Open questions in baryon spectroscopy

Hadron 2001

Protvino, Russia

Volker Credé

- Introduction
- Experimental spectrum of N and Δ resonances
- Theoretical results of different models (in respect of)
  - Missing resonances
  - Peculiar characteristics of the Δ spectrum
  - Parity doubling
- The Crystal Barrel Experiment at ELSA in Bonn
  - Experimental setup and general conception
  - First very preliminary results
    - $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\pi^0$
    - $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\eta$
- Summary and outlook

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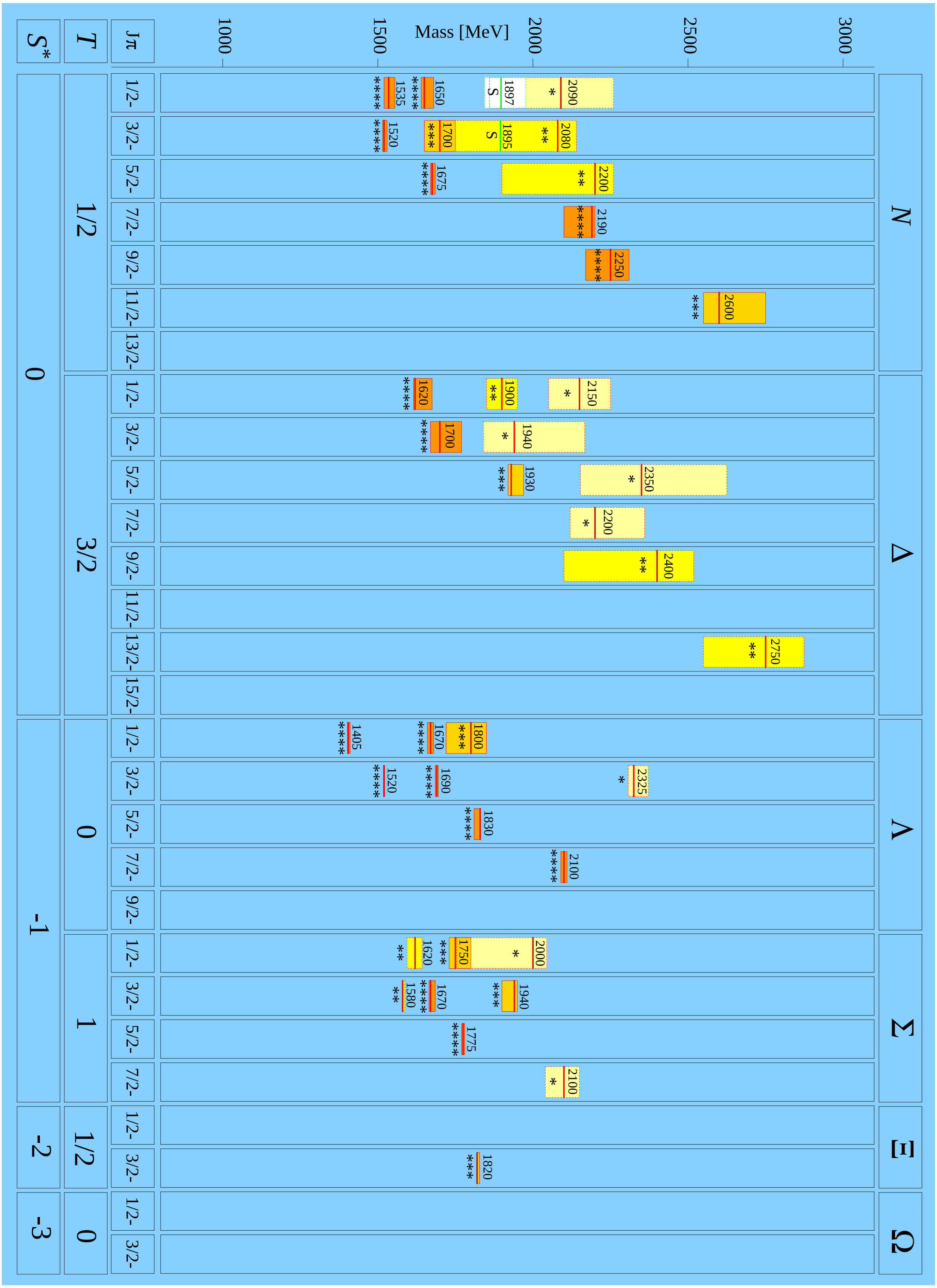
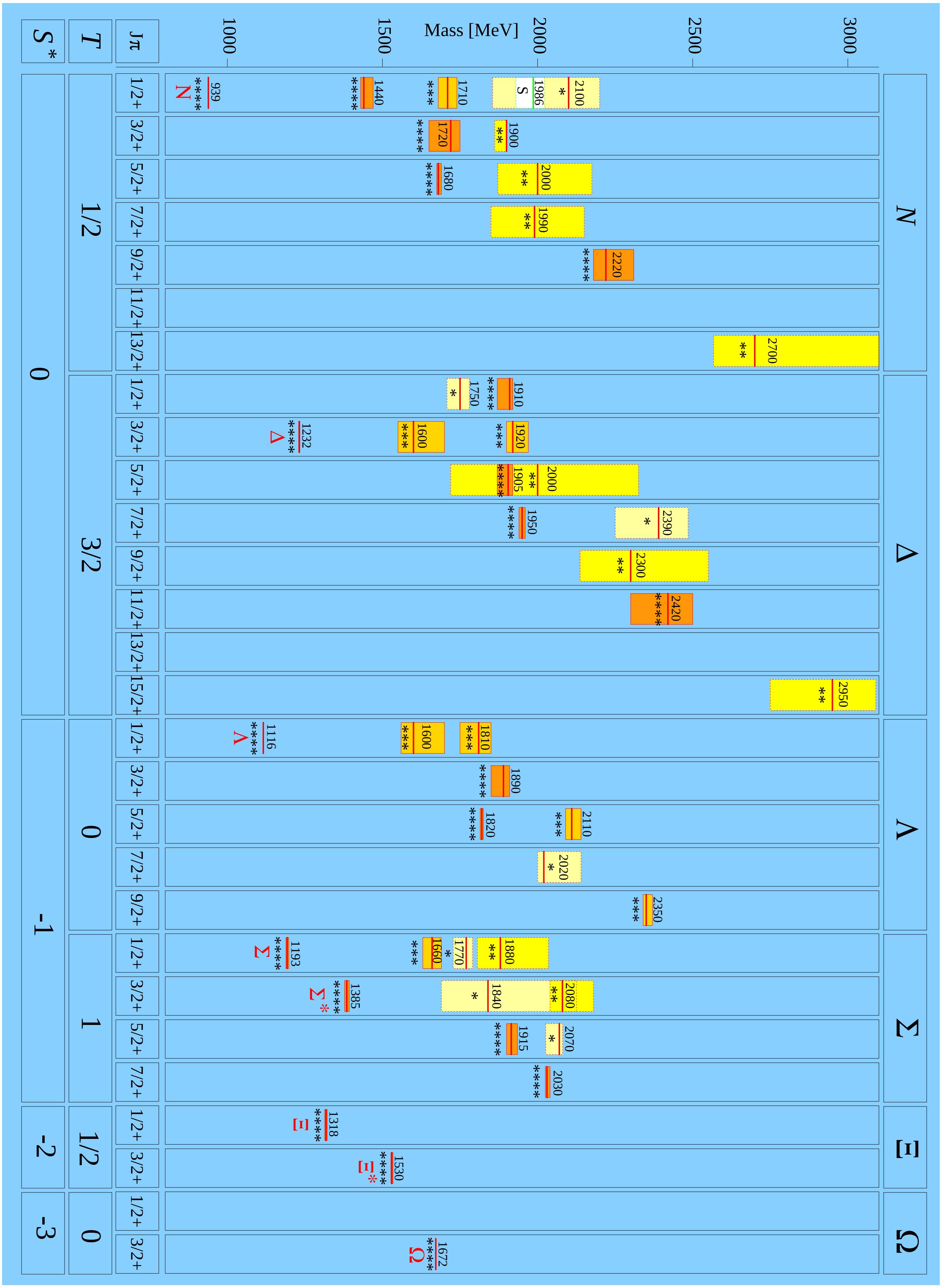


