Transversely polarized Λ production in e^+e^- annihilation and SIDIS processes within a TMD approach

Marco Zaccheddu – Università degli Studi di Cagliari & INFN

In collaboration with:

Umberto D'Alesio, Leonard Gamberg and Francesco Murgia

Sar Wors 2023

Motivations and Contents

Observation of Transverse $\Lambda/\overline{\Lambda}$ Hyperon Polarization in e^+e^- Annihilation at Belle

- 2 data set @$\sqrt{s} = 10.58$ GeV

[Y. Guan et al., Phys. Rev. Lett. 122. 042001 (2019)]

Double hadron production:

- $e^+e^- \rightarrow \Lambda\pi/K + X$: 128 points - bins of the energy fractions z_Λ - $z_{\pi,K}$

Single-inclusive hadron production:

- $e^+e^- \rightarrow \Lambda(jet) + X$: 32 points - $\Lambda(jet)$, in bins of z_Λ - $p_\perp$

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- D'Alesio, Murgia, MZ; *Phys.Rev.D* 102 (2020) 5, 054001
- Callos, Kang, Terry; *Phys.Rev.D* 102 (2020) 9, 096007
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Reanalysis of Belle data within a proper TMD factorization scheme using the evolution equations for TMD FFs → Two open issues!

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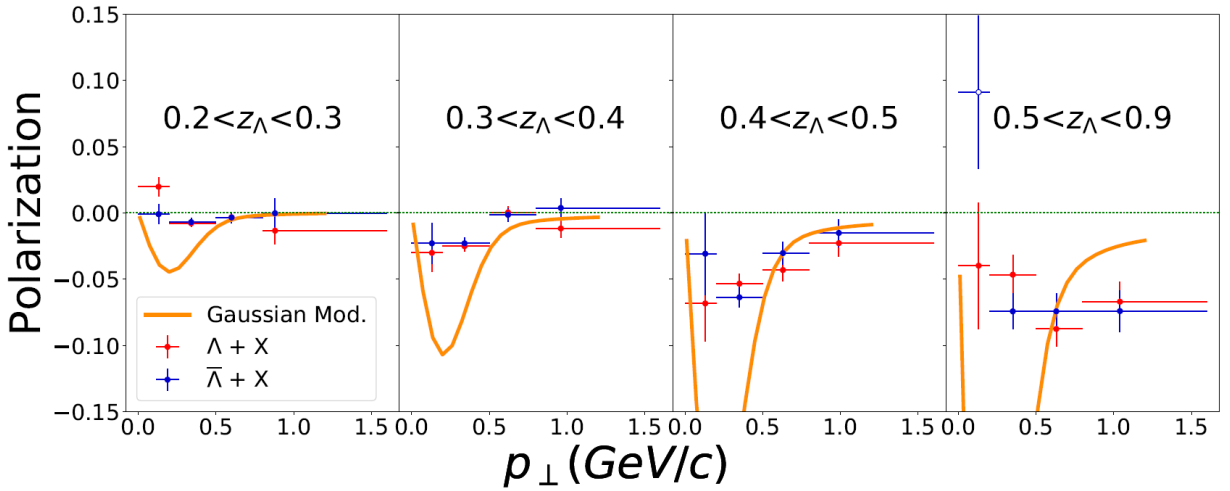
2-h and 1-h data cannot be described by the same non-perturbative model!



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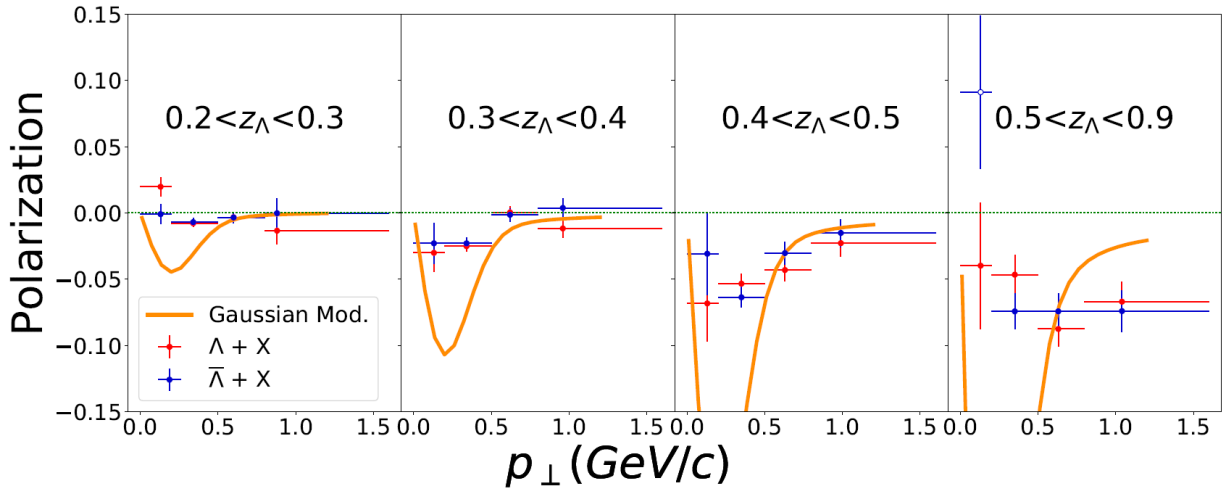

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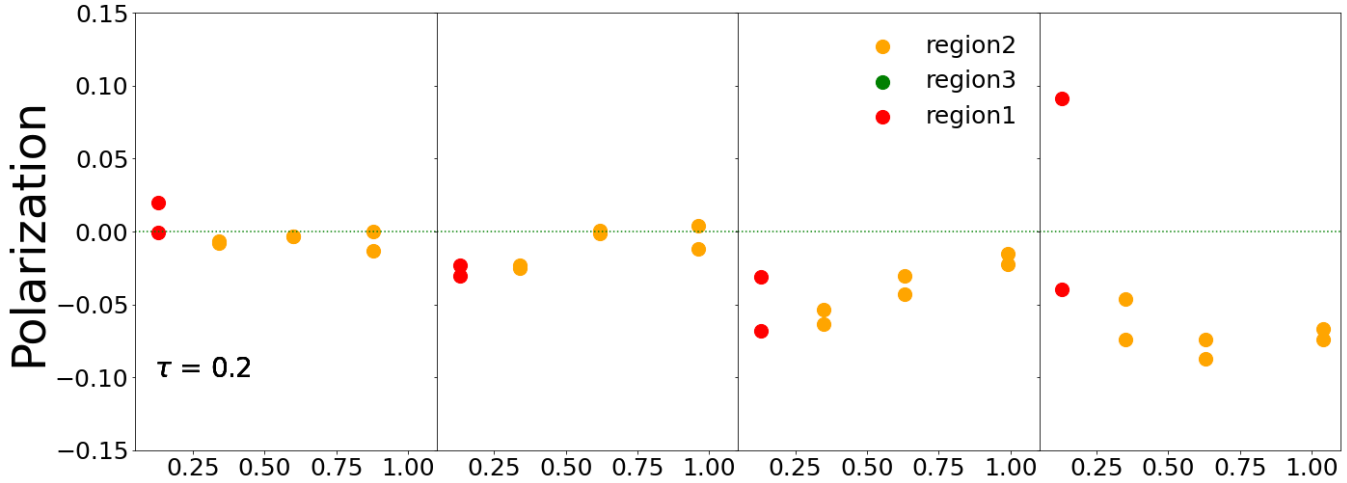
See A. Simonelli's talk!



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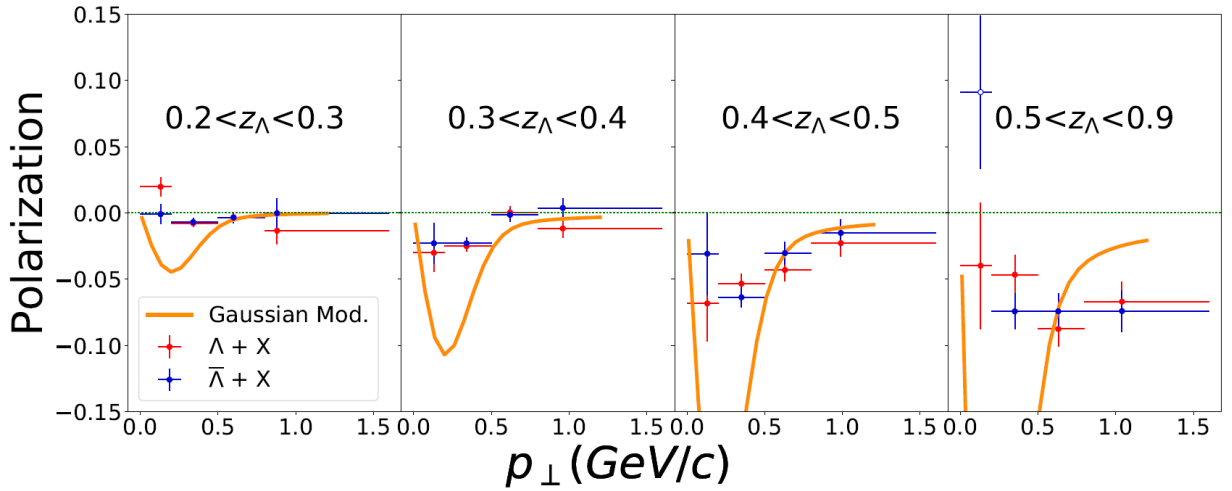

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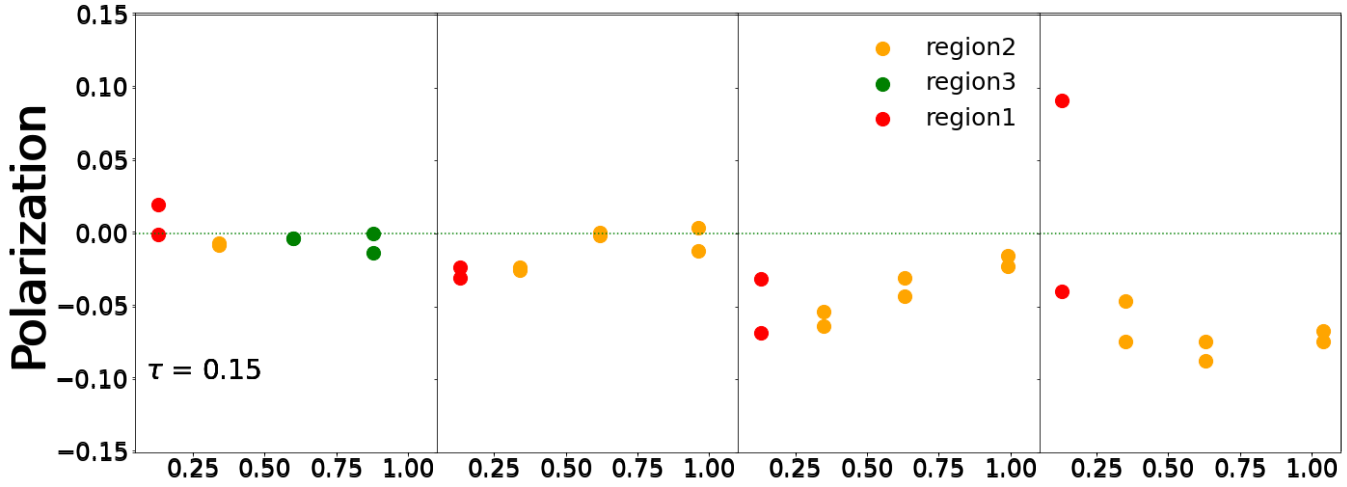

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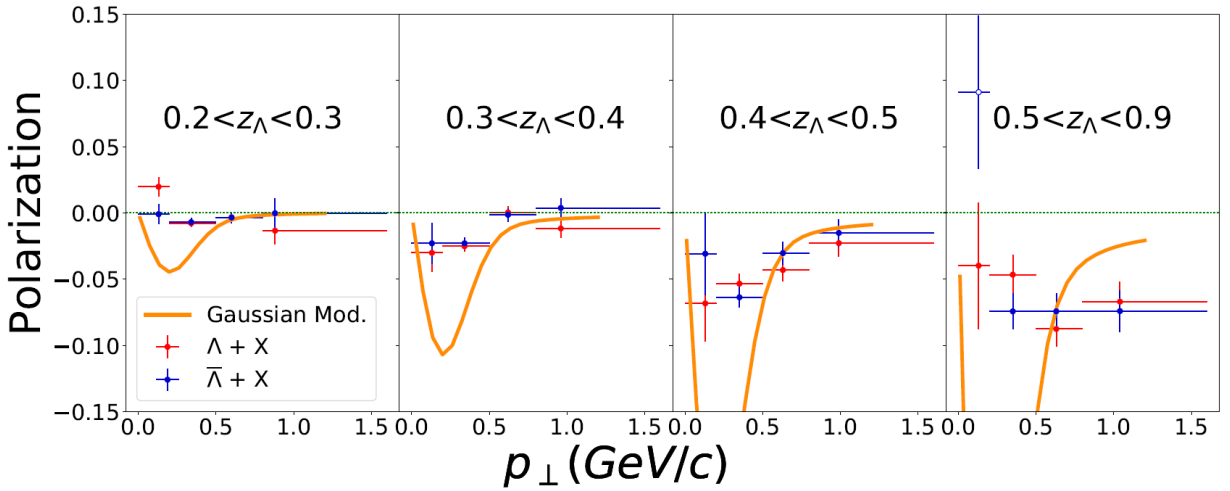

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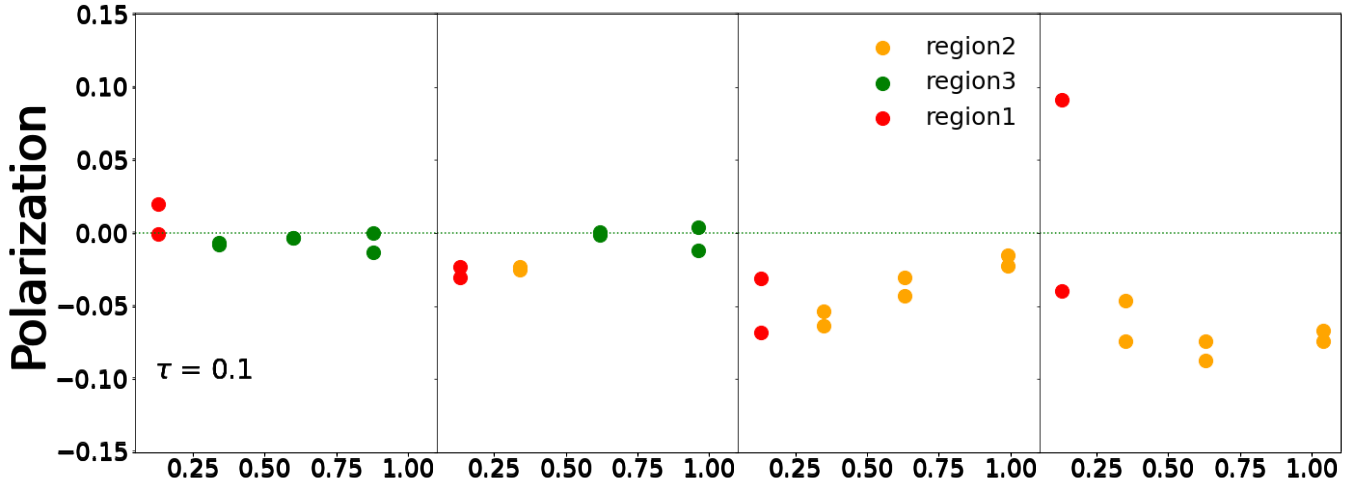

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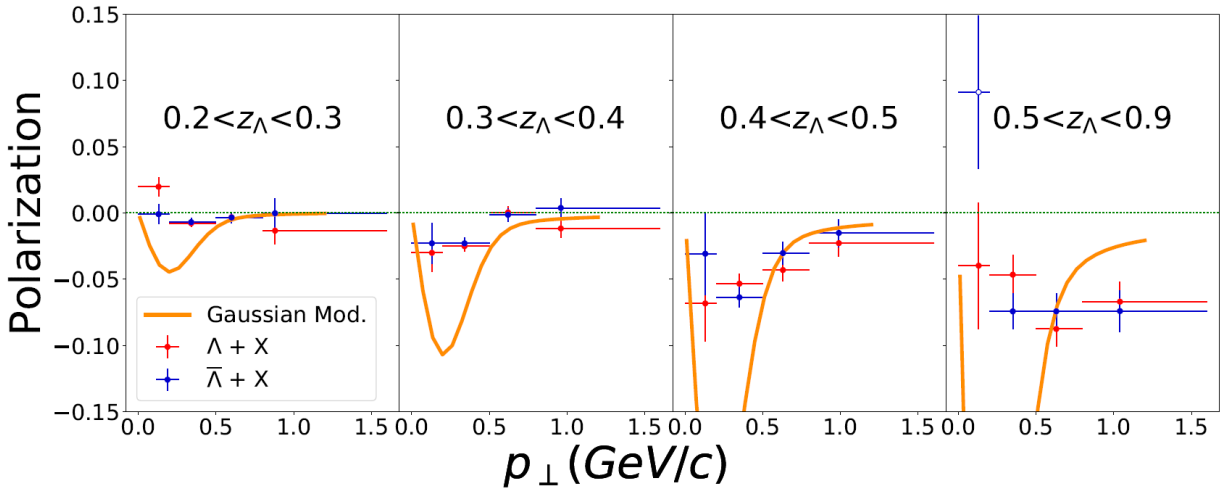

