Measurement of polarization observables in the reaction $\vec{\gamma} p \rightarrow p\pi^0\pi^0$ with the CBELSA/TAPS experiment

Vahe Sokhoyan

Seminar talk
University of Virginia
Charlottesville, 22.10.2013

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

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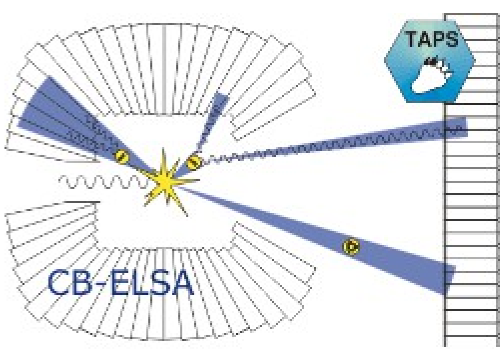
The work performed at:

universitätbonn

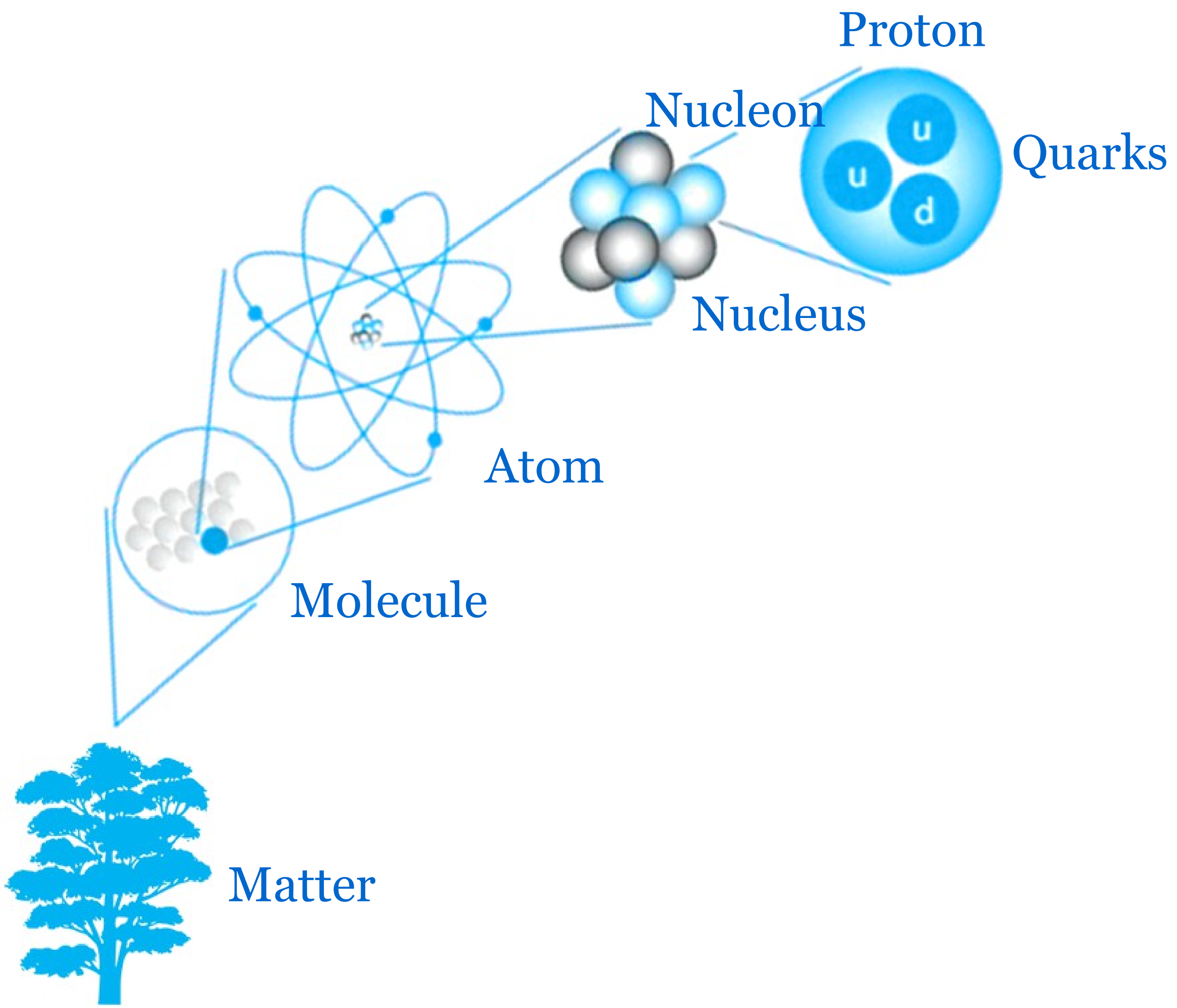
HISKP
Helmholtz-Institut für Strahlen- und Kernphysik



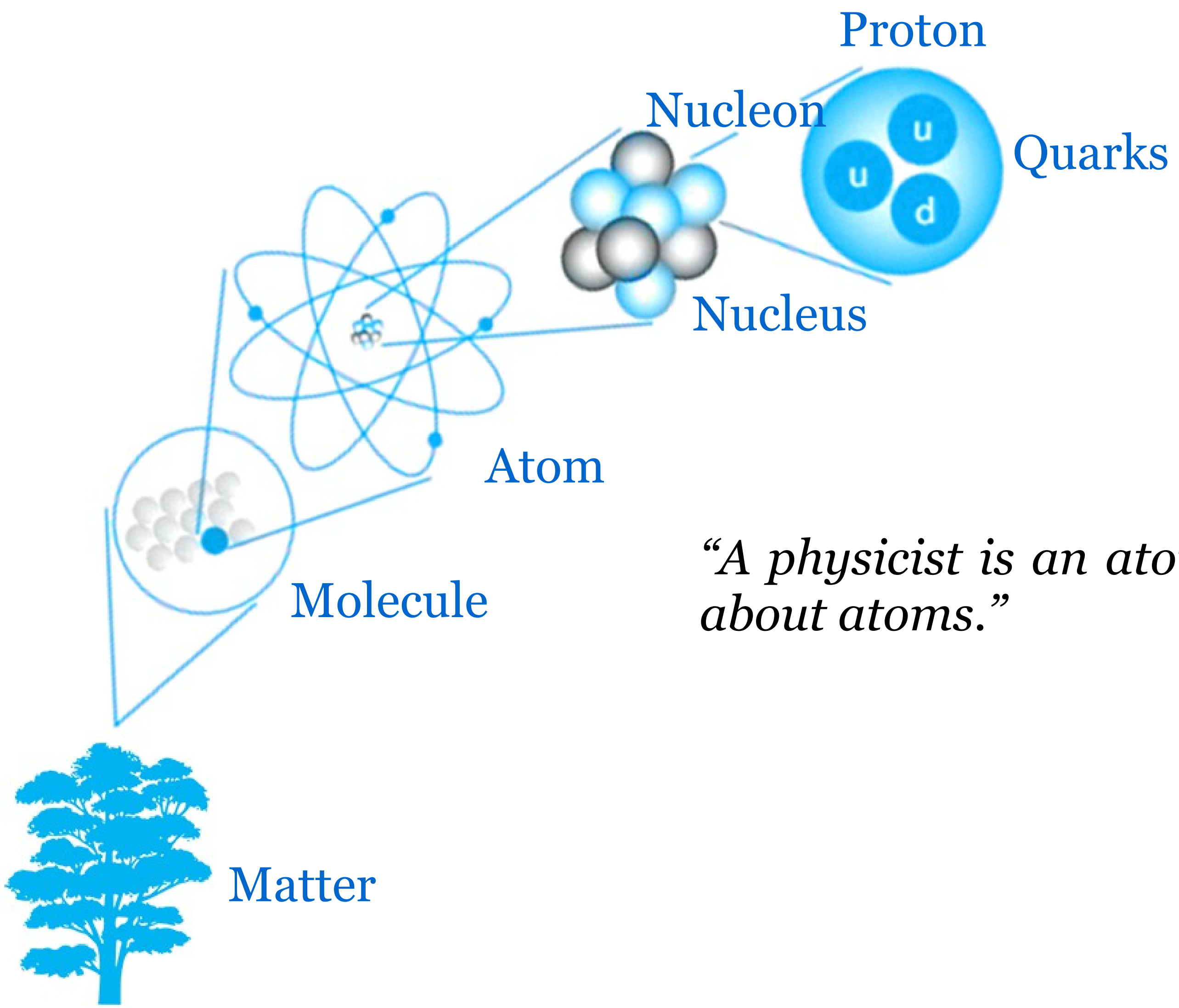
Contents

- Why baryon resonances?
- Why double meson photoproduction?
- Why $2\pi^0$ photoproduction?
- The CBELSA/TAPS experiment
- Sequential decays of resonances
- Polarization observables Σ, I^s and I^c
- Comparison with models
- Summary

Introduction



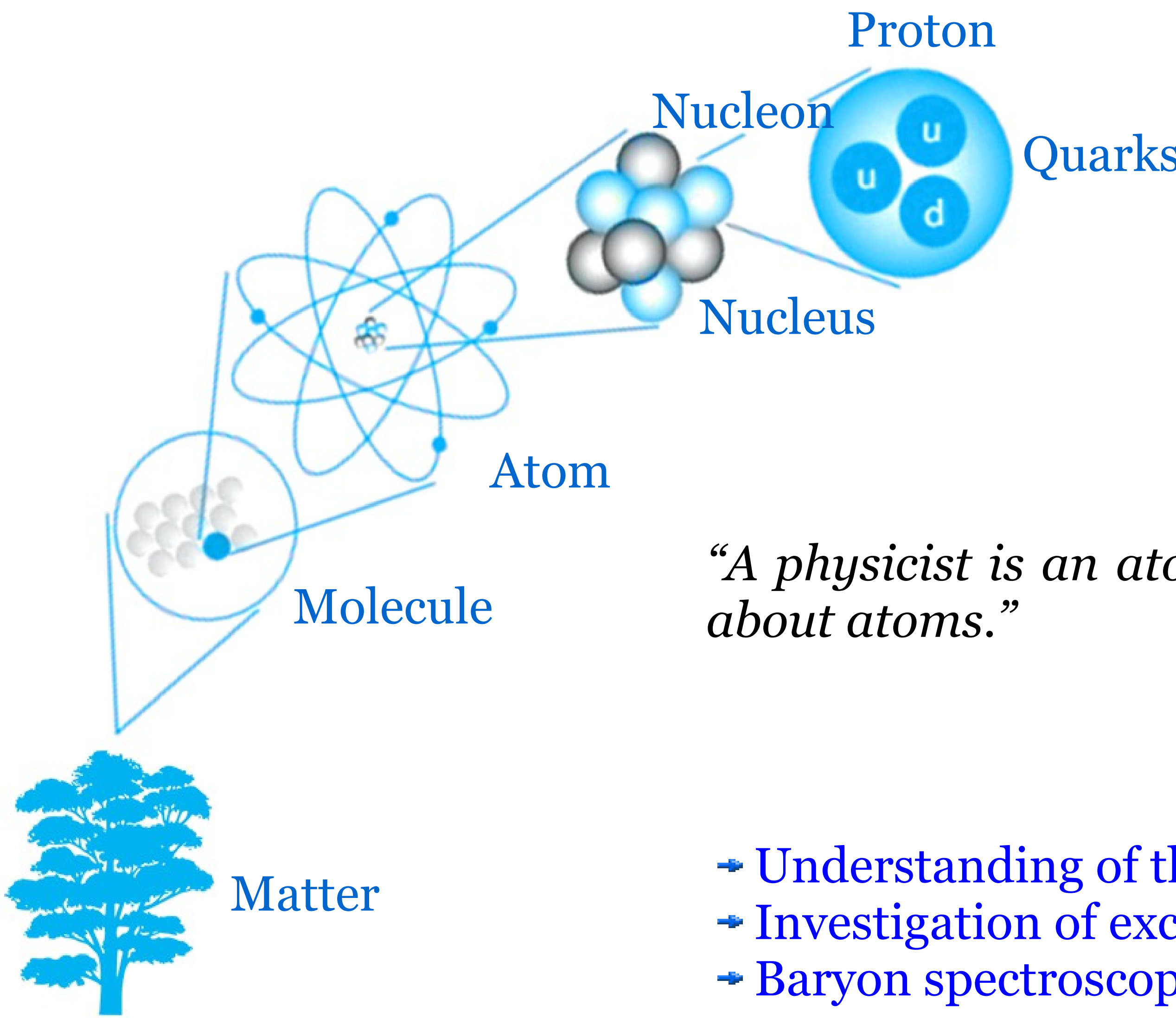
Introduction



"A physicist is an atom's way of knowing about atoms."

George Wald

Introduction



"A physicist is an atom's way of knowing about atoms."

George Wald

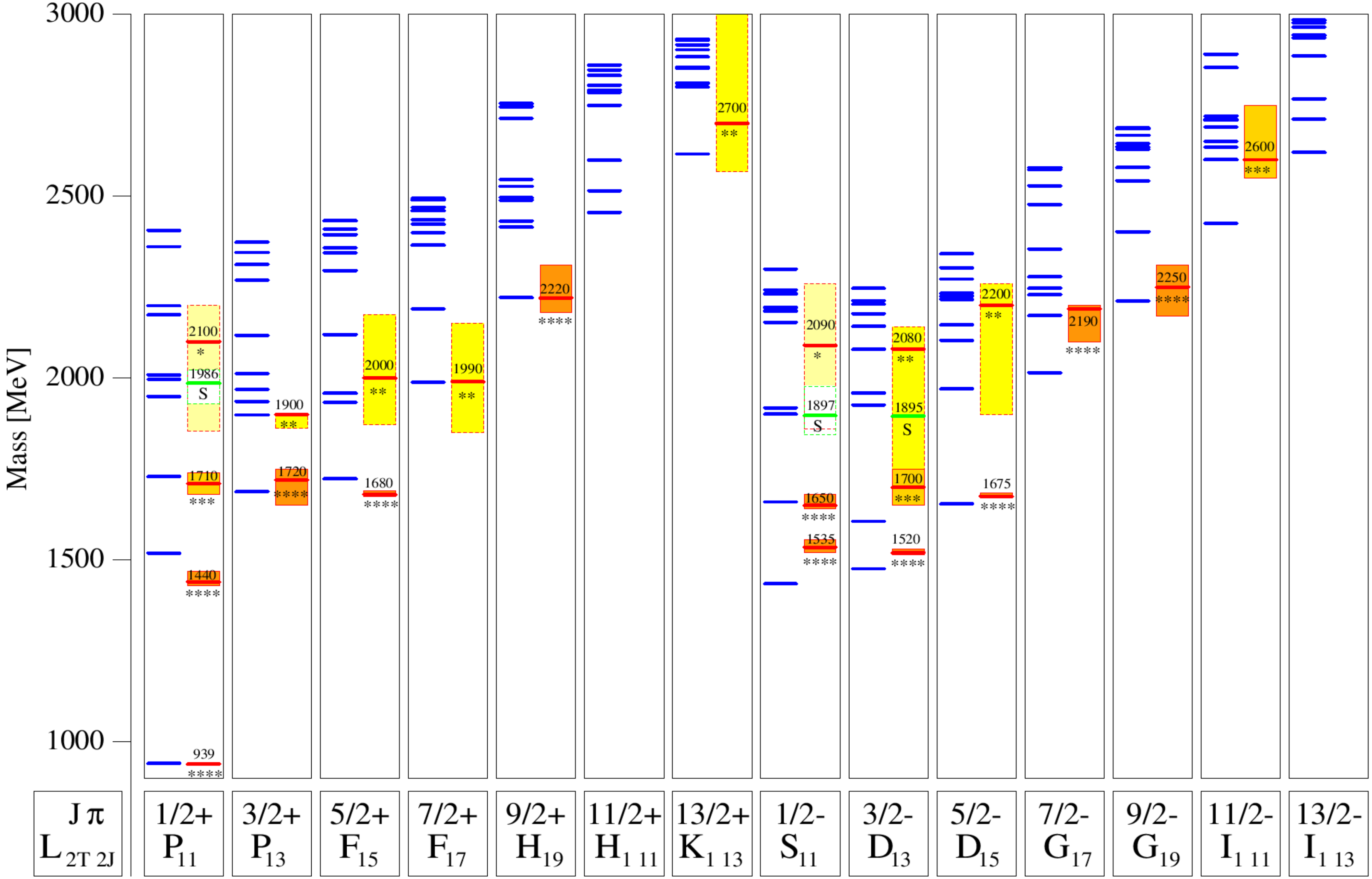
- Understanding of the nucleon structure
- Investigation of excited states
- Baryon spectroscopy

Goal: Gain a good understanding of the spectrum and properties of baryon resonances

Nucleon resonances

Goal: Gain a good understanding of the spectrum and properties of baryon resonances

Above 1.9 GeV missing resonances are predicted by the symmetric quark models



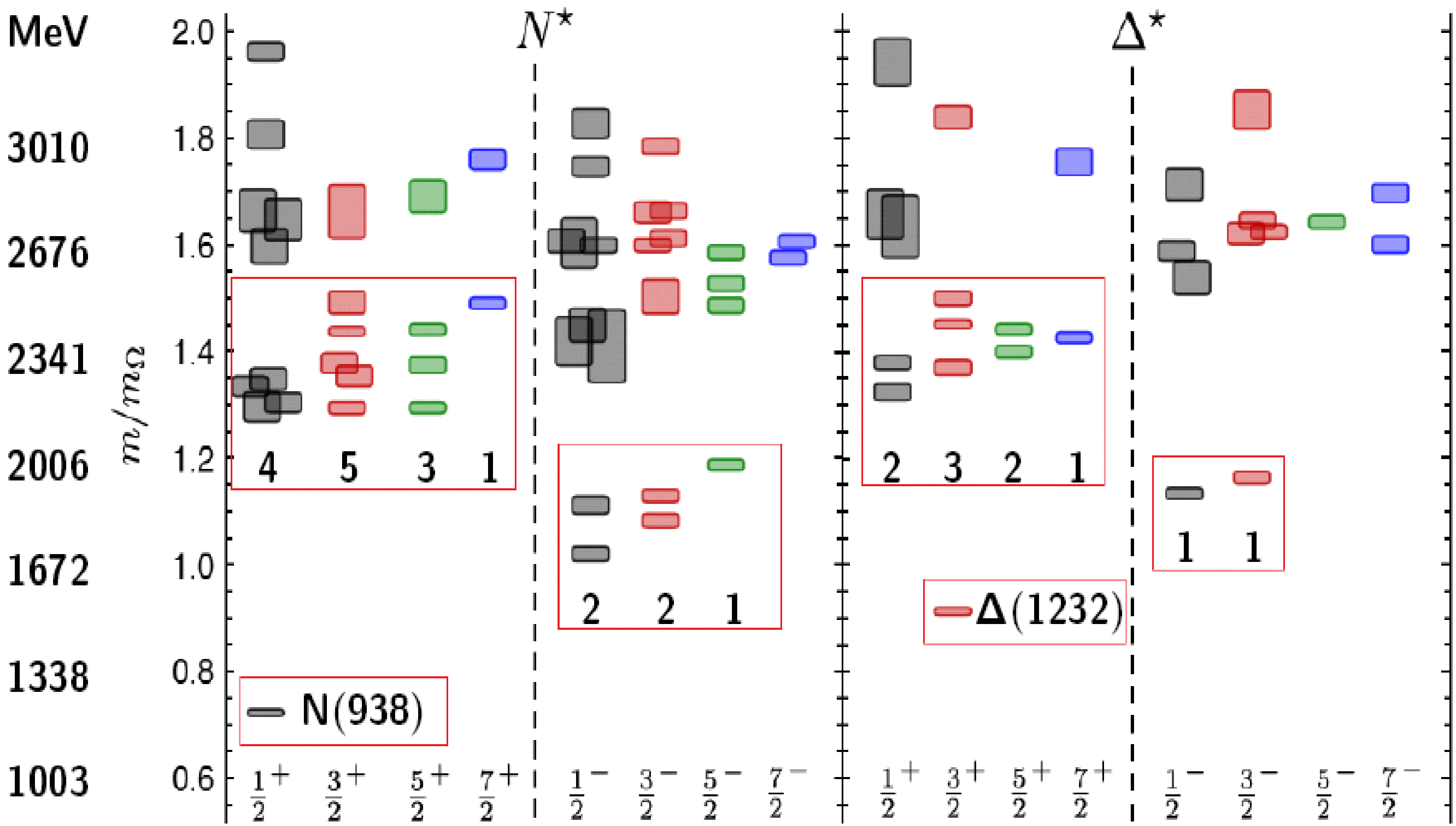
U. Löring et al., Eur. Phys. J. A 10 (2001) 309, 395, 447

Introduction

Goal: Gain a good understanding of the spectrum and properties of baryon resonances

m_π = 396 MeV

R. G. Edwards et al., Phys. Rev. D 84, 074508 (2011)



Resonances

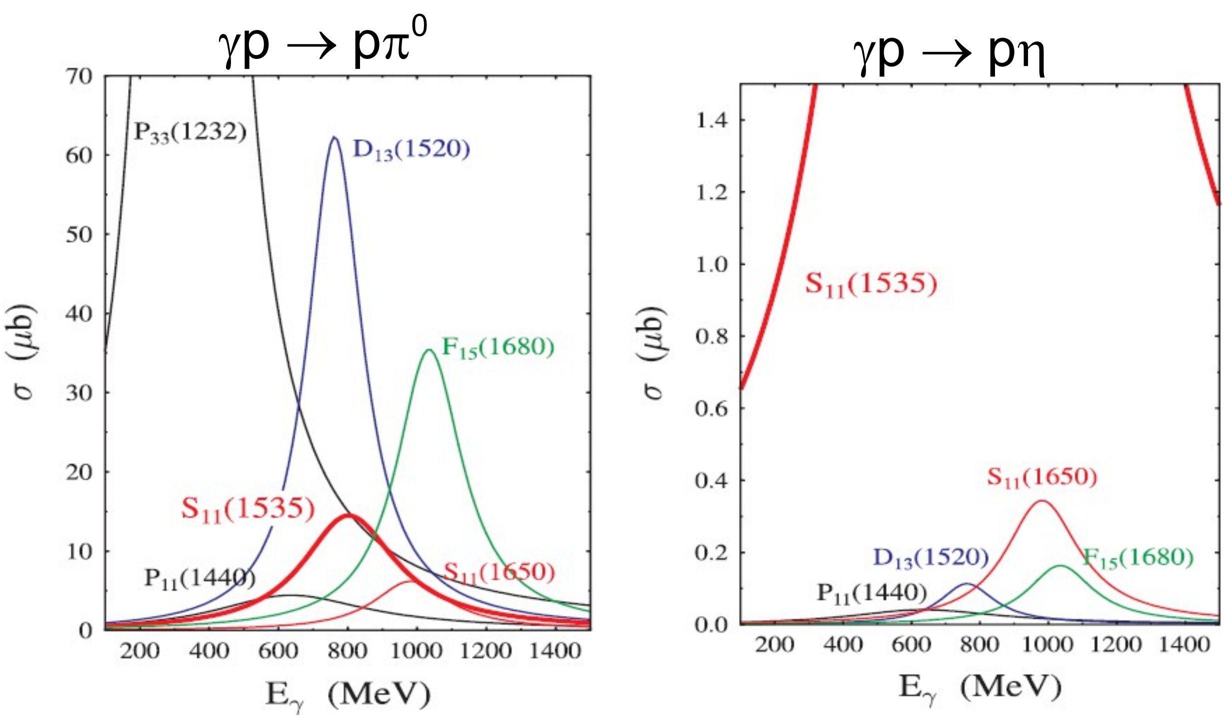
Goal: Gain a good understanding of the spectrum and properties of baryon resonances

Lattice QCD confirms the number of the states in symmetric quark models

R. G. Edwards et al., Phys. Rev. D 84, 074508 (2011)

Experimentally: Broad overlapping resonances

- Partial Wave Analysis necessary
- Measurement of cross-sections and polarization observables
- Different production channels

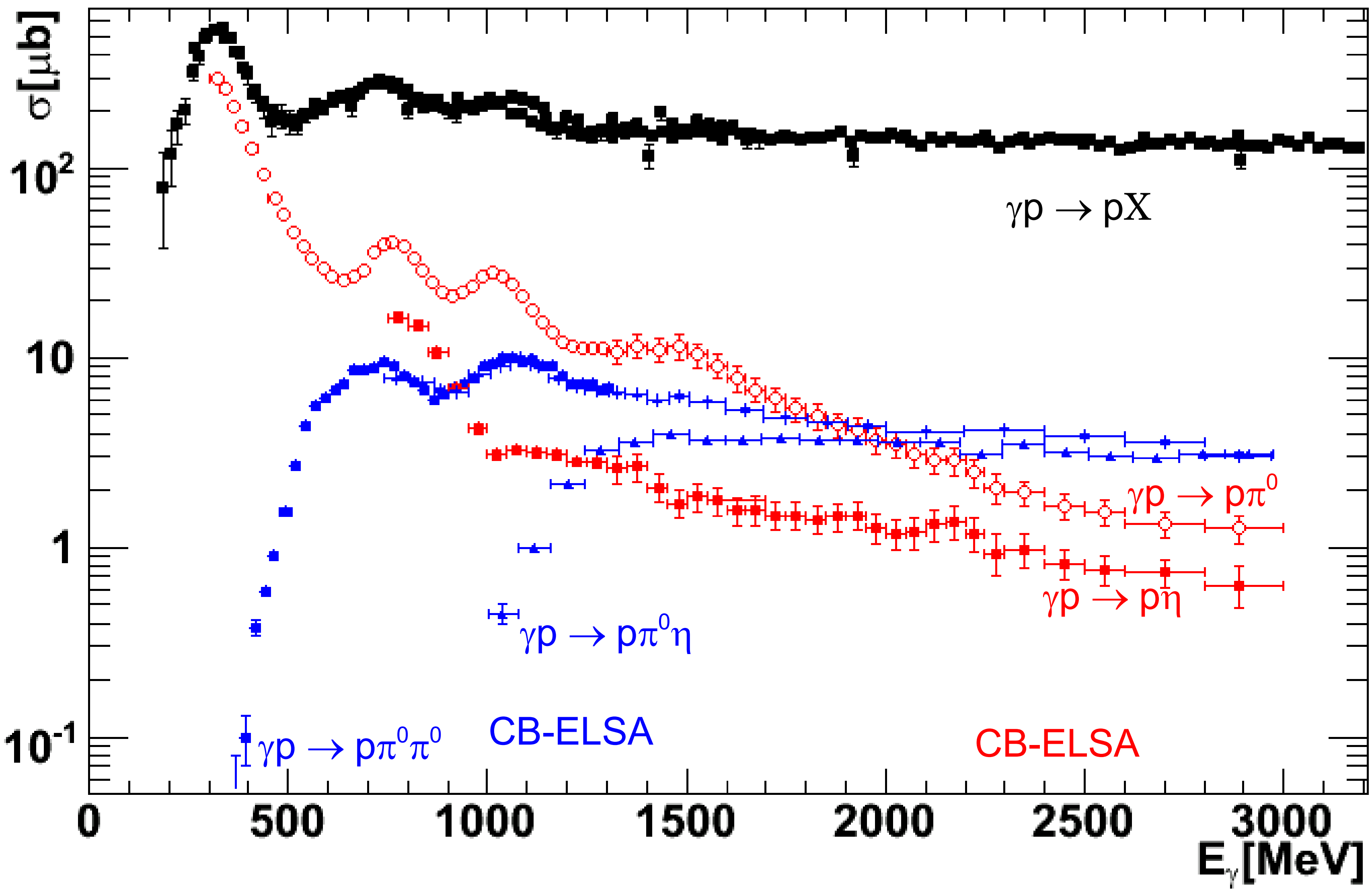


Most of the data obtained with πN scattering

Channels different from πN → Photoproduction experiments

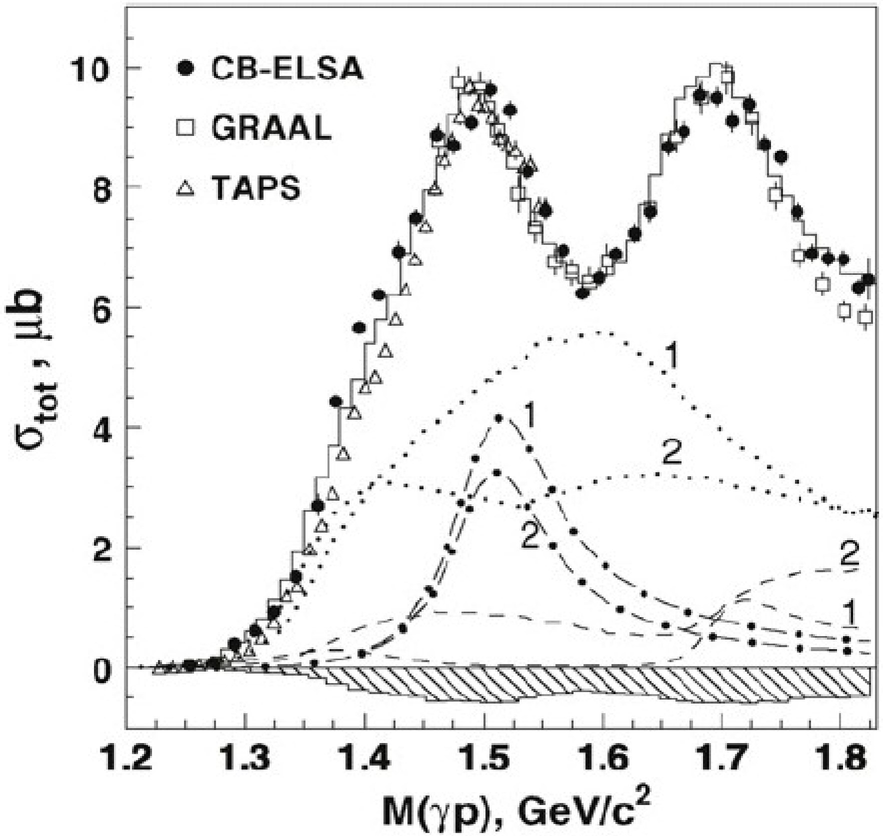
Photoproduction

Goal: Gain a good understanding of the spectrum and properties of baryon resonances



