Pentaquarks

Do they exist?

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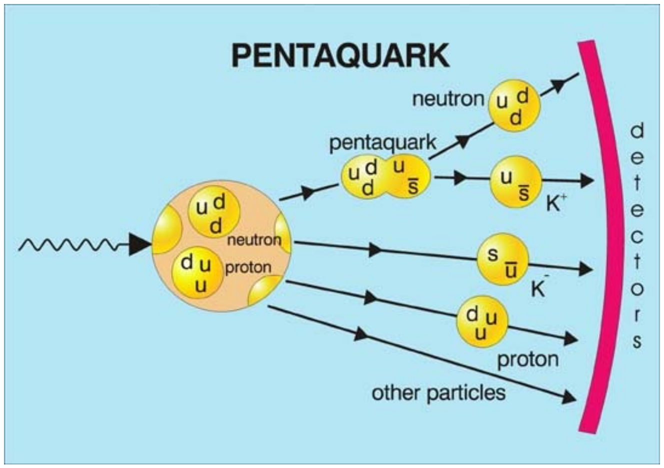
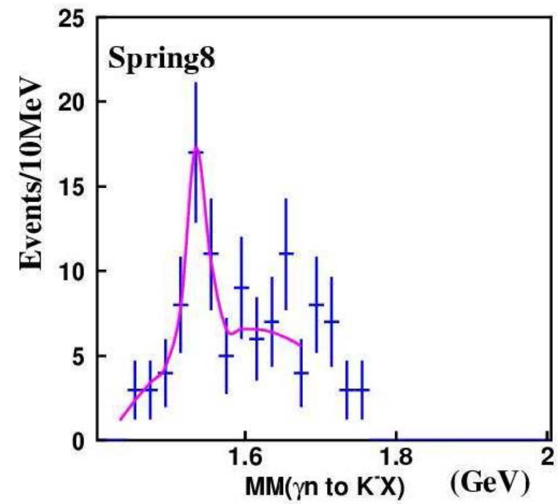
(Avetik Airapetian, Wouter Deconinck)

26 October 2005

Supported by NSF–0244842

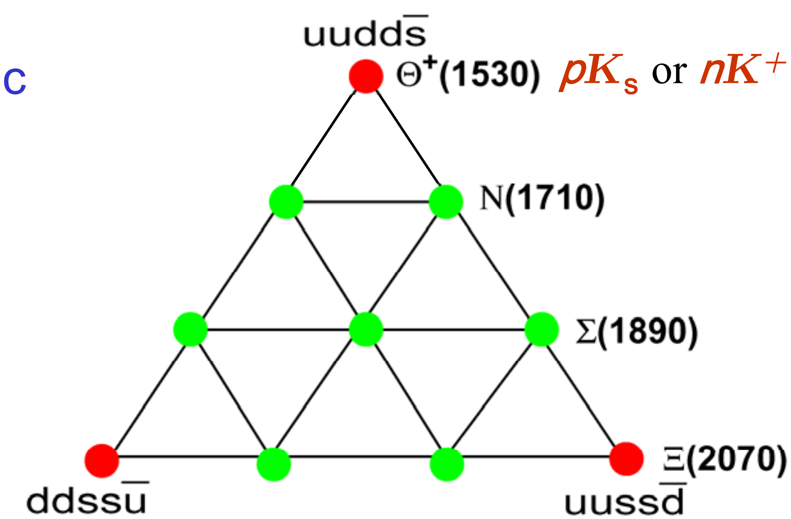
Life in Exciting Times





Before 2003 .... searches for flavor exotic baryons showed no evidence for such states

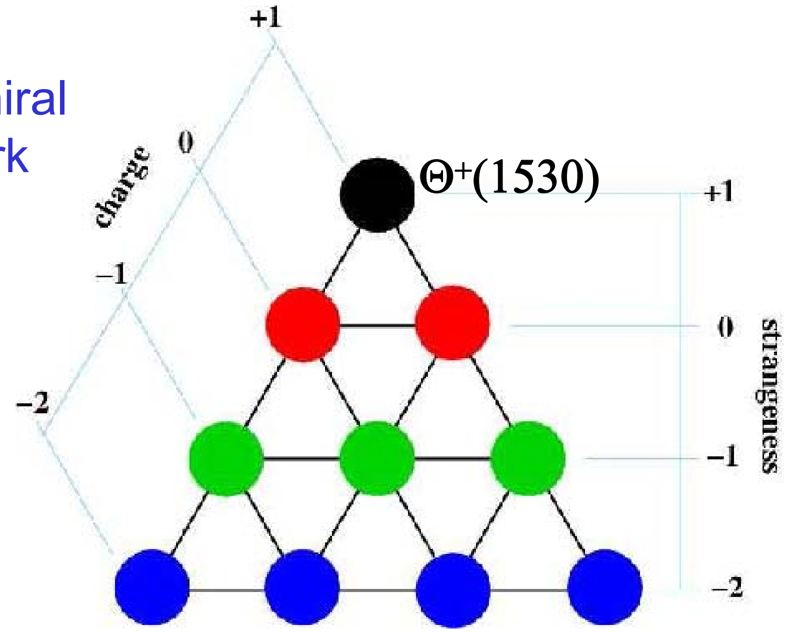
Since 2003 .... Hadronic Physics has been very interesting

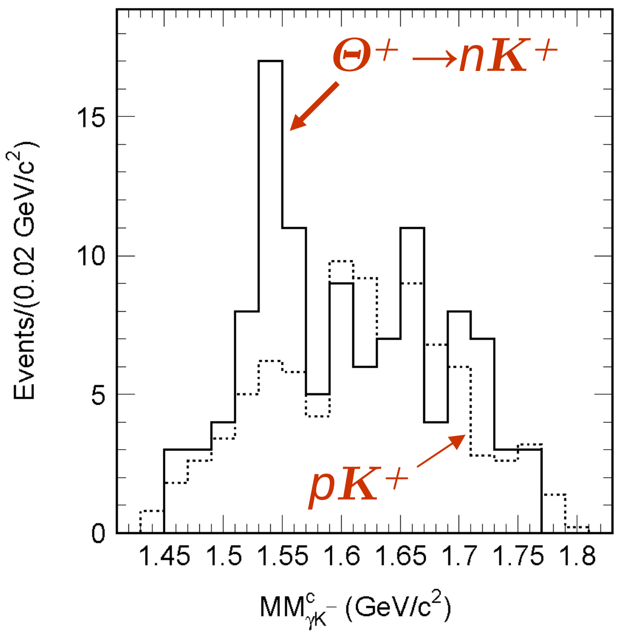


Spectacular Development

1997: Diakonov, Petrov and Polaykov use a chiral soliton model to predict a decuplet of pentaquark baryons. The lightest has S=+1 and a mass of 1530 MeV and is expected to be narrow.

Z. Phys. A359, 305 (1997).



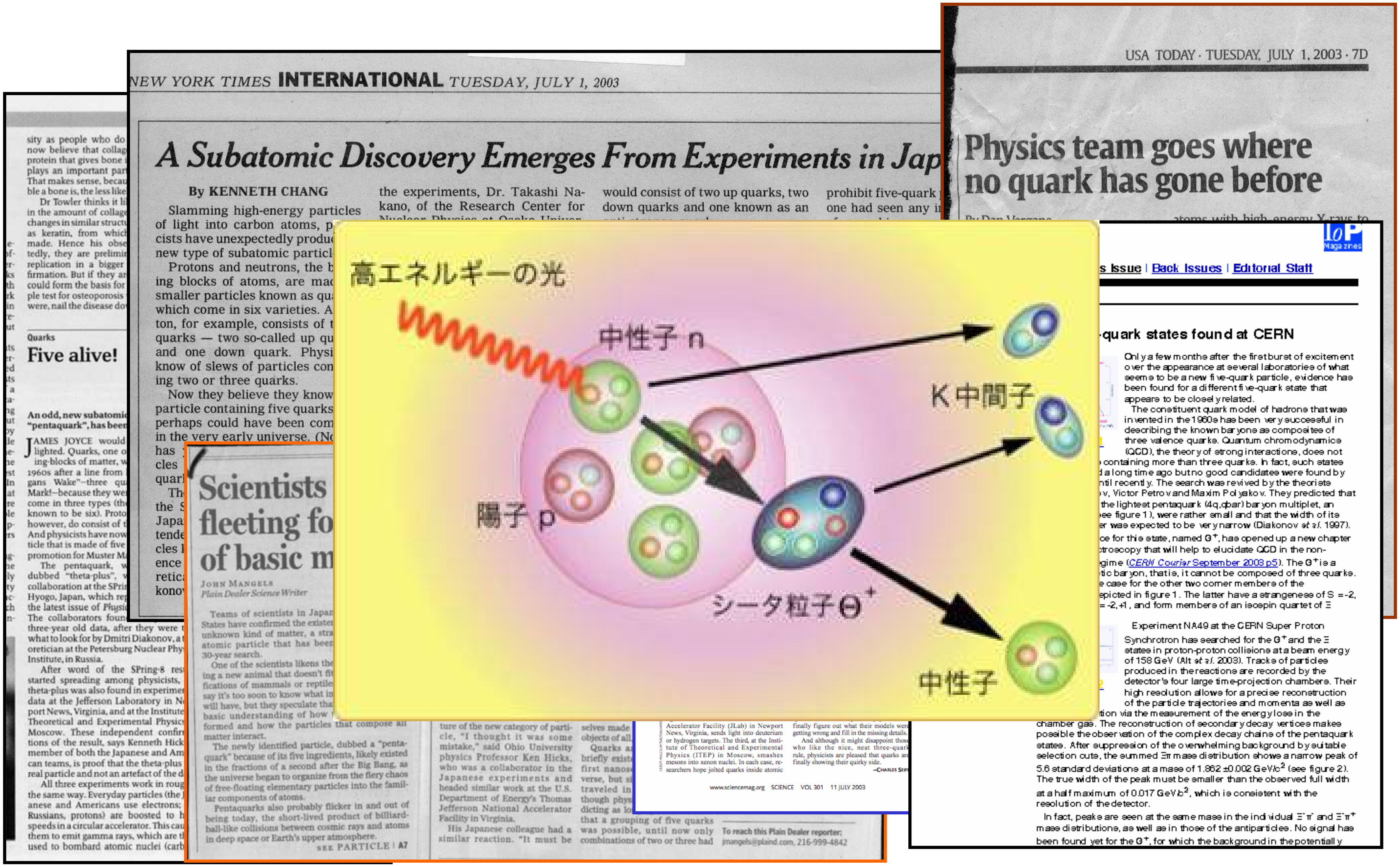


2003: T. Nakano *et al.* $\gamma\, n \rightarrow nK^+K^-$ on a Carbon target.

PRL 91, 012002 (2003).

The Roller Coaster ride begins ….

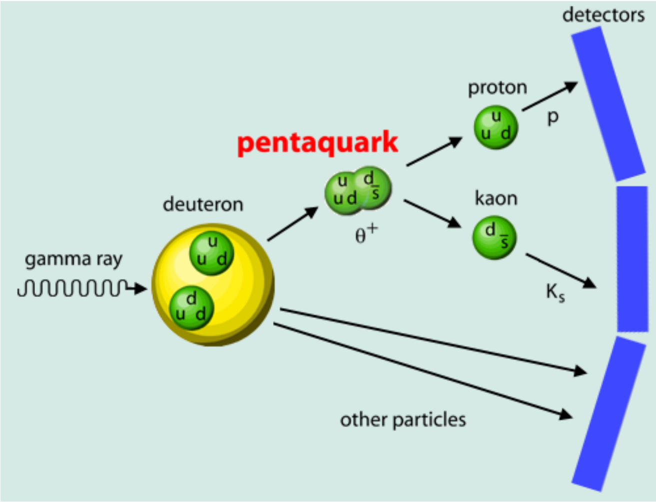
Media Interest (2003)



➢ The reason? In part, because the idea is simple to explain.

What is a Pentaquark

- Minimum quark content is 4 quarks and 1 antiquark
- "Exotic" pentaquarks are those where the antiquark has a different flavor than the other 4 quarks $\left(qqqq\bar{Q}\right)$
- Quantum numbers cannot be defined by 3 quarks alone.



Example: uuds$\bar{s}$, non-exotic

Baryon number = 1/3 + 1/3 + 1/3 + 1/3 - 1/3 = **1**

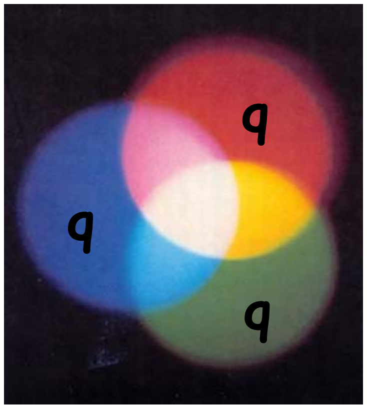
Strangeness = 0 + 0 + 0 − 1 + 1 = **0**

Example: uudd$\bar{s}$, exotic

Baryon number = 1/3 + 1/3 + 1/3 + 1/3 − 1/3 = **1**

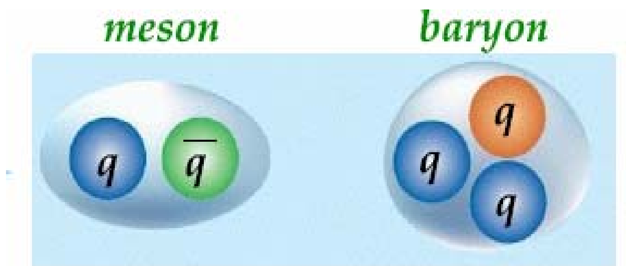
Strangeness = 0 + 0 + 0 + 0 + 1 = **+1**

Quarks are confined inside Colorless Hadrons



Mystery remains:

Of the many possibilities for combining quarks with color into colorless hadrons, only two configurations were found, until now…



Particle Data Group 1986 reviewing evidence for *exotic baryons states*

"…The general prejudice against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that it will be another 15 years before the issue is decided.

PDG dropped the discussion on pentaquark searches after 1988

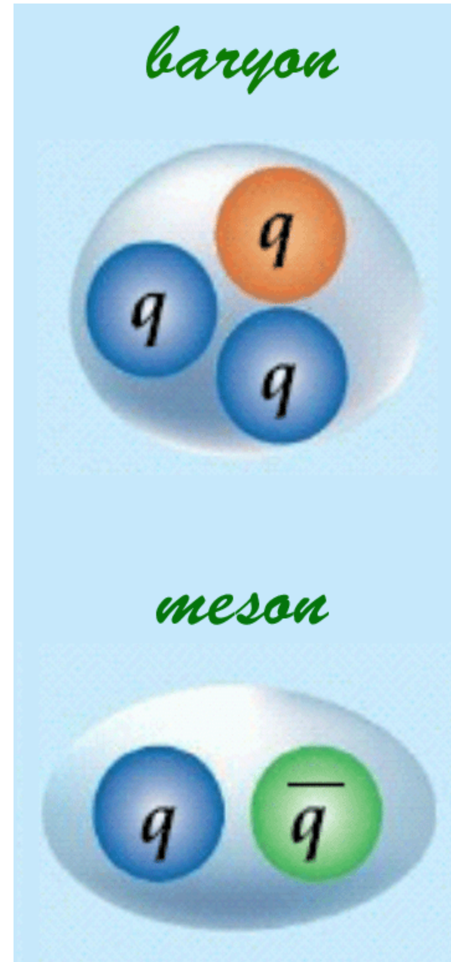
Why is it important to search for Pentaquarks?

- QCD does not prohibit $q^4\bar{q}$ states
  - The width is expected to be large due to "fall-apart":
    - $M(\Theta^+)$ - $M(p + K_s) \approx 100$ MeV above threshold: expect $\Gamma > 175$ MeV unless suppressed by phase space, symmetry or special dynamics
  - Are pentaquarks too broad so be seen in experiments?
- **If it does exist** (with a narrow width) naïve quark models cannot explain it; but correlated quark models can
  - Is the "fall-apart" model too simplisic?
- **If it does not exist** then do we understand why non-perturbative solutions of QCD do not allow it?
  - Can lattice calculations tell us why?
  - it should have far-reaching consequences for understanding the structure of matter

Pentaquark in naïve Quark Model

	u	d	s
Current mass	4 MeV	7 MeV	150 MeV
Constituent mass	350 MeV	350 MeV	470 MeV

The spontaneous breakdown of the chiral symmetry would produce nonzero constituent mass and the massless pseudoscaler Goldstone bosons

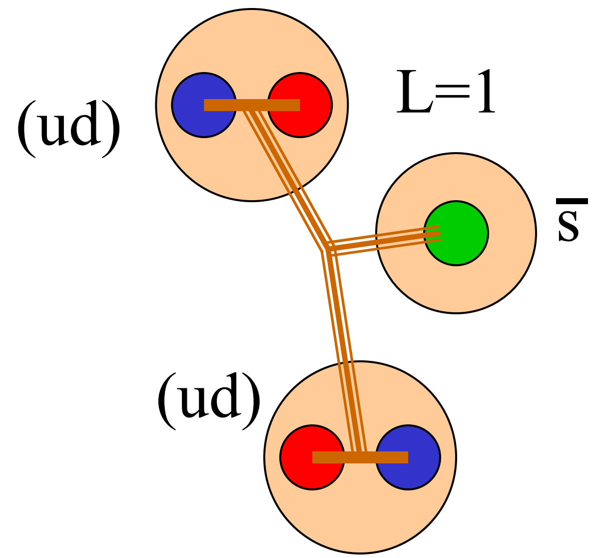


- Pentaquark mass = 4*350+470=1870 MeV
- In addition there is some penalty for p-wave (in case of positive parity)
- So the pentaquark mass must be about 2 GeV in any constituent quark model
- The predicted width is wide (>175 MeV) due to the allowed decay to the baryon and meson with mass well above the threshold
- The ground state has **negative** parity.

"Correlated" Quark Model

Jaffe, Wilczek
PRL 91, 232003 (2003)

- The four quarks are bound into two spin zero, color and flavor 3 diquarks
- For identical diquarks, like $[ud]^2$, the lightest state has negative space parity. So the $q^4\bar{q}$ state has positive parity
- The narrow width is described by relatively week coupling to the nK^+ continuum from which it differs in color, spin and spatial wave functions.



