Is there a chance for future high luminosity e⁻-N (e⁺-N) physics in Europe?

Wolf-Dieter Nowak - DESY Zeuthen
— Int. Workshop on Hadron Structure and Hadron Spectroscopy —
Trieste, Italy, 20.02.2002

Experiments

Short-term: HERMES Run II
(2002+)
COMPASS Stage 1

Medium-term: Upgrade HERMES Spectrometer?
(2007+)
→ New Set of Measurements @ HERA-e?
COMPASS Stage 2?

Long-term: New high-rate, high-resolution spectrometer
(2012+)
to realize ELFE/TESLA-N physics?
→ Unify forces towards future 'eN in Europe'!

Physics

Quark helicity distributions $\Delta q \rightarrow \Delta \Sigma$
Quark transversity distributions $\delta q \rightarrow \delta \Sigma$
Polarized Gluon Distribution $\Delta G$
Generalized Quark Distributions $\rightarrow J_q$
→ Long-term goal $\rightarrow L_q$
THE EFFECTIVE POLARIZED LUMINOSITY FOR A SOLID-STATE FIXED-TARGET EXPERIMENT IS A FACTOR OF ABOUT 25 LOWER THAN FOR POLARIZED ep-COLLIDERS.
2 Proposals

TESLA-N
- Use one (positron) arm of TESLA for polarized fixed target experiment
- Beam energy varied between 30 - 250 GeV
- Use large kinematic domain for $Q^2$ evolution studies
- Transversity distribution
- Gluon polarization

ELFE
- Inject electron beam @ 30 GeV in modified HERA-e
- Use HERA as stretcher ring ⇒ extract high dutyfactor beam
- Fully exploit high resolution for exclusive reactions
- Skewed Parton Distributions
- High precision exclusive reactions

HERMES \rightarrow COMPASS kinematics
HERMES kinematics
Basic Idea: Use one arm of the TESLA collider for a polarized fixed-target experiment to operate in parallel to the collider experiment(s).

☐ Electron (South) arm cannot be used, because kicker magnets would not be fast enough to divert only part of the beam.
⇒ Use positron (North) arm for acceleration
⇒ Static magnet system for separation from the positrons.

☐ The polarized beam constitutes only about 0.04% of the main current
⇒ Additional energy consumption is negligible.

Additionally needed for the experiment, besides target and spectrometer:

☐ Polarized source and injector
☐ Experimental hall and short tunnel
☐ Beam dump
Detector Design Considerations

- Beam energy 250 GeV
  ⇒ Overall dimensions similar to COMPASS

- Good momentum resolution
  ⇒ 3-stage spectrometer
    Stage 1 'Hadron Stage'
    Stage 2 'Electron Stage'
    Stage 3 'Forward Spectrometer'

- Horizontal dipole fields, to direct 'sheet of flame' to the hall floor
  ⇒ Two symmetric halves of the spectrometer: left and right

- Semi-inclusive measurements:
  ⇒ PID as in HERMES:
    Rich, TRD, ECAL
    for Stage 1 and Stage 2,
    Stage 3 only with ECAL
# Polarized Electron Beam

The diagram illustrates the timing and frequency of electron pulses. There are 5 FEL pulses per second, and 5 TESLA pulses per second, with one every 200 ms. The 2830 bunches for e+e- are spaced every 337 ns, with 440 buckets available every 0.77 ns.

### Table: Machine Frequency

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MACHINE FREQUENCY</td>
<td>1.3 GHz ⇒</td>
</tr>
<tr>
<td></td>
<td>ONE BUCKET EVERY</td>
</tr>
<tr>
<td></td>
<td>0.77 ns</td>
</tr>
<tr>
<td>eN-BUNCHES/ S</td>
<td>6.2 \cdot 10^6</td>
</tr>
<tr>
<td>MAX. CURRENT</td>
<td>20 nA</td>
</tr>
<tr>
<td># e⁻/ eN-BUNCH</td>
<td>20000</td>
</tr>
</tbody>
</table>

### Source and Energy

- Source: strained GaAs (SLAC TYPE)
- Energy: 250 GeV
- Also 25-100 GeV possible
- Polarization: ≥ 90 %
4He evaporator cryostat guarantees temperature of 1 K for a heat load of 1 W

⇒ SUFFICIENT POLARIZATION ONLY IN A HIGH MAGNETIC FIELD OF 5 T

⇒ TARGET POLARIZATION MUST SURVIVE HIGH RADIATION DOSES

⇒ DEUTERON TARGET MATERIAL: $^6\text{LiD}$, 
(\(^6\text{Li} \leftrightarrow \alpha + \text{D}\) )
TARGET DILUTION FACTOR 0.44,
TARGET POLARIZATION 0.3

