Searches for Pentaquarks at BaBar

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Representing the BaBar Collaboration

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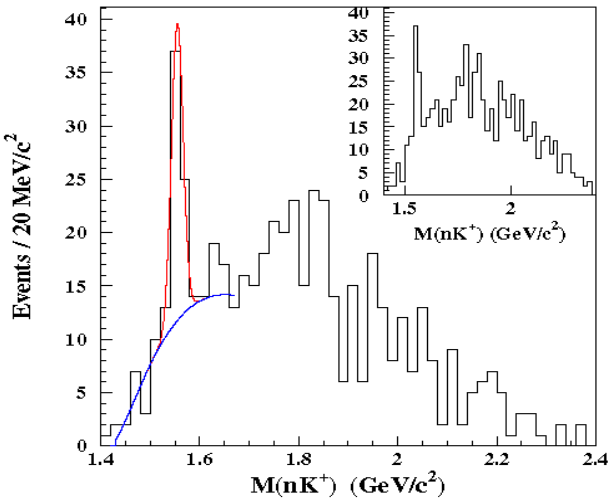
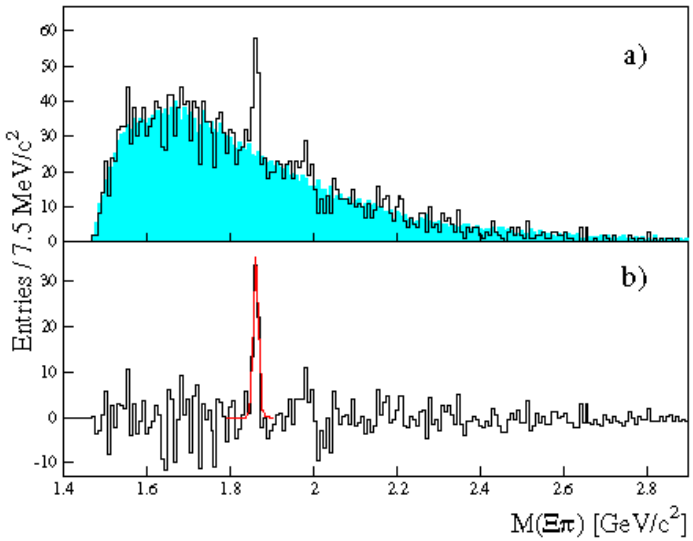
Introduction: Previous Searches

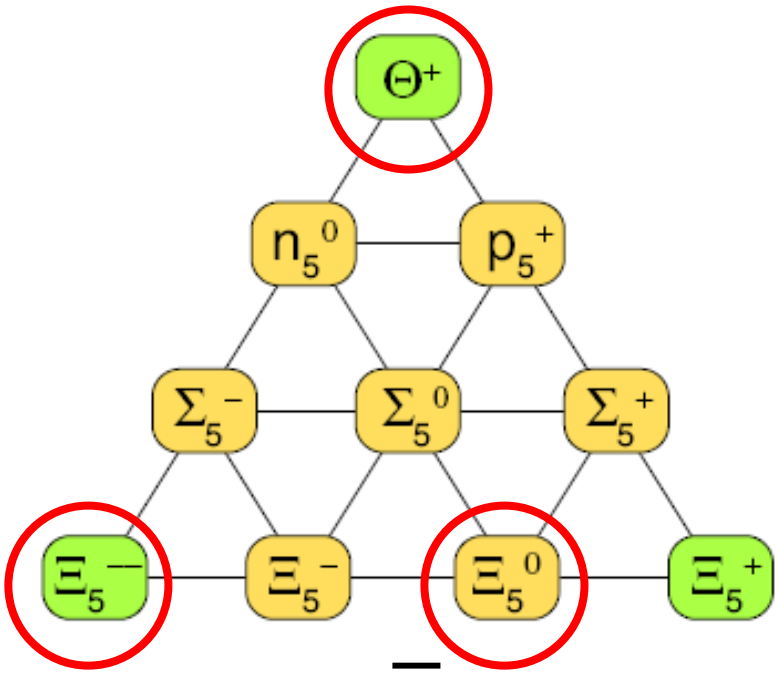




- $\Theta(1540)^+ \rightarrow pK_s$ or nK^+
  - 13 positive claims;
  - 17 negative claims.
- $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$
  - 1 positive claim by NA49 at CERN;
  - 9 negative claims.

Introduction: Theory

The quark model allows the $SU(3)_F$ flavor group to include the following multiplets of five-quark states



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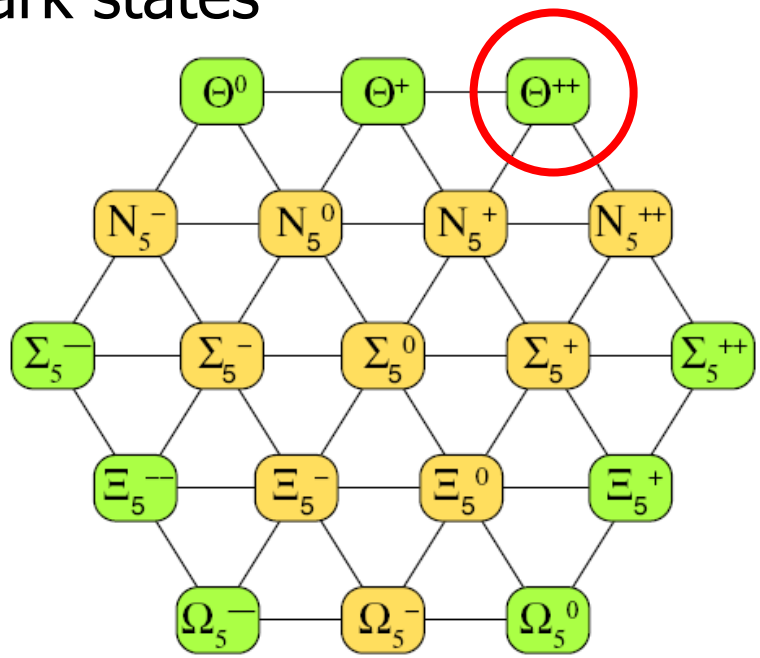

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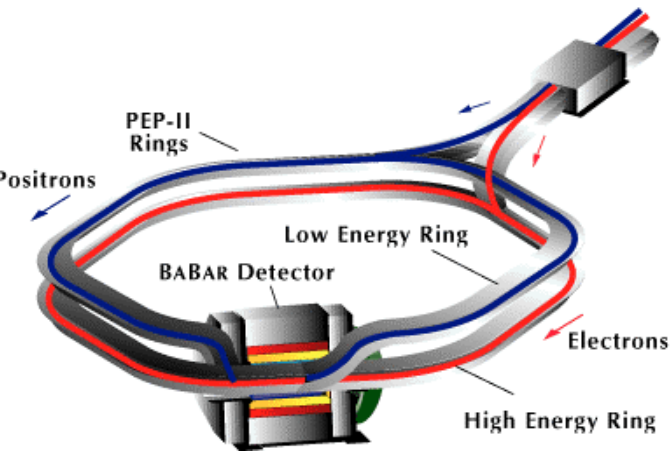
Outline

- $\Theta(1540)^+ \rightarrow pK_s$
  - Inclusive search in electro- and hadro-production on BaBar detector material;
  - Inclusive search in e^+e^- production
- Inclusive search for $\Xi_5(1860)^{--} \rightarrow \Xi^-\pi^-$
- Inclusive search for $\Xi_5(1860)^0 \rightarrow \Xi^-\pi^+$
- $\Theta^{*++} \rightarrow pK^+$ in $B^+ \rightarrow p\bar{p}K^+$ decays.

