gdh-Collaboration

INFN

Helicity dependence of the $N\pi(\pi)$ photoproduction: new results from Mainz

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for the GDH and A2 collaborations

NStar 2002

Nstar 2002 Workshop - Pittsburgh

SUMMARY

- Physical motivations
- Experimental setup
- Results $[\vec{\gamma}\vec{p} \rightarrow N\pi(\pi)]$
- Future outlook $[\vec{\gamma}\vec{n} \rightarrow N\pi(\pi)]$ (with some results)
- Conclusions

The GDH collaboration

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Experimental Programme

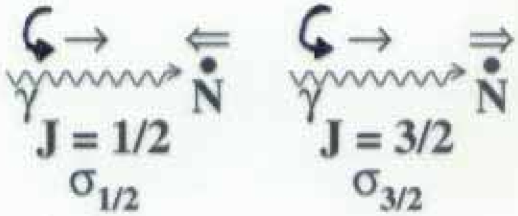
- Experimental check of the Gerasimov-Drell-Hearn sum rule both for proton and neutron at
  - Mainz (MAMI) ($m_\pi \leq E_\gamma \leq$ 800 MeV)
  - Bonn (ELSA) (600 MeV$\leq E_\gamma \leq$ 3 GeV)

- Measurement at Mainz of the helicity dependence of all the
  - $\gamma N \rightarrow N\pi$
  - $\gamma N \rightarrow N\pi\pi$

  channels as a powerful tool to study the properties of baryon resonances $(\Delta, P_{11}, D_{13}, S_{11})$

Gerasimov-Drell-Hearn sum rule

- derived by S.B.Gerasimov (1966) – S.D.Drell, A.C.Hearn (1966)
- absorption of circularly polarized photons by longitudinally polarized nucleons



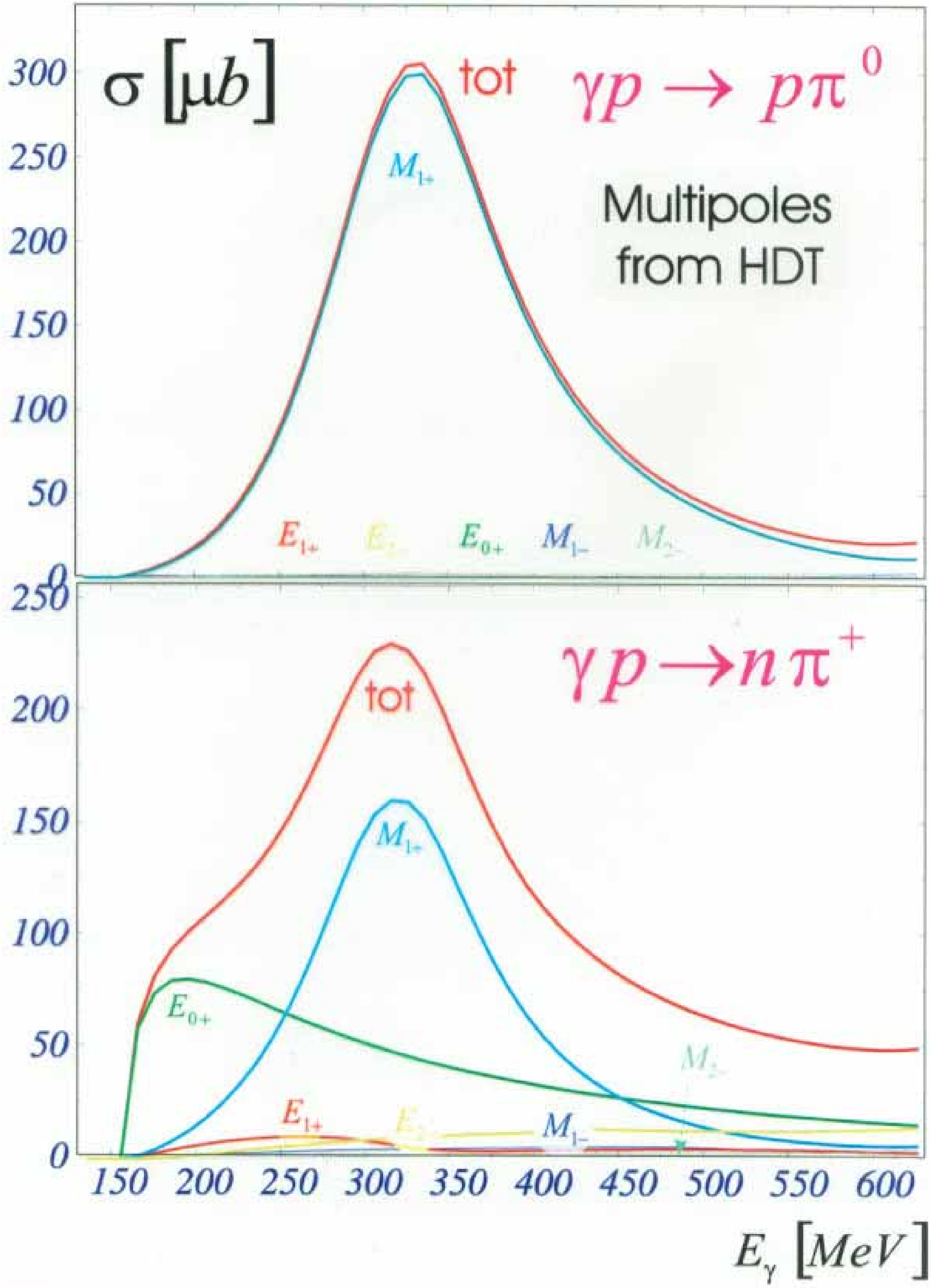
- causality (unsubtracted dispersion relation), optical theorem, low-energy theorems

$$\int_{m_\pi}^{\infty} \frac{(\sigma_{3/2} - \sigma_{1/2})}{E_\gamma}\, \mathrm{d}E_\gamma = \frac{2\pi^2\alpha}{m^2}\kappa^2$$

- fundamental check of our knowledge of the γN interaction
- important comparison test for nucleon models
- "spin polarizability" γ_0 :

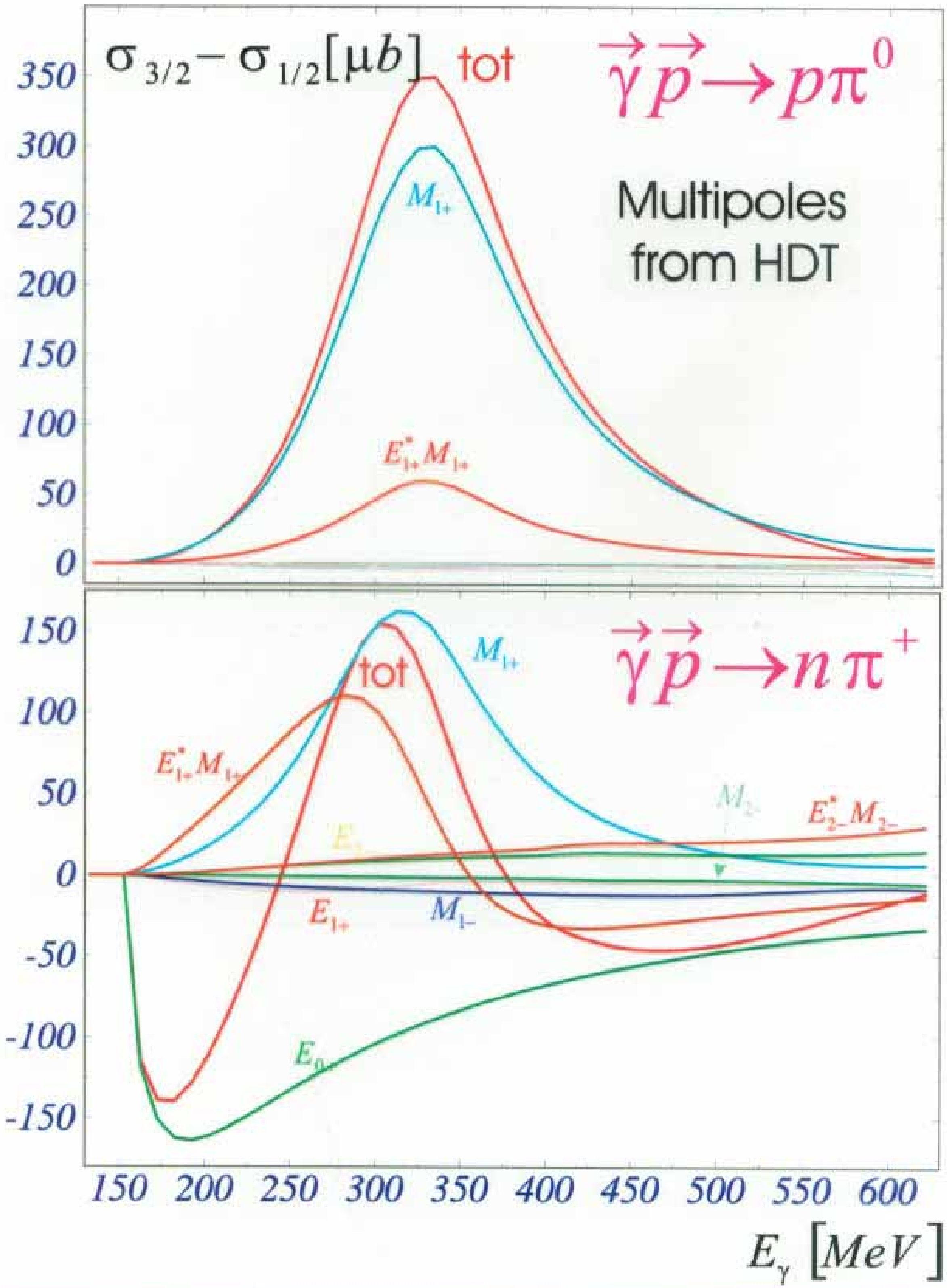
$$\gamma_0 = -\frac{1}{4\pi}\int_{m_\pi}^{\infty} \frac{(\sigma_{3/2} - \sigma_{1/2})}{E_\gamma^3}\, \mathrm{d}E_\gamma$$

Motivation



σ [μb]
tot
$\gamma p \to p\pi^0$
M_{1+}
Multipoles from HDT
E_{1+}
E_{0+}
M_{1-}
$\gamma p \to n\pi^+$
tot
M_{1+}
E_{0+}
E_{1+}
M_{1-}
0
50
100
150
200
250
300
150
200
250
300
350
400
450
500
550
600
E_γ [MeV]

Motivation



$\sigma_{3/2} - \sigma_{1/2} [\mu b]$
tot
$\vec{\gamma}\vec{p} \to p\pi^0$
M_{1+}
Multipoles from HDT
$E^*_{1+}M_{1+}$
$\vec{\gamma}\vec{p} \to n\pi^+$
tot
$E^*_{1+}M_{1+}$
M_{2-}
$E^*_{2-}M_{2-}$
E_{1+}
M_{1-}
E_{0+}
350
300
250
200
150
100
50
0
150
100
50
0
-50
-100
-150
150 200 250 300 350 400 450 500 550 600
E_γ [MeV]

Helicity amplitudes

$$A_{1/2} = \frac{1}{\sqrt{2q}}\langle N^*(J, M = 1/2)|J_+|N(J_i = 1/2, M_i = -1/2)\rangle$$
$$A_{3/2} = \frac{1}{\sqrt{2q}}\langle N^*(J, M = 3/2)|J_+|N(J_i = 1/2, M_i = +1/2)\rangle$$

q : photon momentum

J_+ : hadronic current corresponding to the absorption of a γ with positive helicity on a nucleon N with spin J_i and spin projection M_i leading to a resonance state N^* with spin $J \geq 1/2$ and spin projection M

