Extraction of Transversity and Collins functions

DIS 2013

Stefano Melis
Dipartimento di Fisica, Universita' di Torino
&INFN, Sezione di Torino

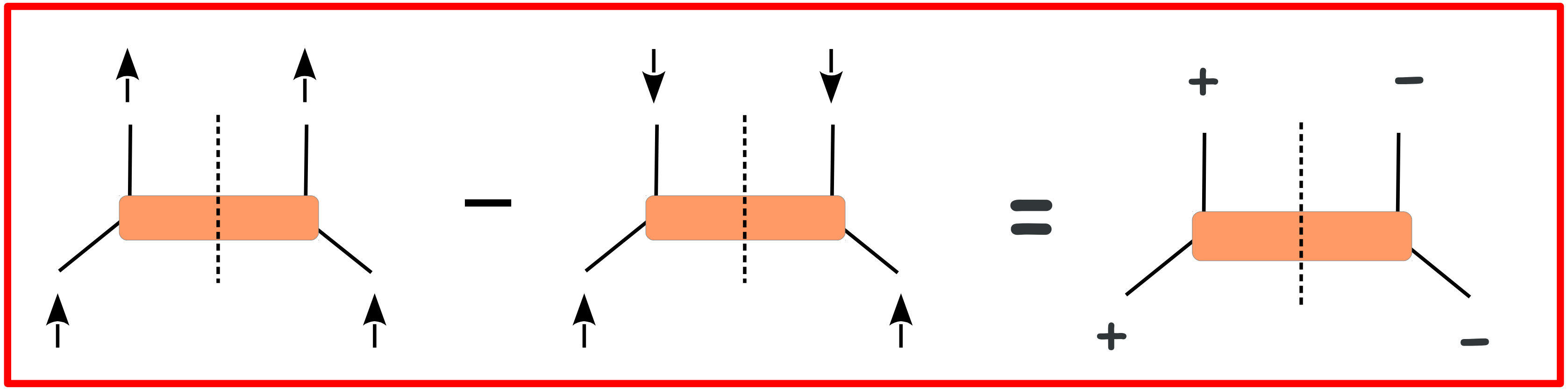
In collaboration with
M.Anselmino, M. Boglione, U. D'Alesio, F. Murgia and A. Prokudin

Outline

- New extraction (BELLE, HERMES and COMPASS D+P)
- Polynomial parametrization of the Collins functions
- Predictions for BaBar
- Conclusions

The Transversity Function

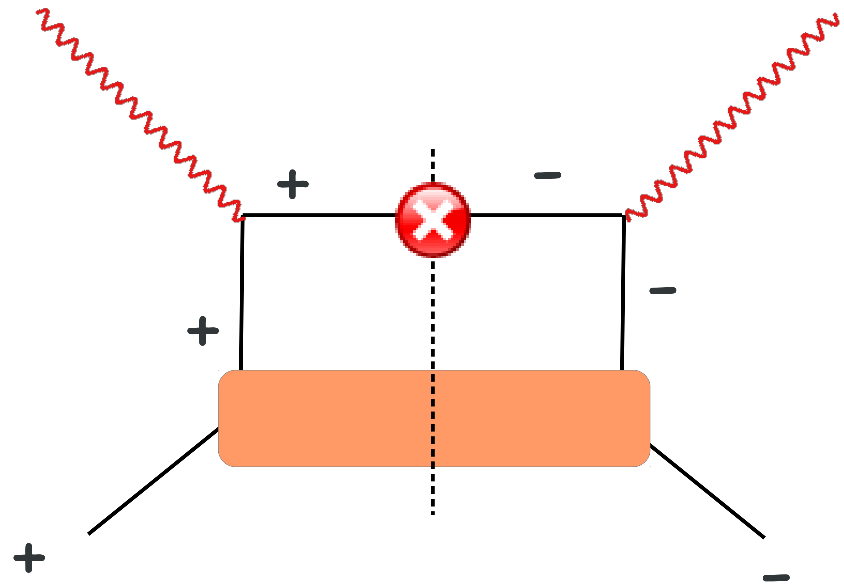
- The transversity is a twist two, collinear, distribution of transversely polarized quarks inside a transversely polarized hadron



- It is off diagonal in the helicity basis, i.e. it is a chiral odd function.

Chiral Odd nature of Transversity

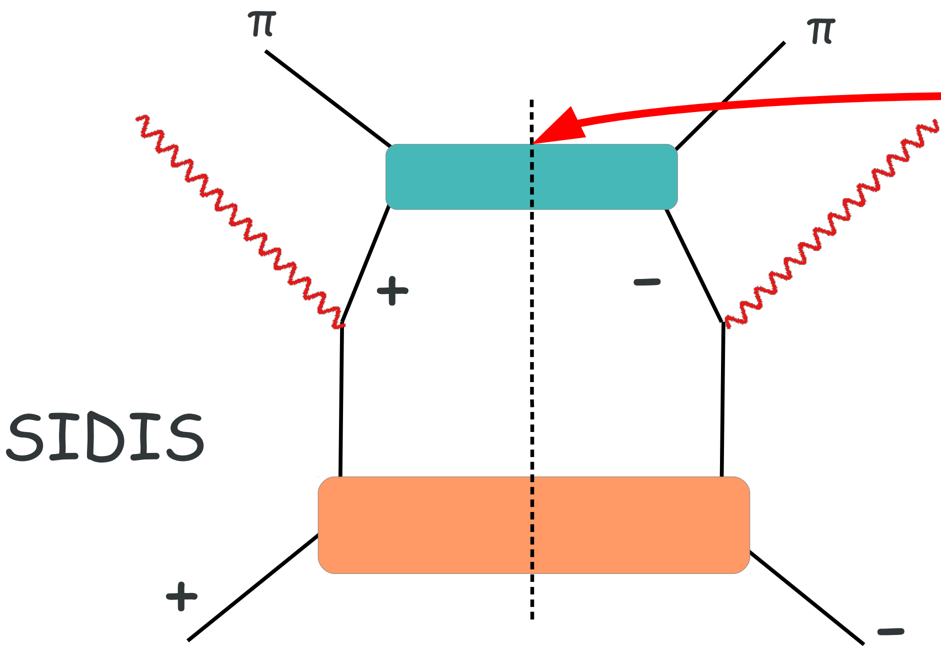
- Chiral Odd: It cannot be measured in DIS processes!

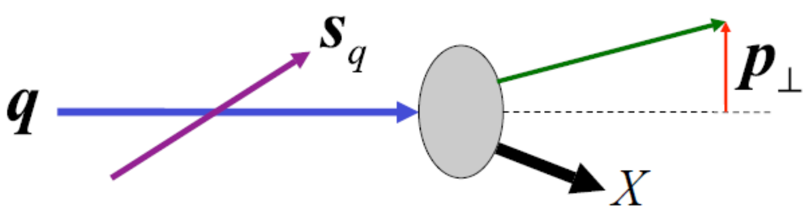


- It needs to be coupled with another chiral odd quantity…
- DIS is our main source of knowledge on the parton distribution.
- The transversity function has been unknown until 2007

Accessing the transversity

- In order to still have the power of DIS, let us consider the SIDIS instead of DIS





- Collins fragmentation function:

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) = \frac{2p_\perp}{zM} H_1^\perp(z,p_\perp) = D_{\pi/q^\uparrow}(z,p_\perp) - D_{\pi/q^\downarrow}(z,p_\perp)$$

Extraction of transversity & Collins functions

- Azimuthal asymmetry in polarized SIDIS

$$d\sigma^{\uparrow} - d\sigma^{\downarrow} = \sum_q h_{1q}(x, \boldsymbol{k}_\perp) \otimes d\Delta\hat{\sigma}(y, \boldsymbol{k}_\perp) \otimes \Delta^N D_{h/q^{\uparrow}}(z, \boldsymbol{p}_\perp)$$

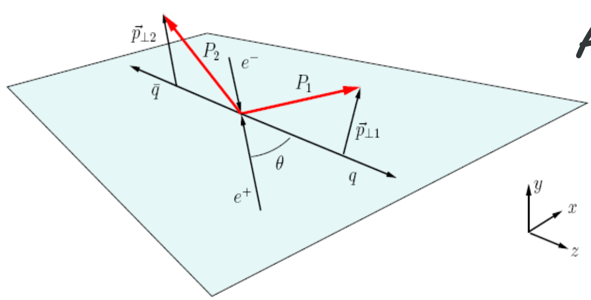
Transversity

Collins function

$$A_{UT}^{\sin(\phi+\phi_S)} \equiv 2\,\frac{\int d\phi\, d\phi_S\, [d\sigma^{\uparrow} - d\sigma^{\downarrow}]\, \sin(\phi+\phi_S)}{\int d\phi\, d\phi_S\, [d\sigma^{\uparrow} + d\sigma^{\downarrow}]}$$

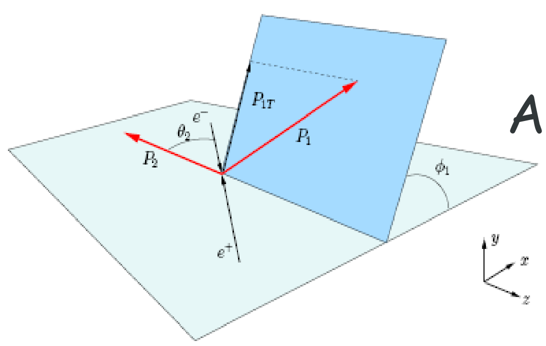
Extraction of transversity & Collins functions

- $e^+e^- \to h_1\, h_2\, X$ BELLE Data



A_{12} asymmetry → **Thrust axis method**

$$A(z_1, z_2, \theta, \varphi_1 + \varphi_2) \equiv \frac{1}{\langle d\sigma \rangle} \frac{d\sigma^{e^+e^- \to h_1 h_2 X}}{dz_1\, dz_2\, d\cos\theta\, d(\varphi_1 + \varphi_2)}$$
$$= 1 + \frac{1}{8} \frac{\sin^2\theta}{1+\cos^2\theta} \cos(\varphi_1 + \varphi_2) \frac{\sum_q e_q^2\, \Delta^N D_{h_1/q^\uparrow}(z_1)\, \Delta^N D_{h_2/\bar{q}^\uparrow}(z_2)}{\sum_q e_q^2 D_{h_1/q}(z_1)\, D_{h_2/\bar{q}}(z_2)}$$



