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BABAR



THE UNIVERSITY
of LIVERPOOL

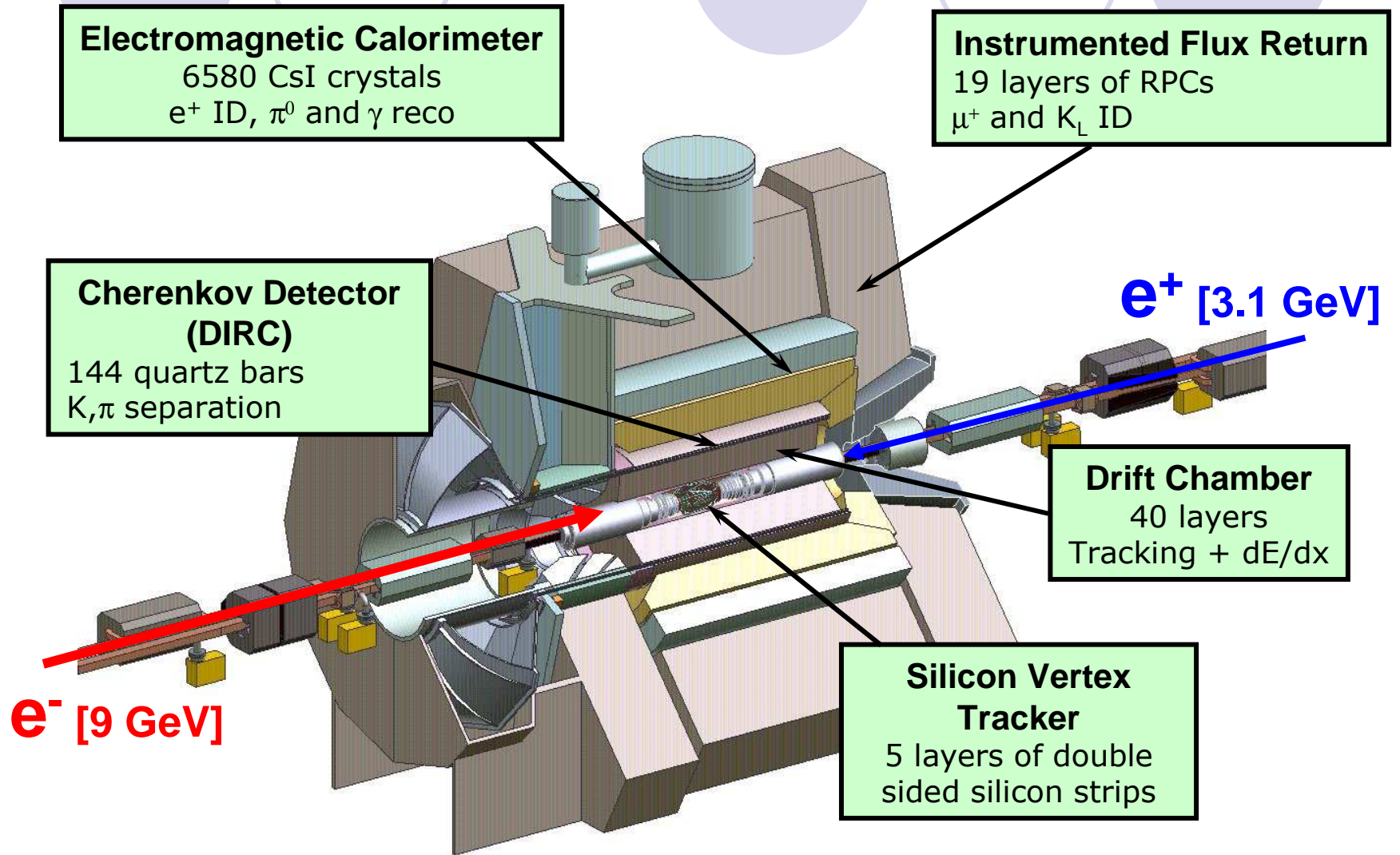
Searches for Inclusive Non-charmed Pentaquark Production with the *BaBar* Detector

Jonathon Coleman

University of Liverpool
for the BaBar Collaboration

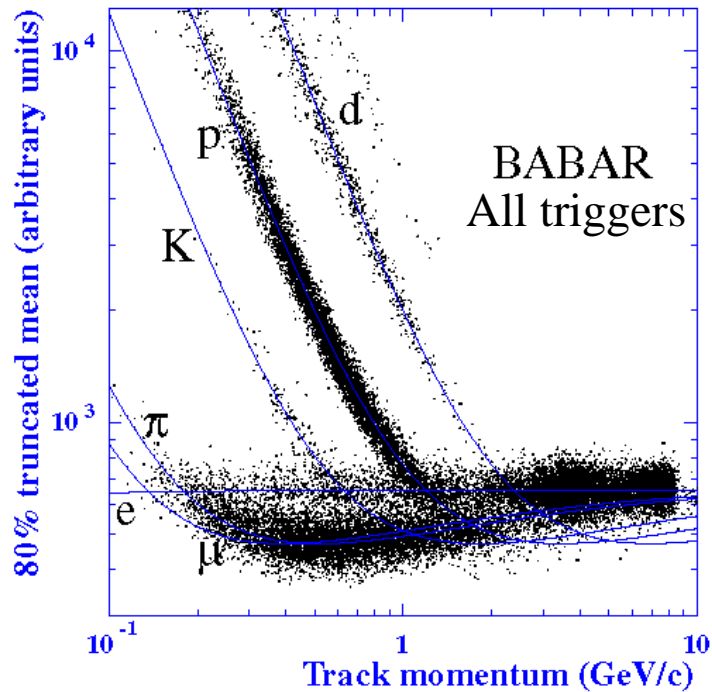
Meeting of
The Division of Particles and Fields
OF THE AMERICAN PHYSICAL SOCIETY

