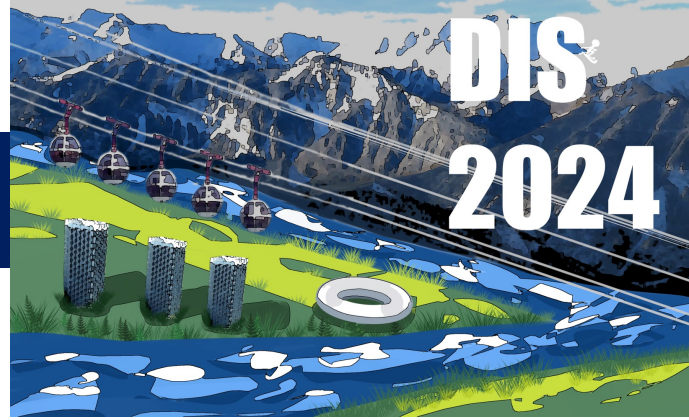
Summary of WG5: Spin and 3D Structure



45 talks in total : 20 experimental and 25 theoretical

Conveners: Julie Roche, Ohio University
Qinghua Xu, Shandong University
Savvas Zafeiropoulos, CPT, Marseille

Disclaimer:
- Lots of interesting results, will focus on new results
- Apologies if missed some topics or not accurate in reporting your results

Longitudinal spin results

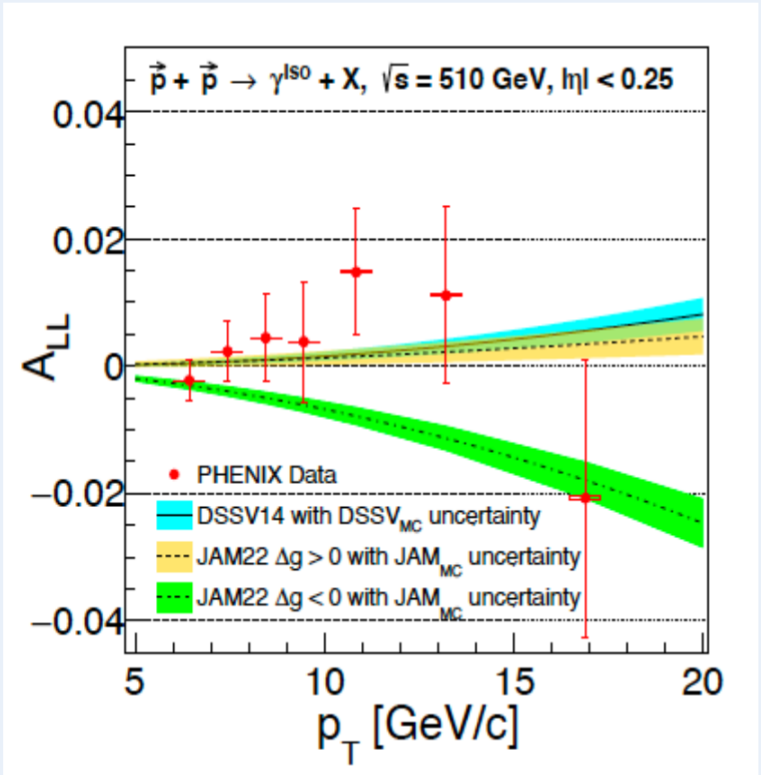
Double Helicity Asymmetry at RHIC and sign of ΔG

- Negative ΔG is clearly not favored by direct photon, di-jet A_{LL}, and inclusive jets tagged with $\pi^{\pm}$

A. Bazilevsky @PHENIX

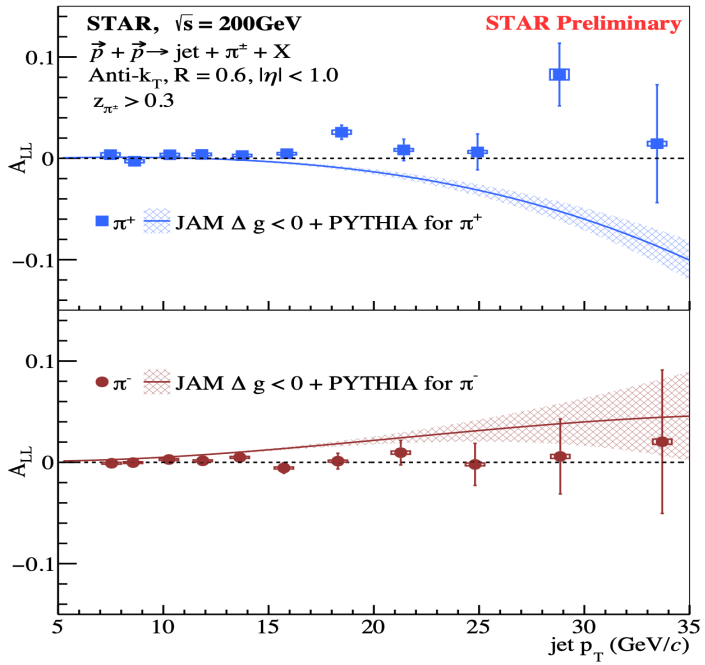
Direct photon A_{LL} in pp collision

PRL130, 251901 (2023)

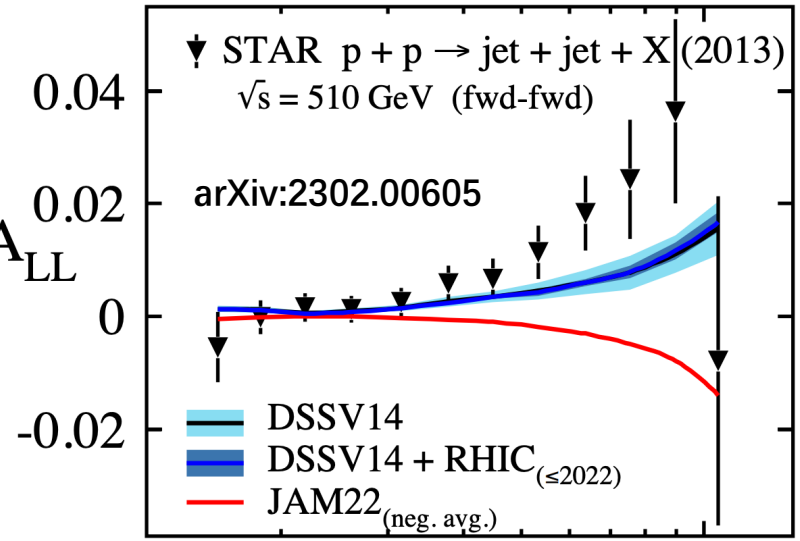


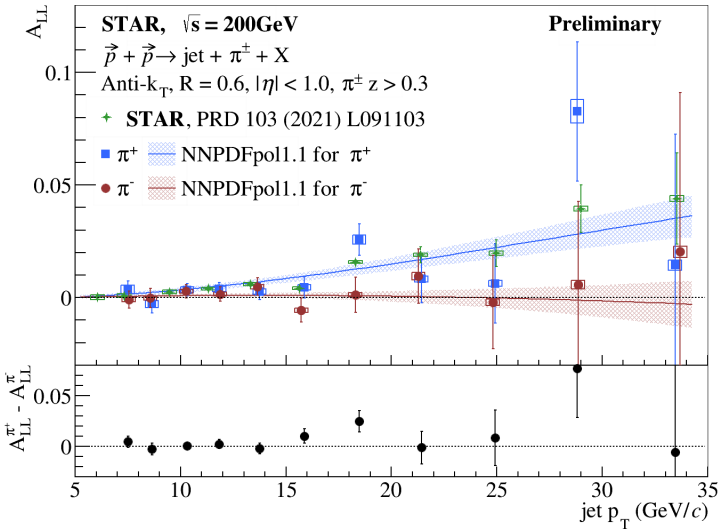
Y. Yu @ STAR

$\pi^{\pm}$ tagged jet A_{LL} in pp collision



X. Chu @ STAR

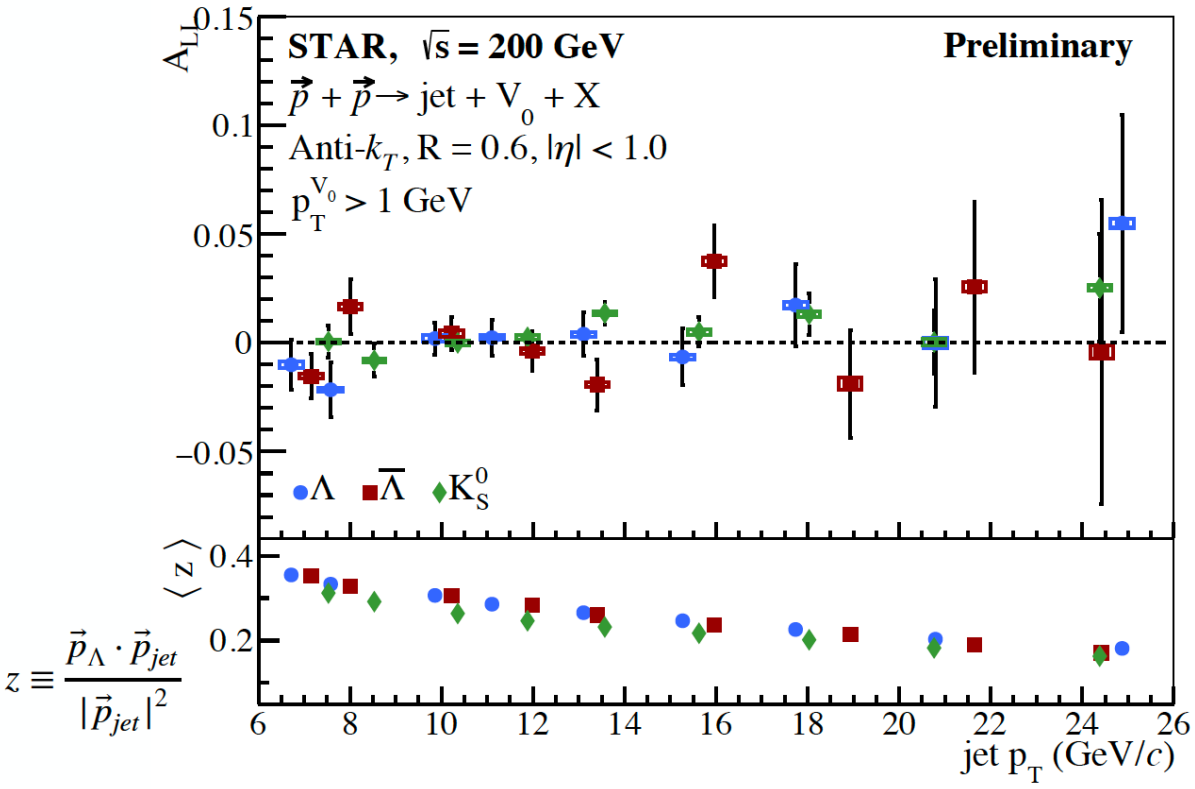




Strange quark helicity: Δs

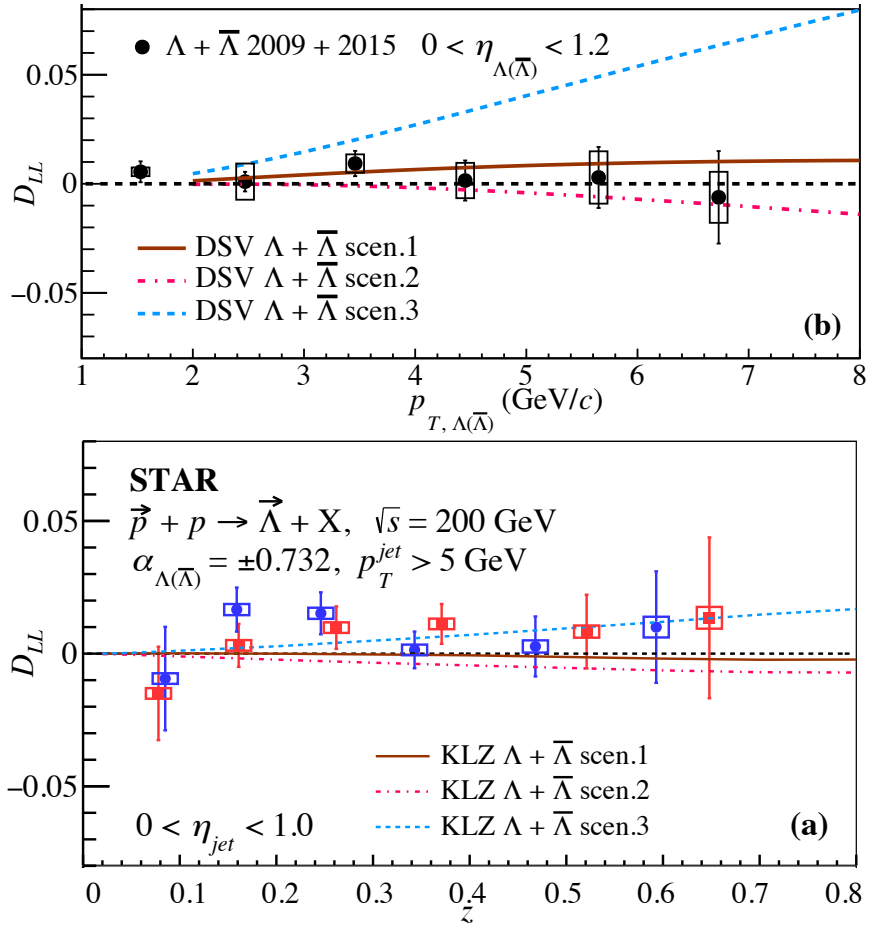
Y. Yu @ STAR

- First measurement of A_{LL} for jets containing $\Lambda, \bar{\Lambda}, K_{0s}$ in pp, sensitive to strange quark polarization



- Longitudinal spin transfer D_{LL} of Λ and $\bar{\Lambda}$ within jets, related to polarized fragmentation functions and strange quark helicity distribution

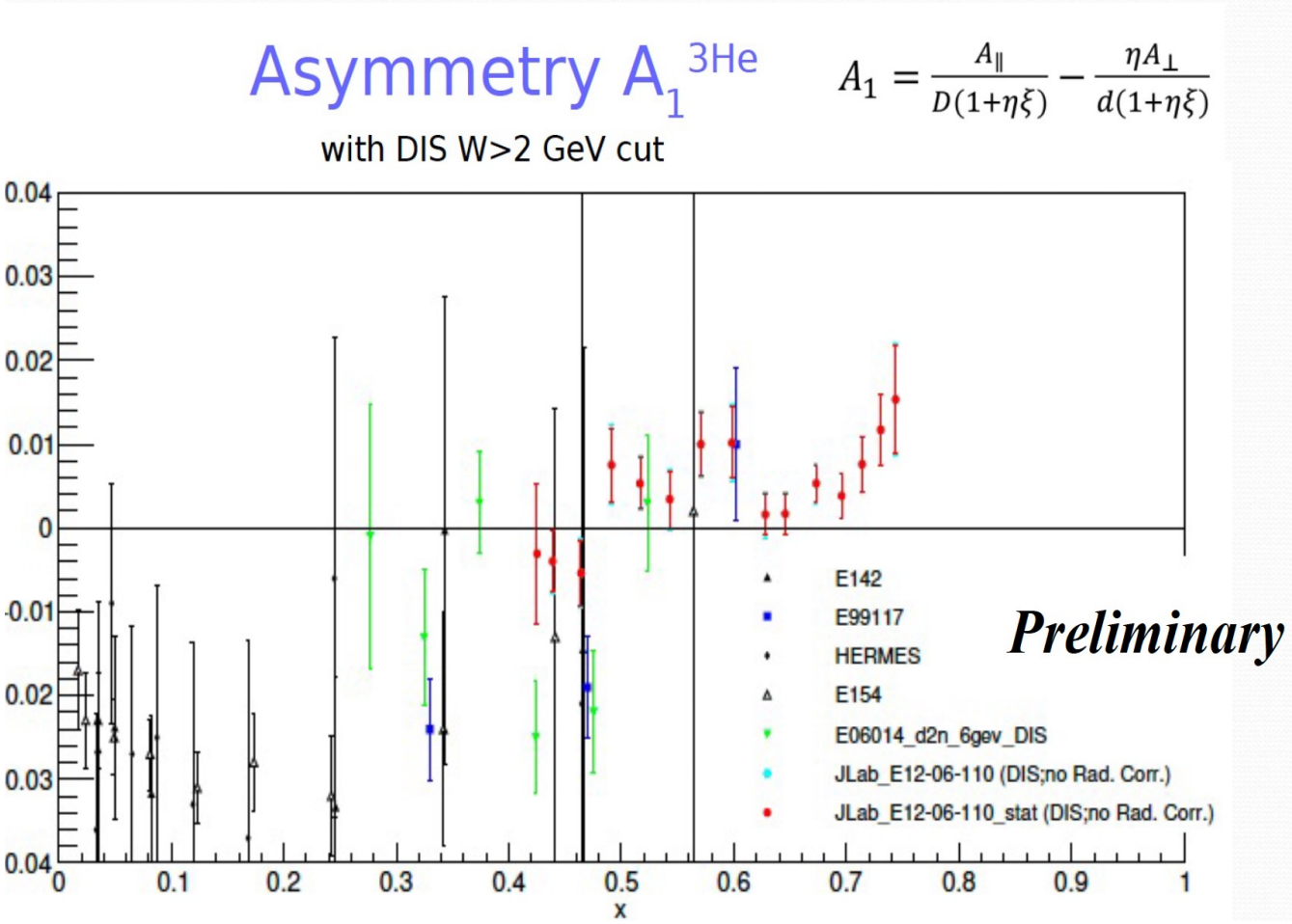
STAR, PRD 109, 12004 (2024)



Parton helicity distribution at high x at JLab

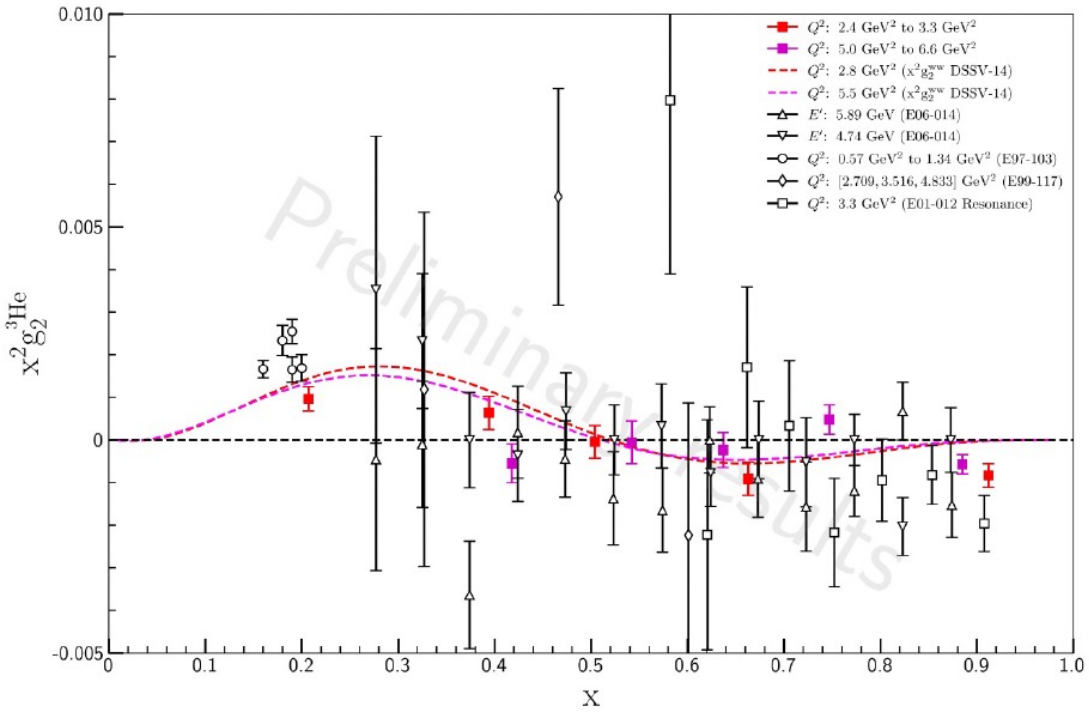
J. Chen @ JLab

A1n@High-x: Preliminary Results ($A_1{}^3He$)



