Experimental investigation of the nucleon transverse structure

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Elba XIII Workshop – June 23\textsuperscript{th} - 27\textsuperscript{th}, 2014.
The unsolved proton

How do the lagrangian degrees of freedom relate to the hadrons we observe?

How the spin and the mass of the nucleon emerge from its constituents characteristics?

How do the nucleon picture change with the resolution of the hard probe (evolution)?

What part of the nucleon spin is due to gluons and sea quarks?

What is the role of the $s$-quark in the nucleon?

Valence description

Valence + sea quarks + gluons
The response of the nucleon to the elastic scattering, as encoded in the electromagnetic form factors, is still not clear:

- two different behaviours depending on the method adopted in the measurement

![Graph showing the response of the nucleon to elastic scattering](image)

**Scaling behaviour**
SLAC, Rosenbluth-like extractions

**New measurements**
@JLab through Polarization Transfer
The partonic substructure: Deep-Inelastic Scattering

By increasing the virtuality of the virtual photon, i.e. by improving the spatial resolution of the probe, the **Deep-Inelastic Scattering** regime is entered.

The partonic substructure is resolved

→ **SCALING BEHAVIOUR**

- point-like constituents are identified (no $Q^2$ dependence)

The nucleon is described in terms of collinear partons sharing its momentum:

$$p_i = x'_i P, s_i$$
### Longitudinal view of the nucleon

**Longitudinal Parton Distribution Functions**

- $q(x)$: number density of an unpolarized quark in an unpolarized nucleon

- $\Delta q(x)$: number density of longitudinally polarized quark in a longitudinally polarized nucleon

- $\delta q(x)$: number density of transversely polarized quarks in a transversely polarized nucleon

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The proton spin puzzle

\[
\frac{1}{2} = S_q + L_q + S_g + L_g
\]

\[
S_q(Q^2) = \frac{1}{2} \int_0^1 \Delta \Sigma(x, Q^2) dx
\]

\[
\Delta \Sigma = \Delta u + \Delta d + \Delta s \ldots
\]

indicating that the quark spins carry \((1 \pm 12 \pm 24)\)% of the proton spin.

In conclusion, measurements have been presented of the spin asymmetries in deep inelastic scattering of polarised muons on polarised protons. The spin-dependent structure function \(g_1\) of the proton has also been determined. The integral \(\int_0^1 g_1(x) dx = 0.114 \pm 0.012 \pm 0.026\) is significantly lower than the value expected from the Ellis–Jaffe sum rule. Assuming the validity of the Bjorken sum rule this result implies that the asymmetry measured from polarised neutrons should be significantly negative over at least part of its \(x\) range. In addition, the result implies that, in the scaling limit, a rather small fraction of the spin of the proton is carried by the spin of the quarks.
From longitudinal to transverse view

Why do we extend the description to a transverse view?

1. new degrees of freedom explored, that offer new insights into the nucleon structure

2. can help in addressing important open questions
   - what is the role of the parton Orbital Angular Momentum (OAM)?
   - s-quark content of the nucleon through the fragmentation process
   - what other contributions have to be included in the computation of the nucleon spin?

→ we need to extend the simple, longitudinal picture and allow transverse degrees!

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5D mapping of the nucleon

Wigner «Mother» functions are quantum-phase distributions of quarks

→ not directly accessible, we can only extract their 3D reductions

Wigner distributions

\[ \rho(x, k^+, b_T) \]

5-D correlations

W(x, b_T, k_T)

\[ \int d^2b_T \]
\[ \int d^2k_T \]

Fourier trf.

\( b_T \leftrightarrow \Delta \)

H(x,0,t)

\[ t = -\Delta^2 \]

\[ \xi = 0 \]

\[ H(x,\xi,t) \]

generalized parton distributions (GPDs), exclusive processes

\[ \int dx \]
\[ \int dxx^{-1} \]

semi-inclusive processes

F_1(t)

form factors elastic scattering

A_{n,0}(t) + 4\xi^2 A_{n,2}(t) + ....

generalized form factors lattice calculations

Picture by A. Bacchetta

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GPDs&TMDs: 3D reductions of the Wigner functions

Wigner Functions: quantum phase-space quark distributions in the nucleon

\[ W_R(r, k) = \int \frac{dk^-}{(2\pi)^2} W_R(r, k) \]

integrated over spatial coordinates:
Tranverse Momentum Distributions
→ accessed through Semi-Inclusive Deep Inelastic Scattering

integrated over momentum space:
Generalized Parton Distributions
→ measured through exclusive reactions

