Nuclear and Particle Physics Conference
26-31 May, 2003, Dubrovnik, Croatia

Hard Exclusive Electroproduction of Vector Mesons and Two Pions

at hermes

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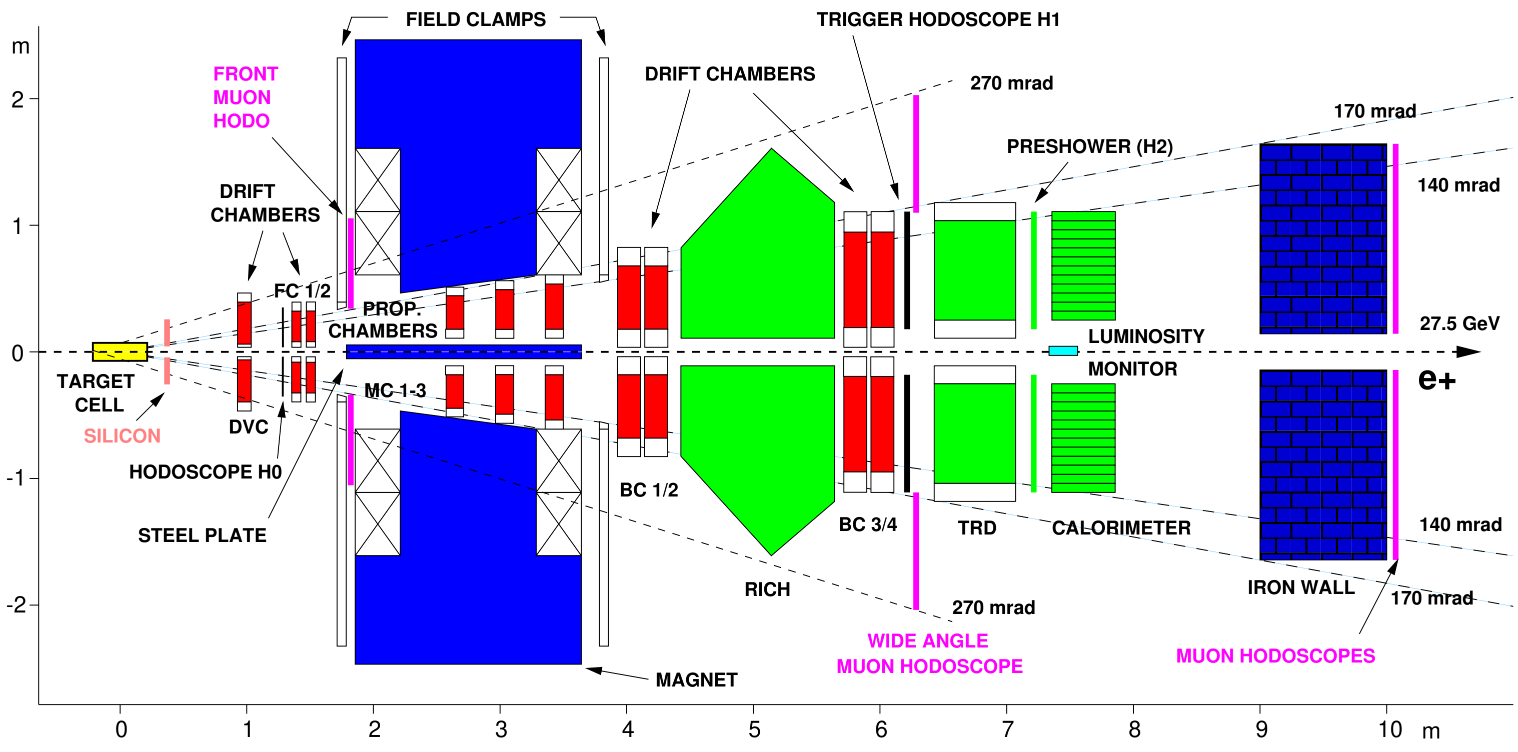
- Kinematics of exclusive reactions
- Production mechanisms of ρ^0 and ϕ
- Color transparency of ρ^0 production
- Isoscalar exchange of $\pi^+\pi^-$ electroproduction
- Summary

The Detector



- Two identical halves of forward spectrometer having acceptance $40 < \Theta < 220$ mrad with momentum resolution $\leq 1\%$

- Electron identification with efficiency $\geq 98\%$ at hadron contamination $\leq 1\%$

- Calorimeter with resolution $\Delta E/E[\%] = 1.5_{\pm 0.5} + 5.1_{\pm 1.1}/\sqrt{E[GeV]}$

- RICH from 1998 with π^{+-} vs K^{+-} and P separation over all kinematic region

The Target and Beam

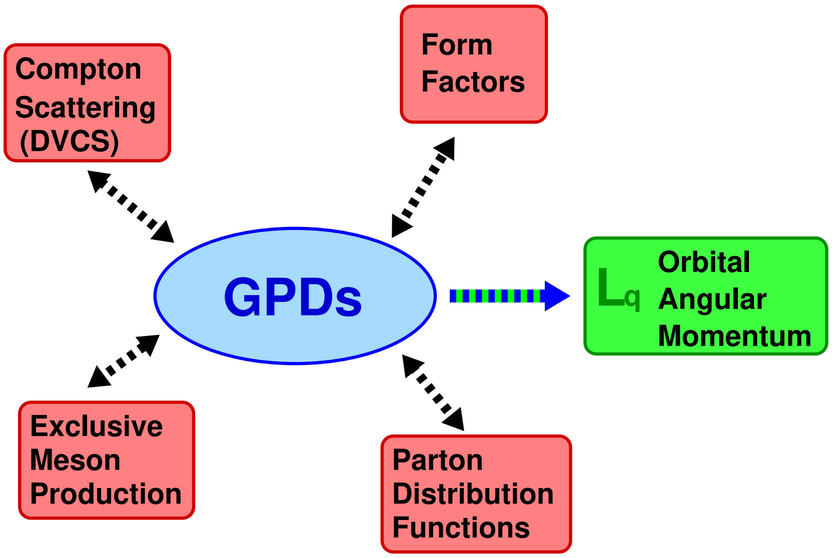
Internal storage cell gas target with high density in 1996-2000:

- polarised: $\sim 10^{14}$ nucl/cm^2, polarization: $\sim 88\%$ for H/D
- unpolarized: $\sim 10^{15}$ nucl/cm^2
- high density runs at the end of the fill in 2000 with ^{1}H, ^{2}D, ^{4}He and ^{20}Ne gases at $\sim 5 \cdot 10^{15}$ nucl/cm^2

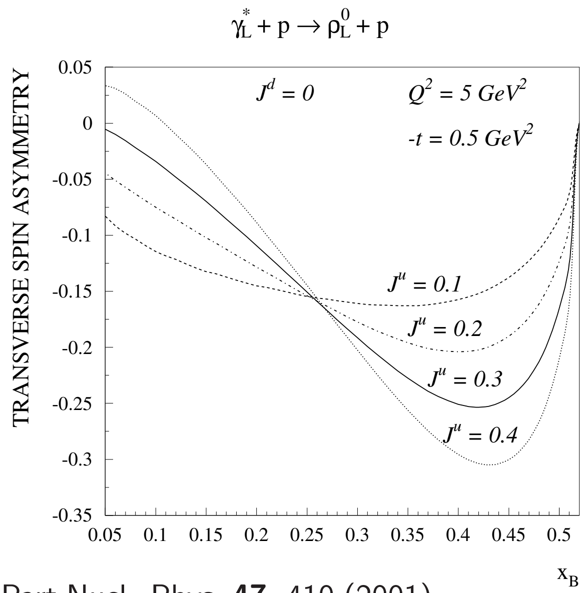
Longitudinally polarized $e^{+(-)}$ beam with

- $P = 27.56$ GeV/c,
- current $50...10$ mA,
- polarization $40...60\%$

Generalized Parton Distributions (GPDs)



- Unified theoretical description of hard exclusive processes via $H^q(x,\xi,t)$, $\tilde{H}$, E, $\tilde{E}$. Quantum numbers of final states allow to select diffrent GPDs:
  - vector mesons $\longrightarrow$ unpolarised GPDs E, H
  - pseudoscalar mesons $\longrightarrow$ polarised GPDs $\tilde{E}$, $\tilde{H}$
  - DVCS $\longrightarrow$ pol. and unpol. GPDs E, $\tilde{E}$, H, $\tilde{H}$
- Open a way to the total spin of the quarks J_q and therefore to their orbital angular momentum L_q:
  $J_q = \frac{1}{2}\Delta\Sigma + L_q$



