Resonances vs Backgrounds: role of MN scattering

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There is a world wide effort in hadron spectroscopy JLab, BESIII, COMPASS, PANDA, Super-B,...

Amplitude analysis is hard ! There is no one-size-fits all prescription and the more constraints the better

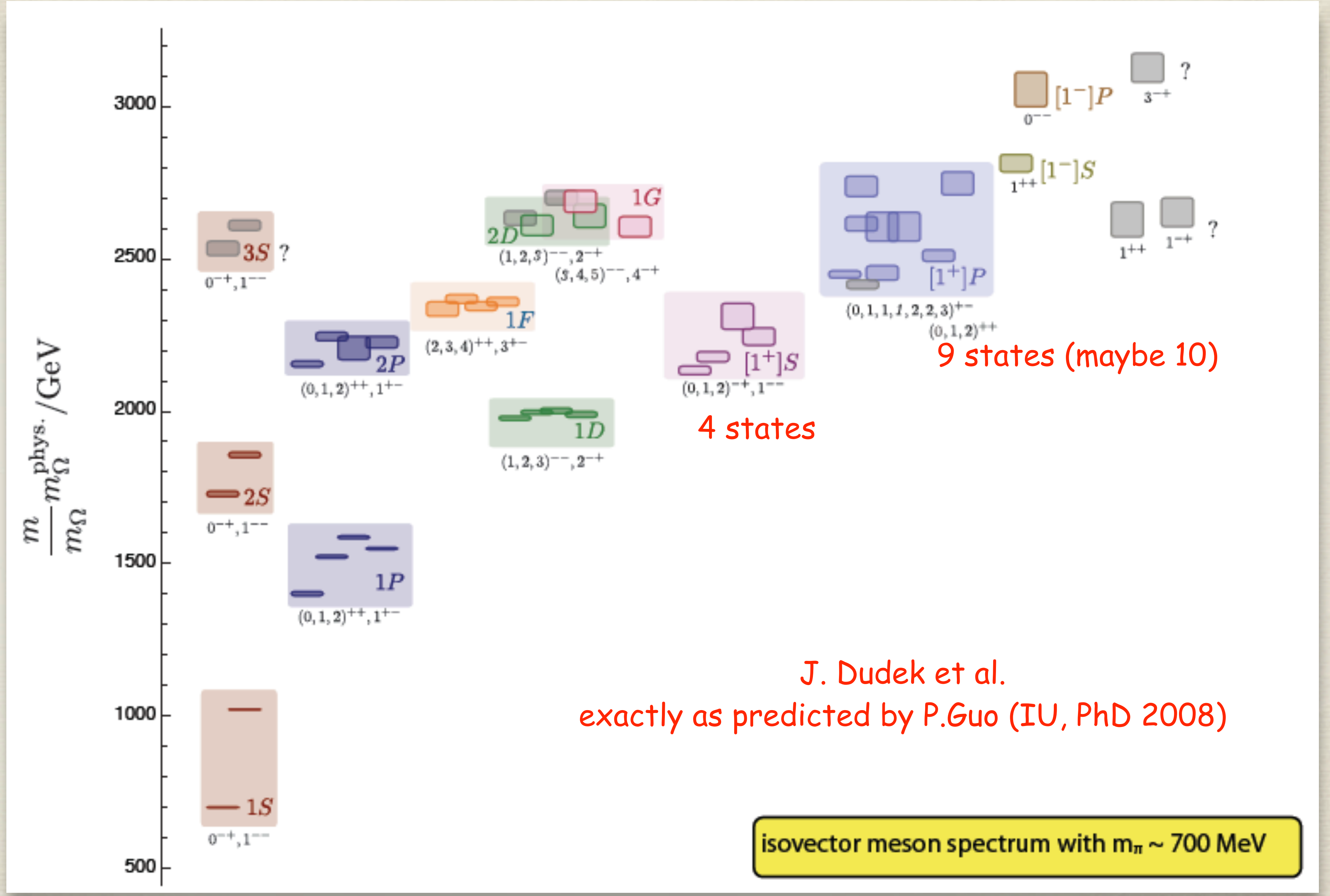
πN, ηN, KN, ... both elastic and inelastic play central role in constraining backgrounds

Examples:

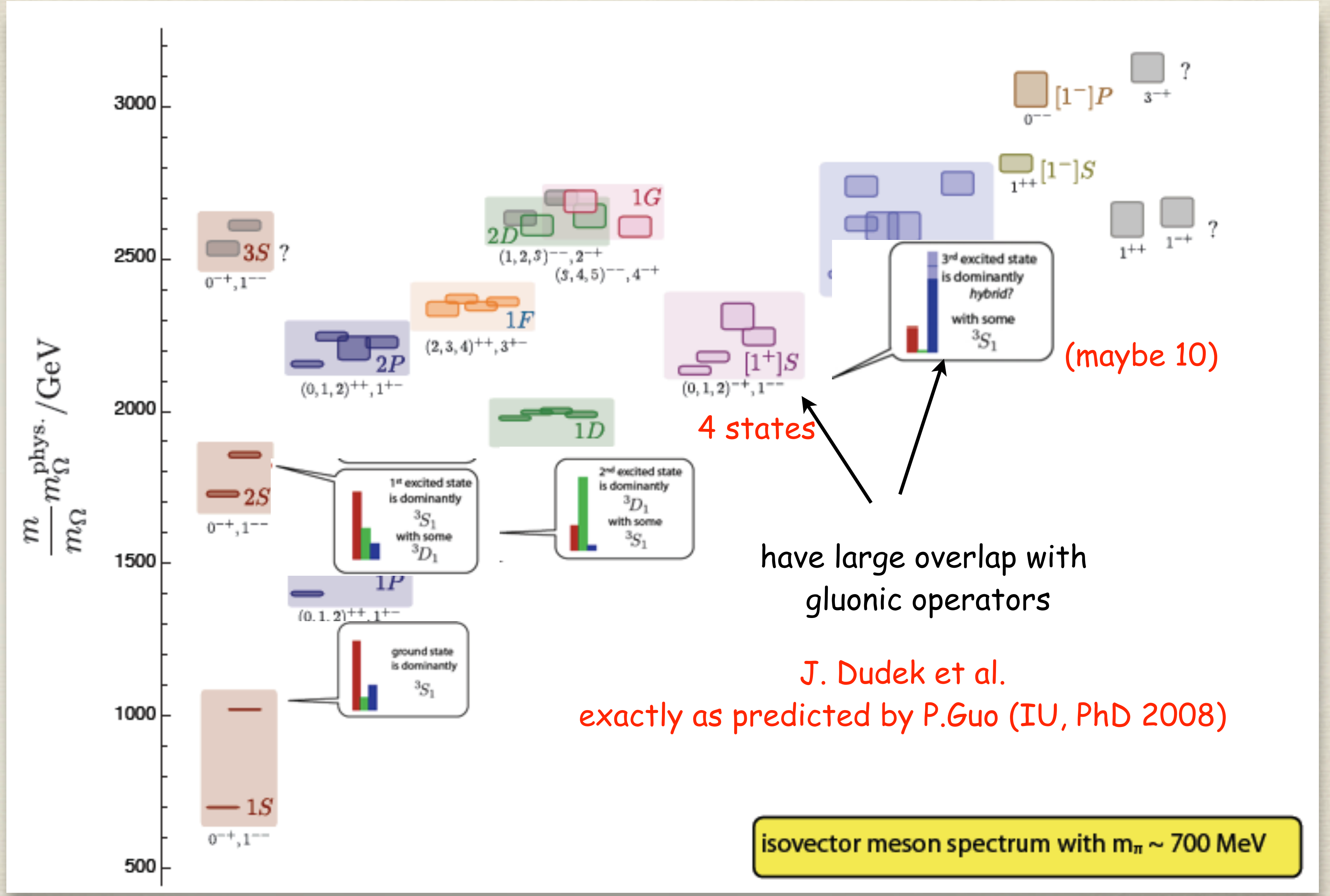
- 3π production and the role of πN scattering in extraction of the a_1 (relevance for π_1 spin-exotic)

- $\pi\eta$ production (ηN scattering) and searches for spin-exotics

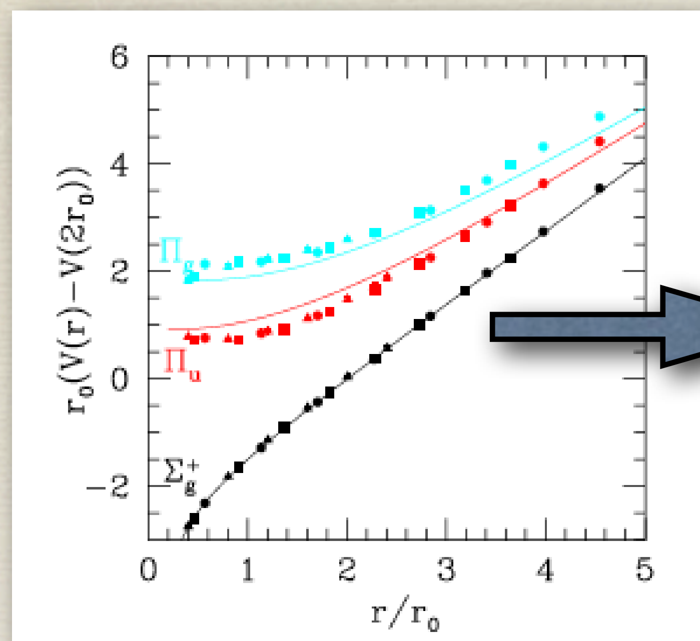
✱ state of the art full spectrum

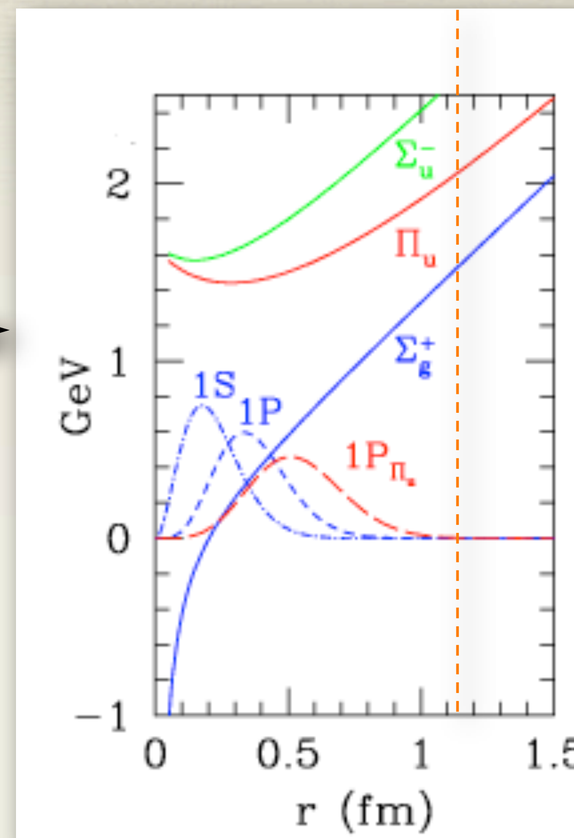


* state of the art full spectrum



$*\quad M = \frac{G}{2} + \rho = 0.8 + 0.75 \sim 1.6\,\text{GeV}$





$*$ $J^{PC} = 1^{-+}$ lowest state

Higher masses have also been resolved

Chiral extrapolations 100-200 MeV (Thomas,APS)

In large-Nc same as for ordinary mesons O(1/Nc) (Cohen)

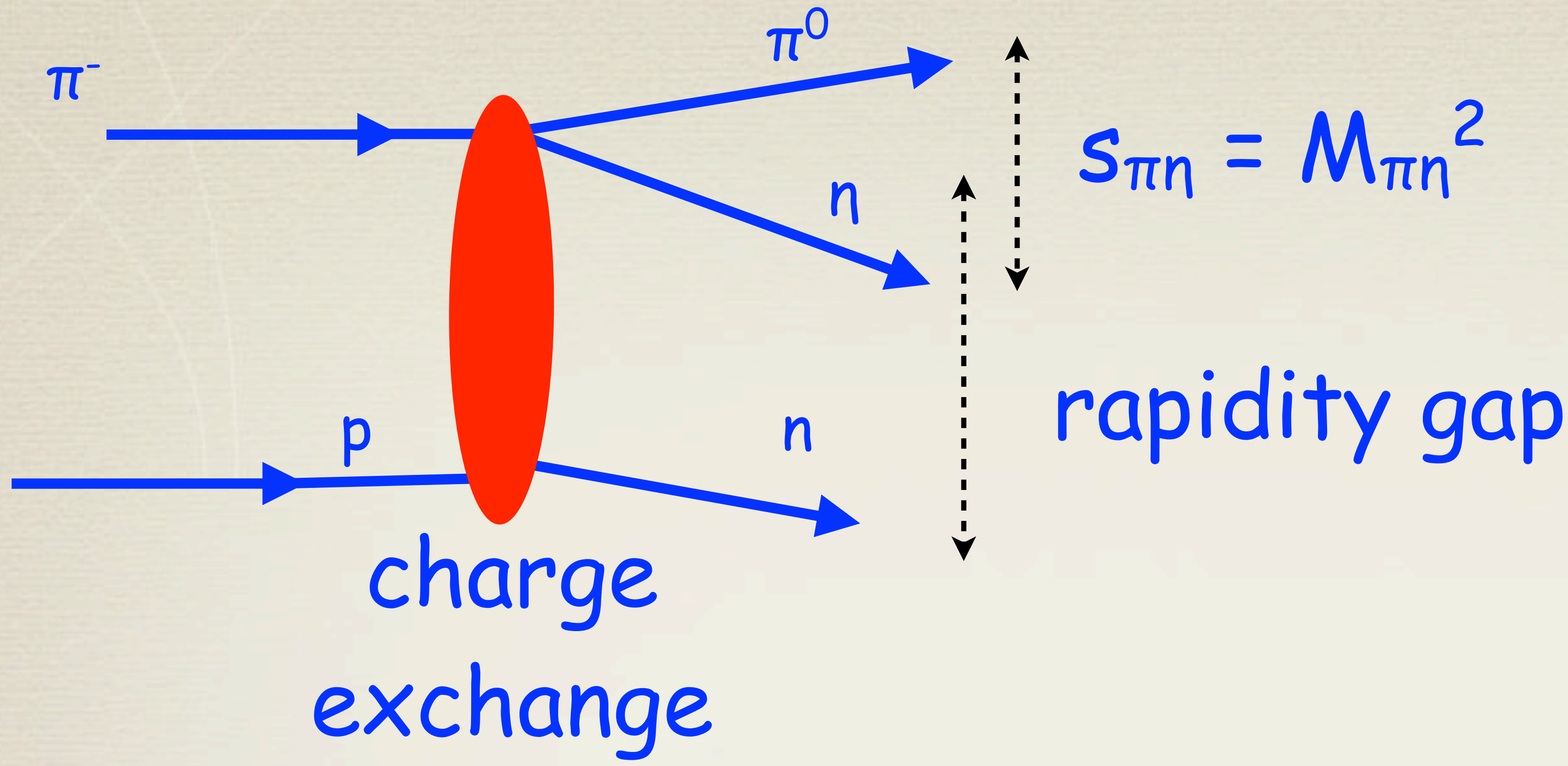
1^{-+} (1.8 GeV)	$b_1\,\pi$	$f_1\,\pi$	$\rho\,\pi$	
PSS	S 73 D 1	S 9 D 0.04	P 13	Γ MeV
IKP	S 51 D 11	S 14 D 7	P 12	

Isgur, Kokosky, Paton (85)
Close, Page (95)
Page, Swanson, Szczepaniak (99)
Close, Dudek (04)

Preliminary (toy) lattice computation of decay widths agrees with models (Michael,McNeile) (Burns,Close)

$\pi^- p \to \eta\pi^- p$	$M = 1370 \pm 16^{+50}_{-30}$ MeV / c^2 $\Gamma = 385 \pm 40^{+65}_{-105}$ MeV / c^2	
$\pi^- p \to \eta\pi^0 n$	No consistent B-W interpretation possible but a weak ηπ interaction exists and can reproduce the exotic wave	
$\pi^- p \to \eta'\pi^- p$	$M = 1597 \pm 10^{+45}_{-10}$ MeV / c^2 $\Gamma = 340 \pm 40^{+50}_{-50}$ MeV / c^2	
$\pi^- p \to \rho^0\pi^- p$ $\pi^- p \to b_1 \pi p$ $\pi^- p \to f_1 \pi p$	$M = 1593 \pm 8^{+29}_{-47}$ MeV / c^2 $\Gamma = 168 \pm 20^{+150}_{-12}$ MeV / c^2	BNL (E852) new analysis reduces the strength but COMPASS find the signal again, JLab large uncertainties

Example $\pi^- p \to \pi^0 \eta n$ (from E852)



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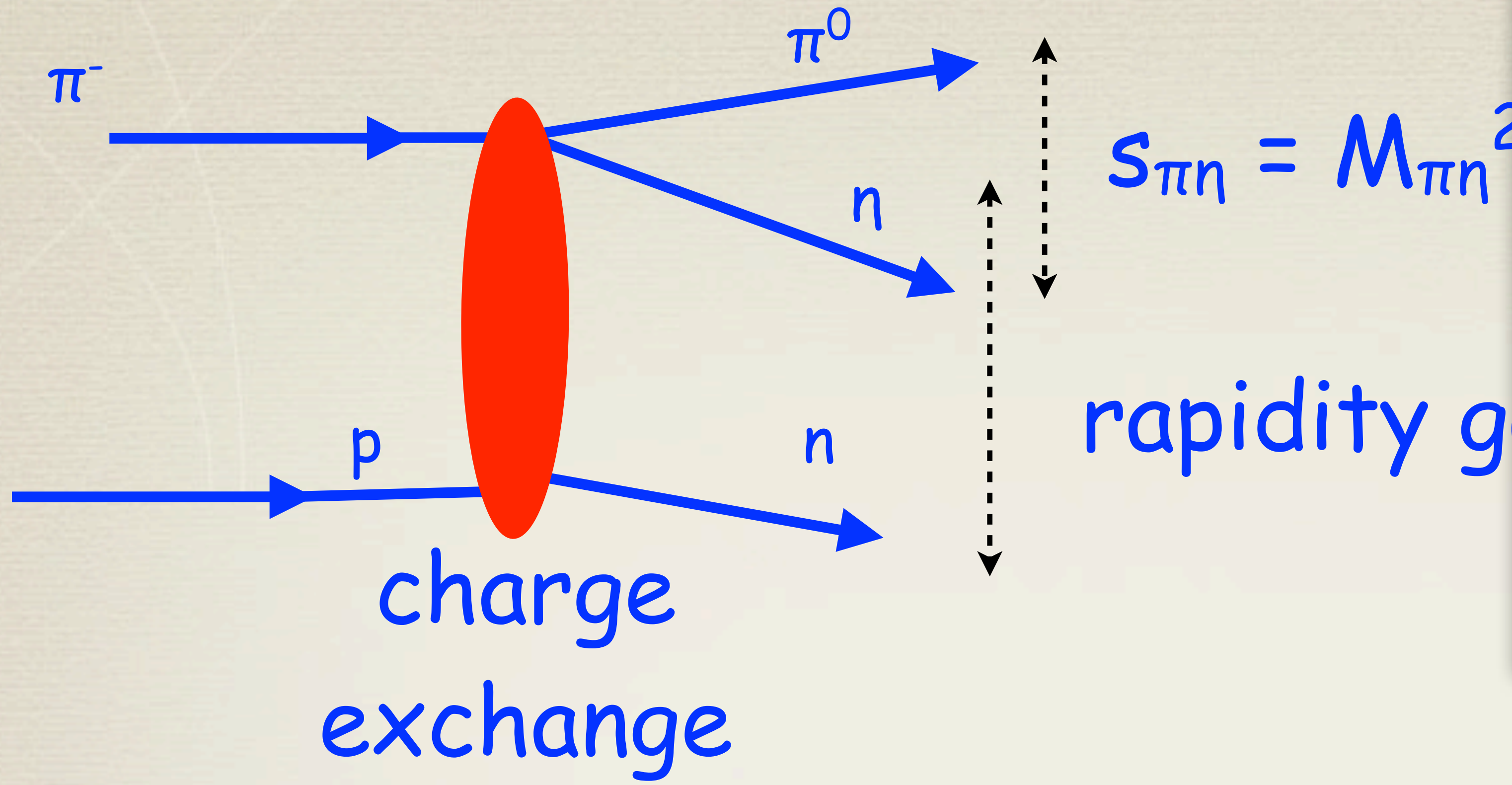

