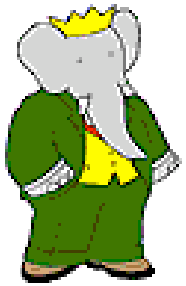
Pentaquark Searches at BaBar

Mathew Graham

University of Wisconsin

For the BaBar Collaboration



BABAR™

ECT Workshop on Exotic Hadrons, Trento, Italy

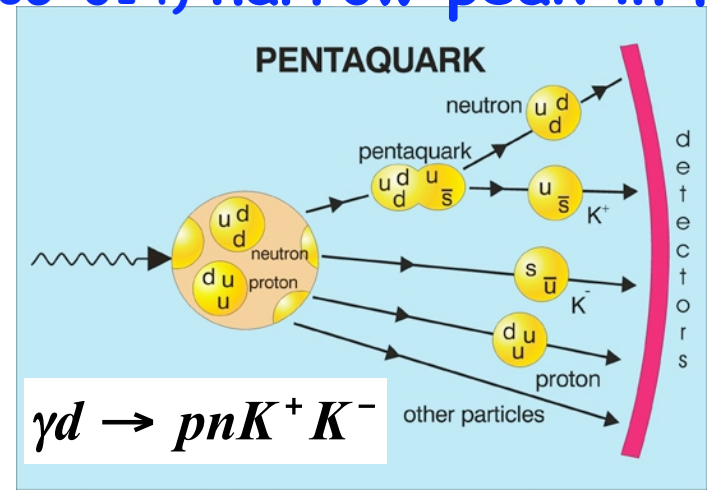
02/24/05

Outline

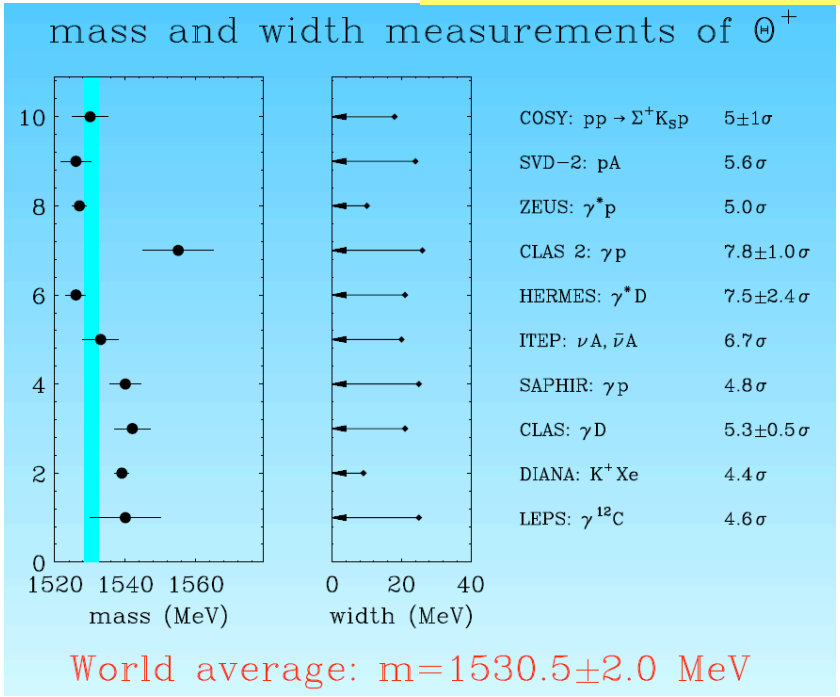
- Introduction
- Inclusive searches in e^+e^- for strange pentaquarks
- B decays into Baryons
  - Search for the Θ^{*++} in $B^+ \rightarrow ppK^+$
  - Search for charmed pentaquarks
- Outlook and Conclusions

Pentaquark Searches

- Triggered by a prediction (Diakonov et al. Z.Phys. A359 (1997) 305-314) narrow peak in K^+n invariant mass was observed



M.Karliner Moriond04



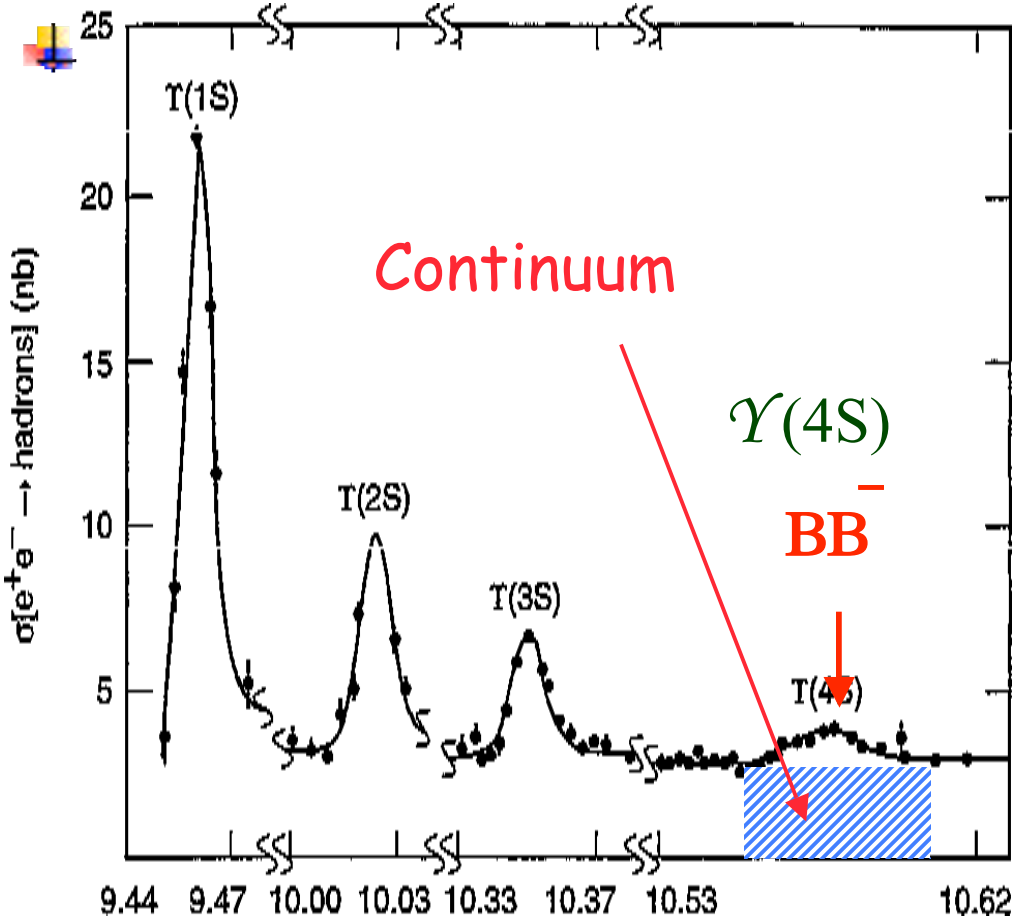
Discovery of Θ^+ (S=+1, $uudd\bar{s}$) has created a lot of excitement

- NA49 gave evidence of Ξ^{--} (S=-2, $dsds\bar{u}$, 1.862 GeV)
- H1 gave evidence of charmed Θ_c^0 ($udud\bar{c}$, 3.1 GeV)
- A number of experiments have reported negative results

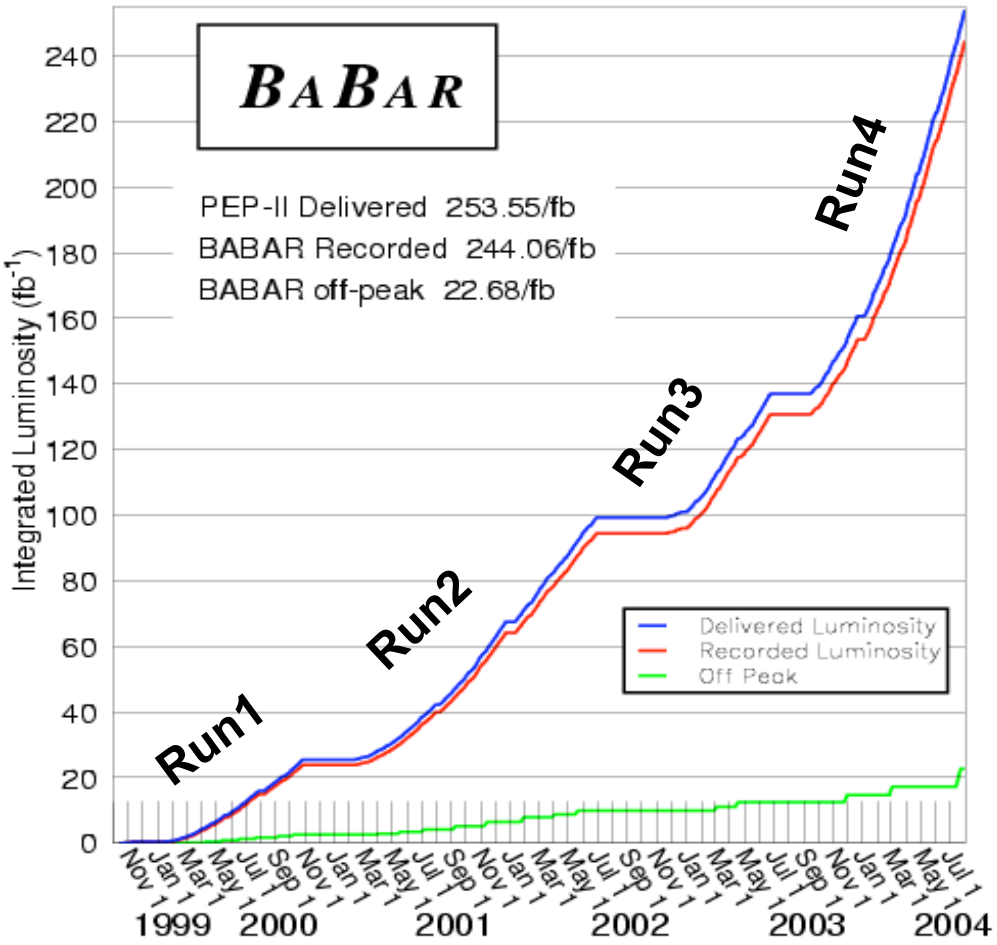
Pentaquark Searches at BaBar

B-Factories operate at Υ(4S) above BB threshold

- Primary design: study B-decays produced in e^+e^- →Υ(4S) →BB
- B factories are also produce copiously u d s c b quarks
  - We can look for pentaquarks either inclusively (e^+e→pQ+X) or exclusively in B-decays (e.g. B→Θ_5p)



PEP-II/BaBar Performance



Integrated Luminosity 1999-2004

PEP-II top luminosity: $9.2 \times 10^{33} cm^{-2} s^{-1}$

221 fb^{-1} on $\Upsilon(4S)$

23 fb^{-1} below $\Upsilon(4S)$

} 244 fb^{-1}

This corresponds to:

