DIS 2008
Summary: Spin Physics WG (theory)

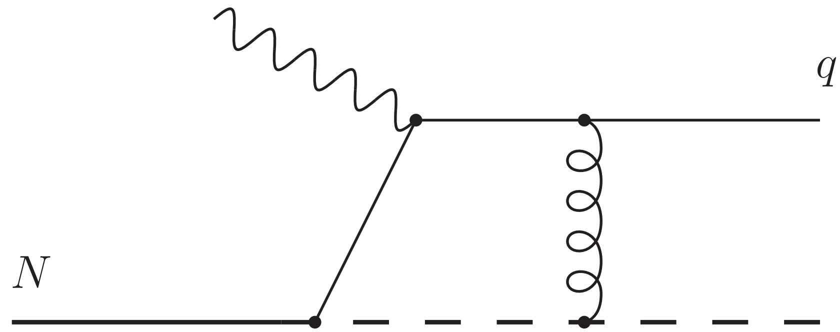
(A. Metz, Temple University, Philadelphia)

- Conveners: E.-C. Aschenauer, A. Bressan, A. Metz, B. Surrow
- 9 sessions (2 joint sessions with Diffraction WG)
- 45 contributions (24 experiment, 21 theory)
- Longitudinal Spin:
  E. Leader, A. Piccione, Ph. Hägler, D. Müller
- Transverse Spin:
  F. Yuan, K. Tanaka, G. Goldstein, C. Lorce, M. Radici, P. Mulders, C. Pisano, A. Prokudin, A. Bacchetta, L. Gamberg, S. Melis, T. Teckentrup
- GPDs, Exclusive Reactions:
  M. Diehl, P. Kroll, K. Kumericki, S. Meißner, L. Schoeffel
- Thanks to speakers!
- Comprehensive summary impossible
- For general context see also talk by X. Ji given on Monday

Main objectives

1. Different (polarization dependent) parton distributions of hadrons
   - Interesting in their own
   - Input for spin sum rule of the nucleon
   - etc.

2. QCD issues in hard processes
   - Study of gluon resummations
   - Role of gluon exchange between active partons and remnants



$\longrightarrow$ observable effects in semi-inclusive DIS (for instance Sivers effect: transverse single spin asymmetry)

$\longrightarrow$ transverse momentum dependent PDFs become process-dependent (non-universality)

$\longrightarrow$ Rescattering effects for hadron-hadron collision with detection of hadronic final state more difficult to handle

