Update on the phenomenology of collinear Dihadron FFs

DIS 2015

Aurore Courtoy

IFPA-Université de Liège (Belgium)
DCI-Universidad de Guanajuato (Mexico)

in collaboration with A. Bacchetta, M Radici and M. Guagnelli in Pavia

Extraction of Transversity

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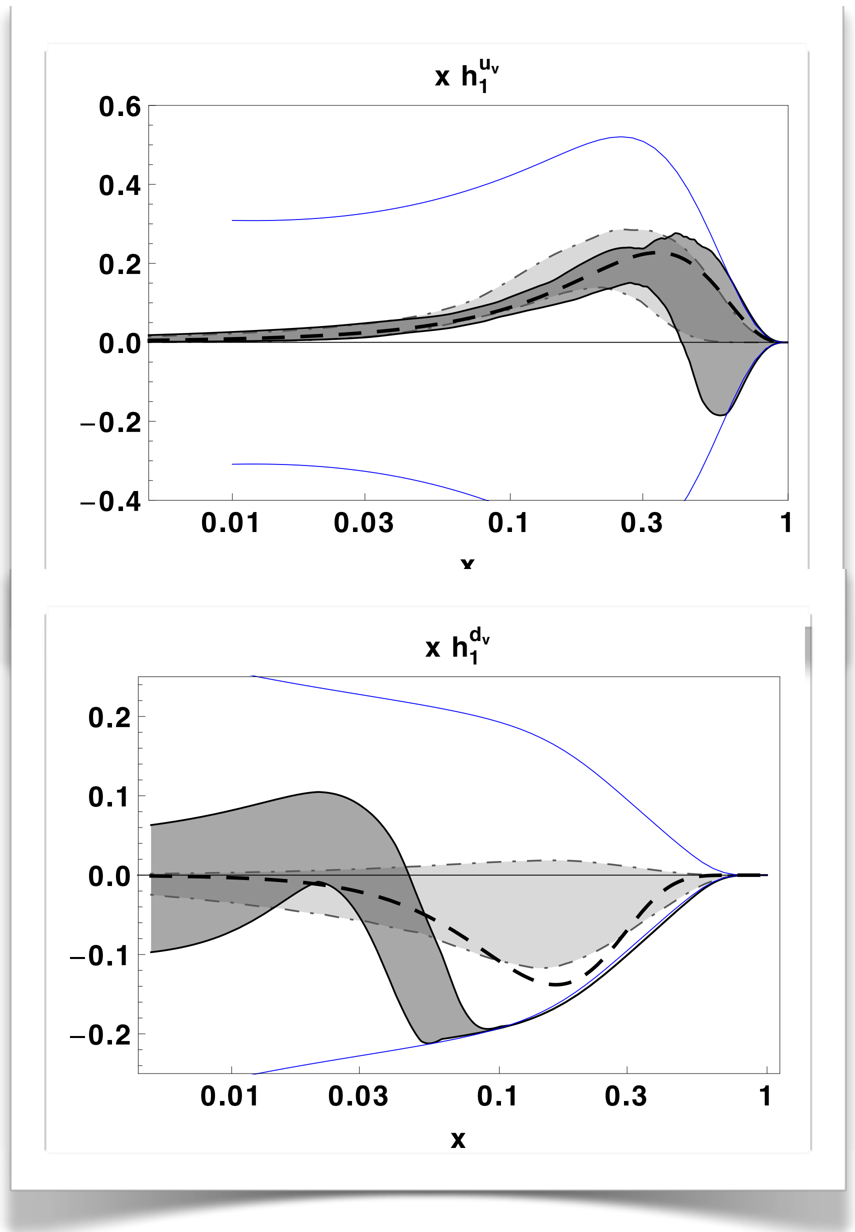
State-of-the-art:
Extractions of transversity

- **TMD extraction** [Anselmino et al, Kang et al]
- **Collinear extraction** [Pavia]
- **GPD extraction** [Goldstein et al]



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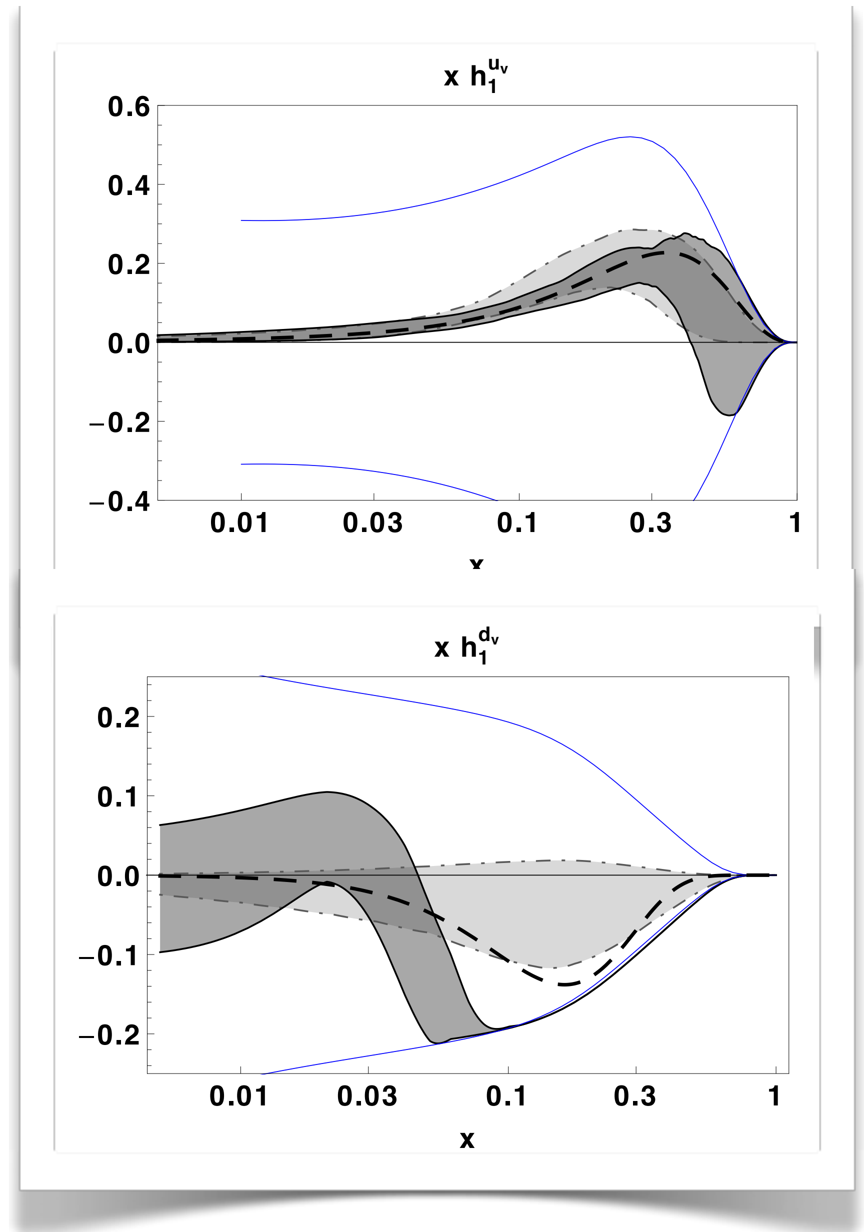
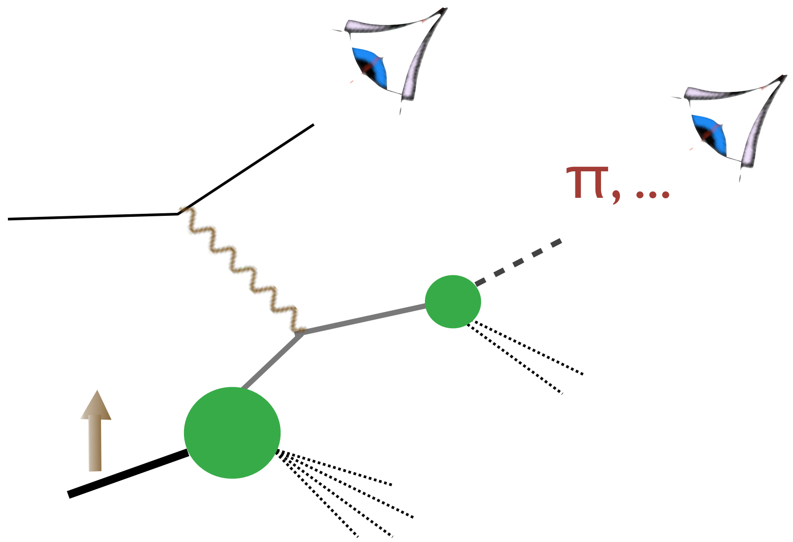
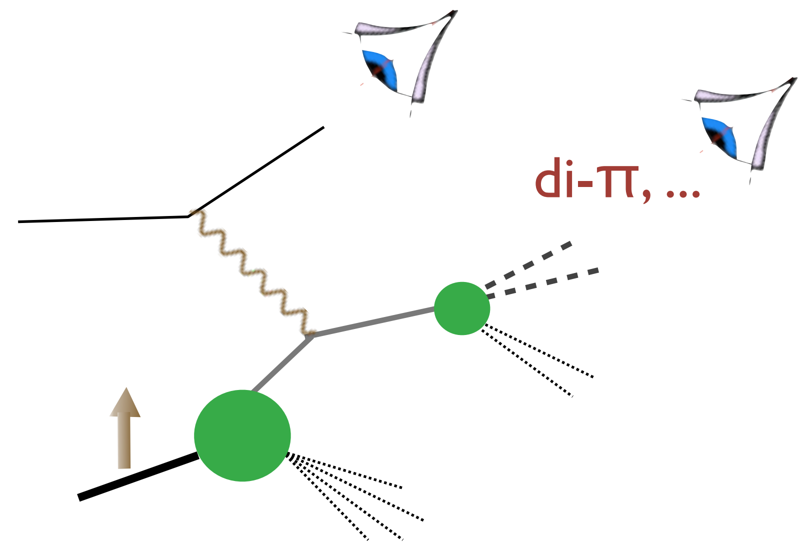


Pavia 15
1503.03495
Submitted to JHEP

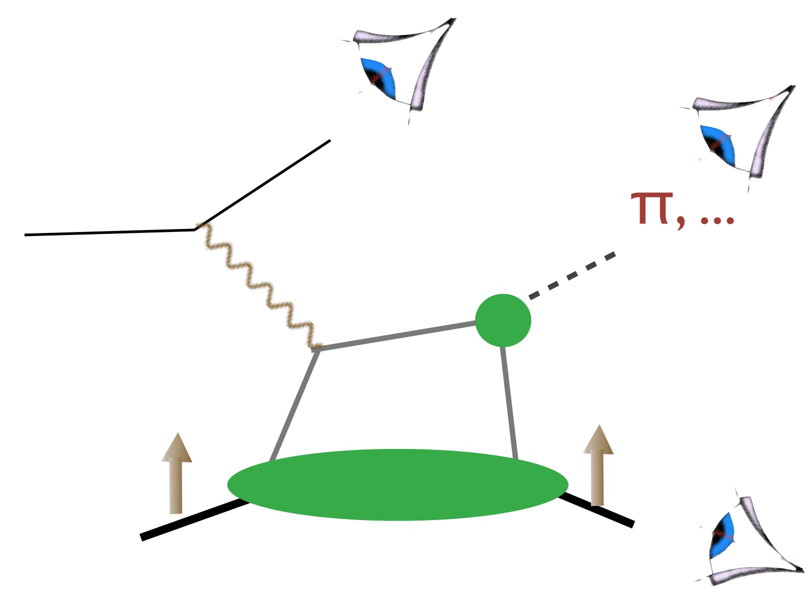
Processes





Semi-inclusive processes

$\sigma \rightarrow$ PDF×dσ×Fragmentation Function

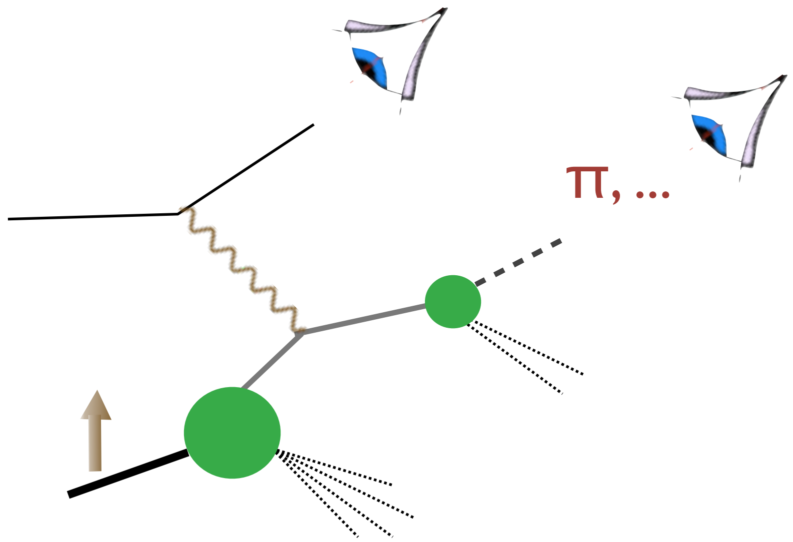


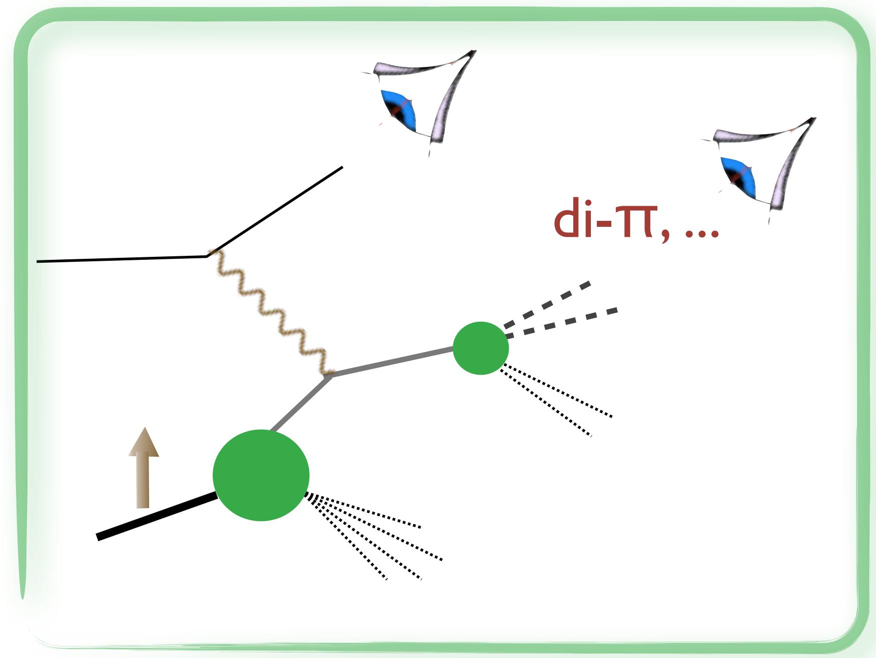
Exclusive processes

$\sigma \rightarrow$ Generalized PDF×dσ× Meson Amplitude

hermes COMPASS Jefferson Lab

Processes





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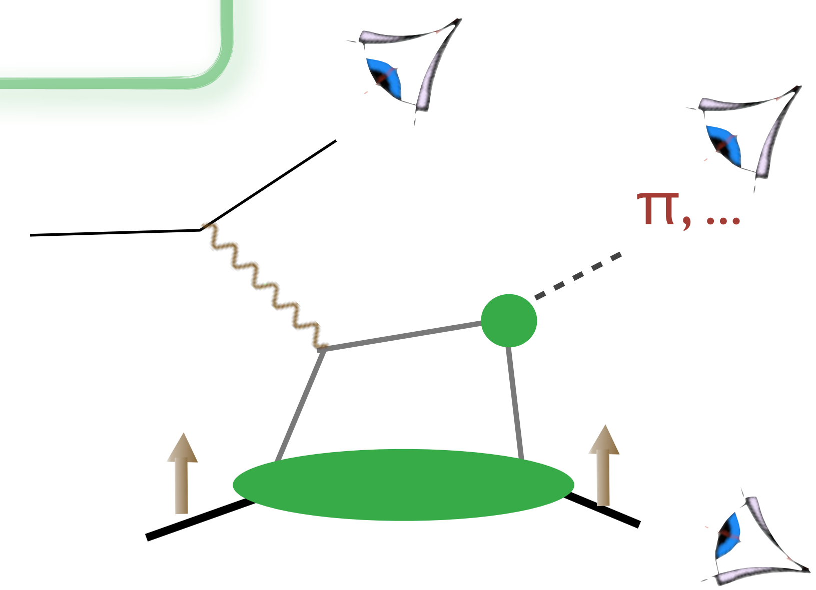


Exclusive processes

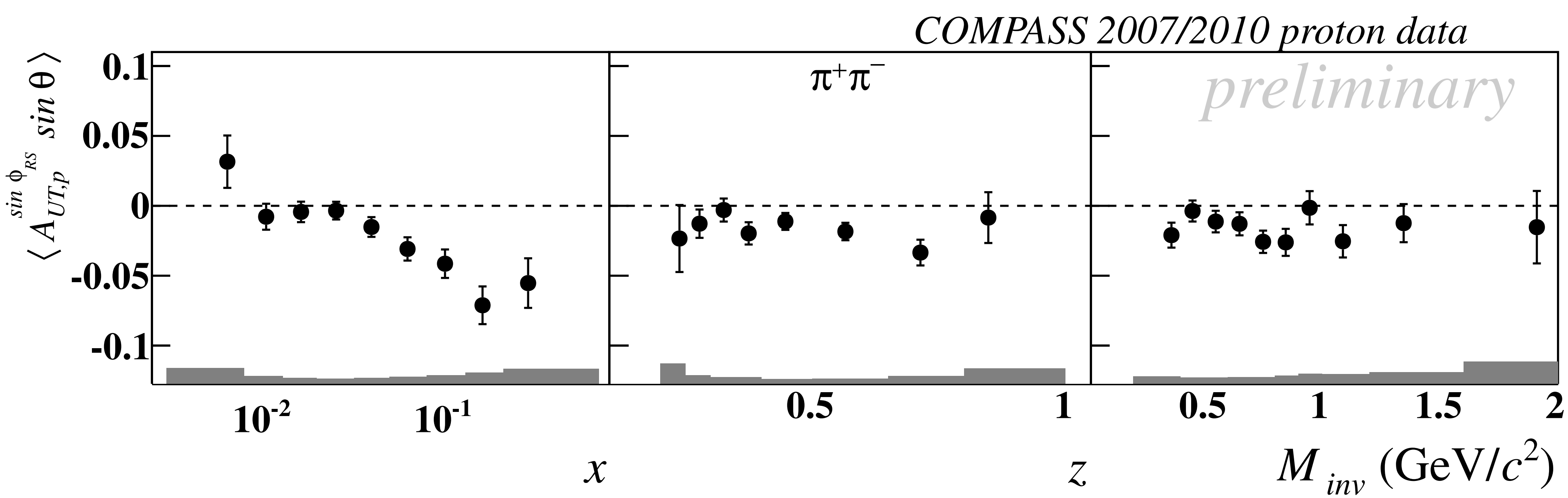
σ→ Generalized PDF×dσ× Meson Amplitude

➡ COMPASS data for identified pions

➡ Two Values for $\alpha_S(M_Z^2)$

➡ Replica methods for both pol. DiFF & transversity

Pavia Fit:
What's new?

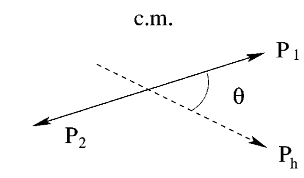


+ COMPASS 2003/2004 deuteron data

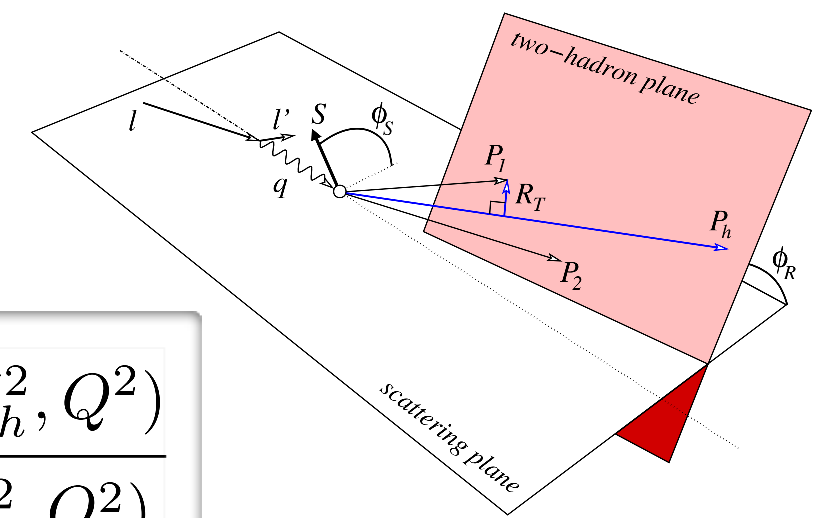
C. Braun

EPJ Web Conf. 85 (2015)

Pavia fitter: 2 steps' approach



SIDIS production of pion pairs



$$A_{\mathrm{DIS}}(x,z,M_h^2,Q^2) = -C_y \, \frac{\sum_q e_q^2 \, h_1^q(x,Q^2) \, \frac{|\bar{R}|}{M_h} \, H_{1,sp}^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}{\sum_q e_q^2 \, f_1^q(x,Q^2) \qquad D_1^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}$$

[Bacchetta, A.C., Radici, PRL 107 (2011)]

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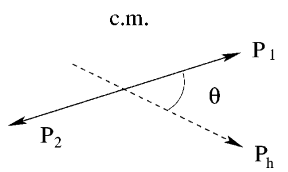

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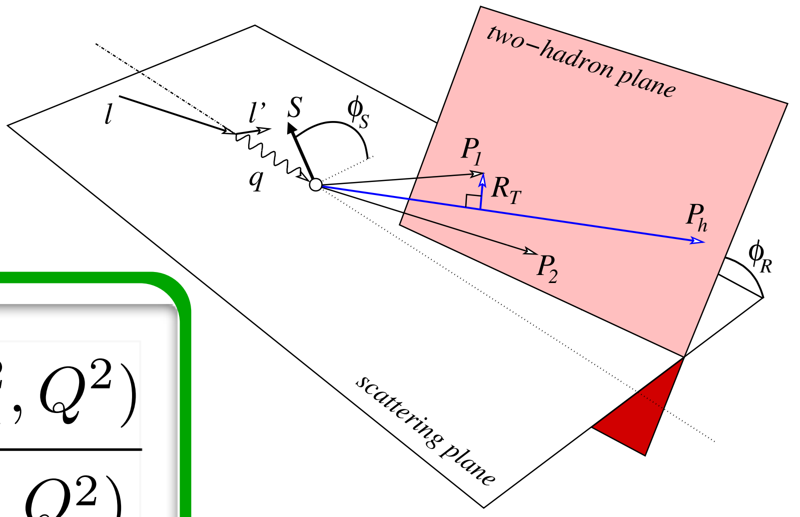

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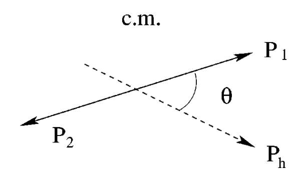
Knowledge on DiFFs leads to $h_1(x, Q^2)$

[Bacchetta, A.C., Radici, PRL 107 (2011)]



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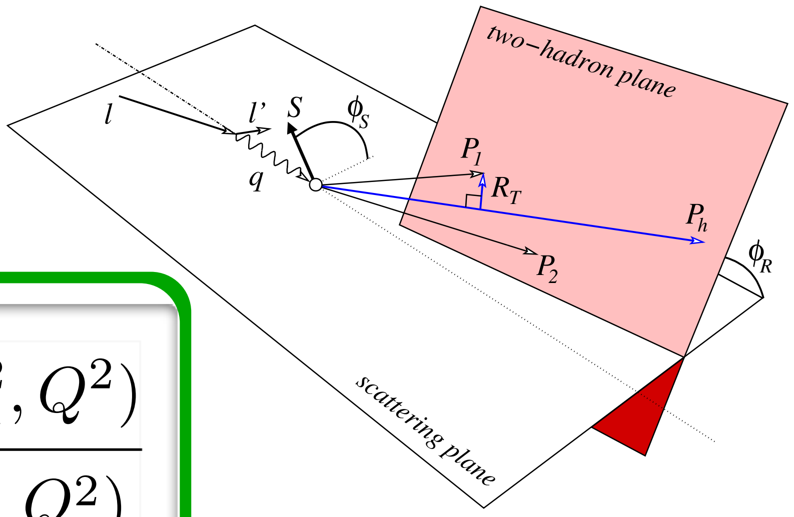

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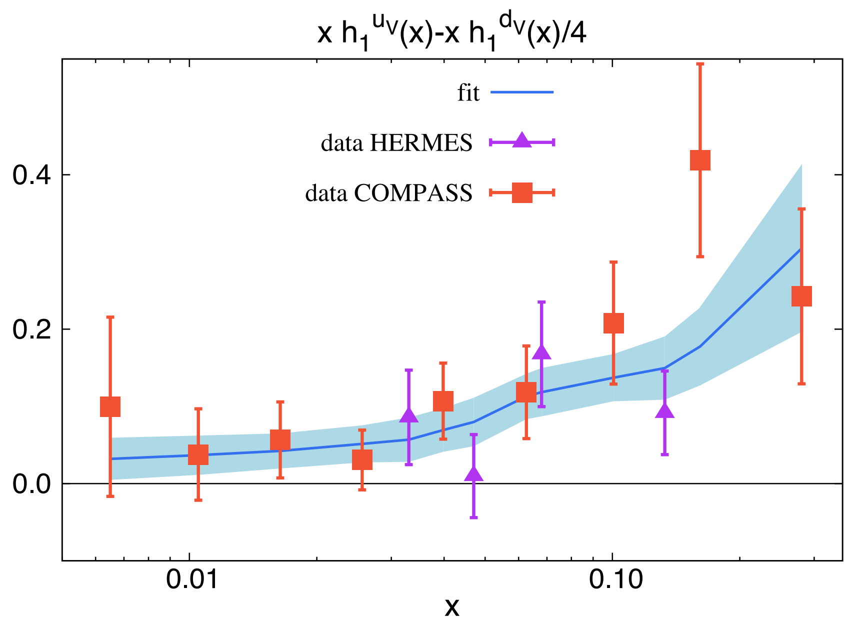
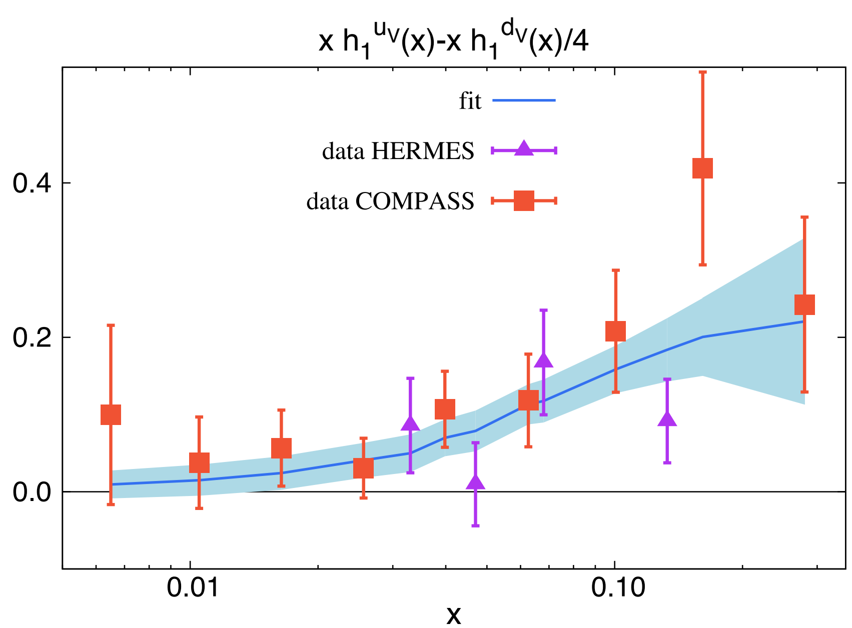
Choose error treatment and functional form

Reminder: Functional Form biases

flexible functional form



rigid functional form



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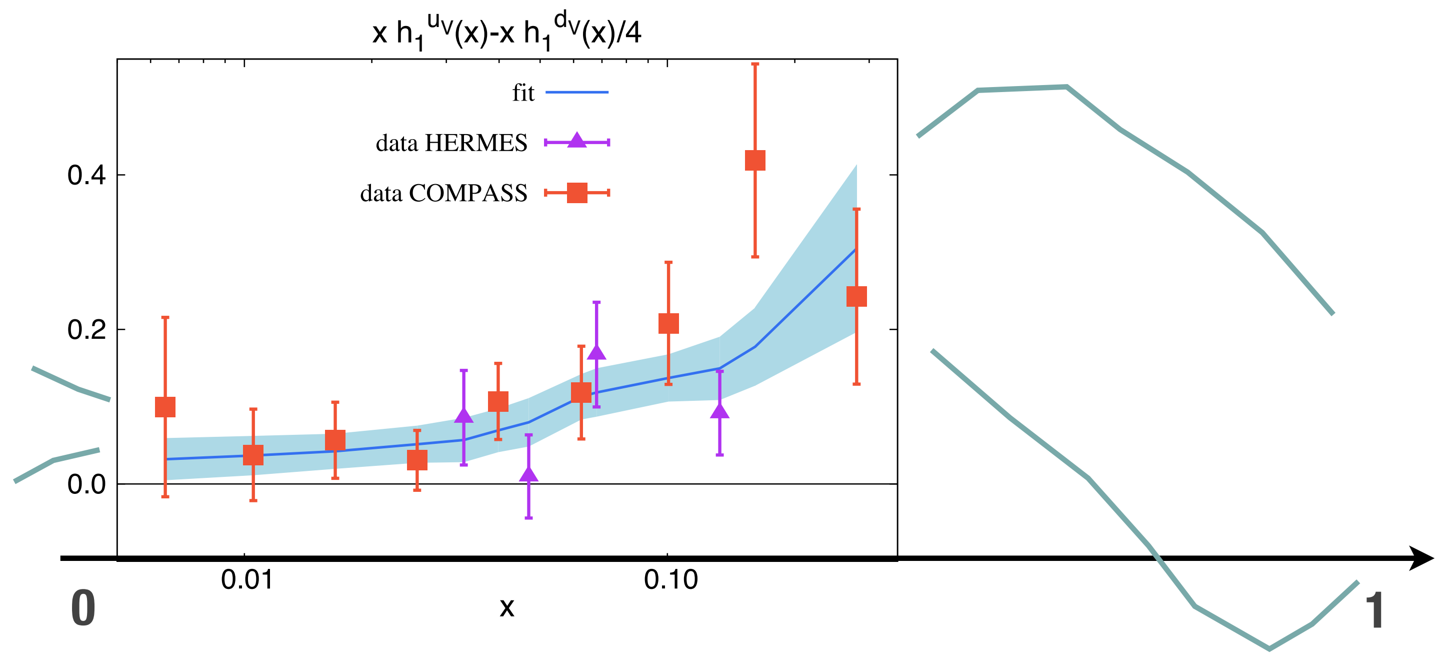

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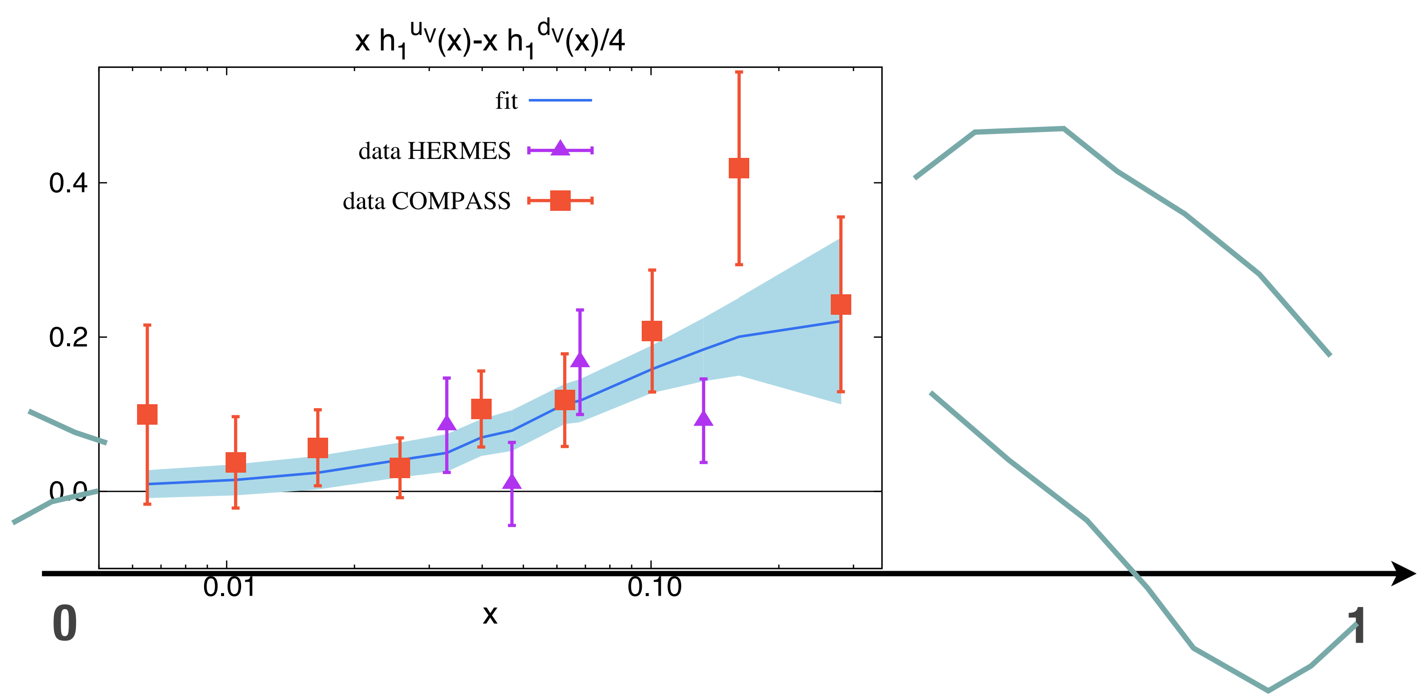

