Θ

“Is it –

or

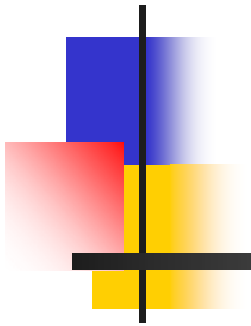
isn’t it?”

High Statistics

Pentaquark

News from CLAS and others

Thomas S. Bauer - NIKHEF



New Results :

- **High Statistics**
  - **from several experiments,**
    but most importantly also
  - **hot news from CLAS**

I'll present some of the results;
discuss aspects of
- **consistency;**
- **impact…**

a way out ??

Febr 2004!

- What about the width???
- How can a state at this energy be so narrow??
- my (an experimentalist's) theoretical prediction is :

$$\Gamma \approx 10^{-22}\ \text{eV}$$

a way out ??

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*) CLAS is one of the "Founding Fathers" of the Pentaquark Saga…

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This talk is restricted to Θ only !!

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Remark :

Last talk here: Febr. 27th, 2004.

At that time:

- **~ 10 "sightings" from low stat. expts.**
- **1 "non-sighting": *Hera-B* .**

During summer 2004:

- **several high stat. expts. publish their results**

***Note:* not dedicated experiments!**

Now: (April 15th, 2005)

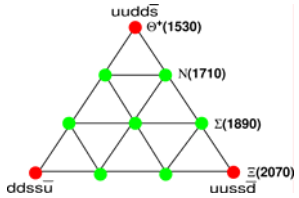
- **1st dedicated high stat. expt. at CLAS publishes.**

Used Sources for this talk:

K. Hicks (Ohio) APS Talk, Tampa, April 15, 2005

R. De Vita (CLAS) APS Talk, Tampa, April 16, 2005

What is a Pentaquark?



QCD is "constructed" to produce
colour-neutral objects only;

this agrees with well-known fact that
only known hadrons are mesons and baryons
***which have* {$q\bar{q}$} or {qqq} content;**

but…

QCD does not forbid colour-neutral objects
with content other than {$q\bar{q}$} or {qqq}.

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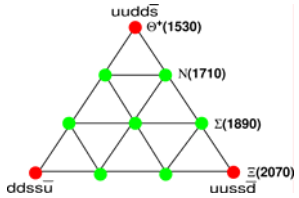

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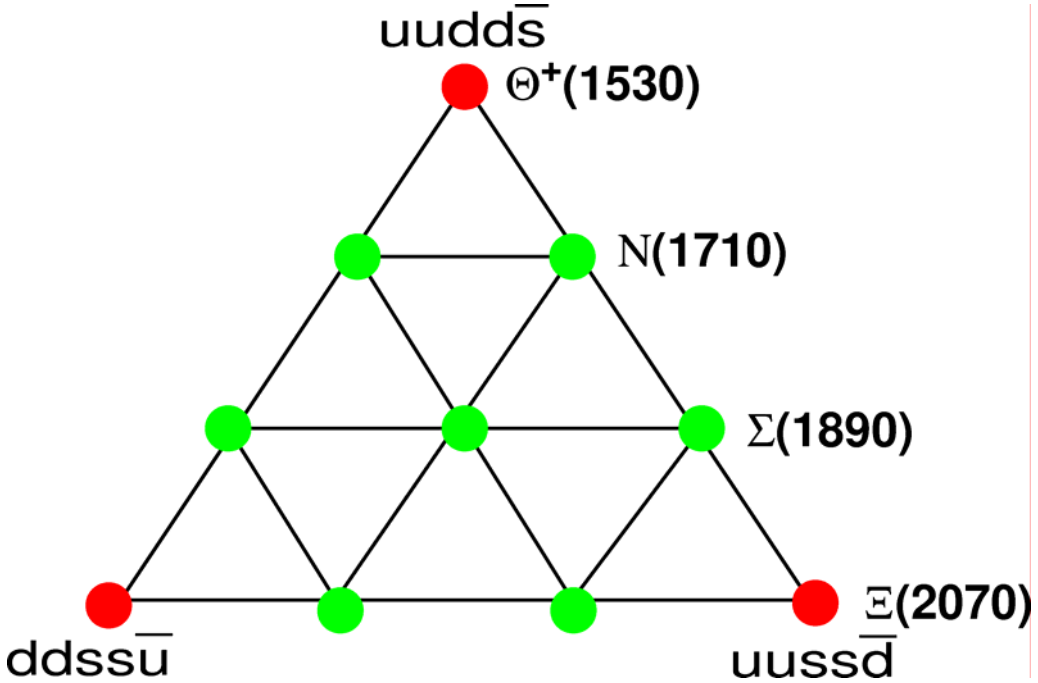
but…

QCD does not forbid colour-neutral objects
with content other than {$q\bar{q}$} or {qqq}.
(in fact – what about sea-quarks?)

The Anti-Decuplett

- **predicted by**
  - **D. Diakonov, V. Petrov, M. Polyakov**
    - **(Z. Phys. A359, 305 (1997))**
- **special through the predictions:**
  - narrow states
  - clear, exotic QN



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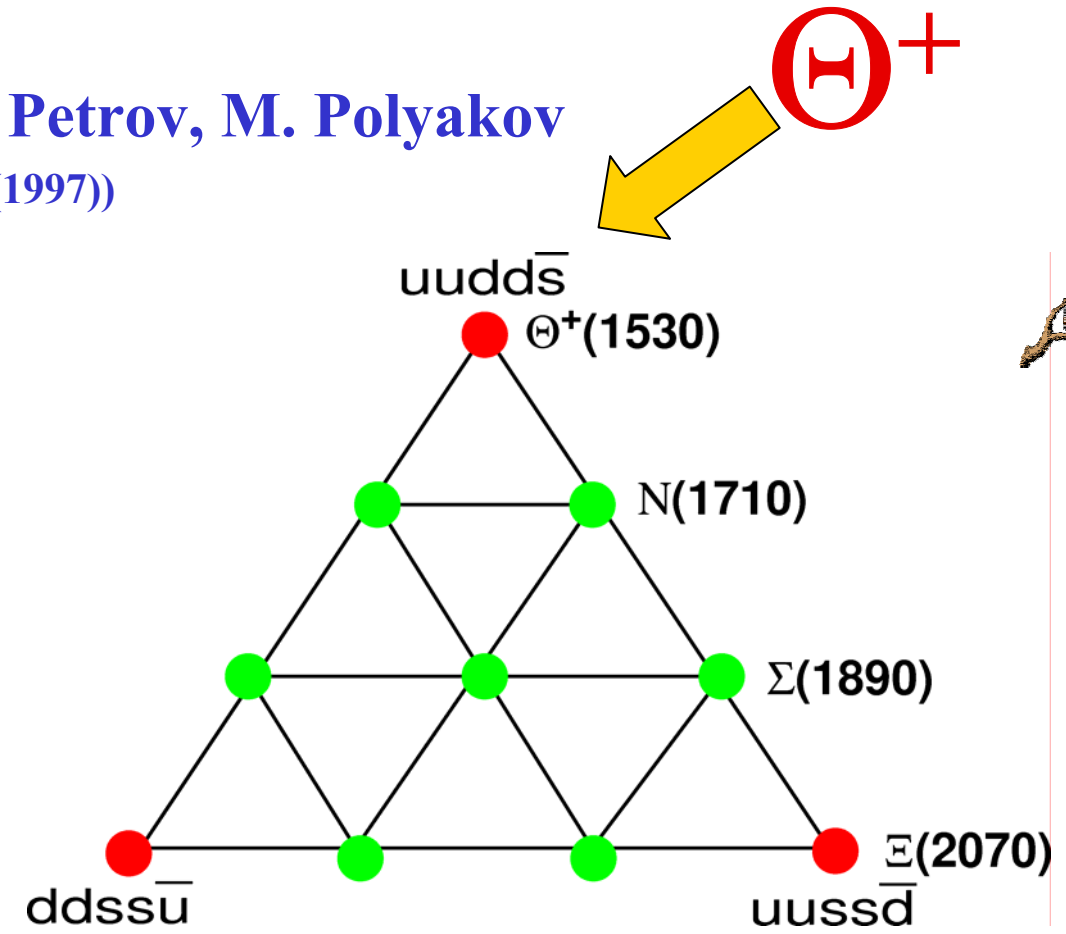

Other "Exotics"

- Λ (1405) discussed as a possible "hybrid" {qqqg}
- The "Roper" (N(1440)) was since long a "hybrid" candidate {qqqg} due to
  - Quantum numbers ($I,J^P = ½, ½^+$)
  - Mass (lowest mass states are N(1520) $^3/_2^-$ and N(1535) $½^-$)
  - e-m couplings… (too large)
- The "Dibaryons" {qqq-qqq} :

  *** **resonances** in the 1980's – discarded nowadays
- . . . (continued next slide)

A special case: “H”

- The “H” {uu-dd-ss}
  - predicted in 1977 by R. Jaffe;
  - ca. 80 MeV below Λ–Λ threshold (original prediction)
  - thus weak decay only!!

    (later predictions: up to slightly above NN-threshold)
- dedicated searches in E888 (Brookhaven)
  - two-step production experiment;
  - many other experiments.

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  - two-step production experiment;
  - many other experiments.

in vain… → **Subject “dormant” since ~ 5 years**

Sightings (status Febr. 2004) :

γ	SPring-8	(Japan)	hep-ex/0301020	08 Jul. 2003
γ	CLAS	(TJLab)	hep-ex/0307018	10 Dec. 2003
γ	SAPHIR	(Bonn)	hep-ex/0307083	30 Sep. 2003
e-scatt.	Hermes	(HERA)	hep-ex/0312044	22 Jan. 2004
	ν-data	(BEBC and Fermilab)	hep-ex/0309042	25 Sep. 2003
$(K^+ + Xe)$	Diana	(ITEP)	hep-ex/0304040	18 Sep. 2003
(p + A)	SVD-2	(Protvino)	hep-ex/0401024	22 Jan. 2004

Sightings (status now – 2005; Θ only) :

γ	SPring-8	(Japan)	hep-ex/0301020	08 Jul. 2003
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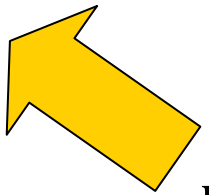
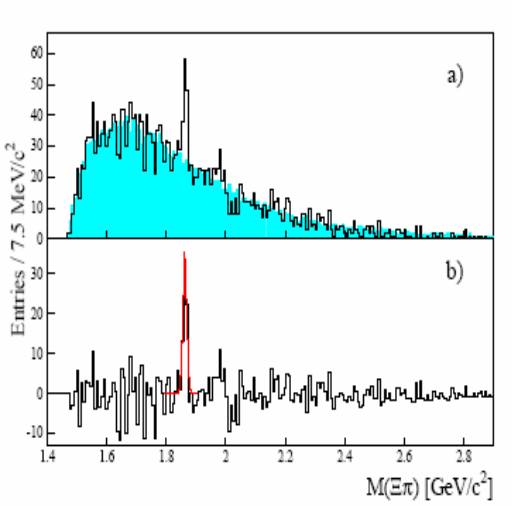
(p + A)	SVD-2	(Protvino)	hep-ex/0401024	22 Jan. 2004
(p + p)	COSY-TOF	(Julich)	hep-ex/0403011	5 Mar. 2004
$(e^+ + p)$	ZEUS	(HERA)	hep-ex/0403051	30 Mar. 2004



new!

Sightings (other than Θ^+) :

CERN/NA49

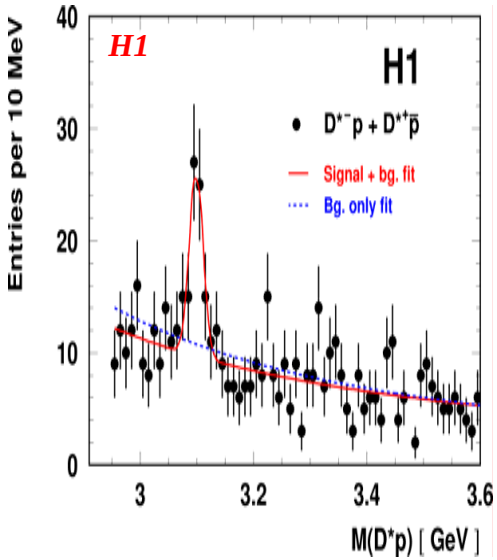


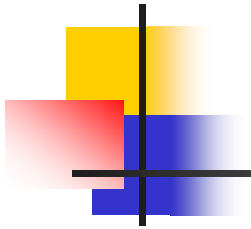
NA49 (CERN) **claims Ξ^{--}(1862 MeV)**

not confirmed by any other expt.

H1 (HERA) **claims charmed PQ,**

not confirmed by (a.o.) ZEUS





Disclaimer:

This talk is restricted to Θ^+ only:

config: $\{uudd\bar{s}\}$

predicted mass: **1540 MeV**

The first sightings:

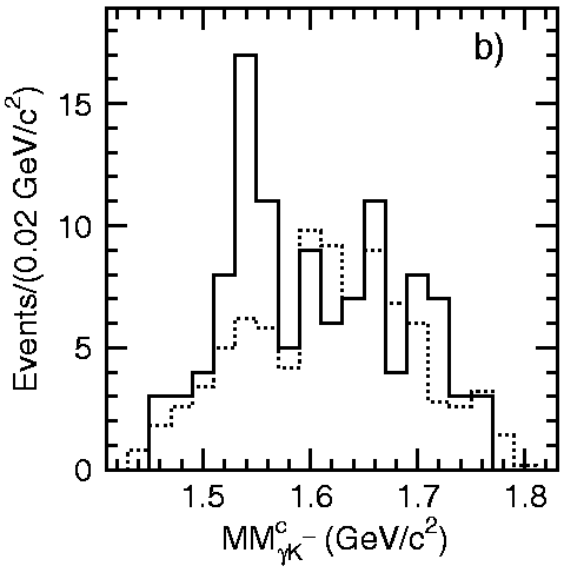
How do they look like?

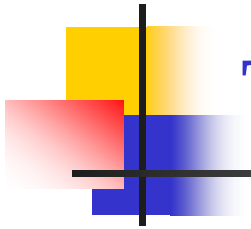
The first sightings:

SPring-8 (LEPS)

How do they look like?

first evidence for Θ^+-state;
19 events in peak.





The first sightings:

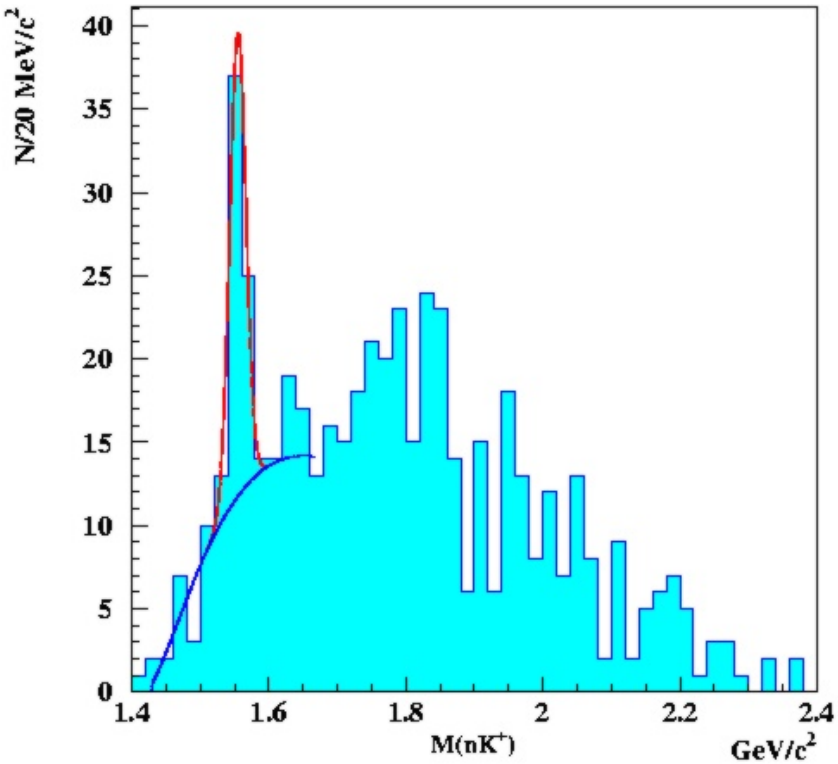
First observation on the proton: CLAS-p

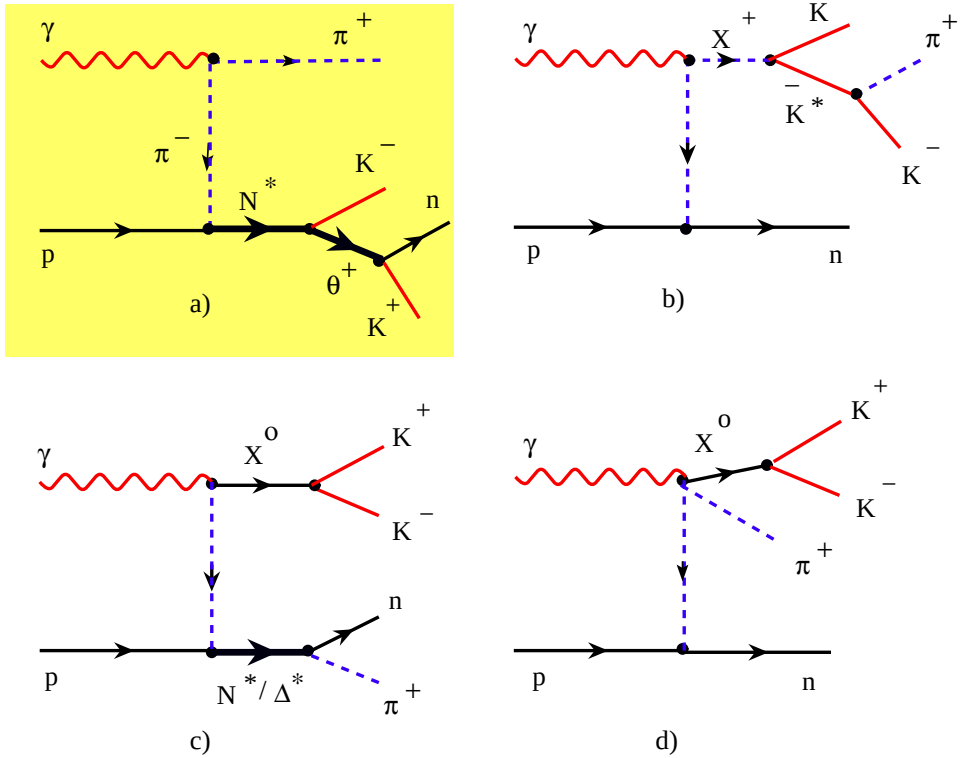
(2004 !! thus old…)

First observation on the proton: CLAS-p

$\gamma p \rightarrow K^- \pi^+ K^+ (n)$

V. Kubarovski et al., PRL92, 032001 (2004)





M = (1.555 ± 0.010) GeV/c²

Statistical significance: (7.8 ± 1.0) σ

Γ = 26 MeV/c²

t-channel process a) selected and **background processes** eliminated with the **cuts** (c.m.):