$\longrightarrow$ They may even endanger factorization

Parton distributions of the nucleon

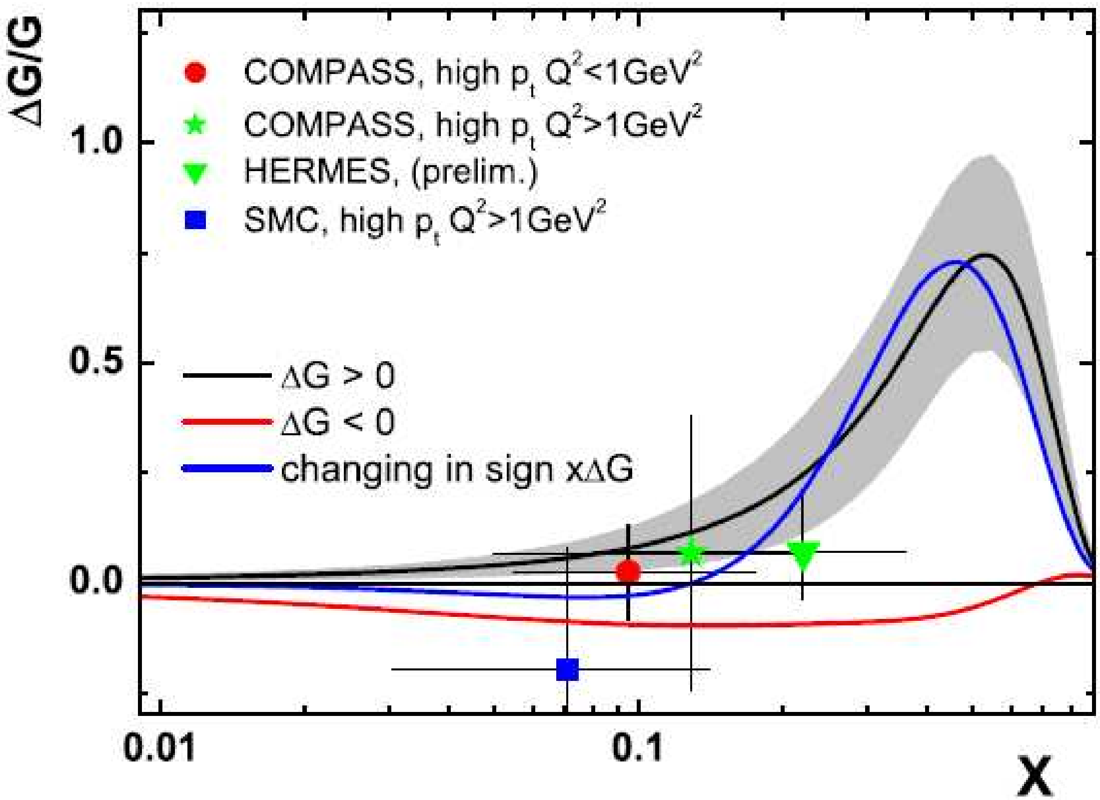
	Quarks				Gluons			
Forward	f_1^q	g_1^q (Δq)	h_1^q $(\Delta_T q)$		g	Δg		
k_T-dependent	f_1^q	$f_{1T}^{\perp q}$	g_{1L}^q	g_{1T}^q	f_1^g	$f_{1T}^{\perp g}$	g_{1L}^g	g_{1T}^g
	h_{1T}^q	$h_{1L}^{\perp q}$	$h_{1T}^{\perp q}$	$h_1^{\perp q}$	h_{1T}^g	$h_{1L}^{\perp g}$	$h_{1T}^{\perp g}$	$h_1^{\perp g}$
Generalized	H^q	E^q	$\tilde{H}^q$	$\tilde{E}^q$	H^g	E^g	$\tilde{H}^g$	$\tilde{E}^g$
	H_T^q	E_T^q	$\tilde{H}_T^q$	$\tilde{E}_T^q$	H_T^g	E_T^g	$\tilde{H}_T^g$	$\tilde{E}_T^g$

- Except of f_1^q, f_1^g, H^q, H^g all parton distributions are related to polarization
- Forward PDFs, TMDs, GPDs (for particular kinematics, and in impact parameter representation) describe strengths of spin-spin and spin-orbit correlations
- Spin-spin and spin-orbit correlations also appear for hydrogen atom in infinite momentum frame (X. Artru, K. Benhizia, 2007)

Gluon polarization and higher twist

(talk by E. Leader)

- Latest version of Leader-Sidorov-Stamenov fit for $\Delta g(x)/g(x)$
- If higher twist effects included in data analysis, three scenarios provide comparable χ^2. If not included, $\Delta g(x) > 0$ is preferred



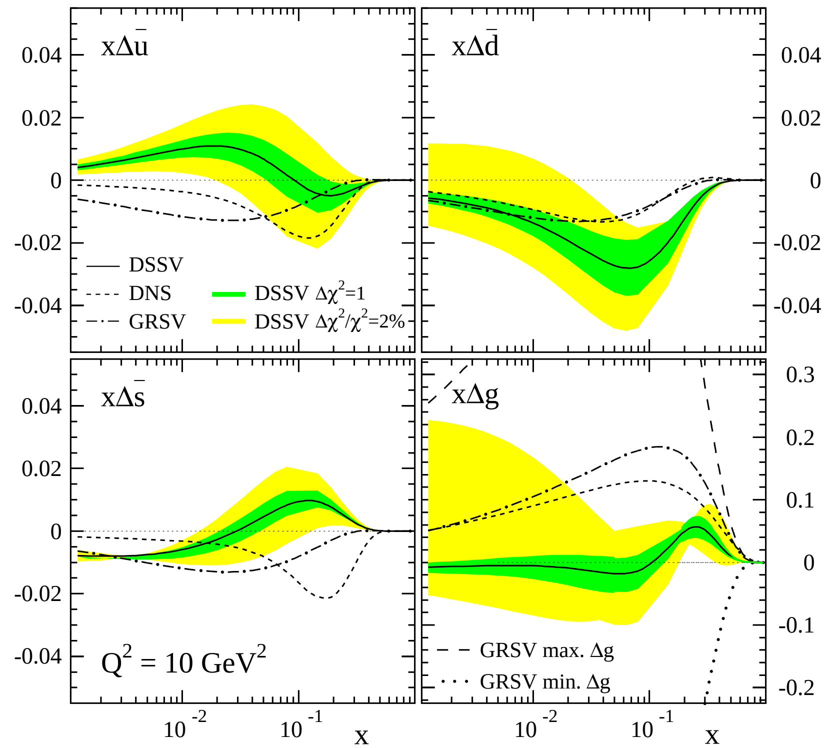
- New Electron Ion Collider (low x, large Q^2) would fix the sign of $\Delta g(x)$

