EMMI RRTF - TOP3 discussion session

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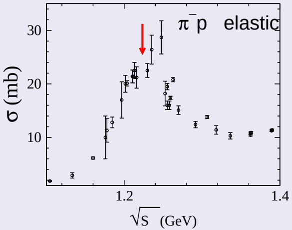
Baryon resonance analysis technique

50's...60's: discovery of p, n, e^+, e^-, π
what about new particles?

try scattering experiments

$\pi^- N$ elastic by E. Fermi:

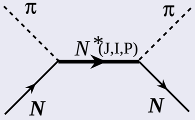


- peak in the elastic cross section
- is it a new particle?
- if yes, which properties ?
- why it appears as a broad peak ?

to identify new a particle
one needs to know production amplitude

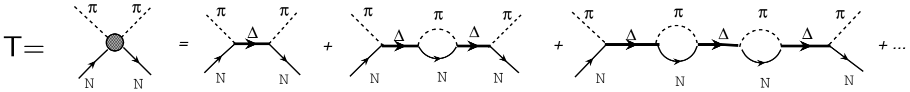
Baryon resonance analysis technique

Resonance production: reaction amplitude



- production vertices are unknown
- if particle is created it should propagate
- scattering amplitude $T \sim (s - m_R^2 + i\epsilon)^{-1}$,

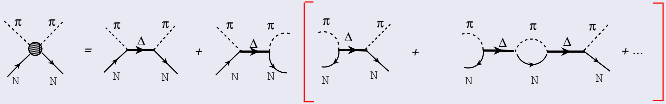
Actual amplitude could be more complicated



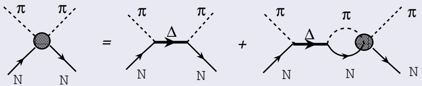
How to solve the problem ?

Baryon resonance analysis technique

$\pi^- N$ scattering amplitude :



infinite sum of all diagrams in the brackets - it is a full amplitude!



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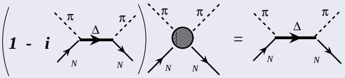
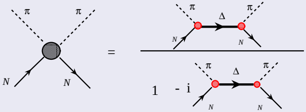


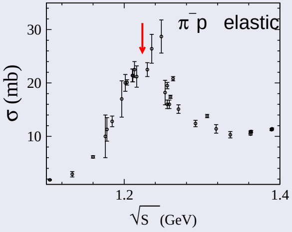


$$= \frac{\frac{\Gamma_{\pi NN*}\Gamma_{\pi NN*}}{s - m_R^2}}{1 - i\frac{\Gamma_{\pi NN*}\Gamma_{\pi NN*}}{s - m_R^2}} = \frac{\Gamma_{\pi NN*}\Gamma_{\pi NN*}}{s - m_R^2 - i\Gamma_{\pi NN*}\Gamma_{\pi NN*}}$$

Breit-Wigner form: finite width for non-vanishing $\Gamma_{\pi NN*}$

Baryon resonance analysis technique

$\pi^- N$ elastic by E. Fermi



Scattering amplitude with Δ

$$T = \frac{\Gamma_{\pi NN^*}\,\Gamma_{\pi NN^*}}{E^2 - m^2 + i\Sigma(\sqrt{s})}$$

pole on the second Riemann sheet

$$E_{\rm pole} = \sqrt{m^2 - i\Sigma(E_{\rm pole})}$$

$$\sigma_{\rm tot}(\sqrt{s}) \sim \frac{F(s)}{(s-m^2)^2 + \Sigma^2(\sqrt{s})}$$

particle with a short lifetime (resonance) $\rightarrow$ peak in the σ_{tot}

... however: still not enough to identify the peak as a resonance excitation

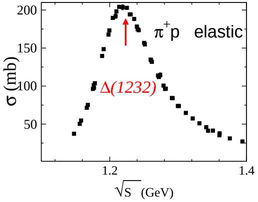
How to extract isospin of $\Delta(1232)$ from experimental data?