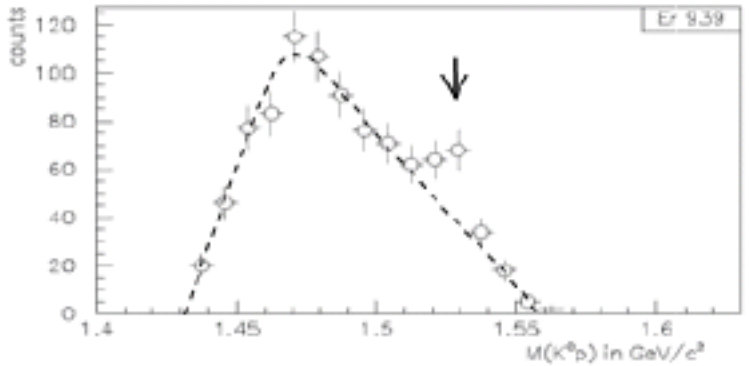
$\cos\theta^*_{\pi+} > 0.8$ and **$\cos\theta^*_{K+} < 0.6$**

The first sightings:

COSY - ToF $pp \rightarrow \Sigma^+ K_s^0 p$

"Another experiment with good evidence …"

taken from: K. Hicks, Review talk, 15 April 2005



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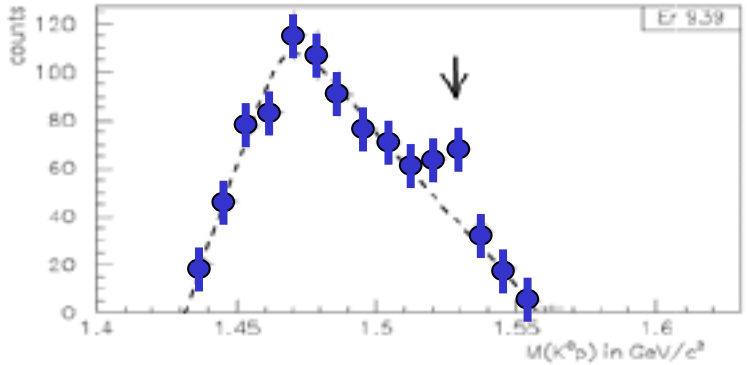


All sightings:

Synoptique view

with thanks to: J. Pochodzalla, 6/2004

The sightings

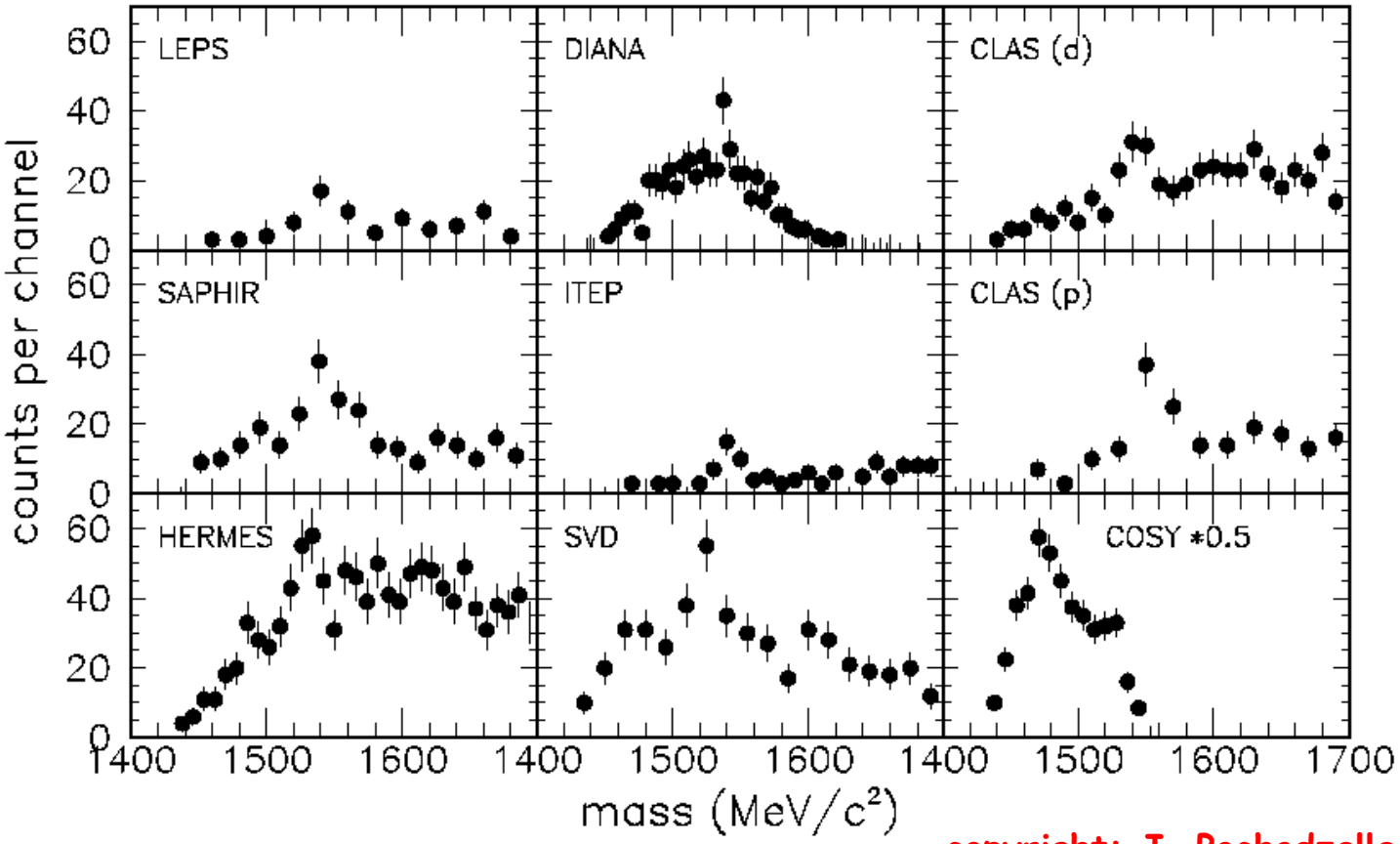
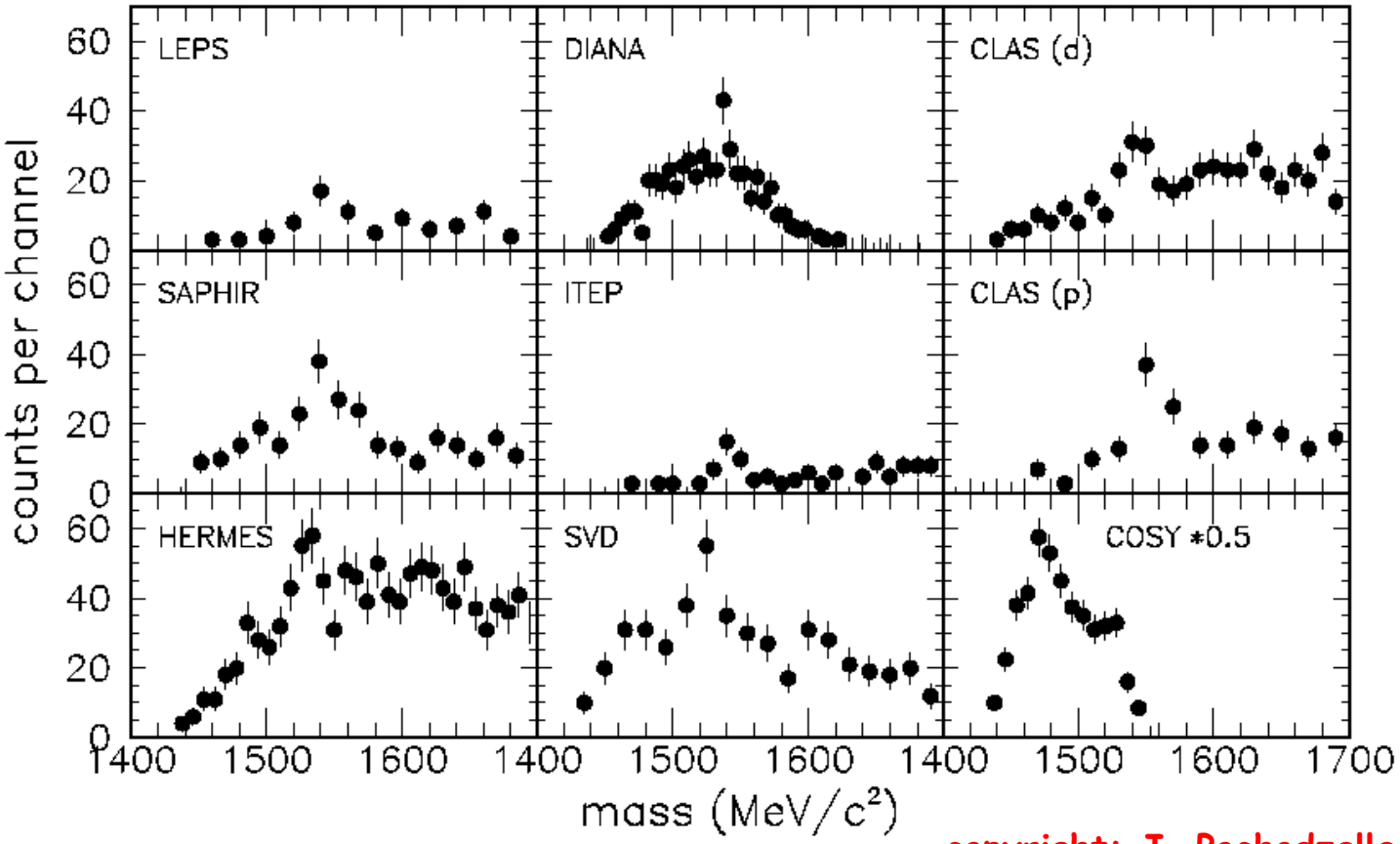


Figure 2: *Summary of the first nine published observations of the* $\Theta^+(1530)$ *resonance.*

The sightings

available spectra rebinned to one common scale.



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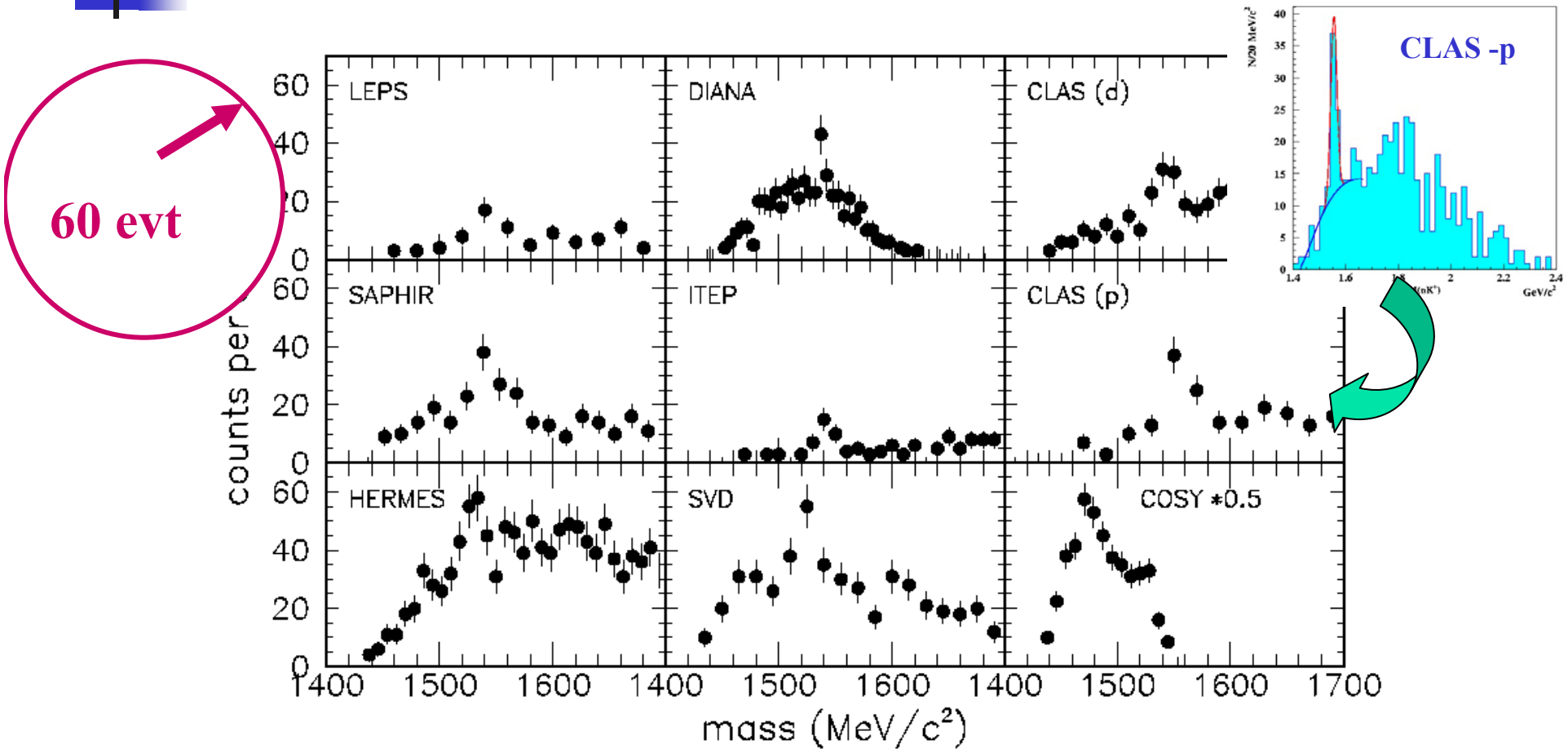

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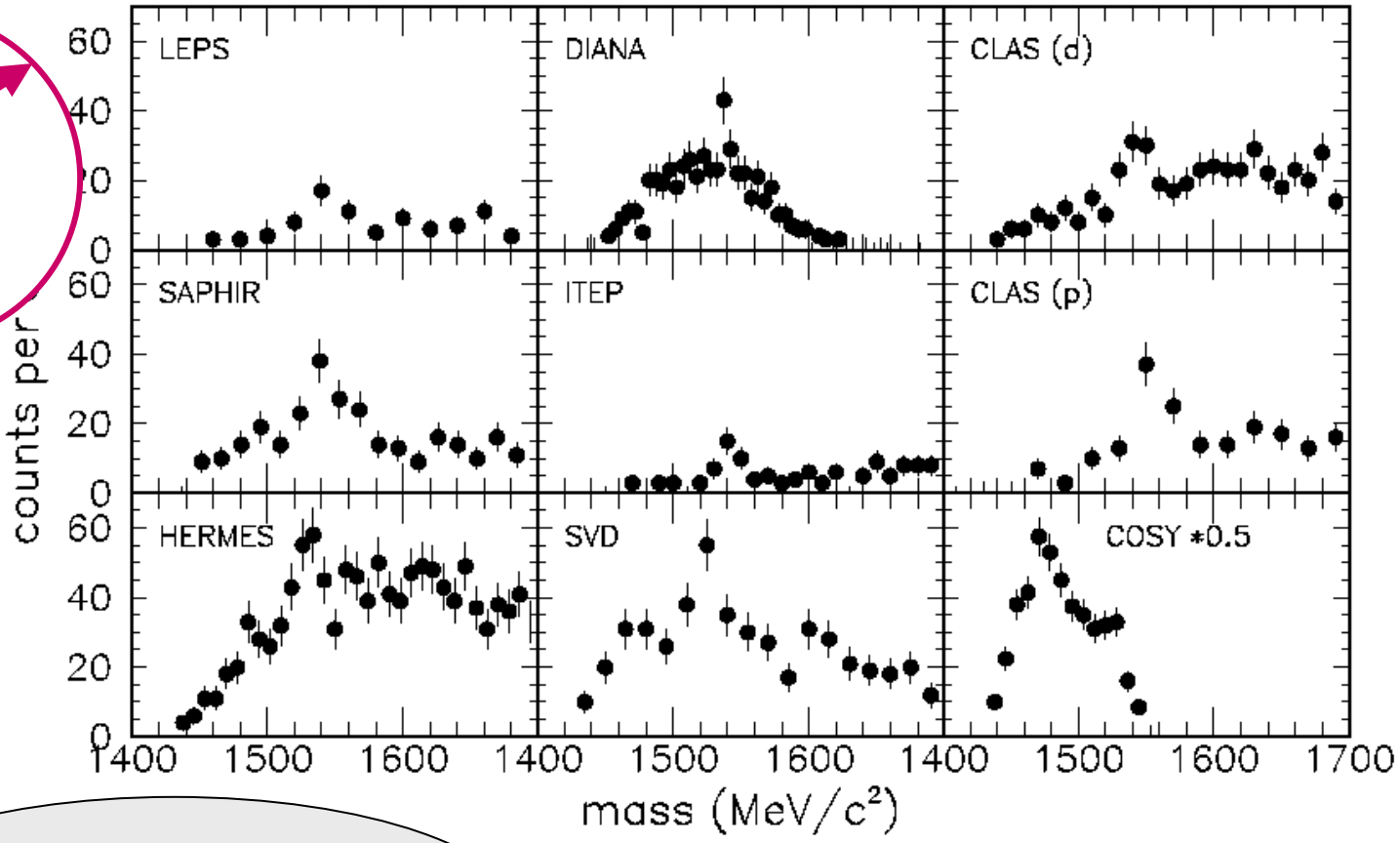
The sightings

60 evt



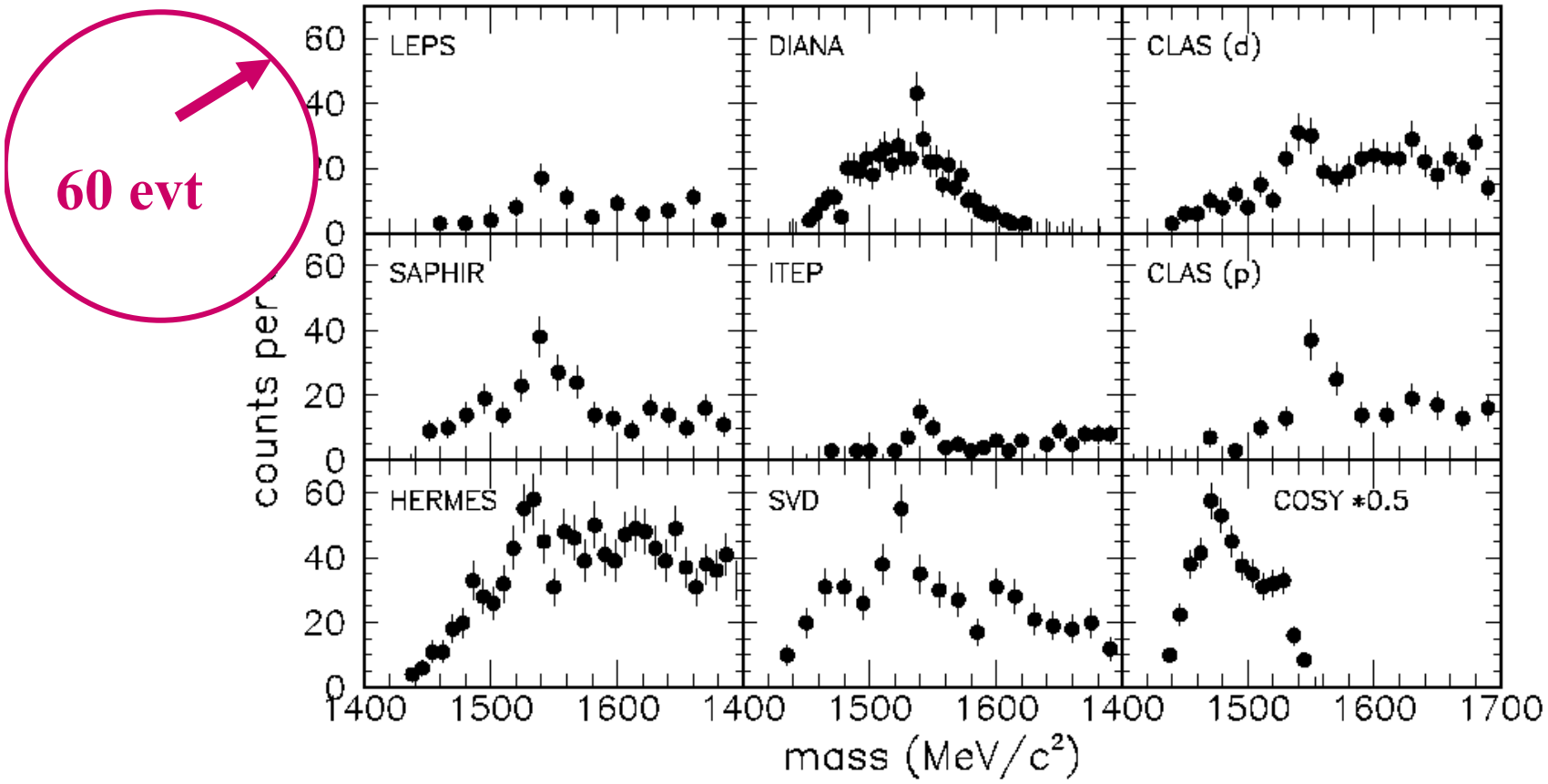
since then no change: K. Hicks , Review, 15 Apr. 2005, …

