ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

R-2945

МАТЕРИАЛЫ XIII МЕЖДУНАРОДНОЙ КОНФЕРЕНЦИИ ПО ФИЗИКЕ ВЫСОКИХ ЭНЕРГИЙ

Беркли 1966 г.

G. Goldhaber

G. Goldhaber
September 5, 1966

PICTORIAL ATLAS OF BOSON RESONANCES

SUPPLEMENT TO THE RAPPORTEUR TALK

ON "BOSON RESONANCES".

G. Goldhaber	Rapporteur
B. C. Shen	Secretary

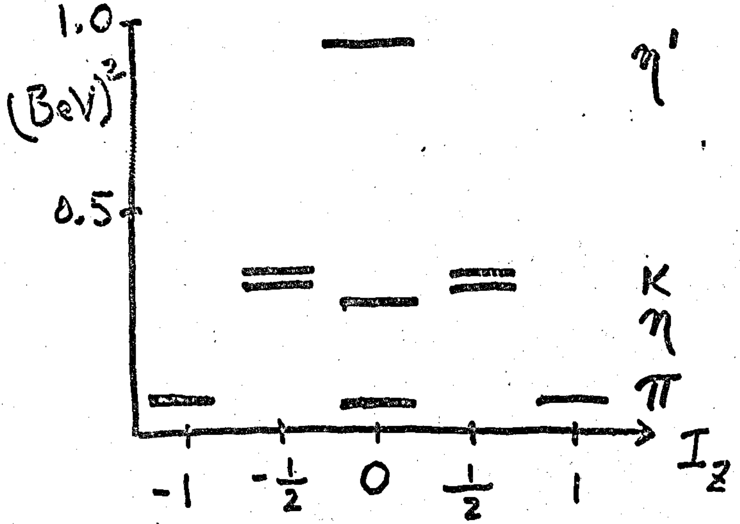
NON STRANGE BOSONS (7a)

N. P. Samios	Discussion Leader
A. R. Clark	Secretary

STRANGE BOSONS (7b)

A. Astier	Discussion Leader
K. W. Lai	Secretary

$J^P = 0^-$ NONET



$C = +1$

$^1S_0(q\bar{q})$

$\theta_0 = 10°$

Is $X^0 \stackrel{?}{=} \eta'$ $M = 959$

$E(1420) \longrightarrow K\bar{K}\pi$

$C = +1$

CONCLUDED FROM:

$E \longrightarrow K_1^0 K_1^0 \pi^0$ 83 ± 21 events

$\not\longrightarrow K_1^0 K_2^0 \pi^0$ 20 ± 25 events (limit)

PREFERED SPIN: 0^-

1^+ (POSSIBLE)

$\eta' \stackrel{?}{=} X^0$ CAN THE X^0 BE AN $I=1$ OBJECT?

COMPARE RATES

	I=0	I=1
$K^- p \to \Lambda X^0$	1	1
$K^- n \to \Lambda X^-$	0	2

Two $K^- d$ Bubble Chamb. Expts.

① MARTIN et al (INDIANA)

FROM KNOWN X^0 PRODUCTION RATES IF $I=1$

PREDICT	FIND
19 ± 6	5 ± 4

② RITTENBERG (LRL)

PREDICT	FIND
19 ± 6	0

$\therefore$ $I=1$ For X^0 Very Unlikely

$M(\delta^-) = 963 \pm 5 \quad \Gamma < 5$

$M(\delta^+) = 966 \pm 8 \quad \Gamma \sim 0$

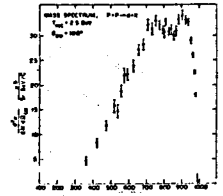
$\Big\} \; M(\delta^\pm) = 964$

$M(X^0) = 959 \quad \Gamma < 3$

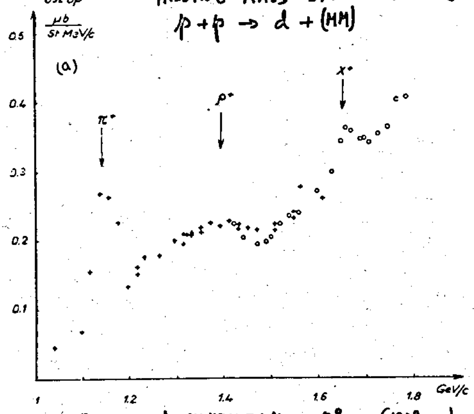
EVIDENCE FOR δ^+ and δ^-

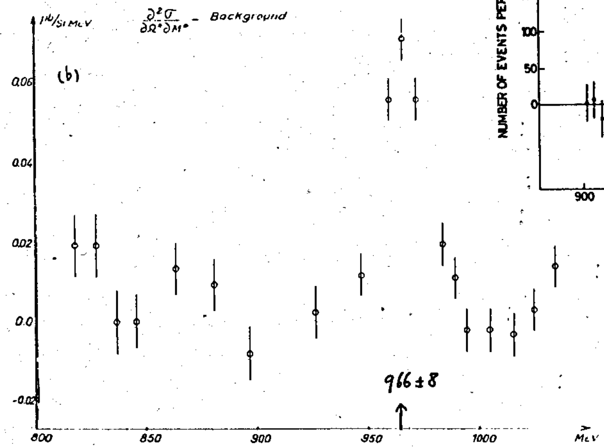
TURKOT et al.

$p + p \to d + X^+$

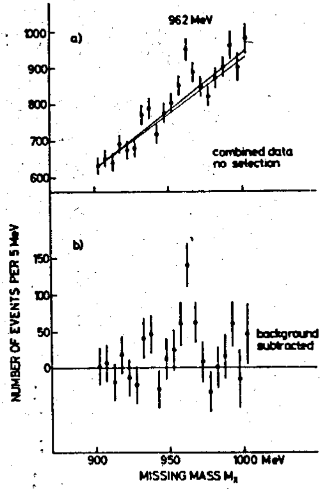


OOSTENS et al
MISSING MASS SPECTROMETER
$p + p \to d + (MM)$





KIENZLE et al.
Missing-mass spectromenter

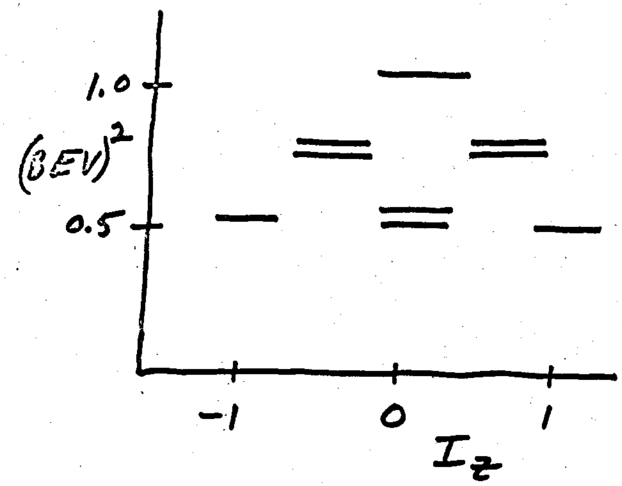


δ^-

VECTOR

$J^P = 1^-$ $C = -1$ NONET

$^3S_1 (q\bar{q})$



$\theta_1 = 40°$

① ϕ SPIN $\bar{p} d \to \phi$

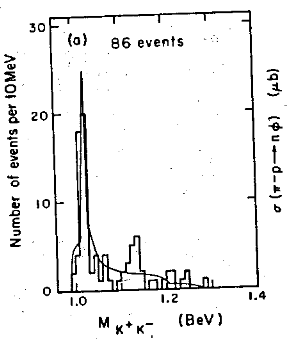
② $\pi^- p \to \phi n$
$\quad \hookrightarrow K^+ K^-$

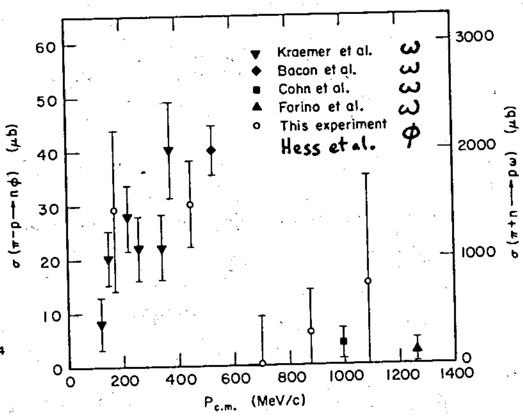
$\sigma(\phi) / \sigma(\omega) \approx 1/50$

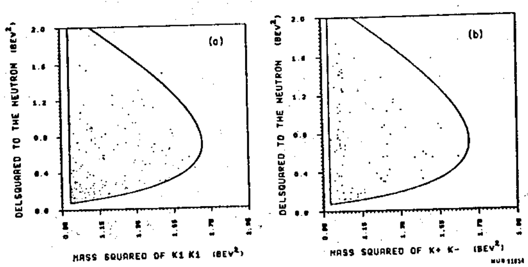
Non-Peripheral ϕ.

③ $\omega - \rho$ Interference ?

Hess et al. $\pi^- p$

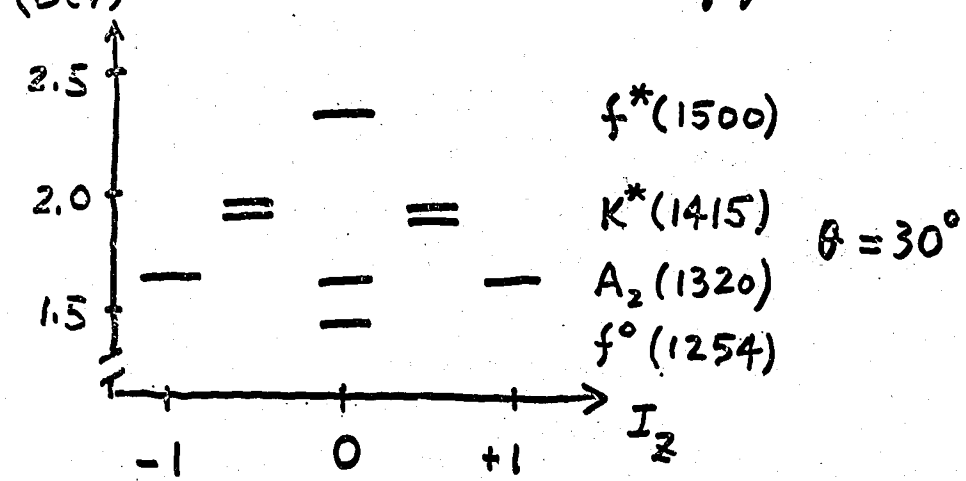






$J^P = 2^+$ NONET

$C = +1$ $\quad {}^3P_2\,(q\bar{q})$



① A_2 SPIN — DEBATED

$A_2 \longrightarrow K\bar{K}$ $J^P = 2^+$ CLEAR CUT (IGNORING 4^+)

$A_2 \longrightarrow \rho\pi$ SPIN DETERMINATION STRONGLY BACKGROUND DEPENDENT 1^+? 2^-?

A_2 MASS: 1280 MeV FOR 8 GeV/c DATA

1320 MeV " 3-4 " "

SPLITTING — DOUBTFUL

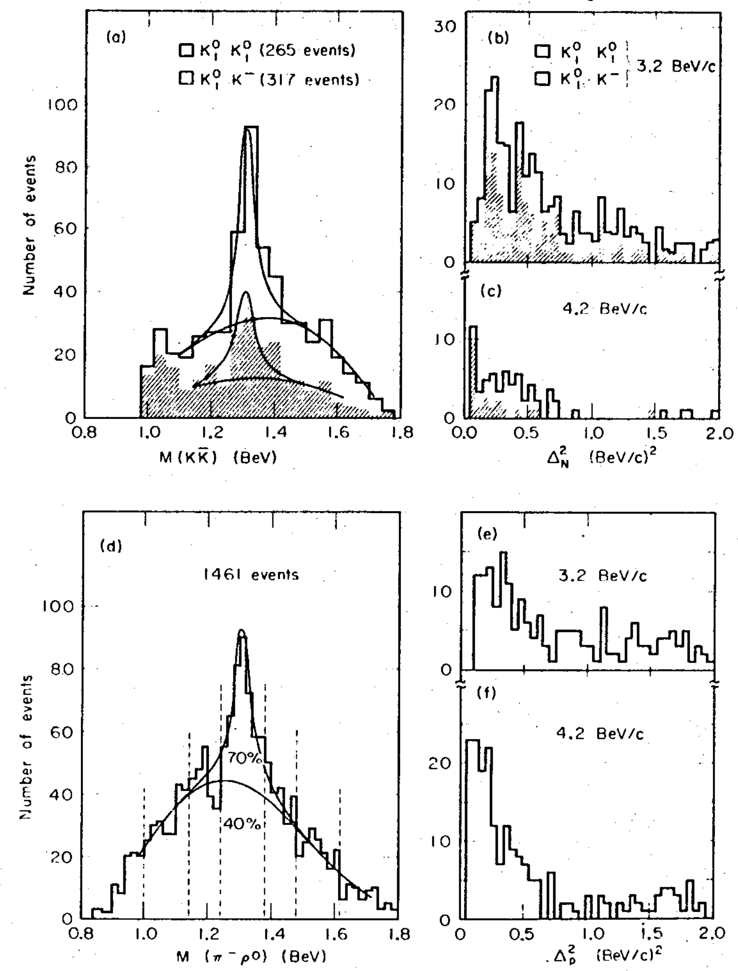
② f^0 SPIN 2^+ CONFIRMATION, $f^0 \rightarrow \pi^0\pi^0$

③ $f^* \rightarrow K\bar{K}^*$ LESS INTENSE, INTERFERENCE WITH E, SPIN 2^+ CONFIRMATION

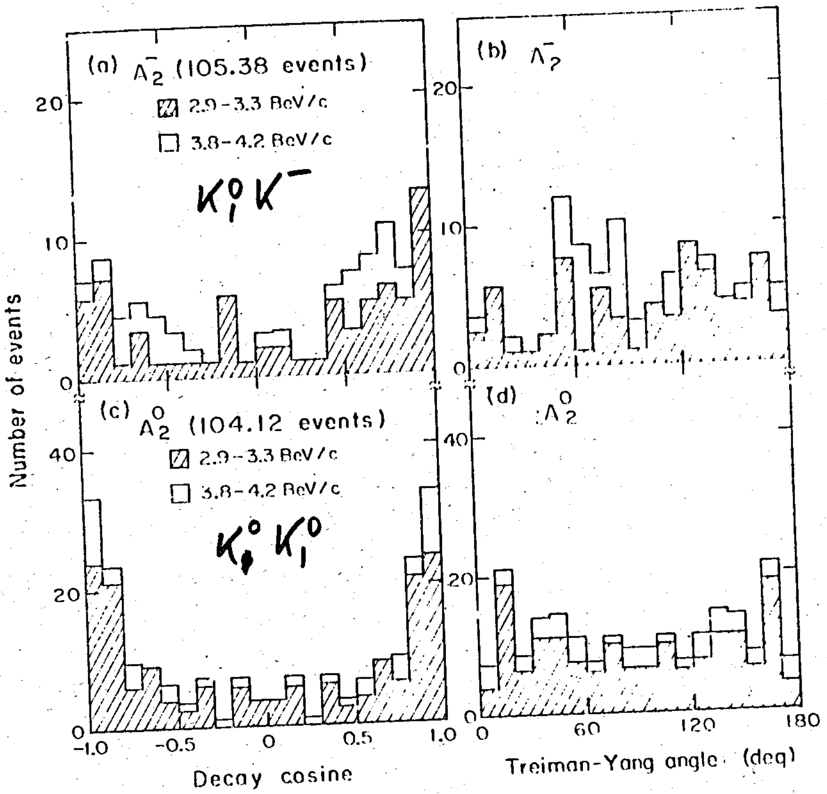
④ $K^*(1415) \rightleftarrows \dfrac{K^*\pi}{K\pi} \sim 0.6$