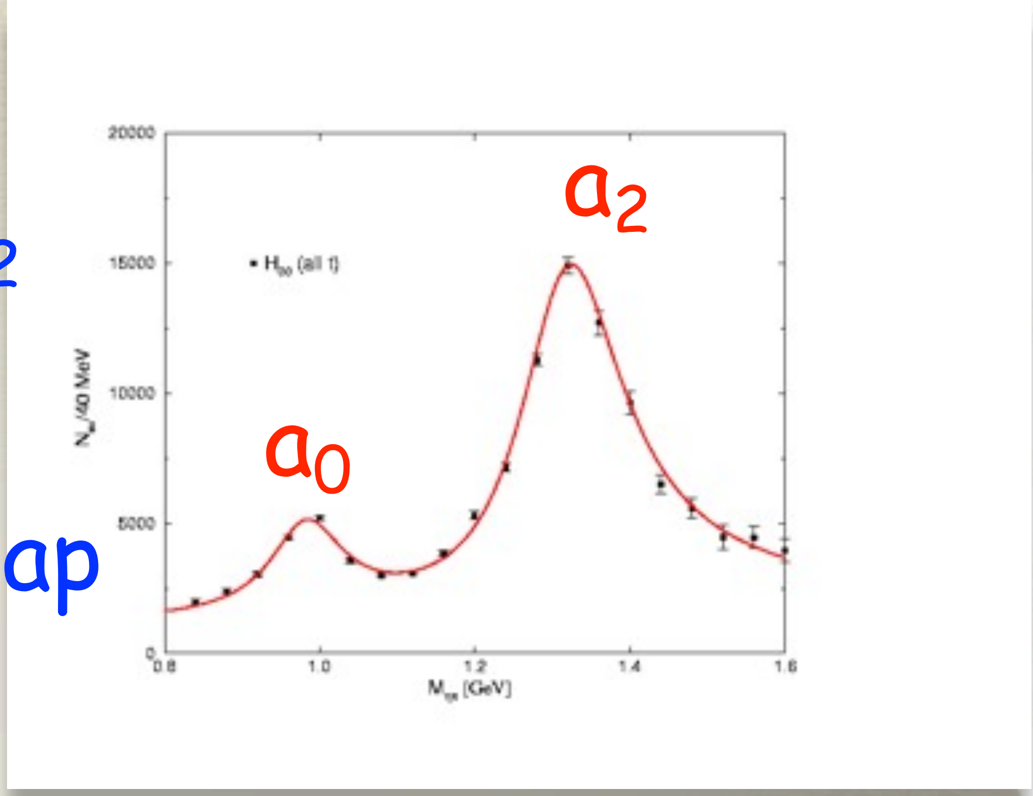

Dominant PW's

$\eta\pi$ in S : a_0

$\eta\pi$ in D : a_2

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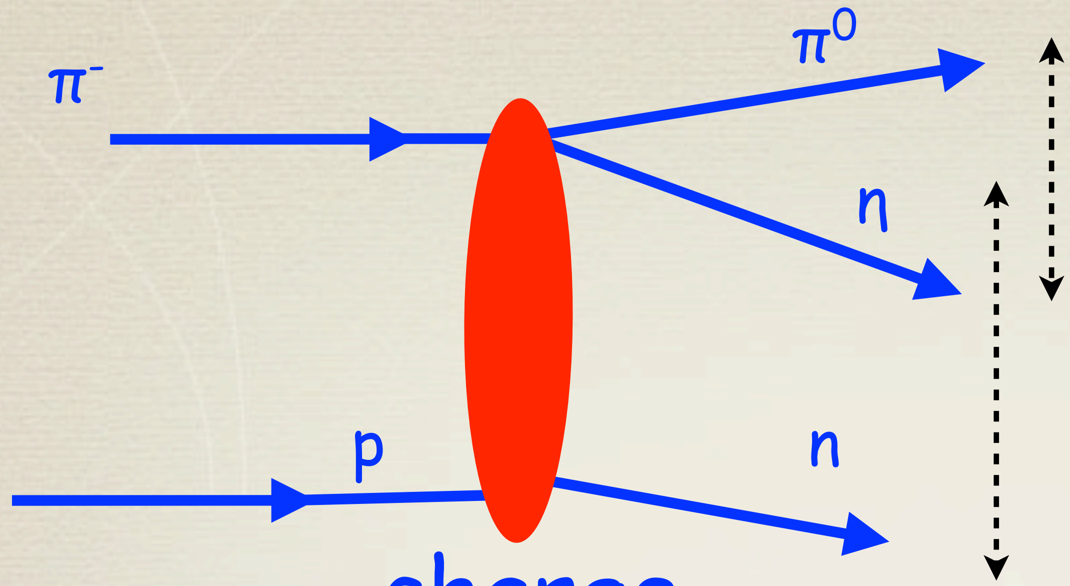
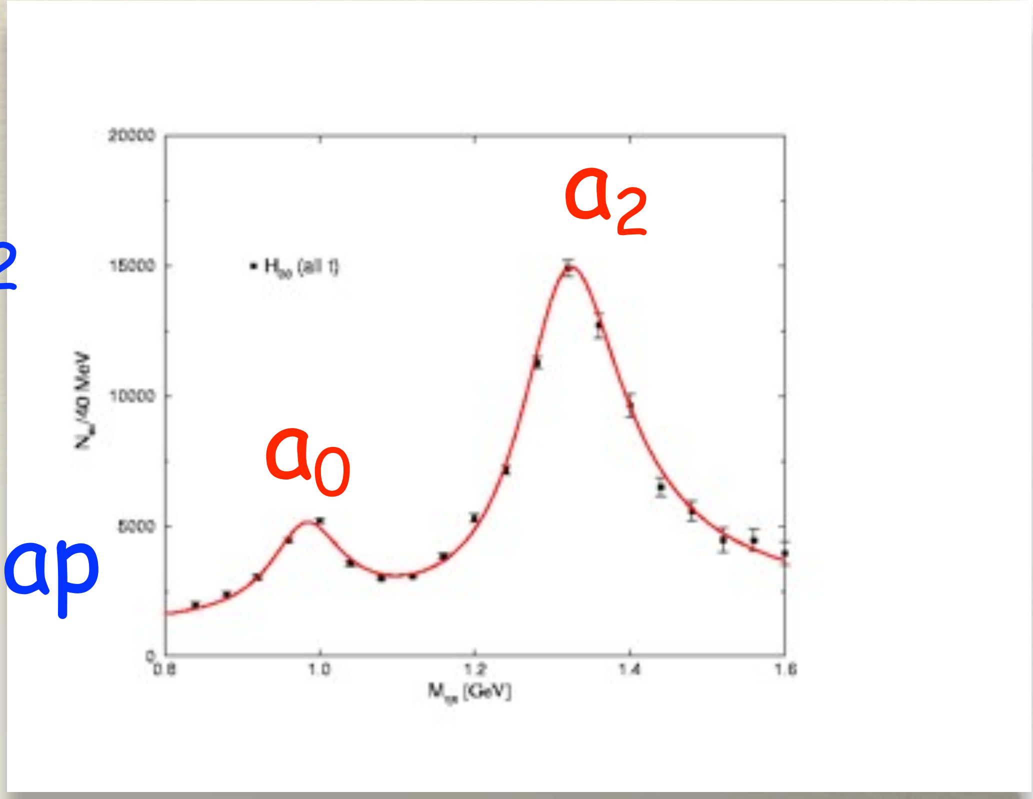
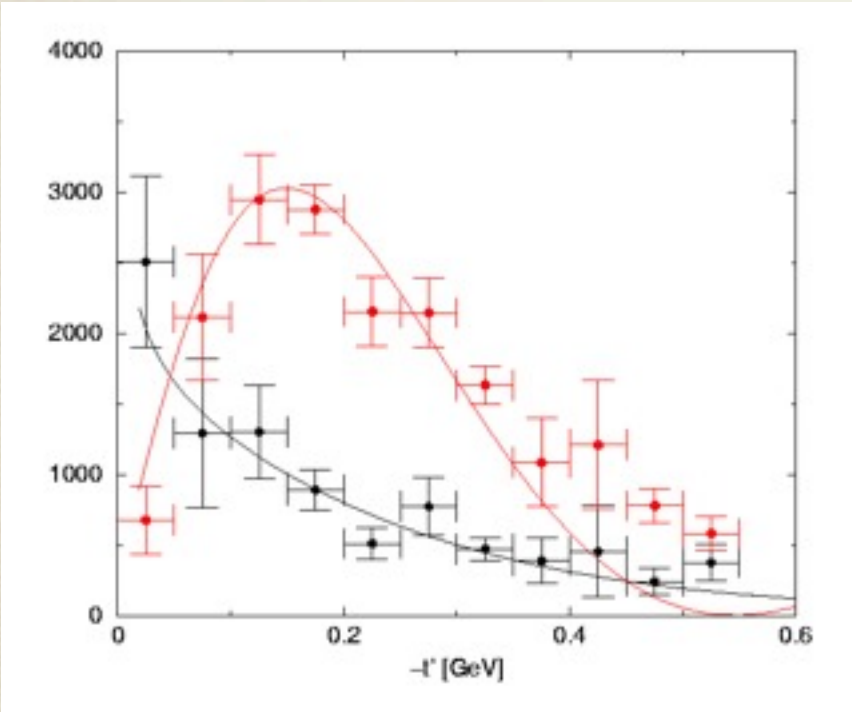


$s_{\pi\eta} = M_{\pi\eta}^2$

rapidity gap

charge exchange





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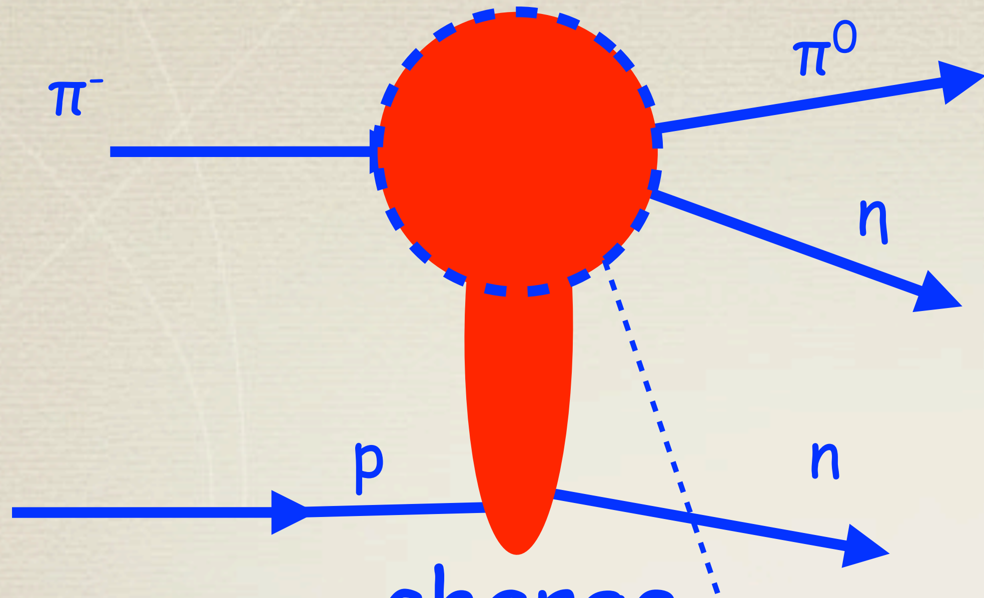

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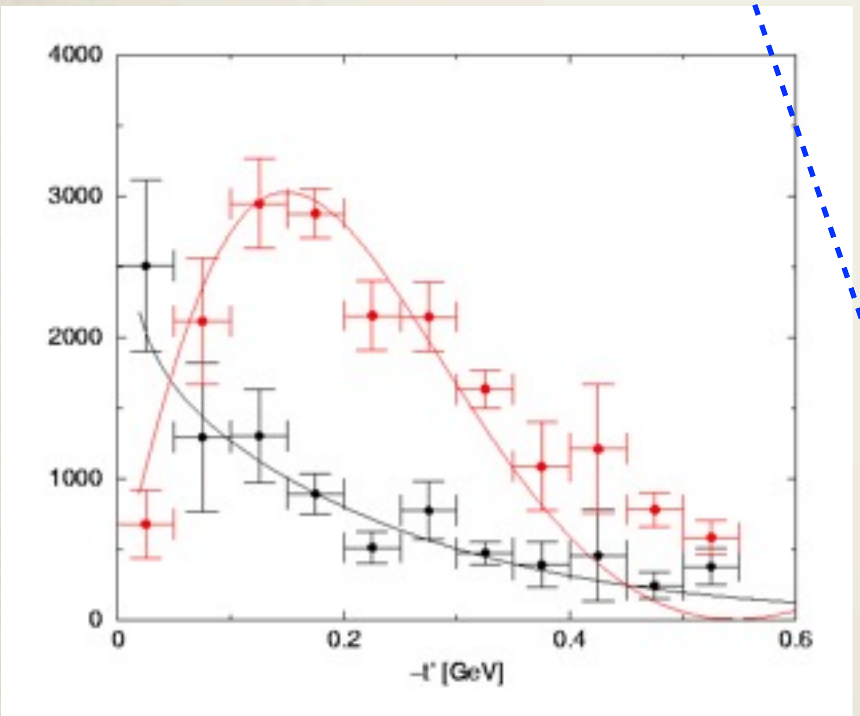
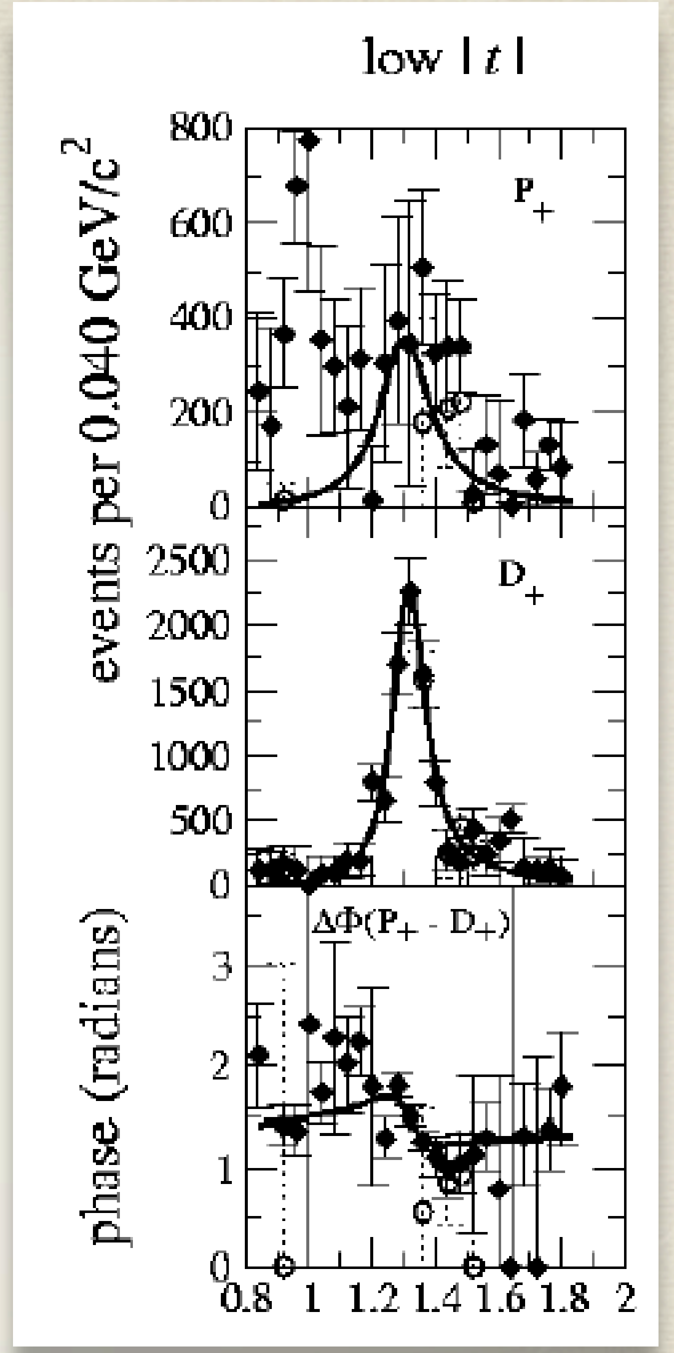
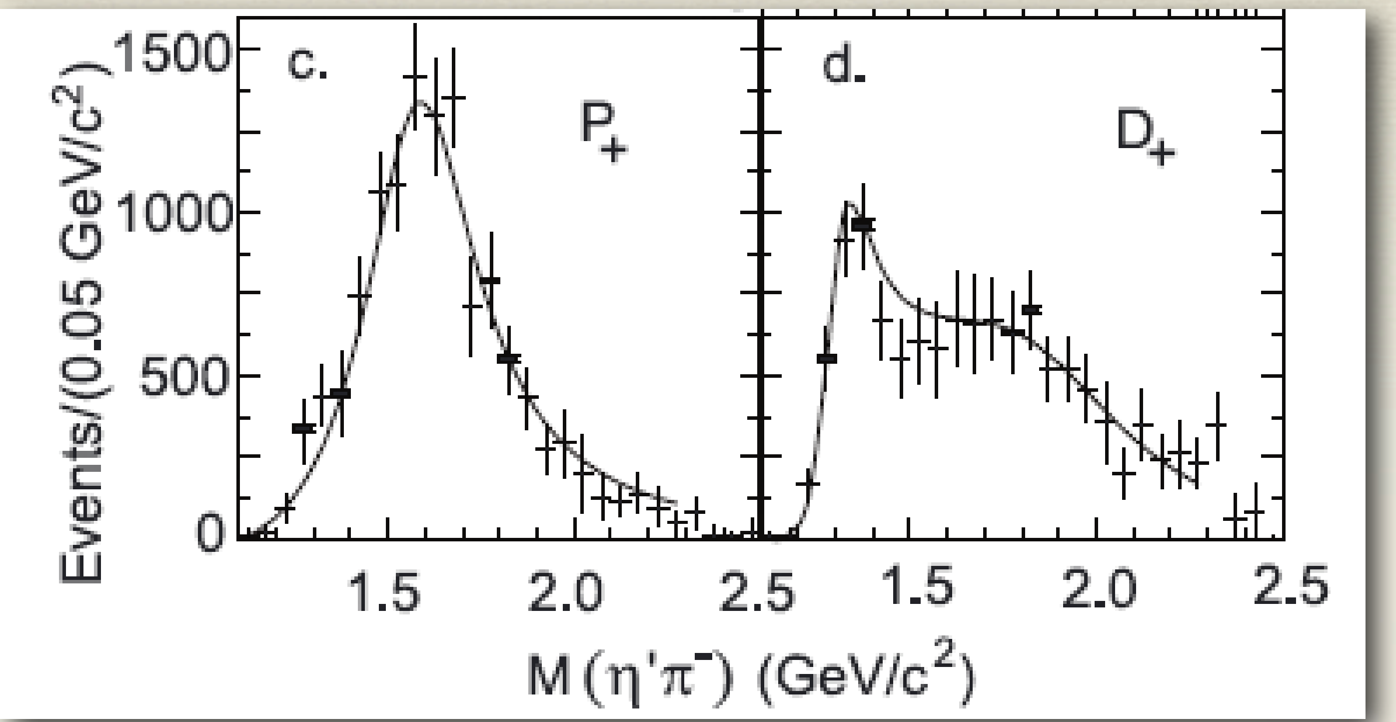