⇒ PROTON TARGET MATERIAL: $\text{NH}_3$,
TARGET DILUTION FACTOR 0.176,
TARGET POLARIZATION 0.8

⇒ AREAL TARGET DENSITY $\sim 1 \text{ g/cm}^2$
TESLA-N figures for 5 Hz operation:

<table>
<thead>
<tr>
<th>LUMINOSITY L $\int L , dt, /s$</th>
<th>$7.5 \cdot 10^{34}$ nucl/cm$^2$/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\int L , dt, /e$-bunch</td>
<td>7.5 nb$^{-1}$</td>
</tr>
<tr>
<td>$\int L , dt, /$eff. day</td>
<td>12 mb$^{-1}$</td>
</tr>
<tr>
<td>$\int L , dt, /$eff. year</td>
<td>1.6 fb$^{-1}$</td>
</tr>
<tr>
<td>C.M. ENERGY</td>
<td>22.3 GeV</td>
</tr>
</tbody>
</table>

TESLA-N ANSATZ FOR EFFICIENCIES:

\[ \varepsilon_{lumi} = \varepsilon_{up\,-\,time} \cdot \varepsilon_{exp} = 0.33 \cdot 0.75 = 0.25 \]

CONSERVATIVE ASSUMPTIONS:

- ONLY THE TIME RESOLUTION OF COMPASS CAN BE REACHED (2 ns)

- ONLY HALF OF THE MAXIMUM CURRENT IS USED TO KEEP THE MULTIPLE EVENT FRACTION SMALL

\[ \Rightarrow 100 \text{ fb}^{-1} \text{ PER YEAR FOR PHYSICS} \]
Event Rates

250 GeV Electrons on a 1g/cm² Target

Möller, $E_e > 1.5$ GeV

$\nu > 3$ GeV

Quasi-real photoproduction

$\nu > 50$ GeV

DIS

($Q^2 > 1$, $W^2 > 4$)

$E_e > 10$ GeV

$E_e > 100$ GeV

No. of events / bunch for $\Theta > \Theta_{\text{min}}$

$\Theta_{\text{min}}, \text{ mrad}$

\[ \frac{N_{\text{DIS}}(E_e > 10)}{N_{\text{photo}}(\nu > 3)} = 2.5 \times 10^{-3} \]

Möller events are kinematically distinguishable from DIS events for $Q^2 > 1$ GeV².
Possible Layout - ELFE

TESLA source

ELFE injection

Return loop

ELFE beam

ELFE extraction

• Return loop to HERA ring
• Modification of HERA-e ring
• Extraction from HERA

Requires:
- Large forward dipole
- Dual RICH detector
- State-of-the-art e.m. calorimeter
- Vacuum chamber to reduce multiple scattering
- Fast scintillating fiber trackers
- Recoil detector
Projected Performance

Exclusive reactions: \( e + p \to e + K^+ + \Lambda/\Sigma \)

Simulation of detector. 
\( E_e = 25 \text{ GeV} \)

⇒ Resolution sufficient to distinguish different exclusive channels.
Motivation (I)

Parton Distributions of the Nucleon
at leading twist in pQCD

\[ q(x, Q^2) \quad \text{Quark Number Density Distribution} \quad (f_1^q) \]
\[ \Delta q(x, Q^2) \quad \text{Quark Helicity Distribution} \quad (g_1^q) \]
\[ \delta q(x, Q^2) \quad \text{Quark Transversity Distribution} \quad (h_1^q) \]
\[ G(x, Q^2) \quad \text{Glueon Number Density Distribution} \]
\[ \Delta G(x, Q^2) \quad \text{Polarized Glueon Distribution} \]

\[ \delta q(x, Q^2) \text{ and } \Delta G(x, Q^2) \text{ presently not known!} \]
Plans

• COMPASS 2001: initial phase
  - SMC polarised target
  - commissioning of RICH1
  - small angle tracking
  - partial large angle tracking
  - hadron calorimetry
  - muon trigger
  - start of data taking for $\Delta G$

• COMPASS 2002
  - COMPASS polarised target
  - straw chambers
  - larger trigger acceptance
  - large angle tracking in stage 2
  - Si detectors
  - hadron and muon beam
  - data taking for $\Delta G$
Expected precision

open charm production 

\[ \langle \frac{\Delta G}{G} \rangle = \frac{A_{\gamma N}^{c\bar{c}}}{\langle a_{LL} \rangle} \approx \frac{1}{p_\mu p_t f \langle D \rangle \langle a_{LL} \rangle} A_{exp}^{c\bar{c}} \]

