GENERALIZED PARTON DISTRIBUTIONS:

POSSIBILITIES WITH

COMPASS

M. DIEHL, DESY

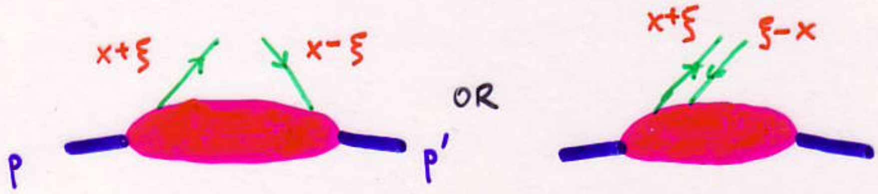
- BRIEF REMINDER : ESSENTIALS
- PHYSICS TO AIM AT
- KEY PROCESSES + OBSERVABLES
- SUMMARY

WHAT ARE GPDs ?

FOURIER TRANSFORMED HADRONIC MATRIX ELEMENTS

$z^{\pm} = (z^0 \pm z^3)/\sqrt{2}$

$$\int dz^- \, e^{i x z^- (p+p')^+} \langle p', s' | \, \bar{\psi}(-z) \, \dots \, \psi(z) \, | p, s \rangle_{z^+=0}$$



PARAMETERIZE BY FUNCTIONS $H, E, \tilde{H}, \tilde{E}, \dots$ OF x, ξ, t

FOR DIFFERENT HADRON AND PARTON SPINS

$= (p-p')^2$

- $H, \tilde{H}$ CONSERVE HADRON SPIN

  $\rightarrow q, \Delta q$ IN FORWARD LIMIT $\xi = 0, t = 0$

  $E, \tilde{E}$ CAN FLIP HADRON SPIN

  NOT SEEN IN FORWARD LIMIT $\rightarrow$ VERY UNKNOWN

- MOMENTS IN x $\rightarrow$ FORM FACTORS

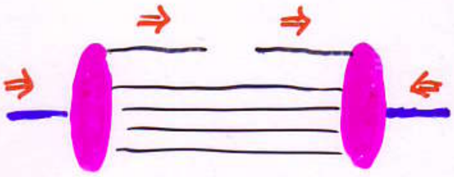
  $$\int dx \; H(x, \xi, t) = F_1(t)$$

  $$\int dx \; E(x, \xi, t) = F_2(t)$$

  KNOWN

  HIGHER MOMENTS $\int dx \, x^n \, H, \dots$ UNKNOWN

ORBITAL ANGULAR MOMENTUM AND



$E(x, \xi, t)$

REQUIRES O.A.M.

$\psi_L \quad \psi^*_{L'} \qquad L - L' = 1$

MOMENTS

FROM $\sum_q e_q \int dx \, (H^q + E^q) = F_1 + F_2$

$$e_q \int_{-1}^{1} dx \;\; E^q(x,0,0) = \mu^q - e_q \int_0^1 dx \, [\, q(x) - \bar{q}(x) \,]$$

" $q - \bar{q}$ " ; μ^2 INDEPENDENT

$$\frac{1}{2} \int_{-1}^{1} dx \;\; x \, E^q(x,0,0) = J^q - \frac{1}{2} \int_0^1 dx \;\; x \, [\, q(x) + \bar{q}(x) \,]$$

" $q + \bar{q}$ " DEPENDS ON μ^2

GLUONS :

$$\frac{1}{2} \int_0^1 dx \;\; E^g(x,0,0) = J^g - \frac{1}{2} \int_0^1 dx \;\; x \, g(x)$$

OBSERVABLES ?

(VERY ROUGHLY)

DVCS BEAM SPIN ASY $\sim F_1 H - \frac{t}{4m^2} F_2 E$

TRANSVERSE TARGET POLARISATION ASY $\sim \frac{t}{4m^2} [\, F_2 H - F_1 E \,]$

p target: $\frac{4}{9}(u+\bar{u}) + \frac{1}{9}(d+\bar{d}) + O(\alpha_s)\, g$

ρ PRODUCTION TTA $\qquad f(E/H)$

$\frac{2}{3}(u+\bar{u}) + \frac{1}{3}(d+\bar{d}) + \frac{3}{4} g$

GOEKE et al '01

HADRON STRUCTURE IN 2+1 D

$$|p^+, \vec{b}_T\rangle = \int d^2\vec{p}_T \; e^{-i\vec{p}_T \vec{b}_T} \; |p^+, \vec{p}_T\rangle$$

- PROTON STATE LOCALISED IN TRANSVERSE PLANE ("IMPACT PARAMETER")
- CAN CHOOSE p^+ LARGE (FAST MOVING PROTON) → CLEAR PARTON INTERPRETATION

