Experimental status of Θ^+ and new result from LEPS

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Outline

- Introduction: What is the Θ^+?
- Why is it interesting?
- What do we know about it?
- How is it seen at LEPS?
- What is the possible nature of the Θ^+?
- What is the next step?

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What are pentaquarks?

- Baryon.
- Minimum quark content is 5 quarks. $(qqqq\overline{Q})$
- "Exotic" penta-quarks are those where the antiquark has a different flavor than the other 4 quarks
- Quantum numbers cannot be defined by 3 quarks alone.

Θ^+: $uudd\bar{s}$

Baryon number = 1/3 + 1/3 + 1/3 + 1/3 – 1/3 = 1

Strangeness = 0 + 0 + 0 + 0 + 1 = 1

e.g. $uudd\bar{c}$, $uuss\bar{d}$

c.f. $\Lambda(1405)$: $uuds\bar{u}$ or uds

Baryon masses in constituent quark model

$m_u \sim m_d = 300 \sim 350$ MeV, $m_s = m_{u(d)} + 130 \sim 180$ MeV

- Mainly 3 quark baryons:
  $M \sim 3m_q$ + (strangeness)+(symmetry)

- p, K, and h are light:
  Nambu-Goldstone bosons of spontaneously broken chiral symmetry.

- 5-quark baryons, naively:
  $M \sim 5m_q$ + (strangeness) +(symmetry)
  1700~1900 MeV for Θ^+

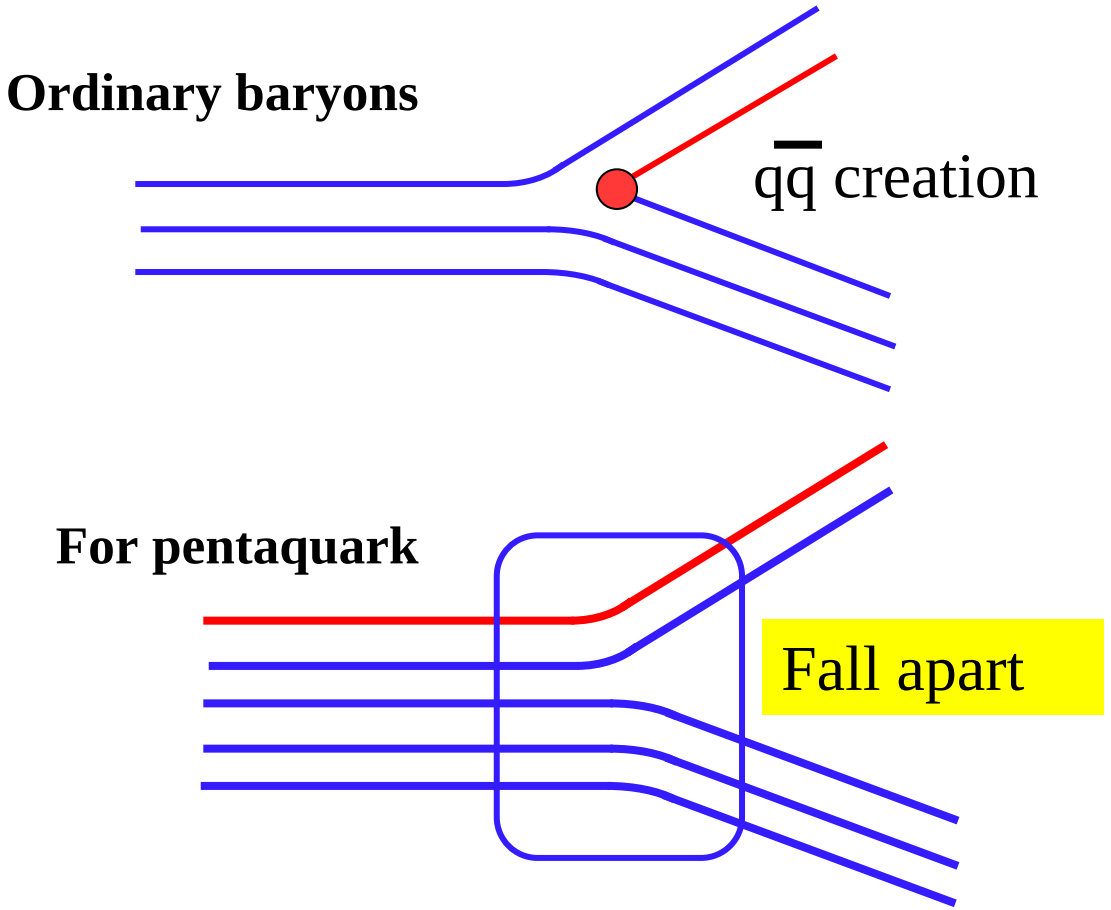
Fall-apart decay problem

- **DPP predicted the Θ^+ with M=1530MeV, Γ<15MeV, and $J^p=1/2^+$.**
- **Naïve QM (and many Lattice calc.) gives M=1700~1900MeV with $J^p=1/2^-$.**
- **But the negative parity state must have very wide width (~1 GeV) due to "fall apart" decay.**

Positive Parity?