- J_+ strongly depends in the quark-quark interactions ($\Rightarrow$ NPQCD)
- helicity amplitudes related to e.m. multipoles, e.g.

$$M_{1+} = -\frac{1}{2\sqrt{3}}(\sqrt{3}A_{1/2} + 3A_{3/2})$$
$$E_{1+} = -\frac{1}{2\sqrt{3}}(\sqrt{3}A_{1/2} - A_{3/2})$$

- $\sigma_{unpol} \propto |A_{1/2}|^2 + |A_{3/2}|^2$

Motivations

Helicity Amplitudes (Proton target)

(units of 10^{-3} GeV$^{-1/2}$)

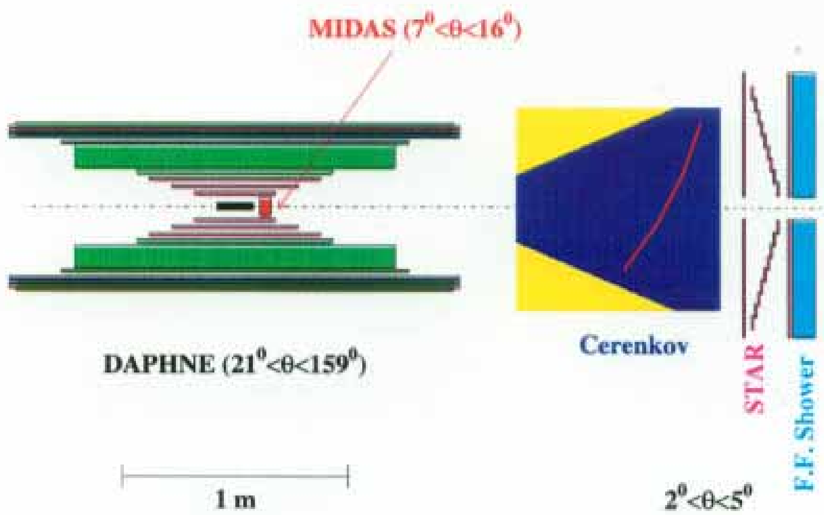
	P_{33} (1232)		P_{11} (1440)	D_{13} (1520)		S_{11} (1535)
	$A^p_{1/2}$	$A^p_{3/2}$	$A^p_{1/2}$	$A^p_{1/2}$	$A^p_{3/2}$	$A^p_{1/2}$
NRCQM (Isgur-Karl)	-103	-179	-24	-23	+128	+147
NRCQM (Sartor-Stancu)	-101	-181	-31	+45	+202	+203
RCQM (Close-Li)	-113	-195	+10	-30	+146	+163
NRCQM+Mix. (Close-Li)	-94	-162	-93	-51	+133	+142
NRCQM+RC (Pfeil *et al.*)	-93	-163	-105	-79	+55	+116
RCQM (Pfeil *et al.*)	-81	-170	-9	-7	+63	+54
RCQM (Kapstick)	-108	-186	+4	-15	+134	+76
Light Front (Kapstick)	-100	-180	+35	+25	+200	+90
Algebraic appr. (Iachello *et al.*)	-91	-157	0	-43	+109	+162
NRCQM+Mix. (Giannini *et al.*)	-93	-162	-69	-47	+85	+116
P.W.Analyses	[-147,-128]	[-264,-247]	[-129,-58]	[-43,-5]	[75,206]	[29,125]
PDB best value	-135±6	-255±8	-65±4	-24±9	+166±5	+90±30

PREVIOUS VALUE

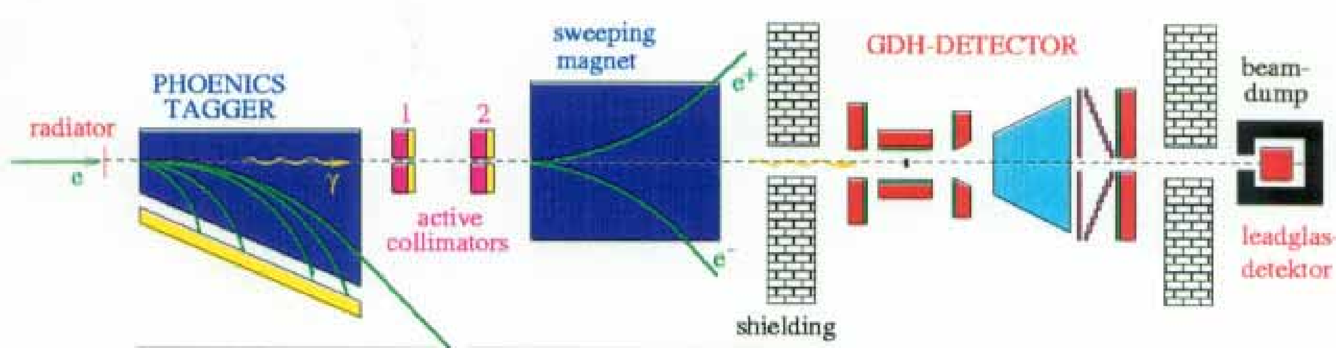
Experimental set-up

- Tagged photon facility of the MAMI/ELSA accelerators
- circularly polarized photons ⇒ helicity transfer from brems-strahlung of linearly polarized electrons (strained GaAs sourc
- Longitudinally polarized nucleons
  - "frozen spin" (deuterated) butanol [$C_4\,H(D)_9\,OH(D)$]
  - ^{6}LiD target (future: ^{3}He gas target)

The GDH Detector at MAMI

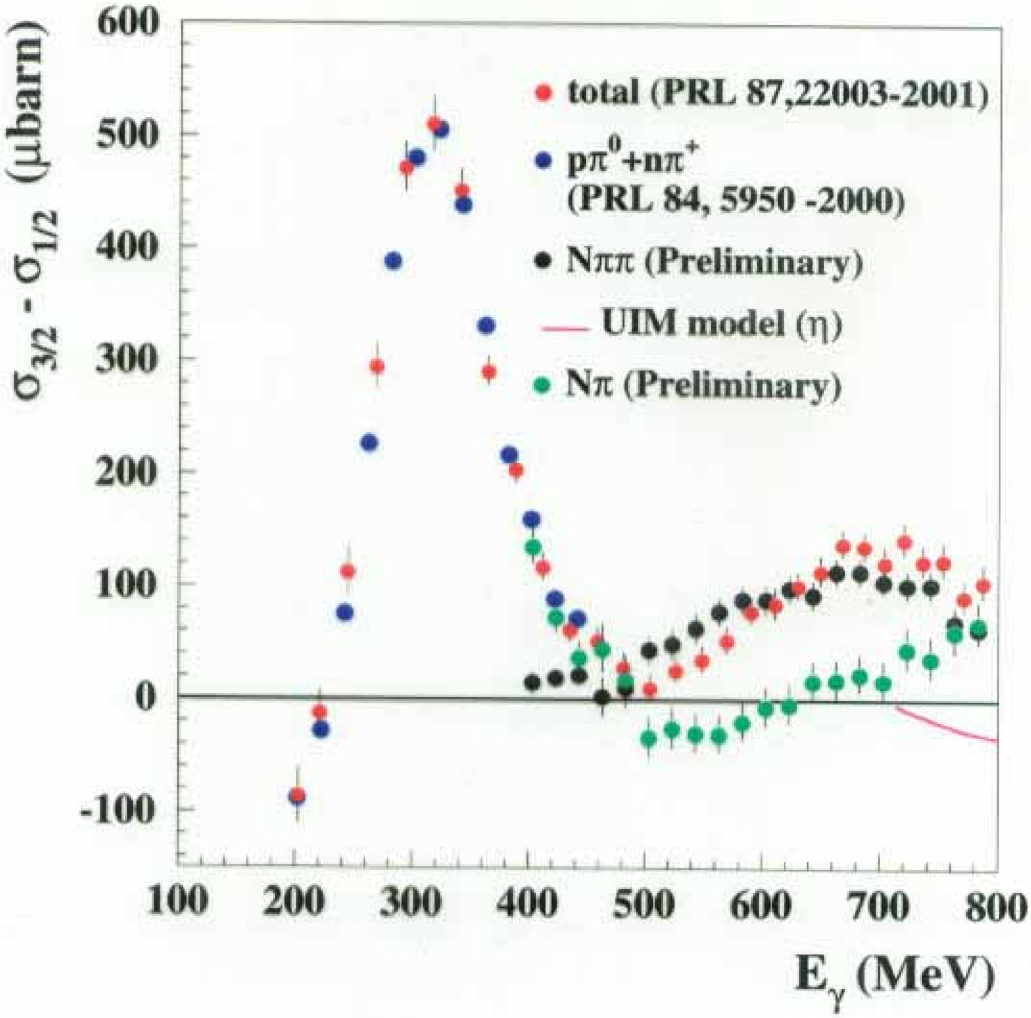


The GDH detector at Bonn



Results

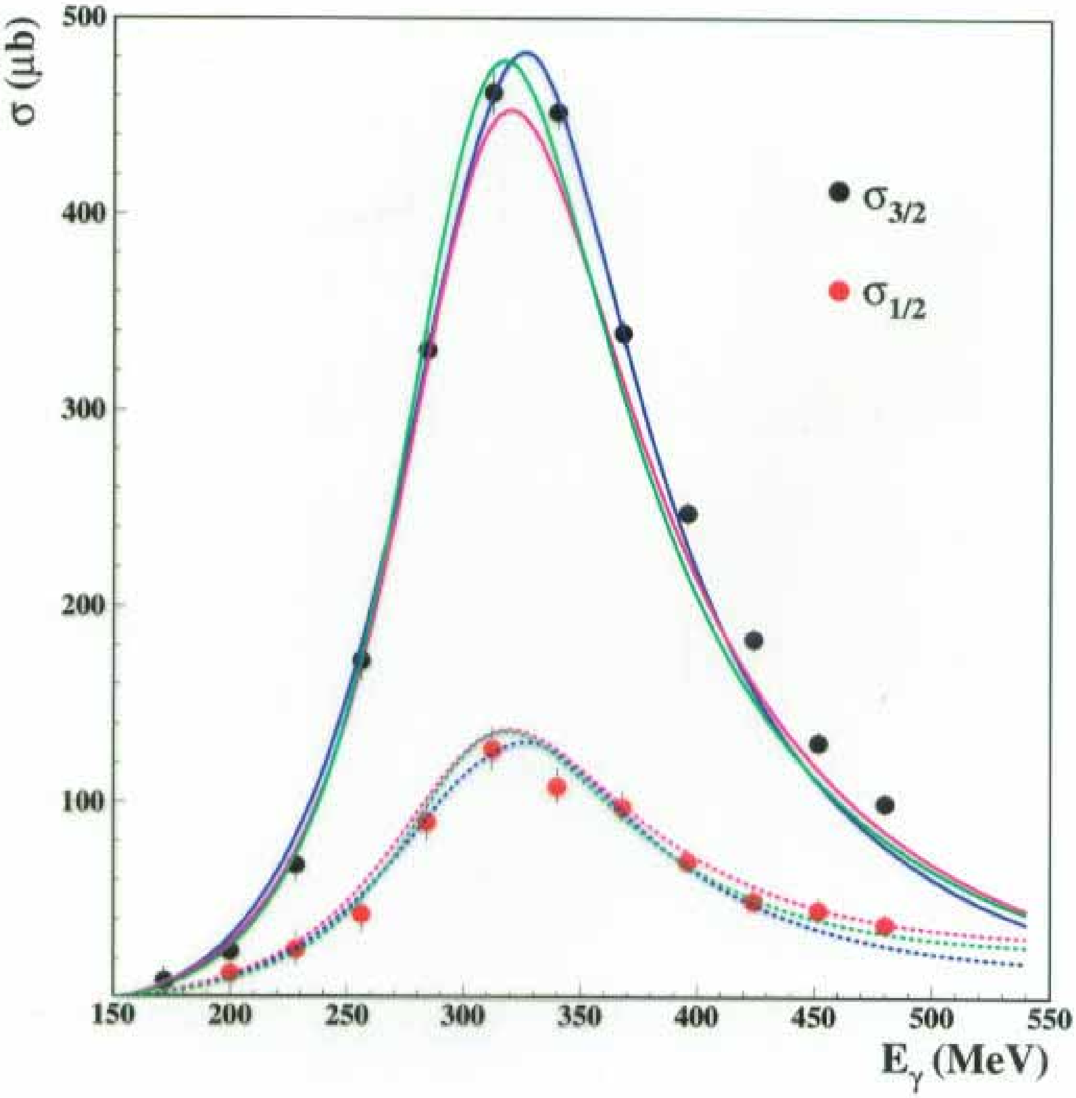
$\vec{\gamma}\vec{p} \rightarrow hadrons$