Global analysis of parton helicity distributions

(D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, arXiv: 08040422)

- First systematic analysis including data from DIS, SIDIS as well as from pp-collisions (production of hadrons and jets)
- All cross sections evaluated at NLO
- Numerics quite challenging
- Main benefit of including pp-data: important constraint on (magnitude of) Δg from STAR data on jet production
- Improvements needed, but now mainly experimental issue

- Results



$\Delta g \quad = \quad \int dx \, \Delta g(x)$ compatible with zero, but still very large errors

$\Delta \bar{u} \quad \neq \quad \Delta \bar{d} \quad \neq \quad \Delta \bar{s}$

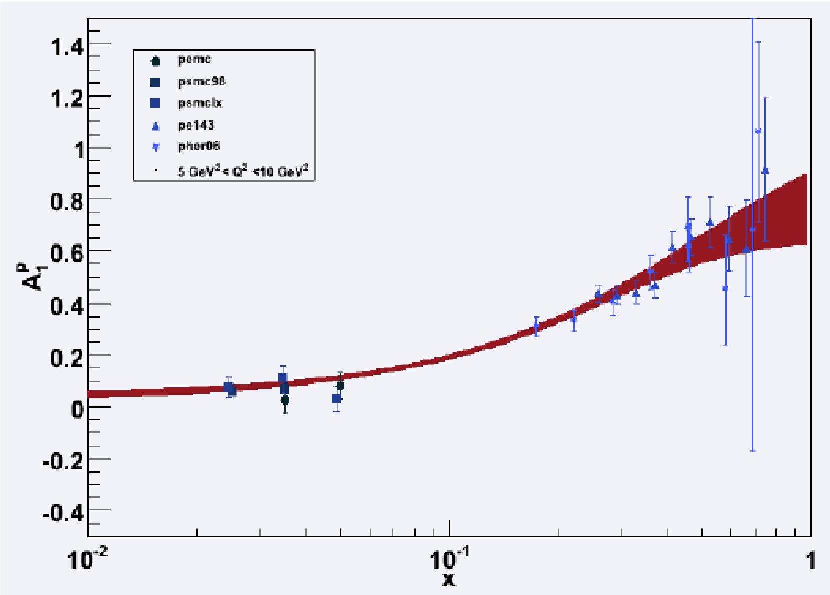
$\Delta \bar{u} \quad > \quad 0$ opposite to most model predictions

Re-evaluation of Bjorken sum rule in MonteCarlo approach

(talk by A. Piccione)

- Data analysis with minimum bias (no parameterization for fit function imposed)
- Improved estimate of errors on observables

  Example: A_1^p in DIS



- Improved estimate of errors on integrals like Bjorken sum rule

$$\int dx \left(G_1^p(x, Q^2) - G_1^n(x, Q^2) \right)$$

Generalized parton distributions, exclusive reactions

(talks by Ph. Hägler, D. Müller, M. Diehl, P. Kroll, K. Kumericki, L. Schoeffel)

1. Motivation

   GPDs crucial for (longitudinal) spin sum rule, and ...

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta g + L_z^g$$

   $\longrightarrow$ total angular momentum of partons related to GPDs:

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

2. Modelling of GPDs

   (Diehl, Kroll, Kumericki, Müller)

   - Unavoidable for analysis of experiments
   - Highly non-trivial due to many theoretical and experimental constraints
   - A lot of recent activity
   - Models reach a new level of accuracy and sophistication (Kumericki, Müller)

3. Phenomenology of hard exclusive reactions

- DVCS: calculations up to NNLO available (Kumericki, Müller)
  $\longrightarrow$ perturbation series shows good convergence

- NLO corrections in hard exclusive meson production (Diehl)
  $\longrightarrow$ 'corrections' can be large (factor 2 or even larger)

- Vector meson production (also beyond leading twist) (Kroll)
  $\longrightarrow$ good agreement with data from H1, ZEUS, E665, HERMES, COMPASS

- Possible future measurement of DVCS (Schoeffel)
  $\longrightarrow$ studying DVCS at COMPASS may add important new information

- etc.

