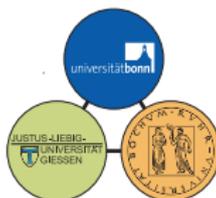


Partial wave analysis of pion- and photon-induced reactions: baryon spectra

Vitaly Shklyar

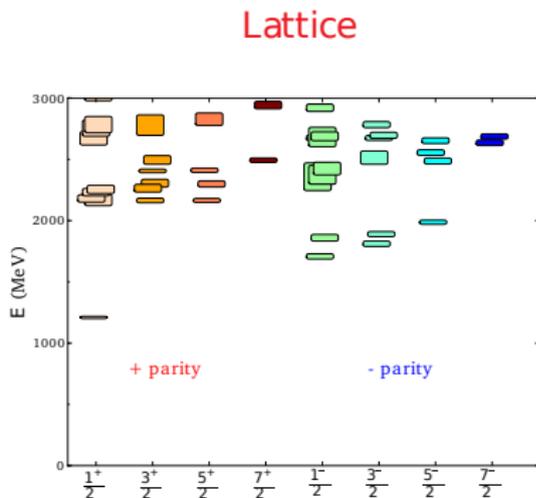
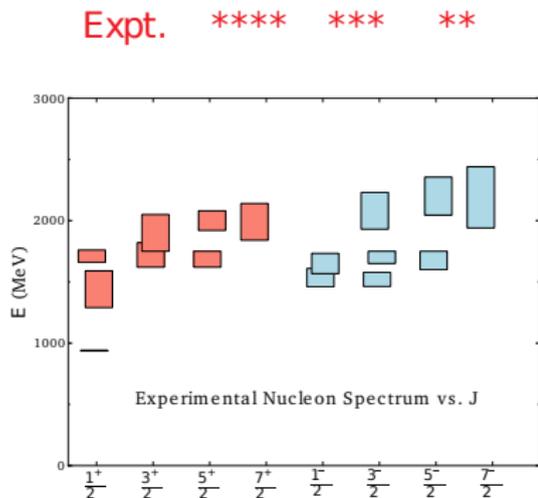
in collaboration with H. Lenske and U. Mosel

Institut für Theoretische Physik
Universität Giessen



Baryon spectrum from lattice QCD

HADRON SPECTRUM COLLABORATION Overall pattern of N^* states



Many more states in the lattice spectrum.

Lattice (QCD)

- more resonances than concluded from PWA
- there are many states above 2 GeV.

Experiment (PWA), Reaction theory

- photoproduction
- back to pion-induced experiments: increase experimental resolution (HADES at GSI, J-PARK).
- study pion-induced inelastic reactions
- investigate cascade reactions $N^* \rightarrow \pi N^* \rightarrow \pi \eta N^*$ etc. : multiparticle production

PWA and Reaction Theory: Motivation

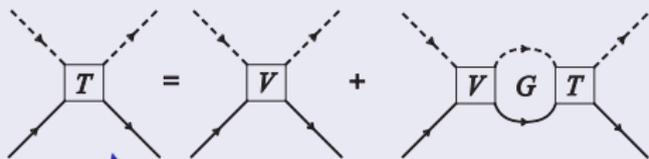
Aim: Extract properties of baryon resonances from experiment

- accepted tool: PWA (decomposition in terms of J, P, I) (Giessen Model, Bonn-Gatchina, EBAC, SAID, Jülich etc.)
- PWA does not substitute dynamics: need to construct the **reaction theory**
- effective degrees of freedom: meson and baryons
- baryon resonance analysis: bring pion- and photon-induced reactions together

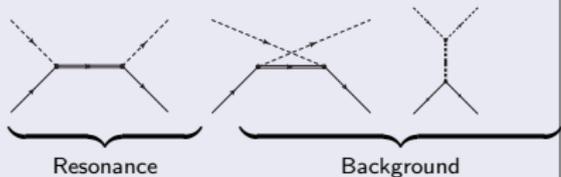
Giessen model. PRC71, 055206 (2005)

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

T-matrix



Interaction terms V_{ij}



multidimensional T-matrix

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

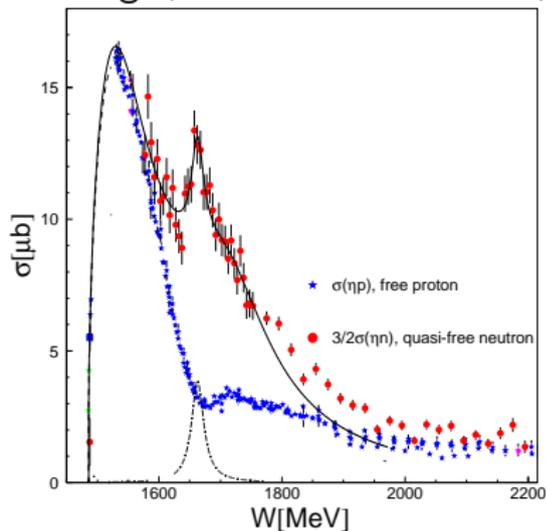
How many channels?