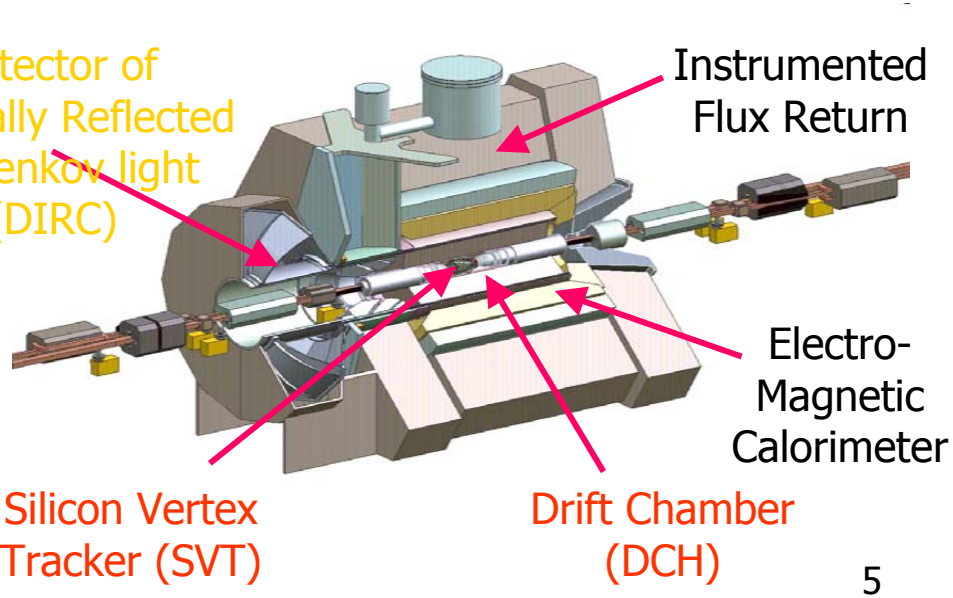
BABAR

PEP-II & BaBar

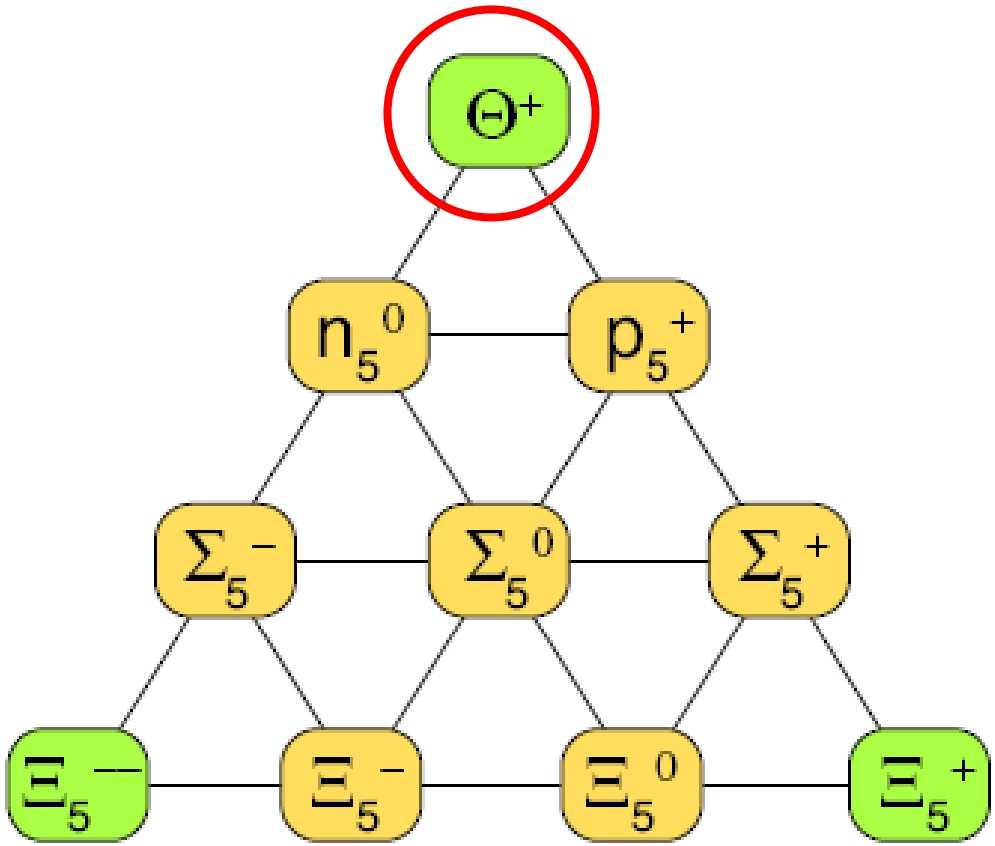


- PEP-II
  - Asymmetric e^+e^- storage ring;
  - Center-of-mass energy at or just below Y(4S) resonance (10.58 GeV);
  - $E_{\text{e- Beam}} \sim 9$ GeV, $E_{\text{e+ Beam}} \sim 3$ GeV.

- BaBar
  - Excellent tracking with SVT and DCH;
  - Excellent particle identification using dE/dx from SVT and DCH; and Cherenkov angles from DIRC.