Ratios of pol/unpol pdfs at x→ 1 provide unambiguous, scale invariant, non-perturbative features of QCD

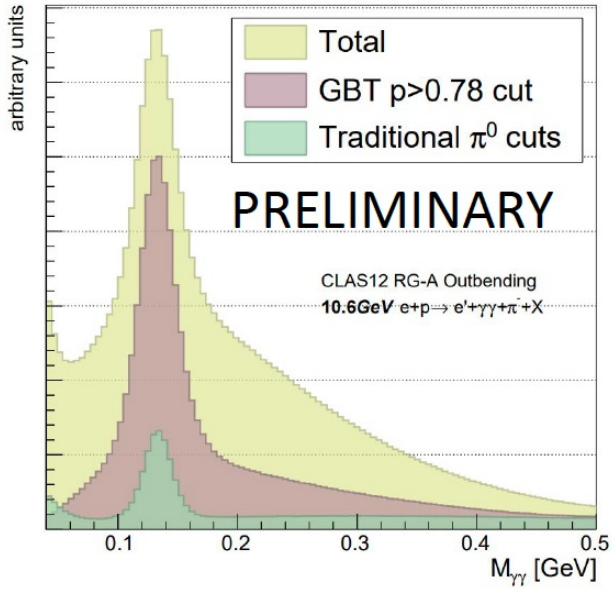
12 GeV d_2^n: Color Polarizability/ Lorentz Force



Preliminary Results on g2n

Dihadron Production $ep \to e\pi^{\pm}\pi^{0}(X)$ @ CLAS12

G. Matousek



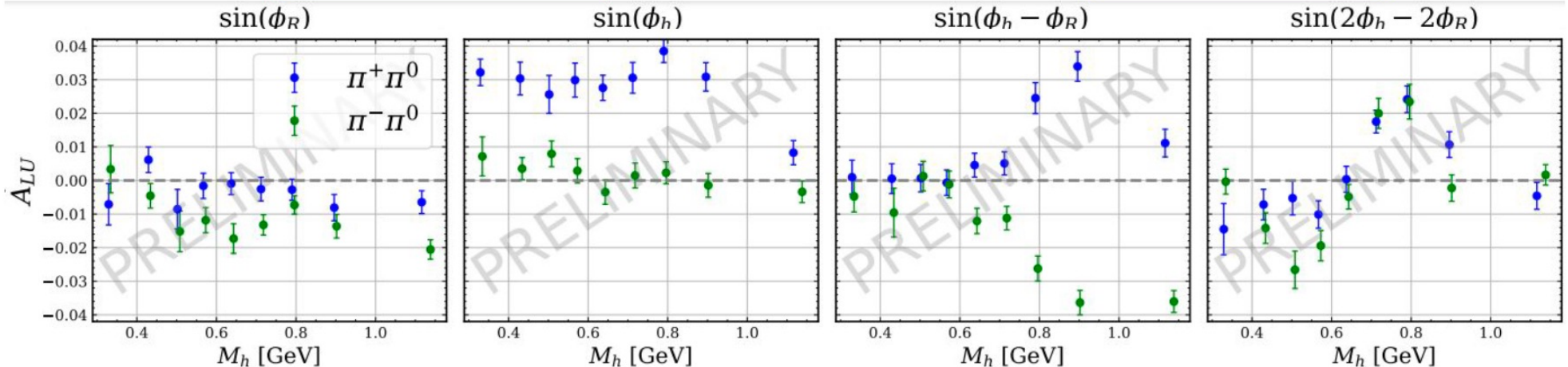
★ Nearest-neighbor GBDT model to reduce γ background

★ Negative **sin(ϕ_R)** asymmetry for **π-π0** → e(x) extraction
★ Strong positive **sin(ϕ_h)** asymmetry for **π+π0** → u quark dominated channels (seen in 1h SIDIS frequently)

★ Isospin symmetries of G_1 DiFF observed in **sin(ϕ_h - ϕ_R)**
★ Strong enhancement near resonant region

$e \otimes H_1^{\perp|\ell,m>}$

$f_1 \otimes G_1^{\perp|\ell,m>}$



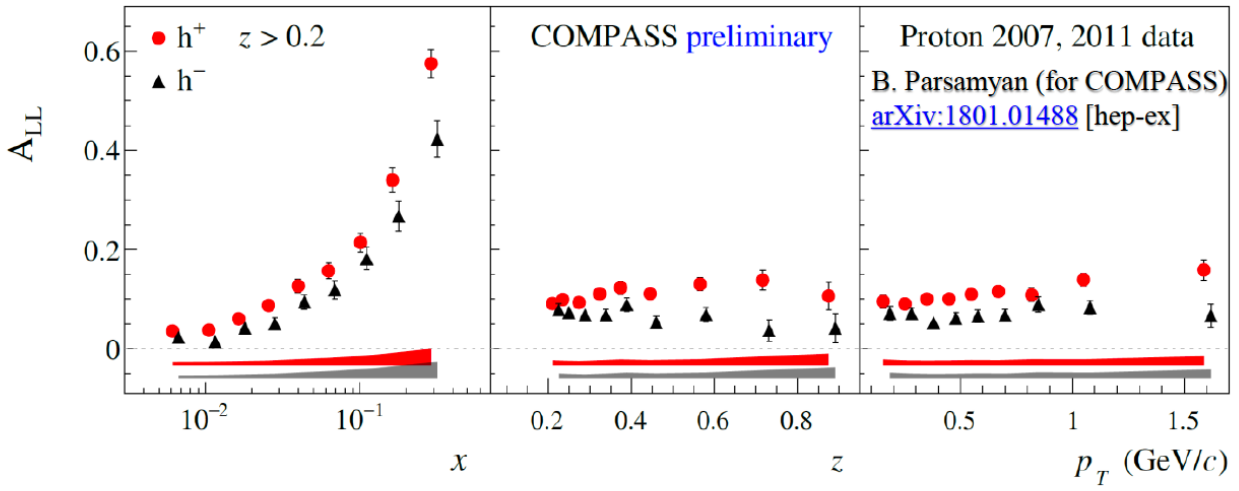
SIDIS: target longitudinal spin dependent asymmetries

B. Parsamyan

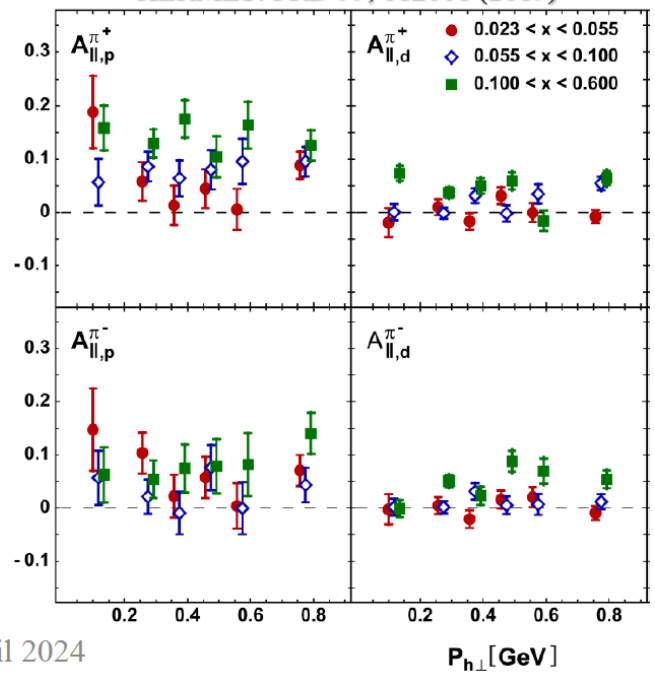
$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_L \lambda \sqrt{1-\varepsilon^2}\, A_{LL} + \ldots\right\}$$

$$F_{LL}^1 = \mathcal{C}\left\{g_{1L}^q D_{1q}^h\right\}$$

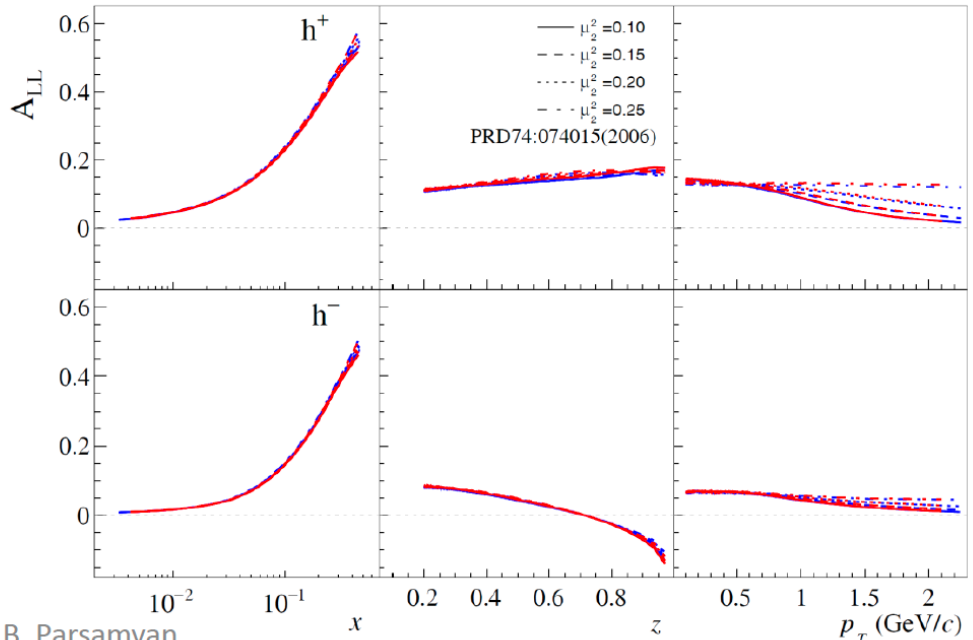
- Measurement of (semi-)inclusive $A_1(A_{LL})$ is one of the key physics topics of HERMES/COMPASS
- Large amount of P/D data
- No P_T-dependence observed



HERMES: PRD 99, 112001 (2019)



COMPASS Proton-2007, -2011 kinematics

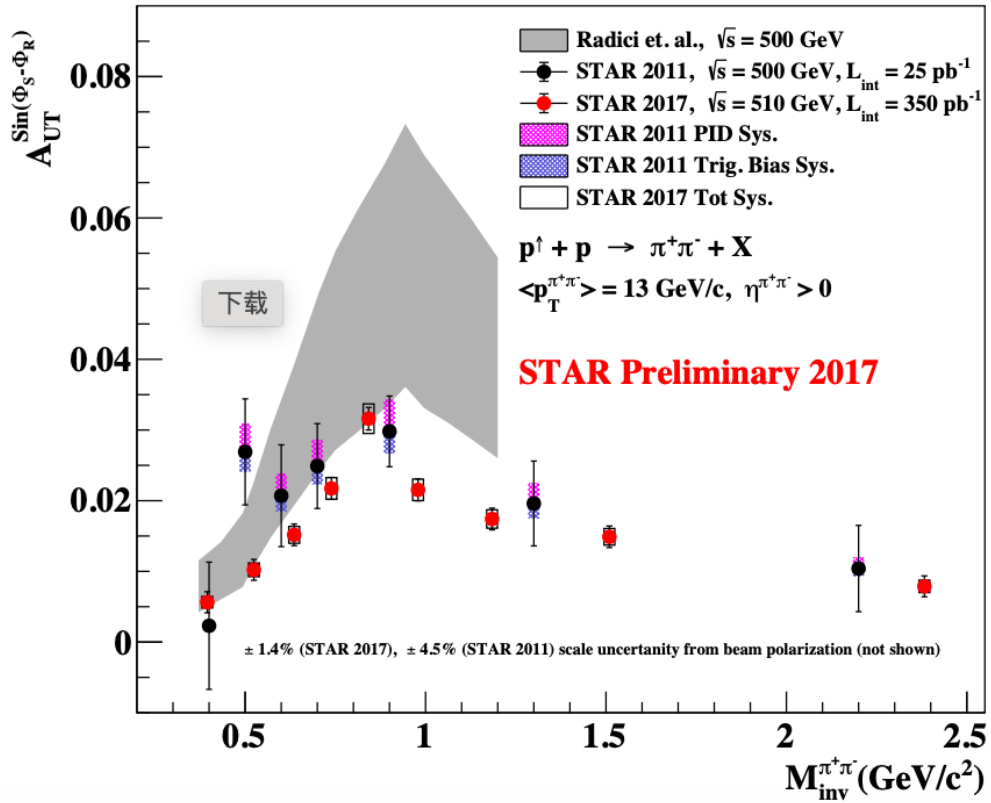


Transverse spin results

Probing transversity with IFF and Collins asymmetry at STAR

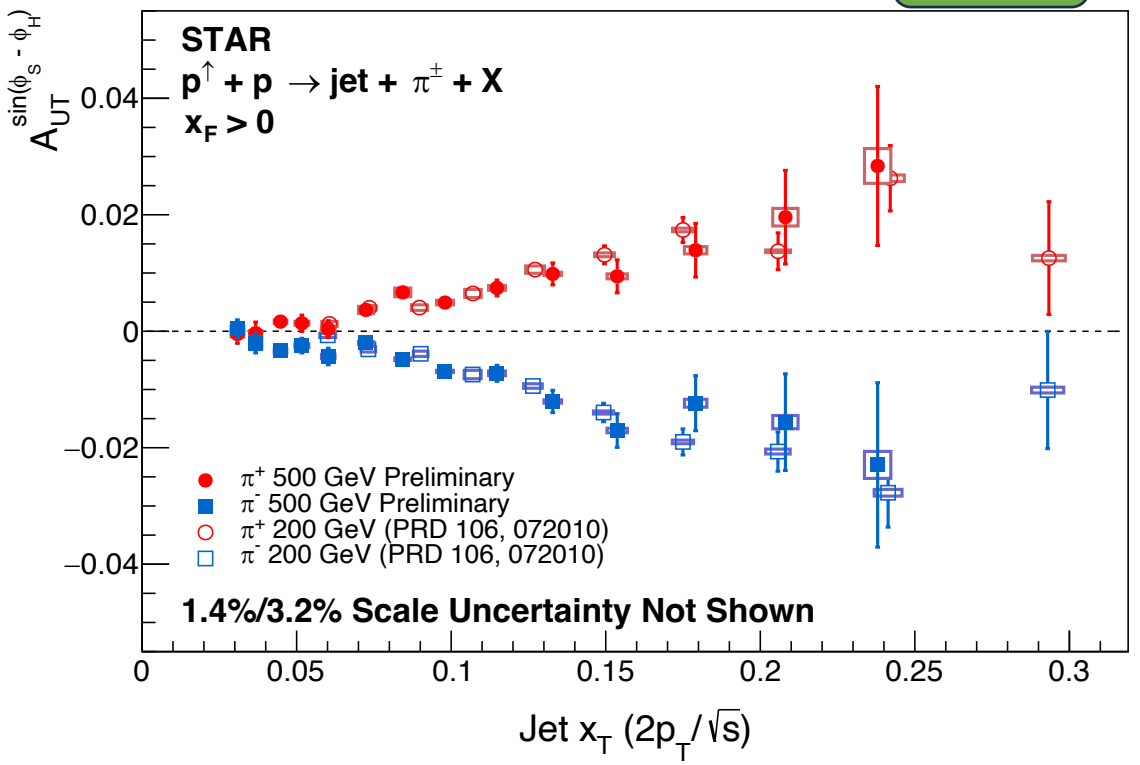
- Preliminary results of IFF asymmetry for charged pion pair in pp 200 & 500 GeV

B. Surrow



- New precision results of Collins asymmetry in pp at 500 GeV from STAR run17 data
- **Excellent agreement with 200 GeV data versus jet $x_T \equiv 2p_T/\sqrt{s}$ scale, almost no energy dependence.**

Y. Xu



Probing transversity with IFF and Collins asymmetry at STAR

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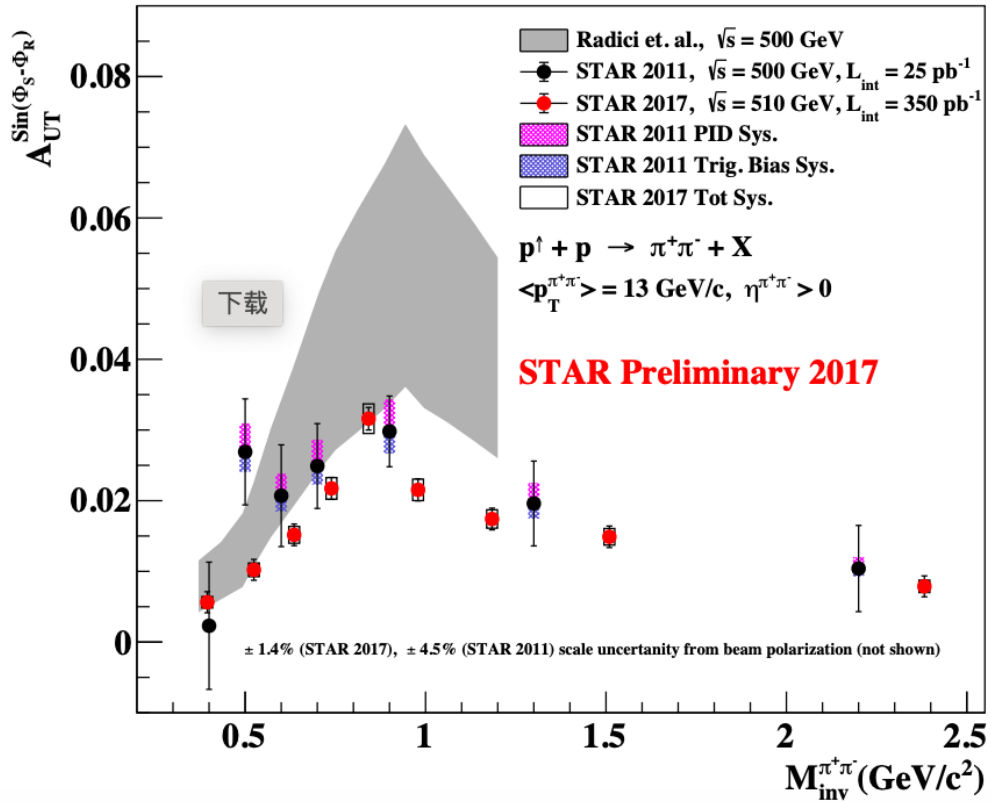

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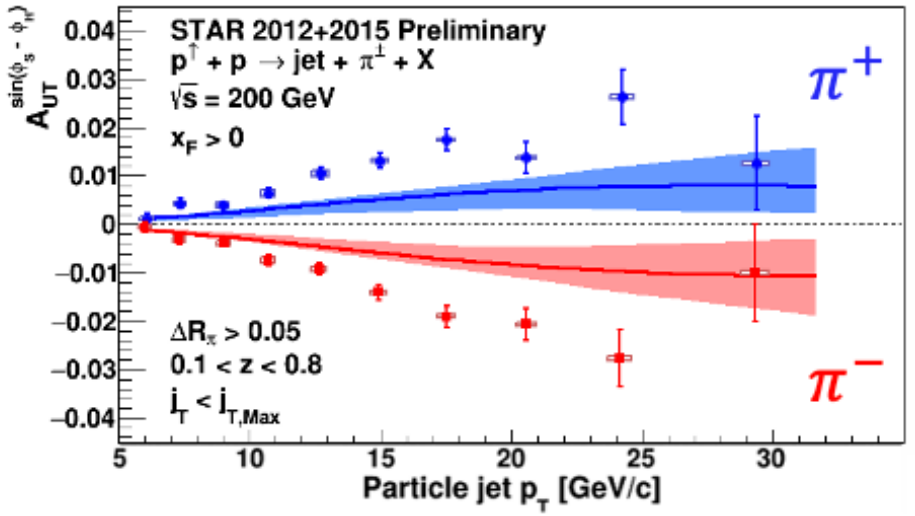
X. Chu

STAR, PRD 106, 072010



***Highlight* in 2023 US-LRP for NP**

Clear need to improve our understanding of these results!