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

$(\gamma/\pi)N \rightarrow \eta N$ reactions

η -photoproduction on the neutron and on the proton

I. Jeagle, B. Krusche EPJA47, 89



First peak: $S_{11}(1535)$

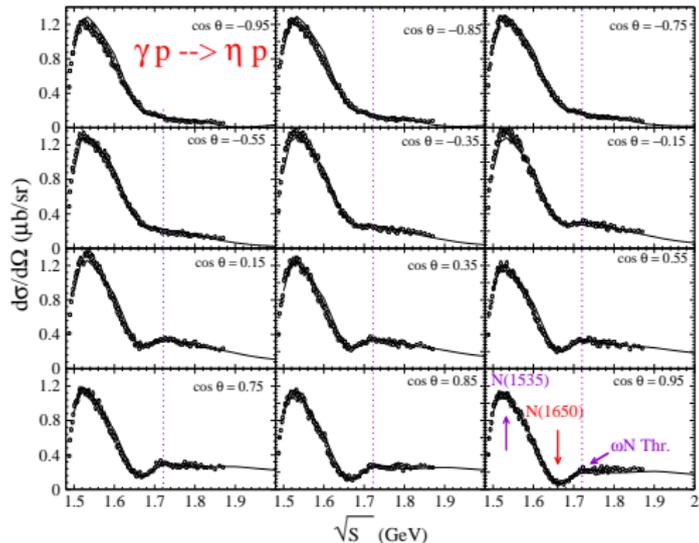
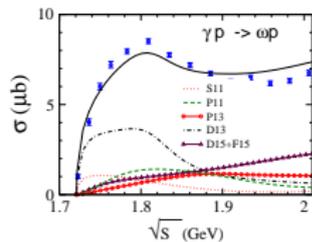
- $\gamma n \rightarrow \eta n$: resonance-like structure at 1.68 GeV
- $\gamma p \rightarrow \eta p$: dip at 1.68 GeV (well seen in new MAMI data PRC82,035208)

Main questions

- Are resonance-like structure in ηn and dip in ηp originated from the same degrees of freedom ?
- Can narrow resonance contribution be attributed to one (or both of these effects)?
- Do these effects have their counterparts in the $\pi^- p \rightarrow \eta n$?

Results for the $\gamma p \rightarrow \eta p$ Shklyar et al PRC87 (2013)

Shklyar et al
PRC71(2005)

