

Spin Physics Working Group: Theory Summary

Rodolfo Sassot
Universidad de Buenos Aires

DIS 2009, Madrid April 2009

Spin Physics Working Group:

Convenors: Carl Gagliardi, Rodolfo Sassot, Gunar Schnell

7 sessions + 2 joint sessions with Diffractive and Vector Mesons WG

45 talks (13 theory)

Topics/Theory Speakers:

Longitudinal Spin: A. Kotzinian, M. Stratmann, F. Taghavi-Shahri

Transverse Spin: F. Conti, U. D'Alesio, D. Boer, E. Boglione, K. Tanaka, B. Toedtli

GPDs, DVCS: G. Goldstein, S. Liuti, A. Mukherjee.

Longitudinal Polarization

Marco Stratmann: improvements to the DSSV analysis

DIS-2009 in Madrid, April 26th - 30th, 2009



Global QCD analysis of polarized PDFs status & prospects

Marco Stratmann

in collaboration with

Daniel de Florian, Rodolfo Sassot, Werner Vogelsang

Marco Stratmann: improvements to the DSSV analysis

DSSV pPDFs presented at DIS 2008

first NLO global analysis DIS, SIDIS, RHIC

focused on Δg

uncertainties with Lagrange Multipliers

New: uncertainties with improved Hessian scheme
variations of the best fit available

detailed analysis of (anti)quark polarization

predictions for RHIC: A_{LL} for charged pions,

jet correlations,

A_L for W

Marco Stratmann: improvements to the DSSV analysis

Questions raised:

DIS-2009 in Madrid, April 26th - 30th, 2009



**Global QCD analysis of polarized PDFs
status & prospects**

Marco Stratmann

in collaboration with

Daniel de Florian, Rodolfo Sassot, Werner Vogelsang

Marco Stratmann: improvements to the DSSV analysis

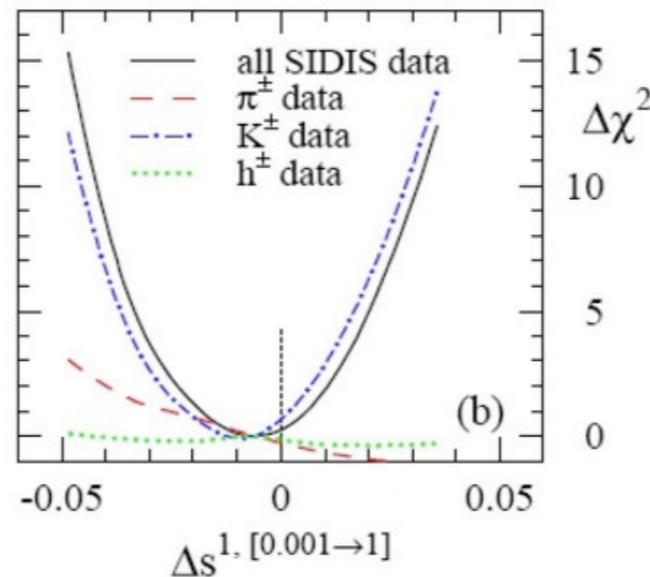
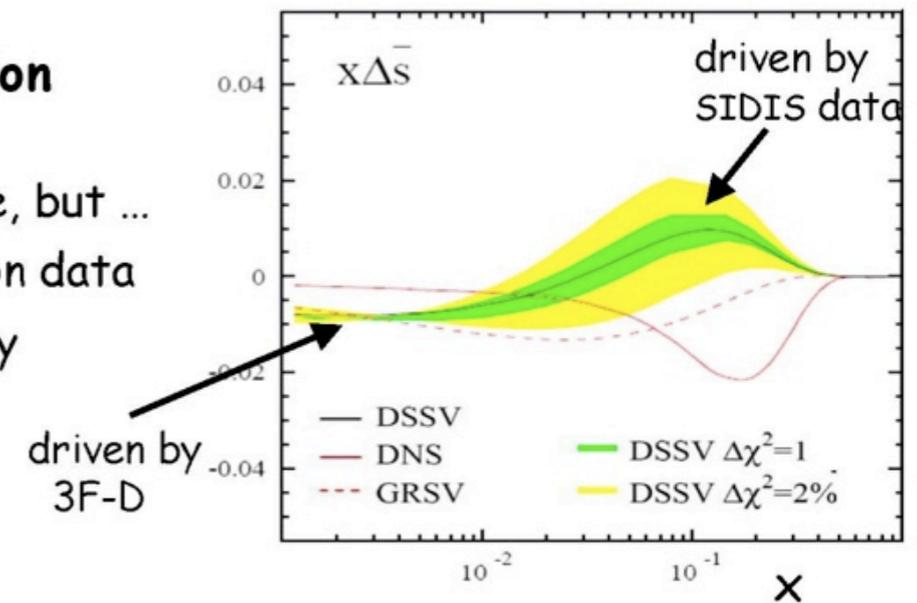
Questions raised:

“strange” issues

DSSV sea polarizations – cont’d

- a strange strangeness polarization

- $\Delta s(x)$ always thought to be negative, but ...
- mainly determined from SIDIS kaon data
- consistent with LO-type analyses by HERMES and COMPASS



striking result, but relies on

- kaon fragmentation
more data available soon (BELLE, ...)
- unpolarized PDFs
unpol. strangeness not well determined

needs further studies – exp. & theory !

Marco Stratmann: improvements to the DSSV analysis

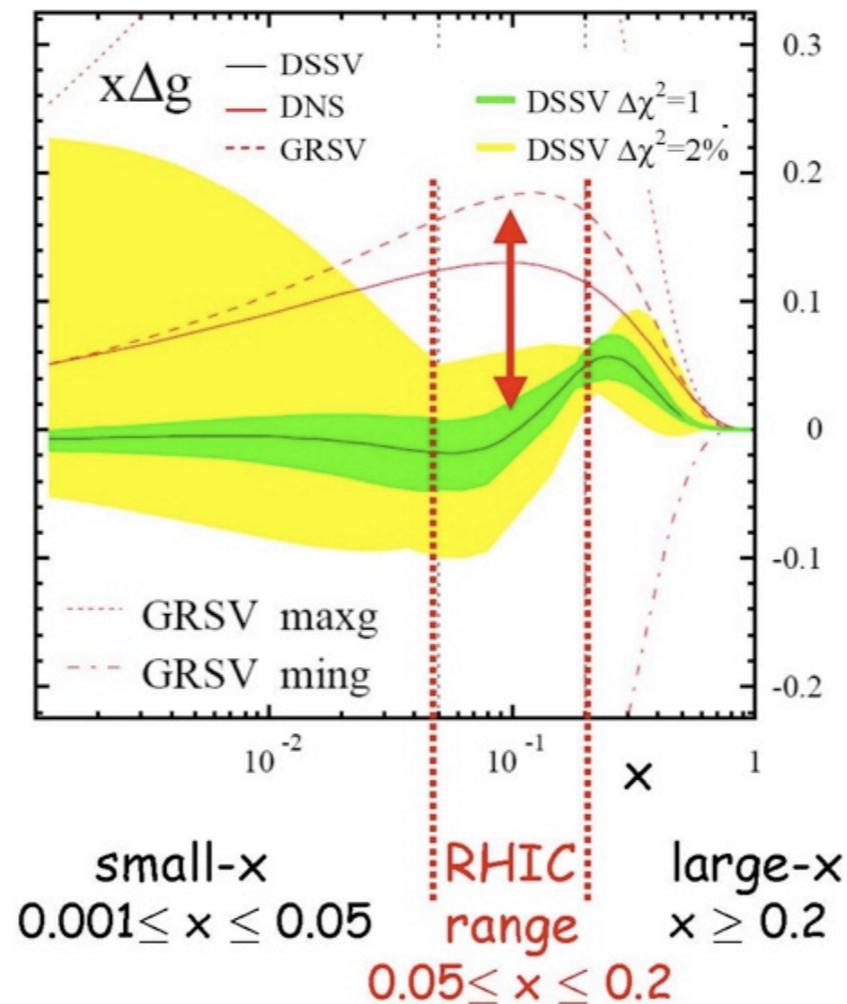
Questions raised:

