Experimental Studies of Deeply Virtual Compton Scattering at JLab

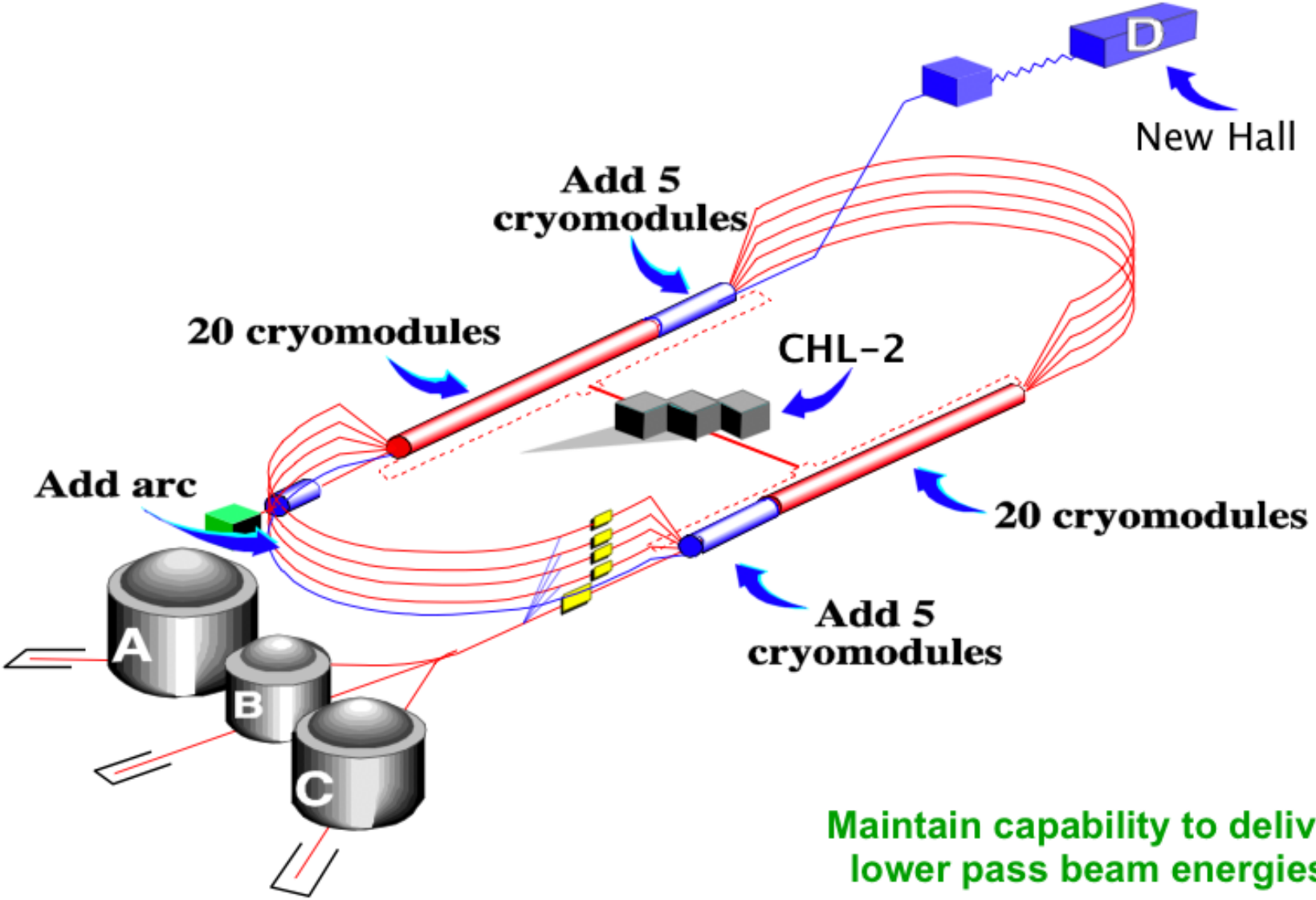
F.-X. Girod

JLab Hall-B

HUGS 2012

Projection for 12 GeV

JLab12



Maintain capability to deliver lower pass beam energies

Enhanced capabilities in existing Halls

GPDs in DVCS program at JLab12

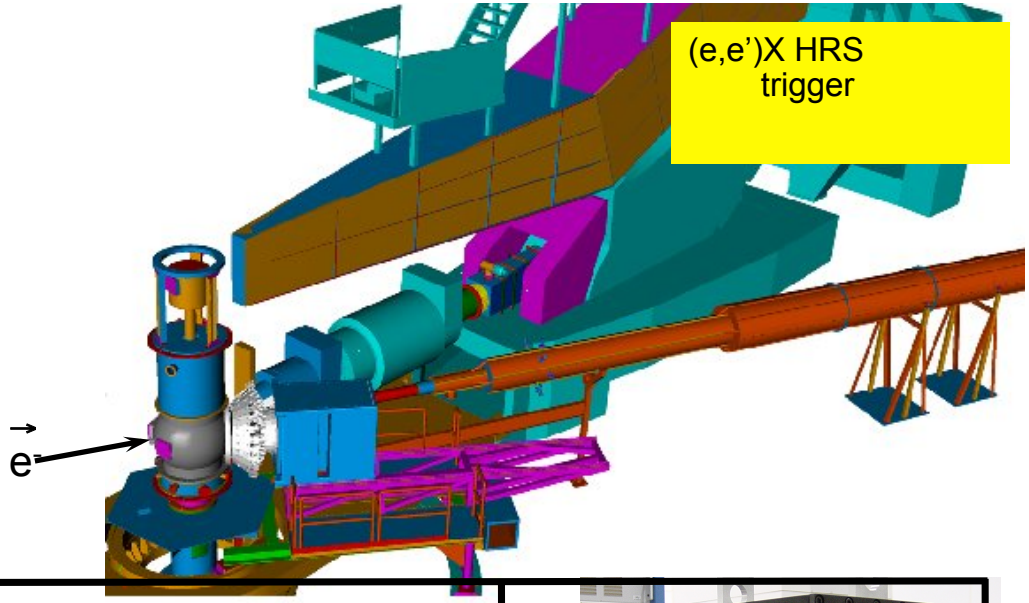
Nucleon polarization	Sensitivity to GPDs	
U	$H, \tilde{H}, E$	E12-06-114 : (A) proton E12-06-119 : (B) proton E12-11-003: (B) neutron
L	$\tilde{H}, H, E$	E12-06-119 : **(NH_3)** (B) proton
T	E, H	E12-11-105 : **(HD)** (B) proton

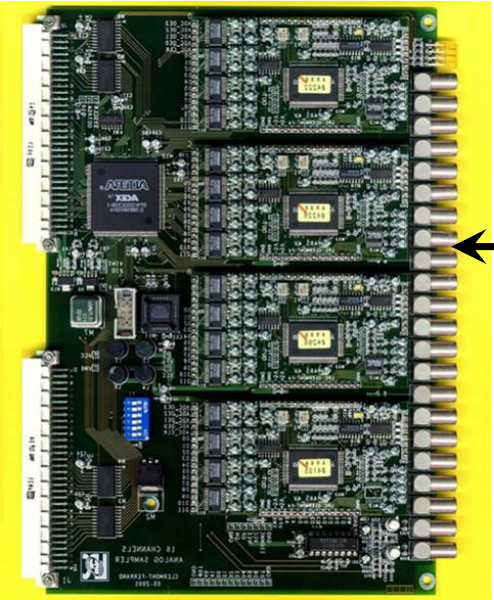
The JLab DVCS program will be carried out in two experimental Halls: **A & B (CLAS12)**

Hall-A DVCS at 12 GeV

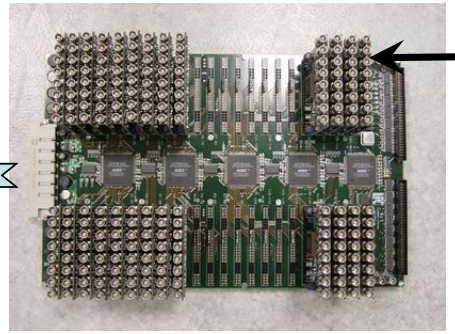
E12-06-114

$L \geq 10^{37}$ cm^2/s
Precision cross sections
- Test factorization
- Calibrate Asymmetries