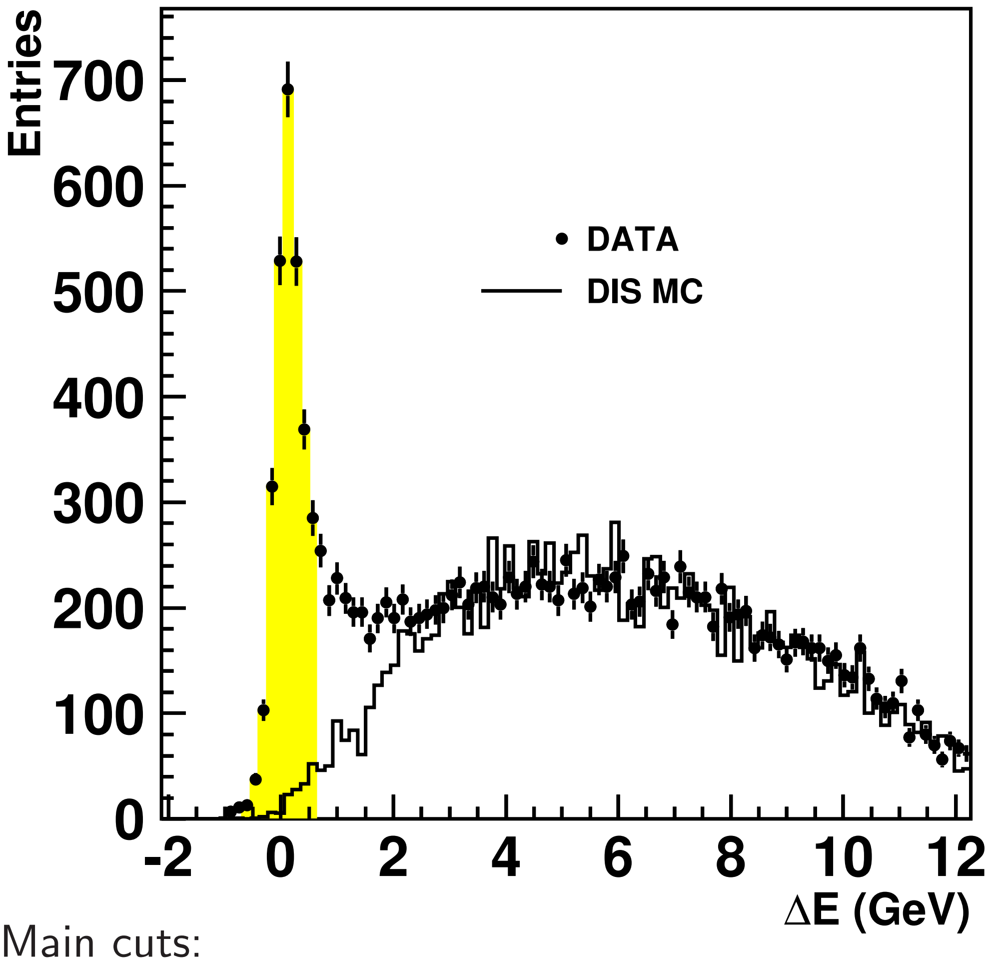
K.Goeke,M.Polyakov,M.Vanderhaeghen,Prog.Part.Nucl. Phys.,**47**, 410,(2001).

GPDs Observables

- Longitudinal component of vector meson production cross section under assumption that H^q proportional to the unpolarized quark distributions taken MRS parametrization: $H^u(x,\xi,t) = 0.5u(x)F^u(t)$ (M.Vanderhaeghren, P.A.M. Guichon, M. Guidal, Phys.Rev.Let.**80** 5064, 1998). Higher twist effects accounted in a phenomenological fasion (M.Vanderhaeghren, P.A.M. Guichon, M. Guidal, Phys.Rev.D **60** 094017, 1998).
- Lepton charge asymmetry of DVCS at unpolarized e^{+-} beams and unpolarized target:
  $$d\sigma(e^+p) - d\sigma(e^-p) \sim cos(\phi) \cdot Re\{H, \tilde{H}\}$$
- Lepton helicity asymmetry of DVCS at long. polarized beam e^{+-} beam and unpolarized target:
  $$d\sigma(e^+p) - d\sigma(e^-p) \sim cos(\phi) \cdot Im\{H, \tilde{H}\}$$

The QCD factorization theorem (J.Collins, L.L.Frankfurt, M.Strikman Phys.Rev.D **56**,2982 (1997)) is intrinsically related to the acces to the GPDs and rigorously not possible without the onset of color transparency (M.Strikman, Nucl.Phys.A663&664,**64**,2000).

Kinematics of exclusive ρ^0



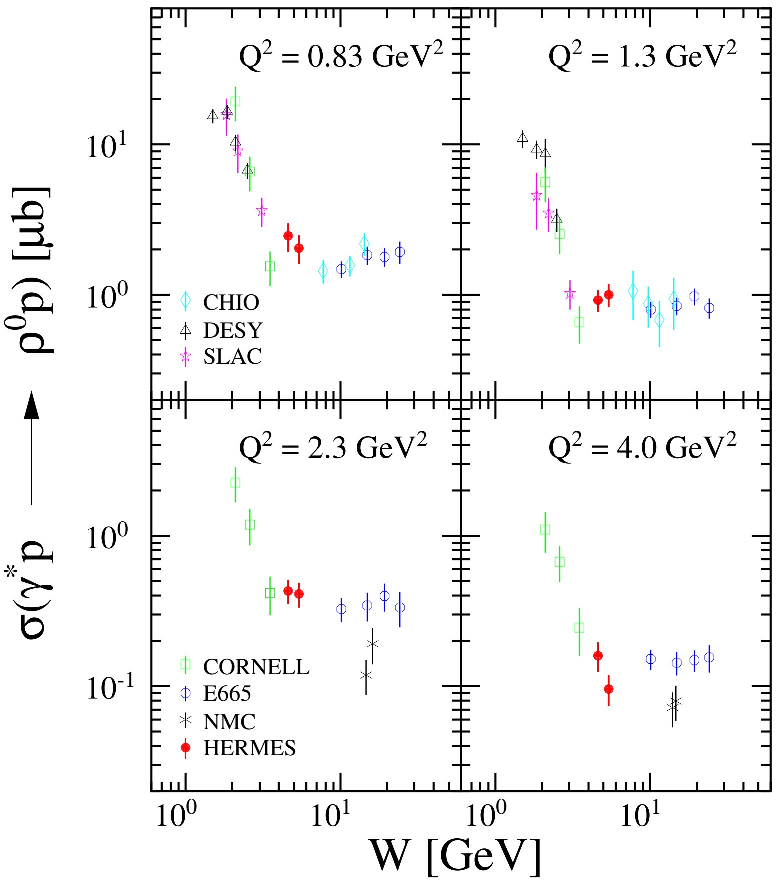
Main cuts:

- ρ^o select exclusive: -0.4 GeV$< \Delta E < 0.4$ GeV
- ρ^o select diffractive: -$t' < 0.4 GeV^2$
- ρ^o select mass: 0.6 GeV$< M_{2\pi} <$1 GeV
- ρ^o eliminate ϕ background: 1.04 GeV $< M_{KK}$

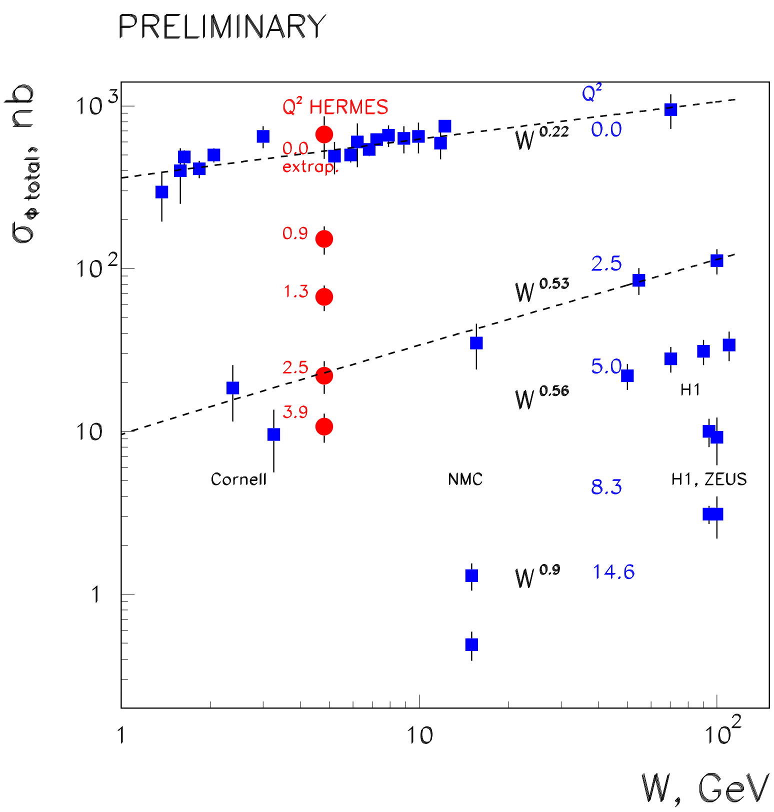
Kinematics:

- $\nu = 5 \div 24$ GeV, $< \nu >= 13.3$ GeV
- $Q^2 = 0.6 \div 6$ GeV^2, $< Q^2 >= 1.7$ GeV^2
- $W = 3. \div 6.5$ GeV, $< W >= 4.9$ GeV
- $x_{Bj} = 0.01 \div 0.35$, $< x_{Bj} >= 0.07$

ρ^o and ϕ Cross Section



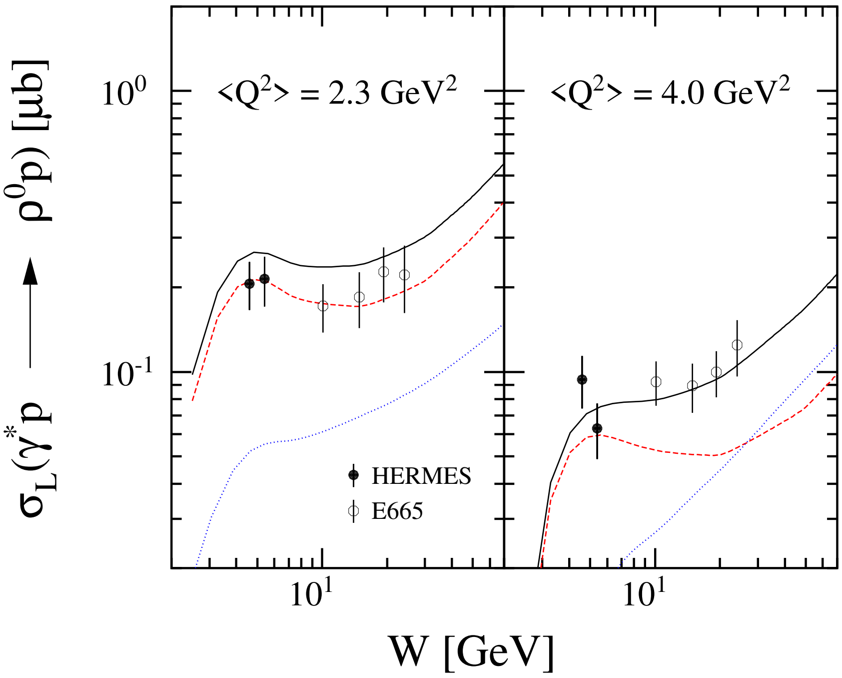
→ ρ^o data are in the transition region where different production mechanisms are involved (HERMES collab. EPJ C 17 (2000) 3, 389-398).



