

Workshop on the Physics Program with High Luminosity Facilities

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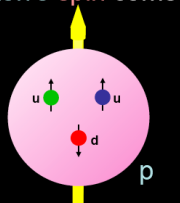
Nucleon Structure from 1D to 3D & orbital motion

Where does the proton's spin come from?

p is made of 2 u and 1 d quark
(Constituent Quark Model)

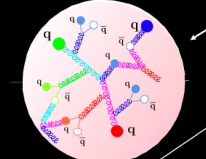
$$S = \frac{1}{2} = \sum S_q$$

Explains magnetic moment of baryon octet



QCD dynamics: Sea quarks and gluons

Check via electron scattering and find quarks carry only ~1/3 of the proton's spin!



$$\frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_q + L_g$$

Jets, pions, A_{LL}

Jaffe-Manohar sum rule
Nucl. Phys. B337, 509 (1990)

Ji sum rule
Ji, PRL 78, 610(1997)

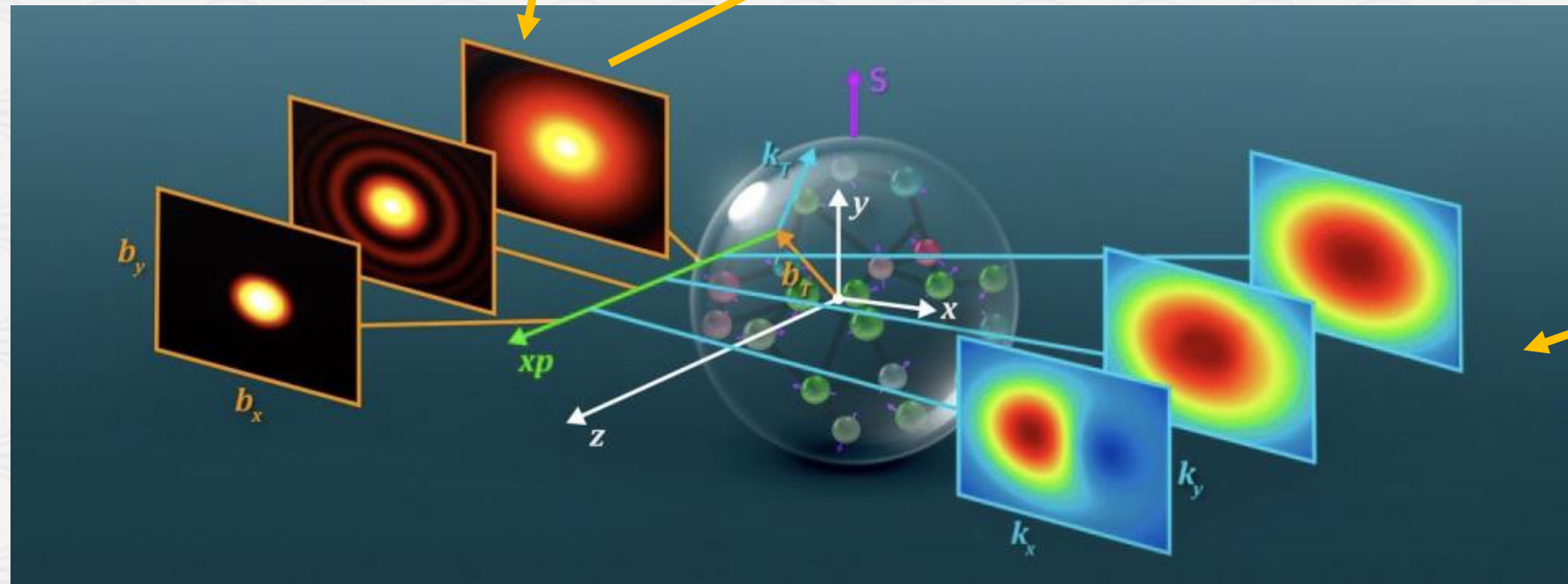
Generalized parton distribution (GPD)