L=1, one unit of orbital angular momentum needed to get $J^P=\frac{1}{2}^+$ as in χSM

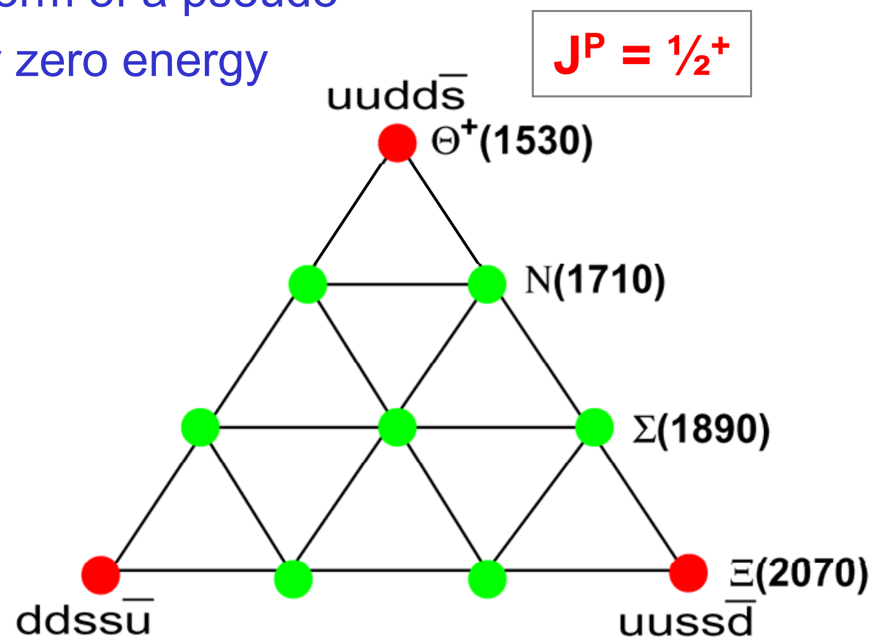
Decay Width:

$$\left\langle [ud][ud]\bar{s} \,\middle|\, [uud][u\bar{s}] \right\rangle = \frac{1}{2\sqrt{6}}\Gamma \approx \frac{200\,MeV}{\left(2\sqrt{6}\right)^2} \approx 8\,MeV$$

Chiral Soliton Model

D.Diakonov *et al*, Z. Phys. A359, 305 (1997).

- Pentaquarks: rotational excitations of the soliton [rigid core surrounded by chiral (meson) fields]
- Extra $q\bar{q}$ pair in pentaquark is added in the form of a pseudo scalar Goldstone meson, which costs nearly zero energy
- In reality, to make the Θ^+ from the nucleon, one has to create a quasi-Goldstone K-meson and confine it inside the baryon of the size >1/M. It costs ~600 MeV
- So the Θ^+ mass is near 1530 MeV.
- Γ = 15 MeV
- Masses are counterintuitive:



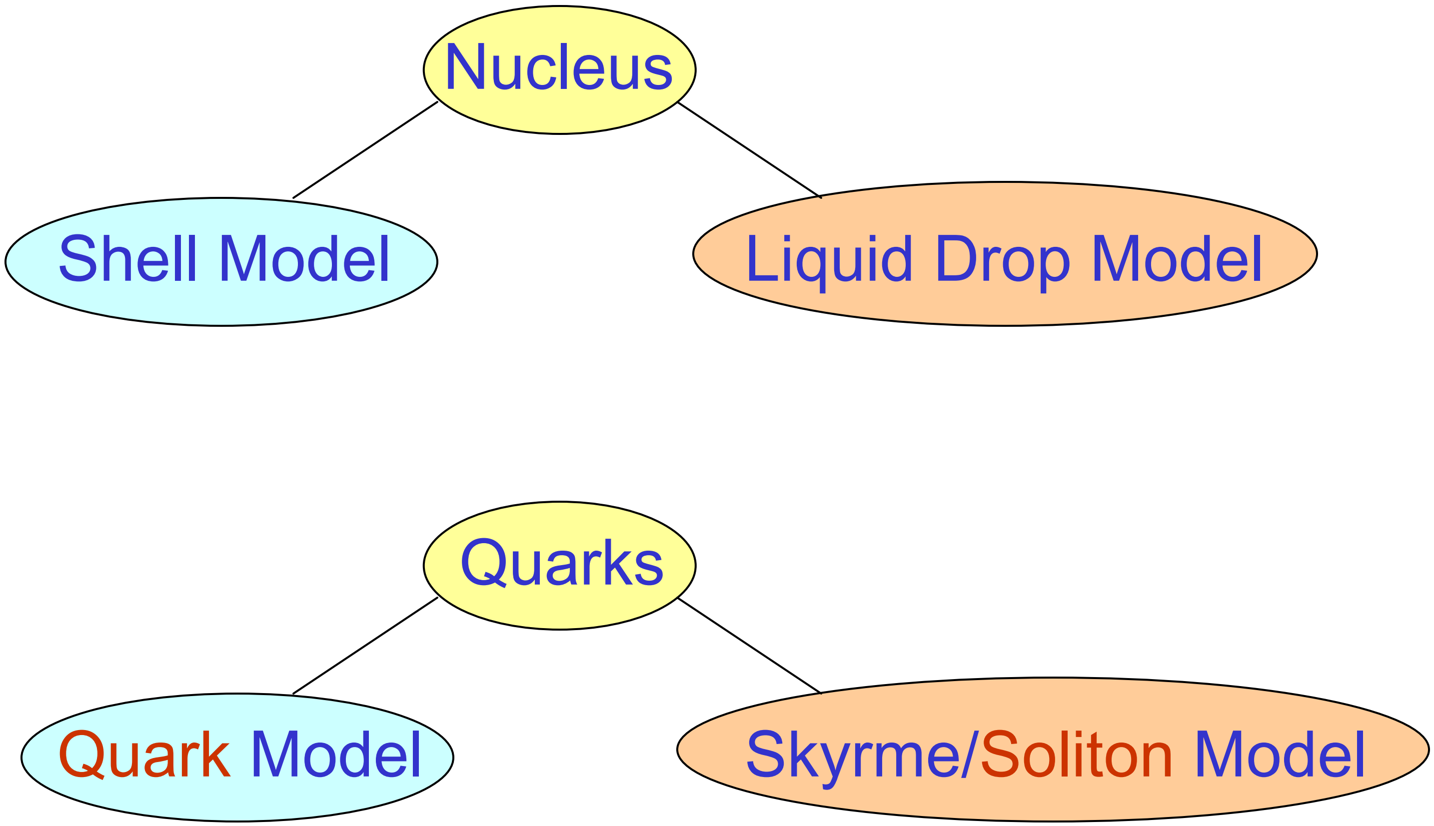
  - $m(\Theta^+) < m(N)$ w/ nucleon q.n.

    naïve QPM: expect strange baryons are heavier than non-strange in given multiplet
  - $m(\Theta^+) = m(\Xi) - 540$ MeV [Θ^+ has 4 light + 1 s quark

    Ξ^{--} has 3 light + 2 s quarks]

    naïve QPM: expect Δm = 150 MeV

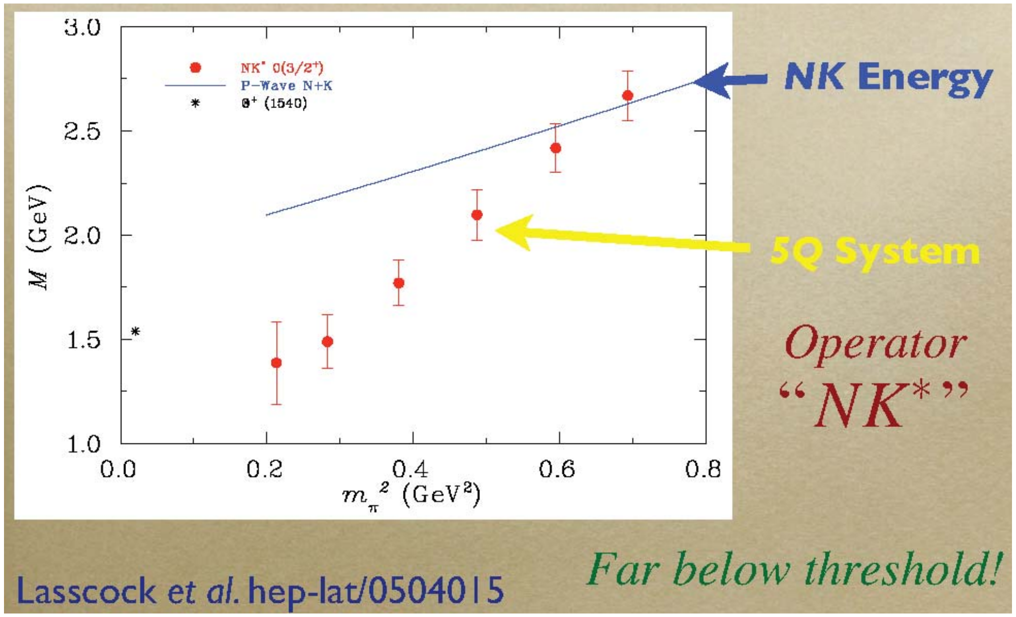
Models: An Analogy



Describe various, not mutually exclusive aspects of nucleus/quarks

Pentaquarks on the Lattice

- It is only known method to derive hadronic properties from first principles
- Several lattice studies performed to see if Θ^+ can be predicted from QCD
- Some studies did not find a pentaquark resonance, only scattering states of weakly-interacting kaons and nucleons → not mature yet (2 more years?)
- Main problem: disentangling KN scattering states from genuine resonances
- Very time consuming: V-dependence, light quarks, small lattice spacing …



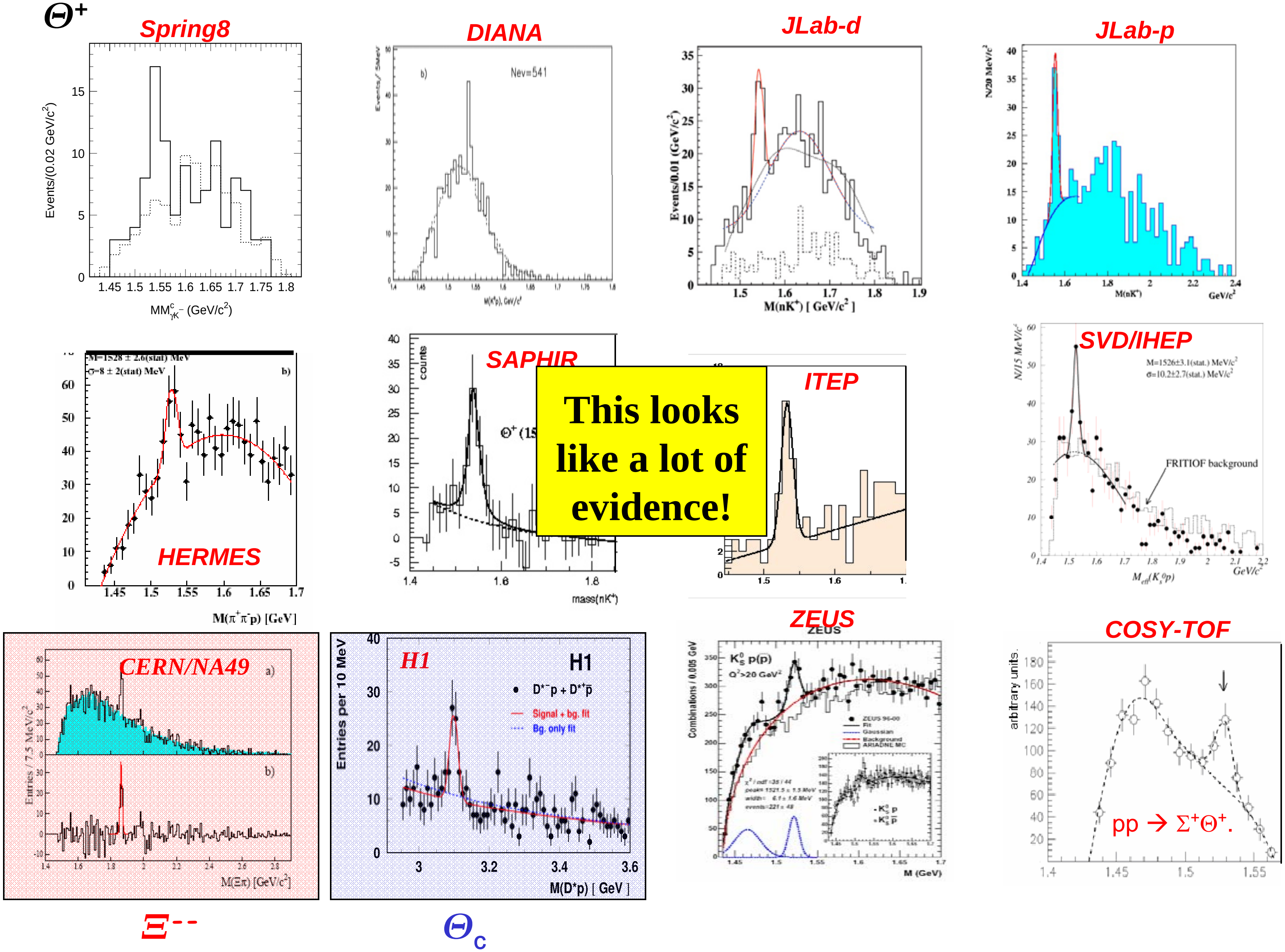
Possible signal for $J^P=3/2^+$?

(in χSM $J^P=½^+$)

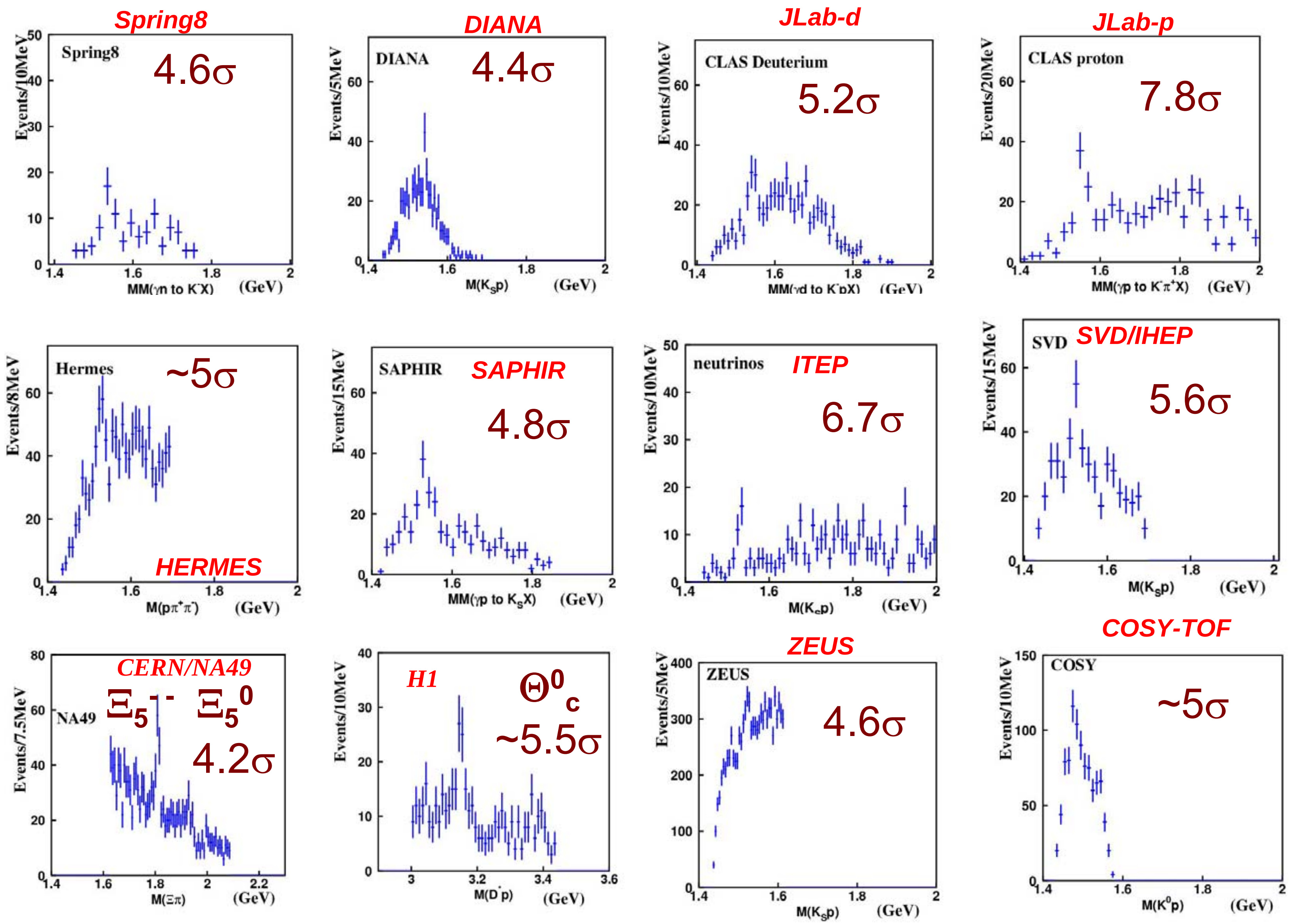
Binding Mechanism:
~500 MeV

Note: N. Ishii et al. get different results!?

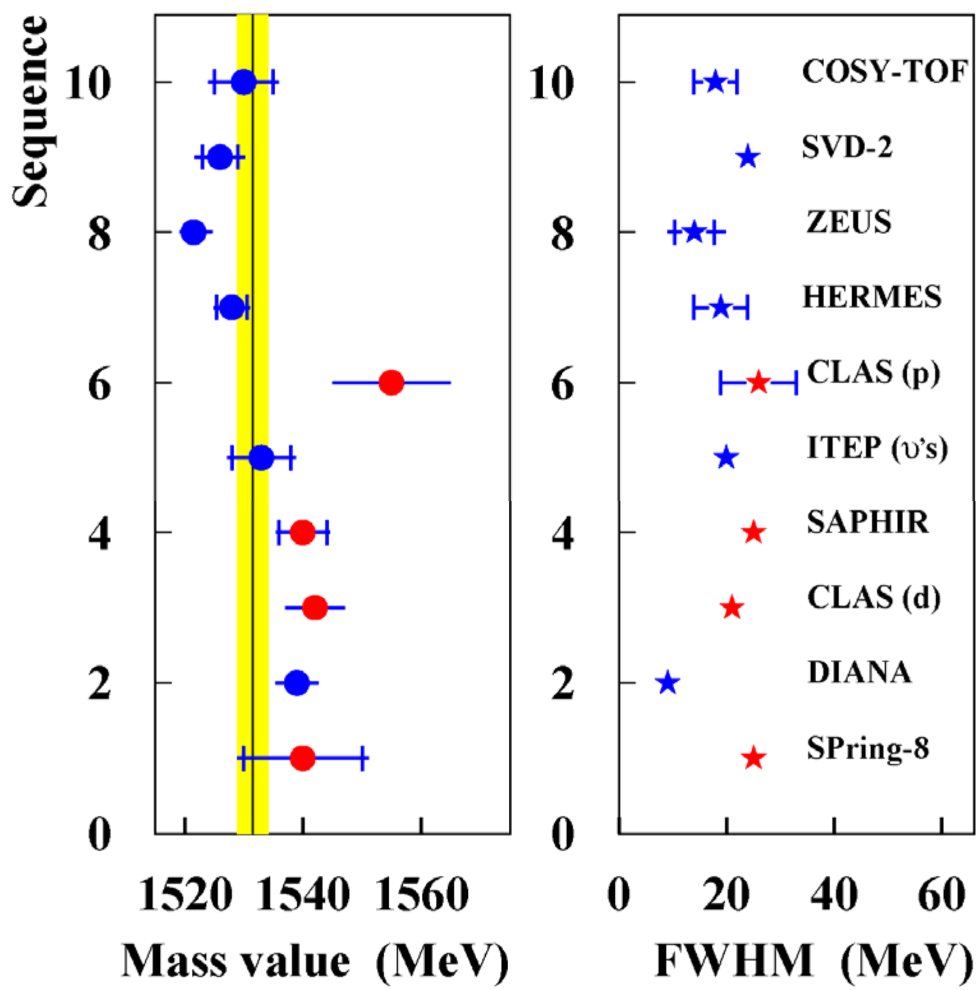
The initial Evidence for Pentaquarks



The Data Undressed



The Θ^+ Mass



Decay channel:

nK^+ pK_s^0

World Average:

1532.5±2.4 MeV

- $m(pK_s^0) < m(nK^+)$
- Could be due to different background shapes and interference effects
- Or it may indicate a serious concern about the existence of the Θ^+ baryon
- Observation of peak in two decay channels in same experiment → would be convincing!

