The Deck Effect in $\pi N \to \pi\pi\pi N$

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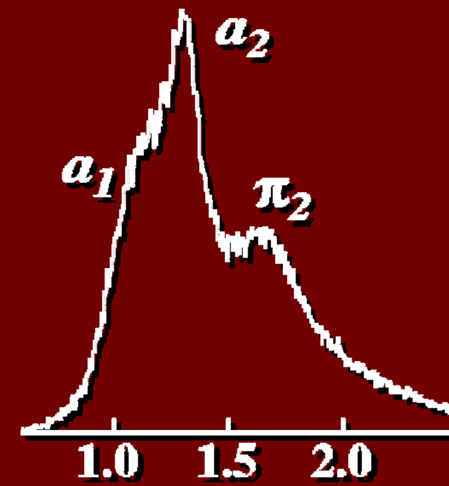
with Adam Szczepaniak, Indiana U.

$\pi p \to \pi\pi\pi p$

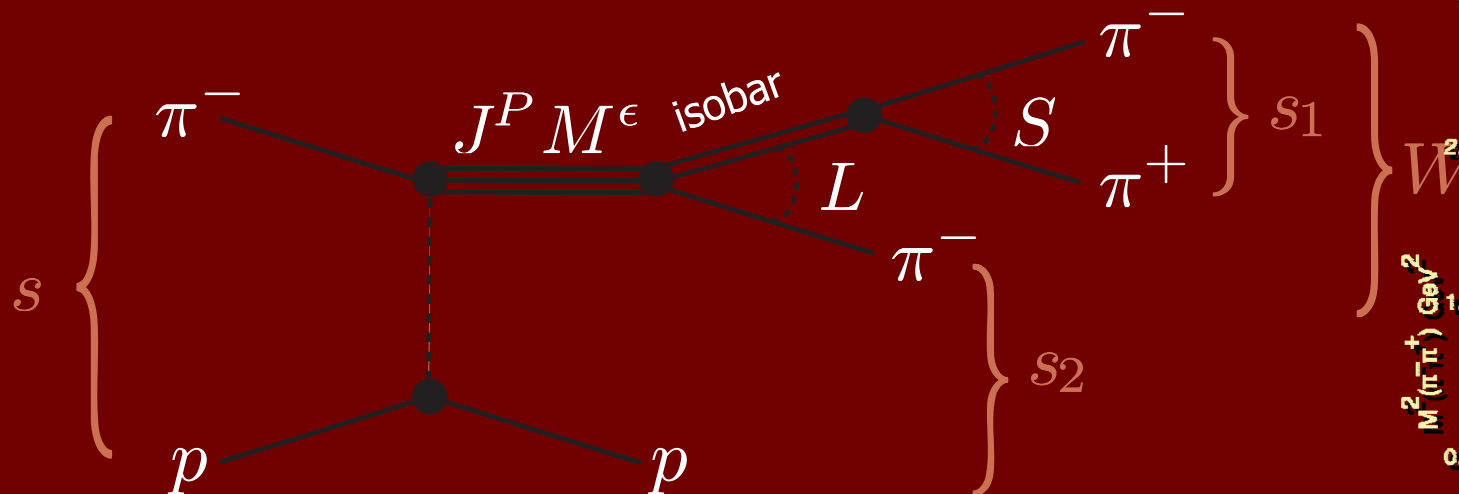


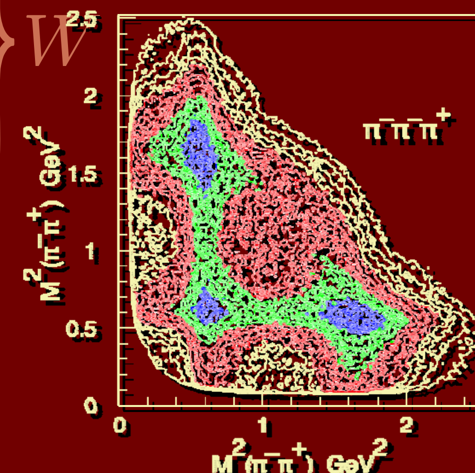
- ★ $I=1,\ G=-$ mesons have been seen in $\pi^+\pi^-\pi^-$

  e.g. $a_2, a_1, \pi_2 \ldots$

- ★ Partial wave analysis exposes the details

  standard PWA based on *isobar model*





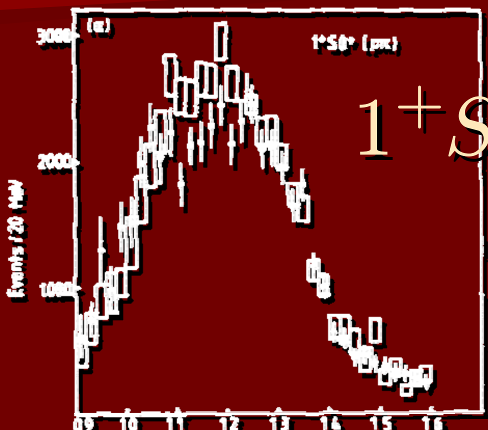
$$I(W,t,s_1,\text{angles}) = \left| \sum_b C_b(W,t) A_b(s_1,\text{angles}) \right|^2$$

$$A_b(s_1,\text{angles}) \sim \sum_\lambda D^{J*}_{M\lambda}(\Omega_1) D^{S*}_{\lambda 0}(\Omega_3) \langle L0; S\lambda | J\lambda \rangle F_L(p_1) F_S(p_3) \Delta^{\text{isobar}}_S(s1)$$