Search for $\Theta(1540)^+ \rightarrow pK_s$



Two Searches for $\Theta(1540)^+$ at BaBar

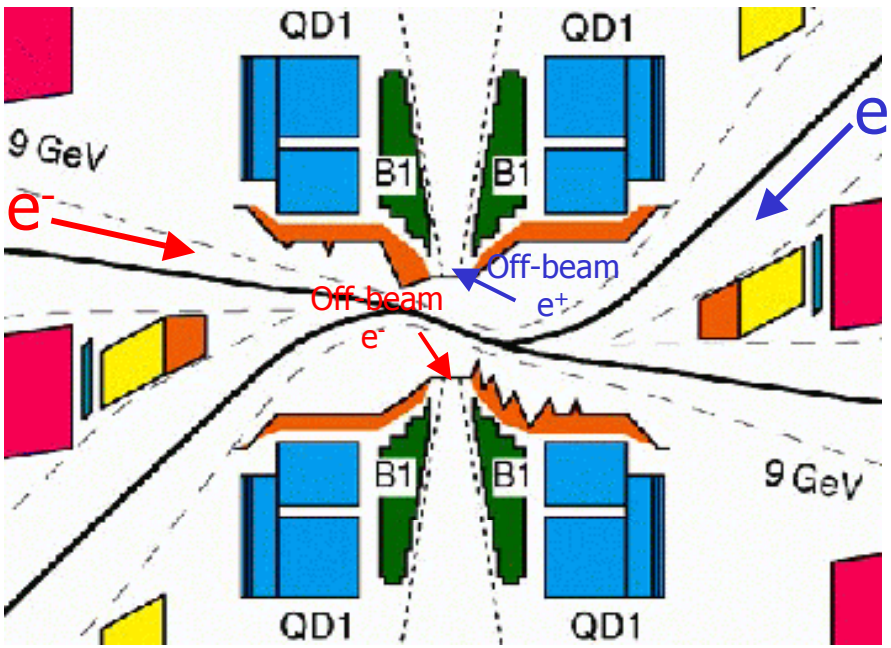
- Search 1:
  - Inclusive search in interactions between material in inner detector and
    - off-beam electrons or positrons (electro-production);
    - hadrons produced in e^+e^- interactions (hadro-production).
- Search 2:
  - Inclusive search in e^+e^- interactions --

    $e^+e^- \rightarrow \text{Anything} + \Theta(1540)^+$

BABAR

Hadro-production and Electro-production at BaBar

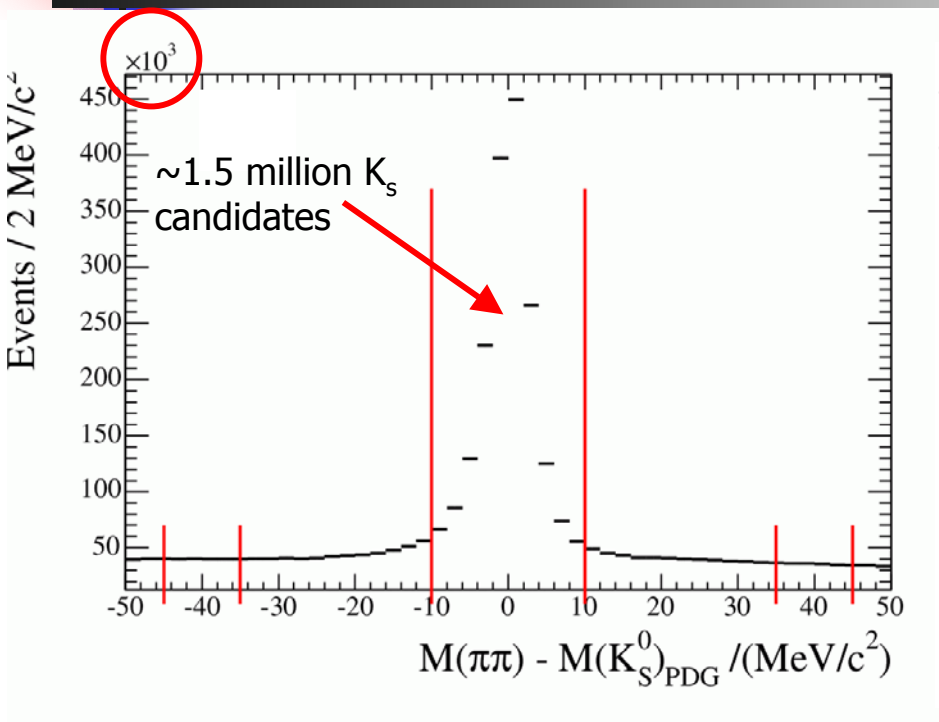
Hadro-production: hadrons produced in e^+e^- collisions interact with the detector material.

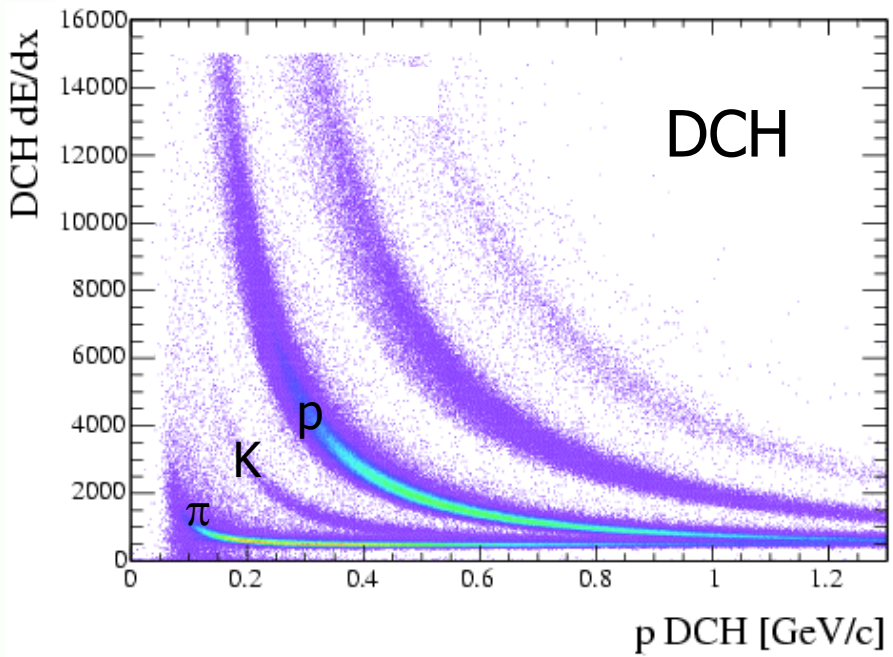


Electro-production: dipole magnets close to the interaction region bend off-beam electrons or positrons causing them to interact with the detector material.

- Roughly similar to a fixed target experiment.

