Is There a Chance for Future High Luminosity e^--N (e^+-N) Physics in Europe ?

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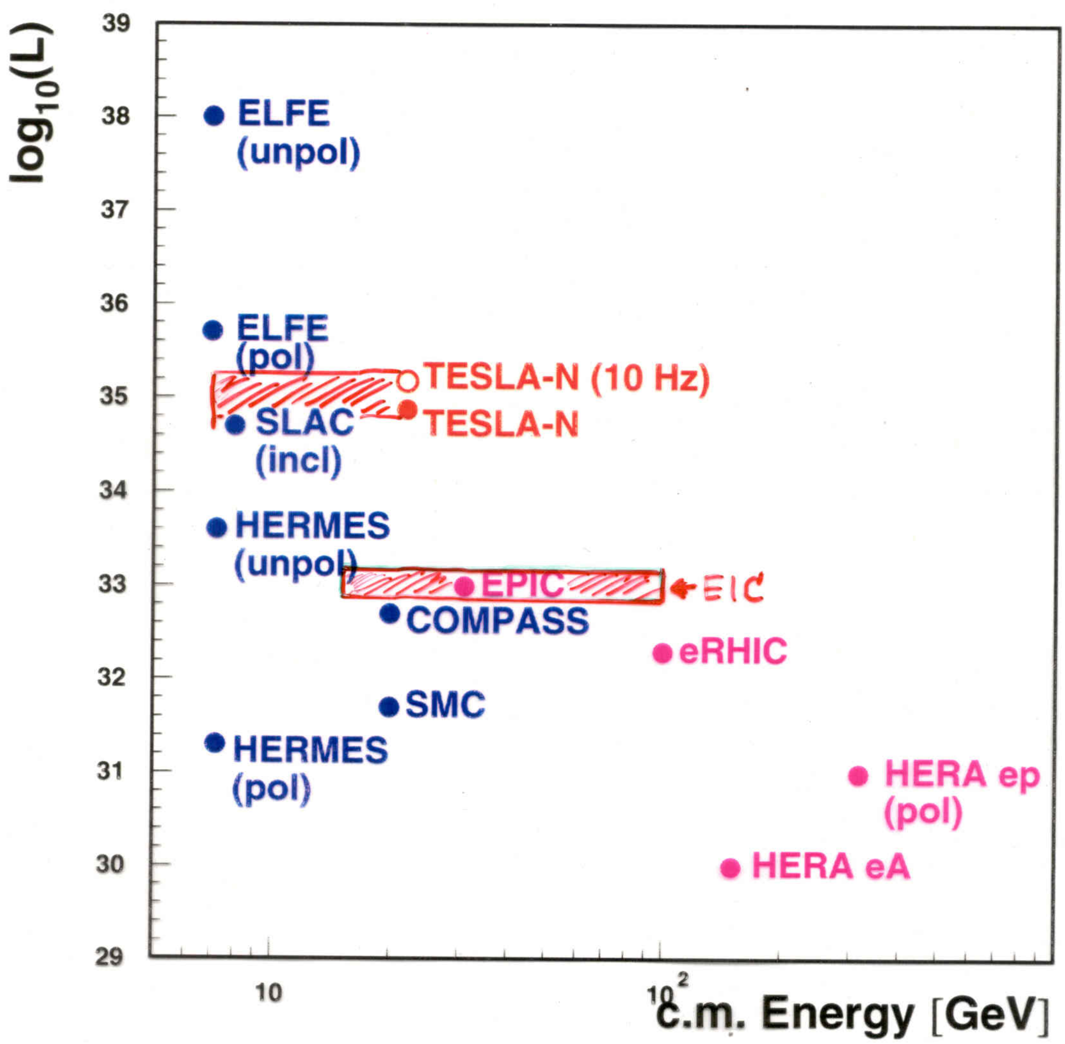
EXPERIMENTS

Short-term: (2002+)	HERMES Run II COMPASS Stage 1
Medium-term: (2007+)	Upgrade HERMES Spectrometer ? ⟶ New Set of Measurements @ HERA-e ? COMPASS Stage 2 ?
long-term: (2012+)	New high-rate, high-resolution spectrometer to realize ELFE/TESLA-N physics ? → Unify forces towards future 'eN in Europe' !

PHYSICS

Quark helicity distributions	Δq	$\rightarrow$	$\Delta\Sigma$
Quark transversity distributions	δq	$\rightarrow$	$\delta\Sigma$
Polarized Gluon Distribution			ΔG
Generalized Quark Distributions		$\rightarrow$	J_q
⟶ Long-term goal		$\rightarrow$	L_q

LUMINOSITY (II)



THE EFFECTIVE POLARIZED LUMINOSITY FOR A SOLID-STATE FIXED-TARGET EXPERIMENT IS A FACTOR OF ABOUT 25 LOWER THAN FOR POLARIZED ep-COLLIDERS.

TESLA-TDR/Appendices :

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

HERMES → COMPASS kinematics

ELFE

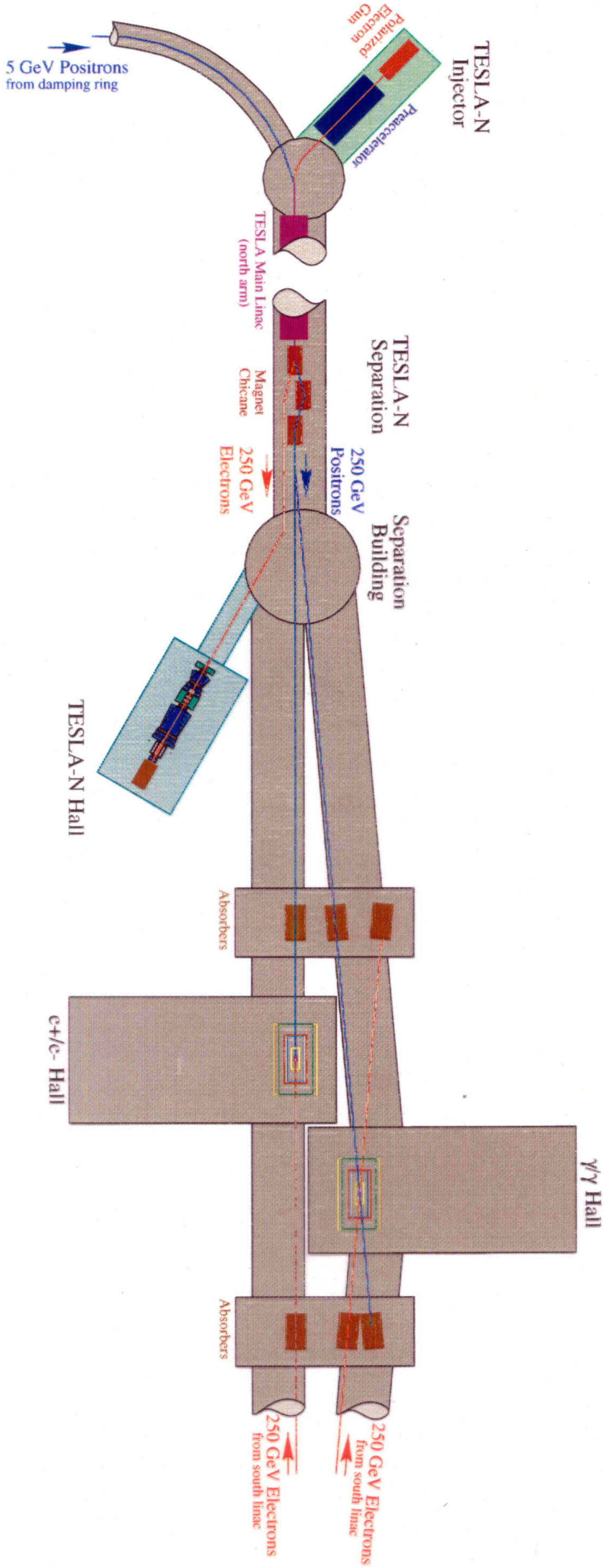
- Inject electron beam @ 30 GeV in modified HERA-e
- Use HERA as stretcher ring ⇒ extract high dutyfactor beam
- Fully exploit high resolution for exclusive reactions

- Skewed Parton Distributions
- High precision exclusive reactions

HERMES kinematics

TESLA-N

Civil Engineering



TESLA-N

A POLARIZED FIXED-TARGET EXPERIMENT AT TESLA

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

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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

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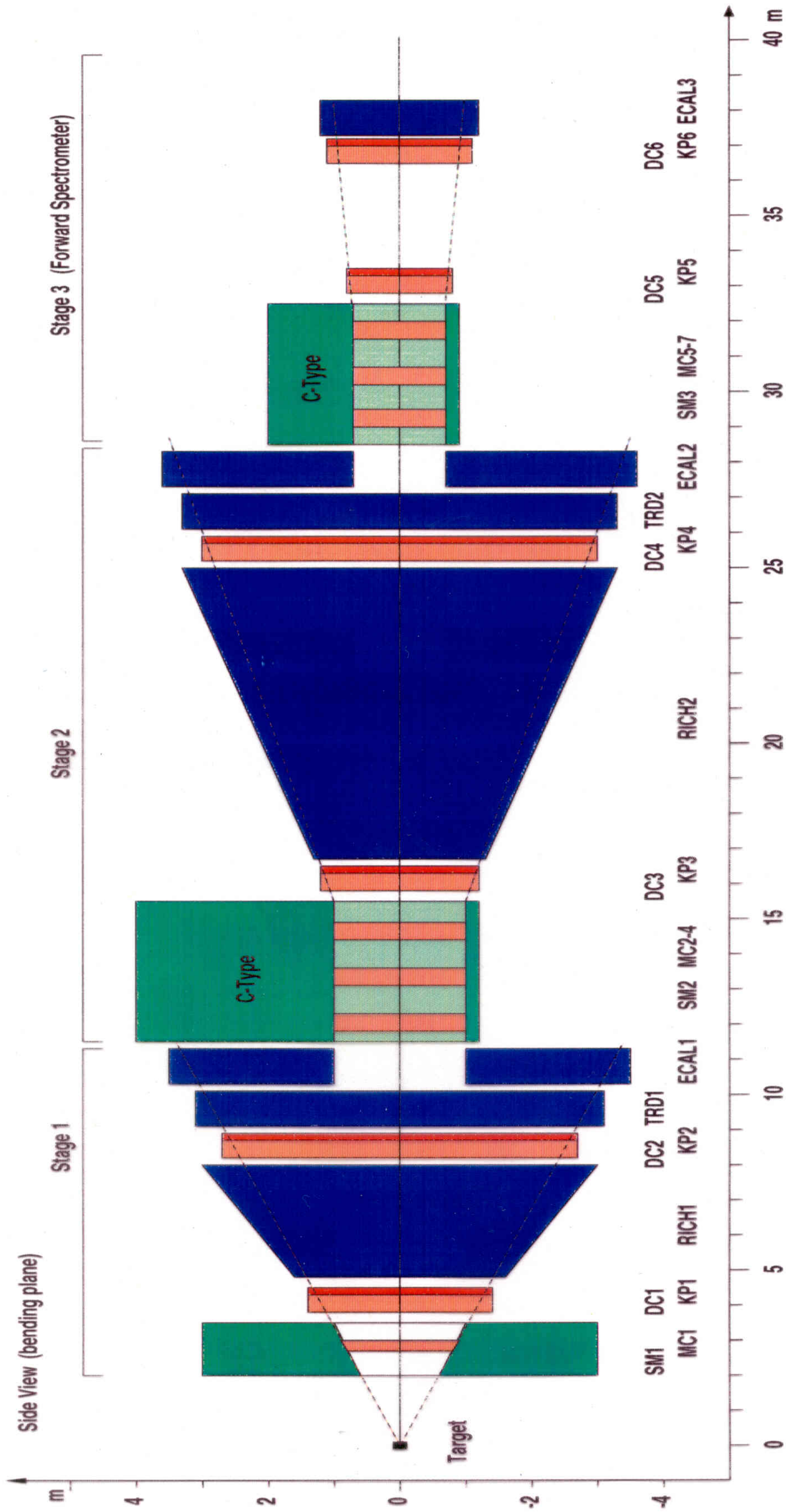
Schematic Spectrometer Design