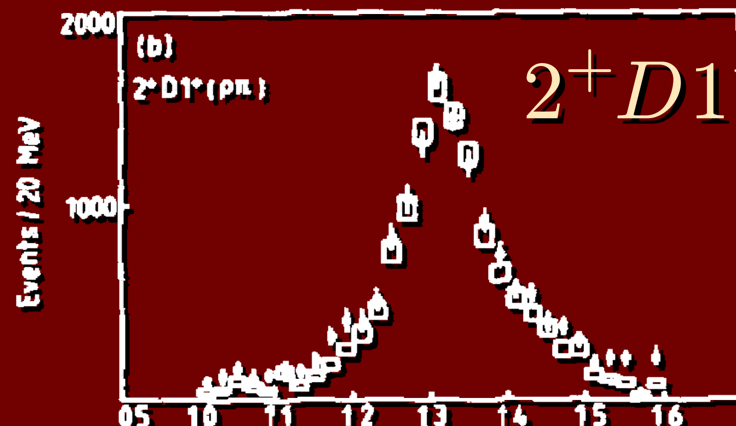
we fix the s1 dependence in isobar model: $\Delta^{\text{isobar}}_S(s1) =$ Breit-Wigner

$\pi\pi\pi$ partial wave analysis

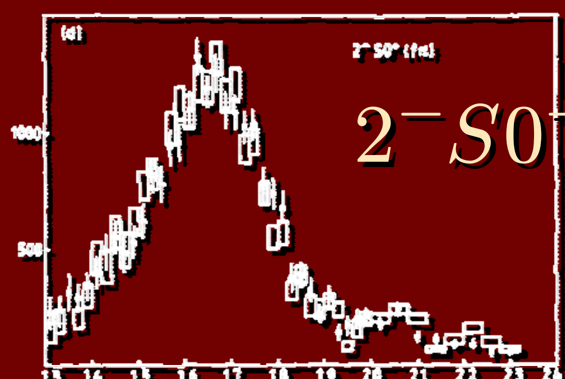
$$I_b(W) = \int dt \ldots \left| C_b(W,t) A_b \right|^2$$



