Pentaquark Searches at BaBar

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Representing the BaBar Collaboration

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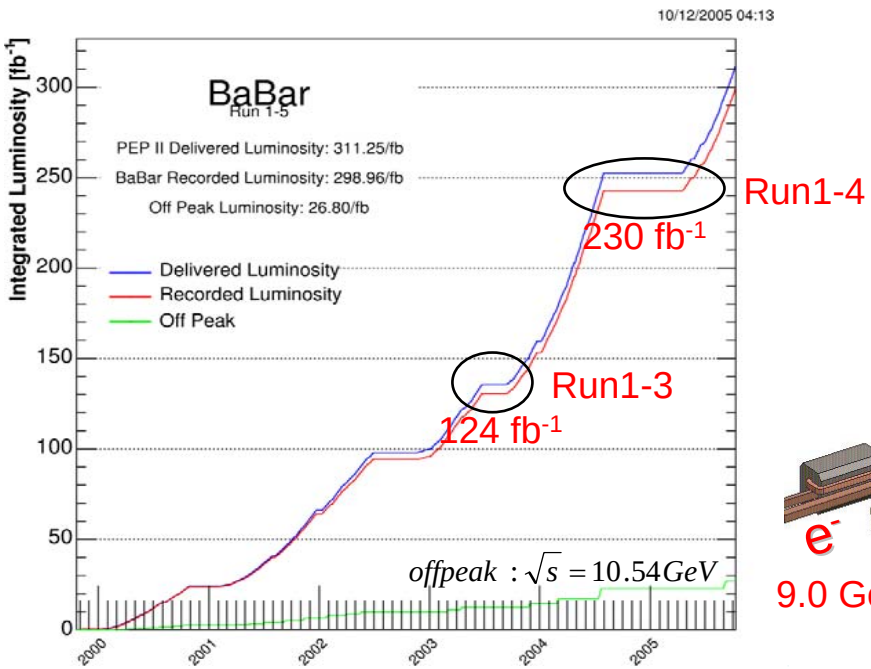
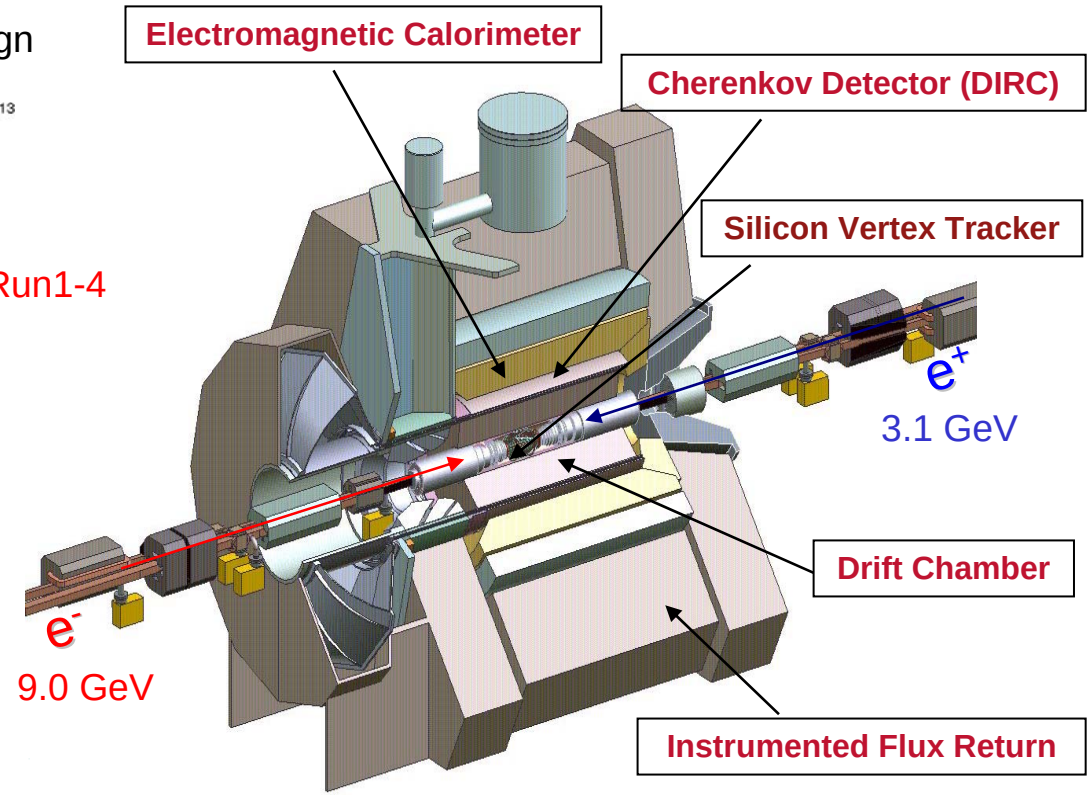
Outline

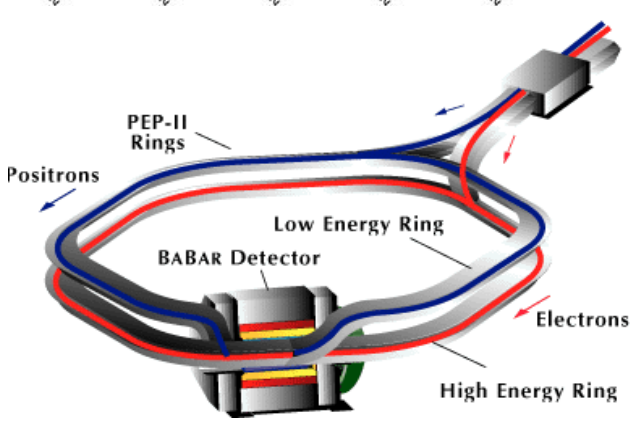
- Introduction to BaBar
- Searches for the strange-pentaquark $\Theta^+(1540)$
  - Inclusive production in $e^+e^- \to$ hadrons
  - Electro- and hadro- production
- Inclusive searches for the strange-pentaquark $\Xi_5^{--}(1862)$, $\Xi_5^0(1862)$, etc.
- Exclusive Search for the predicted strange-pentaquark Θ^{*++}
- Searches for anti-charm pentaquark $\Theta_c(3100)$
  - Inclusive $e^+e^- \to$ hadrons
  - Exclusive $B \to p\bar{p}K$, $Dp\bar{p}(\pi)$ decays

The BaBar Detector at SLAC

peak luminosity reached 10^{34} $cm^{-1}s^{-1}$, 3x design







- Asymmetric → CM boost β = 0.49
- Acceptance → -0.9 < cos(θ*) < 0.8
- Resolution → typically a few MeV/c^2

Search for Strange-Pentaquarks

- 13 claims to see $\Theta^+(1540)$

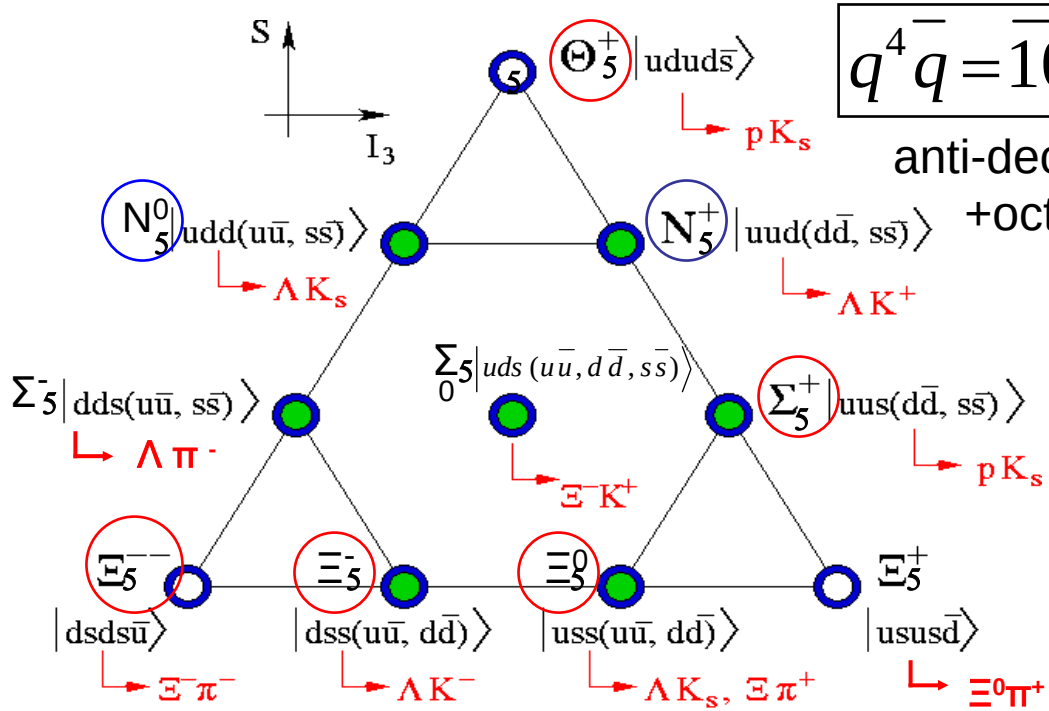
(*): not seen in CLAS new exp. with ~6x and ~40x more data

Exp.	Reaction
LEPS	$\gamma C \rightarrow K^+K^- X$
LEPS	$\gamma d \rightarrow K^+K^- X$
SVD	$p(C,Si,Pb) \rightarrow K_s^0 pX$
DIANA	$K^+Xe \rightarrow K^0p\ (Xe)'$
COSY	$pp \rightarrow K^0p\Sigma^+$
JINR	$p(C_3H_8) \rightarrow K_s^0 pX$
CLAS	$\gamma p \rightarrow p^+K^-K^+(n)$
CLAS*	$\gamma d \rightarrow K^+K^-p(n)$
SAPHIR*	$\gamma p \rightarrow K^+\bar{K}^0(n)$
ITEP	$nNe \rightarrow K^0p\ X$
NOMAD	$N_\mu(Fe,Al,Pb) \rightarrow K_s^0 pX$
HERMES	$e^+d \rightarrow K^0p\ X$
ZEUS	$e^+p \rightarrow e'K^0p\ X$

- NA49 claimed to find Ξ^{--} and Ξ^0 at ~1862 MeV/c^2
- prompted surge of pentaquark search, but most have negative results.