- $(N\pi)$ cross section above 450 MeV = (total) − $(N\pi\pi)$ − $(N\rho)$

Results

$\vec{\gamma}\vec{p} \rightarrow p\pi^0$



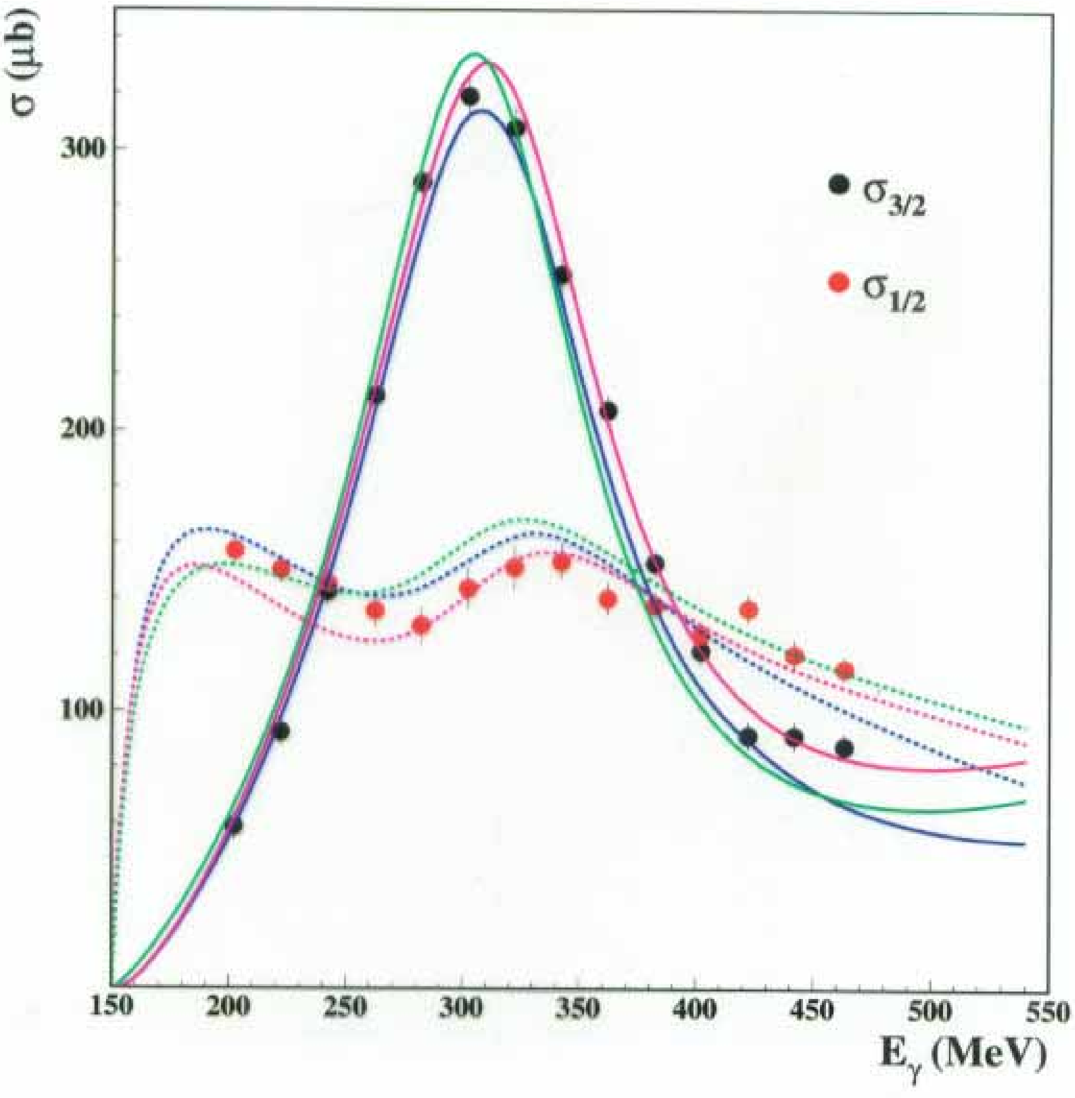
HDT: dispersion theory, Hanstein et al., NPA 632, 521 (99)

SAID: multipole analysis (solution SM02K), R.Arndt et al., nucl-th/0205067

UIM (MAID): multipole analysis, Drechsel et al., PRD 59, 094021 (99)

Results

$\vec{\gamma}\vec{p} \rightarrow n\pi^+$



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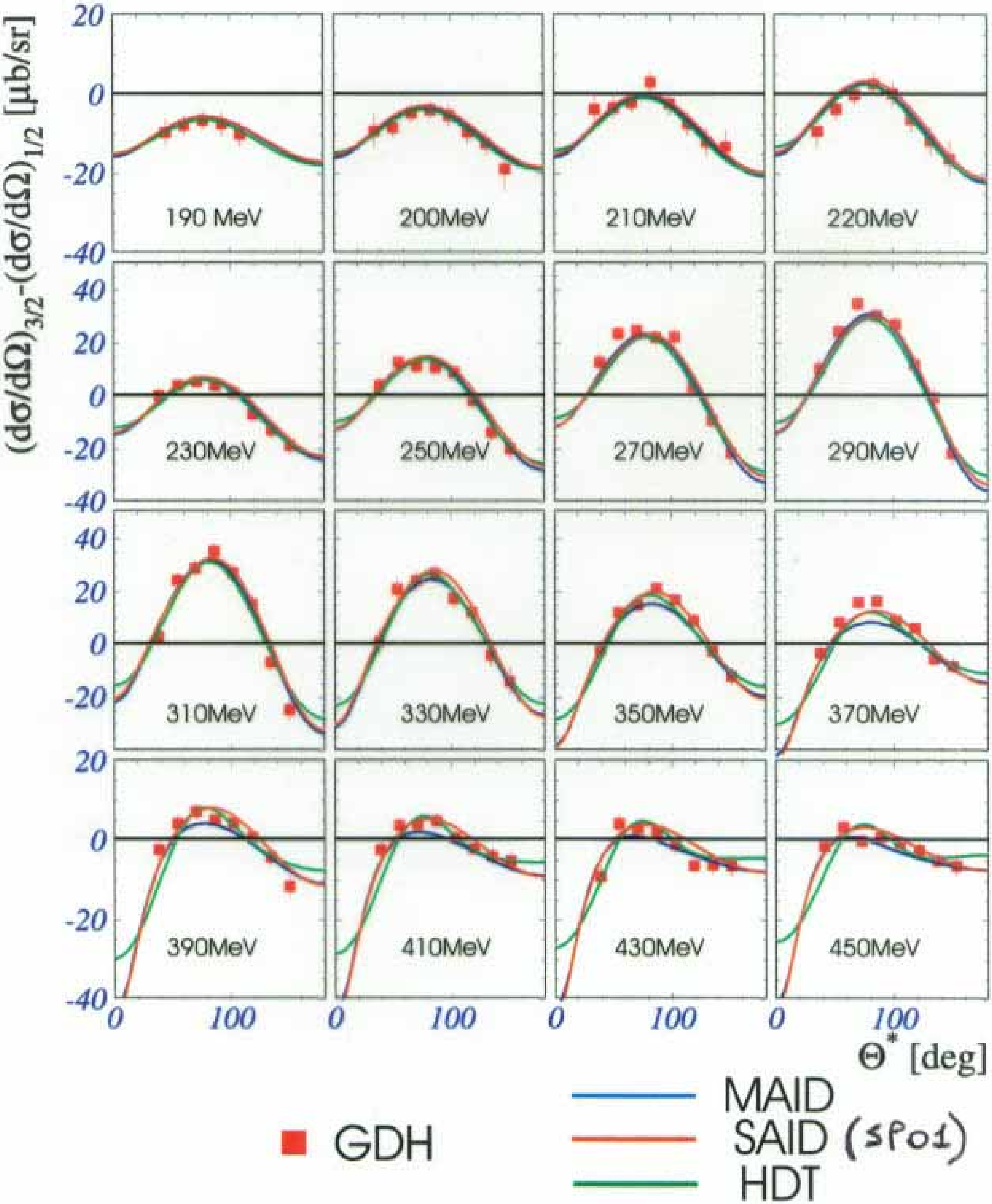
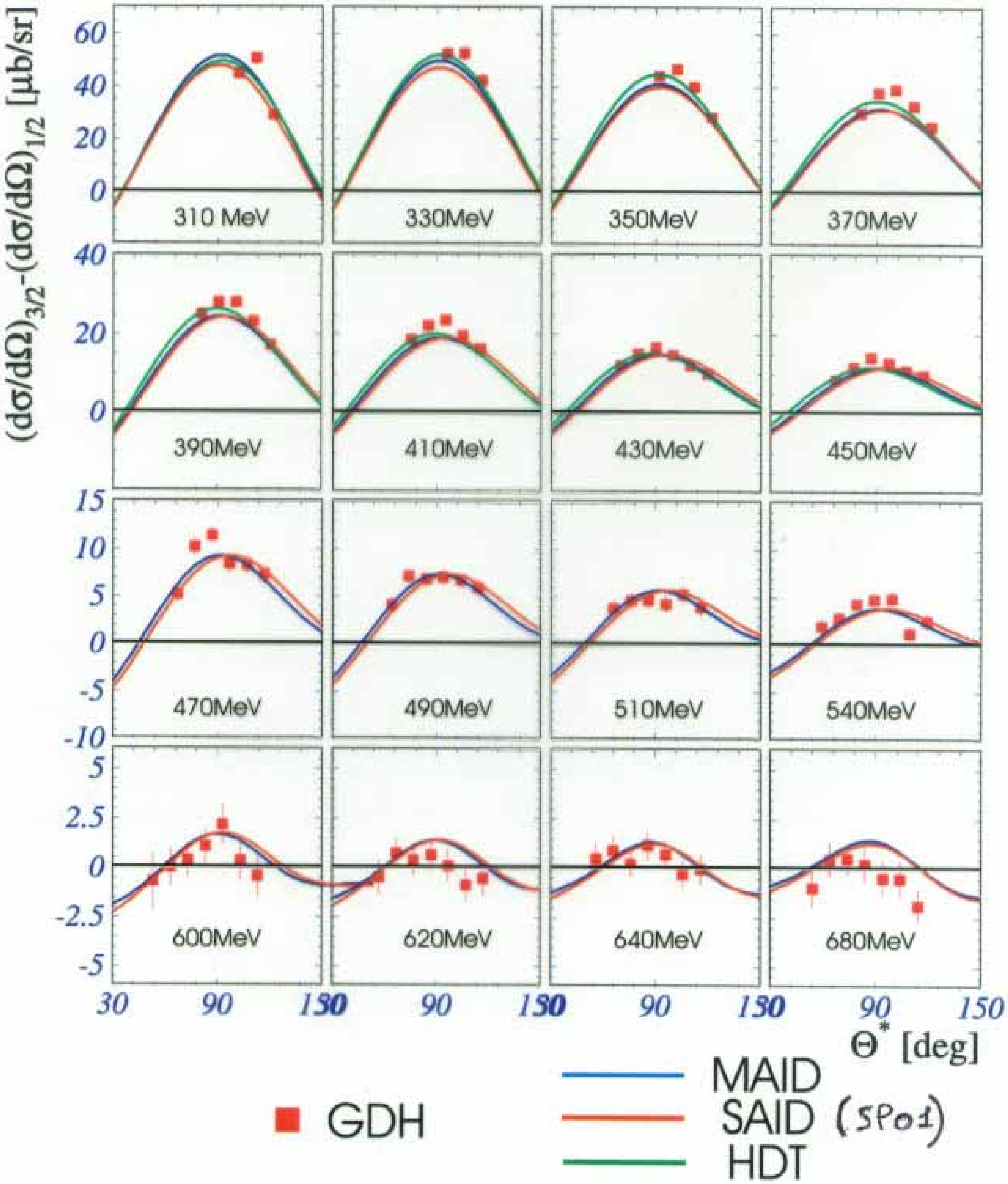