- At high energies: Multi-meson final states play a role of increasing importance!
- Access to resonances with cascading decays

$2\pi^0$ photoproduction



A. Sarantsev et al., PLB 659 (2008) 94
U. Thoma, M. Fuchs et al., PLB 659(2008) 87

CB-ELSA fit (BnGa-PWA)
including additional data from:
single-meson production,
$\pi^- p \rightarrow n 2\pi^0$ (Crystal Ball),
P_{11}-, S_{11}-, P_{33}-, D_{33}- πN
partial waves

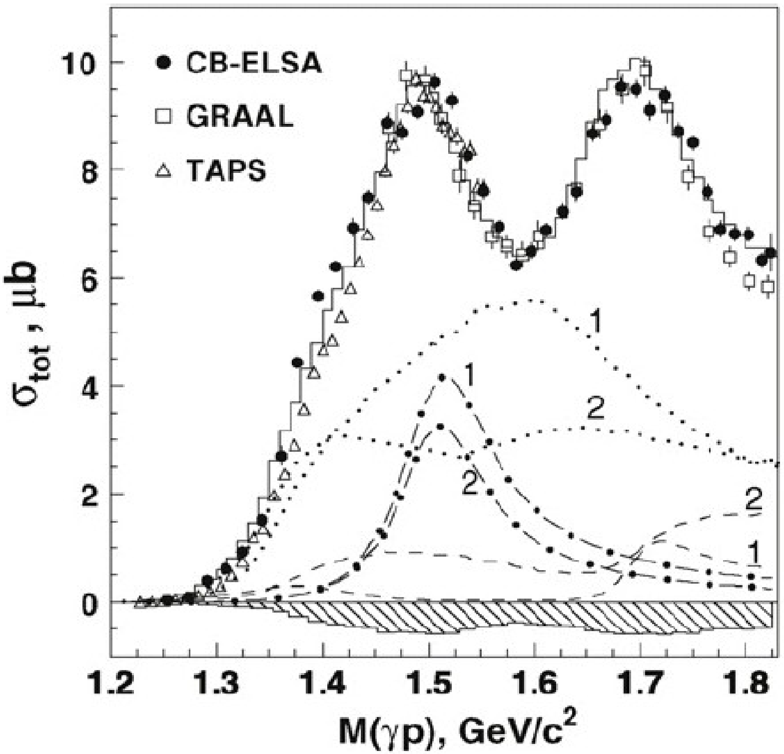
event-based
maximum-likelihood fit

⇒ Determination of resonance properties:
m, $\Gamma_i(\Delta\pi^0, N(\pi\pi)_S, P_{11}\pi, D_{13}\pi, \ldots)$

Dotted: D_{33}, dashed-dotted: D_{13}, dashed: P_{11}

Two equally good solutions:
$D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$ dominant (1)
$D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant (2)

BnGa PWA and Fix model



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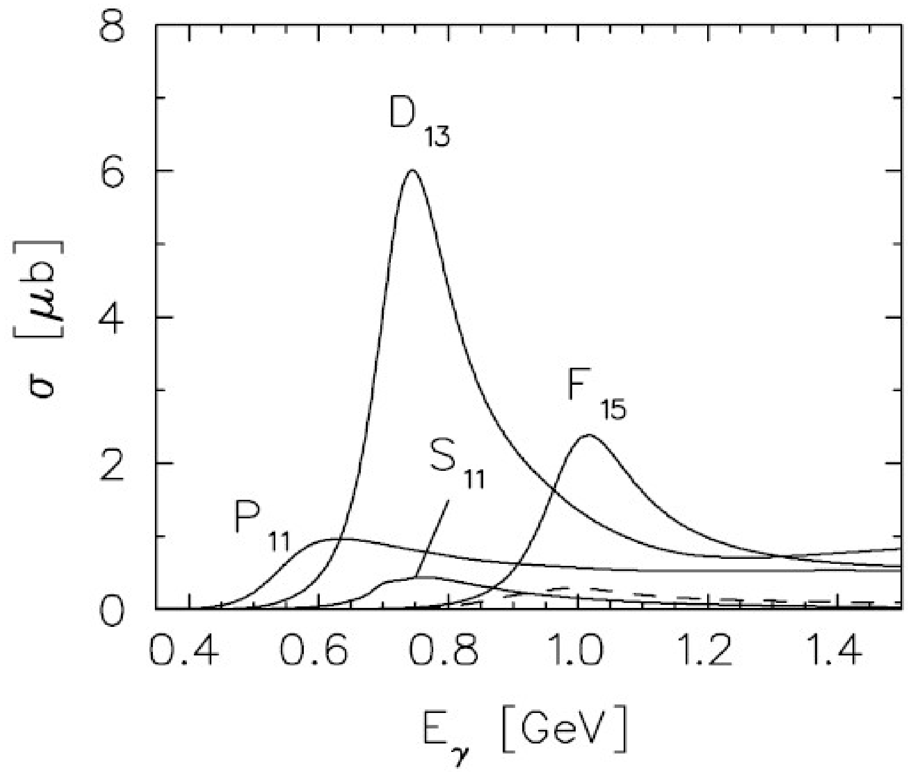

A. Fix, H. Arenhovel, EPJ (A) (2005) 115

Bonn-Gatchina Partial Wave Analysis:
Dotted: D_{33}, dashed-dotted: D_{13}, dashed: P_{11}
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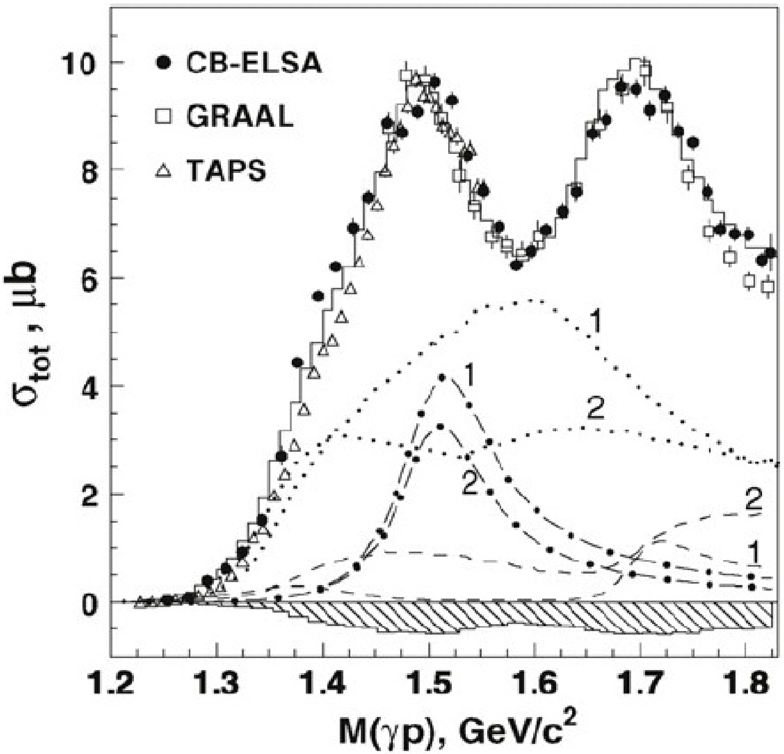
Fix model:
Contributions of $D_{13}(1520)$, $P_{11}(1440)$, $S_{11}(1535)$, $F_{15}(1680)$
Dashed: $S_{31}(1620)$, $P_{13}(1720)$, $D_{15}(1675)$

BnGa PWA and Fix model



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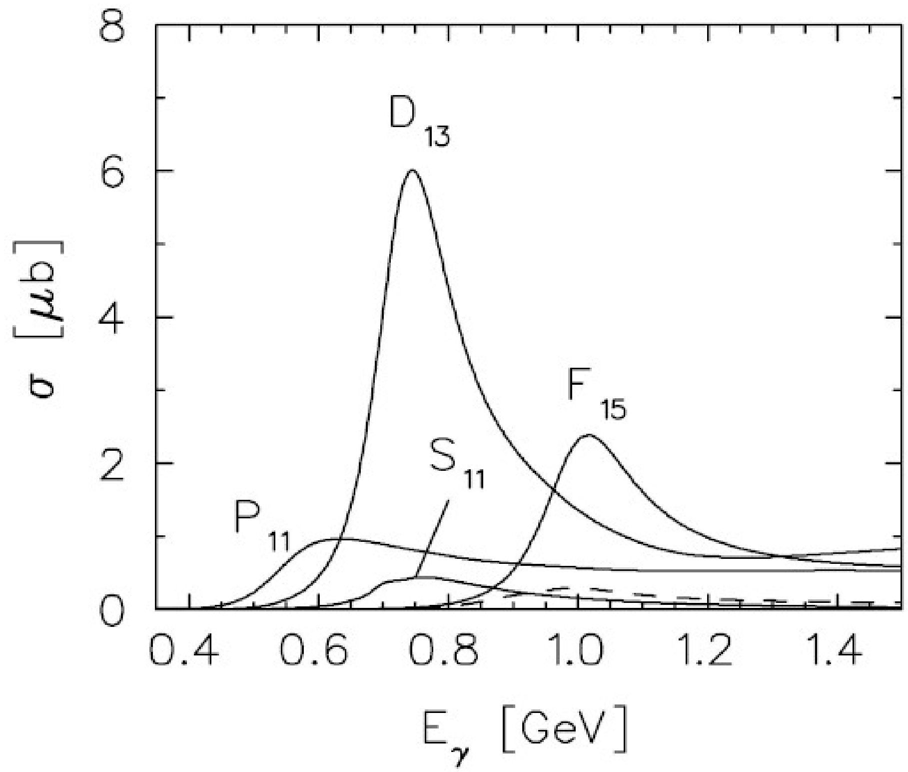

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Measurement of polarization observables necessary!

For a complete experiment, 15 observables are needed!

W. Roberts and T. Oed, Phys. Rev. C 71, 055201 (2005)

Polarization observables

Linearly polarized photon beam, unpolarized target:

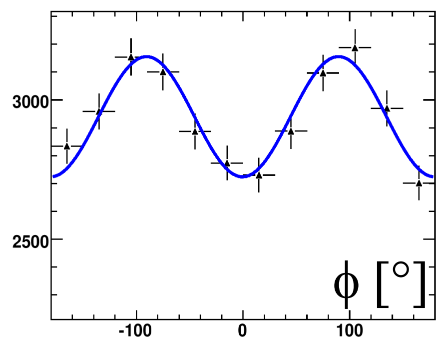
Quasi two-body consideration:

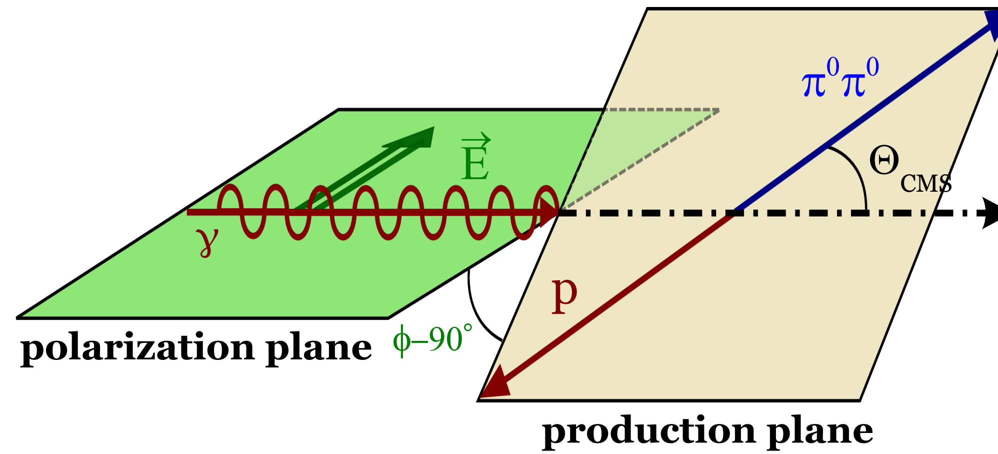
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 [1 + \delta_l \Sigma \cos(2\phi)]$$

$640 \leq m_{\pi\pi} \leq 700$ MeV/c²

$E_\gamma = 1200\text{-}1450$ MeV

$f(\phi) = A(1+\delta_l B\cos 2\phi)$





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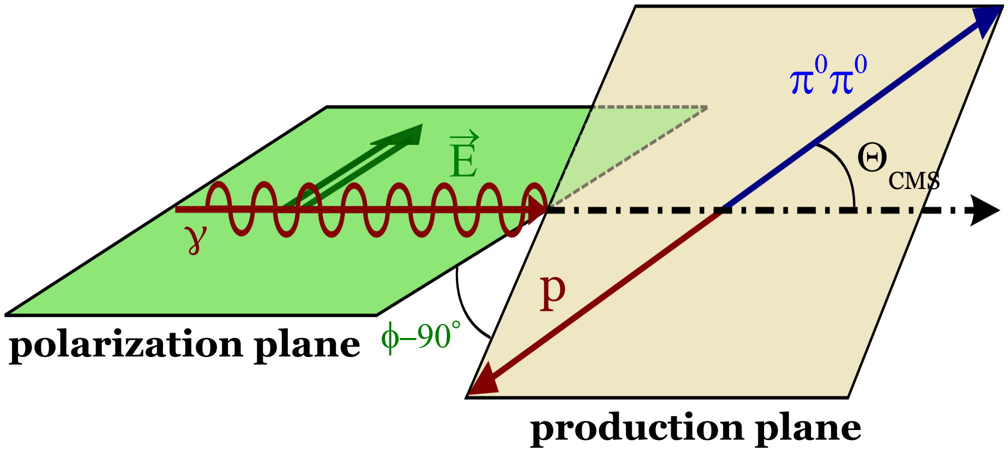

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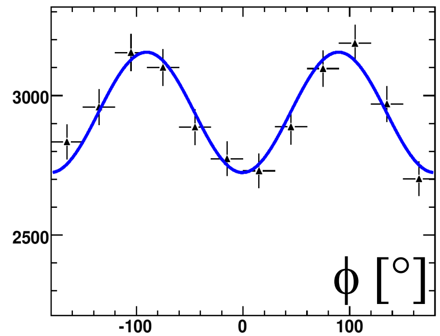

- Three-particle final state: additional plane!

Polarization observables

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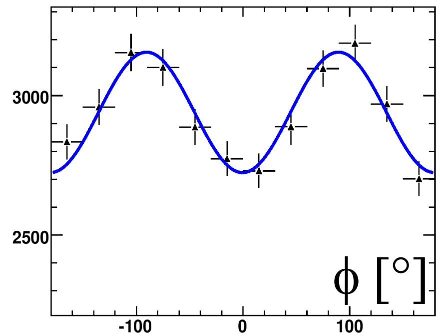

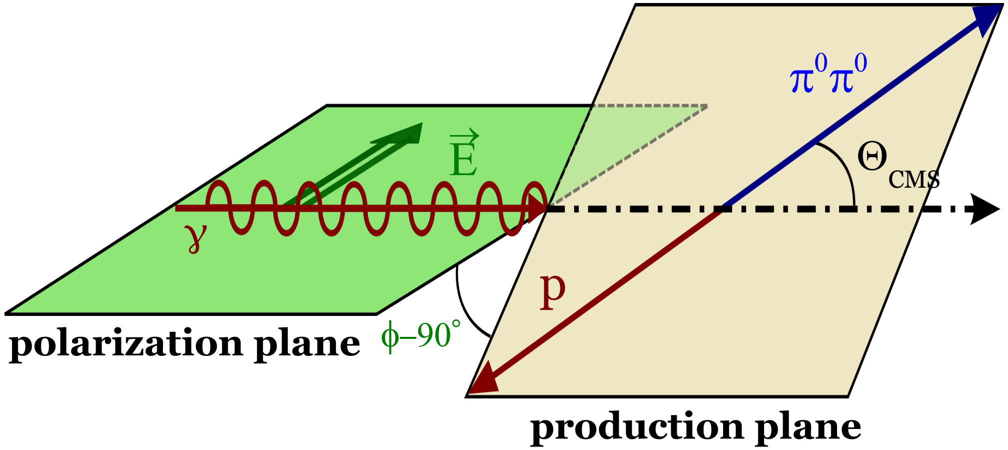

- Three-particle final state: additional plane!
- Additional polarization observables!

Polarization observables

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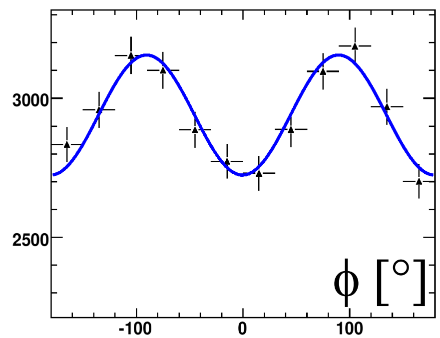
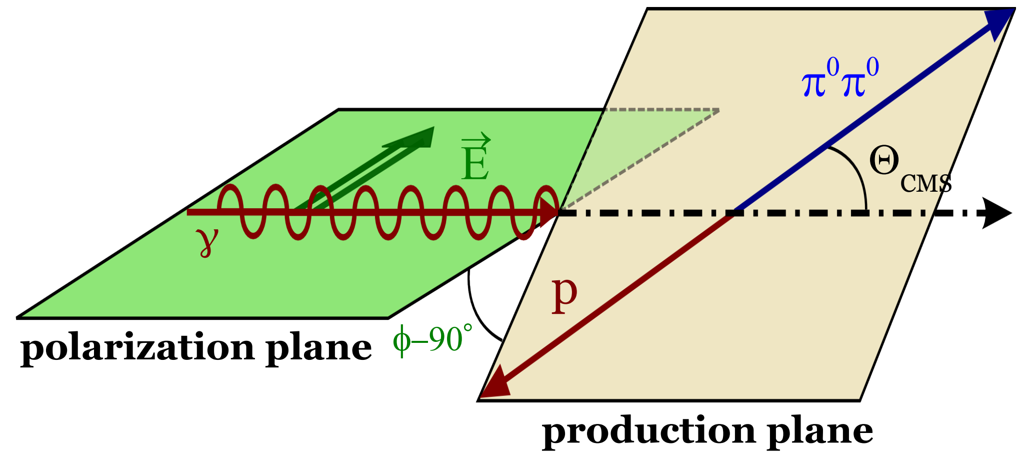




- Three-particle final state: additional plane!
- Additional polarization observables!

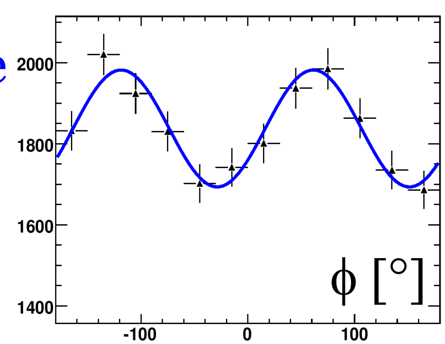
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 + \delta_l [I^s \sin(2\phi) + I^c \cos(2\phi)]\}$$

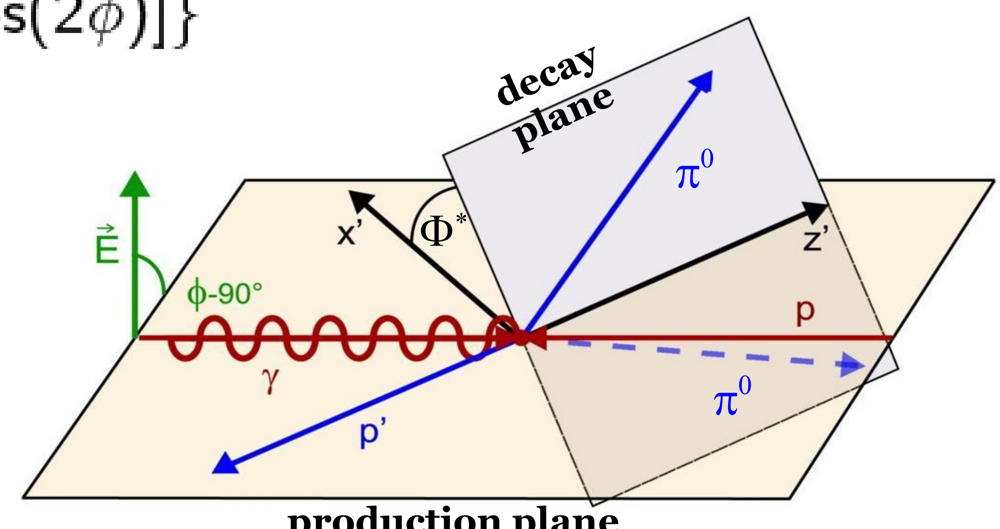
$f(\phi) = A(1+\delta_l(B\sin 2\phi + C\cos 2\phi))$

Limited Φ^* range →

$18^\circ \leq \Phi^* \leq 36^\circ$

E_γ = 970-1200 MeV



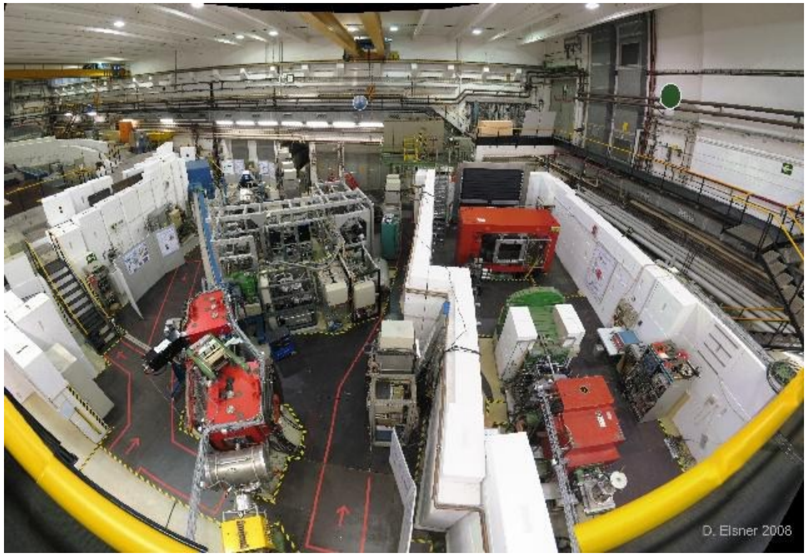


First measurement of I^s and I^c in $\vec{\gamma} p \rightarrow p\pi^0\pi^0$!

