# General remarks and physics case for $\Lambda$ physics and BM via di-hadrons at JLEIC



Anselm Vossen

# General remarks (my perspective)

- What:
  - Formulation of the physics program of interest to the Jlab SIDIS community
  - Ideally extend on EIC white paper and other studies (e.g. Duke Workshop 2010)
  - Maybe revisit golden/silver channels from white paper
- How
  - Use software by EIC SW group, established infrastructure

- Output
  - Ideally identical in format to the parallel EIC effort →need communication and representation
  - Produce document with Physics plans→Merge with EIC yellow paper

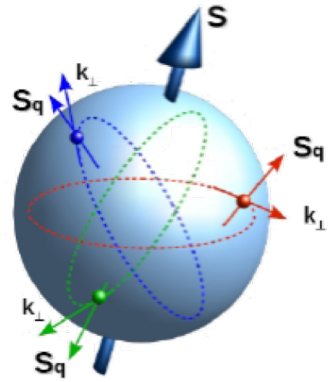
# Physics plans – Spin orbit correlation in Hadronization

# Transverse momentum dependent distributions (TMDs)

| N \ q | U | L | T |
|---|---|---|---|
| U | $f_1$ | | $h_1^\perp$ |
| L | | $g_1$ | $h_{1L}^\perp$ |
| T | $f_{1T}^\perp$ | $g_{1T}$ | $h_1$ $h_{1T}^\perp$ |

- In addition to the spin-spin correlations can have spin momentum correlations!

**Spin-orbit correlations**



# FF picture currently much more sparse --here single hadrons

Observables:

z: fractional energy of the quark carried by the hadron

$p_{h,T}$: transverse momentum of the hadron wrt the quark direction: **TMD FFs**

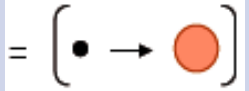
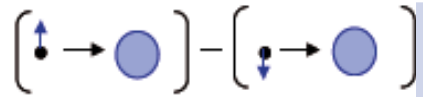
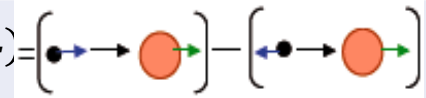
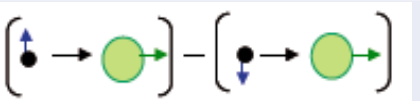
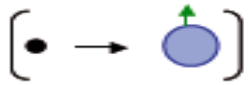
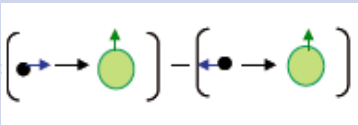
| **Parton polarization →**<br>**Hadron Polarization ↓** | **Spin averaged** | **longitudinal** | **transverse** |
|---|---|---|---|
| spin averaged | $D_1^{h/q}(z, p_T)$ =  | | $H_1^{\perp h/q}(z, p_T)$ =  |
| longitudinal | | | |
| Transverse (here $\Lambda$) | | | |

# Polarization in the final states →Spin-orbit correlations in hadronization

Observables:

z: fractional energy of the quark carried by the hadron

$p_{h,T}$: transverse momentum of the hadron wrt the quark direction: **TMD FFs**

| Parton polarization → / Hadron Polarization ↓ | Spin averaged | longitudinal | transverse |
|---|---|---|---|
| spin averaged | $D_1^{h/q}(z,p_T)$ =  | | $H_1^{\perp h/q}(z,p_T)$ =  |
| longitudinal | | $G_1^{\Lambda/q}(z,p_T)$ =  | $H_{1L}^{h/q}(z,p_T)$  |
| Transverse (here $\Lambda$) | $D_{1T}^{\perp\Lambda/q}(z,p_T)$ =  | $G_{1T}^{h/q}(z,p_T)$=  | $H_1^{\Lambda/q}(z,p_T)$ =  $H_{1T}^{\perp\Lambda/q}(z,p_T)$ =  |

- Analogue →similar to PDFs encoding spin/orbit correlations
- Determining final state polarization needs self analyzing decay ($\Lambda$)
- Gluon FFs similar but with circular/linear polarization (not as relevant for e+e-)