- **Positive parity requires P-state excitation.**
- **Expect state to get heavier.**
- **Need counter mechanism.**

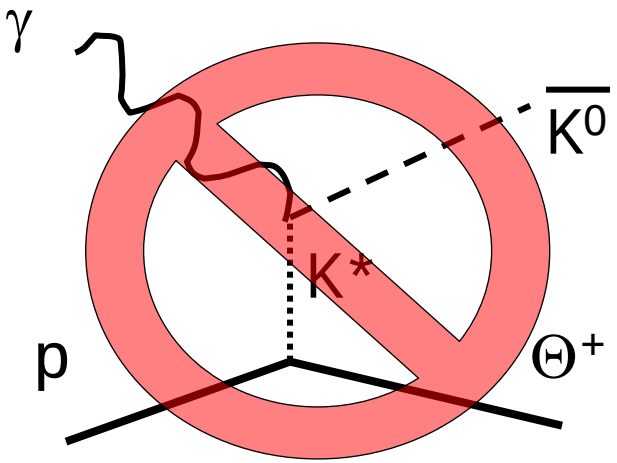
diquark-diquark, diquark-triquark, or strong interaction with "pion" cloud?

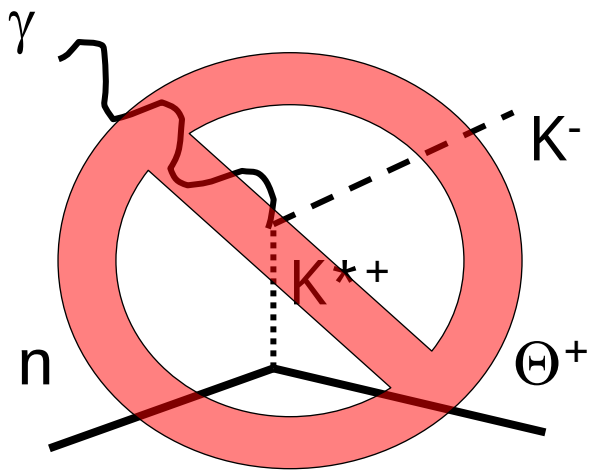


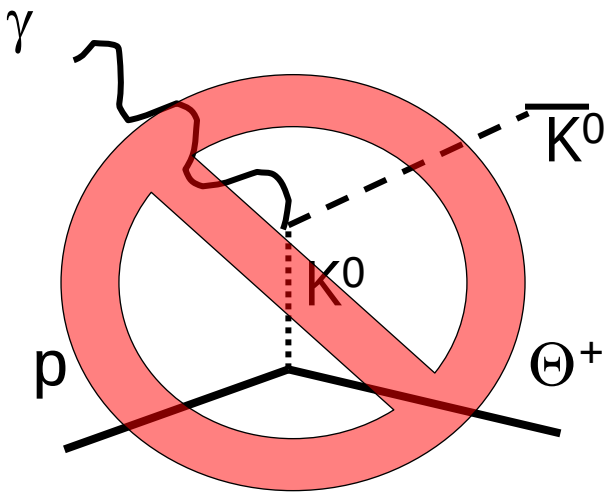
Experimental status

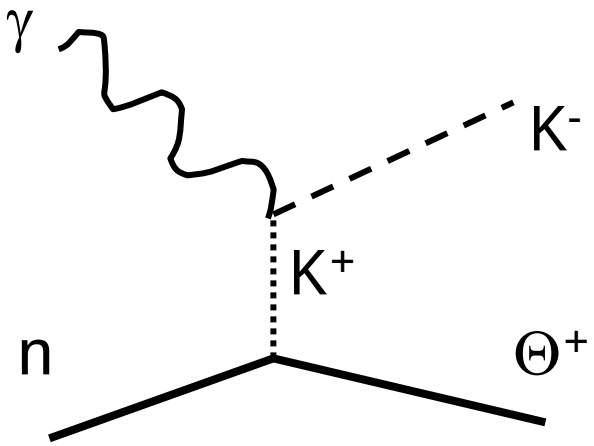
- Not seen in the most of the high energy experiments: The production rate of $\Theta^+/\Lambda(1520)$ is less than 1%.
  - Not likely to an ordinary baryon.
- No published positive result from dedicated experiments CLAS $\gamma p\ \gamma d$, COSY-TOF pp, KEK-PS (π^-,K^-), (K^+,π^+)
- The width must be less than 1 MeV. (DIANA and KEK-B)
- LEPS observed signals in $\gamma\, n \rightarrow K^+K^-n$ and $\gamma d \rightarrow \Lambda(1520)KN$ reactions, which could be inconsistent with CLAS γd experiment (CLAS-g10).