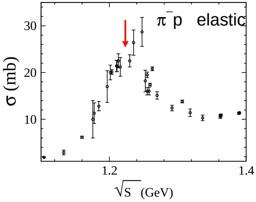
$$|\pi^+ p> = |\tfrac{3}{2}>$$
$$|\pi^- p> = \sqrt{\tfrac{1}{3}}|\tfrac{3}{2}> + \sqrt{\tfrac{2}{3}}|\tfrac{1}{2}>$$

$$T(\pi^+ p \to \pi^+ p) = <\tfrac{3}{2}|T|\tfrac{3}{2}> = T^{\frac{3}{2}}$$
$$T(\pi^- p \to \pi^- p) = \tfrac{1}{3}(T^{\frac{3}{2}} + 2T^{\frac{1}{2}})$$

if $I_{\Delta(1232)} = \frac{3}{2}$ then $T^{\frac{1}{2}} = 0$ and

$$\frac{\sigma^{el}_{tot}(\pi^+ p \to \pi^+ p)}{\sigma^{el}_{tot}(\pi^- p \to \pi^- p)} = 9$$





Experiment

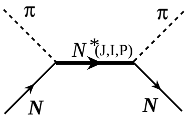
$$\frac{\sigma_{\pi^+ p}}{\sigma_{\pi^- p}}\Big|_{\sqrt{s}=1.23} = \frac{200mb}{22mb} \approx 9$$

$\Delta(1232)$: Isospin $I = \frac{3}{2}$

Isospin decomposition: $T^{\frac{3}{2}} = T(\pi^+ p \to \pi^+ p)$ and

$$T^{\frac{1}{2}} = \tfrac{1}{2}[3T(\pi^- p \to \pi^- p) - T(\pi^+ p \to \pi^+ p)]$$

Baryon resonance analysis technique: Spin of the $\Delta(1232)$.



$\Delta(1232)$: Spin: $\pi N \to \Delta(1232) \to \pi N$-reaction
:
angular distribution is defined by total spin J;
how to extract ?

$\pi N \to \pi N$ differential cross section:

$$\frac{d\sigma}{dcos(\theta)} \sim \sum_{J\,\lambda\,\lambda'} |d^J_{\lambda\lambda'}(\theta)\, T^J_{\lambda\lambda'}(\sqrt{s})|^2$$

There are two independent amplitudes

$\{T^J_{\frac{1}{2},\ \frac{1}{2}}, T^J_{\frac{1}{2},\ -\frac{1}{2}}\} \leftrightarrow \{T^{J+}, T^{J-}\}$

$$T^J_{\frac{1}{2},\ \frac{1}{2}} = T^{J+} + T^{J-} \qquad T^J_{\frac{1}{2},-\frac{1}{2}} = T^{J+} - T^{J-}$$

-rewrite in terms of T^{J-} and T^{J+} parity conserved amplitudes

$$\frac{d\sigma}{dcos(\theta)} \sim \left[\left(d^J_{\frac{1}{2},\frac{1}{2}}(\theta)\right)^2 + \left(d^J_{\frac{1}{2},-\frac{1}{2}}(\theta)\right)^2\right] |T^{J\pm}(\sqrt{s})|^2$$

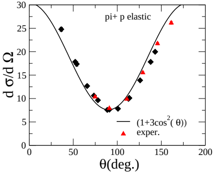
Spin of the Δ(1232).

assuming J$= \frac{3}{2}$:

$$\frac{d\sigma}{dcos(\theta)} \sim \left[\left(d^{\frac{3}{2}}_{\frac{1}{2},\frac{1}{2}}(\theta) \right)^2 + \left(d^{\frac{3}{2}}_{\frac{1}{2},-\frac{1}{2}}(\theta) \right)^2 \right] T^{\frac{3}{2}\pm}(\sqrt{s})$$

$$\frac{d\sigma}{dcos(\theta)} \sim const \times (1 + 3cos^2(\theta))$$

$\sqrt{s} = 1.232$ GeV



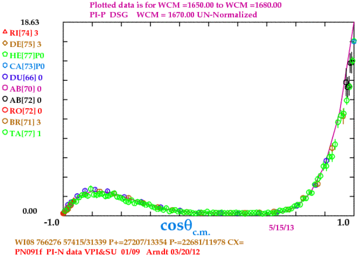
Finally: Δ(1232) Isospin I$=\frac{3}{2}$, Spin J$= \frac{3}{2}$

Inverse task: obtain contributions of given spin from exp. data

$$T^J_{\lambda_N \lambda'_N}(\sqrt{s}) = \int d\theta \, d^J_{\lambda\lambda'}(\theta) \, \frac{d\sigma}{dcos(\theta)}$$

Higher energies, many states

$\pi^- p$ elastic at higher energies



spectrum could be reach: many states + non-resonant background

- write down scattering amplitudes as sum
  $T(\sqrt{s},\theta) = \sum_i \left(\frac{\Gamma_i}{s - m_{R_i}^2 + i m_i \Gamma_i} + T^{non-pole} \right) d^{J_i}_{\lambda\lambda'}(\theta)$
- calculate exp. observables
- compares to the data, fix parameters, extract N^* parameters (poles)

TWO MAIN INGREDIENTS:

- Scattering amplitude (theory).
- Experiment

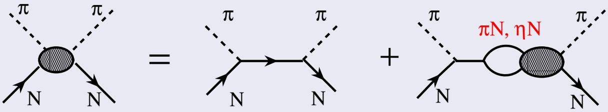
DEFINE THE SCATTERING AMPLITUDE

- parametrizations: T=(Breit-Wigner + non-pole terms), Chew-Mandelstam formalism, + unitarization, dispersion relations: less model dependence
- dynamical models: calculate T using an effective field theory: Lippman-Schwinger/Bethe-Salpeter equations, coupled-channel, Lagrangian input - coupling constants.

