The magic of getting peaks from cuts in experiments: an explanation for the Θ^+ pentaquark" peak

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Brief history of the Theta$^+$ pentaquark
Theoretical reconstruction of the $\gamma\, d \rightarrow K^+ K^- n\, p$ reaction
Experimental cuts
Invariant mass distributions
Statistical fluctuations

The beginning

Evidence **for a narrow S = +1 baryon resonance in photoproduction from the neutron.**
By LEPS Collaboration (T. Nakano *et al.*). Jan 2003. 12pp.
Published in **Phys.Rev.Lett.91:012002,2003**.

The $\gamma n \to K^+K^-n$ reaction on ^{12}C has been studied by measuring both K^+ and K^- at forward angles. A sharp baryon resonance peak was observed at 1.54 ± 0.01 GeV$/c^2$ with a width smaller than 25 MeV$/c^2$ and a Gaussian significance of 4.6 σ. The strangeness quantum number (S)

A large number of experimental papers followed that also saw the signal. It also stimulated a huge number of theoretical papers.

Cited 815 times

PDG:The end

Table 1: Unsuccessful searches for pentaquarks. There are ten more unsuccessful searches for the $\Theta(1540)$, nine for the $\Phi(1860)$, and three for the $\Theta_c(3100)$ listed in our 2006 edition [1].

Experiment	Reaction	Energy, etc.	Limits, etc.
Searches for the $\Theta(1540)^+$			
BABAR [2]	$B^0 \to (pK^0_S)\bar{p}$	$\sqrt{s}$ 10.58 GeV	$< 2 \times 10^{-7}$ per B^0
CLAS [3]	$\gamma p \to (nK^+/pK^0_S)K^0$	E_γ 1.6–3.8 GeV	$\sigma < 0.7$ nb, 100k $\Lambda(1520)$
CLAS [4]	$\gamma d \to (nK^+)pK^-$	E_γ 0.8–3.6 GeV	$\sigma < 0.3$ nb
CLAS [5]	$\gamma d \to (nK^+)\Lambda$	E_γ 0.8–3.6 GeV	$\sigma <$ 5–25 nb
COSY-ANKE [6]	$pp \to (pK^0_S)\Lambda\pi^+$	p_p 3.65 GeV/c	$\sigma < 58$ nb
COSY-TOF [7]	$pp \to (pK^0_S)\Sigma^+$	p_p 3.059 GeV/c	$\sigma < 150$ nb
DELPHI [8]	$Z \to (pK^0_S)X$	$\sqrt{s}$ 91.2 GeV	$< 5.1 \times 10^{-4}$ per Z
FOCUS [9]	$\gamma A \to (pK^0_S)X$	$\bar{E}_\gamma$ 180 GeV	400k $\Sigma(1385)^+$
HERA-H1 [10]	$ep \to (p/\bar{p}K^0_S)eX$	$5 < Q^2 < 100$ GeV^2	$\sigma <$ 30–90 pb
KEK-E522 [11]	$\pi^- p \to K^-(X)$	p_π 1.9 GeV/c	$\sigma < 3.9$ nb
L3 [12]	$\gamma^*\gamma^* \to (p/\bar{p}K^0_S)X$	$E_{\gamma\gamma} > 5$ GeV	$\sigma < 1.8$ nb
NOMAD [13]	$\nu_\mu N \to (pK^0_S)X$		$< 2.13\text{x}10^{-3}$ per evt

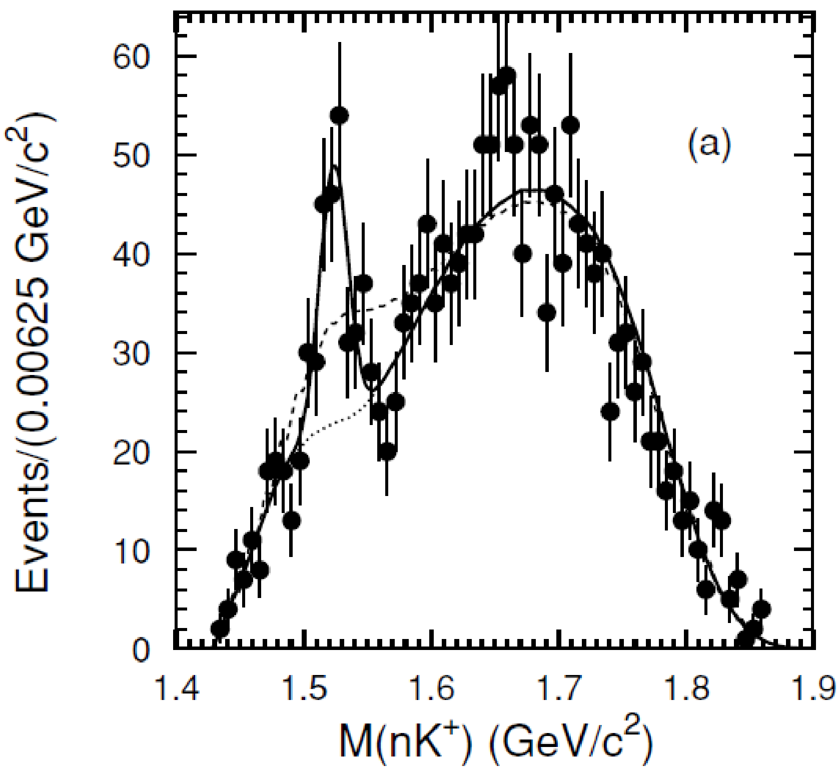
false alarm. The whole story—the discoveries themselves, the tidal wave of papers by theorists and phenomenologists that followed, and the eventual “undiscovery” —is a curious episode in the history of science.

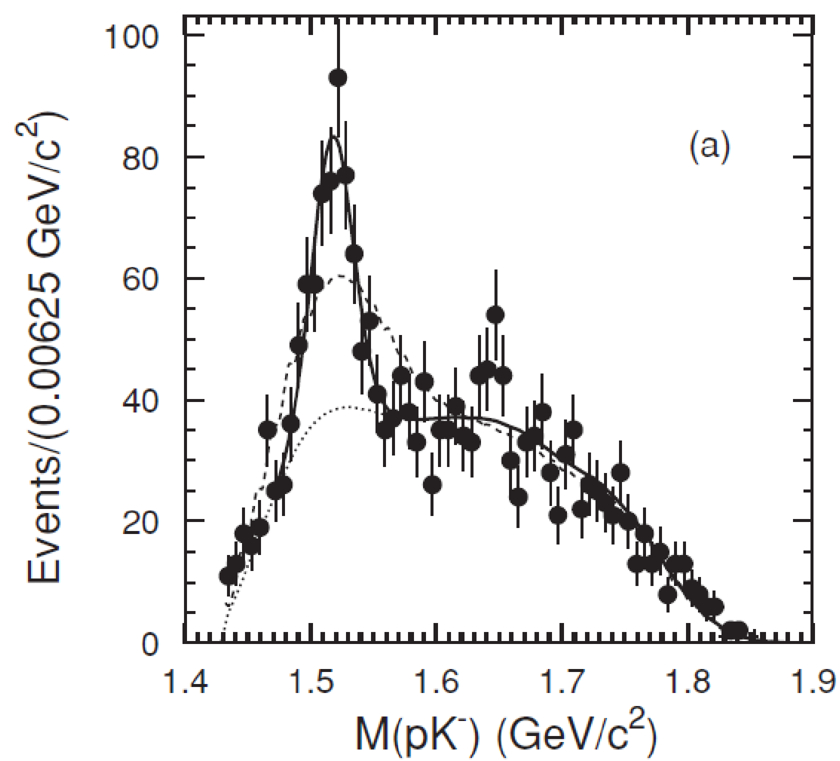
The resurrection

PHYSICAL REVIEW C **79**, 025210 (2009)

Evidence for the Θ^+ in the $\gamma d \rightarrow K^+K^-pn$ reaction by detecting K^+K^- pairs