t-channel photo-production of Θ^+

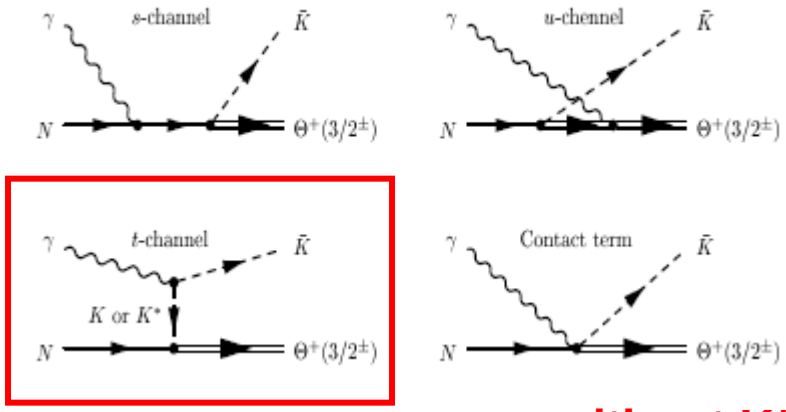








S. Nam et al. hep-ph/05005134



dominant if possible

without K* exchnge

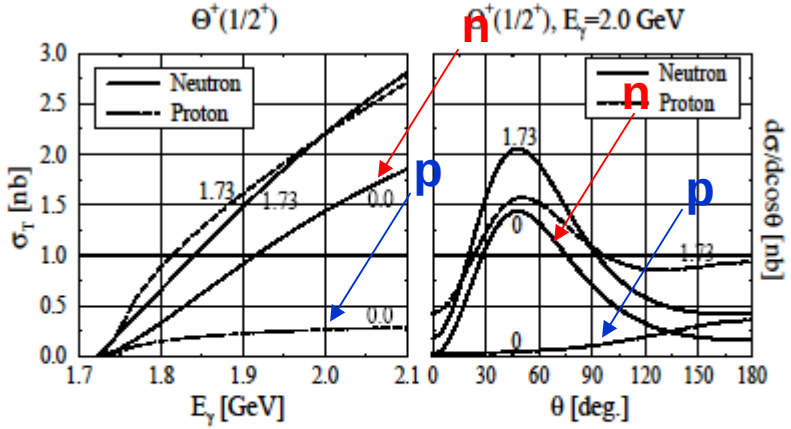


FIG. 4: Total (left) and differential (right) cross sections for $\Theta^+(1/2^+)$. The numbers on the figures denote the values of the coupling constant $g_{K^*N\Theta}$.

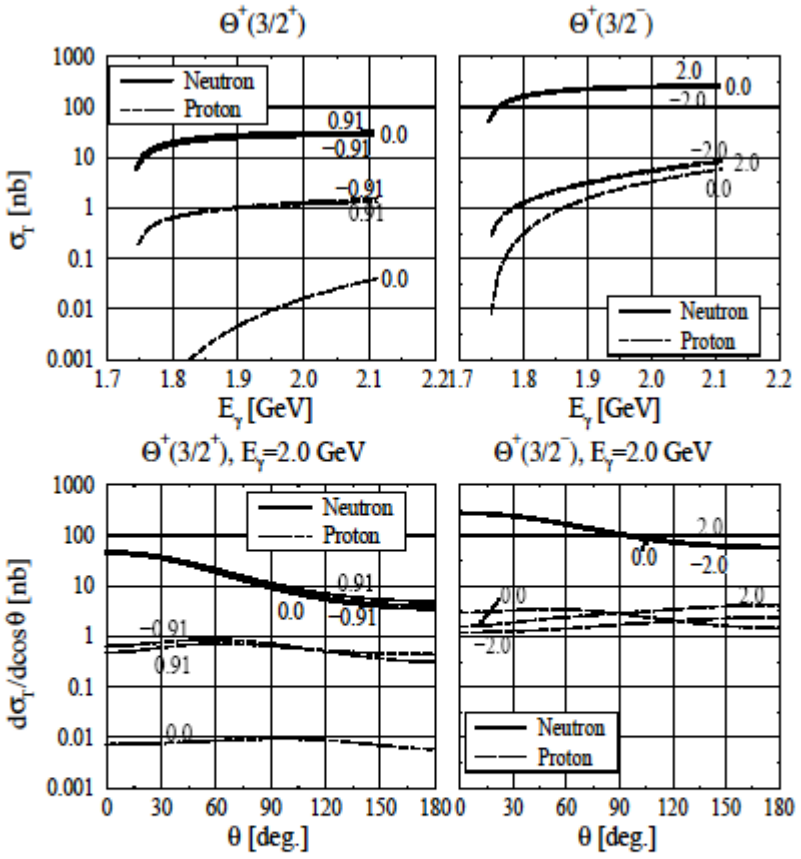
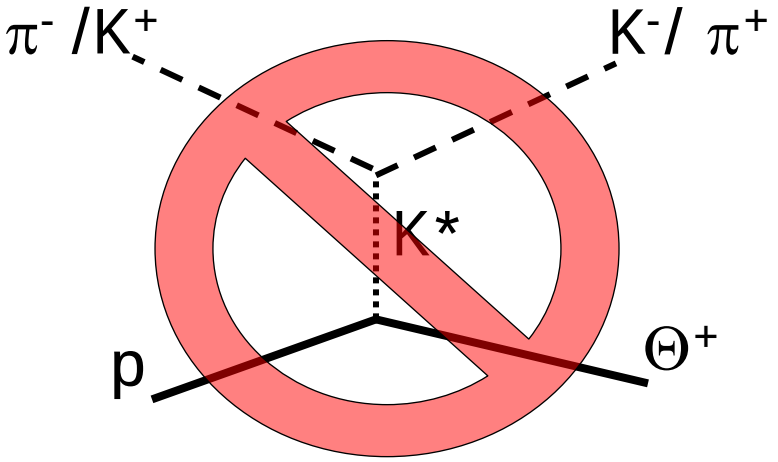
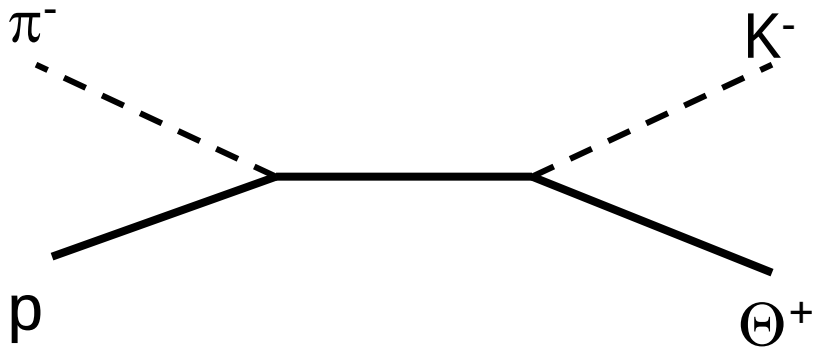
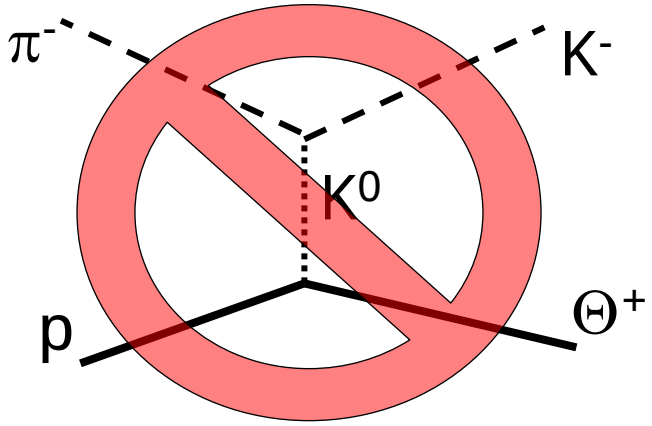