TMDs: 3D imaging in the momentum space
GPDs: 3D imaging in the coordinate space
8 leading-twist TMDs

They depend on the parton longitudinal fraction $x$ and on its transverse momentum $k_T$ → full 3D dynamics

Two natural momentum scales: $Q^2$ & $p_T$, the transverse $p$ of the produced hadron

3 survive the $k_T$-integration and reduce to the longitudinal, 1D PDFs

Off-diagonal elements → interference among wave function of different angular momenta (OAM, spin-orbit effect)
Experimental access to TMDs through SIDIS

Semi-Inclusive Deep-Inelastic Scattering:
(at least) one hadron observed in the final state with the outgoing electron

Structure Functions $\propto TMD \times FF \times C$

→ it also brings information on the fragmentation process, important to understand HADRONIZATION
The nucleon content through the fragmentation process

\[ \sigma^{ep\to ehX} = \sum_q DF \times \sigma^{eq\to eq} \times FF \]

In the structure functions TMDs are coupled to the Distribution Functions:

- they allow to understand how we go from the Lagrangian degrees of freedom – quarks and gluons – to the hadrons we observe
- can shed light on the flavour content of the nucleon

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<thead>
<tr>
<th>N/q</th>
<th>U</th>
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<tr>
<td>U</td>
<td>( D_1 ) Unpolarized</td>
<td>( H_1^{+} ) Collins</td>
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<td>L</td>
<td>( G_{LL} )</td>
<td>( H_{1L}^{+} )</td>
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<td>( D_{1T}^{+} )</td>
<td>( G_{1T} )</td>
<td>( H_{1}^{+} )</td>
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</table>
Transverse correlations inside the nucleon through TMDs

Three transverse degrees of freedom appear:

1. the nucleon transverse spin $\vec{S}^N_{\perp}$
2. the quark transverse spin $\vec{s}^q_{\perp}$
3. the quark transverse momentum $\vec{k}^q_{\perp}$

$\rightarrow$ Correlations explored through specific TMDs, *i.e.* specific modulations in the cross-section

$\rightarrow$ observable also with an unpolarized target

Transversity $\rightarrow$ correlation among $\vec{s}^q_{\perp}$ and $\vec{S}^N_{\perp}$

Sivers function $\rightarrow$ correlation between $\vec{k}^q_{\perp}$ and $\vec{S}^N_{\perp}$

Boer-Mulders $\rightarrow$ correlation among $\vec{s}^q_{\perp}$ and $\vec{k}^q_{\perp}$
Generalized Parton Distributions → transverse spatial images of quarks and gluons as a function of their longitudinal momentum fraction

\[ t = (p - p')^2 \]
\[ \xi \approx \frac{x_B}{2 - x_B} \]

4 GPDs for any quark flavor:
2 helicity-conserving and 2 helicity-flipping

\( H, \text{ vector} \)

\( E, \text{ tensor} \)

\( \tilde{H}, \text{ axial-vector} \)

\( \tilde{E}, \text{ pseudo-scalar} \)
Exploring the Orbital Angular Momentum through GPDs

Under specific kinematical conditions, GPDs relate to PDFs and FFs.

Optical theorem: \textit{forward GPDs} $\rightarrow$ DIS

\[ H^q(x, 0, 0) = \begin{cases} 
q(x), & x > 0 \\
-q(-x), & x < 0 
\end{cases} \]

\[ \tilde{H}^q(x, 0, 0) = \begin{cases} 
\Delta q(x), & x > 0 \\
\Delta q(-x), & x < 0 
\end{cases} \]

\[ \int_{-1}^{+1} dx H^q(x, \xi, t) = F^q_1(t) , \quad \int_{-1}^{+1} dx E^q(x, \xi, t) = F^q_2(t) \]

\[ \int_{-1}^{+1} dx \tilde{H}^q(x, \xi, t) = G^q_A(t) , \quad \int_{-1}^{+1} dx \tilde{E}^q(x, \xi, t) = G^q_P(t) \]

Second $x$- moment $\rightarrow$ Ji's sum rule

\[ J_q = \frac{1}{2} \int_{-1}^{+1} dx \, x \left[ H^q(x, \xi, t = 0) + E^q(x, \xi, t = 0) \right] \]
Accessing GPDs: Deeply-Virtual Compton Scattering

In the Deeply-Virtual Compton Scattering an incident electron exchanges a virtual photon with a quark of the proton. An emission of a real photon from the target follows.

