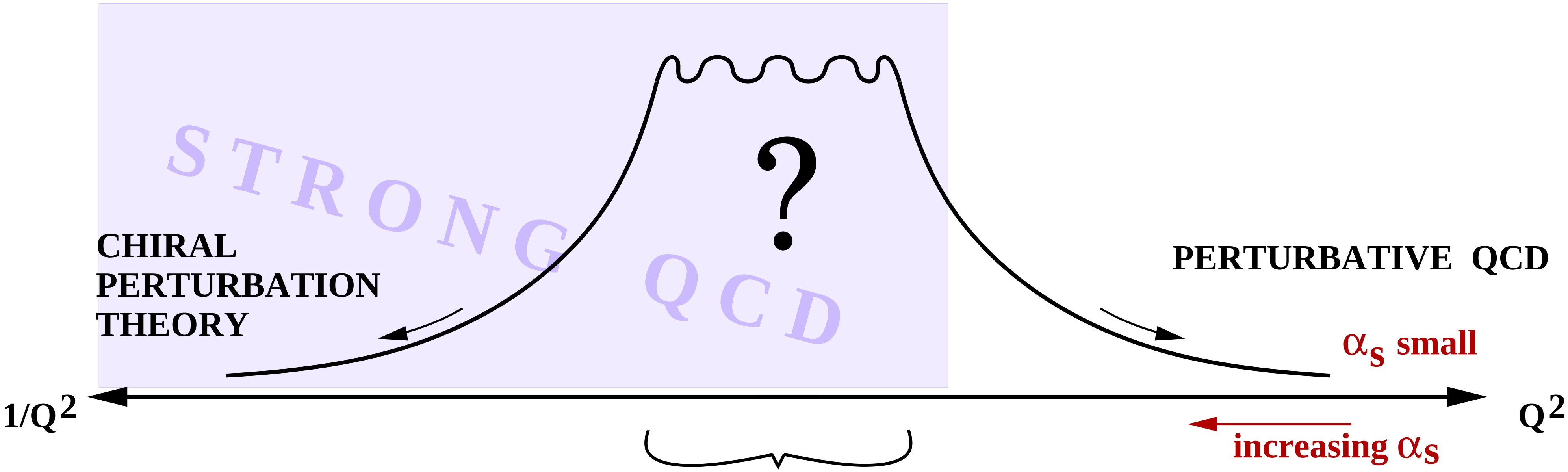
Recent results from the Crystal Barrel experiment at ELSA

U.Thoma, Bonn University

- Introduction
- η- photoproduction
- $2\pi^0$- photoproduction
- $\pi^0\eta$- photoproduction
- Results of the partial wave analysis
- Future
- Summary

QCD: Effects of the running coupling constant α_s:



$\longrightarrow$ **Baryons**

$\longrightarrow$ **Mesons**

Better understanding of strong QCD and the structure of hadrons:

- **What are the relevant degrees of freedom ?**
- **And the effective forces ?**

$\Rightarrow$ **Meson - Spectroscopy, Baryon - Spectroscopy**

Good understanding of the spectrum and the properties of resonances

- **Search for new/missing baryon resonances**

  Investigate the photoproduction of final states different from πN

  (Missing states are expected to decouple from πN)

- **Do these missing states really exist ?**

  Do diquark models describe the spectrum ?

  $\leftrightarrow$ **P_{11}(2100), P_{13}(1900), F_{15}(2000), F_{17}(1990)**

  (both oscillators need to be excited)

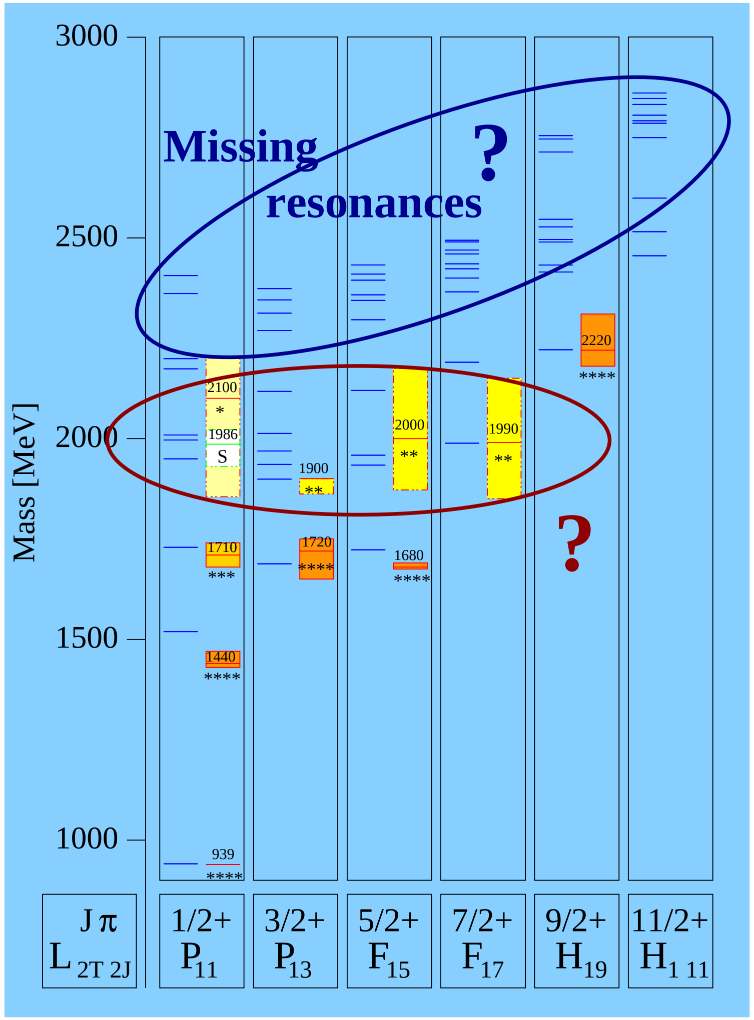
- **Do the neg. parity Δ^*-states $\sim$1900 MeV exist?**

- **Determination of their properties**

  $\longrightarrow$ **Comparison with models**

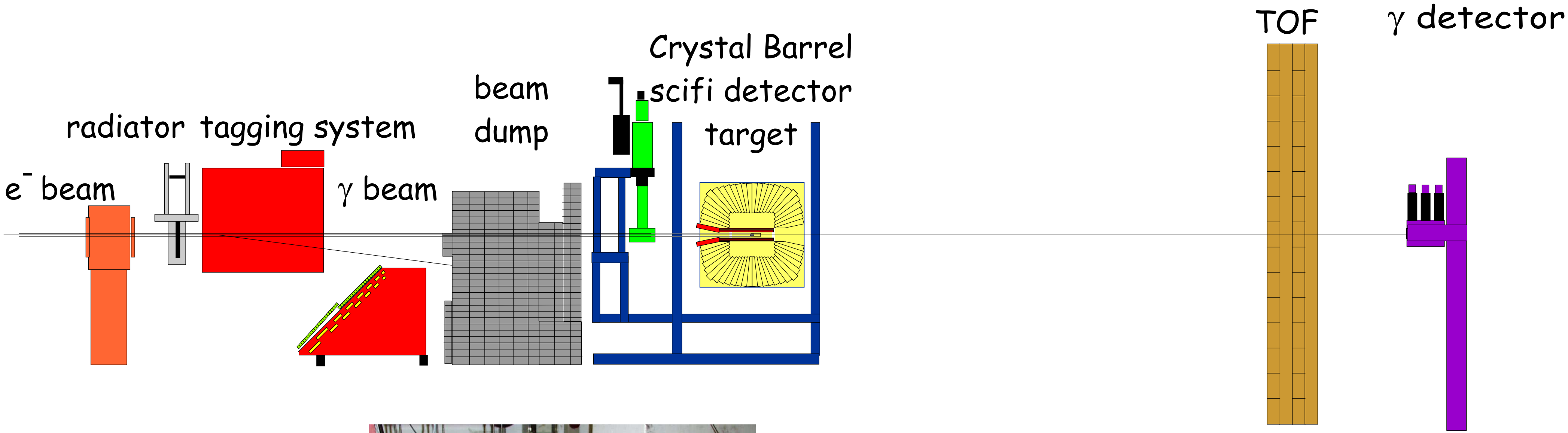
  $\longrightarrow$ **Nature of states, e.g. P_{11}(1440) ?**

U. Loering, B. Metsch, H. Petry et al.:



$\Leftrightarrow$ **At high excitation energies multi-meson final states play a role of increasing importance**

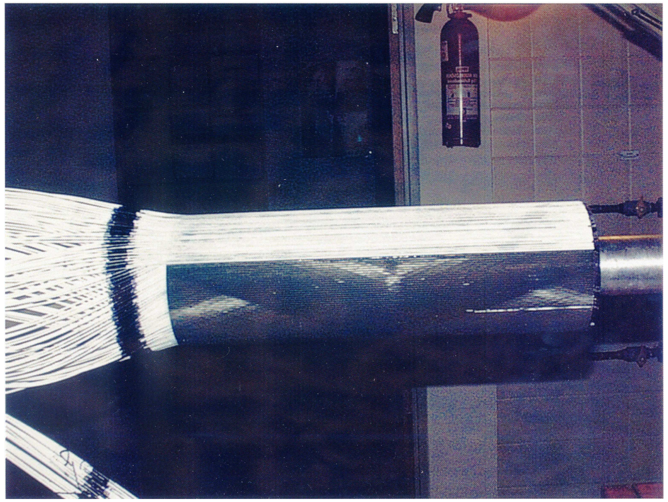
The Crystal Barrel experiment at ELSA



Tagging system

- 14 scintillation counters
- 2 wire chambers (352 energy channels)

Tagging range: 25-95 $\% \, E_{e^-}$



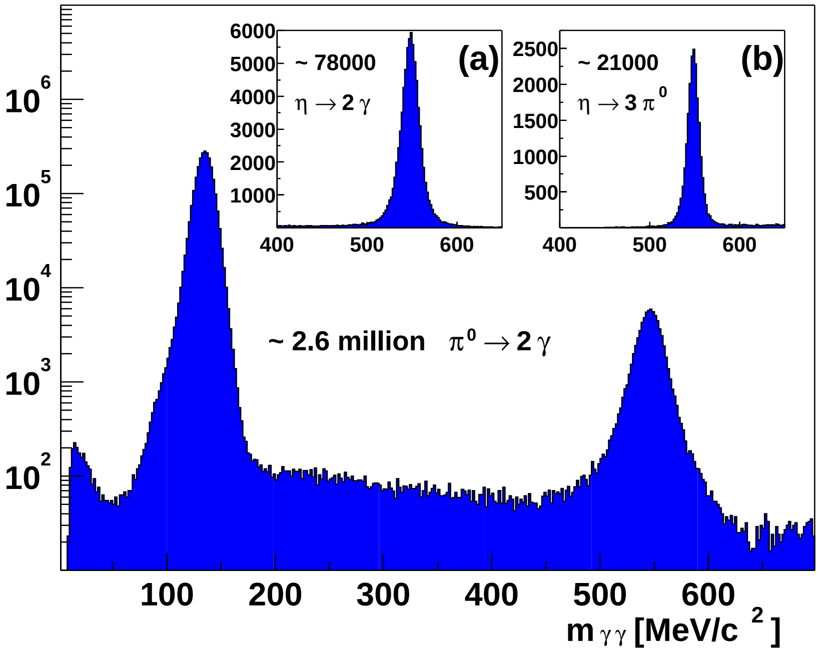
Innerdetector

3 layers of scintillating fibers

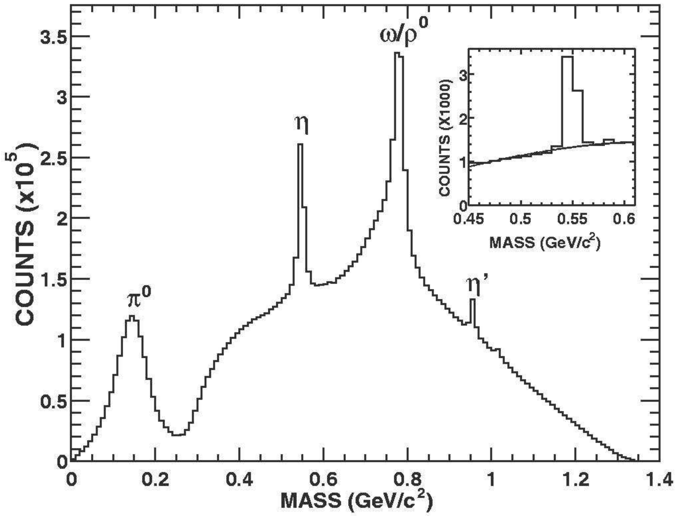
- Additional reconstruction point
- Trigger on charged particles

η - Photoproduction

CB-ELSA:



CLAS:



$$\gamma p \longrightarrow p\,\eta:$$

$$\eta \longrightarrow \gamma\gamma$$

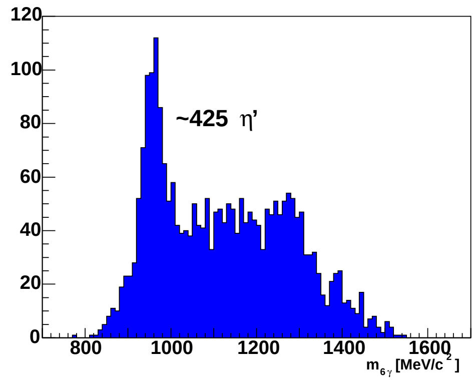
$$\eta \longrightarrow 3\pi^0$$

$\longrightarrow$ **Proton detected**

$\longrightarrow$ **η from missing mass**

$\longrightarrow$ **Photons are detected**

$\longrightarrow$ **Proton direction measured**

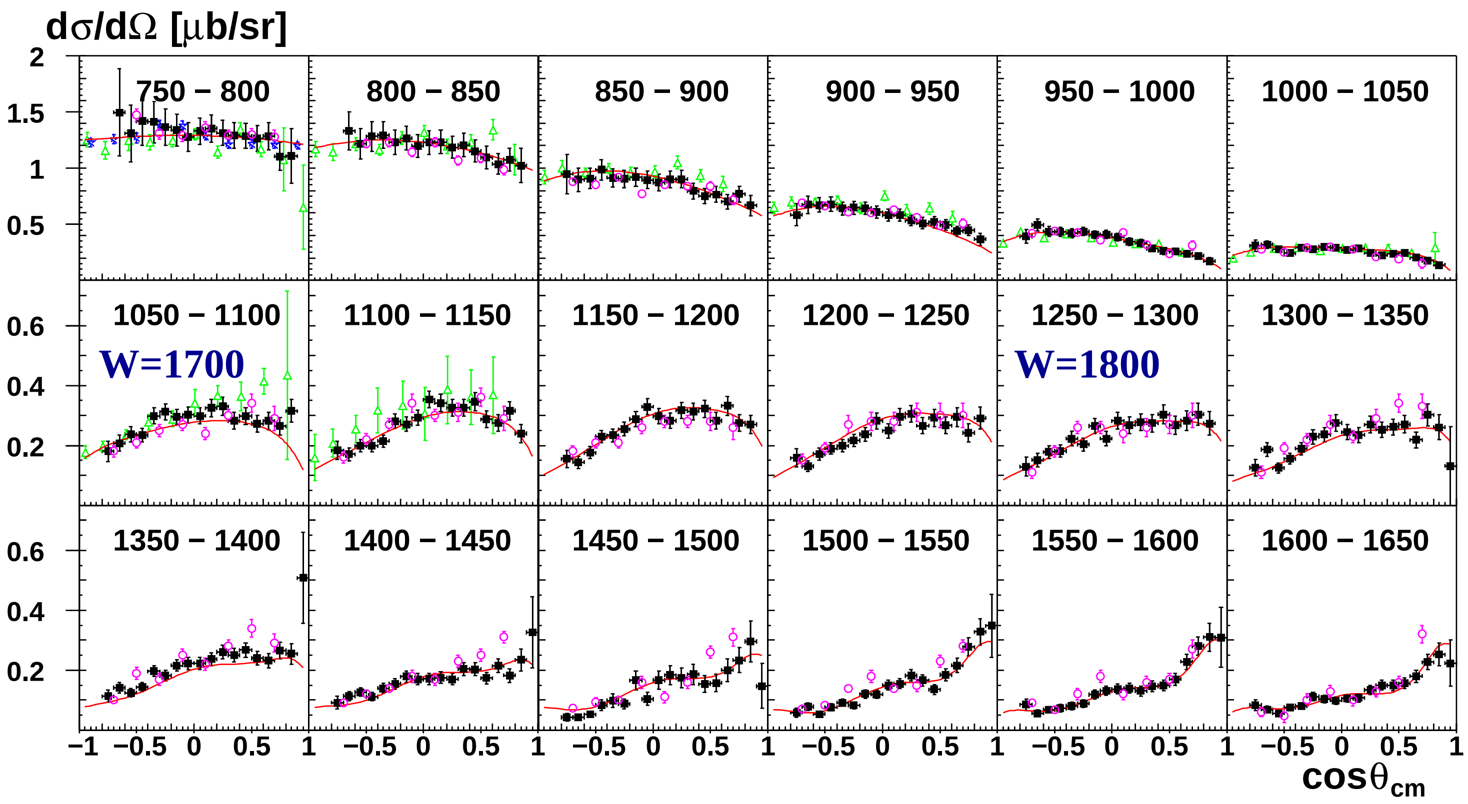


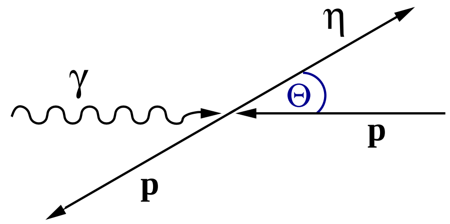
$$\eta' \longrightarrow \pi^0\pi^0\eta$$

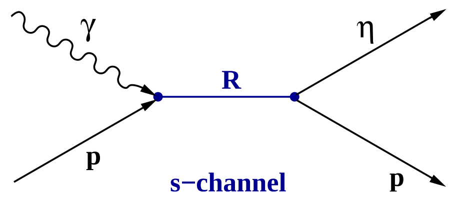
Differential cross section $\gamma p \longrightarrow p\eta$

■ CB-ELSA △ GRAAL ○ CLAS ★ TAPS — CB-ELSA fit

V.Crede, O.Bartholomy et al.,
PRL 94, 012004 (2005)







