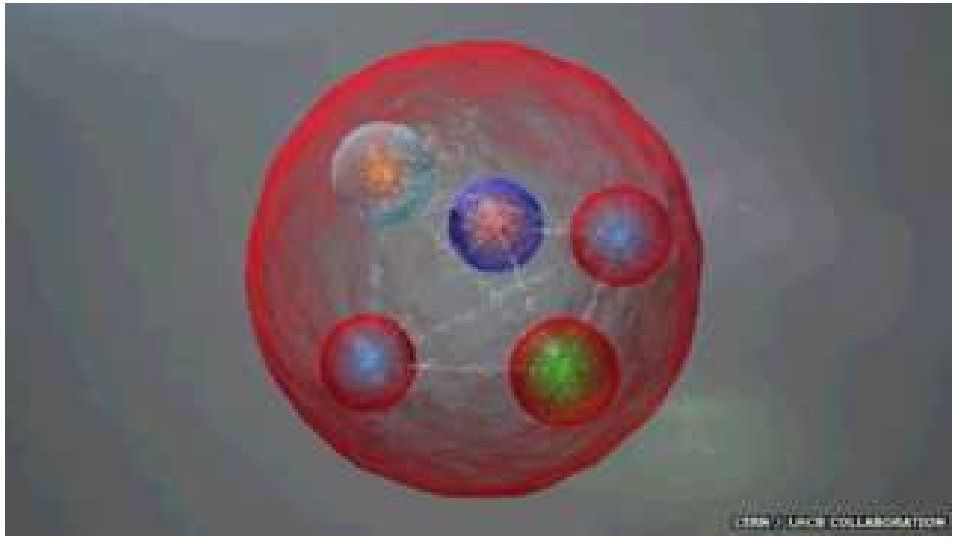
Evidence for the positive-strangeness pentaquark θ^+ in photoproduction with the SAPHIR detector at ELSA

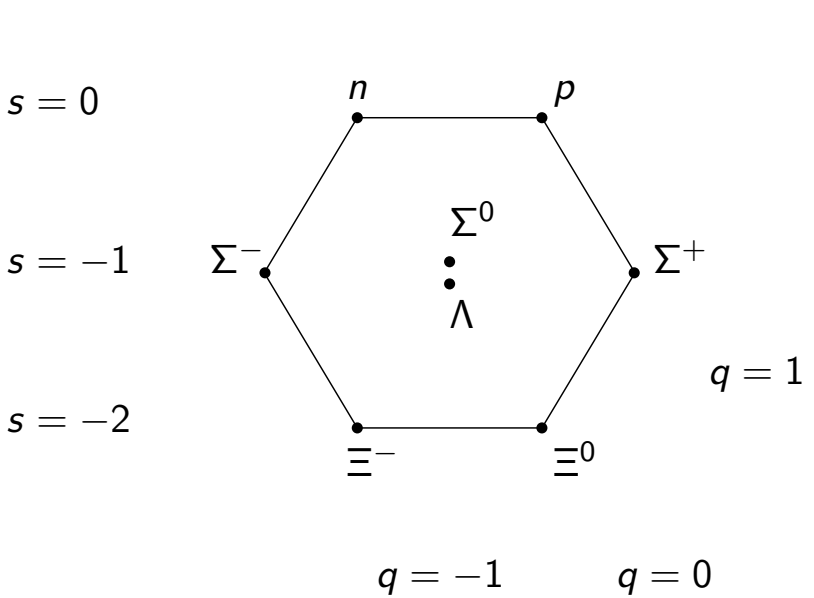


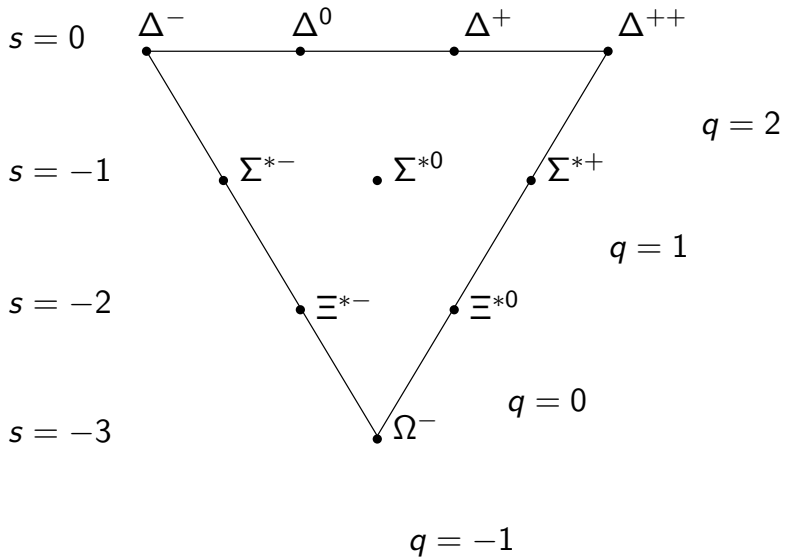
Annika Thiel

HISKP, Universität Bonn

11.06.2015

Baryon Octet and Decuplet

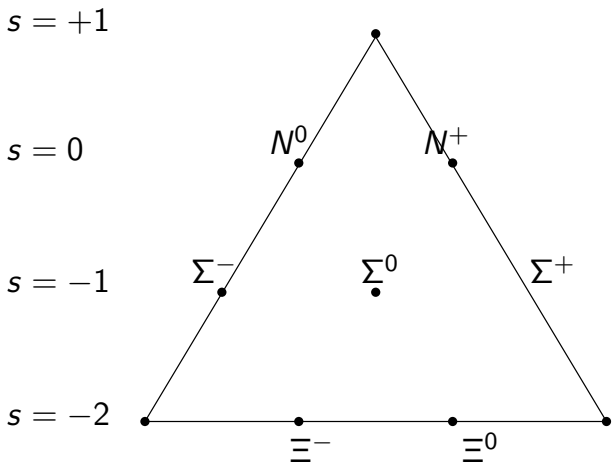




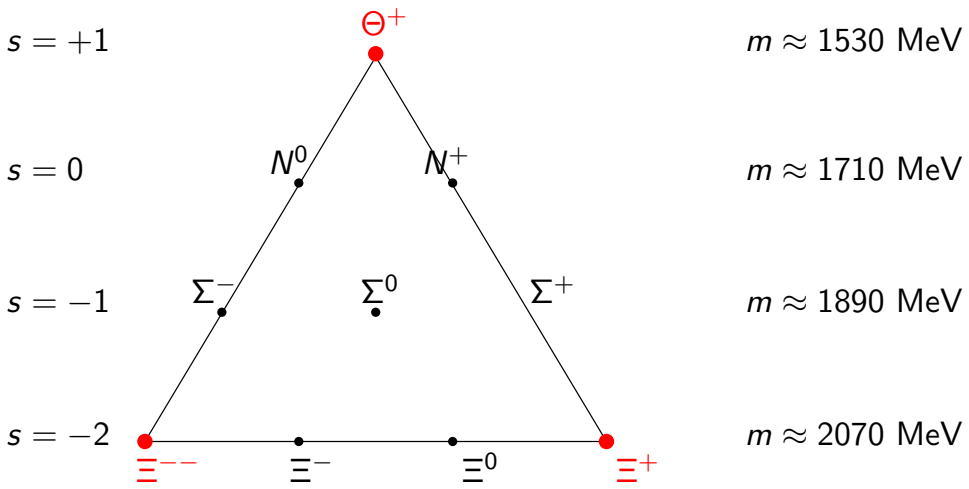
All particles have to be color neutral
$\rightarrow$ qqq or $q\bar{q}$

Are there higher orders? Like $q\bar{q}q\bar{q}$ or $qqqq\bar{q}$?