The process, under appropriate kinematic conditions, gives access to the GPDs.

\[
Q^2 = -(e - e')^2
\]

\[
x_B = \frac{Q^2}{2m \nu}
\]

\[
t = (p - p')^2
\]

\[
\xi \approx \frac{x_B}{2 - x_B}
\]

\[
\nu = E_e - E_{e'}
\]
Accessing GPDs through DVCS observables

The following observables are sensible to different combinations of Compton Form Factors and electromagnetic Form Factors:

1. **Beam-Spin Asymmetry:**
   \[ \Delta \sigma_{LU} \propto \sin \varphi \text{ Im}\{ F_1 \mathcal{H} + \xi (F_1 + F_2) \tilde{\mathcal{H}} + k F_2 \mathcal{E} \}d\varphi \]

2. **Target-Spin Asymmetry:**
   \[ \Delta \sigma_{UL} \propto \sin \varphi \text{ Im}\{ F_1 \tilde{\mathcal{H}} + \xi (F_1 + F_2) \mathcal{H} + k F_2 \mathcal{E} \}d\varphi \]

3. **Double-Spin Asymmetry:**
   \[ \Delta \sigma_{LL} \propto (A + B \cos \varphi) \text{ Re}\left\{ F_1 \tilde{\mathcal{H}} + \xi (F_1 + F_2) \left( \mathcal{H} + \frac{x_B}{2} \mathcal{E} \right) \right\} d\varphi \]

4. **Transverse Target-Spin Asymmetry:**
   \[ \Delta \sigma_{UT} \propto \sin \varphi \text{ Im}\{ k (F_2 \mathcal{H} - F_1 \mathcal{E}) + \ldots \}d\varphi \]

---

The ideal experiment to map the nucleon

Both TMDs\&GPDs need specific experiment characteristics to be explored:

1. Beam energy high enough to reach hard regime

2. large kinematic coverage for full mapping

3. polarized beams\&targets to access ALL the modulations in the cross-sections

4. Different Targets as $H_2$, $D_2$, $NH_3$, $ND_3$ with longitudinal/transverse polarizations

5. High luminosity to extract small cross sections in a fully differential analysis

6. Hermetic detectors (to ensure exclusivity for DVCS) and excellent hadron identification (fragmentation in SIDIS)

$\omega' = \frac{1}{x} + \frac{m^2}{Q^2}$

F. Gross, «Making the case for Jefferson Lab»

The first decade of Science at Jefferson Lab

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Worldwide facilities (a non exhaustive map)

SIDIS in fixed-target experiments e-p:
- Hermes
- JLab (Hall-A, B, C)
- Compass

Fragmentation in $e^+e^-$ annihilations:
- BaBar@SLAC
- Belle@KeK
A joint venture to explore the phase-space

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The **Continuous Electron Beam Accelerator Facility (CEBAF)** is installed in the Thomas Jefferson National Accelerator Facility (Newport News, VA, USA).

- It provides a continuous electron beam with a duty factor ~ 100%;
- with a beam energy up to 6 GeV;
- has a good energy resolution \( \frac{\sigma_E}{E} \sim 10^{-5} \);
- and the beam has a polarization ~ 85%
Jefferson Lab in the 6 GeV era

**Hall-A**
1. Very-high luminosity
2. Test of kinematic approximations (scaling)
3. Transversely-polarized $^3$He target

**Hall-B**
1. High luminosity
2. Large acceptance
3. Unpolarized $^2$H Longitudinally-polarized $^3$NH target

**Hall-C**
1. Very-high luminosity
2. Systematics tests
3. High-precision measurements

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The 12-GeV upgrade

4 experimental halls with a longitudinally-polarized electron beam of $E_e^-$ up to 12 GeV.
Generalized Parton Distributions

1. Does the theoretical description encoded in the Handbag Diagram apply to the kinematics explored with fixed-target experiments? → test of SCALING in Hall-A@JLab

2. DVCS Beam-Spin Asymmetries and transverse spatial distributions of the quarks → $A_{LU}$ in Hall-B@JLab

3. Phenomenological constraints on the OAM from DVCS measurements → neutron $A_{LU}$ & proton $A_{UT}$ in Hall-B@JLab

Transverse Momentum Dependent Distributions

1. Does the target polarization affect the quark momentum distributions? → Sivers @COMPASS & Hermes

2. Is the flavour content of the nucleon as explored through fragmentation consistent with expectations? → Collins @COMPASS & Hermes