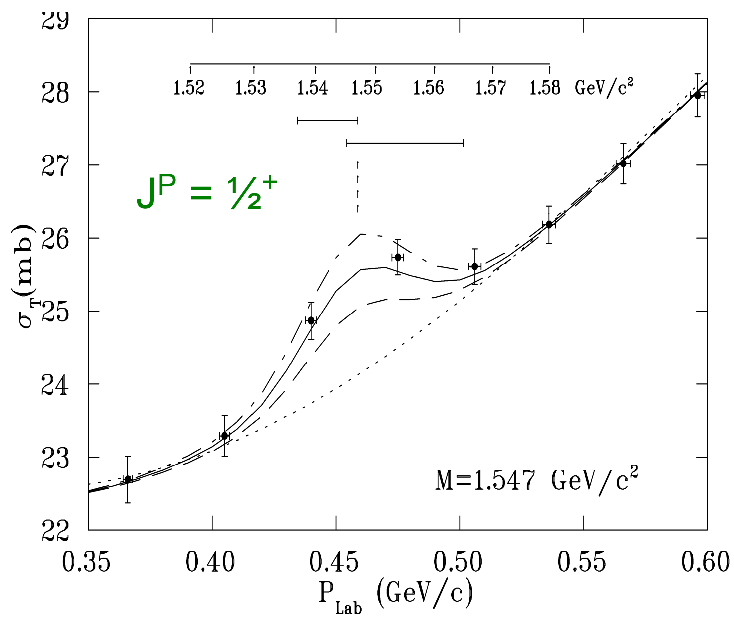
What about the Θ^+ Width?

- Measured width dominated by experimental resolution
- More precise information is obtained in analyses with theoretical constraints:

DIANA, Phys. Atom. Nucl. 66,1715 (2003)	Γ_Θ <9 MeV	
HERMES, PLB585, 213 (2004)	Γ_Θ = 17 ± 9 ± 3 MeV	
S. Nussinov et al., hep-ph/0307357	Γ_Θ < 6 MeV	(non-observation)
R. Arndt et al., PRC68, 42201 (2003)	Γ_Θ < 1 MeV	(non-observation)
R. Cahn and G. Trilling, PRD69, 11401 (2004)	Γ_Θ = 0.9 ± 0.3MeV	(from DIANA results)
A. Sibirtsev, et al., hep-ph/0405099 (2004)	Γ_Θ < 1 MeV	($K^+d \rightarrow K_s pp$)
W. Gibbs, nucl-th/0405024 (2004)	Γ_Θ = 0.9 ± 0.3 MeV	($K^+d \rightarrow X$)

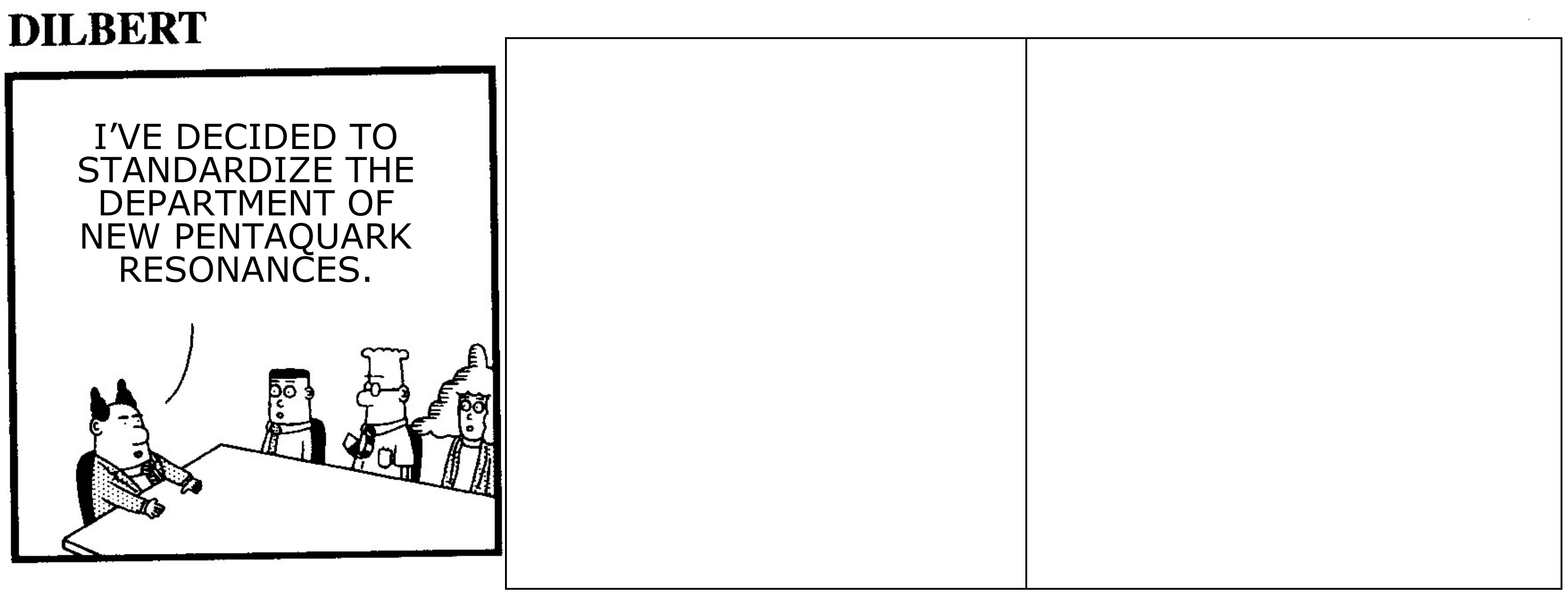
$K^+d \rightarrow X$

Γ_Θ = 0.9 ± 0.3 MeV



- very narrow for a hadronically decaying particle with mass ~100 MeV above threshold!

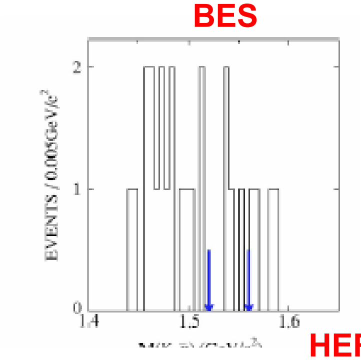
OK, we've seen a Peak...



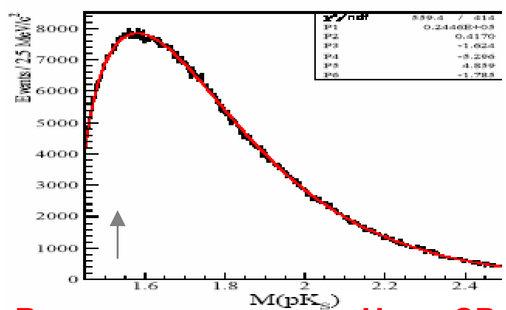
So how do we decide if it is a resonance?

Non-evidence for Pentaquarks

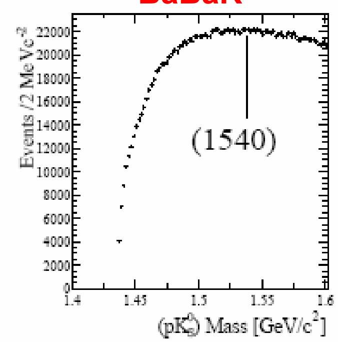
BES



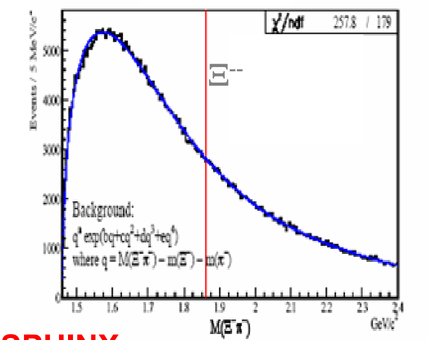
FOCUS



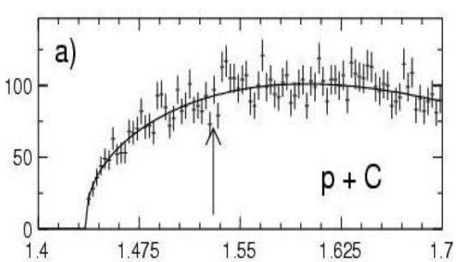
BaBaR



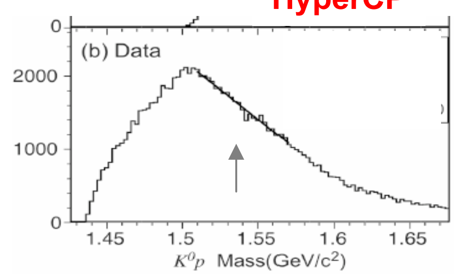
FOCUS



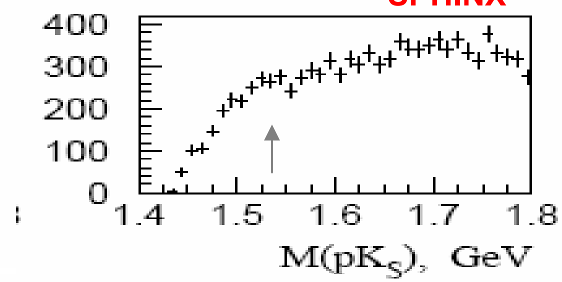
HERA-B



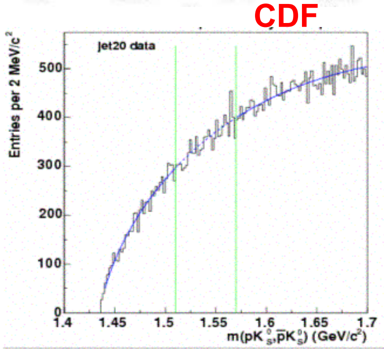
HyperCP



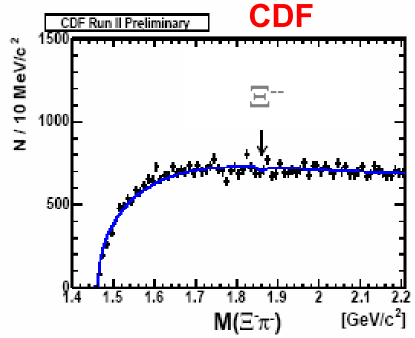
SPHINX



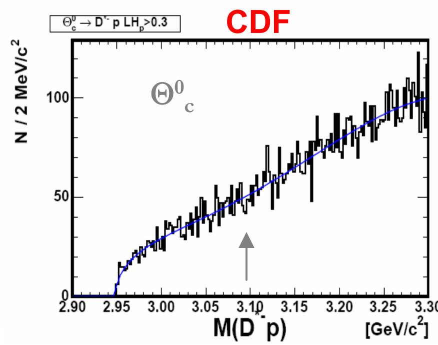
CDF



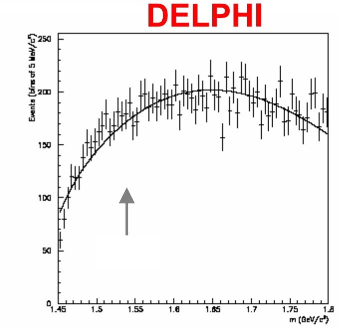
CDF



CDF



DELPHI



Published Null Experiments

Experiment	Reaction	Limit
BES	$e^+e^- \rightarrow J/\Psi \rightarrow \Theta^+\Theta^-$	BR <1.1×10^{-5}
Belle e^+e^-	$\Psi(2S) \rightarrow pK^0$ $K^+Si \rightarrow pK_s^0X$	BR <0.6×10^{-5} Θ/Λ^* <0.02
BaBar	$e^+e^- \rightarrow \Upsilon(4S) \rightarrow pK_s^0$	BR <1.1×10^{-4}
ALEPH	$e^+e^- \rightarrow Z \rightarrow pK_s^0$	BR <0.6×10^{-5}
HERA-B	$pA \rightarrow pK_s^0X$	Θ/Λ^* <0.02
CDF	$pp^* \rightarrow pK_s^0X$	Θ/Λ^* <0.03
HyperCP	$pCu \rightarrow pK_s^0X$	Θ/K^0p <0.3%
PHENIX	$AuAu \rightarrow n^*K^-$	not given
SPHINX	$pA \rightarrow pK_s^0X$	Θ/Λ^* <0.02

+ unpublished results

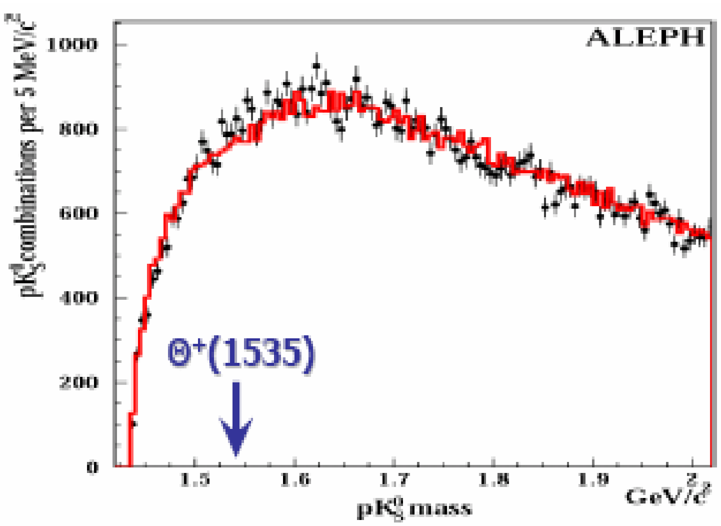
Null Results Θ^+(1540)

ALEPH:

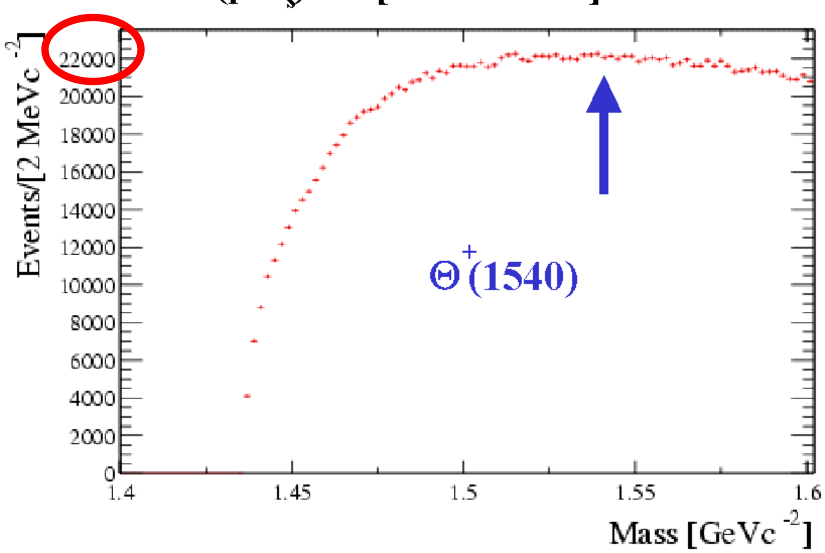
- e^+/e^- collider (LEP 1)
- Pentaquark search in hadronic Z decays
- 3.5 million hadronic Z decays
- σ_{mass} < 5 MeV/c^2

BaBar:

- e^+/e^- collider at SLAC ($\sqrt{s}$ = 10.58 GeV)
- Pentaquark search at or just below Υ(4S)
- Integrated luminosity of 123 fb^{-1}
- σ_{mass} in the range of [2,8] MeV/c^2



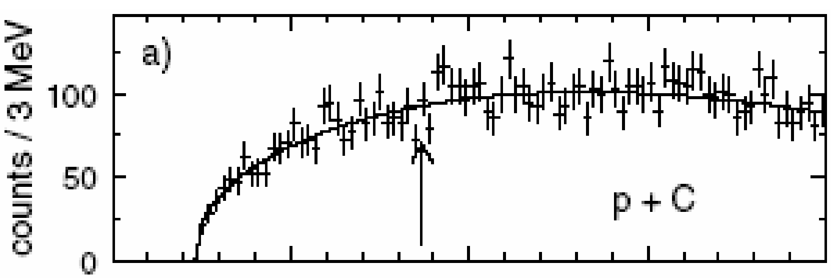
M(p K_s) in [1.44 – 1.60] GeV/c^2



Null Results $\Theta^+(1540)$

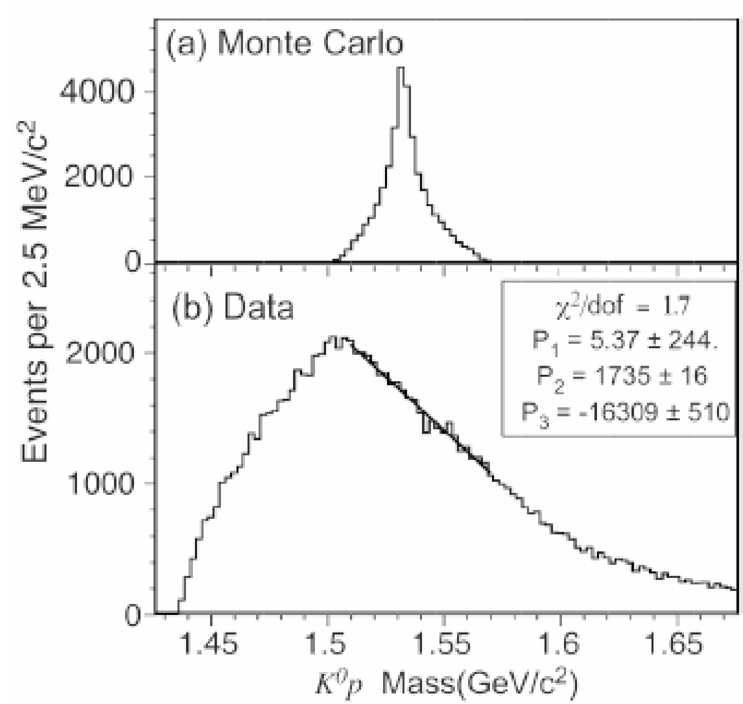
HERA-B:

- Proton beam at 920 GeV/c ($\sqrt{s}$ = 41.6 GeV)
- Different targets (C, Ti, W)
- Rapidity: $-0.7 < y < 0.7$
- σ_{mass} = 3.9 MeV/c^2 @ 1540 Mev/c^2



HyperCP: (M. Longo)

- Mixed beams (p, π, K, hyperons)
- Broad momentum spread (~120 – 250 GeV/c)
- Tungsten and thin kapton window target
- "Largest K_s sample ever recorded."
- σ_{mass} < 2 MeV/c^2 @ 1530 MeV/c^2



Typical Criticism

- It is a kinematic reflection
- It is not statistically significant (“statistical fluctuations”)
- It is due to “ghost tracks”
- It is fake in exclusive reactions
- In inclusive reactions it is not a Θ^+ but a Σ^{*+}
- It is not seen in high statistics experiments

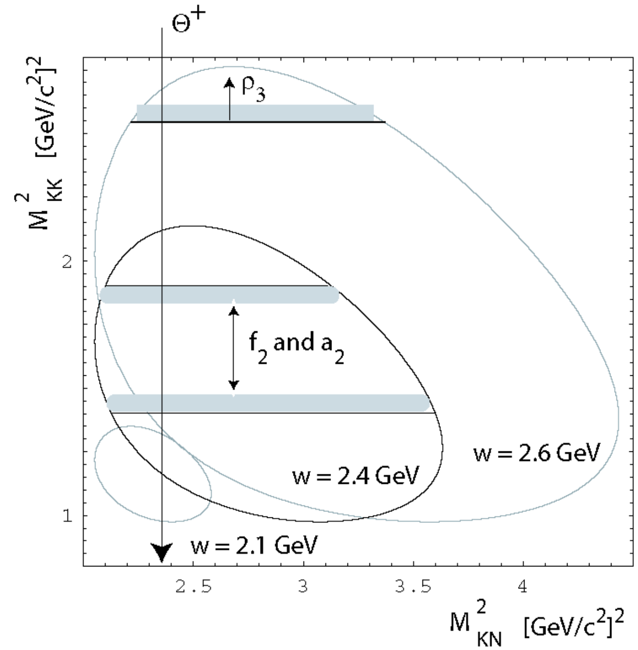
  → it must be wrong!