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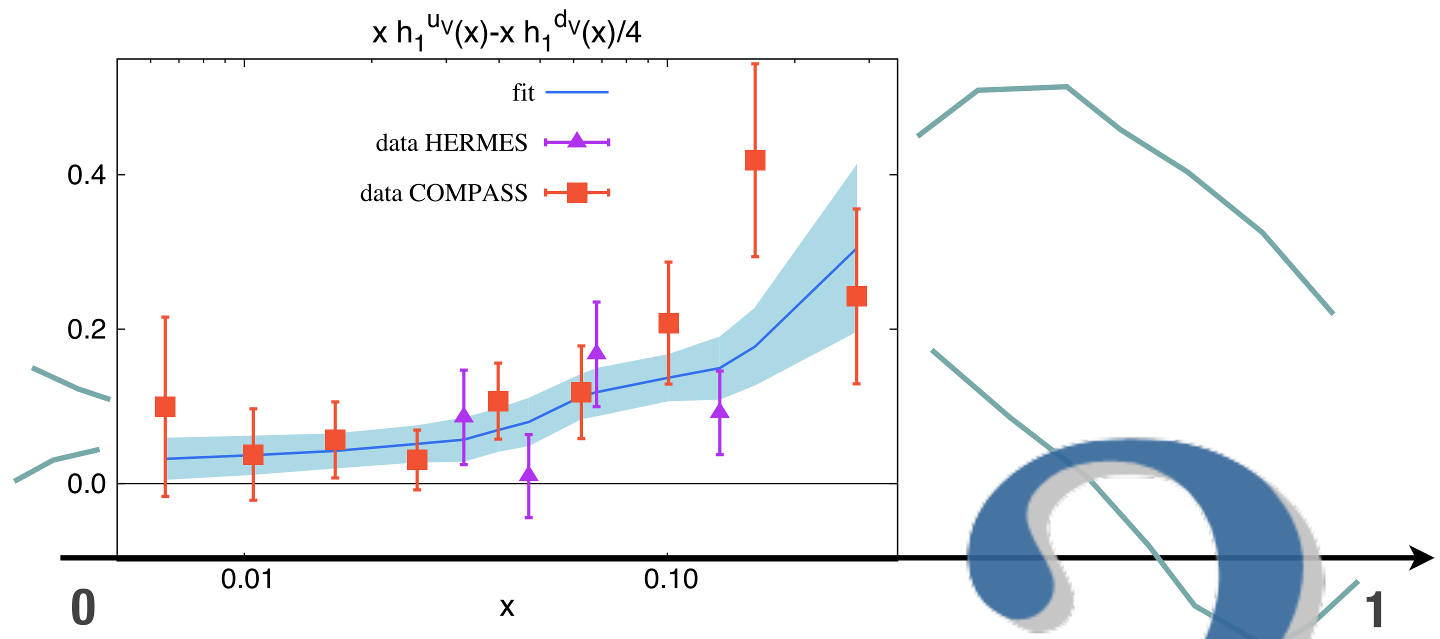

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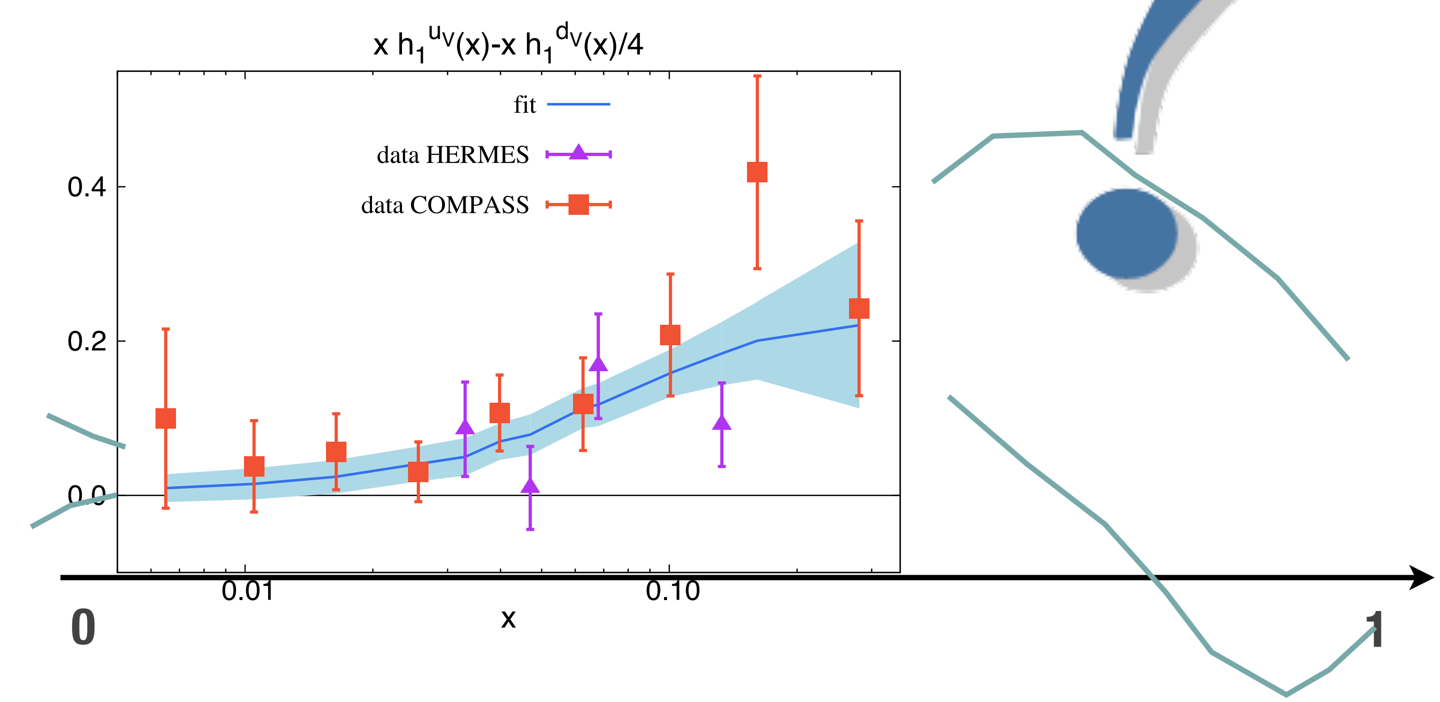

Only constrained by Soffer bound

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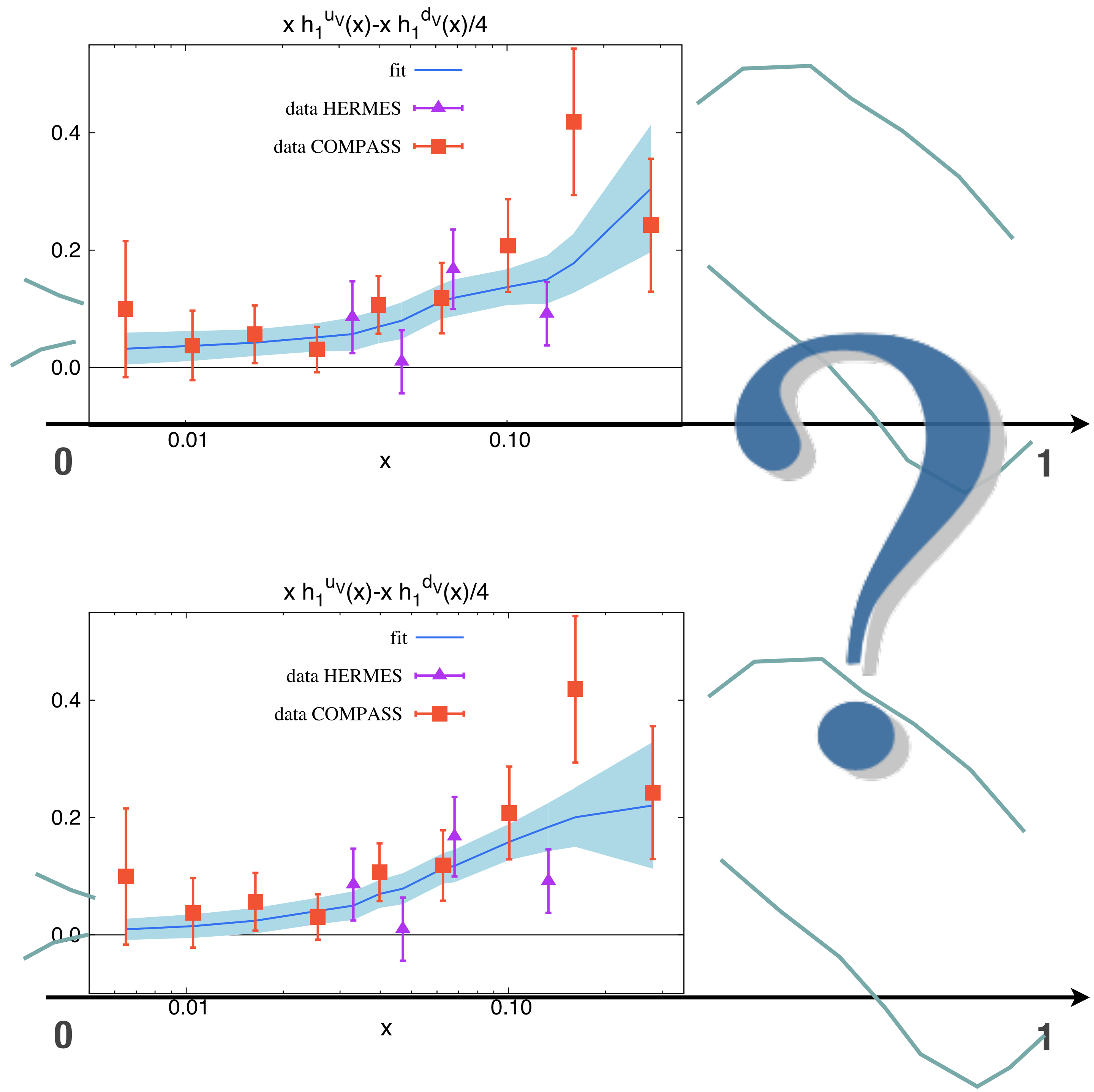
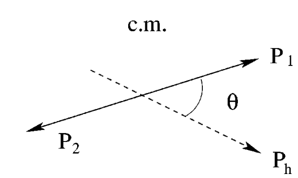
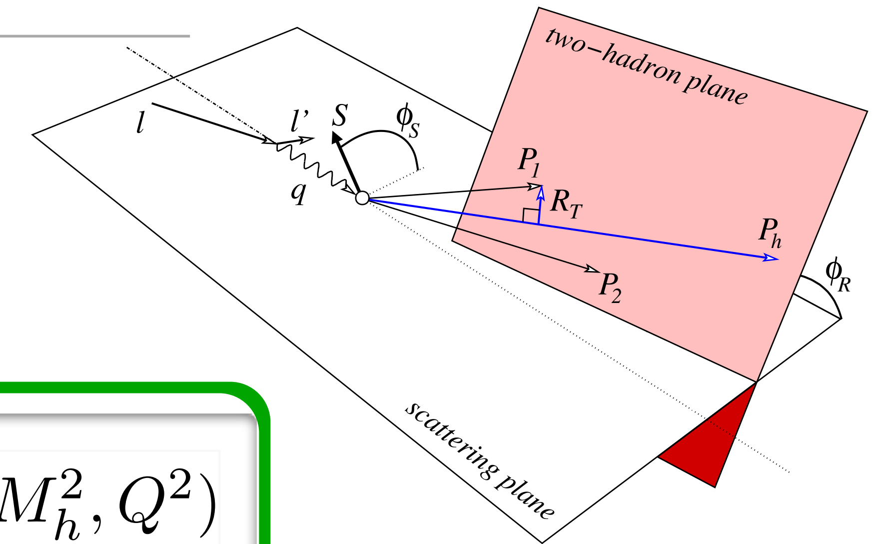


Only constrained by Soffer bound

2013⇒ Replica method to make up for small errors at low- and large-x

Pavia fitter: 2 steps' approach





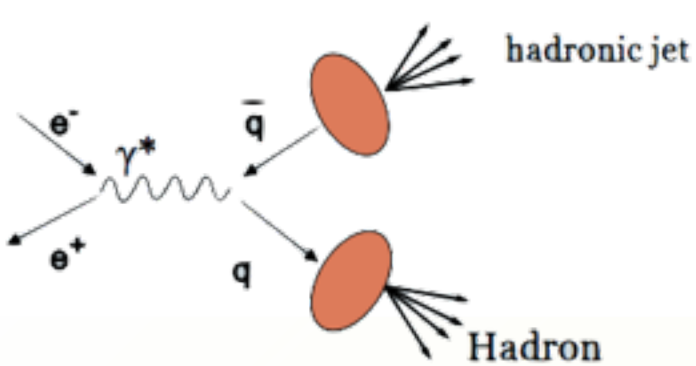
1. SIDIS production of pion pairs

$$A_{\mathrm{DIS}}(x,z,M_h^2,Q^2) = -C_y \frac{\sum_q e_q^2 \boxed{h_1^q(x,Q^2)}}{\sum_q e_q^2\, f_1^q(x,Q^2)} \boxed{\frac{\frac{|\bar{R}|}{M_h}\; H_{1,sp}^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}{D_1^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}}$$

Knowledge on DiFFs leads to h₁(x, Q²)

[Bacchetta, A.C., Radici, PRL 107 (2011)]

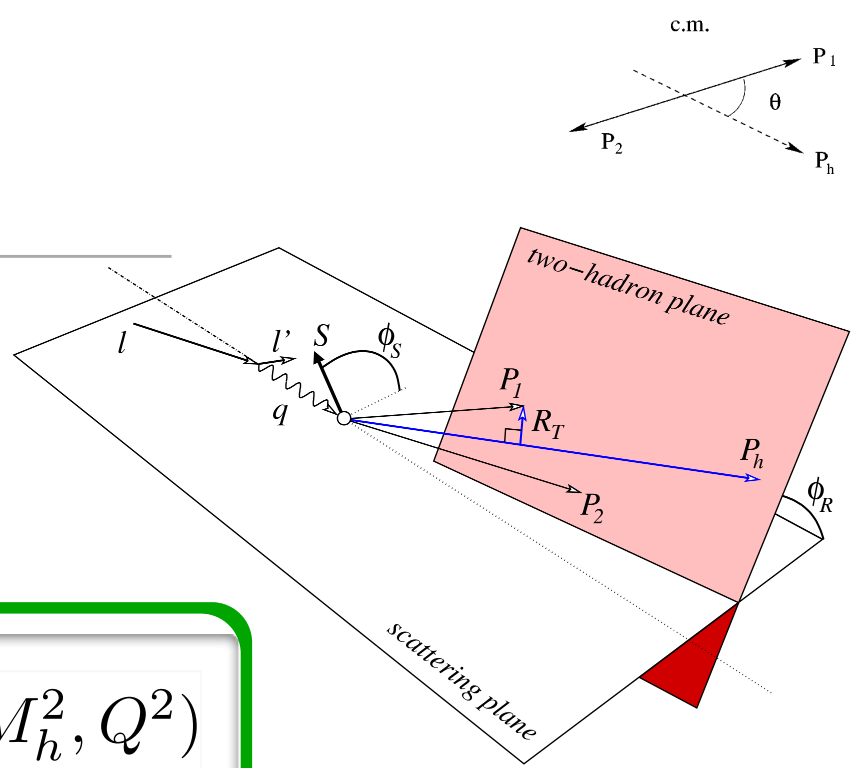
2. SI pion pairs production in e+ e- annihilation @ Belle



$$A_{e^+e^-}(z,M_h^2,\bar{z},\bar{M}_h^2) \propto \boxed{\frac{\sum_q e_q^2 H_{1,\,sp}^{q\to\pi^+\pi^-}(z,M_h^2)\bar{H}_{1,\,sp}^{q\to\pi^+\pi^-}(\bar{z},\bar{M}_h^2)}{\sum_q e_q^2 D_1^{q\to\pi^+\pi^-}(z,M_h^2)\bar{D}_1^{q\to\pi^+\pi^-}(\bar{z},\bar{M}_h^2)}}$$

[A.C., Bacchetta, Radici, Bianconi, Phys.Rev. D85]

Pavia fitter: 2 steps' approach



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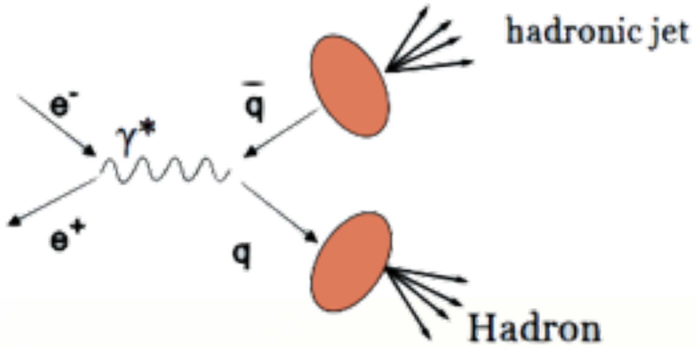
Knowledge on DiFFs leads to $h_1(x, Q^2)$

Now

both h_1 and $H_1^{<}$ with replica method!

2. SI pion pairs production in e+ e- annihilat



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The Replica Approach

Too small errors w.r.t. ABSENCE of data

- generate *n* sets of data with gaussian noise (@1σ) → *n* replicas
- redo the fit *n* times
- keep the 1σ distributed resulting “transversities”, at each data point
- the error band is now made by 68% of the *n* replica point by point

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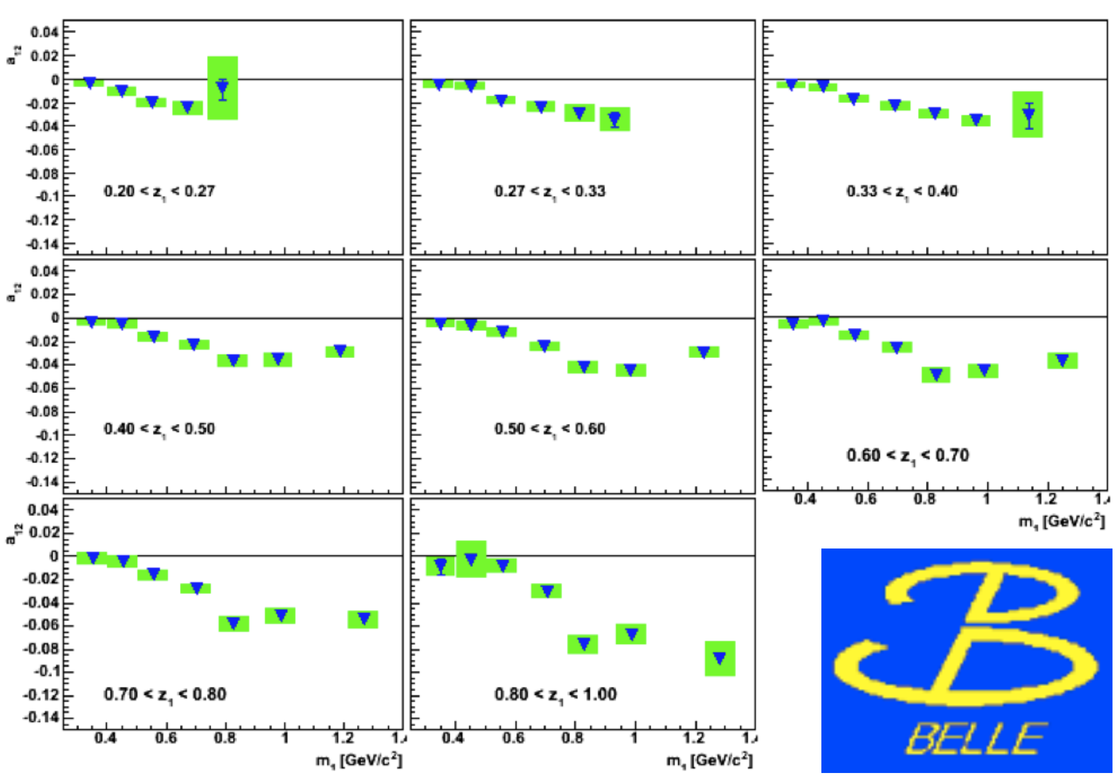

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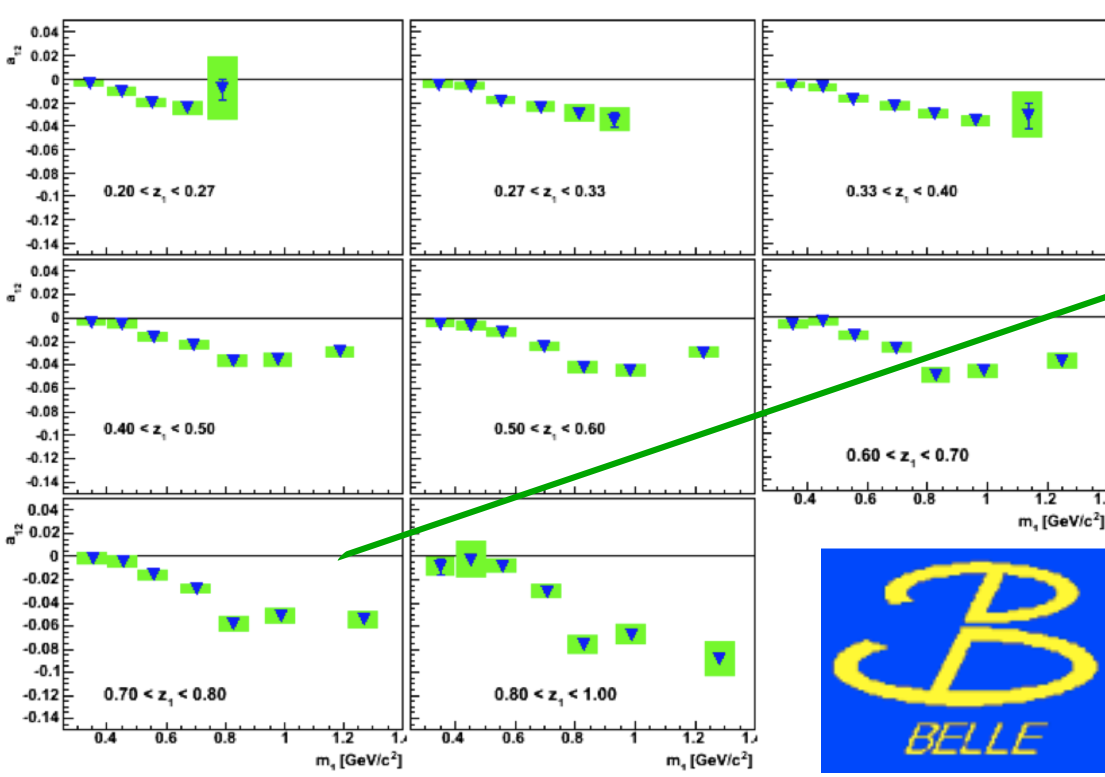
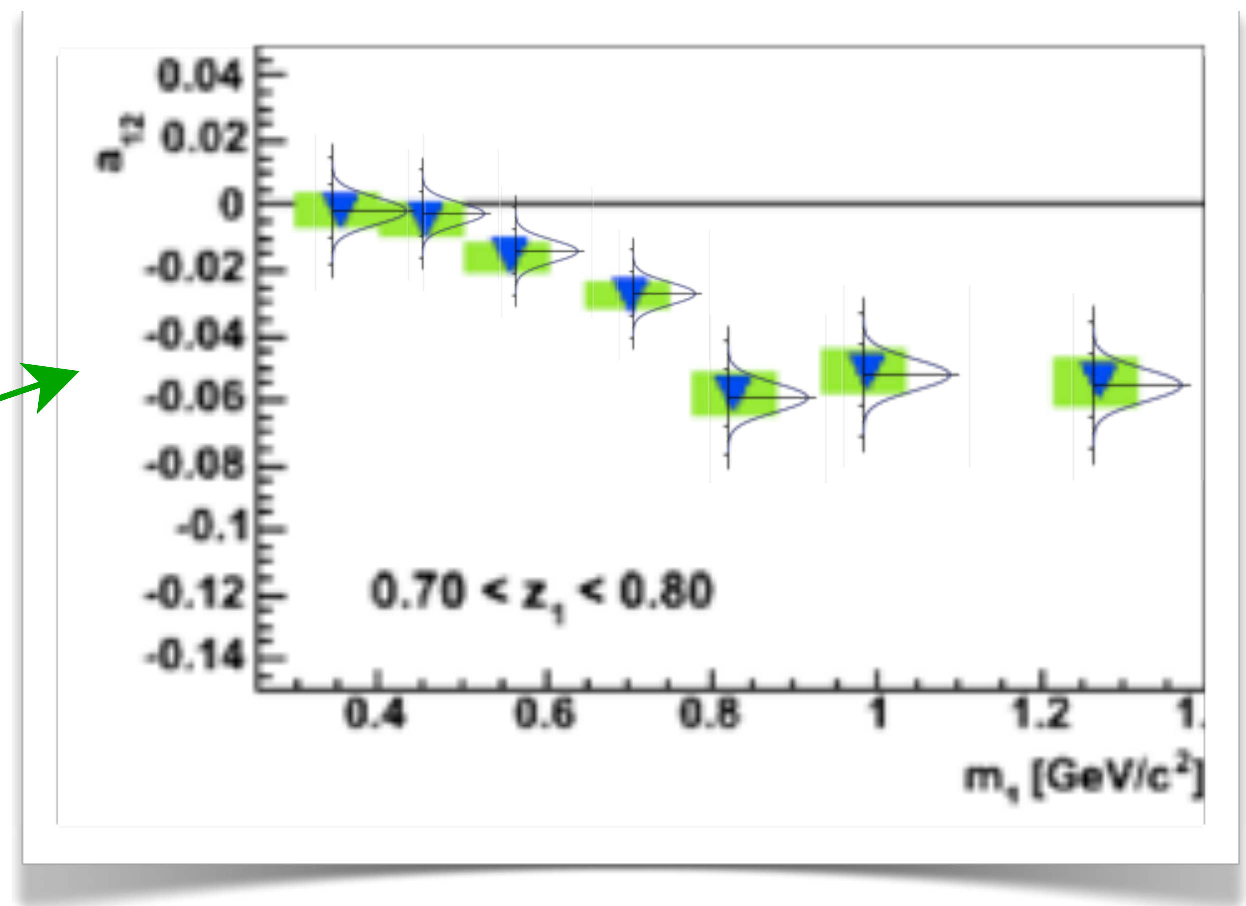
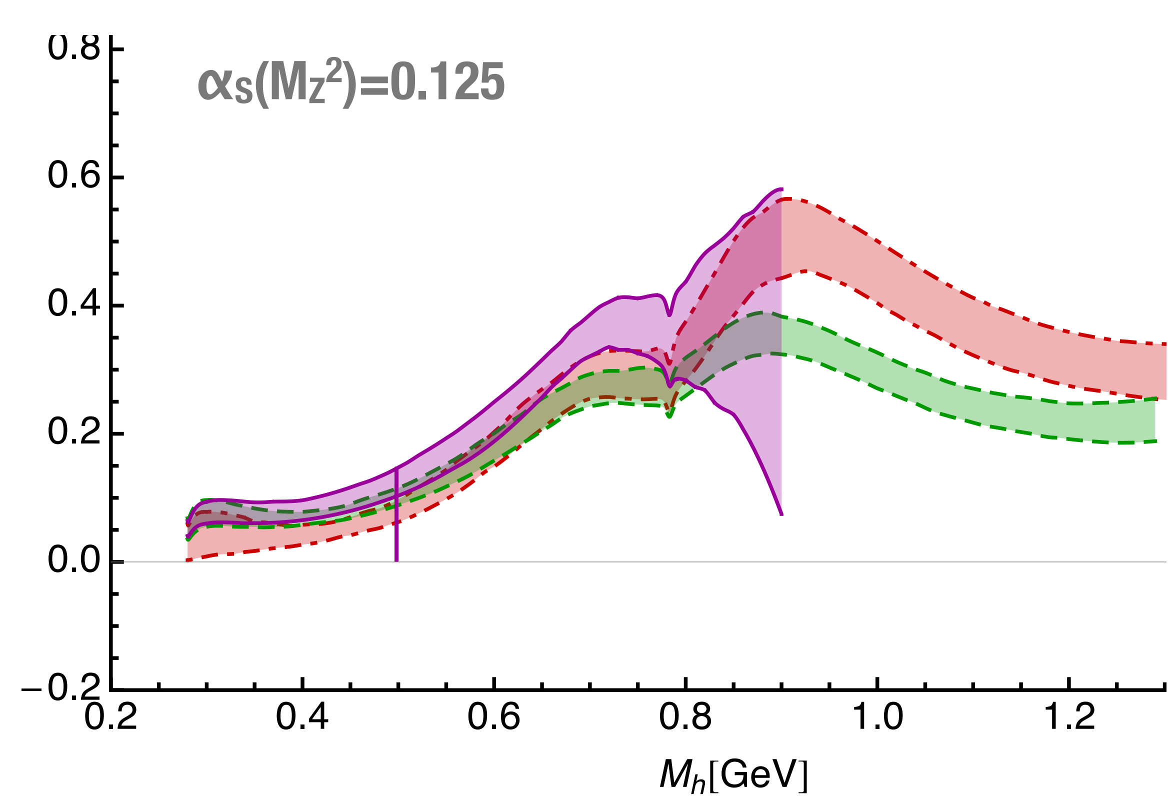
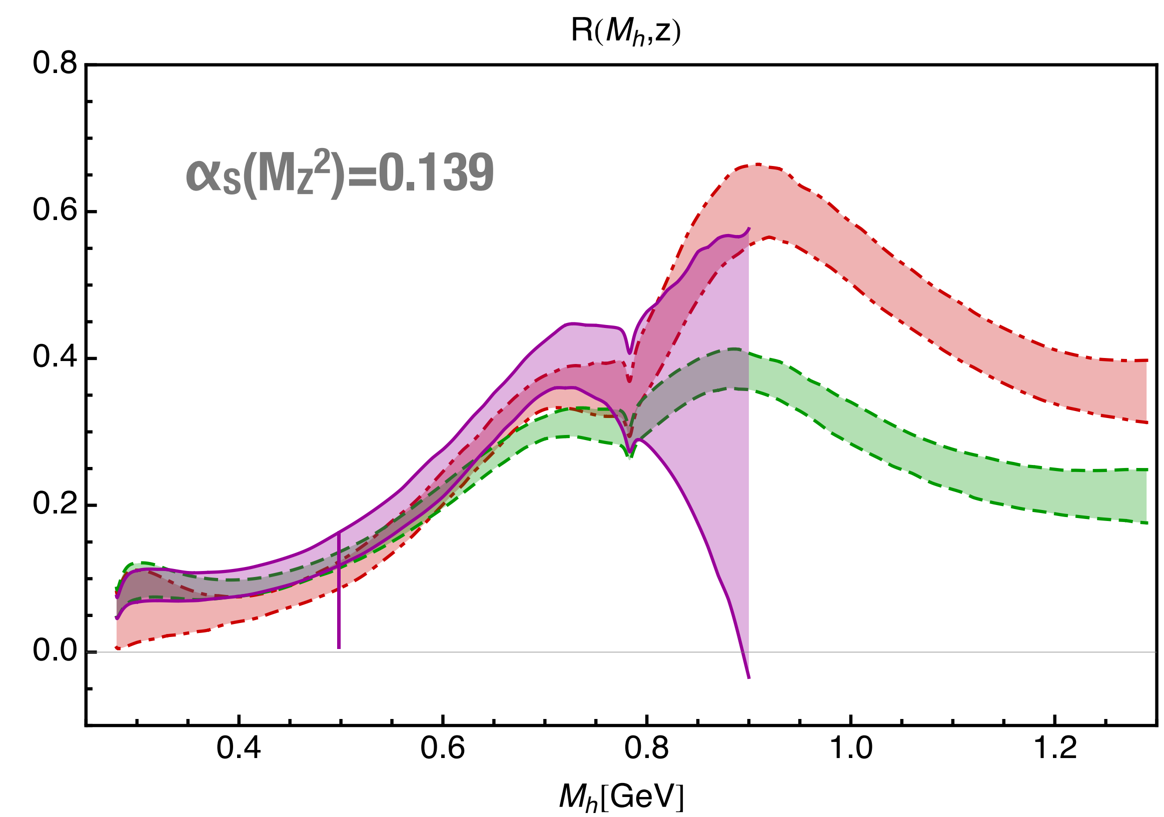




$$R(z, M_h) = \frac{|\mathbf{R}|}{M_h} \frac{H_{1,sp}^{\sphericalangle u}(z, M_h; Q_0^2)}{D_1^u(z, M_h; Q_0^2)}$$