THIS IS ≠

- LOCALIZATION IN 3D
  - ONLY POSSIBLE WITHIN COMPTON WAVELENGTH

    WELL-KNOWN FROM USUAL SPATIAL INTERPRETATION OF FORM FACTORS

  - PARTON INTERPRETATION NON-TRIVIAL FOR PROTON AT REST

    PROPOSED FOR GPDs BELITSKY, JI, YUAN '03

$\vec{b}$ IS CENTER OF MOMENTUM OF PROTON

$$\vec{b} = \frac{\sum_i k_i^+ \vec{b}_i}{\sum_i k_i^+}$$

LORENTZ INVARIANCE

ANALOG ↓ NON-RELATIVISTIC

C.O. MASS

$$\vec{r} = \frac{\sum_i m_i \vec{r}_i}{\sum_i m_i}$$

GALILEAN INVARIANCE

APPLY TO GPDS

BURKARDT '00
RALSTON, PIRE '01

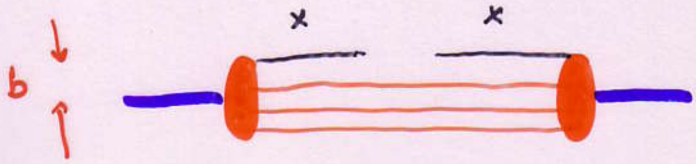
$\boxed{\xi = 0}$

$$\langle p^+, \vec{b} \,|\, \int dz^- \, e^{ix \bar{z} (p+p')^+} \; \bar{\psi}(-z) \cdots \psi(z)_{z^2=0} \, | \vec{b}, p^+ \rangle$$

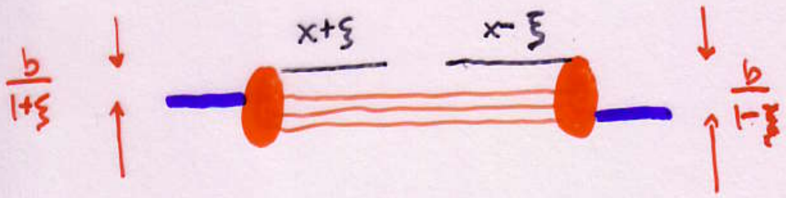
SAME OPERATOR AS BEFORE

$$\propto \quad \int d^2(\vec{p}-\vec{p}') \; e^{i(\vec{p}-\vec{p}')\vec{b}} \; H(x, \xi=0, \; t=-(\vec{p}-\vec{p}')^2)$$

- JOINT DENSITY OF PARTONS WITH MOM. FRACTION x AND TRANSVERSE POSITION $\vec{b}$

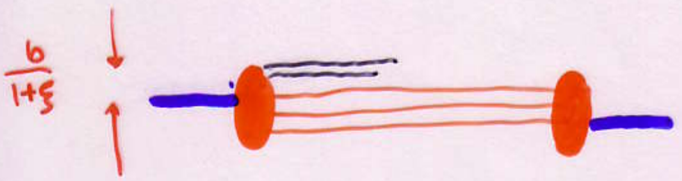


$\boxed{\xi \neq 0}$



PROTON CENTER OF MOMENTUM SHIFTS $\propto \xi \vec{b}$

M.D. '02



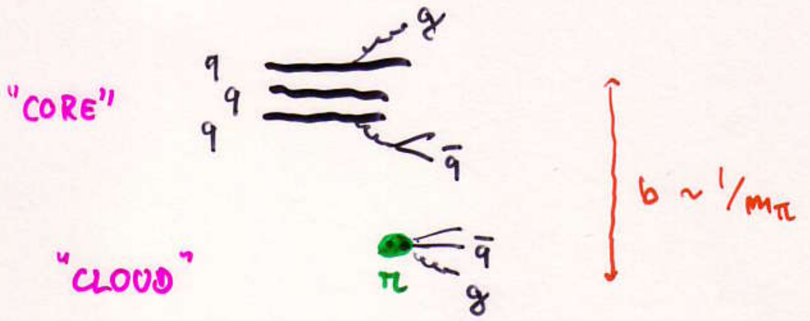
- CORRELATION OF x AND $\vec{b}$ DEPENDENCE

→ DYNAMICS

→ e.g. PARTONS AT LARGE $\vec{b}$ → π CLOUD

STRIKMAN, WEISS '03

(ARTIST'S CARTOON :)



EFFECTIVE AT

$x < m_\pi / m_N$

→ e.g. GRIBOV DIFFUSION

$$\langle b^2 \rangle = \langle b^2 \rangle_0 + 4\alpha' \log \frac{x_0}{x}$$

REGGE SLOPE

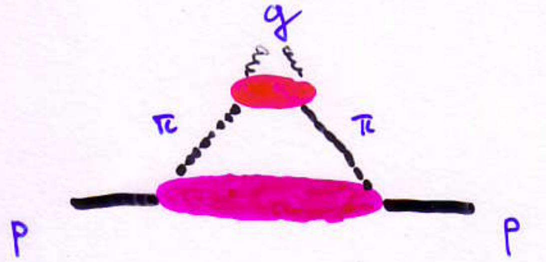
HERA DATA FOR J/ψ PRODUCTION :