Construct the model for the $\pi N \to \pi/\eta N$ transitions

take rescattering in the πN and ηN channels into account

The interaction potentials $V_{\pi N \to \eta N}$ and $V_{\pi N \to \pi N}$ enter to



Coupled-channel problem for $\pi N \to \pi N$ scattering:

$$T_{\pi N\to\pi N} = V_{\pi N\to\pi N} + \int d^4p V_{\pi N\to\pi N}\, G_{\pi N}(p)\, T_{\pi N\to\pi N} + \int d^4p V_{\pi N\to\eta N}\, G_{\eta N}(p)\, T_{\eta N\to\pi N}$$

$$T_{\eta N\to\pi N} = V_{\eta N\to\pi N} + \int d^4p V_{\eta N\to\pi N}\, G_{\pi N}(p)\, T_{\pi N\to\pi N} + \int d^4p V_{\eta N\to\eta N}\, G_{\eta N}(p)\, T_{\eta N\to\pi N}$$

coupled channel problem:

There are four equations for the $T_{\pi N,\pi N}$ $T_{\pi N,\eta N}$ $T_{\eta N,\pi N}$ and $T_{\eta N,\eta N}$. They can be written in the matrix form :

$$\begin{pmatrix} T_{\pi N,\pi N} & T_{\pi N,\eta N} \\ T_{\eta N,\pi N} & T_{\eta N,\eta N} \end{pmatrix} = \begin{pmatrix} V_{\pi N,\pi N} & V_{\pi N,\eta N} \\ V_{\eta N,\pi N} & V_{\eta N,\eta N} \end{pmatrix}$$

$$+ \int d^4 p \begin{pmatrix} V_{\pi N,\pi N} & V_{\pi N,\eta N} \\ V_{\eta N,\pi N} & V_{\eta N,\eta N} \end{pmatrix} \begin{pmatrix} G_{\pi N} & 0 \\ 0 & G_{\eta N} \end{pmatrix} \begin{pmatrix} T_{\pi N,\pi N} & T_{\pi N,\eta N} \\ T_{\eta N,\pi N} & T_{\eta N,\eta N} \end{pmatrix}$$

or more compact:

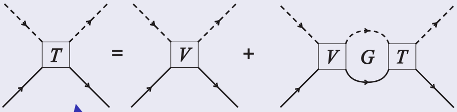
$$[\hat{T}] = [\hat{V}] + i \int \frac{d^4 k}{(2\pi)^4} [\hat{V}] \hat{G_{\mathrm{mB}}} [\hat{T}]$$

- can be easily generalized for any number of channels
- PWD + K-matrix approx $\rightarrow$ algebraic matrix equations

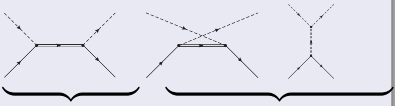
Giessen model. PRC71, 055206 (2005)

Bethe-Salpeter in K-matrix: dynamical model: based on eff. L_{mBB}

T-matrix



Interaction terms V_{ij}



multidimensional T-matrix

$$T = \begin{pmatrix} T_{\gamma N,\gamma N} & T_{\gamma N,\pi N} & T_{\gamma N,K\Lambda} & \cdots \\ T_{\pi N,\gamma N} & T_{\pi N,\pi N} & T_{\pi N,K\Lambda} & \cdots \\ T_{K\Lambda,\gamma N} & T_{K\Lambda,\pi N} & T_{K\Lambda,K\Lambda} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

How many channels?

