

THE IMPORTANCE OF DATA ON π N SCATTERING

D V Bugg, Queen Mary, London

A full understanding of the nucleon and its excitations is fundamental physics. γ N experiment have been doing a great job up to a mass of 2 GeV. They have almost completed establishing the lowest 2 orbital and radial excitations. To complete this task needs a total of 15 or more measurements.

However, it will be more difficult to sort out the third excitations and the fourth, to match meson spectroscopy

How can we accommodate observed states as qqq?

- (i) Ground states are $N^{J=1/2}$ and $\Delta^{J=3/2}$.
- (ii) First radial excitations are $P_{11}(1440)$ and $P_{33}(1600)$: 70^-
- (iii) spin $s=3/2 + L=1 \rightarrow S_{11}(1535)+D_{13}(1520)+D_{15}(1675)$: 70^-
- (iv) $s=1/2 + L=1 \rightarrow S_{11}(1650)+D_{13}(1700)$: 70^-
- (v) $s=3/2 + L=1 \rightarrow S_{31}(1620)+D_{33}(1700)+D_{35}(2040)?$: 70^-
- (vi) 2nd radials: $P_{11}(1710)+P_{33}(1900)?$: 56^+
- (vii) 2nd orbitals, $s=1/2+L=2 \rightarrow F_{15}(1680)+P_{13}(1720)$: $56+70^+, L=2$
- (viii) Radial $s=3/2+L=1 \rightarrow S_{31}(1900)+D_{33}(1940)+D_{35}(1930)?$
- (ix) Radial $s=1/2+L=1 \rightarrow S_{11}(\text{missing})+D_{13}(1875)$

Total of 13 states; no sign of 20^- in the first excitations or 20^+ in the second excitations.

For $L=3$, there are 23 states, ignoring 20^- ; these include $G_{17}(2190)$, $G_{19}(2250)$, $G_{37}(2200)$, $G_{19}(2400)$, $F_{35}(2000)??$ and $F_{37}(2390)$.

There is room for only one $F_{15}(1860)$ or $F_{15}(2030)$ and two D_{15} states.

This looks TOUGH

For $L=4$, there are 33 states expected!!

However, this depends on all states coupling to γN !!

My suggestion is that πN experiments on both elastic and inelastic scattering would help greatly, as found by Hohler and Cutkosky. It is already clear that above masses of $D_{15}(1675)$ and $F_{15}(1680)$, inelastic channels are strong. Then

i) $\text{Im } f(0)$ is given by the optical theorem from σ_{tot} ,

ii) $\text{Re } f(0)$ is given by a dispersion relation:

$$\text{Re } f(0,s) = \frac{1}{\pi} \text{P} \int \frac{\text{Im } f(0,s') ds'}{s' - s} + C$$

iii Even and odd angular momenta are separated by forwards and backward asymmetries.

Kamano (Osaka) suggests mounting an experiment at JPARC on πN elastic and inelastic scattering. What is needed is a detector with almost 4π acceptance, plus a frozen spin target a few cm long: $\sigma_{\text{tot}} \sim 30$ mb, giving a 2 metre mean free path; also a neutron detector covering a large range of angles; it needs to be calibrated with good absolute normalisation using proton-neutron charge exchange reactions (as done at TRIUMF).

A pion beam up to 4.5 GeV (3 GeV mass, hence 3rd excitations) could be made easily at many labs around the world, so the detector is the key element. Could detectors from Babar, Belle, CLEO or KLOE be used for a quick set of measurements (event rates are huge)? Crystals for γ detection are the main cost.

I made a Monte Carlo study summarised in 0709.1256.

π^+p	$\rightarrow \pi^+\pi^0p$	2C	(1)
	$\rightarrow \pi^+\eta p$	2C	(2)
	$\rightarrow \pi^+\omega p$	2C	(3)
	$\rightarrow \pi^+\pi^0\pi^0p$	2C	(4)
	$\rightarrow \Sigma^+K^+$	3C	(5)
π^-p	$\rightarrow \pi^-\pi^0p$	2C	(6)
	$\rightarrow \eta n$	3C	(7)
	$\rightarrow \omega n$	3C	(8)
	$\rightarrow \eta' n$	3C	(9)
	$\rightarrow \pi^-\eta p$	2C	(10)
	$\rightarrow \pi^-\omega p$	2C	(11)
	$\rightarrow \pi^0\pi^0\pi^0n$	3C	(12)
	$\rightarrow \Lambda K^0$	2C	(13)
	$\rightarrow \Sigma^0 K^0$	2C	(14)
	$\rightarrow \Sigma^- K^+$	2C	(15)
π^+p	$\rightarrow \pi^+\pi^+n$	2C	(16)
π^-p	$\rightarrow \pi^+\pi^+\pi^0n$	2C	(17)
	$\rightarrow \pi^-\pi^+n$	2C	(18)
	$\rightarrow \pi^-\pi^+\pi^0n$	2C	(19)

Integrated cross sections >1 mb may be separated with cross-talk ~ 0.5 – 2%. And for 3C fits with $\sigma > 10 \mu\text{b}$. These levels are less than cross-talk or 2nd scattering of exit particles. 10^6 events in <4 hours with a beam intensity 500/s. 80 steps of 30MeV/c from 500-3000 MeV/c take a few months of beam time, e.g. a year realistically. Manley has already fitted ηN data.