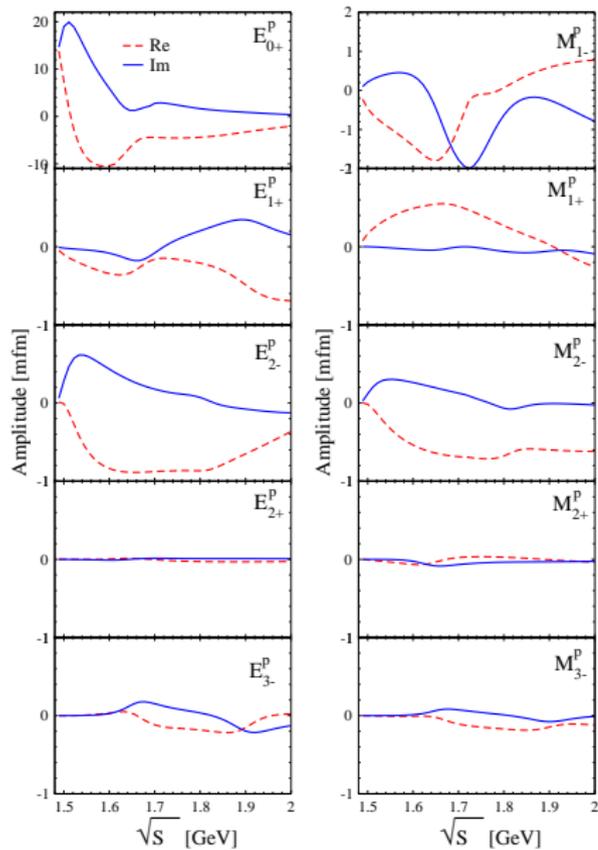


$\gamma p \rightarrow \eta p$: updated Giessen analysis vs. new MAMI 2010 data

We corroborate our previous conclusions: Shklyar et al PLB650,172

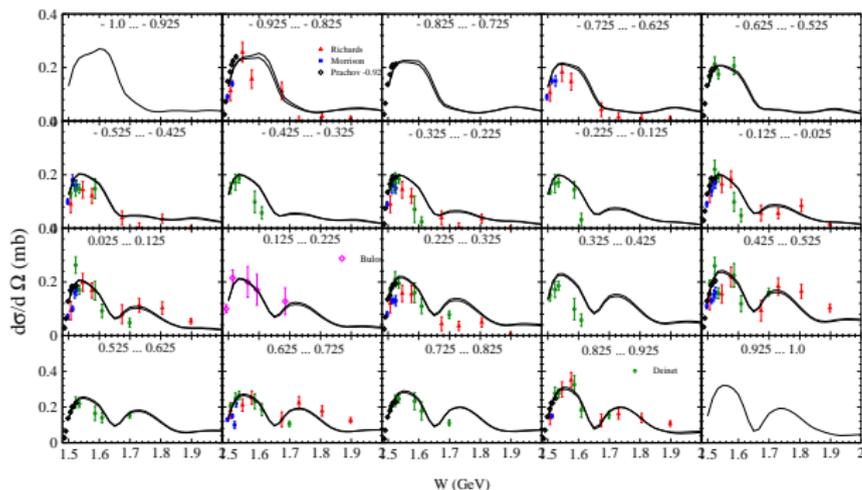
- $S_{11}(1535)$ and $S_{11}(1650)$: destructive interference - dip at 1.68 GeV; effect from $P_{11}(1710)$ is small
- ωN threshold effect is 50 above the dip position- not decisive
- no room for narrow state of 15...20 MeV width

η -photoproduction multipoles Shklyar et al PRC87 (2013)



	$\text{Re } z_0(\text{GeV})$	$-2\text{Im } z_0(\text{MeV})$	$ R (\text{MeV})$	θ^0
$S_{11}(1535)$	1.49	100	15	-51
	1.49-1.53	90-250	30...70	-1...-30
$S_{11}(1650)$	1.65	89	19	-46
	1.64-1.67	100-170	20-50	-50...-80
$P_{11}(1440)$	1.386	277	126	-60
	1.35-1.38	160-220	40-52	-75...-100
$P_{11}(1710)$	1.67	159	11	9
	1.67-1.77	80-380	2-15	-160...+190
$P_{13}(1720)$	1.67	118	12	-45
	1.66-1.69	150-400	7-23	-90...-160
$D_{13}(1520)$	1.492	94	27	-35
	1.505-1.515	105-120	32-38	-5...-15
$D_{13}(1875)$	1.81	98	3	-76
	1.8-1.95	150-250	2-10	20...180
$D_{15}(1675)$	1.64	108	20	-49
	1.655-1.665	125-150	22-32	-21...40
$D_{15}(1680)$	1.66	98	33	-32
	1.665-1.68	110-135	35-45	0...-30

Results for the $\pi^- p \rightarrow \eta p$ production



$\pi^- p \rightarrow \eta n$: updated Giessen coupled-channel analysis

- overlap of $S_{11}(1535)$ and $S_{11}(1650)$ states - destructive interference - dip at 1.68 GeV
- contribution from $P_{11}(1710)$ - second peak
- interference between S_{11} and P_{11} partial waves - second peak at mostly forward angles (**prediction from Giessen Model**).