$\gamma N \to \gamma N$	$\pi N \to \pi N$
$\gamma N \to \pi N$	$\pi N \to 2\pi N$
$\gamma N \to \eta N$	$\pi N \to \eta N$
$\gamma N \to \omega N$	$\pi N \to \omega N$
$\gamma N \to K\Lambda$	$\pi N \to K\Lambda$
$\gamma N \to K\Sigma$	$\pi N \to K\Sigma$

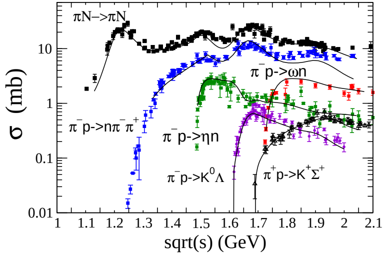
Partial wave version of optical theorem

constraints on partial wave cross sections

$$Im T^{JP}_{\pi N\to\pi N} = \frac{k^2}{4\pi}(\sigma^{JP}_{\pi N\to\pi N} + \sigma^{JP}_{\pi N\to 2\pi N} + \sigma^{JP}_{\pi N\to\eta N} + \sigma^{JP}_{\pi N\to\omega N} + \sigma^{JP}_{\pi N\to K\Lambda} + \sigma^{JP}_{\pi N\to K\Sigma} + \ldots)$$

all reaction data are linked

$\rightarrow$ need for coupled-channel unitary analysis



$$T = \begin{pmatrix} T_{\gamma N,\gamma N} & T_{\gamma N,\pi N} & T_{\gamma N,K\Lambda} & \cdots \\ T_{\pi N,\gamma N} & T_{\pi N,\pi N} & T_{\pi N,K\Lambda} & \cdots \\ T_{K\Lambda,\gamma N} & T_{K\Lambda,\pi N} & T_{K\Lambda,K\Lambda} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

$\leftarrow$ Giessen Model vs experimental data

pion beam experiments vs. photoproduction

"Missing states" and photoproduction:

Pion beam experiment

- Most of our knowledge about N^* properties comes from single channel partial wave analysis (PWA) of πN elastic scattering
- Isospin decomposition is straightforward

surprisingly ... but pion experiments were stopped in 70s

why ? main reasons:

- problems in identification of neutral particles in $\pi^- p \to \eta n$, $K\Lambda$, ωN, ϕN etc scattering: the most of experiments with charged particles in final states

Main argument against pion-beams

- we know everything from hadronic experiments!
- "missing resonances" are weakly coupled to πN: can only be seen in photoproduction !

$N^* \to \pi N$ decays

PDG 2012 main contribution from the analysis of the πN elastic scattering

N^*	$L_{2I\,2J}$	Overall	$Br(N^* \to \pi N)$
$N(939)$	P_{11}	★★★★	—
$N(1440)$	P_{11}	★★★★	55...67 %
$N(1520)$	D_{13}	★★★★	55...65 %
$N(1535)$	S_{11}	★★★★	35...55 %
$N(1650)$	S_{11}	★★★★	50...90 %
$N(1675)$	D_{15}	★★★★	35...45 %
$N(1680)$	F_{15}	★★★★	65...70 %
$N(1700)$	D_{13}	★★★	8 ... 17 %
$N(1710)$	P_{11}	★★★	5 ... 20 %
$N(1720)$	P_{13}	★★★★	9...14 %
$N(1870)$	D_{13}	★★★	10 ... 22 %
$N(1900)$	P_{13}	★★★	10 %
$N(2000)$	F_{15}	★★	9 %

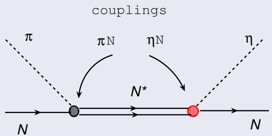
- for $Br(N^* \to \pi N) < 20\%$ no general agreement between different analyses !
- indication for the existence is smaller for higher masses (more degrees of freedom at higher energies, many open channels)
- resonance/background separation is difficult
- πN elastic scattering: increase exp. resolution

Another possibility: inelastic reactions

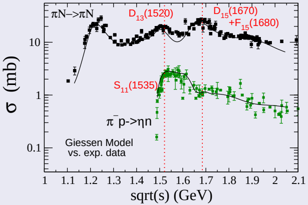
inelastic $\pi N \to \eta N$, ωN, ρN... etc scattering

My argument:

- resonance contribution to e.g. η-production: $\frac{d\sigma}{d\Omega} \sim g^2_{\pi NN^*} g^2_{\eta NN^*}$
- signals from N* with small πN coupling can be visible provided $g^2_{\eta NN^*}$ is large



- signals from N* with small πN coupling less screening by contributions from N* with large πN coupling: no clean signal from $D_{13}(1520)$, $D_{15}(1680)$, $F_{15}(1680)$ in $\pi N \to \eta N$



N^* spectroscopy with pions:

Short summary :

Main argument against pion-beams

- ~~"missing resonances" are weakly coupled to πN: can only be seen in photoproduction~~ NO!
- The pion-induced inelastic reactions provide great possibility to study N^* spectra !