D_1 unchanged (good statistics)



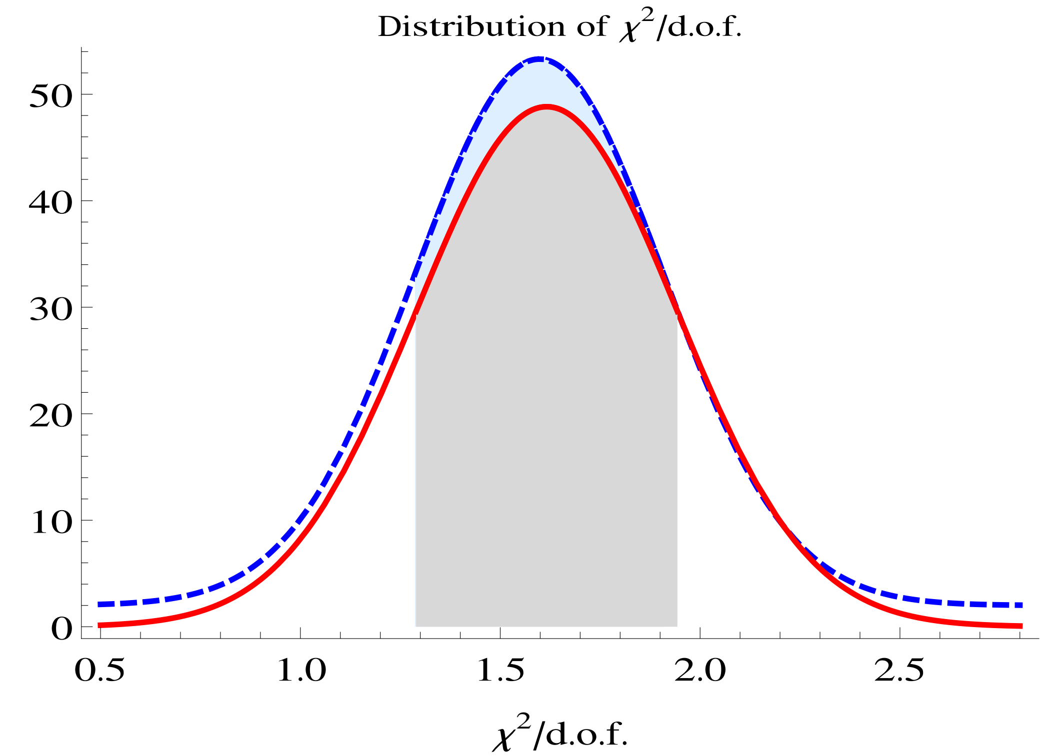


Effect of $\alpha_S(M_Z^2)$ value

Tiny effects on

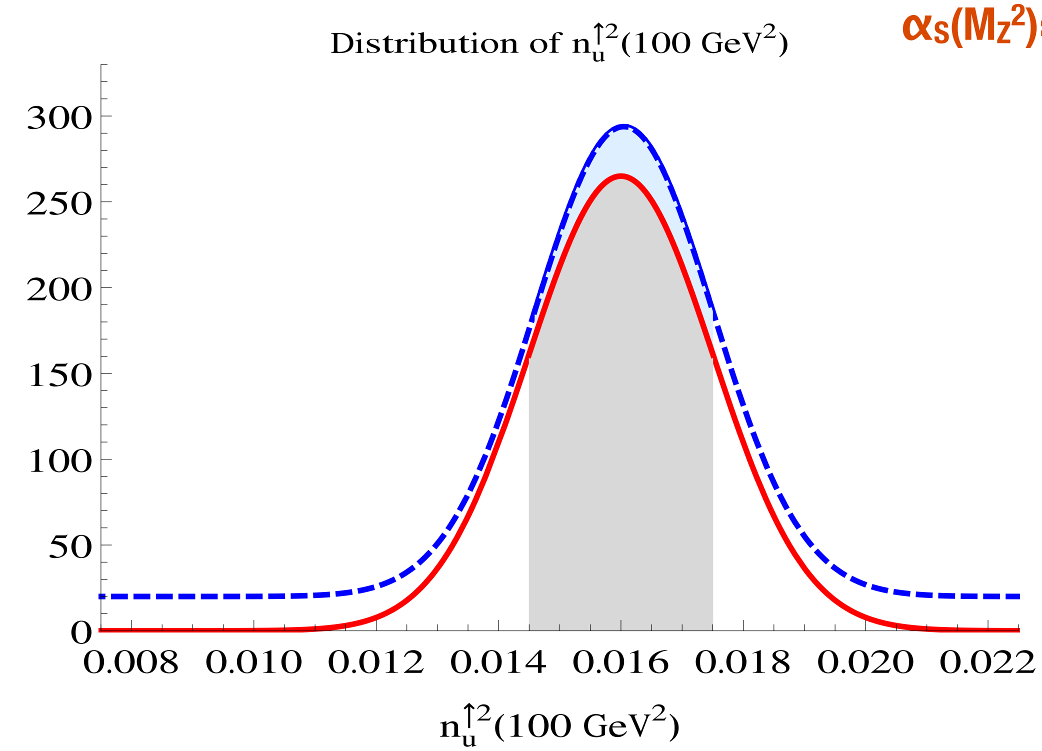
- the Chi2 distribution
- the value of $n_q^{\uparrow}$

$$n_q^{\uparrow}(Q^2) = \int dz\, dM_h\, \frac{|\mathbf{R}|}{M_h}\, H_{1,sp}^{\sphericalangle\, q}(z, M_h; Q^2)$$



$\alpha_S(M_Z^2)$=0.125

$\alpha_S(M_Z^2)$=0.139



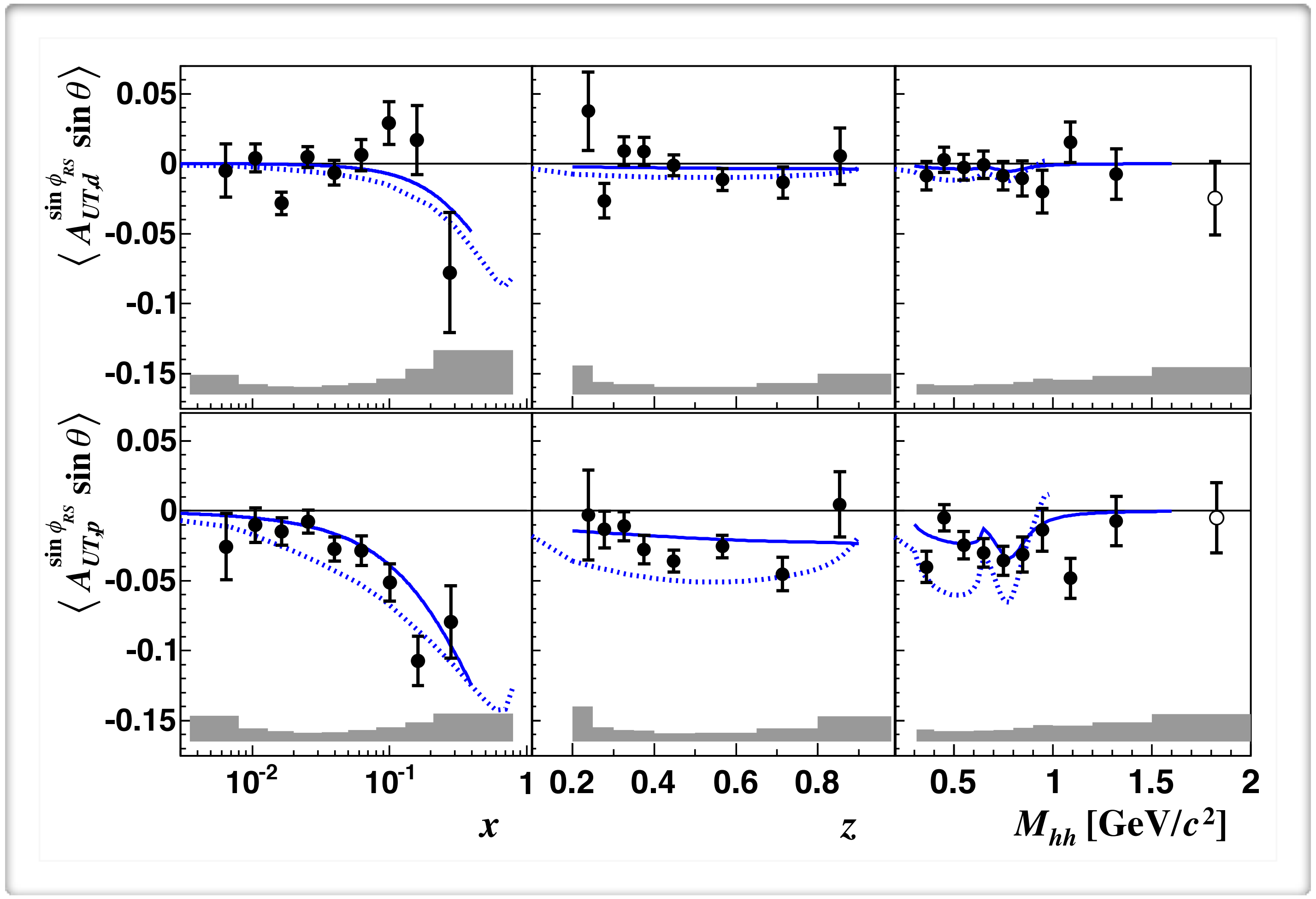
Effect of $\alpha_S(M_Z^2)$ value

SIDIS production of pion pairs

TRIPTIC plot

Deuteron Data

Proton Data



COMPASS range: $0.2<z<1$ & $0.29<M_h<1.29$ GeV

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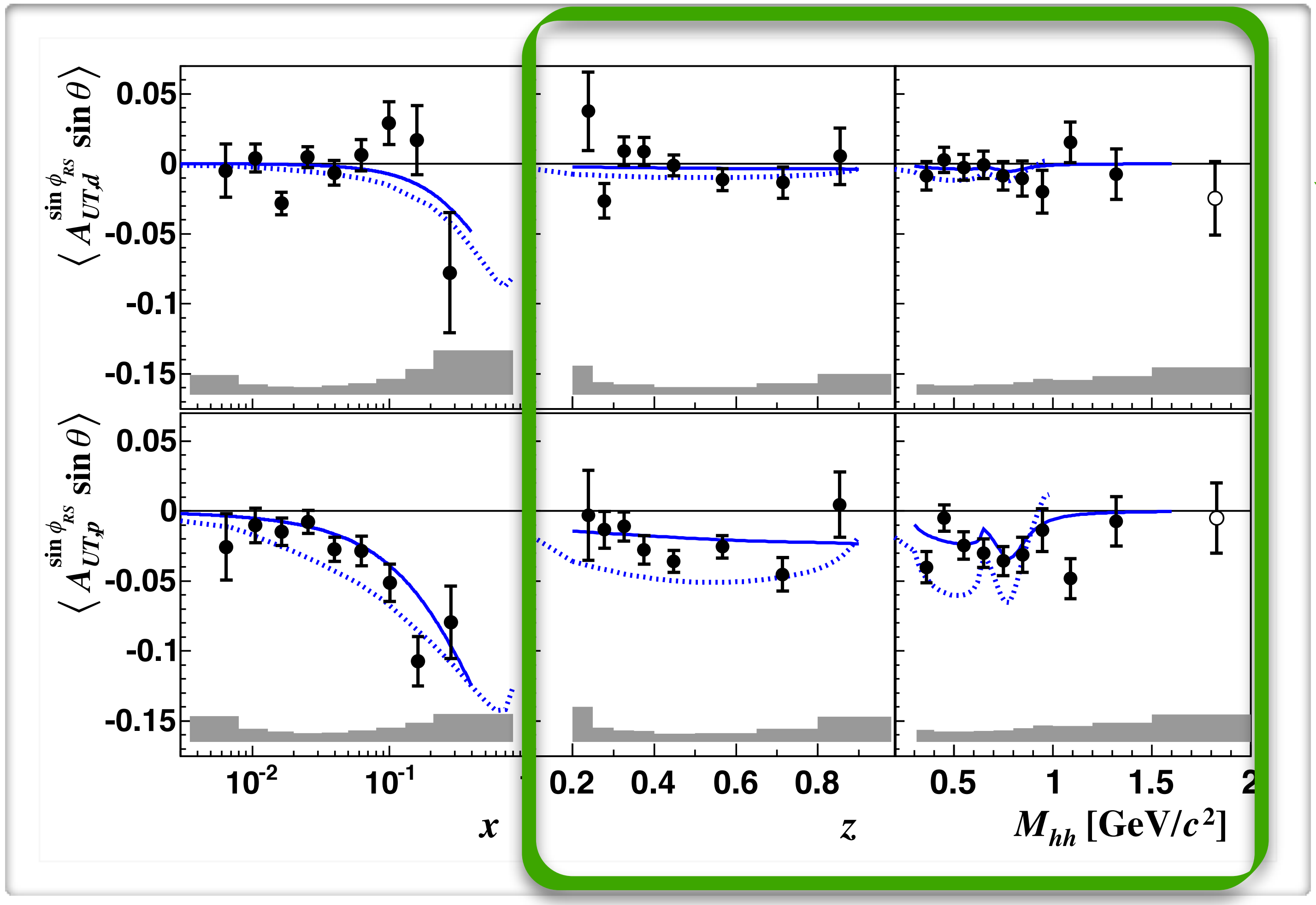

(z, M_h)-dpdence determined by DiFF

COMPASS range: $0.2<z<1$ & $0.29<M_h<1.29$ GeV

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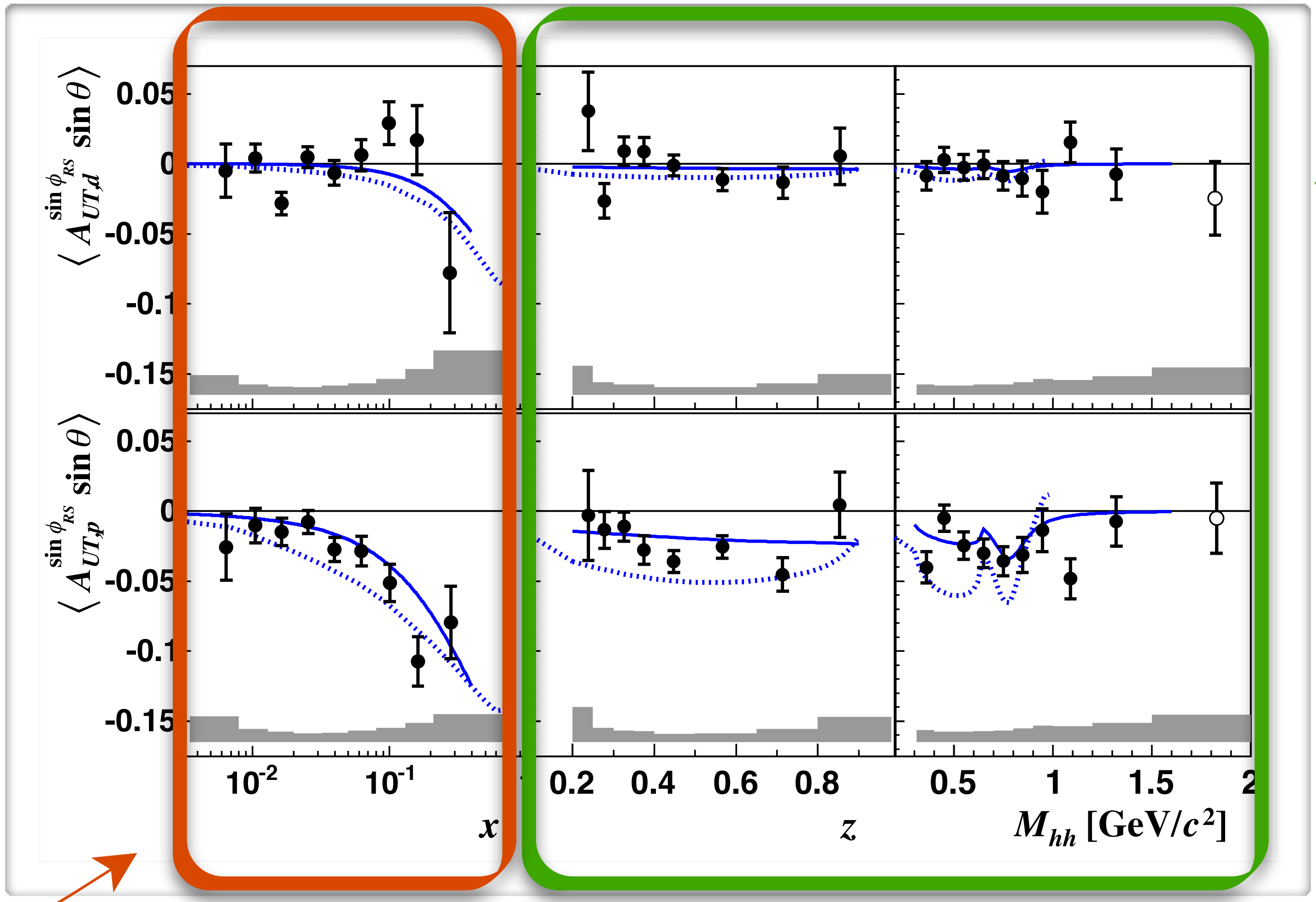

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x-dependence only from Transversity

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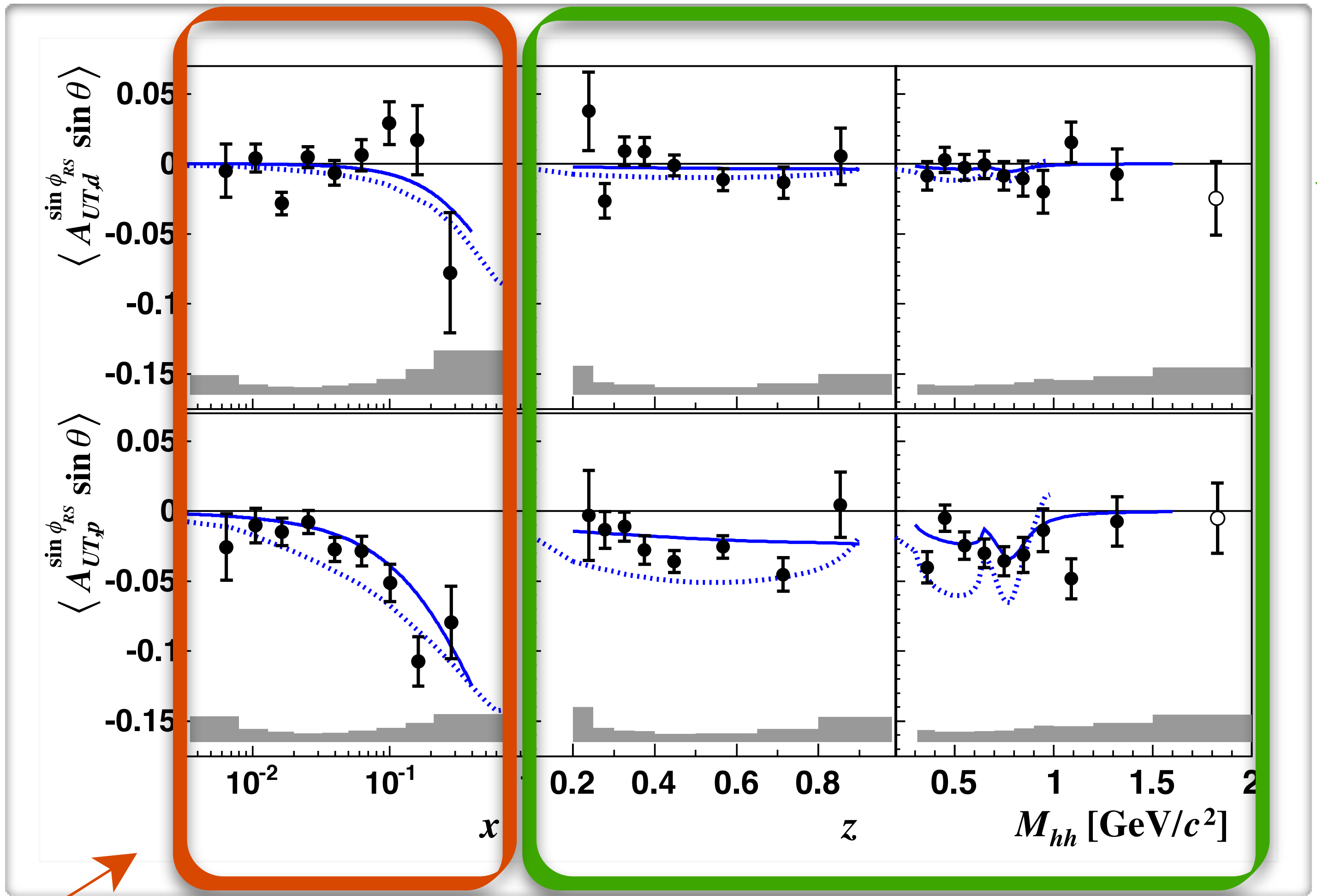

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Transversity from $A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$

$$A^{i}_{\mathrm{DIS}}(x,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^{q\,i}(x,Q^2)\, n_q^{\uparrow\,i}(Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2)\, n_q(Q^2)}$$

i=1,..,n
# repl.

Using symmetries for DiFFs:

$$H_1^{\sphericalangle,\,u} = -H_1^{\sphericalangle,\,d} = -\overline{H}_1^{\sphericalangle,\,u} = \overline{H}_1^{\sphericalangle,\,d}$$

$$D_1^u = D_1^d = \overline{D}_1^u = \overline{D}_1^d\,,$$
$$D_1^s = \overline{D}_1^s\,, \quad D_1^c = \overline{D}_1^c$$

Proton

$$x h_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, x h_1^{d_v}(x,Q^2)\Big|_{i} \propto -A^{i}_{\mathrm{DIS}}(x,Q^2)\,\frac{n_u(Q^2)}{n_u^{\uparrow\,i}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

Deuteron

$$x h_1^{u_v}(x,Q^2) + x h_1^{d_v}(x,Q^2)\Big|_{i} \propto -\frac{5}{3} A^{i}_{\mathrm{DIS}}(x,Q^2)\,\frac{n_u(Q^2)}{n_u^{\uparrow\,i}(Q^2)}\, x\left(f_1^{u+\bar{u}} + f_1^{d+\bar{d}} + \frac{2}{5} f_1^{s+\bar{s}}\right)$$

and combinations of both ...

Transversity from $A_{UT}^{\sin(\Phi_R+\Phi_S)\sin\theta}$

$$A^{i}_{\mathrm{DIS}}(x,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^{q\,i}(x,Q^2)\, n_q^{\uparrow\,i}(Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2)\, n_q(Q^2)}$$

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and combinations of both ...

Now for i=j=1,..,n results for the replica method

The Functional Form

@ Q_0^2

$$x\, h_1^{q_V}(x) = \tanh\left(x^{1/2}\,(A_q + B_q\, x + C_q\, x^2 + D_q\, x^3)\right)\,\left(x\,\mathrm{SB}^q(x) + x\,\mathrm{SB}^{\bar{q}}(x)\right)$$

1st order polynomial

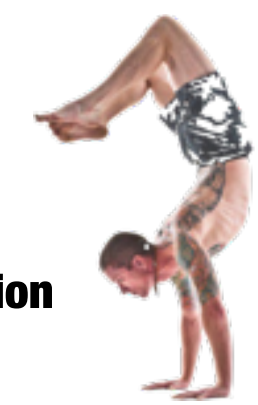
$$A_q + B_q\, x$$

Rigid version

2nd order polynomial

$$A_q + B_q\, x + C_q\, x^2$$

Flexible version



3rd order polynomial

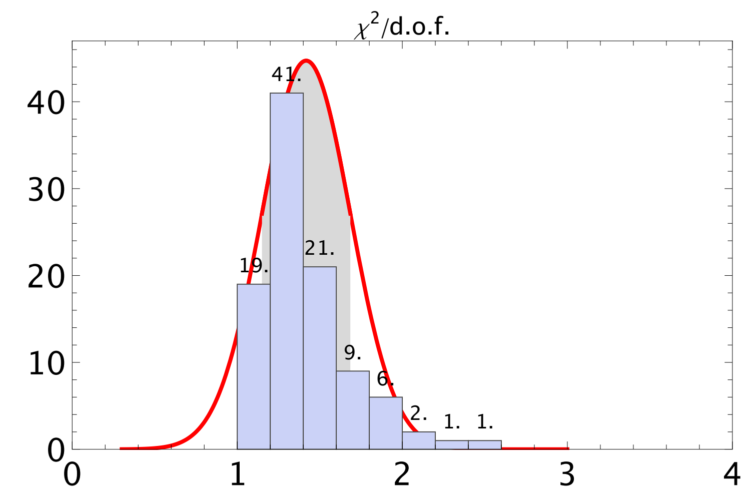
$$A_q + B_q\, x + C_q\, x^2 + D_q\, x^3$$

Extra-flexible version

The Functional Form

@ Q_0^2

$$x\, h_1^{q_V}(x) = \tanh\left(x^{1/2}\,(A_q + B_q\, x + C_q\, x^2 + D_q\, x^3)\right)\ \left(x\,\mathrm{SB}^q(x) + x\,\mathrm{SB}^{\bar{q}}(x)\right)$$

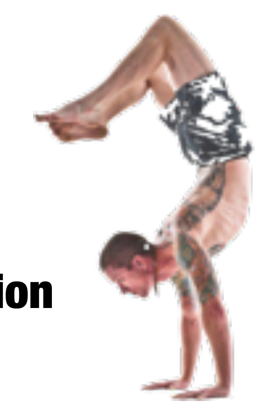


1st order polynomial

$$A_q + B_q\, x$$

Rigid version

2nd order polynomial



$$A_q + B_q\, x + C_q\, x^2$$

Flexible version

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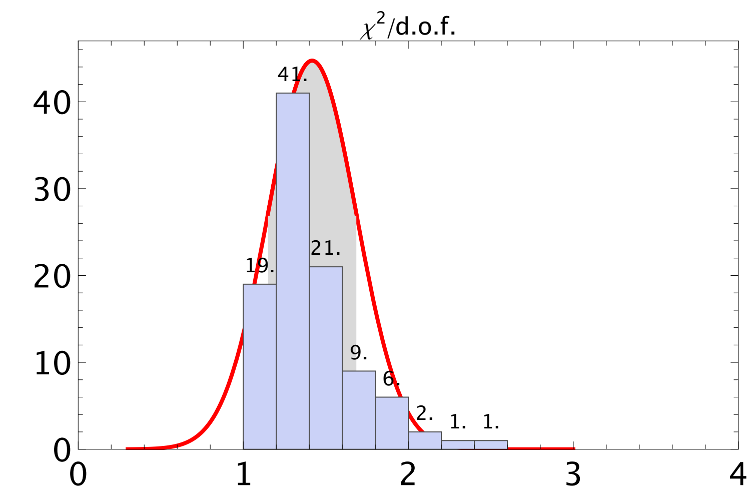

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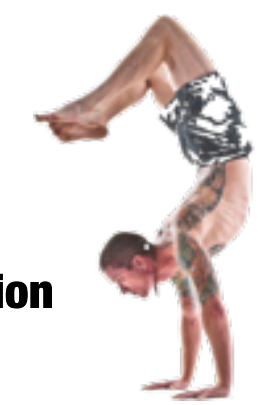


Flexible version

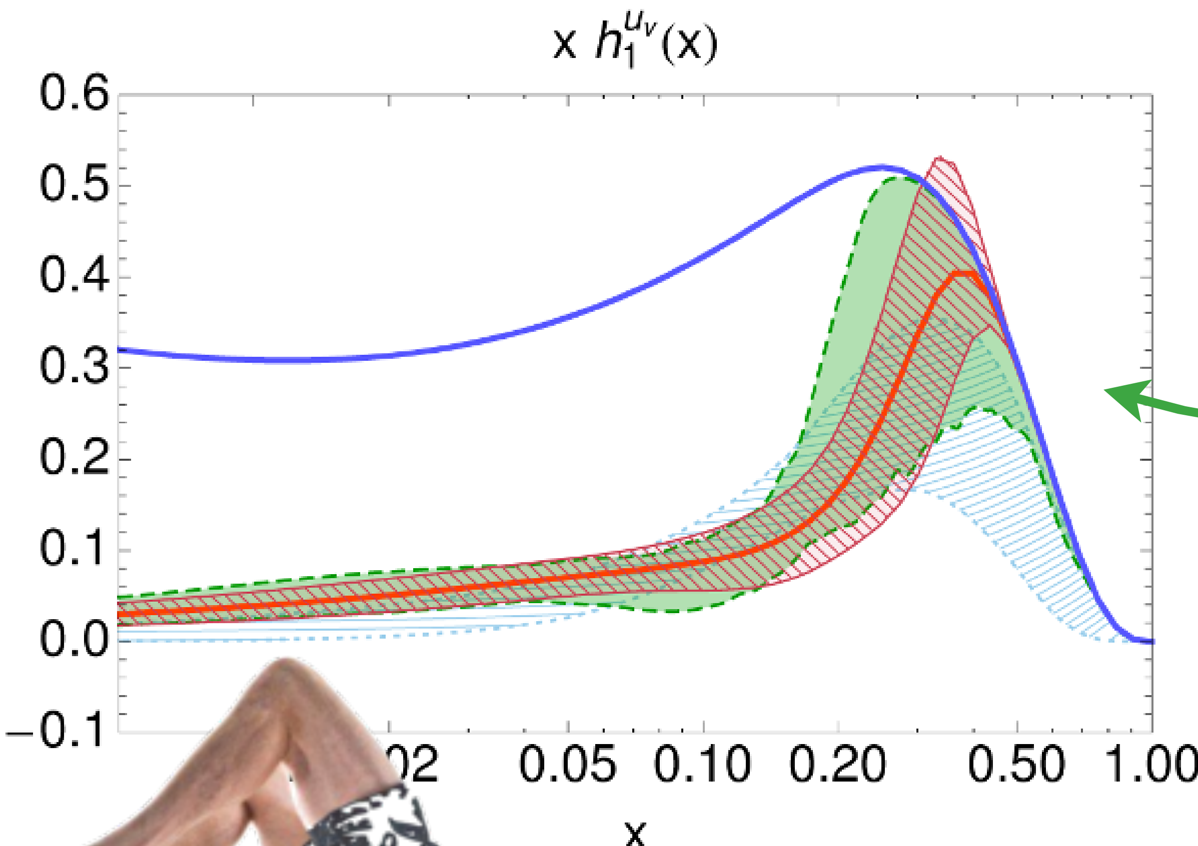
χ^2/d.o.f.	$\alpha_s(M_Z^2) = 0.125$	$\alpha_s(M_Z^2) = 0.139$
rigid	1.42	1.46
flexible	1.65	1.71
extraflexible	1.97	2.07

3rd order polynomial

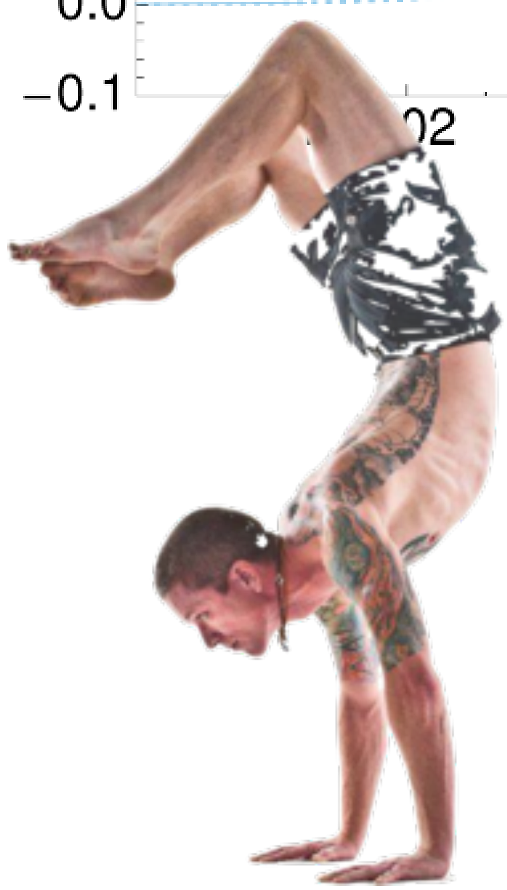
$$A_q + B_q\, x + C_q\, x^2 + D_q\, x^3$$