The non-Sightings

e^+e^-	BES	(Japan)	hep-ex/0402012
e^+e^-	BaBar	(SLAC)	hep-ex/0408064
e^+e^-	Belle	(Japan)	hep-ex/0409010
e^+e^-	LEP	(CERN)	hep-ex/0410080
p-A	Hera-B	(DESY)	hep-ex/0408048
(p-A)	SPHINX	(ITEP)	hep-ex/0407026
(h + A)	HYPERCP	(Fermilab)	hep-ex/0410027
(p + p)	CDF	(Fermilab)	hep-ex/0410024
(A-A)	PHENIX	(RHIC)	hep-ex/0404001

taken from: K. Hicks, Review talk, 15 April 2005

The sightings (again)



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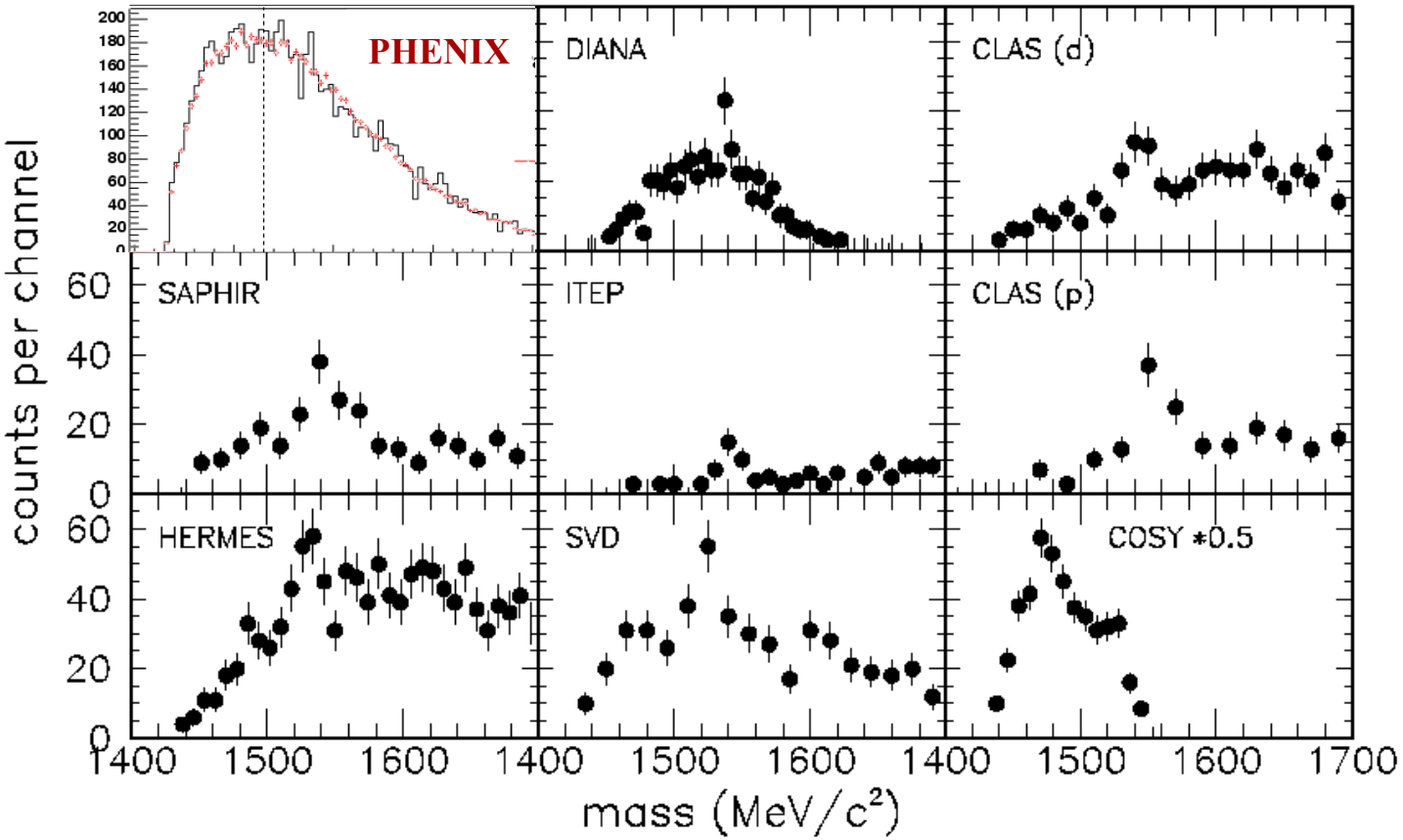
The non-sightings (on top)



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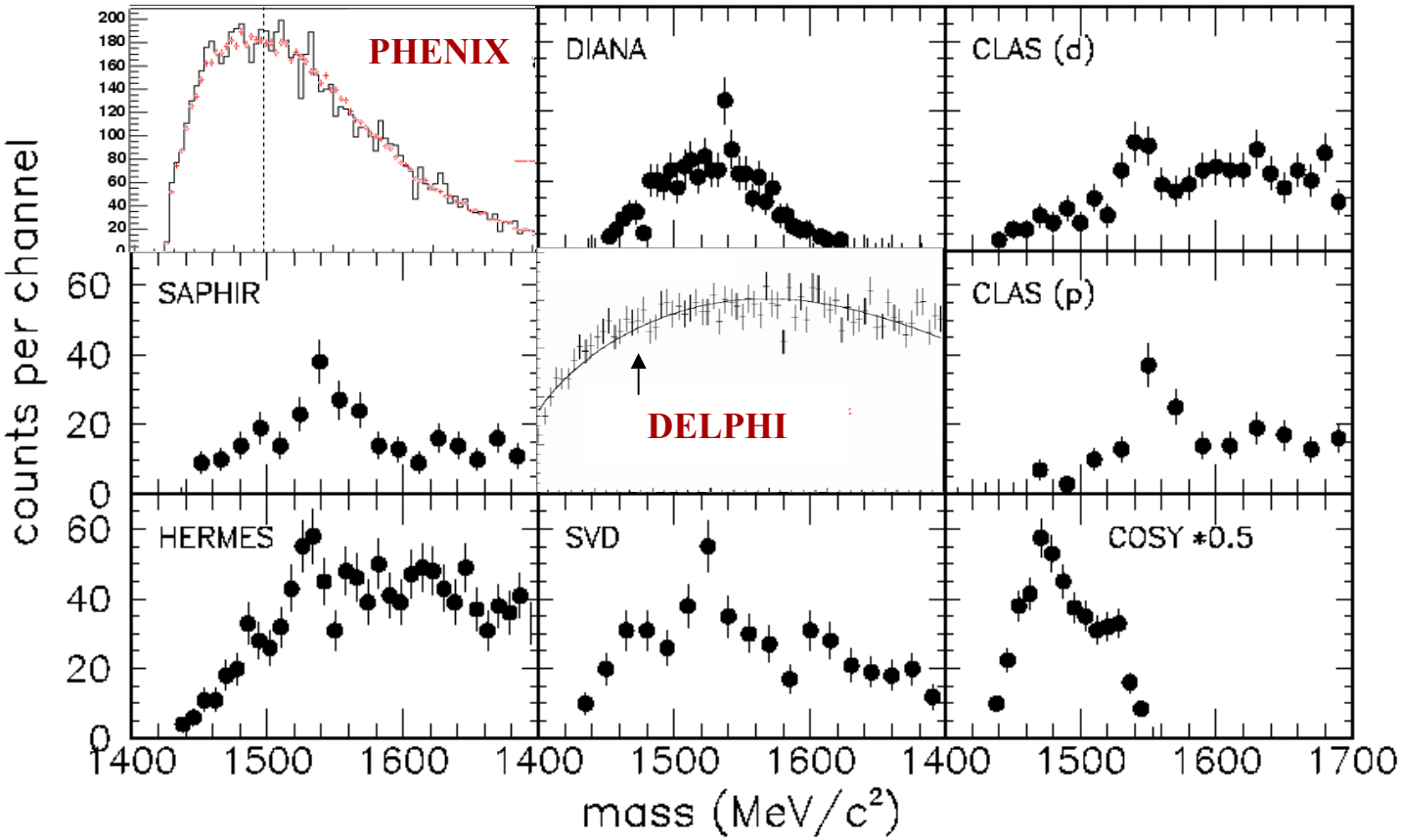

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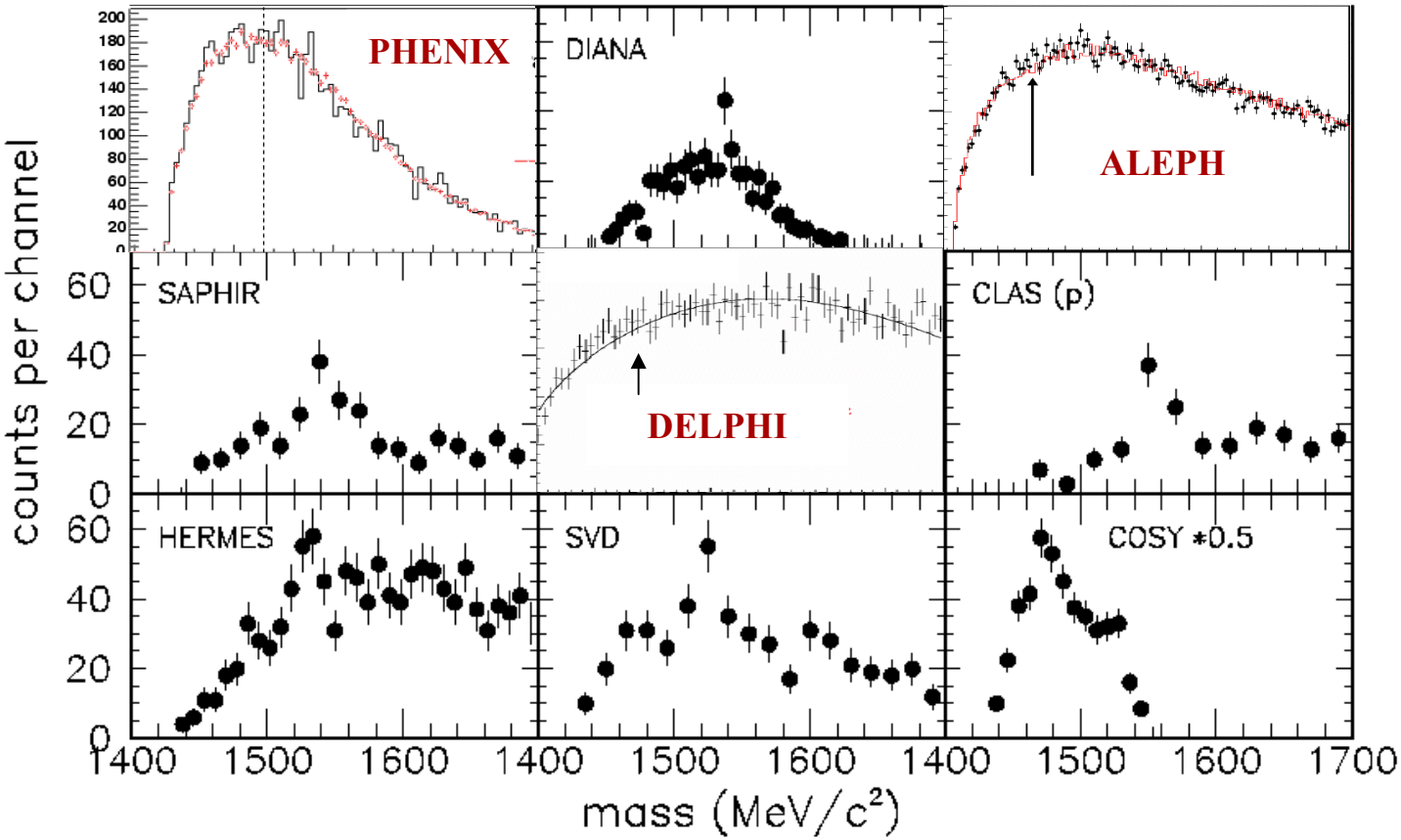

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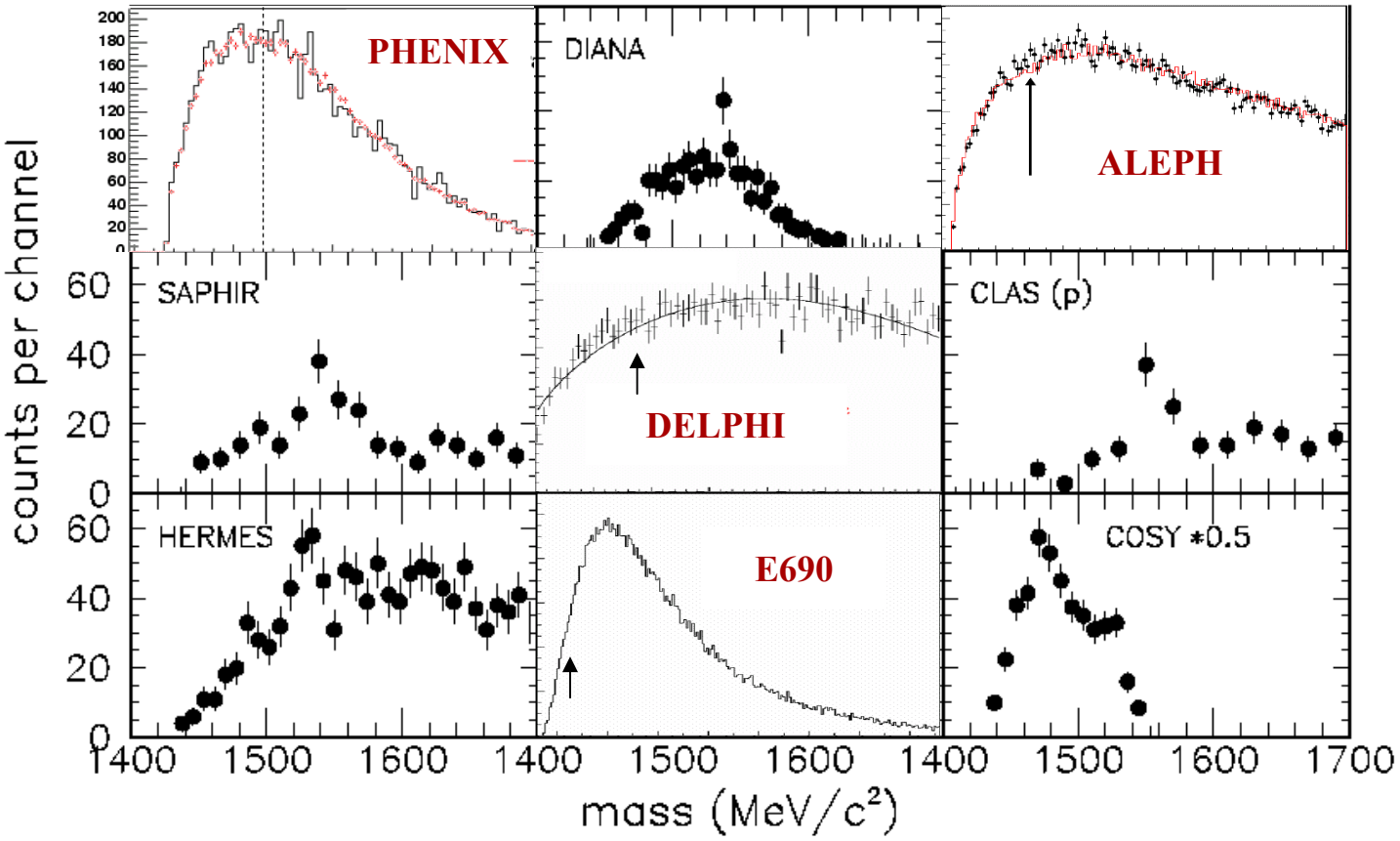

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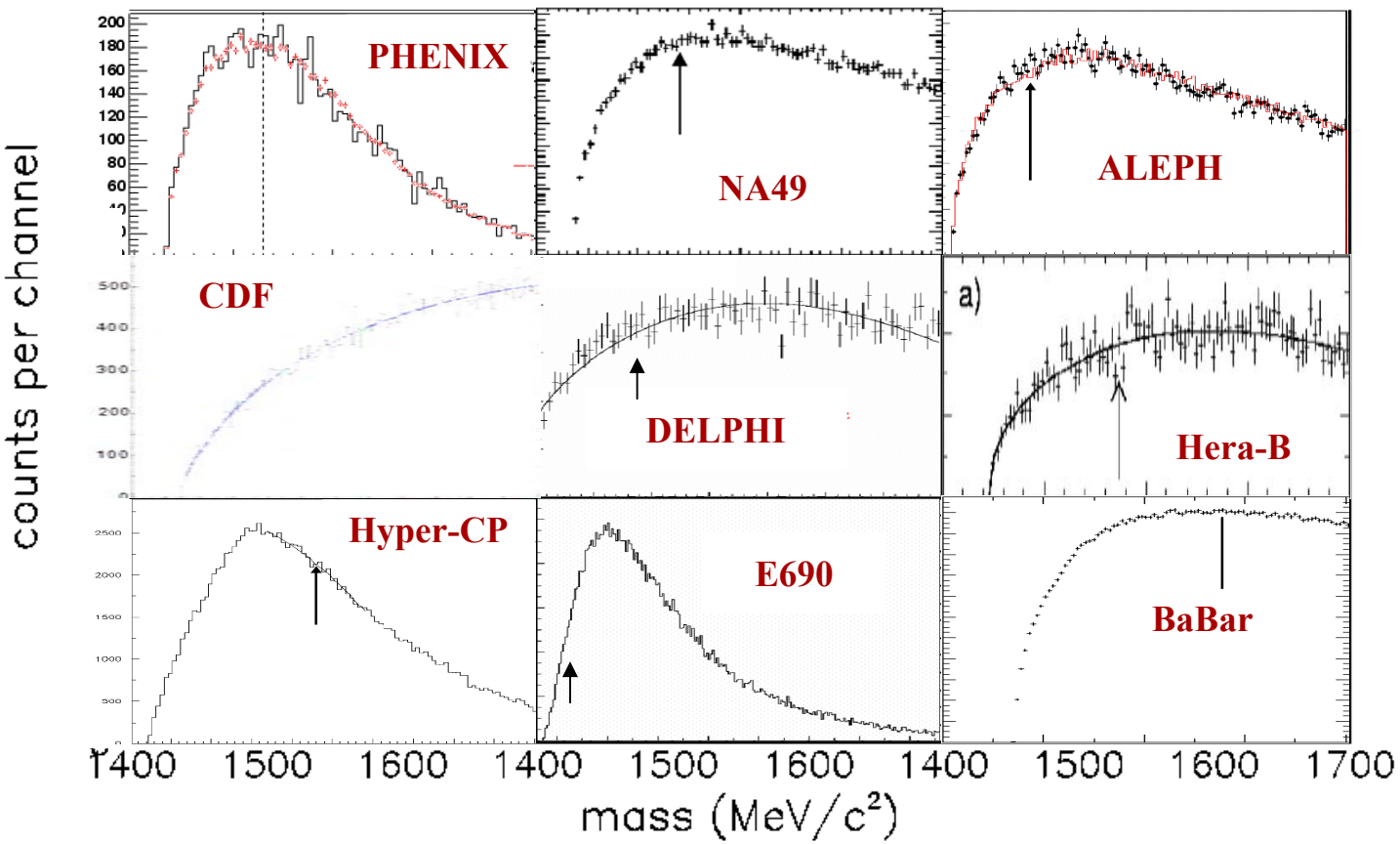
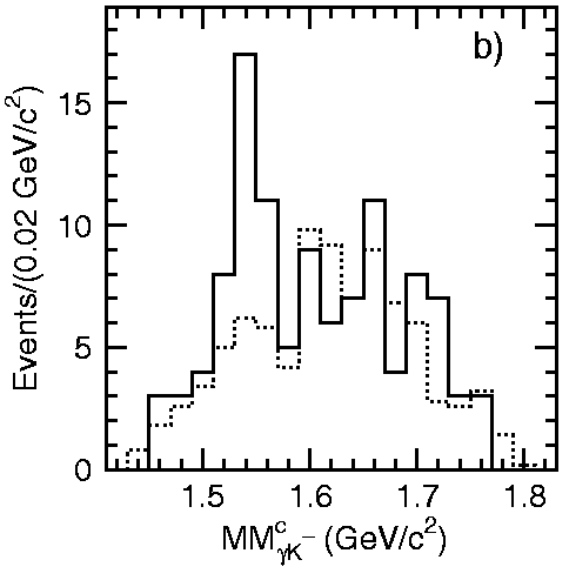


Note: arbitrary mass scale! – marker indicates 1530 MeV/c^2.