T. Nakano,[1] N. Muramatsu,[1] D. S. Ahn,[1] J. K. Ahn,[2] H. Akimune,[3] Y. Asano,[4] W. C. Chang,[5] S. Daté,[4] H. Ejiri,[4] H. Fujimura,[6] M. Fujiwara,[1] S. Fukui,[7] H. Hasegawa,[8] K. Hicks,[9] K. Horie,[10] T. Hotta,[1] K. Imai,[11] T. Ishikawa,[6] T. Iwata,[12] Y. Kato,[1] H. Kawai,[13] Z. Y. Kim,[14] K. Kino,[1] H. Kohri,[1] N. Kumagai,[15] S. Makino,[16] T. Matsuda,[17] N. Matsuoka,[1] T. Matsumura,[18] T. Mibe,[19] M. Miyabe,[11] Y. Miyachi,[20] M. Niiyama,[21] M. Nomachi,[10] Y. Ohashi,[4] H. Ohkuma,[4] T. Ooba,[13] D. S. Oshuev,[5] C. Rangacharyulu,[22] A. Sakaguchi,[10] P. M. Shagin,[23] Y. Shiino,[13] A. Shimizu,[1] H. Shimizu,[6] Y. Sugaya,[10] M. Sumihama,[1] Y. Toi,[17] H. Toyokawa,[15] A. Wakai,[24] C. W. Wang,[5] S. C. Wang,[5] K. Yonehara,[25] T. Yorita,[1] M. Yoshimura,[26] M. Yosoi,[1] and R. G. T. Zegers[27]





The trouble makers

Study of the $\gamma d \to K^+K^- np$ reaction and an alternative explanation for the "$\Theta^+(1540)$ pentaquark" peak

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March 4, 2010

PHYSICAL REVIEW C **81**, 055202 (2010)

The $\gamma d \to K^+K^-np$ reaction and an alternative explanation for the "$\Theta^+(1540)$ pentaquark" peak

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(Received 18 March 2010; published 12 May 2010)

We present a calculation of the $\gamma d \to K^+K^-np$ reaction with the aim of seeing whether the experimental peak observed in the K^+n invariant mass around 1526 MeV, from where evidence for the existence of the Θ^+ has been claimed, can be obtained without this resonance as a consequence of the particular dynamics of the process and the cuts applied in the experimental setup. We find that a combination of facts leads indeed to a peak around 1530 MeV for the invariant mass of K^+n without the need to invoke any new resonance around this energy. This, together with statistical fluctuations that we prove to be large with the statistics of the experiment, is likely to produce the narrower peak observed there.

DOI: 10.1103/PhysRevC.81.055202 PACS number(s): 14.20.Pt

Theoretical model for the reaction

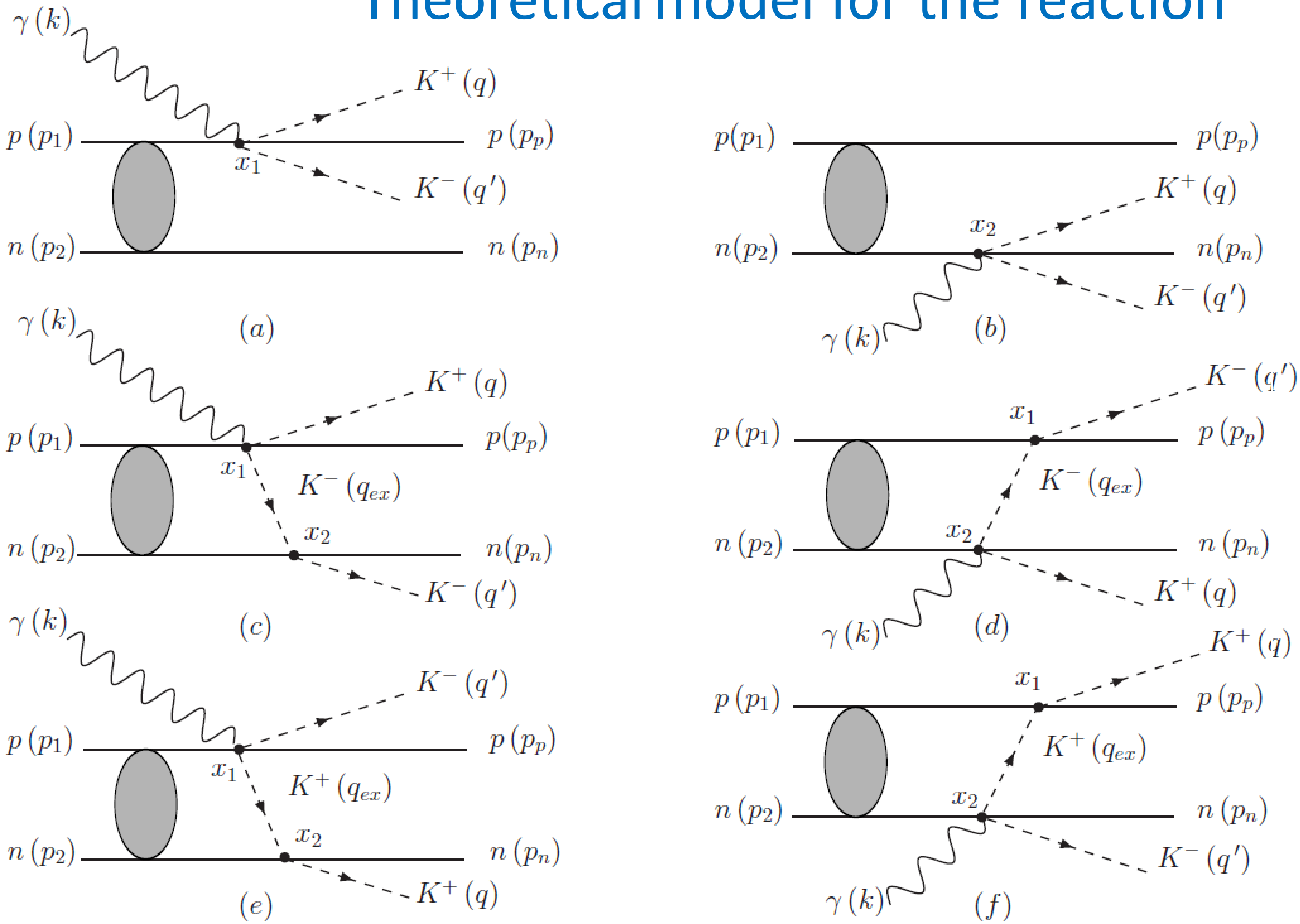


Figure 1: Diagrammatic representation of the model for the $\gamma d \to K^+K^-np$ reaction.

We include ϕ production on the proton and neutron and Λ(1520) production on the proton, the basic ingredients observed experimentally, plus rescattering of the kaons.

At LEPS the proton and neutron are not measured. A prescription must be taken to make a best guess MMSA prescription

$$p_{pn} = p_{miss} = p_\gamma + p_d - p_{K^+} - p_{K^-}$$

From there one determines the p momentum in the pn CM frame
Then boost it to the Lab frame (deuteron at rest). The minimum momentum corresponds when $\vec{p}_{CM}$ goes opposite to $\vec{p}_{miss}$

$$p_{min} = -|\vec{p}_{CM}| \cdot \frac{E_{miss}}{M_{pn}} + E_{CM} \cdot \frac{|\vec{p}_{miss}|}{M_{pn}}$$

$$p_{res} = |\vec{p}_{miss}| - p_{min}$$

$$\vec{p}_n = p_{res} \cdot \frac{\vec{p}_{miss}}{|\vec{p}_{miss}|}$$

This is the momentum assigned to the neutron.

$$|p_{min}| < 100 \text{ MeV}$$

This condition is demanded

Cuts at LEPS to remove the ϕ contribution

In order to remove the contribution from the ϕ production at LEPS one considers events which satisfy that the invariant mass of the K^+K^- pair is bigger than 1030 MeV and bigger than the value obtained from the following expression