But

- May be we know everything from old πN experiments ?

ωN-meson dynamics

ωN-meson dynamics in nuclear medium

- in-medium modification of omega-mesons in nuclei: (HADES, CB-ELSA/TAPS etc)
- broading of the omega meson in nuclear medium but no mass shift
- strong absorption in the nuclear medium

but

- large collisional broading
- what about chiral symmetry restoration ?

Microscopical model is needed

ωN-meson in-medium properties

Building block: ωN scattering amplitude

ωN scattering length

- $\bar{a} = -0.026 + i0.28$ fm, Giessen (coupled-channel) NPA780 187
- $\bar{a} = -0.44 + i0.20$ fm, Lutz, et al(coupled-channel, low partial waves) NPA706:431
- $\bar{a} = +1.60 + i0.30$ fm, Kling, Weise (single channel) NPA630:299

Common feature of above analysis:

- constrained by the $\pi N \to \omega N$ experimental data
- agrees on the value of the imaginary part of the scattering lengths

low density theorem: $i0.28$ corresponds to $\approx$ 60 MeV broading

but too small to explain the strong absorption of ω in medium

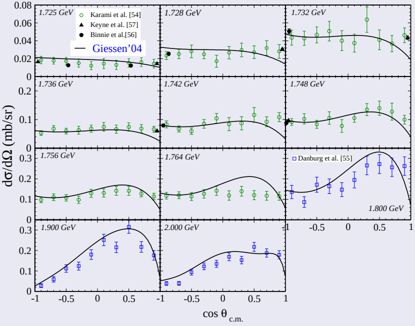
- theory: take in-medium corrections into account
- experiment: is everything clear with old $\pi N \to \omega N$ data?

Giessen model. Results for the $(\pi,\gamma)N \to \omega N$ reactions

ωN: coupled channel analysis Shklyar et al PRC 71:055206:

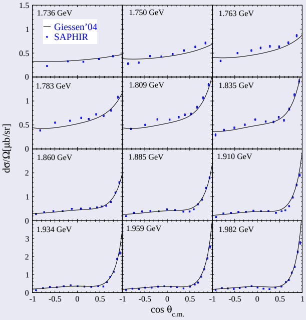
Aim: extract resonance coupling to ωN

$\pi N \to \omega N$



few measurements, low statistic

$\gamma N \to \omega N$

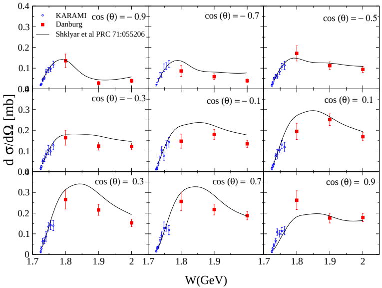


strong *t*-channel pion exchange screens other reaction mechanisms

$\pi N \to \omega N$ database

- W=1.72 to 1.76 GeV: H. Karami, et al NPB154 503 (1979) : 80 datapoints threshold region
- W=1.8 to 2.1 GeV: J.S. Danburg, PR2, 2564(1970) from $\pi^+ D \to \pi^+\pi^-\pi^0 p(p)$: 41 datapoints Fermi-motion, final state interaction!

Shklyar et al, PRC 71:055206,2005



Difficulties:

- ωN has three helicities: need ω-polarization measurements
- Karami data - close to threshold
- region 1.76...2.0 GeV is almost empty - standard PWA not possible
- no polarization measurements
- Problem: N^* extraction ...

Summary of $(\pi/\gamma)N \to \omega N$ reactions

- $\gamma p \to \omega p$: strong t-channel background $\to$ other reaction mechanisms are shadowed: hard to see any resonance contributions
- $\pi N \to \omega N$: almost NO data in the region region 1.76...2.0 GeV - standard PWA not possible
- contributions from many groups: Lutz, Wolf, Friman, Titov, Sibirtsev, Zhao, Shklyar, Mosel, Penner - no general conclusion on N^* contributions

NEED $\pi^- p \to \omega p$ measurements in order to

- get information on N^* couplings to ωN - fill white pages in PDG
- construct microscopical model of ω-dynamics in nuclear medium; explain large collisional broading

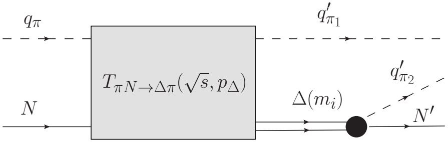
$\pi N \to 2\pi N$ reactions

investigate cascade reactions e.g. $N^* \to \pi N^* \to \pi\pi N$ etc. : multiparticle production

Analysis of $\pi N \to 2\pi N$: Manley, Arndt, Goradia, Teplitz PRD**30**,(1984) 904.