CONSISTENT WITH GLASHOW SOCOLOW

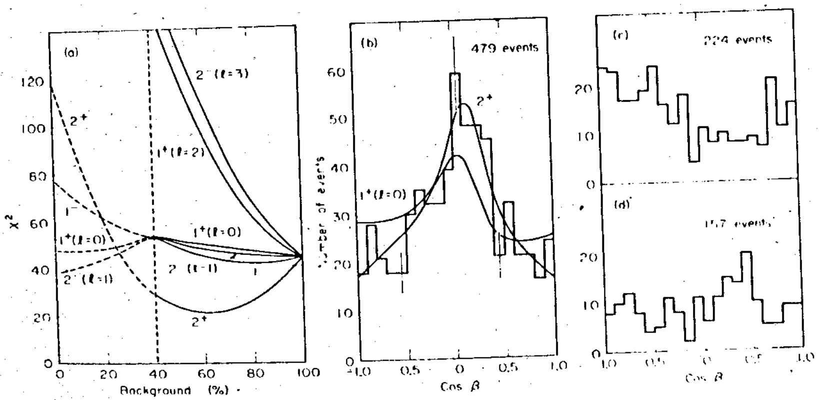
CHUNG et al. $\pi^- p$



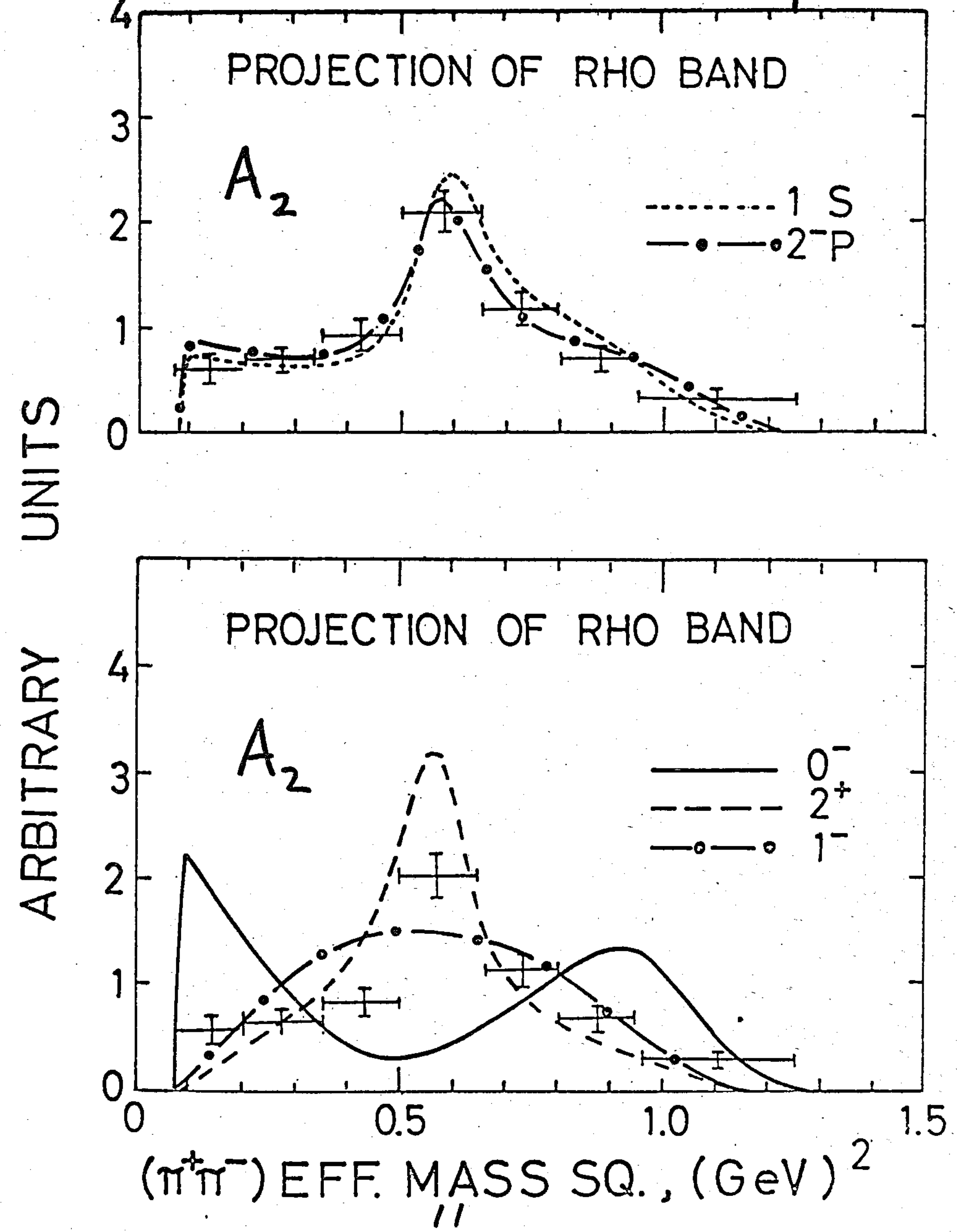
CHUNG et al. $\pi^- p$



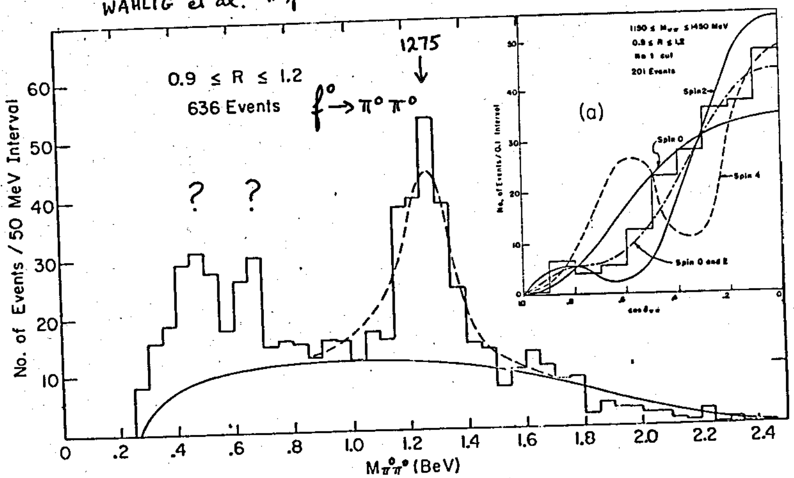
SPIN ANALYSIS FOR $A_2 \to \rho\pi$

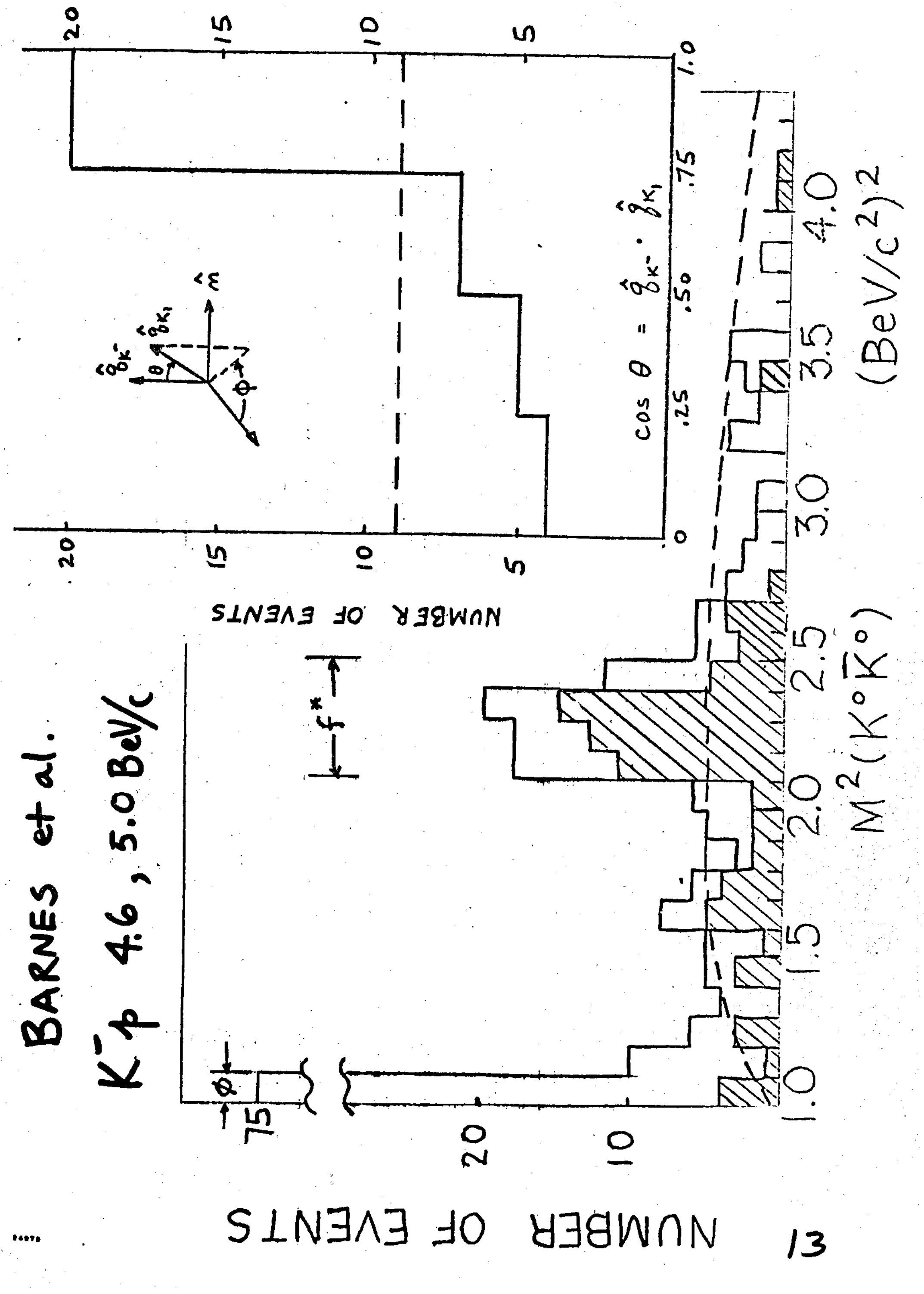


ABC 8 GeV/c $\pi^+ p$

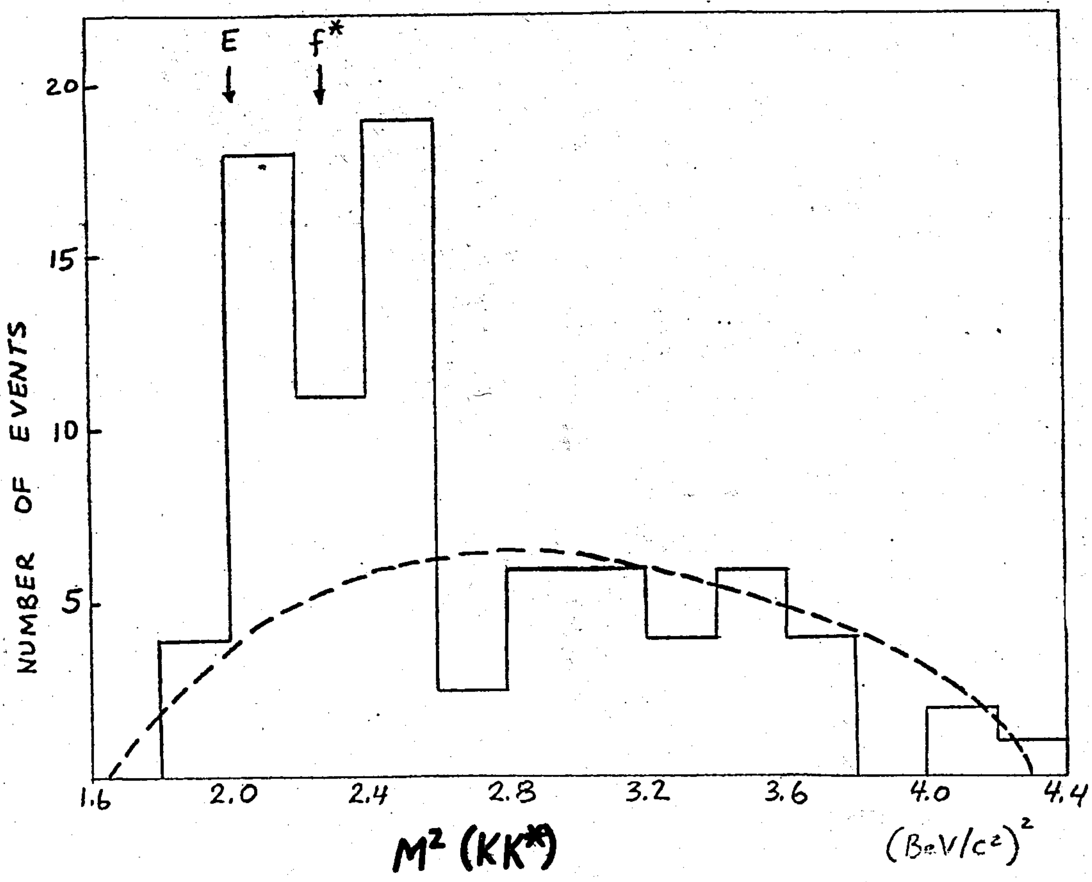


WAHLIG et al. $\pi^- p \to \pi^0 \pi^0 n$ 10 BeV/c SPARK CHAMBERS



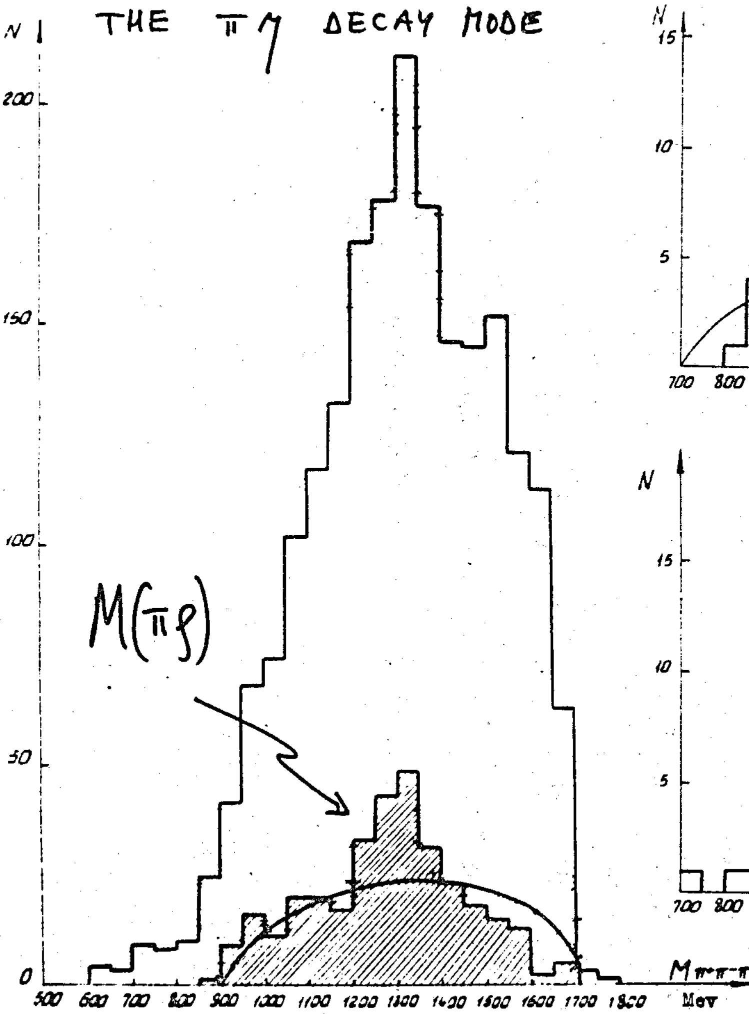


BARNES et al. $K^- p$ 4.6, 5.0 BeV/c

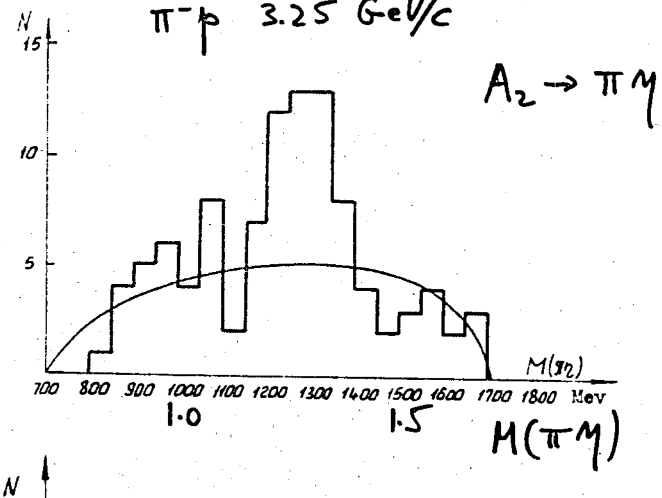


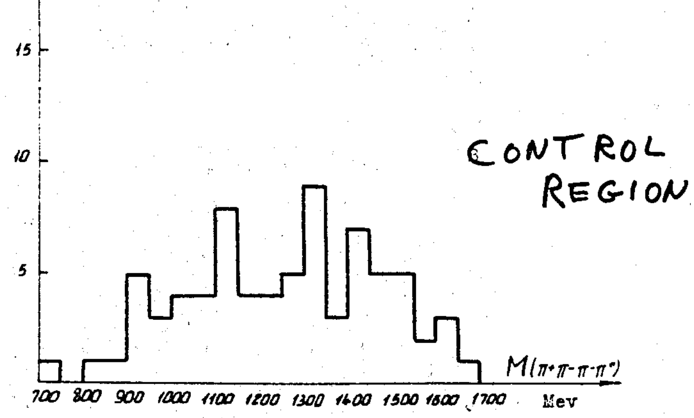
14

ADDITIONAL EVIDENCE ON THE $\pi\eta$ DECAY MODE



DUBOVIKOV et al (MOSCOW)
$\pi^- p$ 3.25 GeV/c





15

$q\bar{q}$ MODEL

$q\bar{q}$, $\ell = 0$:

- $^3S_1$ — $\rho\ \omega\ K^*\ \phi$ — 1^- $C=-1$
- $^1S_0$ — $\pi\ \eta\ K\ \eta'$ — 0^- $C=+1$

$q\bar{q}$, $\ell = 1$:

- $^3P_2$ — $A_2\ f^0\ K^*(1430)\ f^*$ — 2^+ $C=+1$
- $^1P_1$ — 1^+ $C=-1$
- $^3P_1$ — 1^+ $C=+1$
- $^3P_0$ — 0^+ $C=+1$

TO GET 2^- WE NEED $\ell = 2\ q\bar{q}$

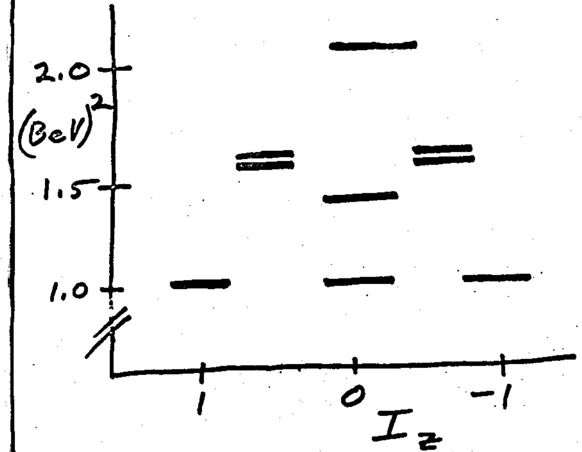
OR "ABNORMAL MODES"

i.e. $qq\bar{q}\bar{q}$ SYSTEMS

!! SPECULATIVE !!

$J^P = 1^+$ NONET (?)

$C = +1$ $\quad 3\,P_1\,(8\bar{8})$



E(1425) {SPIN 0⁻ PROPOSED

$K^*(1320)$ ← New

D (1286) $\quad \theta_{1^+} = 28° \pm 8°$

$A_1(1080)$?

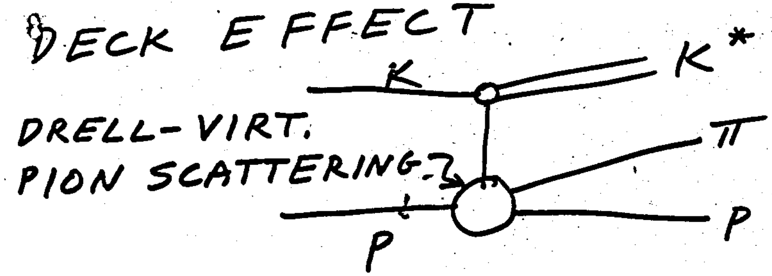
① $K^*(1320) \to K^*(890) + \pi$] INTERFERENCE

$\to \rho K$]

$\to \omega K$

$\not\to K\pi$

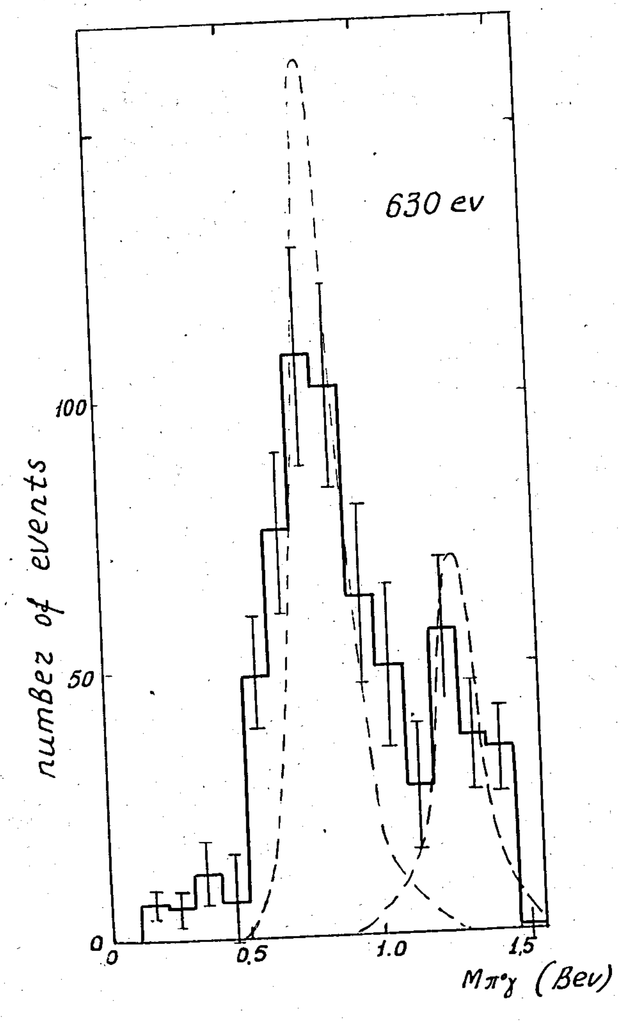
② DECK EFFECT



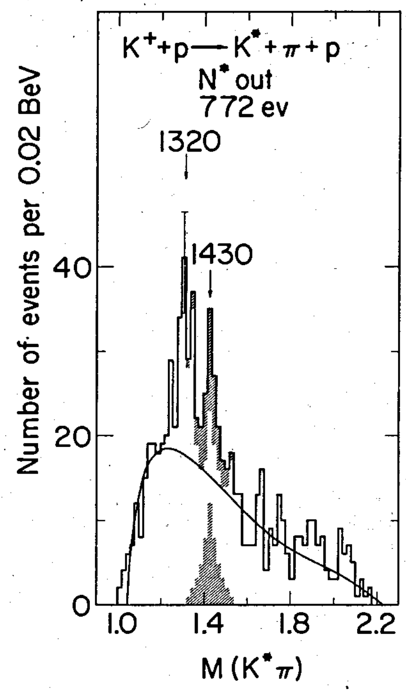
Barmin et. al.

$\pi^- p \rightarrow n + \pi^0 \gamma$ at 2.8 GeV/c

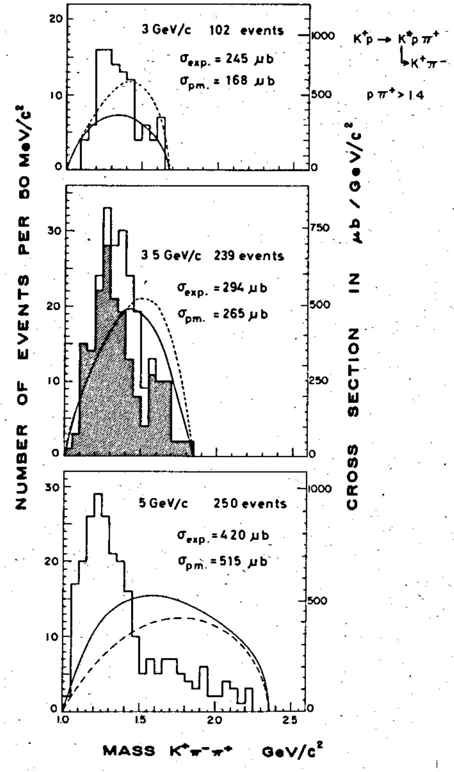
(Propane-Xenon B.C.)



SHEN et al. K^+p 4.6 BeV/c



de BAERE et al. K^+p



K^* (1320) and K^* (1430) PRODUCTION

An interesting phenomenon has been observed relating to K^* (1320) and K^* (1430) production in the K^-p reaction.

$$K^-p \rightarrow K^-\pi^+\pi^-p \qquad (1)$$

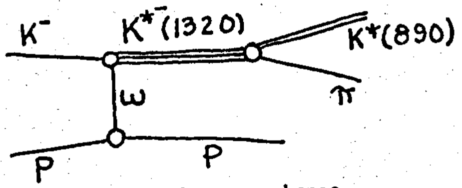
$$\rightarrow K^\circ\pi^\circ\pi^-p \qquad (2)$$

$$\rightarrow K^\circ\pi^+\pi^-n \qquad (3)$$

There is evidence for K^* (1430) production in all of these but K^* (1320) is not produced in the charge exchange reaction (3).

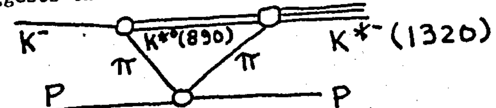
There are two possible explanations:

A. K^* (1320) production proceeds predominantly via isoscalar (ω) exchange.



This is not available in charge exchange

B. A proposal by Morrison suggests a diagram involving the Drell process, ie., virtual pion scattering at the nucleon vertex. He suggests that this enhances resonance formation.



This is suppressed for charge exchange at the lower vertex.