$\Theta(1540)^+$ in Electro- and Hadro-Production: Analysis Details

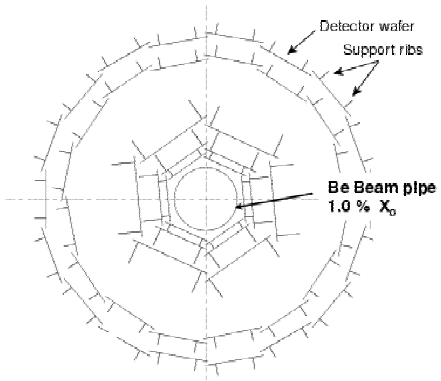


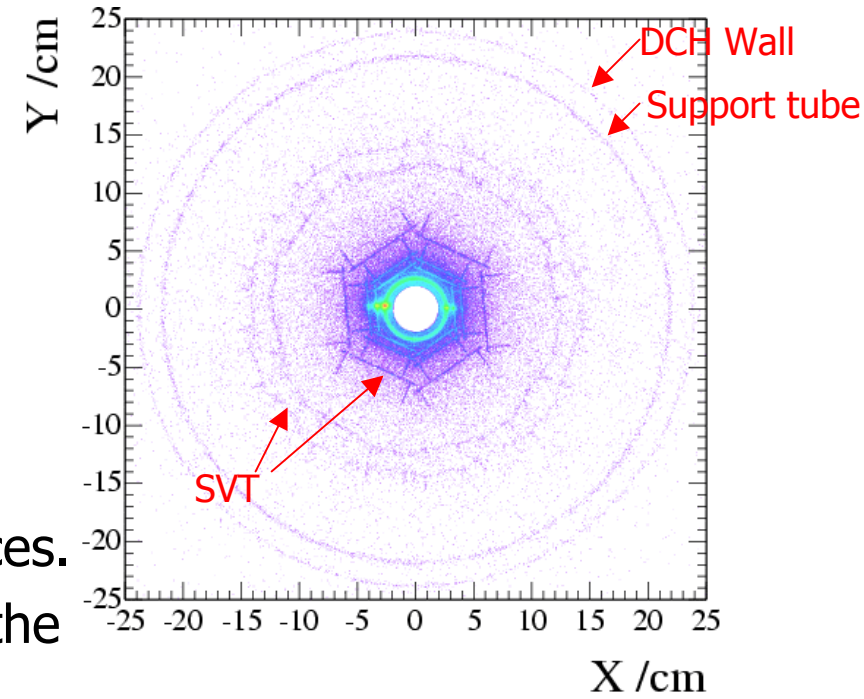


- Use the full BaBar dataset;
- Reconstruct $\Theta(1540)^+ \rightarrow pK_s$, $K_s \rightarrow \pi^+\pi^-$;
- Select K_s with geometric cuts and SVT and DCH dE/dx for π candidates;
- SVT and DCH dE/dx for proton candidates.

Spatial Distribution of pK_s Vertices

Silicon Vertex Tracker

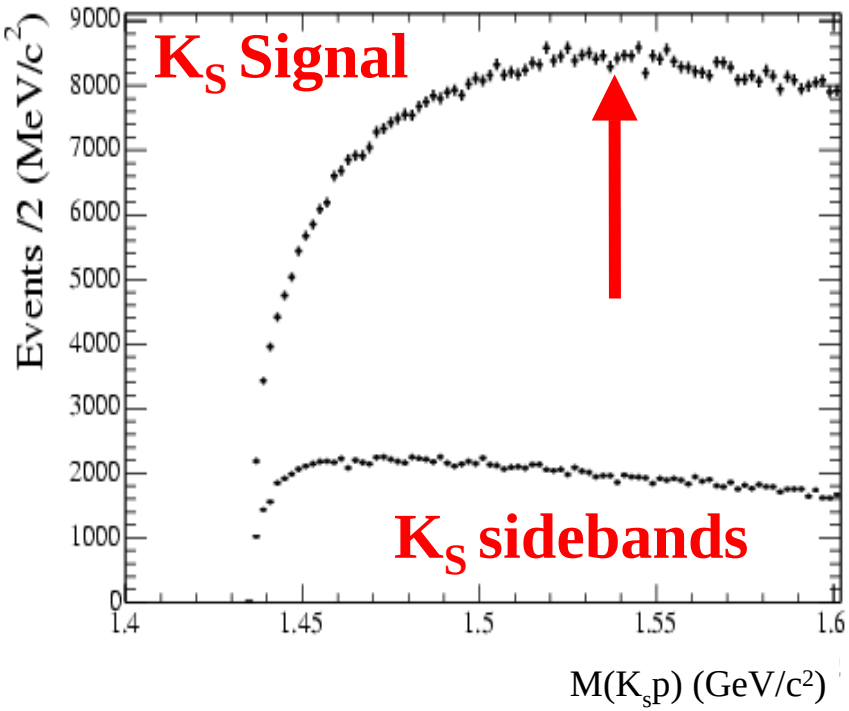




- Plot the x vs. y position of the pKs vertices.
- Can produce features corresponding to the Be beam pipe, SVT wafers and supports, DCH support tube and inner DCH wall.
- Conclude that these pK_s events result from electro- and hadro-production interactions with material in the BaBar detector.

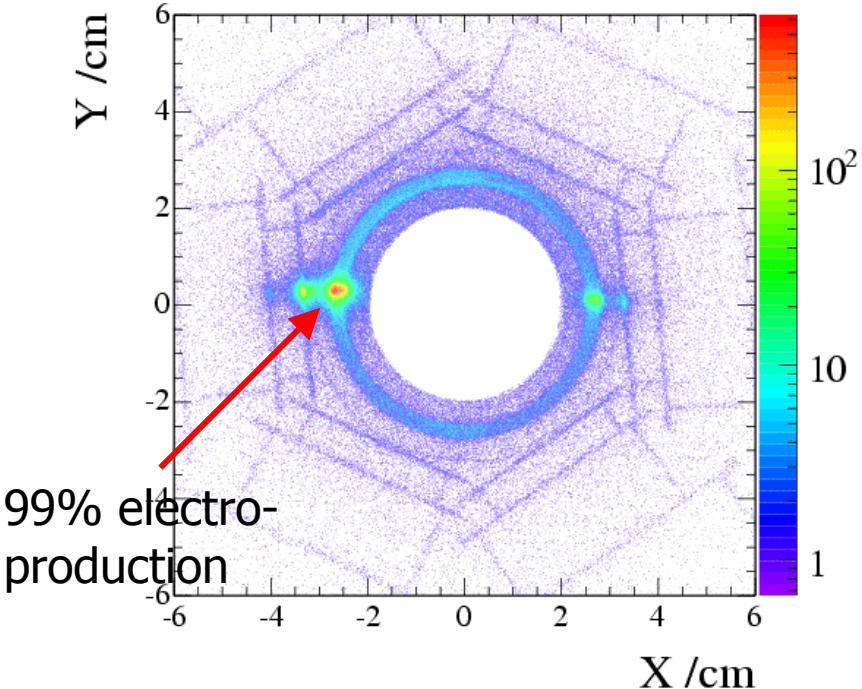
$\Theta(1540)^+$ in Electro- and Hadro-Production: Results