A_0 asymmetry → **Hadronic plane method**

$$A(z_1, z_2, \theta_2, \phi_1) = 1 + \frac{1}{\pi} \frac{z_1\, z_2}{z_1^2 + z_2^2} \frac{\sin^2\theta_2}{1+\cos^2\theta_2} \cos(2\,\phi_1) \frac{\sum_q e_q^2\, \Delta^N D_{h_1/q^\uparrow}(z_1)\, \Delta^N D_{h_2/\bar{q}^\uparrow}(z_2)}{\sum_q e_q^2 D_{h_1/q}(z_1)\, D_{h_2/\bar{q}}(z_2)}$$

Polarized SIDIS& e+e- data:

Extraction of Transversity

Parametrizations

- Gaussian parametrization of the unpolarized PDF & FF:

  - $$f_{q/p}(x,k_\perp) = f_{q/p}(x)\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}$$

  - $$D_{h/q}(z,p_\perp) = D_{h/q}(z)\,\frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}$$

[*] $\langle k_\perp^2\rangle = 0.25\ \mathrm{GeV}^2 \qquad \langle p_\perp^2\rangle = 0.20\ \mathrm{GeV}^2$

[*] Anselmino et al. Phys. Rev. D71 074006 (2005)

Parametrizations

- Parametrization of Transversity function:

✎ $$\Delta_T q(x, k_\perp) = \frac{1}{2}\mathcal{N}_q^T(x)\,[f_{q/p}(x) + \Delta q(x)]\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle_T}}{\pi\langle k_\perp^2\rangle_T}$$

Unpolarized PDF

Helicity PDF

$$\mathcal{N}_q^T(x) = N_q^T\, x^{\alpha_q}(1-x)^{\beta_q}\,\frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\,\beta_q^{\beta_q}}$$

N_q^T, α, β free parameters

Parametrizations

➢Parametrization of the Collins function:

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) = 2\mathcal{N}_q^C(z)\, h(p_\perp)\, D_{\pi/q}(z,p_\perp)$$

- $\mathcal{N}_q^C(z) = N_q^C\; z^\gamma(1-z)^\delta \, \frac{(\gamma+\delta)^{(\gamma+\delta)}}{\gamma^\gamma\delta^\delta}$

- $h(p_\perp) = \sqrt{2e}\,\frac{p_\perp}{M_h}\, e^{-p_\perp^2/M_h^2}$

Unpolarized FF

N_q^C, γ, δ, M_h free parameters

✔Bound:

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) \le 2\, D_{\pi/q}(z,k_\perp)$$

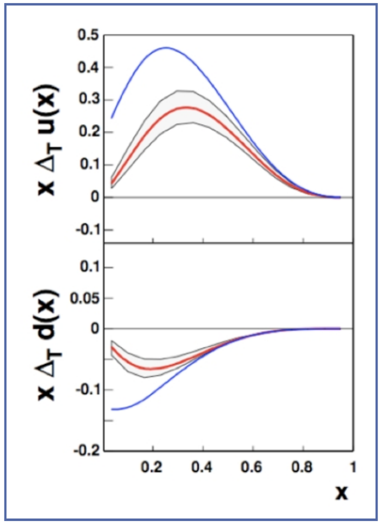
✔Torino vs Amsterdam notation

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) = \frac{2p_\perp}{zM} H_1^\perp(z,p_\perp)$$

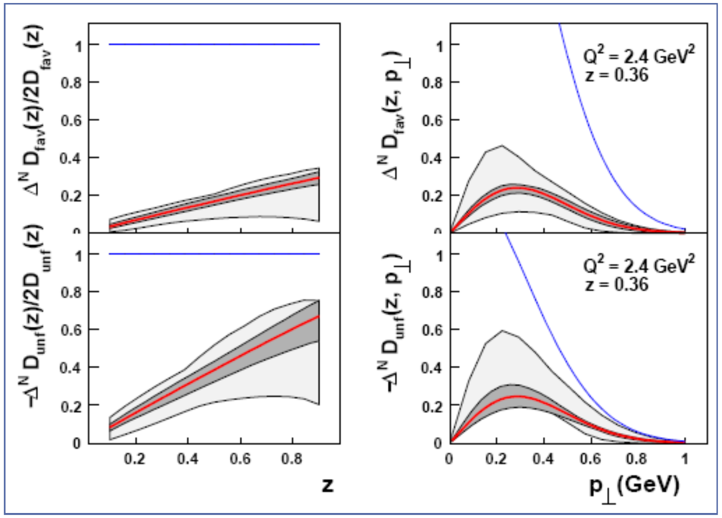
Extraction of transversity & Collins functions

- Simultaneous fit of HERMES, COMPASS D and BELLE (A_{12}^{UL}) data

χ^2_{dof}=1.3



Transversity



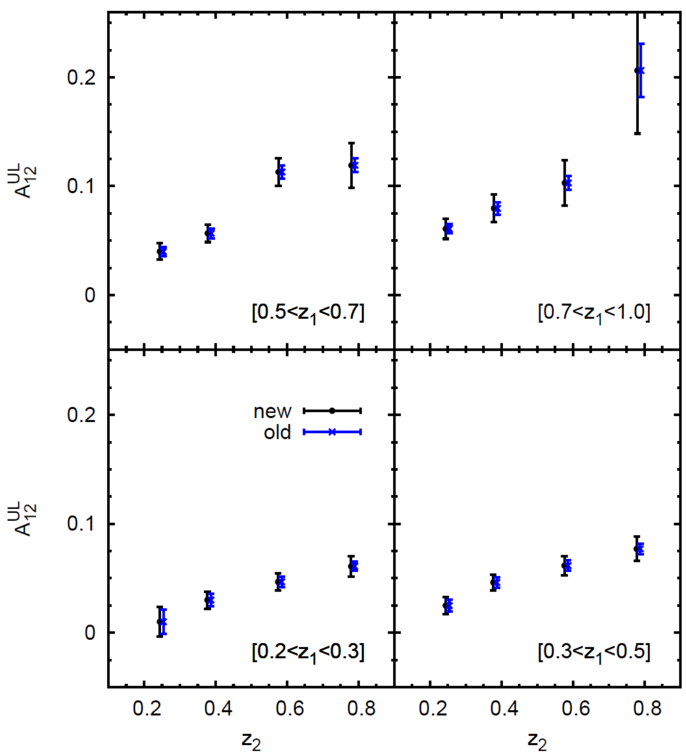
Collins functions

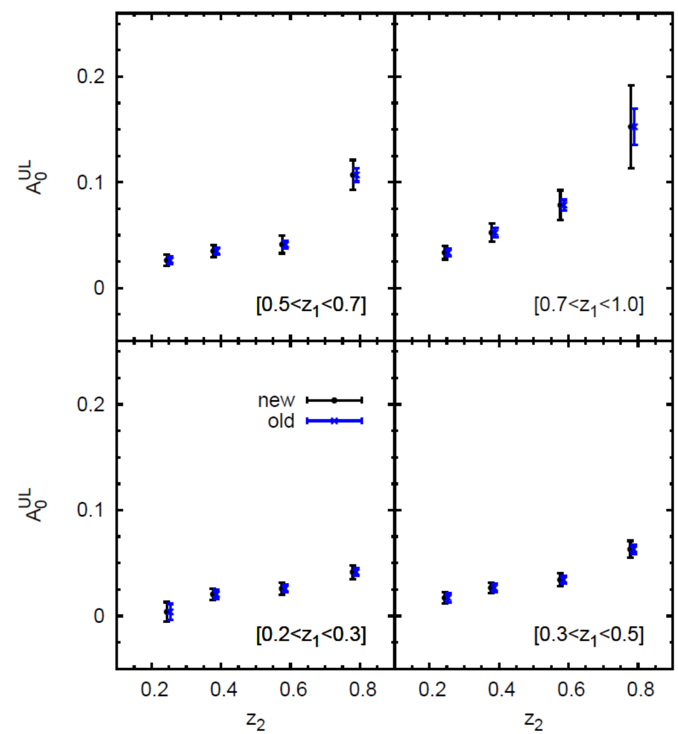
$N_u^T = 0.64 \pm 0.34$	$N_d^T = -1.00 \pm 0.02$
$\alpha = 0.73 \pm 0.51$	$\beta = 0.84 \pm 2.30$
$N_{fav}^C = 0.44 \pm 0.07$	$N_{unf}^C = -1.00 \pm 0.06$
$\gamma = 0.96 \pm 0.08$	$\delta = 0.01 \pm 0.05$
$M_h^2 = 0.91 \pm 0.52\ \mathrm{GeV}^2$	