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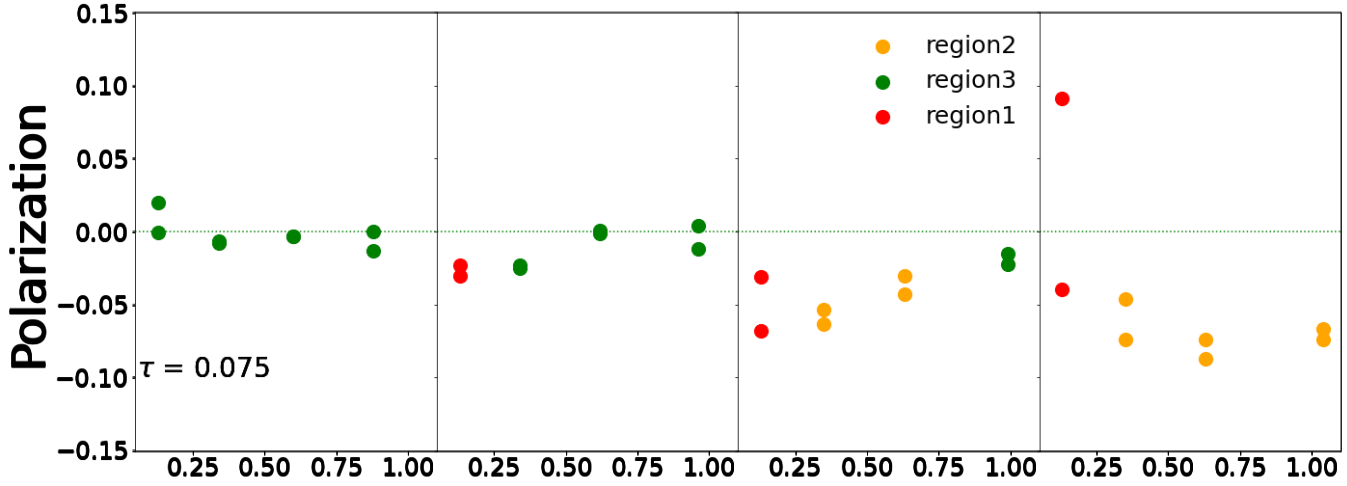

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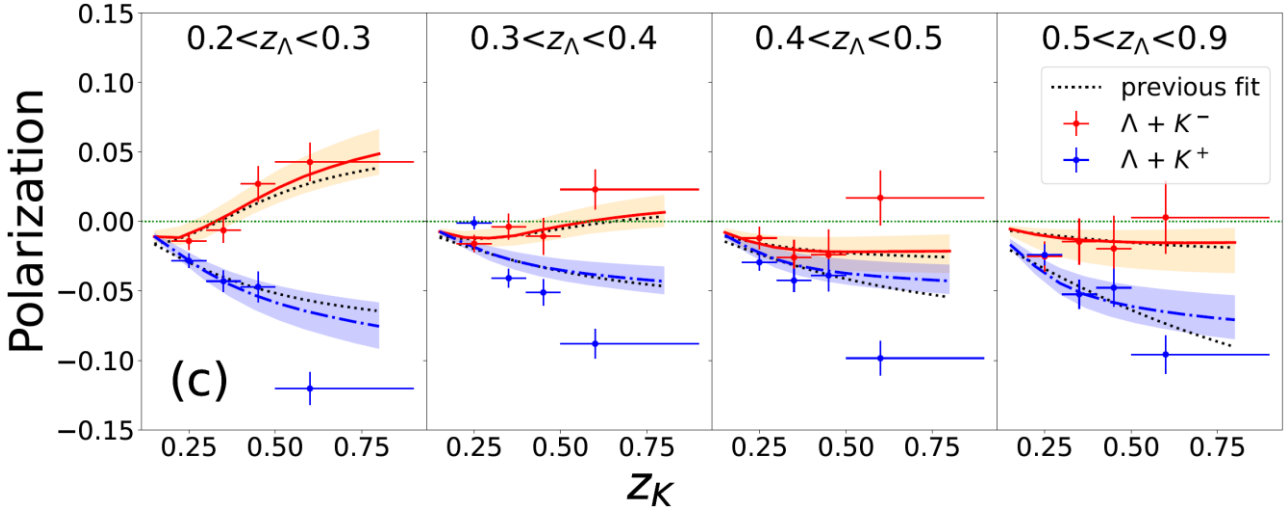

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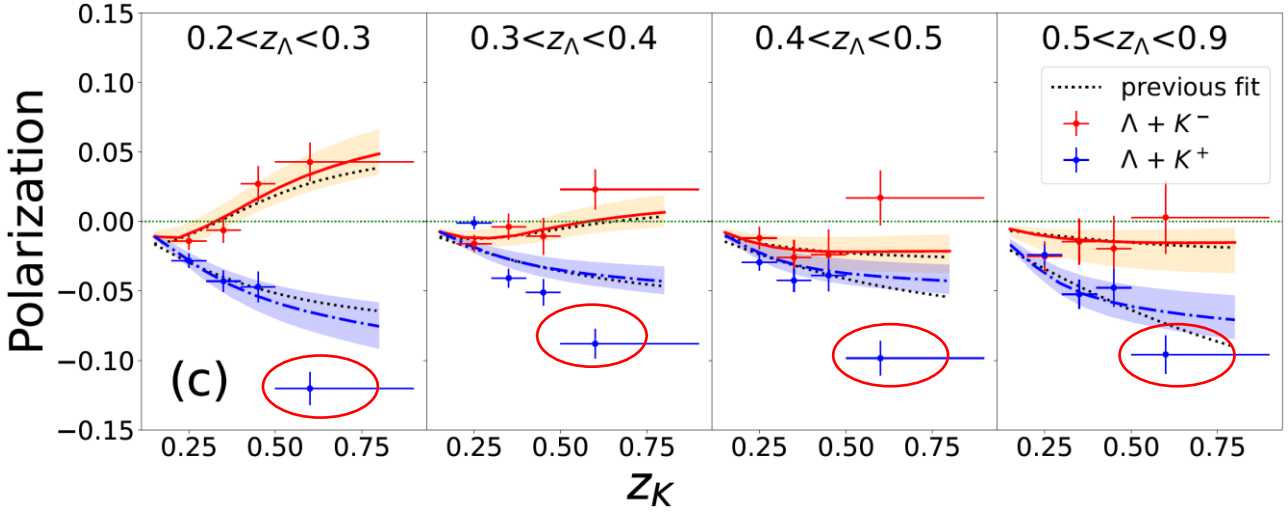

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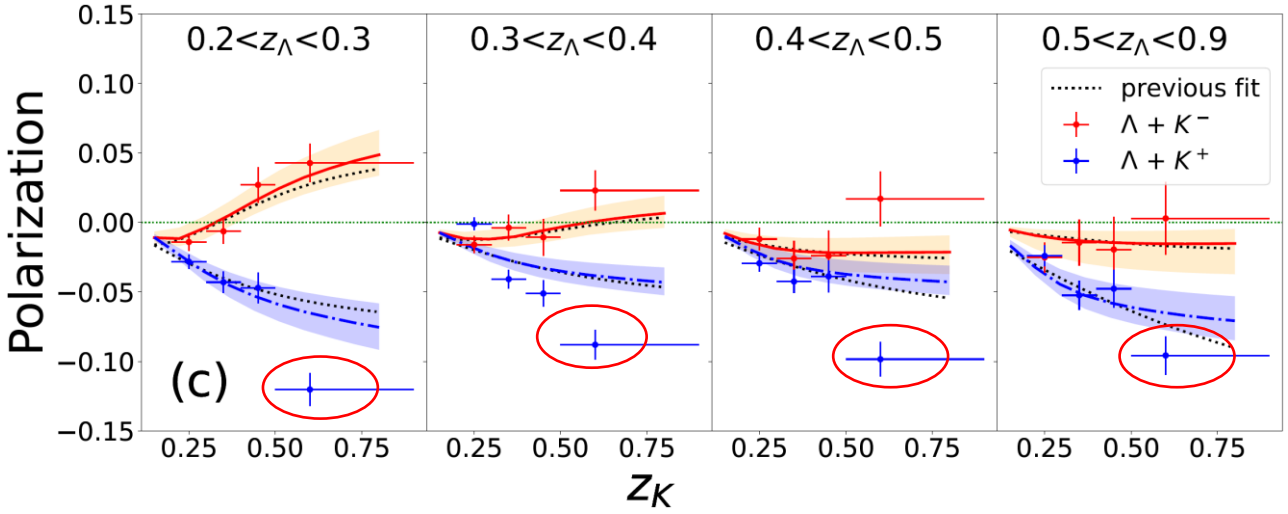

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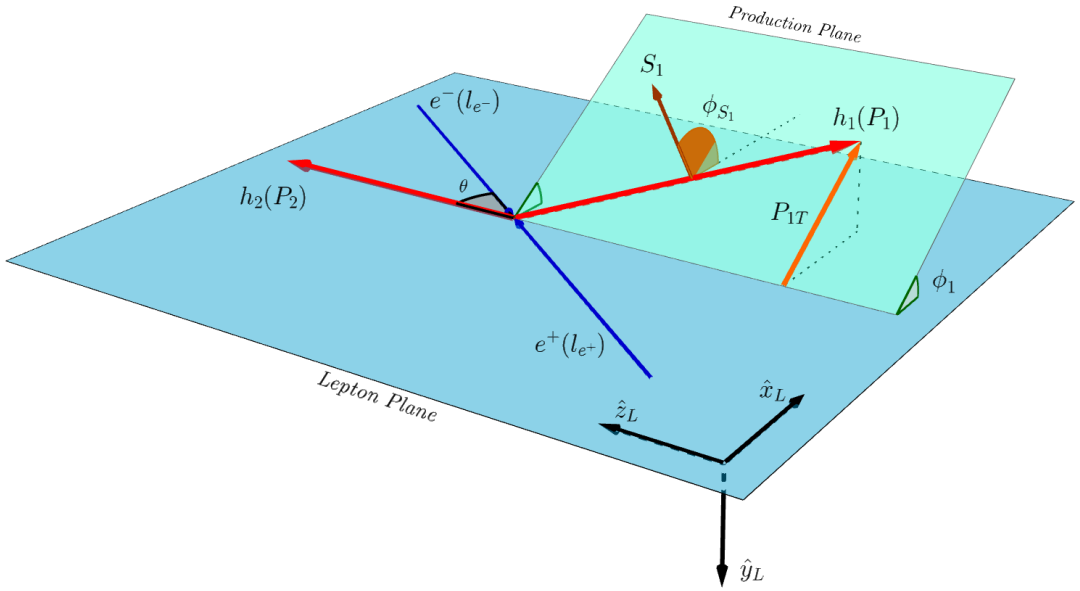
Contents:

- Convolutions and Polarization: $e^+e^- \to h^{\uparrow}{}_1 h_2 X$
- Fit results: Belle 2-h
- SIDIS predictions and Intrinsic Charm
- Conclusions

Double hadron production in e^+e^- processes



Polarization:

$$P_n^{h_1}(z_{h_1}, z_{h_2}) = \frac{M_1 \int dq_T\ q_T\ d\phi_1\ \mathcal{B}_1\left[\widetilde{D}_{1T}^{\perp(1)}\widetilde{\bar{D}}_1\right]}{\int dq_T\ q_T\ d\phi_1\ \mathcal{B}_0\left[\widetilde{D}_1\widetilde{\bar{D}}_1\right]}$$

Convolutions:

$$\mathcal{B}_0\left[\widetilde{D}\widetilde{\bar{D}}\right] = \frac{1}{z_1^2 z_2^2}\sum_q e_q^2 \int \frac{db_T}{2\pi}\, b_T J_0(b_T\, q_T)\, d_{q/h_1}(z_1;\bar{\mu}_b)\, d_{\bar{q}/h_2}(z_2;\bar{\mu}_b)$$

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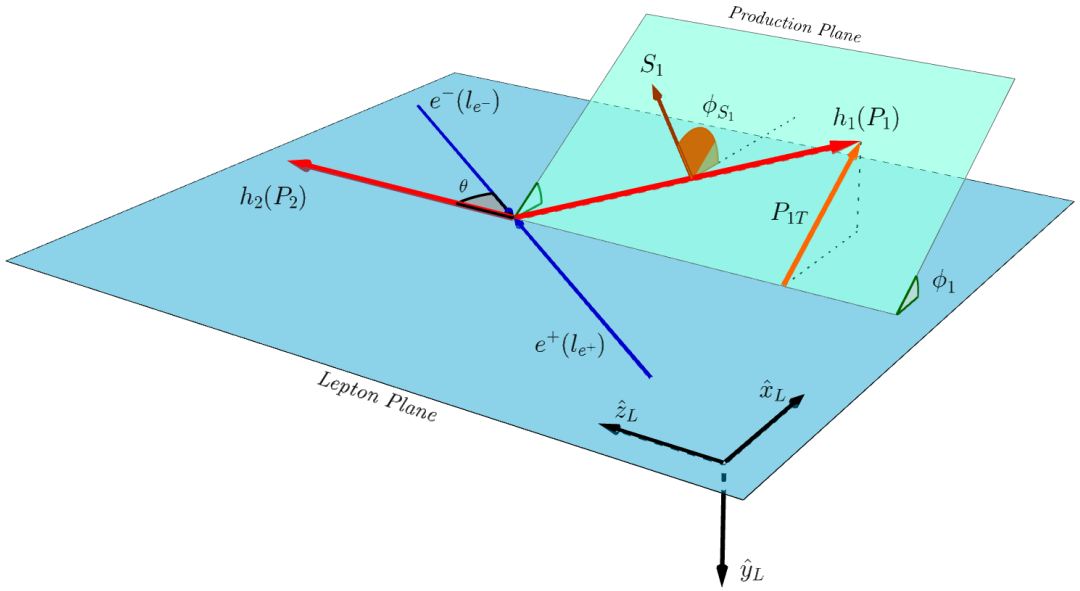

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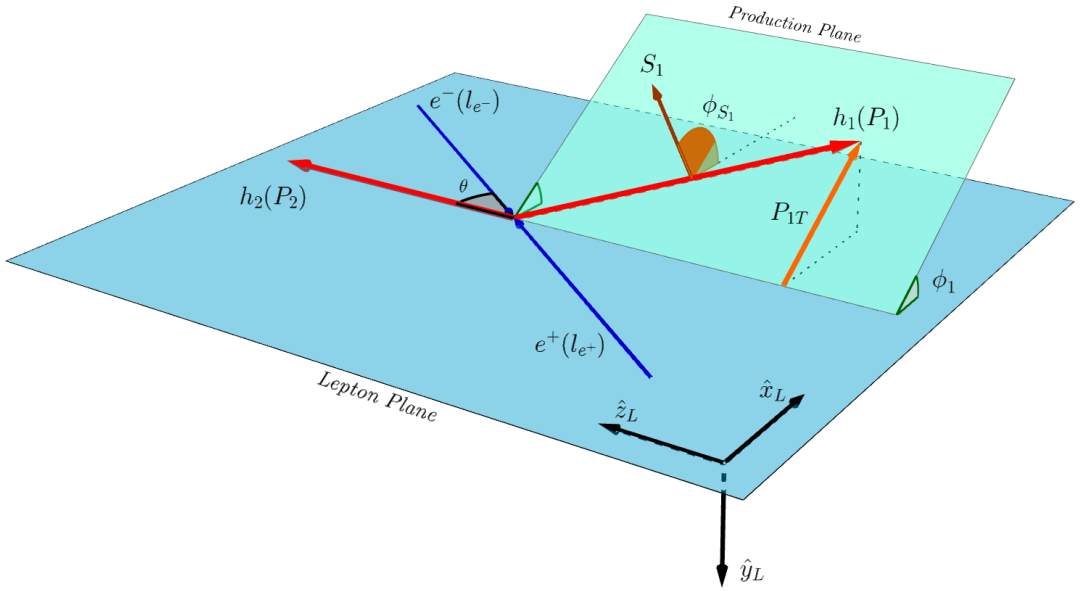

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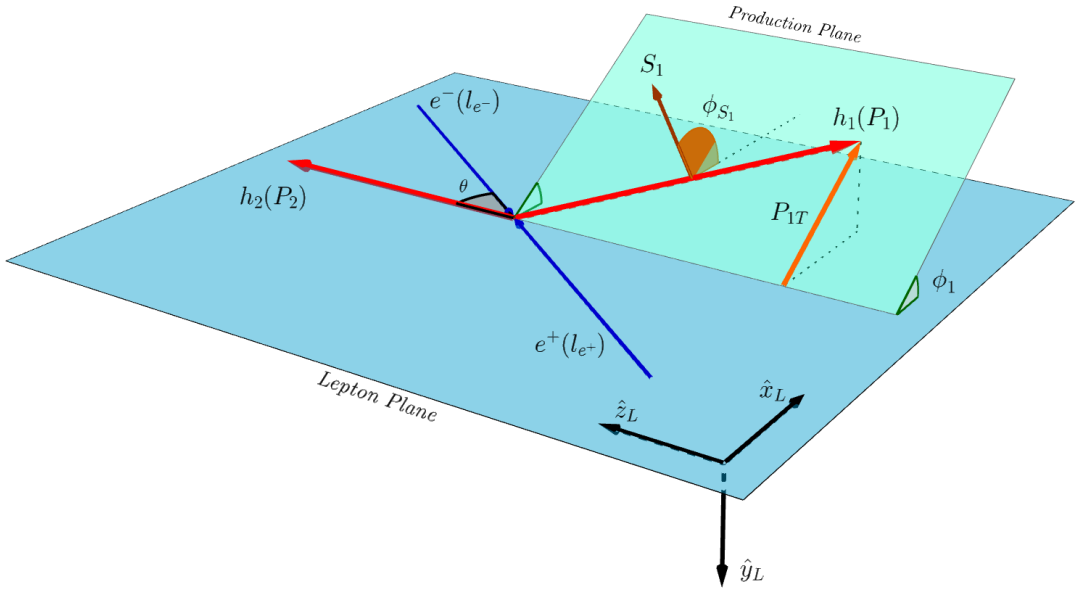

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u, d, s

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u, d, s + charm

Isospin symmetry

- No SU(2): N_u, N_d, N_s, N_{sea}
- SU(2): $N_u = N_d, N_{\bar{u}} = N_{\bar{d}}, N_s, N_{\bar{s}}$

See also:
Chen, Liang, Pan, Song, Wei;
Phys.Lett.B 816 (2021) 136217

Double hadron production in e^+e^- processes

Scenarios considered:

1. No Charm, No SU(2) sym.
   pFFs for: $up, down\ strange\ and\ sea;$

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χ^2_{dof}
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   pFFs for: $up, down\ strange\ and\ sea;$

