$

$$A = \frac{\Delta\sigma}{2\sigma} \propto \frac{I\left(DVCS \cdot BH\right)}{\left|BH\right|^2 + \left|DVCS\right|^2 + I}$$



Sensitivity to CFFs of DVCS spin observables

$$A_{LU(UL)} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \propto \frac{s^I_{1,unp(UL)} \sin\phi}{c^{BH}_{0,unp} + c^I_{0,unp} + (c^{BH}_{1,unp} + c^I_{1,unp})\cos\phi}$$

$$A_{LL} = \frac{\sigma^{++} + \sigma^{+-} - \sigma^{+-} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-} + \sigma^{+-} + \sigma^{+-}} \propto \frac{c^{BH}_{0,LP} + c^I_{0,LP} + (c^{BH}_{1,LP} + c^I_{1,LP})\cos\phi}{c^{BH}_{0,unp} + c^I_{0,unp} + (c^{BH}_{1,unp} + c^I_{1,unp})\cos\phi}$$

Twist 2 approximation ($-t \ll Q^2$)

($\xi = x_B/(2-x_B)$ $k=-t/4M^2$)

Proton **Neutron**

Polarized **beam**, unpolarized target:

$\mathbf{s^I_{1,unp}} \sim \sin\phi$ **Im**$\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}$ ⇒ $Im\{\boldsymbol{\mathcal{H}_p}, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \boldsymbol{\mathcal{E}_n}\}$

Unpolarized beam, **longitudinal** target:

$\mathbf{s^I_{1,UL}} \sim \sin\phi$ **Im**$\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}} + \ldots\}$ ⇒ $Im\{\boldsymbol{\mathcal{H}_p}, \boldsymbol{\tilde{\mathcal{H}}_p}\}$ $Im\{\boldsymbol{\mathcal{H}_n}, \mathcal{E}_n\}$

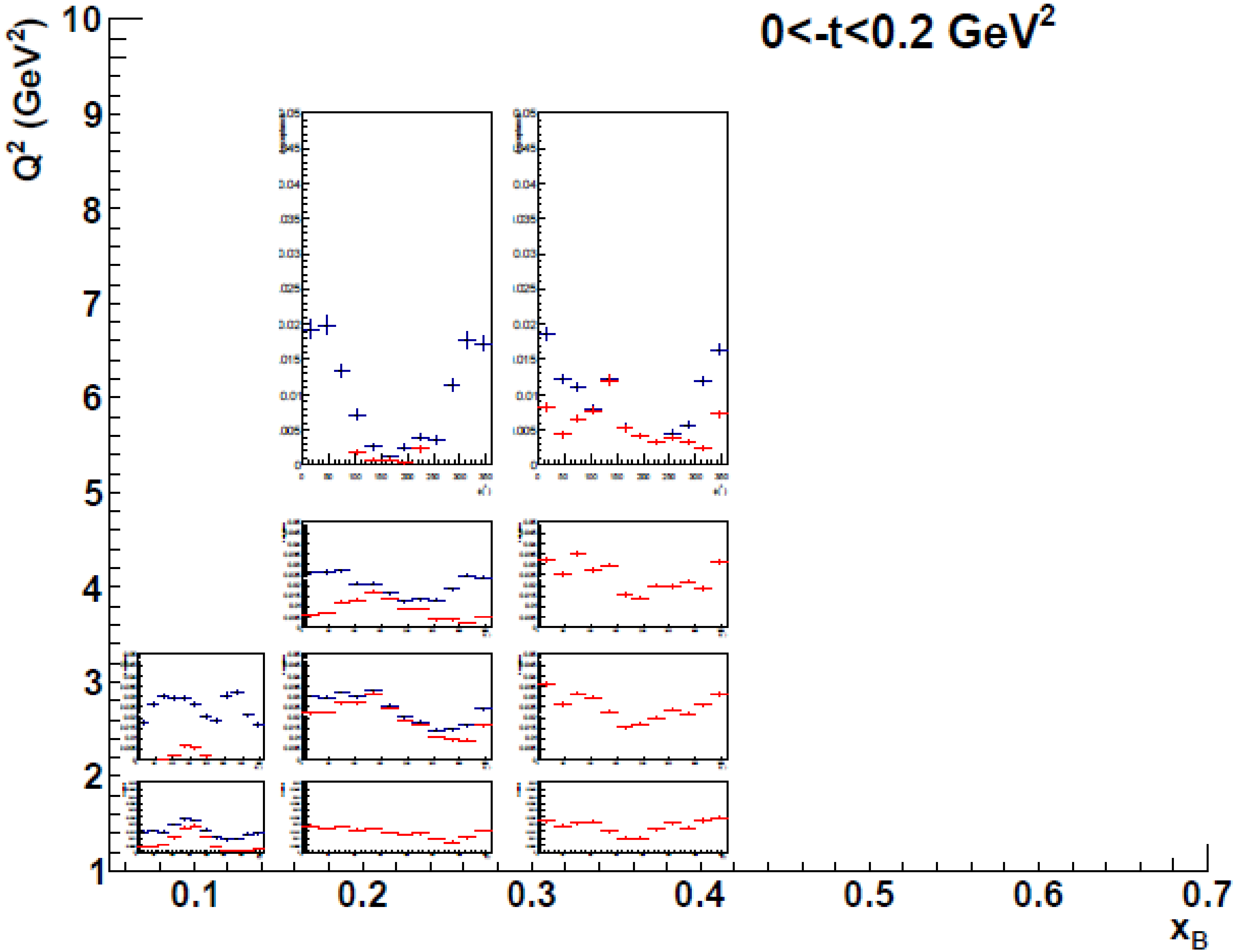
Polarized **beam**, **longitudinal** target:

$\mathbf{c^I_{1,LP}} \sim (A+B\cos\phi)$**Re**$\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E})\ldots\}$ ⇒ $Re\{\boldsymbol{\mathcal{H}_p}, \boldsymbol{\tilde{\mathcal{H}}_p}\}$ $Re\{\boldsymbol{\mathcal{H}_n}, \mathcal{E}_n\}$

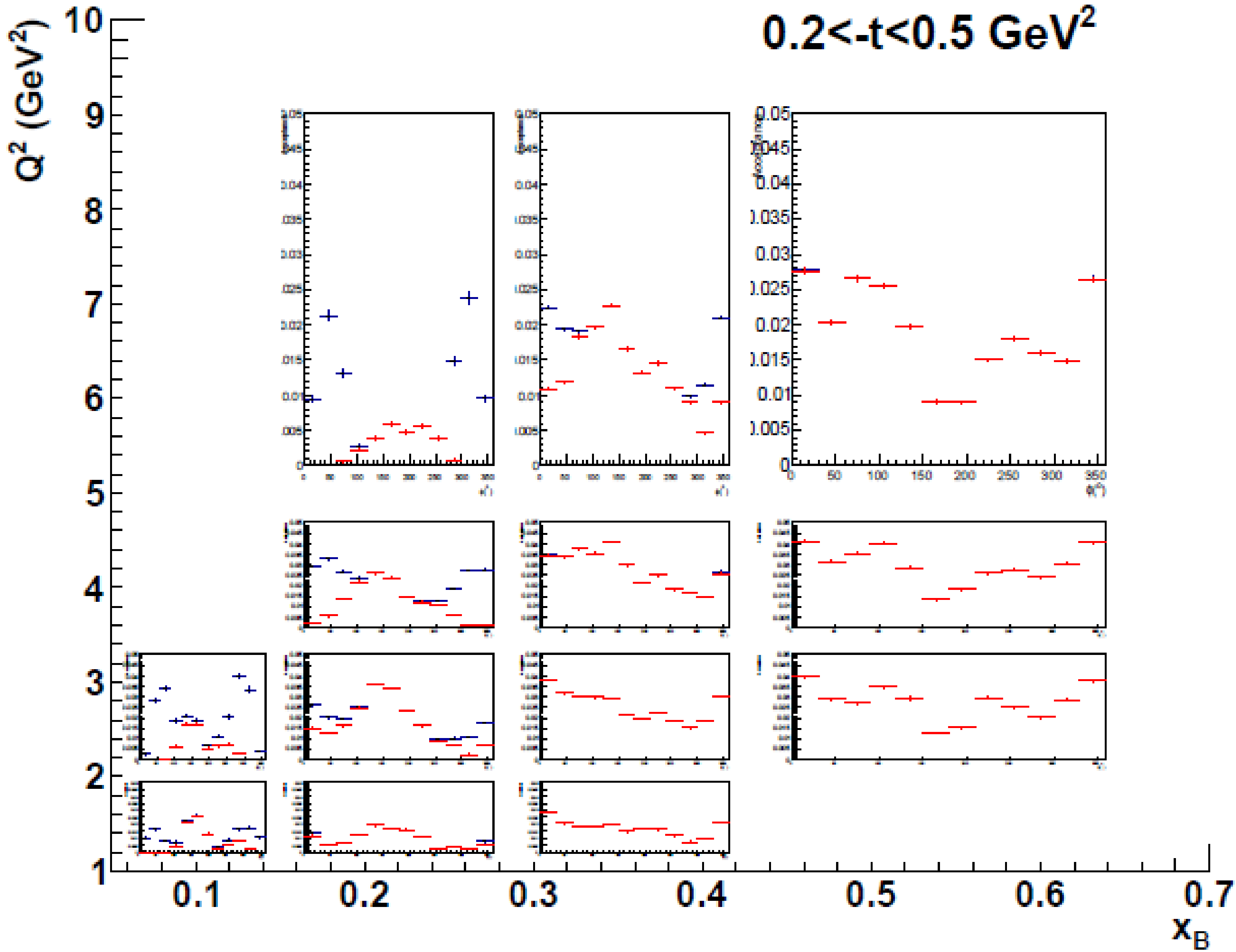
Unpolarized beam, **transverse** target:

$\boldsymbol{\Delta\sigma_{UT}} \sim \cos\phi\sin(\phi_s-\phi)$**Im**$\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}$ ⇒ $Im\{\boldsymbol{\mathcal{H}_p}, \boldsymbol{\mathcal{E}_p}\}$ $Im\{\boldsymbol{\mathcal{H}_n}\}$

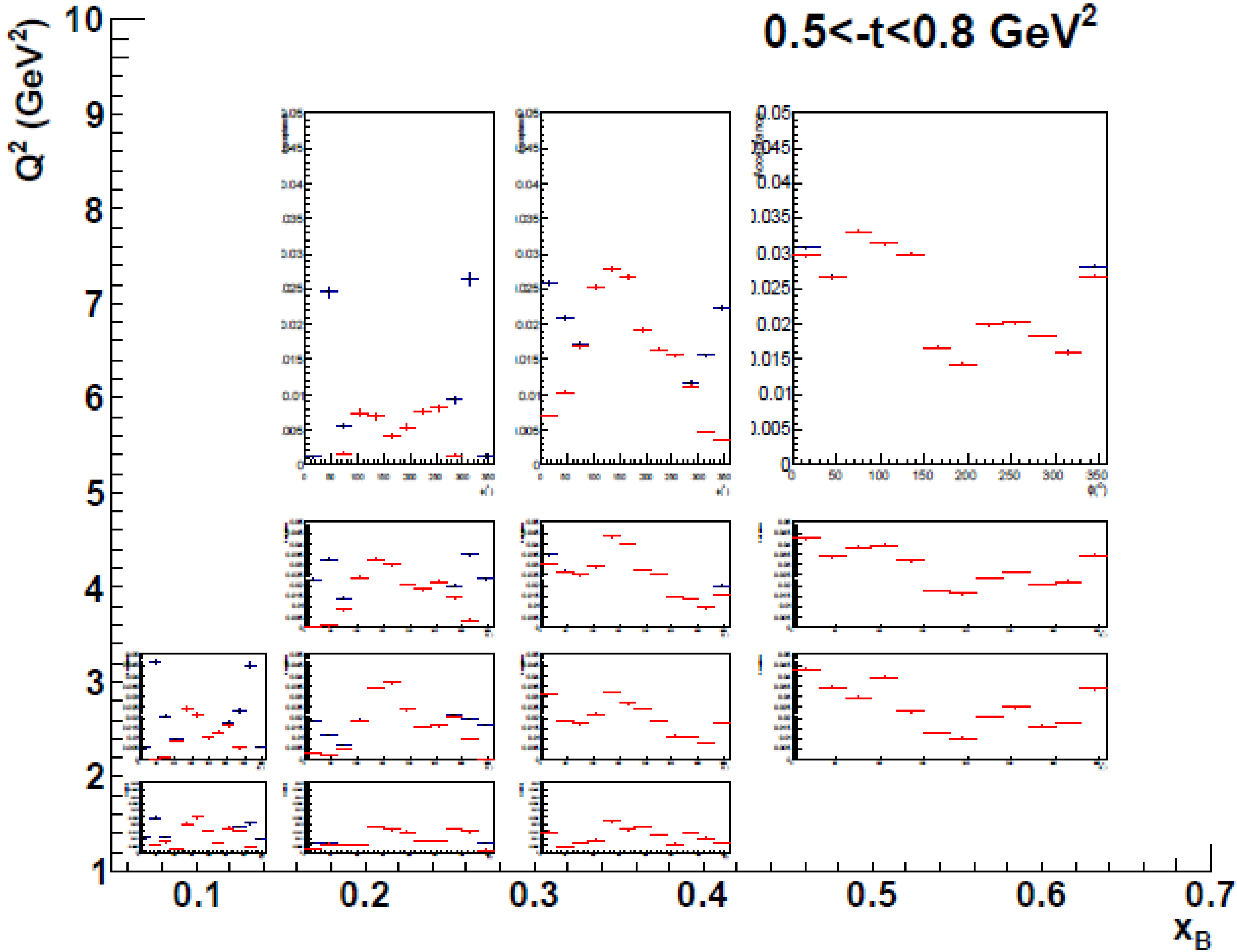
Effect of the Forward Tagger on the acceptance for nDVCS



