Is It Still Possible That the Θ^+ Pentaquark Exists?

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Outline

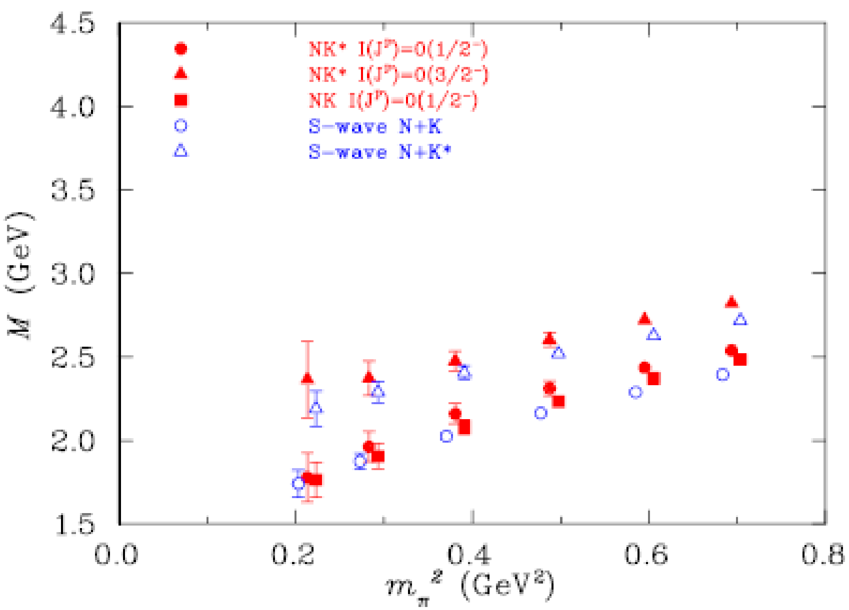
- I will not review +/- experiments…
- Theory: is it still possible?
- Experiment: is it reproducible?
- What can be done at J-PARC.

Lattice Calculations

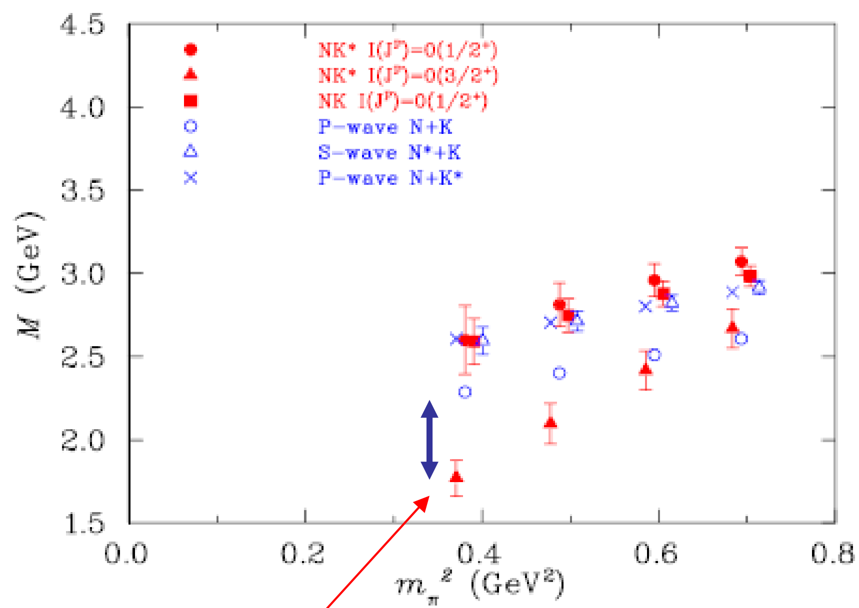
- Many lattice calculations were done for the spin-parity $½^{+}$ and $½^{-}$.
  - Virtually all agree: no pentaquark signal.
- Two lattice calculations done for J=3/2.
  - Most advanced is Lasscock, hep-lat/0504015.
  - Lattice signature: binding increases for lower pion mass—seen for all known baryons.
  - Study was redone with higher lattice statistics.

Lattice Results

Negative parity



Positive parity



Scattering states and NK states have the same mass dependence.

3/2+ shows characteristic signature of resonance behaviour.

