BARYONS 2002:
OUTLOOK

Wolfram Weise

(EC T* Trento and TU Munich)

• Status and Perspectives
• Open Questions and Burning Issues
the Vision:

- Zeroth order **STRONG QCD**: Relativistic **CONSTITUENT QUARKS** with **FLUX TUBE GLUON DYNAMICS**
- Then add **$g\bar{g}$ SEA** and other $1/N_c$ effects as perturbations.

"... possible connection between **CURRENT QUARKS and GLUONS** through **$g\bar{g}$ VACUUM CONDENSATE**..."
First observations of DVCS

- Missing mass spectrum and \( A_{LU}^{\sin \phi} = \frac{2}{N} \sum_{i=1}^{N} \sin \phi_i \):

- Azimuthal (\( \phi \)) distributions from HERMES & JLab:

HERMES, PRL 87(‘01)182001  CLAS Collab., PRL 87(‘01)182002
• Off-shell photon*-quark scattering:
  - Detect $e'$ and $\gamma$, and require: $E_{\text{miss}} = 0$

\[
\int x dx [H(x, \Delta^2, \xi) + E(x, \Delta^2, \xi)] = A_q(\Delta^2) + B_q(\Delta^2)
\]

with $\Delta^2 = -t$ and

\[
\lim_{\Delta^2 \to 0} [A_q(\Delta^2) + B_q(\Delta^2)] = 2J_{\text{quark}} = \Sigma_q + 2\Lambda_q
\]

⇒ DVCS: total quark angular momentum

• Experimental considerations:
  - Interference with Bethe-Heitler process:
    DVCS $\otimes$ BH makes DVCS measurable
  - Detect scattered photon, but suppress $\pi^0$'s
  - Observe azim. asymmetry: $A_{\text{BetheHeitler}}^{LU} = 0$
Resonances in Virtual Compton Scattering

**Hall A - E93-50**

\[ ep \rightarrow e p \gamma \]

- First measurement through entire resonance region
- Advantage over mesons, the lack of final state interaction
- Strong resonance excitations

\[ Q^2 = 1.0 \text{ GeV}^2 \]
\[ \theta^* = 167.2^\circ \]
\[ \phi = 45^\circ \]

Diagram shows 5-fold Differential Cross Sections (pb GeV^{-1} sr^{-2})

- $N^*(1520)$
- $\Delta(1232)$
- $N^*(1650)$
DISPERSION RELATION ANALYSIS OF VCS

\[ \varepsilon = 0.62 \quad q = 0.6 \text{ GeV} \quad \theta = 0^\circ \quad \phi = 0^\circ \]

\[ d^5\sigma \text{ (nb/GeV sr)} \]

\[ J. \text{ Roche et al., Phys. Rev. Lett. 85 (2000)} \]

\[ BH+Born+Pol \]

\[ BH+Born \]

\[ q' \text{ (GeV)} \]

Pasquini, Gorchtein, Drechsel, Metz, Vanderhaeghen;


\[ \times \text{ Sensitivity to} \]

ELECTROMAGNETIC POLARIZABILITIES

OF THE NUCLEON
7. Virtual and Deeply-Virtual Compton Scattering

- Mainz
- JLab
- Hermes

(D)VCS
Bethe-Heitler
CHIRAL SU(3) 
MESON-BARYON DYNAMICS

- Coupled Channels
- Baryon Octet and Decuplet
- Large $N_c$ book-keeping

example: $K^-$p reactions; do Legendre coeff.
Energy-dependence of the Magnetic Dipole Polarisability $\beta_{M1}(\omega)$

H. W. Grießhammer/T. R. Hemmert: nucl-th/0110006;

Strong $\omega$ dependence from $\Delta$: para-magnetic $M1 \rightarrow M1$.

Chiral dynamics part ($N\pi$ physics) small.

$\beta_{M1}(\Delta) \approx -\delta \beta_{M1}(\text{C.T.}) \approx 12 \times 10^{-4} \text{ fm}^3$: anomalously large.