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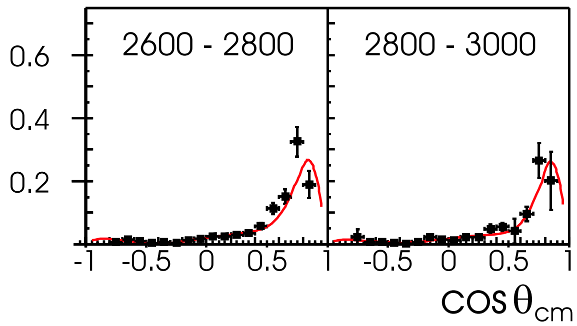
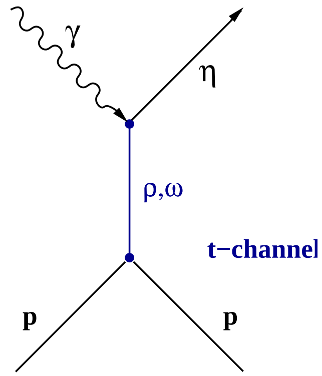
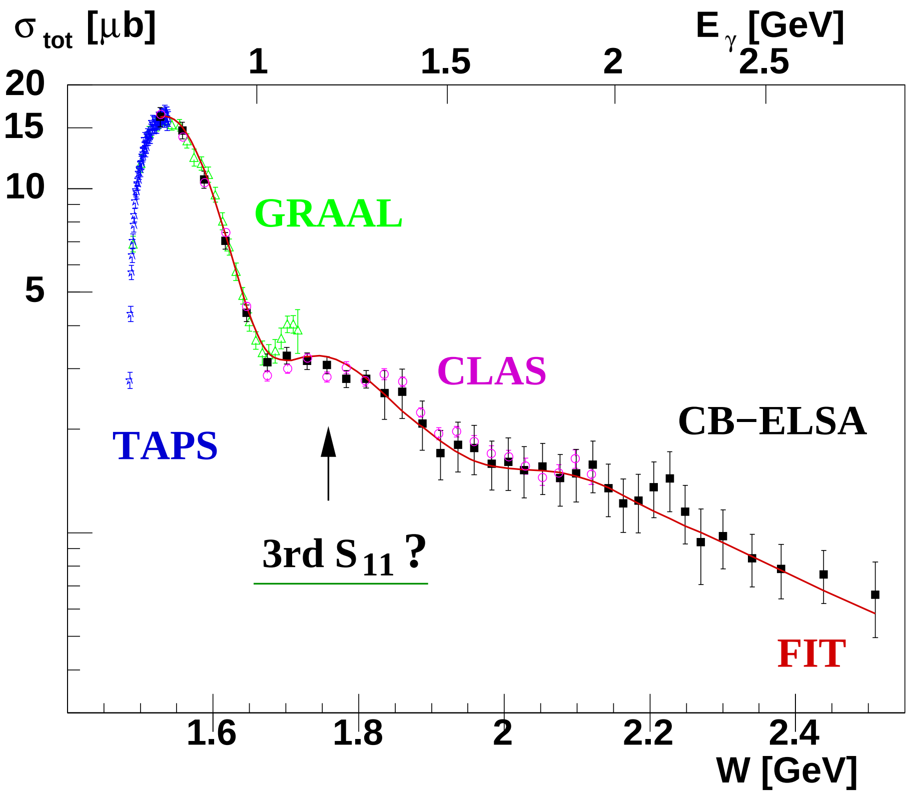




Total cross section $\gamma p \rightarrow p\eta$



CB-ELSA Isobar model fit:

Data included:

- $\gamma p \rightarrow p\eta, \ \gamma p \rightarrow p\pi^0$ **(CB-ELSA)**
- $\gamma p \rightarrow p\eta$ **(TAPS)**
- $\Sigma(\vec{\gamma}p \rightarrow p\eta), \ \Sigma(\vec{\gamma}p \rightarrow p\pi^0)$ **(GRAAL)**
- $\Sigma(\vec{\gamma}p \rightarrow p\pi^0), \ \sigma(\gamma p \rightarrow n\pi^+)$ **(SAID)**

$\Rightarrow$ **S_{11}(1535), D_{13}(1520), S_{11}(1650), F_{15}(1680), P_{13}(1720), D_{13}(2080)**

+ ... + ρ -, ω -t-channel exchange

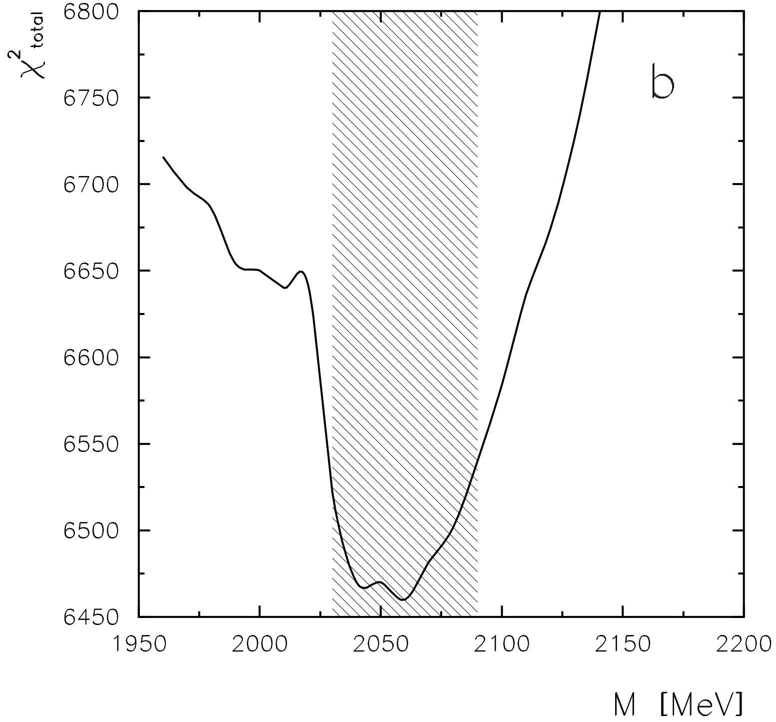
+ new D_{15}: m = 2068 $\pm$ 22 MeV,

Γ = 295 $\pm$ 40 MeV

$\leftrightarrow$ **No need for a 3rd S_{11}!**

New D_{15} -state

- $D_{15}(2060 \pm 30, 340 \pm 50)$:



$N(2200)$ D_{15} $I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ Status: ∗∗

OMITTED FROM SUMMARY TABLE

The mass is not well determined. A few early results have been omitted.

$N(2200)$ BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2200 OUR ESTIMATE				
1900	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
2180±80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1920	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
2228±30	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2240±65	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$

varies strongly !

$N(2200)$ BREIT-WIGNER WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
130	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
400±100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
220	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
310± 50	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
761±139	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$

⇔ **Results vary strongly!**

2π-Photoproduction

Search for $N^*/\Delta^* \rightarrow \Delta\pi$ in $\gamma p \rightarrow p\pi^0\pi^0$

Advantages:

- **No diffractive ρ(770) production**
- **No direct $\Delta^{++}\pi^-$ production**
- **Fewer Born-terms, t-channel exchanges**

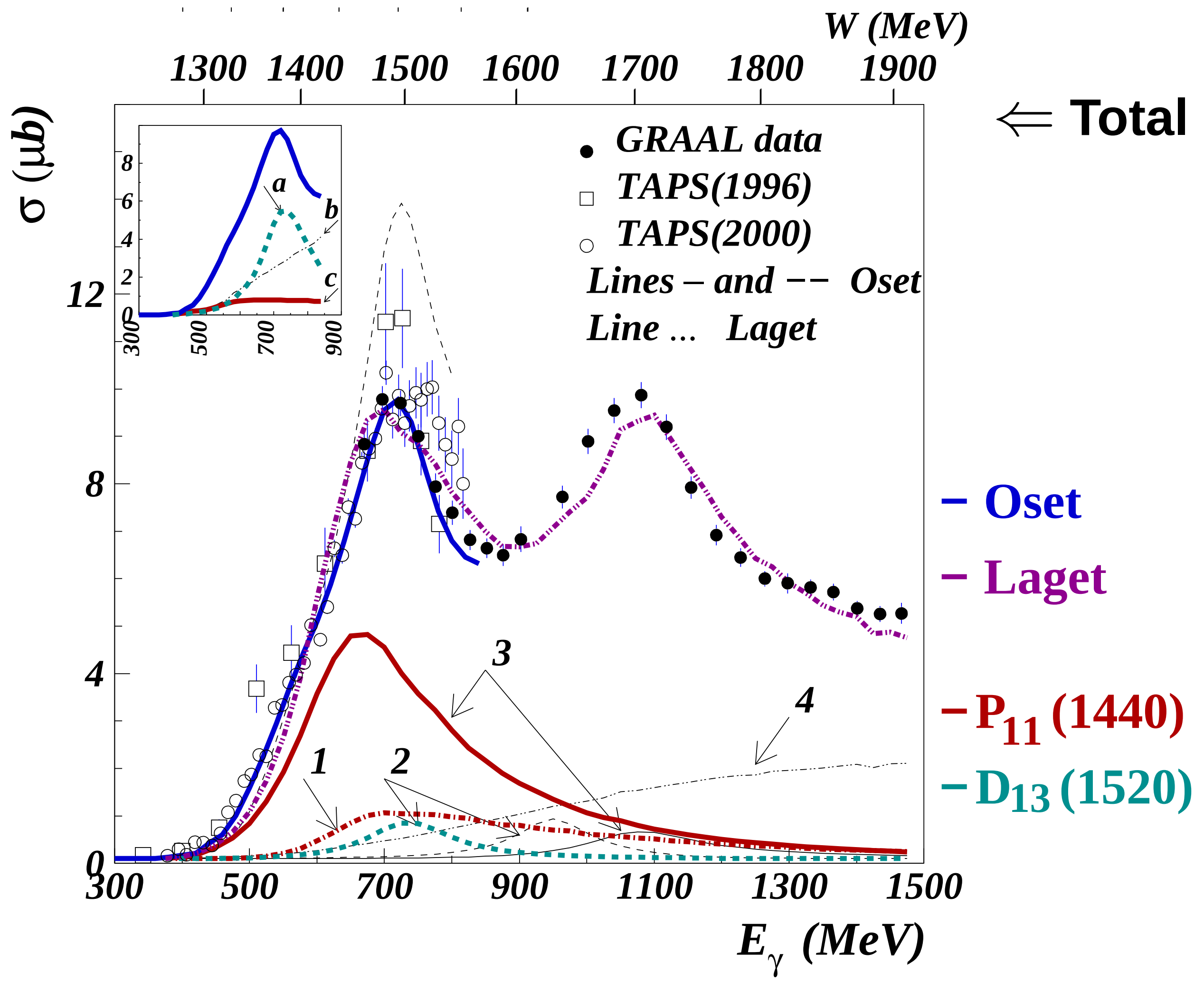
$\Rightarrow \gamma p \rightarrow p\pi^0\pi^0$ **very well suited to investigate $N^*/\Delta^* \rightarrow \Delta\pi$**

Bigger contribution of resonant amplitudes !

(e.g. compared to $\gamma p \rightarrow p\pi^+\pi^-$)

$\Rightarrow$ **CB-ELSA**

$\gamma p \longrightarrow p\pi^0\pi^0$ from TAPS and GRAAL



$\Leftarrow$ **Total cross section**

Data analysed by:

- **Oset et al.:**

  $\Rightarrow$ **$P_{11}(1440)$, $D_{13}(1520)$, $D_{33}(1700)$**

  (limited to low energy)

- **Laget et al.:**

  $\Rightarrow$ **$P_{11}(1440)$, $D_{13}(1520)$, $D_{13}(1700)$, $D_{33}(1700)$, $P_{11}(1710)$**

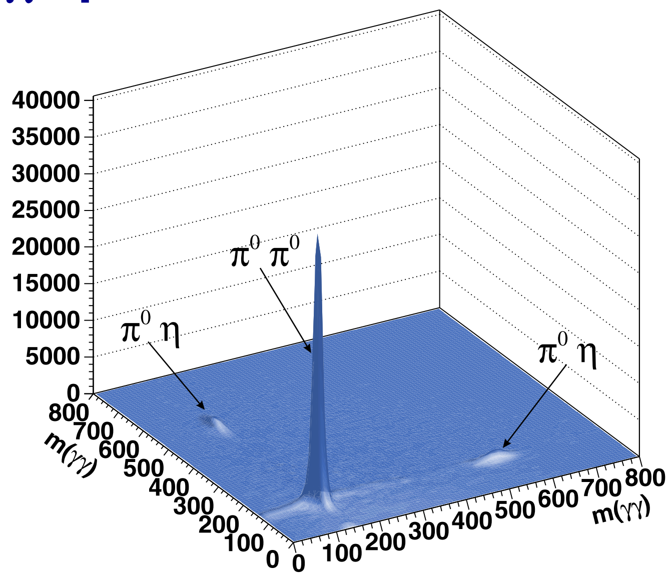
$\Leftrightarrow$ **Big discrepancy:**

Oset: $D_{13}(1520) \longrightarrow \Delta\pi$ dominant, Laget: $P_{11}(1440) \longrightarrow p\sigma$ dominant

$\gamma p \to p\pi^0\pi^0$ – CB-ELSA –

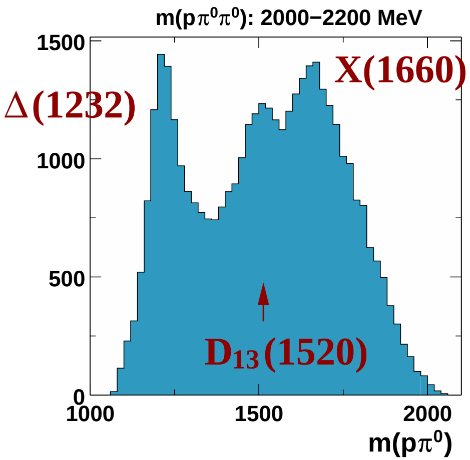
Search for $N^*/\Delta^* \to \Delta\pi$:

$\gamma p \to p4\gamma$:



$\Rightarrow \gamma p \to p\pi^0\pi^0$
and $\gamma p \to p\pi^0\eta$
clearly observed

- $\gamma p \to N^*/\Delta^* \to \Delta\pi^0 \to p\pi^0\pi^0$

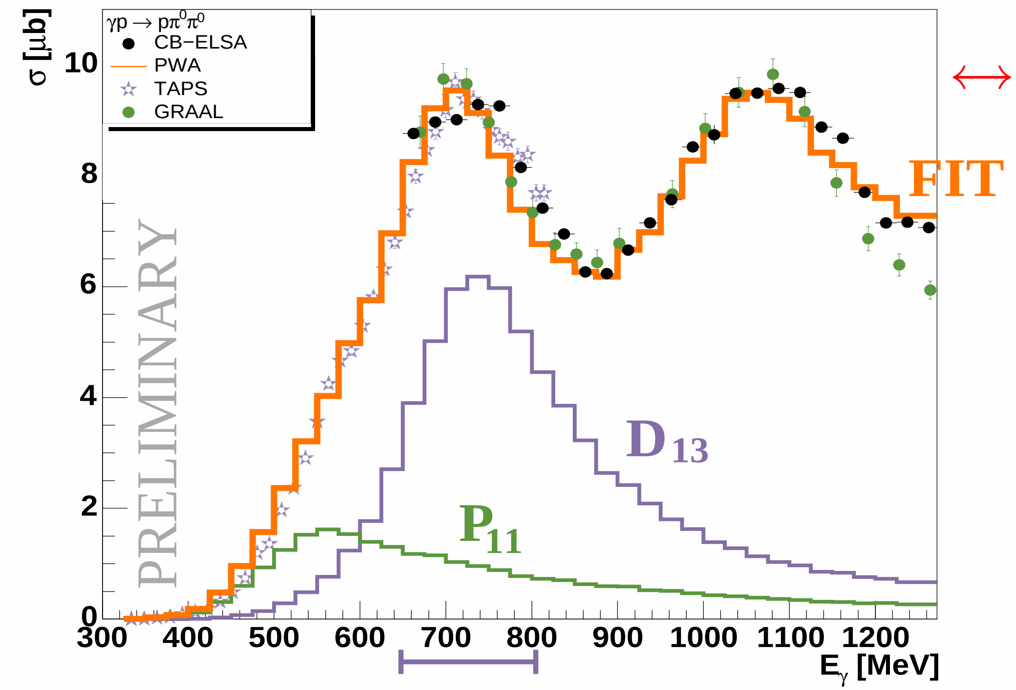


$\Leftarrow m(p\pi^0)$

for $\sqrt{s}$=2000-2200 MeV

for more details on the data
$\to$ see talk by M.Fuchs

Total cross section $\gamma p \longrightarrow p\pi^0\pi^0$ CB-ELSA



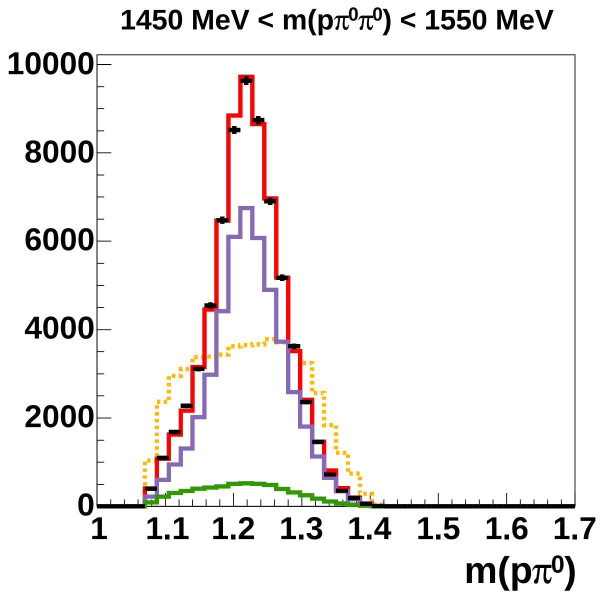
$\longleftrightarrow$ **Event based maximum likelihood fit**

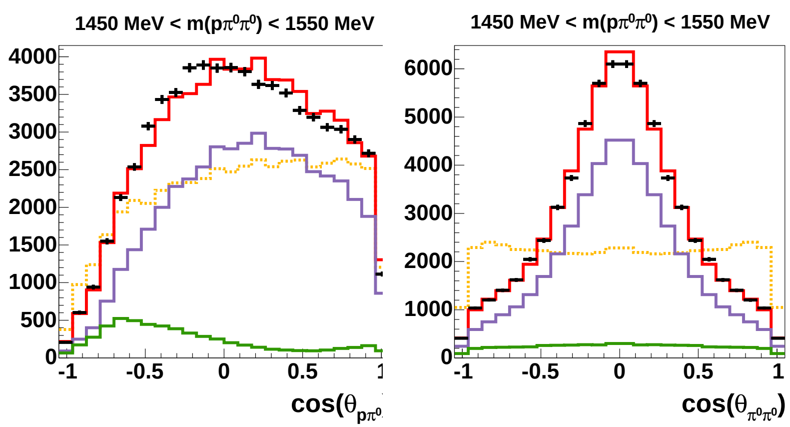
P_{11}(1440), D_{13}(1520), F_{15}(1680), D_{33}(1700), P_{33}(1920), D_{33}(1940), ...