“strange” issues

$$\Delta\chi^2 = ?$$

DSSV gluon polarization

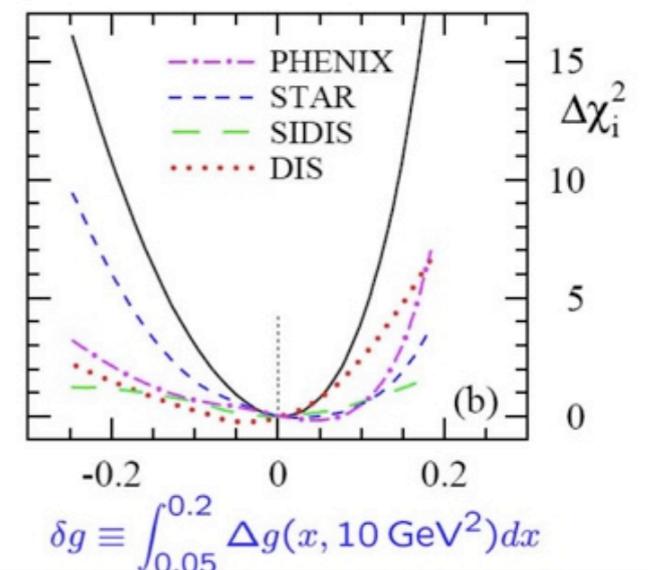
error estimates more delicate: small-x behavior completely unconstrained



study uncertainties in 3 x-regions

find

- $\Delta g(x)$ very small at medium x (even compared to GRSV or DNS)
- best fit has a node at $x \simeq 0.1$
- huge uncertainties at small x



Marco Stratmann: improvements to the DSSV analysis

Questions raised:

“strange” issues

$$\Delta\chi^2 = ?$$

extrapolations

numerical results

$$Q^2 = 10 \text{ GeV}^2$$

$$\Delta f^{1,[x_{\min},1]} \equiv \int_{x_{\min}}^1 \Delta f(x) dx$$

- Δs receives a large negative contribution at small x
- Δg : huge uncertainties below $x \simeq 0.01 \rightarrow$ **1st moment still undetermined**

	$x_{\min} = 0$ best fit	$x_{\min} = 0.001$ $\Delta\chi^2 = 1$	$x_{\min} = 0.001$ $\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta \bar{u}$	0.813	0.793 $^{+0.011}_{-0.012}$	0.793 $^{-0.028}_{-0.034}$
$\Delta d + \Delta \bar{d}$	-0.458	-0.416 $^{+0.011}_{-0.009}$	-0.416 $^{+0.035}_{-0.025}$
$\Delta \bar{u}$	0.036	0.028 $^{+0.021}_{-0.020}$	0.028 $^{-0.059}_{-0.059}$
$\Delta \bar{d}$	-0.115	-0.089 $^{+0.029}_{-0.029}$	-0.089 $^{+0.090}_{-0.080}$
$\Delta \bar{s}$	-0.057	-0.006 $^{+0.010}_{-0.012}$	-0.006 $^{+0.028}_{-0.031}$
Δg	-0.084	0.013 $^{+0.106}_{-0.120}$	0.013 $^{-0.702}_{-0.314}$
$\Delta \Sigma$	0.242	0.366 $^{+0.015}_{-0.018}$	0.366 $^{-0.042}_{-0.062}$

very difficult to give reliable estimates for full moments

both quark and gluons may not contribute much to proton spin
 but we need to go to smaller x to settle this issue
 \rightarrow case for a high-energy polarized ep-collider

Is the present pPDF picture satisfactory?

Is the present pPDF picture satisfactory?

NO!

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

Δg ?

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

Is the present pPDF picture satisfactory?

NO!

12 observables

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

12 observables
5 laboratories

$\Delta g ?$

$\Delta s ?$

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

12 observables
5 laboratories
NLO scheme

$\Delta g ?$

$\Delta s ?$

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

12 observables
5 laboratories
NLO scheme

consistency

$\Delta g ?$

$\Delta s ?$

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

12 observables

5 laboratories consistency

NLO scheme

valence polarization well
constrained

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

12 observables

5 laboratories consistency

NLO scheme

valence polarization well

constrained

surprisingly small in the

measured region

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

Remarkable!

12 observables

5 laboratories consistency

NLO scheme

valence polarization well

constrained

surprisingly small in the

measured region

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

fundamental questions to be answered

Remarkable!

12 observables

5 laboratories consistency

NLO scheme

valence polarization well

constrained

surprisingly small in the

measured region

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

fundamental questions to be answered
we have learned how to do it

Remarkable!

12 observables

5 laboratories consistency

NLO scheme

valence polarization well

constrained

surprisingly small in the

measured region

Is the present pPDF picture satisfactory?

NO!

fundamental questions
unanswered

$\Delta g ?$

$\Delta s ?$

fundamental questions to be answered
we have learned how to do it

Remarkable!