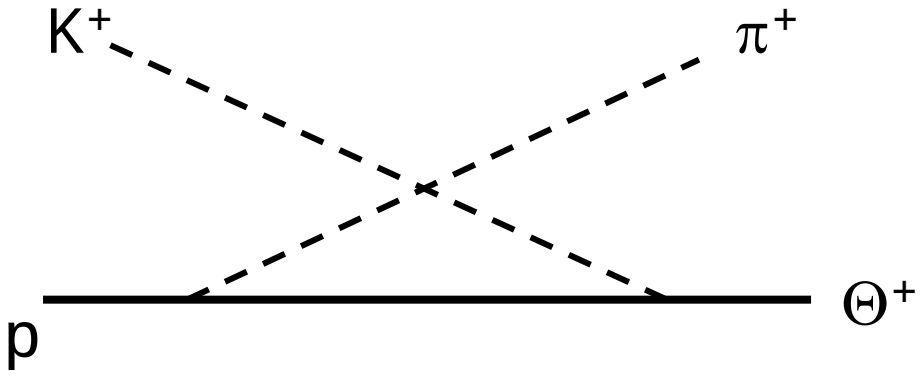
FIG. 3: Upper two panels: Total cross sections for $J^P = 3/2^+$ (left) and for $J^P = 3/2^-$ (right). Lower two panels: Differential cross sections for $J^P = 3/2^+$ (left) and for $J^P = 3/2^-$ (right). The numbers on the figures denote the values of the coupling constant $g_{K^*N\Theta}$.