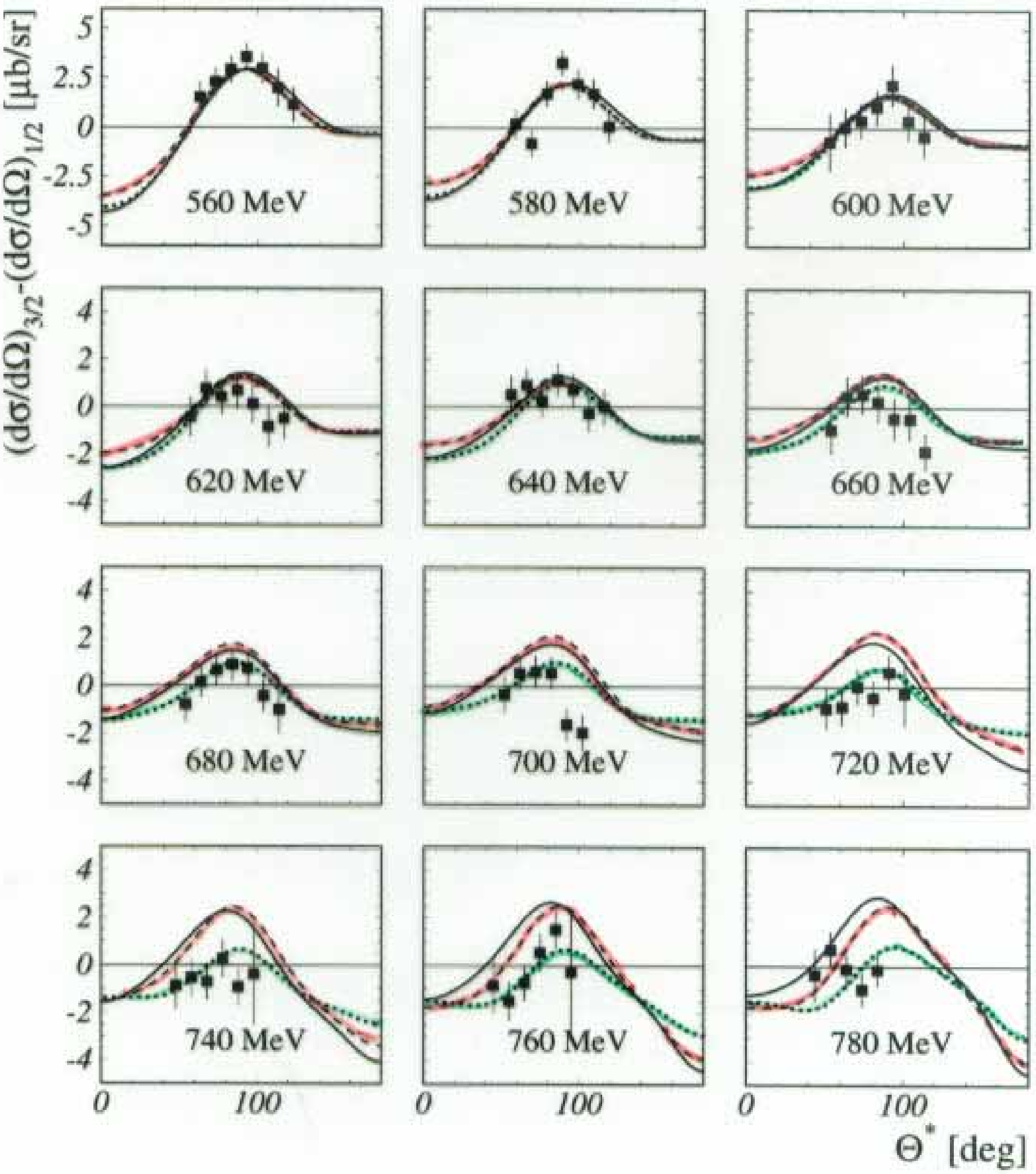
Results

$\vec{\gamma}\vec{p} \rightarrow p\pi^0$



Results

$\vec{\gamma}\vec{p} \rightarrow p\pi^0$



■ GDH data: J. Ahrens et al., PRL 88, 232002 (2002)

—— SAID (SP01)

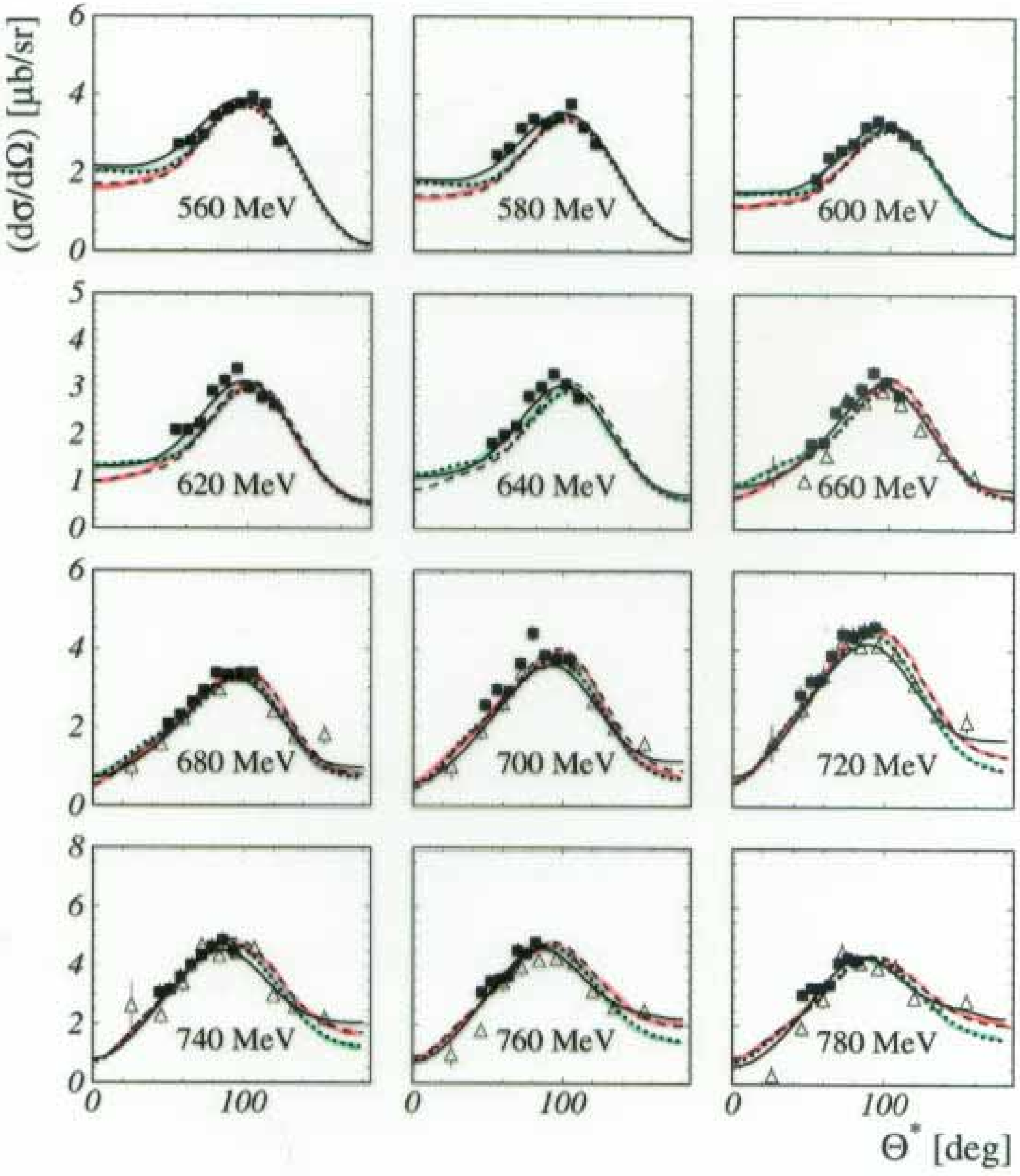
—— UIM

—— Modified UIM

$M_{2-}^{1/2}$: +11% $E_{2-}^{1/2}$: −20%

Results

$\gamma p \rightarrow p\pi^0$



■ GDH data: J. Ahrens et al., PRL 88, 232002 (2002)

△ TAPS data: B. Krusche et al., EPJ A6, 309 (1999)

——— SAID (SP01)

——— UIM

Modified UIM

D_{13} Helicity amplitudes

Solution	$A_{1/2}$	$A_{3/2}$
Standard UIM	-17	164
Modified UIM	-38 ± 3	147 ± 10
PDG "best estimate"	-24 ± 9	166 ± 5