Note the much higher statistics compared to the sightings!!!

The first sighting:

SPring-8 (LEPS)

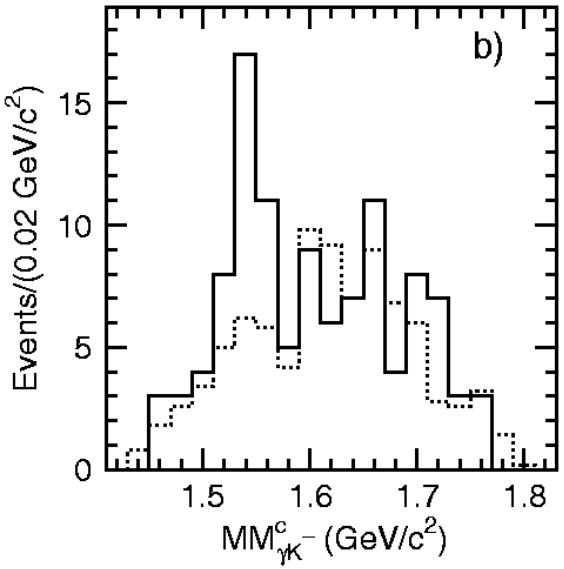


first evidence for Θ^+-state;
19 events in peak.

The first sighting:

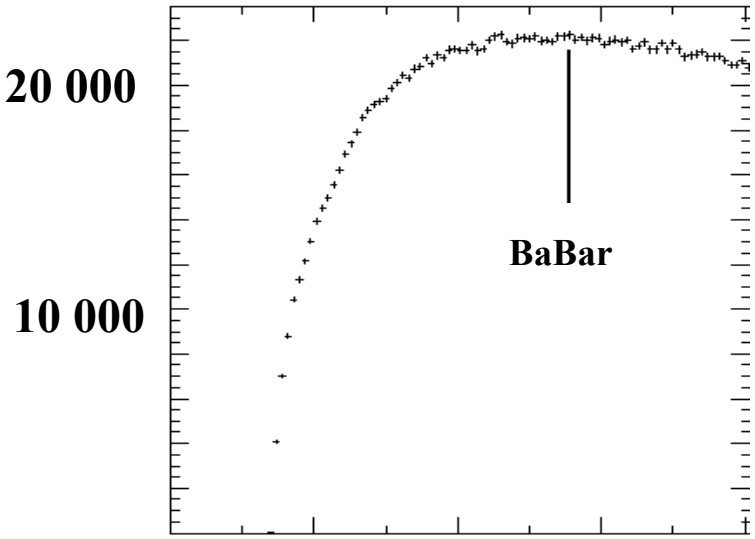
The strongest non-sighting

SPring-8 (LEPS)



first evidence for Θ⁺-state;
19 events in peak.

BaBar



no evidence for Θ⁺-state;
22 000 events per 2 MeV.

BaBar as a specific example

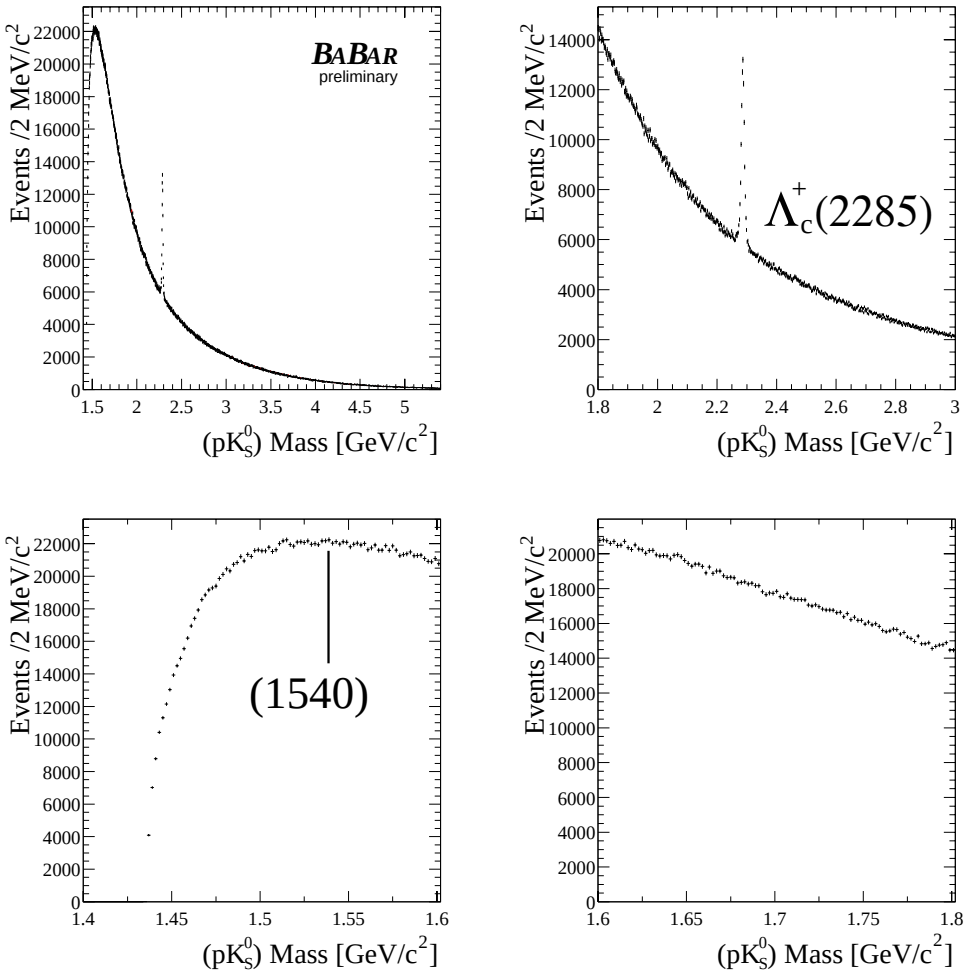


Figure 2: Distribution of the pK_S^0 invariant mass for combinations satisfying all the criteria described in the text. The same data are plotted four times in different pK_S^0 mass regions.

- Note: $\Lambda_c^+ \rightarrow p\, K_s$;
- BR ~ 2.5 % ;
- at 1.54 GeV/c^2:
  - > 20 000 evts/2 MeV/c^2;

BaBar as a specific example:

- e+ e- collision ,
  - → no bias in production process.
- very high statistics;
- very clean events.

- very strong Λ_c^+ signal: ~ 50 000 events
- no sign of Θ^+
  - in spite of favourable BR $BR(\Theta^+/\Lambda_c^+) \approx 10$
- no signal appears when strangeness compensating particle required (or similar conditions).

Sensitivity of non-Sightings

accord. to K. Hicks

- BES (Japan) hep-ex/0402012
- BaBar (SLAC) hep-ex/0408064
- Belle (Japan) hep-ex/0409010
- LEP (CERN) hep-ex/0410080
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- HYPERCP (Fermilab) hep-ex/0410027
- CDF (Fermilab) hep-ex/0410024
- PHENIX (RHIC) hep-ex/0404001

Sensitivity of non-Sightings

accord. to K. Hicks

No	BES	(Japan)	hep-ex/0402012
Maybe	BaBar	(SLAC)	hep-ex/0408064
No	Belle	(Japan)	hep-ex/0409010
No ?	LEP	(CERN)	hep-ex/0410080
No ?	Hera-B	(DESY)	hep-ex/0408048
No ?	SPHINX	(ITEP)	hep-ex/0407026
Maybe	HYPERCP	(Fermilab)	hep-ex/0410027
No ?	CDF	(Fermilab)	hep-ex/0410024
Unknown	PHENIX	(RHIC)	hep-ex/0404001

Sensitivity of non-Sightings

accord. to K. Hicks

Assignment of Sensitivity somewhat unclear,
based on "hand waving arguments" (no good calculation yet) :

- **"must get the 5 quarks localized in space with small velocity."**

However,

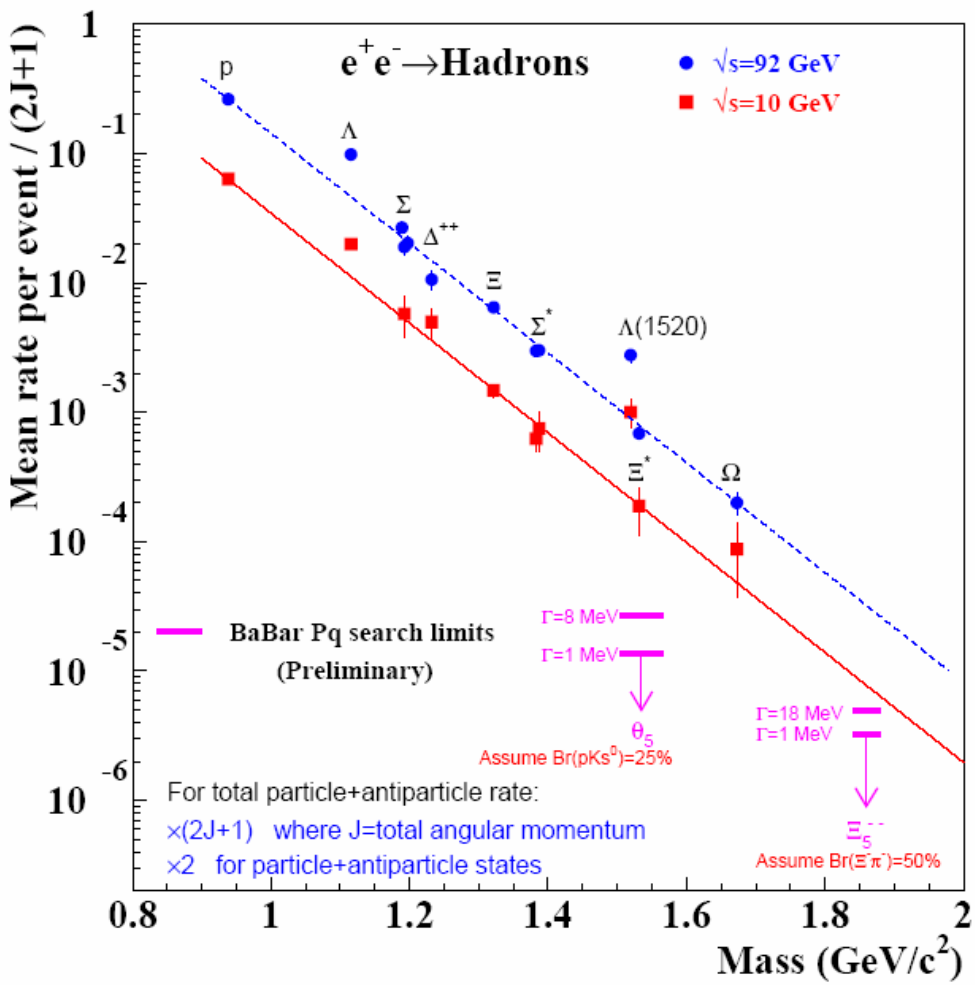
- **COSY (p-A) good,**
  → but all other hadronic interactions bad?
- **BaBar produces Λ_c^+ with BR 10 smaller,**
  and studied hadronic IA as well …

No : CDF (Fermilab) hep-ex/0410024

Unknown PHENIX (RHIC) hep-ex/0404001

Hadron production in e^+e^-

Taken from M. Amarian



Slope:

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

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

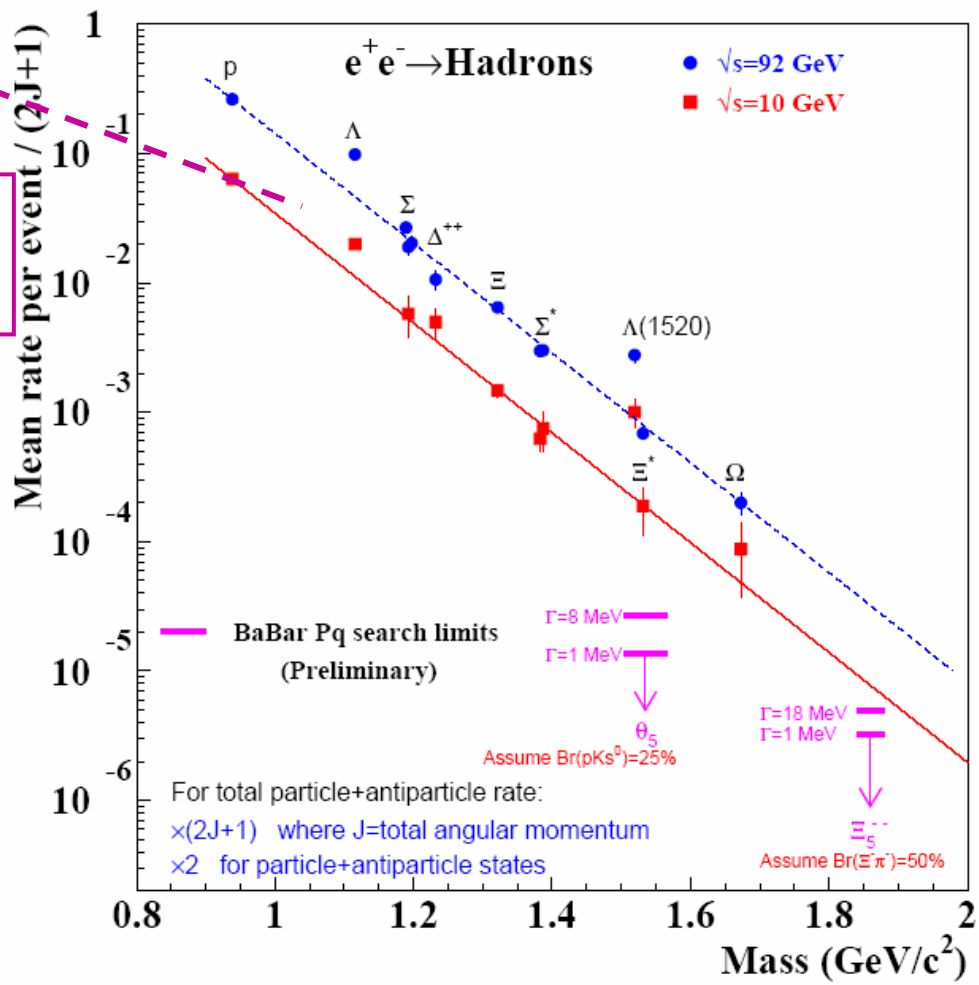
Pentaquarks:
$\sim 10^{-8}$ /GeV/c^2 (?) (need to generate 4 pairs)

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

Hadron production in e^+e^-

Taken from M. Amarian

Slope for p.s. mesons



Slope:

Pseudoscalar mesons:

~ 10^{-2}/GeV/c^2 (need to generate one $q\bar{q}$ pair)

Baryons:

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(need to generate two pairs)

Pentaquarks:

~ 10^{-8} /GeV/c^2 (?) (need to generate 4 pairs)

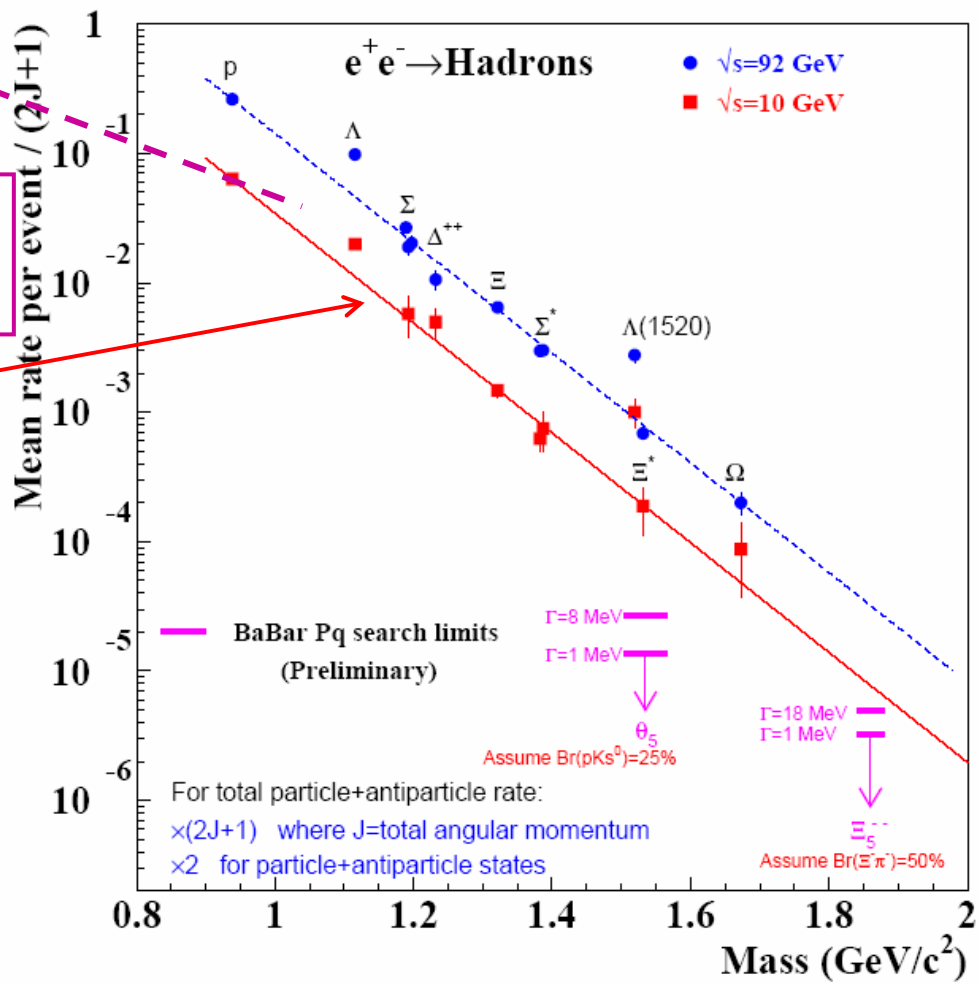
Pentaquark production in direct e^+e^- collisions likely requires orders of magnitudes higher rates than available.

