TWO-PION PRODUCTION IN *αp* SCATTERING

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for the SPES4-π collaboration

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$P_{11}(1440)$ – Roper resonance, the lowest N^* ½, ½ state

EVIDENCE FOR A P_{11} PION-NUCLEON RESONANCE AT 556 MeV†

L. David Roper
Lawrence Radiation Laboratory, University of California, Livermore, California
(Received 17 February 1964)

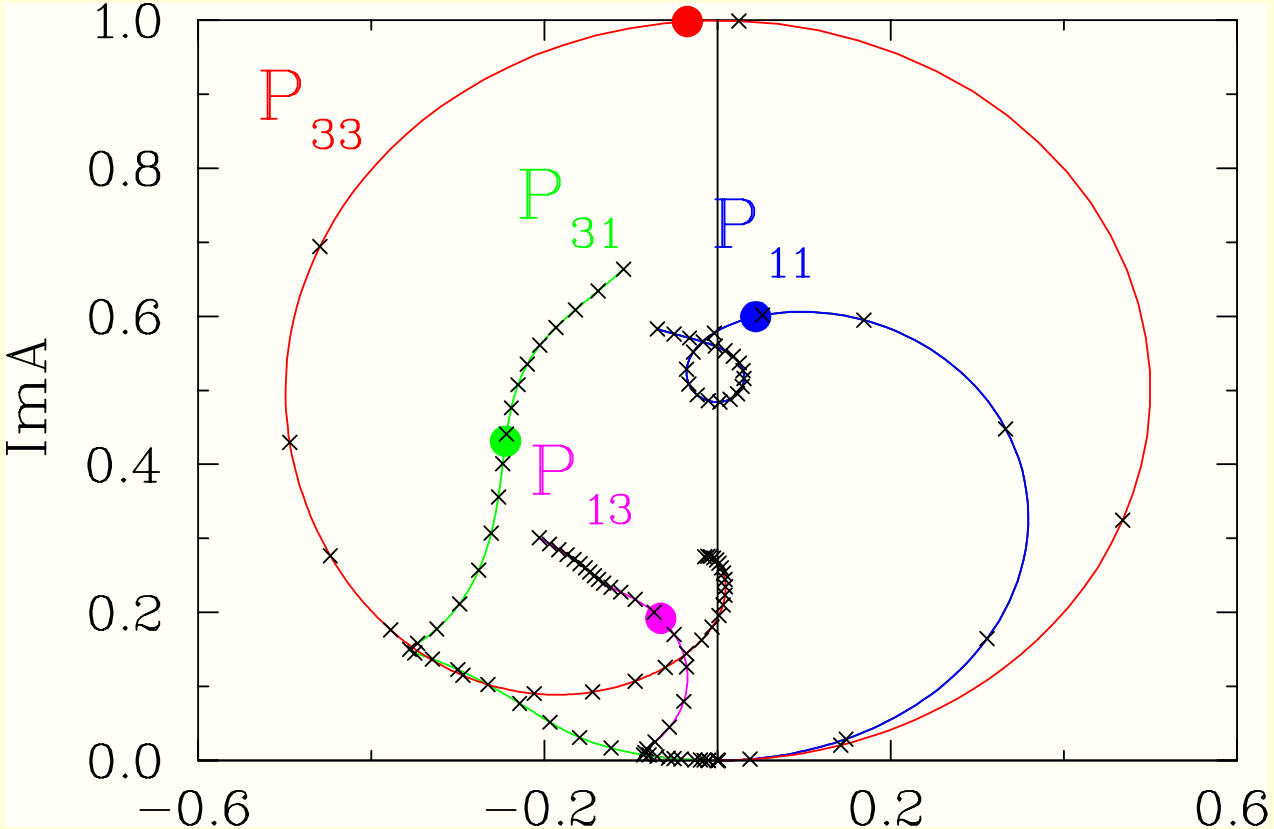
The purpose of this note is to report strong evidence for the existence of a resonance in the P_{11} state of the pion-nucleon system. Previous pion-nucleon resonances were discovered from observations on the qualitative behavior of experimental observables. The resonance suggested in this paper, however, is not associated with conspicuous features in the observables measured so far and has been inferred from a more quantitative analysis.

PDG: M_R = 1420-1470 MeV, Γ_R= 200-450 MeV.
Decay of the Roper resonance: $N^* \to N\pi$ (60-70%); $N \to \pi\pi$ (30-40%);
Two-pion decay of Roper: $N^* \to \Delta\pi \to N\pi\pi$ (20-30%); $N^* \to N\sigma \to N\pi\pi$ (5-10%)

The Roper resonance was studied in πN, γN, αN, pp scattering and in J/ψ decay.

πN partial wave analysis

Argand plot



Roper is an important resonance. It plays a significant role in several nuclear processes.

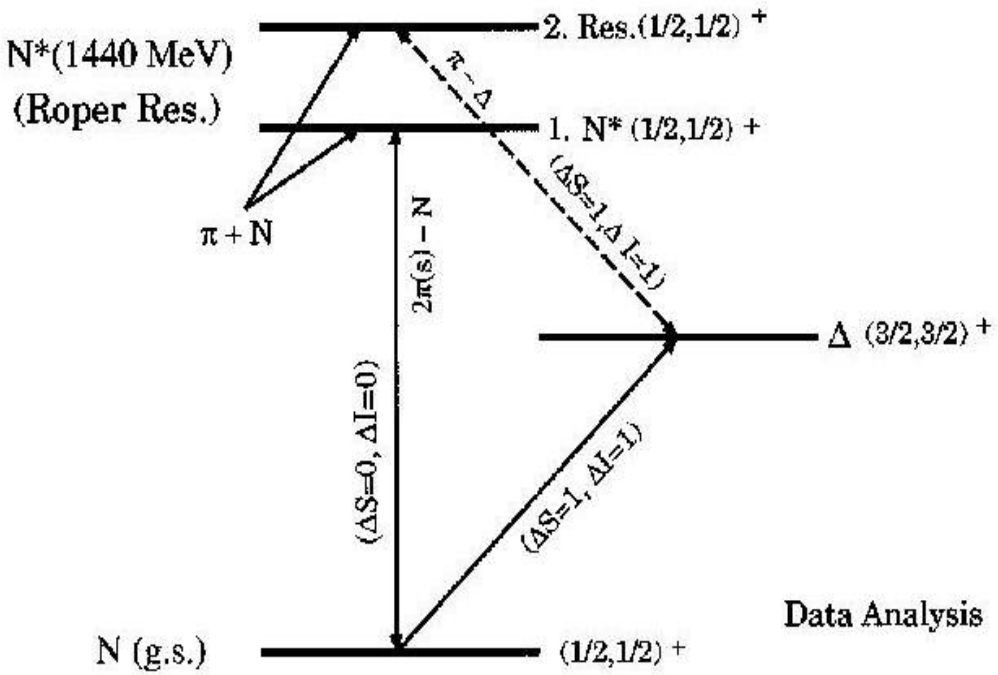
1. 0ne-pion and two-pion production in different intermediate energy reactions.
2. Three-body nuclear forces.
3. Nucleon swelling.
4. Nuclear matter compressibility.

Theoretical models:

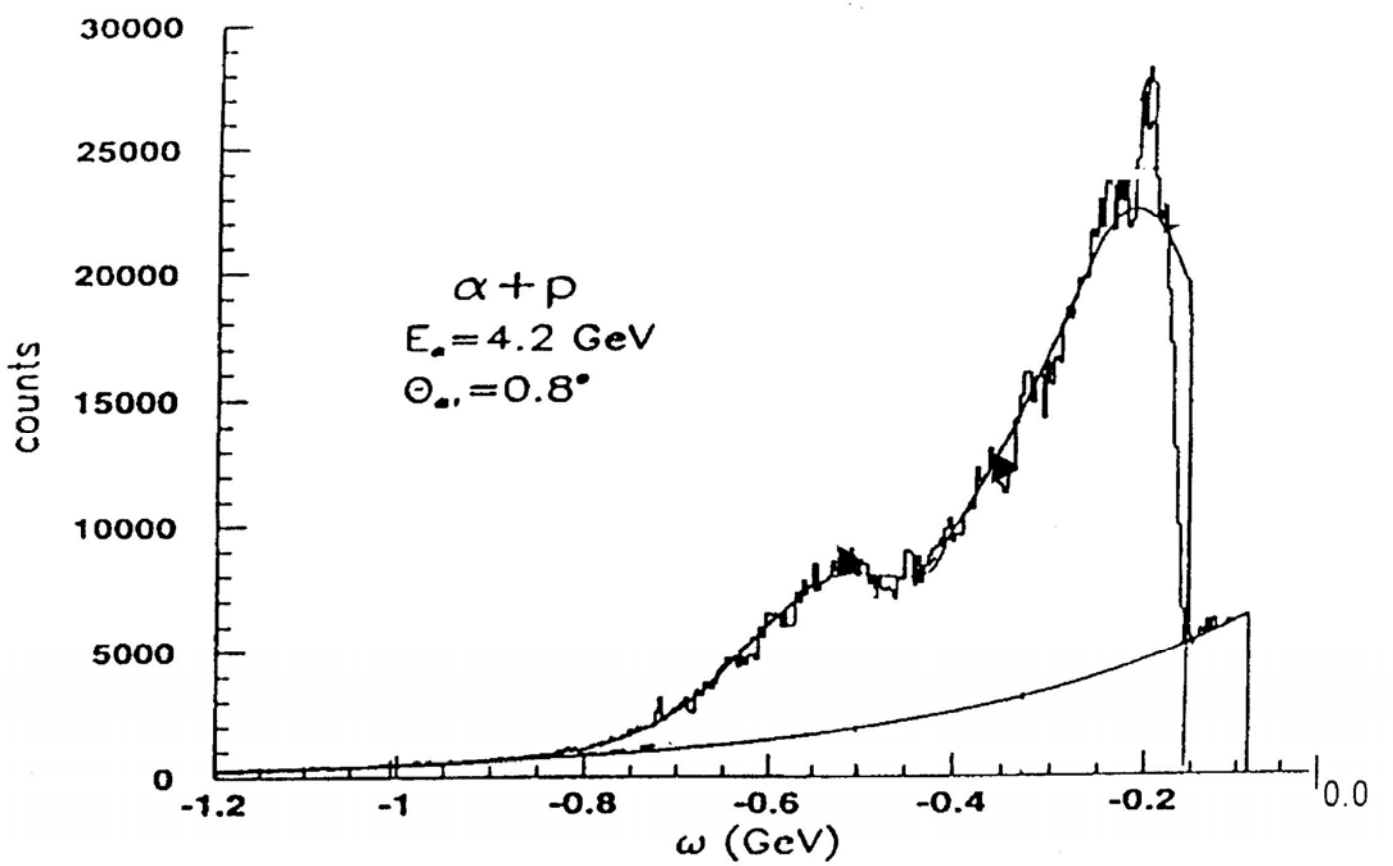
1. Constituent quark model: $(1s)^2(2s)^1$ configuration – breathing mode of the nucleon.
2. Bag model (with sharp or diffuse surface); oscillations of the bag surface.
3. Skyrmion models; mesonic degrees of freedom, no quark degrees of freedom.
4. Hybrid model: (*qqqg*) structure; gluon degrees of freedom.
5. QCD calculations on the lattice.
6. Pentaquark model; four quarks + 1 antiquark.