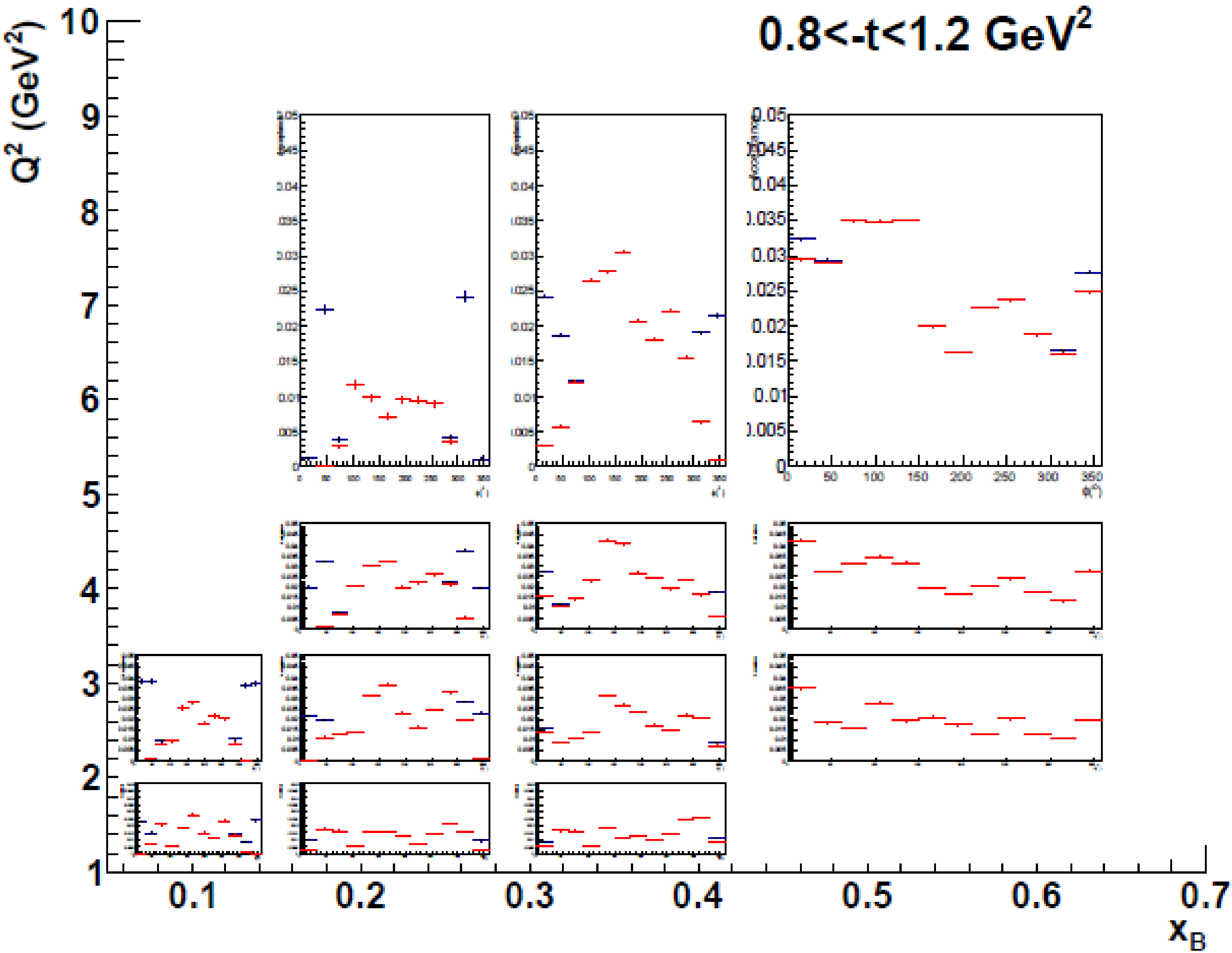
Effect of the Forward Tagger on the acceptance for nDVCS