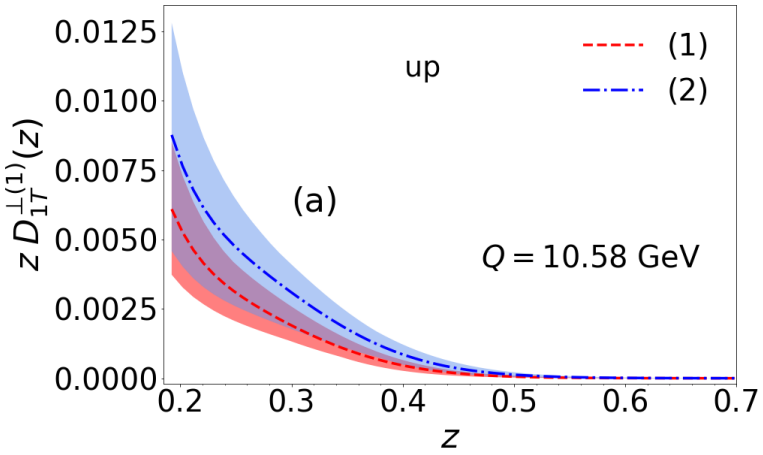
3. Charm, SU(2) sym.
   pFFs for: $up/down, \overline{up}/\overline{down}, strange, \overline{strange}$

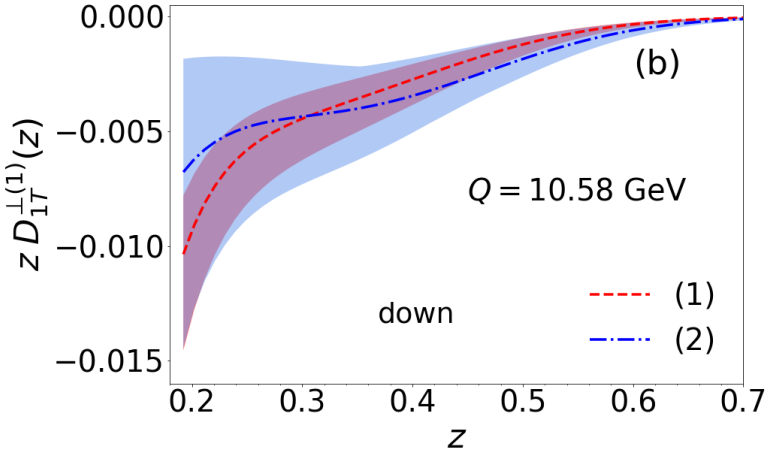
χ^2_{dof}	χ^2_{dof}
96 points	128 points
1,174	1,903
1,259	1,622
1,361	1,645

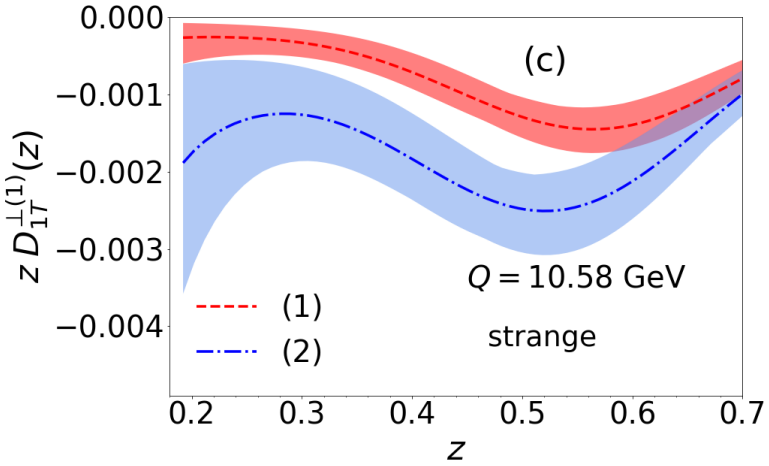
Double hadron production in e^+e^- processes

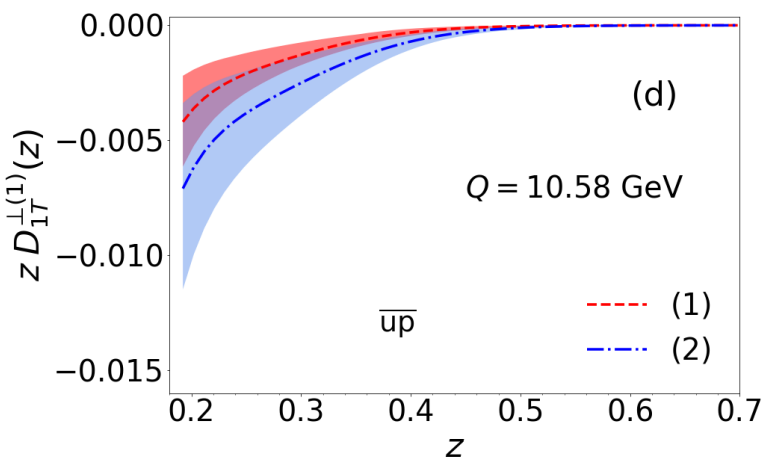
First moments: (1) & (2) scenarios

(1) No Charm, No SU2
(2) Charm, No SU2







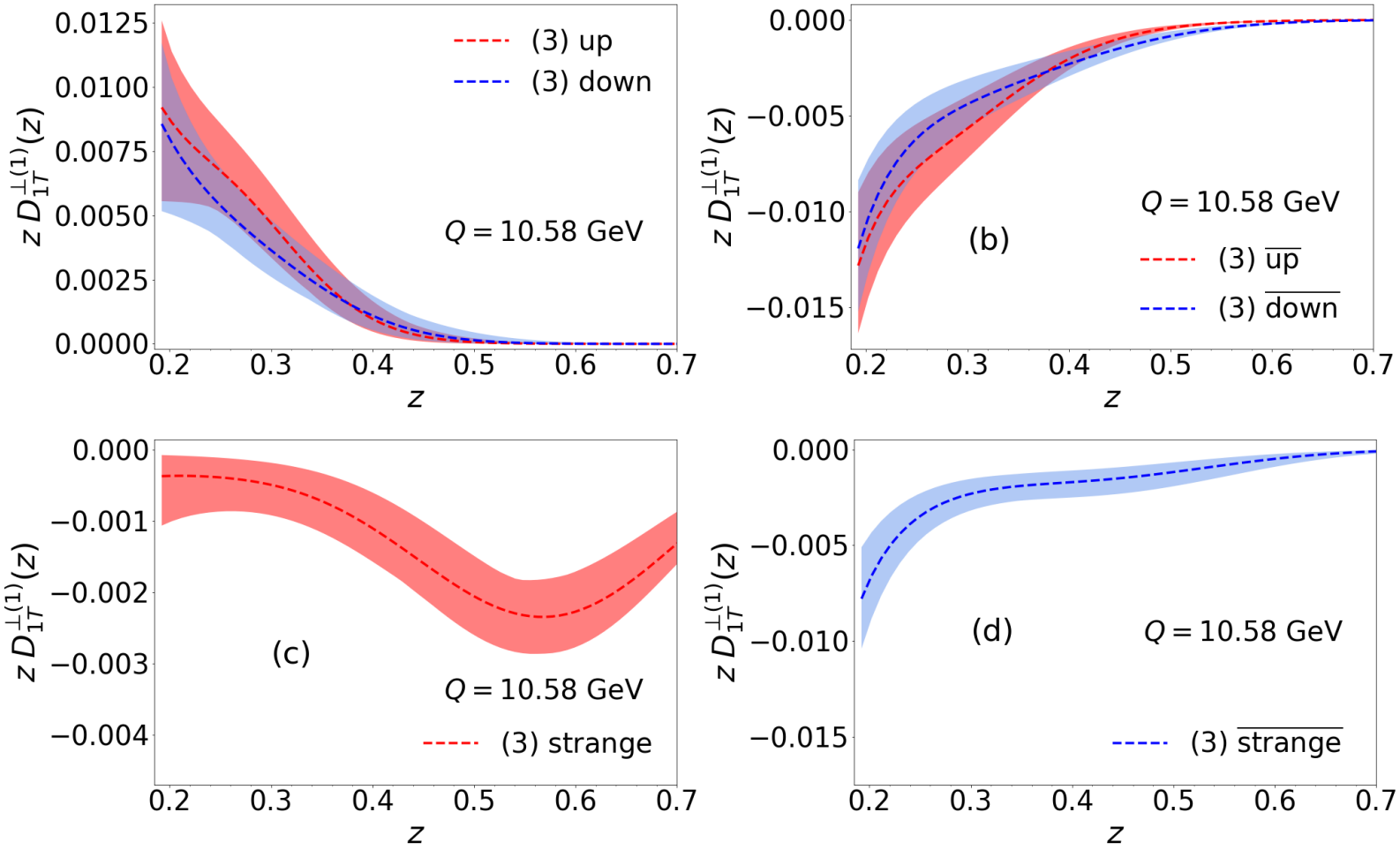


- pFFs are different in magnitude due to the charm contribution;
- up pFF is positive;
- First moments are compatible, except for the strange f.m.
- Similar size for the Gaussian width.

Double hadron production in e^+e^- processes

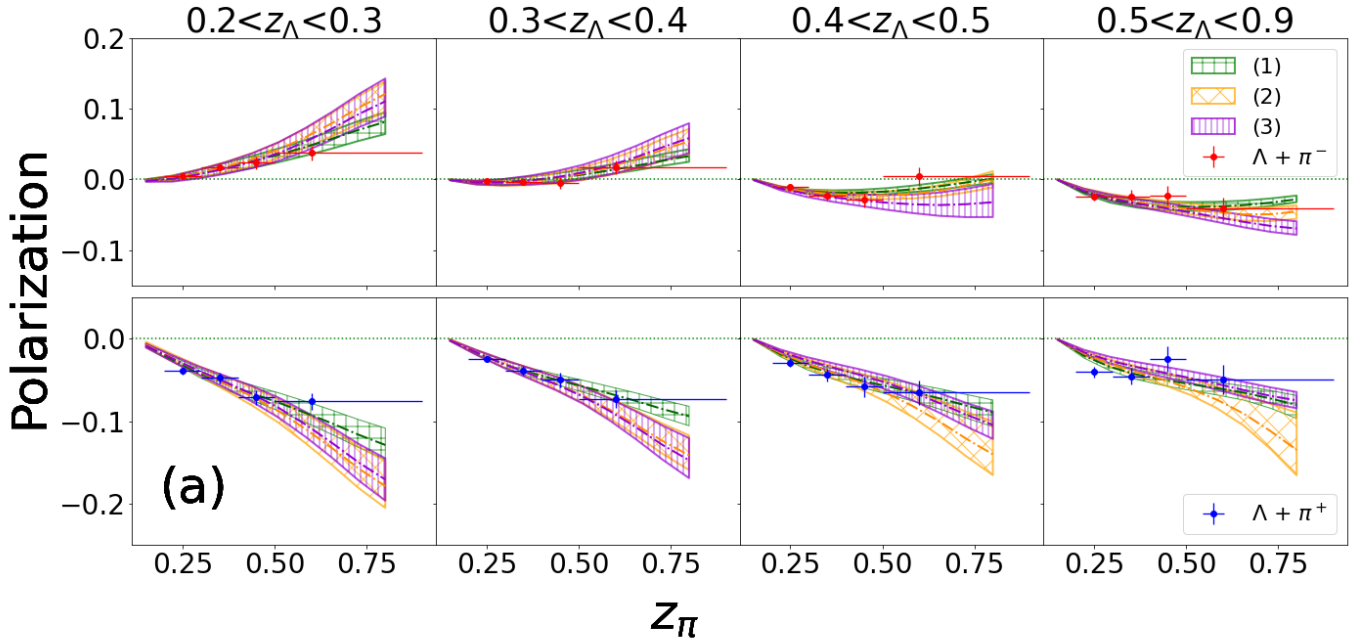
First moments: (3) scenario

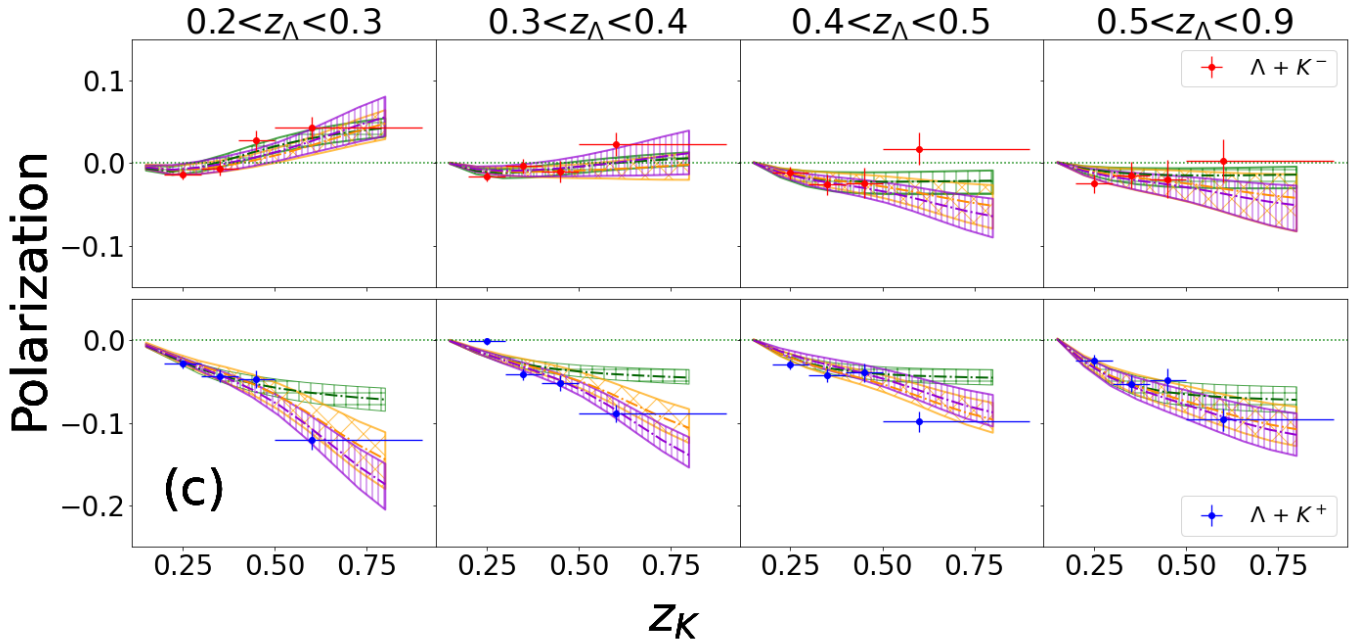
(3) Charm, SU2



- $up/down$ pFFs are positive;
- $\overline{up}/\overline{down}$ pFFs are negative;
- $strange/\overline{strange}$ pFFs are negative;
- up & $\overline{strange}$ compatible with (1,2) scn.
- The negative sea contribution is larger in size;
- Similar size for the Gaussian width.

Double hadron production in e^+e^- processes





(1) No Charm, No SU2
(2) Charm, No SU2
(3) Charm, SU2

- All scenarios can describe $\Lambda\pi^{\pm}, \bar{\Lambda}\pi^{\pm}, \Lambda\mathrm{K}^{-}, \bar{\Lambda}K^{+}$ data;
- Scenario (1) cannot describe $\Lambda\mathrm{K}^{+}, \bar{\Lambda}K^{-}$ data with $z_K > 0{,}5$;
- With the Charm contribution we obtain similar good fits and description

Double hadron production in e^+e^- processes

Some remarks:

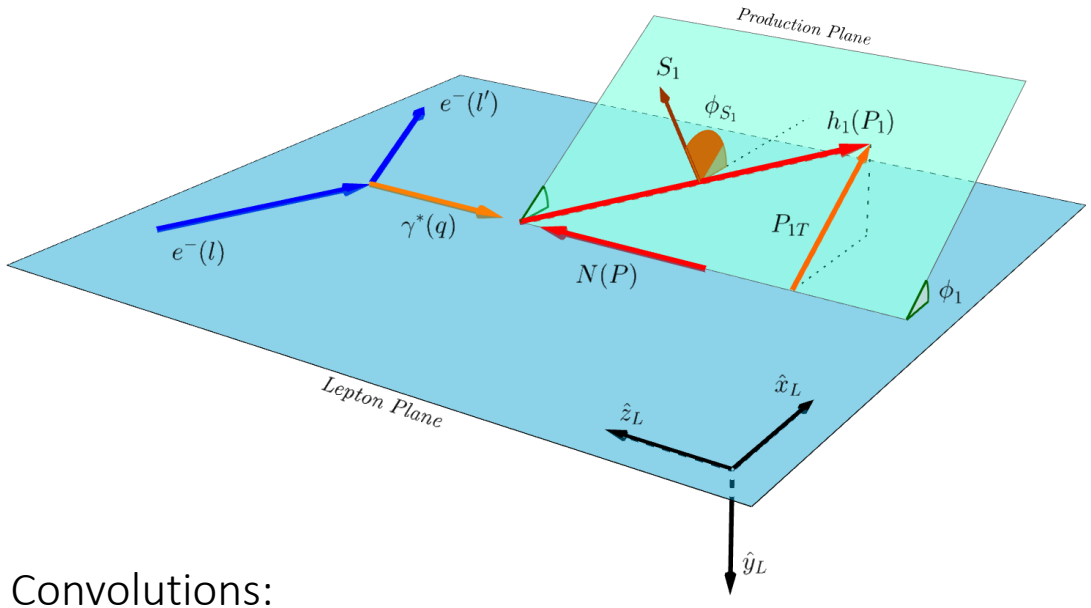
- Charm contribution in the unpolarized C.S. is necessary;
  Attempts were made to include this contribution also in the polarized c.s.
  → No improvements!

- We cannot distinguish between the (2) and (3) scenarios.
  If Normalization factors are free,
  up & $down$ come out opposite, violating the SU(2) symmetry.