○ : strange-pentaquarks searched at BaBar

○ : nonstrange-pentaquarks searched at BaBar

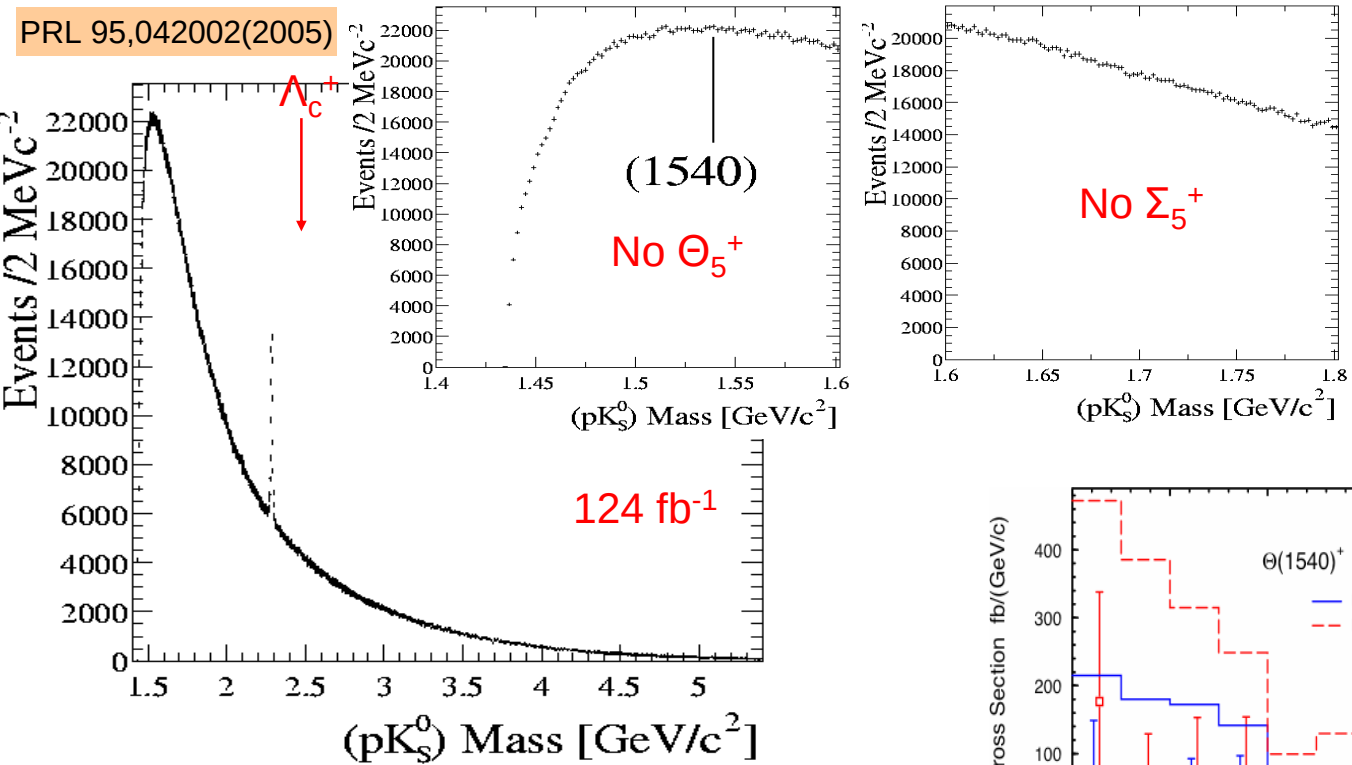


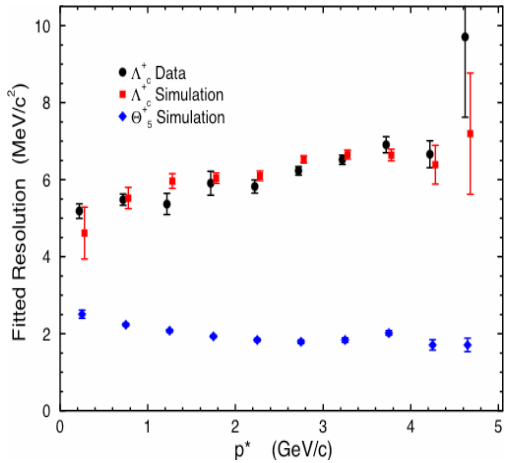
$$q^4\bar{q} = \overline{10} \oplus 8$$

anti-decuplet +octet

Inclusive $\Theta_5^+/\Sigma_5^+ \rightarrow pK_s^0$

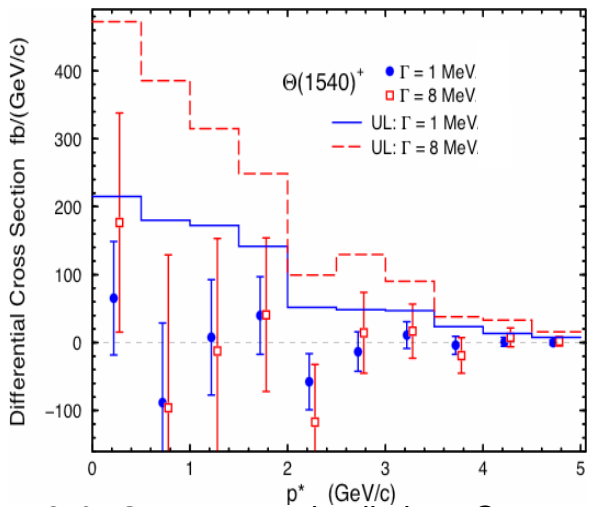
PRL 95,042002(2005)





1) Good agreement between data and MC for Λ_c resolution (~6 MeV)
2) Expect the Θ^+ resolution to be ~2 MeV

- Require signed flight length > 0.5 cm → no evidence
- Associate with a K^- track → no evidence
- Associate with a $\bar{p}$ track → no evidence
- Look at m(K_s^0p) in 2.3<m($K^-K_s^0$p)<2.5 GeV (CLAS) → no evidence



p* is the $\Theta^+(1540)$ momentum in CM.

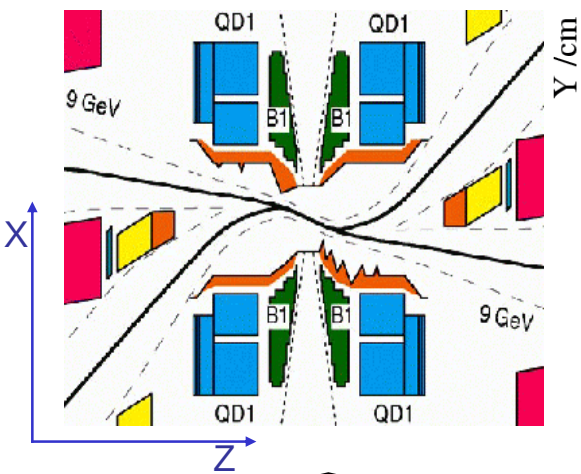
BF($\Theta^+ \rightarrow pK_s^0$) = 1/4 is assumed.

95% CL cross section limit on Θ_5^-:
σ < 171 fb (Γ=1 MeV)
σ < 363 fb (Γ=8 MeV)

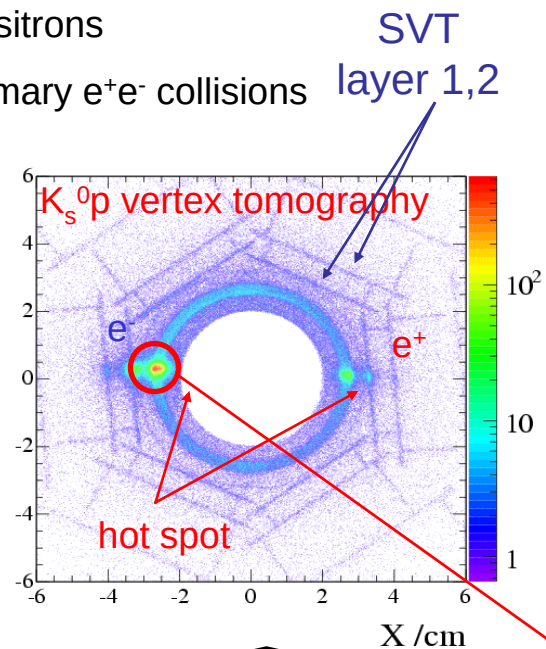
Θ_5^+ in Electro- and Hadro- Production

Detector geometry is used to reject candidates produced in the IR – two main sources of data:

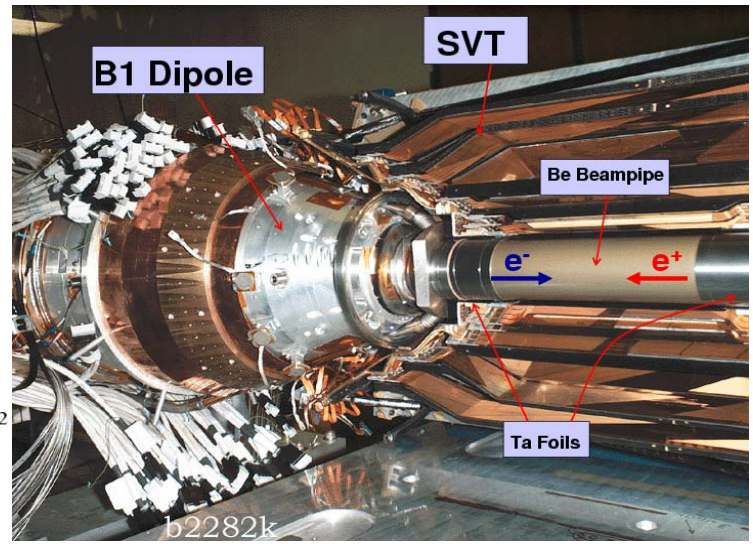
- Beam halo electrons and positrons
- Hadrons produced in the primary e^+e^- collisions

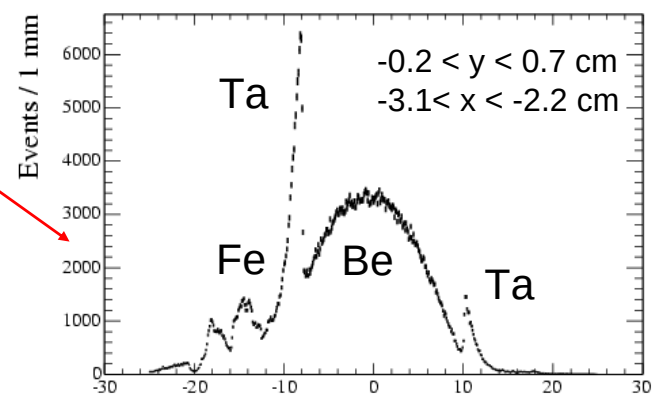


Off-beam electrons and positrons bent into beam pipe by permanent magnet dipoles (in horizontal plane)



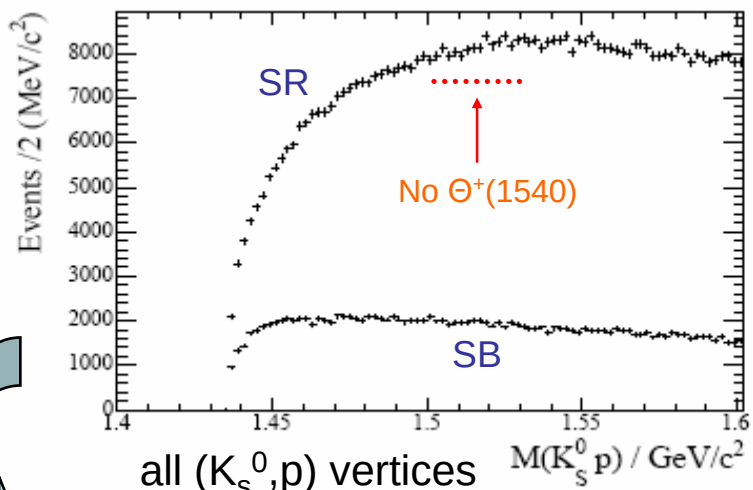
The production vertices of (K_s^0,p) reproduce the BaBar detector structure very well !