"some" exotic wave but nature cannot be established without a dynamical model

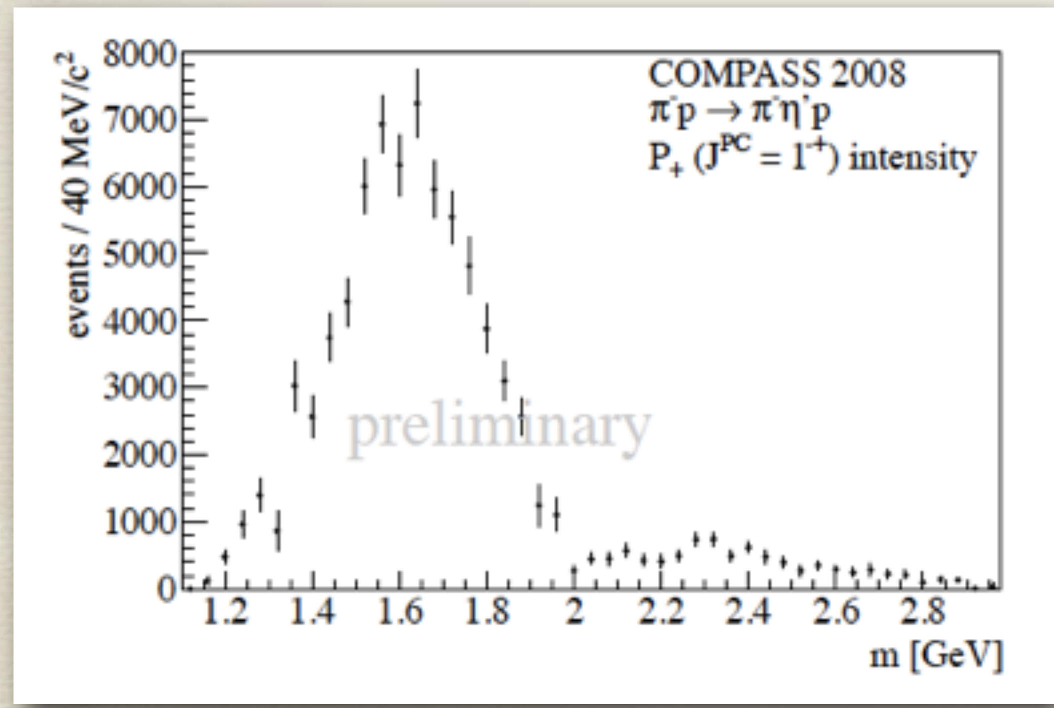
$J^{PC}=1^{-+}$
exotic wave

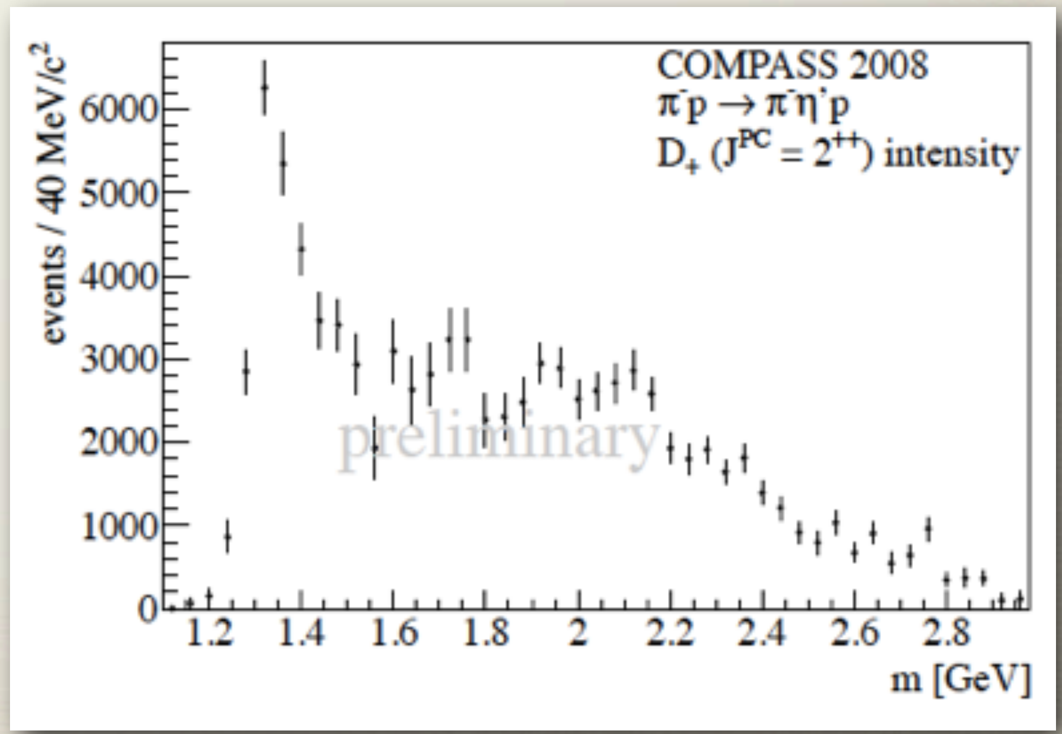
$\pi^- p \to \pi^- \eta' p$



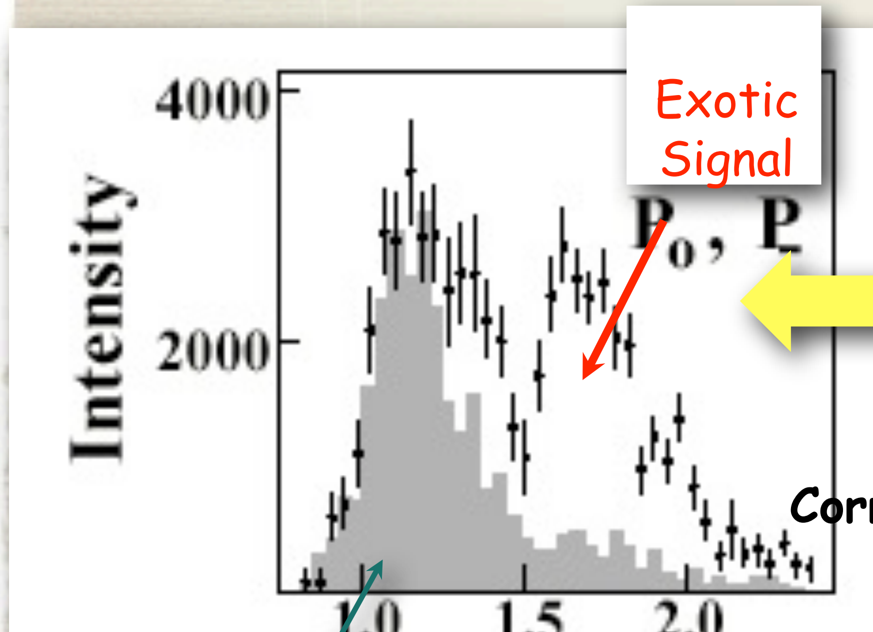
E852

COMPASS

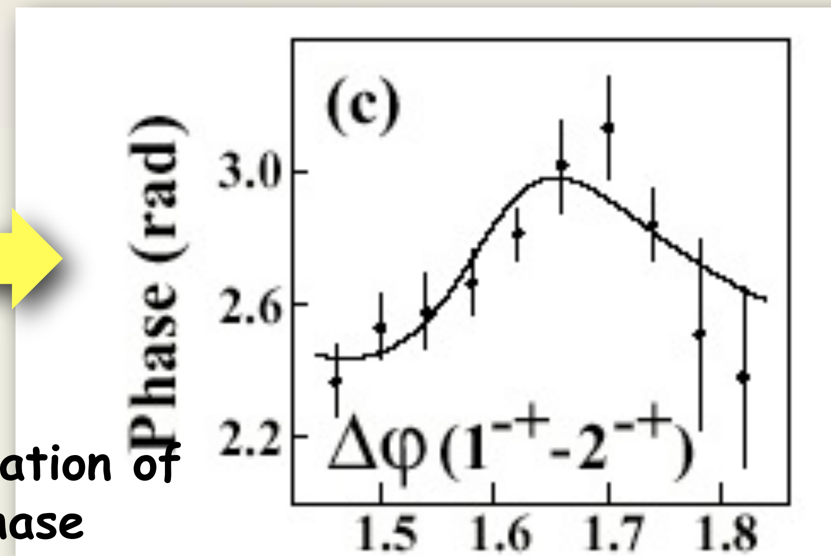




$\pi_1(1600)$ in $\pi^+\pi^-\pi^-$



Correlation of
Phase
&
Intensity



Leakage
From
Non-exotic Wave
due to imperfectly
understood acceptance

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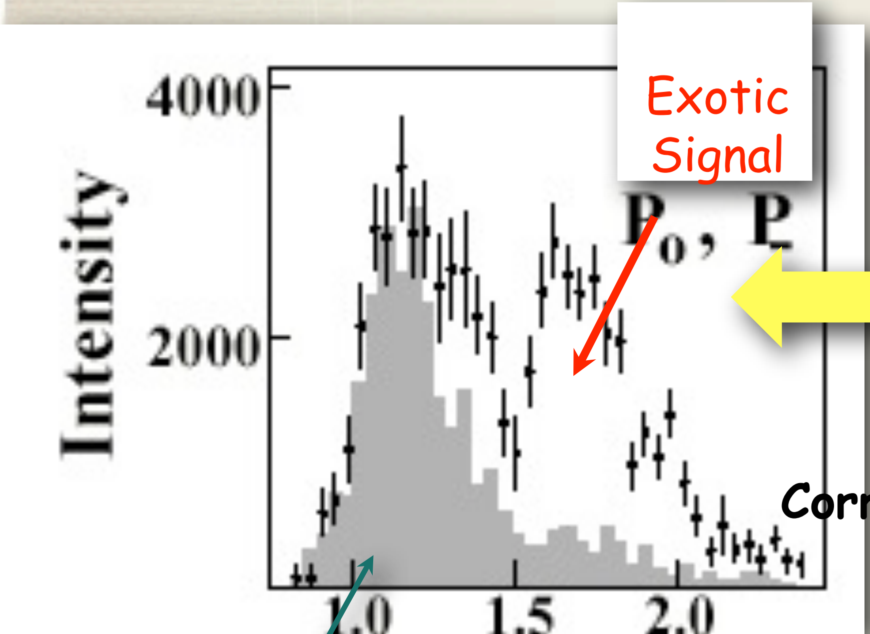
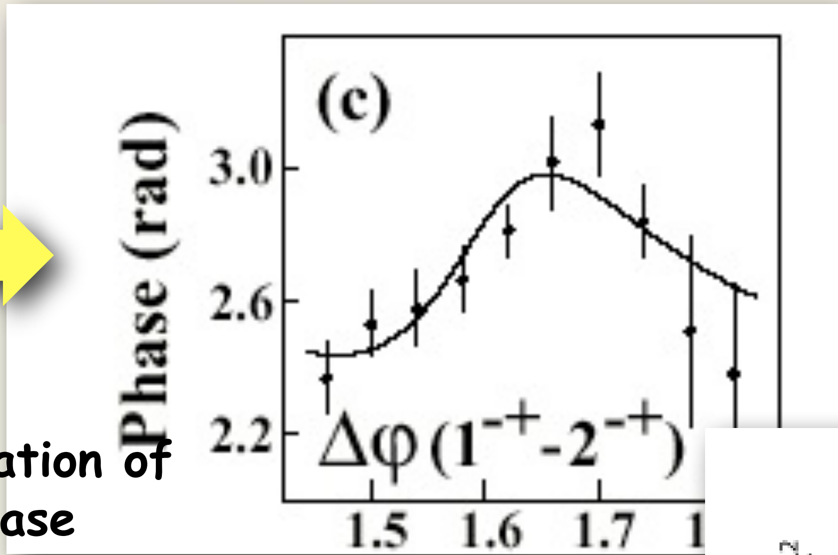


Exotic Signal

Leakage From Non-exotic Wave due to imperfectly understood acceptance



Correlation of Phase & Intensity

E852 result

$$\pi^- p \to \pi_2^-(1600)p$$
$$\pi_2^- \to \rho^0\pi^-$$
$$\rho^0 \to \pi^-\pi^+$$

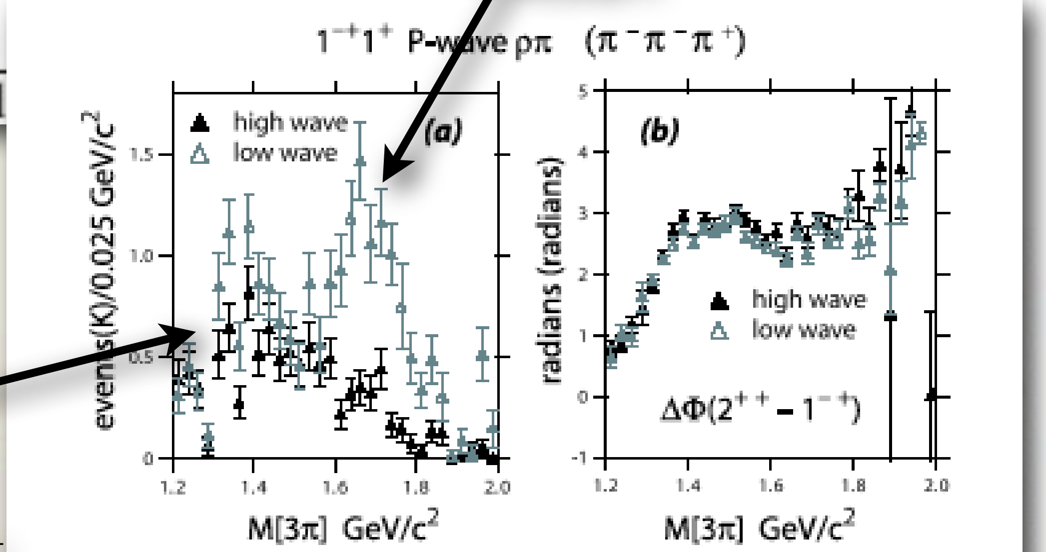


FIG. 25: (a) The $1^{-+}1^+$ P-wave $\rho\pi$ partial wave in the charged mode $(\pi^-\pi^-\pi^+)$ for the high-wave set PWA and the low-wave set PWA and (b) the phase difference $\Delta\Phi$ between the 2^{++} and 1^{-+} for the two wave sets.

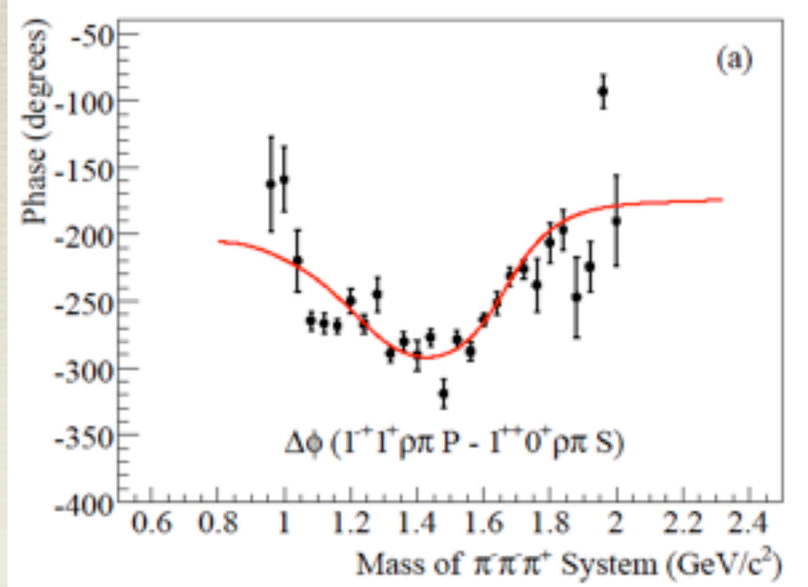
$\pi_1(1600)$ in $\pi^+\pi^-\pi^-$

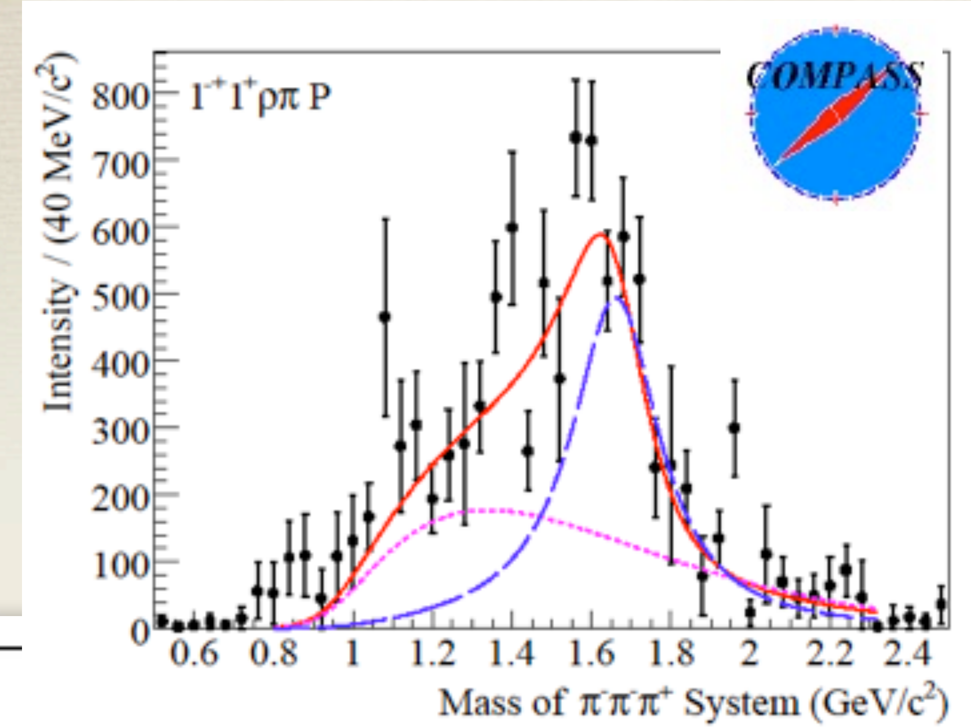
- BW parameters for $\pi_1(1600)$

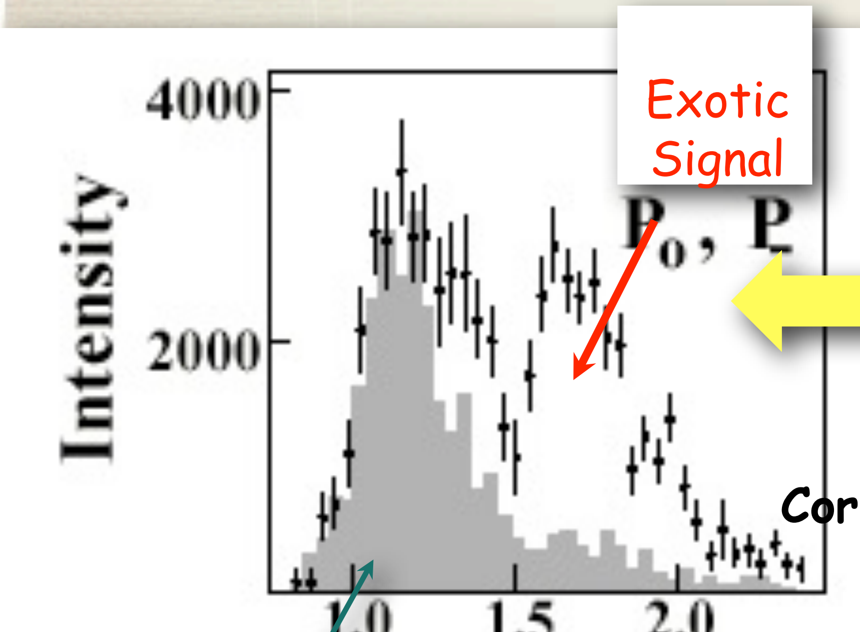
$$M = \left(1660 \pm 10\,^{+0}_{-64}\right)\,\mathrm{MeV}/c^2$$

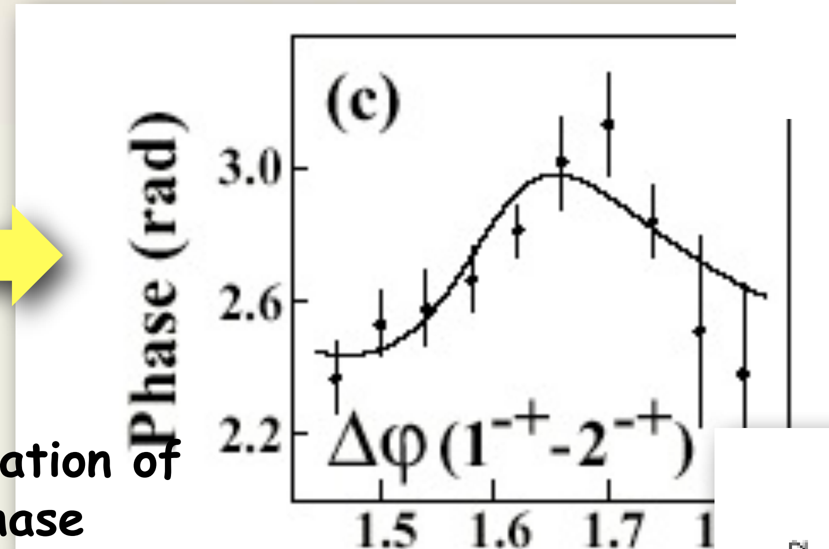
$$\Gamma = \left(269 \pm 21\,^{+42}_{-64}\right)\,\mathrm{MeV}/c^2$$

- Leakage negligible: <5%







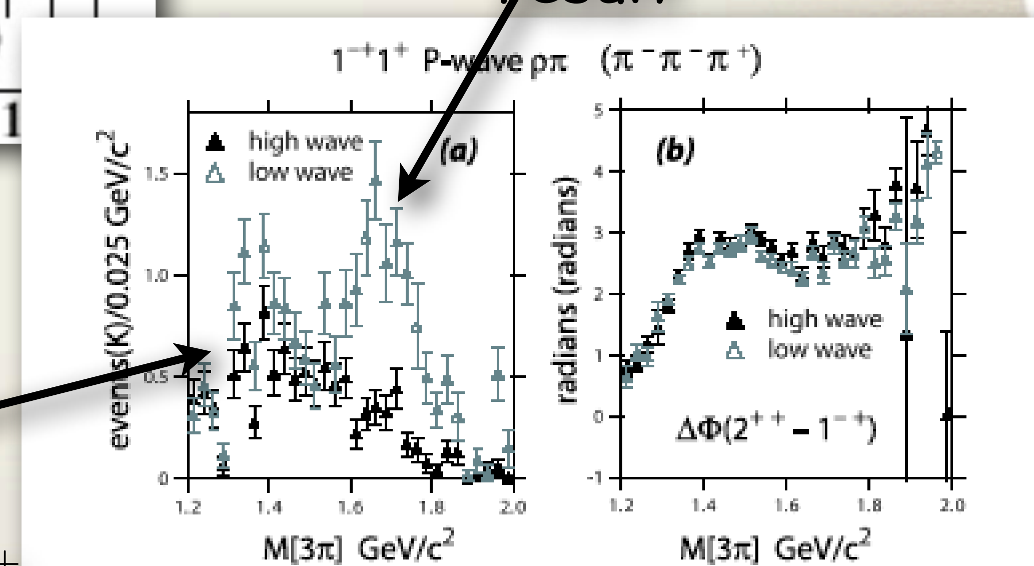


Correlation of Phase & Intensity

Leakage From Non-exotic Wave due to imperfectly understood acceptance

E852 result

$$\pi^- p \to \pi_2^-(1600)p$$
$$\pi_2^- \to \rho^0\pi^-$$
$$\rho^0 \to \pi^-\pi^+$$



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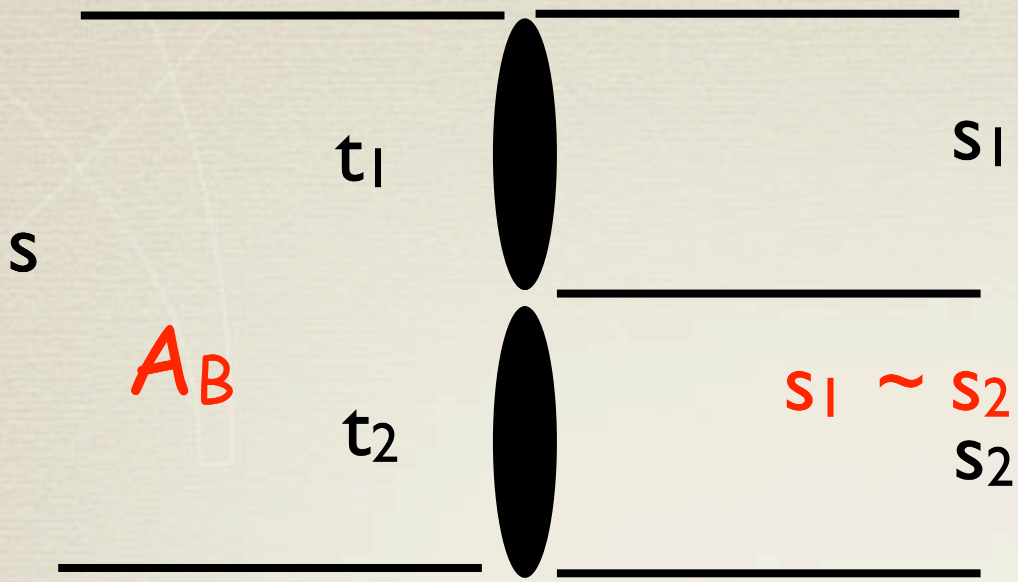
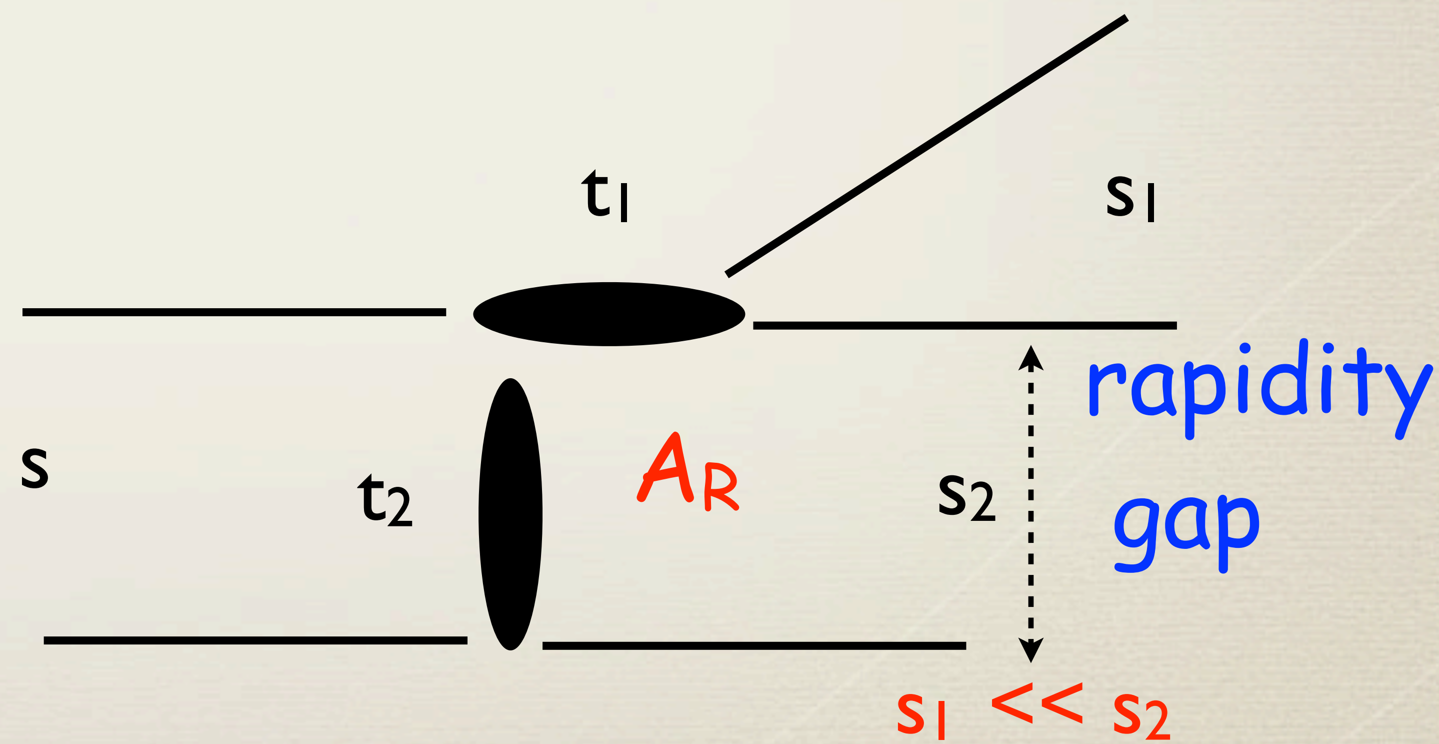
Duality:

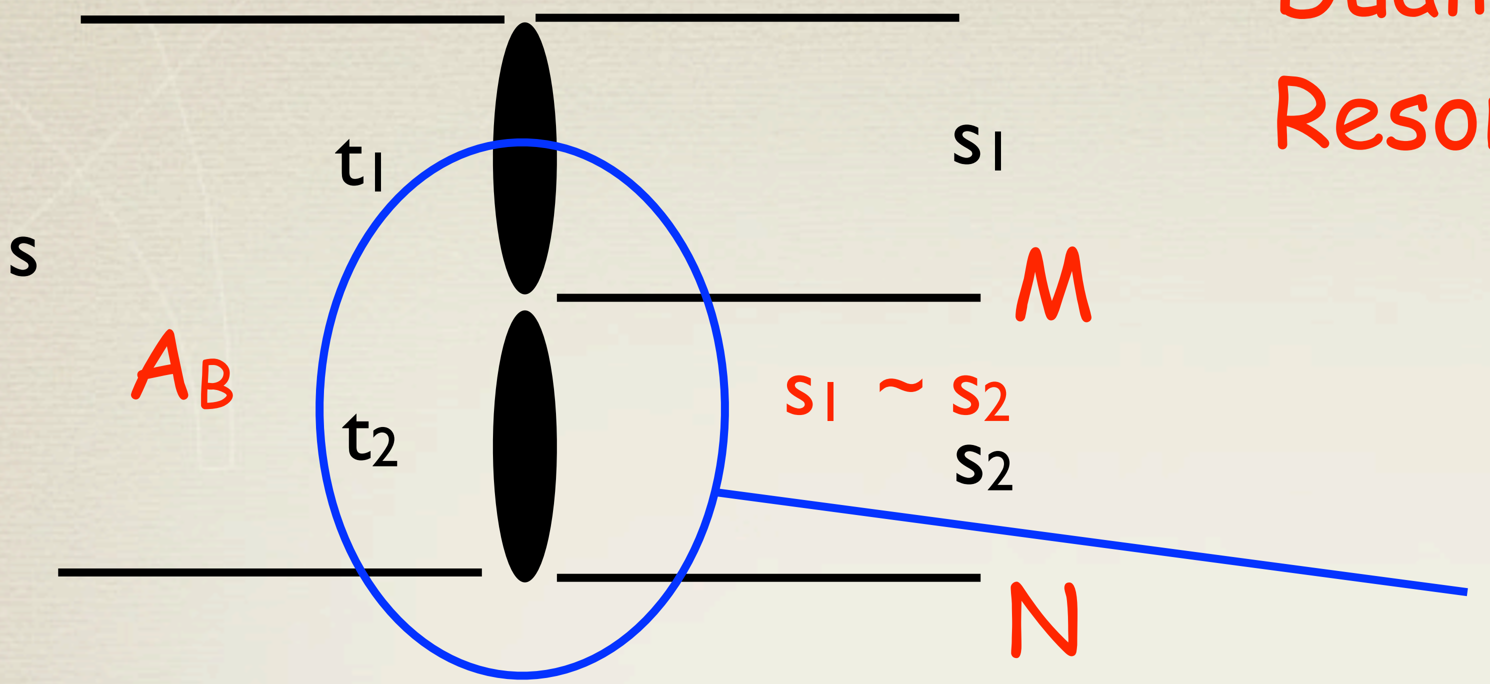
Resonances vs Forces





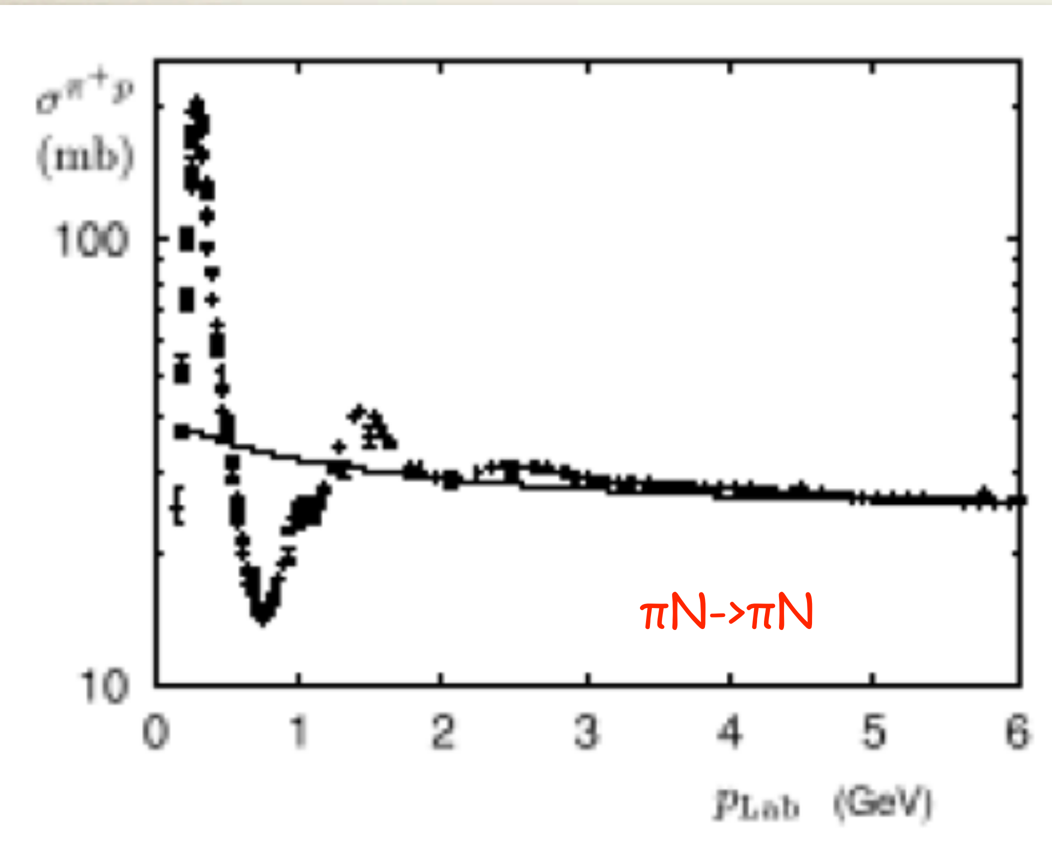
Resonance approximation

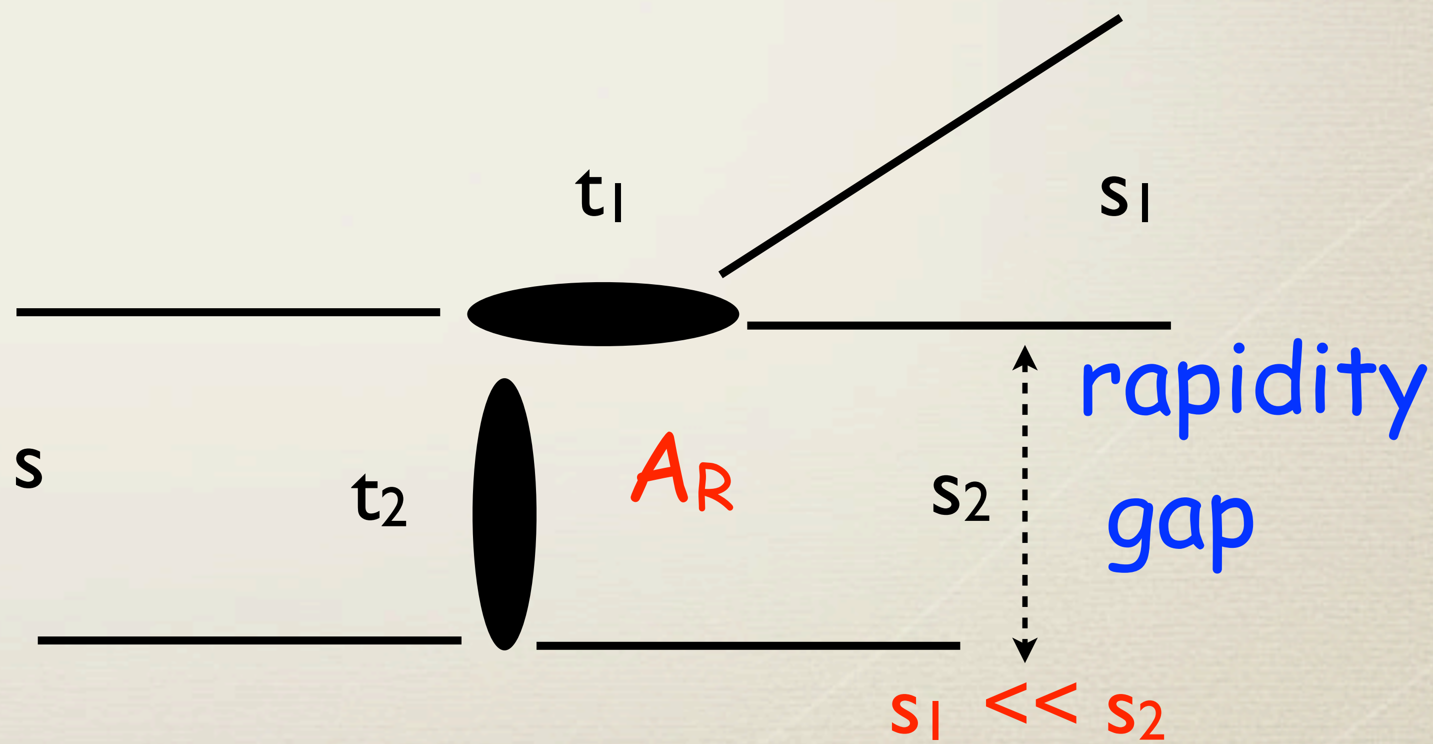
Duality:
Resonances vs Forces



Finite Energy Sum Rules

Meson-Nucleon Scattering amplitude





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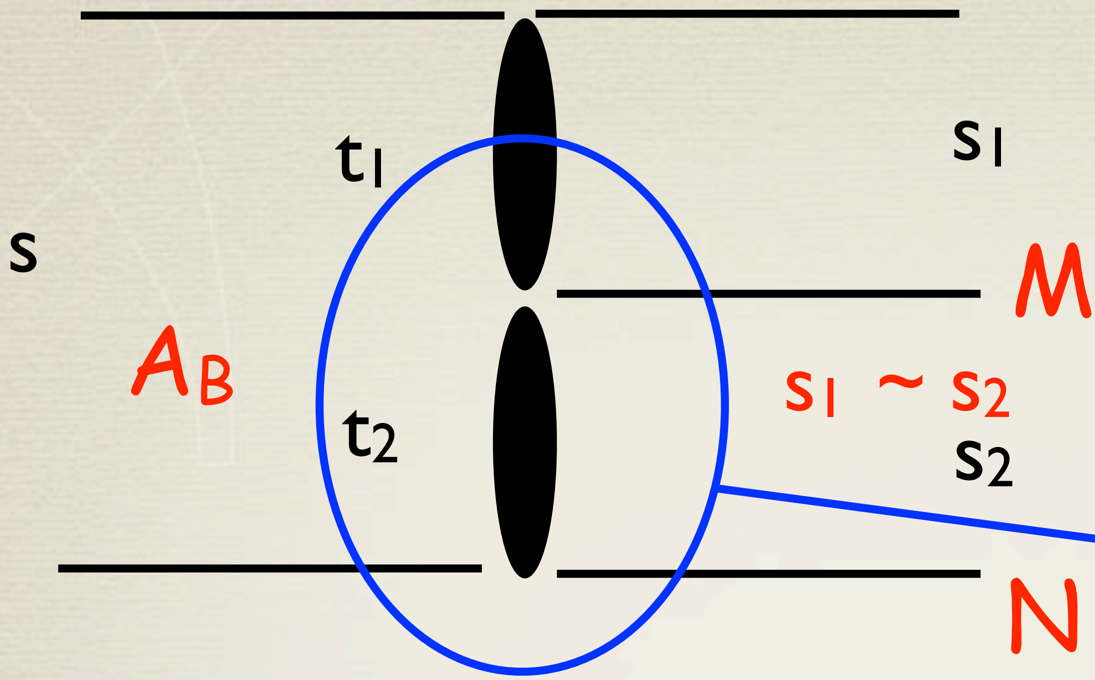
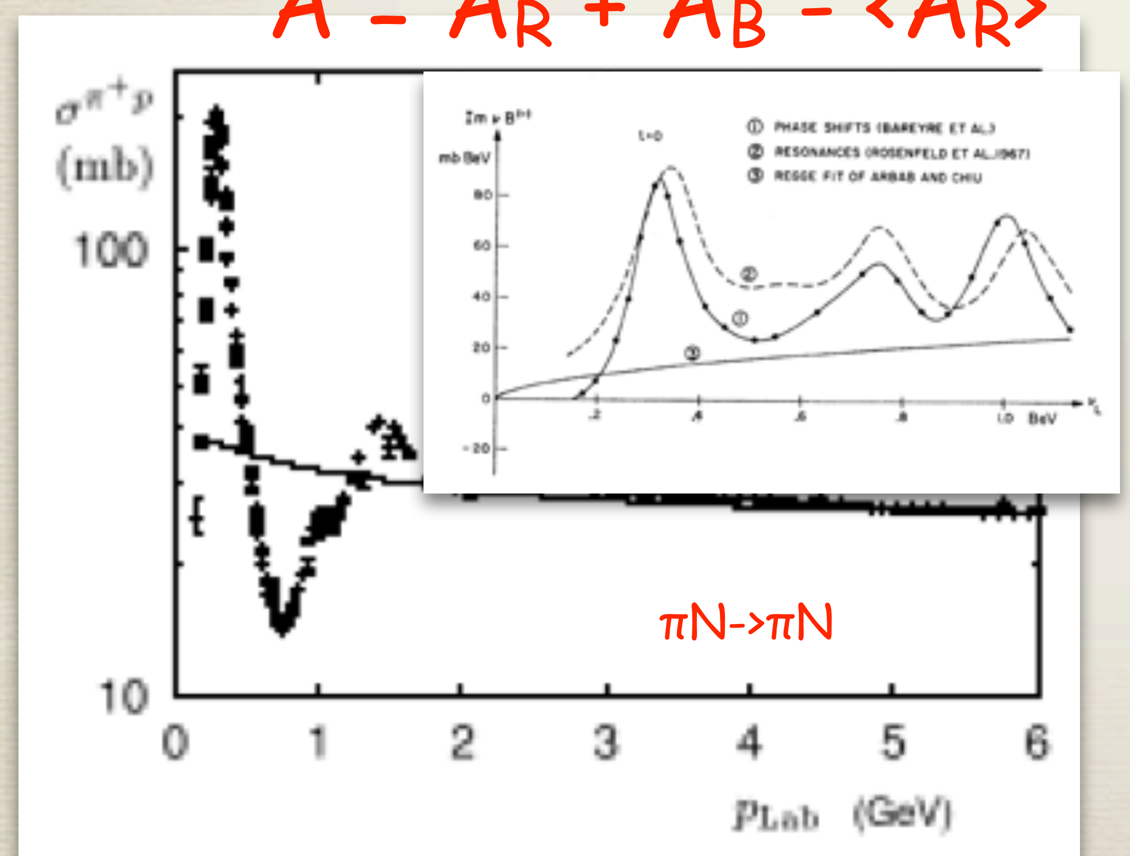
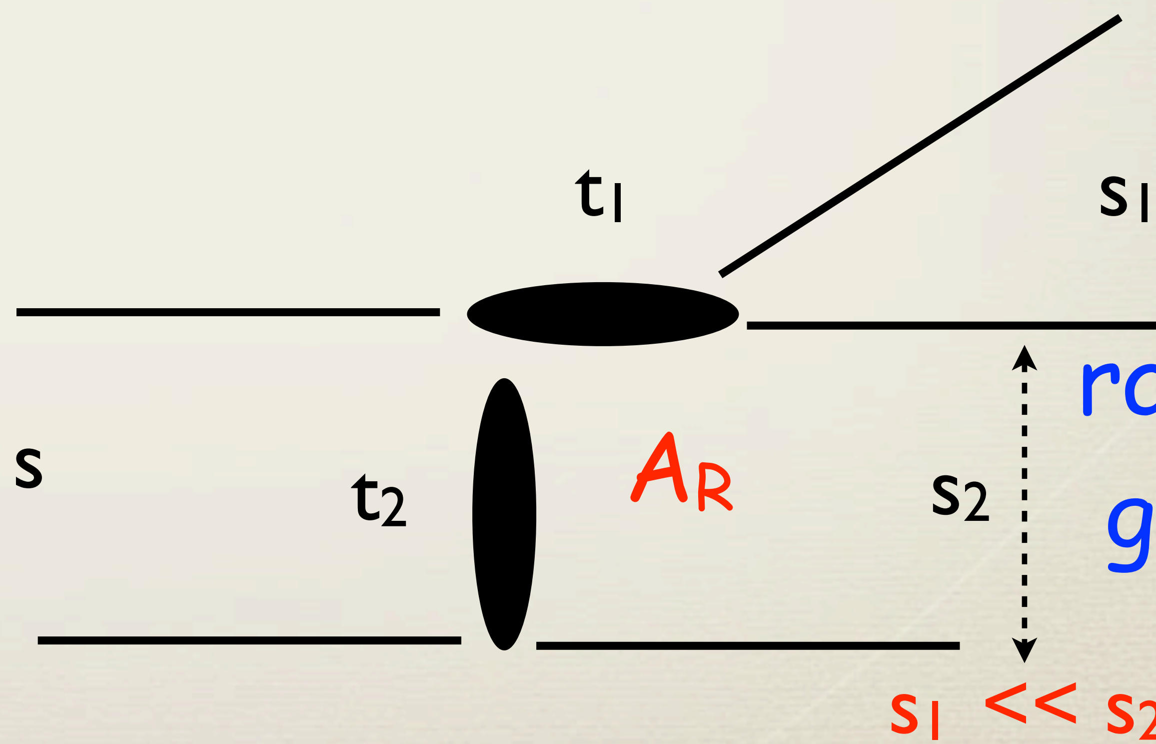


Meson-Nucleon Scattering amplitude

Finite Energy Sum Rules

$A = A_R + A_B - \langle A_R \rangle$





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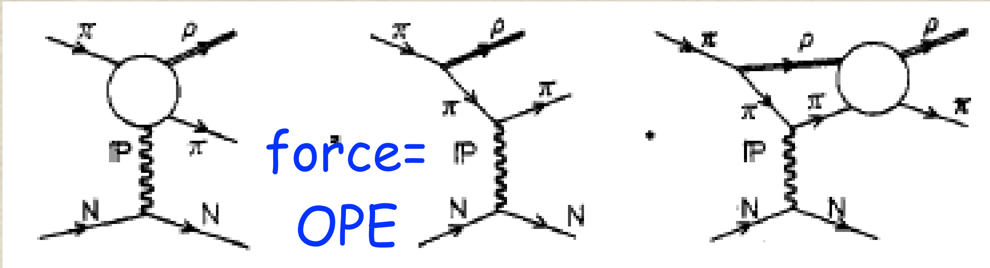
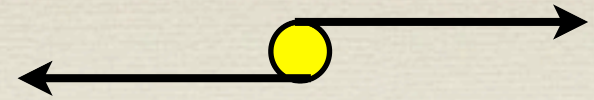
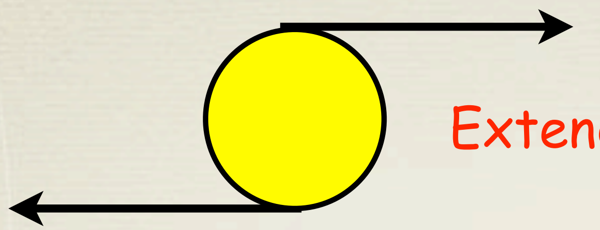
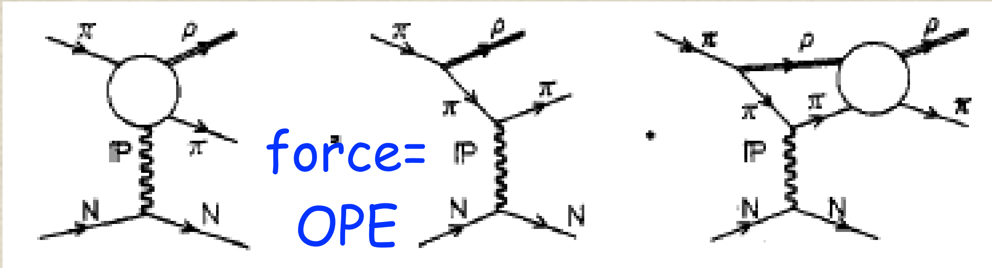


Compact source ~sin δ(E)





Extended source ~cos δ(E)



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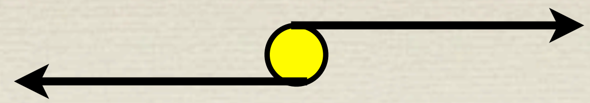