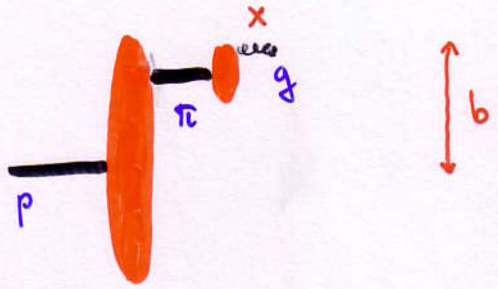
$\alpha' \sim 0.1 \quad GeV^{-2}$

a

- PION CLOUD CONTRIBUTION TO GLUON DISTRIBUTION

M. STRIKMAN, C. WEISS
hep-ph / 0308191



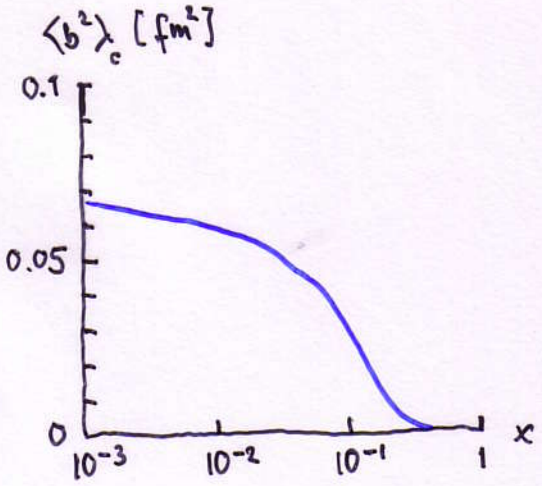


FOR $b \gg 1/m_\pi$

$x \ll m_\pi / m_N$

$$H^g(x, b) \sim \frac{1}{b} e^{-2 m_\pi b}$$

CONTRIBUTION TO AVERAGE $\langle b^2 \rangle$ OF GLUON



$$\langle b^2 \rangle = \langle b^2 \rangle_{bulk} + \langle b^2 \rangle_c$$

ESTIMATED
0.3 fm^2

- PROBE GLUON DISTRIBUTION e.g. IN

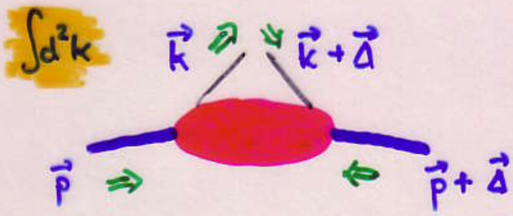
$\gamma^* p \to J/\psi \; p$

$\to \phi \; p$

TWO TYPES OF INFO ON TRANSVERSE STRUCTURE :

GPDs ($\xi = 0$ FOR SIMPLIC.)

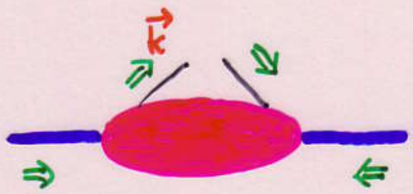
FOURIER



E

O.A.M. FROM $\vec{\Delta}$

k_T DEPENDENT PDFs



SIVERS FCT.