Units: 10^{-3} GeV$^{-1/2}$

$W_R = 1520$ MeV; $\Gamma_\pi/\Gamma = 0.55$; $\Gamma = 120$ MeV

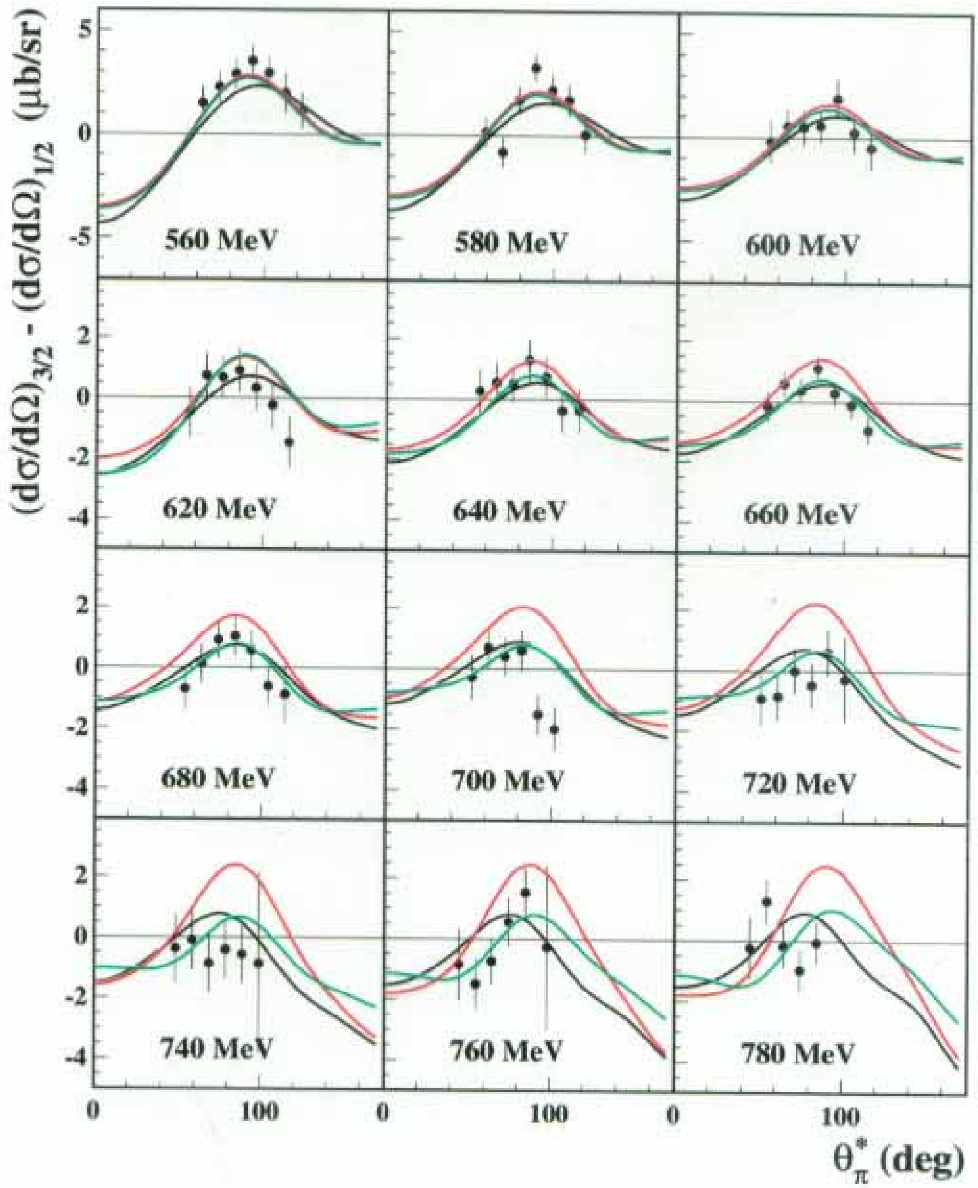
Solution	$A_{1/2}$	$A_{3/2}$
SAID (SM02K)	-24 ± 2	135 ± 2

Units: 10^{-3} GeV$^{-1/2}$

$W_R = 1517$ MeV; $\Gamma_\pi/\Gamma = 0.63$; $\Gamma = 109$ MeV

Results

$\vec{\gamma}\vec{p} \to p\pi^0$



- GDH data: J. Ahrens et al., PRL 88, 232002 (2002)

——— SAID (solution SM02K)

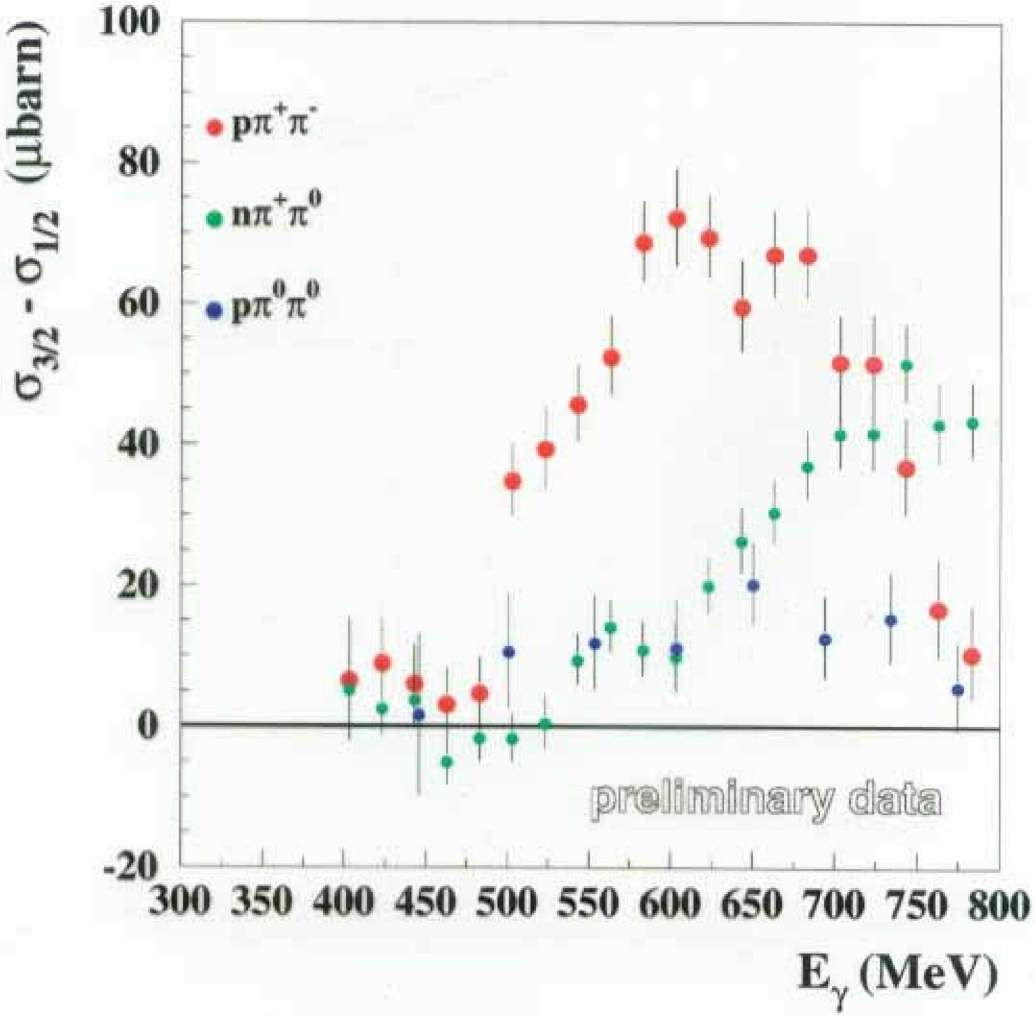
——— UIM

——— Modified UIM

$M_{2-}^{1/2}$: +11% $E_{2-}^{1/2}$: −20%

Results

$\vec{\gamma}\vec{p} \rightarrow N\pi\pi$



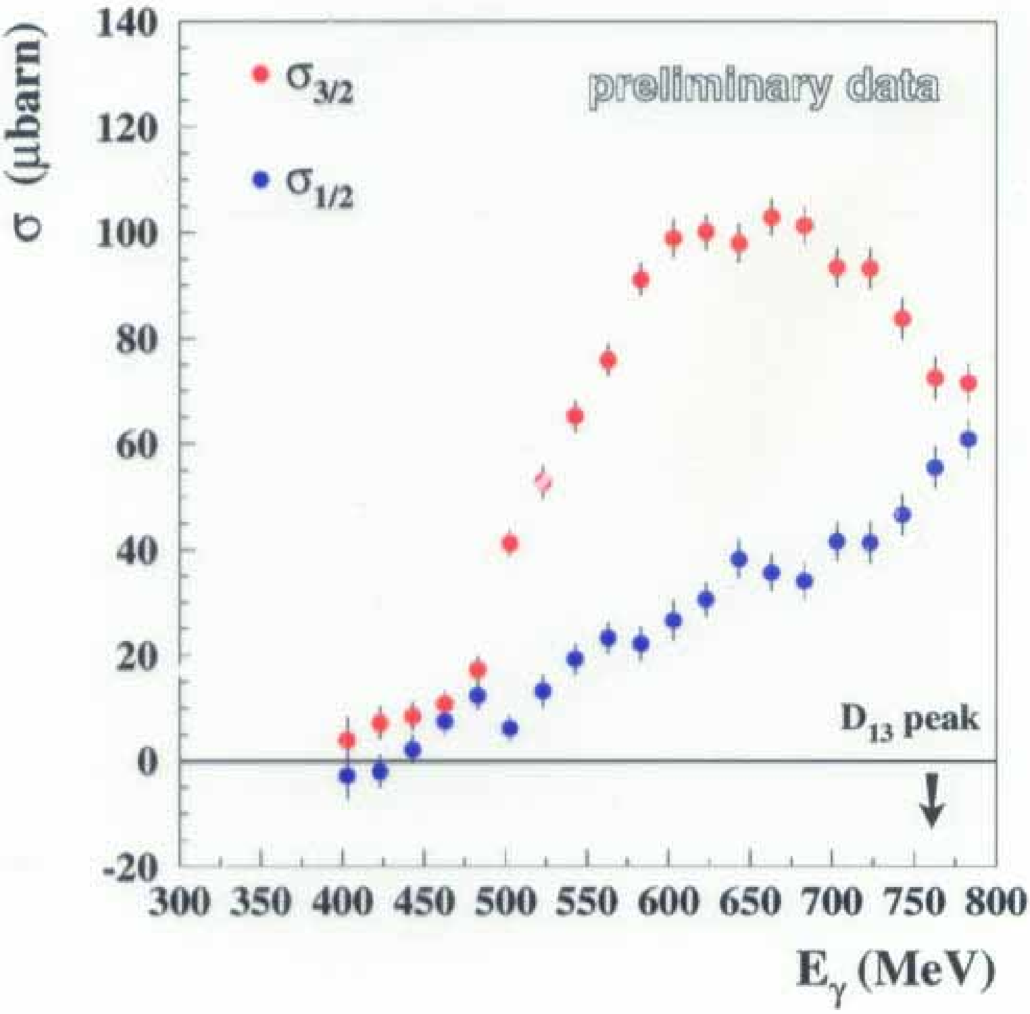
- extrapolation into full acceptance performed using a pure phase space model ($\pi^+\pi^-$; $\pi^0\pi^0$) or Nacher-Oset model ($\pi^+\pi^0$)

- correction is $\simeq$ 20% of the measured cross section for $n\pi^+\pi^0$, $\simeq$ 30% for $p\pi^+\pi^-$, and $\simeq$ 50% for $p\pi^0\pi^0$

- using unpolarized cross sections $\rightarrow$ separation between $\sigma_{3/2}$ and $\sigma_{1/2}$

