History and Geography of Light Pentaquark Searches: Challenges and Pitfalls

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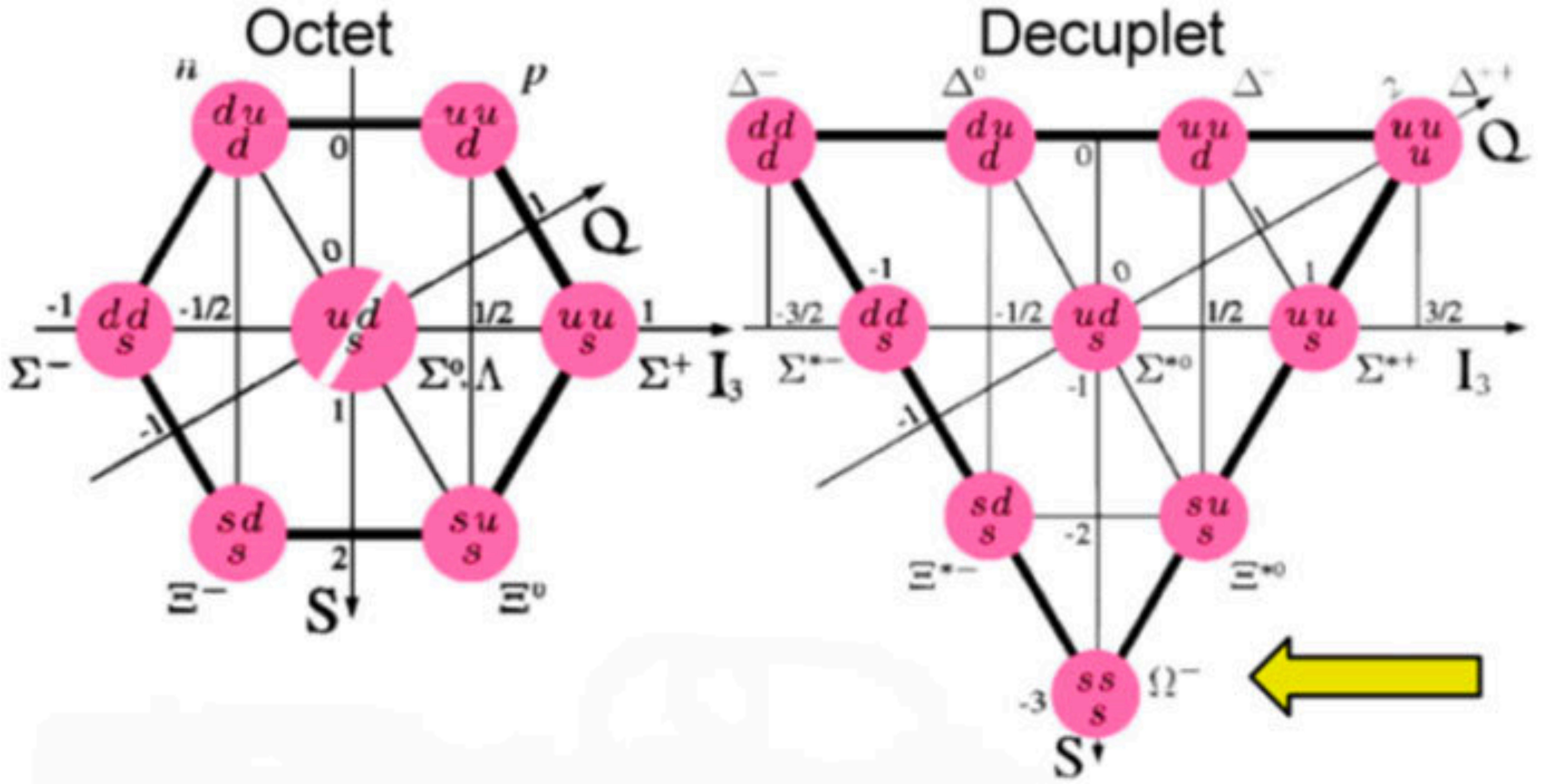
Outlook

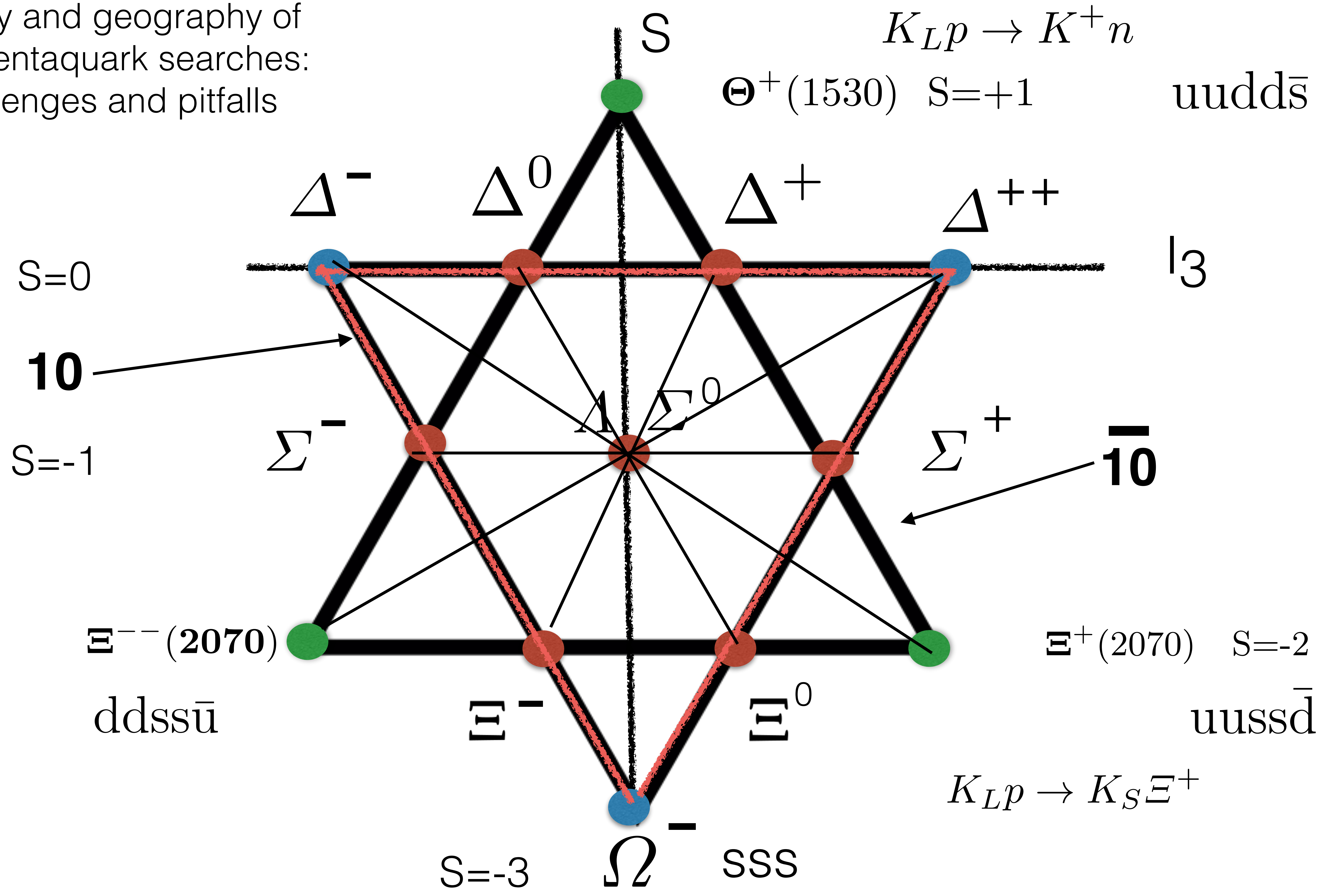
Introduction
Positive Claims
Negative Claims
What to Do Next
KLF at Jlab
Summary



Gell-Mann, PL 8, 1964

Pentaquarks

Eur. Phys. J. Plus (2022) 137:684, M.Amaryan
History and geography of light pentaquark searches: challenges and pitfalls



D. Diakonov, V. Petrov and M. V. Polyakov, Z. Phys. A **359**, 305 (1997).

Where Θ^+ was searched for?

Since 2003 almost all particle and nuclear physics collaborations have been involved,
About few thousand physicists !
~1000 (or more) papers are published!