- Anselmino et. al arXiv: 0812.4366v1

BELLE Erratum

- BELLE Erratum: R. Seidl, PRD 86 (2012) 039905

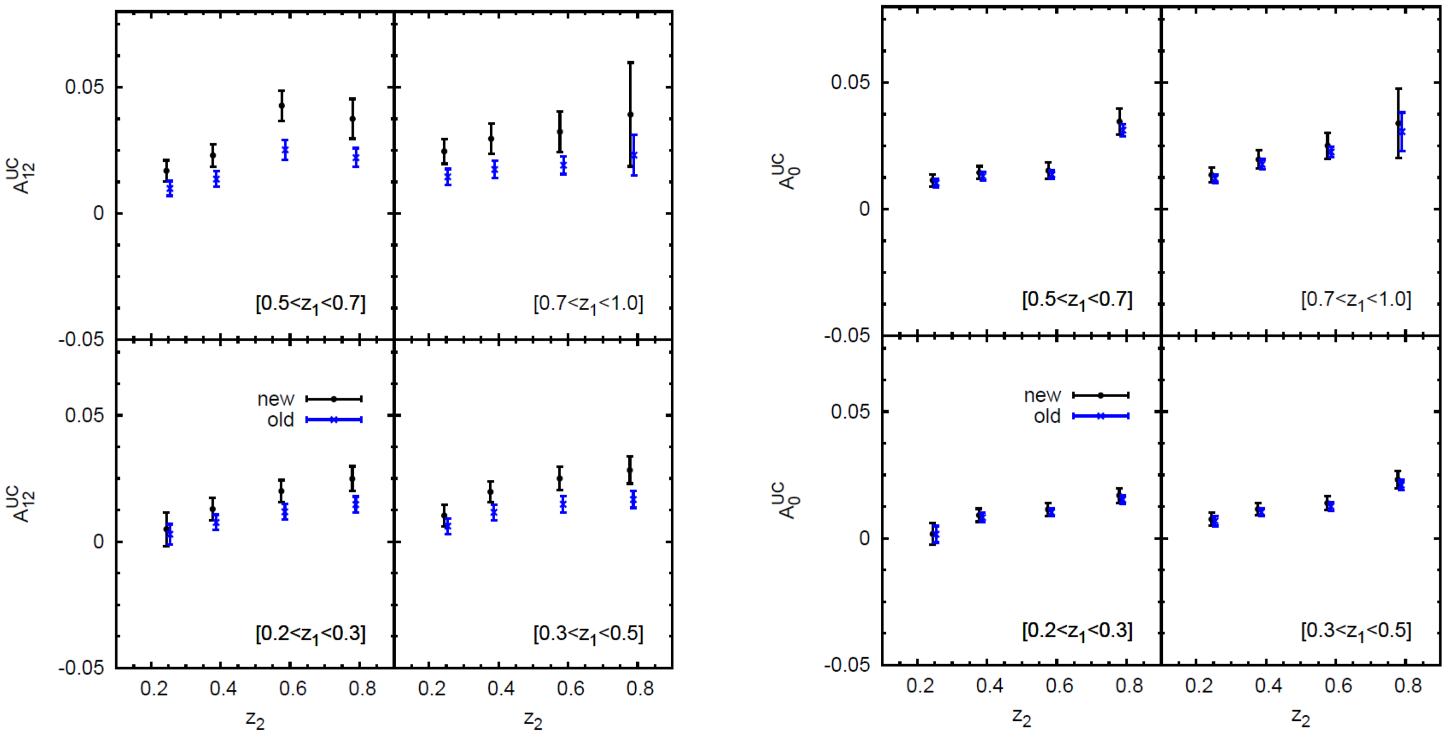




A^{UL}: Same central values, larger errors

BELLE Erratum

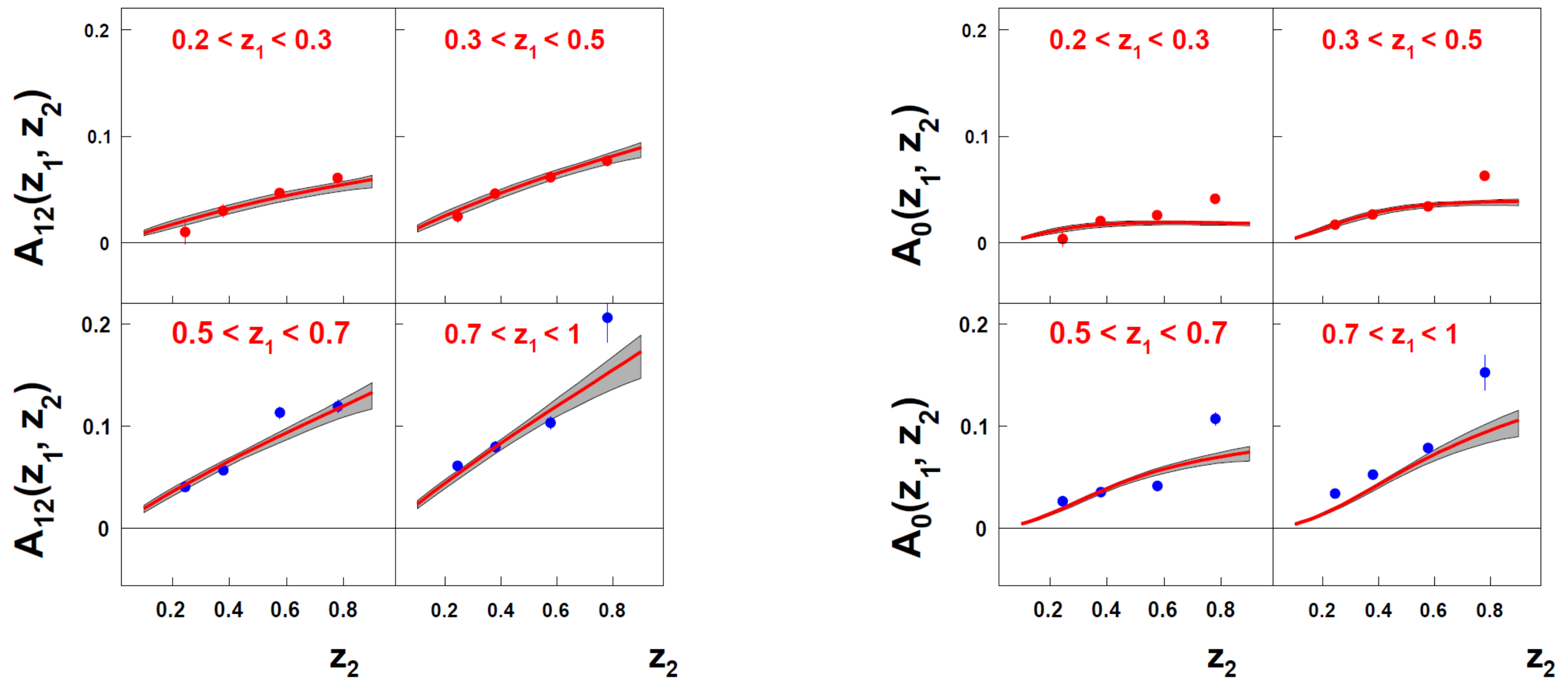
- BELLE Erratum: R. Seidl, PRD 86 (2012) 039905



A^{UC}: Different normalization, larger errors

BELLE Erratum&2008 Extraction

- BELLE Erratum: R. Seidl, PRD 86 (2012) 039905



◇ R. Seidl et al., Phys. Rev. D78

Good news! Previously partial incompatibility between the sets

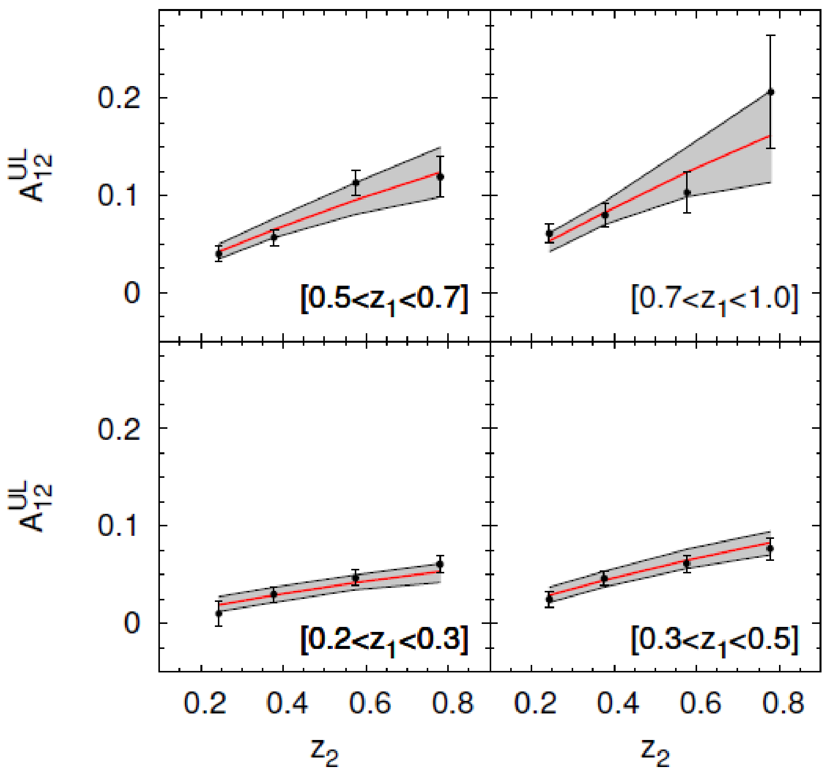
New analysis

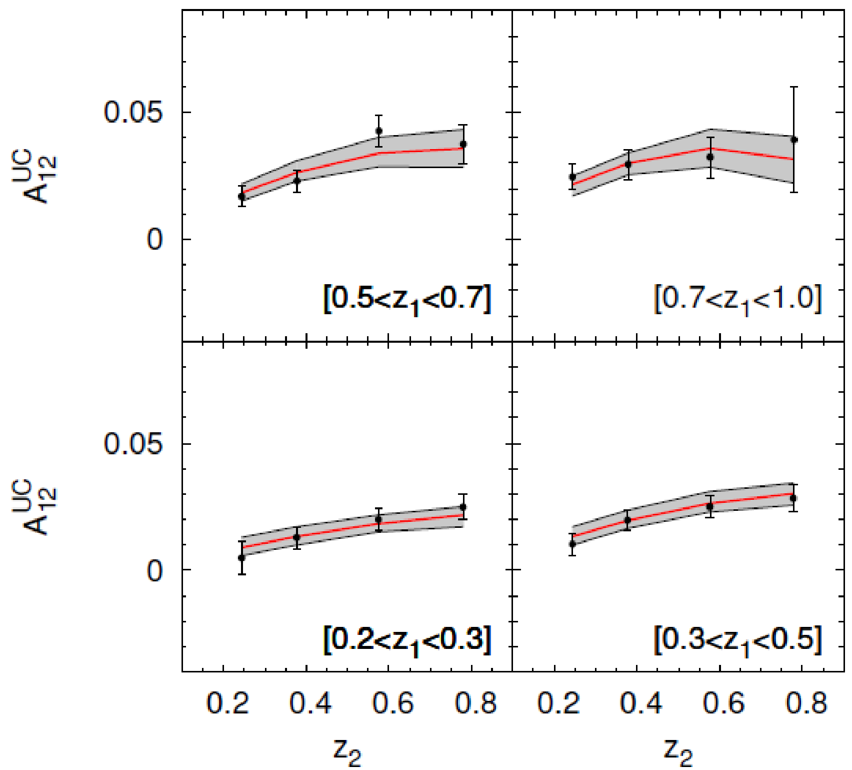
- New analysis:
  - HERMES (2009) π^+ π^-
  - COMPASS Deuteron (2004) π^+ π^-
  - COMPASS Proton (2013) π^+ π^-
  - BELLE A_{12} or A_0