Manley, Arndt, Goradia, Teplitz PRD**30**,(1984) 904.

- isobar appoximation $\pi N \to 2\pi N$ via σN, ρN, $\pi\Delta \to 2\pi$

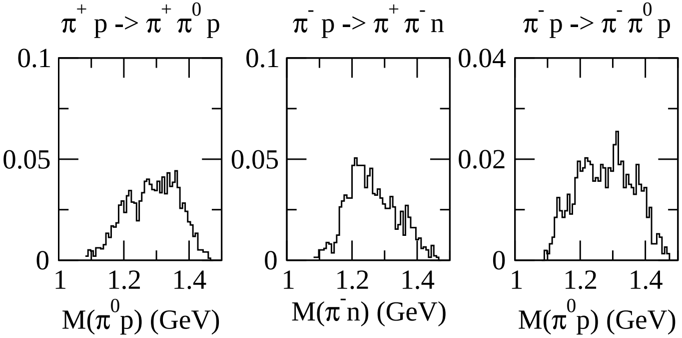


$$T^{J\,P}_{\pi N\to 2\pi N} = T^{J\,P}_{\pi N\to\Delta\pi}(\sqrt{s})\, S_\Delta(p_\Delta, m_\Delta)\, \Gamma_{\Delta\pi N}(q'_{\pi_2}, N')$$

Potential problems:

- no three-body unitarity
- no dependence on isobar mass (momentum)
- poor database based on 240000 events from old bubble-chamber experiments W = 1.2...2 GeV: $\approx$ 9000 events per energy/angular (θ, ϕ) bin for
  $\pi^- p \to \pi^+\pi^- n$, $\pi^- p \to \pi^0\pi^- p$,
  $\pi^+ p \to \pi^0\pi^+ p$, $\pi^+ p \to \pi^+\pi^+ n$
  $\approx$ 2000...3000 events per energy bin for each reaction

$\pi N \to 2\pi N$



π+ p -> π+ π0 p
π- p -> π+ π- n
π- p -> π- π0 p
0.1
0.05
0
0.1
0.05
0
0.04
0.02
0
1
1.2
1.4
M(π0p) (GeV)
M(π-n) (GeV)
M(π0p) (GeV)

$\pi N \to 2\pi N$ reaction

New data came later (most of them are total X-sections) (I.Strakovsky, GWU) but not suited for $N^* \to \rho N$

- W=1221 to 1356 MeV
  $\pi^+ p \to \pi^+ \pi^+ n$ PNPI (1978)
  $\pi^+ p \to \pi^+ \pi^+ n$ TRIUMF (1991)
  $\pi^\pm p \to \pi^\pm \pi^\pm n$ TRIUMF (1998)
  $\pi^+ p \to \pi^+ \pi^0 p$ LAMPF (1994)
  $\pi^+ p \to \pi^- \pi^+ p$ CERN (1990)
- W=1213 to 1527 MeV
  $\pi^- p \to \pi^0 \pi^0 n$ BNL(2004)
- W=1257 to 1302 MeV
  $\pi^\pm p \to \pi^\pm \pi^\pm n$ TRIUMF (1998)(events)
- W=1300 to 1302 MeV
  $\pi^- p \to \pi^+ \pi^- n$ PSI (1993)

Why pion beam experiment for $2\pi N$ is production important?

Pion-induced reactions:

$\pi^- p \to \pi^+\pi^- n$, $\pi^- p \to \pi^0\pi^- p$,
$\pi^+ p \to \pi^0\pi^+ p$, $\pi^+ p \to \pi^+\pi^+ n$
$\pi^- p \to \pi^0\pi^0 n$

- Isospin decomposition : 4 independent isospin amplitudes (in isobar approximation)
- optical theorem $Im T^{JP}_{\pi N\to\pi N} = \frac{k^2}{4\pi}(\sigma^{JP}_{\pi N\to\pi N} + \sigma^{JP}_{\pi N\to 2\pi N} + \ldots)$

Photon-induced reactions:

$\gamma p \to \pi^+\pi^- n$, $\gamma p \to \pi^0\pi^- p$,
$\gamma p \to \pi^0\pi^0 p$

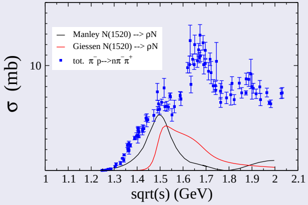
- No isospin decomposition is possible (separation between $I = \frac{1}{2}$ and $\frac{3}{2}$ states is more difficult)
- difficulties with the gauge invariance
- need input from hadronic reactions