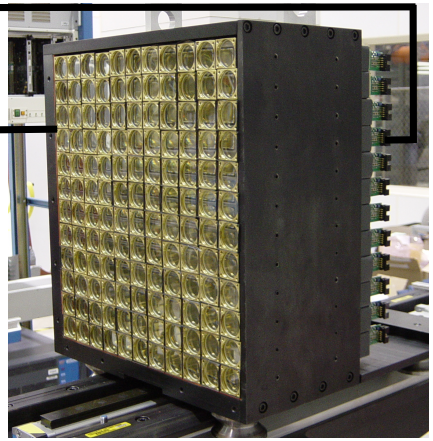




16chan VME6U: ARS
128 samples@1GHz



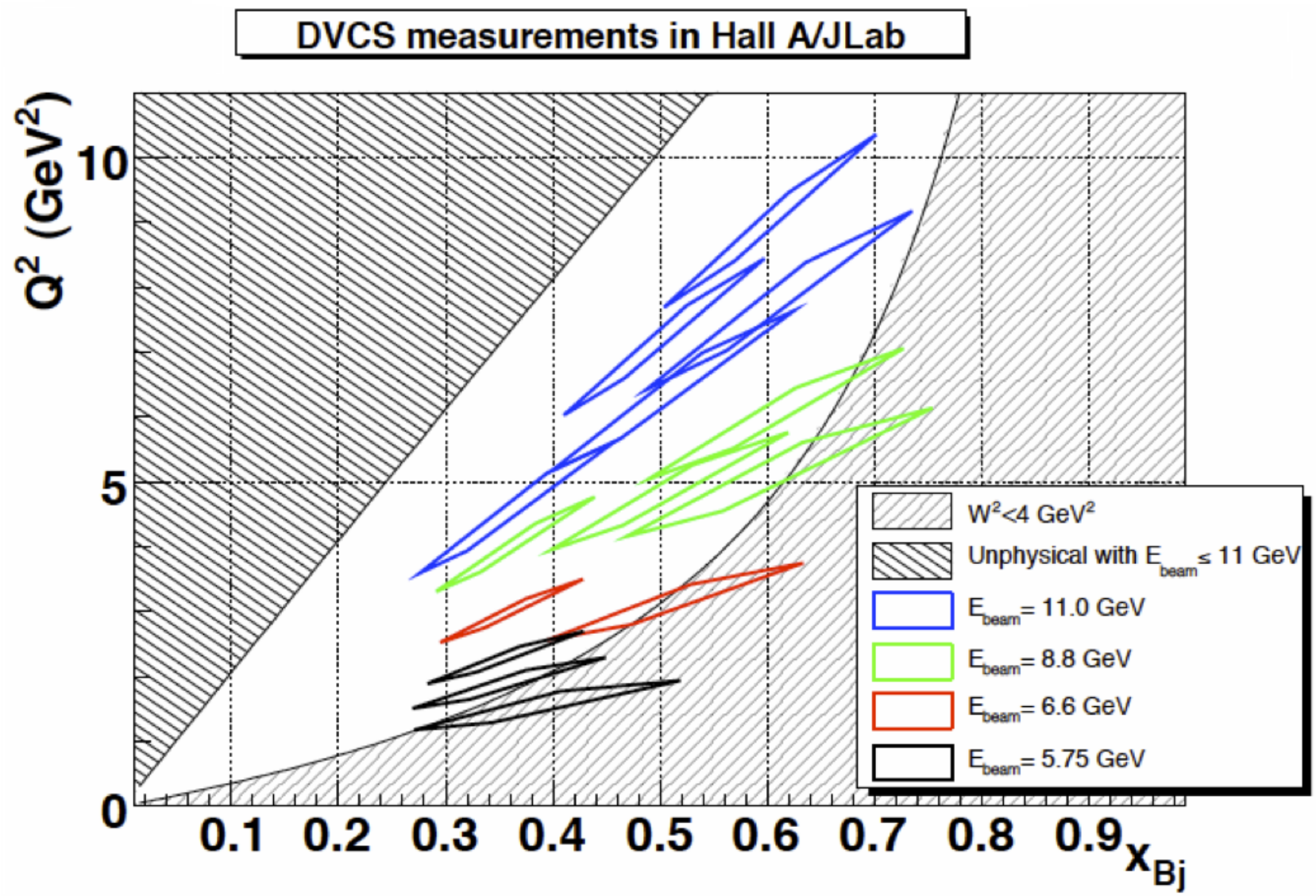
Digital Trigger
Validation



132 PbF_2

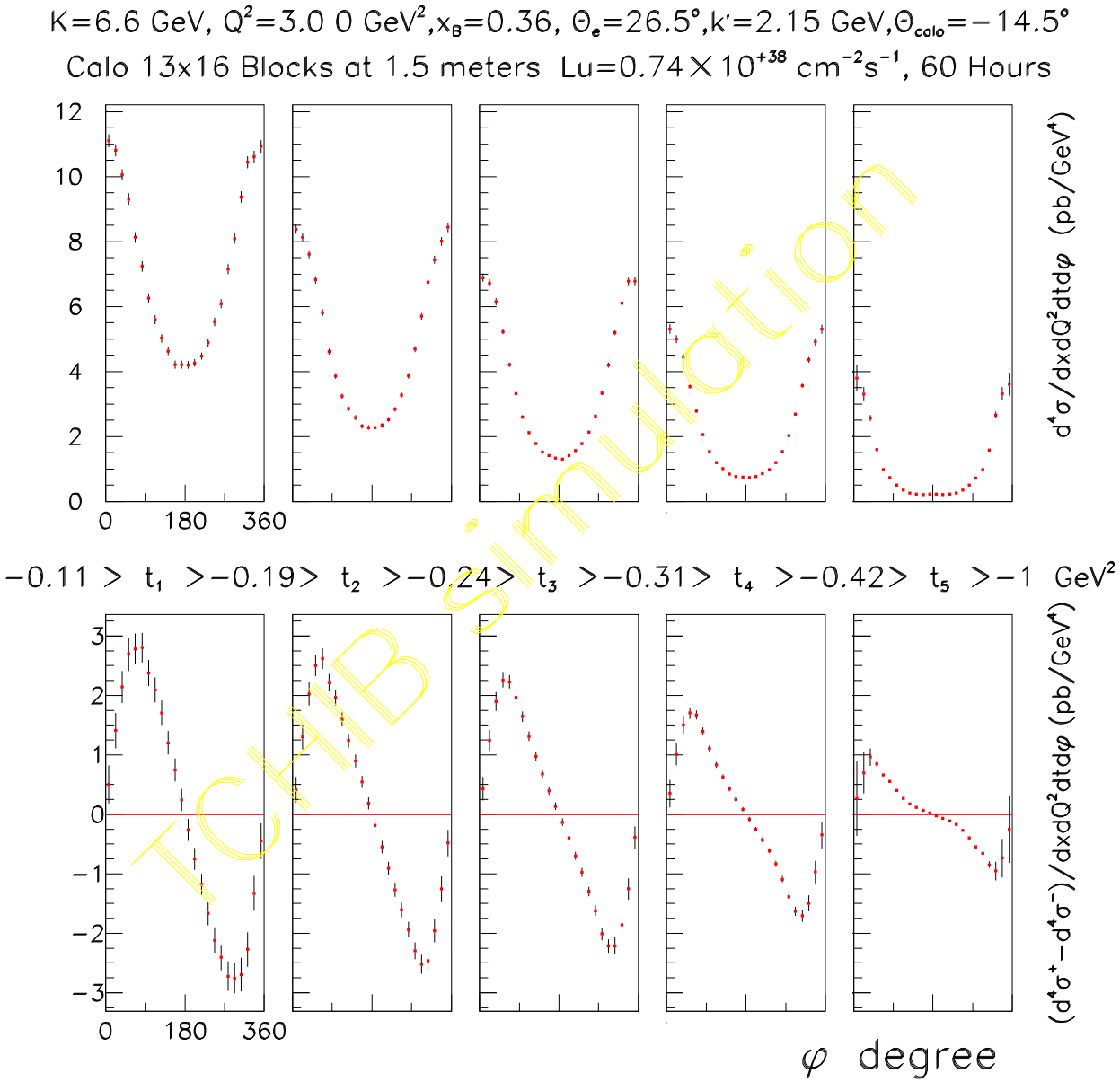
Hall-A DVCS at 12 GeV

E12-06-114



Hall-A DVCS at 12 GeV

E12-06-114



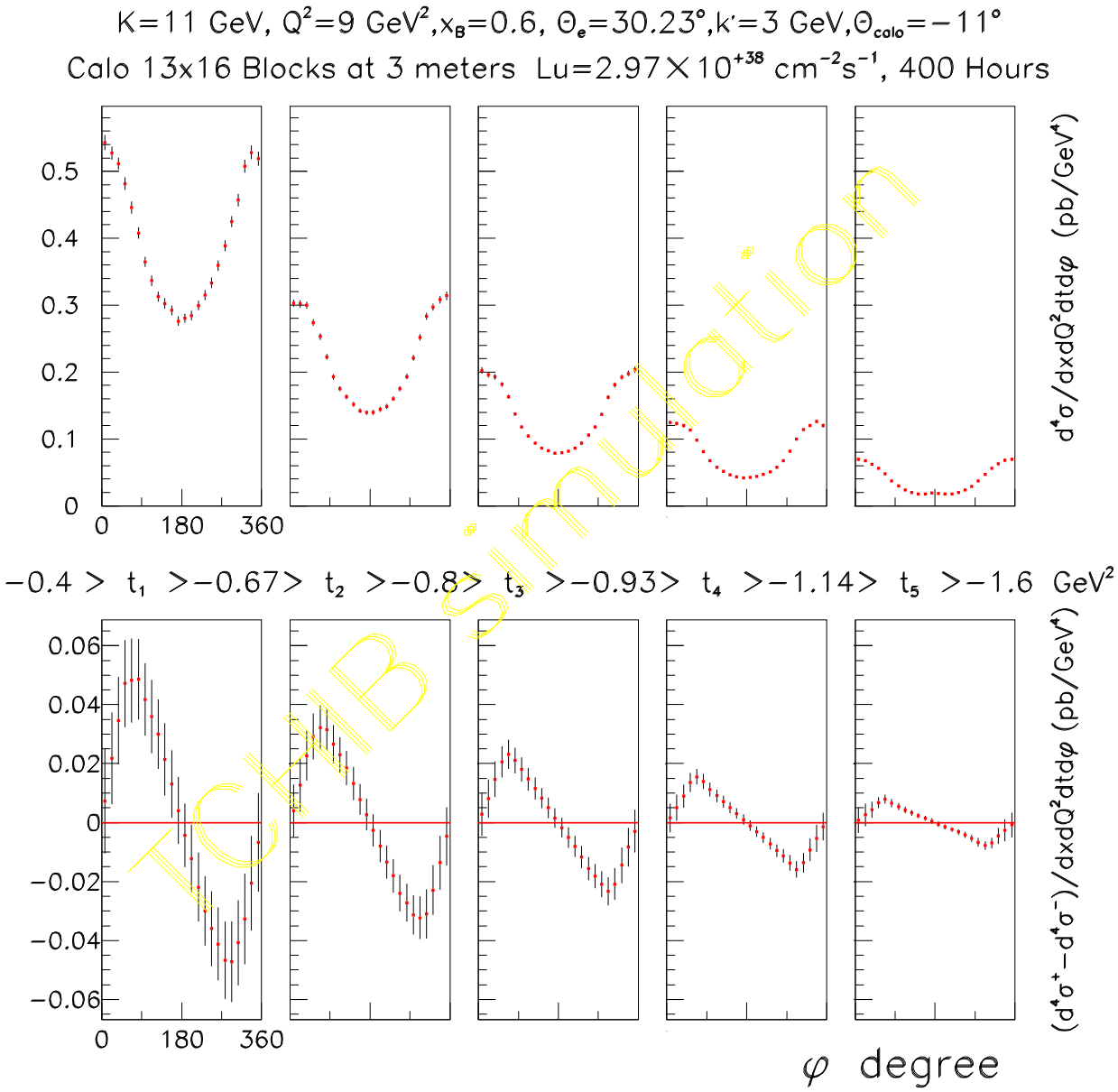
Only highest Q^2 shown
Long lever arm

Rosenbluth separation of $\mathcal{I}$ and DVCS^2

High-precision scaling test on both $\mathcal{R}$e and $\mathcal{I}$m

Hall-A DVCS at 12 GeV

E12-06-114

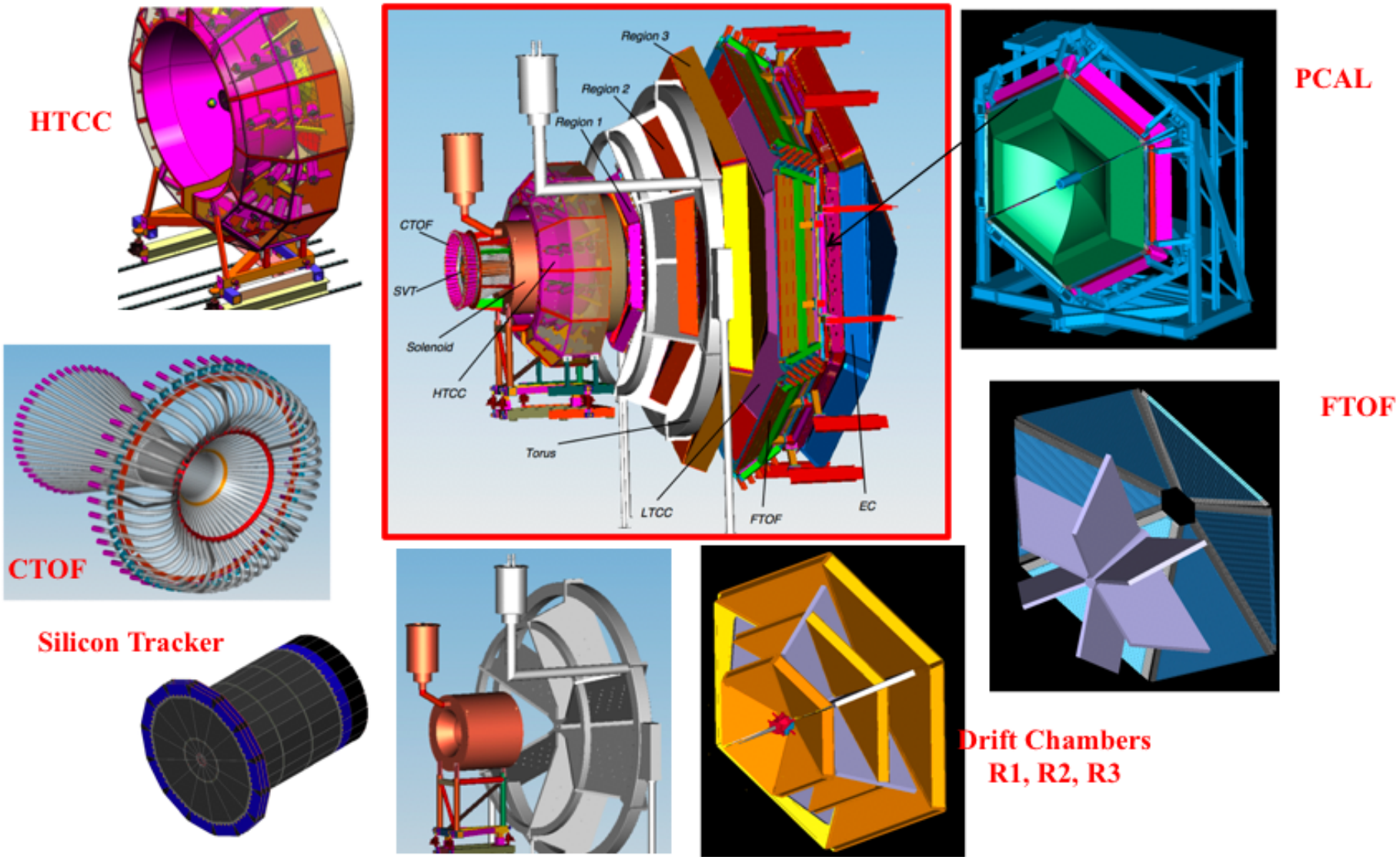


Only highest Q^2 shown
Long lever arm

Rosenbluth separation of $\mathcal{I}$ and DVCS^2

High-precision scaling test on both $\mathcal{R}$e and $\mathcal{I}$m

Upgraded apparatus

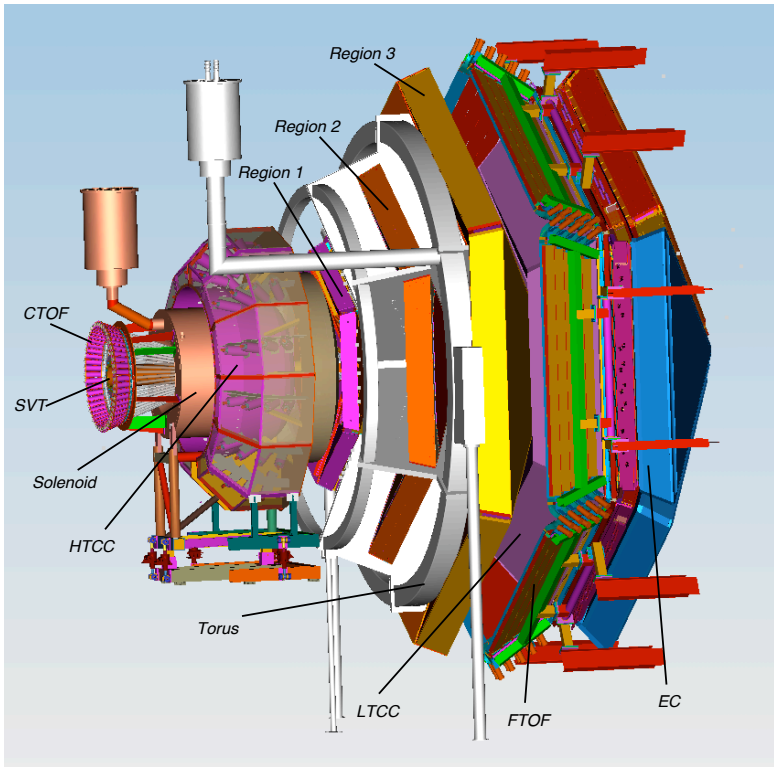


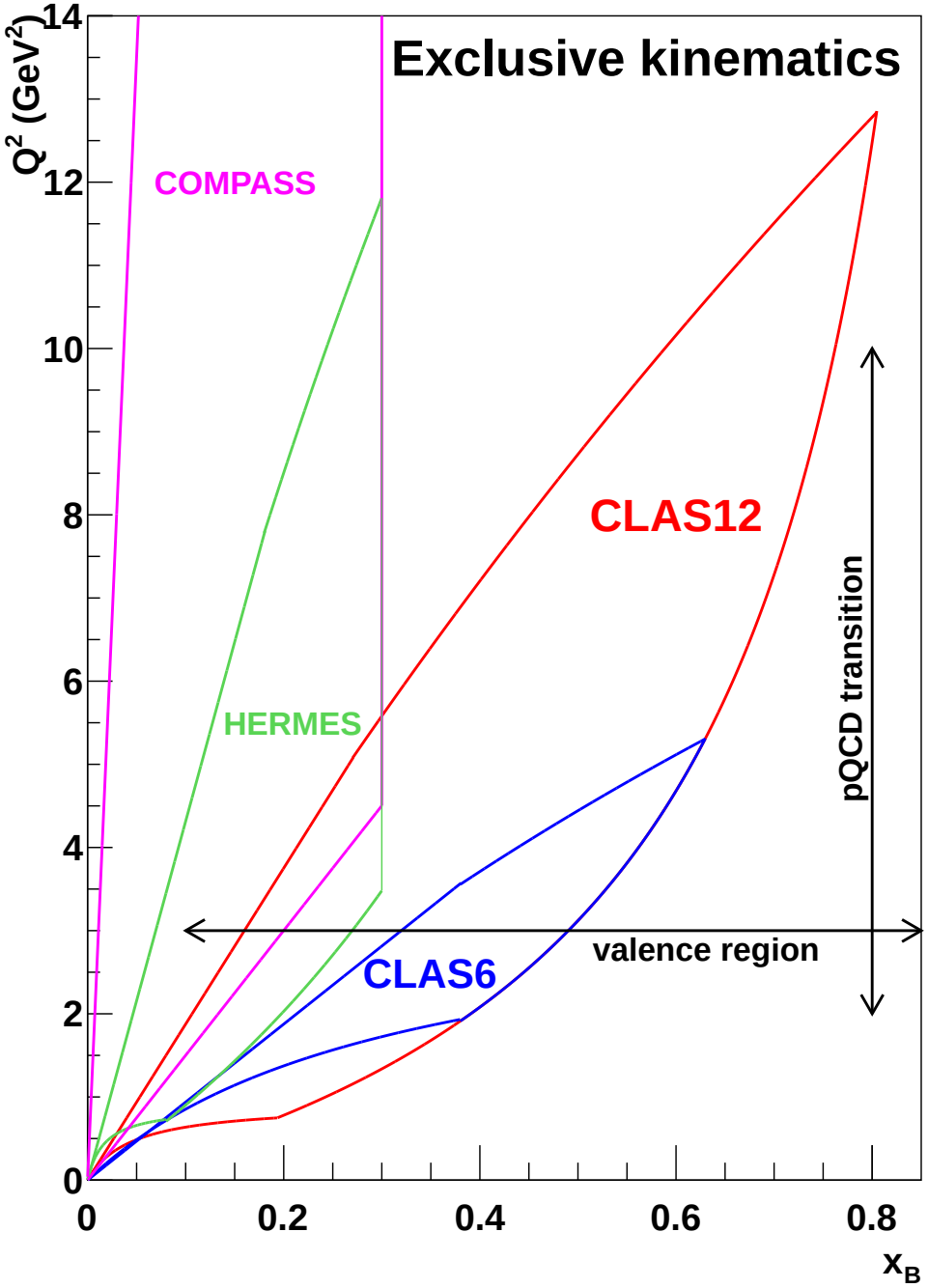
Upgraded apparatus

	Forward detector	Central detector
Angular range		
Tracks	$5 - 40^\circ$	$35 - 125^\circ$
Photons	$2.5 - 40^\circ$	n.a.
Resolution		
$\delta p/p$	$< 1\%$ @ 5 GeV/c	5% @ 1.5 GeV/c
$\delta\theta$	< 1 mr	$<$ 10-20 mr
$\delta\phi$	< 3 mr	< 5 mr
Photon detection		
Energy	> 0.15 GeV	n.a.
$\delta\theta$	4 mr @ 1 GeV	n.a.
Neutron detection		
Efficiency	< 0.7	under dev.
Particle ID		
e/π	Full range	n.a.
π/p	Full range	< 1.25 GeV/c
π/K	Full range	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1 GeV/c
$\pi \to \gamma\gamma$	Full range	n.a.
$\eta \to \gamma\gamma$	Full range	n.a.