256M B decays

510M uds events

317M cc events

Current results use only Runs 1-3

113 fb^{-1} on $\Upsilon(4S)$; 10 fb^{-1} below $\Upsilon(4S)$

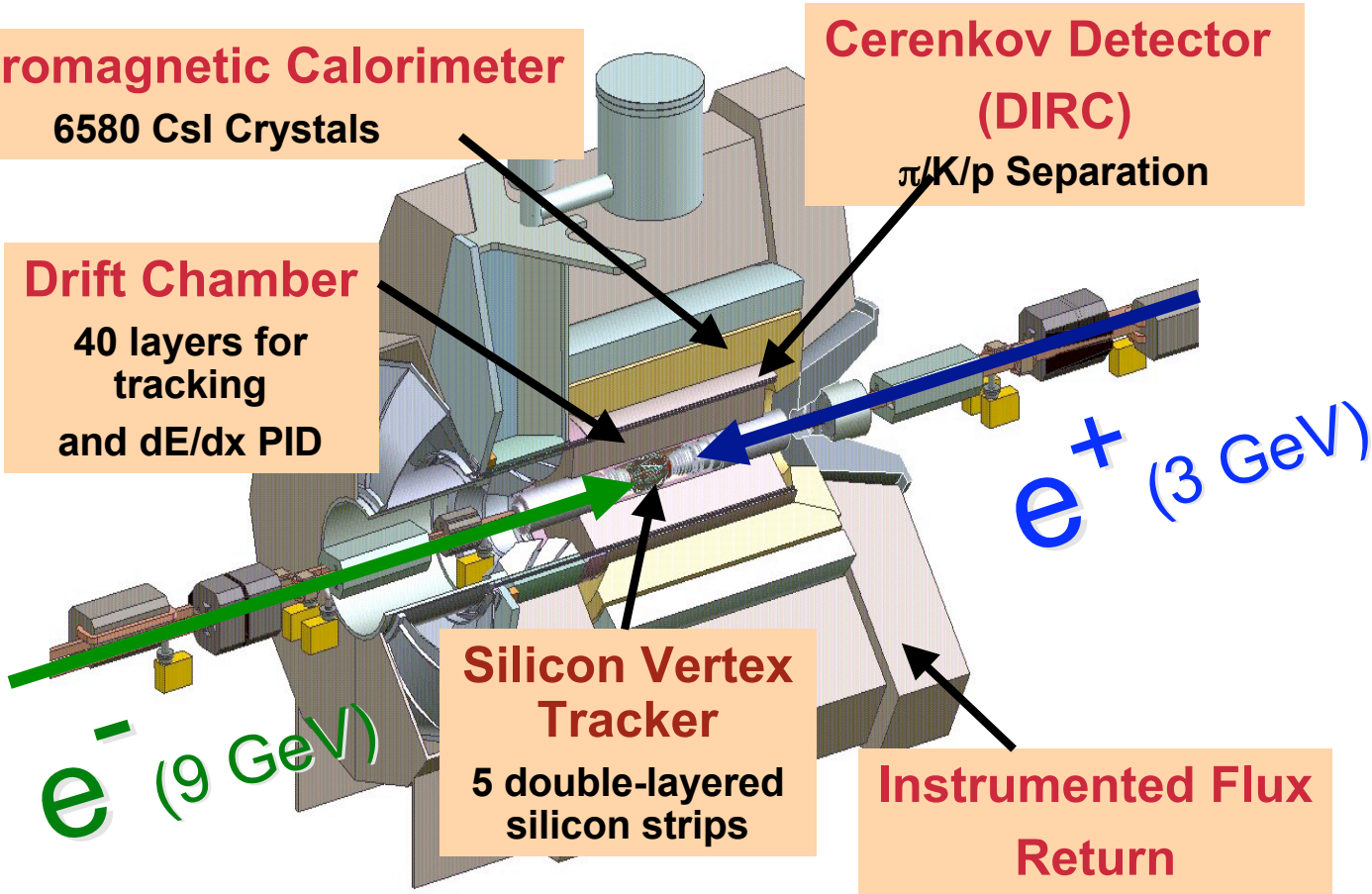
The BaBar Detector

Very good acceptance

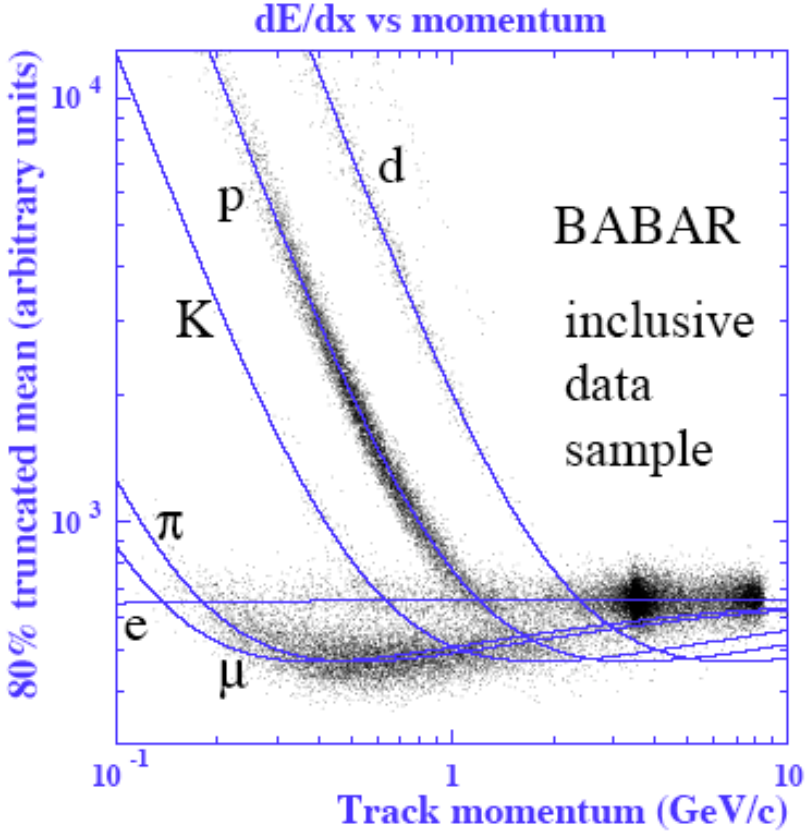
Great PID

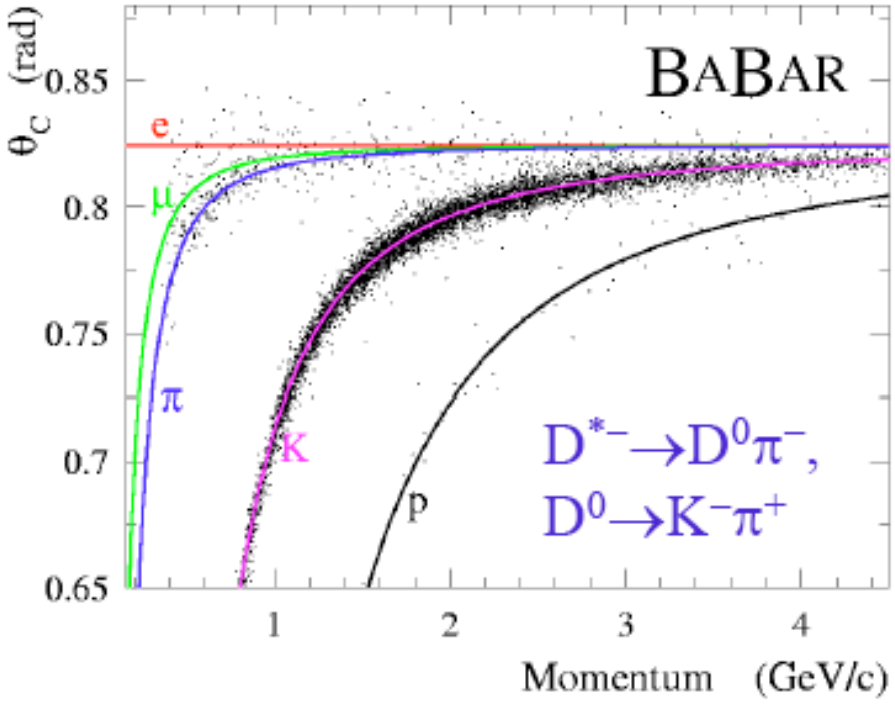
Good mass resolution

→a good spectrometer



Particle Identification





Can separate protons from kaons/pions very well

Our proton selection: Purity>95%, efficiency ~85%

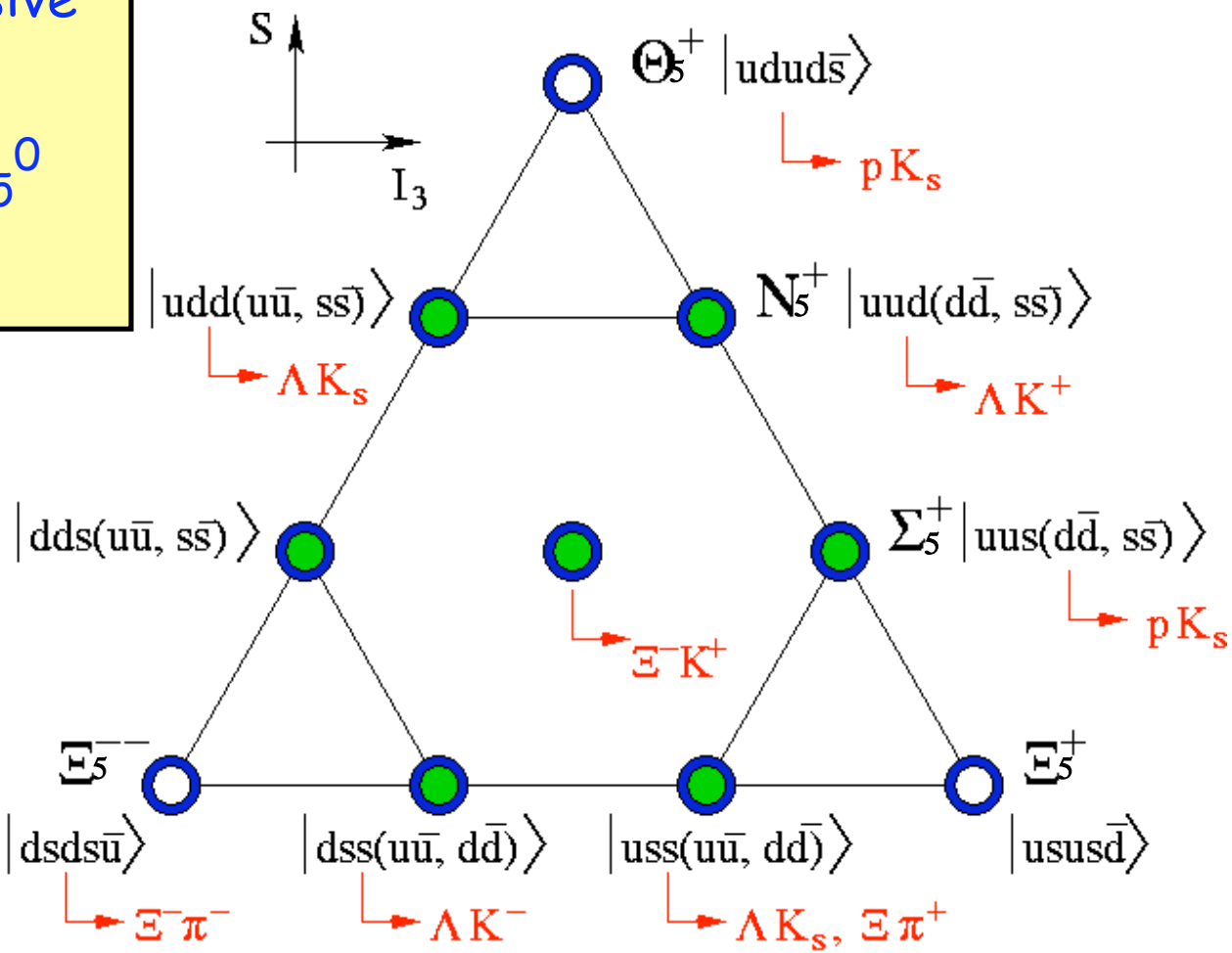
Inclusive Pentaquark Searches

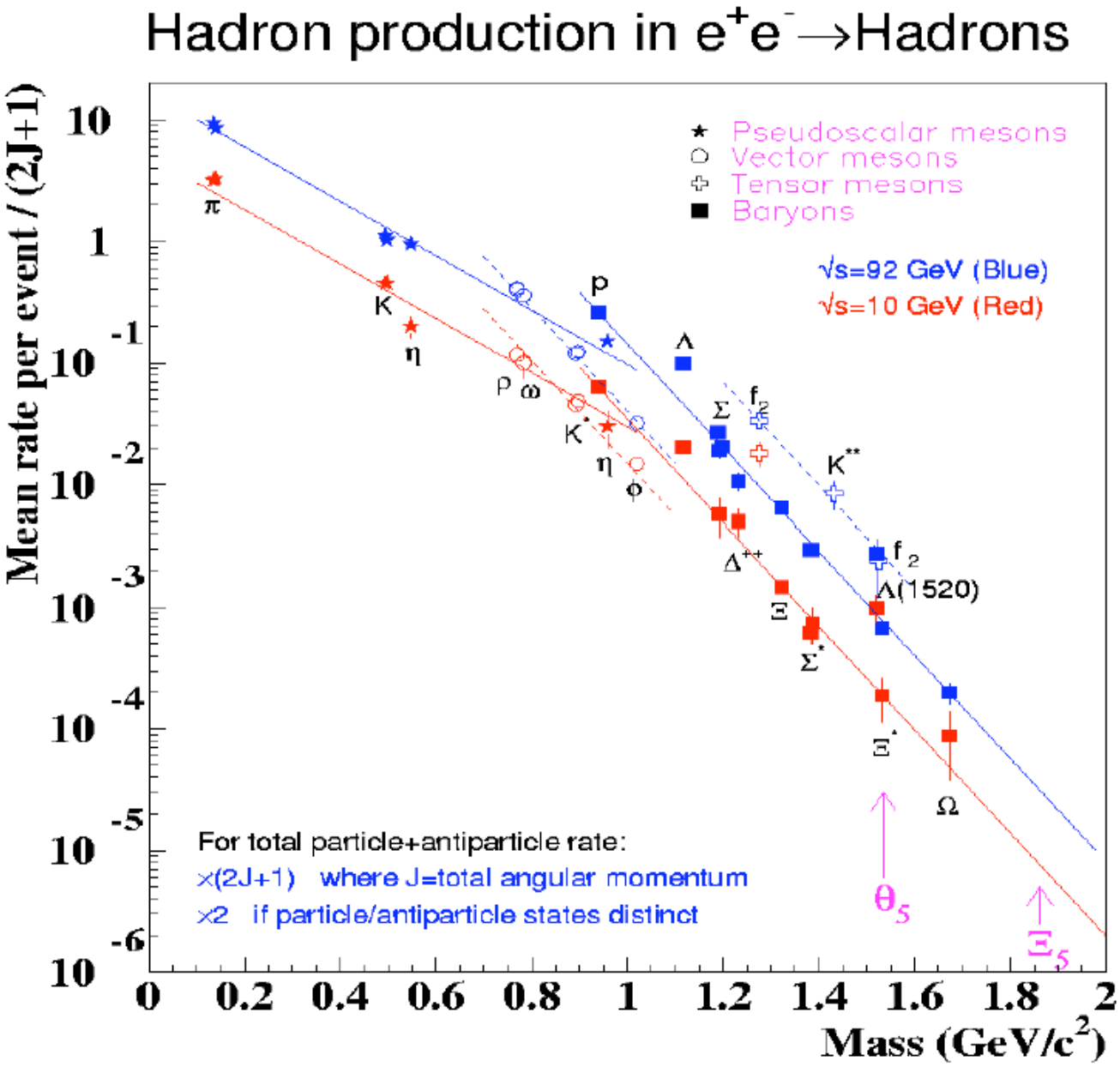
We have performed inclusive searches for:

Θ_5^+ N_5^+ N_5^0 Σ_5^+ Σ_5^0

Ξ_5^0 Ξ_5^- Ξ_5^{--}

Charge conjugation is assumed

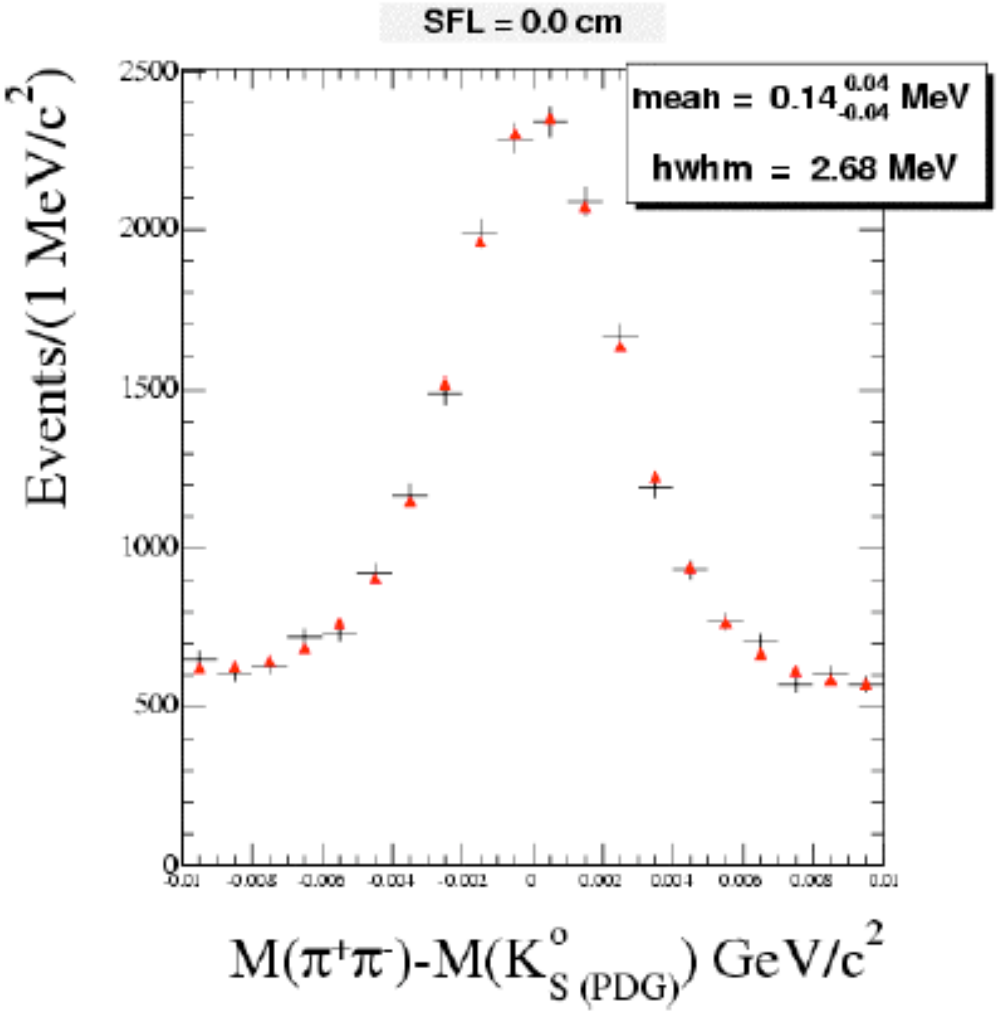




If the Θ_5 were a "normal" baryon… expect a production rate of ~10^{-3}/event We should easily see this!