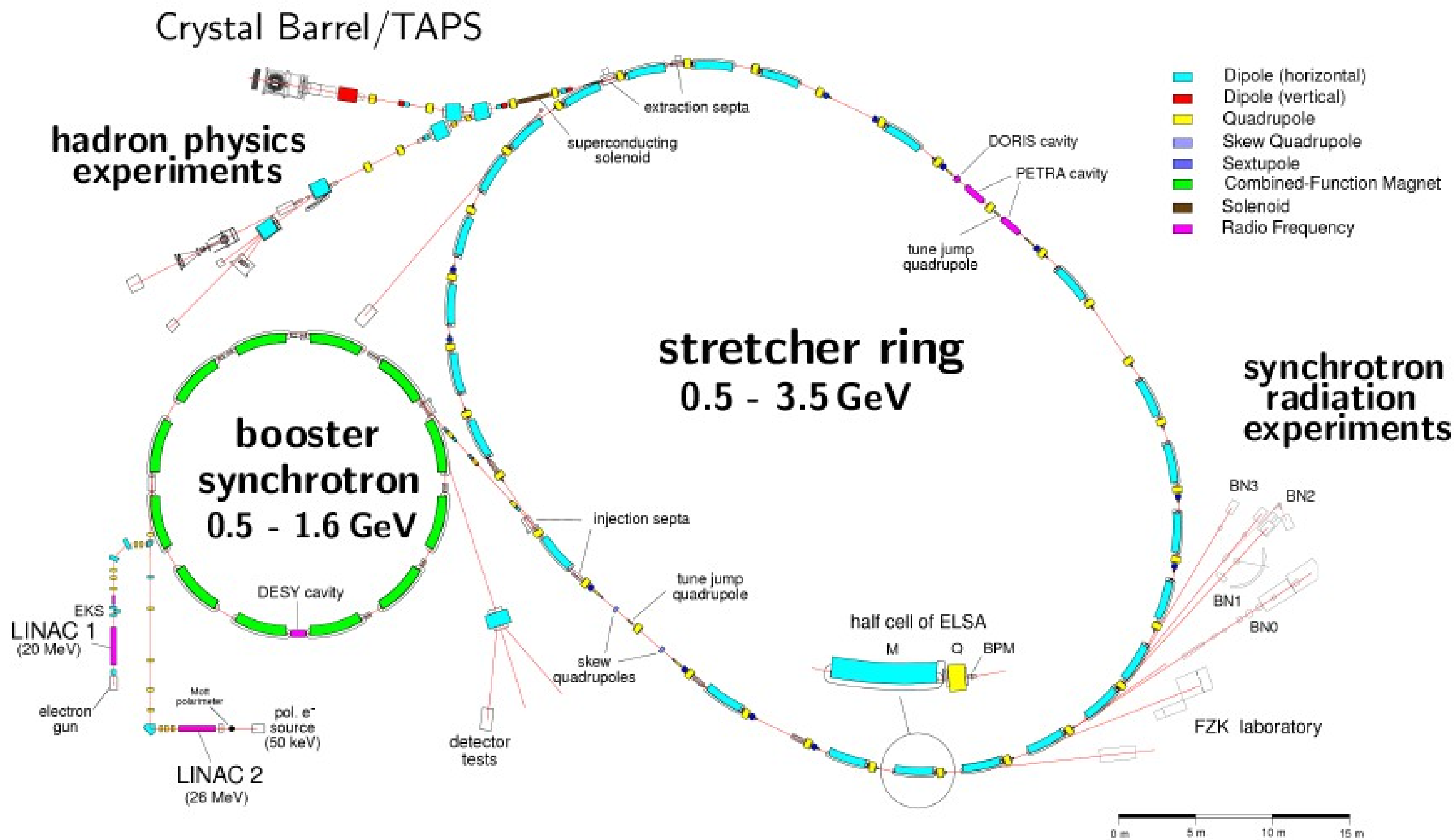
Bonn

HISKP and Physikalisches Institut

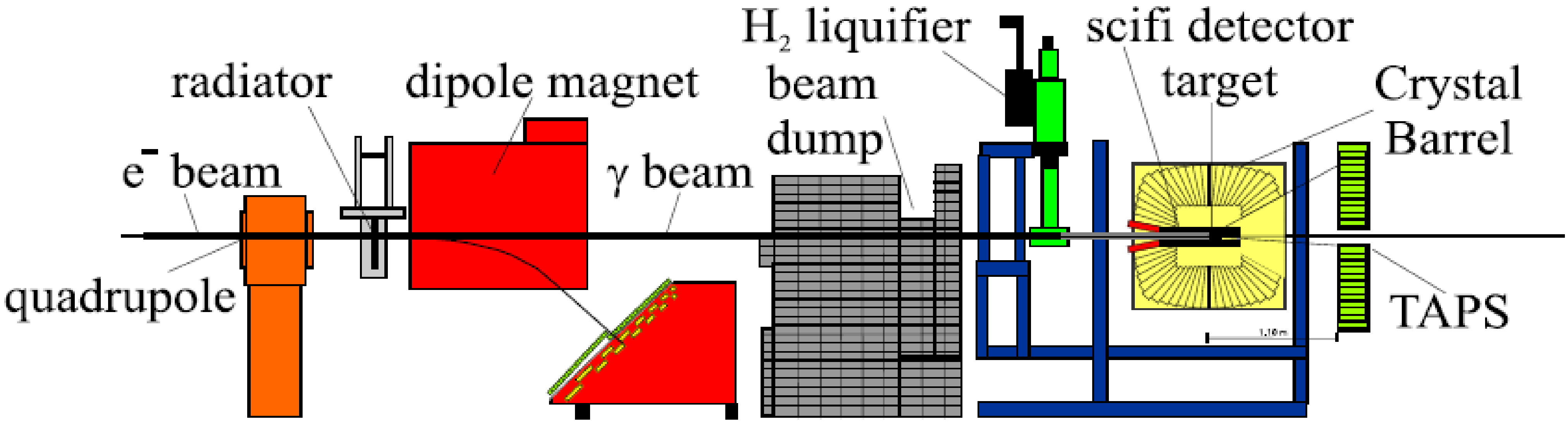
HISKP and Physikalisches Institut

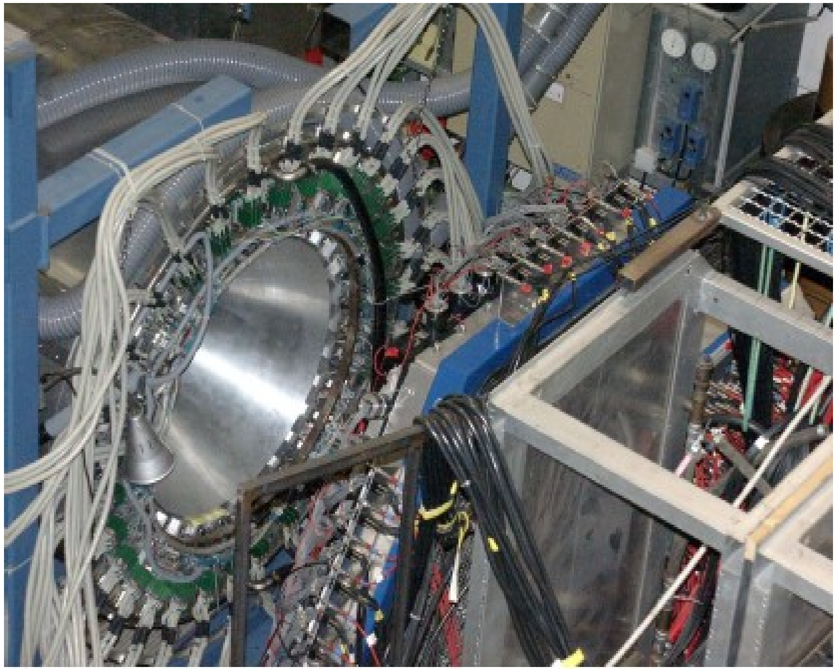


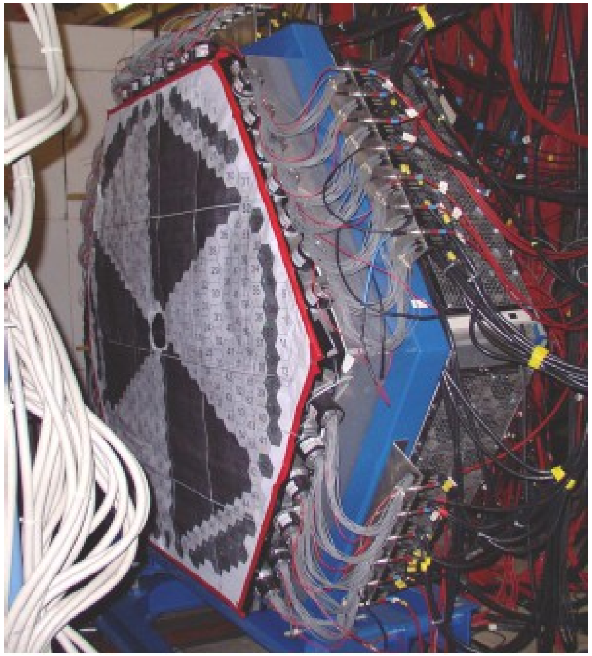
ELSA


Crystal Barrel/TAPS
hadron physics experiments
extraction septa
superconducting solenoid
DORIS cavity
PETRA cavity
tune jump quadrupole
Dipole (horizontal)
Dipole (vertical)
Quadrupole
Skew Quadrupole
Sextupole
Combined-Function Magnet
Solenoid
Radio Frequency
stretcher ring
0.5 - 3.5 GeV
synchrotron radiation experiments
booster synchrotron
0.5 - 1.6 GeV
injection septa
tune jump quadrupole
skew quadrupoles
DESY cavity
EKS
LINAC 1
(20 MeV)
electron gun
Mott polarimeter
pol. e⁻ source
(50 keV)
LINAC 2
(26 MeV)
detector tests
half cell of ELSA
M
Q
BPM
BN3
BN2
BN1
BN0
FZK laboratory
0 m
5 m
10 m
15 m

The CBELSA/TAPS experiment







The data

CBELSA/TAPS:

A: Pol_{max} = 49.2% @E_γ = 1300 MeV

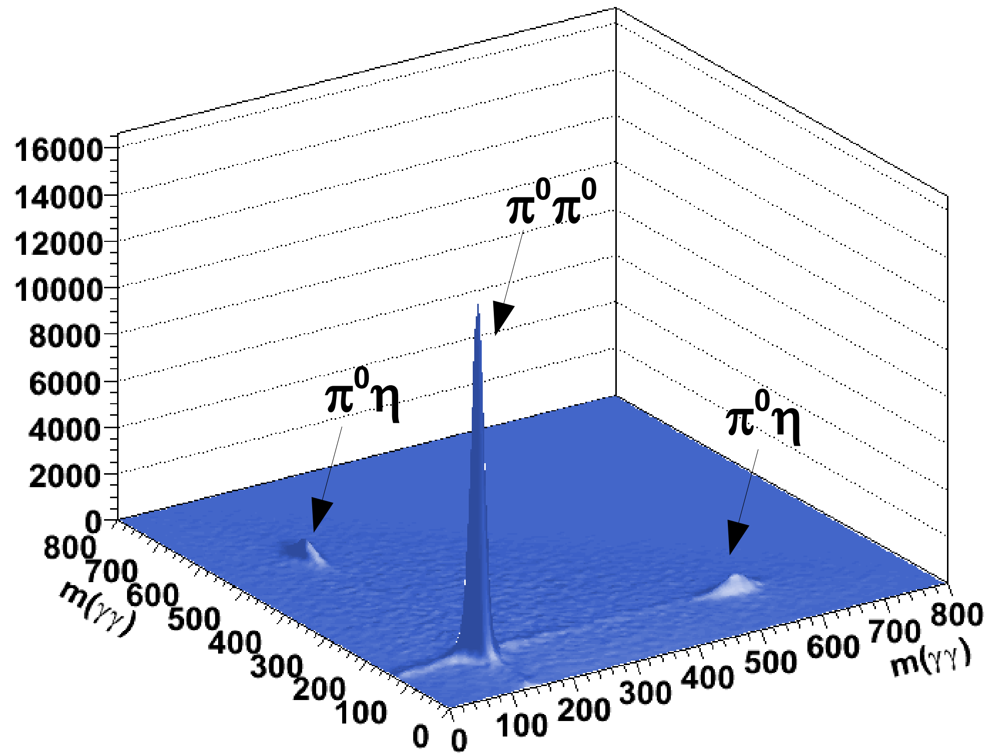
B: Pol_{max} = 38.7% @E_γ = 1600 MeV

- Produced via coherent bremsstrahlung at a diamond crystal

- Liquid hydrogen as target material

Data selected for 4γ (+proton) events

$\gamma p \rightarrow p \pi^0 \pi^0$ clearly observed!

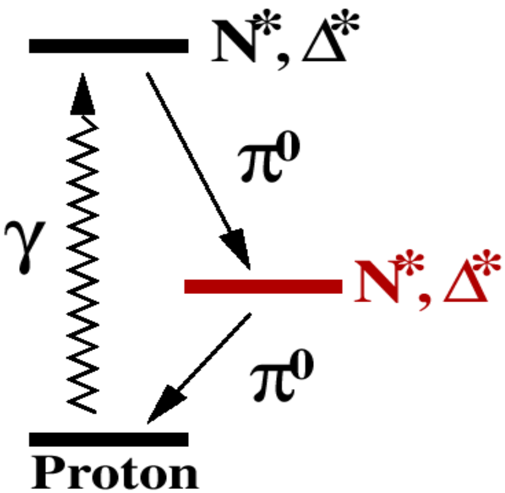


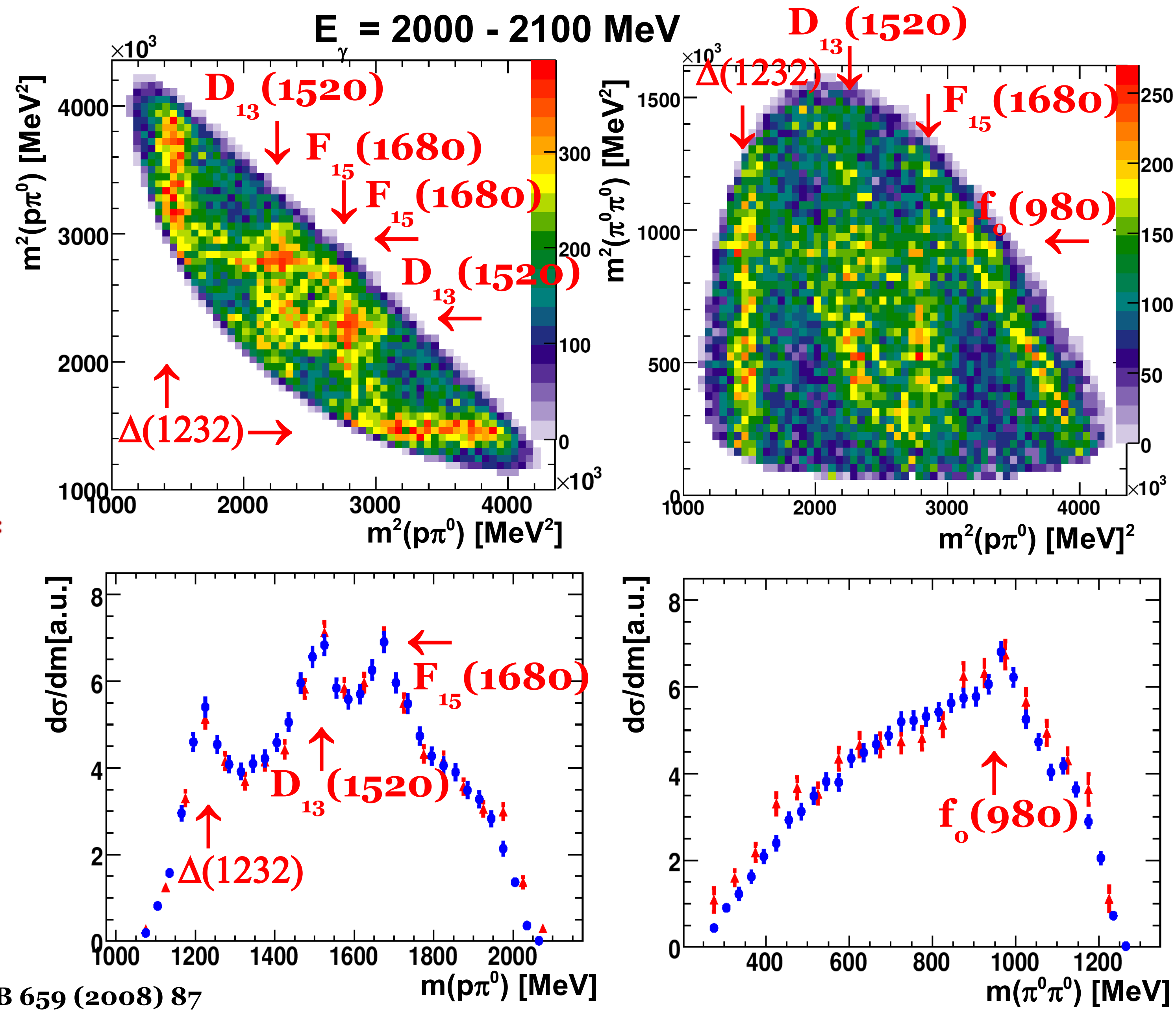
- Full combinatorial analysis
- Cuts on invariant mass, coplanarity, missing mass
- Kinematic fit: $Cl_{\pi\pi}$ > 10% and $Cl_{\pi\pi}$ > $Cl_{\pi\eta}$
- Compatibility with reconstructed information

560,000 events used for determination of polarization observables (E_γ = 970 – 1650 MeV)

After cuts: background contamination < 1%

Sequential decays





CB-ELSA data

E_γ = 2000 - 2200 MeV

U. Thoma, M. Fuchs et al., PLB 659 (2008) 87

CBELSA/TAPS data

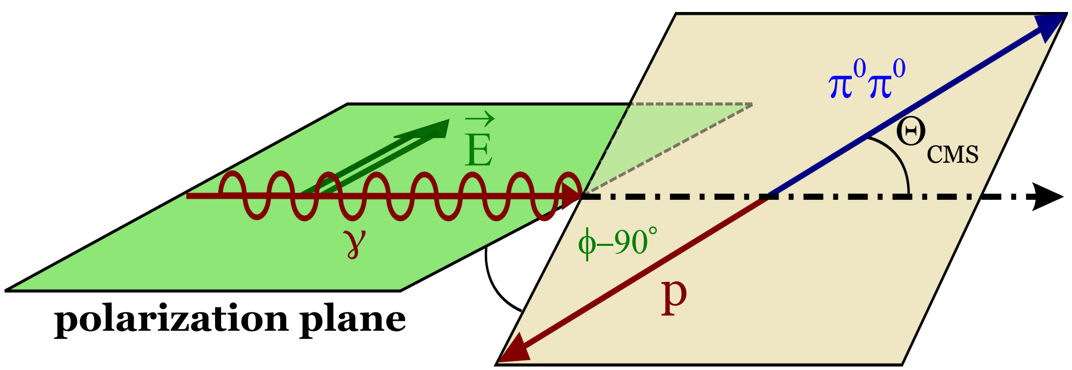
E_γ = 2000 - 2100 MeV

Clear observation of cascading decays!

Polarization observable Σ

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 [1 + \delta_l \Sigma \cos(2\phi)]$$

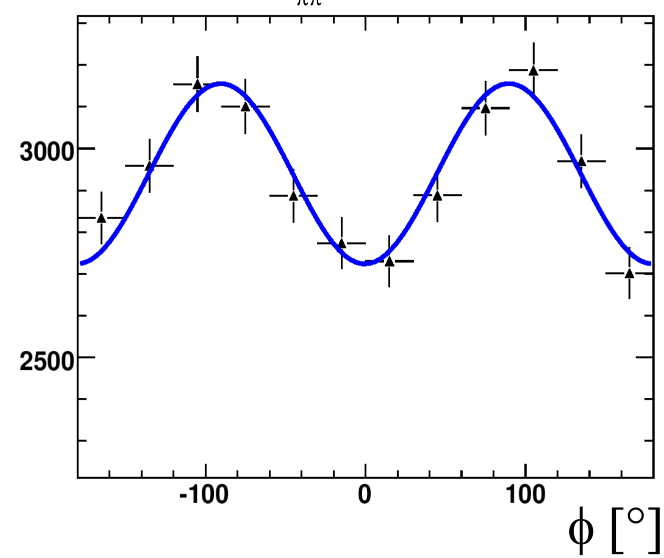
Quasi two-body consideration:



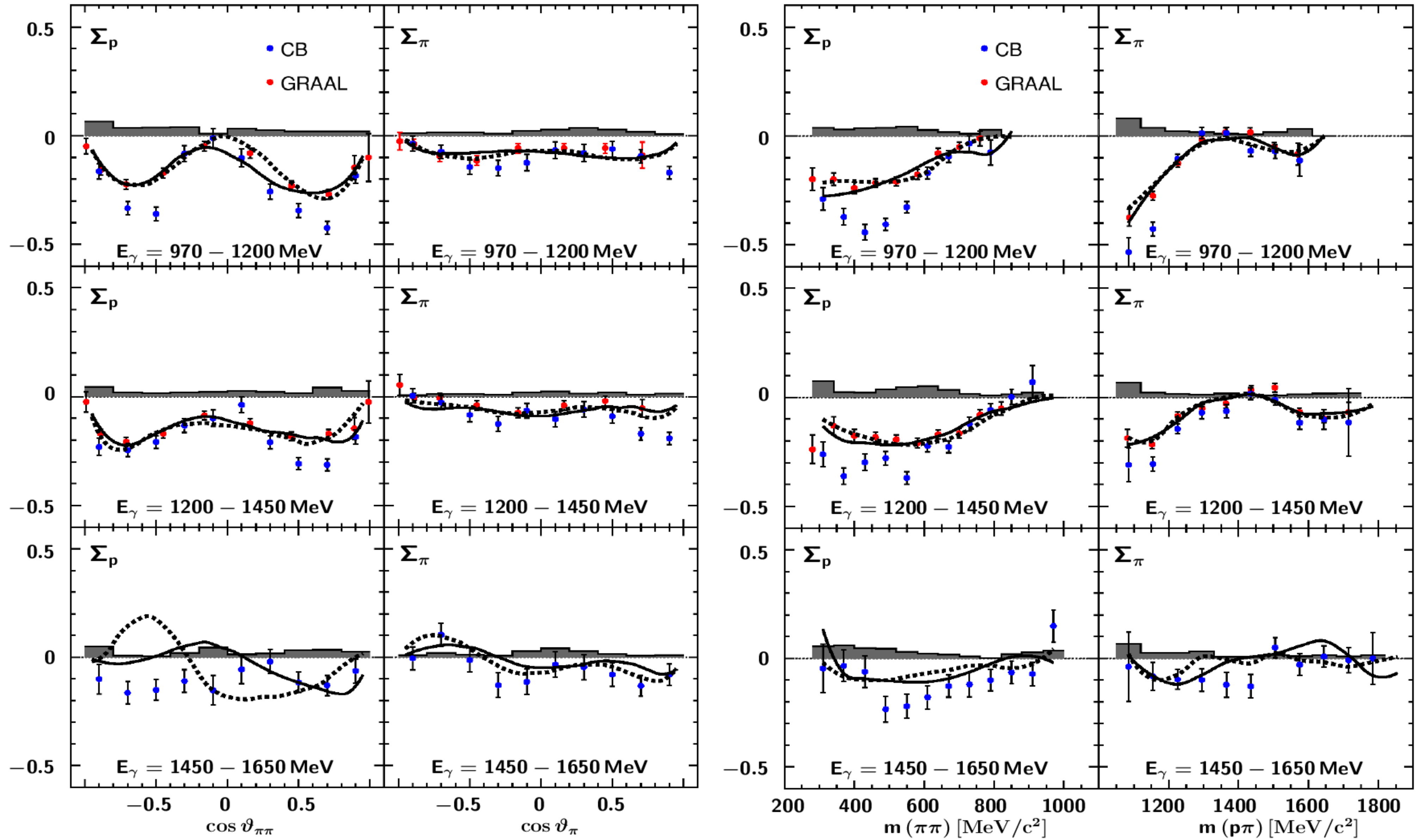
Example of a distribution fitted with $f(\phi) = A(1+\delta_l B\cos 2\phi)$

E_γ = 1200-1450 MeV

$640 \leq m_{\pi\pi} \leq 700$ MeV/c²



Polarization observable Σ



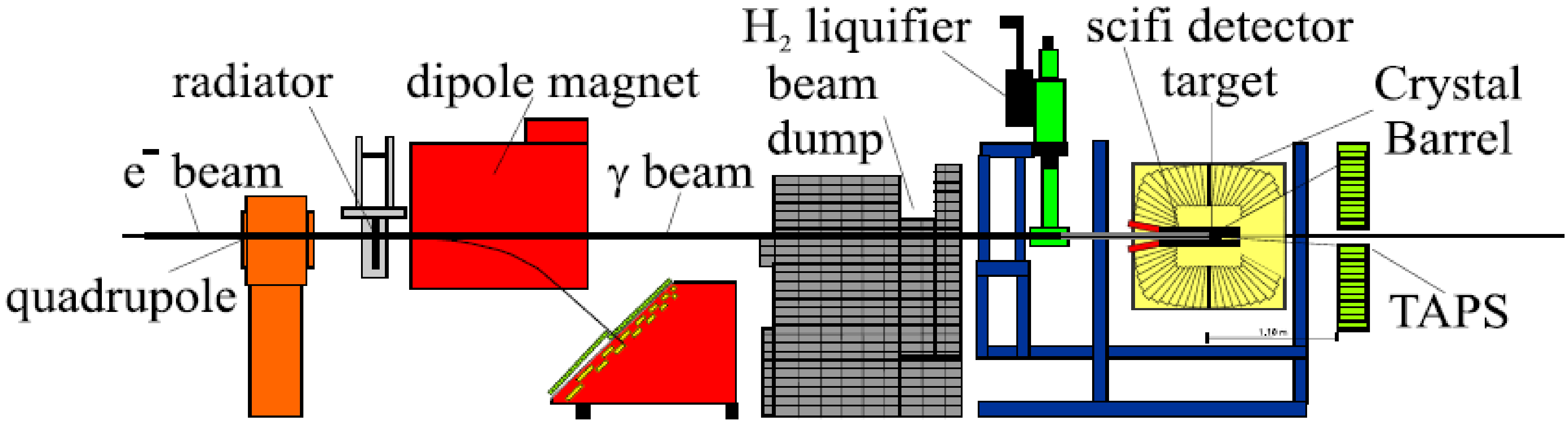
BnGA PWA solutions (PLB 659(2008) 87)

Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

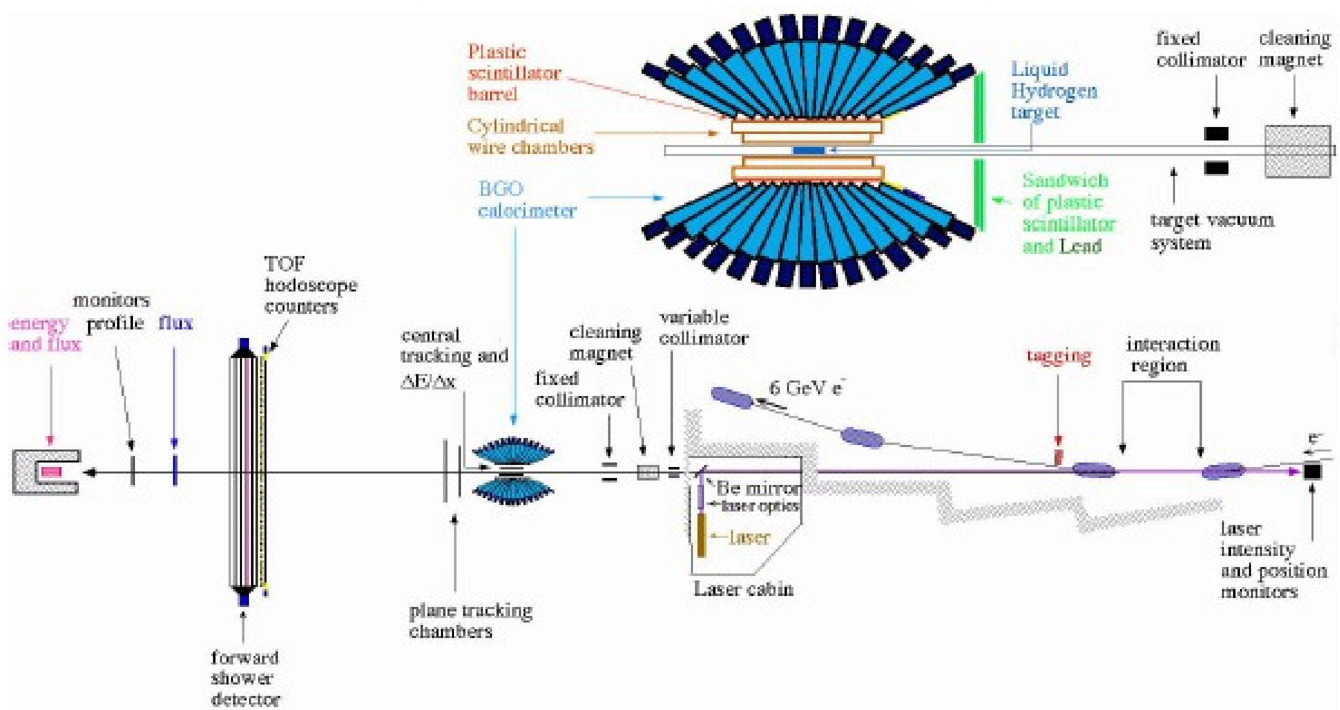
Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$ dominant

Compatibility of the data sets

The CBELSA/TAPS experiment (Bonn, Germany)

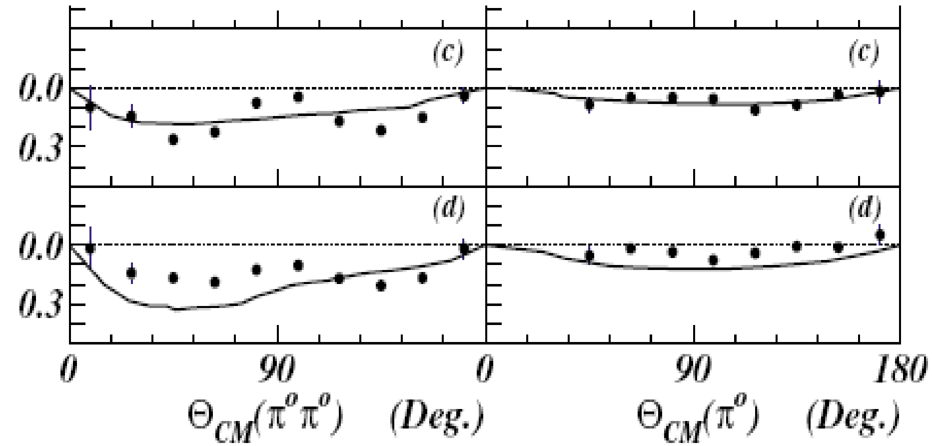


The GRAAL experiment (Grenoble, France)

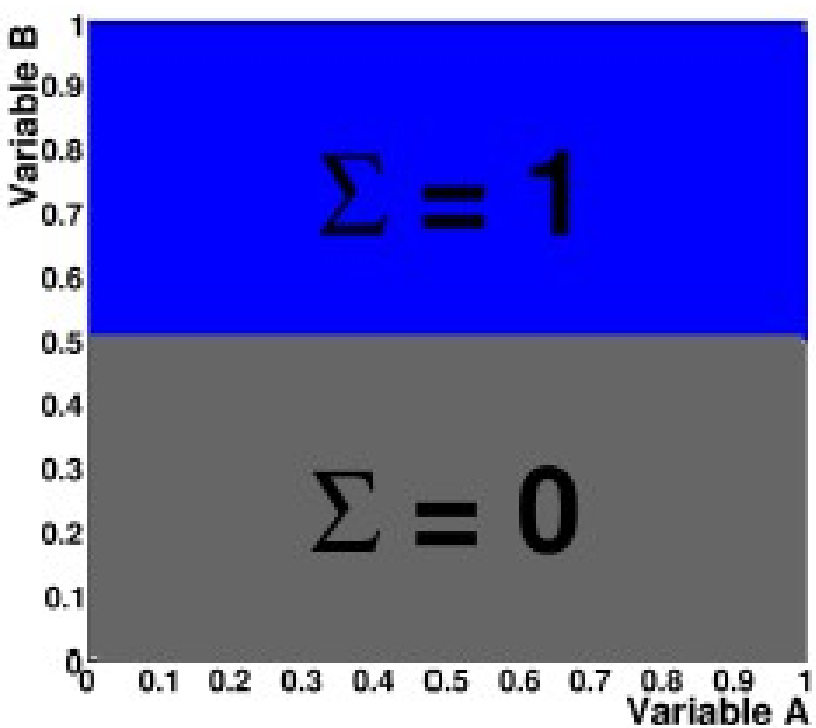


Compatibility of the data sets

- Different phase space coverage
- Different efficiencies
- GRAAL coverage ~ 70% of events retained by CBELSA/TAPS



Assafiri, et al., Phys. Rev. Lett. 90 (2003) 222001.