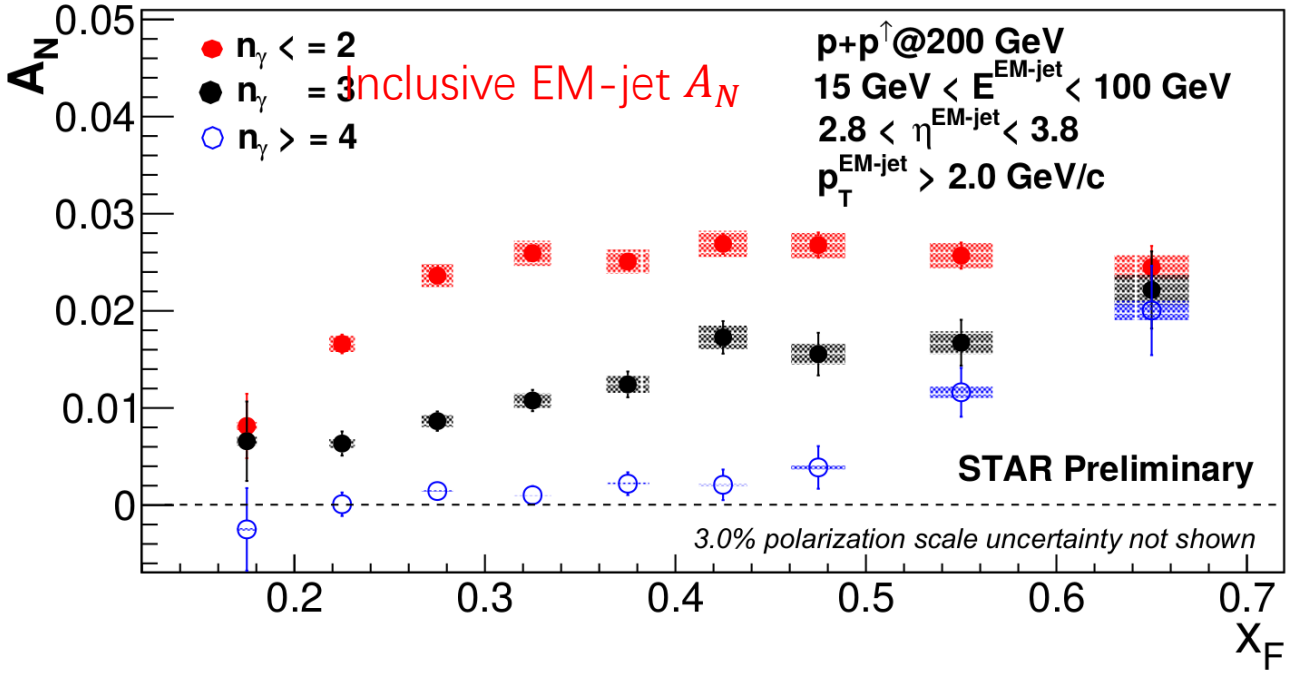
Inclusive and Single diffractive EM-jet A_N at STAR

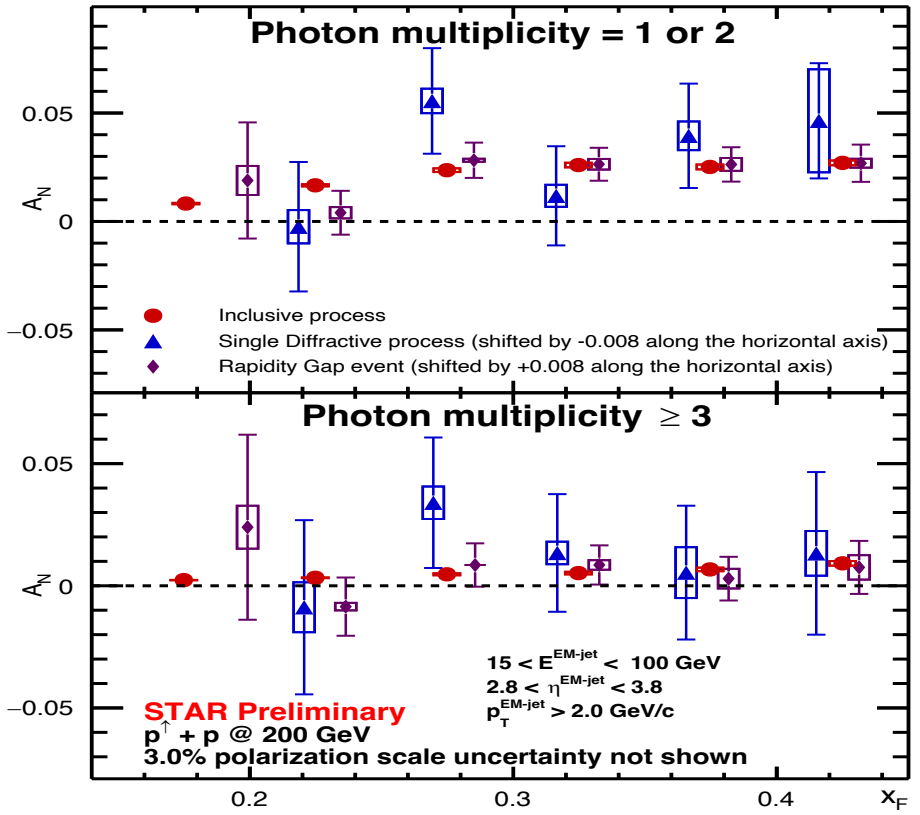
X. Liang

- Conclusion: The single diffractive process can not provide evidence to have significant contribution to large A_N in inclusive process

➢ Inclusive EM-jet consisting 1 or 2 photons show significantly larger A_N

➢ Will large inclusive A_N comes from diffractive processes?





✓ Single Diffractive process, clean but statistics limited

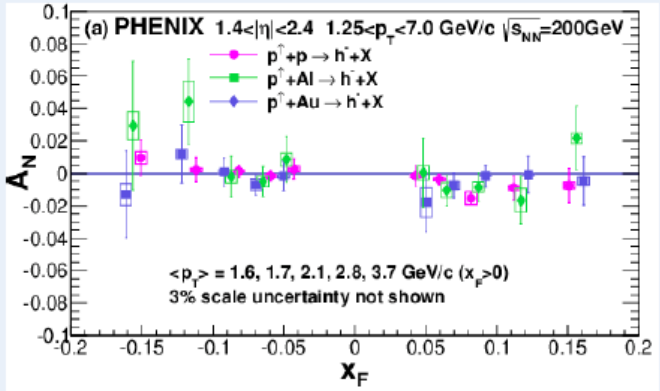
✓ Rapidity Gap event: **Much higher statistics with >50% single diffractive events**

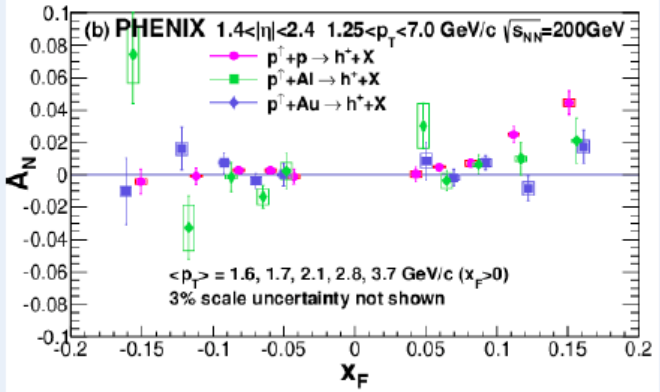
Transverse spin asymmetries in pp/pA at PHENIX

A. Bazilevsky

- A_N of forward hadron in pp/pAl/pAu

PRD108, 072016 (2023)

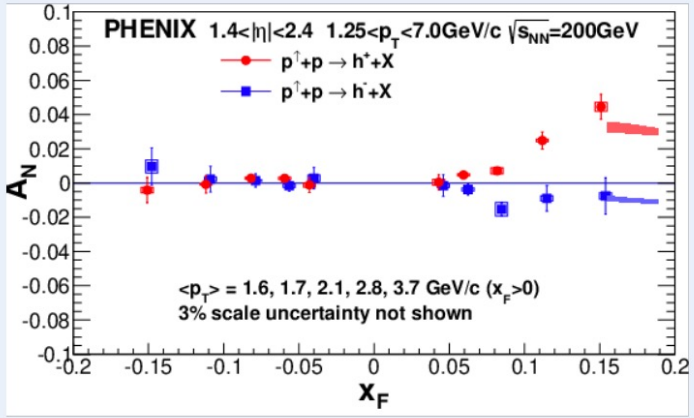




A_N: Forward $h\pm$ and η

D. Loomis

PRD108, 072016 (2023)



Sizable positive A_N for h+

Mix of positive A_N from π+ and positive from K+

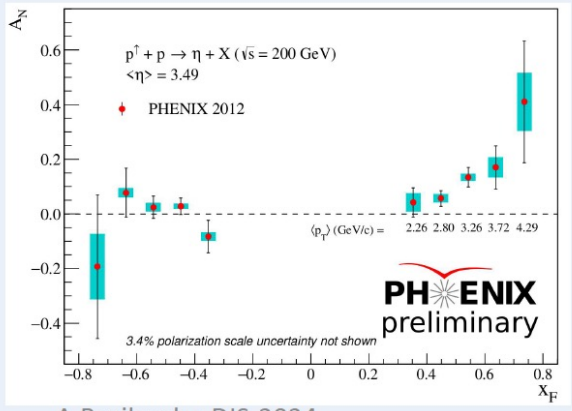
Slightly negative A_N for h-

Mix of negative A_N from π- and positive from K-

Comparison to Twist-3 model

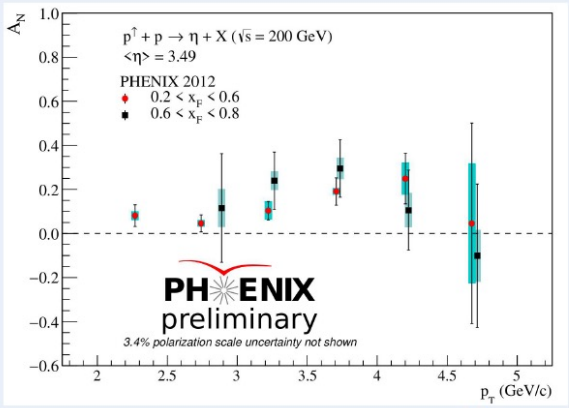
Gamberg, Kang, Pitonyak, Prokudin, Phys.Lett.B 770, 242

See D. Loomis talk, WG5



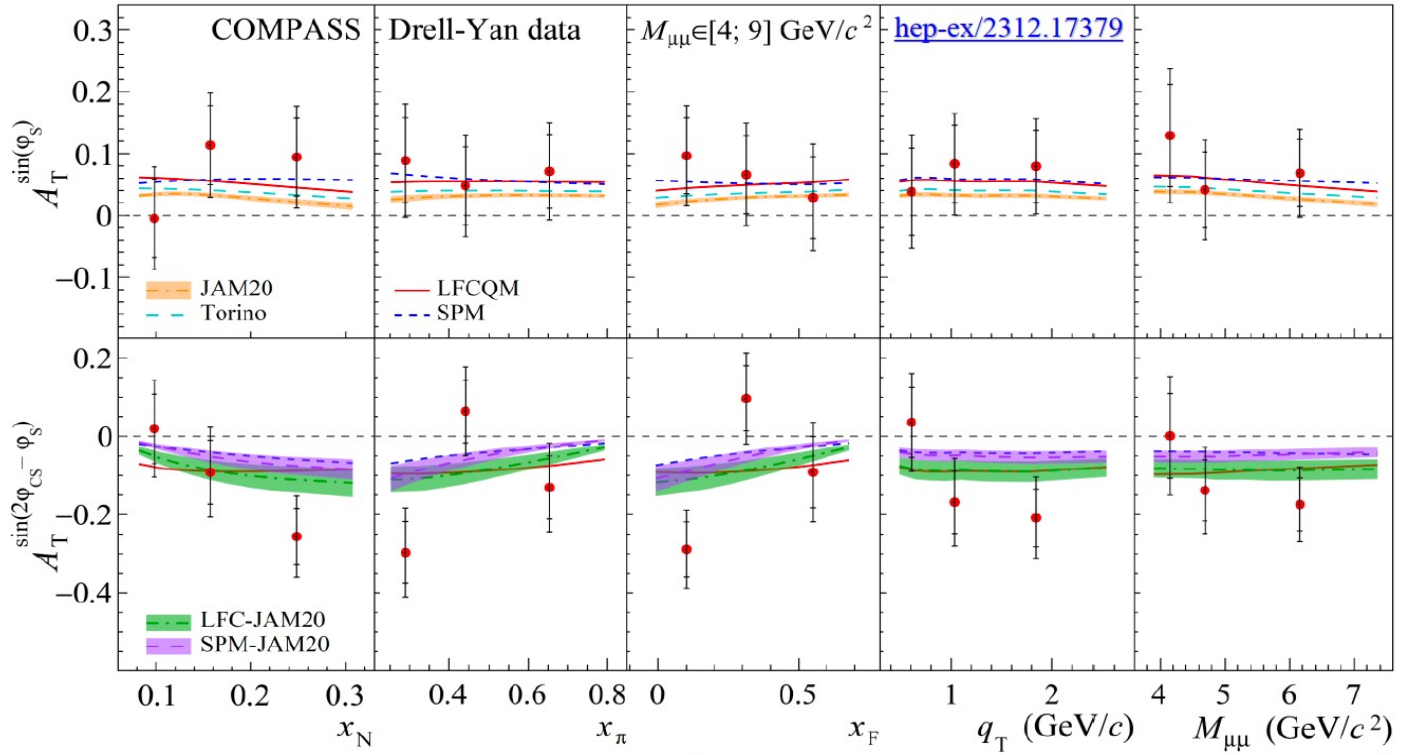
~0 at negative xF
Increasing with positive xF
Similar to π0

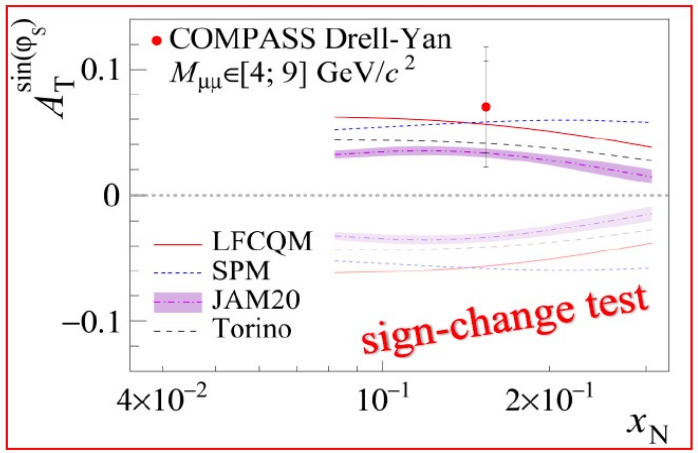
A hint of asymmetry drop at high pT

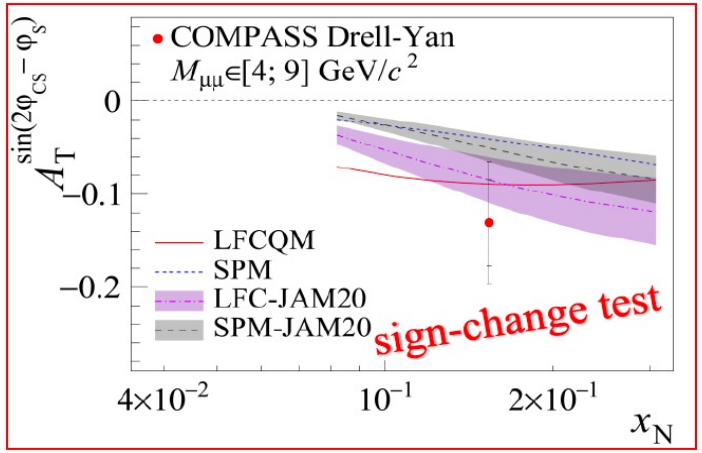


Transverse spin asymmetries in Drell-Yan at COMPASS

M. Niemiec







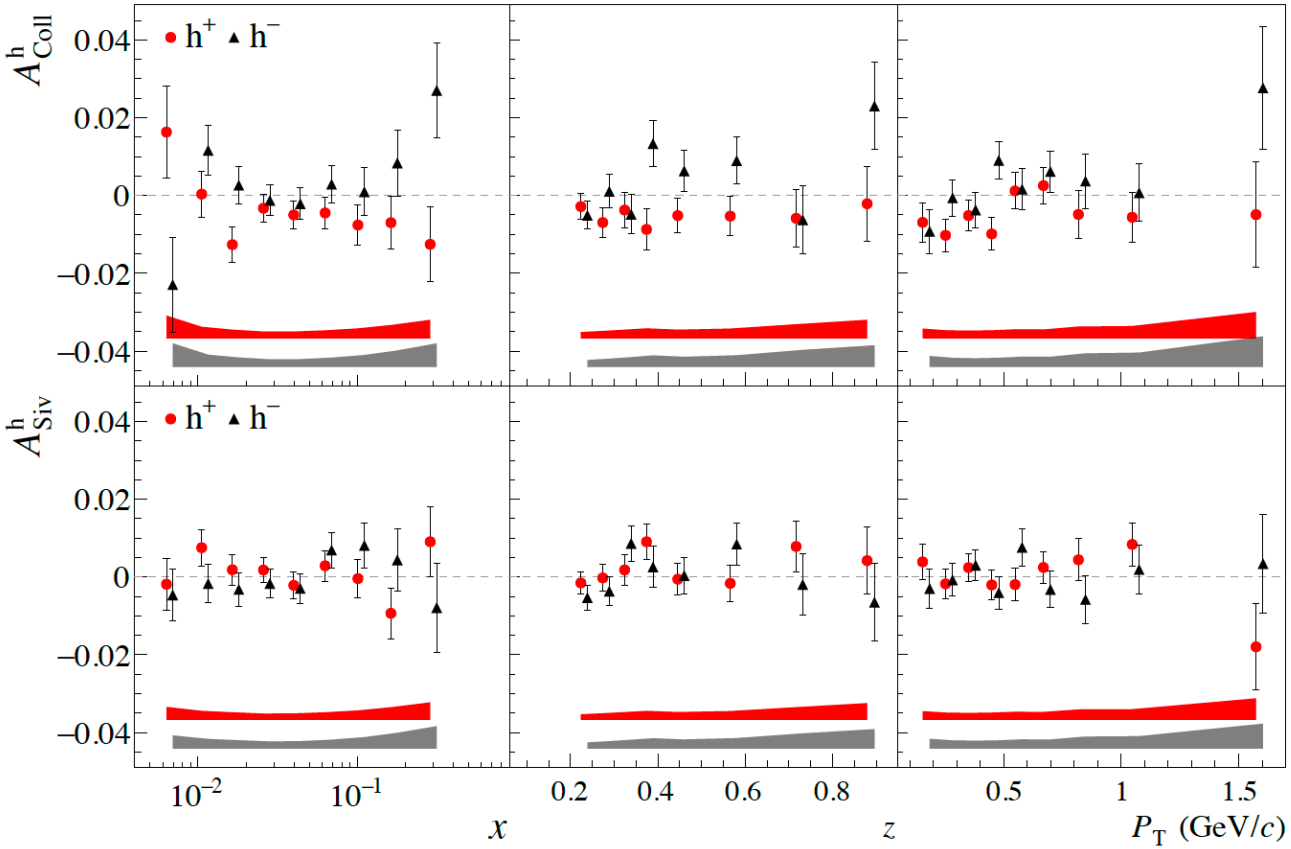
- COMPASS DY data favors the sign-change hypothesis for the Sivers TMD PDF!
- New preliminary results on transverse momentum weighted DY TSA, to overcome the convolution over intrinsic kT

Transverse spin asymmetries in SIDIS at COMPASS

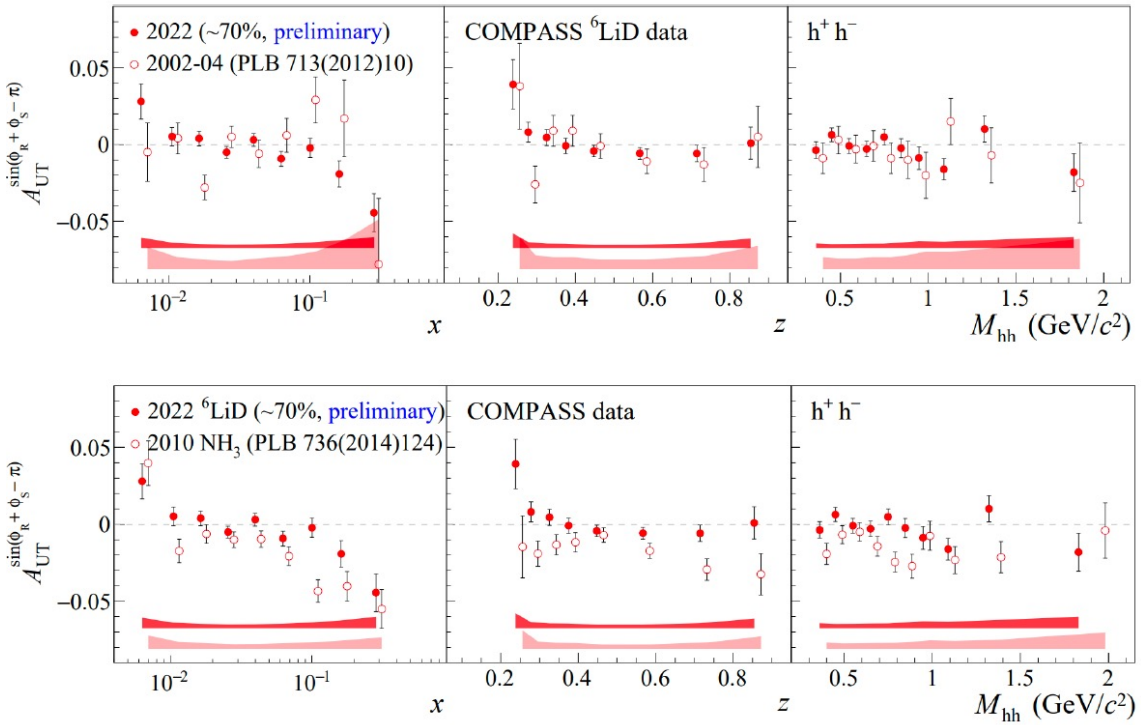
S. Asatryan

- New and very precise Collins and Sivers results from COMPASS 2022 deuteron data
- Providing significant constraints on transversity and Sivers functions!