The Baryon "Anti-Decuplet"



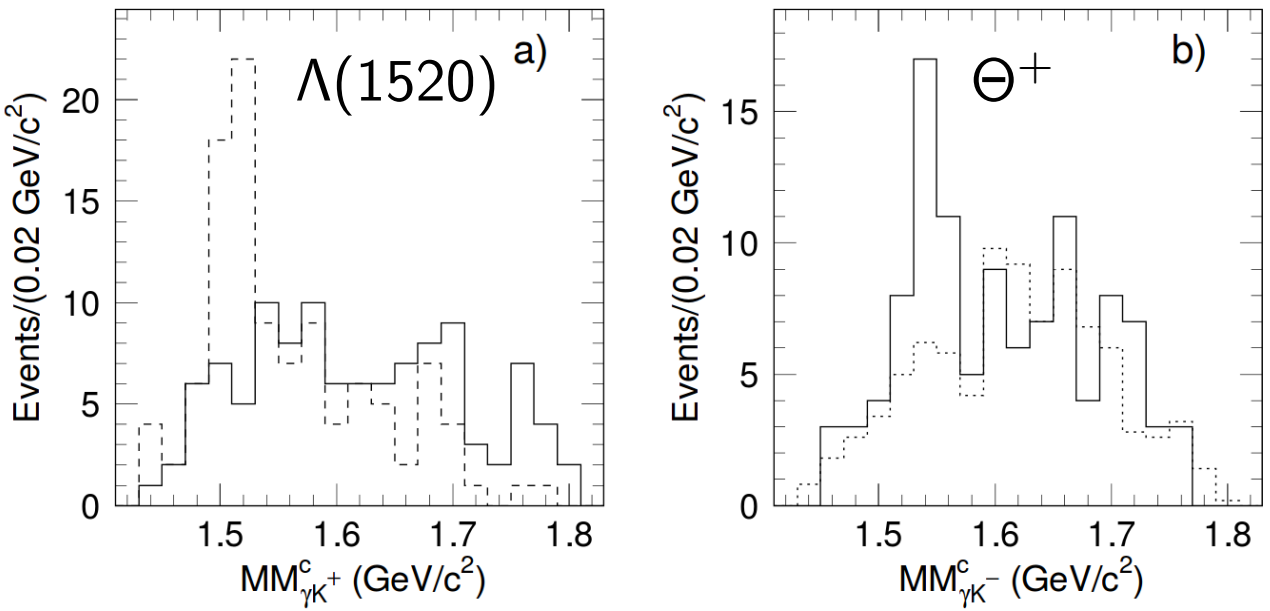
The Baryon "Anti-Decuplet"



- Possible content of the Θ^+: $uudd\bar{s}$
- possible decays:
  $|dduu\bar{s}> \rightarrow |ddu>|u\bar{s}>$ $\quad (\Theta^+ \rightarrow n + K^+)$
  $|dduu\bar{s}> \rightarrow |uud>|d\bar{s}>$ $\quad (\Theta^+ \rightarrow p + K^0)$

First observation: SPring-8 (LEPS)

- $\gamma^{12}C \to K^+K^-X$
- quasi-free neutrons selected by cuts, corrections of Fermi momentum
- mass of (1540 ± 10) MeV
- significance of 4.6σ (36 events in peak)

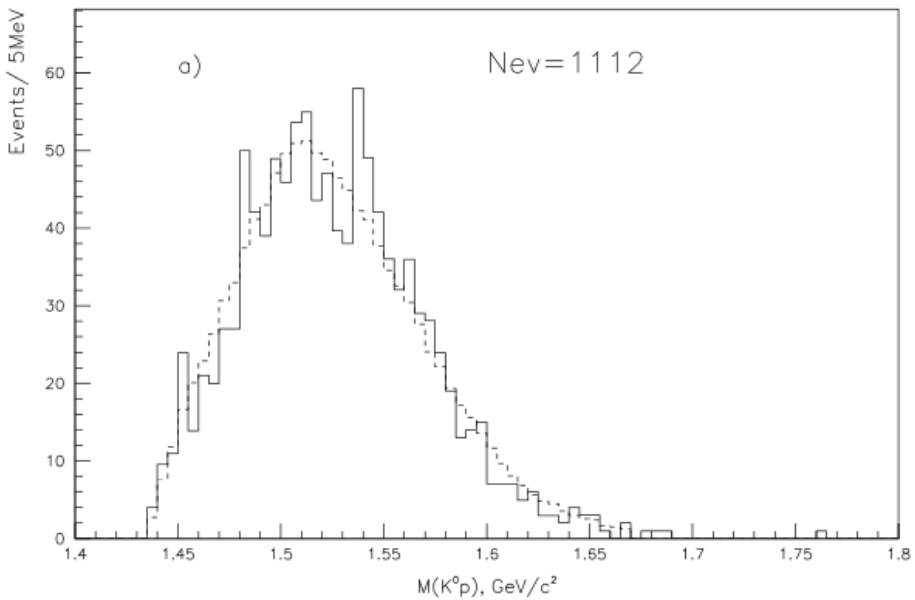


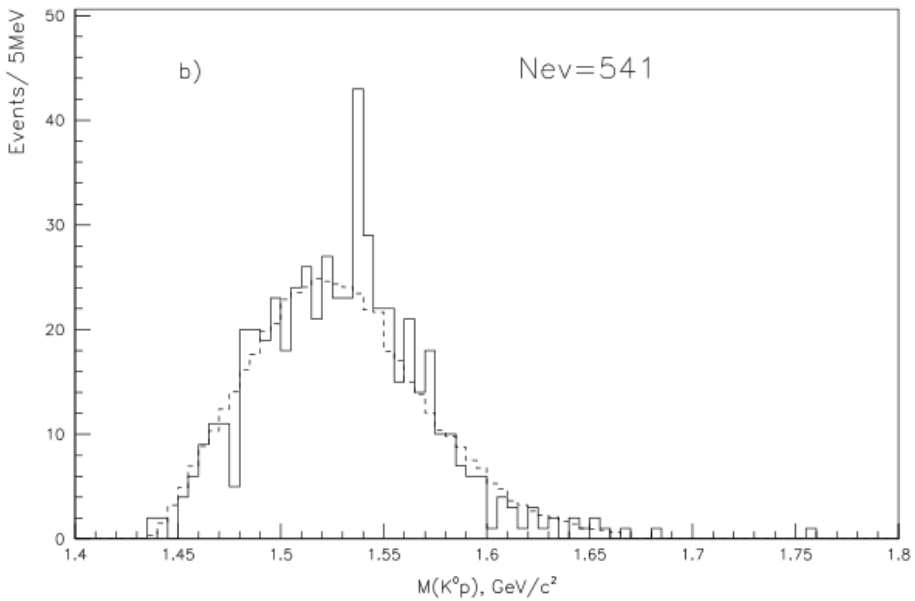
dashed line: proton in the final state, $\gamma p \to K^+K^-p$

solid line: reactions on neutrons $\gamma n \to K^+K^-n$

First observations: DIANA

- DIANA collaboration at ITEP (Moscow)
- bubble chamber
- low-energy K^+Xe collisions
- M$= 1539 \pm 2$MeV and $\Gamma \leq 9$MeV
- significance of 4.4σ



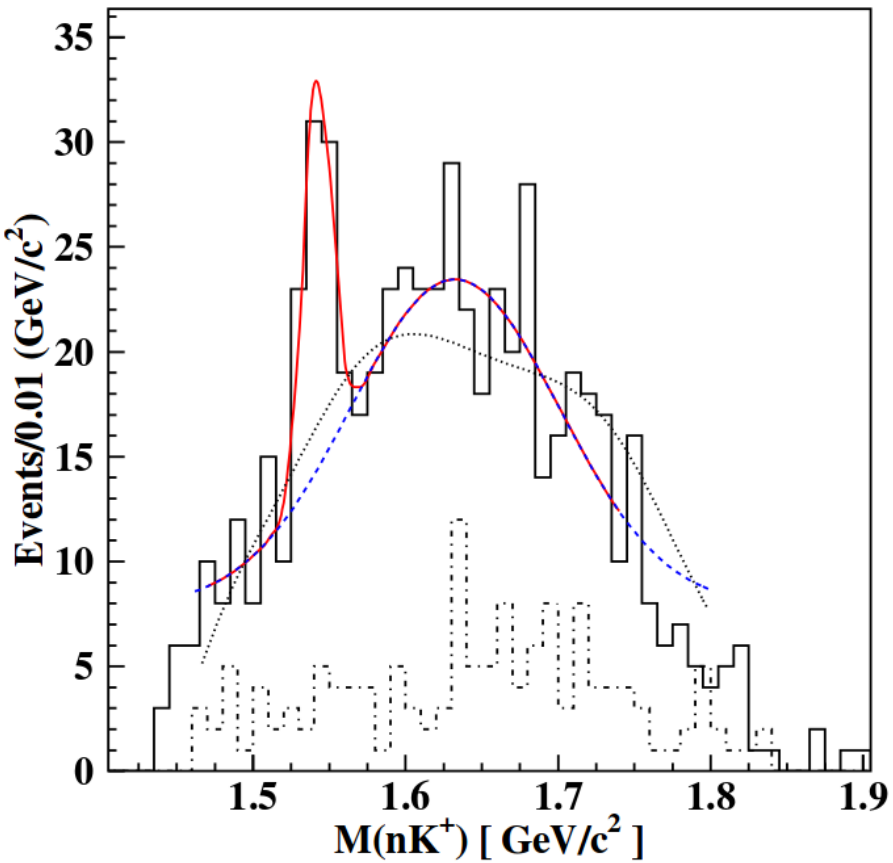


Top: effective mass of the K^0p system

Bottom: additional selections aimed at suppressing proton and K^0 reinteractions in nuclear matter