Inclusive $\Theta^+ \rightarrow pK_s$ Search: K_s Selection

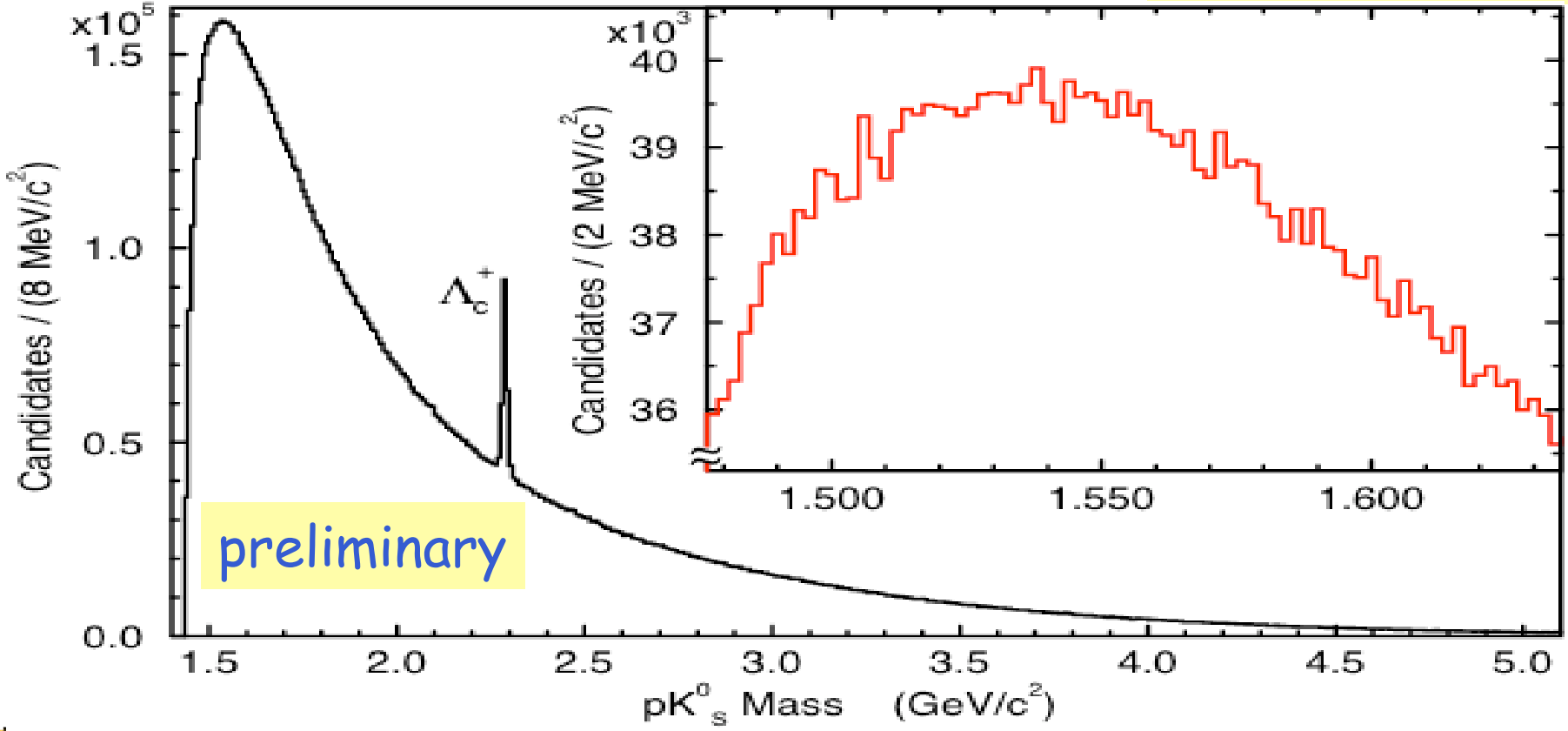
- Ks formed from $\pi^+\pi^-$ pairs
- tracks must project to within 6mm of each other
- flight length from IP to Ks vertex >0
- $|\cos(\theta_H)|<0.8$



Inclusive $\Theta^+ \rightarrow pK_S$ Search

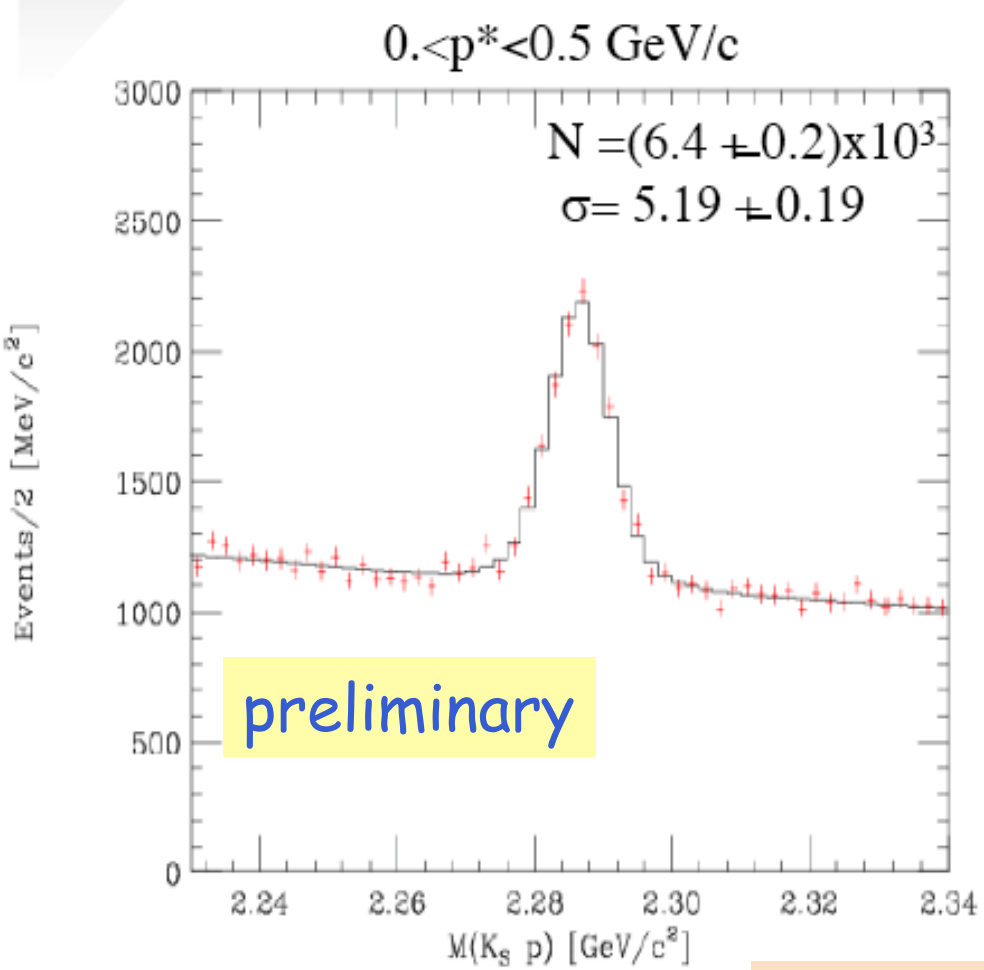
- Clean peak for $\Lambda_c^+ \rightarrow pK_S$ (52K events) but no narrow structure at 1.54 GeV

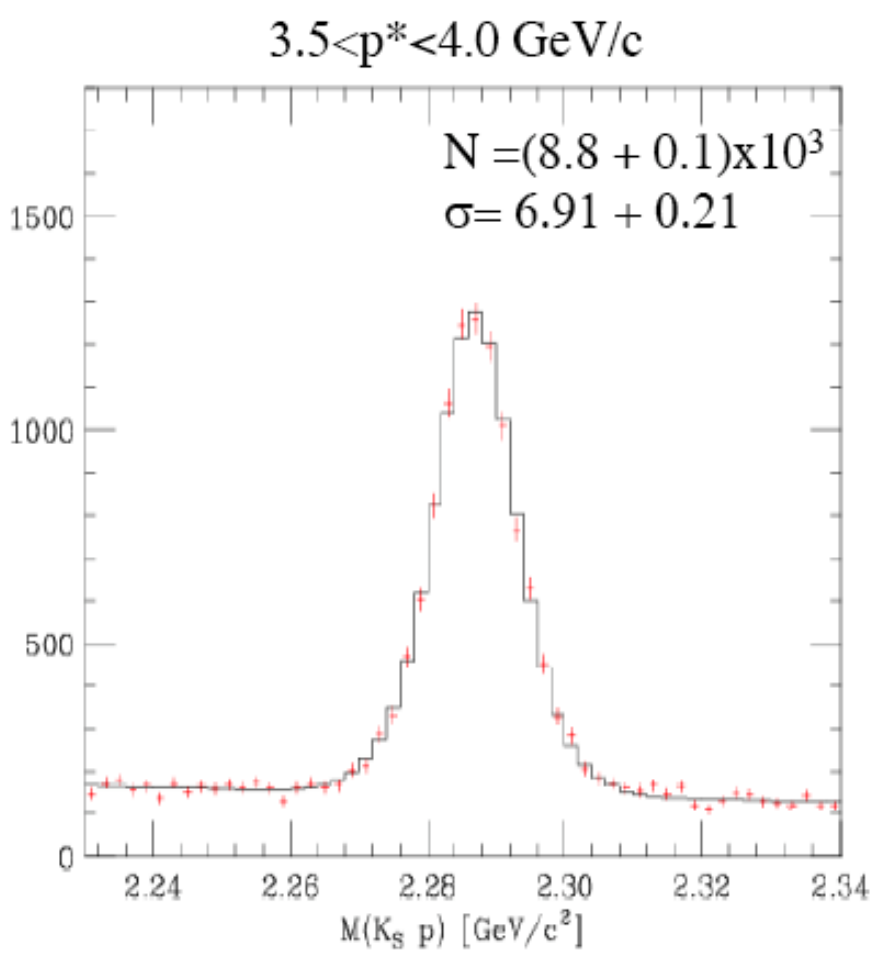
hep-ex/0502004



- Number of checks: stringent cuts on K_S, require recoiling K^- and/or anti-proton with all possible combinations. Λ_c^+ visible but no pentaquark

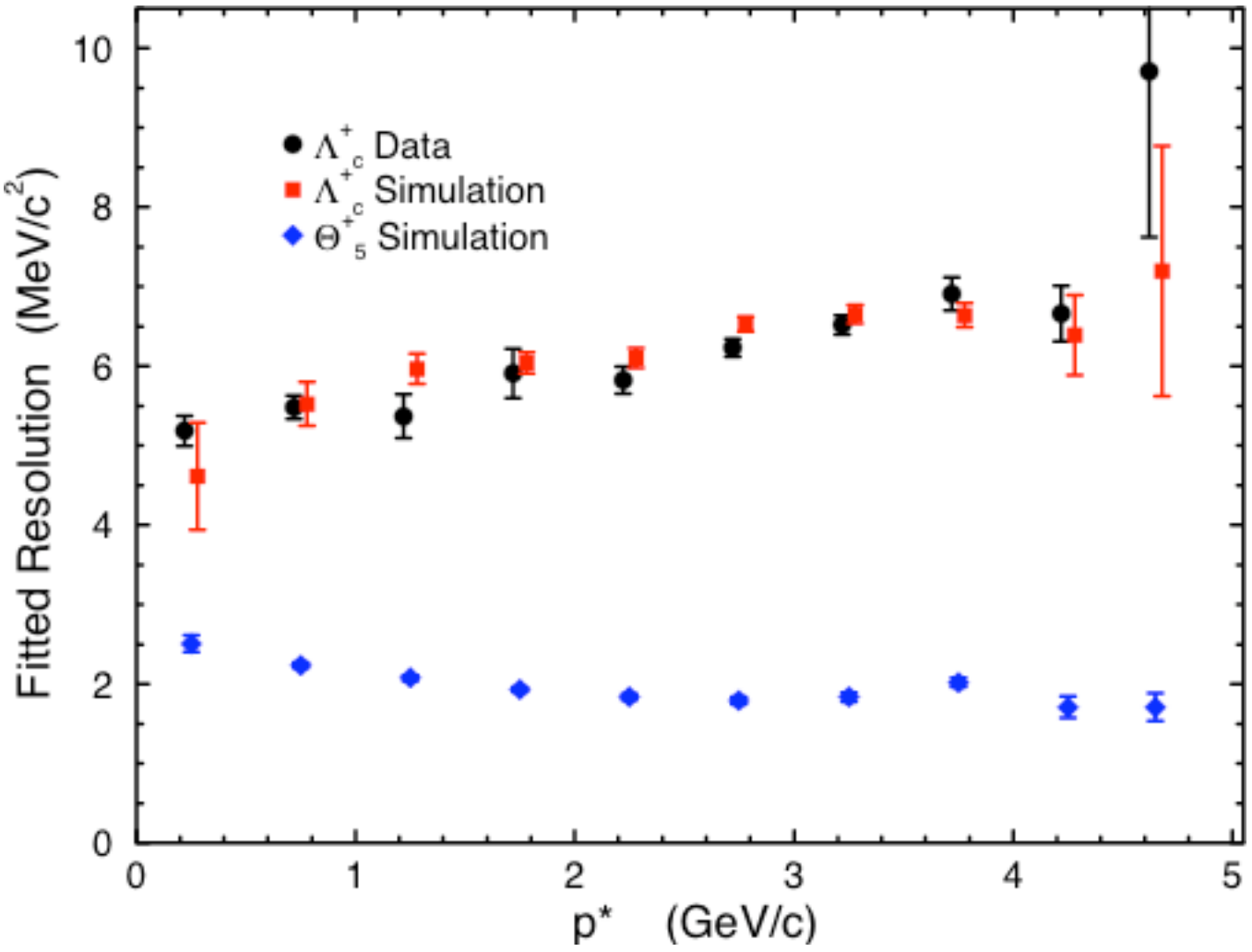
$\Lambda_c^+ \rightarrow pK_s$ Sample





p*→CM momentum

Θ_5^+ and Λ_c^+ Mass Resolution



Terrific agreement between data and MC for Λ_c resolution!