CLAS12

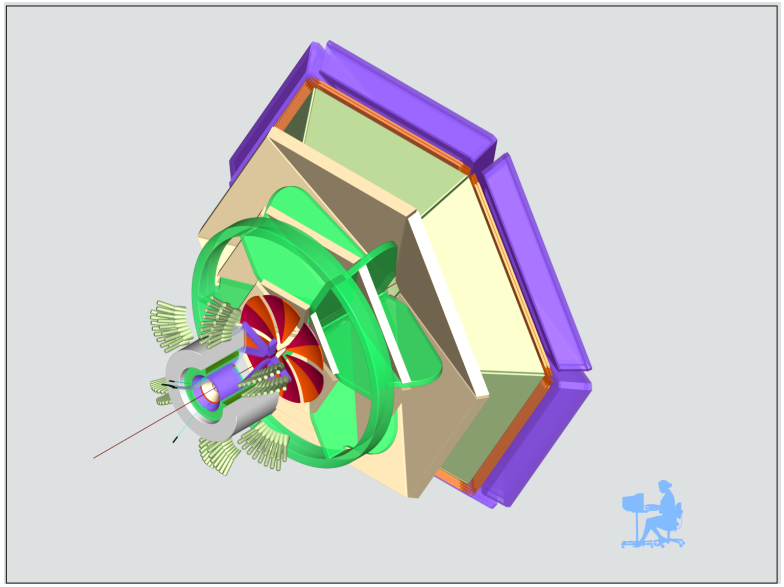
Higher energy
Higher luminosity
Better hermeticity

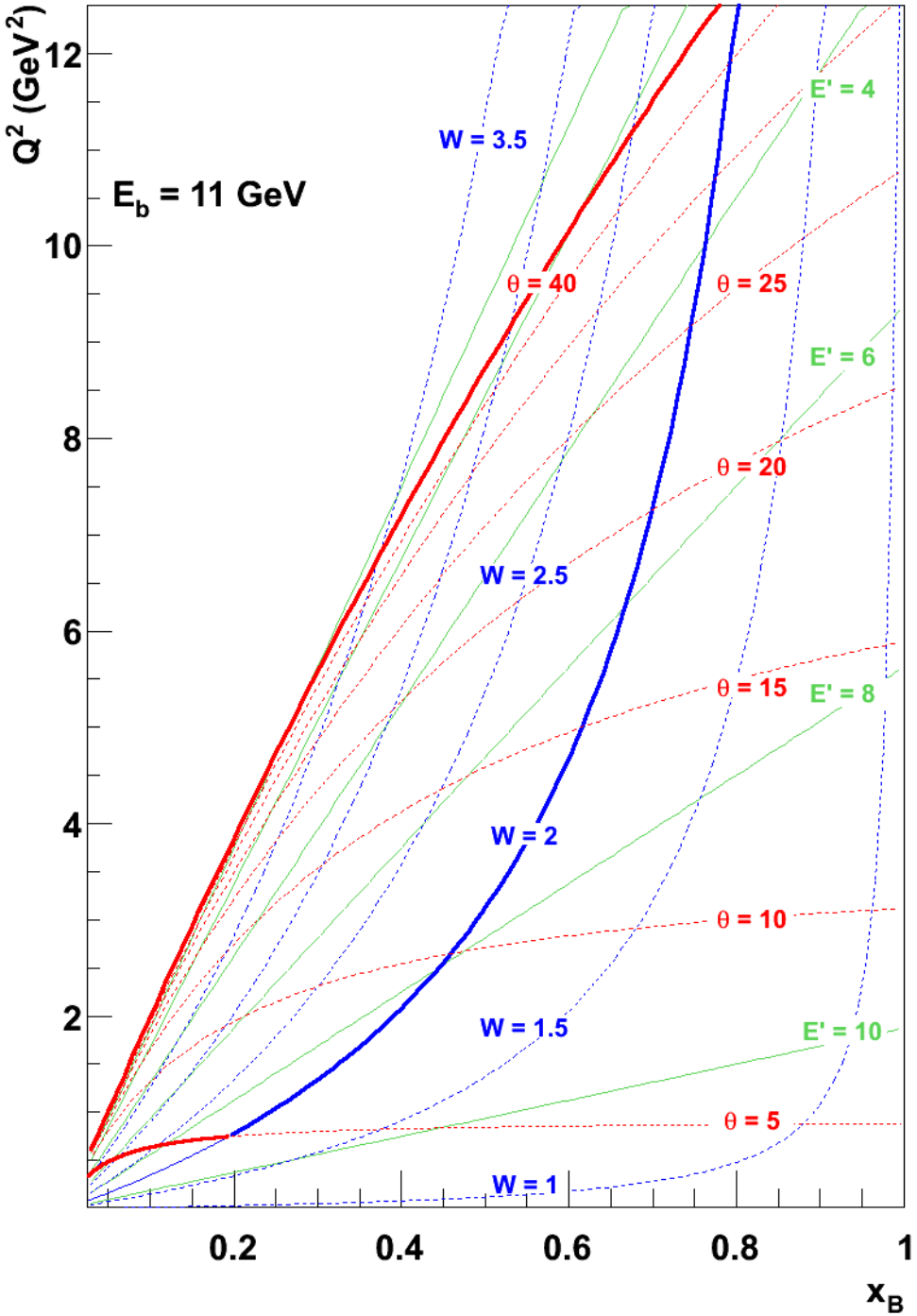




CLAS12

Higher energy
Higher luminosity
Better hermeticity

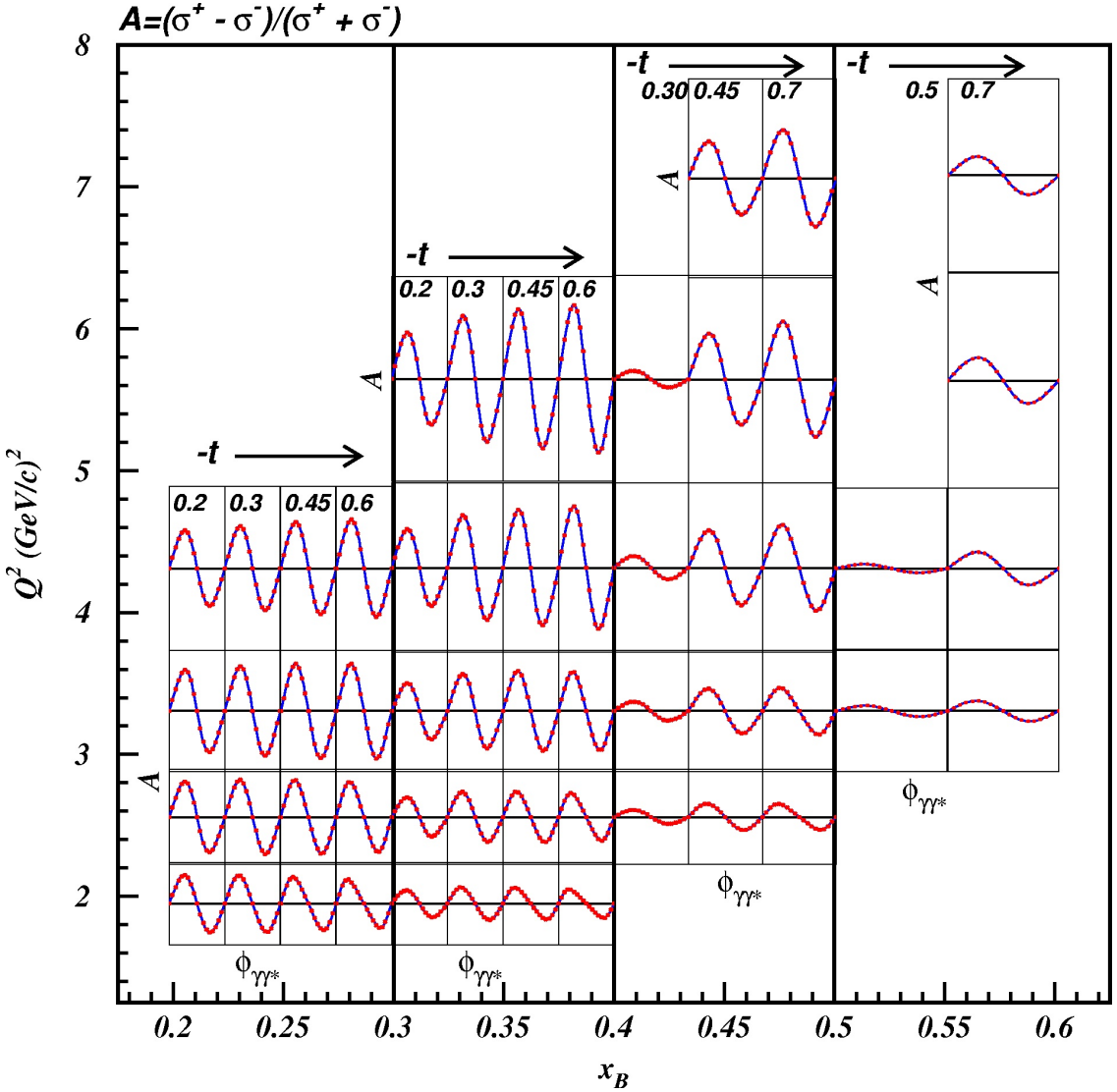




Proton BSA DVCS A_{LU} E12-06-009

80 days @ $\mathcal{L} = 10^{35}$ cm^{-2}s^{-1} with 85% polarized beam

$$A_{LU} \propto F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}$$



Projections for CLAS12

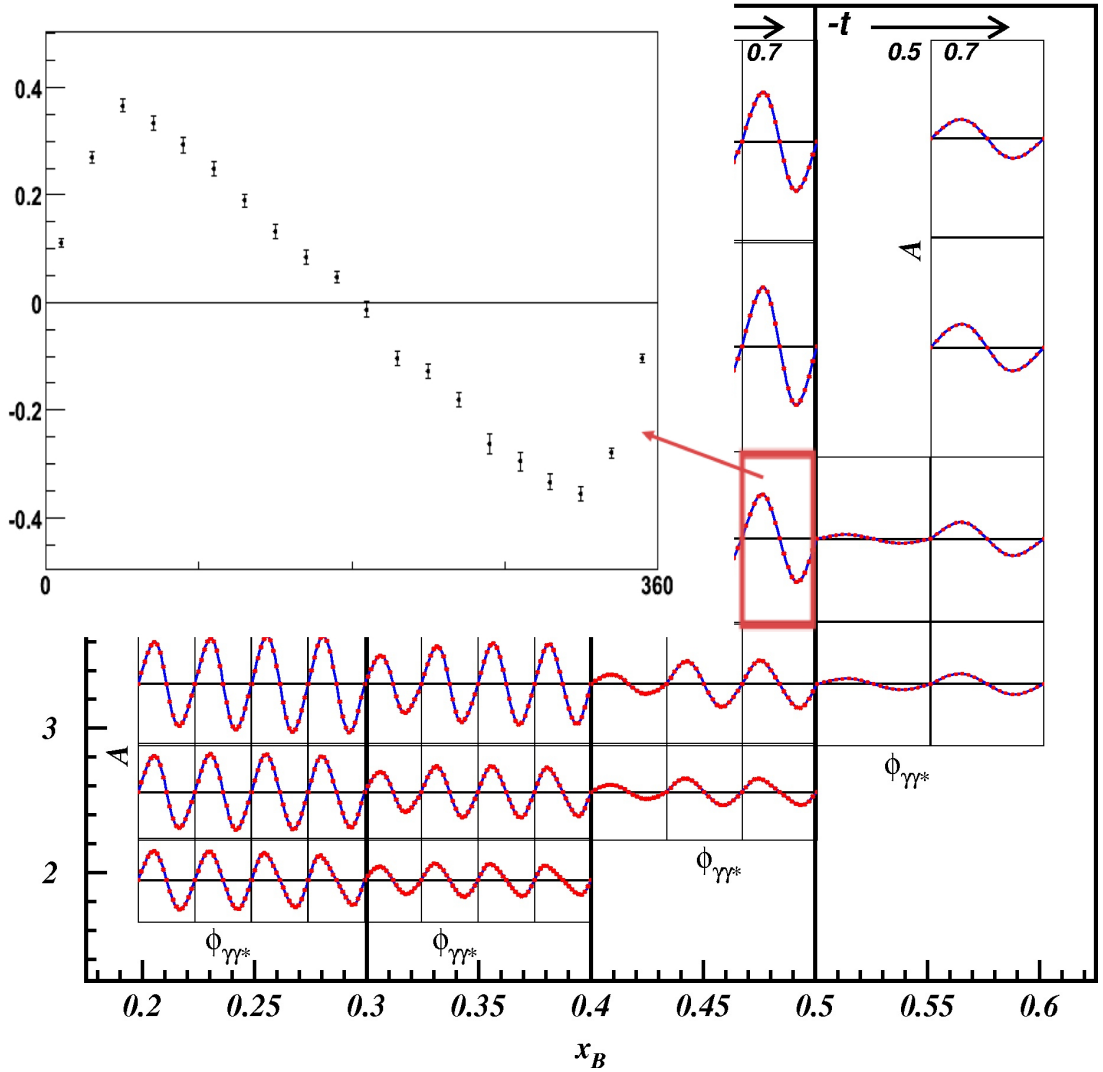
Statistical uncertainties : from 1 % (low Q^2) to 10 % (high Q^2)

Unprecedented statistics over the full ϕ range up to high $x = 0.6$

Proton BSA DVCS A_{LU} E12-06-009

80 days @ $\mathcal{L} = 10^{35}$ cm^{-2}s^{-1} with 85% polarized beam

$$A_{LU} \propto F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}$$



Projections for CLAS12

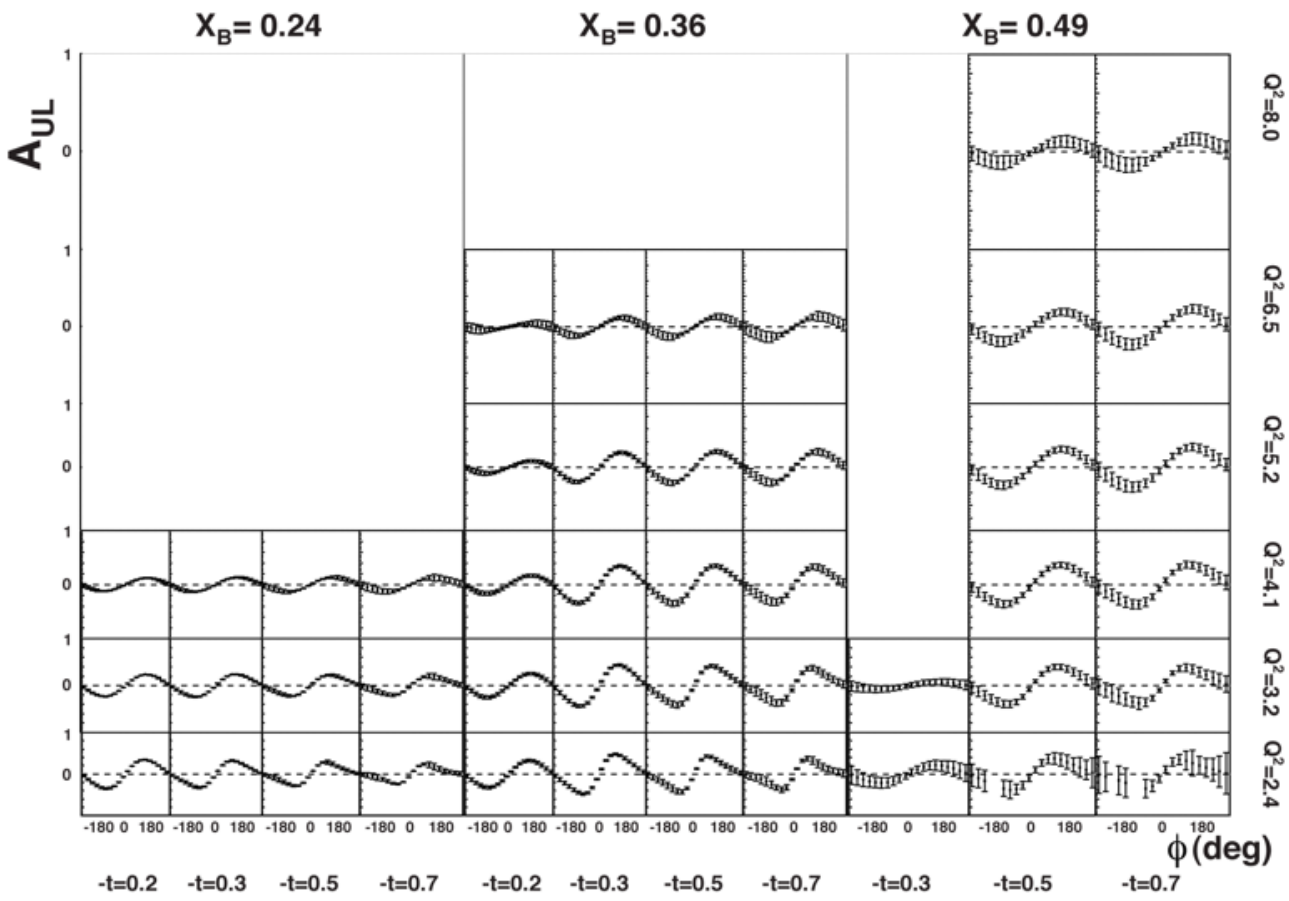
Statistical uncertainties :
from 1 % (low Q^2)
to 10 % (high Q^2)

