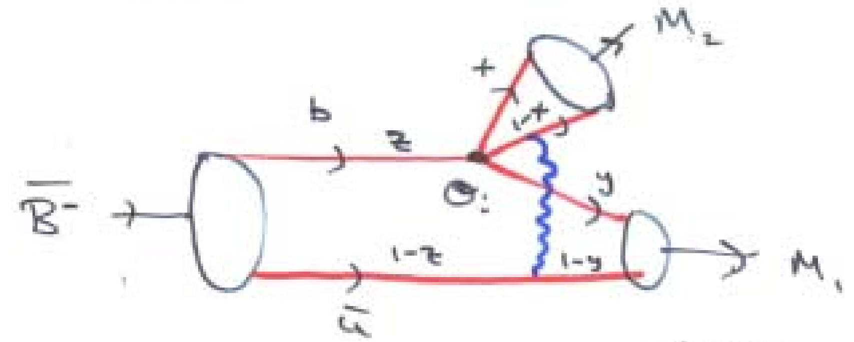
New Analyses of $B \to MM$ in PQCD

BBNS : Beneke, Buchalla, Neubert, Sachrajda

KLS : Keum, Li, Sanda



"octet" non-factorizable

$\alpha_s(k^2)$: BLM scale

* $\mathcal{M}_{B \to M_1 M_2} = \int_0^1 dz \int_0^1 dx \int_0^1 dy$

$$\phi_B(z,Q)\; T_H(z,x,y;Q)\; \phi_{M_2}(x,Q)\; \phi_{M_1}(y,Q)$$

$b\bar{u} \to q\bar{q}\, q\bar{q}$

* No end-point singularities
* Color Transparency
* $Q^2 = O(M_B^2)$: Factorization scale

$$H_{LC}|\Psi\rangle = \mathcal{M}^2|\Psi\rangle$$

$$\langle m|H_{LC}|n\rangle\langle n|\Psi\rangle = \mathcal{M}^2\langle m|\Psi\rangle$$

Discretized Light-Cone Quantization

general solutions obtained: mass spectrum, wavefunctions

* QCD(1+1), QED(1+1) — Eller, Hornbostel, Pauli, SJB
* QCD(1+1) adjoint matter — Klebanov, Dalley, Antonuccio ...
* QED(3+1) — Kalloniatis, Pauli; Krautgärtner, Wölz; van de Sande; Martinovic

Given $\Psi_n(x_i, \vec{k}_{\perp i}, \lambda_i)$, compute

* Form Factors
* Structure Functions, helicity structure
* Decay constants
* Exclusive Amplitudes
* High $\vec{k}_\perp$, $x \to 1$ from PQCD

$\boxed{\text{Can } \psi_H(x, k_\perp), \ \phi_H(x, Q) \text{ be computed in QCD?}}$

- Lattice gauge theory — Sachrajda et al

  moments of pion, nucleon, dist. ampl.

- Dyson-Schwinger, Bethe-Salpeter — Gross, et al

  $$\int \psi_{BS}(k, p)\, dk^- \Rightarrow \psi_{q\bar{q}}(x, k_\perp, \lambda)$$

  ANL C. Roberts, et al

- Discretized Light-Cone Quantization

  1+1

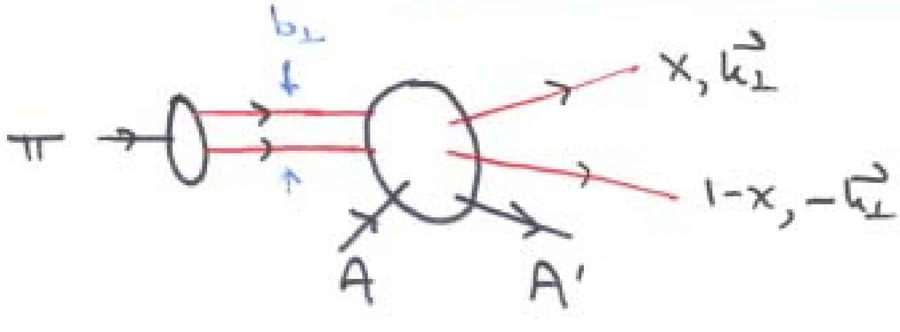
  3+1

  Pauli, S&B et al, Hiller McCartor

- Transverse Lattice + DLCQ — Burkardt, Seal; Bardeen, Rabinovici

- QCD Sum Rules, Diquark Model — Dalley et al

Test of Color Transparency and Measurement of $\psi_\pi(x, k_\perp)$



* "Nuclear Filter"