Results

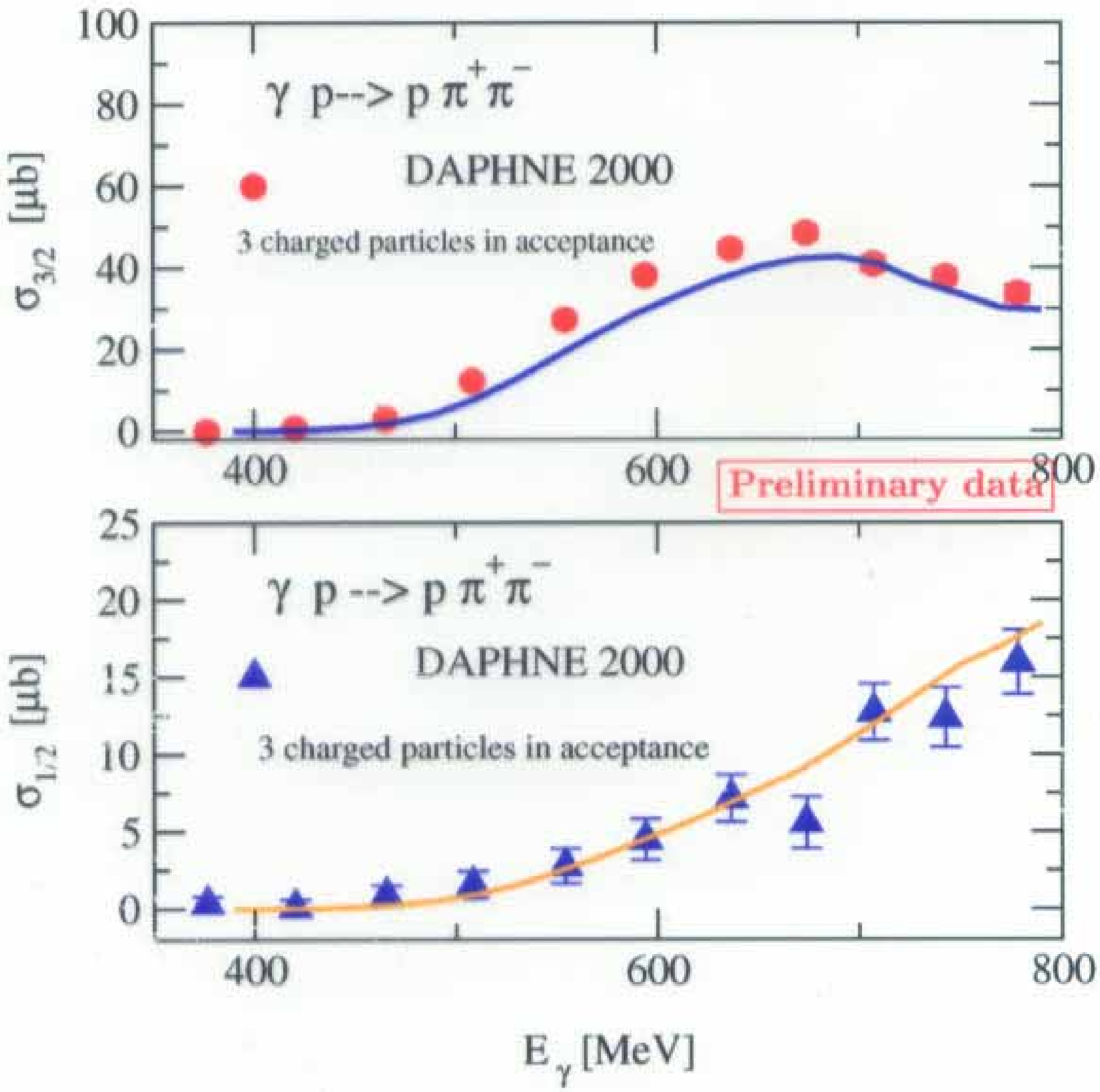
$\vec{\gamma}\vec{p} \to p\pi^+\pi^-$



- D_{13} plays a (very) small role
- Most important mechanism: $\gamma p \to \Delta\pi$
- S -wave $\pi \Rightarrow \sigma_{3/2}$ is dominant

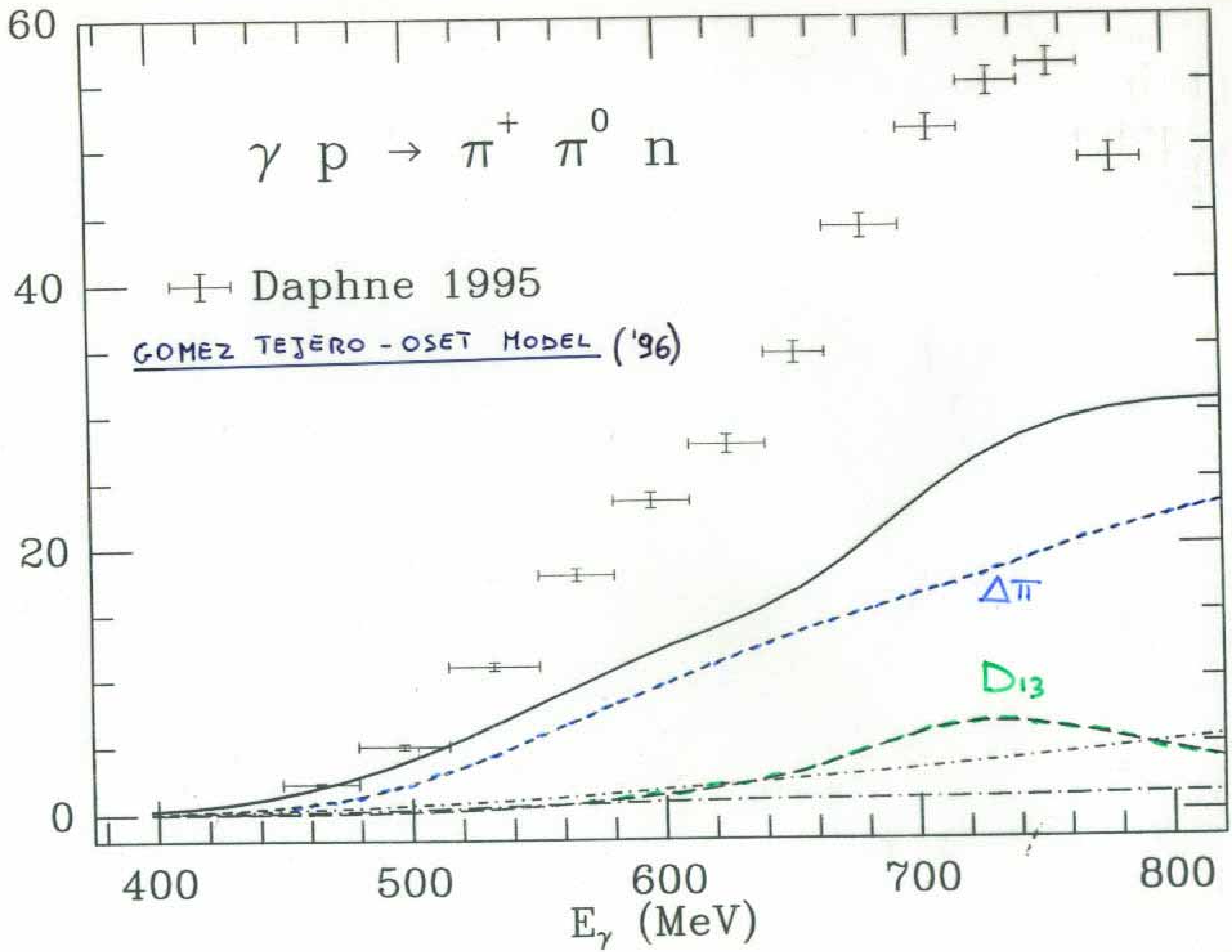
Results

Comparison with Models



- Nacher-Oset model (nucl-th/0106005)

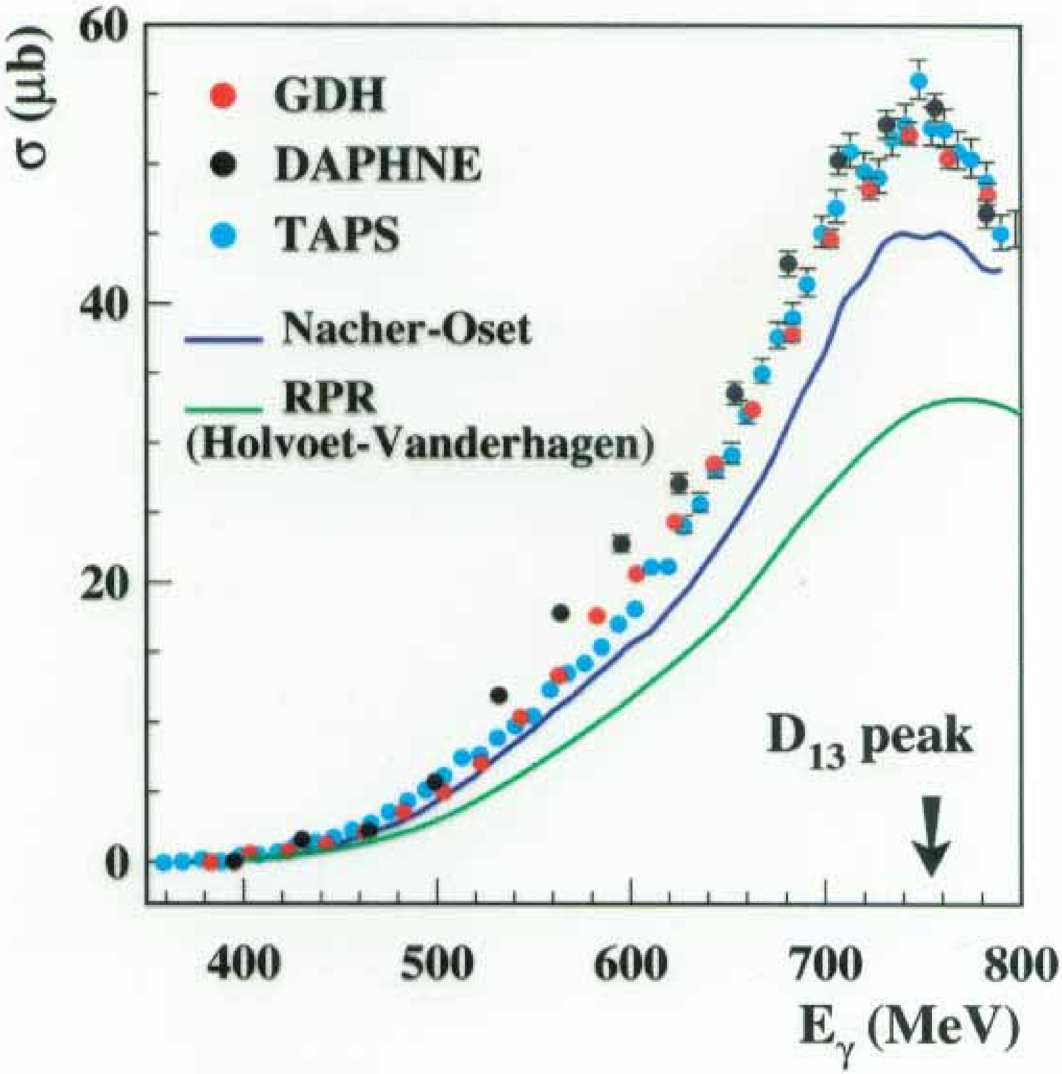
- Data inside DAPHNE acceptance and only for $\simeq 50\%$ of the collected events ($\Rightarrow$ 3 charged particles in DAPHNE)



60
40
20
0
γ p → π+ π0 n
Daphne 1995
GOMEZ TEJERO - OSET MODEL ('96)
Δπ
D13
400
500
600
700
800
Eγ (MeV)

Results

$\gamma p \rightarrow n\pi^+\pi^0$



GDH data: J. Ahrens et al., to be submitted

DAPHNE data: A. Braghieri et al., PLB 363, 46 (1995)

