Excitation of N* resonances in α-p Scattering

Why study of N*'s with α-particles?

Quite unique way to study the scalar structure of excited nucleons !

What did we learn from this probe on the baryon structure?

1. Strong excitation of the $P_{11}(1440)$ observed
   From DWBA calculation of the cross section large fraction of the scalar sum rule found ⟹
   Interpretation as nucleon compression mode &
   Compressibility of the nucleon $K_N \sim 1.3$ GeV
   (from constituent quark model $K_N \sim 3$ GeV)

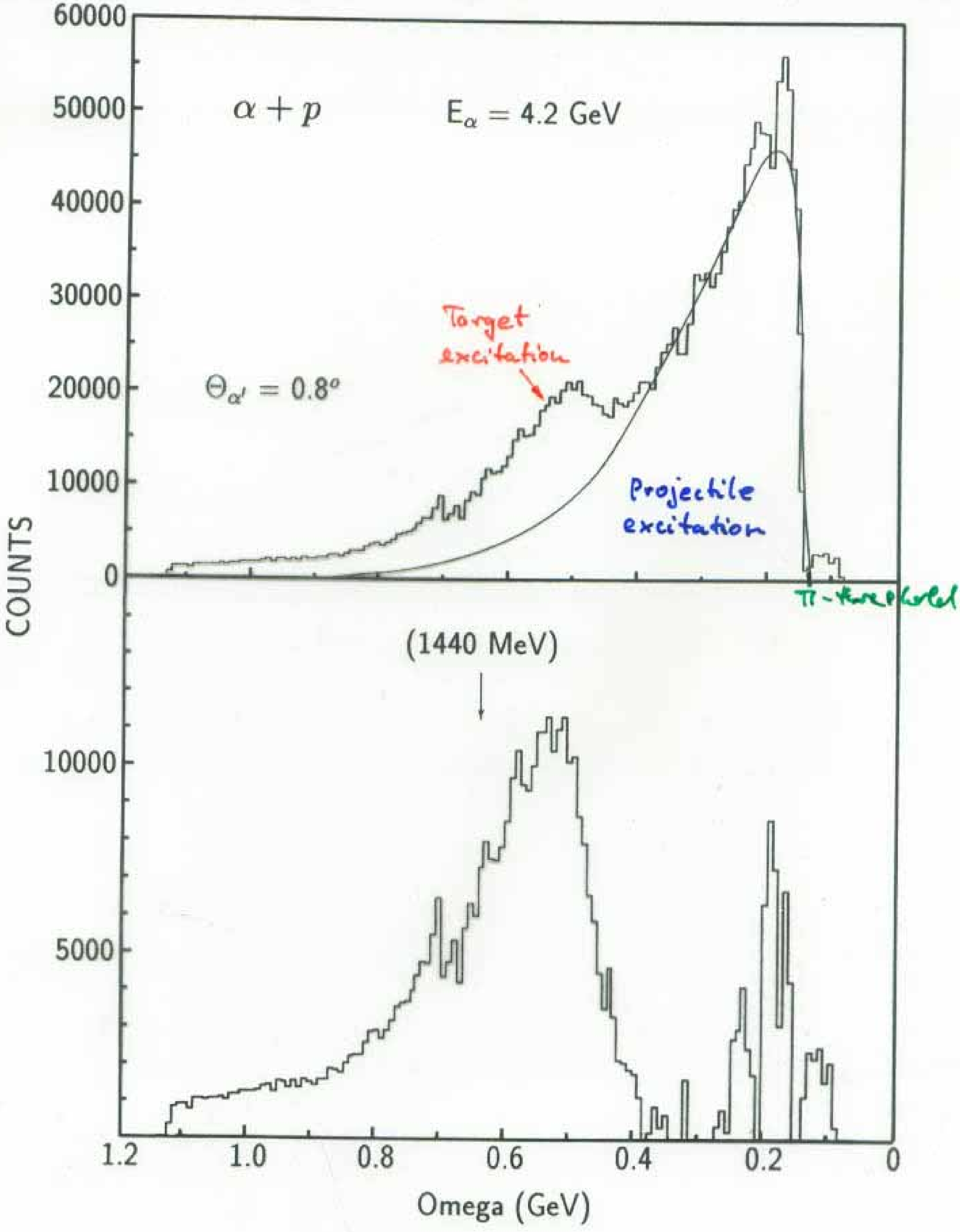
Interesting observation: with $K_N \sim 1.2-1.3$ GeV description of all "monopole excitations" in baryons and mesons up to the charm sector
Universal feature of hadrons?
What is the relation to the quark model?

2. Spectroscopy of the Roper resonance
   (consistent description of α-p, π-N and γ-p)
   → Roper resonance has double structure:
   first resonance: compression (breathing) mode of N
   second resonance: second order Δ excitation