First observations: CLAS

- CLAS (JLAB)
- exclusive reaction $\gamma d \to K^+ K^- pn$
- $M = (1542 \pm 5) MeV$
- significance of $5.3 \pm 0.5\sigma$



4th paper on this topic

Evidence for the positive-strangeness pentaquark Θ^+ in photoproduction with the SAPHIR detector at ELSA [1]

The SAPHIR Collaboration

J. Barth [a], W. Braun [a,2], J. Ernst [b], K.-H. Glander [a], J. Hannappel [a,2], N. Jöpen [a], H. Kalinowsky [b], F. Klein [a], E. Klempt [b], R. Lawall [a], J. Link [b,2], D. Menze [a], W. Neuerburg [a,2], M. Ostrick [a], E. Paul [a], H. van Pee [b], I. Schulday [a], W. J. Schwille [a], B. Wiegers [a,2], F. W. Wieland [a], J. Wißkirchen [a,2], C. Wu [a,2].

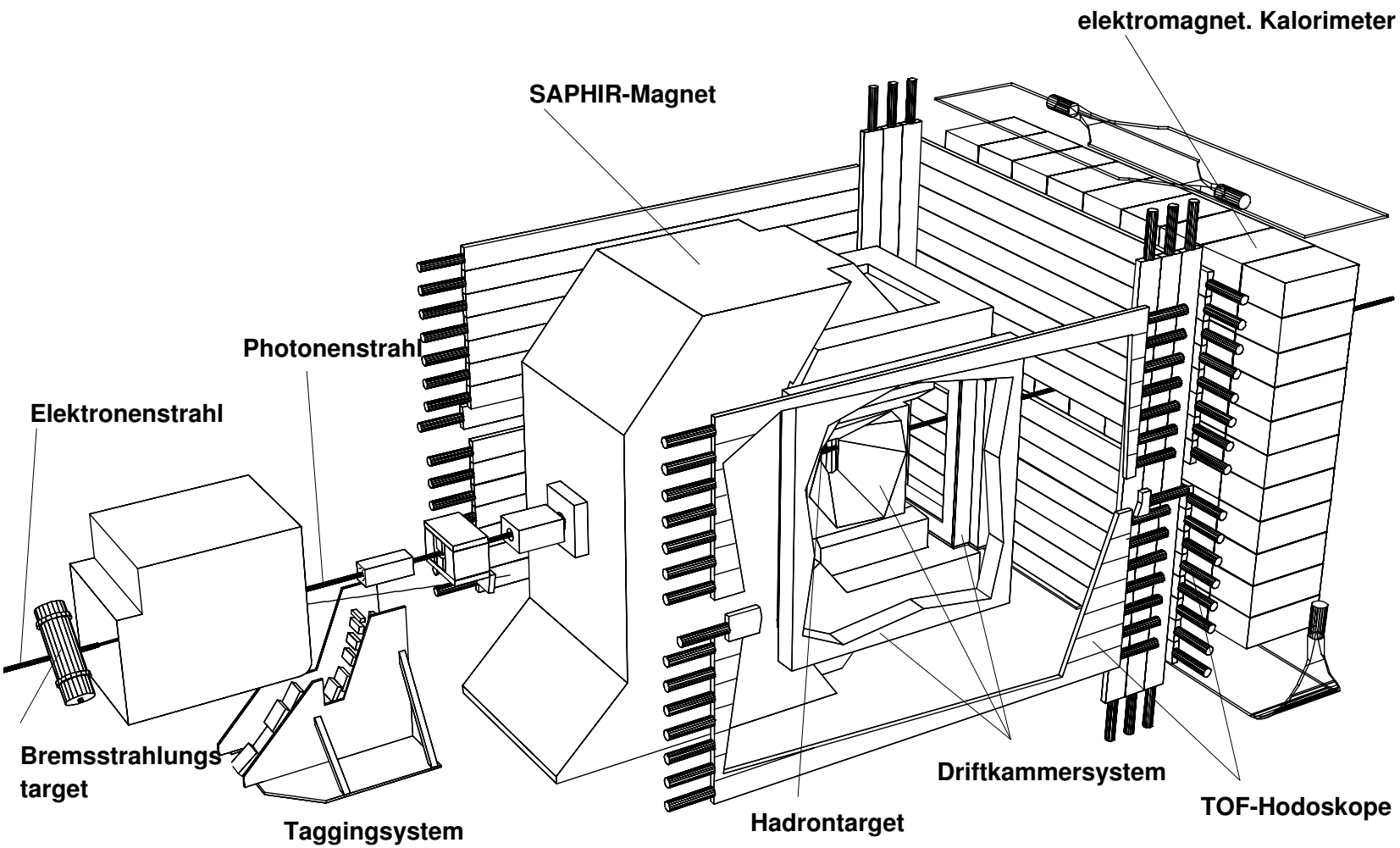
[a] *Physikalisches Institut, Bonn University, Bonn, Germany*

[b] *Helmholtz-Institut für Strahlen- und Kernphysik, Bonn University, Bonn, Germany*

The SAPHIR experiment at ELSA

- Magnetic spectrometer
- covered solid angle $\approx 0.6 \cdot 4\pi$, full polar coverage
- photons produced by bremsstrahlung on a copper foil
- tagging system covered $31\% - 94\% \cdot E_0$ with $E_0 = 2.8$ GeV
- liquid hydrogen target, 8 cm long
- photon counter at the end of the beamline
- Detector system:
  - central drift chamber with 14 cylindrical layers
  - C-shaped magnet
  - planar drift chamber in forward direction
  - drift chambers surrounded by a scintillator wall to measure the time of flight
- operated until 1998