Anselmino et al. arXiv:1303.3822

Extraction of transversity & Collins functions

- FIT I: A_{12} BELLE data UL & UC +COMPASS+ HERMES

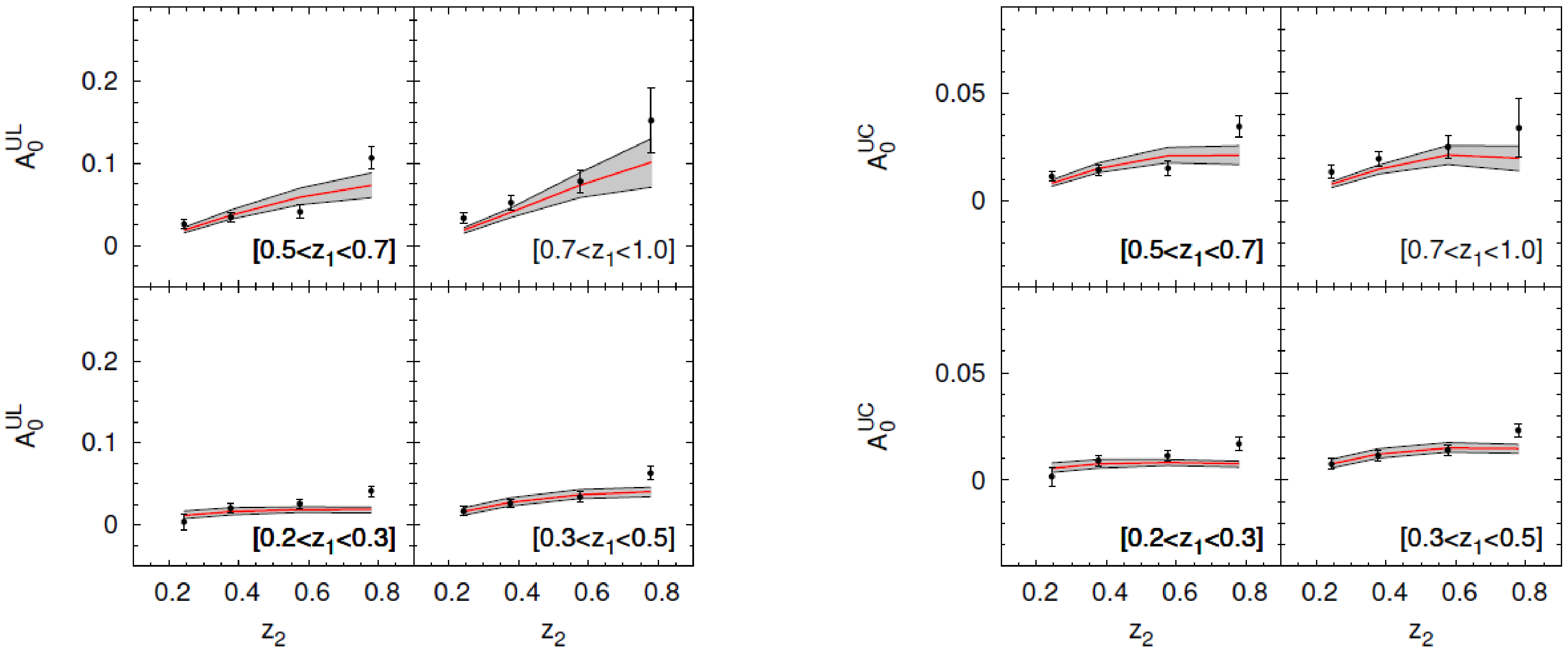




→ Full compatibility between UL and UC

Extraction of transversity & Collins functions

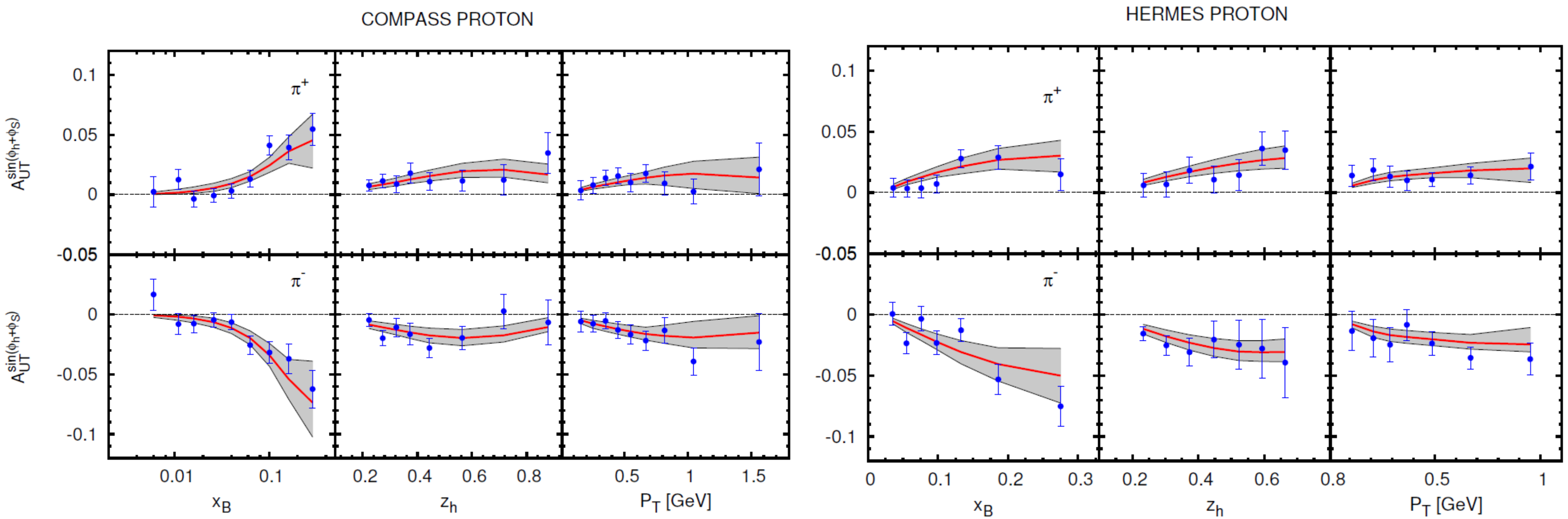
- FIT I: A_{12} BELLE data UL & UC +COMPASS+ HERMES



→ Still tension between the two methods A_0 and A_{12}

Extraction of transversity & Collins functions

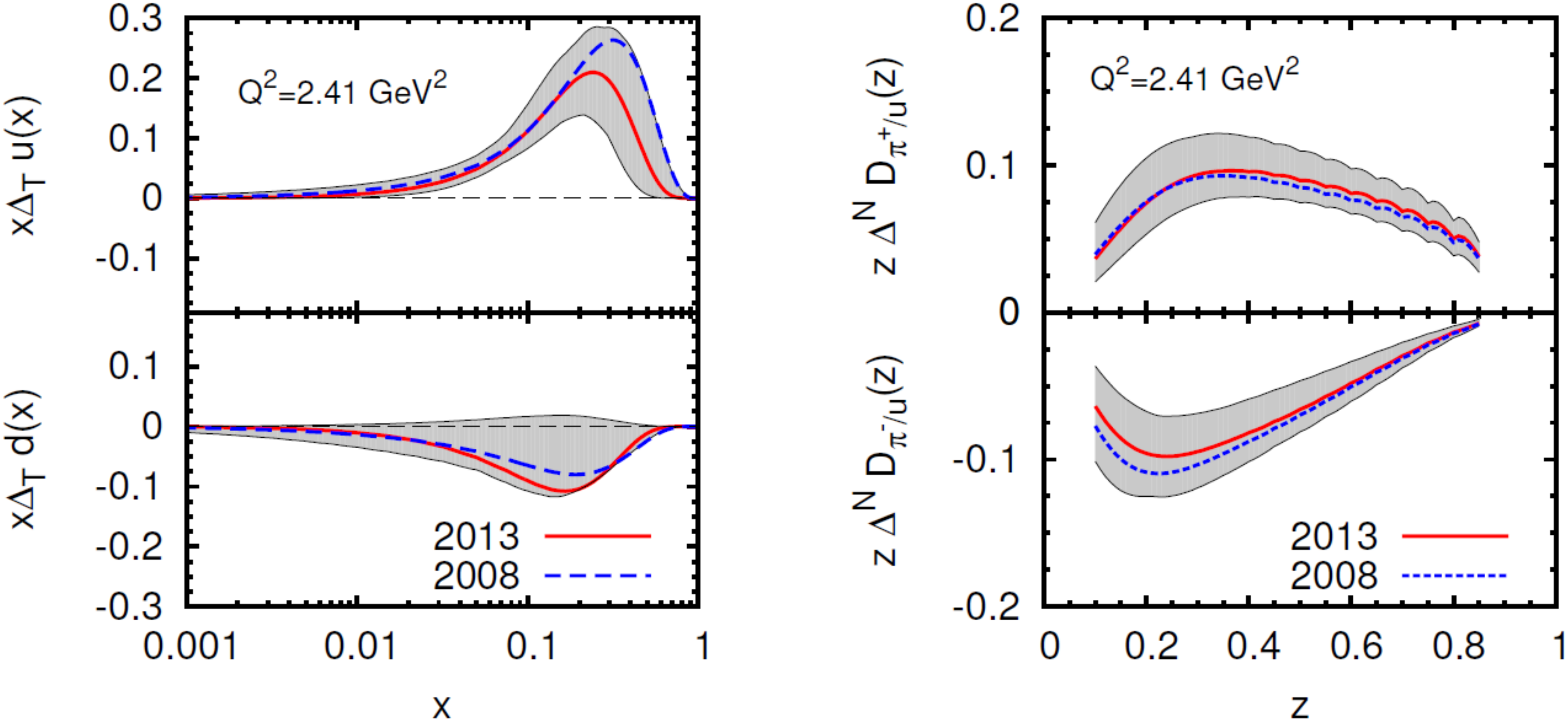
- FIT I: A_{12} BELLE data UL & UC +COMPASS+ HERMES



→ Similar good description of HERMES and COMPASS

Extraction of transversity & Collins functions

- FIT I: A_{12} BELLE data UL & UC +COMPASS+ HERMES



→ Similar results of 2008

Extraction of transversity & Collins functions

- FIT II: A_0 BELLE data UL & UC +COMPASS+ HERMES ???

	FIT DATA 178 points	SIDIS 146 points	A_{12}^{UL} 16 points	A_{12}^{UC} 16 points	A_0^{UL} 16 points	A_0^{UC} 16 points
Standard Parameterization $\chi^2_{\rm d.o.f} = 0.80$	$\chi^2_{\rm tot} = 135$	$\chi^2 = 123$	$\chi^2 = 7$	$\chi^2 = 5$	$\chi^2 = 44$ NO FIT	$\chi^2 = 39$ NO FIT
Standard Parameterization $\chi^2_{\rm d.o.f} = 1.12$	$\chi^2_{\rm tot} = 190$	$\chi^2 = 125$	$\chi^2 = 20$ NO FIT	$\chi^2 = 12$ NO FIT	$\chi^2 = 35$	$\chi^2 = 30$

→ A_0 data cannot be nicely described even if fitted...