Important result: first resonance not seen in γ-p

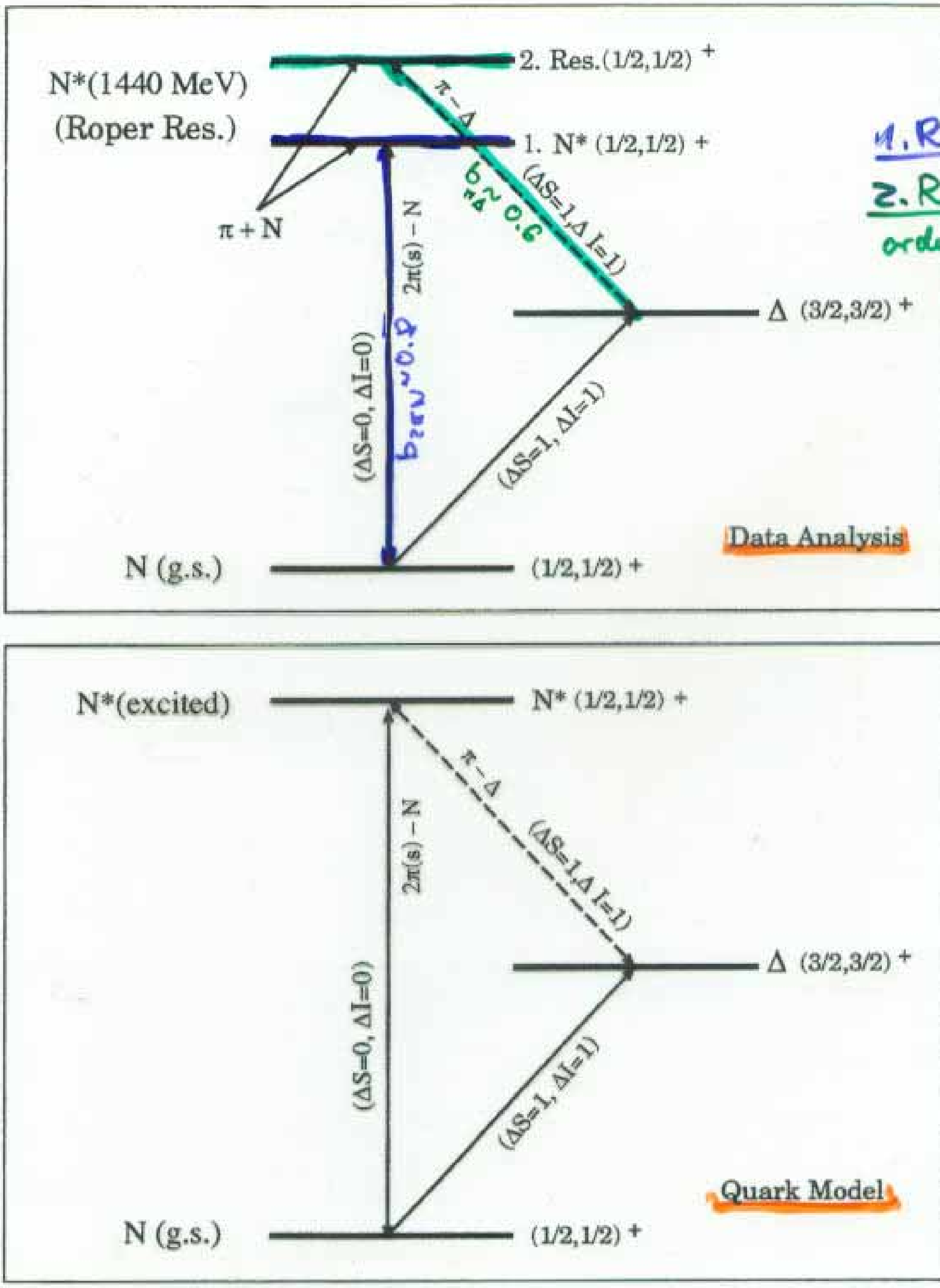
New aspects to be discussed:

1. Excitation of higher N* resonances in α-p
2. First (preliminary) results from exclusive experiment
   $\alpha + p \rightarrow \alpha' (p, \pi^+) X$ at Saturne



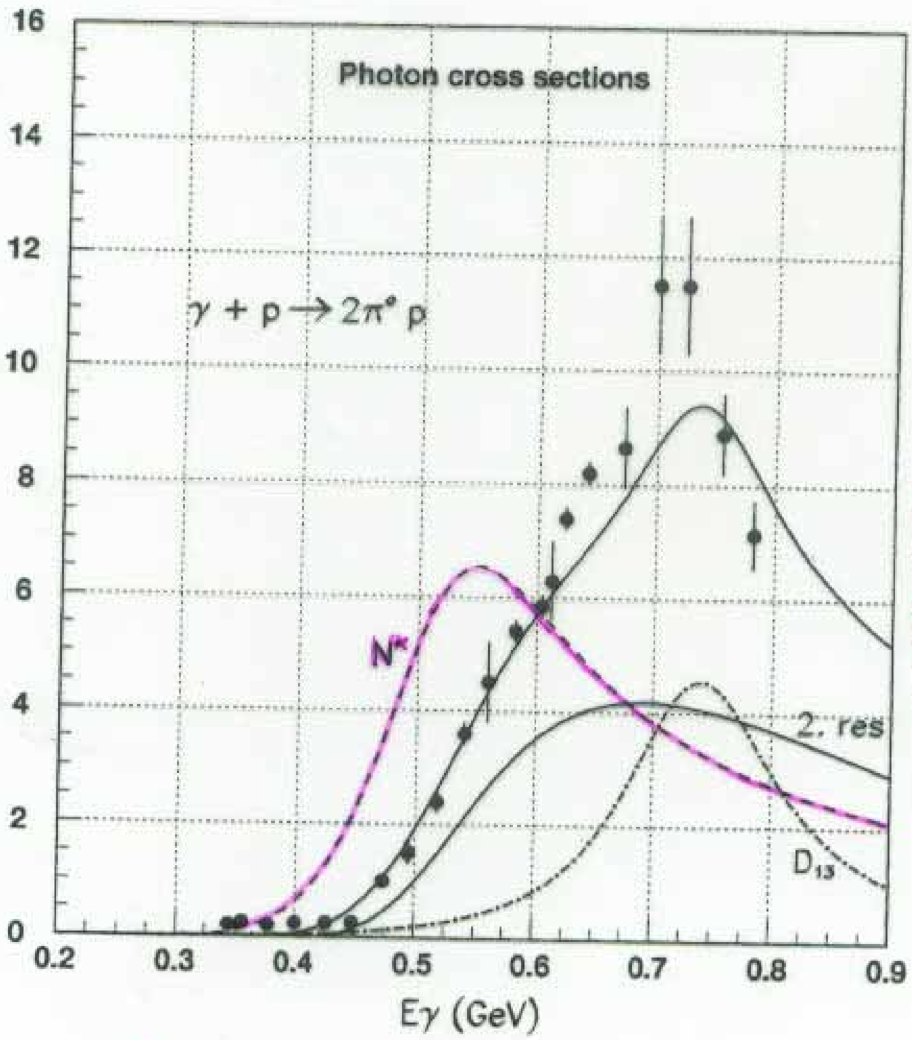
H.P. Morsch et al., Phys. Rev. Lett. 69 (1992) 1336