- 1.5 y with 100 GeV and \(^6\text{LiD} \): \( \delta A_{\gamma N}^{c\bar{c}} = 0.05 \)

- gluon polarisation \( \delta \langle \frac{\Delta G}{G} \rangle = 0.14 \)

- possible improvements:
  - other decay channels
    \[ D^0 \rightarrow K^- \pi^+ \pi^0 \quad 13.8\% \]
    \[ D^0 \rightarrow K^+ \pi^- \pi^+ \pi^+ \quad 8.1\% \]
    \[ D^+ \rightarrow K^+ \pi^- \pi^+ \quad 9.1\% \]
  - D\(^*\) tagging
  - improved analysing power with \( p_T(D^0) \) cut
  - J/\(\psi\) production

E. Kabaß

spin structure 7/01
Polarized Gluon Distribution (I)

Use pairs of high-$p_T$ hadrons to isolate the photon gluon fusion process (PGF). The main background is due to QCD-Compton (QCDC).

Measure the cross section asymmetry

$$A_\parallel = \frac{N_{h+ h}^{\uparrow \downarrow} - N_{h+ h}^{\uparrow \uparrow} - L_{P}^{\uparrow \downarrow}}{N_{h+ h}^{\uparrow \downarrow} - L_{P}^{\uparrow \uparrow} + N_{h+ h}^{\uparrow \uparrow} - L_{P}^{\uparrow \downarrow}}$$

$$\approx \left( \hat{a}_{\text{PGF}} \frac{\Delta G}{G} f_{\text{PGF}} + \hat{a}_{\text{QCDC}} \frac{\Delta q}{q} f_{\text{QCDC}} \right) D$$

$$\hat{a}_{\text{PGF}} = -1 \quad \hat{a}_{\text{QCDC}} \approx 0.5 \quad \text{(Hard scattering asym.)}$$

Hermes Result

1996/97 Data

[PRL 84 (2000) 2584]

(Does not include systematic errors due to Pythia MC)
Expected precision

**hadron pairs**

$$A_{LL}^{HH} \approx \langle a_{LL}^{PGF} \rangle \frac{\Delta G}{G} \frac{\sigma^{PGF}}{\sigma_{tot}} + \langle a_{LL}^{COM} \rangle \frac{\Delta u}{u} \frac{\sigma^{COM}}{\sigma_{tot}}$$

1 y with 200 GeV and $^6$LiD target:

$$A_{LL}^{\gamma N} \quad \delta \langle \frac{\Delta G}{G} \rangle$$

- $H^- H^+$: $-0.2 \pm 0.025 \quad 0.05$
- $K^- K^+$: $-0.12 \pm 0.022 \quad 0.08$

![Graphs of h^+ h^- (p_T > 1.0 GeV/c) and K^+ K^- (p_T > 1.0 GeV/c)]

![Graphs of h^+ h^- (p_T > 1.5 GeV/c) and ΔG/G](spin structure 7/01)
Phenomenological predictions for $Q^2 = 10 \text{ GeV}^2$

**HERMES points in the figure:**

Data with longitudinal target polarization, originally planned until 2005, are to about 80% already on tape thanks to excellent HERA conditions in 2000 and due to an improvement of the target density by about a factor of 2.
QCD improved quark parton model:

\[ g_1^p = \frac{1}{2} \left( \frac{1}{n_f} \sum_{i=1}^{n_f} e_i^2 \right) \left\{ \delta C_{NS} \otimes \Delta q^{NS} \right. \]

\[ + \delta C_S \otimes \Delta \Sigma + \delta C_G \otimes \Delta G \right\} \]

⇒ Parametric form of \( \Delta G(x) \)

Is indirectly determined from QCD NLO fits to \( g_1(x, Q^2) \)

⇒ The fit yields \( \Delta G(Q_0^2) \):

Gluon contribution to nucleon spin:

<table>
<thead>
<tr>
<th></th>
<th>( \Delta G(Q_0^2) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing data</td>
<td>( 0.43 \pm 0.21 )</td>
</tr>
<tr>
<td>Plus 100 fb(^{-1}) TESLA-N(p)</td>
<td>( \pm 0.06 )</td>
</tr>
<tr>
<td>Plus 100 fb(^{-1}) TESLA-N(d)</td>
<td>( \pm 0.04 )</td>
</tr>
</tbody>
</table>
INCLUSIVE MEASUREMENT:
MAP OUT $g_1^p(x, Q^2)$ WITH HIGH PRECISION

PROJECTED STATISTICAL ACCURACY FOR A MEASUREMENT
OF $g_1^p(x, Q^2)$ AT TESLA-N, BASED ON A LUMINOSITY
OF 100 fb$^{-1}$ AND A MINIMUM DETECTOR ACCEPTANCE
OF 5 mrad.