Large N_c Limit

- Investigations at large N_c show whether such a state could exist in pQCD.
  - In the real world, $N_c = 3$, so $1/N_c$ expansion is not always reliable.
- In this limit, a bound heavy quark "pentaquark-like" state exists.
  - Ref: Cohen, Hohler, Lebed (hep-ph/0508199).
  - Is the s-quark heavy enough? Is N_c=3 "big"?

Large N_c Results

Binding energies of heavy “pentaquarks” at large N_c.

Potentials: A (V_0=-60 MeV, r_0=1 fm), B (quadratic potential), C (V_0=-276 MeV, r_0=1 fm).

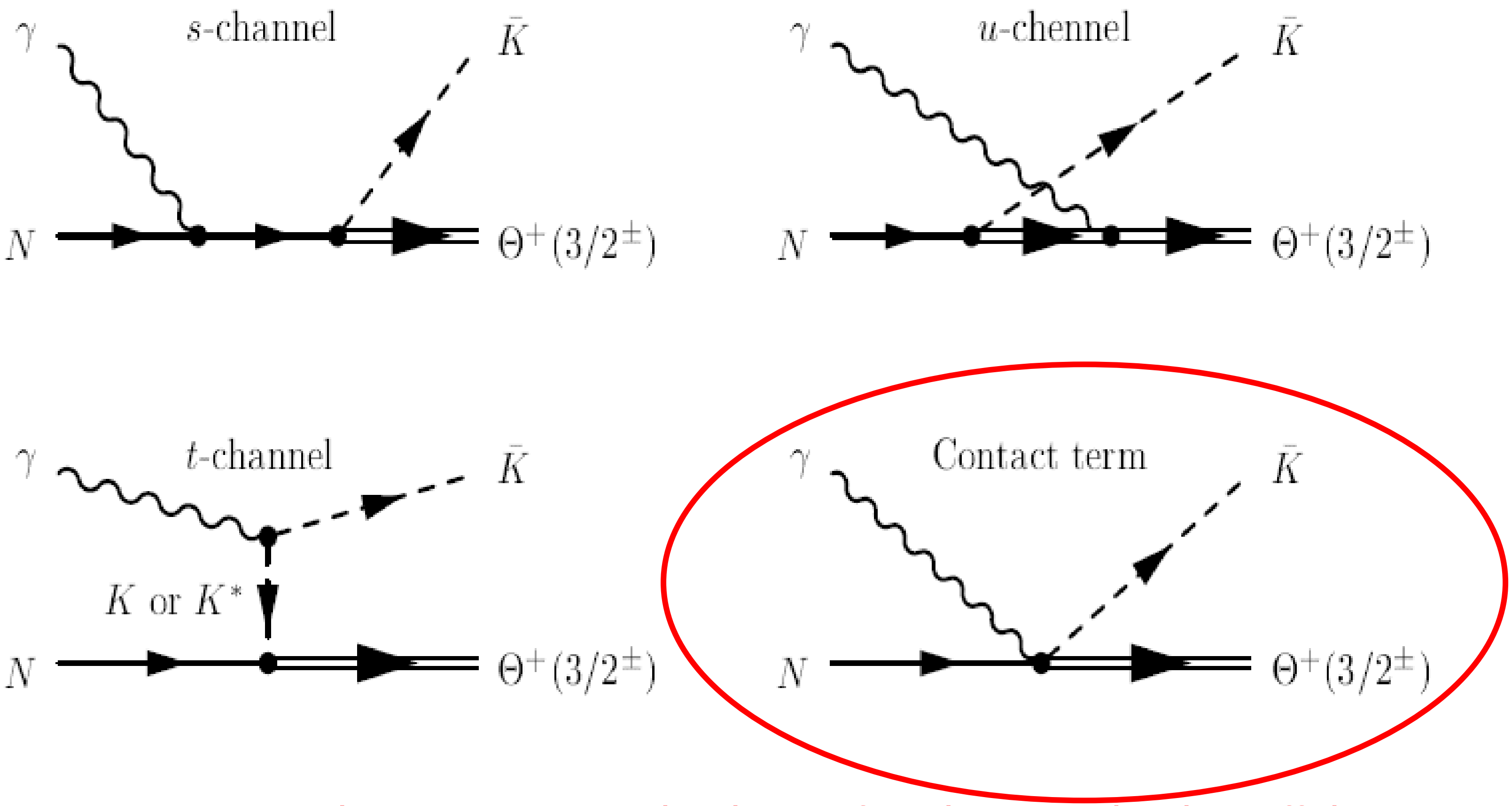
Channel J	S	P	I	A +	A −	B +	B −	C +	C −
$\frac{1}{2}$	$\frac{1}{2}$	−	0	1.30	1.35	3.89	1.92, 3.62	139.38, 142.14	–
			1	–	–	0.35	0.27	–	139.38, 140.76
$\frac{1}{2}$	$\frac{1}{2}$	+	0	–	–	–	–	14.9, 32.39	4, 19.32, 46.5
			1	–	–	–	–	12.72, 18.22, 26.91	9.45
$\frac{1}{2}$	$\frac{3}{2}$	−	0	1.30	1.31	3.89	3.67	140.76	140.76
			1	–	–	–	0.26	140.76	140.76
$\frac{1}{2}$	$\frac{3}{2}$	+	0	–	–	–	–	32.15	3.35, 45.95
			1	–	–	–	–	12.12, 27.19	8.36, 22.08
$\frac{3}{2}$	$\frac{1}{2}$	−	0	1.42	1.31	3.89	3.67	140.76	140.76
			1	–	–	–	0.26	140.76	140.76
$\frac{3}{2}$	$\frac{1}{2}$	+	0	–	–	–	–	15.32, 18.49, 32.43	4.65
			1	–	–	–	–	12.80	17.25, 17.66, 22.91
$\frac{3}{2}$	$\frac{3}{2}$	−	0	1.42	1.25	3.89	3.67	140.76	140.76
			1	–	–	–	0.20	140.76	140.76
$\frac{3}{2}$	$\frac{3}{2}$	+	0	–	–	–	–	18.22, 32.29	–
			1	–	–	–	–	4.18, 23.18	–