Fig.2



1. Res: Radial mode
2. Res: second order excitation of the Δ

Figure 9

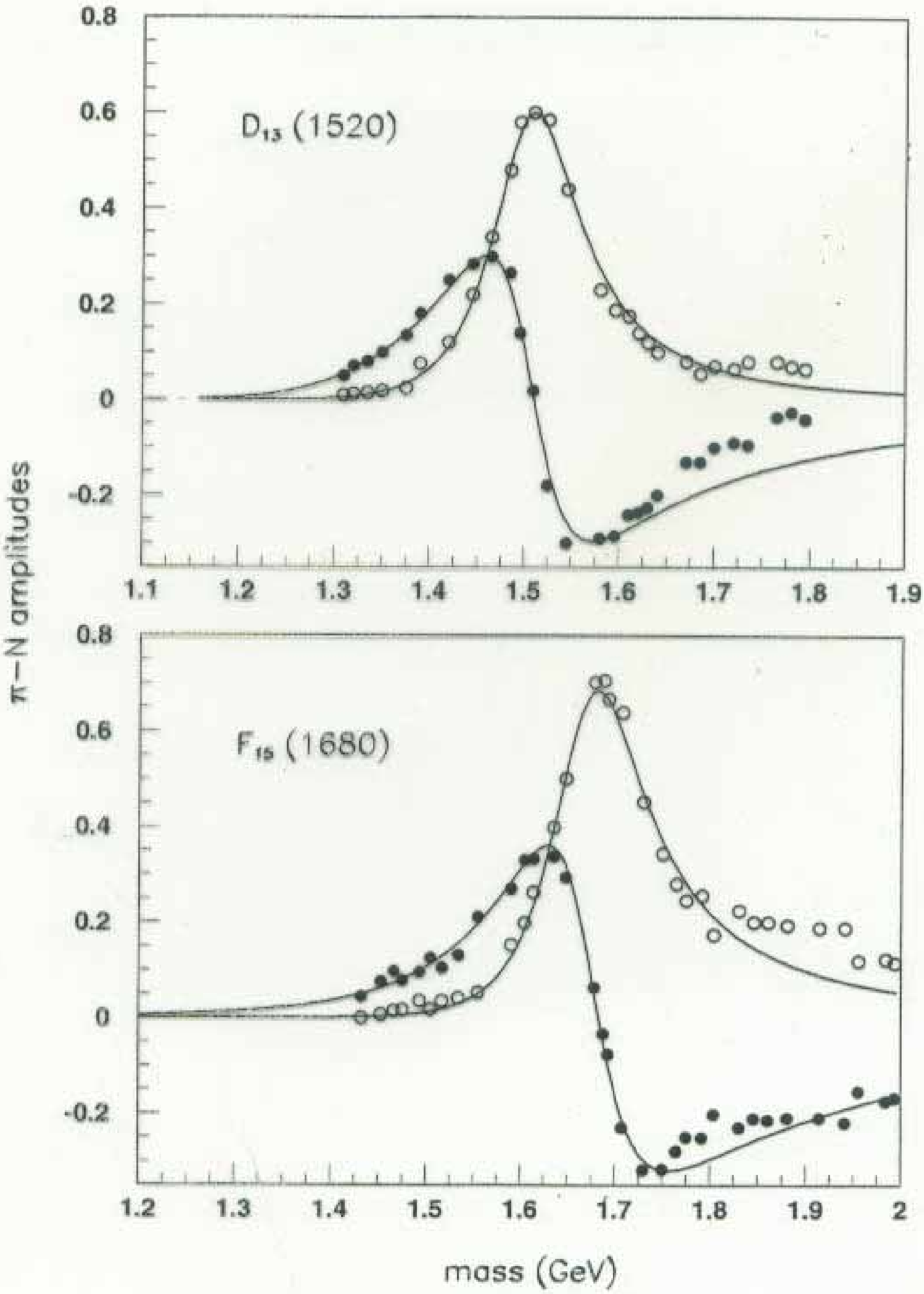


Exp. data from Mainz: F. Härter et al. Phys. Lett. B 401 (1997) 229

First N* (Saturne res.) not observed !?
2. Resonance consistent with π - N

Figure 13

Effect of higher resonances in $\pi^- p$ scattering ?



Calculations of N→N* cross sections

DWBA approach using <u>double folding potentials</u>

$$t_{if}(k) = \int \chi_f^*(r,k')\, V_{tr}^L(r)\, \chi_i(r,k)\, dr$$

where $\chi_{i,f}(r,k)$ are solutions of the Schrödinger equation for elastic scattering of initial and final state using a complex optical potential of the form

$$U(r) = \iint \rho_1(r_1)\, v(r_1+r_2-r)\, \rho_2(r_2)\, dr_1\, dr_2$$

where $\rho_1(r_1)$ and $\rho_2(r_2)$ are densities of p and α-particle.

The transition potential $V_{tr}(r)$ is given by

$$V_{tr}(r) = \iint \rho_{tr}^{N\to N^*}(r_1)\, v(r_1+r_2-r)\, \rho_2(r_2)\, dr_1\, dr_2$$

1. Optical potentials $U(r)$ determined by elastic α-p scattering over large energy region 0-2 GeV.
2. Using $\rho_{tr}^{N\to N^*}(r)$ from baryon models

<u>Calculation of transition density:</u>

1. Constituent quark model (1s→2s for L=0)
2. Vibration of the ground state density (fluid dynamical approach)

$$\rho_{tr}(r) = \sum_i \alpha_i \frac{\partial \rho_{g.s.}(r)}{\partial x_i} + \text{h.o.}$$

where x_i are dynamical parameters of g.s. density

Test of the transition density

The transition densities for N^* excitation are generally quite sensitive to the details of the baryon models. As an example we discuss in the following monopole transition densities for P_{11} excitation in the constituent quark model and for sound modes discussed above. For a 1s→2s single quark excitation the transition density is localized at smaller radii as compared to one derived from collective sound modes, this is shown in Fig. 3.