Mass [MeV]
1000
1500
2000
2500
3000
Jπ
T
S*
N
Δ
Λ
Σ
Ξ
Ω


Mass [MeV]
1000
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Σ
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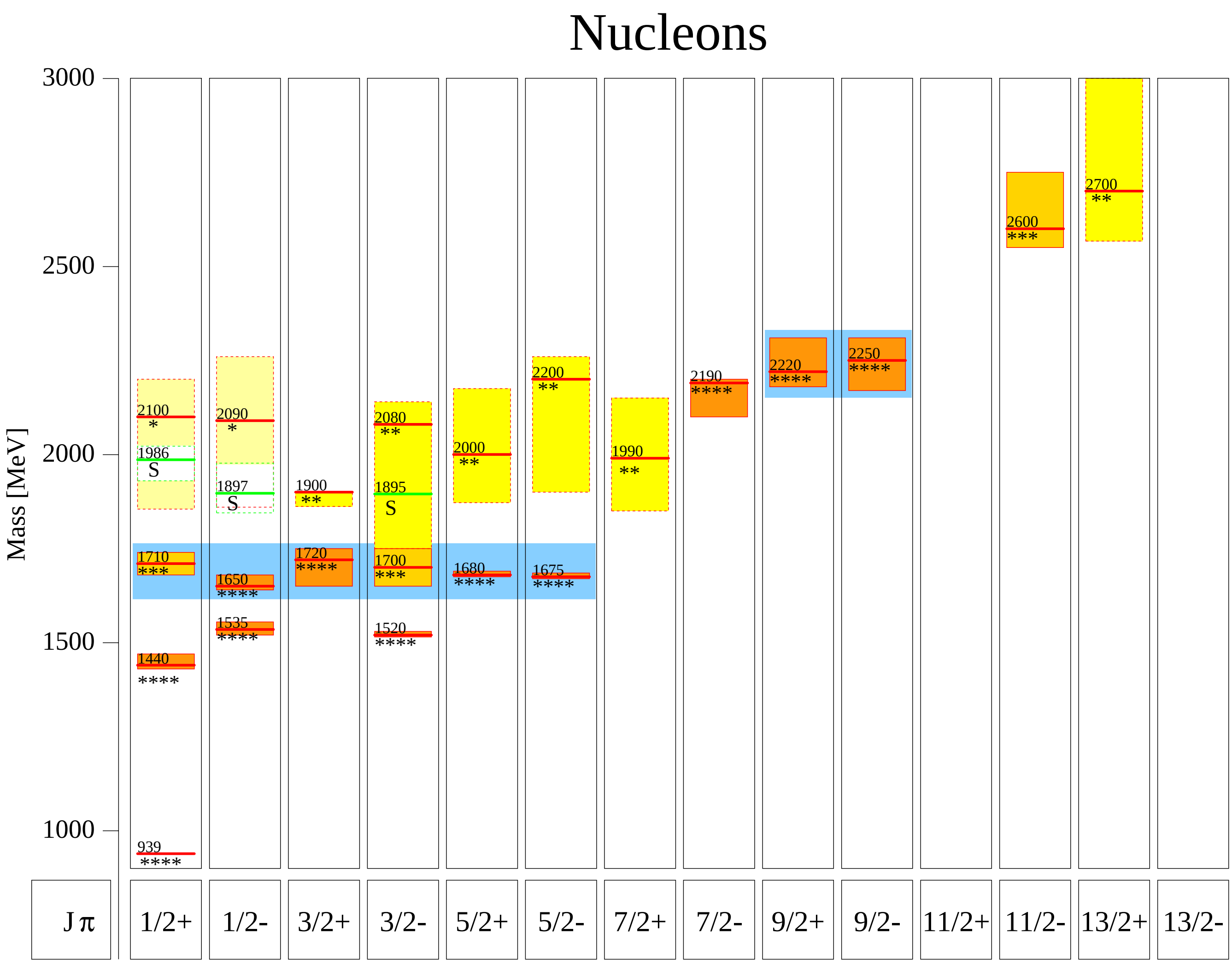
Ω

Characteristics of the experimental spectrum

- Linear Regge trajectories
  → linear confinement potential
- Hyperfine structure (N-Δ mass splitting)
  → spin-dependent mass splittings
  a) gluon-exchange
  b) instanton-induced interaction
- Parity doublets



Theoretical models and results

First approach

- Simple Quark-Oscillator Model
  → correct level ordering

Current works

- Non-relativistic quark model including one-pion exchange (Gloszman and Riska)
- *relativized* quark model (Capstick and Roberts)

→ Δ-Regge trajectories (✔)
however: N-Regge trajectories not correct

→ Wrong spin-orbit couplings

→ No explanation for parity doublets

- Relativistic quark model with instanton-induced forces (Kretschmer, Löring, Metsch, Petry)

→ Acceptable Regge trajectories

→ Natural explanation for parity doublets

Many problems still unsolved

→ Missing resonances and Δ-resonance spectrum

→ Decay properties of resonances

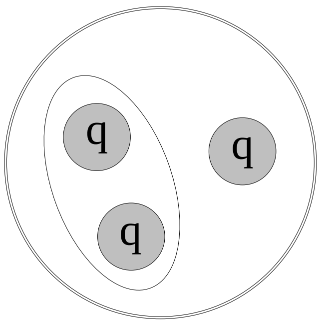
General Physical Motivation

⇒ Search for missing resonances

Quark Model: more baryons predicted than observed

Possible solutions:

a) Baryons have a quark-diquark structure:



one of the internal degrees of freedom is frozen

b) They have not been observed up to now

Nearly all existing data result from πN-scattering experiments

⇒ If the missing resonances do not couple to Nπ, they would not have been discovered!!
(supported by theory)

Conception of the Experiment

- Crystal Barrel Detector
  $\approx$ 4π detector for photons
- Scintillating Fibre Detector
  detection of charged particles leaving the target
- Possible extensions in forward direction
  - Electromagnetic Spectrometer
  - Time of Flight Detector
  - TAPS
  - Lead-Glas-Detector

- Baryon Spectroscopy
- Measurement of threshold cross sections of neutral mesons

$\Rightarrow$ Photo- and electroproduction experiments possible

Is there a symmetry in $B^* \to B\eta$ decays?