12 observables

5 laboratories consistency

NLO scheme

valence polarization well

constrained

surprisingly small in the

measured region

pEIC

Aram Kotzinian: $\bar{\Lambda}$ SIDIS as a probe for Δ_s

Longitudinal target polarization dependence of $\bar{\Lambda}$ polarization and polarized strangeness PDF

Aram Kotzinian

CEA-Saclay, IRFU/Service de Physique Nucléaire, 91191 Gif-sur-Yvette, France

On leave in absence from YerPhI, Armenia and JINR, Russia

DIS 2009, 26-30 April 2009, Madrid

- $\bar{\Lambda}$ polarization
 - ✿ Unpolarized target
 - ✿ Strangeness distribution in nucleon
 - ✿ Polarized target
 - ✿ Polarized strangeness in polarized nucleon
- Conclusions

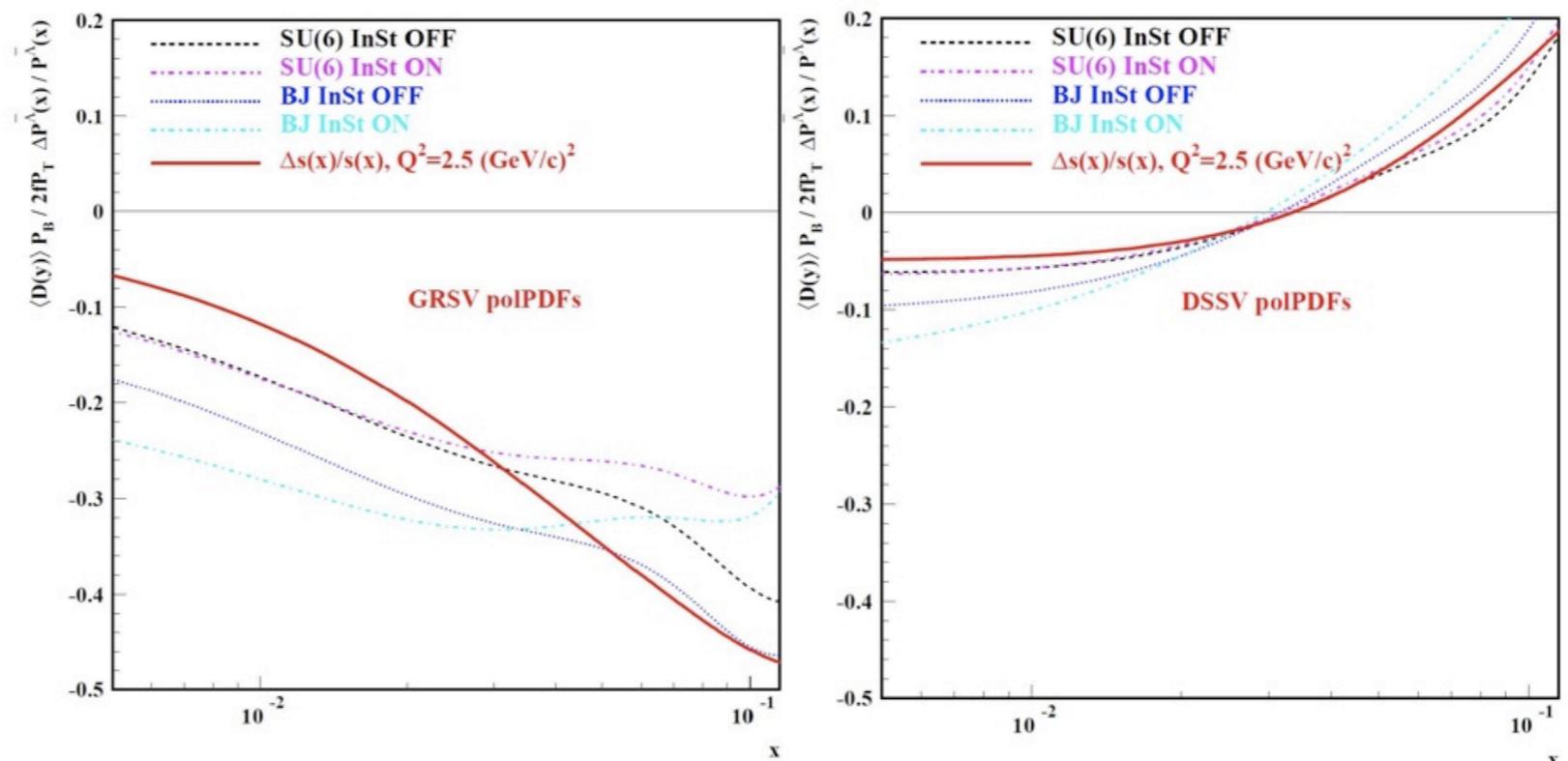
sensitivity to
strangeness

Aram Kotzinian:

$\bar{\Lambda}$ SIDIS as a probe for Δs

sensitivity to pPDFs
(model dependent)

Dependence on pol. PDFs



To verify sign change of $\Delta \bar{s}$
measure in two bins of x : $x < 0.03$ and $0.03 < x$

F. Taghavi Shahri:

from pPDFs to valence quark model

NON-SINGLET SPIN STRUCTURE FUNCTION IN VALON MODEL

Fatemeh Taghavi Shahri

IPM

Firooz Arash, Narjes Javadi Mottaghi

Tafresh University

Mohammad Kamali

Beheshti tarbiat moallem of Mashhad

F. Taghavi Shahri:

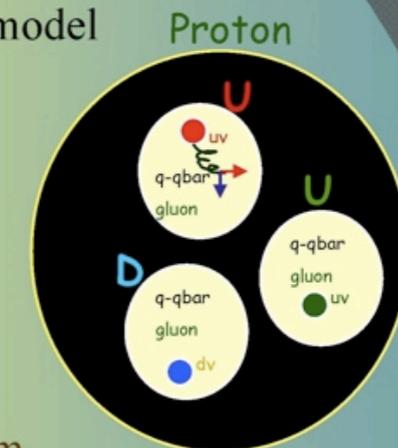
from pPDFs to valence quark model

extending
unpolarized results

good agreement
with data

Study of Nucleon Structure function in the Valon model

- **Valon** : valence quark and its associated sea quarks and gluons.
- The structure of a valon arises from the perturbative dressing of the valence quark in QCD.
- The valons carry all the momentum of nucleon and the quantum number of valon is the quantum number of its valence quark.
- They play a role in scattering problems as the constituent quarks do in bound-state problems.
- At sufficiently low value of Q^2 the internal structure of a valon cannot be resolved.



The existence of the valon can be inferred from the measurement of the Nachtmann moments of the proton structure functions at **Jefferson laboratory**. They point to the existence of a new scaling that can be interpreted as a constituent form factor consistent with the elastic nucleon data. They suggest that there exist extended objects inside the proton and the size of these constituents are 0.2-0.3 fm.(hep-ph/0301206v2)

Transverse Polarization

DIS 2008: precise extraction of transversity, Sivers
and Collins functions from SIDIS and e^+e^- data.

(Anselmino et al. 2008)

DIS 2008: precise extraction of transversity, Sivers
and Collins functions from SIDIS and e^+e^- data.

(Anselmino et al. 2008)

systematic phenomenology

DIS 2008: precise extraction of transversity, Sivers
and Collins functions from SIDIS and e^+e^- data.