Expect the Θ_5 resolution to be ~2 MeV…can measure a width down to <1MeV

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

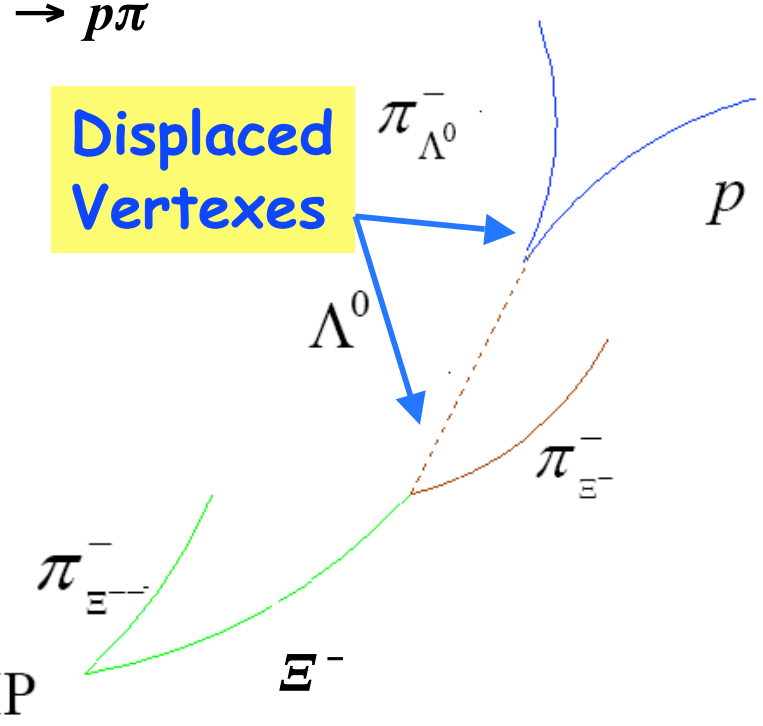
123 fb^{-1}

- NA49 gave evidence of Ξ^{--} (S=+2, dsds$\bar{u}$, 1.862 GeV) and Ξ^0

$$e^+e^- \longrightarrow \Xi_5^{--} X \quad (dsds\bar{u})$$
$$\Xi_5^{--} \longrightarrow \Xi^- \pi^-$$

$$e^+e^- \longrightarrow \Xi_5^{0} X \quad (dssu\bar{d})$$
$$\Xi_5^{0} \longrightarrow \Xi^- \pi^+$$

$$\Xi^- \to \Lambda^0 \pi^-$$
$$\Lambda^0 \to p\pi^-$$

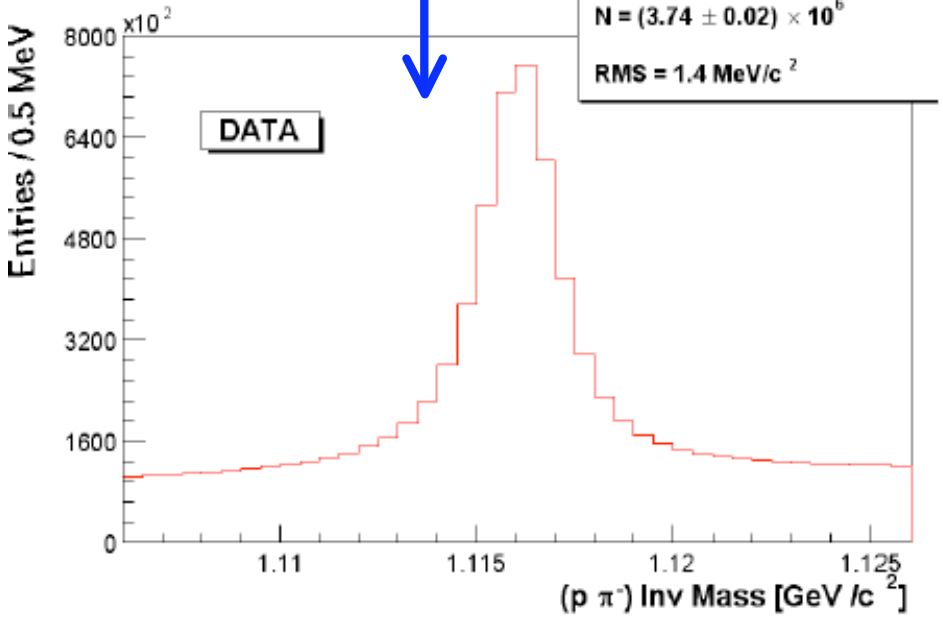


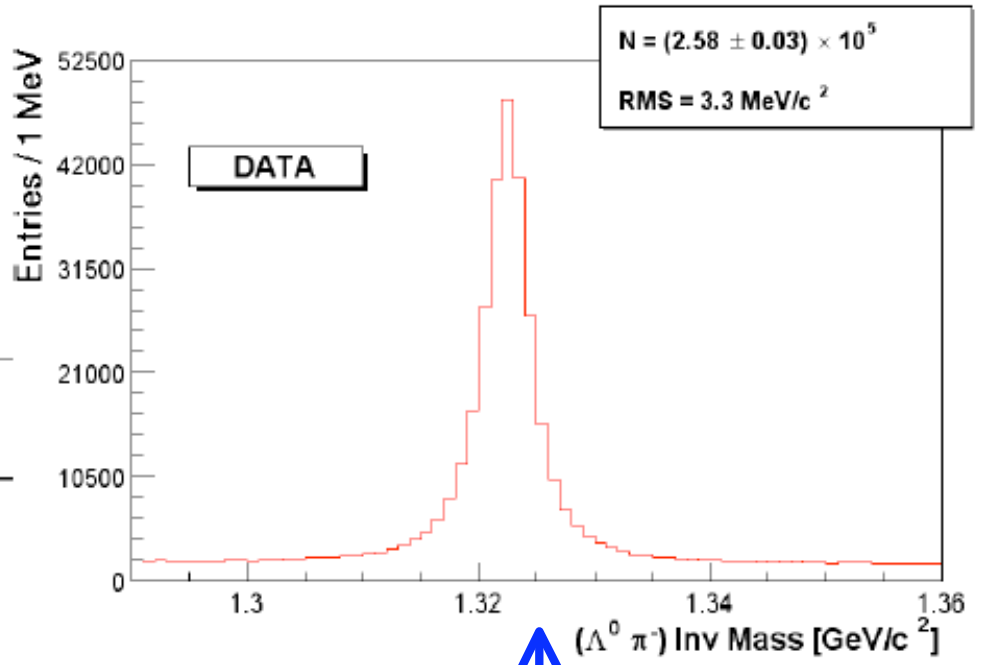
- Two displaced vertexes with loose particle ID
  - *Select masses near nominal Λ^0 and Ξ*
  - *Control samples*
    - *$\Xi(1530)^{*0}$ and $\Xi_c(2470)^0$*

Inclusive Search for Ξ_5: Λ and Ξ Reconstruction

preliminary

pπ Inv. Mass

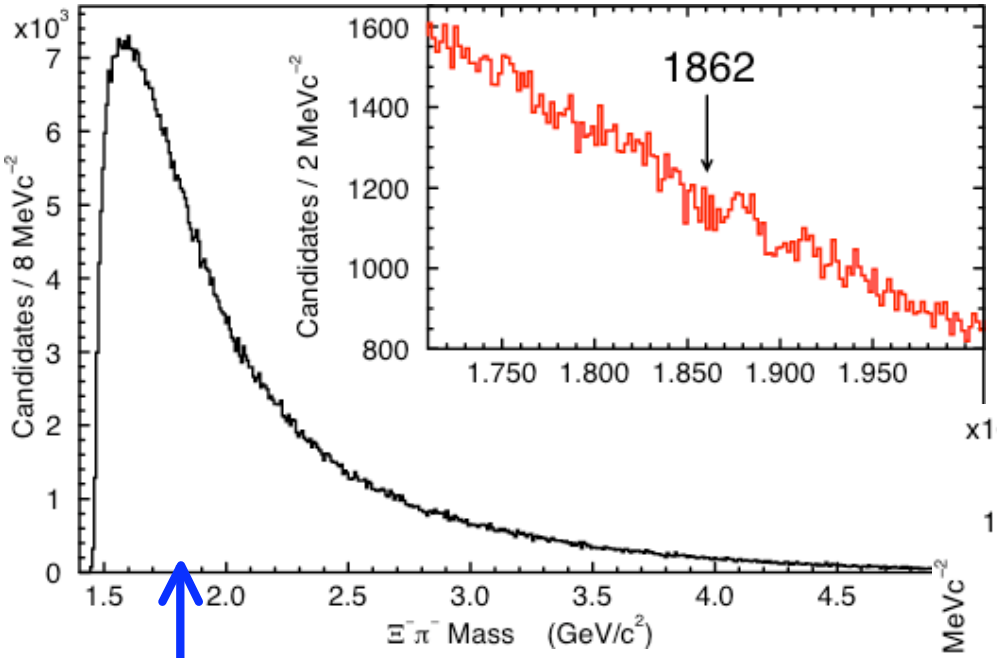




Λπ Inv. Mass

Inclusive Search for Ξ_5^{--} and Ξ_5^0

preliminary

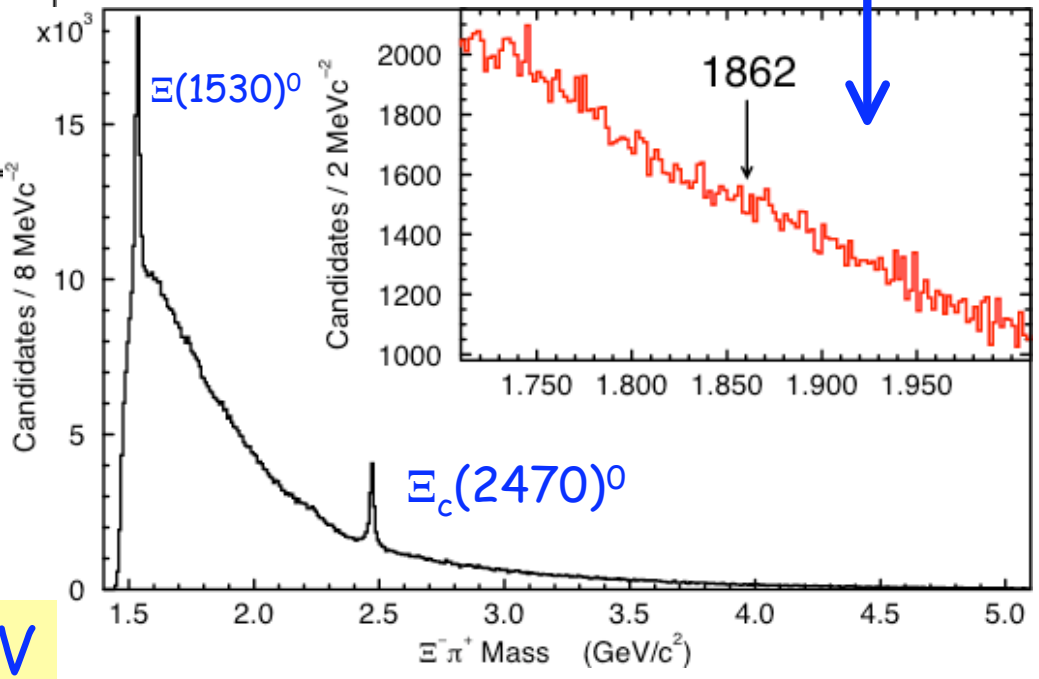


$\Xi_5^{--} \rightarrow \Xi^-\pi^-$

No signal observed

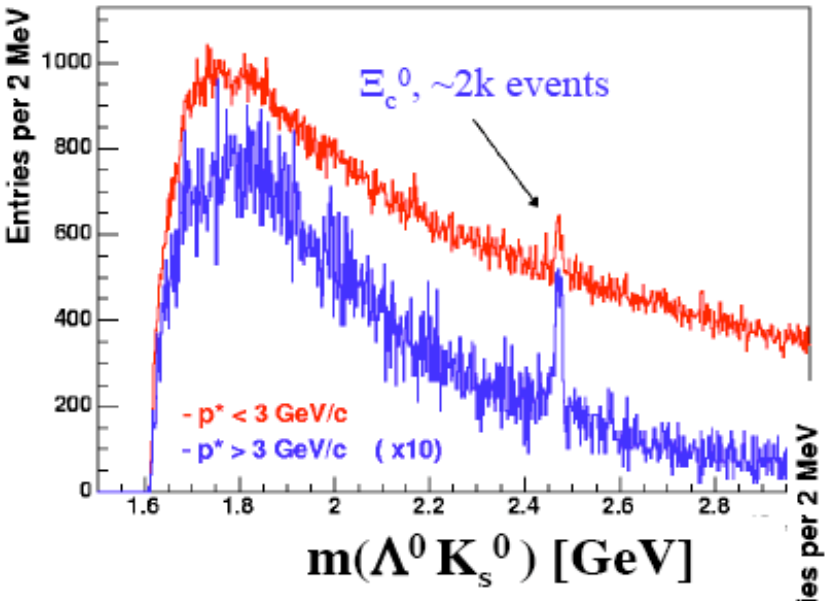
$\Xi_5^0 \rightarrow \Xi^-\pi^+$

No signal observed

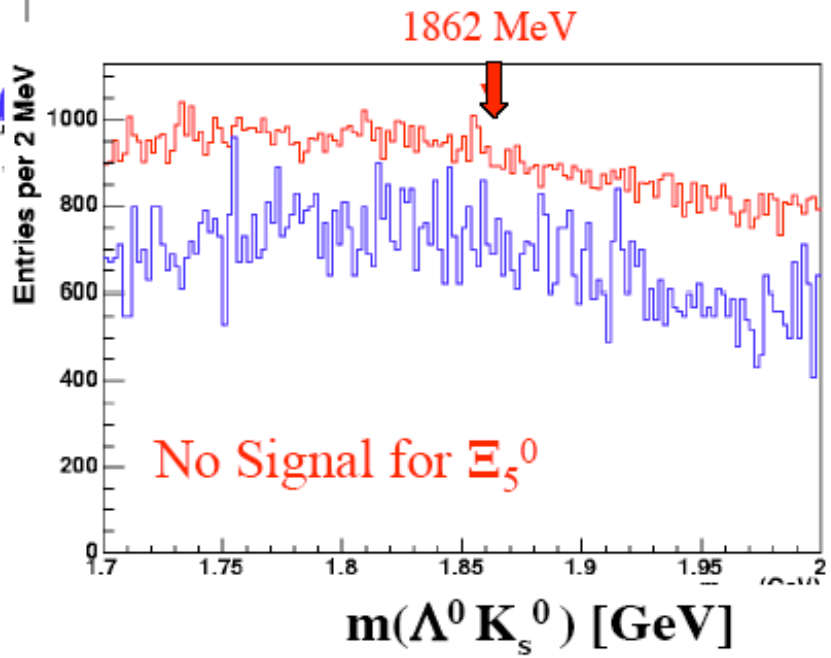


Ξ_5 resolution ~8MeV

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



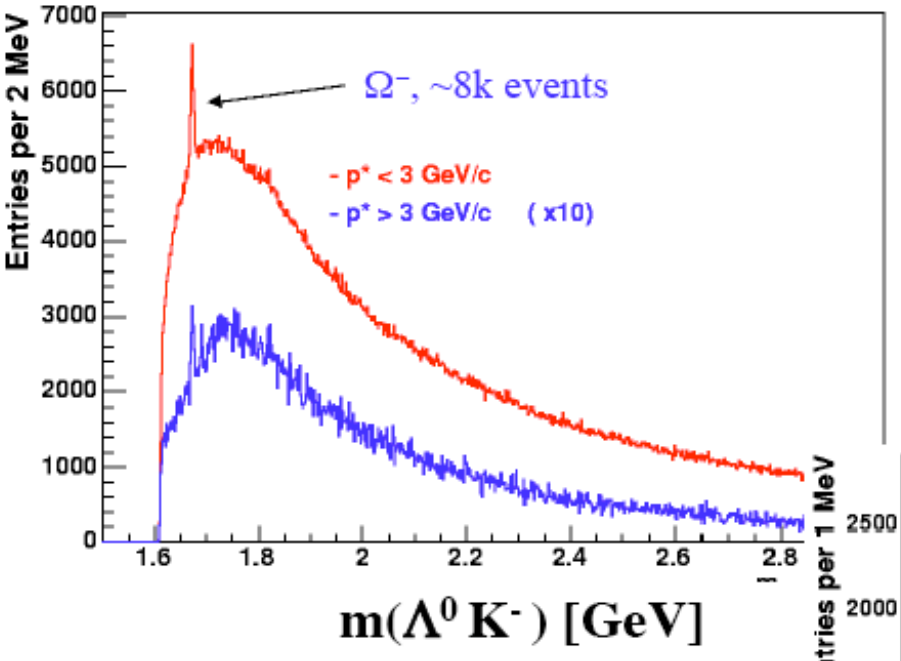
No Signal for Ξ_5^0



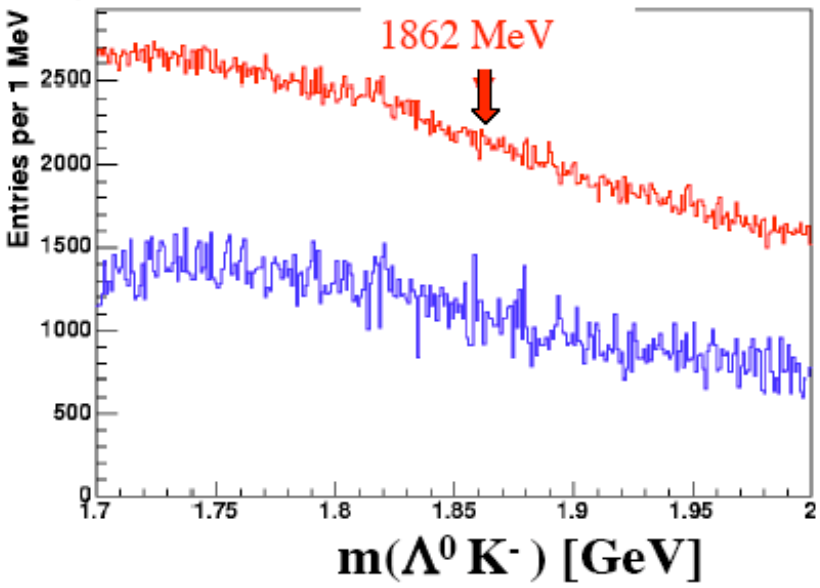
Red: p*<3 GeV

Blue: p*>3 GeV (x10)