$\Rightarrow$ Observation:

N(1535)S_{11} has strong coupling to $N\eta$ $\to$ Why?

Quark model:

N(1535)S_{11} and N(1520)D_{13} are approximately mass degenerate $\to$ doublet of states with $s = \frac{1}{2}$

Quarks may also couple to $s = \frac{3}{2}$

$\Rightarrow$ 3 states corresponding to the observed resonances N(1650)S_{11}, N(1700)D_{13} and N(1675)D_{15}

$s = \frac{3}{2}$	N(1650)S_{11}	N(1700)D_{13}	N(1675)D_{15}
$s = \frac{1}{2}$	N(1535)S_{11}	N(1520)D_{13}	

$\hookrightarrow$ $N\eta$

Explanations:

- Two states S_{11} have appreciable mixing ($\approx 30°$)
  (N. Isgur and G. Karl, Phys. Lett. **72B** (1977) 109.)
- Phenomenological fit to baryon decays ($\approx 30°$)
- Coupled ΣK-$p\eta$ effect (Kaiser, Siegel and Weise)
  $\to$ no genuine 3-quark resonance required
- Amplitude analysis: (G. Hoehler)
  no pole is needed for N(1535)S_{11}
- Quark-diquark structure (Glozman and Riska)

K_α line of nucleon: N(1535)S_{11} or N(1650)S_{11} ?

Negative parity mesons and η decays:

$s = \frac{3}{2}$	N(1650)S_{11}	N(1700)D_{13}	N(1675)D_{15}
$s = \frac{1}{2}$	N(1535)S_{11}	N(1520)D_{13}	

$\hookrightarrow$ Nη $\hookrightarrow$ $\pi^0\pi^0$p ($\pi^0\pi^-$n)

$s = \frac{3}{2}$	Λ(1800)S_{01}	Λ(????)D_{03}	Λ(1830)D_{05}
$s = \frac{1}{2}$	Λ(1670)S_{01}	Λ(1690)D_{03}	

$\hookrightarrow$ $\Lambda\eta$ $\hookrightarrow$ $\pi^0\pi^0\Lambda$

$s = \frac{3}{2}$	Σ(1750)S_{01}	Σ(????)D_{03}	Σ(1775)D_{05}
$s = \frac{1}{2}$	Σ(1620)S_{01}	Σ(1670)D_{03}	

$\hookrightarrow$ $\Sigma\eta$ $\hookrightarrow$ $\pi^0\pi^0\Sigma^0$

- Octets Λ^* and Σ^* upgrades of N^* by 150 MeV
  $\Rightarrow$ Baryons favor SU(3)$_{\text{flavor}}$
- Spin flip required from states with $s = \frac{3}{2}$
  $\Rightarrow$ decay suppressed

$s = \frac{3}{2}$	Δ(1900)S_{31}	Δ(1940)D_{33}	Δ(1930)D_{35}
$s = \frac{1}{2}$	Δ(1620)S_{31}	Δ(1700)D_{33}	

$\hookrightarrow$ $\Delta\eta$? $\hookrightarrow$ $\pi^0\pi^0\Delta$?

The decay of the Δ resonances

Transitions between resonances and final states via transfer of the intrinsic parity of the η into orbital angular momentum between one pair of quarks and back:

$$(\uparrow\downarrow\uparrow) + \eta \quad \longleftrightarrow \quad (\uparrow\,\downarrow\Downarrow\uparrow)$$

$$(\Rightarrow \text{ represents } NS_{11}(1535) \text{ or } \Lambda(1670)S_{01})$$

Assumption for the Δ wave function:

$$(\uparrow\uparrow\uparrow) + \eta \quad \longleftrightarrow \quad (\uparrow\uparrow\,\Downarrow\uparrow)$$

$$(s = \tfrac{3}{2}, L = 1 \rightarrow J = \tfrac{3}{2})$$

$\Delta(1940)D_{33}$ should couple strongly to $\Delta\eta$

$\Downarrow$

Support of quark model

However, there is a conclusion based on bubble chamber data of the reaction $\pi^+ p \rightarrow \pi^+ p\eta$:

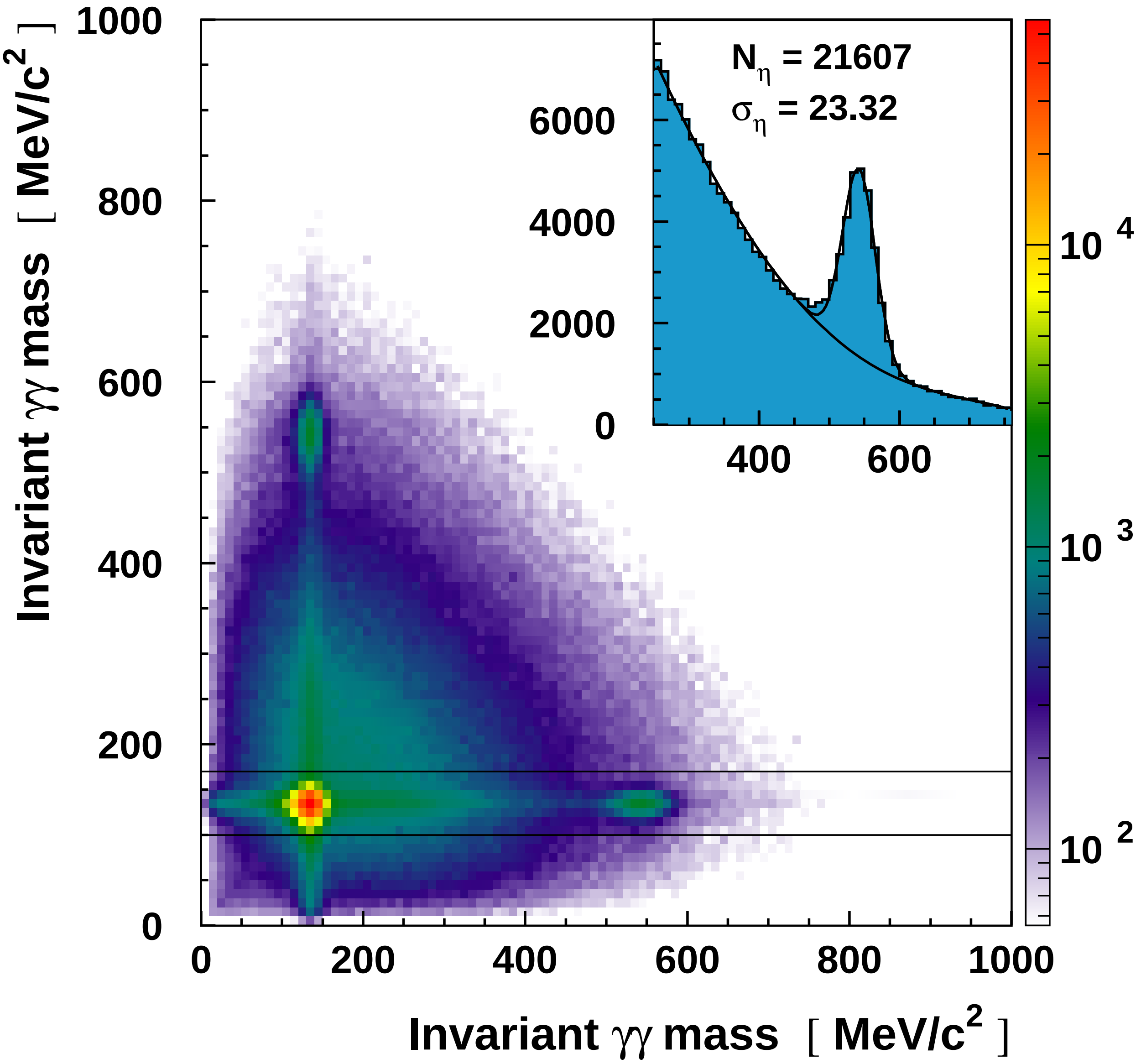
(B.M.K. Nefkens)

$$D_{33}(1700) \rightarrow P_{33}(1232) + \eta$$

$\gamma\,\mathbf{p} \rightarrow \mathbf{p}\,\pi^0\,\eta$

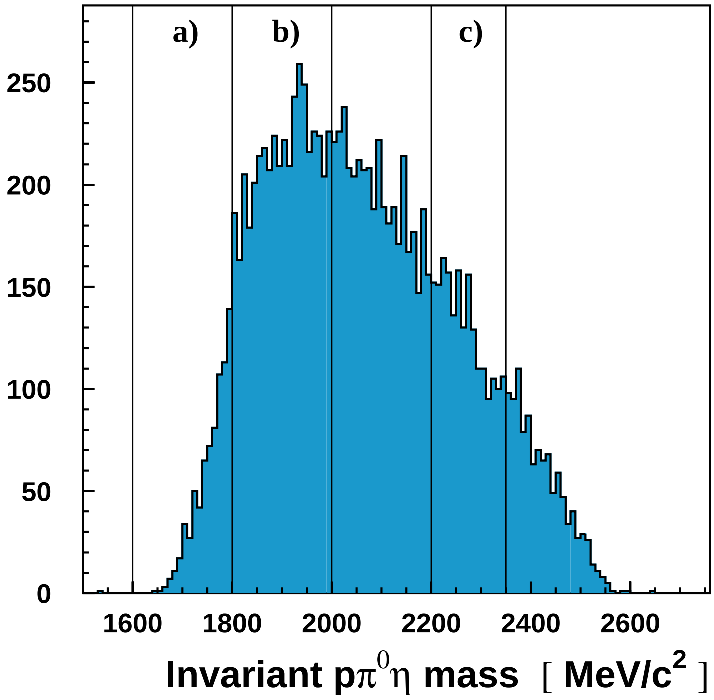
Data comprises about 60 % of 3.2 GeV data:

- $\approx$ 100 000 events of $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\pi^0$
- $\approx$ 20 000 events of $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\eta$

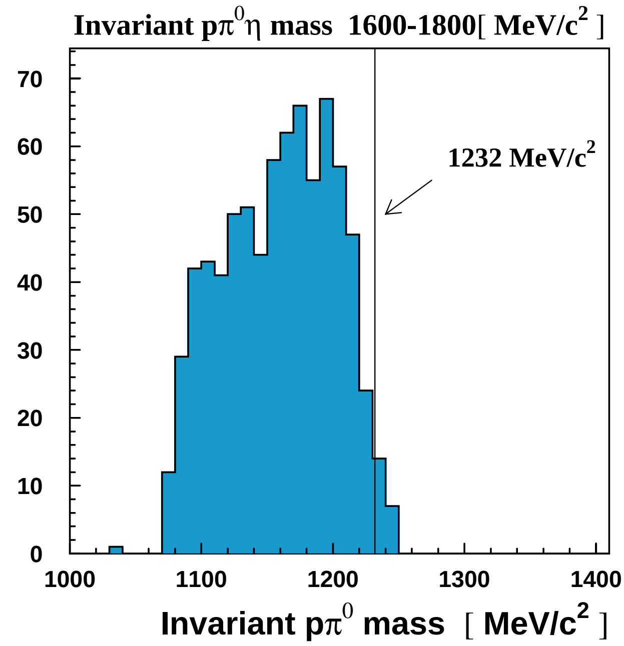


Clear evidence for $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\eta$

$\gamma \, \mathbf{p} \rightarrow \mathbf{p} \, \pi^0 \, \eta$

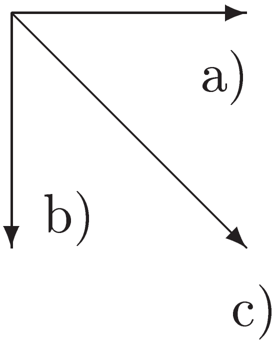


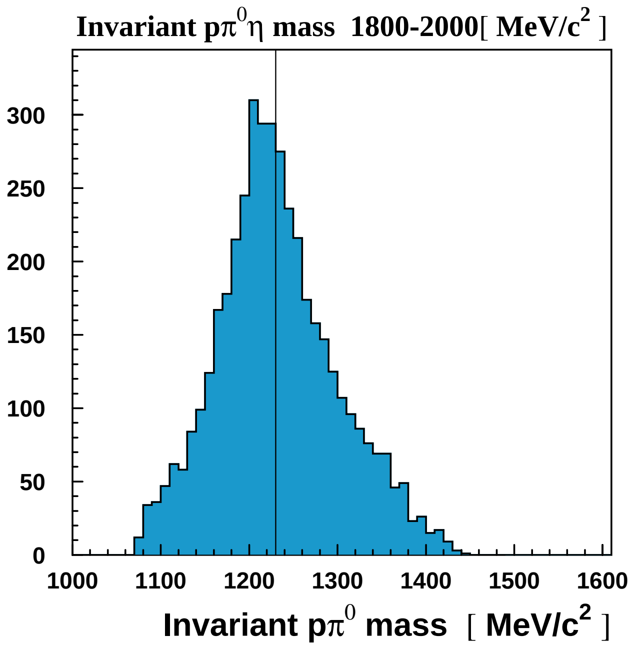
Very preliminary results!!