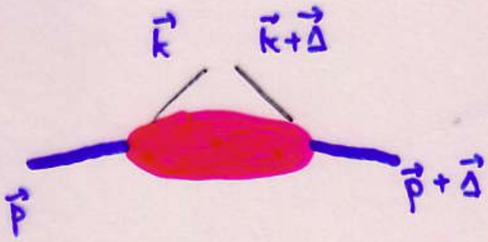
O.A.M. FROM $\vec{k}$

- RELATION FOUND IN SIMPLE MODEL

BURKARDT, HWANG '03

TASK FOR THEORY : UNDERSTAND RELATIONSHIP

k_T DEPENDENT GPDs



$$f(x, \vec{\Delta}, \vec{k})$$

$\downarrow$ FOURIER

$$\tilde{f}(x, \vec{b}, \vec{k})$$

WIGNER FUNCTIONS

BELITSKY, JI, YUAN '03

UNDERSTANDING THE SHAPE AND SIZE OF GPDs

LATTICE QCD

MOMENTS IN x

- SPIN-FLAVOR STRUCTURE
- t - DEPENDENCE

THEORET. CONSIDERATIONS

- SYMMETRIES

  e.g. DOUBLE DISTRIBUT'S

  or WAVE FUNCTION REPRESENTATION

- LIMITS

  e.g. CHIRAL DYNAMICS

  or LARGE N_c

MODELS

GPDs

LONGITUDINAL : REGION $|x| > \xi$ $\quad |x| = \xi$ $\quad |x| < \xi$

HELP FROM LIMIT $\xi = 0$ $\quad >>$ LESS AND LESS KNOWN

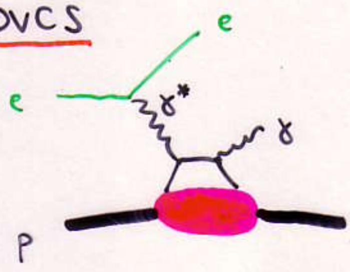
TRANSVERSE $\quad t$ DEPEND'CE AND INTERPLAY WITH x, ξ

DATA

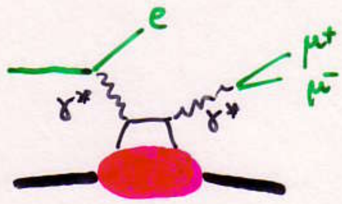
HOW TO MEASURE GPDs ?

NEED EXCLUSIVE SCATTERING PROCESSES WITH A HARD PROBE

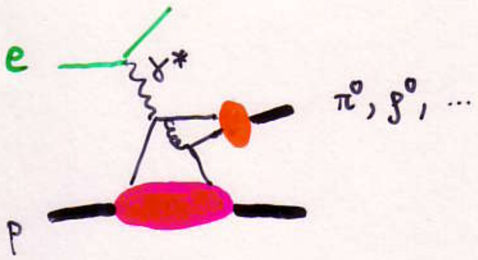
DVCS



DOUBLE DVCS



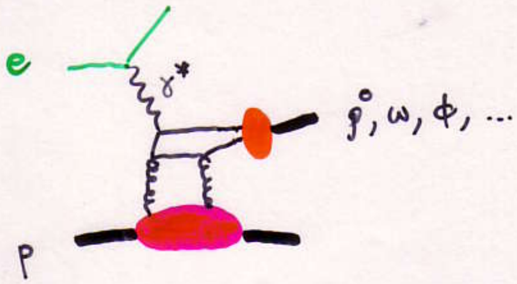
MESON PRODUCTION



ALSO CHARGE EXCHANGE

$\gamma^* p \to \pi^+ n$

$\gamma^* p \to K^+ \Sigma^0$



\+ MANY CHANNELS

SOME WITH RATHER HIGH RATES

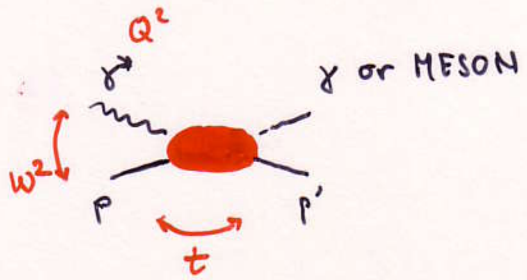
MESON QUANTUM NUMBERS "FILTER" DIFFERENT GPDs

\- THEORETICAL DESCRIPTION MORE COMPLEX

POWER CORRECTIONS POSSIBLY LARGER

→ NEED BIGGER Q^2

KEY PROCESSES + OBSERVABLES



1) VARIABLES

FACTORIZATION THEOREMS REQUIRE

LARGE W^2, Q^2 $\gg$ $-t$, Λ^2_{QCD}

✗ NEED SOME RANGE IF WANT FOURIER TRANSFORM

- x_B AND Q^2 — TIED TOGETHER BY EVOLUTION
  TEST SCALING $\left\{ \begin{array}{l} \text{BEHAVIOR} \\ \text{BREAKING} \end{array} \right.$

  ✗ NEED LEVER ARM

- x_B AND t — CORRELATE LONG. ⊗ TRANSV. STRUCTURE

2) GPDs → PROCESS AMPLITUDES

- AT BORN LEVEL (DVCS, MESONS)

$$\mathcal{A} \propto \underbrace{\int_{-1}^{1} dx \, \frac{1}{x-\xi} \, f(x,\xi,t)}_{\text{ALL } x} \; - i\pi \; \underbrace{f(\xi,\xi,t)}_{x=\xi}$$

$|x| \geq \xi$

- AT $\mathcal{O}(\alpha_s)$

EVOLUTION LINKS x AND Q^2 DEPENDENCE

(AS IN INCLUSIVE DIS)

$$\xi = \frac{x_B}{2-x_B}$$

IF CANNOT RECONSTRUCT x - DEPENDENCE

→ TYPICAL $x \sim \xi$

"MIX" REGIONS  AND 

UNLESS HAVE SEPARATE Im $\mathcal{A}$

→ t DEPENDENCE → TRANSVERSE STRUCTURE

FOR "TYPICAL $x \sim \xi$"

3) **DVCS** BEST THEORY CONTROL

LEADING TWIST (2) : LO , NLO KNOWN
TWIST 3 : LO , NLO IN W.W. APPROX.