Inclusive Search for $\Xi_5^- \rightarrow \Lambda^0 K^-$



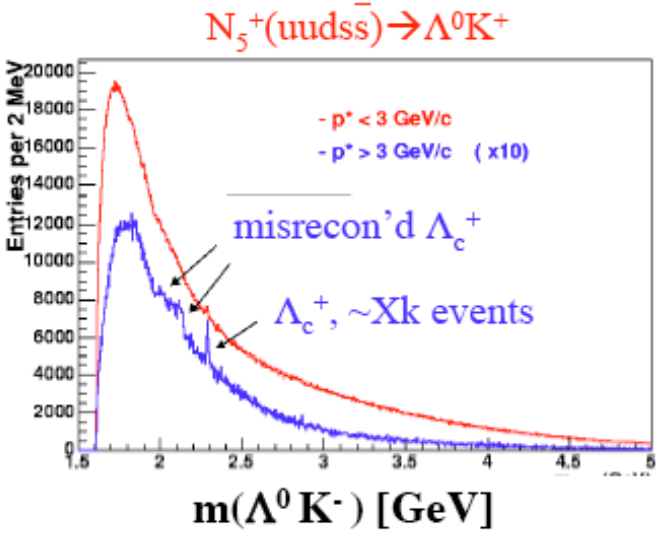
No Signal for Ξ_5^-

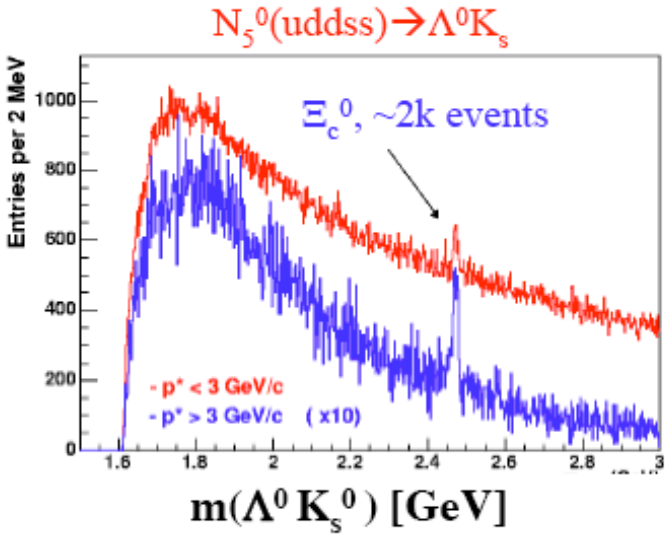


Red: p*<3 GeV

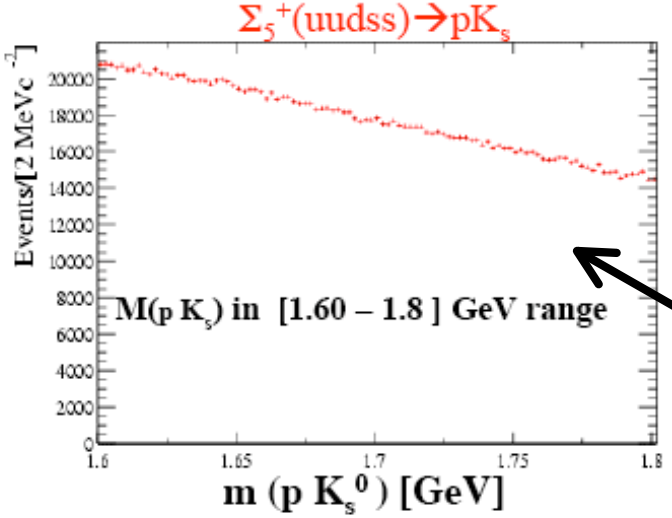
Blue: p*>3 GeV (x10)

More Inclusive Searches…





No signal for N^+ or N^0



Nothing for $\Sigma_5^+ \rightarrow pK_s$

Setting Limits for Θ_5^+

Perform fits in bins of p*

In no bin is a signal observed

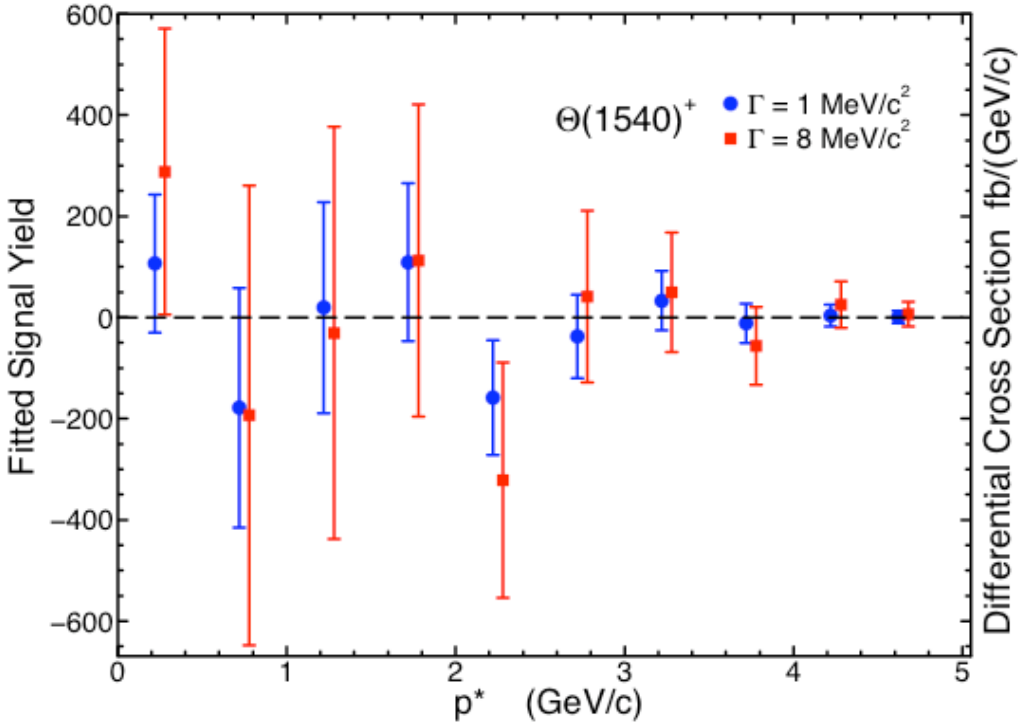
Efficiency correction done bin-by-bin to obtain cross-sections…integrate over p* and get 95%-CL upper limit

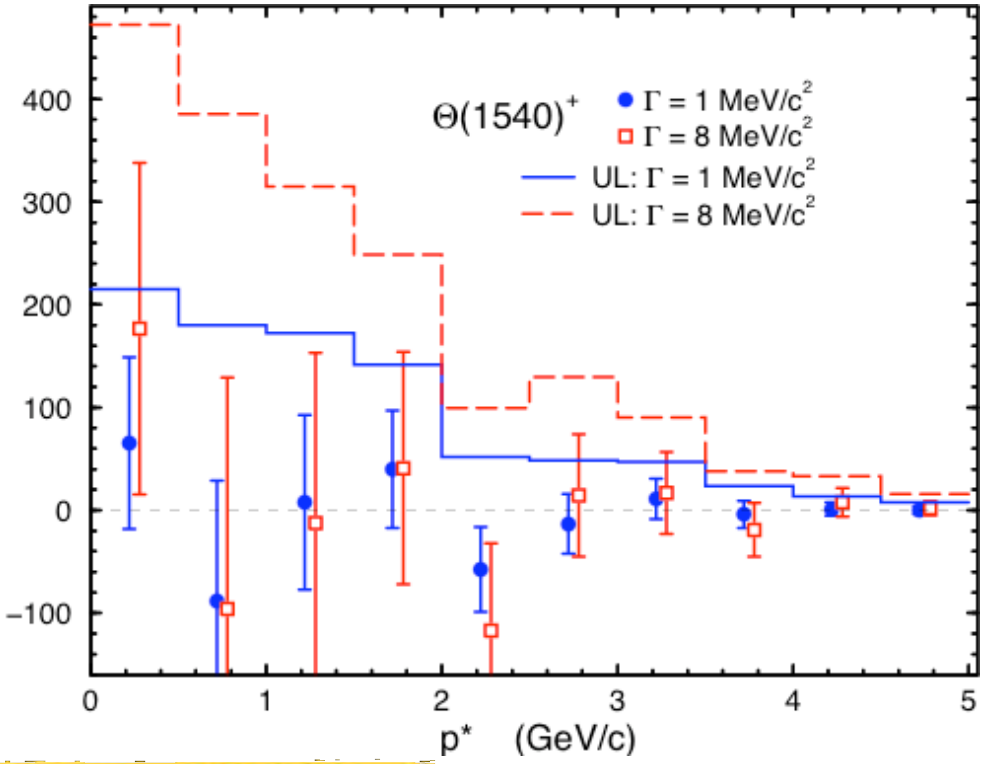
efficiency: 13%-22% (low-->high p*)