H.P. Morsch and P. Zupransky: the Roper resonance consists of two structures.
The first is excited in αN scattering, the second – in γN and πN scattering.

PHYSICAL REVIEW C 61 024002 (1999)

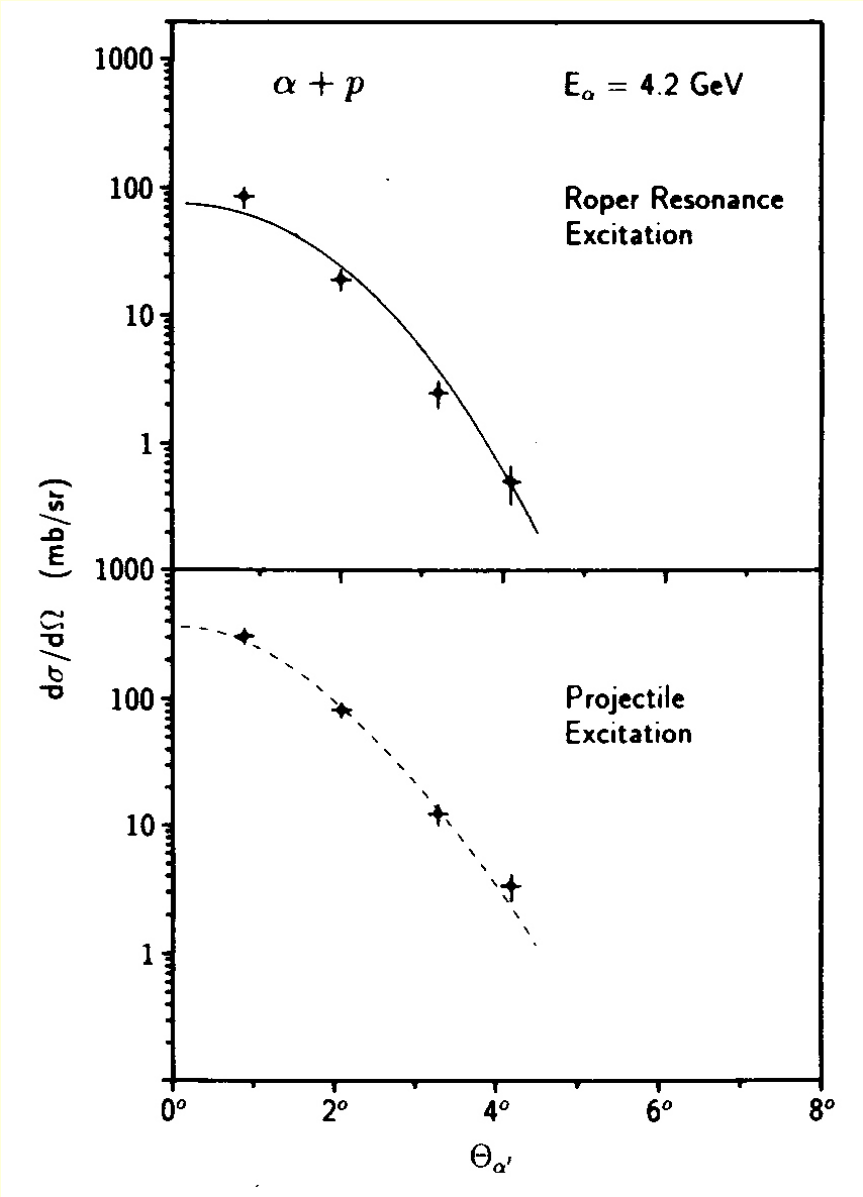


H.P. Morsch *et al*., Phys. Rev. Lett. **69** (1992) 1336.
Radial Excitation of the Nucleon to the P_{11}(1440 MeV) Resonance in Alpha-Proton scattering.



$\omega = E_{\alpha'} - E_{\alpha}$

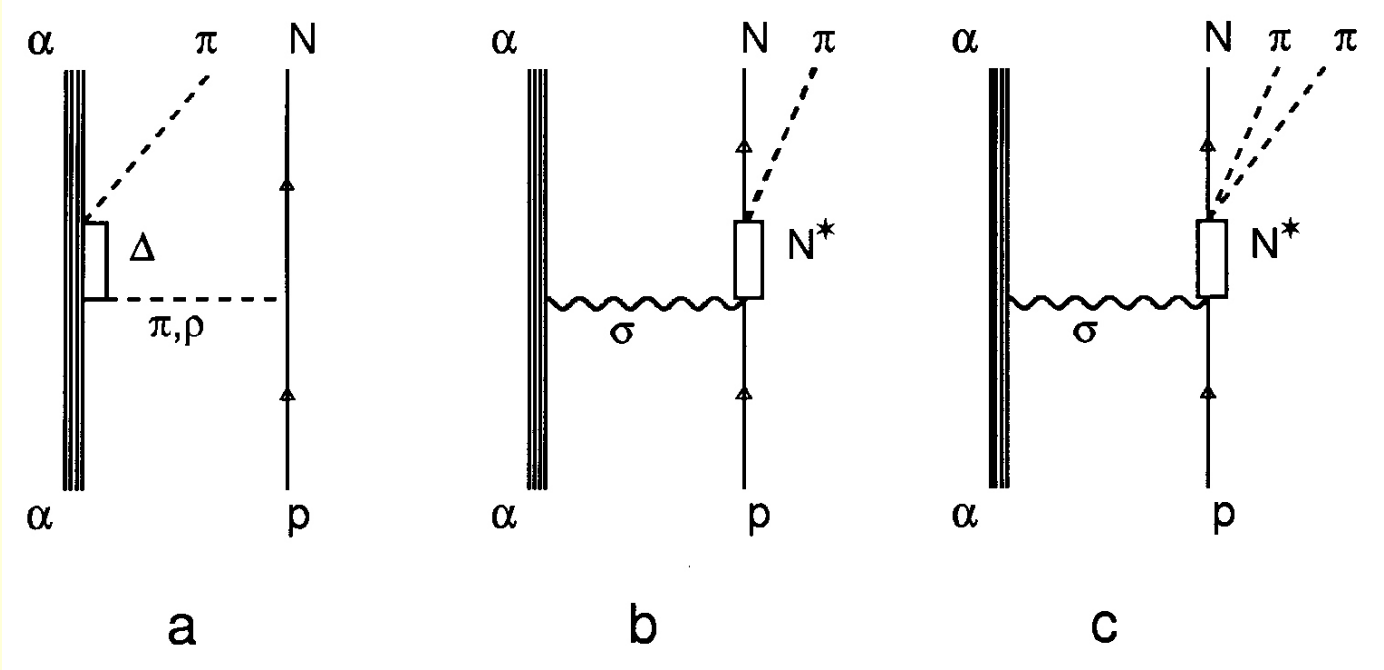
Radial excitation → nuclear matter compressibility



Angular dependences of the cross sections for excitation of the Roper and Delta resonances in *αp* scattering.

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

Main processes in inelastic *αp* scattering

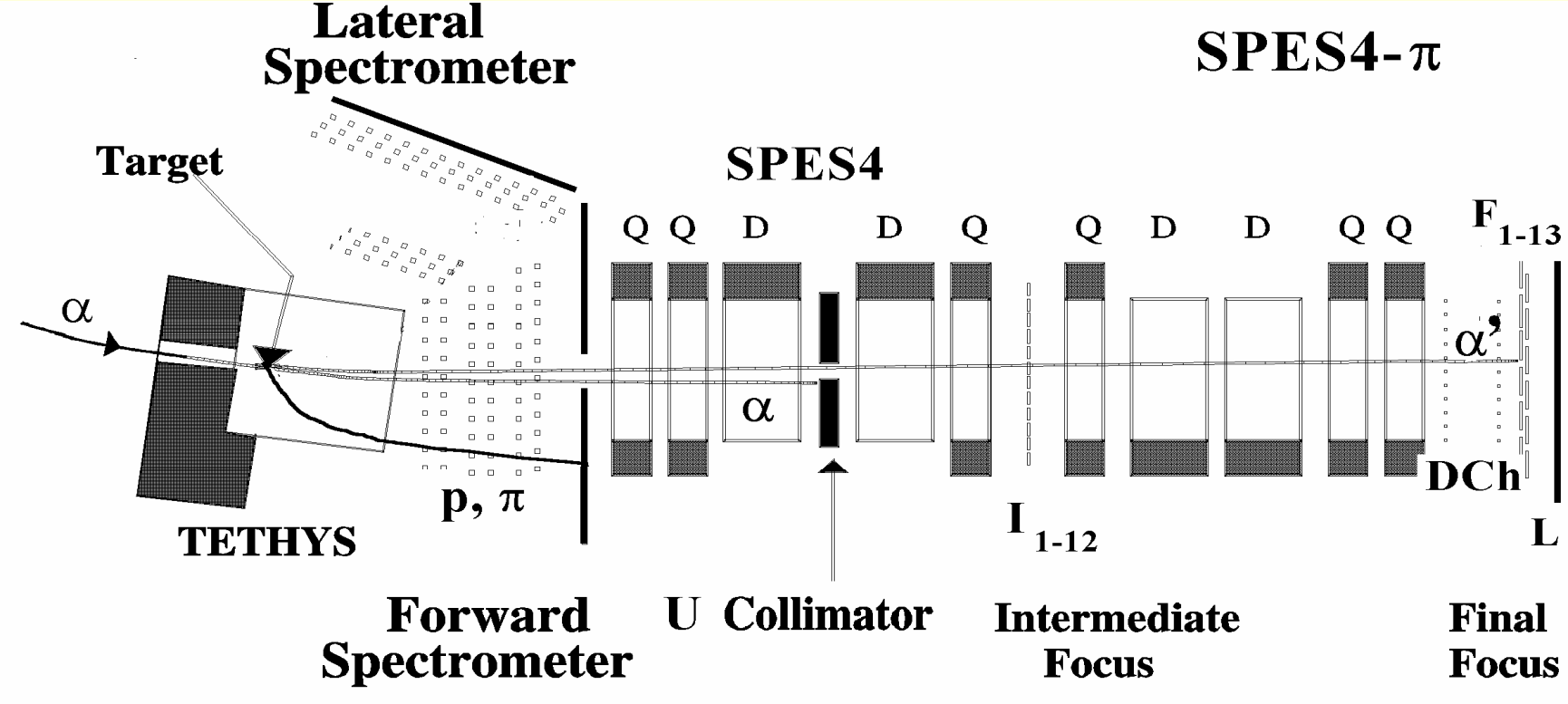


a – excitation of Δ in the projectile *α* particle with the following *π* emission;
b, c – excitation of target proton with the following 1 or 2 pion emission.