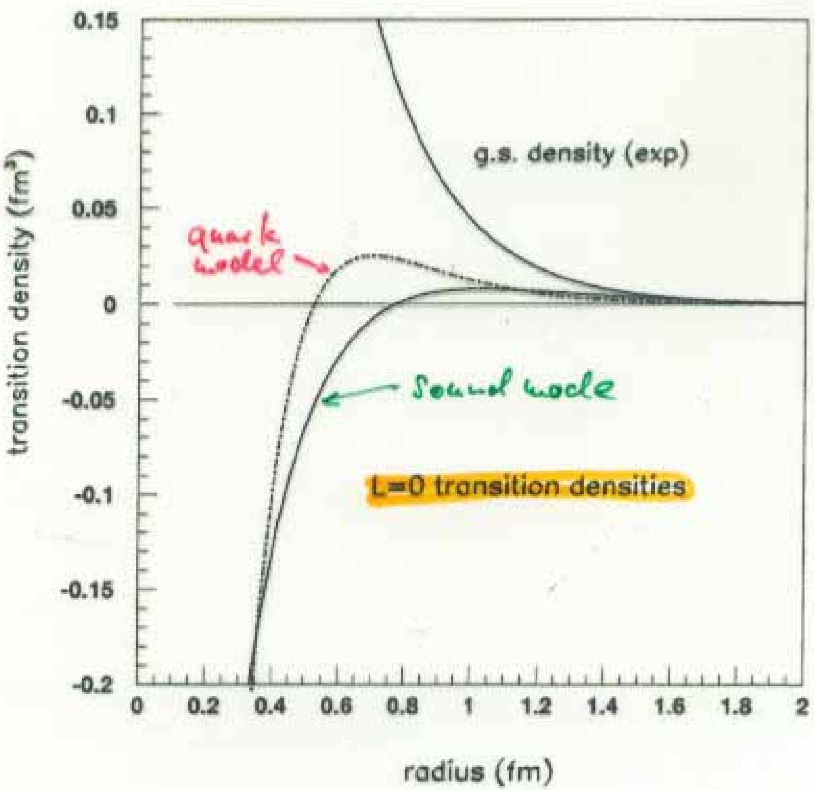


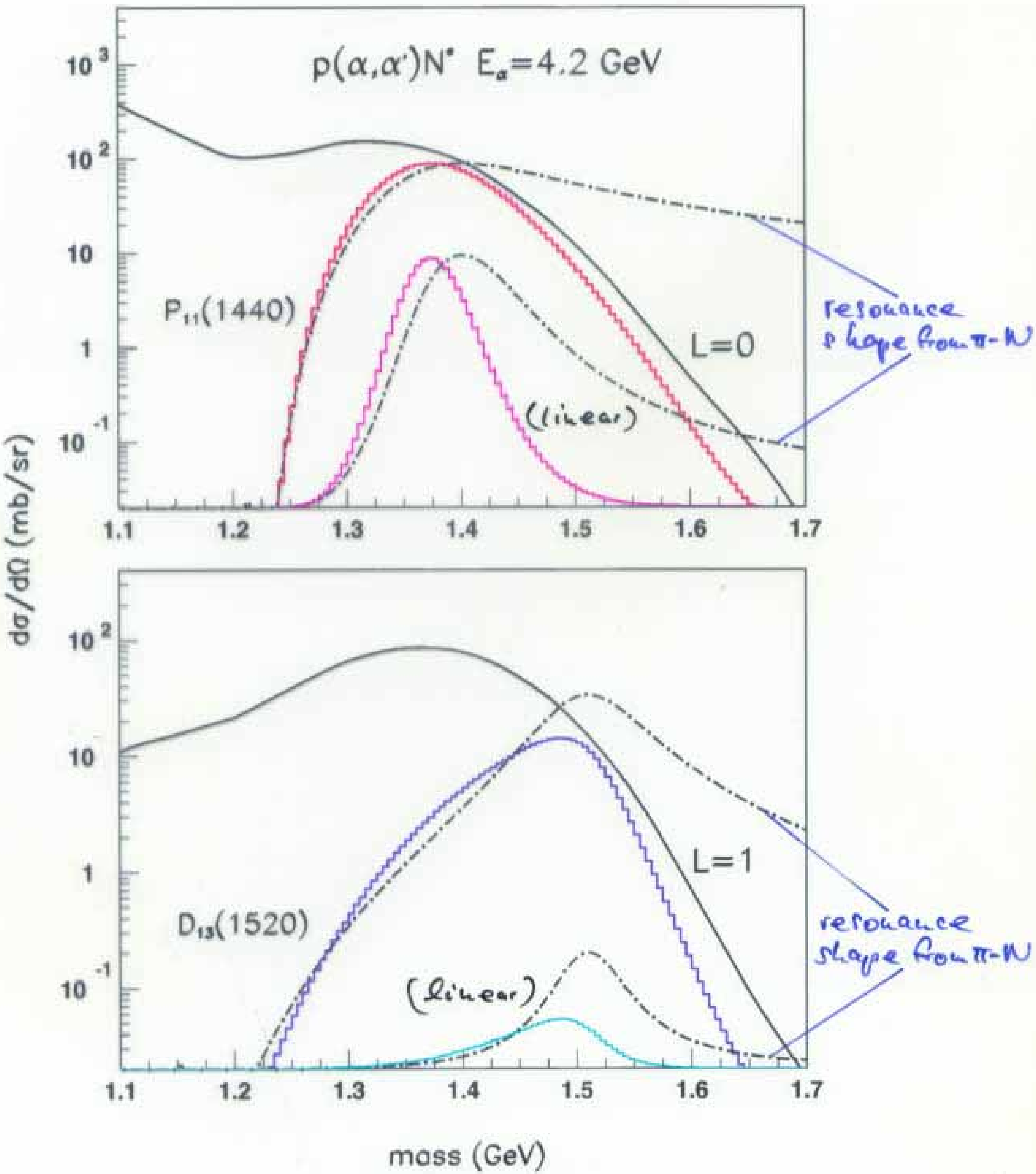
Figure 3: Transition densities of L=0 excitation for sound mode (solid line) and 1s→2s quark excitation (dot-dashed line).