Kinematic Reflections

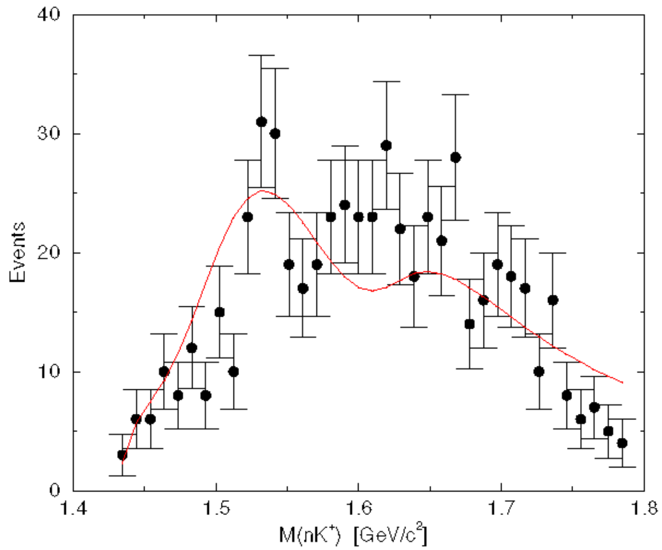
A. Dzierba *et al*, PRD 69, 051901(R) (2004).

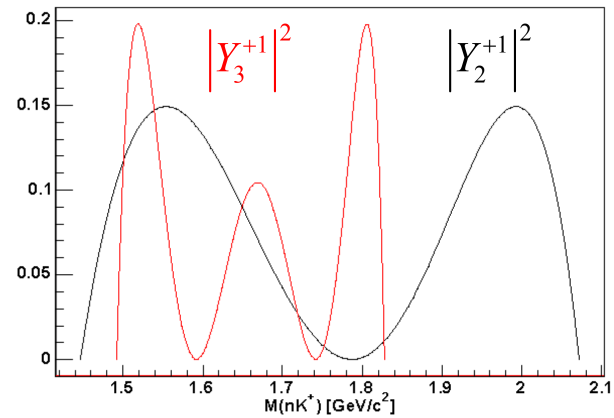
- Low energy experiments:
  - Produce a spin-2 or spin-3 resonance that decays into K^+K^-
  - Have non-uniform populations of $|m|=0,1,2,\ldots$

Produces a broad enhancement near 1.5 GeV



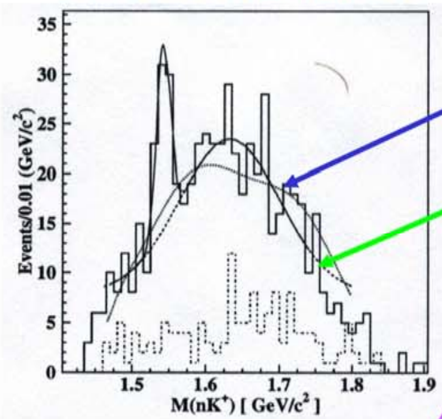
The CLAS $\gamma d \rightarrow pK^+K^-(n)$ data





Statistical Fluctuations

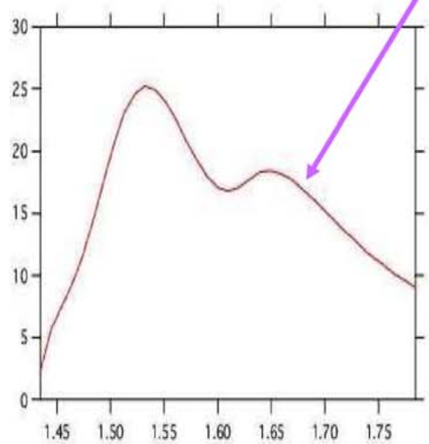
CLAS Published



Simple Physics Background

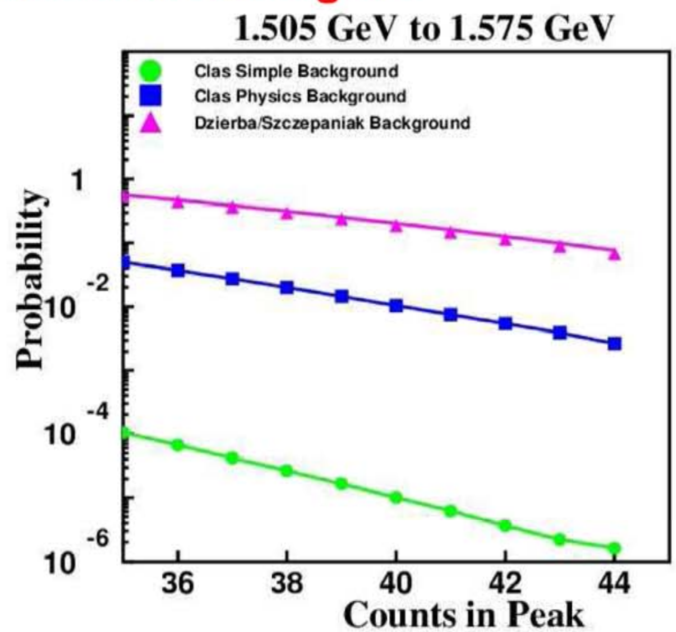
Naïve Background

Dzierba Background



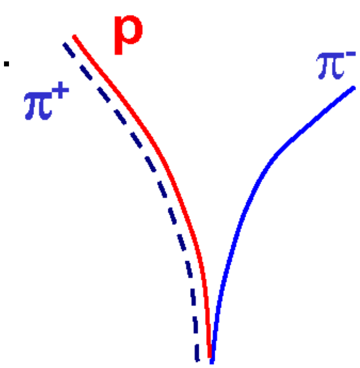
You need to understand your background to claim a new discovery!

Chance of the Background Fluctuating into the observed signal

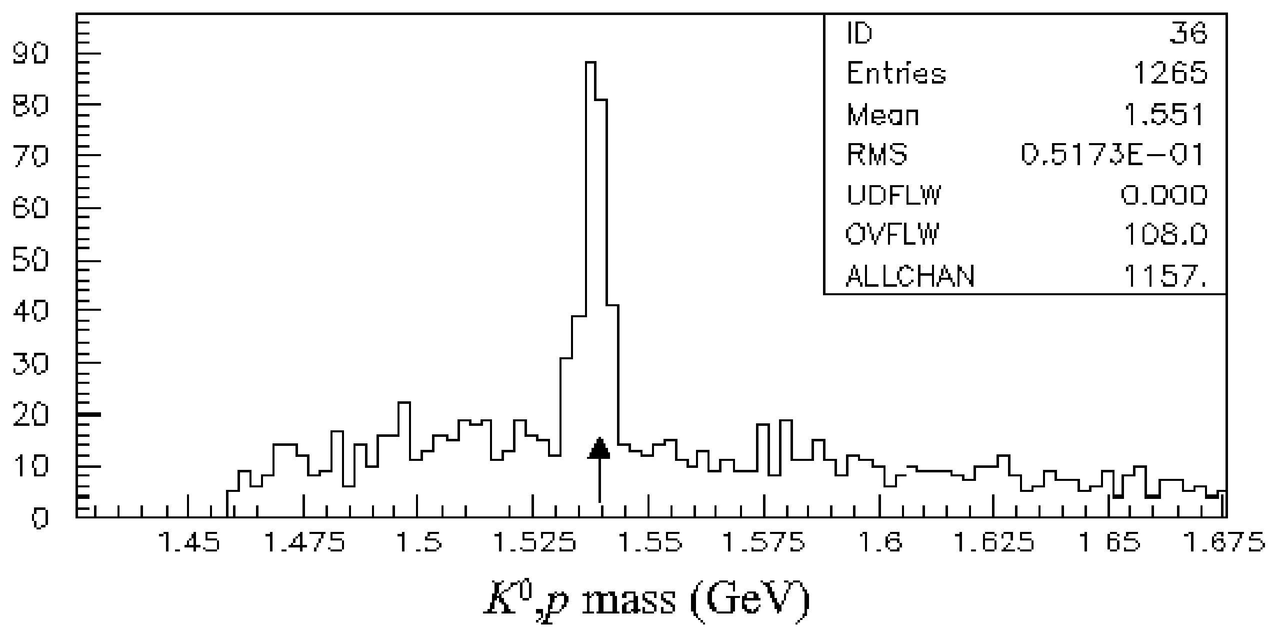


Ghost Tracks

M. Longo *et al*, PRD 69, 051901(R) (2004).



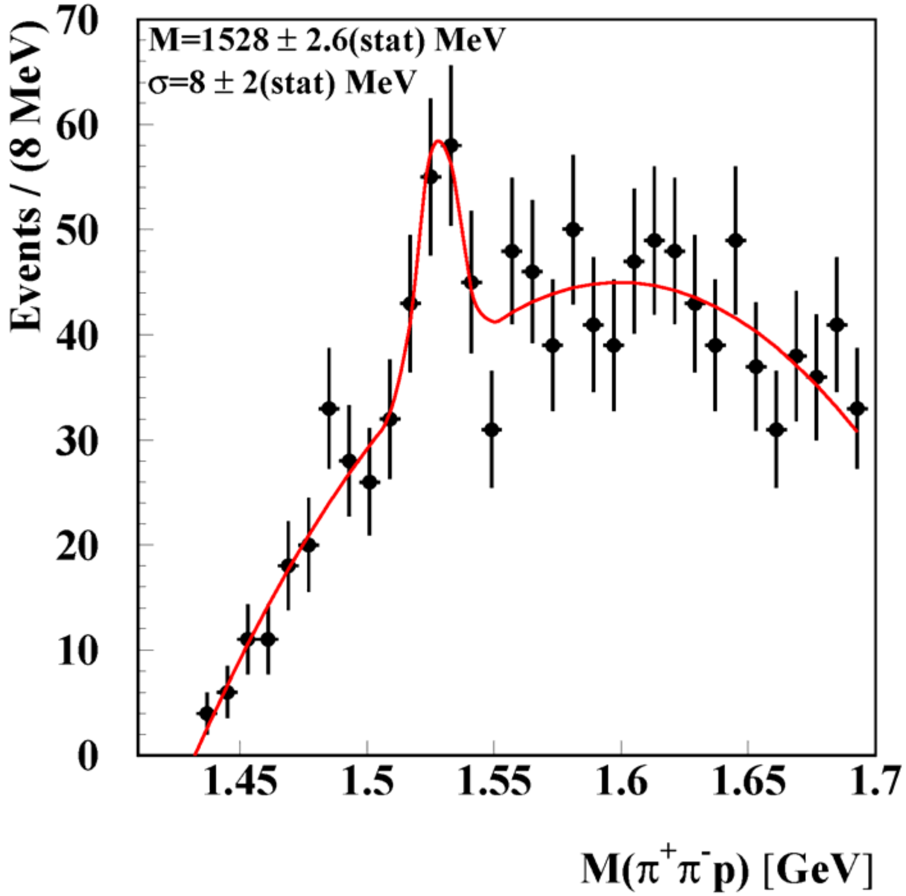
- Ghost tracks from a $\Lambda \to p\pi^-$ can produce a peak near 1.54 GeV. The positive track is used twice – as a p and a π^+
- misinterpret the p as a π^+
- assume that the $\pi^+\pi^-$ pair came from a K_s
- the resulting pK_s pair produces a narrow peak



What about HERMES?

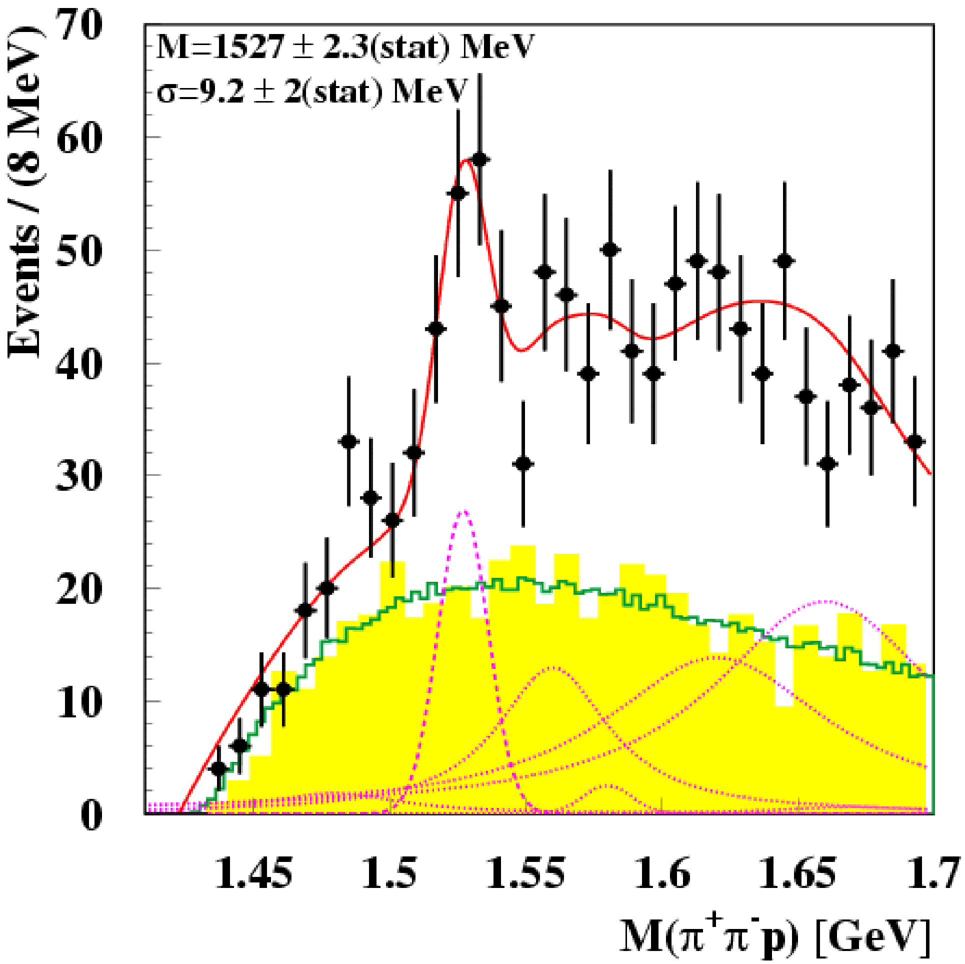
Inclusive quasi-real photo production with 27.6 GeV e^+ on deuterium

$$\gamma^* d \to p K_S^0 X \to p \pi^+ \pi^- X$$



- Excellent hadron identification
  RICH: **π:** 1-15 GeV **p:** 4–9 GeV
- Unbinned fit with 3rd order polynomial plus Gaussian
- Peak is observed at 1528 ± 2.6(*stat*) ± 2.1(*syst*) MeV in pK_S invariant mass distribution
- Width, $\sigma = 8$ MeV, is observably larger than experimental resolution
- Statistical significance is 3.7σ
- No known positively charged strange baryon in this mass region
- No strangeness tagging
- Three models of background were studied

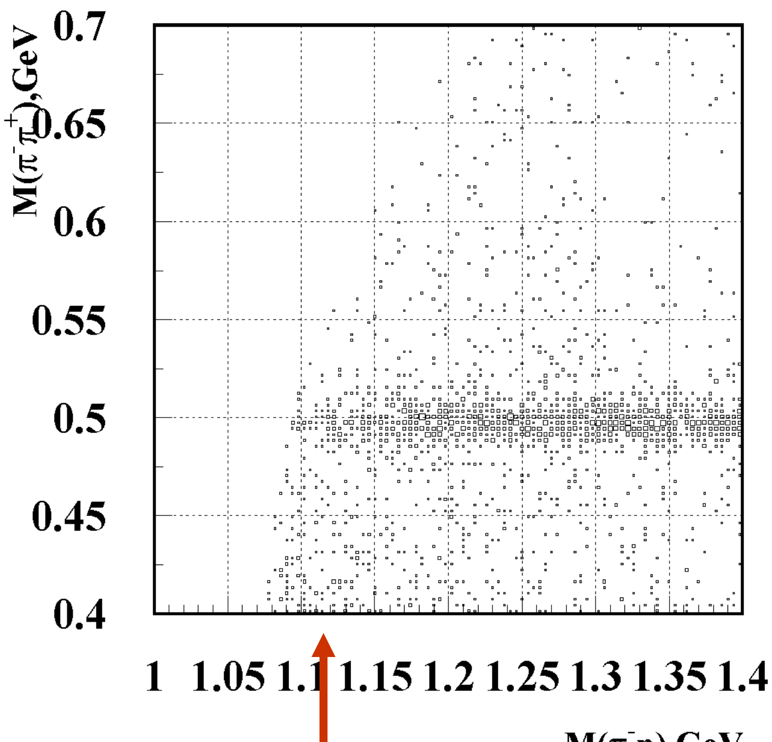
PYTHIA6 and mixed-event backgrounds



- Filled histogram: PYTHIA6 MC (lumi normalized): No resonance structure from reflections of known mesonic or baryonic resonances
- Green histogram: mixed event background normalized to PYTHIA6: reproduces the shape of PYTHIA6 simulation
- Excited Σ^* hyperons not included in PYTHIA6 lie below 1500 MeV and above 1550 MeV
- Mass= 1527 ± 2.3 MeV
- σ= 9.2 ± 2 MeV
- Significance 4.3σ

Fake Peaks?