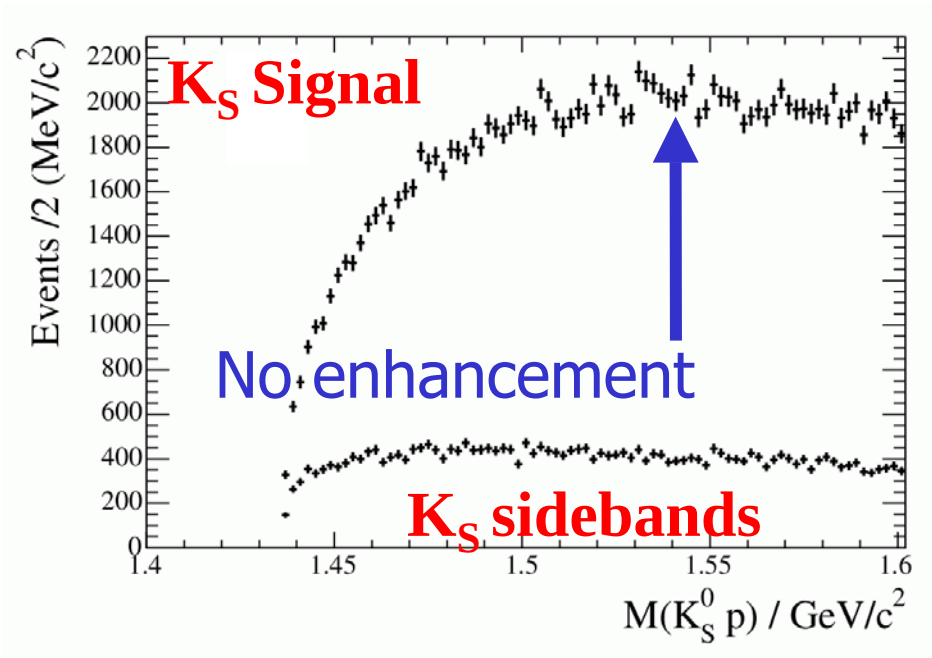
- Plot M(K_sp) for all (both electro- and hadro-produced) K_sp vertices.
- There is no enhancement around 1540 MeV/c^2;
- Summed sidebands are the same width as signal region;
- Mass resolution (HWHM) is 2 MeV/c^2 at 1540 MeV/c^2.



$\Theta(1540)^+$ in Electro-Production Only: Results

- e^+ and e^- beams are bent into head-to-head collisions in the horizontal plane (y=0).
- High-intensity regions at y=0 result primarily from e^+ and e^- collisions instead of hadronic interactions.
- Events produced in electro-production can be greatly enhanced by looking at these regions.

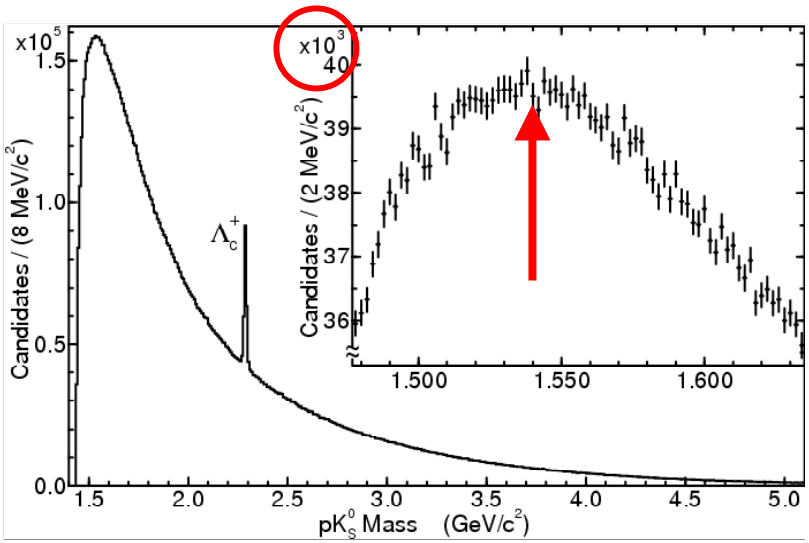




$\Theta(1540)^+$ in e^+e^- Production: Details

- Use 123 fb^{-1} (90% on $\Upsilon(4s)$ resonance, 10% off);
- Reconstruct $\Theta(1540)^+ \rightarrow pK_s$, $K_s \rightarrow \pi^+\pi^-$;
- Select K_s using geometric cuts;
- Identify protons using dE/dx and Cherenkov angle;
  - 55-99% efficiency with 95-99% rejection of π/K.

$\Theta(1540)^+$ in e^+e^- Production: Results

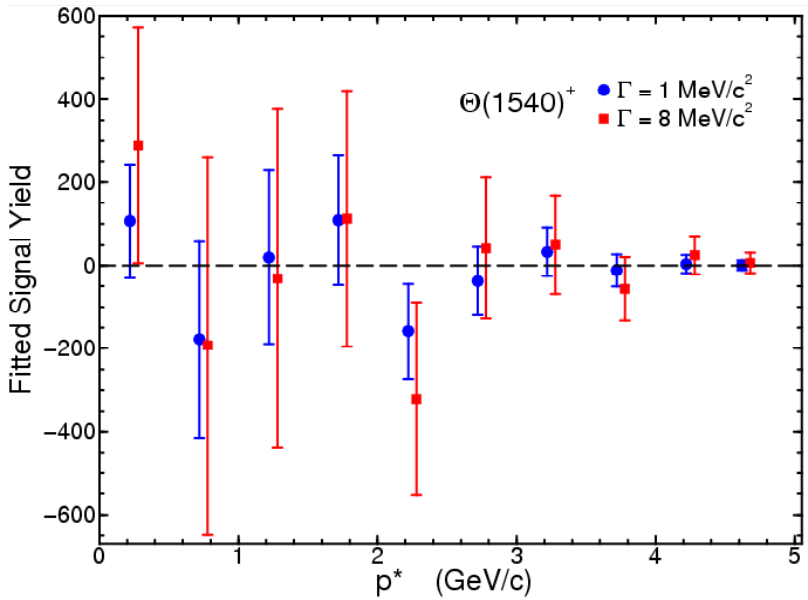


- No enhancement near 1540 GeV/c^2;
- Clear $\Lambda_c^+ \rightarrow pK_s$ signal with 98,000 candidates;
- Mass resolution (HWHM) is 2 MeV/c^2 at 1540 MeV/c^2.