Unprecedented statistics
over the full ϕ range
up to high $x = 0.6$

Proton DVCS TSA A_{UL} E12-06-009

120 days @ $\mathcal{L} = 2 \times 10^{35}$ cm^{-2}s^{-1} with 80% polarized NH_3

$$A_{UL} \propto F_1 \tilde{\mathcal{H}} + \xi G_M \left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) - \cdots$$



Projections for CLAS12

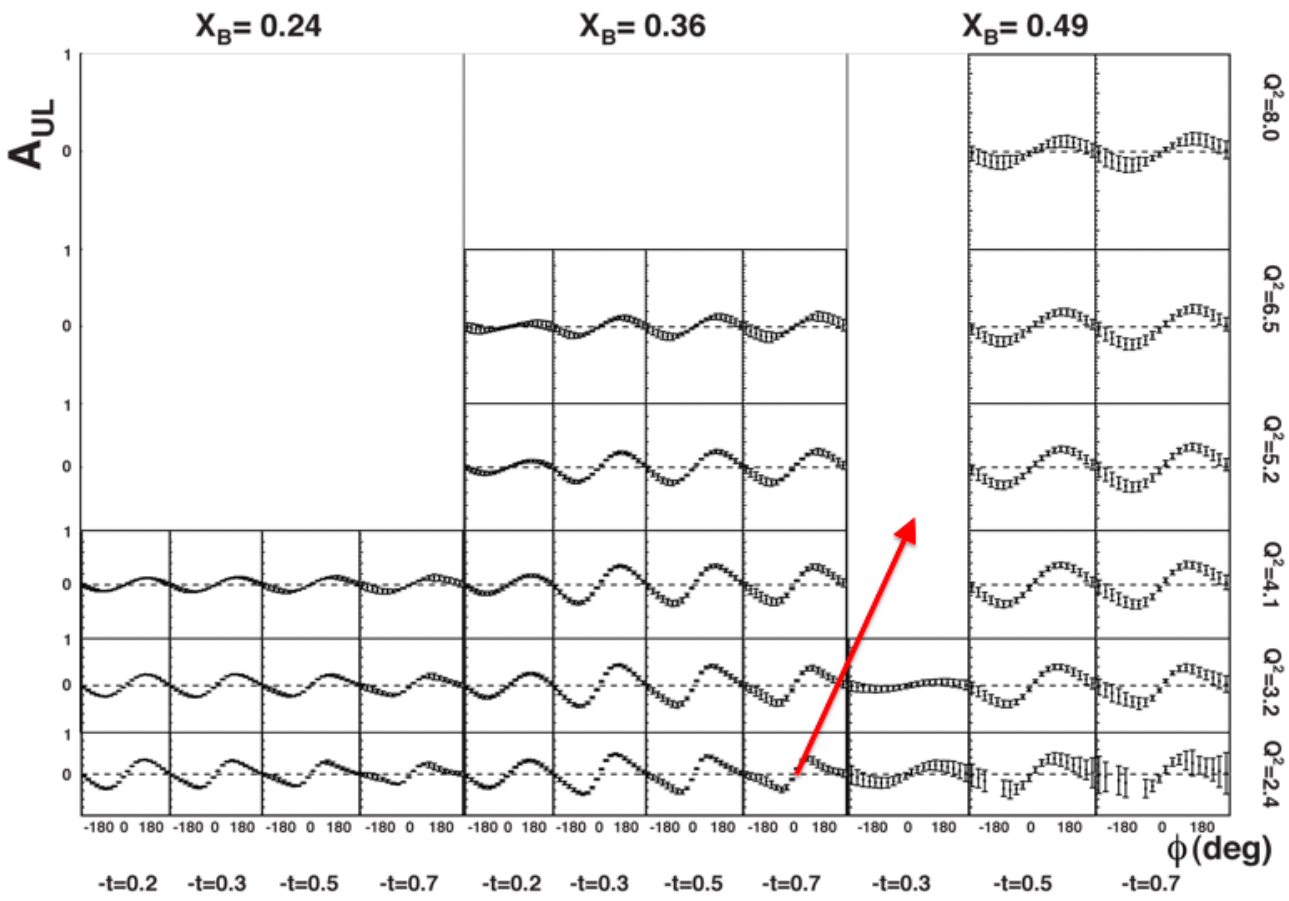
Statistical uncertainties : from 2 % (low Q^2) to 30 % (high Q^2)

Unprecedented statistics over the full ϕ range up to high $x = 0.6$

Proton DVCS TSA A_{UL} E12-06-009

120 days @ $\mathcal{L} = 2 \times 10^{35}$ cm^{-2}s^{-1} with 80% polarized NH_3

$$A_{UL} \propto F_1 \tilde{\mathcal{H}} + \xi G_M \left(\mathcal{H} + \frac{\xi}{1+\xi} \mathcal{E} \right) - \cdots$$



Projections for CLAS12

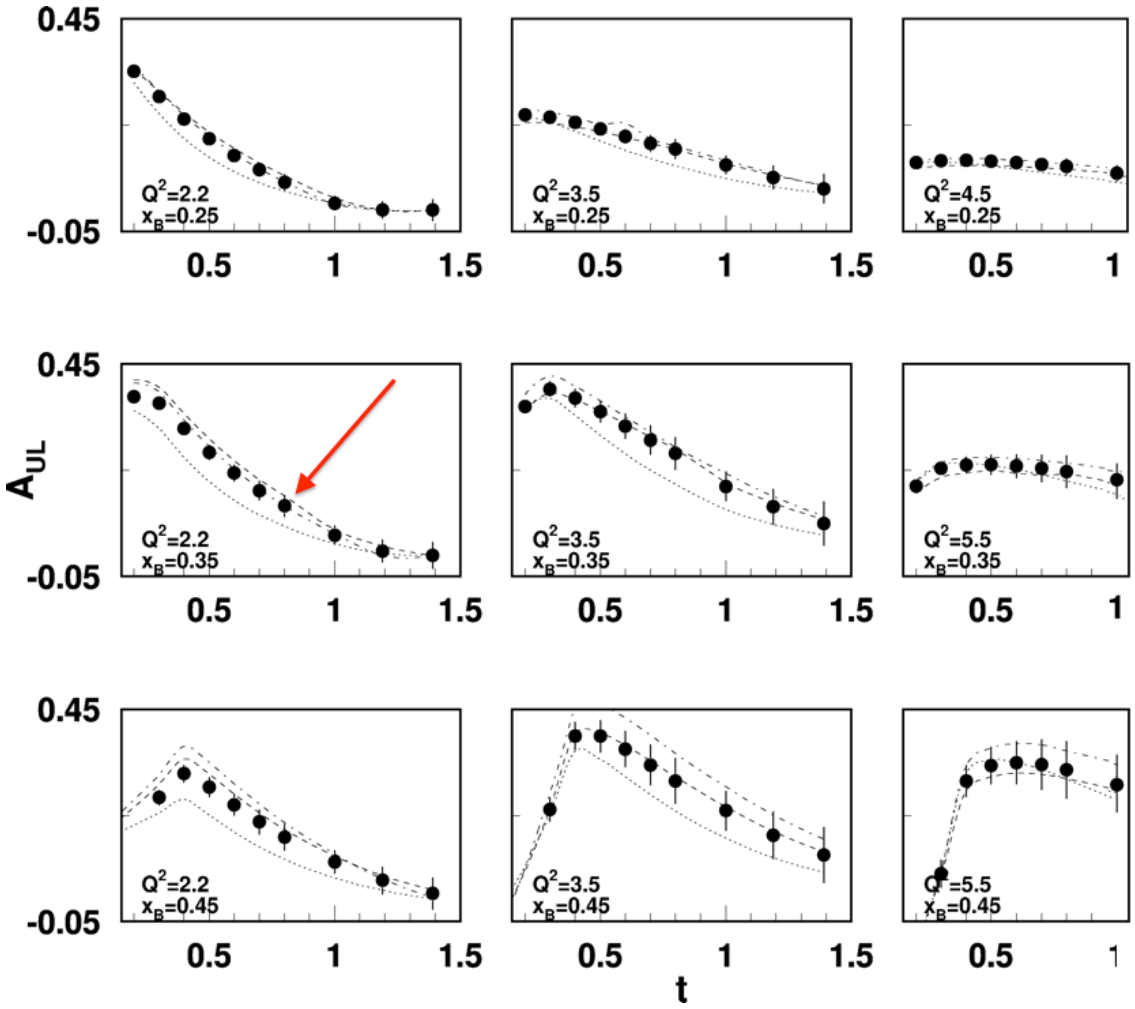
Statistical uncertainties : from 2 % (low Q^2) to 30 % (high Q^2)

Unprecedented statistics over the full ϕ range up to high $x = 0.6$

Proton DVCS TSA A_{UL} E12-06-009

120 days @ $\mathcal{L} = 2 \times 10^{35}$ cm^{-2}s^{-1} with 80% polarized NH_3

$$A_{UL} \propto F_1 \tilde{\mathcal{H}} + \xi G_M \left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) - \cdots$$



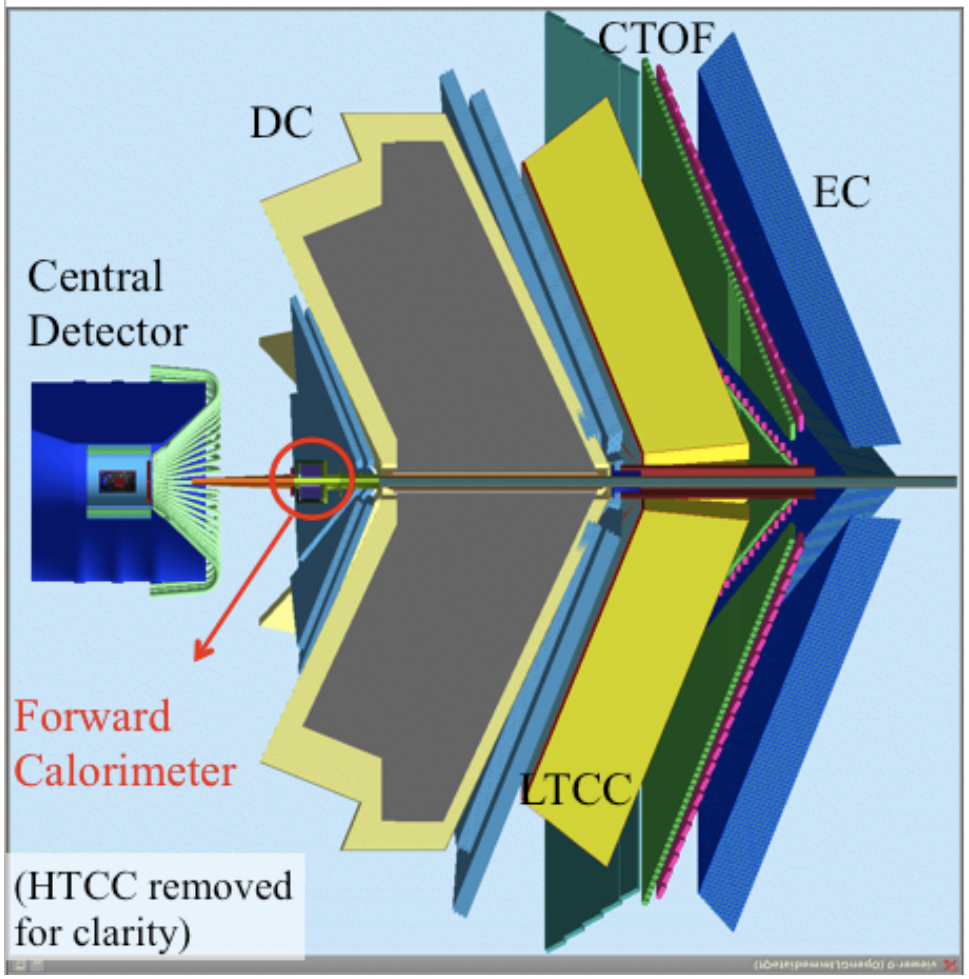
Projections for CLAS12

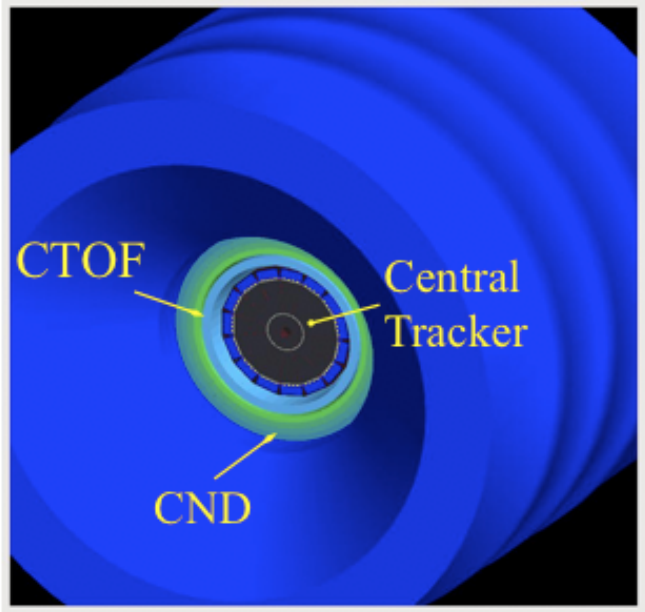
Sample kinematics
for target asymmetry

Change of t-slope with x_B
$\leftrightarrow$
imaging $\Delta q(x_B, b_\perp)$

Neutron DVCS setup

For the detection of the scattered electron and of the DVCS photon: CLAS12 + Forward Calorimeter