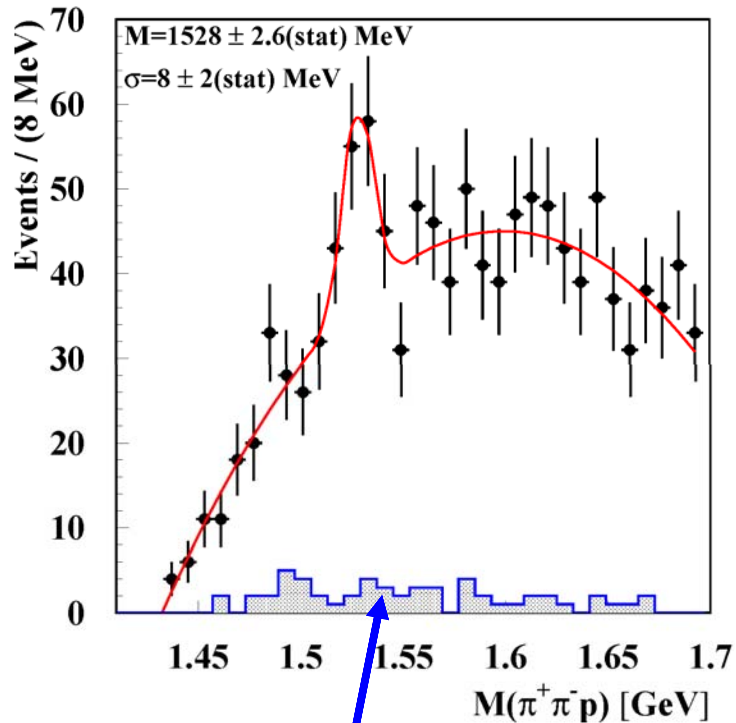
- particle miss-assignment
  - ghost tracks
  - PID "leaks"



expect peak in $M(\pi^- p)$

if π^+ is $\mathbf{p}$ and K_S is $\Lambda(1116)$

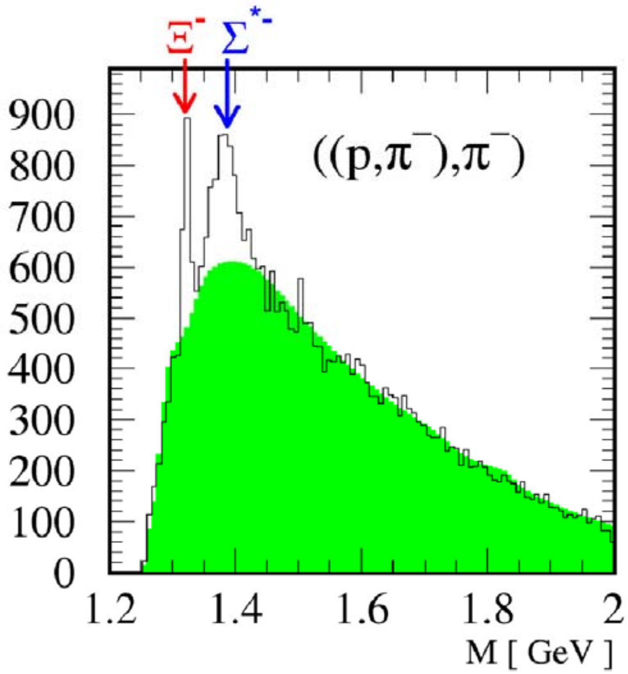
- remove $\Lambda(1116)$ contribution

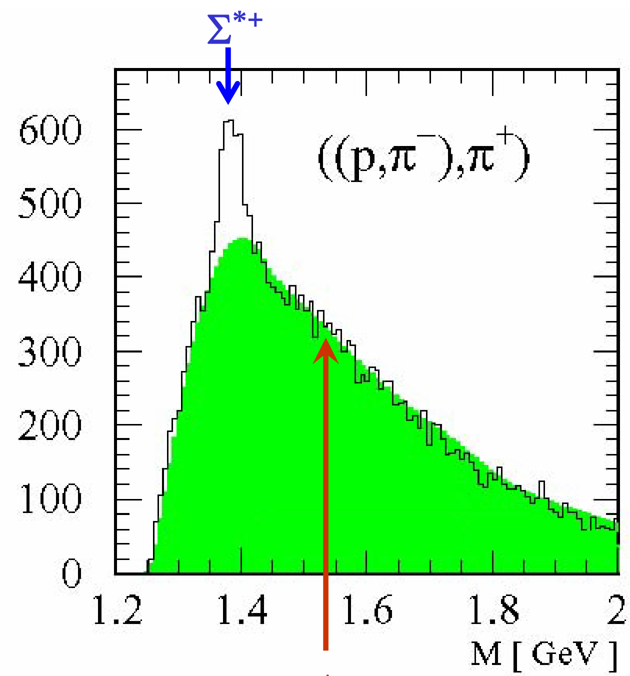


Spectrum of events associated with $\Lambda(1116)$

Θ^+ or Σ^{*+}?

- Is HERMES peak a previously missing Σ^* or a pentaquark state?
- If peak is $\Sigma^{*+} \Rightarrow$ also see a peak in $M(\Lambda\pi^+)$





No peak in $\Lambda\pi^+$ spectrum near 1530 MeV

➡ *but no Σ^*s (1480, 1560, 1580, 1620) too!!!!*
should we say all bumps in pK_s spectrum are pentaquarks?

Pentaquark Situation (April 2005)

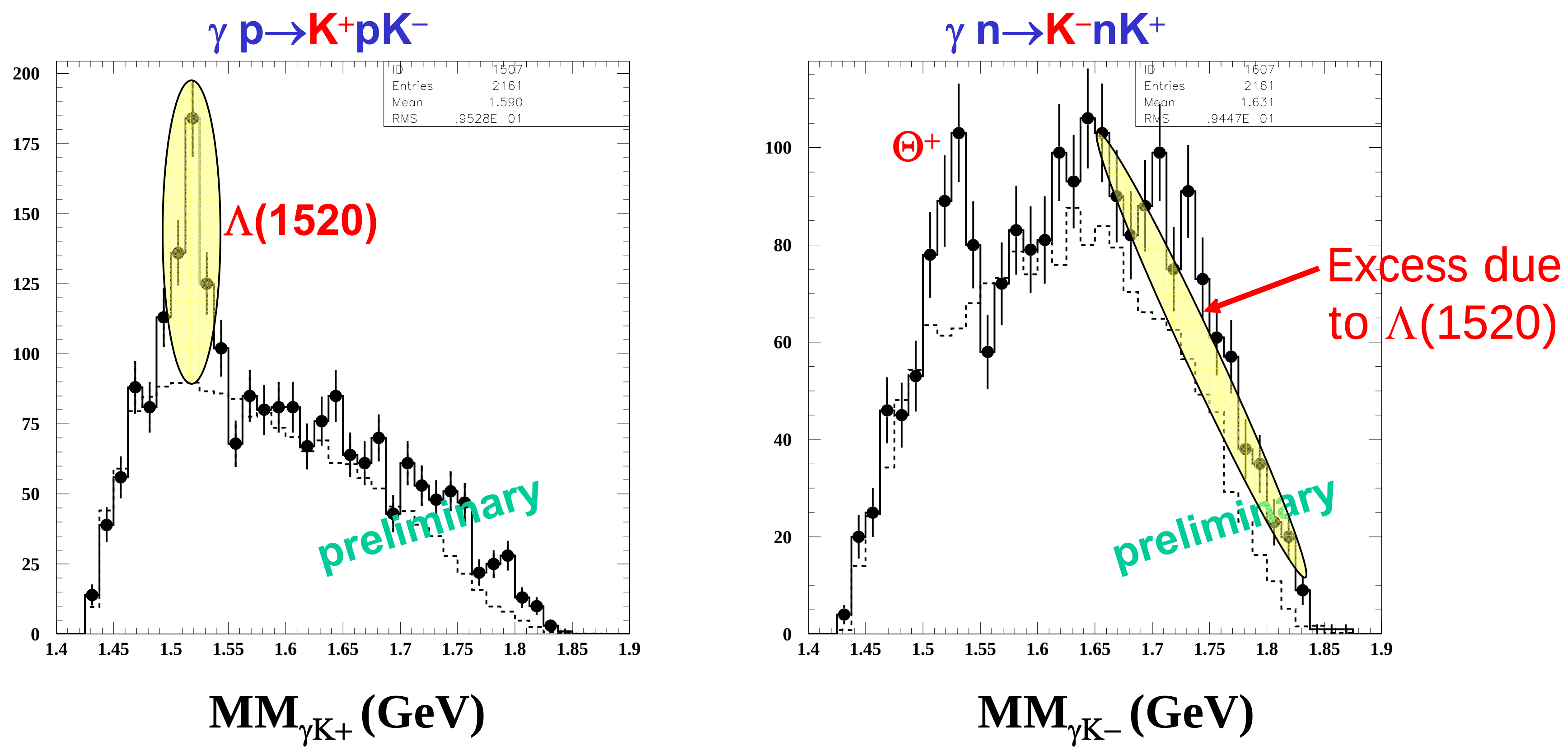
- Dedicated, high-statistics experiments are key
- Advice from Theorists:

Don’t give up too easily...

LEPS Search for Θ^+ in $\gamma d \to K^+K^-n(p)$

- The proton is a spectator (undetected)
- Fermi motion is corrected to get the missing mass spectra
- Background is estimated by mixed events

- Dedicated experiment
- Aimed at 4x stat. of 2003



Conclusions of LEPS group

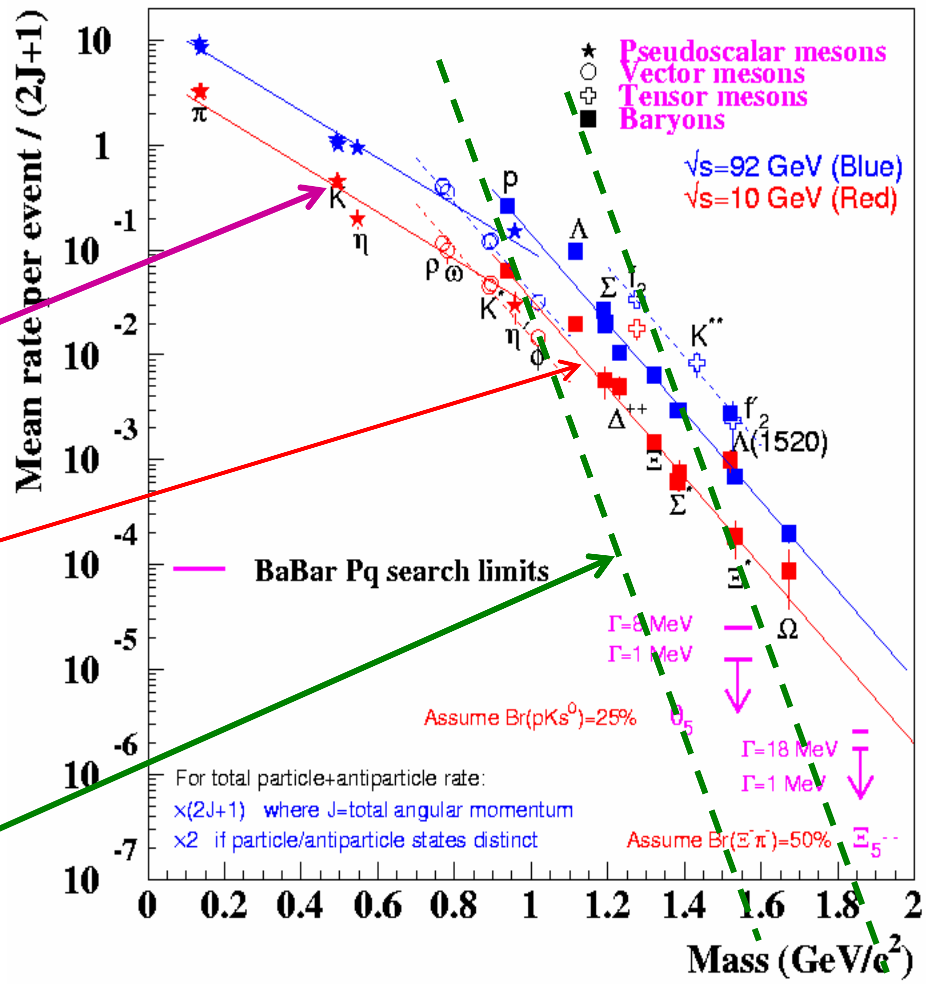
- LEPS high statistics experiment has reconfirmed the peak, very unlikely to be due to statistical fluctuations.
- The preliminary study shows no indication that the peak is generated by kinematical reflections, detector acceptance, Fermi-motion correction, nor cuts.
- "existence ranges from very likely to certain, but further confirmation is desirable" - "three-star" definition by PDG.

Hadron production in e^+e^-

Slope for p.s. mesons

Slope for baryons

Slope for pentaquark??



Slope:

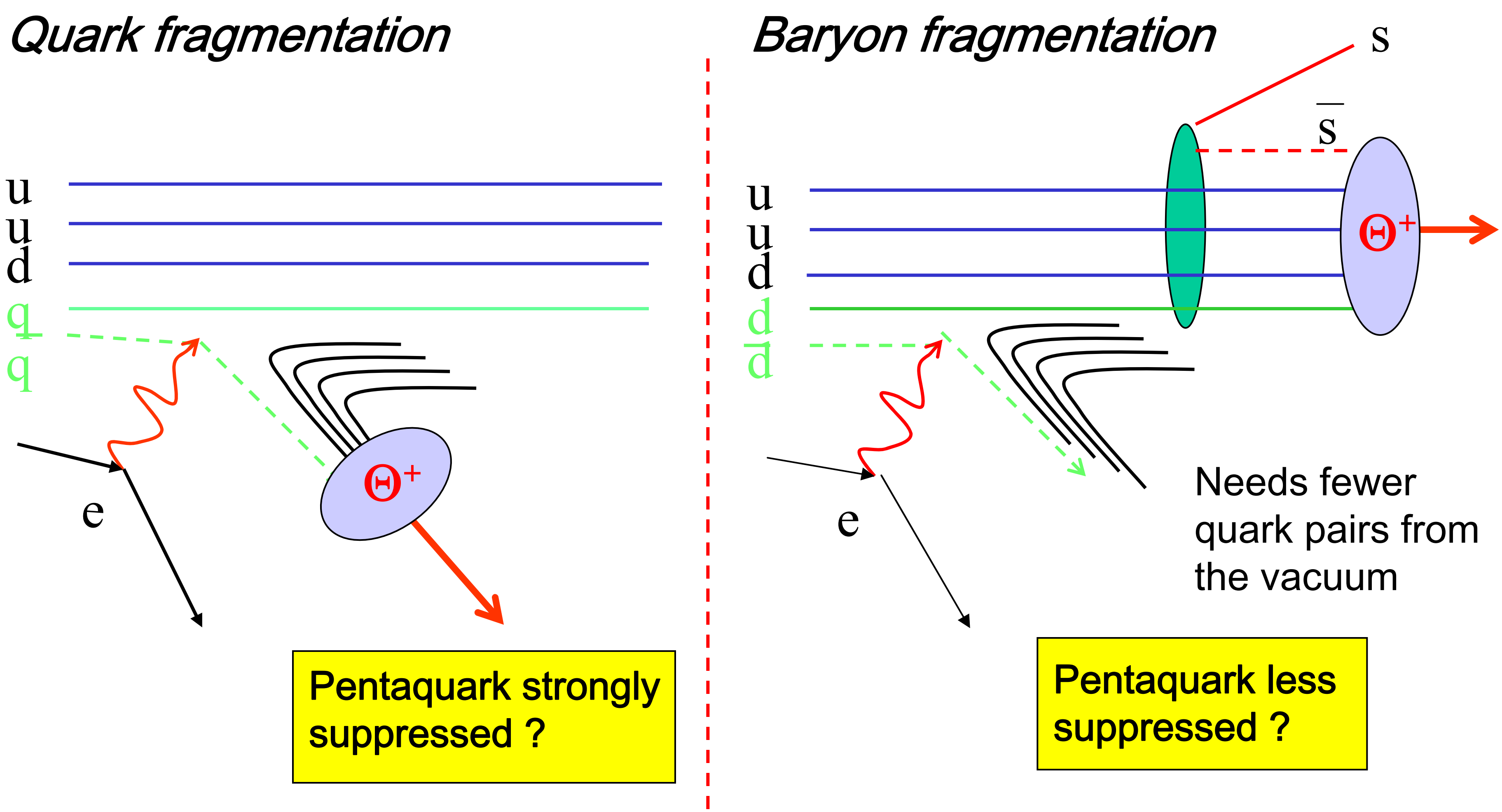
Pseudoscalar mesons:
$\sim 10^{-2}/\mathrm{GeV}/c^2$ (need to generate one $q\bar{q}$ pair)

Baryons:
$\sim 10^{-4}/\mathrm{GeV}/c^2$ (need to generate two pairs)

Pentaquarks:
$\sim 10^{-8}/\mathrm{GeV}/c^2$ (?) (need to generate 4 pairs)

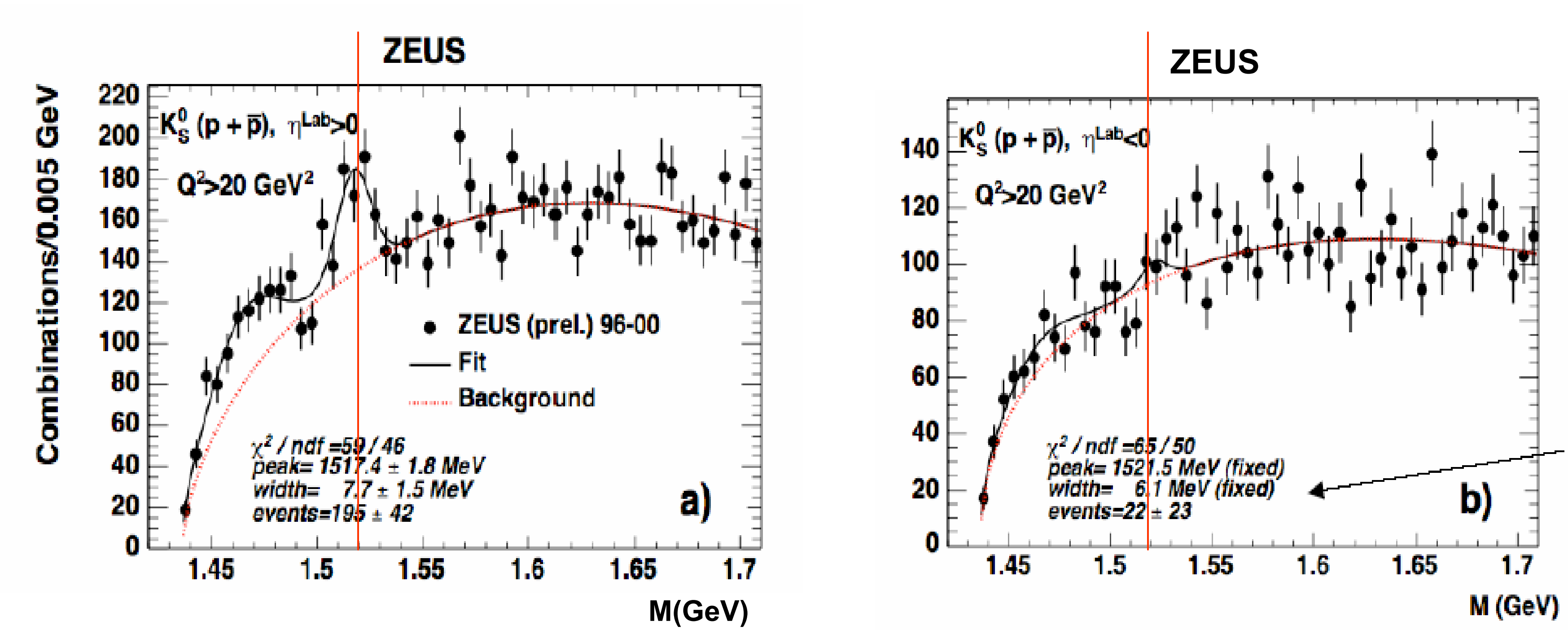
⟹ Pentaquark production in direct e^+e^- collisions likely requires orders of magnitudes higher rates than available.