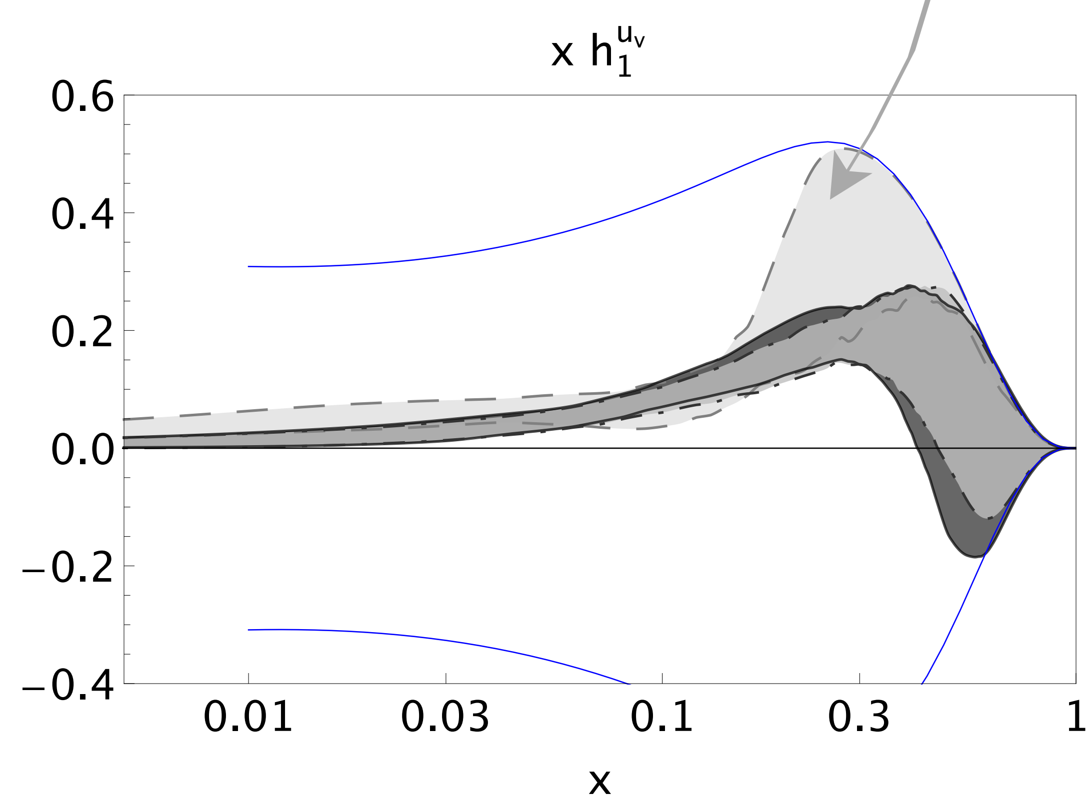
Extra-flexible version

Old and New Fits



OLD 1σ error band from replicas @2.4 GeV^2



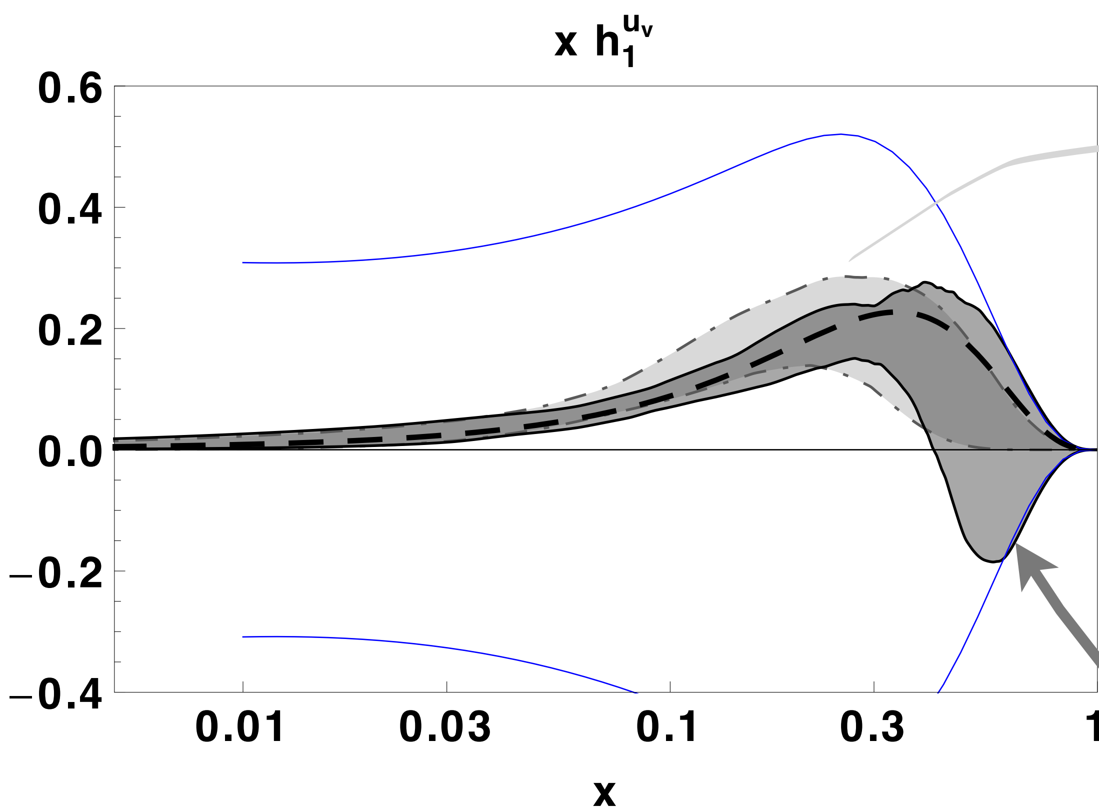


Flexible version

NEW 1σ error band from replicas @2.4 GeV^2

$\alpha_S(M_Z^2)=0.125$ $\alpha_S(M_Z^2)=0.139$

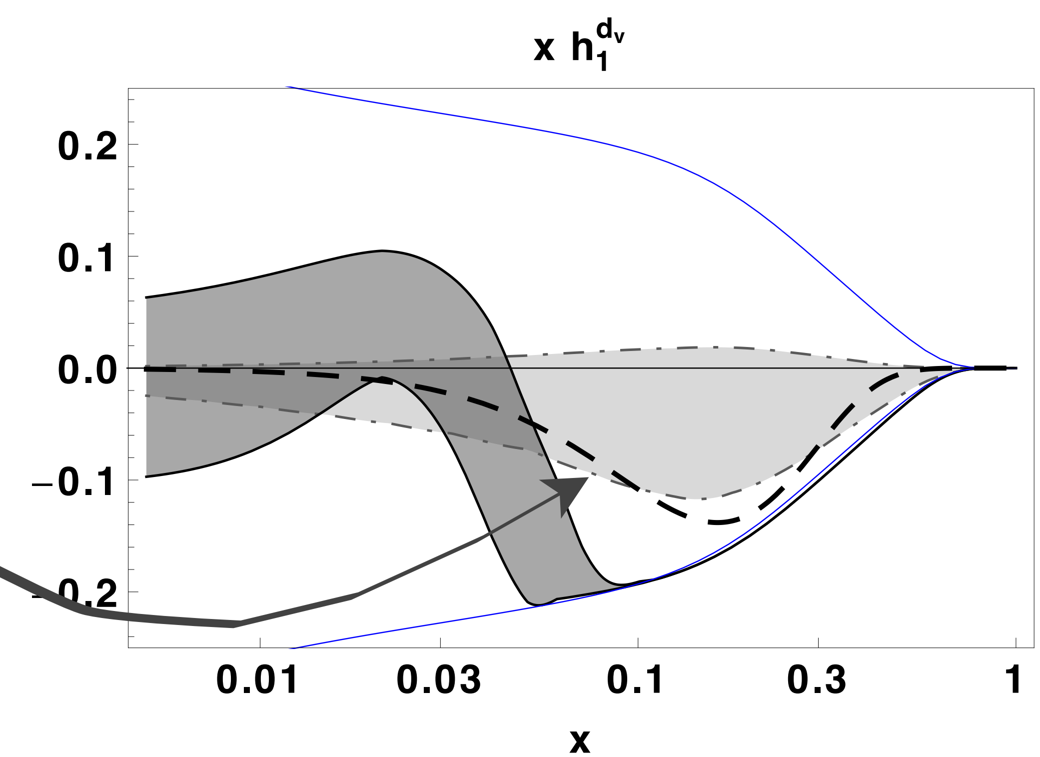
Comparison with Single-hadron extr.



Torino 2013 @2.4 GeV^2

1σ error band from replicas @2.4 GeV^2
flexible scenario 0.125

Kang et al central value



Discrepancy in the d distribution

New proton data don't change that!

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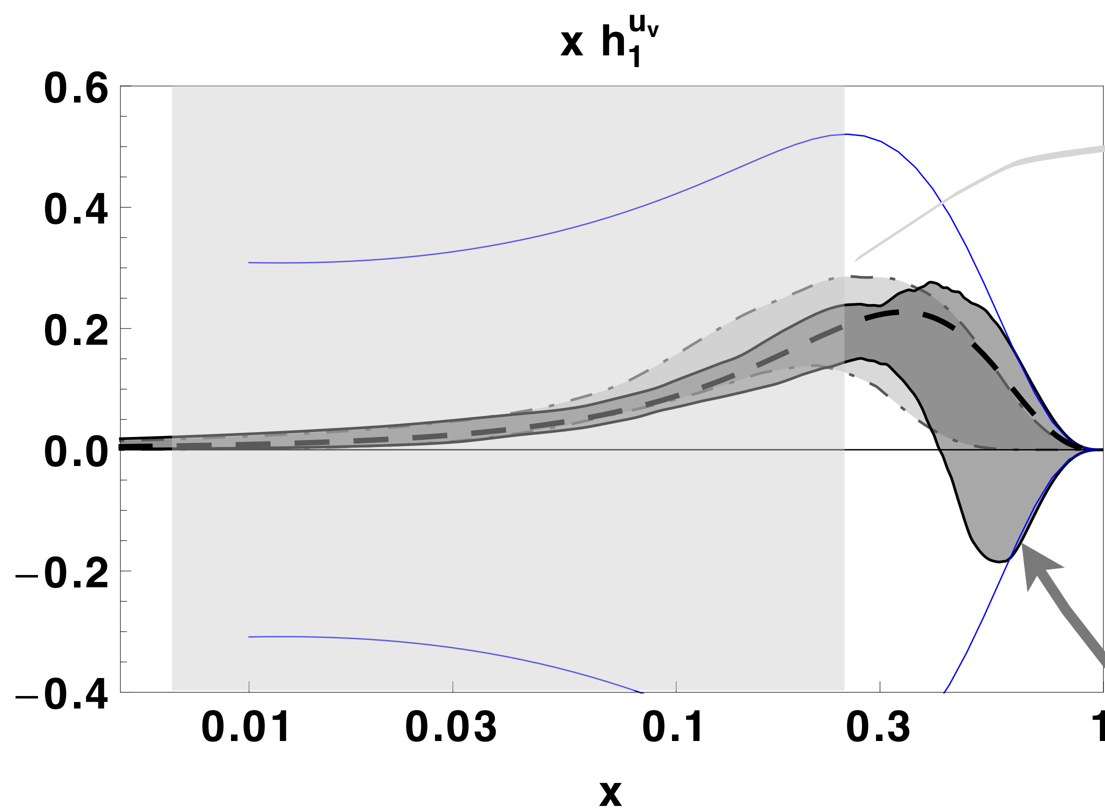

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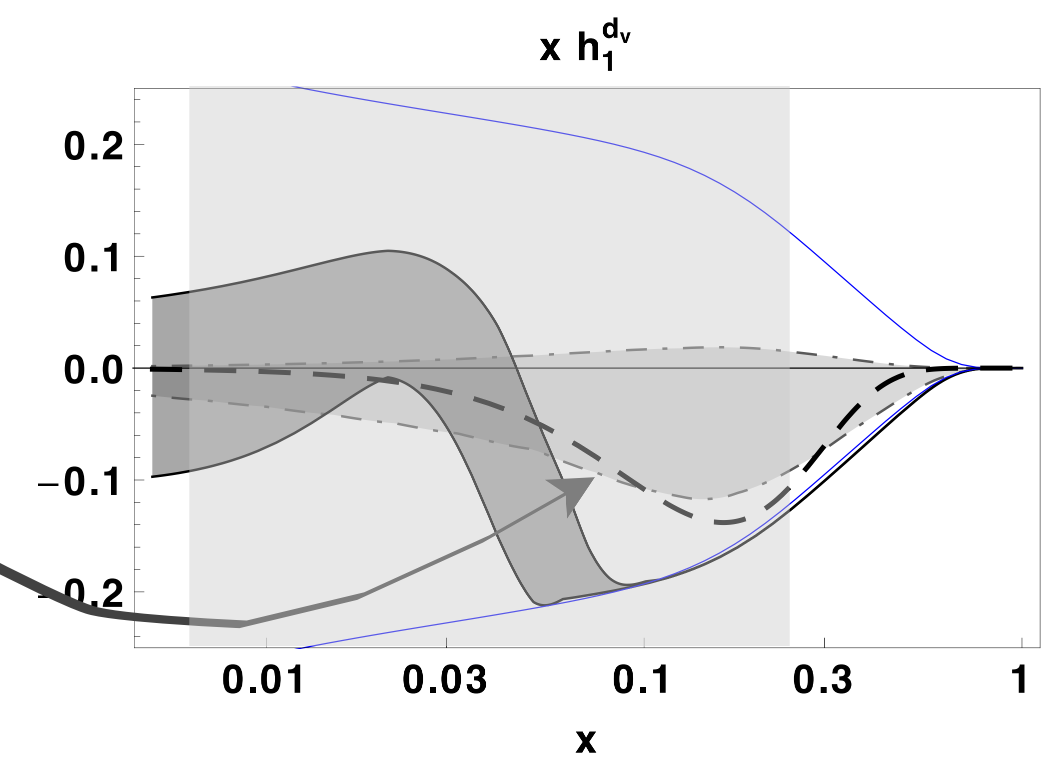

Discrepancy in the d distribution

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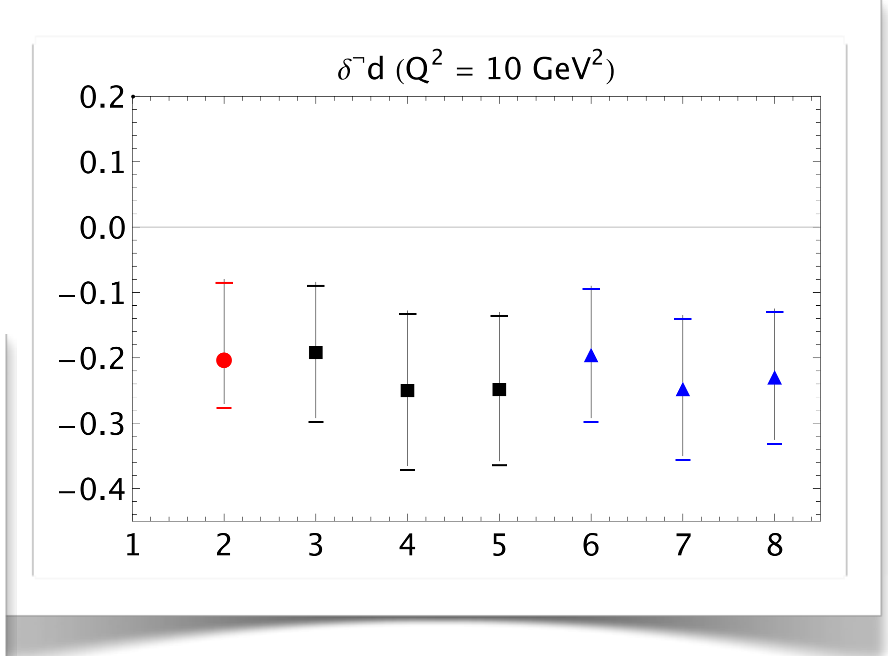
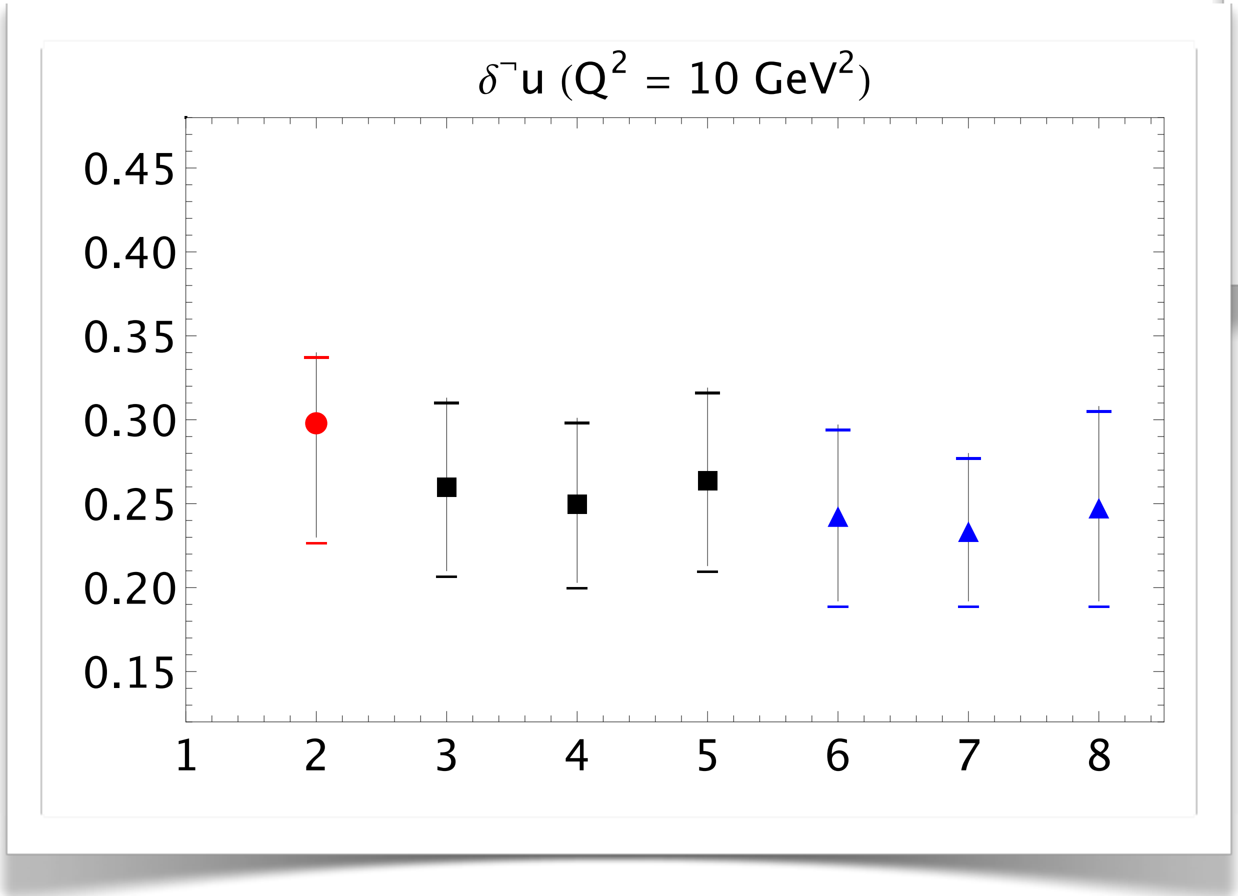
Tensor Charge *where we have data*

1. Kang et al Phys.Rev. D91
2. rigid 0.125
3. flexible 0.125
4. extraflexible 0.125
5. rigid 0.139
6. flexible 0.139
7. extraflexible 0.139



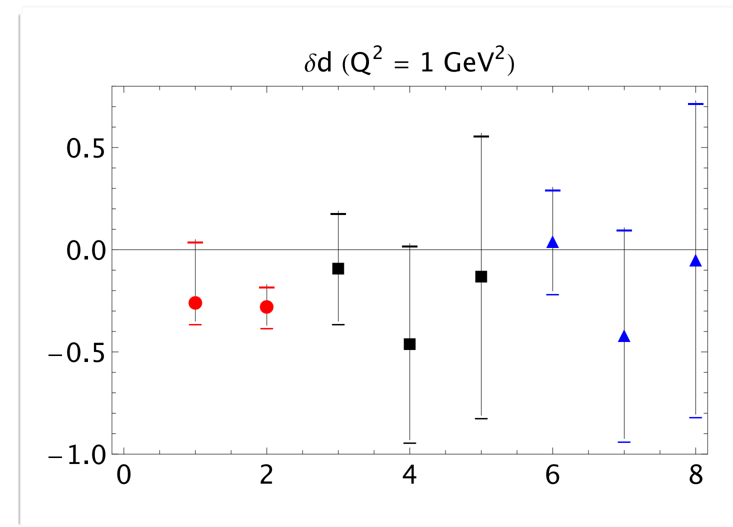


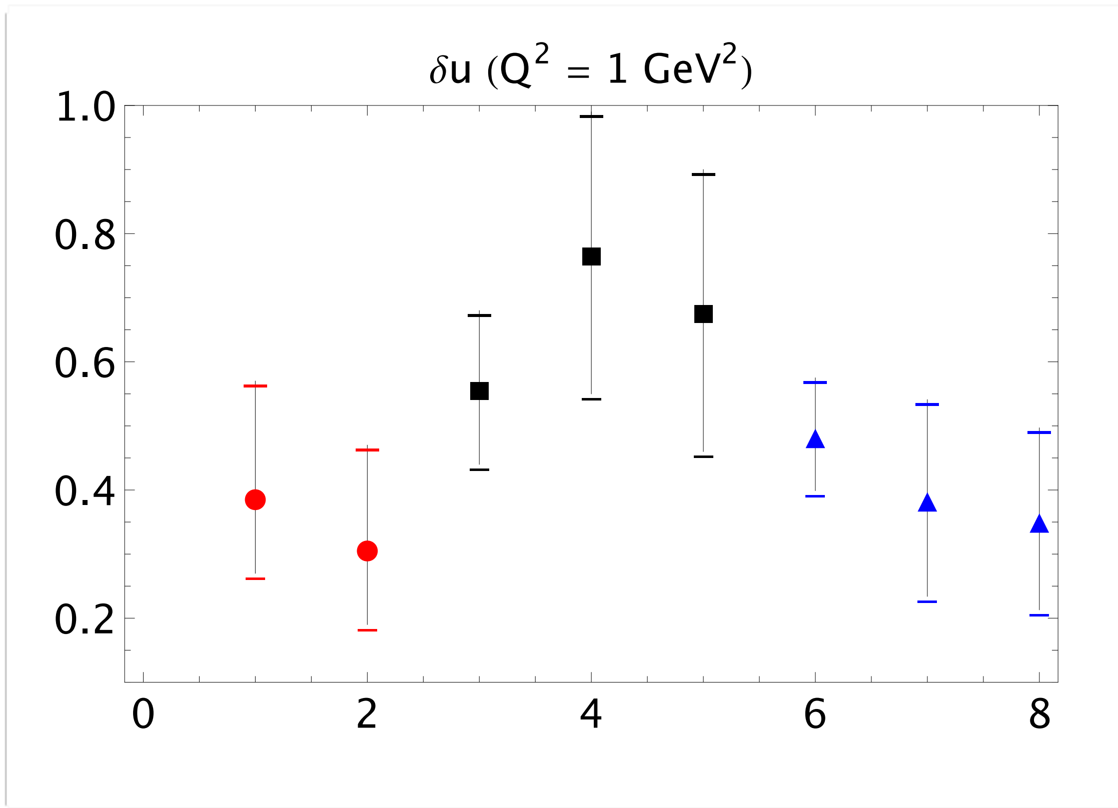
$$\delta q = \int_{6.4\times10^{-3}}^{0.28} dx\, h_1^{q_v}(x)$$

Tensor Charge

full range 10^{-10}- 1

1. Anselmino et al Phys.Rev. D87
2. rigid old
3. flexible old
4. extraflexible old
5. rigid 0.125
6. flexible 0.125
7. extraflexible 0.125





$$\delta q = \int_{\sim 0}^{1} dx\, h_1^{q_v}(x)$$

Tensor Charge's Application

Probe New Fundamental Interactions from Beta Decay

$$N(p_n) \longrightarrow P(p_p)e^-(p_e)\bar{\nu}_e(p_\nu)$$

[Cirigliano et al, JHEP 1302 (2013) 046]

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$$\boxed{N(p_n) \longrightarrow P(p_p)e^-(p_e)\bar{\nu}_e(p_\nu)}$$

can be sketched as

$$\text{``}\left[d \xrightarrow{\Gamma} u\, e^-(p_e)\bar{\nu}_e(p_\nu)\right] \otimes \left[\langle P|\bar{u}\,\Gamma\, d|N\rangle\right]\text{''}$$

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EW: V-A

Standard Model

Structural: g_V & g_A

$$M = -i\frac{G_F}{\sqrt{2}}\,\bar{u}_e\gamma_\mu\left(1-\gamma^5\right)v_\nu\,\langle p|\bar{u}\gamma^\mu\left(1-\gamma^5\right)d|n\rangle\cos\theta_c$$

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New: S, T, P

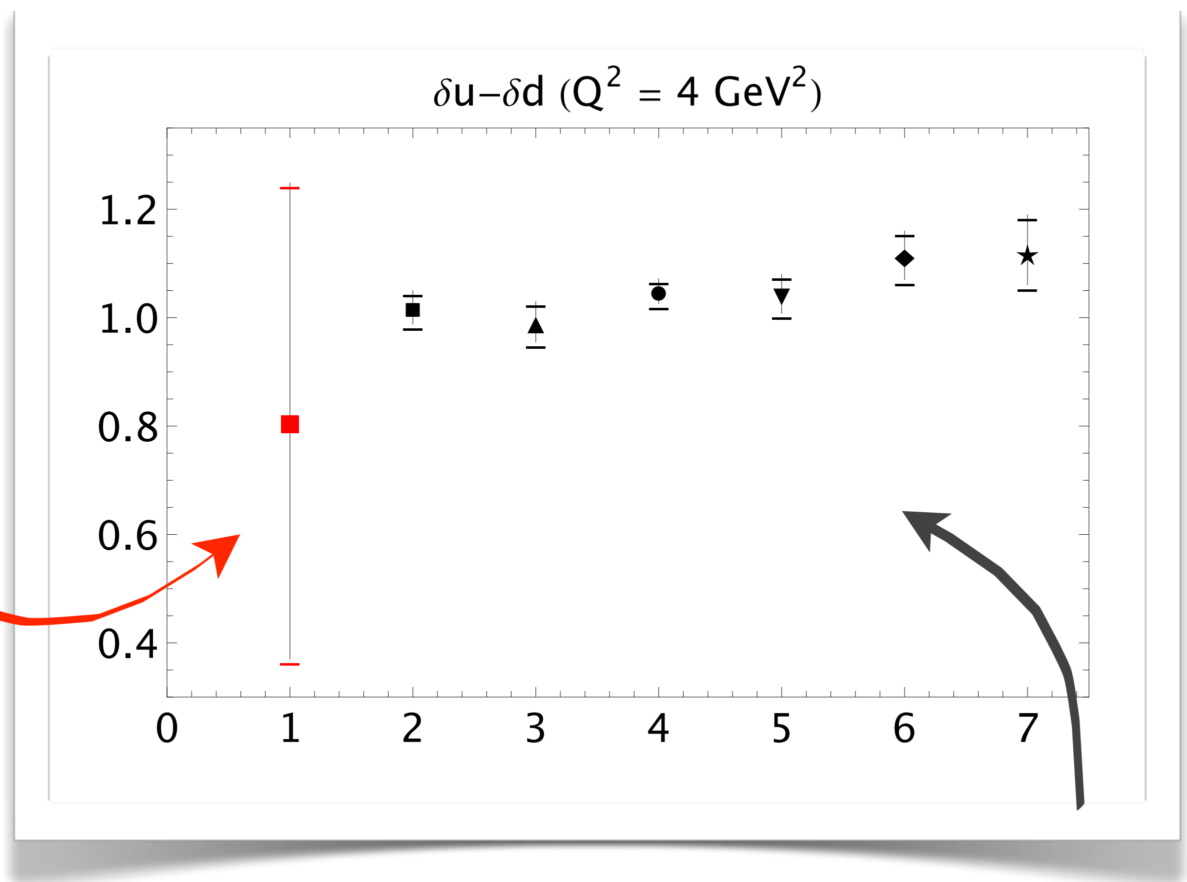
4-fermion interaction
BSM

Structural: g_S, g_T & g_P

[Cirigliano et al, JHEP 1302 (2013) 046]

Isovector Tensor Charge

$$g_T = \delta u_v - \delta d_v$$



New Pavia flexible 0.125

$$g_T = 0.81 \pm 0.44$$

at $Q^2 = 4\ \mathrm{GeV}^2$

[Radici, Courtoy, Bacchetta, Guagnelli, 1503.03495]

Various Lattice QCD results

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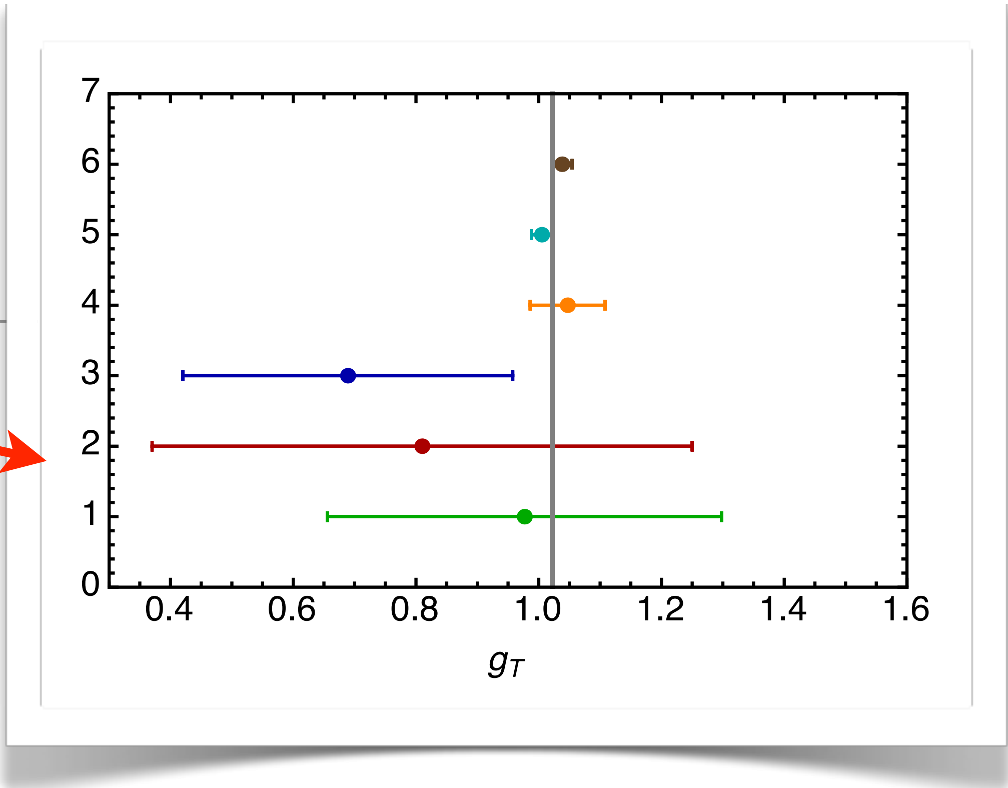
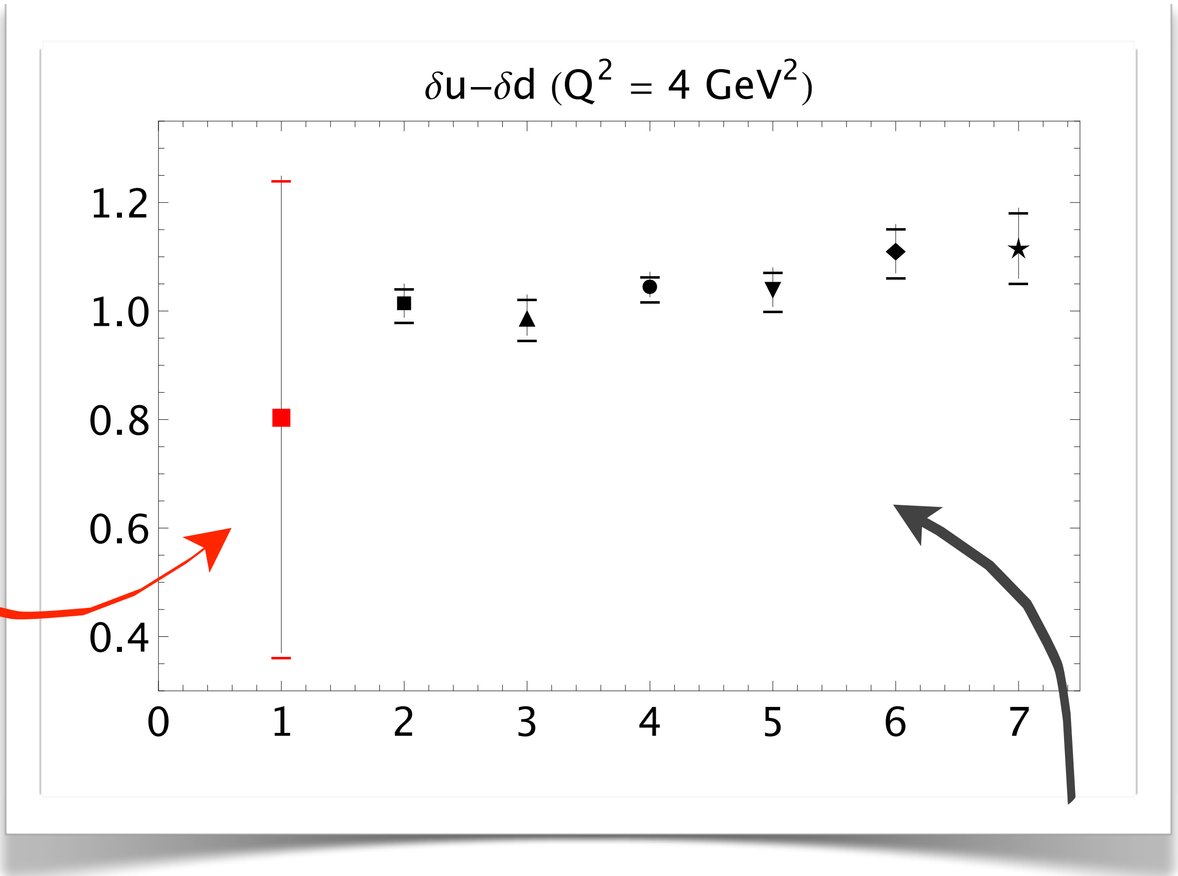


[Courtoy, Baessler, Gonzalez-Alonso, Liuti, 1503.06814]



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Various Lattice QCD results

Can it constrain New Physics interaction?