  Small color-singlet components pass

  large components absorbed — A. Mueller, SJB

* Diffractive production of di-jets

  nucleus left <u>intact</u>

* Jet distributions measure — G. Bertsch, J. Gunion, SJB, F. Goldhaber

  $$\psi_\pi(x, \vec{k}_\perp)$$

  Frankfurt, Miller, Strikman

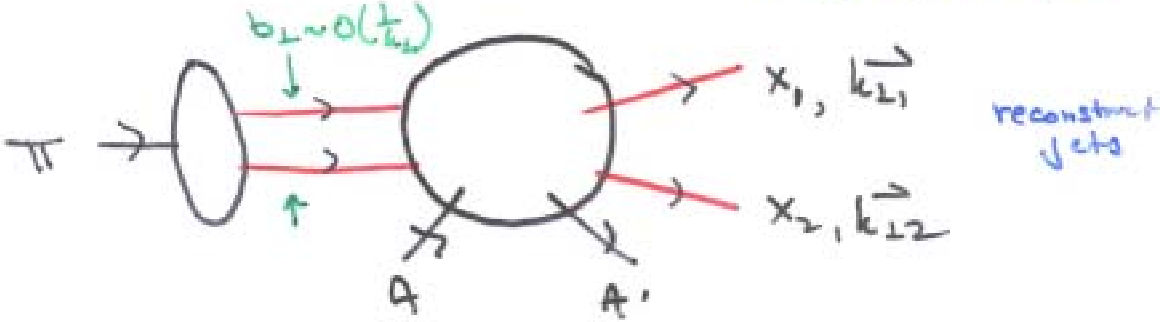
* E791 Fermilab — D. Ashery, R. Weiss-Babai et al

$$\boxed{\text{Measure } \psi_H^{val}(x, k_\perp) \text{ via Diffractive Dissociation}}$$

$$\boxed{\pi A \to q\bar{q} A'}$$

Bertsch, Goldhaber, Gunion, S J B

Frankfurt, Miller, Strikman



$$x_1 + x_2 \cong 1$$

$$\vec{q}_\perp = -\vec{k}_{\perp 1} - \vec{k}_{\perp 2} < R_A^{-1}$$

$\vec{k}_\perp$ large: color transparency $M_A \sim A^1 M_N$

$q_\perp$ small $\quad \frac{d\sigma}{dq_\perp^2} \propto e^{-q_\perp^2 R_A^2/3}$

* $$\int \frac{d\sigma}{dq_\perp^2} dq_\perp^2 \sim \frac{A^2}{R_A^2} \sim A^{4/3}$$

* x, $\vec{k}_\perp$ dist $\Rightarrow \left| \frac{\partial}{\partial k_\perp^2} \psi(x, k_\perp^2) \right|^2$

$\boxed{\text{Hidden Color in Deuteron}}$

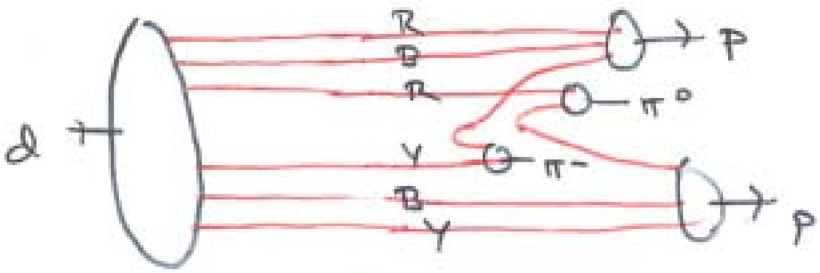
① Dominates at $Q \to \infty$, $b_\perp^i \to 0$ — Lepage Ji SJB