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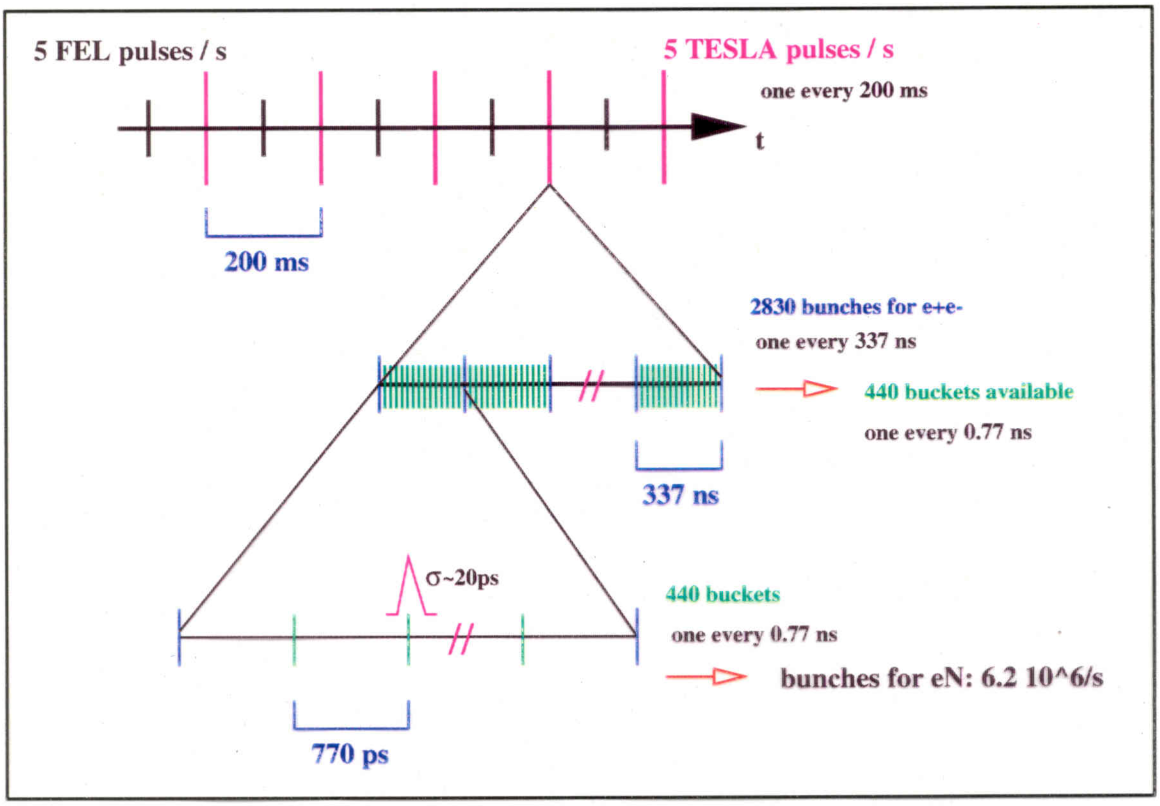
Polarized Electron Beam



MACHINE FREQUENCY	1.3 GHz ⇒ ONE BUCKET EVERY 0.77 ns
eN-BUNCHES / S	$6.2 \cdot 10^6$
MAX. CURRENT	20 nA
# e^- / eN-BUNCH	20000

SOURCE	strained GaAs (SLAC TYPE)
ENERGY	250 GeV ALSO 25-100 GeV POSSIBLE
POLARIZATION	$\geq$ 90 %

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Polarized Target

- ^{4}He 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}LiD, ($^6\mathrm{Li} \leftrightarrow \alpha + \mathrm{D}$)
  target dilution factor 0.44,
  target polarization 0.3

  ⇒ proton target material: NH_3,
  target dilution factor 0.176,
  target polarization 0.8

- areal target density $\sim 1\ \mathrm{g/cm^2}$

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LUMINOSITY (I)

TESLA-N figures for 5 Hz operation:

LUMINOSITY L	$7.5 \cdot 10^{34}$ nucl/cm^2/s
$\int L\, dt$/s	7.5 nb^{-1}
$\int L\, dt$/e-bunch	12 mb^{-1}
$\int L\, dt$/eff. day	1.6 fb^{-1}
$\int L\, dt$/eff. year	600 fb^{-1}(upper limit)
C.M. ENERGY	22.3 GeV

TESLA-N ANSATZ FOR EFFICIENCIES:

$$\varepsilon_{lumi} = \varepsilon_{up-time} \cdot \varepsilon_{exp} = 0.33 \cdot 0.75 = 0.25$$

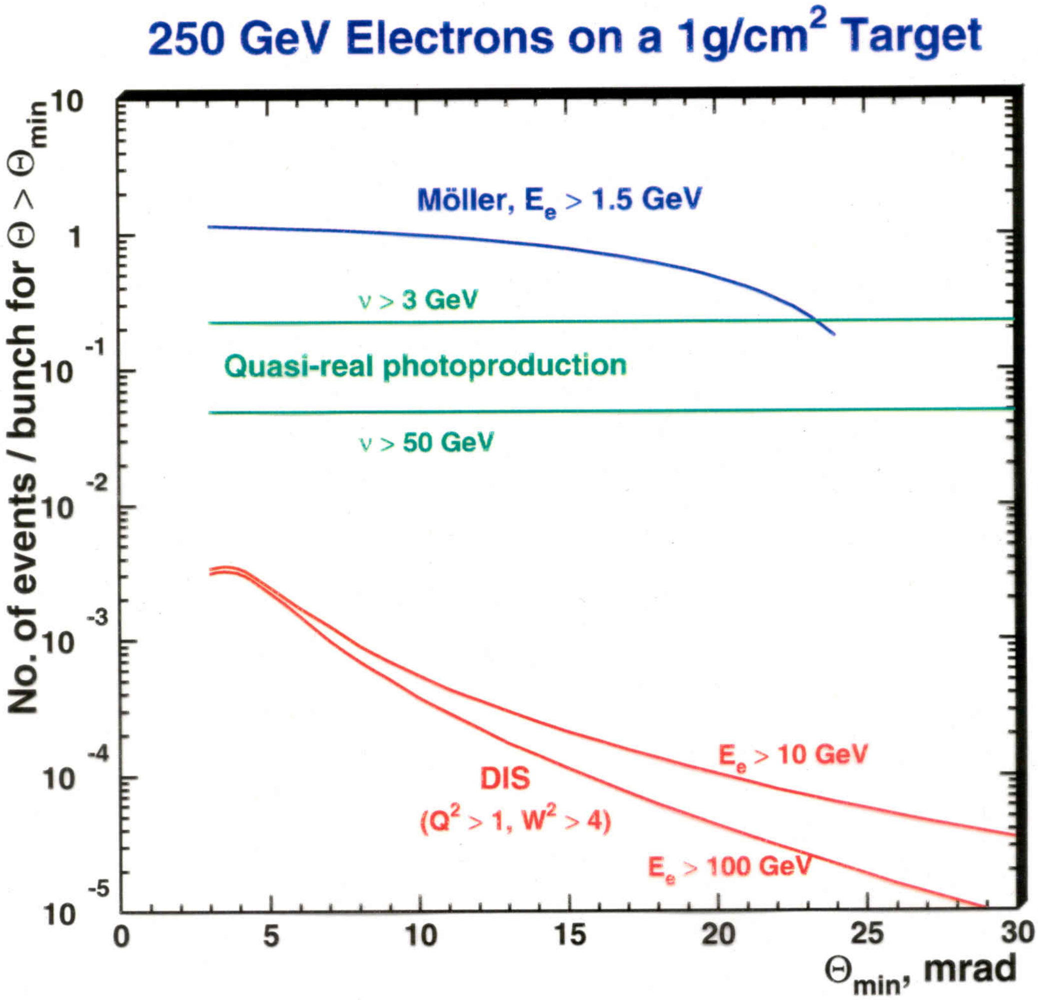
CONSERVATIVE ASSUMPTIONS:

- 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 fb^{-1} PER YEAR FOR PHYSICS

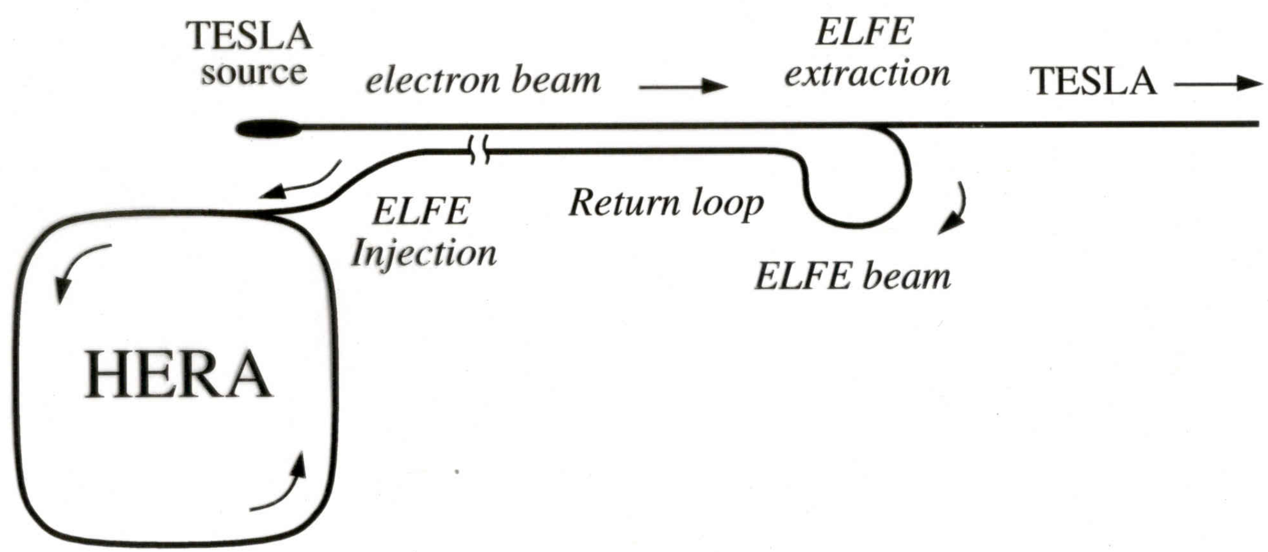
Event Rates



e.g. for Θ_{min} = 10 mrad : $\frac{N_{DIS}(E_e > 10)}{N_{photo}(\nu > 3)} \approx 2.5 \cdot 10^{-3}$

Möller events are kinematically distinguishable from DIS events for $Q^2 > 1$ GeV^2.

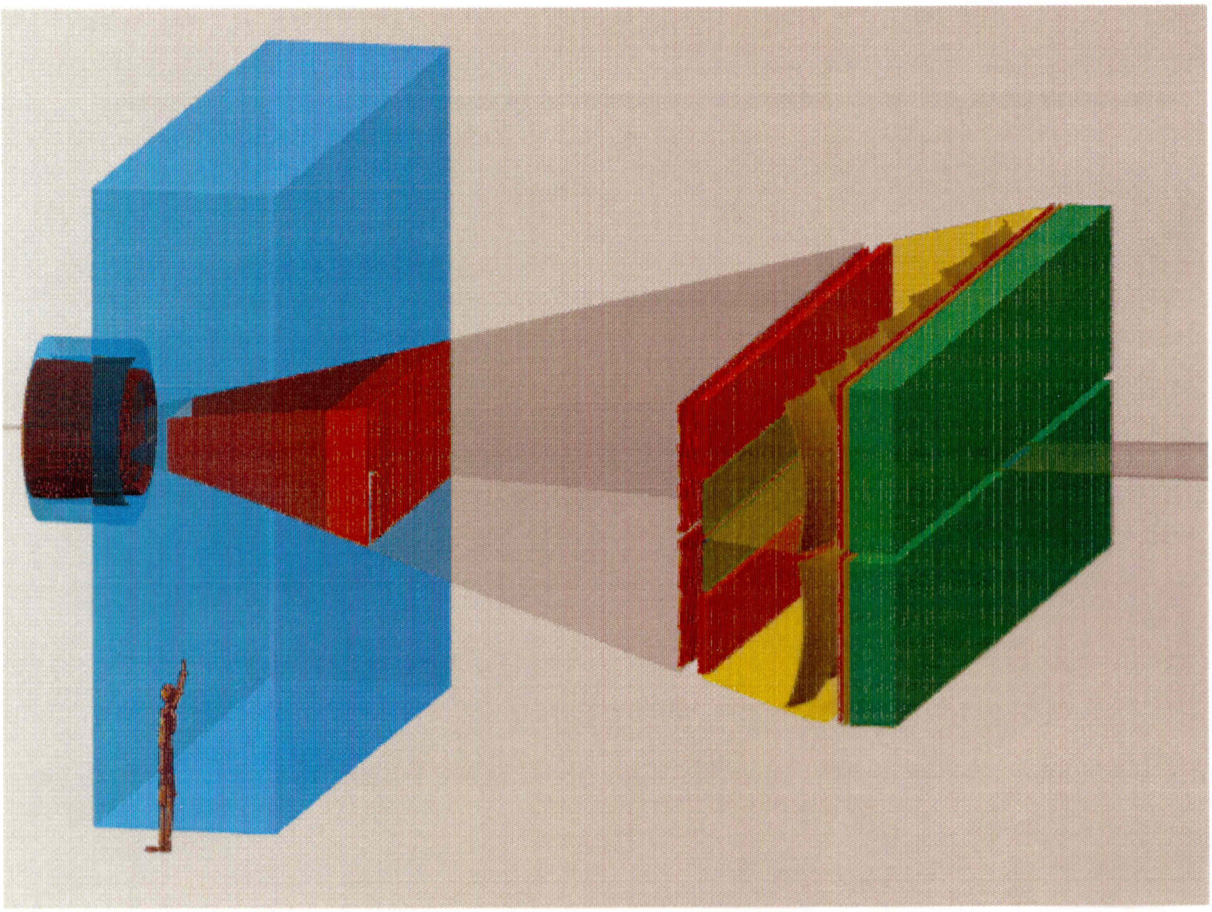
Possible Layout - ELFE



Requires:

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

Spectrometer design - ELFE

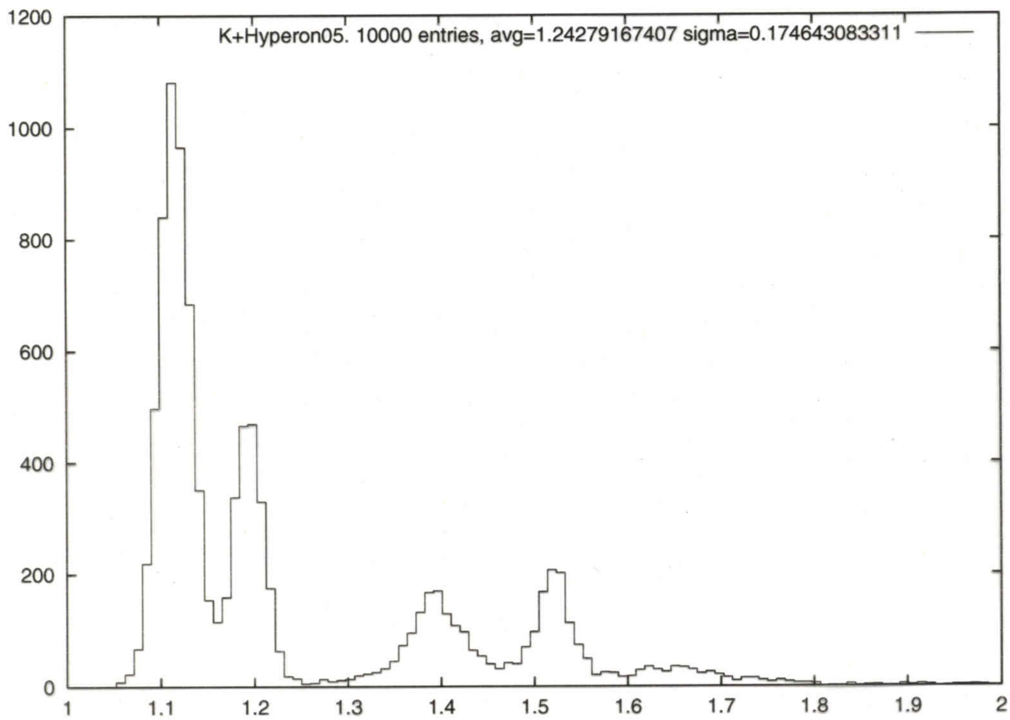


- Large forward dipole
- Dual RICH detector
- State-of-the-art e.m. calorimeter
- Vacuum chamber to reduce multiple scattering
- Fast scintillating fiber trackers
- Recoil detector

ELFE

Projected Performance

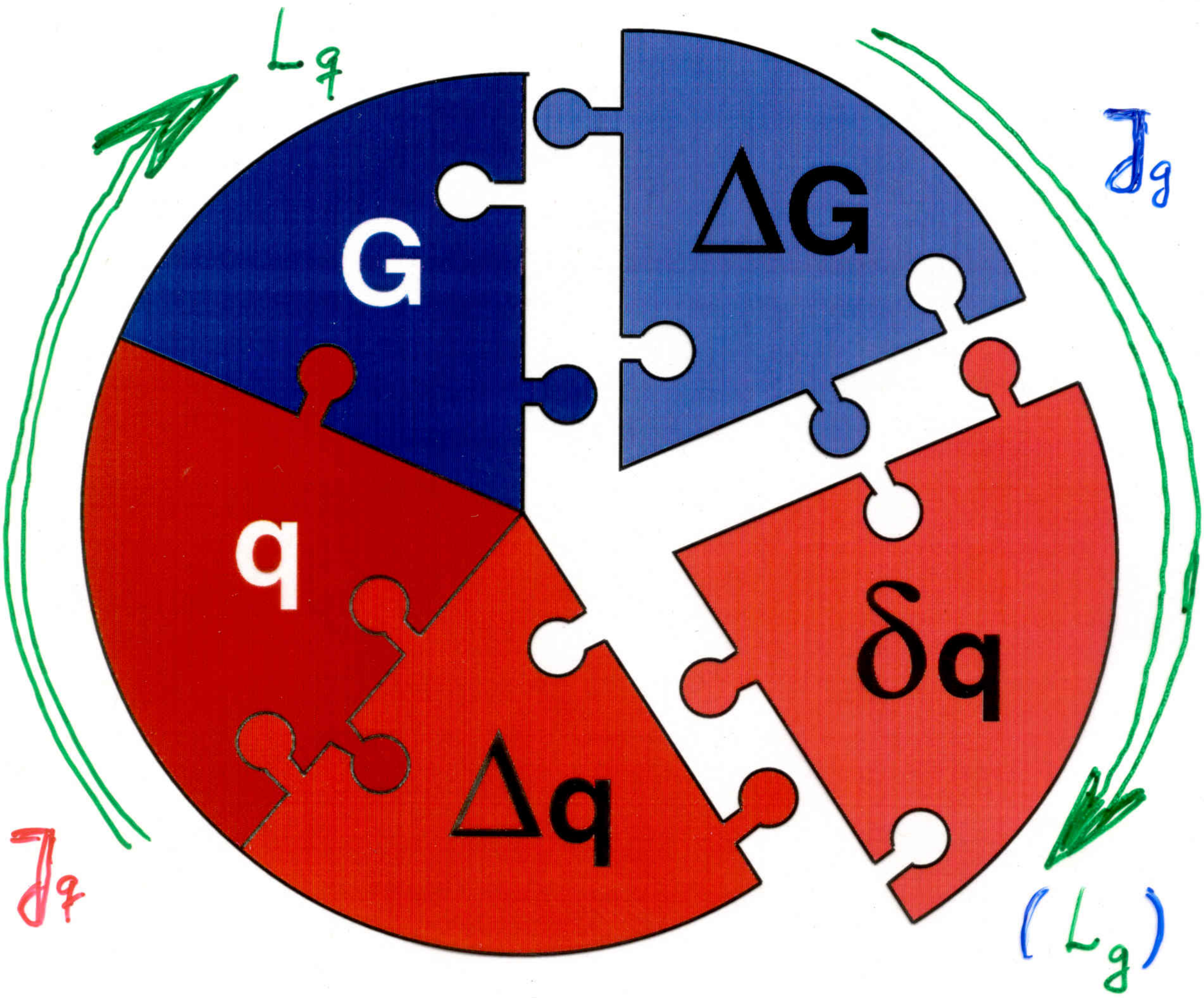
Exclusive reactions: $e + p \to e + K^+ + \Lambda/\Sigma$



Simulation of detector.
$E_e = 25$ GeV

$\Rightarrow$ Resolution sufficient to distinguish different exclusive channels.

Motivation (I)



Parton Distributions of the Nucleon

at leading twist in pQCD

$q(x, Q^2)$	quark number density distribution (f_1^q)
$\Delta q(x, Q^2)$	quark helicity distribution (g_1^q)
$\delta q(x, Q^2)$	quark transversity distribution (h_1^q)
$G(x, Q^2)$	gluon number density distribution
$\Delta G(x, Q^2)$	polarized gluon distribution

$\delta q(x, Q^2)$ and $\Delta G(x, Q^2)$ presently not known !

Plans

- **COMPASS 2001: initial phase**
  - SMC polarised target
  - commisioning of RICH1
  - small angle tracking
  - partial large angle tracking
  - hadron calorimetry
  - muon trigger
  - start of data taking for ΔG

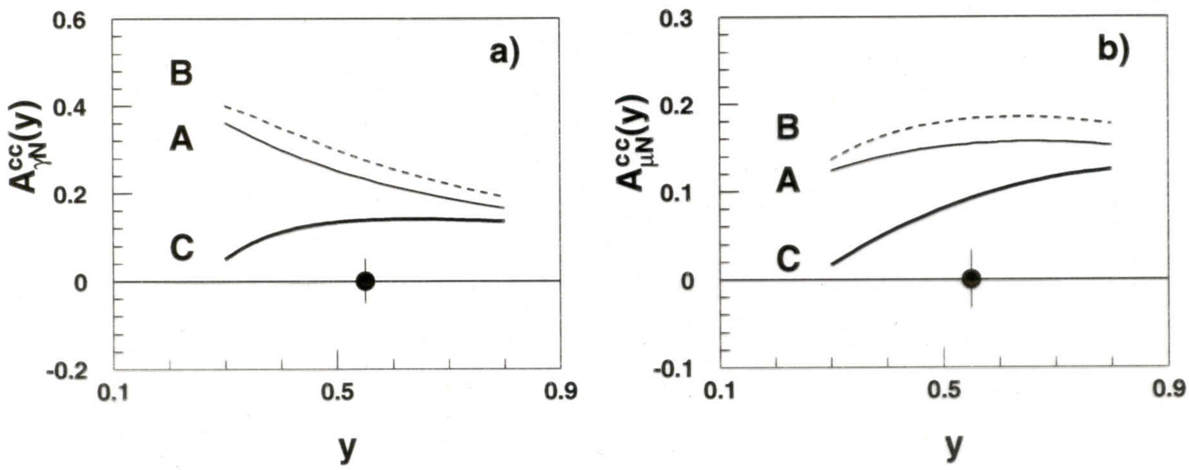
- **COMPASS 2002**
  - COMPASS polarised target
  - straw chambers
  - larger trigger acceptance
  - large angle tracking in stage 2
  - Si detectors
  - hadron and muon beam
  - data taking for ΔG

Expected precision

open charm produktion $D^0 \to K\pi$ 4%

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

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



- **gluon polarisation** $\delta \langle \frac{\Delta G}{G} \rangle = 0.14$

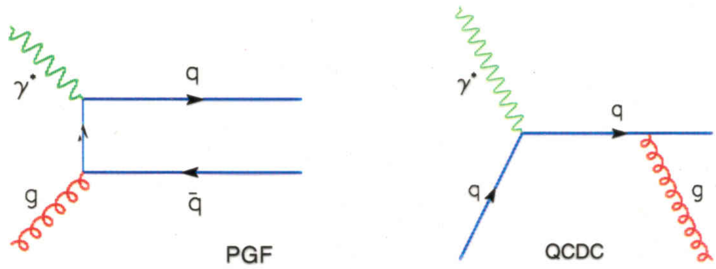
- **possible improvements:**
  - other decay channels

$D^0 \to K^- \pi^+ \pi^0$	13.8%
$D^0 \to K^+ \pi^- \pi^+ \pi^+$	8.1%
$D^+ \to K^+ \pi^- \pi^+$	9.1%

  - D^* tagging
  - improved analysing power with $p_T(D^0)$ cut
  - J/ψ production

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

$$A_{\|} = \frac{N^{\uparrow\downarrow}_{h^+h^-} L^{\uparrow\uparrow} - N^{\uparrow\uparrow}_{h^+h^-} L^{\uparrow\downarrow}}{N^{\uparrow\downarrow}_{h^+h^-} L_P^{\uparrow\uparrow} + N^{\uparrow\uparrow}_{h^+h^-} L_P^{\uparrow\downarrow}}$$

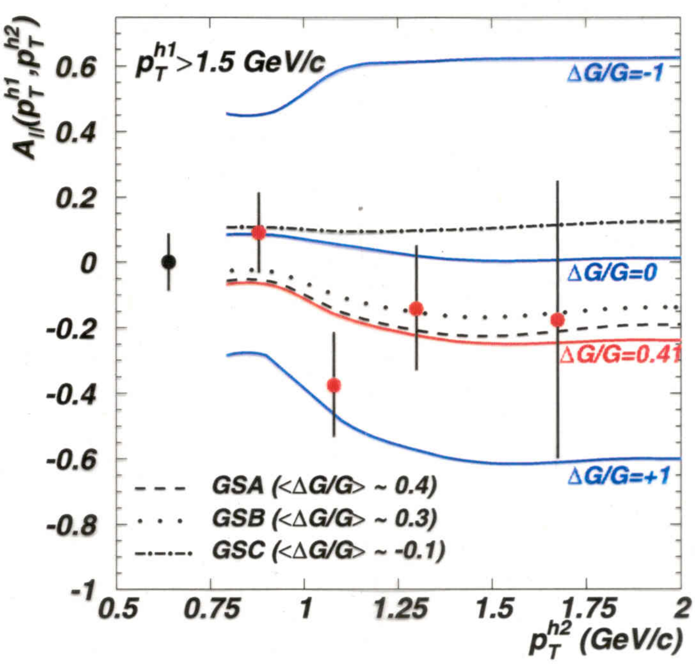
$$\approx \left(\hat{a}_{\mathrm{PGF}} \frac{\Delta G}{G} f_{\mathrm{PGF}} + \hat{a}_{\mathrm{QCDC}} \frac{\Delta q}{q} f_{\mathrm{QCDC}} \right) D$$

$\hat{a}_{\mathrm{PGF}} = -1$ $\hat{a}_{\mathrm{QCDC}} \approx 0.5$ (hard scattering asym.)