COMPASS, arXiv:2401.00309



- New dihadon spin asymmetries results, alternative way to access transversity PDF

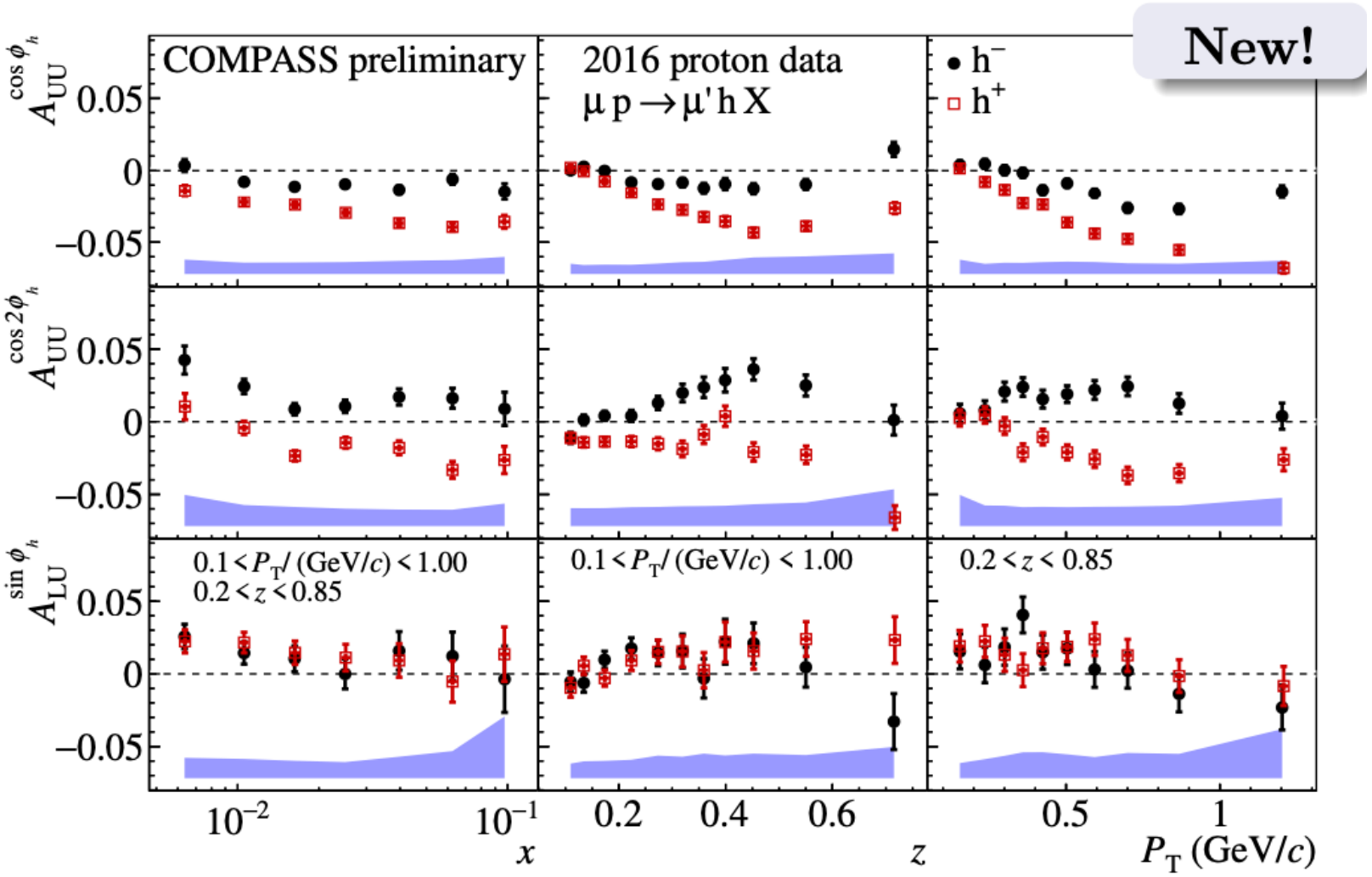


Unpolarized/spin independent

Unpolarized SIDIS asymmetries at COMPASS

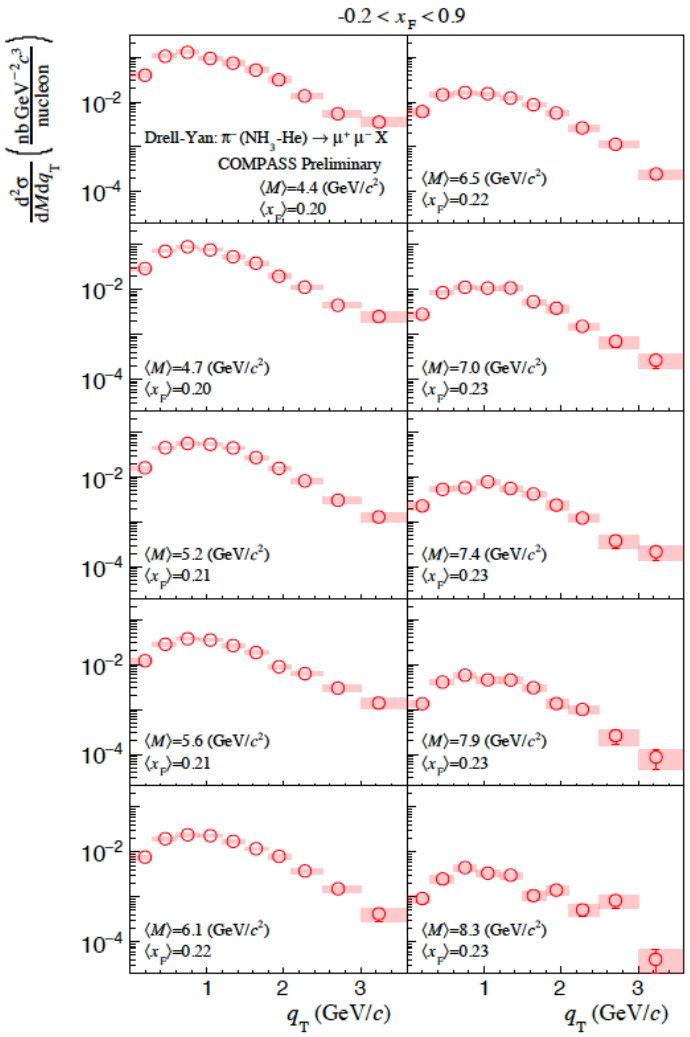
V. Benesov

- New SIDIS azimuthal asymmetries



COMPASS contribution to pion TMD PDF

V. Andrieux



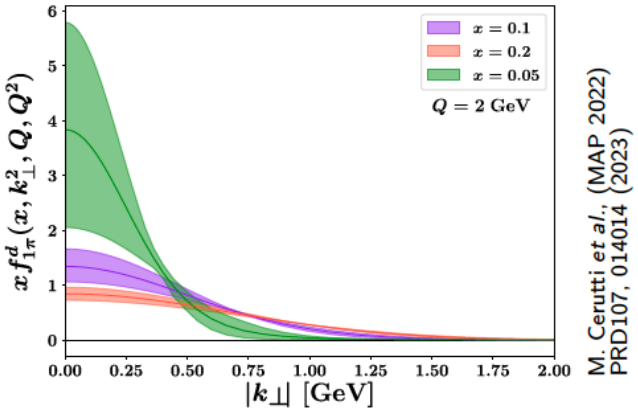
Pion-induced Drell-Yan cross section

New inputs to extract π TMD PDF with minimum nuclear effects in

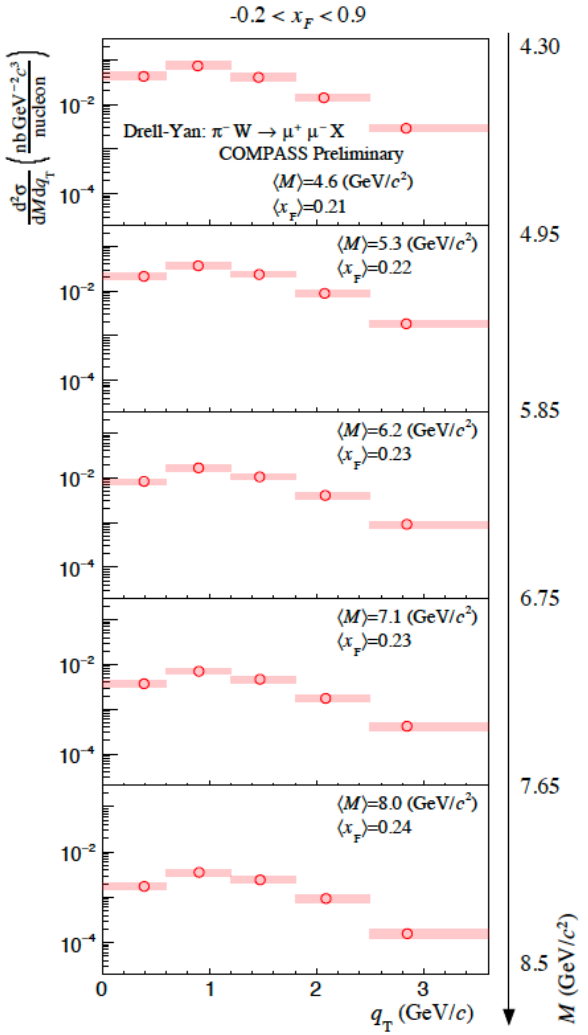
⇐ NH_3-He

and W target →

for comparison with past experiments (E615 and E532)



M. Cerutti *et al.*, (MAP 2022) PRD107, 014014 (2023)

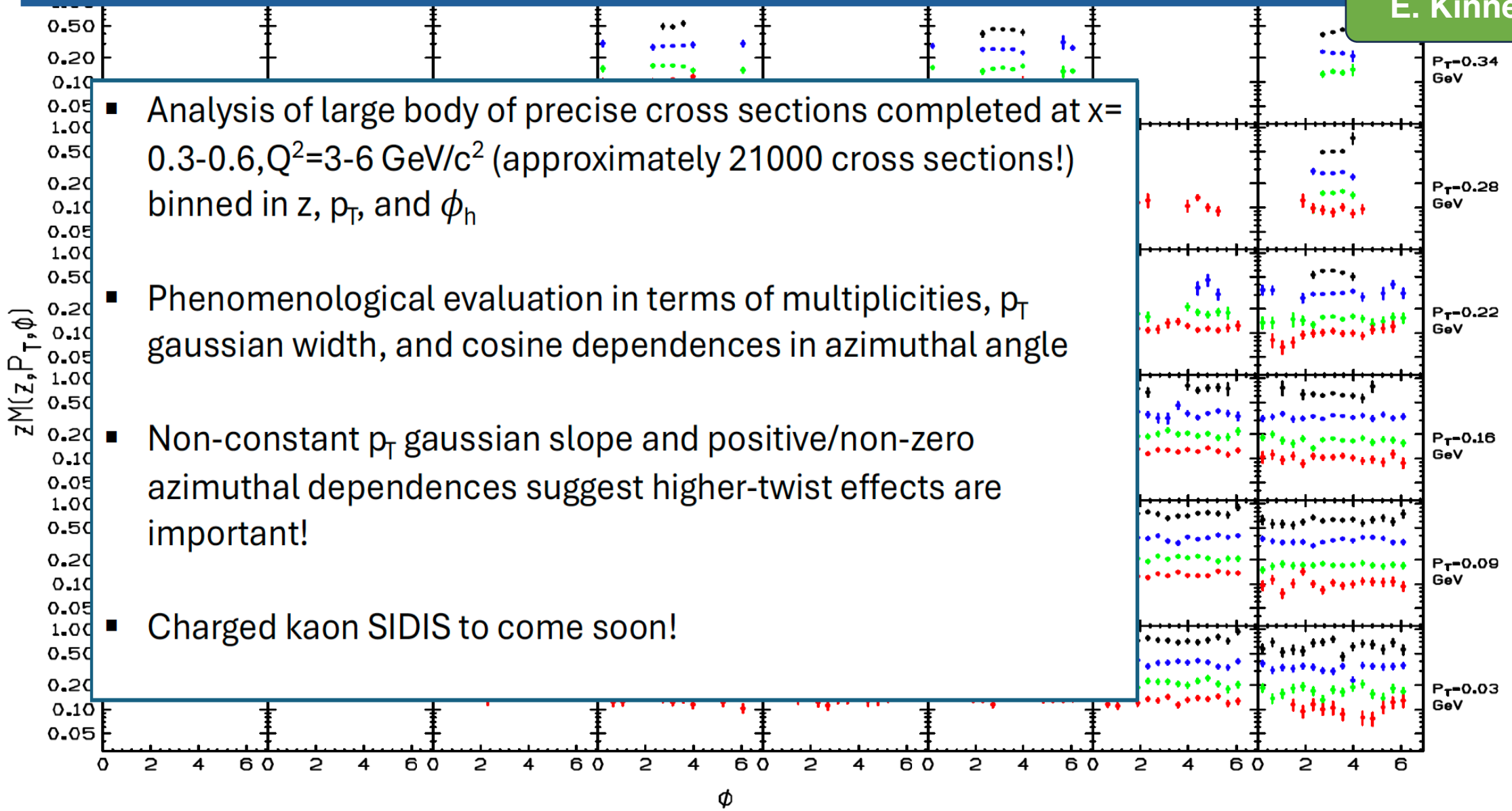


Dependence of Charged Pion Production on Transverse Momentum from Semi-Inclusive Deep Inelastic Electron Scattering from 1H and ^{2}H

Hall C @JLab

E. Kinney

- Analysis of large body of precise cross sections completed at x= 0.3-0.6,Q^2=3-6 GeV/c^2 (approximately 21000 cross sections!) binned in z, p_T, and ϕ_h
- Phenomenological evaluation in terms of multiplicities, p_T gaussian width, and cosine dependences in azimuthal angle
- Non-constant p_T gaussian slope and positive/non-zero azimuthal dependences suggest higher-twist effects are important!
- Charged kaon SIDIS to come soon!

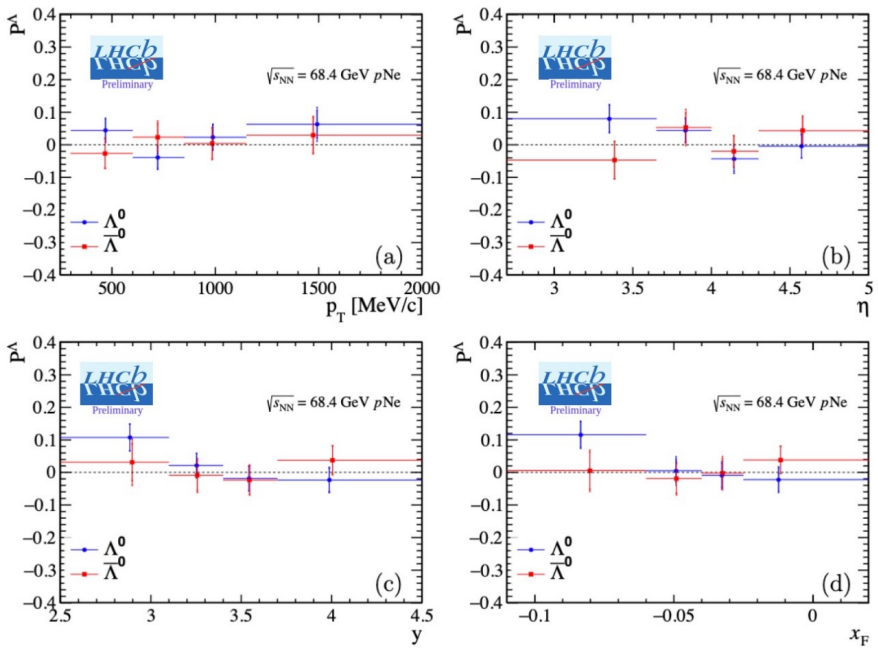


Hadron in jet production & Λ polarization at LHCb

Transverse Λ and $\bar{\Lambda}$ polarization measurement

LHCb-PAPER-2024-009
in preparation

C. Nuñez



Polarization in bins of p_T, η, y, and x_F

- $300 < p_T < 3000$ MeV/c
- $2 < \eta < 5$

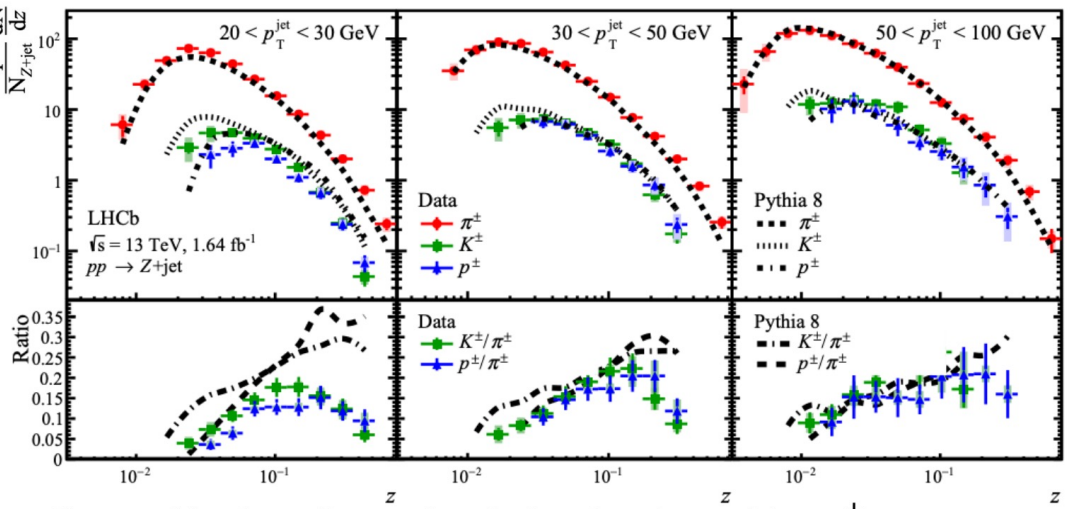
$$P(\Lambda) = 0.029 \pm 0.019 \pm 0.012$$
$$P(\bar{\Lambda}) = 0.003 \pm 0.023 \pm 0.014$$