Nucleons have spin $\frac{1}{2}$, so polarisation data are essential. Data on N and S spin orientations can be taken together in a cylindrical detector.

$P_N d\sigma/d\Omega \propto \text{Im } f^*g$ and $P_S \propto \text{Re } f^*g$; g = spin flip amplitude.

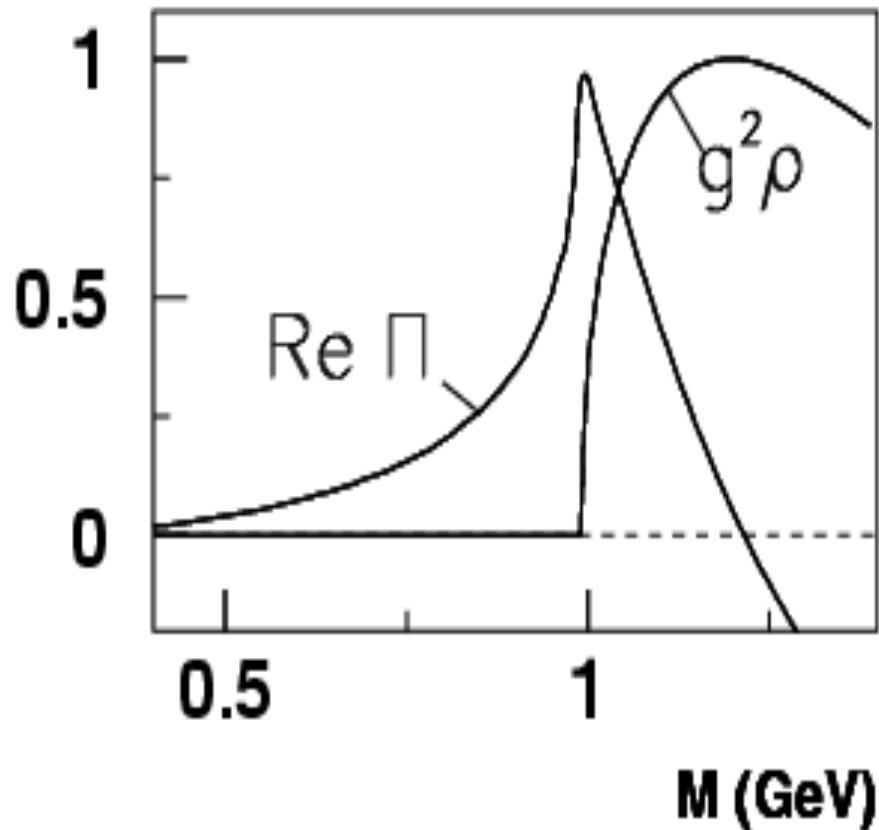
Longitudinal polarisation is less useful because it depends only on the difference of intensities for the two orientations.

A neutron detector at a distance ~ 2.5 m is needed over angles as close as possible to $0-90^\circ$; (or 2 detectors, one for $0-45$ and the second for 45 to 90°).

Cusps

At the opening of a threshold, e.g. ωN , $\text{Im } f$ rises from threshold. To satisfy analyticity,

$$\text{Re } f = \frac{1}{\pi} \text{P} \int \frac{\text{Im } f(s') ds'}{s' - s}$$



A form factor $FF = \exp(-\alpha k^2)$ is used here with $R = 0.8$ fm. Svarc and collaborators have formulated a clever scheme to derive this form factor from the data: 1211.5303, 1202.1295 and 1302.3491.

Cusps are not restricted to sharp thresholds. They arise for any threshold, but the effects are smaller for broad thresholds like ρ , σ , $f_2(1270)$, $a_2(1320)$, etc; these need to be evaluated folding in their line-shapes ('Woolly cusps'). They attract resonances to thresholds. I suspect this happens at the ρN threshold and contributes to $S_{11}(1650)$. Remember too, that the amplitude needs to be continued analytically below threshold. The $P_{11}(1440)$ is obviously affected by the σN threshold, where there is a strong rise in the real part of the amplitude related to the imaginary part by a dispersion relation.

SUMMARY: My opinion is that it is realistic and important to complete spectroscopy of N and Δ states up to the third radial excitation at least. Where the experiments are done is a matter of politics and money. K-N is also obviously of interest.

ADVERT: Galaxies are naturally explained as condensates in the graviton-nucleon interaction. This eliminates Dark Matter and makes strong predictions for Dark Energy.

See 1304.7483, now published by the Canadian Journal of Physics as 91 (8), 668-675 (2013).