3-body final state → 5-dimensional phase space

Projections can be misleading!

Compatibility of the data sets

- Different phase space coverage
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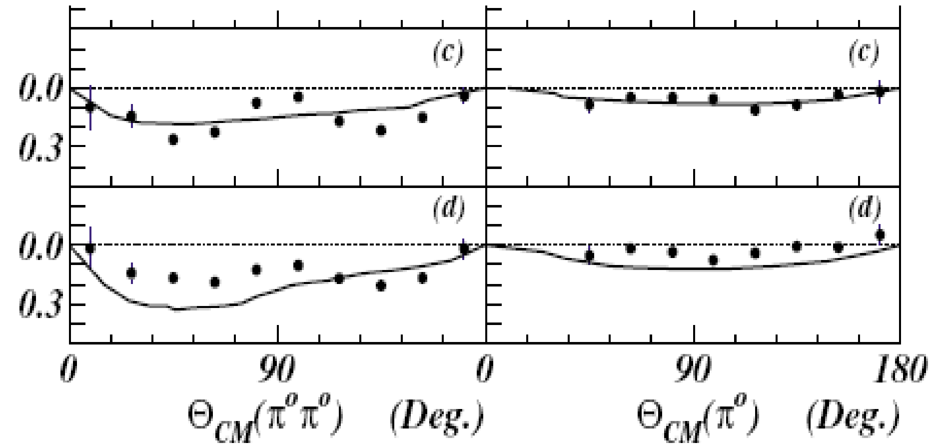
- GRAAL coverage ~ 70% of events retained by CBELSA/TAPS



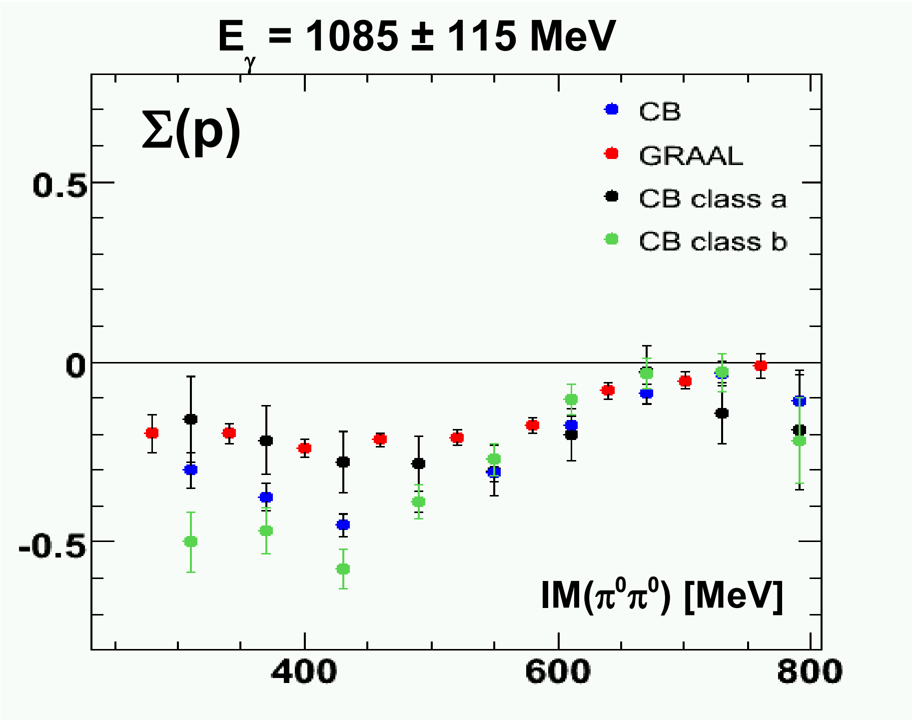
Assafiri, et al., Phys. Rev. Lett. 90 (2003) 222001.

Trying to repeat the acceptance of GRAAL experiment approximately:

a) **4 γ (25<Θ<155)**

b) 3 γ (25<Θ<155) +

γ (Θ<25)



Compatibility of the data sets

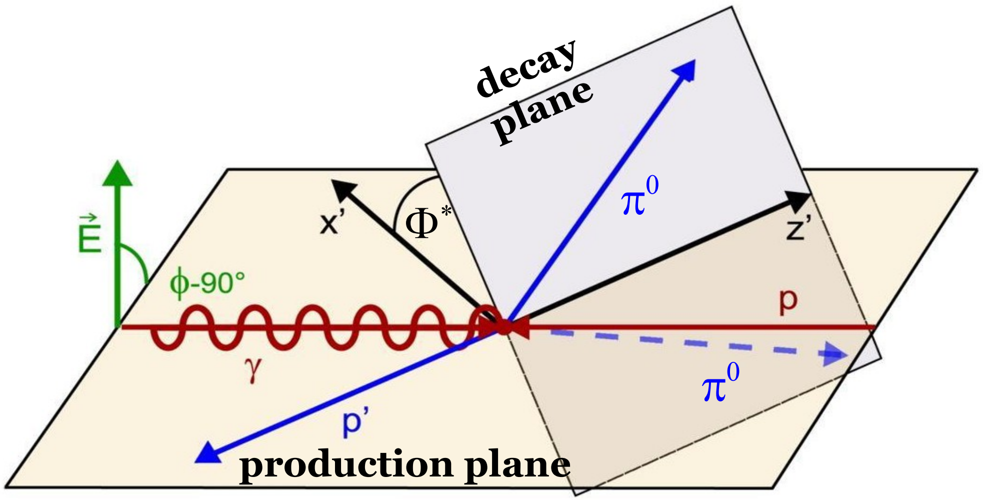
- **Measured observables are valid for the phase covered by given experiment!**
- Discrepancies can probably be explained by acceptance differences
- Important for models

Solution:

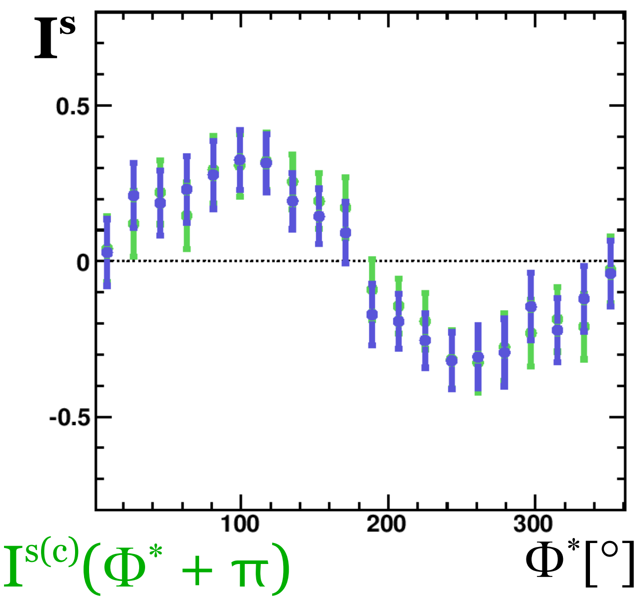
- Either application of a 5-dimensional acceptance correction
- Or a proper (event-based) determination of the systematic error

Polarization observables I^s and I^c

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 + \delta_l[I^s \sin(2\phi) + I^c \cos(2\phi)]\}$$



π^0 in the production plane

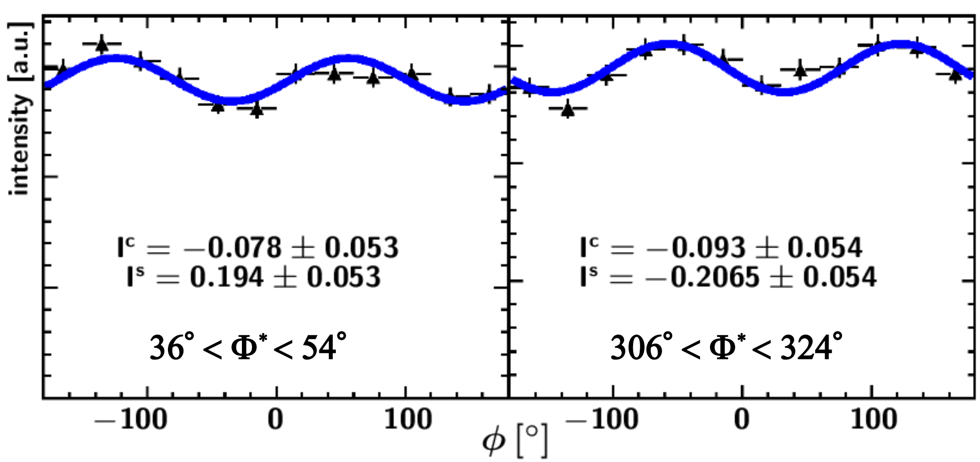


$$I^c(\Phi^*) = I^c(2\pi - \Phi^*)$$

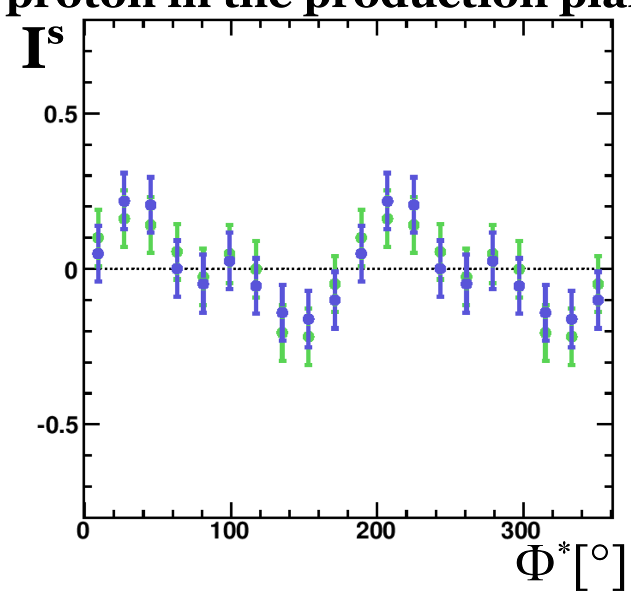
$$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$$

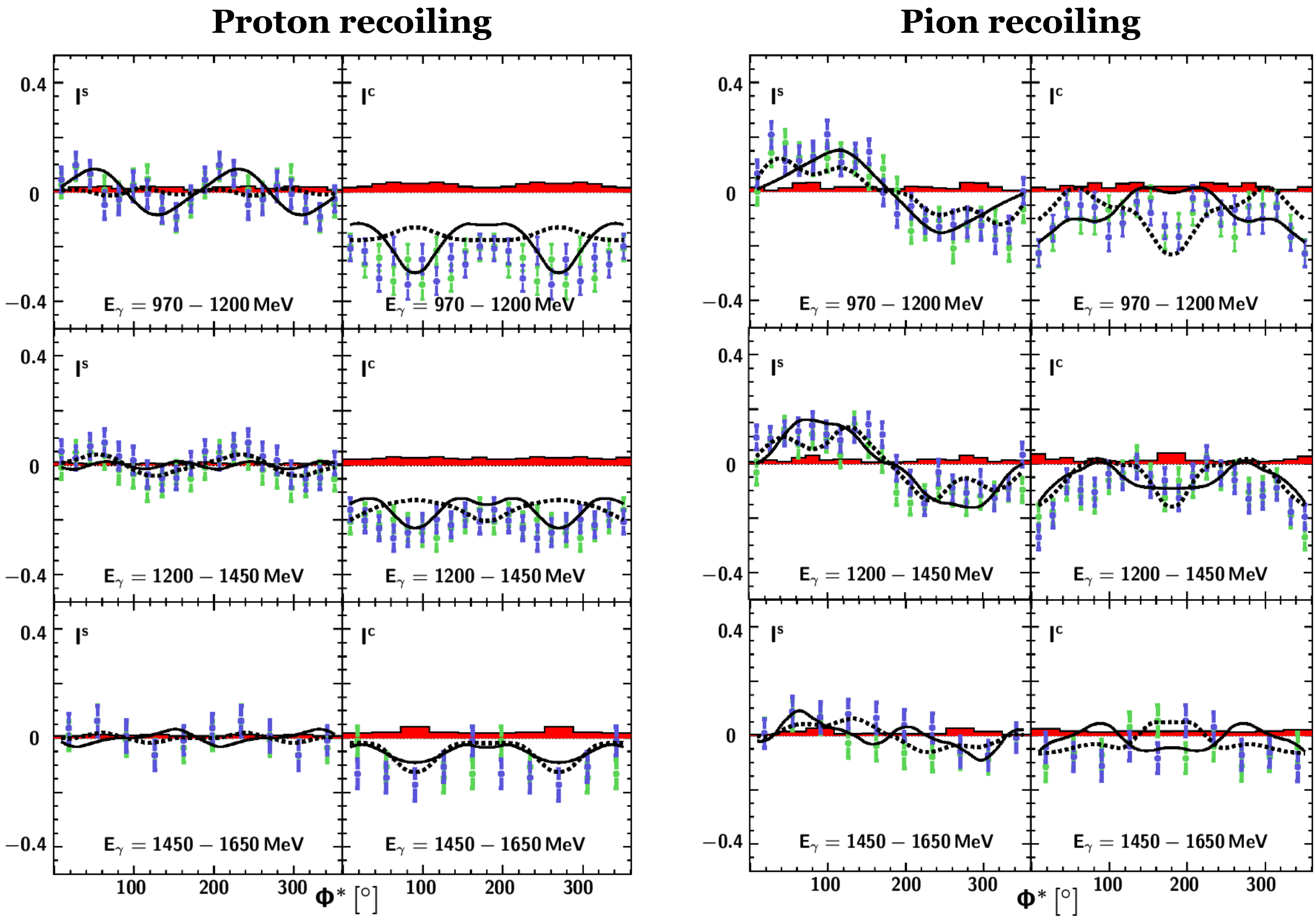
$$I^{s(c)}(\Phi^*) = I^{s(c)}(\Phi^* + \pi)$$

$$f(\phi) = A(1+\delta_l(B\sin 2\phi + C\cos 2\phi))$$



proton in the production plane



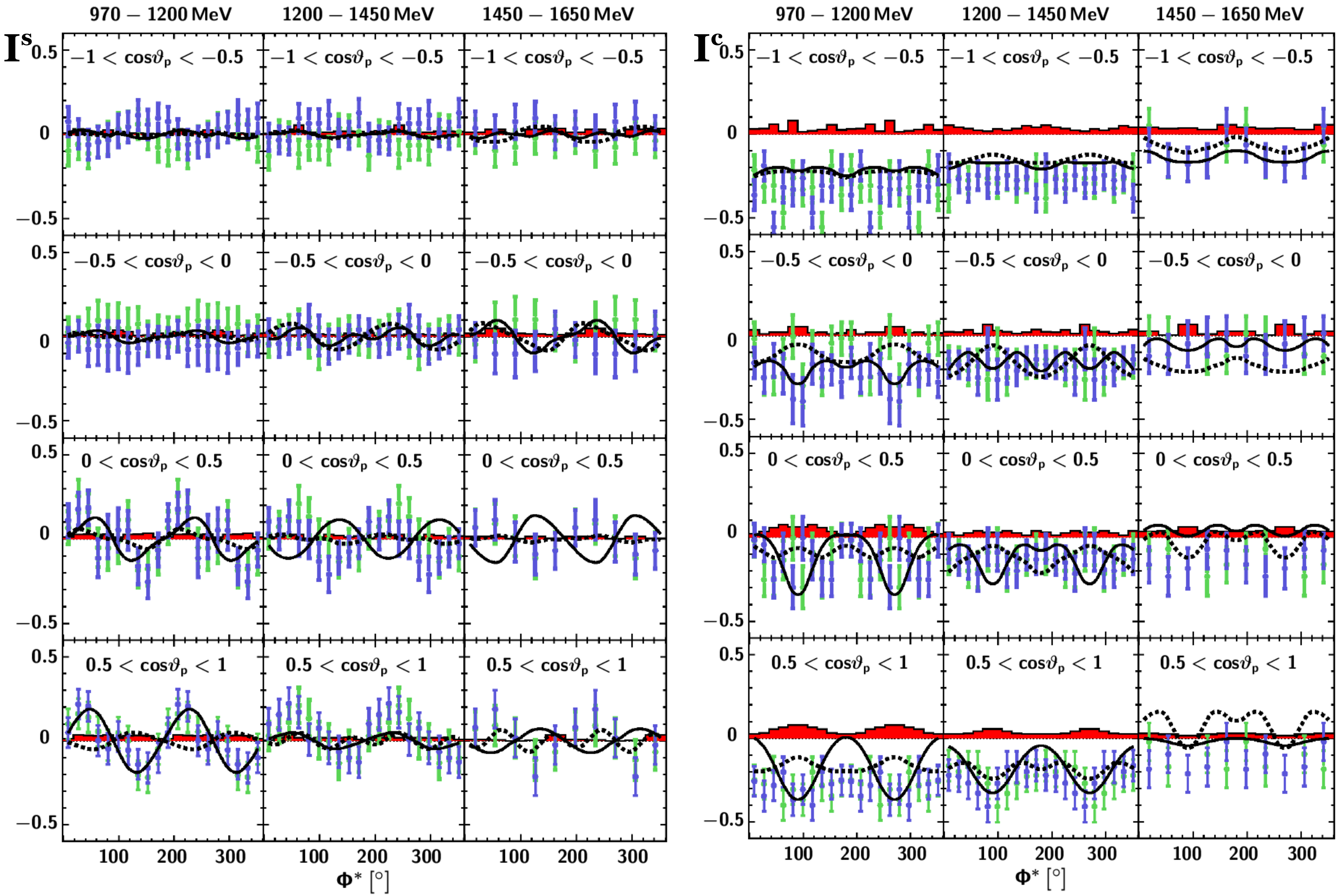


$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$ and $I^c(\Phi^*) = I^c(2\pi - \Phi^*)$

Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

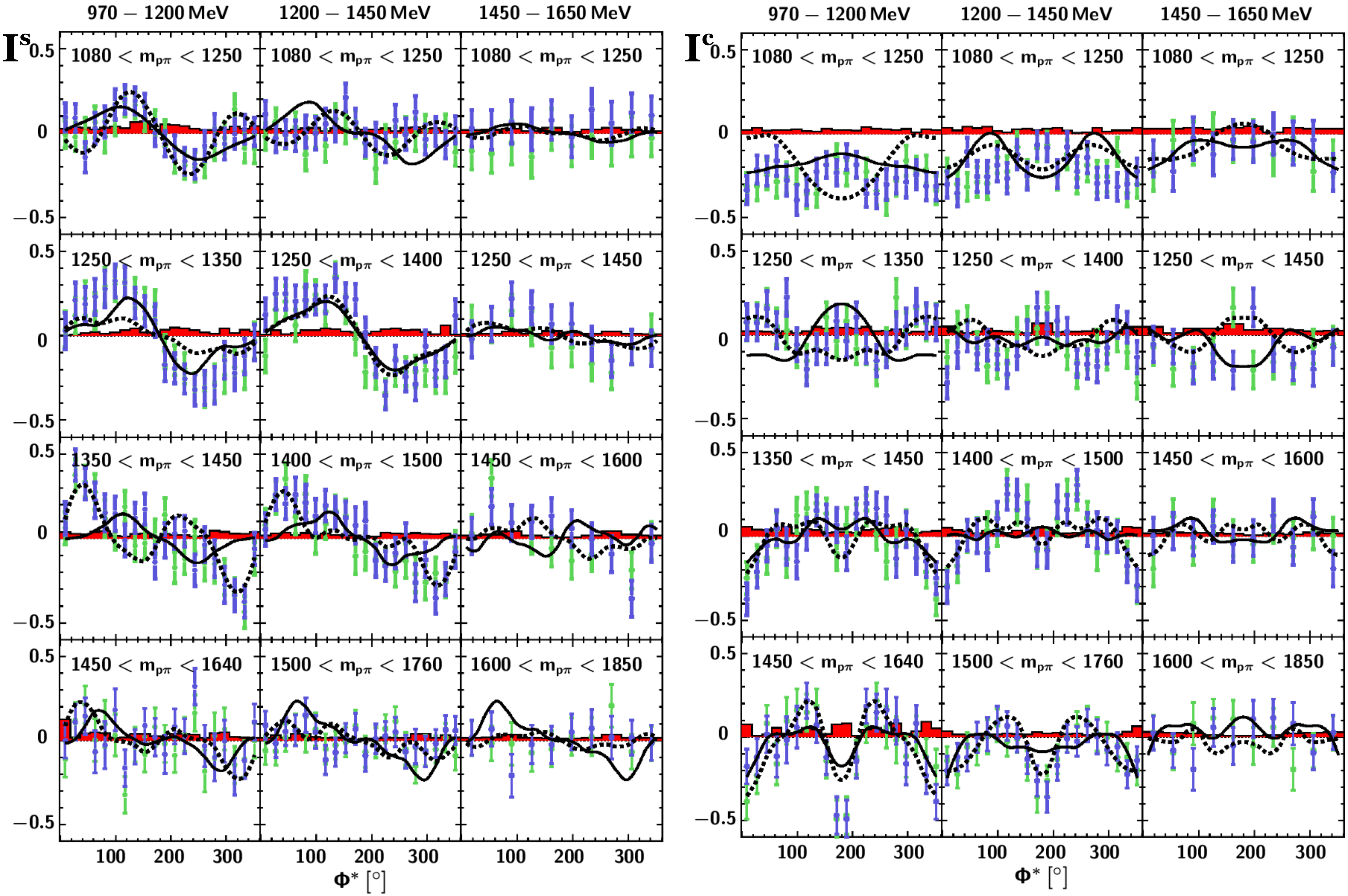
Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$ dominant

$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$ $I^c(\Phi^*) = I^c(2\pi - \Phi^*)$



Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(\text{D-wave})}$ dominant
Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(\text{S-wave})}$ dominant

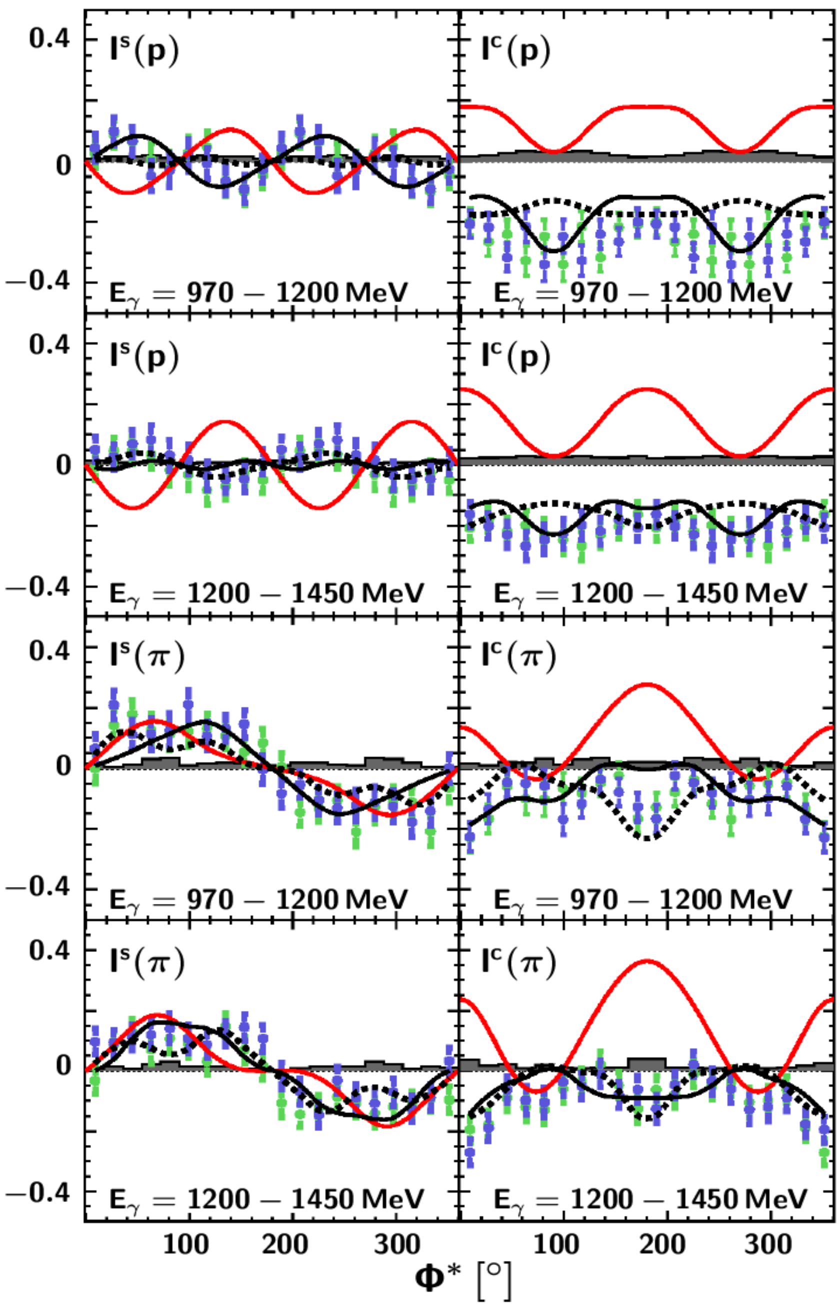
$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$ $I^c(\Phi^*) = I^c(2\pi - \Phi^*)$



Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$ dominant

Comparison with models



- BnGa PWA: Significant contributions of $D_{33}(1700)$, $D_{13}(1520)$, $P_{11}(1440)$
- Fix model: Significant contributions of $D_{13}(1520)$, $P_{11}(1440)$, $F_{15}(1680)$

➔ Clear distinction between two models!
➔ Importance of the $D_{33}(1700)$ resonance for the reaction $\gamma p \rightarrow p\pi^0\pi^0$

BnGa PWA: $D_{33}(1700)\rightarrow \Delta\pi_{(D\text{-wave})}$ dominant (solid), $D_{33}(1700)\rightarrow \Delta\pi_{(S\text{-wave})}$ dominant (dashed)
Red: calculation of the Fix model

Summary

- Sequential decays observed: γ p→ N*/Δ*→ Δπ, $D_{13}(1520)\pi$, $F_{15}(1680)\pi$
- Determination of the polarization observable Σ
- First measurement of the observables I^S and I^C in $\vec{\gamma}$ p→ p $\pi^o\pi^o$
- New constraints for the PWA
- Clear distinction between the BnGa PWA and the Fix model
- Data are presently included in the BnGa PWA
- Published for $\vec{\gamma}$ p→ p $\pi^o\eta$

E. Gutz, V. S., H. van Pee et al. Eur. Phys. J. A 35 (2008) 291

E. Gutz, V. S., H. van Pee et al. Phys. Lett. B 687 (2010), 11

- Two papers in preparation for $\vec{\gamma}$ p→ p $\pi^o\pi^o$

Supported by the Deutsche Forschungsgemeinschaft (SFB/TR-16)

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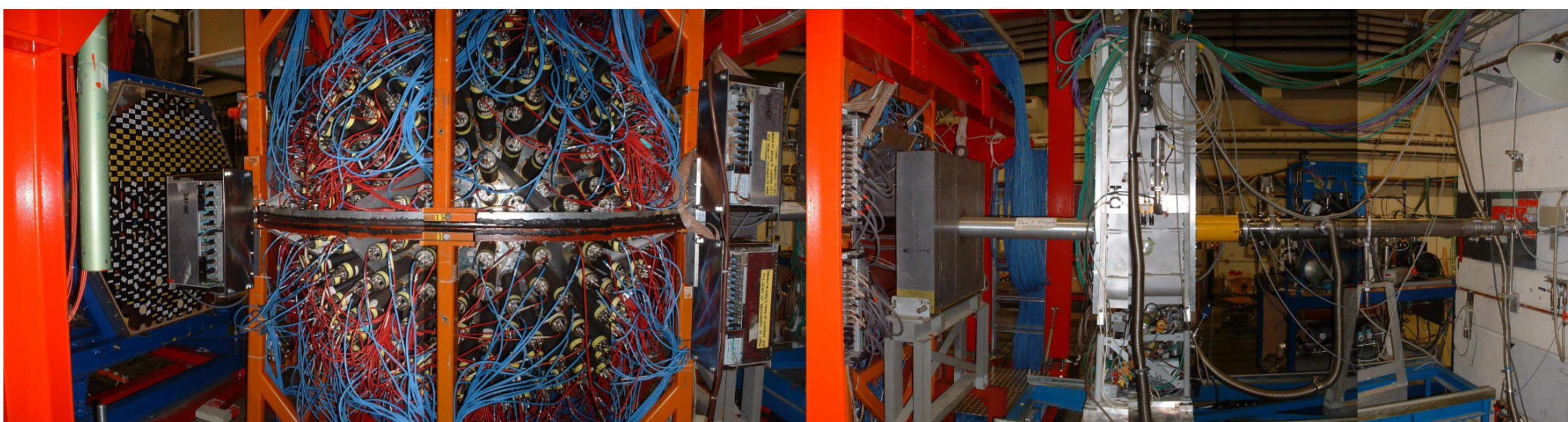
Institut für Kernphysik

A2

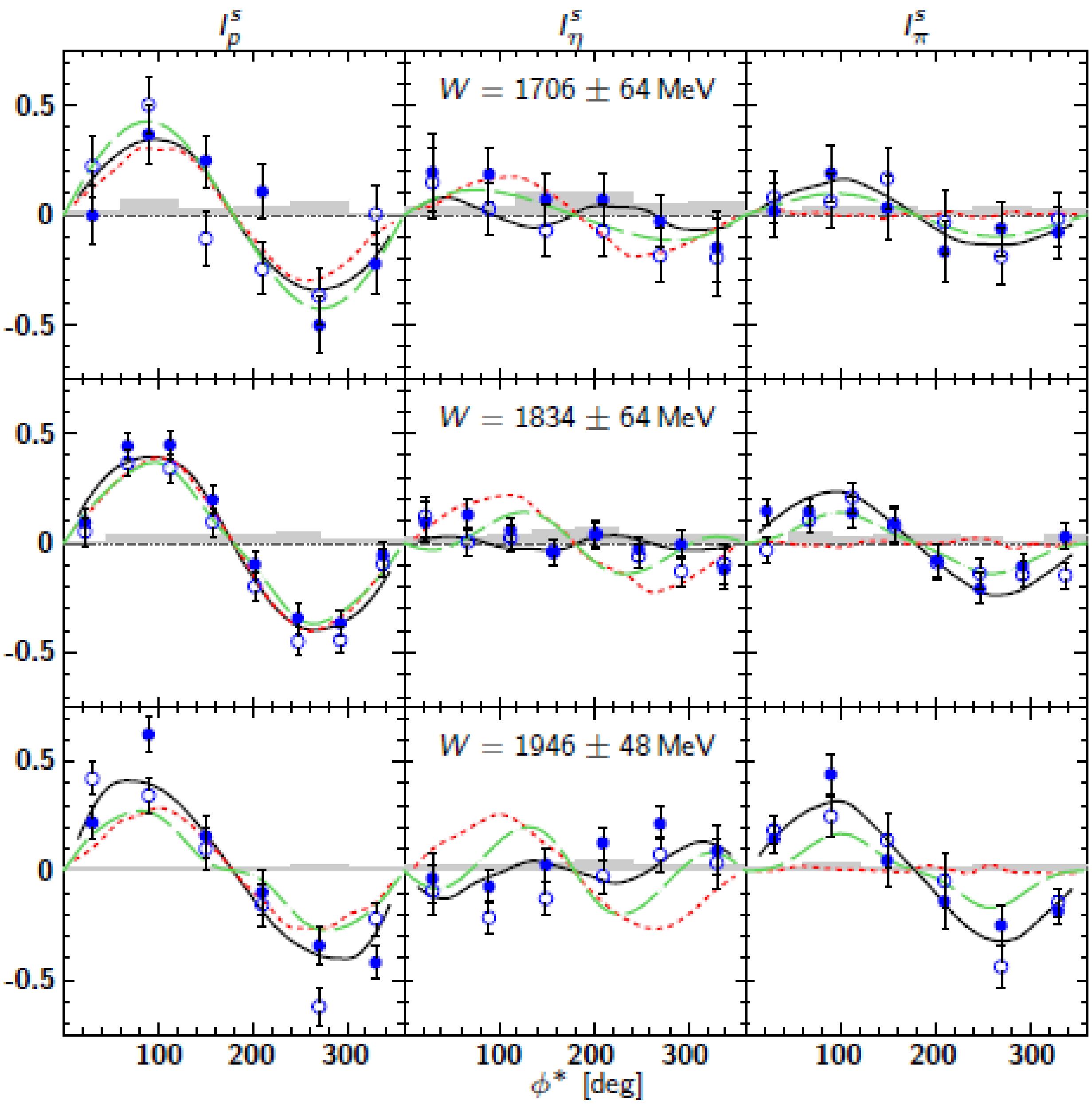


Measurement of the Proton Scalar Polarizabilities at MAMI

Thank you for your attention!

Backup

$\pi^0\eta$ photoproduction, Eric Gutz (Bonn)



E.G., V. Sokhoyan, H. van Pee et al.
Phys. Lett. B 687 (2010), 11

Closed symbols:
$I^s(\phi^*)$
Open symbols:
$-I^s(2\pi - \phi^*)$

Bars: Systematic error estimate

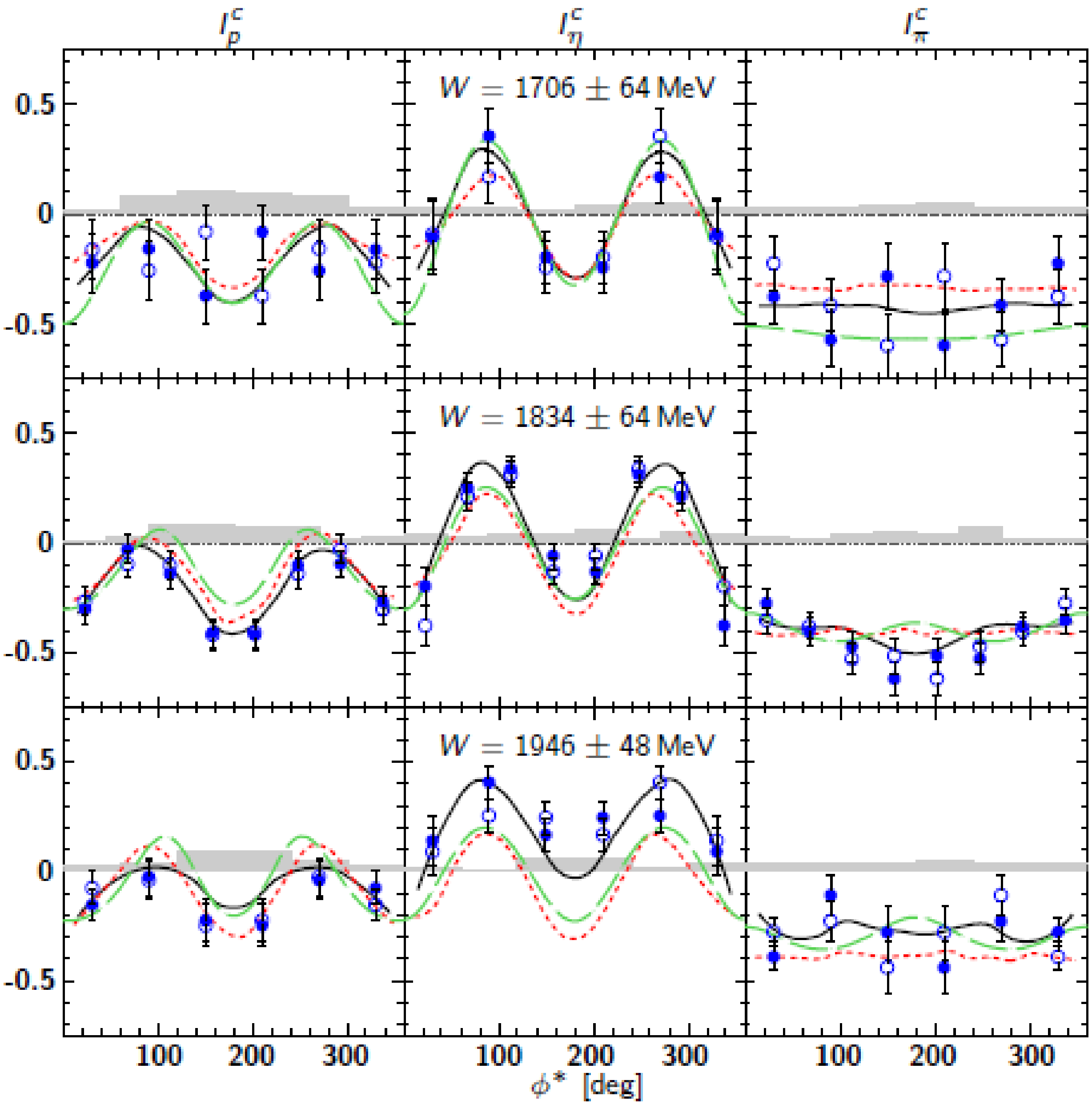
Curves:

— BnGa-PWA

— Valencia model
M. Döring, E. Oset, U.-G. Meißner
Eur. Phys. J. A 46 (2010) 315

— Fix isobar model
A. Fix et al., Phys. Rev. C 82 (2010) 035207

$\pi^o\eta$ photoproduction, Eric Gutz (Bonn)



E.G., V. Sokhoyan, H. van Pee et al.
Phys. Lett. B 687 (2010), 11

Closed symbols:
$I^c(\phi^*)$
Open symbols:
$I^c(2\pi - \phi^*)$

Bars: Systematic error estimate

Curves:

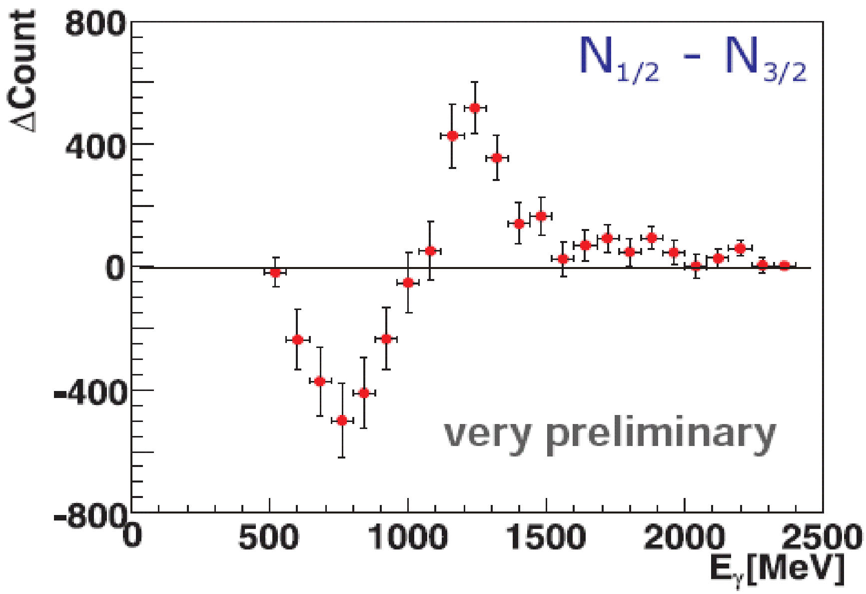
— BnGa-PWA

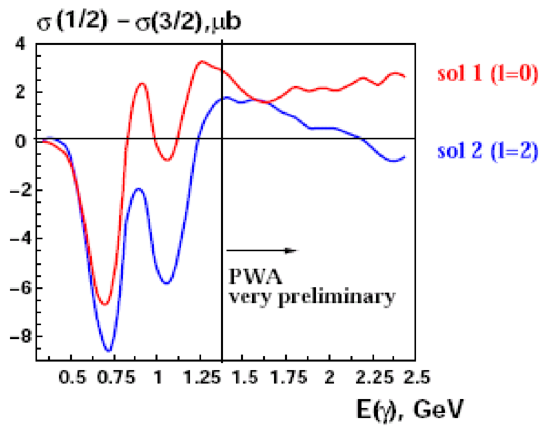
— Valencia model
M. Döring, E. Oset, U.-G. Meißner
Eur. Phys. J. A 46 (2010) 315

— Fix isobar model
A. Fix et al., Phys. Rev. C 82 (2010) 035207

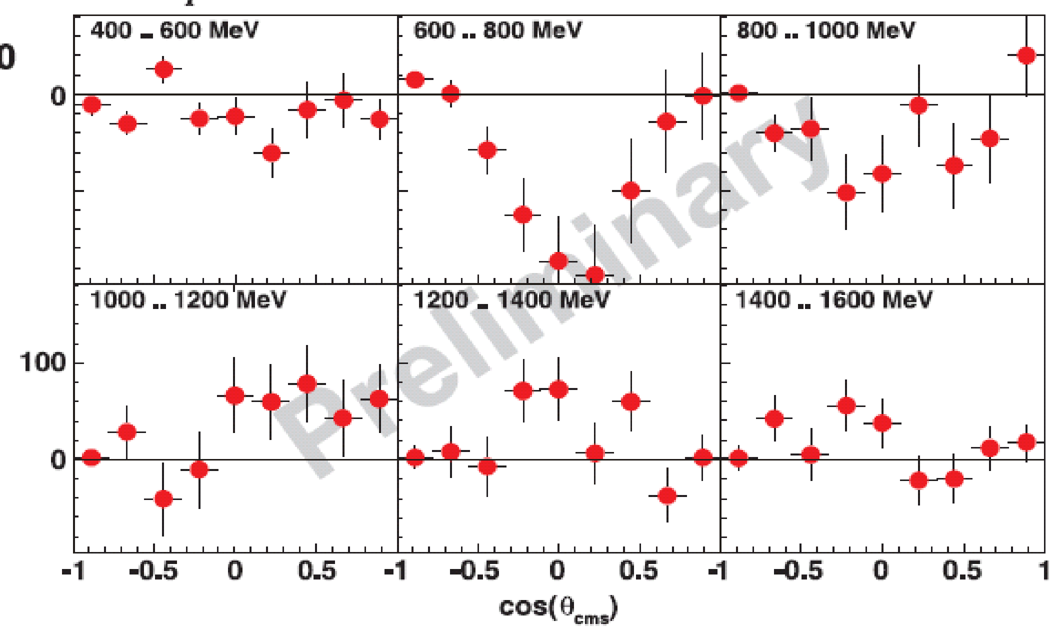
Double polarized measurements

CBELSA/TAPS data $\vec{\gamma}\vec{p} \longrightarrow p\pi^0\pi^0$ (D.Piontek, Bonn)





cos θ_p-distributions:



Count rate differences plotted

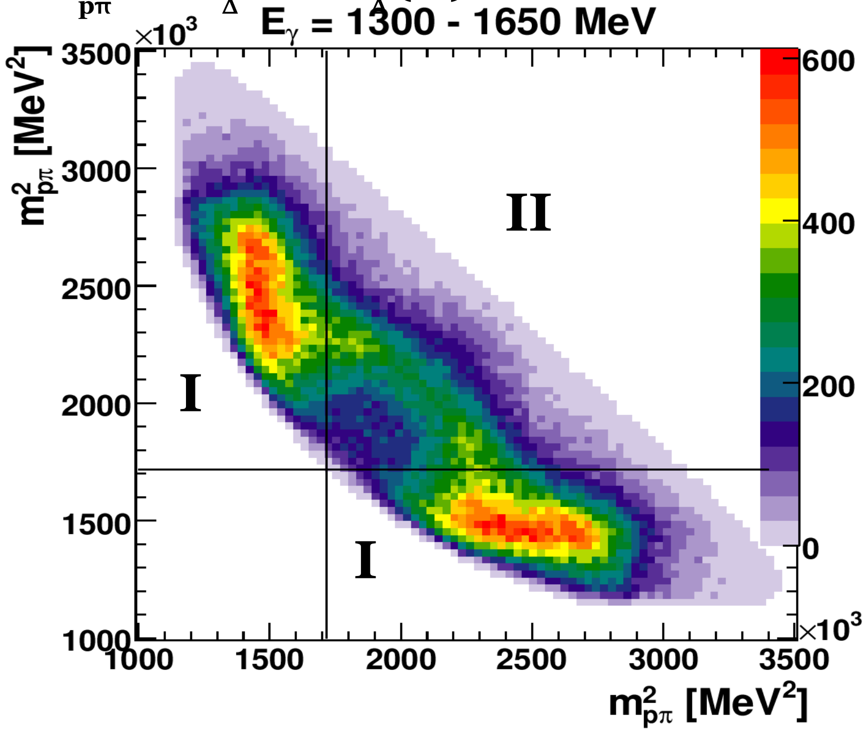
first look into differential distributions (very preliminary)

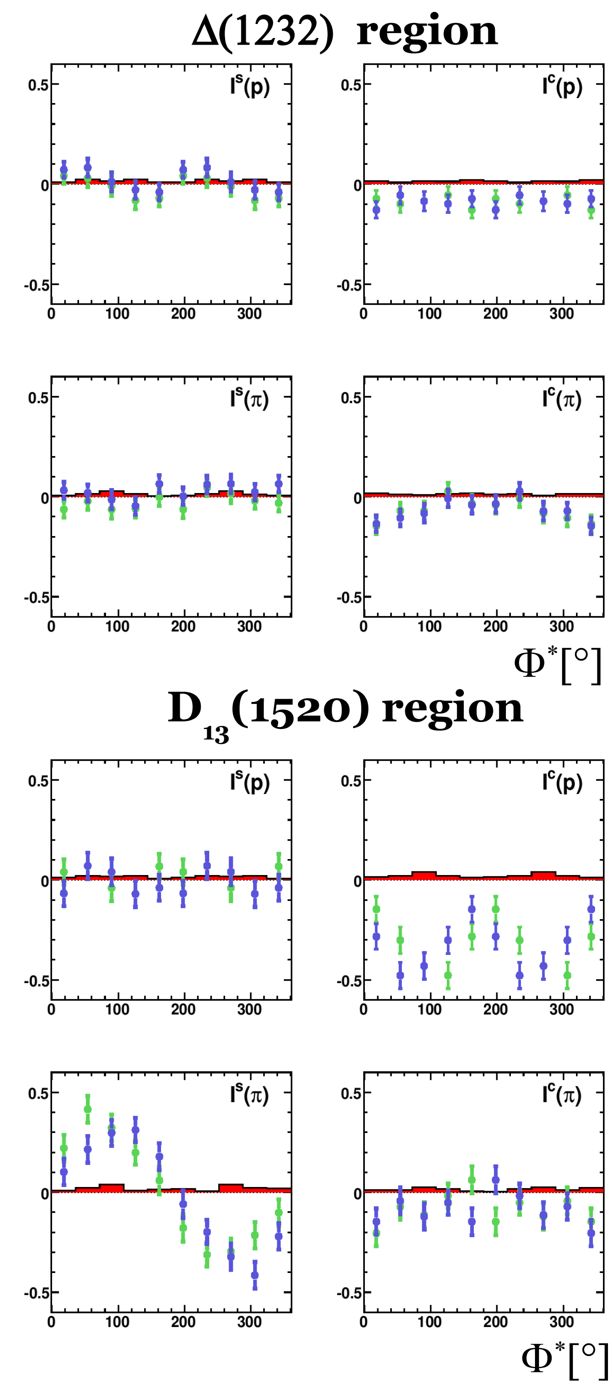
Sensitivity to resonance decays

Separation of $D_{13}(1520)$ and $\Delta(1232)$ regions:

$m_{p\pi} < m_{\Delta} + 2/3\,\Gamma_{\Delta}$ (I)

$m_{p\pi} > m_{\Delta} + 2/3\,\Gamma_{\Delta}$ (II)





Very different patterns observed

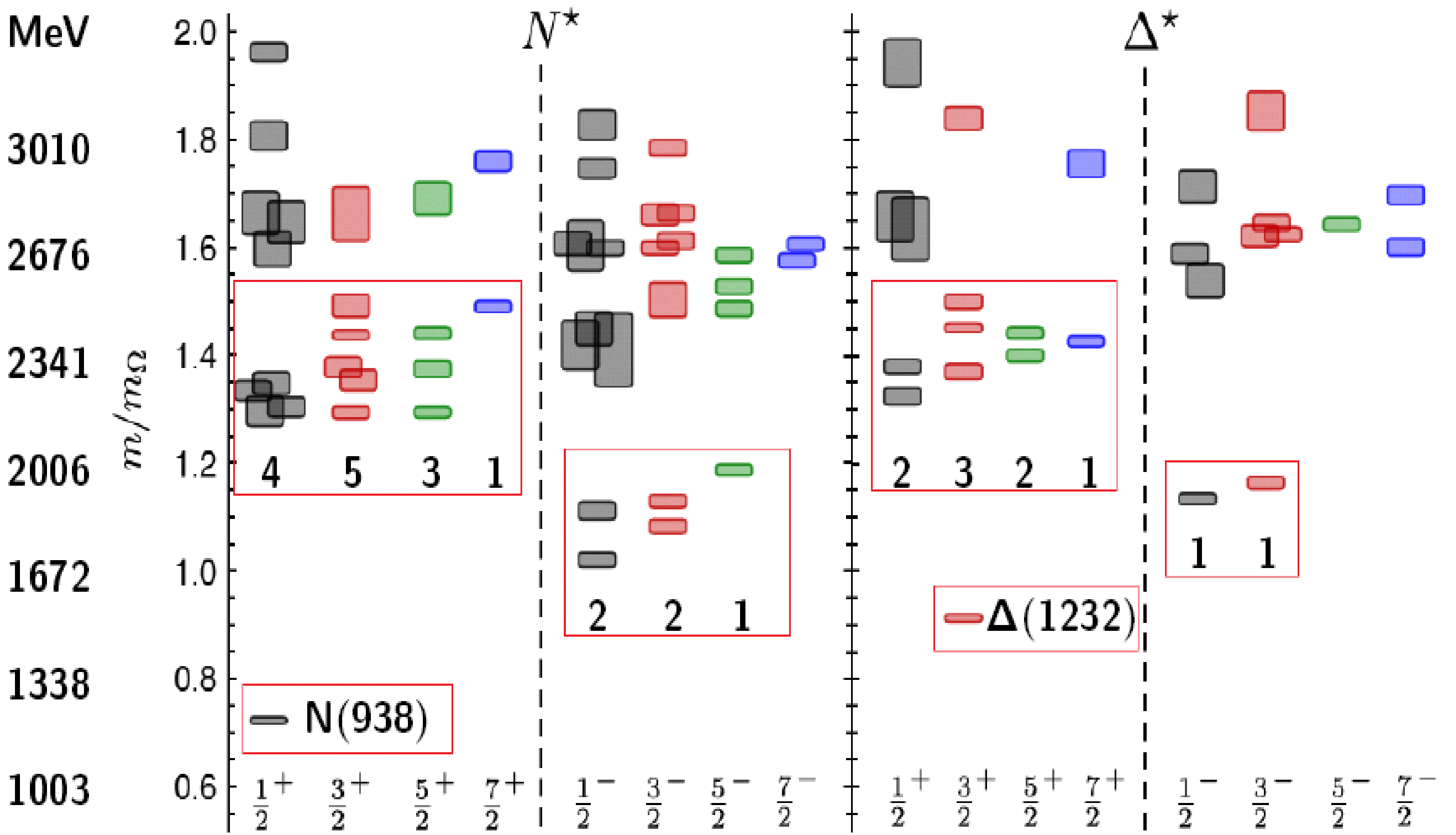
BnGa PWA: N(1900) and N(1975) both being 3/2+ states mostly contribute to the $D_{13}(1520)\pi$ decay in the mass range 1800-2000 MeV

Introduction

Goal: Gain a good understanding of the spectrum and properties of baryon resonances

$m_\pi = 396$ MeV

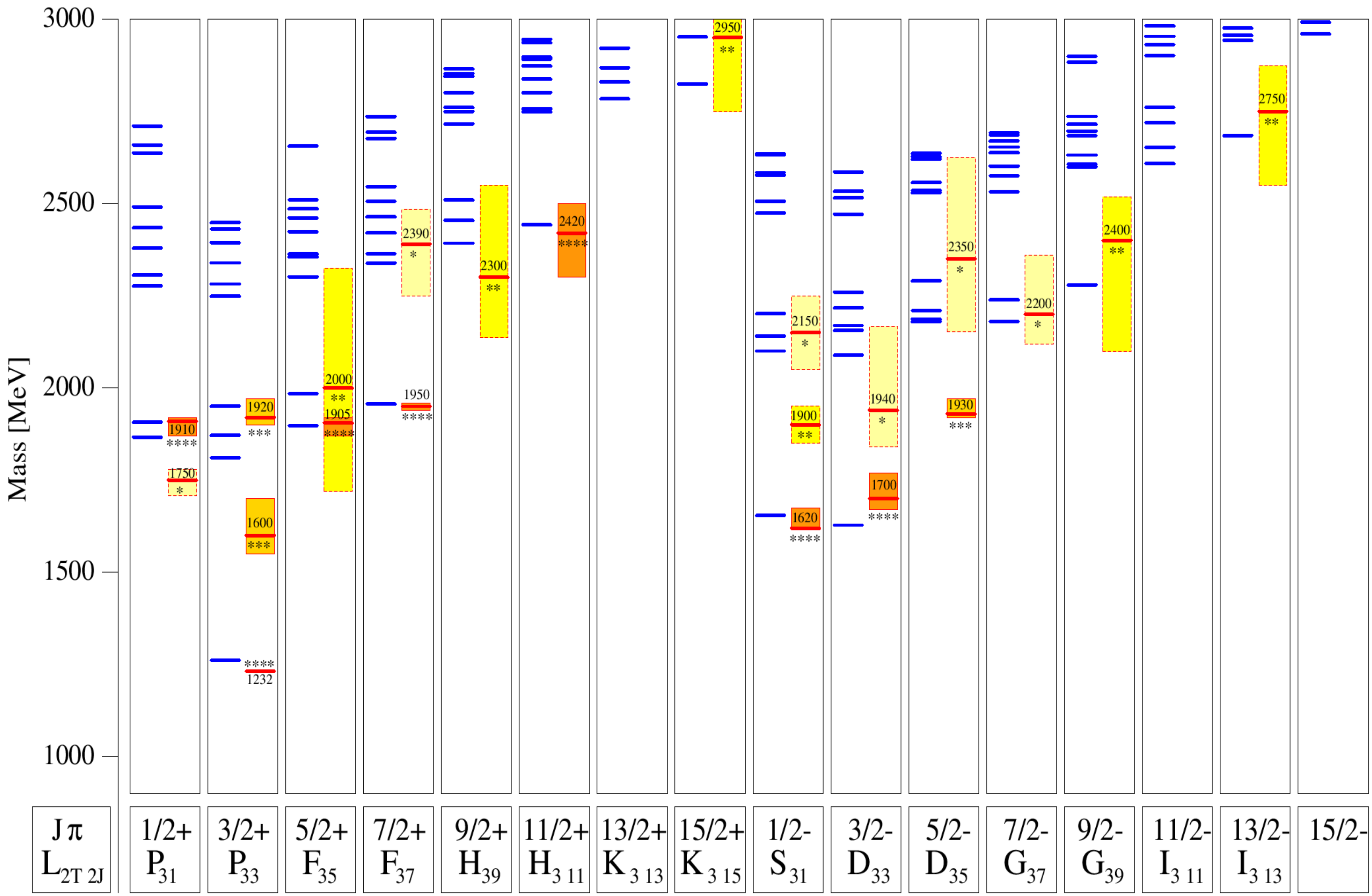
R. G. Edwards et al., Phys. Rev. D 84, 074508 (2011)



Introduction

Goal: Gain a good understanding of the spectrum and properties of baryon resonances

Above 1.9 GeV missing resonances are predicted by the symmetric quark models



Maximum Likelihood

The Method: Event-based maximum likelihood fit

Function which has to be maximised:

$$\mathcal{L} = \prod_{i=1}^{N} \omega(\vec{x}_i, \vec{p})$$

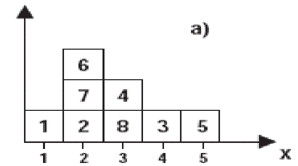
Product over N data points $\vec{x}_i$
ω: probability density distribution
$\vec{p}$: parameter vector

$\mathcal{L}$ = Probability to reproduce the data sample $\{\vec{x}_1, \ldots, \vec{x}_N\}$ with a given probability density distribution

Maximum of $\mathcal{L}$ reached
$\Longrightarrow$ best description of the data.