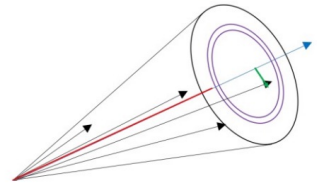
Λ_c^+ polarization at LHCb

- LHCb unpolarized pp $\sqrt{s} = 13$ TeV
  - Transverse polarization in lab frame (%):
    $P_x(\Lambda_c^+) = 60.32 \pm 0.68 \pm 0.98 \pm 0.21$
  - Longitudinal polarization in lab frame (%):
    $P_z(\Lambda_c^+) = -24.7 \pm 0.6 \pm 0.3 \pm 1.1$

TMD jet fragmentation functions for identified hadrons: $\pi^\pm, K^\pm, p^\pm$

PRD 108, L031103 (2023)





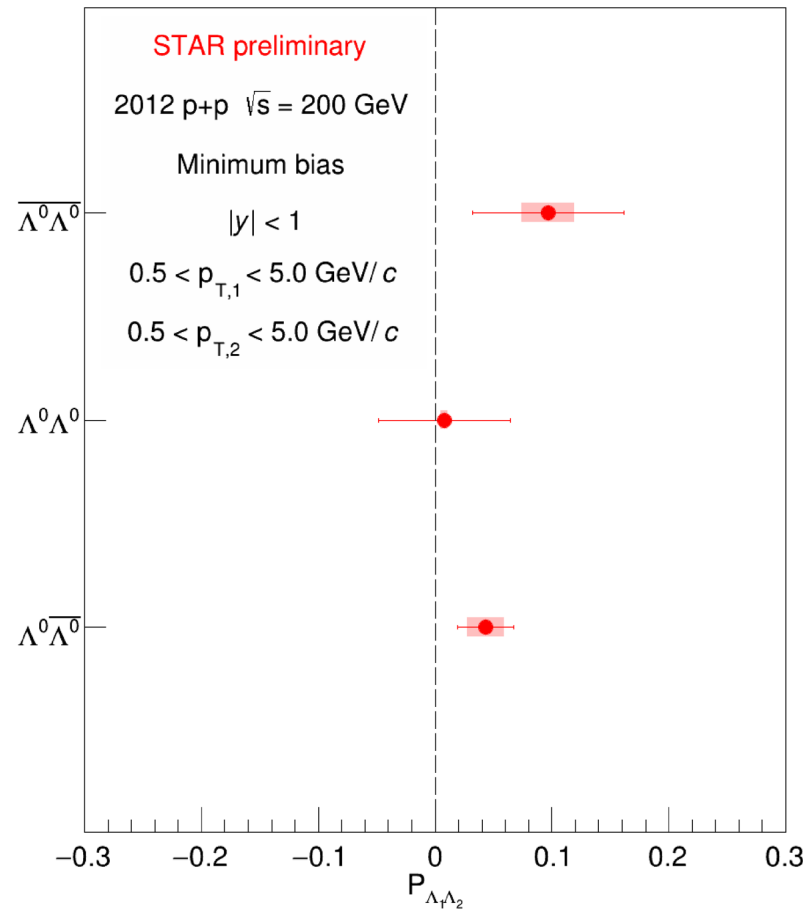
$$z = \frac{p_{jet} \cdot p_h}{|p_{jet}|^2}$$

- Charged hadron formation in jet dominated by $\pi^\pm$
- Heavier hadrons require larger momentum fraction, z, for formation

Λ SPIN-SPIN CORRELATIONS

J. Vanek

- $P_{\Lambda_1\Lambda_2}$ are consistent with zero within uncertainties
- Hint of polarization signal for $\Lambda^0\overline{\Lambda}^0$ pairs at 2σ statistical significance
- Data suggest no significant spin-spin correlation of initial state s (anti-)quark pair
  - This measurement provides upper limit on Λ^0 hyperon spin-spin correlations in p+p collisions at $\sqrt{s} = 200$ GeV
- First experimental search for Λ^0 hyperon spin-spin correlations - **We encourage theory colleagues to calculate this from different physics frameworks**

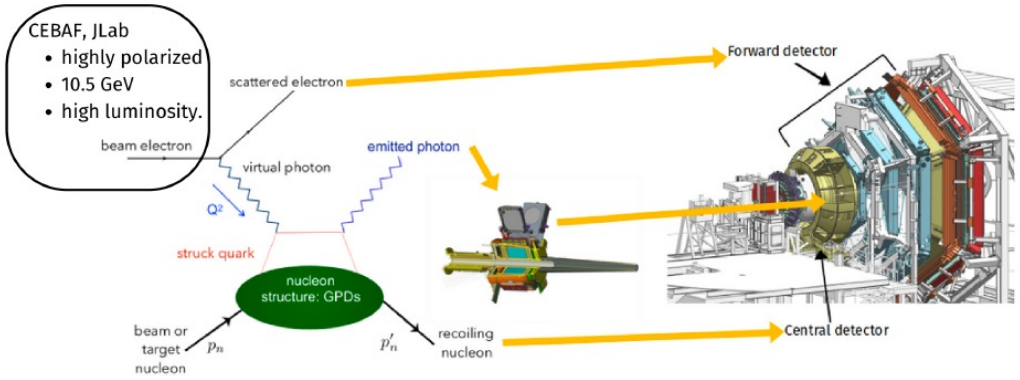


GPD study

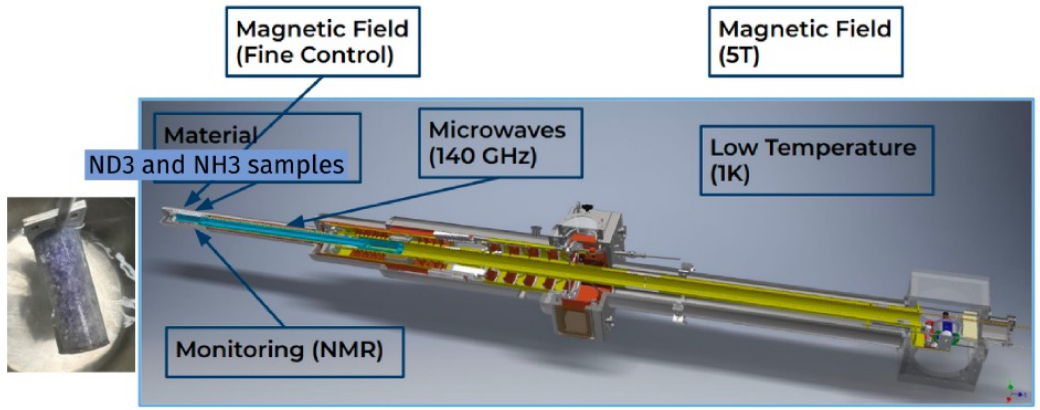
DVCS on polarized nucleons with CLAS12

N. Pilleux

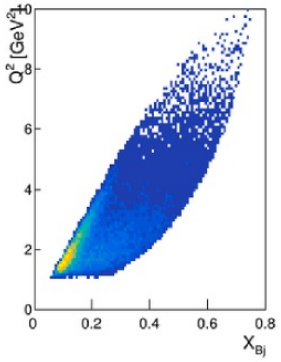
- Deeply Virtual Compton Scattering measurements on longitudinally polarized protons and neutrons are used to access Generalized Parton Distributions and will allow for their flavor decomposition.

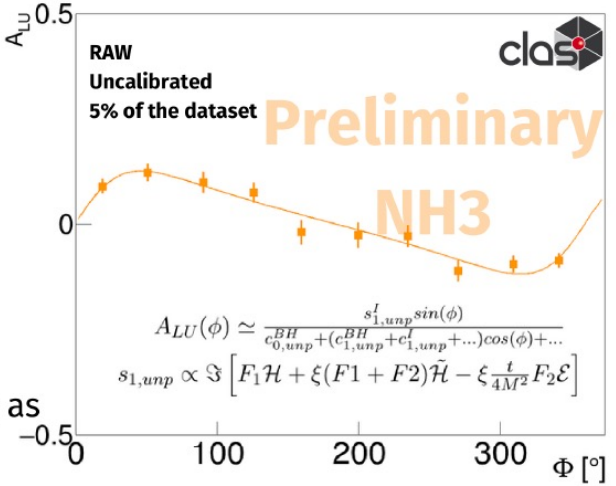


- The first CLAS12 polarized target experiment took place last year !
- It relies on the great performance of the target system.

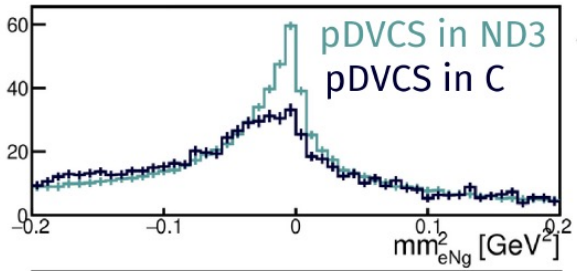


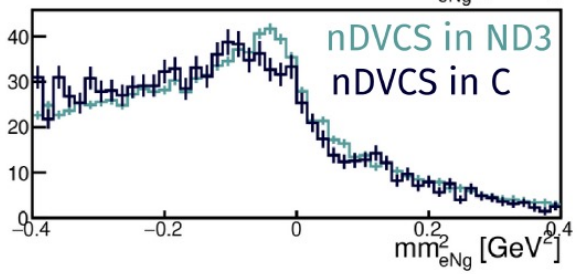
- As data is being processed, first results with protons in H indicate a healthy state of the data and analysis tools.

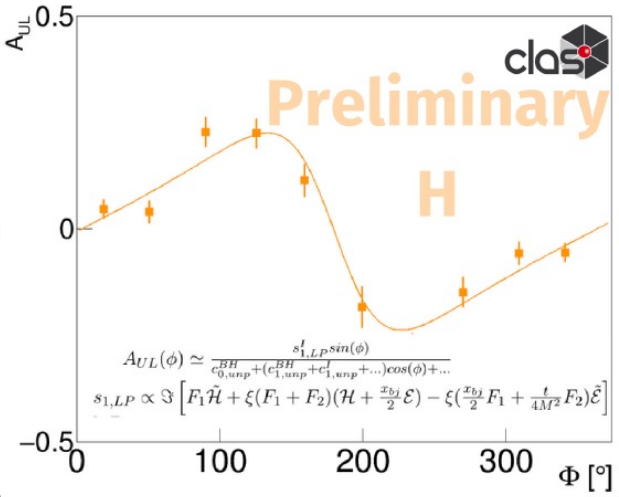




- More exciting results are coming as data will soon be available for p and n in D !





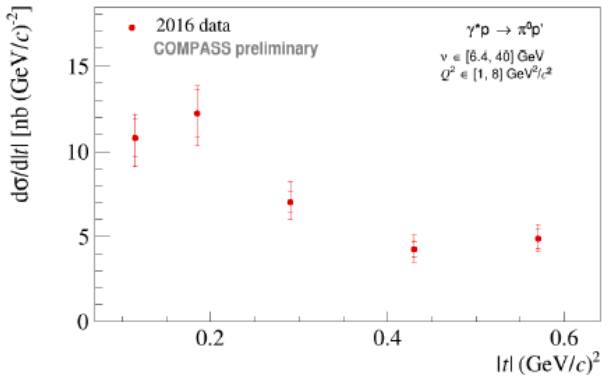


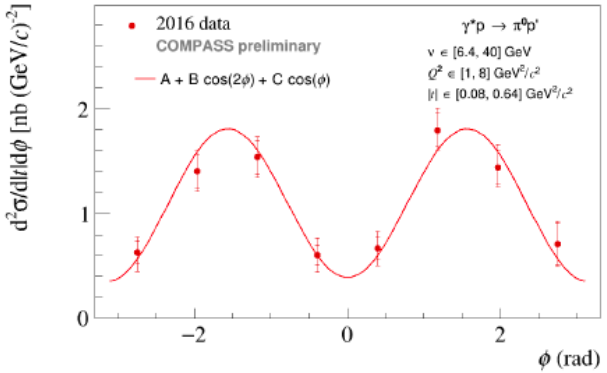
Exclusive π^0 cross-section on unpolarized proton target at COMPASS

M. Peskova

$|t|$-dependence and ϕ-dependence of exclusive π^0 cross-section on unpolarised proton target:

- New, preliminary 2016 COMPASS results at low ξ (or $\langle x_B \rangle = 0.134$), input for constraining phenomenological models (Goloskokov&Kroll, Goldstein&Liuti)





- Statistics of 2016 about 2.3× larger than of published results from 2012 pilot run
- The whole collected 2016/2017 statistics $\sim 9\times$ larger then 2012 $\rightarrow$ planned to process all available data and head towards publication of 2016 and then combined 2016/2017 results

Theory

Lattice QCD

Rapid developments in the last decade

Progress towards 3d distributions (from quasi and pseudo distributions)

Novel approach employing the Gradient Flow allowing for moment calculations without the traditional limitations

Moving gradually towards precision calculation

A. Shindler: arXiv:2311.18704

A. Shindler on the calculation of PDF moments utilizing the Gradient Flow

Lattice regularization has prevented the direct calculation of high moments of parton distribution functions (PDFs) for more than 40 years

- Hadronic matrix element of flowed operators

$$\hat{\mathring{O}}_n^{rs}(x,t) = \bar{\mathring{\chi}}^r(x,t)\gamma_{\{\mu_1}\overleftrightarrow{D}_{\mu_2}\cdots\overleftrightarrow{D}_{\mu_n\}}\mathring{\chi}^s(x,t) - \text{terms with } \delta_{\mu_i\mu_j}$$

$$\left\langle h(p)|\hat{\mathring{O}}_n^{rs}(t)|h(p)\right\rangle \rightarrow \left\langle x^{n-1}\right\rangle(t)$$

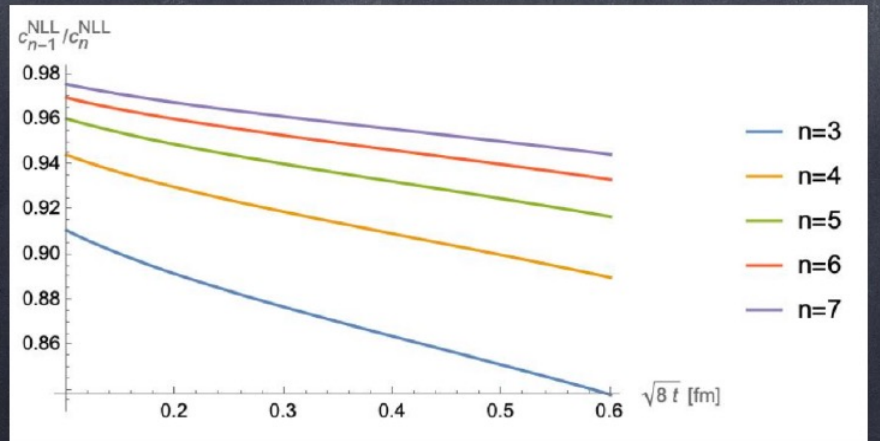
Multiplicative renormalization

Vanishing external spatial momenta

- Perform continuum limit and matching

$$\left\langle x^{n-1}\right\rangle^{\overline{\text{MS}}}(\mu) = c_n(t,\mu)^{-1}\left\langle x^{n-1}\right\rangle(t)$$

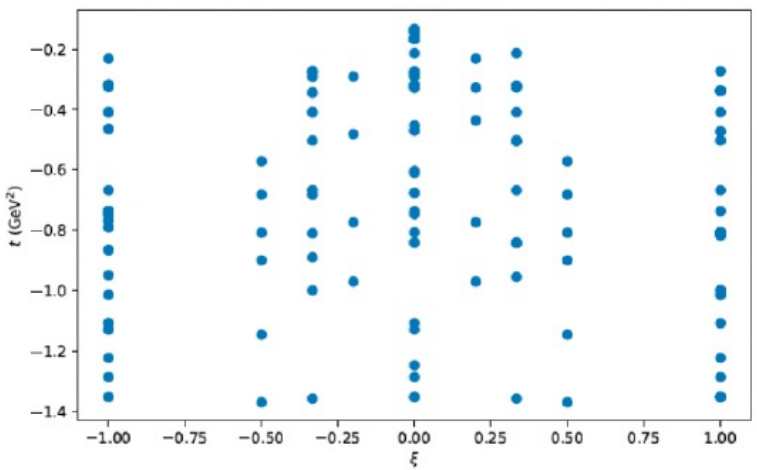
$$c_n^{(1)}(t,\mu) = 1 + \frac{\overline{g}^2(\mu)}{(4\pi)^2}C_F\left[\gamma_n \log\left(8\pi\mu^2 t\right) + B_n\right] + O(\overline{g}^4)$$

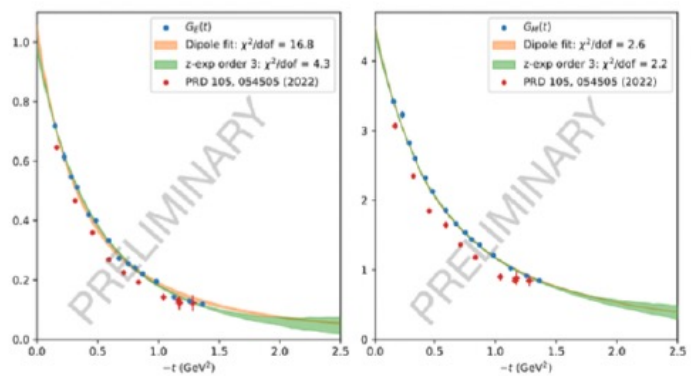


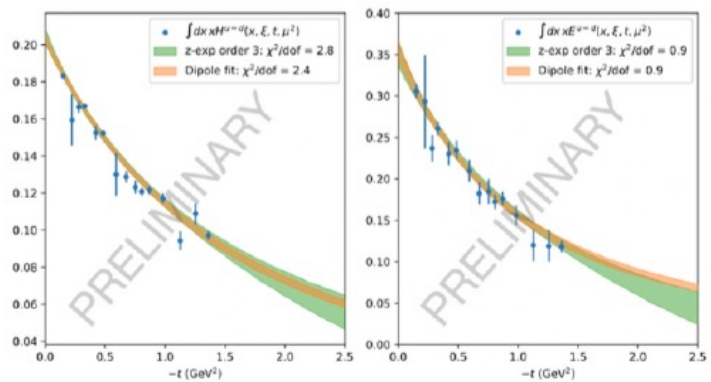
Lattice QCD (Ioffe time distributions) S. Zafeiropoulos for the Hadstruc Collaboration

LQCD can access GPDs without being hampered by the deconvolution problem

- Kinematic coverage of our simulations, elastic form factors and gravitational form factors