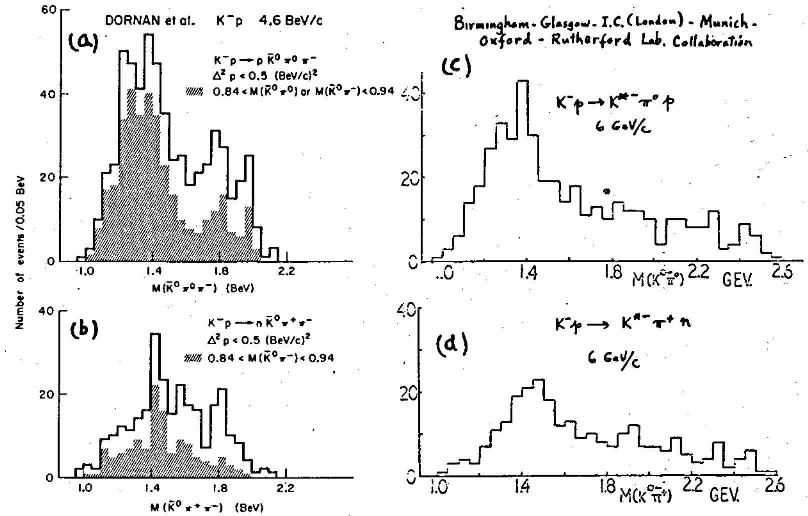
Evidence for this effect comes from DORNAN et al, K^-p 4.6 BeV/c,

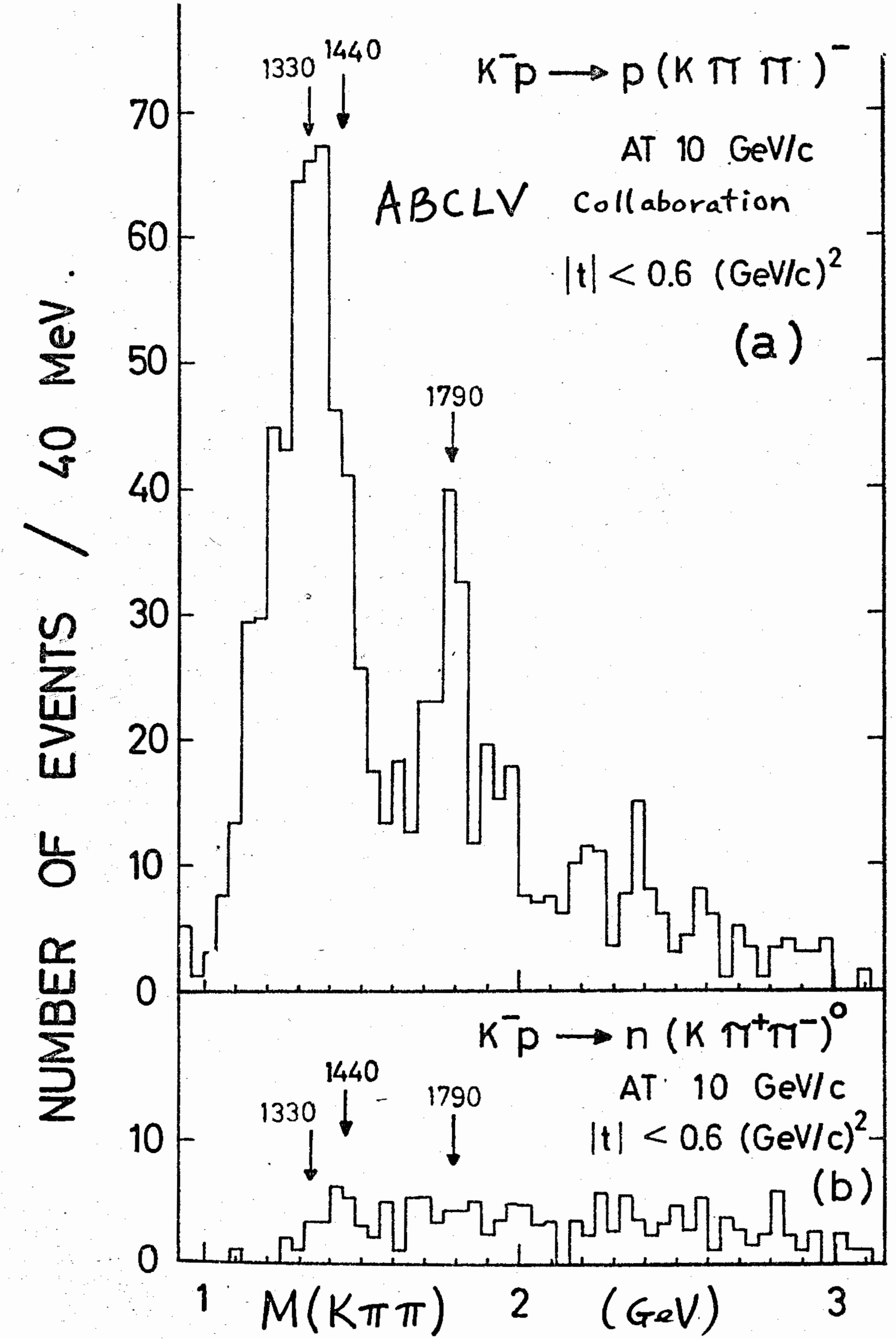
B, G, I.C(L), M, O, RL 6 GeV/c,

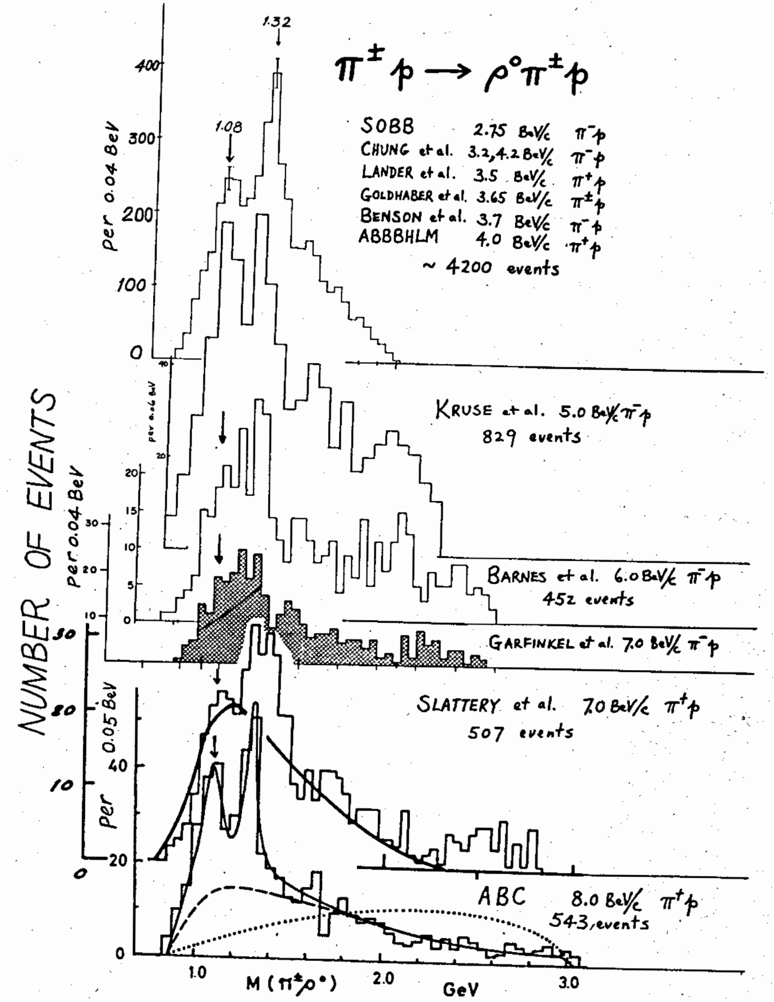
Argonne 4 + 5 GeV/c,

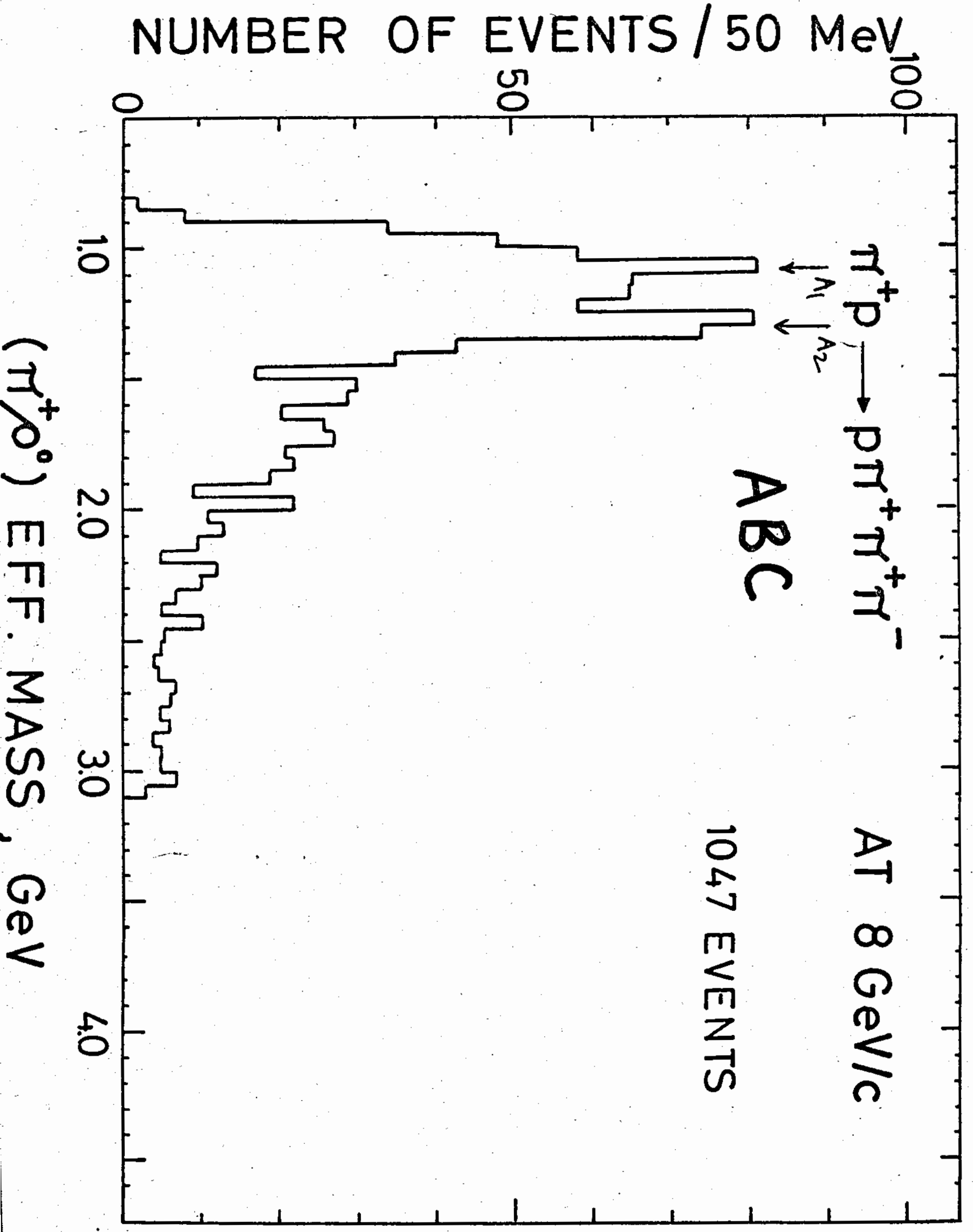
and particularly clear cut from

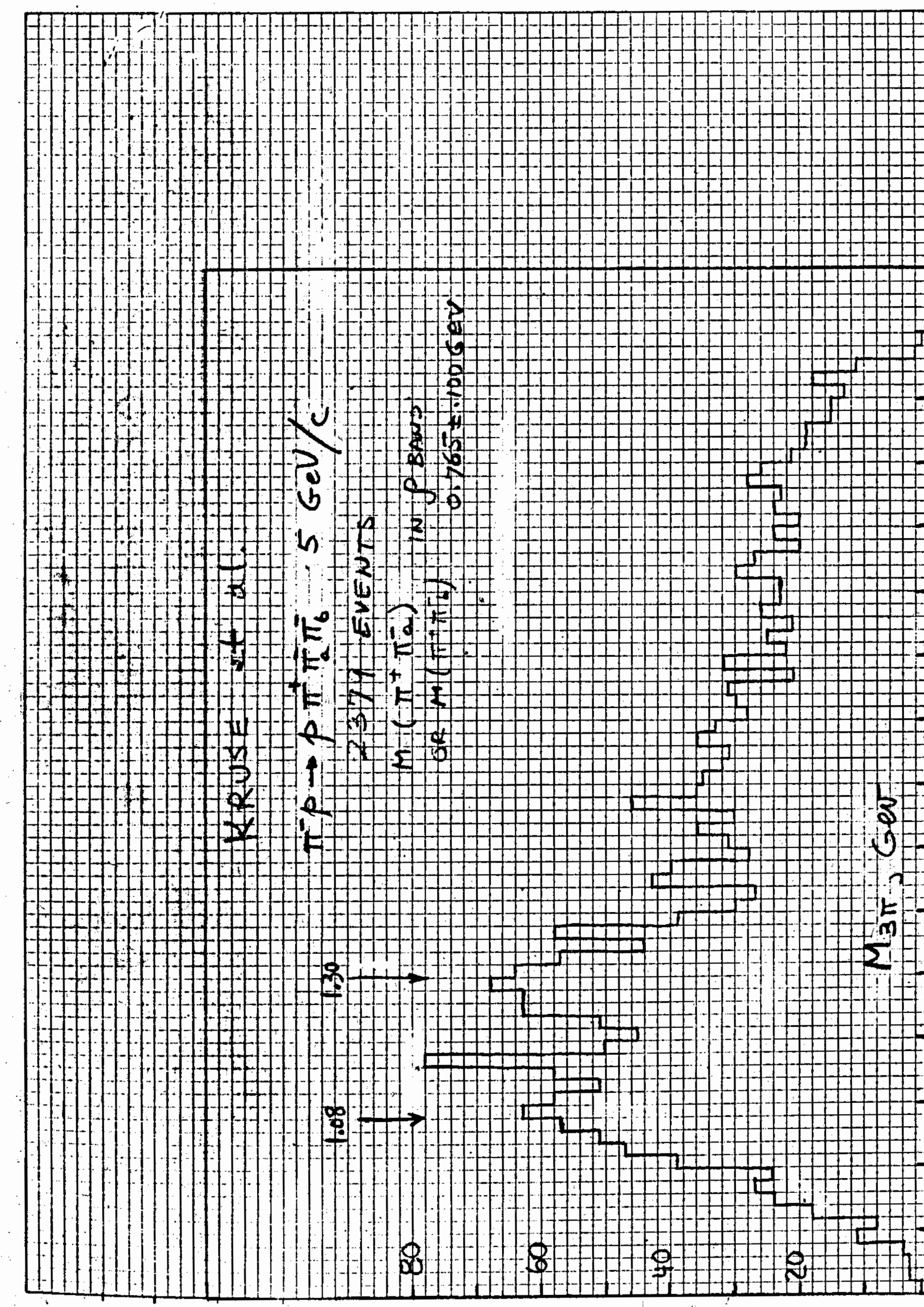
ABCLV 10 GeV/c

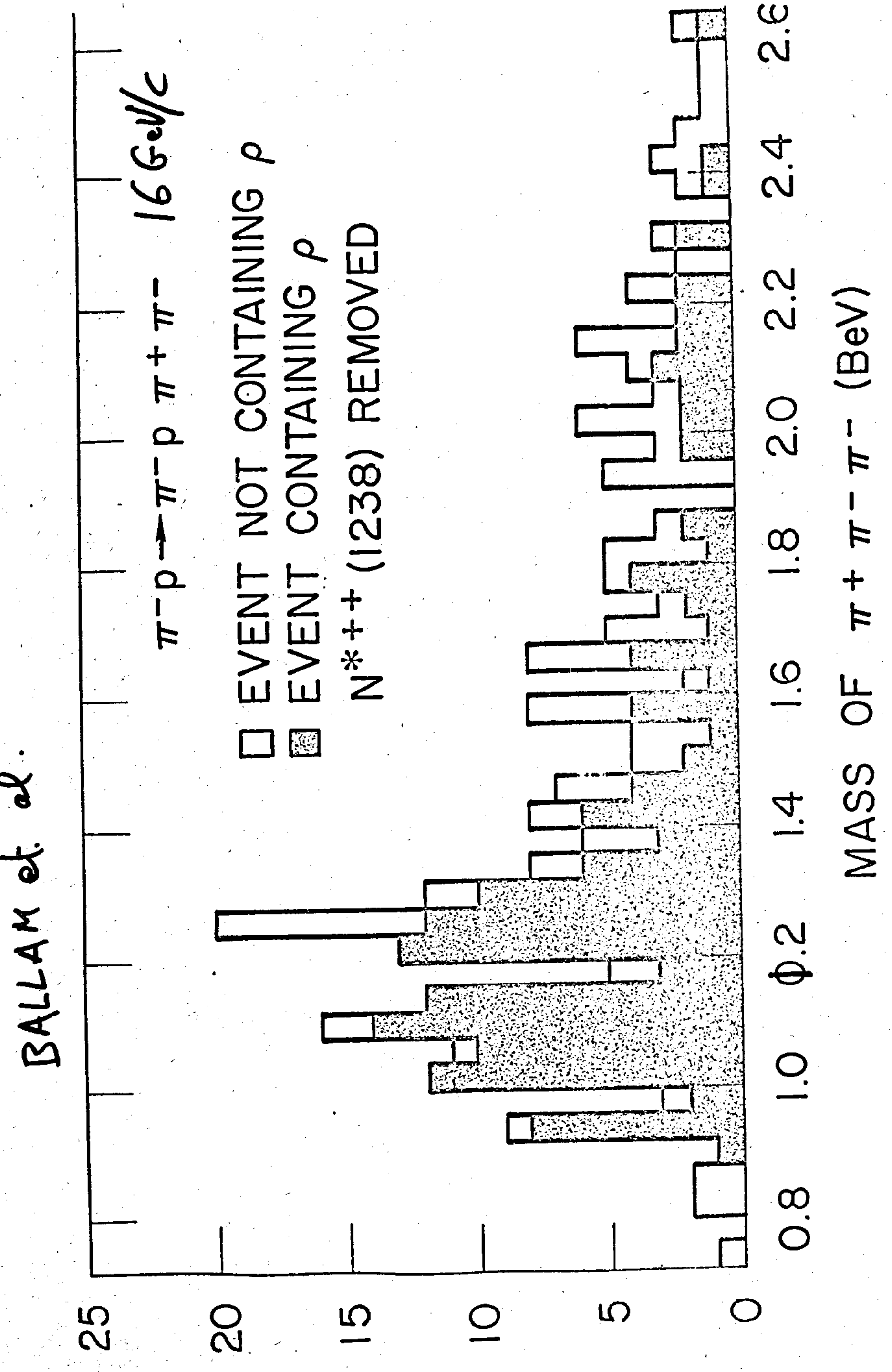


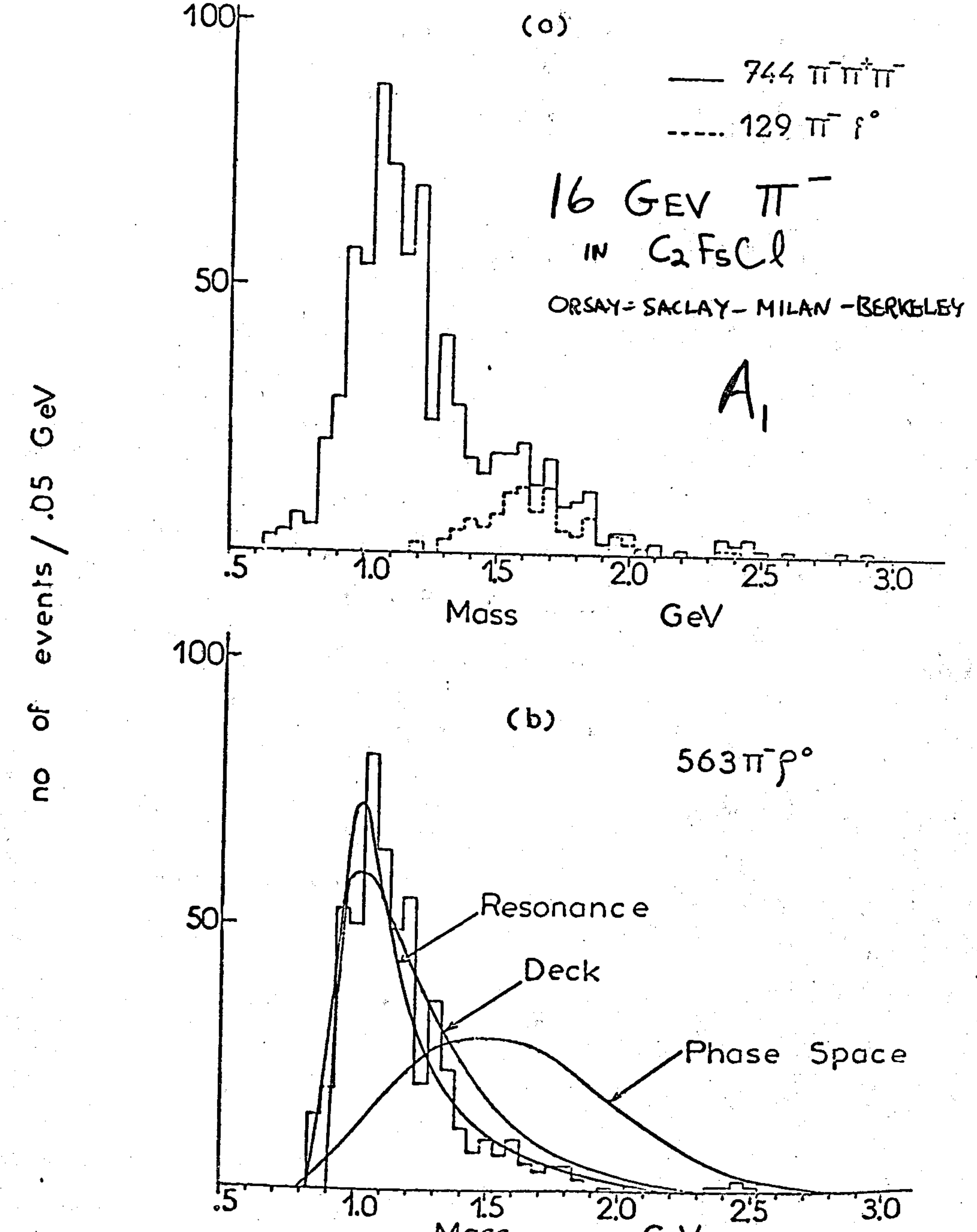

K⁻p → p (K π π)⁻
AT 10 GeV/c
ABCLV Collaboration
|t| < 0.6 (GeV/c)²
(a)
1330
1440
1790
K⁻p → n (K π⁺π⁻)⁰
AT 10 GeV/c
|t| < 0.6 (GeV/c)²
(b)
NUMBER OF EVENTS / 40 MeV
M(Kππ) (GeV)
0
10
20
30
40
50
60
70
1
2
3


π± p → ρ⁰π± p
1.32
1.08
SOBB 2.75 BeV/c π⁻p
CHUNG et al. 3.2, 4.2 BeV/c π⁻p
LANDER et al. 3.5 BeV/c π⁺p
GOLDHABER et al. 3.65 BeV/c π±p
BENSON et al. 3.7 BeV/c π⁻p
ABBBHLM 4.0 BeV/c π⁺p
~ 4200 events
per 0.04 BeV
KRUSE et al. 5.0 BeV/c π⁻p
829 events
BARNES et al. 6.0 BeV/c π⁻p
452 events
GARFINKEL et al. 7.0 BeV/c π⁻p
SLATTERY et al. 7.0 BeV/c π⁺p
507 events
ABC 8.0 BeV/c π⁺p
543 events
NUMBER OF EVENTS
per 0.05 BeV
M (π±ρ⁰)
GeV
1.0
2.0
3.0


NUMBER OF EVENTS / 50 MeV
0
50
100
π⁺p → pπ⁺π⁺π⁻
A1
A2
ABC
AT 8 GeV/c
1047 EVENTS
1.0
2.0
3.0
4.0
(π⁺ρ⁰) EFF. MASS, GeV


KRUSE et al.
π⁻p → pπ⁺π⁻a π⁻b 5 GeV/c
2374 EVENTS
M(π⁺π⁻a)
OR M(π⁺π⁻b) IN ρ BAND
0.765±.100 GeV
1.08
1.30
M3π, GeV
EVENTS/20 MEV
20
40
60
80
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2


BALLAM et al.
π⁻p → π⁻p π⁺π⁻ 16 GeV/c
EVENT NOT CONTAINING ρ
EVENT CONTAINING ρ
N*++ (1238) REMOVED
MASS OF π⁺π⁻π⁻ (BeV)
EVENTS PER 40 MeV


(a)
744 π⁻π⁺π⁻
129 π⁻ ρ°
16 GeV π⁻
in C2F5Cl
ORSAY-SACLAY-MILAN-BERKELEY
A1
no of events / .05 GeV
Mass GeV
(b)
563π⁻ρ°
Resonance
Deck
Phase Space
Mass GeV

$J^P = 0^+$

$C = +1 \quad {}^3P_0 (q\bar{q})$

WHERE IS IT?