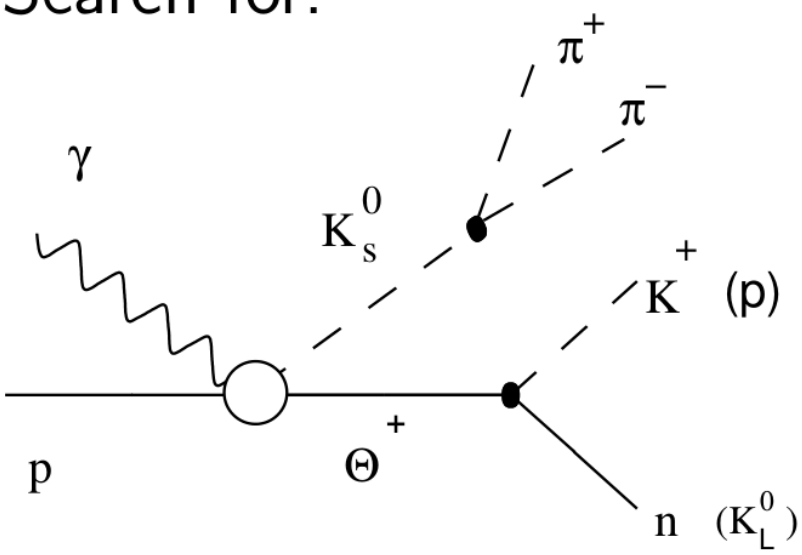
The SAPHIR experiment at ELSA

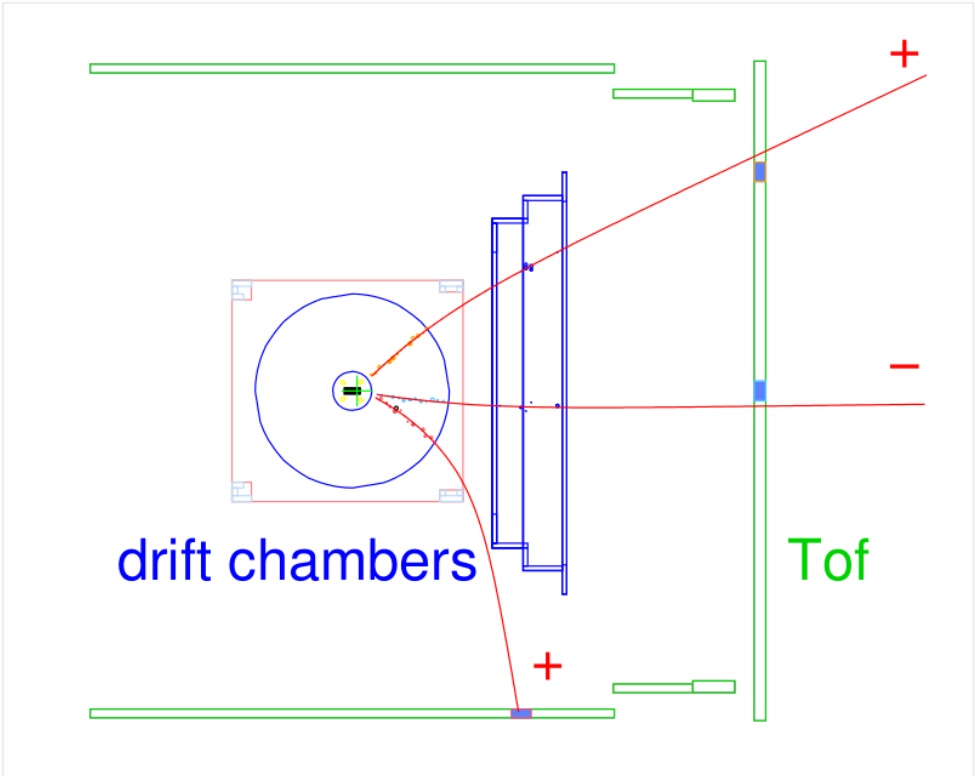


Analysis

Reaction: $\gamma p \to \Theta^+ K_s^0; \quad \Theta^+ \to nK^+; \quad K_s^0 \to \pi^+\pi^-$

Search for:





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- Kinematic cuts on $\gamma p \to n\pi^+\pi^- K^+$ (c.l. $> 1\%$) and $\gamma p \to n\pi^+\pi^-\pi^+$ (c.l. $< 1\%$)

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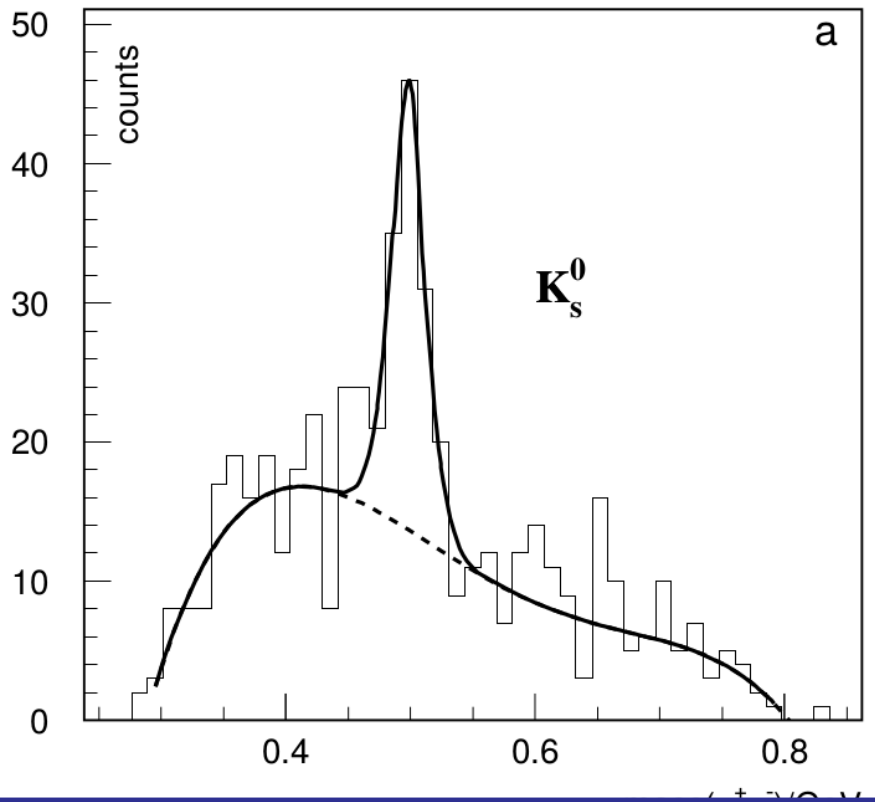
- Cut on the $\pi^+\pi^-$ invariant mass $\to$ identify K_s^0



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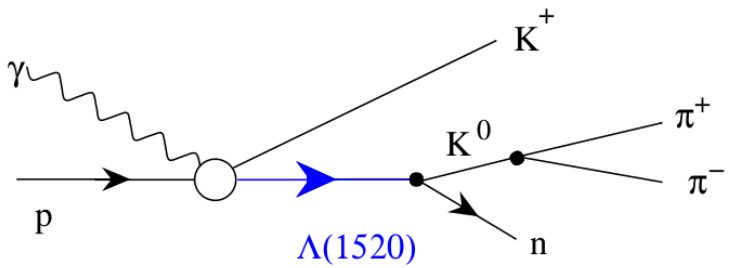
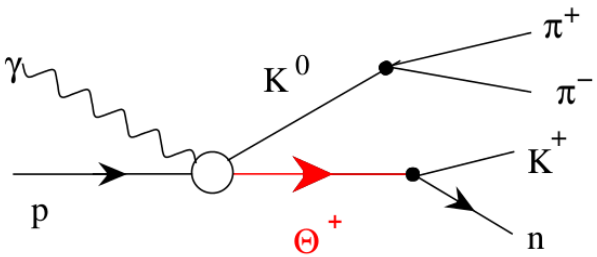
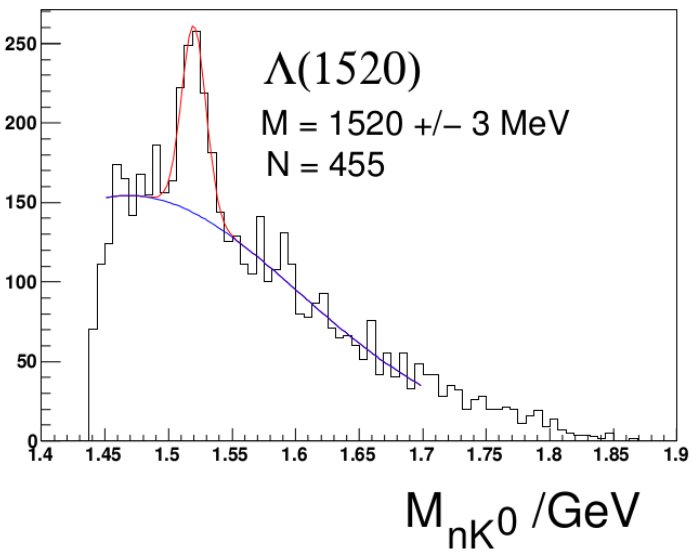
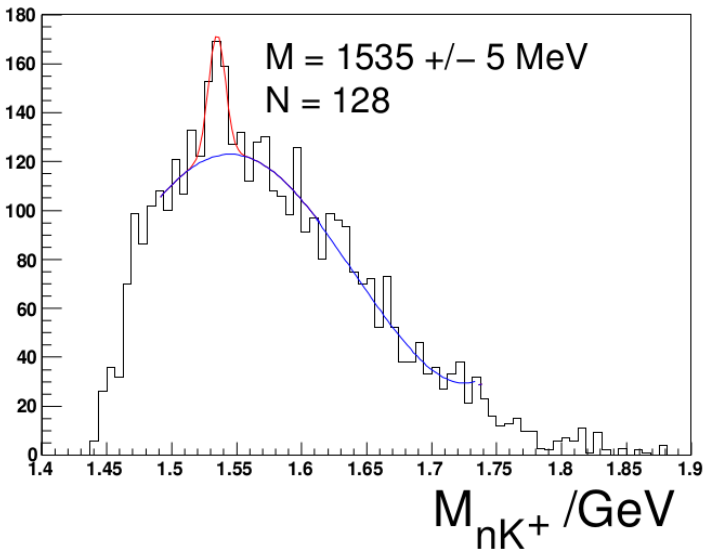
- K_s^0 preferentially produced in forward direction $\to$ cut $\cos\theta_{K_s^0} > 0.5$