Effective theories approach

$$\Delta\mathcal{L}_{\text{eff}} = -\frac{G_F V_{ud}}{\sqrt{2}}\,\epsilon_T\,\bar{u}\sigma^{\mu\nu}(1-\gamma_5)d\cdot\bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e$$

Nucleon effective coupling from Beta Decay Exp.

$$C_T = \frac{4\,G_F V_{ud}}{\sqrt{2}} g_T\,\epsilon_T \quad\Longrightarrow\quad |g_T\epsilon_T| < 6\cdot 10^{-4}$$

[Pattie et al, Phys.Rev. C88]
[Wauters et al, Phys.Rev. C89]

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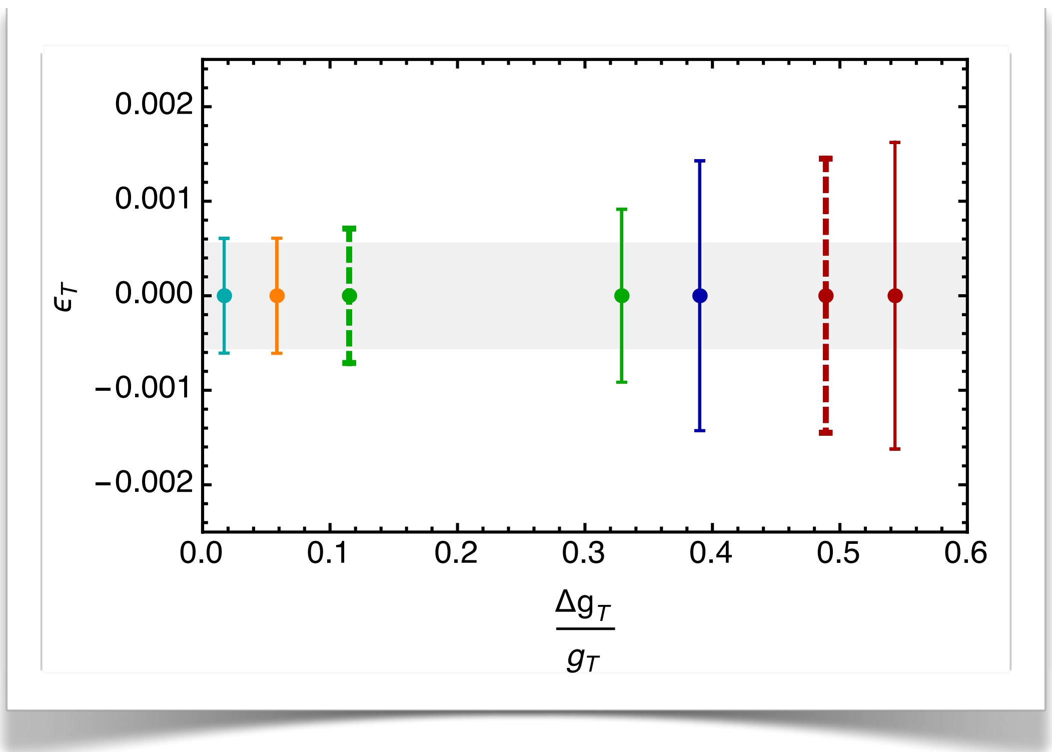

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Pavia flexible

GGL

Torino 2013

Bhattacharya et al Lattice

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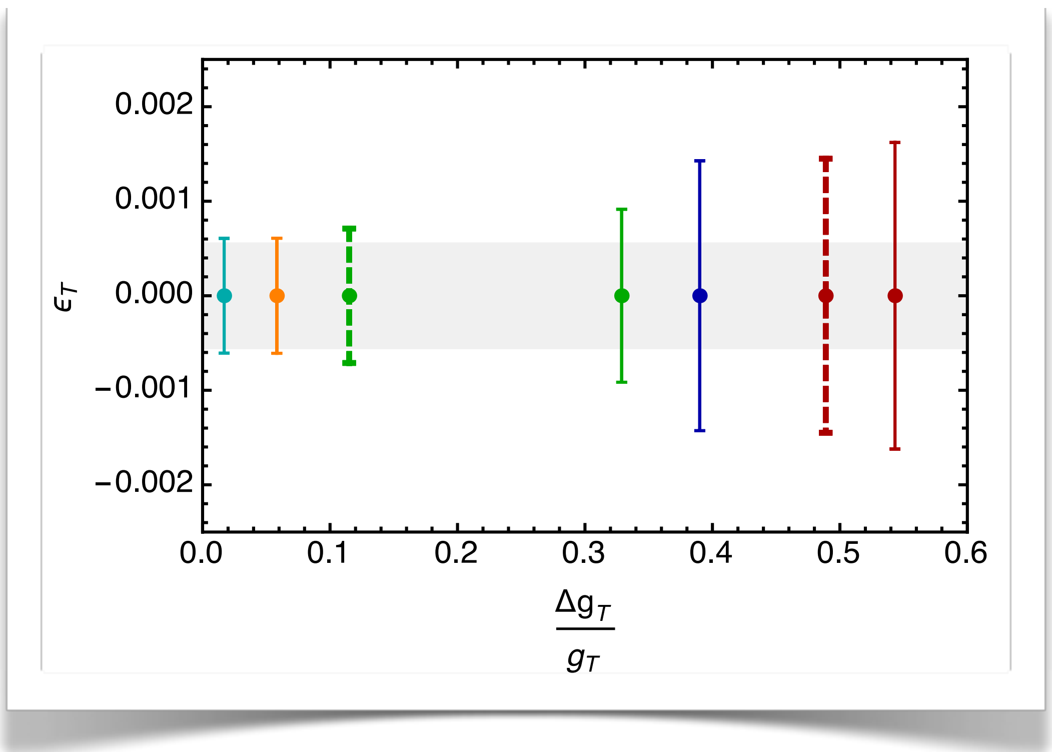

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Pavia flexible

GGL

Torino 2013

Bhattacharya et al Lattice

Bali et al lattice

Dotted curves:
Projection of NEW error after JLab@12

Conclusion

Extraction of valence transversities from collinear framework

- **NEW fit in the REPLICA method for**
  - $H_1^{<}$
  - h_1
- **NEW COMPASS data on proton + identified pions**

  ➡ lower distribution for u_V, no drastic change for d_V
- **Two values for $\alpha_S(M_Z^2)$**

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Beyond the fit...

➡ Impact of tensor charge on New Physics? [1503.06814]

➡ DiFF and twist-3 observables: Analysis of BSA at CLAS & extraction of e(x) [1405.7659]

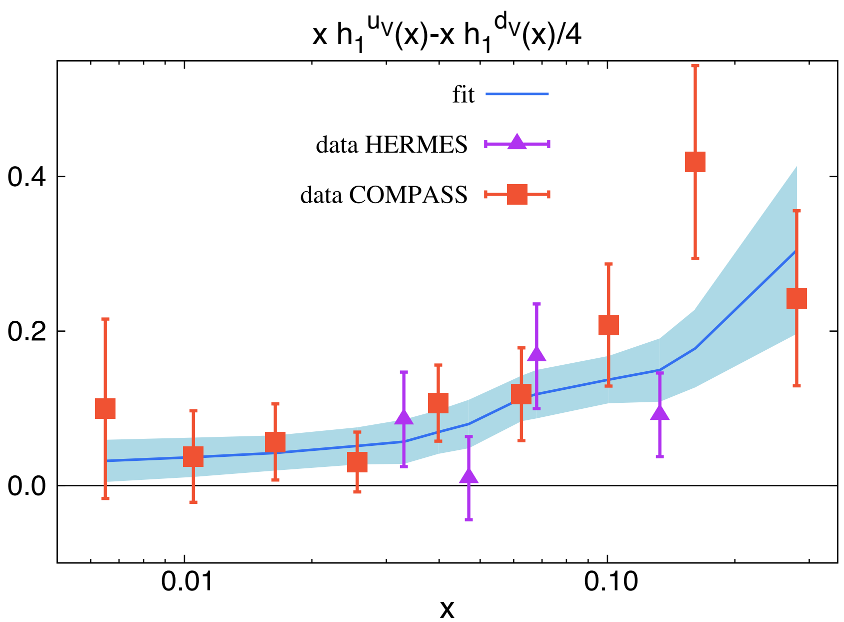
➡ P↑-P at RHIC (to be considered in the future) [1504.00415]

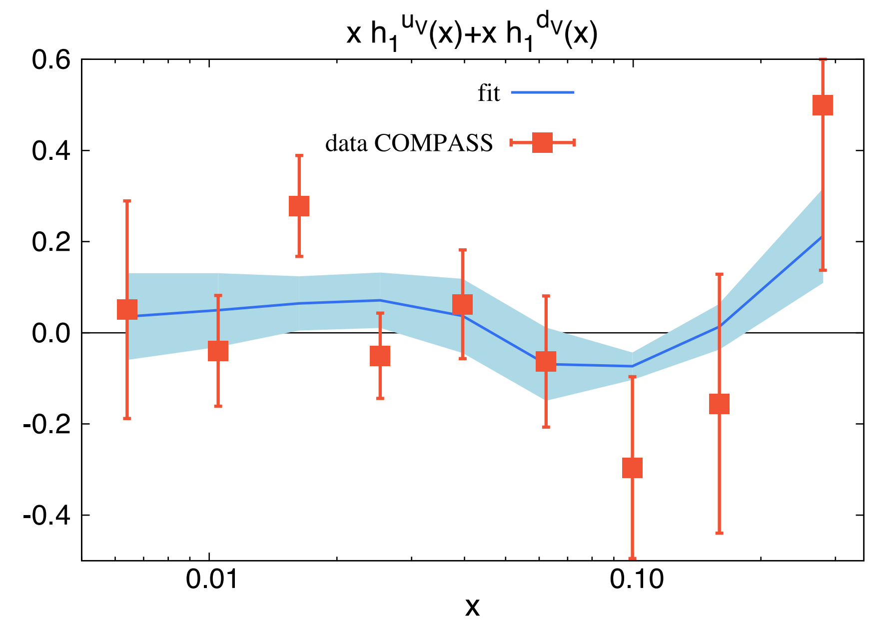
Back-up slides

Comparison with extraction

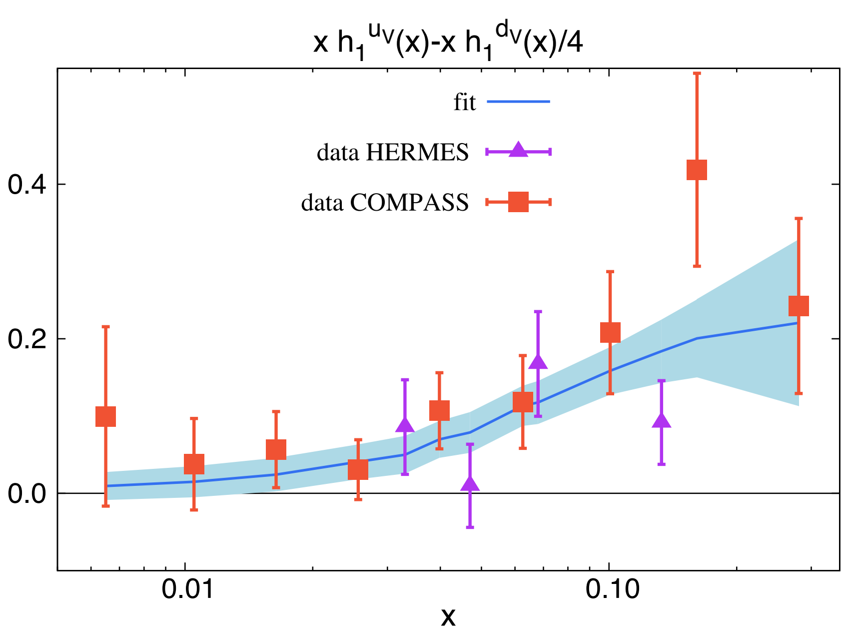
PROTON

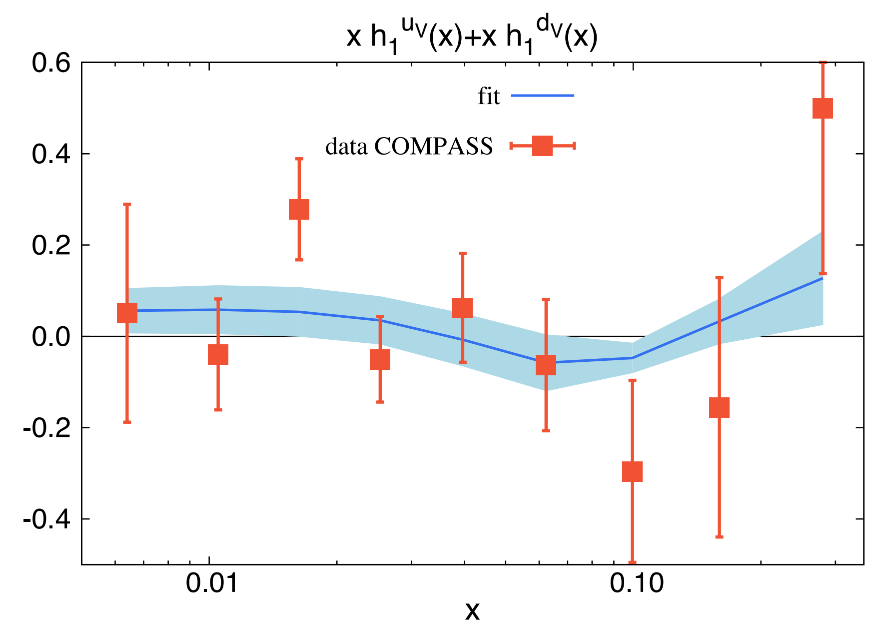
DEUTERON





flexible functional form





rigid functional form

Monte Carlo Approach:

some illustrations

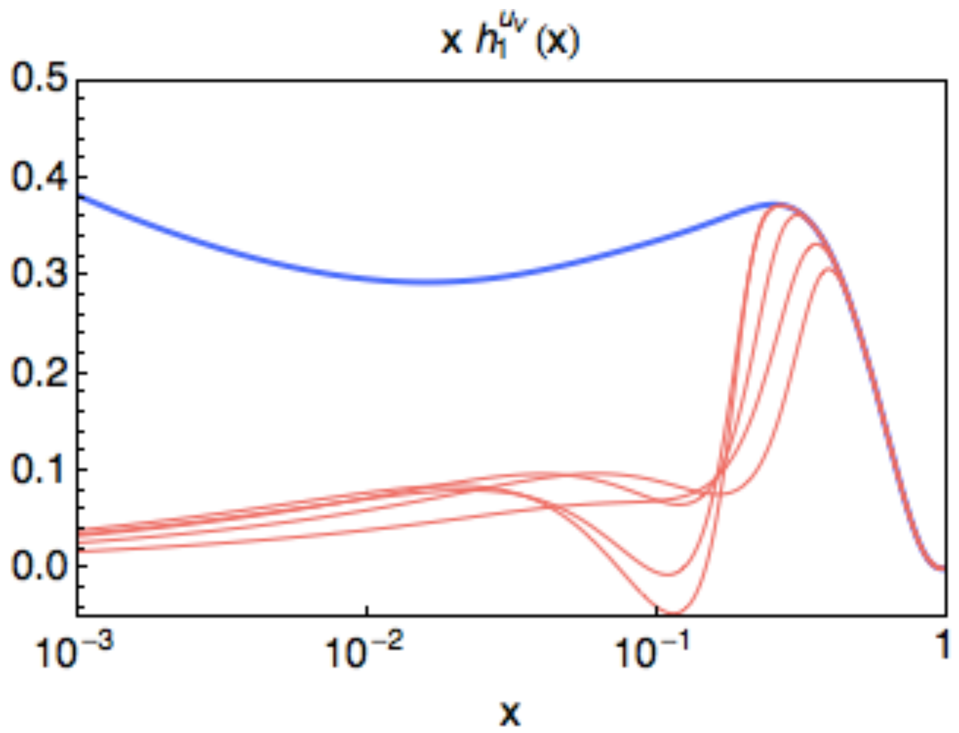
Can we find “unforeseen” replica?

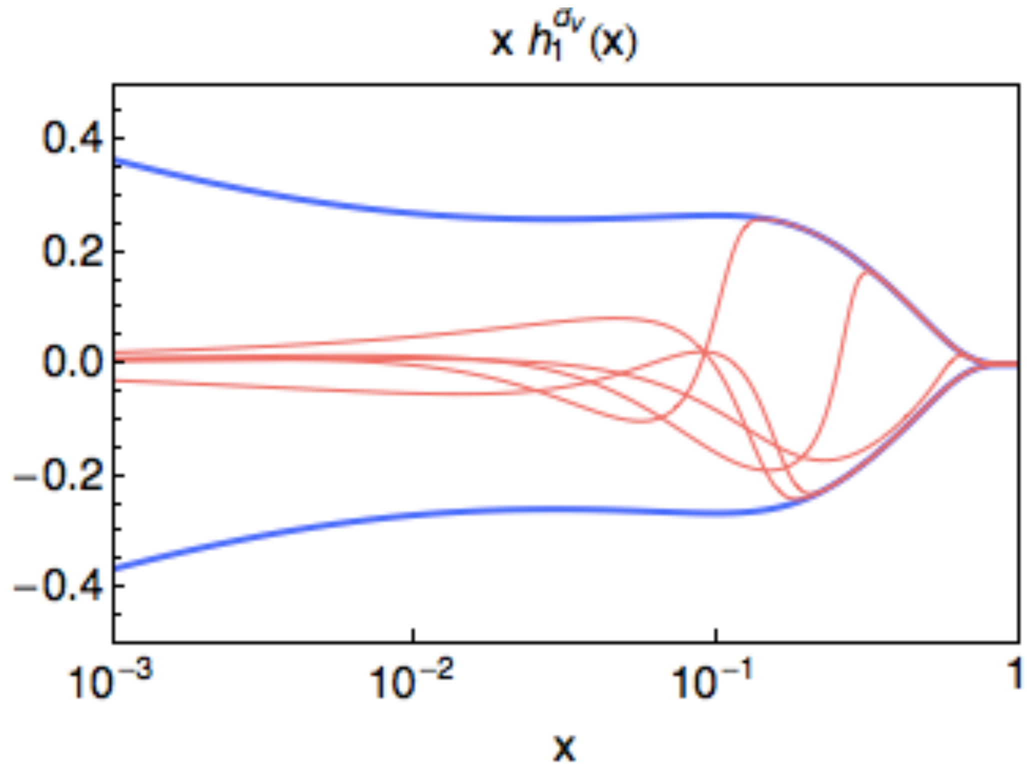
Monte Carlo Approach:

some illustrations

Can we find "unforeseen" replica?

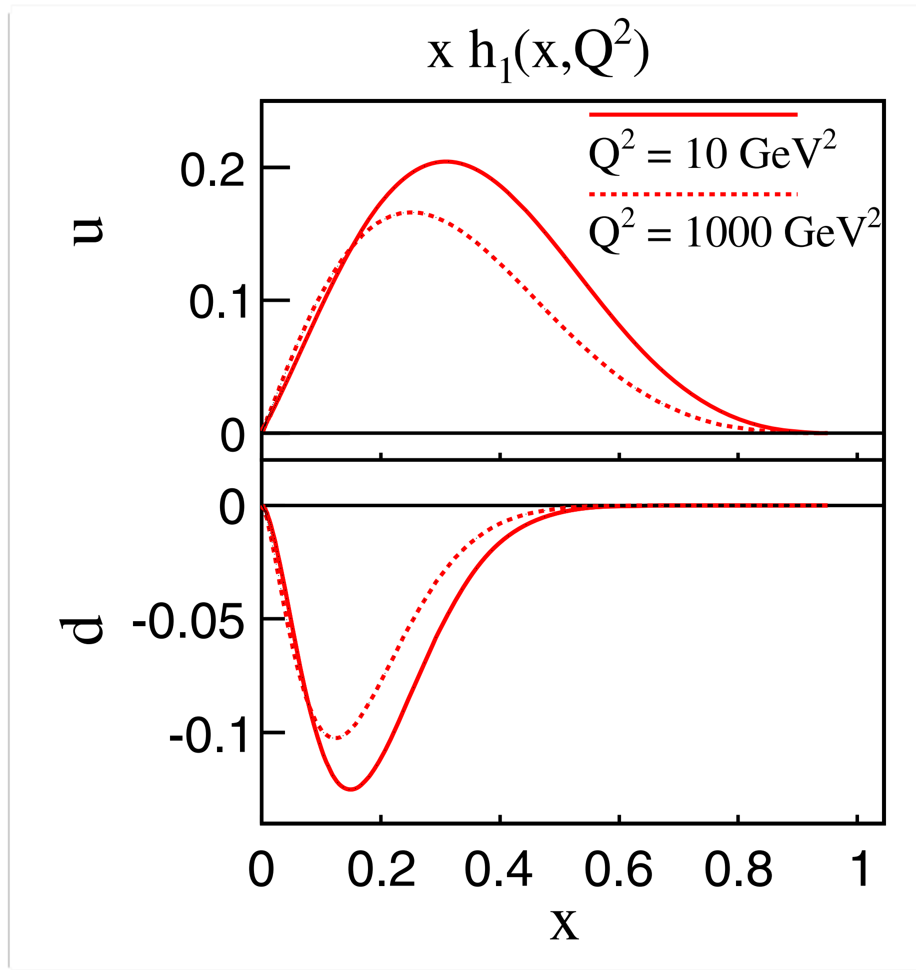
Yes, here at 1GeV^2

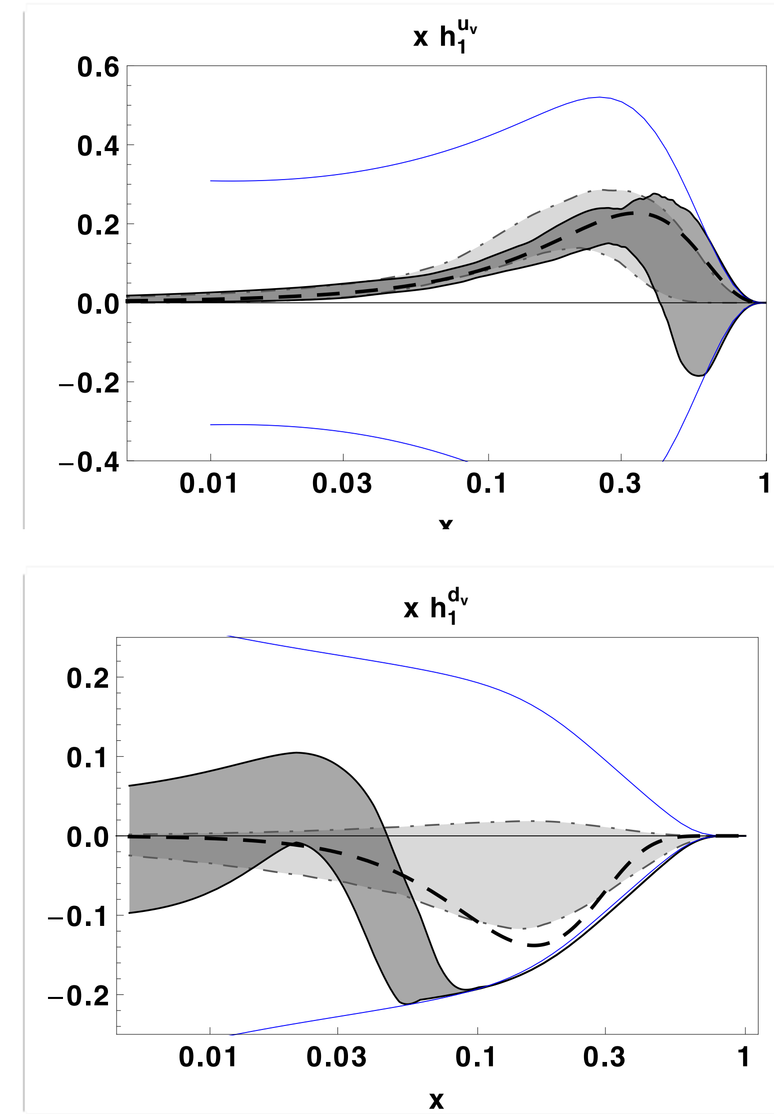




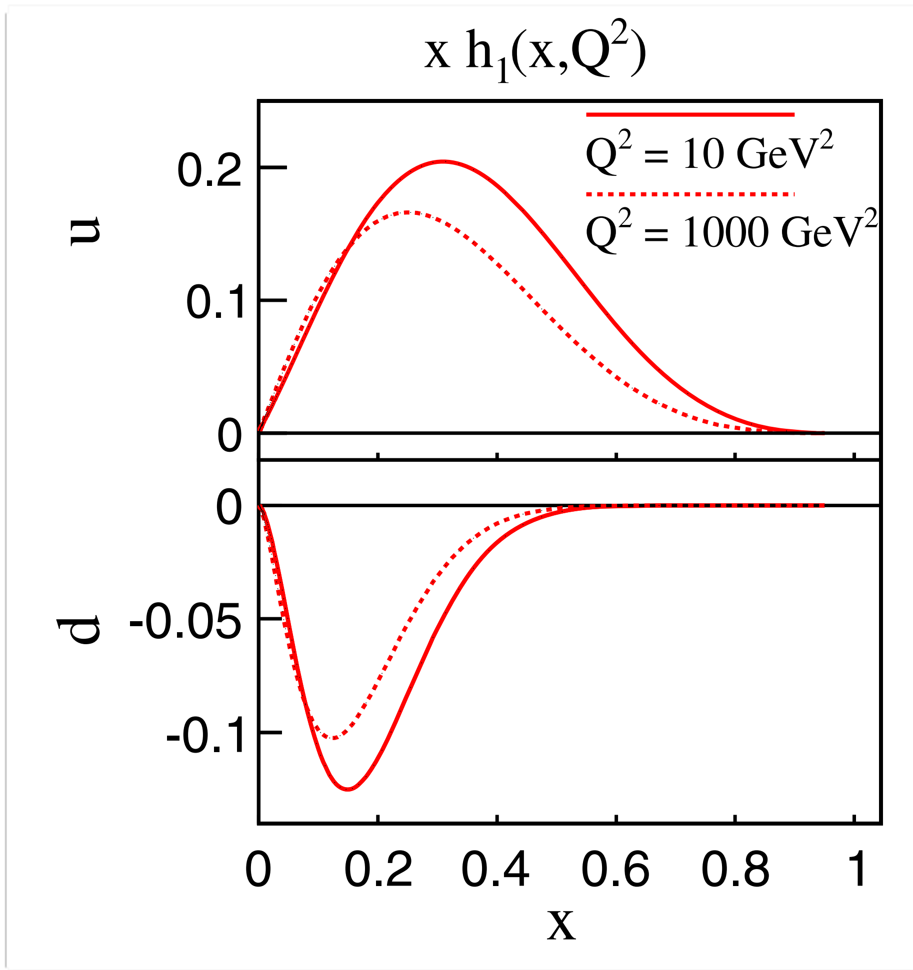
χ^2/dof

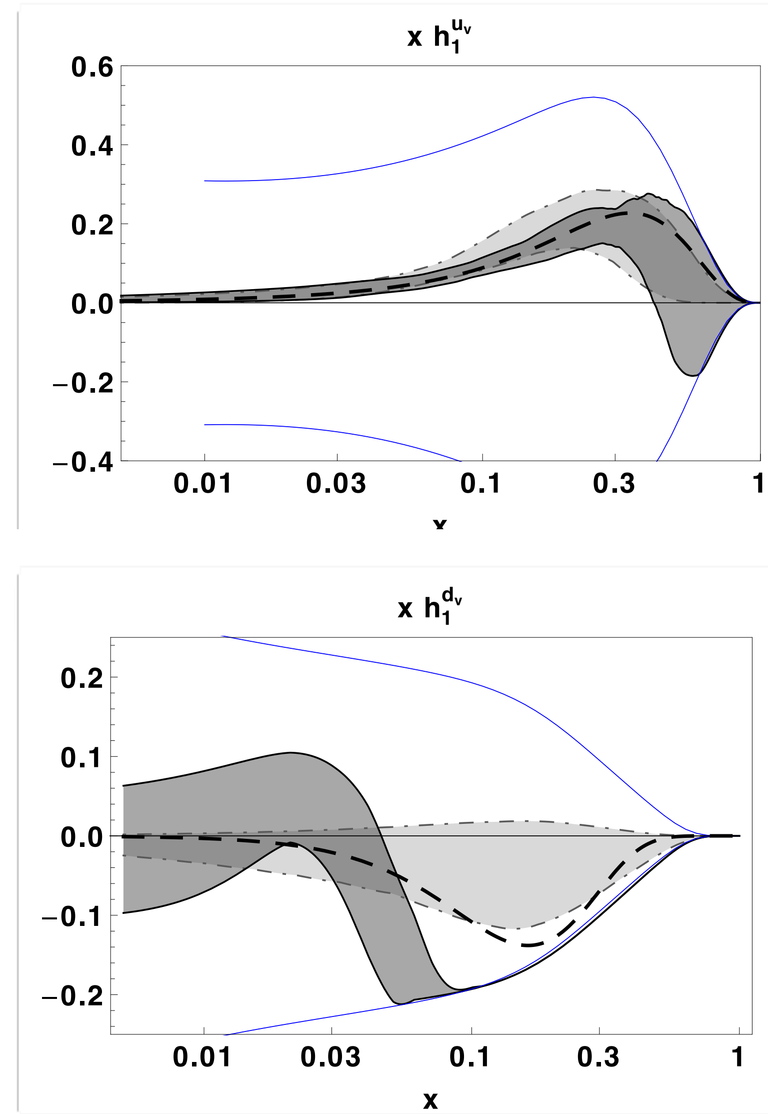
1.56557
1.42199
1.79911
2.07397
1.75523





State-of-the-art:
Extractions of transversity





Anselmino et al [Phys.Rev. D87]
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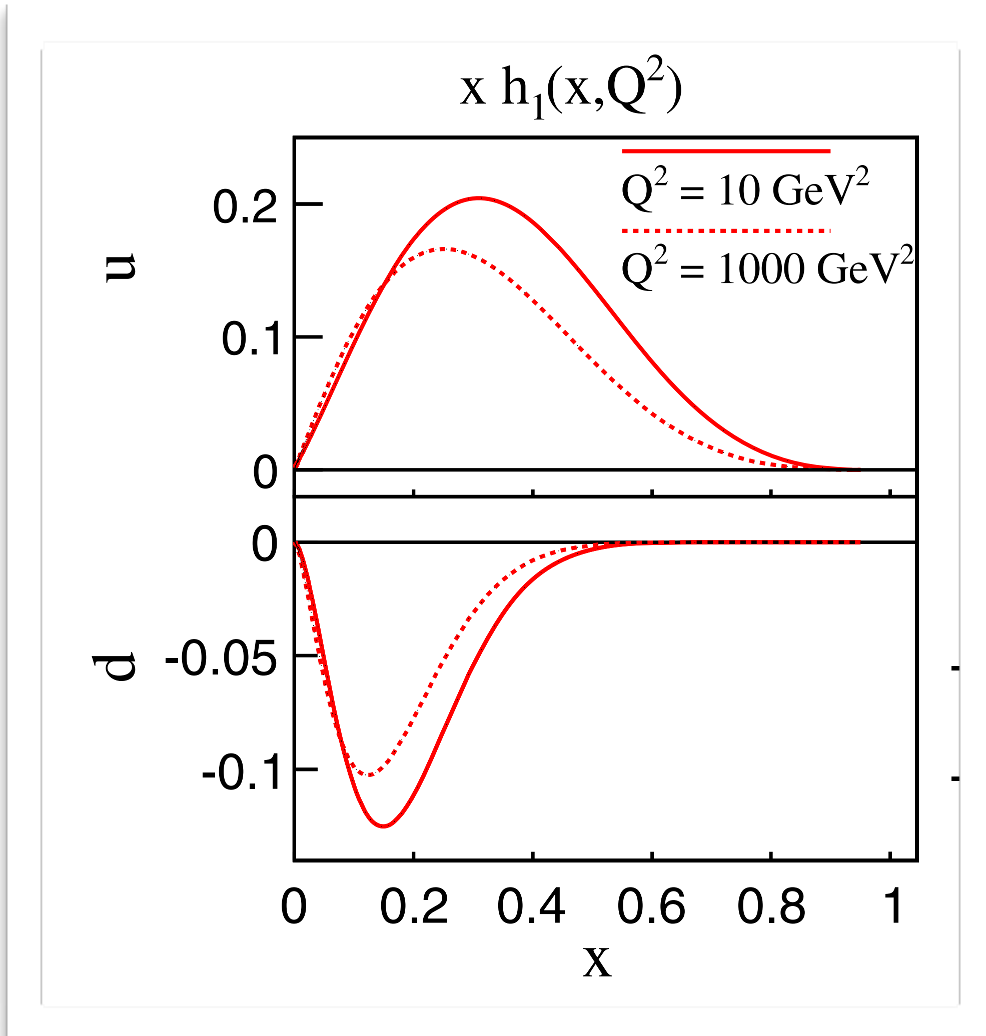