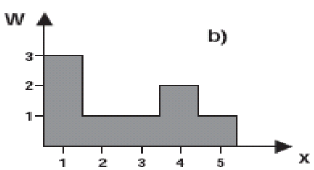
Additional advantage:
No binning needed !

Data points:



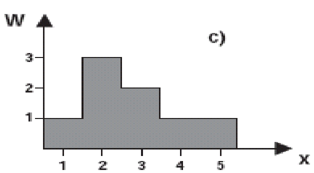
Probablity distributions:

ω_1 :



$\Rightarrow 3 \cdot 1 \cdot 2 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1 = 6$

ω_2 :



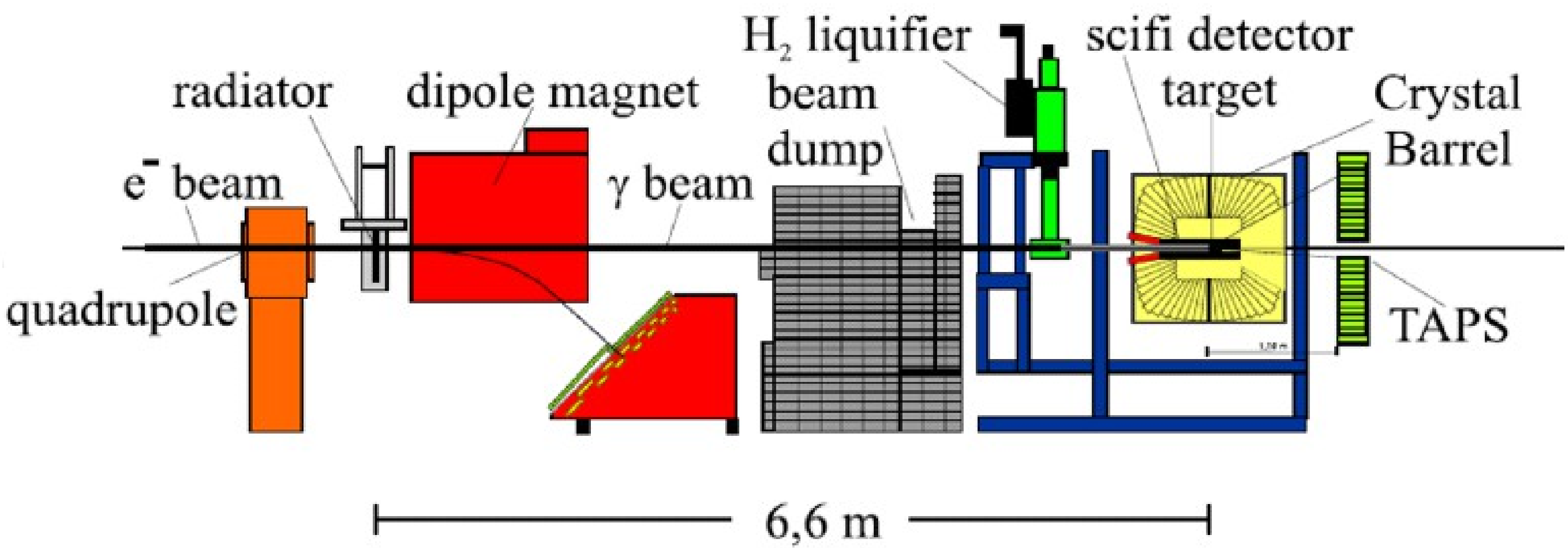
$\Rightarrow 1 \cdot 3 \cdot 1 \cdot 2 \cdot 1 \cdot 3 \cdot 3 \cdot 2 = 108$

Baryon resonances

56	S=1/2;L=0;N=0		$N_{1/2^+}$(939)			939 MeV
	S=3/2;L=0;N=0			$\Delta_{3/2^+}$(1232)		1232 MeV
70	S=1/2;L=1;N=0		$N_{1/2^-}$(1535)	$N_{3/2^-}$(1520)		1530 MeV
	S=3/2;L=1;N=0		$N_{1/2^-}$(1650)	$N_{3/2^-}$(1700)	$N_{5/2^-}$(1675)	1631 MeV
	S=1/2;L=1;N=0		$\Delta_{1/2^-}$(1620)	$\Delta_{3/2^-}$(1700)		1631 MeV
70	S=1/2;L=1;N=2		$N_{1/2^-}$(2090)	$N_{3/2^-}$(2080)		2151 MeV
	S=3/2;L=1;N=2		$N_{1/2^-}$	$N_{3/2^-}$	$N_{5/2^-}$	2223 MeV
	S=1/2;L=1;N=2		$\Delta_{1/2^-}$(2150)	$\Delta_{3/2^-}$		2223 MeV
56	S=1/2;L=1;N=1		$N_{1/2^-}$	$N_{3/2^-}$		1779 MeV
	S=3/2;L=1;N=1		$\Delta_{1/2^-}$(1900)	$\Delta_{3/2^-}$(1940)	$\Delta_{5/2^-}$(1930)	1950 MeV
56	S=1/2;L=2;N=0		$N_{3/2^+}$(1720)	$N_{5/2^+}$(1620)		1779 MeV
	S=3/2;L=2;N=0	$\Delta_{1/2^+}$(1910)	$\Delta_{3/2^+}$(1920)	$\Delta_{5/2^+}$(1905)	$\Delta_{7/2^+}$(1950)	1950 MeV
70	S=1/2;L=2;N=0		$N_{3/2^+}$	$N_{5/2^+}$		1866 MeV
	S=3/2;L=2;N=0	$N_{1/2^+}$	$N_{3/2^+}$(1900)	$N_{5/2^+}$(2000)	$N_{7/2^+}$(1990)	1950 MeV
	S=1/2;L=2;N=0		$\Delta_{3/2^+}$	$\Delta_{5/2^+}$		1950 MeV
70	S=1/2;L=3;N=0		$N_{5/2^-}$	$N_{7/2^-}$		2151 MeV
	S=3/2;L=3;N=0	$N_{3/2^-}$	$N_{5/2^-}$(2200)	$N_{7/2^-}$(2190)	$N_{9/2^-}$(2250)	2223 MeV
	S=1/2;L=3;N=0		$\Delta_{5/2^-}$	$\Delta_{7/2^-}$(2200)		2223 MeV
56	S=1/2;L=3;N=1		$N_{5/2^-}$	$N_{7/2^-}$		2334 MeV
	S=3/2;L=3;N=1	$\Delta_{3/2^-}$	$\Delta_{5/2^-}$(2350)	$\Delta_{7/2^-}$	$\Delta_{9/2^-}$(2400)	2467 MeV
56	S=1/2;L=4;N=0		$N_{7/2^+}$	$N_{9/2^+}$(2220)		2334 MeV
	S=3/2;L=4;N=0	$\Delta_{5/2^+}$	$\Delta_{7/2^+}$(2390)	$\Delta_{9/2^+}$(2300)	$\Delta_{11/2^+}$(2420)	2467 MeV
70	S=1/2;L=5;N=0		$N_{9/2^-}$	$N_{11/2^-}$(2600)		2629 MeV
56	S=3/2;L=5;N=1	$\Delta_{7/2^-}$	$\Delta_{9/2^-}$	$\Delta_{11/2^-}$	$\Delta_{13/2^-}$(2750)	2893 MeV
56	S=1/2;L=6;N=0		$N_{11/2^+}$	$N_{13/2^+}$(2700)		2781 MeV
	S=3/2;L=6;N=0	$\Delta_{9/2^+}$	$\Delta_{11/2^+}$	$\Delta_{13/2^+}$	$\Delta_{15/2^+}$(2950)	2893 MeV
70	S=1/2;L=7;N=0		$N_{13/2^-}$	$N_{15/2^-}$		3033 MeV
56	S=3/2;L=7;N=1	$\Delta_{11/2^-}$	$\Delta_{13/2^-}$	$\Delta_{15/2^-}$	$\Delta_{17/2^-}$	3264 MeV
56	S=1/2;L=8;N=0		$N_{15/2^+}$	$N_{17/2^+}$		3165 MeV
	S=3/2;L=8;N=0	$\Delta_{13/2^+}$	$\Delta_{15/2^+}$	$\Delta_{17/2^+}$	$\Delta_{19/2^+}$	3264 MeV

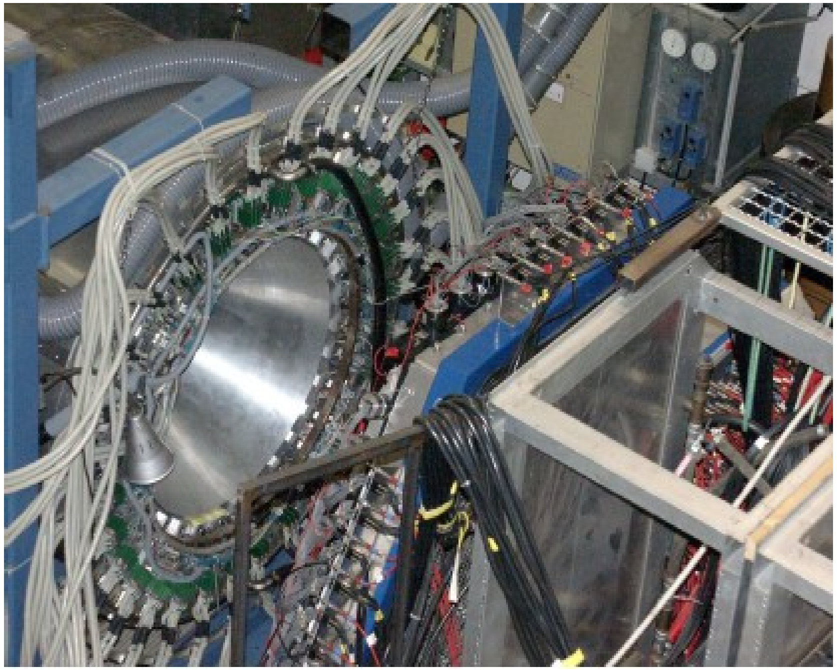
Table 20: Multiplet structure of nucleon and Δ resonances. The table contains all known resonances except radial excitations of the $N_{1/2^+}$(939) and $\Delta_{3/2^+}$(1232).

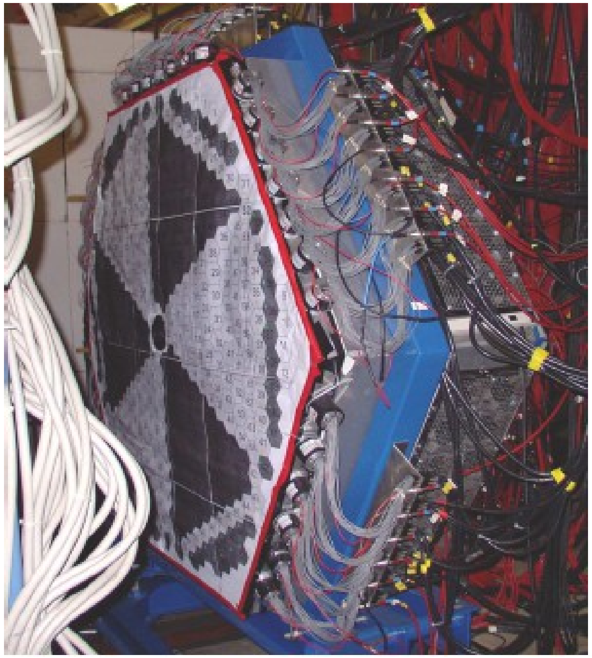
The CBELSA/TAPS experiment



- Tagger
  - 14 scintillator bars
  - MWPC
  - 480 scintillating fibres
- Inner detector
  - 513 scintillating fibres
  - Θ-coverage 28°-172°
- Crystal Barrel
  - 1290 CsI(Tl) crystals
  - Θ-coverage 30°-168°
- TAPS
  - 528 BaF_2 modules
  - Plastic vetos
  - Θ-coverage 5.8°-30°

The CBELSA/TAPS experiment





1290 CsI(Tl) crystals

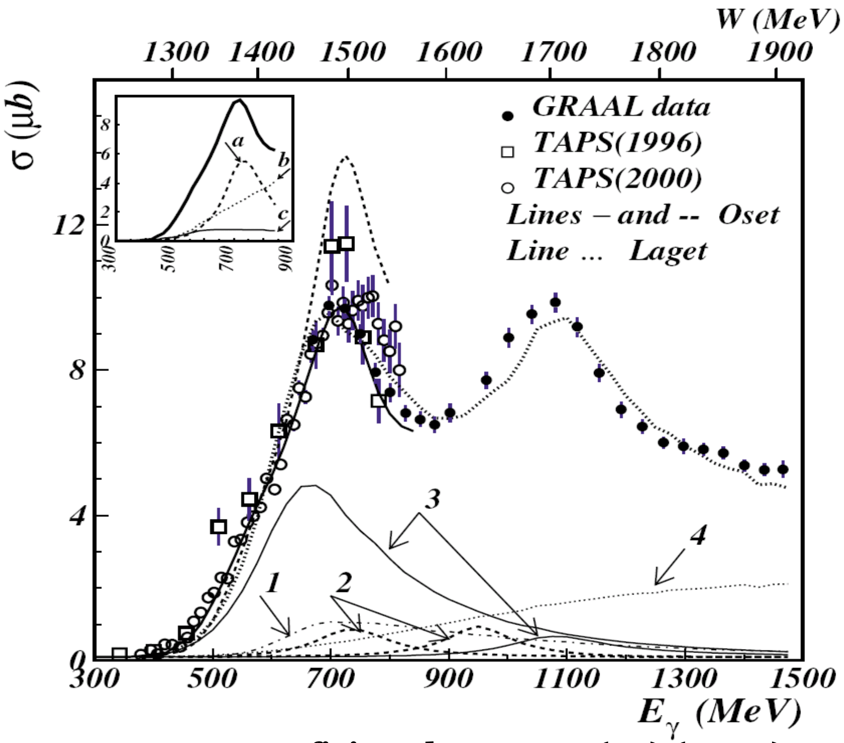
$\Theta = 30^\circ - 168^\circ$

528 BaF_2 crystals

Veto system

$\Theta = 5.8^\circ - 30^\circ$

Models: Valencia and Laget



Y. Assafiri et al., PRL 90 (22) (2003)

Laget model:

P_{11} (1440), P_{11} (1710), D_{13}(1520), D_{13}(1700), D_{33}(1700).

Dominance of the P_{11}(1440)→ Nσ channel

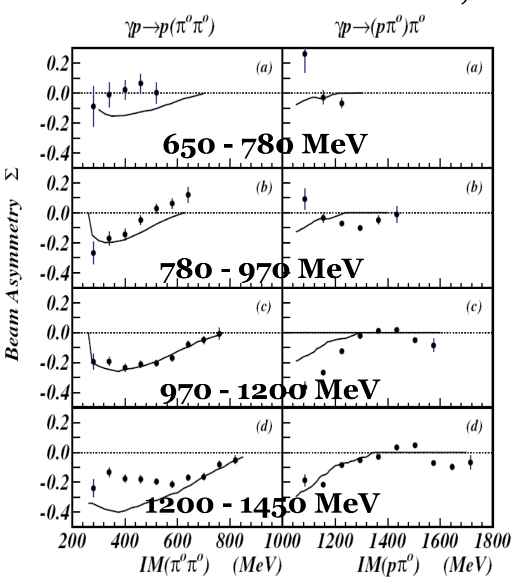
P_{11}(1440)→ Δπ (1) / D_{13}(1520), D_{13}(1700)→ Δπ (2) /

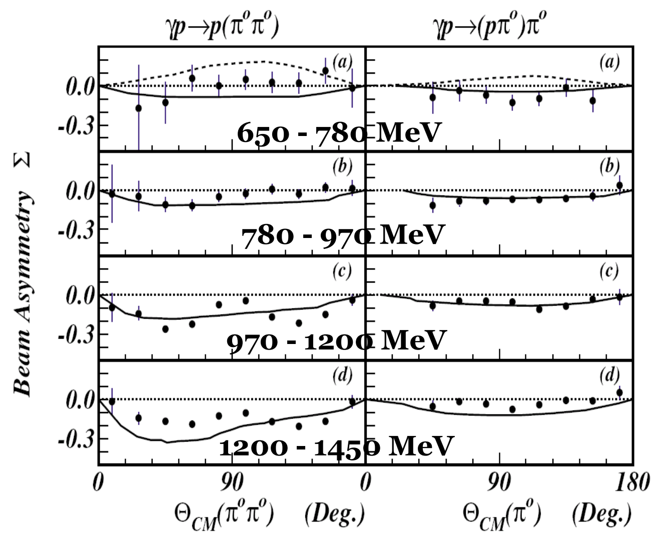
P_{11}(1440), D_{13}(1710)→ σp (3) / σp (4)

Valencia model:

D_{13}(1520), P_{11} (1440), D_{13}(1700) and other resonances

Dominance of the D_{13}(1520)→ Δπ channel





GRAAL: Polarization observable Σ (linearly polarized photons, unpolarized target)

GDH Collaboration: circularly polarized beam, longitudinally polarized target:

$\sigma_{3/2} > \sigma_{1/2}$ → D_{13}(1520) favored

J. Ahrens et al., PLB 624 (2005) 173

Bonn-Gatchina PWA:

Dominance of D_{13}(1520) and D_{33}(1700)

A. Sarantsev et al., PLB 659 (2008) 94

Polarization observables

Single meson production:

W.-T. Chiang, F. Tabakin, Phys. Rev. C 55 (1997) 2054

$$I_0 \Sigma = \frac{1}{2}(|b_1|^2 + |b_2|^2 - |b_3|^2 - |b_4|^2)$$

Double meson production:

W. Roberts, T. Oed, Phys. Rev. C 71 (2005) 052002

$$\begin{aligned} I_0 I^c &= 2\Re\left(-(b_1^+ b_1^{-*}) - b_2^+ b_2^{-*} - b_3^+ b_3^{-*} - b_4^+ b_4^{-*}\right) \\ I_0 I^s &= 2\Im\left(b_1^+ b_1^{-*} + b_2^+ b_2^{-*} + b_3^+ b_3^{-*} + b_4^+ b_4^{-*}\right) \end{aligned}$$

b_i: Transversity amplitudes

The data

CBELSA/TAPS:

A: Pol$_{max}$ = 49.2% @E$_\gamma$ = 1300 MeV

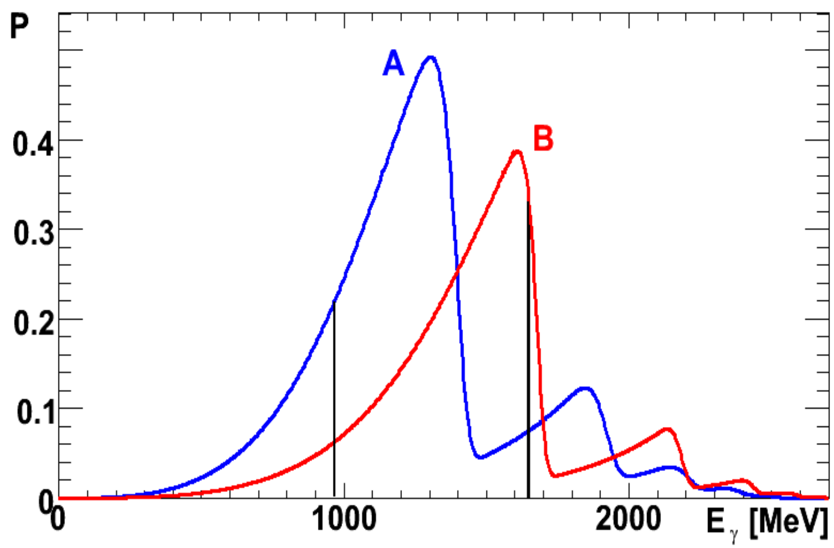
B: Pol$_{max}$ = 38.7% @E$_\gamma$ = 1600 MeV

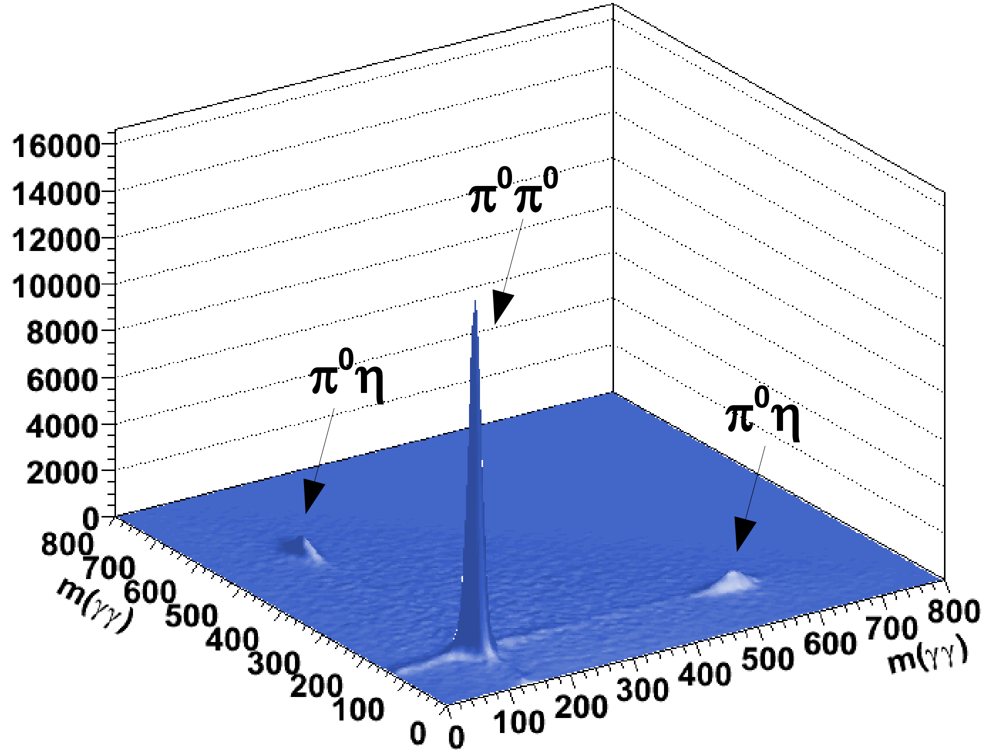
- Produced via coherent bremsstrahlung at a diamond crystal

- Liquid hydrogen as target material

Data selected for 4γ (+proton) events

$\gamma\, p \rightarrow p\, \pi^0 \pi^0$ clearly observed!



