Experimental Probes

Discussion session about "experimental measurements that can be most helpful to generate advances in areas of interest to the workshop"

Discussion leaders: Elke Aschenauer & Daniel Boer

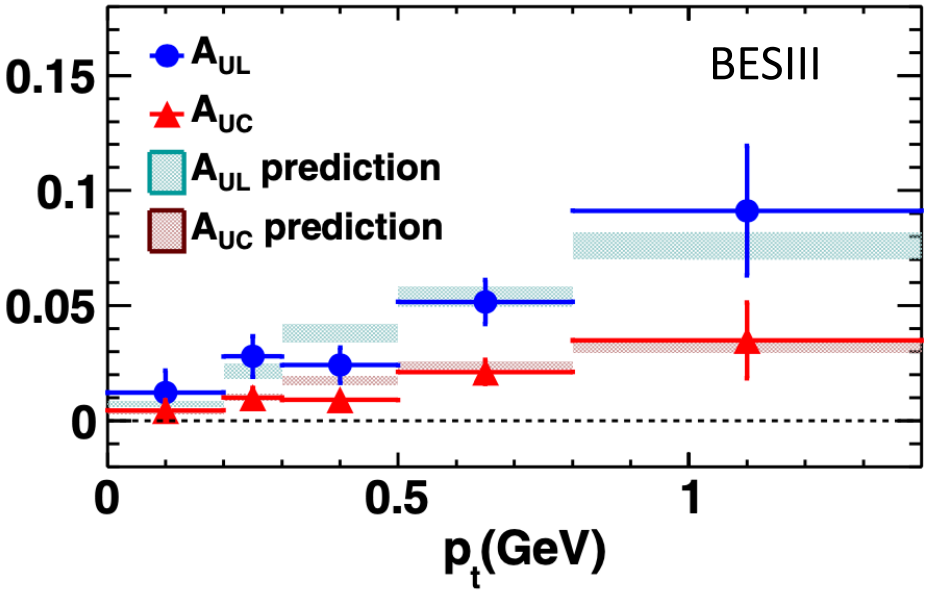
REF2020, online at Higgs Centre, Edinburgh, December 11, 2020

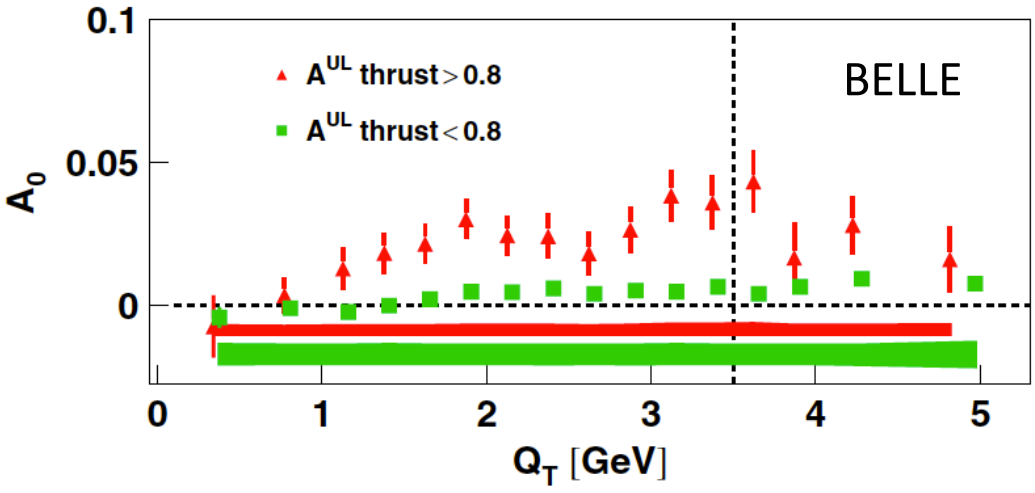
topics for discussion

- Tests of TMD evolution
- Process dependence of TMDs
- TMD factorization breaking
- Non-universality due to soft factors
- High and low q_T matching
- Small-x & saturation effects
- GTMDs
- ...