4. Lattice QCD and the spin sum rule
(Hägler)

- Sum rule

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L^q + \Delta g + L^g$$

- Results for total angular momentum of quarks ($Q^2 = 4\,\mathrm{GeV}^2$)

$$J^u = 0.22 \pm 0.02 \qquad\qquad J^d = 0.00 \pm 0.02$$

- Results for orbital angular momentum of quarks

$$L^u = 0.20 \pm 0.04 \qquad\qquad L^d = -0.20 \pm 0.04$$

- Quark orbital motion apparently does not contribute much to nucleon spin

- Statistical errors very small

- Systematic errors (effects due to finite size and discretization, large pion mass, etc.) hard to quantify at present

- Precise determination of Δg still of crucial importance!

Extraction of transversity

(talk by A. Prokudin)

- Method: exploiting the Collins effect

$$\sigma_{SIDIS} \sim h_1^q(x, \vec{k}_T^2)\, H_1^{\perp\, q/H}(z, \vec{p}_T^2) + \ldots$$

$\longrightarrow$ data from COMPASS and HERMES

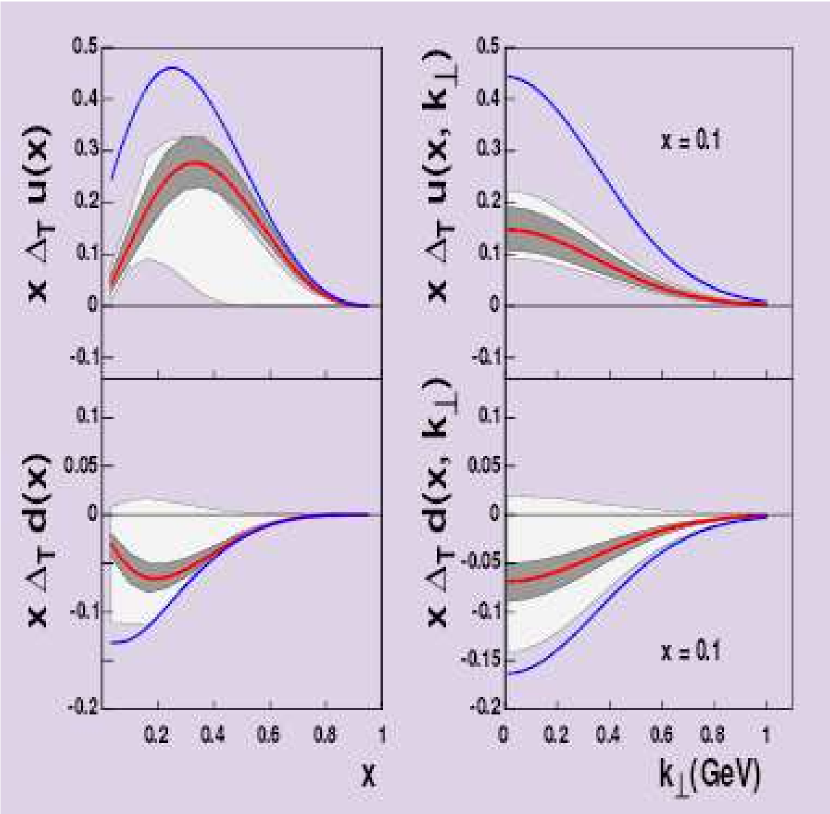
- Collins function $H_1^\perp$ from $e^+\, e^- \longrightarrow H_1\, H_2\, X$

$$\sigma_{e^+e^-} \sim (H_1^\perp)^2 + \ldots$$

$\longrightarrow$ data from Belle

- New, much more precise data lead to improved fit

- Results



$\longrightarrow$ $h_1^u(x) > 0$ $\quad$ $h_1^d(x) < 0$ $\quad$ (in agreement with most models)

$\longrightarrow$ Soffer bound not saturated

$\longrightarrow$ Significant improvement compared to previous fit (from same group)

$\longrightarrow$ Statistical errors already rather small, systematic errors hard to quantify at present

Alternative ways of exploring transversity

1. Dihadron fragmentation in semi-inclusive DIS
   (talk by M. Radici)

$$\sigma \sim h_1(x)\, H_1^{q\to 2H}(z, M_h)$$

   $\longrightarrow$ formalism exists, SIDIS data exist, but $H_1^{q\to 2H}$ poorly constrained at present

2. Exclusive pion production of the nucleon
   (talk by G. Goldstein)
   $\longrightarrow$ data exist, formalism has to be completed (twist-3 effect)

