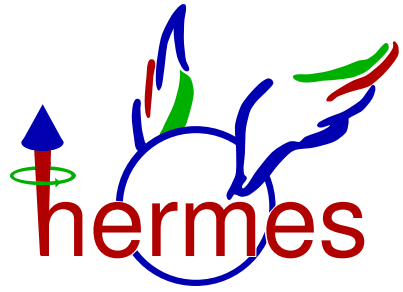
Electroproduction of Exclusive $\pi^+\pi^-$ at



Riccardo Fabbri

NIKHEF

on behalf of the *HERMES* Collaboration

SPIN 2004

Trieste, October 2004

- Hard Exclusive Production of $\pi^+\pi^-$ and GPDs
- Legendre Moments
- Measurements vs $m_{\pi\pi}$ and x
- Conclusions and Outlook

Hard Exclusive Production of $\pi^+\pi^-$

$e^+p \to p\,\pi^+\pi^-$ $\qquad$ $e^+d \to d\,\pi^+\pi^-$

- Polarized & non-polarized data
- data taking 1996-2000
- Main kinematical cuts:

  $Q^2 > 1$ GeV^2, $W > 2$ GeV, $x > 0.1$
- Hadrons considered as pions

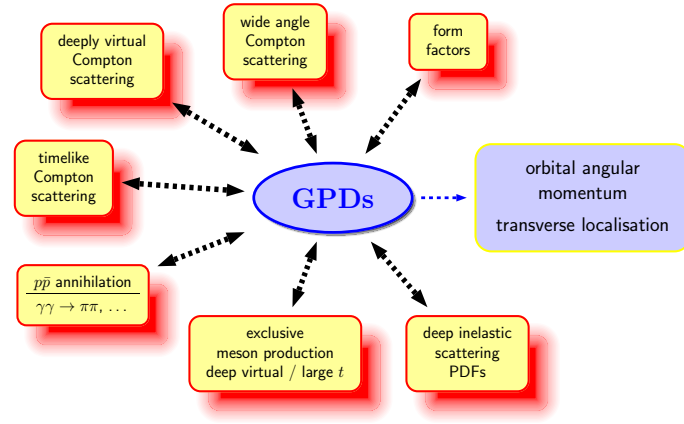
Hard Exclusive Production of $\pi^+\pi^-$

$$e^+p \to p\,\pi^+\pi^- \qquad\qquad e^+d \to d\,\pi^+\pi^-$$

- ✦ Polarized & non-polarized data
- ✦ data taking 1996-2000
- ✦ Main kinematical cuts:

  $Q^2 > 1$ GeV^2, $W > 2$ GeV, $x > 0.1$
- ✦ Hadrons considered as pions

☞ Process interpreted in GPD framework!



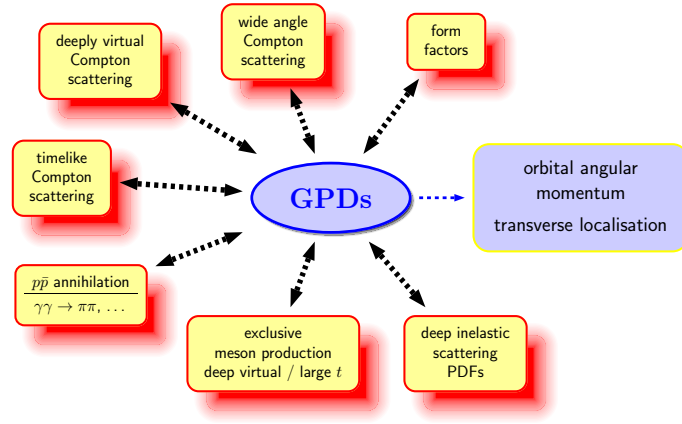
Hard Exclusive Production of $\pi^+\pi^-$

$$e^+p \to p\,\pi^+\pi^- \qquad\qquad e^+d \to d\,\pi^+\pi^-$$

- ✦ Polarized & non-polarized data
- ✦ data taking 1996-2000
- ✦ Main kinematical cuts:

  $Q^2 > 1$ GeV^2, $W > 2$ GeV, $x > 0.1$
- ✦ Hadrons considered as pions

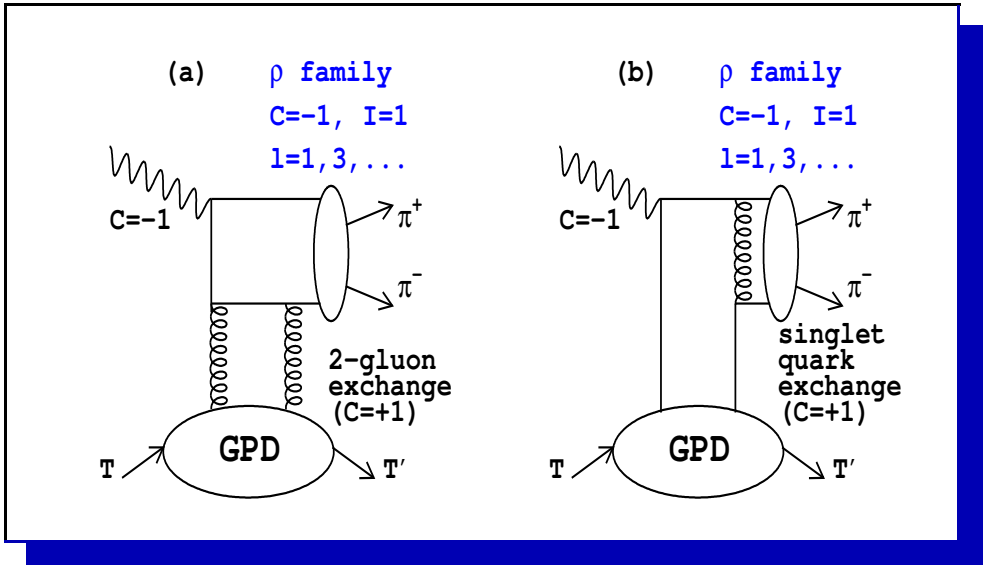
☞ Process interpreted in GPD framework!



- ✦ Process provides additional constraints of *GPDs*
- ✦ Sensitive to interference between different $\pi^+\pi^-$ isospin states
- ✦ Results published in Phys. Lett. B 599 (2004) 212

Hard Exclusive Production of $\pi^+\pi^-$

Which channels may contribute?



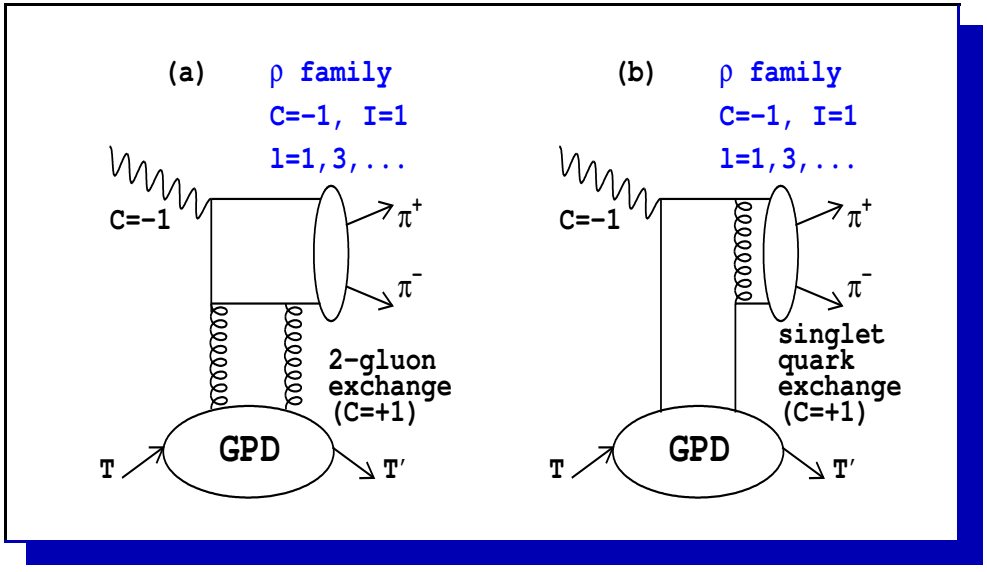
Example:

- ρ^0:

$$I(J^{PC})=1(1^{--})$$

Hard Exclusive Production of $\pi^+\pi^-$

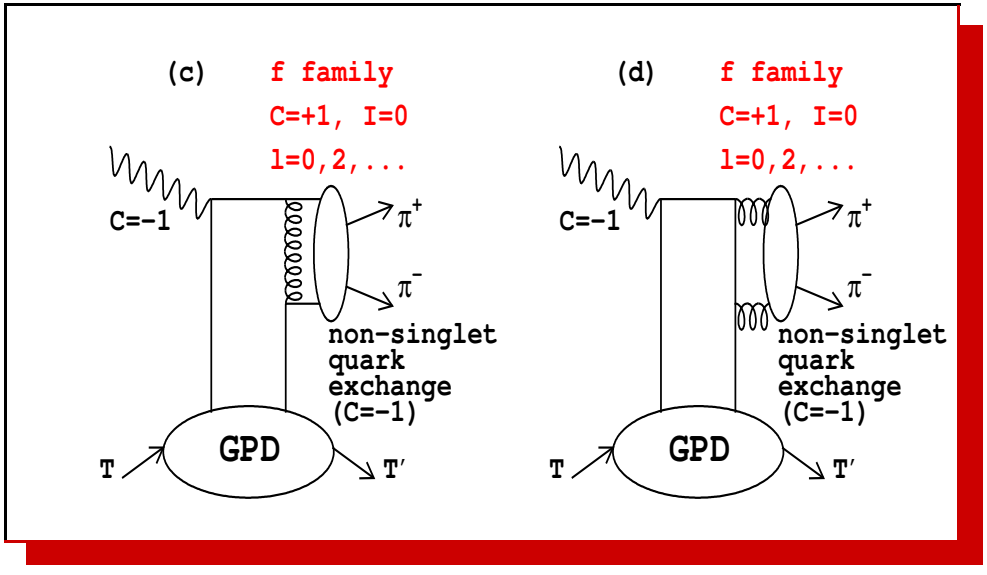
Which channels may contribute?