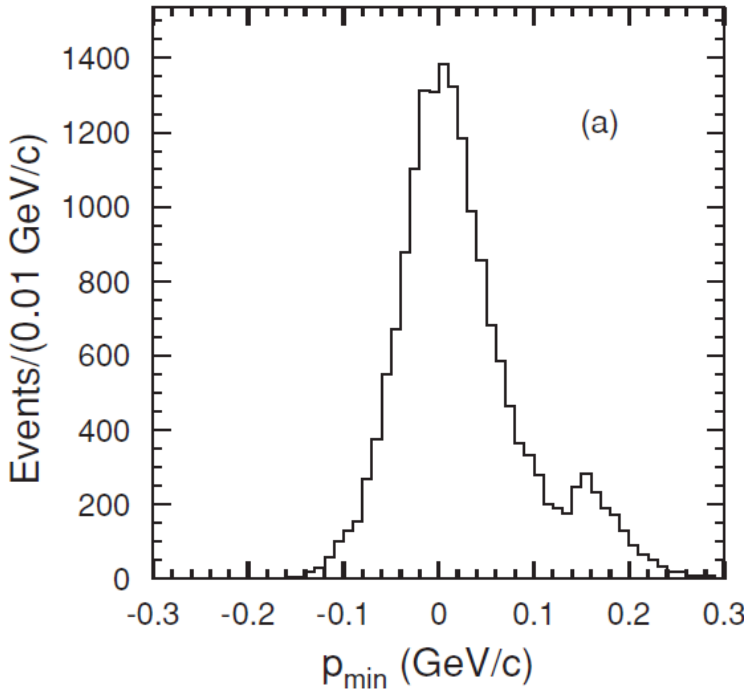
$$1020\,\mathrm{MeV} + 0.09 \times (E_\gamma^{eff}(\mathrm{MeV}) - 2000\,\mathrm{MeV}) \tag{5}$$

where E_γ^{eff} is defined as the effective photon energy

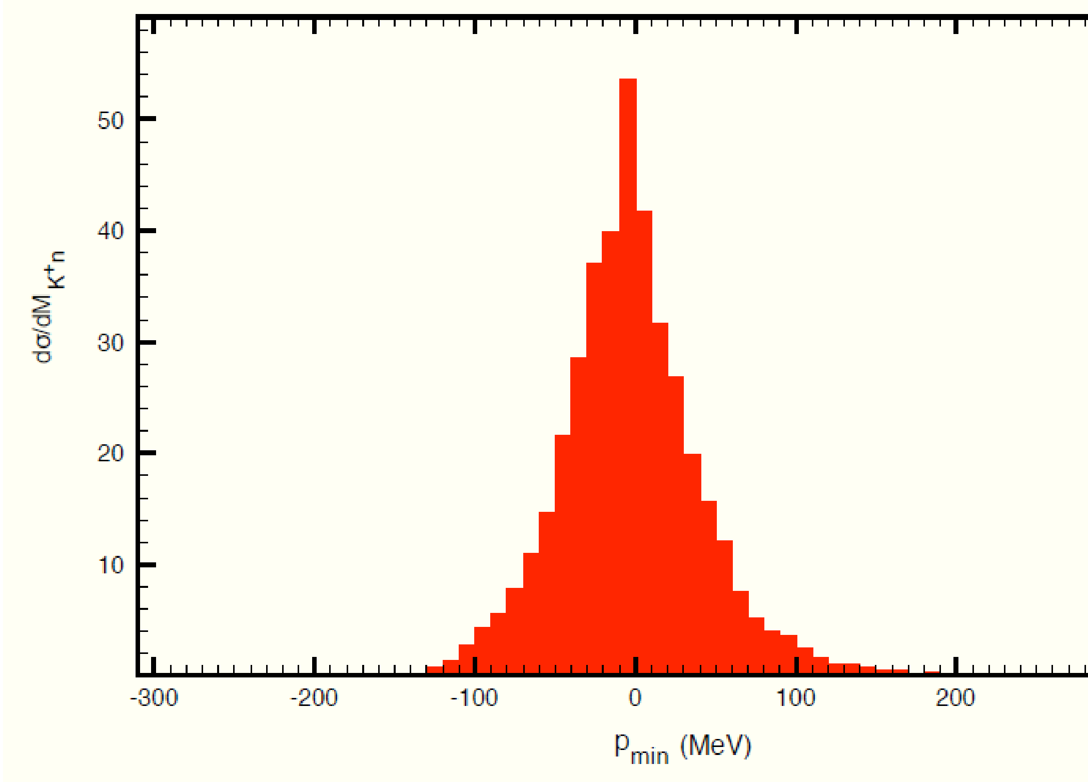
$$E_\gamma^{eff} = \frac{s_{K^+K^-n} - M_n^2}{2M_n} \tag{6}$$

with $s_{K^+K^-n}$ the square of the total center of mass energy for the K^+K^-n system calculated using the MMSA approximation to determine the momentum of the neutron assuming the proton as spectator. In [6] only events for which $2000\,\mathrm{MeV} < E_\gamma^{eff} < 2500\,\mathrm{MeV}$ are considered,

P_{min}(exp)



P_{min}(theo)



Recall: when reconstructing the K^+ n invariant mass, p_p is taken as p_{min}

However, the real momentum distribution is different !!