$0.0045 < x < 0.5$
Transversity at HERMES

Measure $\delta q(x)$ in SIDIS at HERMES via

(1) Twist-3 pion production in SIDIS (Jaffe, Ji, 93)

(2) Measurement of the transverse polarization of $\Lambda$'s in the current fragmentation region (Baldracchini, 82 Jaffe, 96)

(3) Observation of the Collins effect in quark fragmentation (through the measurement of pion single target-spin asymmetries) (Collins, 93, Kotzinian, 95, Mulders et al, 96)

(4) Measurement of a correlation in 2-meson production (between transverse spin vector of target nucleon and normal to the two-meson plane) (Jaffe et al., 97)

(5) Measurement of spin-1 hadron production in SIDIS (Bacchetta, Mulders, 00)

Note: Methods (2)-(5) require a transversely polarized target only

Projections for $ep^+(d^+) \rightarrow e'\pi X$

$E = 27.5$ GeV, $P_T = 0.75$

Statistics expected for 2001+: $7 \cdot 10^6$ reconstr. DIS events

DIS cuts: $Q^2 > 1$ GeV$^2$, $W > 2$ GeV, $0.02 < x < 0.7$, $y < 0.85$

From HERMES MC: pion distributions, acceptance

Cuts for pion kinematics:
$x_F > 0., z > 0.1, P_{h\perp} > 0.05$ GeV
TRANSVERSITY THROUGH THE
COLLINS EFFECT: METHOD

WEIGHTED ASYMMETRY
[MULDERS, TANGERMANN 96, KOTZINIAN, MULDERS 97]

\[ A_T(x, y, z) \equiv \frac{\int d\phi^l \int d^2 P_{h\perp} \frac{|P_{h\perp}|}{z M_h} \sin(\phi_s^l + \phi_h^l) \left( d\sigma^\uparrow - d\sigma^\downarrow \right)}{\int d\phi^l \int d^2 P_{h\perp} \left( d\sigma^\uparrow + d\sigma^\downarrow \right)} \]

\( \phi_s^l \) IS AZIMUTHAL ANGLE OF TARGET SPIN VECTOR W.R.T. \( \gamma^* \) AXIS

FACTORIZATION w.r.t. \( x \) AND \( z \):

\[ A_T(x, y, z) = f \cdot P_T \cdot D_{nn} \cdot \frac{\sum_q e_q^2 \delta q(x) H_{1}^{\perp(1)q}(z)}{\sum_q e_q^2 q(x) D_1^q(z)} \]

\( D_{nn} = (1 - y)/(1 - y + y^2/2) \): TRANSVERSE SPIN TRANSFER COEFFICIENT

NOTE: \( H_{1}^{\perp(1)q} \) ACCESSIBLE FROM \( e^+e^- \) DATA (LEP,BELLE)
**Expected precision**

- **Measured asymmetry**
  for 30 days real data taking using charged $\pi$

- **Selection**

  $\nu > 15 \text{ GeV}, \ E' > 5 \text{ GeV}, \ z > 0.1$

  $z_{\text{min}} = 0.1$

- $z_{\text{min}} = 0.3$

- **Improvement** with $\pi^0$ identification

  E. Kabub \text{Zeuthen 7/01}
OPTION 1: PROTON TARGET

Projections for $\delta u(x)$ and $H_1^{(1)u}(z)/D_1^{u}(z)$

OPTION 2: DEUTERON TARGET

Projections for $\delta u(x) + \delta d(x)$ and $H_1^{(1)u}(z)/D_1^{u}(z)$

⇒ HERMES chose option 1 for 2001+

NOTE: $\delta d$ extraction possible by adding option 2
(→ combined analysis)

1[V. Korotkov, W.-D. N., K. Oganessyan, EPJC 18, 639 (2001)]
QUARK TRANSVERSITY FROM SEMI-INCLUSIVE PIONS (II)

DEFINE PURITIES:

\[ P_q^h(x, Q^2, z) = \frac{e_q^2 q(x) D_1^q(z)}{\sum_q e_q^2 q(x) D_1^q(z)} \]