Θ^+ production in (π^-,K^-) and (K^+,π^+) reactions



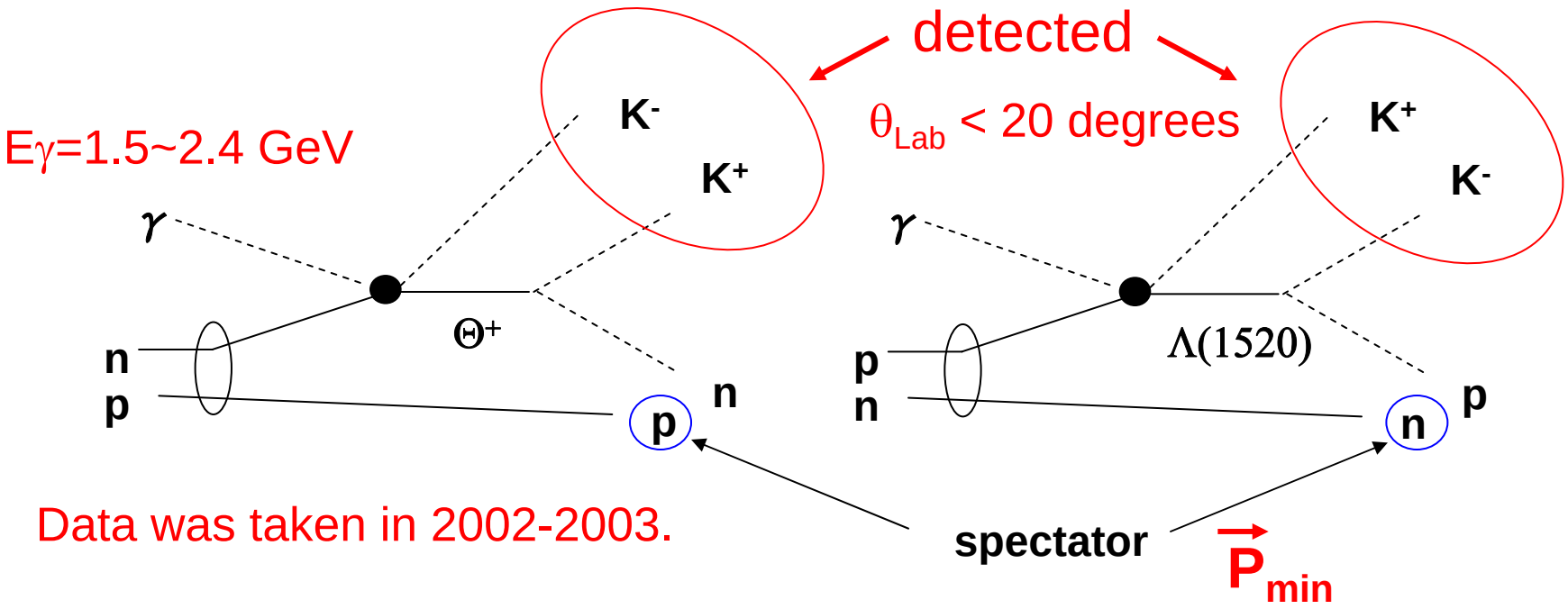






Backward peak

Θ^+ search at LEPS/SPring-8



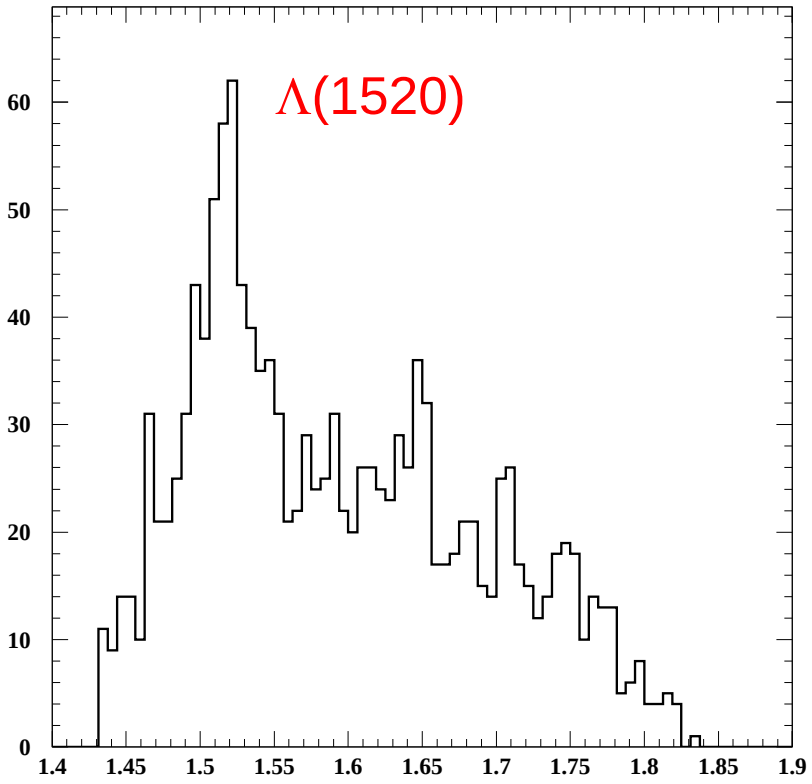
Data was taken in 2002-2003.

- Both reactions are quasi-free processes.
- Fermi-motion effect should be corrected.

Minimum momentum for the spectator nucleon is used to select quasi-free processes and correct Fermi-motion broadening in the nK invariant mass estimation.