$\rightarrow$ Promote $\Delta(1232)$ to leading order in combined chiral & large $N_c$ expansion.
Test of Chiral Perturbation Theory

$\gamma^* + p \rightarrow p + \pi^0$  Total Cross Section vs. $Q^2$

\[ \Delta W = 0.5 \text{ MeV} \]

\[ \Delta W = 1.5 \text{ MeV} \]

\[ \Delta W = 2.5 \text{ MeV} \]

\[ \Delta W = 3.5 \text{ MeV} \]

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\[ Q^2 = 0 \quad \text{A. Schmidt et al., Phys. Rev. Lett. 87, 232501 (2001).} \]
\[ Q^2 = 0.05 \text{ GeV}^2/c^2 \quad \text{H. Merkel et al., Phys. Rev. Lett. 88, 012301 (2002).} \]
\[ Q^2 = 0.1 \text{ GeV}^2/c^2 \quad \text{M. O. Distler et al., Phys. Rev. Lett. 80 2294 (1998).} \]
Low Energy Region

- Low energy expansion breaks down, once resonances are produced!
6. **Chiral Symmetry** and **Chiral Dynamics**

("QCD LITE")

- **Chiral Perturbation Theory** and beyond
5. STRANGENESS

in the NUCLEON

VECTOR CURRENT \langle p(1S)_{\gamma}p \rangle

from parity-violating e-scattering

(F. Maas)

\[ G_E^S + 0.4G_M^S = 0.025 \pm 0.034 \quad (Q^2=0.5 \text{ GeV}^2) \]

HAPPLEX \& JLAB:

\[ \text{Progress from MAXINE:} \]

limits on strange vector current in the proton were set by part
Key observables and experiments which will measure them

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Experiment</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta g$</td>
<td>COMPASS</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>HERMES</td>
<td>2002+</td>
</tr>
<tr>
<td></td>
<td>RHIC</td>
<td>2002-05</td>
</tr>
<tr>
<td></td>
<td>SLAC E-161</td>
<td>2005</td>
</tr>
<tr>
<td>Flavour separation</td>
<td>HERMES</td>
<td>2002</td>
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<tr>
<td></td>
<td>RHIC</td>
<td>2002-04</td>
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<tr>
<td>$A_{pol}$</td>
<td>RHIC</td>
<td>2002+</td>
</tr>
<tr>
<td>Transversity, $h_1$</td>
<td>COMPASS</td>
<td>2004+</td>
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<td></td>
<td>HERMES</td>
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<tr>
<td></td>
<td>RHIC</td>
<td>2002+</td>
</tr>
<tr>
<td>Transversity from $e^+e^-$</td>
<td>BELLE</td>
<td>2002</td>
</tr>
<tr>
<td>DVCS plus meson production</td>
<td>COMPASS</td>
<td>2004+</td>
</tr>
<tr>
<td></td>
<td>HERMES</td>
<td>2004-05</td>
</tr>
<tr>
<td></td>
<td>SLAC E-159</td>
<td>2006</td>
</tr>
</tbody>
</table>

(from: S. Bass, A. de Roeck, Trento proceedings 2001)

$\Delta G$: high $p_T$ pairs

and

[Diagram of Feynman diagram involving $\pi^-$ and $\pi^+$]
Transverse polarization

- Three leading order distribution functions:

\[ f_1 = \quad \text{momentum carried by quarks} \]
\[ g_1 = \quad \text{longitudinal quark spin, } \Delta \Sigma \]
\[ h_1 = \quad \text{transverse quark spin, } \delta \Sigma \]

- Importance of \( h_1(x) \) measurements:
  - HERMES data: \( \Delta \Sigma = 0.30 \pm 0.04 \pm 0.09 \)
  - \( \Delta \Sigma \) is so small because of axial anomaly:
    * Redistribution of angular momentum in nucleon:
      \[
      \frac{1}{2} \Delta \Sigma \approx +0.15, \quad \Delta G \approx +1.0, \quad L_z \approx -0.65
      \]
    * Redistribution is less in transverse case:
      \[
      \Delta \Sigma < \delta \Sigma < 1 \quad \text{(Quark Parton Model)}
      \]
      \[
      \Delta \Sigma = 0.18(10) \quad \text{and} \quad \delta \Sigma = 0.56(9)
      \]
- Expected data quality with '00 data included:

**HERMES Δq extraction — MC projection**

- MC: 96/97 $\bar{H} + 98-00 \bar{D}$
- HERMES publ. PLB 464 (1999) 123

- CTEQ4LQ / (1+R)
- GRSV 2000 / (1+R)
First moment of $g_1$ for the proton

JLab/CLAS

PRELIMINARY

$Q^2(\text{GeV}^2)$
$g_1(x)$ for the proton

JLab/CLAS

$g_1^p$

$W=2$

- $Q^2=0.91 \text{ GeV}^2$
- $A_1+\eta A_2$
  parameterization
- Simula et al.