② Probably changes normalization

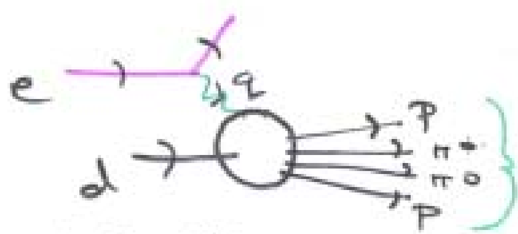
of TH by large factor — Farrar Zhang

③ $\Psi_{HC} \Rightarrow$ multihadron state ?

Diffractive dissociation $d \to pp\pi\pi$ — Hoyer Diehl SJB



Miller SJB



look for dominant final state

low mass system

$p^{\pm} = p^0 \pm p^z$

Light-Cone Quantization of QCD

(Dirac: Front Form)

Quantize at fixed $\tau = t + z/c$, $A^+ = 0$ lcg

$P^- = i \frac{\partial}{\partial \tau}$; $P^+, \vec{P}_\perp$ kinematical

$\mathcal{L}_{QCD} \Rightarrow H^{LC}_{QCD} = P^- P^+ - \vec{P}_\perp^2$

$$\boxed{H^{LC}_{QCD} \, |\Psi\rangle = \mathcal{M}^2 \, |\Psi\rangle}$$

eigenvalues of H^{LC}_{QCD} $\left\{ \begin{array}{l} \text{bound state} \\ \text{continuum sol'ns} \end{array} \right.$

eigenfunctions of H^{LC}_{QCD} $\left\{ \begin{array}{l} \text{wavefunctions} \\ \text{scattering states} \end{array} \right.$

* independent of $P^+, \vec{P}_\perp$!
* J_z conserved
* Minkowski space, no fermion doubling
* Direct connection to physics
* vacuum trivial (possible zero modes)

H.C. Pauli
SJB

DLCQ (3+1)

Periodic boundary conditions

$$-L < x^- < L \quad , \quad -L_\perp < x, y < L_\perp$$

$\Rightarrow$ Discrete momenta:

$$P_i^+ = \frac{\pi}{L} n_i \quad , \quad \vec{P}_{\perp i} = \frac{\pi}{L_\perp}(n_{xi}, n_{yi})$$

$$P^+ = \frac{\pi}{L} K \quad , \quad \Sigma_i n_i = K$$

$$x_i = \frac{P_i^+}{P^+} = \frac{n_i}{K} > 0$$

* Fock state number limited by K

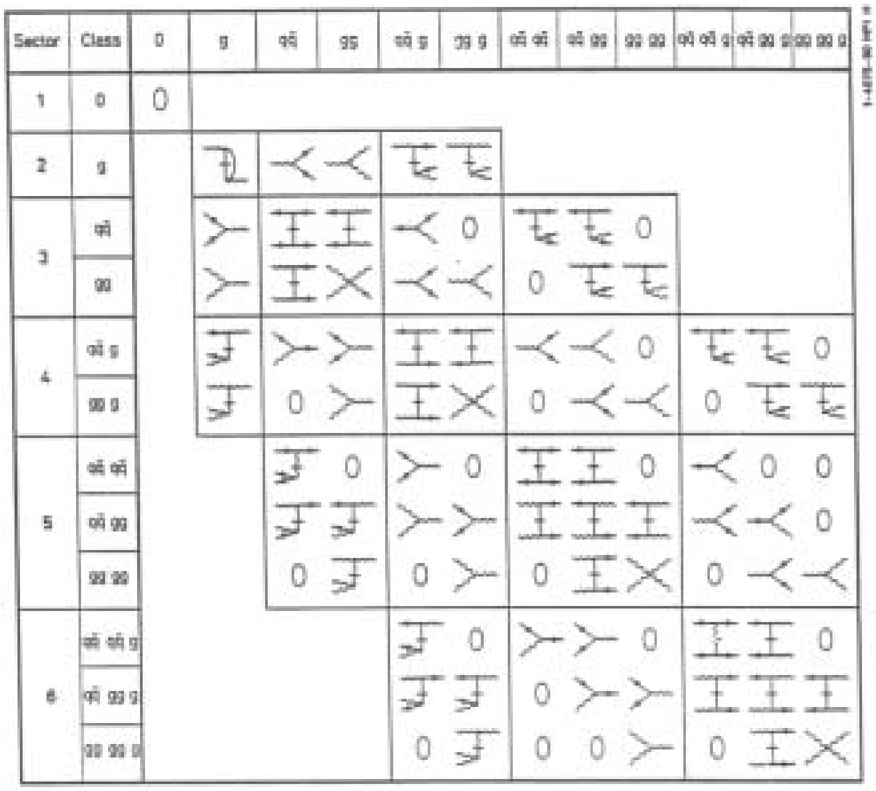
$$\sum_i \frac{m_i^2 + P_{\perp i}^2}{x_i} < \Lambda^2 \qquad \text{limits } n_x, n_y$$