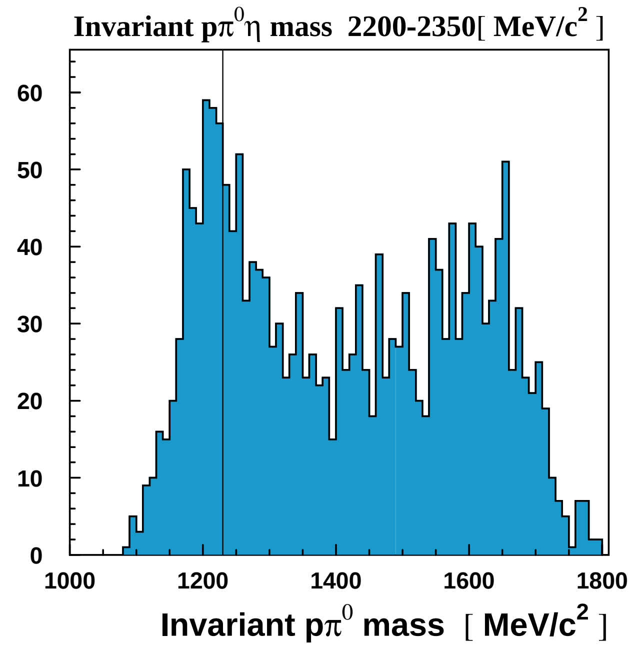


Indications for

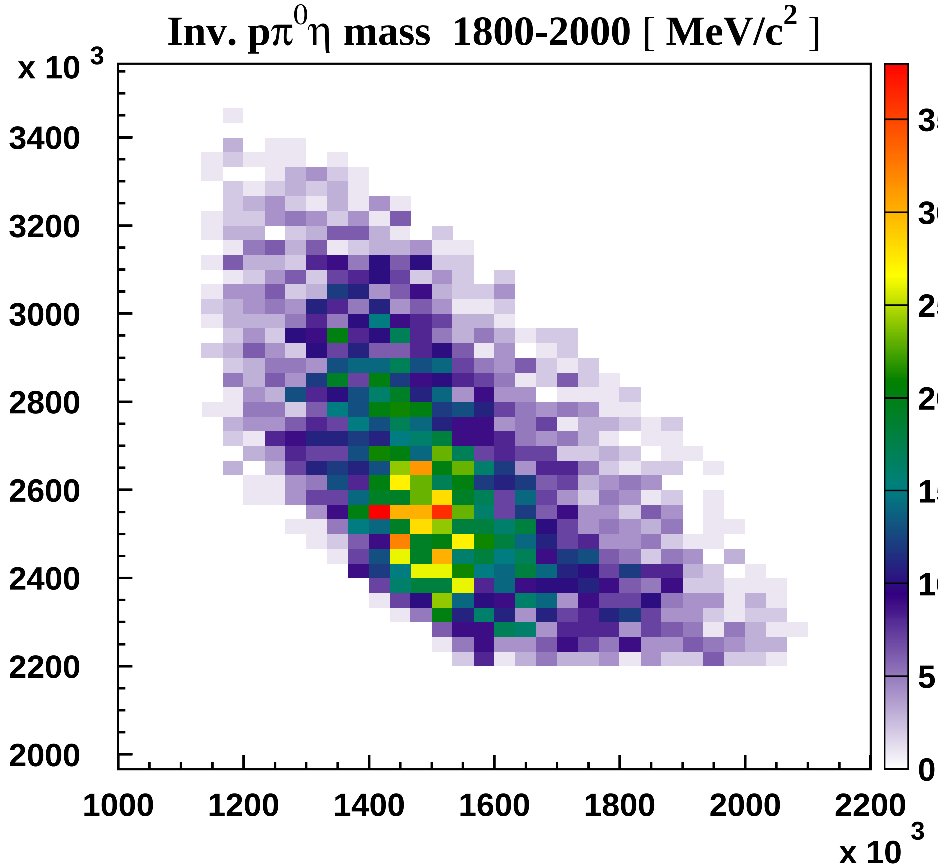
$\Delta(1940)D_{33} \rightarrow \Delta\eta$?