① $S^*(1068) \to K_1 K_1 \quad I=0, J^{PG} = 0^{++}$

RESONANCE OR SCAT LENGTH?

$M = 1068 \qquad a = 2 + i\,0.2$ F

$\Gamma = 80 \qquad$ TO $3.3 + i\,0.2$

② $S_0 (720)$ NOT CONVINCINGLY CONFIRMED YET

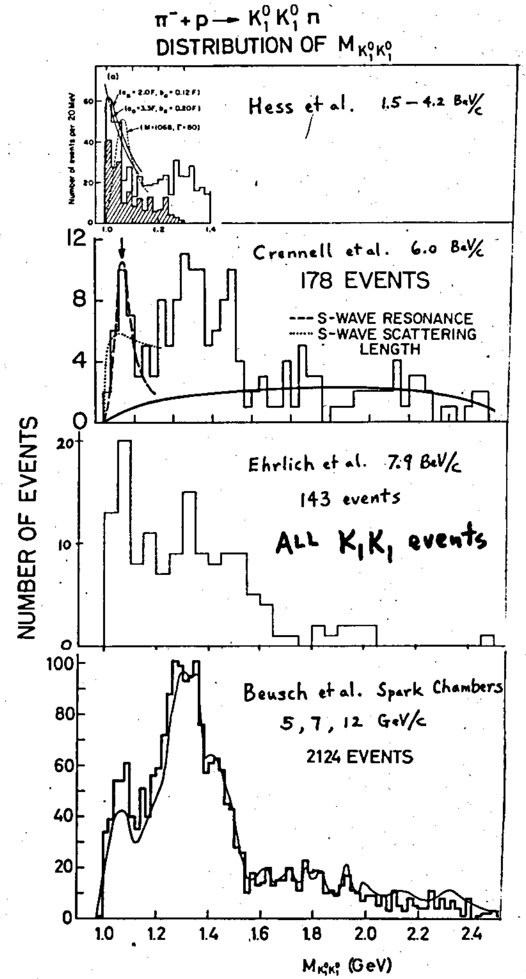
③ $K^{\pm} K_1$ (~1000) $I = 1$, $J^{PG} = 0^{+-}$?

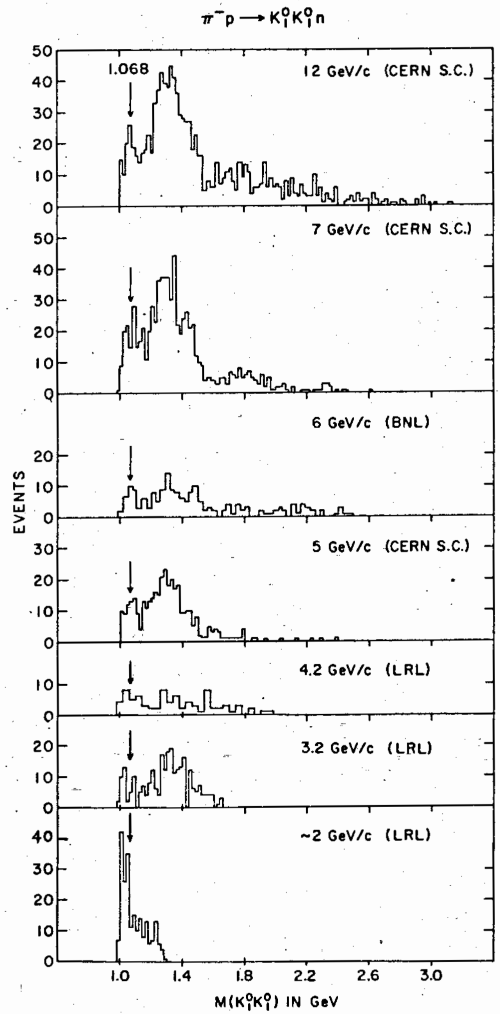
SCAT LENGTH ?

④ $\kappa(720)$ SHARP κ ($\Gamma < 20$) DISPROVED. WIDE EFFECT $\Gamma \sim 50$ MEV MAY BE PRESENT

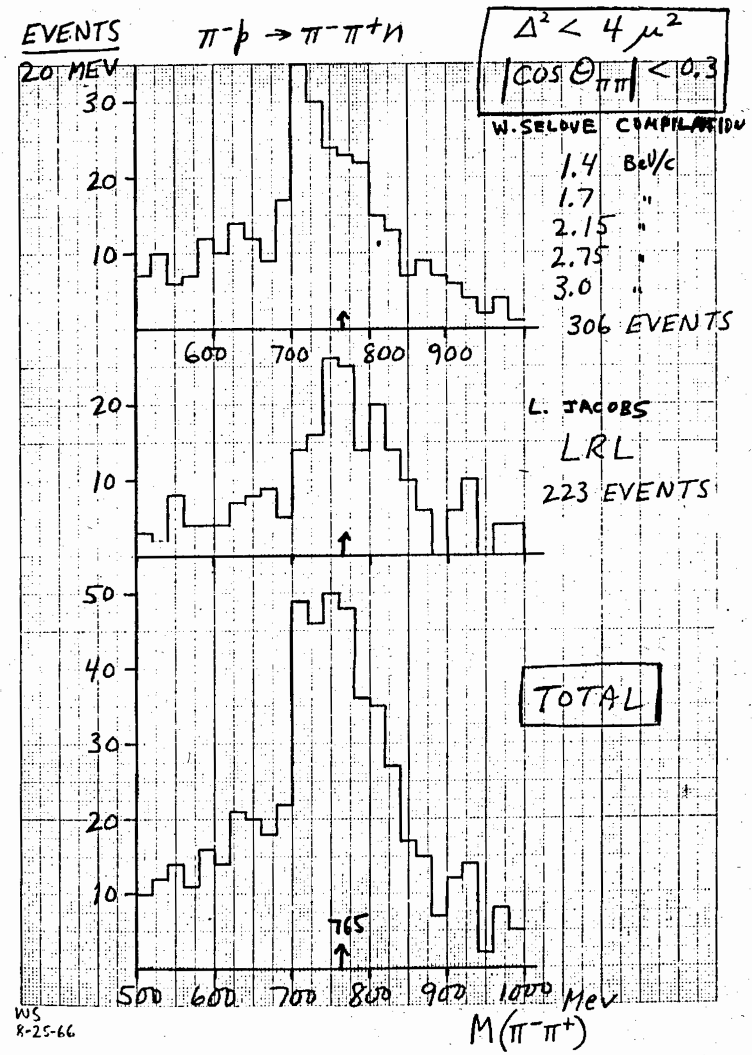
COULD BE INTERFERENCE $K\pi$ WITH $N\pi$ BAND

SAME GOES FOR $\sigma(400)$



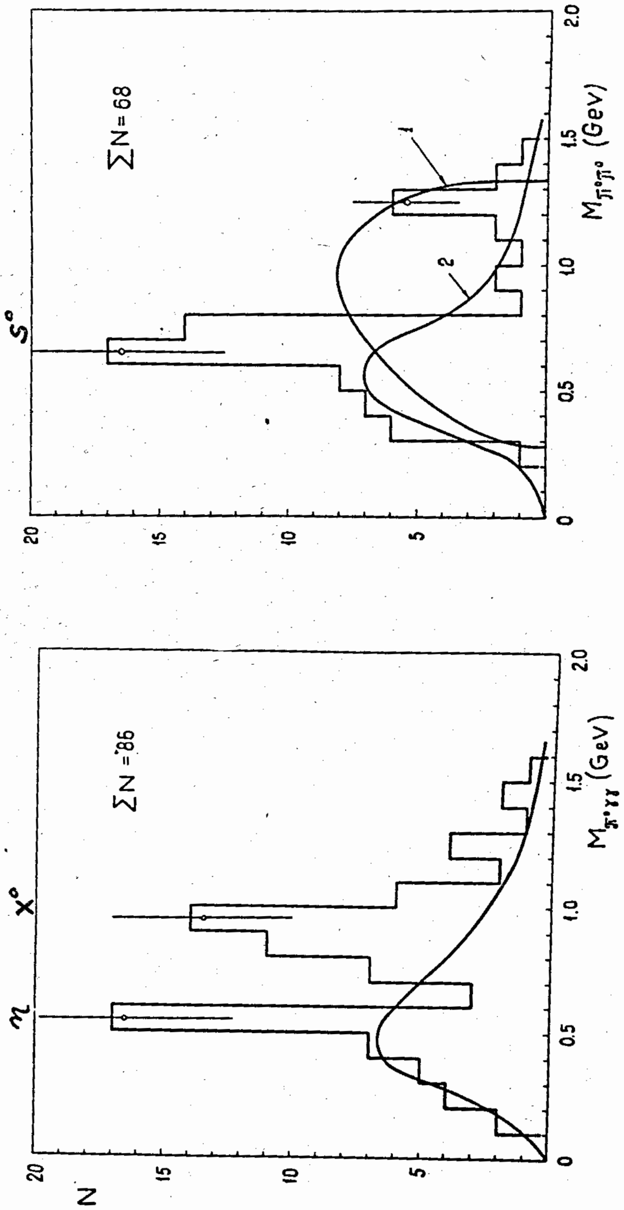


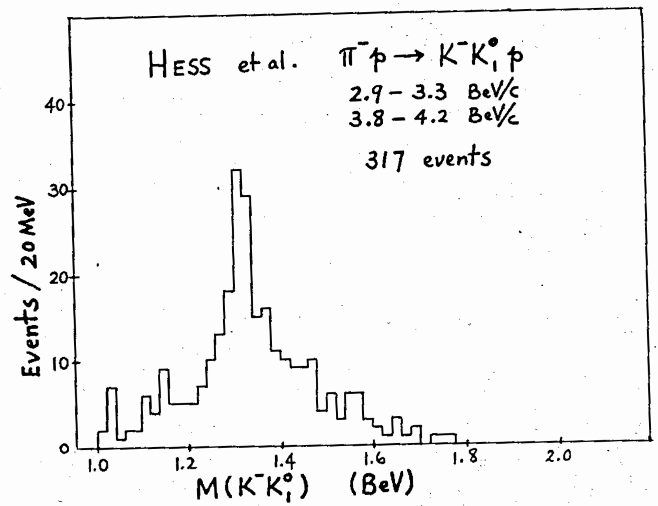
π⁻p ⟶ K₁⁰K₁⁰n
1.068
12 GeV/c (CERN S.C.)
7 GeV/c (CERN S.C.)
6 GeV/c (BNL)
5 GeV/c (CERN S.C.)
4.2 GeV/c (LRL)
3.2 GeV/c (LRL)
~2 GeV/c (LRL)
EVENTS
M(K₁⁰K₁⁰) IN GeV

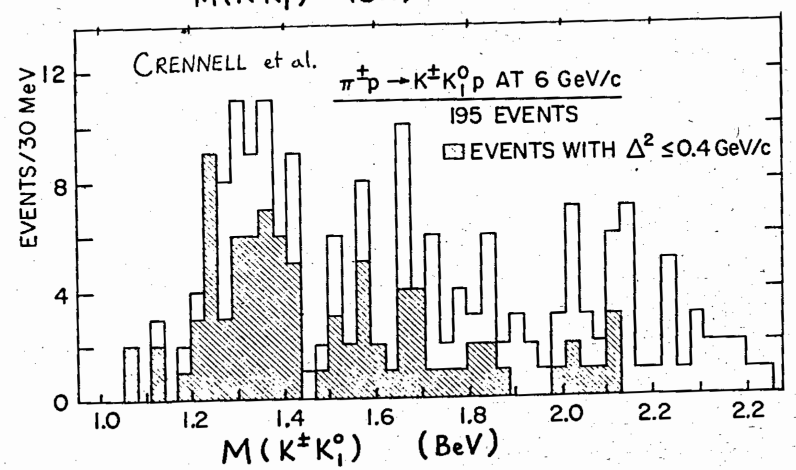


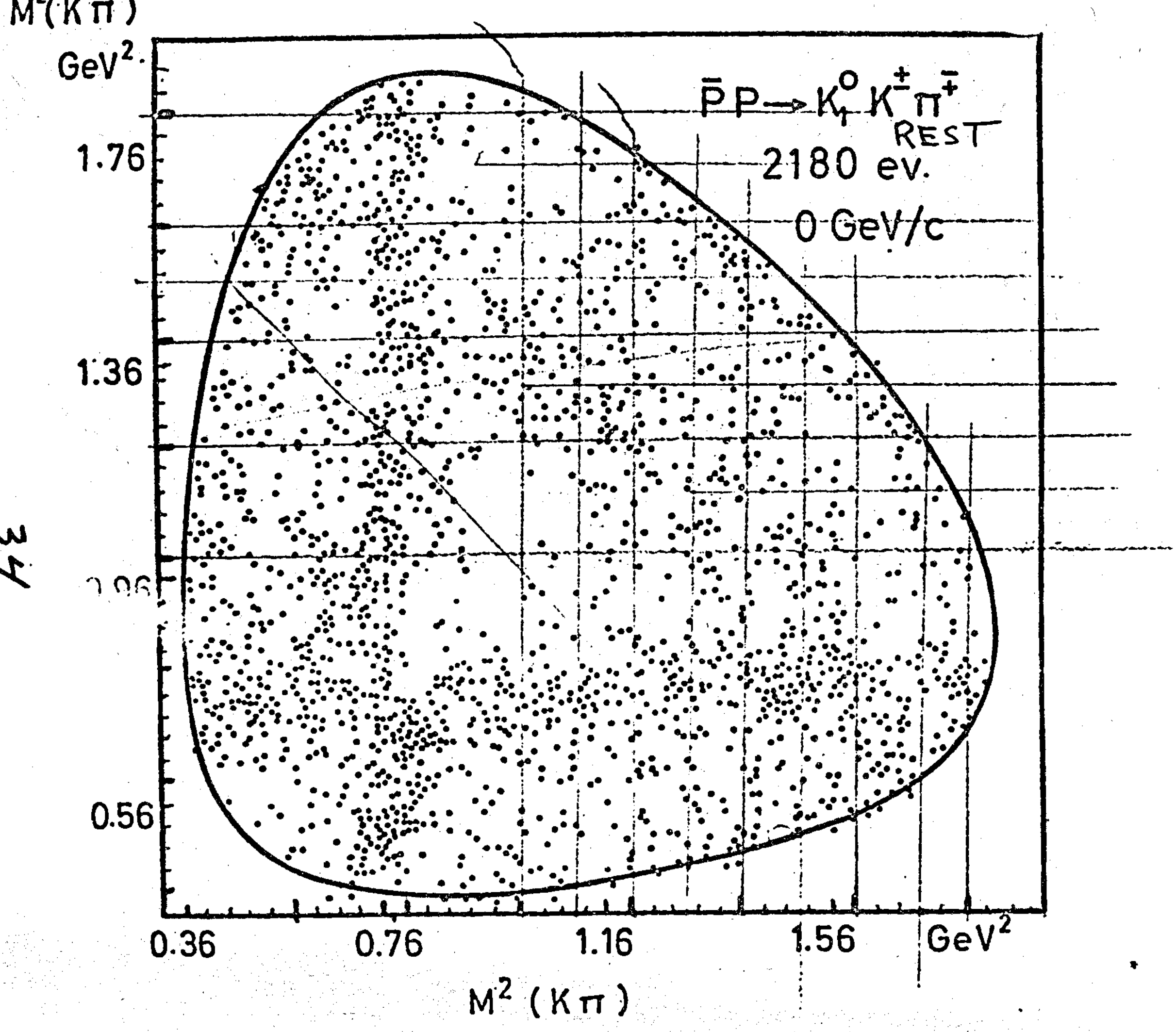
EVENTS
20 MEV
π⁻p → π⁻π⁺n
Δ² < 4 μ²
|cos θ_ππ| < 0.3
W. SELOVE COMPILATION
1.4 BeV/c
1.7 "
2.15 "
2.75 "
3.0 "
306 EVENTS
L. JACOBS
LRL
223 EVENTS
TOTAL
765
Mev
M(π⁻π⁺)
WS
8-25-66