Tests of TMD evolution

BES-III, BELLE, LEP data on Double Collins effect appear roughly consistent with TMD evolution





COMPASS, HERMES & JLab SIDIS data span a too small energy range → EIC

Tests of TMD evolution

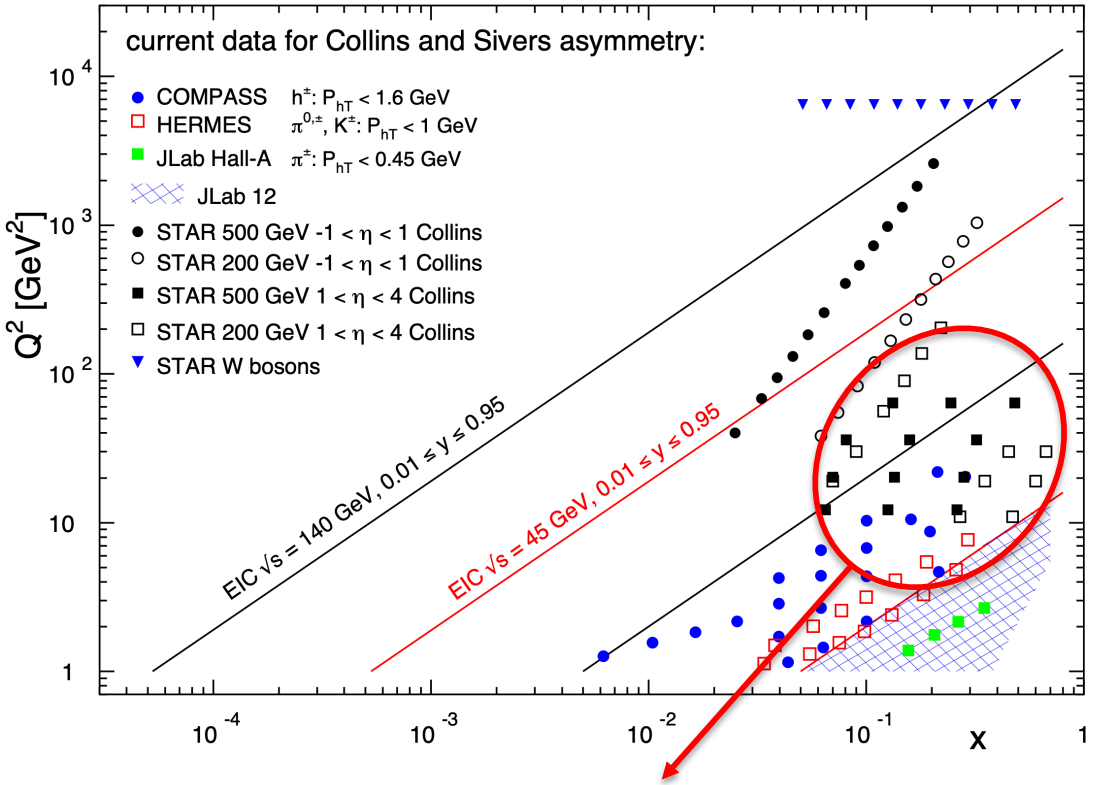
- EIC: detailed map of Q^2 dependence of Sivers and Collins asymmetries
- NICA & LHC: (pseudo-)scalar charmonium vs bottomonium vs Higgs production, drawback: discrete Q^2 points
- EIC, RHIC & LHC: pair production processes allow variations of the invariant mass of the pair (such as dijets or J/ψ pairs Scarpa et al, 2020)

- Other promising options?

RHIC the TMD machine

- Wide kinematic coverage
- access to (un)polarized TMDs in final and initial state
- access to TMD evolution
- large overlap with EIC kinematics
  - → test of universality
  - → test of sign change
  - → test of factorization breaking

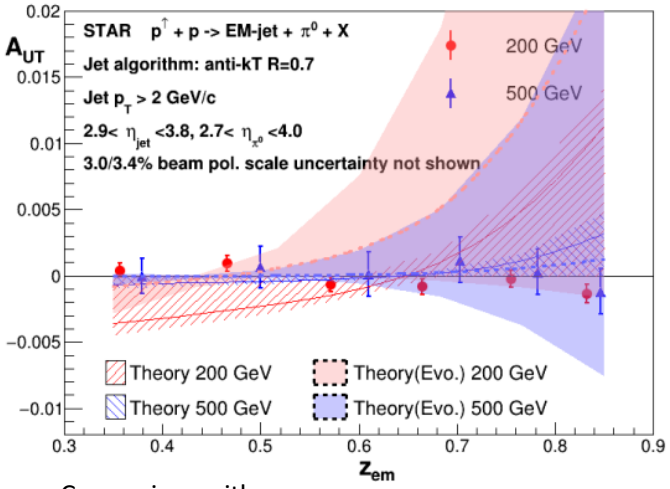
RHIC will stop running in 2025
→ need to make sure all the data, which are needed, are taken