+ background amplitudes

combined fit with single meson photoproduction and $\pi^- p \longrightarrow n\pi^0\pi^0$ (CBall) in progress

Angular distributions:



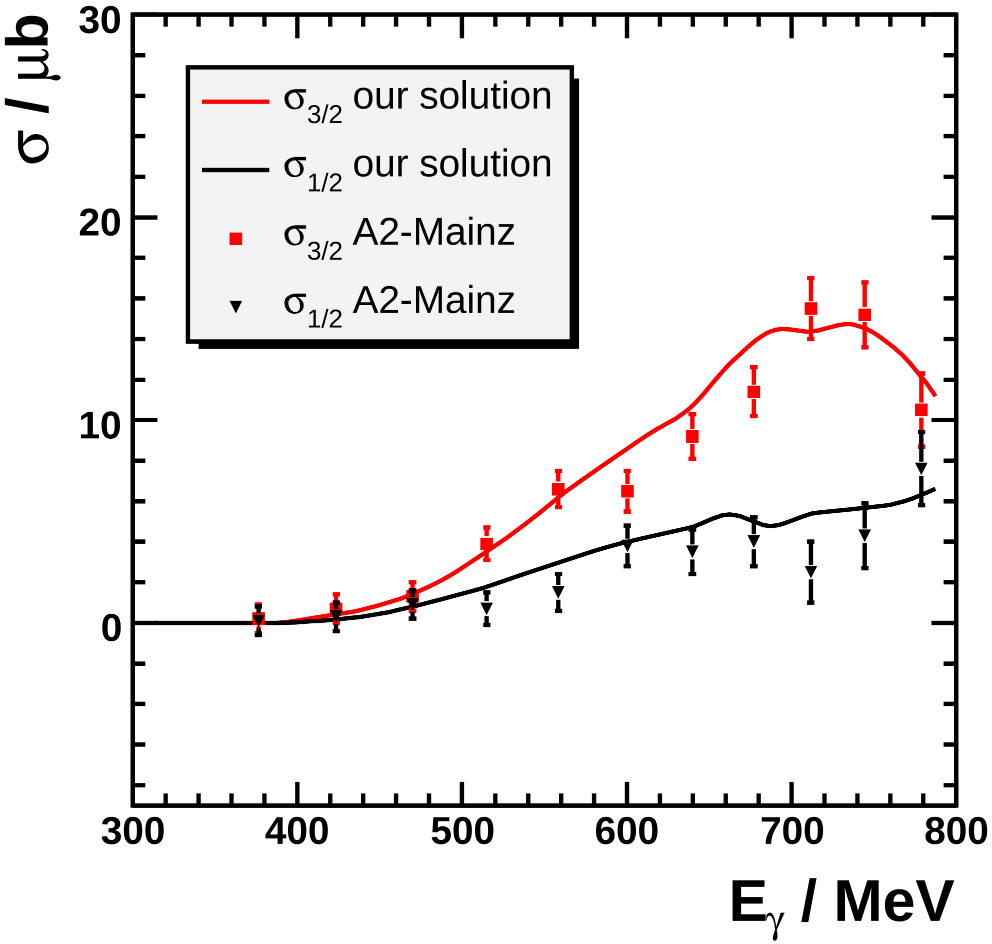


$\Longrightarrow$ D_{13}(1520) $\longrightarrow \Delta\pi$ clearly dominates

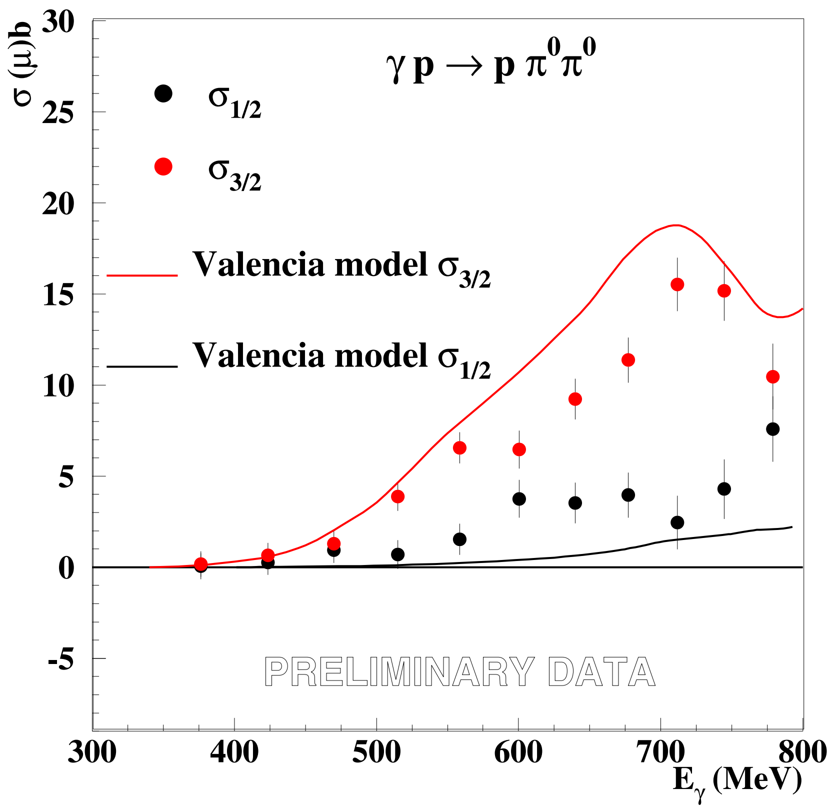
$\Longrightarrow$ Our result: incompatible with Laget

Results for our PWA in comparison to $\sigma_{3/2}, \sigma_{1/2}$ $\vec{\gamma}\vec{p} \longrightarrow p\pi^0\pi^0$ from Daphne at MAMI

Amplitudes adjusted to our unpolarised data only!:

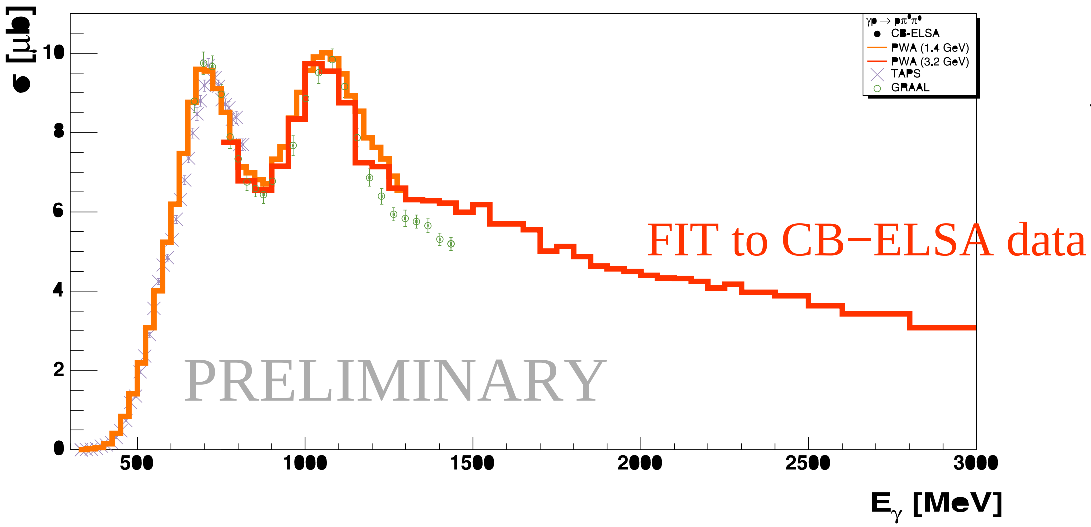


Oset et al.:



Total cross section $\gamma p \longrightarrow p\pi^0\pi^0$

$\longrightarrow$ **Extension of the energy range up to 3 GeV**



$\longrightarrow$ **PWA $\Rightarrow$ Determination of resonance properties:**

m , Γ, couplings ($\longleftrightarrow$ combined fit)

$\longrightarrow$ **Comparison with models**

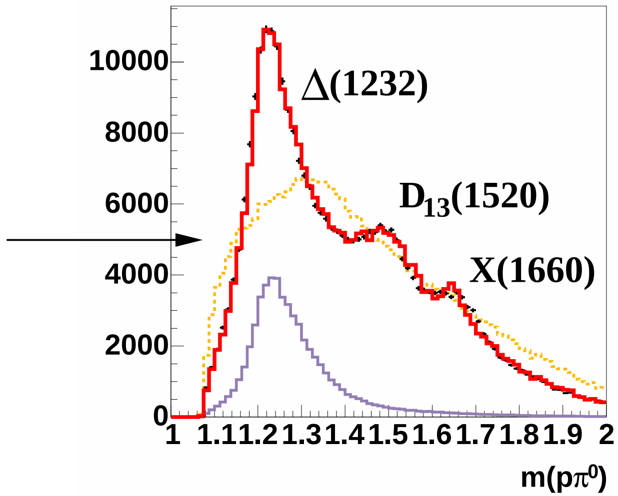
Clear observation of baryon cascades:

$\gamma p \longrightarrow N^*/\Delta^* \longrightarrow \Delta\pi$

$\gamma p \longrightarrow N^*/\Delta^* \longrightarrow$ **D_{13}(1520)** π

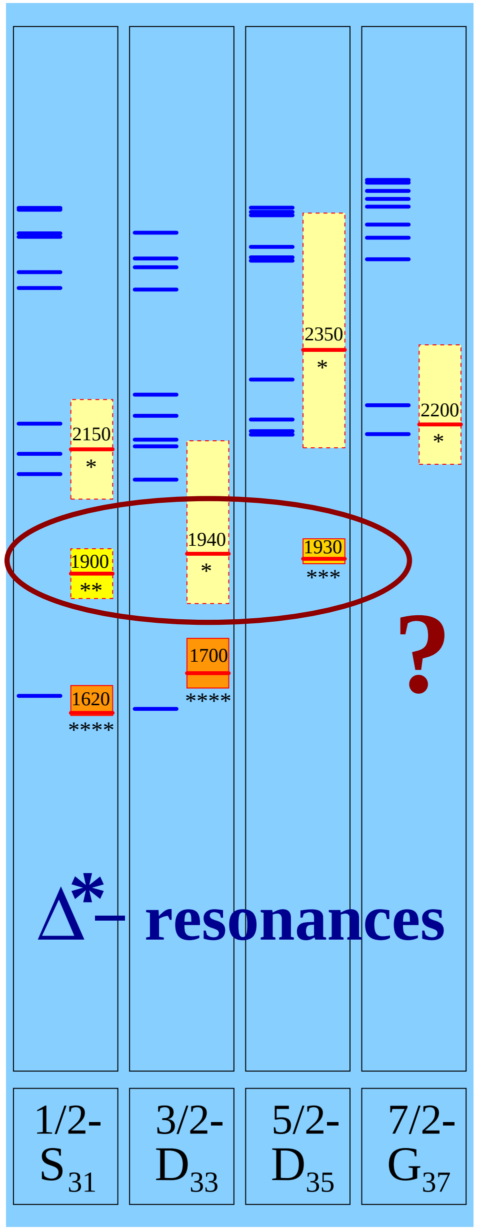
$\gamma p \longrightarrow N^*/\Delta^* \longrightarrow N^*/\Delta^*$ **($\sim$ 1660)** π

$\longrightarrow$ **Observed for the first time in this data**



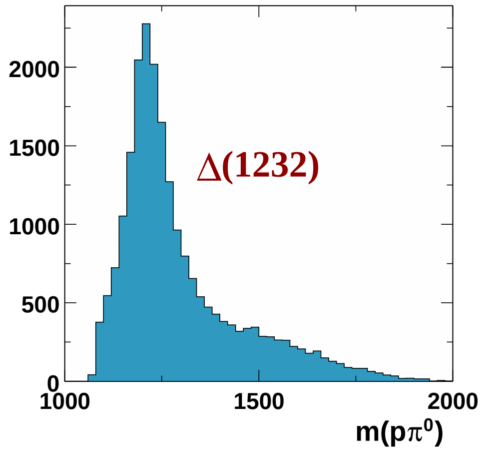
$\Rightarrow \gamma p \longrightarrow N^*/\Delta^*$ **which do not couple to πN or γN could be produced in such cascade decays**

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



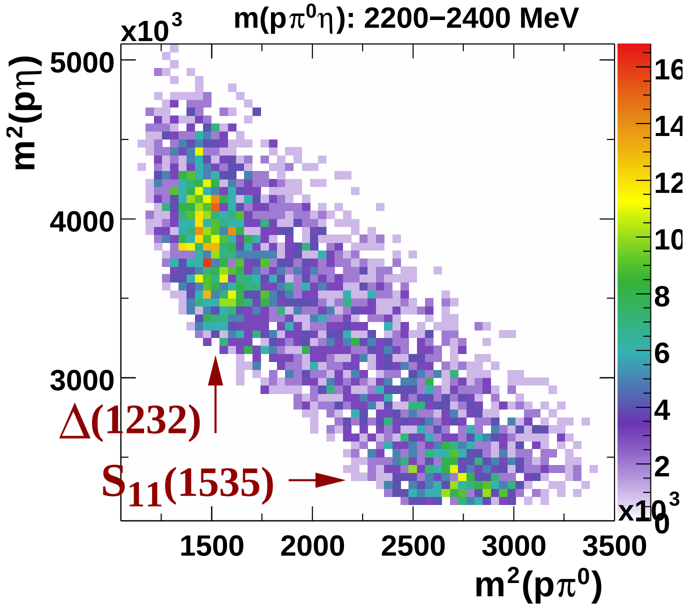
U. Loering et al.

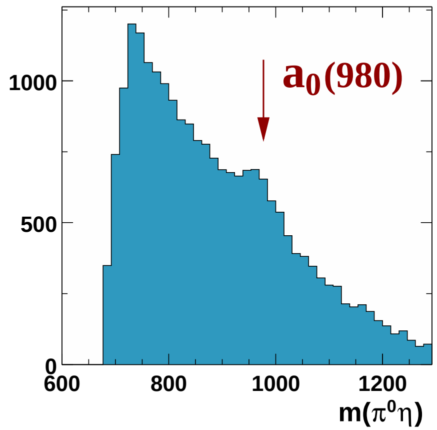
- $\gamma p \rightarrow \Delta^* \rightarrow \Delta(1232)\eta \rightarrow p\pi^0\eta$



$\Rightarrow$ $\Delta(1232)$ **clearly observed !**

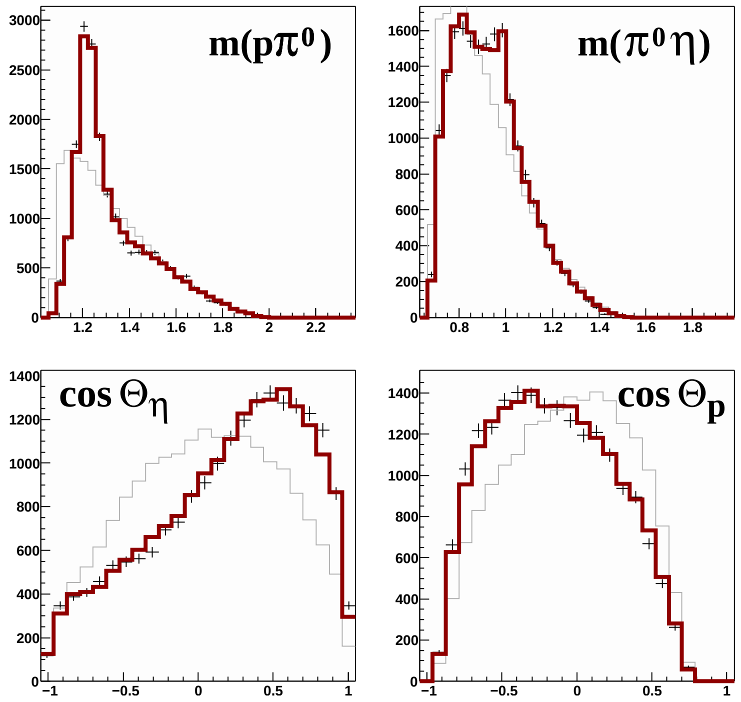
but there are also additional interesting structures :





$\gamma p \longrightarrow p\pi^0\eta$

Partial wave analysis:



$\Rightarrow$ $\Delta^*(\sim 1900)$ $J^P = \frac{3}{2}^-$ needed

+ hints for a possible new resonance
+ observation of baryon cascades

but: 3 ambiguous solutions found ....

Problem of the partial wave analysis

– Especially at higher energies –

$\leftrightarrow$ Ambiguous solutions

(similar quality of data description reached with different sets of contributing amplitudes)

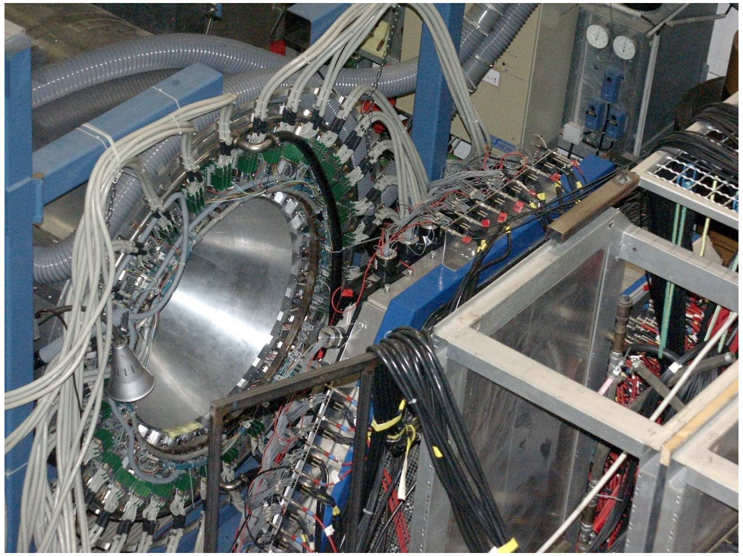
$\Rightarrow$ **Need for polarisation experiments !**

$\leftrightarrow$ Additional constraints for PWA

- Distinguish between ambiguous solutions
- Higher sensitivity on smaller contributions
- Further confidence in results

$\Rightarrow$ **Single and double polarisation experiments necessary**

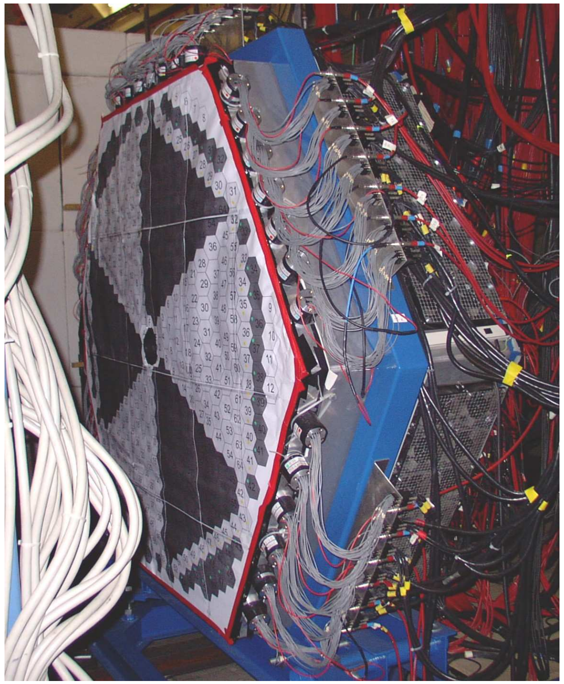
CB-TAPS and linear polarisation



Data taking Sep'2002 - Dec'2003

Crystal Barrel

$\longrightarrow$ **90 CsI(Tl)-crystals removed**



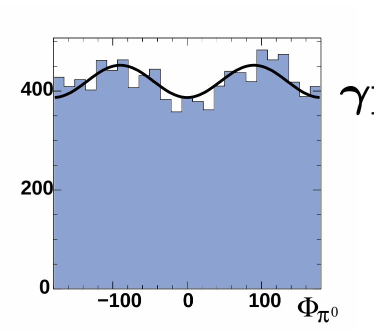
TAPS:

- $528\ BaF_2$- crystals
- High granularity
- Fast trigger

+ linearly polarised photons:

$\longleftrightarrow$ Φ **-asymmetry expected:**

$$N(\Phi) = N_0(1 - P_T \cdot \Sigma * \cos 2\Phi)$$



$\gamma p \longrightarrow p\pi^0\pi^0$

$\Rightarrow$ **Data analysis in progress ...**

future double polarisation experiments

$\longrightarrow$ see talk by H.Schmieden

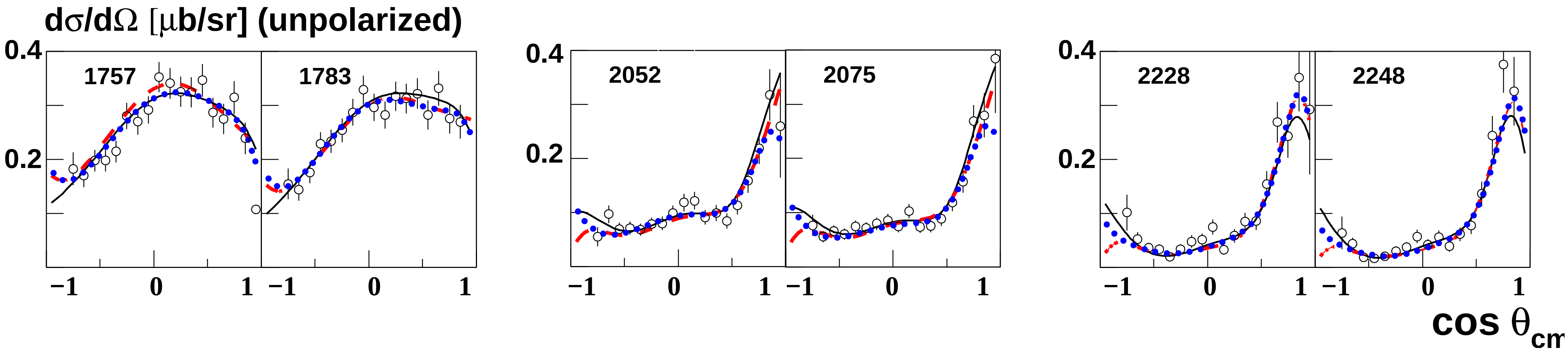
Double polarisation experiments $\gamma p \rightarrow p\eta$