Pentaquark in fragmentation?



High energy production mechanism

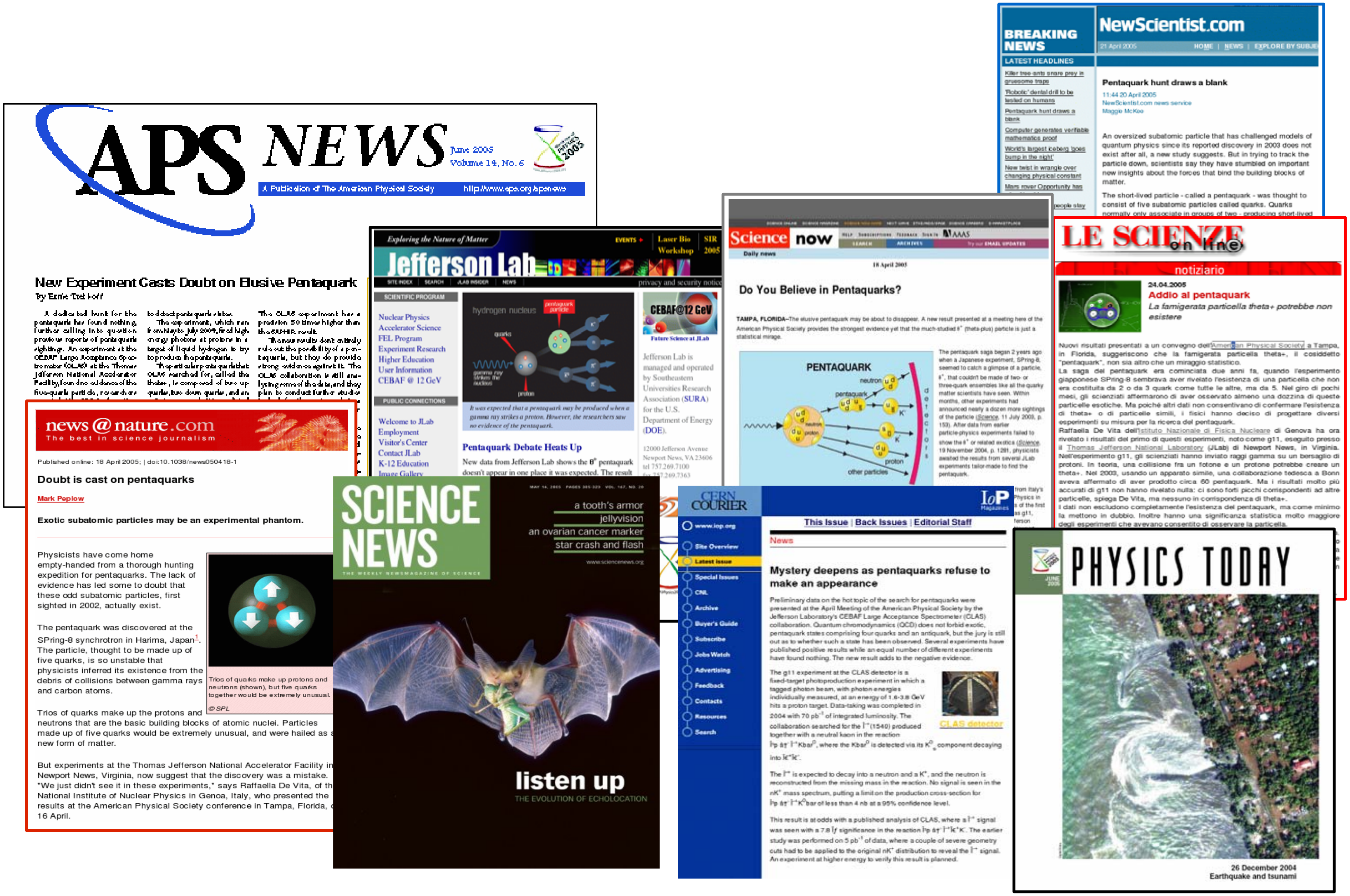
$$ep \rightarrow epK_s^0 X$$



Θ^+ produced mostly at forward rapidity $\eta^{Lab} > 0$, and medium $Q^2 > 20$ GeV^2.

Consistent with Θ^+ production in baryon fragmentation

Media Interest (2005)



And More ….

➢ R.L. Jaffe (MIT) at DIS 05 Madison:

Life and Death among the Hadrons

"May it rest in peace"

New CLAS Result I

- Dedicated experiment
- Aimed at 10x stat. of 2003

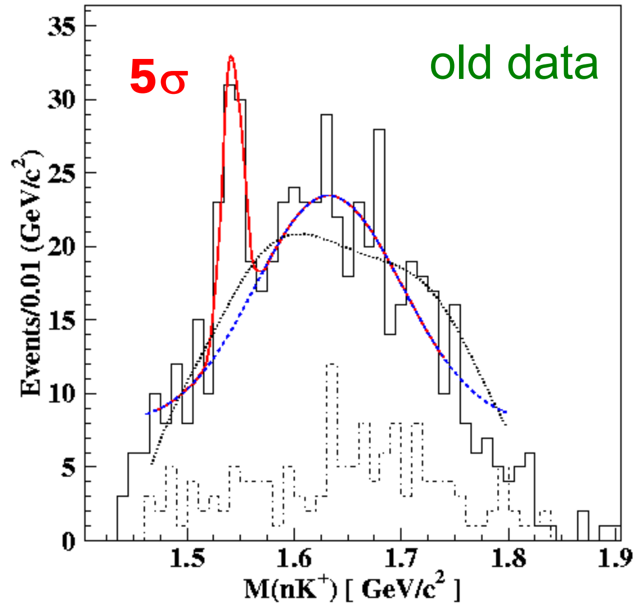
$$\gamma d \rightarrow pK^- nK^+$$

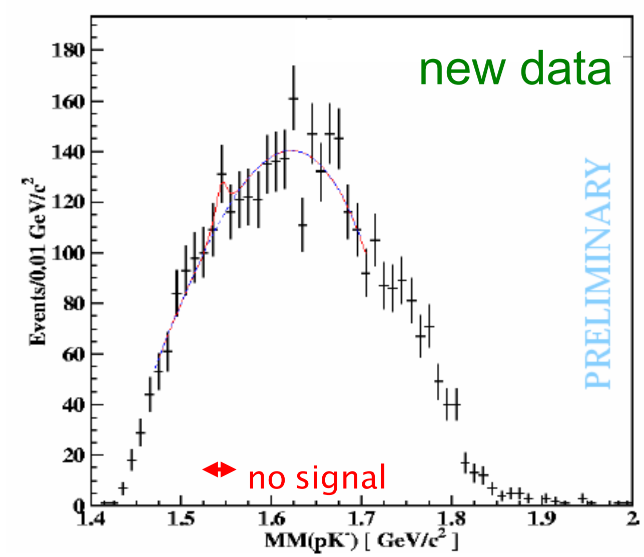
- The new high-statistics data show no signal
  $\Rightarrow$ Set upper limit on cross section

$$\gamma n \rightarrow K^- \Theta^+$$

$\sigma_{\Theta+} < 5$ nb (95% CL)
model dependent

- In previous result the background is underestimated. New estimate of the original data gives a significance of ~3σ, possibly due to a fluctuation.





New CLAS Result II

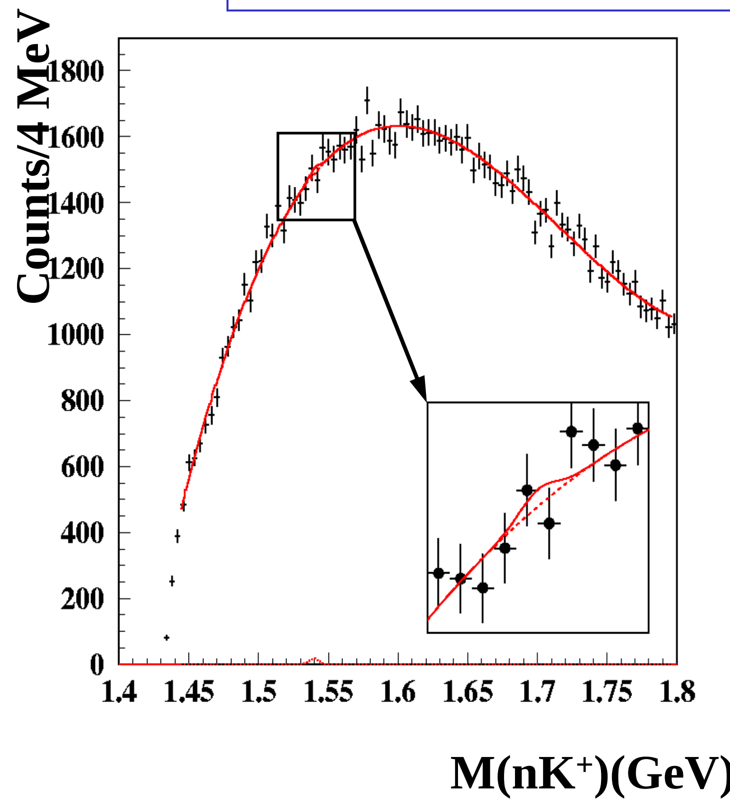
- Dedicated experiment
- Aimed at 10x stat. of 2003

$$\gamma p \rightarrow \bar{K}^0 n K^+$$

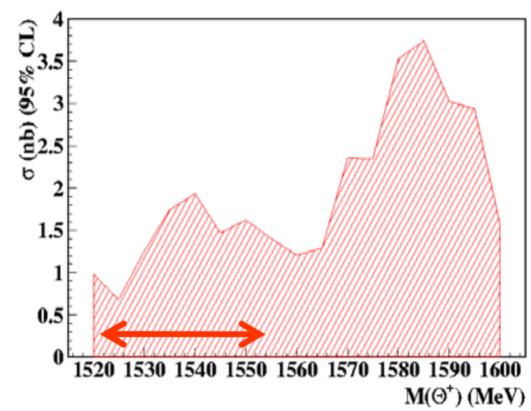
- The nK^+ mass spectrum is smooth
  $\Rightarrow$ Set upper limit on cross section

$$\gamma p \rightarrow \bar{K}^0 \Theta^+$$

$\sigma_{\Theta+} < 2$ nb (95% CL)
$\Theta/\Lambda* < 0.002$



- comparison with competing experiment possible



Comparison with SAPHIR results

Observed Yields

SAPHIR

$N(\Theta^+)/N(\Lambda^*) \sim 10\%$

CLAS

$N(\Theta^+)/N(\Lambda^*) < 0.2\%$
(95%CL)

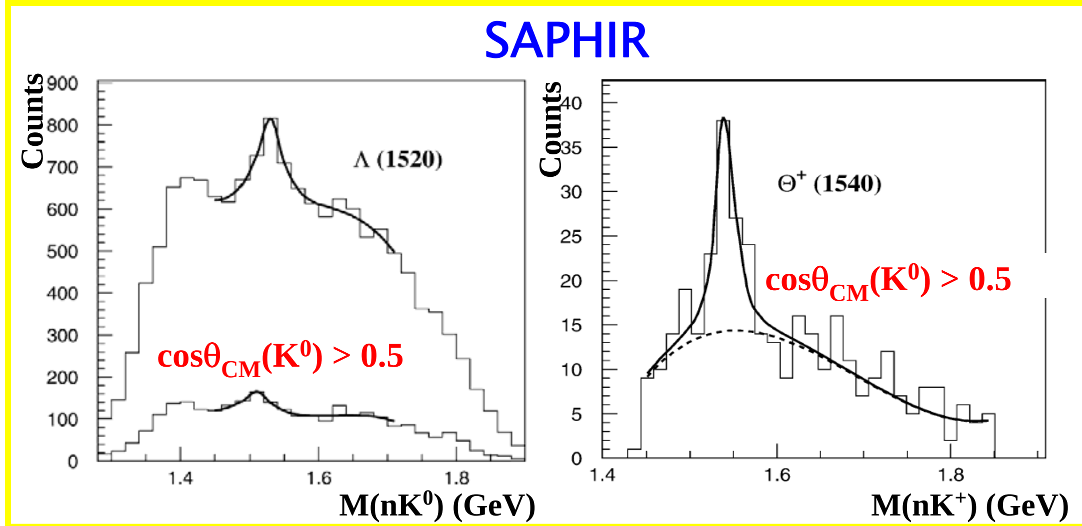
Cross Sections

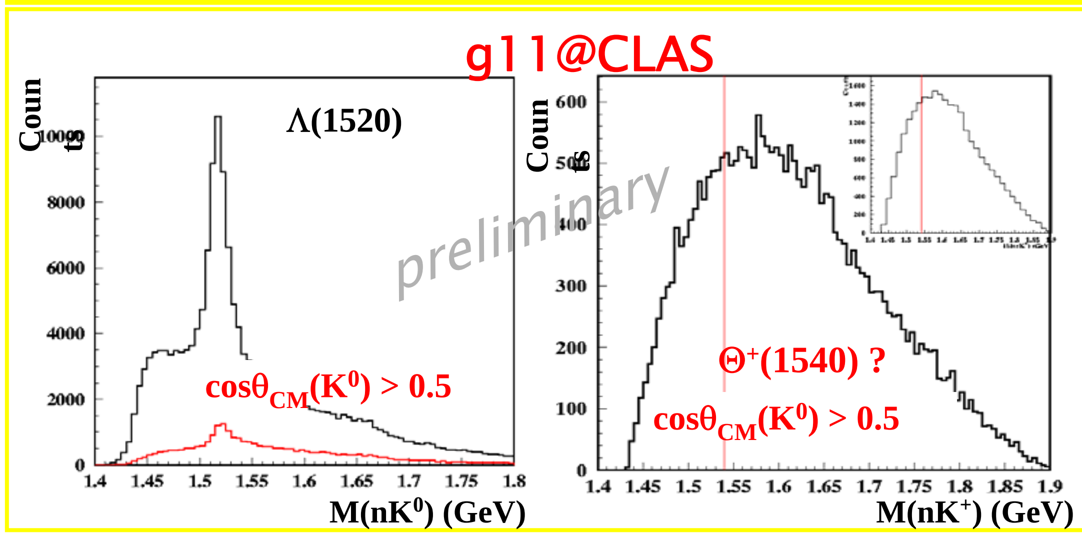
SAPHIR

$\sigma_{\gamma p \to K^0 \Theta^+} \sim 300$ nb
reanalysis 50 nb (unpublished)

CLAS

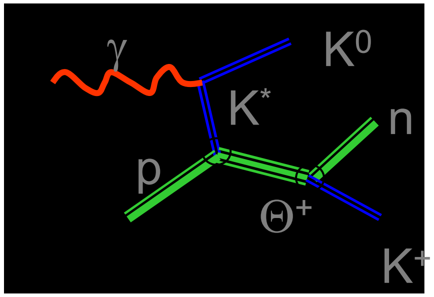
$\sigma_{\gamma p \to K^0 \Theta^+} < 2$ nb





Impact on Θ^+ production mechanism

- The CLAS result puts a very stringent limit on a possible production mechanism of the Θ^+, e.g. it implies a very small coupling to K*.



- But: "Null-result from CLAS does not lead immediately to the absence of Θ^+."

Nam, Hosaka and Kim, hep-ph/0505134

Lipkin and Karliner, hep-ph/0506084

Dynamical Model Calculations

Effective Lagrangean model W. Roberts, PRC70, 065201 (2004)

Γ_Θ = 10 MeV	1/2$^+$	1/2$^-$	3/2$^+$	3/2$^-$	
$\gamma p \rightarrow nK^+\overline{K^0}$	44.8	27.9	26.0	110.5	nb
$\gamma n \rightarrow nK^+K^-$	54.5	18.0	22.8	229.9	nb

Γ_Θ = 1 MeV	1/2$^+$	1/2$^-$	3/2$^+$	3/2$^-$	
$\gamma p \rightarrow nK^+\overline{K^0}$	4.3	2.4	2.3	10.0	nb
$\gamma n \rightarrow nK^+K^-$	5.6	1.7	2.2	24.0	nb

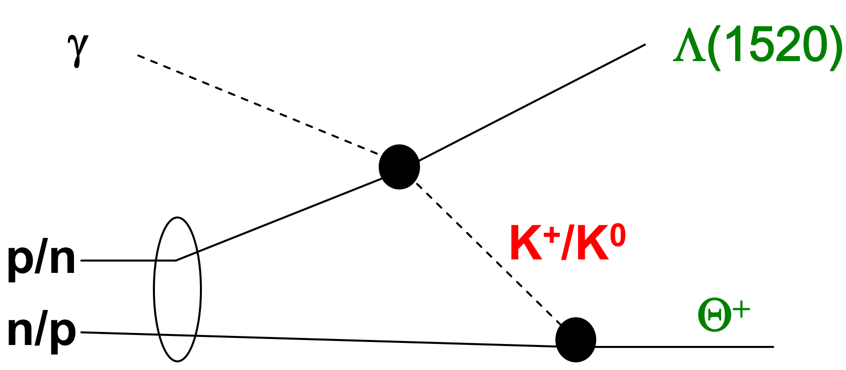
- CLAS limits of 2nb on the proton and of 5nb on the neutron do not exclude a Θ^+ with Γ = 1 MeV for J^P = 1/2$^-$, 3/2$^+$.

Note: similar calculations by other theorists.