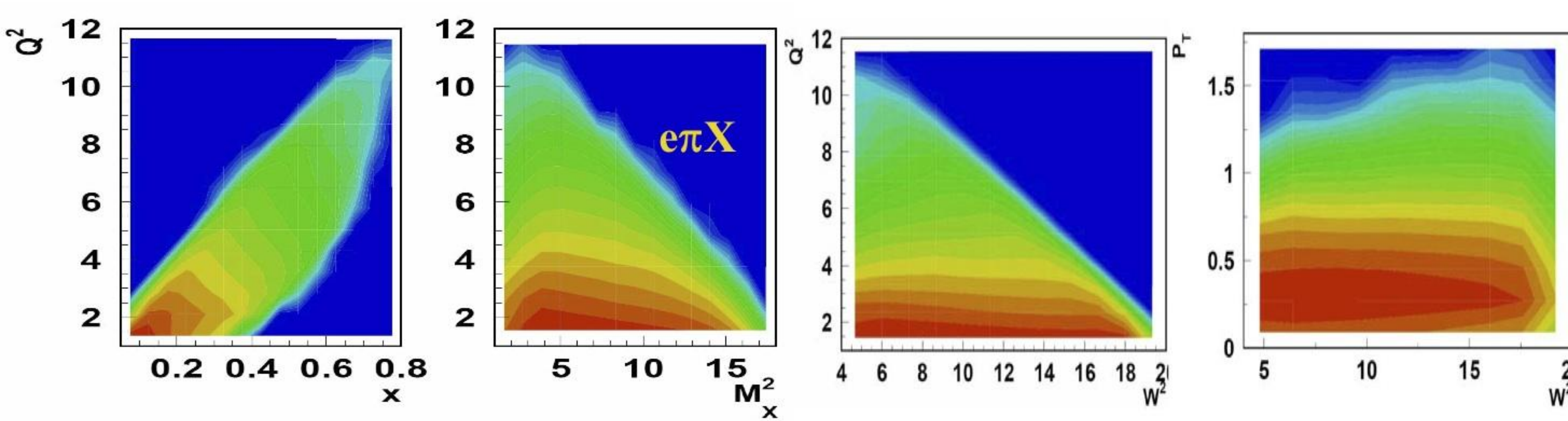
Effect of the Forward Tagger on the acceptance for nDVCS