HERMES result 1996/97 data

[PRL 84 (2000) 2584]

(does not include systematic errors due to PYTHIA MC)



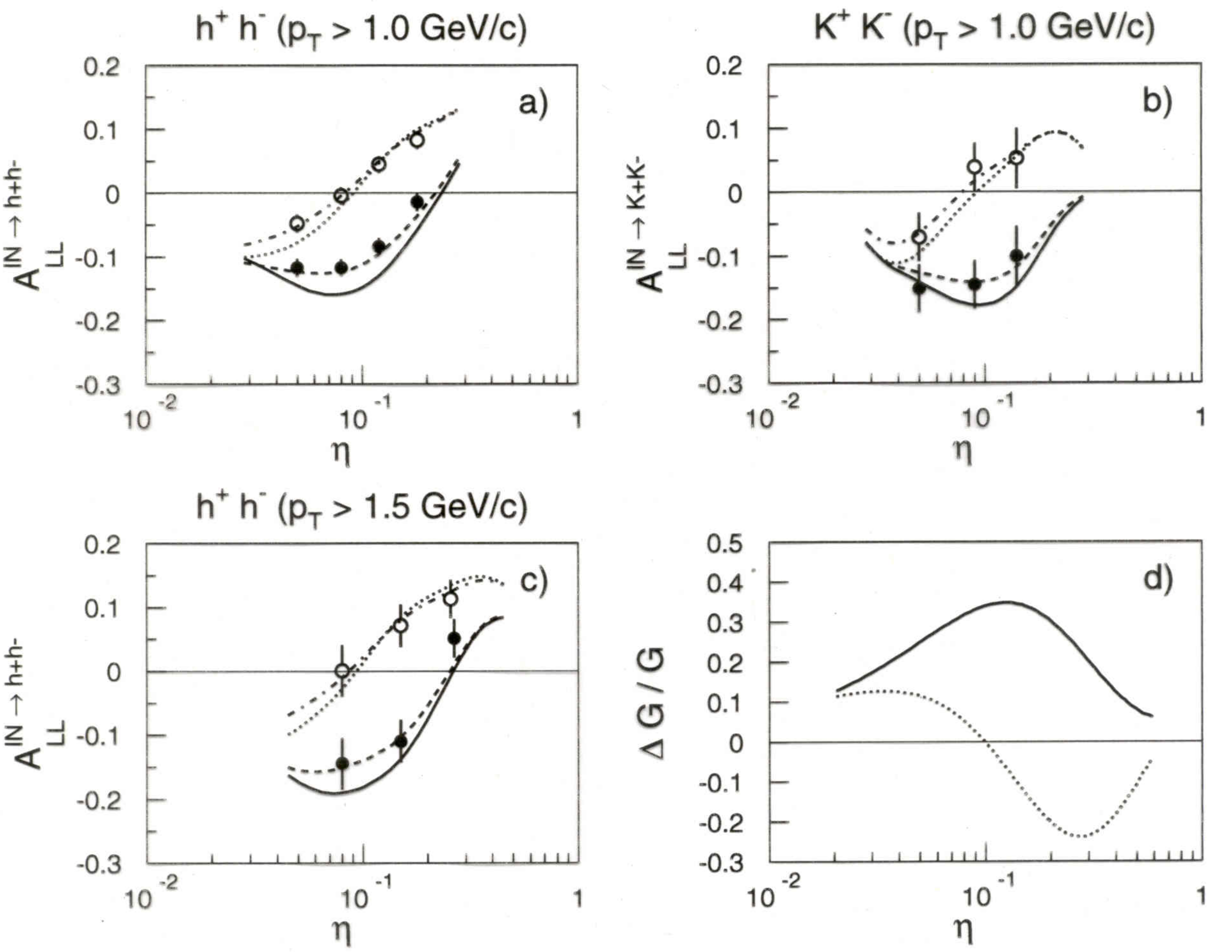
Expected precision

hadron pairs

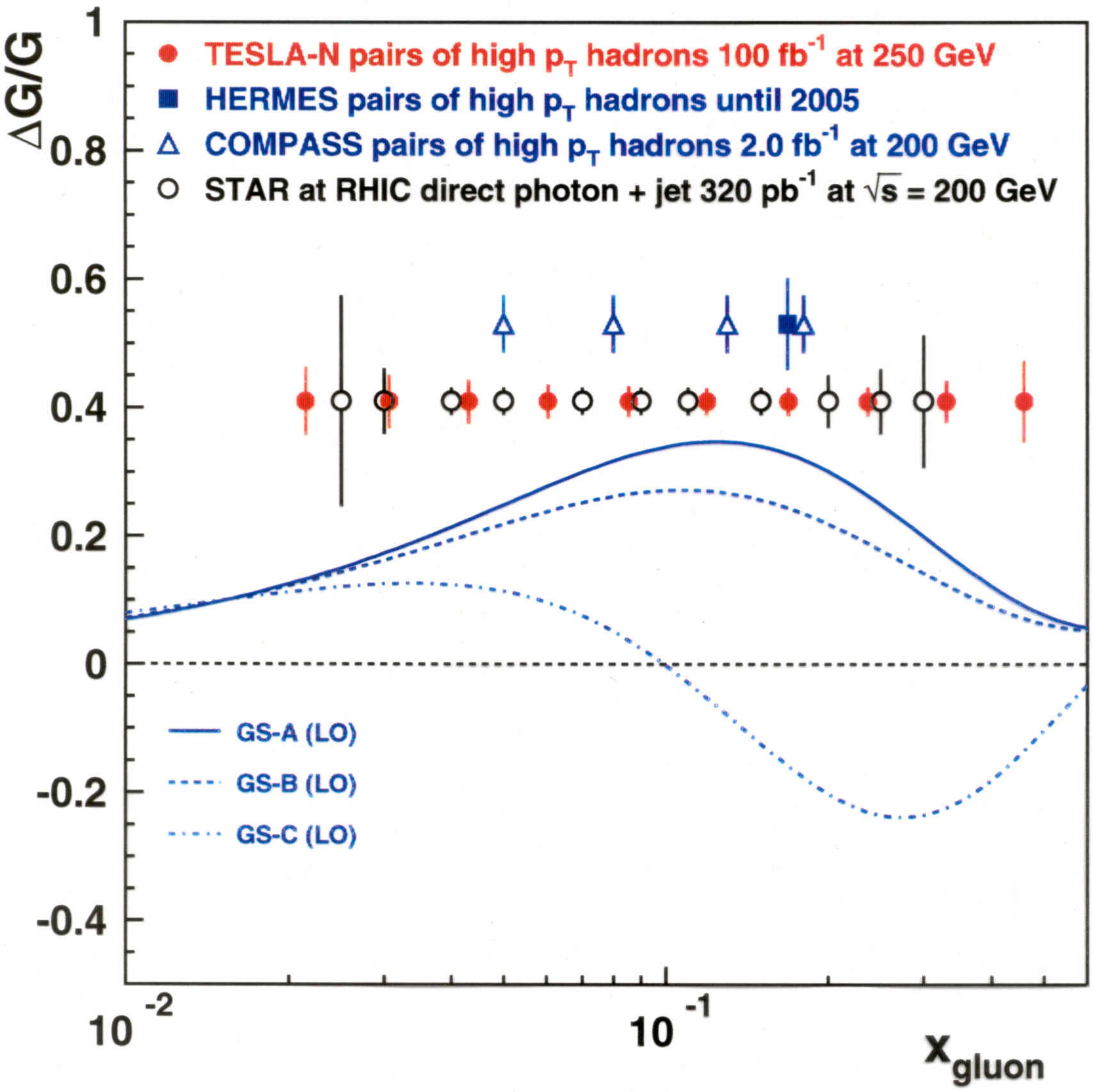
$$A_{\rm LL}^{\rm HH} \approx \langle a_{\rm LL}^{\rm PGF}\rangle \langle \frac{\Delta G}{G}\rangle \frac{\sigma^{\rm PGF}}{\sigma^{\rm tot}} + \langle a_{\rm LL}^{\rm COM}\rangle \langle \frac{\Delta u}{u}\rangle \frac{\sigma^{\rm COM}}{\sigma^{\rm tot}}$$

1 y with 200 GeV and ^{6}LiD target:

	$A_{\rm LL}^{\gamma \rm N}$	$\delta\langle \frac{\Delta G}{G}\rangle$
$\rm H^-H^+$	-0.2 ± 0.025	0.05
$\rm K^-K^+$	-0.12 ± 0.022	0.08



(DIRECT) FUTURE MEASUREMENTS OF THE GLUON POLARIZATION



PHENOMENOLOGICAL PREDICTIONS FOR $Q^2 = 10\ \text{GeV}^2$

HERMES POINT 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.

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Polarized Gluon Distrib. (III)

QCD improved Quark Parton Model:

$$g_1^p = \frac{1}{2}\left(\frac{1}{n_f}\sum_{i=1}^{n_f} e_i^2\right)\left\{\delta C_{NS}\otimes\Delta q^{NS} + \delta C_S\otimes\Delta\Sigma + \delta C_G\otimes\Delta G\right\}$$

⇒ 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:

	$\Delta G(Q_0^2)$
existing data	0.43 ± 0.21
plus 100 fb^{-1} TESLA-N(p)	± 0.06
plus 100 fb^{-1} TESLA-N(d)	± 0.04

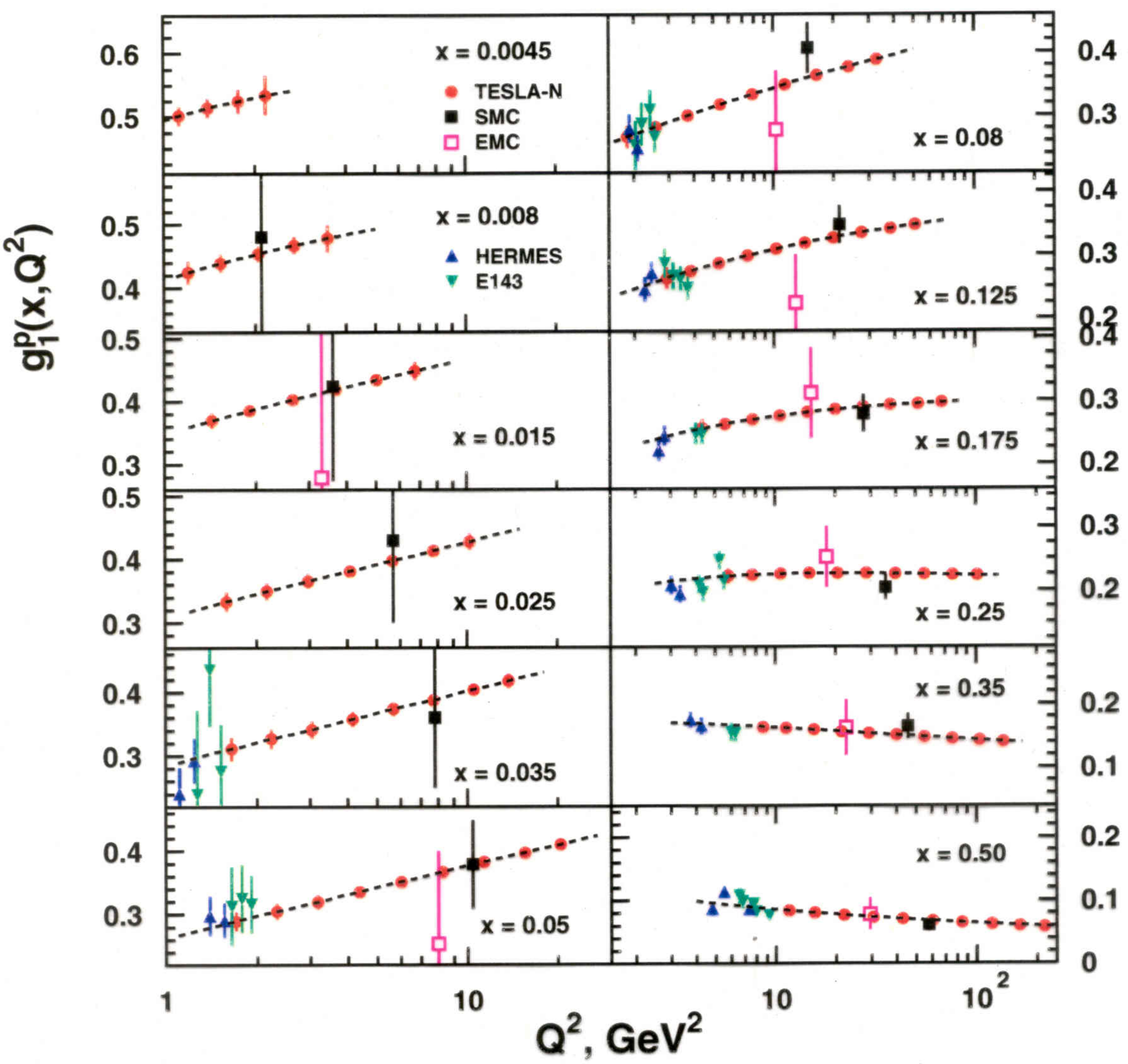
!