STRUGALSKI et al (Dubna)
Xenon Bubble Chamber



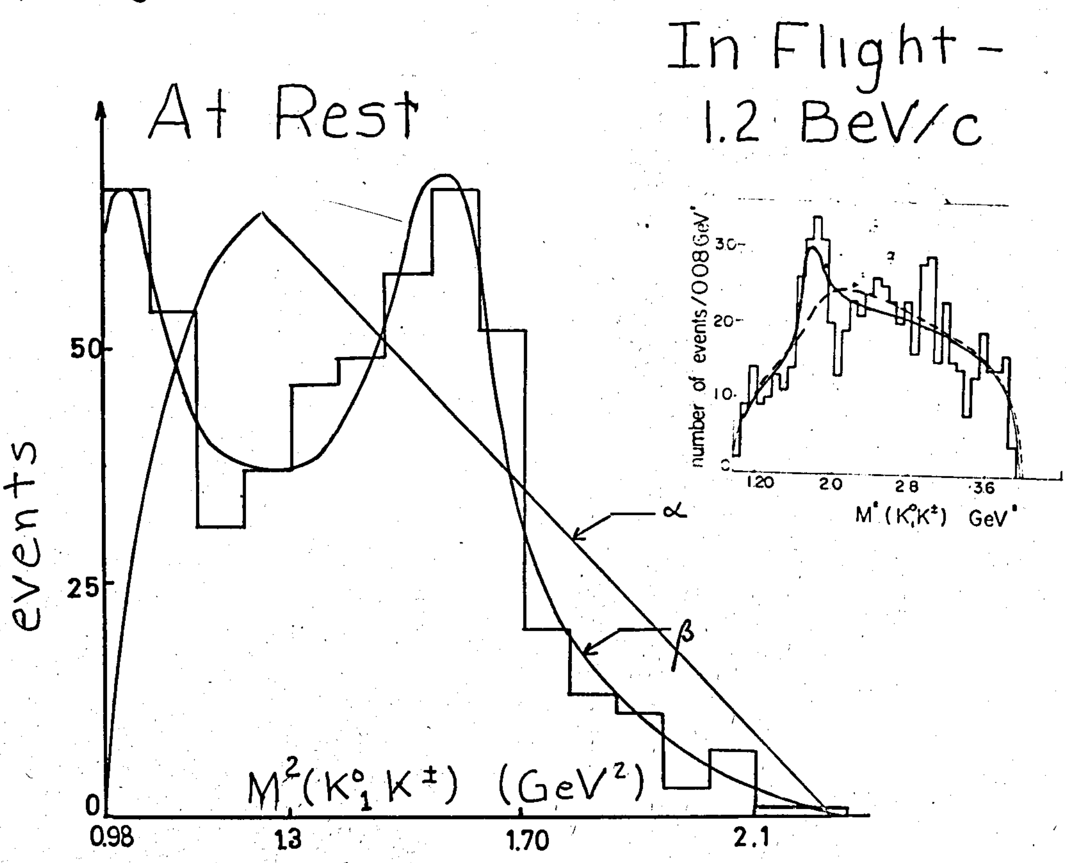


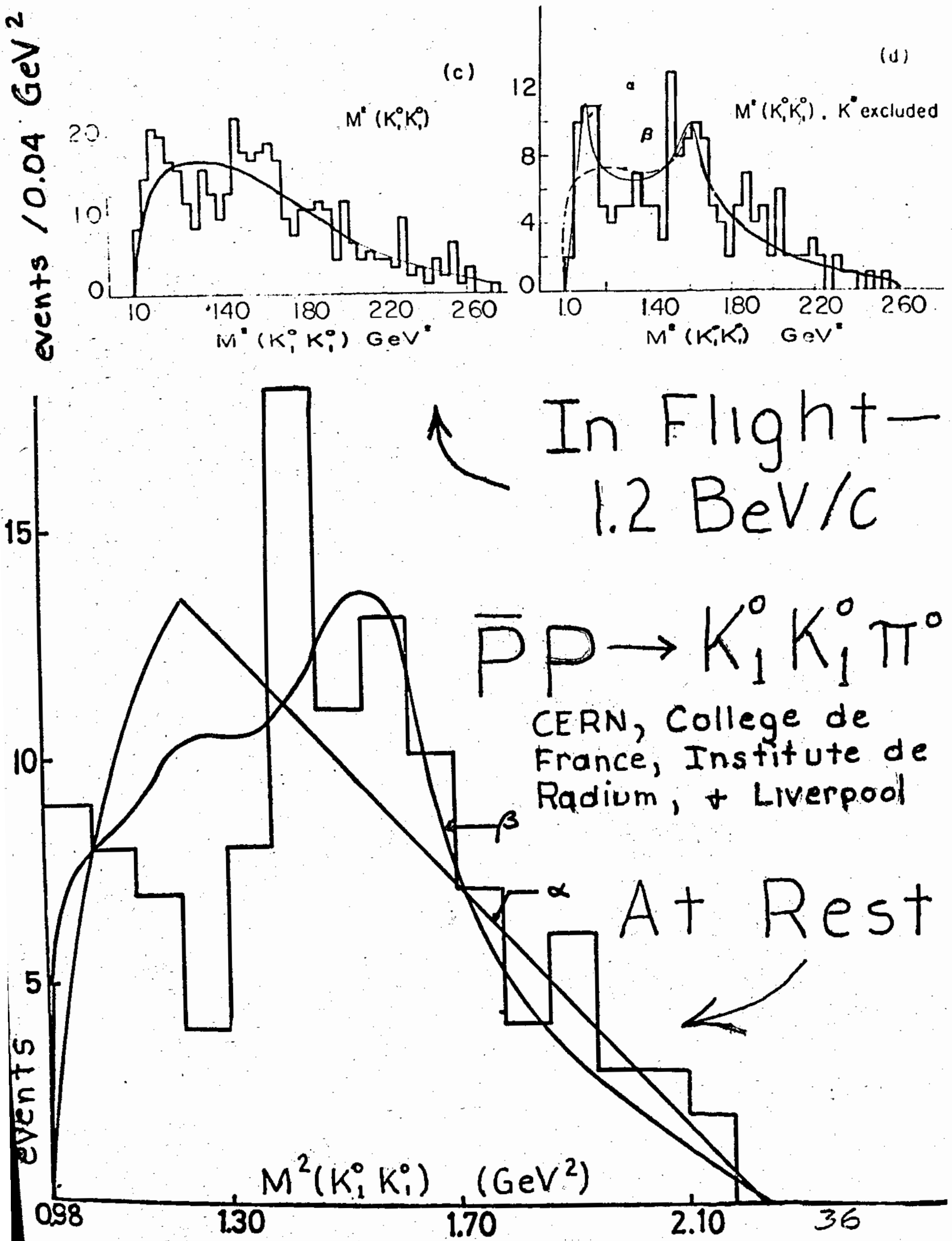




$\bar{P}P \longrightarrow K_1^0 K^{\pm} \pi^{\mp}$

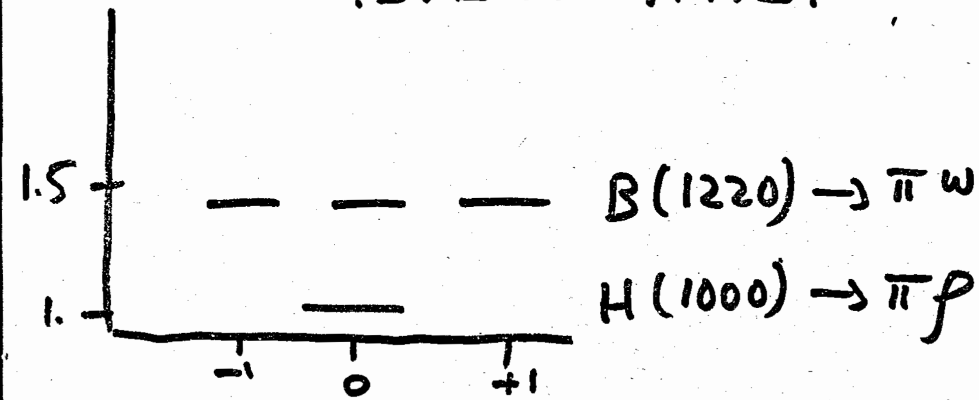
CERN, College de France, Institute de Radium, & Liverpool





$J^P = 1^+$ 	$C = -1$ 	${}^1P_1(q\bar{q})$ } OR $J^P = 2^-$ $C = -1$ ${}^3D_2(q\bar{q})$

! SPECULATIVE !



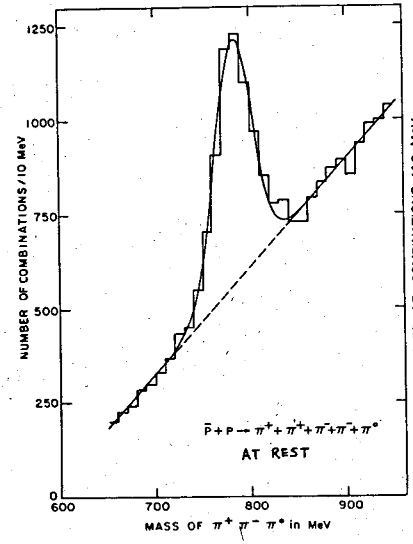
① B REVIVED $\bar{p}p \to B^{\pm} + \pi^{\mp}$

② H CONFIRMED $\pi^+ d \to H^0 pp$

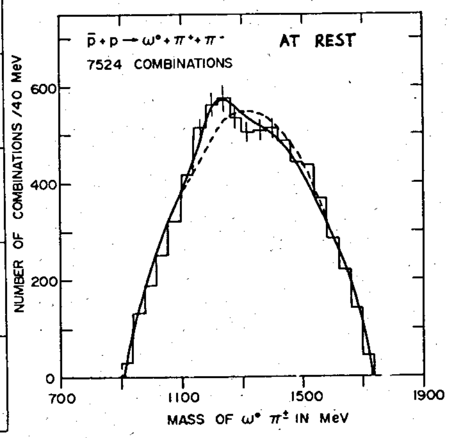
Seen at 3.65 BeV/c

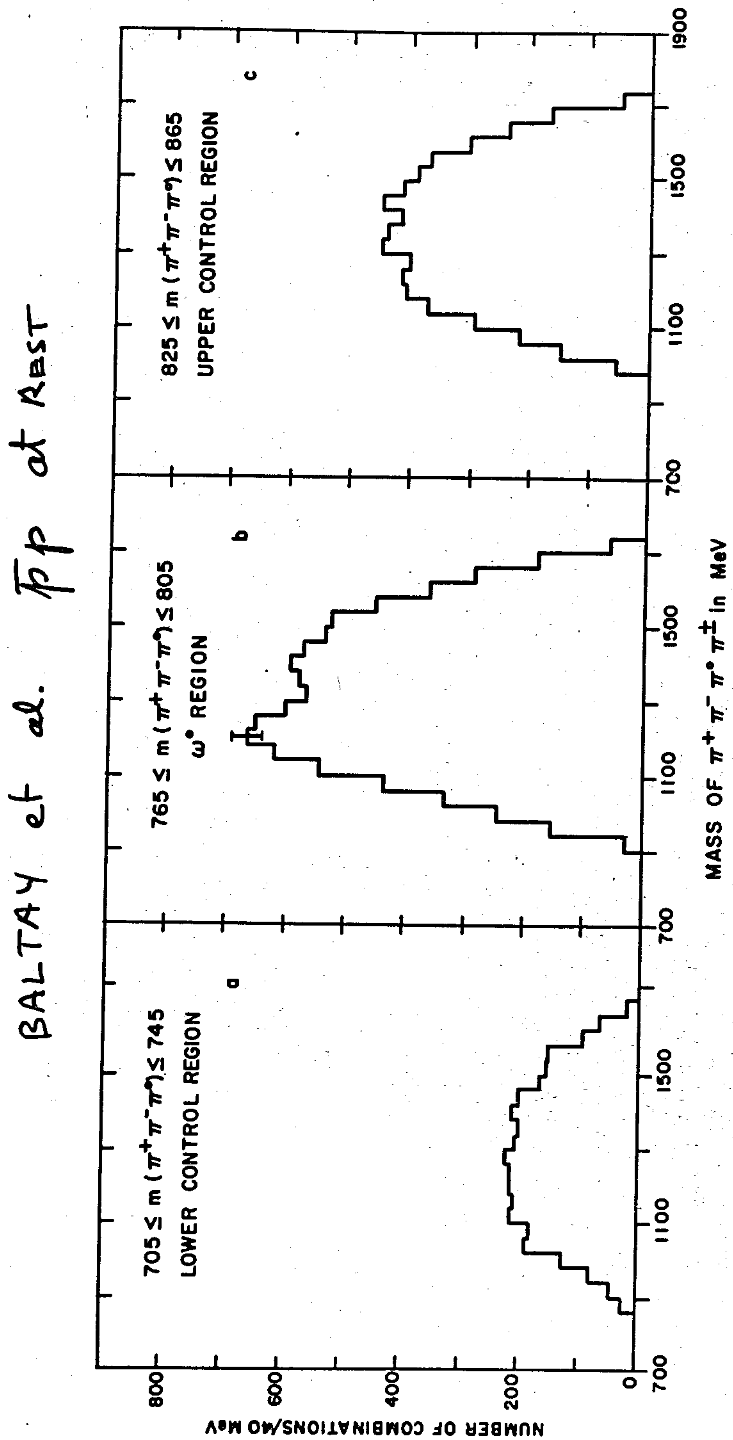
NOT at 5.1 BeV/c

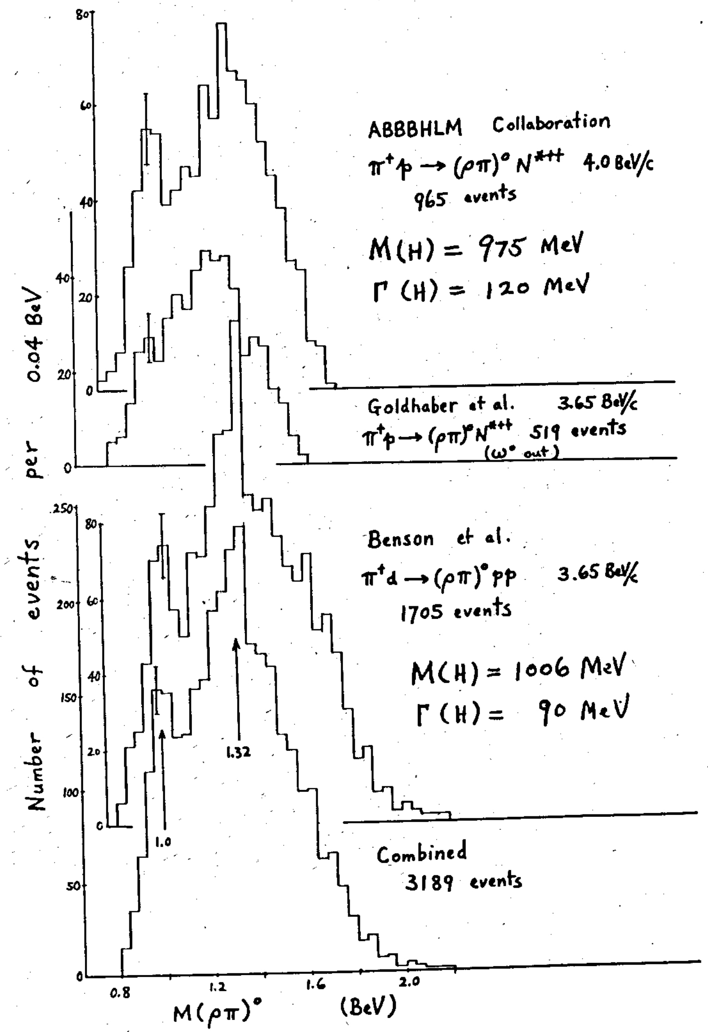
IF NO MIXING G-M-O REQUIRES $M(K^*) = 1060$ MeV

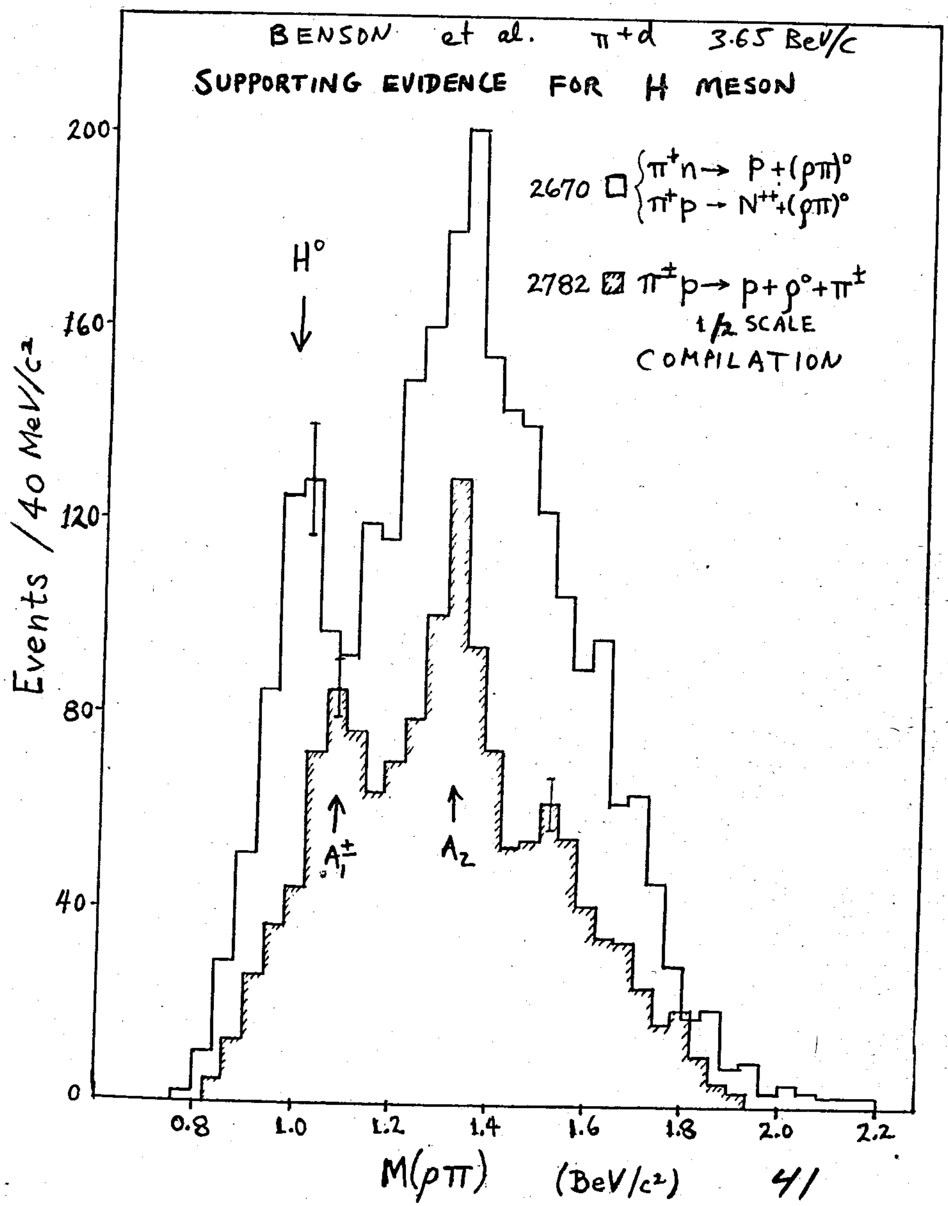

NUMBER OF COMBINATIONS / 10 MeV
p̄ + p → π⁺ + π⁺ + π⁻ + π⁻ + π°
AT REST
MASS OF π⁺ π⁻ π° in MeV

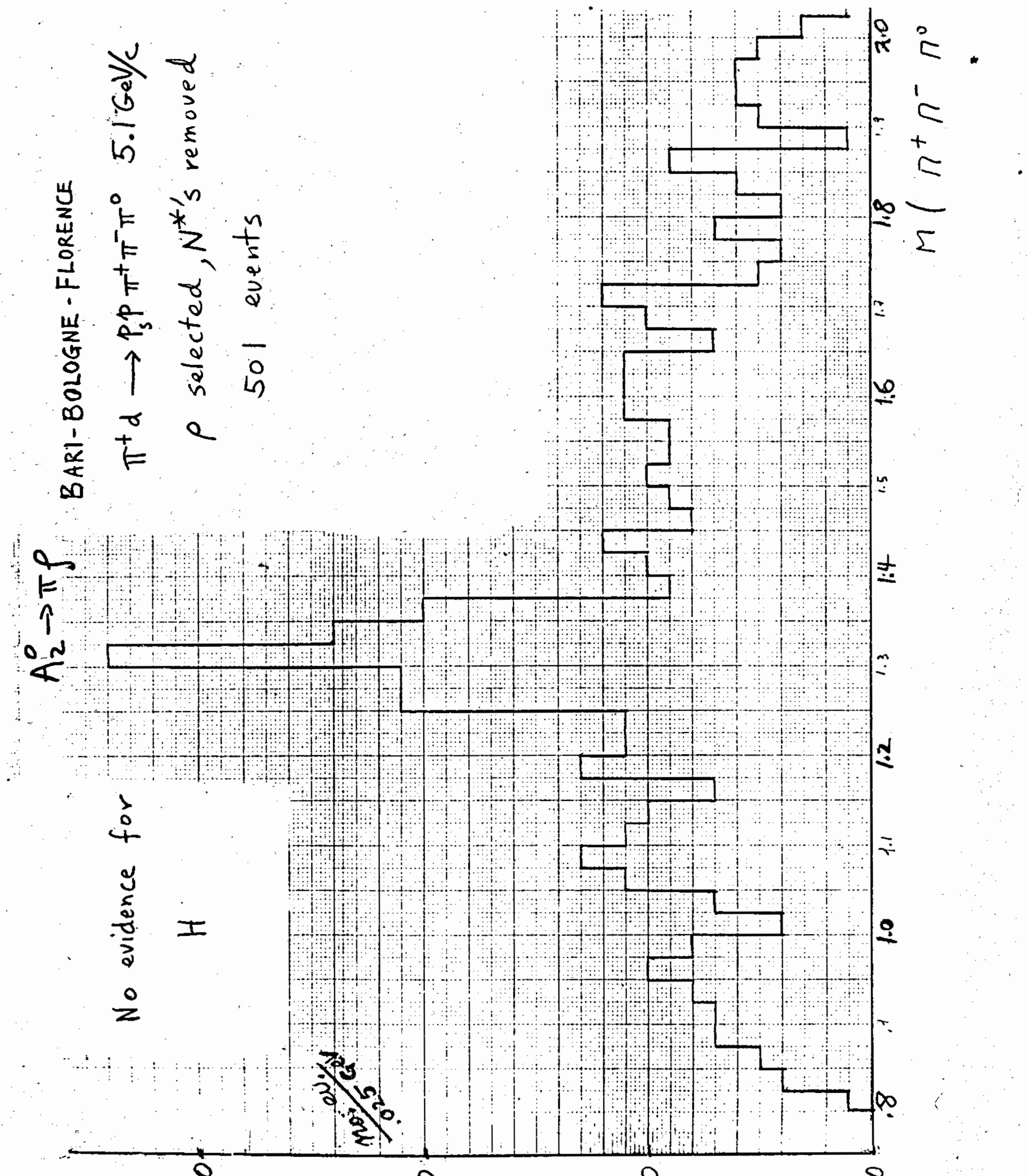
BALTAY et al.


p̄ + p → ω° + π⁺ + π⁻
AT REST
7524 COMBINATIONS
NUMBER OF COMBINATIONS /40 MeV
MASS OF ω° π± IN MeV


BALTAY et al. p̄p at REST
705 ≤ m (π⁺π⁻π°) ≤ 745
LOWER CONTROL REGION
765 ≤ m (π⁺π⁻π°) ≤ 805
ω° REGION
825 ≤ m (π⁺π⁻π°) ≤ 865
UPPER CONTROL REGION
NUMBER OF COMBINATIONS/40 MeV
MASS OF π⁺ π⁻ π° π± in MeV


ABBBHLM Collaboration
π⁺p → (ρπ)° N*++ 4.0 BeV/c
965 events
M(H) = 975 MeV
Γ (H) = 120 MeV
Goldhaber et al. 3.65 BeV/c
π⁺p → (ρπ)° N*++ 519 events
(ω° out)
Benson et al.
π⁺d → (ρπ)° pp 3.65 BeV/c
1705 events
M(H) = 1006 MeV
Γ (H) = 90 MeV
Combined
3189 events
Number of events per 0.04 BeV
M(ρπ)° (BeV)
1.0
1.32


BENSON et al. π⁺d 3.65 BeV/c
SUPPORTING EVIDENCE FOR H MESON
2670 □ π⁺n → p + (ρπ)°
π⁺p → N⁺⁺ + (ρπ)°
2782 ▨ π±p → p + ρ° + π±
1/2 SCALE
COMPILATION
H°
A₁±
A₂
Events / 40 MeV/c²
M(ρπ) (BeV/c²)



The M = 1650 MeV Region, S = 0

It has become clear at this conference that there are two or more objects located at this general mass region.