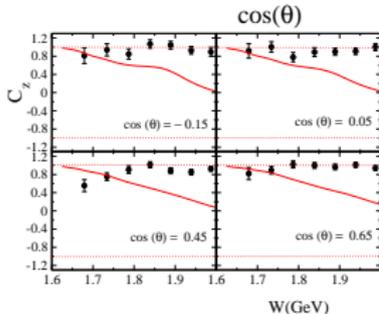
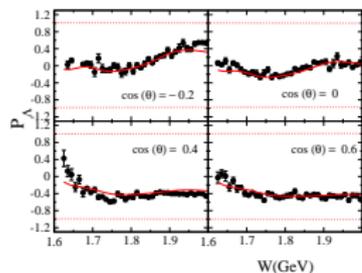
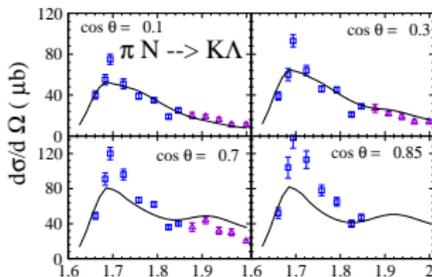
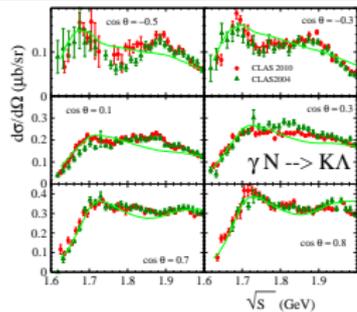
New results on $(\pi/\gamma)N \rightarrow \eta N$ reaction

- PWA the high statistic MAMI data, resonance parameters (poles parameters), ηN scattering lengths, η -multipoles are extracted
Shklyar et al PRC87 (2013)
- unified picture from Giessen Model **in terms of** $S_{11}(1535)$, $S_{11}(1650)$ **and** $P_{11}(1710)$
- **NO FURTHER PROGRESS without new** $\pi N \rightarrow \eta N$ **measurements**
- support HADES for a new pion beam experiment

$(\gamma/\pi)N \rightarrow K\Lambda$ reactions

- updated analysis of strangeness production
- full experiment (CLAS, CB-ELSA, GRAAL):
 $\frac{d\sigma}{d\Omega}$, C_z , C_x , P , Σ , T , O_z , O_x
reaction is overdetermined
- combined analysis of $\gamma p \rightarrow K\Lambda$ and $\pi N \rightarrow K\Lambda$ reaction

GiM vs $\gamma/\pi \rightarrow K\Lambda$ reactions



- Gi Model $S_{11}(1535)$, $P_{13}(1720)$, $P_{13}(1900)$
- good description of exp. data except C_z ; EBAC -similar behavior
- missing N^* contributions?
- consistency between $\gamma N \rightarrow K\Lambda$ and $\pi N \rightarrow K\Lambda$ data ?

Double spin asymmetries. Explanation

Electromagnetic coupling of N^* :

Electromagnetic component:
(multipoles) E and M

\leftrightarrow

Helicity amplitudes $A_{\frac{1}{2}}^P$ and $A_{\frac{3}{2}}^P$

- spin- $\frac{1}{2}^-$ resonance $S_{11}(1650)^{****}$:
electric coupling: no spin flip $\rightarrow C_z=1$
- spin- $\frac{1}{2}^+$ resonance $P_{11}(1710)^{**}$:
magnetic coupling: spin flip $\rightarrow 1 < C_z < -1$
- spin- $\frac{3}{2}^+$ resonance $P_{13}(1900)^{**}$:
electric and magnetic coupling: both spin flip and non-flip
combination of $A_{\frac{1}{2}}^P$ and $A_{\frac{3}{2}}^P$ is crucial
 $A_{\frac{1}{2}}^P + A_{\frac{3}{2}}^P$ spin rotation is possible $\rightarrow 1 < C_z < -1$