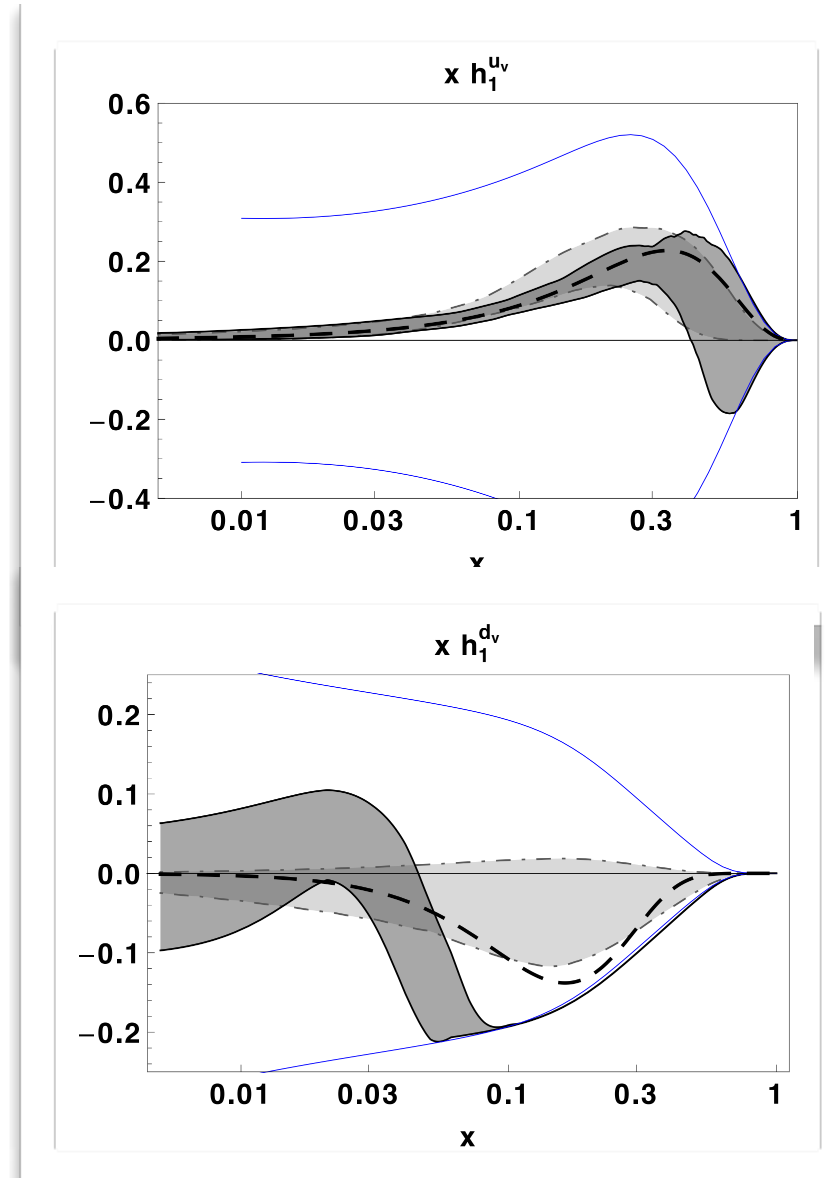

Talk by A. Prokudin

Anselmino et al [Phys.Rev. D87]
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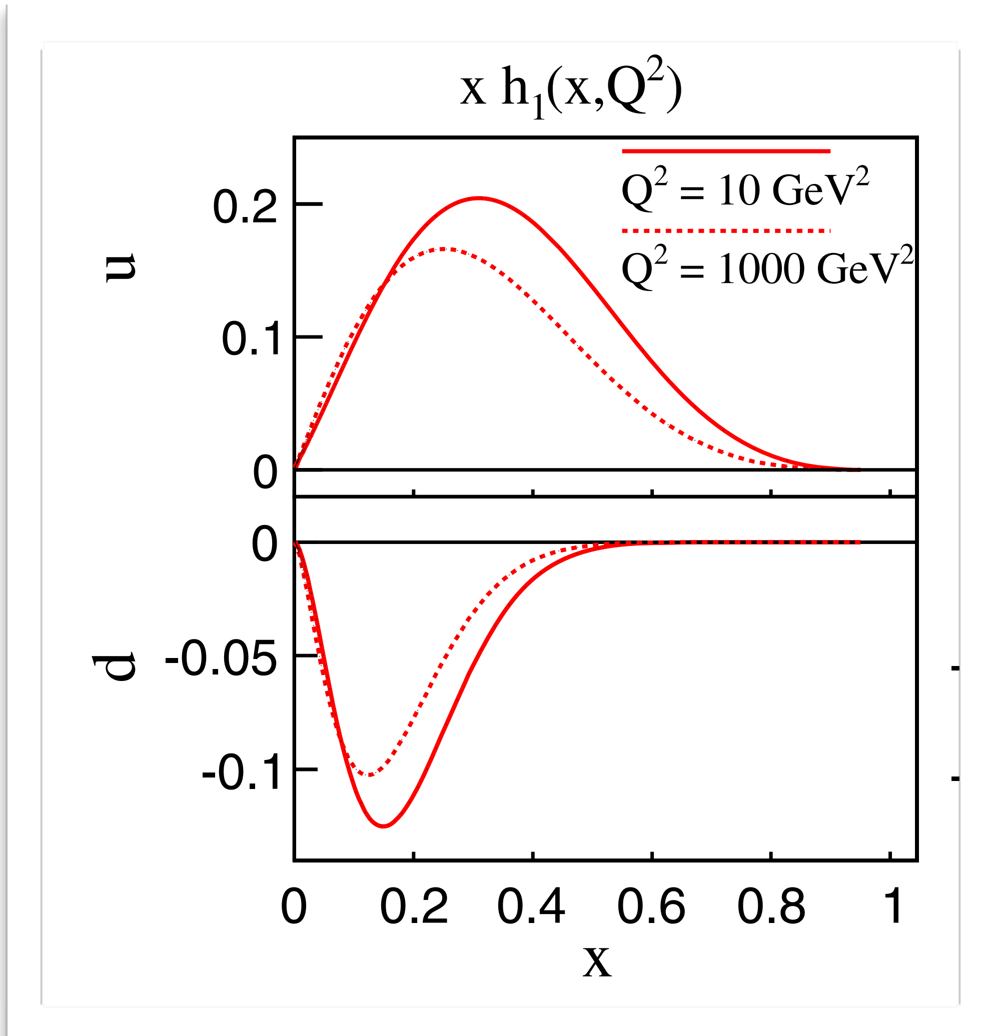

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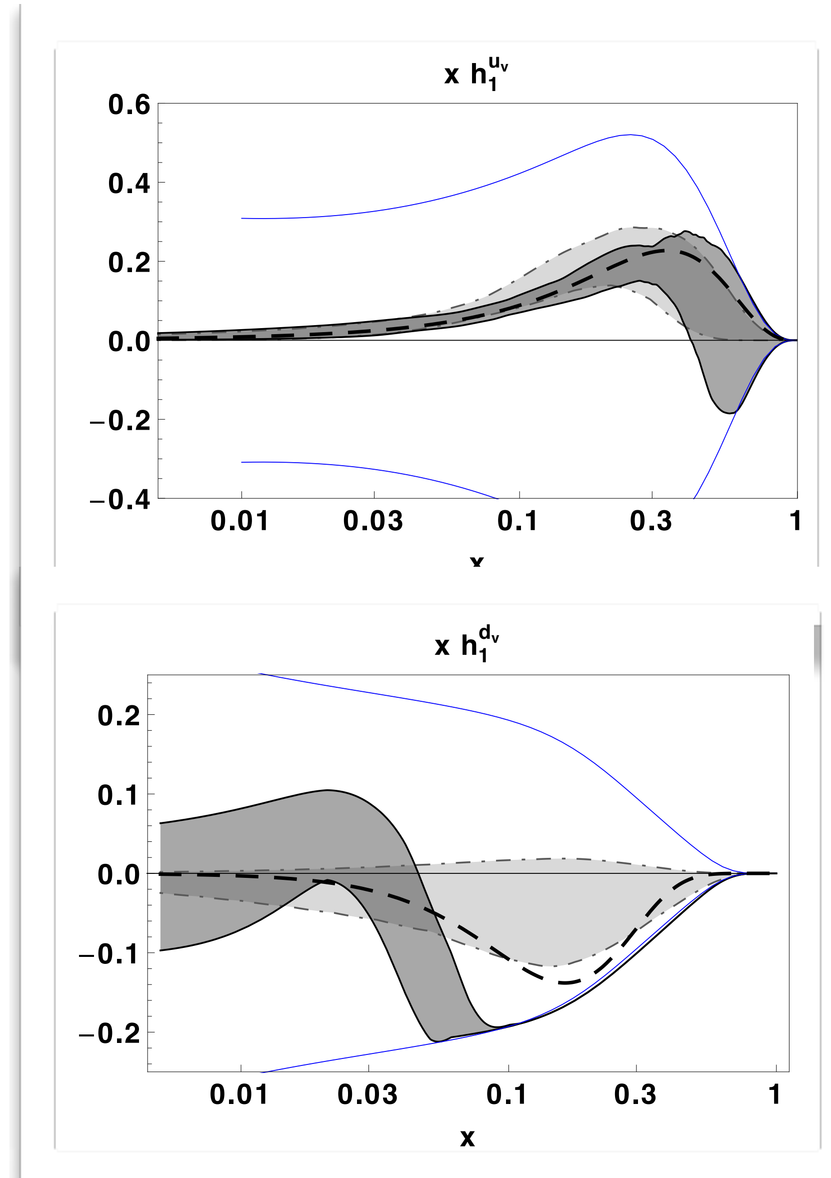

This talk

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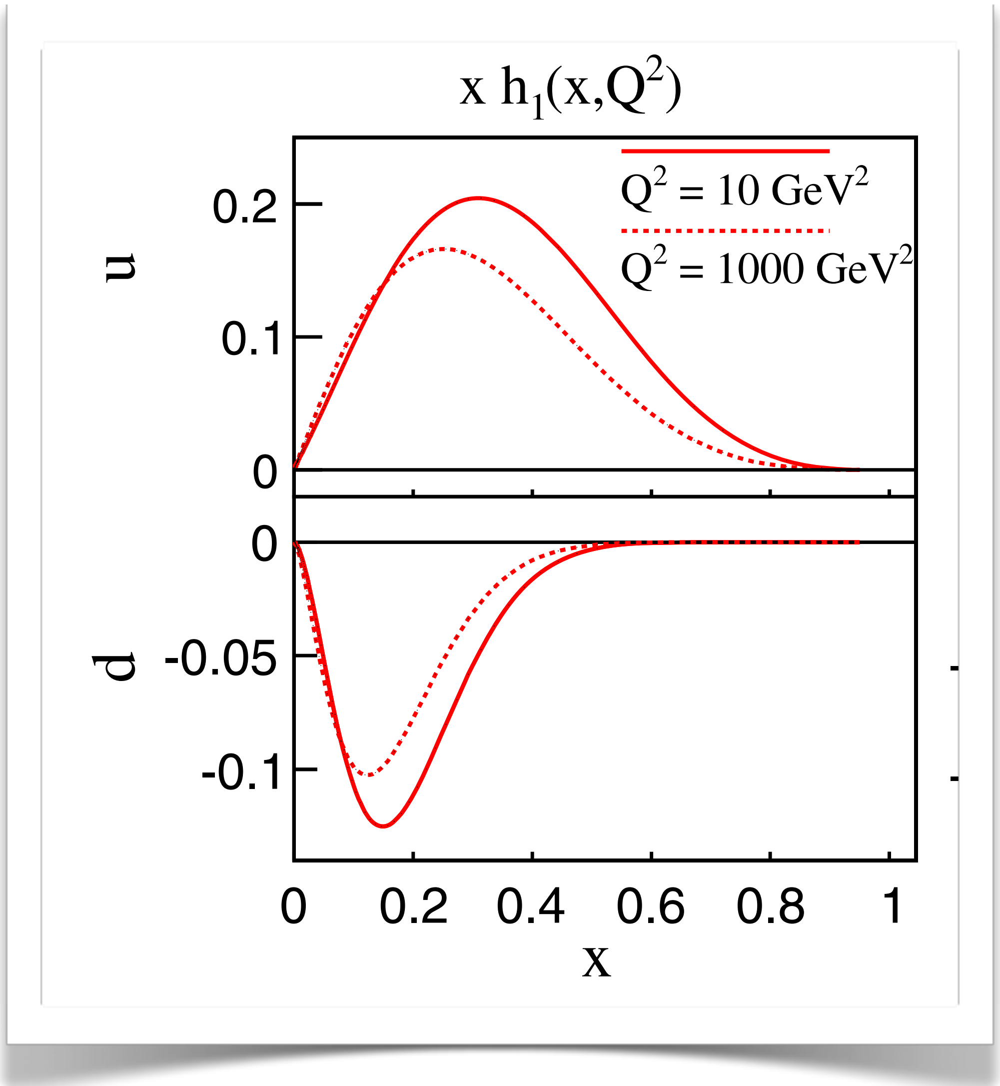
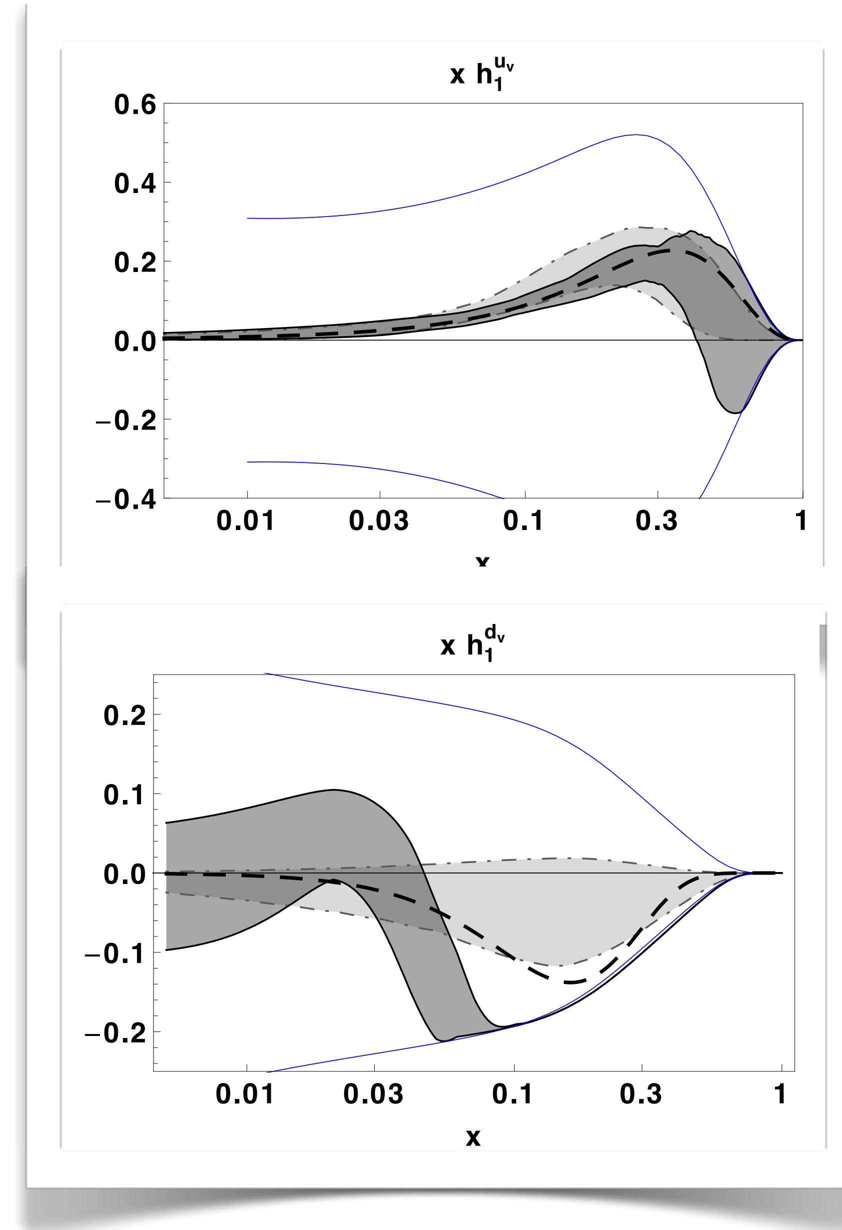
Extractions of transversity





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This talk

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State-of-the-art: Extractions of transversity

Pavia 15
1503.03495
Submitted to JHEP

Two complementary approaches

- partner of Collins FF
- convolution

$$\boxed{\int d^2\mathbf{p}_T d^2\mathbf{k}_T\, \delta^2(\mathbf{k}_T + \mathbf{q}_T - \mathbf{p}_T)\, h_1(x, k_T)\, H_1^{\perp}(z, p_T)}$$

- QCD evolution: TMD evolution
- ongoing progresses

[Rogers, Aybat, Prokudin, Bacchetta,...]

- need input Functional Form of the transversity

- partner of chiral-odd DiFF
- simple product

$$\boxed{h_1(x)\, H_1^{\sphericalangle}(z, M_h)}$$

- QCD evolution: DGLAP evolution
- known

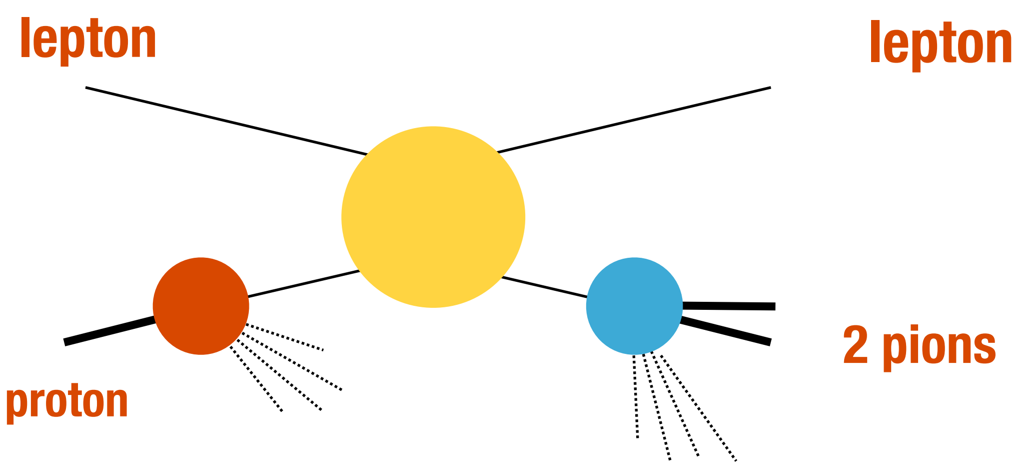
[Bacchetta, Radici, Ceccopieri]

- no need for input Functional Form of the transversity
- direct extraction point by point

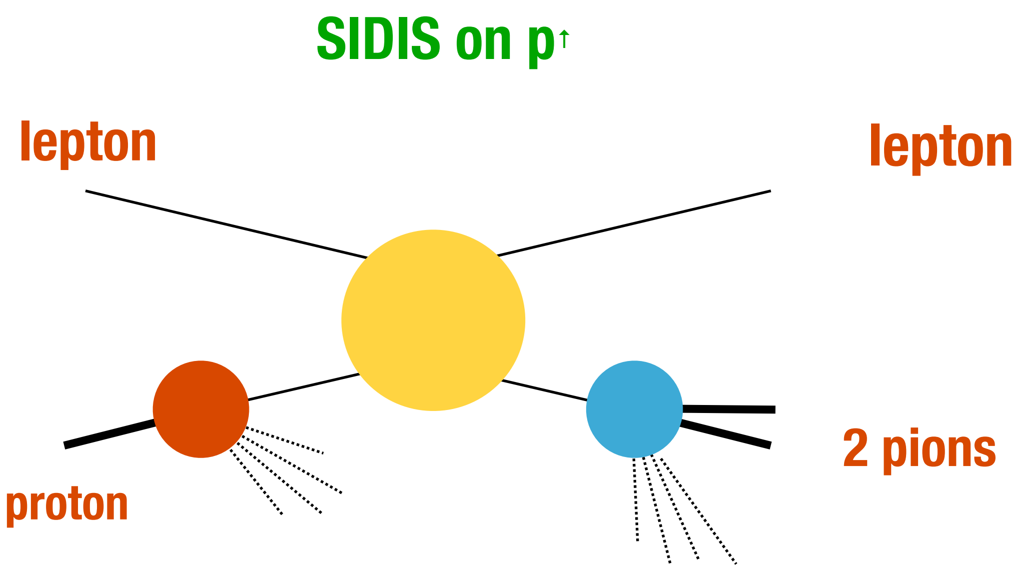
Frameworks for DiFFs

Frameworks for DiFFs

SIDIS on p↑



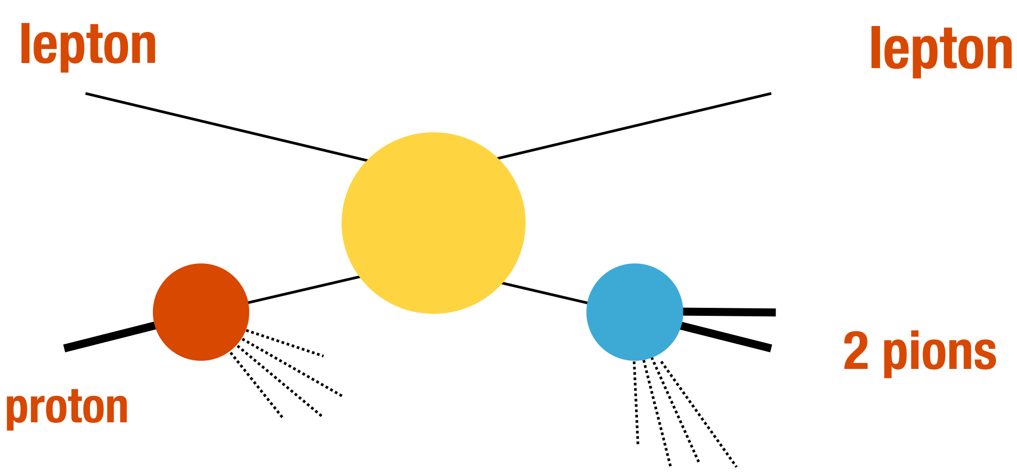
Frameworks for DiFFs



Talks by
N. Makke
C. Braun
S. Gliske

Frameworks for DiFFs

SIDIS on $p^{\uparrow}$



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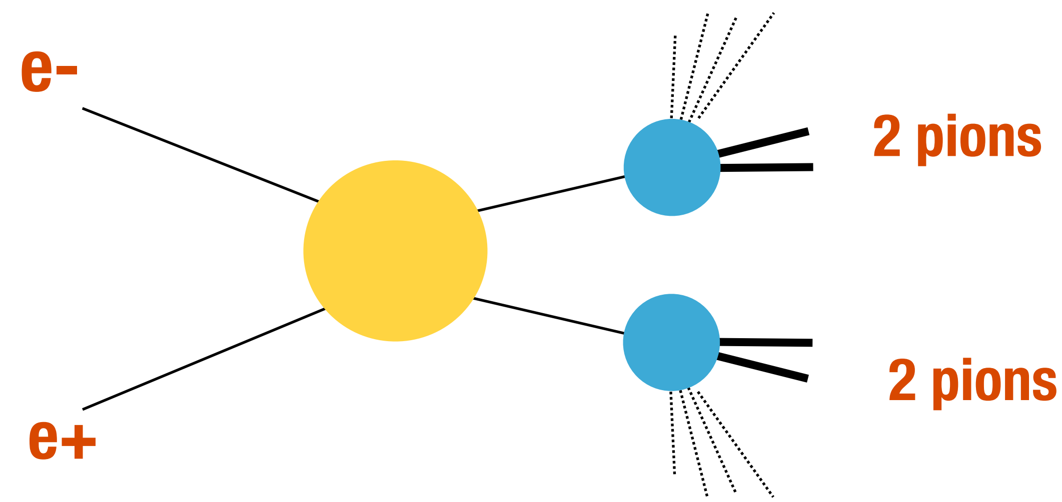
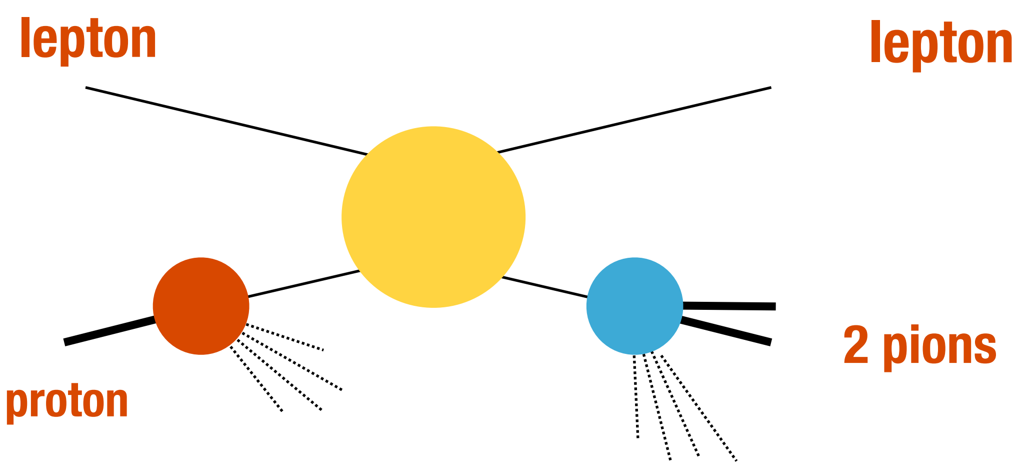
$e^{+}e^{-}$ to pion pairs



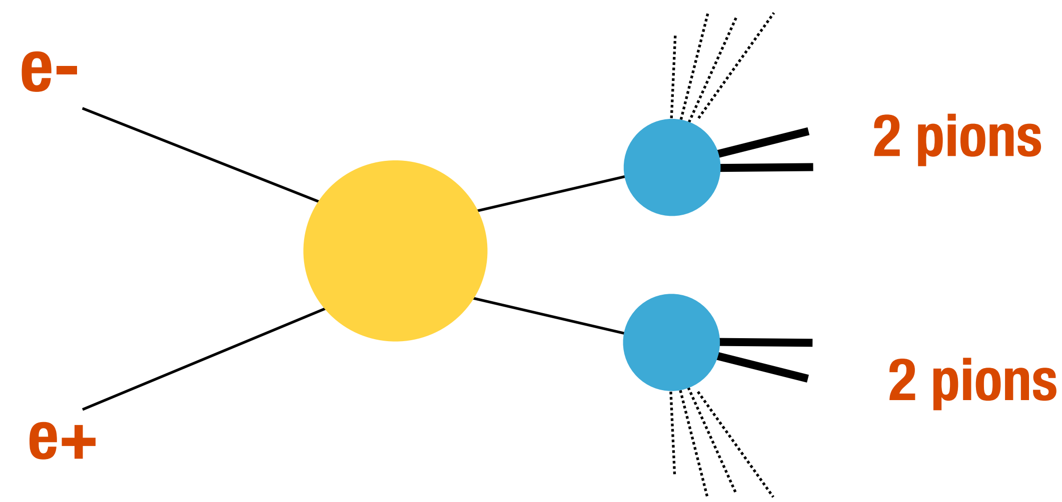
Frameworks for DiFFs

SIDIS on p$^{\uparrow}$



Talks by
N. Makke
C. Braun
S. Gliske

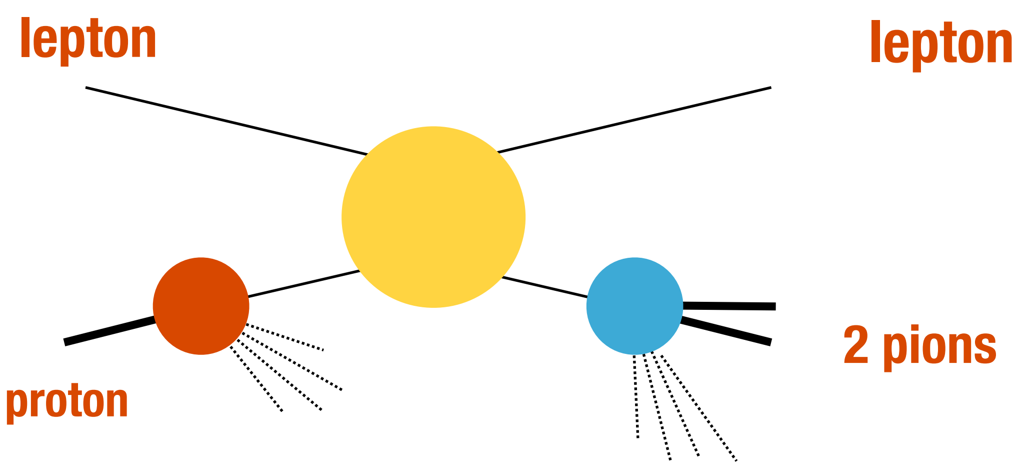
e^+e^- to pion pairs



Talk by
I. Garzia

Frameworks for DiFFs

SIDIS on p↑



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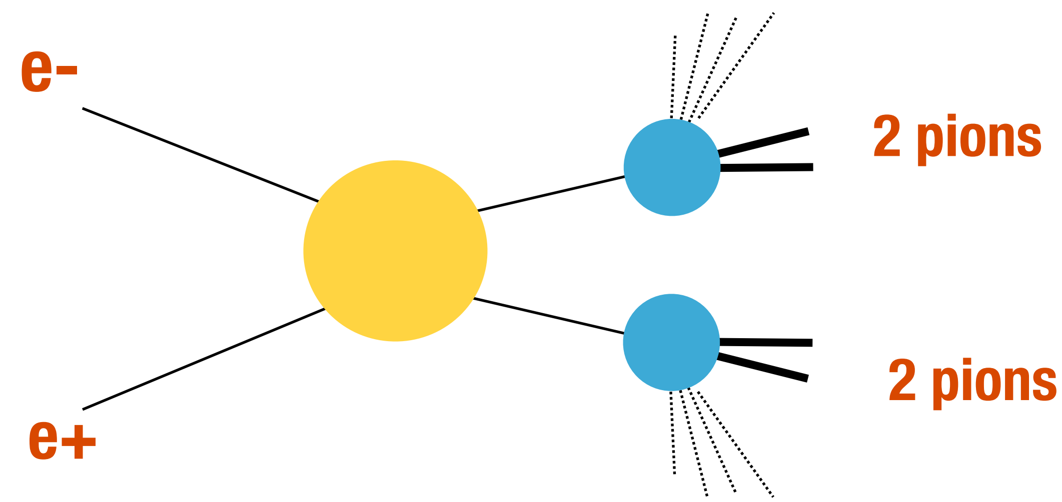