USA: CLAS, ?
BABAR, D0,
HyperCP,
STAR, PHENIX

Europe:
SAPHIR, COSY,
HERMES, ZEUS,
H1, HERA-B,
NOMAD, ALEPH

Russia:
DIANA,
SVD,
Dubna,
SPHINX

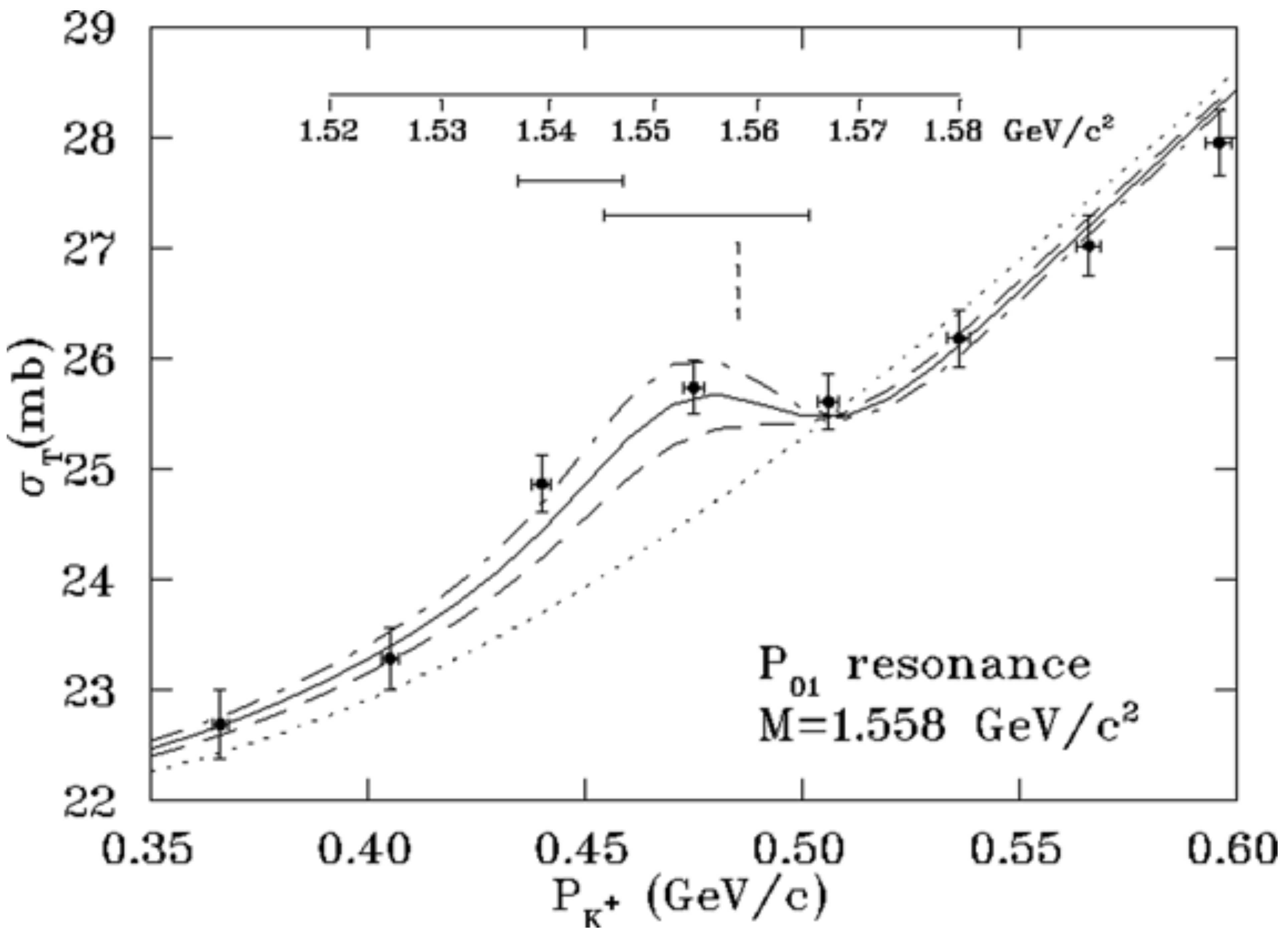
China:
BES

Japan:
SPRING-8
BELLE

1992 Particle Data Group Review

The evidence for [pentaquark]1 resonances was reviewed in our 1976 edition . . . However, the results permit no definite conclusion-the same story heard for 20 years. The standards of proof must simply be more severe here than in a [scattering reaction] in which many resonances are already known to exist. The skepticism about baryons not made of three quarks, and the lack of any experimental activity in the area, make it likely that another 20 years will pass

K+d Scattering Data from



T.Bowen et al., Rev. D 2, 2599-2608

However, the possibility of a resonance peak would be more believable if a second set of data for K+d scattering in this mass range were available for confirmation. Unfortunately, no other data exist, and it will likely be years until new data are taken for this reaction since the only accelerator facility in the world
that could do this is J-PARC in Japan

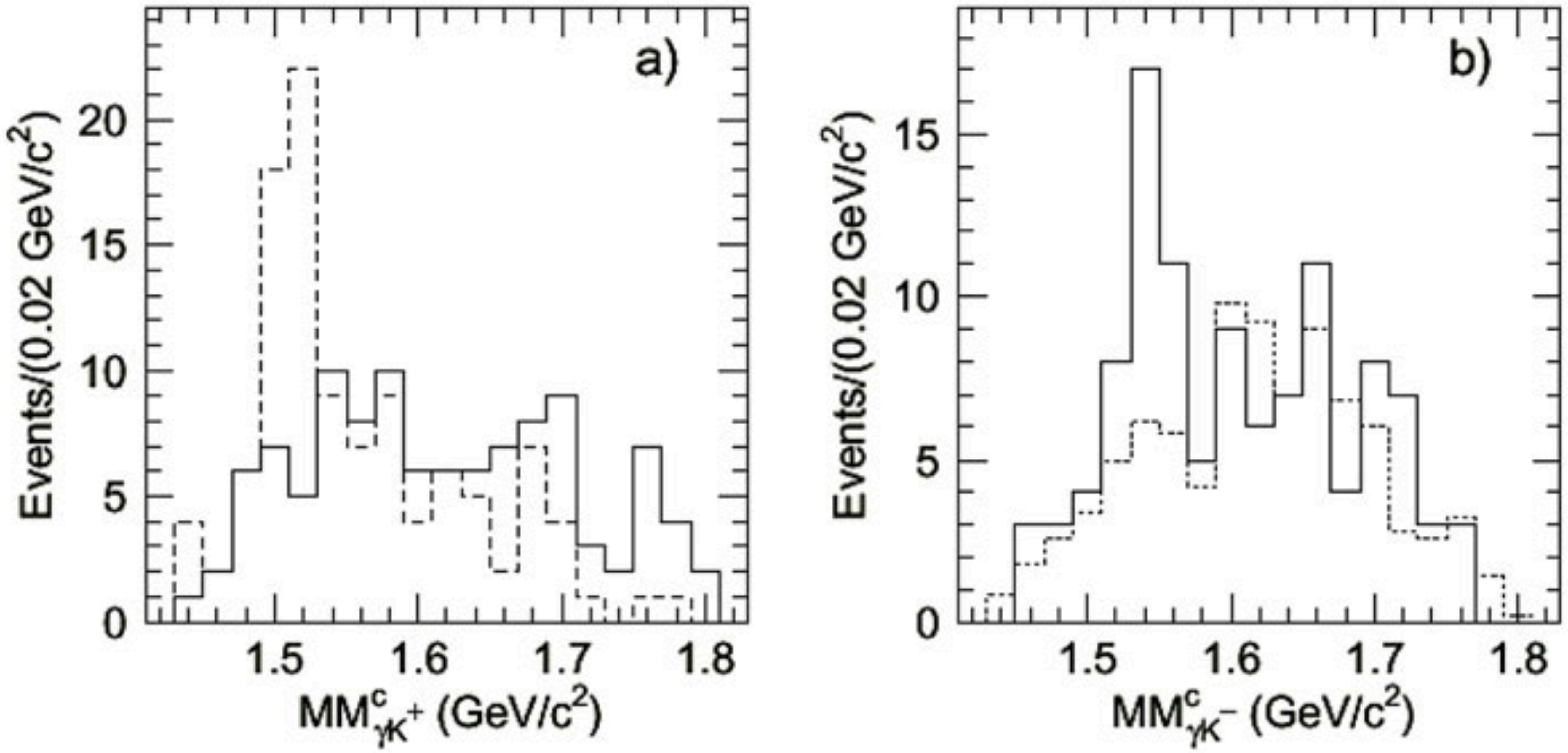
K.Hicks, Eur. Phys. J. H 37, 1–31 (2012)

We’ll come back to this later in this talk

New Era

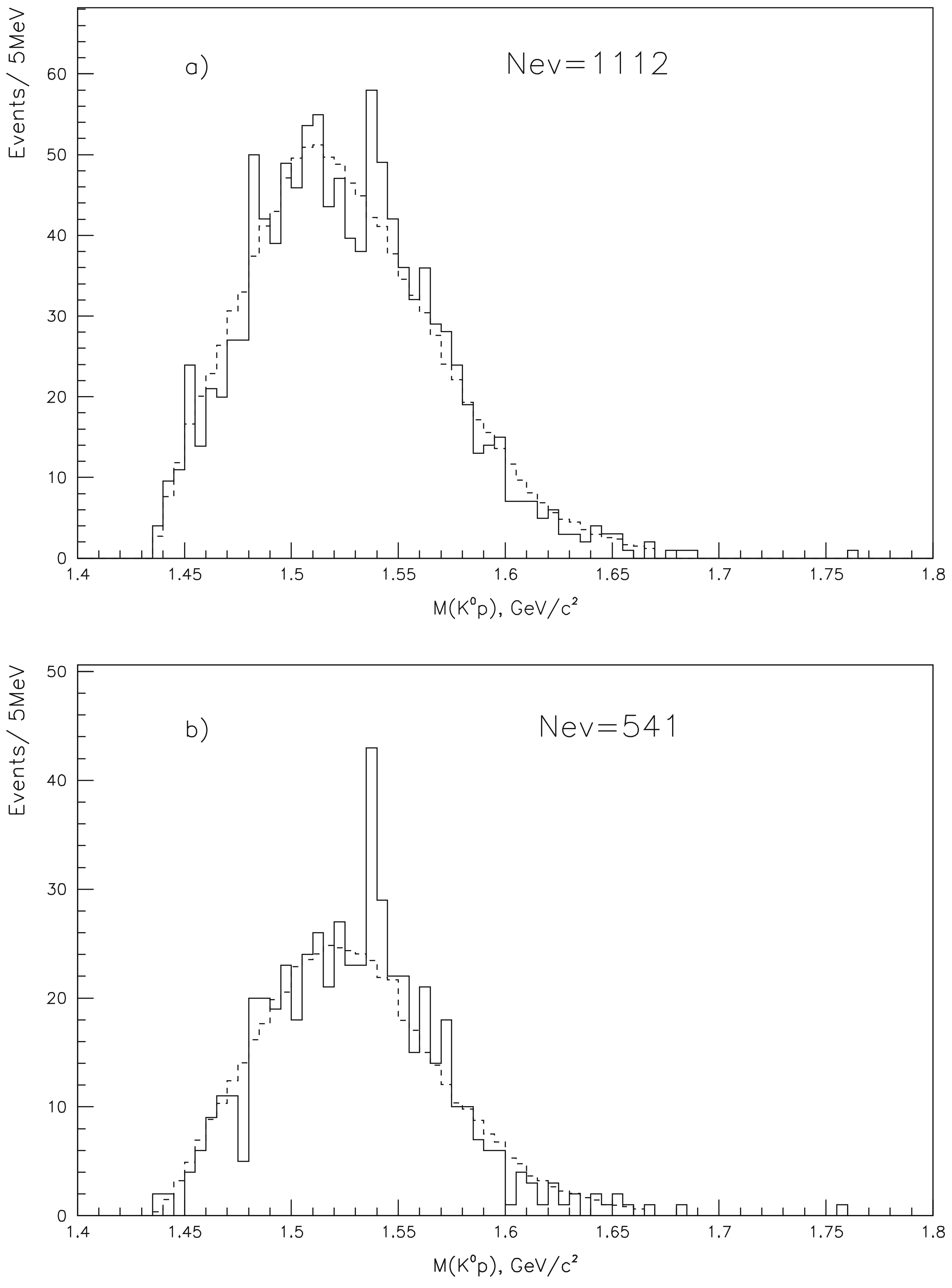
LEPS in Japan

T. Nakano et al. (LEPS), Evidence for a Narrow S = +1 Baryon Resonance in Photoproduction from the Neutron, Phys. Rev. Lett. 91, 012002 (2003)



Mass spectra for the reaction γC → K+K−X where X is the undetected recoil nucleus, from reference [23]. A peak for the well-established Λ(1520) is shown in the dashed histogram of the left panel, and for the purported Θ+ by the solid histogram of the right panel.