Relative sign of g_A and g_H.

I=0, $J^P=3/2^+$

Effective Lagrangian Model

Nam, Hosaka, Kim, hep-ph/0505134.



The contact term is absent for photoproduction off the proton.

Effective Models: Results

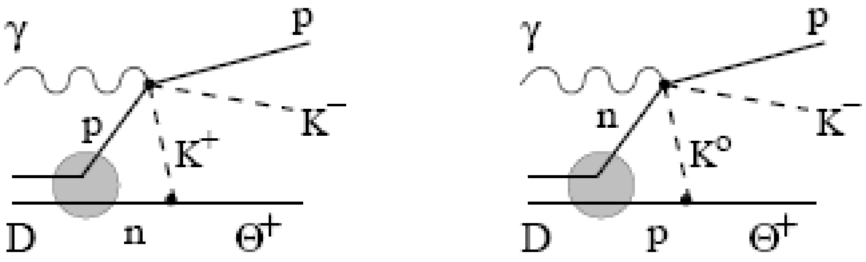
The contact term is responsible for large differences between the proton and neutron targets. For J=3/2, the cross section is at small angles.

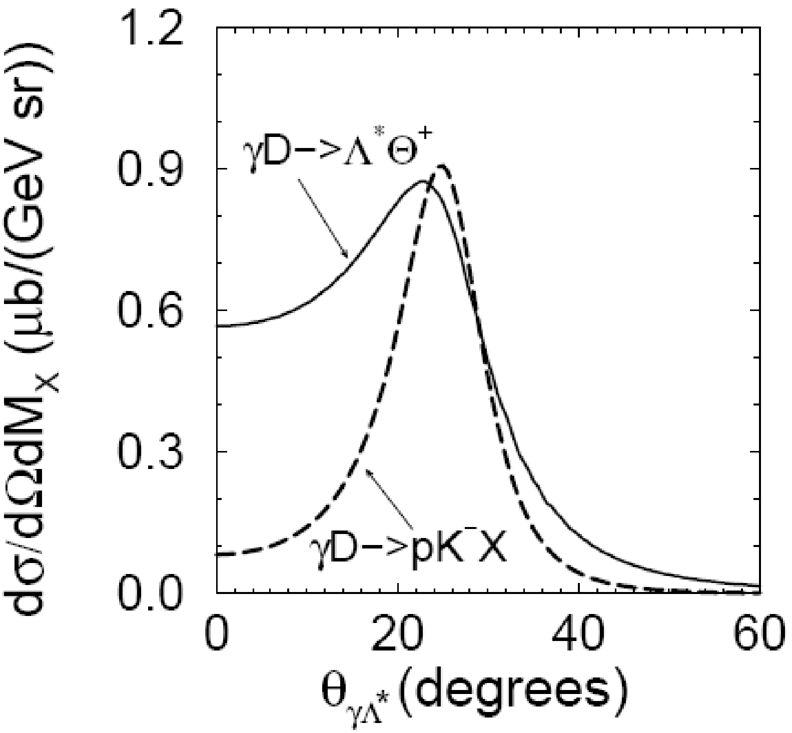
J^P	$3/2^+$		$3/2^-$		$1/2^+$	
$g_{KN\Theta}$	0.53		4.22		1.0	
$g_{K^*N\Theta}$	± 0.91		± 2		± 1.73	
Target	n	p	n	p	n	p
σ	~ 25 nb	~ 1 nb	~ 200 nb	~ 4 nb	~ 1 nb	~ 1 nb
$\frac{d\sigma}{d\cos\theta}$	Forward	$\sim 60^\circ$	Forward	$-$	$\sim 45^\circ$	$\sim 45^\circ$

