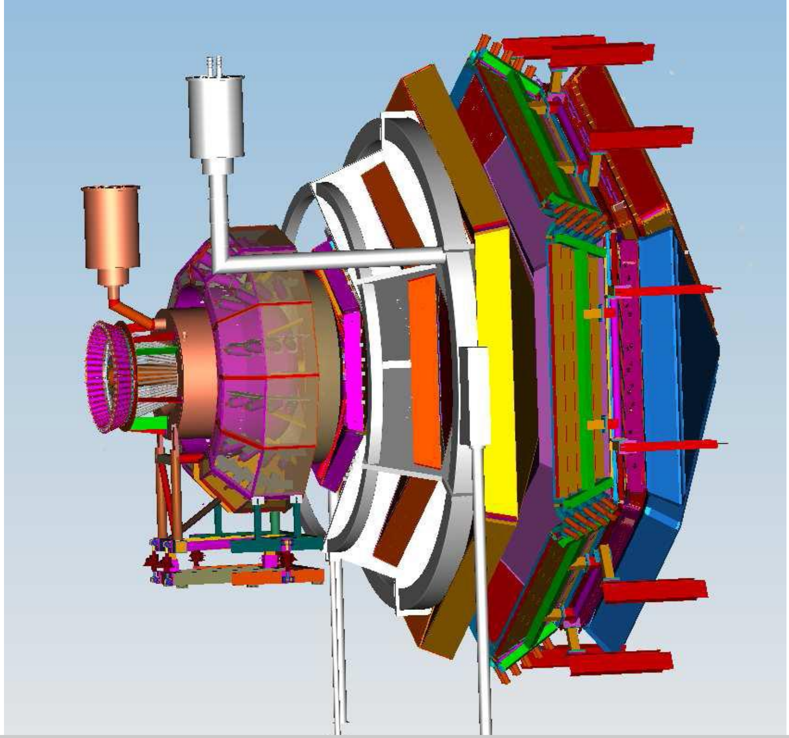
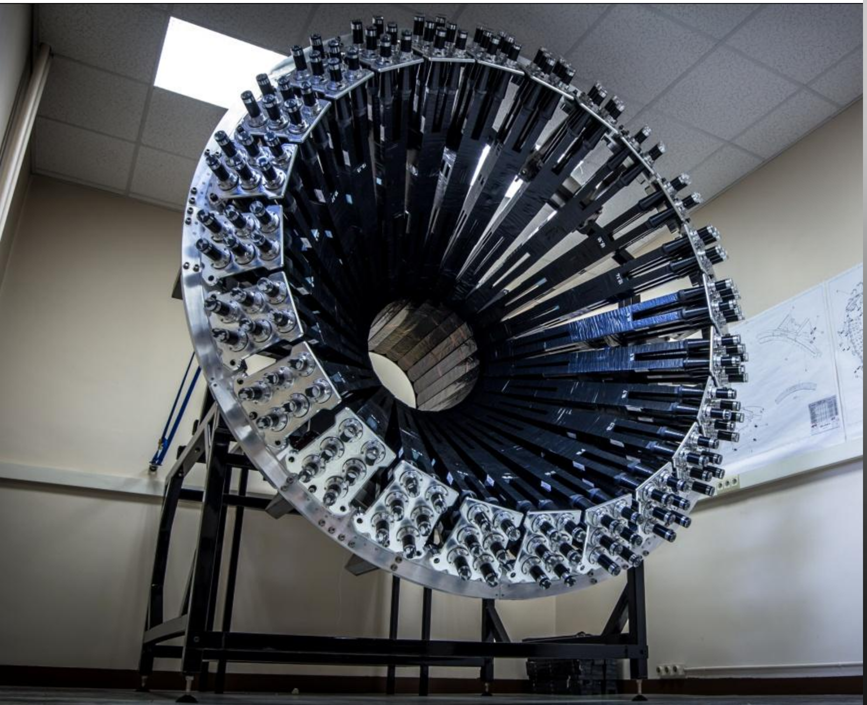
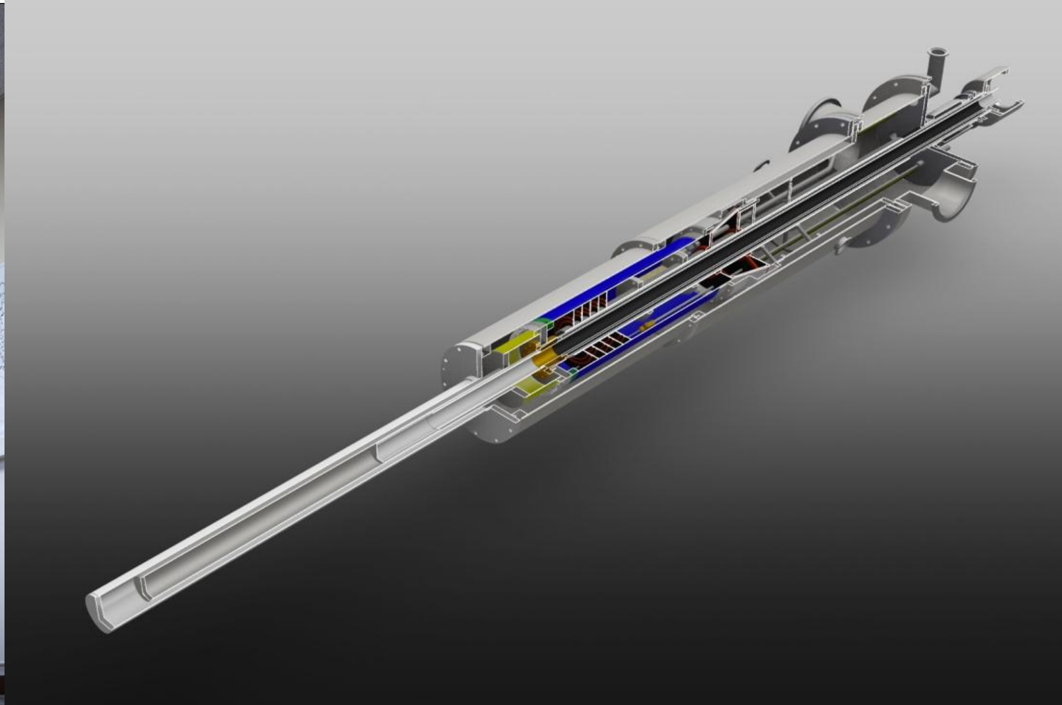
Minisession on the extension of the polarized ND3 CLAS12 run group



Silvia Niccolai IPN ORSAY

CLAS Collaboration meeting, 10/22/2015





Reasons and purpose of this session

PR12-15-004: Deeply Virtual Compton Scattering on the neutron with a longitudinally polarized deuterium target (A. Biselli, C. Keith, S. Niccolai, S. Pisano, D. Sokhan):

- Presented at **PAC43**, requesting **100 days (plus overhead)** of running time on **ND3**, 50 shared with the existing run group (RG-Cb), plus **50 days of new beam time**
- **Conditionally approved (C2)** by the PAC, must come back to the next PAC, broken into TWO proposals: a « parasitic » one for the already-approved 50 days (needing only CLAS approval), and a new proposal, requesting new beam time, that will go through the PAC
- For the new proposal, it was asked to **add other physics channels** to better support and motivate the need to extend the existing run group

- **Outline:**
  - ➢ Quick overview of the polarized nDVCS experiment
  - ➢ PAC response
  - ➢ CLAS12 run groups
  - ➢ Other possible channels

Approved DVCS experiments for JLab@12 GeV

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	$\Re e\tilde{\mathcal{H}}_p$, $\Re e\mathcal{H}_p$	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**	$\Im m\mathcal{H}_n$		**PR12-15-004**
DSA(n)	**Long. pol. ND3**	$\Re e\mathcal{H}_n$		**PR12-15-004**

A **complete experimental program** is approved for **proton DVCS**
(CLAS12, Hall A, Hall C)

Only the beam-spin asymmetry measurement (*Im*($\mathcal{E}_n$)) for neutron DVCS is currently approved for JLab@12 GeV

Flavor separation of GPDs

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

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

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

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

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

Measurements of DVCS on neutron target are crucial for the completion of a comprehensive GPD program for JLab@12 GeV

We propose to extend the JLab experimental program for nDVCS, started with the beam-spin asymmetry (E12-11-003), by measuring for the first time target-spin single and double asymmetries

Polarized neutron DVCS setup

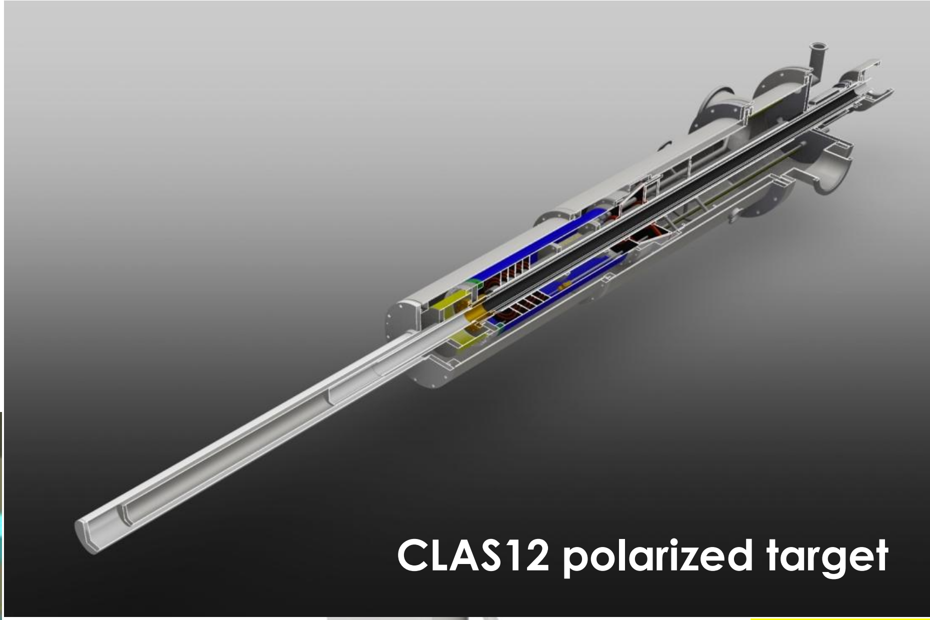
Detected in forward CLAS12

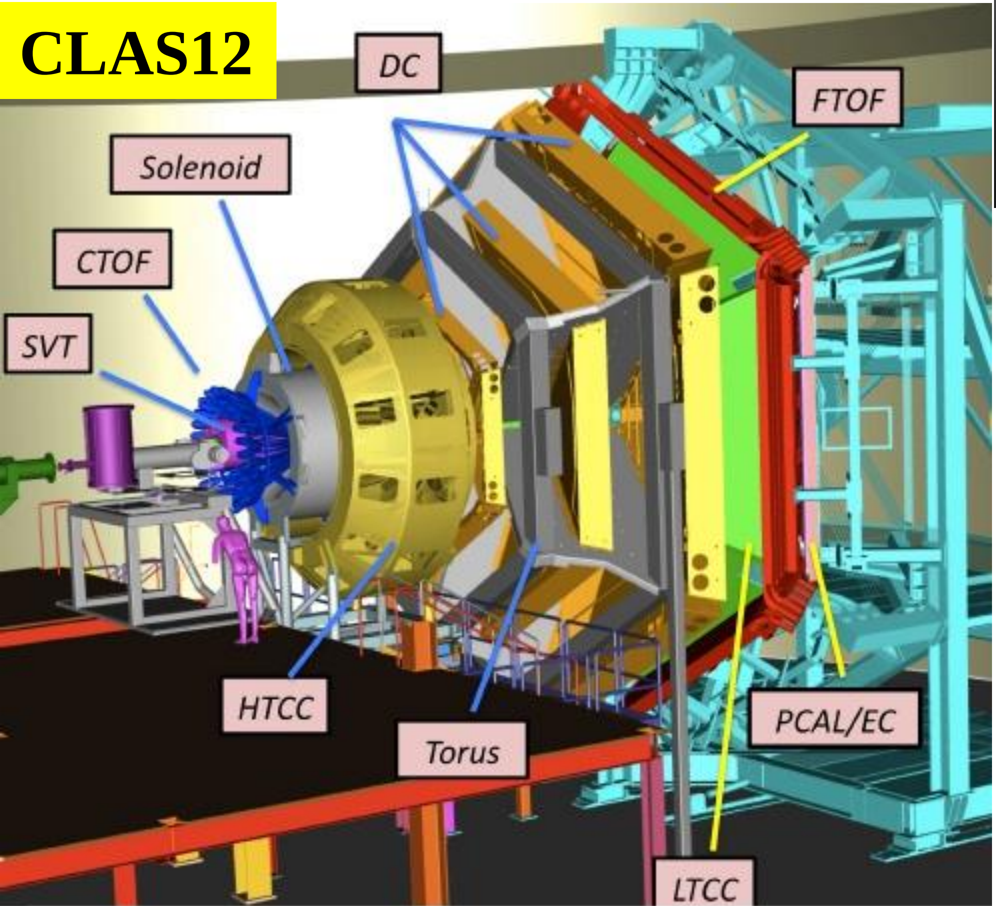
Not detected

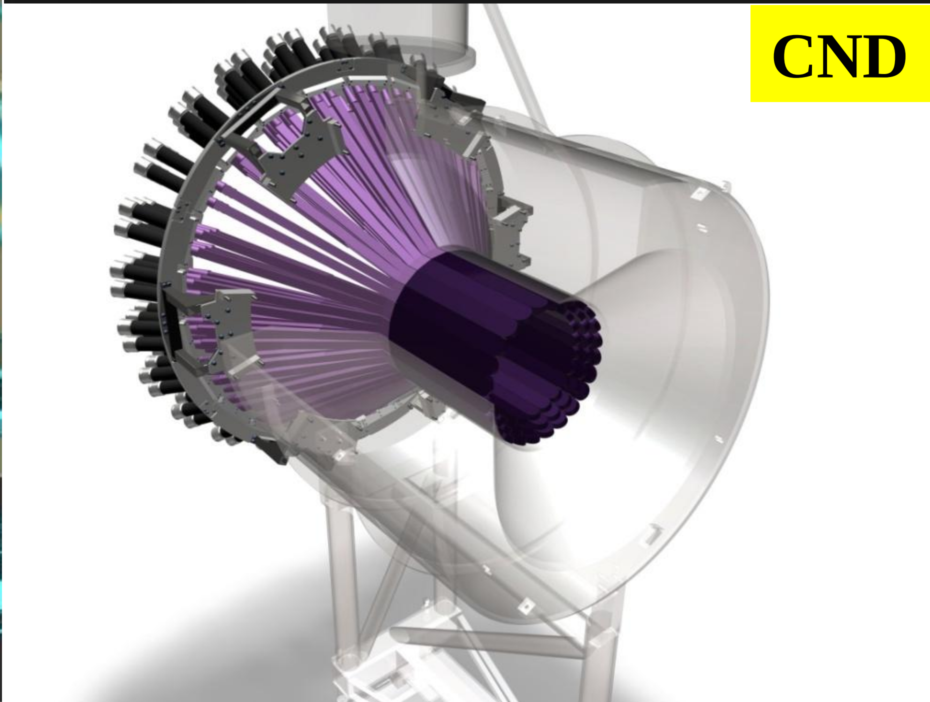
$\vec{e}\vec{d} \rightarrow e' n \gamma (p)$

Detected in CND and EC

Detected in EC+PCAL







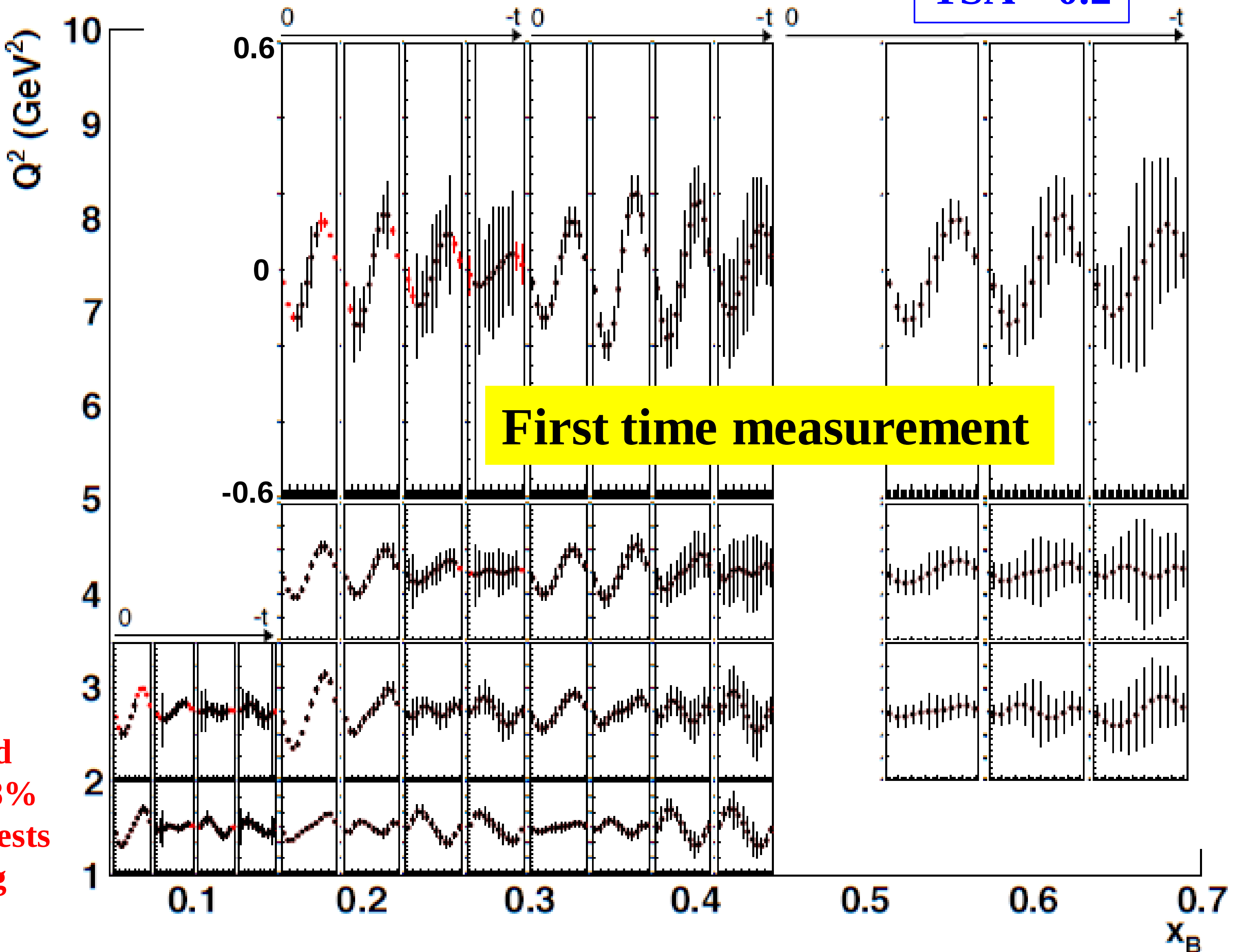
Projected results: target-spin asymmetry