Example:

- ρ^0:

$$I(J^{PC})=1(1^{--})$$



Example:

- non-resonant S-wave & f_0:

$$I(J^{PC})=0(0^{--})$$

- f_2:

$$I(J^{PC})=0(2^{--})$$

Legendre Moments

The elusive *f*-meson family channel can be highlighted through its interference with the ρ-meson family.

$$\frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta} \propto \sum_{JJ'\lambda\lambda'} \rho^{JJ'}_{\lambda\lambda'} Y_{J\lambda}(\theta,\phi) Y^{\star}_{J'\lambda'}(\theta,\phi)$$

Legendre Moments

The elusive f-meson family channel can be highlighted through its interference with the ρ-meson family.

$$\frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta} \propto \sum_{JJ'\lambda\lambda'} \rho^{JJ'}_{\lambda\lambda'} Y_{J\lambda}(\theta,\phi) Y^{\star}_{J'\lambda'}(\theta,\phi)$$

Spin Density Matrix:

$$\boxed{\rho^{J\,J'}_{\lambda\lambda'}}$$

Legendre Moments

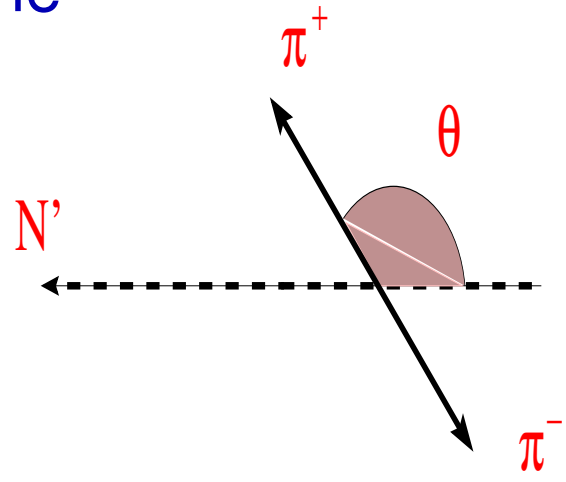
The elusive *f*-meson family channel can be highlighted through its interference with the ρ-meson family.

$$\frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta} \propto \sum_{JJ'\lambda\lambda'} \rho^{JJ'}_{\lambda\lambda'} Y_{J\lambda}(\theta,\phi) Y^{\star}_{J'\lambda'}(\theta,\phi)$$

Sensitivity to the interference by using the

Legendre Moments:

$$\langle P_l(cos\theta)\rangle^{\pi^+\pi^-} = \frac{\int_{-1}^{1} dcos\theta\, P_l(cos\theta)\, \frac{d\sigma^{\pi^+\pi^-}}{dcos\theta}}{\int_{-1}^{1} dcos\theta\, \frac{d\sigma^{\pi^+\pi^-}}{dcos\theta}}$$



Legendre Moments

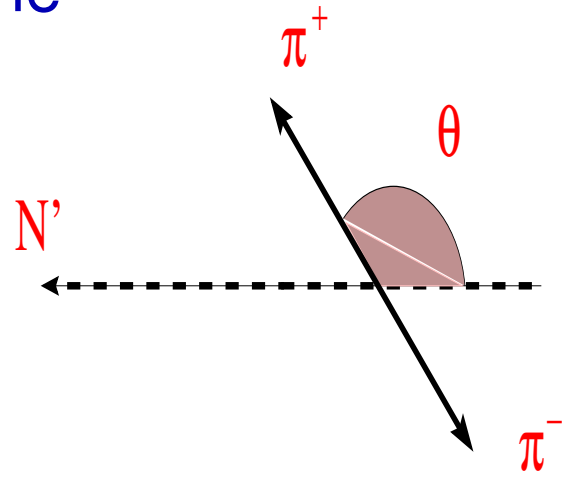
The elusive *f*-meson family channel can be highlighted through its interference with the ρ-meson family.

$$\frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta} \propto \sum_{JJ'\lambda\lambda'} \rho^{JJ'}_{\lambda\lambda'} Y_{J\lambda}(\theta,\phi) Y^{\star}_{J'\lambda'}(\theta,\phi)$$

Sensitivity to the interference by using the

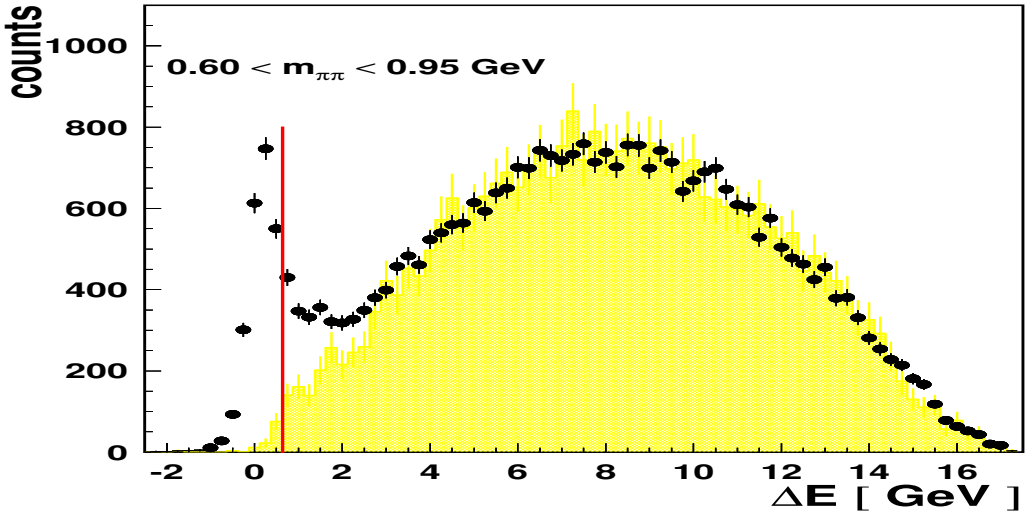
Legendre Moments:

$$\langle P_l(cos\theta)\rangle^{\pi^+\pi^-} = \frac{\int_{-1}^{1} dcos\theta\, P_l(cos\theta)\, \frac{d\sigma^{\pi^+\pi^-}}{dcos\theta}}{\int_{-1}^{1} dcos\theta\, \frac{d\sigma^{\pi^+\pi^-}}{dcos\theta}}$$

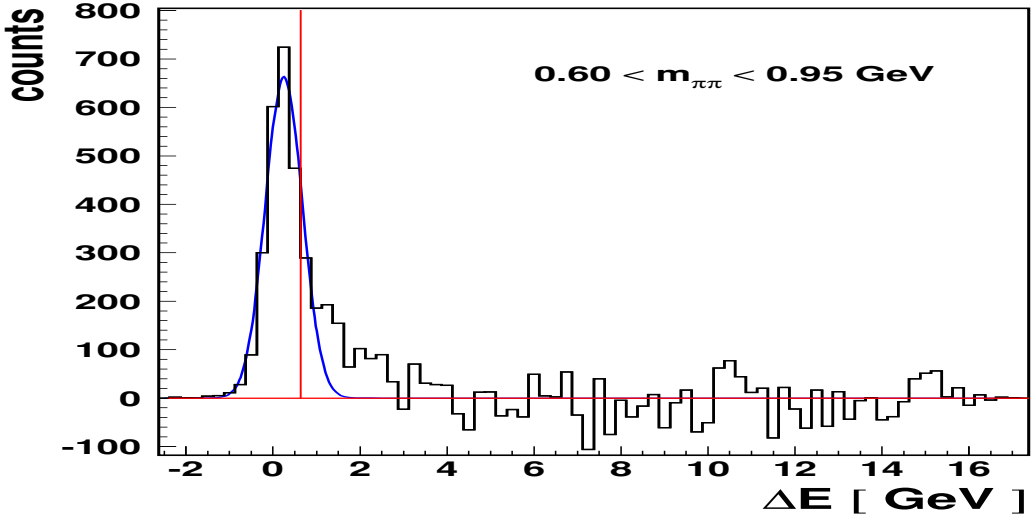


Through angular asymmetries, weak channels as f_0 and f_2 dominated by ρ production can be highlighted.