New: LEPS Search in $\gamma d \rightarrow \Lambda(1520)nK^+$

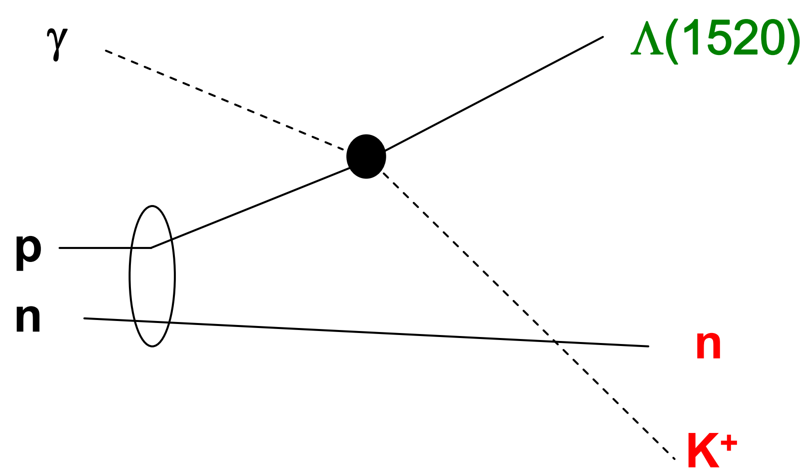
- Θ^+ identified by pK^- missing mass from deuteron.
  $\Rightarrow$ No Fermi correction is needed.
- nK^- and np final state interactions are suppressed.
- If $s\bar{s}$(I=0) component of a γ is dominant in the reaction, the final state NK has I=0. (Lipkin)

Possible reaction mechanism



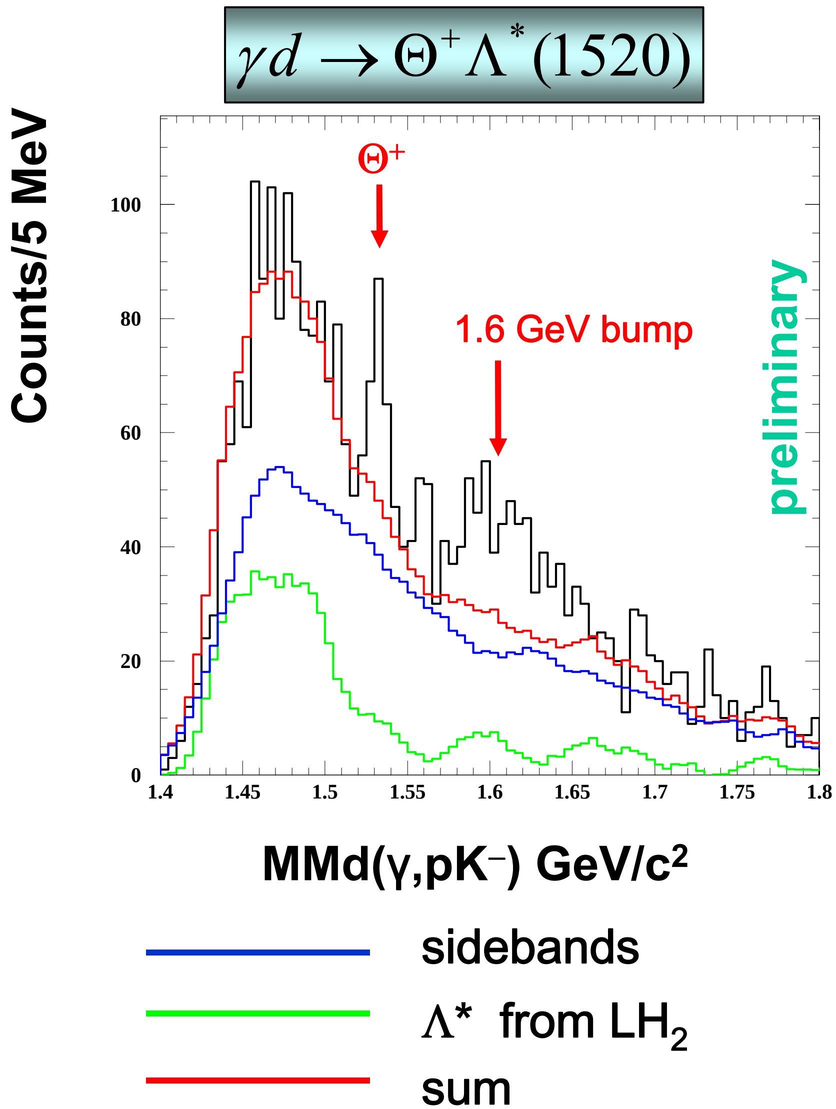
Θ^+ can be produced by re-scattering of K^+.

Main source of background



quasi-free $\Lambda(1520)$ production (estimate from LH_2 data)

LEPS: pK^- missing mass spectrum

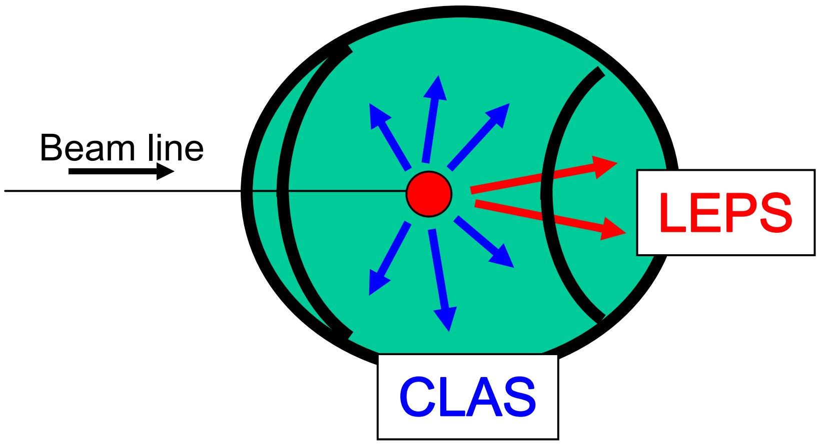


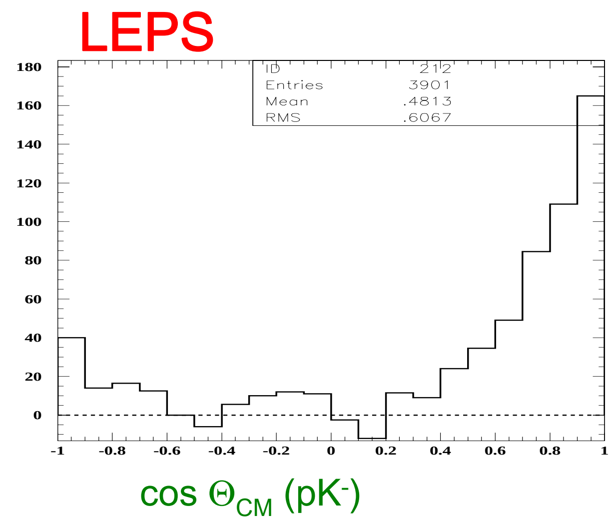
Excesses are seen at 1.53 GeV and at 1.6 GeV above the background level.

1.53-GeV peak: $\frac{S}{\sqrt{S+B}} \sim 5$?

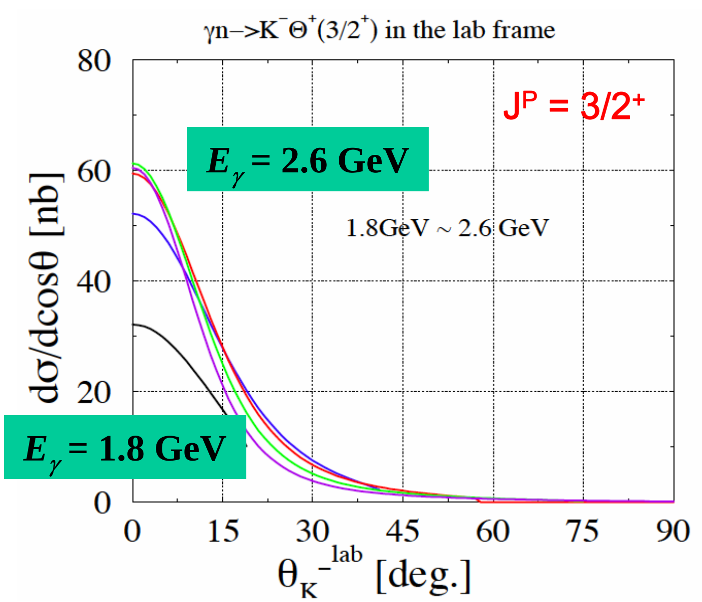
mostly from $p_{nK} \sim 0.42$ GeV
outside CLAS acceptance …

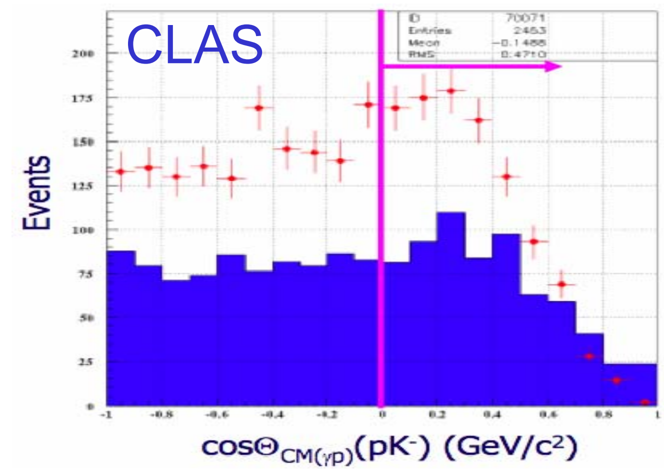
LEPS vs. CLAS



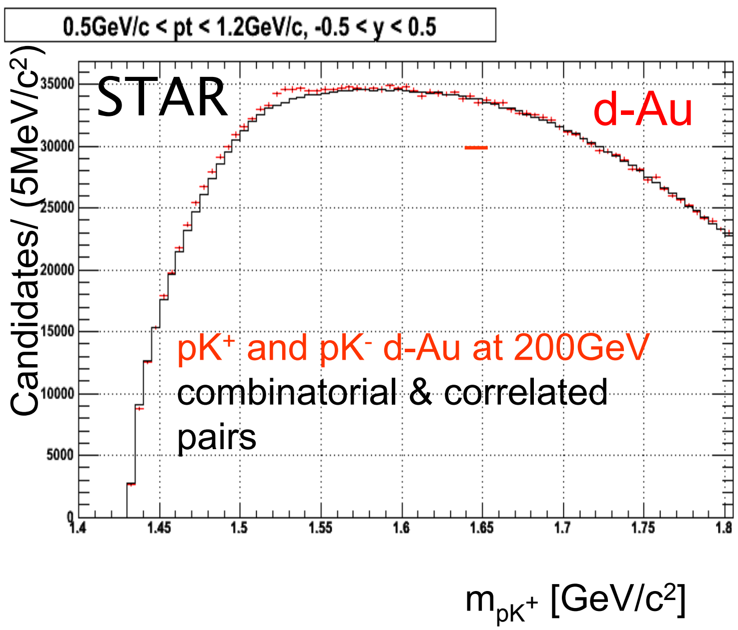


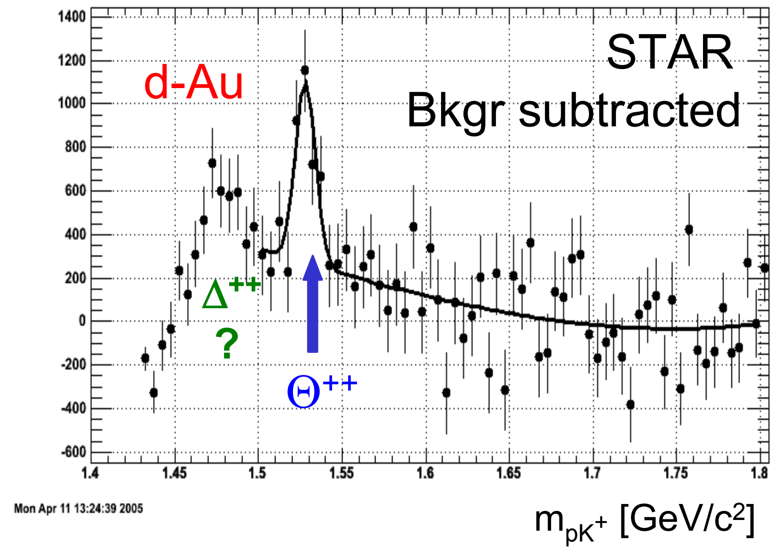
Nam *et al*, hep-ph/0505134

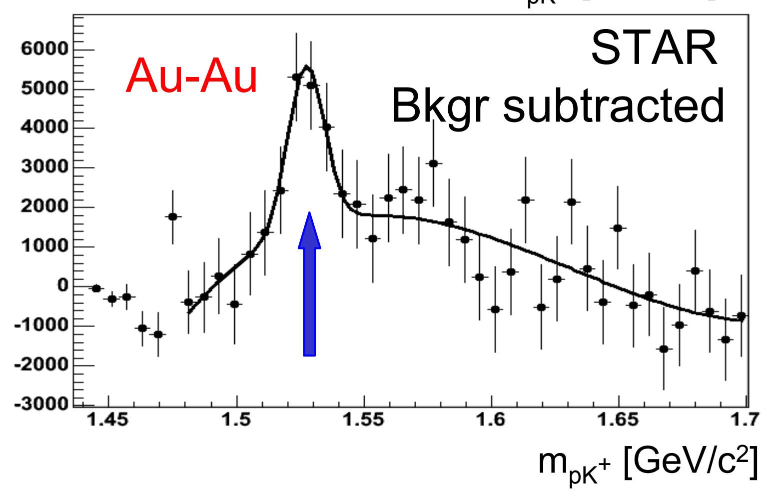




New: STAR d-Au results: Θ^{++}







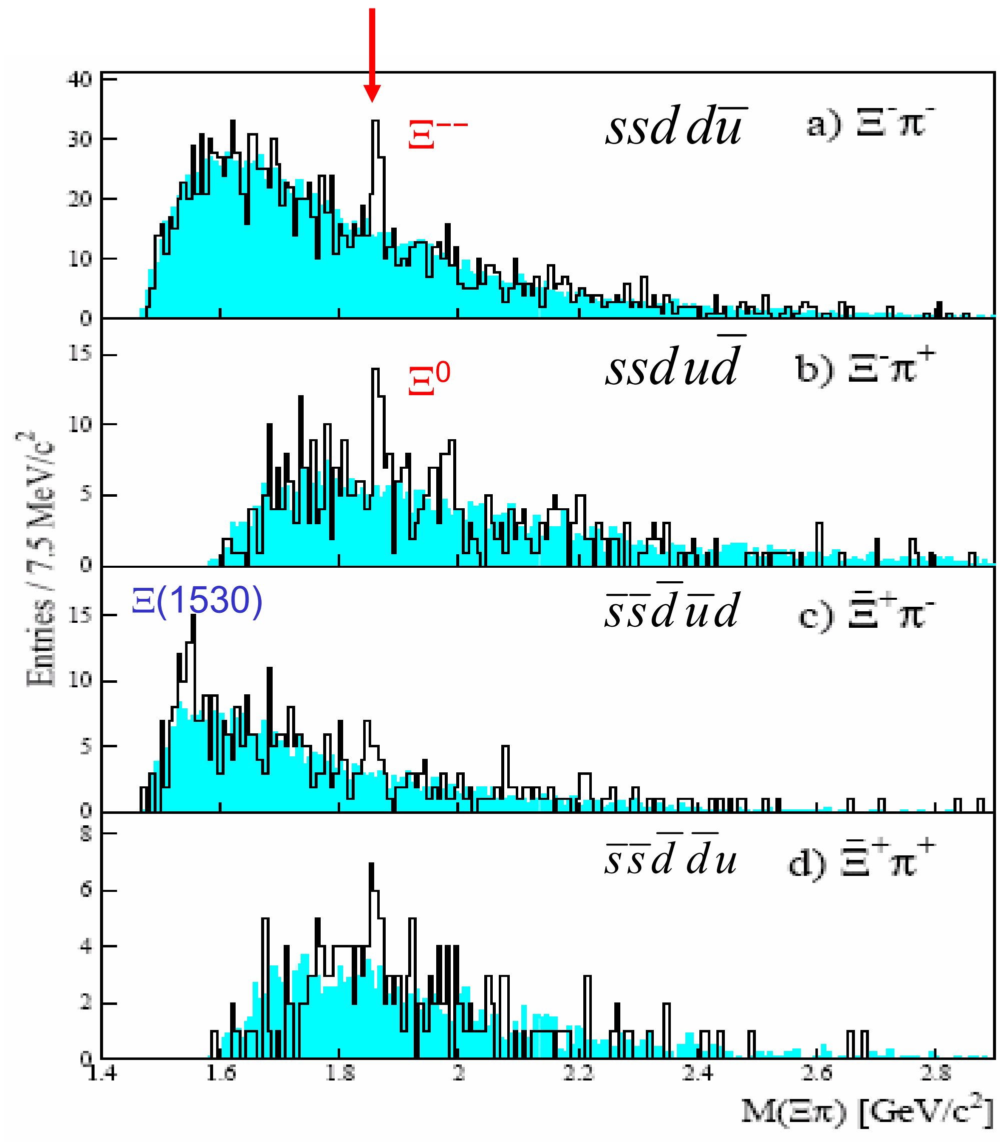
- 5σ observation of Θ^{++}
  also Θ^{+} with lower significance

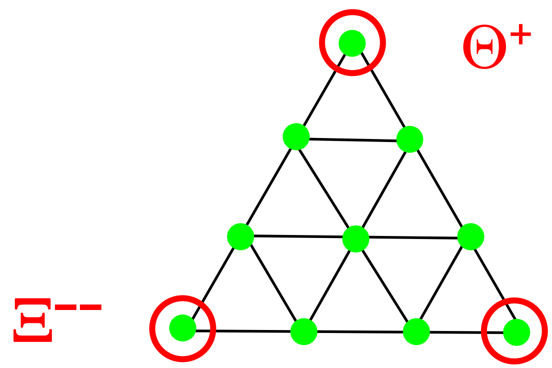
"The observed yield at STAR is so small. Such that many experiments would not have the sensitivity to see it."

Cascade Pentaquark Ξ^{--}(1860)

C. Alt et al., (hep-ex/0310014)

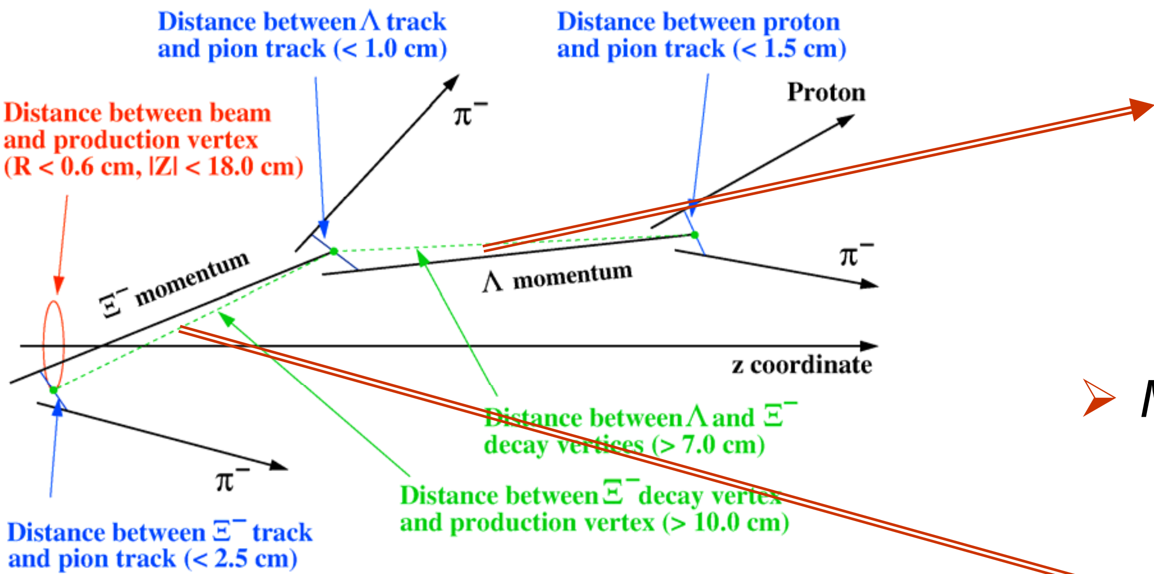
M=1862 ± 2 MeV





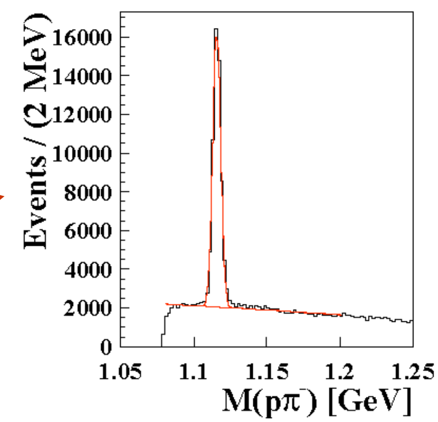
HERMES search for Ξ^{--} (1862)

- Channel: $\Xi^{--} \rightarrow \Xi^{-}\pi^{-} \rightarrow \Lambda\pi^{-}\pi^{-}$
- Topology:

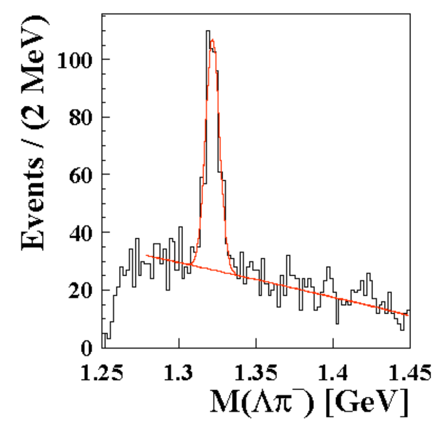


- Selected Λ events ($\pm 3\sigma$ window)
- Selected Ξ^- events ($\pm 3\sigma$ window)

- $M(p\pi^-)$ with Λ

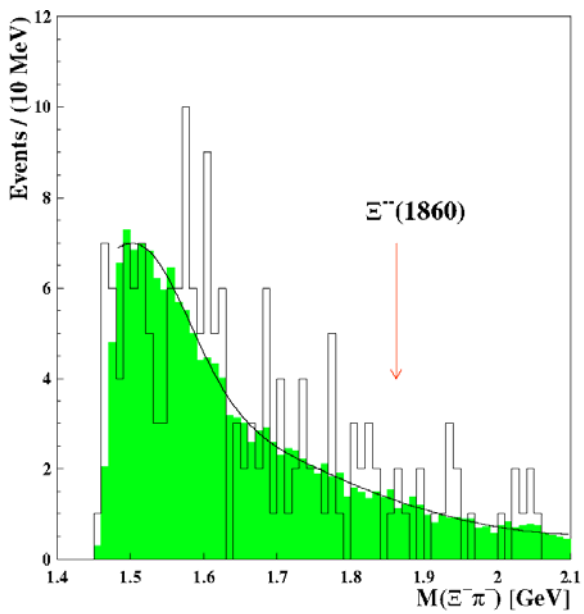


- $M(p\pi^-\pi^-)$ with Ξ^-

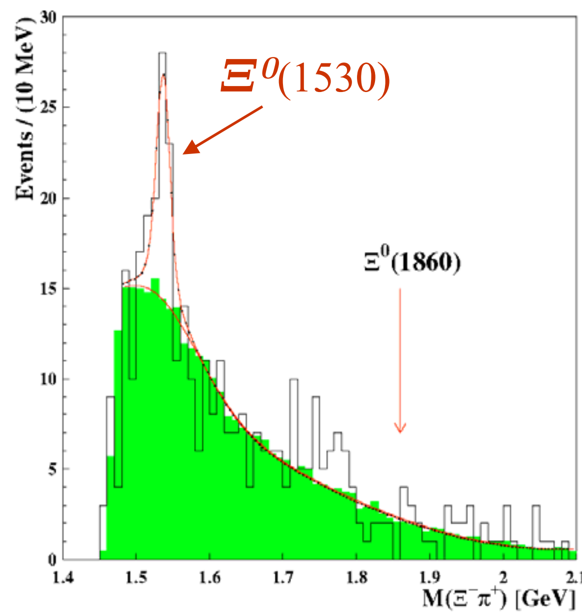


Ξ^{--} (1862) search (II)

- $M(p\pi^-\pi^-\pi^-)$ spectrum



- $M(p\pi^+\pi^-\pi^-)$ spectrum

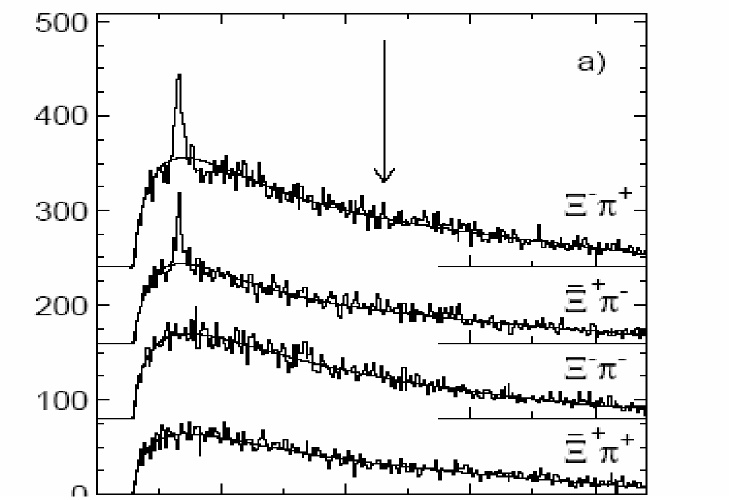


- mixed-event background
- No Ξ peaks around 1860 MeV
- $\Xi^0(1530)$ seen, as expected

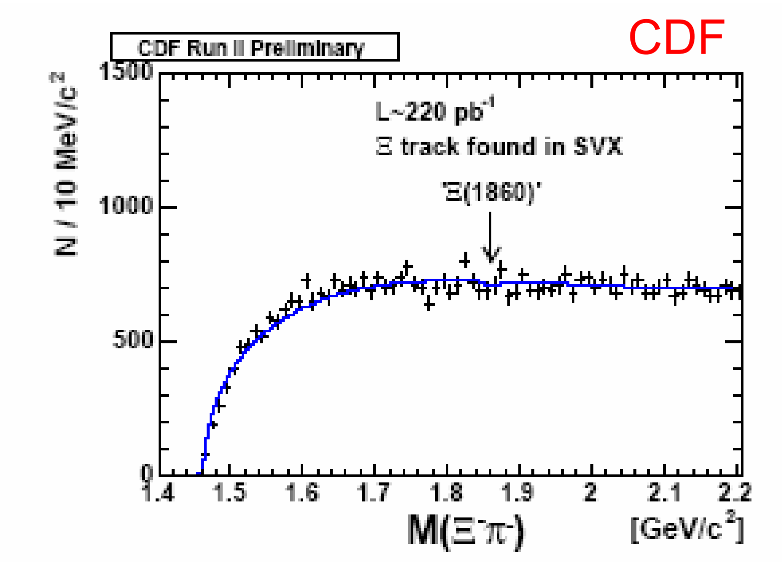
- upper limit $\sigma(\Xi^{--})$: 1.0–2.1 nb
- upper limit $\sigma(\Xi^0)$: 1.2–2.5 nb
- $\sigma(\Xi^0(1530))$ = 8.8–24 nb

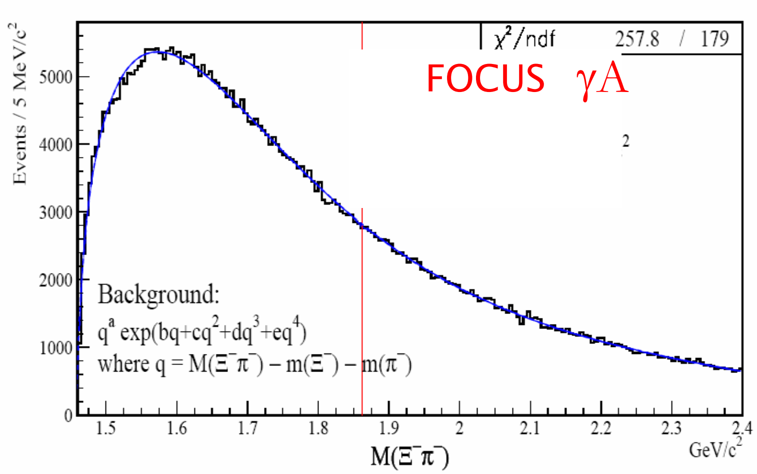
Other Null results for Ξ^{--}(1862)

HERA-B



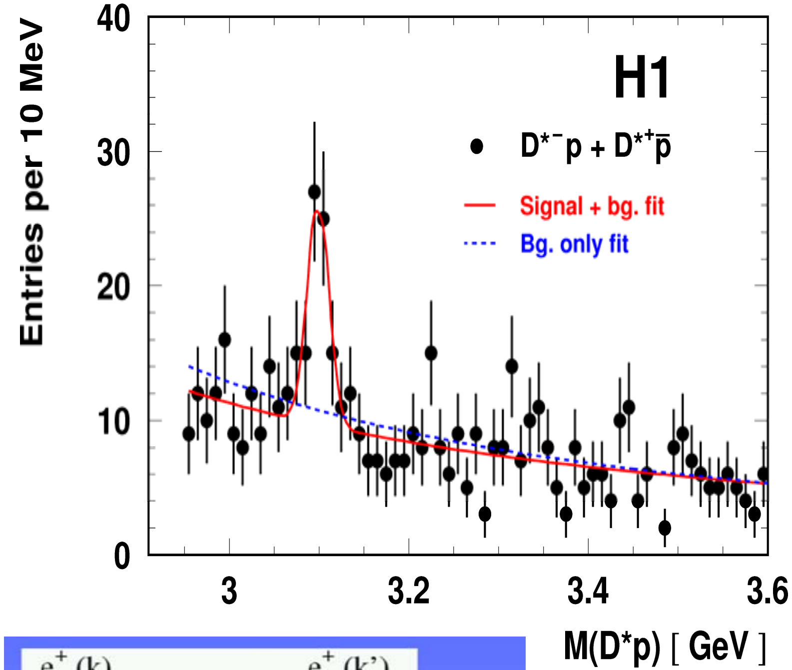
$p\bar{p} \rightarrow \pi\Xi X$

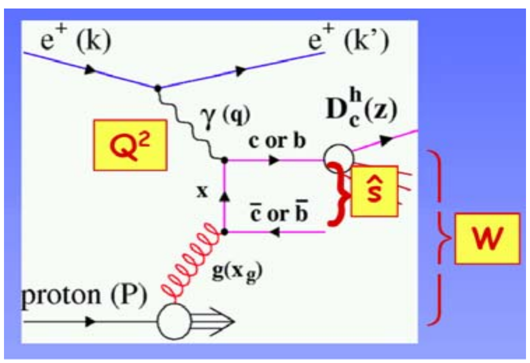


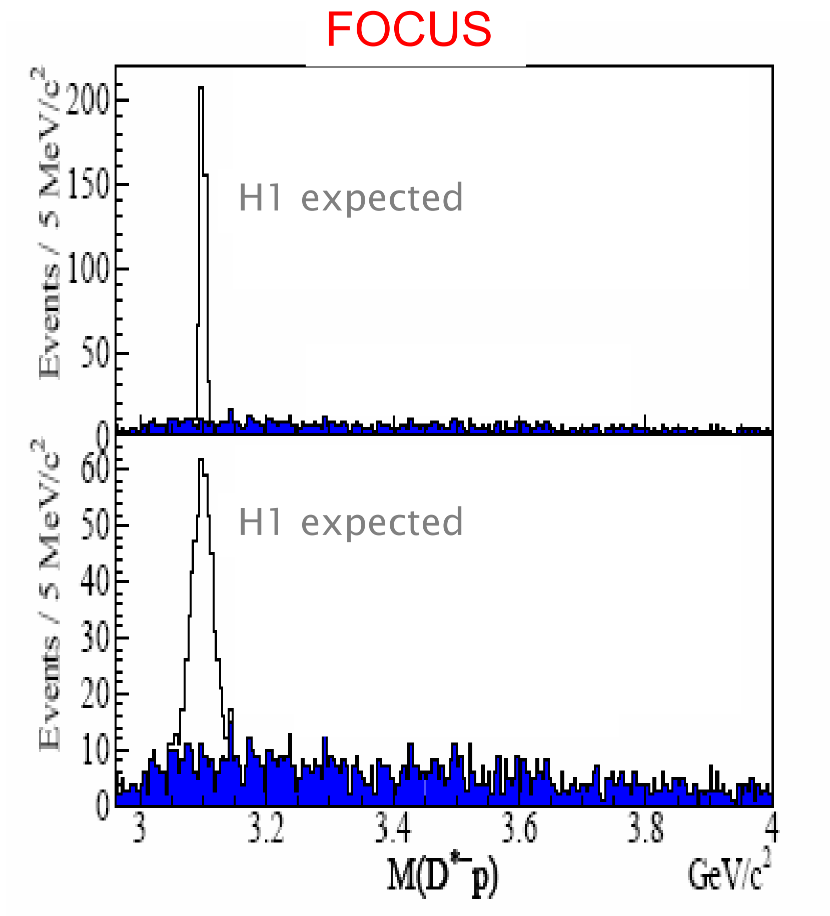


- Ξ^{--} (1862) not seen by 10 experiments
- Only one observation.

Charmed Pentaquark $\Theta^0_c(3100)$?







- ➢ Signal also in photo-production
- ➢ FOCUS experiment (+ 4 others) claim incompatibility with H1

Status: Pentaquark-2005 (Oct 20-22 JLab, VA)

	Group	Signal	Backgr.	Significance publ.	$s/\sqrt{b+s}$	Comments
Θ^+	SPring8	19	17	4.6σ	3.2σ	
	SPring8	56	162	?	3.8σ	
	~~SAPHIR~~	~~55~~	~~56~~	~~4.8σ~~	~~5.2σ~~	New CLAS–p
	DIANA	29	44	4.4σ	3.4σ	
	~~CLAS(d)**~~	~~43~~	~~54~~	~~5.2σ~~	~~4.4σ~~	New CLAS–d
	CLAS(p)	41	35	7.8σ	4.7σ	
	ν	18	9	6.7σ	3.5σ	
	HERMES	51	150	$3.4-4.3\sigma$	3.6σ	
	COSY	57	95	$4\text{-}6\sigma$	4.7σ	
	ZEUS	230	1080	4.6σ	6.4σ	
	SVD	41	87	5.6σ	3.6σ	
Ξ^{--}	~~NA49~~	~~38~~	~~43~~	~~4.2σ~~	~~4.2σ~~	? HERA–B, CDF
Θ_c	~~H1~~	~~50.6~~	~~51.7~~	~~$5-6\sigma$~~	~~5.0σ~~	? ZEUS
	SPring8	200	285		5.0σ	$\Lambda^*(nK^+)$
	STAR	2,250	150,000		5.5σ	Θ^{++} candidate
	SVD–2	370	2000		7.5σ	Improved analysis

Conclusions: Experiment (P. Stoler)

- The situation cannot be put into *any neat package.*
- New very high quality exclusive experiments from CLAS have repeated earlier experiments by SAPHIR and CLAS, and contradicted earlier positive observations.
- The new CLAS results do not exclude a state of <1 MeV width.
- There have been new positive reports from LEPS, SVD-2 and STAR.
- Beyond that there is a lot of overwhelming negative evidence which appear to push the observed pentaquark signals into narrower corners.

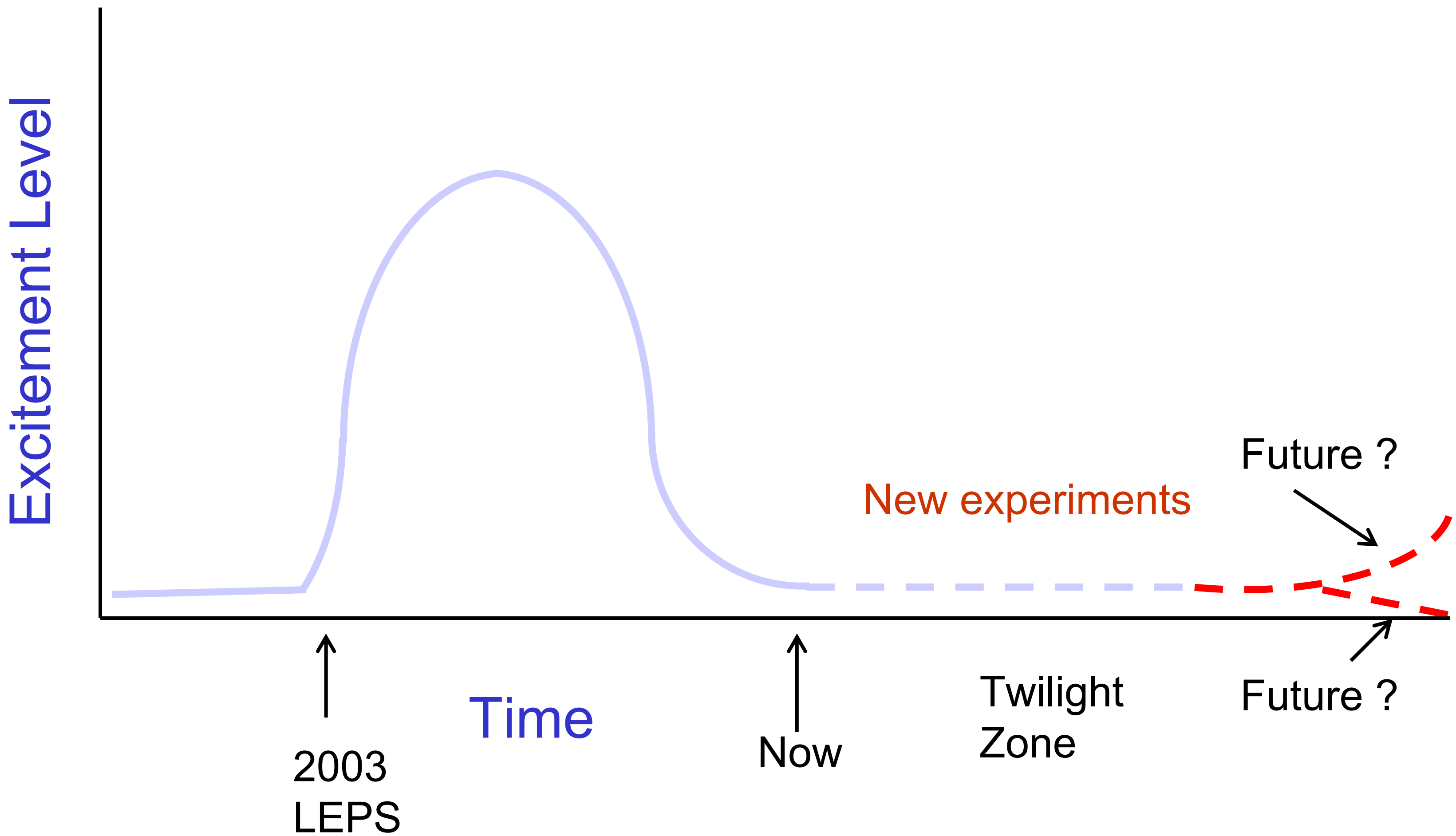
Conclusions: Theory (M. Karliner)

- The pentaquark is not in good health, but it is still alive…
- Crucial open questions:
  - why do some experiments see it and other not
  - maybe does not exist (pessimistic view)
  - what is production mechanism (optimistic view)
  - if Θ^+ exists, why is it so narrow
  - why is cross section forward (LEPS, ZEUS)
  - is there an energy & Q^2 dependence
- Gold plated experiment: K^+ on nucleus at low momentum
- Ball is in experimental court!

Prognosis

- Analysis is continuing at Spring8, JLab, COSY, HERMES, H1, ZEUS, SVD-2, STAR, PHENIX
- New measurements planned at SPring8 (March 2006), JLab 2006)
- H1, ZEUS, HERMES high luminosity run until July 2007
- Higher statistics data from STAR, PHENIX
- Limited additional statistics from B-factories, Fermilab and CERN
- Focus moved from bump hunting to more quantitative estimations of cross sections or upper limits

Pentaquark Vital Signs



Quote about Pentaquarks by a distinguished American

"…the reports of my death are exaggerated."

…Mark Twain