Conclusion: the CLAS null result for the proton target is consistent with this calculation and hence does not rule out the existence of the Θ^+.

Soft Formation Model

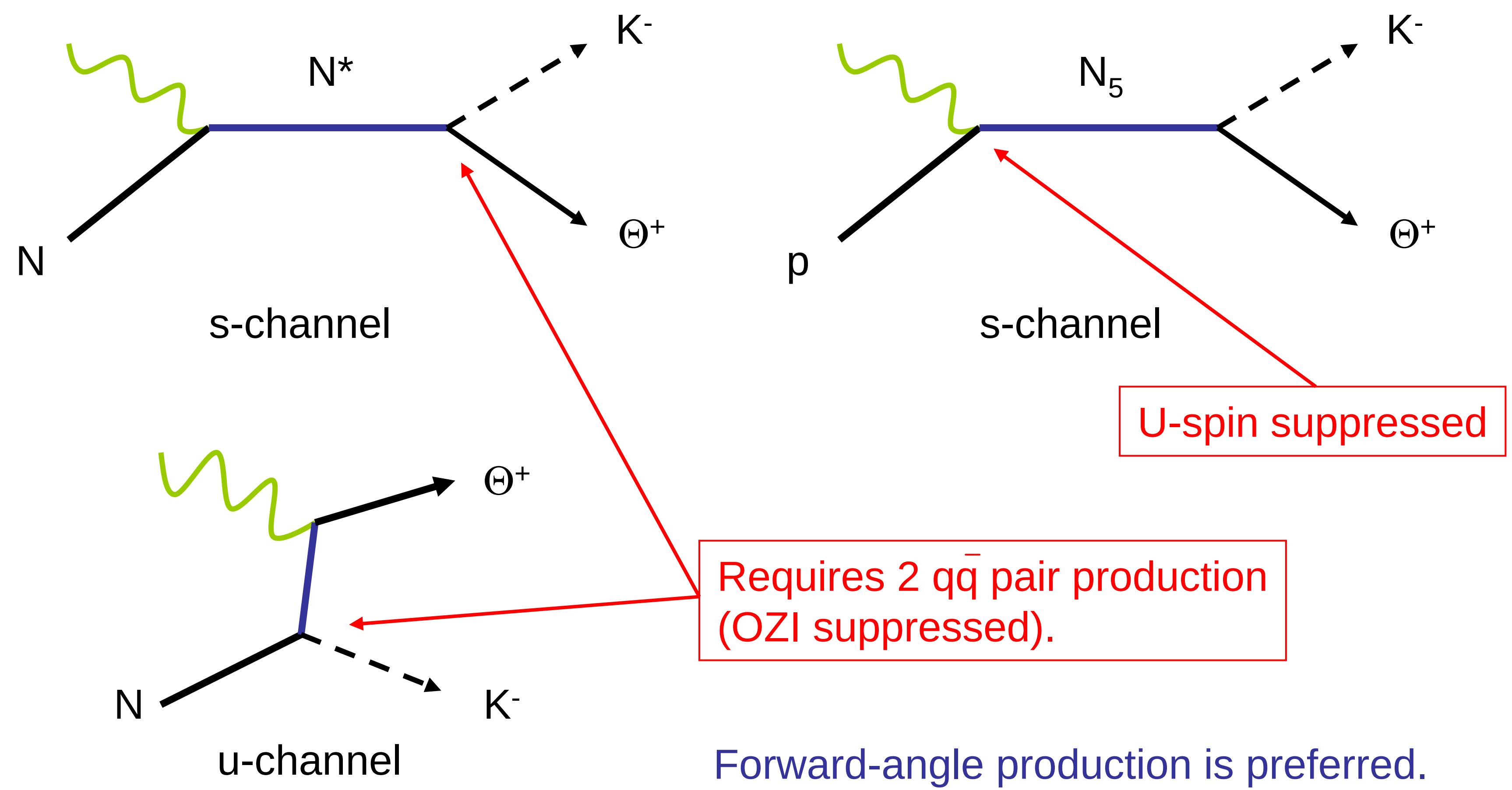
Titov, Kampfer, Date, Ohashi
nucl-th/0607054.