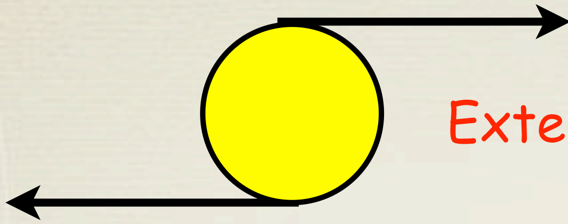

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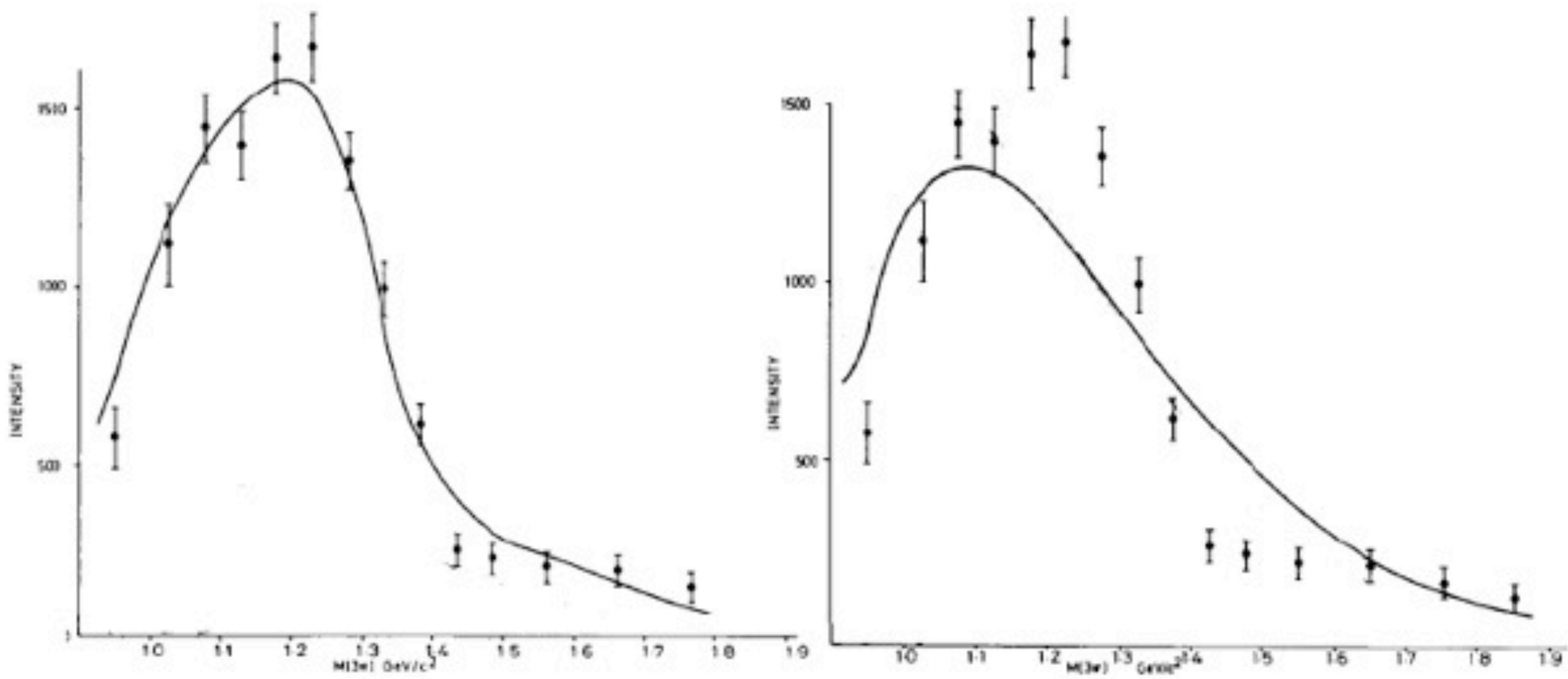
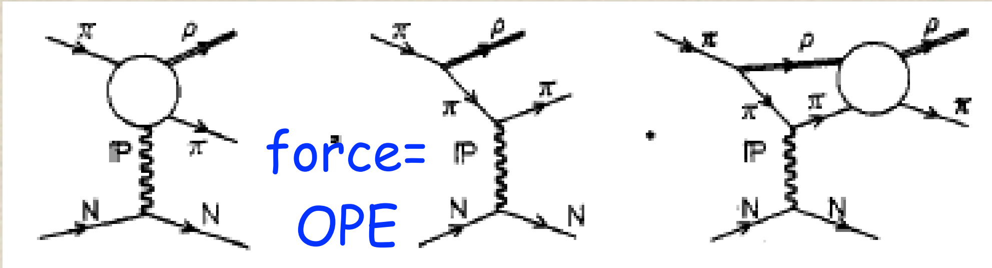


M.G.Bowler,(1975)

Figure 11: Fit to the 1^+ $\rho\pi$ intensity from $\pi^- p \to \pi^-\pi^-\pi^+ p$ at $E_\pi = 25$ and $E_\pi = 40$ GeV, CERN data [70], with (left) both long-range production from one pion exchange and short-range direct production and (right) short-range direct production only [63].



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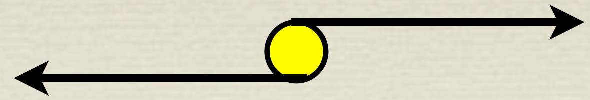

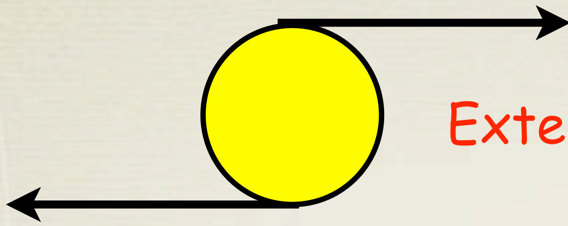

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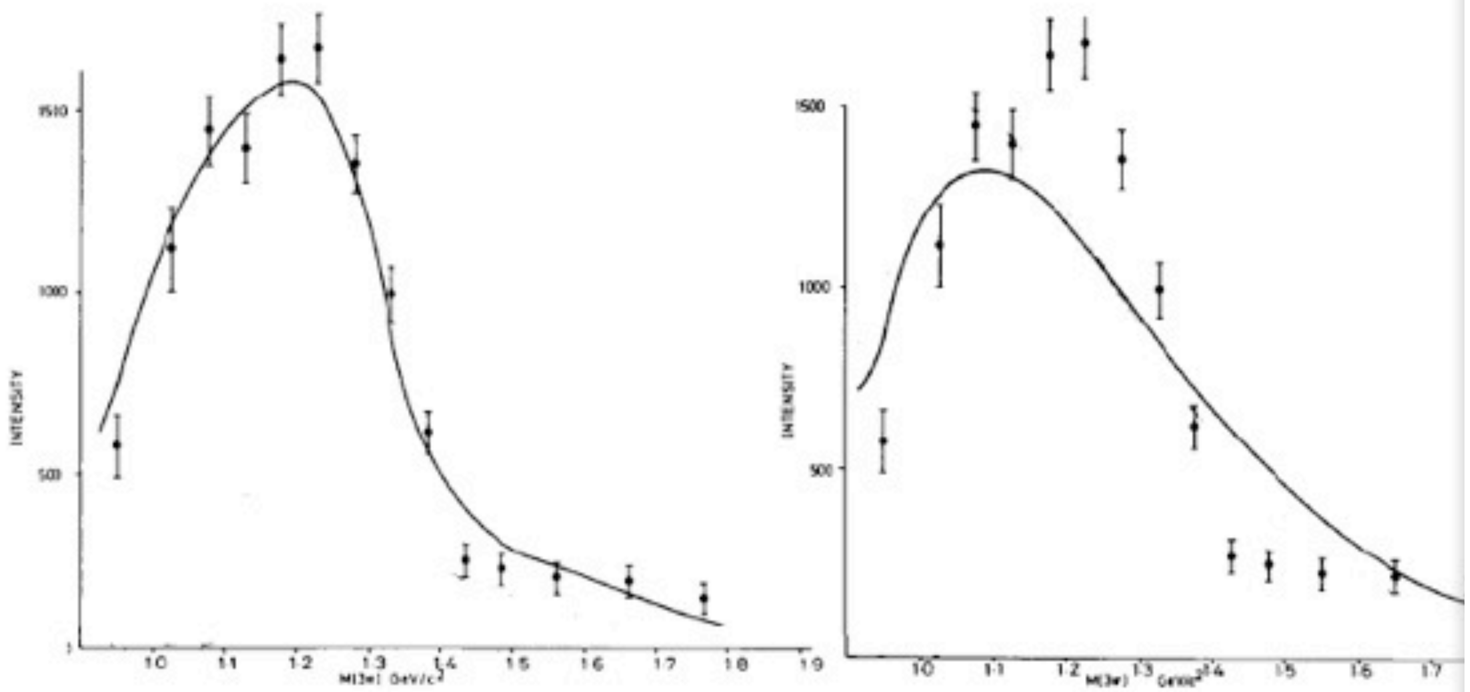

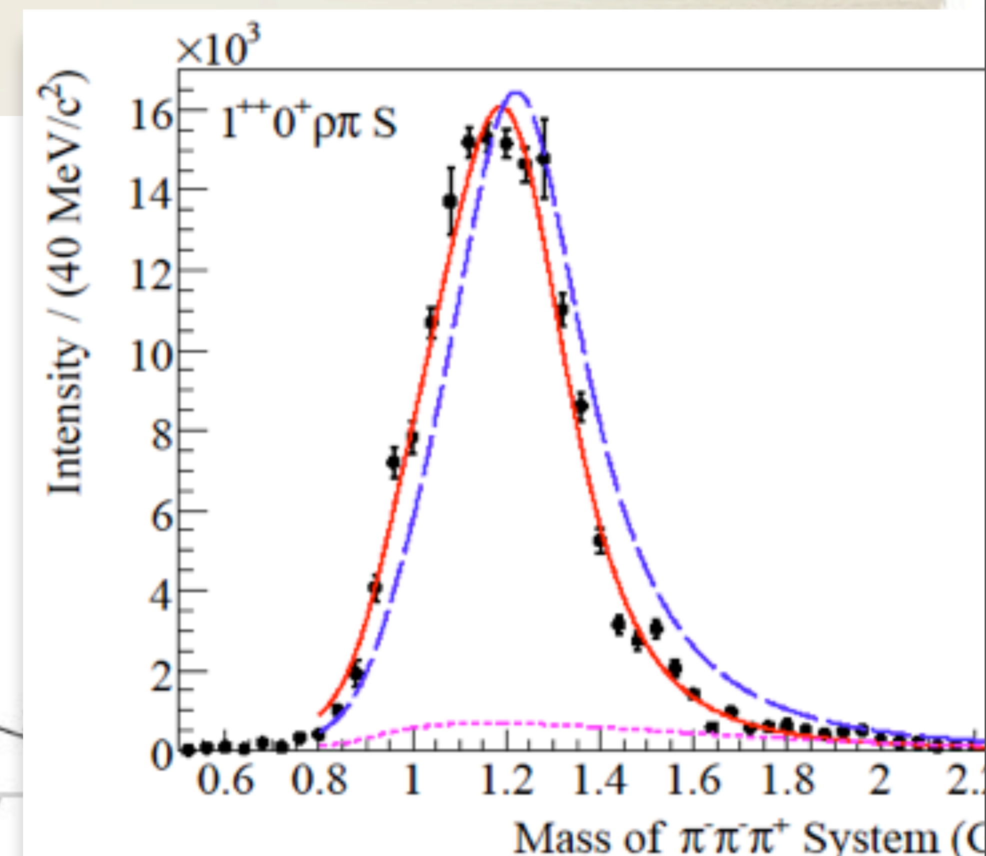

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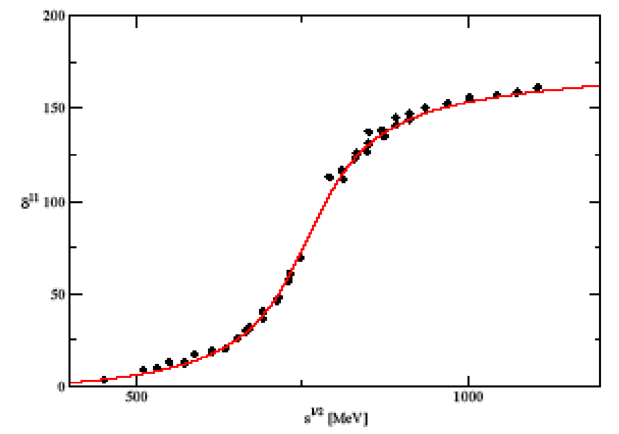


FIG. 24: $\pi\pi$ vesctor-isovector phase shift

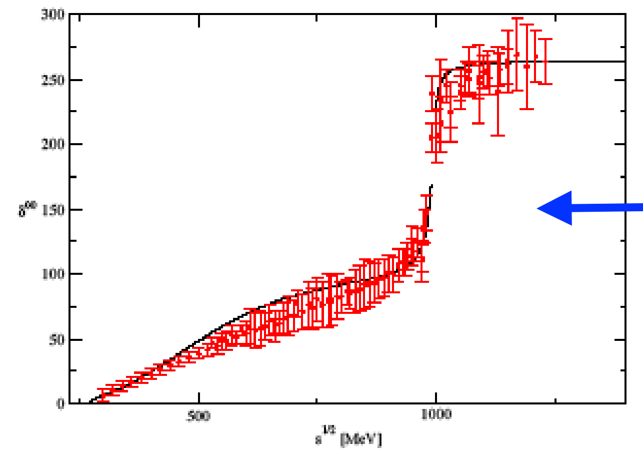


FIG. 23: $\pi\pi$ scalar-isoscalar phase shift

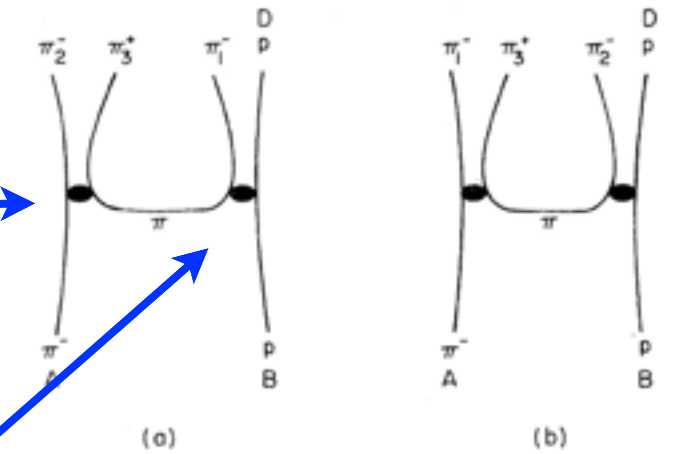
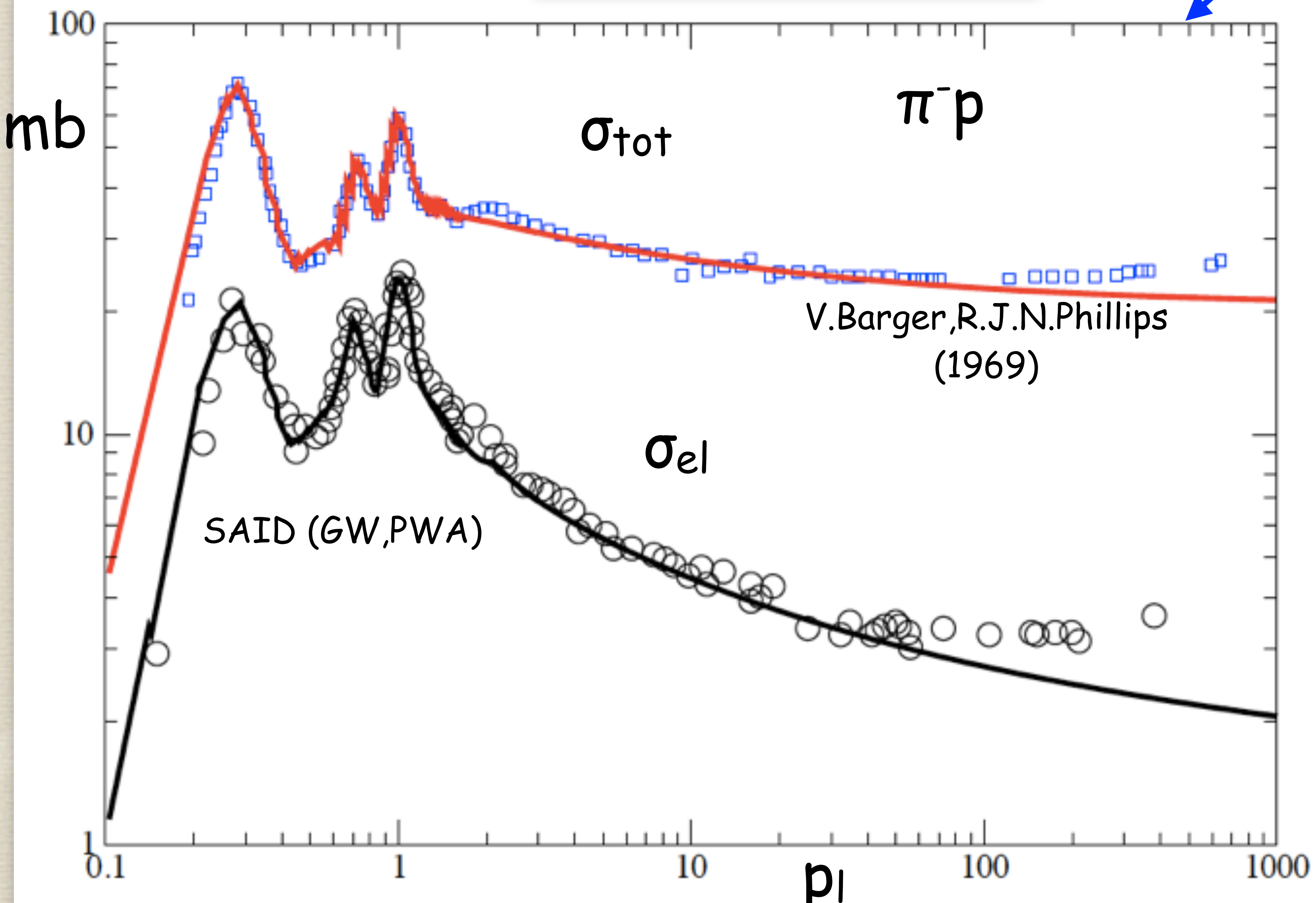
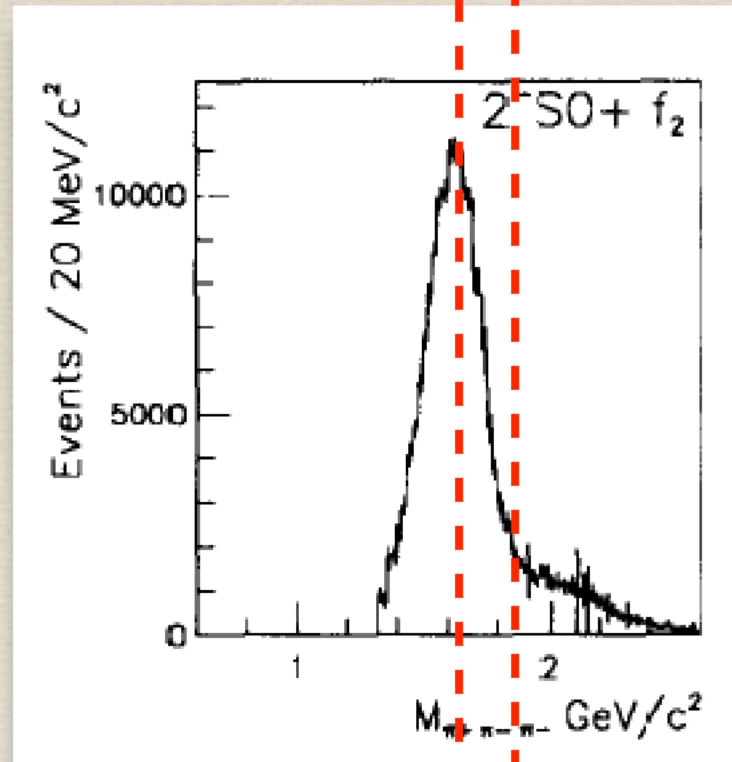
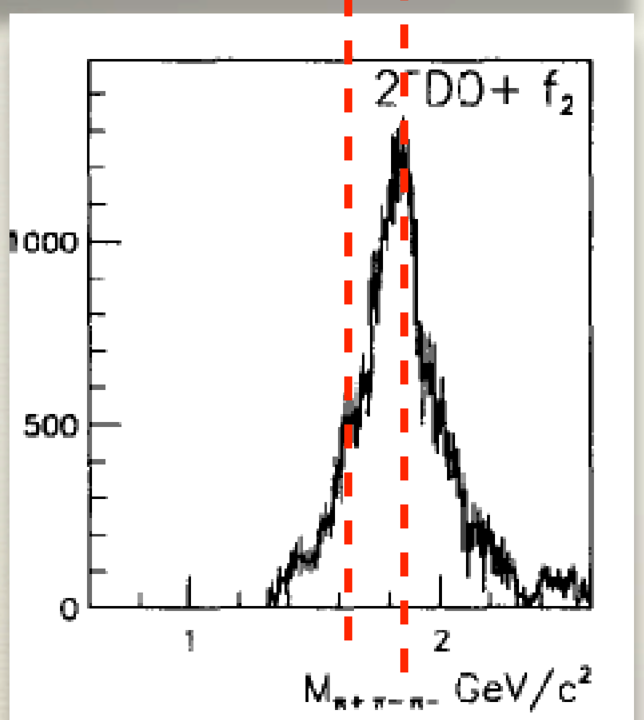


FIG. 1. The two amplitudes considered in this paper. Each has a $\pi^+\pi^-$ scattering amplitude and a $\pi^- p$ elastic amplitude connected by a Reggeized pion propagator.