The BaBar detector at PEP-II

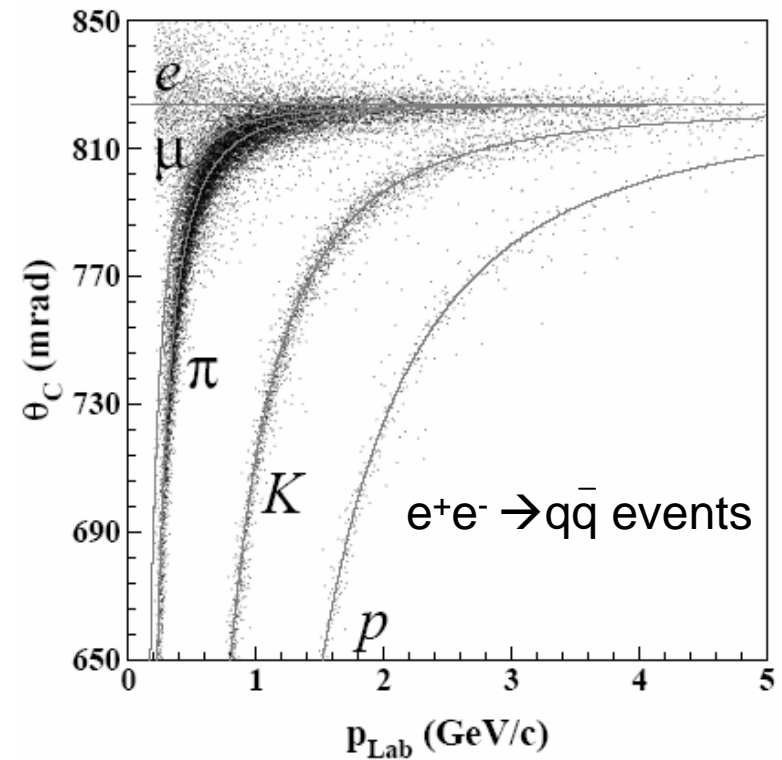


Particle Identification

dE/dx from Drift Chamber



Cherenkov angle from DIRC

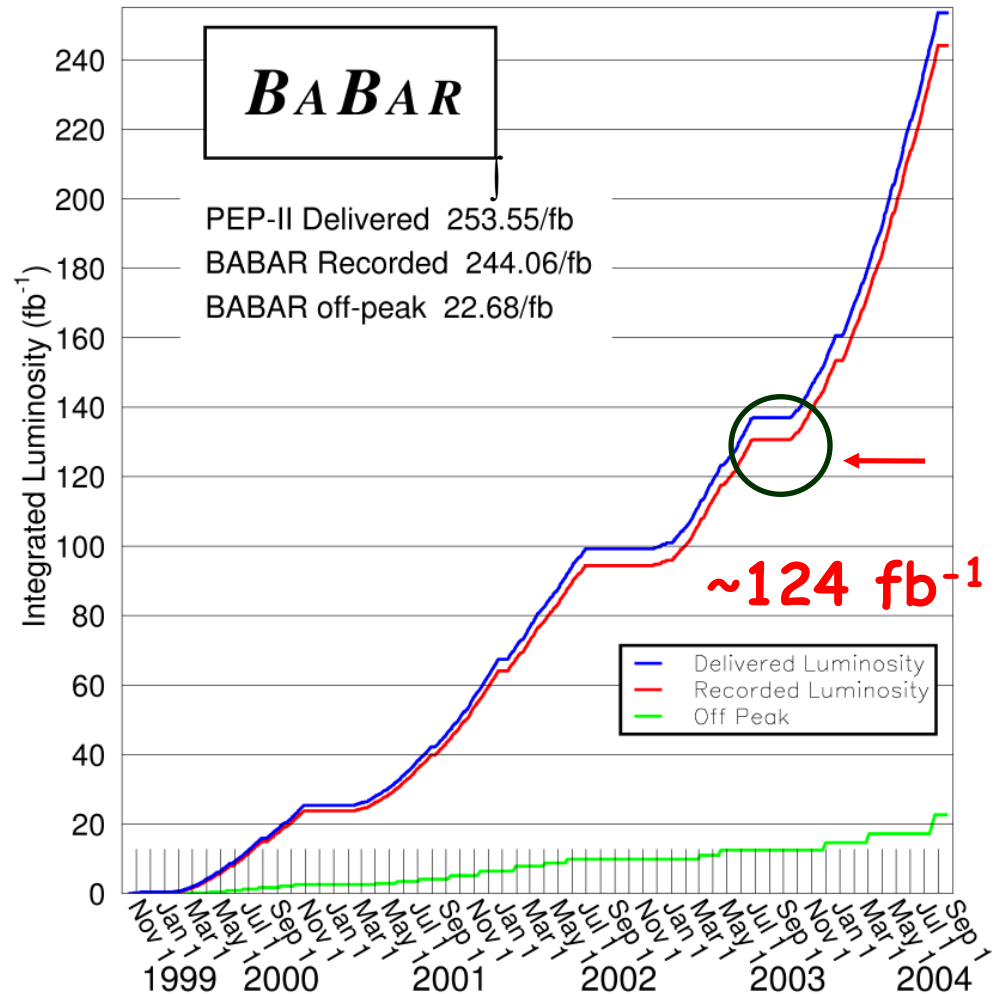
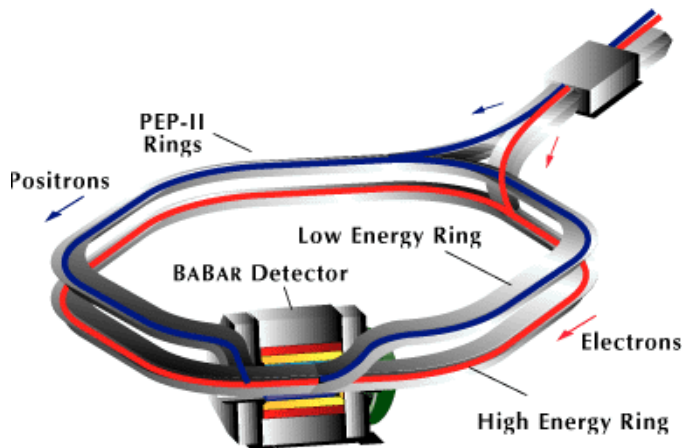


Excellent discrimination among p , π , K

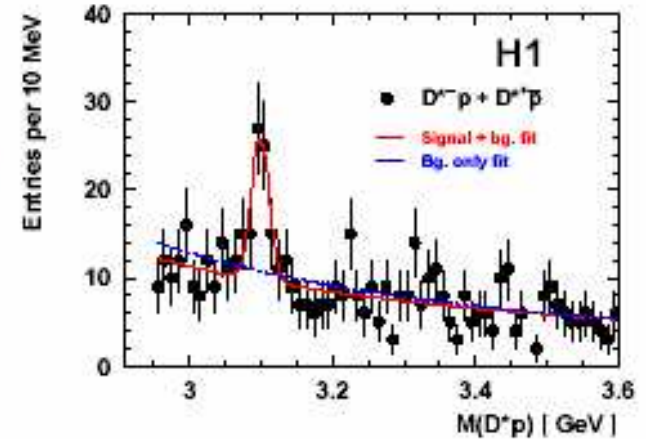
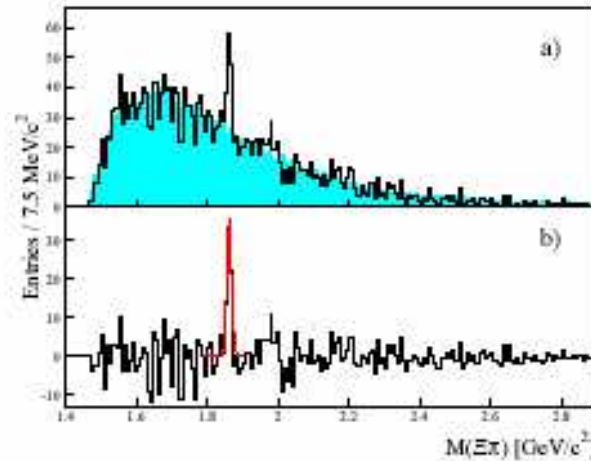
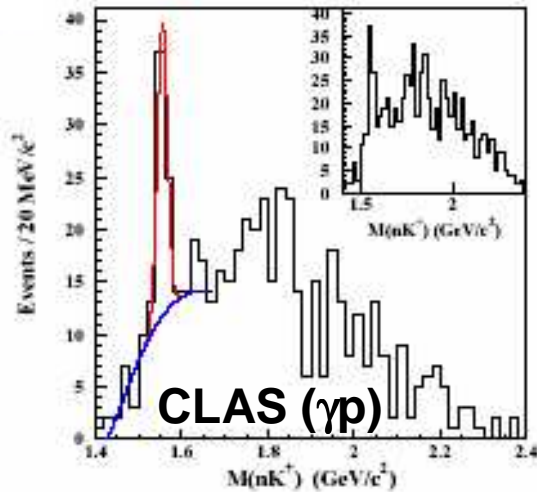
Data Sample for this Analysis

2004/08/23 09.21

- $\int L \sim 124 \text{ fb}^{-1}$
- c.m. energy $\sim 10.58 \text{ GeV}$
- On $Y(4S)$ resonance and $\sim 40 \text{ MeV}$ below resonance
- Inclusive search
 - Sensitive to all processes (B-decays, qq, \dots)



What Has Been Observed....