# Specific Plans – Lambda physics

- $\Lambda^{\uparrow}$ polarization measurement
  - First observation in SIDIS
  - Universality? (T-odd, chiral-even)
  - Flavor structure of polarizing FF (with $He^3$)
- Further topics
  - $\Lambda^{\uparrow}$ clean access to transversity
  - Spin orbit correlation in fragmentation (worm-gear FFs…)

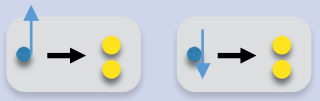
# SIMILAR: OAM IN THE FINAL STATE→ DI-HADRON FRAGMENTATION FUNCTIONS

Additional Observable:

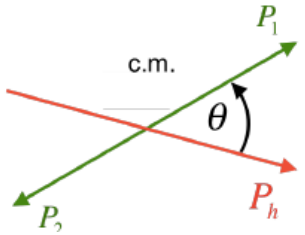
$\vec{R} = \overrightarrow{P_1} - \overrightarrow{P_2}$ :

The relative momentum of the hadron pair is an additional degree of freedom:

*the orientation of the two hadrons w.r.t. each other and the jet direction can be an indicator of the quark transverse spin*

| **Parton polarization →**<br>**Hadron Polarization ↓** | **Spin averaged** | **longitudinal** | **transverse** |
|---|---|---|---|
| spin averaged | $D_1^{h/q}(z,M)$  | | $\boldsymbol{H_1^{\perp h/q}(z, p_T \mathbf{M, (Ph),} \theta)}$ 'Di-hadron Collins' |
| longitudinal | | | |
| Transverse | **Type equation here.** | **$G_1^{\perp}(z,M,P_h,\theta)$=**<br>T-odd, chiral-even<br>→jet handedness<br>QCD vaccum strucuture  | **$H_1^{\sphericalangle}(z,M,(P_h),\theta)$=.**<br>T-odd, chiral-odd<br>Colinear  |

- Relative momentum of hadrons can carry away angular momentum
  - Partial wave decomposition in θ→Needs to be mapped completely!! (no information yet)
    - Energy dependence? (→VM fractions….)
  - Relative and total angular momentum →In principle endless tower of FFs



# Specific Plans – di-hadrons, application BM

- We expect that TMD di-hadron FFs can access the Boer-Mulders function w/o contributions from Cahn effect (and some higher order effects)
- BM is a ‘silver’ channel in the White paper
- If BM can be isolated that way, it presumably also makes it easier to break the pT convolution of FF and TMD.

# Energy/Lumi

- Currently planned for JLEIC 22 -98 GeV, lumi driven (at least for higher energies) by GPD program
- In general look at full energy range, each channel will have different requirements
- Some general remarks
  - Lower energies needed for overlap with existing experiments
  - Higher energies
    - + offer lever arm from TMD evolution, overlap with perturbative regime, larger transverse momentum range, better current/target separation, sea quarks etc
    - – questions about TMD evolution (still something to measure?) Don't want to end up in purely perturbative regime
- For the channels proposed here
  - $\Lambda^{\uparrow}$
    - Low-mid energies might be best for overlap with Belle, transversity extraction, staying in non-perturbative regime
    - Highest energy might be good to explore twist-3 framework
  - Di-hadrons
    - For BM low-mid could be best. Highest energies might wash out the effect