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

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

- L = **10^{35}cm^{-2}s^{-1}** for ND^3 @ **10 nA**, Time = **100 days**
- $D_f = 0.7$; $P_t = 0.4$

TSA ~ 0.2



- 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 if Forward Tagger can be used (8% occupancy in DC1): tests with Gemc + tracking underway

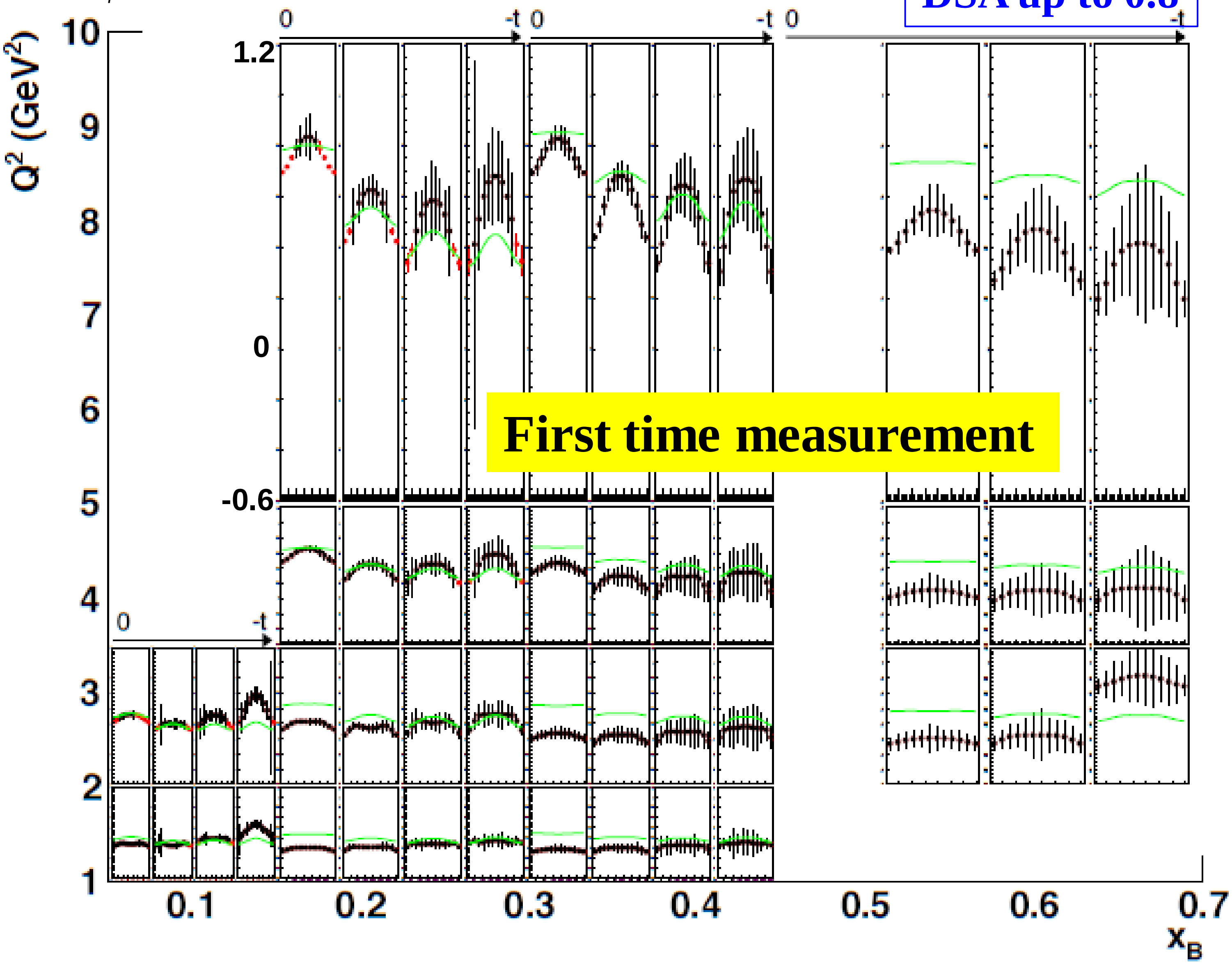
Projected results: double spin asymmetry

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

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

- L = $\mathbf{10^{35} cm^{-2} s^{-1}}$ for ND^3 @ **10 nA**, Time = **100 days**
- $D_f = 0.7$; $P_t = 0.4$; $P_b = 0.85$

DSA up to 0.8



- 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 if Forward Tagger can be used

Green curves: BH

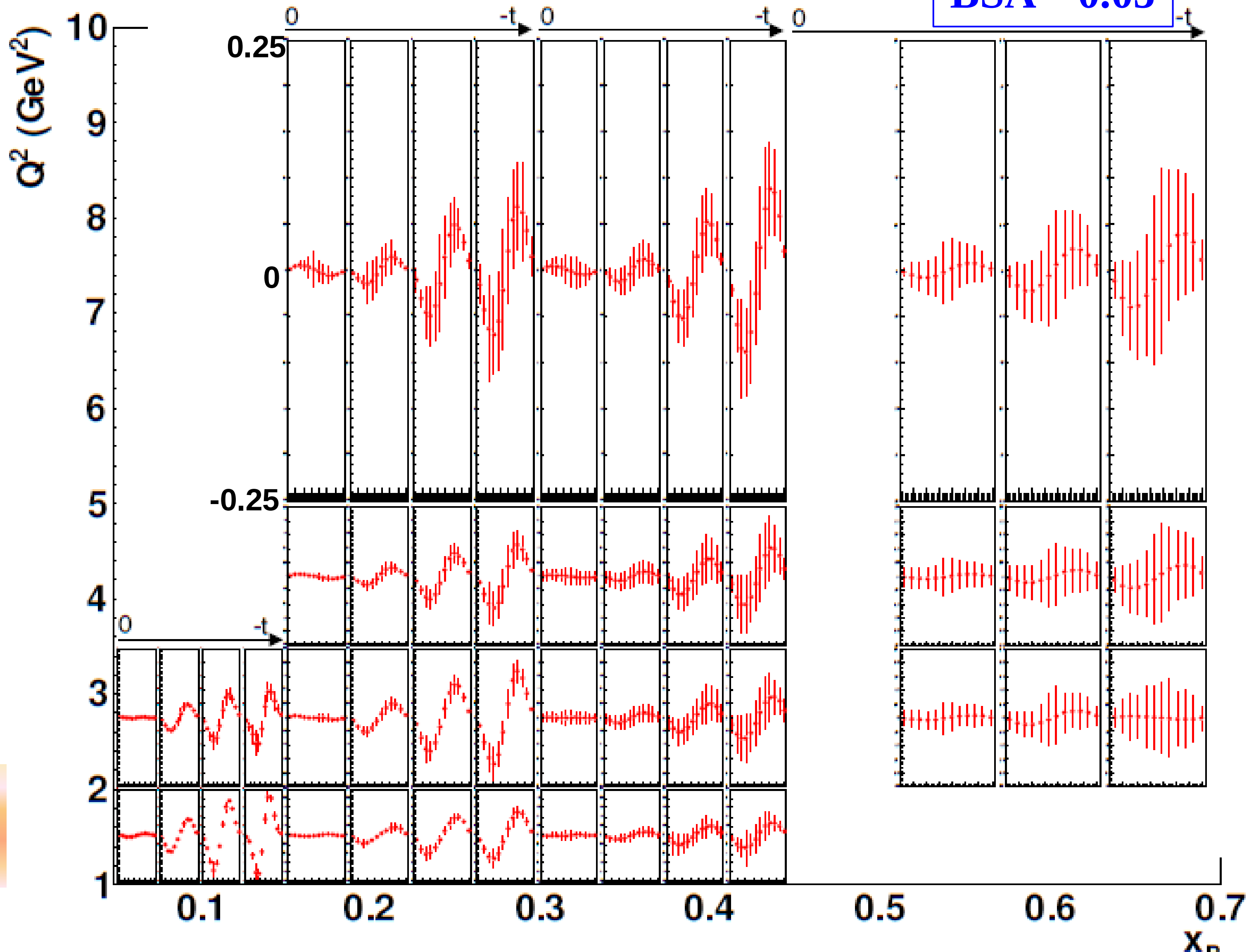
Projected beam spin asymmetry from E12-11-003

✓Count rates computed with nDVCS+BH event generator + CLAS12 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

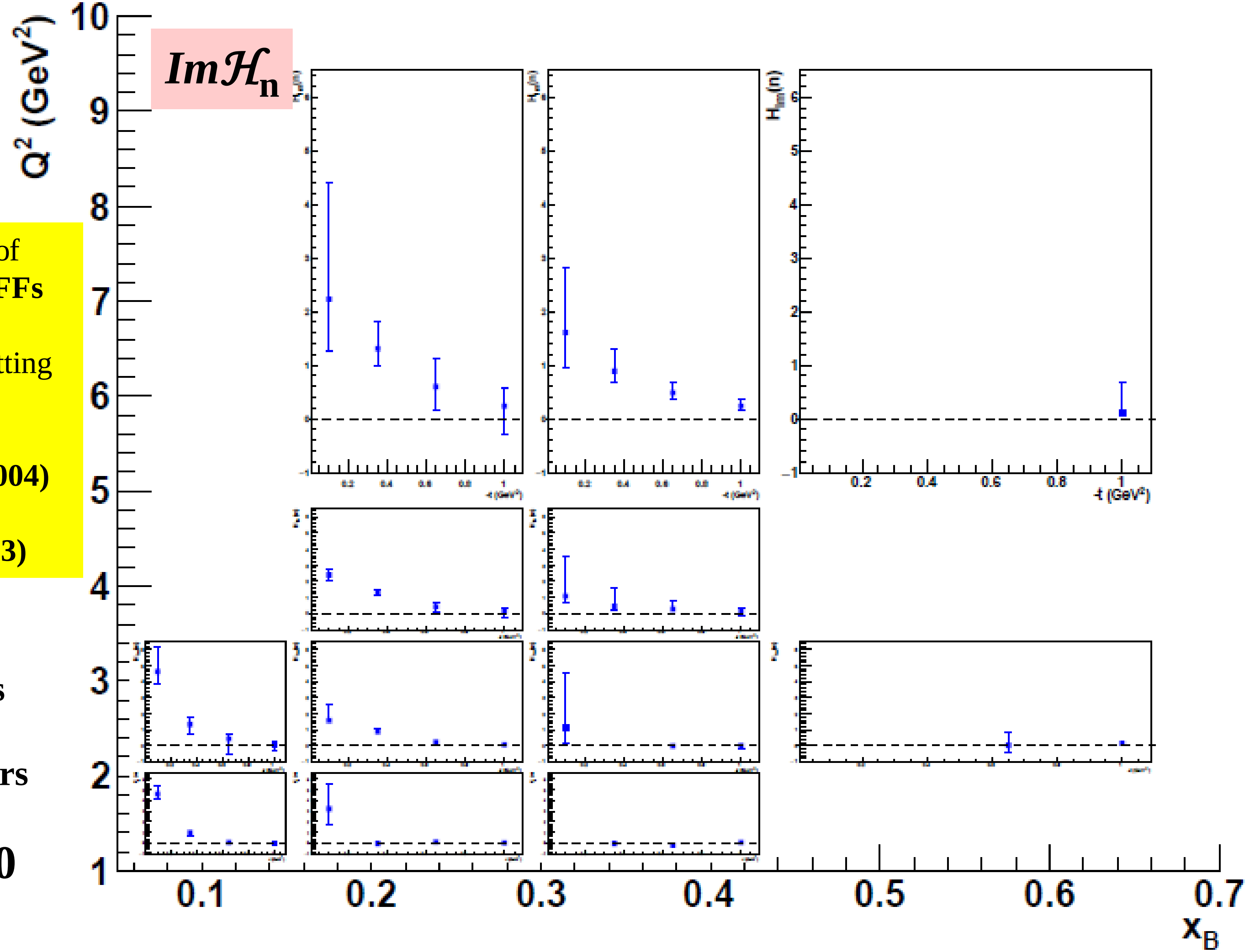
BSA ~ 0.05



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

High-impact experiment

Combined analysis of PR12-15-004 and E12-11-003

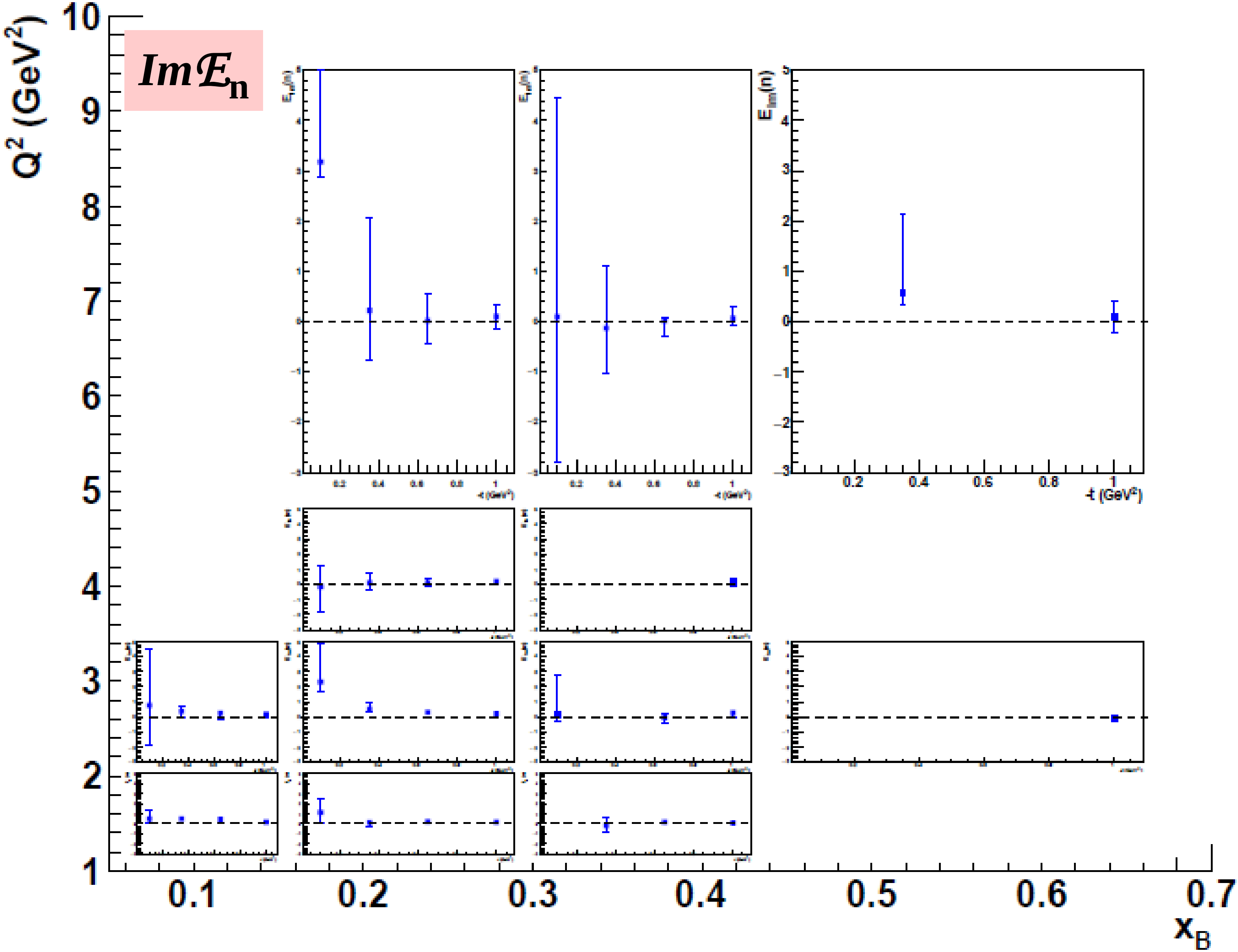


Extraction of **neutron CFFs** using **M. Guidal**'s fitting code. Fit of **TSA, DSA (PR12-15-004) and BSA (E12-11-003)**

7 CFFs as free fit parameters

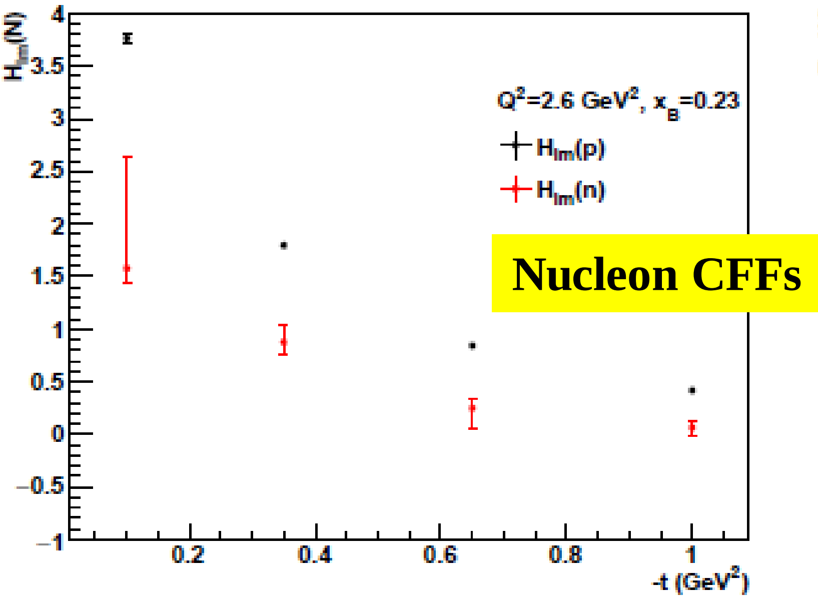
$Im\tilde{\mathcal{E}} = 0$

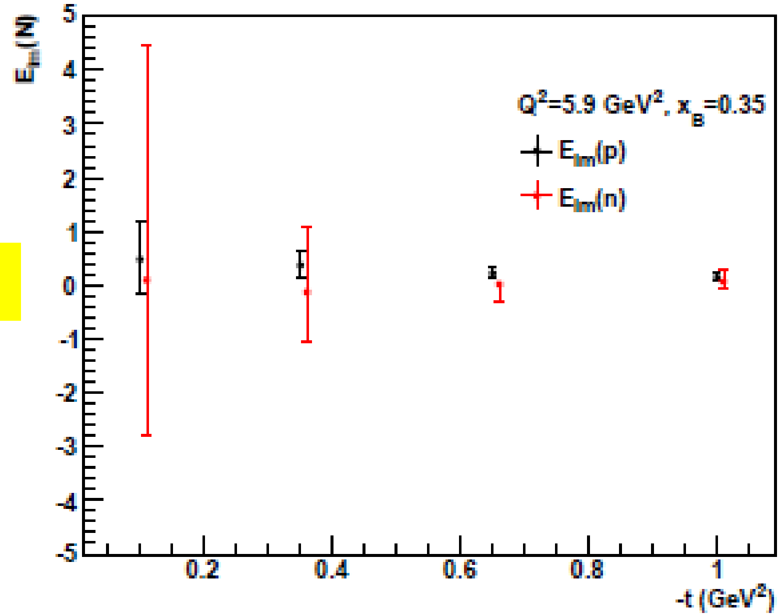
Combined analysis of PR12-15-004 and E12-11-003