Exclusive Event Selection

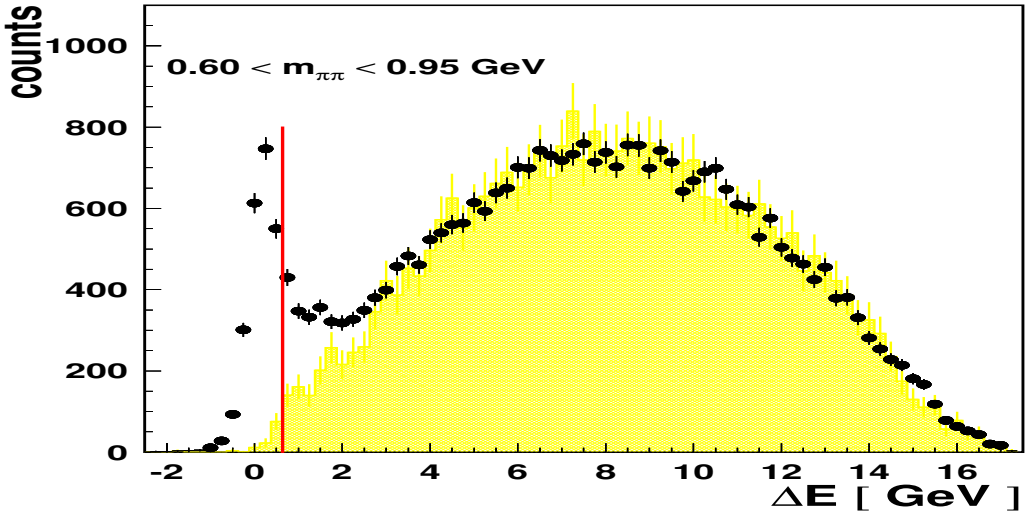


☞ Bg shape simulated with LEPTO

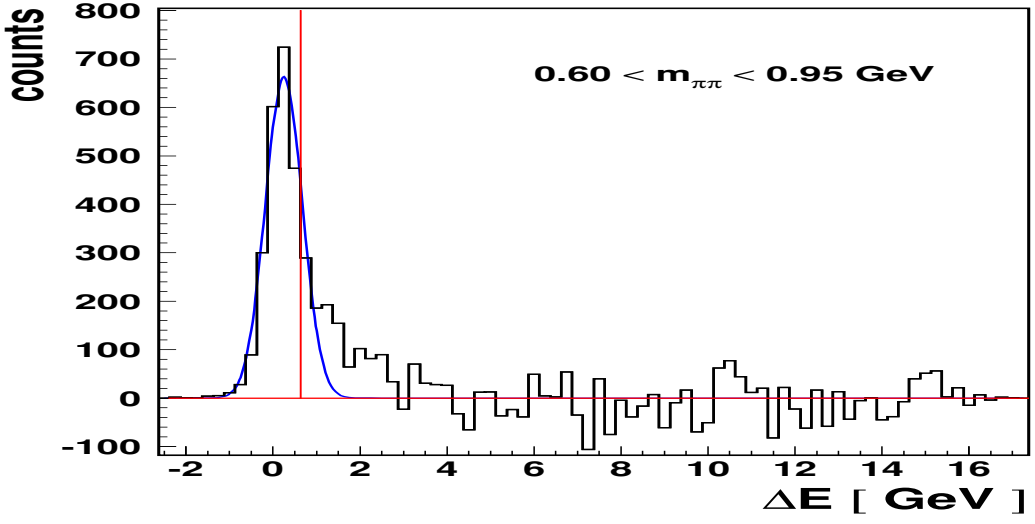


☞ Exclusive signal extracted

Exclusive Event Selection



☞ Bg shape simulated with LEPTO

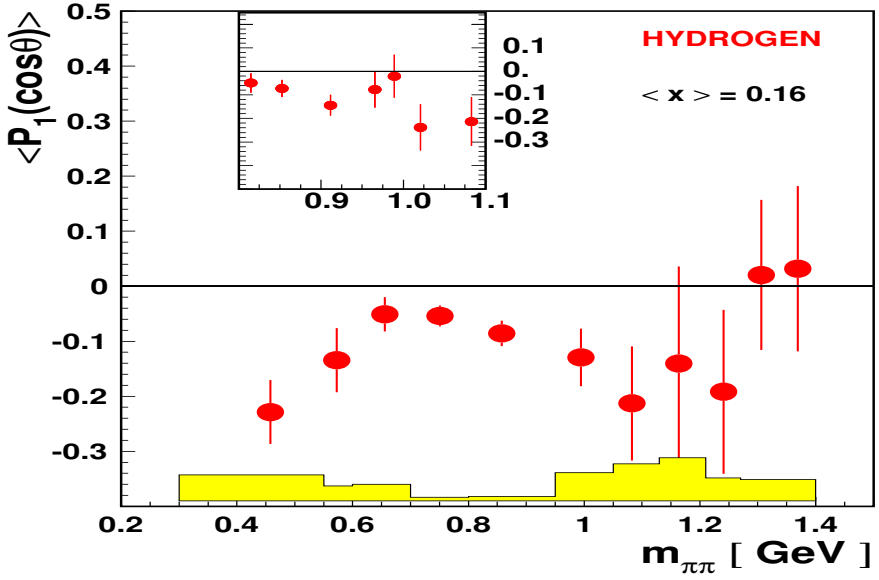


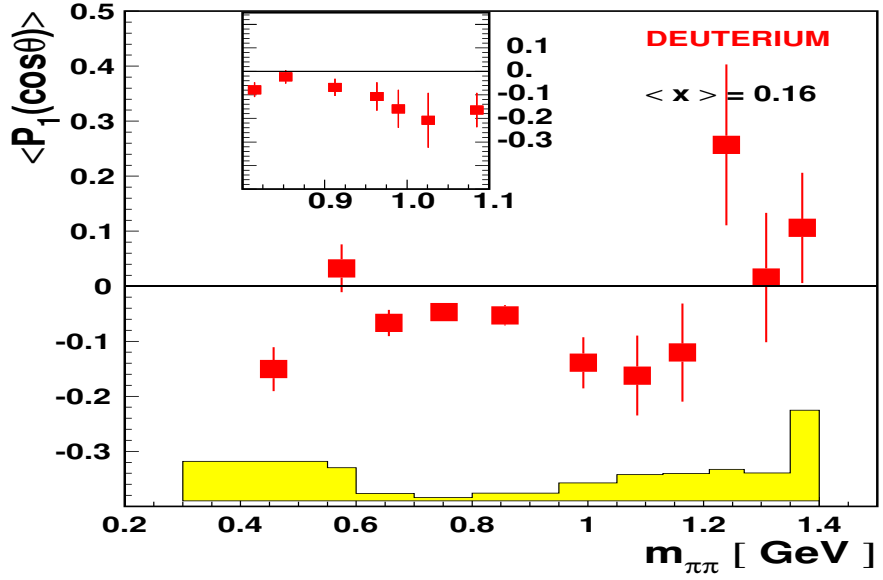
☞ Exclusive signal extracted

✦ Optimized exclusive region chosen was $\Delta E < 0.625$ GeV

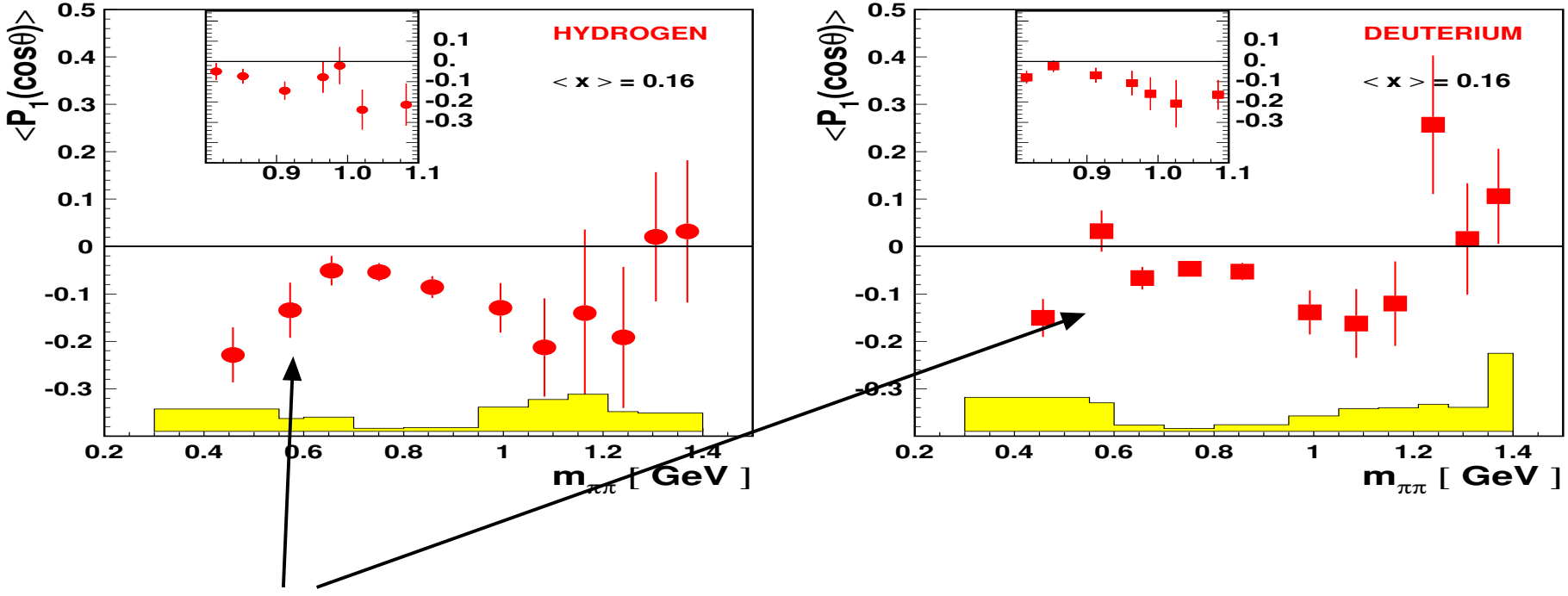
✦ Moments evaluated in that exclusive region & Bg subtracted according Sg/Bg

$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$





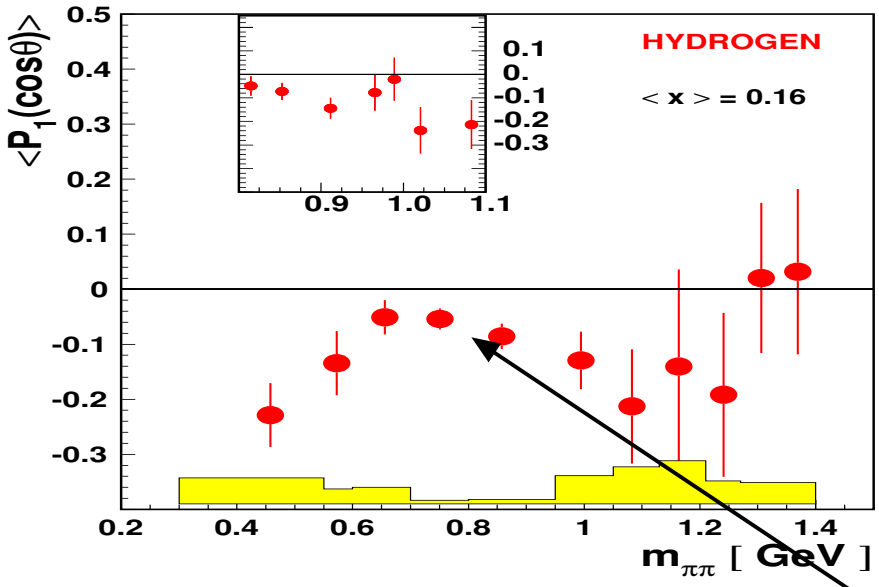
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

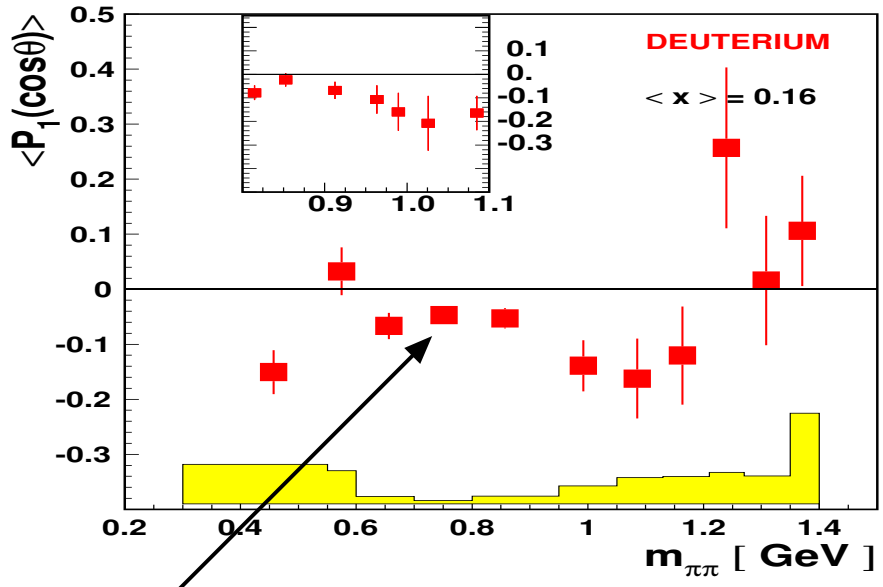


Interference between non-resonant S-wave and lower ρ^0 tail

$m_{\pi\pi} < 0.6\,\text{GeV}$

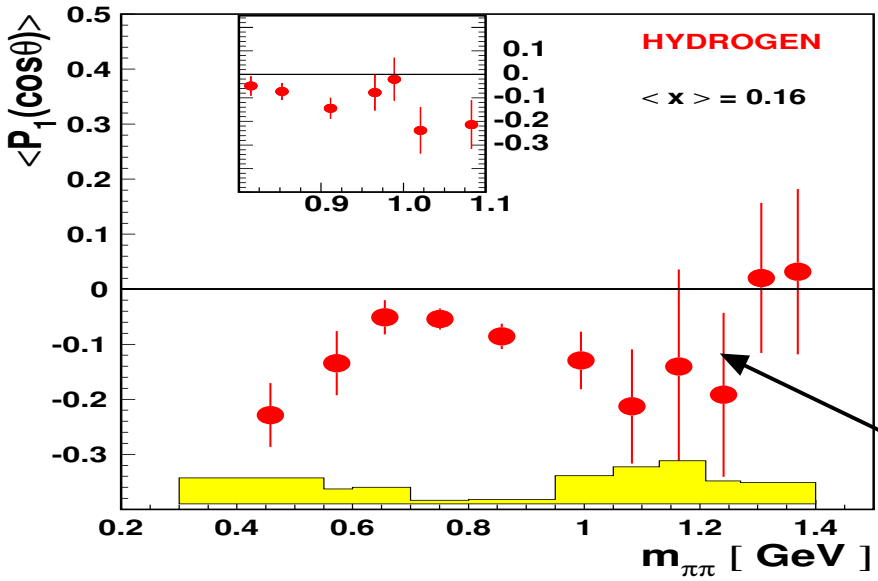
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