In this model, with an almost-on-shell Kaon, the cross section is very forward peaked.

Suppressed Kinematics



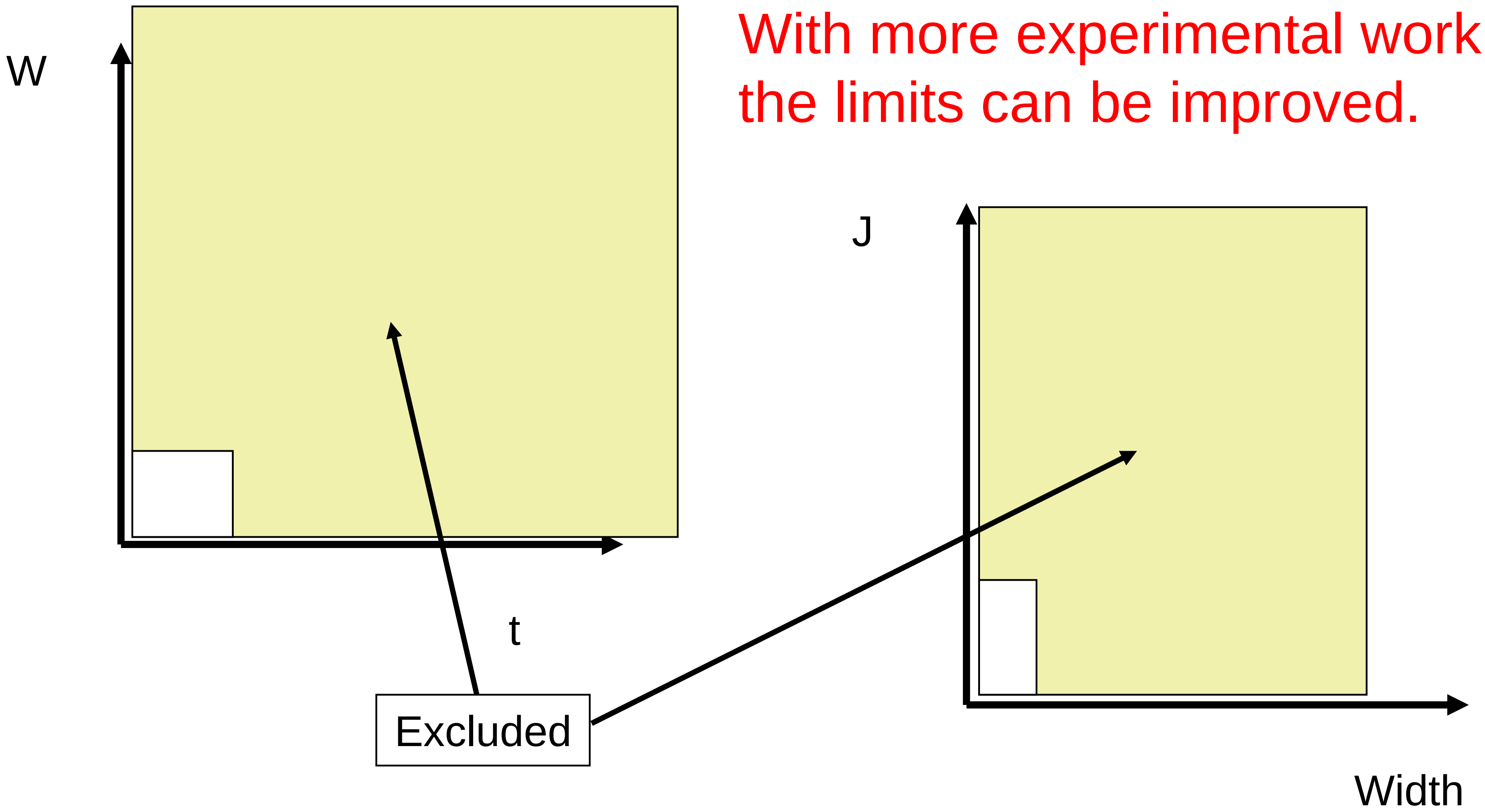
Forward-angle production is preferred.