Standard parametrization of the Collins function

- Parametrization of the z-dependent part of the Collins function:

$$\Delta^N D_{\pi/q^\uparrow}(z,p_\perp) = 2\mathcal{N}_q^C(z)\, h(p_\perp)\, D_{\pi/q}(z,p_\perp)$$

$$\boxed{\mathcal{N}_q^C(z) = N_q^C\; z^\gamma (1-z)^\delta \,\frac{(\gamma+\delta)^{(\gamma+\delta)}}{\gamma^\gamma \delta^\delta}}$$

Our standard parametrization

- It is equal to 0 at z=0 and z=1

New parametrization of the Collins function

- Let us try to change the parametrization of the z-dependent part of the Collins function:

$$\Delta^N D_{\pi/q^\uparrow}(z, p_\perp) = 2\mathcal{N}_q^C(z)\, h(p_\perp)\, D_{\pi/q}(z, p_\perp)$$

$$\mathcal{N}_q^C(z) = N_q^C \, z\,[(1-a-b) + a\,z + b\,z^2]$$

NEW Polynomial parametrization

- It is equal to 0 at z=0 and equal to N_q at z=1

Extraction of transversity & Collins functions

- FIT III and IV: Polynomial Parametrization

	FIT DATA 178 points	SIDIS 146 points	A_{12}^{UL} 16 points	A_{12}^{UC} 16 points	A_0^{UL} 16 points	A_0^{UC} 16 points
Standard Parameterization $\chi^2_{\rm d.o.f} = 0.80$	$\chi^2_{\rm tot} = 135$	$\chi^2 = 123$	$\chi^2 = 7$	$\chi^2 = 5$	$\chi^2 = 44$ NO FIT	$\chi^2 = 39$ NO FIT
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Polynomial Parameterization $\chi^2_{\rm d.o.f} = 0.81$	$\chi^2_{\rm tot} = 136$	$\chi^2 = 123$	$\chi^2 = 8$	$\chi^2 = 5$	$\chi^2 = 45$ NO FIT	$\chi^2 = 39$ NO FIT
Polynomial Parameterization $\chi^2_{\rm d.o.f} = 1.01$	$\chi^2_{\rm tot} = 171$	$\chi^2 = 141$	$\chi^2 = 44$ NO FIT	$\chi^2 = 27$ NO FIT	$\chi^2 = 15$	$\chi^2 = 15$

Extraction of transversity & Collins functions

- FIT III and IV: Polynomial Parametrization

	FIT DATA 178 points	SIDIS 146 points	A_{12}^{UL} 16 points	A_{12}^{UC} 16 points	A_0^{UL} 16 points	A_0^{UC} 16 points
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- If we fit A_{12} data we get the same description obtained with the std par.
- Almost identical Collins function, again the description of A_0 is not so good

Extraction of transversity & Collins functions

- FIT III and IV: Polynomial Parametrization

	FIT DATA 178 points	SIDIS 146 points	A_{12}^{UL} 16 points	A_{12}^{UC} 16 points	A_0^{UL} 16 points	A_0^{UC} 16 points
Standard Parameterization $\chi^2_{\rm d.o.f} = 0.80$	$\chi^2_{\rm tot} = 135$	$\chi^2 = 123$	$\chi^2 = 7$	$\chi^2 = 5$	$\chi^2 = 44$ NO FIT	$\chi^2 = 39$ NO FIT
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→ If we fit A_0 data we can improve their description

→ Still tension with A_{12}

Extraction of transversity & Collins functions

- FIT III and IV: Polynomial Parametrization

	FIT DATA 178 points	SIDIS 146 points	A_{12}^{UL} 16 points	A_{12}^{UC} 16 points	A_{0}^{UL} 16 points	A_{0}^{UC} 16 points
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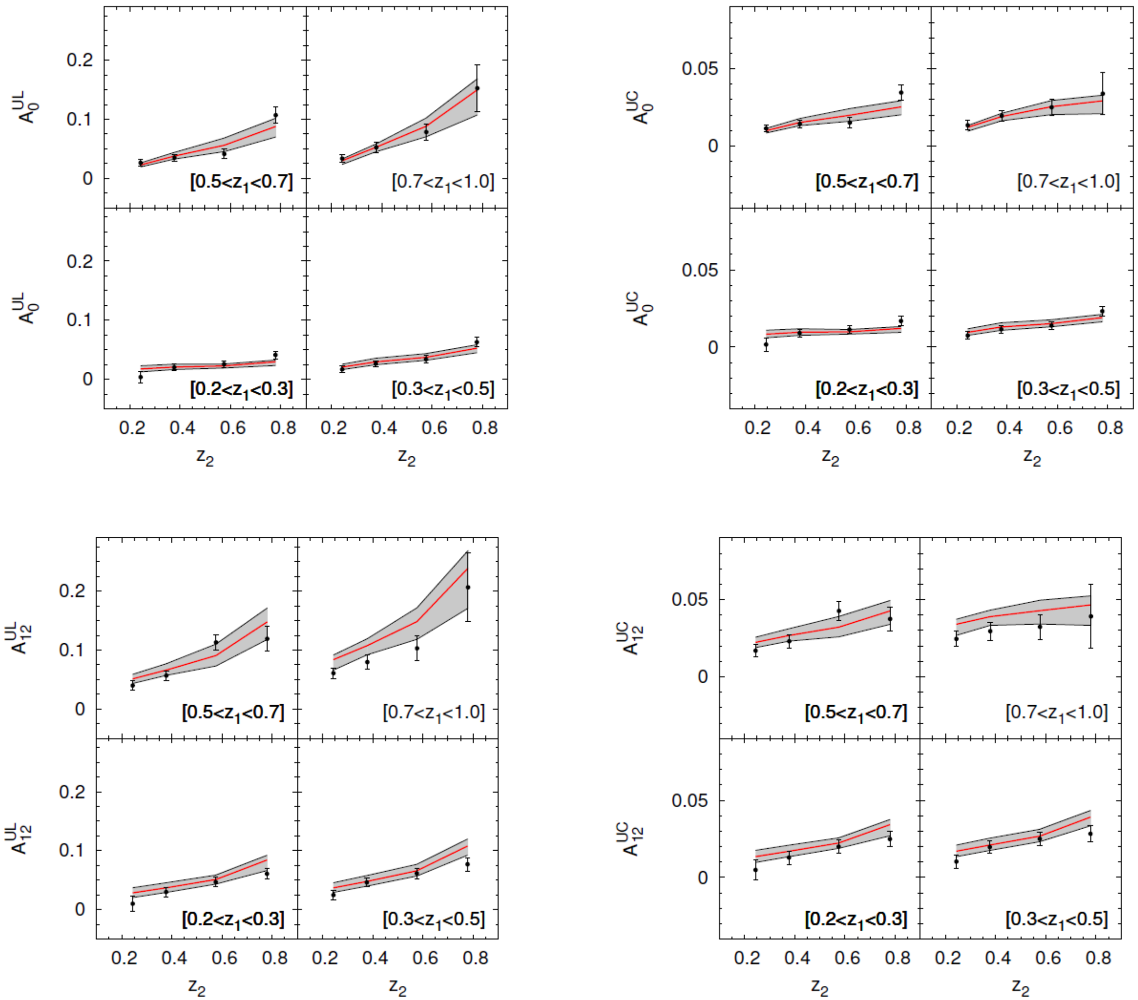
→ If we fit A_0 data we can improve their description

→ Still tension with A_{12}

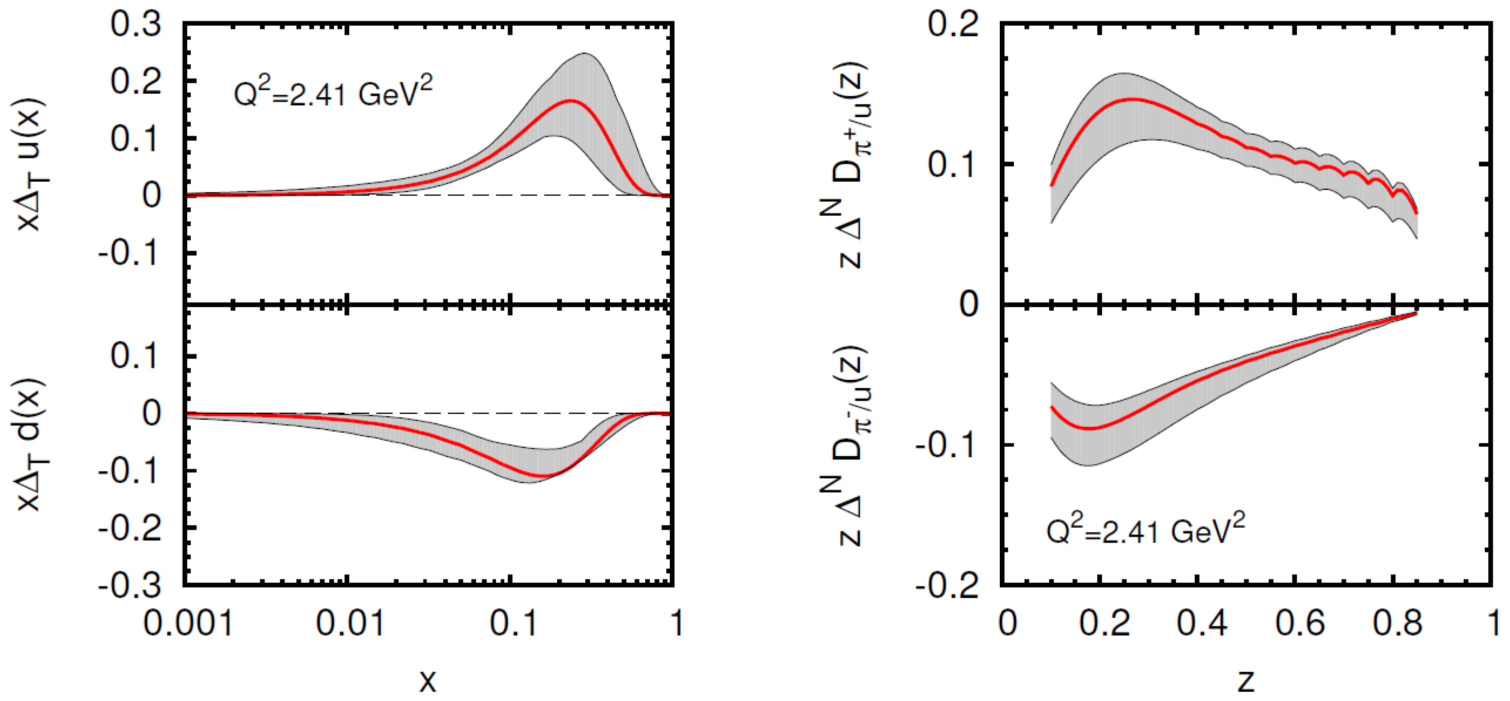
Extraction of transversity & Collins functions