DIANA at ITEP



M(K0p)

V.V. Barmin et al. (DIANA), Observation of a baryon resonance with positive strangeness in K+ collisions with Xe nuclei, Phys. Atom. Nucl. 66, 1715-1718 (2003); Yad. Fiz. 66, 1763 (2003)

CLAS at Jlab

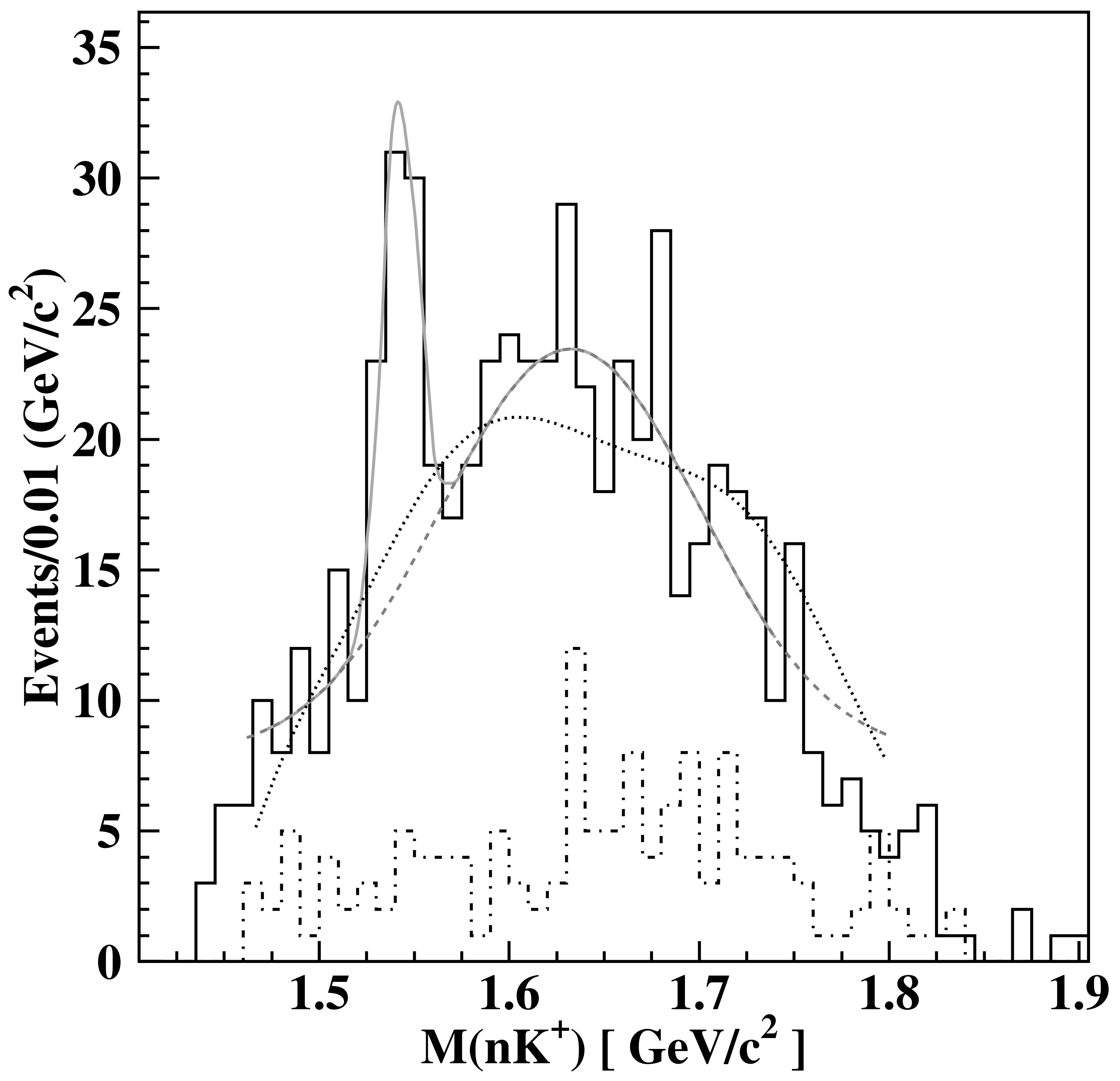


Fig. 6. Mass spectra for the reaction γd → K+K−p(n). where the invariant mass of the K+n system has been plotted. The curves show various estimates of the background shape, alongwith a Gaussian curve at the Θ+ peak. The dotted histogram is background associated witha known resonance (the Λ(1520)).

S. Stepanyan et al. (CLAS), Observation of an Exotic S = +1 Baryon in Exclusive Photoproduction from the Deuteron, Phys. Rev. Lett. **91**, 252001 (2003)

Various Experiments

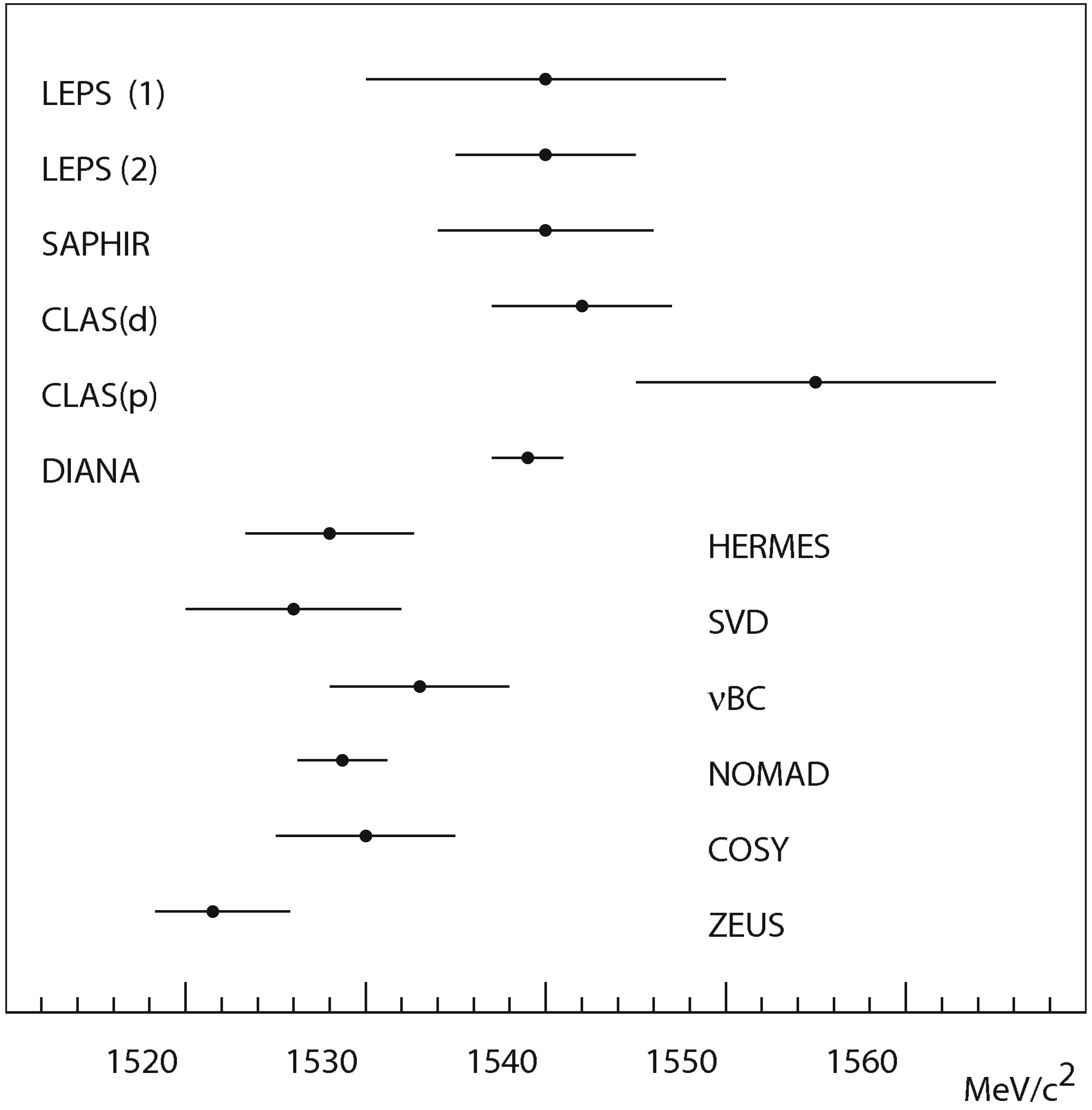
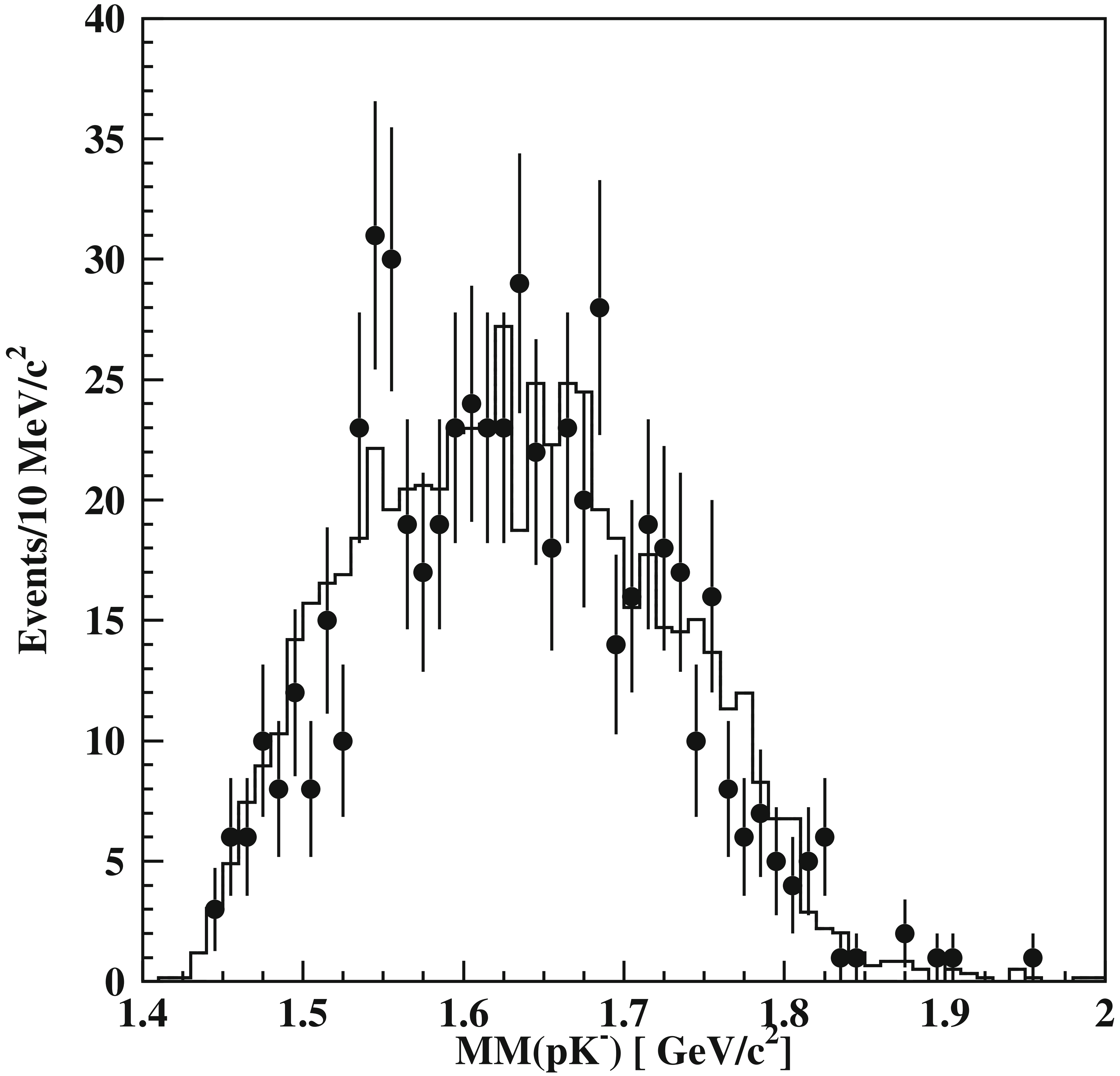