$e^+e^- \to \Theta(1540)^+ X$

95% CL UL σ<
171 (363) fb for
Γ=1 (8) MeV

assume BF for $\Theta(1540)^+ \to pK_S$ is 1/4





Setting Limits for Ξ_5^{--}

$e^+e^- \to \Xi(1860)^{--}X$

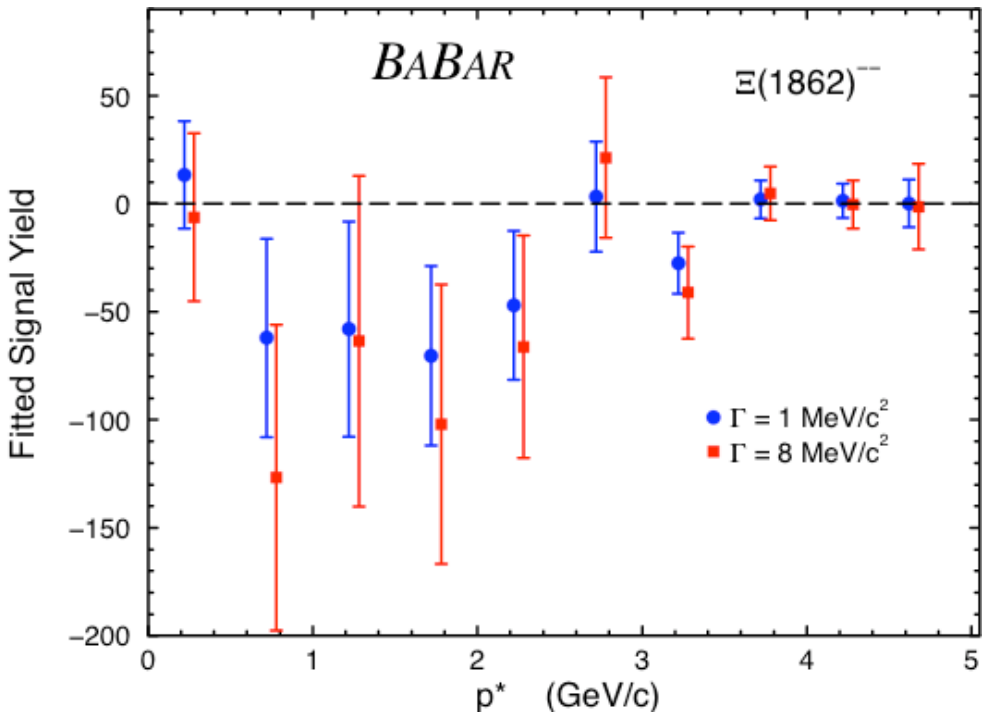
Same procedure as for Θ_5^+

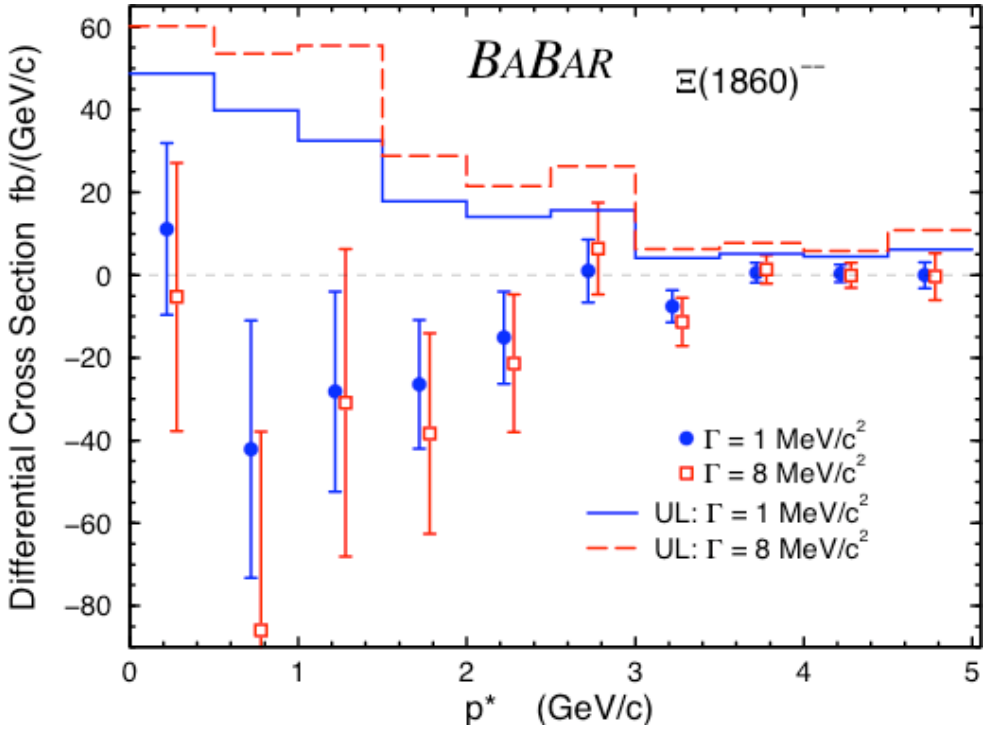
Again, in no bin is a signal observed

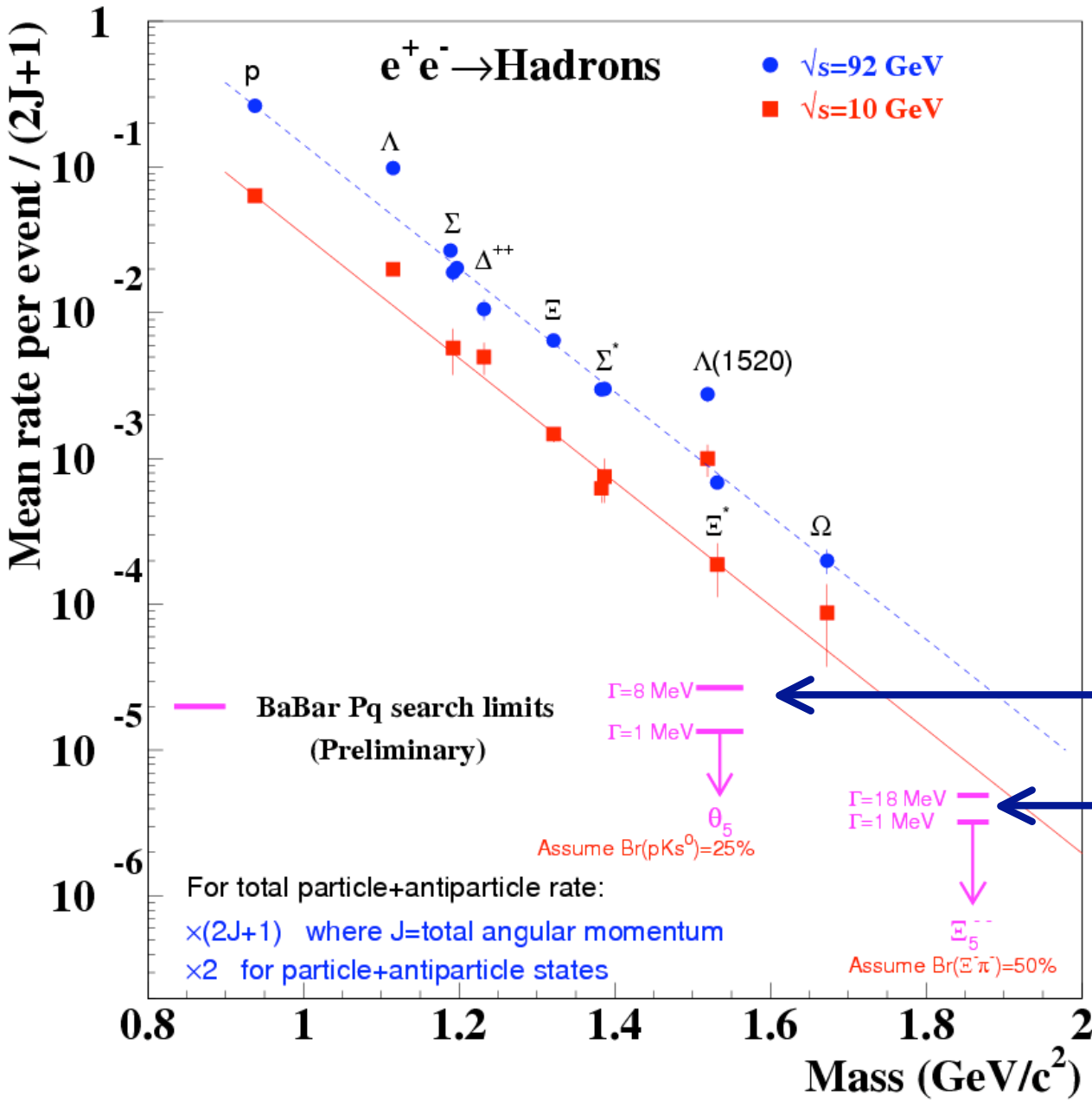
efficiency: 6.5%-12% (low-->high p*)

95% CL UL σ<
25 (36) fb for
Γ=1 (18) MeV

assume BF for $\Xi(1860)^{--} \to \Xi\pi$ is 1/2







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

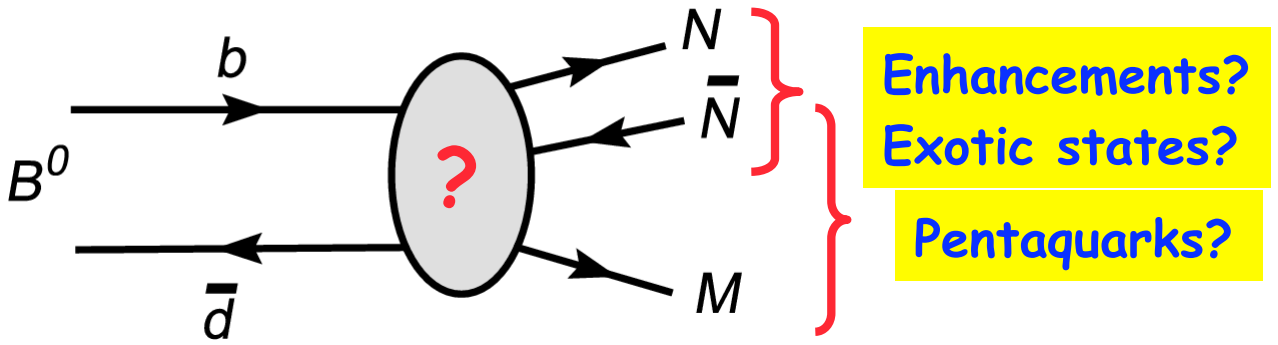
BaBar pentaquark production limits

Baryon Production in B Decays

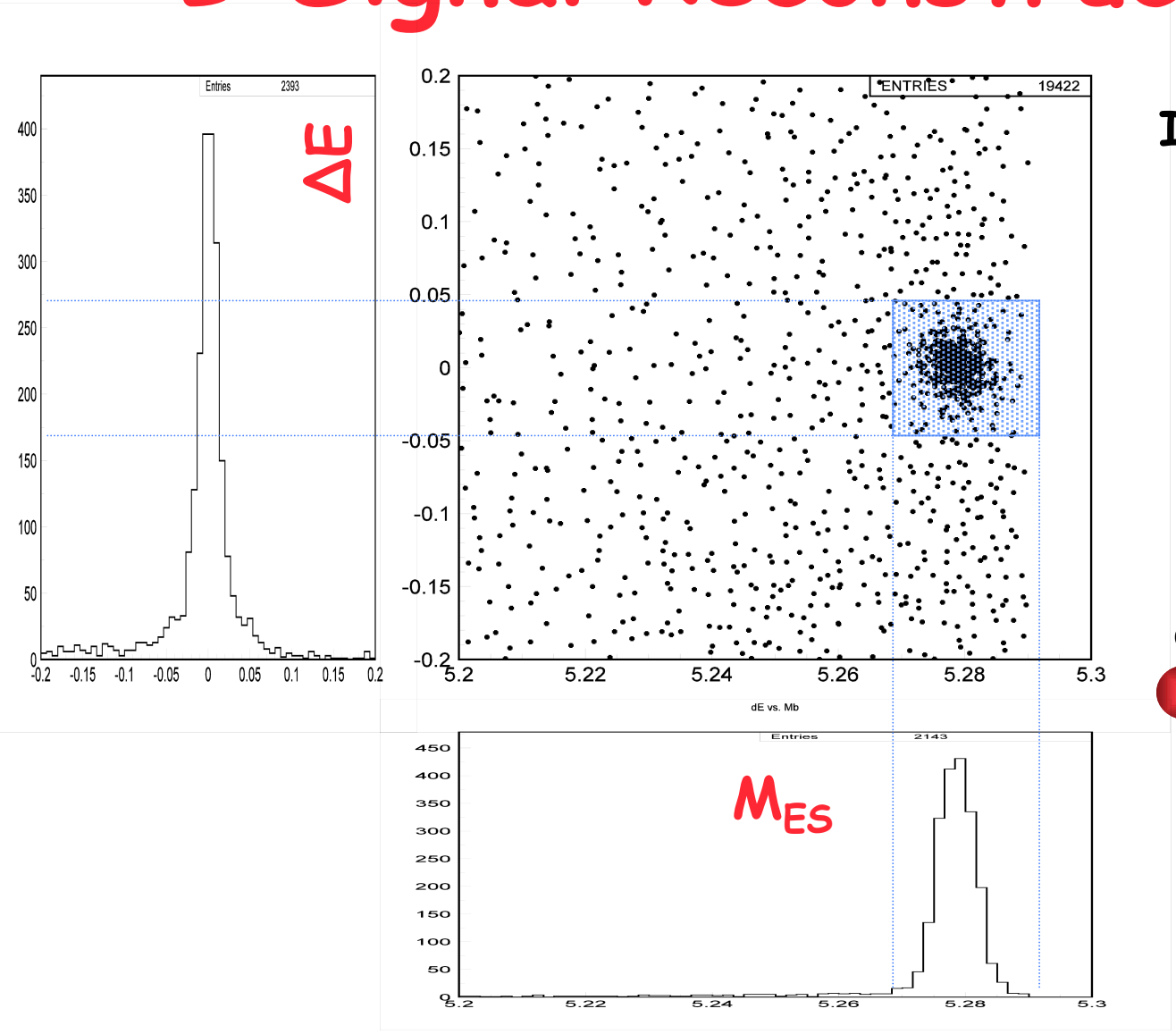
- Little is understood in Baryon production in B decays
- Because of B-Factories, we are starting to get some insight
  - B→Baryons not saturated by B→charmed baryons
- Dominance of multi-body final states

BR(B→2body)< BR(B→3body)< BR(B→4body)

Baryon-Antibaryon enhancements? Exotic states?



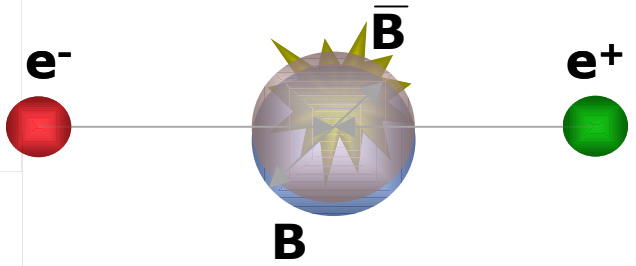
B Signal Reconstruction



In $\Upsilon(4S)$ rest frame:

$$\Delta E = E_B - E_{beam}$$

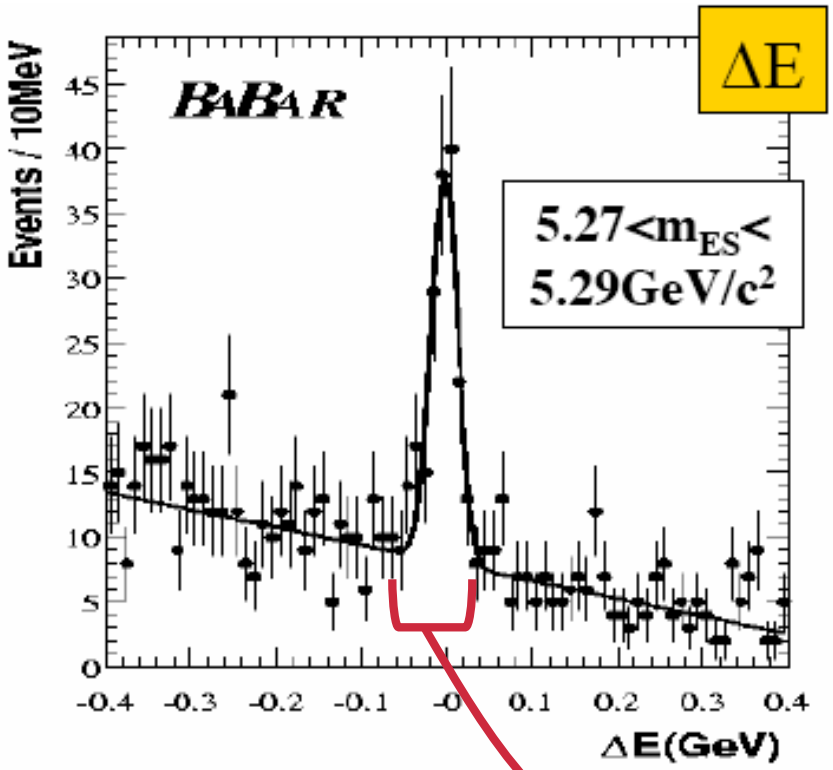
$$M_{ES} = \sqrt{E_{beam}^2 - p_B^2}$$

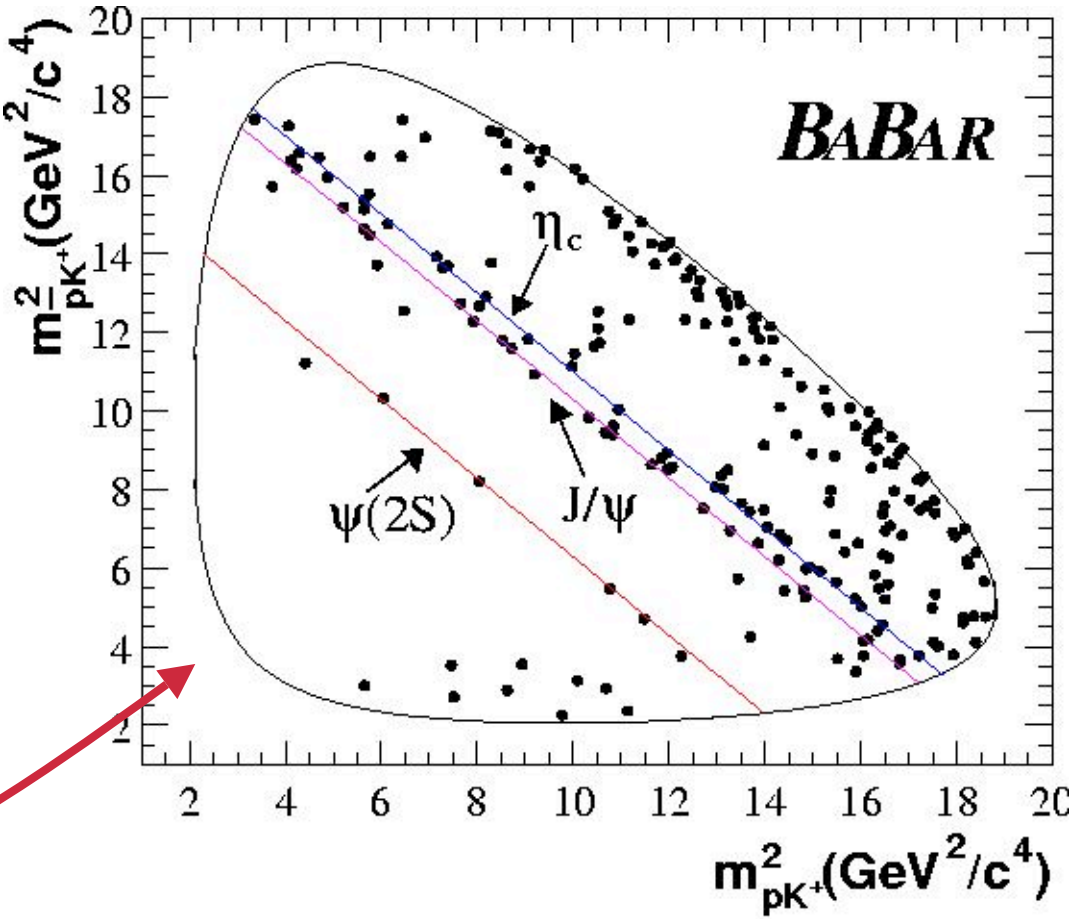


Search for $\Theta^{*++} \to pK^+$ in $B^+ \to p\bar{p}K^+$

Preliminary 82 fb^{-1}

hep-ex/0408037





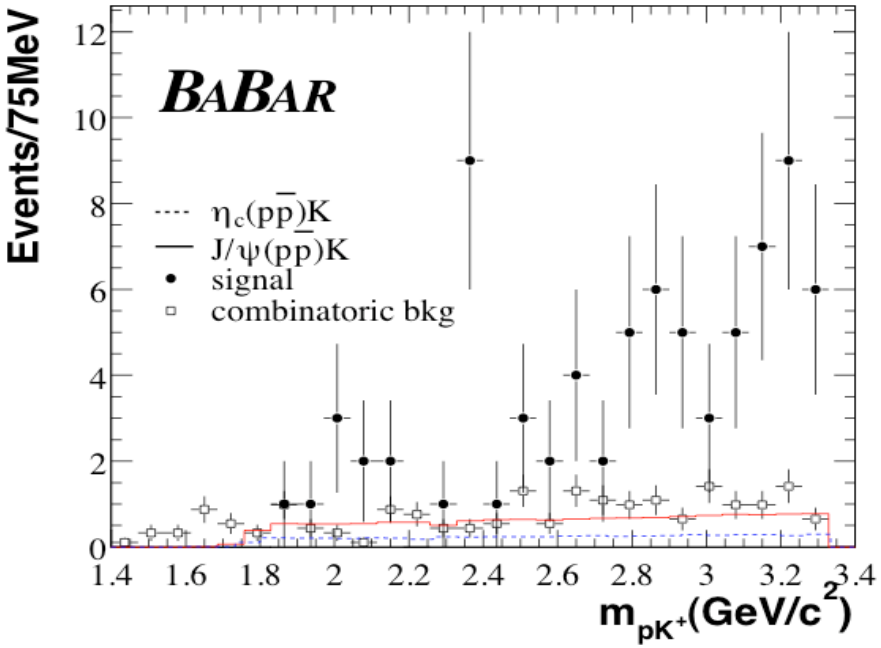
Search for $\Theta^{*++} \to pK^+$ in $B^+ \to p\bar{p}K^+$