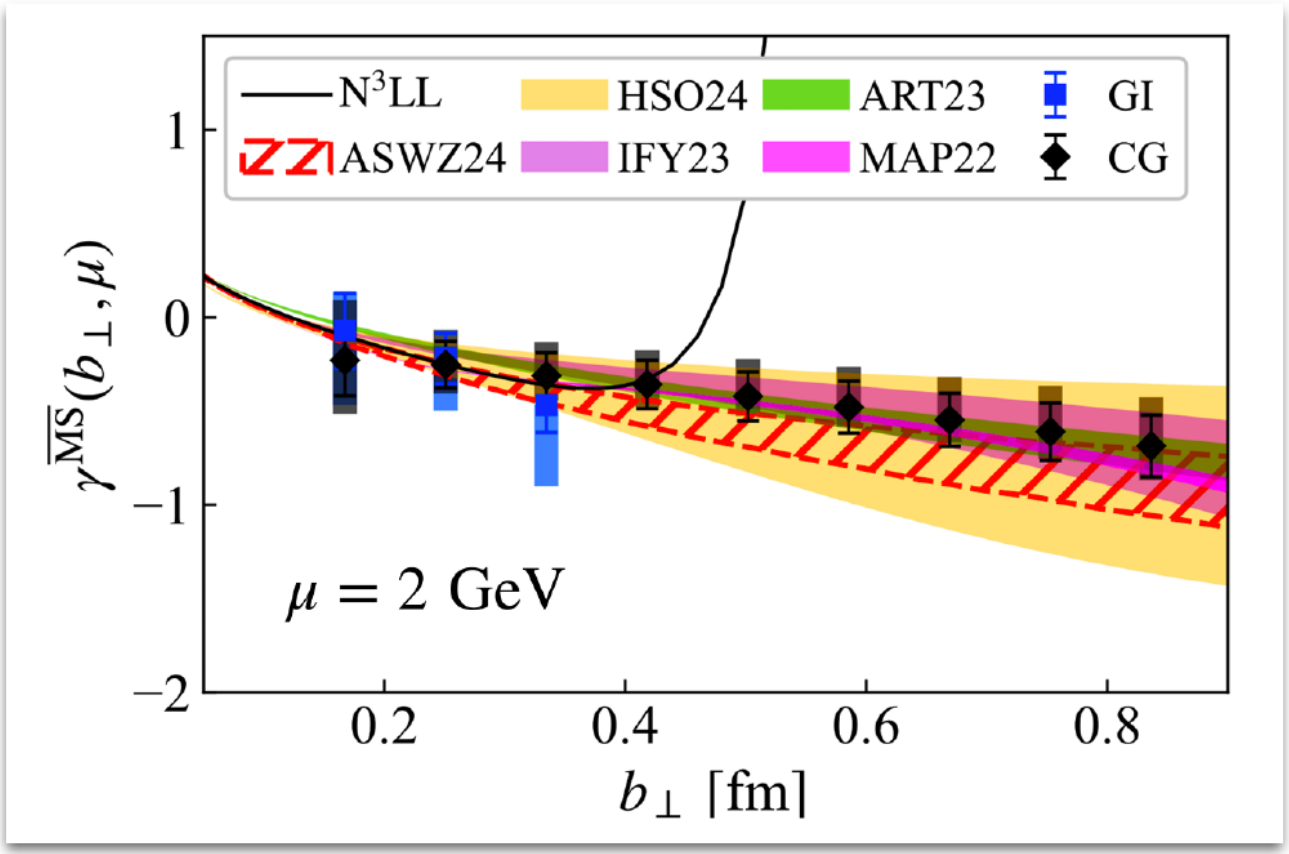




Swagato Mukherjee on the calculations of the Collins-Sopper Kernel

Summary: nonperturbative CS kernel

Bollweg et al.: Phys. Lett. B 852, 138617 (2024)



Phenomenology

(And not only that…)

Great progress also in all fronts from the pheno side (GPDs, TMDs, new processes, global fits,…)

Extensive use of AI and NN seems to have contributed substantially to this progress

Enhanced x-sensitivity from new exclusive processes

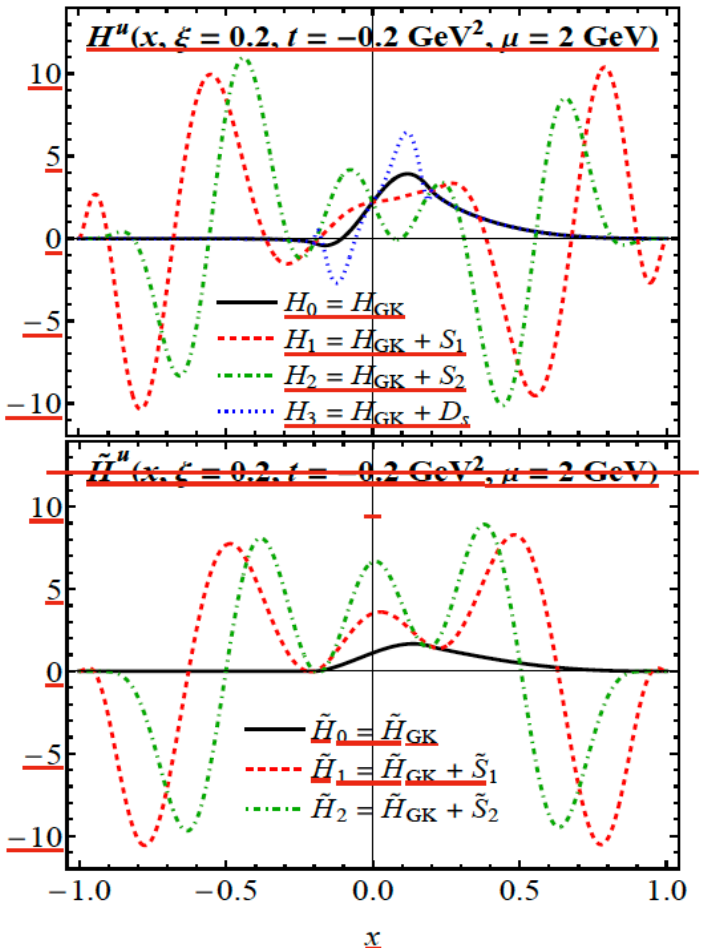
J. Qiu & Z. Yu @ WG5

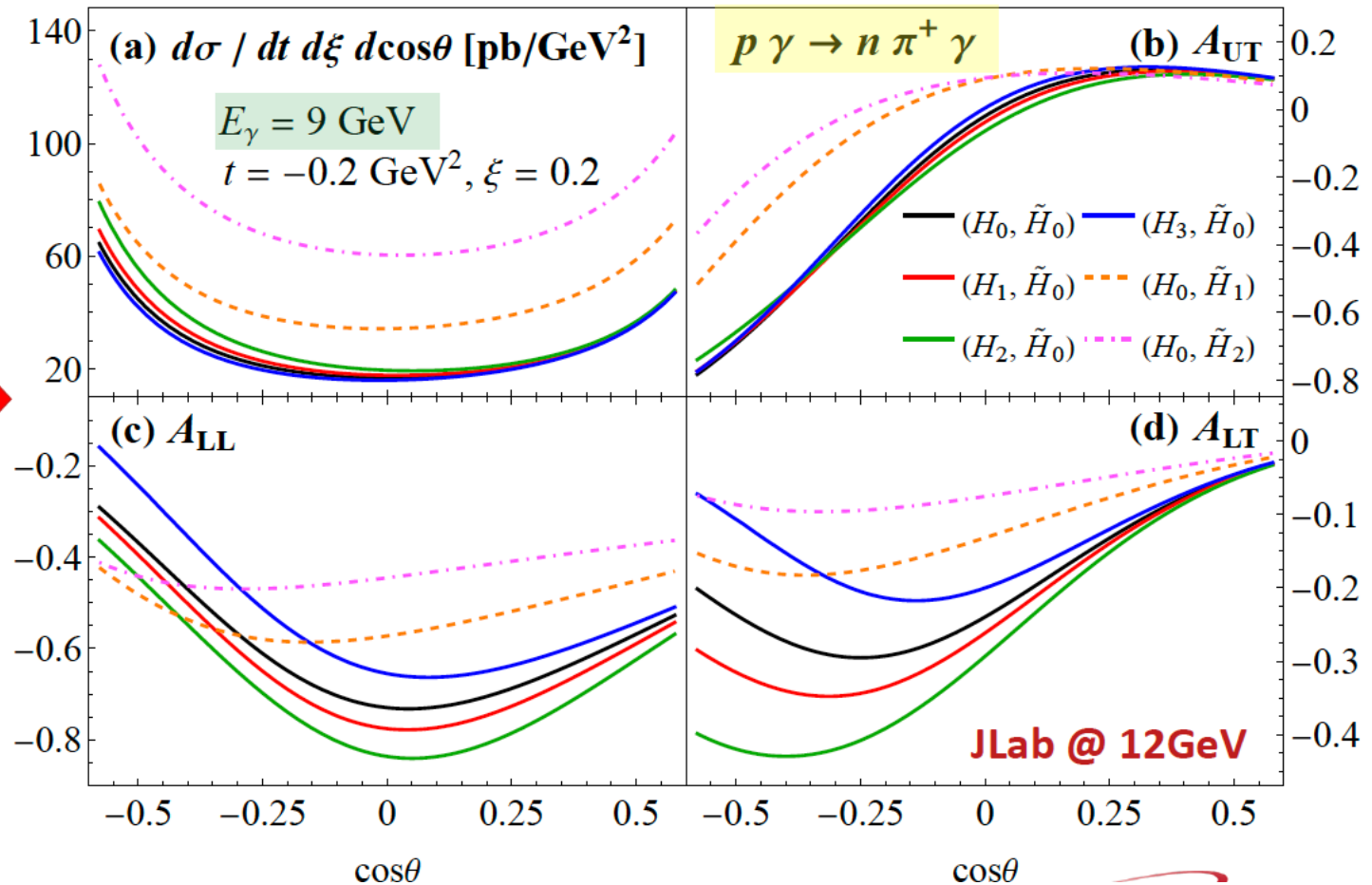
GPD models = GK model + shadow GPDs

Can't be distinguished by DVCS, DVMP, …

$$\int_{-1}^{1} \frac{dx\, S(x,\xi)}{x-\xi\pm i\epsilon} = 0$$

But, can be clearly distinguished by New observables at JLab, …





Anomalous dimensions for hard exclusive processes

Sam Van Thurenhout

- GPDs are important objects for the description of 3D hadronic structure. They are accessible in hard exclusive processes and correspond to hadronic matrix elements of QCD operators.
- For phenomenological studies, one also needs to know the scale dependence of the GPDs. This is characterized by the anomalous dimensions of the QCD operators. Because of mixing with total-derivative operators for exclusive processes, one actually has an anomalous dimension matrix (ADM).
- One way to reconstruct the elements of this matrix is by the use of a consistency relation

$$\gamma^{\mathcal{D}}_{N,k} = \binom{N}{k} \sum_{j=0}^{N-k} (-1)^j \binom{N-k}{j} \gamma_{j+k,\,j+k} + \sum_{j=k}^{N} (-1)^k \binom{j}{k} \sum_{l=j+1}^{N} (-1)^l \binom{N}{l} \gamma^{\mathcal{D}}_{l,j}$$

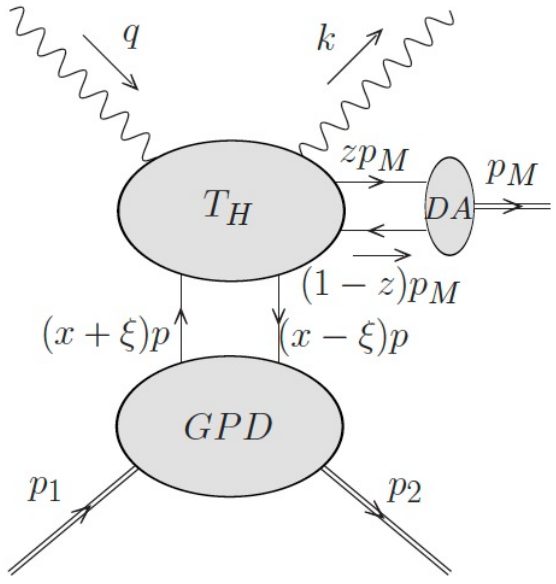
✓The reconstruction of the elements of the ADM using this relation can be automated using computer algebra methods. This makes it, in principle, straightforward to apply also at higher orders in perturbation theory.

Exclusive photoproduction of a photon-meson pair with large invariant mass

-S. Wallon

$$\gamma(q) + N(p_1) \to \underbrace{\gamma(k) + M(p_M)}_{M^2_{\gamma M} \propto p^2_\perp : \text{hard scale}} + N'(p_2)$$

$$\mathcal{A} = \int_{-1}^{1} dx \int_{0}^{1} dz \; T_H(x, \xi, z) \; GPD(x, \xi, t) \; DA(z)$$



- $\gamma N \to \gamma M N'$: $M = \pi^{\pm}, \rho^{0,\pm}_{L,T}$

  R. Boussarie, B. Pire, L. Szymanowski, S. Wallon: [1609.03830]

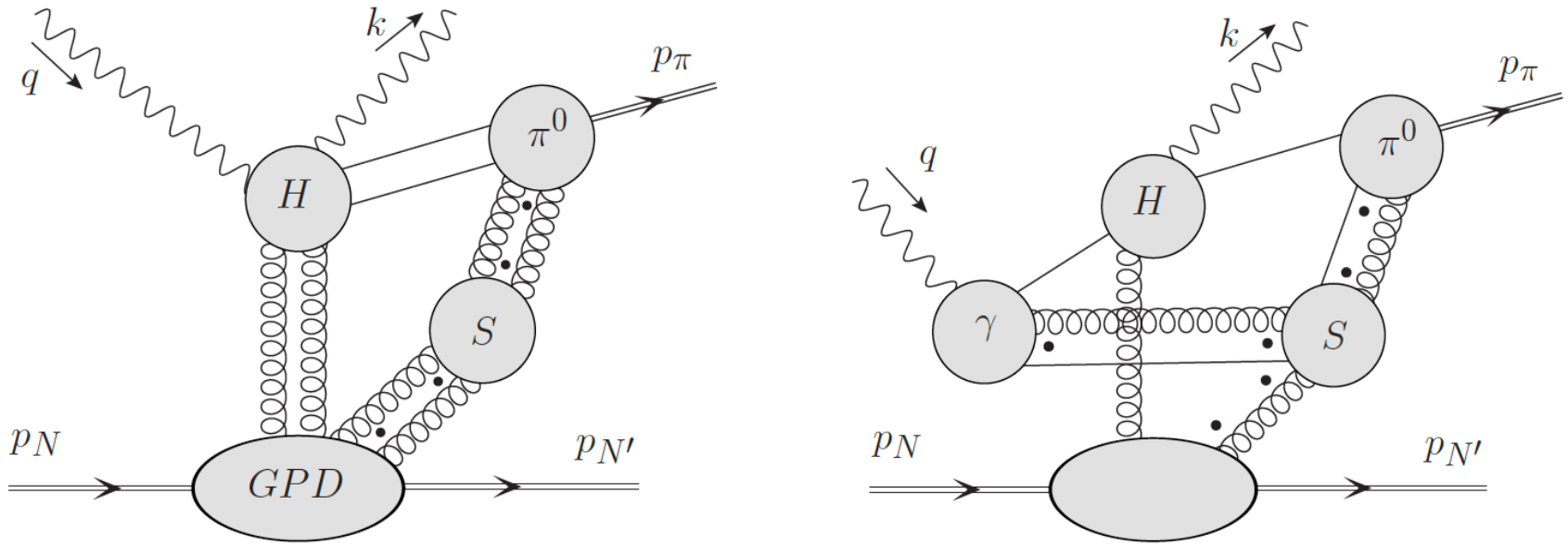
  G. Duplančić, K. Passek-Kumerički, B. Pire, L. Szymanowski, S. Wallon: [1809.08104]

  G. Duplančić, S. Nabeebaccus, K. Passek-Kumerički, B. Pire, L. Szymanowski, S. Wallon: [2212.00655, 2302.12026]

- Sensitive to chiral-odd GPDs at the *leading twist* when $M = \rho_T$.
- Various observables computed (cross sections/polarisation asymmetries), covering kinematics at JLab, COMPASS, EIC, LHC in UPCs
- Good statistics at various experiments, particularly at *JLab*.
- *Small* ξ limit of quark GPDs can be studied at collider experiments.

Breakdown of collinear factorisation in exclusive photoproduction of a $\pi^0\gamma$ pair with large invariant mass

-Saad Nabeebaccus

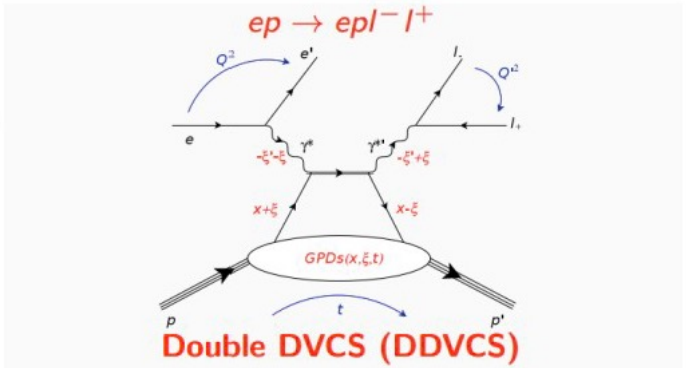


- $M = \pi^0$ ($J^{PC} = 0^{-+}$) sensitive to *gluon* GPDs also. Calculation at LO and leading twist already divergent!!.
- Origin of divergence traced to Glauber pinch (present in gluon exchange channel only): S. Nabeebaccus, J. Schönleber, L. Szymanowski, S. Wallon [2311.09146].
- Glauber pinch has same power scaling as the collinear pinch:
  $\Longrightarrow$ breaks collinear factorisation at *leading twist*.
- Such factorisation breaking effects are absent in the quark GPD channel

DDVCS experimental observables

by Juan Sebastian Alvarado

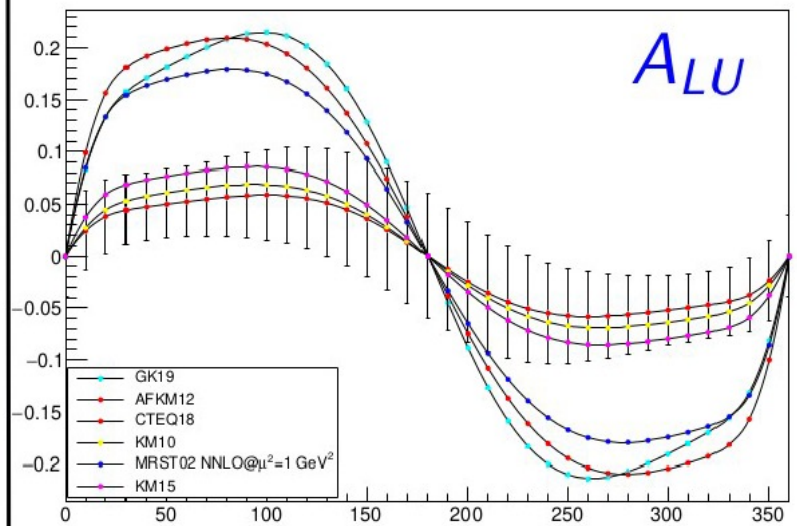
- The ξ' dependence of the DDVCS observables allow us to access more information about GPDs.



$$\mathcal{H}(\xi', \xi, t) = \sum_q e_q^2 \left\{ \mathcal{P} \int_{-1}^{1} dx\, H^q(x, \xi, t) \left[\frac{1}{x - \xi'} + \frac{1}{x + \xi'} \right] - i\pi \left[H^q(\xi', \xi, t) - H^q(-\xi', \xi, t) \right] \right\}$$

- GPD measurement at independent $x = \xi'$ and ξ values.
- Generalizes the results from DVCS and TCS. See Victor's talk on Wednesday!