Fig. 13. Mass of the Θ^+ peak reported by various experiments (listed by collaboration name) along with the quoted uncertainty shown by the error bar (figure reproduced from Ref. [50]).

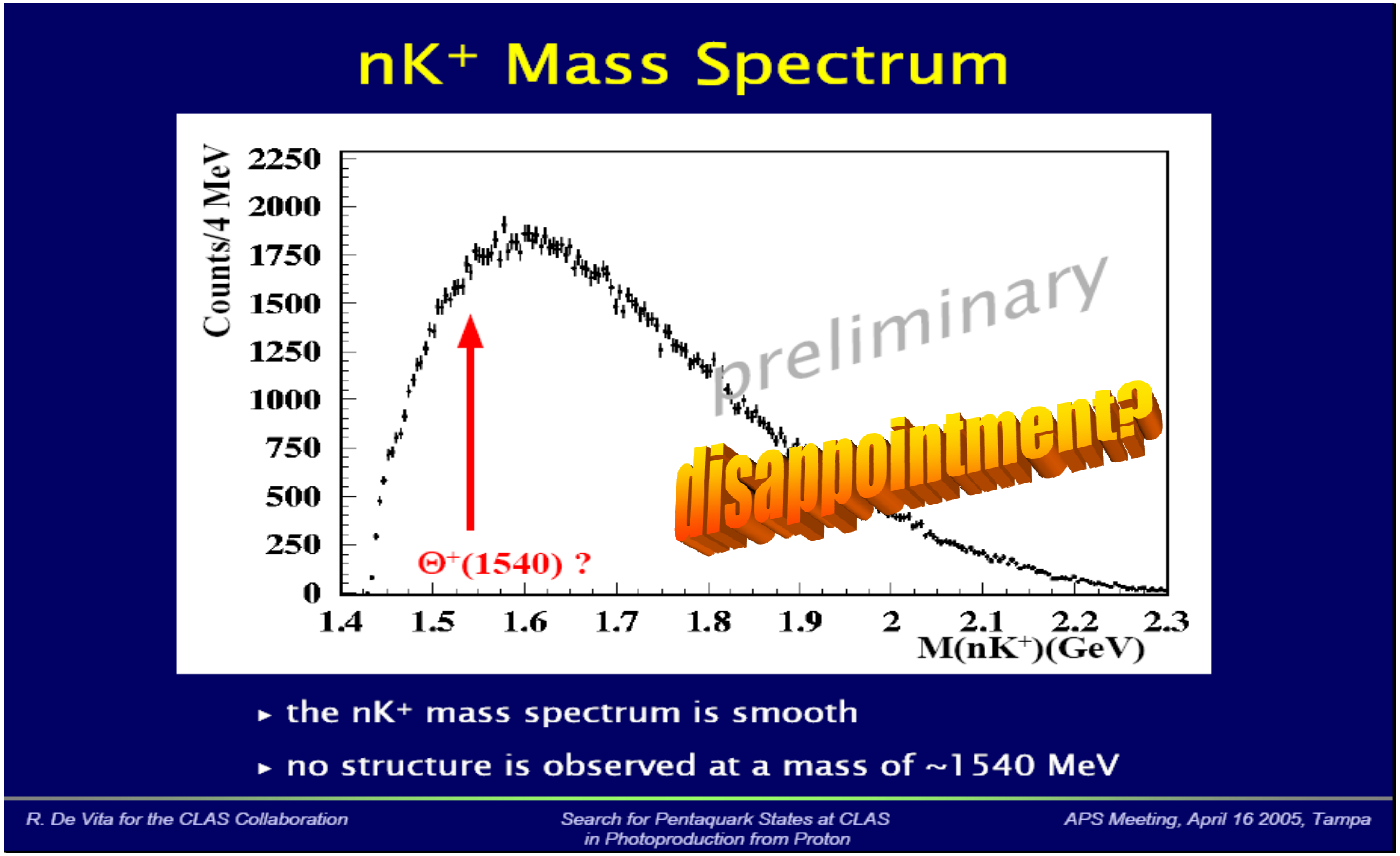
More details from Hicks's Review

What happened next ?



In 2004 CLAS measured the same reaction on a deuteron
with high statistics (~6 times higher) plotted as a histogram
with no sign of the peak

CLAS at Tampa 2005

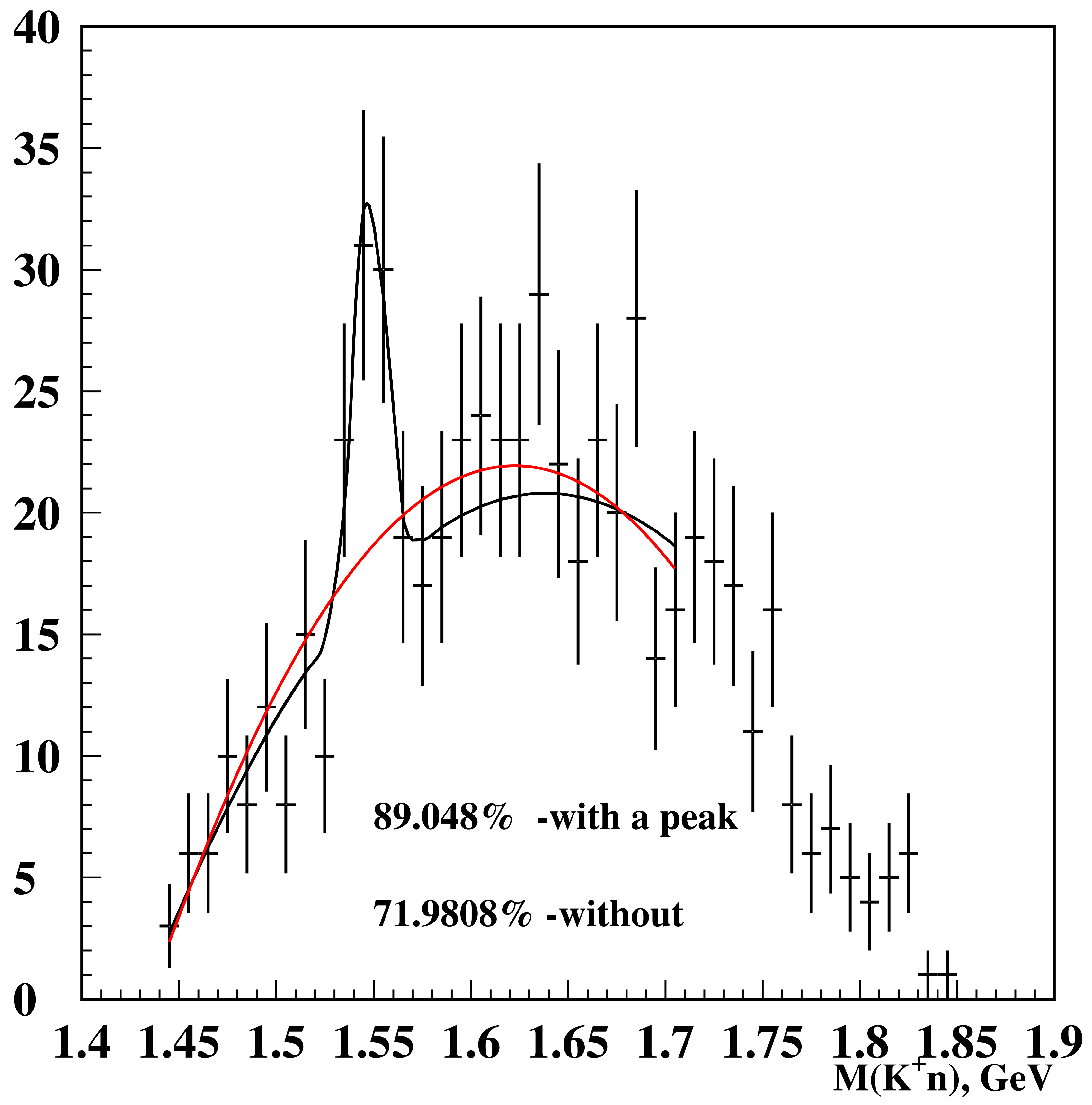


Since then the fate of Θ^+ was decided, but was it justified?

This is the question.

Was the claim statistically significant?