STAR forward upgrade
ECal + Hcal and tracking

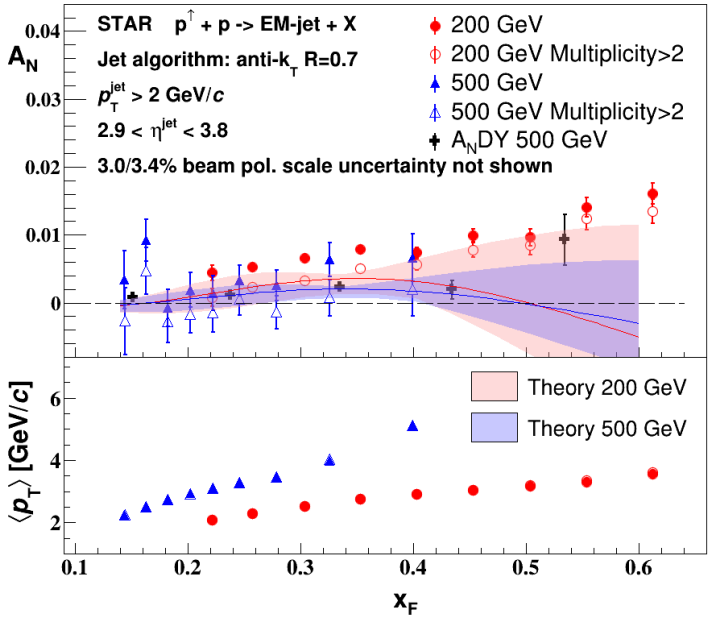
Very Recent Results @ $2.8 < \eta < 4.0$

Collins asymmetries are small.

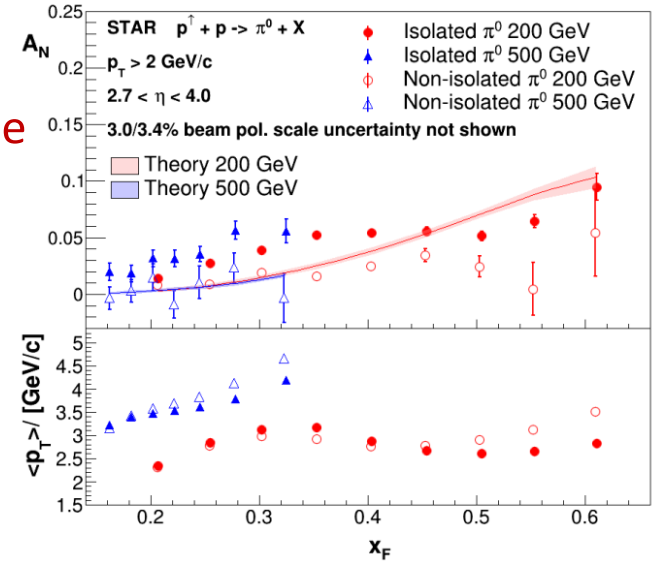


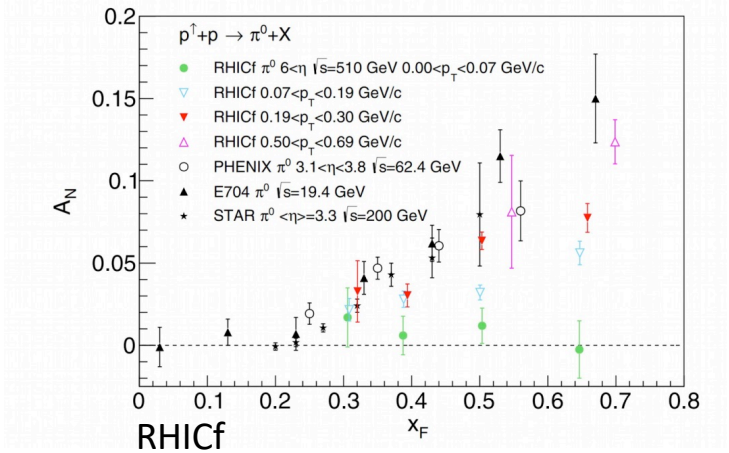
Comparison with
Z. Kang et al., PLB 774, 635 (2017)
L. Gamberg et al., PRL 110, 232301 (2013)
J. Cammarota et al., arxiv:2002.08384

Jet asymmetries are consistent with previous results.



Pion asymmetries increase with isolation.