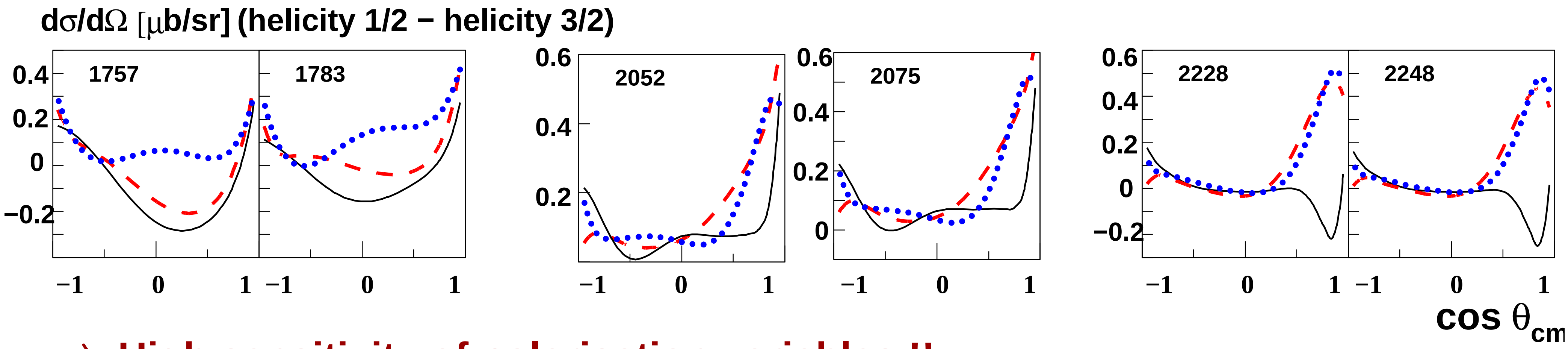
SFB/TR16

Sensitivity on the quantum numbers of the new $D_{15}(2070)$

— : best solution: $D_{15}(2070)$

— : $1/2^-$ state substitutes $D_{15}(2070)$ — : $1/2^+$ state substitutes $D_{15}(2070)$





⇒ **High sensitivity of polarisation variables !!**

Summary

- **High quality data has been taken**
  - **Extends the covered angular and energy range**

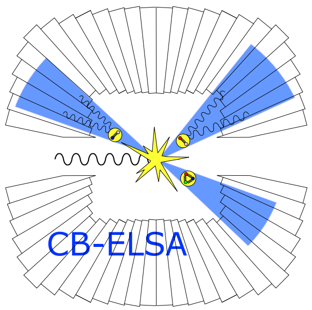
$\longrightarrow$ **First evidence for new resonances: D_{15}(2070) $\longrightarrow p\eta$**
(Combined PWA of data on $\gamma p \rightarrow p\pi^0, p\eta, K\Lambda, K\Sigma$: hints for additonal new states)

$\longrightarrow$ **Determination of resonance properties (combined PWA)**

$\longrightarrow$ **Clear observation of baryon cascades in $\gamma p \longrightarrow p\pi^0\pi^0$, $\gamma p \longrightarrow p\pi^0\eta$**
- decays via D_{13}(1520)π^0 and S_{11}(1520)π^0

$\Leftrightarrow$ **Already very interesting !**

But there is a lot more to be discovered $\Rightarrow$



within the

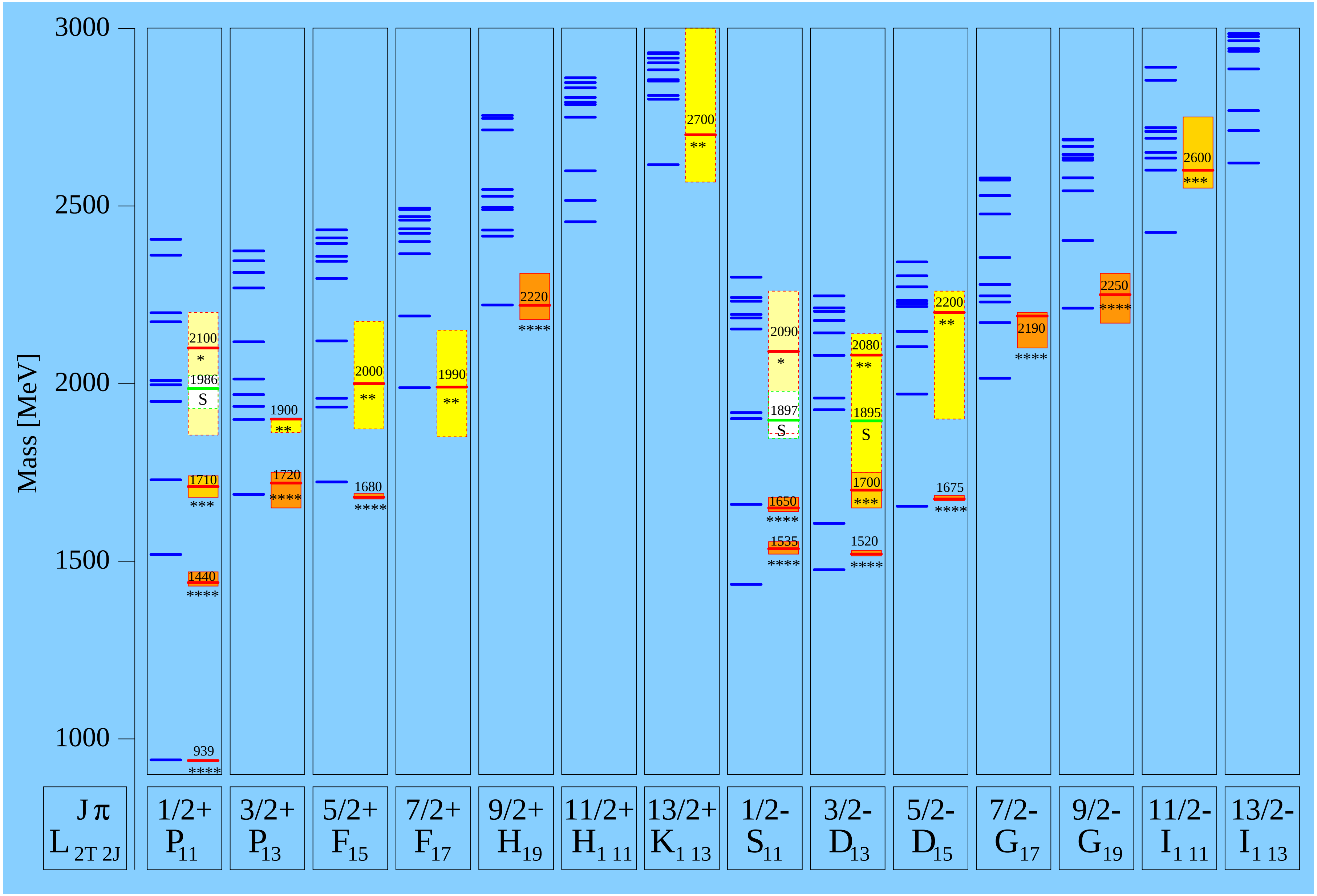
SFB/TR16

$\leftrightarrow$ **Polarisation experiments**

$\Rightarrow$ **Detailed testing ground for quark models, lattice QCD calculations ...**

Thank you !

N*-Resonances with instanton induced forces



U. Loering,

B. Metsch,

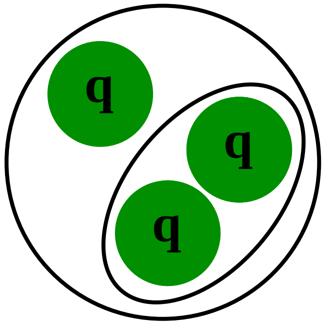
H. Petry et al.

Search for missing resonances

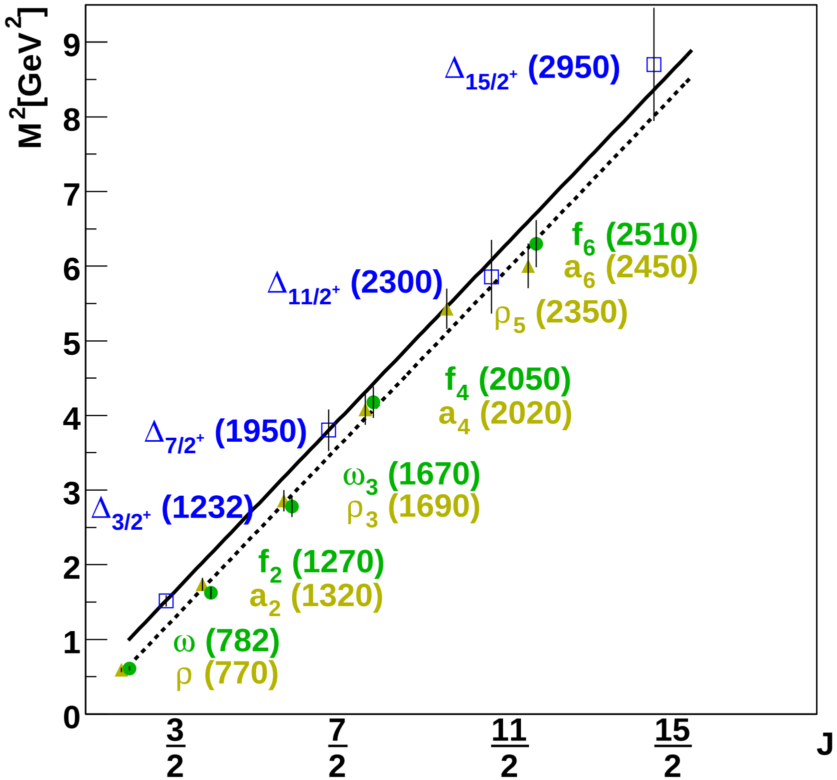
Quark model : **More Baryons predicted than observed**

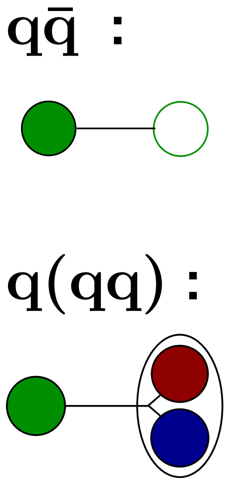
Possible explanations:

⇔ **Baryons have a quark-diquark structure:**



One of the internal degrees of freedom is frozen





Search for missing resonances

$\Leftrightarrow$ **They have not been observed up to now**

Nearly all existing data from πN- scattering experiments

$\Leftrightarrow$ **Missing states decouple from πN (supported by theory)**

Missing resonances:

$\longrightarrow$ **Many states are predicted to couple significantly to e.g.:**

$$\mathbf{N\eta,\ N\eta',\ N\omega,\ \Delta\pi,\ N\rho,\ \Delta\eta,\ \Delta\omega,\ and\ \underline{\gamma p}}$$

$\Rightarrow$ **Big discovery potential of photoproduction experiments**

In addition:

Measurement of resonance properties

- **Photocouplings, partial widths ....**

$\Rightarrow$ **Additional information** $\longleftrightarrow$ **Discrimination between different models**

Future: Double polarisation experiments

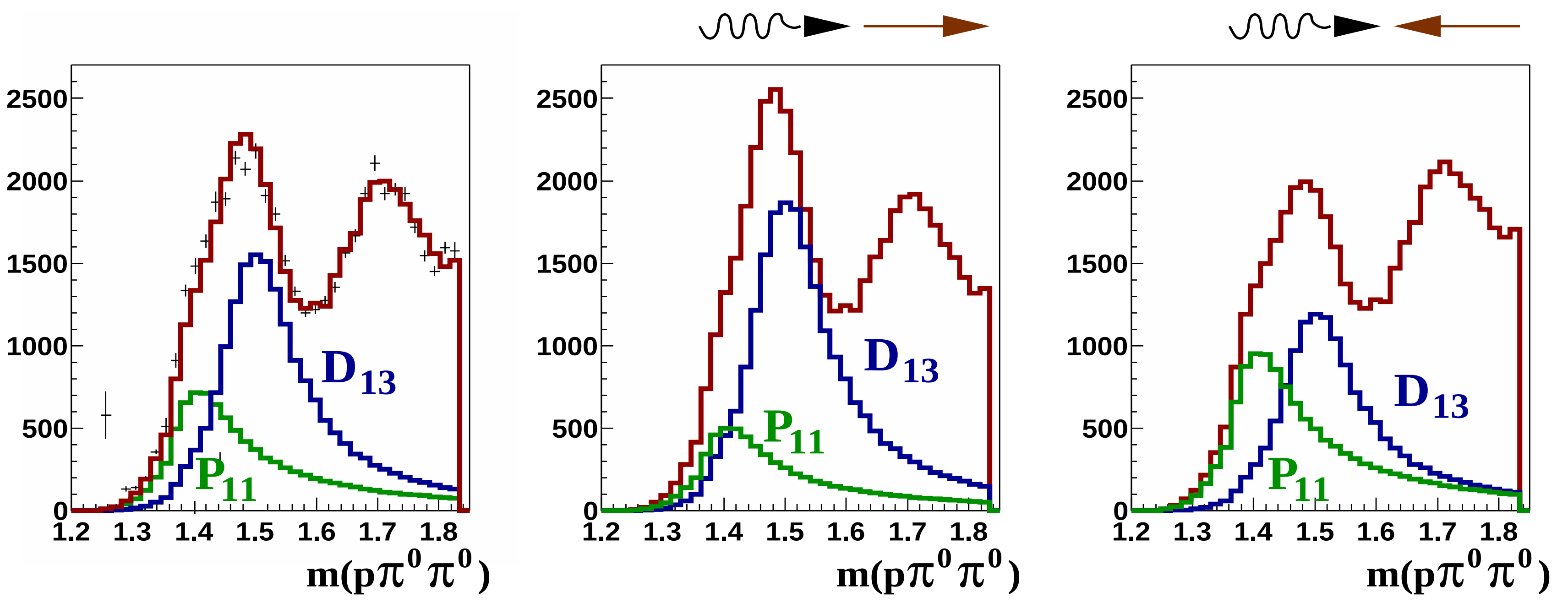
SFB/TR16

$\longrightarrow$ **Discrimination between ambiguous solutions in the PWA**

$\longrightarrow$ **Higher sensitivity to small contributions**

Simulations:

- $\gamma p \longrightarrow p\pi^0\pi^0$ **- circular polarised beam on longitudinal polarised target:**



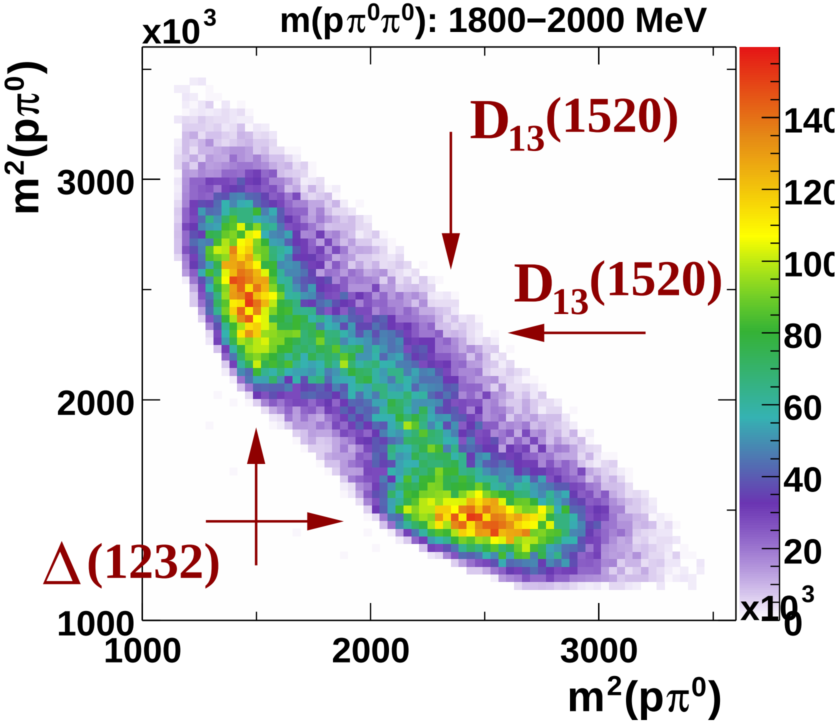
assumes:

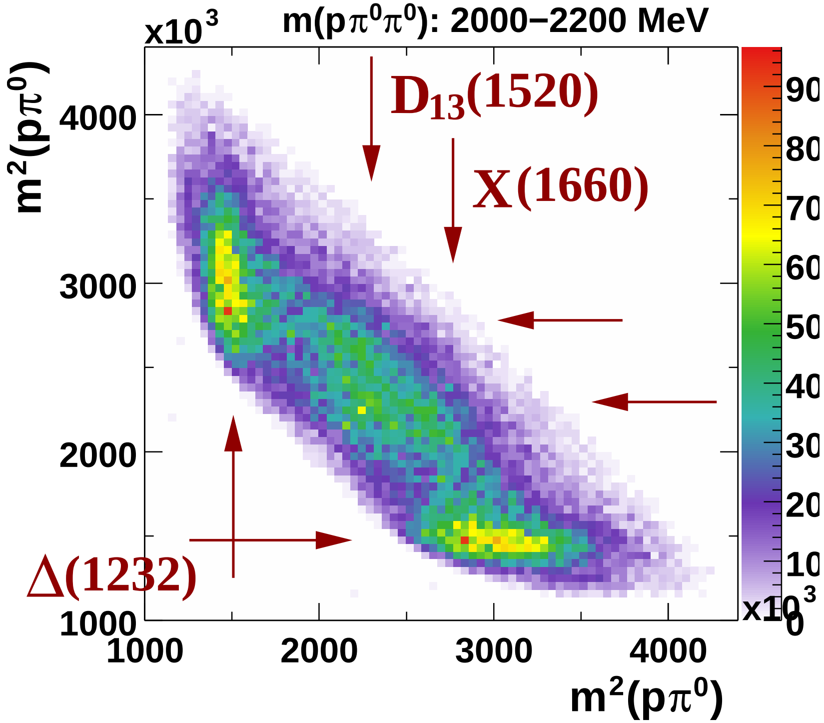
50% circular polarisation (beam)

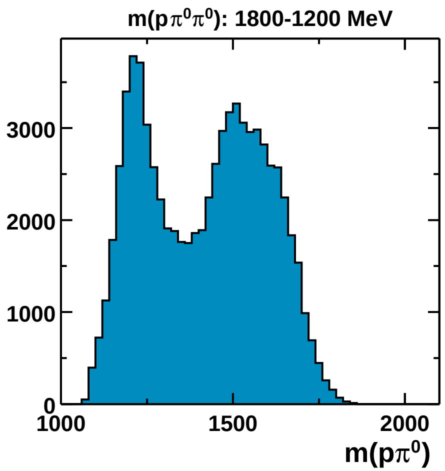
50% longitudinal polarisation (target)

.... starting 2006 ......