↑ stat. error

TESLA-N:

Polarized Gluon Distrib. (IV)

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 Λ'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 $ep^{\uparrow}(d^{\uparrow}) \to e'\pi X$

$E = 27.5$ 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

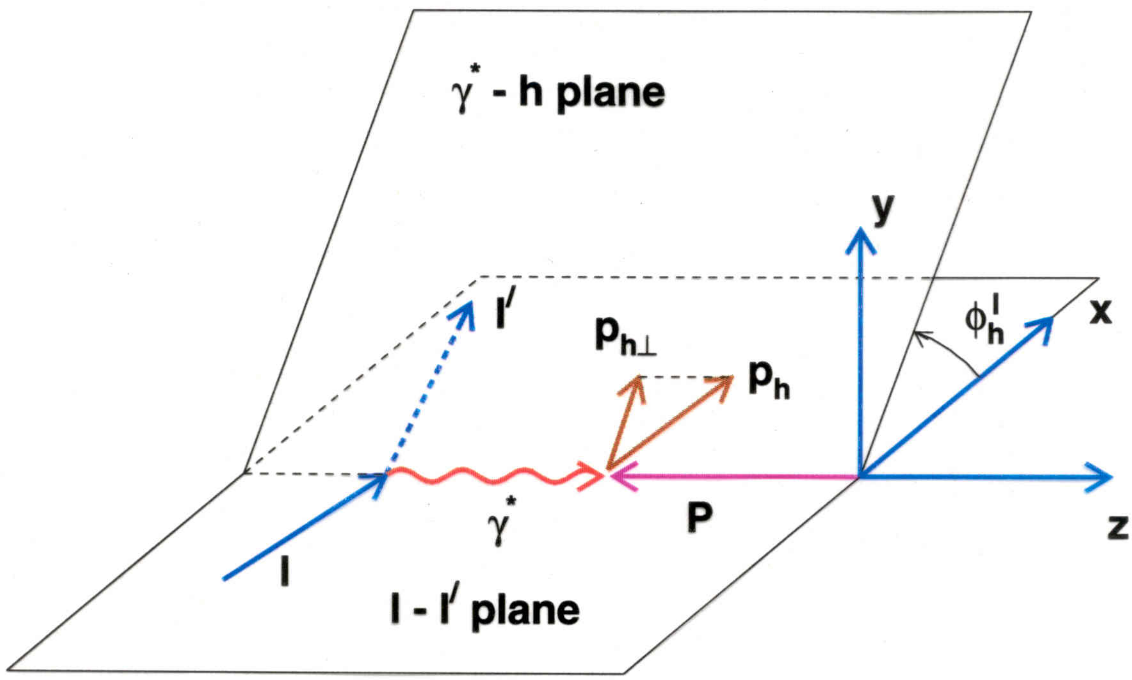
Transversity through the Collins Effect: Method

WEIGHTED ASYMMETRY

[Mulders, Tangermann 96, Kotzinian, Mulders 97]

$$A_T(x, y, z) \equiv \frac{\int d\phi^\ell \int d^2 P_{h\perp} \frac{|P_{h\perp}|}{zM_h} \sin(\phi_s^\ell + \phi_h^\ell)\ (d\sigma^\uparrow - d\sigma^\downarrow)}{\int d\phi^\ell \int d^2 P_{h\perp} (d\sigma^\uparrow + d\sigma^\downarrow)}$$

ϕ_s^l is azimuthal angle of target spin vector w.r.t. γ^* 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

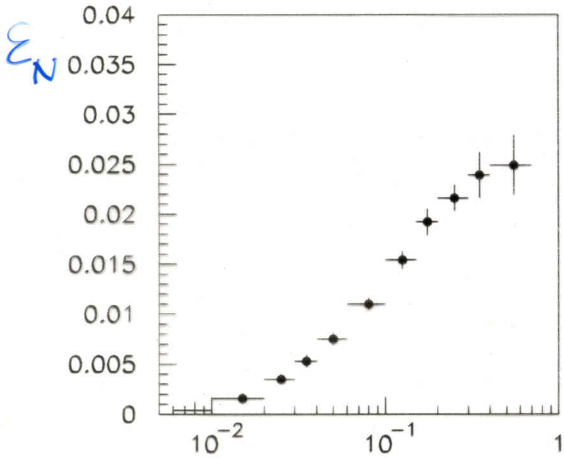
NOTE: $H_1^{\perp(1)q}$ accessible from e^+e^- data (LEP,Belle)

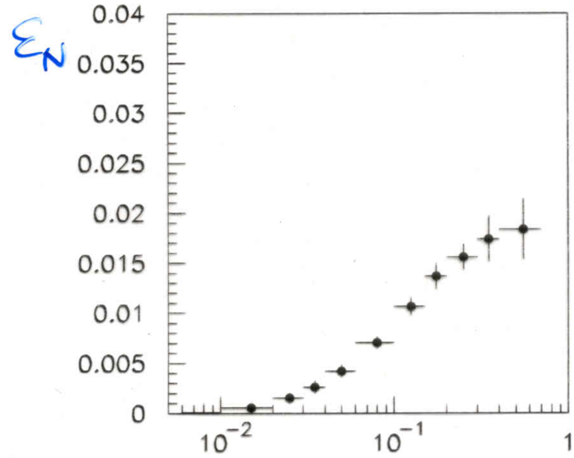
Expected precision

- **Measured asymmetry**
  for 30 days real data taking using charged π
- **Selection**

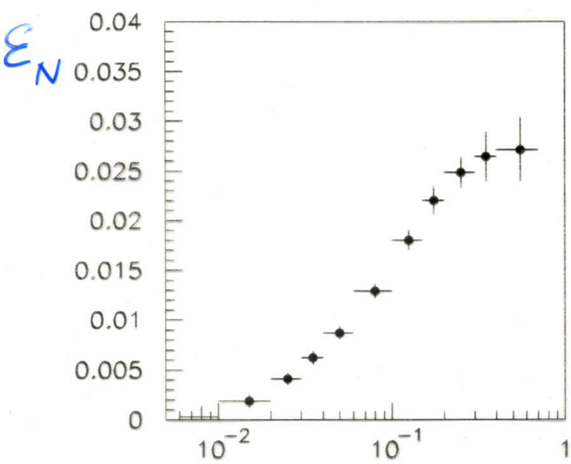
$$\nu > 15\,\mathrm{GeV}\,,\ E' > 5\,\mathrm{GeV}\,,\ z > 0.1$$

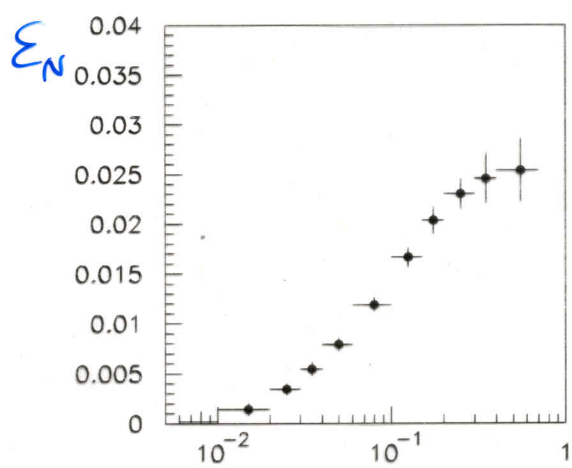
$$z_{\mathrm{min}} = 0.1$$





$$z_{\mathrm{min}} = 0.3$$





without

with sec. interactions (target material)

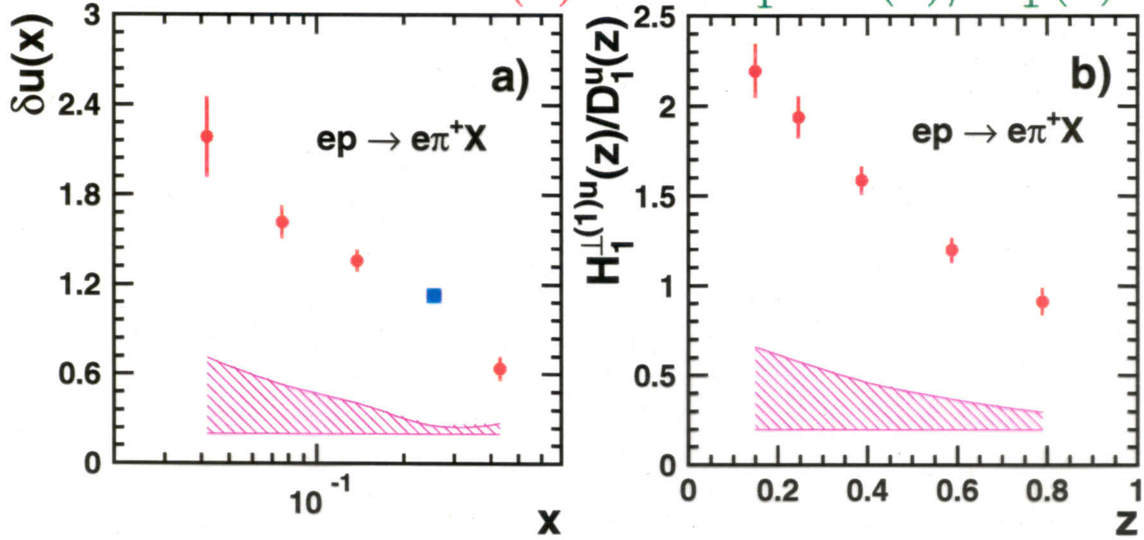
- **Improvement** with π^0 identification

HERMES 2002 +

TRANSVERSITY THROUGH THE COLLINS EFFECT: PROSPECTS [1]

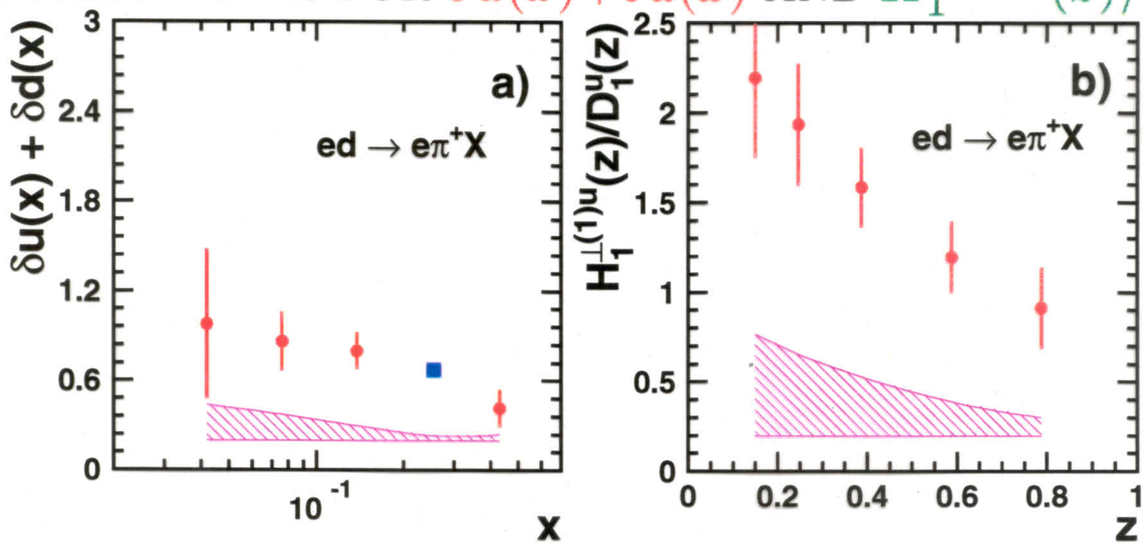
OPTION 1: PROTON TARGET

PROJECTIONS FOR $\delta u(x)$ AND $H_1^{\perp(1)u}(z)/D_1^u(z)$



OPTION 2: DEUTERON TARGET

PROJECTIONS FOR $\delta u(x)+\delta d(x)$ AND $H_1^{\perp(1)u}(z)/D_1^u(z)$



⇒ HERMES CHOSE OPTION 1 FOR 2001+

NOTE: δd EXTRACTION POSSIBLE BY adding OPTION 2 (→ COMBINED ANALYSIS)