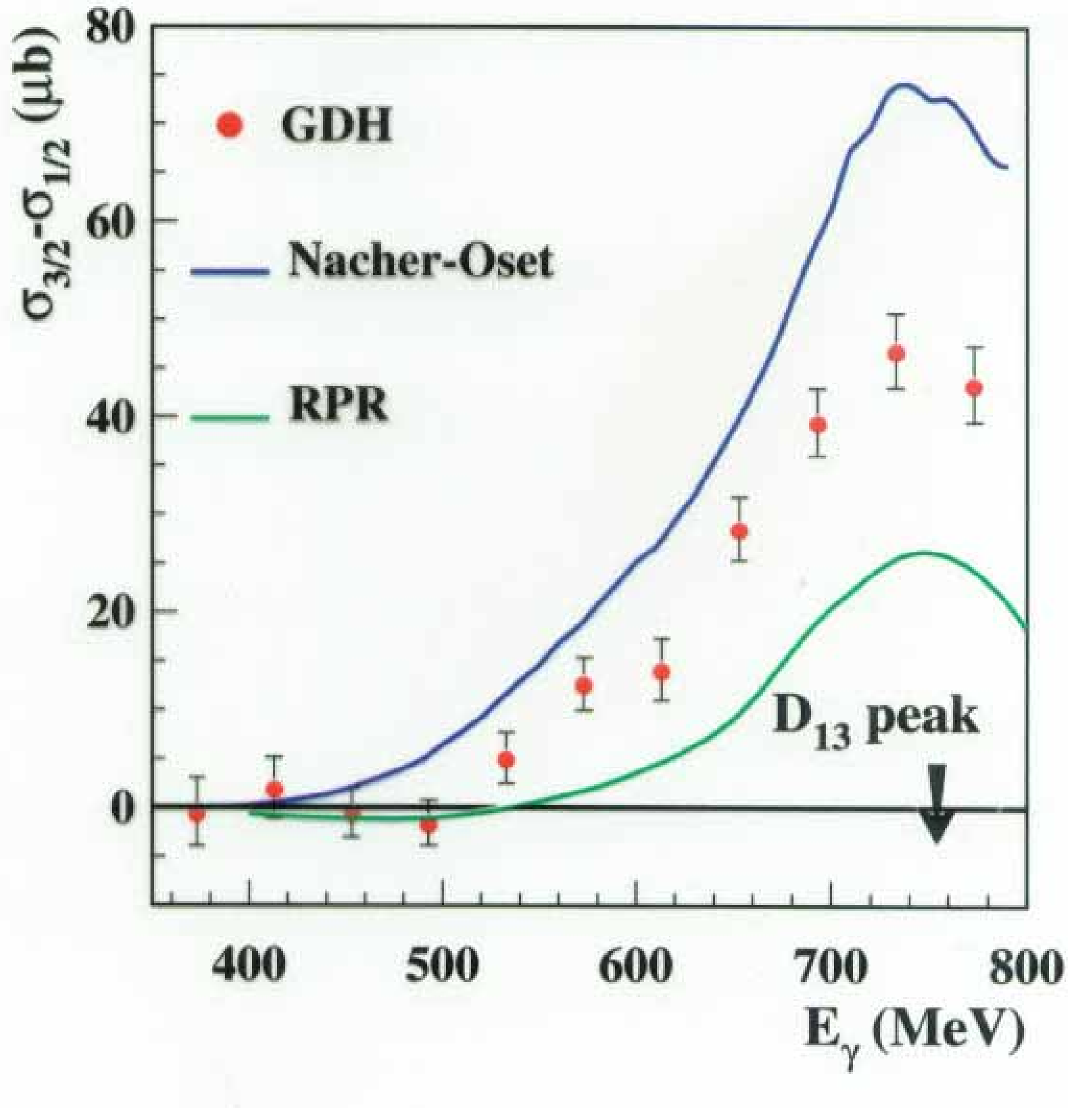
TAPS Data: W. Langgartner et al., PRL 87, 052001 (2001)

—— J.Nacher, E.Oset, NPA 697, 372 (2002) ($D_{13} \rightarrow n\rho^+$)

—— H.Holvoet, PhD thesis, University of Gent (2001)

Results

$$\vec{\gamma}\vec{p} \rightarrow n\pi^+\pi^0$$



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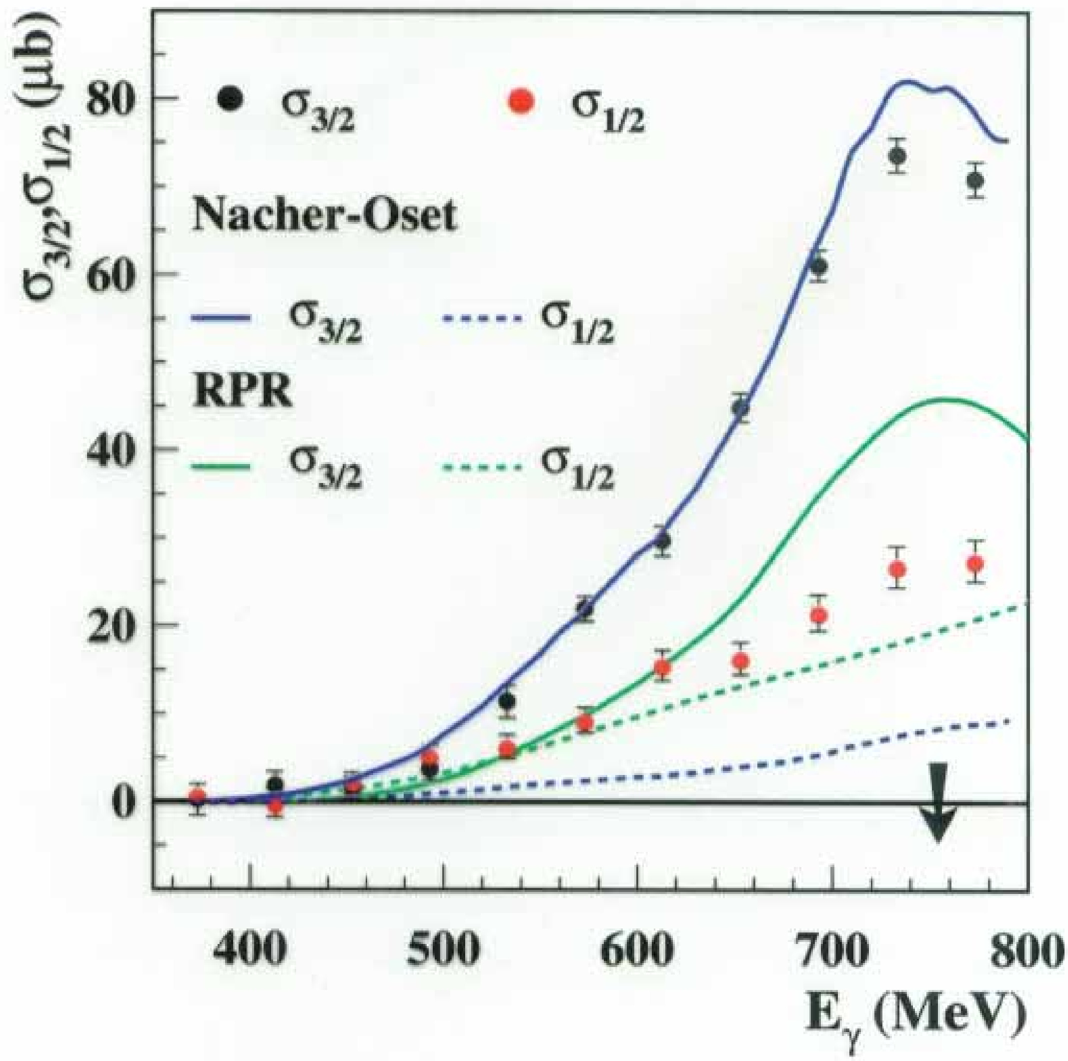
Results

$\vec{\gamma}\vec{p} \to n\pi^+\pi^0$



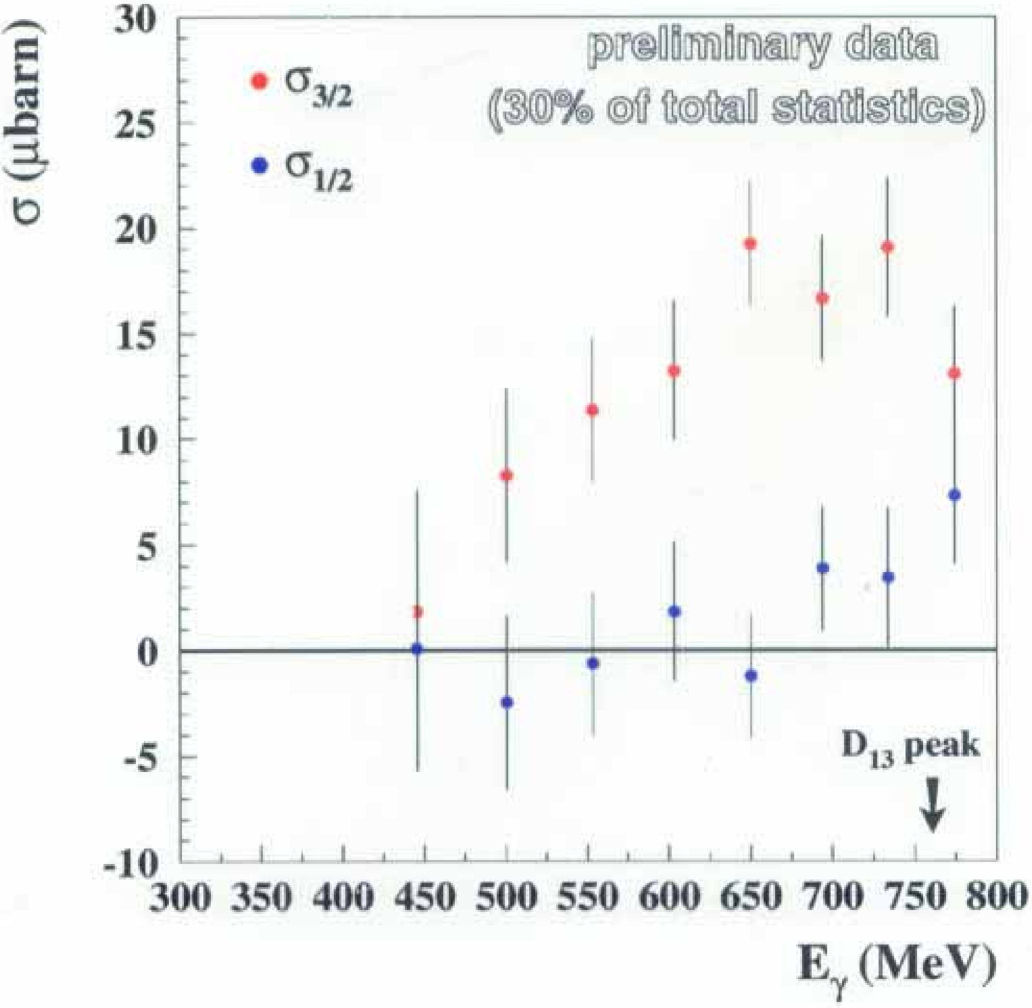
- From previous DAPHNE (PRC 60, 055201 -1999-) and TAPS (PRL 87, 052011 -2001-) data (invariant mass distributions): $\pi\pi$ correlation in the final state

- The most important contribution is given by $\gamma p \to D_{13} \to n\rho^+$

- Non-negligible background mechanisms: $\gamma p \to N\rho$ ($\pi\Delta$)

Results

$$\vec{\gamma}\vec{p} \to p\pi^0\pi^0$$



- Statistics too low (and extrapolation too large) to draw "sound" conclusions
- D_{13} plays an important role, as expected from $\pi\pi, p\pi$ invariant mass distributions (TAPS, EPJ A9, 5 -2000-)
- No (relevant) contribution is given by P_{11}

Outlook

GDH sum rule on the neutron

- **Total cross section measurement** $\Rightarrow$ "inclusive" method (no partial channel separation)