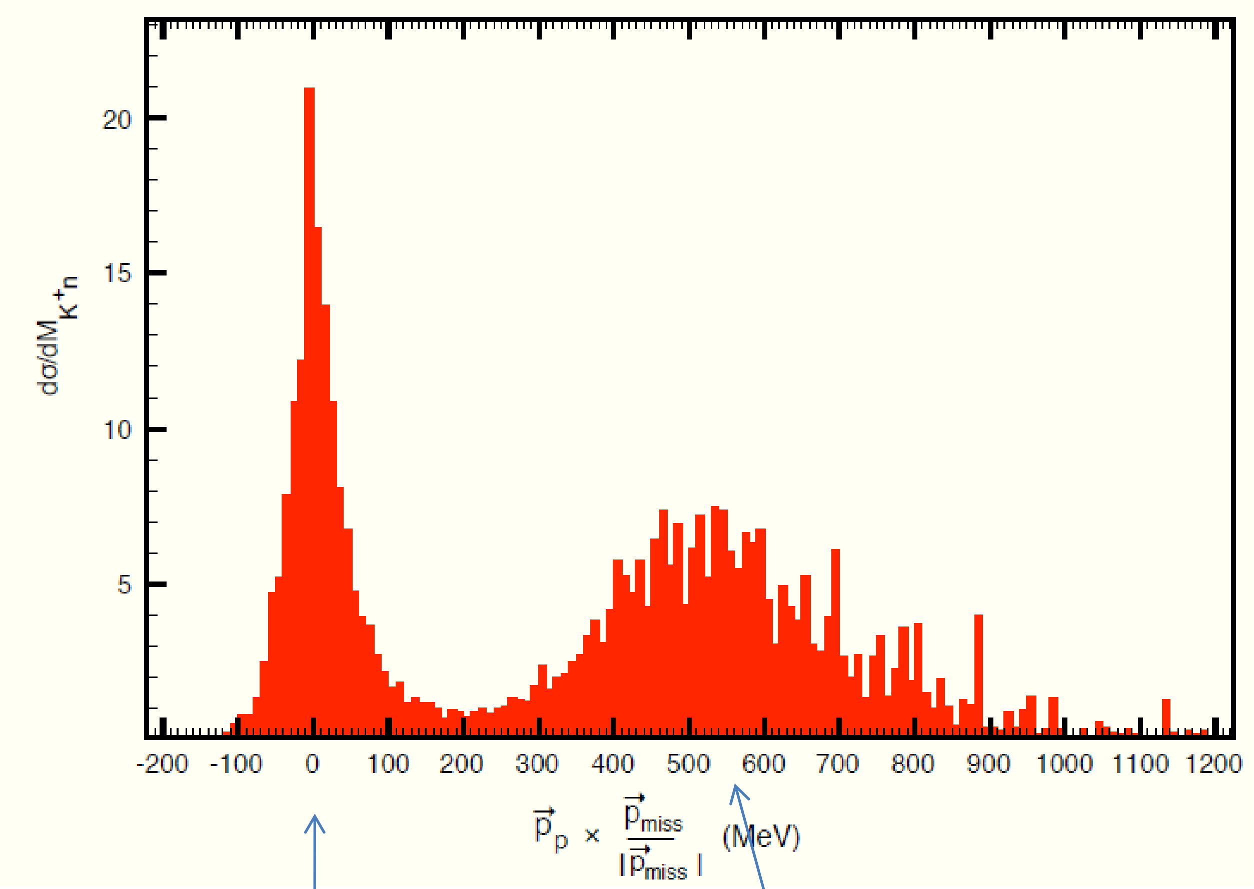


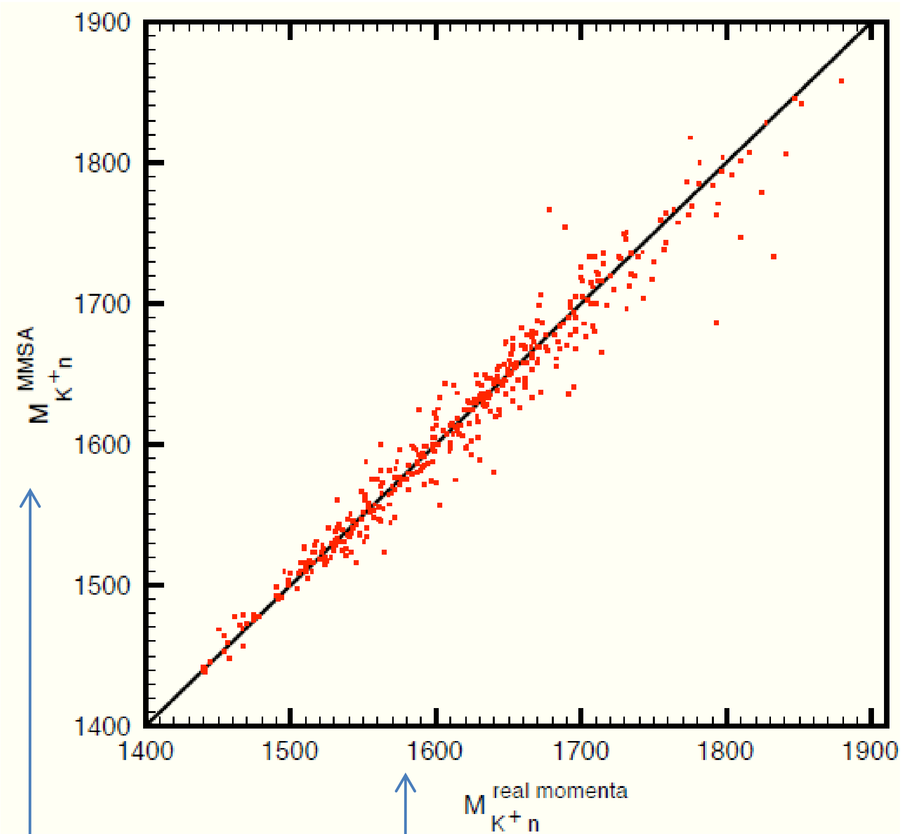
Figure 22: Distribution for the real proton momentum component along the $\vec{p}_{miss}$ direction.