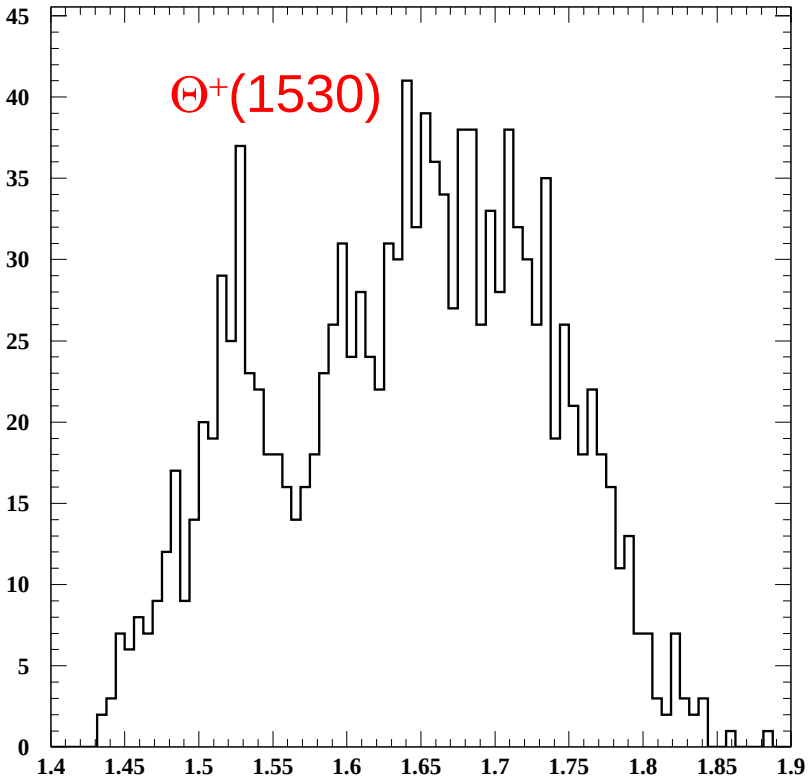
Minimum momentum dependence

$|p_{min}| < 50$ MeV/c



M_{pK^-} (GeV/c^2)

$|p_{min}| < 50$ MeV/c

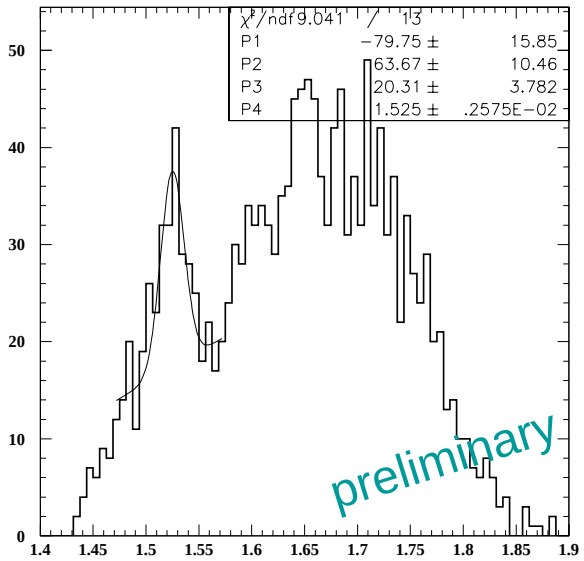


M_{nK^+} (GeV/c^2)

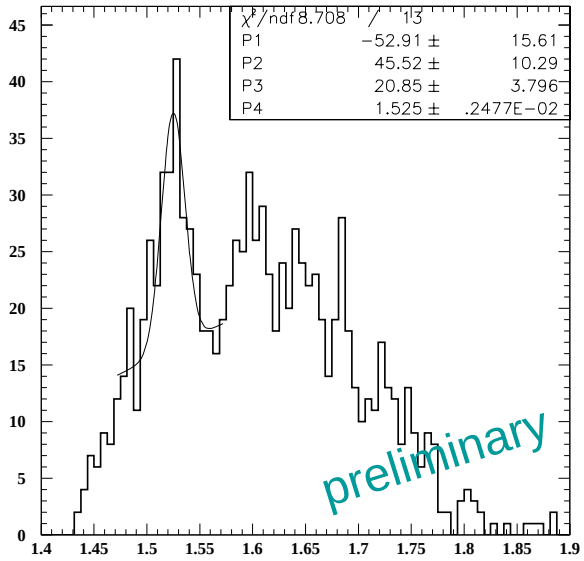
→ Strong indication of the quasi-free processes.

Statistical Significance

$|p_{min}|$<70 MeV/c



MpK⁻ > 1.54 GeV/c²



- Spectrum is fitted with a Gaussian + linear BG function with an estimated mass resolution (11 MeV/c^2).
- Significance is estimated by dividing the Gaussian peak height by its uncertainty. Estimated significance is ~5.

Θ^+ Cross-section

- Flat angle distribution and no energy dependence were assumed.
- Preliminary analysis gave $d\sigma/d\Omega \sim 0.01$ μb/sr, about 10 % of the $\Lambda(1520)$ production cross-section by assuming a constant matrix element. → Flat angular and energy dependence were assumed.
- More than one order of magnitude larger than CLAS-g10 upper limit of σ_{tot}~3 nb (95%CL).

Can be consistent?