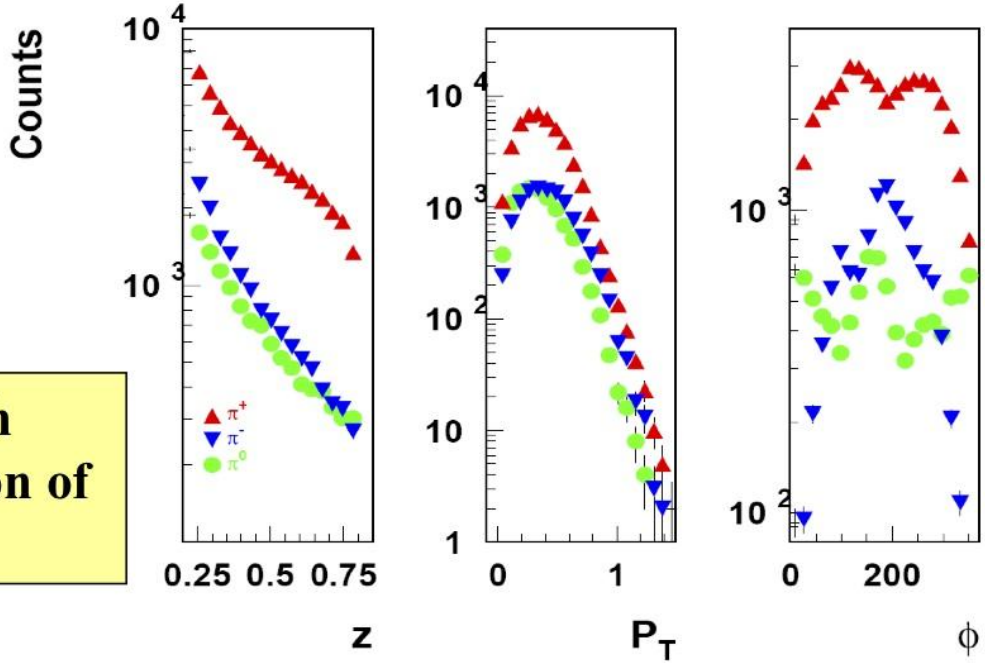


Effect of the Forward Tagger on the acceptance for nDVCS



Pion distributions in ep→e'πX



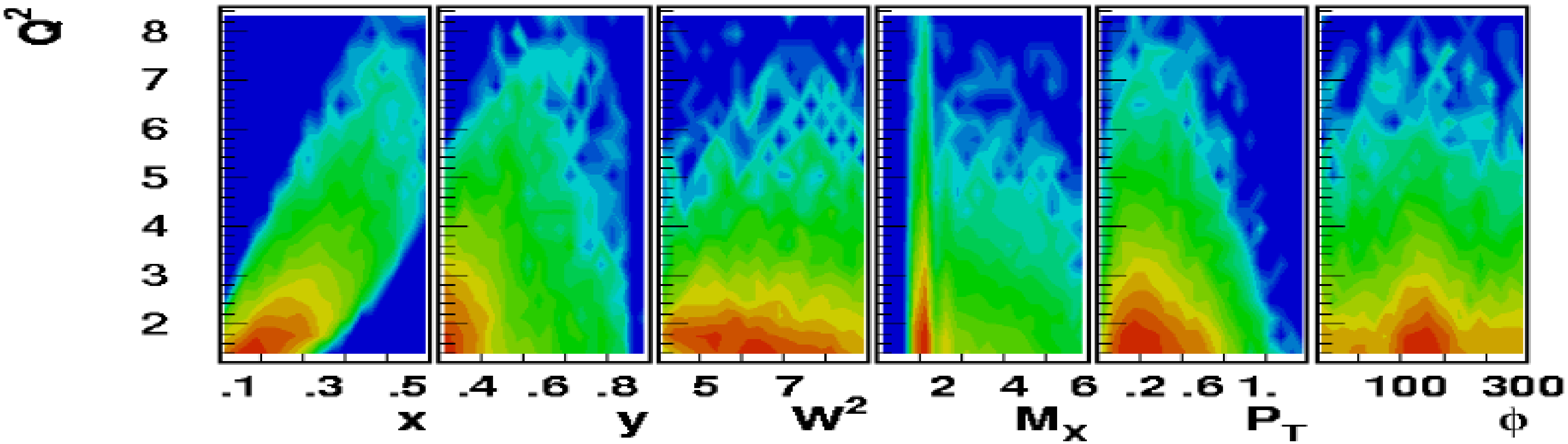


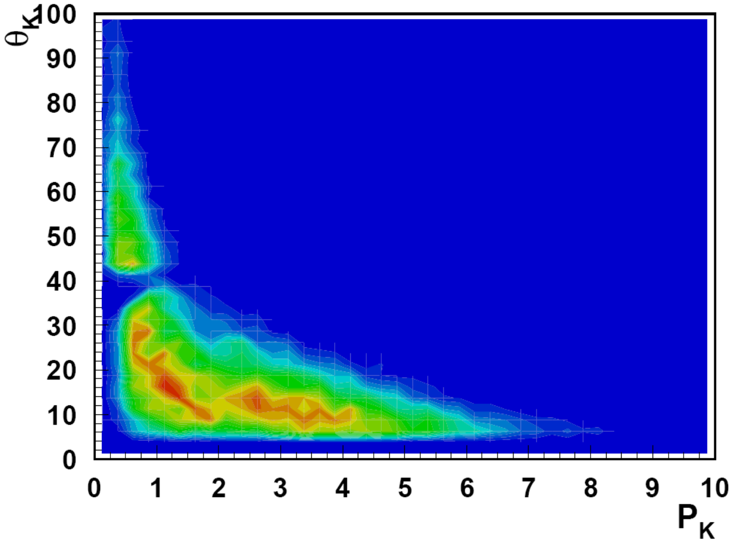
SIDIS kinematics

$Q^2 > 1 GeV^2$
$W^2 > 4 GeV^2 (10)$
$y < 0.85$
$M_X > 2 GeV$

Large Q^2, M_X, and P_T accessible with CLAS12 are important for separation of Higher Twist contributions

Kaon distributions in ep→e'KX





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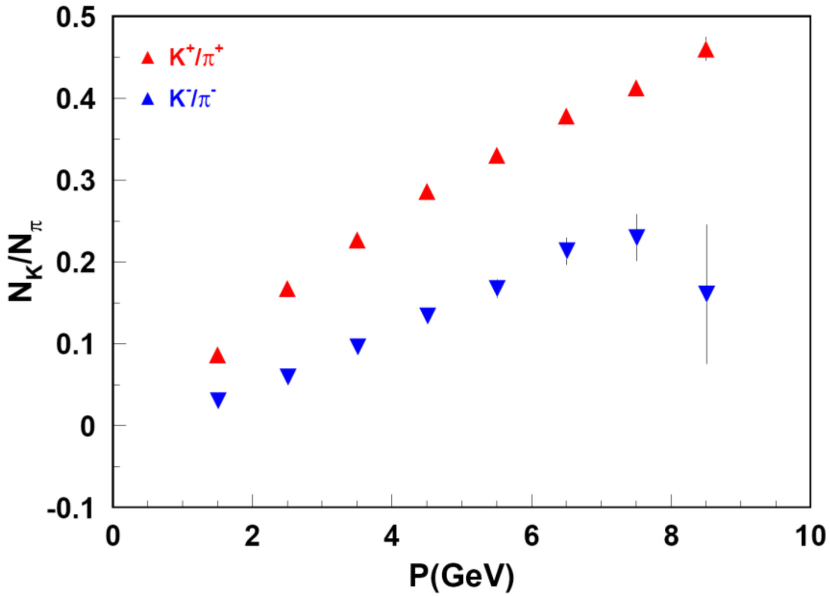
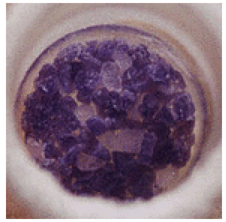


High energy kaons are at small angles ($\theta < 30^o$)

