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Strong Interactions, Unitarity, and Field Theory: a Case for the Hamiltonian Approach

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- Lessons of History (analytical S-matrix vs. perturbation theory)

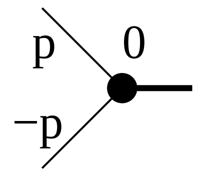
- Field Theory (universal properties, consistent approximations)

- Multi-channel (γN, πN, FSI, multiple pions, η, K's)

Isobar model: "dressed perturbation theory" $\longrightarrow$ widths not necessarily consistent with decay channels, incoherent sum, i.e., no final states interaction, t-exchange non-trivial.

Chiral perturbation theory: (very) low energy physics $\longrightarrow$ derivatives in the interaction generate unitarity violations at higher energies through strong interaction. Hard to go beyond three-particle states. Unitarization is not well-defined and does not take away the fact that the interactions are too strong at large momenta.

S-matrix: no microscopic motivation, high-t problems (explained by parton models of hadrons), difficult to implement symmetries (gauge, CVC, PCAC). However, models important aspects of hadron physics (s-t duality, unitarity saturation, etc.).

The lowest order approximation of a state: 

$$\int_0^\infty dx^0 S_0(x)\mathcal{L}_I \psi^\dagger(0)|0\rangle = \frac{1}{E - H_0} V|\phi_0\rangle = |\psi\rangle$$

In terms of on-shell, asymptotic energies:

$$|\psi\rangle = \int_{\text{threshold}}^\infty dE\ \gamma(E)\ |\phi(E)\rangle$$

the spectroscopic densities $\gamma(E)$ have known singularities:

$$\gamma(\omega) = \alpha\delta(E - \omega) + \frac{\beta(\omega)}{E - \omega}$$

where E is the scattering energy.

The approximations are in the functional form of the spectroscopic density $\beta(\omega)$:

- 1- and 2-particle phase space reproduces the bubble sum result.

- Expansions in a basis are possible for systematic improvement.

- Multiple particle states can be approximated by phase space, which allows one to treat, e.g., multiple pion states (3,4,5π..).

- t-exchange reproduced exactly with 2-dim $\beta(\omega, \omega')$ (where ω' is the energy of the two-particle "parent state").

Always tell people where there free lunch was cooked.

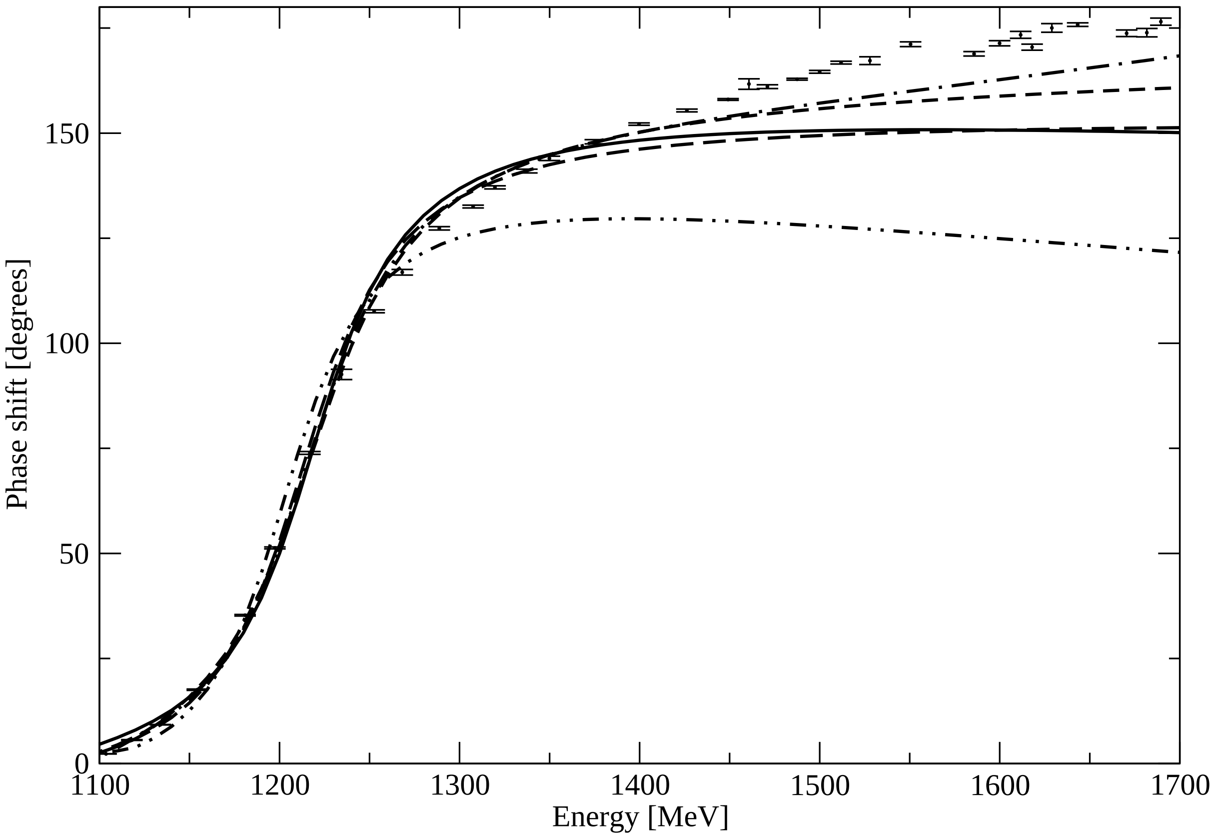
The scattering problem (Lippmann-Schwinger: $\psi = 1/(E - H_0)V\psi$ or Hamiltonian: $(E - H_0)\psi = V\psi$) is a discrete problem, because of the discrete number of spectroscopic density functions $\beta_i(\omega)$.