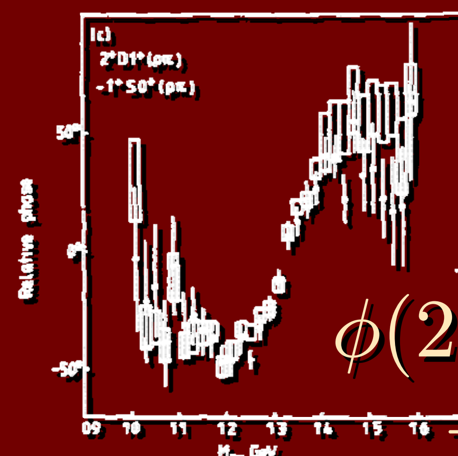
$1^+S0^+\ \rho\pi$



$2^+D1^+\ \rho\pi$



$2^-S0^+\ f_2\pi$

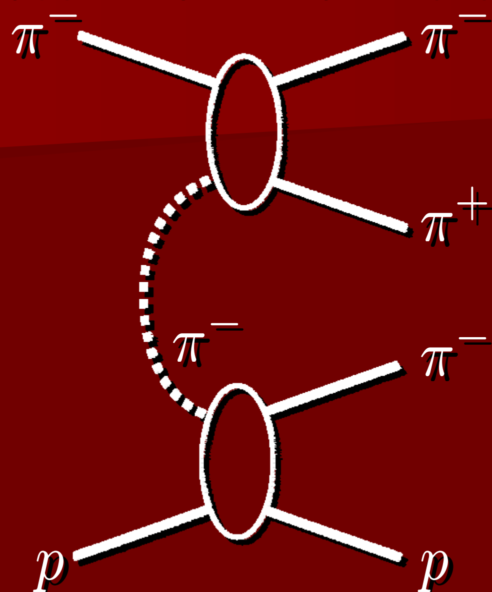


$\phi(2^+D1^+\ \rho\pi - 1^+S0^+\ \rho\pi)$

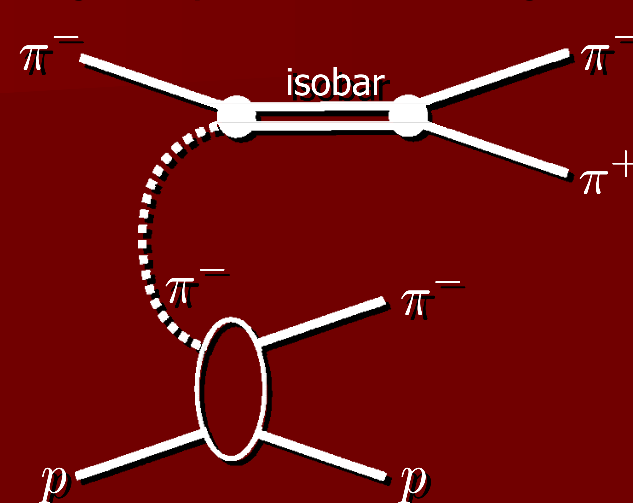
ACCMOR data

diffractive dissociation and the 'Deck'

★ long been known that this is not the only diagram possible, see e.g. R.T.Deck (1964)



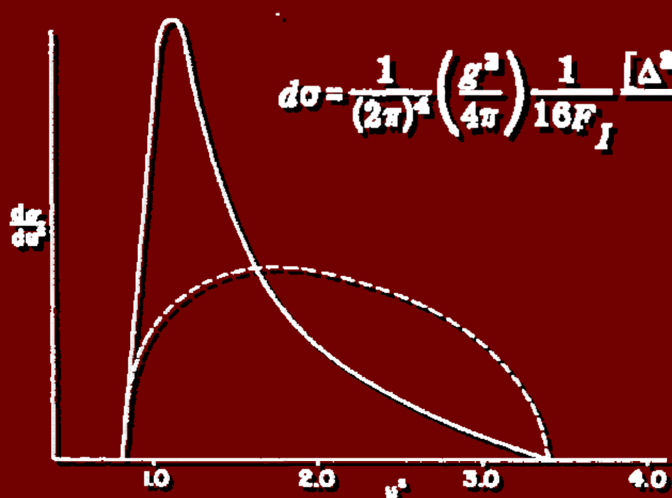
$\approx$



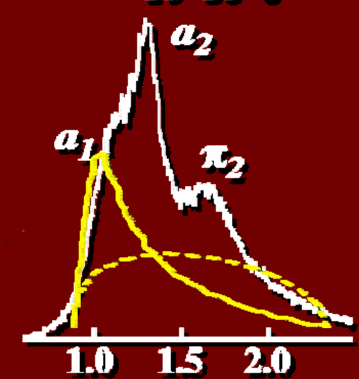
diffractive dissociation $\pi \to \rho\pi$

+ near-on-shell $\pi p \to \pi p$

$$d\sigma = \frac{1}{(2\pi)^4}\left(\frac{g^2}{4\pi}\right)\frac{1}{16F_I}\frac{[\Delta^2-(m_2-m)^2][\Delta^2-(m_2+m)^2]}{m_2^2}\frac{F(\Delta^2)}{(\Delta^2-m^2)^2}|M_{\pi N}'|^2\delta^4(p_f-p_i)\frac{d\vec{q}_1 d\vec{q}_2 d\vec{q}}{q_{10}q_{20}q_0}.$$

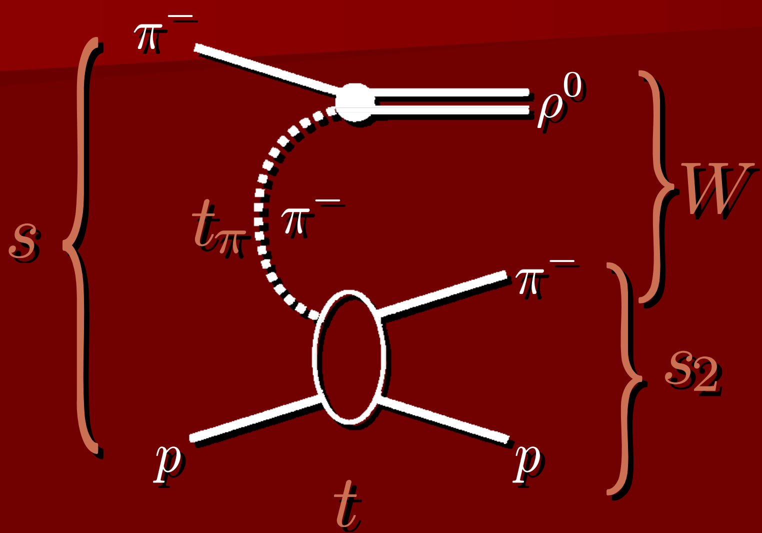


large enhancement near threshold



Stodolsky's Deck

- ★ Stodolsky demonstrated kinematic origin of the enhancement and its partial wave structure



use a conventional pion propagator $\frac{1}{t_\pi - m_\pi^2}$

diffractive (Pomeron) $\pi N \to \pi N$

$$\sim i s_2 e^{at}$$

$$A \sim \frac{s_2}{t_\pi - m_\pi^2}$$

in the interesting kinematic region $t \to t_{\min},\ s \gg W^2, m_p, m_\pi, m_\rho$

we find $s_2 \to s \frac{m_\pi^2 - t_\pi}{W^2 - m_\pi^2}$

$$A(t \to t_{\min}, s \gg W^2) \sim \frac{s}{W^2 - m_\pi^2}$$ "Stodolsky pole"