N(1520) D_{13} state

Manley et al: PRD(1984)

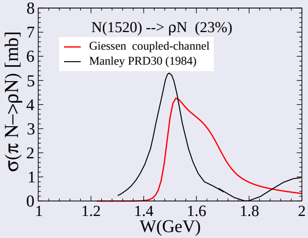
$M_R = 1.52\text{MeV}$
Γ_{tot}=120MeV

strong N(1520)$\rightarrow 2\pi N$
Br(ρN) ≈20%



- need diff. x-sections of $\pi^- p \rightarrow \pi\pi N$

Giessen Model (CC): $\pi N \rightarrow \rho N$



- Giessen : overlapping of spectral functions of $N^*(1520)$ and ρ-meson: non-symmetric
- Giessen: no effect below 1.4 GeV
- Manley: no ρ-spectral function: should be updated

Summary of the $\pi N \to 2\pi N$ reactions

- important for understanding ρ-meson dynamics and resonance couplings
- could solve many puzzles in non-strange baryon spectroscopy: origin and properties of the $P_{11}(1440)$, $P_{11}(1710)$, $D_{13}(1520)$ etc.

Theory

- analysis of Manley et. al. should be updated!

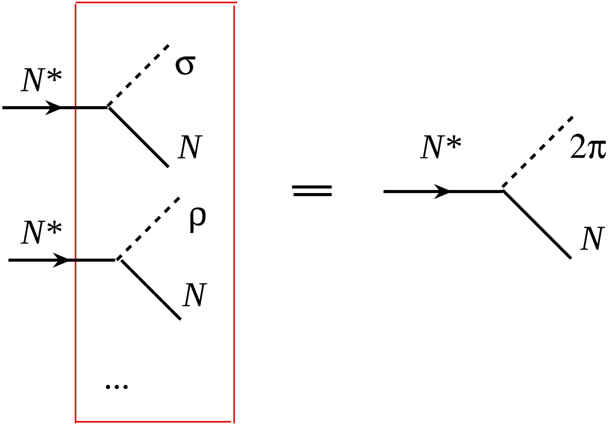
Experiment

- need for new measurements $\pi N \to 2\pi N$ in region 1.2...2.GeV

Next step: improve description of the $2\pi N$ channel

so far: N^* decay into 'generic' 2π channel

- take $2\pi N$ inelastic flux into account
- $N^* \to 2\pi N$ couplings constrained by $\sigma^{JI}_{\pi N \to 2\pi N}$



$\pi N \to 2\pi$ channel in the first resonance energy region

Roper resonance N(1440) properties:

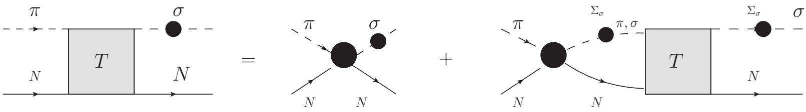
- Manley & Saleski PRD30 904, $Br(\Delta\pi) = 22\%$ $Br(\sigma N) = 9\%$
- Vrana et al PRPL328, $Br(\Delta\pi) = 16\%$ $Br(\sigma N) = 12\%$
- Sarantsev et al PLB659,94, $Br(\Delta\pi) = 17\%$ $Br(\sigma N) = 21\%$

- Julich Model: PRC62: pion exchange is responsible for a large amount of attraction: P(1440) is dynamically generated
- Crystal Ball PRL91(2003): PWA of the $2\pi^0$-subsystem: σ-meson production via pion exchange is small
- Crystal Ball PRL69(2004): measurement of the $\pi N \to 2\pi^0 N$-reaction: no direct evidence for a strong σN subchannel

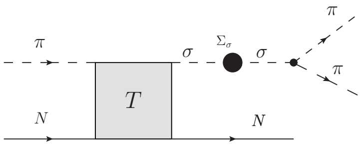
$\pi N \to 2\pi$ channel in the first resonance energy region

BSE in the isobar approximation:

system of coupled-channel integral equations

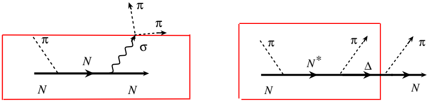


$\pi N \to 2\pi N$ amplitude from BSE



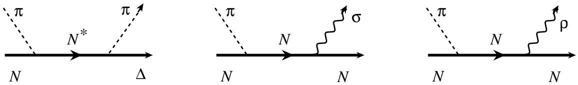
$+\ \pi N \to \rho N,\ \pi N \to \pi\Delta$ etc