Experimental Situation

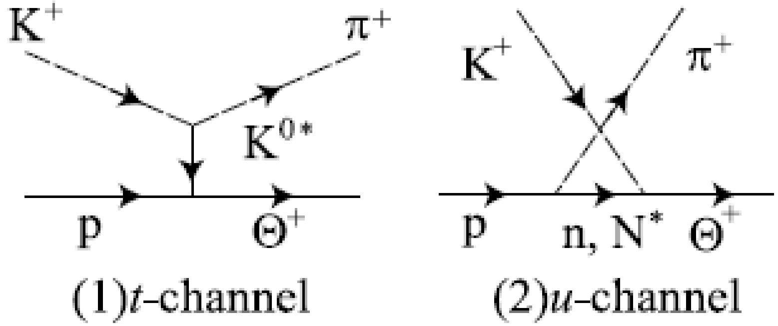
- There are many null results.
  - No Θ^+ from e^+e^- or high energy collisions.
  - 3 positive cases repeated, all null results.
- Only 2-3 results still appear viable:
  - LEPS $\gamma d \rightarrow K^+ K^- X$ (forward angle).
  - CLAS $\gamma p \rightarrow \pi^+ K^- K^+ n$ (π^+ goes forward).
  - DIANA bubble chamber data (reproduced?)

Exclusion Regions for Θ+

The Θ^+ is "painted into a corner". With more experimental work, the limits can be improved.

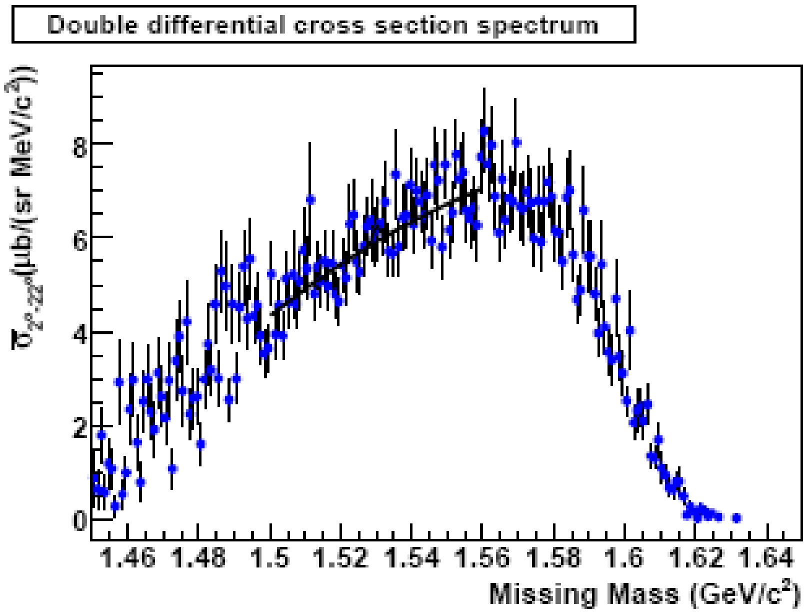


KEK experiment



Miwa et al., The E559 Collaboration arXiv:0712.3839.

Backward angles not detected in this experiment.



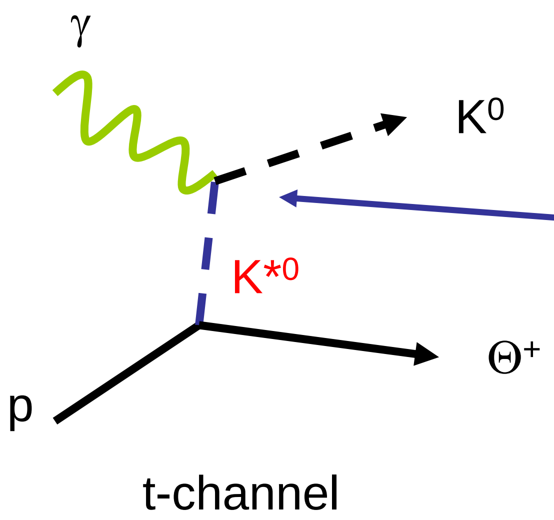
Lack of signal means either:

1) Θ^+ does not exist
2) K* coupling is very small.