- SEPARATION OF Re $\mathcal{A}$, Im $\mathcal{A}$
- MIGHT USE Q^2 DEPENDENCE TO CONSTRAIN x

COMPETITION $\sigma_{\text{BETHE-HEITLER}} \sim \frac{1}{t}$

$\sigma_{\text{COMPTON}} \sim \frac{1}{Q^2 y^2}$ $y = \frac{Q^2}{x_B S_{ep}}$

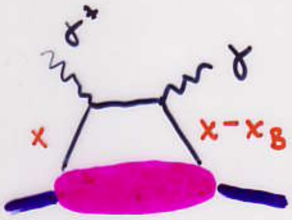
↳ COMPTON X SECTION, TARGET SPIN ASYMM'S

↳ INTERFERENCE FROM BEAM OR TARGET SSA'S
$\propto \text{Im}\, \mathcal{A}_{DVCS}$

↳ INTERFERENCE FROM e^+ VS e^- BEAM
$\propto \text{Re}\, \mathcal{A}_{DVCS}$

X NEED TO MEASURE ϕ ($\measuredangle$ LEPTON vs HADRON PLANE)

- $\left.\begin{matrix}\text{Re}\\ \text{Im}\end{matrix}\right\} \mathcal{A}_{\gamma^* p \to \gamma p}$ CARRY VERY DIFFERENT INFORM. ON GPDs :



$$\propto \int dx \frac{GPD(x, x_B, t)}{x - x_B + i\epsilon}$$

$$= ⨍ dx \frac{GPD(x, x_B, t)}{x - x_B}$$

$$- i\pi \; GPD(x_B, x_B, t)$$

- WITH μ BEAM REVERSE CHARGE + POLARIZ. SIMULTANEOULY

  - CAN STILL SEPARATE ALL TERMS SINCE STRUCTURE IS

$$e_\mu \quad \text{Re}\, \mathcal{A} \quad \cos(n\varphi)$$

$$e_\mu P_\mu \quad \text{Im}\, \mathcal{A} \quad \sin(n\varphi)$$

GENERAL STRUCTURE FOR UNPOL. TARGET , POL. BEAM :

$$d\sigma(\mu p \to \mu p \gamma) = d\sigma_{BH} + e_\mu \, d\sigma^{U}_{INT} + e_\mu P_\mu \, d\sigma^{P}_{INT}$$

$$+ \; d\sigma^{U}_{VCS} + P_\mu \, d\sigma^{P}_{VCS}$$

WITH $d\sigma_{\dots} \left\{ \begin{matrix} \text{EVEN} \\ \text{ODD} \end{matrix} \right\}$ IN ϕ

CAN ONE RELIABLY SUBTRACT $d\sigma_{BH}$ WHEN IT IS LARGE ?

MESON CHANNELS

→ HELP SEPARATE SPIN - FLAVOR STRUCTURE

N.B. FORM FACTORS CONSTRAIN (INTEGRATED OVER x)

$F_1(t)$, $F_2(t)$ $\quad q - \bar{q}$ FOR u, d

$g_A(t)$ $\quad \Delta q + \Delta\bar{q}$ $\quad u - d$

+ INFO FROM PARITY VIOLATING ELASTIC SCATT.

- VECTOR MESONS ρ^0, ω, ϕ ; J/ψ

  H, E IN COMBINATIONS $q + \bar{q}$ AND g

  SAME AS IN COMPTON SCATT.

  e.g. ρ^0 : $\frac{2}{3}(u+\bar{u}) + \frac{1}{3}(d+\bar{d}) + \frac{3}{4} g$

- u/d SEPARATION : DVCS ON p, n (*) X

  MESON CHANNELS

- ALSO K^* PRODUCTION , IF USE FLAVOR SU(3) RELATIONS

- f_2 , $\pi^+\pi^-$ IN CONTINUUM : $q - \bar{q}$

- π^0, K^0 $\quad \Delta q - \Delta\bar{q}$ $\quad \pi^+, K^+$ ALSO $\Delta q + \Delta\bar{q}$

  η, η'

X (*) MUST KNOW IF $d \to d$ OR $d \to n + p$

MORE ON MESON PRODUCTION

- $\gamma^* p \to \underbrace{\pi^+\pi^-}_{} p$

  OFF THE ρ PEAK

  CAN HAVE QUANTUM NUMBERS OF ρ $C=-1$

  OR f_0, f_2 $=+1$

$\pi^+\pi^-$ ANGULAR DISTRIBUTION $\to$ INTERFERENCE

e.g.

$$\frac{\int d(\cos\theta)\, \cos\theta \, \frac{d\sigma}{d\cos\theta}}{\int d(\cos\theta)\, \frac{d\sigma}{d\cos\theta}} = \langle \cos\theta \rangle \sim \frac{\mathrm{Im}\, A_\rho^* A_f}{|A_\rho|^2 + |A_f|^2}$$

$\to$ HERMES PRELIM.