$\pi N \rightarrow 2\pi N$ reactions

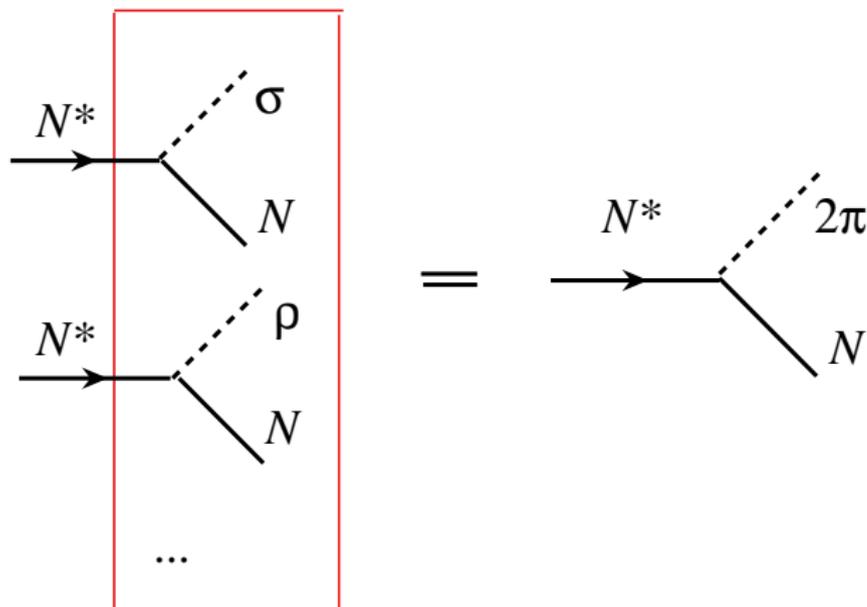
investigate cascade reactions e.g. $N^* \rightarrow \pi N^* \rightarrow \pi\pi N$ etc. :
multiparticle production

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

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

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

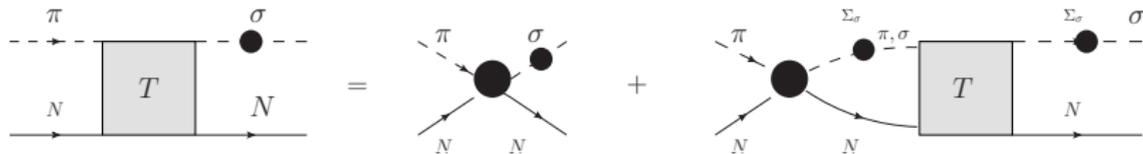
- take $2\pi N$ inelastic flux into account
- $N^* \rightarrow 2\pi N$ couplings constrained by $\sigma_{\pi N \rightarrow 2\pi N}^{JJ}$



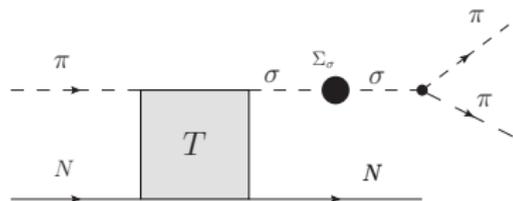
$\pi N \rightarrow 2\pi$ channel in the first resonance energy region

BSE in the isobar approximation:

system of coupled-channel integral equations



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



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

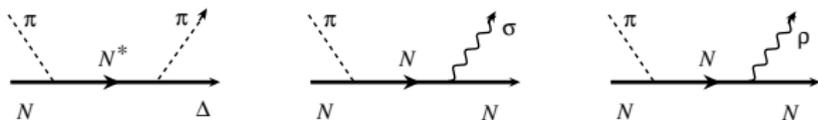
Next step: improve description of the $2\pi N$ channel

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

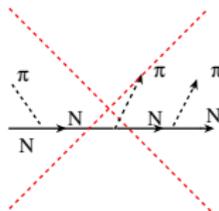


Assumptions

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



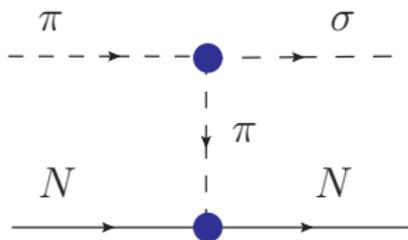
- two-step diagrams are neglected



Roper resonance $N(1400)$ 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, $Br(\Delta\pi) = 21\%$ $Br(\sigma N) = 17\%$
- Jülich 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 $\pi N \rightarrow 2\pi^0 N$ -reaction: no direct evidence for a strong σN subchannel

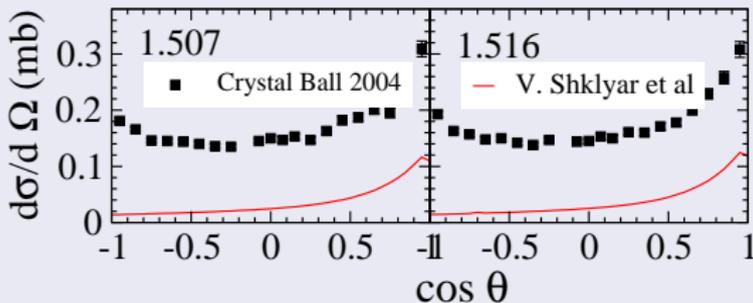
t-channel pion exchange: σN how large?