➤ FIT IV: A_0 BELLE data UL & UC +COMPASS+ HERMES-POLYNOMIAL



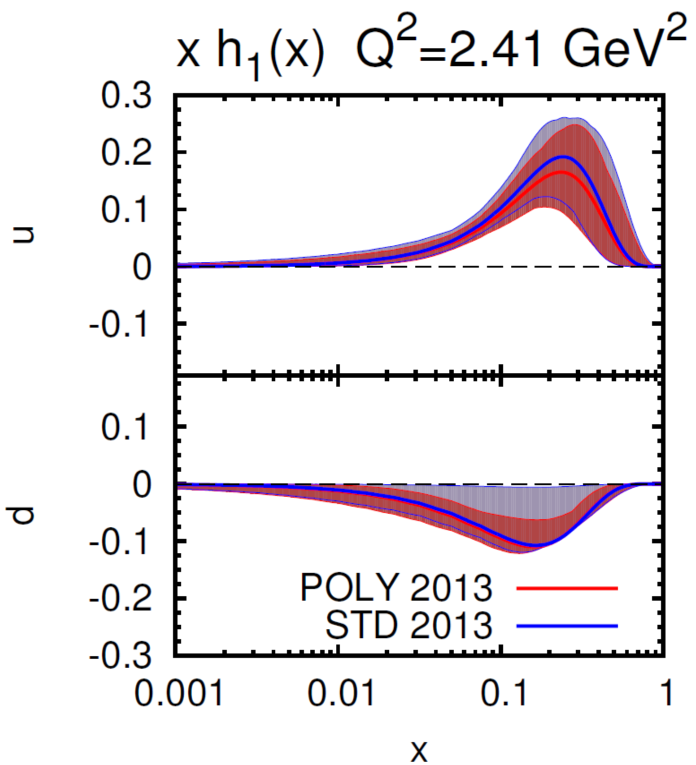
Extraction of transversity & Collins functions

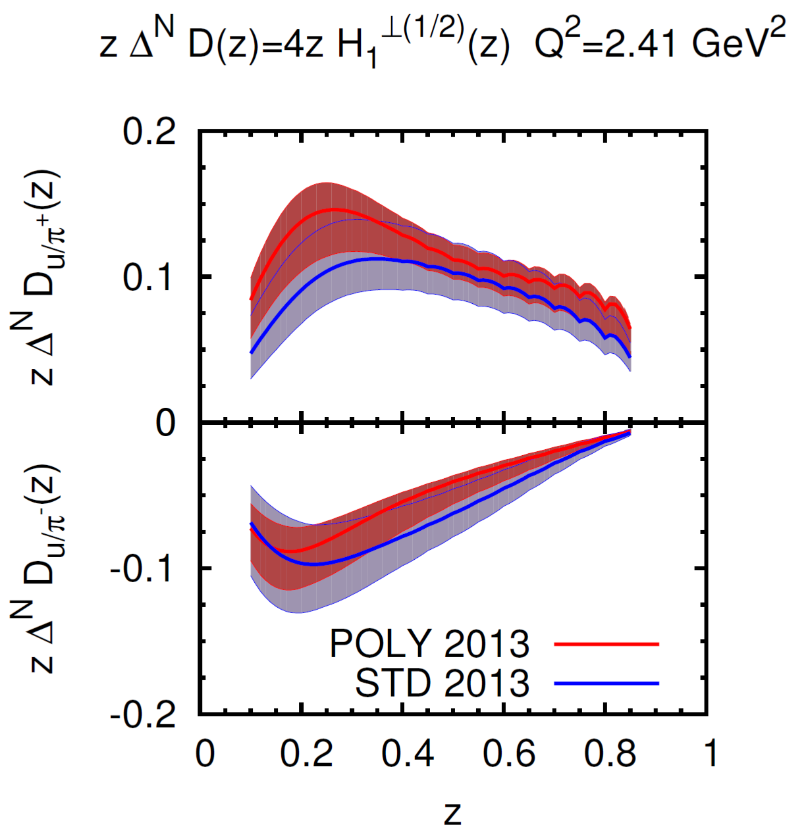
- FIT IV: A_0 BELLE data UL & UC +COMPASS+ HERMES POLYNOMIAL



Extraction of transversity & Collins functions

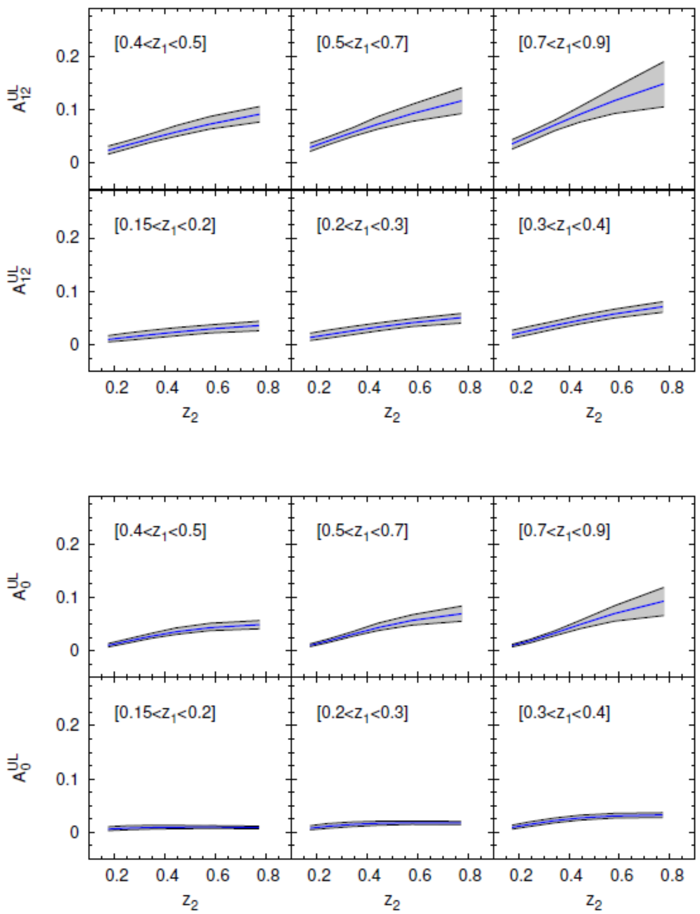
- FIT II vs FIT IV (POLYNOMIAL vs STD; FITTED A_0)



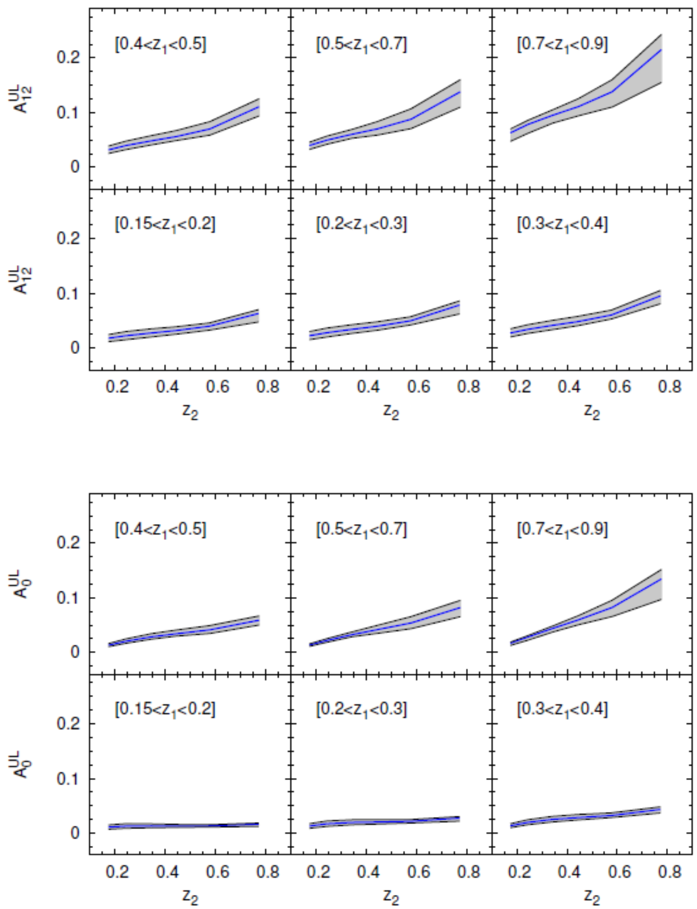


- ➔ Same transversity
- ➔ Different Collins functions (but not dramatically different)