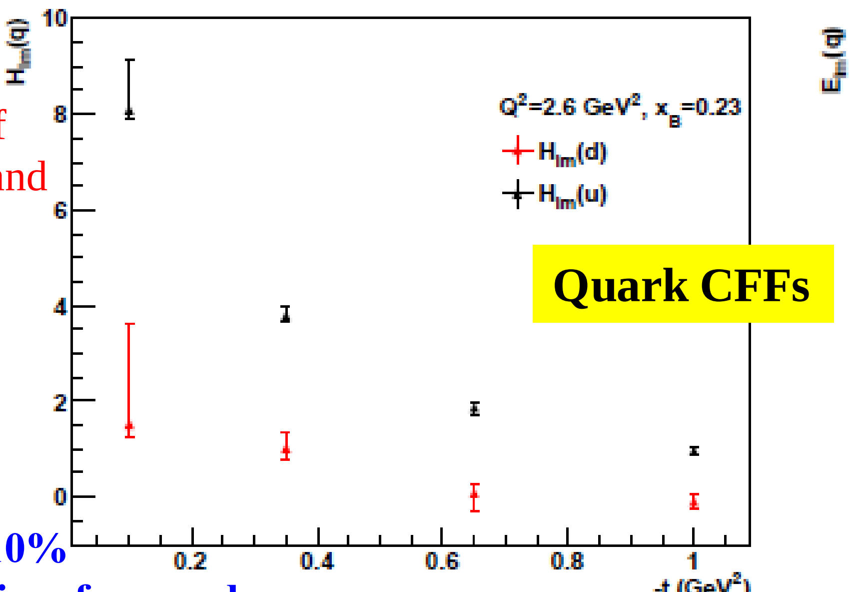
Projections for flavor separation ($Im\mathcal{H}$, $Im\mathcal{E}$)

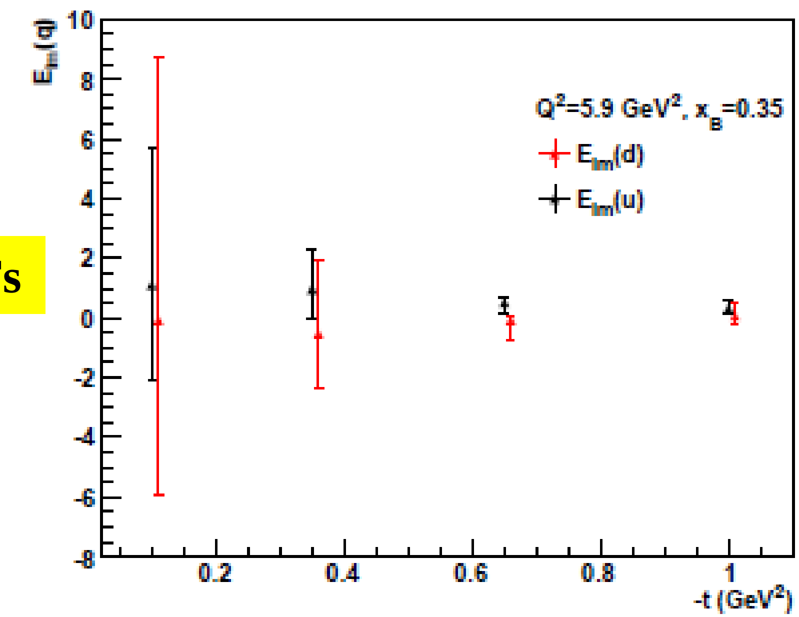
Fit using all the projected **pDVCS** asymmetries of the CLAS12 program





Fit using the projected **nDVCS** asymmetries of PR12-15-004 and E12-11-003





σ(pDVCS) ≈ 10σ(nDVCS)
Neutron eff = 10%
~ Same beam time for p and n

Summary of setup and beam-time request

Experimental setup:
- **CLAS12**
- **Longitudinally polarized ND_3 target (P_t~40%)**
- **Central Neutron Detector (ready!)**

Beam energy: 11 GeV
Beam polarization: 85%

Production data taking at 10^{35} cm^{-2}s^{-1} on ND_3	100 days
Target work	12 days
Production data taking on ^{12}C target	10 days
Moeller polarimeter runs	3 days
Total beam time request	125 days

Half of the requested beam time can be shared with Run Group Cb
We request 62 days of new beam time

PAC43 outcome: C2

The PAC considers such a proposal an important piece of the main physics program dedicated to the exploration and interpretation of GPDs.
It can be carried out in parallel with the physics explored by RG-C (E12-06-109, E12-07-107, E12-09-007b) for 50% of the beam time requested. In that the proposal can be considered as a parallel experiment, well worth of being performed.

The PAC points out that the presentation procedure followed by this proposal is unusual. As a parallel experiment it should have been discussed and presented within the RG-C. The request of 62 additional days, independently of the other experiments in the same RG-C, is also anomalous. It should be considered in the context of creating a new run group, potentially optimizing the CLAS12 configuration for the measurement, including a possible suite of new experiments that would also make use of the additional running period.

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

CLAS12 experiments and run groups

Proposal	Physics	Contact	Rating	Days	Group	New 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
E12-06-112	Proton's quark dynamics in SIDIS pion production	Avakian	A	60					
E12-06-119	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					
E12-12-001	Timelike Compton Scatt. & J/ψ production in e+e-	Nadel-Turonski	A-	120					
E12-12-007	Exclusive φ meson electroproduction with CLAS12	Stoler, Weiss	B+	60					
PR12-12-008	Photoproduction of the very strangest baryon	Guo	--	80					
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
PR12-11-109 (a)	Dihadron DIS production	Avakian	-	-					
E12-09-007a	Study of partonic distributions in SIDIS kaon production	Hafidi	A-	56					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	Contalbrigo	A-	TBA					
E12-11-003	DVCS on neutron target	Niccolai	A	90					
E12-06-109	Longitudinal Spin Structure of the Nucleon	Kuhn	A	80	170 **(50 days ND3)**	Polarized target RICH (1 sector) Forward tagger	11	**C** **S. Kuhn**	NH_3 ND_3
E12-06- 119(b)	DVCS on longitudinally polarized proton target	Sabatie	A	120					
E12-07-107	Spin-Orbit Correl. with Longitudinally polarized target	Avakian	A-	103					
PR12-11-109 (b)	Dihadron studies on long. polarized target	Avakian	-	-					
E12-09-007(b)	Study of partonic distributions using SIDIS K production	Hafidi	A-	110					
E12-09-009	Spin-Orbit correlations in K production w/ pol. targets	Avakian	B+	103					
E12-06-106	Color transparency in exclusive vector meson production	Hafidi	B+	60	60		11	**D**	Nuclear
E12-06-117	Quark propagation and hadron formation	Brooks	A-	60	60		11	**E**	Nuclear
E12-10-102	Free Neutron structure at large x	Bueltman	A	40	40	Radial TPC	11	**F**	Gas D_2
TOTAL approved run time (PAC days)				1491	**559**				

Other reaction channels

- **DVMP** (for GPDs): π^0, π^-, ρ^0 , ρ^-, ω… (Problem: at leading twist TSA should vanish) **Christian Weiss**
- **nTCS: Pawel N. Turonsky**
- **nSIDIS: Silvia Pisano, Harut Avakian, Aurore Courtoy, Marco Contalbrigo**
- **Inclusive:** is more data necessary/pleasant to have? **Sebastian** (couldn't make it today)
- **Baryon resonances: Viktor Mokeev**, **Volker Burkert**, **Ralph Gothe**
- Nuclear physics folks?

Questions:

How will be the « extension proposal » be organized?

Do we need accurate simulations for each channel?

If yes: Manpower? Software tools (generators)?

Or can we do a detailed job for nDVCS only (it is already done…) and just talk about the physics relevance of the other reactions? ASK THE PAC!

Do we want to have a slightly different setup than for the first half?

Is the FT useful/interesting for other channels?

And what about the dual target design? Is it useful for everyone in RG-C?

Back up slides

PR12-15-004: Deeply Virtual Compton Scattering on the neutron with a longitudinally polarized deuterium target

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

Silvia Niccolai

PAC43, JLab, 7/7/2015

A CLAS collaboration proposal

Final remarks

*« The multi-dimensional imagining of the nucleon is **a core mission of the 12 GeV JLab program**. It hardly needs saying that **the flavor separation of GPDs is critical** to understanding the workings of the nucleon. Such separation requires studies not only with the proton as a target but with light nuclei too, so as **to allow access to a neutron** as a target. **This experiment using CLAS12 will provide a precise mapping of single and double target-spin asymmetries with an excellent coverage of phase space.** »*

*« The use of a longitudinally polarized target allows **target-spin and double spin asymmetries** to be measured, which are **directly related to CFFs**. These in turn are connected to the **real and imaginary parts of GPDs**, at particular kinematic points. World studies on the proton have begun and the newly completed Central Neutron Detector promises to **provide invaluable complementary information on the neutron**. This is **essential** to the success of this program.*

W. Melnitchouk, M.R. Pennington
Theory Center's Technical Advisory Report on PR12-15-004

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 ($-t \ll Q^2$)

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

Proton **Neutron**

Polarized **beam**, unpolarized target:

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

$Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \boldsymbol{\mathcal{E}}_\mathbf{n}\}$

Unpolarized beam, **longitudinal** target:

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

$Im\{\boldsymbol{\mathcal{H}}_\mathbf{n}, \mathcal{E}_n\}$

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

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

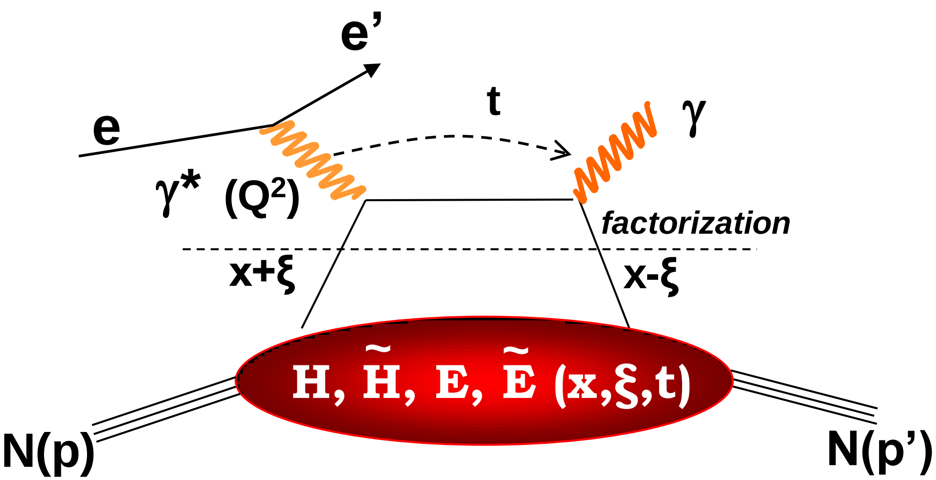
$Re\{\boldsymbol{\mathcal{H}}_\mathbf{n}, \mathcal{E}_n\}$

Unpolarized beam, **transverse** target:

$\boldsymbol{\Delta\sigma_{UT}} \sim \cos\phi\sin(\phi_s - \phi)\mathbf{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}$ $\Longrightarrow$ $Im\{\boldsymbol{\mathcal{H}}_\mathbf{p}, \boldsymbol{\mathcal{E}}_\mathbf{p}\}$

$Im\{\boldsymbol{\mathcal{H}}_\mathbf{n}\}$

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

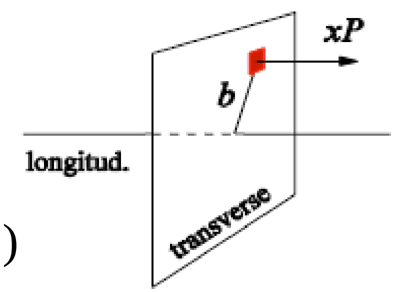
conserve nucleon spin	Vector: $H(x,\xi,t)$	Axial-Vector: $\tilde{H}(x,\xi,t)$
flip nucleon spin	Tensor: $E(x,\xi,t)$	Pseudoscalar: $\tilde{E}(x,\xi,t)$

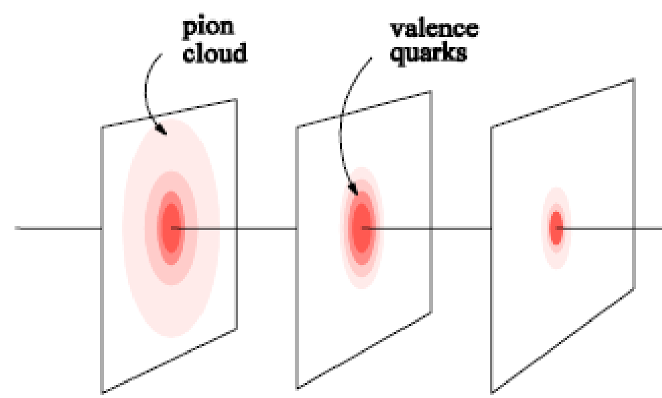
Nucleon tomography

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

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

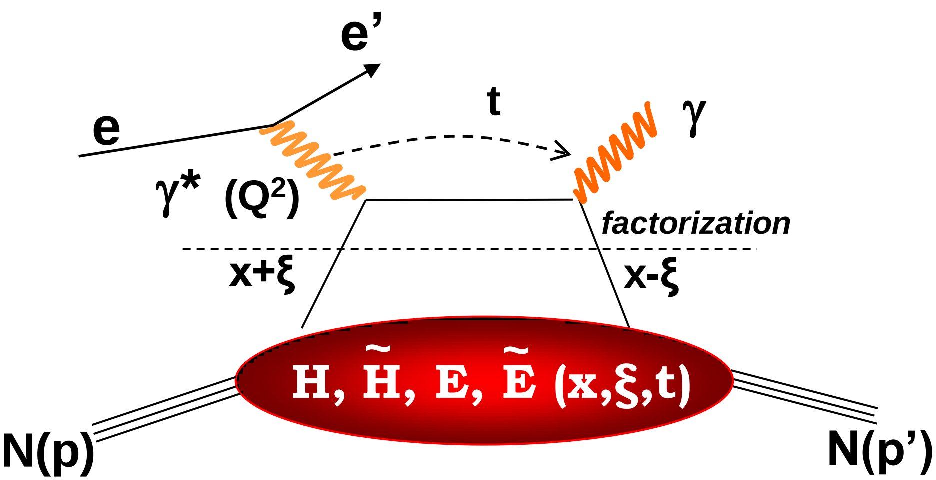
M. Burkardt, PRD 62, 71503 (2000)





$x < 0.1$ $\quad x \sim 0.3$ $\quad x \sim 0.8$

Deeply Virtual Compton Scattering and GPDs



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

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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)

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

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)

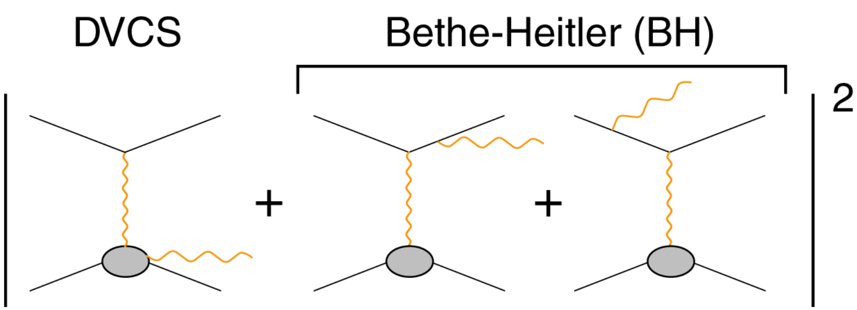
$$T^{DVCS} \sim P\int_{-1}^{+1} \frac{GPDs(x,\xi,t)}{x\pm\xi}dx \pm i\pi GPDs(\pm\xi,\xi,t)+\dots$$

Only ξ and t are accessible experimentally

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

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

σ(eN ⟶ eNγ) =

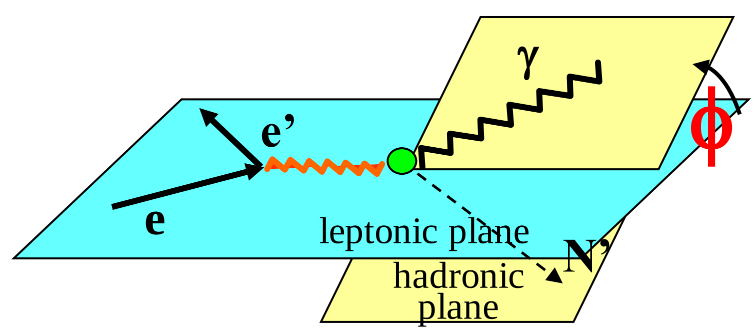


BH is calculable (electromagnetic FFs)

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

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

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



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:

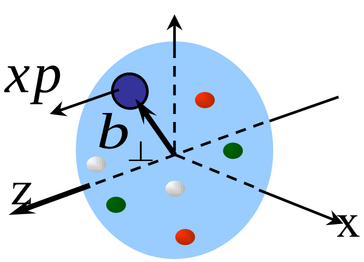
- ***Im$\mathcal{H}$* has steeper t-slope than *Im$\widetilde{\mathcal{H}}$*: axial charge more "concentrated" than the electric charge**