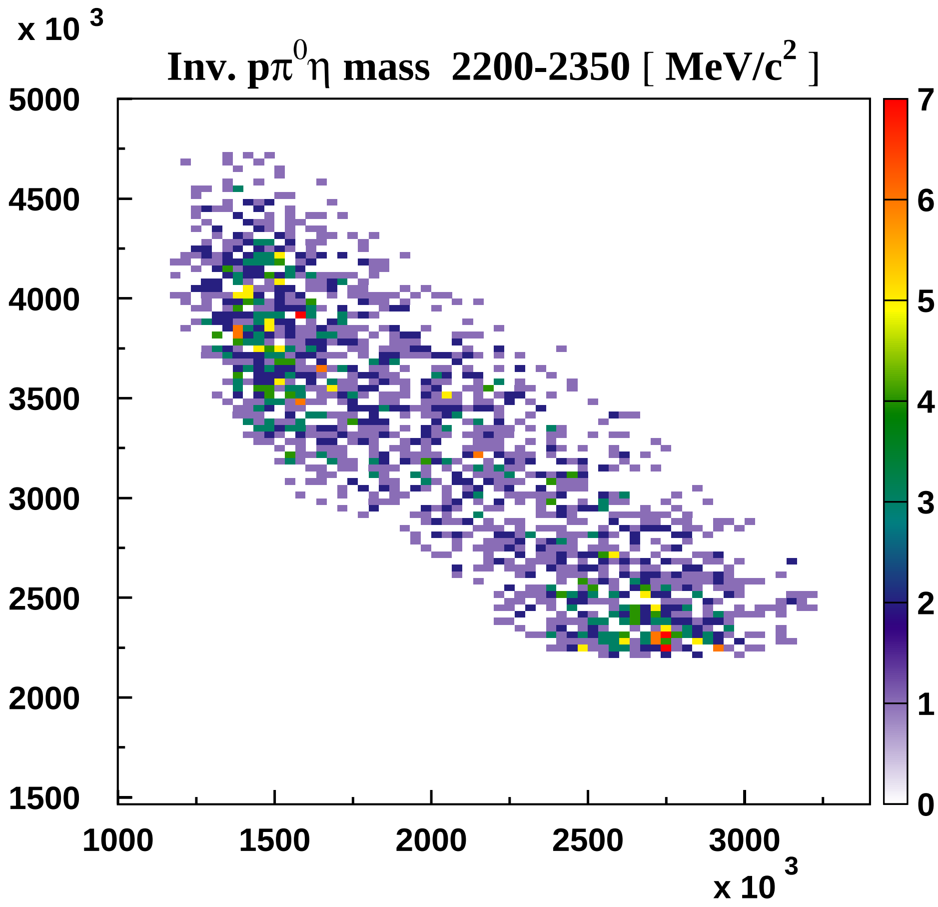




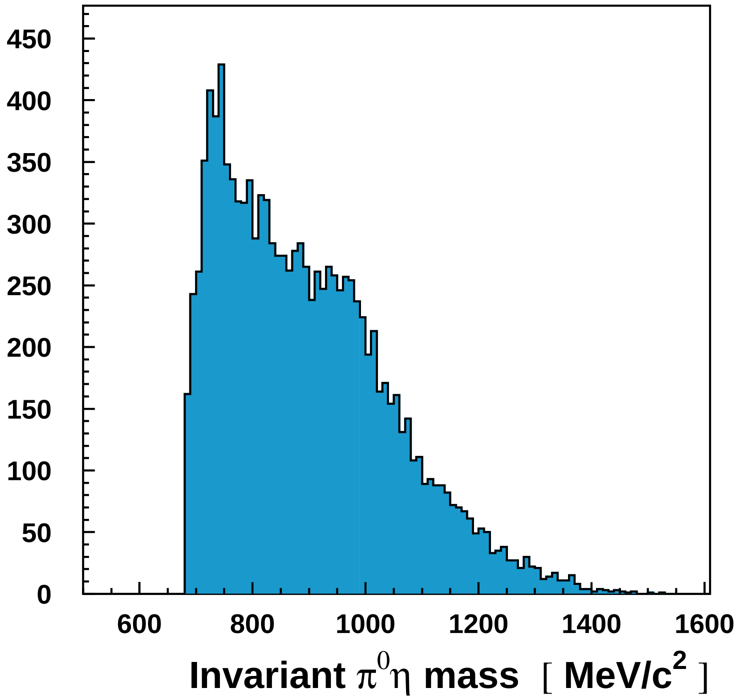


$\gamma\, p \;\rightarrow\; p\, \pi^0\, \eta$

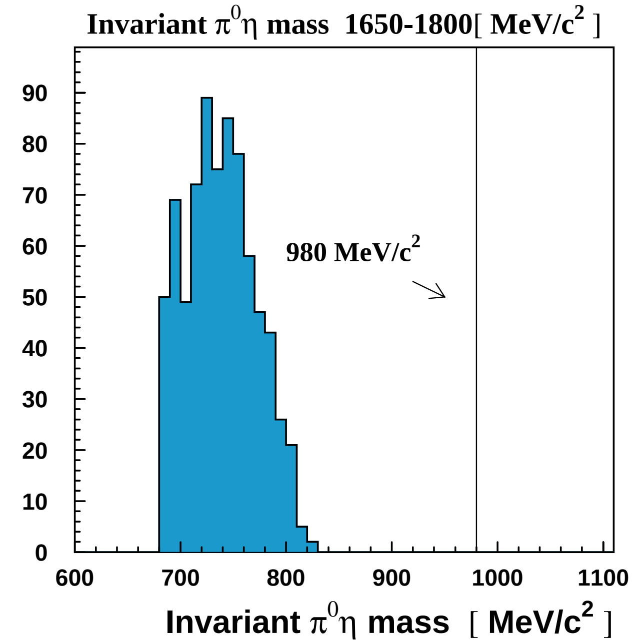




$\gamma\, \mathbf{p} \;\rightarrow\; \mathbf{p}\, \pi^0\, \eta$

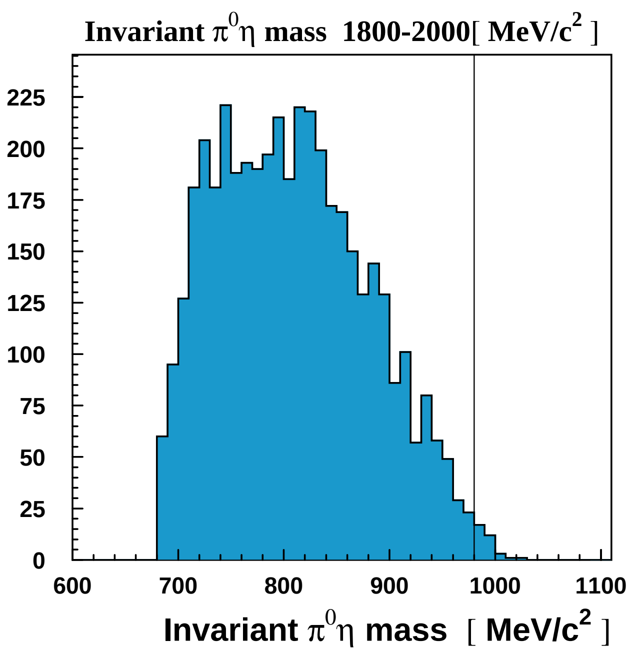


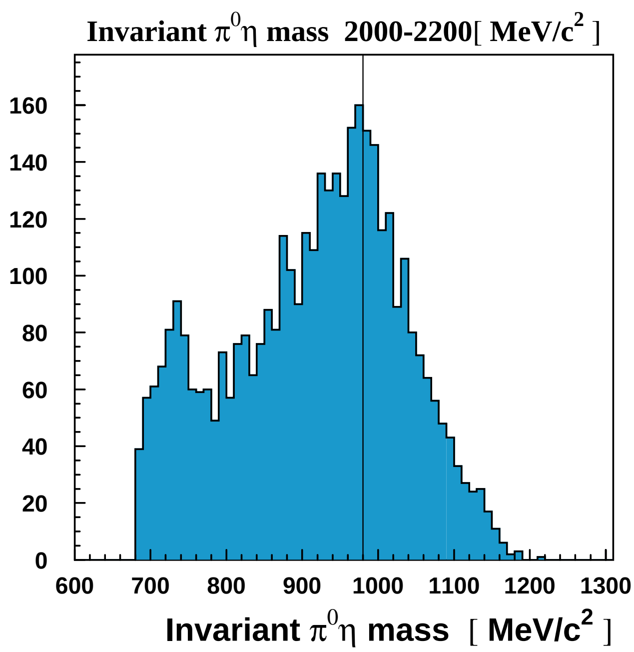
Very preliminary results!!