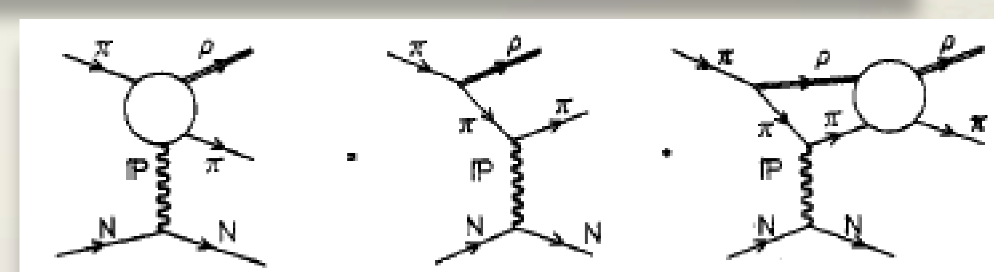


Moving $\pi_2(1670)$ peak

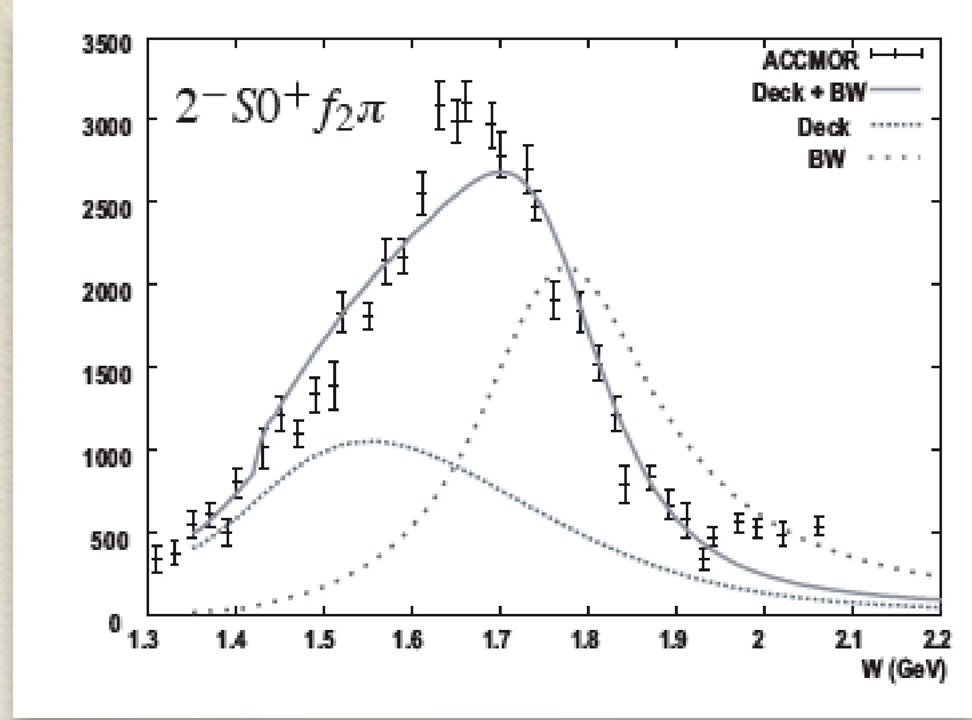


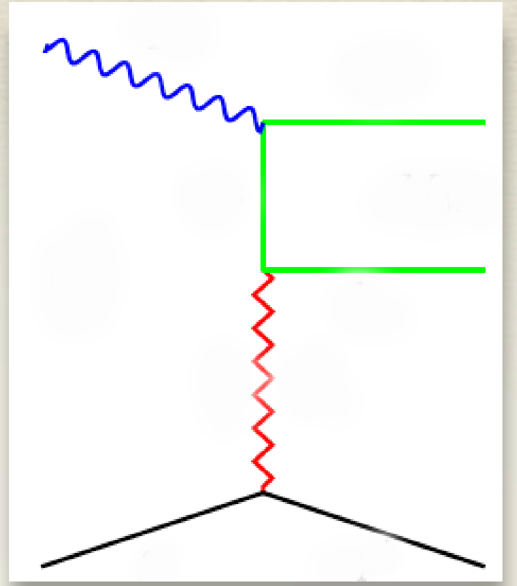


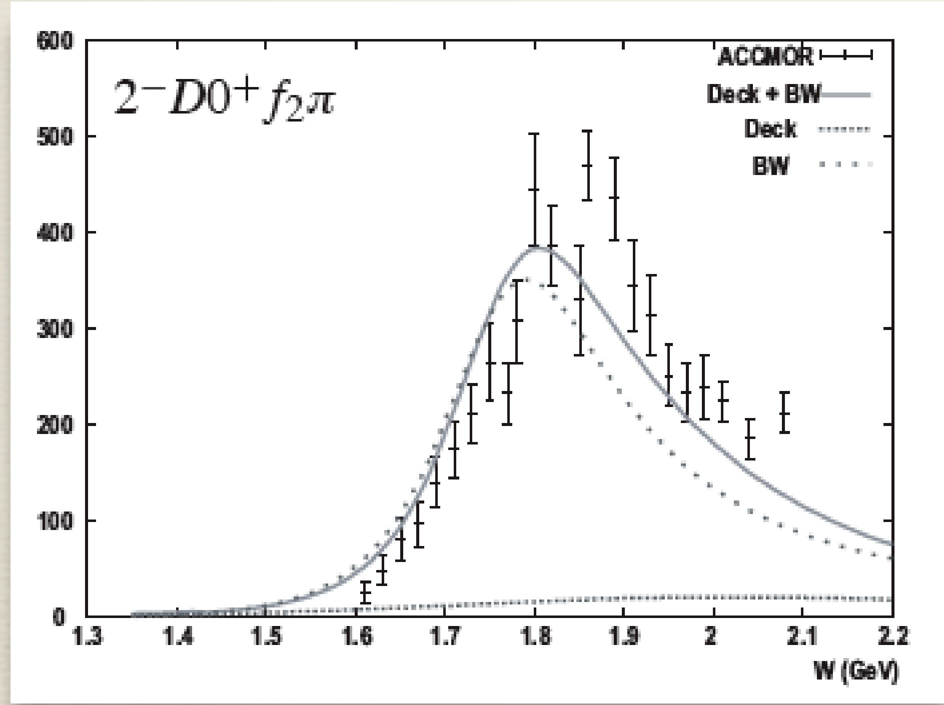
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
1672.4± 3.2 OUR AVERAGE		Error includes scale factor of 1.4. See the ideogram below.			
1749 ±10 ±100	145k	LU 05	E852		$18\ \pi^- p \to \omega\pi^-\pi^0 p$
1676 ± 3 ± 8		[1] CHUNG 02	E852		$18.3\ \pi^- p \to \pi^+\pi^-\pi^- p$
1685 ±10 ± 30		[2] BARBERIS 01			$450\ p p \to p_f\, 3\pi^0 p_s$
1687 ± 9 ± 15		AMELIN 99	VES		$37\ \pi^- A \to \omega\pi^-\pi^0 A^*$
1669 ± 4		BARBERIS 98B			$450\ p p \to p_f\, \rho\pi\, p_s$
1670 ± 4		BARBERIS 98B			$450\ p p \to p_f\, f_2(1270)\pi\, p_s$
1730 ±20		[3] AMELIN 95B	VES		$36\ \pi^- A \to \pi^+\pi^-\pi^- A$
1690 ±14		[4] BERDNIKOV 94	VES		$37\ \pi^- A \to K^+ K^-\pi^- A$
1710 ±20	700	ANTIPOV 87	SIGM	−	$50\ \pi^- \mathrm{Cu} \to \mu^+\mu^-\pi^- \mathrm{Cu}$
1676 ± 6		[4] EVANGELISTA 81	OMEG	−	$12\ \pi^- p \to 3\pi p$
1657 ±14		[4,5] DAUM 80D	SPEC	−	$63\text{–}94\ \pi p \to 3\pi X$
1662 ±10	2000	[4] BALTAY 77	HBC	+	$15\ \pi^+ p \to p 3\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1742 ±31 ± 49		ANTREASYAN 90	CBAL		$e^+e^- \to e^+e^-\pi^0\pi^0\pi^0$
1624 ±21		[1] BELLINI 85	SPEC		$40\ \pi^- A \to \pi^-\pi^+\pi^- A$
1622 ±35		[6] BELLINI 85	SPEC		$40\ \pi^- A \to \pi^-\pi^+\pi^- A$
1693 ±28		[7] BELLINI 85	SPEC		$40\ \pi^- A \to \pi^-\pi^+\pi^- A$
1710 ±20		[8] DAUM 81B	SPEC	−	$63{,}94\ \pi^- p$
1660 ±10		[4] ASCOLI 73	HBC	−	$5\text{–}25\ \pi^- p \to p\pi_2$

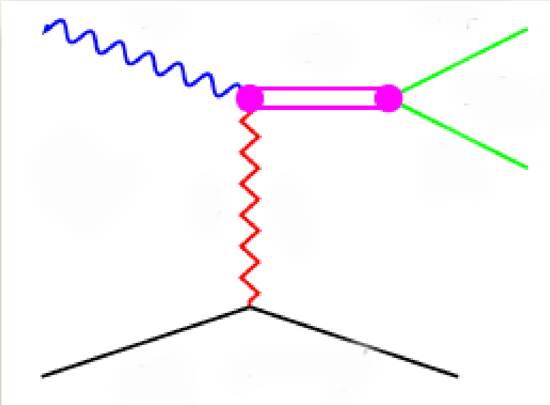


Duality @ work ?



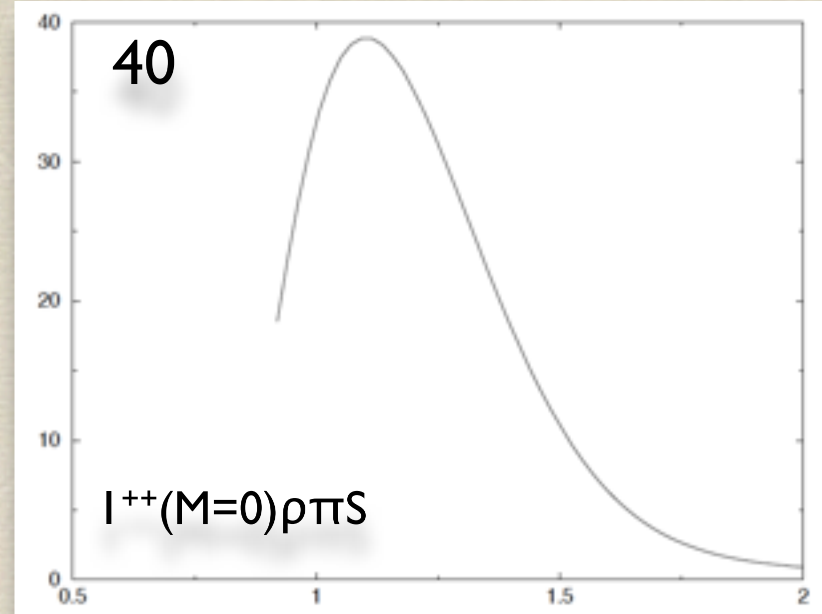




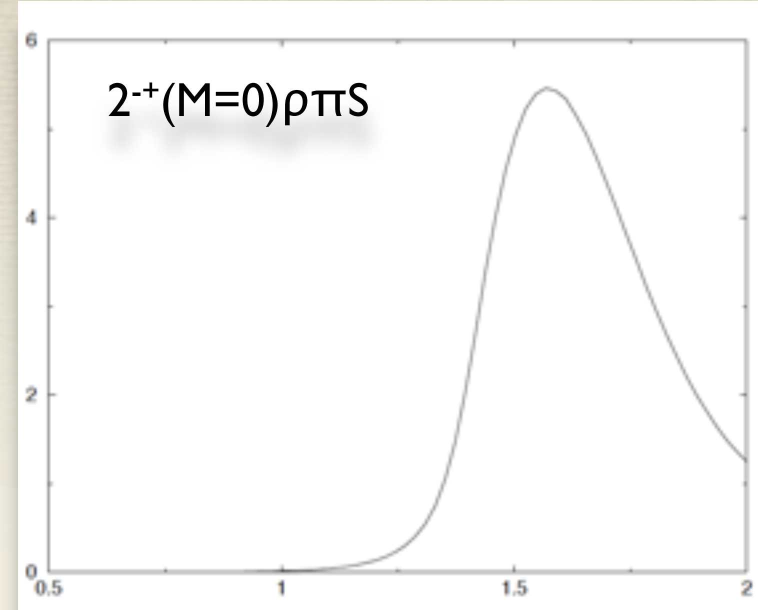


J,Dudek, AS (2006)

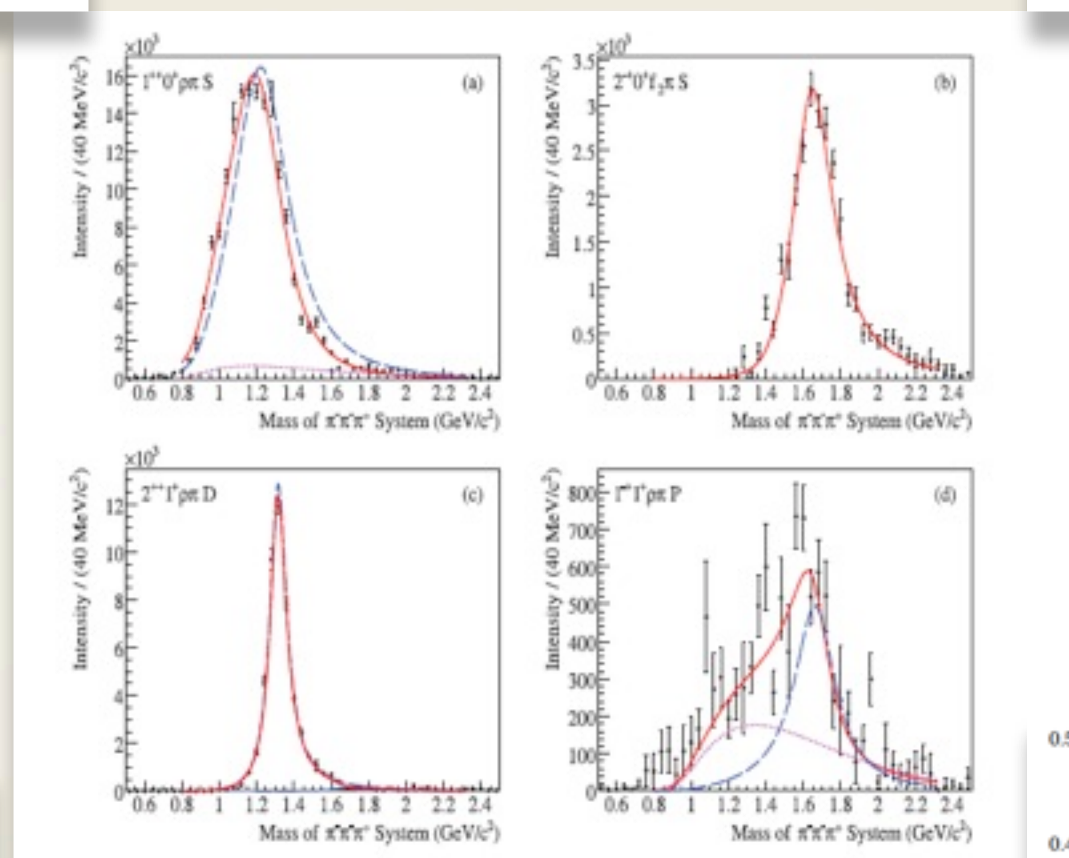
Isobar-type fits could involve spurious resonances



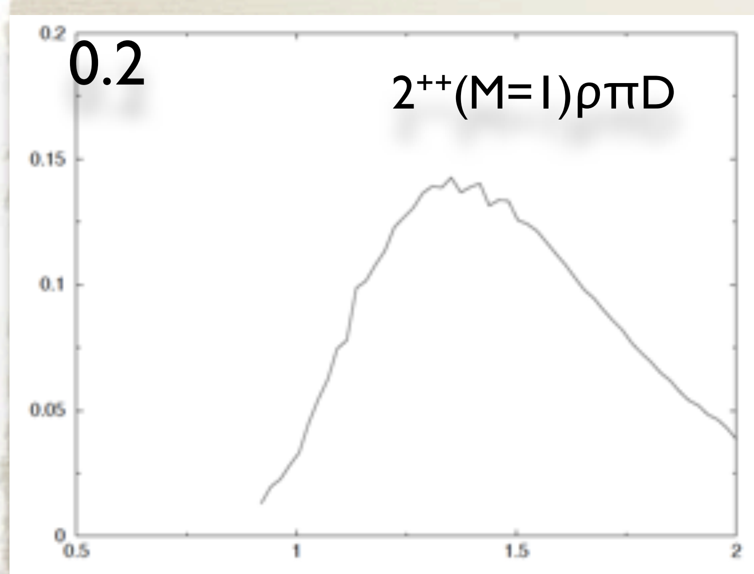
40
1++(M=0)ρπS



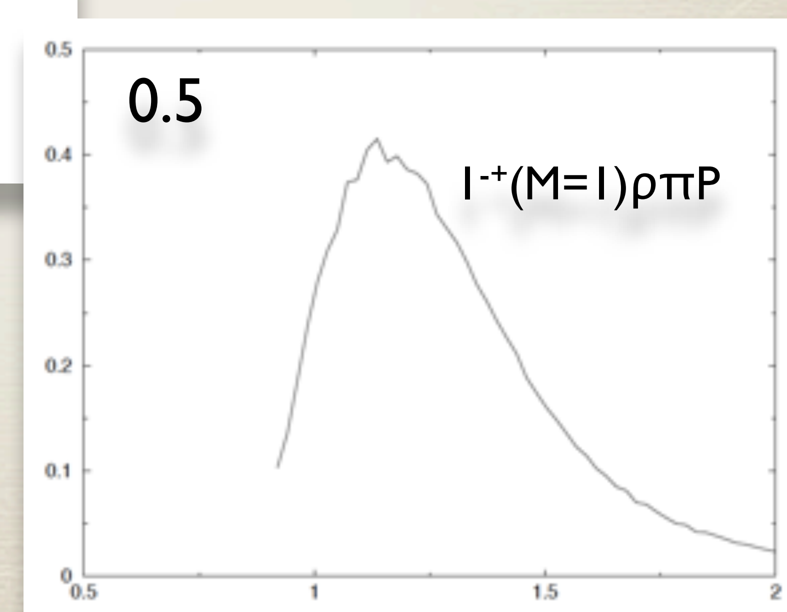
6
2-+(M=0)ρπS



Intensity / (40 MeV/c²)
Mass of π⁻π⁻π⁺ System (GeV/c²)
(a)
(b)
(c)
(d)