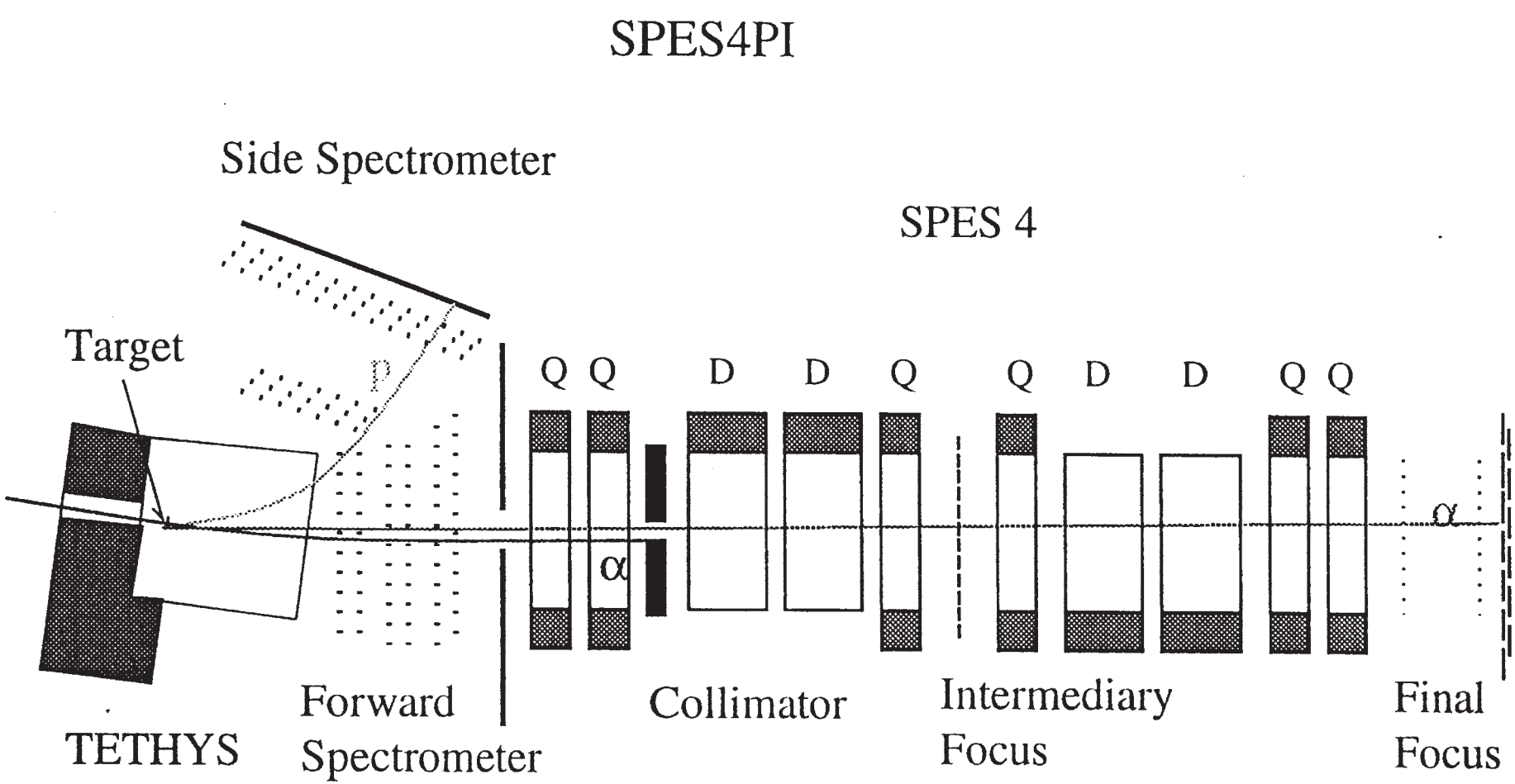
Due to *I*=0 of the projectile *α* particle and due to isospin conservation, a direct excitation of Δ in the target proton is forbidden.
The two-pion production reaction is the cleanest N* channel which does not interfere with the reaction through the Δ resonance production.

SPES4- π installation, general view

(not on scale)



A semiexclusive experiment on αp scattering at E_α=4.2 GeV



TETHYS: Magnet poles 1 x 1 m^2; vertical gap 0.5 m; H – up to 1.3 Tesla
SPES4 spectrometer – 33 m long

SPES4-π parameters:

SPES4: angular acceptance $\Delta\theta_x$ = +/- 17.5 mrad
angular acceptance $\Delta\theta_y$ = +/- 22.8 mrad
momentum acceptance $\Delta q/q$ = +/- 5 %
momentum resolution $\delta q/q$ = 0.8 %

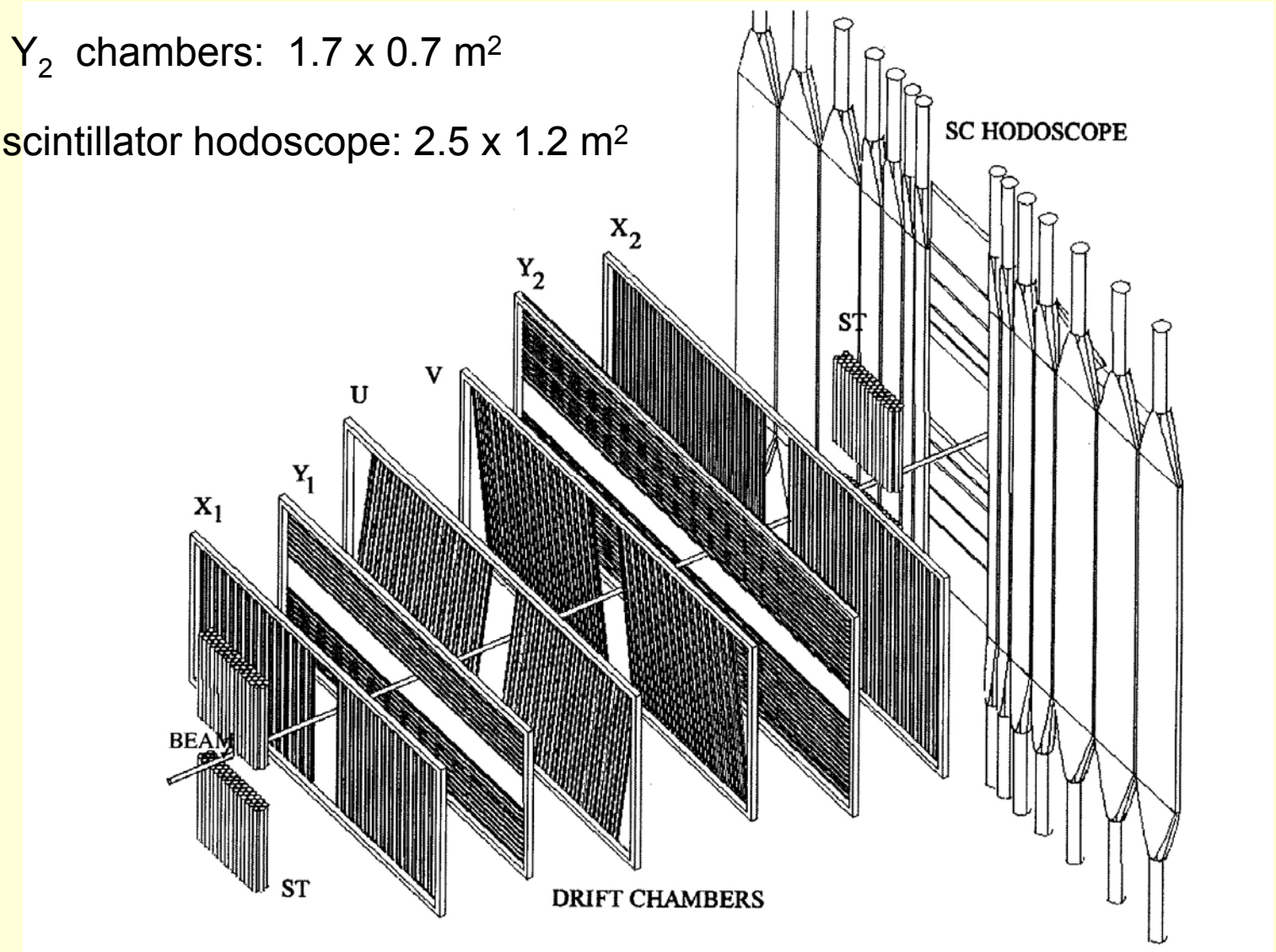
FS: angular acceptance $\Delta\theta_x$ = 0.9 rad
angular acceptance $\Delta\theta_y$ = 0.3 rad
angular resolution $\delta\theta_x$, $\delta\theta_y$ = 0.02 rad
momentum resolution $\delta q/q$ = ~ 4 %

Target: liquid hydrogen, 60 mm in length

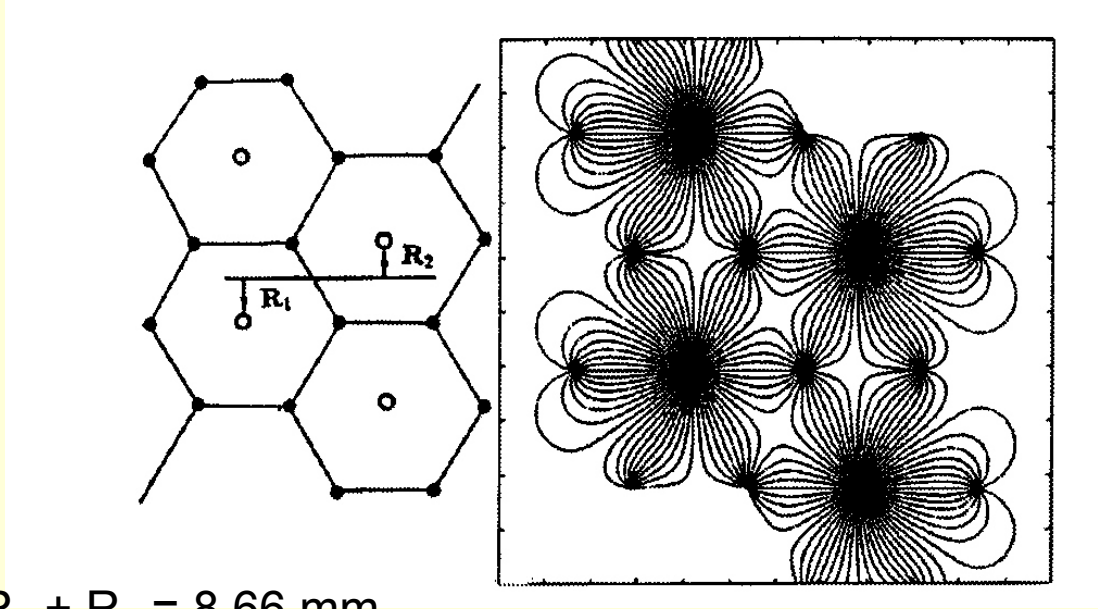
Detector system of the Forward Spectrometer