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Scaling test for DVCS in Hall-A

Beam-polarized and unpolarized cross sections with high precision at different electron-beam energies to test the scaling $\rightarrow Q^2$ dependence of $d\sigma$ at fixed $x_B$.

$$\Delta\sigma_{LU} \propto \sin \varphi \text{Im}\{F_1 \mathcal{H} + \xi (F_1 + F_2 \overline{\mathcal{H}}) + kF_2 \mathcal{E}\} d\varphi$$

Large $Q^2$ region explored with high statistics

High-statistics $A_{LU}$ extraction@Hall-B in the 6 GeV era

First CLAS DVCS devoted experiment

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\( \Delta \sigma_{LU} \propto \sin \varphi \text{ Im}\{F_1 \mathcal{H} + \xi (F_1 + F_2) \mathcal{H} + k F_2 \mathcal{E}\} d\varphi \)
From GPDs to quark spatial distributions

$-t$ dependence of the imaginary part of the GPD $H$ can be translated into the spatial charge density

arXiv:1303.6600
M. Guidal, H. Moutarde, M. Vanderhaeghen
Quark orbital angular momentum & GPD $E$

$J_q = \frac{1}{2} \int_{-1}^{+1} dx \, x \left[ H^q(x, \xi, t = 0) + E^q(x, \xi, t = 0) \right]$ 

To access $E_u$ & $E_d$ both $E_p$ & $E_n$ are needed.

Proton GPD $E_p$: cos $\varphi$ modulation in $\sigma_{UT}$ on proton

Neutron GPD $E_n$: $A_{LU}$ on the neutron

$(H, E)_u(\xi, \xi, t) = \frac{9}{15} [4(H, E)_p(\xi, \xi, t) - (H, E)_n(\xi, \xi, t)]$

$(H, E)_d(\xi, \xi, t) = \frac{9}{15} [4(H, E)_n(\xi, \xi, t) - (H, E)_p(\xi, \xi, t)]$
Spin-Orbit information through the Sivers Function

Non-zero Sivers \( \rightarrow \) distribution of quarks in transverse momentum affected by the direction of the nucleon’s spin

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Collins Function: the kaon puzzle and the role of the $s$-quark

Scattering on $u$-quark dominate $\rightarrow$ same Fragmentation behaviour expected for pions and kaons

$k^+ \text{ Collins bigger than } \pi^+ \text{ one } \rightarrow \text{ what is the role of the } s\text{-quark?}$
Looking the nucleon at a higher resolution

With an increasing $Q^2$, both sea-quarks and gluons degrees of freedom start to play a more and more important role.

Jefferson Lab and Hermes explored the valence-quark region, while COMPASS moved toward the sea-quark one.

What about the gluon-dominated regime?

What it the spatial distributions of sea-quarks and gluons?

How do gluon contribute to the nucleon spin?

Where the saturation of gluon densities begins?

How does the nuclear environment affect the parton distributions?

EIC White Paper
Electron-Ion Collider

- A collider is needed to reach the gluon-saturated domain
- Electron probe will provide the unmatched precision of the electromagnetic probes
- Dynamical interplay between sea quarks & gluons through their distributions
- Change of distributions when going from small to large $x$, to relate sea and valence quarks
- Dependence on the quark flavours
EIC candidates

Current polarized DIS data:
- CERN
- DESY
- JLab
- SLAC

Current polarized BNL-RHIC pp data:
- PHENIX π0
- STAR 1-jet

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Conclusions

- Despite being a building block of the observed matter, the nucleon – protons and neutrons – is far from being fully understood.

- The mechanisms leading from its constituents to its macroscopic characteristics, as its mass and spin, are not clear.

- To shed light on these aspects it is needed to access nucleon transverse degrees of freedoms, both in momentum (TMDs) and in coordinate (GPDs) space.

- Semi-Inclusive Deep-Inelastic Scattering provides access to the correlations among the transverse degrees of freedom, and allows to explore the fragmentation mechanism.

- The role of the $s$-quark in the nucleon is still unclear → Fragmentation Functions can bring information on the role this flavour plays inside the proton.

- New data are coming in the close (JLab12&COMPASS) and far (EIC) future.

- Stay tuned!
backup
Sensitivity to GPDs in observables - Compton Form Factors

Only \((\xi, t)\) are experimentally accessible, not \(x\). GPDs will enter in the observables through

\[
\int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i\epsilon} = \mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} - i\pi H(\xi, \xi, t)
\]

The two parts will be accessible through observables sensible to the *imaginary* \((A_{LU}, A_{UL})\) or the *real part* \((A_{LL}, A_{BeamCharge})\) of the amplitude.