Analyticity (and unitarity, and renormalization) enters through the Hilbert transform:

$$\tilde{\beta}^2_{ij}(E) = \int_{\text{threshold}}^{\infty} d\omega \frac{\beta_i(\omega)\beta_j(\omega)}{E - \omega}$$

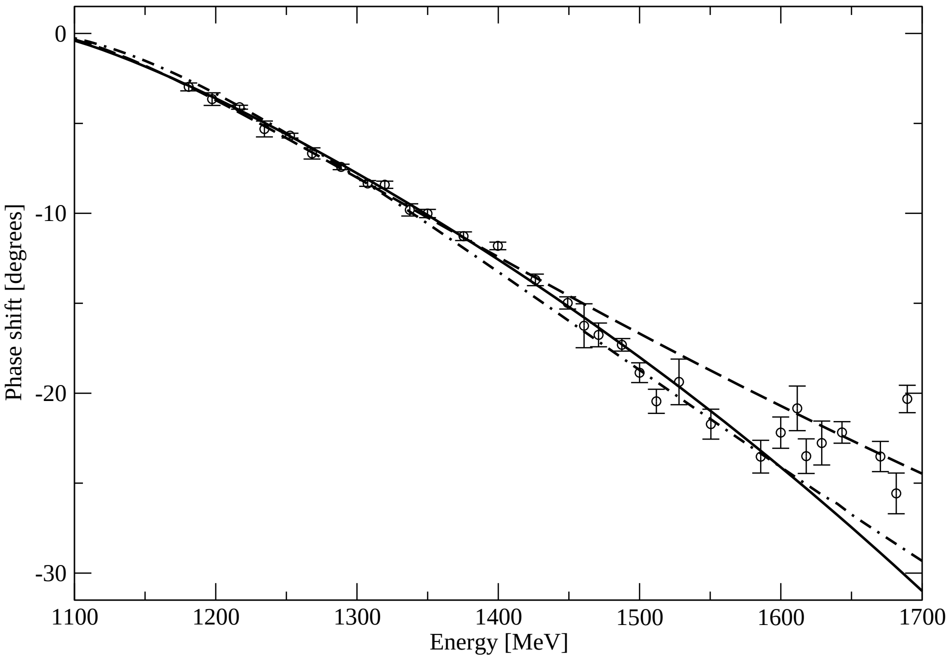
Divergences in $\tilde{\beta}^2_{ij}(E)$ correspond to those of the perturbation theory.