$\pi N \to 2\pi N$ reaction via ρN, $\pi\Delta$ channels

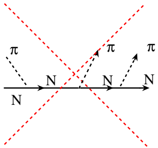


Assumptions

- decays $N^* \to \rho N$, σN, $\pi\Delta$ drive the $\pi N \to 2\pi N$ channel



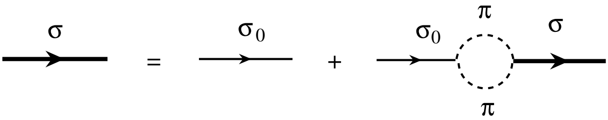
- two-step diagrams are neglected



σ-meson dynamics

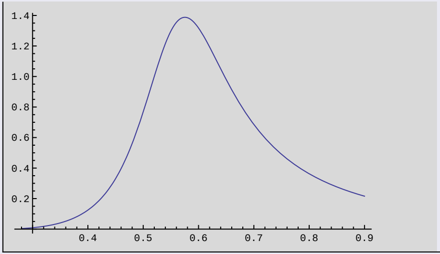
propagator of the σ-meson

$$D(s) = \frac{1}{s - m_\sigma^2 + i\Sigma_\sigma(s)}$$

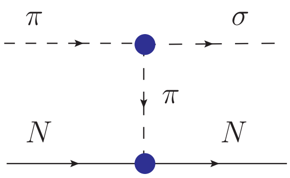


$$A_\sigma(s) = \frac{1}{\pi} \frac{\Sigma_\sigma(s)}{(s - m_\sigma^2)^2 + \Sigma_\sigma(s)^2}$$

spectral function A_σ



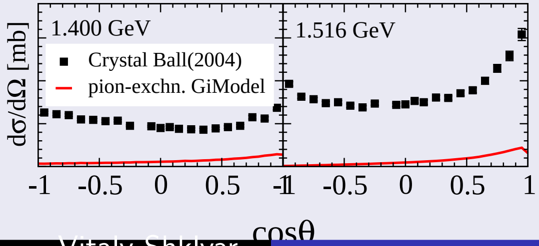
t-channel pion exchange: σN how large?



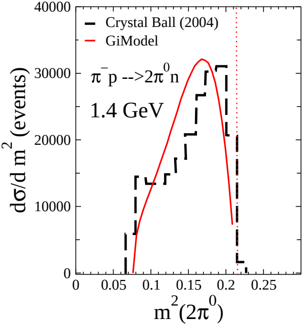
- coupling constants are well fixed
- $g_{\pi NN} = 13$, $g_{\sigma\pi\pi} = 2$ correspond to $m^0_\sigma = 600\text{MeV}$, $\Gamma_{\sigma\pi\pi} = 600\text{MeV}$
- contribution from the t-channel diagram is well fixed

- shed light on the σ-meson dynamics
- background mechanism in $\pi N \to 2\pi N$ reaction

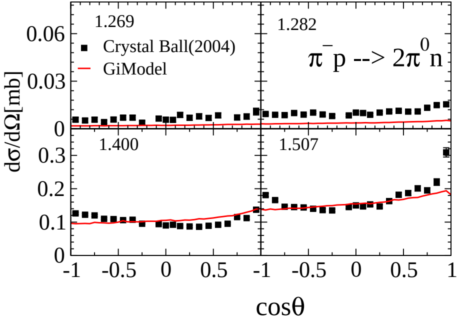
$\pi^- p \to \pi^0\pi^0 n$: t-channel pion exchange: very small !



Giessen Model vs. Crystal Ball data

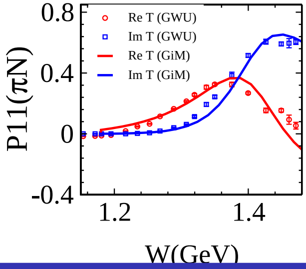


Roper resonance



- good description of the $\pi^- p \to 2\pi^0 n$ data
- three-body unitarity is maintained

$$\mathrm{Im}\, T^{11}_{\pi N} = \frac{k^2}{4\pi}\left(\sigma^{11}_{\pi N} + \sigma^{11}_{2\pi^0 N}\right)$$



GIModel for $\pi^- p \to \pi^0 \pi^0 n$ reaction

- model space is extended to include σN, $\pi\Delta$, and ρN channels
- $t-$channel pion exchange in σN channel is very weak - underestimate the data.
- do not rule out dynamical pole; however if it exists the contribution to the production cross section should be small
- calculation with a genuine Roper resonance: nice description of the CB-measurements