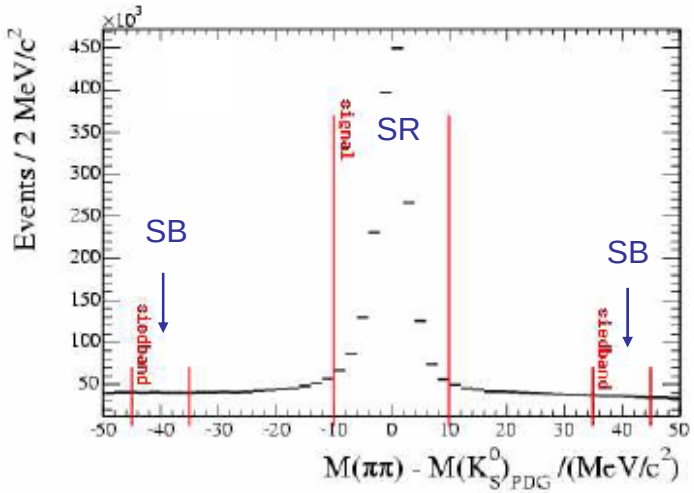


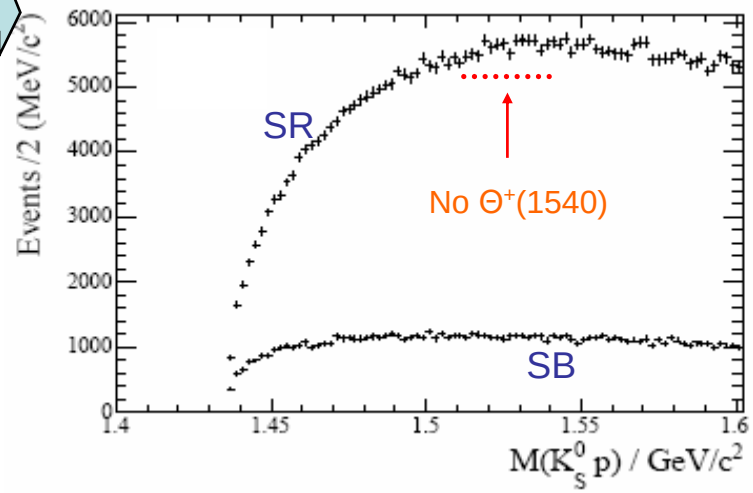
Z_{vtx} e^- side profile (cm)

pK_s^0 Invariant Mass Distributions (Preliminary)

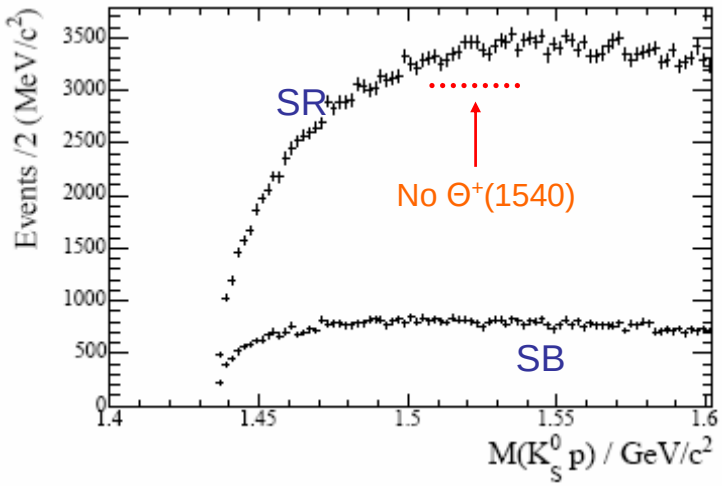


all (K_s^0,p) vertices



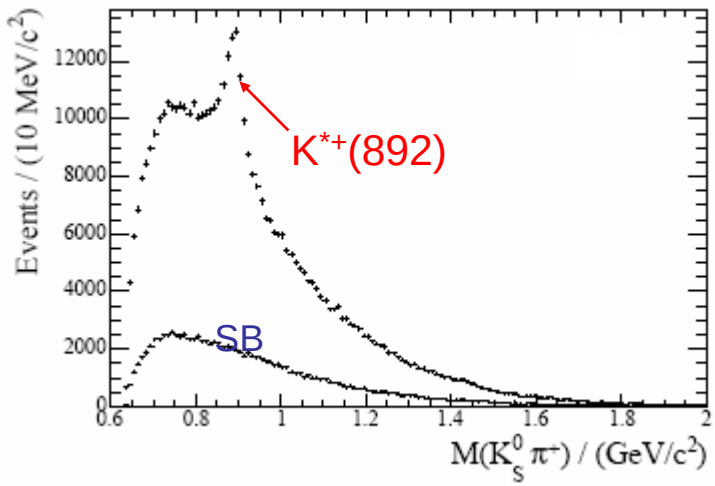


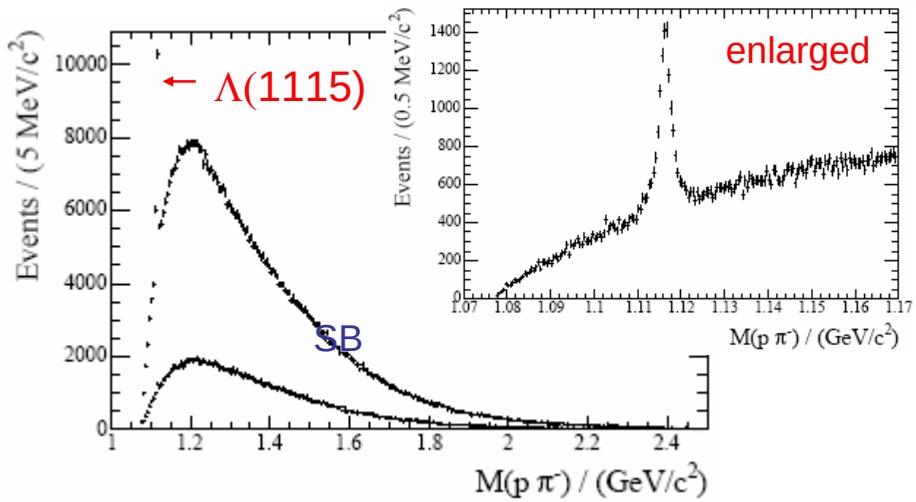
(K_s^0,p) vertices with at least an associated track satisfying DOCA < 0.5 cm



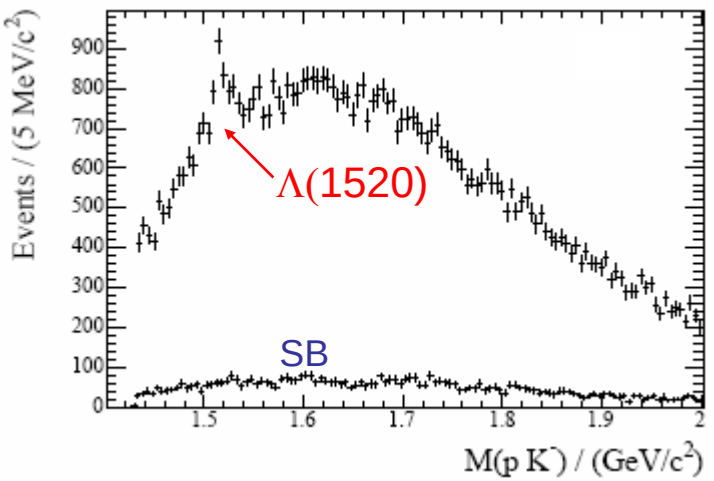
(K_s^0,p) vertices without an associated baryon or $\bar{p}$.

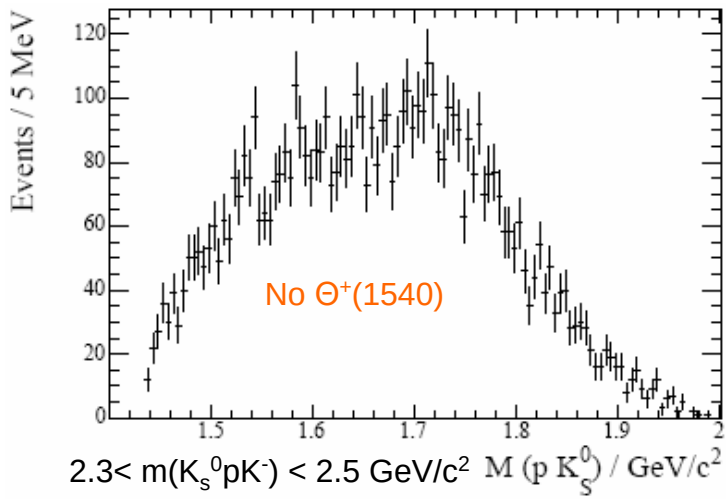
pK_s^0 Invariant Mass with Associated $\pi^\pm$ or $K^\pm$ (Preliminary)





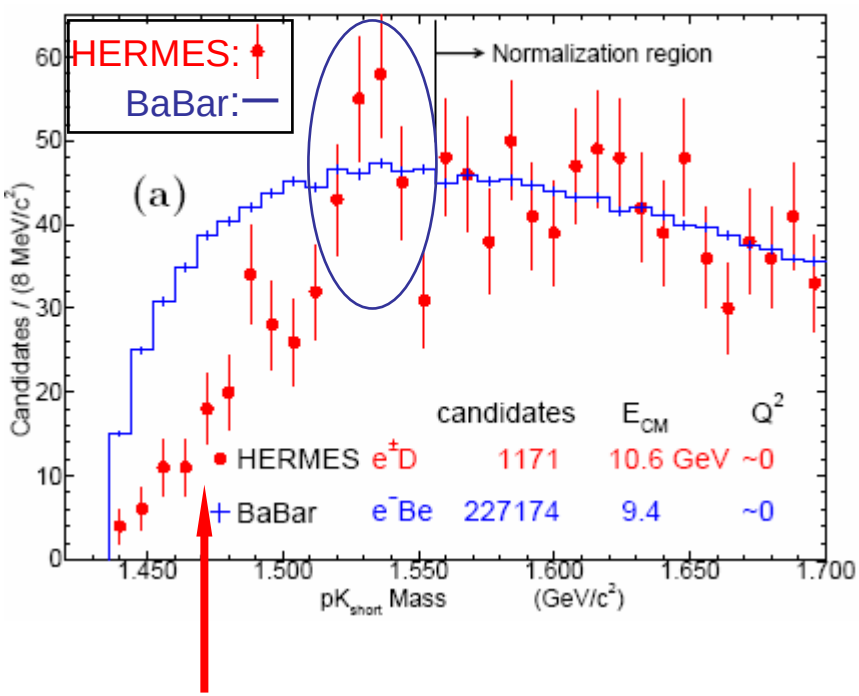
Associate with a $\pi^\pm$ or $K^\pm$ track → find $K^{*+}(892)$, $\Lambda(1115)$, $\Lambda(1520)$, but no evidence for Θ^+



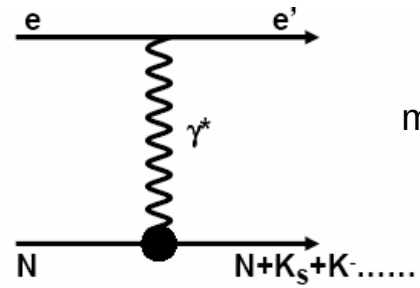


$2.3 < m(K_s^0 pK^-) < 2.5$ GeV/c²

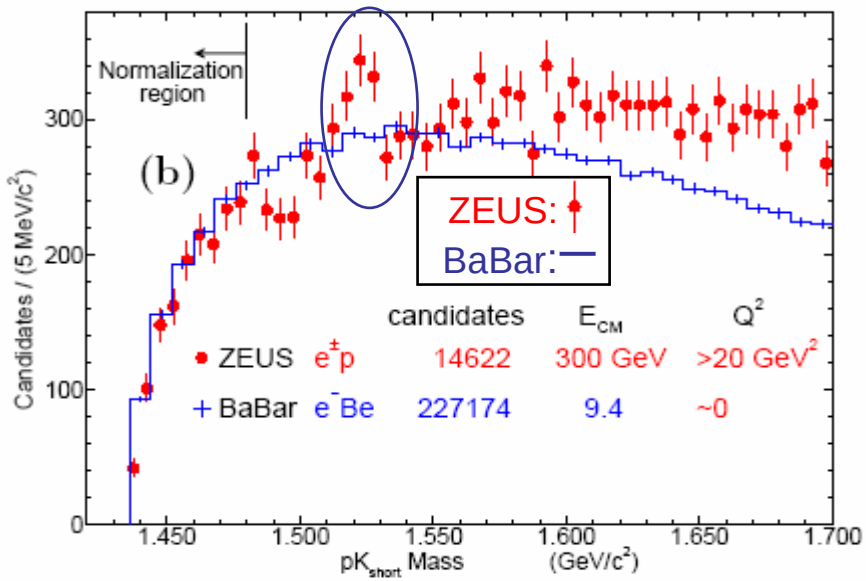
Comparison to Other Exp. In Electroproduction



Possible acceptance loss in low mass region: proton momentum > 4 GeV/c, pion momentum > 1 GeV/c, K_s^0 momentum > 3 GeV/c, K_s^0 flight length > 7 cm.