[1][V.Korotkov, W.-D.N.,K.Oganessyan, EPJC 18, 639 (2001)]

TESLA-N

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 $x \simeq 0.25$, low Q^2

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

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

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

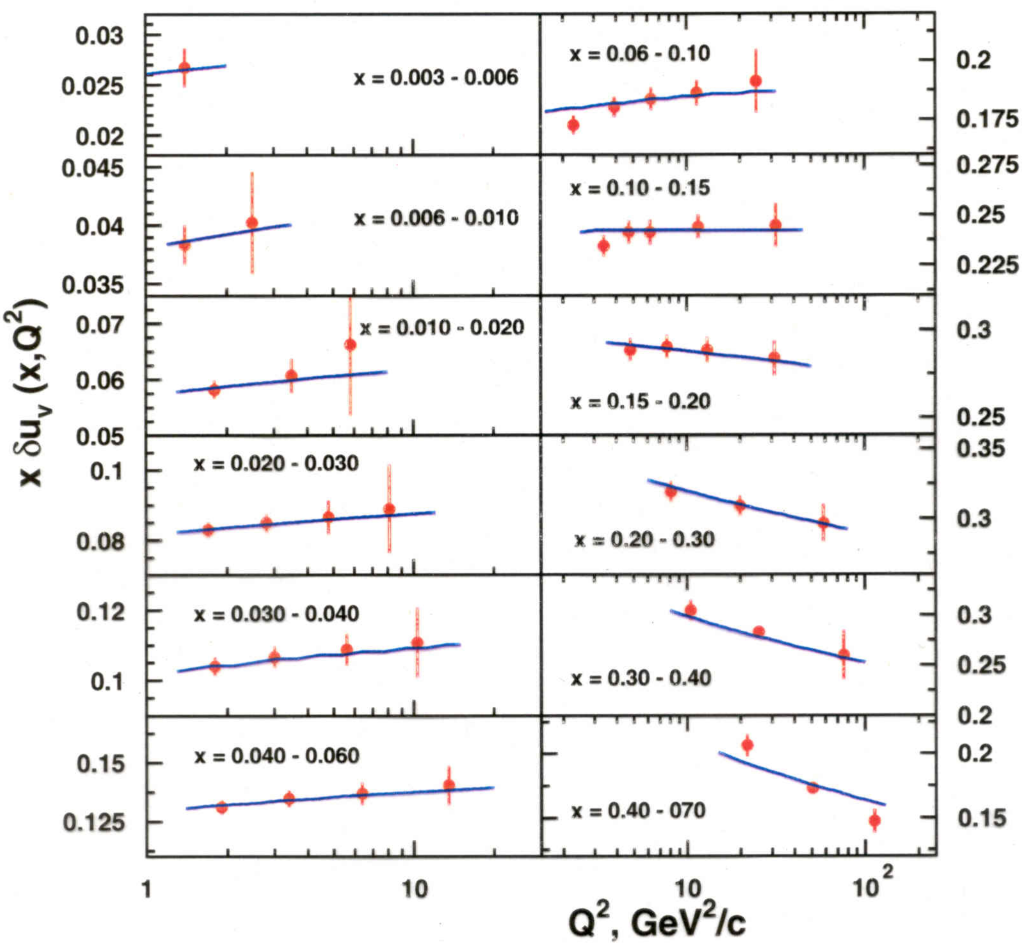
$\Rightarrow$ OVERCONSTRAINED SYSTEM OF COUPLED EQUATIONS.

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:

$$\delta u = 0.88 \pm 0.01, \ \delta d = -0.32 \pm 0.02$$

!

Skewed Parton Distributions and DVCS

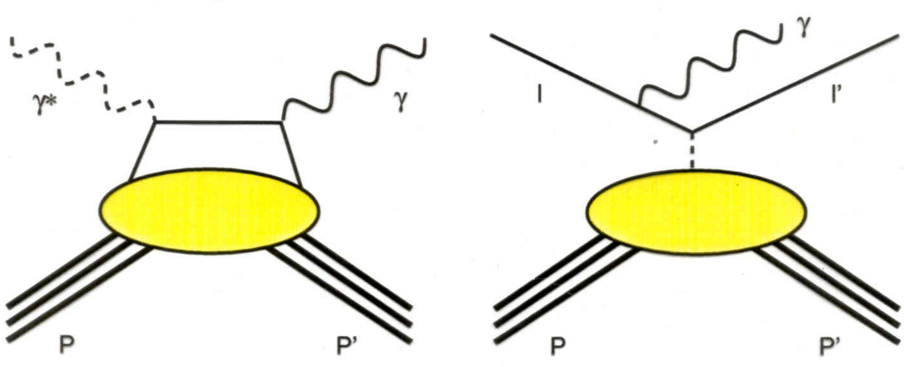
Skewed (or Generalized, or off-forward)
Parton
Distributions:

Unified theoretical description of inclusive and (hard) exclusive processes

Simplest hard exclusive process: $ep \to ep\gamma$
$(\gamma^* p \to \gamma p)$

Consider $\gamma^* p$ in Bjorken limit $\Longrightarrow$
Deeply Virtual Compton Scattering

- Highly virtual quark in γ^* scattering
  $\longrightarrow$ propagates perturbatively
- Simplest (and dominating) QCD mechanism to form Compton final state: quark radiates real γ and falls back to nucleon ground state
  ('hand-bag' subprocess in pQCD)
  $\Downarrow$



DVCS   Bethe-Heitler $\Rightarrow$ p.t.o.

$\Rightarrow$ Interference gives access to DVCS amplitudes

DVCS and Bethe-Heitler

Bethe-Heitler (BH):

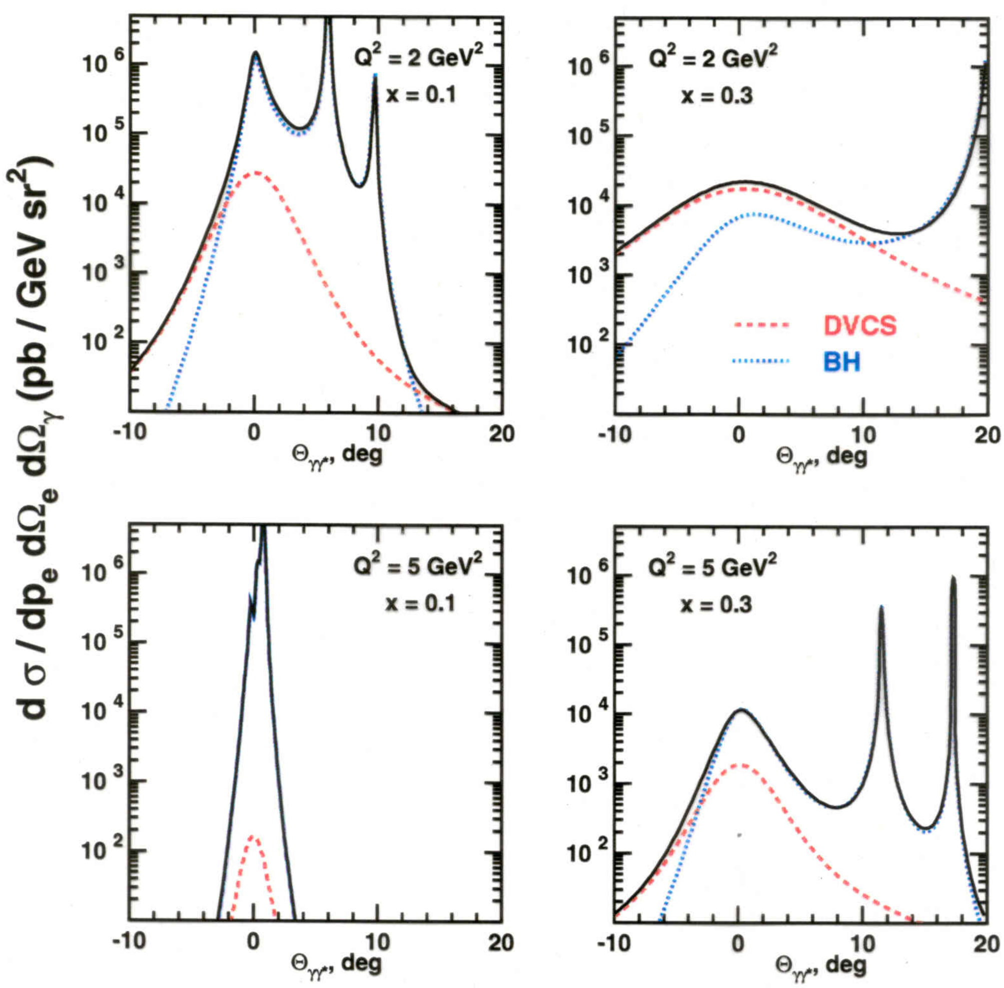
(Elastic lepton-proton scattering with γ radiation by lepton in initial or final state)

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): $1^\circ \leq \Theta_{\gamma\gamma^*} \leq 5^\circ$

'In-plane' cross section: scattering plane = reaction plane (see below)



DVCS dominated by BH in most of kin. region !

DVCS-BH interference:

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

In DVCS: 4 different quark SPDs (per flavor)

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

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

$\Downarrow$ $\qquad\qquad\qquad$ $\Downarrow$

unpolarized $\qquad$ polarized $\qquad$ SPDs

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

$$H^q(x, 0, 0) = q(x), \quad \widetilde{H}^q(x, 0, 0) = \Delta q(x)$$

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

SPDs and DVCS (III)

1st MOMENTS connected via sum rules to form factors.

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

$\Longrightarrow$ TOTAL QUARK ANGULAR MOMENTUM [X.JI]:

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

Real and imaginary parts of DVCS amplitudes $\mathcal{H}_1, \widetilde{\mathcal{H}}_1, \mathcal{E}_1, \widetilde{\mathcal{E}}_1$ can be expressed through SPDs $H, \widetilde{H}, E, \widetilde{E}$. ($P$ denotes Cauchy's principal value):

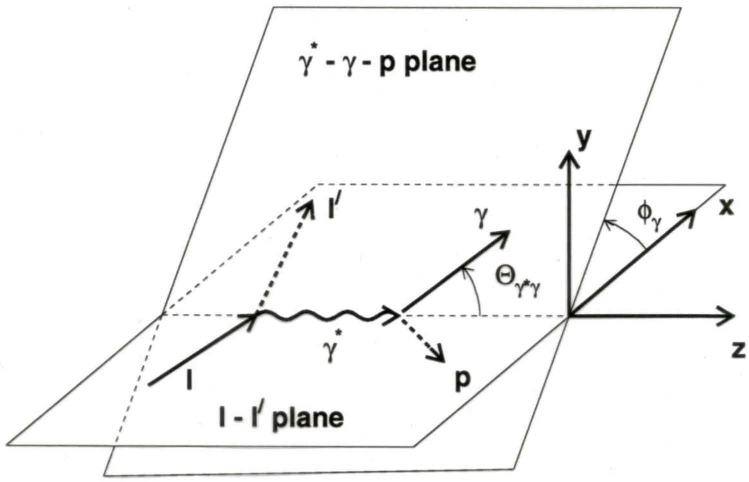
$$\begin{aligned}
\mathrm{Im}\,\mathcal{H}_1 &= -\pi \sum_q e_q^2 (H(\xi, \xi, \Delta^2) - H(-\xi, \xi, \Delta^2)) \\
\mathrm{Im}\,\widetilde{\mathcal{H}}_1 &= -\pi \sum_q e_q^2 (\widetilde{H}(\xi, \xi, \Delta^2) + \widetilde{H}(-\xi, \xi, \Delta^2)) \\
\mathrm{Re}\,\mathcal{H}_1 &= \sum_q e_q^2 \left[P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

Analogous expressions for amplitudes $\mathcal{E}_1$, $\widetilde{\mathcal{E}}_1$.

$\Longrightarrow$ Extraction of SPDs will be a complex task

ϕ-DEPENDENCE OF ASYMMETRIES

DVCS KINEMATICAL CONFIGURATION:



ϕ_γ: azimuthal angle between scattering and reaction plane.

ϕ_γ: ASYMMETRIES SHOW DIFFERENT CHARACTERISTICS

A) MEASURE LEPTON CHARGE ASYMMETRY:
unpolarized beam, unpolarized target (A_{ch})

$$\Delta_{\rm ch} d\sigma^{\rm unpol} \equiv d\sigma(e^+p) - d\sigma(e^-p)$$
$$\sim \cos(\phi_\gamma) \times \mathrm{Re}\left\{ F_1\mathcal{H}_1 + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right\}$$

$\Rightarrow$ ACCESS TO REAL PART OF $\mathcal{H}_1, \widetilde{\mathcal{H}}_1$!