Hadron production in e^+e^-

Taken from M. Amarian

Slope for p.s. mesons

Slope for baryons



Slope:

Pseudoscalar mesons:

~ 10^{-2}/GeV/c^2 (need to generate one $q\bar{q}$ pair)

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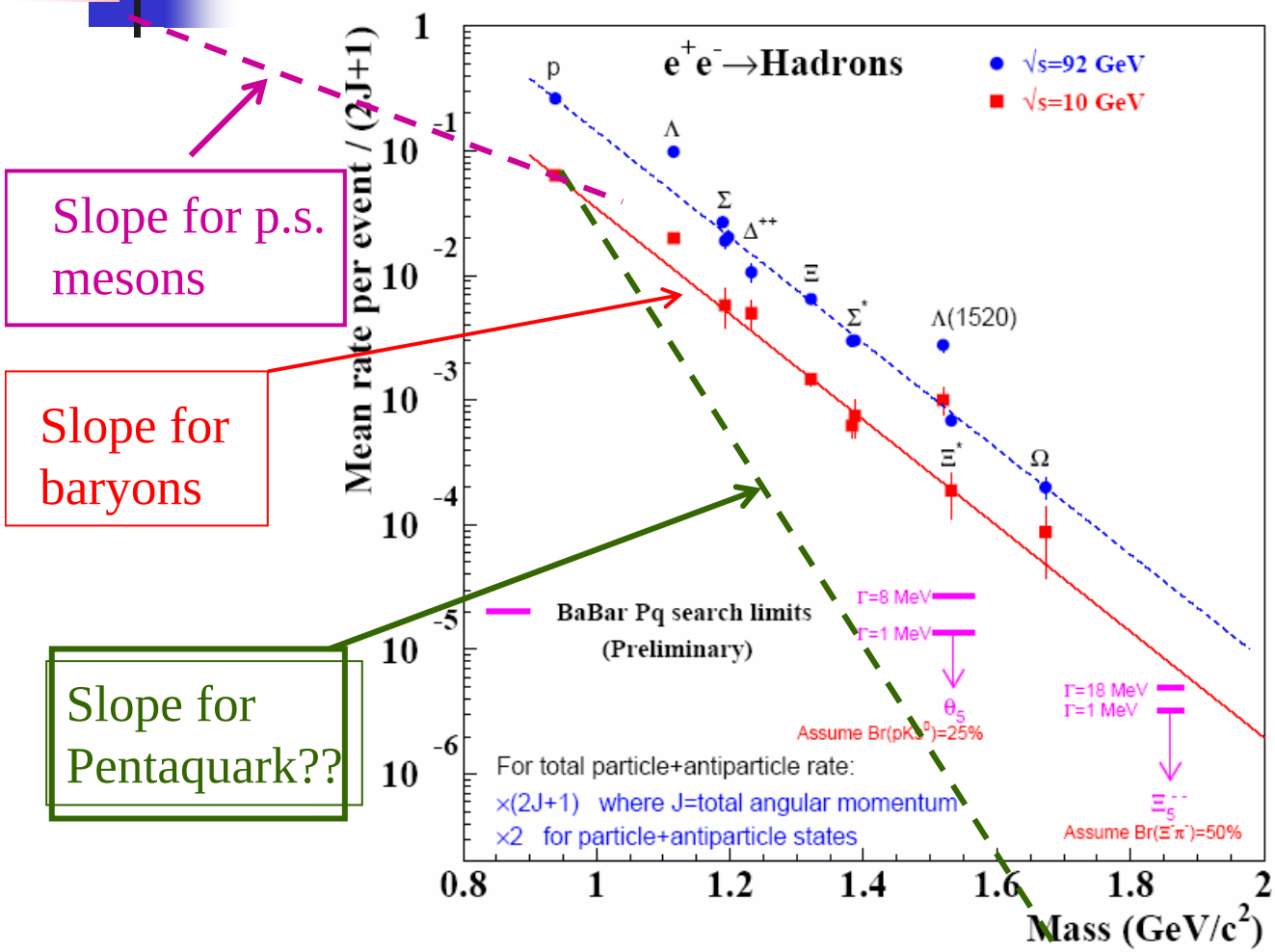

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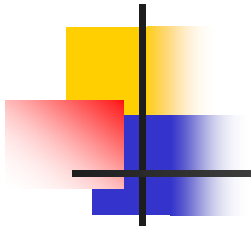


CLAS

Experiment in question:

g11

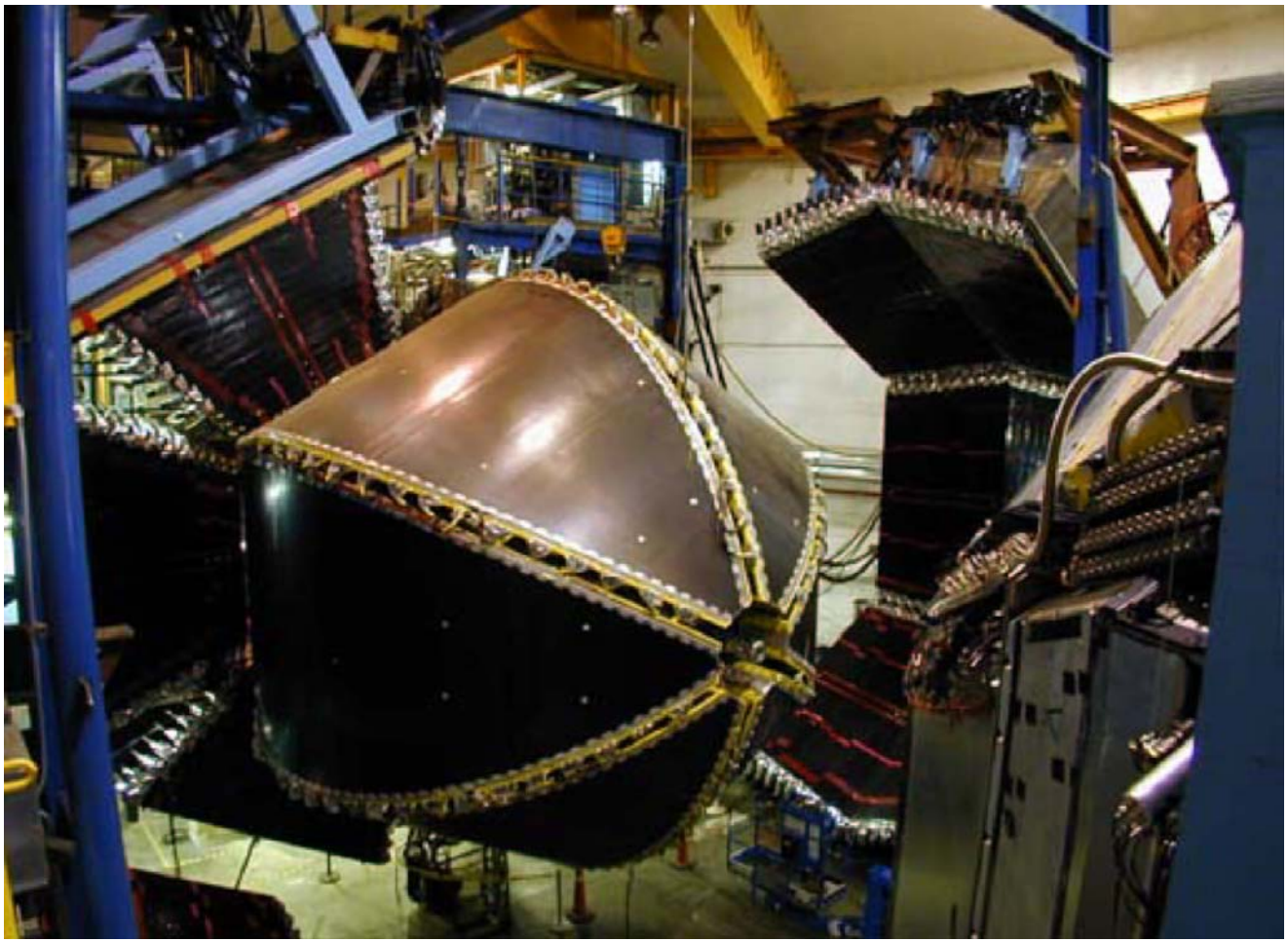
All relevant info taken from

R. De Vita, APS Meeting

Tampa, April 16, 2005

http://www.phy.ohiou.edu/~hicks/thplus/New/RDeVita-APS05.pdf

CLAS



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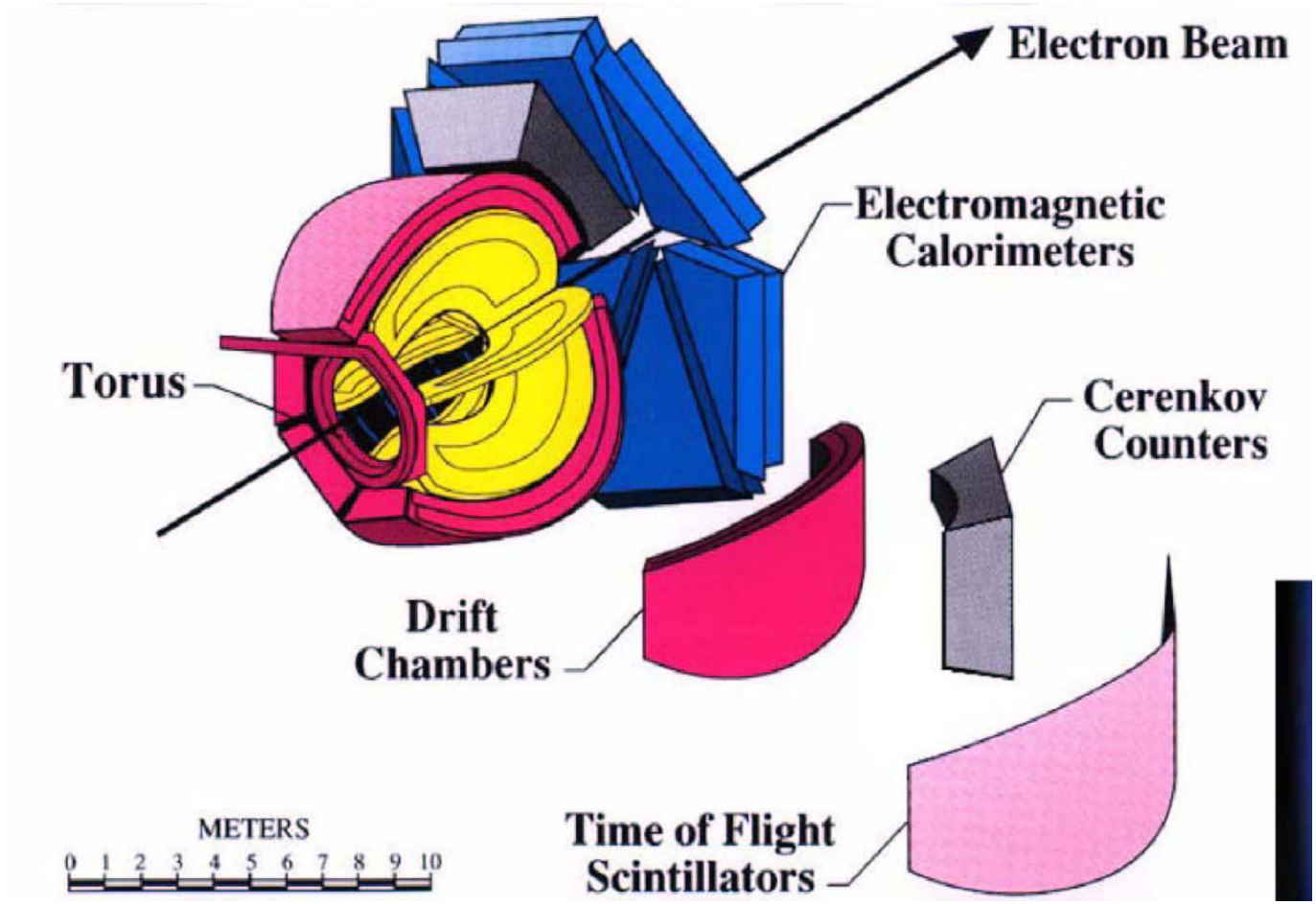

Electron Beam
Electromagnetic Calorimeters
Torus
Cerenkov Counters
Drift Chambers
Time of Flight Scintillators
METERS
0 1 2 3 4 5 6 7 8 9 10

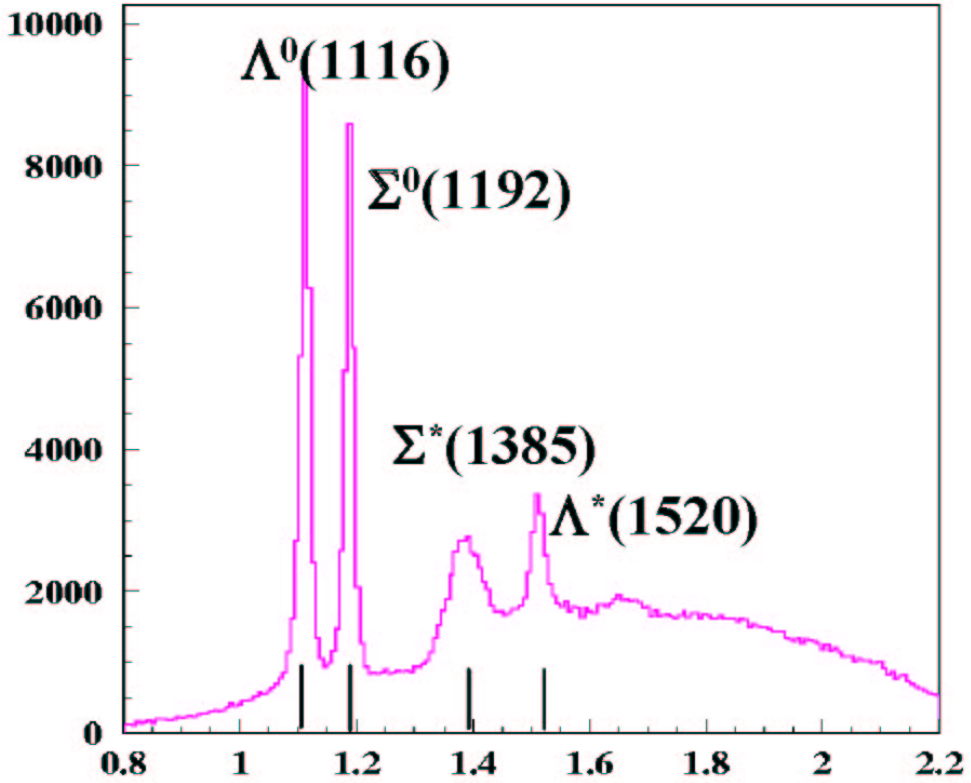
CLAS ($\gamma + {}^2D$, $\gamma + {}^1H$)

Some salient features:

- Large acceptance experiment, several years of operation;
- domain: Baryon resonances;
- E_γ < 2.9 GeV and < 5 GeV , (respectively)
- **H_2** target and **^2D** target ;
- PID through ToF and magnetic field;
- Correction for Fermi-motion (when needed).

CLAS

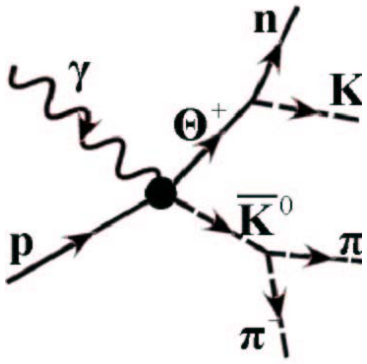
g11-data



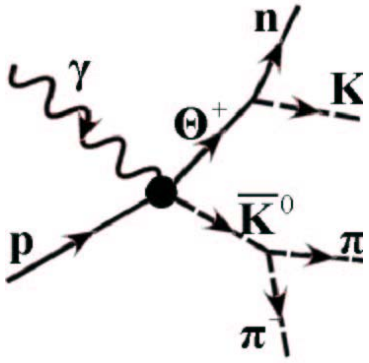
CLAS

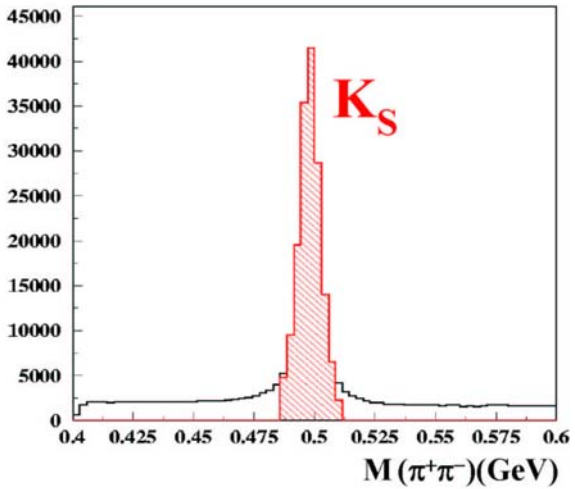
g11

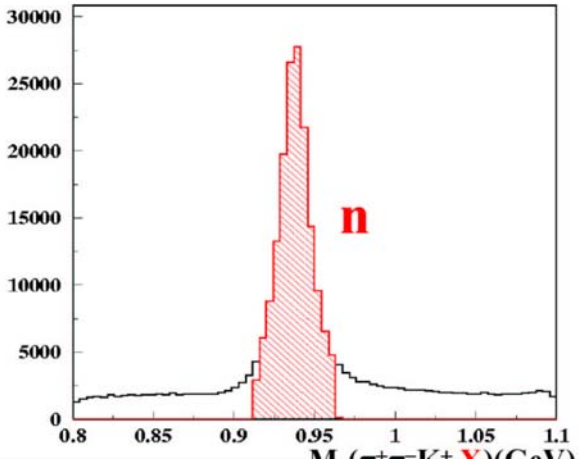
- $7 * 10^9$ events recorded
- Luminosity ~ 70 pb^{-1}
- 10 times more statistics than previous run.