Different shapes at high momentum expected from different CM energies.

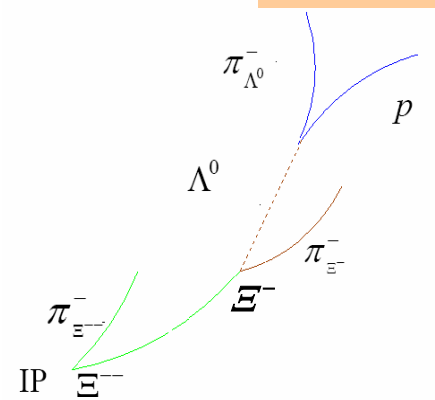


No Σ(1480) or Θ^+(1540) seen

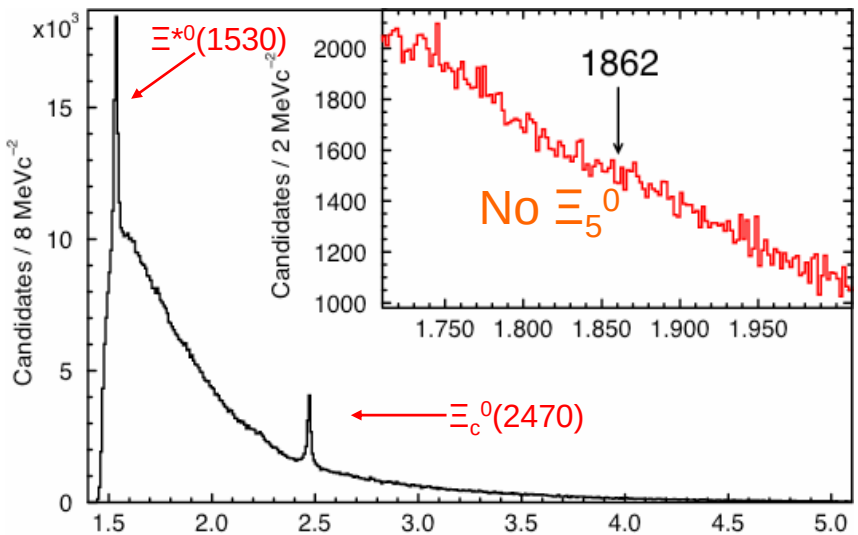
Flux unknown → can't set cross section limit

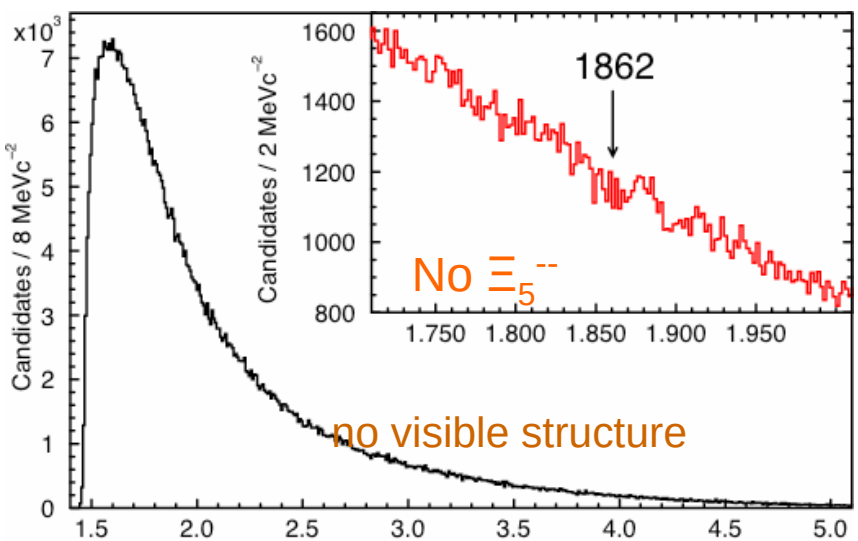
Inclusive Search for $\Xi_5^{--} \rightarrow \Xi^- \pi^-$ and $\Xi_5^0 \rightarrow \Xi^- \pi^+$

PRL 95,042002(2005)



Resolutions of Ξ^{*0} and Ξ_c^0 are about 7-9 MeV/c^2,expect Ξ_5^0 resolution ~8 MeV/c^2





assume BF($\Xi_5^{--} \rightarrow \Xi^-\pi^-$) = ½:

95% CL cross section limit on Ξ_5^{--}:

σ < 22 fb (Γ= 1 MeV)

σ < 34 fb (Γ= 18 MeV)

Inclusive Searches for $\Xi_5^0, N_5^0, \Xi_5^-, N_5^+$

a) Investigated octet state Ξ_5^0 and N_5^0 decays $\Xi_5^0/N_5^0 \rightarrow \Lambda^0 K_s^0$, found peak of Ξ_c^0 events, but no evidence of Ξ_5^0 or N_5^0

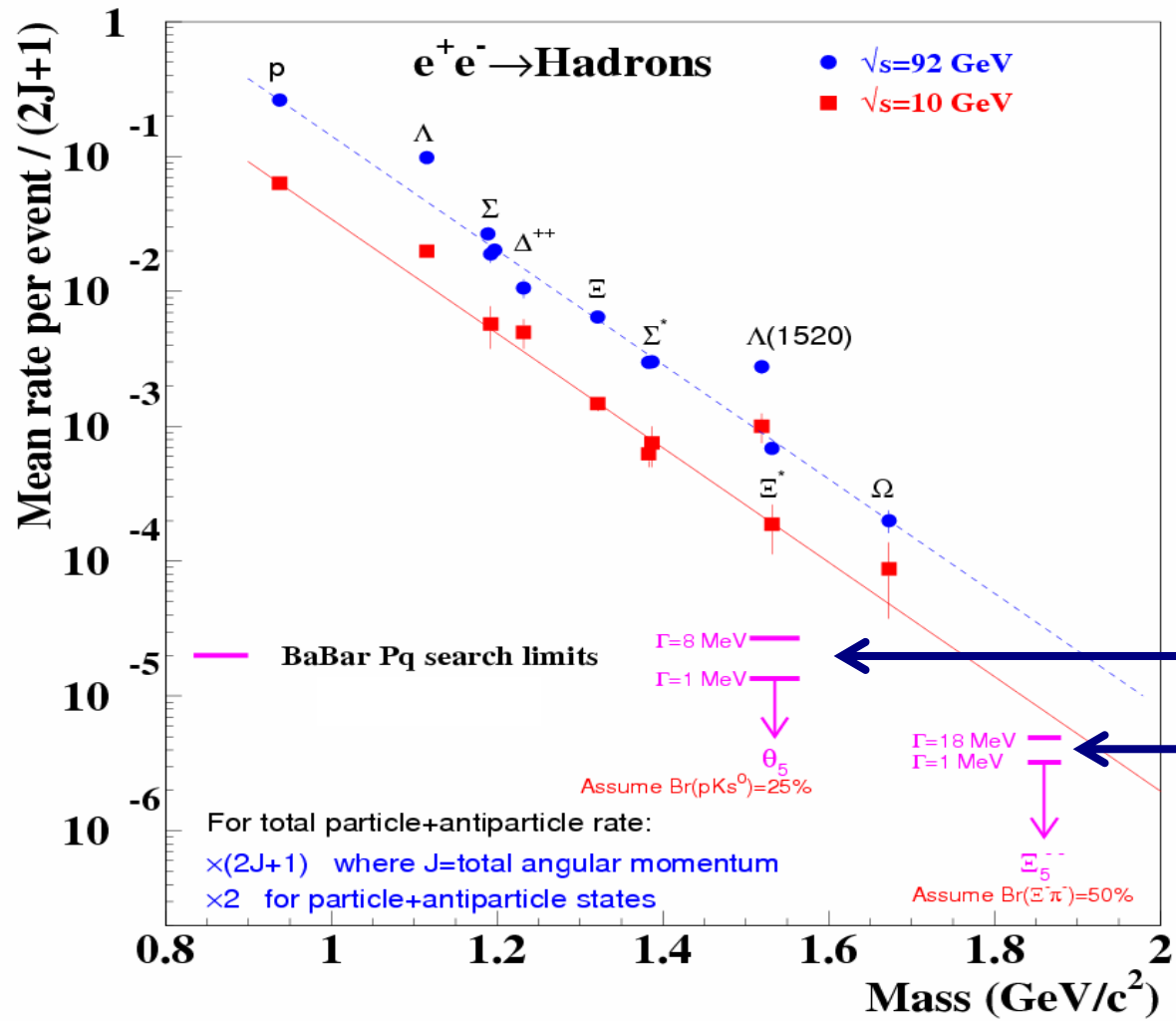
b) Investigated octet state decays $\Xi_5^- \rightarrow \Lambda^0 K^-$ and $\Xi_5^- \rightarrow \Lambda^0 K^+$, found clear signal of Ω^- and Λ_c^+, but no evidence of Ξ_5^- or N_5^+

c) Investigated octet/anti-decuplet state strange-pentaquark decays into $\Sigma^0 K^\pm$, $\Sigma^0 K_s^0$, found signal of Λ_c^+, Ξ_c^0, but again no evidence of any strange-pentaquark is found

See Backup Slides

Θ_5^+ and Ξ_5^{--} Production Limits Compared with Known Baryons

PRL 95,042002(2005)