Clear Evidence for

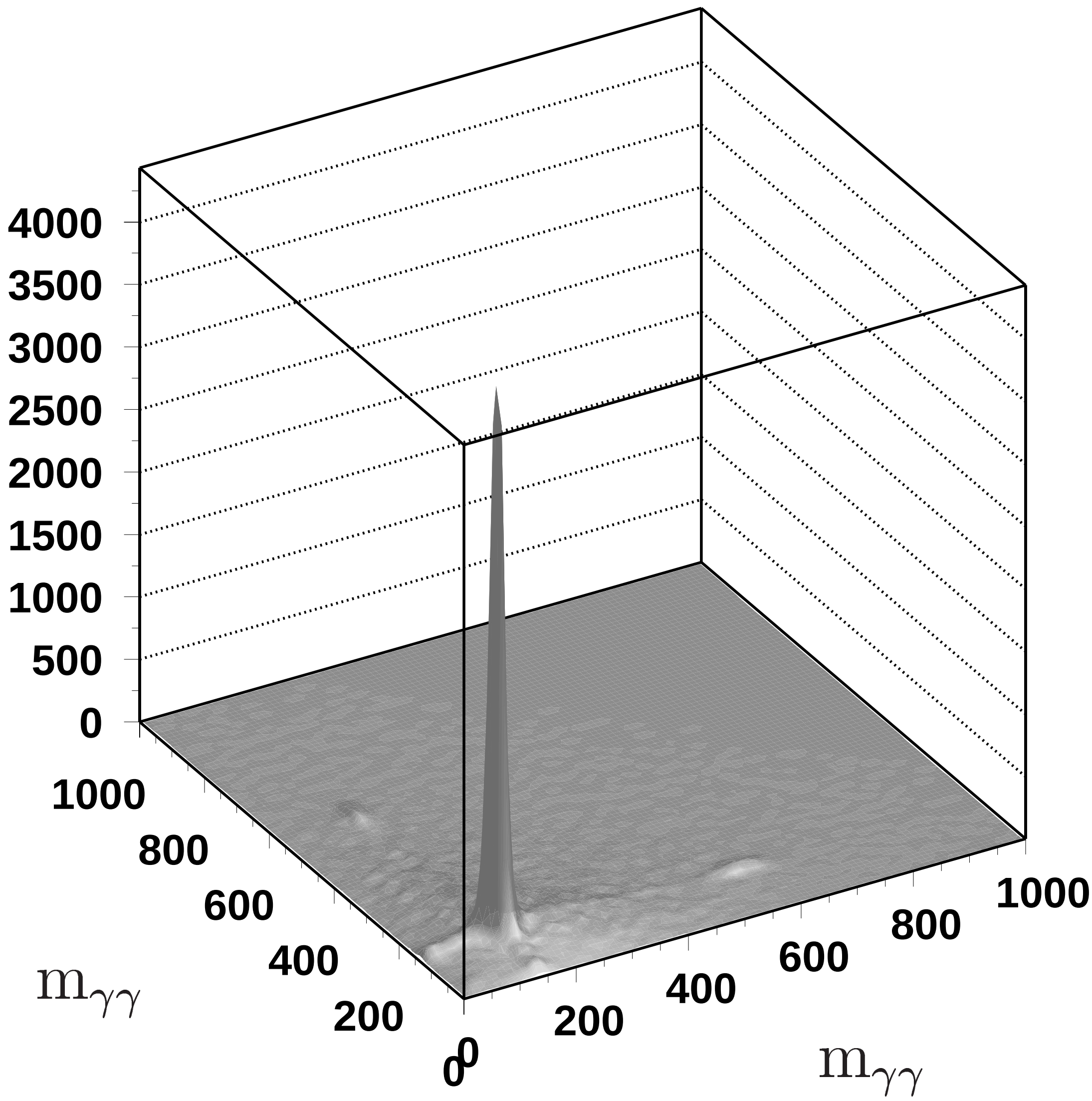
$a_0(980) \rightarrow \pi^0\eta$





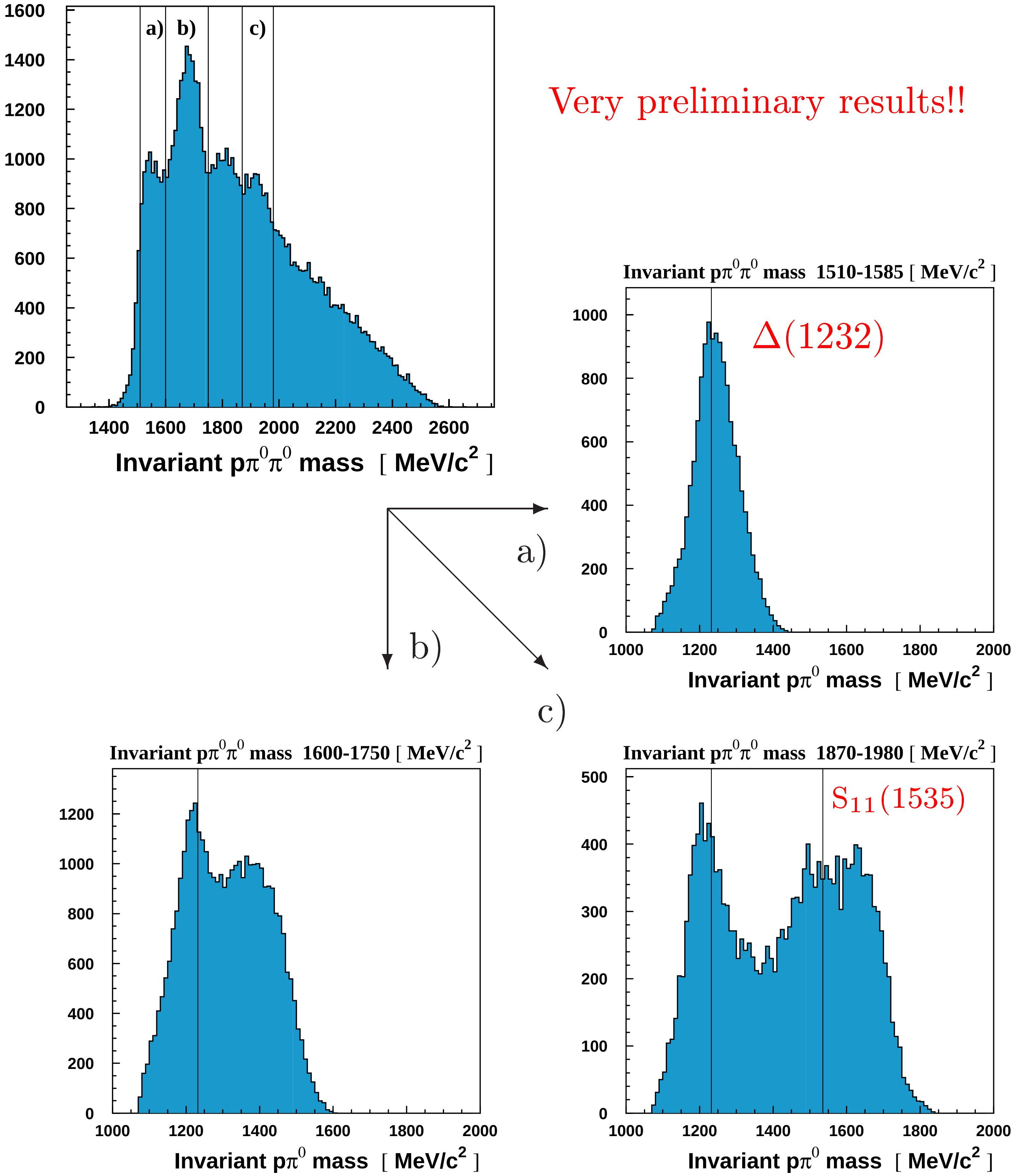
$\gamma\,\mathbf{p} \rightarrow \mathbf{p}\,\pi^0\,\pi^0$