$$\frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + (L_q + L_g)$$

$$\frac{1}{2} = J_q + J_g$$

$$J_q = \frac{1}{2} \int_{-1}^1 dx x [H^q(x, 0, 0) + E^q(x, 0, 0)]$$

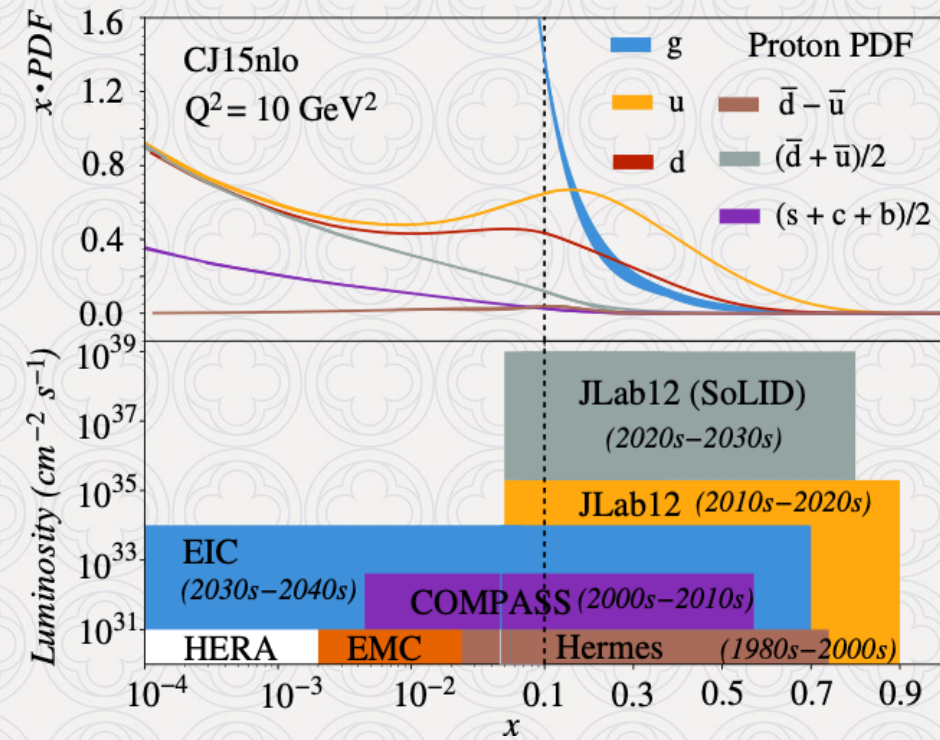
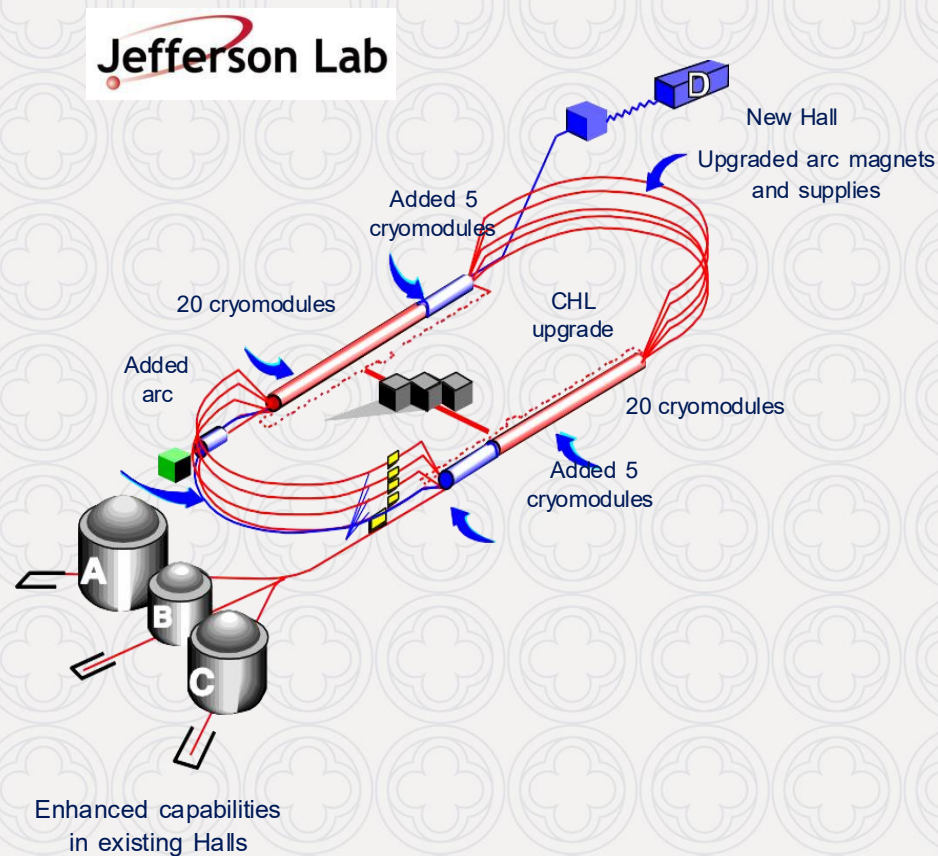
X.D. Ji, PRL91, 062001 (2003); Belitsky, Ji, Yuan, PRD69,074014 (2004)