Claims for Exotic Narrow Baryons:

$\theta^+(ududs\bar{s})$:

LEPS+CLAS+others

$m \sim 1525 \rightarrow 1555 \text{ MeV/c}^2$

$\Gamma < 21 \text{ MeV}$

$\Xi^-(dsds\bar{u})$:

NA49

$m = 1862 \pm 2 \text{ MeV/c}^2$

$\Gamma < 18 \text{ MeV}$

$\theta_c^0(ududc\bar{c})$:

H1

$m = 3099 \pm 6 \text{ MeV/c}^2$

$\Gamma < 28 \text{ MeV}$

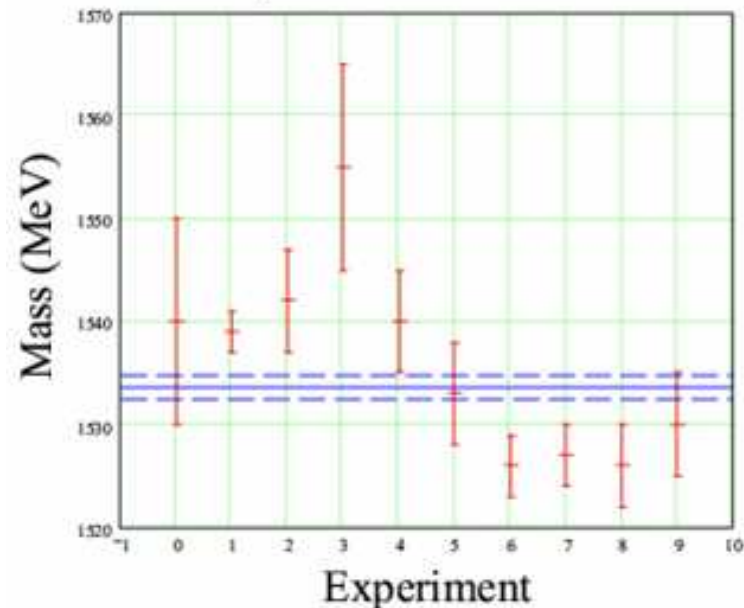
After failing to find any convincing evidence for exotic baryons for over 30 years: Θ^+ (1540)

No.	Experiment	Channel	Mass (MeV)
0	LEPS	K^+n	1540 ± 10
1	DIANA	K^0p	1539 ± 2
2	CLAS	K^+n	1542 ± 5
3	CLAS	K^+n	1555 ± 10
4	SAPHIR	K^+n	1540 ± 5
5	ITEP	K^0p	1533 ± 5
6	HERMES	K^0p	1526 ± 3
7	ZEUS	K^0p	1527 ± 2
8	SVD	K^0p	1526 ± 4
9	COSY-TOF	K^0p	1530 ± 5

Inclusive

- Broad range of mass values
 - Mean Mass: **1534 MeV/c²**
 - RMS: **> 10 MeV/c²**
 - Narrow Resonance: **($\Gamma < 9$ MeV)**

- Several (>10) observations
- different environments
- typically 4 – 7 σ significance



Negative Searches



Θ^+ **Not** seen by CDF, HyperCP,
E690, HERA-B, Aleph,
Delphi, Phenix

$\Xi_{3/2}$ **Not** seen by CDF, E690,
HERA-B, WA49.....

Note: All of these are inclusive production searches

Search for Inclusive Pentaquark Production in e^+e^- Annihilation at *BaBar*

- Characterized by:
 - Very large data sample ($\sim 124\text{fb}^{-1}$)
 - Excellent mass resolution
 - Excellent PID
 - Good Efficiency
 - If produced in jets or B-Decays should be seen

The BaBar Search Strategy

- Pentaquark theory predicts Θ_5^+ , Ξ_5 to be members of a $\overline{10}_5+8_5$