# Generators

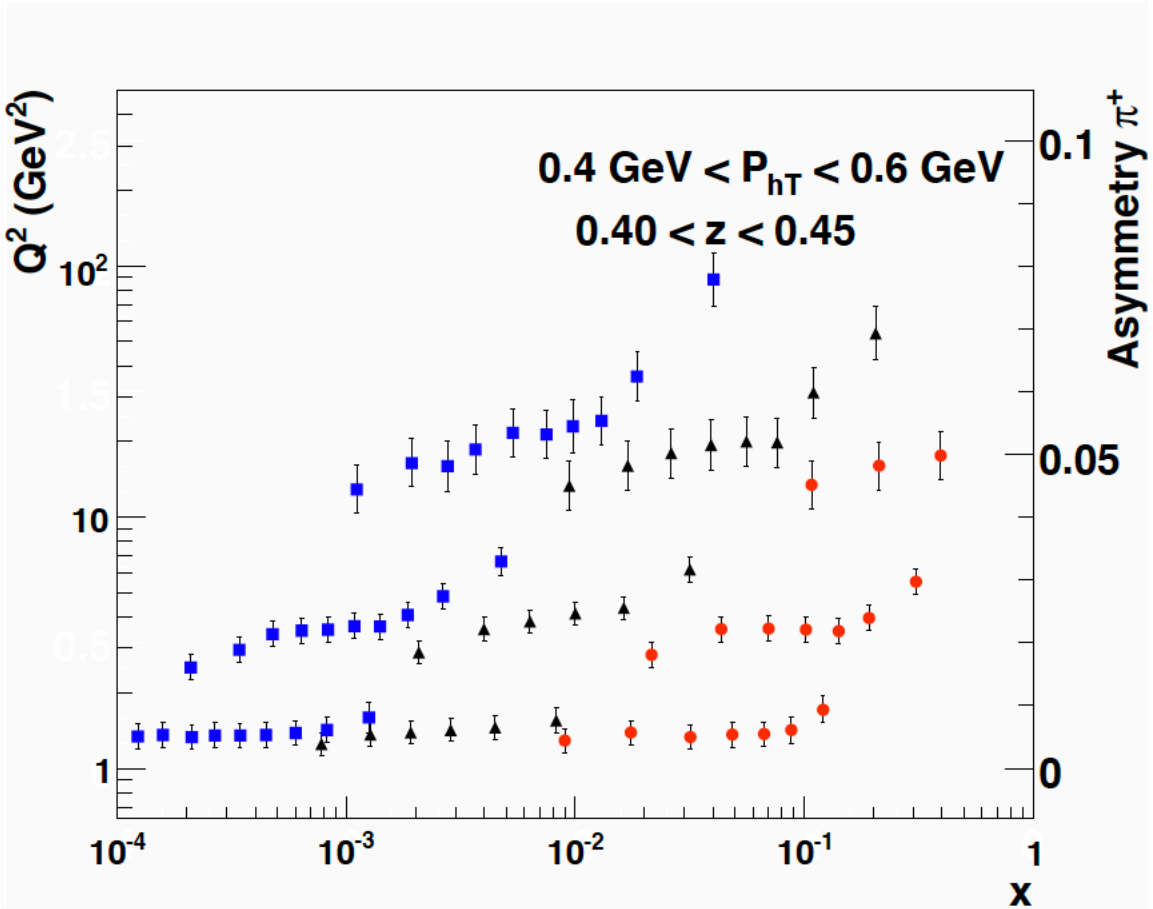
- Make use of other EIC efforts
  - Most likely focus on Pythia (Most EIC sims seem to use 6.4.28)
  - Possible Pythia TMD extensions?
- Optional: For di-hadrons renew effort in TMDGen