Analysis


γ
K+
K0
π+
π−
p
Λ(1520)
n


γ
K0
π+
π−
K+
p
Θ+
n

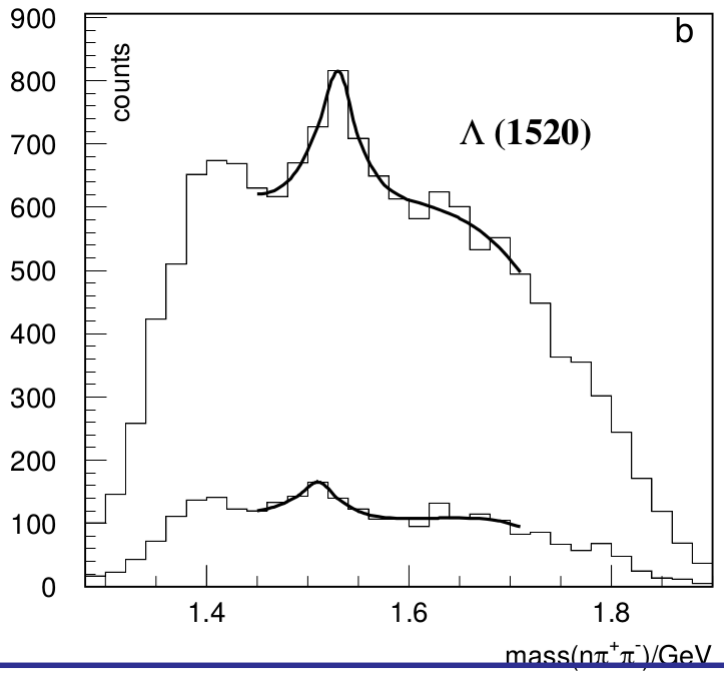

Λ(1520)
M = 1520 +/− 3 MeV
N = 455
M_nK0 /GeV


M = 1535 +/− 5 MeV
N = 128
M_nK+ /GeV

Analysis

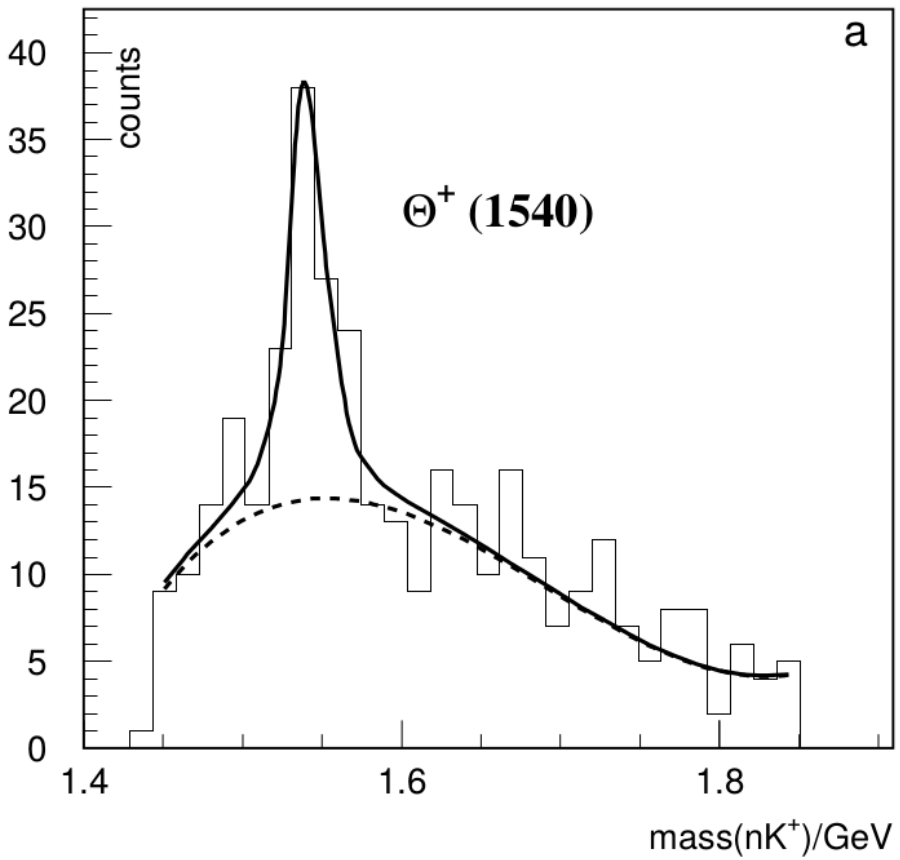
Reaction: $\gamma p \to \Theta^+ K_s^0; \quad \Theta^+ \to nK^+; \quad K_s^0 \to \pi^+\pi^-$

- Kinematic cuts on $\gamma p \to n\pi^+\pi^- K^+$ (c.l. $> 1\%$) and $\gamma p \to n\pi^+\pi^-\pi^+$ (c.l. $< 1\%$)
- Identification of the π^+, π^-, K^+ by time of flight
- Cut on the $\pi^+\pi^-$ invariant mass $\to$ identify K_s^0
- K_s^0 preferentially produced in forward direction $\to$ cut $\cos\theta_{K_s^0} > 0.5$
- Invariant mass of $n\pi^+\pi^-$: $\Lambda(1520)$ observed $\to$ cut $\cos\theta_{\pi^+\pi^-} > 0.5$



Results of the SAPHIR experiment

- $M_{\Theta^+} = 1540 \pm 4 \pm 2$ MeV
- $\Gamma_{\Theta^+} < 25$ MeV at 90% c.l.
- significance 5.2σ



Further investigations

- Is the Θ^+ an isospin 0 or 1 state?

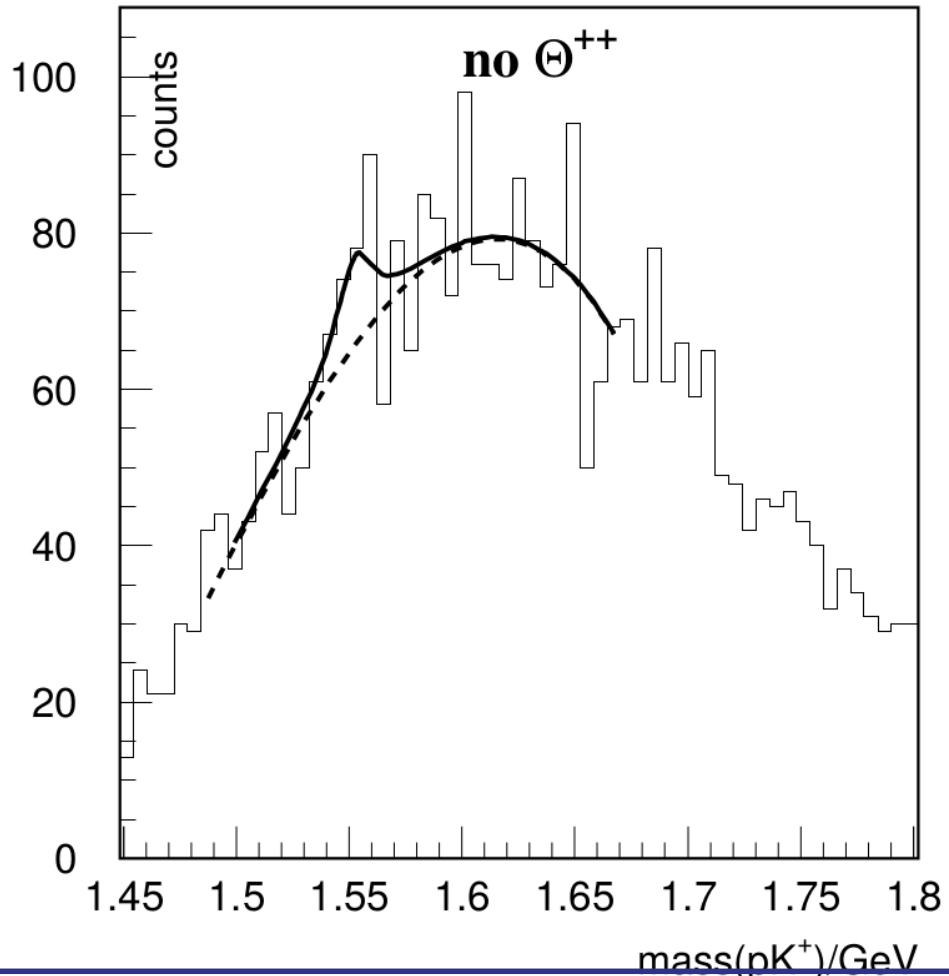
$\rightarrow$ If isospin 1: Θ^0 and Θ^{++} would exist