3. Transverse double spin asymmetry in Drell-Yan
   (talk by K. Tanaka)

$$A_{TT} \sim \frac{h_1^{q/H_1}(x_1)\, h_1^{\bar{q}/H_2}(x_2) + (x_1 \leftrightarrow x_2)}{f_1^{q/H_1}(x_1)\, f_1^{\bar{q}/H_2}(x_2) + (x_1 \leftrightarrow x_2)}$$

   $\longrightarrow$ very promising observable (collinear picture, very large effects in $p\bar{p}$ DY, ...), quite stable when including QCD corrections (fixed order and resummation), but no data at present

Tensor charge calculations

(talk by C. Lorce)

- New calculation in ChQSM (including higher Fock-States)
  $\longrightarrow$ value of δq depends on quadrupole deformation of nucleon, $\delta s \neq 0$, ...

- Compilation of calculations

Model (Q_0^2 GeV^2)	$\delta u(Q_0^2)$	$\delta d(Q_0^2)$	$\delta u(Q^2)$	$\delta d(Q^2)$
NRQM (0.08)	1.33	−0.33	0.97	−0.24
MIT Bag (0.76)	1.09	−0.27	0.99	−0.25
CDM (0.16)	1.22	−0.31	0.99	−0.25
CQM (0.64)	0.80	−0.15	0.72	−0.13
LC (0.08)	1.17	−0.29	0.85	−0.21
Spect. (0.06)	1.22	−0.25	0.83	−0.17
Latt. (1.96)	0.84	−0.23	0.80	−0.22
χQSM1 (0.36)	1.12	−0.42	0.97	−0.37
χQSM2 (0.36)	0.89	−0.33	0.77	−0.29
χQSM3 (0.36)	1.17	−0.31	1.01	−0.28

- Numbers extracted from experiment (from Prokudin)

$$\delta u = 0.59^{+0.14}_{-0.13} \qquad \delta d = -0.20^{+0.05}_{-0.07} \qquad (Q^2 = 0.8\,\mathrm{GeV}^2)$$

$\longrightarrow$ once systematic errors fully under control certain models will be ruled out
$\longrightarrow$ looking at antiquarks will also be helpful to discriminate between models

Extraction of Sivers function

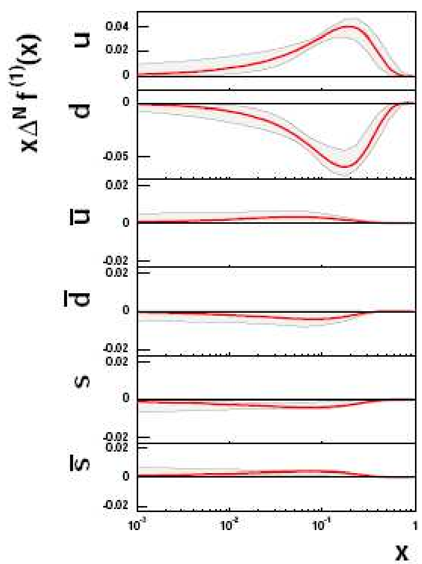
(talk by S. Melis)

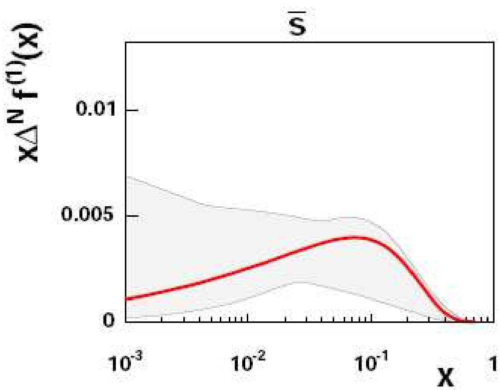
- Method: transverse single spin asymmetry in semi-inclusive DIS

$$\sigma_{SIDIS} \sim f_{1T}^{\perp q}(x, \vec{k}_T^{\,2})\, D_1^{q/H}(z, \vec{p}_T^{\,2}) + \ldots$$

$\longrightarrow$ data from COMPASS and HERMES

- Results





$\longrightarrow$ effects for u and d quark equal in magnitude but opposite in sign
(in agreement with large N_c-prediction, recall cancellation between L^u and L^d)

$\longrightarrow$ antiquarks small, but effect for $\bar{s}$ definitely nonzero

$\longrightarrow$ predictions for future measurements at COMPASS (hydrogen target) and JLab

Boer-Mulders function in photon-jet production at the Tevatron

(talk by C. Pisano)