(Anselmino et al. 2008)

systematic phenomenology
path of PDFs, pPDFs and FFs, but for distributions
relevant for transversely polarized nucleons

DIS 2008: precise extraction of transversity, Sivers
and Collins functions from SIDIS and e^+e^- data.

(Anselmino et al. 2008)

systematic phenomenology
path of PDFs, pPDFs and FFs, but for distributions
relevant for transversely polarized nucleons

towards global fits

DIS 2008: precise extraction of transversity, Sivers
and Collins functions from SIDIS and e^+e^- data.

(Anselmino et al. 2008)

systematic phenomenology

path of PDFs, pPDFs and FFs, but for distributions
relevant for transversely polarized nucleons

towards global fits

check and exploit factorization and universality

DIS 2008: precise extraction of transversity, Sivers
and Collins functions from SIDIS and e^+e^- data.

(Anselmino et al. 2008)

systematic phenomenology

path of PDFs, pPDFs and FFs, but for distributions
relevant for transversely polarized nucleons

towards global fits

check and exploit factorization and universality

higher order QCD on the way

Umberto d'Alesio: phenomenological study SSA $lp \rightarrow \pi + X$
as intermediate step between SIDIS $pp \rightarrow \pi + X$

using Anselmino's group
parameterization.

Madrid, April 26-30, 2009

**Single Spin Asymmetries
in $lp \rightarrow h + X$ processes**

Umberto D'Alesio

Physics Department and INFN
University of Cagliari, Italy

DIS 2009

XVII International Workshop on Deep-Inelastic Scattering and Related Subjects

April 26-30, 2009 Madrid

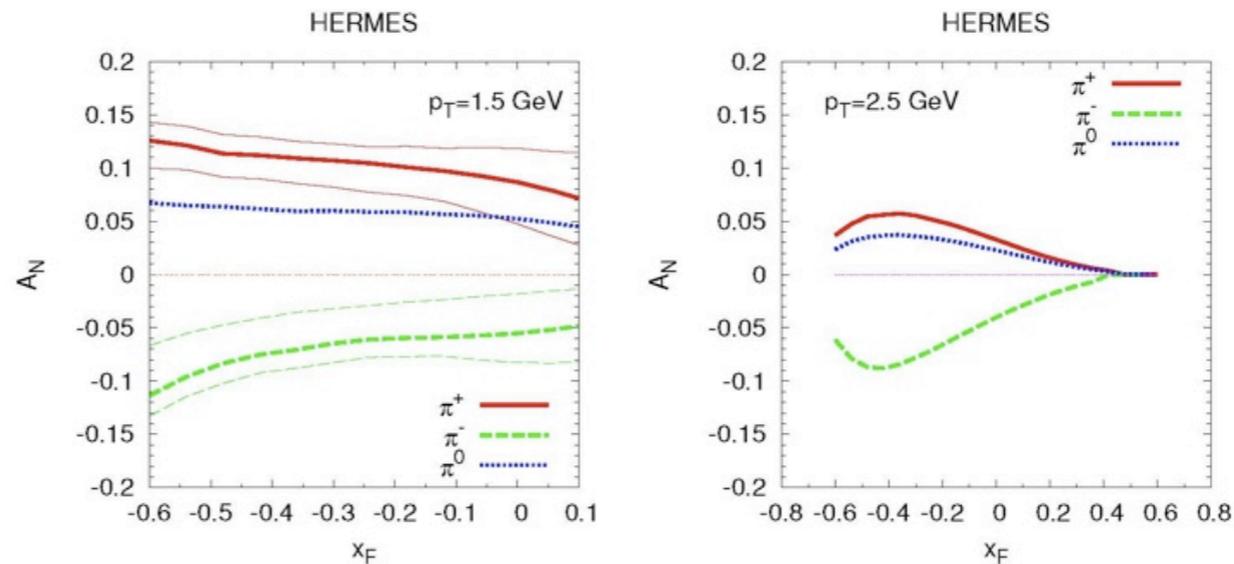
M. Anselmino, M. Boglione, UD, S. Melis, F. Murgia, A. Prokudin

Umberto d'Alesio: phenomenological study SSA $lp \rightarrow \pi + X$ as intermediate step between SIDIS $pp \rightarrow \pi + X$

using Anselmino's group
parameterization.

significant Sivers effect

Madrid, April 26-30, 2009



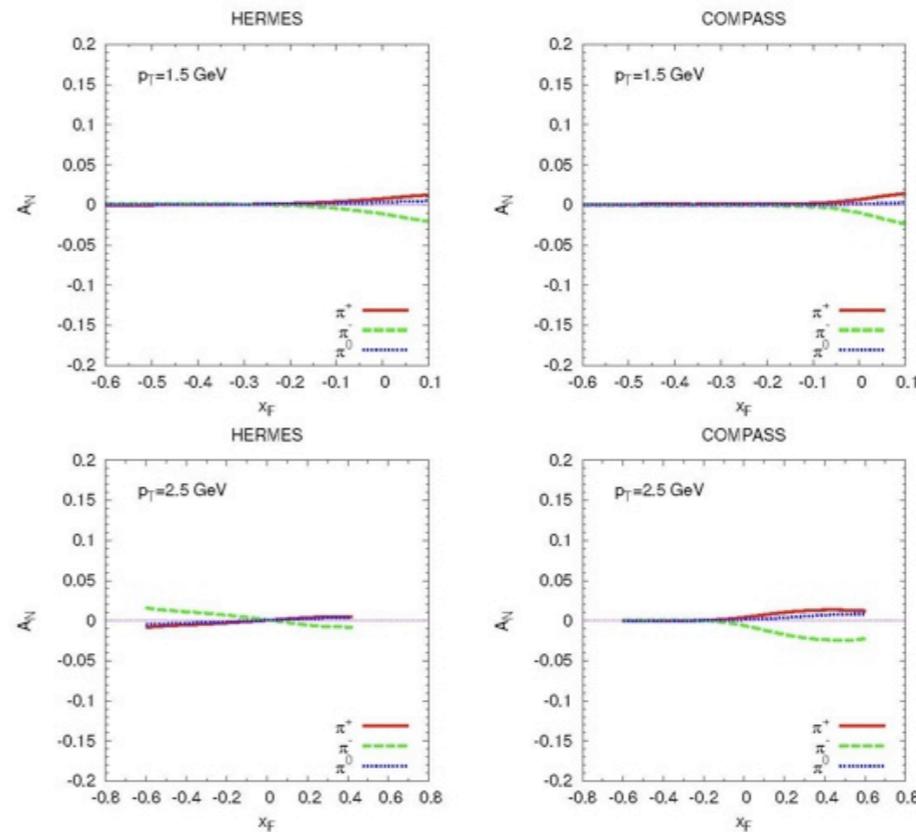
Sivers effect for π production at HERMES; thin curves: uncertainty bands for π^\pm