BaBar Predictions

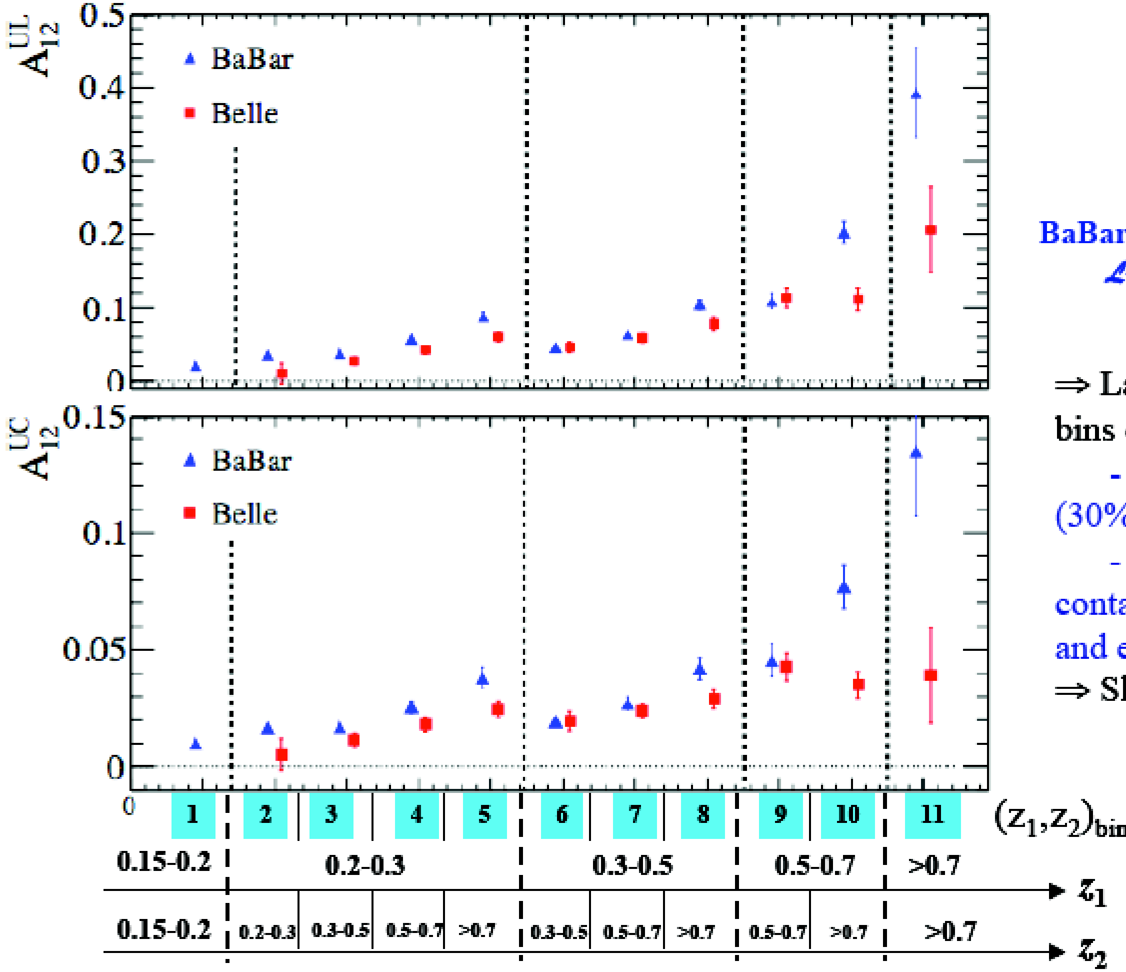


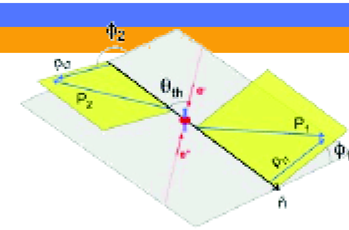
FIT I



FIT IV

RF12: BaBar/Belle comparisons





BaBar ($0.15<z<0.9$) $\mathcal{L}$~470 fb^{-1}

Belle ($0.2<z<1$) $\mathcal{L}$~547 fb^{-1}

PRD 86, 039905(E) (2012)

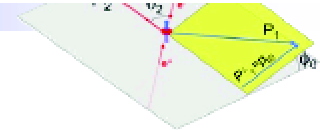
⇒ Large discrepancy in the last two bins of z:

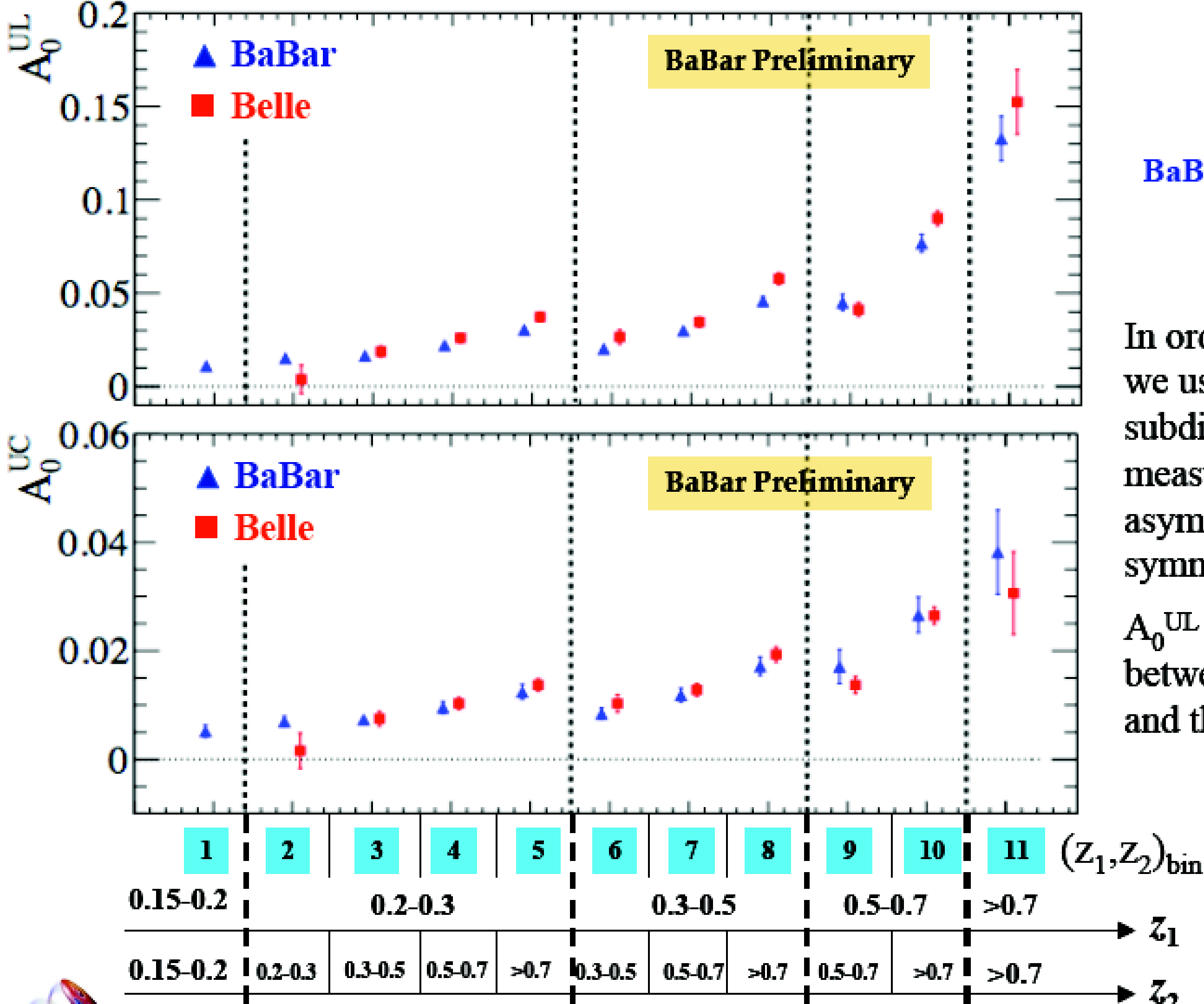
- bin-by-bin correction factors (30%)
- $z<0.9$ to remove the contamination from μμγ background and exclusive events

⇒ Slightly higher at lower z

Conclusions

- New extraction of transversity and Collins functions
- UL and UC data fully compatible
- COMPASS & HERMES full compatible without TMD evolution
- A_{12} analysis in agreement with 2008 analysis
- A_0 is better described if we change parametrization
- Tension between A_{12} and A_0 sets
- BaBar predictions



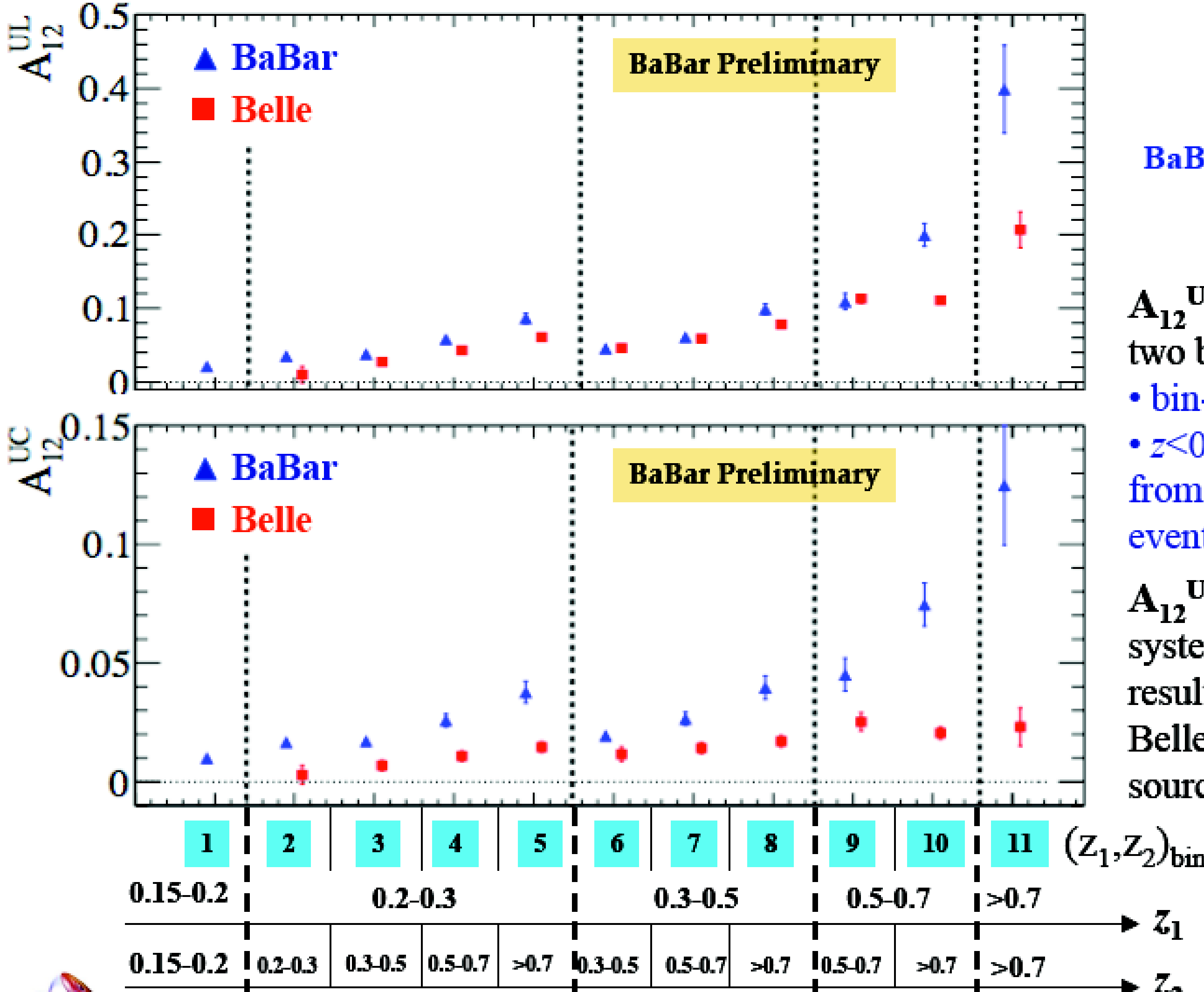


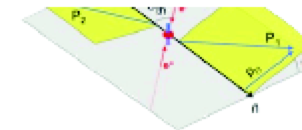
BaBar (0.15<z<0.9)
$\mathcal{L}$~470 fb^{-1}

Belle (0.2<z<1)
$\mathcal{L}$~547 fb^{-1}
PRD 78, 032011 (2008)

In order to perform this comparison, we used 10 (+1) symmetrized z-bin subdivisions, averaging the measured Belle and BaBar asymmetries which fell in the same symmetric bins

A_0^{UL} and A_0^{UC} : good agreement between the BaBar asymmetries and the Belle results.