- Investigate the polarization in:
  e^+e^- at different energies → we cannot distinguish between (2) & (3) scenarios

SIDIS

Semi-inclusive Deep Inelastic Scattering



Polarization:

$$P_n^{h_1}(x_B, z_h) = \frac{M_1 \int dq_T\; q_T\; d\phi_1\; \mathcal{B}_1\left[\widetilde{f}_1 \widetilde{D}_{1T}^{\perp(1)}\right]}{\int dq_T\; q_T\; d\phi_1\; \mathcal{B}_0\left[\widetilde{f}_1 \widetilde{D}_1\right]}$$

Convolutions:

$$\mathcal{B}_0\left[\widetilde{f}_1 \widetilde{D}_1\right] = \frac{1}{z^2}\sum_q e_q^2 \int \frac{db_T}{(2\pi)}\, b_T J_0(b_T\, q_T)\, f_{N/q}(x;\bar{\mu}_b)\, d_{q/h}(z;\bar{\mu}_b)$$
$$\times\, M_{f_1}(b_c(b_T), x)\, M_{D_h}(b_c(b_T), z)\, e^{-g_K(b_c(b_T);b_{\max})\ln\left(\frac{Q^2 z}{x M_P M_h}\right) - S_{\rm pert}(b_*;\bar{\mu}_b)}$$

$$\mathcal{B}_1\left[\widetilde{f}_1 \widetilde{D}_{1T}^{\perp(1)}\right] = \frac{1}{z^2}\sum_q e_q^2 \int \frac{db_T}{(2\pi)}\, b_T^2 J_1(b_T\, q_T)\, f_{N/q}(x;\bar{\mu}_b)\, D_{1T,q}^{\perp(1)}(z;\bar{\mu}_b)$$
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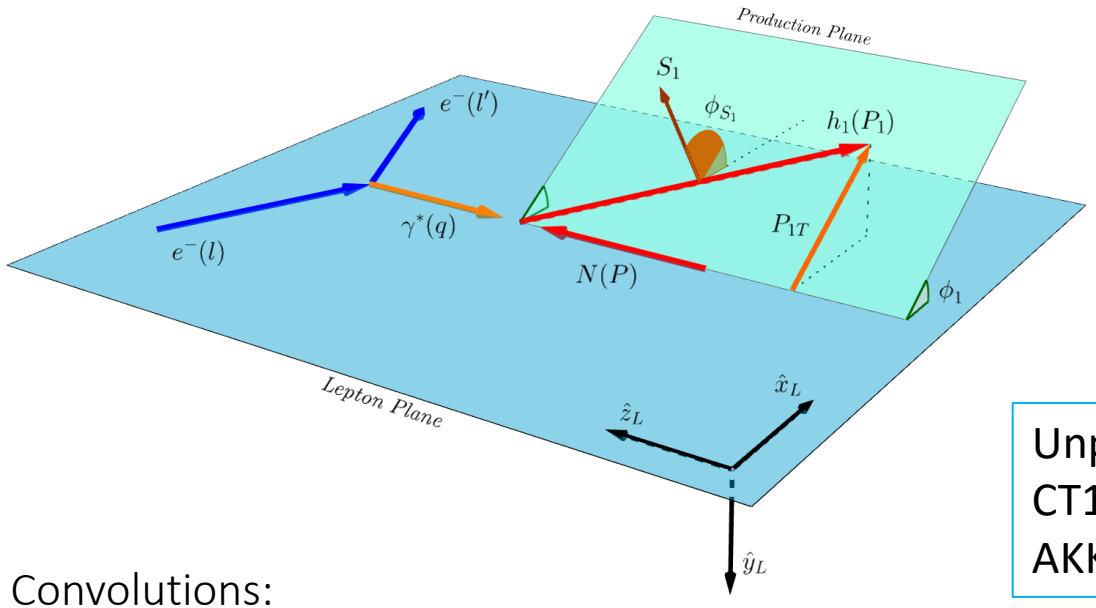
Semi-inclusive Deep Inelastic Scattering



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Unpolarized functions:
CT14nnlo set for proton
AKK set for Λ

Convolutions:

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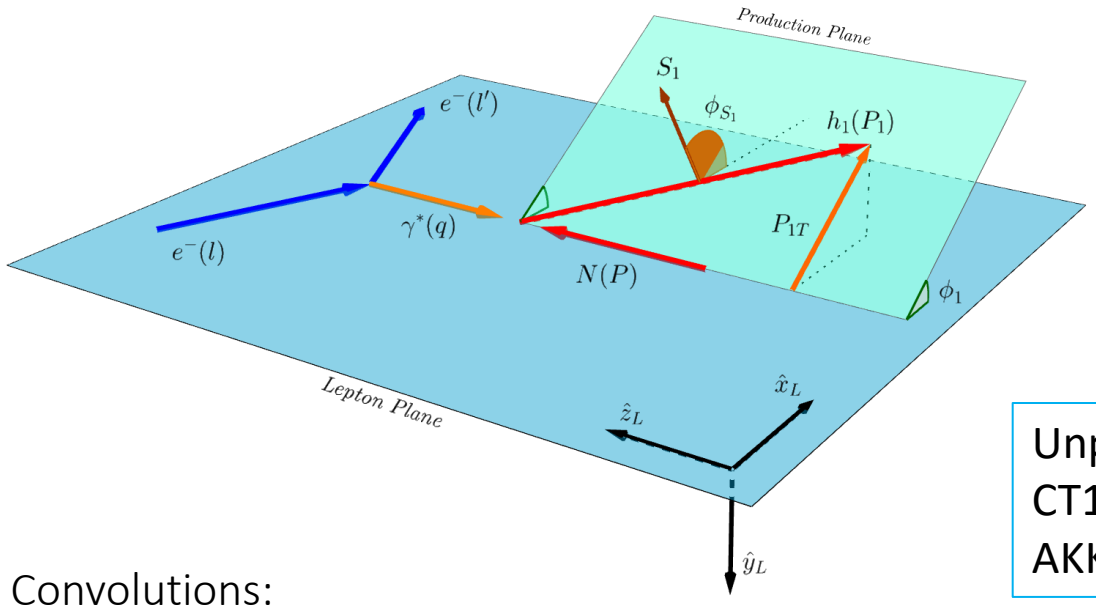

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Non-perturbative functions from Bacchetta et al., *JHEP* 06 (2017) 081

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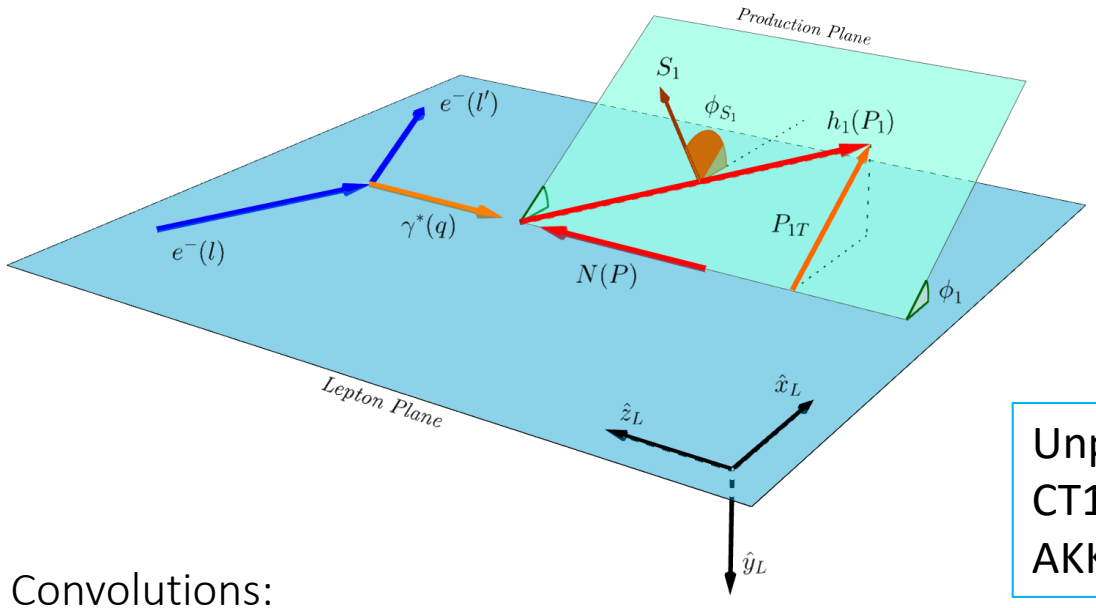

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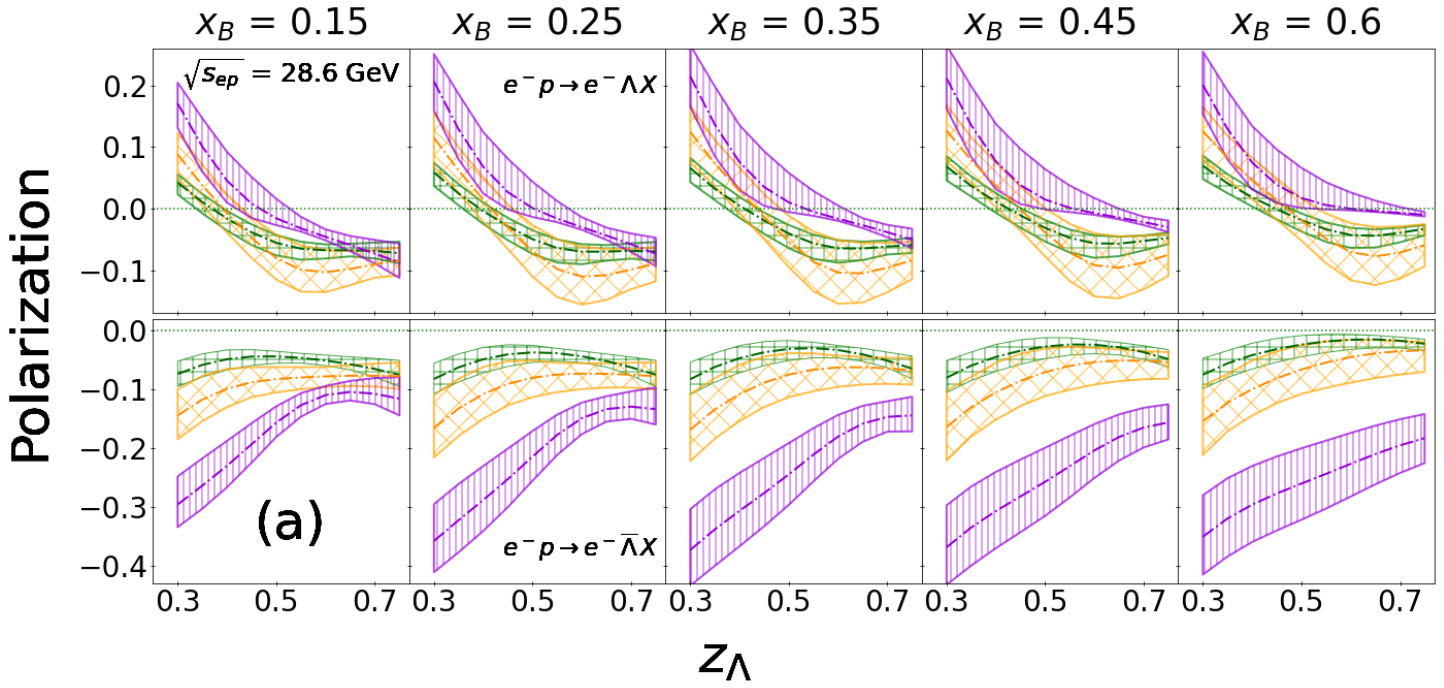
Predictions are given at different energies:

E_N (GeV)	E_{e^-} (GeV)	$\sqrt{s_{eN}}$ (GeV)
41	5	28.6
100	10	63.2

$$s = 4E_N E_e\,, \quad Q^2 = x_B y s$$

Semi-inclusive Deep Inelastic Scattering



(1) No Charm, No SU2
(2) Charm, No SU2
(3) Charm, SU2

Electron – Proton

- (1) & (2) scenarios: polarization of similar size and behavior;
- Λ pol. decreases and becomes negative;
- $\bar{\Lambda}$ is always negative;
- $\sqrt{s_{ep}}$=28,6 pol. has the same size, for greater values there is a general reduction as x_B grows.

- (3) scenario: similar size;
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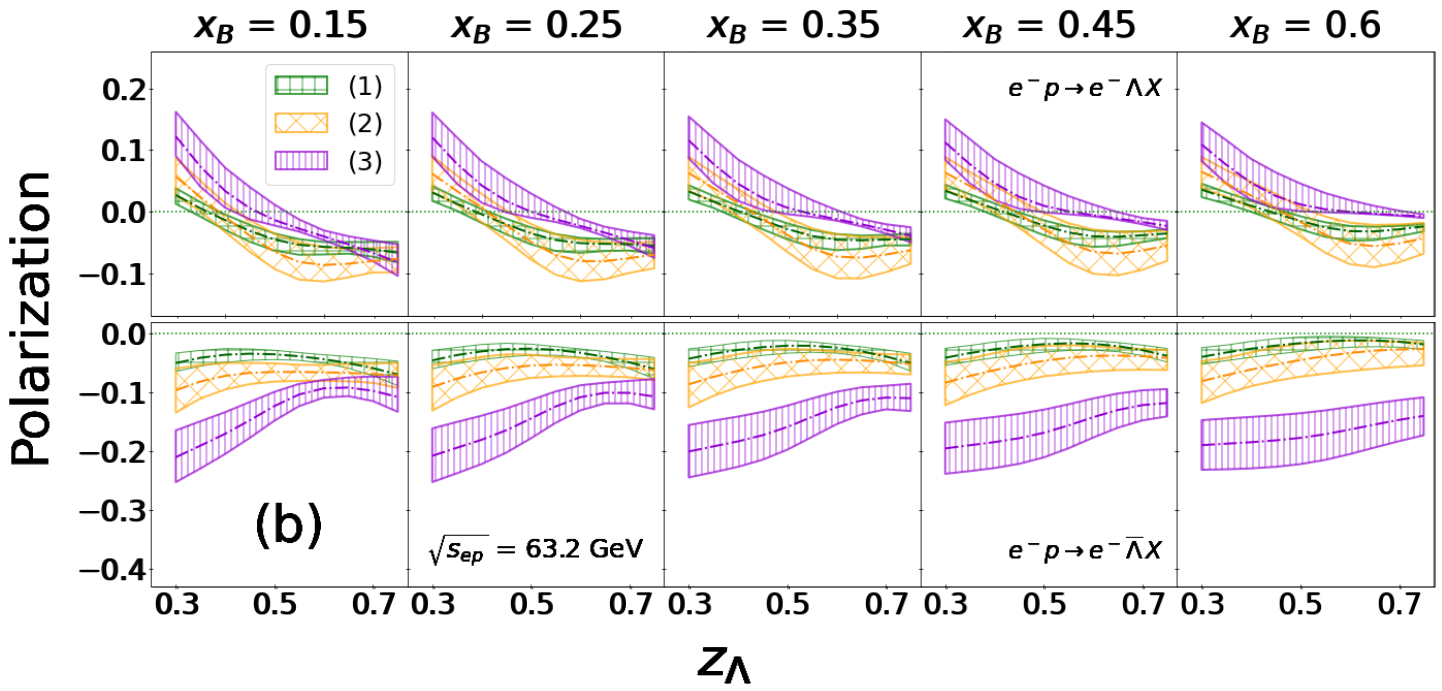
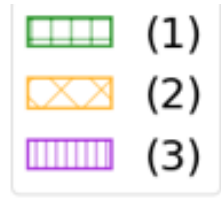
Semi-inclusive Deep Inelastic Scattering





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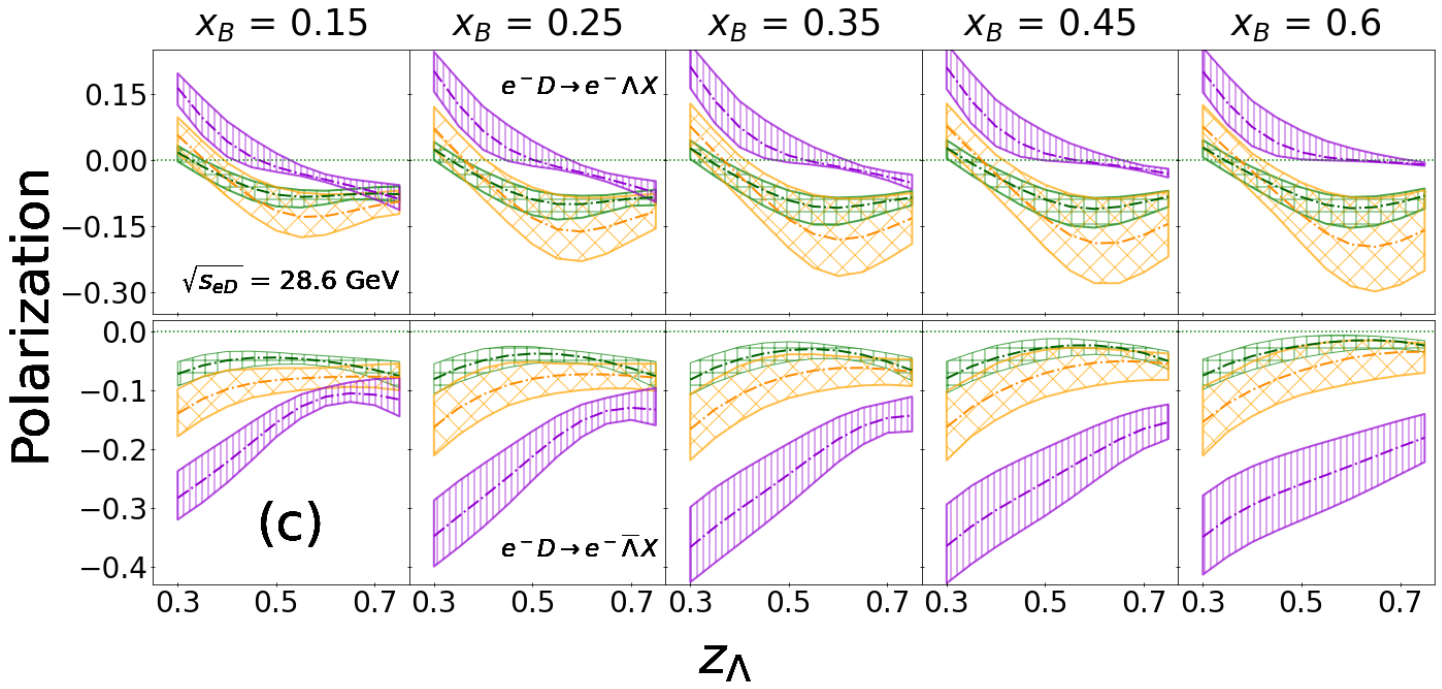