→ ϕ data are consistent with "IPomeron" (or two-gluon) exchange.

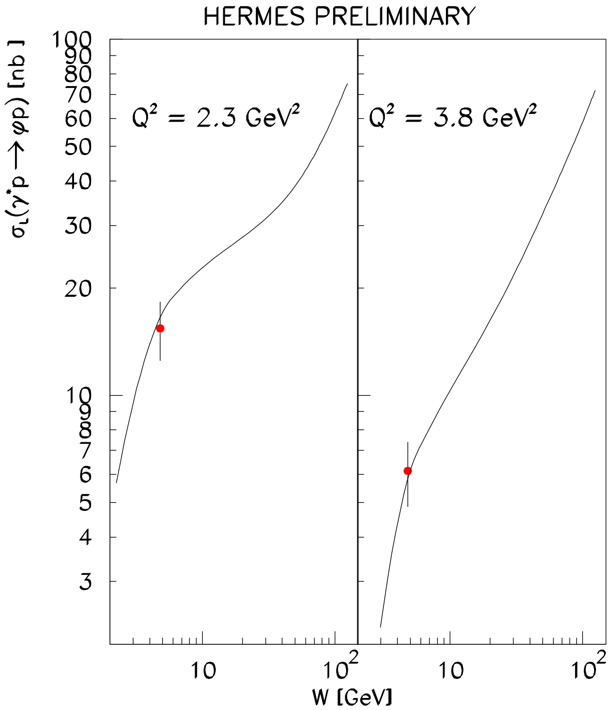
ρ^0 and ϕ Longitudinal Cross Sections

Compared with calculations of M.Vanderhaeghren, P.A.M. Guichon, M. Guidal, Phys.Rev.Let.**80** 5064, (1998).



(Blue: 2-gluon exchange, red: quark exchange, black: sum.)

$\longrightarrow$ Domination of quark exchange at $W \sim 5$ GeV for ρ^0

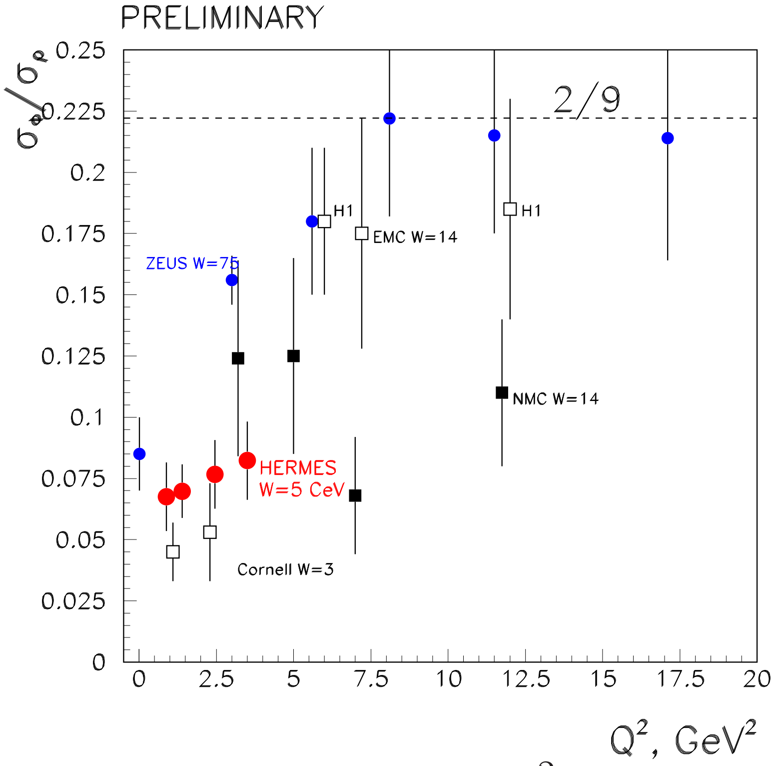


(Black curve: 2-gluon exchange)

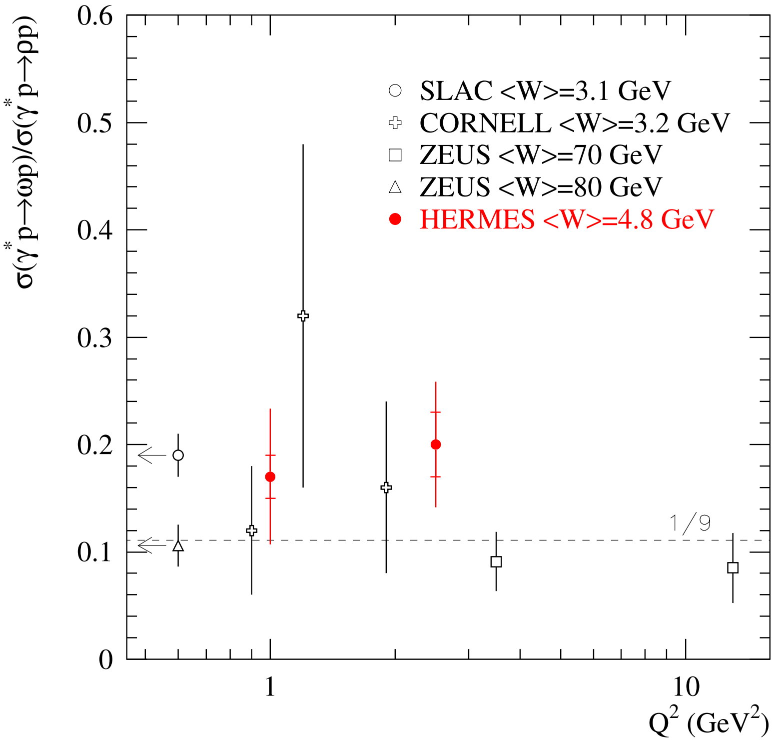
$\longrightarrow$ Domination of gluon exchange for ϕ meson.

Ratios of $\sigma_\phi/\sigma_{\rho^o}$, $\sigma_\omega/\sigma_{\rho^o}$

Asymptotic SU(4) pQCD predicts: $\rho^o : \omega : \phi : J/\Psi = 9 : 1 : 2 : 8$