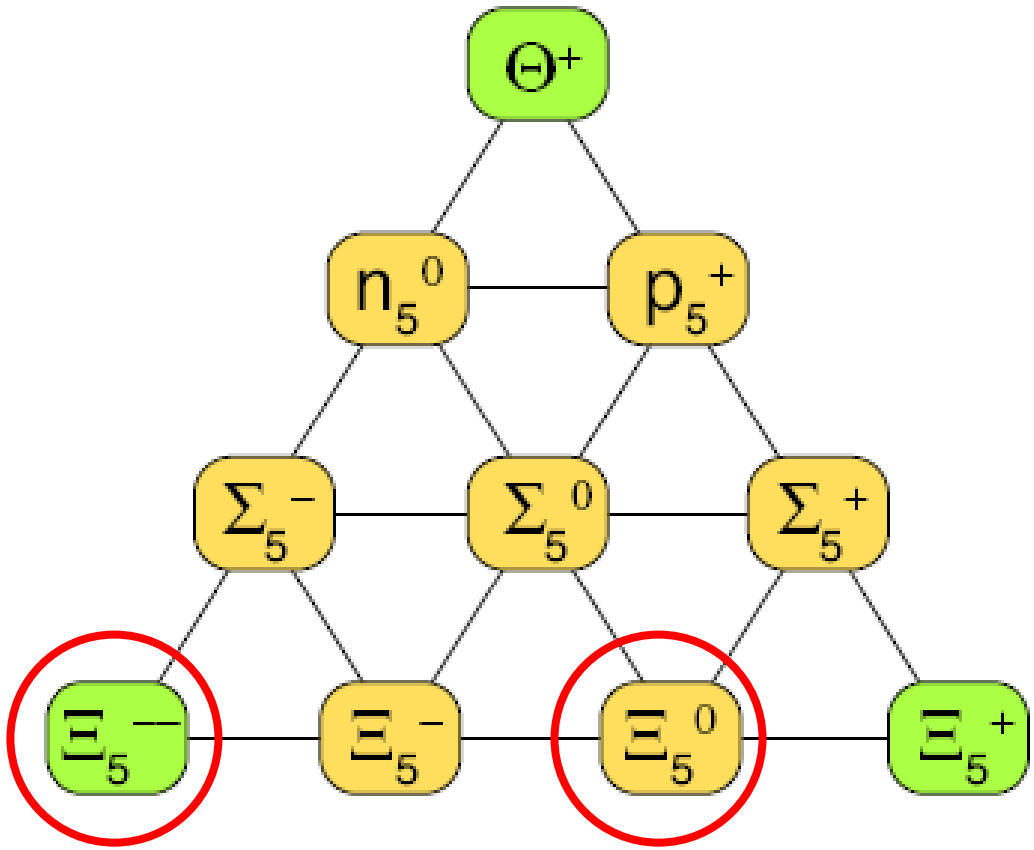
The production mechanism for pentaquarks is unknown. Perhaps if we look at different momentum regions we will see a signal….

$\Theta(1540)^+$ in e^+e^- Production: Yield vs. Momentum

- Define $p^* \equiv$ momentum of Θ^+ candidate in Y(4s) rest frame;
- Separate events into 10 p^* bins 500 MeV/c wide;
- Fit signal for each bin using two different estimates for $\Gamma_{\Theta(1540)}$: 8 and 1 MeV/c^2;
- Yields consistent with zero.



Search for $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$



Search for $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$: Analysis Details

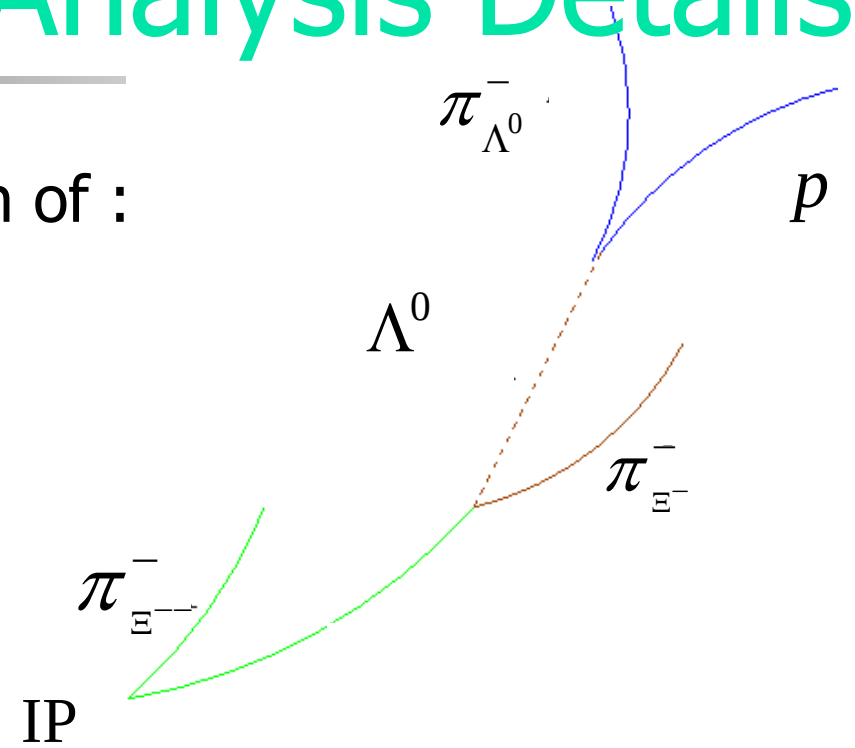
We look for inclusive production of :

$$e^+e^- \longrightarrow \Xi_5^{--} X$$

$$\Xi_5^{--} \longrightarrow \Xi^- \pi^-$$

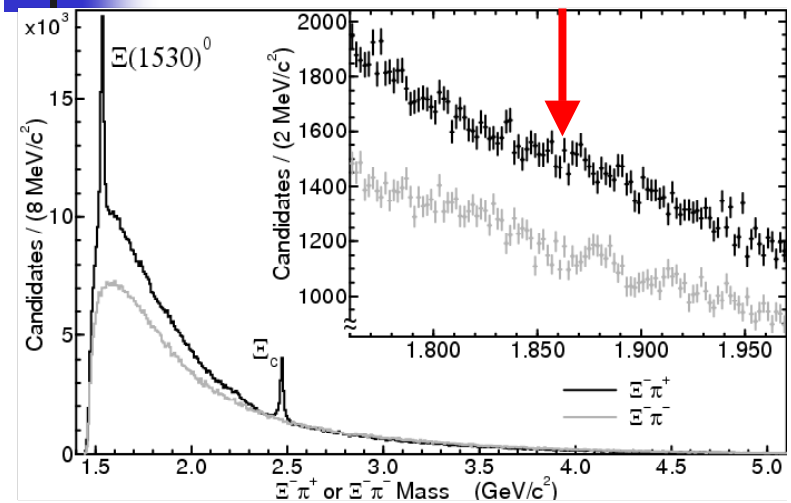
$$e^+e^- \longrightarrow \Xi_5^{0} X$$

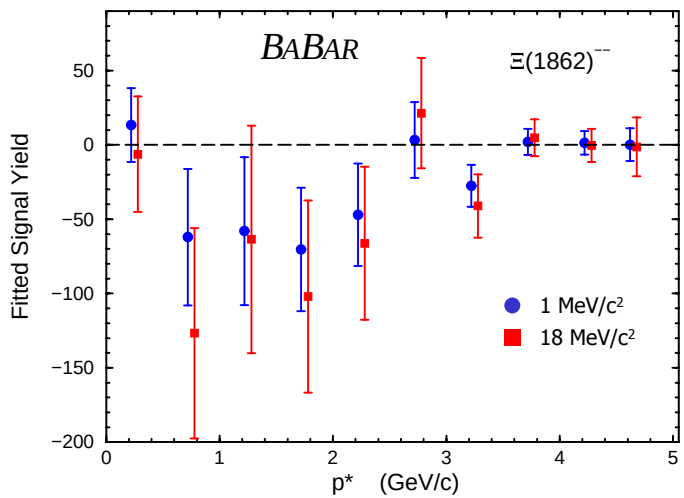
$$\Xi_5^{0} \longrightarrow \Xi^- \pi^+$$