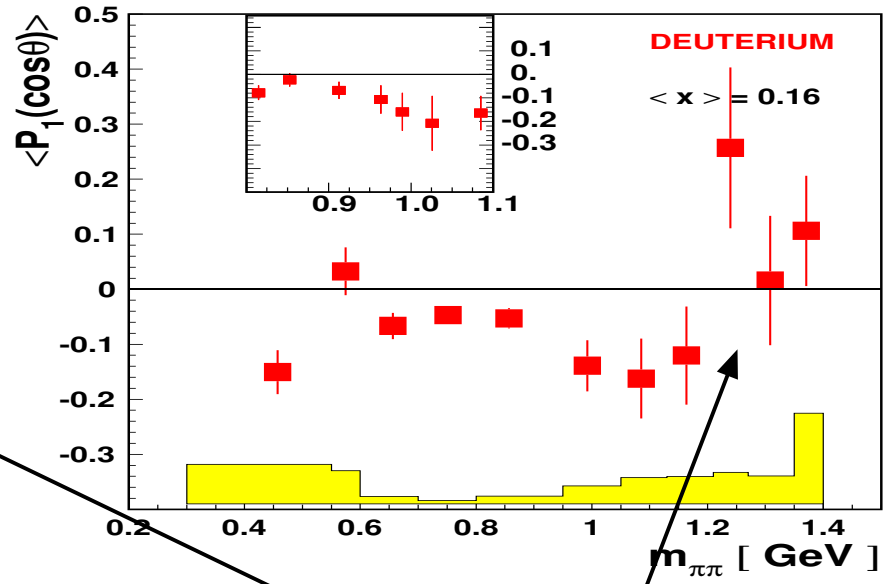




Minimum interference between S-P waves $m_{\pi\pi} \sim 0.77\,\text{GeV}$

$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

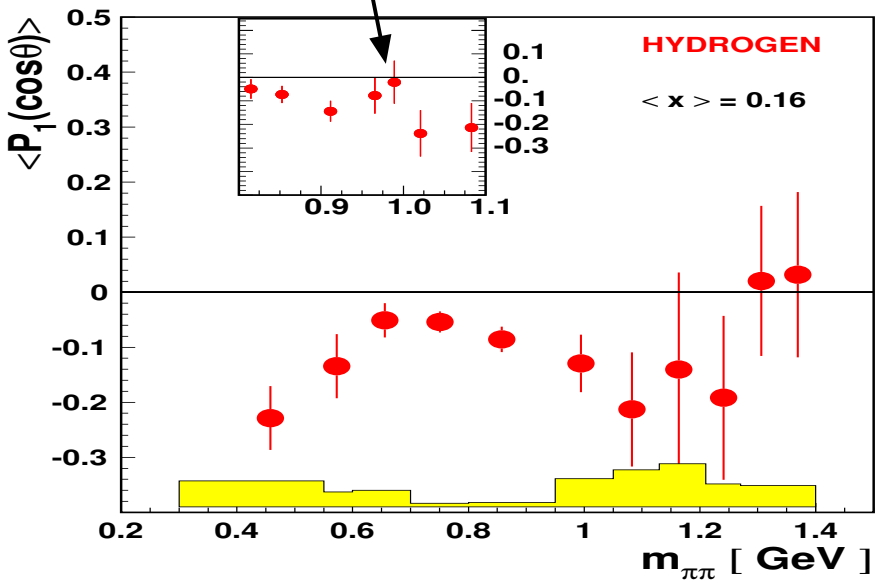


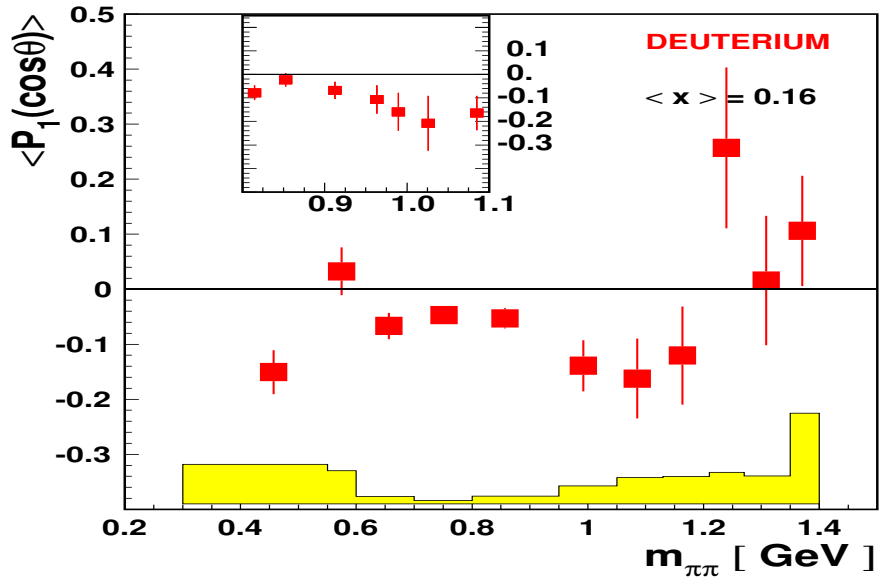


Indication of ρ^0-f_2 interference $m_{\pi\pi} \sim 1.3\,\text{GeV}$

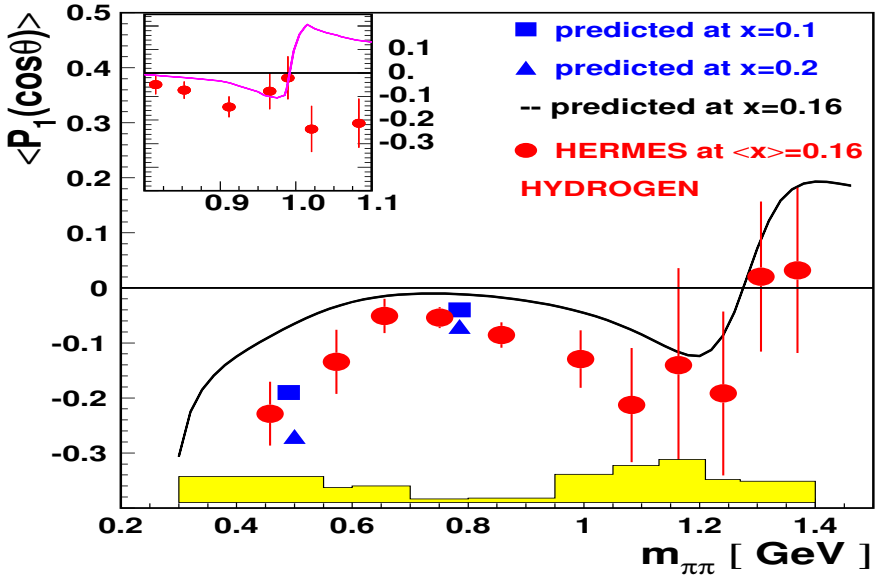
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

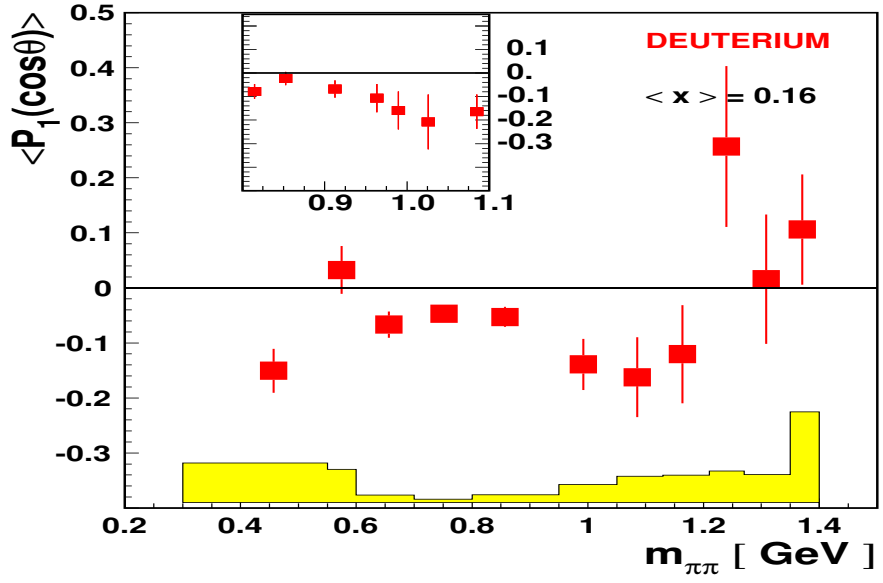
ρ^0-f_0 interference?