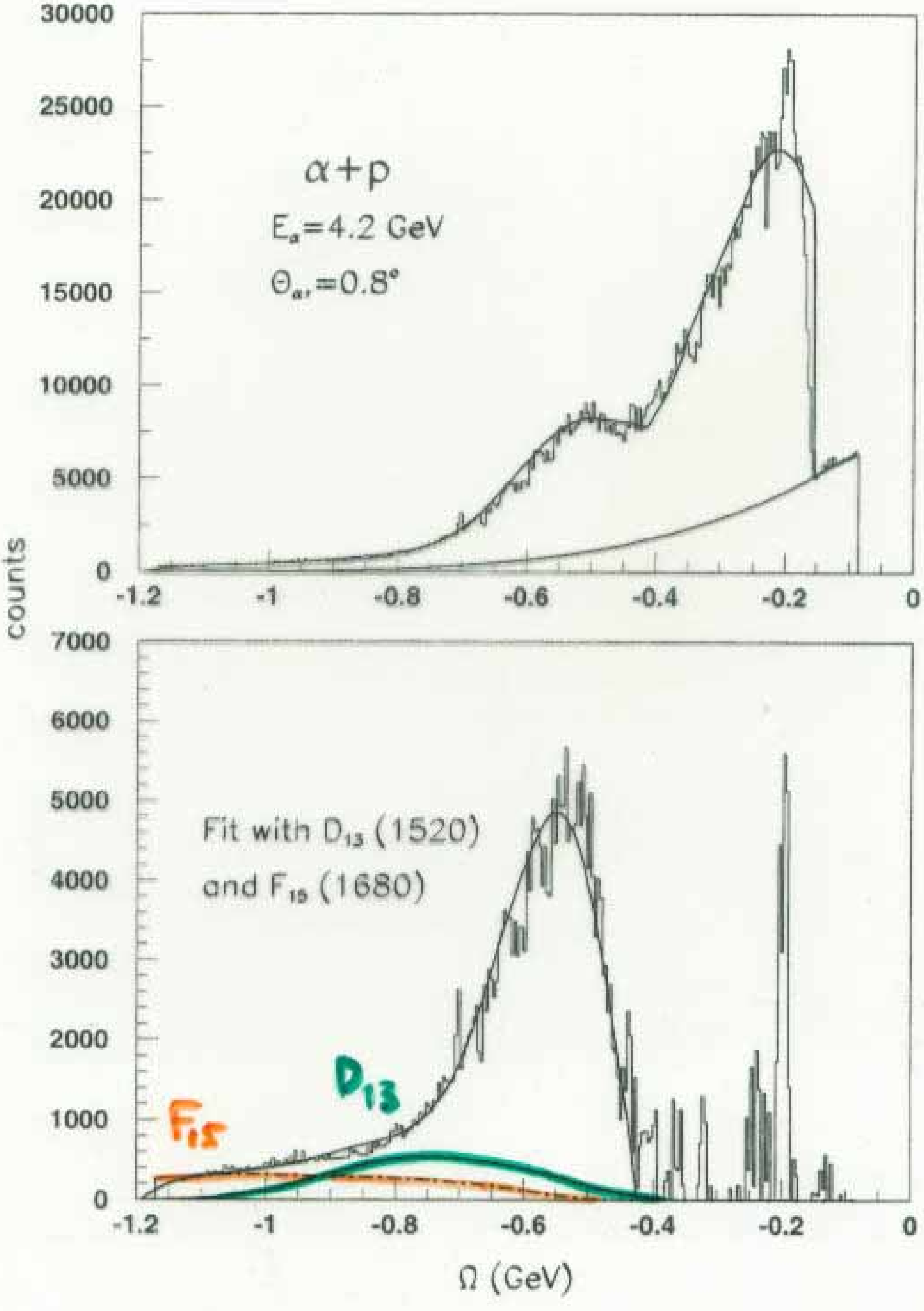
In p-α scattering the interior part of the scattering potential is damped out to some extent by absorption, therefore inelastic cross sections are more sensitive to the surface region. DWBA calculations indicate[12] a direct dependence of the cross section on the transition radius. The α-p scattering data of ref.11 are well described assuming that about the full energy weighted sum rule strength is exhausted in the Roper resonance excitation. This supports strongly the picture of a sound mode. For single quark excitation much smaller cross sections are obtained which cannot describe the experimental α-p data.

good descr. of α-p data by sound mode!

quark model gives too small cross sections.