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

Search for $\Xi_5(1860)$: Results

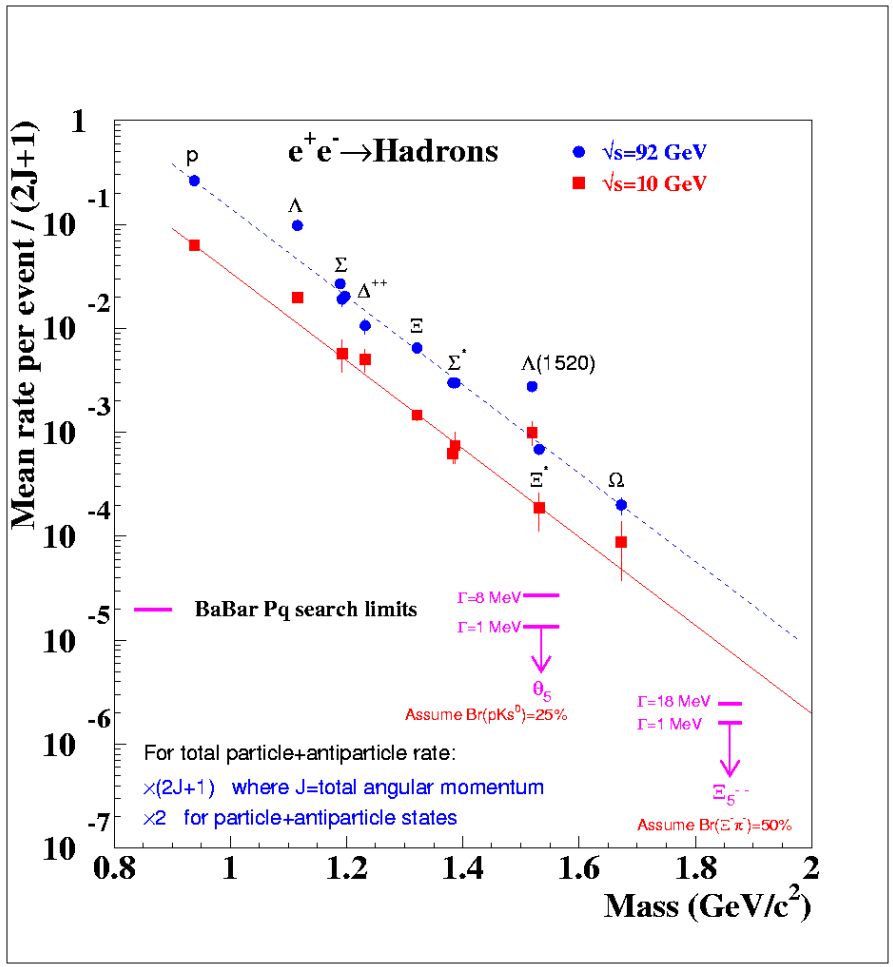




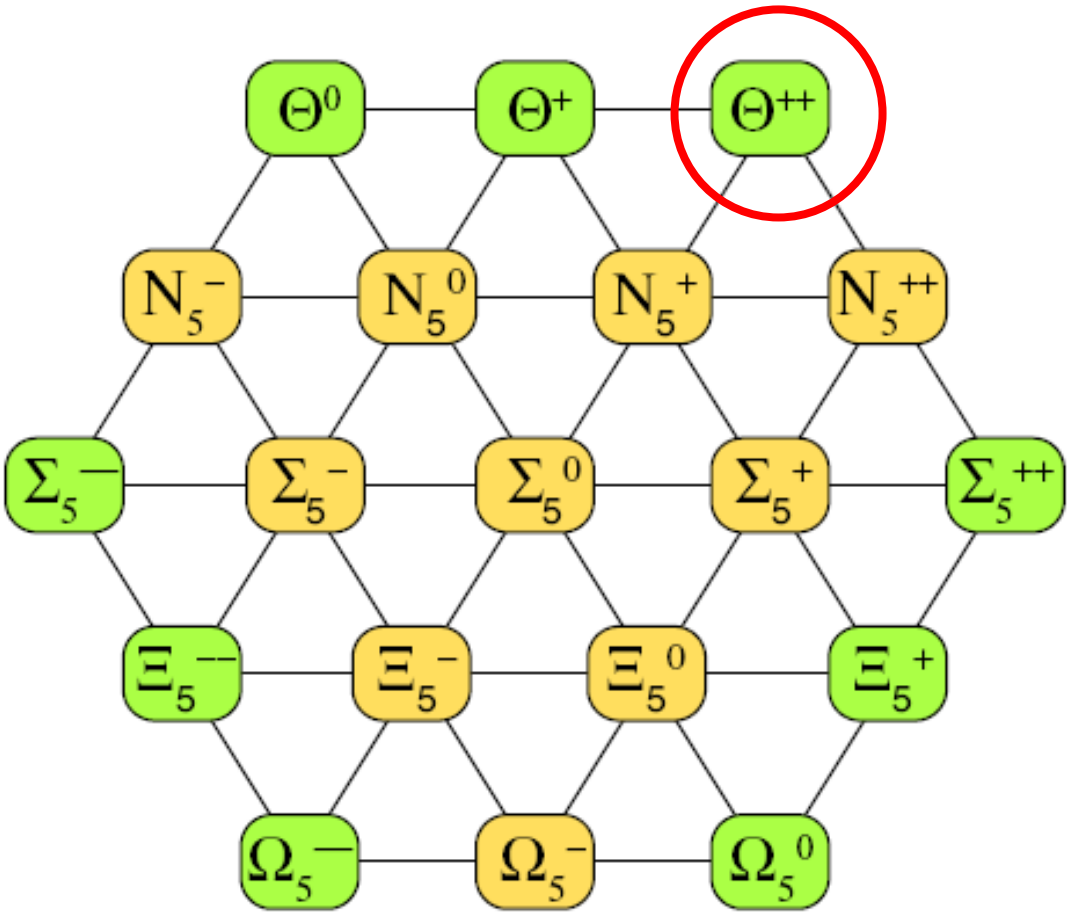
- No enhancement around 1860 MeV/c^2.
- See clear peaks for $\Xi(1530)^0$ (24,000 candidates) and $\Xi_c(2470)^0$ (8,000 candidates).
- Fit $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$ signal in 10 p^* bins 500 MeV/c wide using $\Gamma_{\Xi(1860)}$ of 1 and 18 MeV/c^2.
- Signal is consistent with zero for all p^* bins.