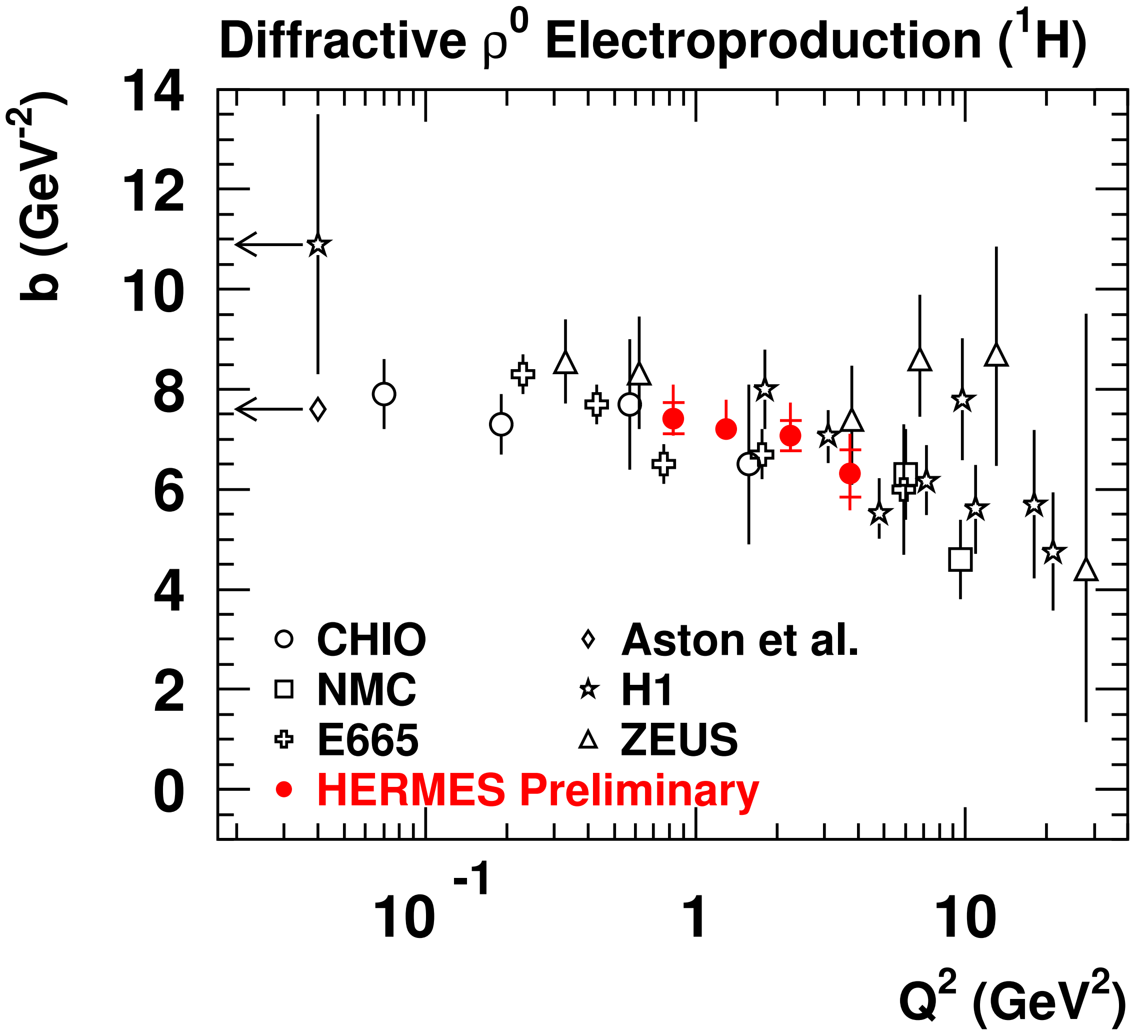


$\longrightarrow$ $W-$dependence of $\sigma_\phi/\sigma_{\rho^o}$ at $Q^2 = 2.5 \sim 4$ GeV^2.



$\longrightarrow$ Domination of quark exchange for ρ^o production at $W \sim 5$ GeV is in agreement with comparison of $\sigma_L^{\rho^o}$ with GPDs based calculations.

$b(Q^2)$ - "Photon Shrinkage"



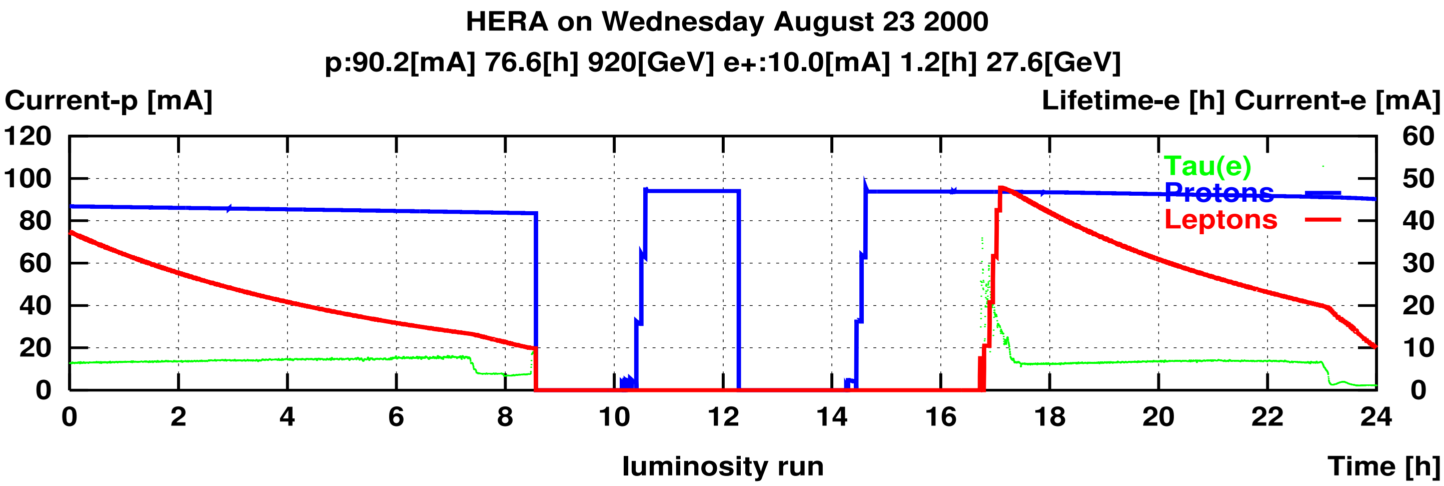
$\longrightarrow$ Size of virtual photon controlled via Q^2

Nuclear Targets

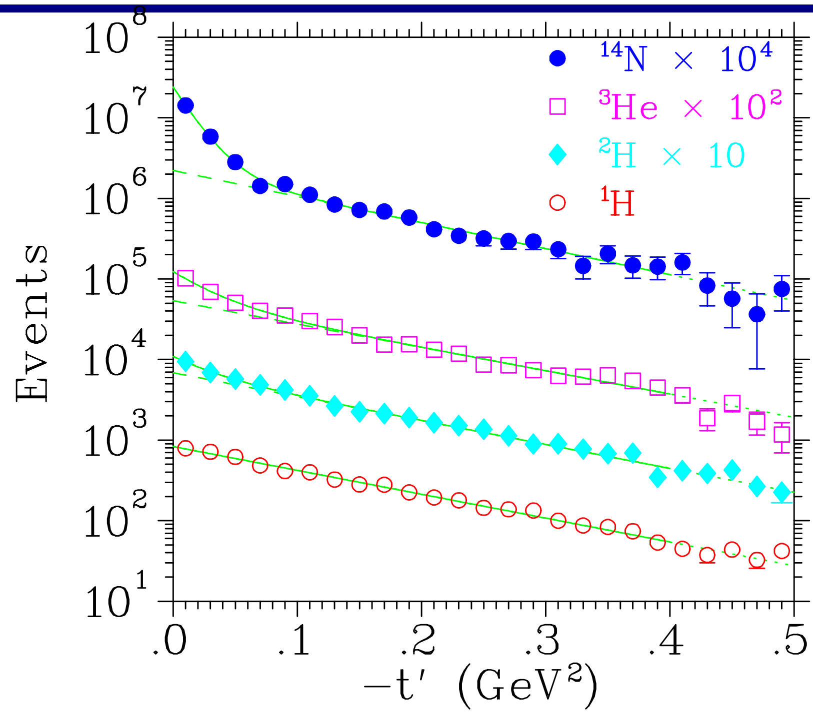
In 1995 - 2000 data on polarized and unpolarized gas targets have been accumulated:

gas	luminosity, pb^{-1}
^{1}H	261.3
^{2}D	371.3
^{3}He	109.0
^{4}He	22.6
^{14}N	49.5
^{20}Ne	88.4
^{84}Kr	25.0

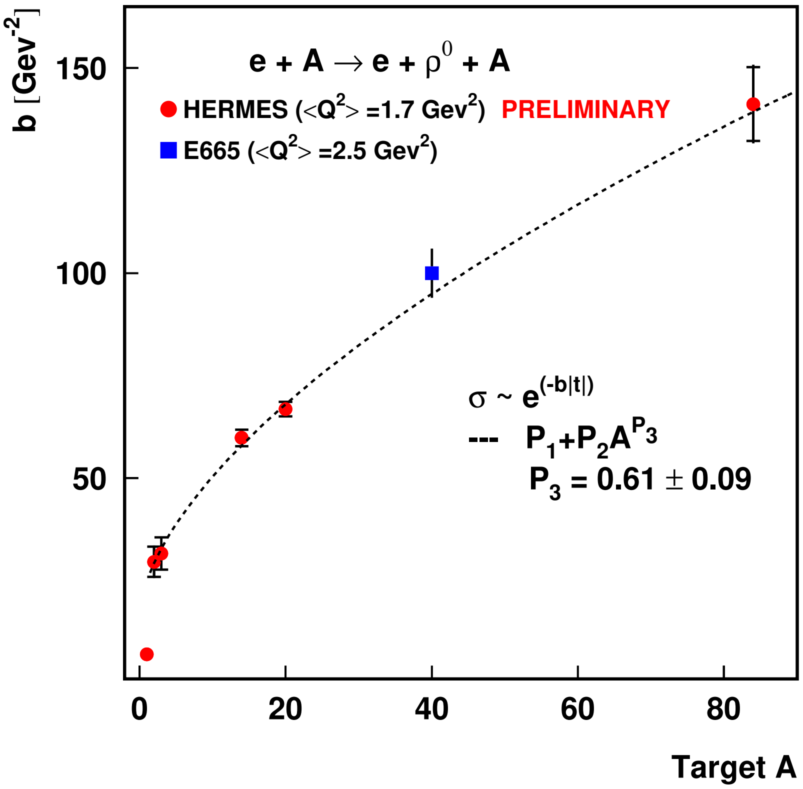
High density runs at the end of the fill in 2000 with $^{1}H,^{2}D,^{4}He$ and ^{20}Ne gases at $\sim 5 \cdot 10^{15}$ nucl./cm^2.