Results of DWBA calculations using folding (N→N*) form factors



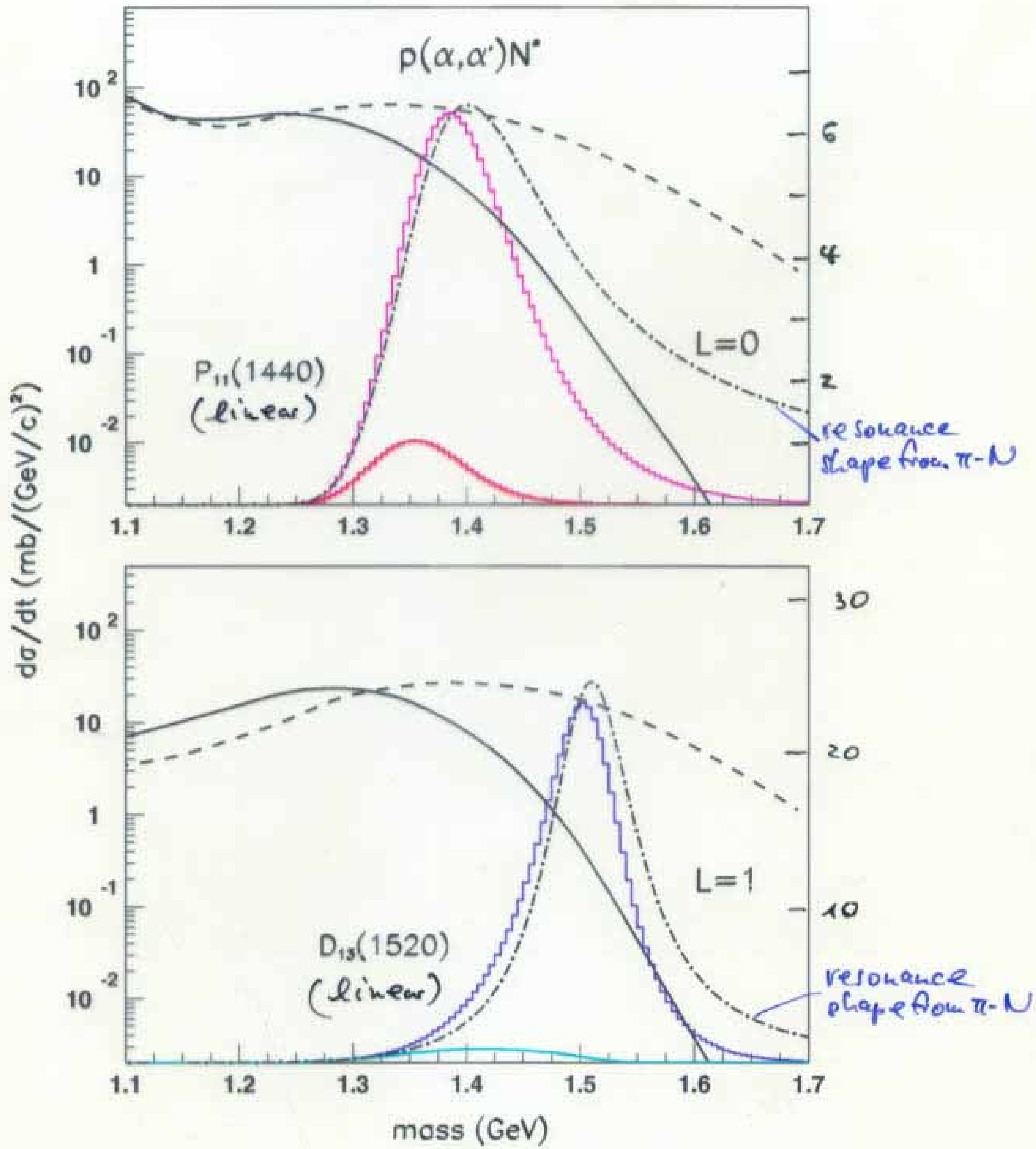


α+p
E_α=4.2 GeV
$\Theta_{\alpha'}$=0.8°
counts
Fit with D_{13} (1520)
and F_{15} (1680)
F_{15}
D_{13}
Ω (GeV)

N* resonance excitation

in α-p scattering at $E_\alpha = 4.2$ GeV (Saturne)

in p-α scattering at $E_p = 2.2$ GeV (COSY)