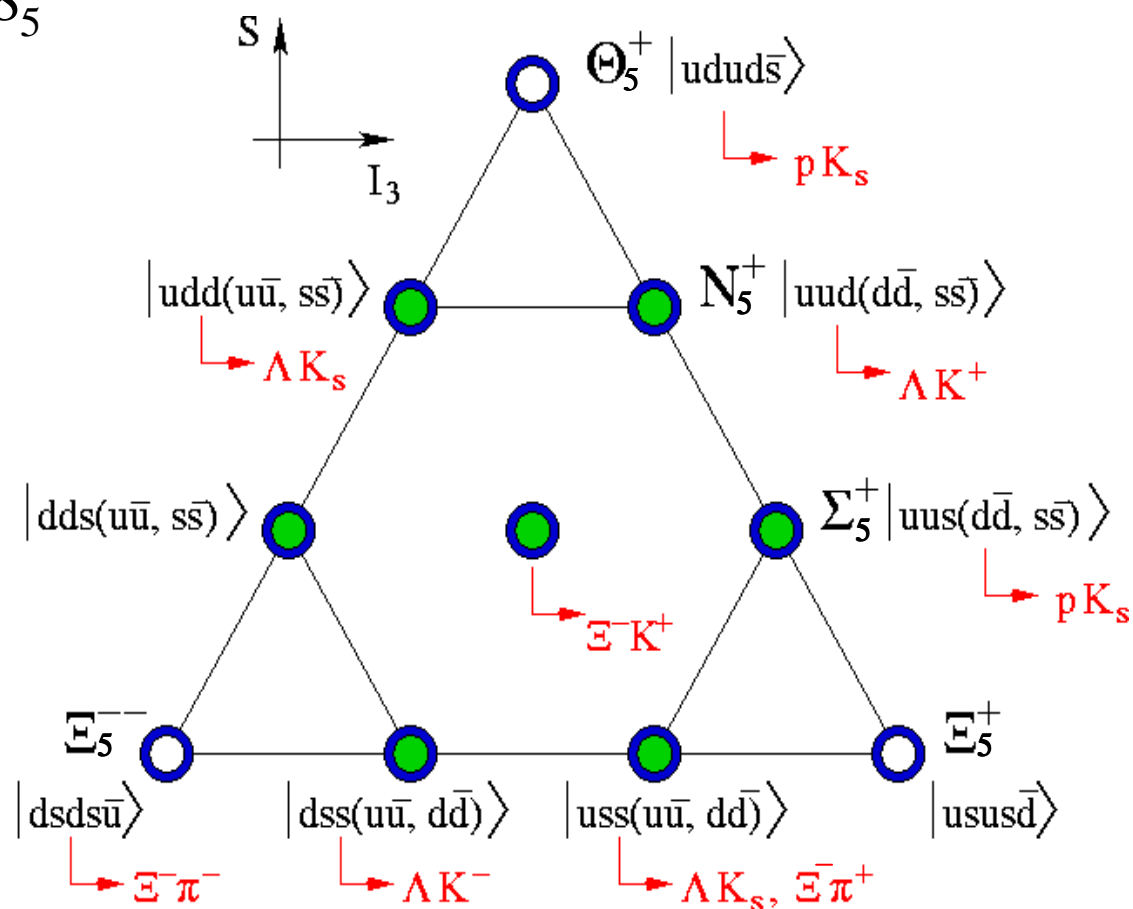
e.g. D. Diakonov et al

Z. Phys. A 359, 305 (1997)

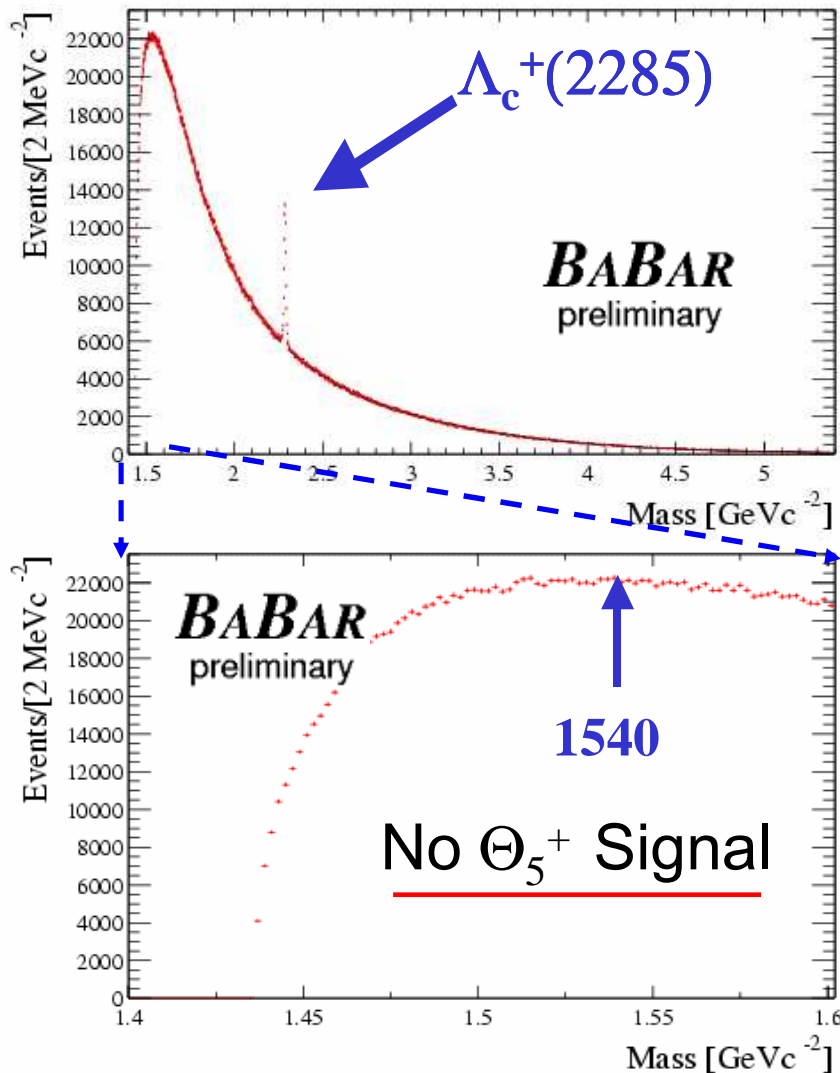
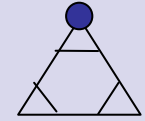
- Search inclusively for: Θ_5^+ , Ξ_5^{--} , Ξ_5^0 and other $\overline{10}_5+8_5$ states

- Independent of production mechanism e.g: $\gamma\gamma$, B-decay, jets...

- CC implied throughout



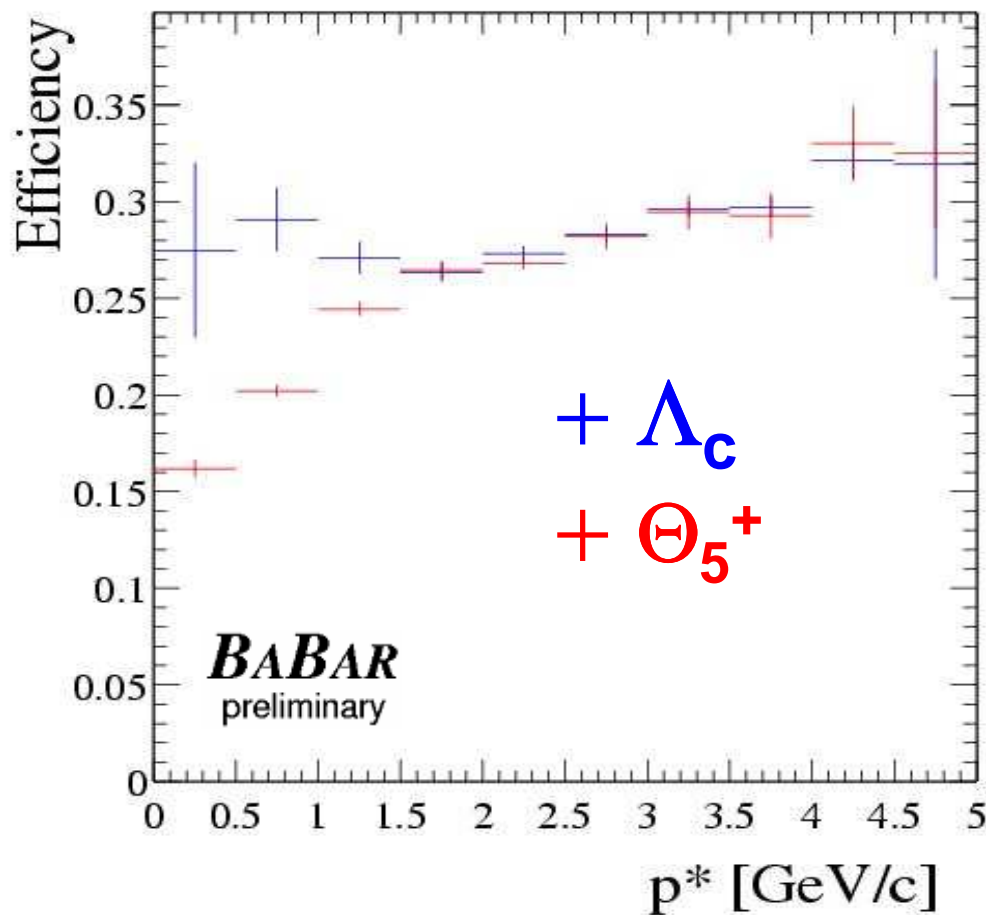
Search for $\Theta_5(1540)^+ \rightarrow p K_s^0$



- Clean $K_s^0 \rightarrow \pi^+\pi^-$ selection using geometry, loose PID
- Clean protons using dE/dx and Cherenkov angle
- Clear Λ_c^+ signal with $\sim 97,000$ events
- No structure near $1540 \text{ MeV}/c^2$
- Only narrow structure Λ_c^+

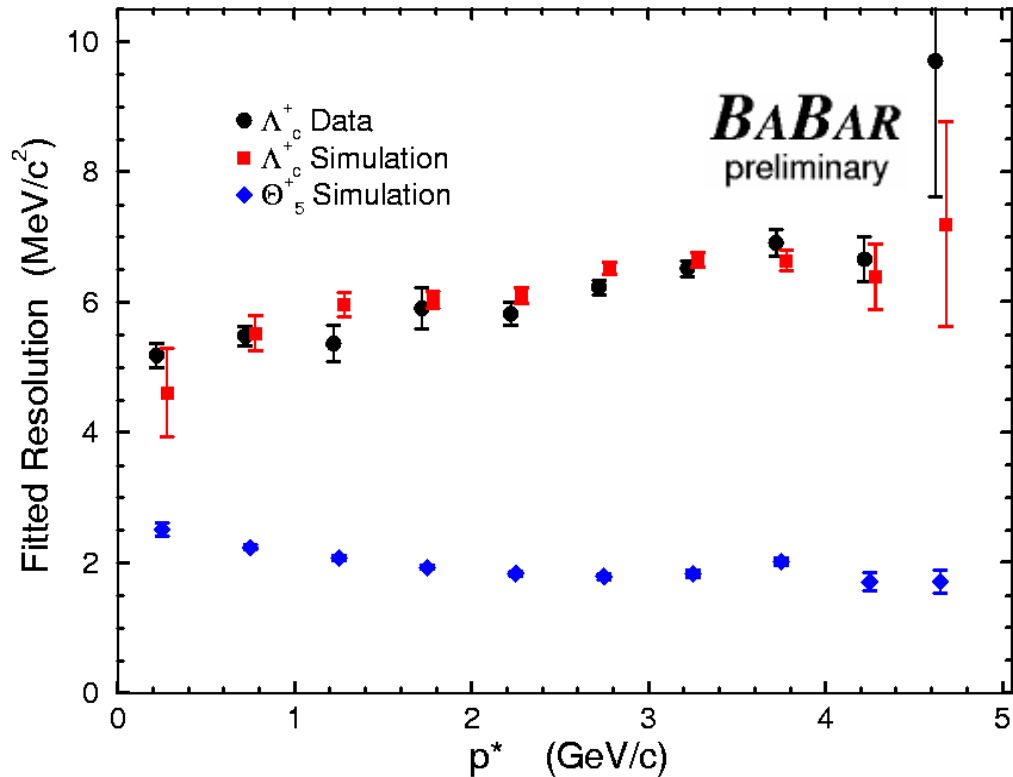
Many additional/different criteria applied
→ same conclusion

Detection Efficiency



- Efficiency typically
~25-35% for $\Lambda_c^+ \rightarrow p K_s^0$
and
~15-35% for $\Theta^+ \rightarrow p K_s^0$
- dominated by fiducial losses due to boosted CM system

$\Lambda_c^+ \rightarrow p K_s^0$ Control Sample



- Fit Λ_c signal in 0.5 GeV/c p^* intervals
- HWHM Values for MC and data agree well