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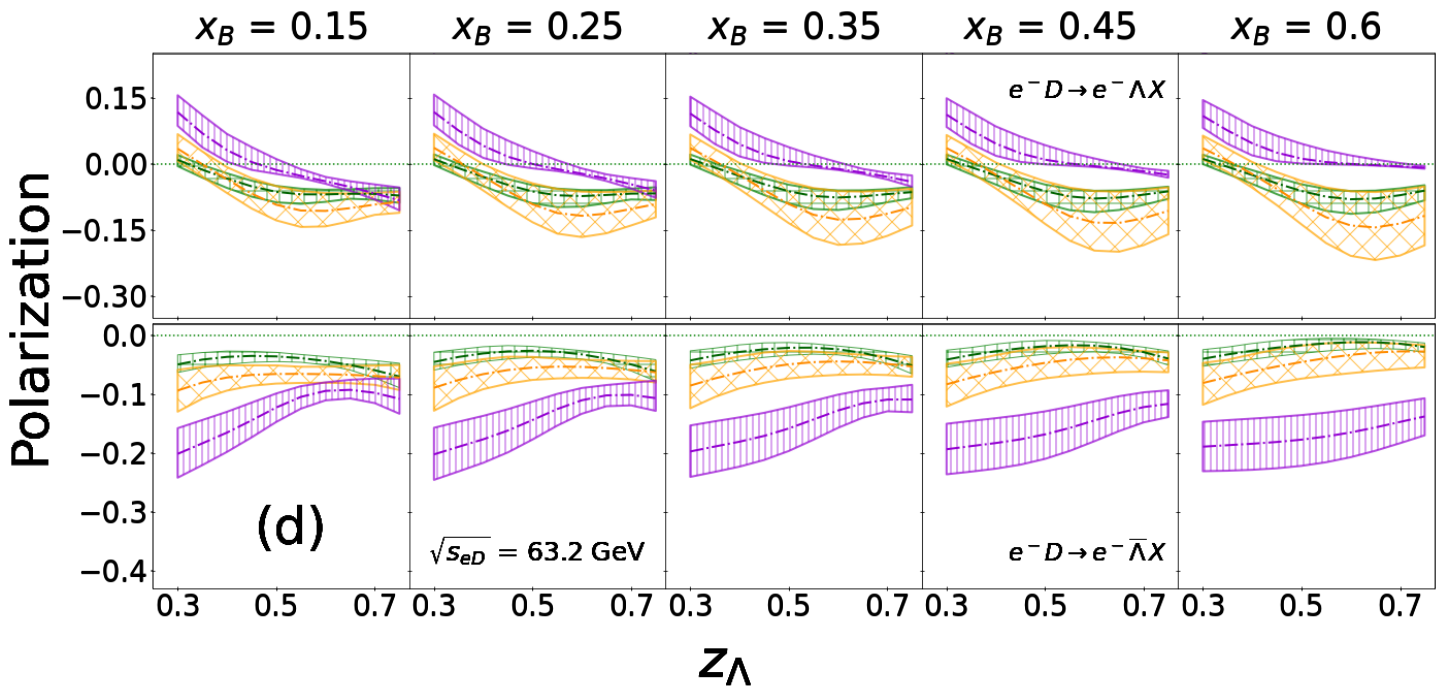
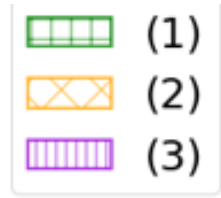
Semi-inclusive Deep Inelastic Scattering





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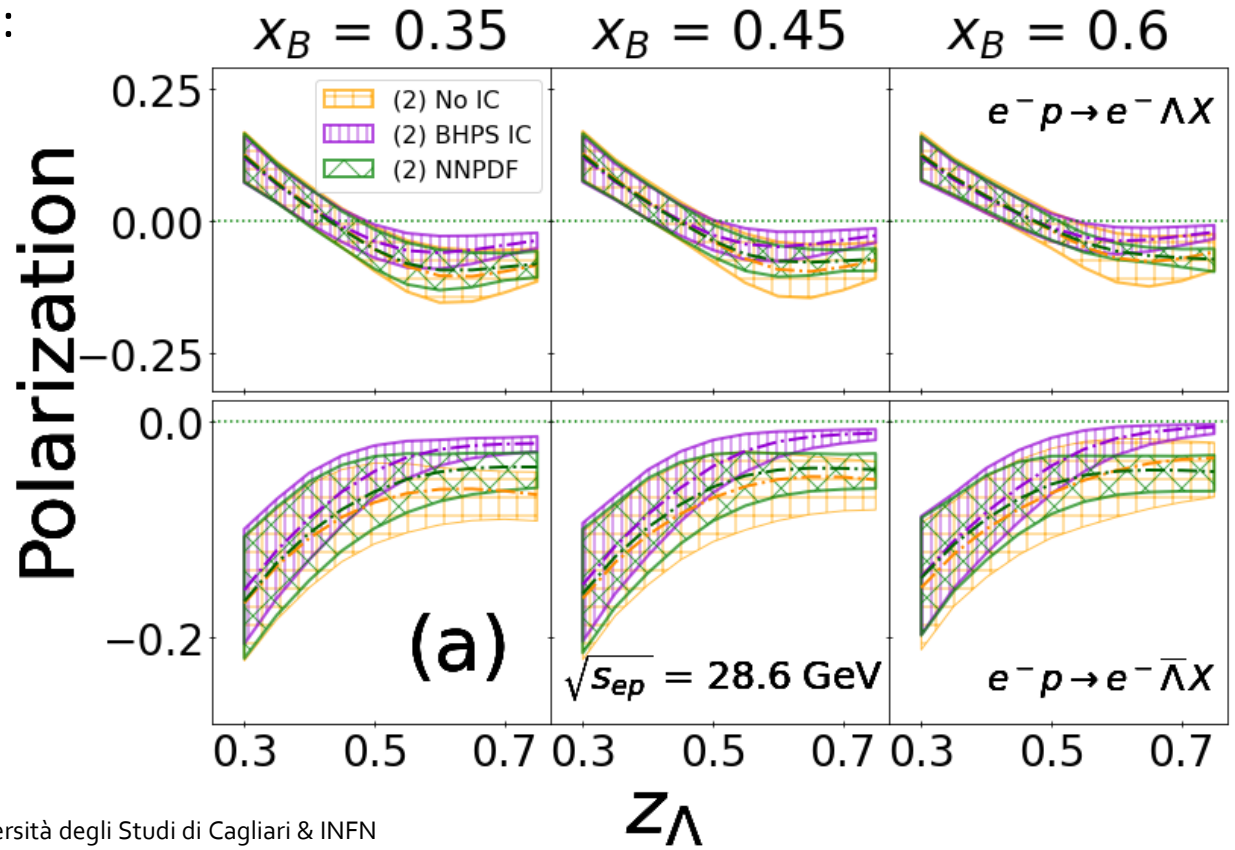
Semi-inclusive Deep Inelastic Scattering

The charm contribution in the fragmentation process is relevant

Intrinsic Charm (IC) component in the proton:
•CT14nnloIC set with BHPS model [T.-J. Hou et al., *JHEP* 02 (2018) 059]
•NNPDF4.0nnlo set [NNPDF Coll., *Eur.Phys.J.C* 82 (2022) 5, 428]

(2) Scenario:

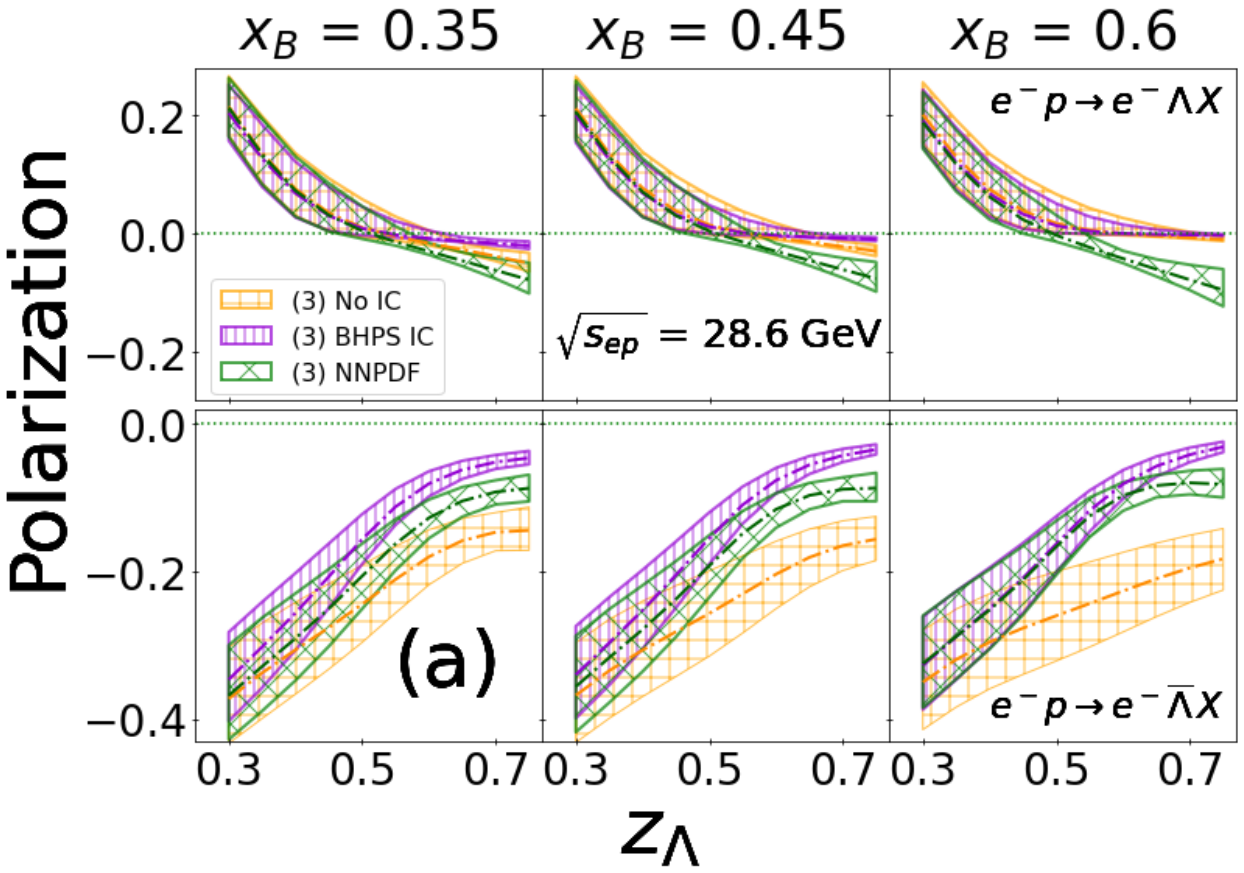


(2) Charm, No SU2

- BHPS and NNPDF: similar polarization of previous predictions
- Same behavior is present for greater values of the c.m. energy.

Semi-inclusive Deep Inelastic Scattering

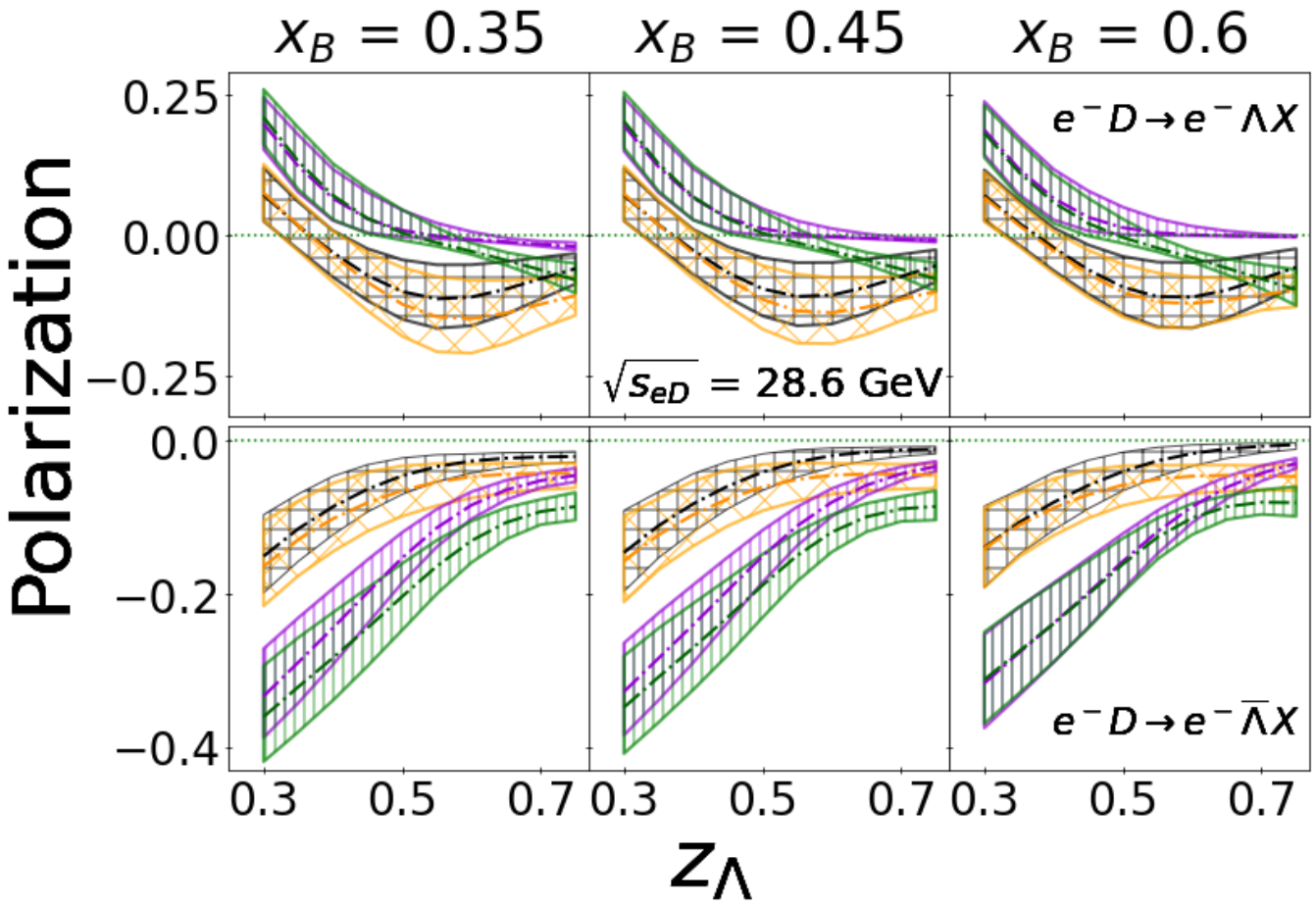
(3) Scenario:



(3) Charm, SU2

- Estimates vary significantly as x_B increases;
- $\bar{\Lambda}$ estimates with BHPS and NNPDF different from the previous ones;
- Λ :decreases to zero
- Λ : NNPDF become negative

Semi-inclusive Deep Inelastic Scattering



(2) Charm, No SU2
(3) Charm, SU2

- Λ : the predictions are compatible
- $\bar{\Lambda}$: within (2) and (3) are still different

Conclusions

- Double hadron production in e^+e^-:
  Fit results

  Charm is necessary

  (2) and (3) scenarios cannot be distinguished → open issue!

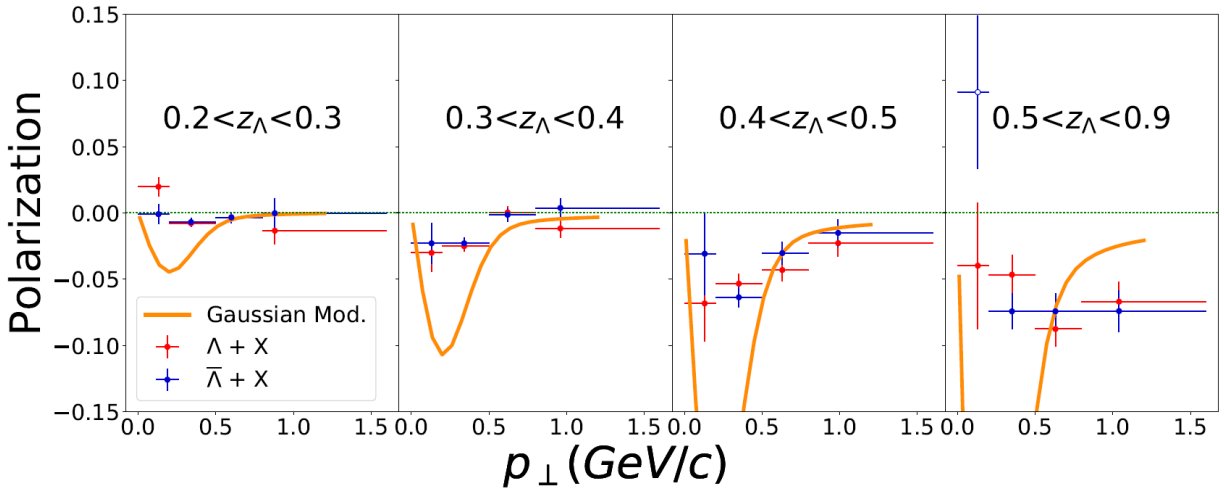
- SIDIS:
  predictions for the transverse Lambda polarization

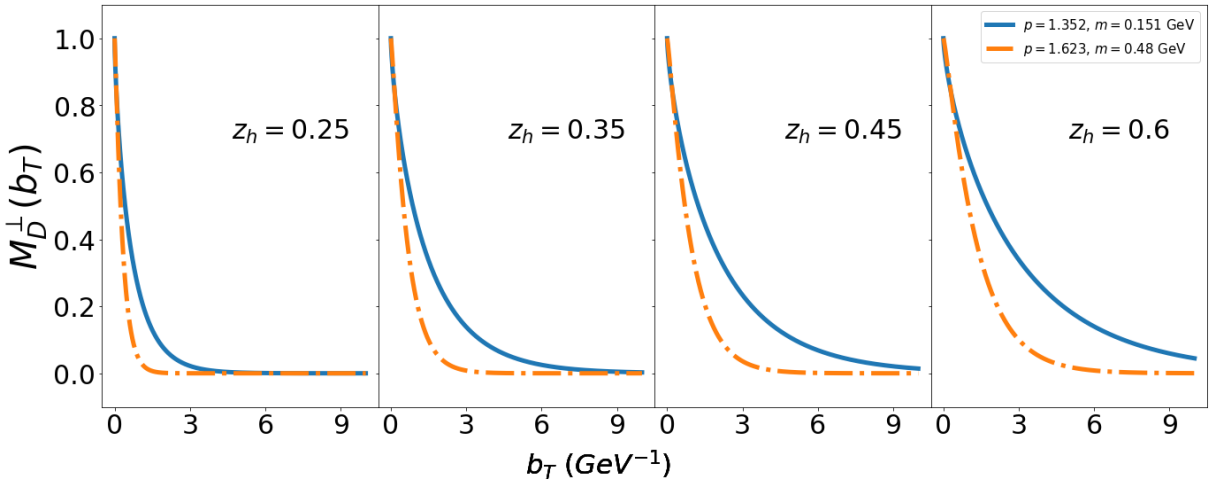
  (2) and (3) scenarios predictions are different and can be distinguished

Motivations and Contents

2-h and 1-h data cannot be described by the same non-perturbative model!