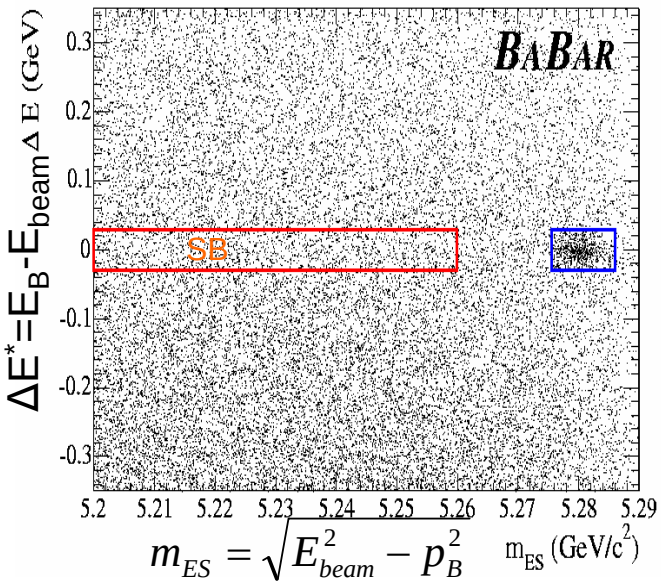


Limits on Θ_5^+ and Ξ_5^{--} are smaller than expected for "normal" baryons

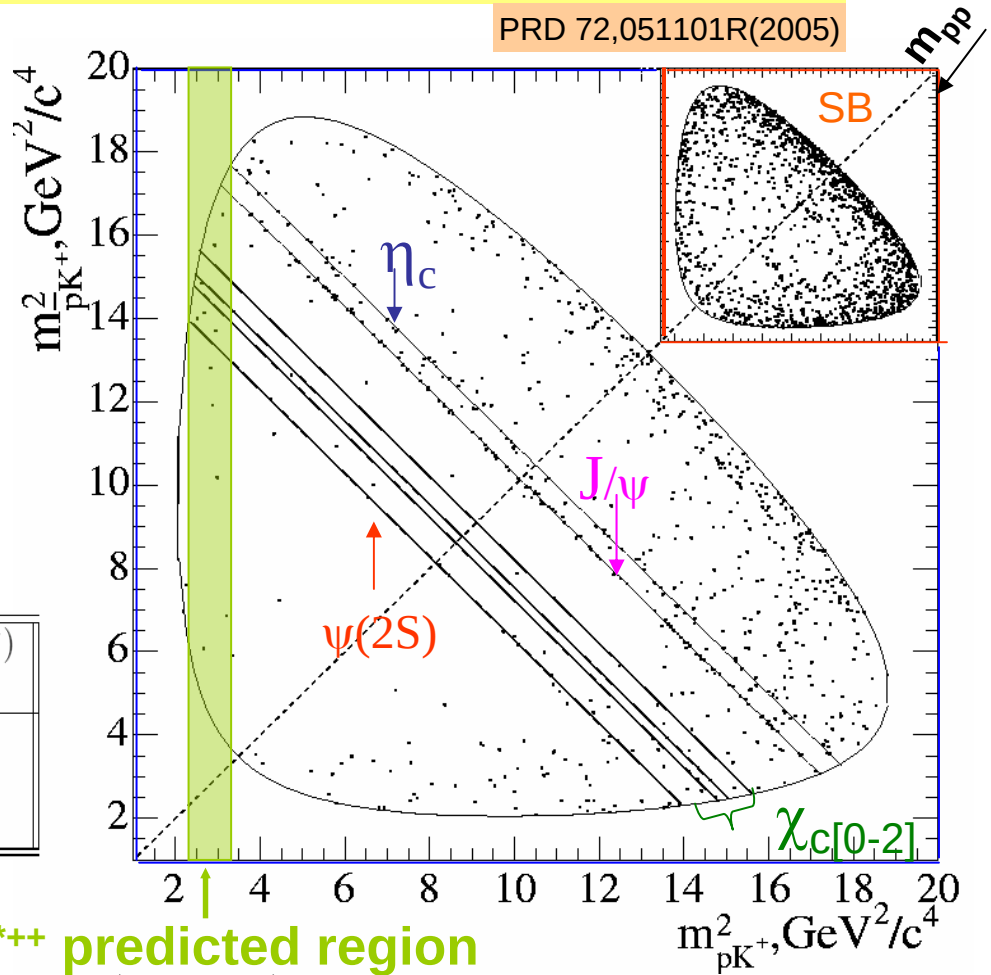
BaBar pentaquark production limits

Search for Θ*++ in Exclusive Decay $B^+ \to \Theta^{*++} p \to p K^+ \bar{p}$

PRD 72,051101R(2005)



Mass Region, GeV/c^2	$\mathcal{B}(B^+ \to \Theta^{*++}\bar{p}) \times \mathcal{B}(\Theta^{*++} \to pK^+)$ UL $\times 10^{-7}$ @ 90% CL
$1.4 < m_{pK^+} < 1.5$	0.5
$1.5 < m_{pK^+} < 1.7$	0.9
$1.7 < m_{pK^+} < 2.0$	1.2

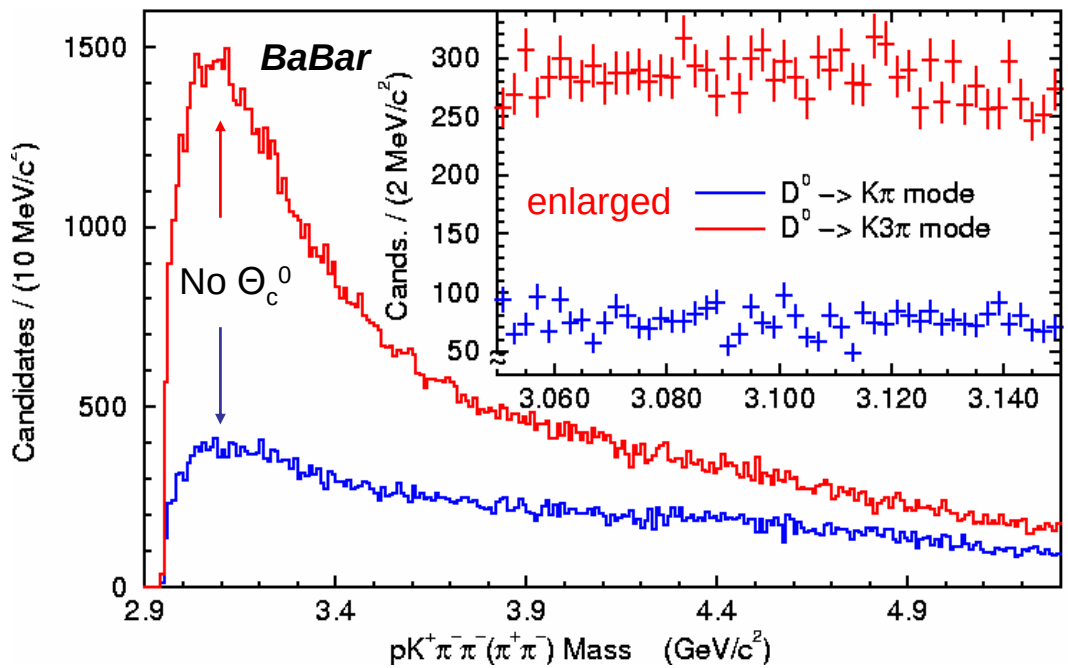


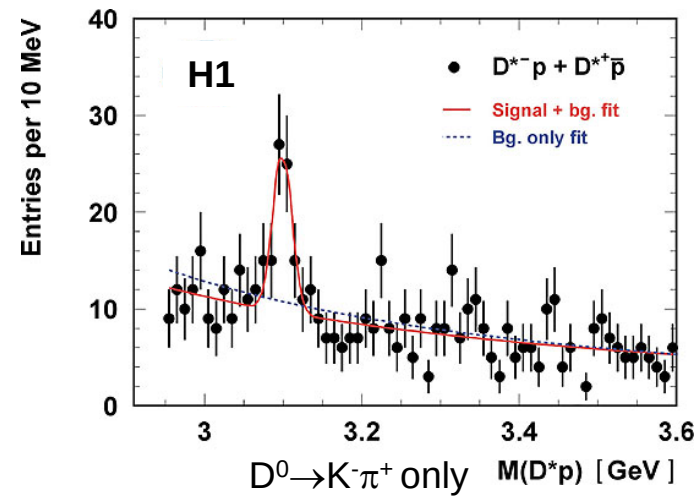
- BELLE result with 140 fb^{-1}:
- $\boldsymbol{B}(B^+ \to \Theta^{*++} p) \times \boldsymbol{B}(\Theta^{*++} \to pK^+) < 0.9 \times 10^{-7}$ at 90% CL for $m(\Theta^{*++}) = 1.71$ GeV/c^2

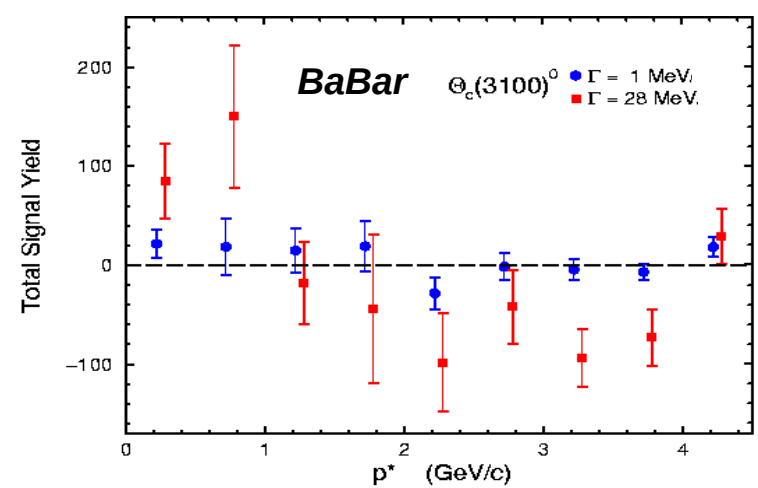
Θ*++ predicted region

$|uuud\bar{s}\rangle$

Inclusive Search for $e^+e^- \to \Theta_c^0(D^{*-}p)X$ (Preliminary)



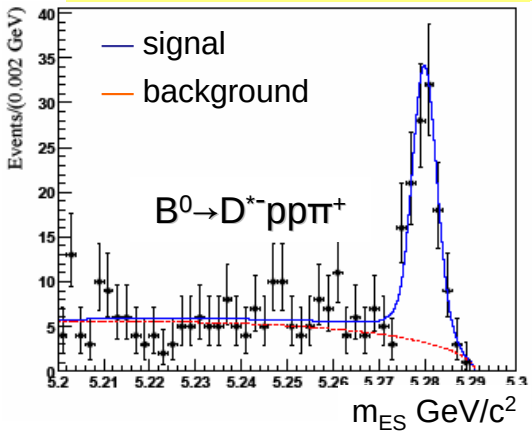


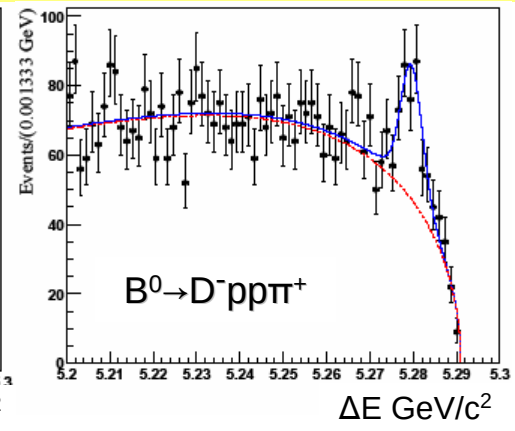


- mass resolution of Θ_c^0 ~3 MeV
- $D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+\pi^+\pi^-$ or $K^-\pi^+$
- After cuts ~73k $D^0 \to K^-\pi^+\pi^+\pi^-$ events and ~55k $D^0 \to K^-\pi^+$ events from 2 sources: c-jets and B decays