Further investigations

- Is the Θ^+ an isospin 0 or 1 state?

$\rightarrow$ If isospin 1: Θ^0 and Θ^{++} would exist

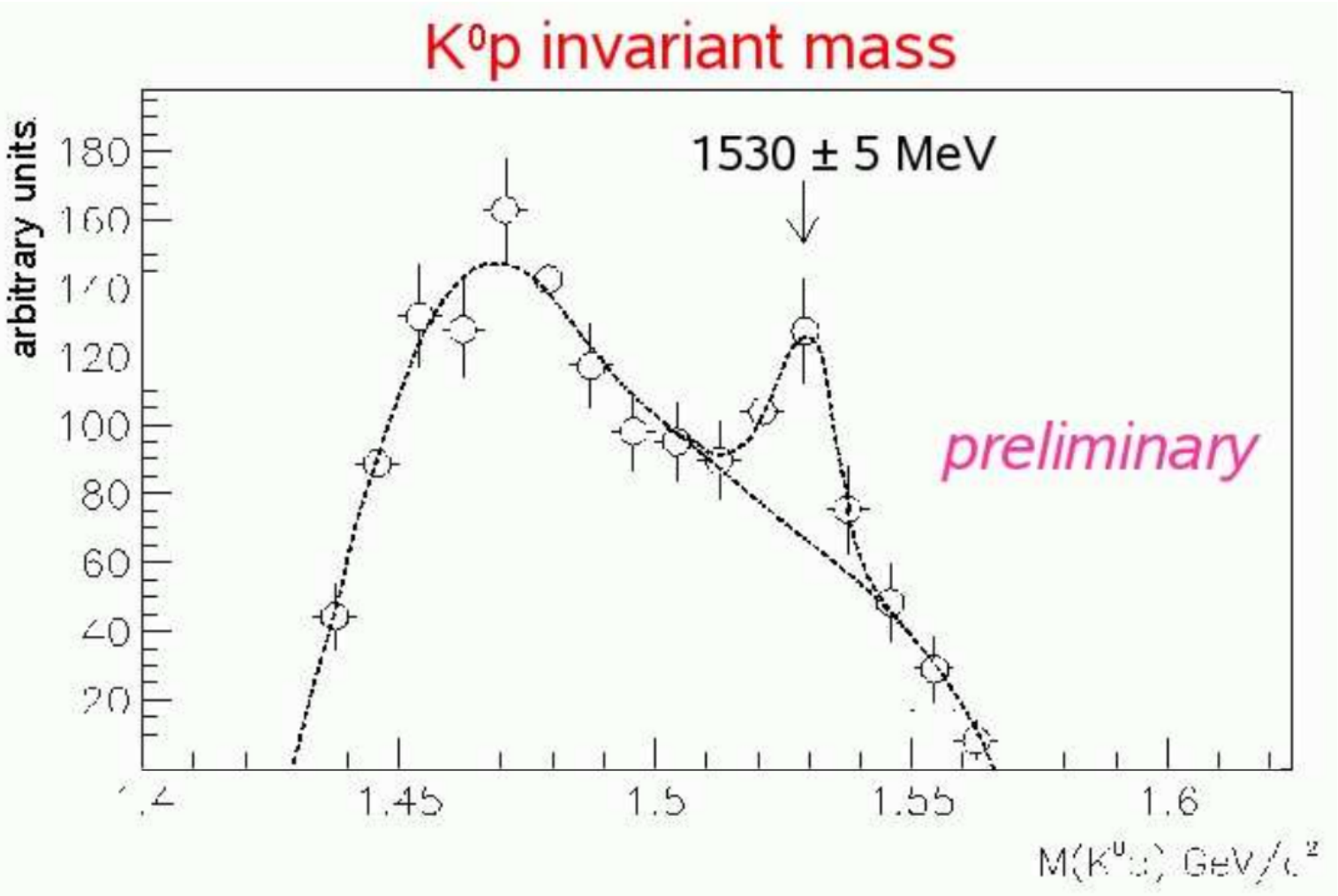
- investigation of the reaction $\gamma p \rightarrow \Theta^{++} K$; $\quad \Theta^{++} \rightarrow p K^+$