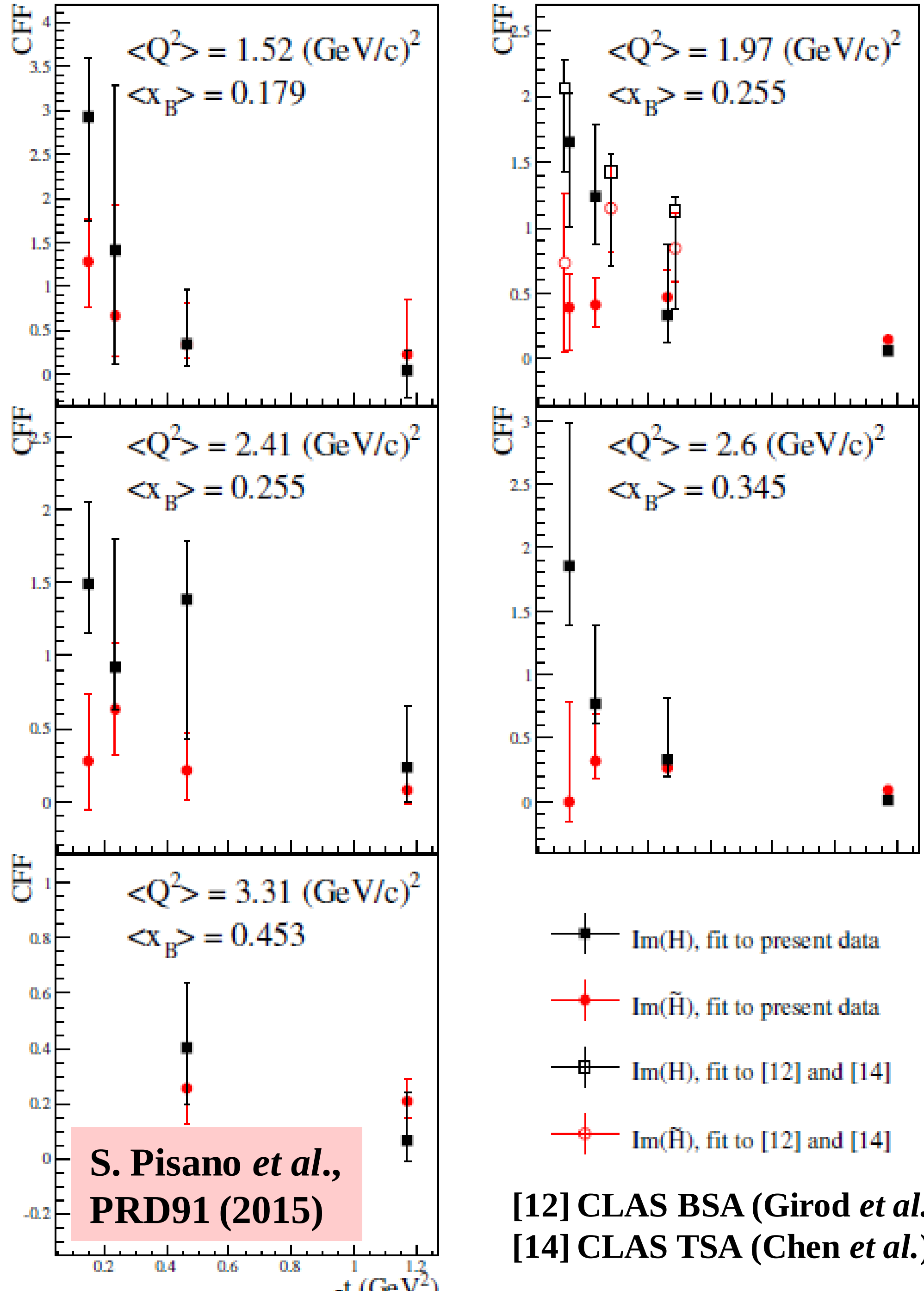
- ***Im$\mathcal{H}$*, flatter t-slope at high x_B: faster quarks (valence) at the core of the nucleon, slower quarks (sea) at its perifery**

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

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

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



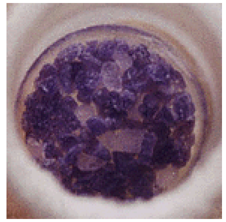


S. Pisano *et al.*, PRD91 (2015)

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

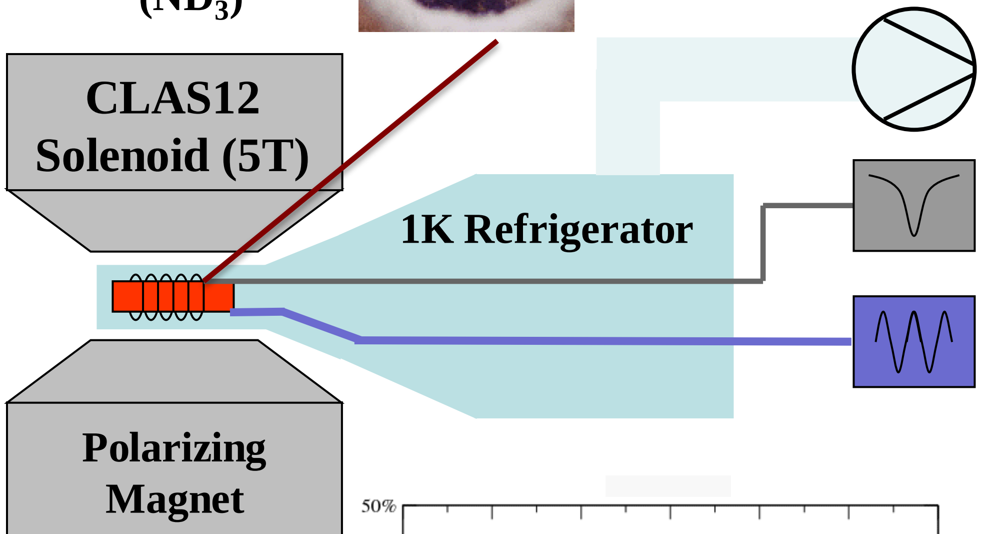
The CLAS12 longitudinally polarized target

Irradiated deuterated ammonia (ND_3)



UVA, ODU, CNU and JLab

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

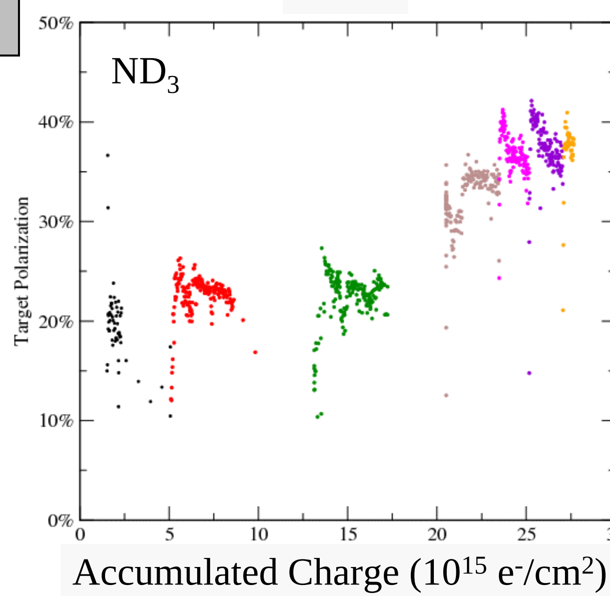


Pumping system

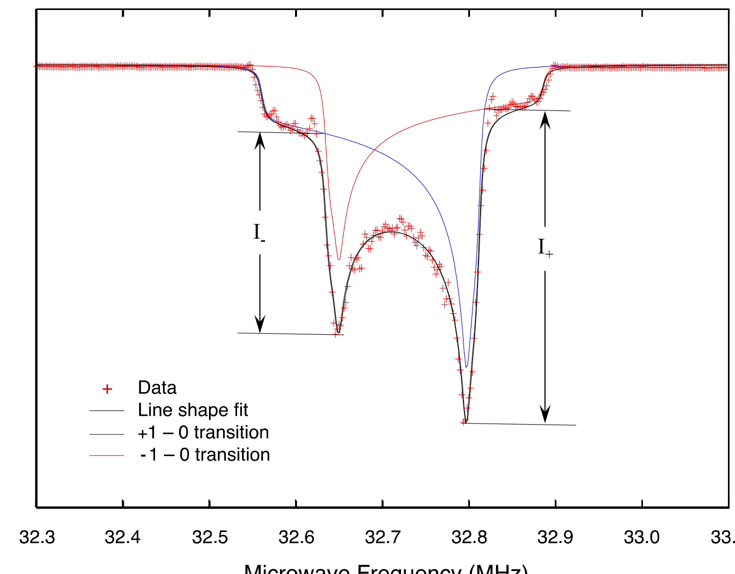
NMR

Microwaves (140 GHz @ 5T)

ND_3 polarization improves with "cold dose"

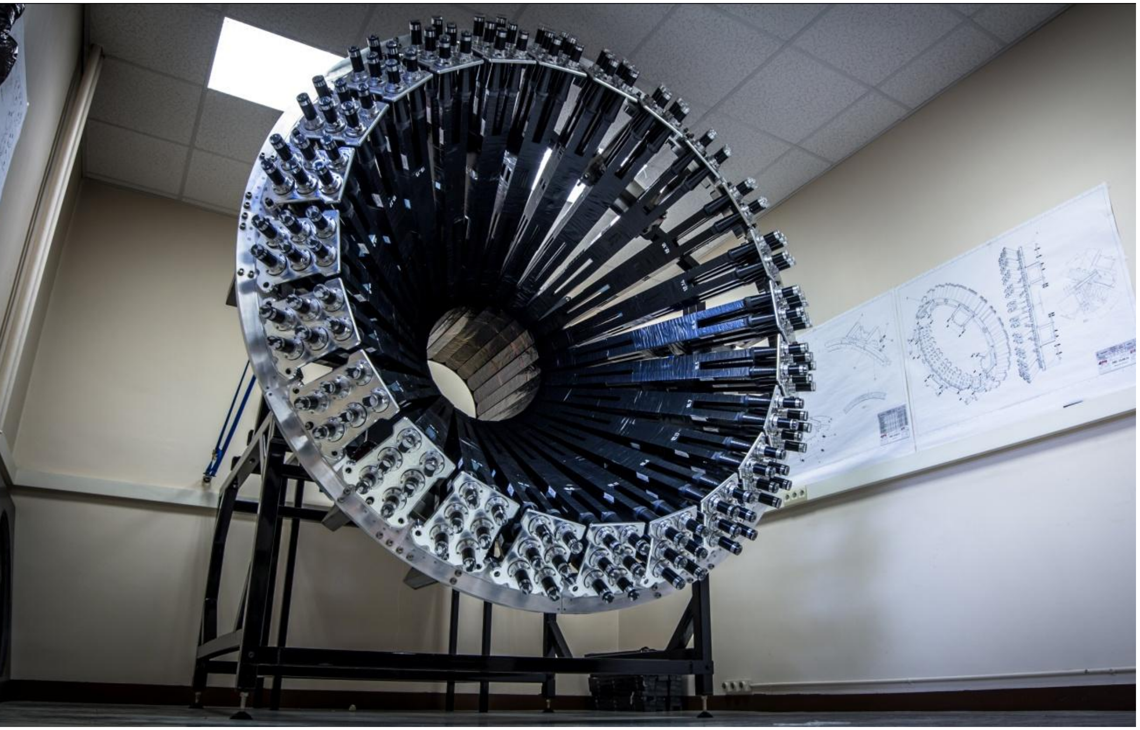


NMR line shape of ND_3



Central Neutron Detector (CND)

Main physics goal: detect the recoiling neutron in nDVCS → The CND must ensure:
- **good neutron/photon separation for $0.2<p_n<1$ GeV/c → ~150 ps time resolution**
- **momentum resolution $\delta p/p < 10\%$**
- **no stringent requirements for angular resolutions**

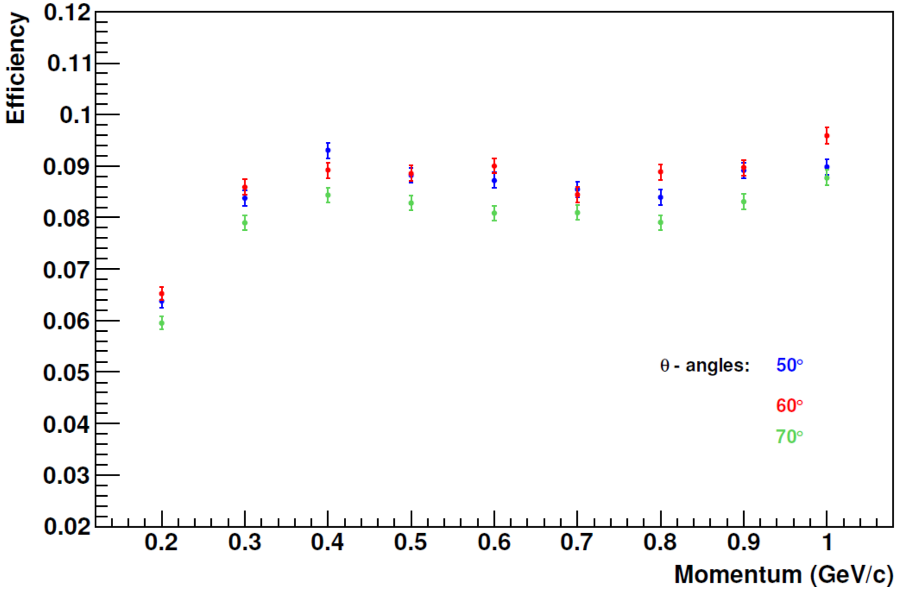


Project status:
- **CONSTRUCTION COMPLETED**
- Detector shipped to JLab (9 boxes, 2.5 tons), **received on 6/2/2015**
- HV calibrations of PMTs completed
- Simulations for radiation dose
- Strength tests for glue
- In-field tests for shieldings
- Assembly in mechanical structure done in Orsay
- **Cosmic data analysis: σ_t ~150 ps for all blocks**

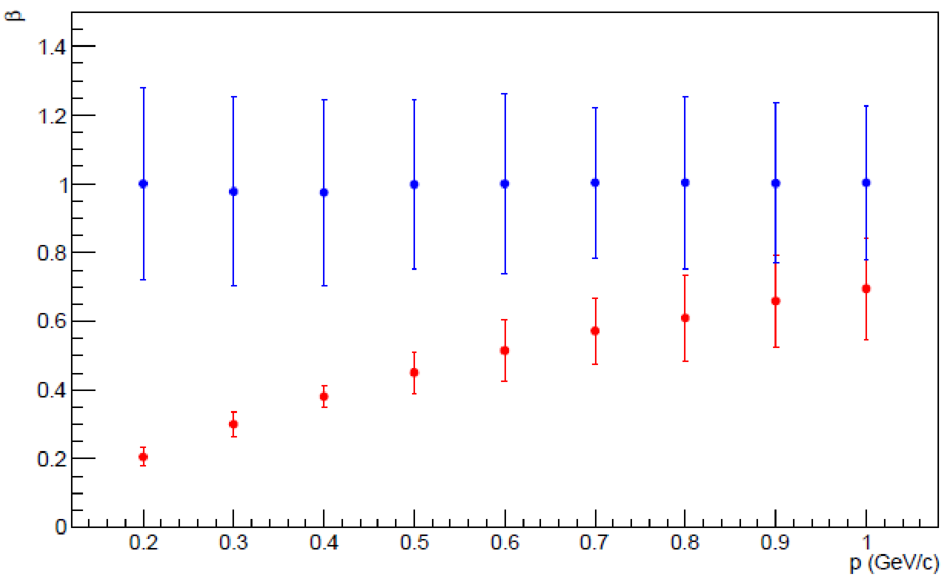
CND design: scintillator barrel - 3 radial layers, 48 bars per layer coupled two-by-two downstream by a "u-turn" lightguide, 144 long light guides with PMTs upstream

IPN ORSAY

CND: expected performances (Monte Carlo)

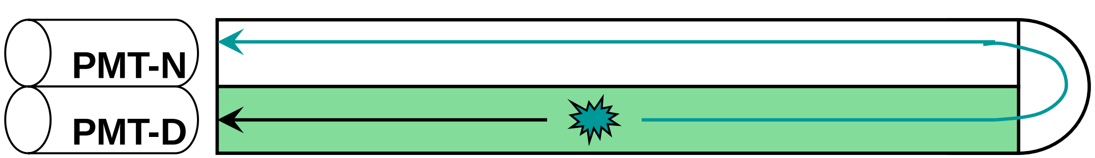


GEANT4 simulations used to evaluate:
- efficiency
- PID (neutron/photon separation)
- momentum and angular resolutions
- definition of reconstruction algorithms
- background studies



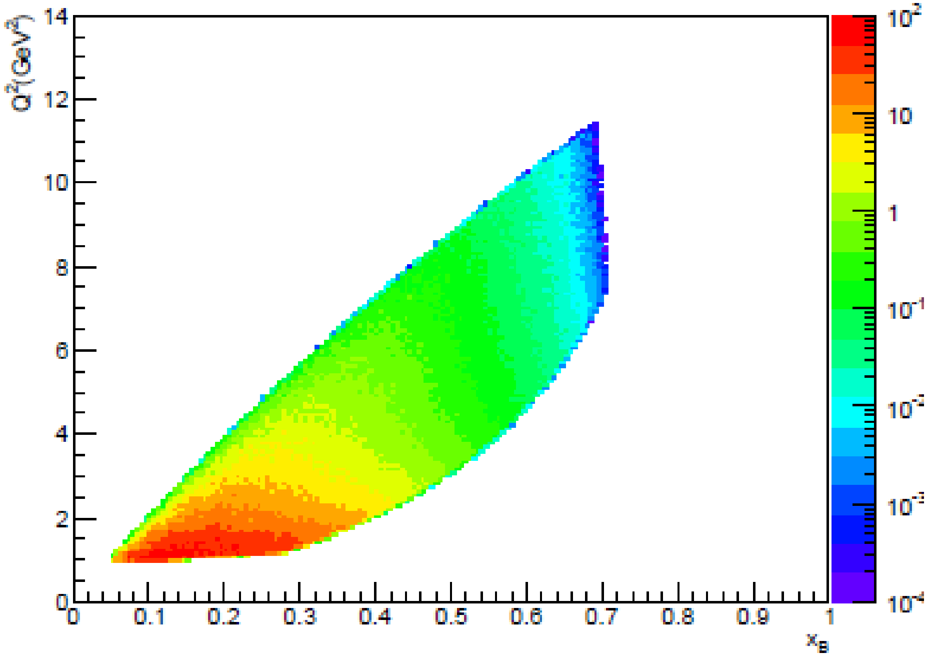
Measured σ_t and light loss due to u-turn implemented in the simulation