- 2-h Power-Law model
- 1-h Power-Law model





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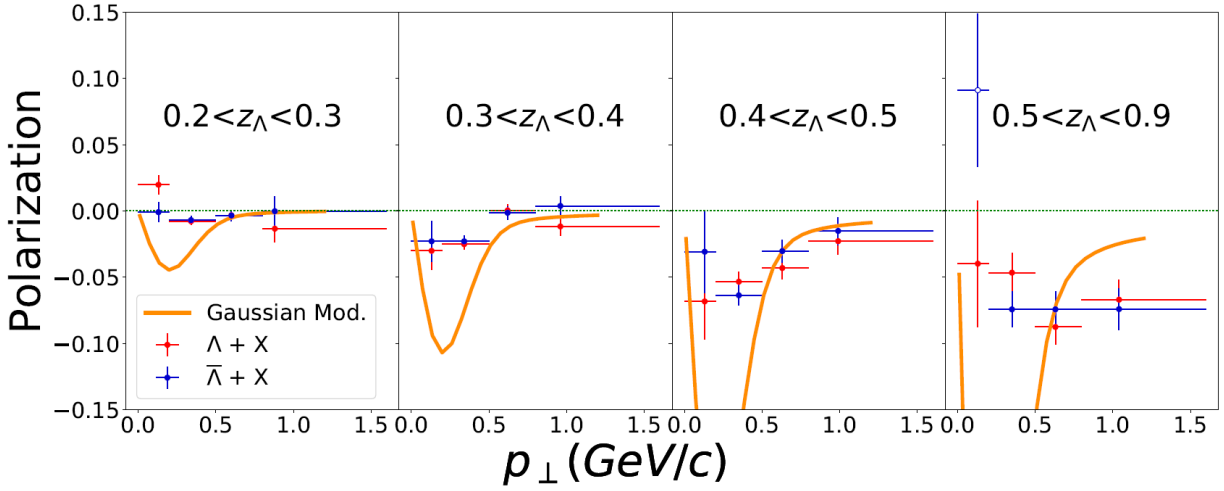
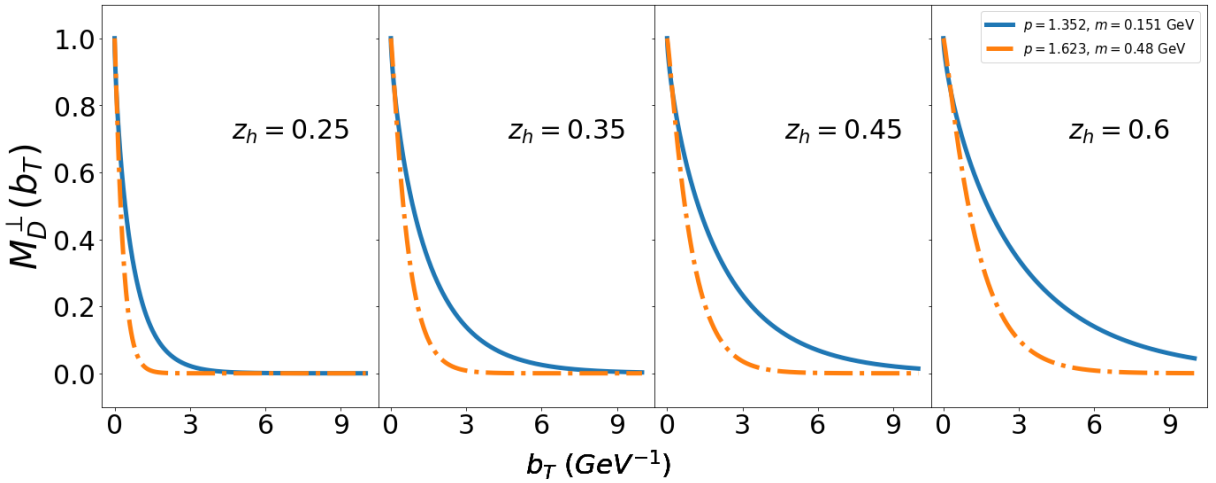
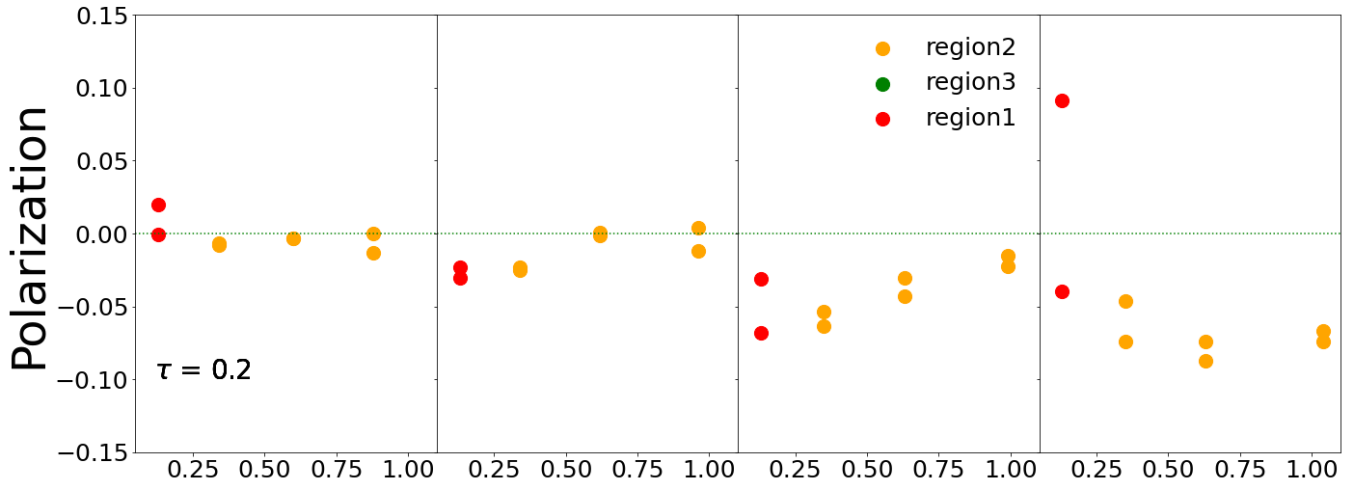




Data can be analyzed within a different scheme.

See A. Simonelli's talk!



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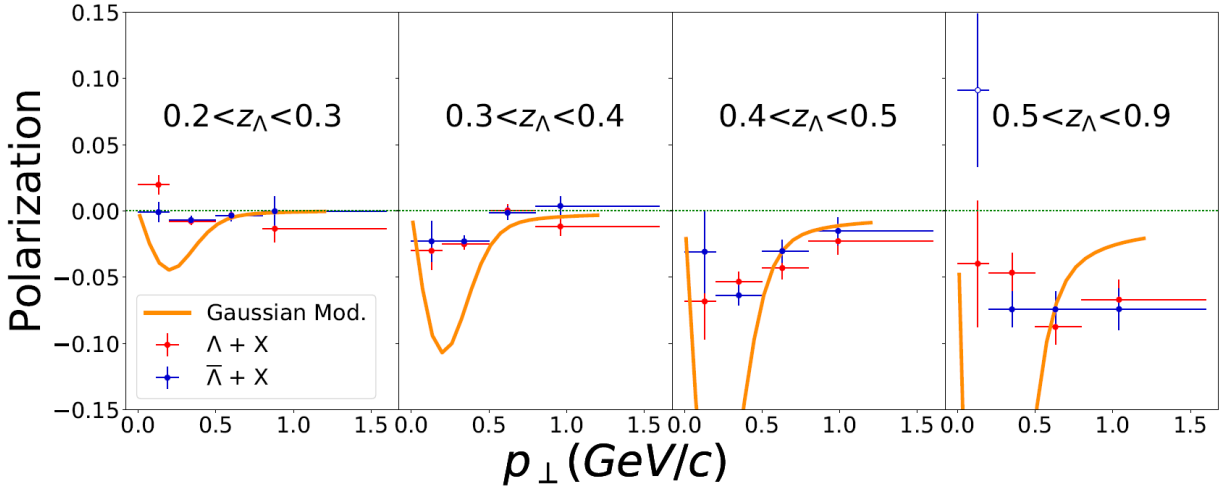

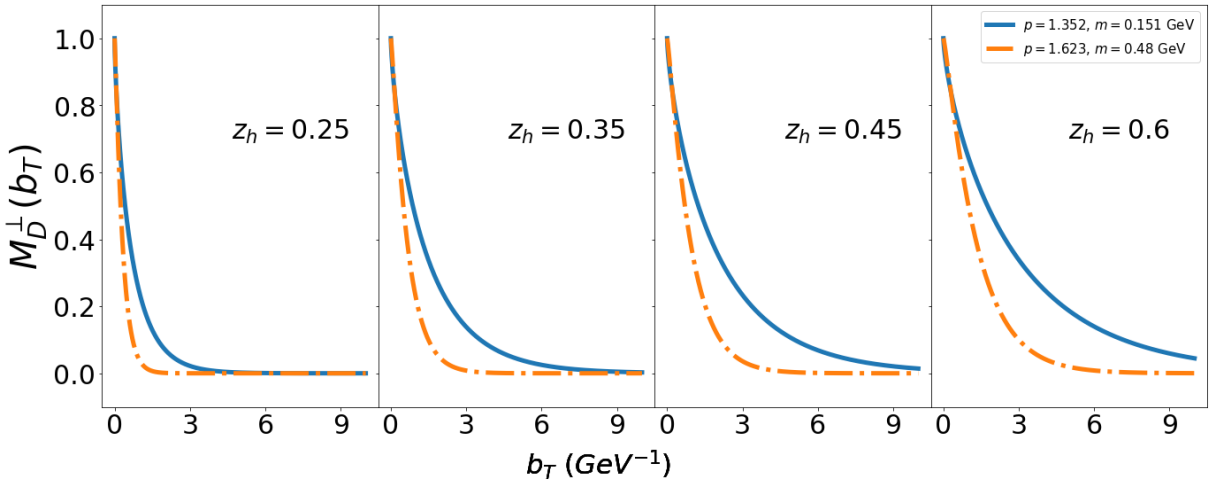

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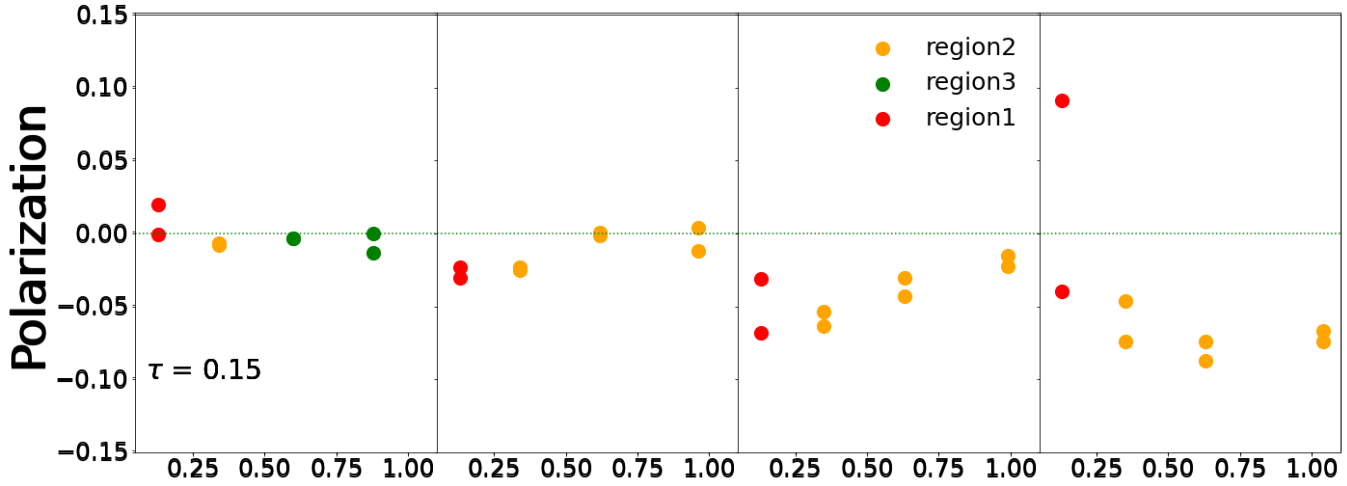

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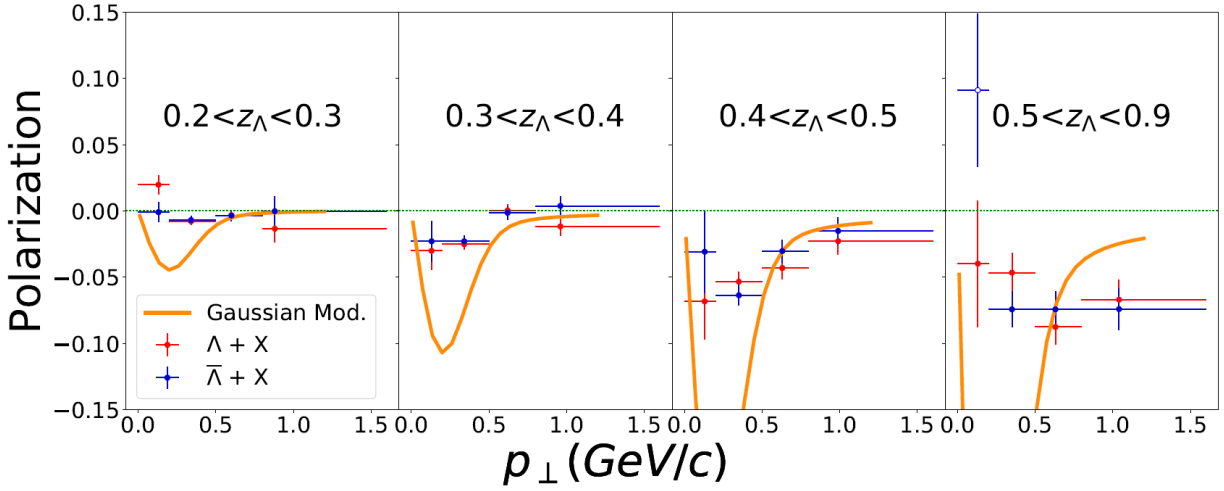