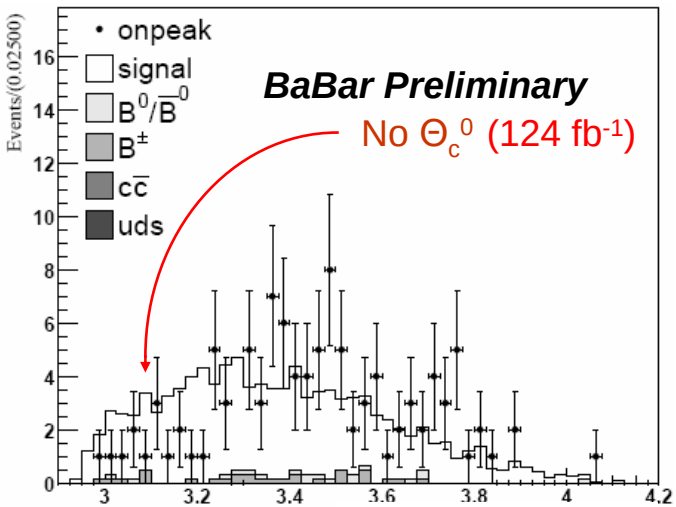
Exclusive Search for Θ_c^0 in $B^0 \to D^{*-} p\bar{p}\pi^+$ and $B^0 \to D^- p\bar{p}\pi^+$

(Preliminary)

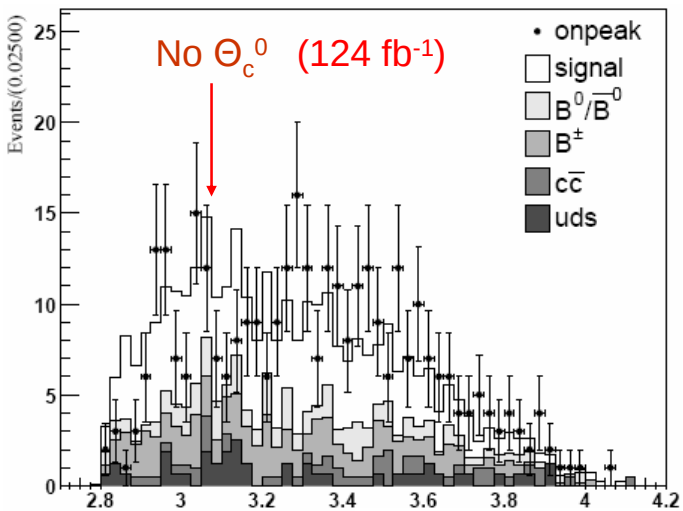




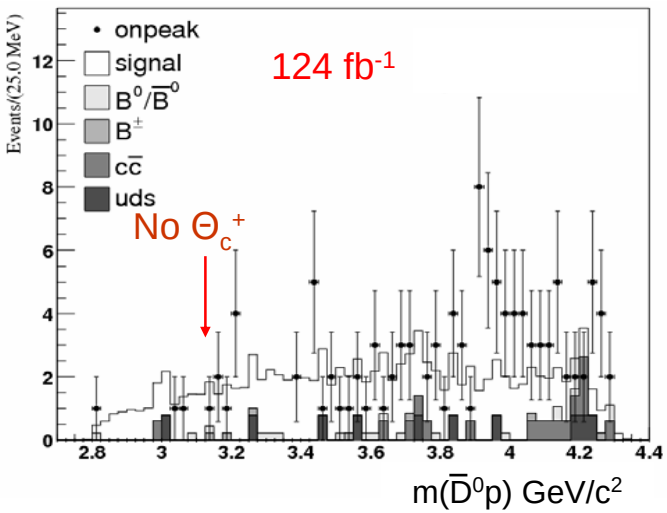
- $D^{*-}p/D^-p$ combinations have exotic quark content $uudd\bar{c}$
- Observed $p\bar{p}$ threshold enhancement effect
- Also Looked at $D^0 \to K^-\pi^+\pi^+\pi^+$ and $D^0 \to K^-\pi^+\pi^0$ → no evidence
- Cut out the $p\bar{p}$ threshold enhancement → no evidence

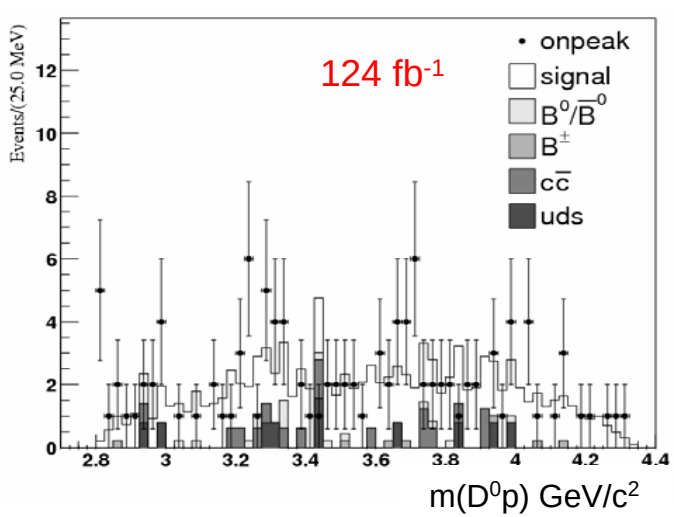


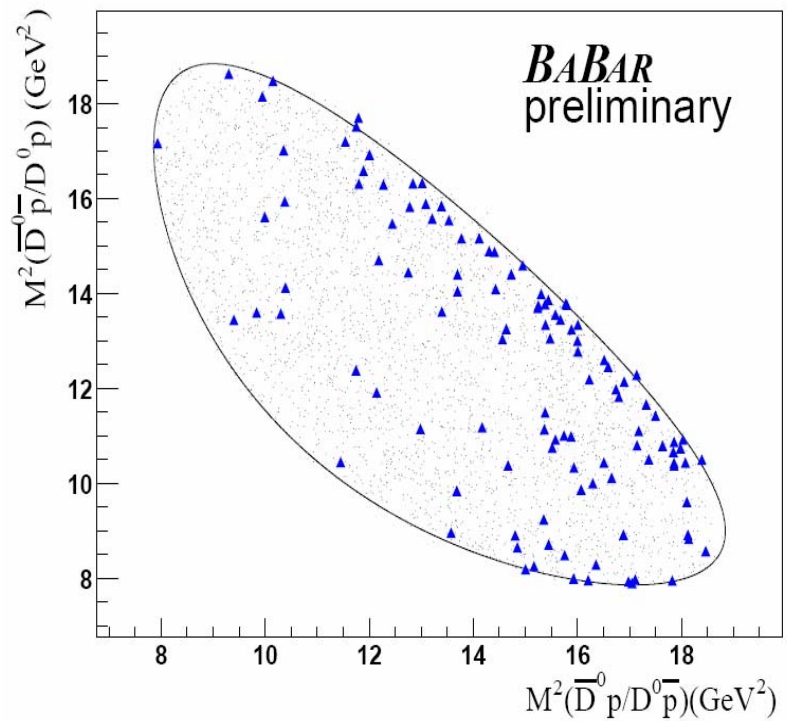
Only $D^0 \to K^-\pi^+$ mode



Exclusive Search for Θ_c^+ Pentaquark in $B^0 \to \bar{D}^0 p \bar{p}$







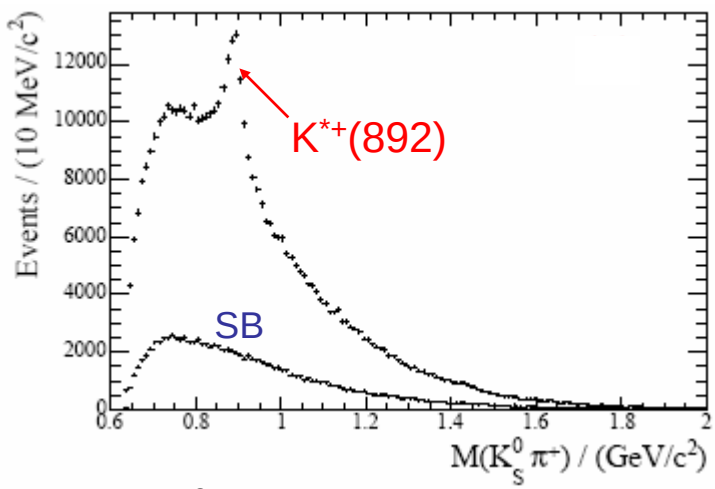
- $\bar{D}^0 p$ combination has exotic quark content $uuud\bar{c} \to$ possible pentaquark candidate
- Observed similar $p\bar{p}$ threshold enhancement effect
- Study in progress with more data for the effect of event accumulation at ~4.0 GeV/c^2 in $m(\bar{D}^0 p)$ distribution

Conclusions

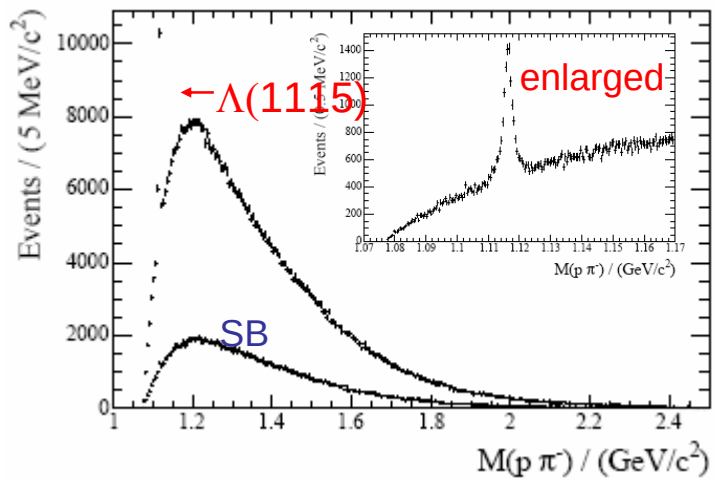
- Pentaquark searches of BaBar have yielded negative results:
  - No narrow peaks for hypothesized $\overline{10}$+8 states in several search modes
  - Limits on production rates of $\Theta^+(1540)$, $\Xi^{--}(1860)$ are well below those of ordinary baryons of similar mass
  - No $\Theta^+ \rightarrow pK_s^0$ in hadro- and electro-production in detector material
  - No Θ^{*++} observed in $B^+ \rightarrow p\bar{p}K^+$ from $B^+ \rightarrow \Theta^{*++}\bar{p} \rightarrow pK^+\bar{p}$
  - No $\Theta_c(3100)$ observed inclusively or from $B^0 \rightarrow Dp\bar{p}(\pi^+)$
- Well-known baryons like Λ^0, Ξ^-, Ξ^{*0}, Ω^-, Ξ_c^0, Λ_c^+ are found in our data, highlighting potential for study of ordinary and charmed baryons at BaBar in many ongoing analyses.