1. The g meson G = +1 I ≥ 0

   a. There is overwhelming evidence that in the $\pi^+ - \pi^-$ mass spectrum there exists a structure beyond the very prominent ρ and f° peaks. This comes from $\pi^- p \to \pi^+\pi^- n$ and $\pi^+ d \to \pi^+\pi^- pp$ at a series of energies.

   b. From the reactions

      $\pi^\pm p \to \pi^\pm \pi^0 p$

      there is evidence (not 100% established) for an enhancement at ~1620 MeV. This would be G = +1, I ≥ 1

   c. Some evidence has been presented for $(1680)^- \to \pi\pi\pi\pi$

      Conte et al. $\to \rho\pi\pi$ 75%

      $\to \rho\rho$? <40%

2. The σ (1640) "meson," G = -1, I ≥ 1. A compilation of 3 sets of data on $\pi^+ p \to \pi^+\pi^-\pi^+ p$ from 7 - 8.5 GeV/c shows an enhancement 1640 MeV.

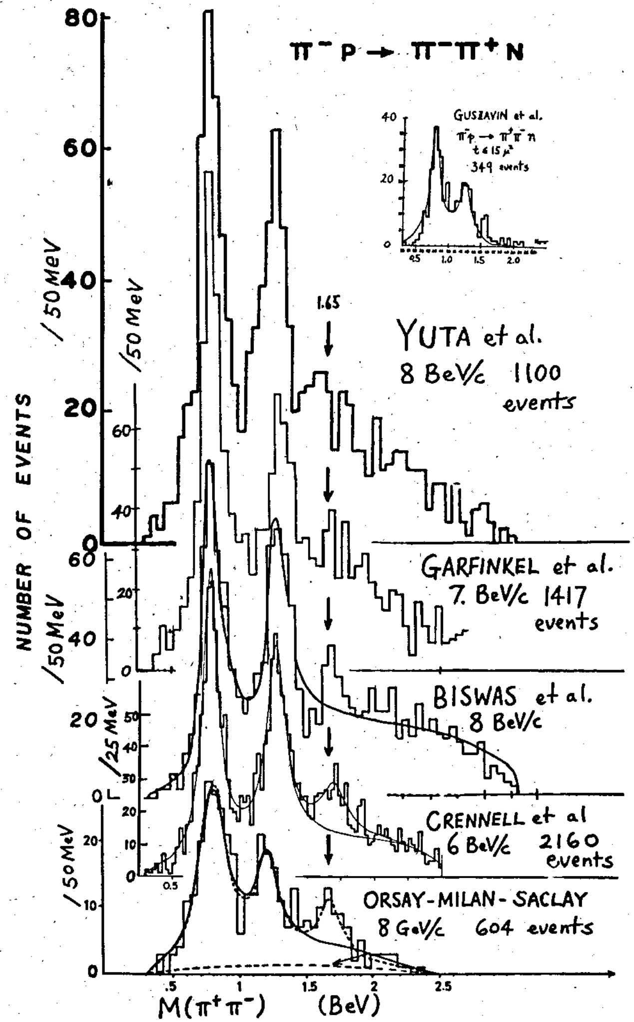
   $\sigma^+(1640) \to \pi^+\pi^-\pi^+$

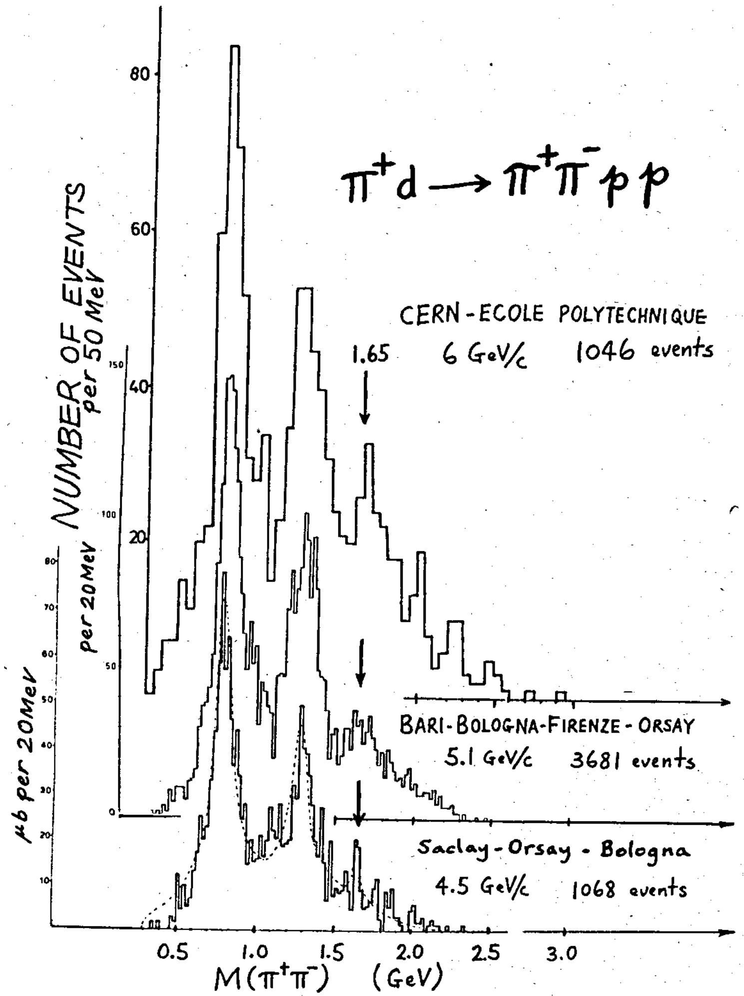
   $\not\to \rho^0\pi^+$ (very little)

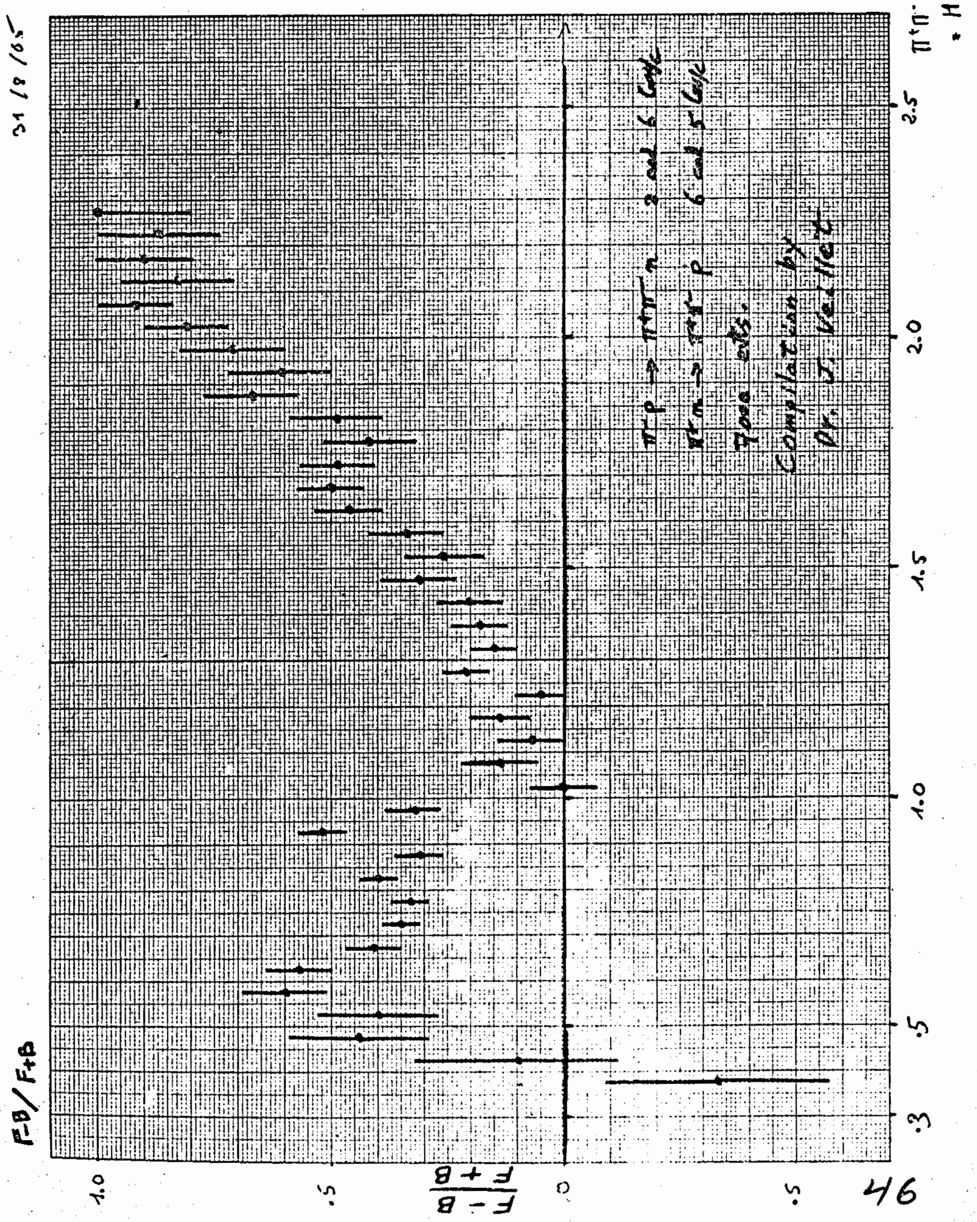
   $\to f^0\pi^+$

   $M(\sigma) = 1640 \pm 15$, $\Gamma(\sigma) \approx 100$

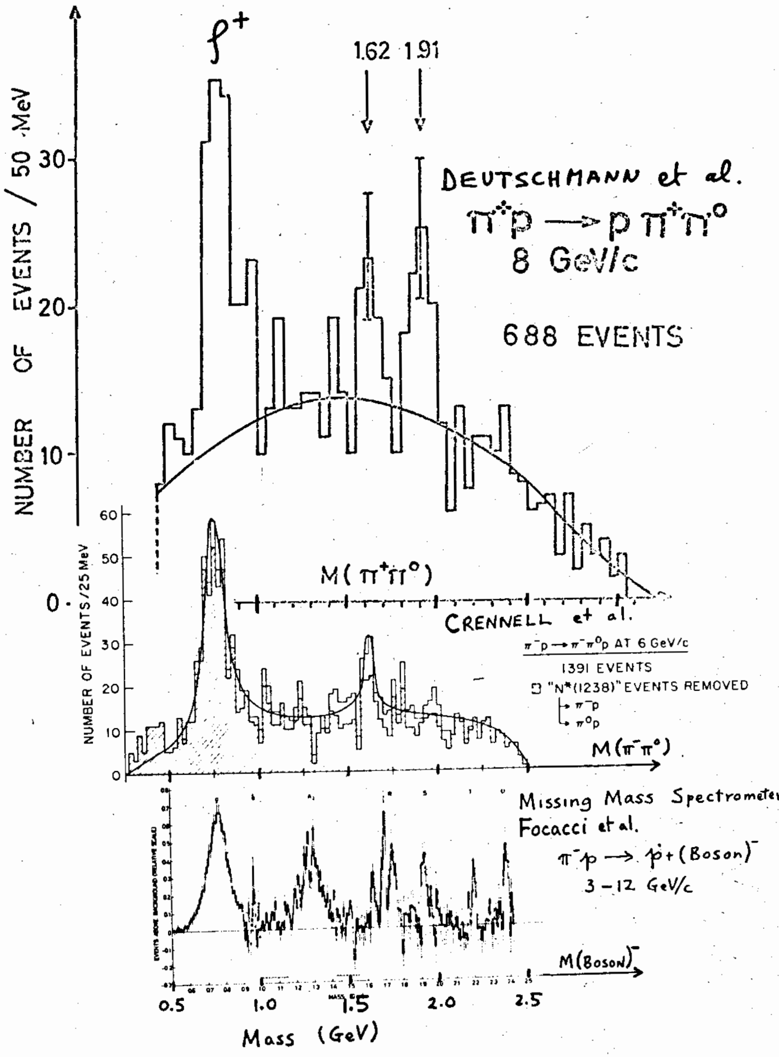
   A very similar result is also presented by Guzavin from 4.7 GeV/c $\pi^- p$. As always the suggestion comes to mind that this is related to the Deck effect with f° production this time. In fact, a suggestion of such on enhancement was observed in the 16 GeV/c π^- nucleus data in the E.P. heavy liquid chamber.


π⁻ p → π⁻π⁺ N
GUSZAVIN et al.
349 events
YUTA et al.
8 BeV/c 1100 events
1.65
GARFINKEL et al.
7. BeV/c 1417 events
BISWAS et al.
8 BeV/c
CRENNELL et al
6 BeV/c 2160 events
ORSAY-MILAN-SACLAY
8 GeV/c 604 events
NUMBER OF EVENTS
/50 MeV
/25 MeV
M(π⁺π⁻) (BeV)


π⁺d → π⁺π⁻pp
NUMBER OF EVENTS per 50 MeV
per 20 MeV
μb per 20 MeV
CERN-ECOLE POLYTECHNIQUE
1.65 6 GeV/c 1046 events
BARI-BOLOGNA-FIRENZE-ORSAY
5.1 GeV/c 3681 events
Saclay-Orsay-Bologna
4.5 GeV/c 1068 events
M(π⁺π⁻) (GeV)



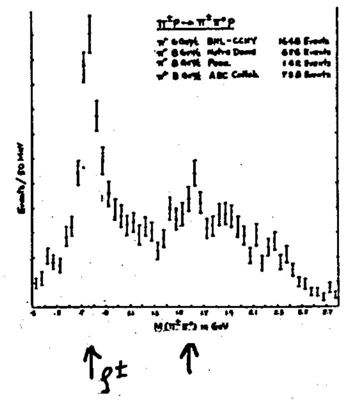
F−B / F+B
Compilation by
Dr. J. Veillet



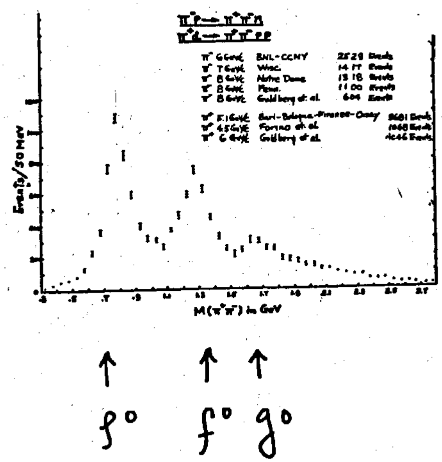
ρ+
1.62 1.91
DEUTSCHMANN et al.
π+p → p π+π0
8 GeV/c
688 EVENTS
NUMBER OF EVENTS / 50 MeV
M(π+π0)
CRENNELL et al.
π−p → π−π0p AT 6 GeV/c
1391 EVENTS
"N*(1238)" EVENTS REMOVED
NUMBER OF EVENTS/25 MeV
M(π−π0)
Missing Mass Spectrometer
Focacci et al.
π−p → p+(Boson)−
3 − 12 GeV/c
M(Boson)−
Mass (GeV)