$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

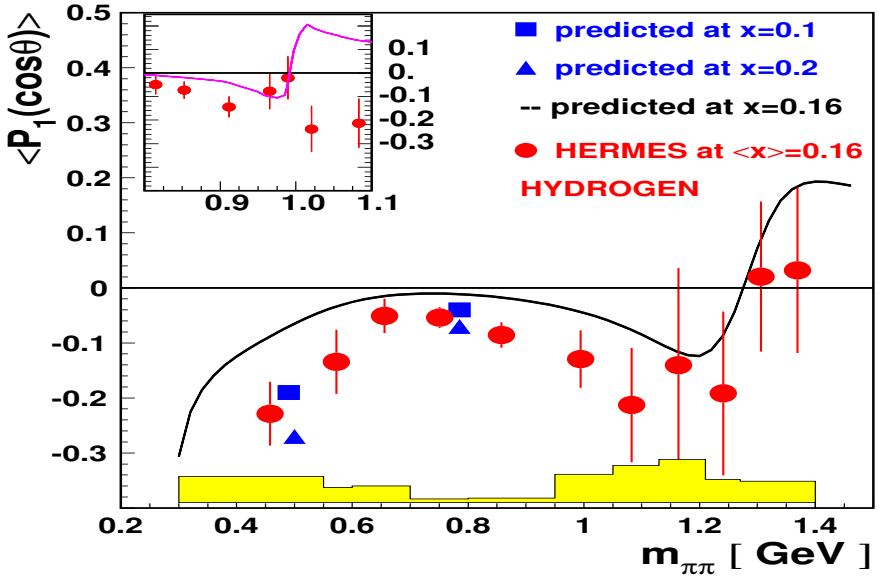


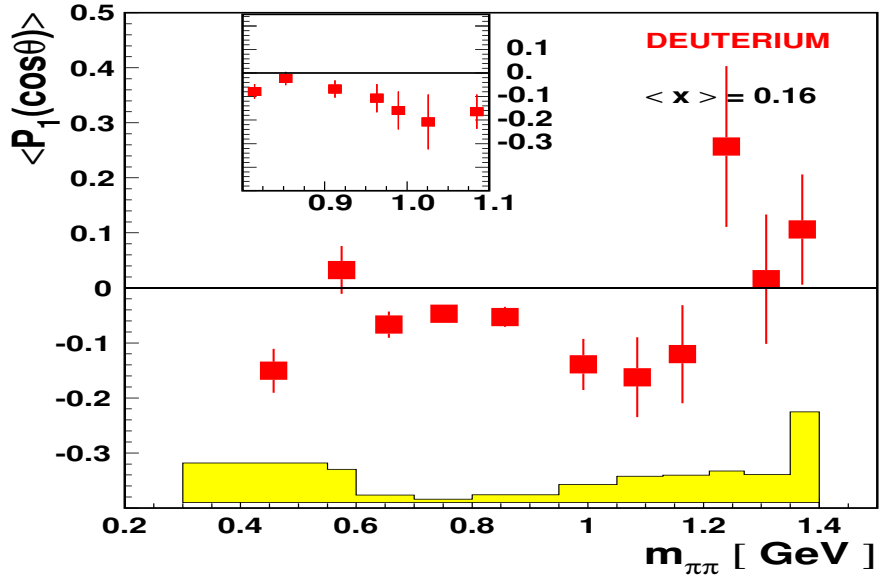


- B.Lehmann-Dronke, P.V.Pobylitsa, M.V.Polyakov, A.Schäfer, K.Goeke:
  - Phys. Lett. B **475**, (2000) 147, $\Rightarrow$ **gluon *GPD* neglected**
  - Phys.Rev. D **63**, (2001) 114001, $\Rightarrow$ **with gluon *GPD* in the nucleon**
- Ph. Hägler et al.:
  - Eur. Phys. Jour. C 26 (2002) 261

$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

Reasonable agreement of GPD theory with data

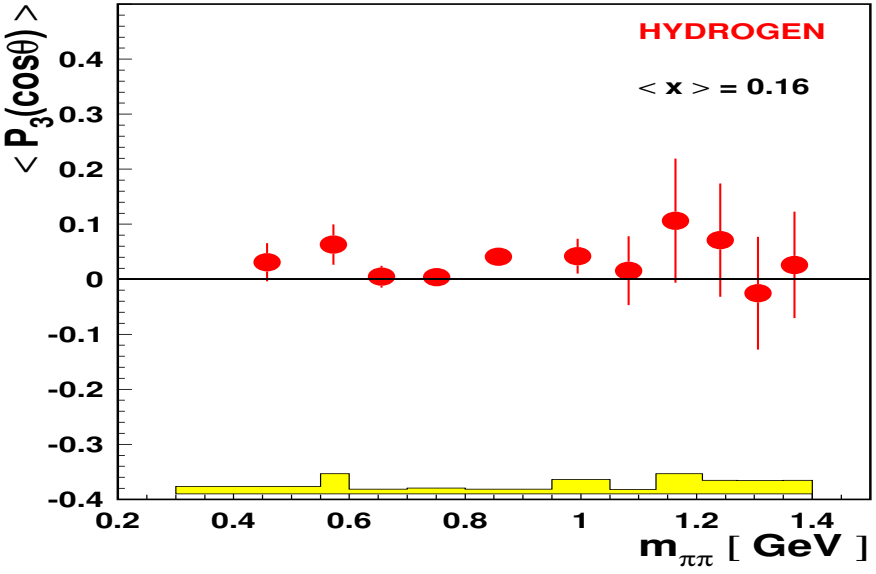


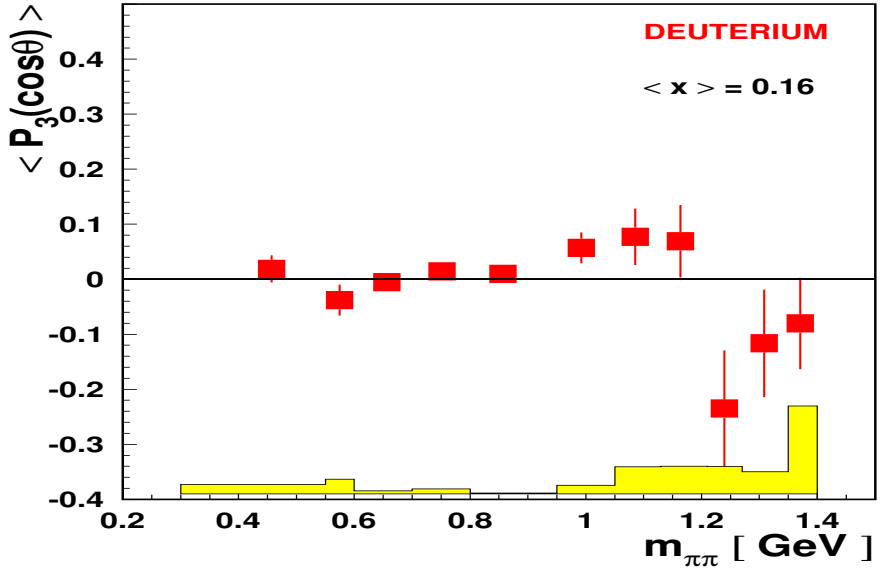


- B.Lehmann-Dronke, P.V.Pobylitsa, M.V.Polyakov, A.Schäfer, K.Goeke:
  - Phys. Lett. B **475**, (2000) 147, $\Rightarrow$ **gluon *GPD* neglected**
  - Phys.Rev. D **63**, (2001) 114001, $\Rightarrow$ **with gluon *GPD* in the nucleon**
- Ph. Hägler et al.:
  - Eur. Phys. Jour. C 26 (2002) 261

$m_{\pi\pi}$-dependence of $\langle P_3(cos\theta)\rangle$

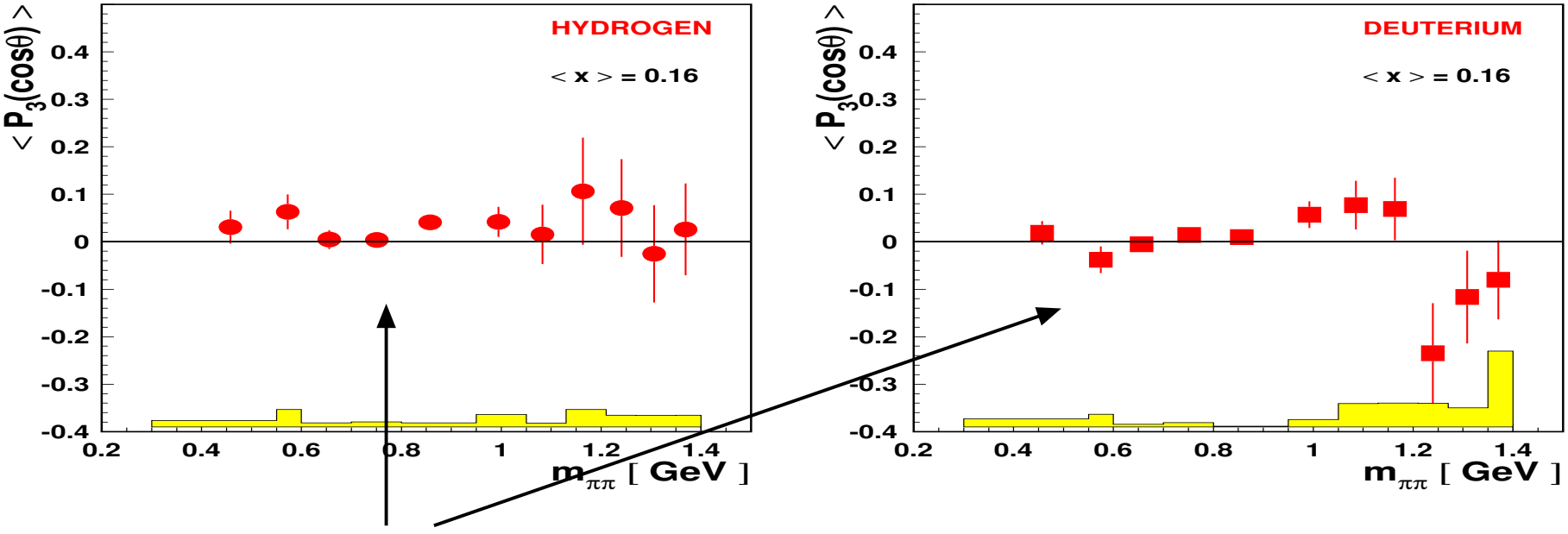
☞ $\langle P_3(cos\theta)\rangle$ **sensitive to** ρ^0-f_2 **interference ONLY!**





$m_{\pi\pi}$-dependence of $\langle P_3(cos\theta)\rangle$

☞ $\langle P_3(cos\theta)\rangle$ **sensitive to** ρ^0**-**f_2 **interference ONLY!**