Fig. 4 Kolmogorov–Smirnov tests performed for the "peak hypothesis" and the "null hypothesis" show the confidence level of both assumptions



M. Amaryan Eur. Phys. J. Plus (2022) 137:684

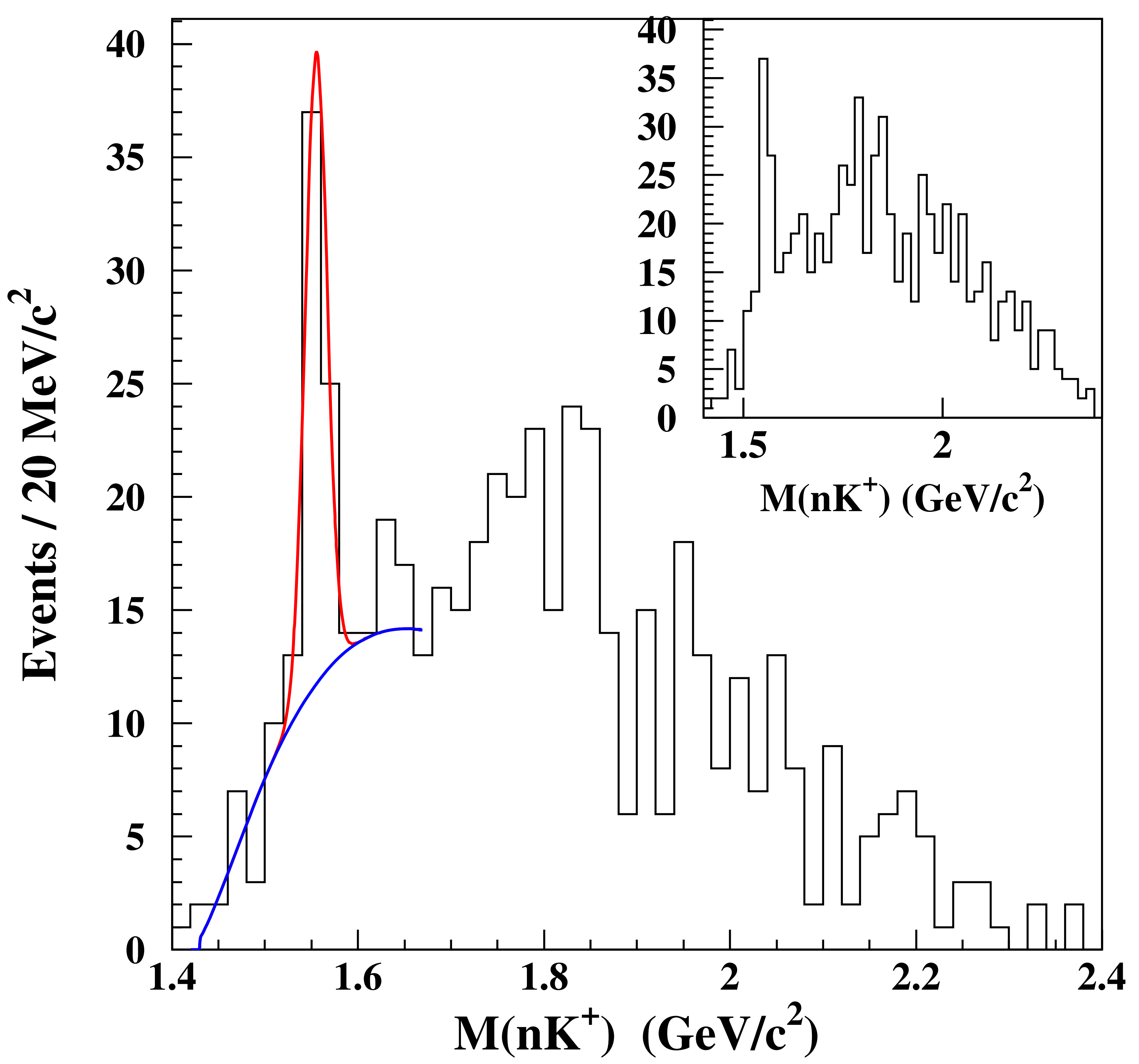
History and geography of light pentaquark searches: challenges and pitfalls

Where we stand?

- **The CLAS has set up an upper limit for the cross section**
- Many experiments do not see a signal, but should they see it?
- Some previous positive results still hold
- Is the case closed?
- Can we increase sensitivity to the tiny cross section ?
- What must be done in order to convince ourselves in existence or in absence of the resonance ?

(Slide from my talk at the CLAS Coll. Meeting in Feb. 2012)

Fig. 5 nK^+ invariant mass spectrum. For details about cuts applied, see Ref. [8]



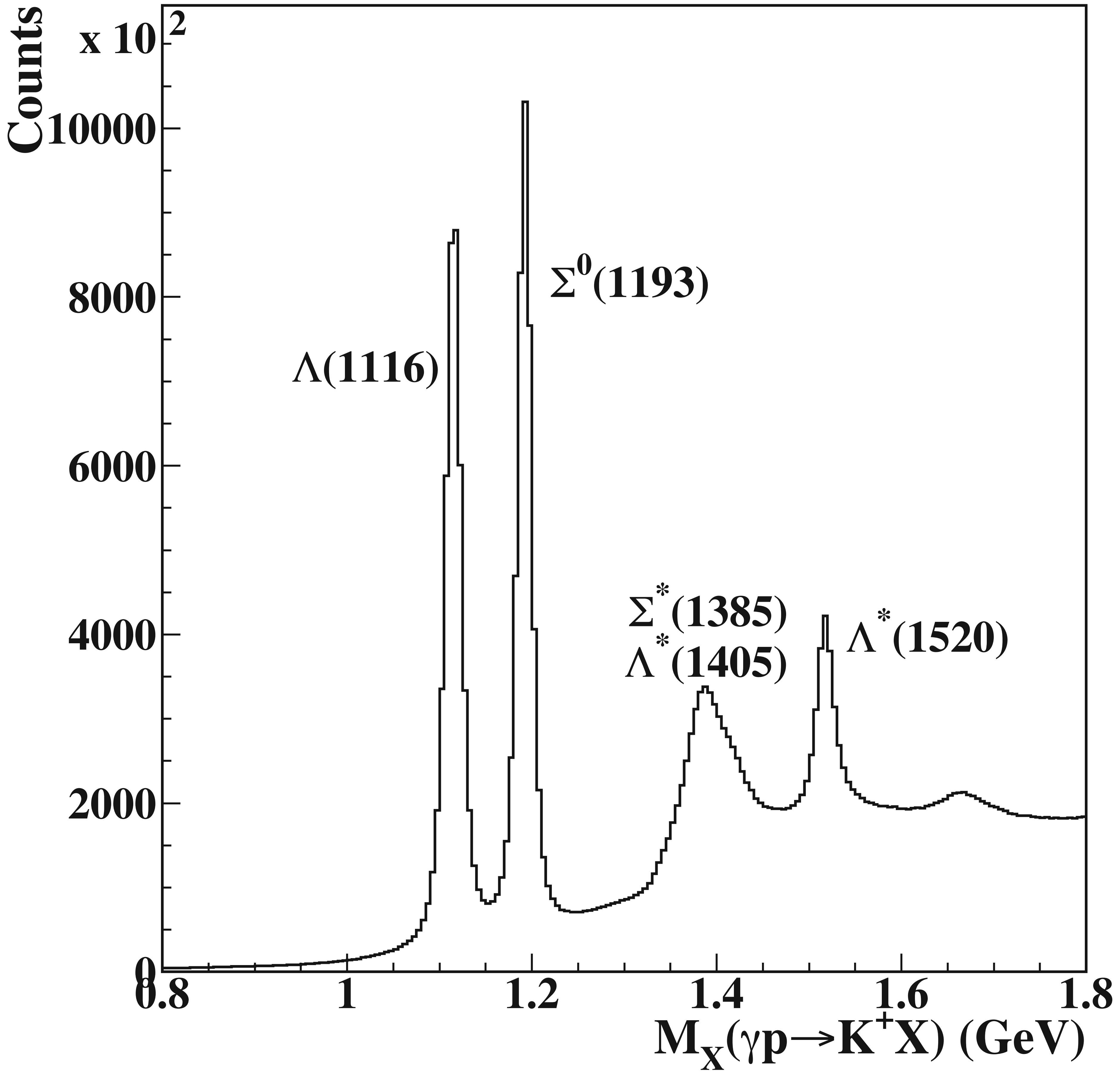
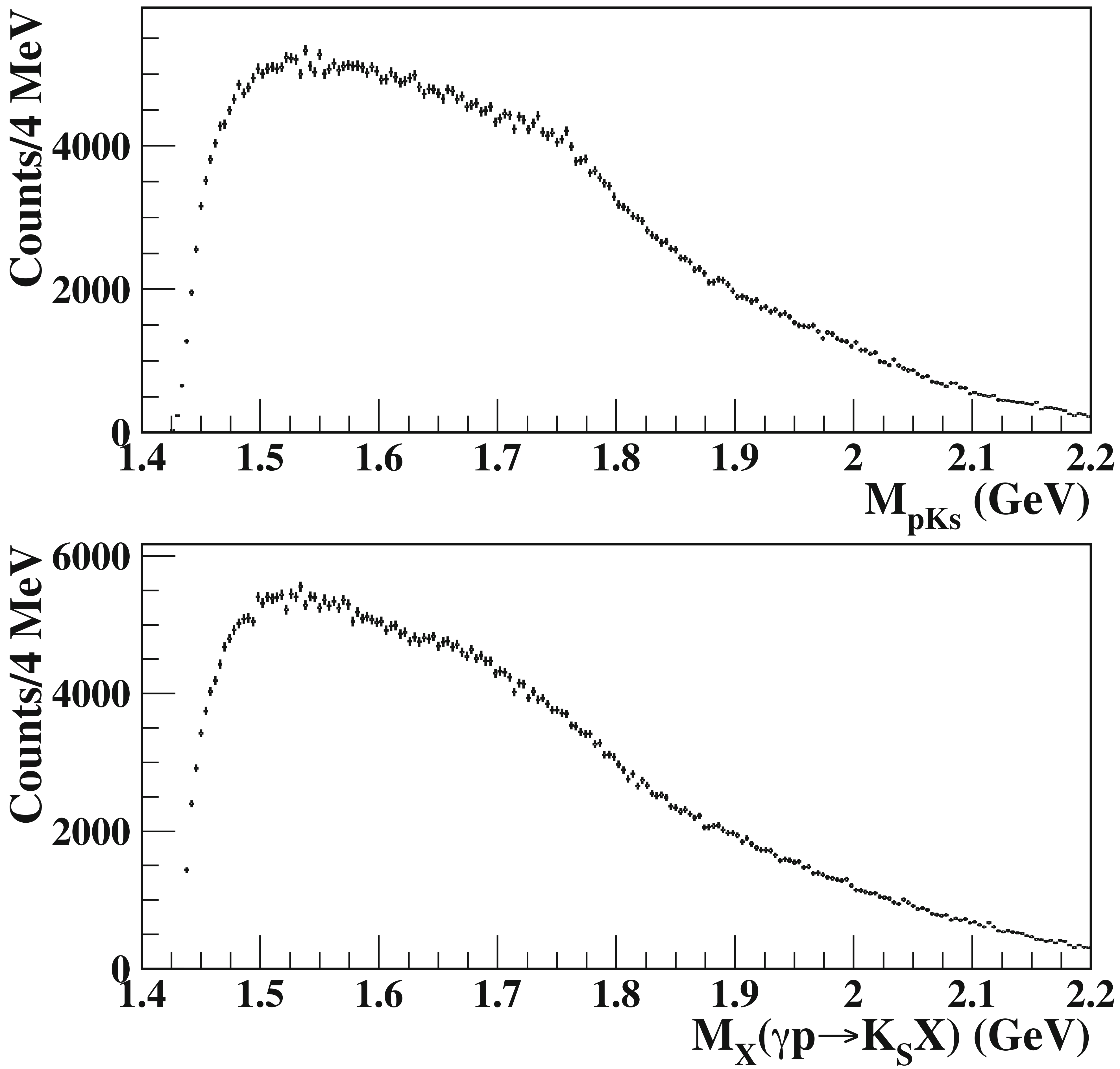