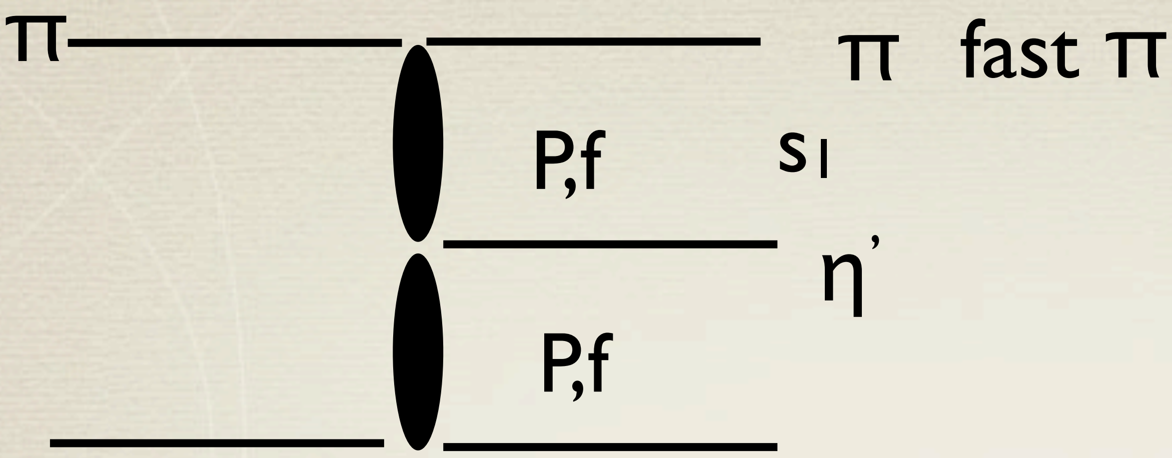


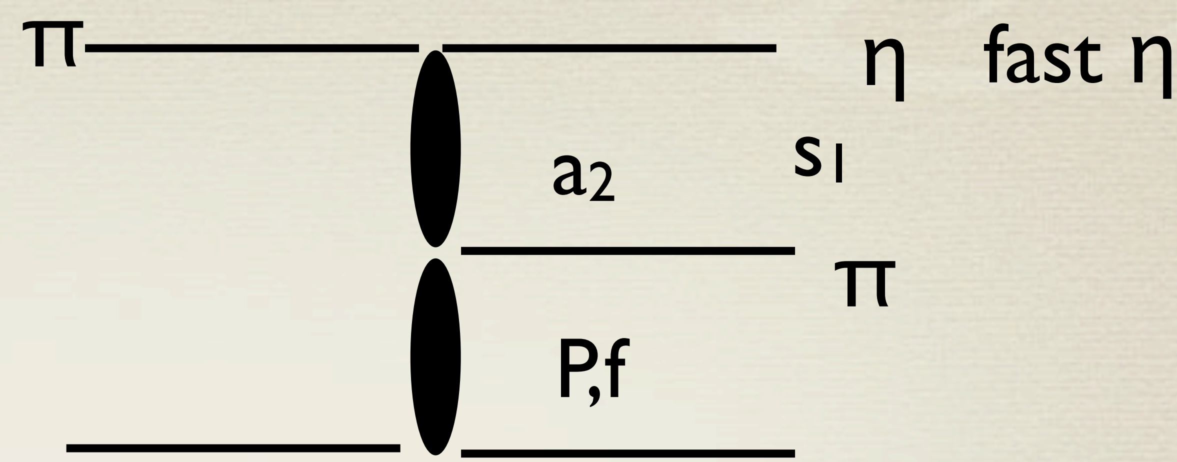
0.2
2++(M=1)ρπD

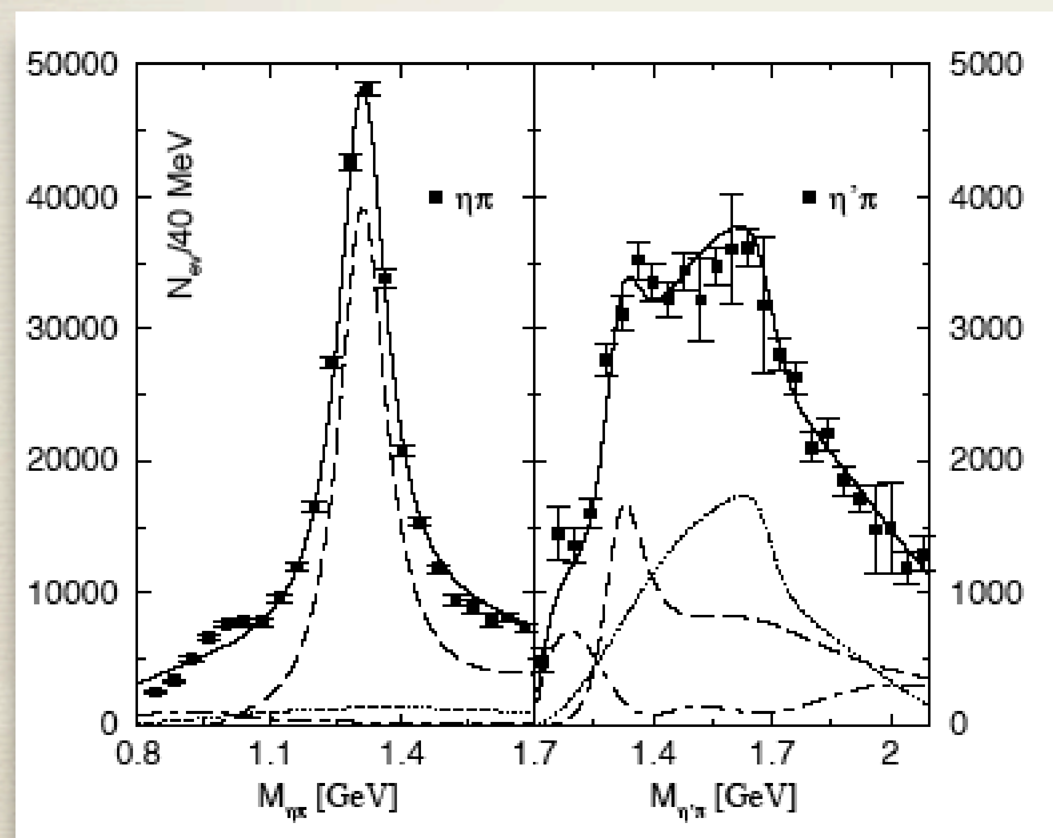


0.5
1-+(M=1)ρπP

Duality in η(‘)π





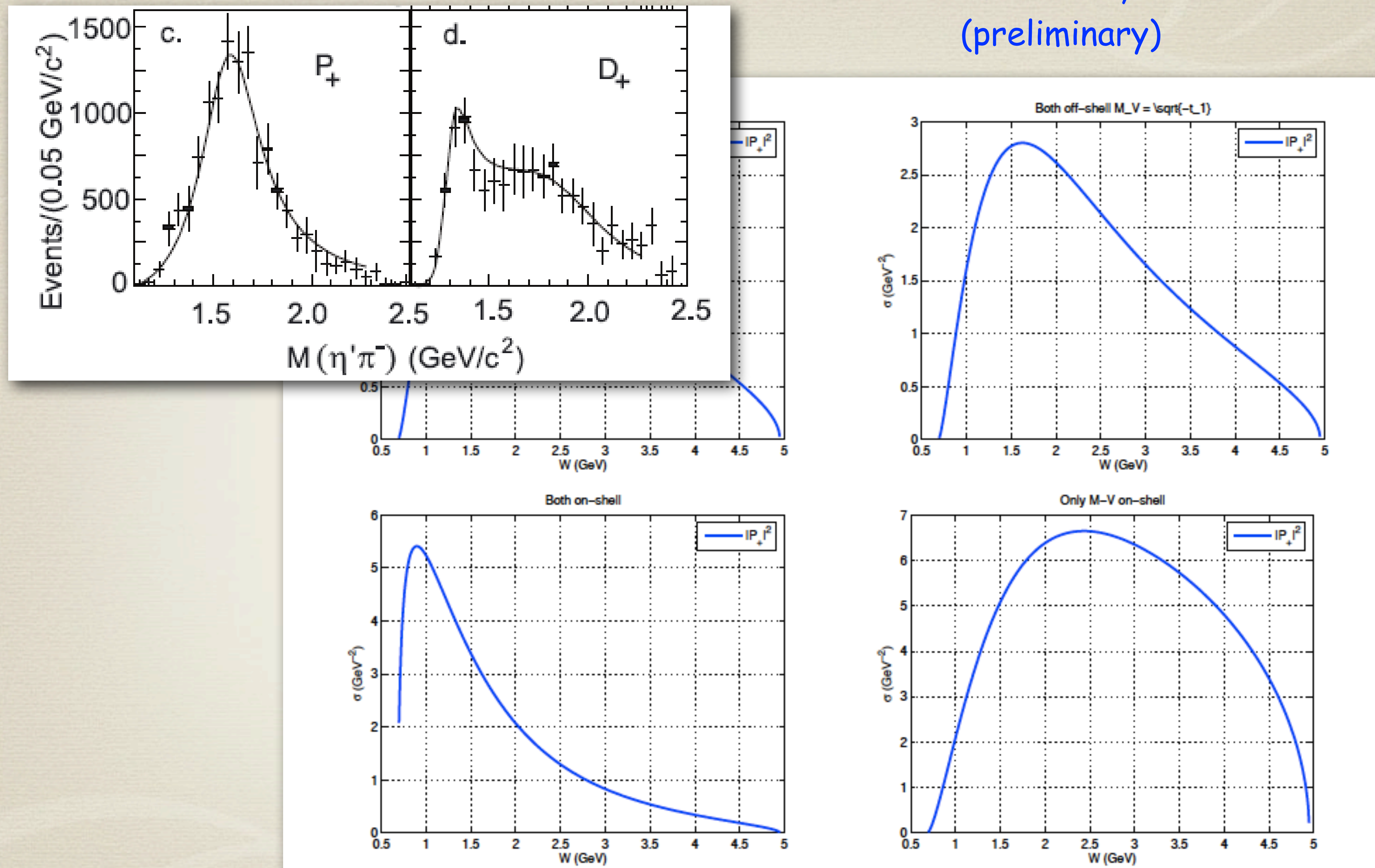


broad backgrounds possible

P-wave dominance expected
(from $0^-0^-0^-$ +NPE)

$$T \sim \epsilon_{\mu\nu\alpha\beta} p_1^\mu p_2^\nu p_3^\alpha p_4^\beta \times \hat{T}(s_1, s_2, t_1, t_2)$$

V.Mathieu, APS
(preliminary)

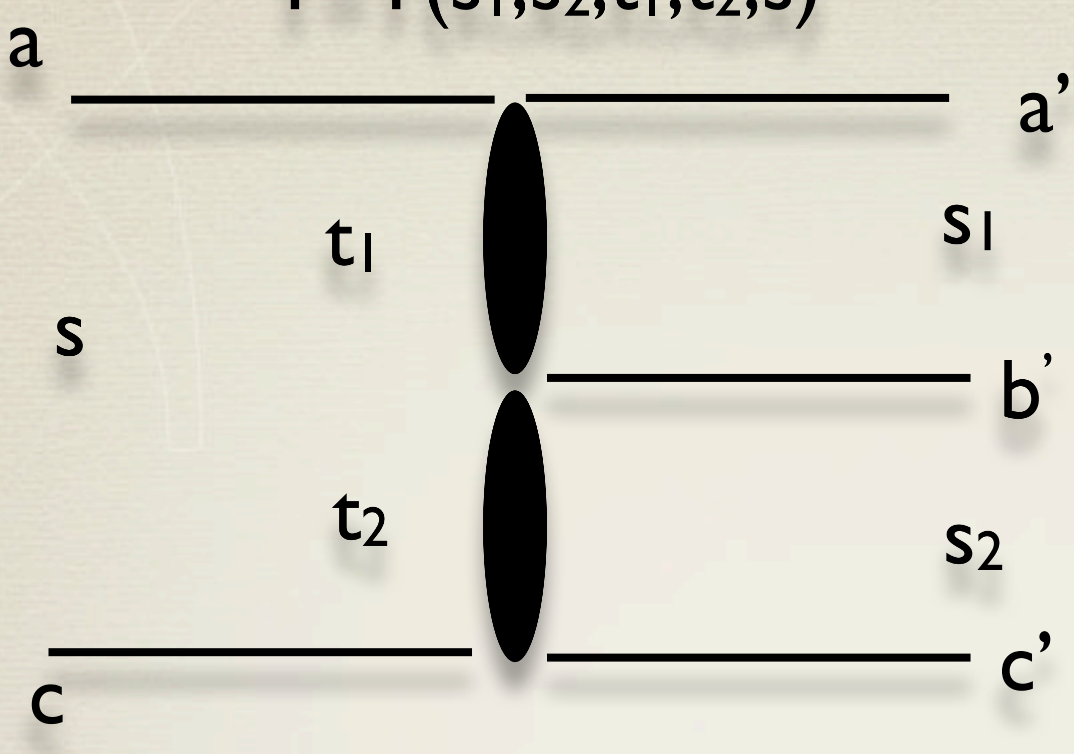


DOUBLE REGGE EXCHANGE PHENOMENOLOGY

T. SHIMADA and A.D. MARTIN
Department of Physics, Durham University, UK

A.C. IRVING
DAMTP, Liverpool University, UK

$T=T(s_1,s_2,t_1,t_2;s)$



$$V_1(\eta, t_1, t_2) = \frac{1}{\Gamma(-\alpha_1)\,\Gamma(-\alpha_2)} \sum_{n=0}^{\infty} \frac{1}{n!}\, \Gamma(-\alpha_1+n)\,\Gamma(-\alpha_2+\alpha_1-n)\,\eta^{-n}$$

$$\times\, \beta(\alpha_1-n, t_1, t_2)\,, \tag{6}$$

with an identical expression for V_2 except that $\alpha_1 \leftrightarrow \alpha_2$. The minimal choice for the residue, $\beta(\lambda, t_1, t_2) = \beta_0$ with β_0 independent of λ, thus leads to the concise parametrization

$$V_1 = \beta_0\, \frac{\Gamma(\alpha_1-\alpha_2)}{\Gamma(-\alpha_2)}\; {}_1F_1\!\left(-\alpha_1, 1-\alpha_1+\alpha_2, -\frac{1}{\eta}\right) \tag{7}$$

and $V_2 = V_1(\alpha_1 \leftrightarrow \alpha_2)$. This agrees with the double Regge limit of the scalar dual amplitude [7].

R.C. Brower, C.E. DeTar, J.H. Weis, Regge theory for multiparticle amplitudes
PHYSICS REPORTS (Section C of Physics Letters) 14, no. 6 (1974) 257–367.

The requirement that the amplitude is free of simultaneous discontinuities in two overlapping channel invariants leads to the general form [1]

$$T = \Gamma(-\alpha_1)\,\Gamma(-\alpha_2)[(-\alpha' s)^{\alpha_1}(-\alpha' s_2)^{\alpha_2-\alpha_1}\, V_1(\eta, t_1, t_2)$$

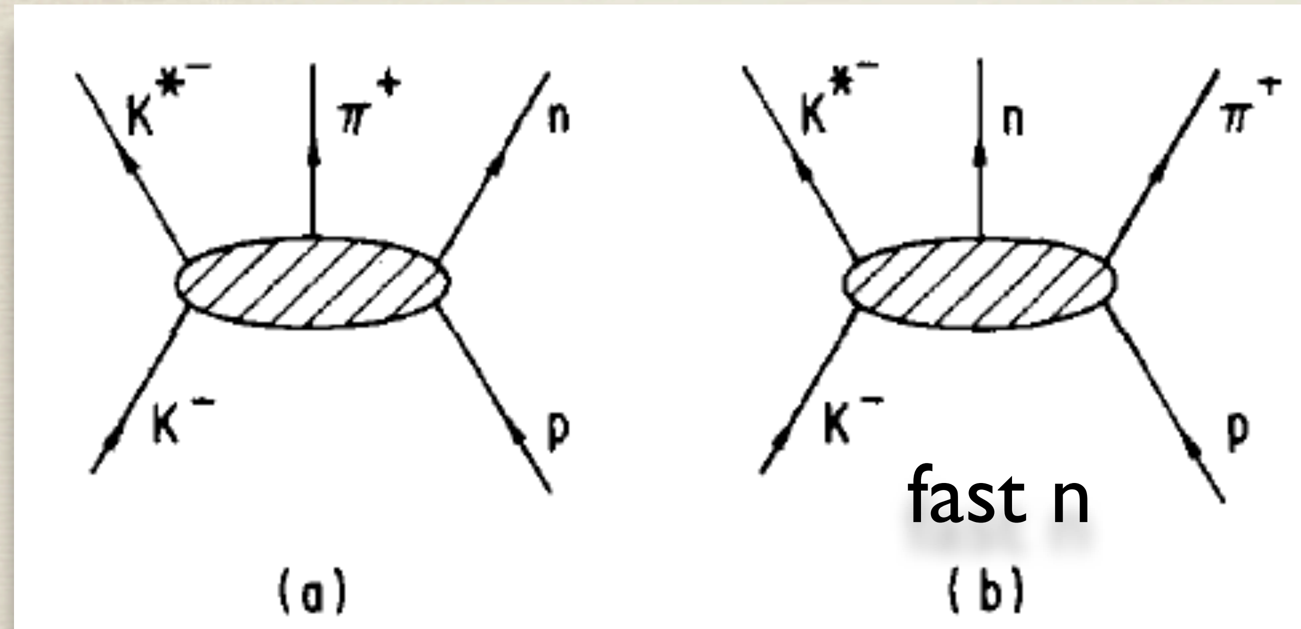
$$+\,(-\alpha' s)^{\alpha_2}(-\alpha' s_1)^{\alpha_1-\alpha_2}\, V_2(\eta, t_1, t_2)]\,, \tag{3}$$

where the reggeon-reggeon-particle vertex functions, V_i, are regular functions of η.

Earlier analyses

E.L.Berger, J.Vergeest (1976)

DOUBLE EXCHANGE MODEL DESCRIPTION OF THE CHARGE EXCHANGE REACTION $K^- p \rightarrow K^* \pi^+ n$



fast n

other channels flavor exotic

Earlier analyses

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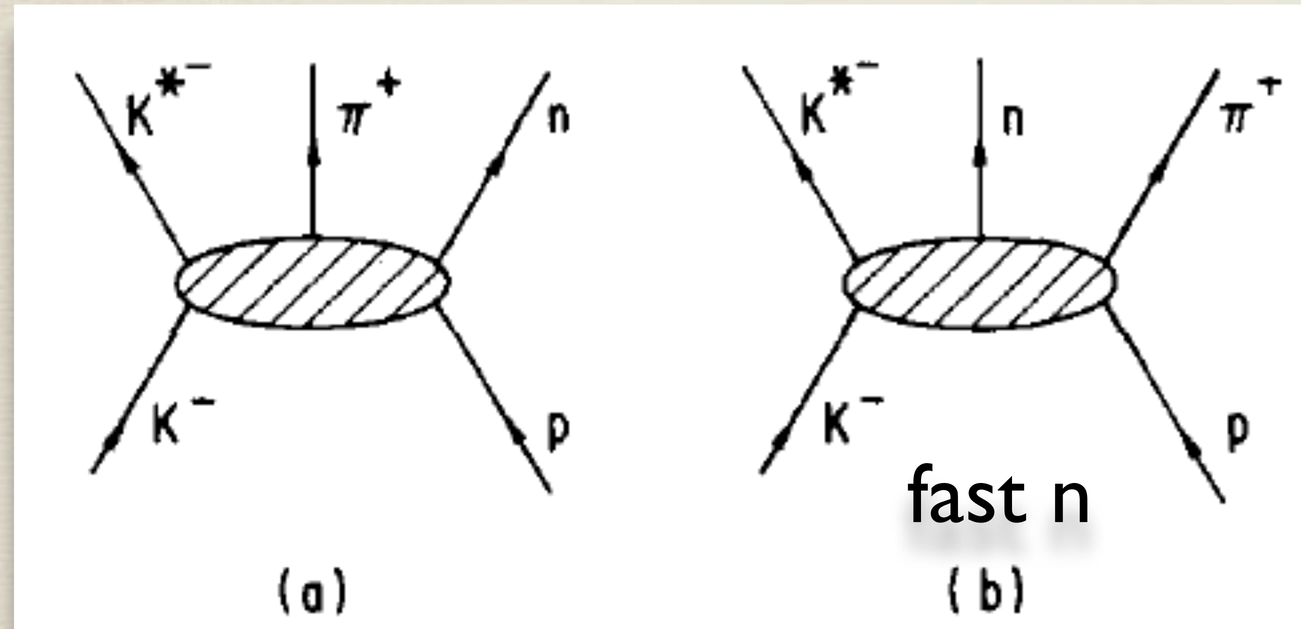
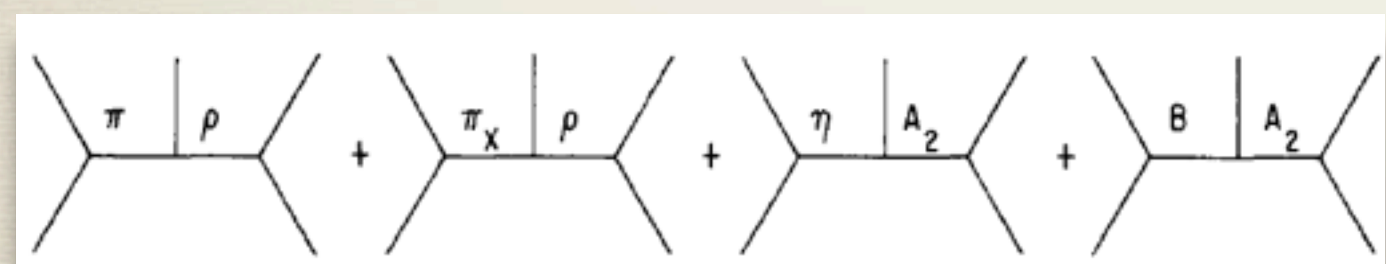
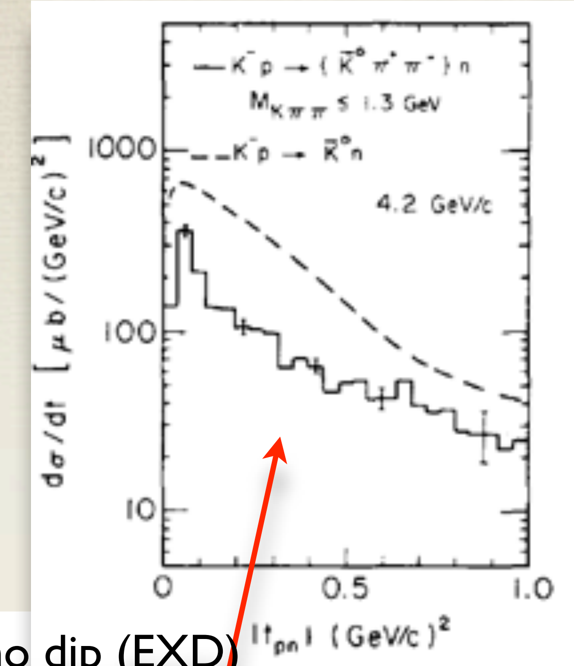
DOUBLE EXCHANGE MODEL DESCRIPTION OF THE CHARGE EXCHANGE REACTION $K^- p \rightarrow K^* \pi^+ n$



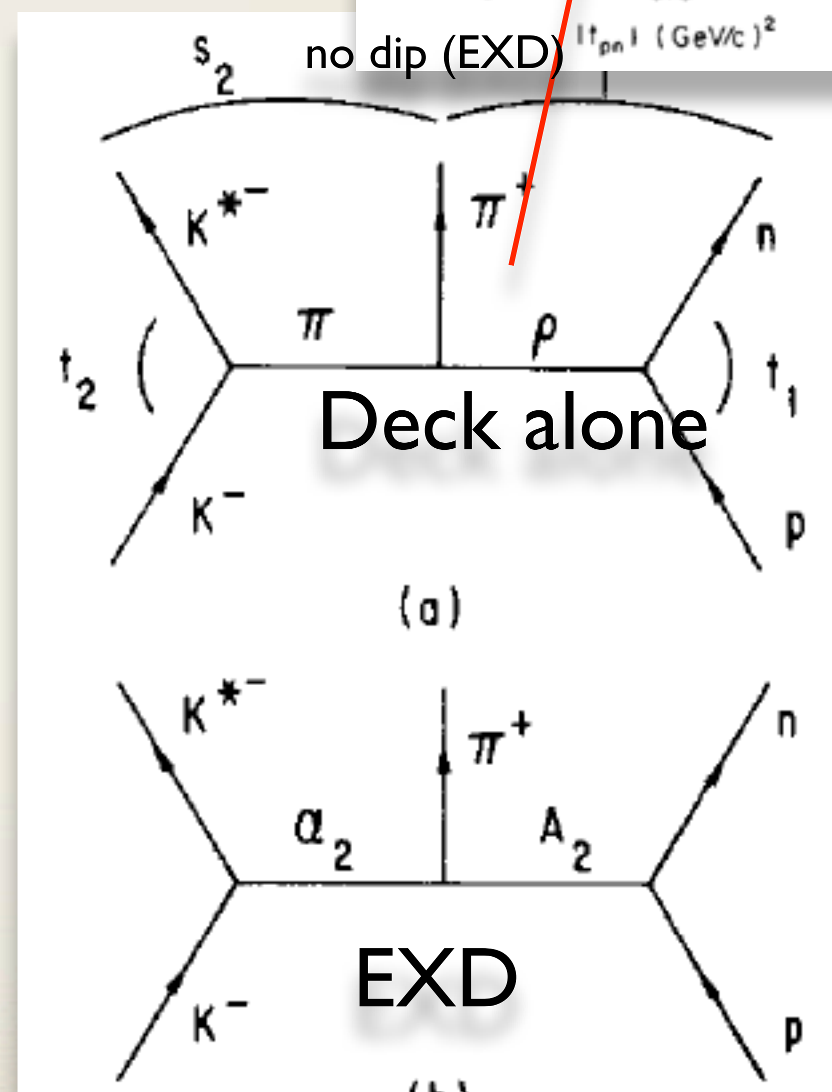
fast n

other channels flavor exotic





no dip (EXD)