* Continuum limit $K \to \infty$

Applications to Yukawa theory (3+1)

Hiller, McCartor, SJB

QCD (3+1)

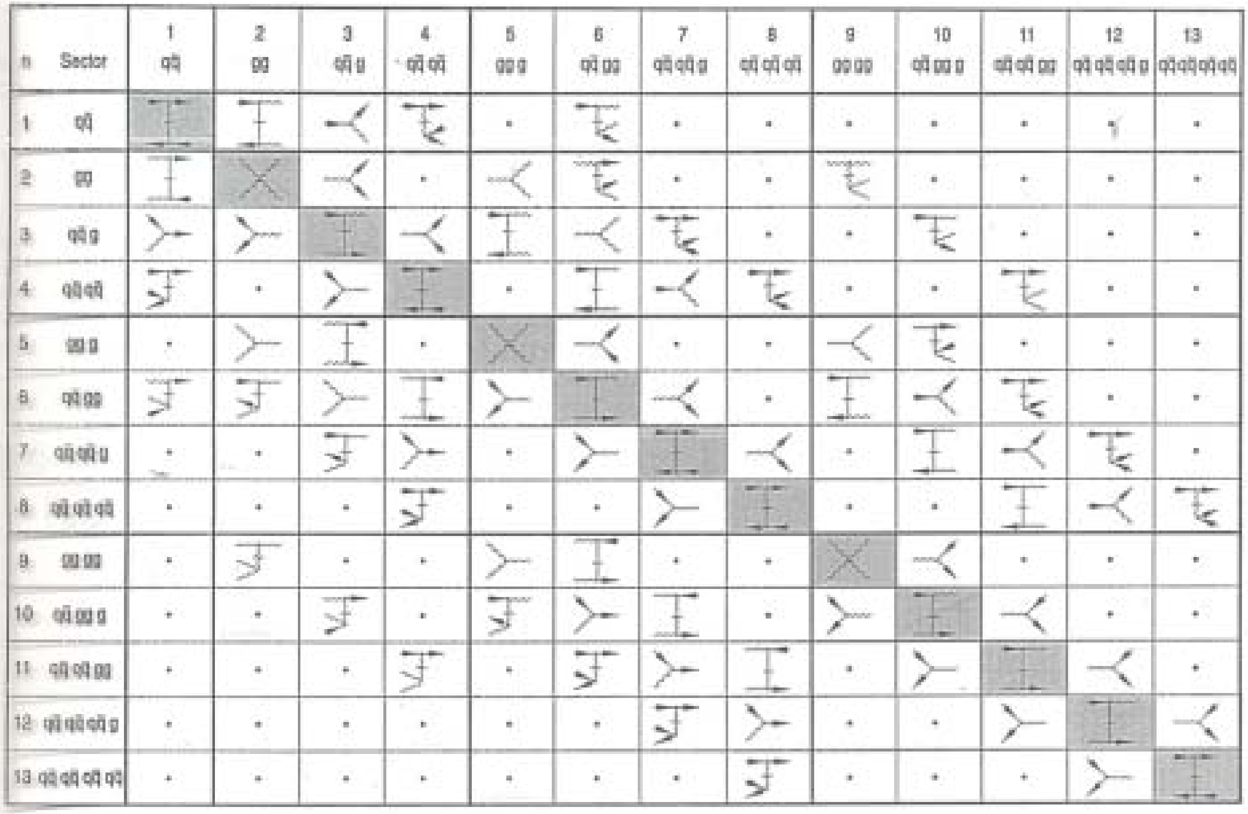


DLCQ: $\langle n | H^{I}_{LC} | m \rangle$

$$\left(M^2 - \sum_n \frac{k_\perp^2 + m^2}{x} \right) \psi_n = \sum_m \langle n | H^{I}_{LC} | m \rangle \psi_m$$

PBC: $k^+ = \frac{2\pi}{L} n$, $\vec{k}_\perp = \frac{2\pi}{L_\perp} \vec{n}_\perp$

H. C. Pauli



n Sector
1 $q\bar{q}$
2 gg
3 $q\bar{q}\,g$
4 $q\bar{q}\,q\bar{q}$
5 $gg\,g$
6 $q\bar{q}\,gg$
7 $q\bar{q}\,q\bar{q}\,g$
8 $q\bar{q}\,q\bar{q}\,q\bar{q}$
9 $gg\,gg$
10 $q\bar{q}\,gg\,g$
11 $q\bar{q}\,q\bar{q}\,gg$
12 $q\bar{q}\,q\bar{q}\,q\bar{q}\,g$
13 $q\bar{q}\,q\bar{q}\,q\bar{q}\,q\bar{q}$

J^z conservation for each LC Fock comp.

X Ji

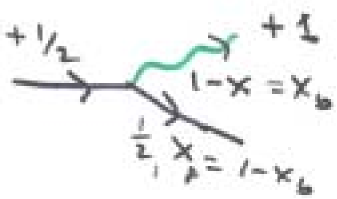
$$J^z_{(n)} = \sum_{j=1}^{n} S^z_j + \sum_{j=1}^{n-1} l^z_j$$

Hwang
Ma
Schmidt
SJB

Only $\underbrace{(n-1)}$ relative l^z_j !

$$J^z \, |\psi^\uparrow_{\lambda_f,\lambda_b}\rangle = 1/2 \, |\psi^\uparrow_{\lambda_f,\lambda_b}\rangle$$