INTEREST OF A_f

* SENSITIVE TO "$q - \bar{q}$"

$\rho, \phi, \ldots$ AND COMPTON GIVE "$q + \bar{q}$" AND g

* EXAMINE $q\bar{q}$ AND gg CONTENT OF f MESONS AT SHORT DISTANCE

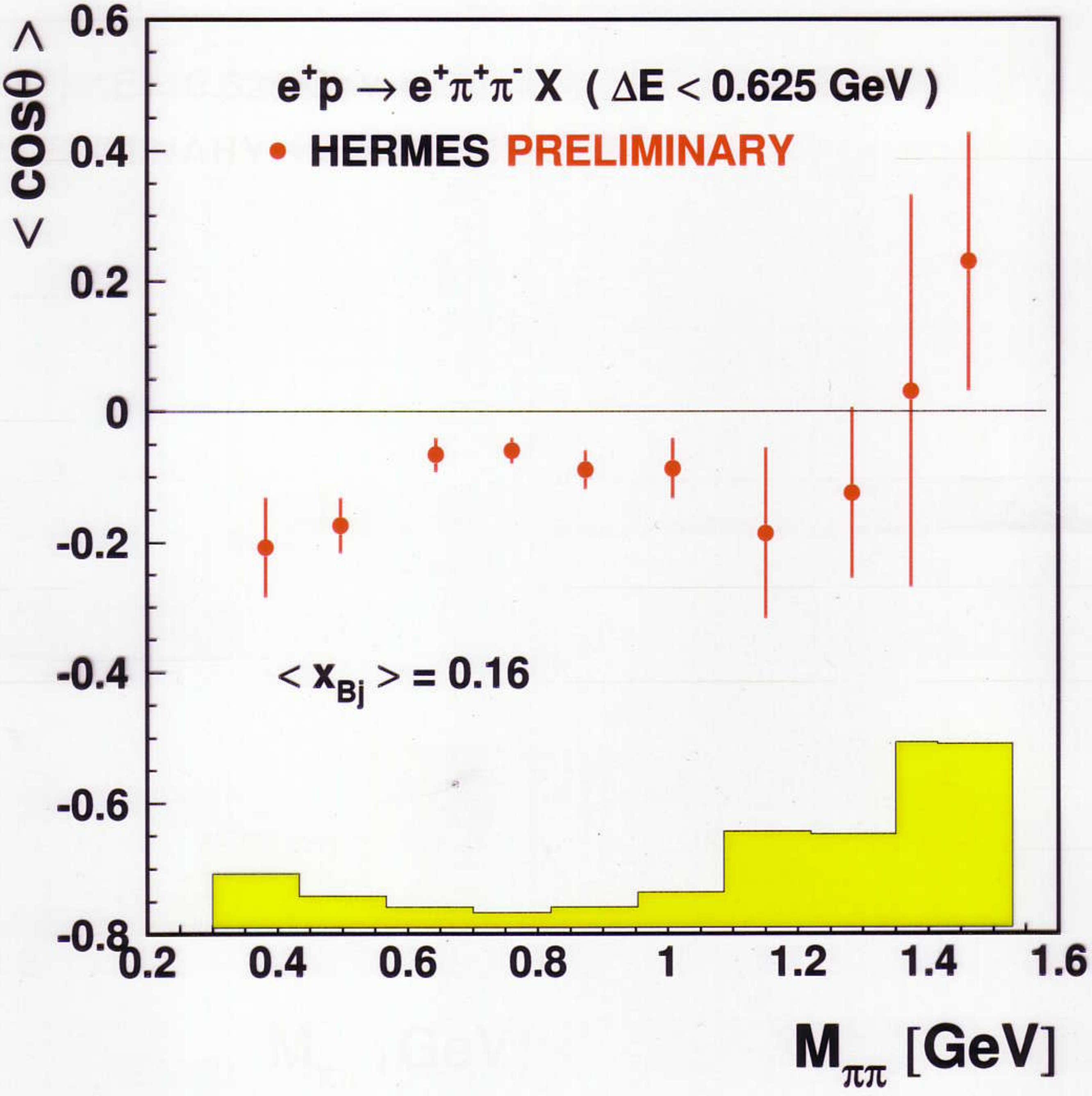
- $\gamma^* p \to \pi_1(1400)\, N$ ANIKIN et al. '04