X_2, Y_2 chambers: 1.7 x 0.7 m^2

The scintillator hodoscope: 2.5 x 1.2 m^2



Hexagonal structure of the drift chambers of the Forward Detector



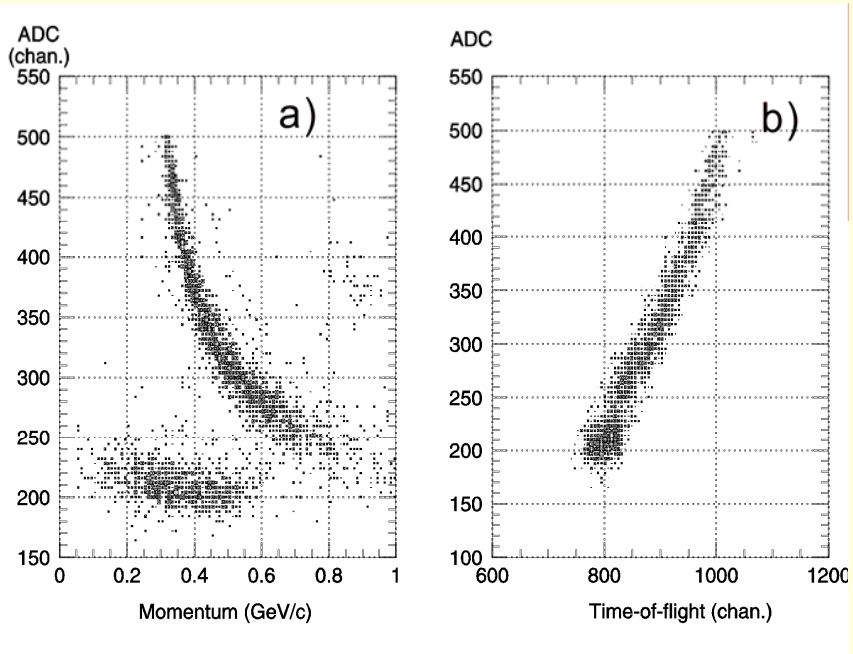
2000 channels

$R_1 + R_2 = 8.66$ mm

Ar + C_2H_6 50% / 50% ,
HV= 2.2 kV
drift velocity = 50 mμ/ns

Space resolution in a test experiment – σ = 0.15 mm;
Space resolution in the real experiment- σ = 0.6 mm

Forward spectrometer of SPES4-π installation



- a) The energy loss versus momentum correlation for secondary protons and pions.
- b)The energy loss vs. TOF correlation for secondary particles (p, π).

ω acceptance for different momentum settings of SPES4

D) p_α/Z=3.35 GeV/c

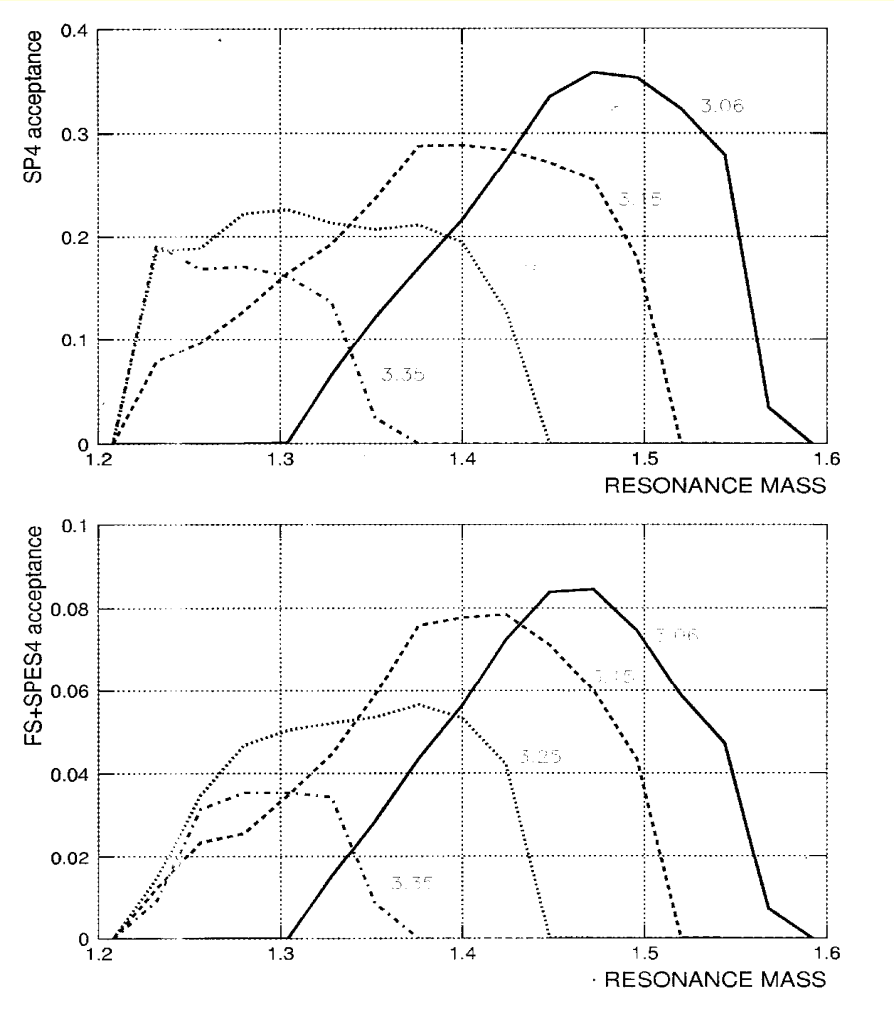
C) p_α/Z=3.25 GeV/c

B) p_α/Z=3.15 GeV/c

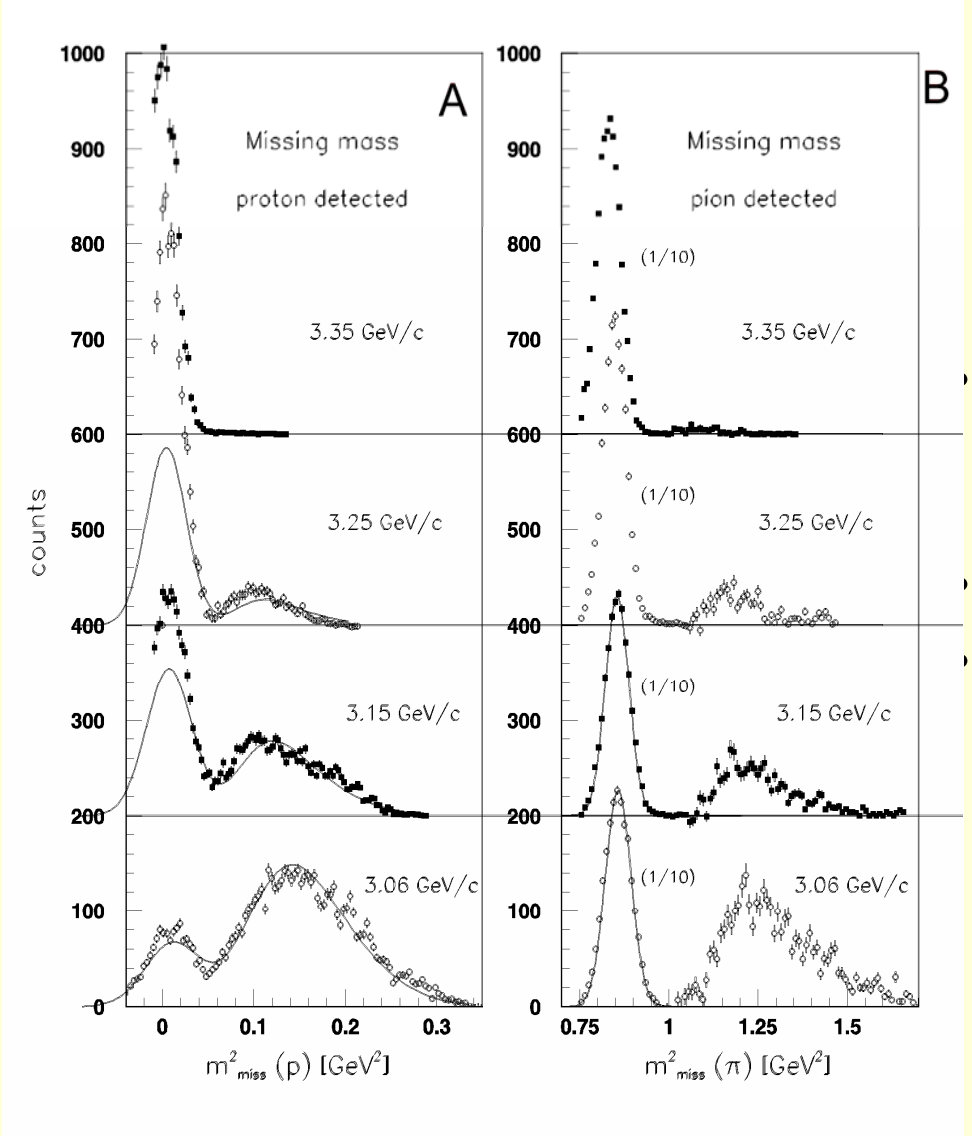
A) p_α/Z=3.06 Gev/c

$\omega = E'_\alpha - E_\alpha$

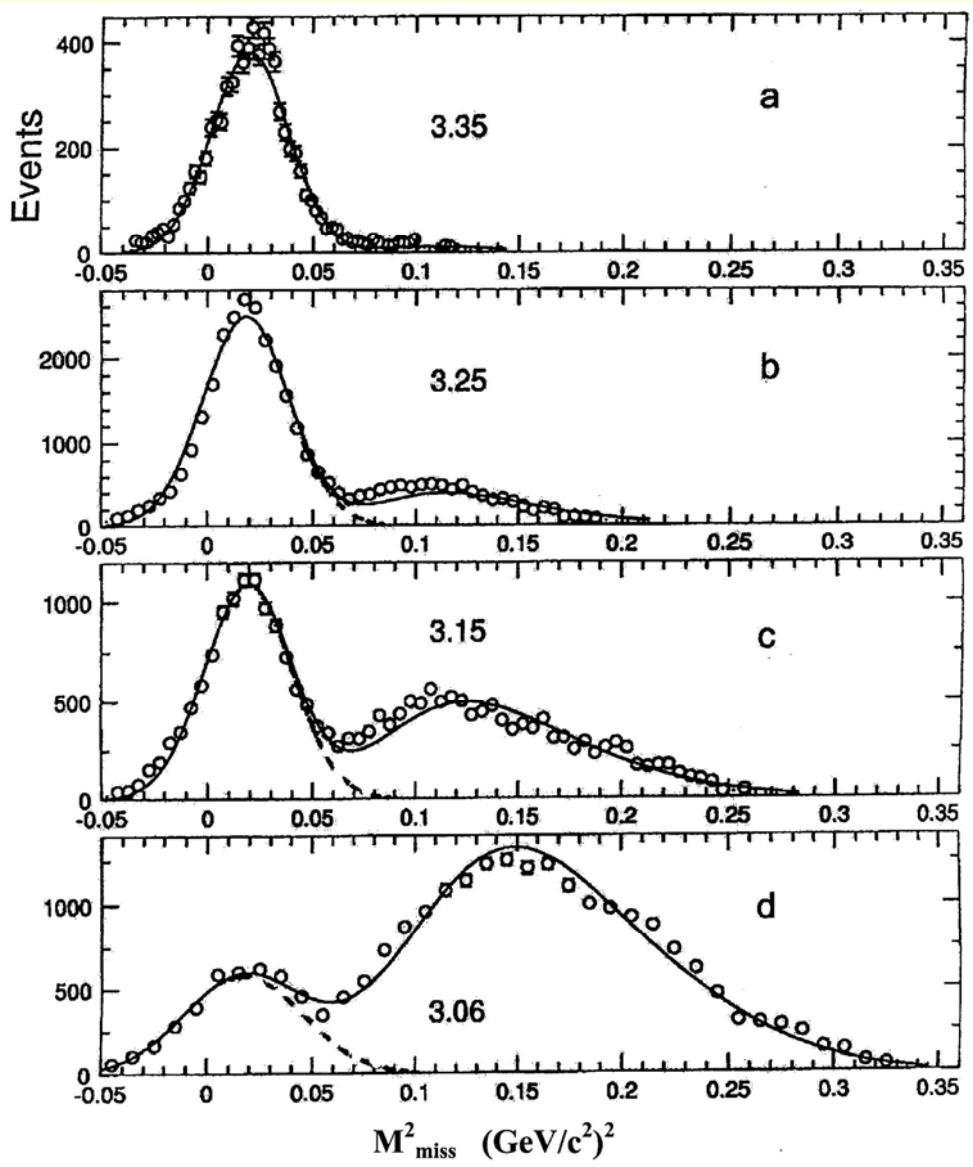
SPES4 and SPES4-π acceptances for αp reaction for different momentum settings