CLAS

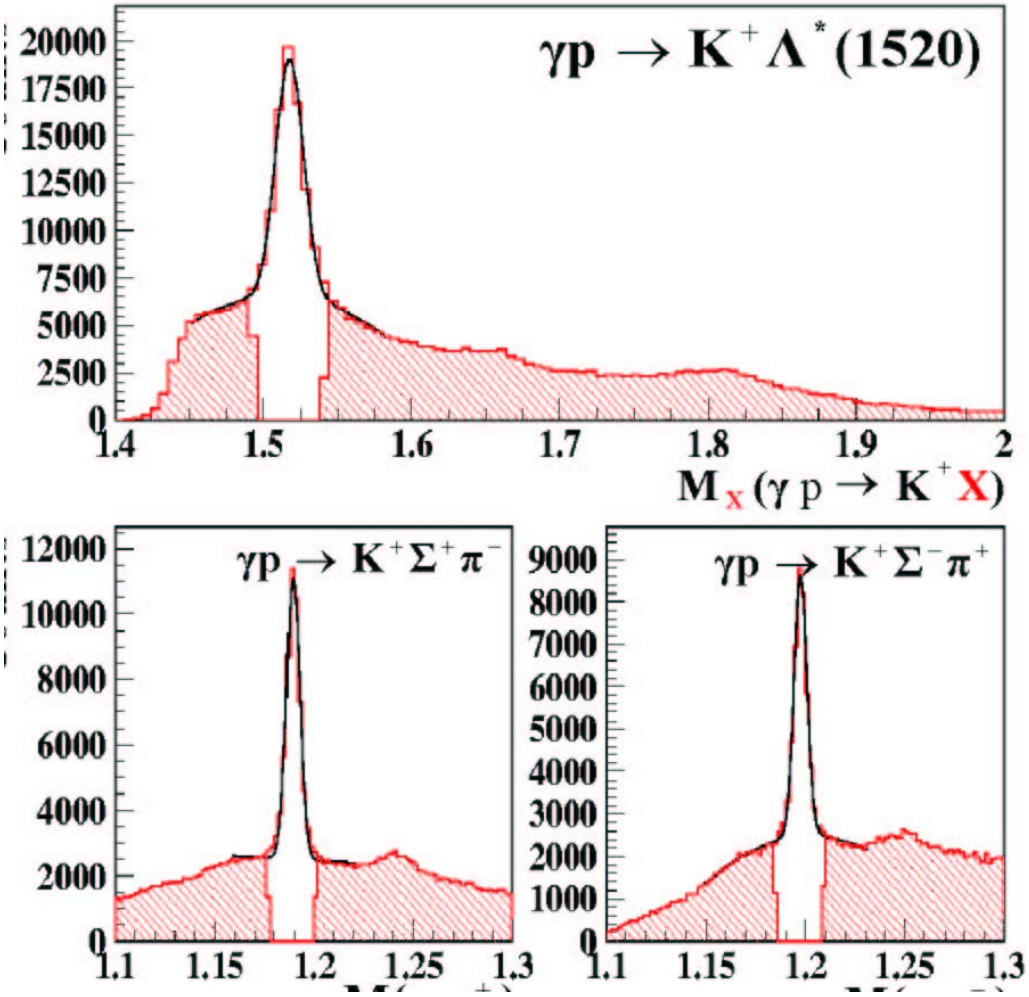






- K^0 via K_s;
- final state through missing mass;
- strangeness tagging via K^+;
- Full statistics → 120 000 evts.

CLAS

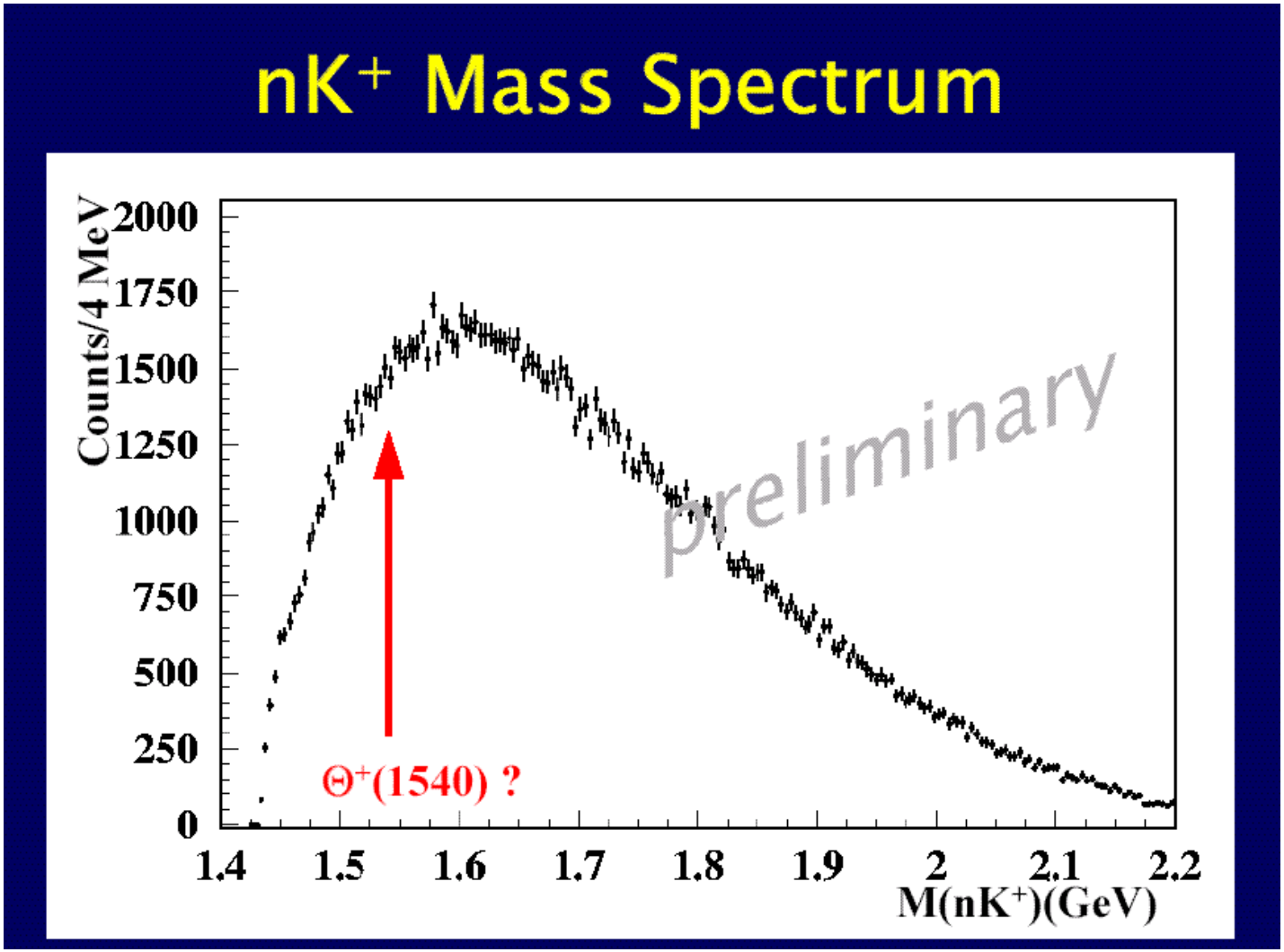


$N_{\Lambda} = 91\,300$

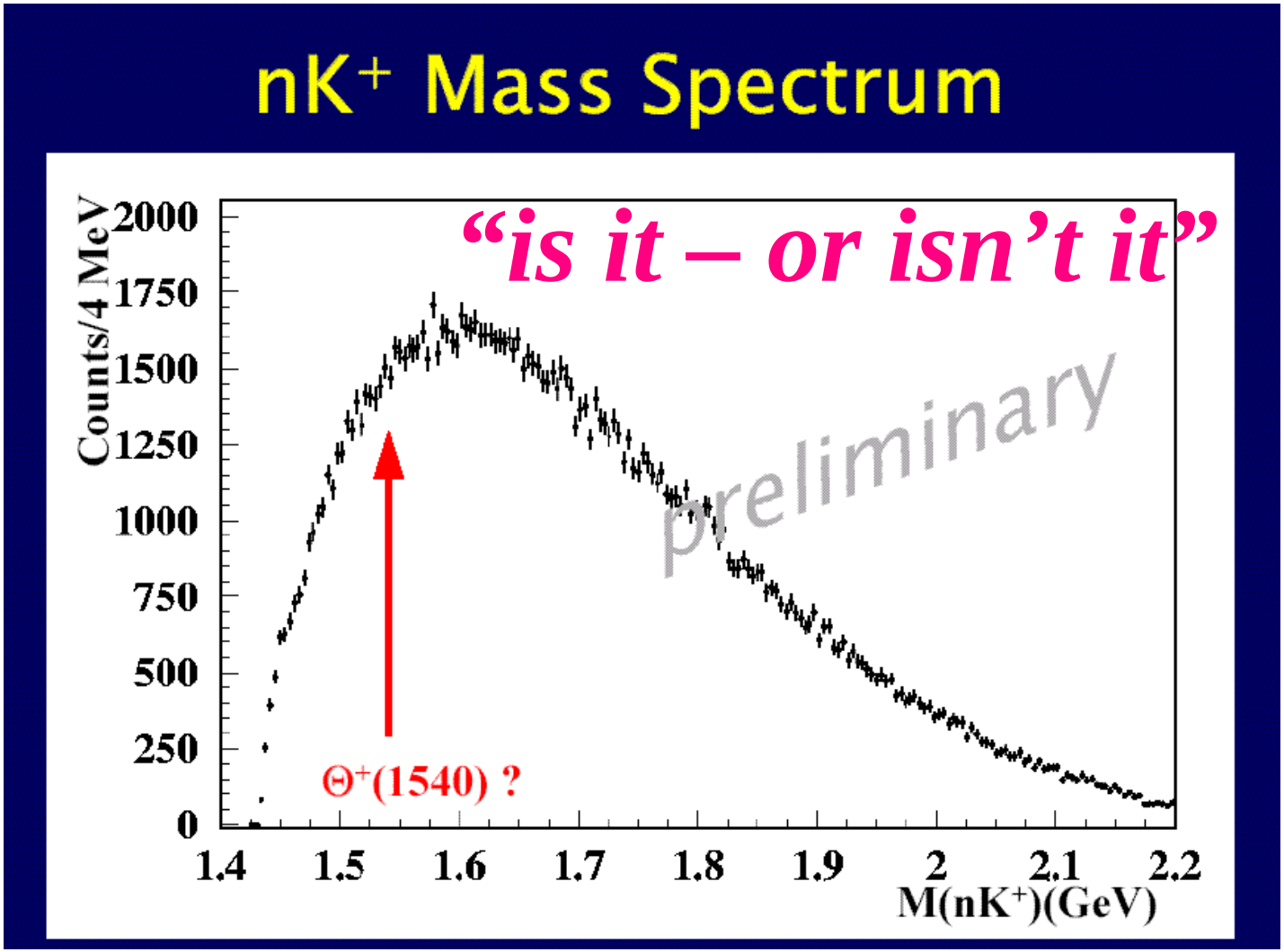
$N_{\Sigma+} = 36\,200$

$N_{\Sigma-} = 26\,800$

CLAS


nK+ Mass Spectrum
Counts/4 MeV
2000
1750
1500
1250
1000
750
500
250
0
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
M(nK+)(GeV)
Θ+(1540) ?
preliminary

CLAS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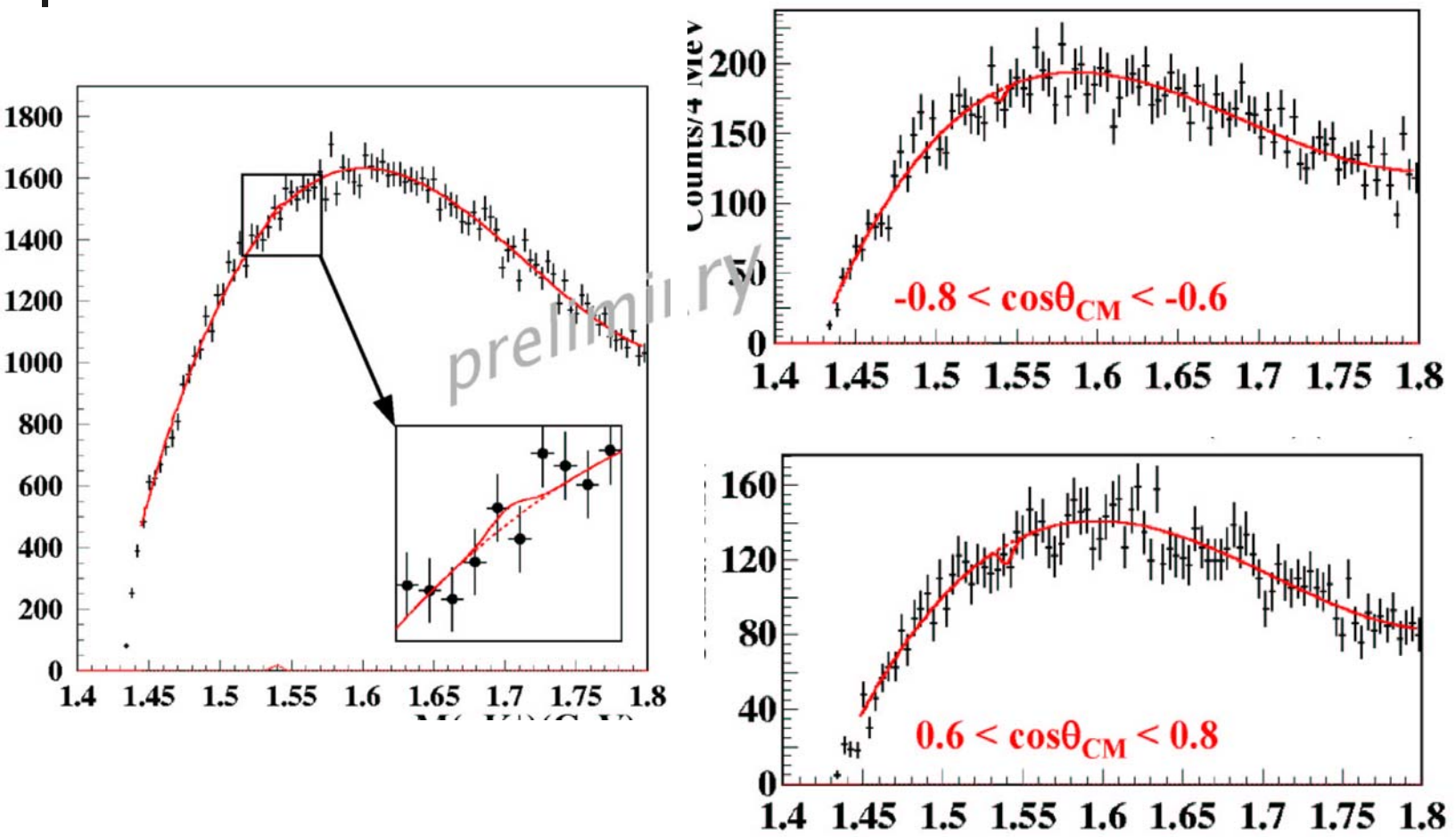
1800
1600
1400
1200
1000
800
600
400
200
0
1.4 1.45 1.5 1.55 1.6 1.65 1.7 1.75 1.8
Counts/4 MeV
200
150
100
50
0
-0.8 < cosθCM < -0.6
1.4 1.45 1.5 1.55 1.6 1.65 1.7 1.75 1.8
160
120
80
40
0
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1.4 1.45 1.5 1.55 1.6 1.65 1.7 1.75 1.8

CLAS – comparison with SAPHIR

Comparison with SAPHIR results

Observed Yields

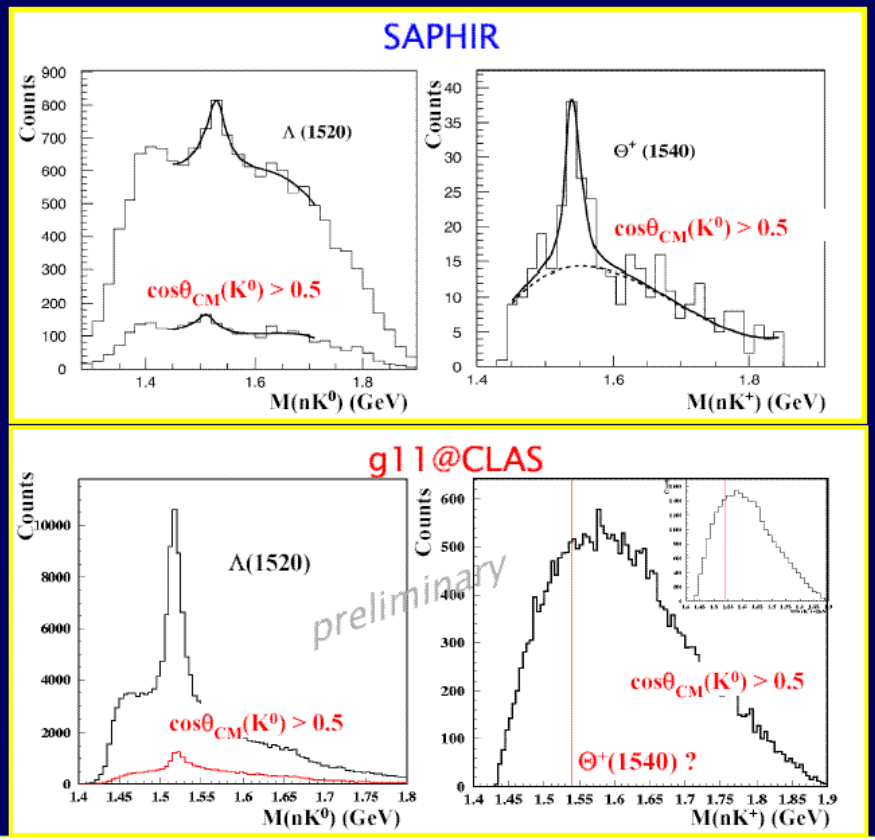
SAPHIR
$N(\Theta^+)/N(\Lambda^*) \sim 9\%$

CLAS
$N(\Theta^+)/N(\Lambda^*) < 0.5\%$
(95%CL)

Cross Sections

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

CLAS
$\sigma_{\gamma p \to \Theta^+ K^0} < 1\text{-}4$ nb



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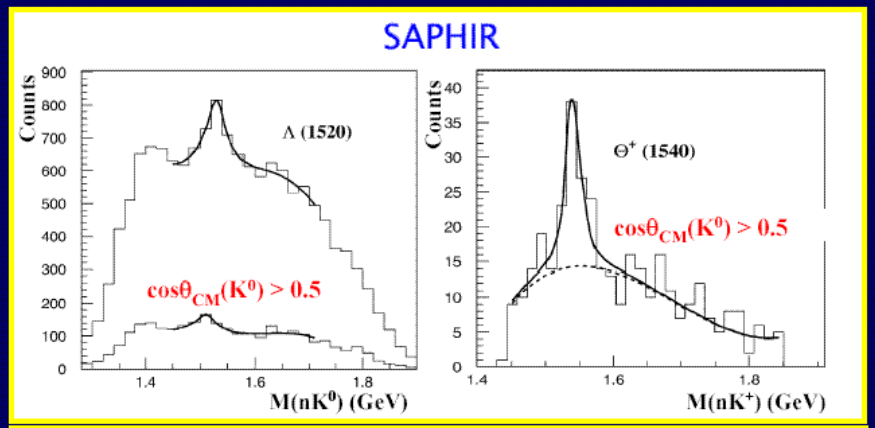