Stodolsky's Deck

★ This simple model tells us a lot

the propagation and scattering of the virtual pion is described by $\frac{s}{W^2 - m_\pi^2}$ which has no angular dependence

so this model produces $\pi\rho$ with $M = 0$

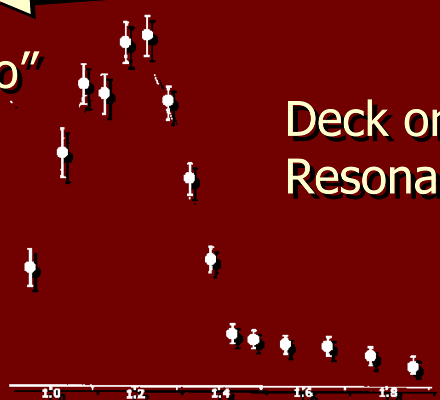
and the $\pi\rho$ are in a relative S-wave

★ Stodolsky's Deck will generate amplitude dominantly in the

$$0^- S 0^+ \epsilon\pi$$
$$1^+ S 0^+ \rho\pi$$
$$2^- S 0^+ f_2\pi$$

waves

the "A_1 imbroglio"



Deck or Resonance ?

need for an a_1 resonance finally established in τ decays

beyond Stodolsky's Deck

- ★ These properties are modified if the pion propagation is not just $\frac{1}{t_\pi - m_\pi^2}$

  for example, with an off-shell pion form-factor at either vertex $\frac{e^{b t_\pi}}{t_\pi - m_\pi^2}$

  or with a Reggeised pion $\sim \frac{e^{i \frac{\pi}{2} \alpha(t_\pi)}}{t_\pi - m_\pi^2}$

  the extra t_π dependence puts some Deck amplitude into higher *L* -waves

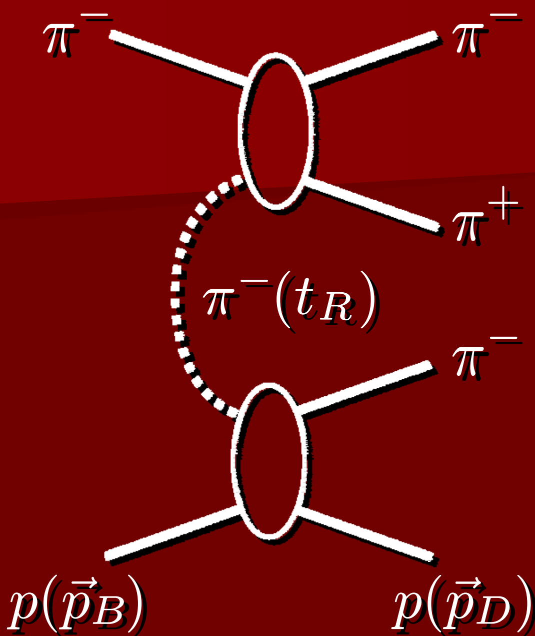
- ★ 'sophisticated' models developed to describe the Deck – I'll use the Ascoli et al. model to demonstrate the ingredients

PHYSICAL REVIEW D VOLUME 8, NUMBER 11 1 DECEMBER 1973

Partial-Wave Analysis of the Deck Amplitude for $\pi N \to \pi\pi\pi N$*†

G. Ascoli, L. M. Jones,
B. Weinstein, and H. W. Wyld, Jr.
Physics Department, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801
(Received 6 August 1973)

Ascoli Deck model



$$\frac{8\pi\sqrt{s_1}}{q_1}\frac{1}{2i}[\eta_S(s_1)e^{2i\delta_S(s_1)}-1](2S+1)P_S(\theta_{\pi\pi})$$

expt[al] $\pi\pi$ phase-shift

$$\frac{1}{m_\pi^2-t_R}\, e^{-i\pi\alpha(t_R)/2}\left(\frac{s'-u'}{2s_0}\right)^{\alpha(t_R)}$$

Regge pion exchange

$$\bar{u}(p_D)[\mathcal{A}-i\gamma\cdot p_1\mathcal{B}]u(p_B)$$

low $s_{\pi N}$ - expt[al] πN phase shift

high $s_{\pi N}$ - Regge param[n]