  $\hookrightarrow \pi\eta$ CANDIDATE FOR HYBRID MESON

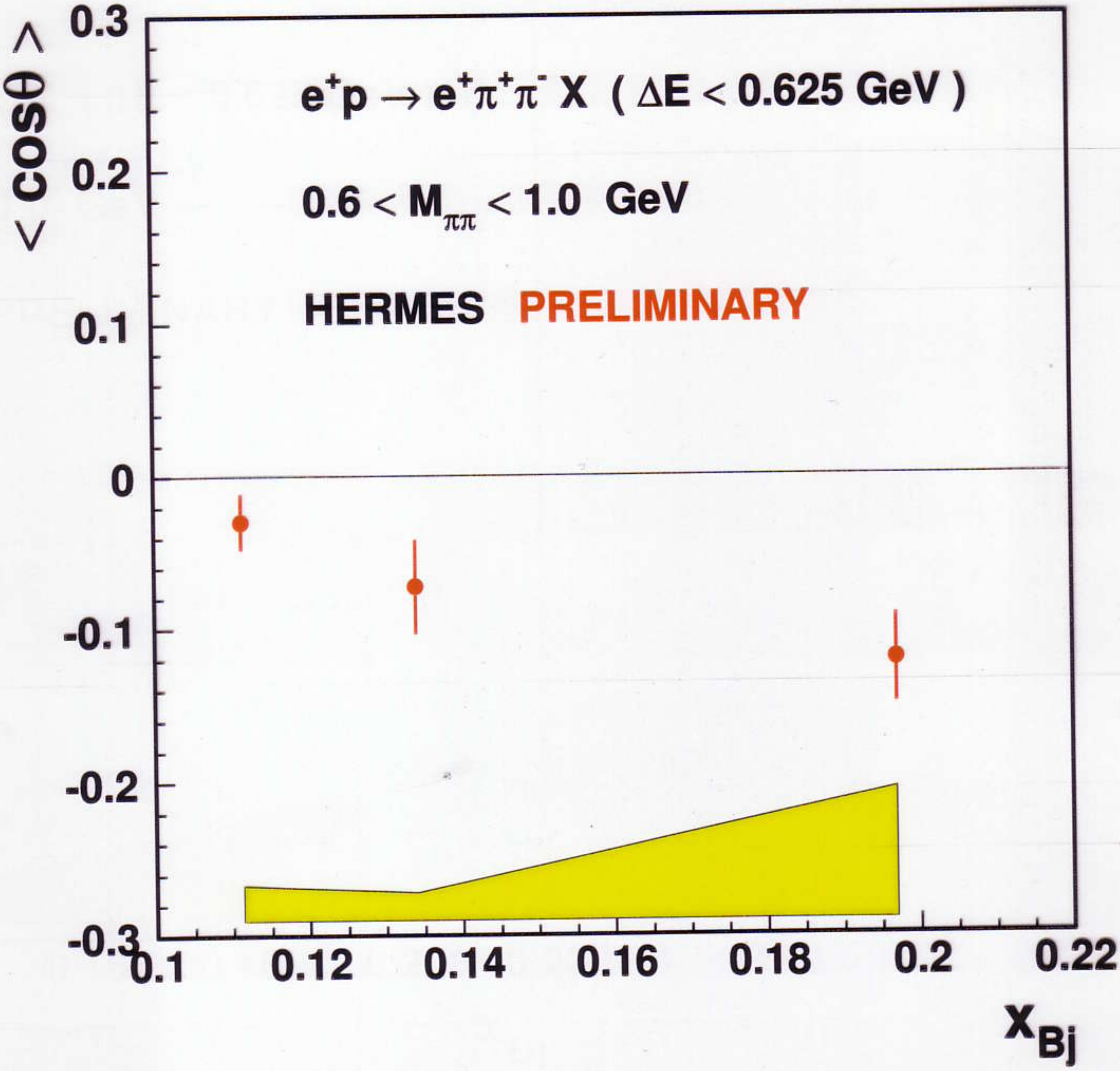
  QCD SUM RULE ESTIMATES SUGGEST :