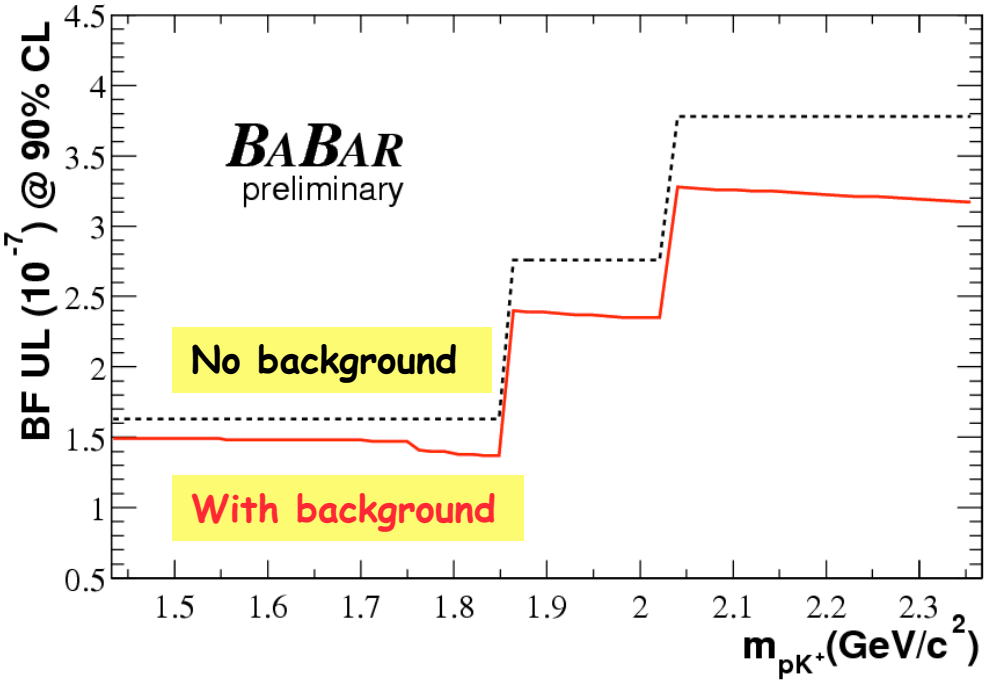
Preliminary

82 fb^{-1}

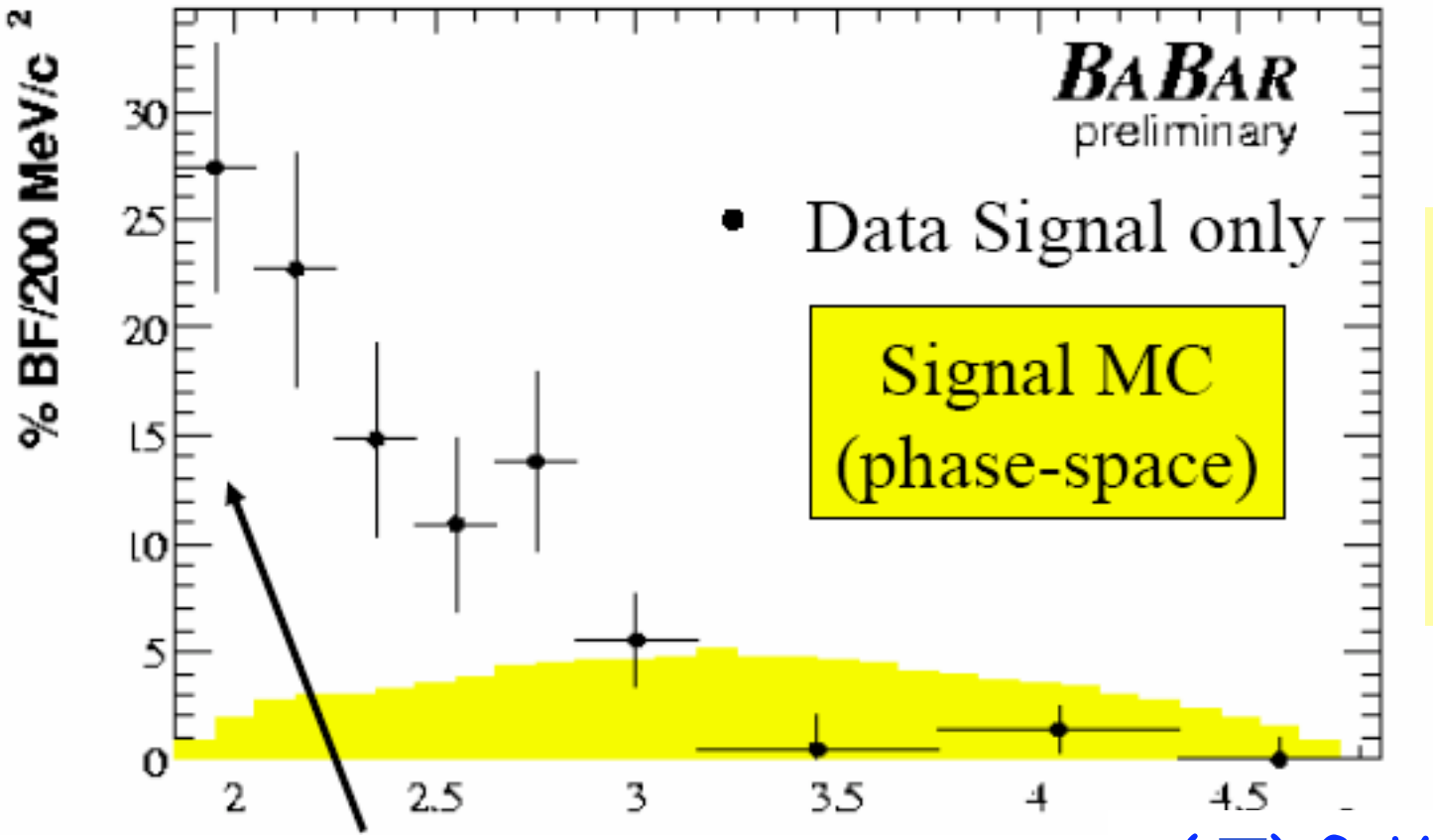
- Pentaquark $\Theta^{*++} \to pK^+$ ($uu\bar{u}ds$) predicted to lie in $1.43 < M(pK^+) < 1.70$ GeV
  - No evidence was found for $\Theta^{*++} \to pK^+$, 90% CL limits were set
  - Other experiments have also reported negative searches

$$BF(B^+ \to \Theta^{*++}\bar{p}) \times BF(\Theta^{*++} \to pK^+) < 1.49 \times 10^{-7}$$





$B^+ \to p\bar{p}K^+$: $p\bar{p}$ Invariant Mass



Low mass enhancement in $p\bar{p}$

Enhancement

is asymmetric

...more high momenta protons than antiprotons (for B^+ decays)