From proton as spectator

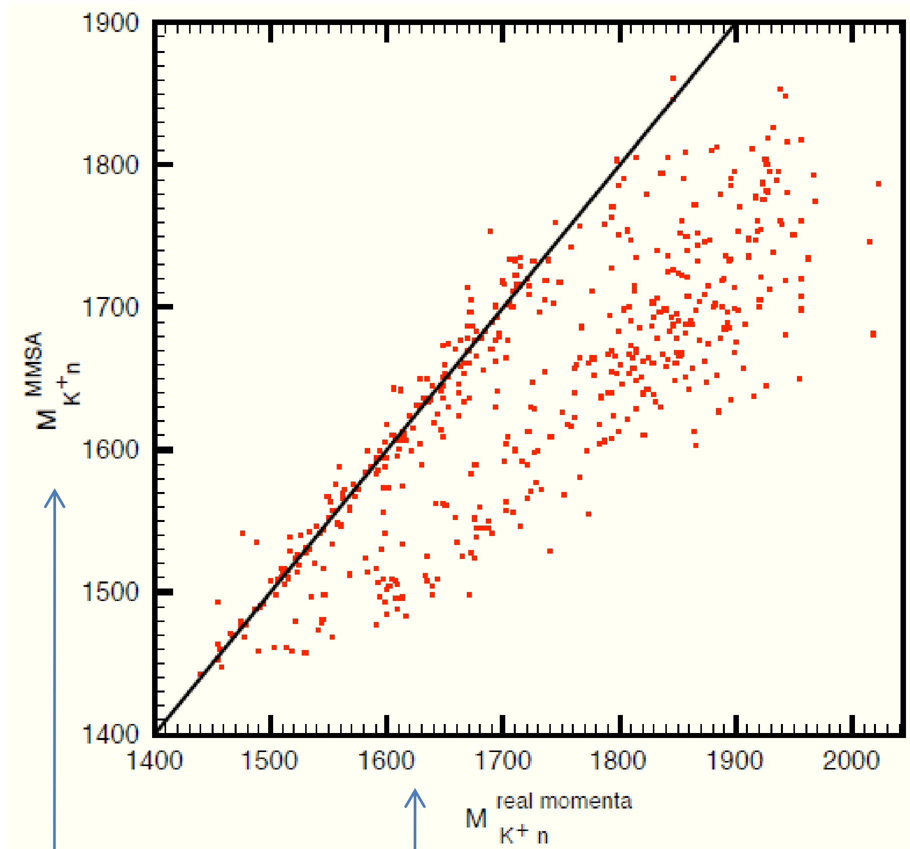
From neutron as spectator

Correspondence between real momenta and momenta from experimental prescription

Case of proton as spectator



General case, full theoretical model



MMSA

Real momenta

MMSA

Real momenta

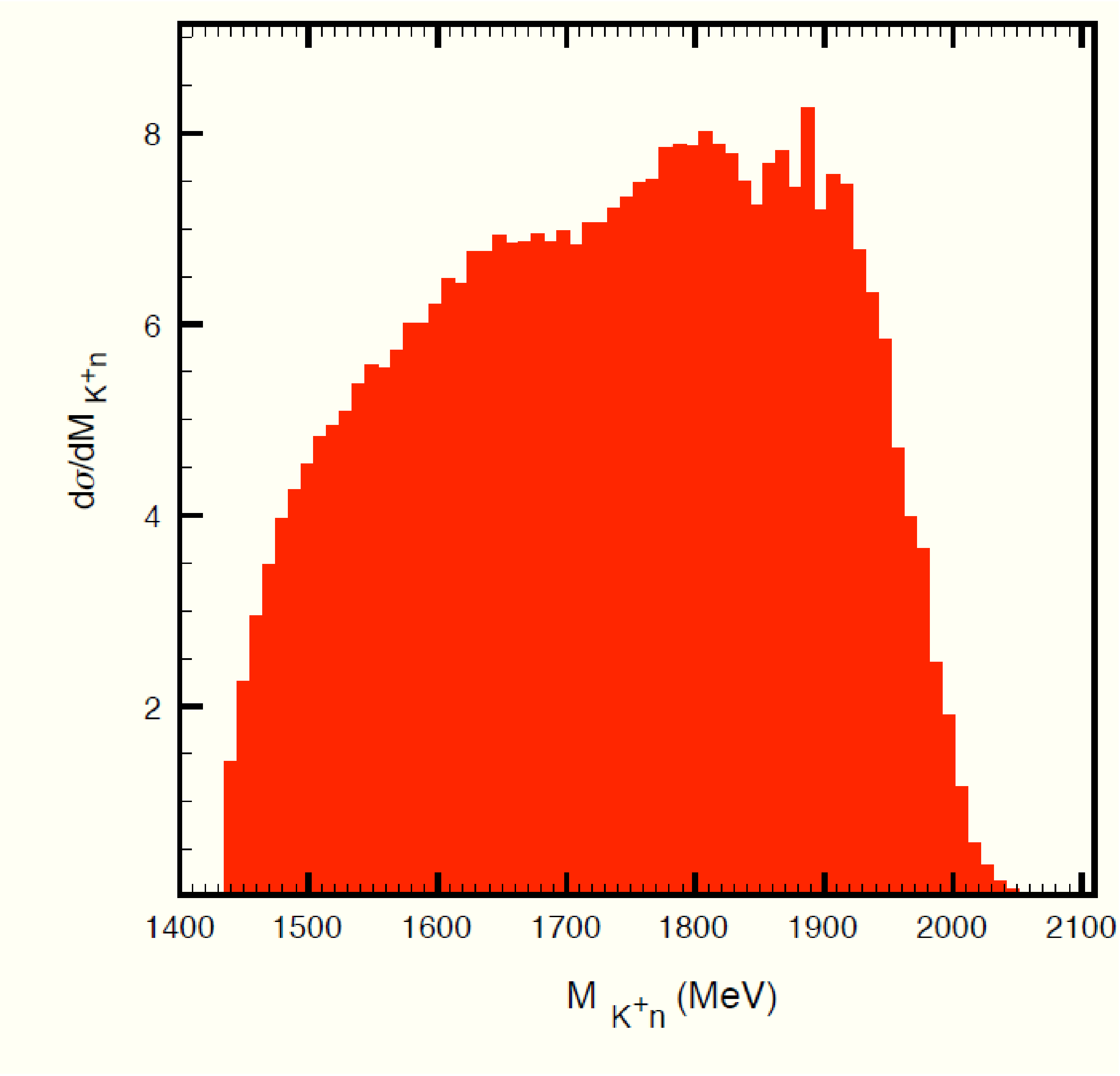
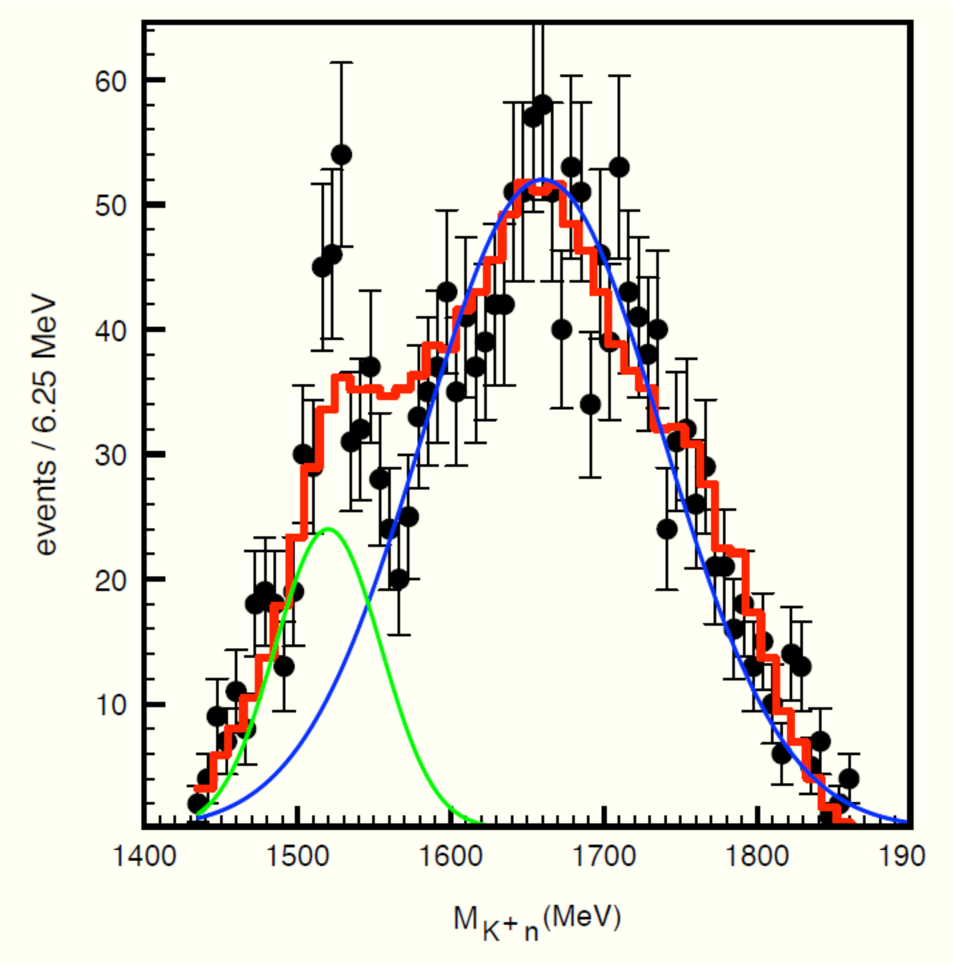
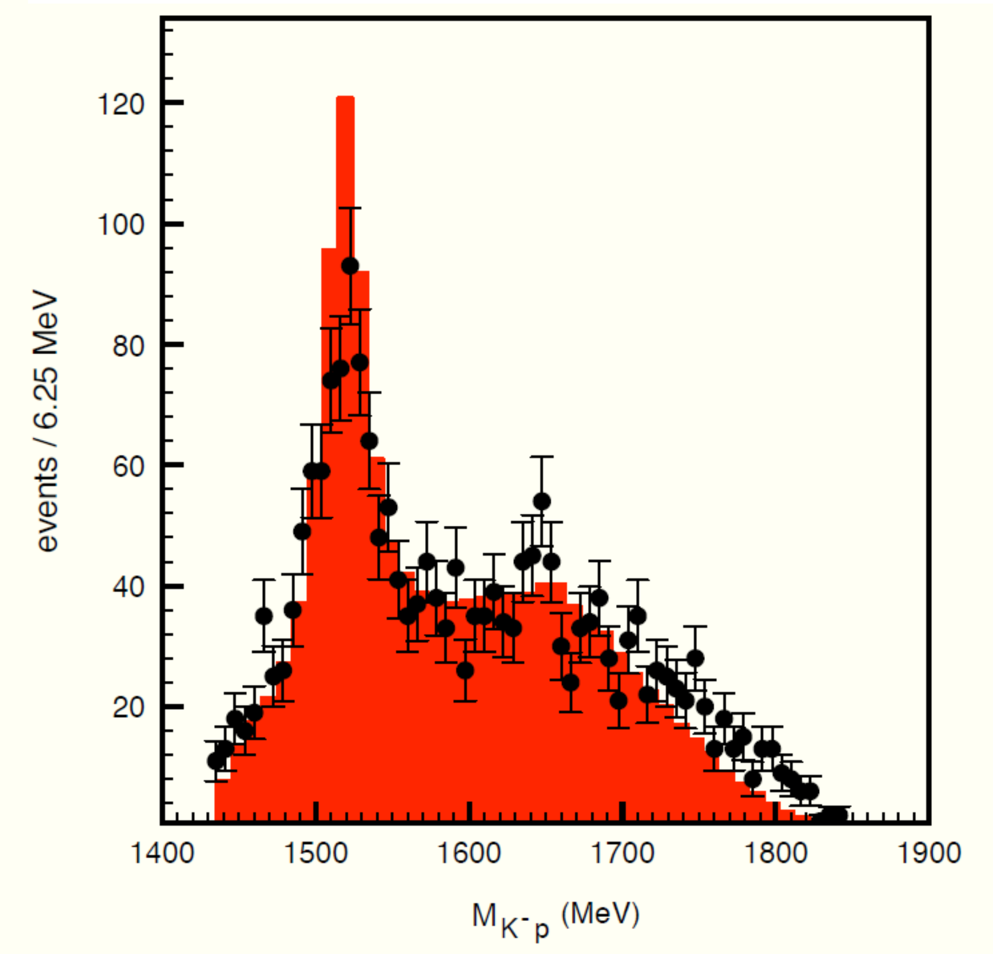


FIG. 2: M_{K+n} invariant mass distribution calculated using the real momenta and with a ϕ cut of $M_{K+K-} > 1050$ MeV.

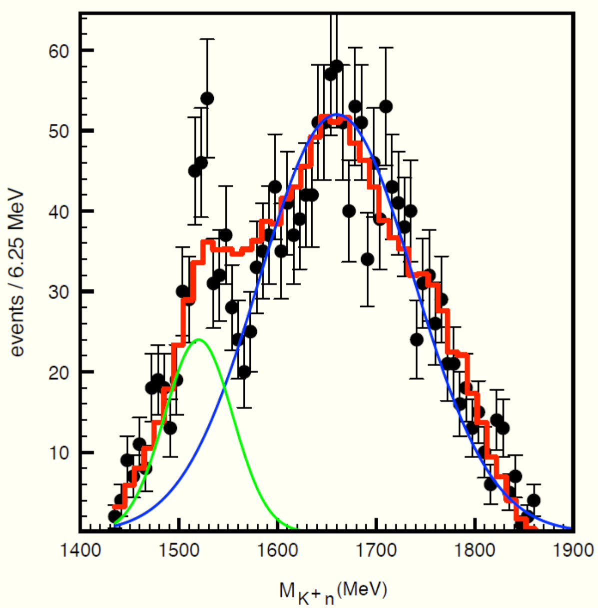
Inv. Mass distributions for $K^+ n$ and $K^- p$, using the MMSA, normalized to data





Red curve: large statistics theoretical curve with the cuts of LEPS and the MMSA prescription