ASSUME FLAVOR-INDEPENDENT POLARIZED FRAGMENTATION FUNCTION \( H_1^{\perp (1)}(z) \):

\[
\frac{1}{P_T \cdot D_{nn}} \cdot A_p^{\pi^+} = \frac{\delta u(x, Q^2)}{u(x, Q^2)} \cdot \frac{H_1^{\perp (1)}(z)}{D_1(z)} \cdot P_{u(p)}^{\pi^+} + \frac{\delta \bar{d}(x, Q^2)}{\bar{d}(x, Q^2)} \cdot \frac{H_1^{\perp (1)}(z)}{D_1(z)} \cdot P_{\bar{d}(p)}^{\pi^+}
\]

RESOLVE NORMALIZATION AMBIGUITY:
\( \delta q = \Delta q \) at \( x \approx 0.25 \), low \( Q^2 \)

4 \cdot N_{(x,Q^2)} \cdot N_z \text{ MEASUREMENTS } (A_{p,d}^{\pi^+ (\pi^-)})

4 \cdot N_{(x,Q^2)} + N_z \text{ UNKNOWN PARAMETER}

\( (\delta u, \delta d, \delta \bar{u}, \delta \bar{d}(x, Q^2), H_1^{\perp (1)}(z)/D_1(z)) \)

\( \Rightarrow \) OVERCONSTRAINED SYSTEM OF COUPLED EQUATIONS.

IF KAON ASYMMETRIES ARE MEASURED IN ADDITION, THE DISTRIBUTIONS \( \delta s(x, Q^2) \) AND \( \delta \bar{s}(x, Q^2) \) CAN BE INCLUDED AS WELL.
TESLA-N

QUARK TRANSVERSITY FROM SEMI-INCLUSIVE PIONS (IV)

PROJECTION FOR THE VALENCE u-QUARK TRANSVERSITY DISTRIBUTION BASED ON 100 fb^{-1} AND A MINIMUM DETECTOR ACCEPTANCE OF 5 mrad.

TENSOR CHARGE / TRANSVERSE SPIN OF THE NUCLEON: (‘ALL-VALENCE OBJECT’) 

\[
\delta \Sigma(Q^2) = \sum_q \int_0^1 dx (\delta q(x, Q^2) - \delta \bar{q}(x, Q^2))
\]

⇒ chiral symmetry!

PROJECTED ACCURACIES AT \(Q^2 = 1\) GeV^2:

\[
\delta u = 0.88 \pm 0.01, \quad \delta d = -0.32 \pm 0.02
\]
Skewed Parton Distributions and DVCS

Skewed (or Generalized, or off-forward) Parton Distributions:

Unified theoretical description of inclusive and (hard) exclusive processes

Simplest hard exclusive process: $ep \rightarrow ep\gamma$

$(\gamma^*p \rightarrow \gamma p)$

Consider $\gamma^*p$ in Bjorken limit $\Rightarrow$

Deeply Virtual Compton Scattering

- Highly virtual quark in $\gamma^*$ scattering $\rightarrow$ propagates perturbatively
- Simplest (and dominating) QCD mechanism to form Compton final state: quark radiates real $\gamma$ and falls back to nucleon ground state

('hand-bag' subprocess in pQCD)

$
\begin{array}{c}
\text{DVCS} \\
\text{Bethe-Heitler} \Rightarrow \text{p.t.o.}
\end{array}$

$\Rightarrow$ Interference gives access to DVCS amplitudes
DVCS AND BETHE-HEITLER

BETHE-HEITLER (BH):
(Elastic lepton-proton scattering with γ radiation by lepton in initial or final state)

INTERFERING PROCESS LEADING TO SAME FINAL STATE
Can be exactly calculated when Dirac and Pauli form factors known

CROSS SECTIONS AT E=27.5 GeV (HERMES): $1^\circ \leq \Theta_{\gamma p} \leq 5^\circ$
'In-plane' cross section: scattering plane = reaction plane (see below)

DVCS DOMINATED BY BH IN MOST OF KIN. REGION!

DVCS-BH INTERFERENCE:
⇒ USE BH AS A VEHICLE TO STUDY DVCS!
SPDs AND DVCS (II)

- **Skewed Parton Distributions:**
  Generalization of usual Parton Distributions and nucleon form factors

- **Usual parton distributions (PDs):** Probability to find a parton in the nucleon with momentum fraction $x$

- **SPDs:** Interference of 2 wave functions:
  Parton with $x + \xi$ emitted from nucleon,
  Parton with $x - \xi$ falls back
  (SPDs sensitive to momentum correlations)

**Variables:**

- **Parton long. momentum fractions** $x$ and $\xi$

- $\gamma^* \rightarrow \gamma$ mom. transfer $\Delta^2 = (p_{\gamma^*} - p_{\gamma})$ (or $t$)