★ kinematics are not simple, but note one important dependence:

$$E_1=\frac{W^2+m_\pi^2-s_1}{2W},$$

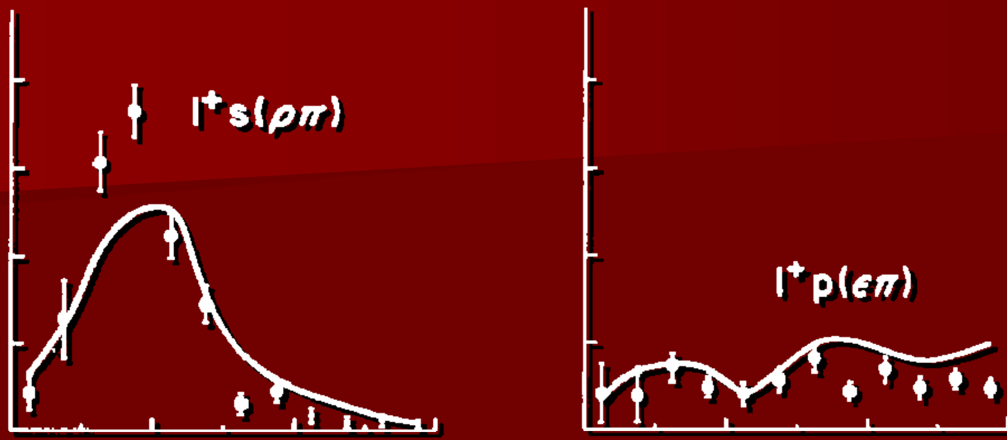
$$s_{\pi N}=m_\pi^2+m_p^2+2E_D E_1$$
$$-2p_D p_1(\cos\epsilon\cos\theta_1+\sin\epsilon\sin\theta_1\cos\varphi_1),$$

$$t_R=m_\pi^2+s_1-2E_A(W-E_1)+2p_A p_1\cos\theta_1,$$

amplitude has s_1 dependence beyond just the 'isobar' factor

this will not be captured correctly by the isobar-model PWA

Ascoli cont...



sort of shape we expect,

some amplitude in *P*–wave,

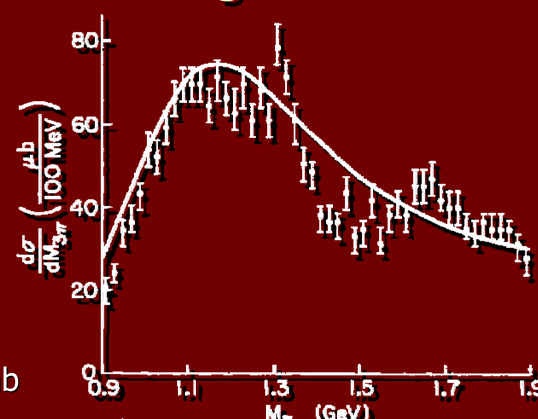
but, *too much* Deck?

★ The Ascoli scheme has some interpretative problems

By Reggeising the pion (and by indirectly using the Pomeron) we've modeled the entire $\pi N \to \pi\pi\pi N$ amplitude in the large $W, s_{\pi N}, s$ limit.

But we don't have large W - we're in the resonance region

Concept of Regge duality comes up – this amplitude is approximately dual to resonances in W?



multi-Regge theory

why go back to this?

★This was the state of the art circa 1980, and little consideration has been given since

- the Deck effect has not gone away!

★good, high statistics data in the 21st century:

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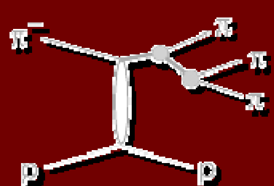
Exotic and $q\bar{q}$ resonances in the $\pi^+\pi^-\pi^-$ system produced in π^-p collisions at 18 GeV/c

(E852 Collaboration)

(Received 19 November 2001; published 12 March 2002)

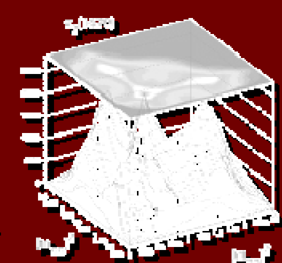
250,000 events



3π Analysis

Resource Web Site

HIGH ENERGY PHYSICS – TASK D   INDIANA U – BLOOMINGTON



20,000,000 events

Welcome to the resource web site for the analysis of 3 pion data from E852

Approximately 10M events each of the following reactions with an incident pion beam of momentum 18 GeV/c:

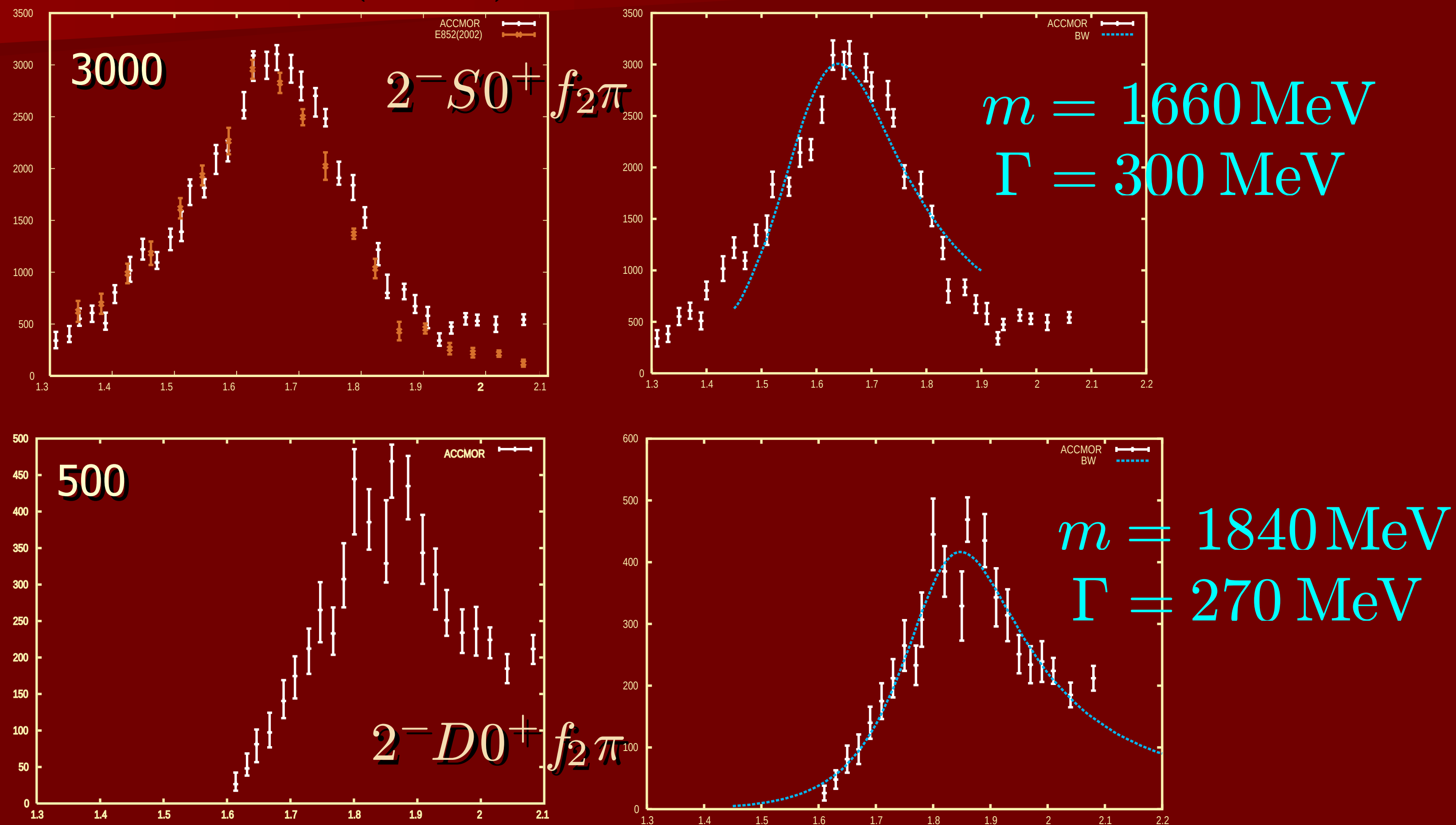
$\pi^- p \to \pi^- \pi^- \pi^+ p$

$\pi^- p \to \pi^- \pi^0 \pi^0 p$

publications to come

do we need the Deck effect?

★The a_1 is the classic example – but there is an arguably more important case - the $\pi_2(1670)$, often used as a reference wave to extract other res.



ACCMOR/E852(2002) data

do we need the Deck effect?