Interplay of Energy and Intensity

Structure of visible matter probed at JLab and the future EIC

Discoveries in Physics are often enabled by high-precision measurements



Experimental Considerations

- Large acceptance, high luminosity
 - Statistical precision
 - Multi-dimensional binning
 - Help reduce some systematic uncertainties
 - L/T separation
 - Q^2 and P_T
- Polarization (transverse and longitudinal) measurements
 - pol. NH_3 target
 - pol. ^3He and ND_3 targets (pol. “n”)
- Azimuthally symmetric detection system
 - Spin dependent yields
 - Spin asymmetries
 - Unpolarized cross sections & multiplicities
- Crucial to have kinematic coverage of both valence and sea quark regions
- State-of-the-art higher-order QED effects included at event generator level
- AI adoption to speed up analysis timeline

Experimental Prospects

- 12-GeV CEBAF (valence-quark dominant region)
 - Hall A
 - SBS (SIDIS pol. ^3He)
 - SoLID-Lite (SIDIS pol. ^3He & NH_3)
 - Complementarity in kinematics
 - Hall B (CLAS 12& CLAS12+, SIDIS (L/T Pol. Targets), VM production)
 - Hall C (SIDIS L/T separation)
- COMPASS & AMBER (SIDIS & Drell-Yan)
- Fragmentation Functions from BELLE and BELLE-II
- Future EIC, first 5-year science (SIDIS and jet substructure)
- Other facilities and experiments

Theoretical Advances

- Lattice QCD
 - Statistical and systematic uncertainties
 - Comparison with extracted TMDs from experiments
 - Benchmark quantity: tensor charge
- Global analyses
 - JLab 12-GeV SIDIS data from all halls (“event based” phenomenology)
 - JLab 12-GeV, HERMES, COMPASS, BELLE-II, EIC, and others
 - How to validate and refine by experimental inputs?
- Factorization and universality*
- SIDIS L/T Separation
- Collinear structure, fragmentation, and the limits of reconstruction
- QED Radiative Effects
 - Traditional approach
 - Factorized approach
 - Further development (hybrid approach)

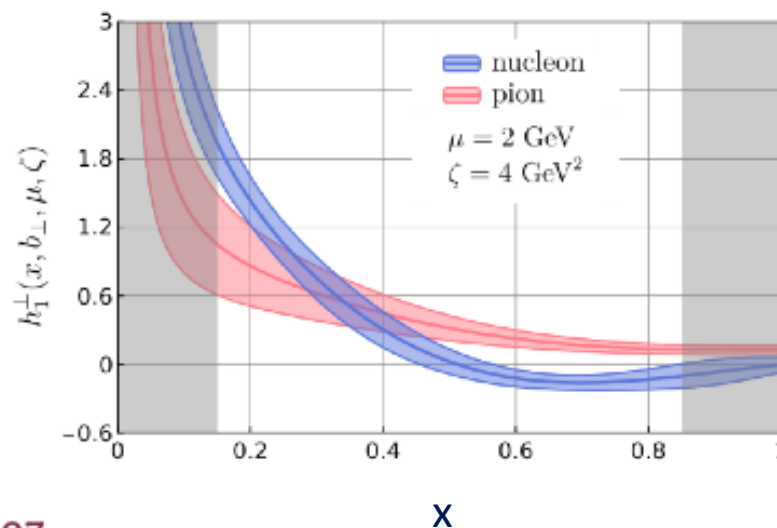
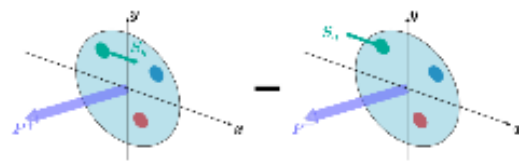
The Boer-Mulders function

§ Boer-Mulders $h_1^\perp(\mathbf{x}, b_\perp)$: a time-reversal-odd TMD

- Correlates quark transverse polarization with transverse momentum
- In an unpolarized hadron — it needs the staple link to be non-zero

§ Computed for both the pion and the nucleon

- 2+1f clover fermion, $a=0.098$ fm, 338-MeV pion mass
- NLO matching with RGR; boosted momenta up to 2.11 GeV $b_{\text{perp}}=0.196$ fm



LPC, 2502.11807

Plan for the whitepaper contribution

- Key science message
- High-lumi and large-acceptance lead to precision
- Impact driven by precision and theory-experiment collaboration
- It will be organized based on the key points presented before