Coherent and incoherent ρ^0

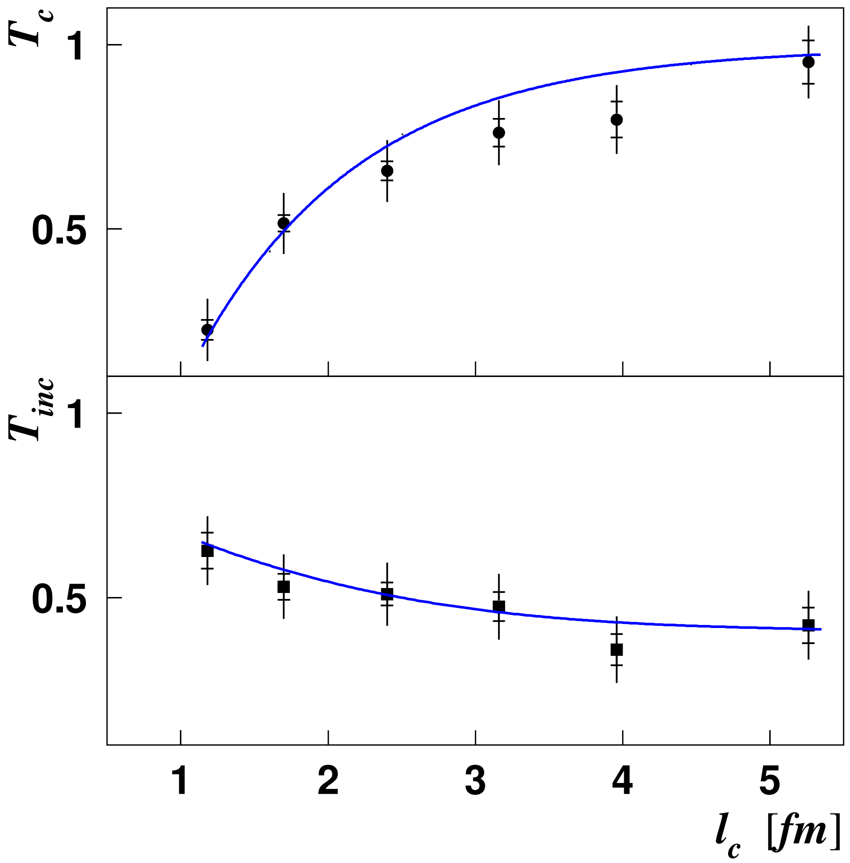


At $-t \leq 0.045$ GeV^2 coherent ρ^0 dominates at $-t \geq 0.09$ GeV^2 incoherent.



$b \approx r_A^2/3$ is in agreement with world data of nuclear size measurements (H.Alvensleben et al, Phys.Rev.Let. **24**,792 (1970)).

Coherent length effects

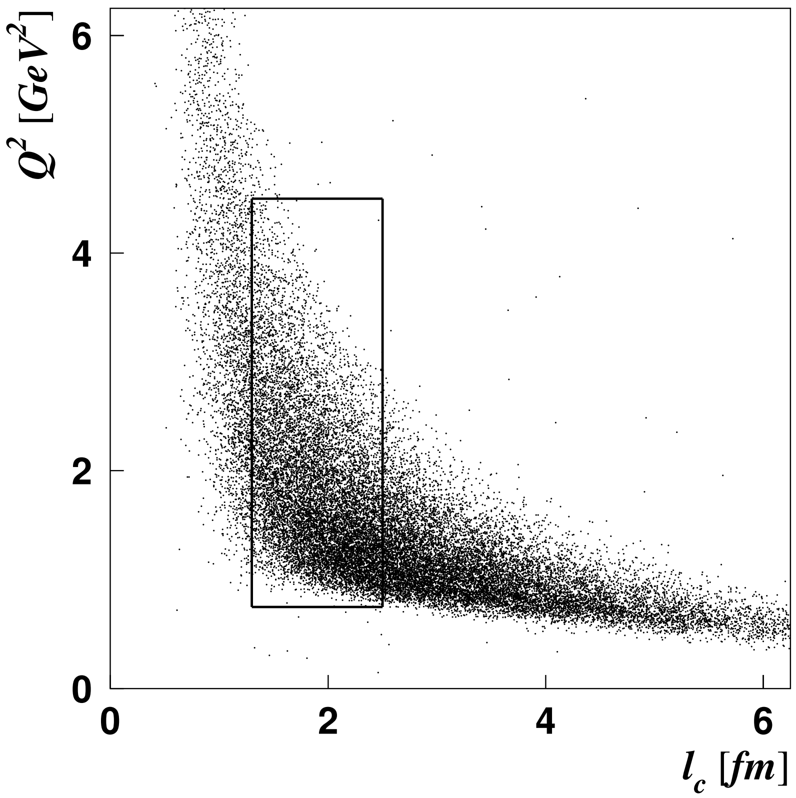


(HERMES collab., Phys.Rev.Let., **90**, 5, 052501, Feb. 2003)

Absorption due to combined effect of initial and final state interactions for incoherent ρ^0 and additionional effect of nuclear formfactor for coherent ρ^0.

Agreement with calculations (blue curves) based on (B.Z. Kopeliovich et al, Phys.Rev. C, **65**, 035201, 2002) aprroach and also recent calculations for incoherent production (T.Falter, K.Gallmeister and U.Mosel, nucl-th/0212107).

Kinematics of exclusive ρ^0

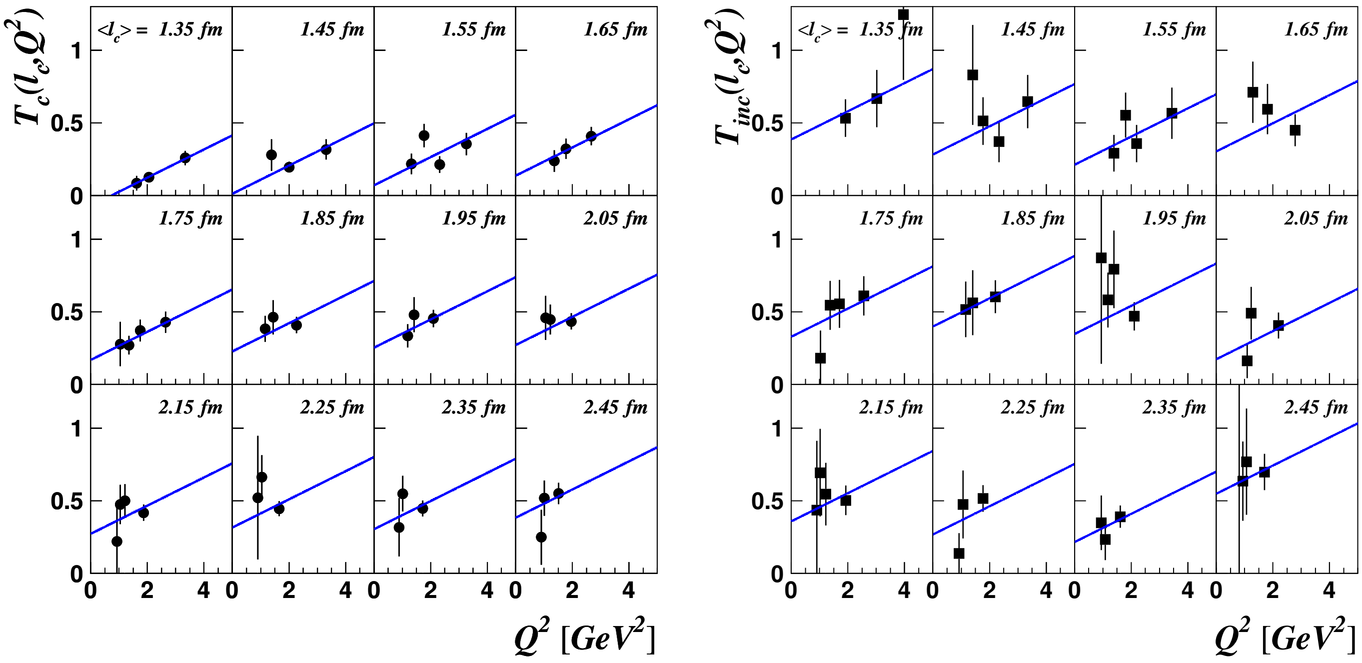


allows to apply 2-dimensional analysis of Q^2 and l_{coh} dependences and well matches nuclear dimension:

- radius of the nucleus: $r_{^{14}N} \simeq 2.5$ fm
- transverse size of the qq wave packet
  $r_{q\bar{q}} \sim 1/ < Q^2 > \simeq 0.4$ fm $< r_p = 1$ fm
- coherence length: distance traversed by qq
  $l_c = \frac{2 \cdot \nu}{Q^2 + m_V^2} = 0.6 \div 8$ fm
  $< l_c >= 2.7$ fm
- formation length: distance needed for qq to develop into hadron:
  $l_{form} = \frac{2 \cdot \nu}{m_{V'}^2 - m_V^2} = 1.3 \div 6.3$ fm
  $< l_{form} >= 3.47$ fm

Color Transparency:

The QCD factorization theorem (J.Collins, L.L.Frankfurt, M.Strikman Phys.Rev.D **56**,2982 (1997)) is rigorously not possible without the onset of color transparency (M.Strikman, Nucl.Phys.A663&664,**64**,2000):
$r(qq)$ decreases with the increase of Q^2,
$Tr^A(Q^2, l_{coh}) = \sigma^A_{(in)coh}/\sigma^H$ grouths with Q^2