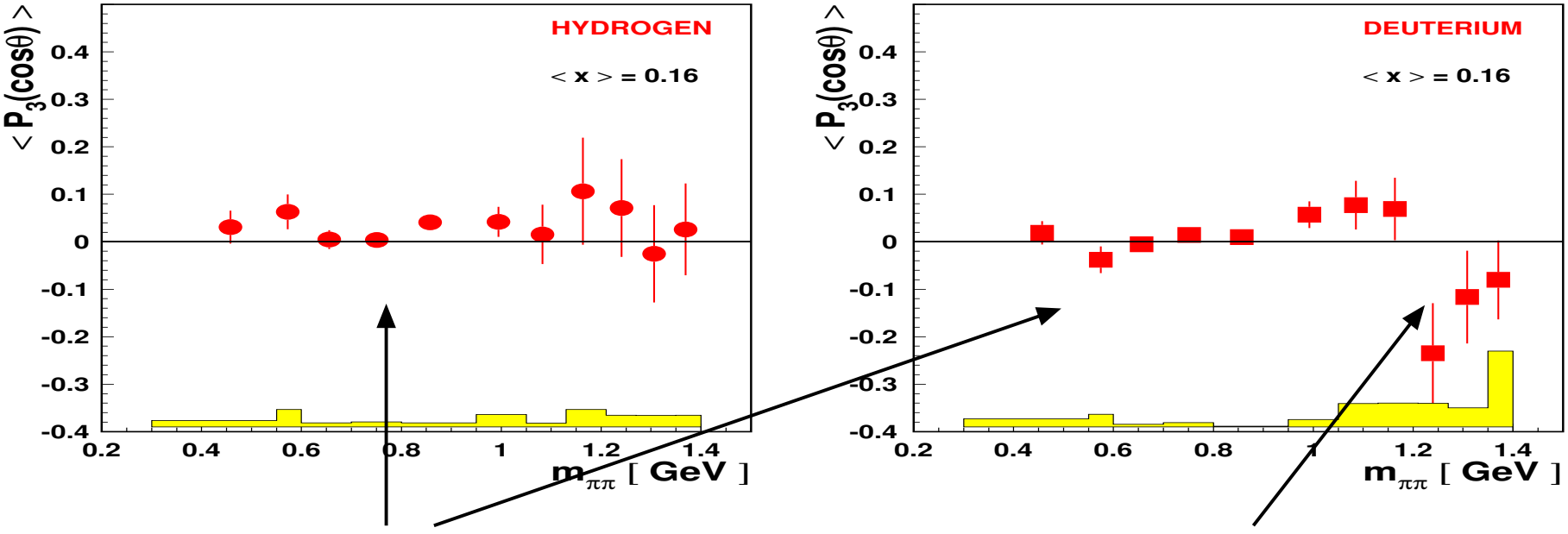


D-wave not expected:

☞ **flat null distribution!**

$m_{\pi\pi}$-dependence of $\langle P_3(cos\theta)\rangle$

☞ $\langle P_3(cos\theta)\rangle$ **sensitive to** ρ^0-f_2 **interference ONLY!**

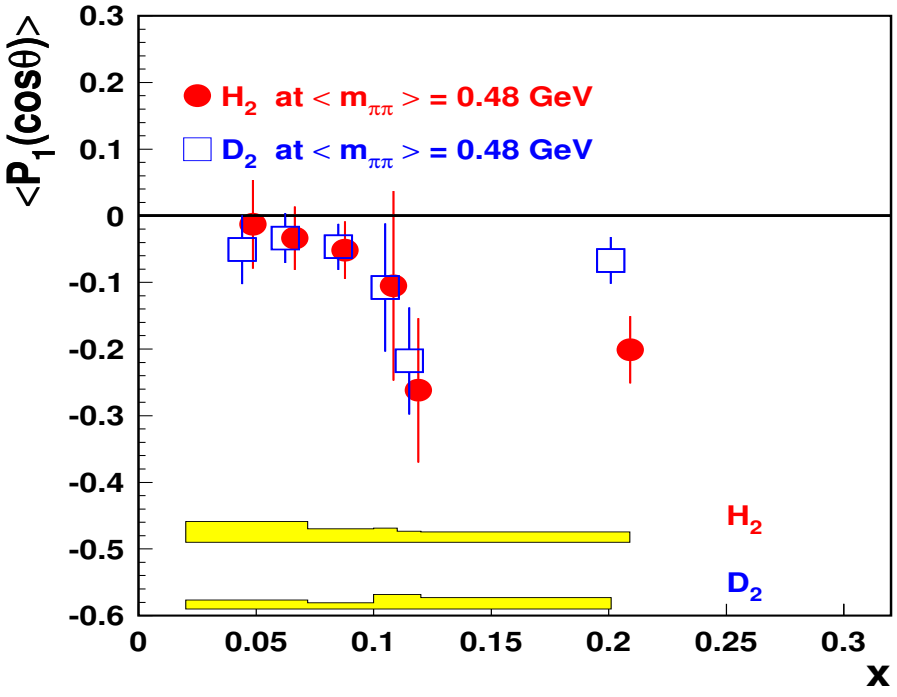


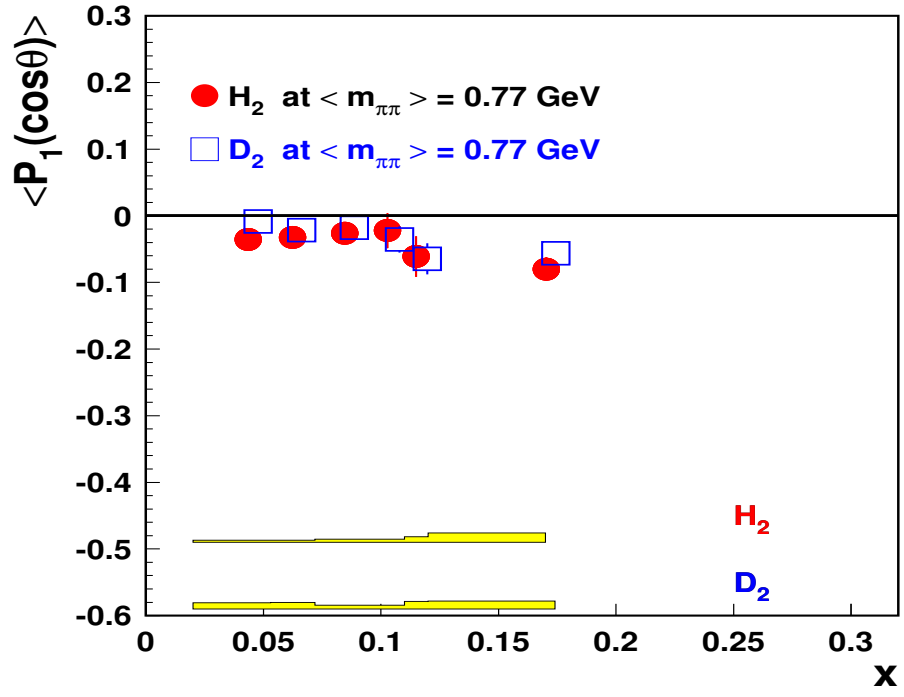
D-wave not expected:

☞ **flat null distribution!**

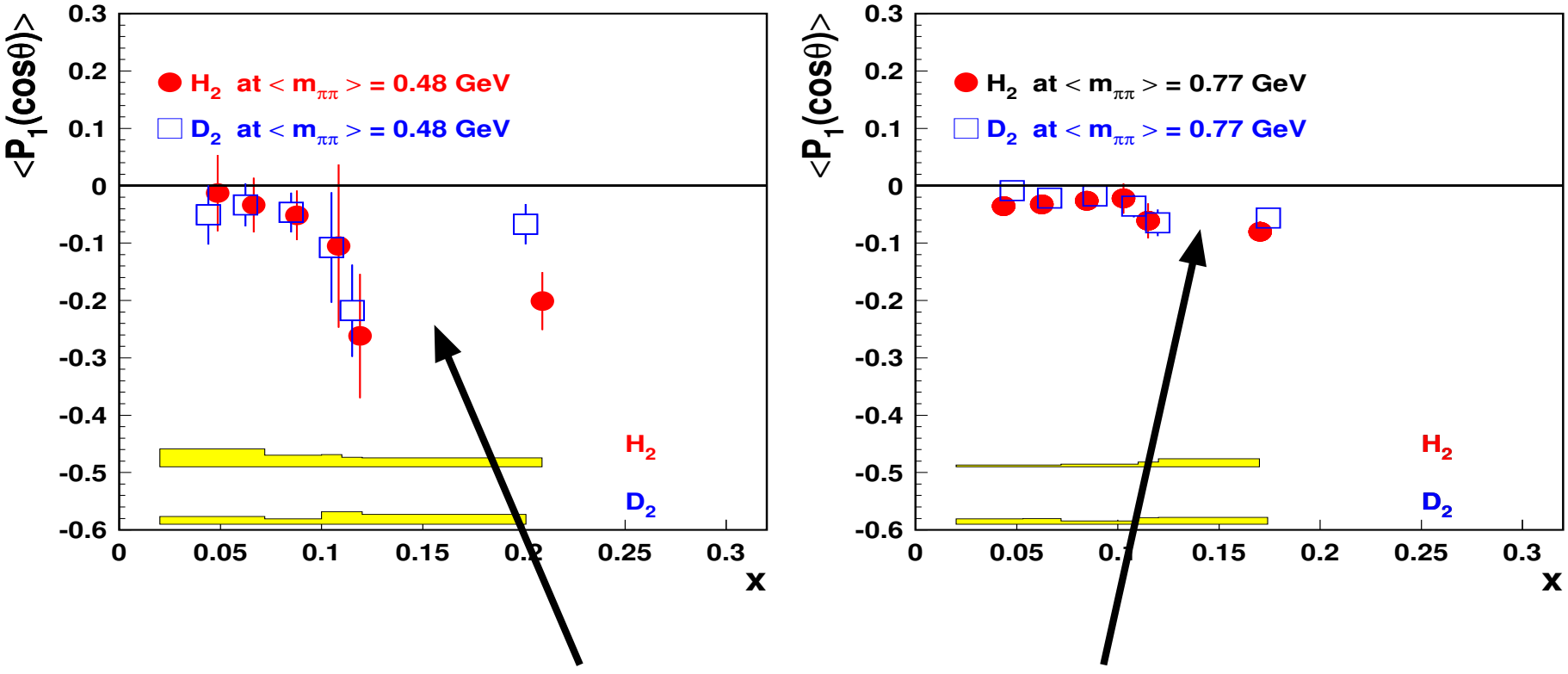
Indication of ρ^0-f_2 interference $m_{\pi\pi} \sim 1.3\,\text{GeV}$