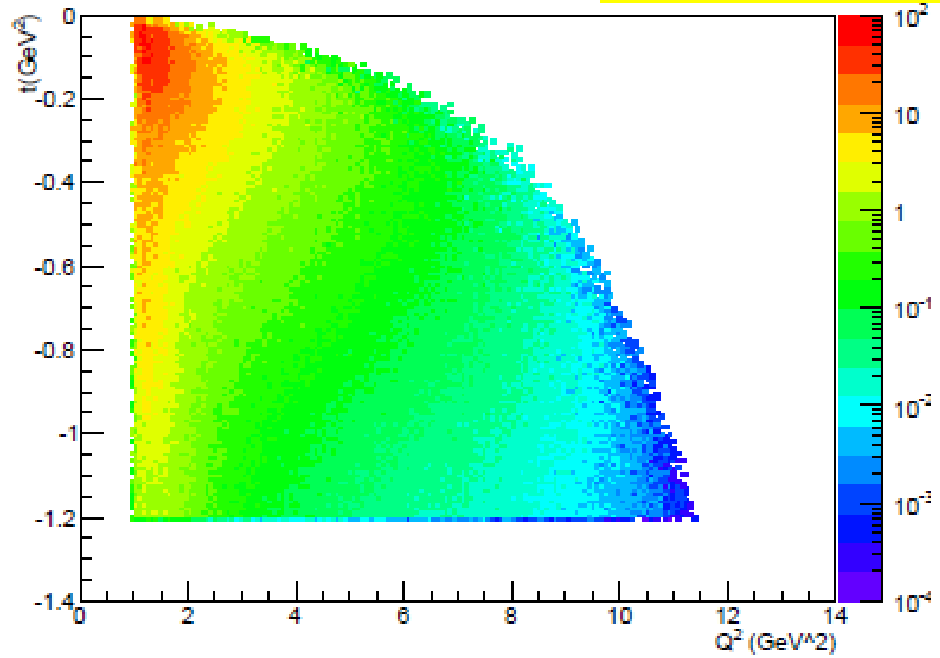
Efficiency ~ 8-9%
for a threshold of 3 MeV, TOF<8 ns
and p_n = 0.2 - 1 GeV/c

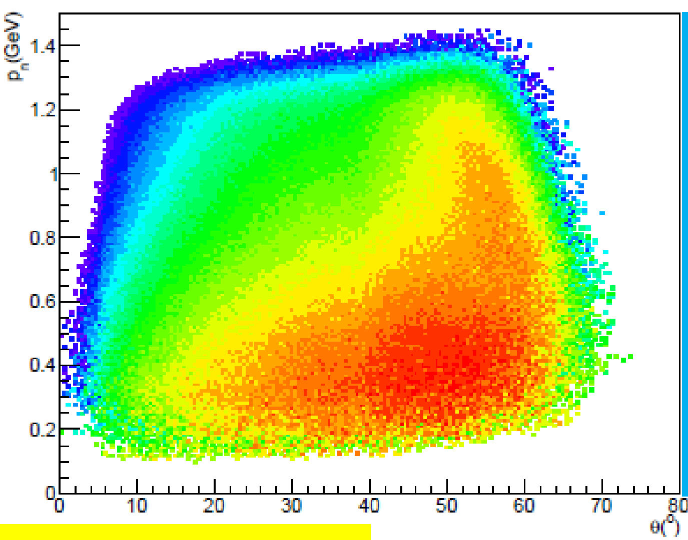


nDVCS@CLAS12: kinematics and acceptances

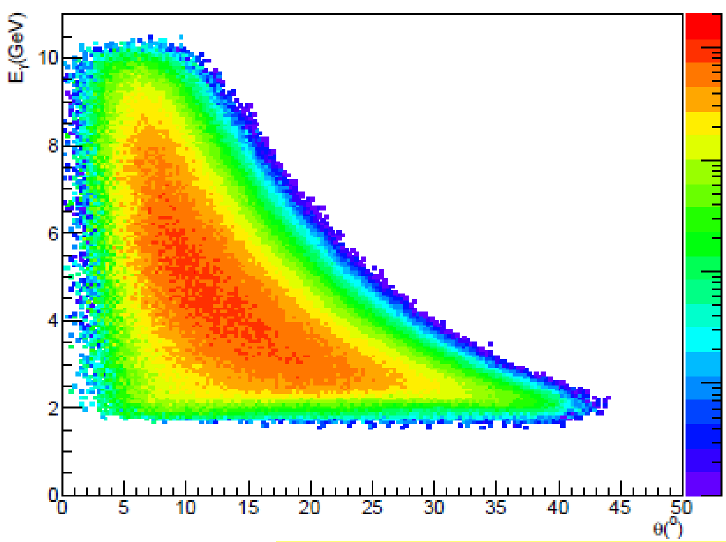
ed→e'nγ(p)







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

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

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

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

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**

Definitions of nDVCS observables

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

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

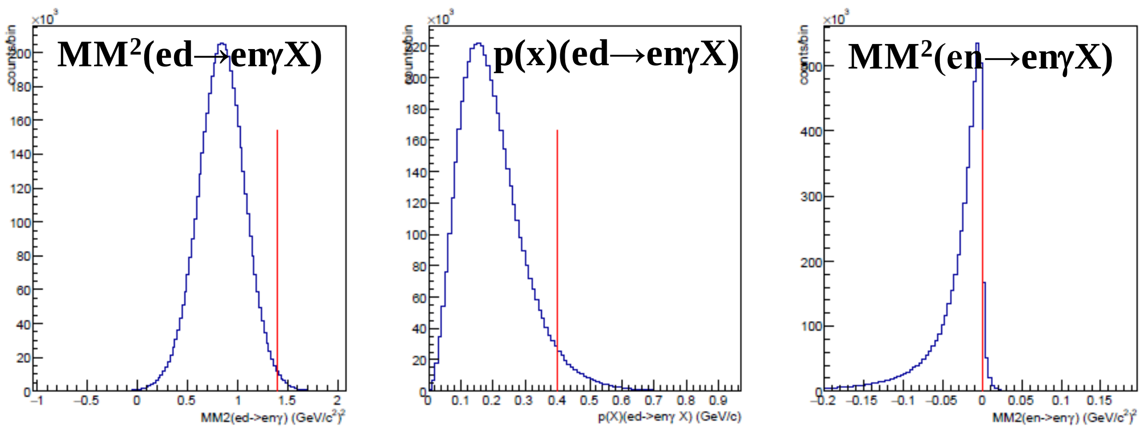
Target-spin asymmetry

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

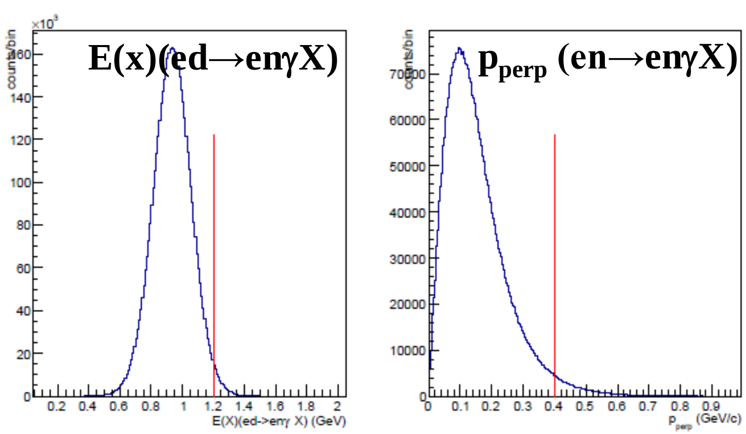
$$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{D_f P_b\left(P_t^-\left(N^{++} + N^{-+}\right) + P_t^+\left(N^{+-} + N^{--}\right)\right)}$$

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)

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

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

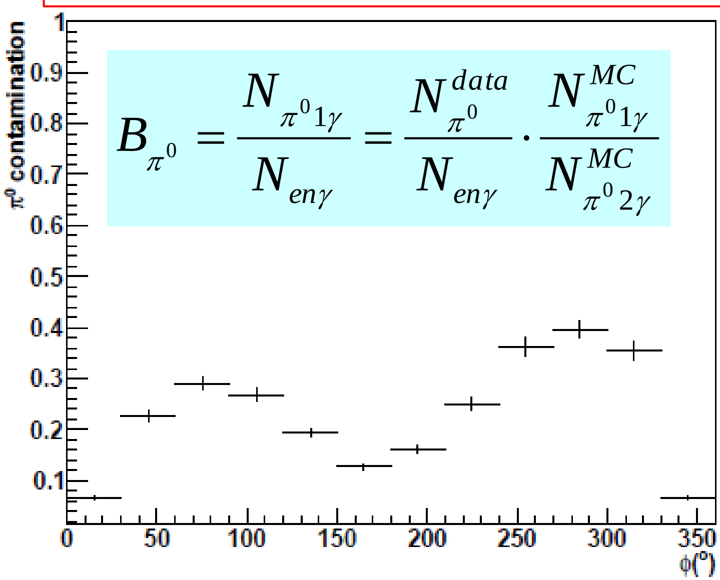
$Re\{\mathcal{H}_n, \mathcal{E}_n\}$

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

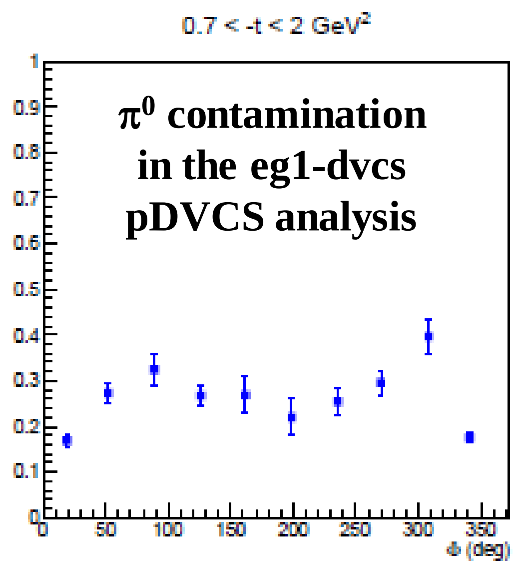
Charge-normalized DVCS/BH yield

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

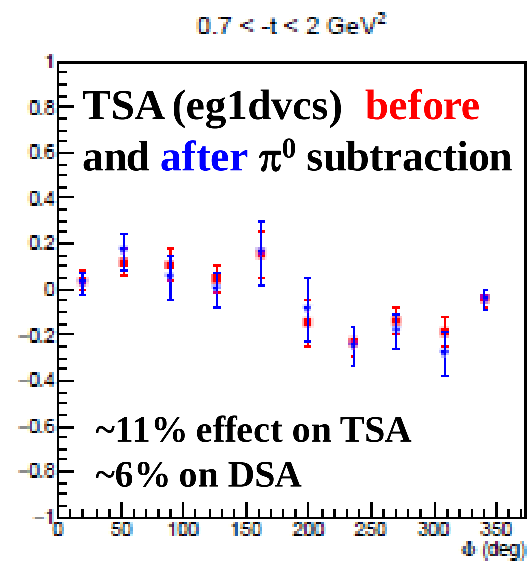
Projected π^0 contamination vs ϕ



$$B_{\pi^0} = \frac{N_{\pi^0 1\gamma}}{N_{en\gamma}} = \frac{N_{\pi^0}^{data}}{N_{en\gamma}} \cdot \frac{N_{\pi^0 1\gamma}^{MC}}{N_{\pi^0 2\gamma}^{MC}}$$



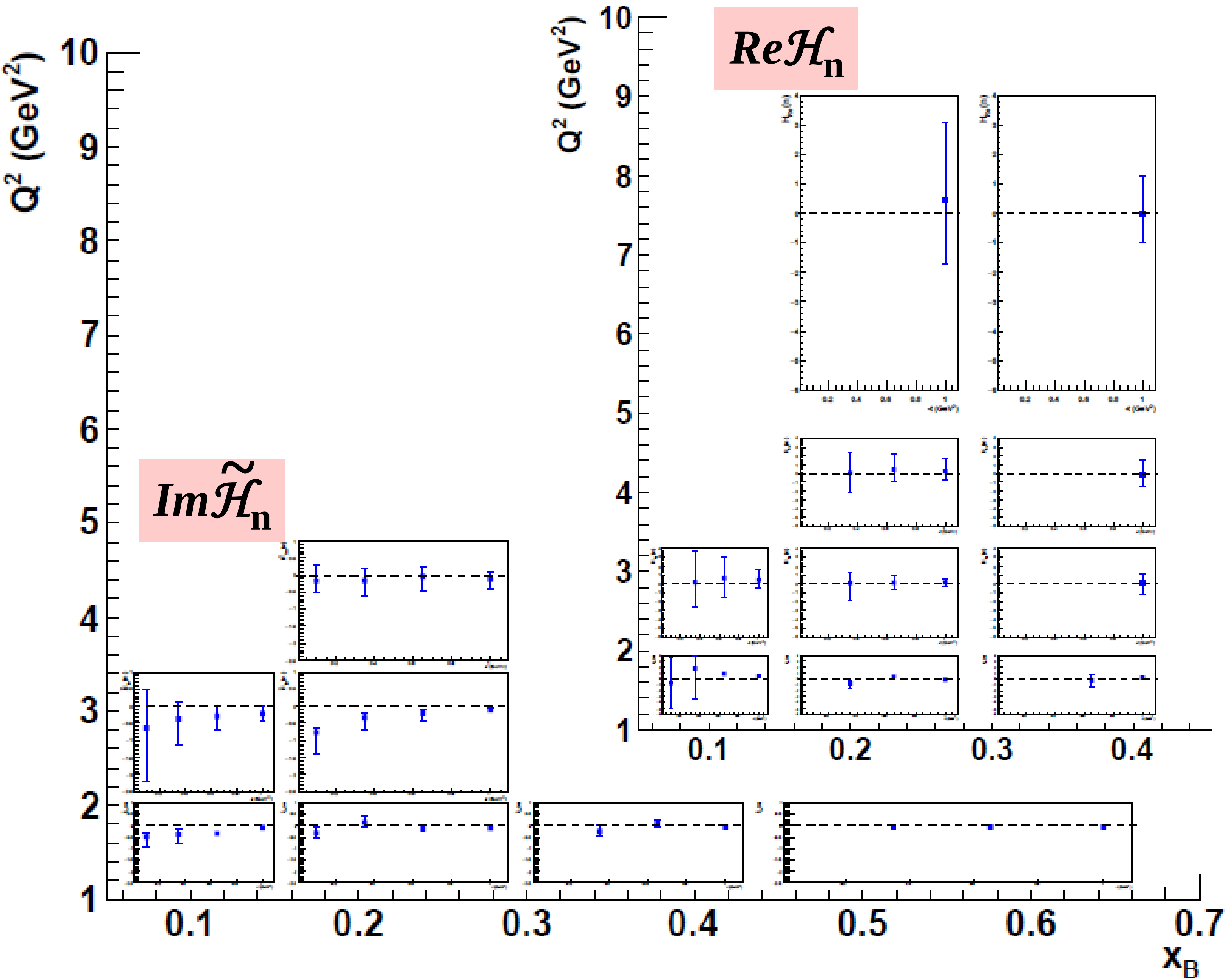
π^0 contamination in the eg1-dvcs pDVCS analysis



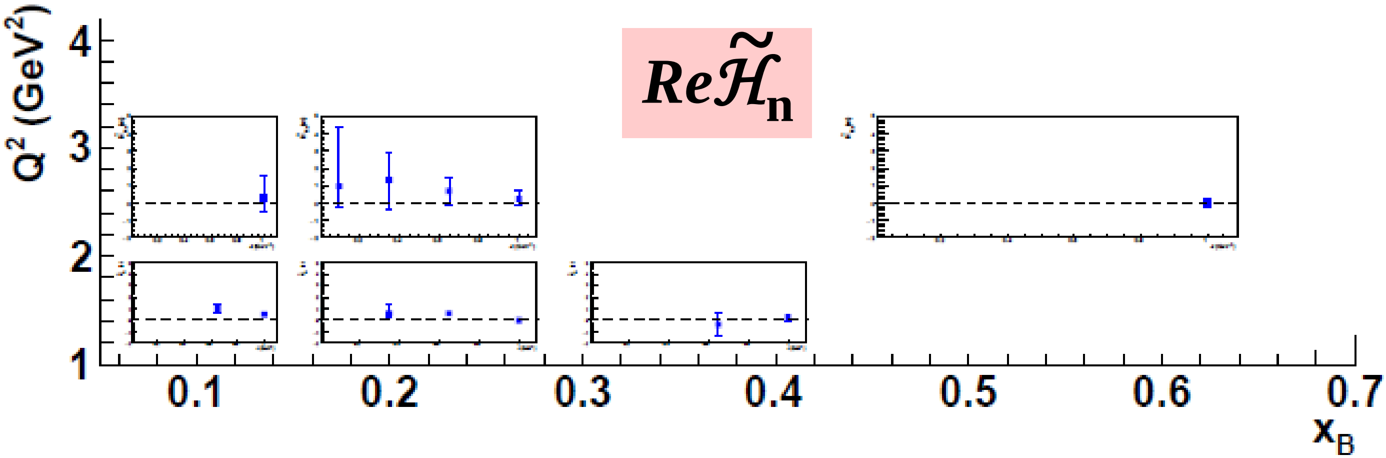
TSA (eg1dvcs) before and after π^0 subtraction