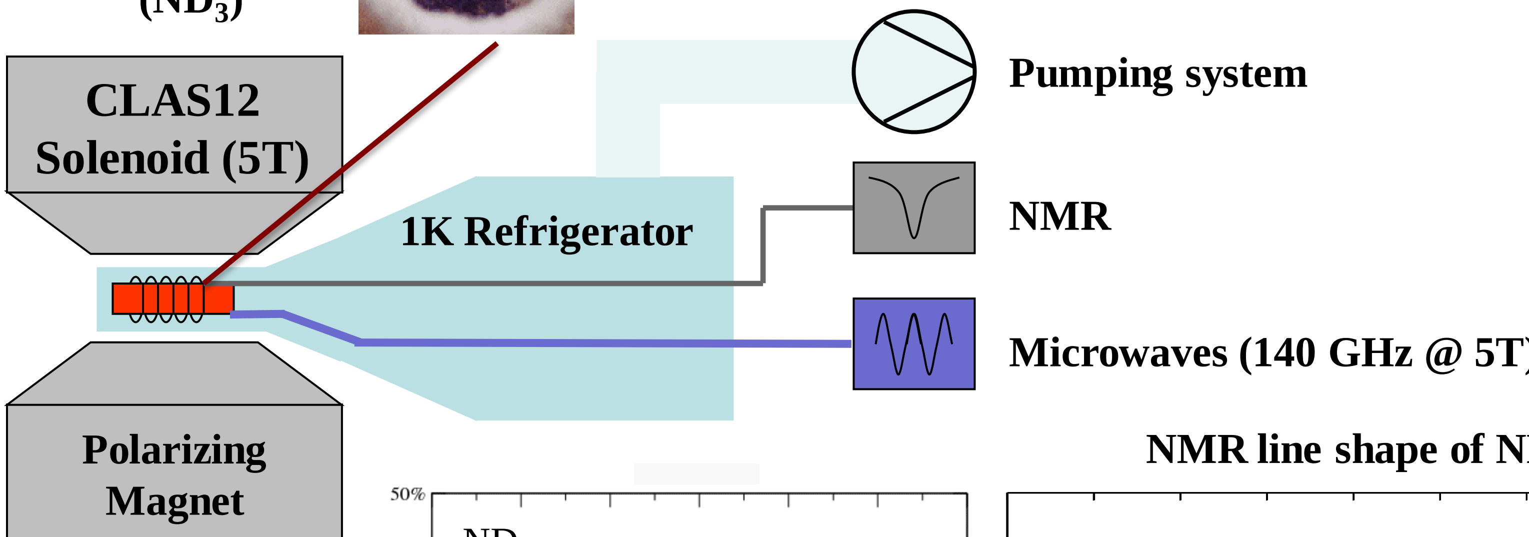
The CLAS12 longitudinally polarized target

Irradiated deuterated ammonia (ND_3)