Fig. 6 Missing mass of K^+. See Ref. [20] for more details

20. R. De Vita, C.L.A.S. Collaboration et al., Phys. Rev. D **74**, 032001 (2006).

Fig. 8 pK_S invariant mass (top) and K_S missing mass (bottom) for the reaction $\gamma p \to \bar{K}^0 K^0 p$ after all cuts, see [20] for more details



The 2009 PDG Review rewritten by Wohl states:

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.

So the fate of the pentaquark was decided to not exist, but was it justified?

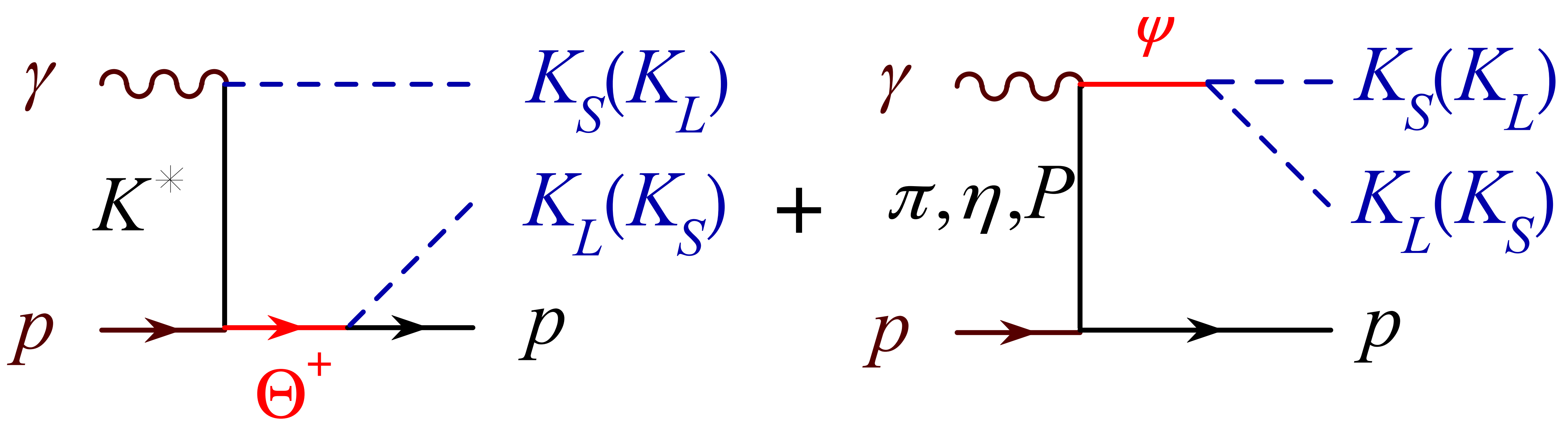
What can be studied in photoproduction?

$$\gamma + d \to K^+ K^- pn$$
$$\gamma + p \to K^+ \pi^+ K^- n$$
$$\gamma + p \to \bar{K}^0 K^+ n$$
$$\gamma + p \to \bar{K}^0 K^0 p$$

How about reflections? Did anybody care?

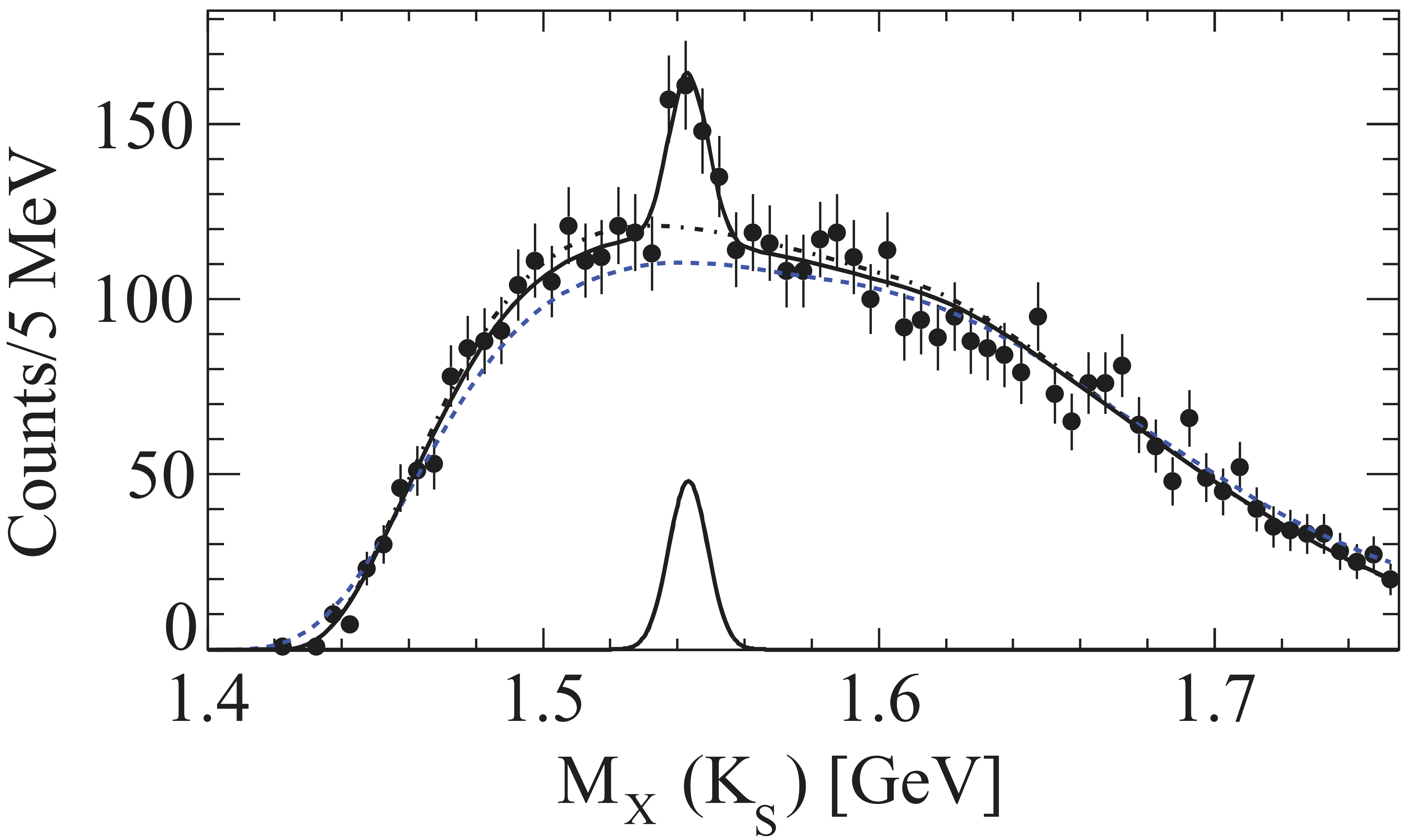
Only partially!

Interference



24. M. Amarian, D. Diakonov, M.V. Polyakov, Phys. Rev. D **78**, 074003 (2008)

Fig. 10 Missing mass of K_S. The dashed line is the result of the photoproduction of the ϕ meson Monte Carlo. The dashed–dotted line is a modified Monte Carlo distribution, and the solid line is the result of a fit with a modified Monte Carlo distribution plus Gaussian function

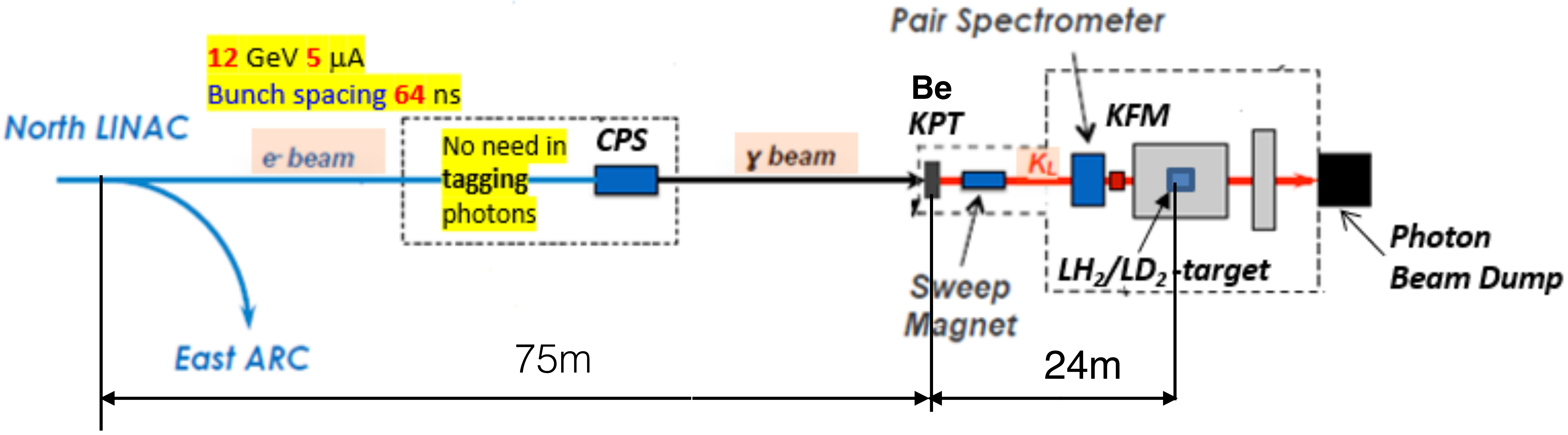


25. M.J. Amaryan et al., Phys. Rev. C **85**, 035209 (2012)

K-long Facility at Jlab (KLF)