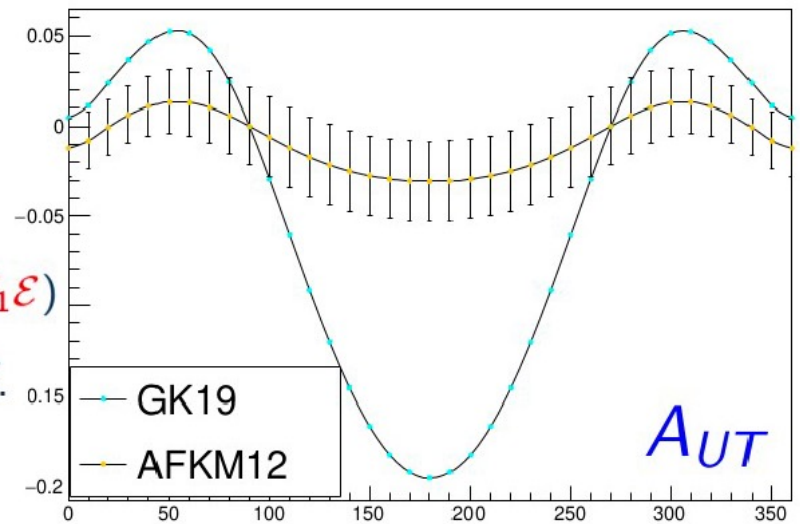
K.Deia. V. Martinez-Fernandez et al. Phys. Rev. D 107.9 (2023), p. 094035



- $A_{LU} \propto \sin(\phi)\Im\left((F_1\mathcal{H} - kF_2\mathcal{E}) + \xi'(F_1 + F_2)\tilde{\mathcal{H}} \right)$
- $A_{UU}^{\cos} \propto \cos(\phi)\Re\left(\frac{\xi'}{\xi}(F_1\mathcal{H} - kF_2\mathcal{E}) + \xi(F_1 + F_2)\tilde{\mathcal{H}} \right)$
- $A_{UL} \propto \sin(\phi)\Im\left(F_1\tilde{\mathcal{H}} + \xi'(F_1 + F_2)\left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) - \xi\left(\frac{\xi}{1+\xi}F_1 + kF_2\right)\tilde{\mathcal{E}} \right)$
- $A_{LL} \propto A + B\cos(\phi)$
  - $A \propto \Re\left(\xi(F_1 + F_2)\left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) + F_1\tilde{\mathcal{H}} - \xi\left(\frac{\xi}{1+\xi}F_1 + kF_2\right)\tilde{\mathcal{E}} \right)$
  - $B \propto \Re\left(\xi(F_1 + F_2)\left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) + \frac{\xi'}{\xi}F_1\tilde{\mathcal{H}} - \xi'\left(\frac{\xi}{1+\xi}F_1 + kF_2\right)\tilde{\mathcal{E}} \right)$

$$A_{UT} \sim \sin(\Phi - \phi)\cos(\phi)\frac{2k}{1+\xi}\frac{\xi'}{\xi}\Im\left(F_2\mathcal{H} + F_1\mathcal{E}\right)$$

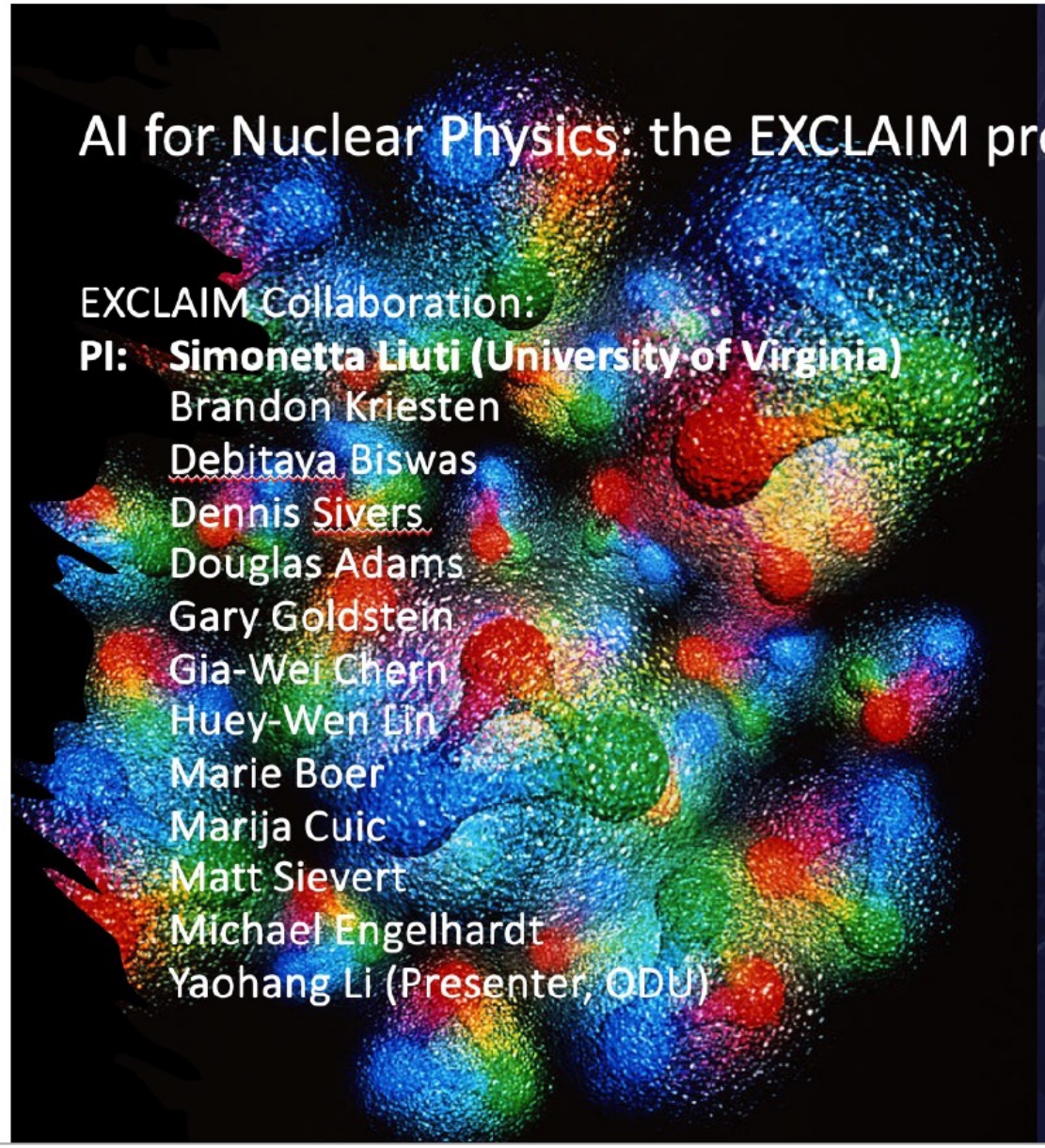
✓ Good opportunity to measure GPD E.



- At JLab kinematics:
  - Measurements of A_{LU}, A_{LL} and $A_{UU}^{\cos}$ are sensitive to models.
  - The measurements can be achieved within 100 days of beam time.
- At EIC kinematics:
  - A_{LU} and $A_{UU}^{\cos}$ are sensitive to models.
  - The measurements can be achieved within 1 effective year of beam time.

AI application for Deeply Virtual Exclusive Scattering

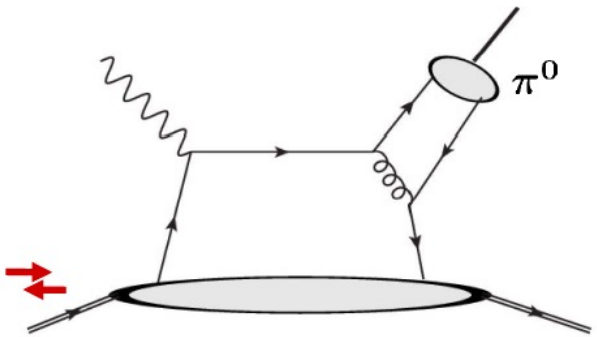
Y. Li



- Extracting 3D information from data is an unprecedented challenging problem which is uniquely highly-dimensional with respect to what done in DIS
- It is important to keep developing ML-based approaches and to build a platform with benchmarks for the community to compare results with both epistemic and aleatory uncertainties
- Developing a new paradigm shift towards Physics Aware AI

Probing quark **Orbital Angular Momentum** in ep collisions

Shohini Bhattacharya's talk, Tuesday 12 noon



Exclusive π^0 production in ep collisions

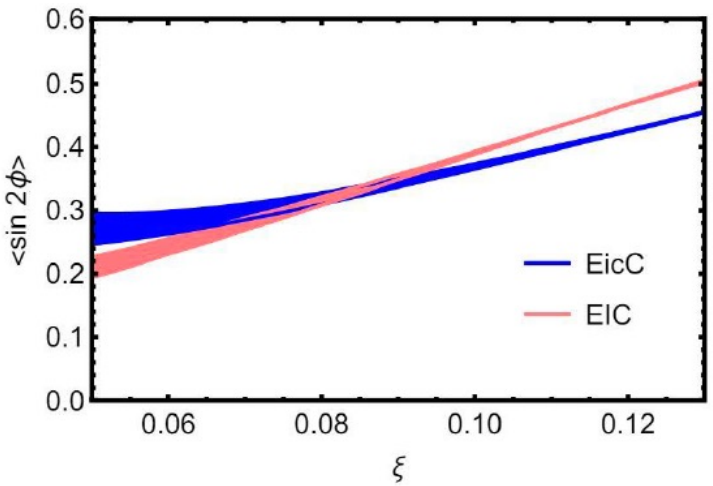
$$\frac{d\sigma}{dtdQ^2dx_Bd\phi} = \frac{(N_c^2-1)^2\alpha_{em}^2\alpha_s^2 f_\pi^2 \xi^3 \Delta_\perp^2}{2N_c^4(1-\xi^2)Q^{10}(1+\xi)}\left[1+(1-y)^2\right]$$

$$\times\left\{\left[|\mathcal{F}_{1,1}+\mathcal{G}_{1,1}|^2+|\mathcal{F}_{1,4}+\mathcal{G}_{1,4}|^2+2\frac{M^2}{\Delta_\perp^2}|\mathcal{F}_{1,2}+\mathcal{G}_{1,2}|^2\right]+\cos(2\phi)a\left[-|\mathcal{F}_{1,1}+\mathcal{G}_{1,1}|^2+|\mathcal{F}_{1,4}+\mathcal{G}_{1,4}|^2\right]\right.$$

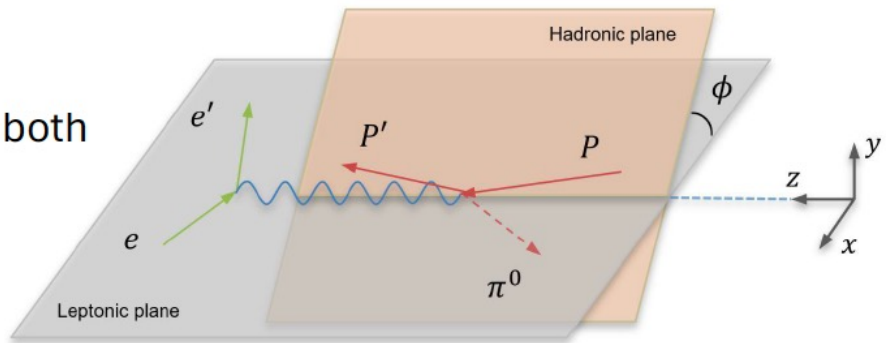
$$\left.+\lambda\sin(2\phi)\,2a\,\mathrm{Re}\left[(i\mathcal{F}_{1,4}+i\mathcal{G}_{1,4})\left(\mathcal{F}_{1,1}^*+\mathcal{G}_{1,1}^*\right)\right]\right\}$$

arXiv: 2312.01309

Distinguished experimental signature of quark OAM



Asymmetries are substantial for both EIC & EicC kinematics



Angular momentum distributions inside a quark dressed with a gluon

A. Mukherjee

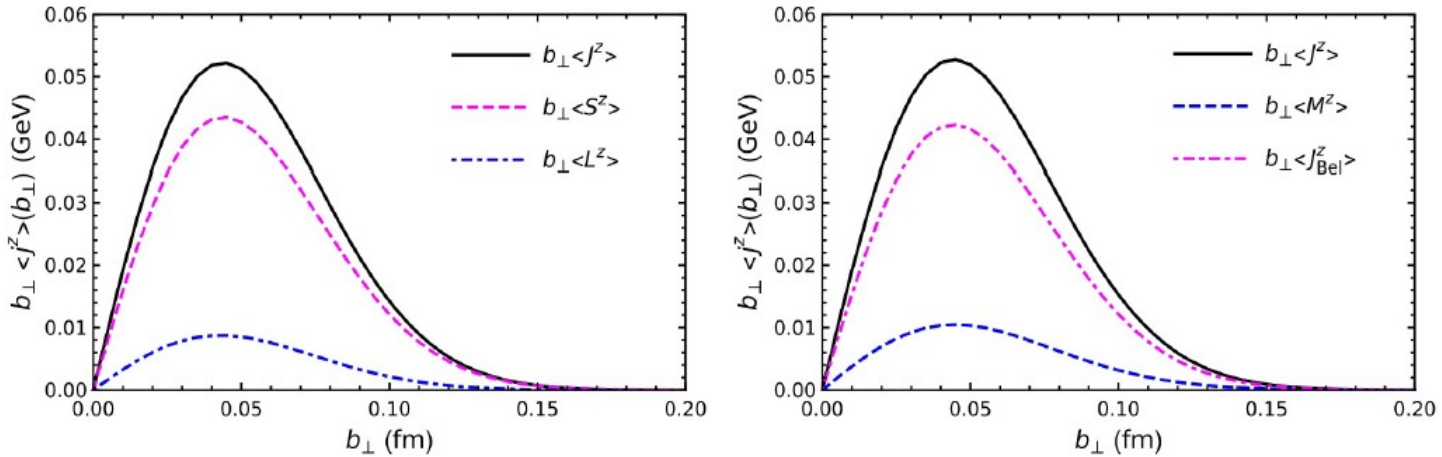


FIG. 1. Longitudinal angular momentum distribution of quarks as a function of impact parameter $b_\perp$. Left: Sum of the kinetic orbital AM $b_\perp\langle L^z\rangle$ (dot-dashed line) and spin AM $b_\perp\langle S^z\rangle$ (dashed line) given by kinetic total AM $b_\perp\langle J^z\rangle$ (solid line). Right: Kinetic total AM $b_\perp\langle J^z\rangle$ (solid line) is given by the sum of Belinfante total AM $b_\perp\langle J^z_{\rm Bel}\rangle$ (dot-dashed line) and the correction term corresponding to the total divergence $b_\perp\langle M^z\rangle$ (dashed line). Here, $m = 0.3$ GeV, $g = 1$, $C_f = 1$, and $\Lambda = 1.7$ GeV. We chose the Gaussian width $\sigma = 0.1$ GeV.

Belinfante vs kinetic decomposition

Relativistic composite spin-1/2 state with a gluonic degree of freedom

Spin distribution dominates over OAM distribution, similar to other calculations for proton

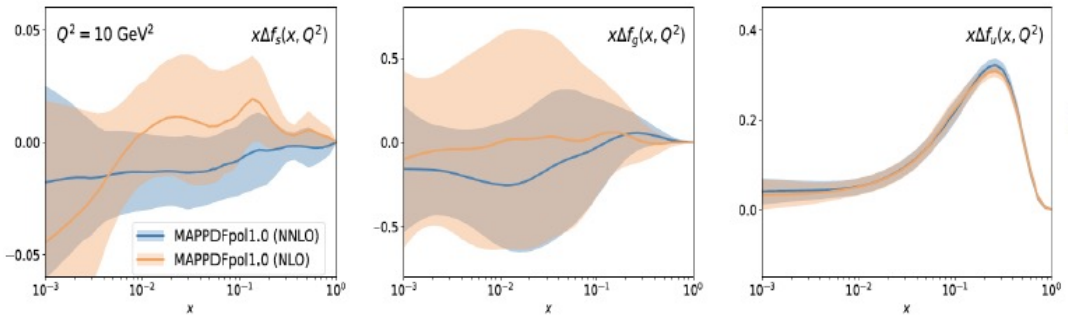
Superpotential term is positive throughout, in contrast to some other model calculations, where it has a positive core but negative near the periphery

R. Singh, S. Saha, AM, N. Mathur PRD 109, 016022 (2024)

Polarized PDFs at NNLO

A. Chiefa

MAPPDF pol1.0



Moderate impact, except for Δf_g and $\Delta f_s^{(-)}$

No sign of strange asymmetry

Non-trivial interplay between NNLO corrections and SIDIS experimental data

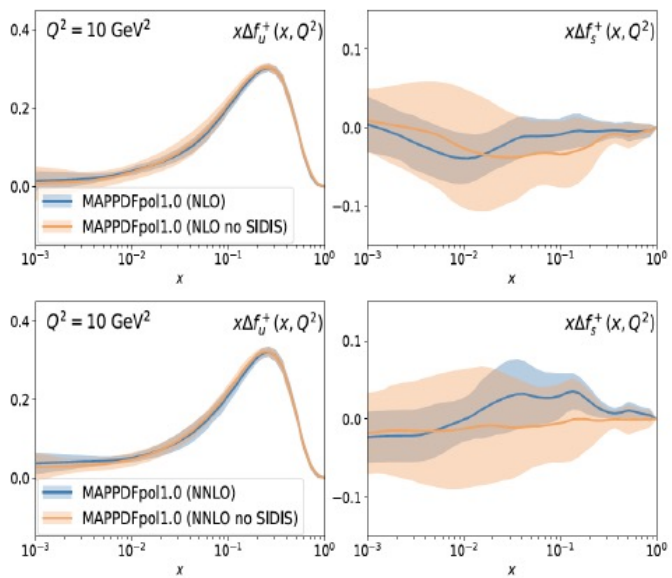
uncertainties for Δf_u^+ (and Δf_d^+ as well) reduce at NLO, but increase at NNLO

↓

This behaviour is not observed for Δf_s^+

↓

Further investigations for pion data and FFs needed



Uncertainty reduction for Δf_s^+ w/ SIDIS included

Determination with SIDIS data still compatible with the global one

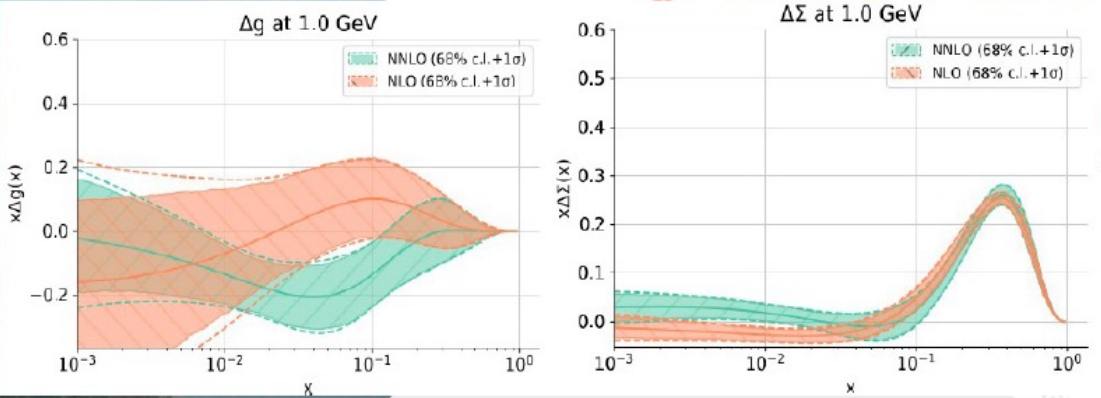
Strangeness still compatible with zero even w/ SIDIS data