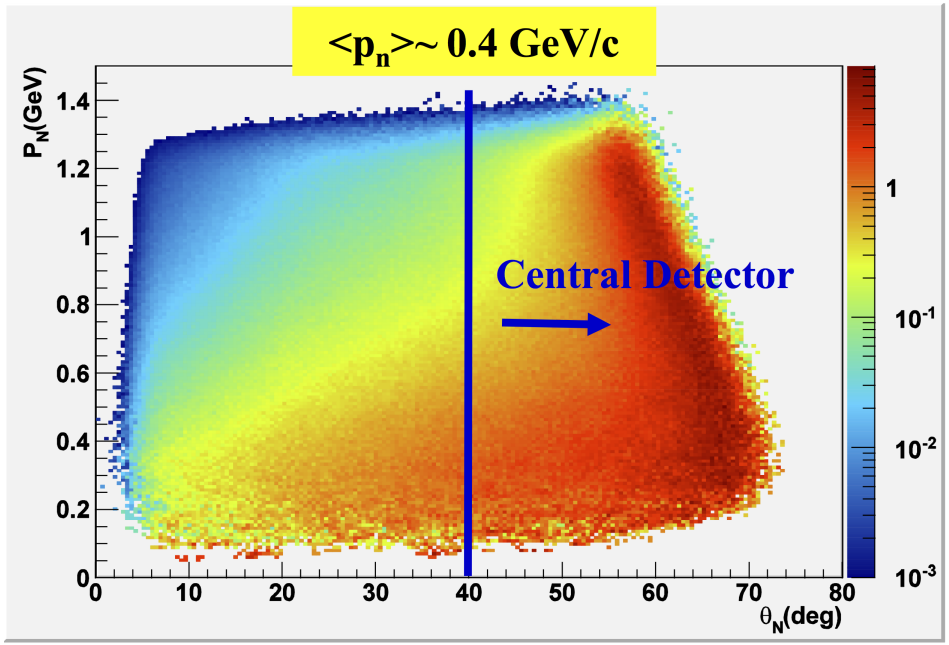


For the detection of the recoil neutron: Central Neutron Detector (CND)

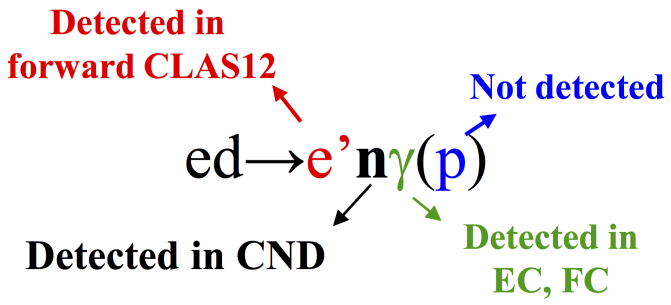
Detection efficiency : 7 to 10 %

Acceptance for charged particles:
- **Central (CD), $40^o<\theta<135^o$**
- **Forward (FD), $5^o<\theta<40^o$**

Acceptance for photons:
- **FC $2.5^o<\theta< 5^o$**
- **EC, $5^o<\theta<40^o$**



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



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

In the hypothesis of **absence of FSI**:
$p^{\mu}_{p} = p^{\mu}_{p'}$ → **kinematics are complete**
detecting **e', n (p,θ,ϕ), γ**

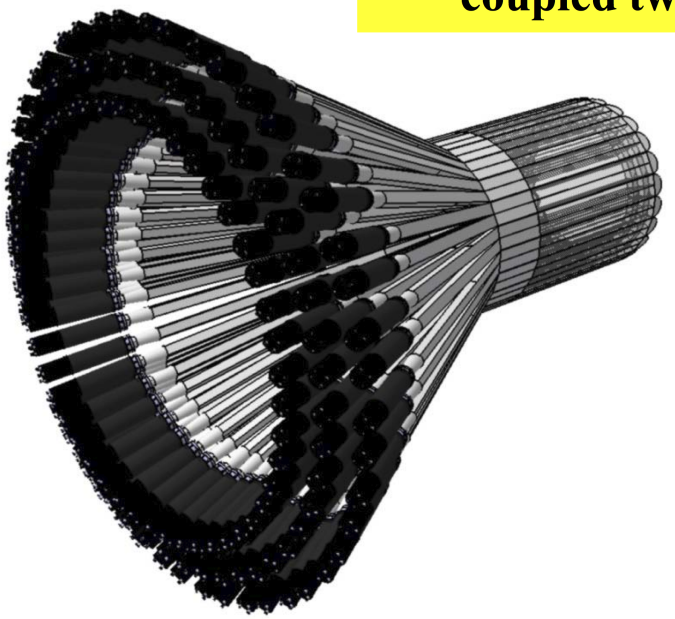
FSI effects will be estimated measuring
enγ, epγ, on deuteron
in this same experiment
and compare with free-proton data

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**

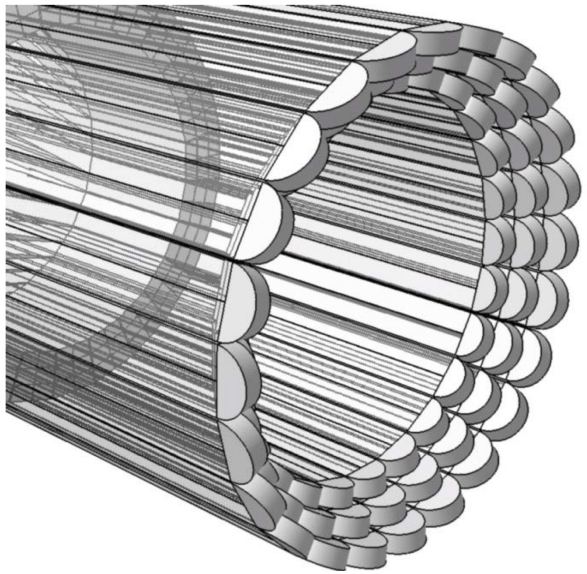
→ The CND must ensure:
- **good neutron identification** for $0.2<p_n\leq 1$ GeV/c
→ **σ(TOF) ~ 150 ps** for n/γ β−separation
- momentum resolution **up to 10%**
- no stringent requirements for angular resolutions

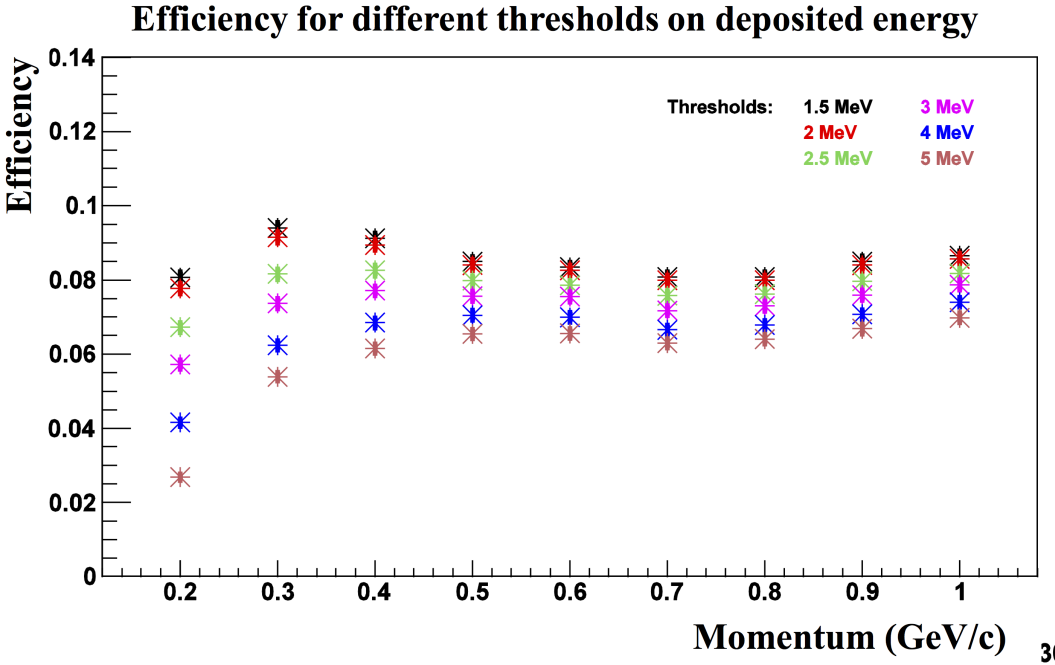
➢ **CTOF** can also be used for neutron detection
➢ Central Tracker (SVT+MM): **veto for charged particles**
• **limited space available** (~10 cm thickness)
→ limited neutron detection efficiency
→ no space for light guides upstream
• **strong magnetic field** (~5 T) → problems for light readout
*Three 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

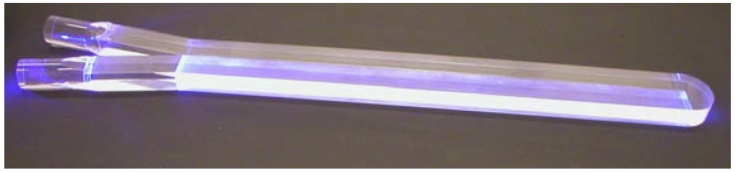


The light comes out only at the upstream side of the CND, goes through bent light guides (1.5m) arriving to ordinary PMTs, placed in the low-field region



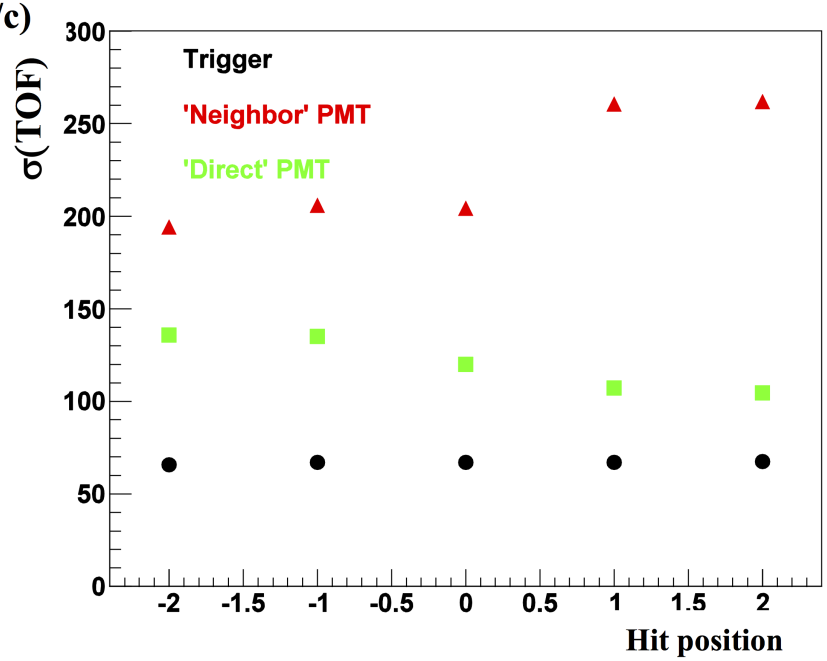


Efficiency ~ 8-10%
for a threshold of 2 MeV, TOF<8 ns
and p_n = 0.2 - 1 GeV/c



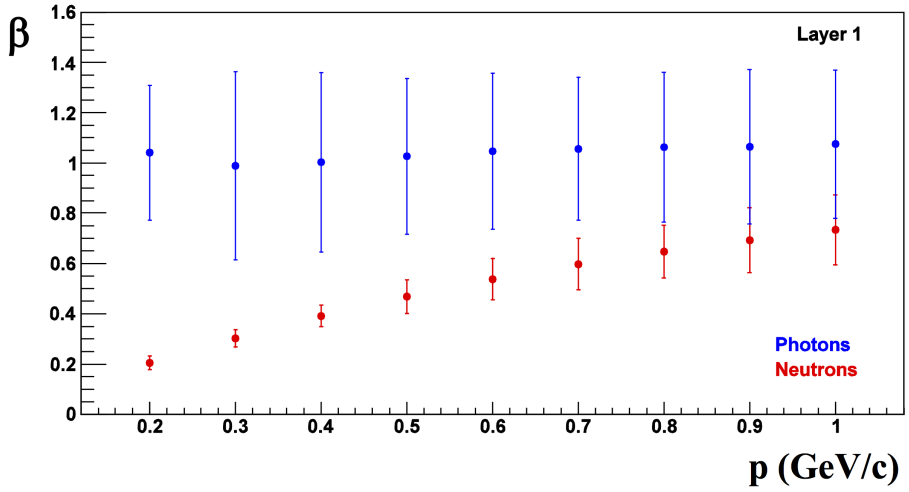
- GEANT4 simulations done for:
  - **efficiency**
  - **PID** (neutron/photon separation)
  - **momentum and angular resolutions**
  - **definition of reconstruction algorithms**
  - **background studies**
- Cosmic-rays **measurements** on a **prototype**

Measured values of σ(TOF) and light loss due to u-turn implemented in the simulation

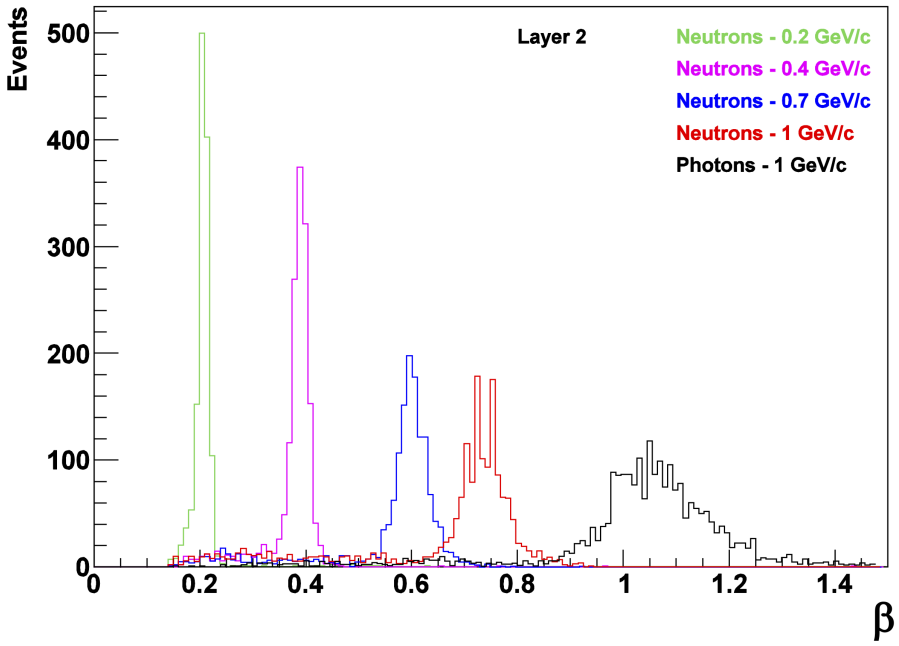


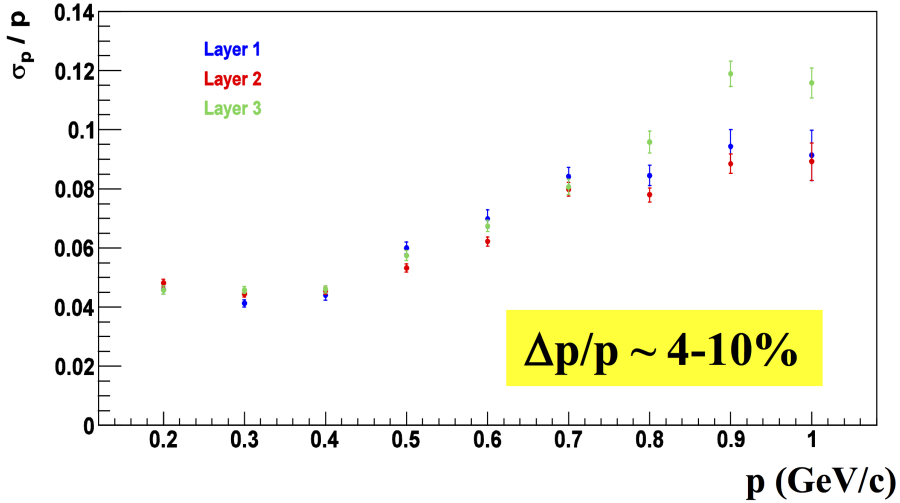
n/γ misidentification for p_n <1 GeV/c

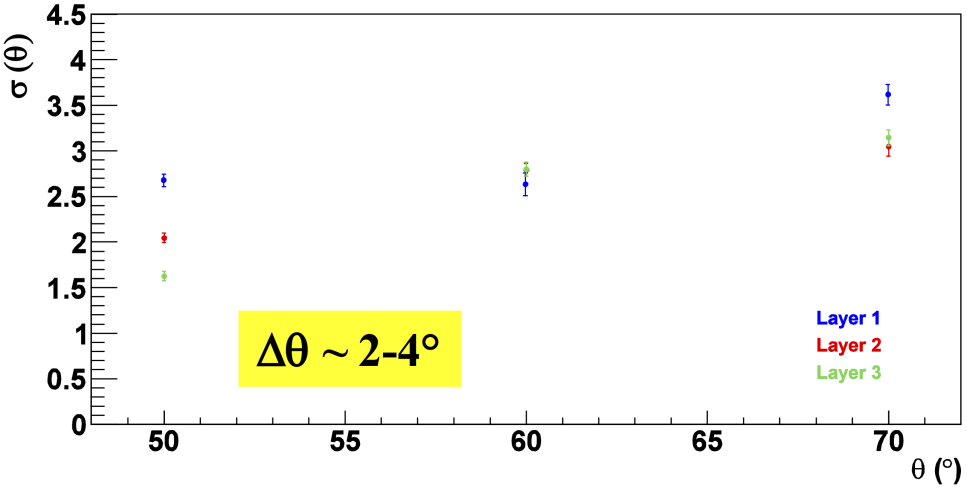
Error bars on the β - axis represent 3 σ