Saturne Experiment
exclusive

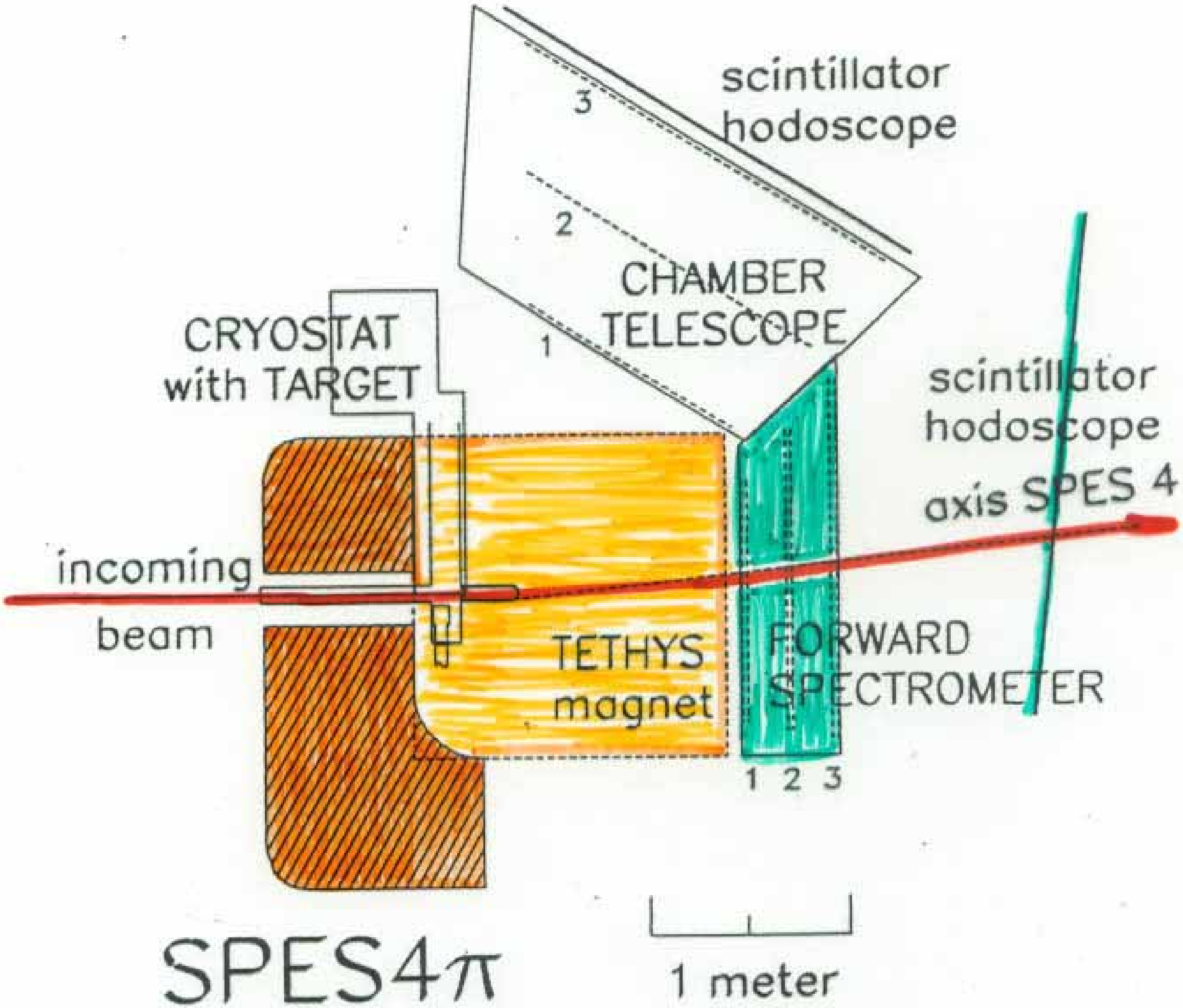
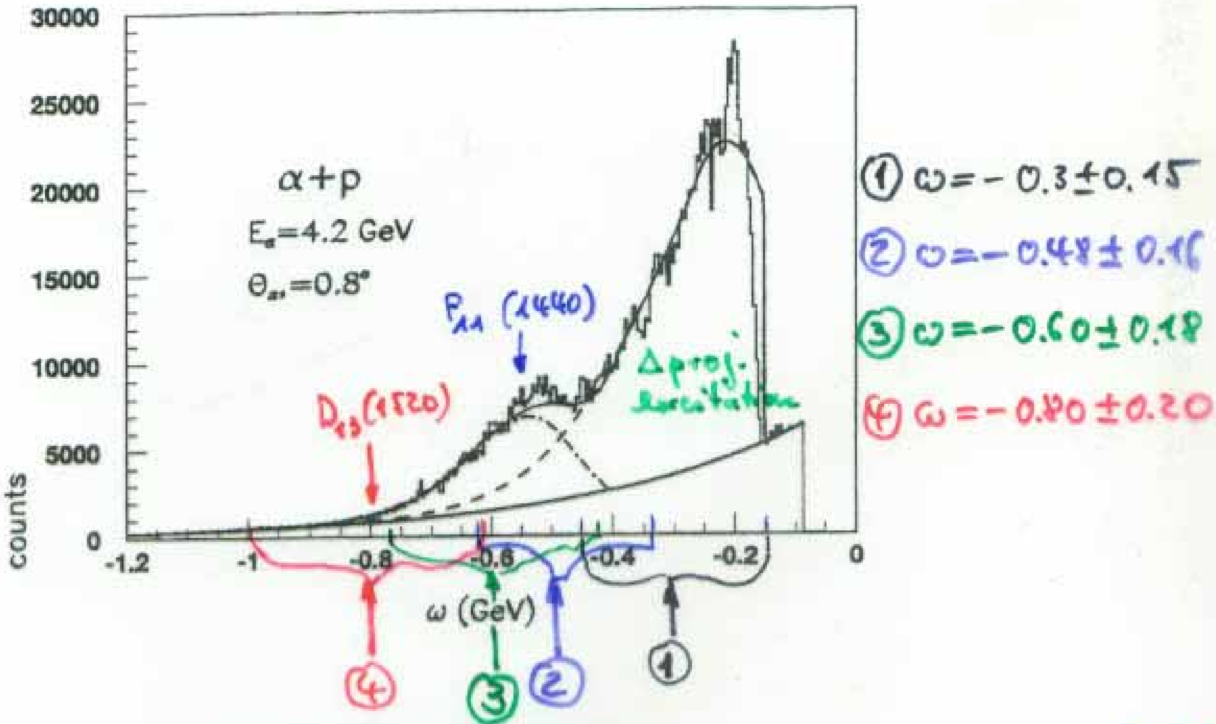
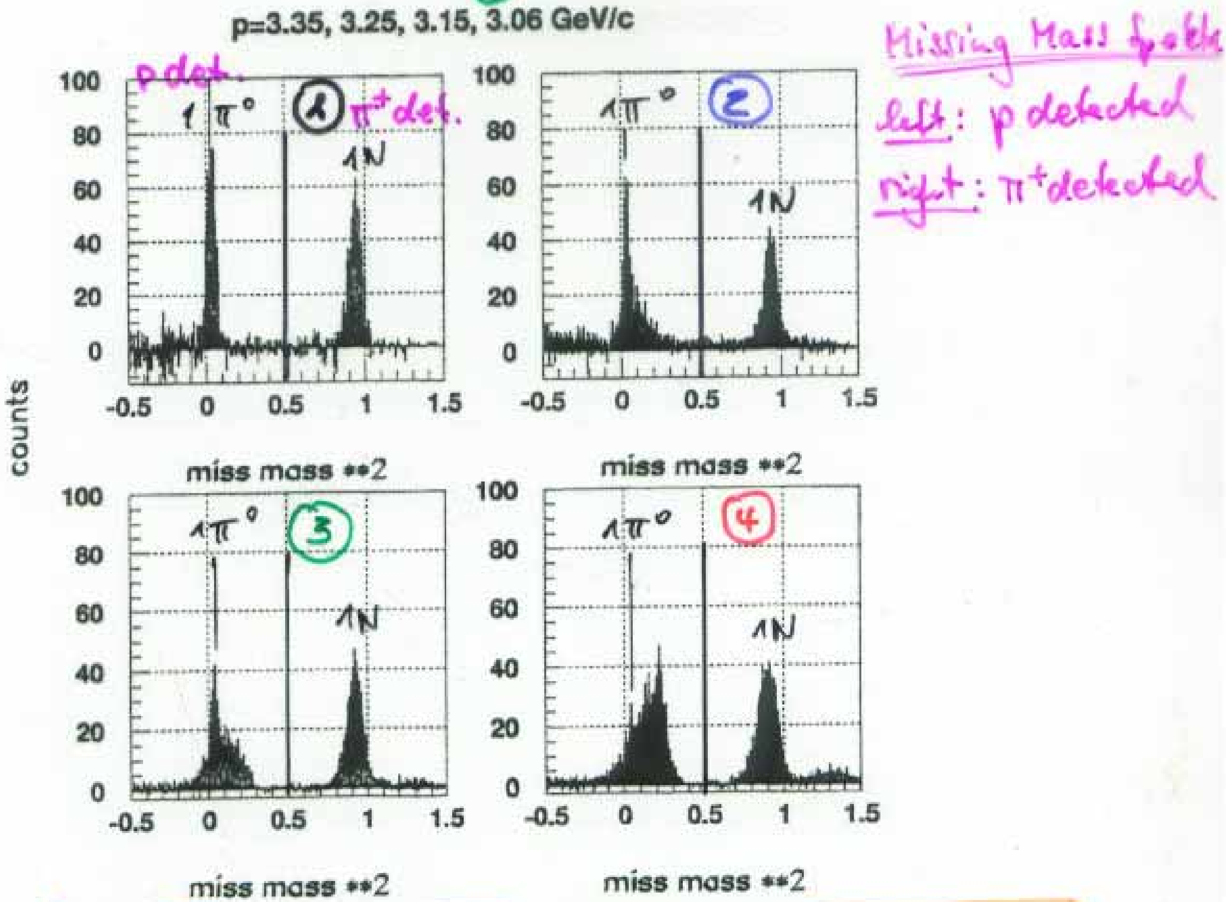