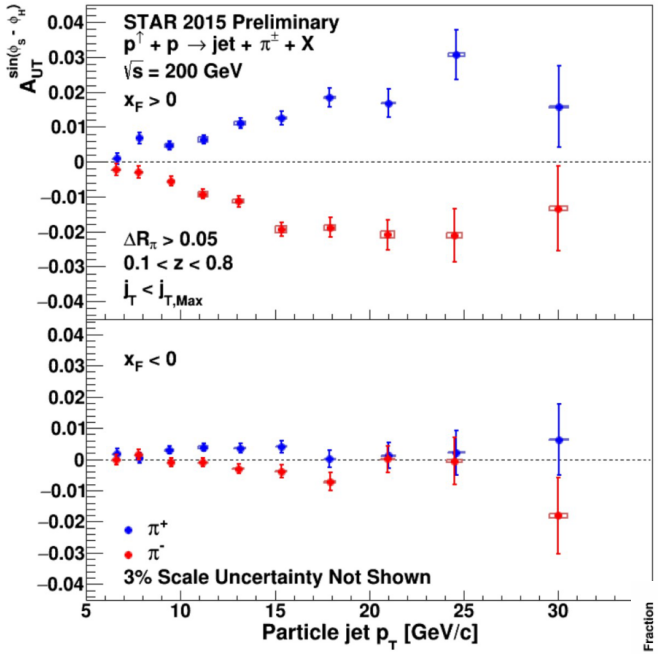




RHICf
PRL 124, 252501 (2020)

Very Recent Results

Collins through hadron in jet at midrapidity -1 < η <1

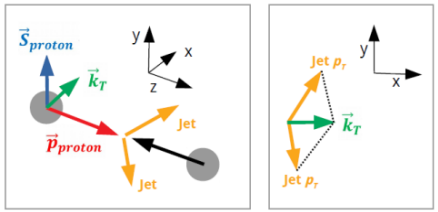


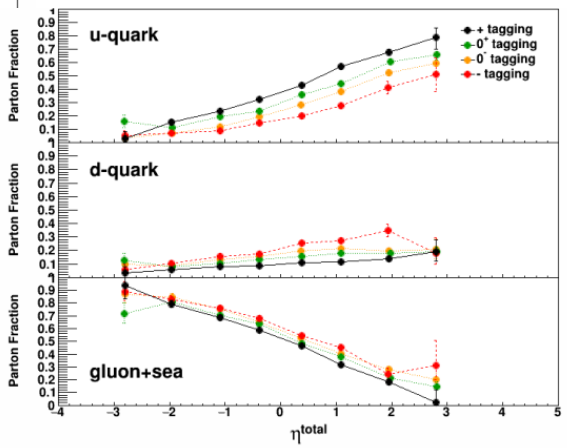
Spin Asymmetries in Di-jets

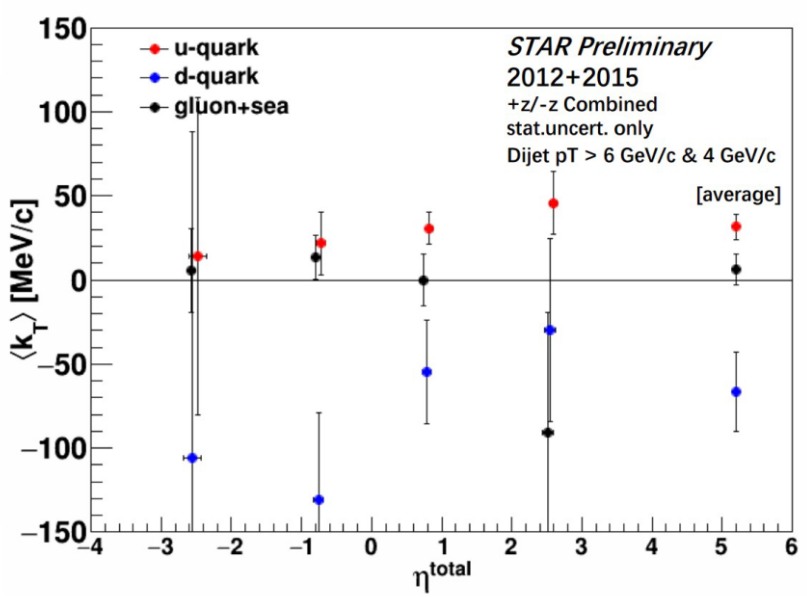
- Correlation between proton spin and parton k_T

$$\left\langle \vec{S} \cdot (\vec{p} \times \vec{k}_T) \right\rangle \neq 0$$

- Enhance quark flavor with charge tagging
  - Track p_T weighted charge
  - $\eta_{total} = \eta_1 + \eta_2$
  - Unfolded to parton $\langle k_T \rangle$
- More data on disk, $\sqrt{s} = 510$ GeV