  $q\bar{q}$ COUPLING AT SHORT DISTANCE

  NOT SO SMALL



HERMES hep-ex/0211008



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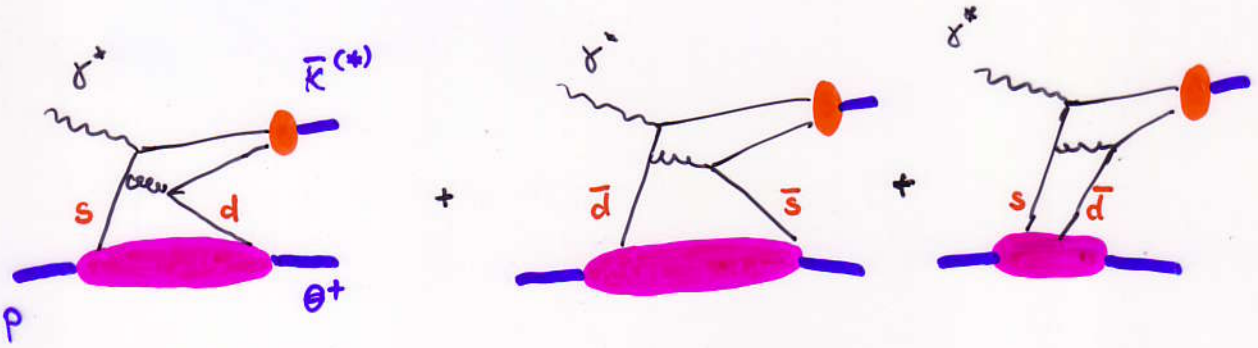
PROBING PENTAQUARKS AT SHORT DISTANCE

H.D., PIRE, SZYMANOWSKI
'03

e.g. $\gamma^* p \to \bar{K}^0 \, \Theta^+$ ($\Theta^+ \to K N$)

$\to \bar{K}^{0*} \, \Theta^+$

($\bar{K}^{0*} \to K^- \pi^+$) TAGS STRANGENESS



PROBE PARTON ARRANGEMENT IN Θ^+ RELATIVE TO NUCLEON

DVCS → DOUBLE DVCS

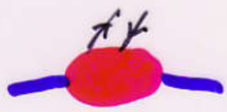
$$\int dx\, \frac{H(x,\xi,t)}{x-\xi+i\epsilon} = \ldots - i\pi\, H(\xi,\xi,t)$$

$$\int dx\, \frac{H(x,\xi,t)}{x-\rho+i\epsilon} = \ldots - i\pi\, H(\rho,\xi,t)$$

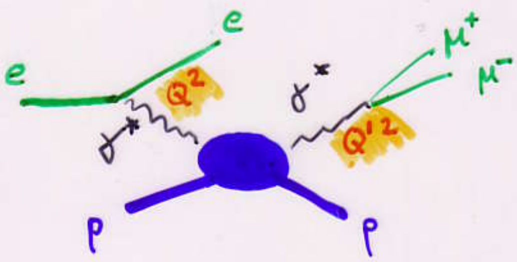
NEED EITHER Q^2 OR Q'^2 LARGE

$$\xi = \frac{Q^2+Q'^2}{2P.q} \qquad \rho = \frac{Q^2-Q'^2}{2P.q}$$

→ SCAN GPDs IN REGION

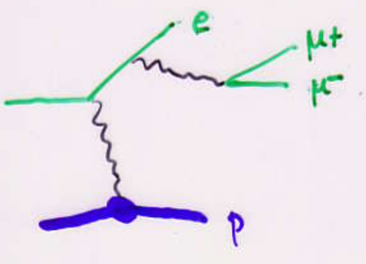


$\sim \frac{1}{Q'^2}\, \frac{1}{Q^2 y^2}$

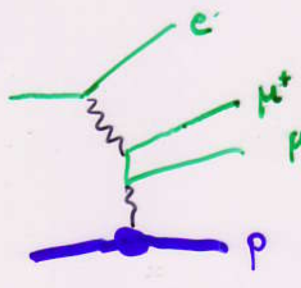


GUIDAL, VANDERHAEGHEN '02
BELITSKY, MÜLLER '02
+ KIRCHNER '03

- 2 TYPES OF BETHE-HEITLER



$\sim \frac{1}{Q'^2}\, \frac{1}{t}$



$\sim \frac{1}{Q^2 y^2}\, \frac{1}{t}$

ALWAYS BIG IF Q'^2 LARGE

$\mu^+\mu^-$ ANGULAR DISTRIBUTION
→ INTERFERENCE TERM

BERGER, M.D., PIRE '01

SUMMARY : POSSIBILITIES FOR COMPASS

(A PERSONAL VIEW)

- PHYSICS GOALS : TRANSVERSE PROFILE OF $q, \bar{q}, g$ AS FUNCTION OF THEIR MOMENTUM FRACTION(S)

ORBITAL ANGULAR MOM: WILL REQUIRE TRANSVERSE TARGET POLARIZATION

- TRY TO COVER LARGE PART OF KINEMATICS :

Q^2 LARGE $\gg$ $-t$, hadronic scale

GOOD LEVER ARM IS VALUABLE

AT DIFFERENT x_B

- DVCS : CROSS SECTION , BEAM CHARGE AND SPIN ASYMMETRY

(OR BETTER : X SECTION DIFFERENCE)

- VARIOUS MESON CHANNELS

ACCESS TO q VALENCE, SEA, GLUONS , q FLAVOR