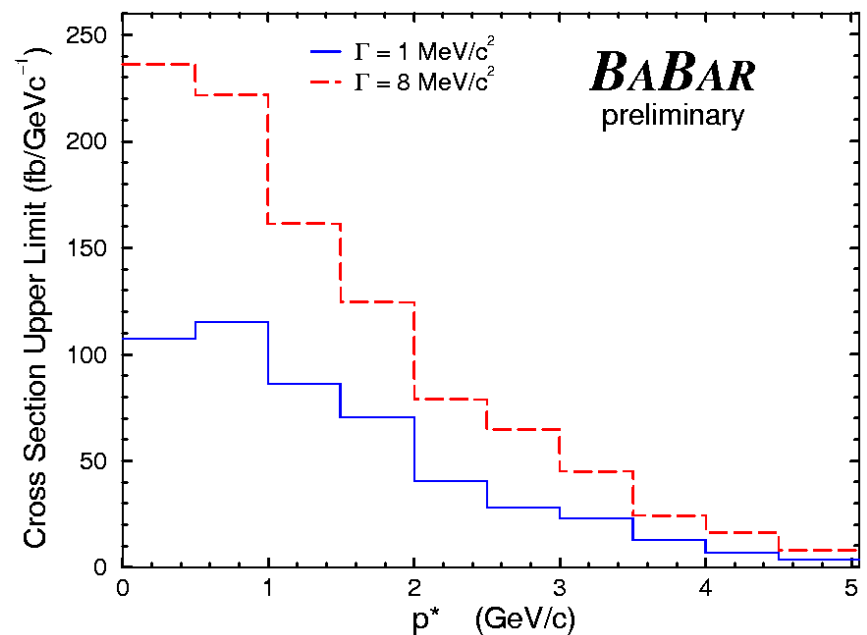
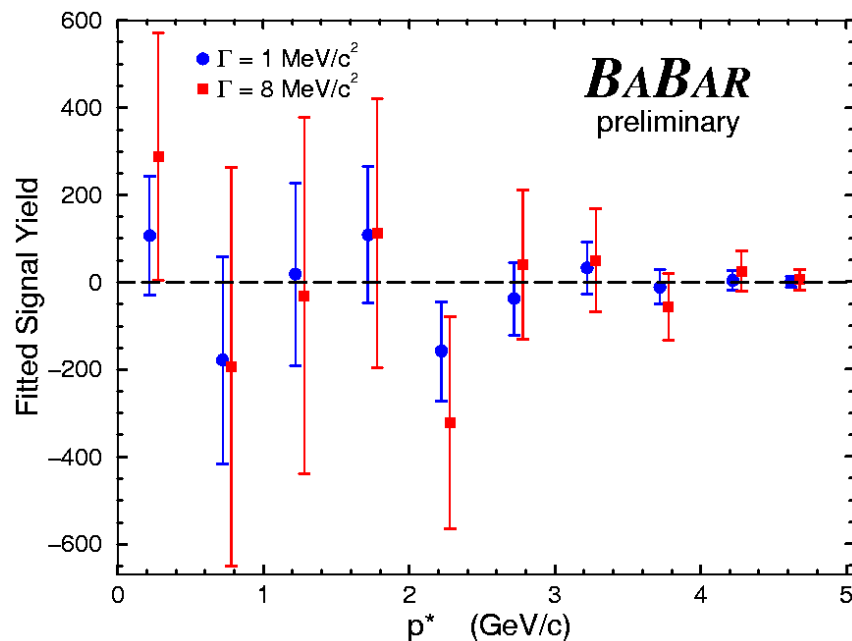
Implies MC resolution reliable for Θ_5 (~ 2 MeV/c²)
(small due to closeness to threshold)

$\Theta(1540)^+$ Cross Section and Upper Limit

(fit: P-wave Breit-Wigner lineshape \otimes resolution function + polynomial background)

• yield consistent with zero

• 95% c.l. cross section U.L.



• **Differential Limit**
independent of production
mechanism

• **Model Independent Integral**

Total cross section U.L. @ 95% c.l.

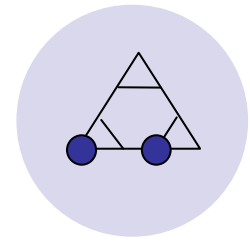
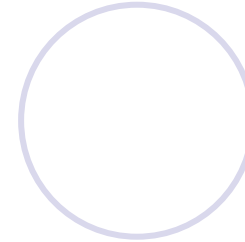
$\Gamma = 1 \text{ MeV}$