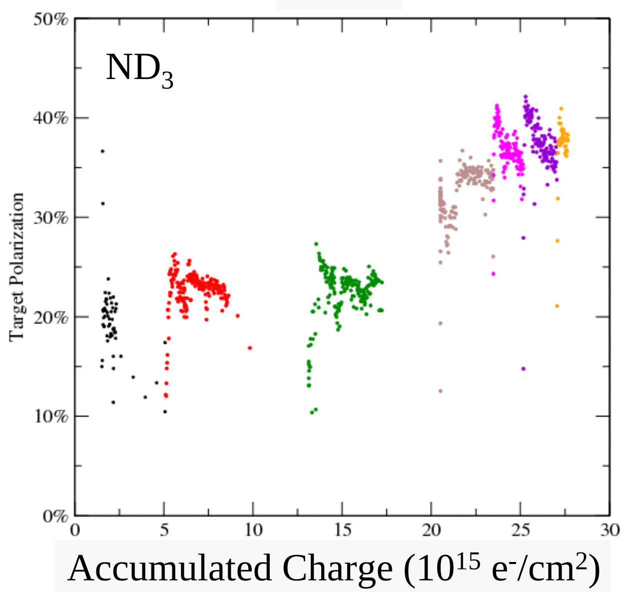


UVA, ODU, CNU and JLab

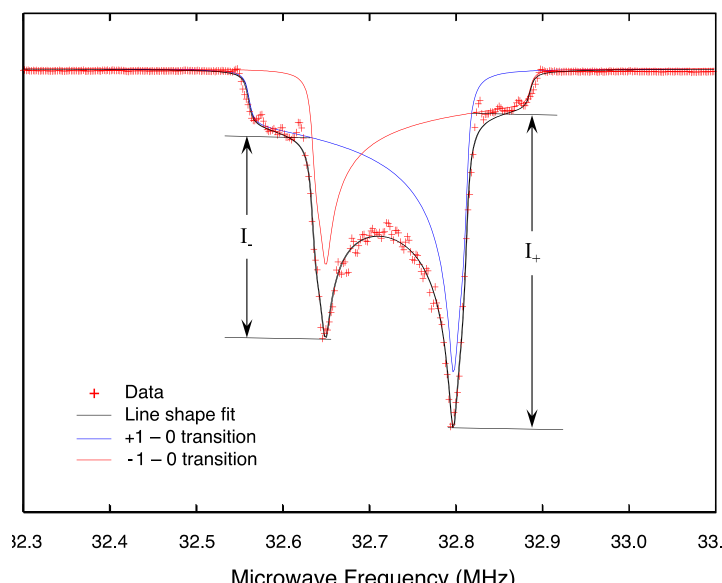
L=4 cm; r = 1.25 cm
P ~ 40%
L ~10^{34} $cm^2 s^{-1}$ /nA

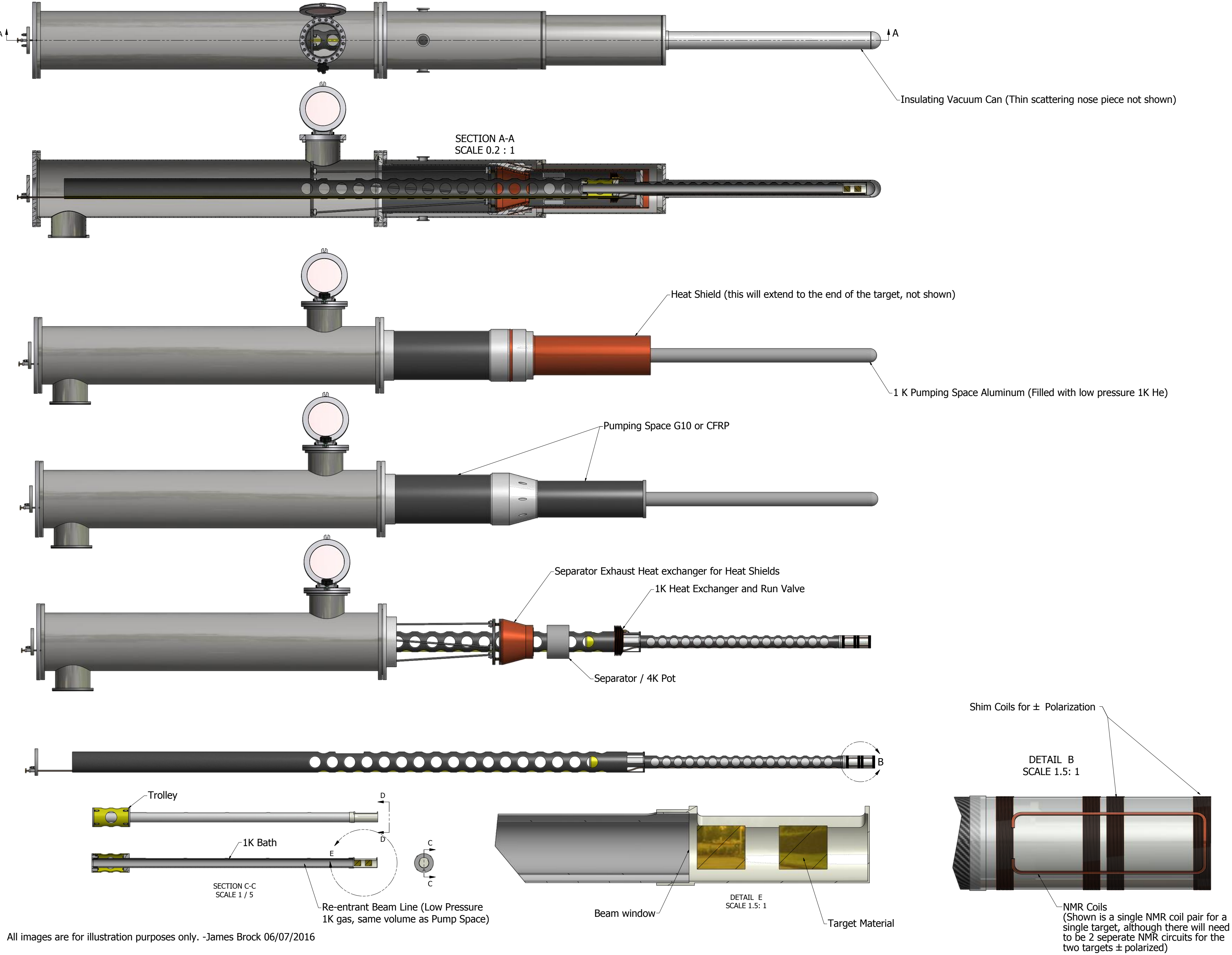


ND_3 polarization improves with "cold dose"



NMR line shape of ND_3





All images are for illustration purposes only. -James Brock 06/07/2016