- ^{2}H: $\mu \sim \mu_p + \mu_n \Rightarrow \underset{p\ n}{\uparrow\uparrow}$

$$I^d_{exp} \sim I^n_{GDH} + I^p_{GDH} + I_{nucl.eff.}$$

- ^{3}He: $\mu \sim \mu_n \Rightarrow \underset{p\ p\ n}{\uparrow\downarrow\uparrow}$ (**S state with $\sim 90\%$ prob.**)

$$I^{he}_{exp} \sim I^n_{GDH} + \alpha I^p_{GDH} + I_{nucl.eff.}$$

$\alpha \simeq 0.1$

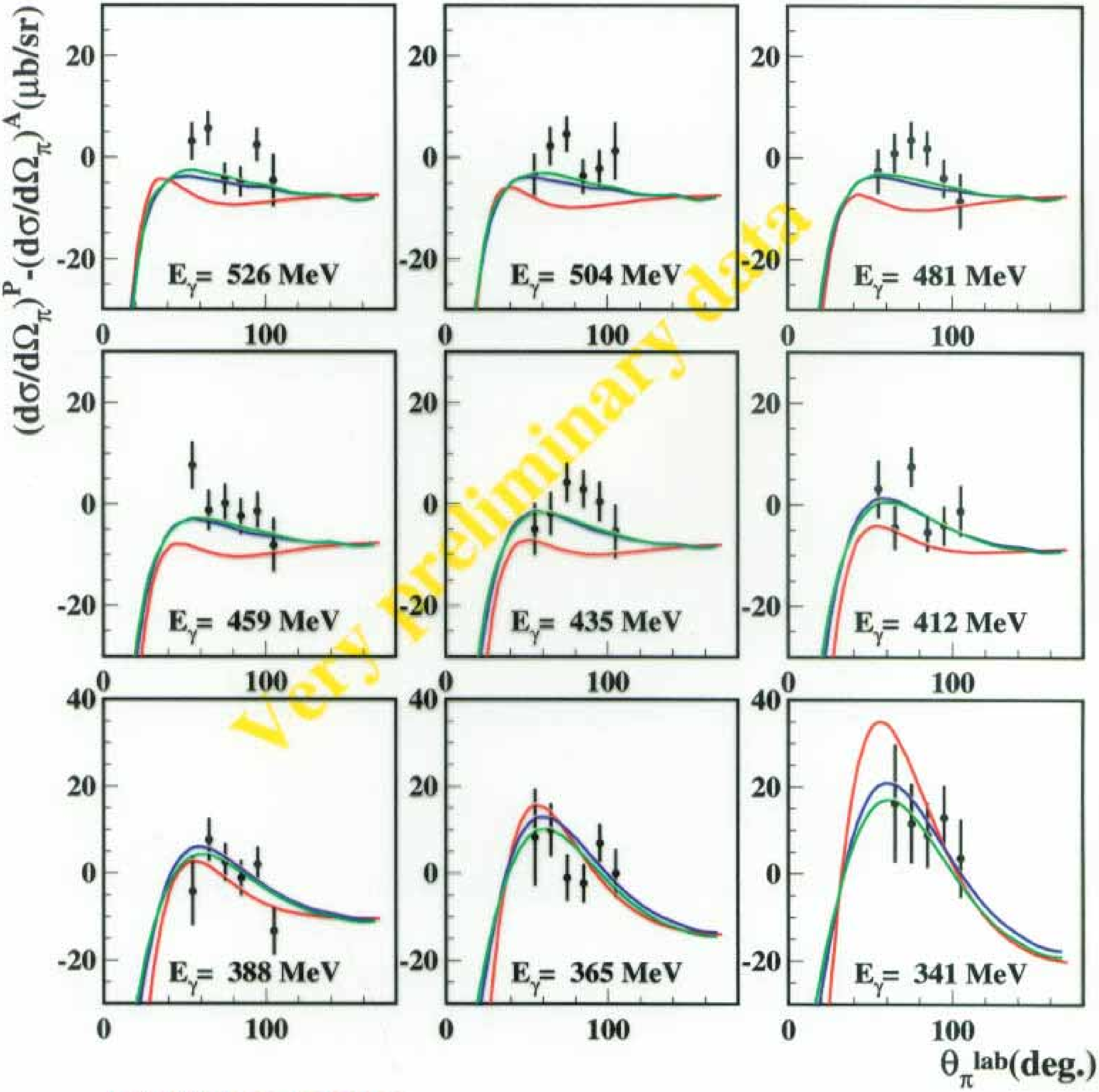
$\Downarrow$

smaller corrections

^{3}He better suited to get an estimate of I^n_{GDH}

^{2}H better suited to measure $\vec{\gamma}\vec{n} \rightarrow N\pi(\pi)$

$\vec{\gamma}\,\vec{D} \rightarrow p\pi^- p_s$



Arenhövel $\gamma n \rightarrow p\pi^-$ free

Arenhövel $\gamma D \rightarrow p_s p\pi^-$ IA

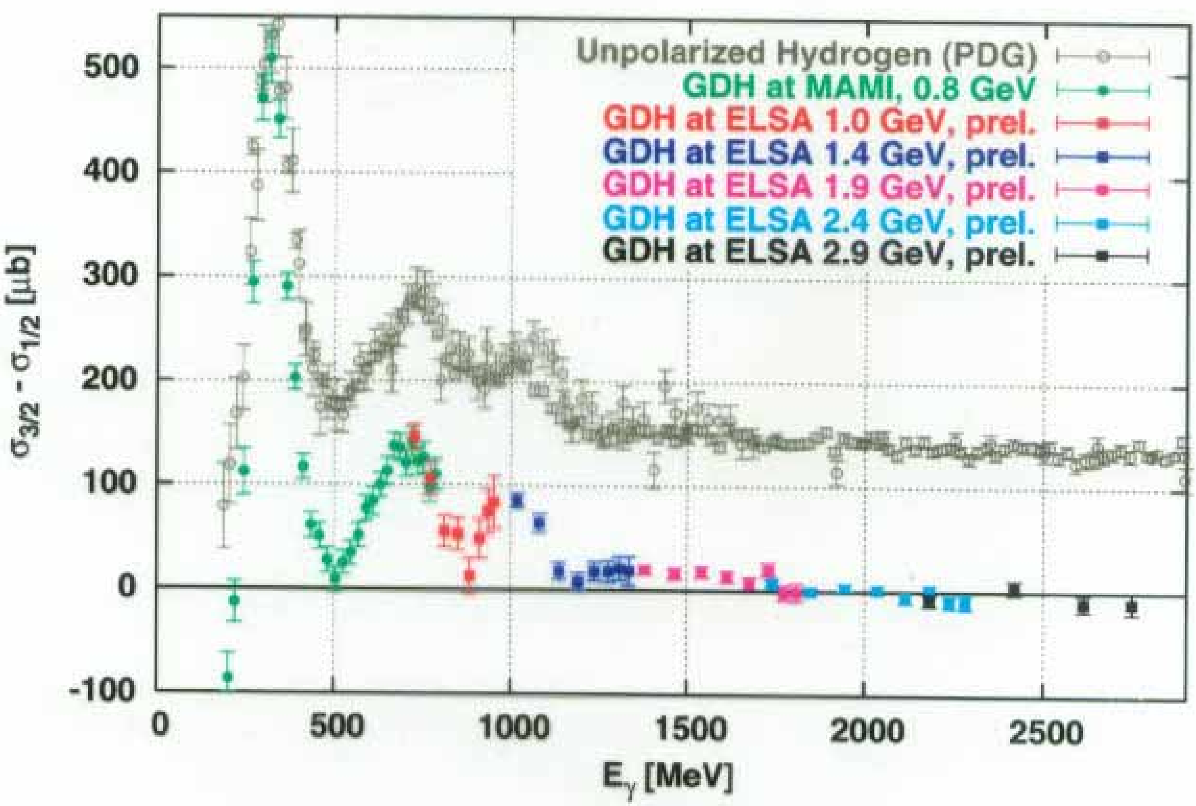
Arenhövel $\gamma D \rightarrow p_s p\pi^-$ IA+FSI

Model:E.Darwish,Ph.D.Thesis,Mainz(02)

Data:C.A.Rovelli,Dipl.Thesis,Pavia(02)

Results

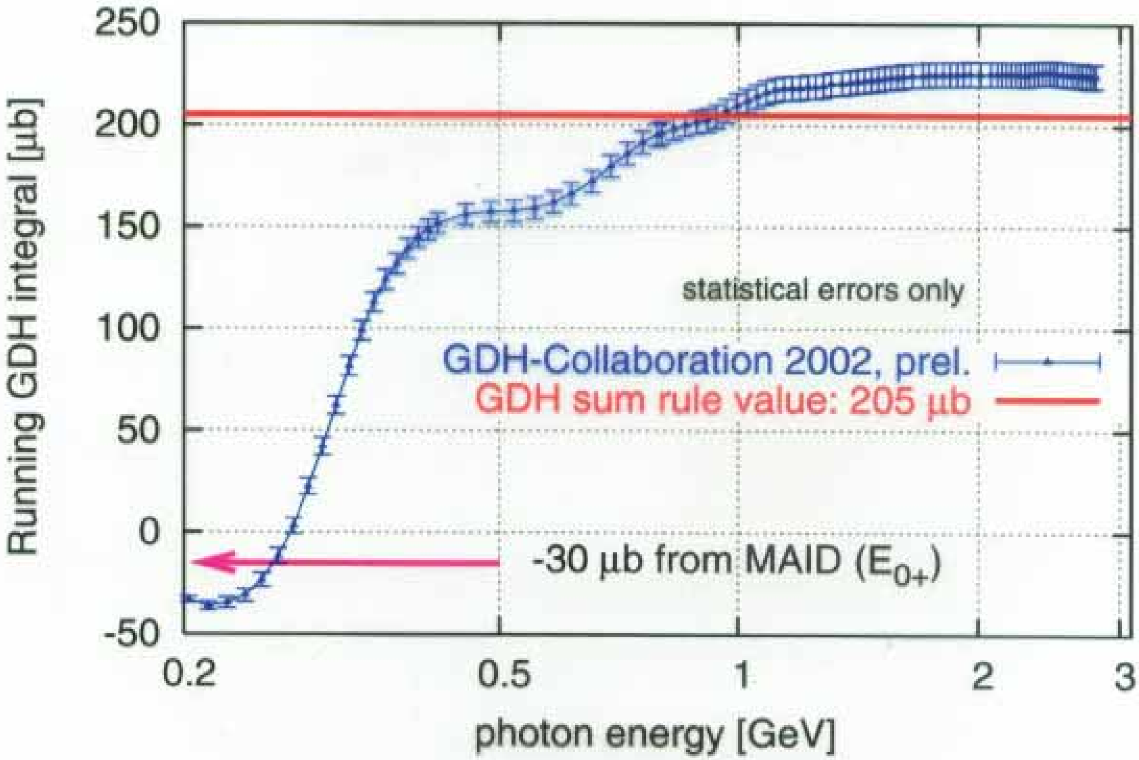
Inclusive $\vec{\gamma}\vec{p} \rightarrow hadrons$



- Mainz (MAMI) data: J. Ahrens et al. PRL 87, 02203 (2001)
- Bonn (ELSA) data: Preliminary

Results

Inclusive $\vec{\gamma}\vec{p} \rightarrow hadrons$



- Running GDH integral= $\int_{200\ \mathrm{MeV}}^{E_\gamma^{max}} \frac{(\sigma_{3/2} - \sigma_{1/2})}{E_\gamma}\, \mathrm{d}E_\gamma$
- $I_{GDH}[140 - 200\ \mathrm{MeV}] \simeq -30\ \ \mu b$ (multipole analyses)
- $I_{GDH}[> 3\ \mathrm{GeV}] \approx [-10, -20]\ \ \mu b$ (Regge-like models)

Final remarks

- After a long "hunt" for the GDH sum rule, we are almost there.
  The (generalized) GDH sum rule is on the schedule of all existing $e/\mu/\gamma$ facilities
- Results from Mainz/Bonn:
  - the GDH sum rule value for the proton is (slightly) overshooted at $E_\gamma = 3$ GeV
    If I would gamble, I would bet that the GDH sum rule (on the proton) is verified.
  - Spin polarizability $\gamma_0 \sim -80/-90 \cdot 10^{-6} fm^4$
- Helicity dependence of the $N\pi(\pi)$ channels is a powerful tool to better understand the baryon resonance properties
  $\Rightarrow D_{13}$ properties are different from the "expected" ones
- Additional measurements both on proton and on the neuteron (higher photon energies; all relevant partial channels) are needed to get a more complete picture both on the resonance properties and on the GDH sum rule.