Backup Slides

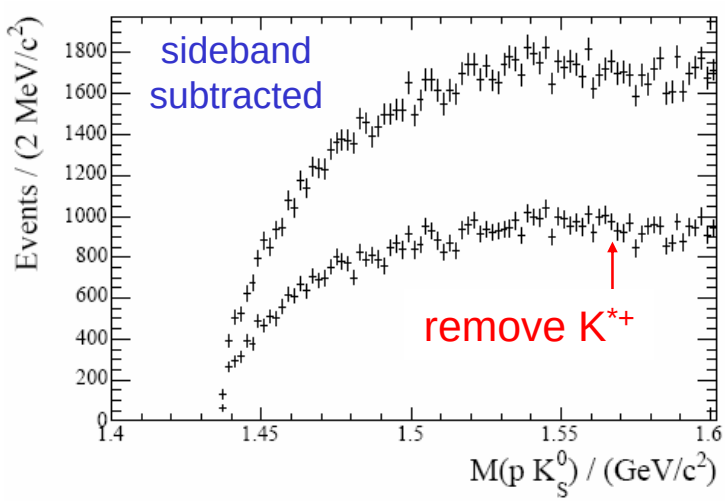
pK_s^0 Associated with $\pi^\pm$ in Electro- or Hadron-Production

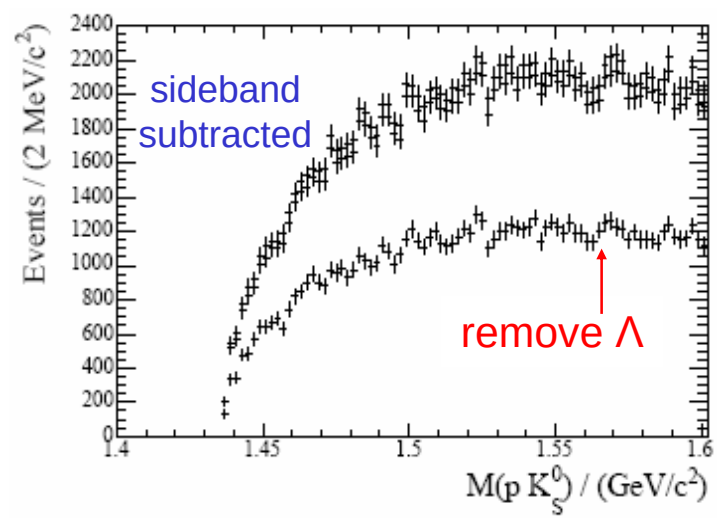


(K_s^0,p) associated with π^+

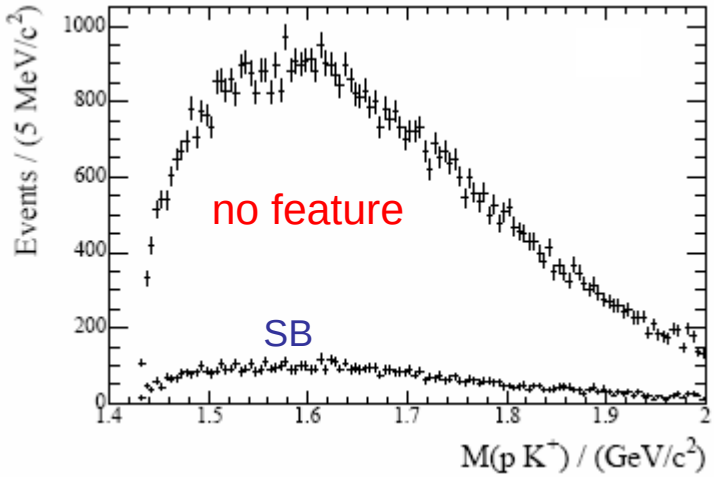


(K_s^0,p) associated with π^-

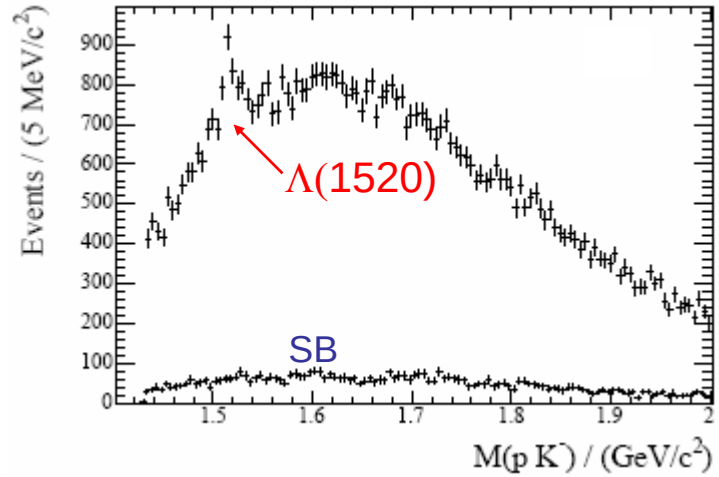




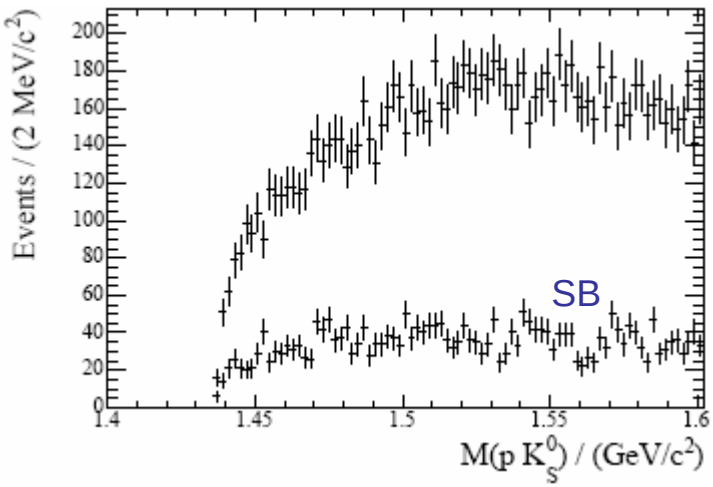
pK_s^0 Associated with $K^{\pm}$ in Electro- or Hadron-Production

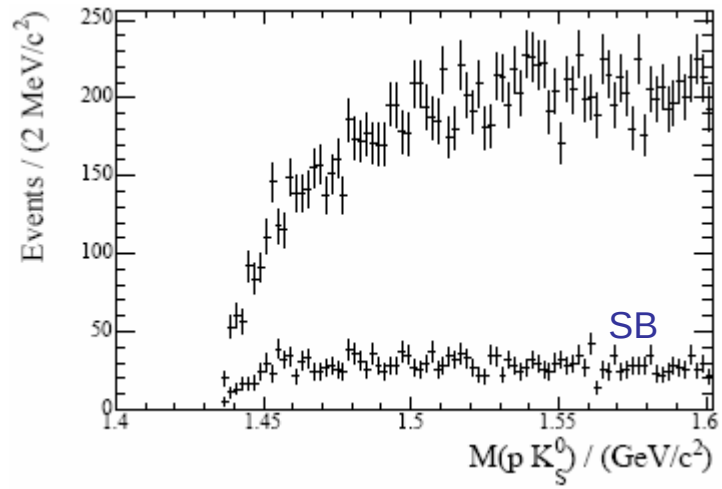


(K_s^0,p) associated with K^+

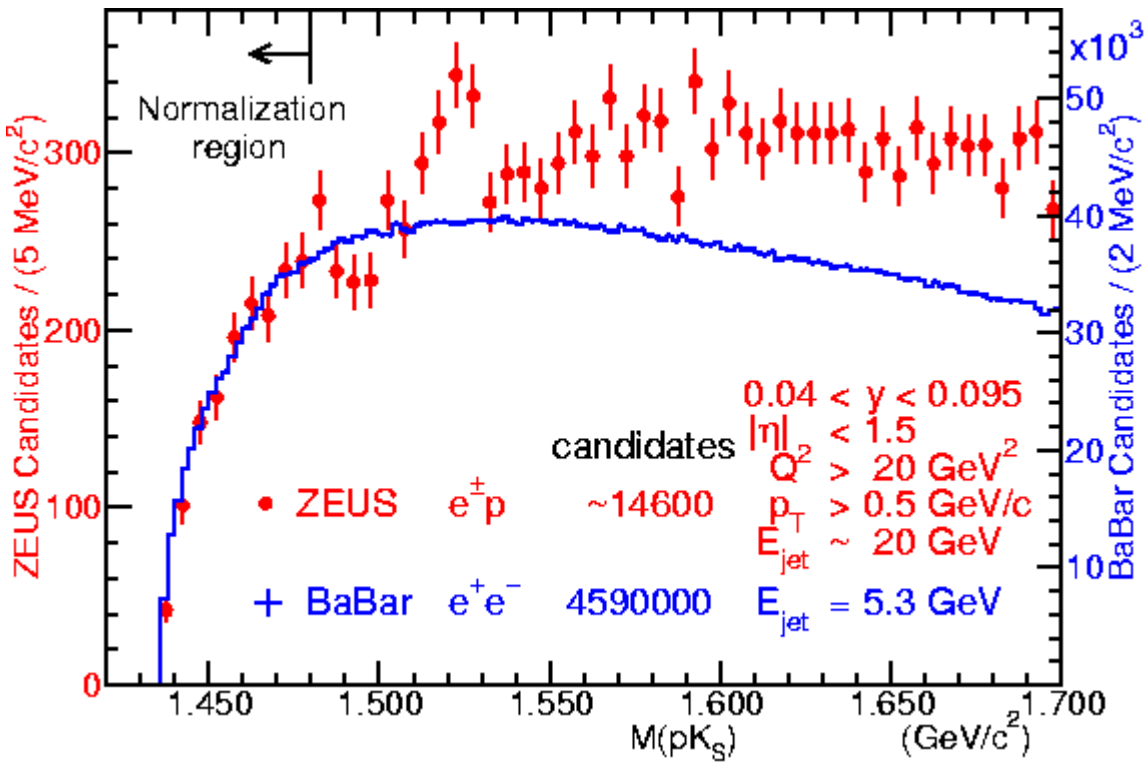


(K_s^0,p) associated with K^-

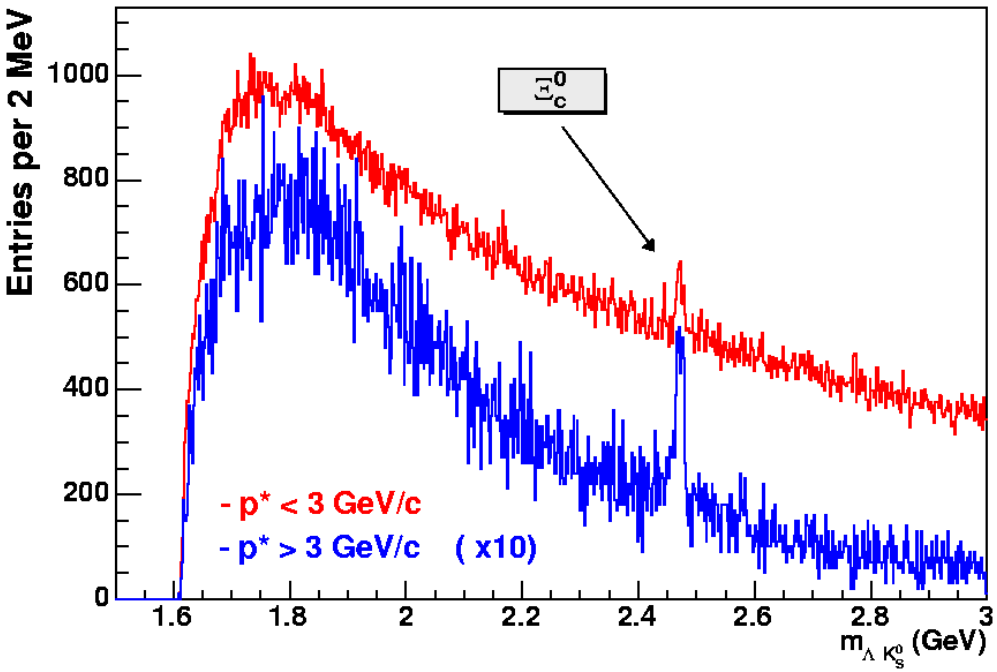




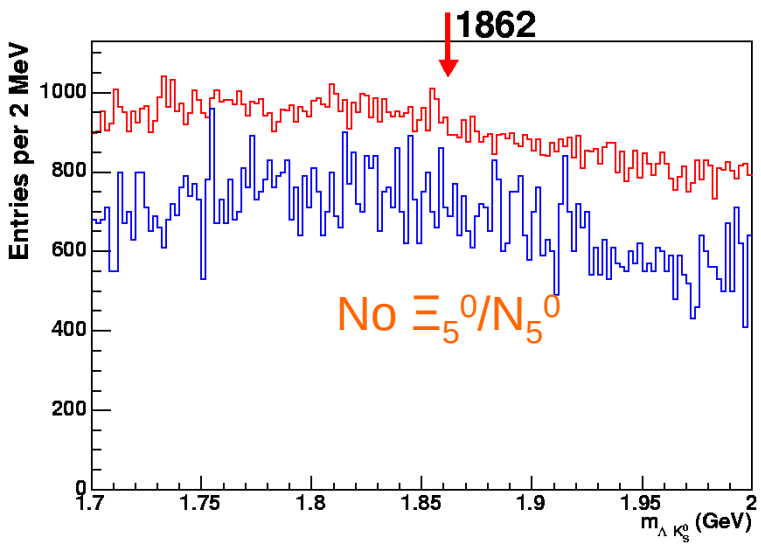
BaBar Inclusive pK_s^0 Data Compared with ZEUS