**In DVCS:** 4 different quark SPDs (per flavor)

$H^q(x, \xi, \Delta^2), \tilde{H}^q(x, \xi, \Delta^2)$ conserve nucleon helicity

$E^q(x, \xi, \Delta^2), \tilde{E}^q(x, \xi, \Delta^2)$ flip nucleon helicity

\[ \downarrow \quad \downarrow \]

unpolarized polarized SPDs

**In the limit $\Delta^\mu = 0$ (i.e. $\xi = 0$):**

\[ H^q(x, 0, 0) = q(x), \quad \tilde{H}^q(x, 0, 0) = \Delta q(x) \]

$q(x)$ and $\Delta q(x):$ quark distr. and quark helicity distr.
(no 'usual' PD equivalents for $E^q$ and $\tilde{E}^q$)
SPDs and DVCS (III)

1st MOMENTS connected via sum rules to form factors.

2nd MOMENT of unpolarized SPDs in limit $\Delta^2 = 0$:

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

REAL AND IMAGINARY PARTS OF DVCS AMPLITUDES $\mathcal{H}_1, \tilde{\mathcal{H}}_1, \mathcal{E}_1, \tilde{\mathcal{E}}_1$ CAN BE EXPRESSED THROUGH SPDs $H, \tilde{H}, E, \tilde{E}$. (P denotes Cauchy’s principal value):

\[
\begin{align*}
\text{Im } \mathcal{H}_1 &= -\pi \sum_q e_q^2 (H(\xi, \xi, \Delta^2) - H(-\xi, \xi, \Delta^2)) \\
\text{Im } \tilde{\mathcal{H}}_1 &= -\pi \sum_q e_q^2 (\tilde{H}(\xi, \xi, \Delta^2) + \tilde{H}(-\xi, \xi, \Delta^2)) \\
\text{Re } \mathcal{H}_1 &= \sum_q e_q^2 [P \int_{-1}^{+1} H(x, \xi, \Delta^2) \left( \frac{1}{x - \xi} + \frac{1}{x + \xi} \right) dx] \\
\text{Re } \tilde{\mathcal{H}}_1 &= \sum_q e_q^2 [P \int_{-1}^{+1} \tilde{H}(x, \xi, \Delta^2) \left( \frac{1}{x - \xi} - \frac{1}{x + \xi} \right) dx]
\end{align*}
\]

ANALOGOUS EXPRESSIONS FOR AMPLITUDES $\mathcal{E}_1, \tilde{\mathcal{E}}_1$.

EXTRACTION OF SPDs WILL BE A COMPLEX TASK
**ϕ-DEPENDENCE OF ASYMMETRIES**

**DVCS kinematical configuration:**

\[ \phi_\gamma: \text{azimuthal angle between scattering and reaction plane.} \]

\[ \phi_\gamma: \text{ASYMMETRIES SHOW DIFFERENT CHARACTERISTICS} \]

**A) MEASURE LEPTON CHARGE ASYMMETRY:**

unpolarized beam, unpolarized target \((A_{ch})\)

\[ \Delta_{ch}d\sigma^{\text{unpol}} \equiv d\sigma(e^+p) - d\sigma(e^-p) \]

\[ \sim \cos(\phi_\gamma) \times \text{Re} \left\{ F_1\mathcal{H}_1 + \frac{x_B}{2 - x_B}(F_1 + F_2)\tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right\} \]

⇒ **ACCESS TO REAL PART OF \(\mathcal{H}_1, \tilde{\mathcal{H}}_1\)**

**B) MEASURE LEPTON HELICITY ASYMMETRY:**

long. polarized beam, unpolarized target \((A_{LU})\)

\[ \Delta d\sigma \equiv d\sigma(e^+p) - d\sigma(e^-p) \]

\[ \sim \sin(\phi_\gamma) \times \text{Im} \left\{ F_1\mathcal{H}_1 + \frac{x_B}{2 - x_B}(F_1 + F_2)\tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right\} \]

⇒ **ACCESS TO IMAGINARY PART OF \(\mathcal{H}_1, \tilde{\mathcal{H}}_1\)**
**A NEW Recoil Detector for Hard Exclusive Reactions**

<table>
<thead>
<tr>
<th>DVCS</th>
<th>(\gamma^* p \rightarrow \gamma p)</th>
<th>(H \tilde{H} E \tilde{E})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>exclusive pseudoscalar meson production</td>
<td>(\gamma^* p \rightarrow \pi^0 p)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\gamma^* p \rightarrow \pi^+ n)</td>
</tr>
<tr>
<td></td>
<td>exclusive vector meson production</td>
<td>(\gamma^* p \rightarrow \rho^0 p)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\gamma^* p \rightarrow \omega p)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\gamma^* p \rightarrow \phi p)</td>
</tr>
</tbody>
</table>

**Schematic cross section**
SPDs modeled according to

[M. Vanderhaeghen, P. Guichon, M. Guidal, PRD 60 (99) 094017]

Most simple ansatz is to neglect $\xi$ dependence.