Deck alone

EXD

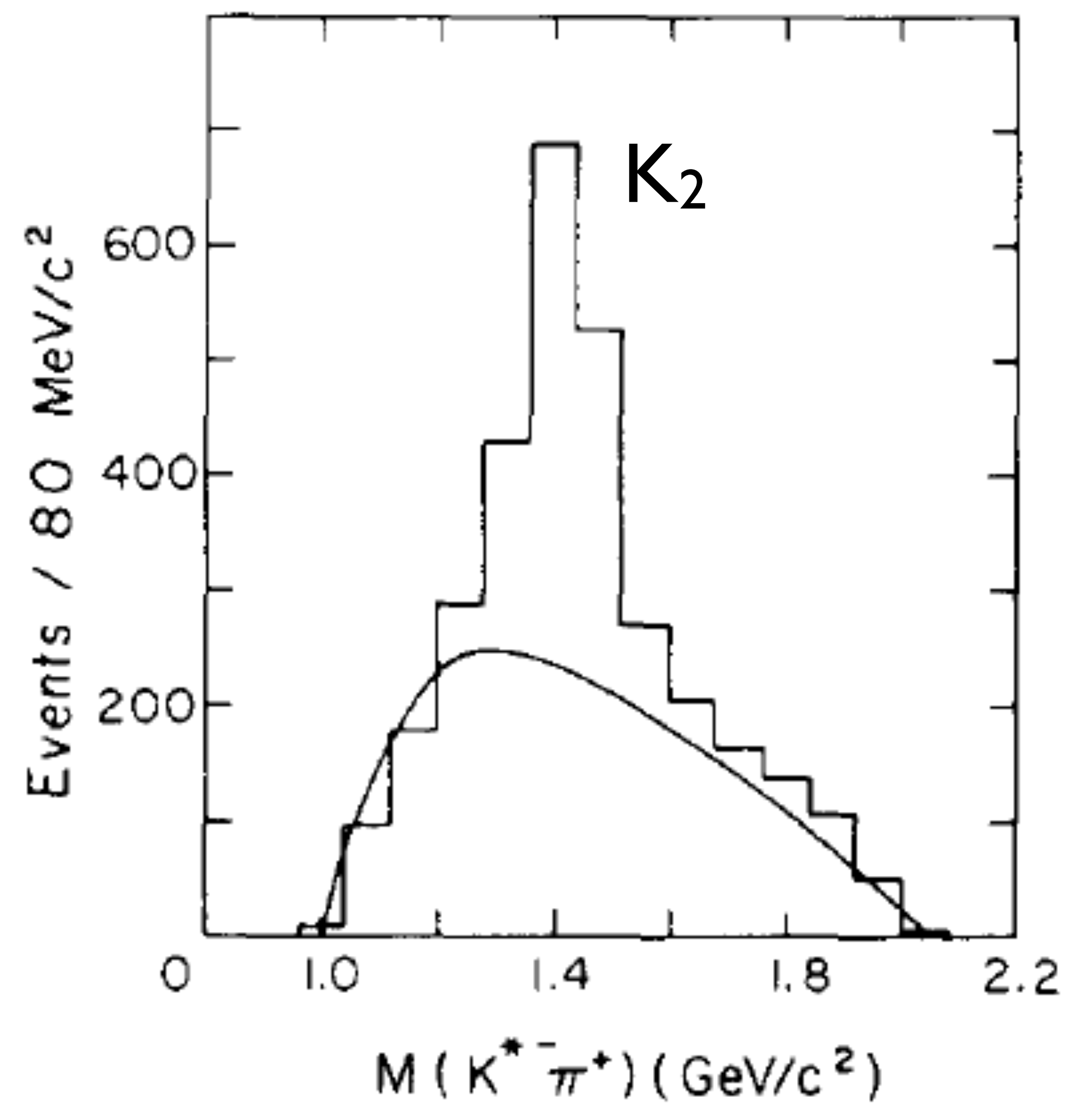
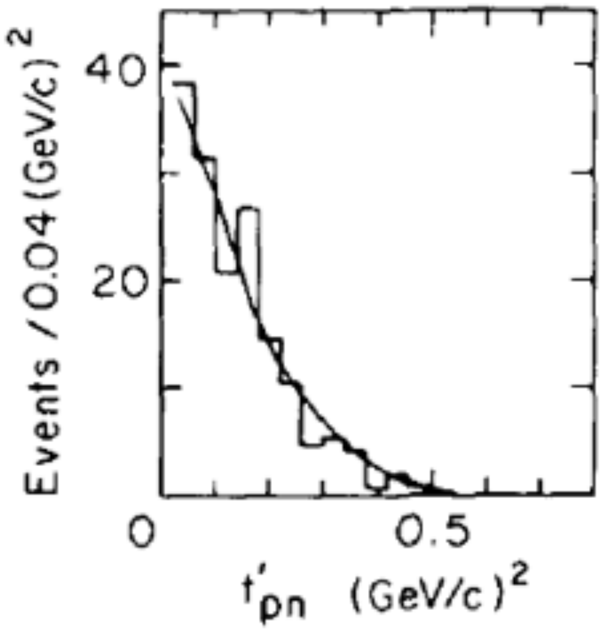


Fig. 6. Distribution in the $(K^{*-}\pi^{+})$ invariant mass from $K^{-}p \rightarrow K^{*}\pi^{+}n$ at 4.2 GeV/c for the sample with $|t_{pn}| \leqslant 0.8\ (\mathrm{GeV}/c)^2$. The theoretical curve is obtained from eq. (2.12) of the text and is normalized to the data in the region $M(K^{*}\pi) \leqslant 1.28$ GeV.



~exp(7t) from Deck

~exp(3t)

Fig. 10. Distribution in t'_{pn} for events satisfying the selections $M(K^*\pi) \leqslant 1.3$ GeV, $M(n\pi^+) \geqslant 1.34$ GeV, and $|t_{KK^*}| \leqslant 0.3$ (GeV/c)^2.

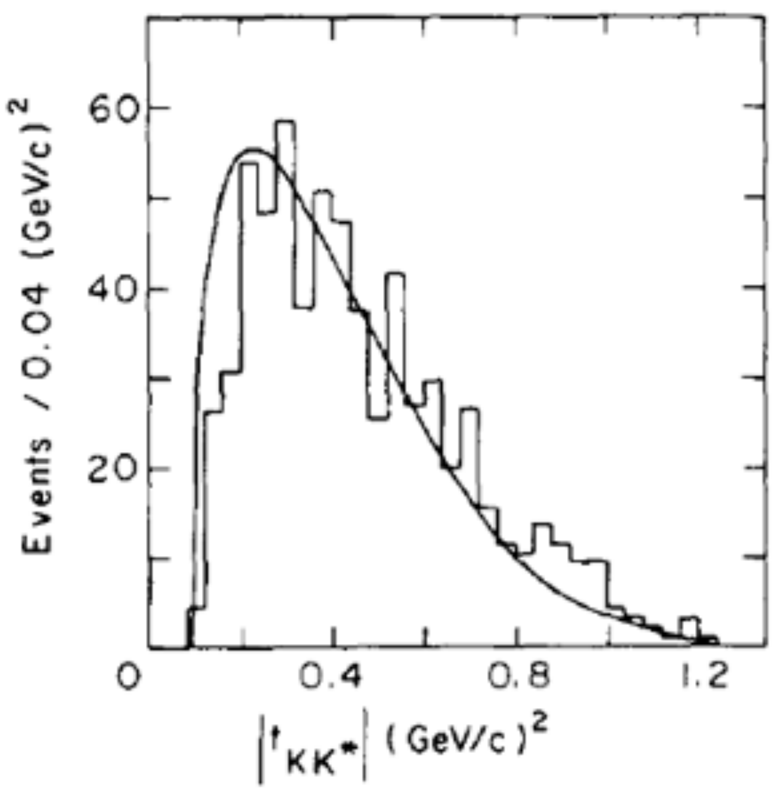


Fig. 8. Distribution in t_{KK^*}, with the same selections as in fig. 7.

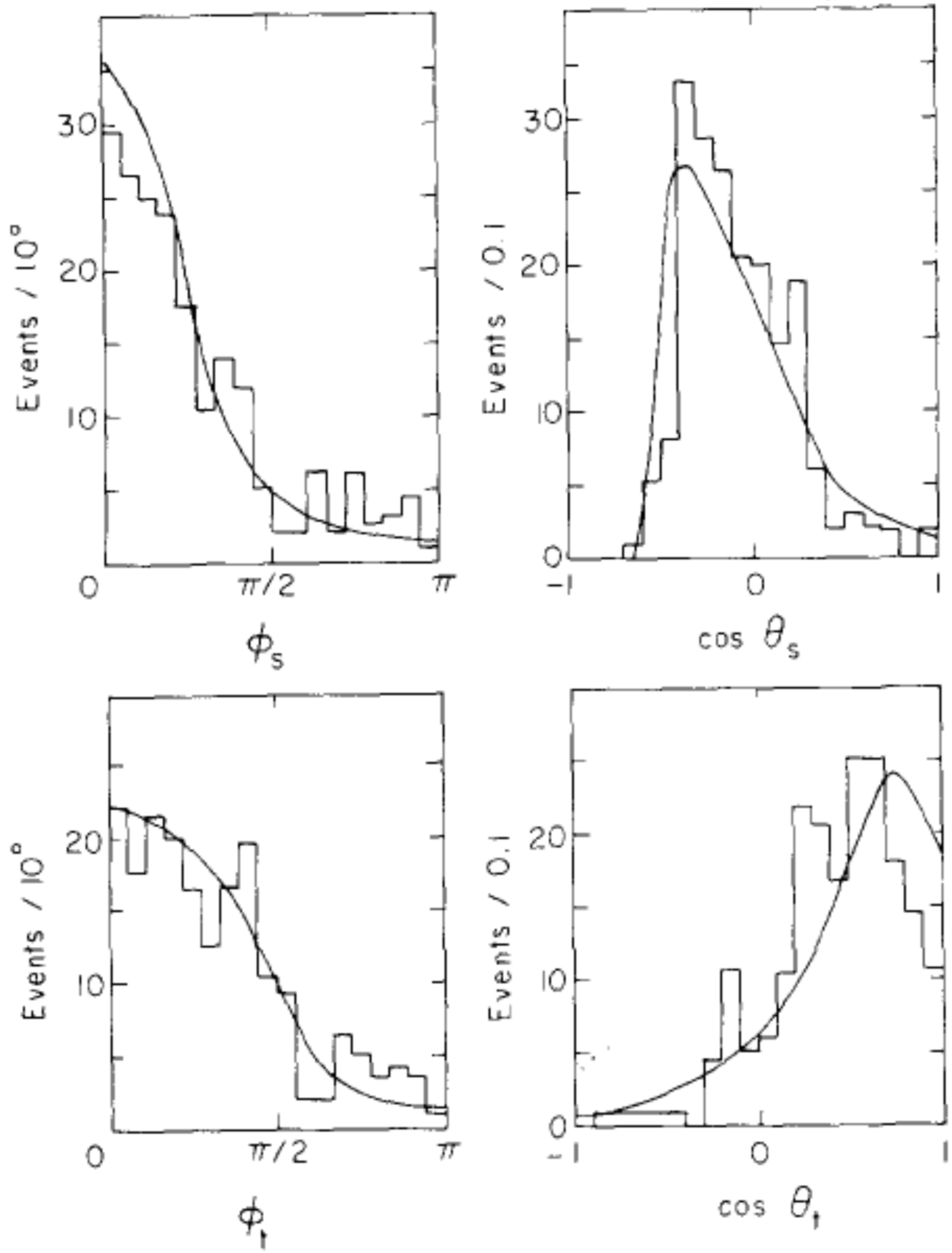


Fig. 11. Distributions in the decay angles of the K^* in the $(K^*\pi)$ rest frame for events satisfying the selections listed in the caption of fig. 10.

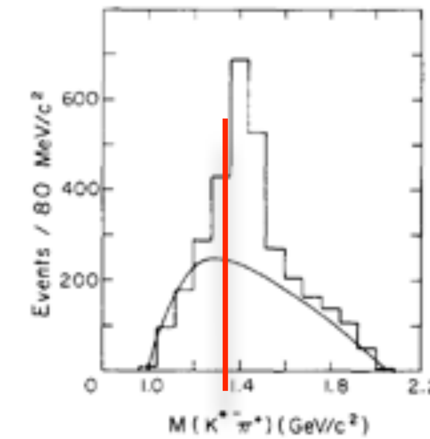


Fig. 6. Distribution in the $(K^{*-}\pi^+)$ invariant mass from $K^-p \to K^*\pi^+n$ at 4.2 GeV/c for the sample with $|t_{pn}| \leq 0.8$ (GeV/c)^2. The theoretical curve is obtained from eq. (2.12) of the text and is normalized to the data in the region $M(K^*\pi) < 1.28$ GeV.

Summary

Meson-Nucleon scattering amplitudes are needed to determine backgrounds under resonances

"Technology" exists for a self-consistent PWA (FESR)

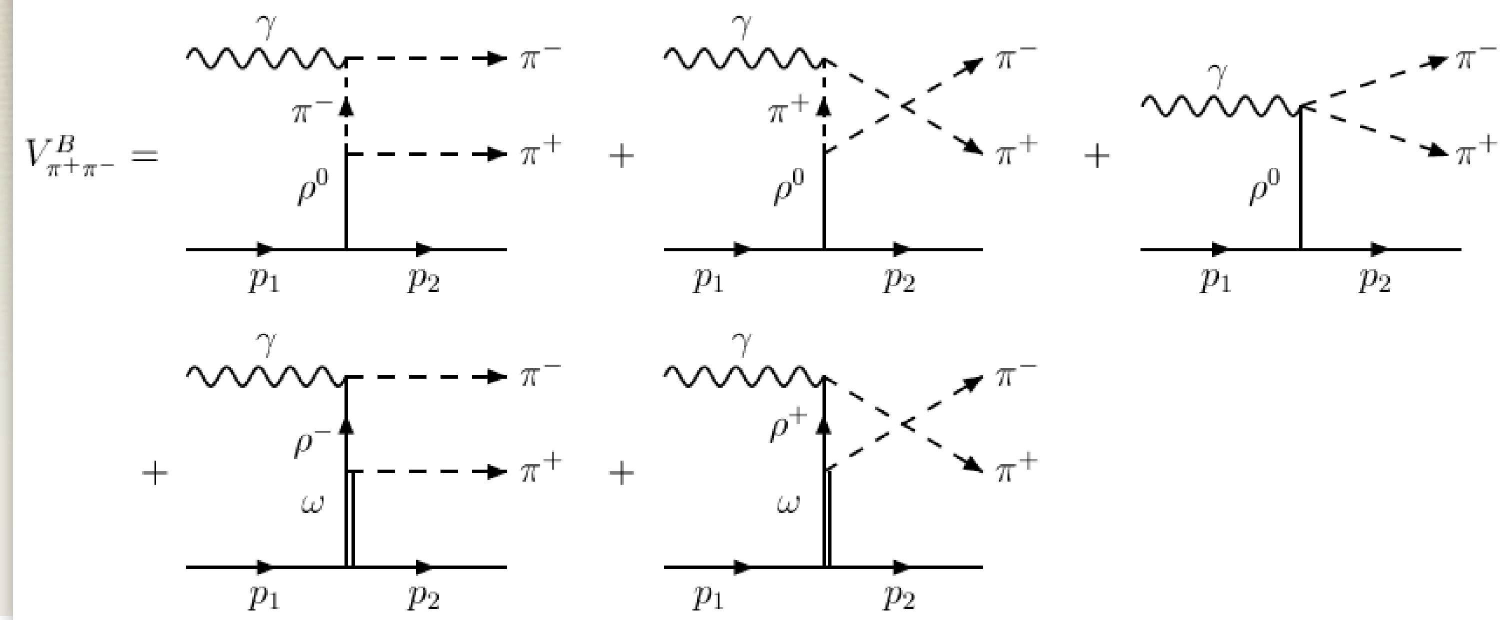
ηN, a_2 production: dual to exotic channels

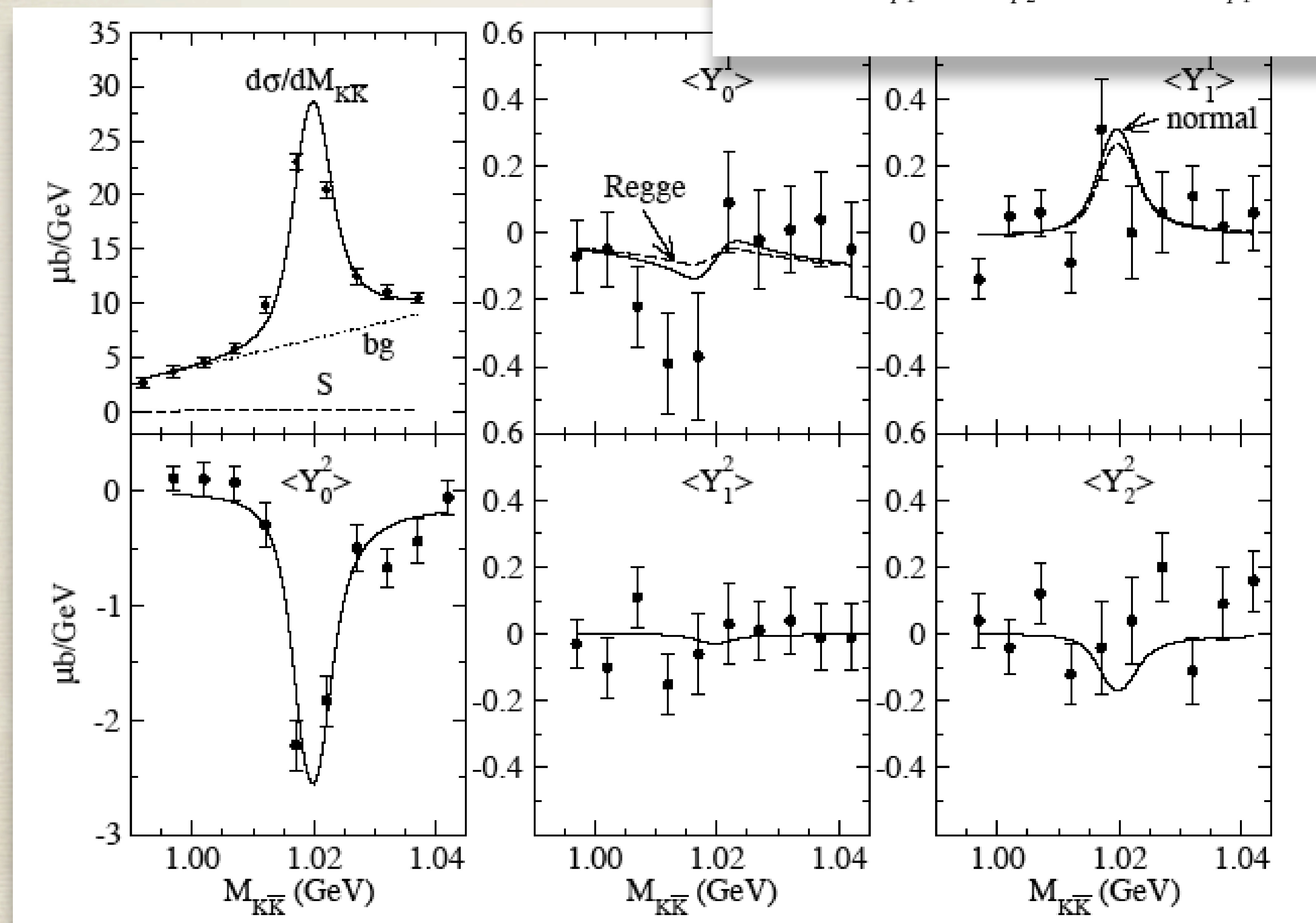
K^+p, K^+n, dual to flavor exotic channels

Lesniak, Kaminski, Bibrzycki, AS

Fit to Daresbury, 4GeV data

Born diagrams of the $\pi^+\pi^-$ photoproduction in the S-wave

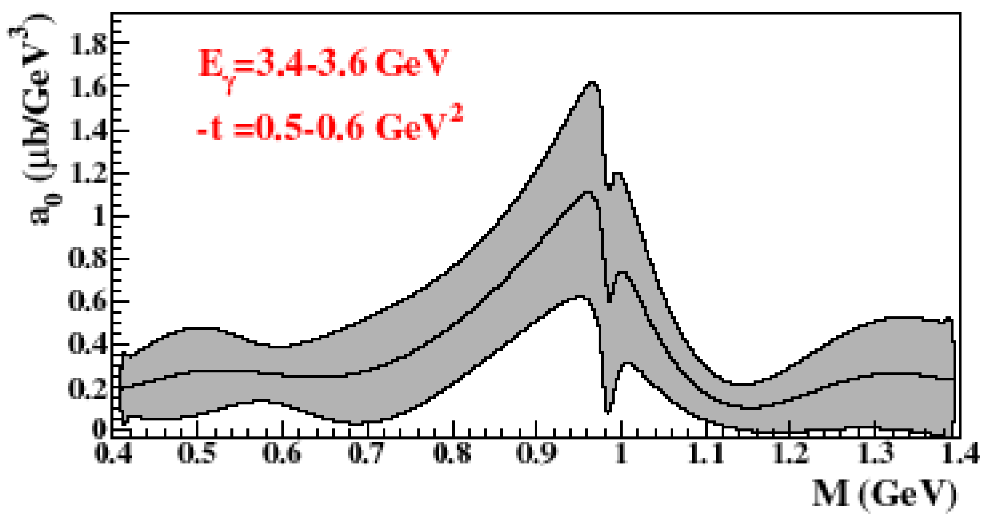




First measurement of direct $f_0(980)$ photoproduction on the proton

(The CLAS Collaboration)

$$a(s) = \left[\frac{1+S(s)}{2}\right] a_L(s) - \frac{1}{D(s)} P.V. \int_{s_{th}} \frac{ds'}{\pi} \frac{\rho(s')N(s')a_L(s')}{s'-s}$$



separation between direct resonance production and fsi ambiguous without KK data

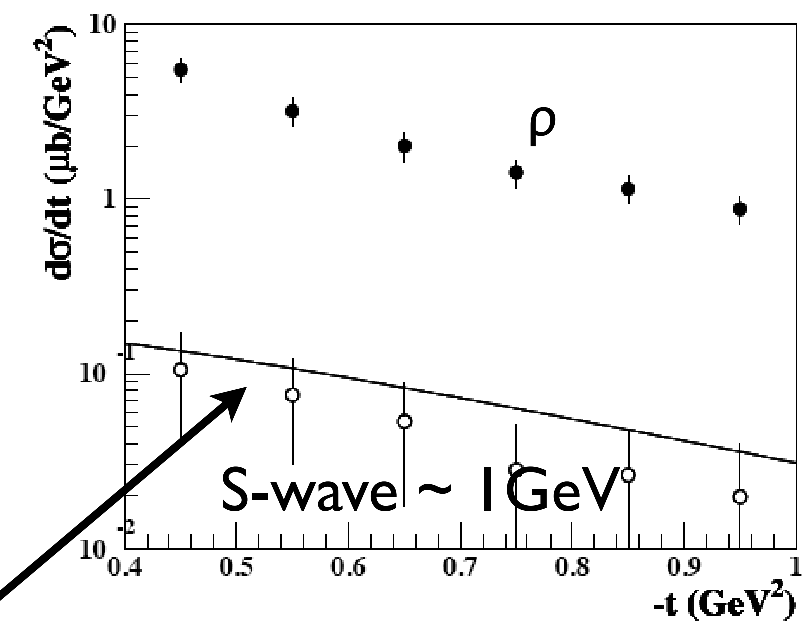


FIG. 3: Partial wave differential cross sections $d\sigma/dt$ in the photon energy range $E_\gamma = 3.0-3.8$ GeV, for the P-wave (solid dots) and S-wave (open circles) integrated in the $M_{\pi\pi}$ mass range 0.4-1.2 GeV and 0.98 ± 0.04 GeV, respectively. The error bars include statistical and systematic uncertainties summed in quadrature. The line is a model prediction for the S-wave from Ref. [25, 26].

[25] L. Bibrzycki, L. Lesniak and A. P. Szczepaniak, Eur. Phys. J. C **34**, 335 (2004).
[26] C. R. Ji *et al.*, Phys. Rev. C **58**, 1205 (1998).