Inclusive Search for $\Xi_5^0/N_5^0 \rightarrow \Lambda^0 K_s^0$

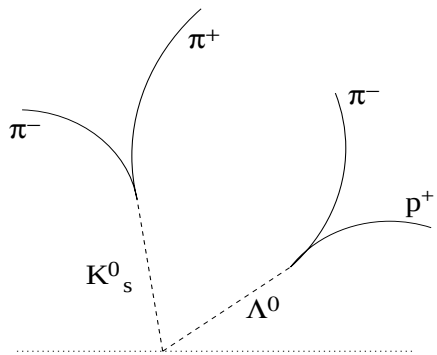


I=1/2: octet states

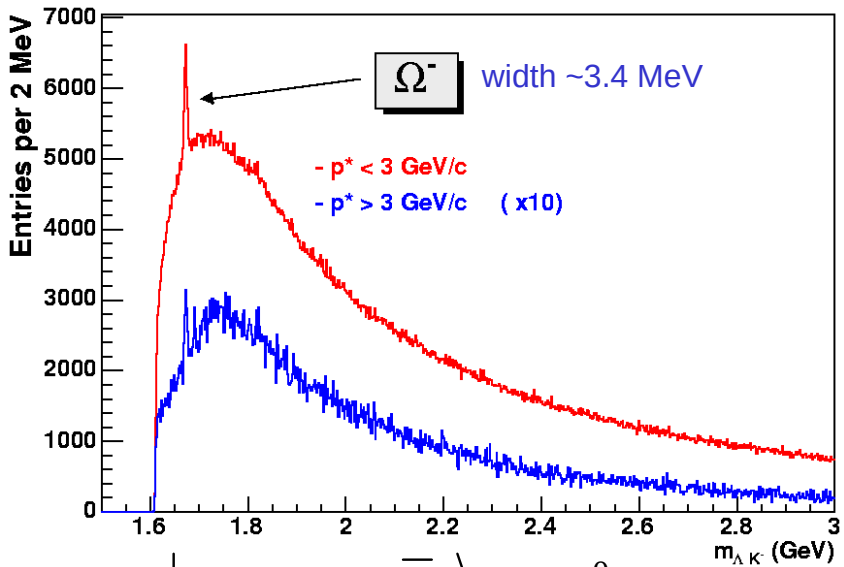


95% CL upper limit on Ξ_5^0 production cross-section x brachning fraction of Ξ_5^0 :

$\sigma \times BF(\Xi_5^0 \rightarrow \Lambda^0 K_s^0) < 82.8$ fb (Γ=1 MeV)
$\sigma \times BF(\Xi_5^0 \rightarrow \Lambda^0 K_s^0) < 204.7$ fb (Γ=18 MeV)

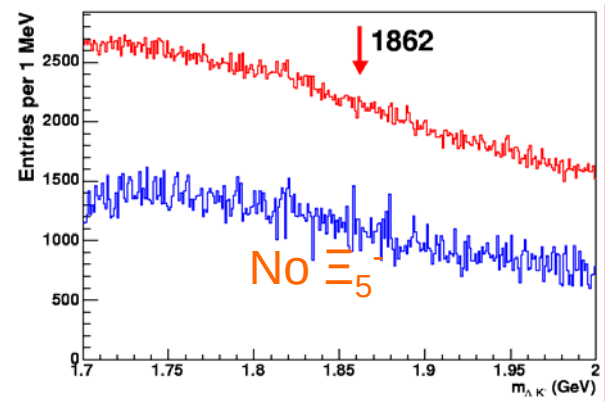


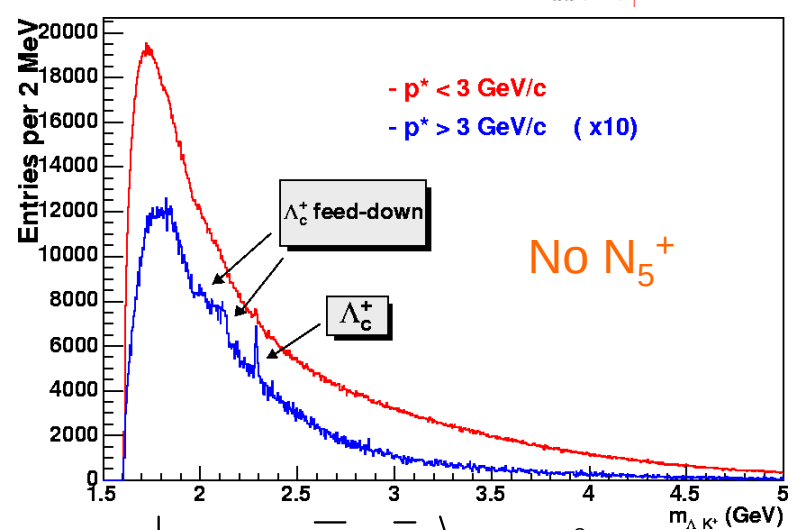
Inclusive Search for $\Xi_5^- \to \Lambda^0 K^-$, $N_5^+ \to \Lambda^0 K^+$



$$\Xi_5^- \left| dss(u\bar{u}, d\bar{d}) \right\rangle \to \Lambda^0 K^-$$

I=1/2: octet states



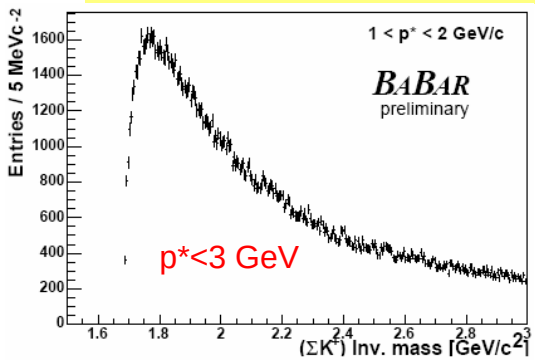


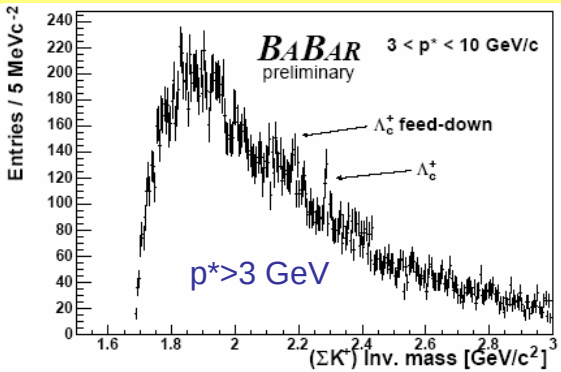
$$N_5^+ \left| uud(d\bar{d}, s\bar{s}) \right\rangle \to \Lambda^0 K^+$$

95% CL upper limit on Ξ_5^- production cross-section x brachning fraction of Ξ_5^- :

$\sigma \times BF(\Xi_5^- \to \Lambda^0 K^-) < 83.6$ fb (Γ=1 MeV)
$\sigma \times BF(\Xi_5^- \to \Lambda^0 K^-) < 181.0$ fb (Γ=18 MeV)

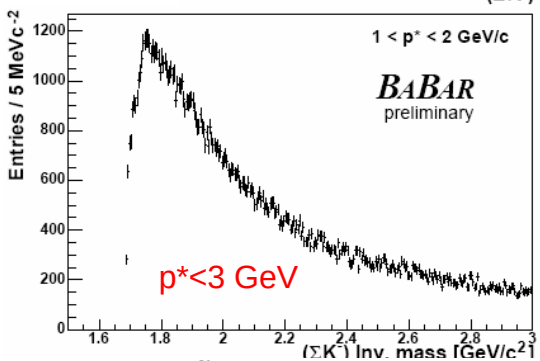
Additional Inclusive Search for $\Sigma^0 K^{\pm}, \Sigma^0 K_s^0$

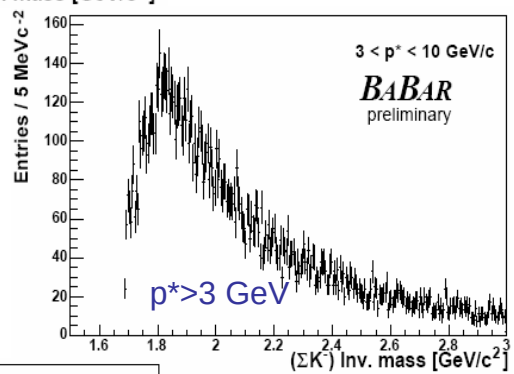


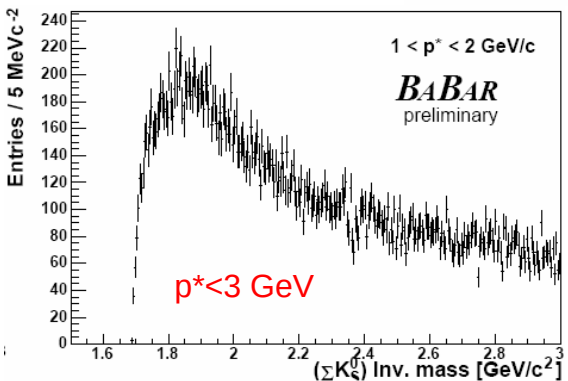


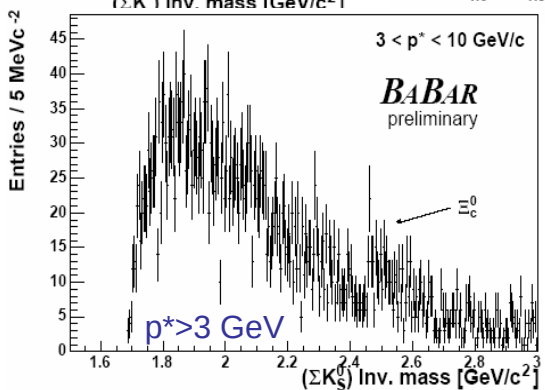
$\Rightarrow \Sigma^0 K^+$

$\Sigma^0 K^- \Leftarrow$









$\Rightarrow \Sigma^0 K_s^0$