- coupling constants are well fixed
- $g_{\pi NN} = 13$, $g_{\sigma\pi\pi} = 3.25$ correspond to $m_{\sigma}^0 = 600\text{MeV}$, $\Gamma_{\sigma\pi\pi} = 600\text{MeV}$
- contribution from the t-channel diagram is well fixed

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

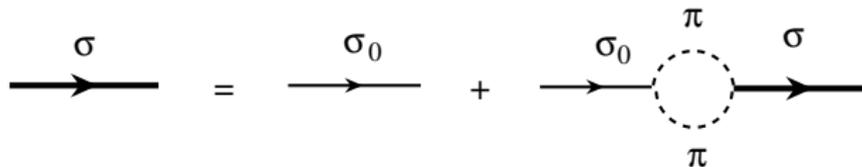
t-channel pion exchange: very small !



σ -meson dynamics

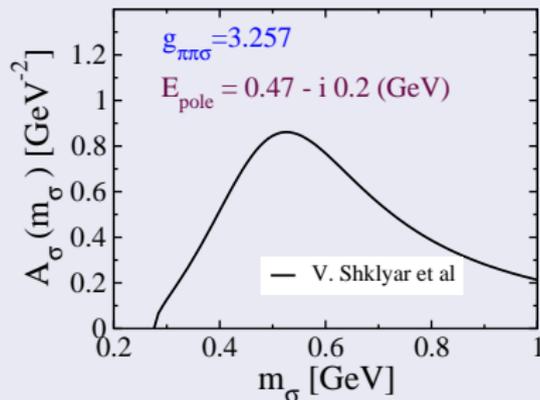
propagator of the σ -meson

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

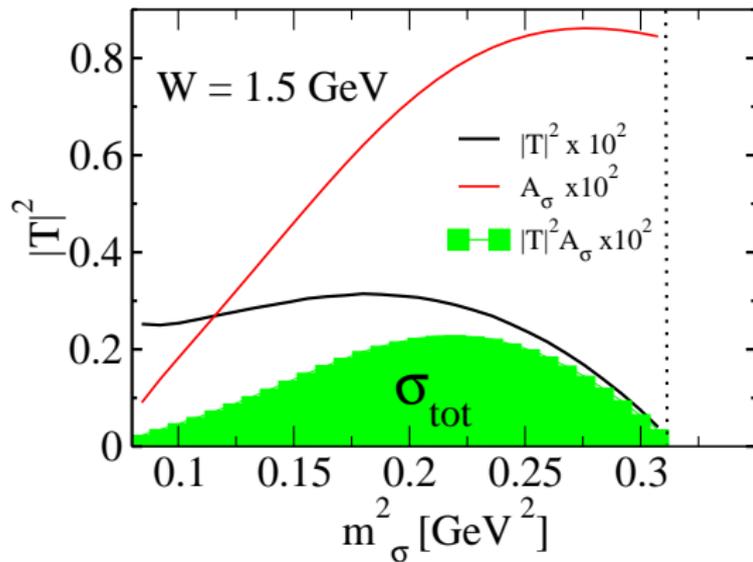


$$A_\sigma(s) = \frac{1}{\pi} \frac{\Sigma_\sigma(s)}{(s - m_\sigma^2)^2 + \Sigma_\sigma^2(s)}$$

spectral function A_σ

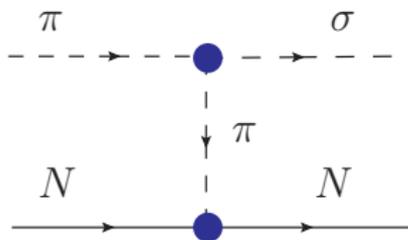


Effect from the σ -spectral function



$$\sigma_{\text{tot}} = \int_{4m_\pi^2}^{(W-m_N)^2} dm_\sigma^2 |T(m_\sigma^2)|^2 A_\sigma(m_\sigma^2)$$

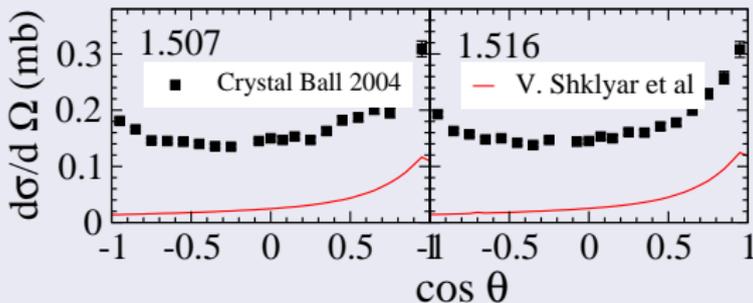
t-channel pion exchange: σN how large?