αp-reaction



- Missing mass squared spectra for 4 accepted momentum intervals:
- A) secondary protons detected
- B) secondary pions detected



Spectra of M^2_{miss} for 4 momentum settings of SPES4

$M_{miss} = M(X)$ in the studied reaction

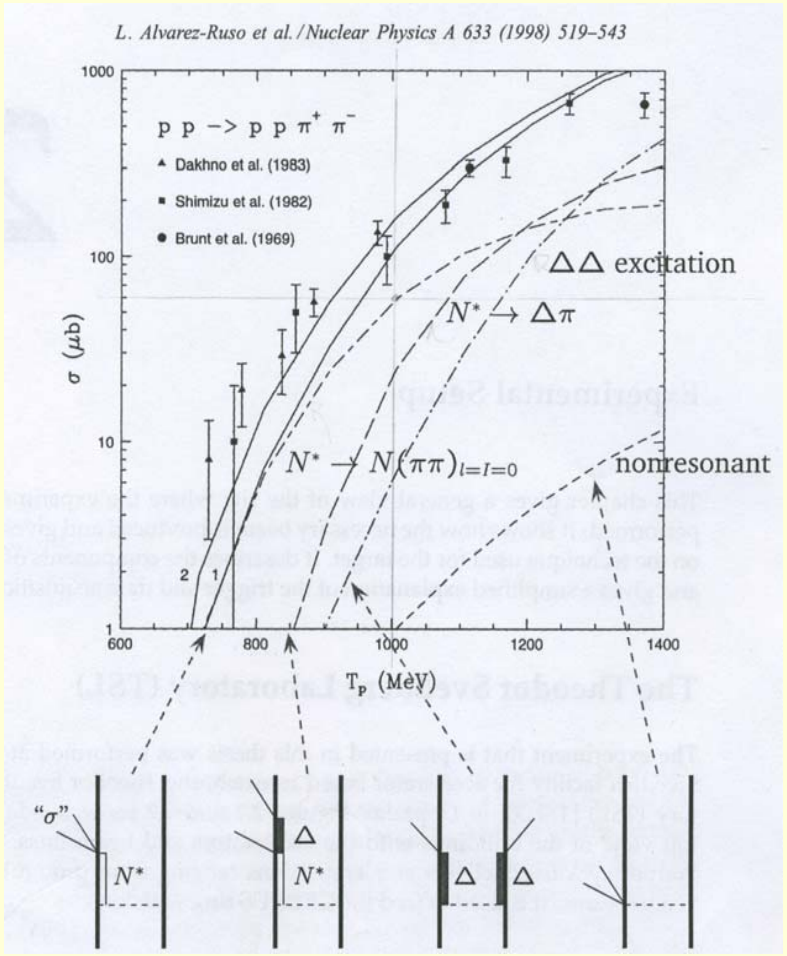
$$\alpha p \rightarrow \alpha p X$$

a) p_α/Z = 3.35 Gev/c
b) p_α/Z = 3.25 GeV/c
c) p_α/Z = 3.15 GeV/c
d) p_α/Z = 3.06 GeV/c

One-pion events – from the decays of Δ and Roper to $p\pi^0$
Two-pion events – from the decays of Roper to $p\pi^0\pi^0$ and $p\pi^+\pi^-$

In the region of the excitation energy corresponding to excitation of the Roper resonance (SPES4 momentum settings p_α/Z = 3.15 and 3.06 GeV/c), the two-pion Roper decay is the dominant decay channel

Two-pion production channels



- Excitation functions for different channels of two-pions production in the reaction pp->pp$\pi+\pi-$

Different possible processes of the two-pion production in *αp* scattering

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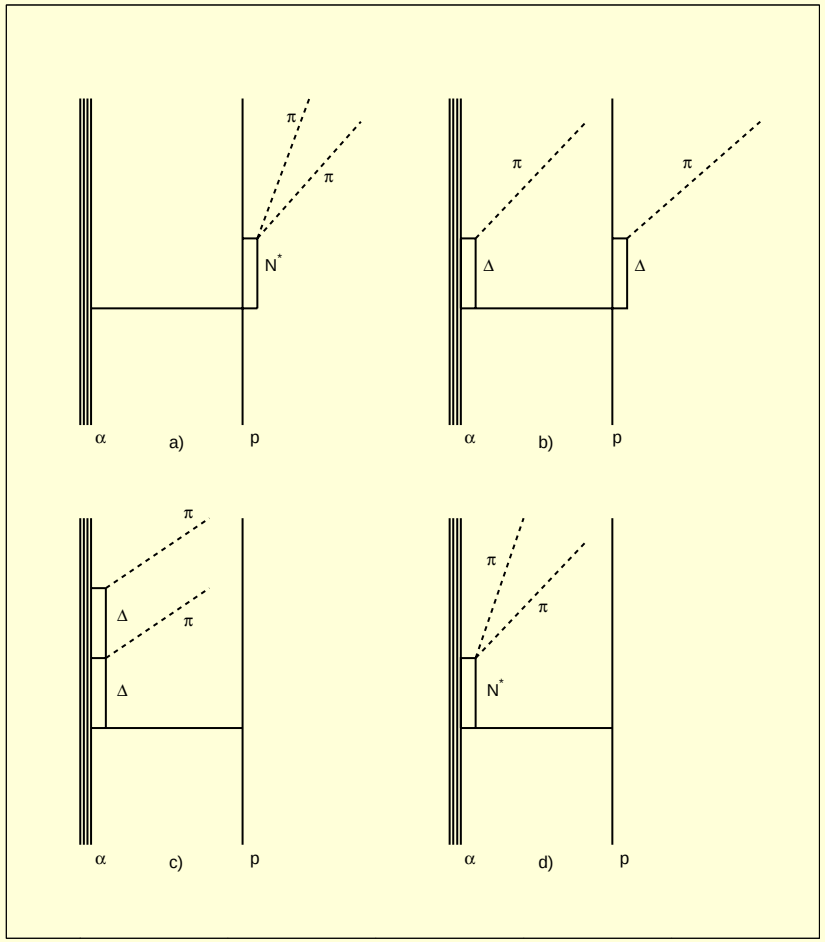
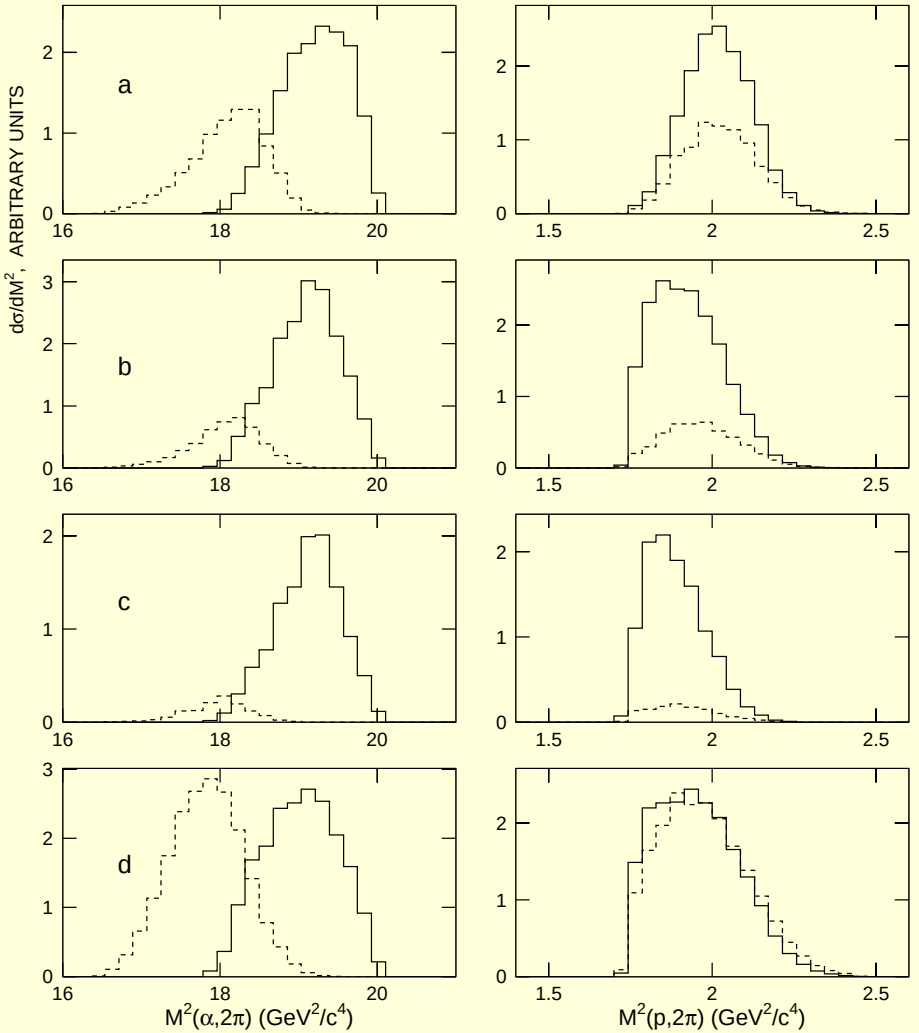
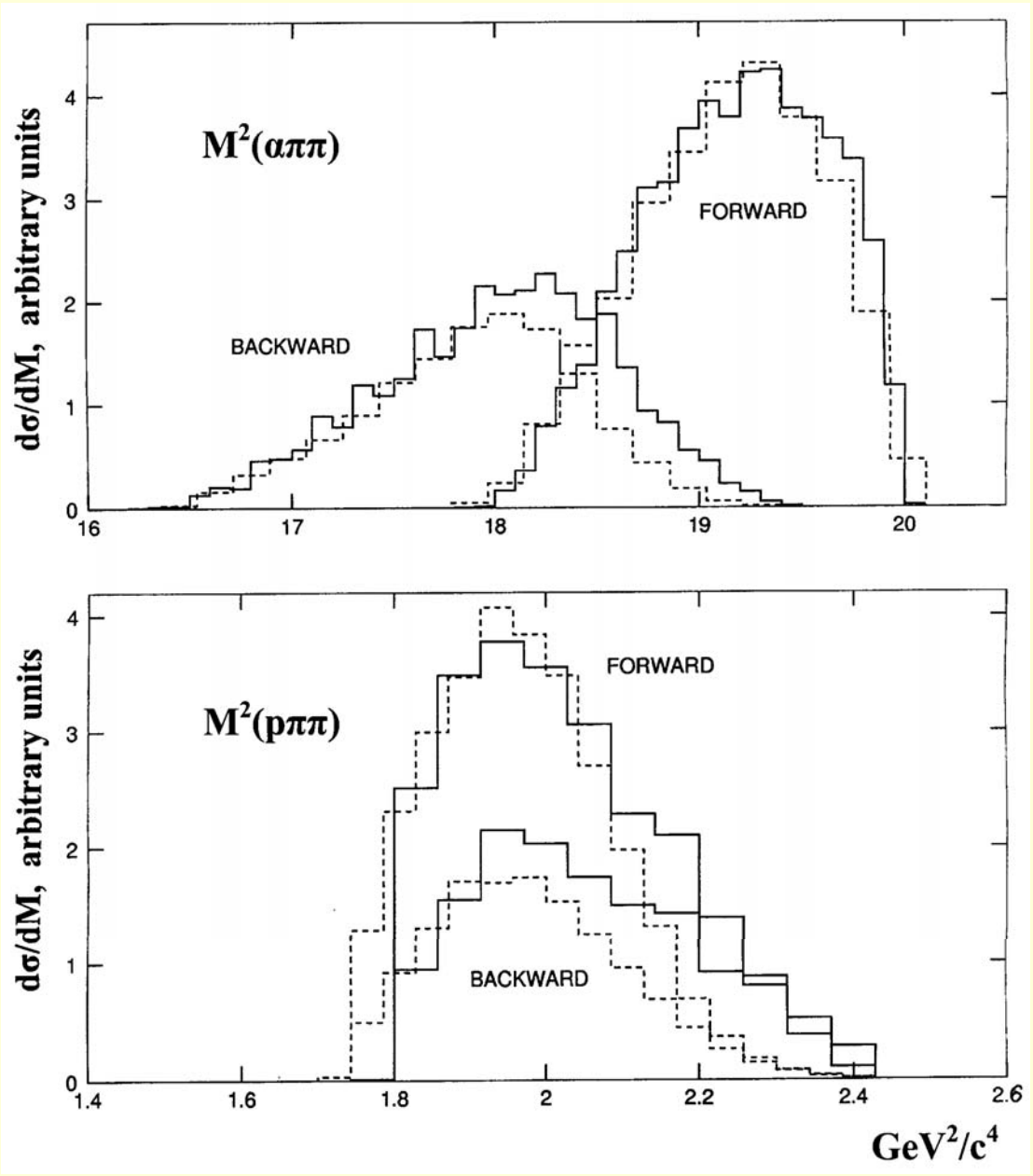