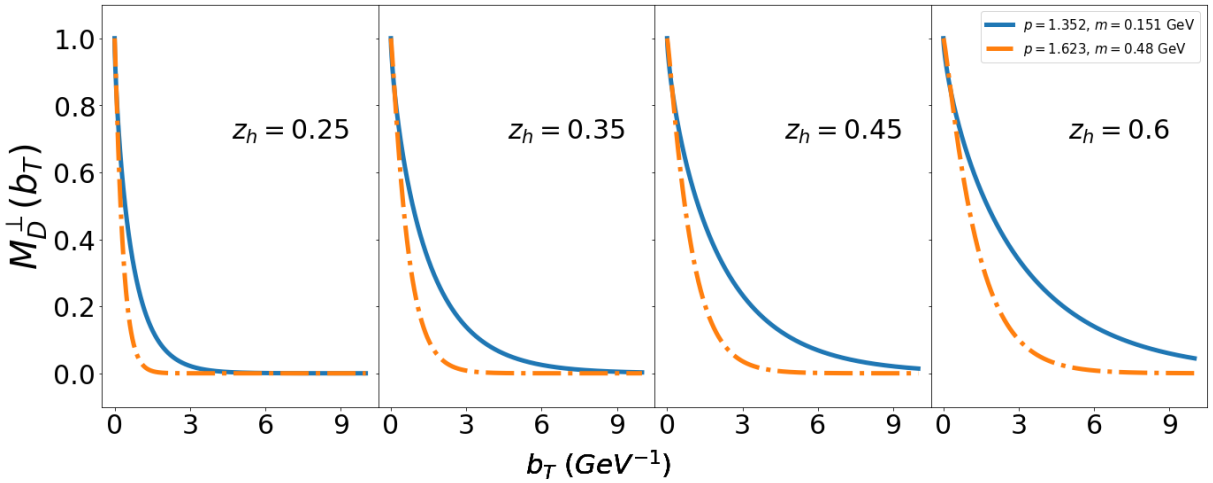

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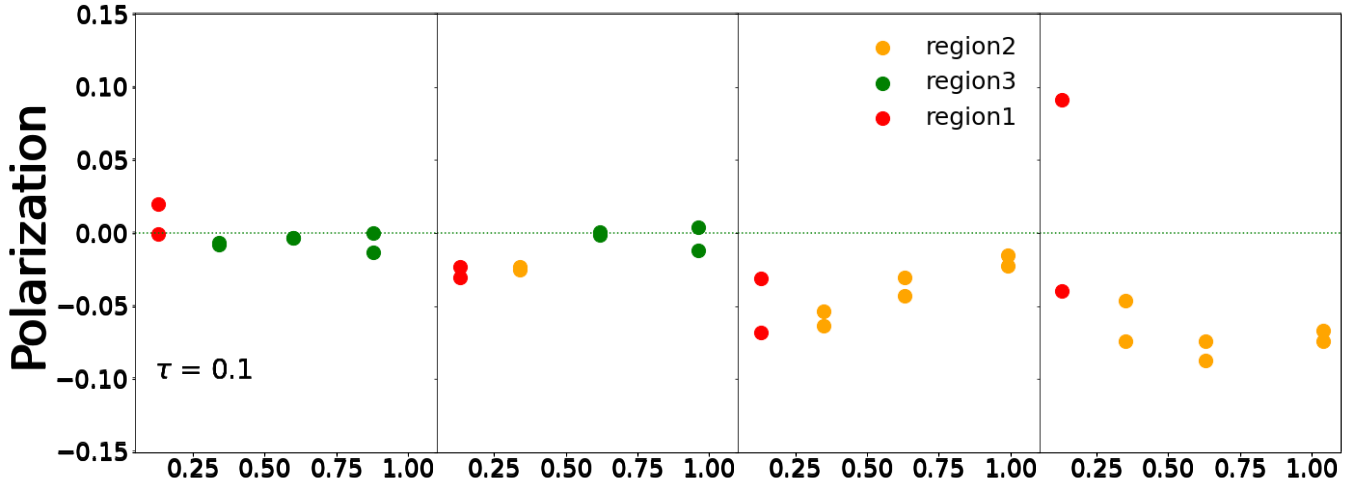
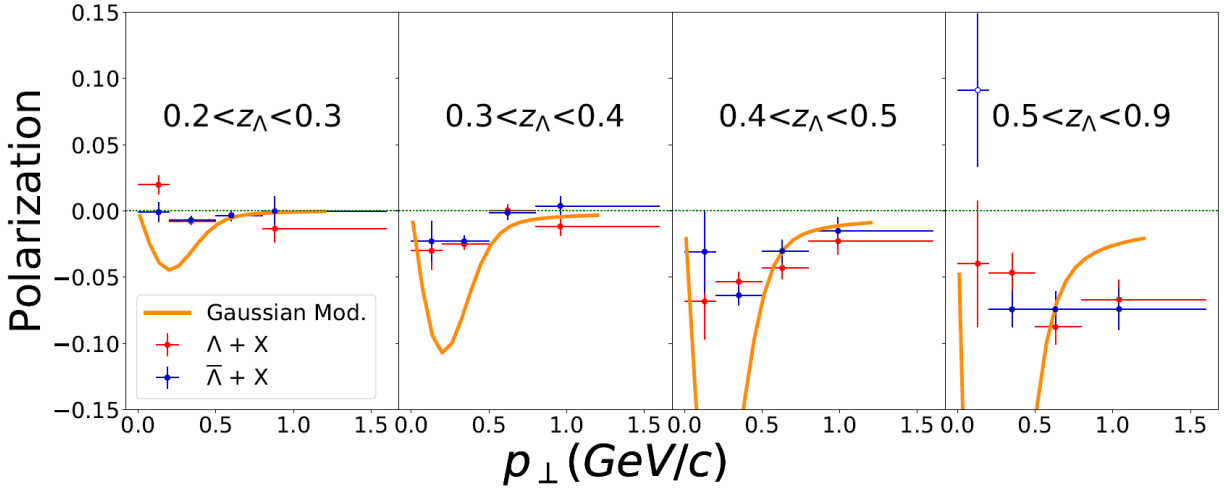


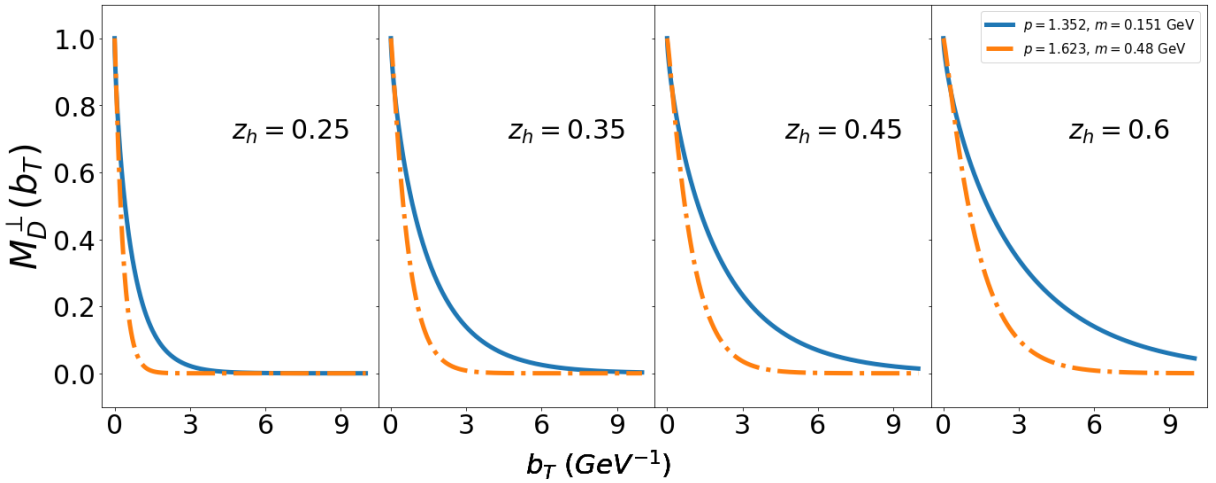
Data not binned in Thrust!

Motivations and Contents

2-h and 1-h data cannot be described by the same non-perturbative model!

- 2-h Power-Law model
- 1-h Power-Law model





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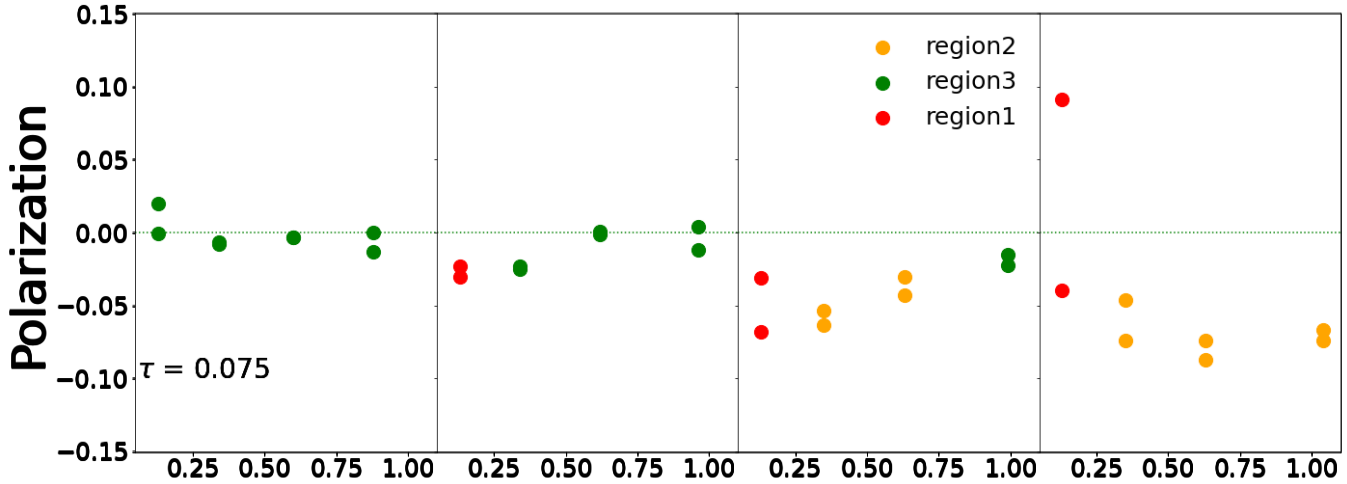

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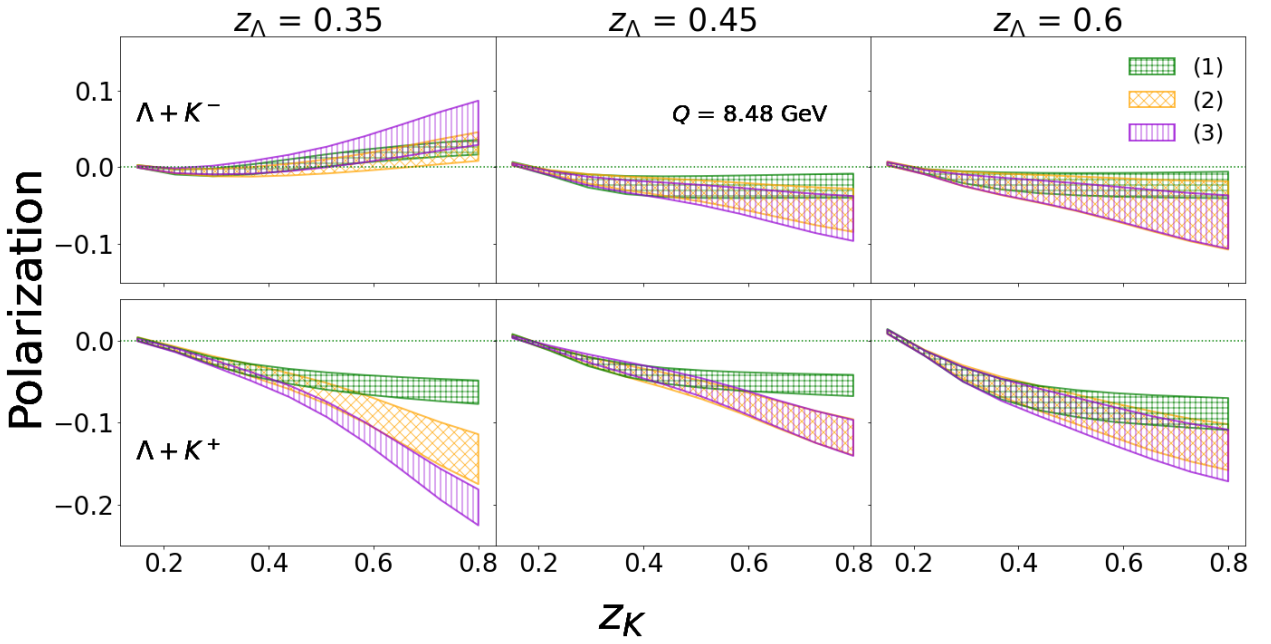
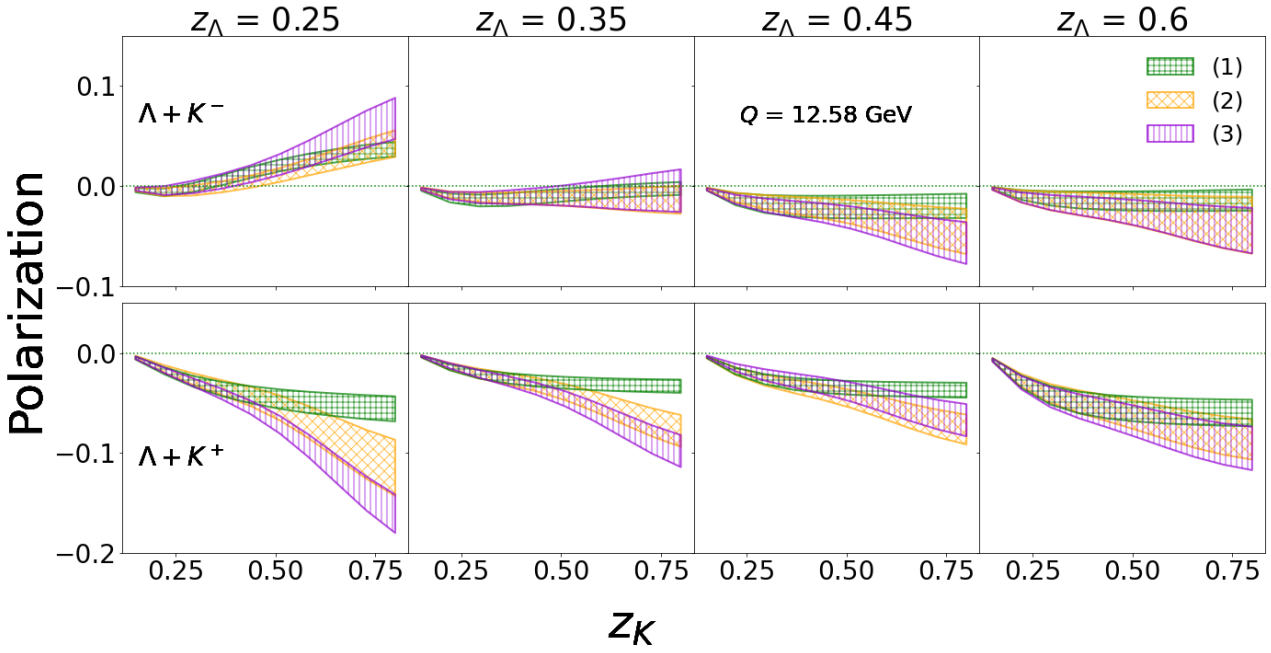
Double hadron production in e^+e^- processes



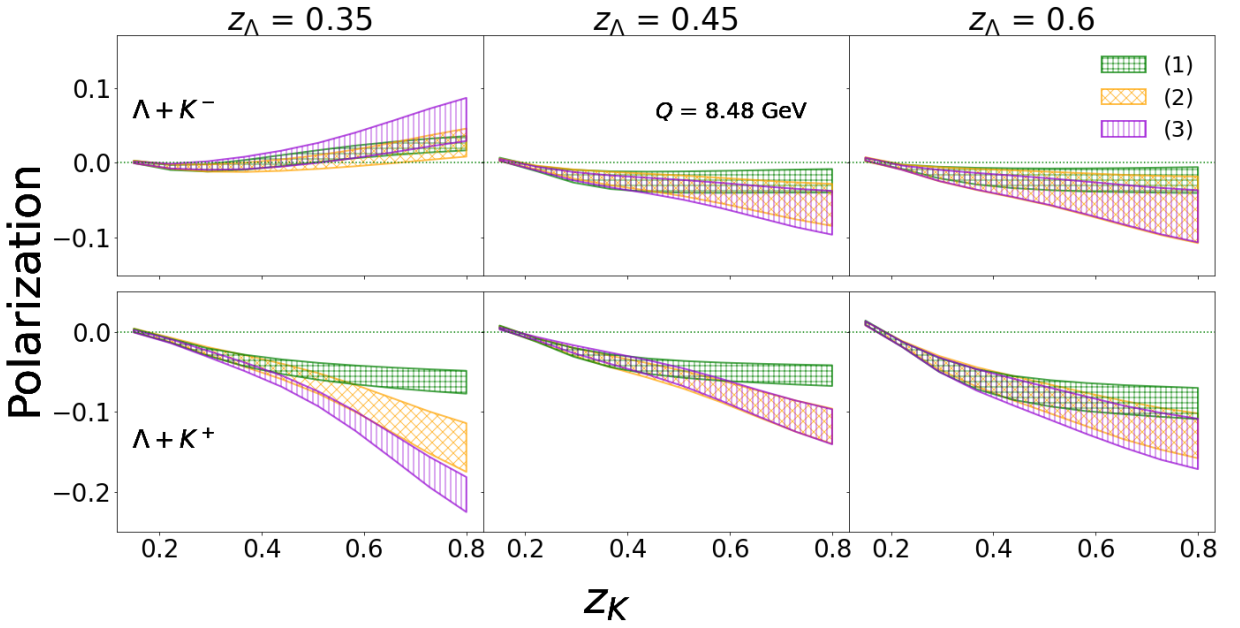


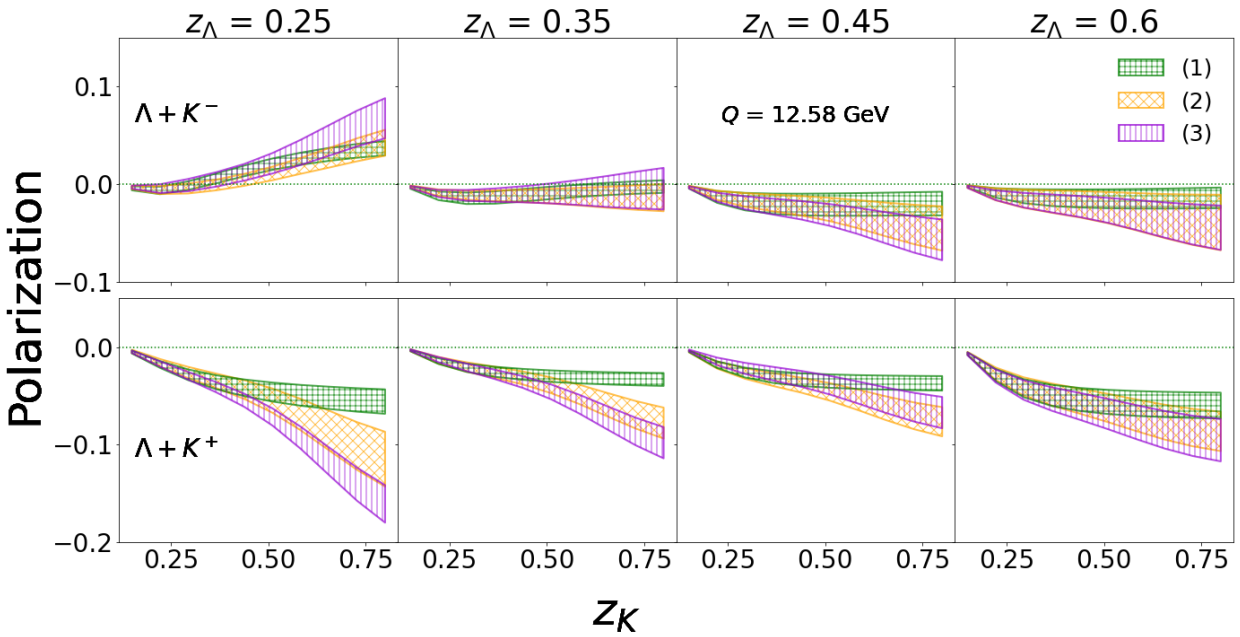
(1) No Charm, No SU2
(2) Charm, No SU2
(3) Charm, SU2

Predictions at different energies:

- All scenarios lead to similar predictions for $\Lambda\pi^{\pm}, \bar{\Lambda}\pi^{\pm}, \Lambda K^-, \bar{\Lambda}K^+$;
- Scenario (1): different polarization for $\Lambda K^+, \bar{\Lambda}K^-$ with $z_K > 0{,}5$;
- Scenarios (2) & (3) bands are almost totally overlapped: they cannot be distinguished!