x-dependence of $\langle P_1(cos\theta)\rangle$



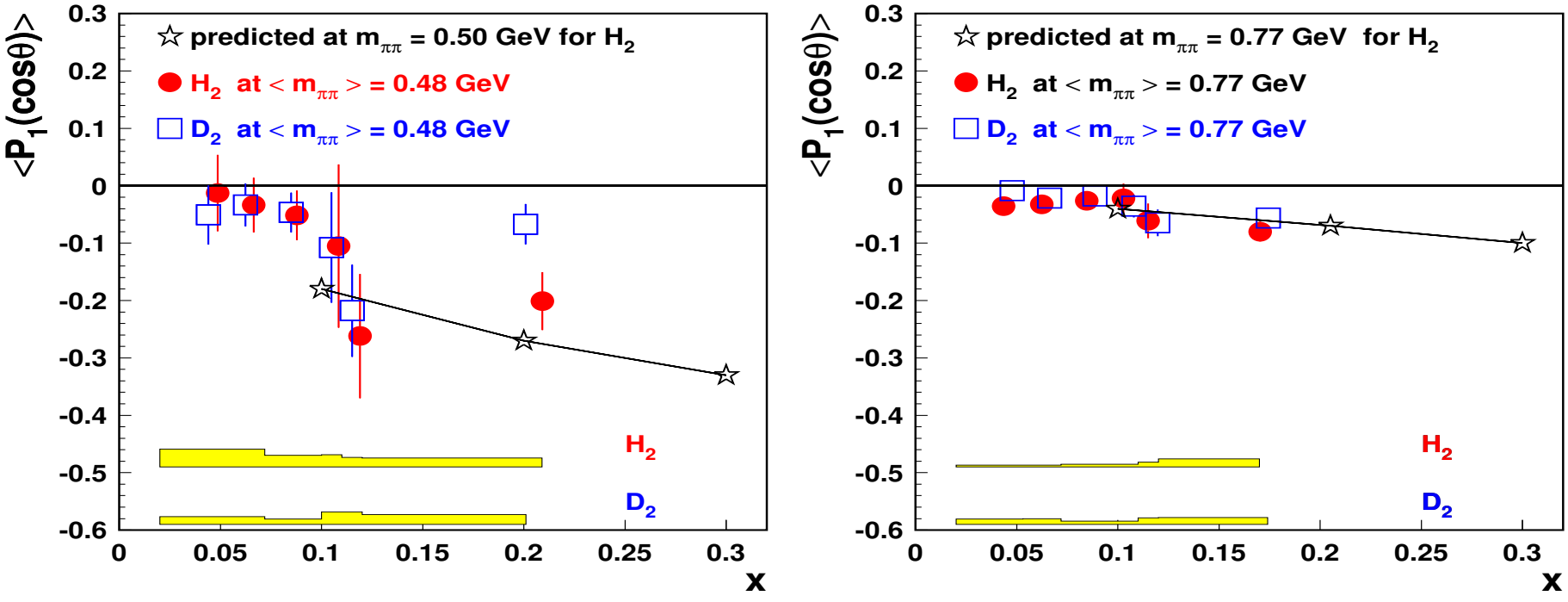


x-dependence of $\langle P_1(cos\theta)\rangle$



Increasing interference VS x between
non-resonant S-wave and ρ^0
$\Rightarrow$ increased contribution of non-singlet $q\bar{q}$ exchange

x-dependence of $\langle P_1(cos\theta)\rangle$

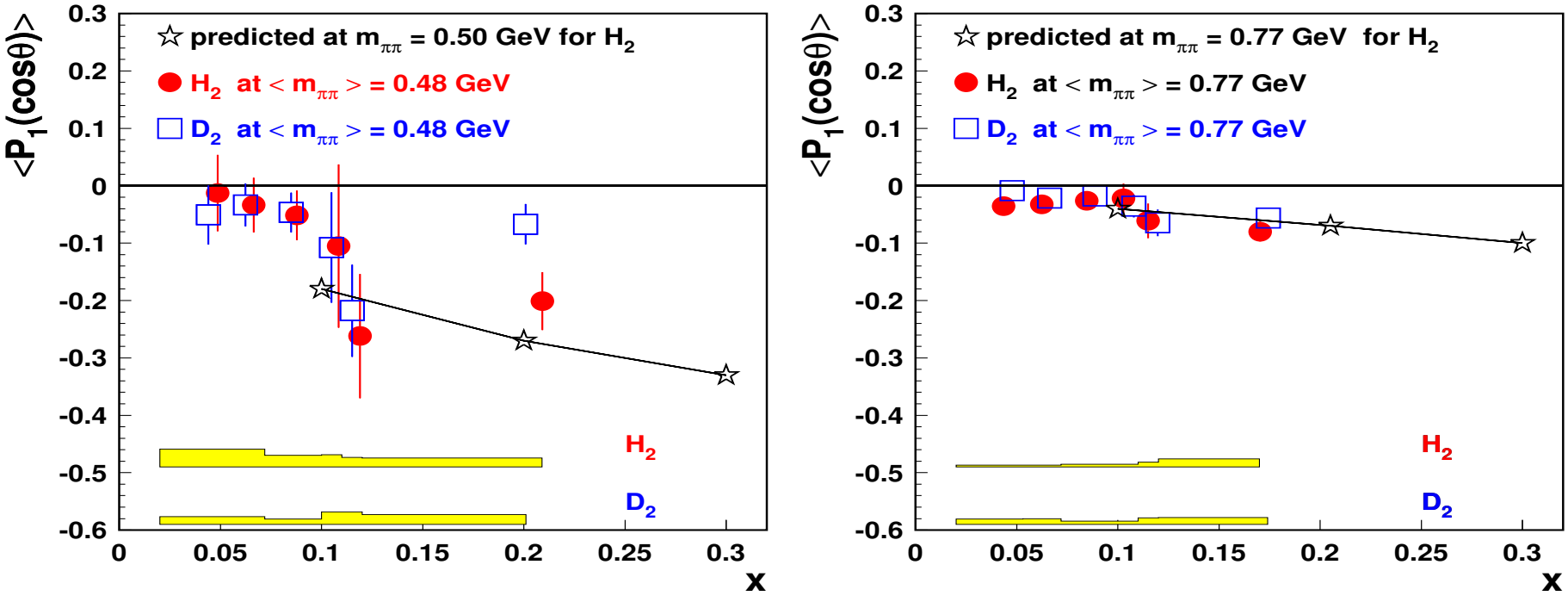


✦ B.Lehmann-Dronke, P.V.Pobylitsa, M.V.Polyakov, A.Schäfer, K.Goeke:

☞ Phys. Lett. B **475**, (2000) 147

$\Rightarrow$ **gluon** *GPD* **neglected**

x-dependence of $\langle P_1(cos\theta)\rangle$



- B.Lehmann-Dronke, P.V.Pobylitsa, M.V.Polyakov, A.Schäfer, K.Goeke:
  - Phys. Lett. B **475**, (2000) 147
    - $\Rightarrow$ **gluon** *GPD* **neglected**

Reasonable agreement of theory with data

Disentangle the f-meson Family

Analizing Legendre moments in the f_2 region:

Longitudinal f_2:

$$\langle P_1 + \tfrac{7}{3} P_3 \rangle = 2\sqrt{\tfrac{5}{3}}\rho_{00}^{21}$$

Transverse f_2:

$$\langle P_1 - \tfrac{14}{9} P_3 \rangle = \tfrac{4\sqrt{5}}{3}\rho_{11}^{21}$$

Disentangle the f-meson Family

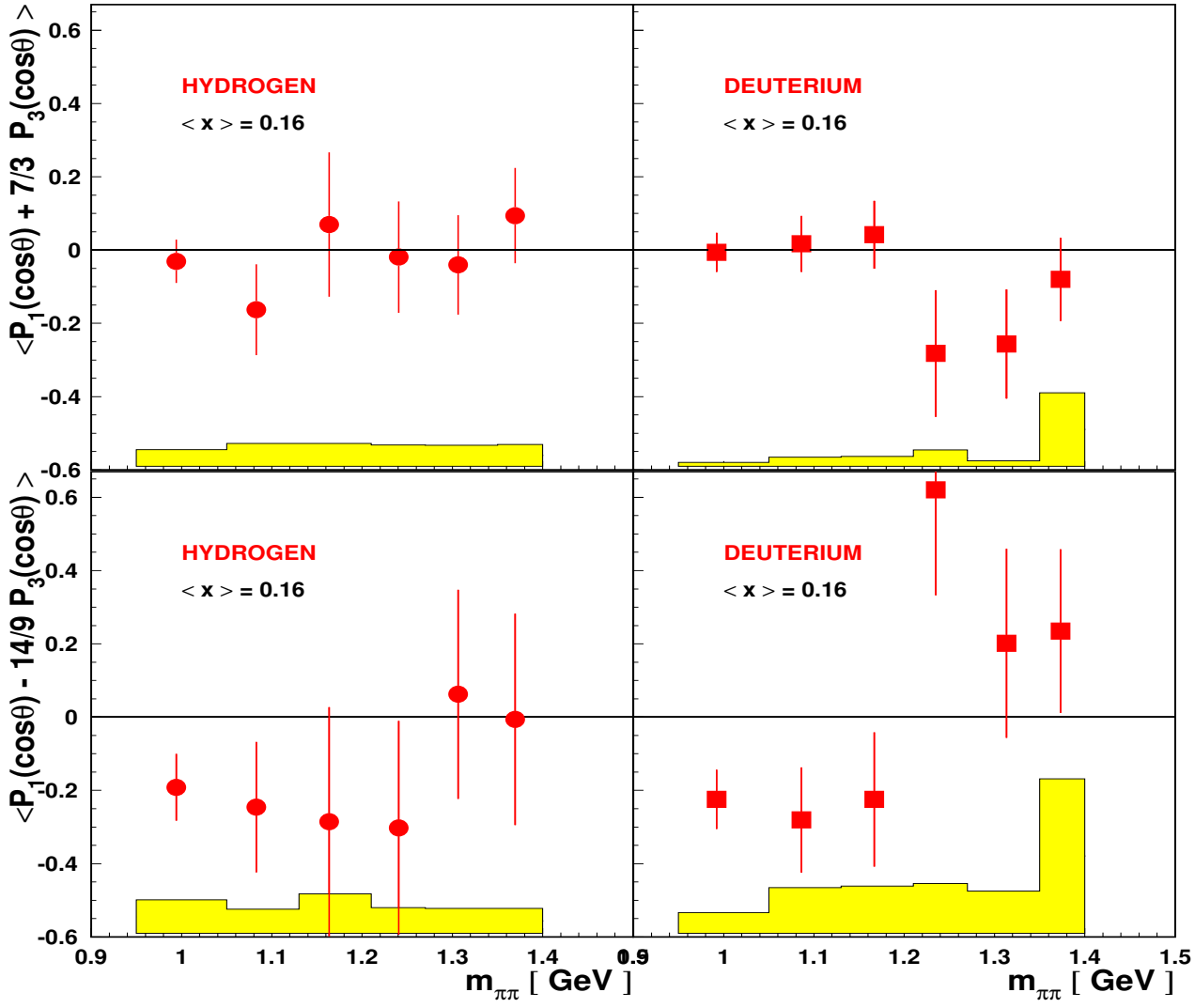
Analizing Legendre moments in the f_2 region:

Longitudinal f_2:

$$\langle P_1 + \tfrac{7}{3} P_3 \rangle = 2\sqrt{\tfrac{5}{3}}\rho^{21}_{00}$$

Transverse f_2:

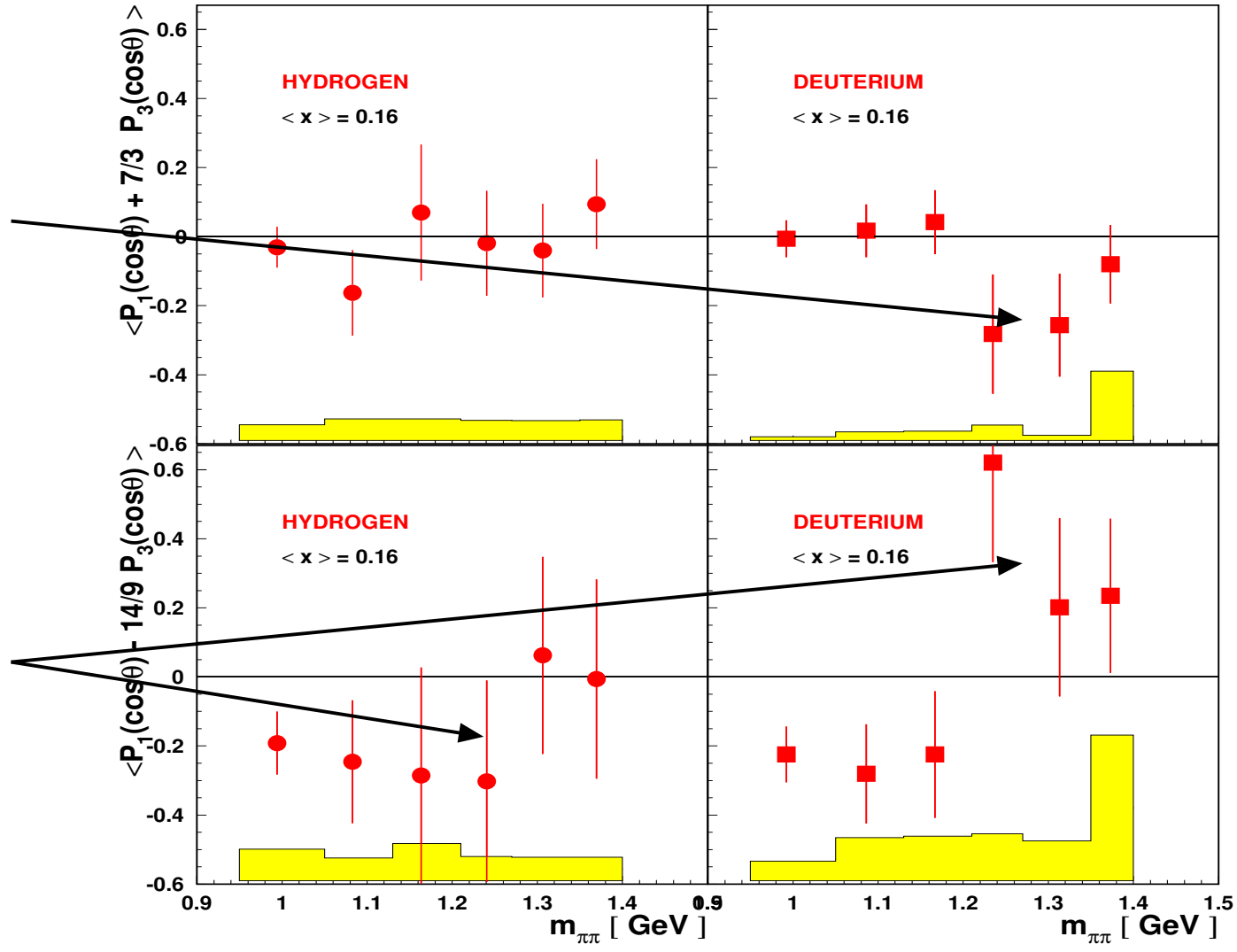
$$\langle P_1 - \tfrac{14}{9} P_3 \rangle = \tfrac{4\sqrt{5}}{3}\rho^{21}_{11}$$



Disentangle the f-meson Family

Indication of interference between ρ^0 and longitudinal f_2

Indication of interference between ρ^0 and transverse f_2

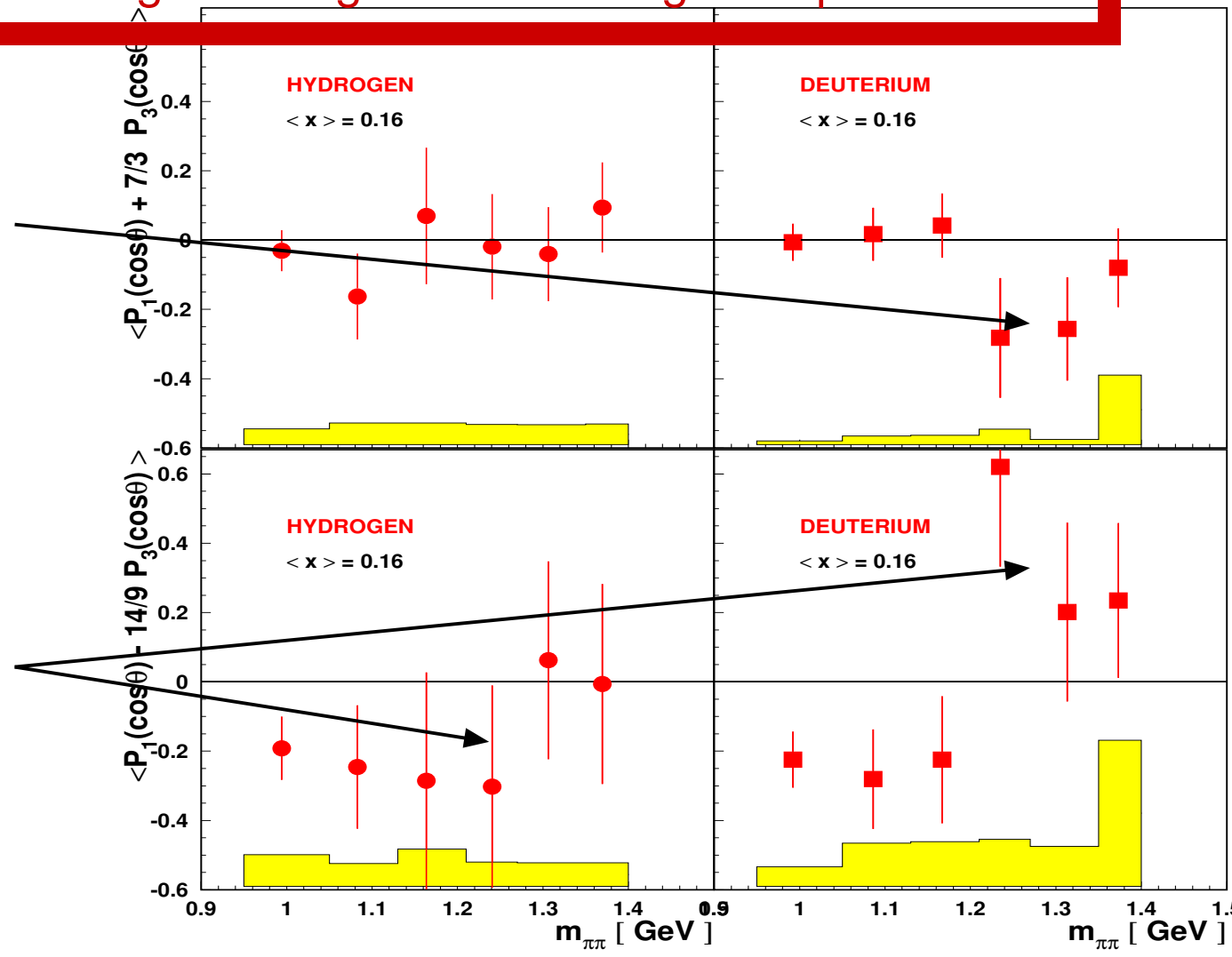


Disentangle the f-meson Family

In f_2-region higher-twist transverse contribution to moments possibly as large as longitudinal leading-twist production

Indication of interference between ρ^0 and longitudinal f_2

Indication of interference between ρ^0 and transverse f_2



Conclusions

- First measurement of angular asymmetry in $\pi^+\pi^-$ hard exclusive electroproduction;

Conclusions

- First measurement of angular asymmetry in $\pi^+\pi^-$ hard exclusive electroproduction;
- Results on Legendre Moments show signatures of $I = 1$ and $I = 0$ interference:
  $\Rightarrow$ elusive f-meson family channel highlighted;

Conclusions

- First measurement of angular asymmetry in $\pi^+\pi^-$ hard exclusive electroproduction;
- Results on Legendre Moments show signatures of $I = 1$ and $I = 0$ interference:
  $\Rightarrow$ elusive f-meson family channel highlighted;
- Different contributions from f-family disentangled:
  $\Rightarrow$ Higher-twist transverse contribution as large as longitudinal leading-twist one in f_2 region;

Conclusions

- First measurement of angular asymmetry in $\pi^+\pi^-$ hard exclusive electroproduction;
- Results on Legendre Moments show signatures of $I = 1$ and $I = 0$ interference:
  $\Rightarrow$ elusive f-meson family channel highlighted;
- Different contributions from f-family disentangled:
  $\Rightarrow$ Higher-twist transverse contribution as large as longitudinal leading-twist one in f_2 region;
- Good agreement between data and theory:
  $\Rightarrow$ possible constraints of the *GPD*s.
  $\Rightarrow$ constraints of the non-singlet $q\bar{q}$ distribution.

Conclusions

- First measurement of angular asymmetry in $\pi^+\pi^-$ hard exclusive electroproduction;
- Results on Legendre Moments show signatures of $I = 1$ and $I = 0$ interference:
  $\Rightarrow$ elusive f-meson family channel highlighted;
- Different contributions from f-family disentangled:
  $\Rightarrow$ Higher-twist transverse contribution as large as longitudinal leading-twist one in f_2 region;
- Good agreement between data and theory:
  $\Rightarrow$ possible constraints of the *GPD*s.
  $\Rightarrow$ constraints of the non-singlet $q\bar{q}$ distribution.

Possible development:

Analysis of Legendre Moments at low x sensitive to Odderon $(3g)$-Pomeron $(2g)$ interference.