- $\gamma p \longrightarrow N^*/\Delta^* \longrightarrow X\pi^0 \longrightarrow p\pi^0\pi^0$

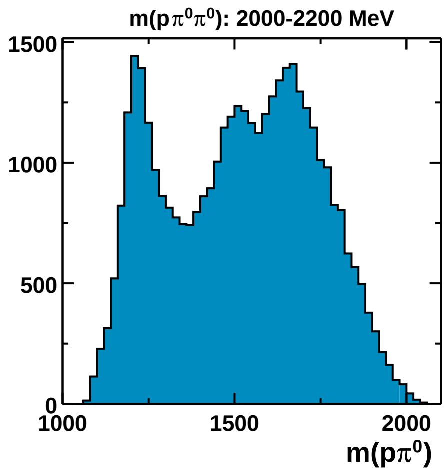






$X = \Delta(1232)$

$X = D_{13}(1520)$

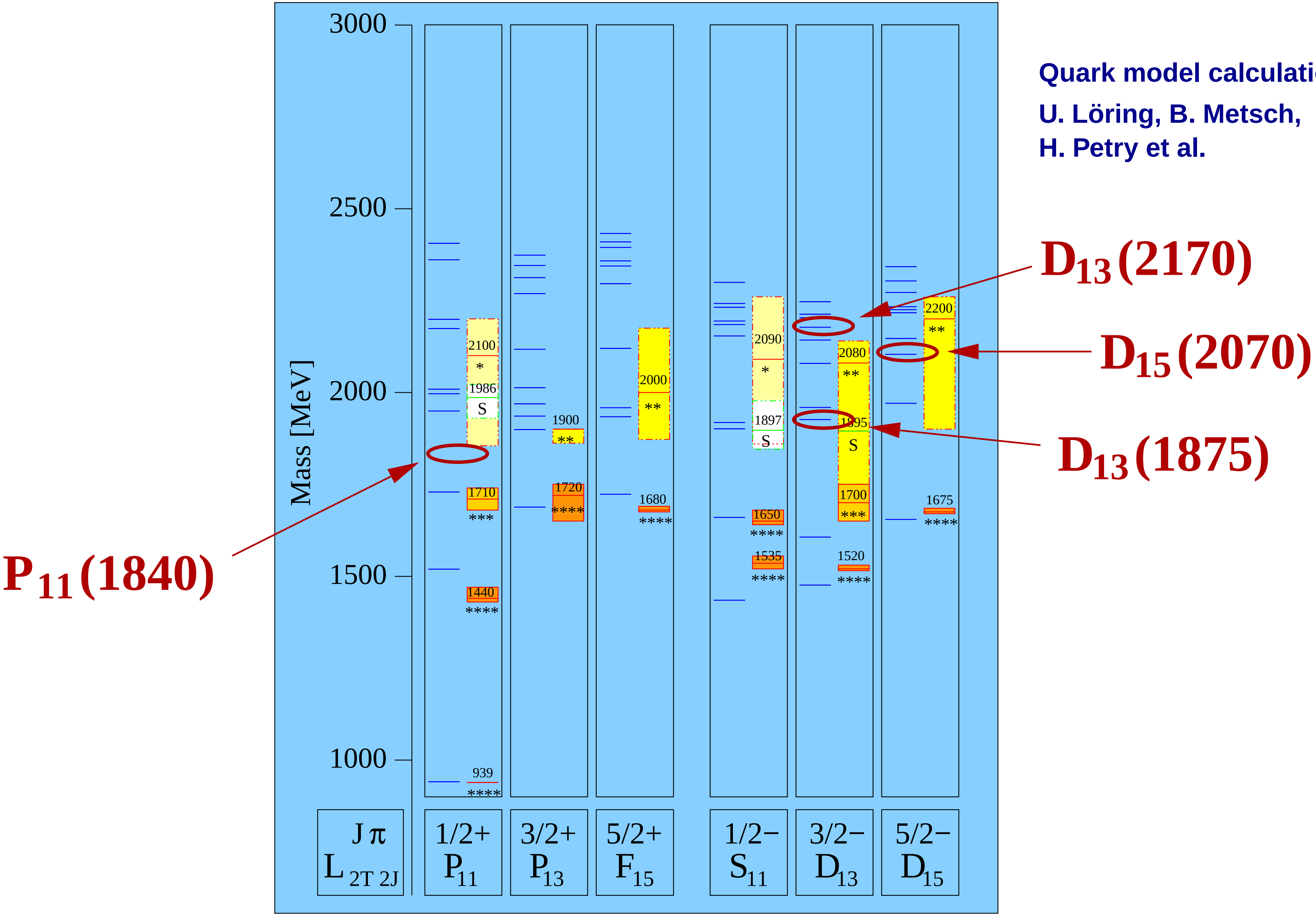


$X = \Delta(1232)$

$X = D_{13}(1520)$

$X = X(1660)$

The new states - a comparison with the quark model -

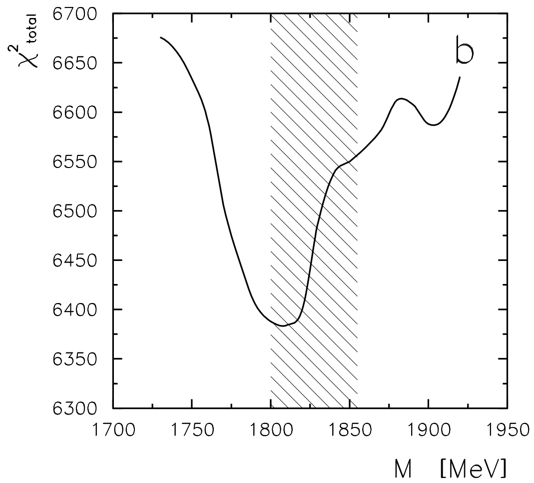


Quark model calculations by:

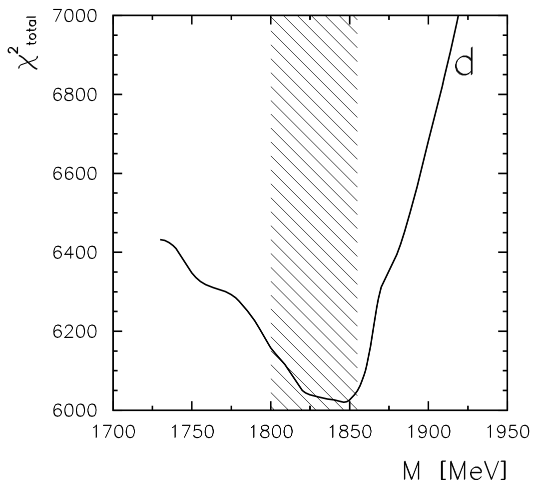
U. Löring, B. Metsch,
H. Petry et al.

New P_{11}

- $P_{11}(1840^{+15}_{-40}, 140^{+30}_{-50})$:



$p\pi^0$, $p\eta$- data



$K\Lambda$, $K\Sigma$- data

$N(2100)$ P_{11} $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: *

OMITTED FROM SUMMARY TABLE

$N(2100)$ BREIT-WIGNER MASS

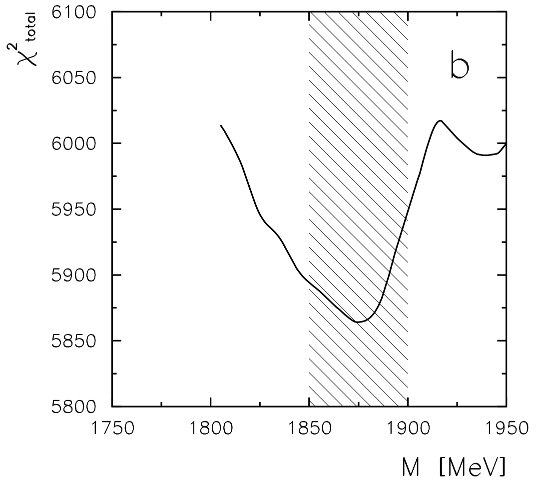
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2100 OUR ESTIMATE				
1885±30	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
2125±75	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2050±20	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2084±93	VRANA	00	DPWA	Multichannel
$1986\pm26^{+10}_{-30}$	PLOETZKE	98	SPEC	$\gamma p \to p\eta'(958)$
2203±70	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$

$N(2100)$ BREIT-WIGNER WIDTH

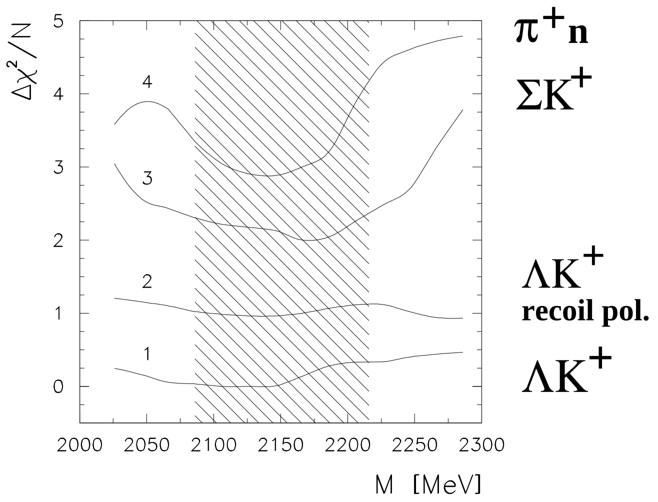
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
113± 44	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
260±100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
200± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1077±643	VRANA	00	DPWA	Multichannel
$296\pm100^{+60}_{-10}$	PLOETZKE	98	SPEC	$\gamma p \to p\eta'(958)$
418±171	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$

New D_{13} -states

- $D_{13}(1875 \pm 25, 80 \pm 20)$:



- $D_{13}(2166^{+50}_{-80}, 300 \pm 65)$:



$N(2080)$ D_{13} $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: ∗∗

OMITTED FROM SUMMARY TABLE

There is some evidence for two resonances in this wave between 1800 and 2200 MeV (see CUTKOSKY 80). However, the solution of HOEHLER 79 is quite different.

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** (1982).

$N(2080)$ BREIT-WIGNER MASS

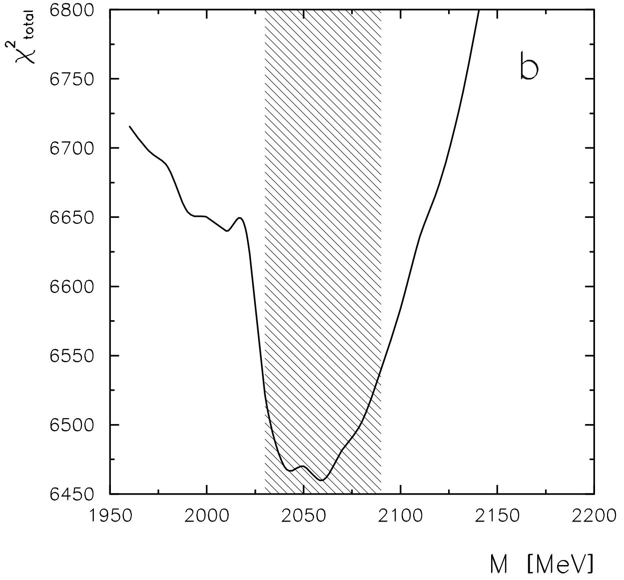
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2080 OUR ESTIMATE				
1804 ± 55	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1920	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
1880 ± 100	[1] CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2060 ± 80	[1] CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1900	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
2081 ± 20	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1946 ± 1	PENNER	02C	DPWA	Multichannel
1895	MART	00	DPWA	$\gamma p \to \Lambda K^+$
2003 ± 18	VRANA	00	DPWA	Multichannel
1986 ± 75	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
1880	BAKER	79	DPWA	$\pi^- p \to n\eta$

$N(2080)$ BREIT-WIGNER WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
450 ± 185	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
320	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
180 ± 60	[1] CUTKOSKY	80	IPWA	$\pi N \to \pi N$ (lower m)
300 ± 100	[1] CUTKOSKY	80	IPWA	$\pi N \to \pi N$ (higher m)
240	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
265 ± 40	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
859 ± 7	PENNER	02C	DPWA	Multichannel
372	MART	00	DPWA	$\gamma p \to \Lambda K^+$
1070 ± 858	VRANA	00	DPWA	Multichannel
1050 ± 225	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
87	BAKER	79	DPWA	$\pi^- p \to n\eta$

New $\mathrm{D_{15}}$ -state

- $\mathbf{D_{15}(2060 \pm 30, 340 \pm 50)}$:



$N(2200)\ D_{15}$	$I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ Status: **

OMITTED FROM SUMMARY TABLE

The mass is not well determined. A few early results have been omitted.

$N(2200)$ BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2200 OUR ESTIMATE				
1900	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
2180±80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1920	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
2228±30	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2240±65	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$

varies strongly !

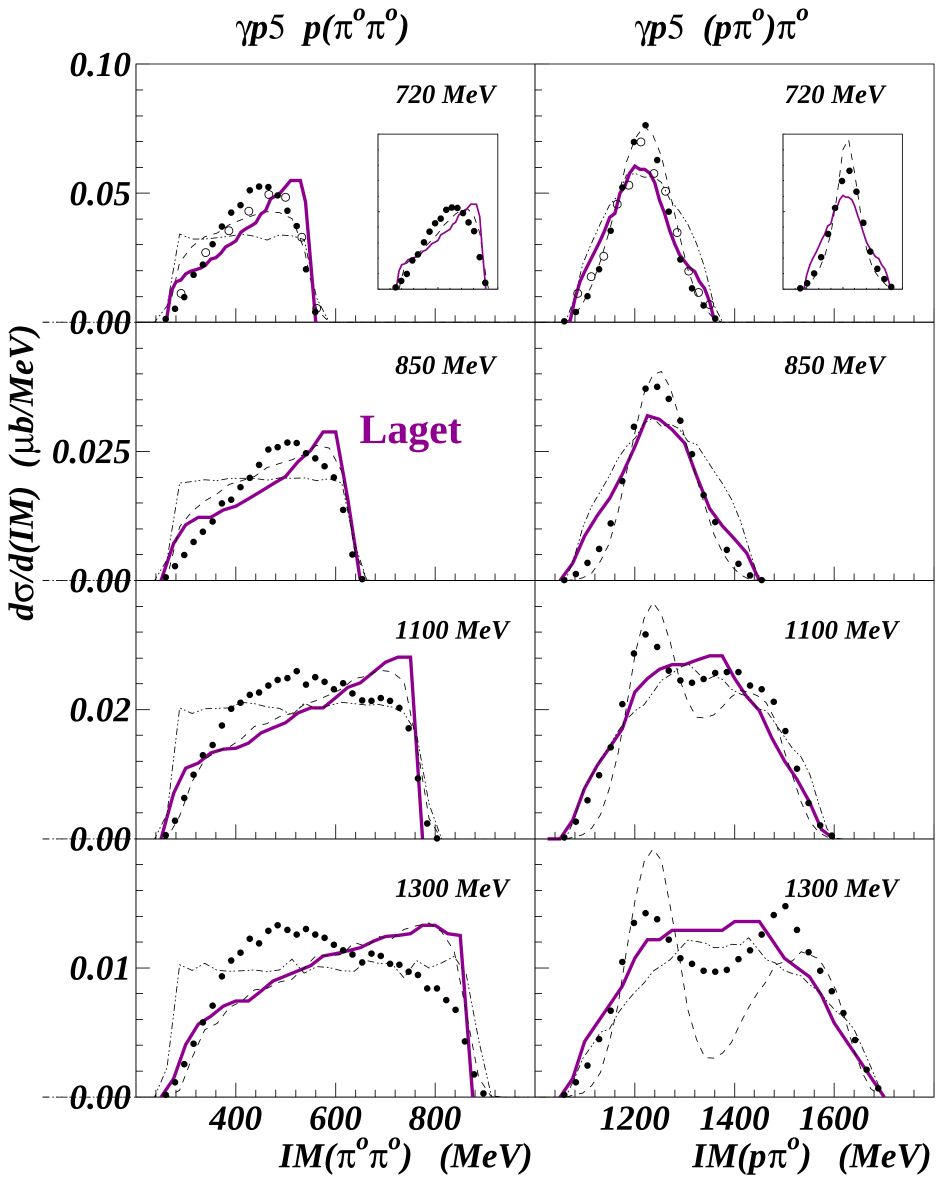
$N(2200)$ BREIT-WIGNER WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
130	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
400±100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
220	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
310± 50	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
761±139	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$

$\Leftrightarrow$ **Results vary strongly!**

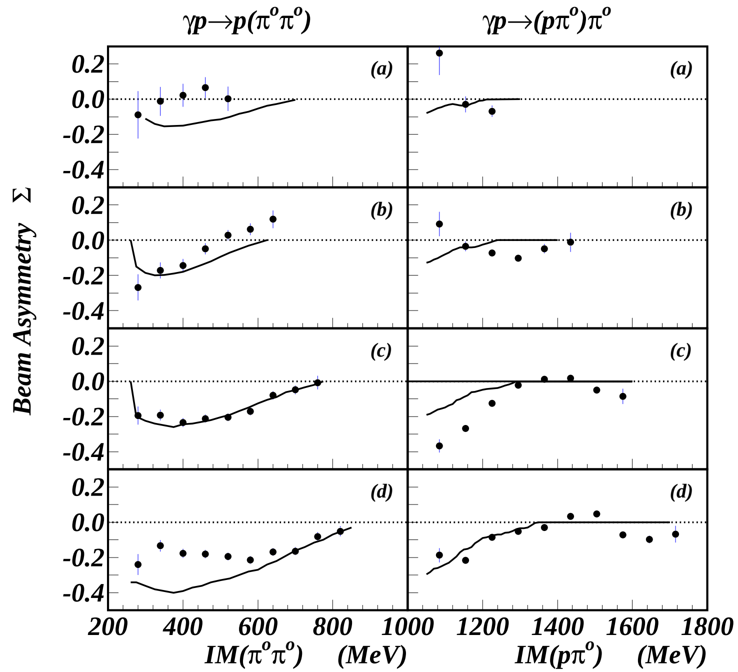
$\vec{\gamma}p \rightarrow p\pi^0\pi^0$

Invariant masses:



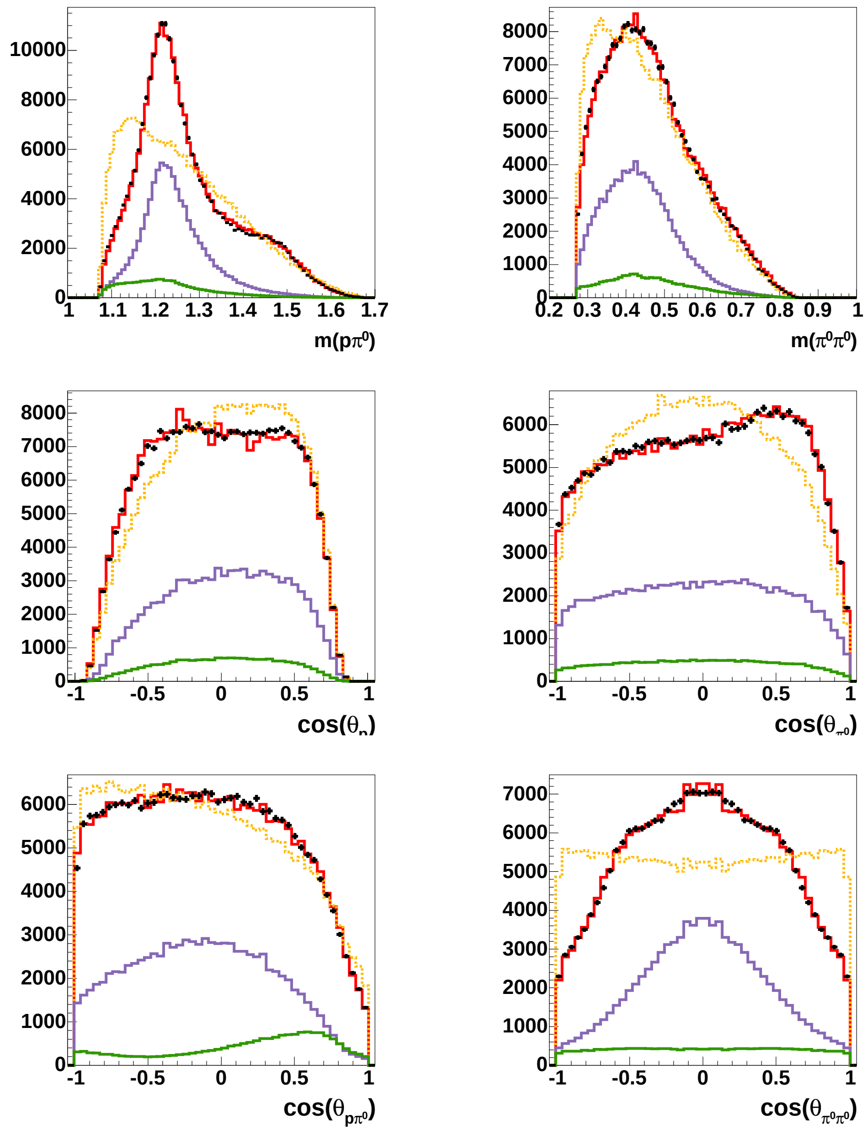
Beam asymmetry:

(compton back-scattered γ-beam $\leftrightarrow$ linear polarisation)

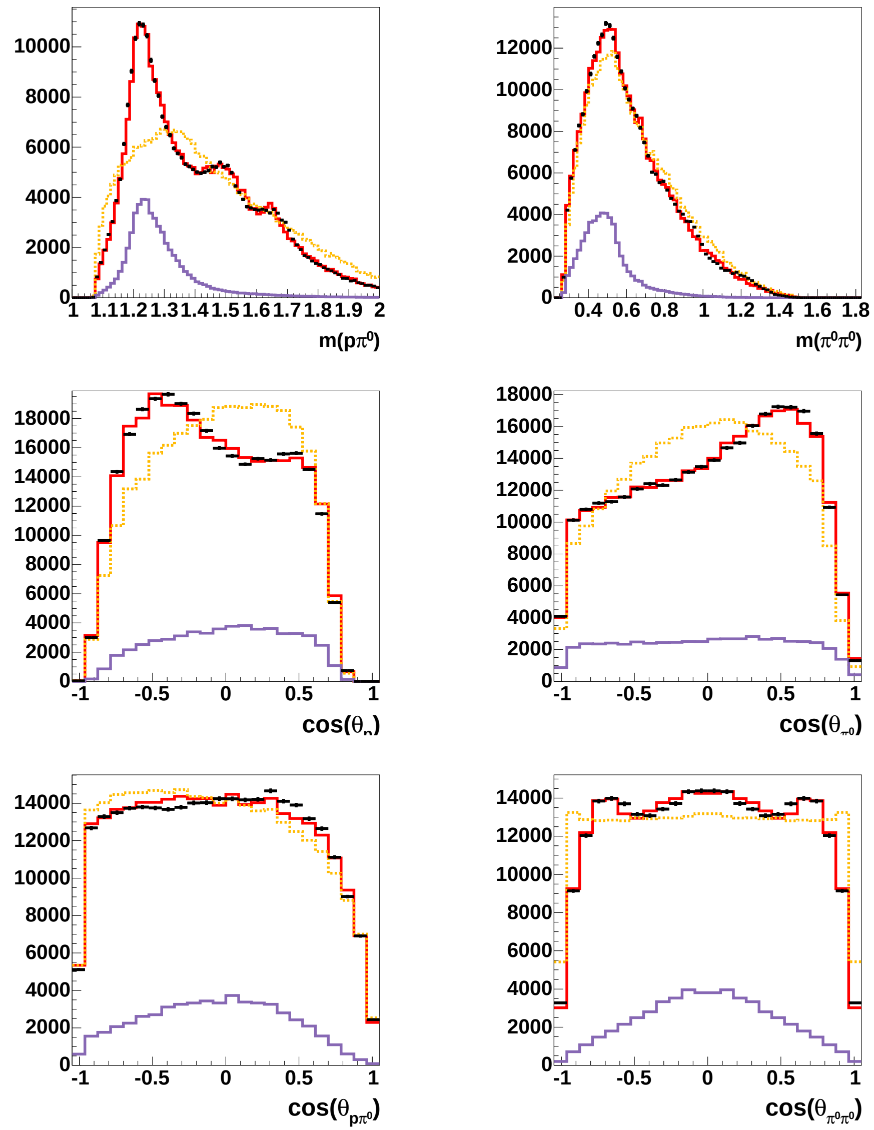


Quality of the data description

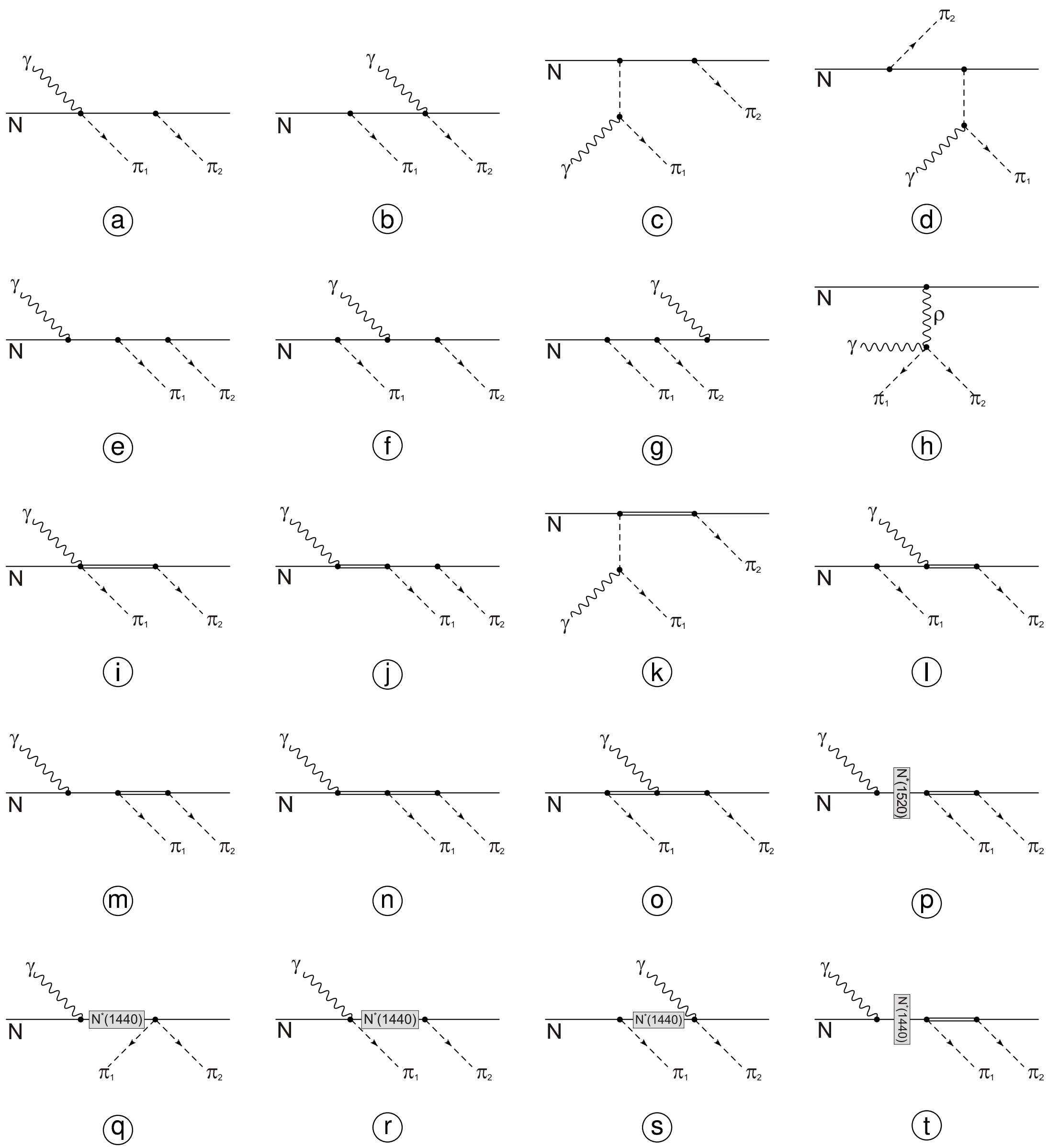
$\mathbf{E_{e^-} = 1.4\,GeV: \;\; E_\gamma = 0.37 - 1.3\,GeV:}$



$\mathbf{E_{e^-} = 3.2\,GeV: \;\; E_\gamma = 0.8 - 3.0\,GeV:}$



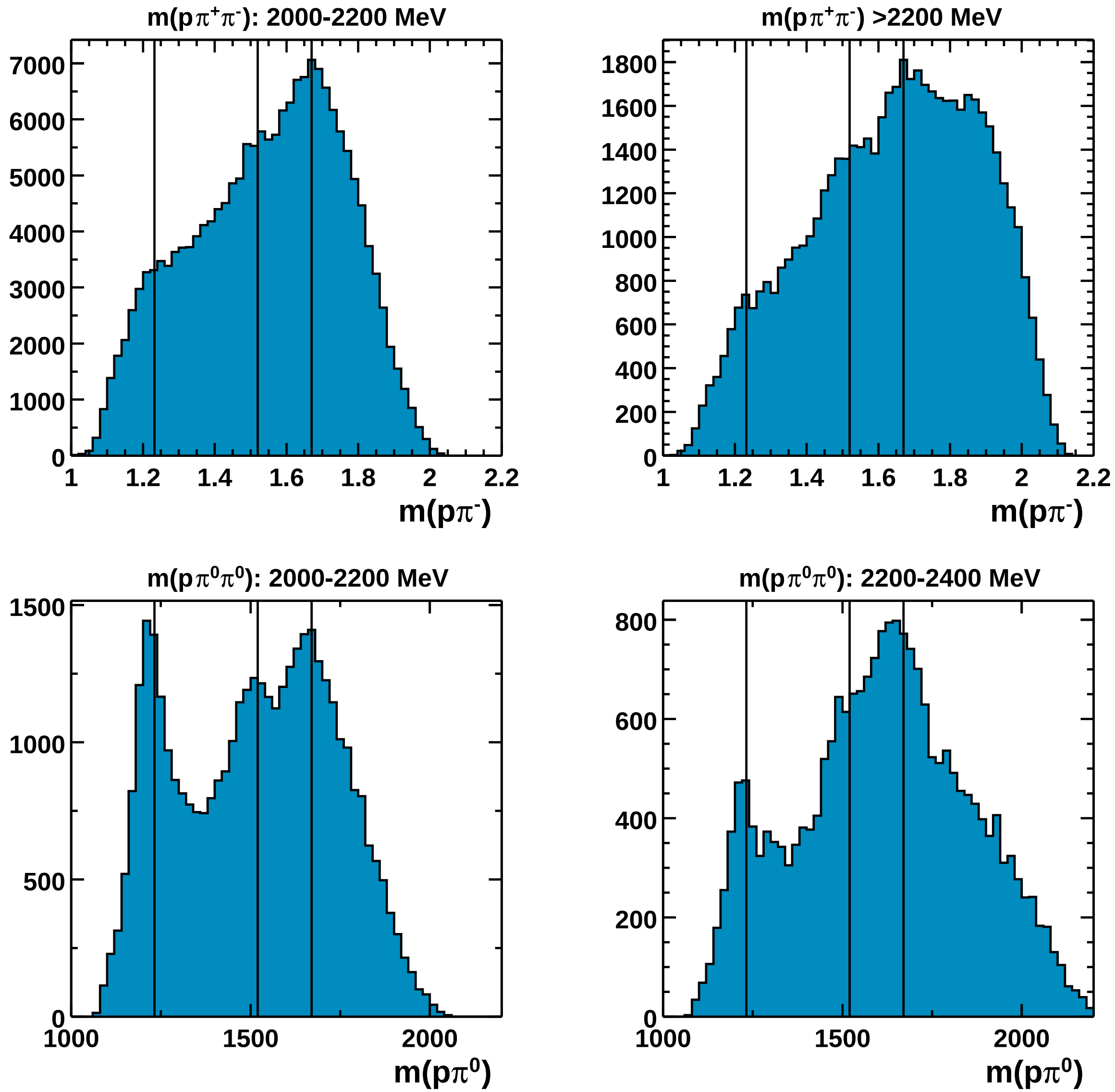
Diagrams included by Oset



$\gamma p \longrightarrow p\pi^0\pi^0$ and $\gamma p \longrightarrow p\pi^+\pi^-$ from CB-ELSA and CLAS

CLAS:

CB-ELSA:



$\gamma p \longrightarrow N^*/\Delta^*$

$\longrightarrow X\pi$

$X = \Delta(1232)$

$X = D_{13}(1520)$

$X = X(1660)$

$\Rightarrow$ **Similar resonance structures in both data sets !**

Partial wave analysis of $\gamma p \longrightarrow p\pi^0\pi^0$

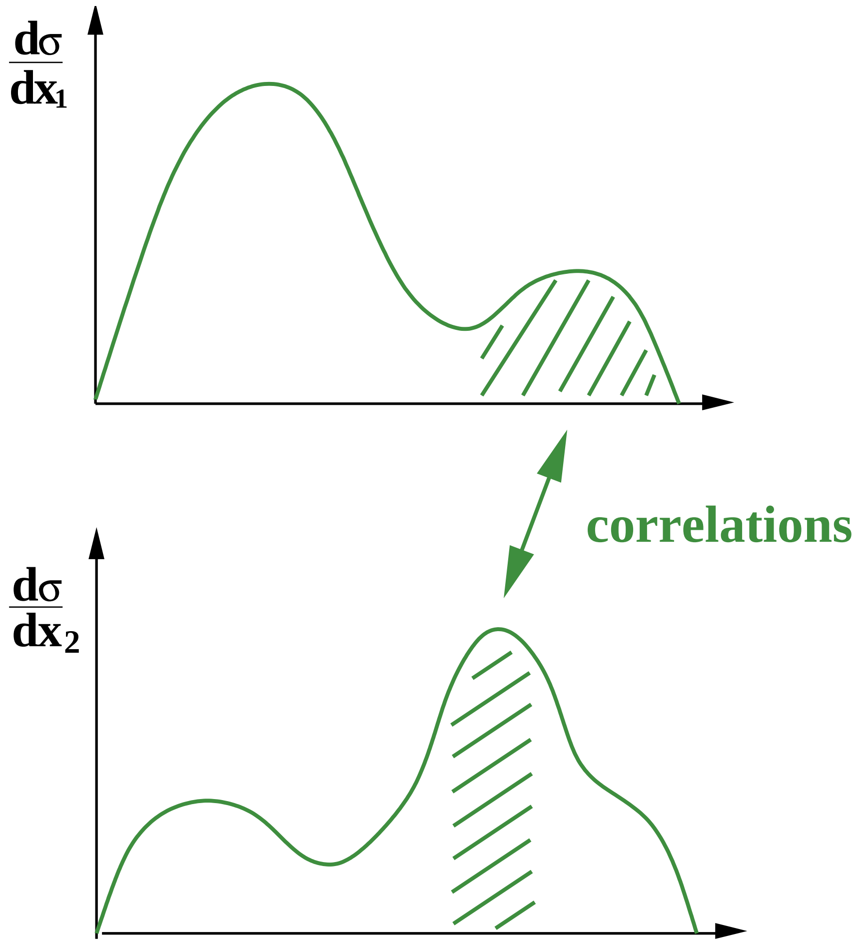
- **Isobar model**
- **Breit-Wigner (or K-matrix) parametrisation for the resonances**
- **s- and t-channel amplitudes included**
- **unbinned maximum likelihood fit**

$\longrightarrow$ **Event based**

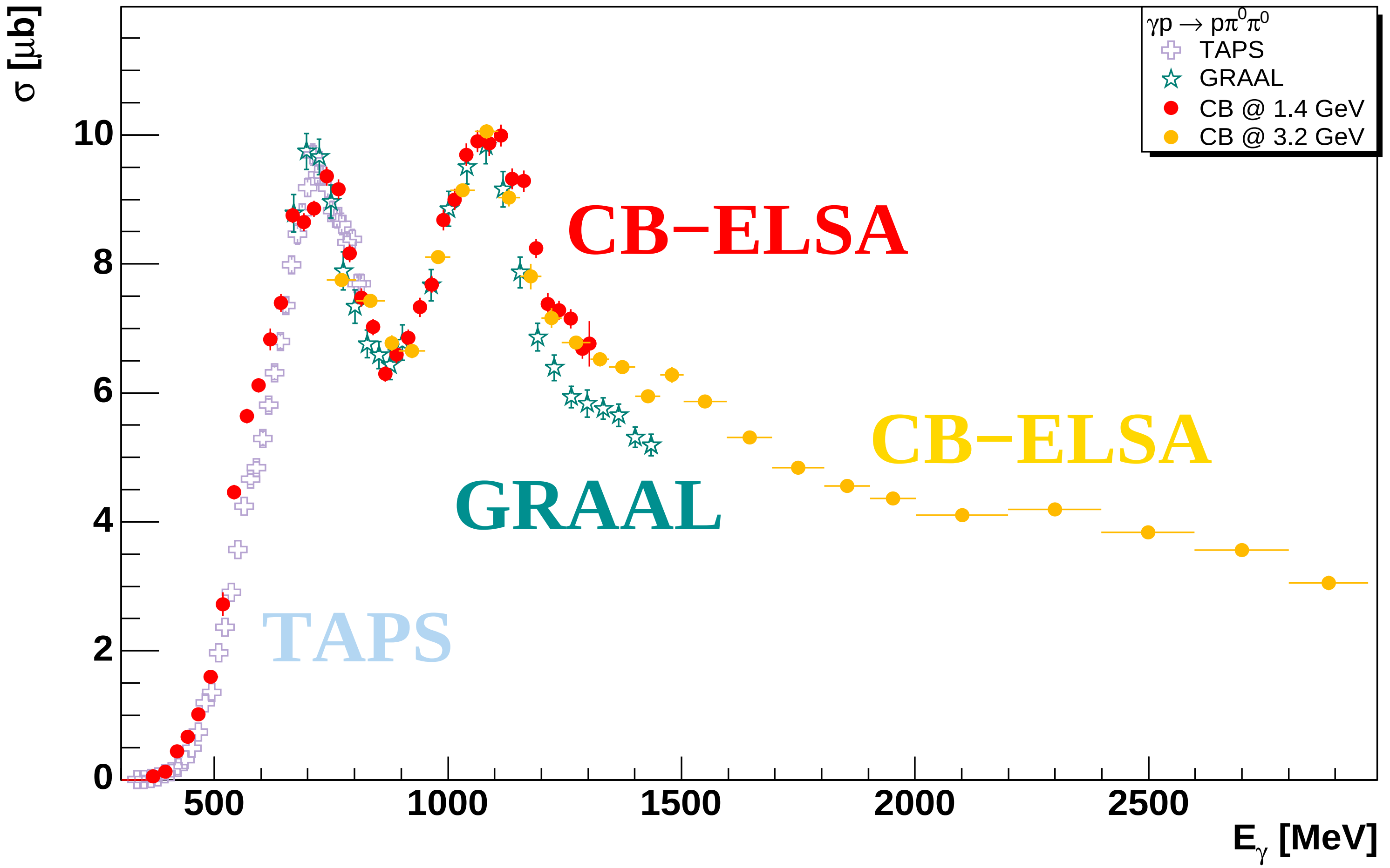
$\longrightarrow$ **Takes all correllations properly into account**

(5 independent variables)

$\Rightarrow$ **No fitting of projections !**



Total cross section $\gamma p \rightarrow p\pi^0\pi^0$



$\gamma p \longrightarrow p\eta$ - results of different analyses

$\leftrightarrow$ **not yet including the CB-ELSA data**

- **Isobar model, ETA-MAID (Chiang et al.)**

$\Rightarrow$ **S_{11}(1535), D_{13}(1520), S_{11}(1650), D_{15}(1675), F_{15}(1680), D_{13}(1700), P_{11}(1710), P_{13}(1720), ρ -, ω -t-channel exchange**