Umberto d'Alesio: phenomenological study SSA $lp \rightarrow \pi + X$
as intermediate step between SIDIS $pp \rightarrow \pi + X$

using Anselmino's group
parameterization.

significant Sivers effect
negligible Collins effect

Madrid, April 26-30, 2009



Collins effect for π production at HERMES and COMPASS

Mariaelena Boglione: Sivers and Collins effects in $pp \rightarrow \pi + X$

combined description
of SSA in SIDIS and pp

Sivers and Collins effects: from SIDIS to proton-proton scattering

1

MARIAELENA BOGLIONE

Based on work in collaboration with M. Anselmino, U. D'Alesio, S. Melis, F. Murgia, A. Prokudin



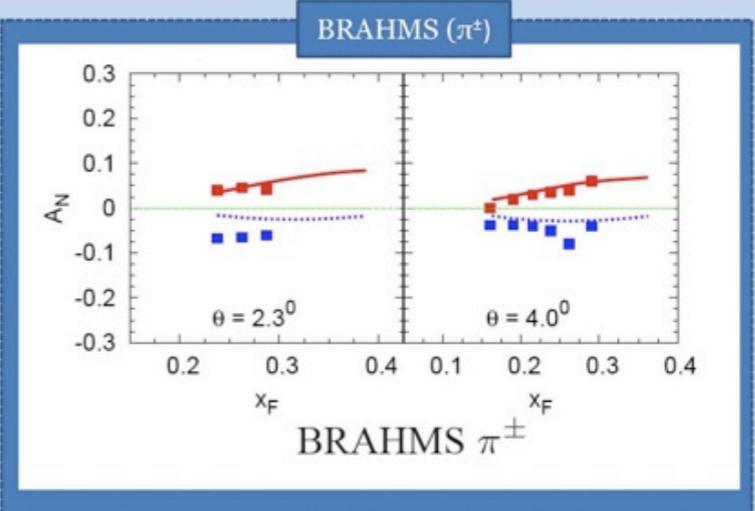
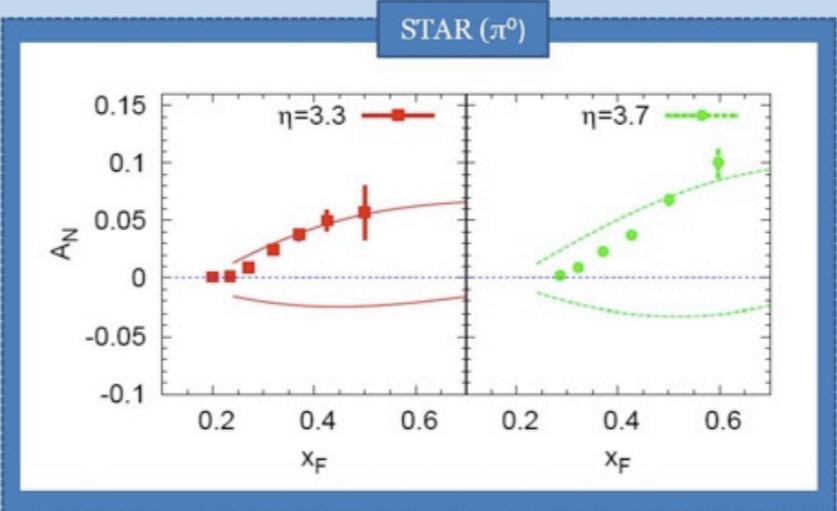
Mariaelena Boglione: Sivers and Collins effects in $pp \rightarrow \pi + X$

combined description
of SSA in SIDIS and pp

From SIDIS to Polarized proton-proton scattering
 β_q parameter scan

13

Sivers effect



Mariaelena Boglione: Sivers and Collins effects in $pp \rightarrow \pi + X$

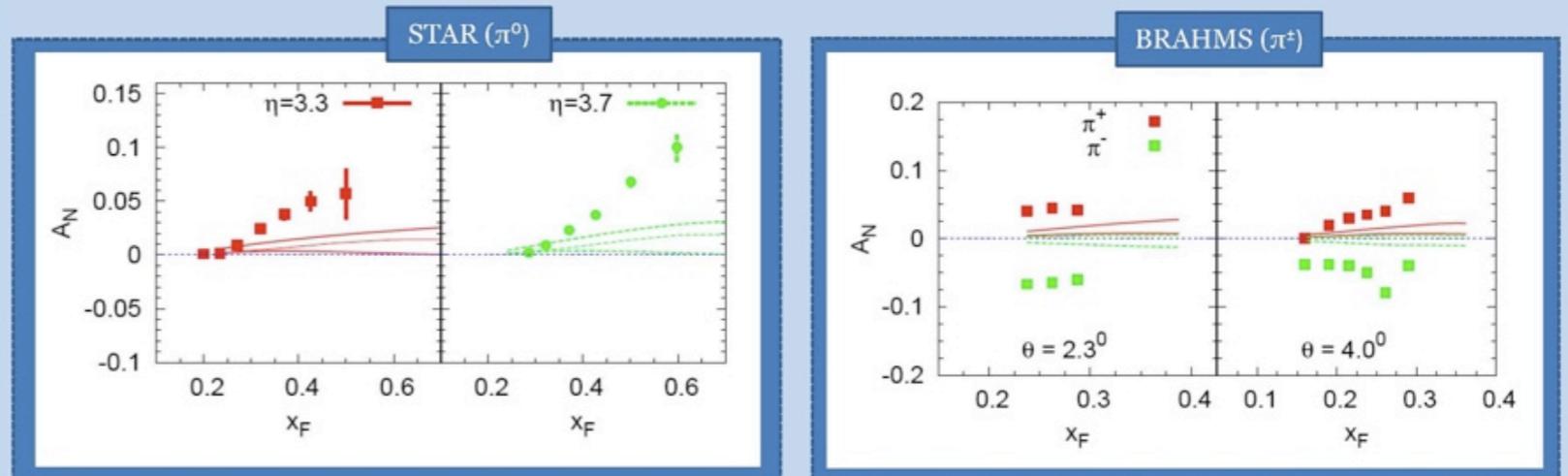
combined description
of SSA in SIDIS and pp

towards a global analysis
in transverse spin

From SIDIS to Polarized proton-proton scattering
 β_q parameter scan

14

Collins effect



NOTE: Issues on detailed evolution of Collins function to be studied further



Daniel Boer: Transverse Λ polarization at LHC

in pp and pPb

test for polarization
mechanisms/models

polarizing FF

saturation region

Transverse Λ polarization at the LHC

Daniël Boer
VU University Amsterdam

Outline

- Brief review of transverse Λ polarization in $p + p \rightarrow \Lambda + X$
- Possible underlying mechanism in the intermediate to high p_T region:
transverse momentum and spin dependence in the fragmentation process
- Other consequences and suggestions for investigations at the LHC:
 - $p + p \rightarrow \Lambda^\uparrow + \text{jet} + X$ at midrapidity
 - $p + Pb \rightarrow \Lambda^\uparrow + X$ in the forward region

Kazuhiro Tanaka:

update of SSA calculations

twist-3 quark-gluon
correlations.