< 183 fb

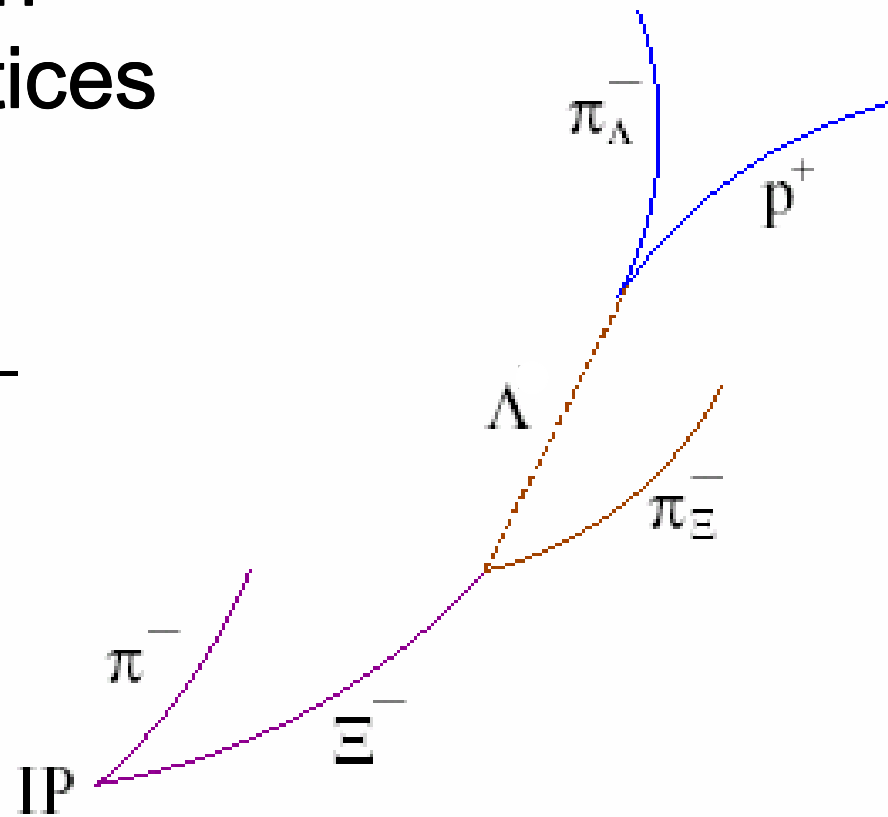
$\Gamma = 8 \text{ MeV}$

< 363 fb

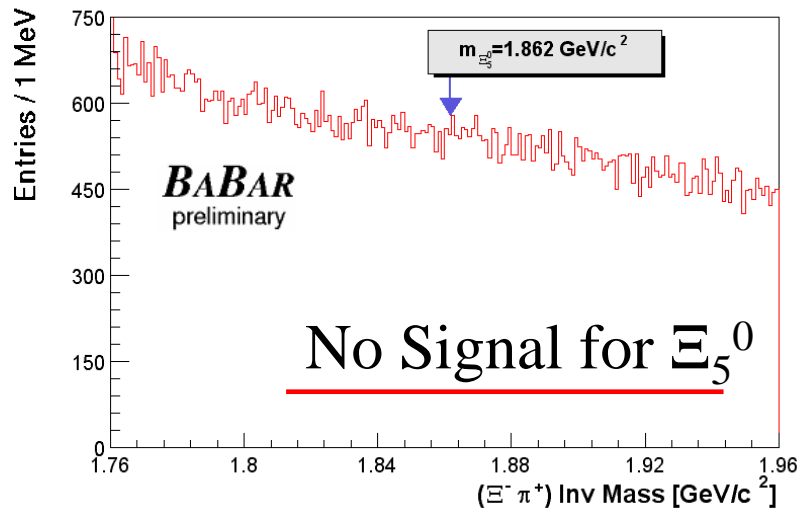
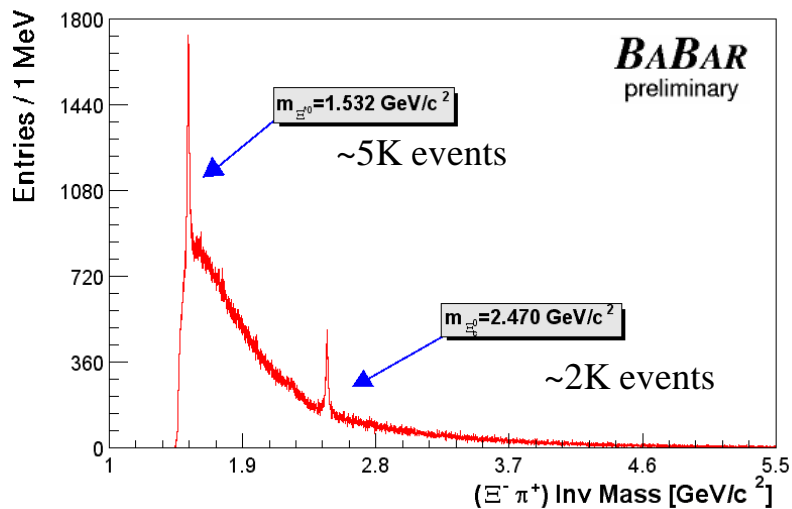
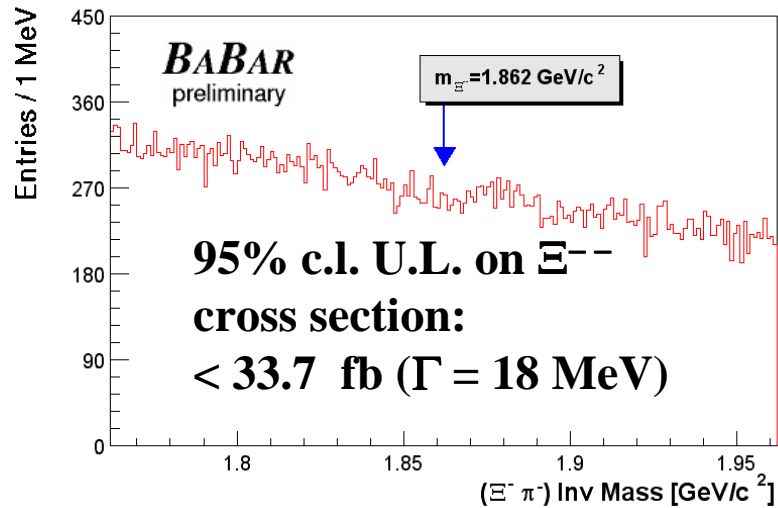
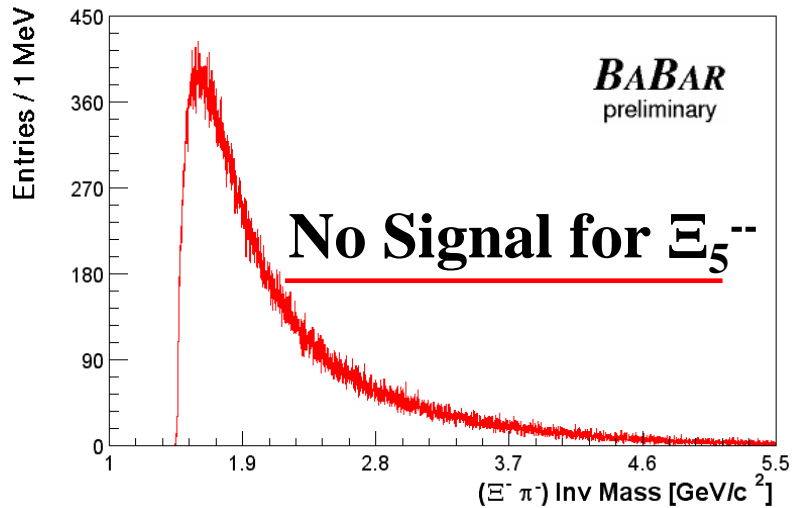
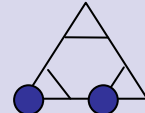
Search for: $\Xi_5(1862)^- \rightarrow \Xi^- \pi^+$
 $\Xi_5(1862)^0 \rightarrow \Xi^- \pi^+$



- Geometrical selection of two displaced vertices
- Loose particle ID
- Select masses near the nominal Λ and Ξ^- masses
- Control signals:
 $\Xi^{*0}(1530) \rightarrow \Xi^- \pi^+$
 $\Xi_c(2470) \rightarrow \Xi^- \pi^+$

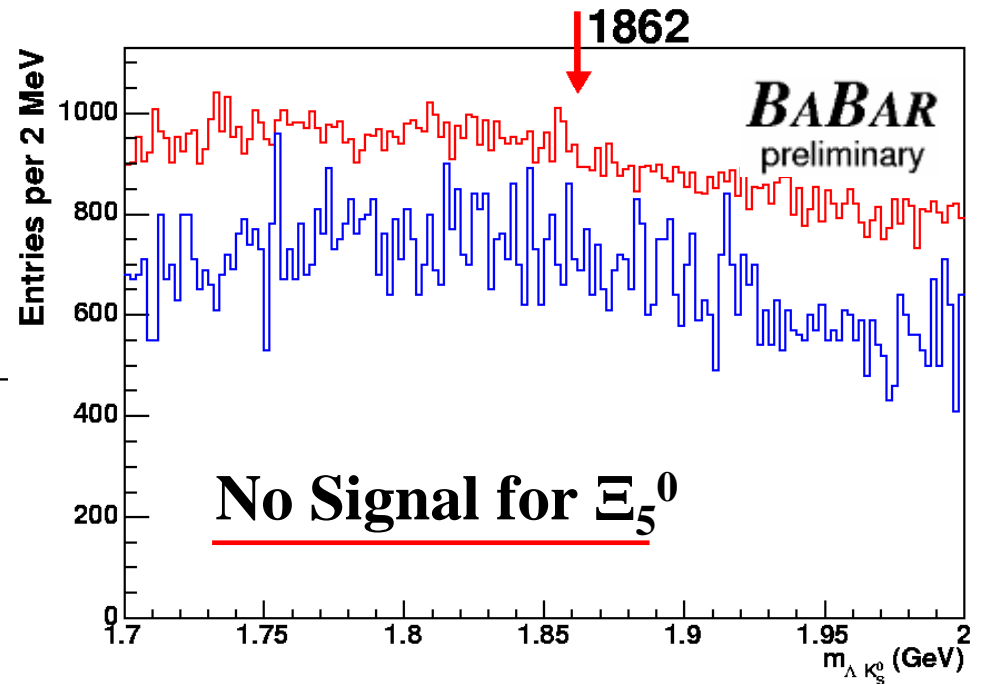
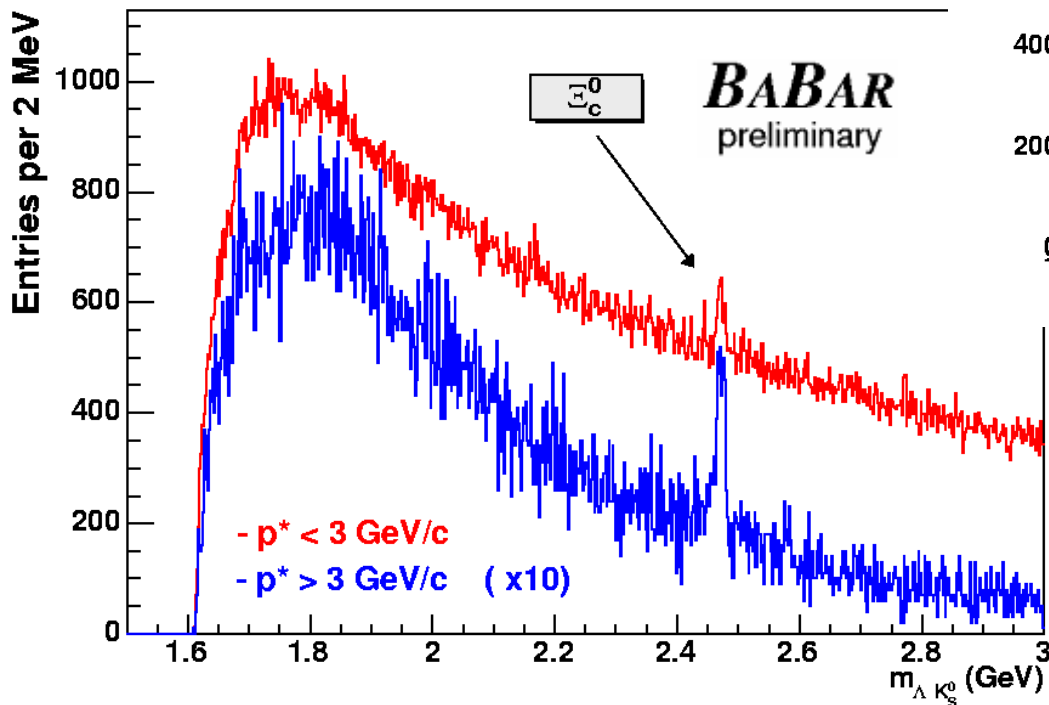