The following *Compton Form Factors* are introduced (experimentally observable):

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

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

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Deep Inelastic Scattering

$\sigma_{NC}(x, Q^2) \times 2^i$

$Q^2 (GeV^2)$

$g_1^p(x, Q^2) + c(x)$

$Q^2 (GeV^2)$

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Semi-Inclusive DIS cross-section

\[
\frac{d\sigma^h}{dx\,dy\,d\phi\,dz\,d\phi\,dP^2_{h\perp}} = \frac{\alpha^2}{xyQ^2\,2\,(1-\epsilon)} \left( 1 + \frac{\gamma^2}{2\,r} \right)
\]

\[
\begin{align*}
\{ & F_{UU,T} + \epsilon F_{UU,L} \\
+ & \lambda_l \left[ \sqrt{2\epsilon(1-\epsilon)} \sin(\phi) F_{LU}^{\sin(\phi)} \right] \\
+ & S_L \left[ \sqrt{2\epsilon(1+\epsilon)} \sin(\phi) F_{UL}^{\sin(\phi)} + \epsilon \sin(2\phi) F_{UL}^{\sin(2\phi)} \right] \\
+ & S_T \left[ \sin(\phi - \phi S) \left( F_{UT,T}^{\sin(\phi - \phi S)} + \epsilon F_{UT,L}^{\sin(\phi - \phi S)} + \epsilon \sin(\phi + \phi S) F_{UT}^{\sin(\phi + \phi S)} + \epsilon\sin(3\phi - \phi S) F_{UT}^{\sin(3\phi - \phi S)} + \sqrt{2\epsilon(1+\epsilon)} \sin(\phi S) F_{UT}^{\sin(\phi S)} + \sqrt{2\epsilon(1-\epsilon)} \sin(2\phi - \phi S) F_{UT}^{\sin(2\phi - \phi S)} \right) \right] \\
+ & S_T \lambda_l \left[ \sqrt{1-\epsilon^2} \cos(\phi - \phi S) F_{LT}^{\cos(\phi - \phi S)} + \sqrt{2\epsilon(1-\epsilon)} \cos(\phi S) F_{LT}^{\cos(\phi S)} + \sqrt{2\epsilon(1-\epsilon)} \cos(2\phi - \phi S) F_{LT}^{\cos(2\phi - \phi S)} \right] \}
\end{align*}
\]

18 structure functions appear in the cross-section

\[ F_{ij,K} \propto DF \otimes FF \]

They can be identified through specific modulations

It is important combine measurements with unpolarized/longitudinally/transversely-polarized beam\&targets
Upgraded halls@12 GeV

**High Resolution Spectrometer (HRS) pair**
and specialized large installation experiments

**Super High Momentum Spectrometer (SHMS)**
at high luminosity and forward angles

**Hall-A**

**Hall-A - SoLID**

**Hall-C**

**Hall-B**

**CLAS12:** large acceptance, high luminosity

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Deeply-Virtual Compton Scattering & GPD knowledge

**DVCS data in the valence region**

- Hall-A: unpolarized and beam-polarized cross-section
- Hall-B: beam-spin asymmetries, longitudinally-polarized target spin-asymmetries
- HERMES: beam-charge, beam-spin and target-spin asymmetries

All included in CFFs extractions

→ $H_{Im} CFF$ constrained at the level of 15%

Wanted:
1. more observables
2. more precise data
3. larger phase-space coverage

- **COMPASS**: DVCS program (2016) → 160 GeV muon beam (recoil detector for full exclusivity): $x_B = 0.01 \div 0.1$ region explored
- **JLAB12**: Hall-A, B, C → high-statistics in a wide kinematics

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12-GeV DVCS program

- Nucleon polarization
  - Unpolarized: $H, \bar{H}, E$
  - Longitudinally-polarized: $\tilde{H}, H, E$
  - Transversely-polarized: $E, H$

- Sensitivity to GPDs
  - E12-06-114: Hall-A, p
  - E12-06-119: Hall-B, p
  - E12-11-003: Hall-B, n
  - E12-13-010: Hall-C, p
  - PR12-06-108: Hall-B, p

- Good mapping in the $(x_B, Q^2, -t)$ bins → big impact in constraining CFFs

Two processes contribute to the same \((e, p, \gamma)\) final state: Bethe-Heitler and Deeply-Virtual Compton Scattering.