Approved by PAC in 2020 for 200 days of beam time

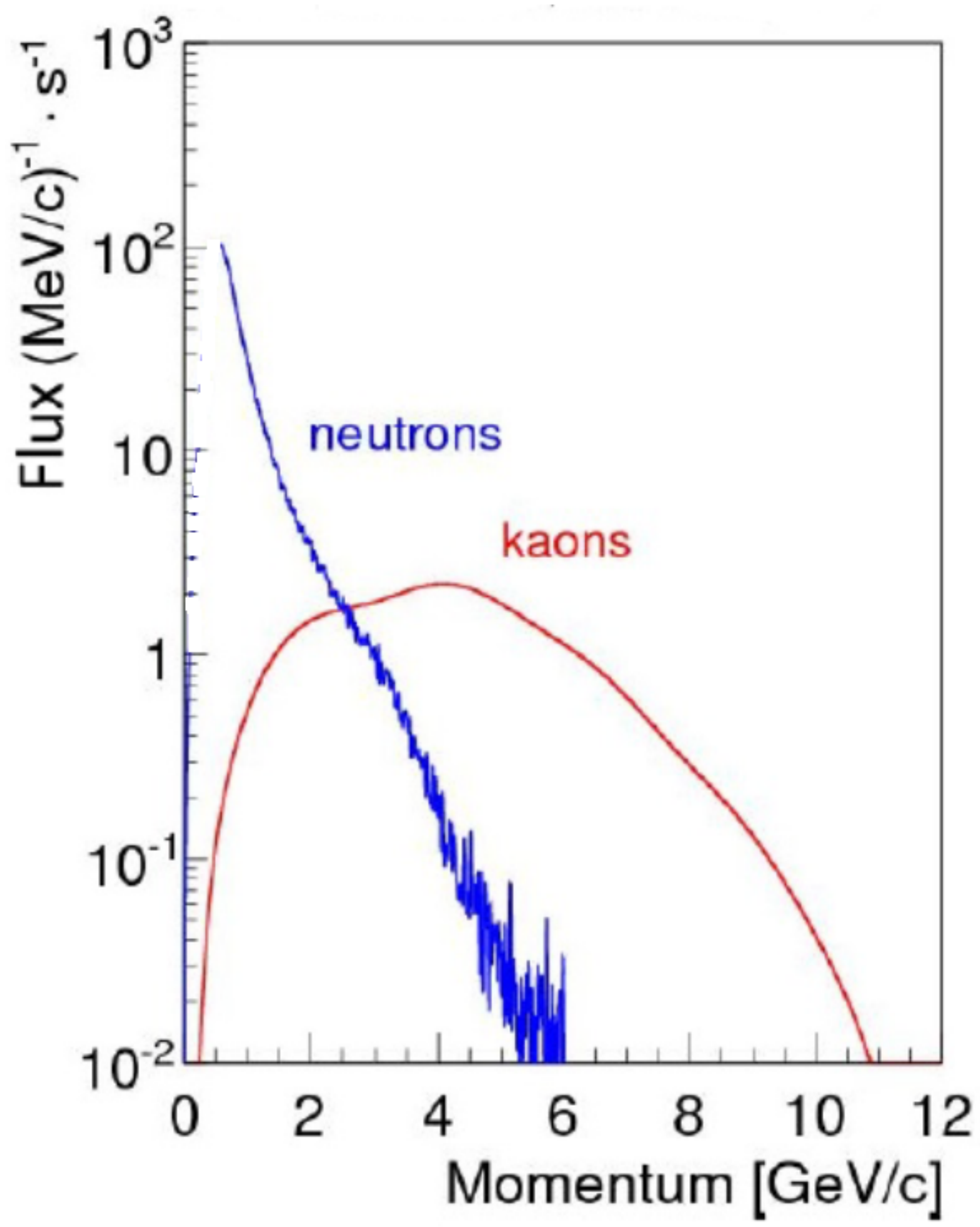
Hall-D beamline and GlueX Setup



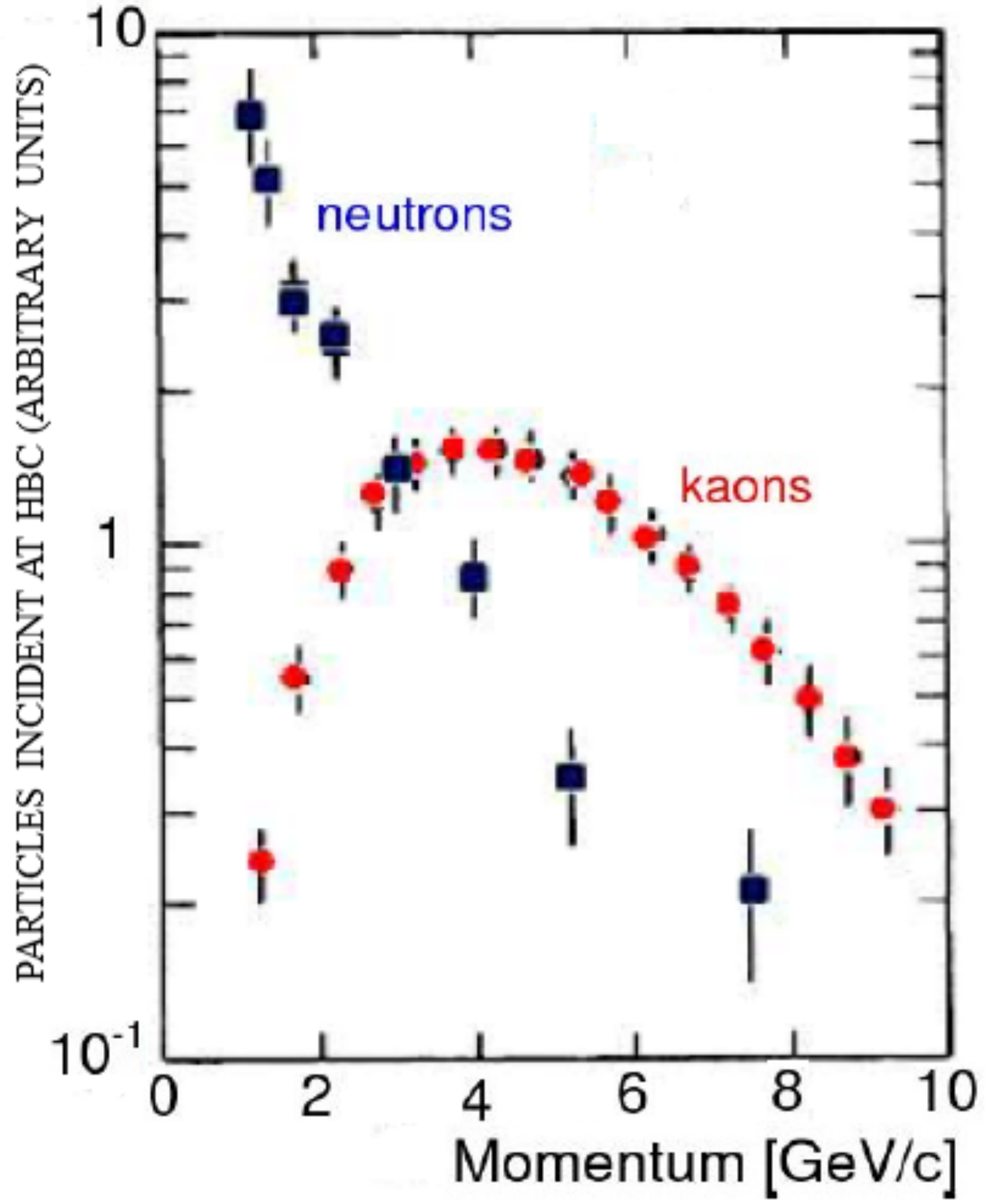
https://arxiv.org/pdf/2008.08215.pdf

K_L Beam Flux

JLab 12 GeV



SLAC 16 GeV



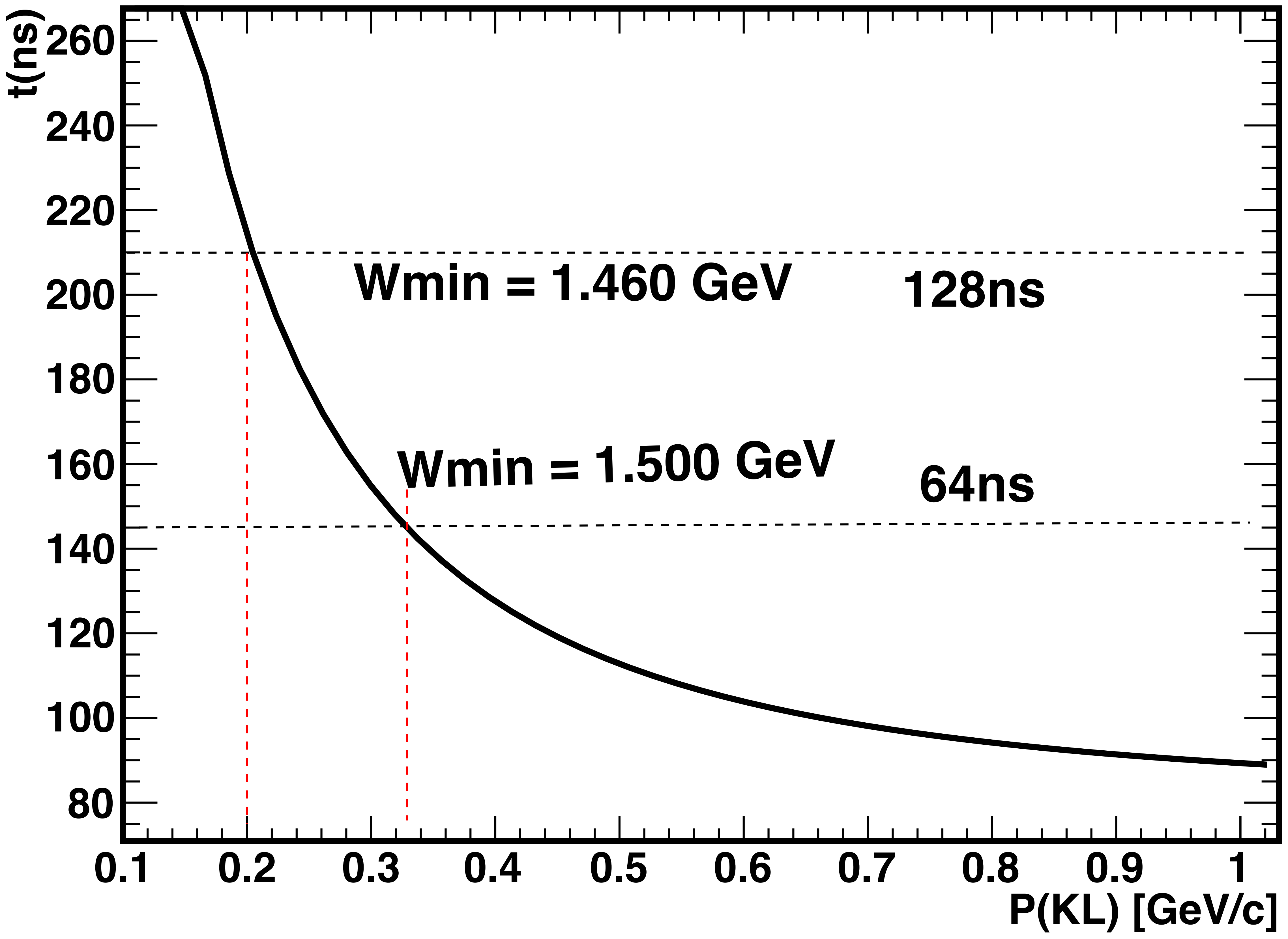
$$N(K_L)/sec \sim 10^4 \rightarrow \frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

Electron Beam Parameters

$E_e = 12\ GeV$ $\quad$ $I = 5\ \mu A$

Bunch spacing $\quad$ $64\ ns$

128 ns confirmed feasible



5.7 K_L Momentum Determination and Beam Resolution

The mean lifetime of the K_L is 51.16 nsec ($c\tau = 15.3$ m) whereas the mean lifetime of the K^- is 12.38 nsec ($c\tau = 3.7$ m) [1]. For this reason, it is much easier to perform measurements of K_Lp scattering at low beam energies compared with K^-p scattering.

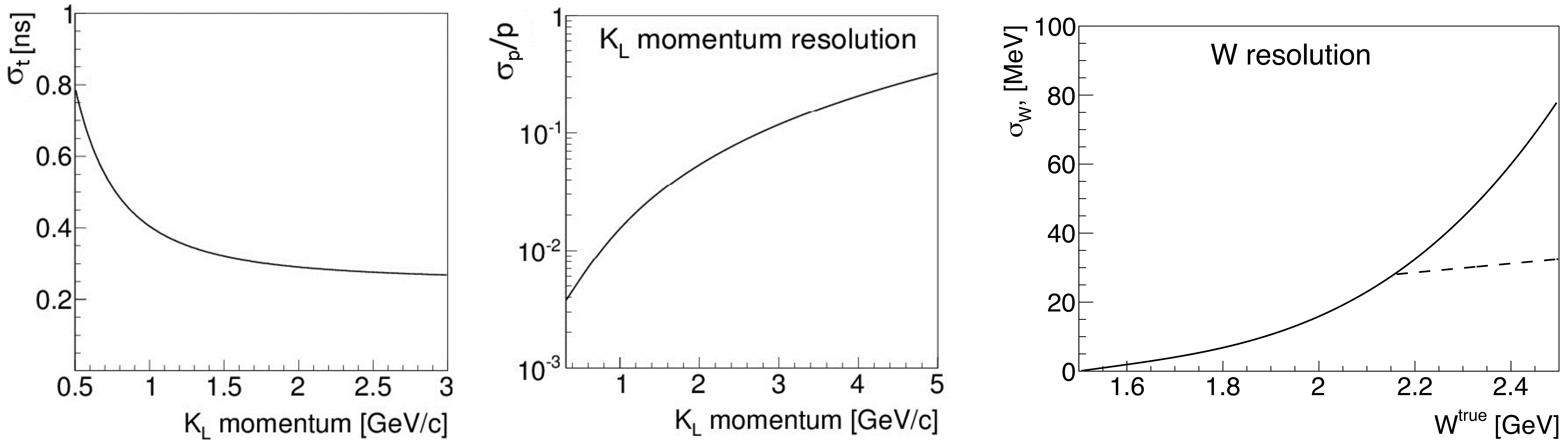
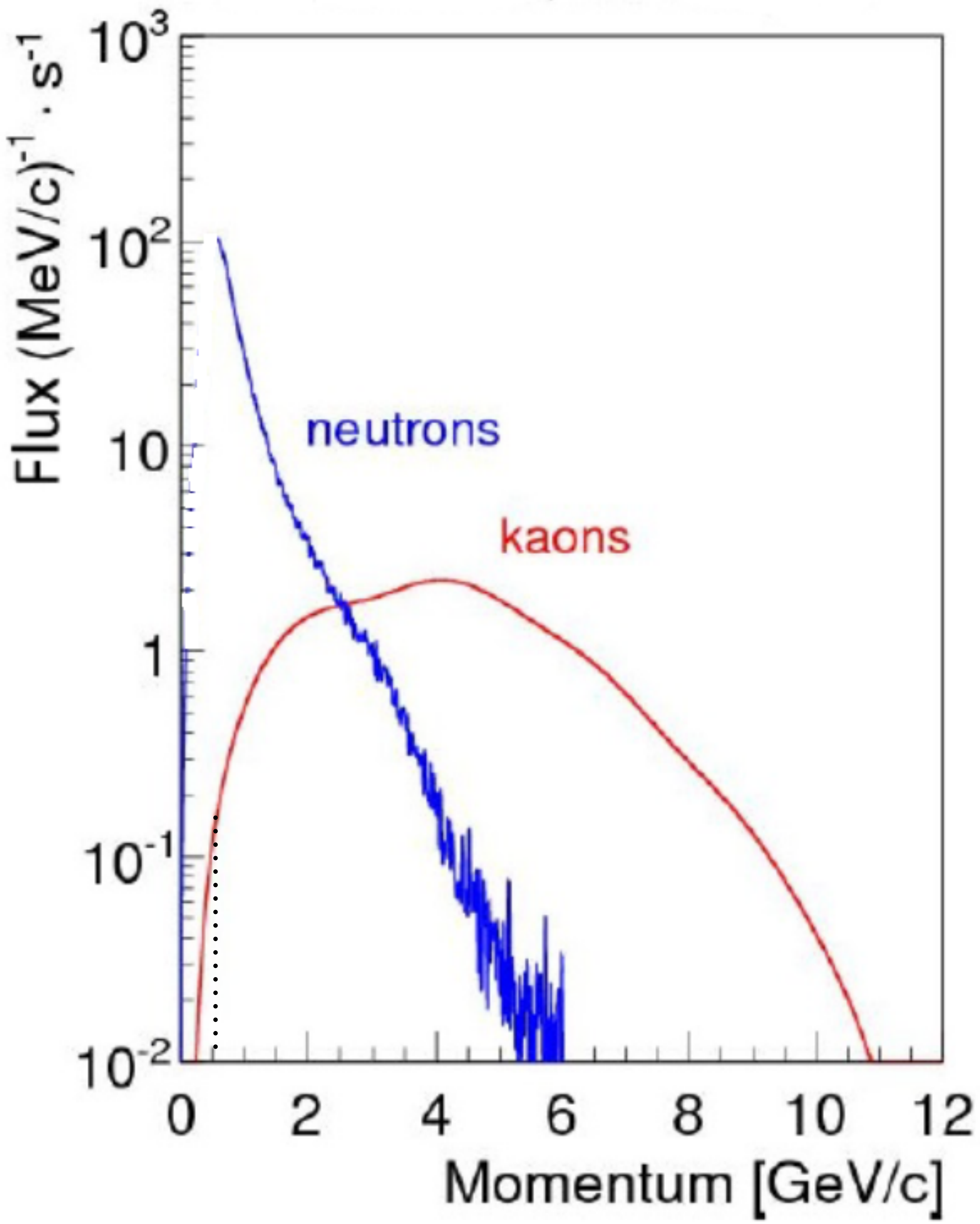


Figure 30: Left: Time resolution (σ_t) for K_L beam as a function of K_L-momentum. Middle: Momentum resolution (σ_p/p) as a function of momentum (note, log scale). Right: Energy resolution (σ_W) as a function of energy. The dashed line shows approximate W resolution from reconstruction of the final-state particles.