- **Giessen coupled channel analysis (Penner, Mosel)**

$\Rightarrow$ **S_{11}(1535), D_{13}(1520), S_{11}(1650), D_{15}(1675), F_{15}(1680), P_{11}(1710) (small), ρ -, ω -t-channel exchange**

- **Chiral constituent quark model (Saghai,Li)**

$\Rightarrow$ **all known *** and **** -resonances, no t-channel exchange**

$\Leftrightarrow$ **3rd S_{11} resonance needed M = 1780 MeV, Γ= 280 MeV**

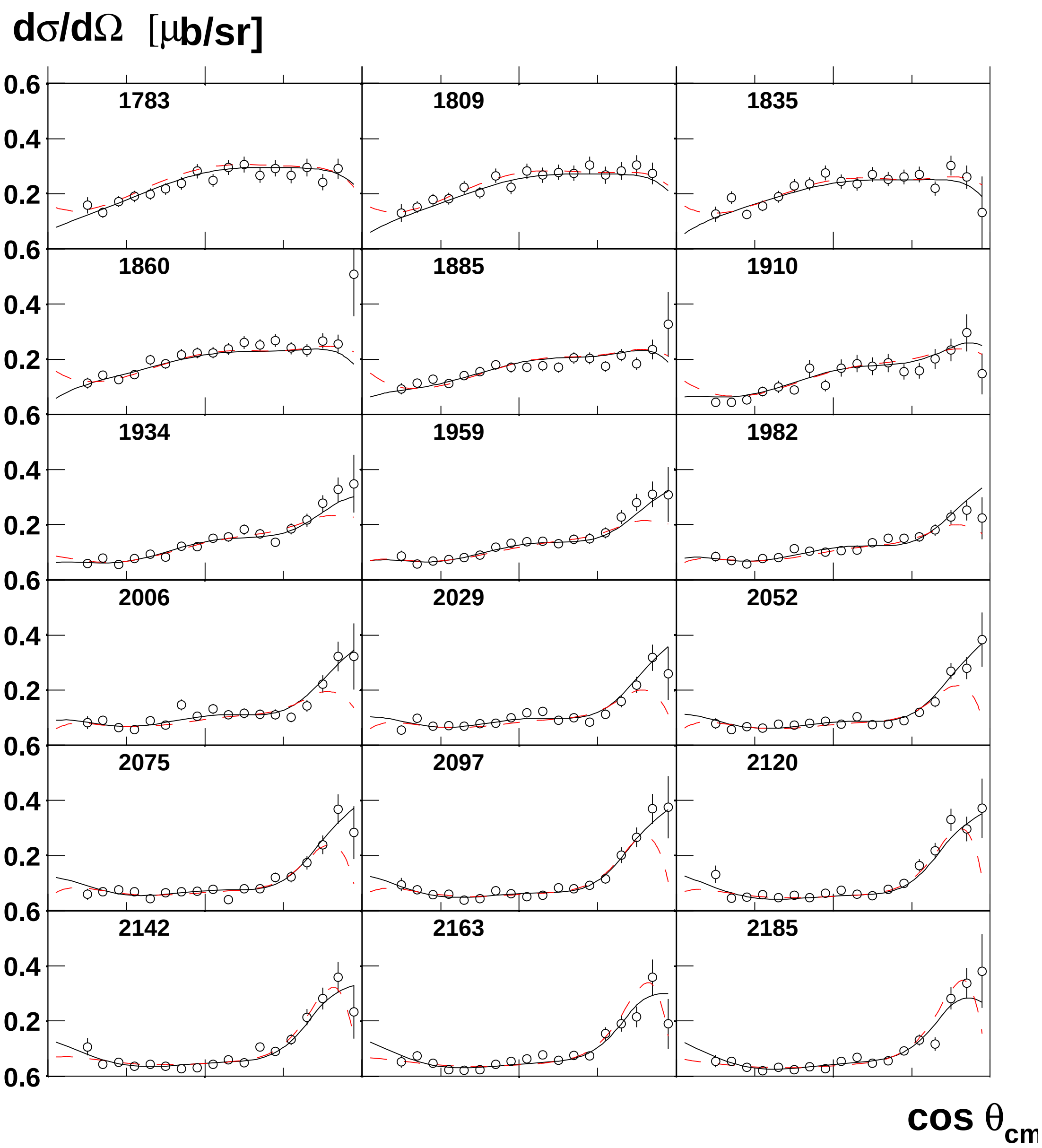
The new $D_{15}(2070)$

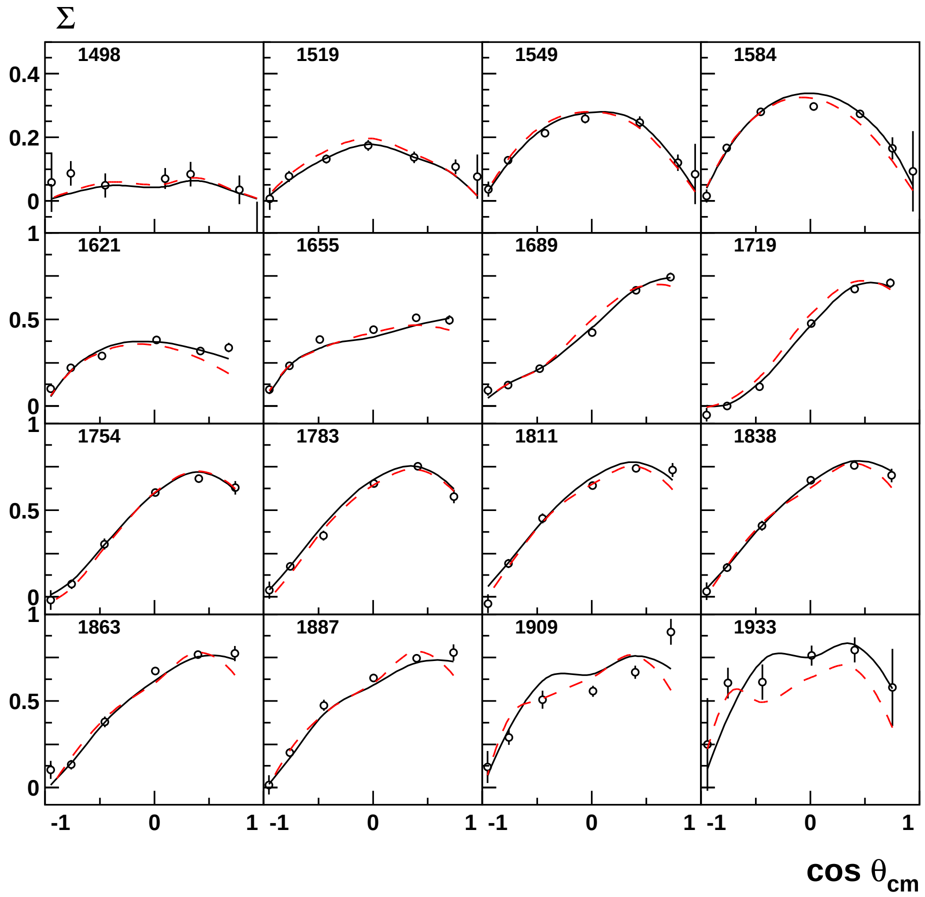
Resonance	$\mathrm{N(2070)D_{15}}$				
J^P	$\Delta\chi^2_{\mathrm{tot}}$	$\Delta\chi^2_{p\pi^0}$	$\Delta\chi^2_{p\eta}$	$\Delta\chi^2_{\Lambda K+}$	$\Delta\chi^2_{\Sigma K}$
omitted	1588	940	199	94	269
repl. by $1/2^-$	1027	669	128	111	-45
repl. by $3/2^-$	1496	851	214	-46	157
repl. by $7/2^-$	1024	765	108	-1	19
repl. by $9/2^-$	872	656	112	-9	118
repl. by $1/2^+$	832	674	115	55	33
repl. by $3/2^+$	1050	690	141	-42	20
repl. by $5/2^+$	766	627	113	48	123
repl. by $7/2^+$	807	718	112	-67	215
repl. by $9/2^+$	1129	847	131	7	-9

Best fit with / without the new $D_{15}(2070)$ $\gamma p \rightarrow p\eta$

—: best solution with new $D_{15}(2070)$

—: best fit without $D_{15}(2070)$

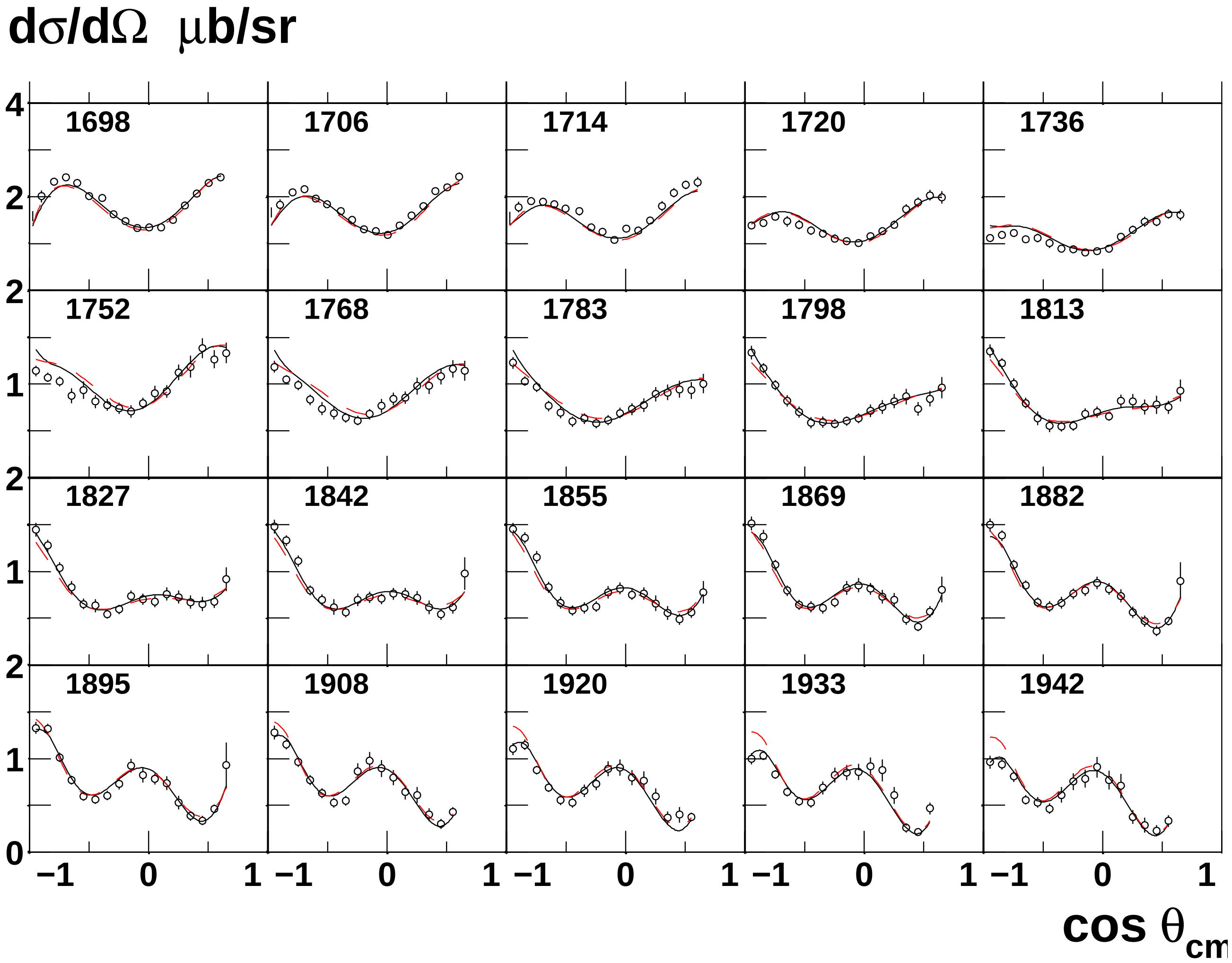




Best fit with / without the new $D_{15}(2070)$ $\gamma p \longrightarrow p\pi^0$

—: best solution with new $D_{15}(2070)$

—: best fit without $D_{15}(2070)$



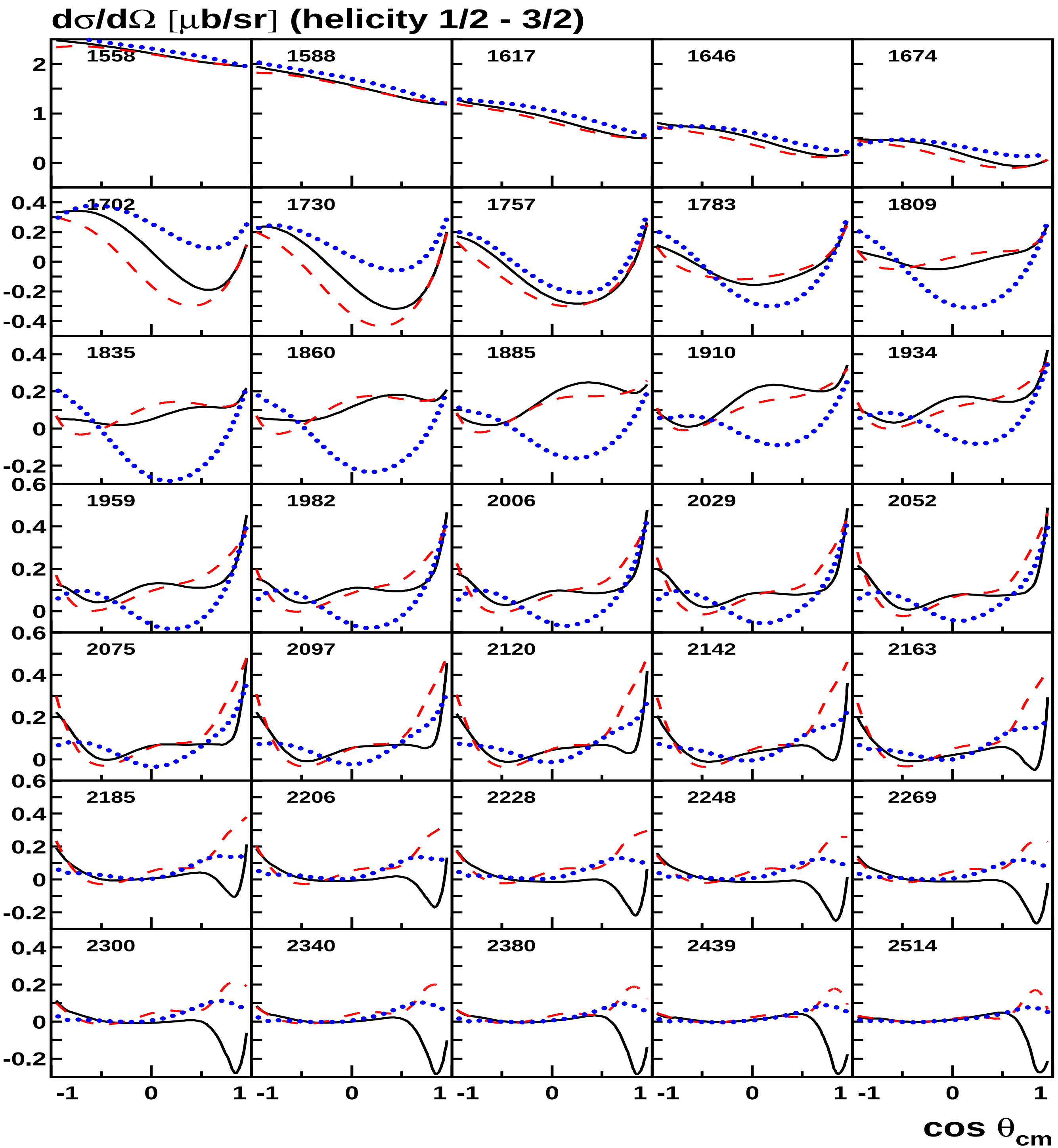
$\gamma p \to p\eta$

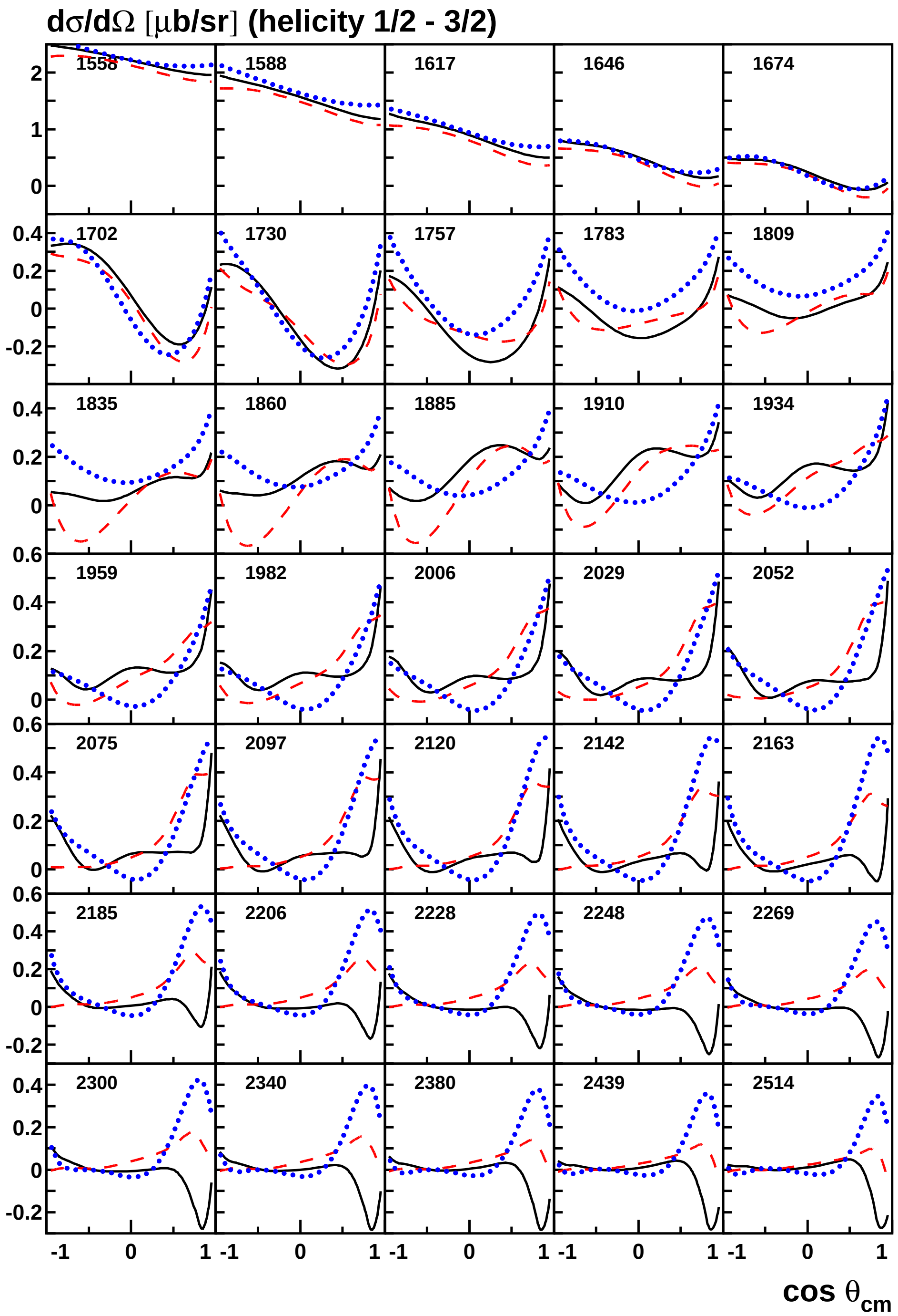
$D_{15}(2070)$

substituted by a

$7/2^-$ **or** $7/2^+$ **state**

$$\leftrightarrow \quad \frac{d\sigma_{1/2}}{d\Omega} - \frac{d\sigma_{3/2}}{d\Omega}$$