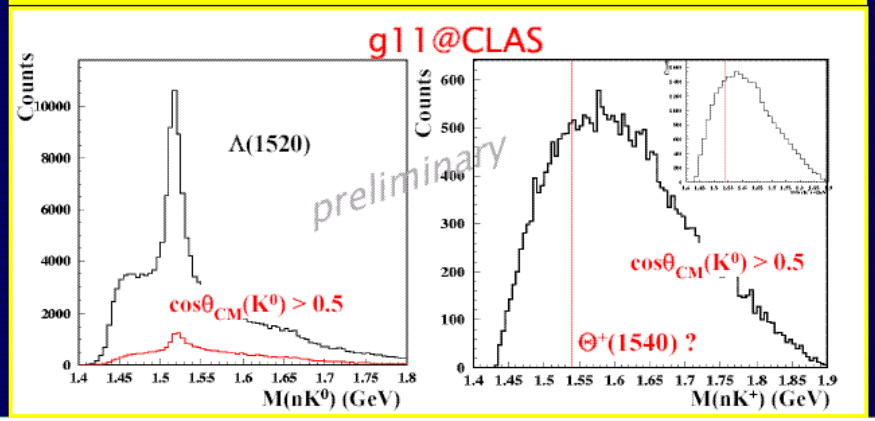

remember:
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$$\frac{\sigma(\Theta^+)}{\sigma(\Lambda^*)} \sim 1$$

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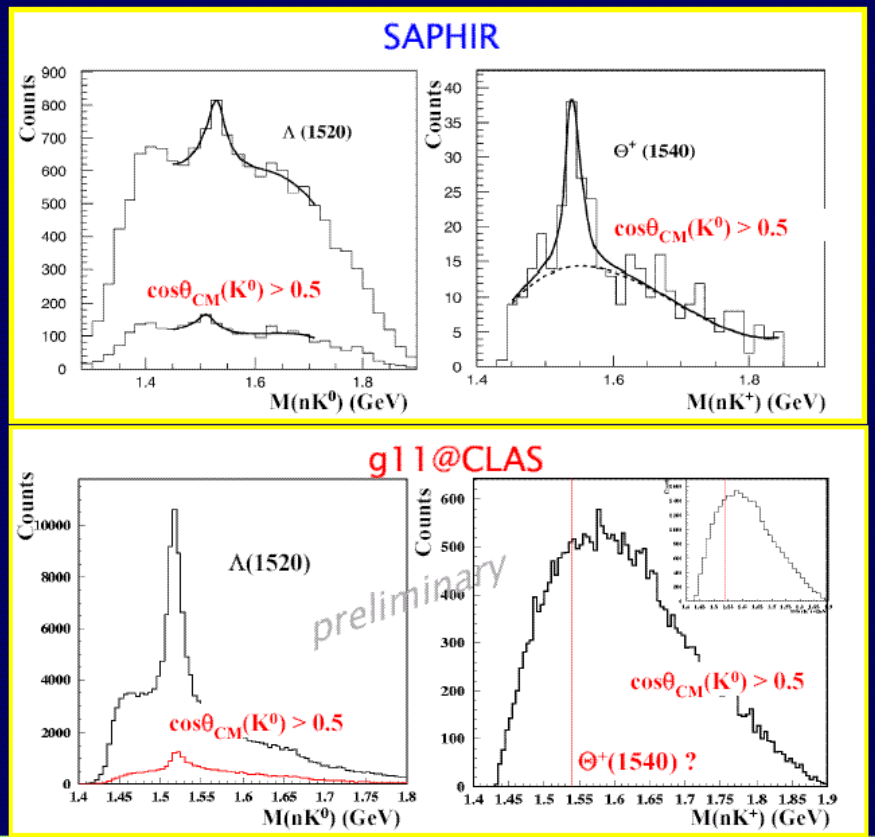

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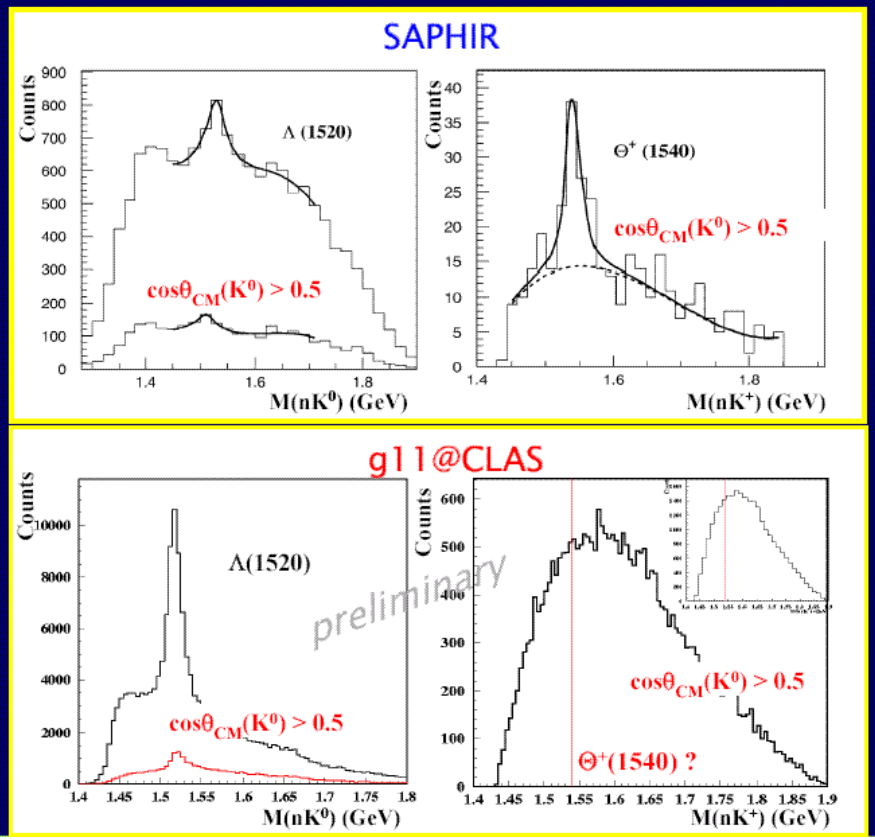

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500

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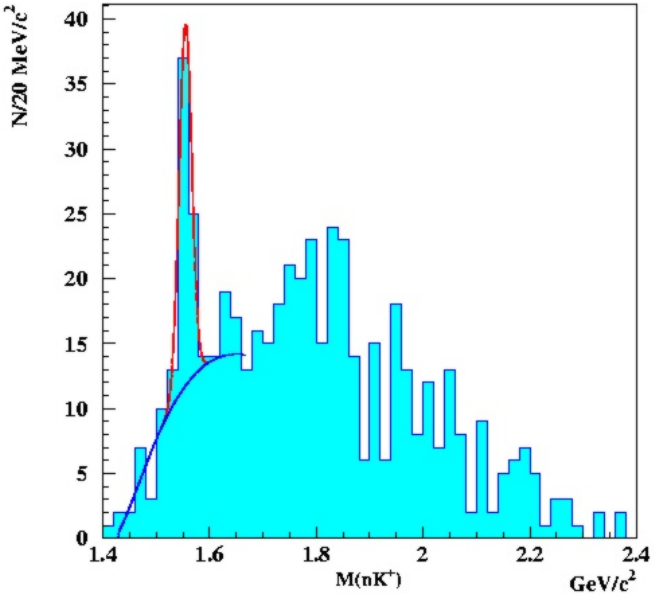
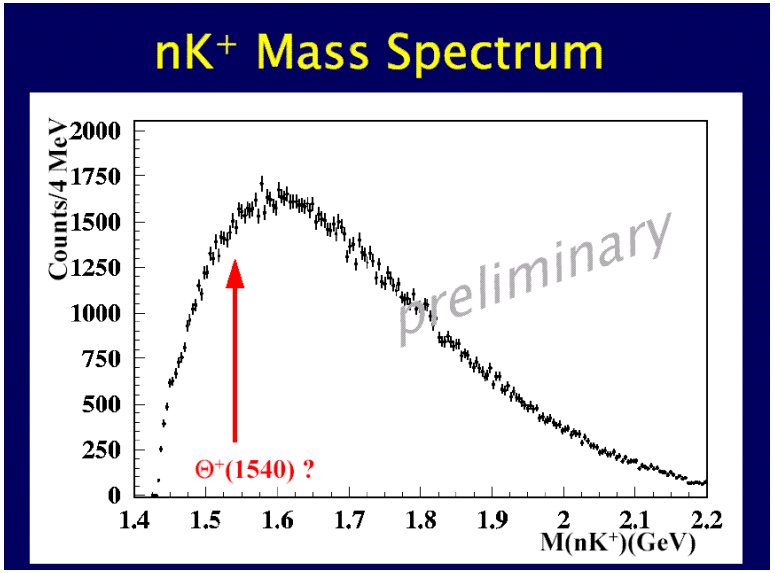
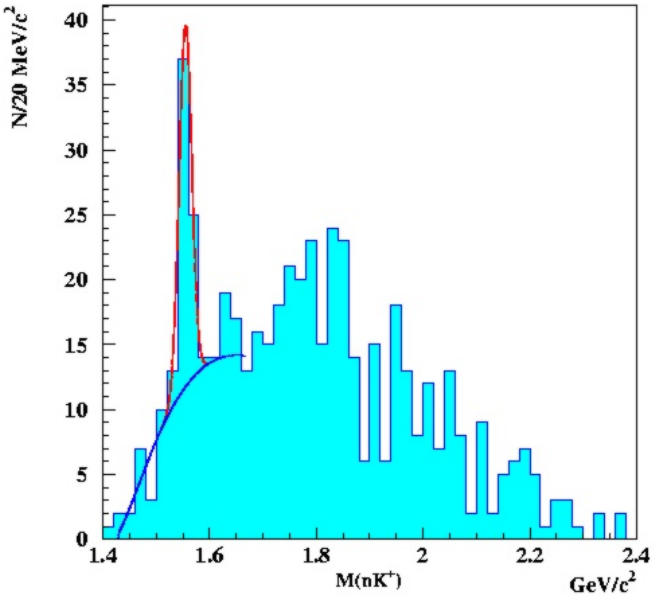
CLAS – comparison with CLAS

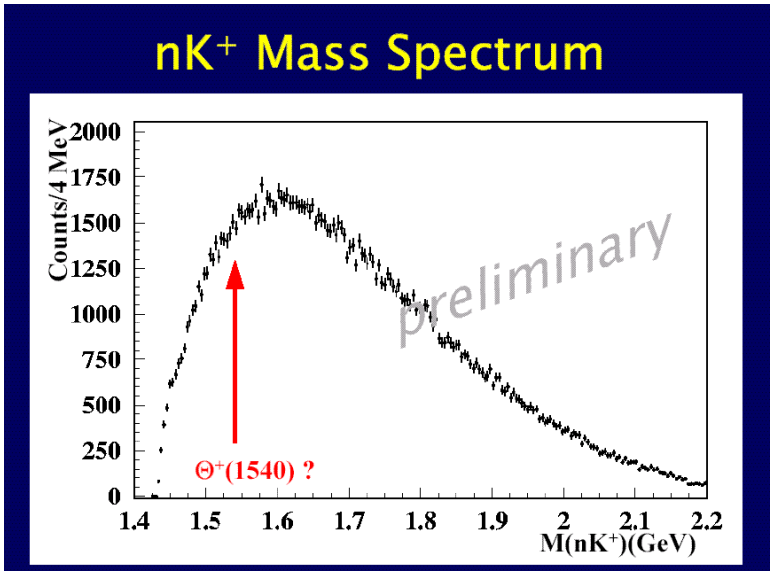




CLAS – comparison with CLAS

Just a statistical glitch?





Is this just a statistical glitch?

might be … after all, there are

Freak Waves

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self-field theory

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Finding the formula for freak waves

20 June 2001

Freak waves are a major threat to ships and offshore structures such as oilrigs, but they are notoriously difficult to predict. This could be set to change following simulations of water wave dynamics by physicists at the University of Torino in Italy. Miguel Onorato and colleagues adapted the Schrödinger equation - which usually describes the wave-like properties of quantum particles - to establish the sea conditions that give rise to rogue waves (M Onorato *et al* 2001 *Phys. Rev. Lett.* 86 5831).

Random conditions in the ocean occasionally produce mammoth waves. A wave must be at least ? ? times the height of the so-called significant wave

Is this just a statistical glitch?

© Picture-Alliance/DPA/DPAWEB

Riesige Wellen mit über 35 Metern Höhe galten bis vor kurzem noch als Seemannsgarn

Riesige Wellen, über 35 Meter hoch, haben in den letzten 20 Jahren über 200 Großschiffe zum Untergang gebracht. Sind die Wellen-Ungetüme eine Folge der

Is this just a statistical glitch?

© Picture-Alliance/DPA/DPAWEB

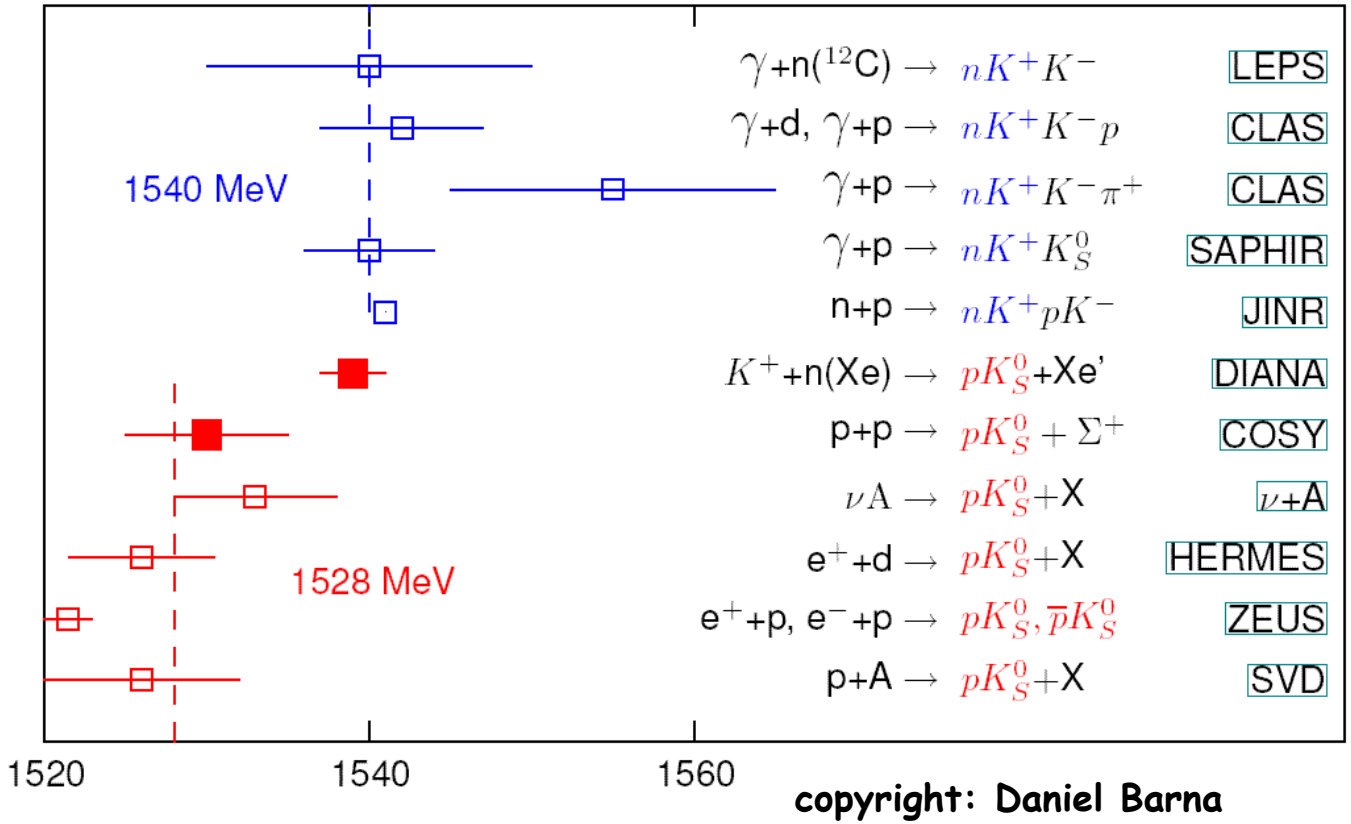
Riesige Wellen mit über 35 Metern Höhe galten bis vor kurzem noch als Seemannsgarn

Freak waves, up to 35 m high, have claimed 200 large ships during the past 20 years…

Is this just a statistical glitch?

Let's check …

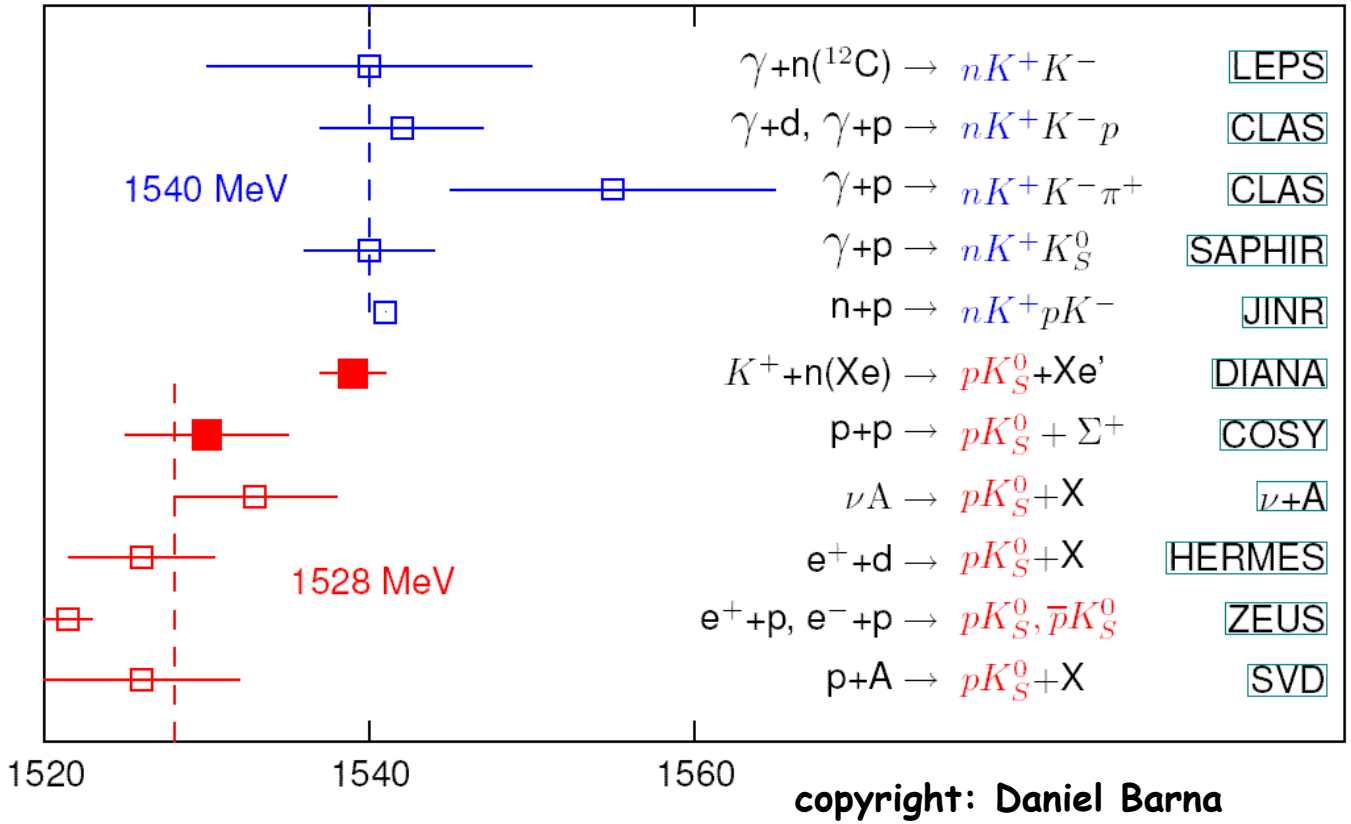
Masses from the different experiments



NOTE: M_{Θ^+} clusters in two groups

Masses from the different experiments

$M_{\Lambda 1520}$



1518 MeV

1518 MeV

1522 MeV

NOTE: M_{Θ^+} clusters in two groups

but $M_{\Lambda 1520}$ is close to book value (when available)

Is this just a statistical glitch?