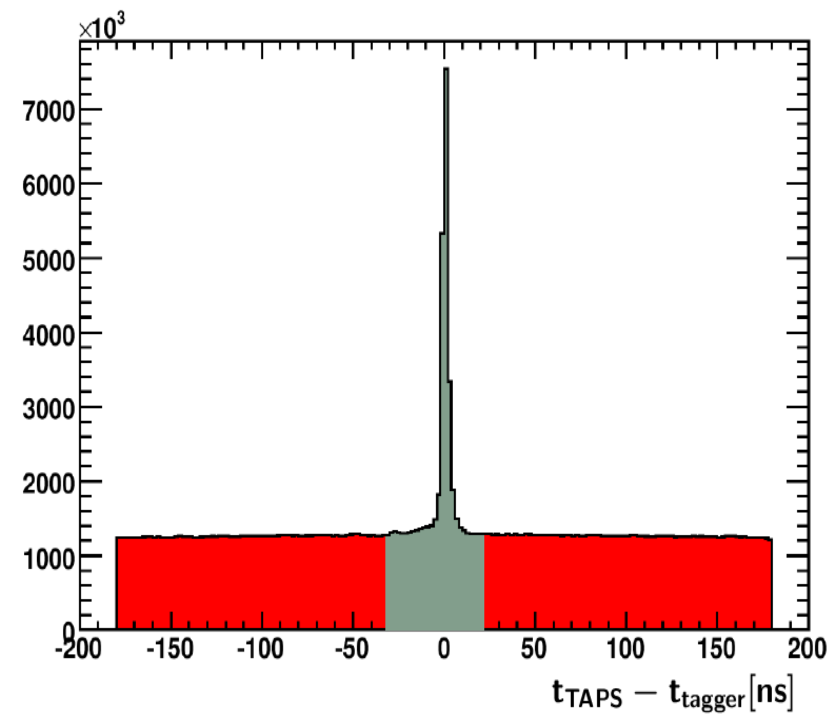


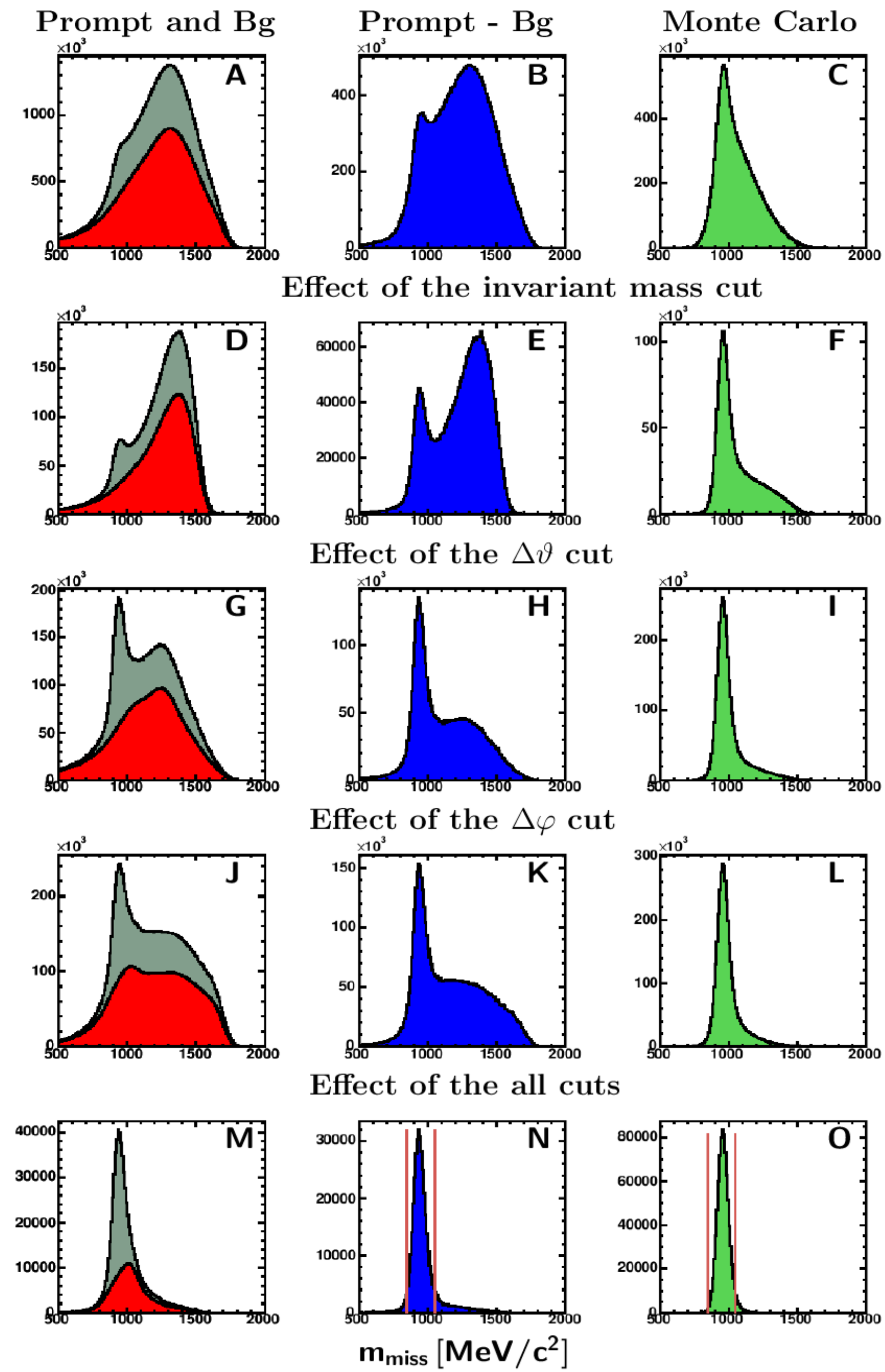
The data

Preselection:

Cut on $2\pi^0$ invariant mass
Coplanarity cut
$\Delta\vartheta$ cut
Missing mass cut

Full combinatorial analysis
Time coincidence analysis





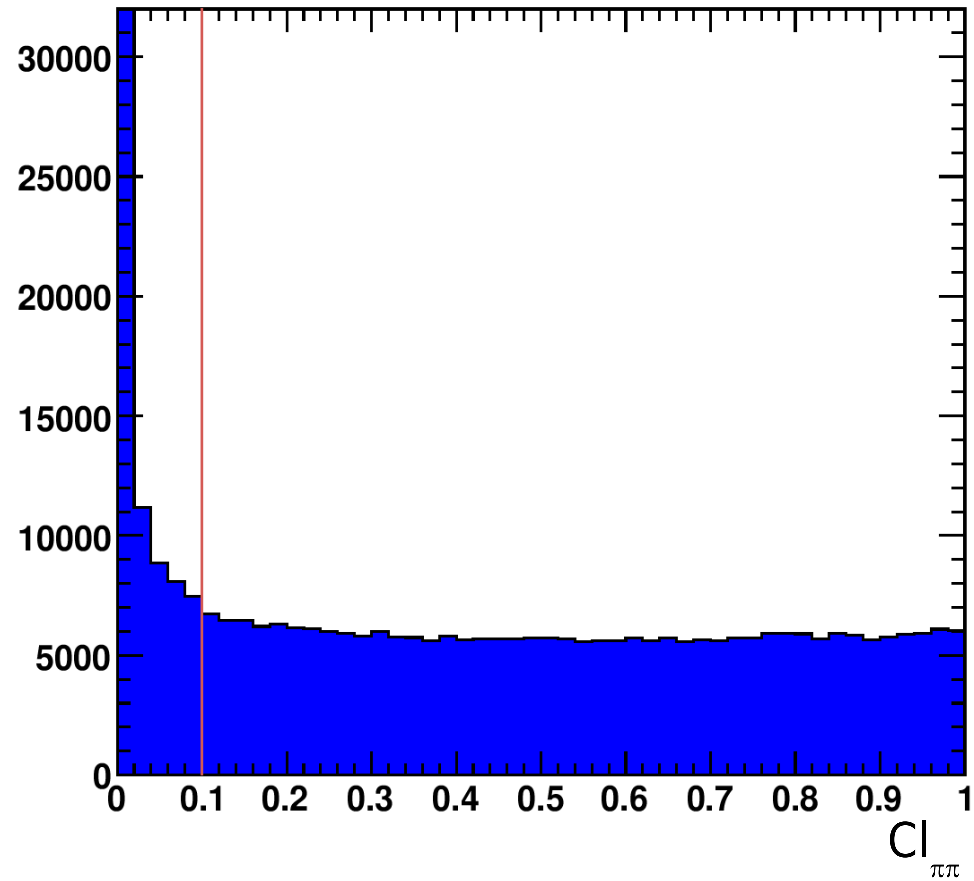
Data analysis

Preselection:

Combinatorial analysis
Cut on $2\pi^0$ invariant mass
Coplanarity cut
Missing mass cut

Application of the kinematic fit:

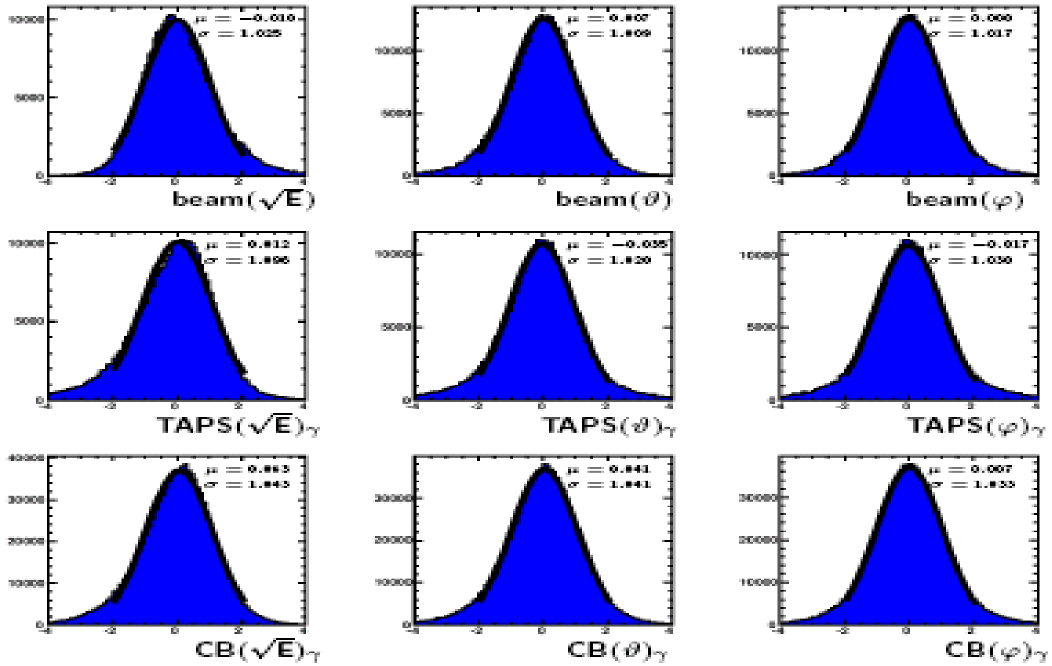
$CI_{\pi\pi} > 10\%$
$CI_{\pi\pi} > CI_{\pi\eta}$
Compatibility with reconstruction



561,443 events used for determination of polarization observables (E_γ = 970 – 1650 MeV)

After cuts: background contamination < 1%

Pulls



$$pull_i = \frac{\delta y_i}{\sqrt{\sigma_i^2 - \sigma_i'^2}}$$

The data

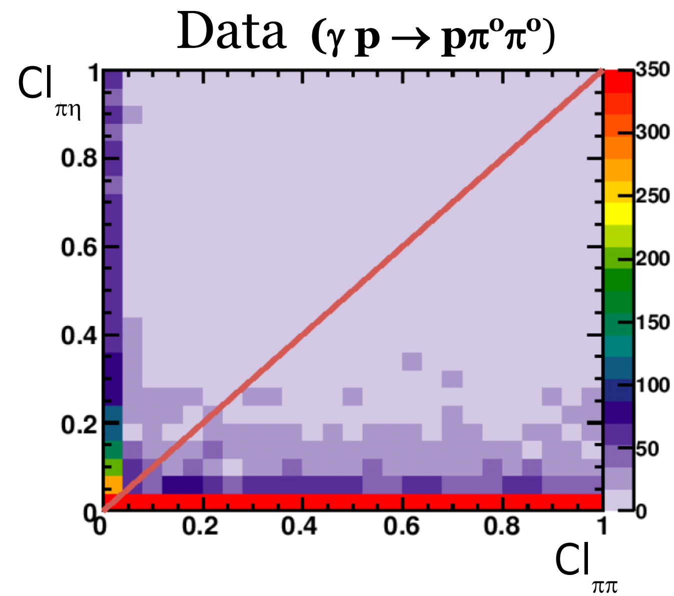
Application of the kinematic fit:

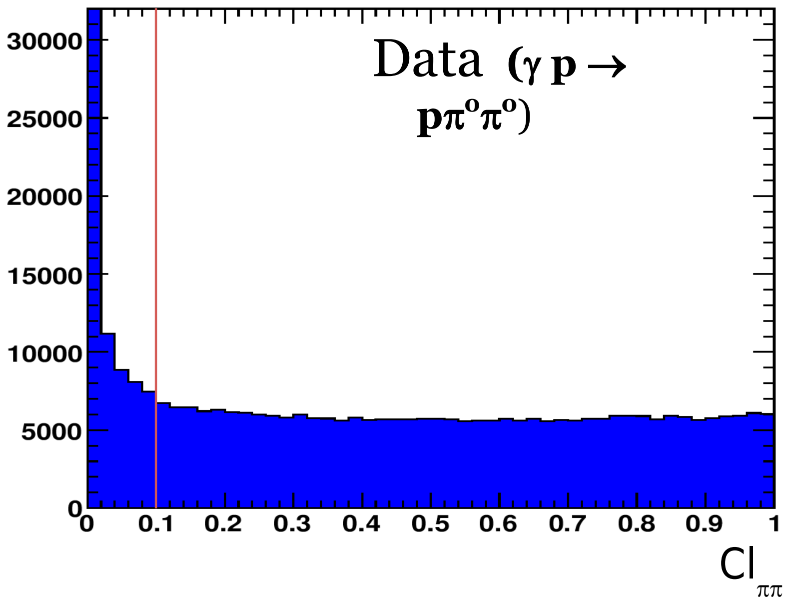
Combination with best Cl selected

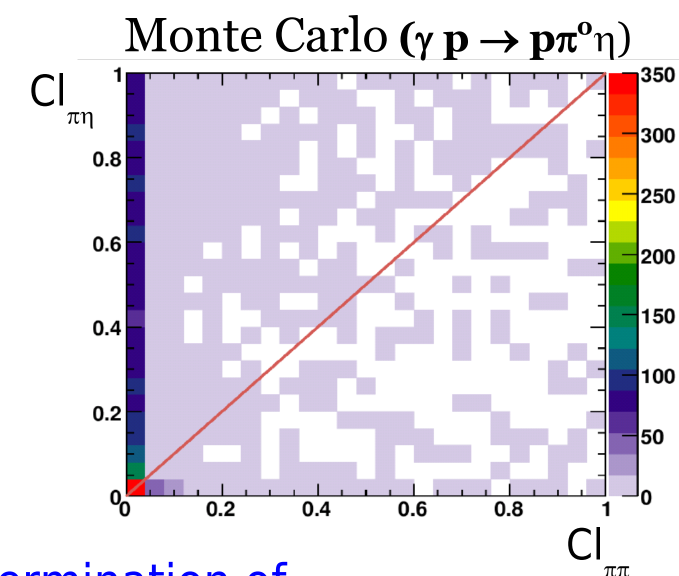
$CI_{\pi\pi} > 10\%$

$CI_{\pi\pi} > CI_{\pi\eta}$

Compatibility with reconstruction

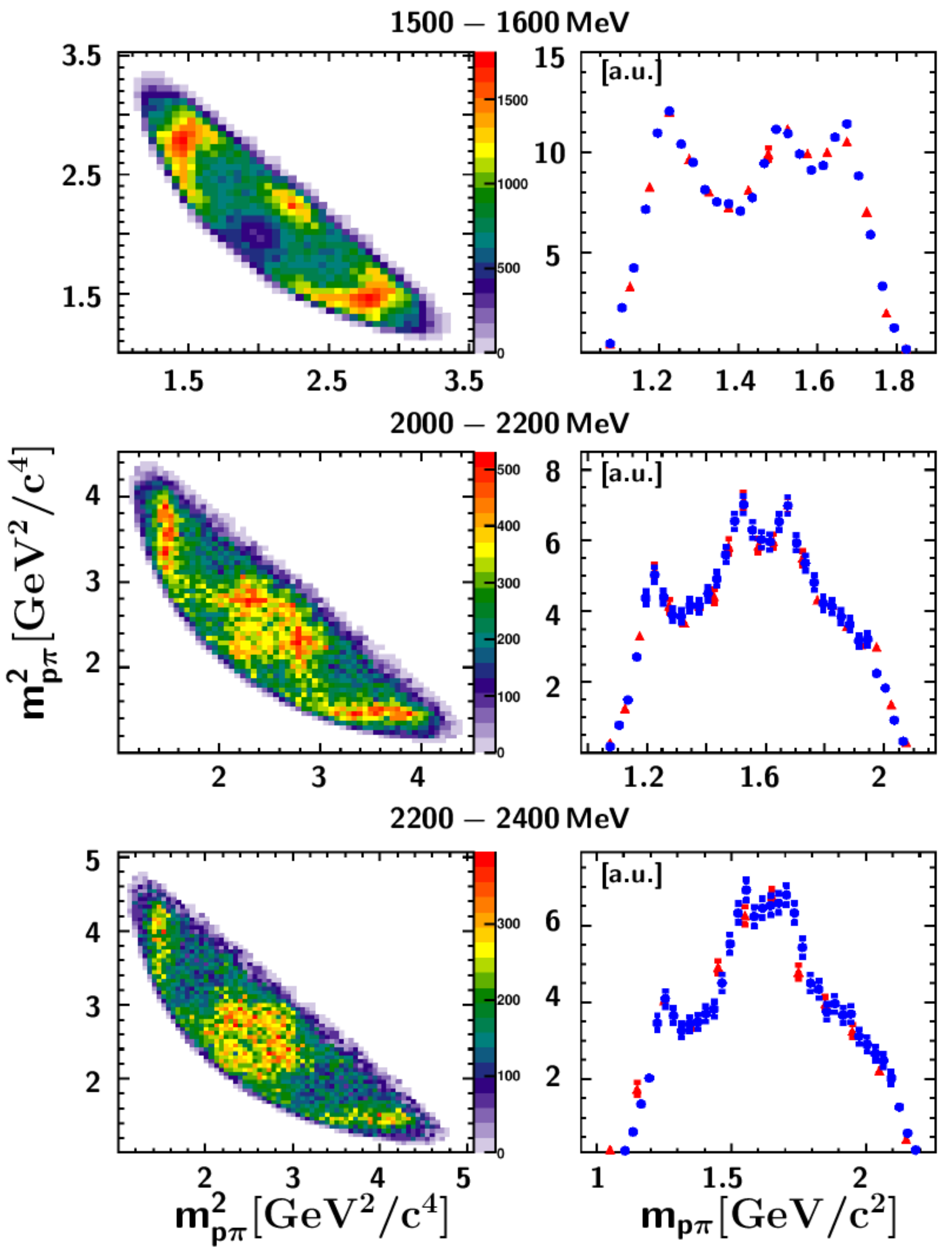


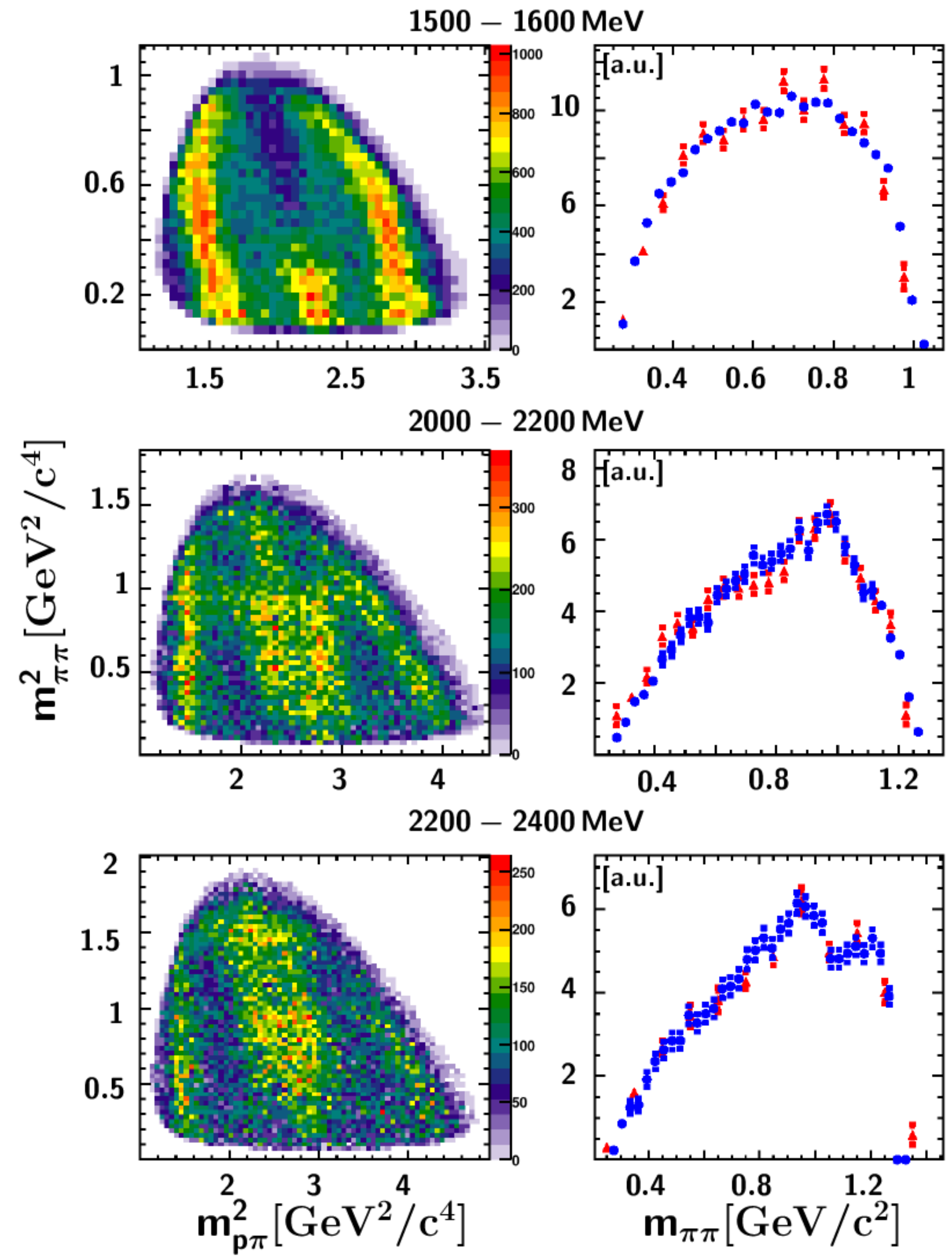




561,443 events used for determination of polarization observables (E_γ = 970 – 1650 MeV)

After cuts: background contamination < 1%


1500 — 1600 MeV
2000 — 2200 MeV
2200 — 2400 MeV
[a.u.]
$m^2_{p\pi}$ [GeV^2/c^4]
$m_{p\pi}$ [GeV/c^2]

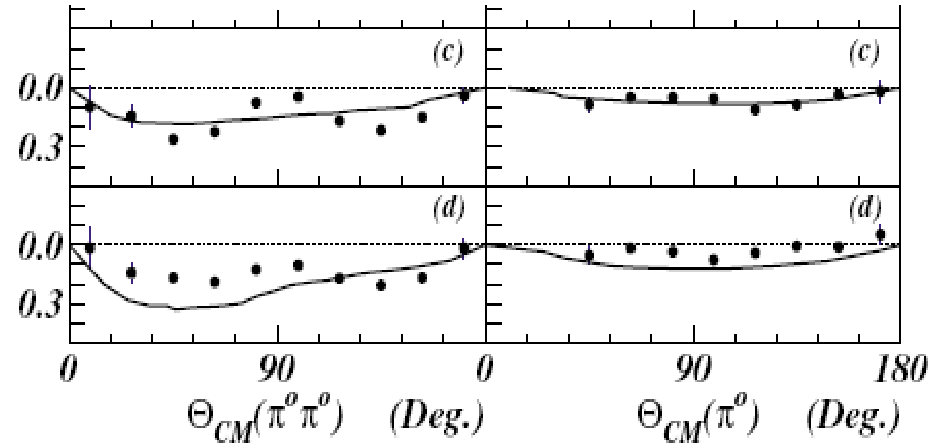

1500 — 1600 MeV
2000 — 2200 MeV
2200 — 2400 MeV
[a.u.]
$m^2_{\pi\pi}$ [GeV^2/c^4]
$m^2_{p\pi}$ [GeV^2/c^4]
$m_{\pi\pi}$ [GeV/c^2]

Compatibility of the data sets

Different phase space coverage

Different efficiencies

GRAAL coverage ~ 70% of events retained by CBELSA/TAPS



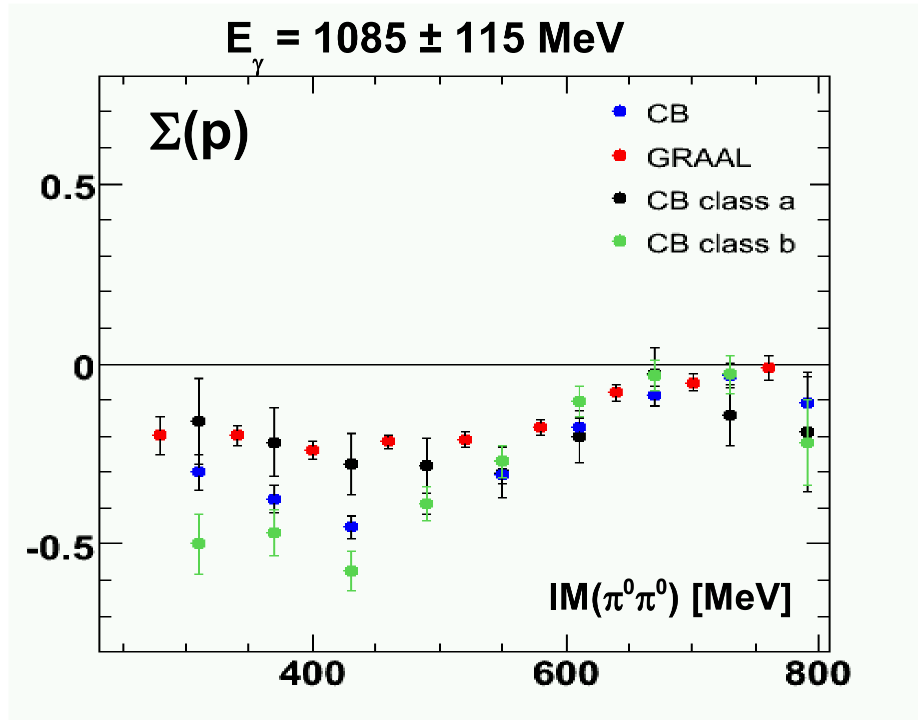
Assafiri, et al., Phys. Rev. Lett. 90 (2003) 222001.