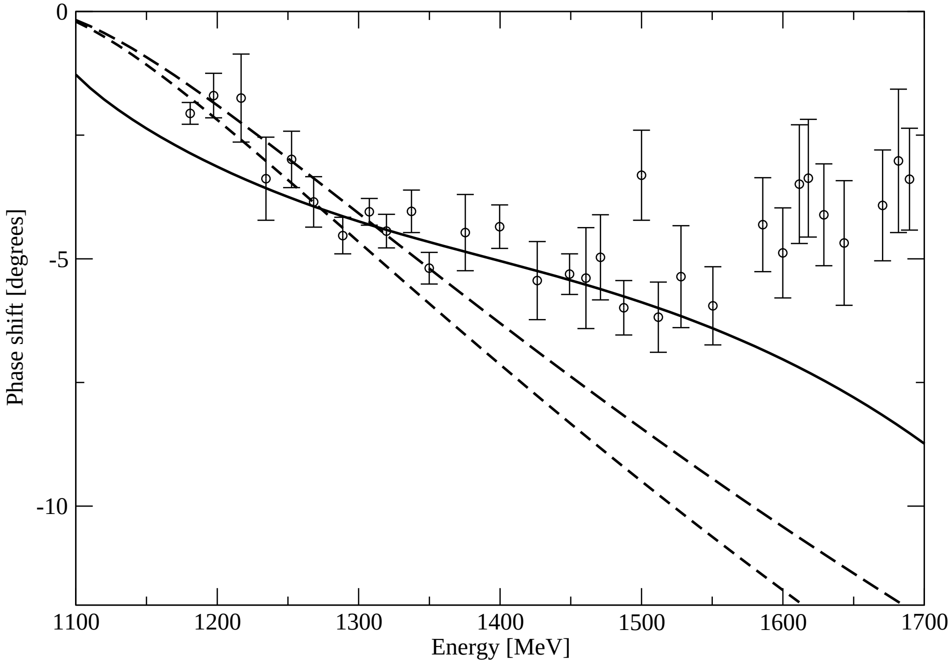
Different models for the $P_{33} = \Delta$.



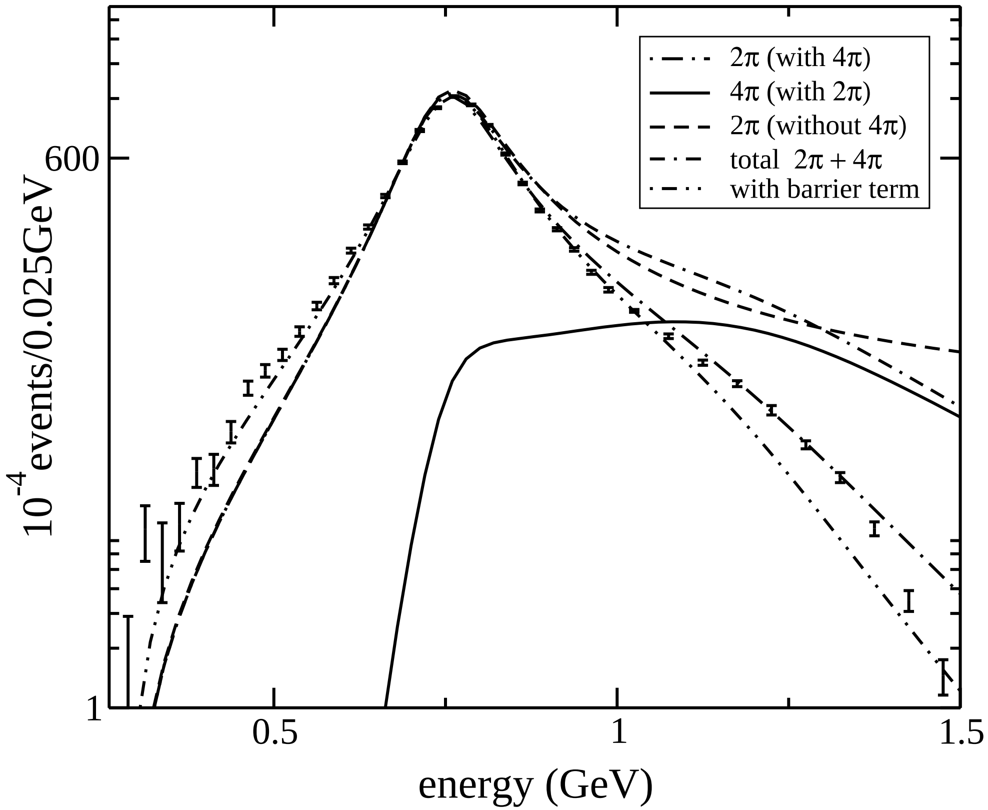
("$\bar{N}\gamma^5\gamma^\mu N[\pi, \partial_\mu \pi^*]$", "$\bar{N}\gamma^5\gamma^\mu \Delta \partial_\mu \pi$," "$\bar{N}\gamma^5 \Delta \pi$," etc.)

The same models for the P_{31} and the P_{13}.





Fitting **only** coupling constants and renormalization constants!



The rho meson with coupling to the two−pion and the four−pion state.
The coupling to the four−pion state is required to suppress the high−energy two−pion decay.

Everybody, who wants to extract relevant (universal) information from resonant hadron scattering data, will have to make some approximations.

Unitarity, coupled-channel effects, crossing symmetry, Regge, more-than-two-particle final states, final-state interactions, all play a role.

Approximating the energy (momentum) dependence of each of the relevant states is a good way to get a handle on the complexity.