Upper limit is 3.5 μb/sr (2^o-22^o), much small than theory estimate.

CLAS proton experiment

The s- and u-channel diagrams are suppressed, and no contact diagram.



For a neutral particle, this must be a M1 (spin-flip) operator.

The exchange particle must be a K^{*0}.

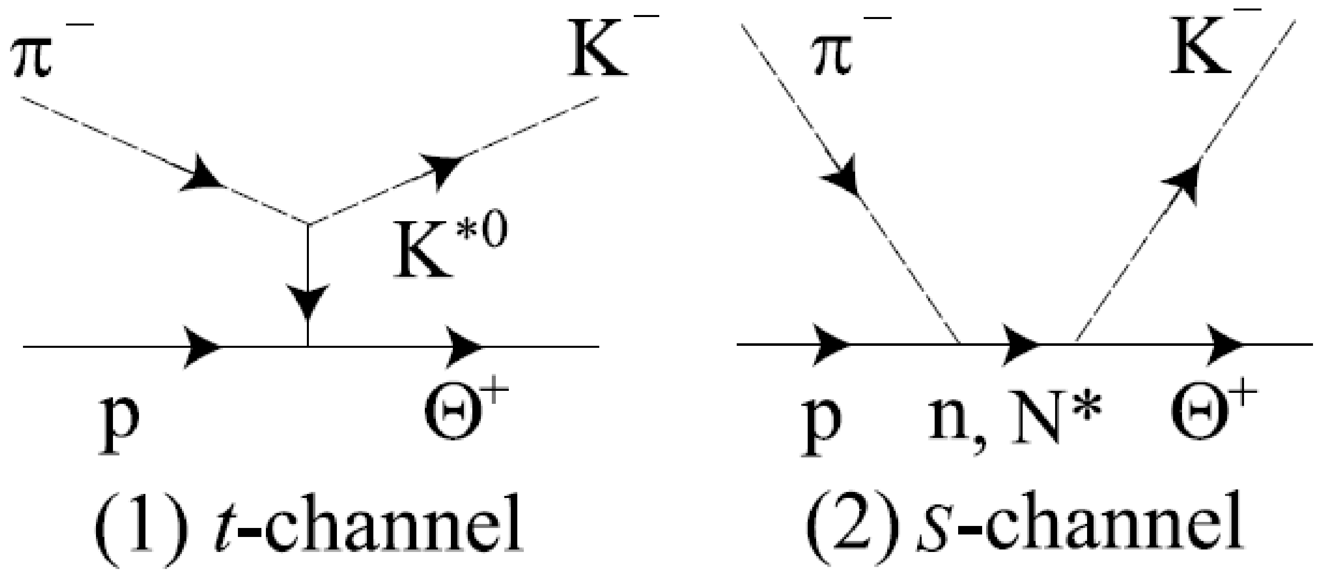
If the coupling vertex $N\Theta^+K^*$ is small, then this could explain why the (first) CLAS proton experiment gives a null result.

The second CLAS proton experiment ($\gamma p \rightarrow \pi^+ K^- \Theta^+$) is still allowed.

If the Θ^+ exists:

- Then you must believe that it:
  - Has soft form factor (near on-shell formation)
  - Has a small decay branch from high-mass N*
  - Has a small width (small overlap of w.f.)
  - Is only produced at forward angles
  - Has a small coupling to K* meson
- This is a long list of requirements.
  - Caveat Emptor!

J-PARC proposal



If the K* coupling is small, then the s-channel process should dominate. Here, the intermediate state must be a N_5 (non-strange pentaquark) to avoid OZI suppression.

Summary

- Theory suggests that it is still possible that a Θ^+ pentaquark exists with $J^P=3/2^+$.
  - If so, then production only at forward angles.
- Experiments suggest that only a small kinematic window is available to the Θ^+.
  - The LEPS experiment is in this window.
  - A "formation" experiment is still needed.
- J-PARC will be able to either confirm the Θ^+ or close the door on its existence.