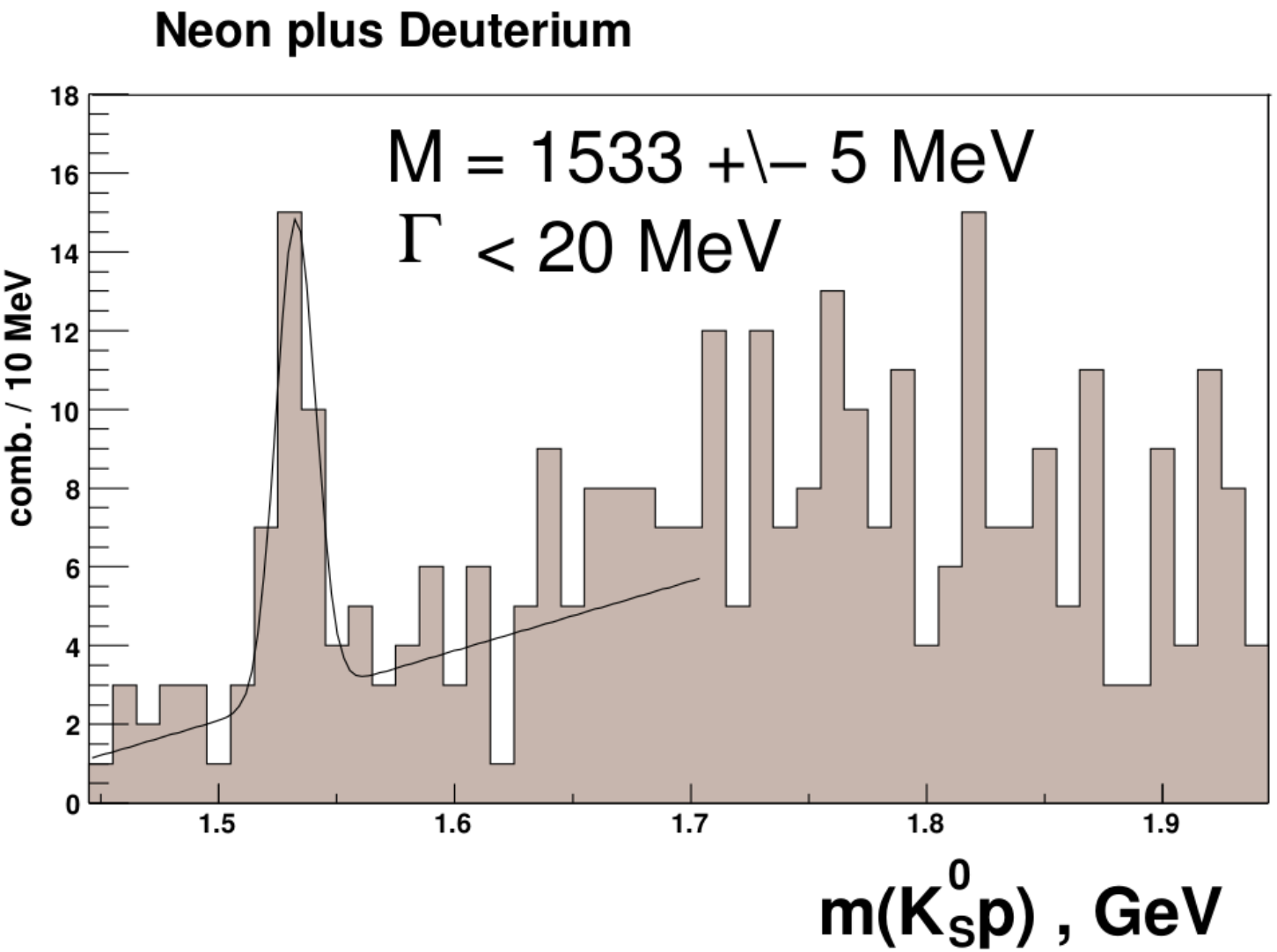
Other experiments

experiment	reaction	decay channel	mass (MeV)	statistical significance
Spring-8	$\gamma n \to K^- \Theta^+$	$K^+ n$	1540 ± 10	5σ
DIANA	$K^+ n \to K^- \Theta^+$	$K^0_S p$	1539 ± 2	4σ
SAPHIR	$\gamma p \to K^0_S \Theta^+$	$K^+ n$	1540 ± 6	5σ
CLAS	$\gamma n \to K^- p \Theta^+$	$K^+ n$	1542 ± 5	5σ
CLAS	$\gamma p \to K^- \pi^+ \Theta^+$	$K^+ n$	1540 ± 5	5σ
CLAS	$\gamma p \to K^- \pi^+ \Theta^+$	$K^+ n$	1555 ± 10	8σ
CLAS	$\gamma p \to K^0_S \Theta^+$	$K^+ n$	1573 ± 5	4σ
CLAS	$\gamma p \to K^0_S \Theta^+$	$K^+ n$	1523 ± 5	4σ
CLAS	$\gamma p \to K^0_S \Theta^+$	$K^+ n$	1571 ± 10	
BC	$\nu A \to \Theta^+ \, X$	$K^0_S p$	1533 ± 5	7σ
HERMES	$ed \to \Theta^+ \, X$	$K^0_S p$	1526 ± 5	6σ
ZEUS	$e^\pm p \to \Theta^+ \, X$	$K^0_S p$	1527 ± 3	
COSY/TOF	$pp \to \Sigma^+ \Theta^+ \, X$	$K^0_S p$	1530 ± 5	5σ