I refer to the following Fig.23 in KLF proposal. Here we have about 0.1K_L/s at 0.45 GeV/c in 1MeV bin. This means 0.9M K_L/100 days ~1M K_L/100 days



Number of H atoms in the GlueX Target is 0.09x40x6.02x10^{23}~ 2.4x10^{24}

Total luminocity L, in 100 days is: L=10^{6} x 2.4 x 10^{24}=2.4x10^{30}

Assuming cross section of K_Lp-> K^{+}n =5mb= 5x10^{-27}

Number of expected events in 100 days in a 1MeV bin at P(K)=0.45 GeV/c is:

N=5x10^{-27}x2.4x10^{30}=12x10^{3} ~10^{4} in 100 days

Then for the Theta Peak at the width of 0.34 MeV we get:

$$N_{peak} = \frac{\Gamma \times N_{bkgd} \times (107\ mb) \times B_i B_f}{\sigma^{CE} \times \Delta m_0} =$$

$$\frac{0.34 \times 10^4 \times 107 \times 0.25}{5 \times 1} = 1.8 \times 10^4$$

Summary

- Experimental Data with High Statistics show that some of previous claims on the observation of pentaquark were not reproducible. This created the notion that all previous reports were unjustified.

- However it is obvious that new wave of experiments was devoted to check previous claims and not necessarily all measures were taken to make a search.

- The new experimental program at Jlab with KLF facility will provide undoubtful evidence of either existence of non-existence of light pentaquark.