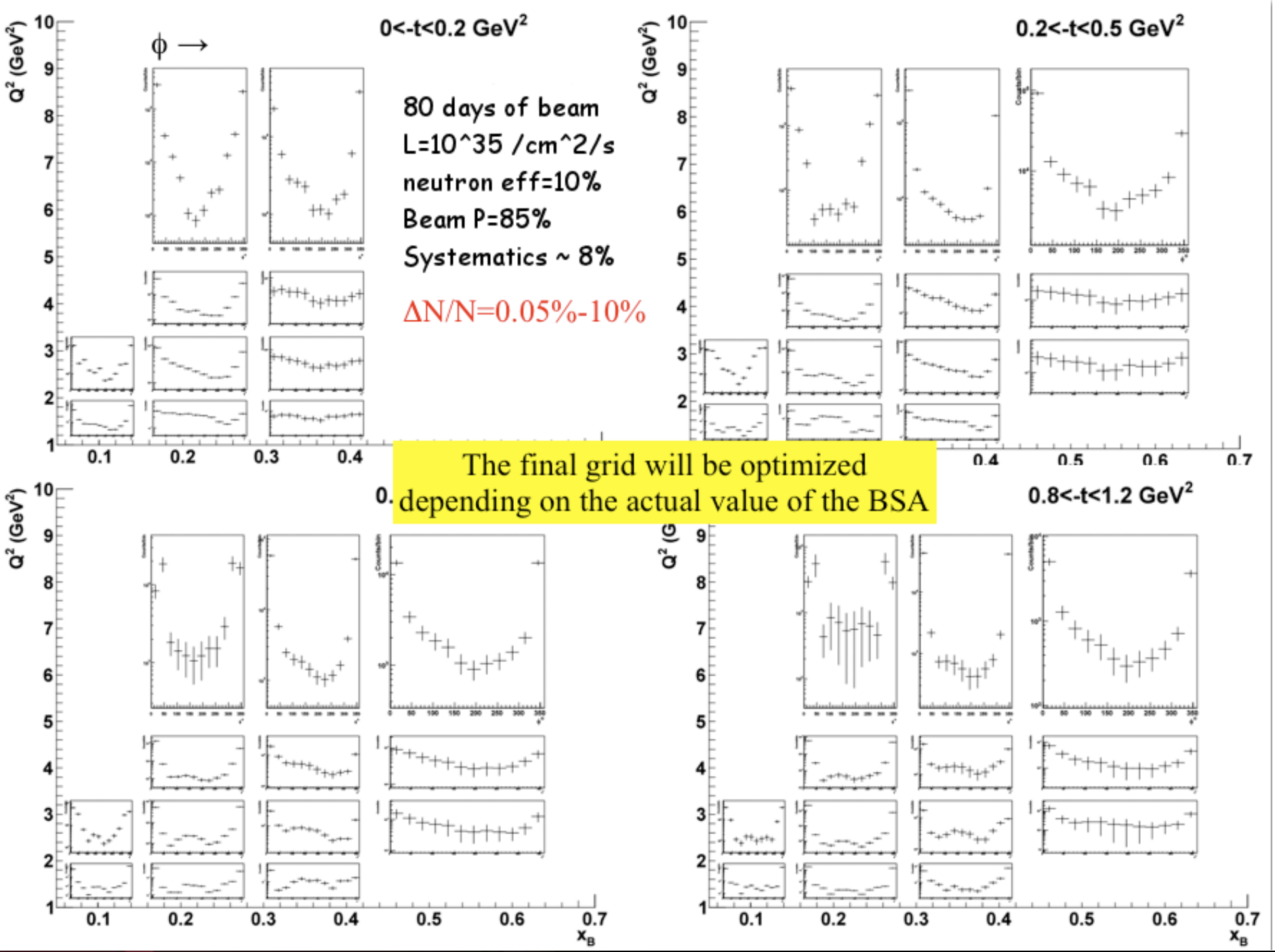


Equal n/γ yields assumed



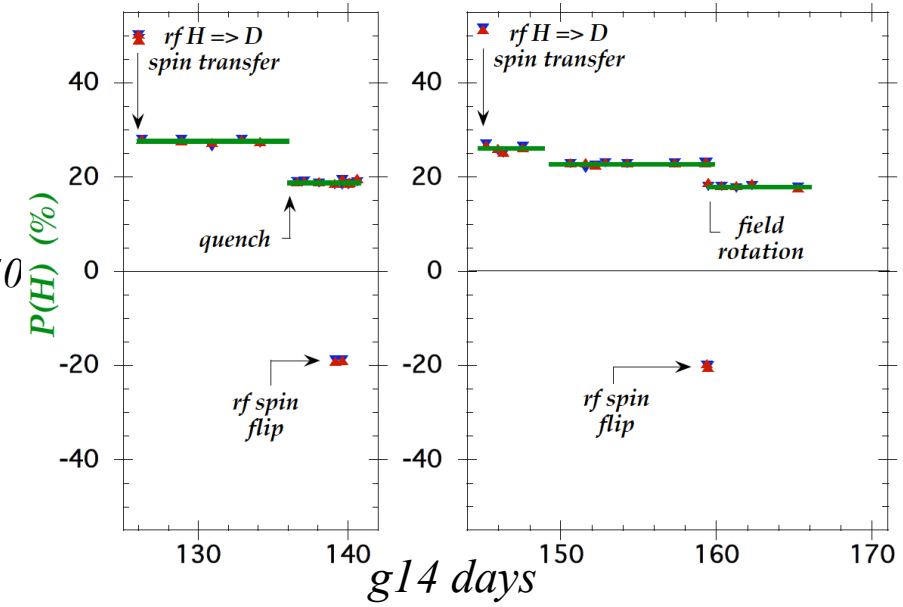





0<-t<0.2 GeV²
0.2<-t<0.5 GeV²
0.8<-t<1.2 GeV²
φ →
Q² (GeV²)
x_B
80 days of beam
L=10^35 /cm^2/s
neutron eff=10%
Beam P=85%
Systematics ~ 8%
ΔN/N=0.05%-10%
The final grid will be optimized
depending on the actual value of the BSA

HDice DVCS proposal

- *HD targets condensed, polarized and aged to the Frozen-Spin state in HDice Lab*
- *transferred as solid, polarized HD between cryostats*
- *In-Beam Cryostat (IBC) operates in Hall at 50 mK, 0.9 tesla*
- *g14 ran from Nov/11 to May/12 with 15mm Ø ×50mm long HD cells*
- *γ-beam lifetimes ~ years with 10^8 γ/s*

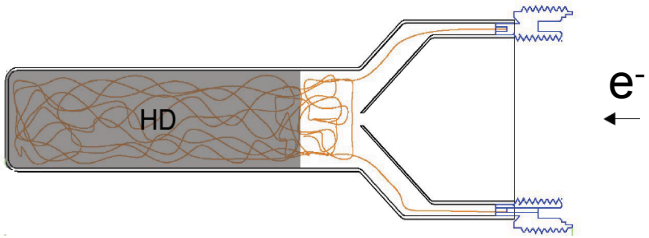


Material	gm/cm^2	mass fraction (%)
HD	0.735	78%
Al	0.139	15%
C_2ClF_3	0.065	7%

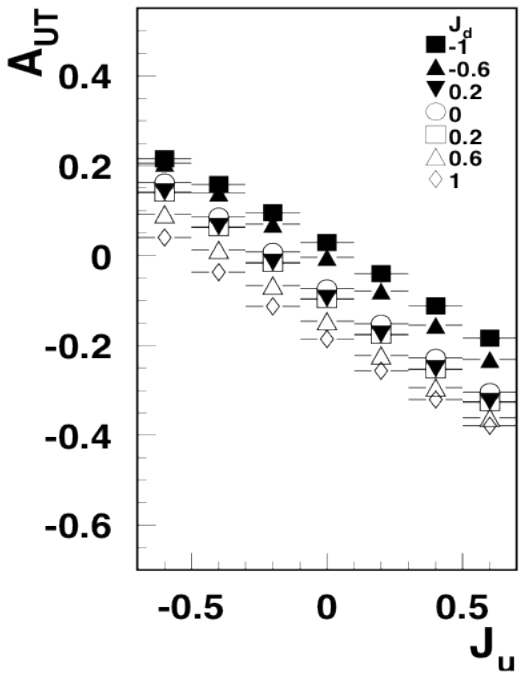
- *HD targets used for eHD tests in Feb/12 and Mar/12*

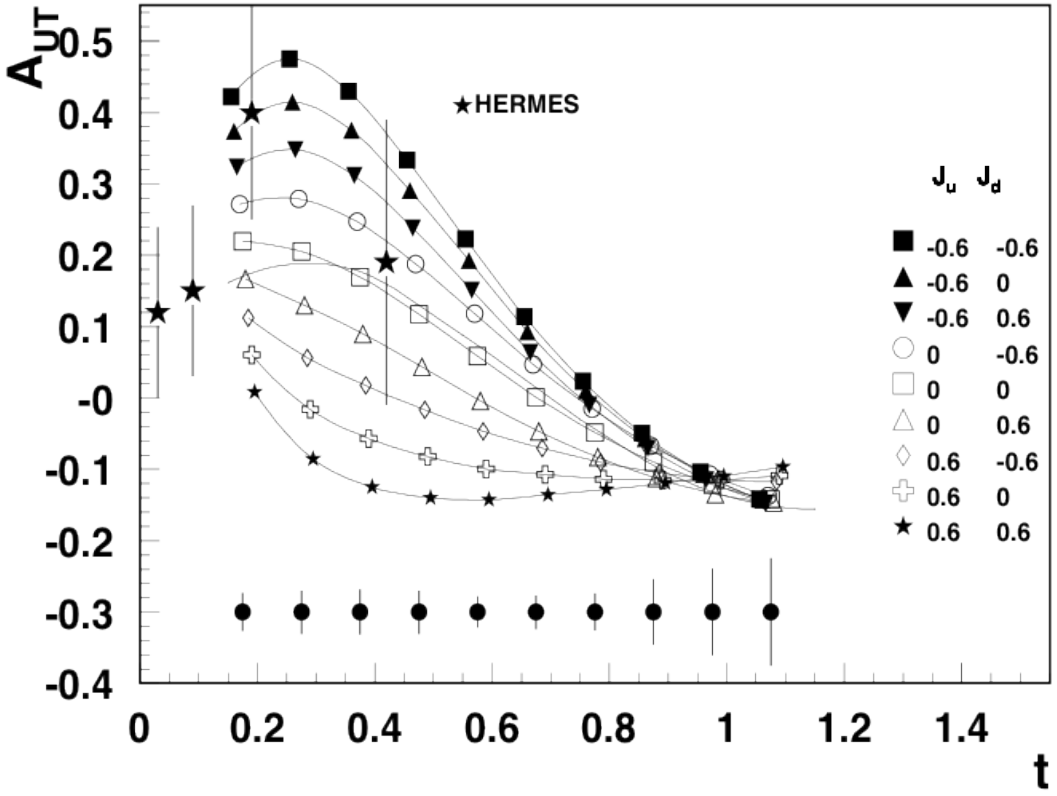
➔ *H polarization does not appear to suffer radiation damage with 1 nA; D does*

➔ *heat removal needs improvement – faster raster, larger diameter cell, shorter, additional cooling wires, …*