The reaction is the same: $\gamma n \rightarrow K^- \Theta^+$

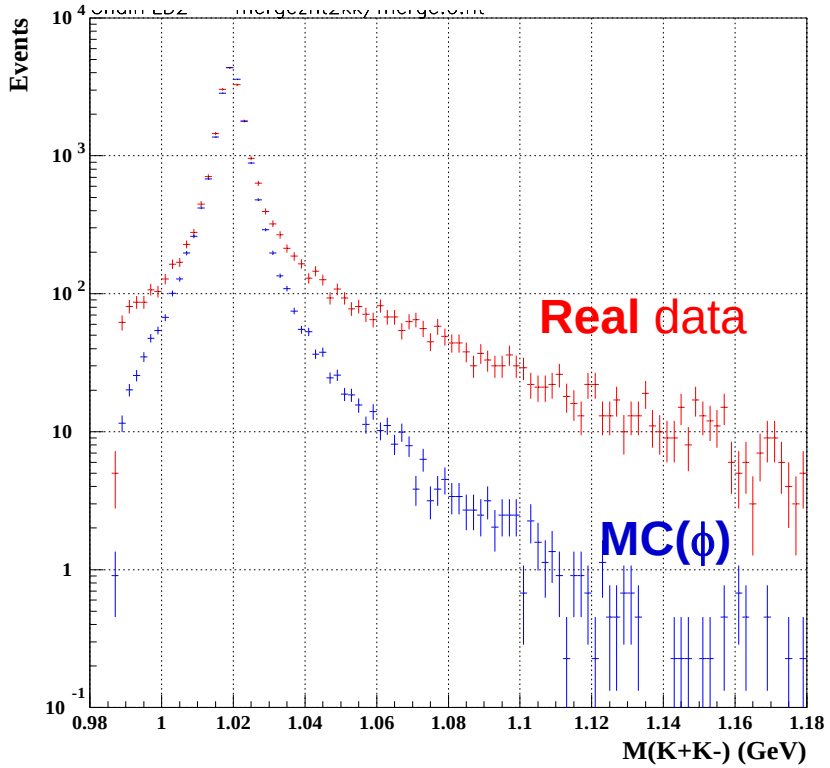
LEPS		CLAS
Good forward angle coverage	⟷	Poor forward angle coverage
Poor wide angle coverage	⟷	Good wide angle coverage
Low energy	⟷	Medium energy
Symmetric acceptance for K^+ and K^-	⟷	Asymmetric acceptance
$M_{KK} \gtrsim 1.04$ GeV/c^2	⟷	$M_{KK} > 1.07$ GeV/c^2
Select quasi-free process	⟷	Require re-scattering or large Fermi momentum of a spectator

LEPS: $\theta_{LAB} < 20$ degree $\quad |t| < 0.6$ GeV^2

CLAS: $\theta_{LAB} > 20$ degree

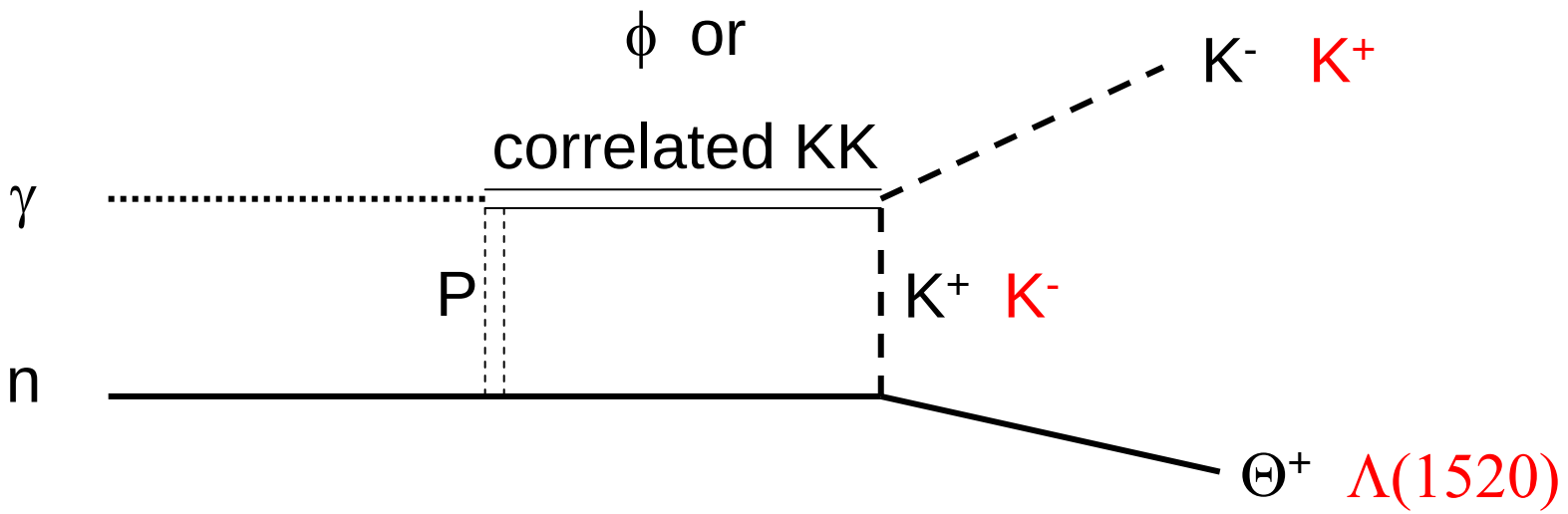
Θ^+ might be a soft object.

KK invariant mass



- LEPS acceptance is larger for events with smaller KK invariant mass.
- Most of the events have KK invariant mass below 1.1 GeV.

Interference?



ϕ is produced in forward angles.