\[
\sigma = |BH|^2 + I(BH \cdot DVCS) + |DVCS|^2
\]

\(I(BH \cdot DVCS)\) gives rise to spin asymmetries, which can be connected to combinations of GPDs.
Semi-Inclusive DIS@JLab with 12 GeV

- Three halls involved
- ALL Beam/Target combinations explored
- Different targets for FLAVOR SEPARATION
- multi-D mapping

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<td>U</td>
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<td>T</td>
<td>$f_{1T}^-$</td>
<td>$g_{1T}$</td>
<td>$h_1, h_{1T}^+$</td>
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**proton** ($H_2, NH_3, HD$)  
**deuterium** ($D_2, ND_3$)  
**helium** ($^3He$)

**E12-06-112**: $\pi^+, \pi^-, \pi^0$  
**E12-09-008**: $k^+, k^-, k^0$  
**E12-09-017**: $\pi^+, \pi^-, k^+, k^-$  
**C12-11-102**: $\pi^0$

**E12-06-112**: $\pi^+, \pi^-, \pi^0$  
**E12-09-008**: $k^+, k^-, k^0$

**E12-09-008**: $k^+, k^-, k^0$  
**E09-009**: $k^+, k^-, k^0$

**C12-11-108** (SoLID)  
**PR12-11-111**: $\pi^+, \pi^-, \pi^0, k^+, k^-, k^0$  
**PR12-12-009**: di-hadron SIDIS

**E10-006**: $\pi^+, \pi^-(\text{SoLID})$  
**E12-09-018**: $\pi^+, \pi^-, k^+, k^-(\text{SBS})$

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### Physics Program@Hall-B in the 12-GeV era

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<th>Days</th>
<th>Group</th>
<th>New equipment</th>
<th>Energy</th>
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<td>Hard exclusive electro-production of $\pi^0, \eta$</td>
<td>Stoler</td>
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<td>E12-12-007</td>
<td>Exclusive $\phi$ meson electroproduction with CLAS12</td>
<td>Stoler, Weiss</td>
<td>B+</td>
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<td>Photoproduction of the very strangest baryon</td>
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<td>Neutron magnetic form factor</td>
<td>Gilfoyle</td>
<td>A-</td>
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<td>Neutron detector RICH (1 sector) Forward tagger</td>
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<td>liquid $D_2$ target</td>
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<td>Dihadron DIS production</td>
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<td>E12-09-007a</td>
<td>Study of partonic distributions in SIDIS kaon production</td>
<td>Hafidi</td>
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<td>Boer-Mulders asymmetry in K SIDIS w/ H and D targets</td>
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<td>Color transparency in exclusive vector meson production</td>
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<td>E12-06-117</td>
<td>Quark propagation and hadron formation</td>
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<td>Free Neutron structure at large $x$</td>
<td>Bueltman</td>
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<td>Radial TPC</td>
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<td>TOTAL approved run time (PAC days)</td>
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JLab12 impact on $Im(\mathcal{H})$ & $Re(\mathcal{H})$

$H_{Re}$ fit of $\sigma_{tot}, A_{UL}, A_{UL}, A_{LL}, A_{UX}, A_{UY}, A_{LX}, A_{LY}$

$H_{Im}$ fit of $\sigma_{tot}, A_{UL}, A_{UL}, A_{LL}, A_{UX}, A_{UY}, A_{LX}, A_{LY}$


Elba XIII Workshop – June 23th - 27th, 2014
$^3\text{He} \rightarrow 60\text{-cm long target}$
Projected luminosity: $2 \times 10^{37} \text{ electron} - \text{nucleon} \text{ cm}^{-2}\text{s}^{-1}$
($2 \times 10^{36} \text{ electron} - \text{polarized neutron} \text{ cm}^{-2}\text{s}^{-1}$)
SBS for SIDIS experiments

Beam path

Distance from the target to the detector, cm
- Central angle $\theta_c$, degree: 417, 14
- Horizontal range: $\Delta\theta_h$, degree: ±3.6
- Vertical range: $\Delta\theta_v$, degree: ±12
- Angular resolution: $\sigma_{\theta_v}$, degree: 0.02
- Vertex resolution (along beam), cm: 0.2
- Momentum resolution $\sigma_p/p$: 0.001$x$[GeV]

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1. tracker
2. gas Cherenkov counter
3. two-layer electromagnetic calorimeter
4. scintillator hodoscope