$\Xi^- \pi^-$, $\Xi^- \pi^+$ Invariant Mass



Search for $\Xi_5^0 \rightarrow \Lambda K_s^0$

- Analysis method similar to above
- Control Signal:
 $\Xi_c^0 \rightarrow \Lambda K_s^0$ (~2K events)



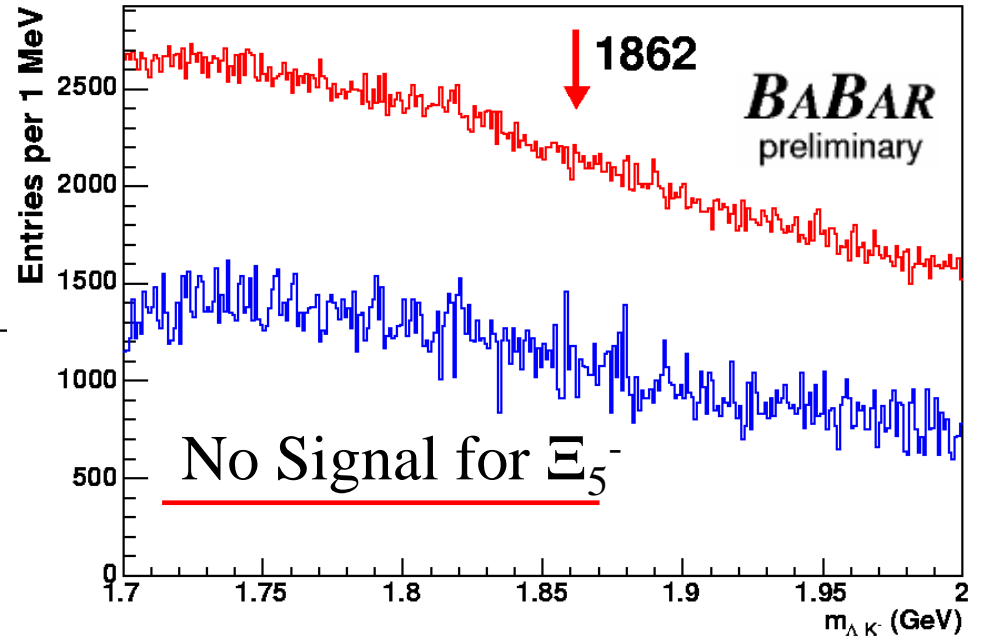
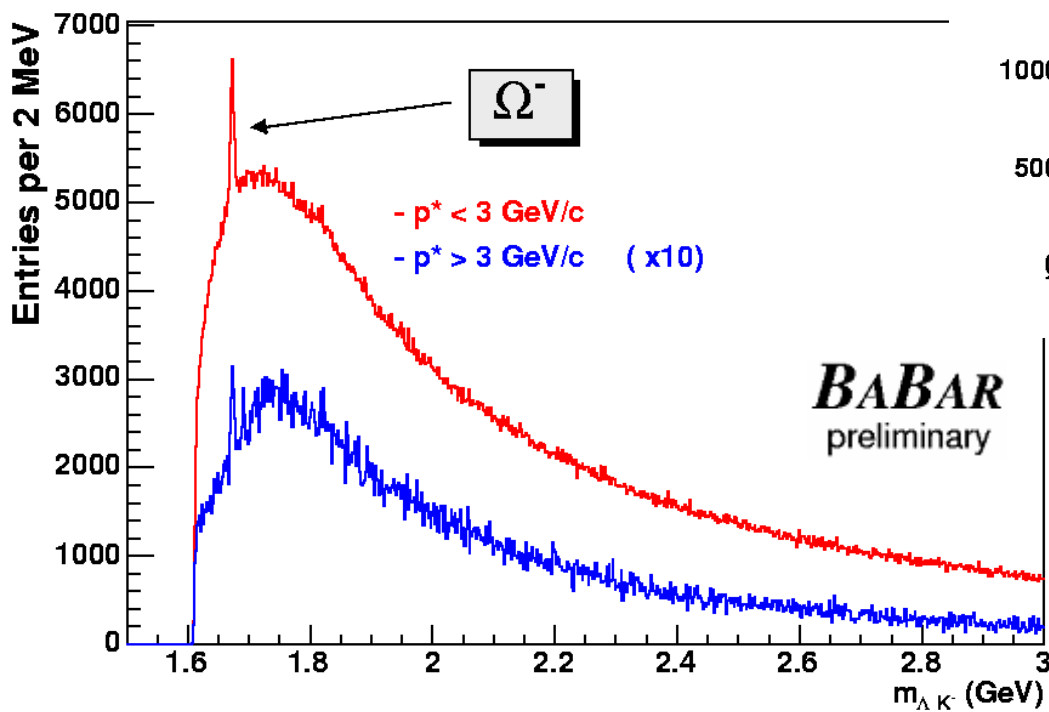
95% c.l. U.L. on Ξ_5^0 production cross section x BF:

$$< 83 \text{ fb} \quad \Gamma=1\text{MeV}$$

$$< 205 \text{ fb} \quad \Gamma=18\text{MeV}$$

Search for $\Xi^- \rightarrow \Lambda K^-$

- Λ selection as above
- Combine with identified K^-
- Control signal Ω^- (~8K events)