Helicity retention at $x_b \to 1$

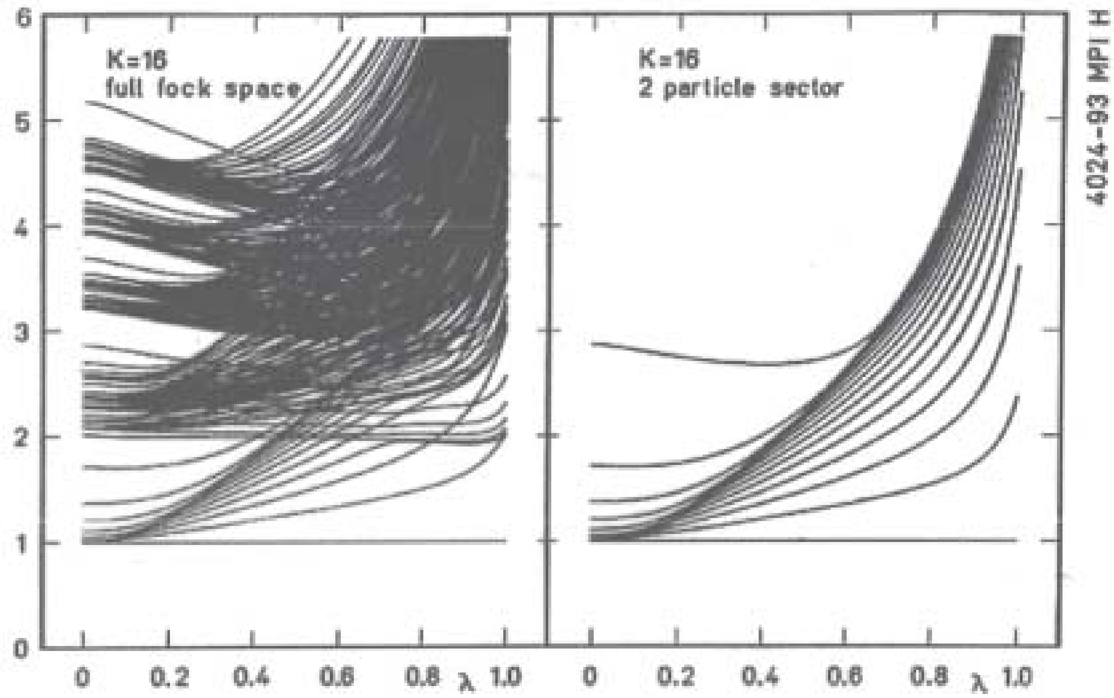


$$|\psi^\uparrow_{1/2,1}|^2 \sim \frac{1}{(1-x_b)^2}\varphi^2$$

SJB + GPL

Burkardt, Schmidt
SJB

QED (1+1)



Eller
Pauli
QB

Some advantages of Light-Front-Quantized QCD

* No Fermion doubling
* Multiple fermion flavors
* Minkowski space
* Gauge-Fixed : Physical Degrees of Freedom
* Manifest Frame-Independence : P^+, $\vec{P}_\perp$ arbitrary
  J_z kinematical
* LF. Vacuum Trivial — Zero modes
* Vanishing anomalous gravitomagnetic moment
  $$B(0) \equiv 0 \; ; \; \lim_{MR \to 0} \mu_A = 0$$
* DLCQ discretization retains symmetries
  continuum limit : $K \to \infty$
* LF Wavefunctions, continuum solns., amplitudes, phases as well as spectra
* Solns for QCD(1+1), SUSY(1+1)
  QCD(3+1) : Challenging!

Advances in Light-Cone Quantization

* Progress in DLCQ — Pauli + SJB

  - 3+1 Yukawa Theory
  - Pauli-Villars Reg.
  - Chiral Properties

  Hiller, McCartor, SJB

* U.V. Regularization, DLCQ for Gauge Theory — Prokhvatilov, Franke et al, Paston

* SDLCQ ! — Pinsky, Trittmann, Hiller

* LC gauge prescriptions — Bassetto, Vian

  - Renormalization in lcq — Thorn, Srivastava + SJB, Nakawaki

* Spontaneous Symmetry Breaking ϕ^4 in 3+1 — Grange, Werner

Pirner

  - add zero mode to DLCQ?

  - Zero Modes and θ, Bosonization — Przeszowski, McCartor, Shifman, Martinovic

Recent Progress : DLCQ (3+1)

J. Hiller
G. McCartor
SJB

$$H_I^{LC} = g \bar{\Psi} \phi \Psi$$

Yukawa theory:

bound state 1 fermion
+ unlimited # bosons

- UV regularization 3 Pauli-Villars scalars

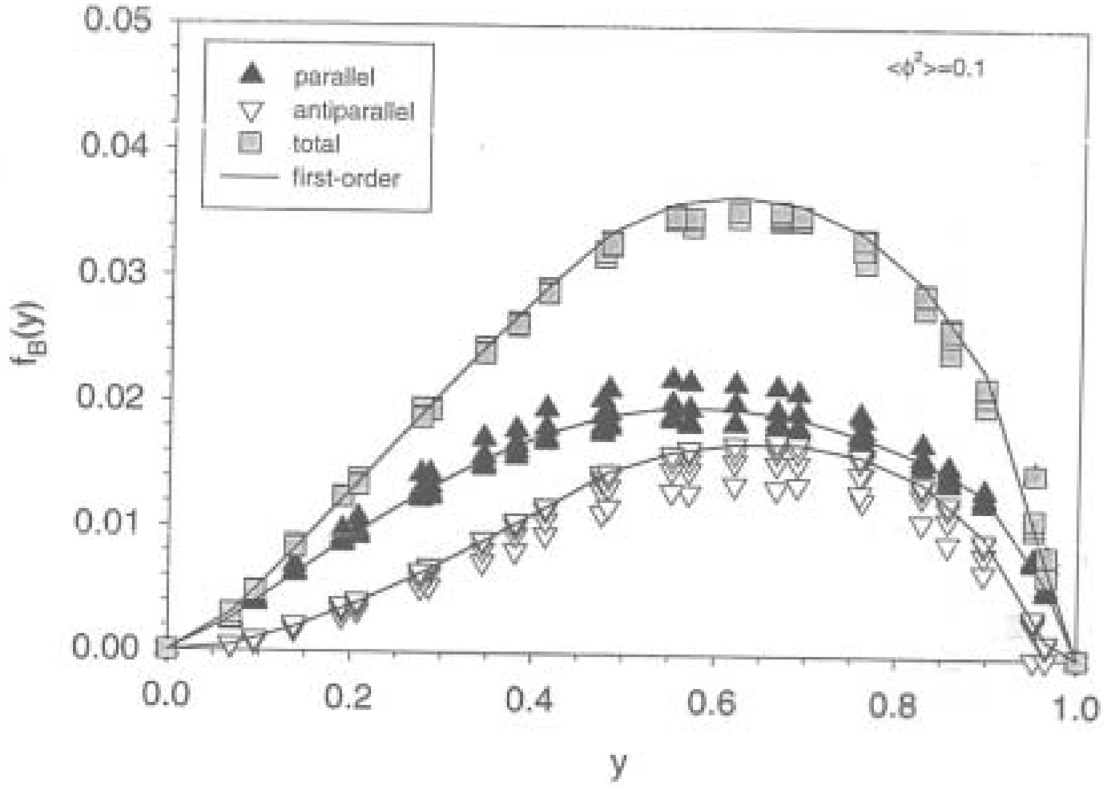
- Reproduces chiral properties of PT.

- Diagonalize H^{LC}

$$\Rightarrow \quad \Psi_n (x_i, \vec{k}_{\perp i}, \lambda_i) \qquad 3+2$$

Multiparton distributions
Form factors
distributions in $x_i, \vec{k}_{\perp i}$

QCD : P.V regularization or SUSY



parallel
antiparallel
total
first-order
<ϕ²>=0.1
0.05
0.04
0.03
0.02
0.01
0.00
f_B(y)
0.0
0.2
0.4
0.6
0.8
1.0
y