HDice DVCS proposal



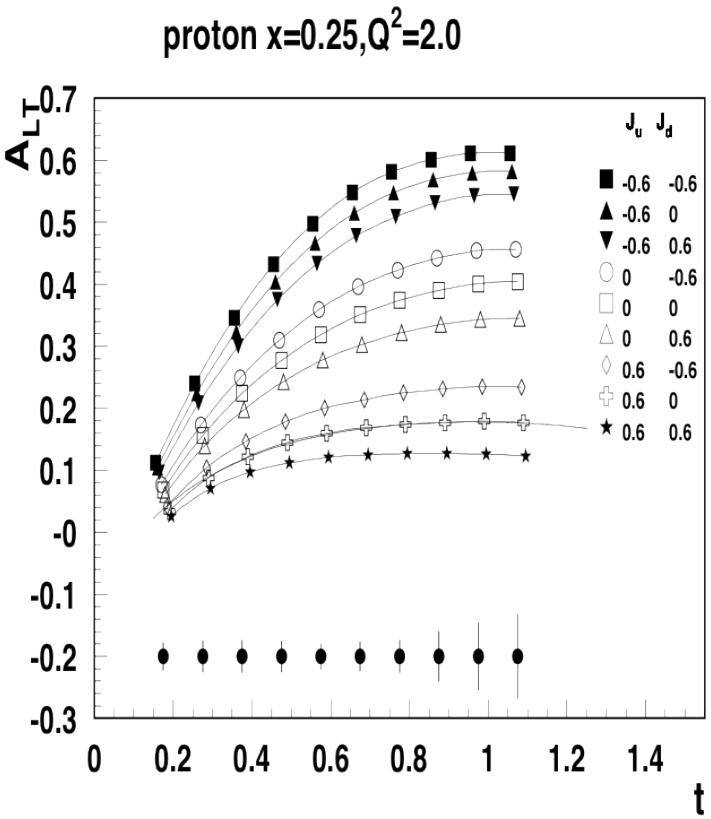


HDice DVCS proposal

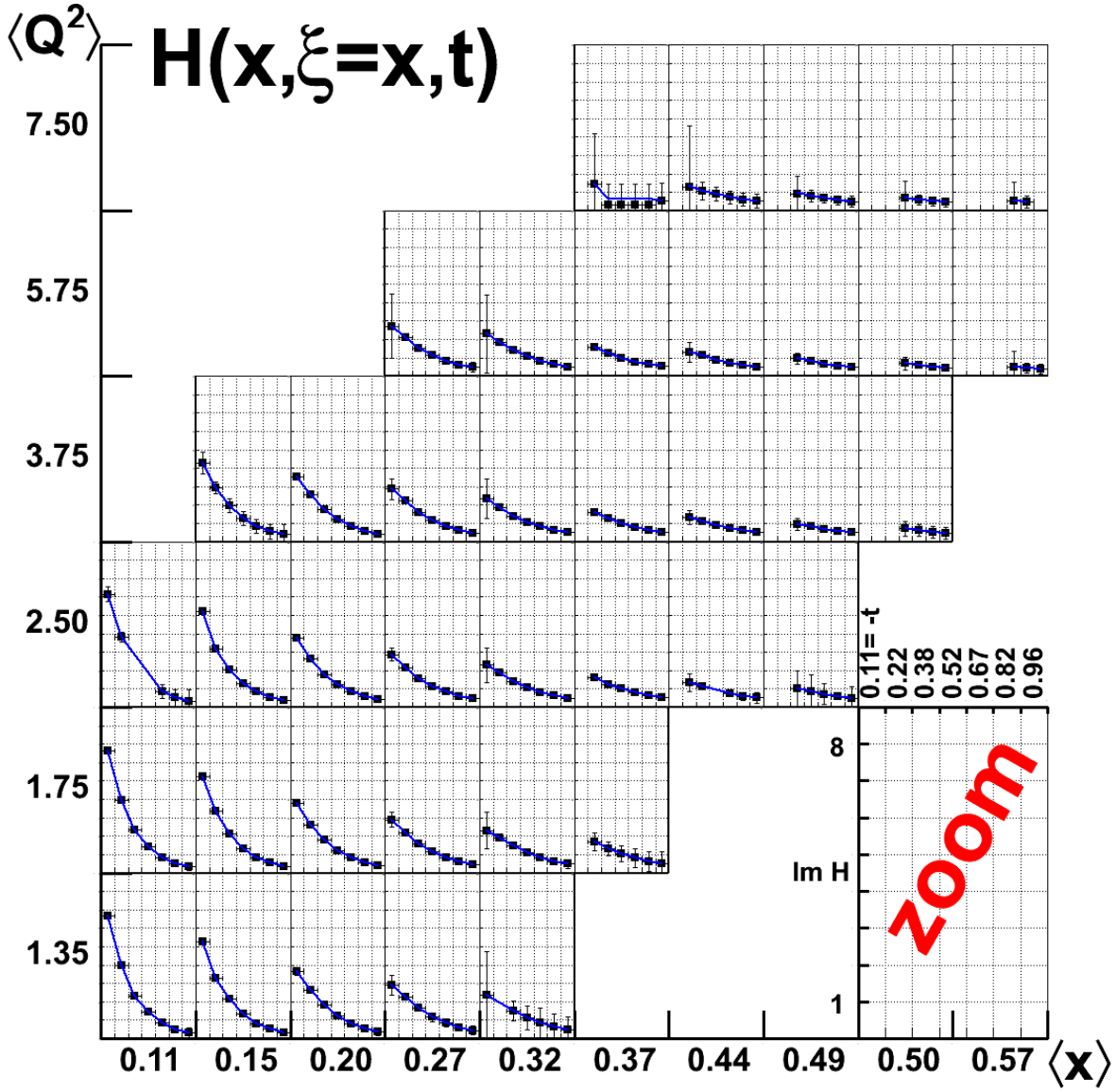
$$A_{LT} = \frac{(d^4\sigma^{\rightarrow\uparrow} + d^4\sigma^{\leftarrow\downarrow}) - (d^4\sigma^{\rightarrow\downarrow} + d^4\sigma^{\leftarrow\uparrow})}{(d^4\sigma^{\rightarrow\uparrow} + d^4\sigma^{\leftarrow\downarrow}) + (d^4\sigma^{\rightarrow\downarrow} + d^4\sigma^{\leftarrow\uparrow})}$$

$$A_{LT}^{\sin(\phi_S-\phi)\sin\phi} = \frac{1}{\pi}\int_0^{2\pi} d\phi \sin(\phi) A_{LT}^{\sin(\phi_S-\phi)}$$

$$A_{LT}^{\sin(\phi_S-\phi)} \propto A_{LT,BH}^{\sin(\phi_S-\phi)} + \frac{1}{2-x}\left(x^2 F_1 - (1-x)\frac{t}{M^2}F_2\right)\mathcal{H} + \left\{\frac{t}{4M^2}\left(\frac{x}{\xi}F_1 + x\xi F_2\right) + x\xi F_1\right\}\mathcal{E}$$

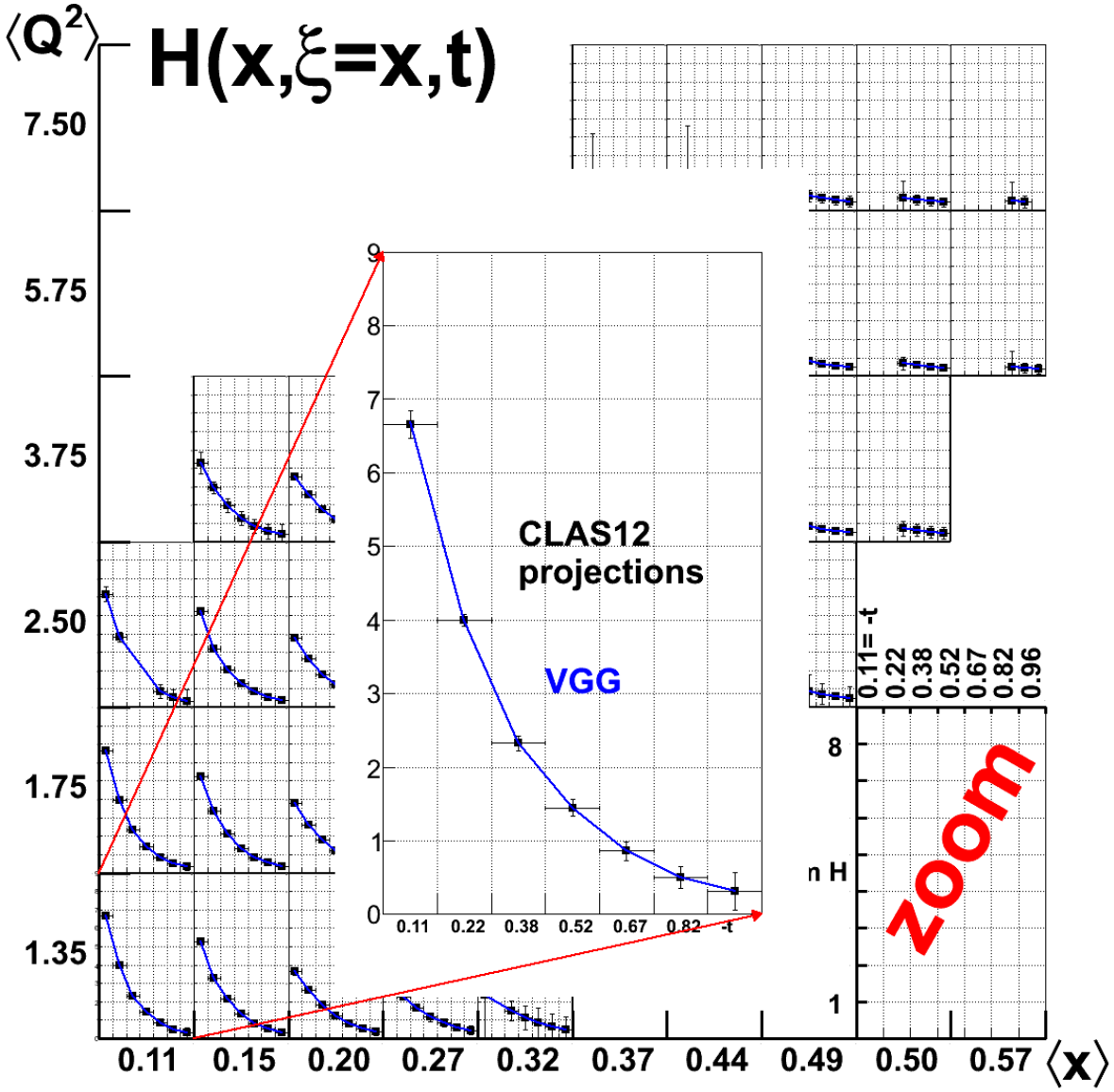


Projected impact on GPD extraction methods



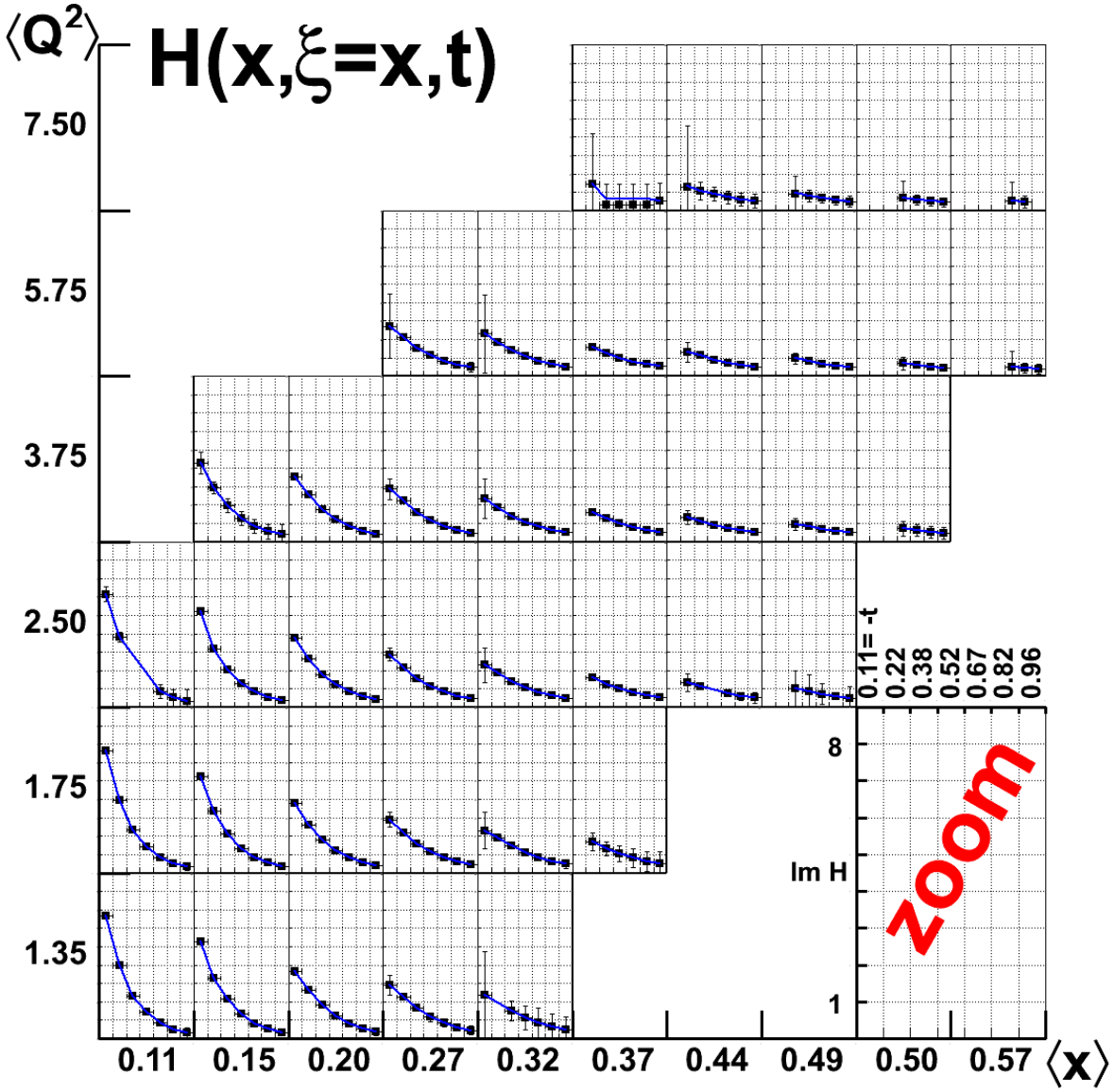
Using simulated data based on VGG model. Input GPD H extracted with good accuracy

Projected impact on GPD extraction methods



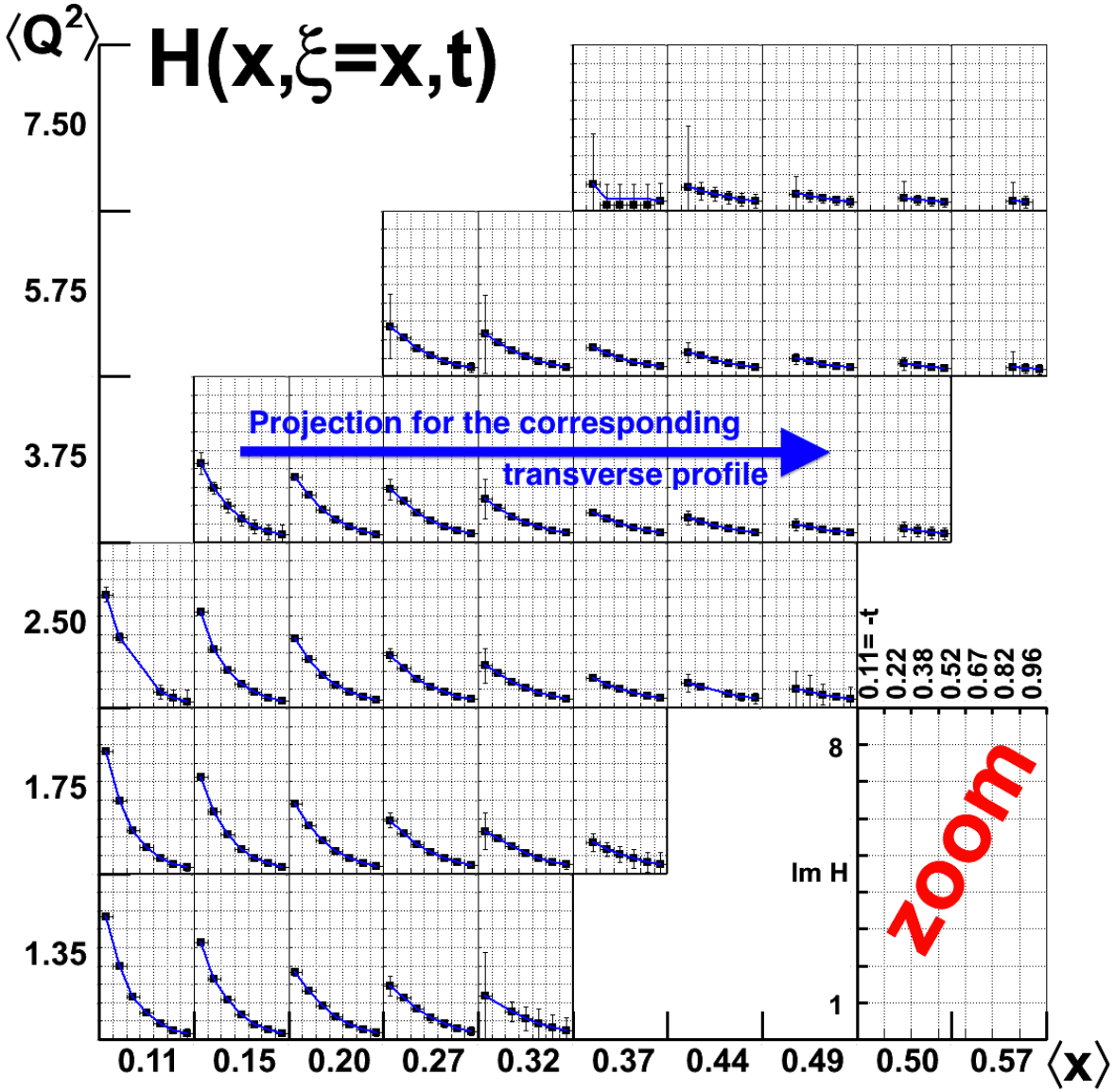
Using simulated data based on VGG model. Input GPD H extracted with good accuracy

Projected impact on GPD extraction methods



Using simulated data based on VGG model. Input GPD H extracted with good accuracy

Projected impact on GPD extraction methods



Using simulated data based on VGG model. Input GPD H extracted with good accuracy

Parton density in a transversly polarized nucleon :

$$\rho_X(x,\vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2}\left[H(x,0,t) - \frac{E(x,0,t)}{2M}\frac{\partial}{\partial b_y}\right] e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$

is not experimentally accessible
What is directly accessible is the Fourier transform of GPD$(x=\xi,t)$:
overlap between active quark initially carrying momentum fraction 2ξ and finally almost 0
(not a probability, relation to density requires specific models/parameterizations)