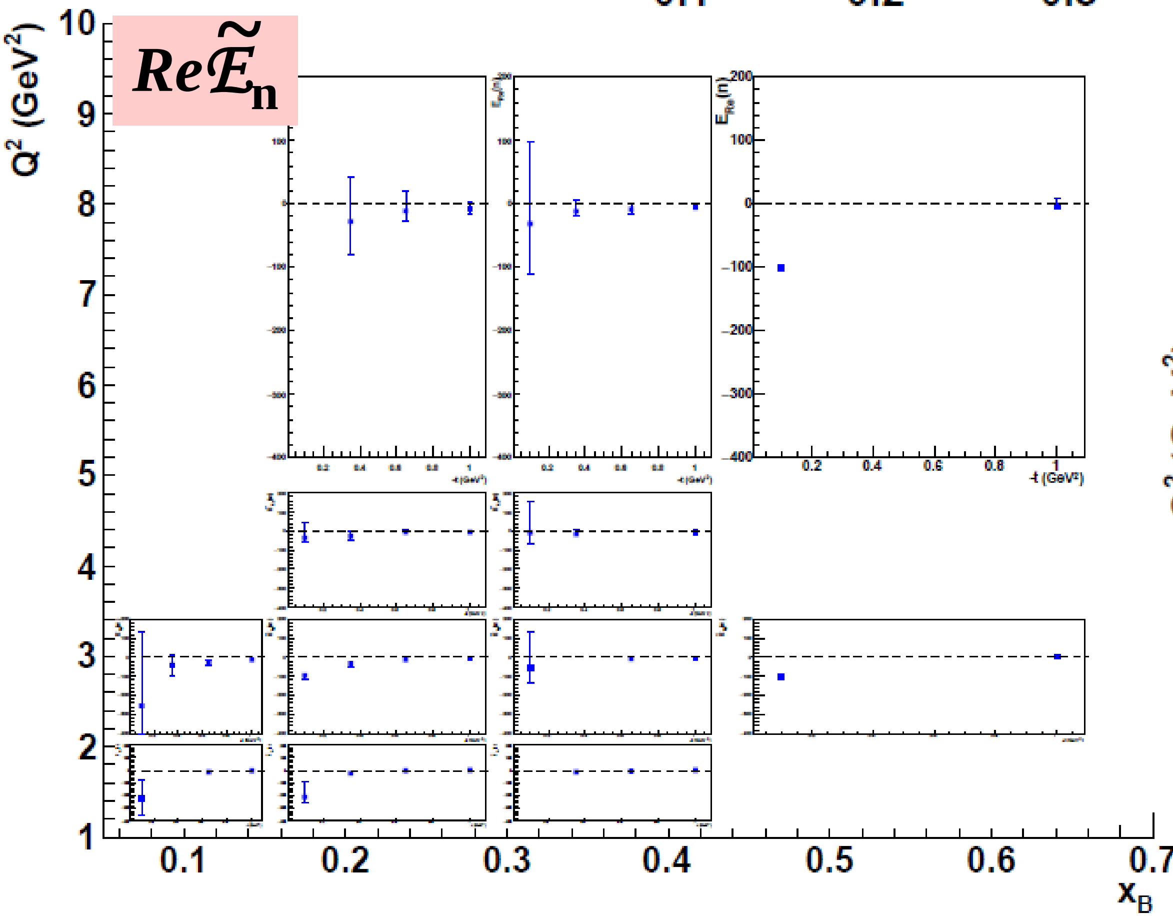
~11% effect on TSA
~6% on DSA

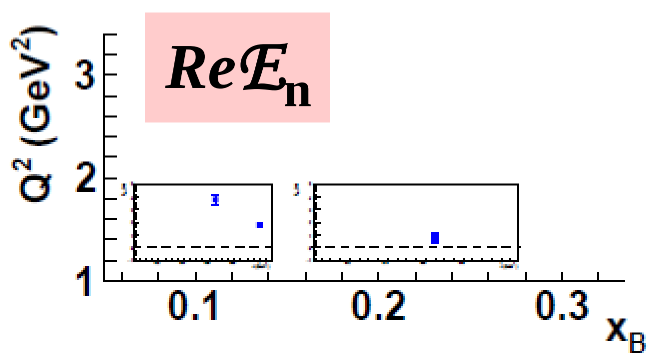
Combined analysis of PR12-15-004 and E12-11-003



Combined analysis of PR12-15-004 and E12-11-003

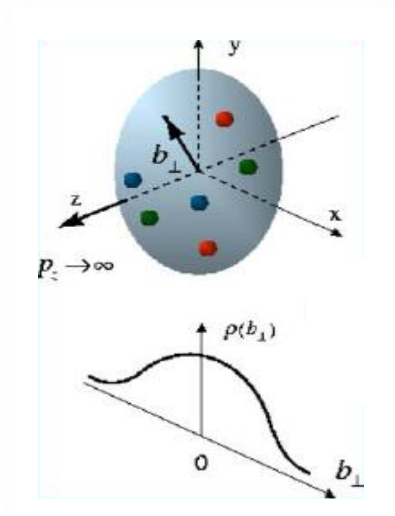


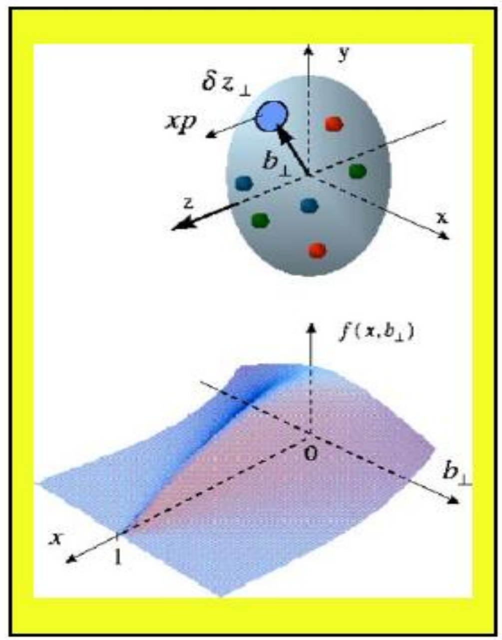


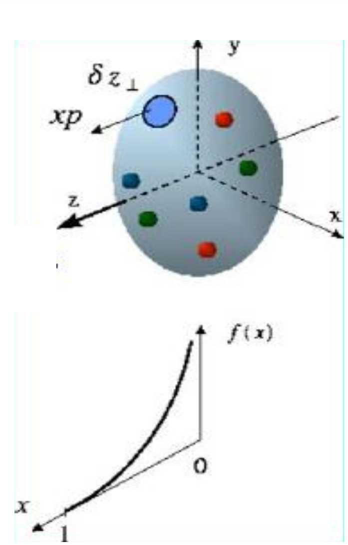


Electron scattering to study nucleon structure

GPDs: H, E, $\tilde{H}$, $\tilde{E}$
Fully correlated quark distributions in both coordinate and momentum space

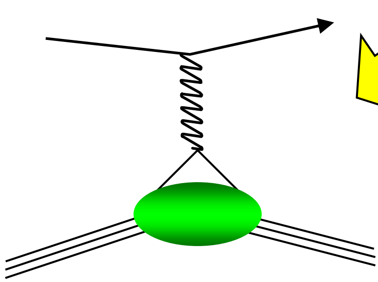


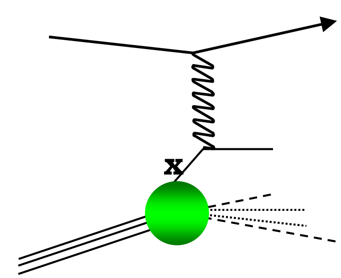




Form factors: **transverse quark distribution** in coordinate space

Parton distributions: **longitudinal quark distribution** in momentum space





$$\int H(x,\xi,t)dx = F_1(t) \quad (\forall\ \xi)$$
$$\int E(x,\xi,t)dx = F_2(t) \quad (\forall\ \xi)$$

Accessible in hard exclusive processes

$$H(x,0,0) = q(x),$$
$$\tilde{H}(x,0,0) = \Delta q(x)$$

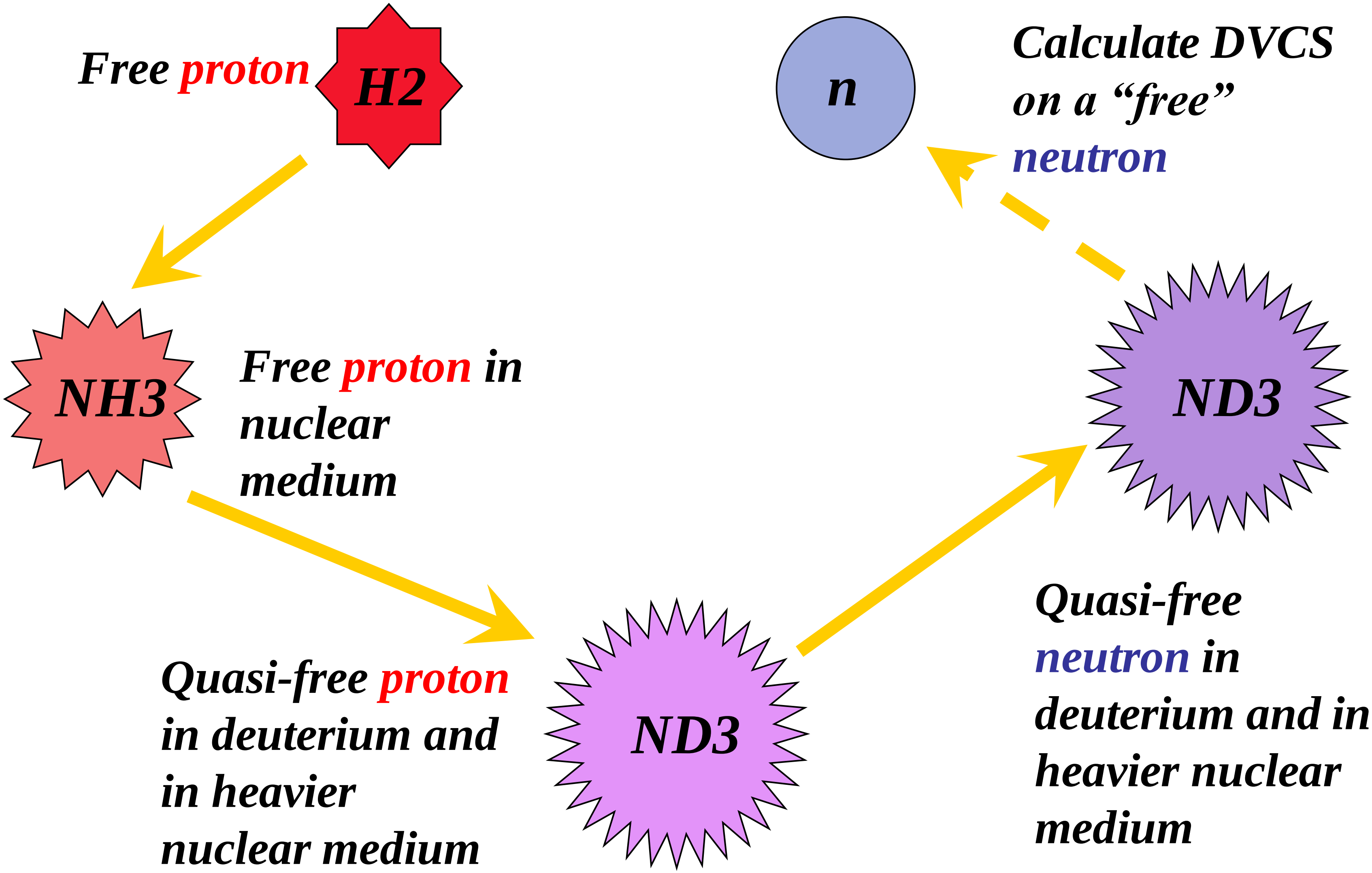
Target Overhead

Operation	Frequency	Number	Time required	Total
Cold dose	na	3	24 hr	72 hr
NMR calibration	8 days	12	4 hr	48 hr
Anneal	4 days	17	4 hr	68 hr
Sample change	25	2	8 hr	16 hr

Overhead total: 8.5 days

Experience has shown that the overhead can be significantly reduced by coordinating target operations with beam outages.

Extracting n-DVCS from ND3 data



Accidentals in the CND

• Electromagnetic background studies were carried out for E12-11-003 (liquid deuterium target): **negligible effects on the CND**
• **ND_3** target can bring **higher background:**

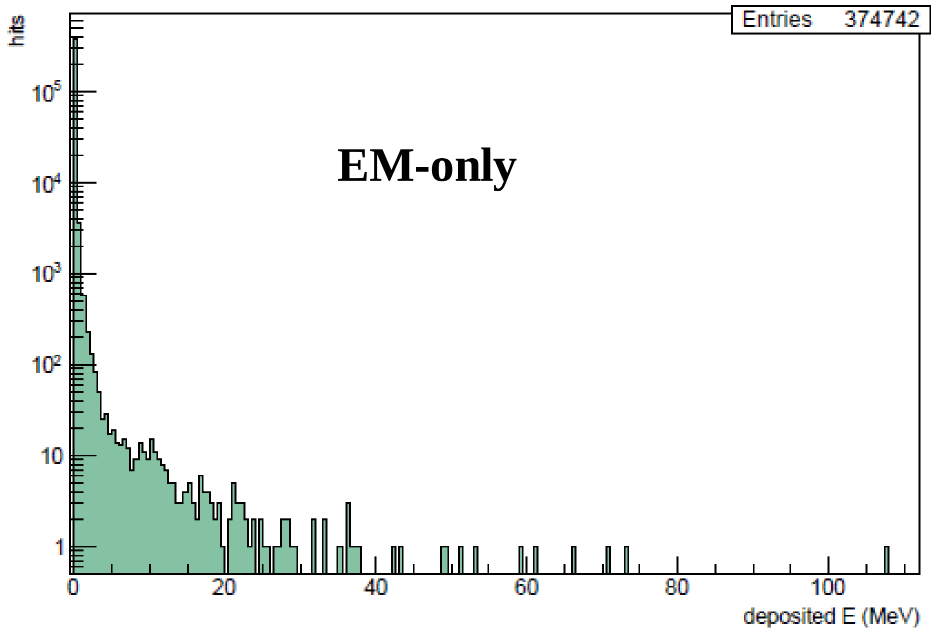
Gemc simulations of background:
ND_3 target, 10 nA, 124 ns, $L=10^{35}$ cm^2 s^{-1}

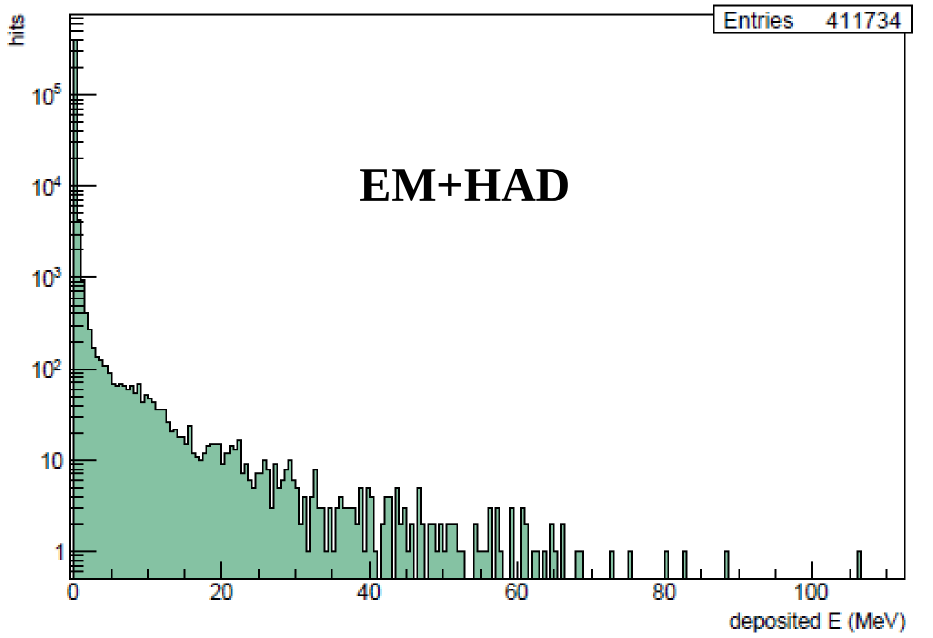
CND reconstruction **cuts for neutrons** (Edep, β)

Different physics list tested:
- **Electromagnetic only**: probability of accidentals passing CND cuts **0.0012**
- **Electromagnetic + Hadronic** (2 cases tested, ~same results): probability **0.007**

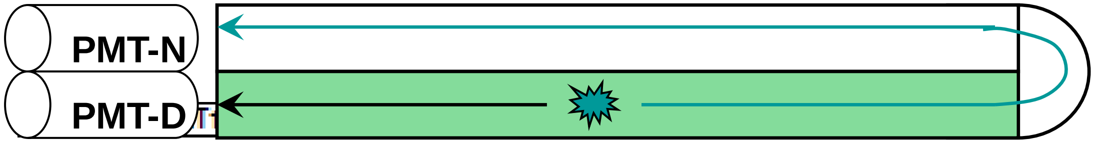
Count rate for eγ events with $E_\gamma>2$ ~ 50 hz (upper limit, π^0 SIDIS ~9 hz)

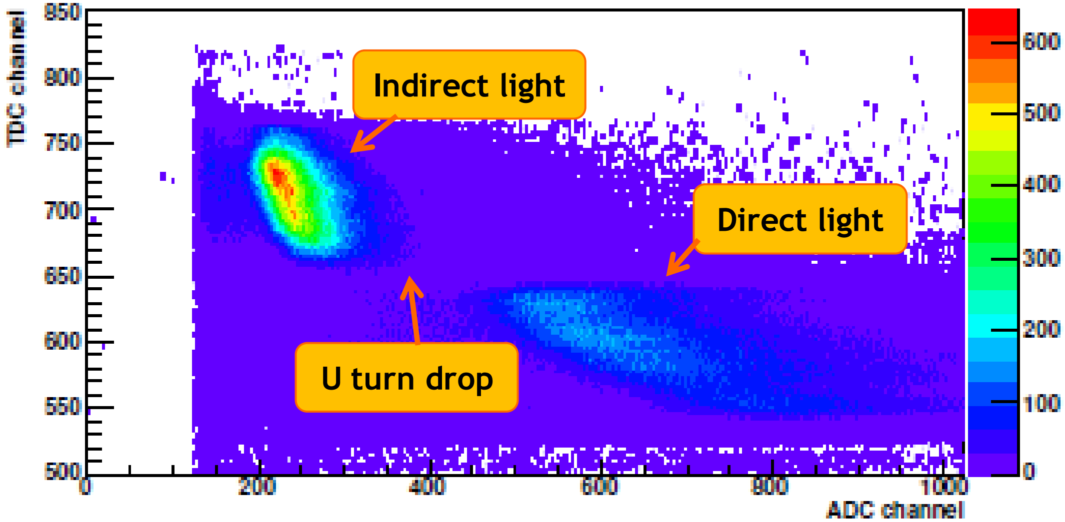
Cout rate for accidentals: 0.06 hz for EM; 0.35 hz for EM+HAD (before exclusivity cuts)
Count rate for real enγ events: ~1 hz