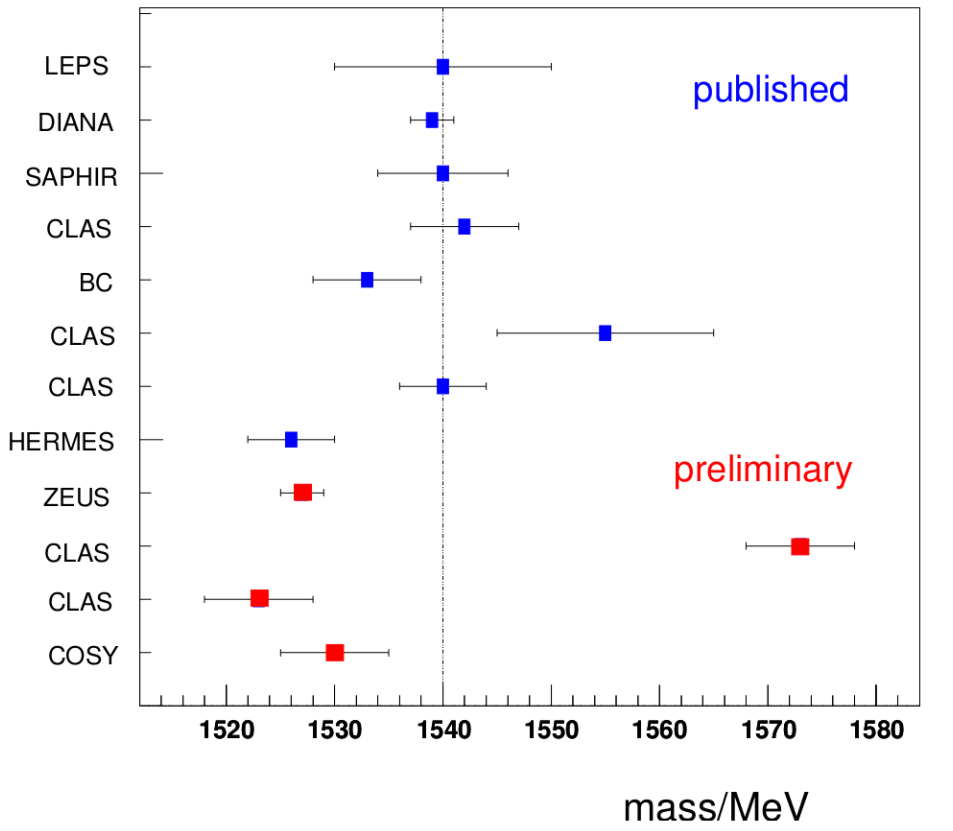
COSY-TOF: $pp \to \Sigma + pK_s^0$



Neutrino interactions in bubble chambers

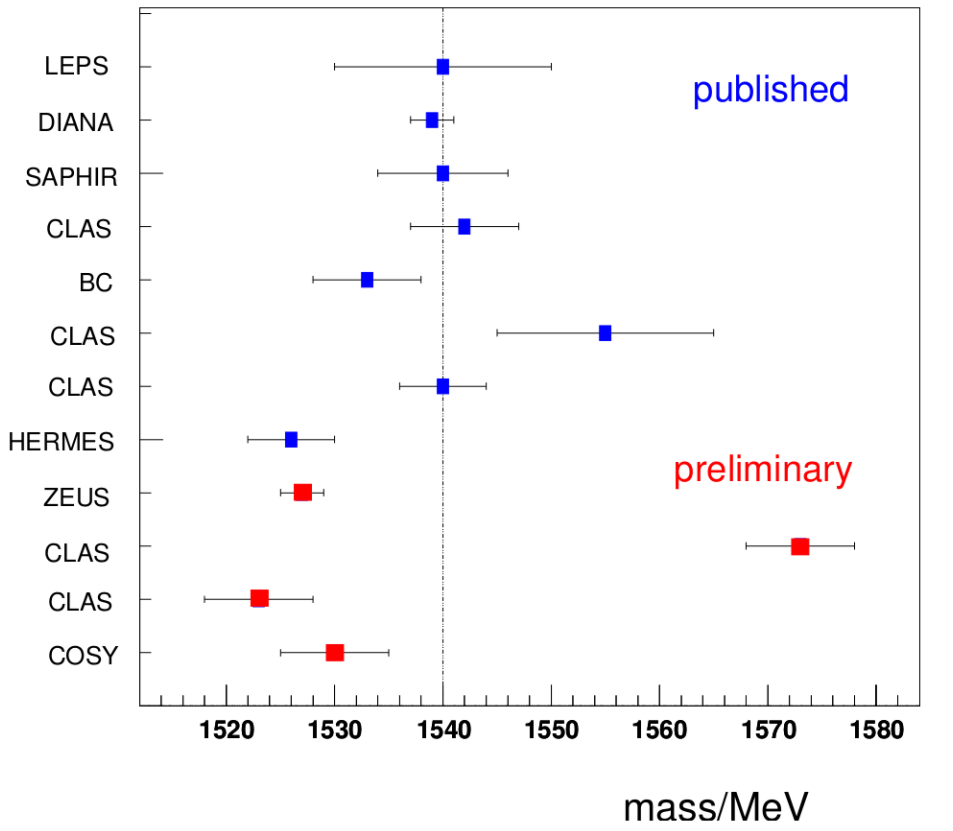


Other experiments



$\rightarrow$ 10 experiments saw a excess in a similar mass region

Other experiments

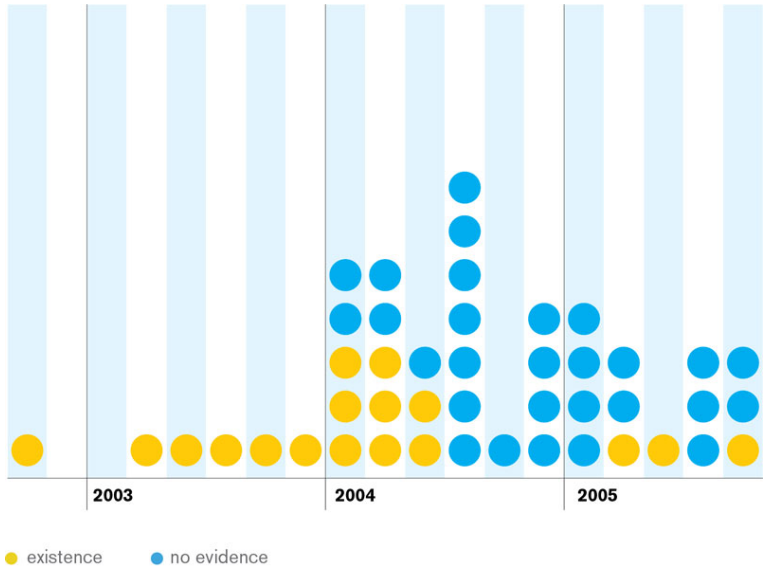


$\rightarrow$ 10 experiments saw a excess in a similar mass region

In 2004 a new SFB was granted in Bonn to further look into this (among other things)... :)

Non-Observations

- Several non-observations from different experiments e.g.
  - BES
  - Belle
  - BaBar
  - HERA-B
  - CDF
  - PHENIX



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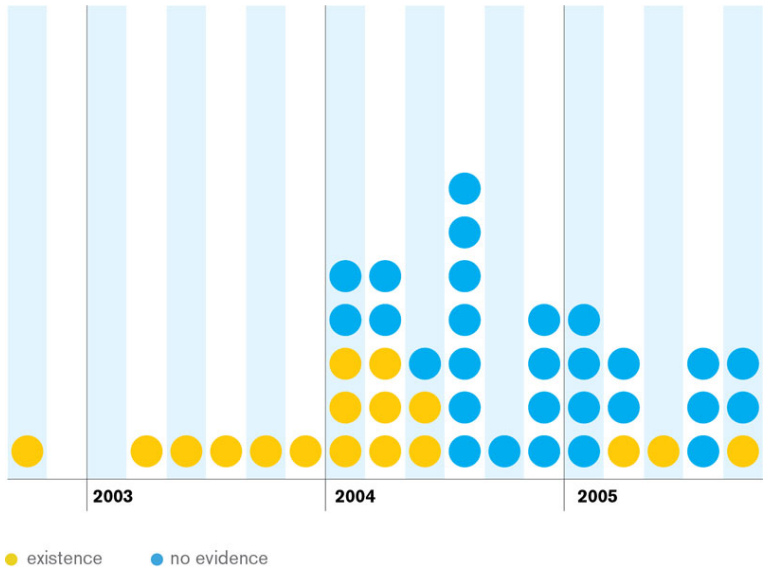


- Experiments were repeated with higher statistics, but signal was not observed any more!
- Most papers were retracted in the next years...
- SAPHIR: re-analysis by taking the second decay vertex of the K_s^0 into account
  $\rightarrow$ signal of the Θ^+ gone? (Not published...)

Criticism (to all experiments)

- Very small cuts at the edge of the acceptance
  $\rightarrow$ repeat everything with simulated data
- Some cuts unmotivated. Just to enhance the signal?
  $\rightarrow$ blind analysis
- Background below the peaks not well known
- Overestimation of statistics and significance

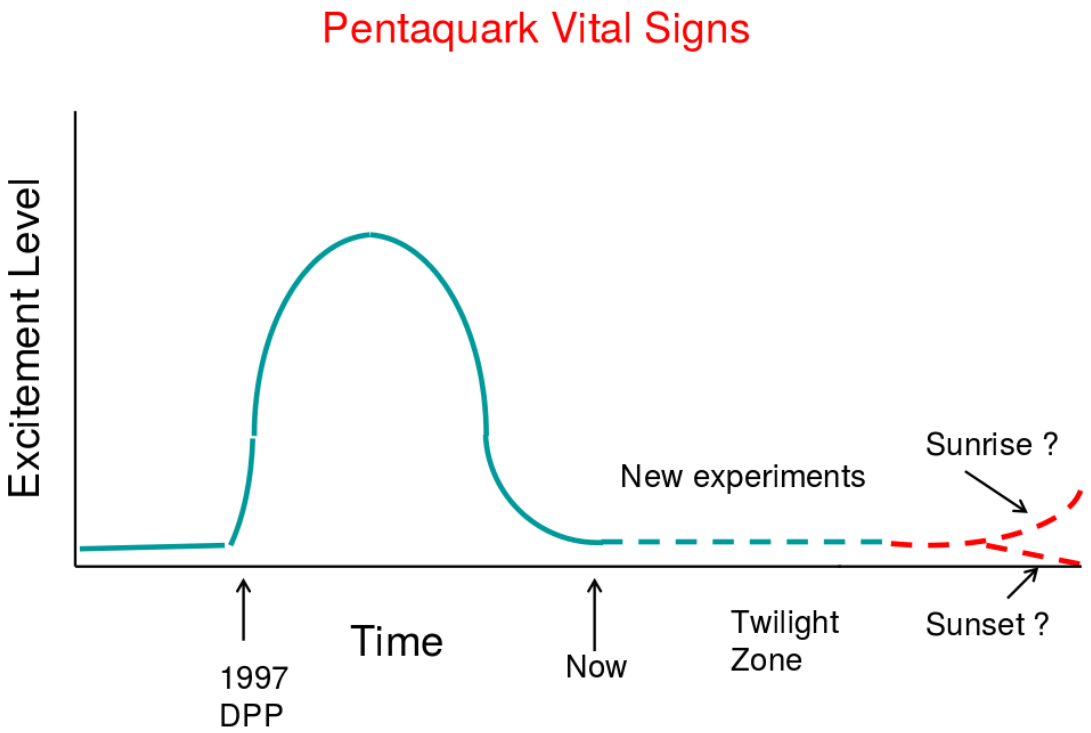
PDG 2006

"There has not been a high-statistics confirmation of any of the original experiments that claimed to see the θ^+; there have been two high-statistics repeats from Jefferson Lab that have clearly shown the original positive claims in those two cases to be wrong; there have been a number of other high-statistics experiments, none of which have found any evidence for the θ^+; and all attempts to confirm the two other claimed pentaquark states have led to negative results. **The conclusion that pentaquarks in general, and the θ^+, in particular, do not exist, appears compelling.**"

PDG 2008

"There are two or three recent experiments that find weak evidence for signals near the nominal masses, but there is simply no point in tabulating them in view of the overwhelming evidence that the claimed pentaquarks do not exist. The only advance in particle physics thought worthy of mention in the American Institute of Physics Physics News in 2003 was a false alarm. **The whole story – the discoveries themselves, the tidal wave of papers by theorists and phenomenologists that followed, and the eventual undiscovery – is a curious episode in the history of science**"

Conclusion and Outlook



- Be careful with your analysis :)
- Observation of a pentaquark $|uudc\bar{c}>$ at 4400 MeV with LHCb in 2015?

References

- LEPS: http://arxiv.org/pdf/hep-ex/0301020.pdf
- DIANA: http://arxiv.org/pdf/hep-ex/0304040v4.pdf
- SAPHIR: http://arxiv.org/pdf/hep-ex/0307083.pdf
- Review article: http://iopscience.iop.org/article/10.1088/1742-6596/9/1/035/pdf
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- Conference 2003: https://www.jlab.org/intralab/calendar/archive03/pentaquark/program.h
- Conference 2005: https://www.jlab.org/conferences/pentaquark/
- Talk: http://wwwa1.kph.uni-mainz.de/Bosen/archive/talks/2004/lectures/Ostrick.pdf