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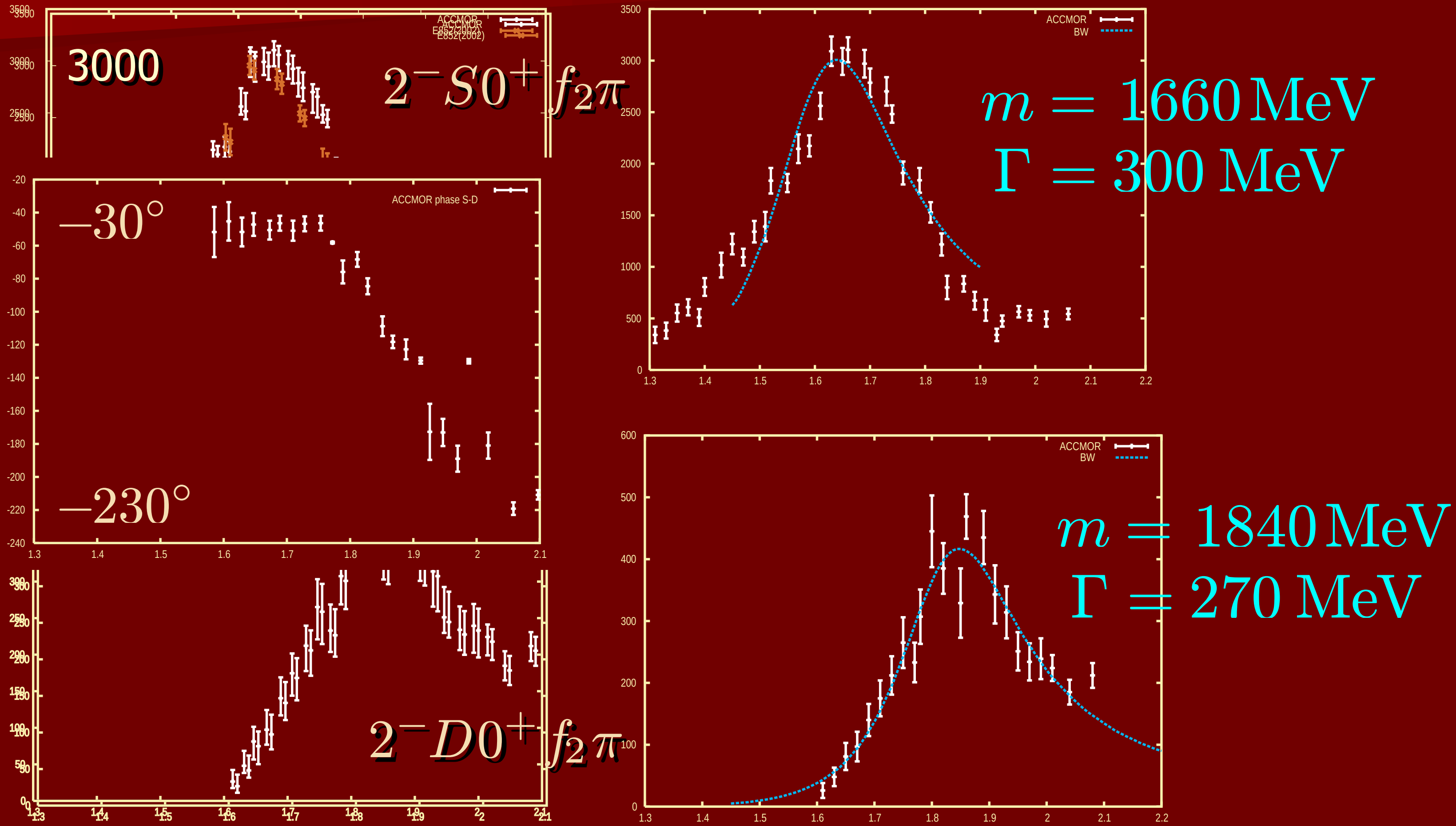
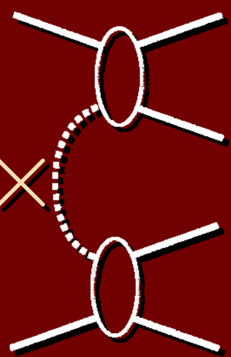
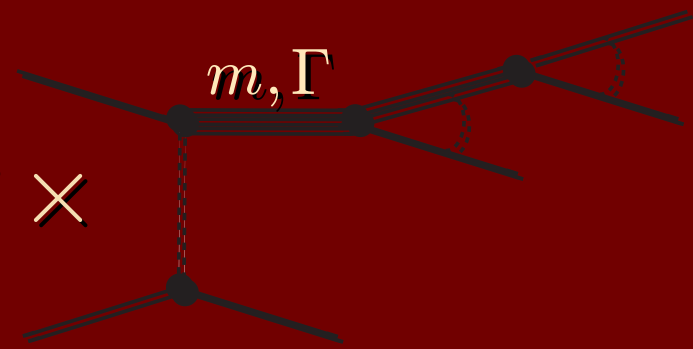


ACCMOR/E852(2002) data

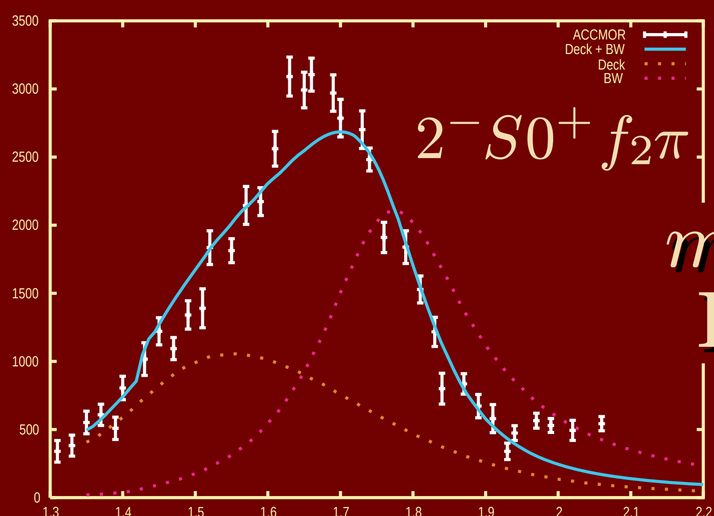
could Deck explain the $\pi_2\binom{1660}{1840}$?