Process dependence of TMDs

- Sign change relation tests for both quark and gluon Sivers functions:

$$f_{1T}^{\perp q[\mathrm{SIDIS}]}(x, k_T^2) = -f_{1T}^{\perp q[\mathrm{DY}]}(x, k_T^2)$$

$$f_{1T}^{\perp\, g\,[e\,p^{\uparrow}\to e'\,Q\,\overline{Q}\,X]}(x, p_T^2) = -f_{1T}^{\perp\, g\,[p^{\uparrow}\,p\to\gamma\,\gamma\,X]}(x, p_T^2)$$

- TMD FF universality studies in e^+e^-
- WW vs DP gluon distributions at small x

- Other promising options?

TMD factorization breaking

- Color entanglement factorization breaking Rogers, Mulders, 2010
- Modified factorization expressions, like in $pp \rightarrow Q\,\bar{Q}\,X$ (additional angular dependent soft factor) Catani, Grazzini, Torre, 2014
- Extra spin asymmetries from TMD fact. breaking in hadron-hadron collisions Rogers, 2013
- Di-jets in $pp^{\uparrow}$ at RHIC: does small asymmetry point to small factorization breaking effects?
- Best way to bound or demonstrate fact. breaking?

Non-universality due to soft factors

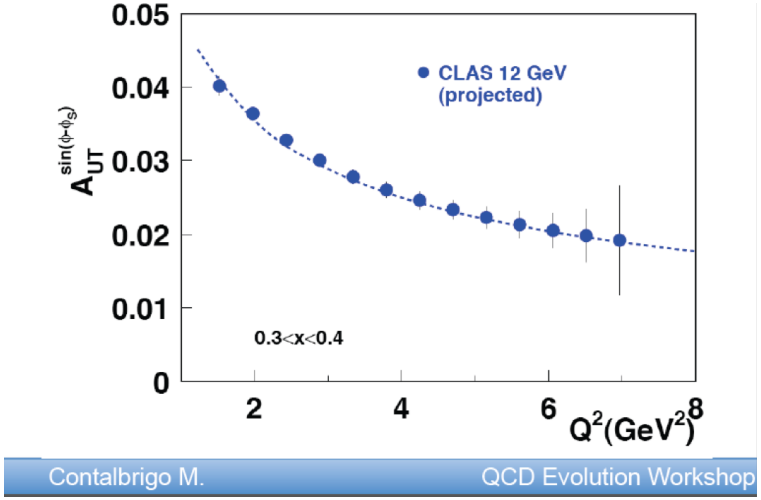
- Di-jet and di-hadron production in SIDIS involves a different soft factor than single inclusive SIDIS

  Zhu, Sun,Yuan, 2013; del Castillo, Echevarria, Makris, Scimemi, 2020
- $e^+e^- \rightarrow$ (h thrust) X and $e^+e^- \rightarrow$ h h' X involve different TMD FF definitions Boglione & Simonelli, 2020
- Similar problem arises in jet SIDIS vs SIDIS, different TMDs Boer, Duke 2010 workshop

- How to deal with the loss of predictive power?
- What are the prospects of measuring any of these differences?

High and low q_T matching

- Matching of TMD expressions at low q_T to the collinear factorization expressions at high q_T
- Data at low Q have no or small $M \ll q_T \ll Q$ region
- Z-boson q_T distribution
- Importance of non-perturbative part (large b part of Rapidity An. Dim. Vladimirov et al or S_{NP})



Key measurements?

Small x & saturation effects

- Angular coefficients & Lam-Tung relation in DY & Z boson production at LHC Balitsky et al
- Helicity distributions at small-x non-eikonal spin dependent Wilson lines Kovchegov et al
- Hybrid factorization, Sudakov factors Feng Yuan et al
- $p^{\uparrow}A \to h^{\pm}X$ at $x_F<0$ to probe spin-dependent odderon Boer et al, 2016
- ...

GTMDs

- Diffractive dijet production at EIC Hatta, Xiao, Yuan, 2016
- Dijet in UPC at LHC Hagiwara et al, 2017; Altinoluk et al, 2018
- Di-hadron production through DPS in pA
  Lappi, Schenke, Schlichting, Venugopalan, ’16; Boer, van Daal, Mulders, Petreska, ’19
- …

Other promising options?