Invariant mass simulated spectra of $M^2(\alpha\pi\pi)$ and $M^2(p\pi\pi)$.

Solid curves – protons in the forward hemisphere, dashed curves –protons in the backward hemisphere





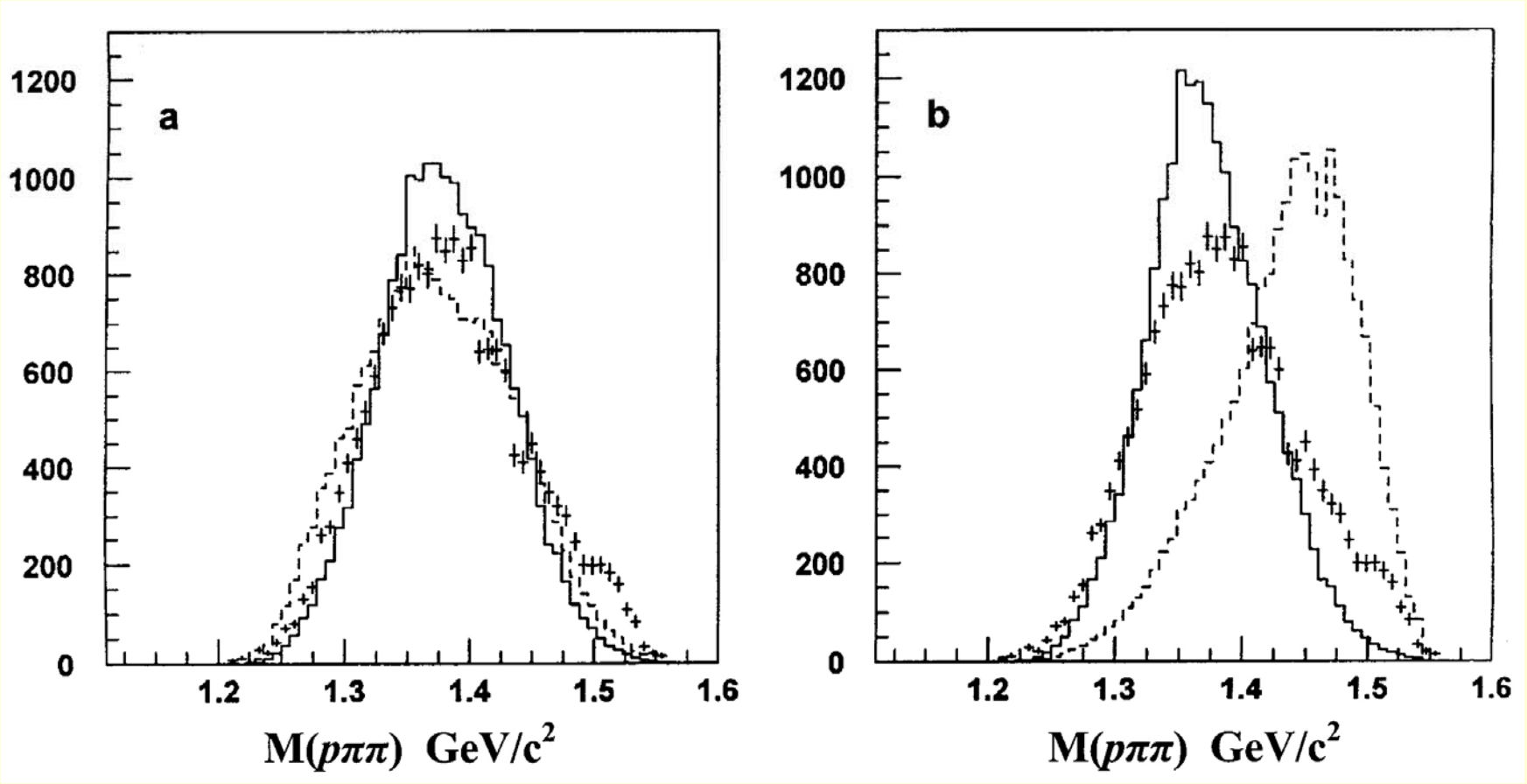
A comparison of the simulated spectra of $M^2(\alpha\pi\pi)$ and $M^2(p\pi\pi)$ with the experimental data for the assumed process of the Roper excitation in the target proton

Dashed line histograms – the simulated spectra; solid line histograms – the experimental data

p_α/Z=3.06 GeV/c

A comparison of the simulated spectra of $M(p\pi\pi)$ with the experimental one

(The data from all SPERS4 momentum settings are included)