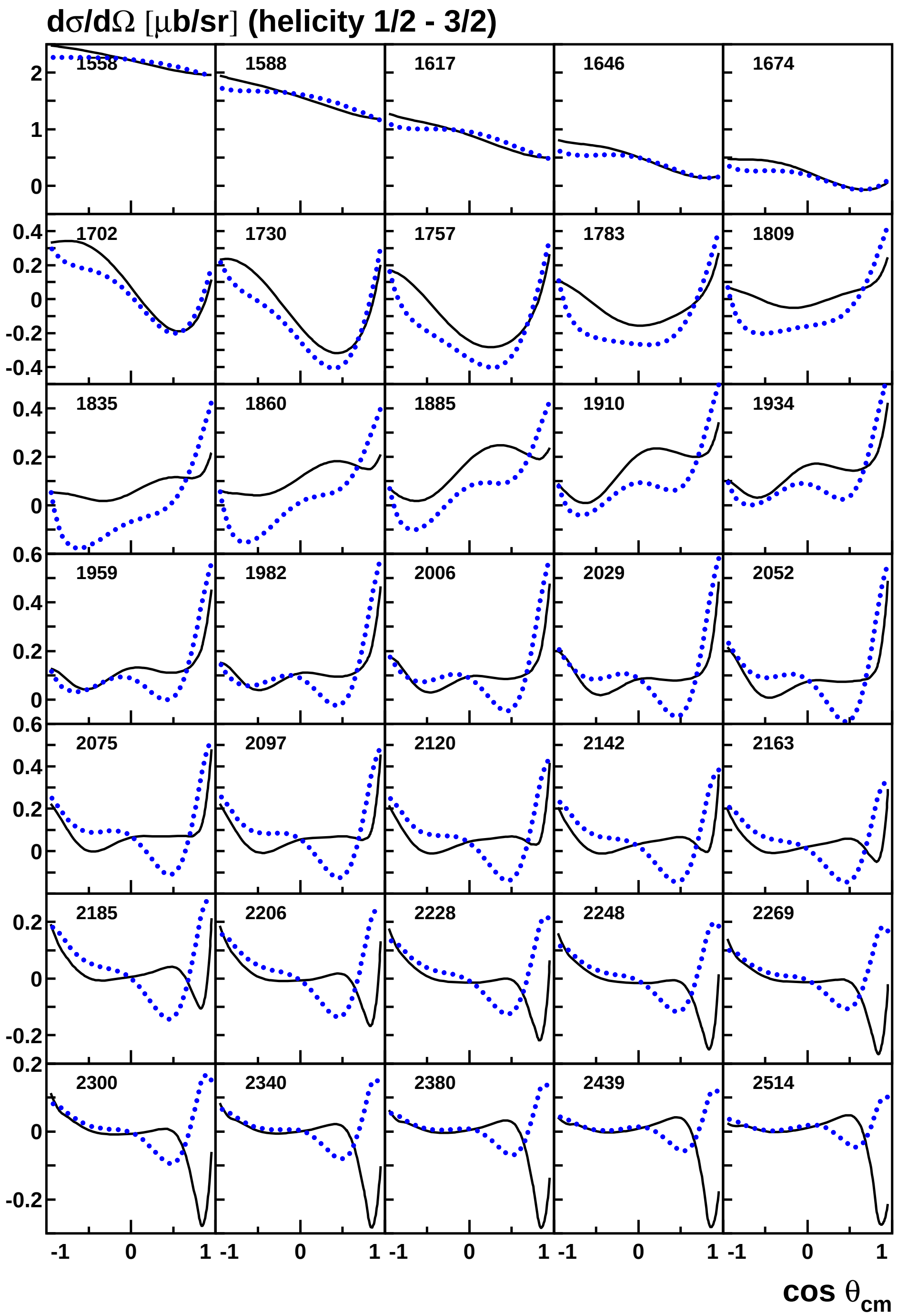


Differential cross section
helicity 1/2 - helicity 3/2

—: best solution, includes new $D_{15}(2070)$

—: $3/2^-$ state substitutes $D_{15}(2070)$

—: $3/2^+$ state substitutes $D_{15}(2070)$

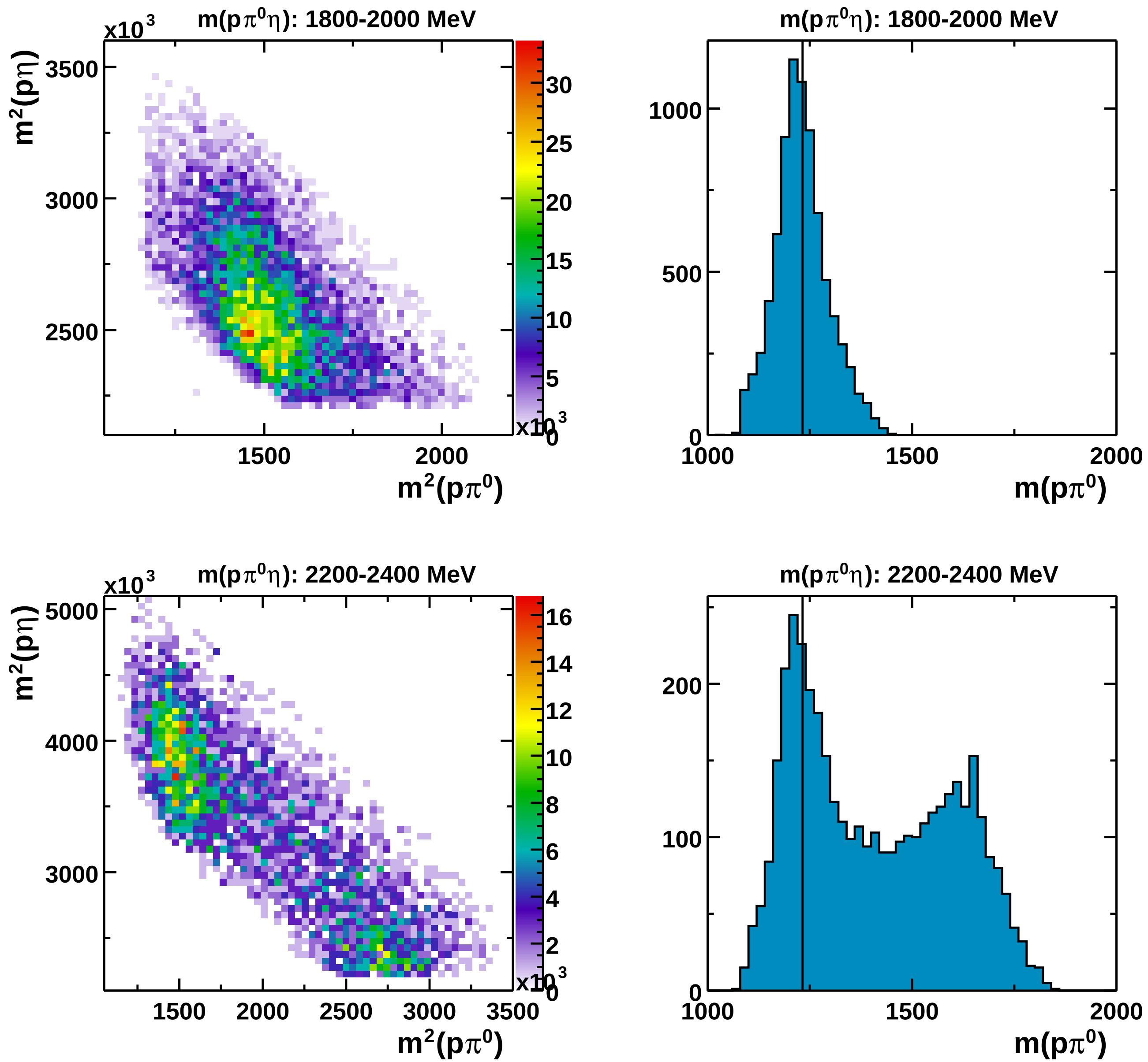


Differential cross section helicity 1/2 - helicity 3/2

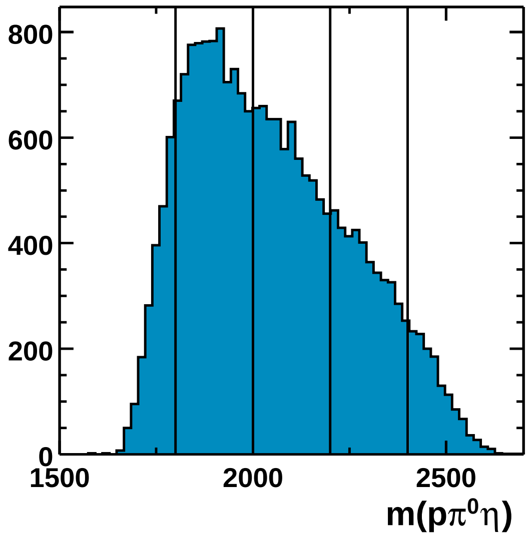
—: best solution, includes new $D_{15}(2070)$

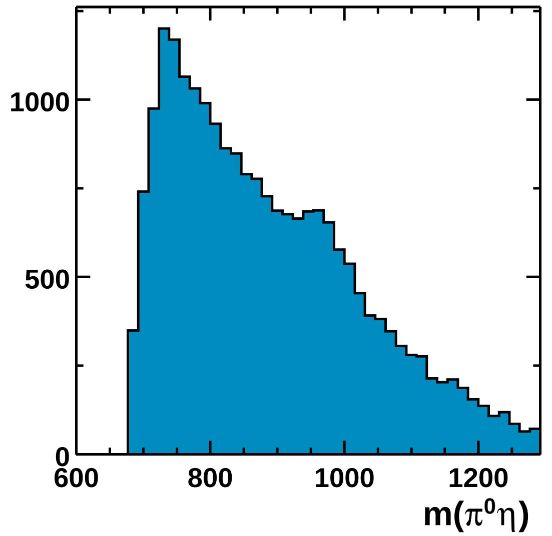
—: $5/2^+$ state substitutes $D_{15}(2070)$

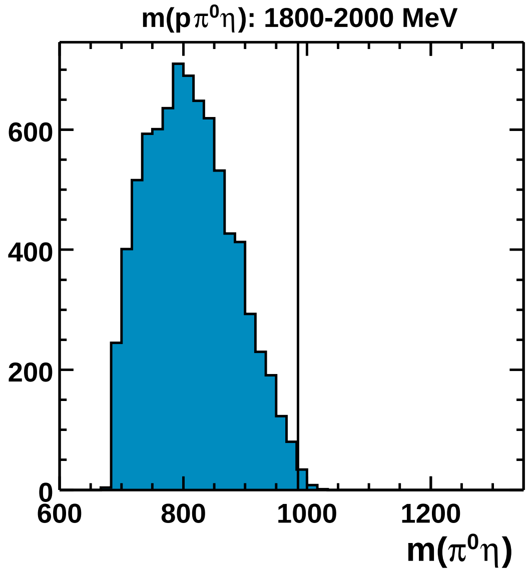
$\gamma p \rightarrow p\pi^0\eta$

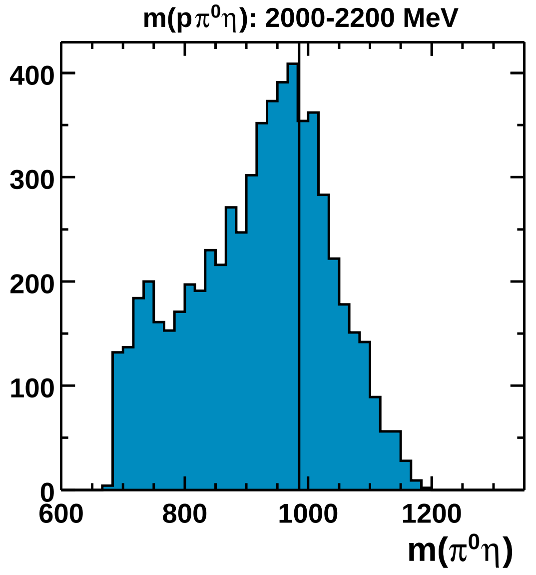


$\gamma p \rightarrow p\pi^0\eta$

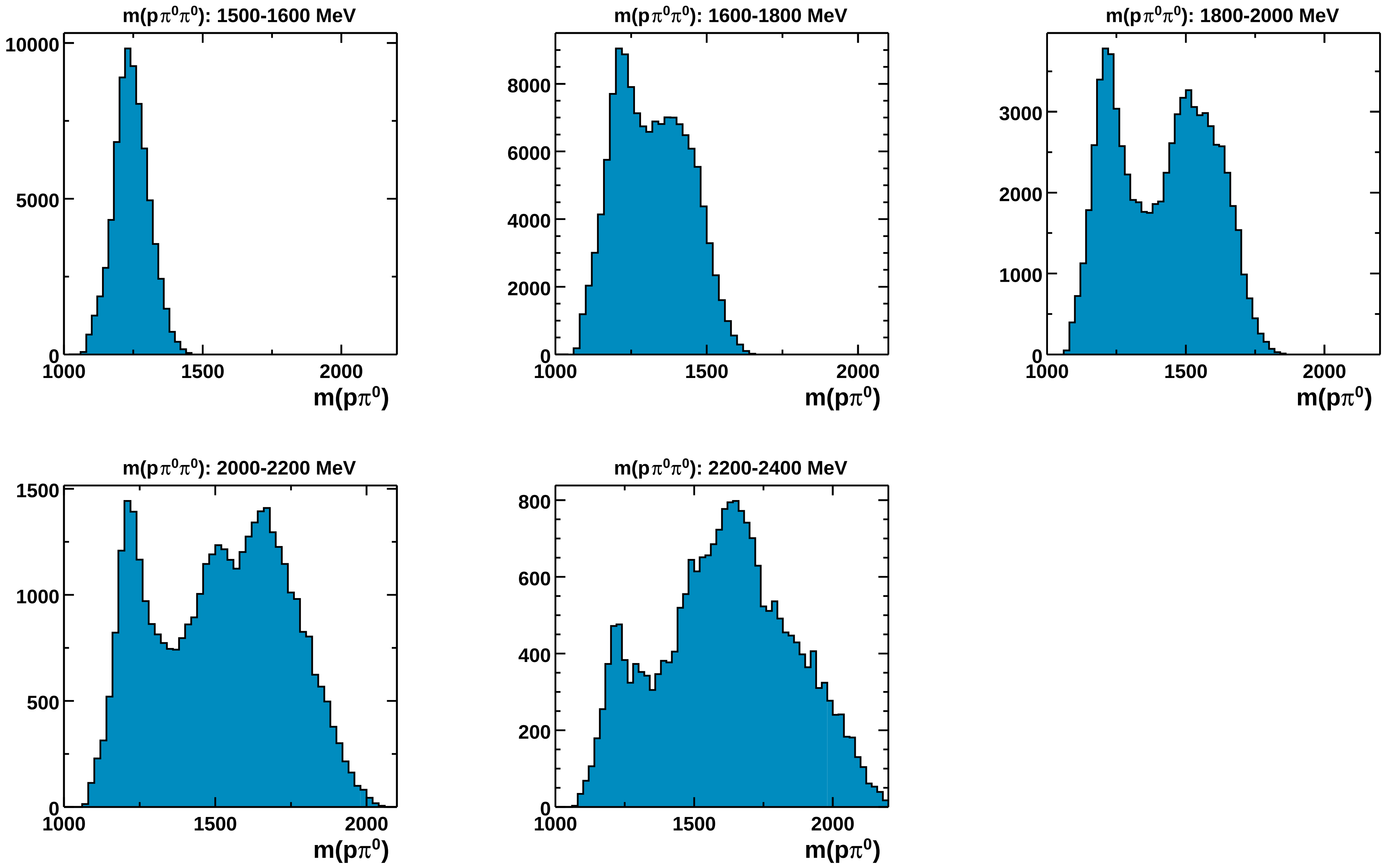




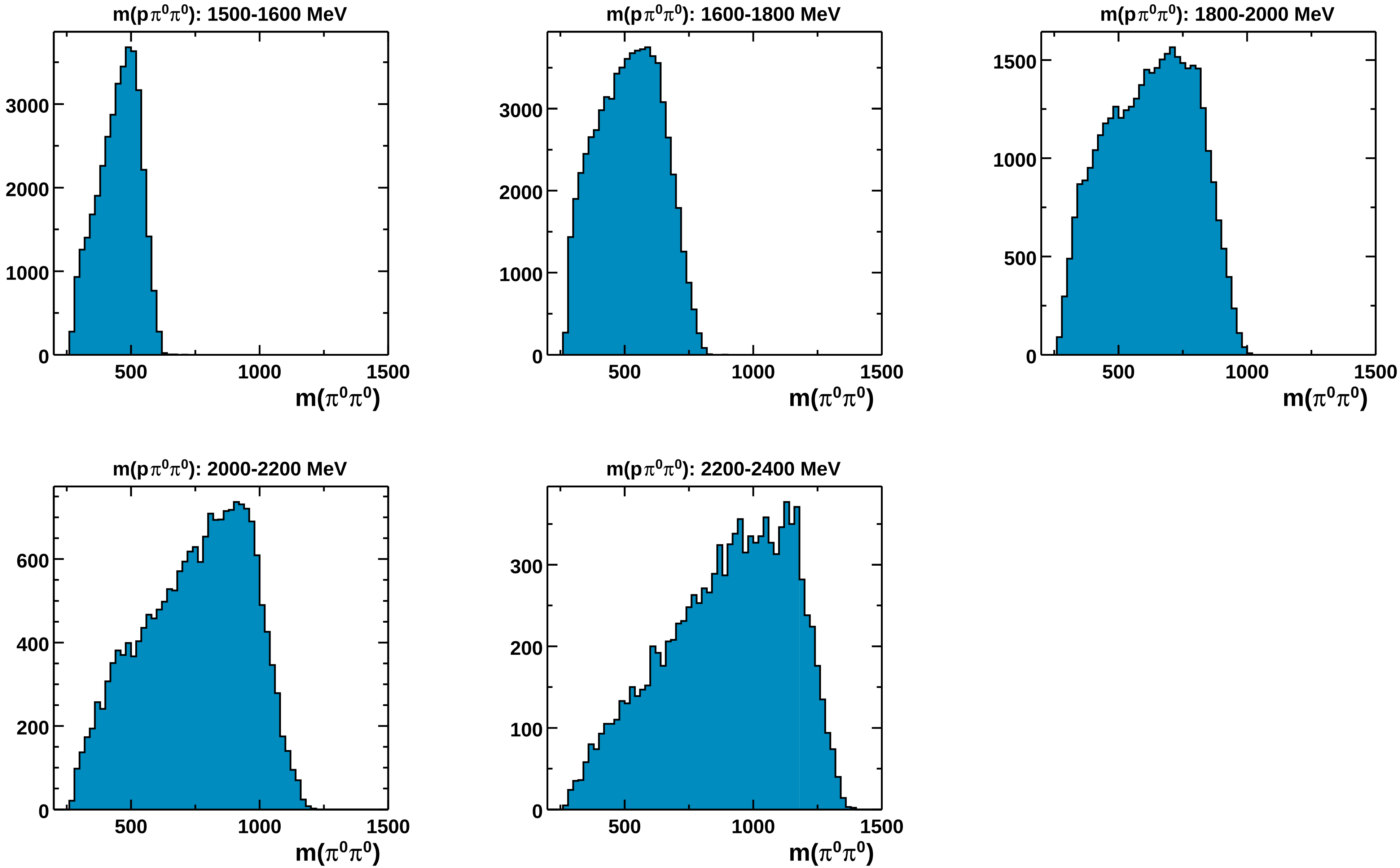




$\gamma p \rightarrow p\pi^0\pi^0$, $m(p\pi^0)$



$\gamma p \to p\pi^0\pi^0$, $m(\pi^0\pi^0)$



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