Red area: theoretical prediction with LEPS cuts and MMSA prescription



60
50
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events / 6.25 MeV
1400
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1600
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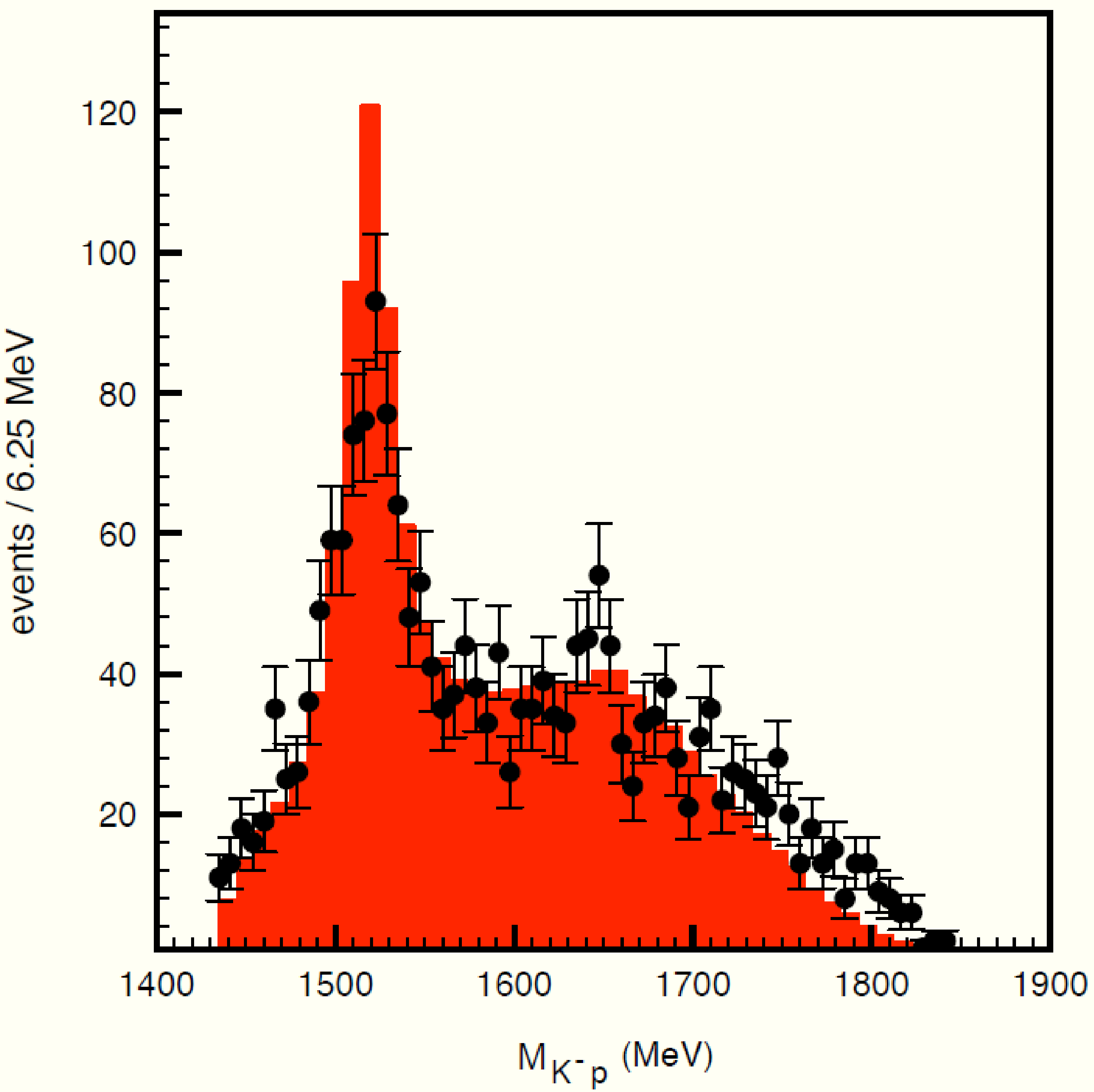
M_{K^+n}(MeV)



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events / 6.25 MeV
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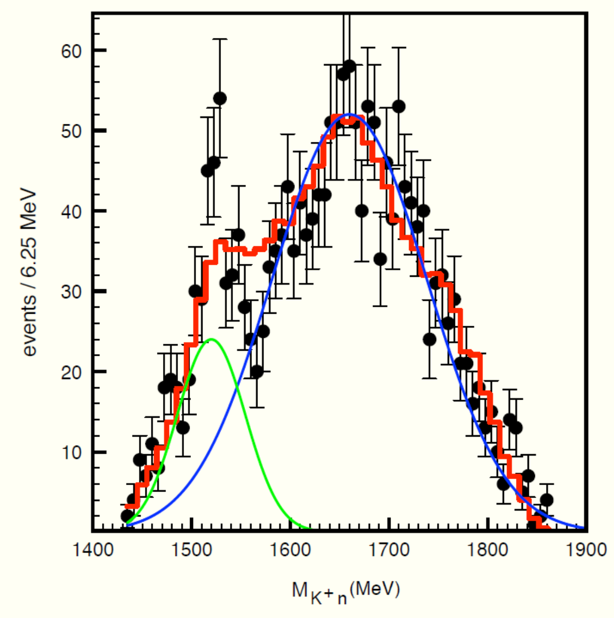
1900
M_{K^-p} (MeV)