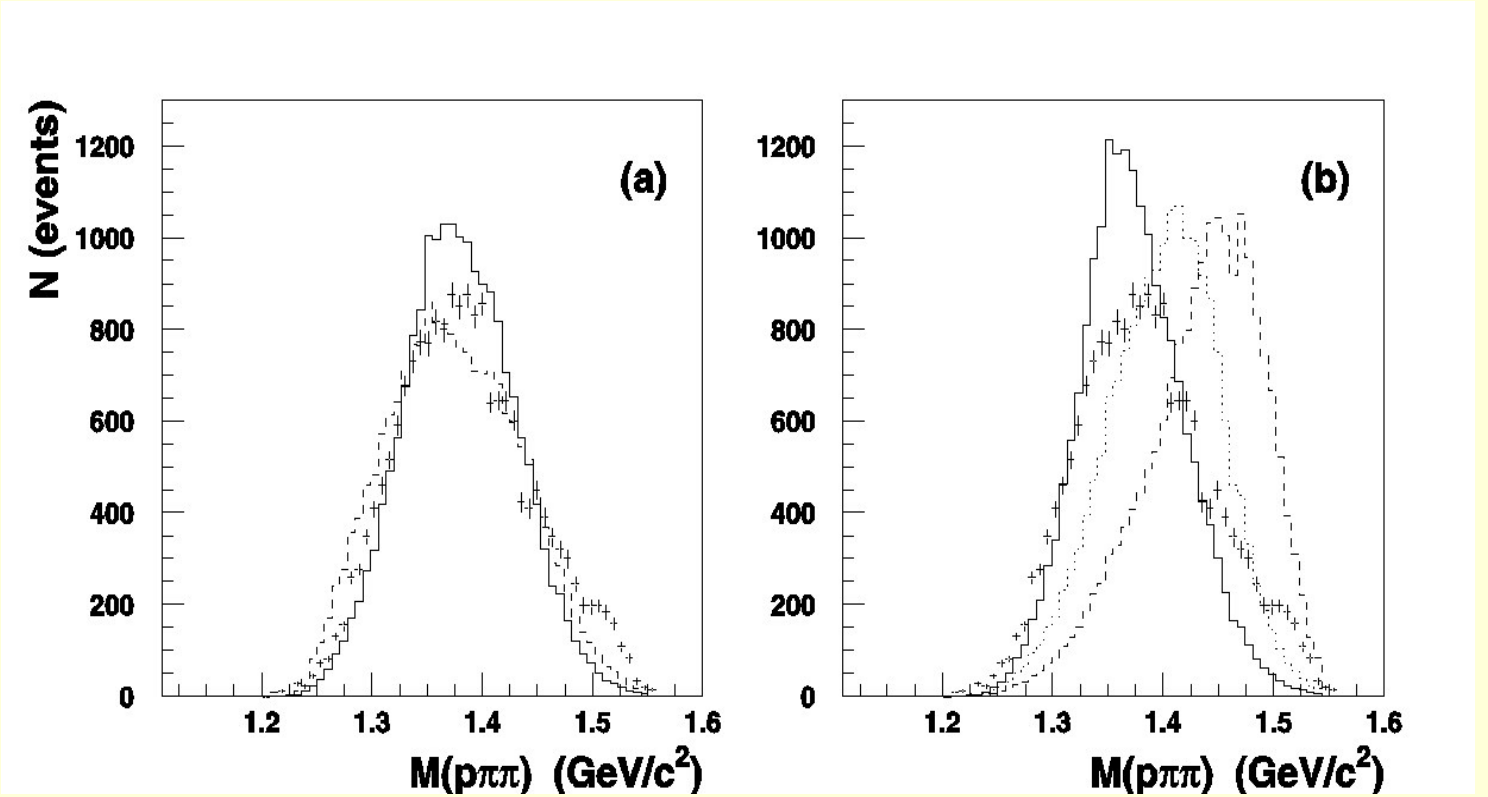


Dashed line – phase space
Solid line – Roper: M=1440 MeV, Γ=350 MeV

Dashed line – D_{13} resonance
Solid line – Roper: M=1390 MeV, Γ=190 MeV

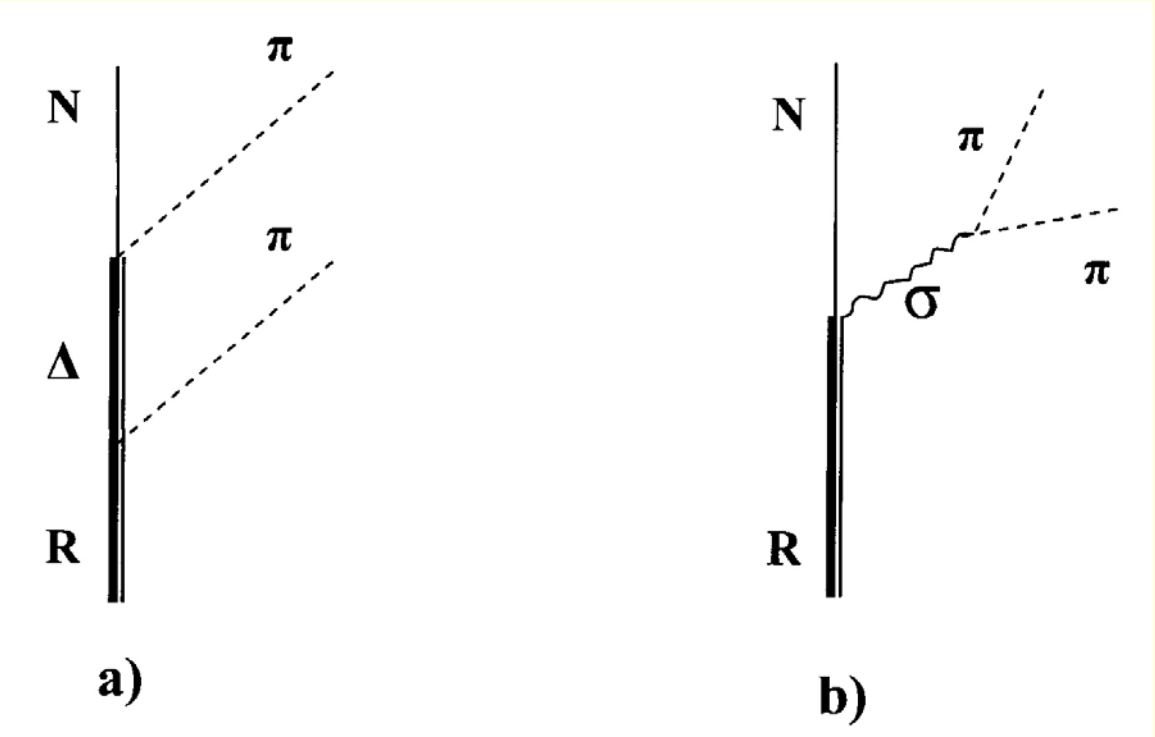
Crosses – experimental data

A comparison of the simulated spectra of M(pππ) with the experimental one.



- Dashed line – D13 resonance.
- Solid and dotted (in the middle) lines are Roper with M = 1390 MeV and a new with M = 1485 MeV according R.Arndt et al. (2006)

Possible two-pion production routes of the Roper resonance decay



A sequential decay through Δ

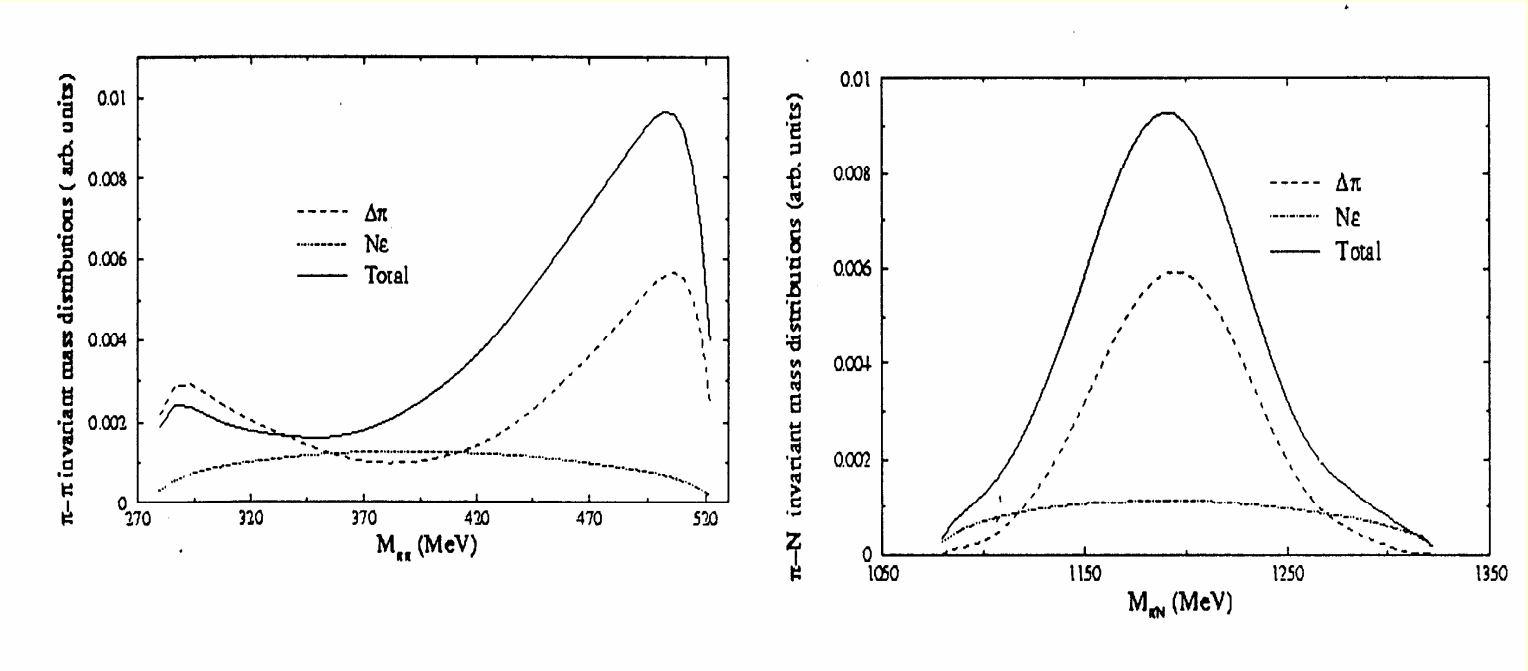
A decay through an intermediate σ- meson

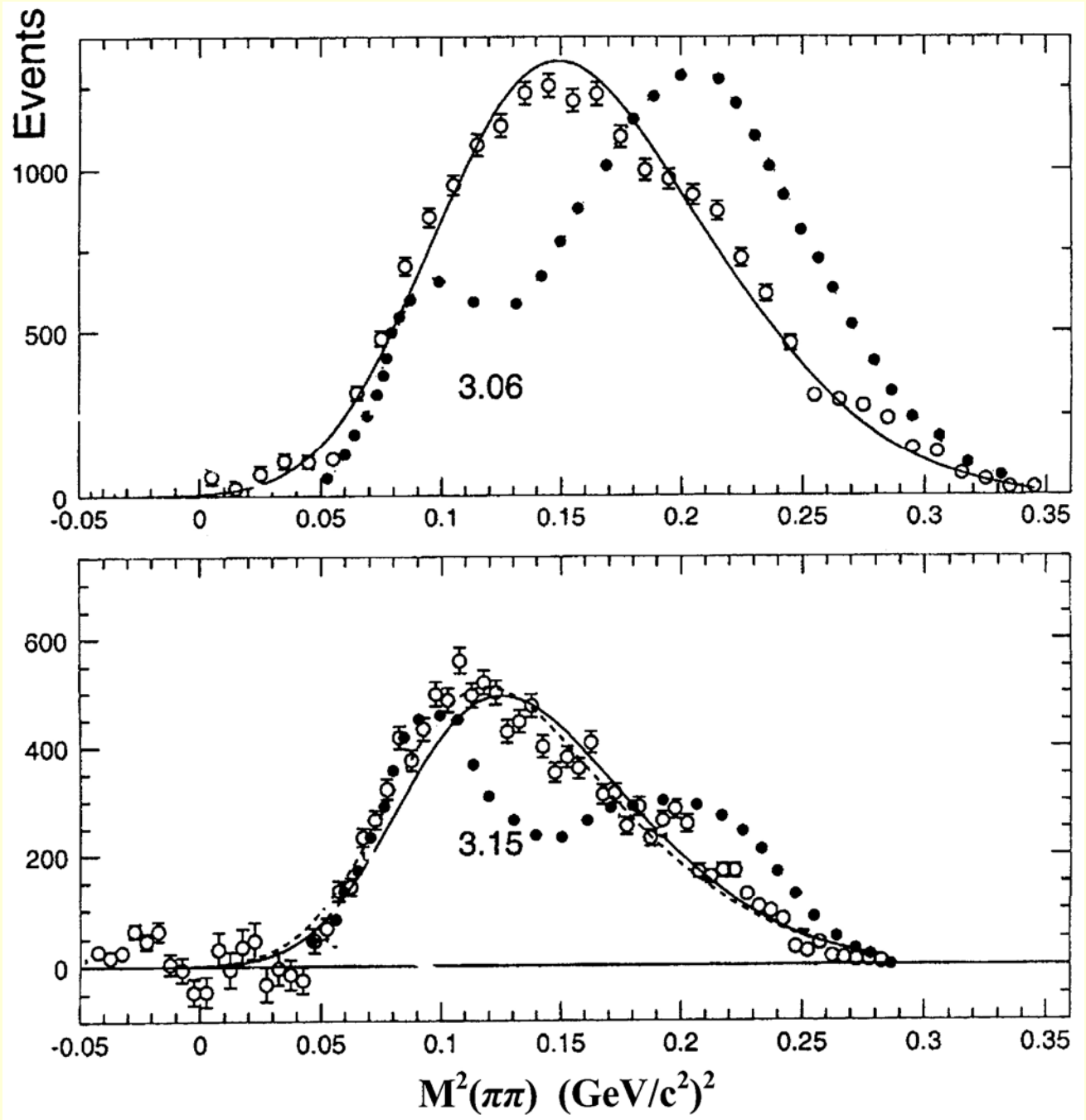
According to E. Hernandez, E. Oset and M.J. Vicente Vacas (Phys. Rev. C **66** (2002)), the spectra of $M(\pi\pi)$ are essentially different for these two Roper decay processes