Talk by
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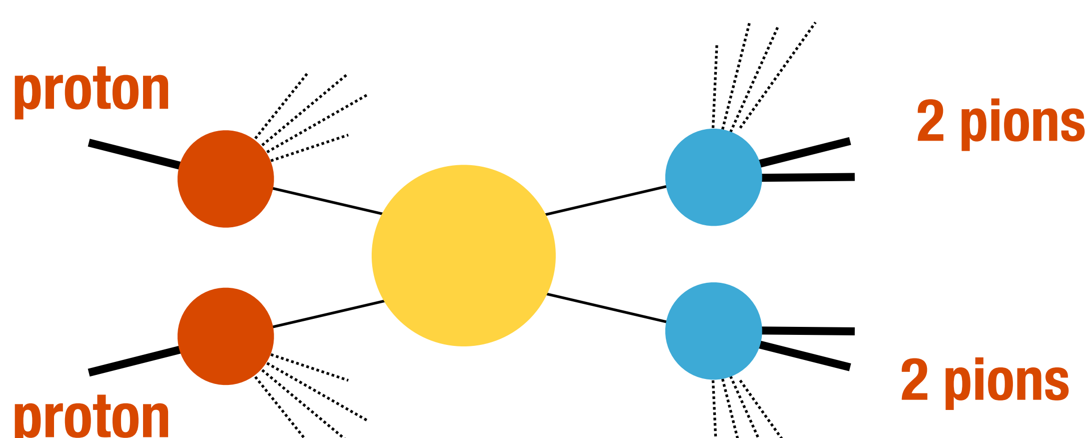
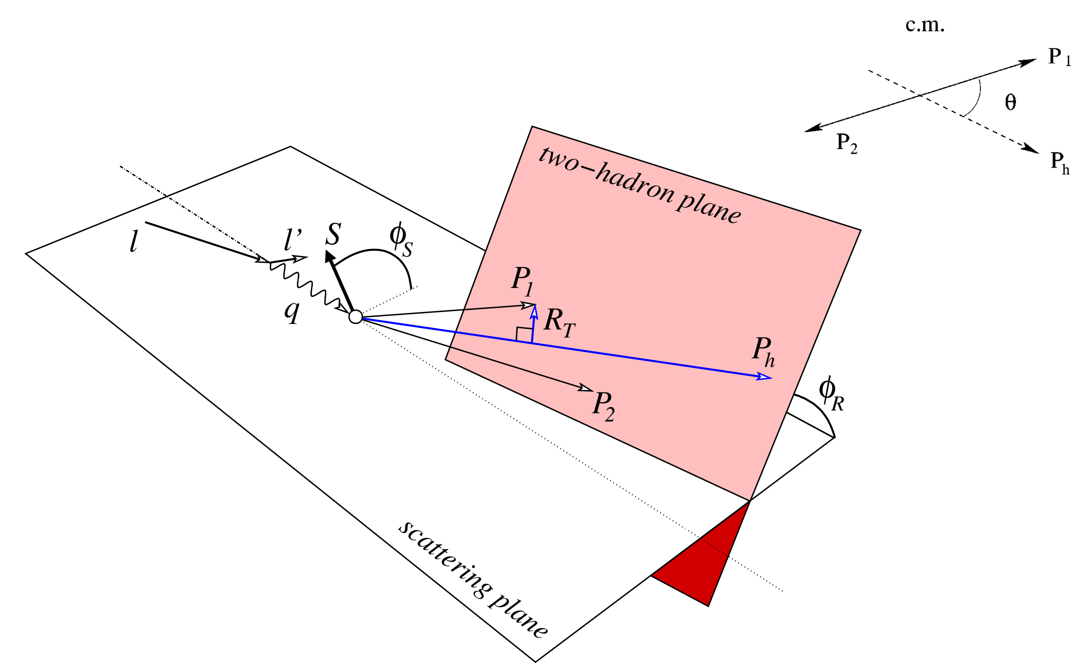
pp↑ to pion pairs



SIDIS production of pion pairs



Chiral-odd DiFF:

Distribution of hadrons inside the jet

is related to the

Direction of the transverse polarization of the fragmenting quarks

$$A_{\mathrm{DIS}}(x,z,M_h^2,Q^2) = -C_y \frac{\sum_q e_q^2\, h_1^q(x,Q^2)\, \frac{|\bar{R}|}{M_h}\, H_{1,sp}^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}{\sum_q e_q^2\, f_1^q(x,Q^2) \quad D_1^{q\to\pi^+\pi^-}(z,M_h^2,Q^2)}$$

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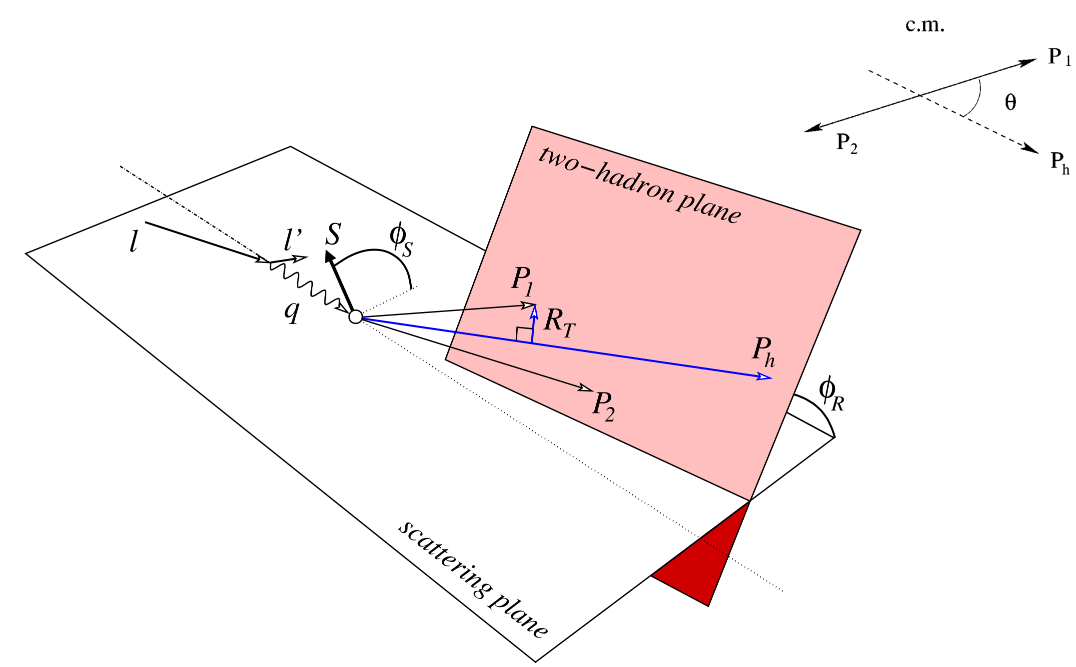

$$A_{\mathrm{DIS}}(x, z, M_h^2, Q^2) = -C_y \, \frac{\sum_q e_q^2 \, \boxed{h_1^q(x, Q^2)} \, \frac{|\bar{R}|}{M_h} \, H_{1,sp}^{q \to \pi^+\pi^-}(z, M_h^2, Q^2)}{\sum_q e_q^2 \, f_1^q(x, Q^2) \, D_1^{q \to \pi^+\pi^-}(z, M_h^2, Q^2)}$$

Knowledge on DiFFs leads to $h_1(x, Q^2)$

Fitting the Valence Transversities

Fitting the Valence Transversities

Constraints from first principles

✦ Soffer bound

$$2|h_1^q(x,Q^2)| \leq |f_1^q(x,Q^2) + g_1^q(x,Q^2)| \equiv 2\,\mathrm{SB}^q(x,Q^2)$$

✦ $h_1(x=1)=0$; the parton model predicts $h_1(x=0)=0$ but too restrictive in QCD

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QCD evolution with HOPPET code

✦ of the Soffer bound: LO evolution of $f_1(x)$ from MSTW08 & $g_1(x)$ from DSS

✦ of the DiFF & h_1: LO as in previous papers

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Choice of Functional Form ⟵ the CRUCIAL point for further uses

$$x\, h_1^{q_V}(x,Q_0^2) = FF(\mathrm{param},x,Q_0^2)\,\left(x\,\mathrm{SB}^q(x,Q_0^2) + x\,\mathrm{SB}^{\bar{q}}(x,Q_0^2)\right)$$

with FF defined [-1,1]

Fitting the Valence Transversities

Constraints from first principles

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Transversity from e p$^{\uparrow}$→e' ($\pi^+\pi^-$) X @ HERMES

$$x h_1^{u_v}(x,Q^2) - \frac{1}{4}\, x h_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\mathrm{DIS}}(x,Q^2)\, \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar{q}}(x,Q^2)$$

with 1-to-100 GeV^2 evolution correction: small corrections

HERMES range: -0.259^{-1} (± 25% theo. err.) from fit

integrated in mean values

Transversity from e p$^\uparrow$→e' ($\pi^+\pi^-$) X @ HERMES

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integrated in mean values

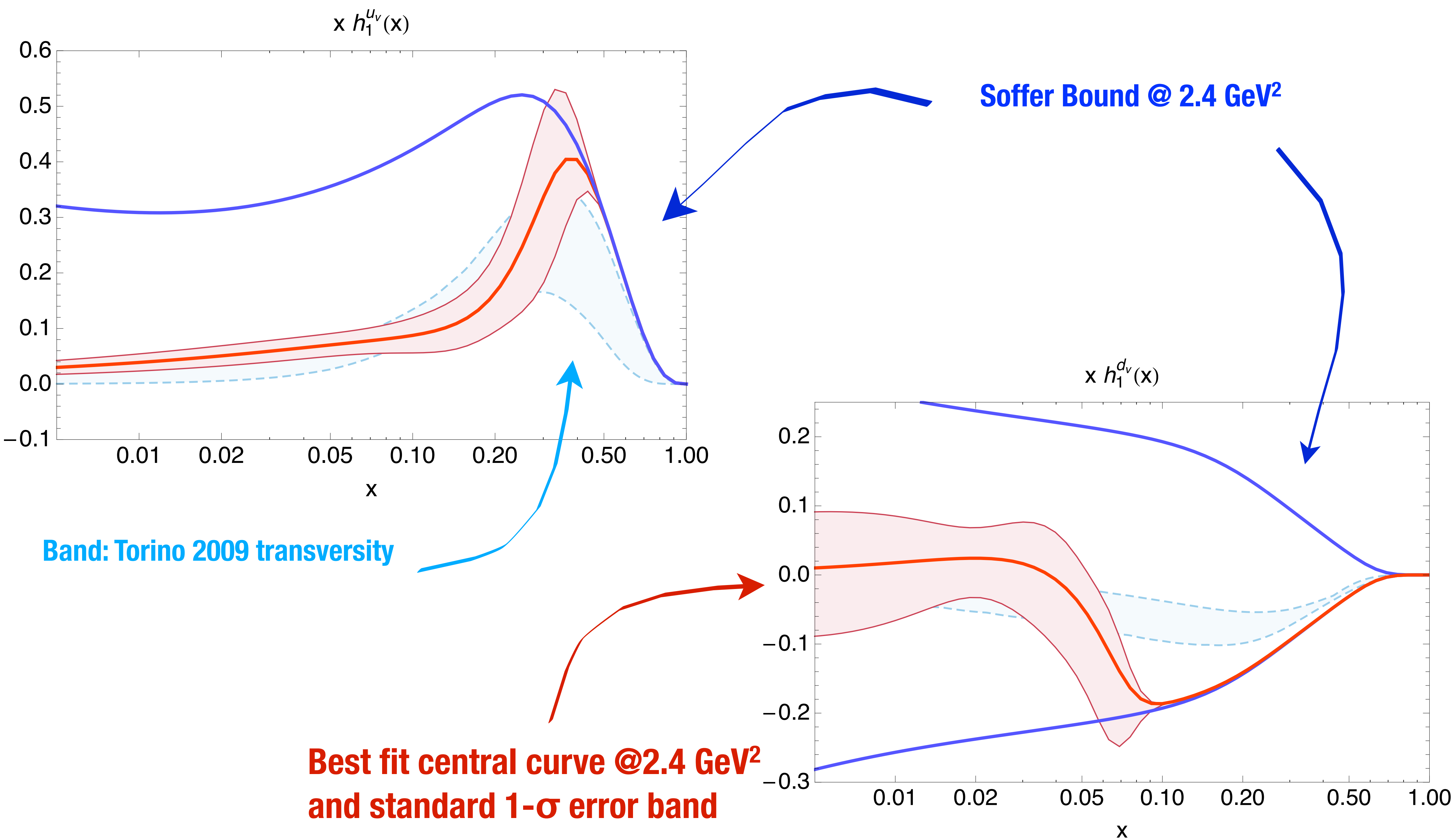
Transversity from e p$^\uparrow$→e' ($\pi^+\pi^-$) X @ COMPASS 2007

$$x h_1^{u_v}(x,Q^2) - \tfrac{1}{4}\, x h_1^{d_v}(x,Q^2) = -C_y^{-1}\, A_{\rm DIS}(x,Q^2)\, \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} \sum_{q=u,d,s} \frac{e_q^2}{e_u^2}\, x f_1^{q+\bar q}(x,Q^2)$$

with 1-to-100 GeV^2 evolution correction: negligible corrections

COMPASS range: -0.208^{-1} (± 19% theo. err.) from fit

Our Flexible Functional Form *2nd order polynomial*



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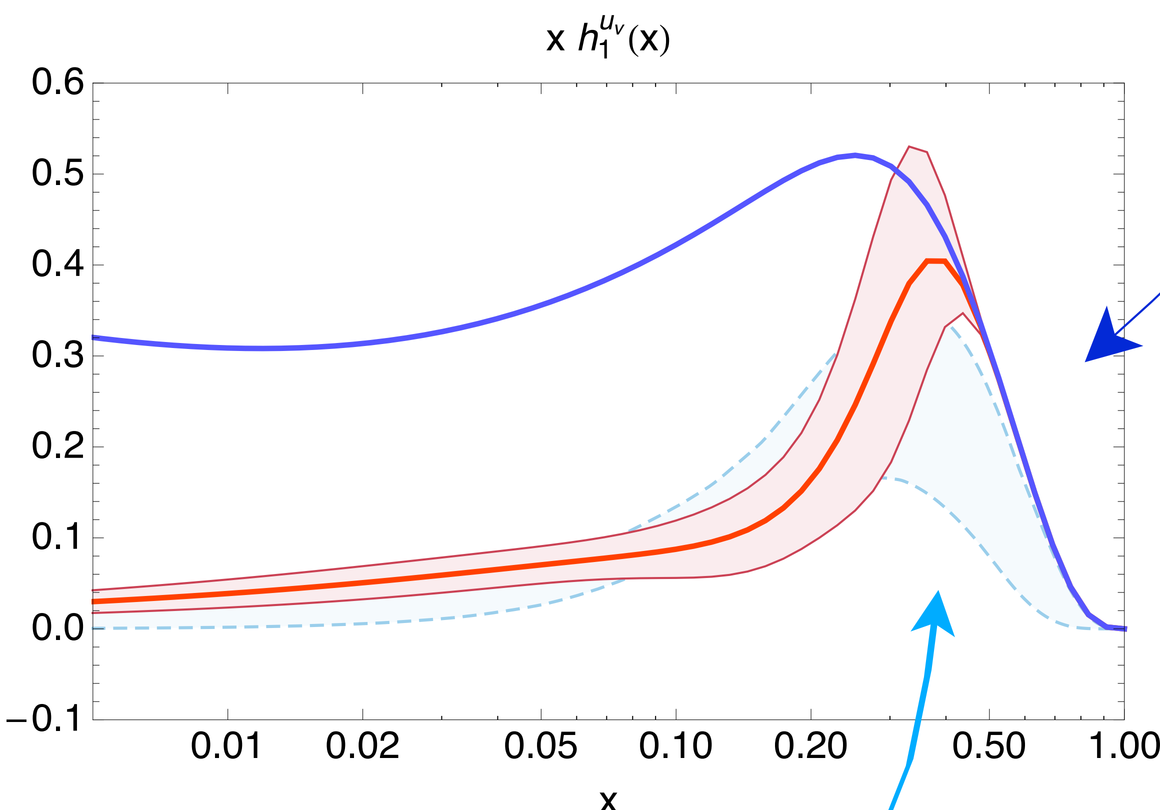
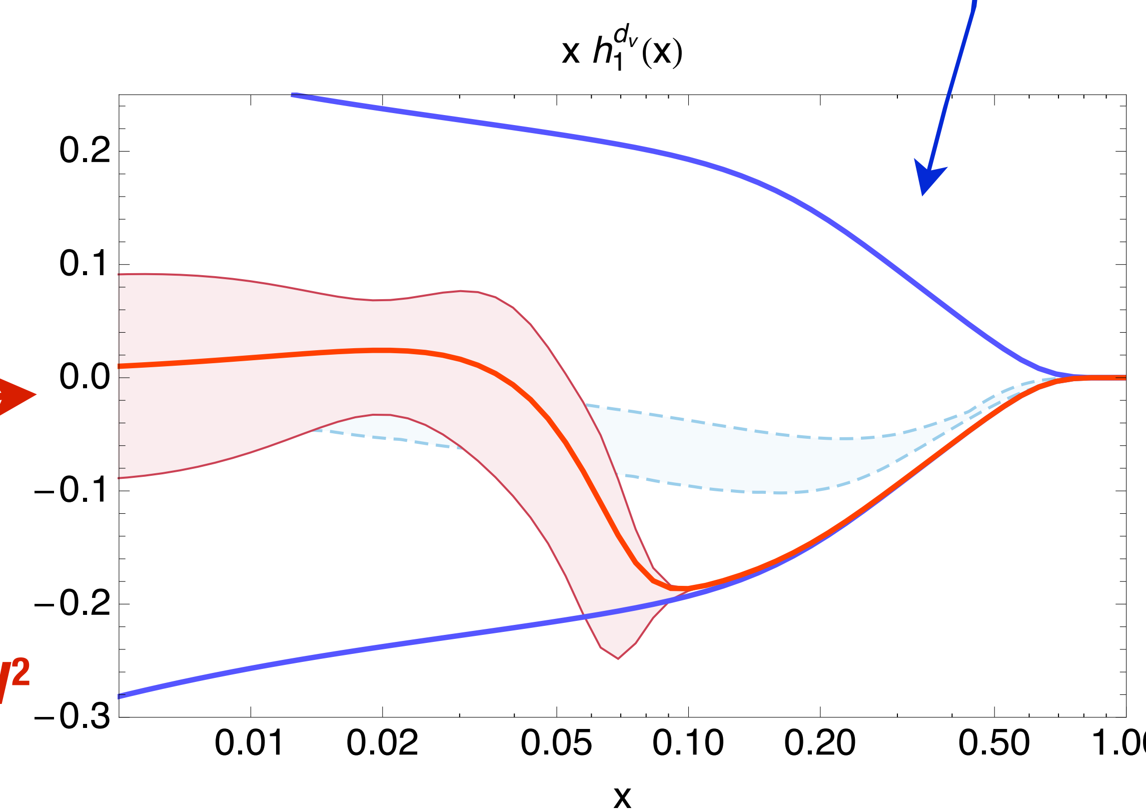
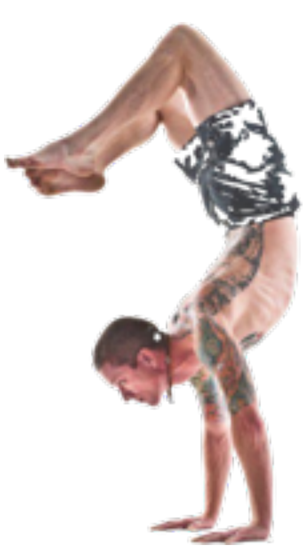


Soffer Bound @ 2.4 GeV^2



Band: Torino 2009 transversity



Best fit central curve @2.4 GeV^2
and standard 1-σ error band

Flexible version

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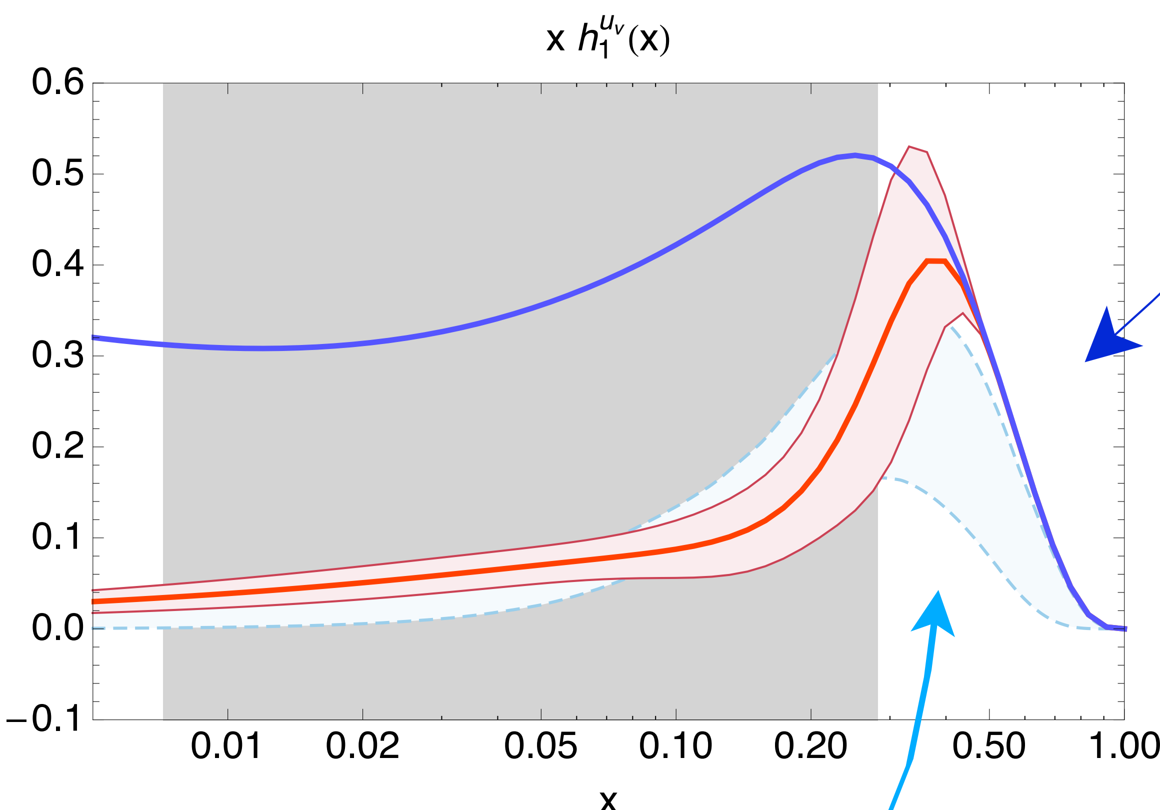

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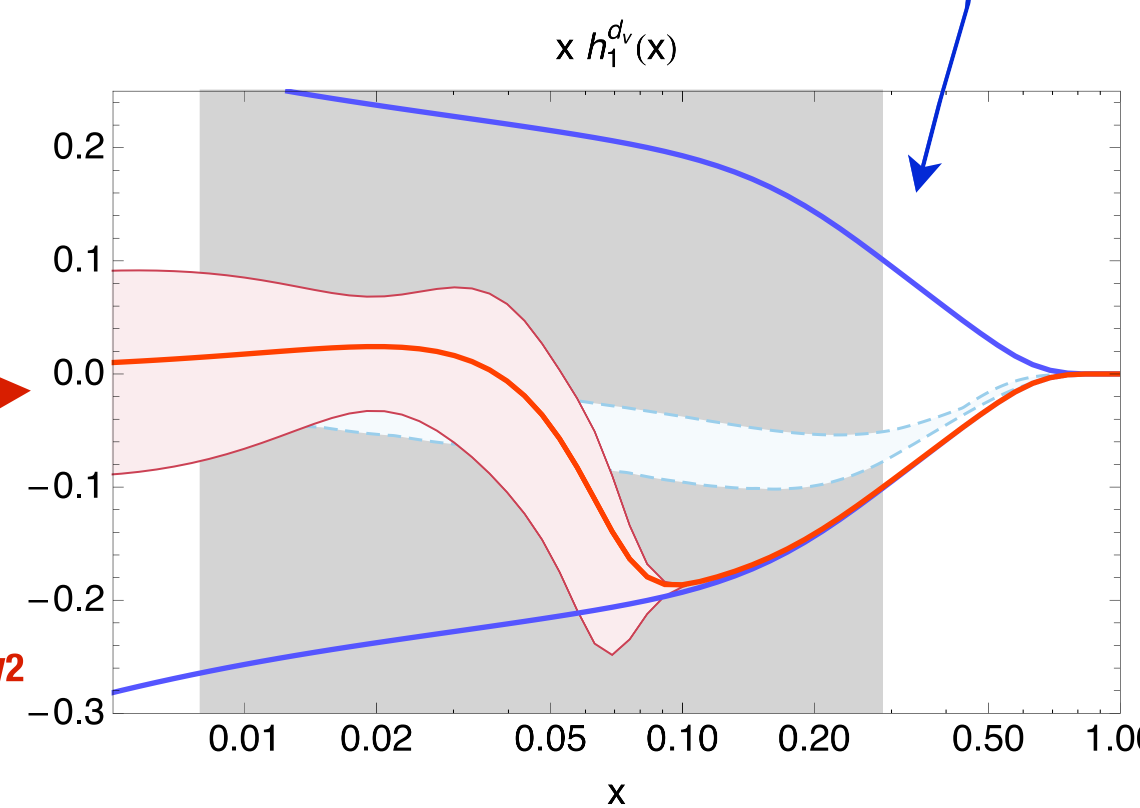

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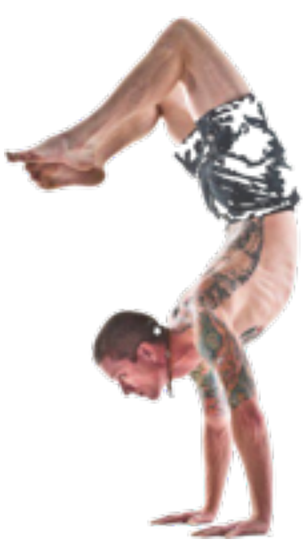
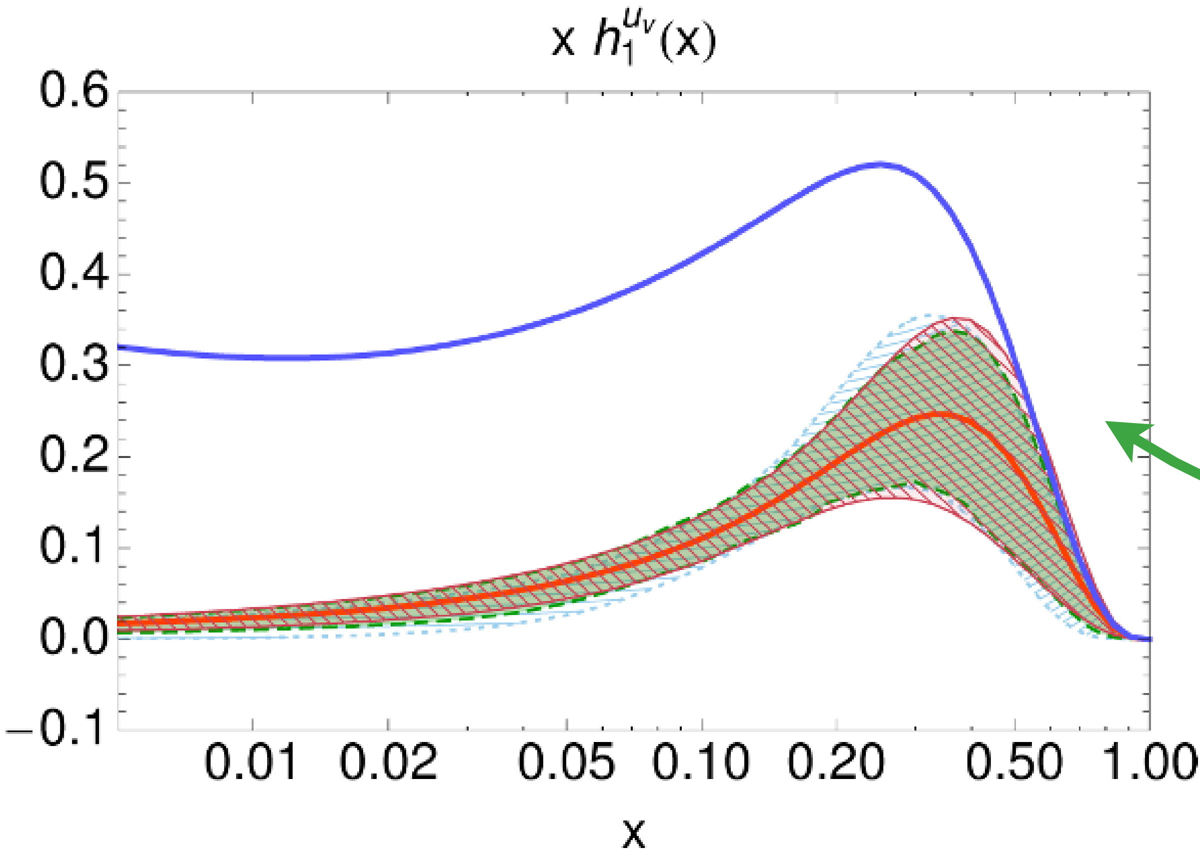


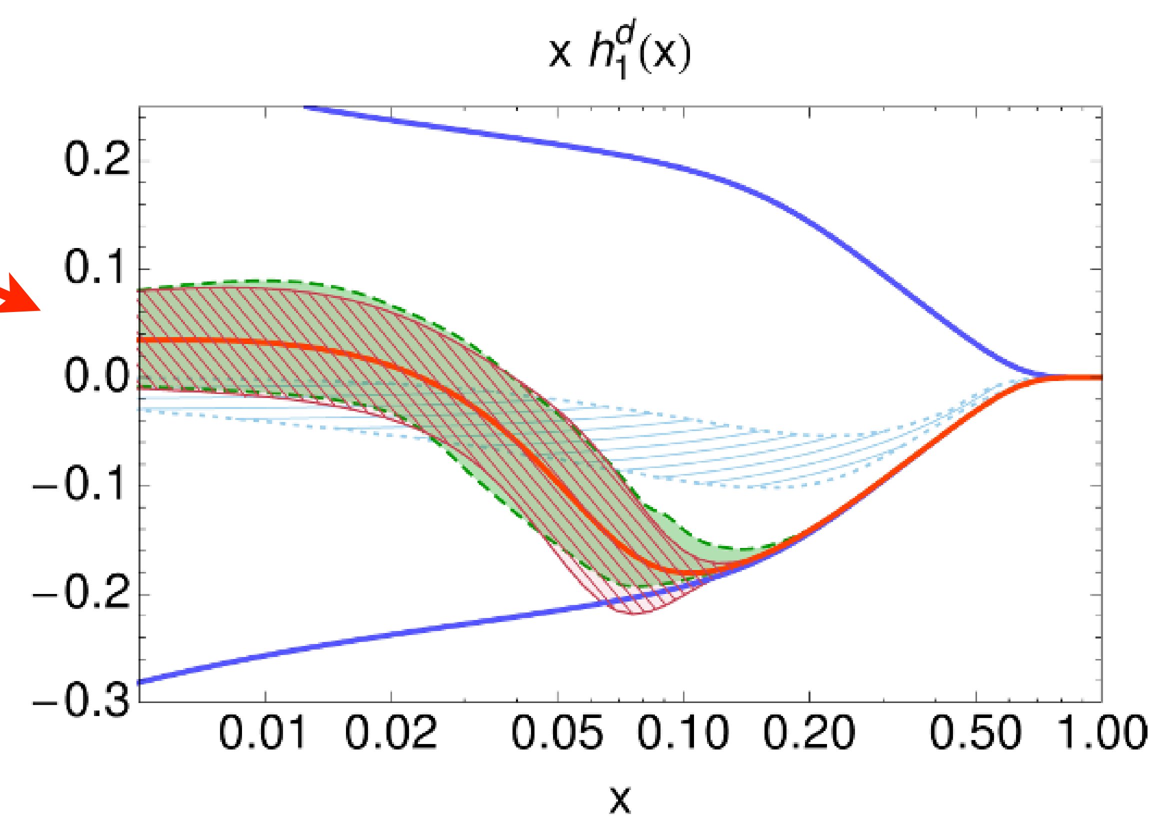
Flexible version

The Error Analysis: *the Monte Carlo approach*

1st order polynomial



1σ error band from replicas @2.4 GeV^2



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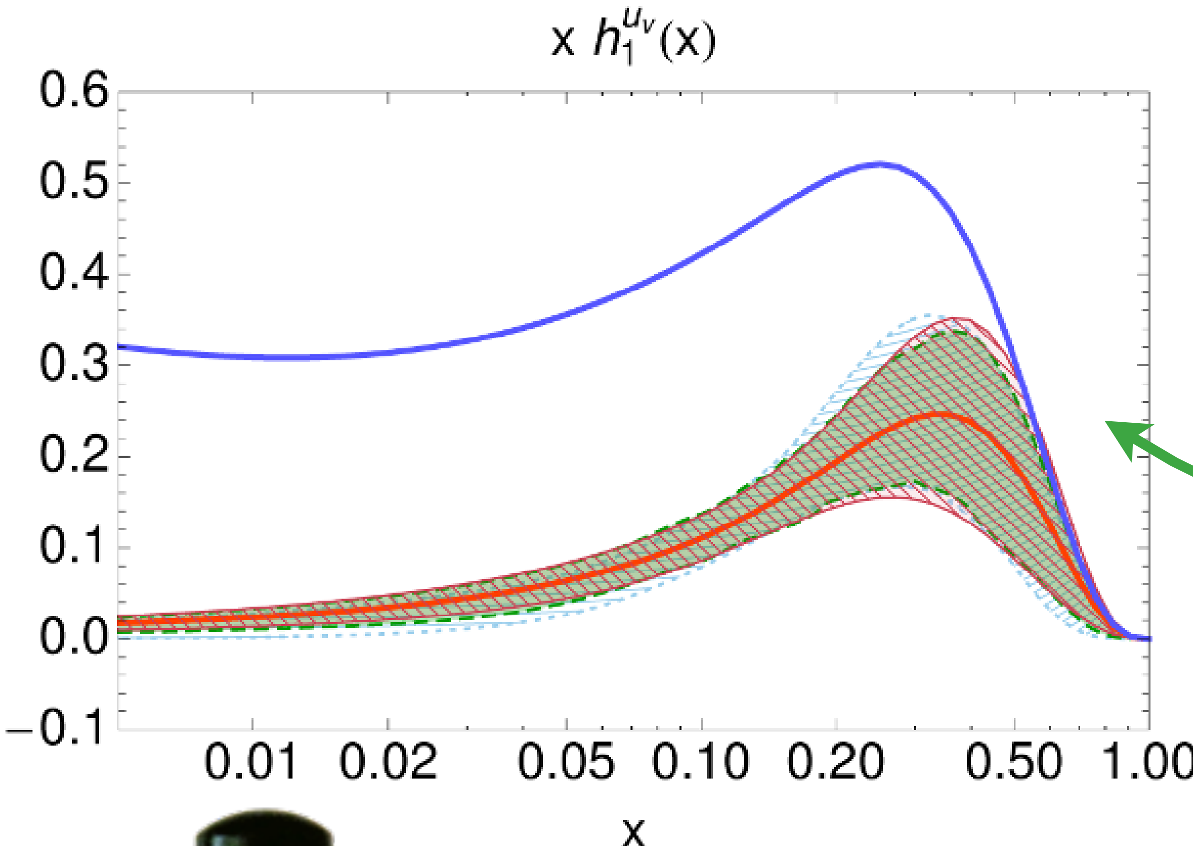
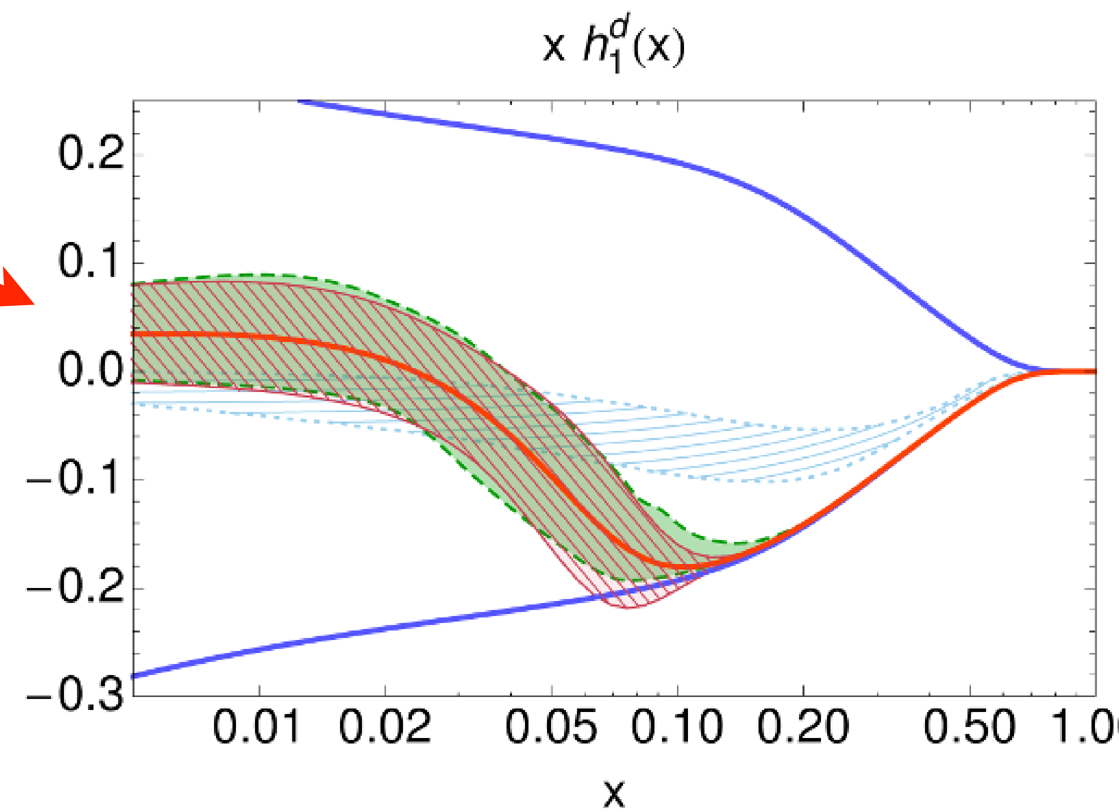