B) MEASURE LEPTON HELICITY ASYMMETRY:
long. polarized beam, unpolarized target (A_{LU})

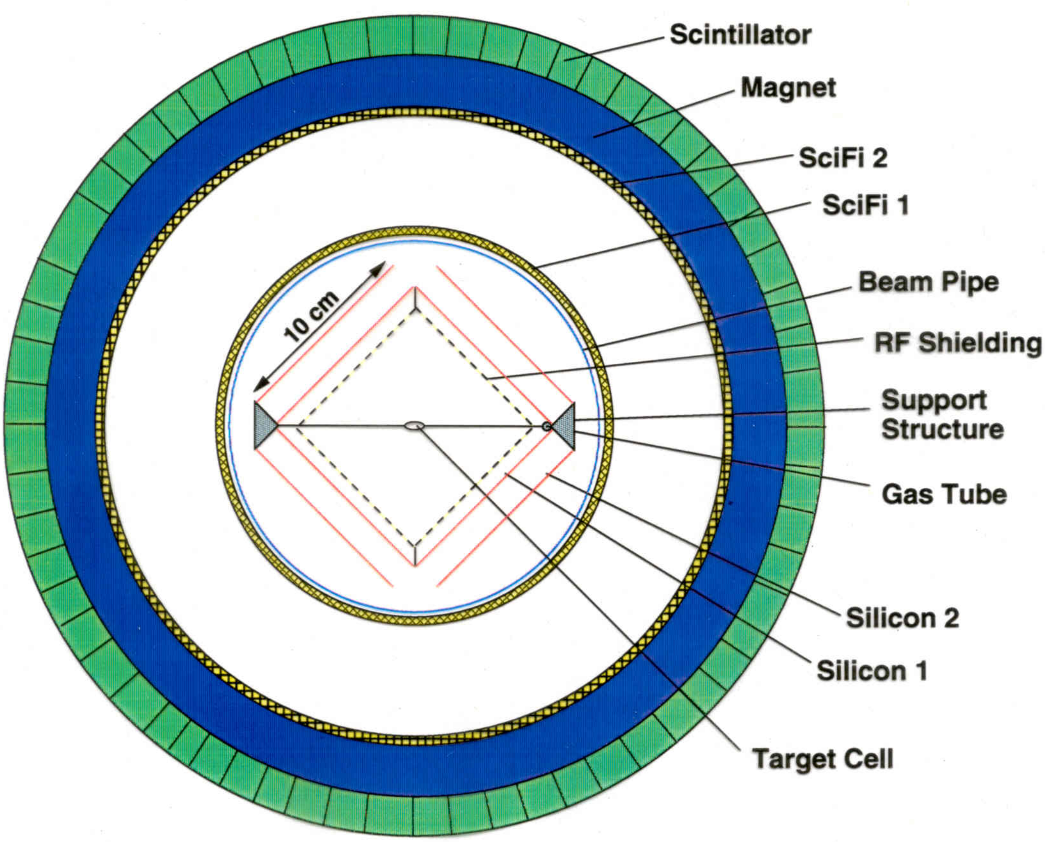
$$\Delta d\sigma \equiv d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p)$$
$$\sim \sin(\phi_\gamma) \times \mathrm{Im}\left\{ F_1\mathcal{H}_1 + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right\}$$

$\Rightarrow$ ACCESS TO IMAGINARY PART OF $\mathcal{H}_1, \widetilde{\mathcal{H}}_1$

HERMES: 2004+

A new Recoil Detector for Hard Exclusive Reactions

DVCS	$\gamma^* p \longrightarrow \gamma p$		$\mathbf{H}\ \tilde{\mathbf{H}}\ \mathbf{E}\ \tilde{\mathbf{E}}$
exclusive pseudoscalar meson production	$\gamma^* p \longrightarrow \pi^0 p$		$\tilde{\mathbf{H}}\ \tilde{\mathbf{E}}$
	$\gamma^* p \longrightarrow \pi^+ n$		
exclusive vector meson production	$\gamma^* p \longrightarrow \rho^0 p$		$\mathbf{H}\ \mathbf{E}$
	$\gamma^* p \longrightarrow \omega\ p$		
	$\gamma^* p \longrightarrow \phi\ p$		



Schematic cross section

2004+

HERMES Measurements with a Recoil Detector, Projections (I)

▷ SPDs modeled according to

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

Most simple ansatz is to neglect ξ dependence. Then e.g.

$$H^{u/p}(x,\xi,\Delta^2) = u(x)\, F_1^{u/p}(\Delta^2)/2$$

$$H^{d/p}(x,\xi,\Delta^2) = d(x)\, F_1^{d/p}(\Delta^2)$$

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

similar expressions for $H^{q/p} \to \widetilde{H}^{q/p}$.

▷ $u(x)$ 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: $2\ fb^{-1}$
(unpolarized target)

▷ HERMES acceptance taken in account for all involved particles

▷ kinematical cuts

$E_e > 3.5\ GeV$ $E_\gamma > 1\ GeV$ $P_p > 0.2\ GeV$

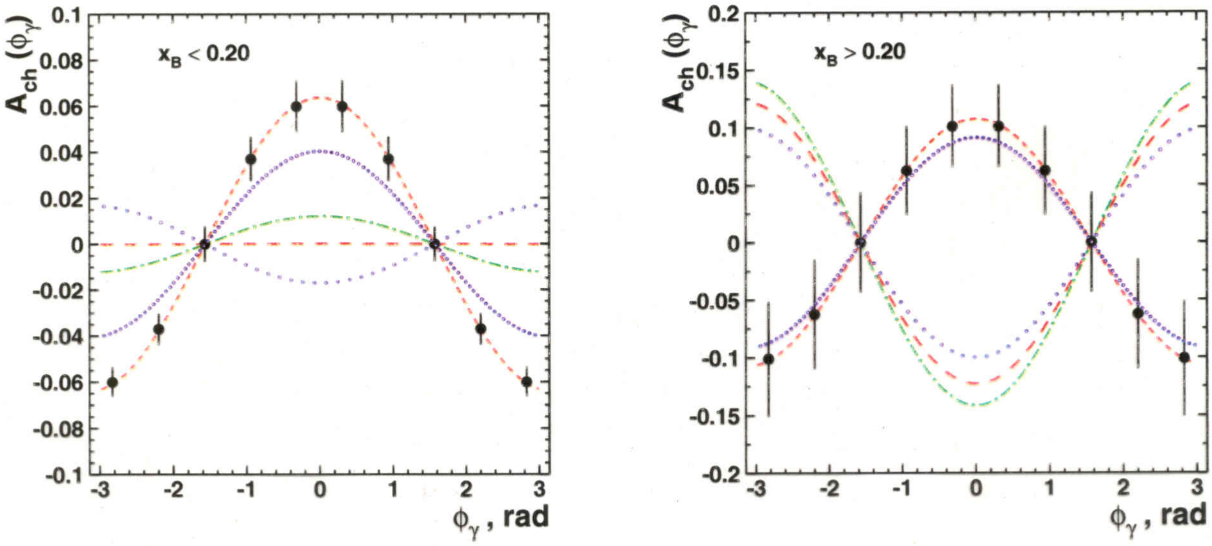
$W^2 > 4\ GeV^2$ $Q^2 > 1\ GeV^2$ $15 < \Theta_{\gamma\gamma^*} < 70\ mrad$

2004 +

HERMES Measurements with a Recoil Detector, Projections[3] (II)

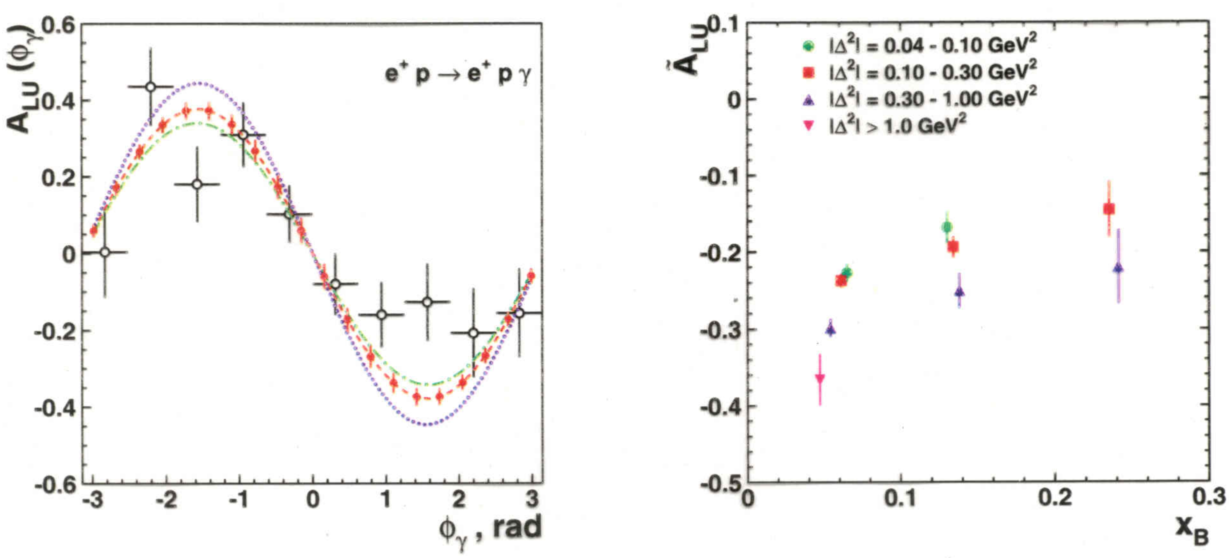
A) Measure lepton charge asymmetry in DVCS:

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)