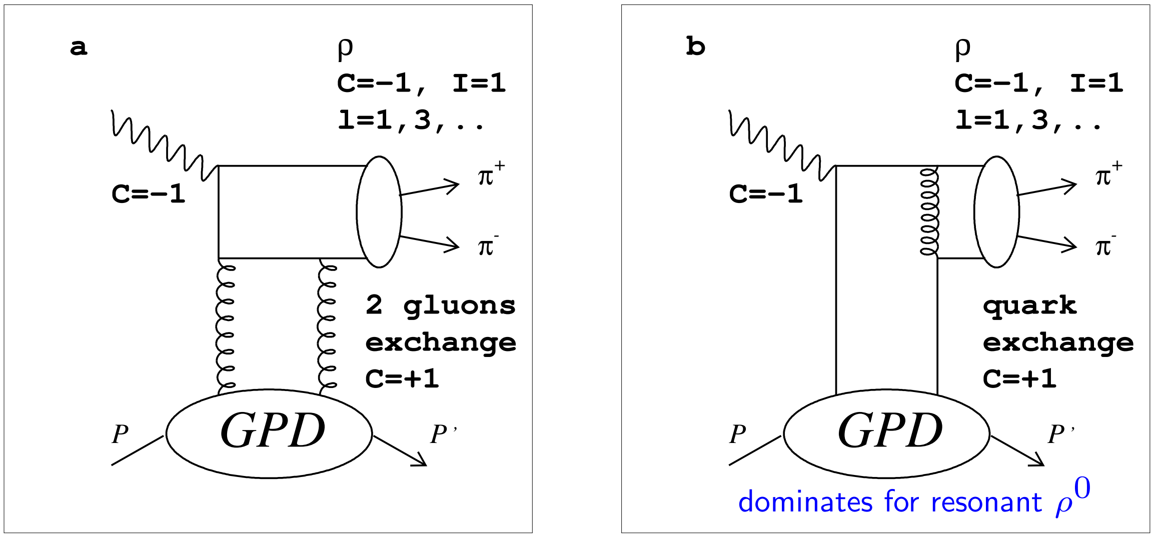


Common fit at fixed l_{coh} provides positive slope of Q^2–dependence of nuclear transparency on nitrogen (HERMES collab., Phys.Rev.Let., **90**, 5, 052501, Feb. 2003):

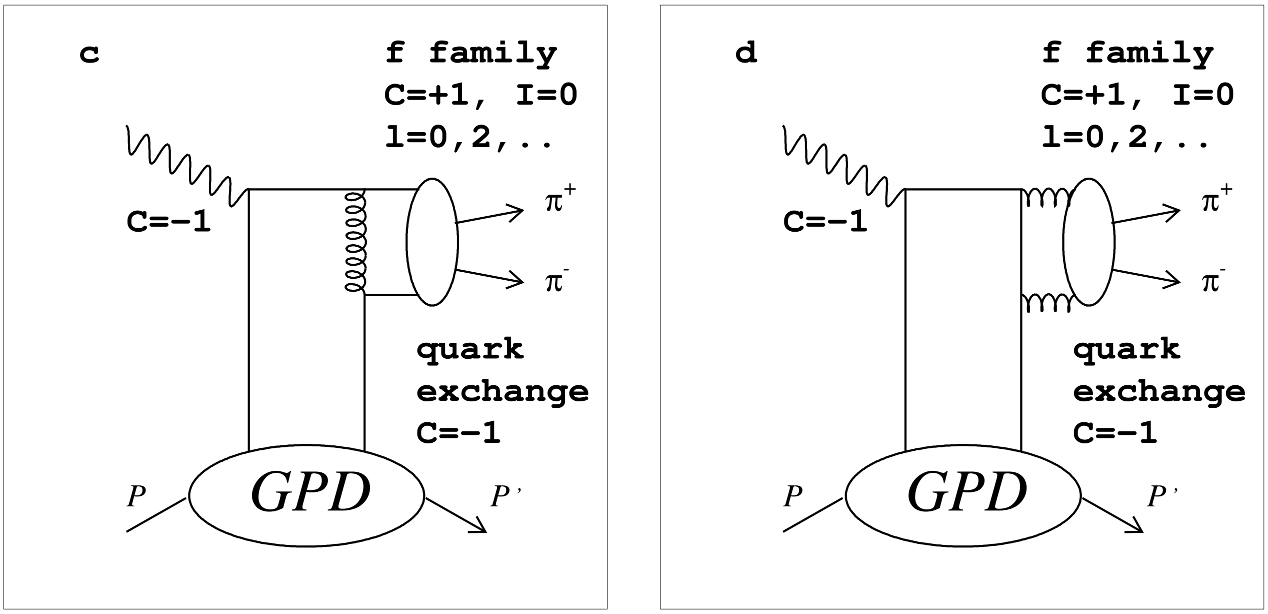
data	Slope of Q^2-dependence, GeV^{-2}	Prediction, GeV^{-2}
N incoh.	$0.089 \pm 0.050(\pm 0.046_{st} \pm 0.020_{syst})$	0.060
N coh.	$0.070 \pm 0.030(\pm 0.027_{st} \pm 0.017_{syst})$	0.048
N combined	0.074 ± 0.023	0.058

Agreement with theoretical calculations (B.Z. Kopeliovich et al, Phys.Rev. C, **65**, 035201, 2002) where slope of Q^2-dependence was derived from the onset of the CT effect.

$\pi^+\pi^-$ production beyond ρ^0

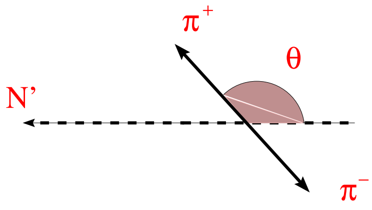


Isovector exchange: same quantum numbers for γ^* and $\pi^+\pi^-$



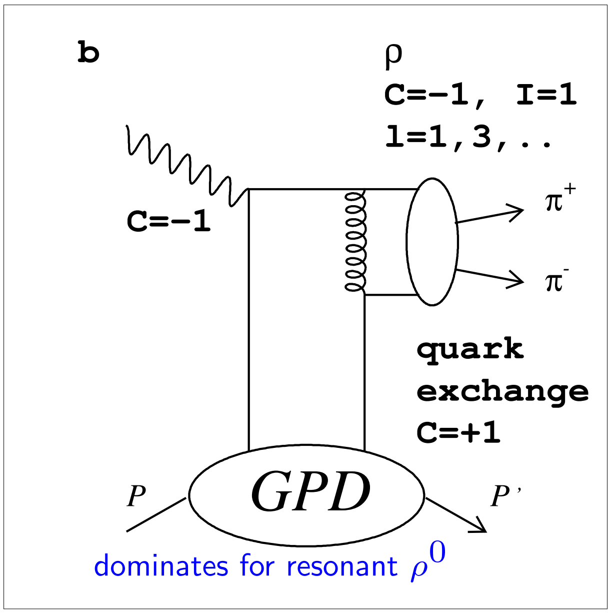
Interference with isoscalar exchange of $\pi^+\pi^-$ production can be observed via Legendre Polynomial moment:

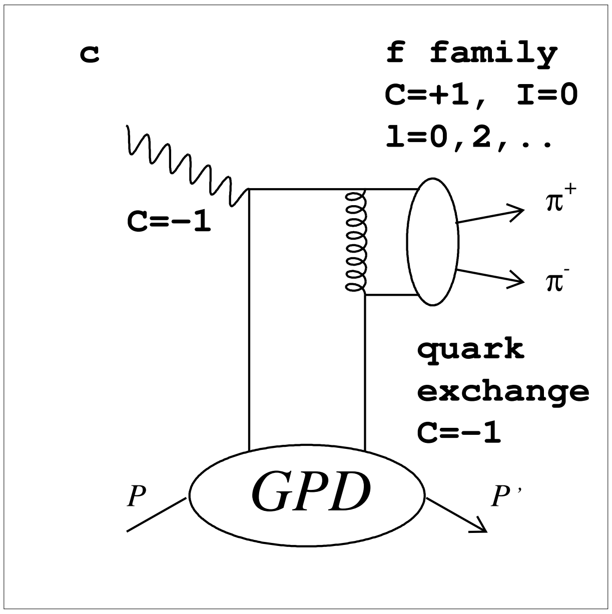
$$< P_l(\cos\Theta) >= \frac{\int_{-1}^{1} d\cos\Theta P_l(\cos\Theta)\frac{d\sigma^{\pi^+\pi^-}}{d\cos\Theta}}{\int_{-1}^{1} d\cos\Theta\frac{d\sigma^{\pi^+\pi^-}}{d\cos\Theta}}$$



where Θ is angle of π^+ and recoil in $\pi^+\pi^-$ rest frame,
B.Lehmann-Dronke et al., Phys.Lett. B **475** (2000) 147; Phys.Rev.D **63** (2001) 114001 .