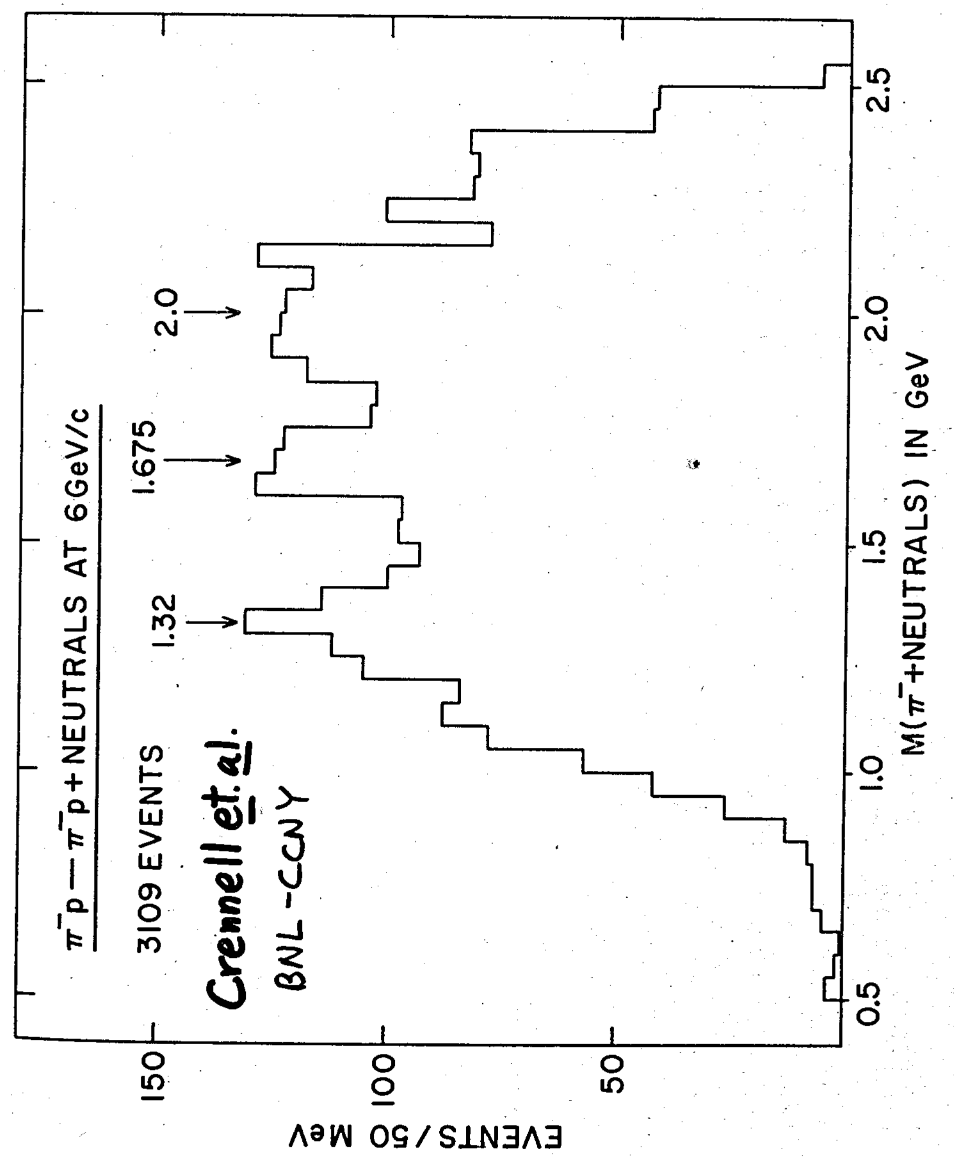
COMPILATION

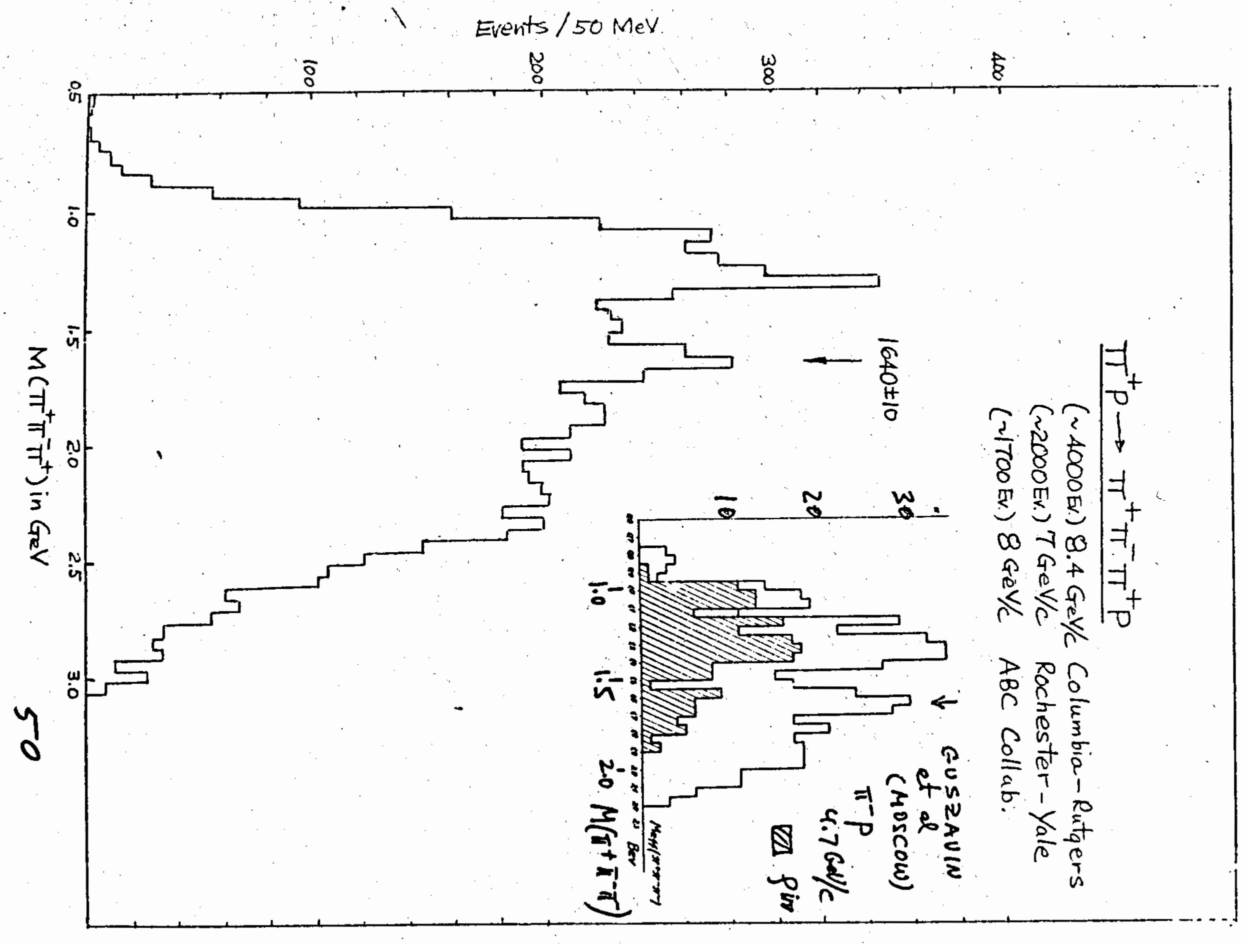
$\pi^\pm \pi^0$



$\pi^+ \pi^-$





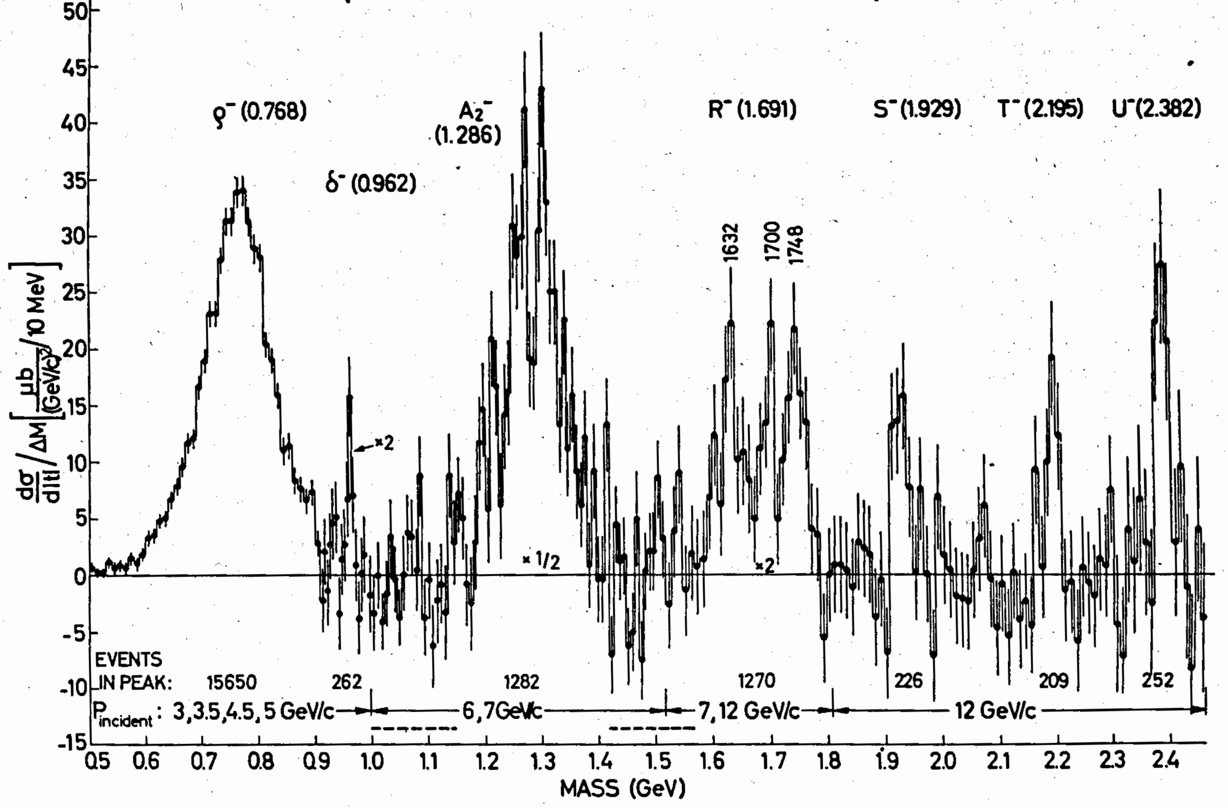


S = 0 Pion Resonances in the Mass Region of 1.65 GeV

G = +1				G = −1		G = Unknown	
I ≥ 0		I ≥ 1		I ≥ 1			
m	Γ	m	Γ	m	Γ	m	Γ
1675 ± 30 (Goldberg *et al.*)	200 ± 50	1625 (Crennell *et al.*)	60	1640 ± 10 (ABC, Columbia-Rutgers, Rochester-Yale)	100 ± 10	1632 ± 10	34 ± 3 (Focacci *et al.*)
1650 (BBFO)		1620 (Deutschmann *et al.*)				1699 ± 10	30 ± 3 (Focacci *et al.*)
1700 (Crennell *et al.*)	~200			1630 ± 30 (Guszavin *et al.*)	~100	1748 ± 10	28 ± 3 (Focacci *et al.*)
1670 ± 20 (Biswas *et al.*)		1680 (Conte *et al.*)	160			1675 (Crennell *et al.*)	~200
1610 ± 40 (Kernan *et al.*)	155 ± 85						

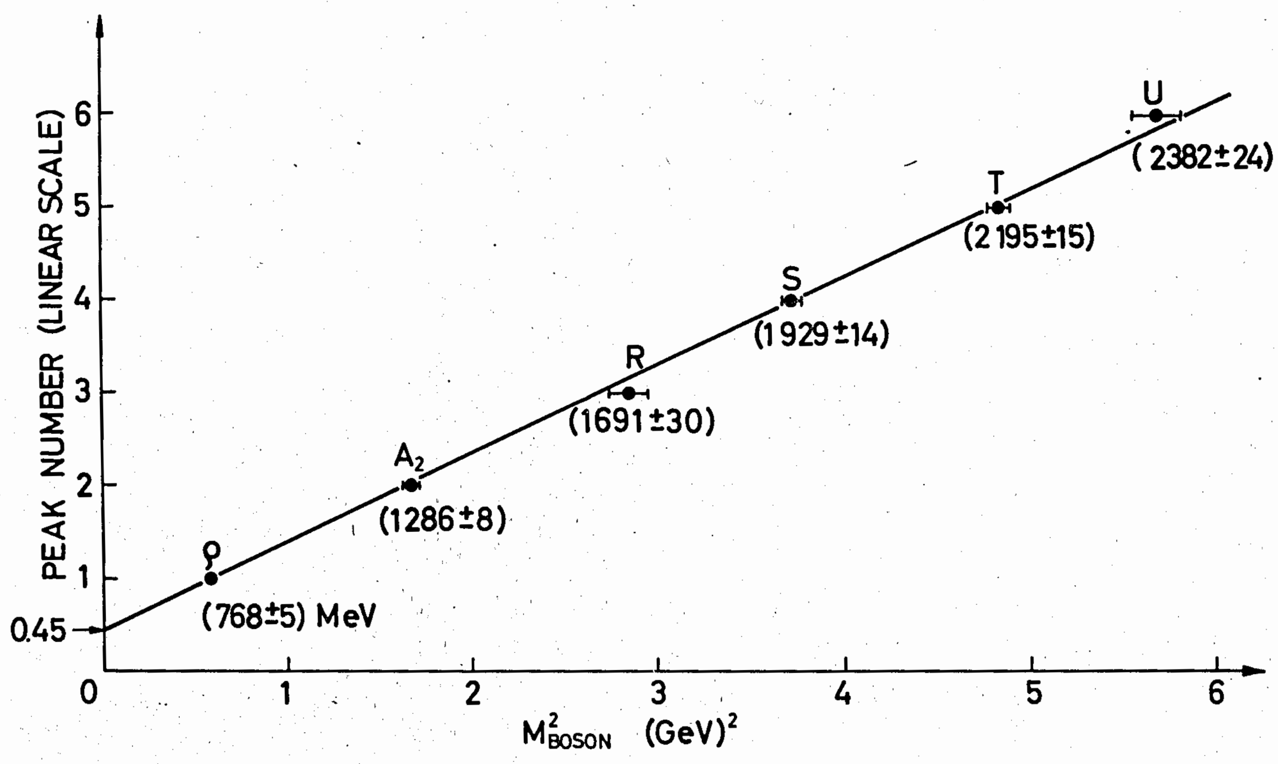
FOCACCI et al.

BOSON MASS-SPECTRUM IN $\pi^- + P \to P + (BOSON)^-$ AT $|\bar{t}| = 0.2\ (GeV/c)^2$
(MISSING-MASS SPECTROMETER AT CERN)



52

FOCACCI et al.



53

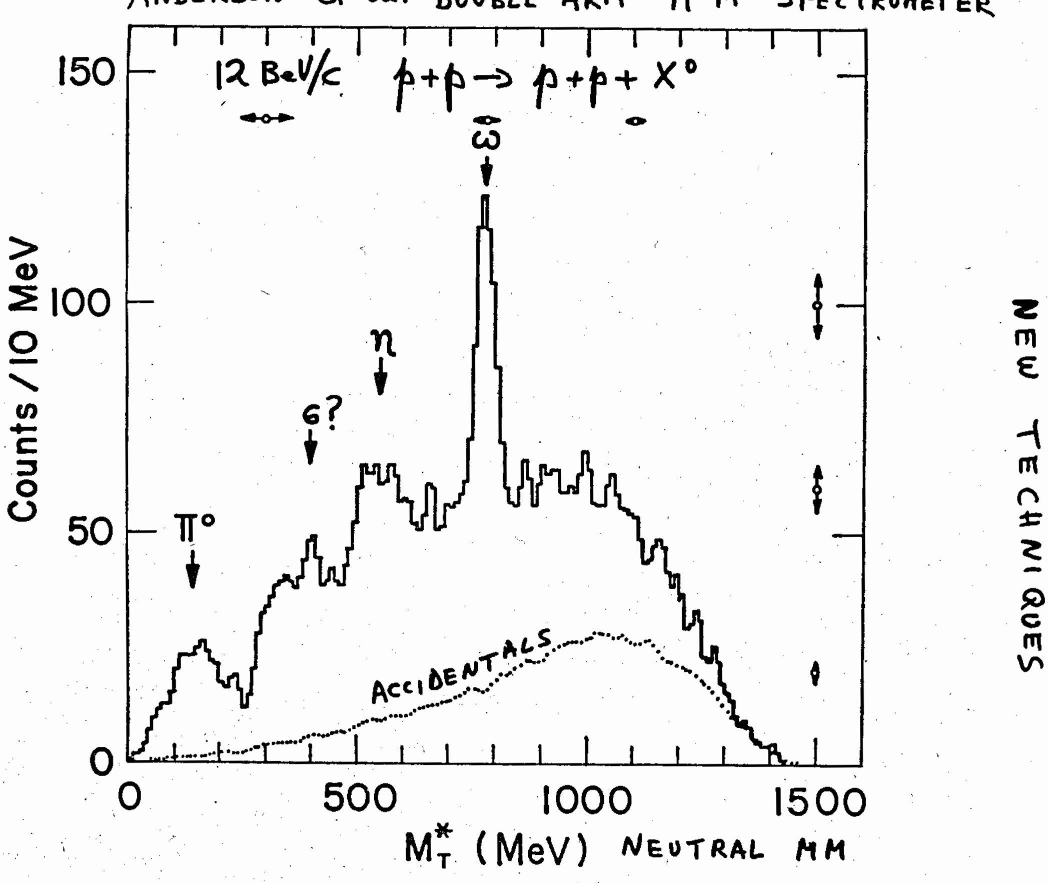
BOSON MISSING MASS SPECTROMETER CERN

Name	Mass M (MeV)	Exp. resolution $\Gamma_{exp.}$ (MeV)	Physical width Γ (MeV)	P_1 (± 1%)	Statistical Significance (Standard deviations)	No. of events in peak in Fig. 1	Signal/ back-ground***)	t limits $(GeV/c)^2$	dσ/dt in the t limits $\mu b/(GeV/c)^2$	Decay mode	Reference
ρ^-	768 ± 5	28 ± 5	127 ± 5	3.0 3.5 4.5 5.0 }		15,600 ± 170	1.6 : 1	0.10 - 0.14 0.14 - 0.17 0.17 - 0.22 0.22 - 0.26	770 ± 150 *) 770 ± 170 580 ± 100 370 ± 110	1σ > 97.4%	1,2
δ^-	962.5 ± 5	24 ± 4	≤ 5	3.0 3.5 4.5 5.0 }	5.0	262 ± 52	1 : 5	0.11 < t < 0.21	8.9 ± 3**)	$\frac{1\sigma}{\geq 3\sigma} = 1.3^{+0.9}_{-0.7}$	4,3
A_2^-	1286 ± 8	36 ± 4	98 ± 5	6.0 7.0	17	1282 ± 63	1 : 1.5	0.31 < t < 0.39	400 ± 120	$\frac{1\sigma}{3\sigma} = 1.05 \pm 0.1$	5 9
A_2' A_2''	1260 ± 10 1312 ± 10			6.0 7.0 }	1 peak and 2 peaks equally probable: P = 5% - 10%	$\frac{A_2'}{A_2''} \simeq 1:1$	1 : 6 1 : 6			$\frac{1\sigma}{3\sigma} \approx 1$	9 9
R^-	1691 ± 15	31 ± 3	116 ± 3	7.0 12.0 }	13.5 1 peak: P = 1 % 2 " : P = 1 % 3 " : P = 20-60% ($R_{1, 2, 3}$)	1270 ± 94	1 : 6	0.23 < t < 0.28	125 ± 30	1σ = 0.30 ± 0.06 +) 3σ = 0.67 ± 0.10 >3σ = 0.03 ± 0.03	7,9
R_1	1632 ± 13	34 ± 3	≤ 21		~~4.0~~ 5	360 ± 70 ~~160 ± 40~~	1 : 4.7		35 ± 10	1σ = 0.37 ± 0.13 3σ = 0.59 ± 0.21 >3σ = 0.04 ± 0.04	9
R_2	1700 ± 15	30 ± 3	≤ 30	7.0 12.0 }	6.6	485 ± 73 ~~250 ± 30~~	1 : 3.3		43	1σ = 0.42 ± 0.11 3σ = 0.56 ± 0.14 >3σ = 0.01 ± 0.01	9
R_3	1748 ± 15	28 ± 3	≤ 38		6.1	425 ± 74 ~~254 ± 41~~	1 : 3.5		47	1σ = 0.14 ± 0.08 3σ = 0.80 ± 0.18 >3σ = 0.05 ± 0.05	9
S^-	1929 ± 14	22 ± 2	≤ 35	12.0	5.5	226 ± 41	1 : 7	0.22 < t < 0.36	35 ± 12	$1\sigma = 0.06^{+0.15}_{-0.06}$ $3\sigma = 0.92^{+0.08}_{-0.20}$ $>3\sigma = 0.02^{+0.13}_{-0.02}$	8
T^-	2195 ± 15	39 ± 4	≤ 13	12.0	5.1	209 ± 41	1 : 7	0.22 < t < 0.36	29 ± 10	$1\sigma = 0.04^{+0.11}_{-0.04}$ $3\sigma = 0.94^{+0.06}_{-0.19}$ $>3\sigma = 0.02^{+0.13}_{-0.02}$	8
U^-	2382 ± 24	62 ± 6	≤ 30	12.0	5.9	252 ± 43	1 : 6	0.28 < t < 0.36	42 ± 14	1σ = 0.30 ± 0.10 3σ = 0.45 ± 0.15 >3σ = 0.25 ± 0.10	8

*) dσ/dt normalized to 4 GeV/c (average momentum)

NEW TECHNIQUES

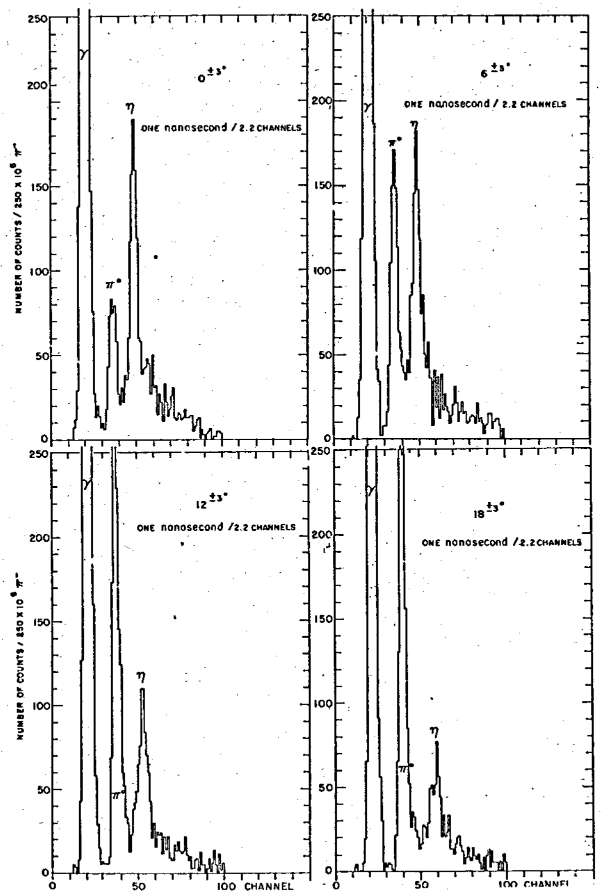
ANDERSON et al. DOUBLE ARM M M SPECTROMETER



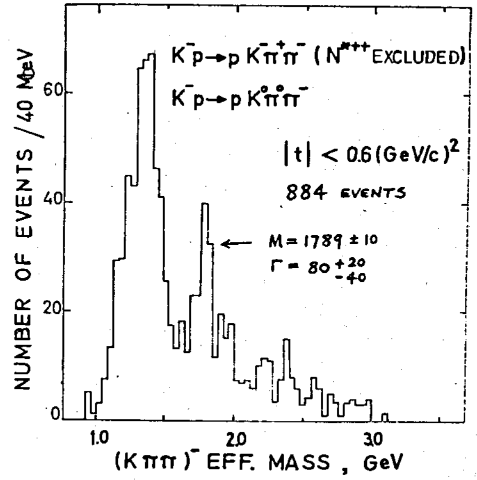
NEW TECHNIQUE

HYMAN et al. $\pi^- p$ 805 MeV/c

NEUTRON-TIME-OF-FLIGHT SPECTROMETER

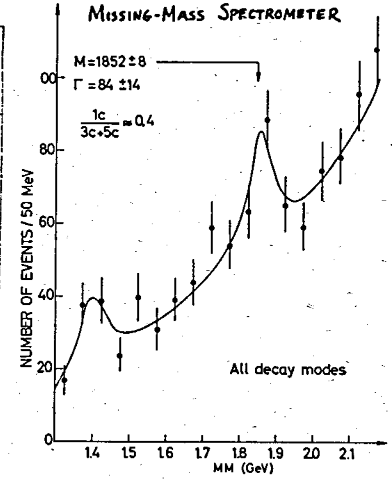


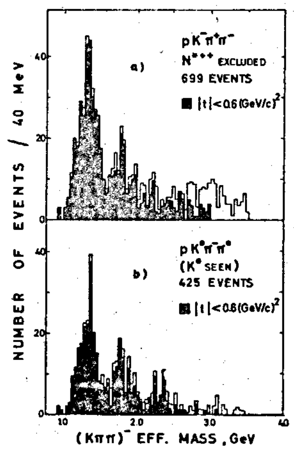
$K^- p$ 10 GeV/c BARTSCH et al.