★Try something simple to test if Deck-style amplitude can help:

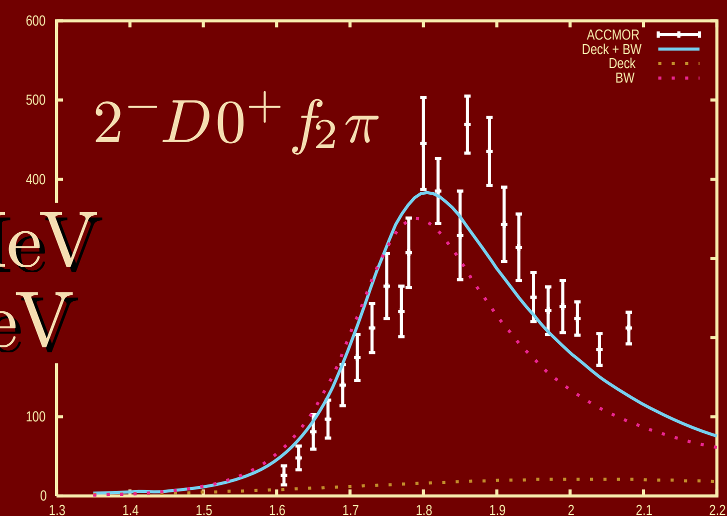
add direct resonance production to a Deck "background" of the Ascoli type

$\mathcal{M} = A \times$  $+ \; B \times$ 

★Perform a simultaneous fit to the $2^- S0^+ f_2\pi$, $2^- D0^+ f_2\pi$ waves



$$m = 1780\,\mathrm{MeV}$$
$$\Gamma = 250\,\mathrm{MeV}$$



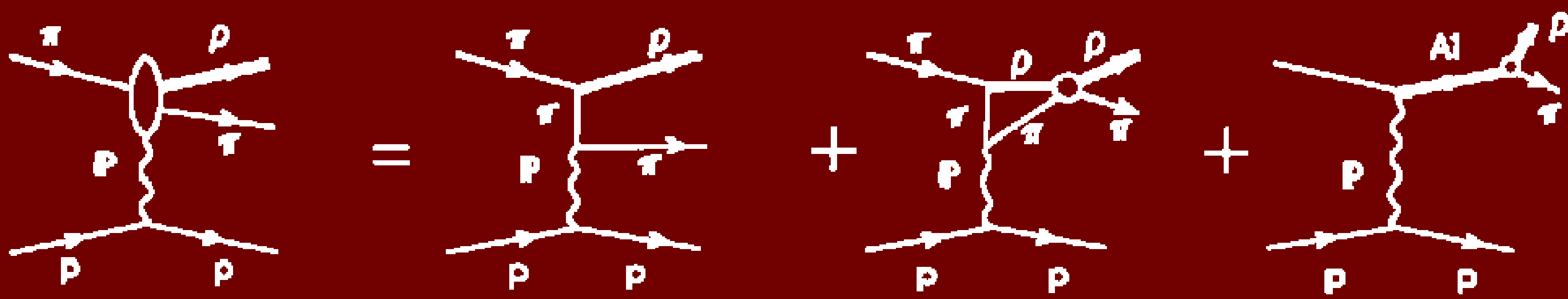
could Deck explain the $\pi_2\binom{1660}{1840}$?

★promising – suggests the Deck 'bump' is in the right place to account for the peak shift

but, large phase motion is not explained, and we worry about double counting

★more theoretically justified scheme promoted by Aitchison & Bowler and others

Deck as a Born term – with subsequent rescattering



limits itself to an isobar picture, but implements two-particle unitarity

★fits in this vein will follow shortly using both simple Stodolsky and more sophisticated Deck models

the new data

★new data from E852 opens up new possibilities

enough events to consider 'fine-binned' t -dependence of partial waves

$0.08 \leq t \leq 0.10$; $0.10 \leq t \leq 0.12$; $0.12 \leq t \leq 0.14$; $0.14 \leq t \leq 0.16$; $0.16 \leq t \leq 0.18$;
$0.18 \leq t \leq 0.23$; $0.23 \leq t \leq 0.28$; $0.28 \leq t \leq 0.33$; $0.33 \leq t \leq 0.38$; $0.38 \leq t \leq 0.43$;
$0.43 \leq t \leq 0.48$; $0.48 \leq t \leq 0.53$; $0.53 \leq t \leq 0.58$

minor waves, such as $2^- S 1^+ f_2 \pi$ are statistically significant
$2^- D 1^+ f_2 \pi$

multiple wave-sets considered to ensure robustness

new charge combination available $\pi^- \pi^0 \pi^0$

conclusion

- ★ resonances are not the only features of the *S*–matrix and if we want to properly understand the meson spectrum we need to take into account these other dynamical effects

- ★ the Deck effect, while not fully understood theoretically, has a simple kinematic origin. It affects low *L* partial waves near threshold, manifesting itself as an asymmetric bump

- ★ interpreting PWA phase information has been done with reference to the $\pi_2(1670)$ which may be 'polluted' by an as yet unknown degree of Deck

- ★ attempts are underway using past and 'future' data to understand this