-- Gehrmann and Stirling ($Q^2=1.0$)
-- Edelmann et al. ($Q^2=1.0$) (’99) PRELIMINARY

Raffaella De Vita – INFN
BARYONS 2002, Jefferson Lab, March 3-8 2002
Overview of existing $x g_1(x)$ data:

- Proton
- Deuteron
- Neutron ($^3$He)
4. Spin Structure

* HERMES (G. van der Steenhoven)

\[ \Delta \Sigma_q = \Delta u + \Delta d + \Delta s = 0.3 \pm 0.1 \]
\[ = 1 - 2 (\Delta G + L_z) \]

- flavour decomposition
- Gluon contribution \( \Delta G \)
- transverse spin \( \delta \Sigma_q \)

* JLab (R. DeVita)

- Spin structure and resonances
THEORY

- VARIETY of MODELS (Review: T. Sato)

- STATUS:
  - Physics of $\Delta$ RESONANCE: o.k.
  - 2nd RESONANCE region: important to get $\pi\pi\pi$ CHANNELS under control?
  - 3rd and "higher" RESONANCE region: MUCH to do: detailed resonance vs. background analysis etc.

- Hints & Comments:
  - Reminder of FANO THEORY (W. Lichterick)
    (see: Atomic physics & quantum optics)
  - Quest for PARITY DOUBLETS
    (Cohen & Glozman)
GERASIMOV-DRELL-HEARN Sum Rule

\[ \int_{\omega_{th}}^{\infty} \frac{d\omega}{\omega} \left[ \sigma_{-\frac{1}{2}}(\omega) - \sigma_{\frac{1}{2}}(\omega) \right] = \frac{2\pi^2 \alpha}{M^2} \kappa \]

\[ \text{high energy part of GDH integral needs to be tested!} \]

(SLAC E-159)
Double polarization measurements

Polarized beams and targets: first results

- MAINZ
- LEGS
- BONN

- Predictions based on multipole analysis do not include $N\pi\pi$ and $\eta$ channels
- Unitary Isobar Model is missing strength in the second resonance region
- Contributions to GDH sum-rule and $\gamma_0$ spin polarizability are measured for the first time.

PRL 87(2001)022003
Braghieri, Michel
\[ \gamma + p \rightarrow \omega + p \quad \text{Beam asymmetry } \Sigma \]

\[ E_{\gamma} = 1.27 \text{ GeV} \]

\[ \theta_{\omega} \text{ cm (deg)} \]

- - - - t-exchange terms only (Q. Zhao)
- - - full calculation including s-u N* contributions

The beam asymmetry \( \Sigma \) is very sensitive to the inclusion of the N* resonances.

The inclusion of the diffractive t-exchange terms alone produces no asymmetry.

First preliminary results from GRAAL.
Sizable contribution from N* resonances.

Model from Zhao includes
\[ P_{11}(1440), \quad S_{11}(1535), \]
\[ D_{13}(1520), \quad P_{13}(1720), \]
\[ F_{15}(1680), \quad P_{13}(1900), \]
\[ F_{15}(2000) \]

Jlab 5 march 2002
Baryons 2002
Annalisa D'Angelo
$\gamma + p \rightarrow \eta + p$

Graal and Mainz data

Graal data cover the full resonance.

They show a "structure" at 1050 MeV, confirmed by new CLAS data

Pasyuk

Red curve: SAID BO12
Blue curve: eta MAID
Green curve: B. Saghai and Z. Li

Jlab 5 March 2002
Baryons 2002
Annalisa D’Angelo
$K^+$ Photoproduction

**SPRING-8** (T. Nakano)

$\Lambda(1405)$

$\Lambda(1520)$

$\Lambda(1405)$ as $K\Lambda$ quasibound state? (Kaiser et al., '95)

$\Lambda(1520)$

Very Preliminary
Search for resonances in hyperon production

**CLAS**

$ep \rightarrow eK^+Y$

Forward hemisphere

$0 < \cos(\Theta_K) < 1$, $Q^2 = 0.7 \text{ (GeV/c)}^2$

$\sigma_T + \epsilon_L \sigma_L$

Backward hemisphere

$-1 < \cos(\Theta_K) < 0$, $Q^2 = 0.7 \text{ (GeV/c)}^2$

$\sigma_T + \epsilon_L \sigma_L$

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Niculescu/Feuerbach

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Prepimedary
Resonances in $\gamma^* p \rightarrow p\pi^+\pi^-$