BaBar ($0.15<z<0.9$) $\mathcal{L}\sim 470\ fb^{-1}$

Belle ($0.2<z<1$) $\mathcal{L}\sim 547\ fb^{-1}$

PRD 78, 032011 (2008)

A_{12}^{UL}: large discrepancy in the last two bins of z

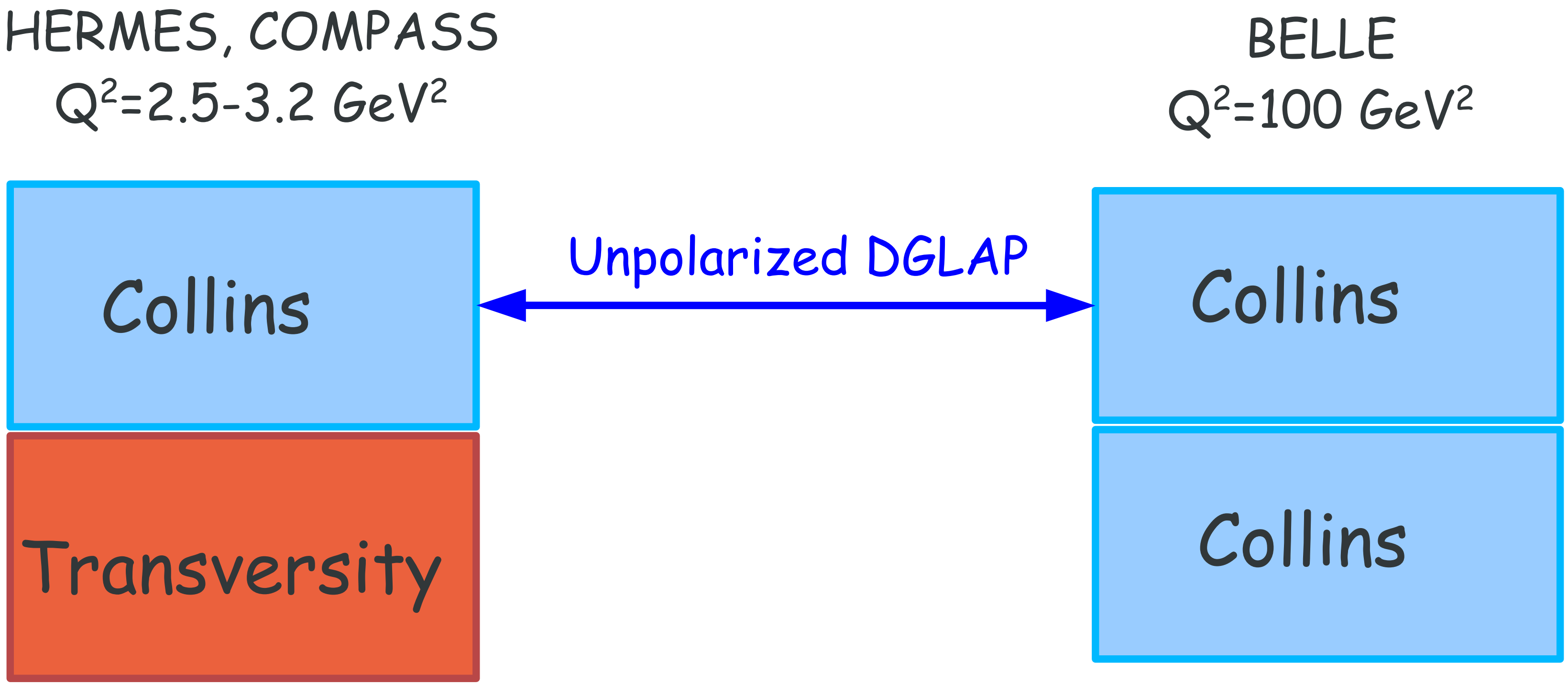
- bin-by-bin correction factors (30%)
- $z<0.9$ to remove the contamination from $\mu\mu\gamma$ background and exclusive events

A_{12}^{UC}: BaBar asymmetry systematically above the Belle results for all z.

Belle analysts are investigating the source of discrepancies.

TMD evolution

- TMD evolution for the Collins function is still unknown.
- TMD evolution can suppress the Collins function at large Q^2 (Boer, 2001)



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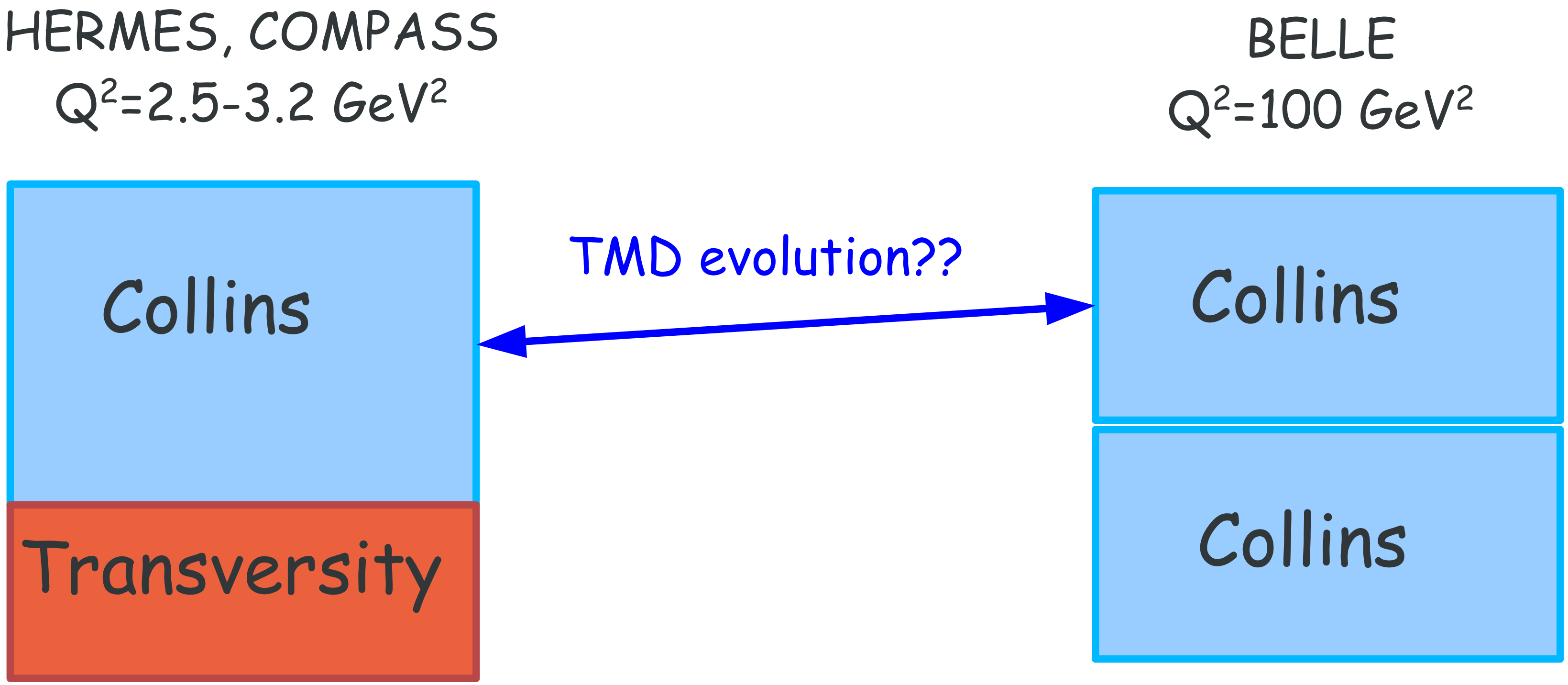
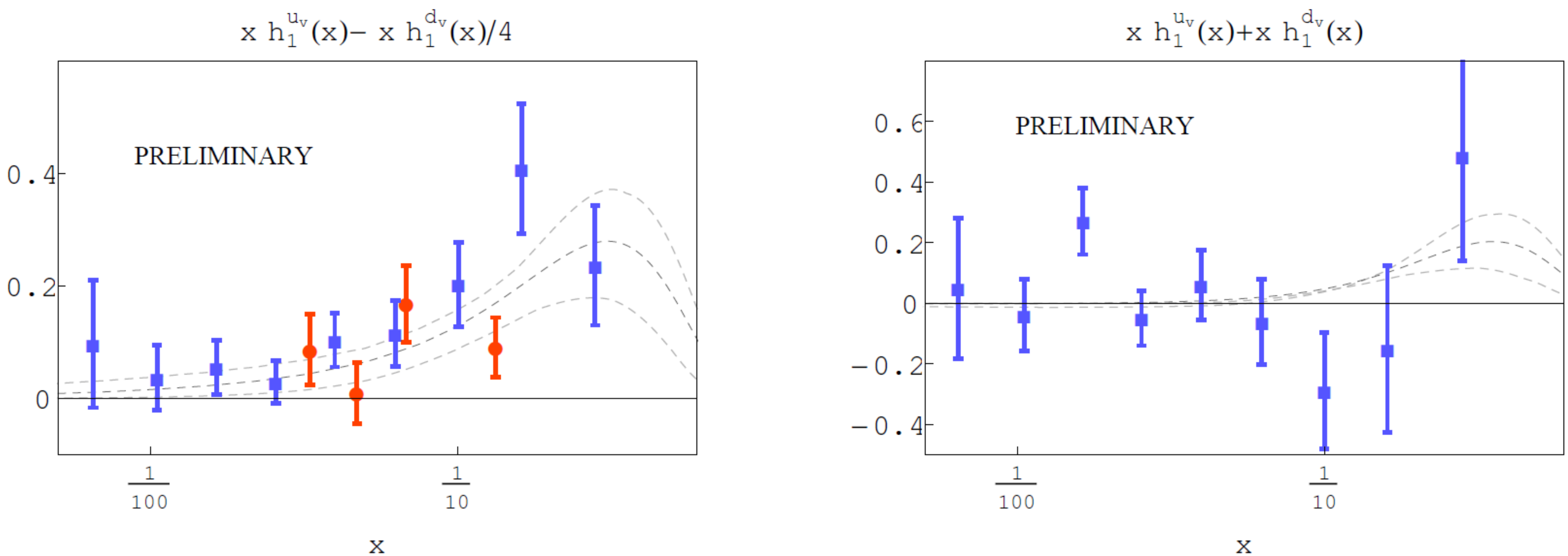


The dihadron way: Pavia group extraction

- Comparison Pavia 2012-Torino 2008



Bacchetta, Courtoy, Radici.,arXiv:1206.1836