# Peoplepower

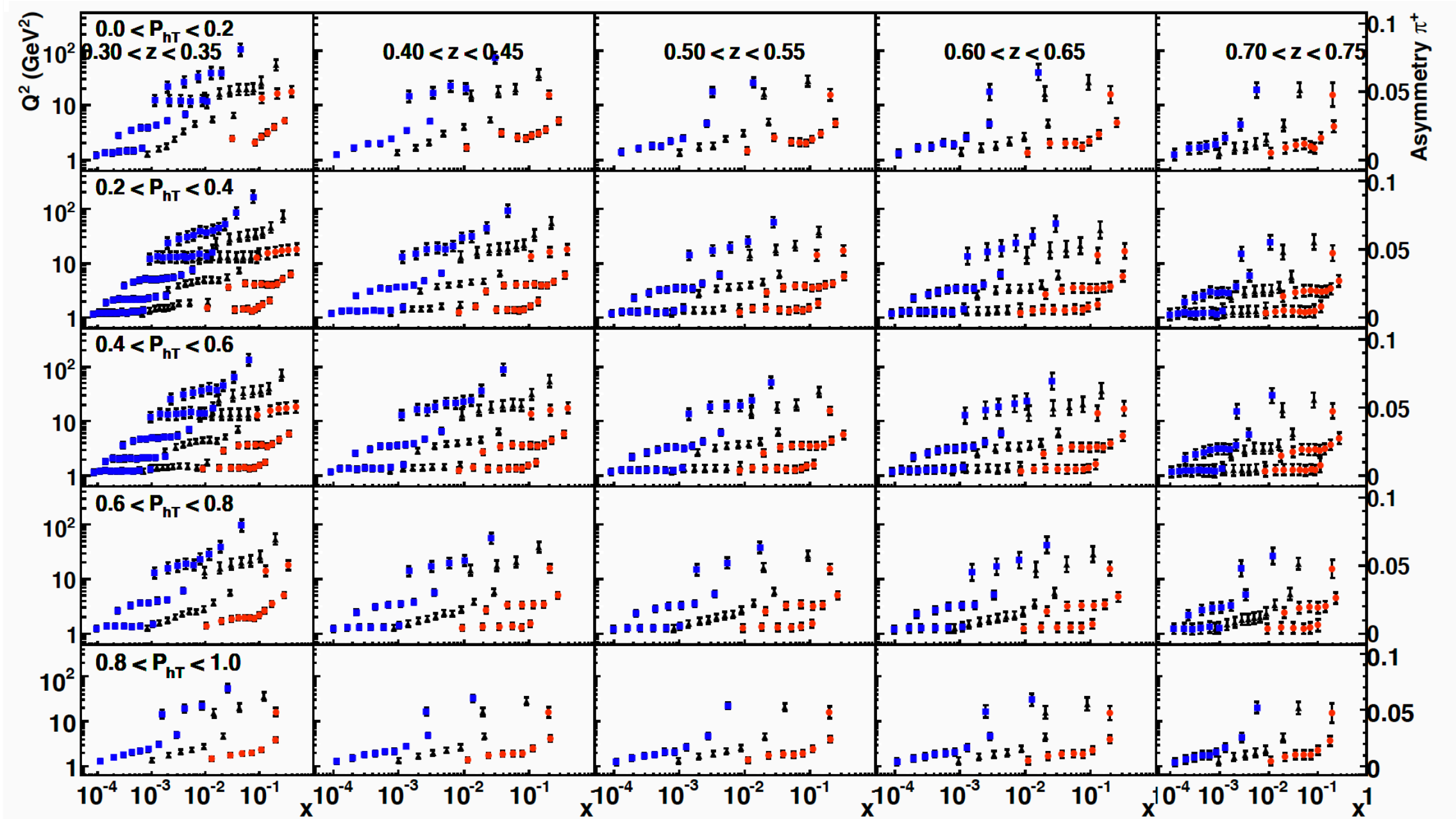
- Anselm Vossen
- Chris Dilks (PD) →will attend MIT kick-off meeting
- Future students

# Summary & Outlook

- Planning for regular meetings every $n$ weeks?




Coverage for sqrtS=150, 50,15 GeV


0.0 < P_hT < 0.2
0.30 < z < 0.35
0.40 < z < 0.45
0.50 < z < 0.55
0.60 < z < 0.65
0.70 < z < 0.75
0.2 < P_hT < 0.4
0.4 < P_hT < 0.6
0.6 < P_hT < 0.8
0.8 < P_hT < 1.0
Q² (GeV²)
x
Asymmetry π⁺

| Deliverables | Observables | What we learn | Phase I | Phase II |
|---|---|---|---|---|
| Sivers + unp. TMD quarks and gluon | SIDIS with Tran. polarization/ion; di-hadron (di-jet) heavy flavor | Quant. Interf. Multi-parton & Spin-Orbit correlations | valence+sea quarks, overlap with the fixed target exp. | 3D Imaging of quarks & gluon; $Q^2$ ($P_\perp$) range QCD dynamics |
| Chiral-odd functions: Transversity; Boer-Mulders | SIDIS with Tran. polarization/ion; di-hadron production | $3^{rd}$ basic quark PDF; novel hadronization effects | valence+sea quarks, overlap with the fixed target exp. | $Q^2$ ($P_\perp$) range for detailed QCD dynamics |

Table 2.1. Science Matrix for TMD physics: 3D structure in transverse momentum space: golden measurements (upper part) and silver measurements (lower part).