**Theoretical update of twist-3
single-spin asymmetry
in semi-inclusive DIS**

Kazuhiro Tanaka (Juntendo U)

with Y. Koike (Niigata U)

Kazuhiro Tanaka:

update of SSA calculations

twist-3 quark-gluon correlations.

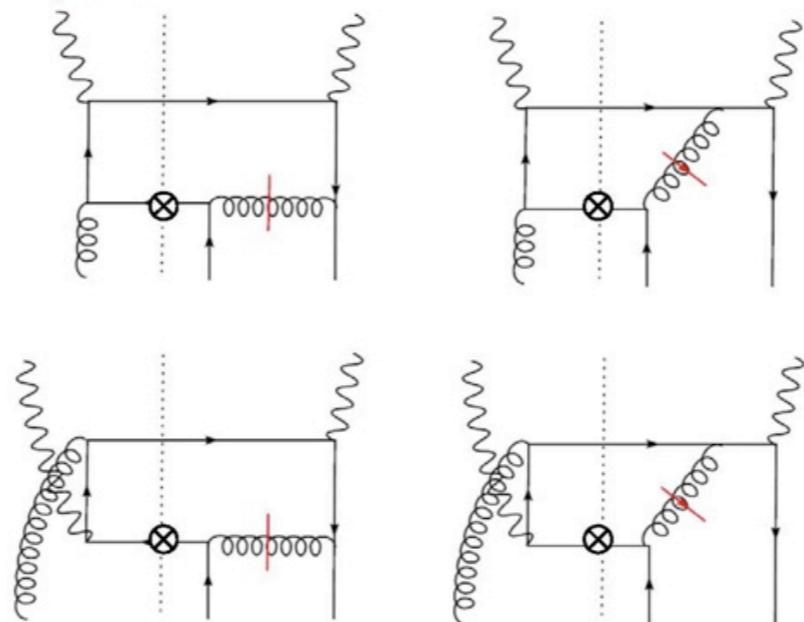
contributions without counterpart in TMD approach.

new partonic subprocesses for SFP

$$d\sigma^{\text{tw}3} \sim \epsilon^{\alpha p n S_{\perp}} \int dx_1 dx_2 dz \text{Tr} \left[\frac{\partial S_{\sigma}(k_1, k_2) p^{\sigma}}{\partial k_{2\perp}^{\alpha}} \Big|_{k_i = x_i p} \not{n} \otimes \overset{(\sim)}{G}_F(x_1, x_2) \otimes D(z) \right]$$

$G_F(0, x)$ $\tilde{G}_F(0, x)$ SFP

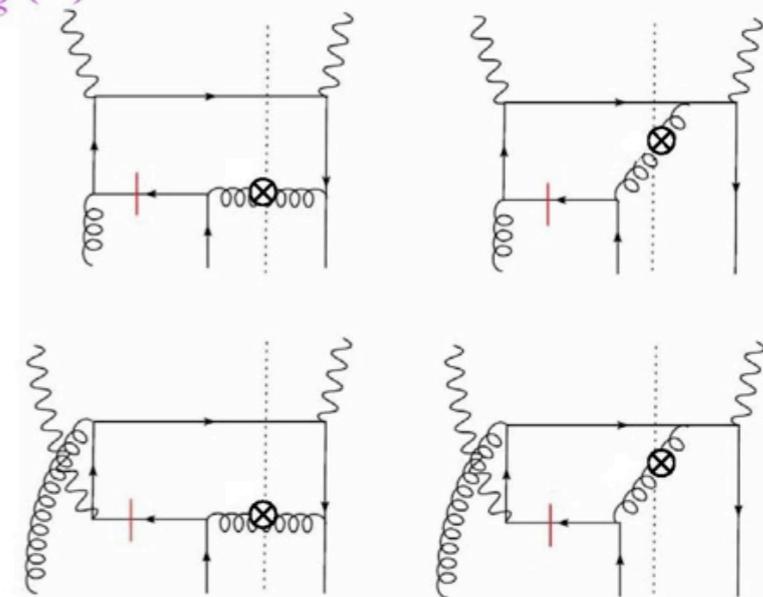
$D_{\bar{q}}(z)$:



+ mirror diagrams

$$\hat{\sigma}_{\text{SFP}}(\bar{q} \rightarrow \pi) = -\hat{\sigma}_{\text{SFP}}(g \rightarrow \pi)$$

$D_g(z)$:



+ mirror diagrams

$$\begin{aligned} & \sin(\phi_h - \phi_S) \left[\sigma_1^{\text{tw}3} + \sigma_2^{\text{tw}3} \cos(\phi_h) + \sigma_3^{\text{tw}3} \cos(2\phi_h) \right] \\ & + \cos(\phi_h - \phi_S) \left[\sigma_4^{\text{tw}3} \sin(\phi_h) + \sigma_5^{\text{tw}3} \sin(2\phi_h) \right] \end{aligned}$$

2- and 3-Loop Heavy Flavor Corrections to Transversity

J. Blümlein, S.Klein, B. Tödli

- **Transversity** also receives **heavy flavor** corrections. In high luminosity measurements of **SIDIS** one may even try to select just this sub-sample.
- These corrections are described by the **Wilson Coefficients** of the respective processes, which factorize at $Q^2 \gg m^2$ into **heavy quark operator matrix elements (OMEs)** and the light flavor Wilson coefficients.
- The OMEs, which are universal quantities, were calculated to $O(\alpha_s^2)$ completely, and to $O(\alpha_s^3)$ for the fixed Mellin moments $N = 1 \dots 13$.
- \Rightarrow also obtain the $\propto T_f$ part of the **3-loop anomalous dimension** confirming and extending earlier results in the literature.