Momentum space

GPD$(x=\xi,t)$ are fitted with

$$H_{exp}(x,t) = N_H e^{B_H t}$$
$$E_{exp}(x,t) = N_E e^{B_E t}$$

$$H_{dip}(x,t) = \frac{N_H}{\left(1-\frac{t}{M_H{}^2}\right)^2}$$
$$E_{dip}(x,t) = \frac{N_E}{\left(1-\frac{t}{M_E{}^2}\right)^2}$$

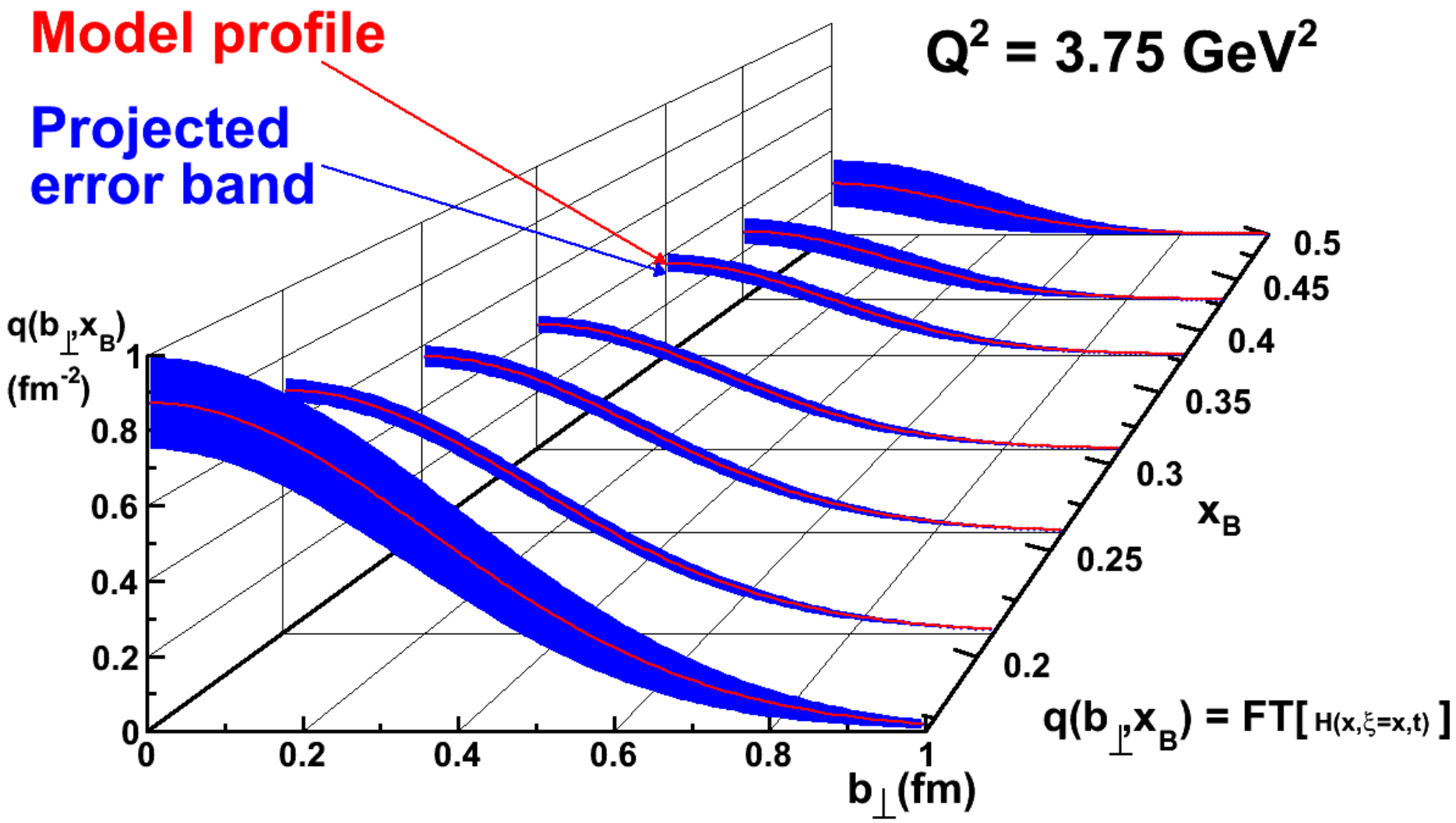
Position space

corresponding to the overlap function

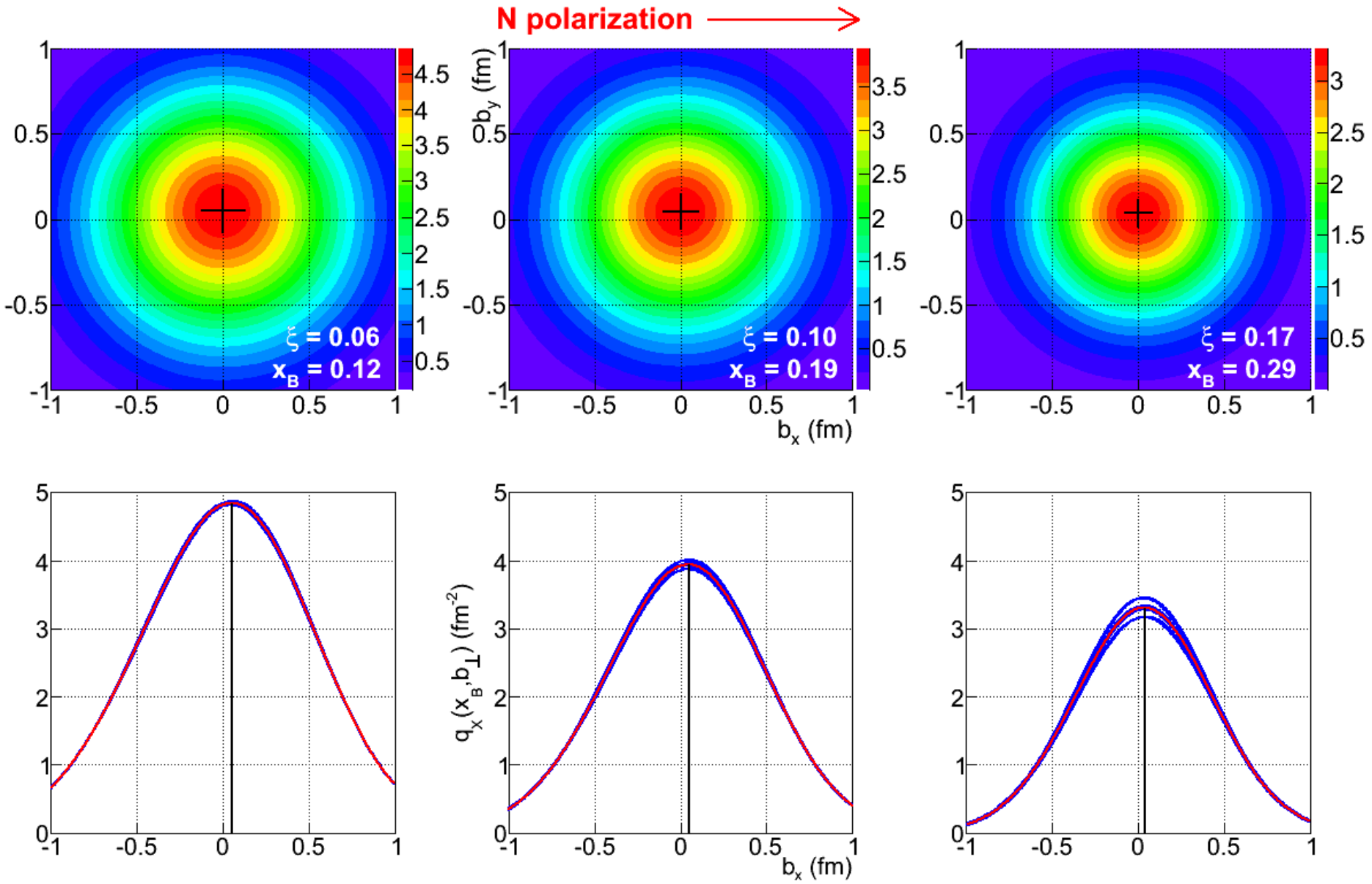
$$\rho_{exp} = \frac{N_H}{4\pi B_H} e^{-b^2/4B_H} + \frac{N_E b_y}{16\pi M B_E{}^2} e^{-b^2/4B_E}$$

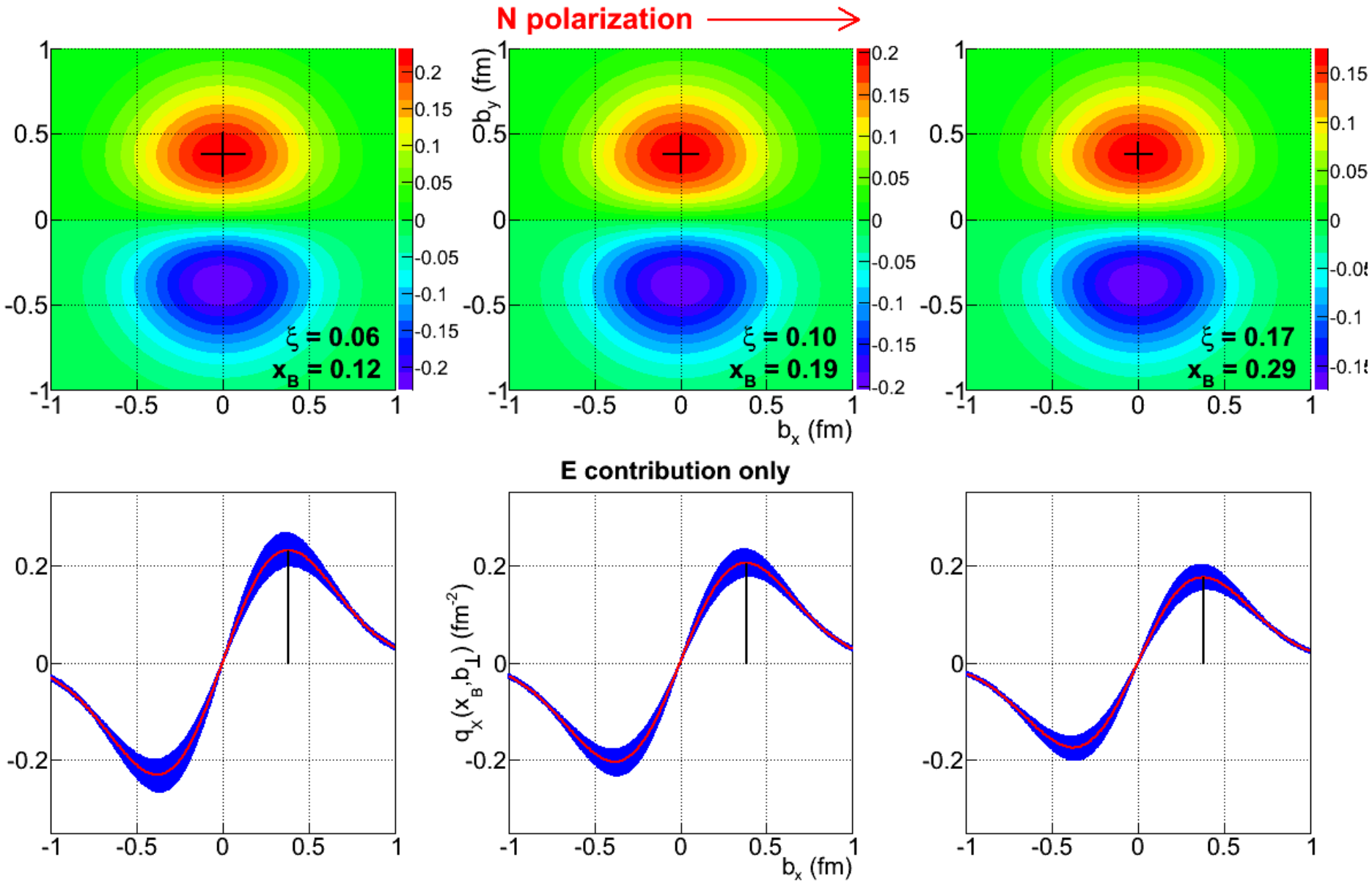
$$\rho_{dip} = \frac{N_H b M_H{}^3}{4\pi} K_1(bM_H) - \frac{N_E b_y M_E{}^3}{8\pi M}\left(\frac{K_1(bM_E)}{b} - \frac{M_E}{2}\left[K_0(bM_E)+K_2(bM_E)\right]\right)$$

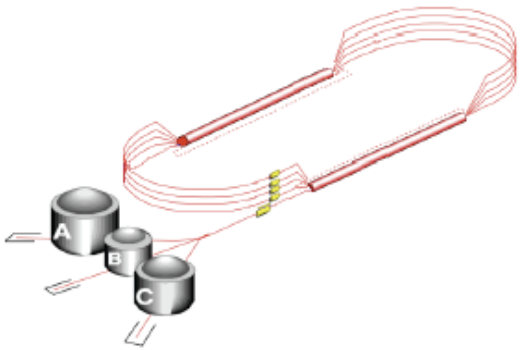
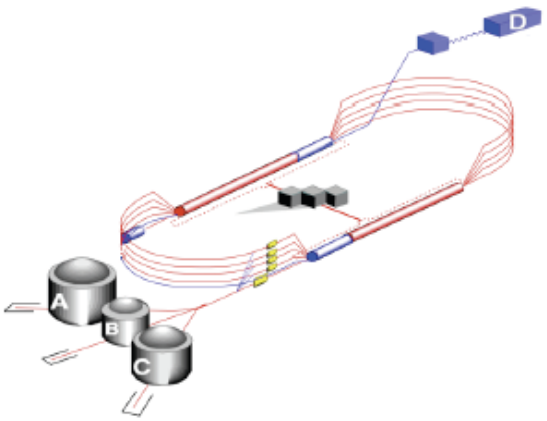
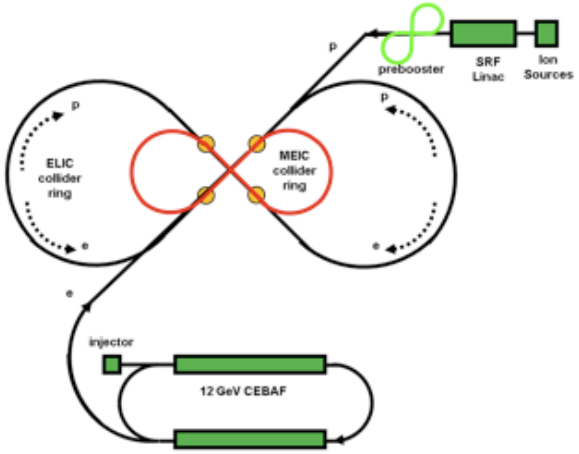
Projection for the Nucleon transverse profile



Precision tomography in the valence region


N polarization
ξ = 0.06
x_B = 0.12
ξ = 0.10
x_B = 0.19
ξ = 0.17
x_B = 0.29
b_y (fm)
b_x (fm)
q_x(x_B,b_⊥) (fm^-2)


N polarization
ξ = 0.06
x_B = 0.12
ξ = 0.10
x_B = 0.19
ξ = 0.17
x_B = 0.29
b_y (fm)
b_x (fm)
E contribution only
q_x(x_B,b_⊥) (fm^-2)
b_x (fm)

Summary

- A unified framework for nucleon tomography has been established
- The first dedicated results on Compton Scattering suggest precocious handbag dominance
- Accurate information on Generalized Parton Distributions in the valence region and at moderate momentum transfer was gathered
- The long range plan to extract GPDs has begun
- Interplay between spin and flavor decompositions requires also other reactions
- JLab 12 GeV will precisely test scaling and carry out the tomography of valence quarks
- Future measurements are planned at CERN/Compass and DESY/Panda
- The EIC will expand the reach and probe the sea and gluons
- Essential for QCD backgrounds at LHC and beyond