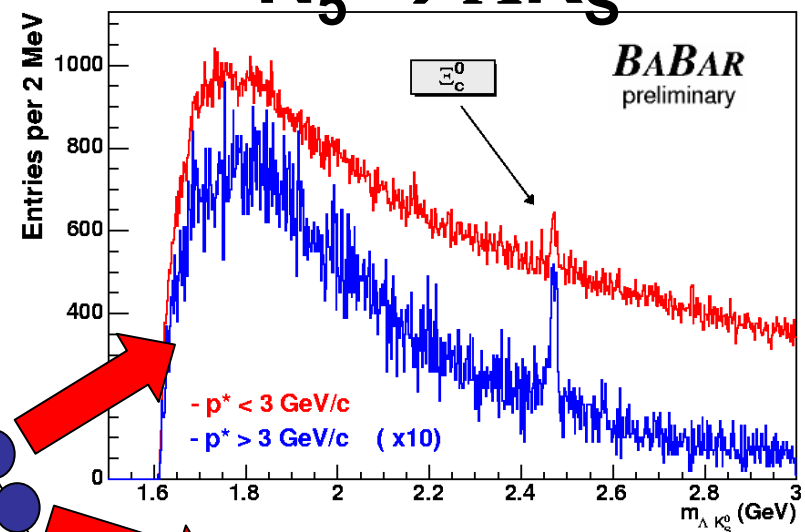
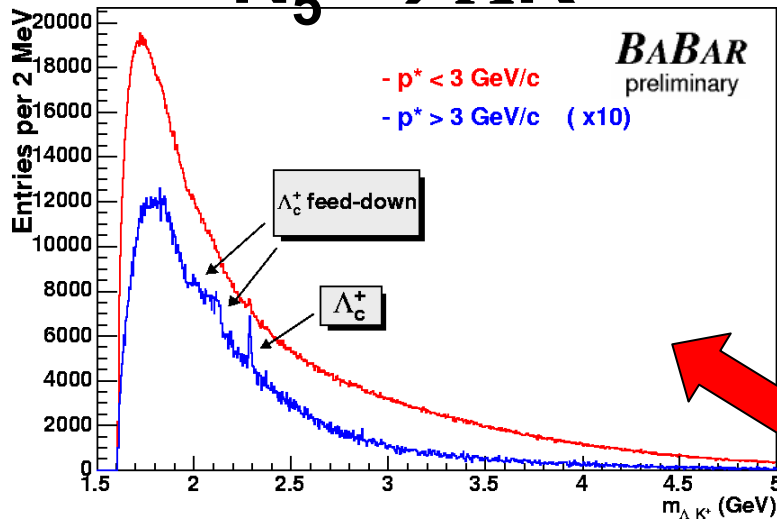


95% c.l. U.L. on production cross section \times BF :

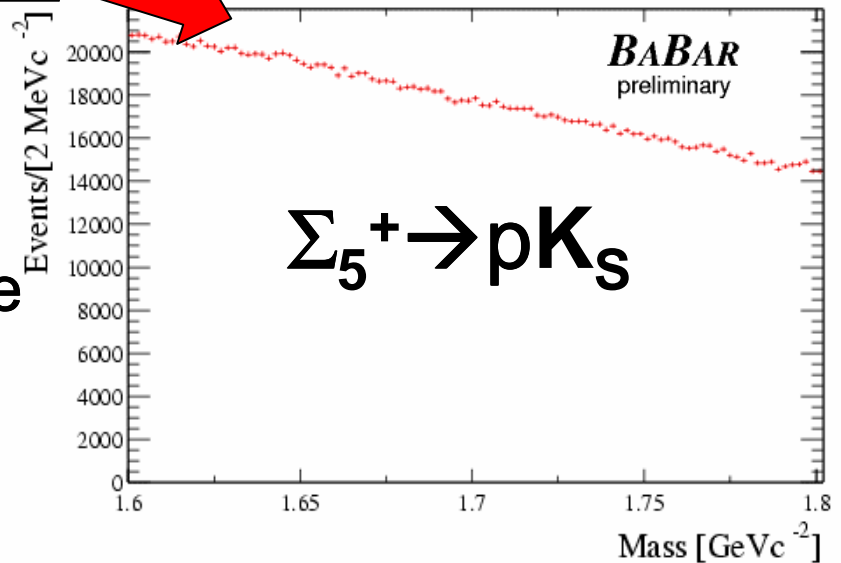
$$< 84 \text{ fb} \quad \Gamma=1\text{MeV}$$

$$< 181 \text{ fb} \quad \Gamma=18\text{MeV}$$

Additional Searches



- Also $\Sigma^0 K^+$, $\Sigma^0 K^-$, $\Sigma^0 K_S^0$
- No unexpected narrow structure



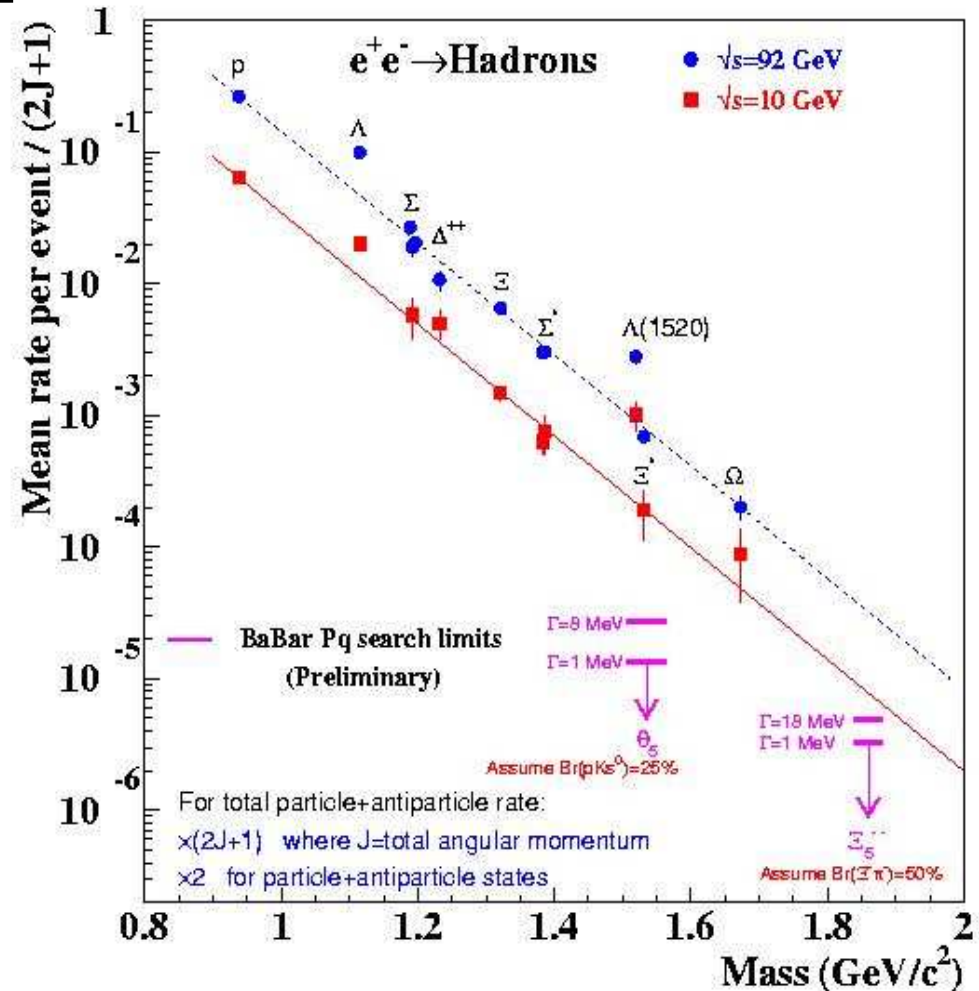
Results in perspective

- Assume pentaquarks have $J = \frac{1}{2}$
- expect $\text{BF}(\Theta_5^+ \rightarrow pK_s^0) = 25\%$
- expect $\text{BF}(\Xi_5^{--} \rightarrow \Xi^- \pi^-) \sim 50\%$
- BF for Ξ_5^-, Ξ_5^0 very unclear

If pentaquark production follows the trend for ordinary baryon production then we expect:

- $\sim 8 \times 10^{-4} \Theta_5^+$ per $q\bar{q}$ event
- $\sim 4 \times 10^{-5} \Xi_5^{--}$ per $q\bar{q}$ event

- Limits are below expectations;
 Θ_5^+ : 1.1×10^{-4} ($\Gamma = 8 \text{ MeV}$)
 Ξ_5^{--} : 2×10^{-5} ($\Gamma = 18 \text{ MeV}$)



Summary



- **Large Λ , Ξ^- , Ξ^{*0} , Ω^- , Ξ_c^0 , Λ_c^+ signals observed in e^+e^- interactions**
- **No signal for any pentaquark state:**
 - Production of $\Theta_5(1540)^+$, $\Xi_5(1860)^-$ well below that of ordinary baryons of similar mass.
 - No narrow peaks for other $\overline{10}_5+8_5$ states in several search modes.
- **The Search Continues.....**