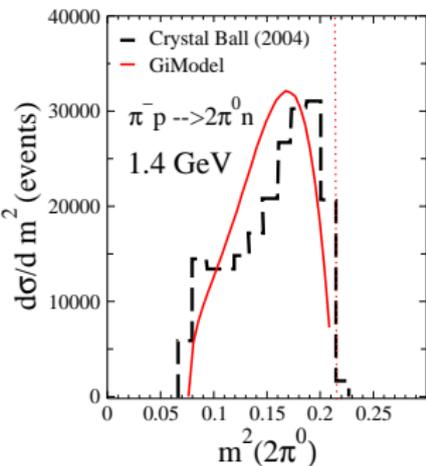
- coupling constants are well fixed
- $g_{\pi NN} = 13$, $g_{\sigma\pi\pi} = 2$ correspond to $m_{\sigma}^0 = 600\text{MeV}$, $\Gamma_{\sigma\pi\pi} = 600\text{MeV}$
- contribution from the t-channel diagram is well fixed

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

t-channel pion exchange: very small !



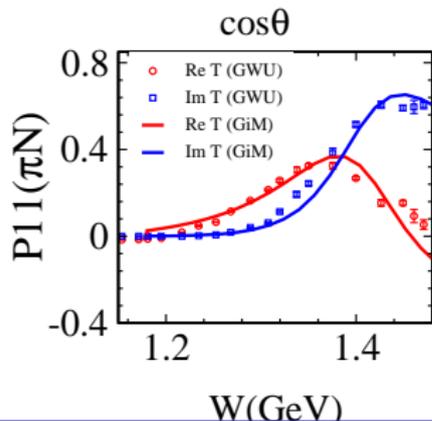
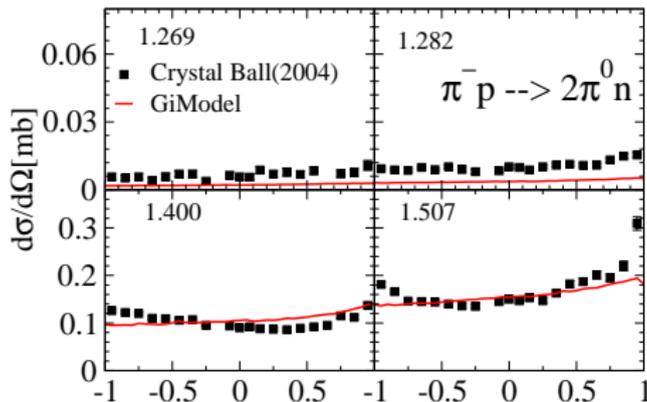
Giessen Model vs. Crystal Ball data



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

$$\text{Im } T_{\pi N}^{11} = \frac{k^2}{4\pi} (\sigma_{\pi N}^{11} + \sigma_{2\pi^0 N}^{11})$$

Roper resonance

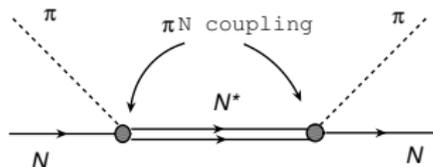


GiModel for $\pi^- p \rightarrow \pi^0 \pi^0 n$ reaction

- model space is extended to include σN , $\pi \Delta$, and ρN channels
- t -channel pion exchange underestimates the $2\pi^0$ 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

Elastic πN scattering: weak $N^* \rightarrow \pi N$ coupling

- resonance contribution to the cross section: $\frac{d\sigma}{d\Omega} \sim g_{\pi NN^*}^4$
- the standard PWA **might be not sensitive** to N^* with small πN coupling
- signal from N^* with small πN coupling **are shadowed** by contributions from N^* with large πN coupling

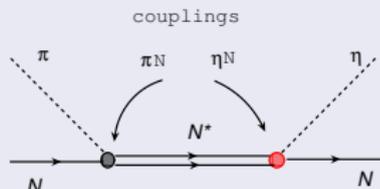


Another possibility: inelastic reactions

inelastic $\pi N \rightarrow \eta N, \omega N, \rho N \dots$ etc scattering

My argument:

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



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