- Process: $p\,\bar{p} \longrightarrow \gamma\,\mathrm{jet}\,X$

  $\longrightarrow$ access to $h_1^{\perp}(x, \vec{k}_T^{\,2})$
  $\longrightarrow$ spin physics without polarization of any external particle

- Nonzero azimuthal asymmetry

- Effect very similar to observed $cos(2\Phi)$ modulation in unpolarized Drell-Yan measurements, but smaller, may nevertheless be measurable

- Effect largest in mid-rapidity region

Wandzura-Wilczek approximation for TMDs

(talk by T. Teckentrup)

- WW-type relation

$$g_{1T}^{(1)}(x) \approx x \int_x^1 \frac{dy}{y}\, g_1(y) \quad \text{with} \quad g_{1T}^{(1)}(x) = \int d^2\vec{k}_T\, \frac{\vec{k}_T^{\,2}}{2M^2}\, g_{1T}(x, \vec{k}_T^{\,2})$$

$$h_{1L}^{\perp\,(1)}(x) \approx -x^2 \int_x^1 \frac{dy}{y^2}\, h_1(y)$$

- Longitudinal twist-2 single spin asymmetry in semi-inclusive DIS depends on $h_{1L}^{\perp}$

- Calculation using WW-type relation in agreement with HERMES data
  $\longrightarrow$ provides new check of WW approximation

- Turning the argument around one may get complementary information on h_1

Universality and factorization issues

(drastic shortcuts, unfortunately, ...)

- Gluon exchange between active partons and remnants leads to non-trivial universality for (some of the) TMDs

$$f_{1T}^{\perp}|_{SIDIS} = -f_{1T}^{\perp}|_{DY}$$

- In more complicated processes (like $p\,p \to \text{jet}\,\text{jet}\,X$) no longer such simple relation, even factorization becomes questionable (at most non-standard factorization), enormous recent activity

1. Universality of Collins function for hadron identified in jet
   (talk by F. Yuan)
   - No fundamental symmetry allows one to establish universality
   - One has to investigate the pole structure of the fragmentation process
   - Calculation up to 2-loop presented
   - Main result

$$H_1^{\perp}\Big|_{jet} = H_1^{\perp}\Big|_{SIDIS} = H_1^{\perp}\Big|_{e^+e^-}$$

   $\longrightarrow$ Collins effect inside jet may be studied at RHIC

2. Simplifying matters for hadron-hadron collisions
   (talk by P. Mulders)

   - In processes like $p\,p \longrightarrow \mathrm{jet\,jet}\,X$ each partonic subprocess has own parton distribution
     $\longrightarrow$ no longer of practical use

   - (In some cases) weighting cross section according to

$$\sigma_W \sim \int dp_T\, w(p_T)\, \sigma(p_T)$$

     leads to drastic simplifications

   - Non-universality condenses in calculable factors

3. Analysis of gluon pole matrix elements
   (talk by L. Gamberg)

   - Gluon pole matrix elements appear in certain single spin asymmetries

   - For fragmentation process they vanish

   - Vanishing directly related to universality of fragmentation functions

Interesting additional topics

(important for spin physics, but of more general use)

1. Description of semi-inclusive DIS from low to high $P_{h\perp}$
   (talk by A. Bacchetta)
   - Power behavior for all SIDIS structure functions as function of $P_{h\perp}$ determined in model independent way
   - Comparison of factorization formalisms in intermediate $P_{h\perp}$ range
     $\longrightarrow$ for low $P_{h\perp}$ TMD-factorization, for large $P_{h\perp}$ collinear factorization
   - Matches and mismatches observed
   - Important conclusion: TMD-factorization beyond leading twist not established
     (nicely confirms earlier indication)

2. Parameterization of generalized TMDs (GTMDs) of the nucleon
   (talk by S. Meißner)
   - GTMDs contain GPDs and TMDs in certain limits ($\longrightarrow$ mother functions)
   - Complete parameterization of GTMDs provided
   - One application: GTMD-analysis allows one to check status of proposed non-trivial relations between GPDs and TMDs
     $\longrightarrow$ no support for such relations
     $\longrightarrow$ none of the relations can have a model independent status

Summary

1. Considerable efforts and progress in theory of high-energy spin physics

2. Many of the important developments included in DIS 2008 program, but not all of them

3. Summary talk makes another crude selection

4. New, interesting results likely to come out during the next year

5. Also considerable efforts and progress on experimental side
   $\longrightarrow$ summary talk by Andrea Bressan