F. Hekhorn

NNPDF pol2.0

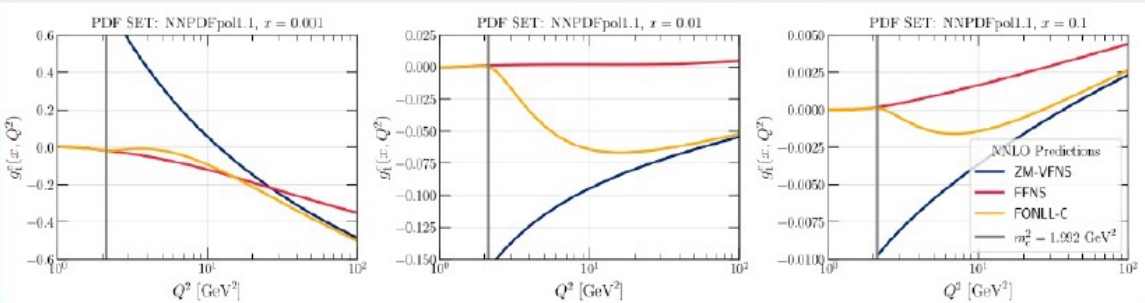
Centre of Excellence in Quark Matter

NNPDF



Towards NNPDFpol2.0

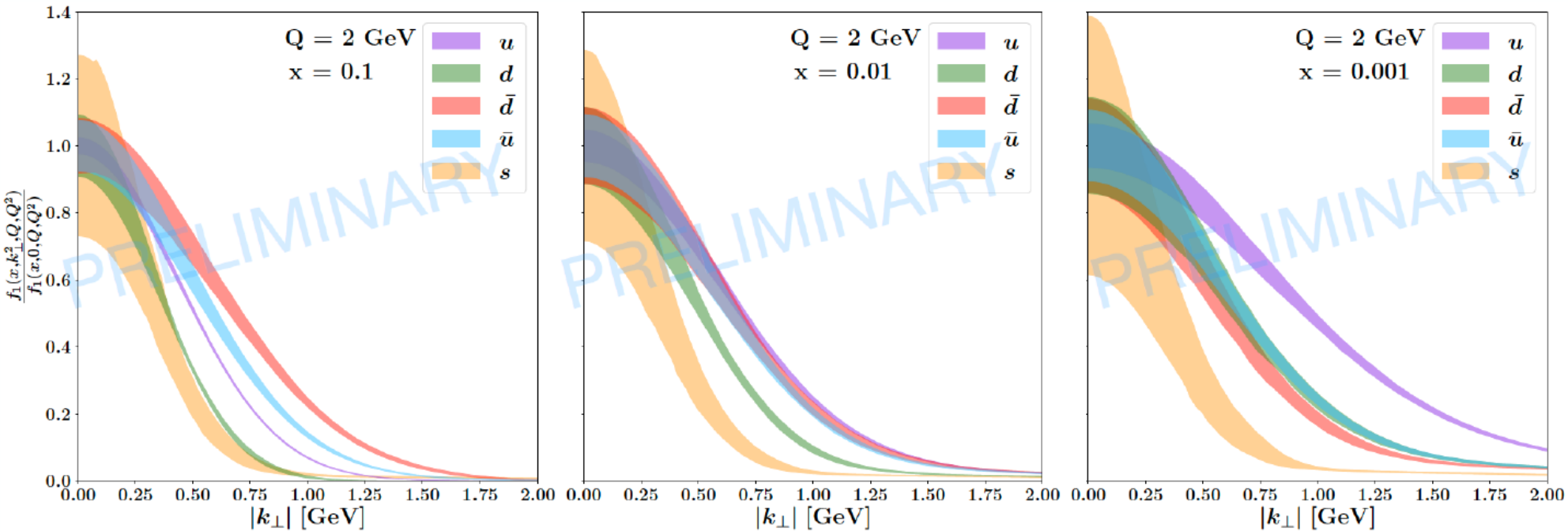
Felix Hekhorn



MAPTMD24 extraction - TMD PDFs

L. Rossi

- ***MAPTMD24*** will be the ***first flavour dependent*** extraction of unpolarized quarks TMDs in the proton from a ***global*** fit

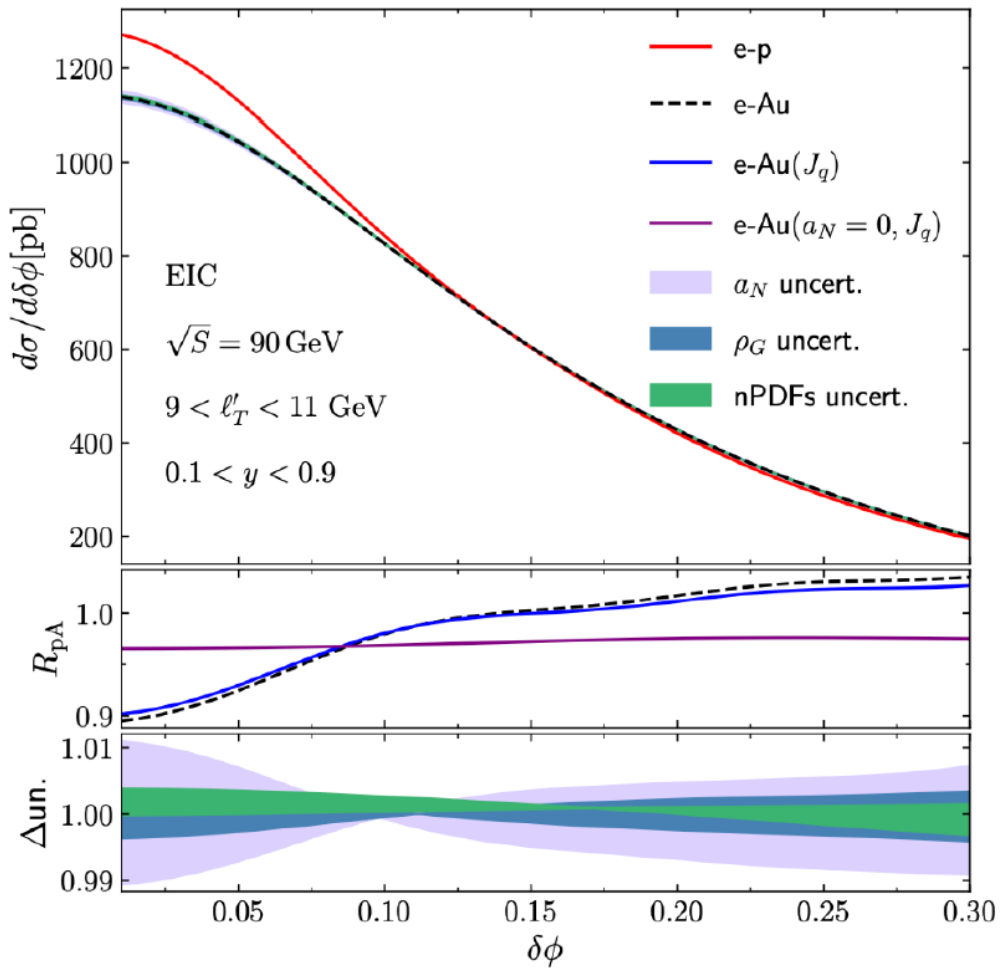


Very different $k_\perp$ - behaviours! → ***It changes also by varying x***

Precision three-dimensional imaging of nuclei using recoil-free jets

Dingyu Shao

Shen Fang, Wei-Yao Ke, Ding-Yu Shao, John Terry 2311.02150



- **TMD factorization and resummation of lepton-jet correlation in both e-p and e-A collisions has been studied.**
- **In e-p collision, resummation accuracy has been improved to NNNLL + $\mathcal{O}(\alpha_s^2)$ using a recoil-free jet axis.**
- **In e-A collision, this process can serve as a robust probe of the three-dimensional structure for bound nucleons.**

Hidden soft effects from TMD extractions

A. Simonelli

Standard TMD
(e.g. SIDIS, DY, DIA)

$$d\sigma = |H|^2 \int \frac{d\vec{b}_T}{(2\pi)^2} e^{-i\,\vec{q}_T\cdot\vec{b}_T}\; D_A^\star(z_A, b_T, y_A - y_1)\, S(b_T, y_1 - y_2)\, D_B^\star(z_B, b_T, y_2 - y_B)$$

SOFT FACTOR

$$= e^{(y_1-y_2)K(b_T)+P(b_T)}$$

CS-kernel

P-term: **hidden soft effect**

Standard TMD definition independent of P-term

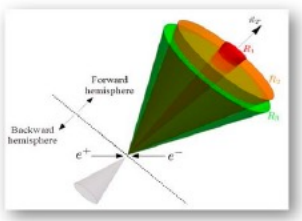
$$D = D^{\text{uns.}} \sqrt{\frac{S_{\infty - y_1}}{S_\infty\, S_{y_1-(-\infty)}}}$$

However, the P-term **disappears** in standard TMD cross sections ($D^* \propto e^{-\frac{1}{2}P}$)

$$D(z, b_T, y_{\text{had}} - y_1) = D^\star(z, b_T, y_{\text{had}} - y_1) e^{-\frac{1}{2}P(b_T)}$$

Look for a non-standard case, where to access directly D^*

Single-Inclusive Annihilation (**SIA**) with thrust $e^+e^- \to h\,X$

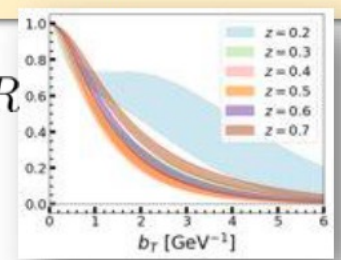


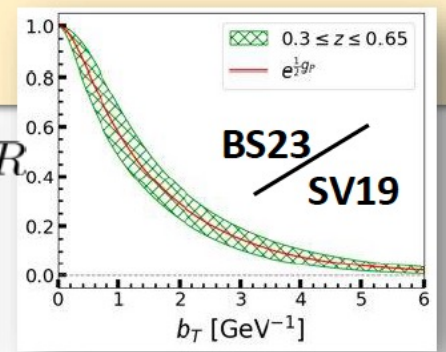
$$d\sigma_{R_2} = |H|^2 \int \frac{du}{2\,i\,\pi} e^{u\tau} \int \frac{d\vec{b}_T}{(2\pi)^2} e^{iz\vec{P}_T\cdot\vec{b}_T}$$

$$J(u, \infty - y_j)\frac{\widehat{S}(u, y_1 - y_2)}{\widehat{S}(u, \infty - y_2)} D^\star(z, b_T, y_{\text{had}-y_1})$$

$$R = \frac{\text{TMD extraction from beyond standard process}}{\text{TMD extraction from standard process}} = e^{-\frac{1}{2}P(b_T,\mu)}$$

FIRST PHENO EXPLORATION





Matching between TMD and twist-3 factorizations in the transversely polarized hyperon production

Shinsuke Yoshida

- The twist-3 cross section for the SSA in $\Lambda^\uparrow$ production was completed very recent at the lowest order

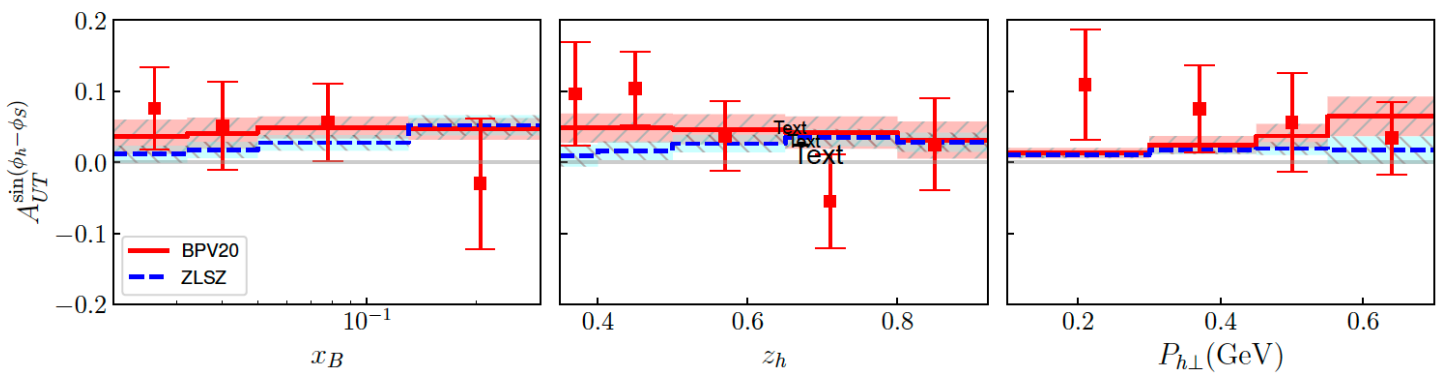
- We calculated the one-loop corrections to the TMD operator and found the relation with the collinear twist-3 functions

- Using this relation, we confirmed that the TMD and the collinear twist-3 give the consistent results in $\Lambda_{QCD} \ll P_T \ll Q$

- The consistency will play a role in future phenomenological studies as that in the pion production has done

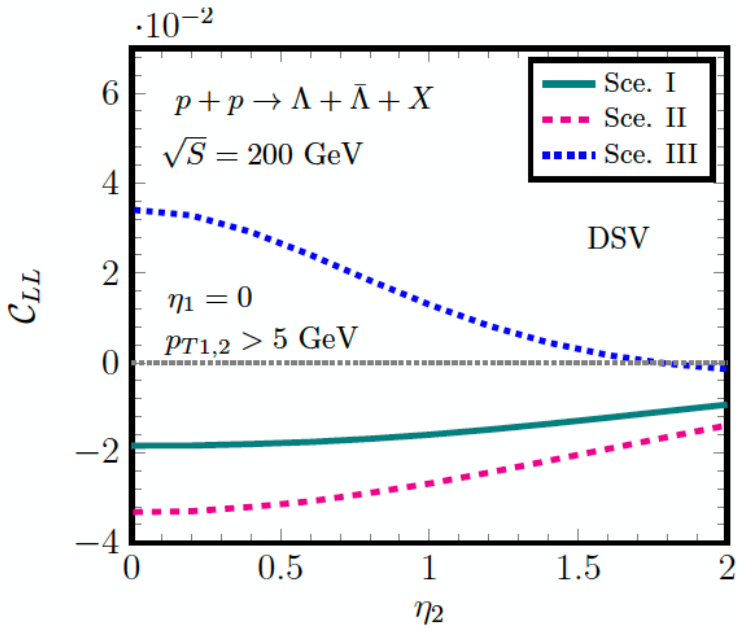
-Y. Deng

The Sivers function extracted from pion's and kaon's data can be well matched with ρ^0's data. This result serves as a test of the universality of Sivers function.

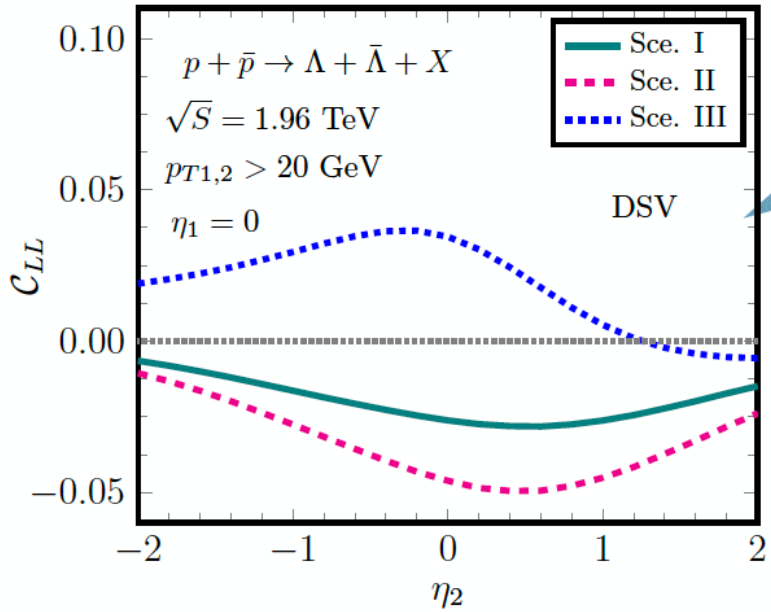


Polarization Correlation in unpolarized pp collisions

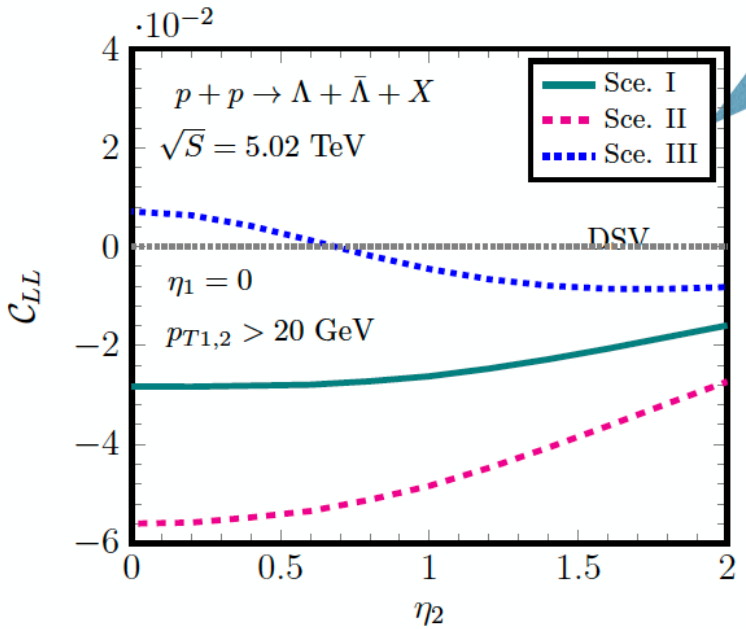
-Shuyi Wei



RHIC



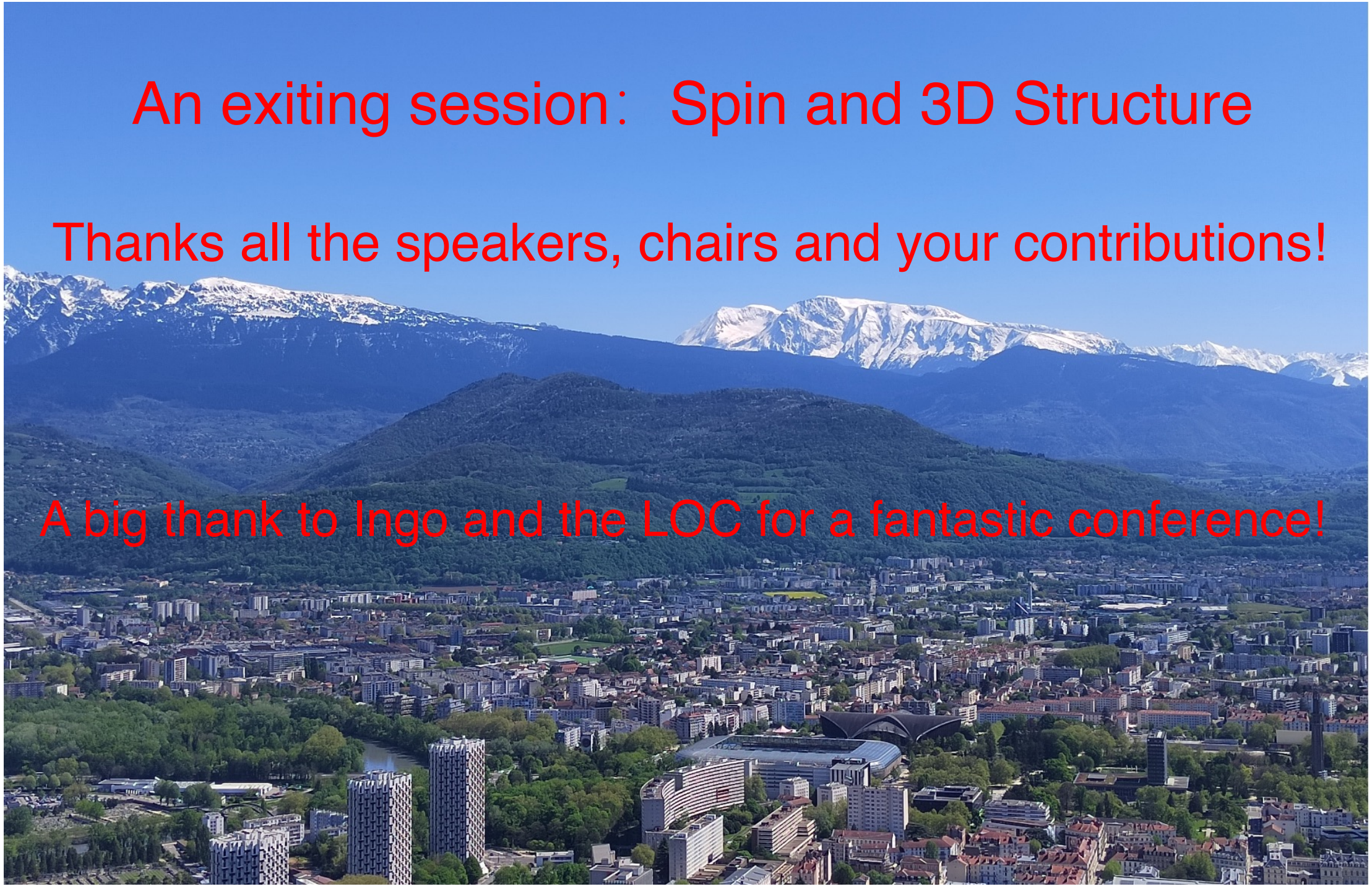
Tevatron



LHC

Equipped with longitudinal polarization correlation of dihadron, we can explore polarized fragmentation function (G_{1L}) in unpolarized pp collisions.

Fragmentation of circularly polarized gluons


An exiting session: Spin and 3D Structure
Thanks all the speakers, chairs and your contributions!
A big thank to Ingo and the LOC for a fantastic conference!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