Comparison of Pentaquark and Baryon Production Rates

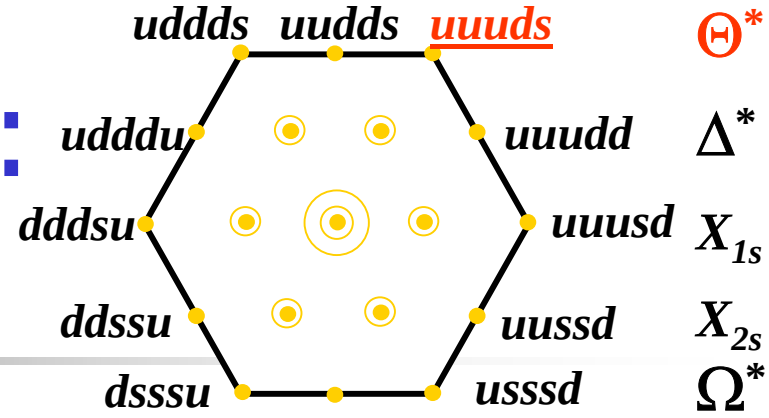
- Assume the following:
  - pentaquarks have J = ½;
  - BF($\Theta_5(1540)^+ \rightarrow pK_s$) = 25%;
  - BF($\Xi_5(1820)^{--} \rightarrow \Xi^-\pi^-$) = 50%.
- BF for Ξ^0 is very unclear.
- Limits are below expectations for baryons:
  - $\Theta_5(1540)^+$ by a factor of 7-16;
  - $\Xi_5(1820)^{--}$ by a factor of 4-5.



Search for Θ^{*++}



Θ^{*++} Pentaquark: Current Status



Theoretical Predictions	m(Θ^{*++}), GeV/c^2	$\Gamma(\Theta^{*++})$, MeV
B.Wu & B.Q.Ma, Phys.Rev.D, **69** 077501(2004)	1.6	<43
D. Borisyuk *et al,* hep-ph/0307370	1.595	80
H. Walliser *et al.*, J.Exp.Theor.Phys., **97** 433(2004)	1.64-1.69	
J. Ellis *et al.*, JHEP 0405:002		37-66

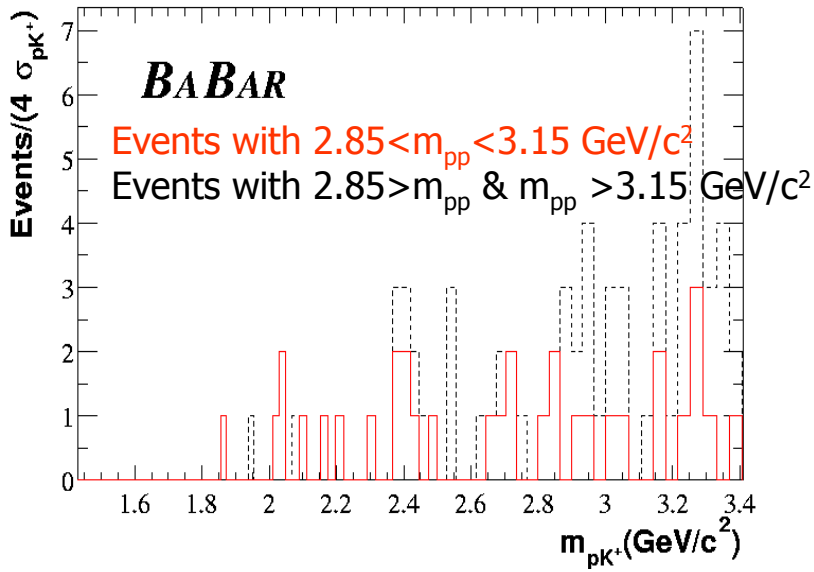
- $\Theta^{*++} \rightarrow K^+p$ mode thought to be dominant
- Searches for new particles in K^+p scattering: no sign of Θ^{*++}, constrains $\Gamma(\Theta^{*++})$<15MeV
- Not seen by experiments that claim Θ^+ (CLAS, HERMES, SAPHIR, ZEUS)
- No previous searches in B decays (idea: Phys.Lett.B, **587** 62(2004))

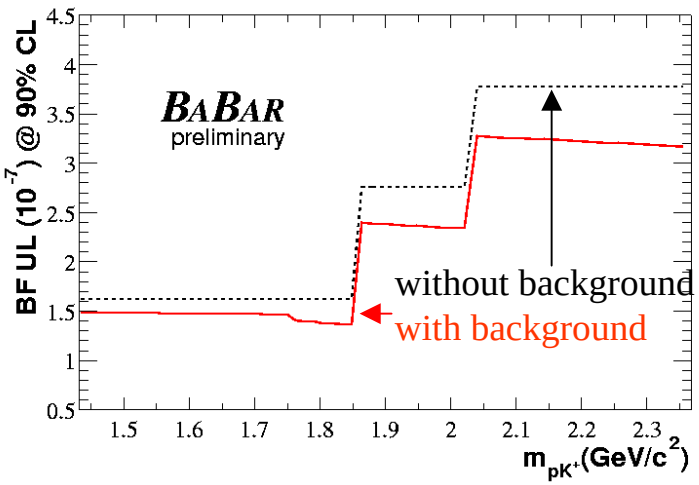
Search for Θ^{*++}: Analysis Details

- Search for $\Theta^{*++} \rightarrow pK^+$ in $B^+ \rightarrow p\bar{p}K^+$
- Use 81 fb^{-1} on the $\Upsilon(4S)$ resonance (89M $B^{\pm}$ mesons)
- Use tracking, particle ID and pair-production kinematics to isolate $B^{\pm} \rightarrow p\bar{p}K^{\pm}$ signal
- Major Backgrounds:
  - Baryons from the continuum (suppress topologically)
  - B decays with charmonium: $B^{\pm} \rightarrow XK^{\pm}$, $X \rightarrow p\bar{p}$ ($X=\eta_c, J/\psi, \chi_c, \psi(2S)$)

Search for Θ^{*++}: Results

- Plot M_{pK+} signal events inside and outside the charmonium region $2.85 < M_{pp} < 3.15\ GeV/c^2$.
- No evidence of a Θ^{*++} signal.
- Establish upper limits for three different regions of M_{pK+}.





Summary

- There is copious production Λ^0, Ξ^-, Ξ^{*0}, Ω^-, $\Xi_c{}^0$, $\Lambda_c{}^+$ baryons at BaBar;
- There is no evidence for $\Theta(1540)^+ \rightarrow pK_s$ in e^+e^- interactions, or electro- or hadro-production in the detector material;
- There is no evidence for $\Xi_5(1860)^{--}$ or $\Xi_5(1860)^0$ states;
- Limits on $\Theta(1540)^+$ and $\Xi_5(1860)^-$ production are well below baryons of similar mass;
- There is no evidence for $\Theta^{*++} \rightarrow pK^+$ in $B^+ \rightarrow p\bar{p}K^+$.