αp-reaction

Manley approach for two-pions decay of Roper resonance

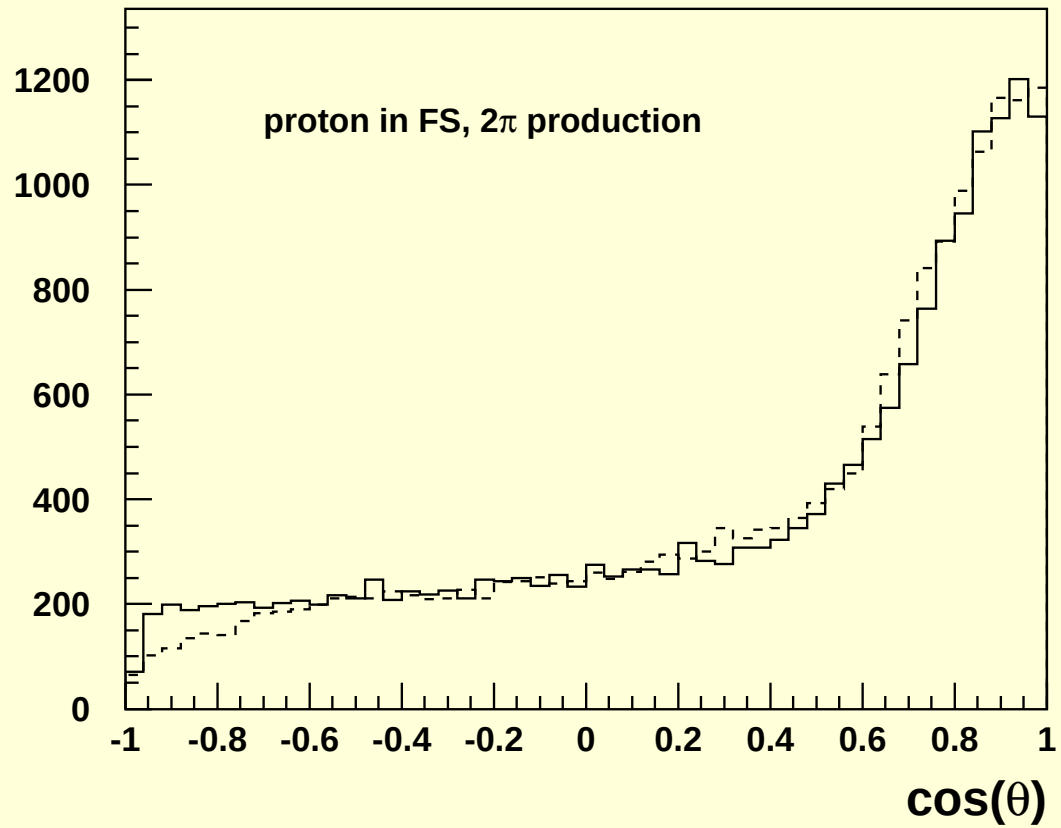
from: E.Hernandez et al., PRC (2002) 65201





Spectra of $M^2(\pi\pi)$ for the SPES4 momentum settings 3.06 and 3.15 GeV/c

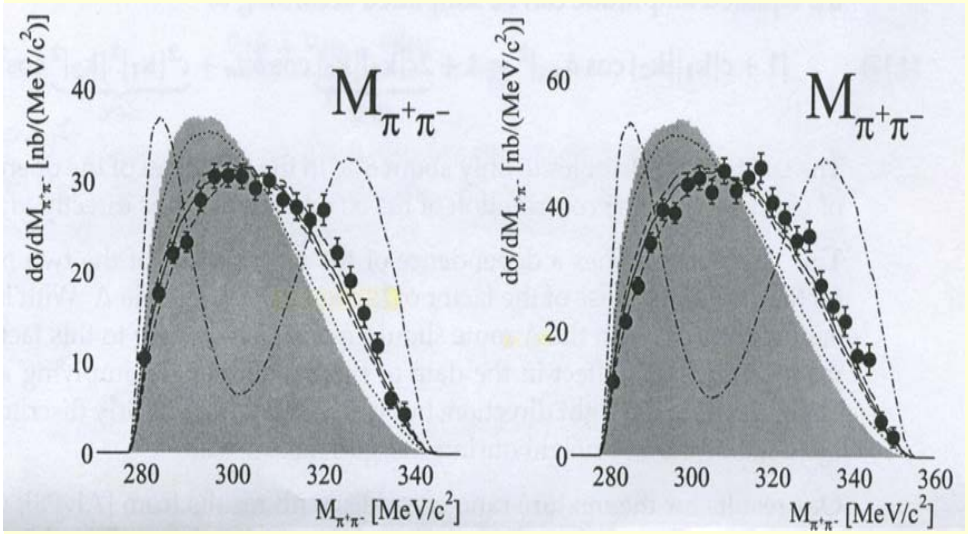
Open points – experimental data; solid curves – results of simulations assuming $N^* \rightarrow N\sigma \rightarrow N\pi\pi$ decay; dots – results of simulations assuming $N^* \rightarrow \Delta\pi \rightarrow N\pi\pi$ decay



Angular distributions of the scattered protons in the *N CM-system**
(distorted by the SPES4-π acceptance)

Solid line – result of the simulation assuming isotropic decay;
dashed line – experimental data

pp - reaction



- Reaction pp→pp$\pi\pi$ at 750 and 775 MeV.
- M($\pi\pi$) invariant mass spectra.

CONCLUSIONS

Our data are compatible with the assumption that the studied $p(\alpha,\alpha')p\pi\pi$ reaction proceeds via scalar excitation (σ exchange) in the target proton of the Roper resonance as an intermediate state,
which decays predominantly through the $N^* \rightarrow N\sigma \rightarrow N\pi\pi$ channel.

The obtained results are in favour of the statement of P.-H. Morsch *et al*.
that the resonance excited in αp scattering at the excitation energy around 1440 MeV is the breathing excitation mode of the nucleon.

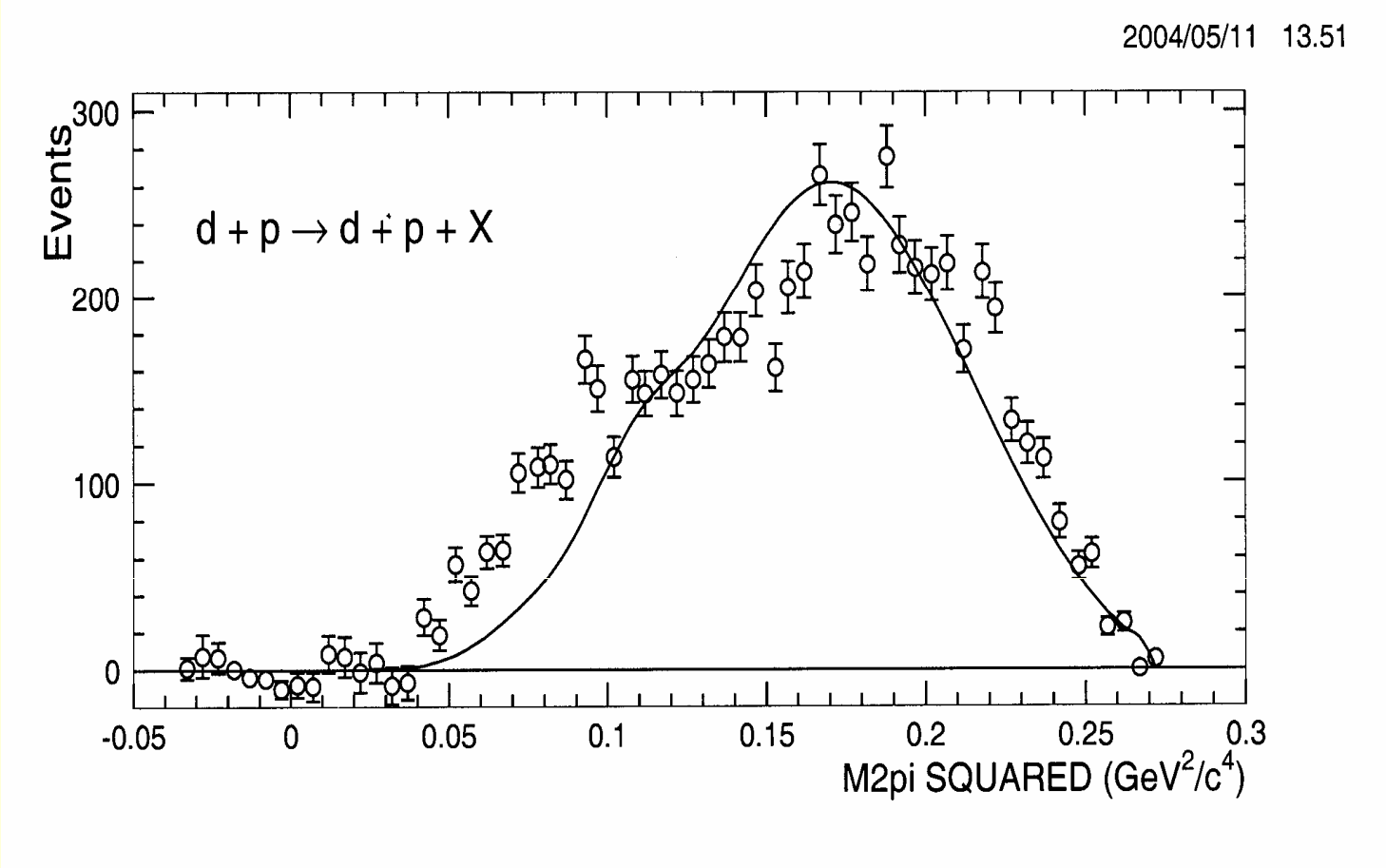
Our results are very different from PDG predictions based on πN data,
however our results nicely correlate with the results of recent investigations of the two-pion production in inelastic *pp* scattering at energies near 0.7 GeV:
Bo Hoistadt *et al*. (CELSUS-WASA collaboration),
Nucl. Phys. A **721** (2002) 192301,
J. Patzold *et al*., Phys. Rev. C **67** (2003) 052202R.
H.Clement *et al*., arXiv:nucl-ex/0612015 v1

According to these investigations, the Roper resonance excited in inelastic *pp* scattering also decays predominantly by emitting two pions through the intermediate σ state.

CONCLUSIONS

- **The experimental data does not support also the new values of the Roper resonance parameters, obtained by R.Arndt et all (2006).**

dp-reaction


2004/05/11 13.51
Events
300
200
100
0
d + p → d + p + X
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
M2pi SQUARED (GeV²/c⁴)