events / 6.25 MeV
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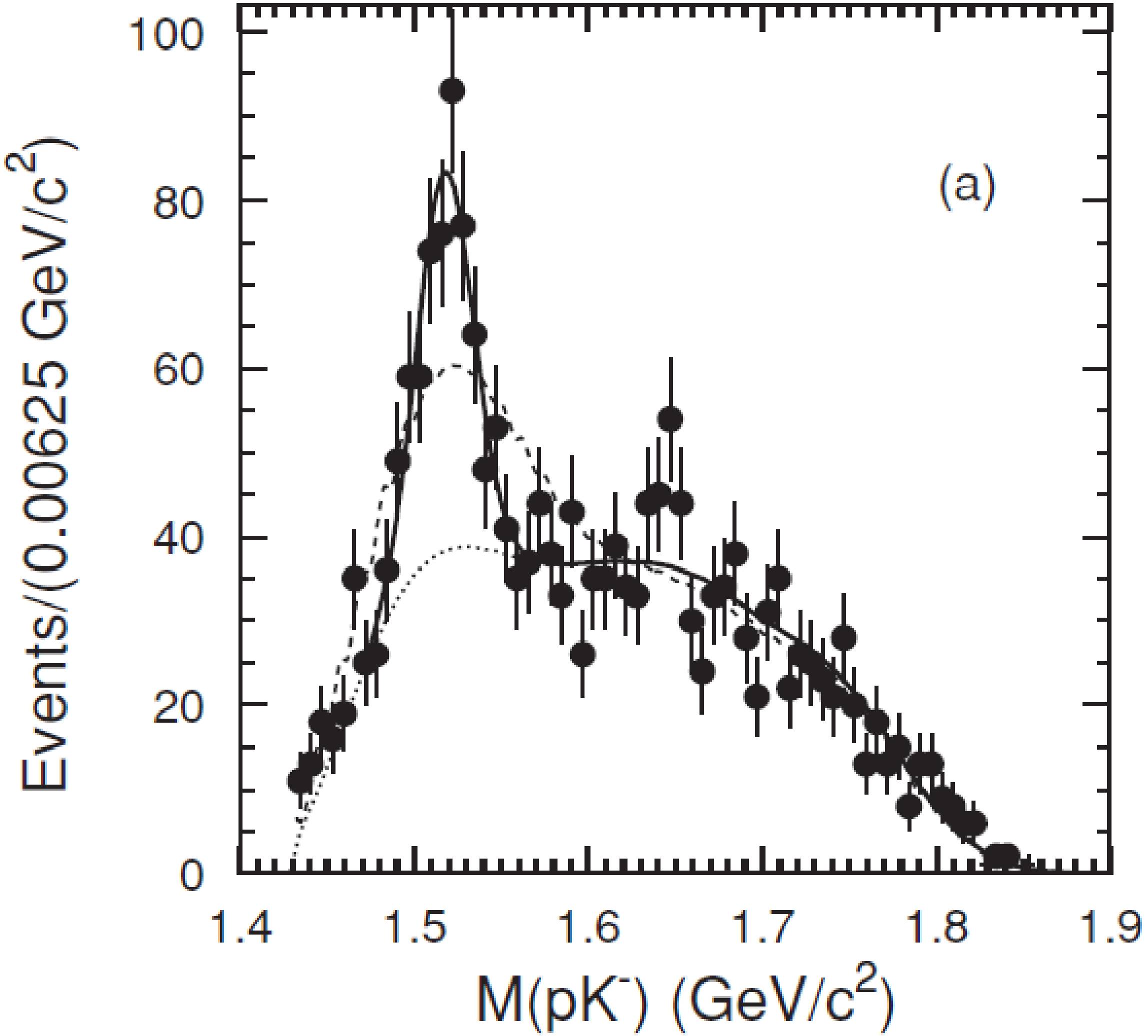
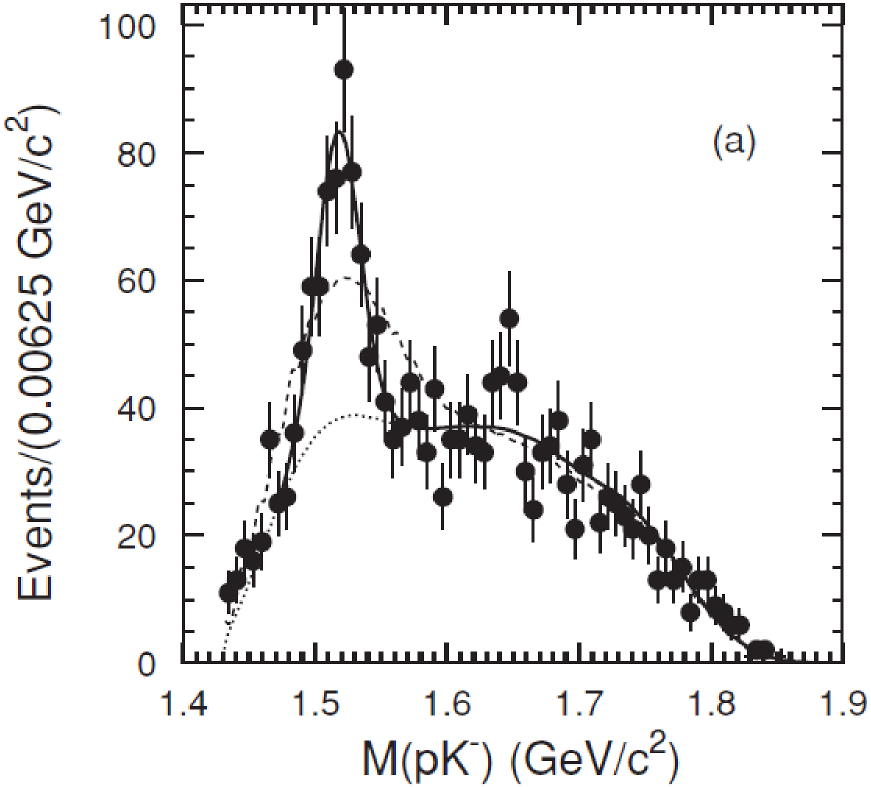
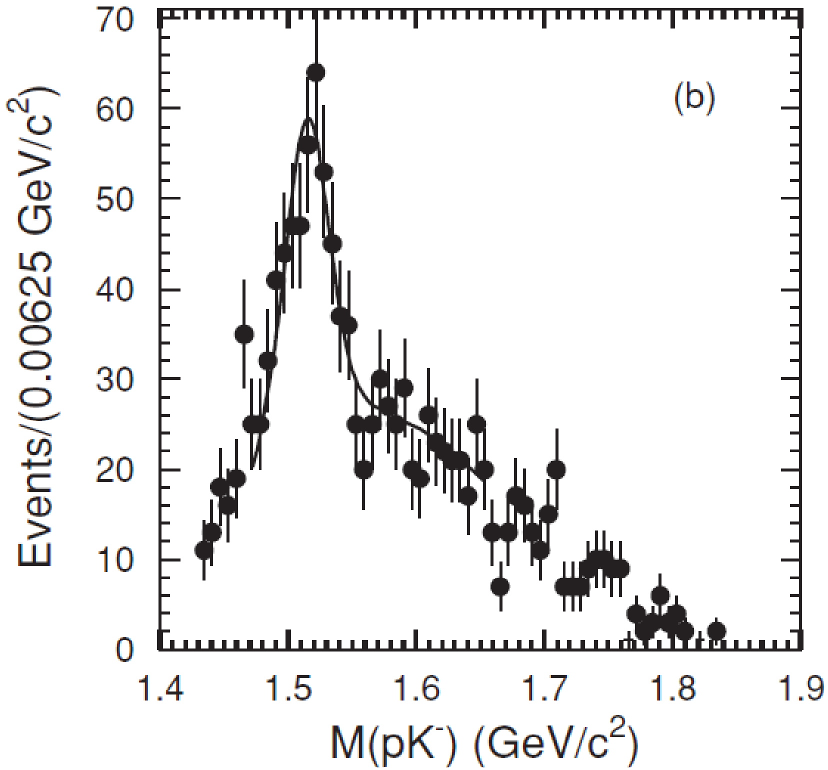
M_{K^+n}(MeV)


Events/(0.00625 GeV/c^2)
0
20
40
60
80
100
(a)
1.4
1.5
1.6
1.7
1.8
1.9
M(pK$^-$) (GeV/c^2)

Effect of the change of cuts





Standard LEPS cut

$M(K^+K^-) > 1.05 \quad \mathrm{GeV}/c^2$

Event production simulations with the Von Neumann method

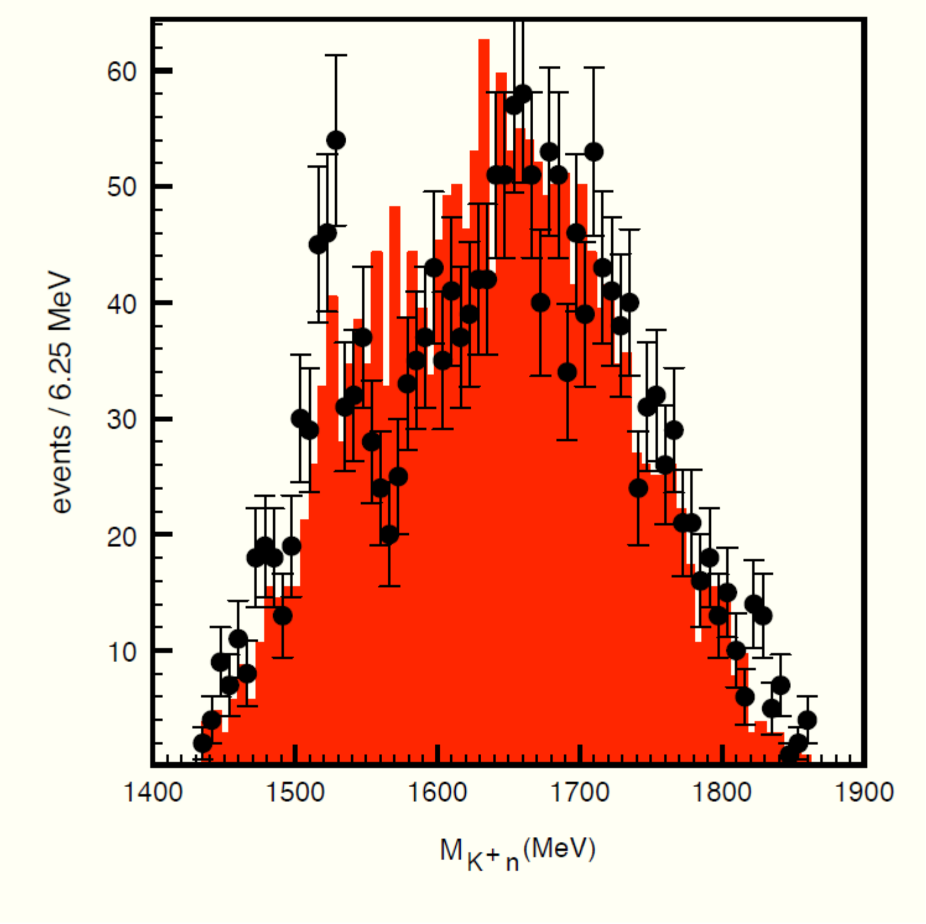


FIG. 5: M_{K^+n} invariant mass distribution calculated with $\sim$ 2000 events, the MMSA prescription and the cut $M_{K^+K^-} >$ 1030 MeV compared with the experimental data of [6] (shown as dots in the figure).