- No flux normalisation ($\frac{1}{E}$)
- No efficiency correction ($\approx$ flat)
- No final tracking (*semi-final*)
  $\rightarrow$ preliminary results

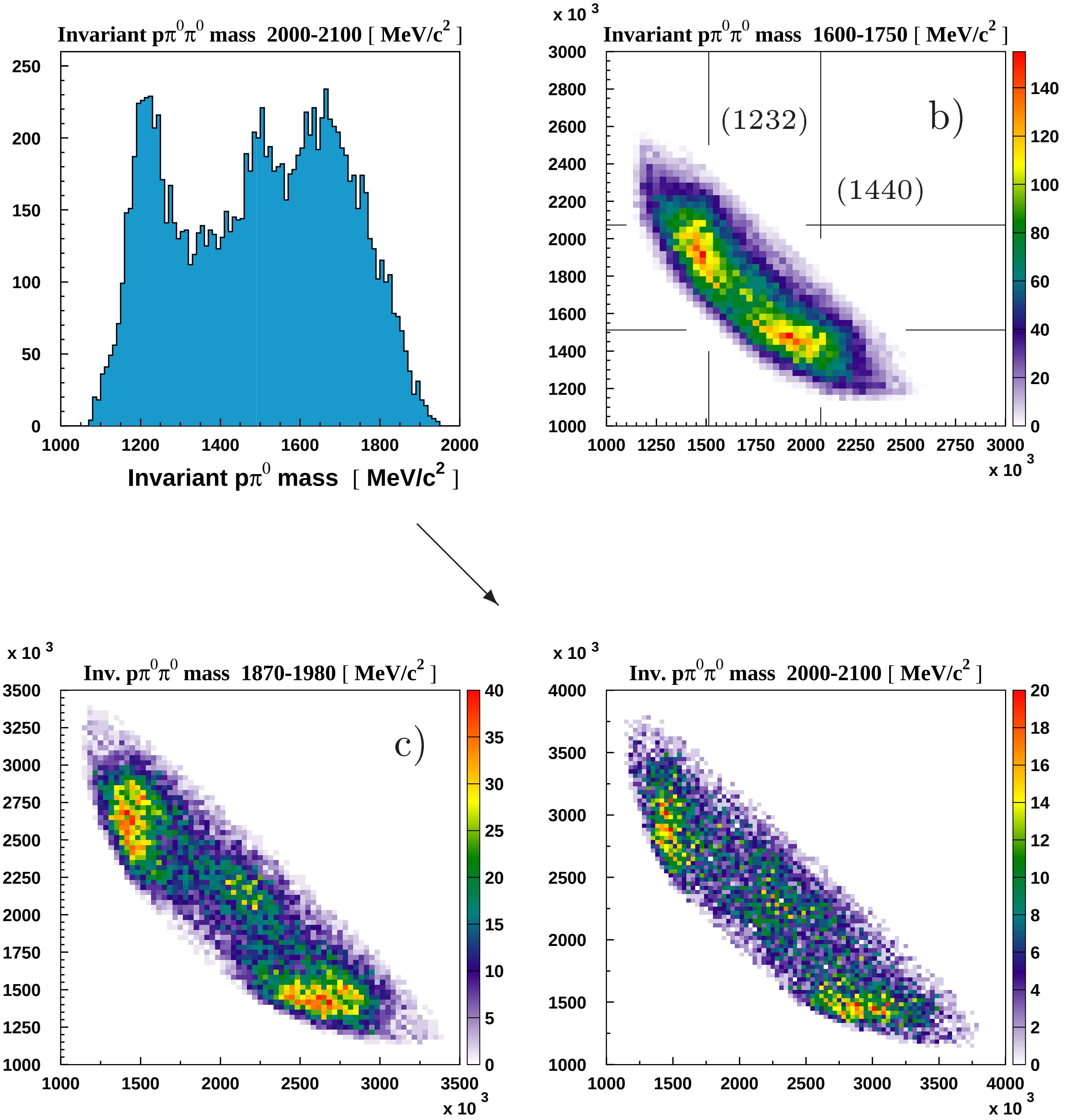


Clear evidence for $\gamma\,\mathrm{p} \rightarrow \mathrm{p}\,\pi^0\,\pi^0$

$\gamma \mathbf{p} \rightarrow \mathbf{p}\,\pi^0\,\pi^0$



$\gamma\, \mathbf{p} \;\rightarrow\; \mathbf{p}\, \pi^0\, \pi^0$



Summary

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

- 1. mass region (1510 - 1585) MeV
  $\rightarrow$ decays via $\Delta(1232)\pi^0$
- 2. mass region (1600 - 1750) MeV
  $\rightarrow$ decays via $\Delta(1232)\pi^0$
  $\rightarrow$ indications for decays via $X(1430)\pi^0$
- 3. mass region (1800 - 2100) MeV
  $\rightarrow$ decays via $\Delta(1232)\pi^0$
  $\rightarrow$ decays via $S_{11}(1535)$ and $X(m > 1600)$

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

- mass region (1800 - 2000) MeV
  $\rightarrow$ $\Delta(1232)\eta$ decays obvious ($\Delta(1940)D_{33}$?)
- mass region (2000 - 2200) MeV
  $\rightarrow$ clear evidence for $\Delta(1232)\eta$ decays
  $\rightarrow$ clear evidence for $S_{11}(1535)\pi^0$ decays
  $\rightarrow$ $pa_0(980)$ strong $\rightarrow$ structure of $a_0(980)$?
- mass region (2200 -) MeV
  $\rightarrow$ $X(m > 2200)$ decaying into $\Delta(1232)\eta$?

Summary and outlook

Good quality of data in various channels.

$\Downarrow$

Nucleon-resonance structures already visible

Missing resonances?

Further investigation of nucleon excitation spectrum!

- Improvement of reconstruction
- Determination of cross sections
- Partial wave analyses (PWA)