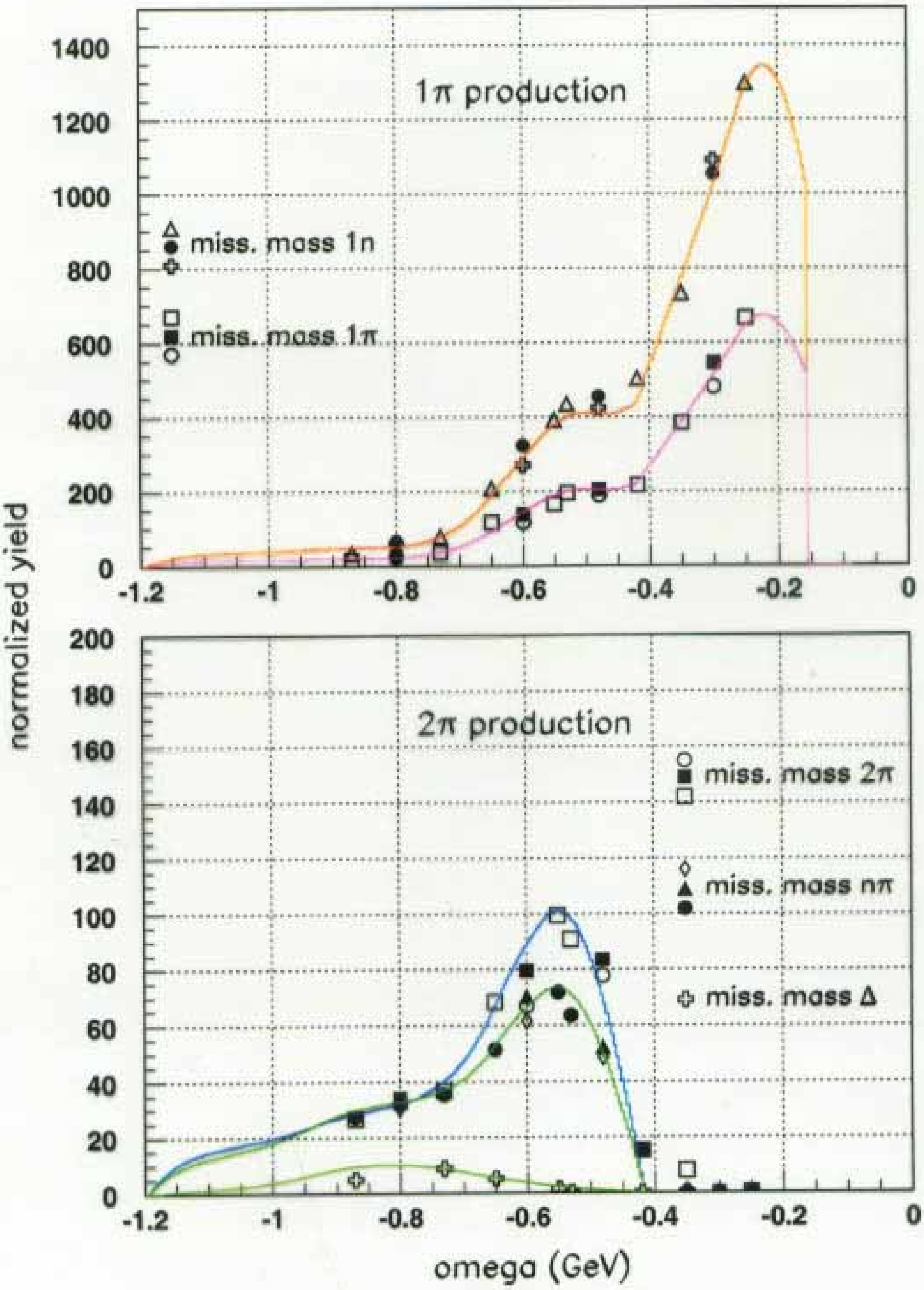
Figure 3: Schematic view of the coincidence set-up involving the SPES 4 spectrometer to detect scattered α-particles and a non-focussing magnet spectrometer TETHYS to detect coincident particles.

Newest Results from SPES 4π





Separation of $N^* \to N\pi$
$N^* \to N\, 2\pi$ possible!


1π production
miss. mass 1n
miss. mass 1π
2π production
miss. mass 2π
miss. mass nπ
miss. mass Δ
normalized yield
omega (GeV)

Conclusion

[1.] From the study of α-p scattering we have strong indications, that the quark model is not adequate to describe the observed data on N* excitations:

The lowest N* resonances are dominantly scalar excitations (with large scalar sum rule strength)

$\Rightarrow$ Interpretation as compression modes related to hadron compressibility

How can we understand these features?
New effective degree of freedom
What is the relation to the underlying quark structure?

[2.] Roper resonance New results from exclusive α-p experiment (very preliminary)

no $\pi\Delta$ decay of N* (1440) observed

$\rightarrow$ confirmation of double resonance picture?

soon results on $B\left(\frac{N^* \to \pi N}{N^* \to 2\pi N}\right)$ and $B\left(\frac{N^* \to 2\pi(S)N}{N^* \to 2\pi(P)N}\right)$

[3.] Experimental program in preparation at COSY

$p + \alpha \rightarrow \alpha_{rec} + N^*$ with E_p up to 2.5 GeV

large increase of N* excitation

full acceptance for measurement of N* decays.