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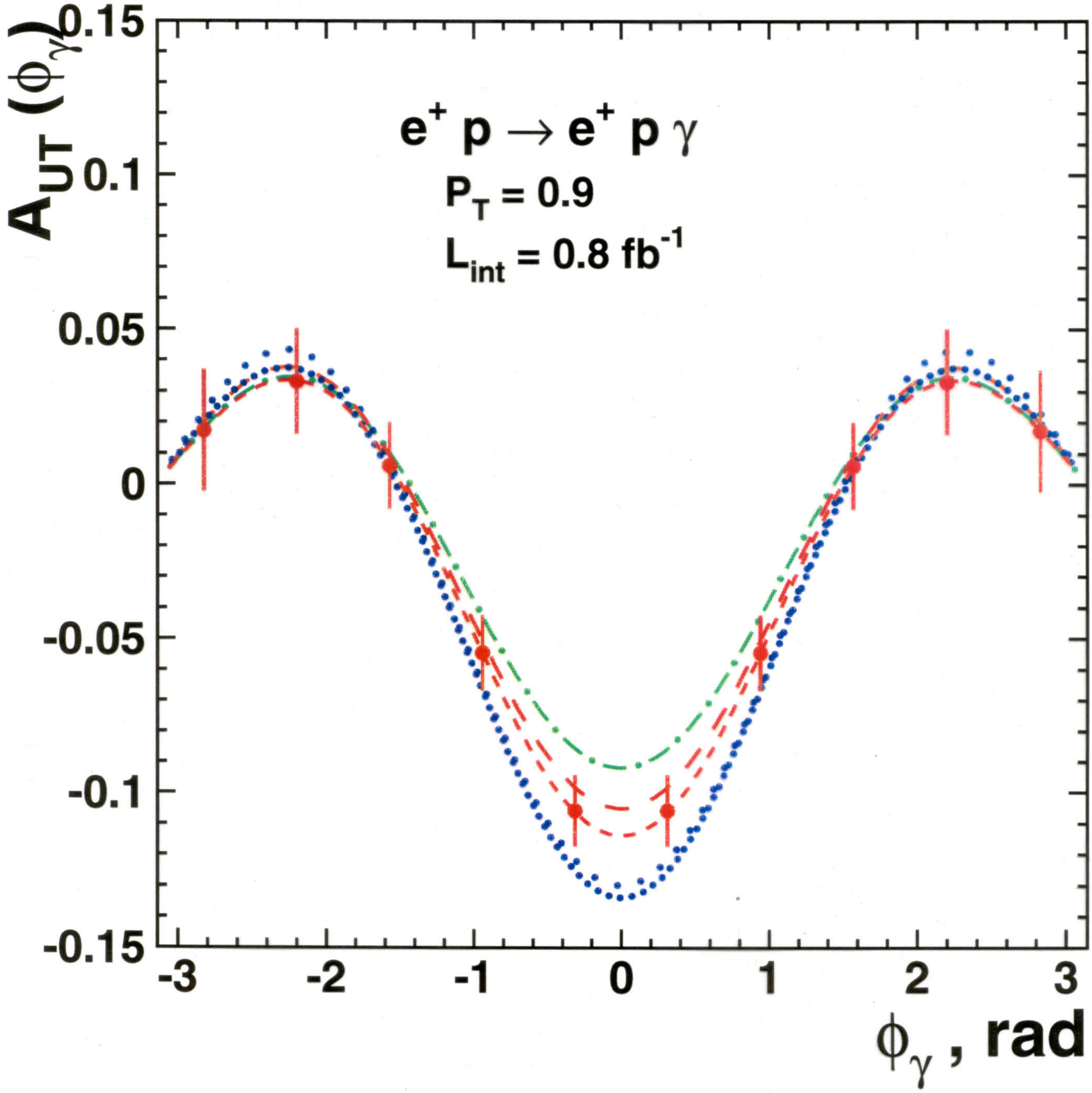
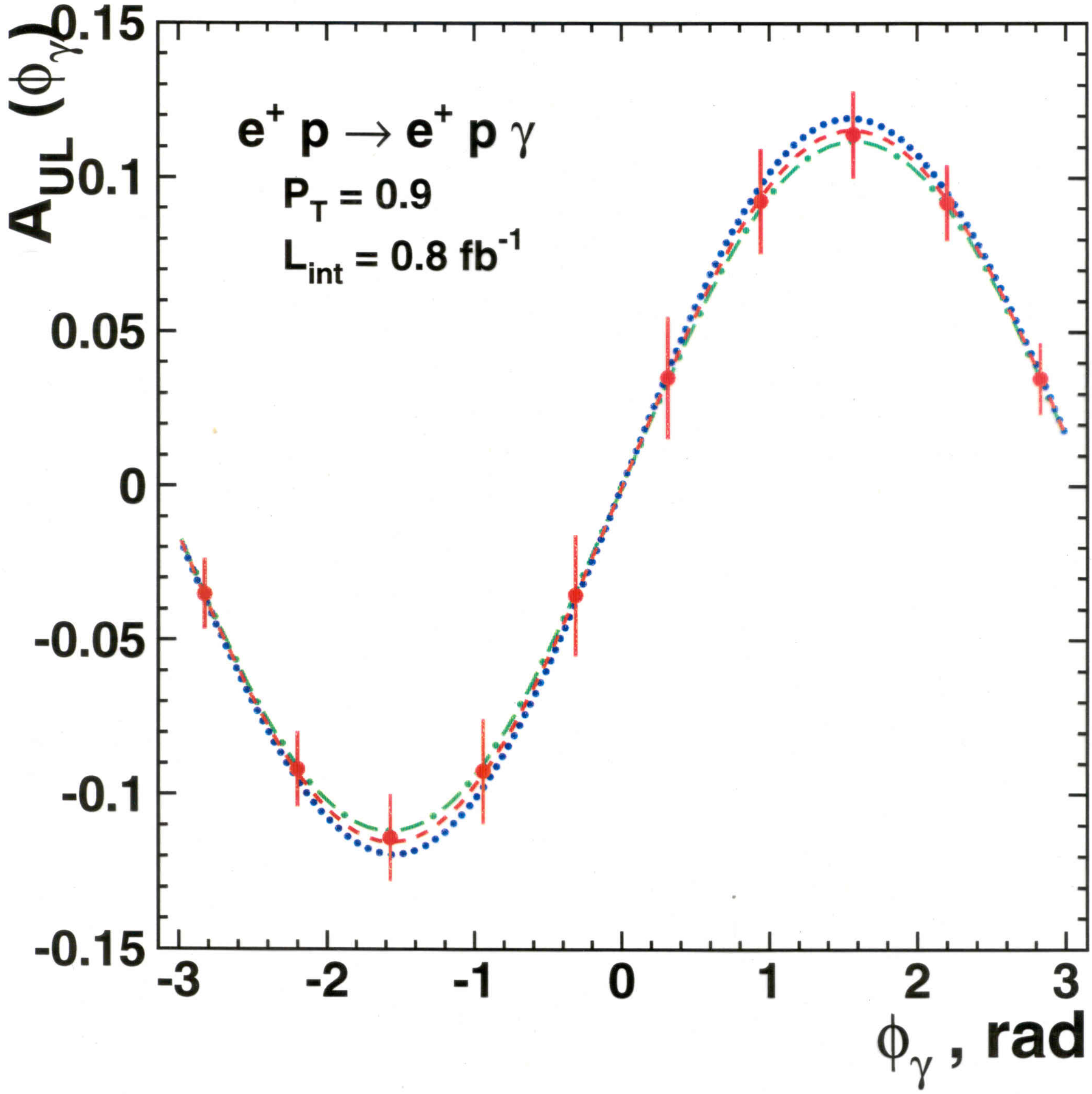
[3] [V.Korotkov, W.-D.N., hep-ph/0108077] → EPJ C. 03/02



$A_{UT}(\phi_\gamma)$
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
$e^+ p \to e^+ p \gamma$
$P_T = 0.9$
$L_{int} = 0.8\ fb^{-1}$
-3
-2
-1
0
1
2
3
ϕ_γ , rad

[Korotkov]

[Korotkov]



$A_{UL}(\phi_\gamma)$
$e^+ p \to e^+ p \gamma$
$P_T = 0.9$
$L_{int} = 0.8\ fb^{-1}$
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-3
-2
-1
0
1
2
3
ϕ_γ , rad

$$H^q \sim q(x)\cdot F_1^q(\Delta^2)$$
$$\tilde{H}^q \sim \Delta q_v(x)\cdot g_A^q(\Delta^2)$$

skewedness-independent

$b=1$, $b=3$: $H^q \sim \cdot H_{DD}^q(x,\xi)$ ⋮

double distribution (H_{DD}); skewedness-dependent (ξ)

$b=1$, $b=3$:

$$H^q \sim \cdot \left\{ H_{DD}^q(x,\xi) + \Theta(\xi-|x|)\frac{1}{N_f} D\left(\frac{x}{\xi}\right)\right\}$$

"D-term" for correct polynomialibility properties (diff. sign for H & E → cancels in Ji's 2nd moment)

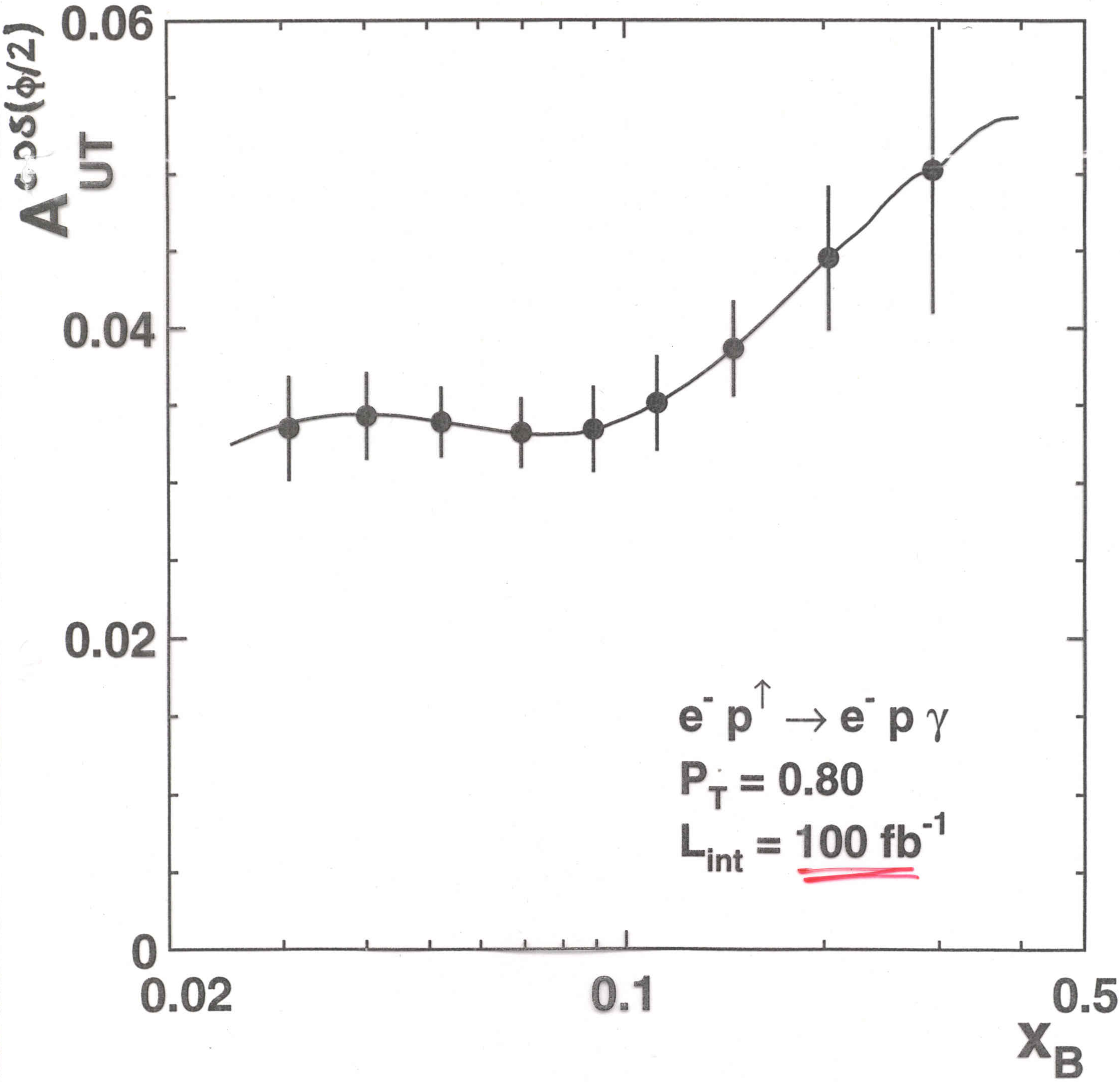
$$H_{DD}^q(x,\xi) = \int_{-1}^{1} dy \int_{-1+|y|}^{1-|y|} dt\, \delta(x-y-t\xi)\, h(y,t)\, q(y)$$

$q(y)$: ordinary qu. distr.

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

Note: $b\to\infty$ means skewedness-independent

High luminosity
TESLA-N / ELFE - type exp.
w/ transv. pol. target



[Korotkov]

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, ΔG, expected to be well measured in a few years [COMPASS, RHIC] this may not allow to separate L_g, since for the integrals:

$$J_g \neq \Delta G + L_g$$

[R.L. Jaffe, The Theory of the Nucleon Spin, hep-ph/0008038, Phil.Trans.Roy.Soc.Lond. A359 (2001) 391]

$\Longrightarrow$ 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:

DIS: $F_2(x, Q^2) = \int_x^1 \frac{dy}{y} C_i(\frac{x}{y}, Q^2)\, f_i(y, Q^2)$

↑ only one variable

moments in x; inverse Mellin transform → $f_i(x, Q^2)$

↑ x_B

DVCS: $GPD(x, \xi, t, Q^2)$

↑ internal variable; ↑ $f(x_B)$: two variables → deconvolution not possible!

Theoretical work-around [A.F.]:

- believe that Q^2-dep. of twist-2 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 tw-4 / tw-2 ≪ tw-2
- measure enough (many!) data points in Q^2 for every x_B
- solve (large!) matrix equation → $GPD(x, \xi, t, Q^2)$

⇒ worth to be studied in more detail (feasibility!)

W.-D. Nowak

2010+

WHICH MACHINE FOR WHICH PHYSICS ?

Trieste, Feb. 20 '02

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

Physics	Measured functions	processes	Targ.	σ	t	Q^2	E_{beam}
EXCLUSIVE REACTIONS: • Total quark angular momentum J_q *) (→ Orbital quark ang. mom. L_q) 1st step: J_q (2006+)	GPDs: Ji's relation: $J_q = \lim_{t \to 0} \int x\,dx \{H^q(x,\xi,t) + E^q(x,\xi,t)\}$ 1st: H^u (< 2006 ?)	DVCS: H, E; $\tilde{H}, \tilde{E}$ DVEM: pseudoscalar: $\tilde{H}, \tilde{E}$ vector: H, E	U T	low → high $\int \mathcal{L}dt$	low t → recoil det.	1 … 20 GeV^2	30 … 100 GeV
SEMI-INCLUSIVE DIS: • PRECISE Measurement of • tensor charge → (→ chiral symmetry breaking) *) • axial charge →	transversity distribution $\delta q(x,Q^2) \equiv h_1^q(x,Q^2) \equiv \Delta_T^q(x,Q^2)$ $\delta\Sigma(Q^2) = \int dx \{\delta q(x,Q^2) - \delta\bar{q}(x,Q^2)\}$ $\Delta\Sigma(Q^2) = \int dx \{\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\}$	DIS + SIDIS • need $eN \to e'KX$ to access $\delta s(x,Q^2)$	T L	high precision: high $\int \mathcal{L}dt$	don't care	1 (5) … 20 (30) GeV^2	50 … 200 GeV

*) fundamental issues !

Summary of requests:

- polarized targets (T, L); solid-state
- sufficient duty cycle (1…10%)

} $\int \mathcal{L}dt \gtrsim 100\ fb^{-1}/year$!

- Variable beam energy (30… 100… 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
  Δu, Δd, $\Delta \bar{u}$, $\Delta \bar{d}$, ΔG, (Δs), δu, (δd), (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 $\longrightarrow$ '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