Francesco Conti:

spectator diquark model for TMDs

comprehensive
picture

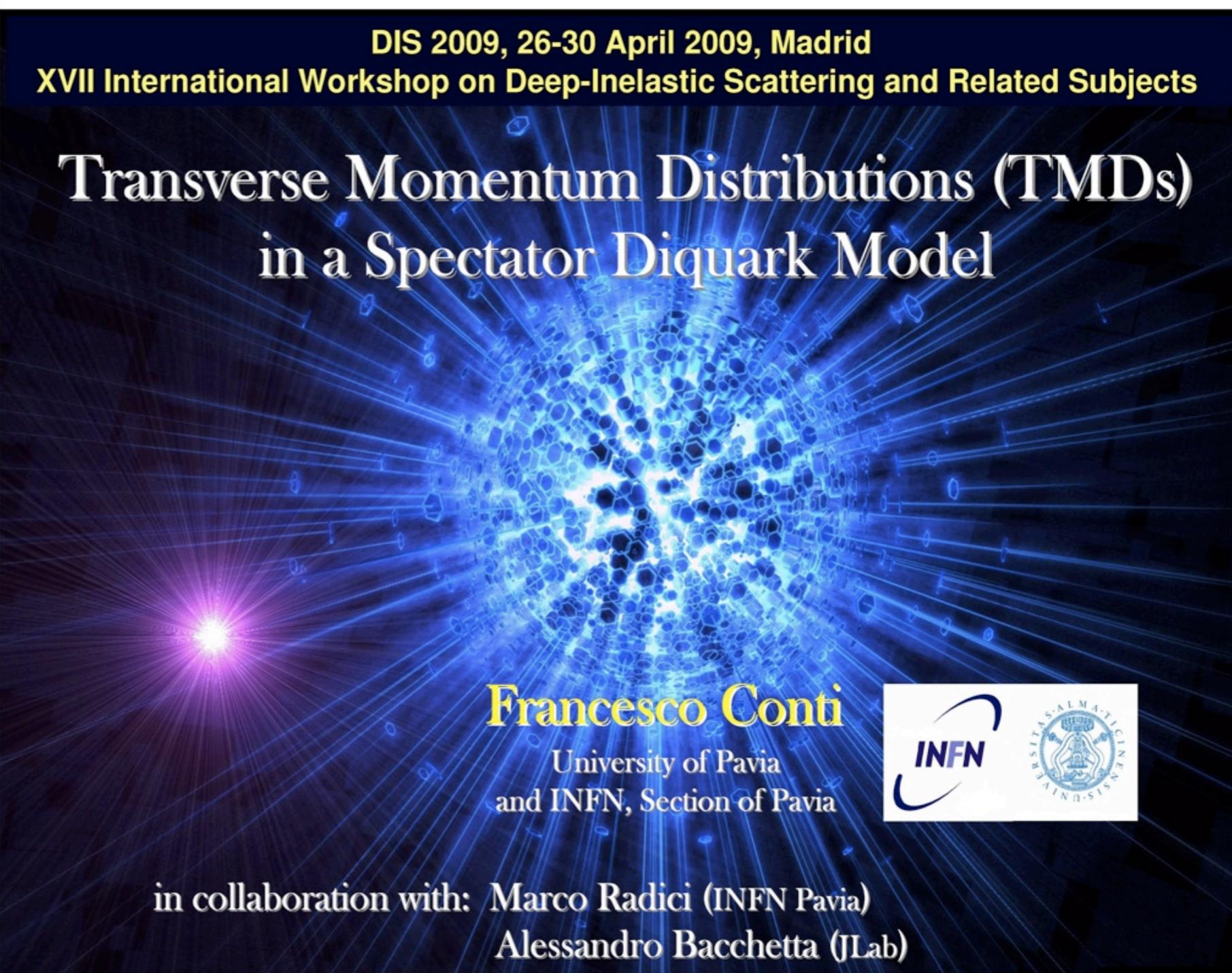
potentialities

DIS 2009, 26-30 April 2009, Madrid
XVII International Workshop on Deep-Inelastic Scattering and Related Subjects

Transverse Momentum Distributions (TMDs)
in a Spectator Diquark Model

Francesco Conti
University of Pavia
and INFN, Section of Pavia

in collaboration with: Marco Radici (INFN Pavia)
Alessandro Bacchetta (JLab)



Francesco Conti: spectator diquark model for TMDs

comprehensive picture

potentialities

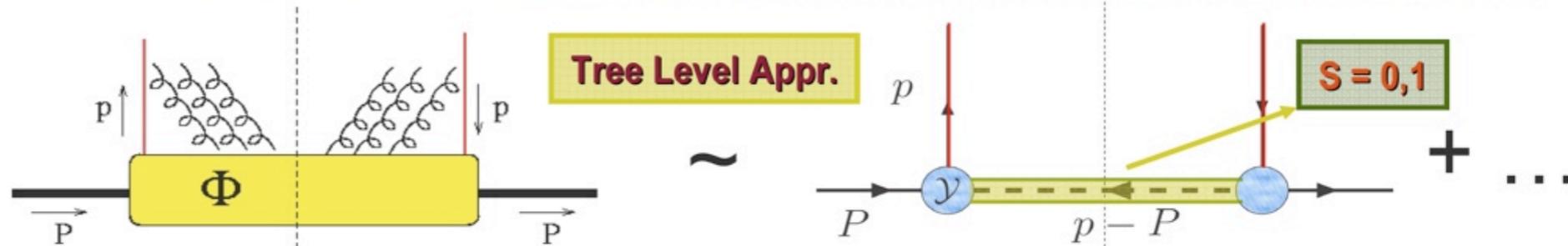
The Spectator Diquark Model

Φ correlator involves matrix elements on **bound hadronic states**, whose partonic content is neither known nor computable in pQCD (low energy region!) \Leftrightarrow **model calculations** required!

SPECTATOR DIQUARK model:

Jakob, Mulders, Rodrigues, N.P. **A626 937 (97)**
 Bacchetta, FC, Radici, **PRD 78 074010 (08)**

- ◆ Replace the sum over intermediate states in Φ with a single state of definite mass (on shell) and coloured.
- ◆ Its quantum numbers are determined by the action of the quark fields on $|P, S\rangle$, so are those of a diquark!



$$\Phi_D(x, \mathbf{p}_T, S) = \frac{1}{(2\pi)^3} \frac{1}{2(1-x)P^+} \bar{\mathcal{M}}_D^{(0)}(S) \mathcal{M}_D^{(0)}(S) \Big|_{p^2 = \tau(x, \mathbf{p}_T^2)} \quad \mathcal{M}_D^{(0)}(S) = \langle p - P | \psi(0) | P, S \rangle$$

$$(p - P)^2 = M_D^2 \longrightarrow p^2 = \tau(x, \mathbf{p}_T^2) = \frac{\mathbf{p}_T^2 + L_D^2(m^2)}{1-x} + m^2$$

$$L_D^2(m^2) = xM_D^2 + (1-x)m^2 - x(1-x)M^2$$

N-q-Dq form factor generally depending on a cutoff parameter Λ_D

Simple, Covariant model: analytic results for ALL leading twist TMDs, mainly 3 parameters.