Trying to repeat the acceptance of GRAAL experiment approximately:

a) **4 γ (25<Θ<155)**

b) 3 γ (25<Θ<155) +

γ (Θ<25)

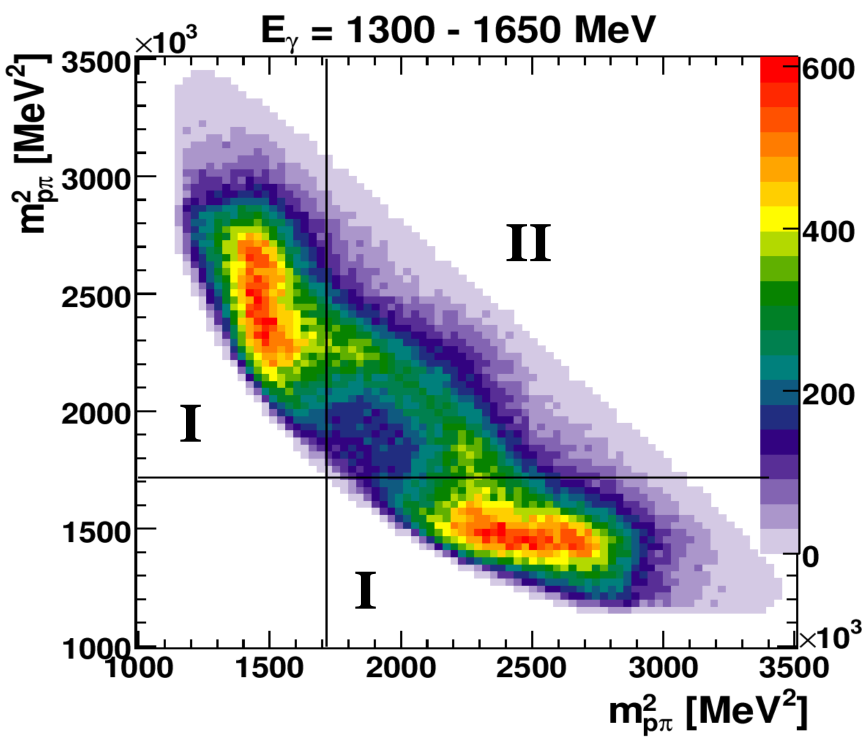


Sensitivity to resonance decays

Separation of $D_{13}(1520)$and $\Delta(1232)$ regions:

$\mathbf{m_{p\pi}} <$ $\mathbf{m_{\Delta} + 2/3\ \Gamma_{\Delta}}$ **(I)**

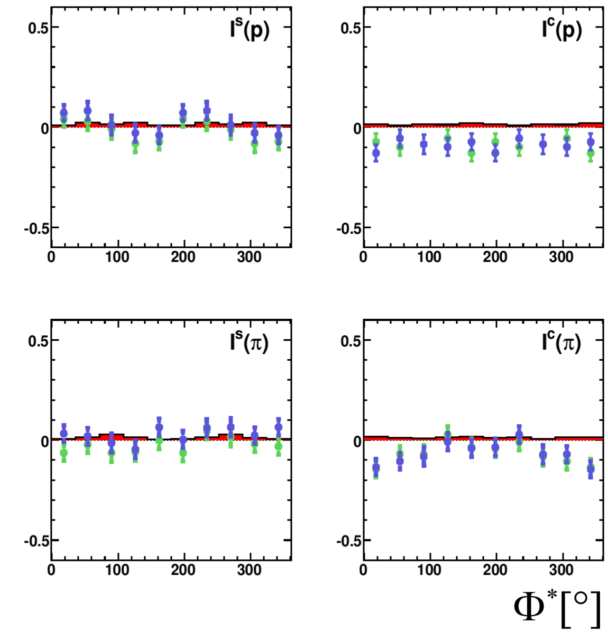
$\mathbf{m_{p\pi}} >$ $\mathbf{m_{\Delta} + 2/3\ \Gamma_{\Delta}}$ **(II)**



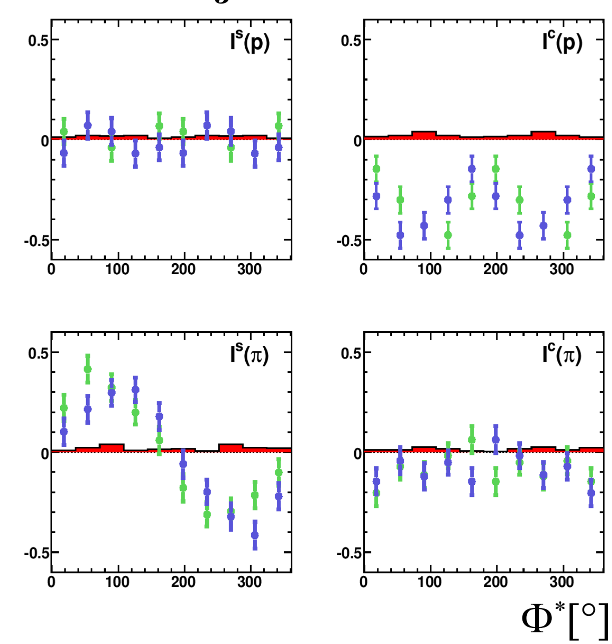
Very different patterns observed

BnGa PWA: N(1900) and N(1975) both being 3/2+ states mostly contribute to the $D_{13}(1520)\pi$ decay in the mass range 1800-2000 MeV

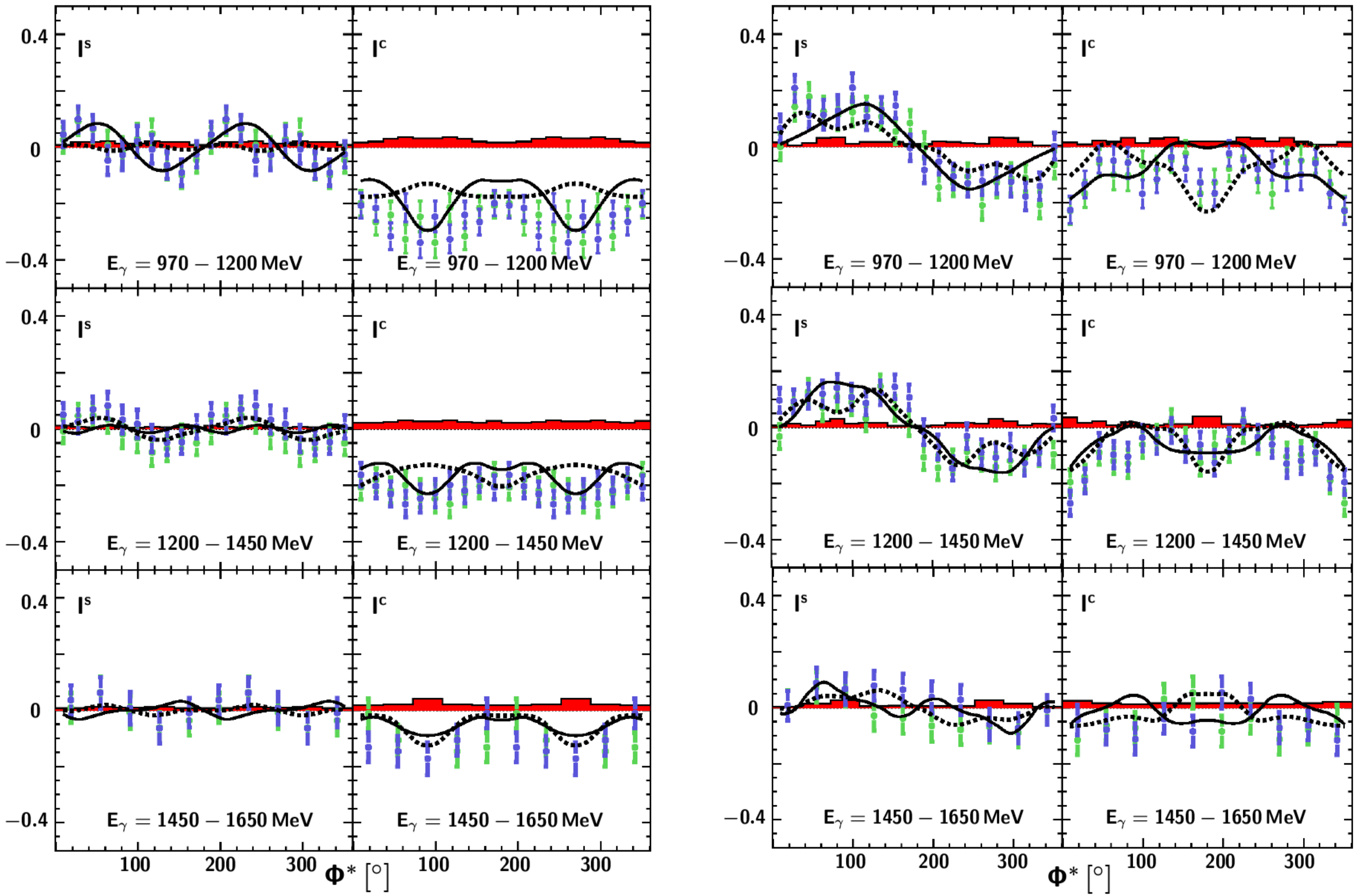
Δ(1232) region



D_{13}(1520) region



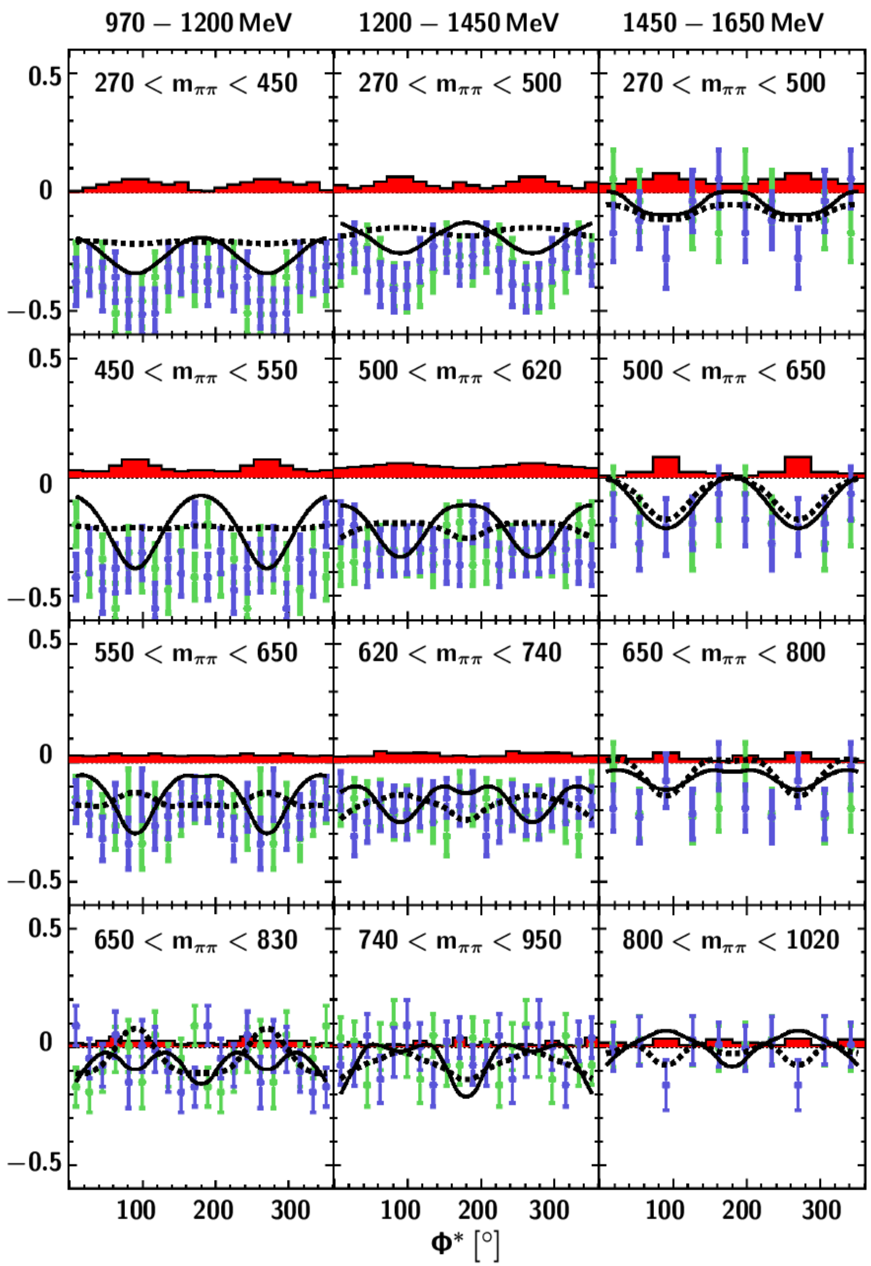
Proton recoiling **Pion recoiling**

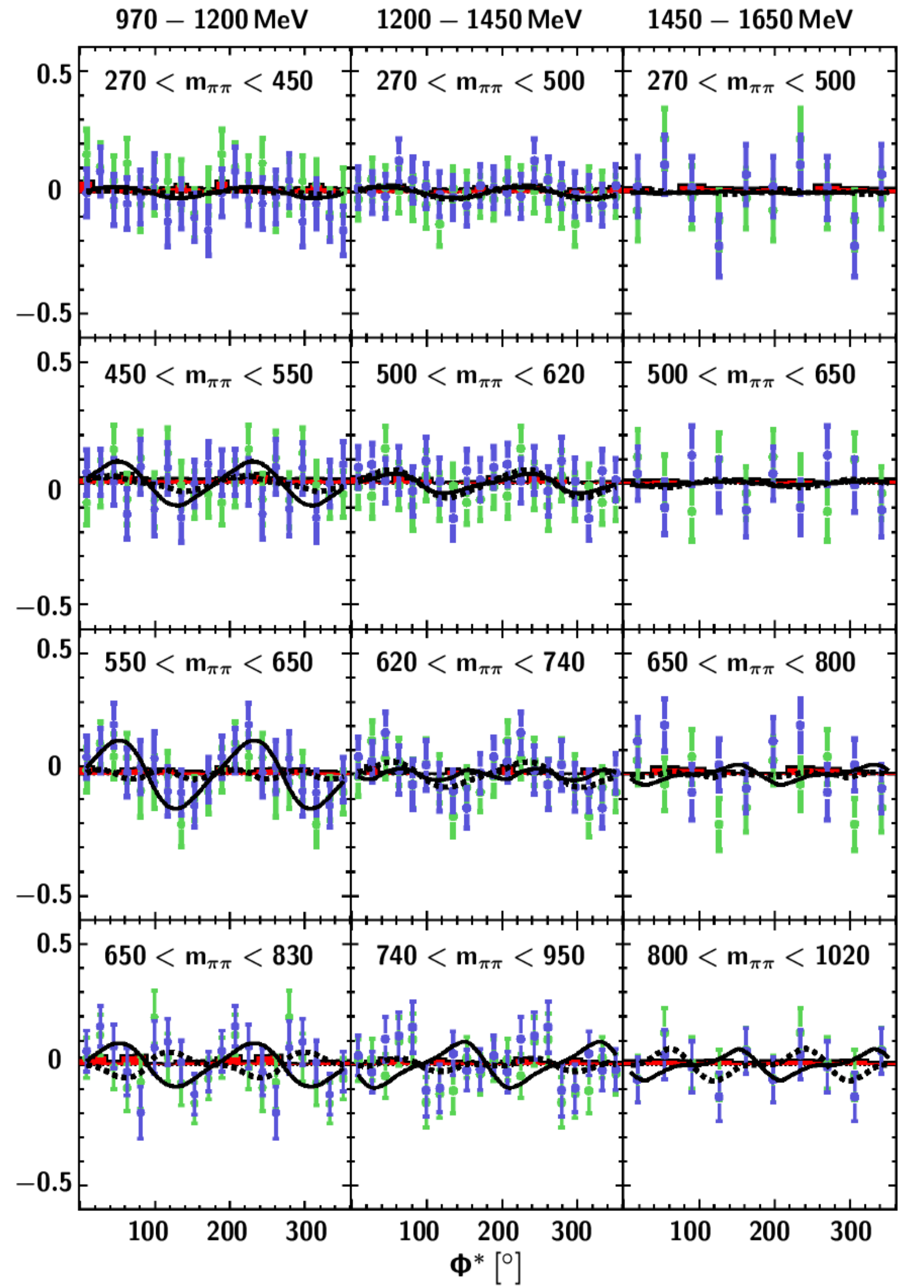


$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$ and $I^c(\Phi^*) = I^c(2\pi - \Phi^*)$

Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$

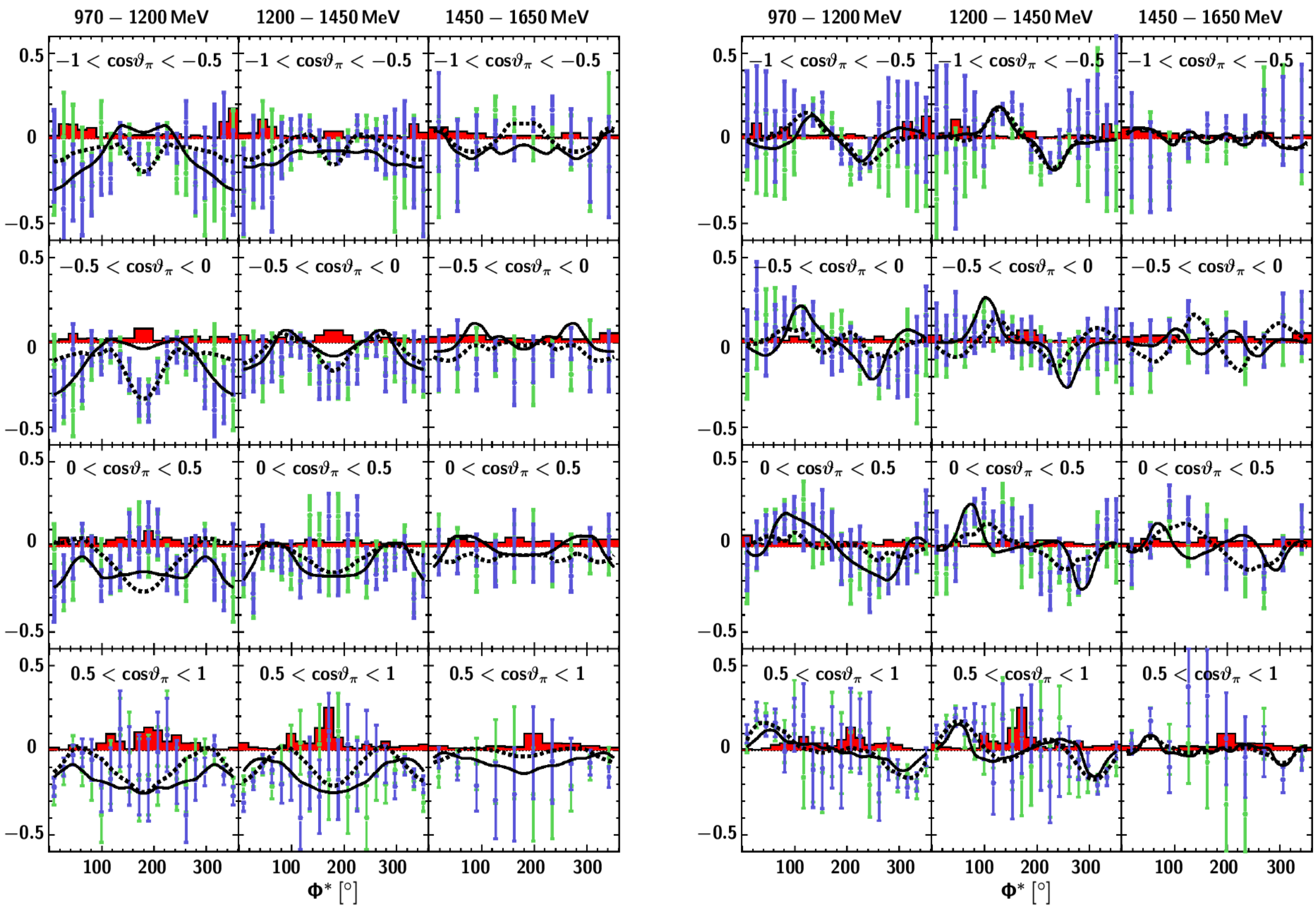




$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$ and $I^c(\Phi^*) = I^c(2\pi - \Phi^*)$

Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$

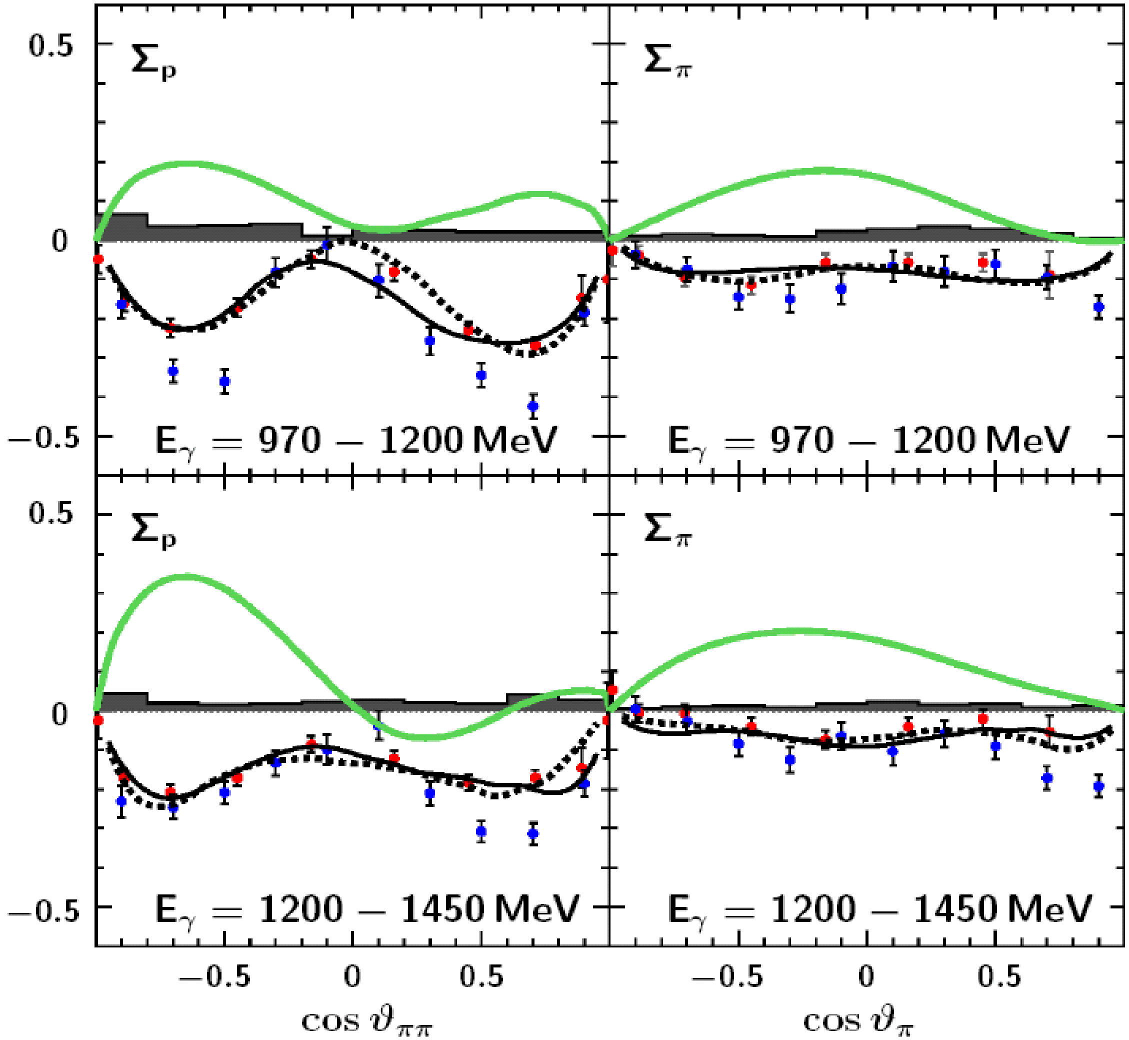


$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$ and $I^c(\Phi^*) = I^c(2\pi - \Phi^*)$

Solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

Dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$

Comparison with models



BnGa PWA: solid: $D_{33}(1700) \rightarrow \Delta\pi_{(D\text{-wave})}$ dominant

BnGa PWA: dashed: $D_{33}(1700) \rightarrow \Delta\pi_{(S\text{-wave})}$ dominant

Green: calculation of the Fix model

Different resonance contributions:

BnGa PWA:

Significant contributions of

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

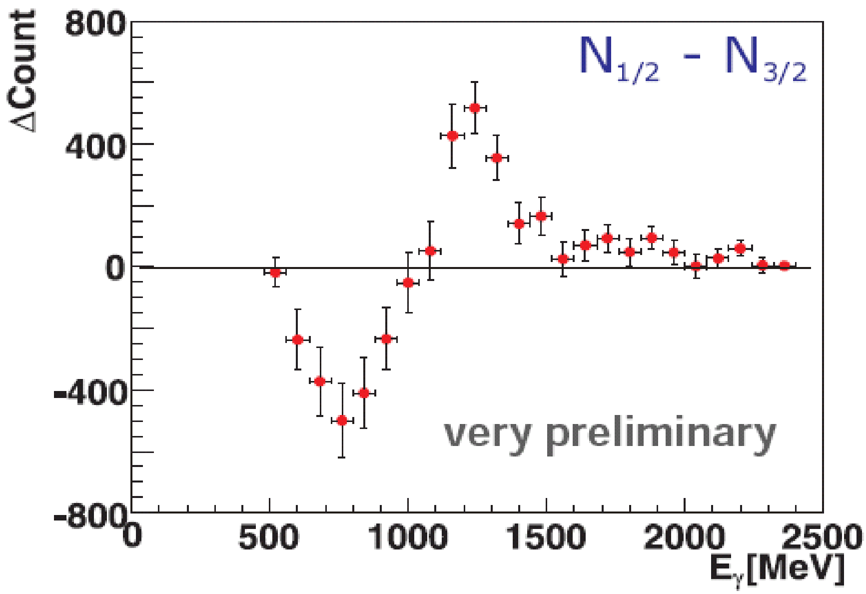
Fix model:

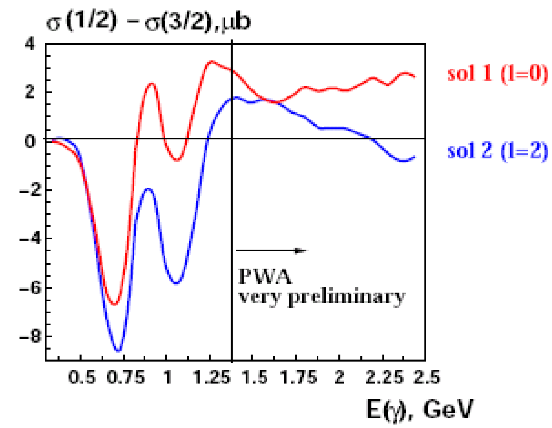
Significant contributions of

$D_{13}(1520)$, $P_{11}(1440)$, $F_{15}(1680)$

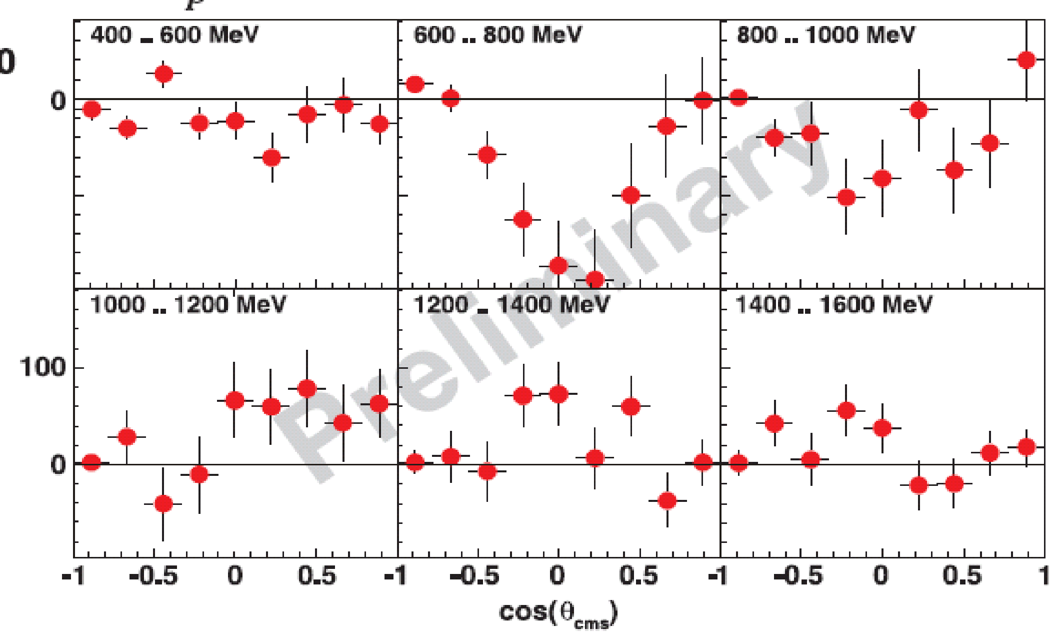
Outlook

CBELSA/TAPS data $\vec{\gamma}\vec{p} \longrightarrow p\pi^0\pi^0$ (D.Piontek, Bonn)





cos θ_p-distributions:



Count rate differences plotted

first look into differential distributions (very preliminary)