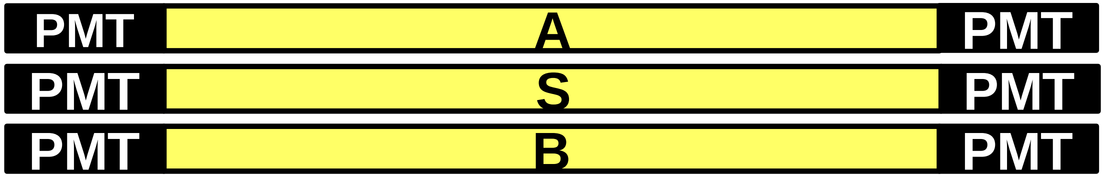


CND: performances (cosmic data)





Triple-coincidence measurement (one week of data per block)

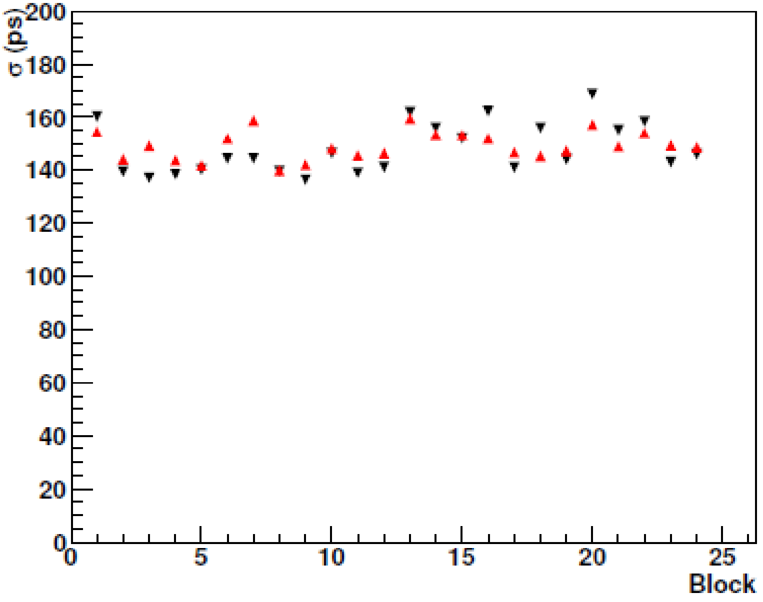


$$T_{ref} = (T_{AL} + T_{AR} - T_{BL} - T_{BR})/2$$

$$T_S = (T_{SL} + T_{SR})/2$$

$$T_{cosmic} = (T_{AL} + T_{AR} + T_{BL} + T_{BR})/4 - T_S$$

$$\sigma_S = \sqrt{\sigma^2{}_{cosmic} - (\sigma_{ref}/2)^2}$$



Extraction of Compton Form Factors from DVCS observables

8 CFF

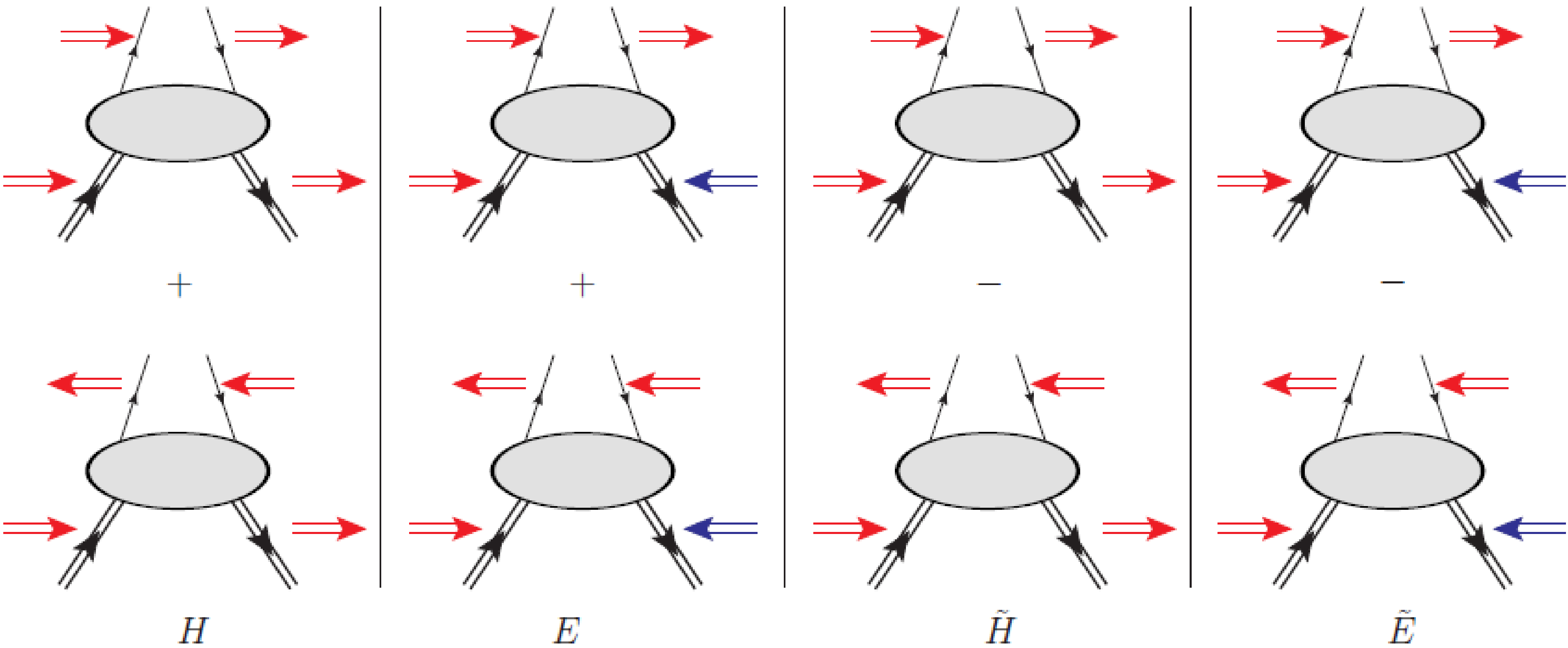
$$\left\{\begin{aligned}
\mathrm{Re}(\mathcal{H}) &= P\int_0^1 dx\left[H(x,\xi,t)-H(-x,\xi,t)\right]C^+(x,\xi)\\
\mathrm{Re}(\mathcal{E}) &= P\int_0^1 dx\left[E(x,\xi,t)-E(-x,\xi,t)\right]C^+(x,\xi)\\
\mathrm{Re}(\tilde{\mathcal{H}}) &= P\int_0^1 dx\left[\tilde{H}(x,\xi,t)+\tilde{H}(-x,\xi,t)\right]C^-(x,\xi)\\
\mathrm{Re}(\tilde{\mathcal{E}}) &= P\int_0^1 dx\left[\tilde{E}(x,\xi,t)+\tilde{E}(-x,\xi,t)\right]C^-(x,\xi)\\
\mathrm{Im}(\mathcal{H}) &= H(\xi,\xi,t)-H(-\xi,\xi,t)\\
\mathrm{Im}(\mathcal{E}) &= E(\xi,\xi,t)-E(-\xi,\xi,t)\\
\mathrm{Im}(\tilde{\mathcal{H}}) &= \tilde{H}(\xi,\xi,t)-\tilde{H}(-\xi,\xi,t)\\
\mathrm{Im}(\tilde{\mathcal{E}}) &= \tilde{E}(\xi,\xi,t)-\tilde{E}(-\xi,\xi,t)
\end{aligned}\right.$$

$$\text{with } C^{\pm}(x,\xi)=\frac{1}{x-\xi}\pm\frac{1}{x+\xi}$$

M. Guidal: **Model-independent fit**, at fixed Q^2, x_B and t of DVCS observables
8 unknowns (the CFFs), non-linear problem, strong correlations
Bounding the domain of variation of the CFFs with model (5xVGG)
M. Guidal, Eur. Phys. J. A 37 (2008) 319

Deeply Virtual Compton Scattering and GPDs

At leading order QCD, twist 2, chiral-even (quark helicity is conserved), quark sector
→ 4 GPDs for each quark flavor

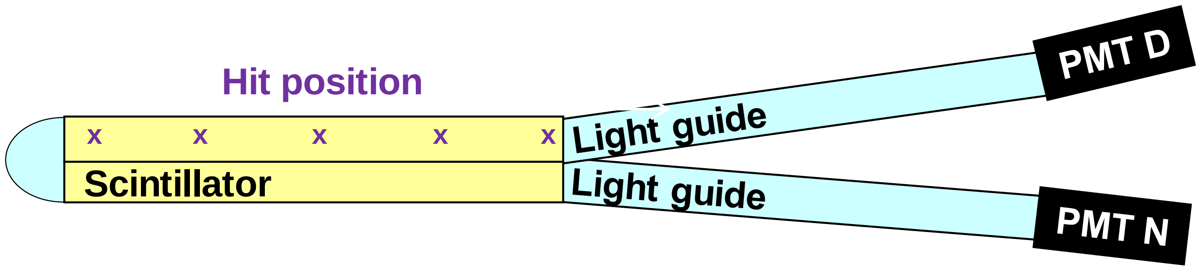


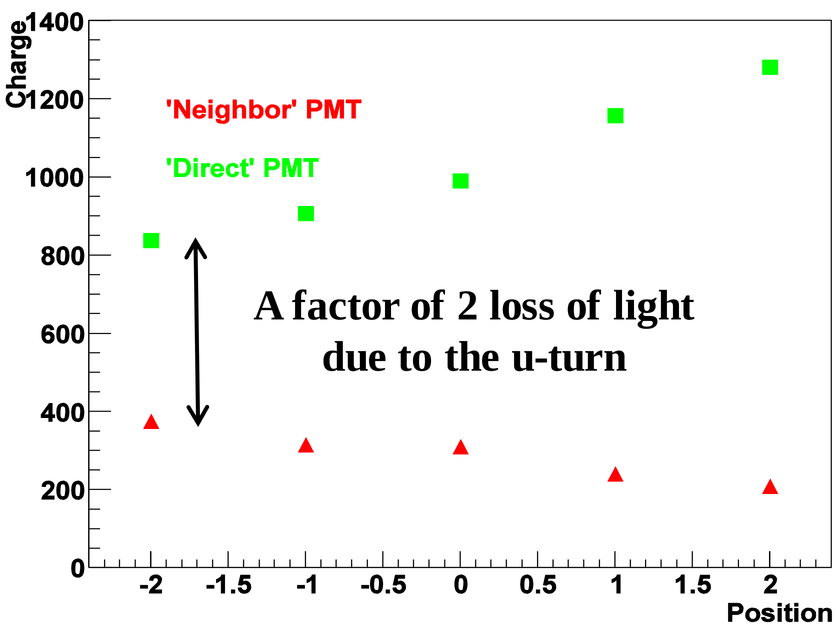
conserve nucleon spin **Vector: H (x,ξ,t)** **Axial-Vector: $\tilde{H}$ (x,ξ,t)**

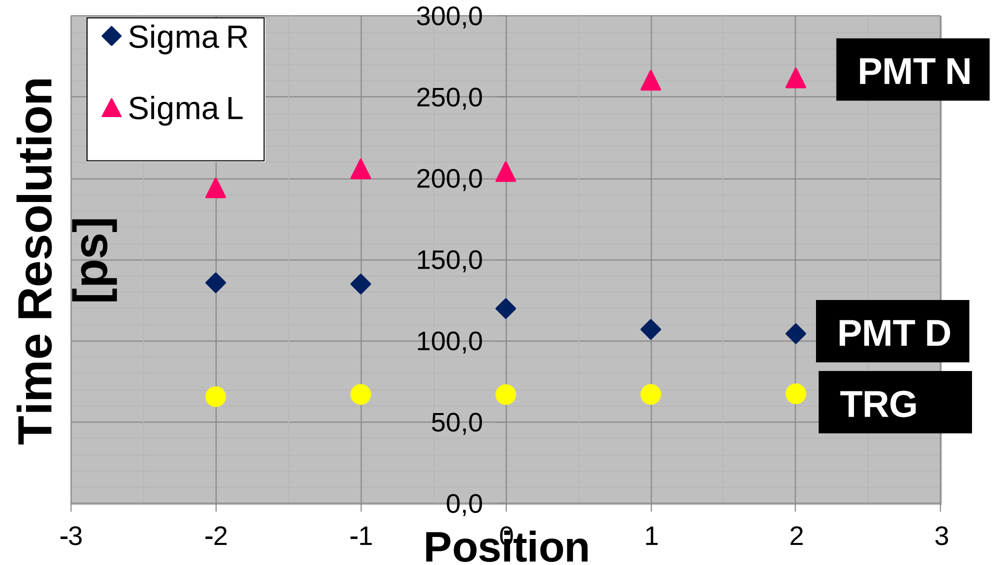
flip nucleon spin **Tensor: E (x,ξ,t)** **Pseudoscalar: $\tilde{E}$ (x,ξ,t)**

One-layer prototype

2 scintillators BC408 (700 mm long) coupled to two PMTs R2083 (R9779) by means of 1500 mm long light guide, wrapping with Al foil, semicircular light guide at the “u-turn”

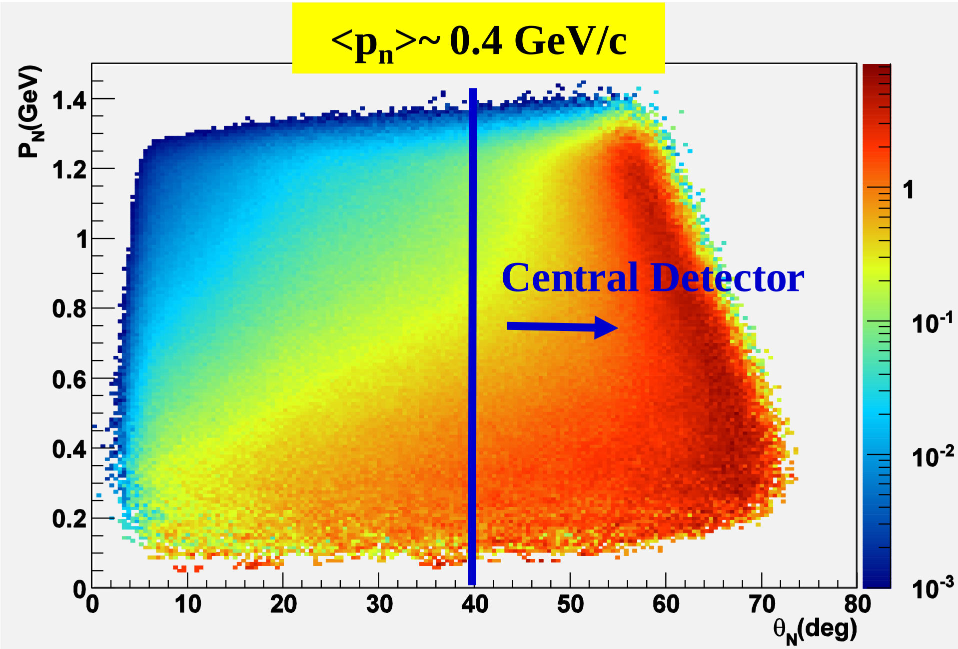






$\sigma(D) \in [105, 136]$ ps
$\sigma(N) \in [194, 262]$ ps

CND: requirements



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

Detected in forward CLAS12

Not detected

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

Detected in CND

Detected in EC, FC

$$\mathbf{p^\mu_e + p^\mu_n + p^\mu_p = p^\mu_{e'} + p^\mu_{n'} + p^\mu_{p'} + p^\mu_\gamma}$$

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

$\mathbf{p^\mu_p = p^\mu_{p'}} \to$ **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

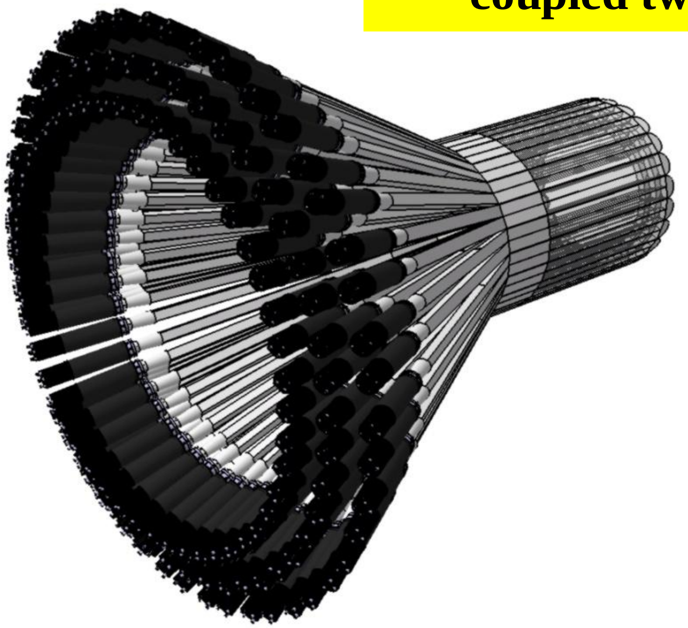
Resolution on **MM(enγ)** studied with nDVCS event generator + electron and photon resolutions obtained from CLAS12 FastMC
+ design specs for Forward Calorimeter
→ dominated by photon resolutions

→ 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

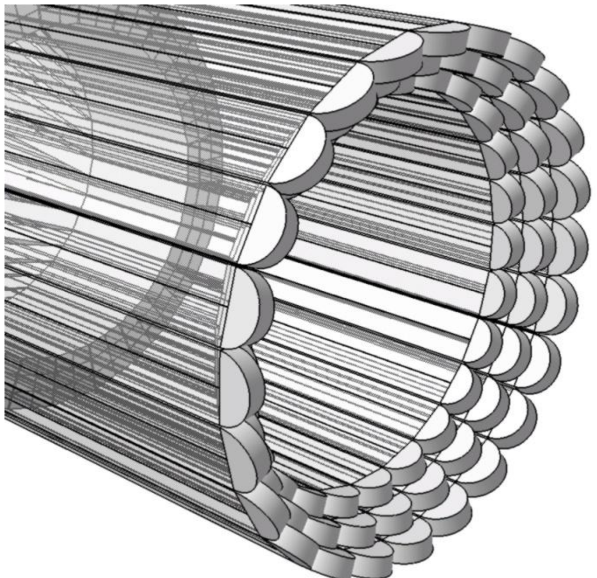
CND: constraints and chosen design

➢ **CTOF** can also be used for neutron detection
➢ Central Tracker (SVT+MM): **veto for charged particles**
• **limited space available** (~10 cm thickness)
→ limited neutron detection efficiency
→ no space for light guides upstream
• **strong magnetic field** (~5 T) → problems for light readout
Three kinds of ***B-field-resistant photodetectors*** *tested:* ***SIPMs, APDs, MCP-PMs***