- 10 experiments claim positive sightings
- significances are large (between 4 and >7!)

but (this means: *discovery*!!)

- many internal inconsistencies:
  - masses don't match;
  - Hermes-CLAS: $\Lambda(1520)$ / Θ^+ ratio;
  - Zeus doesn't see charmed PQ, seen by H1;
  - Zeus p and $\bar{p}$ results don't match;
  - widths are inconsistent;
  - and more …

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- many internal inconsistencies:
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  - Herm
  - Zeus
  - Zeus
  - width
  - and more …

"It is difficult to see how the ZEUS peak can be the Θ^+ unless many other experiments are wrong." **(K. Hicks)**

Should we trust Theory?

- **well …**
- **QCD is a recognized theory**
  - **but …**

  no exact calculations yet for fragmentation processes.
- Lattice calculations start to emerge, but with contradicting results.
- **More**: quark model calculations and Lattice calculations do not agree wrt. parity.
- This applies also to cross section predictions…

Thus, don't use it as argument…

Is this just a statistical glitch?

Or is it something else?

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Or is it something else?

Note from the literature:

H. C. Anderson (1837) described a comparable behaviour in:

“ Keiserens nye Klaeder”

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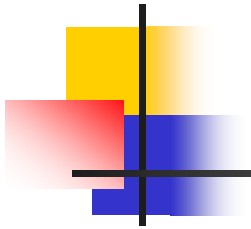
“ Keiserens nye Klaeder”

“The King’s new clothes”



So, is there nothing positive?

Some spin-off effects

- Spring-8 : cited 315 times in 2004
- Diakonov : cited 256 times
- DIANA : cited 248 times
- CLAS : cited 235 times
- NA49 : cited 181 times
- SAPHIR : cited 140 times
- …

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Note: BBC had the news before the Pentaquark was confirmed

BBC NEWS WORLD EDITION

Last Updated: Tuesday, 1 July, 2003, 19:05 GMT 2

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Behold the pentaquark

By Dr David Whitehouse
BBC News Online science editor

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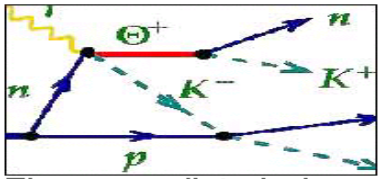
The discovery involves quarks - particles that make up the protons and neutrons usually found in the nuclei of atoms.



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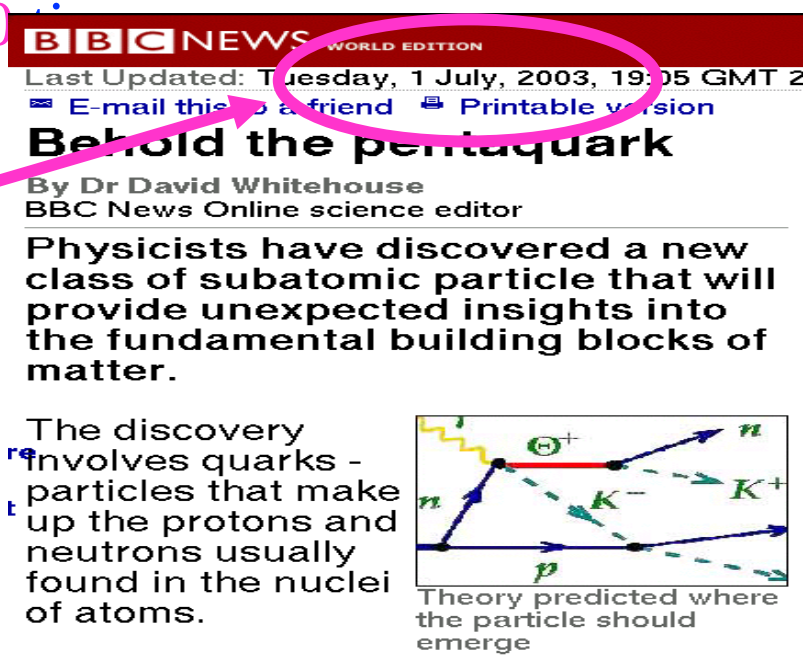
17 days before 1st confirmation was available to scientists…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Theory predicted where the particle should emerge

What if the Θ^+ doesn't exist?

Then we are back to the real problem:

"Why only mesons and hadrons?"

Note: **if Nature doesn't realize all the previsions of our theory, then theory (most likely) is the culprit.**

Most likely reason:

Some fundamentals not yet implemented.

Therefore: **the non-existence of PQ's is more exciting than their existence.**

Towards a Summary and Conclusion

- Many experiments have claimed **positive evidence** for Pentaquarks;
- many non-sightings have set **stringent upper limits**;

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includes CLAS-g11!

Towards a Summary and Conclusion

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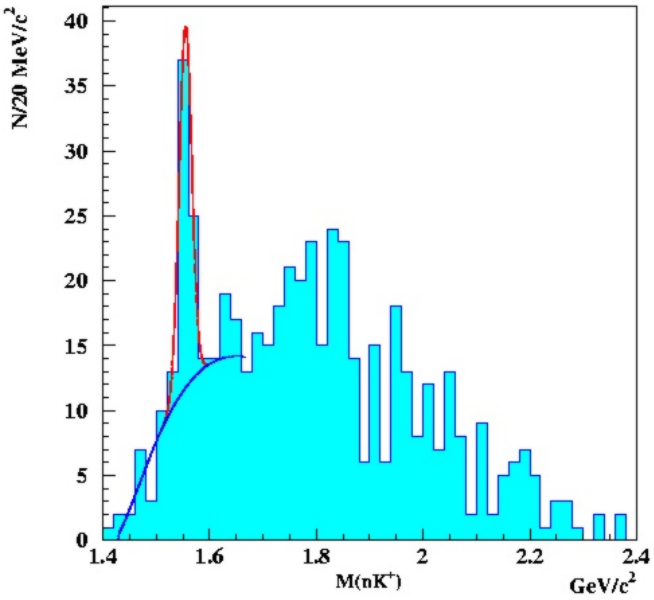
- many non-sightings have set **stringent upper limits**;
- **strict correlation:**
  - positive sightings are correlated with small statistics,
  - non sightings are correlated with large statistics; *)
- positive sightings find large cross sections, ***includes CLAS-g11!***

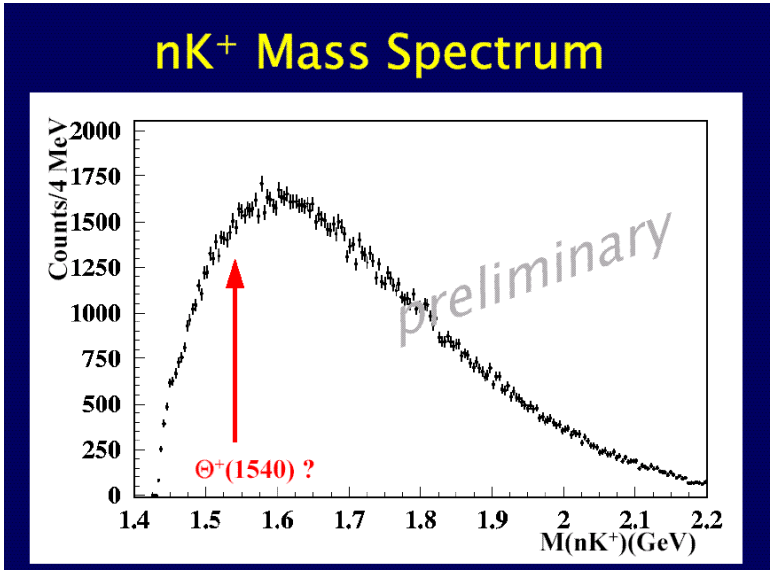
  but are at variance with established resonances;
- **large internal discrepancies persist:**
  - Masses disagree by many σ;
  - Cross sections differ by orders of magnitude;
  - Pairs of experiments mutually exclude each other;
  - …

Is it – or isn't it ?

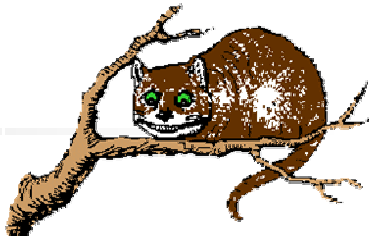
CLAS 2003/2004



CLAS 2005 g11



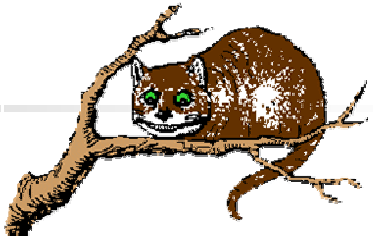
Summary



The risk persists that

Pentaquarks are ephemeral events escaping the strict laws of physics.

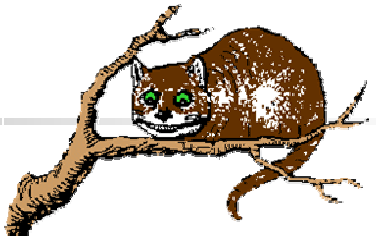
Summary



The risk persists that

Pentaquarks are ephemeral events escaping the strict laws of physics.

Summary



The risk persists that

Pentaquarks are ephemeral events escaping the strict laws of physics.

“I wish you wouldn’t keep appearing and vanishing so suddenly; you make me quite giddy!”

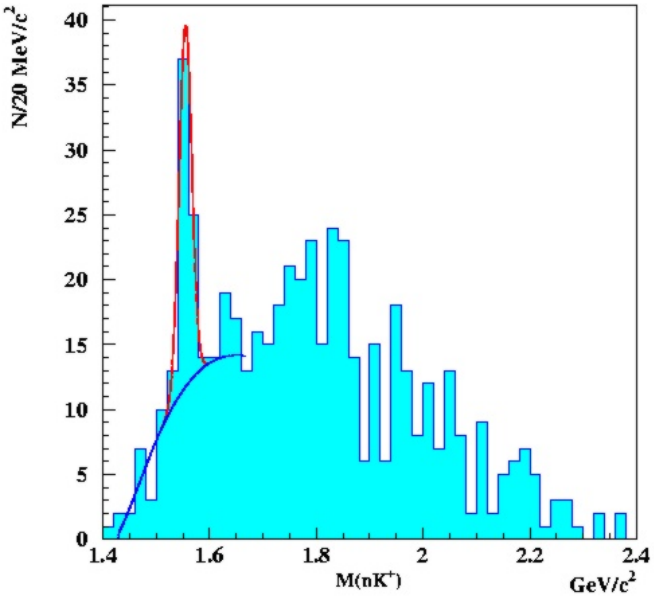
“I wish you wouldn’t keep appearing and vanishing so suddenly; you make me quite giddy!”

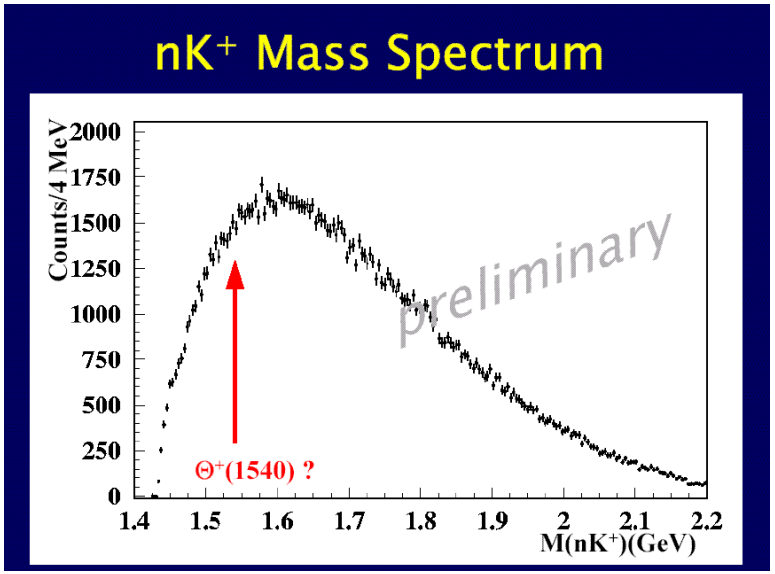
“All right,” said the PQ; and this time it vanished quite slowly, beginning with the end of the tail, and ending with a cynical grin, which remained some time after the rest of it had gone.

The End

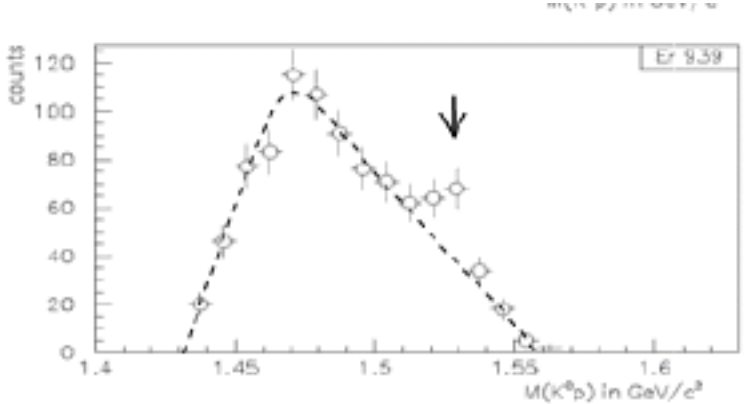
CLAS – comparison with CLAS

Just a statistical glitch?

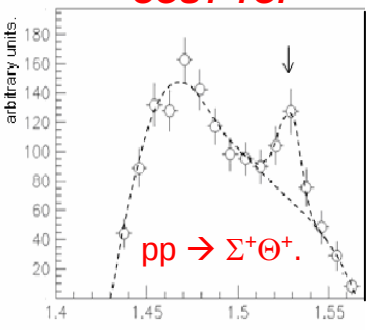




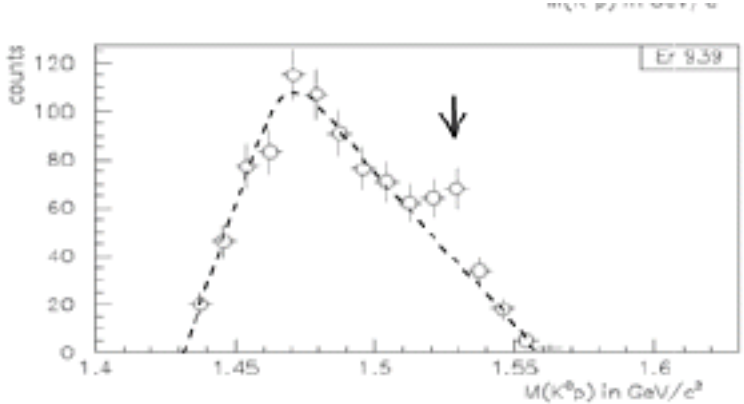
Hadronic

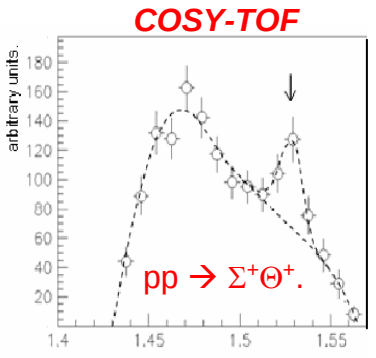


COSY-TOF

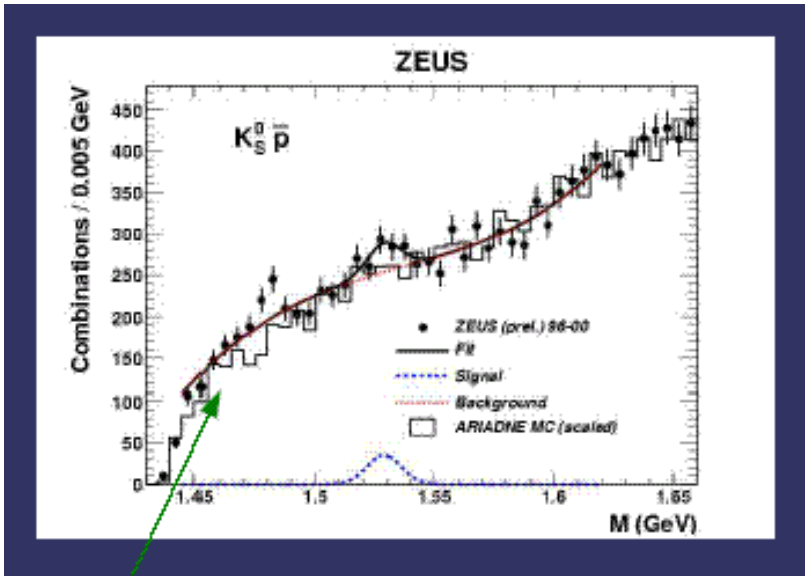


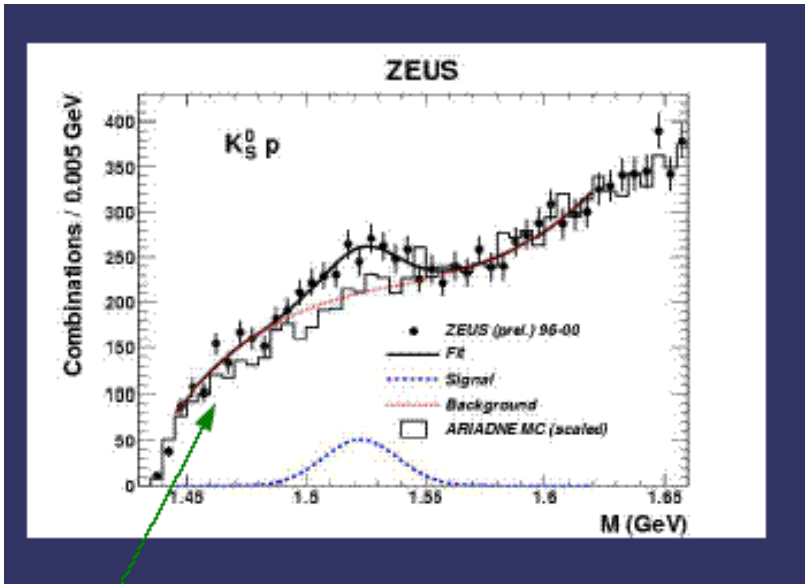
Hadronic interactions are no good





ZEUS (HERA)





- **anti-p channel << p-channel;**
- **Sum of 2 channels < p-channel ...**