$\pi^+\pi^-$ production beyond ρ^0



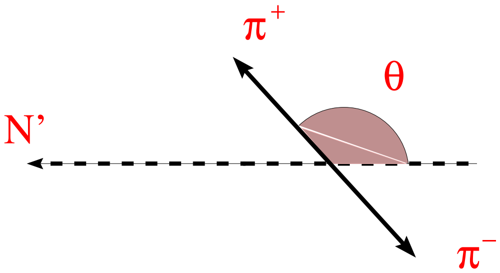


Isovector (left): same quantum numbers for γ^* and $\pi^+\pi^-$
Isoscalar (right): $C = +1$, $I = 0$, $l = 0$ for $\pi^+\pi^-$

Interference between isoscalar and isovector exchange can be observed via Legendre Polynomial moment:

$$< P_l(\cos\Theta) >= \frac{\int_{-1}^{1} d\cos\Theta P_l(\cos\Theta)\frac{d\sigma^{\pi^+\pi^-}}{d\cos\Theta}}{\int_{-1}^{1} d\cos\Theta \frac{d\sigma^{\pi^+\pi^-}}{d\cos\Theta}}$$

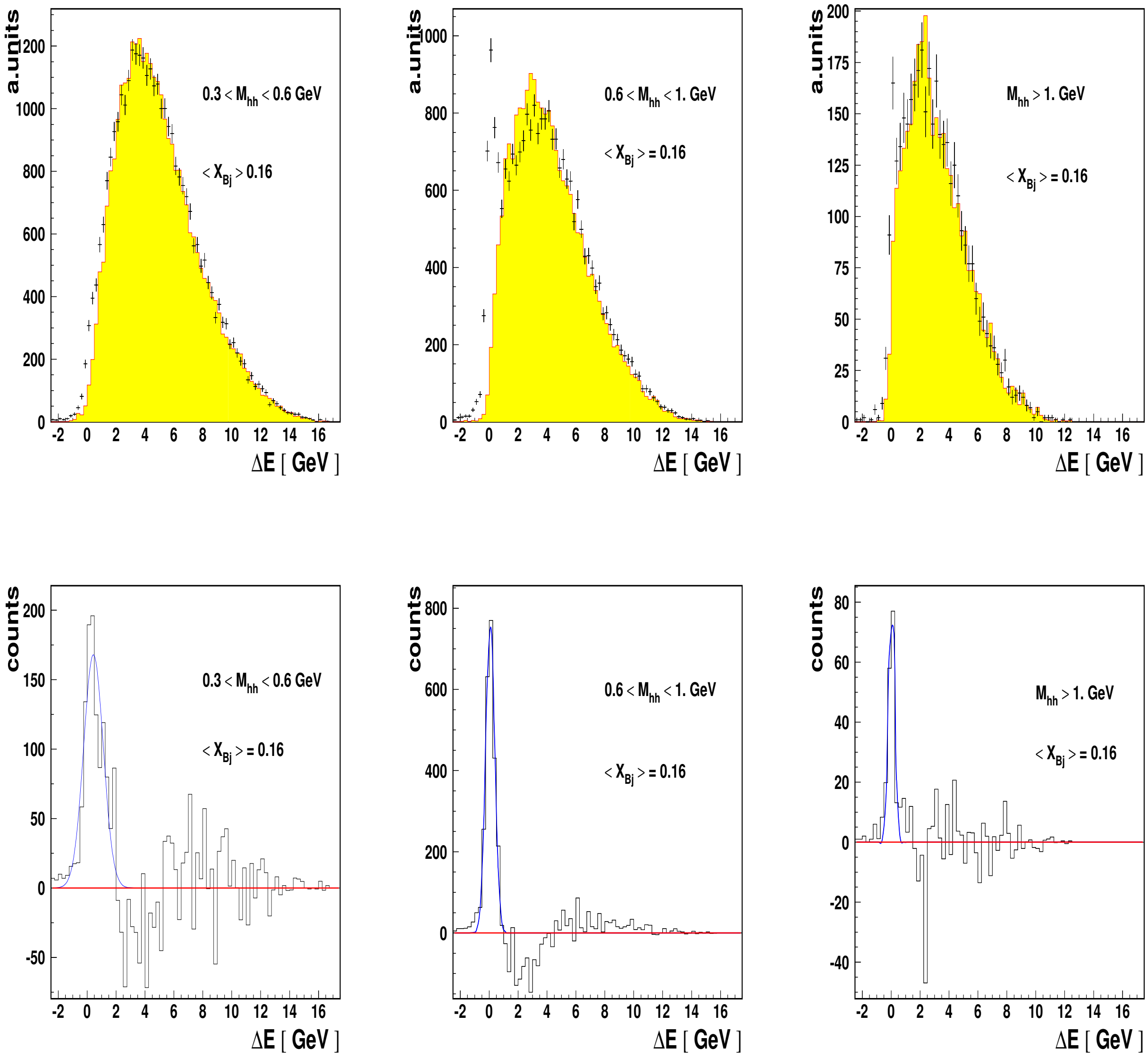
where Θ is angle of π^+ and recoil in $\pi^+\pi^-$ rest frame,
B.Lehmann-Dronke et al., Phys.Lett. B **475** (2000) 147; Phys.Rev.D **63** (2001) 114001 .



Exclusive $M_{\pi^+\pi^-}$ data

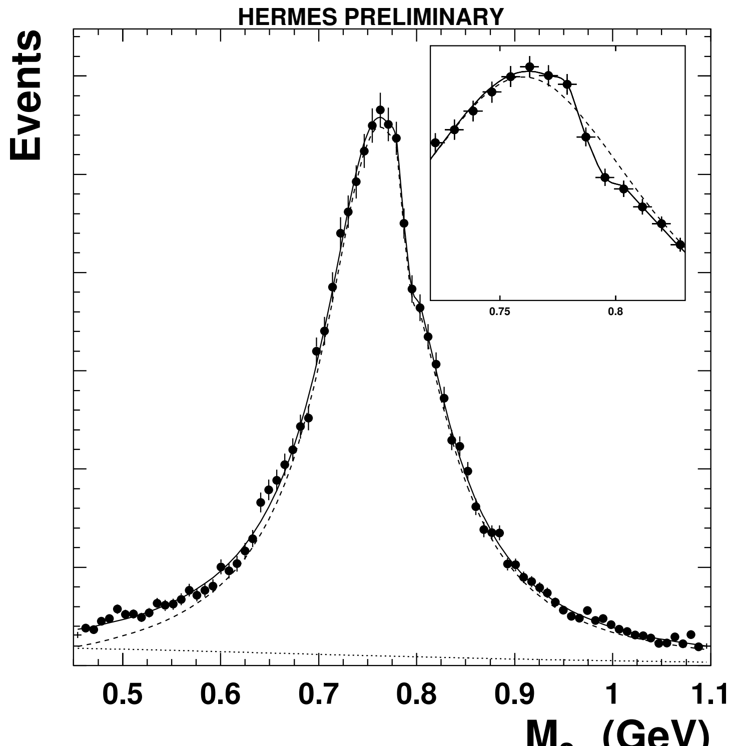
Cuts $X_{Bj} > 0.1$ and $Q^2 > 1.0$ GeV^2 used to enhance the interference between isoscalar and isovector channels.
Exclusive events selected by $\Delta E < 0.625$ GeV

$$e^+p \longrightarrow e^+\pi^+\pi^-X$$

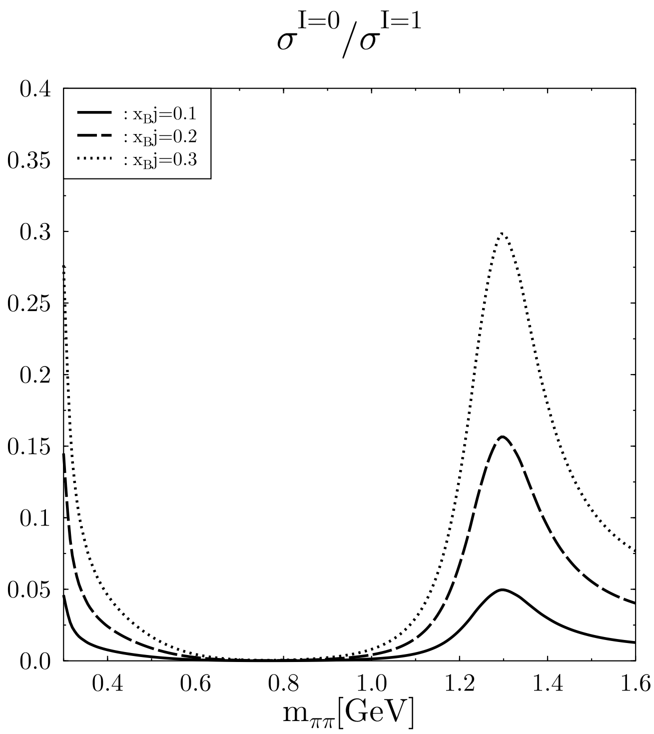


Stable exclusive peak observed over entire $M_{\pi\pi}$ region for proton and deuteron targets.
$< x_{Bj} >= 0.16$ and $< Q^2 >= 3$ GeV^2

$M_{\pi^+\pi^-}$ data



Dashed: Ross-Stodolsky $M_{\pi\pi}$ with $\rho^0 - \omega$ interference
Dotted: non-resonant background
Solid: sum.