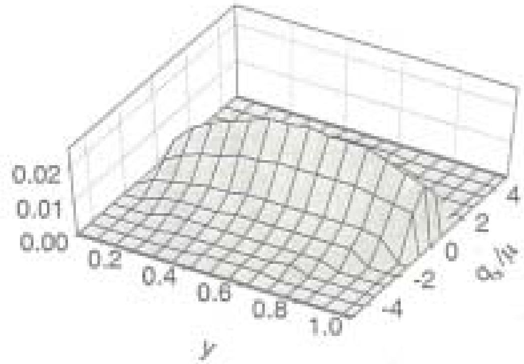


FIG. 13. The parallel-helicity, one-boson amplitude $\phi_{\sigma\sigma}^{(1,0,0,0)}$ as a function of longitudinal momentum fraction y and one transverse momentum component q_x in the $q_y = 0$ plane. The parameter values are $K = 29$, $N_\perp = 7$, $M = \mu$, $\Lambda^2 = 50\mu^2$, $\mu_1^2 = 10\mu^2$, $\mu_2^2 = 20\mu^2$, $\mu_3^2 = 30\mu^2$, and $\langle :\phi^2(0): \rangle = 0.25$.

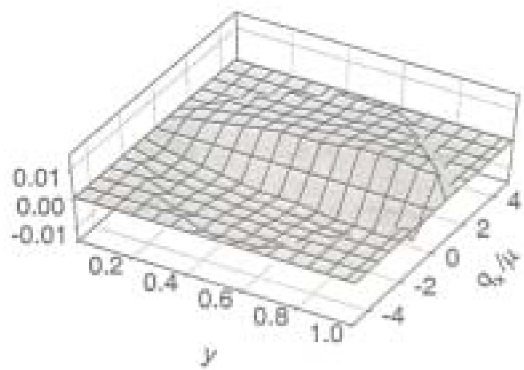


FIG. 14. Same as Fig. 13 but for antiparallel bare helicity.