Then e.g.

$$H^{u/p}(x, \xi, \Delta^2) = u(x) F^{u/p}_1(\Delta^2)/2$$

$$H^{d/p}(x, \xi, \Delta^2) = d(x) F^{d/p}_1(\Delta^2)$$

$$H^{s/p}(x, \xi, \Delta^2) = 0$$

Similar expressions for $H^{q/p} \rightarrow \tilde{H}^{q/p}$.

$u(x)$ and $d(x)$:

Usual unpolarized quark distributions

Proton and neutron el. magn. form factors used to construct flavor-dependent Dirac and Pauli form factors

Annual integrated luminosity: $2 \text{fb}^{-1}$

(Unpolarized target)

Hermes acceptance taken in account for all involved particles

Kinematical cuts

$$E_e > 3.5 \text{ GeV} \quad E_\gamma > 1 \text{ GeV} \quad P_p > 0.2 \text{ GeV}$$

$$W^2 > 4 \text{GeV}^2 \quad Q^2 > 1 \text{GeV}^2 \quad 15 < \Theta_{\gamma\gamma^*} < 70 \text{mrad}$$
HERMES Measurements with a Recoil Detector, Projections\(^3\)(ii)

A) Measure lepton charge asymmetry in DVCS:
unpolarized beam, unpolarized target

B) Measure lepton helicity asymmetry in DVCS:
polarized beam, unpolarized target (no D-term)

Open circles in left panel: HERMES preliminary (1996/97 data)

\(^3\)[V. Korotkov, W.-D. N., hep-ph/0108316] \(\rightarrow\) EPJ C. 03/02
$e^+ p \rightarrow e^+ p \gamma$

$P_T = 0.9$

$L_{int} = 0.8 \text{ fb}^{-1}$
$e^+ p \rightarrow e^+ p \gamma$

$P_T = 0.9$

$L_{int} = 0.8 \text{ fb}^{-1}$
\[ H^{\ast} \sim q(x) \cdot F^{\ast}(\Delta^2) \]

\[ H^{\ast} \sim \Delta q_v(x) \cdot G_{\alpha}(\Delta^2) \]

Skewness-independent

\[ \begin{array}{c}
\begin{array}{c}
 b=1 \\
 b=3
\end{array}
\end{array} \]

\[ H^{\ast} \sim \frac{q(x)}{2} \cdot H_{DD}^{\ast}(x, \xi) \]

Skewness-dependent

double distribution

\[ \begin{array}{c}
\begin{array}{c}
 b=1 \\
 b=3
\end{array}
\end{array} \]

\[ H^{\ast} \sim \frac{q(x)}{2} \cdot \left\{ H_{DD}^{\ast}(x, \xi) + \Theta \left( \xi - \xi \right) \frac{1}{N_{\xi}} D \left( \frac{\xi}{\xi} \right) \right\} \]

"D-term" for correct polynomial-ability properties
(diff. sign for \( H \& E \)
\( \rightarrow \) cancels in Ji's 2nd moment)

\[ H_{DD}^{\ast}(x, \xi) = \int dy \int dt \delta(x-y-t\xi) h(y,t) q(y) \]

ordinary qu. distr.

\[ h(y,t) = \frac{\Gamma(26+2)}{2^{26+1} \Gamma^2(6+1)} \cdot \frac{[1-(y^2+t^2)]^6}{(1+y)^{26+1}} \]

Note: \( b \to \infty \) means skewness-independent
High luminosity
TESLA-N/ELFE - type exp.
w/ transv. pol. target

\[ e^{-} p \uparrow \rightarrow e^{-} p \gamma \]
\[ P_{T} = 0.80 \]
\[ L_{\text{int}} = 100 \text{ fb}^{-1} \]
LONG-TERM OBJECTIVES

Once $J_q$ will have been determined from (a variety of) GPD measurements with acceptable accuracy, two remaining major unknowns in the nucleon spin puzzle get into reach:

$L_q$: Quark Orbital Angular Momentum, through

\[ J_q = \frac{1}{2} \Delta \Sigma + L_q \]

Since quark contribution to the nucleon spin, $\Delta \Sigma$, well measured already now.