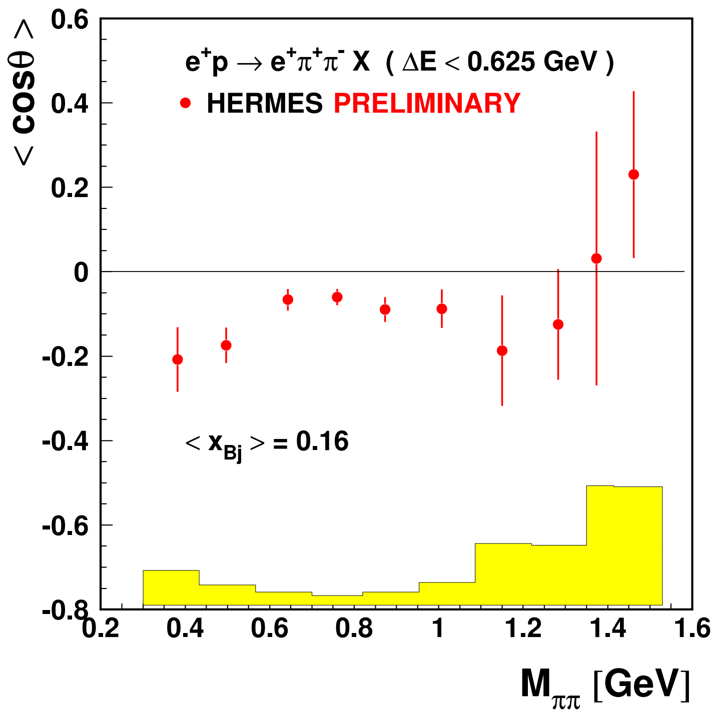


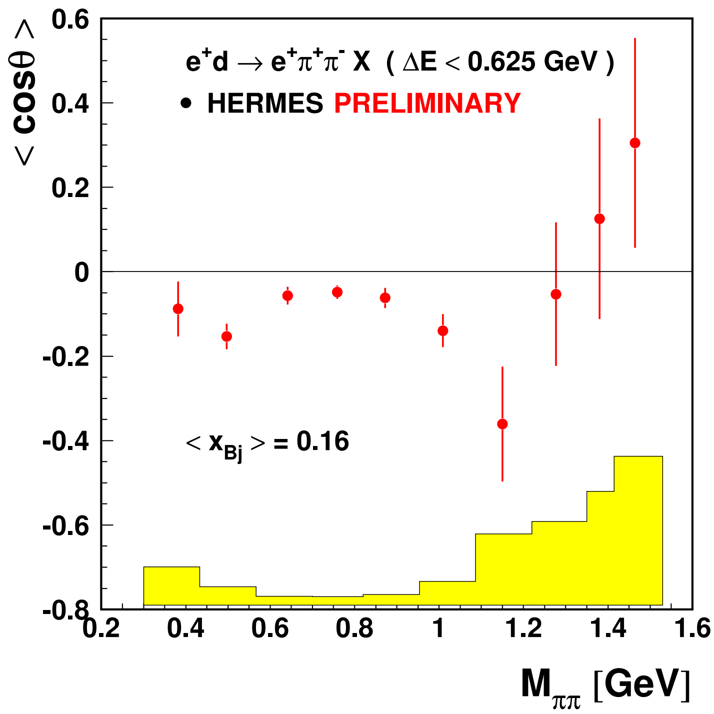
B.Lehmann-Dronke et al., Phys.Lett. B **475** (2000) 147

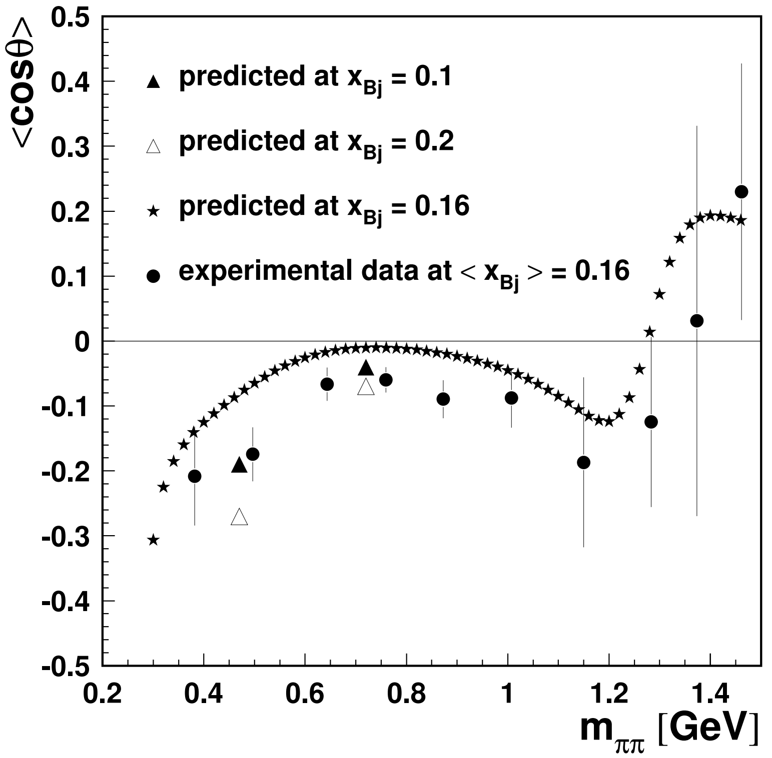
$\longrightarrow$ Study exclusive $\pi^+\pi^-$ at $0.3 < M_{\pi\pi} < 1.4$ GeV.

$< P_1(\cos\Theta) > = < \cos\Theta > (M_{\pi^+\pi^-})$

as interference between $\pi^+\pi^-$ in $P-$wave and in $S, D-$wave.

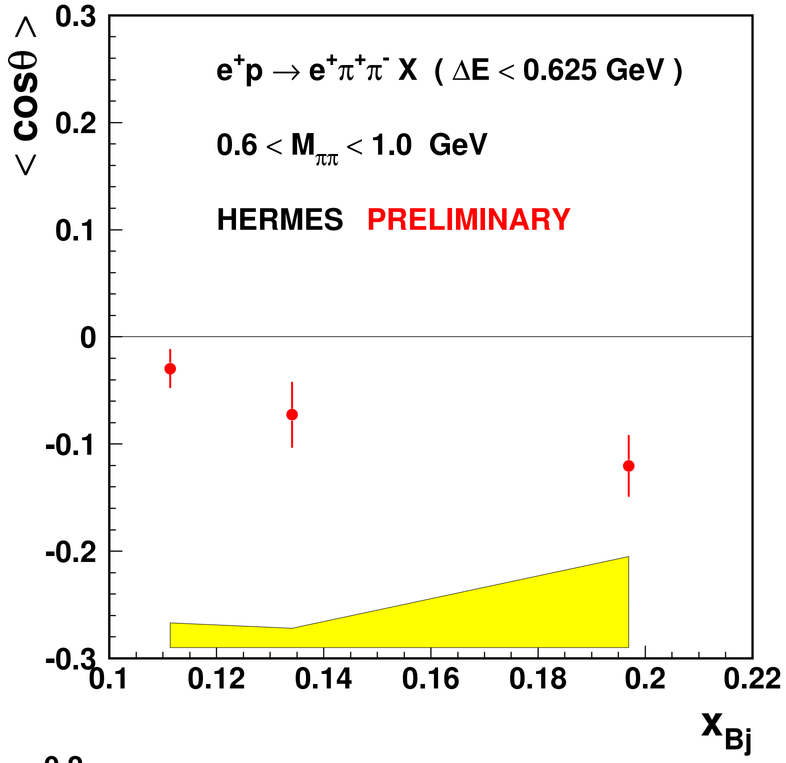


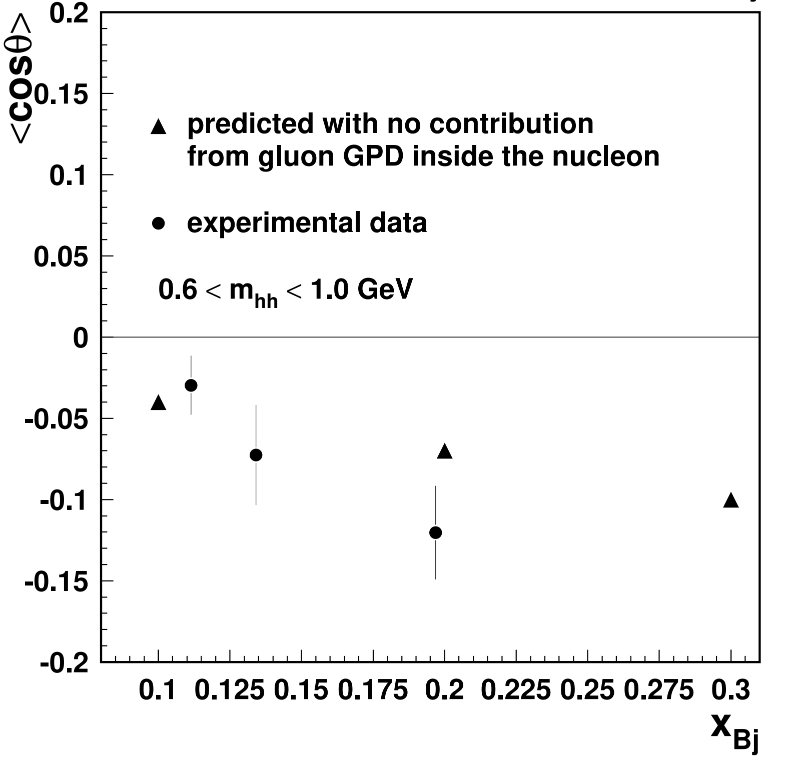




Calculations without gluon contribution (B.Lehmann-Dronke et al., Phys.Lett. B **475** (2000) 147; Phys.Rev.D **63** (2001) 114001).

$< \cos\Theta > (x_{Bj})$





B.Lehmann-Dronke et al., Phys.Lett.B **475** (2000) 147; Phys.Rev.D **63** (2001) 114001

$\longrightarrow$ Good agreement with theoretical predictions. Sizable admixture of isoscalar and isovector pion pairs at large enough x_{Bj}.

Summary

More and more results relevant to GPDs are accumulated:

- Longitudinal cross sections of VM production are in agreement with GPD predictions
- Color transparensy of exclusive ρ^0 production supports factorization
- First measurement of the interference between the isoscalar and isovector channel in hard exclusive $\pi^+\pi^-$ electroproduction

New data are coming:

- A transversely polarized proton target in the current running period will complement the data from longitudinaly polarized target.
- New results are expected for transverse spin asymmetries of exclusive pion and vector meson production.
- Significant inprovement in resolution and systematics for hard exclusive reactions expected from the operation of the Recoil Detector in future.