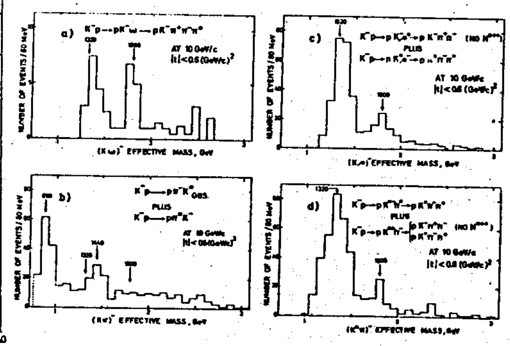
DUBAL et al $K^- p$ 12 GeV/c

Missing-Mass Spectrometer



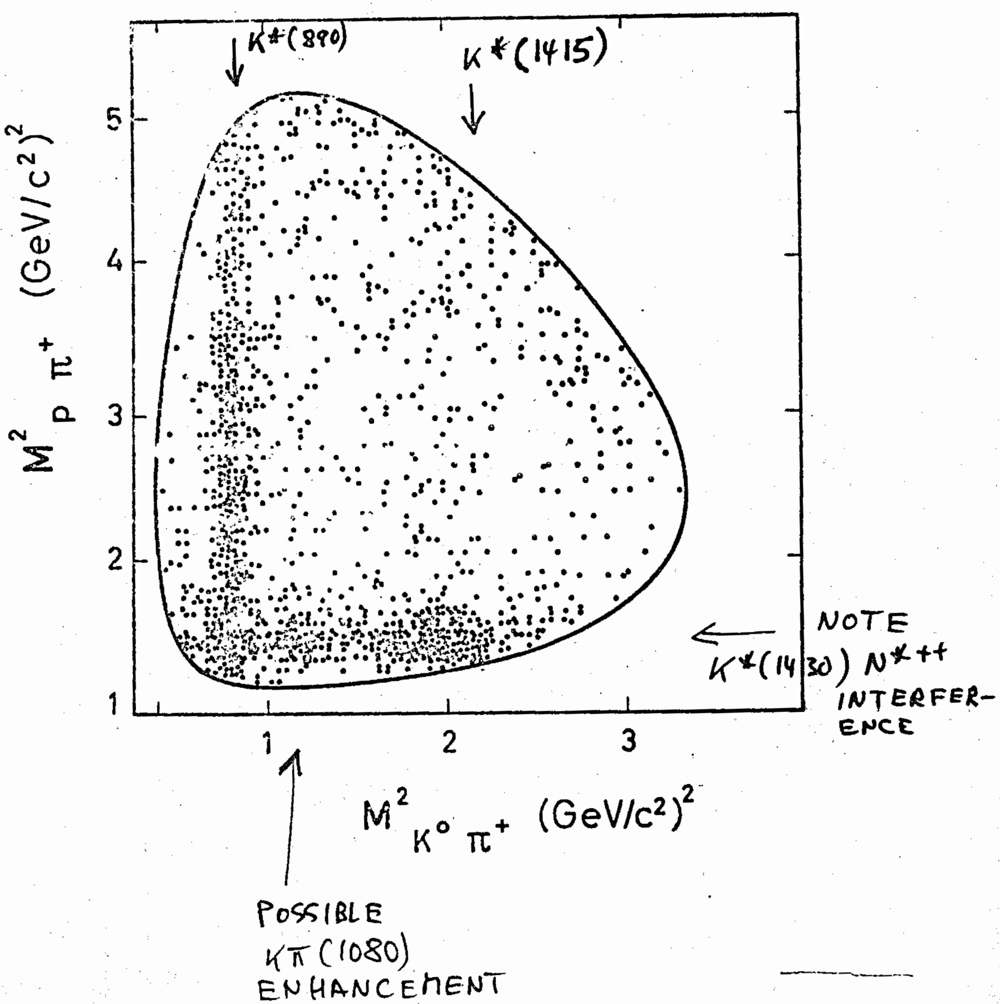


BARTSCH et al. 10 BeV/c $K^- p$

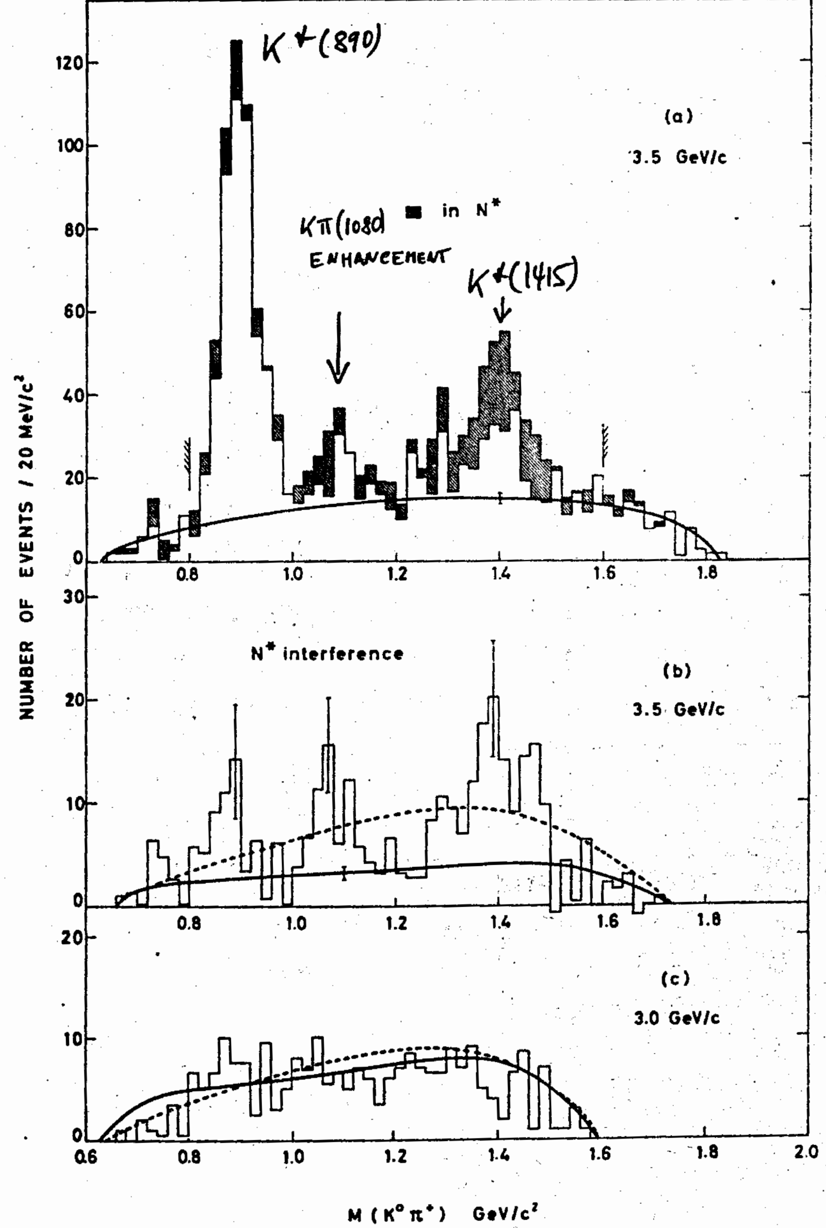


$L \to K^*(890)\pi$	35 ± 12 %
$K^*(1400)\pi$	8.5 ± 5 %
$K\rho$	7.5 ± 5 %
$K\omega$	10 ± 6 %
$K\pi\pi$	40 ± 15 %

De BAERE et al. $K^+p \rightarrow K^0\pi^+p$
3.5 GeV/c



De BAERE et al. $K^+p \rightarrow K^0\pi^+p$



$q\bar{q}$ STATES

STATE	C	J^P	CANDIDATES	NAME
$^1S_0$	+	0^-	$\pi\ \eta\ K\ \eta'(?)$	PSEUDO SCALAR
$^3S_1$	−	1^-	$\rho\ \omega\ K^*\ \phi$	VECTOR
$^3P_0$	+	0^+	$S^*(?)$, $S_0(700)(?)$	SCALAR
$^3P_1$	+	1^+	A_1, $K^*(1320)$, D, E [?]	AXIAL VECTOR
$^1P_1$	−	1^+	B, H ··· [?]	IRRED. TENSOR
$^3P_2$	+	2^+	A_2, f^0, $K^*(1430)$, f'	TENSOR
$^1D_2$	+	2^-		
$^3D_2$	−	2^-	B, H, ... [?]	
"ABNORMAL MODES"	$qq\bar{q}\bar{q}$ STATES			
0^-	−	0^-	NO DEFINITE CANDIDATES	
0^+	−	0^+		
1^-	+	1^-		
2^+	−	2^+		

$$\omega(783) \to \frac{\pi^0\gamma}{\pi^+\pi^-\pi^0} = (1.5 \pm 0.6)\%$$ Baglin et. al. (E.P.-Bergen)

$$\to \frac{\pi^+\pi^-}{\pi^+\pi^-\pi^0} = (0.04 \pm 0.10)^2$$ Button-Shafer (LRL)

$$\to \frac{e^+e^-}{\pi^+\pi^-\pi^0} = (0.5-6)\times 10^{-4}$$ 95% C.L. Binnie et. al. (I.C. London, Manchester)

$$\to \frac{e^+e^-}{\pi^+\pi^-\pi^0} = (1.1 \pm 0.3)\times 10^{-4}$$ Azimov et. al. (Dubna)

$$\sigma(\varphi \to e^+e^-) \le (0.12 \pm 0.08)\times 10^{-4}\ \text{mb}$$

Assume $\sigma(\varphi \to K\bar{K}) \simeq 10\ \mu b$,

$$\varphi(1020) \to \frac{e^+e^-}{K\bar{K}} \le (0.12 \pm 0.08)\times 10^{-2}$$

Azimov et. al. (Dubna)

$$\eta(549) \rightarrow \frac{\pi^0\gamma\gamma}{\gamma\gamma} < 0.5 \text{ (90\% C.L.)}$$

Wahlig et al
(MIT - PISA)

$$\rightarrow \frac{\pi^0\gamma\gamma}{\gamma\gamma} = 0.86 \pm 0.4$$

Strugalski et al
(Dubna)

$$\rightarrow \frac{\pi^0\pi^0\pi^0}{\gamma\gamma} < 0.42 \quad \text{"}$$

$$\rightarrow \frac{\pi^0 e^+ e^-}{\text{All } \eta} < 0.0023 \text{ (90\% C.L.)}$$

Baglin
(EP - Berkeley)

SHEN et al. SPECULATIVE

Decay rates via vector plus pseudoscalar mesons for the A_1 nonet hypothesized in the text.

Resonance	Decay mode	Experimental decay rate, Γ (MeV)	Matrix element	P/M^2	Predicted Γ
$A_1(1080)$	$\rho\pi$	~ 125[a]	$4H^2$	0.205	125 input
$K^*(1320)$	$K^*\pi$]	80±20[b]	$1.5H^2$	0.193	44
	ρK]		$1.5H^2$	0.11	26
	ωK	$6\pm^{4}_{6}$ [b]	$1.5\sin^2\theta_1 H^2$ [c]	0.089	9
D(1286)	"$K^*\bar{K}$"[d]	40±10[a]	$6\sin^2\theta H^2$		d
E(1420)	$K^*\bar{K}$	60±10[a]	$6\cos^2\theta H^2$	0.076	56[e]

a. From compilation by Rosenfeld et al., reference 18.

b. This experiment.

c. The ω-ϕ mixing angle, θ_1, is taken to be 40 deg.

d. The D mass lies below threshold for $K^*\bar{K}$ production. The simple phase-space estimate is thus not applicable.

e. A mixing angle of ~20 deg is obtained by using the Gell-Mann–Okubo formula linear in mass. This value of the mixing angle predicts a decay rate of 60 MeV for $E \rightarrow K^*\bar{K}$.

Alexander Lipkin and Scheck

$$R = \frac{\langle\pi^- p \,|\, m' n\rangle}{\langle\pi^- p \,|\, m\, n\rangle} = \frac{\langle\pi^+ p \,|\, m' N^{*++}\rangle}{\langle\pi^+ p \,|\, m\, N^{*++}\rangle} = \frac{\cos\gamma - \sqrt{2}\sin\gamma}{\sin\gamma + \sqrt{2}\cos\gamma}$$

MIXING ANGLES FOR MESON NONETS

J^P	LAI and Schumann: QUARK MODEL USING CROSS SECTION RELATIONSHIP, Positive R	Negative R	SU(3) MASS FORMULA †, Linear	Quadratic	Benson et. al.: Quark Model Using Cross Section Relationship, Positive R	Negative R
0^-	$-28^{o\,+9^o}_{\;\;-6^o}$	$-81^{o\,+5^o}_{\;\;-10^o}$	$\pm 23.4^o$	$\pm 10.4^o$	$-19^o \pm 7^o$ $-31^o \pm 5^o$ $-28^{o\,+6^o}_{\;\;-8^o}$	-90^o -78^o
1^-	$35^o \pm 7^o$ ‡ $(R \approx 0)$		$\pm 37.5^o$	$\pm 40.2^o$	$27^o \pm 4^o$	$43^o \pm 4^o$
2^+	$26^o \pm 2.5^o$	$47^o \pm 3^o$	$\pm 29.9^o$	$\pm 31.3^o$		

GOLDBERG et al. SU_3 COMPARISONS

J^P	Decay	SU_3 Factor	Predicted Rate	Experimental Rate
$1^- \to 0^- + 0^-$	$K^*(890) \to K\pi$	1/4	Input	49 ± 3
	$\rho(765) \to 2\pi$	1/3	171 ± 8	125 ± 25
	$\phi(1020) \to K\bar{K}$	$1/2\cos^2\theta_1$	3.1 ± .5	3.3 ± .5
$2^+ \to 0^- + 0^-$ $\alpha = 3.9 \pm 1$ GLASHOW & SOCOLOW USED $\alpha = 2\sqrt{2}$	$A_2(1320) \to K\bar{K}$	12	Input	4.5 ± 1.5
	$f^o(1250) \to \pi\pi$	$3(2\sin\theta_2 + \alpha\cos\theta_2)^2$	Input	118 ± 20
	$f^o(1250) \to K\bar{K}$	$4(\sin\theta_2 - \alpha\cos\theta_2)^2$	6 ± 4	2 ± 2
	$f^o(1250) \to \eta^o\eta^o$	$(2\sin\theta_2 - \alpha\cos\theta_2)^2$	0.3 ± 0.3	small
	$A_2(1320) \to \eta^o\pi$	8	8 ± 3	3 ± 2
	$K^{**}(1410) \to K\pi$	18	30 ± 11	39 ± 20
	$K^{**}(1410) \to K\eta^o$	2	0.9 ± 0.3	2 ± 2
	$f^*(1500) \to \pi\pi$	$3(2\cos\theta_2 - \alpha\sin\theta_2)^2$	2 ± 4	0 ± 6
	$f^*(1500) \to K\bar{K}$	$4(\cos\theta_2 + \alpha\sin\theta_2)^2$	33 ± 18	51 ± 25
	$f^*(1500) \to \eta^o\eta^o$	$(2\cos\theta_2 + \alpha\sin\theta_2)^2$	9 ± 4	small
$2^+ \to 1^- + 0^-$	$A_2(1320) \to \rho\pi$	4	Input	80 ± 14
	$K^{**}(1410) \to K^*\pi$	3/2	20 ± 4	43 ± 15
	$K^{**}(1410) \to \rho K$	3/2	5.0 ± 1.4	14 ± 5
	$K^{**}(1410) \to \omega^o K$	$3/2(\sin^2\theta_1)$	1.5 ± 0.5	7 ± 4
	$f^*(1500) \to K^*K$	$6\cos^2\theta_2$	7 ± 4	< 34 ± 15 *NEW

MASS OF THE $K^*(1400)$

Group	Experiment	$K\pi$ decay: # evts peak/bkgd	$K\pi$ decay: Mass	$K\pi$ decay: Remarks	$K^*\pi$ decay: # evts pk./backgrd.	$K^*\pi$ decay: Mass	$K^*\pi$ decay: Remarks
British Coll.	3.5 GeV/c K^-	35/15	1400 ± 10		?		
British Coll.	6 GeV/c K^-	?	1402 ± 8	N* scanty	?	$1430 \pm ?$	N* scanty
EP + S + A	3 GeV/c K^-	60/110	1404 ± 15	N* scanty	120/180	1400 ± 20	N* without influence
ANL + N	4.1 and 5.5 GeV/c K^-	170/200	1392 ± 10	N* removed	60/90	$\sim 1450 \pm ?$	N* without influence
CERN (M)	7 and 12 GeV/c K^-	15/?	1400 ± 10	from $K\pi$ and $K\pi\pi$ decay together (using mass spectrometer)			
LRL (M)	4 GeV/c K^-	35/0	1430 ± 20	Y* scanty			
BNL	6 GeV/c π^-	45/20	1407 ± 10	Y* scanty			
Wisconsin	3.54 GeV/c K^+	?	1425 ± 10	Global fit of $K\pi$ and $K\pi\pi$ events			
CERN-Brussels	3.5 GeV/c K^+	90/?	$1399 \pm ?$	N* removed			
CERN-Brussels	3.5 GeV/c K^+	90/?	1428 ± 17	N* scanty			
CERN-Brussels	5 GeV/c K^+	70/30	1430 ± 20	K*N* production			
LRL (G)	4.6 GeV/c K^+	20/10	1390 ± 30	N* removed	50/180	1430 ± 10	N* removed

BRANCHING RATIOS OF THE $K^*(1400)$

Group	Experiment	$K^*\pi/K\pi$	$K\rho/K\pi$	$K\omega/K\pi$	$K\eta/K\pi$
EP + S + A	3 GeV/c K^-	1.1 ± 0.7	0.35 ± 0.25	0.2 ± 0.2	0.05 ± 0.05
ANL + N	4.1 GeV/c K^-	0.47 ± 0.15	0.34 ± 0.25		
ANL + N	5.5 GeV/c K^-	0.65 ± 0.15	0.36 ± 0.30		
Wisconsin	3.54 GeV/c K^+	1.7 ± 0.55	0.3 ± 0.2	0.03 ± 0.03	0.06 ± 0.06
LRL (G)	4.6 GeV/c K^+	0.63 ± 0.20		$0.05^{+0.03}_{-0.05}$	
LRL (G)	4.6 GeV/c K^+	0.65 ± 0.20			

SPIN AND PARITY OF THE $K^*(1400)$

Group	Experiment	Results
E P + S + A	3 GeV/c K^-	$\chi^2 / \langle \chi^2 \rangle$ for 2^+; 1^-; 3^- = 6/6; 19/7; 15/4
B N L	6 GeV/c π^-	$\chi^2 / \langle \chi^2 \rangle$ for 2^+; 1^- = 2/4; 9/4
A N L + N	4.1 and 5.5 GeV/c K^-	1^- and 2^+ almost equally favored. (1^- a little bit more)

I-SPIN OF THE $K^*(1400)$

	Group:	Experiment	Argument
Production	B N L	6 GeV/c $\pi^\pm$	$\pi^+ p \longrightarrow \Lambda^0 K^+ \pi^+ / \pi^- p \longrightarrow \Lambda^0 K^+ \pi^-$ = 9/1 if I = 3/2 Experimentally: 3 events seen/80 expected
	Wisconsin	3.54 GeV/c K^+	$K^+ p \longrightarrow (K^0 \pi^+) \pi^+ n$ Exp. no enhancement in $(K^{*+} \pi^+)$ mass distribution.
	L R L	4.6 GeV/c K^+	$(K\pi)^{*0} N^{*++} / (K\pi)^{*+} N^{*+} / (K\pi)^{*++} N^{*0}$ = 63/16/27 if I = 3/2; 9/1/0 if I = 1/2 Experimental results consistent with the last ratios
Decay	E P + S + A	3 GeV/c K^-	$(\bar{K}^0 \pi^- \pi^0) \longrightarrow (\bar{K}^0 \pi^-) \pi^0 / (\bar{K}^0 \pi^- \pi^0) \longrightarrow (\bar{K}^0 \pi^0) \pi^-$ = 1/1 if I = ½. Exp. 1.06 ± 0.7
	A N L + N	4.1 and 5.5 GeV/c K^-	$K^{**-} \longrightarrow \bar{K}^0 \pi^- / K^{**-} \longrightarrow K^- \pi^0$ = 2/1 if I = ½. Exp. 1.84 ± 0.5

$\bar{p}d$ at REST BETTINI et al.

TABLE I

Channel	percentage of all $\bar{p}n$ annihilations	Notes
$\bar{p}+d \to p_{sp}+$		
1 prong	16.4 ± 0.5	
$\pi^- + \pi^0$	≤ 0.7 (1)	
3 prongs	59.7 ± 1.2	
$\pi^- + \pi^- + \pi^+$	1.57 ± 0.21	($40\%\ \rho^0\pi^-$, $40\%\ f^0\pi^-$, $20\%\ \pi^-\pi^-\pi^+$)
$(\rho^0 + \pi^-)$	~ 0.63	
$(f^0 + \pi^-)$	~ 0.94 (2)	
$\pi^- + \pi^- + \pi^+ + \pi^0$	21.8 ± 2.2	($\sim 40\%\ \rho\pi\pi$, $\sim 60\%\ 4\pi$)
$(\rho^0\pi^-\pi^0 + \rho^-\pi^+\pi^- + \rho^+\pi^-\pi^-)$	~ 8.7	
$(A_2^0 + \pi^-)$	≤ 3.3 (1)	
$(\omega^0 + \pi^-)$	0.41 ± 0.08 (2)	
$(\eta^0 + \pi^-)$	≤ 0.25 (1),(2)	
5 prongs	23.4 ± 0.7	
$\pi^- + \pi^- + \pi^- + \pi^+ + \pi^+$	5.15 ± 0.47 (3)	
$\pi^- + \pi^- + \pi^- + \pi^+ + \pi^+ + \pi^0$	15.1 ± 1.0	($\sim 70\%\ \omega 3\pi$, $30\%\ 6\pi$)
$\omega^0 + \pi^- + \pi^- + \pi^+$	12.0 ± 3.0 (2)	
7 prongs	0.39 ± 0.07	

(1) At a 90% confidence level.
(2) Corrected for neutral decay
(3) Dominated by a strong $\rho^0\rho^0$ interaction (See Ref. 4).

$\pi\pi$ Phase Shifts or Resonance Parameters

$\delta_{\ell=0}$, I=0 (bracket spanning the first six rows)

Phase shift	$M(\pi\pi)$ (MeV)	Γ (MeV)	Source	Interpretation
$\sim 0°$	700–750		Walker et al.	Resonance?
	720	< 50	Selove	Resonance
$35° \sim 55°$	400–500		Jacobs + Selove	Phase shift
$\sim 20°$ $\sim 57°$	300–325 600–625		Jones	Phase shift
	430 ± 70	400^{+400}_{-150}	Lovelace	Resonance
Decreasing δ_{00} from 2π at threshold			Cook	phase shift
I=0 ℓ=2 $\pi\pi$ Resonance	785	~5–20	Desai	Resonance
$\delta_{00} - \delta_{11} = 27° \pm 18°$	280–350		Birge et al.	phase shift