$J_g$: Gluon Total Angular Momentum, through

\[ \frac{1}{2} = J_q + J_g \]

NOTE: Although gluon contribution to the nucleon spin, $\Delta G$, expected to be well measured in a few years [COMPASS, RHIC] this may not allow to separate $L_g$, since for the integrals:

\[ J_g \neq \Delta G + L_g \]


⇒ More theor. work possibly very helpful
Why a large $Q^2$ range may be very useful for GPD meas.? 
(thanks to P. Guichon pointing to this) 
[A. Freund, hep-ph/9903488]

Deconvolution problem:

\[
\text{DIS} : \quad F_2(x, Q^2) = \int \frac{dy}{y} C_i \left( \frac{x}{y}, Q^2 \right) f_i(y, Q^2) 
\]

only one variable
moments in $x$; inverse Mellin transform $\Rightarrow f_i(x, Q^2)$

\[
\text{DVCS} : \quad \text{GPD} (x, f, t, Q^2) 
\]

internal variable $f(x_b)$: two variables $\Rightarrow$ deconvolution not possible!

Theoretical work-around [A.F.]:

- believe that $Q^2$-dep. of amplitude is known for $Q^2 > Q_0^2$
- measure large enough $Q^2$-range to distinguish this log $Q^2$-behaviour from twist-4 ($\sim 1/Q^2$) behaviour
- analyze region where twist-4/twist-2 $\ll$ twist-2
- measure enough (many!) data points in $Q^2$ for every $x_b$
- solve (large!) matrix equation $\Rightarrow \text{GPD} (x, f, t, Q^2)$

$\Rightarrow$ worth to be studied in more detail (feasibility!)}
2010+

WHICH MACHINE FOR WHICH PHYSICS?

Trieste, Feb. 20 '02

Flagship' topics to study hadron structure at a high-luminosity fixed-target eN-facility

<table>
<thead>
<tr>
<th>Physics</th>
<th>Measured functions</th>
<th>processes</th>
<th>exp. requests</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXCLUSIVE REACTIONS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Total quark angular momentum $J_q$ (*)</td>
<td>$F_1$'s relation: $J_q = \lim_{t \to 0} \frac{1}{2\pi} \int dx { H_1^q(x, t) + E(x, t) }$</td>
<td>DVCS: $H_1^E$, $H_1^T$</td>
<td>U</td>
</tr>
<tr>
<td>1st step: $J_q$ (2006 +)</td>
<td>$F_2^{1s} = H_1^E &lt; 2006$</td>
<td>DVEM: pseudoscalar: $H_1^E$, vector: $H_1^T$</td>
<td>T</td>
</tr>
<tr>
<td>SEMI-INCLUSIVE DIS:</td>
<td>transversity distribution $\Delta g(x, Q^2) = \Delta g_T(x, Q^2) \equiv \Delta g^0(x, Q^2)$</td>
<td>DIS + SIDIS</td>
<td>L</td>
</tr>
<tr>
<td>• PRECISE Measurement of tensor charge ($\rightarrow$ chiral symmetry breaking)</td>
<td>$\Delta \Sigma(x^2) = \int dx { \Delta g(x, Q^2) - \bar{\Delta g}(x, Q^2) }$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• axial charge</td>
<td>$\Delta \Sigma(x^2) = \int dx { \Delta g(x, Q^2) + \bar{\Delta g}(x, Q^2) }$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*) fundamental issues!

Summary of requests:

- Polarized targets ($T, L$); solid-state
- Sufficient duty cycle ($1-10\%$)
- Variable beam energy ($30 \ldots 100 \ldots 200$ GeV)
OUTLOOK (as of 20.02.2002)

First contours of a road map towards a future high-luminosity fixed-target electron (positron)-nucleon experiment in Europe become clearly visible:

- **SHORT-TERM** (2002-2006):
  COMPASS and HERMES Run II,
  in conjunction with RHIC-Spin & Jlab,
  will give *accurate* (first) answers on
  $\Delta u, \Delta d, \Delta \bar{u}, \Delta \bar{d}, \Delta G, (\Delta s), \delta u, (\delta d), (H^u)$

- **MEDIUM-TERM** (2007+):
  'Window' for a measurement of $H^u, \tilde{H}^u, E^u$
  at HERA-e after upgrade of HERMES target & spectrometer → 'Flagship' physics:
  $\Rightarrow$ Determination of the u-quark
  total angular momentum

- **LONG-TERM** (2012+):
  There exists a chance for one experiment, to
  be realized most economically in conjunction
  with a TESLA-like machine allowing for a
  duty cycle above 1% and a variable energy
  range above 30 GeV
  $\Rightarrow$ the best combination of ELFE/TESLA-N
  physics under the (then) given conditions
  should be envisaged