Double hadron production in e^+e^- processes





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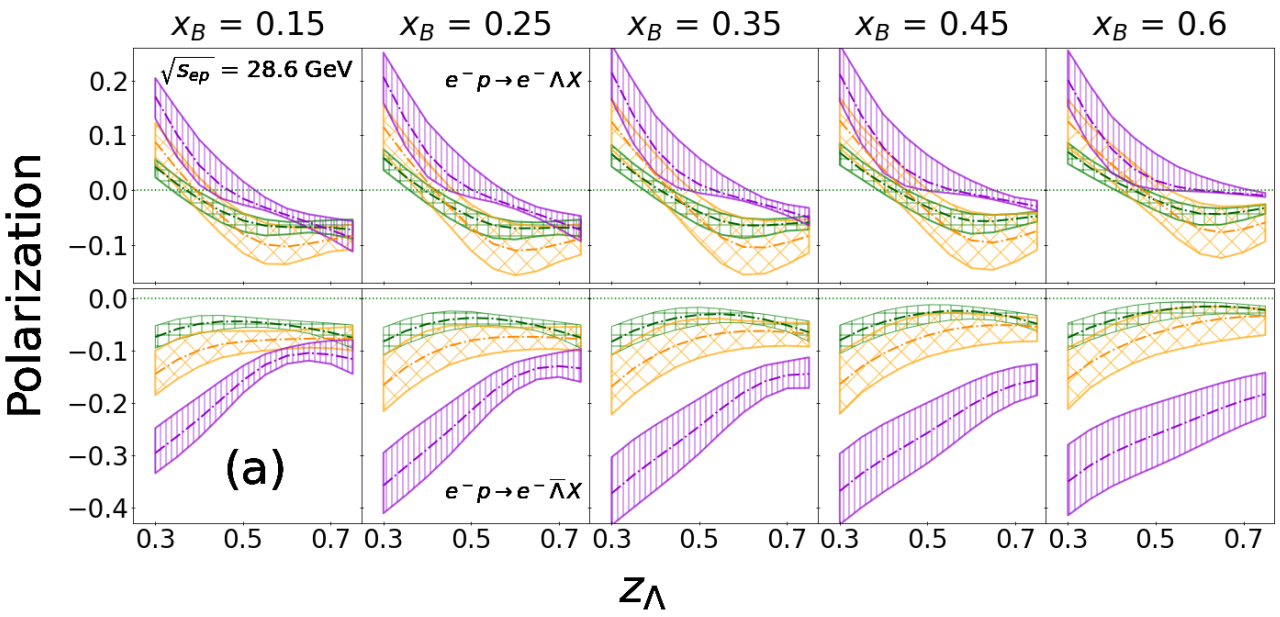
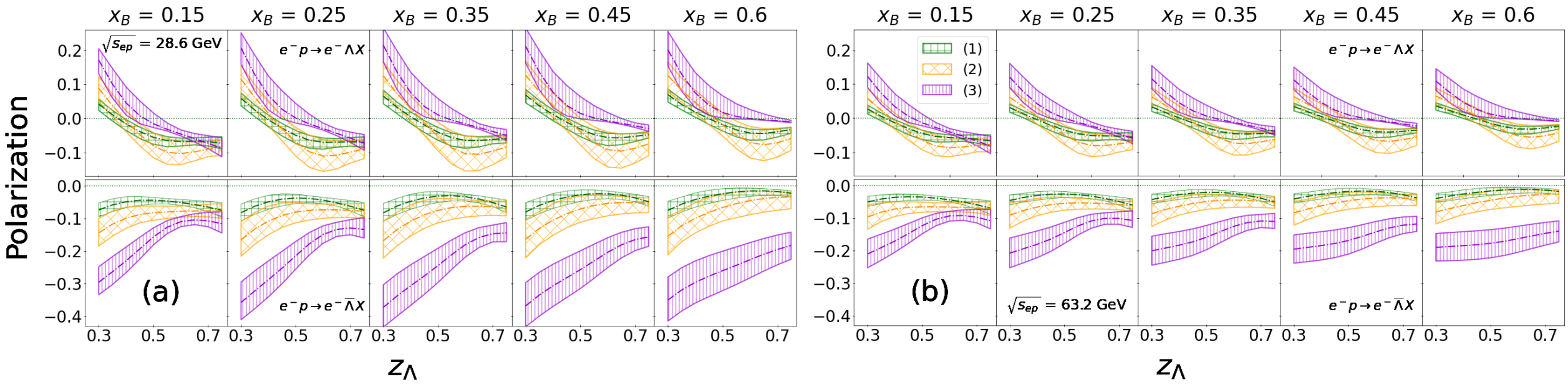
Semi-inclusive Deep Inelastic Scattering



- (1) & (2) scenarios: polarization of similar size and behavior;
- Λ pol. decreases and becomes negative;
- $\bar{\Lambda}$ is always negative;
- $\sqrt{s_{ep}}$=28,6 pol. has the same size, for greater values there is a general reduction as x_B grows.

- (3) scenario: similar size;
- Λ pol. similar or slightly greater size;
- $\bar{\Lambda}$ most significant difference;

Semi-inclusive Deep Inelastic Scattering



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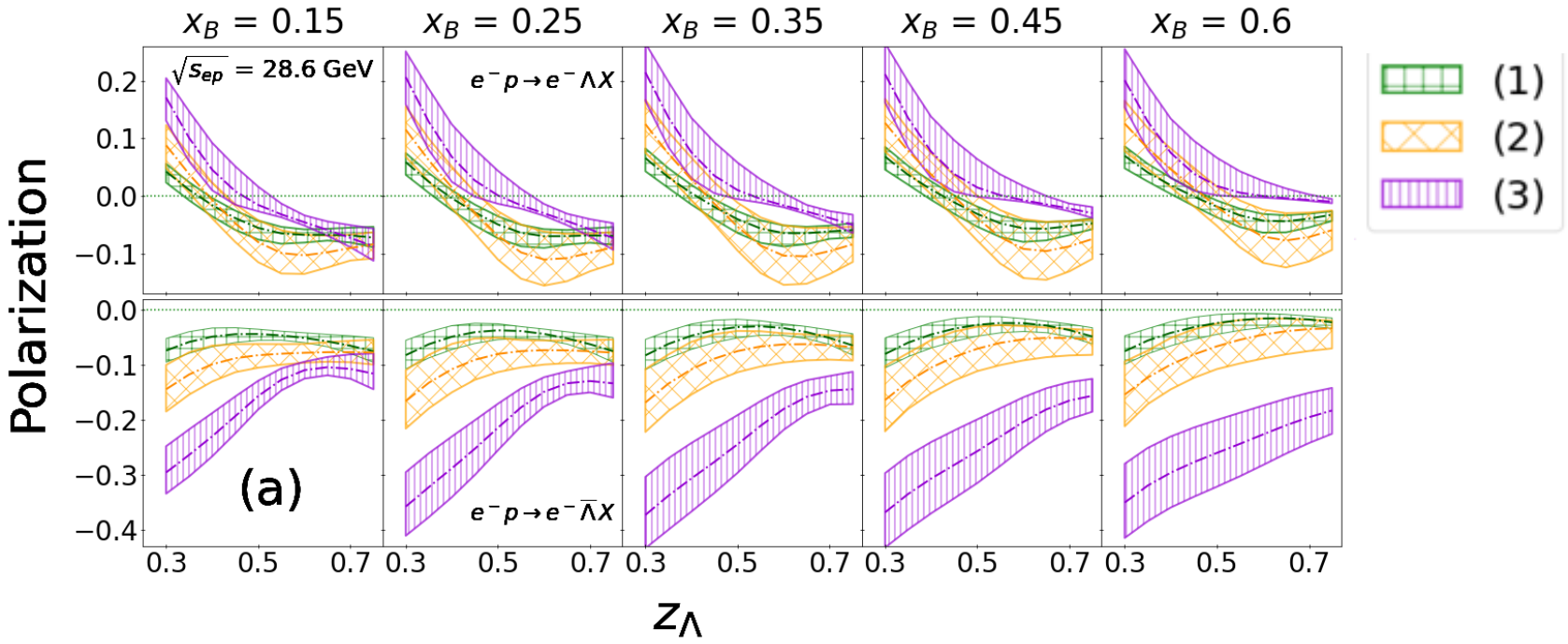

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Semi-inclusive Deep Inelastic Scattering

The charm contribution in the fragmentation process is relevant

Intrinsic Charm (IC) component in the proton:
- CT14nnloIC set with BHPS model [T.-J. Hou et al., *JHEP* 02 (2018) 059]
- NNPDF4.0nnlo set [NNPDF Coll., *Eur.Phys.J.C* 82 (2022) 5, 428]

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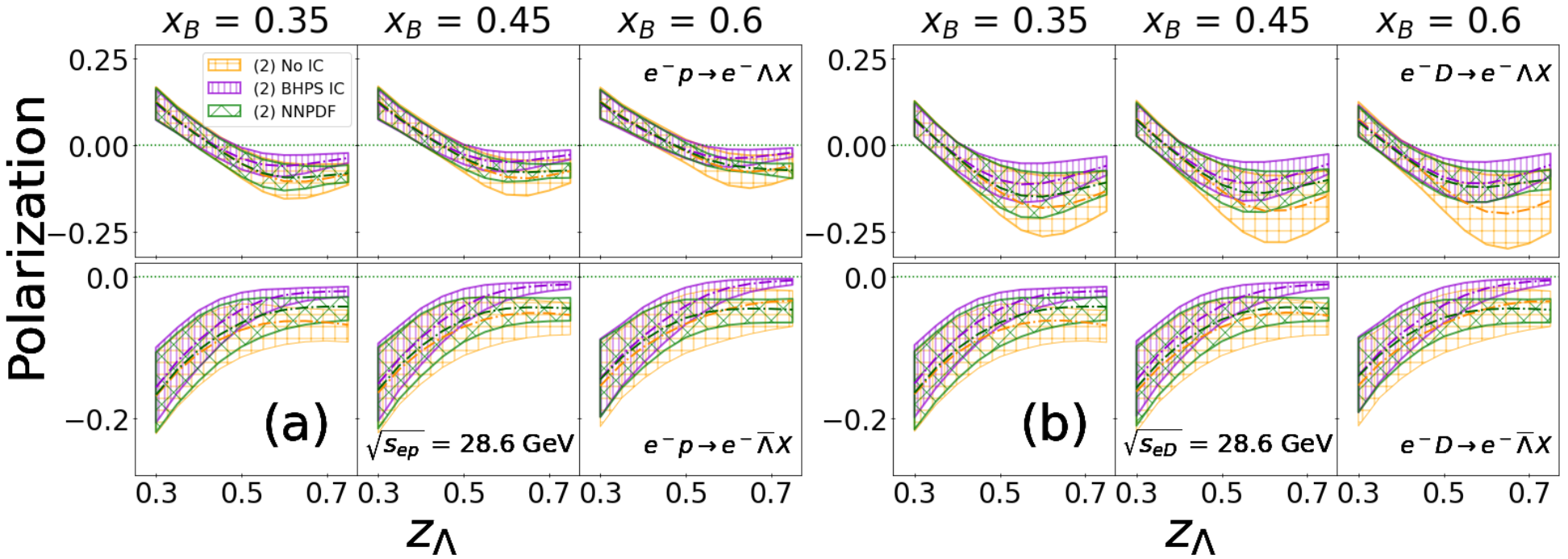
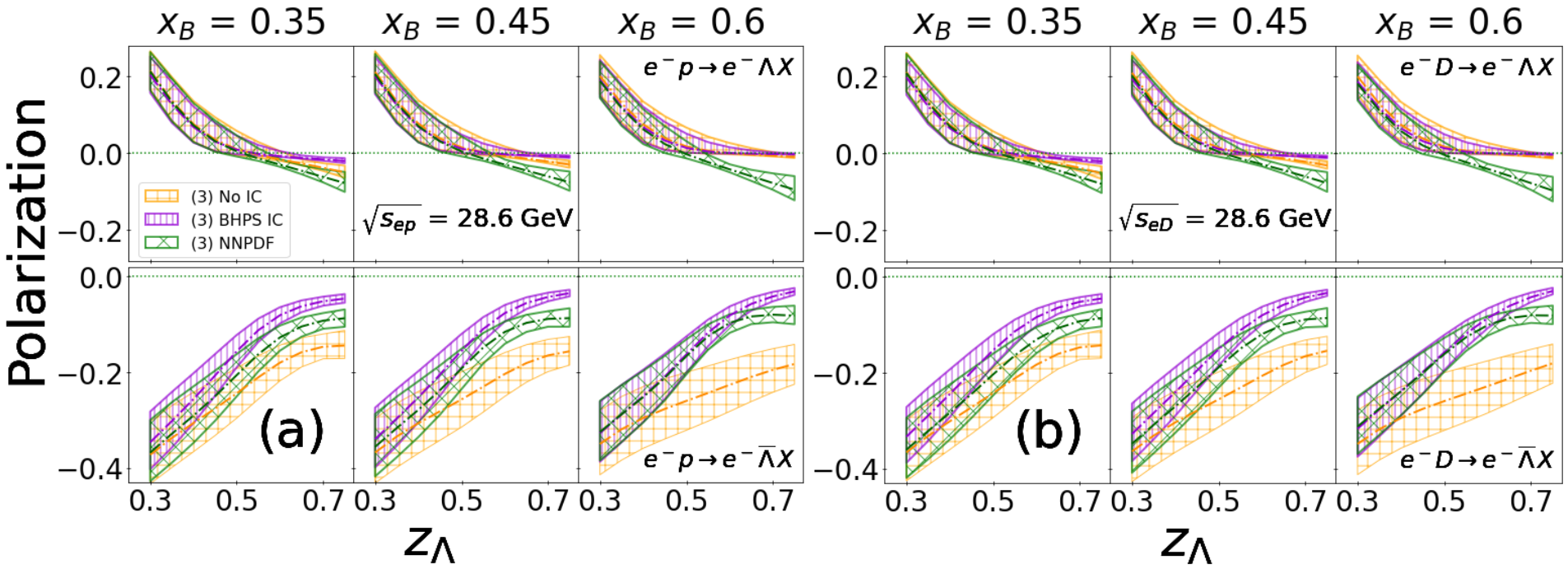
(2) Scenario:

- BHPS and NNPDF: similar polarization of previous predictions
- Same behavior is present for greater values of the c.m. energy.



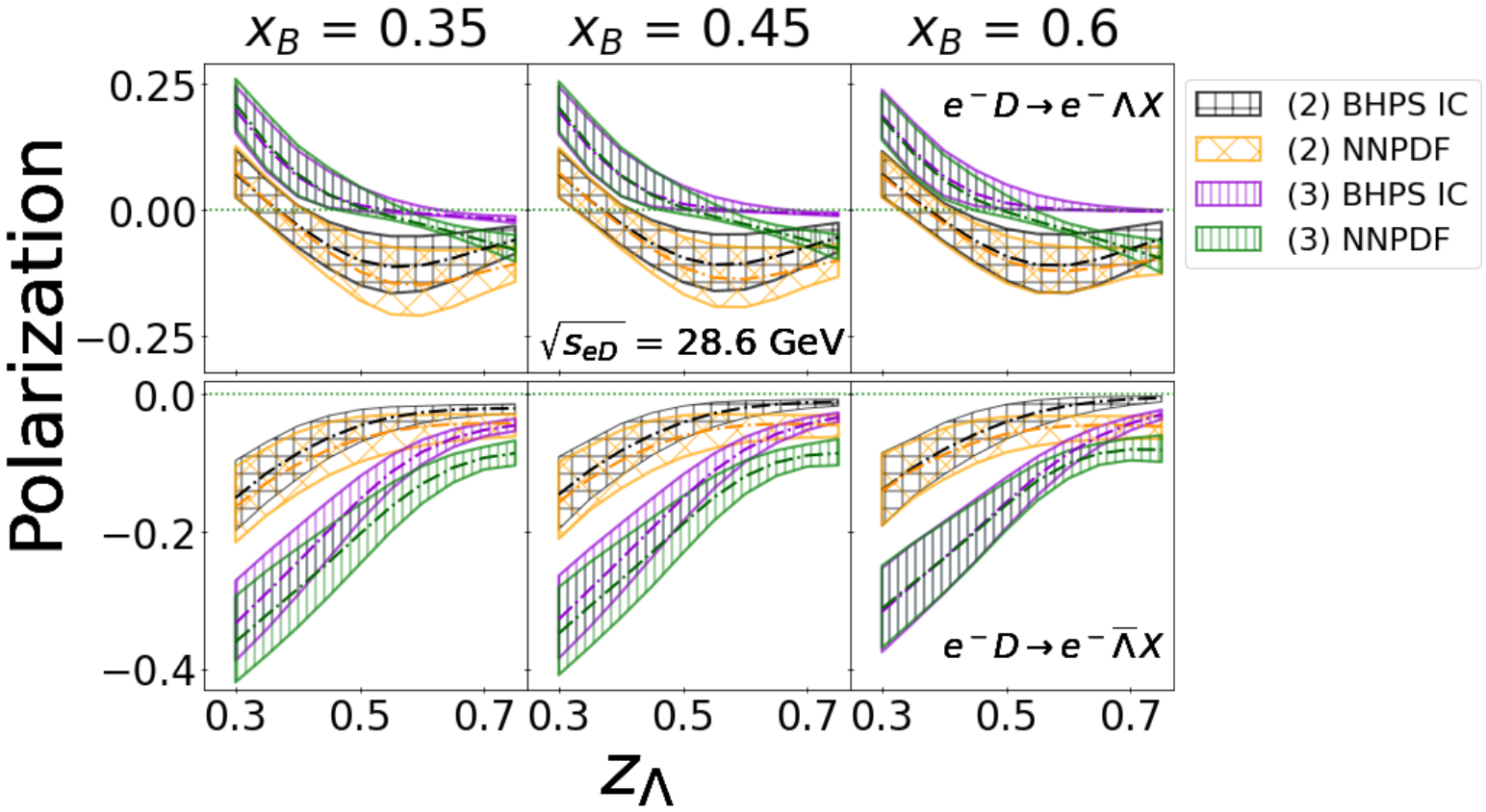
Semi-inclusive Deep Inelastic Scattering

(3) Scenario:



- Estimates vary significantly as x_B increases;
- $\bar{\Lambda}$ estimates with BHPS and NNPDF different from the previous ones;
- Λ :decreases to zero
- Λ : NNPDF become negative

Semi-inclusive Deep Inelastic Scattering



- Λ : the predictions are compatible
- $\bar{\Lambda}$: within (2) and (3) are still different