**CLAS**

Genova-Moscow Isobar model fit

$\Gamma_{N\pi\pi}$ PDG

$\Gamma_{N\gamma}$ AO/SQTM

Total cross section

$Q^2 = 0.65$ GeV$^2$

$Q^2 = 0.95$ GeV$^2$

$Q^2 = 1.30$ GeV$^2$

missing resonance strength
$E_2/M_1$ Ratio

$N \rightarrow \Delta$

$\frac{\text{Re}(E_{1+} M_{1+})}{|M_{1+}|^2}$

$Q^2(\text{GeV}^2)$

-0.02

... Looking forward!
Multipole Analysis for $\gamma^* p \rightarrow p \pi^0$

$Q^2 = 0.9 \text{ GeV}^2$

$|M_{1+}|^2$

$\text{Re}(E_{1+}M_{1+}^*)$

$|M_{1+}|^2$

$\text{Re}(S_{1+}M_{1+}^*)$

L.C. Smith

CLAS

Jefferson Lab
3. BARYON RESONANCES

significant progress:

* CLAS
* MAINZ
* BONN
* GRAAL
* LEGS
Reminder of **Quasiparticles** in Many-Body Systems

Example: **Quasi-Electrons** in electron gas

Coulomb interaction screened by cloud of electron-hole excitations

Quasiparticles interact weakly

But: **Constituent Quarks** experience

- **Confinement**
- Relatively strong residual interactions
  - Both gluon (color) exchange
  - Spin-flavour dependent interactions (e.g. Goldstone pion exchange)
**Quark Propagator**

\[ S_E(p) = \frac{Z(p^2)}{i\gamma \cdot p + M(p^2)} \]

*Euclidean*

**Landau gauge**

**Lattice**

*Adelaide group*

*Lei*\_weber et al.

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**Compare: Constituent Quark Mass from Instantons**

(D. Diakonov)

\[ M(p) \]

**Instanton size** \( \approx \frac{1}{3} \) fm

\[ M(0) = \frac{\pi \frac{p}{N_c R^2}}{2} \approx 350 \text{ MeV} \]

---

... but:

*No confinement!*
2. Constituent Quarks

- How many Quarks in a Baryon?
  a) Spectroscopy: \( N = 3 \)
  (S. Capstick)
  b) Deep-Inelastic Scattering:
  (HERA; R. Yoshida) \( N_f \to \infty \)
  \[ \int_0^1 \frac{dx}{x} F_2(x) = \int d\ln x F_2 \to \infty \]

- Interpolate between "3" and "\( \infty \)"
  "Constituent Quarks"
  (fuzzy concept?)

\[ \text{(Y. Simonov)} \]

\[ \text{Vacuum Structure} \]

\[ \text{Ground State} \]

\[ \text{Quark} \]

\[ \text{Diquark} \]

\[ \text{Excited States (Regge traj.)} \]
Comparison with Data

- Can use lowest 4 moments to reconstruct $x$-dependence of $u_n(x) - d_n(x)$

Detmold, Melnitchouk....

- Dark shading is world data
- Light shading **chiral extrapolation**
$g_A \quad N_f = 2$

Fit ansatz: $g_A = A + B(m_\pi r_0)^2 + C(a/r_0)^2$
$g_A$ on the LATTICE: "Full" QCD

G. Schierholz

$g_A = 1.26$
Chiral Extrapolation of Lattice QCD Results (part II)

Proton, Neutron Magnetic Moment

\[ \mu \text{[n.m.]} \]

\[ m_\pi \text{[GeV]} \]

Pade fit
\[ \mu_i = \frac{\hat{\mu}_i}{1 + \alpha_i m_\pi + \beta_i m_\pi^2} \]

(A.W. Thomas)

Calculated using Chiral Effective Field Theory
(incl. \( \Delta(1232) \) in NLO)

(T. Hemmert, W.W.)

\[ \text{Lattice, near future: } m_\pi \sim 0.3 \text{ GeV} \]
Overview of Hadron Masses

- Behave like constituent quark model for $m_\pi$ above 400–500 MeV:

Leinweber, Wright......
1. LATTICE QCD

**FLUX TUBE**

Gluonic Action Density around STATIC SOURCES \([SU(2)_c]\)  


**STATIC QQ POTENTIAL**

[Graph showing the static QCD potential with annotations](graph)

(Reviews by R. Edwards, Ch. Davis)
OUTLOOK SUMMARY

★ BARYON: fascinating QCD - MANY-BODY PROBLEM

★ the FIELD is HEALTHY:

DATA driven 

BRAIN driven

COMPUTER driven

high PRECISION

"Intelligent" theoretical approaches

Constrained by symmetries of QCD

LATTICE QCD steadily increasing power ... towards observables

future:

JLab upgrade

MAMIC

HERMES II

COMPASS

SPRING-8