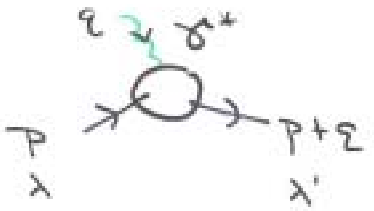
I have them
3+1
DLCQ

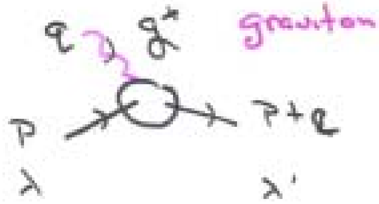
Hiller
McCartor
SD3

DLCQ (3+1)

* Model shows good convergence
* Reliable calculation of
  - structure functions, matrix elements, distribution amplitudes, etc.
* PV regularization renders theory finite
  ⇒ broken SUSY regularization
* Encouraging for QCD (3+1)
  - Feynman + gauge formulation of the Doubly Transverse LCG P. Srivastava, SJB
  - Chiral properties?
  - Heavy Quarkonium application color octet component

Electromagnetic and Gravitational Form Factors





$$\langle p+q \uparrow | \frac{J^+(0)}{2p^+} | p \uparrow \rangle = F_1(q^2)$$

electromagnetic

$$\langle p+q \uparrow | \frac{J^+(0)}{2p^+} | p \downarrow \rangle = -(q_1 - iq_2) \frac{F_2(q^2)}{2M}$$

$$\langle p+q \uparrow | \frac{T^{++}(0)}{2p^{+2}} | p \uparrow \rangle = A(q^2)$$

gravity

$$\langle p+q \uparrow | \frac{T^{++}(0)}{2p^{+2}} | p \downarrow \rangle = -(q_1 - iq_2) \frac{B(q^2)}{2M}$$

* Choose $q = (q^+, q^-, \vec{q}_\perp) = \left(0, \frac{2p\cdot q}{p^+}, \vec{q}_\perp\right)$

$p = (p^+, p^-, \vec{p}_\perp) = \left(p^+, \frac{M^2}{p^+}, \vec{0}_\perp\right)$

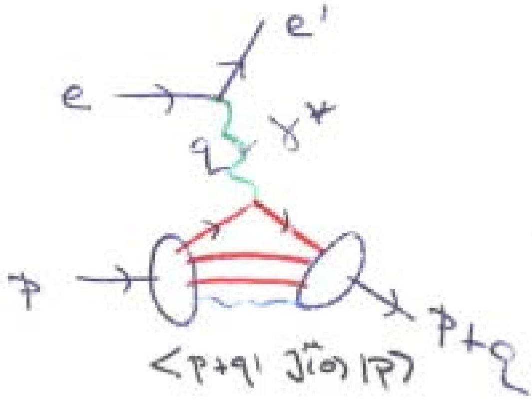
$2p\cdot q = -q^2 = Q^2 = \vec{q}_\perp^{\,2}$

diagonal $n = n'$ only!

Lepton-Proton Elastic Scattering

Sensitive to proton structure

at the amplitude level



$$q^2 = -Q^2 = t$$

$$p'^2 = (p+q)^2 = M^2$$

$$\mathcal{M}(ep \to ep) = \mathcal{M}_{pT} \cdot F_p(Q^2)$$

prob ampl. to stay intact

$$F_p(Q^2) = \sum_n \int \Pi\, d^2k_\perp\, dx\, \psi_n^\dagger(x, \vec{k}_\perp)\, \psi_n(x, \vec{k}'_\perp)$$

← sum over all n≥3

Drell-Yan West

$$\vec{k}'_\perp = \begin{cases} \vec{k}_\perp + (1-x)\vec{q}_\perp & \text{struck} \\ \vec{k}_\perp - x\,\vec{q}_\perp & \text{spects} \end{cases}$$

$$q_\perp^2 = Q^2 = -q^2$$

Exact Formula! All helicities

timelike

SJB + Drell

D-S. Hwang SJB