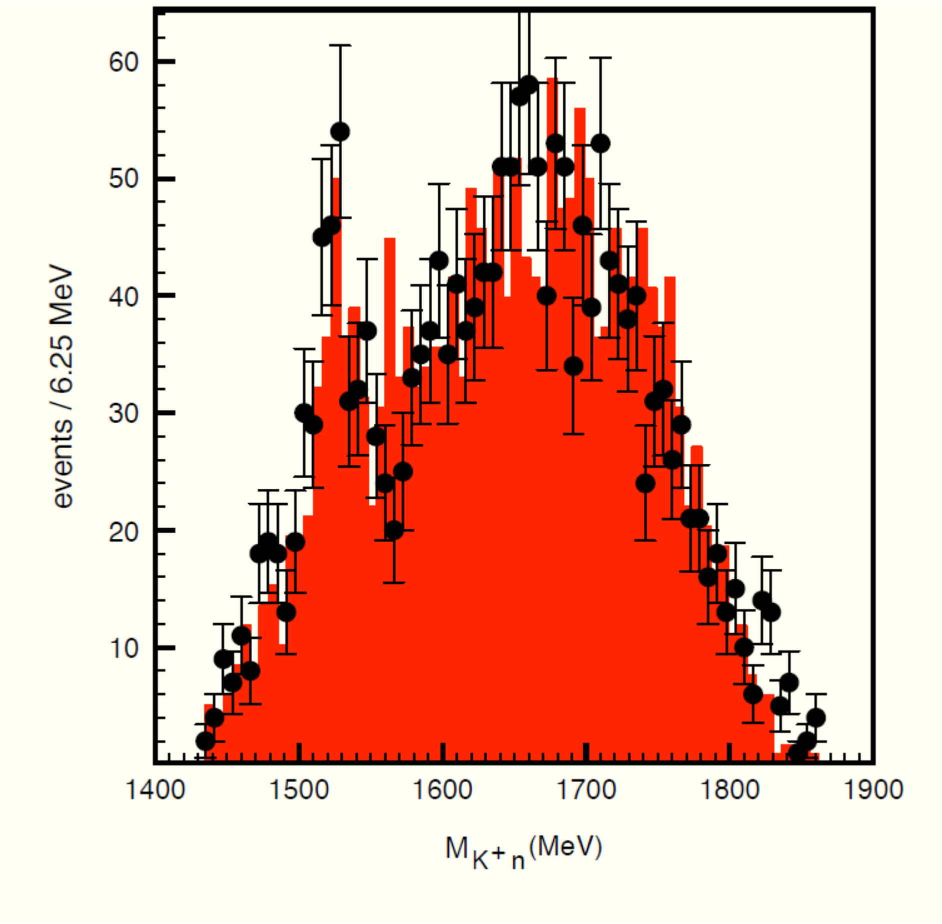


FIG. 6: M_{K^+n} invariant mass distribution calculated with $\sim$ 2000 events and the same cuts as those made in [6] compared with the experimental data of [6] (shown as dots in the figure).

Conclusions

We found that the LEPS set up leads unavoidably to a (broad) peak for the $K^+ n$ invariant mass distribution around 1530 MeV.

The limited statistics of LEPS, 2000 events, leads to fluctuations. The measurement of the $K^- p$ distribution shows the size of the fluctuations and they are large enough to justify the “extra” strength of the LEPS peak in the $K^+ n$ mass around 1530 MeV on top of the “exact” distribution.

We also showed how it is possible to get peaks or make them disappear by changing the cuts.

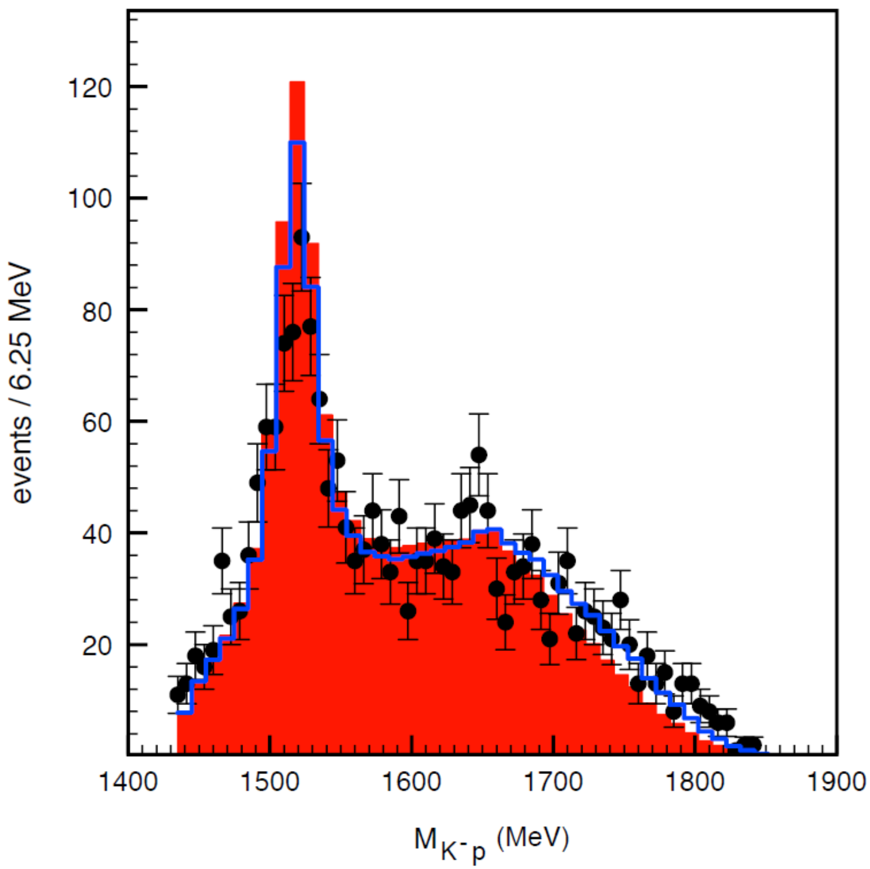
Is there a “Θ^+ pentaquark”?

This is not the right question,

The right question is: Can one claim evidence for the “Θ^+”from the LEPS experiment, as was done in the paper of PRC (2009)?

The answer, after the present work, is clear: NO

The case in favour of the Θ^+ from the LEPS reaction is lost after the findings of the present work .



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events / 6.25 MeV
1400
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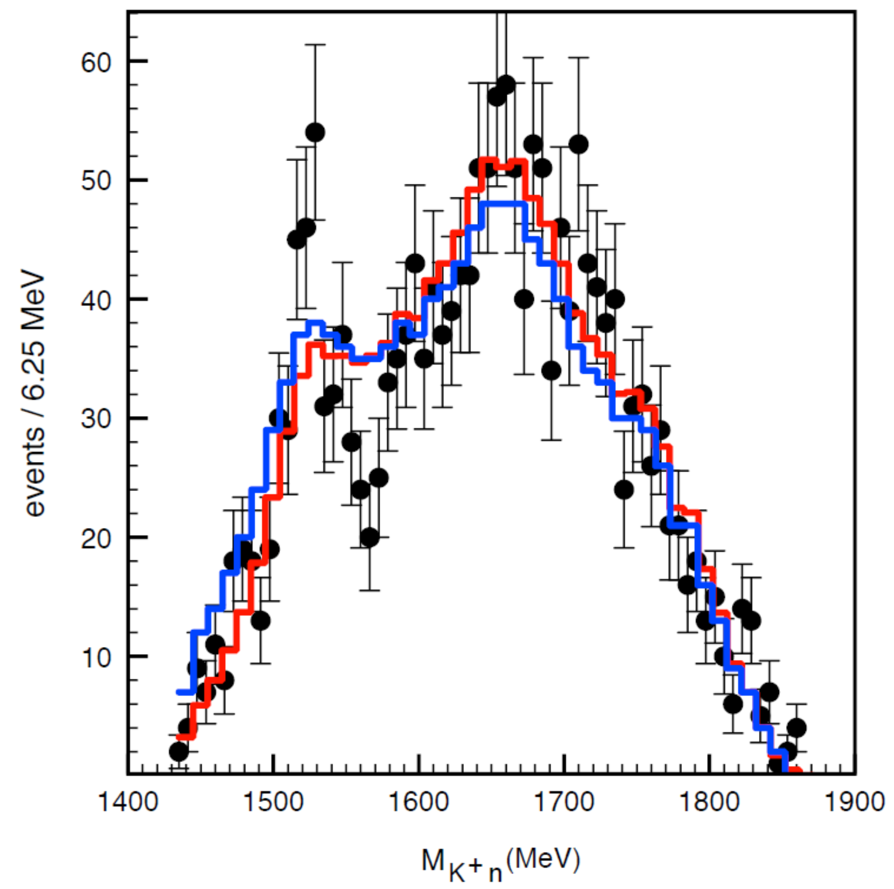
M_{K^-p} (MeV)



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events / 6.25 MeV
1400
1500
1600
1700
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1900
M_{K^+n}(MeV)

$\Theta^+(1540)$

R.I.P.

Requiescat in pacem

For non latin people: let it rest in peace

Eulogy

Its life was short but exciting. It showed theoreticians that they knew less about hadron structure than they thought they knew.

It showed us all that with determination you can always get what you want, but in science this is treacherous, because you can also get what does not exist.