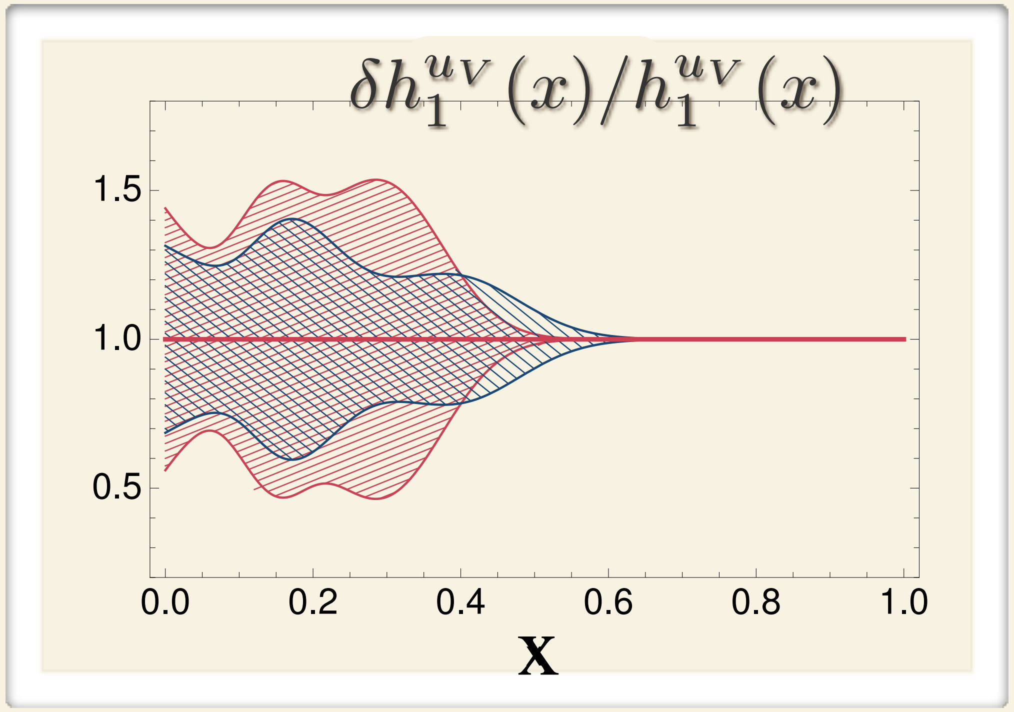
1σ error band from replicas @2.4 GeV²

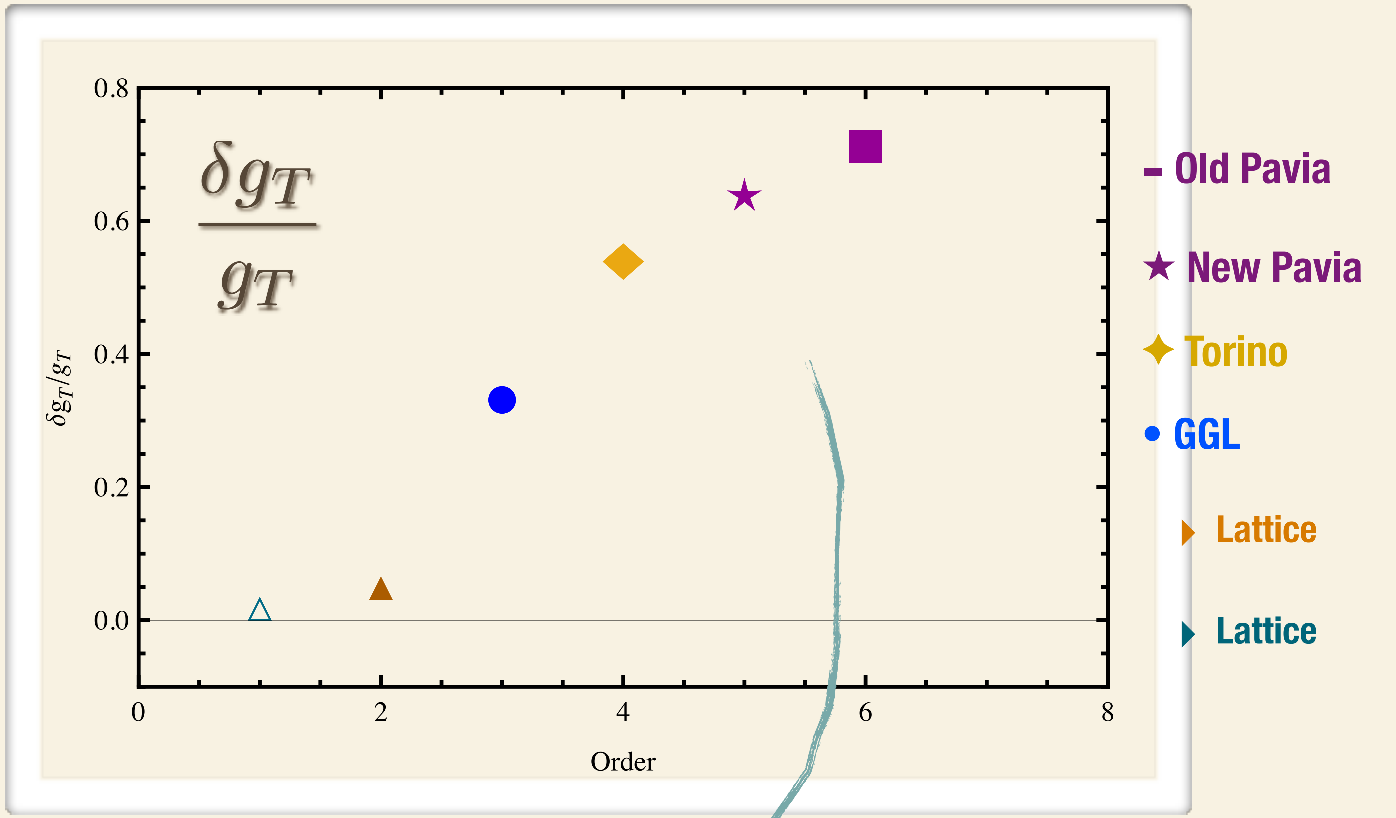
Best fit central curve @2.4 GeV²
and standard 1σ error band

Rigid version



ESTIMATES FROM EXPERIMENTAL PROJECTIONS

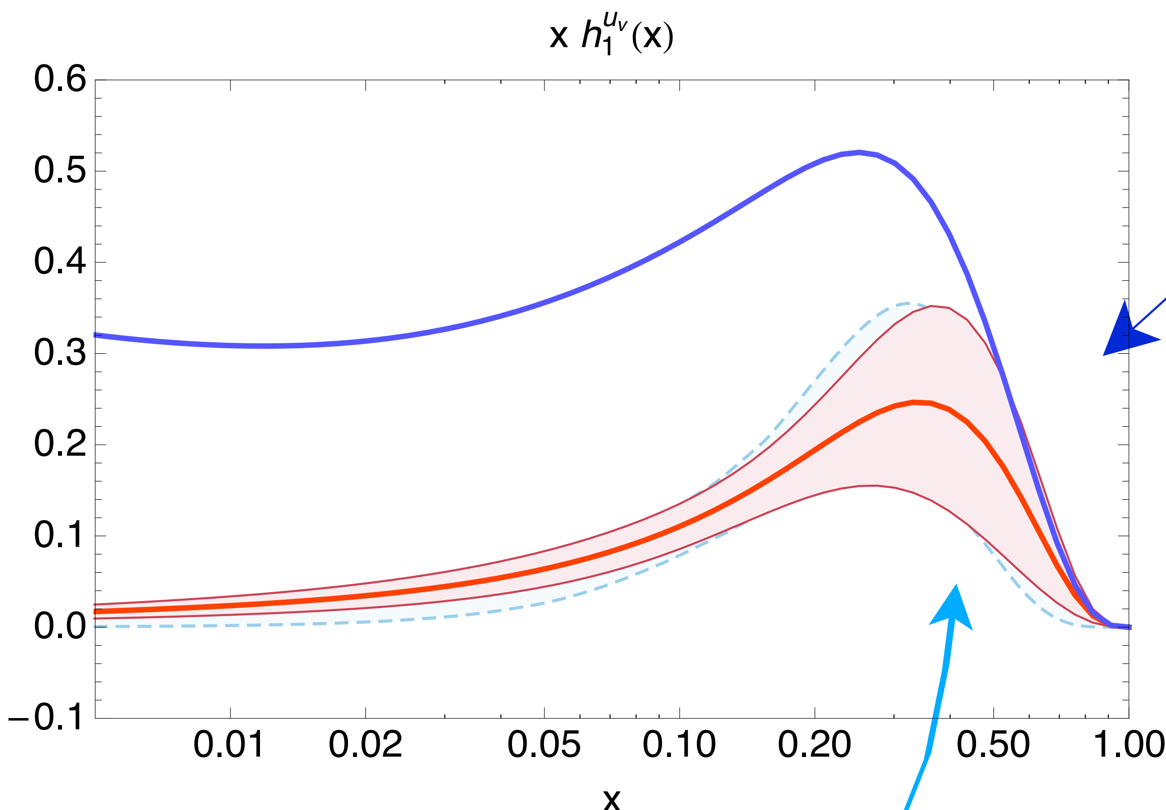




- old Pavia fit with artificial data in future range
- includes both CLAS12 on proton and SoLID on neutron
- to be up-dated with new Pavia fit

[A.C.,González-Alonso, Liuti, in progress]

Our Rigid Functional Form *1st order polynomial*



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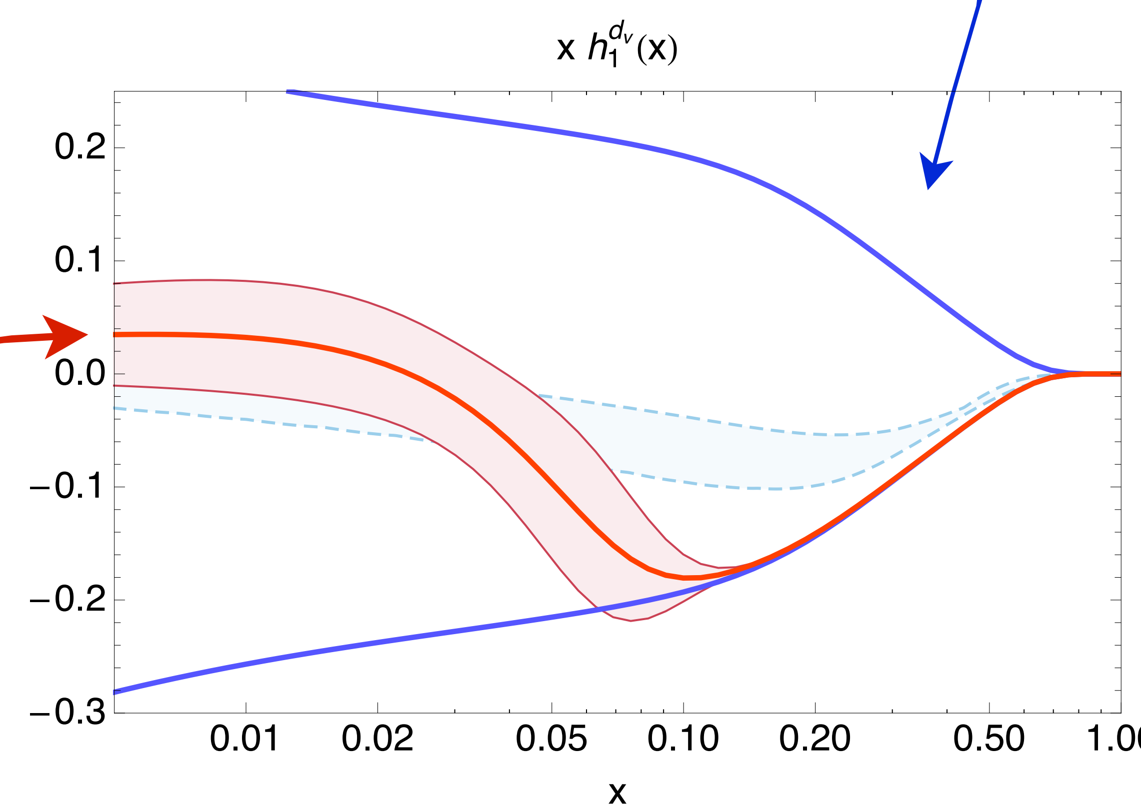

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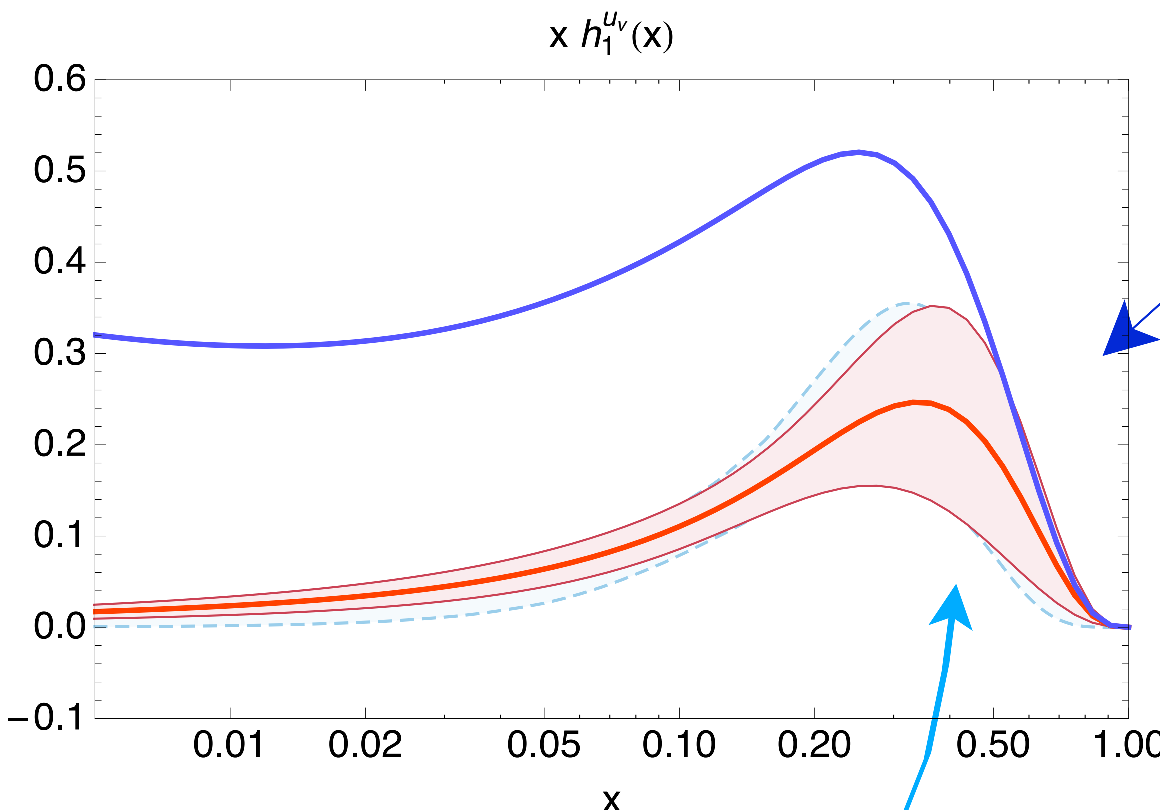

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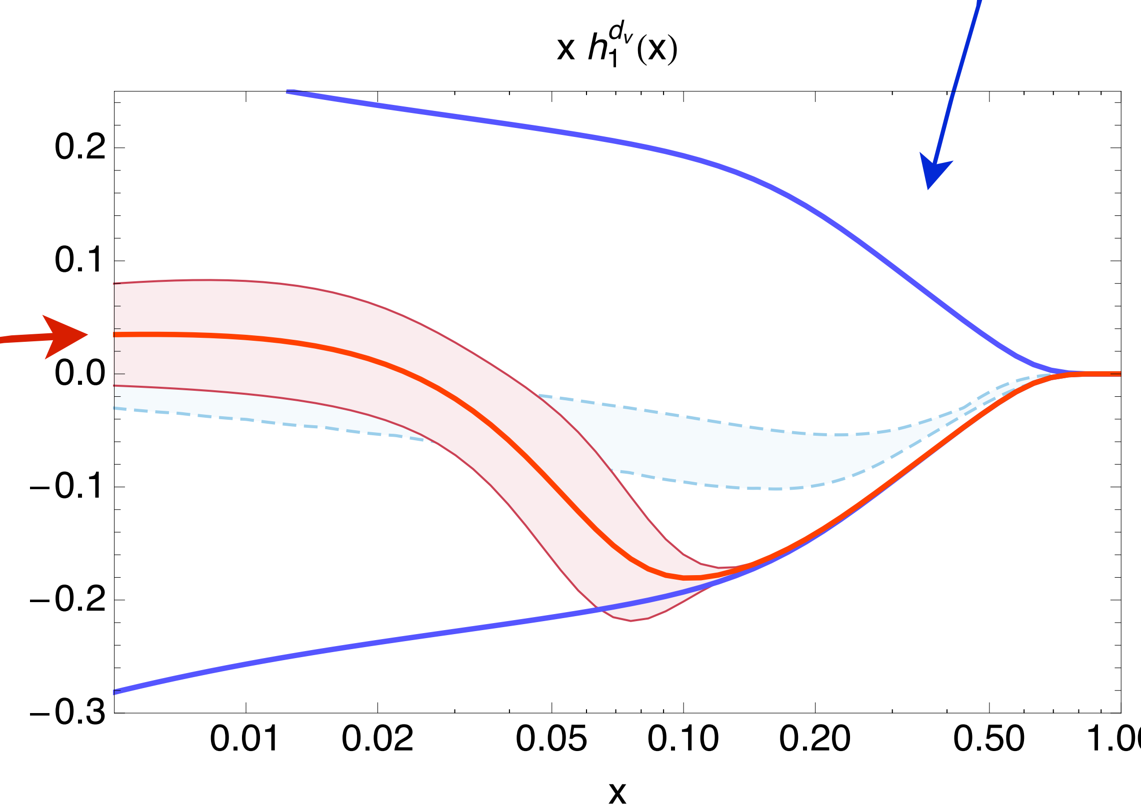

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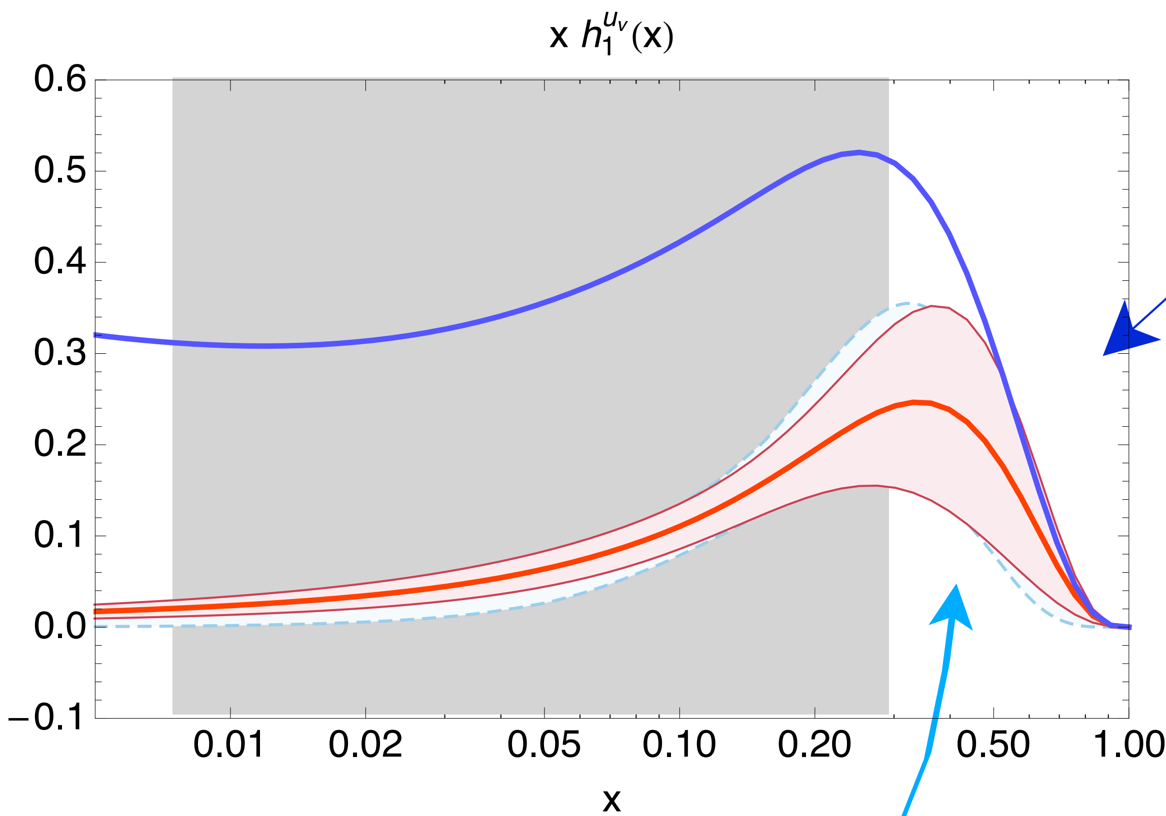

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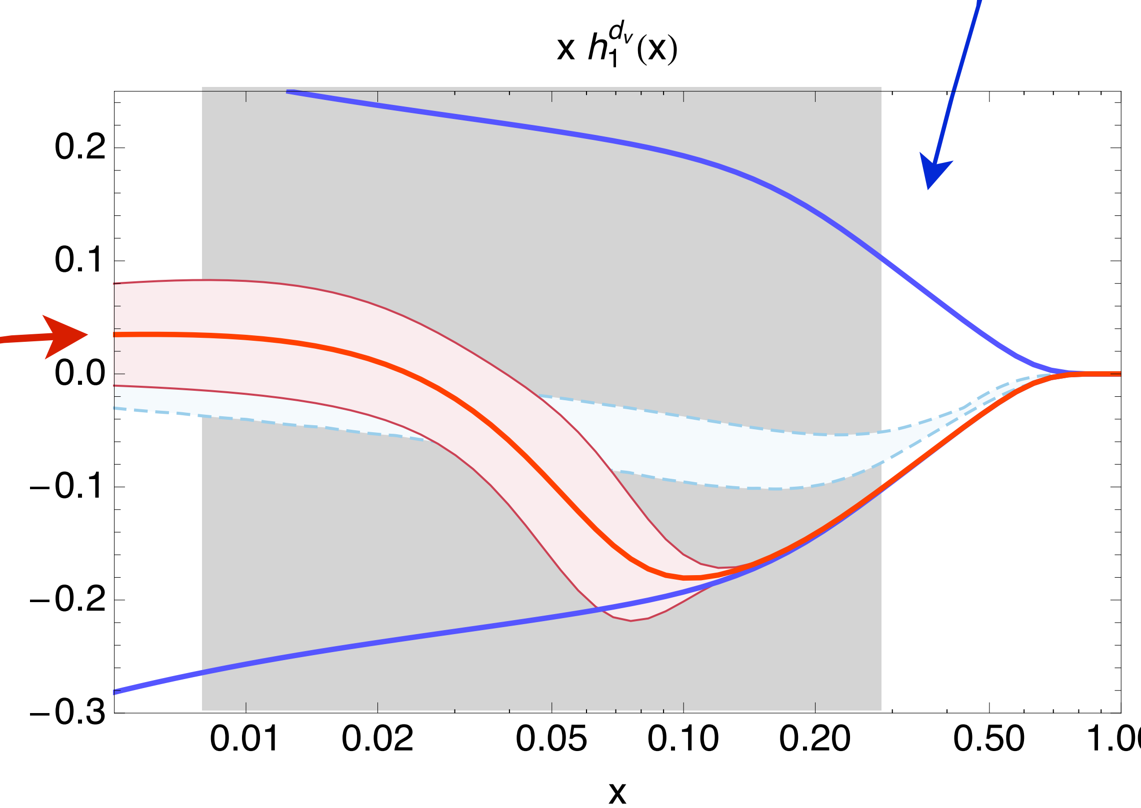

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Rigid version

Dihadron SIDIS

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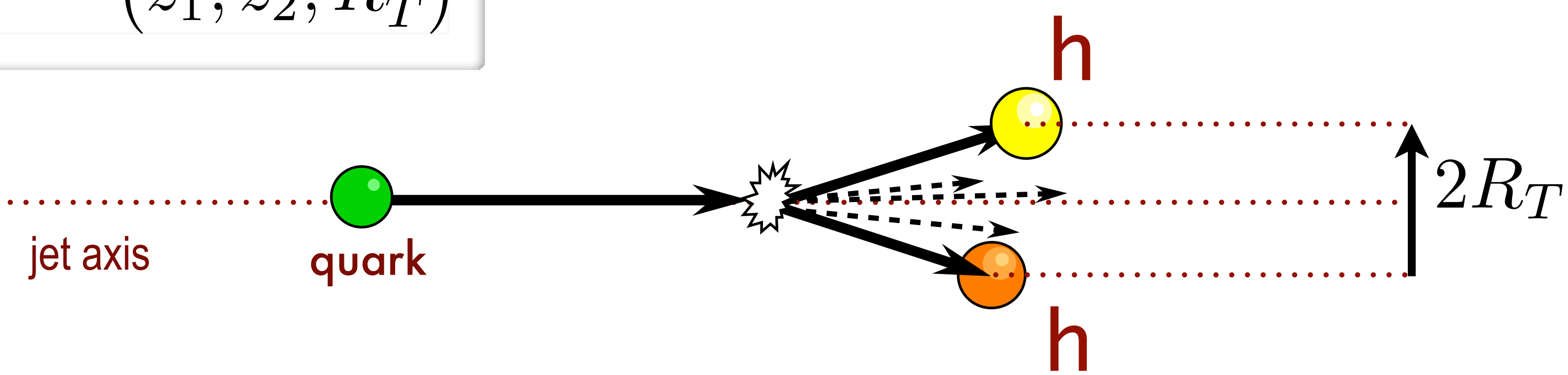
Collinear factorization

$$D_1^{q\to h_1 h_2}\left(z_1, z_2, R_T^2\right)$$



Here: $D_1^{q\to\pi^+\pi^-}(z, M_h)$ $z = z_1 + z_2$ $2\,|\mathbf{R}| = \sqrt{M_h^2 - 4m_\pi^2}$

Dihadron SIDIS

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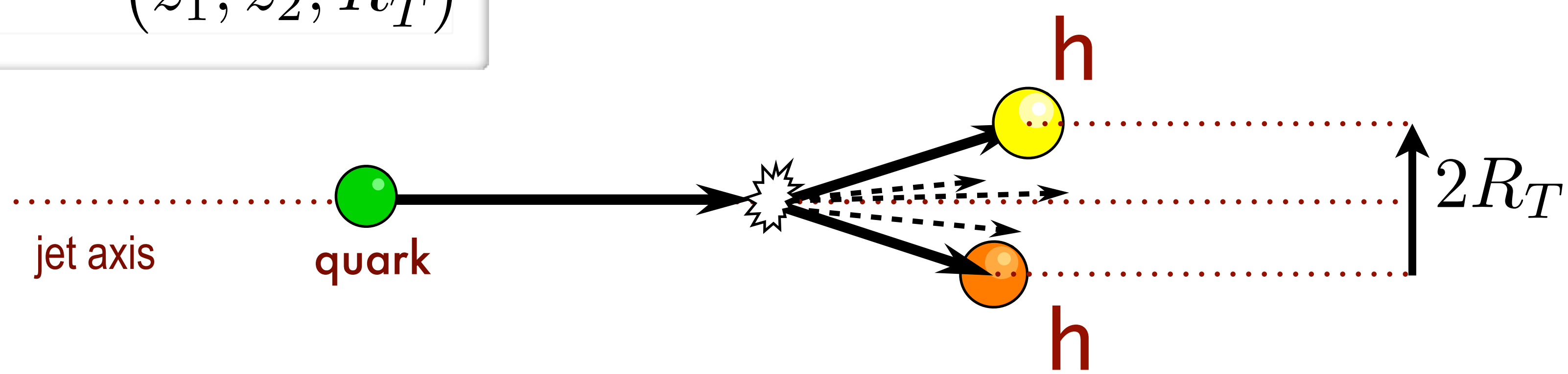

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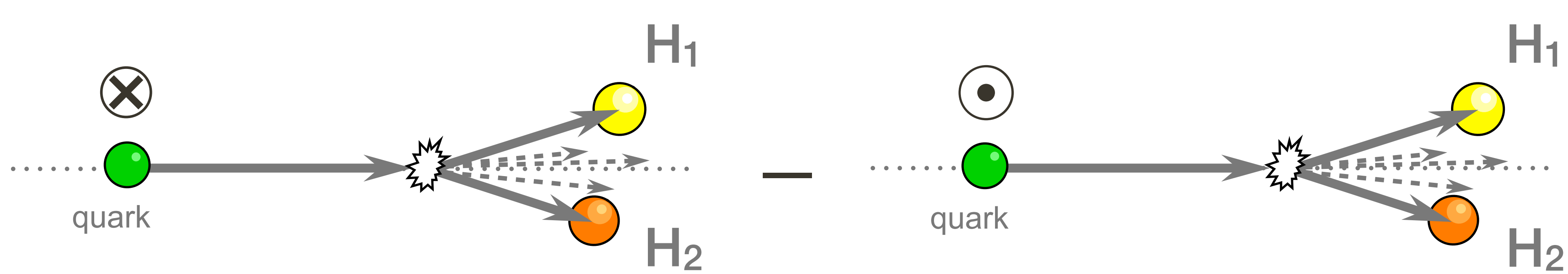
$$H_1^{\sphericalangle\, q\to H_1 H_2}(z_1, z_2, R_T^2)$$



transverse pol. of the fragm. quark ↔ angular distribution of hadron pairs in the transverse plane