Generalized Parton Densities

Simonetta Liuti:

GPDs from data

how to combine data
and theoretically
motivated
parameterizations

towards a global analysis

Strategies to extract GPDs from data

Simonetta Liuti

University of Virginia

DIS 2009, 26-30 April 2009

Madrid

Simonetta Liuti:

GPDs from data

how to combine data
and theoretically
motivated
parameterizations

towards a global analysis

Summary of Constraints

Constraints from Form Factors

$$\int_0^1 dX H^q(X, t) = F_1^q(t) \quad \text{Dirac}$$

$$\int_0^1 dX E^q(X, t) = F_2^q(t), \quad \text{Pauli}$$

Constraints from Polynomiality

$$H_n^q(\xi, t) = \sum_{i=0}^{\frac{n-1}{2}} A_{n,2i}^q(t) \xi^{2i} + \text{mod}(n, 2) \xi^n C$$

$$E_n^q(\zeta, t) = \sum_{i=0}^{\frac{n-1}{2}} B_{n,2i}^q(t) \xi^{2i} - \text{mod}(n, 2) \xi^n C$$

Constraints from PDFs

$$q(x) = H_q(x, 0, 0)$$

Further Theoretical Constraints:

Sensible prediction for hadron shape at $x \rightarrow 1$

Sensible prediction for k_T dependence (connection with TMDs!

(SI and Tone in 2004)

Simonetta Liuti:

neutral pion electroproduction

What π^0 electroproduction really measures

Simonetta Liuti
University of Virginia
DIS 2009, 26-30 April 2009
Madrid

Simonetta Liuti:

neutral pion electroproduction

extraction of
tensor charge
Burkardt's moments

What goes into the quark-hadron amplitudes?

$$\mathcal{F}(\zeta, t) = -i\pi \sum_q e_q^2 [F^q(\zeta, \zeta, t) - F^q(-\zeta, \zeta, t)] + \mathcal{P} \int_{1-\zeta}^1 dX \left(\frac{1}{X-\zeta} + \frac{1}{X} \right) F^q(X, \zeta, t).$$

Generalized Form Factors

$\mathcal{H}_T, \mathcal{E}_T, \tilde{\mathcal{H}}_T, \tilde{\mathcal{E}}_T$

$$H_T(X, 0, 0) = h_1(X) = \text{transversity}$$

$$\int h_1(X, Q^2) dX = \delta q = \text{tensor charge}$$

$$\tilde{\mathcal{E}}_2 = 2\tilde{\mathcal{H}}_T + \mathcal{E}_T$$

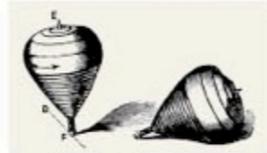
Boer-Mulders \Rightarrow

$$\int E_2(X, 0, 0) dX = \kappa_T = \text{Burkardt's moment}$$

$$\int h_1^\perp(X, k_T) dX \sim -\kappa_T \quad (\text{M. Burkardt, A.M.})$$

Gary Goldstein:

Dispersion relations for GPD



**Limitations on Dispersion Relations
for
Generalized Parton Distributions**

Gary R. Goldstein

Tufts University

Simonetta Liuti

University of Virginia

Presentation for

DIS 2009

Madrid, Spain

April, 2009

many interesting
and subtle points



Lessons from examples

- Moderate reach of E_γ ($J_{lab} < 12$ GeV)
or $s < 25$ GeV² = (5 GeV)² not far from t -dependent thresholds
- Non-forward dispersion relations require some model-dependent analytic continuation
- Difference between direct & dispersion Real $H(\zeta, t)$ depends on thresholds – is subtraction “constant” really constant?
- Antiquark distributions are critical for crossing symmetric amplitudes & GPDs
- DVCS & Bethe-Heitler interference measures complex $H(\zeta, t)$ directly – Direct Real from data complements DR constraints & necessitates determination of ERBL GPD region away from ridge $x = \xi$.

Asmita Mukherjee:

chiral even & chiral odd GPDs

relativistic two body
model inspired in
field theory

*Chiral-odd and Chiral-even Generalized Parton Distributions in Transverse
and Longitudinal Position Space*

Asmita Mukherjee

Indian Institute of Technology, Mumbai, India

- Chiral Odd GPDs : Why they are interesting
- Overlap representation of Chiral-odd GPDs
- Simple example : electron at one loop
- GPDs in position space
- Phenomenological study

DIS 09; Madrid, April 2009

In collaboration with D. Chakrabarti (IIT Kanpur), R. Manohar (IIT Bombay)

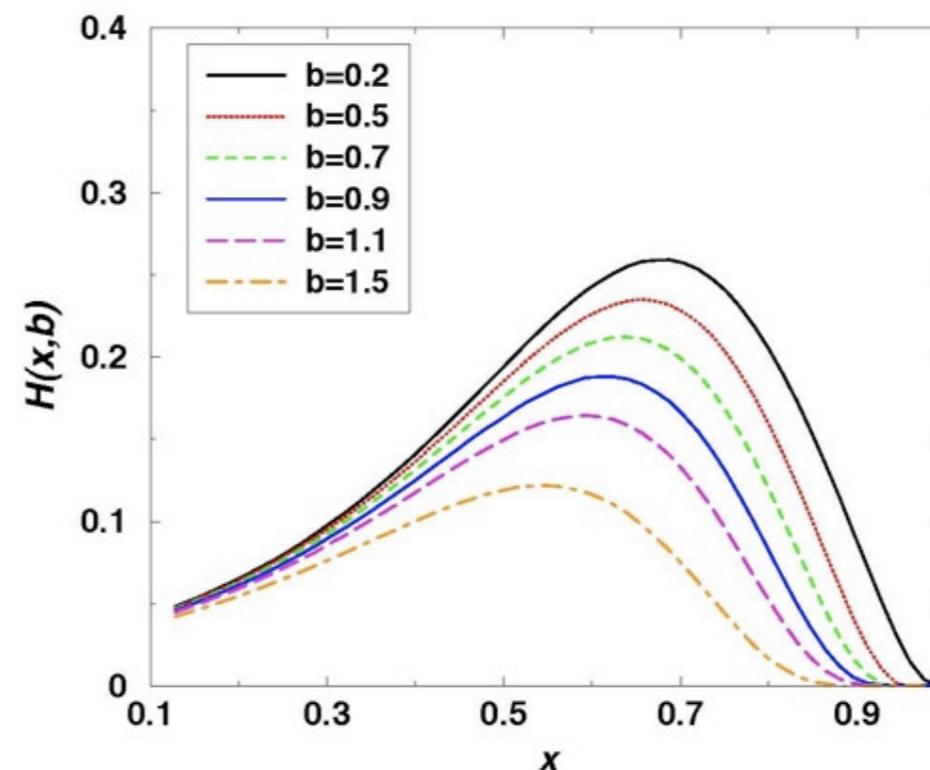
Asmita Mukherjee:

chiral even & chiral odd GPDs

relativistic two body
model inspired in
field theory

GPD parameterization
in position space

GPD model in position space



- Used parametrization of

Ahmad, Honkanen, Liuti, Taneja (2007)

- We have used parametrizations set I (u quark) at scale 0.09 GeV^2

Summary (Experimental Talks)

Outlook:

More than 20 years of sustained efforts to measure and extract p PDFs have matured significantly.

We have a clear and consistent picture of the quark/gluon helicity in the region covered by experiments.

Our knowledge on transverse polarization is evolving fast.