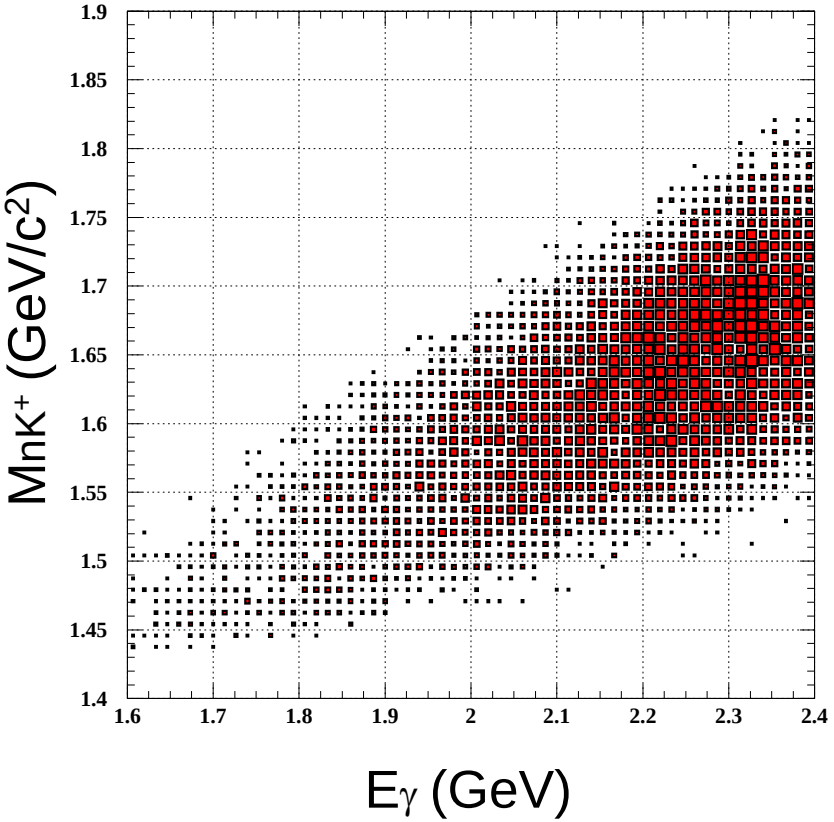
ϕ production cross-section increases with Eγ .

γ couples to KK through VMD much stronger than EM.

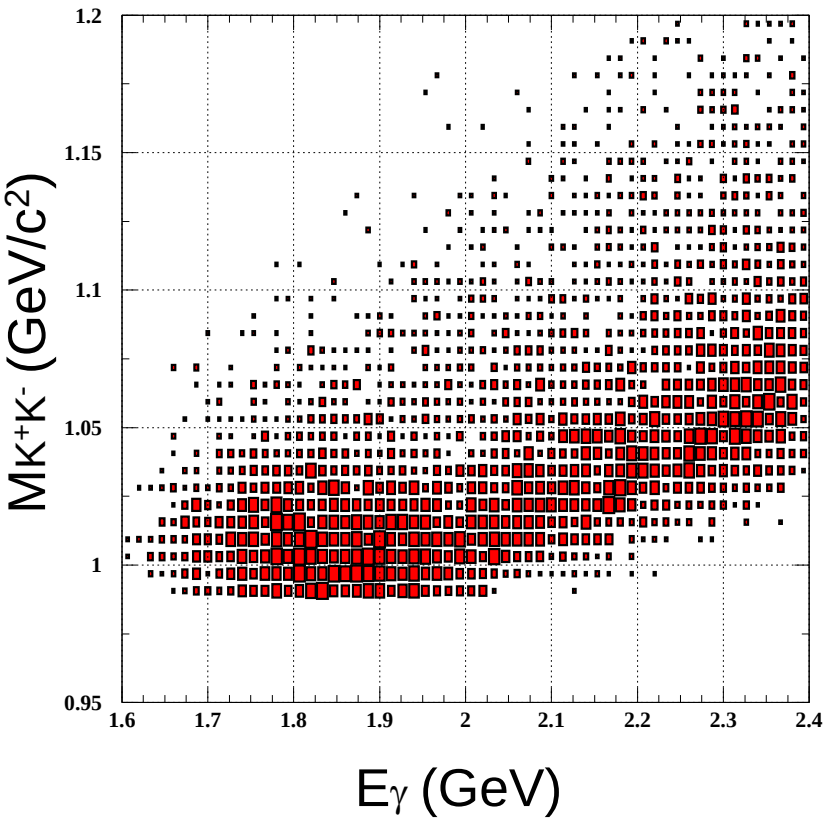
Θ^+ production amplitude is large when ϕ and K^+ close to be real.

Kinematical region covered by LEPS

ϕ events（real data）



$\Theta^+(1530)$ signals (MC data)



Next steps

1.Final result with optimized ϕ exclusion cut will be open soon.

2.New data set with 3 times more statistics has been already taken.

3. Blind analysis will be carried out to check the peak (in this year).

4. A new experiment with a Time Projection Chamber was started. → wider angle coverage and Θ^+ reconstruction in pK_s decay mode.

5. If the peak is confirmed, we will submit a proposal to do a complete search for Θ^+ by using a low energy K^+ beam at J-PARC.

The formation experiment will not be affected by a form factor.

Ultimate answer may be given at J-PARC