Final design: scintillator barrel
3 radial layers, 48 bars per layer
coupled two-by-two by "u-turn" lightguides



The light comes out only at the upstream side of the CND, goes through bent light guides (1.5m) arriving to ordinary PMTs, placed in the low-field region



Chosen design for the CND

- **Plastic scintillator**: compromise between **neutron efficiency** (~1% /cm) and **fast response**
- Photon-neutron separation → measurement of **β** via Time-Of-Flight

$$\beta = \frac{l}{TOF \cdot c}$$

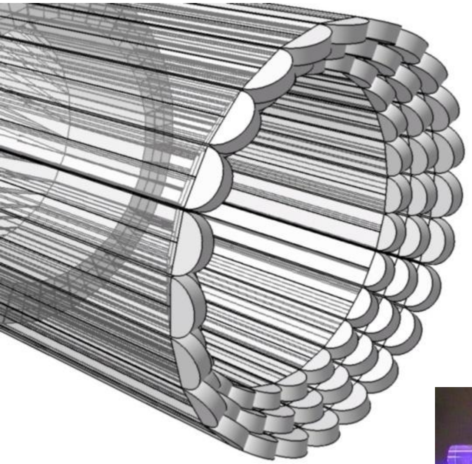
TOF: time from the interaction vertex to the impact point; *l:* path lenght
β+ PID (m) → momentum

$$l = \sqrt{z^2 + h^2}$$

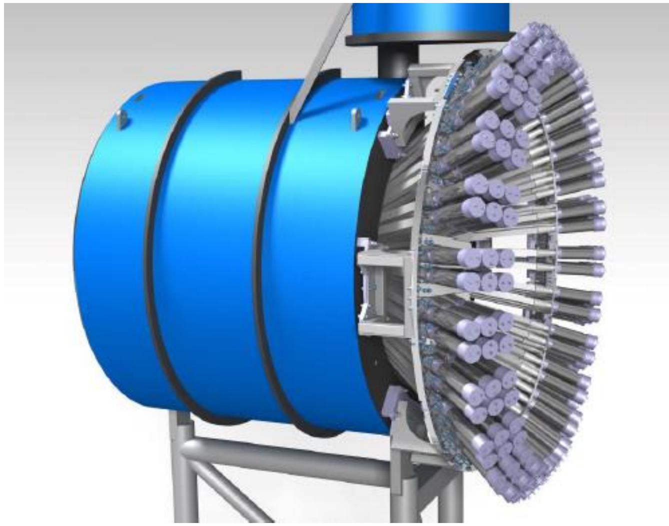
z: hit position along the scintillator bar;
h: radial distance of the hit from the vertex → requires **radial segmentation**

$$z = \frac{1}{2} v_{eff} \left(t_{left} - t_{right} \right)$$

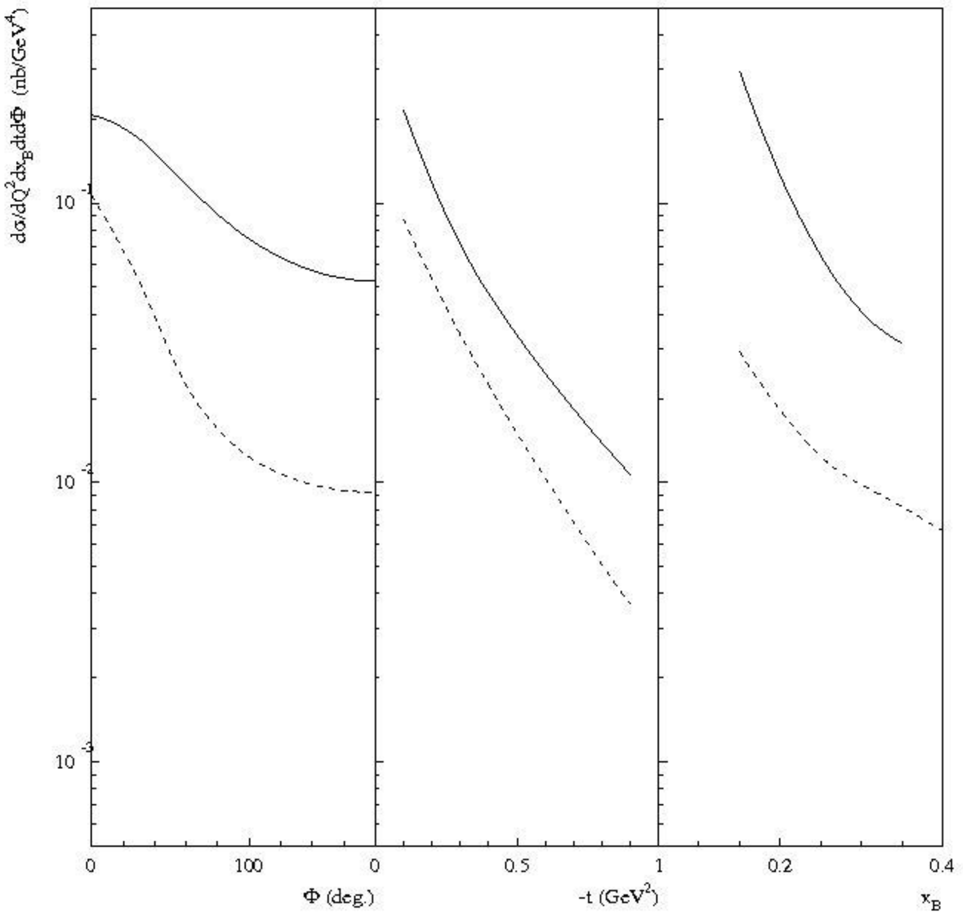
v_{eff} : light velocity in the scintillator bar;
$t_{left,right}$: time measured at the two ends of the bar→ **double readout**
z → θ



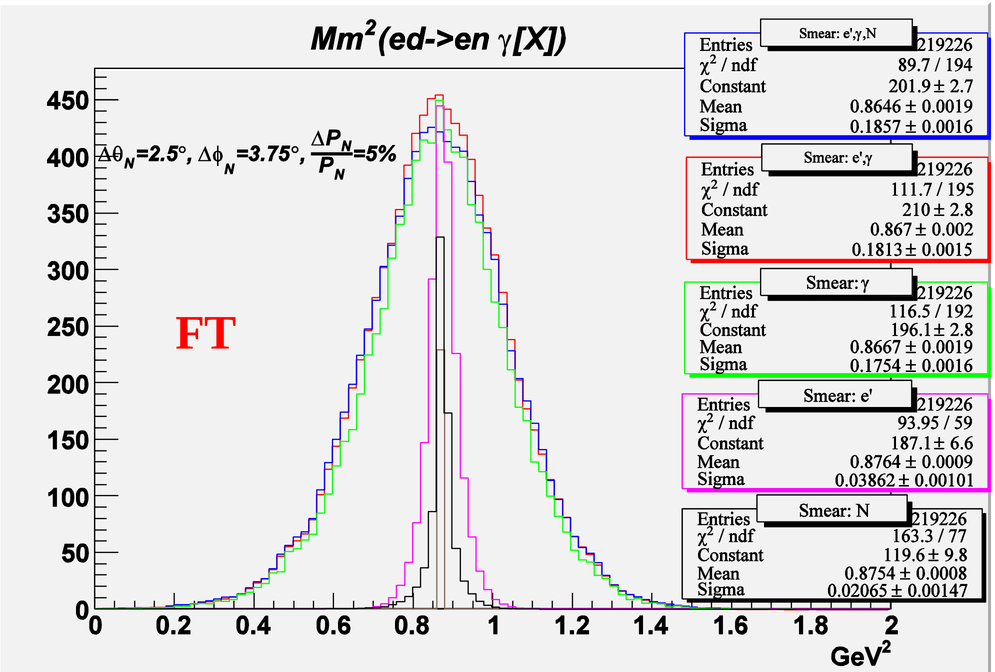
CND design: **scintillator barrel**
3 radial layers, 48 bars per layer
coupled two-by-two by **"u-turn" lightguides**, light read **upstream** by **PMTs** connected to the bar via **1.5m-long light guides**

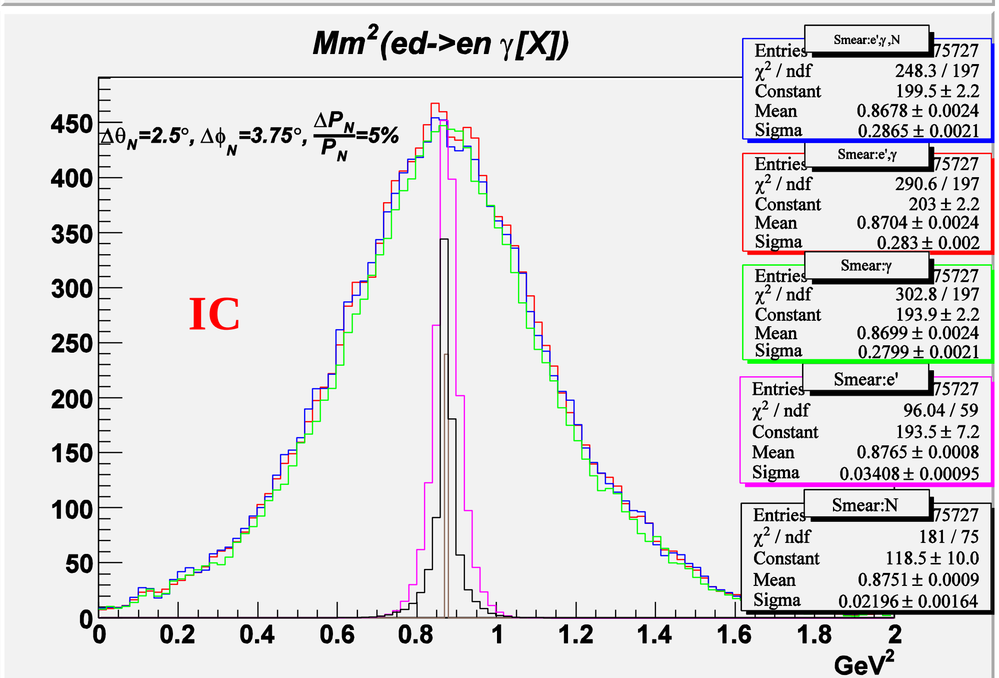


pDVCS & nDVCS: comparison of cross sections



Central Neutron Detector for nDVCS: requirements





nDVCS event generator + electron and photon resolutions obtained from CLAS12 FastMC + design specs for Forward Tagger or IC

Photon resolution contributes to 94% (97%) of the width of MM

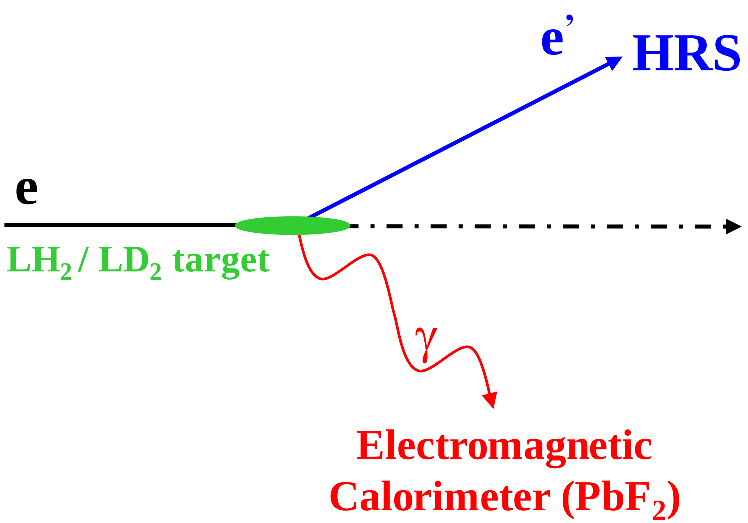
→ The CND must ensure:

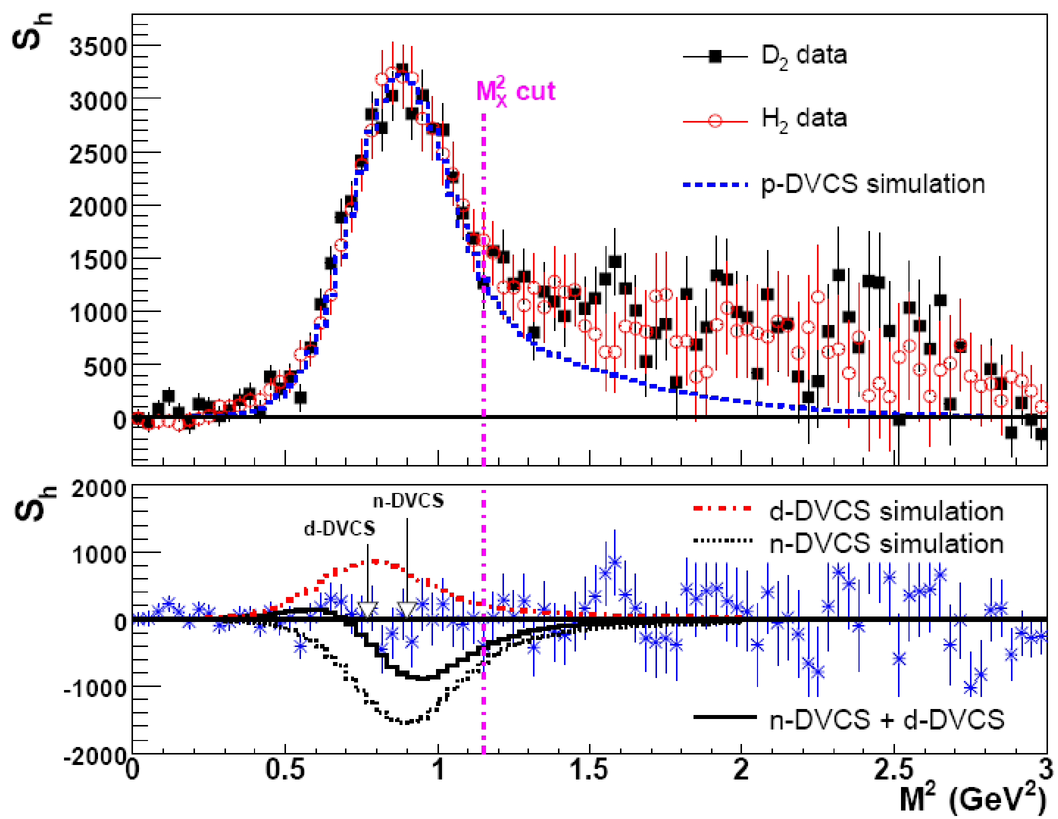
- **good neutron identification** for $0.2<p_n<1.2$ GeV/c → **σ(TOF)~150 ps** for n/γ separation using β
- momentum resolution **below 10%**
- no stringent requirements for angular resolutions

First measurement of nDVCS: Hall A

M. Mazouz et al., PRL 99 (2007) 242501

E_e= 5.75 GeV/c P_e = 75 %
L = 4 ·10^{37} cm^{-2} · s^{-1}/nucleon





Active nucleon identified via missing mass

Analysis done in the impulse approximation:

$$D(e,e'\gamma)X = p(e,e'\gamma)p + n(e,e'\gamma)n + d(e,e'\gamma)d + \cdots$$

Q^2 = 1.9 GeV^2
x_B = 0.36
0.1 GeV^2 < -t < 0.5 GeV^2

Subtraction of **quasi-elastic proton** contribution deduced from H_2 data convoluted with Fermi motion of the nucleon

Twist-2

$$\frac{d^5\Sigma_{\mathrm{D-H}}}{d^5\Phi} = \frac{1}{2}\left[\frac{d^5\sigma^+}{d^5\Phi} - \frac{d^5\sigma^-}{d^5\Phi}\right]$$

$$= \left(\Gamma_d^{\Im}\,\Im\mathrm{m}\left[\mathcal{C}_d^I\right]^{exp} + \Gamma_n^{\Im}\,\Im\mathrm{m}\left[\mathcal{C}_n^I\right]^{exp}\right)\sin(\phi_{\gamma\gamma})$$

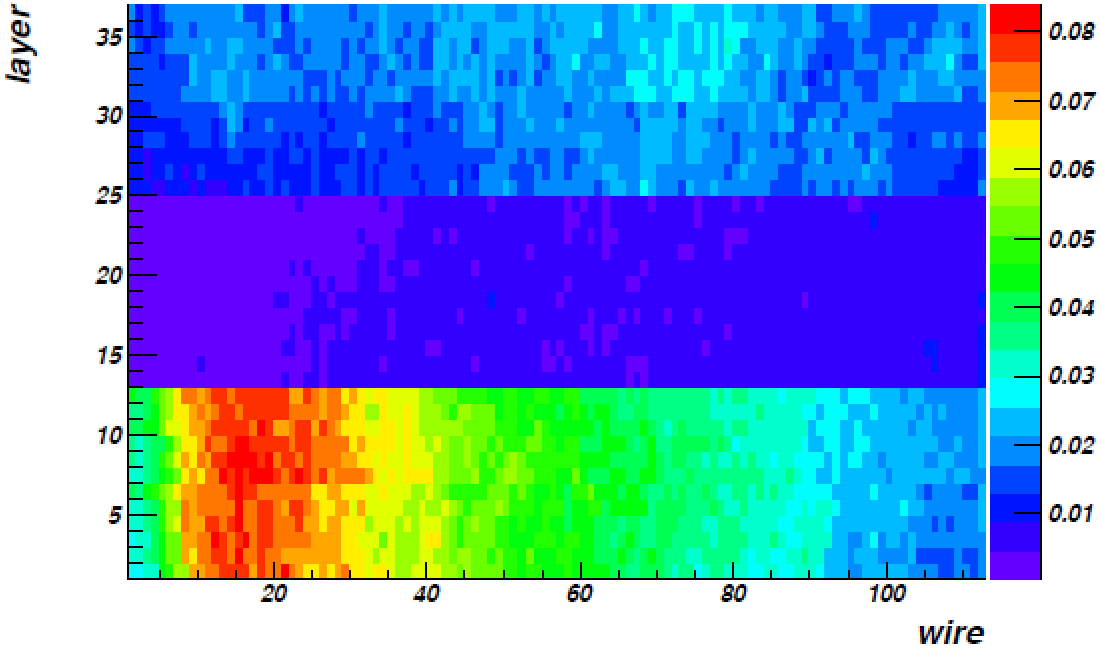


Figure 30: Occupancy in the first region of the CLAS12 drift chambers, for the configuration with FT and rastered beam.

Configuration	Occupancy
FT + no raster	5%
FT + raster	8%
no FT + raster	2.2%
no FT + no raster	2%