$B^0 \to D^{(*)-} p\bar{p}\pi^+$ and $B^0 \to \bar{D}^{(*)0} p\bar{p}$

New Observation

Preliminary

112.5 fb^{-1}

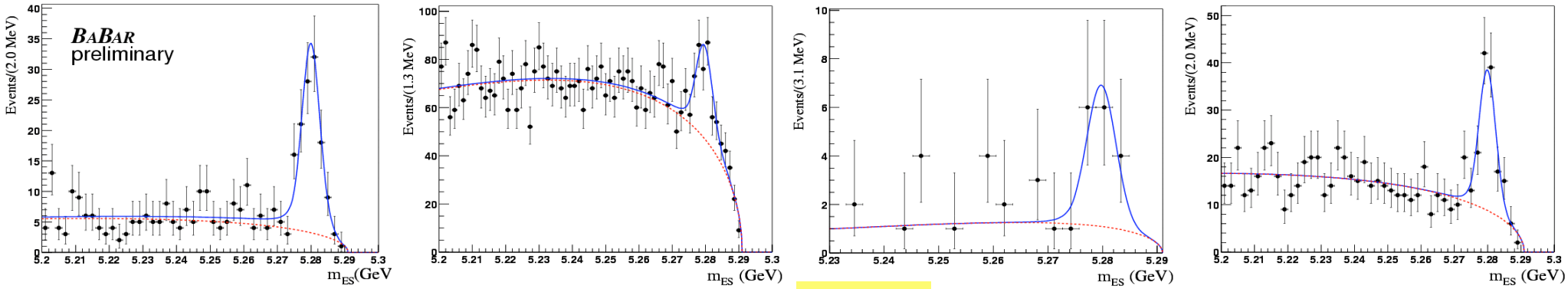
hep-ex/0408035

$B^0 \to D^{*-} p\bar{p}\pi^+$ 130 ± 14

$B^0 \to D^- p\bar{p}\pi^+$ 238 ± 22

$B^0 \to D^{*0} p\bar{p}$ 13 ± 4

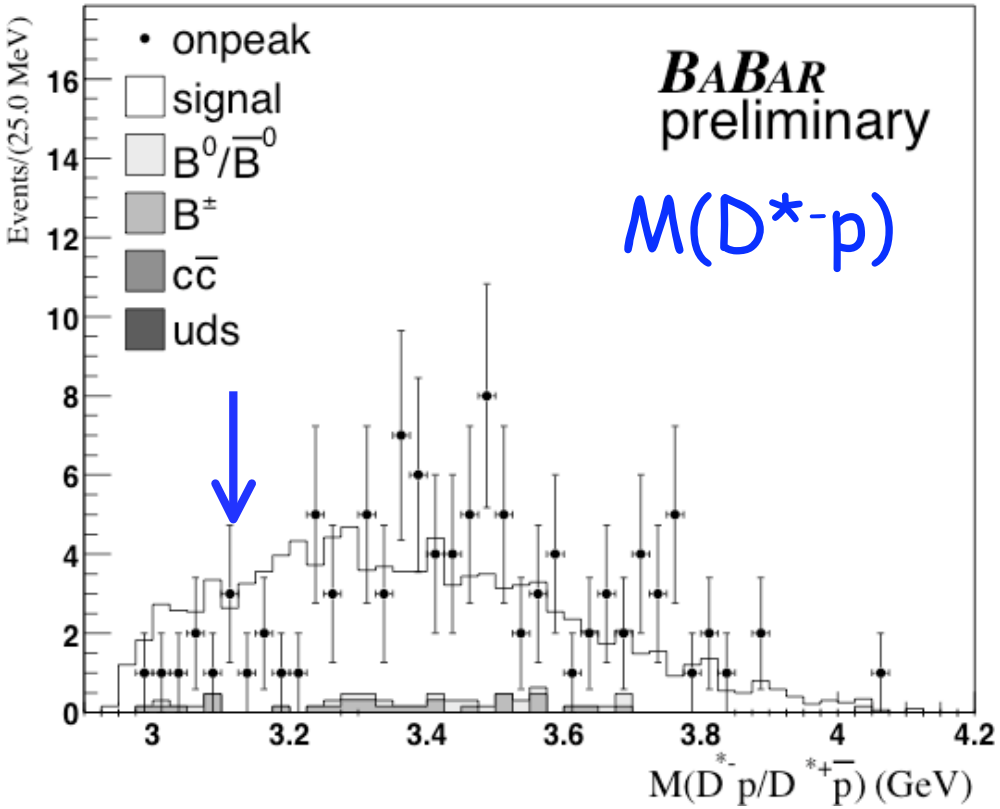
$B^0 \to D^0 p\bar{p}$ 96 ± 11

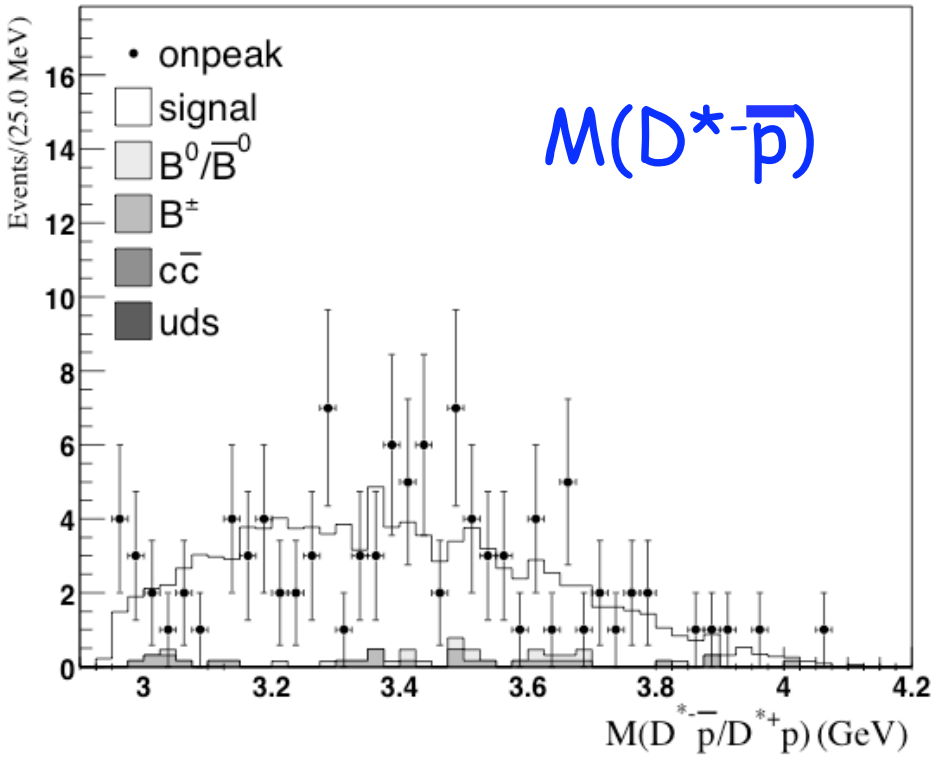


BaBar

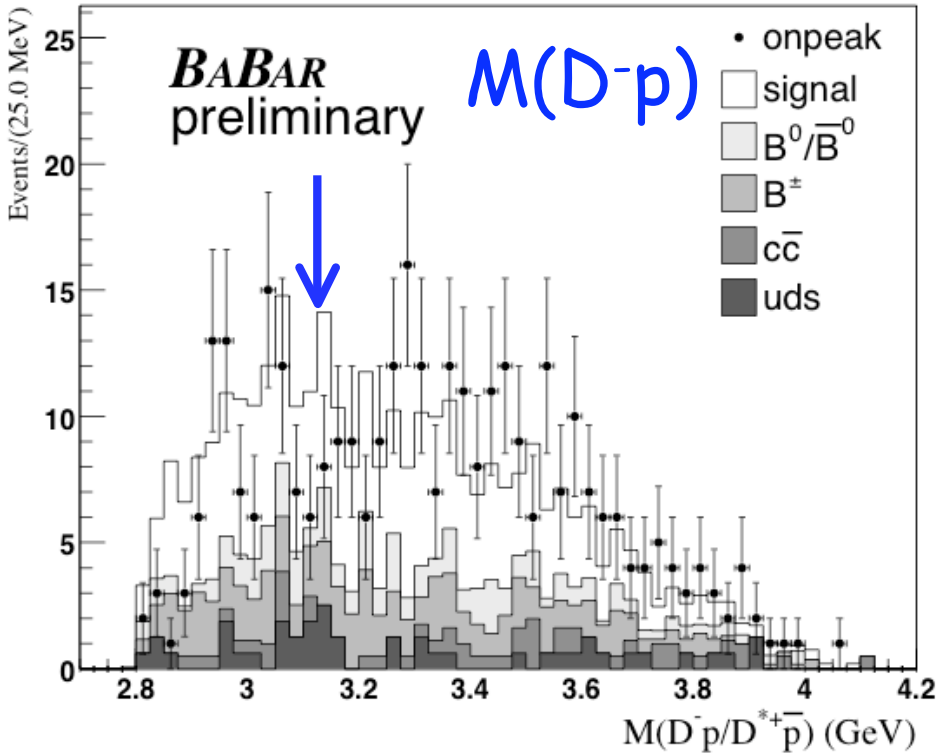
Final state	Significance	$\mathcal{B}(10^{-4})$	Reference $\mathcal{B}(10^{-4})$	
$B^0 \to D^{*-} p\bar{p}\pi^+$	13σ	$5.61 \pm 0.59 \pm 0.73$	$6.5^{+1.3}_{-1.2} \pm 1.0$	CLEO
$B^0 \to D^- p\bar{p}\pi^+$	13σ	$3.80 \pm 0.35 \pm 0.46$		New Decay
$B^0 \to \overline{D}^{*0} p\bar{p}$	4.0σ	$0.67 \pm 0.21 \pm 0.09$	$1.20^{+0.33}_{-0.29} \pm 0.21$	Belle
$B^0 \to \overline{D}^0 p\bar{p}$	12σ	$1.24 \pm 0.14 \pm 0.12$	$1.18 \pm 0.15 \pm 0.16$	

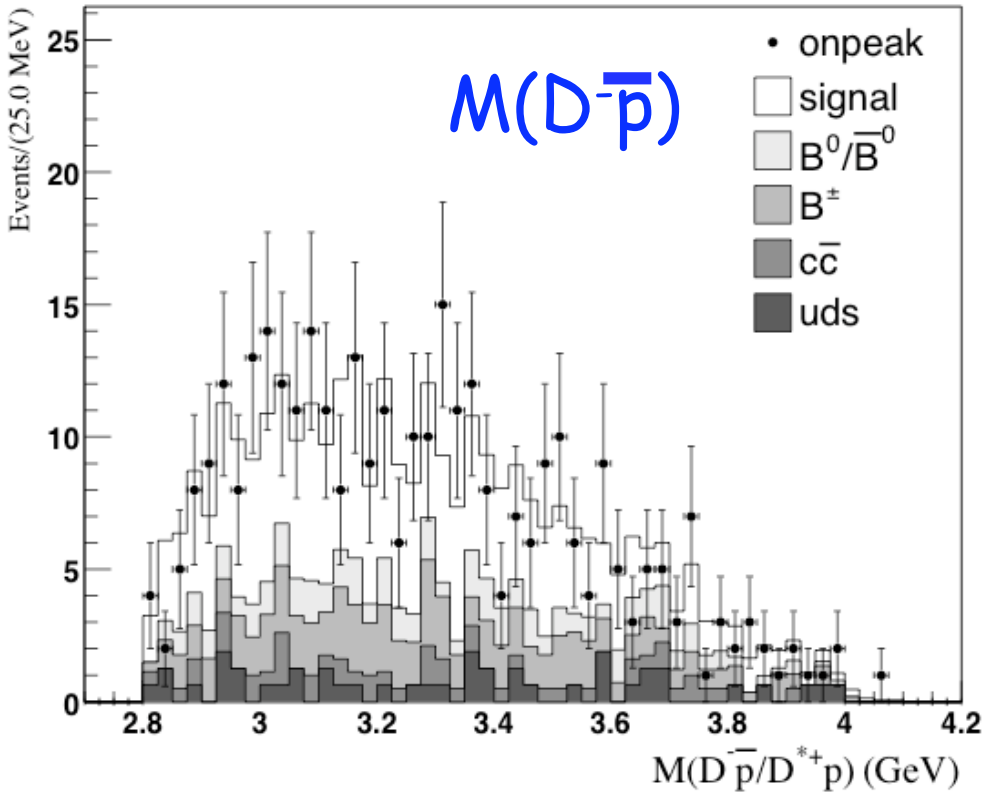
Mass Projections: $B^0 \rightarrow D^{*-} p p \pi^+$





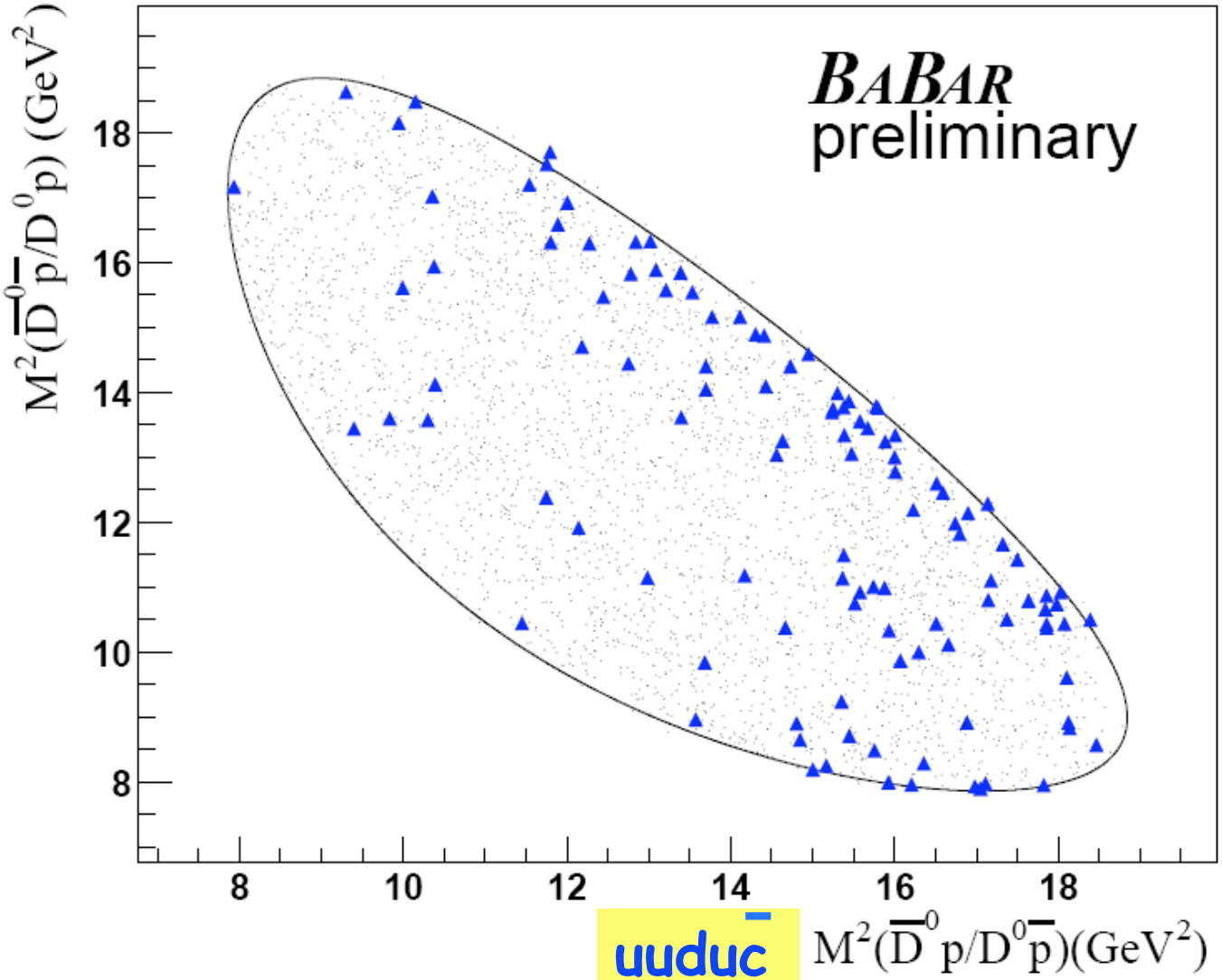
Mass Projections: $B^0 \to D^- p\bar{p}\pi^+$





Dalitz Plot of $B^0 \to \bar{D}^0 p\bar{p}$

$\bar{u}d\bar{u}uc$

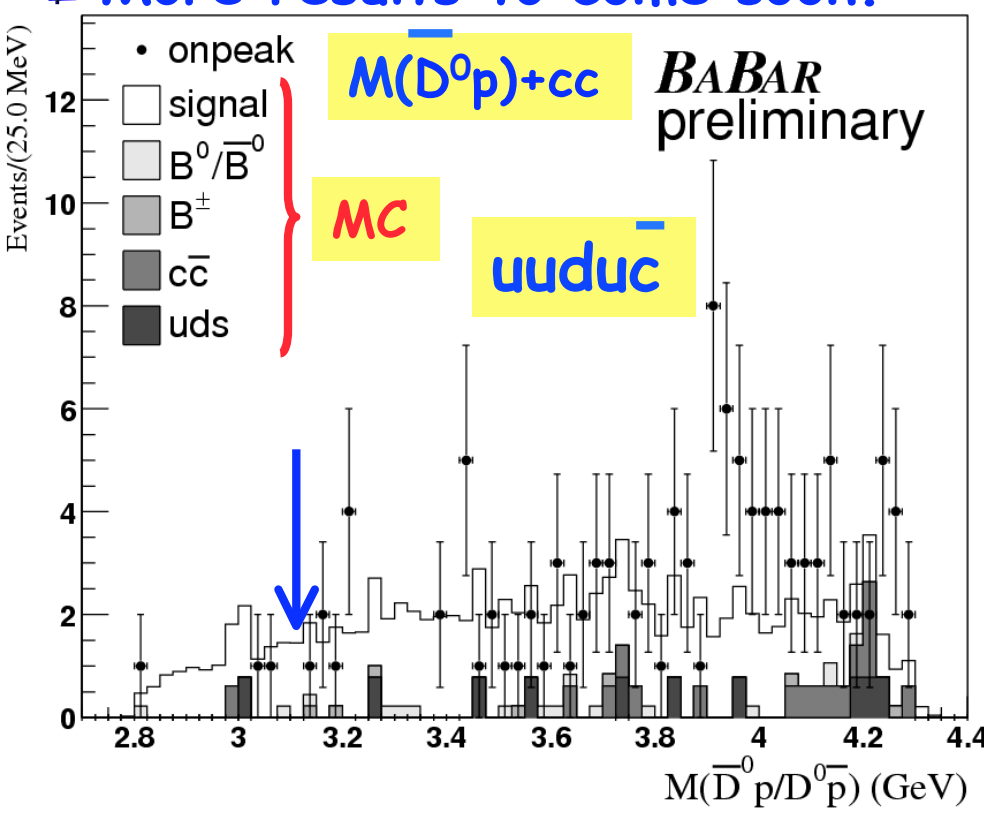


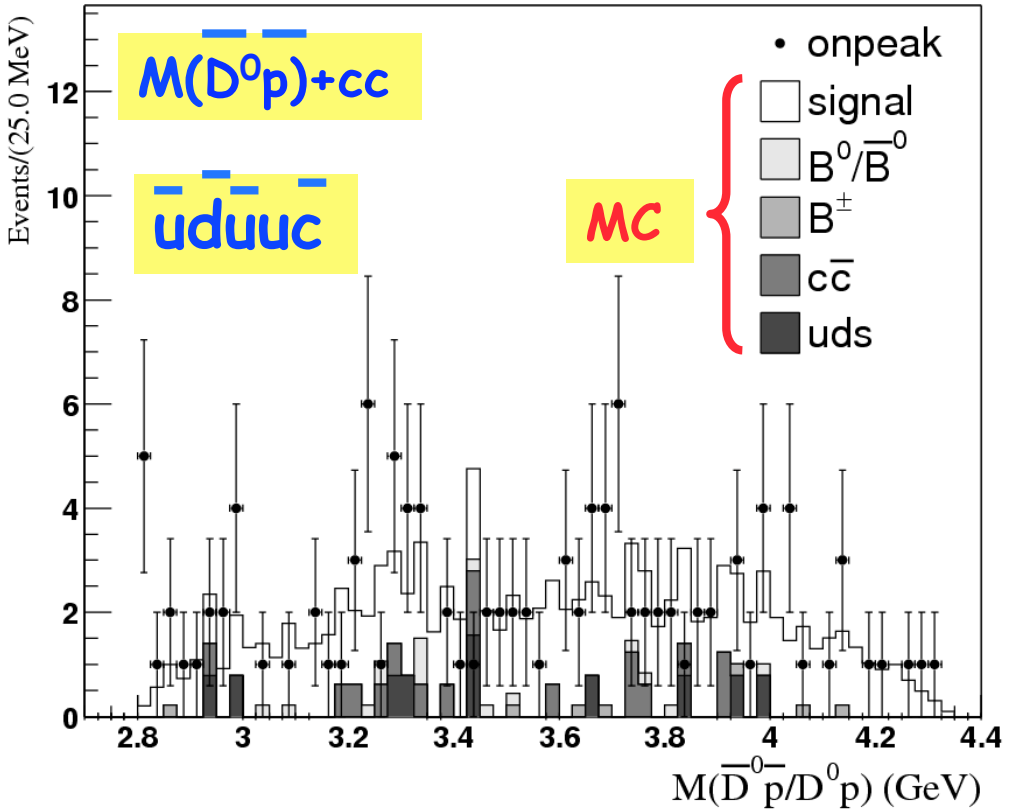
$uud\bar{u}c$

112.5 fb^{-1}

Mass Projections: $B^0 \to \bar{D}^0 p\bar{p}$

- As in the $B^+ \to p\bar{p}K^+$, we see an asymmetric $p\bar{p}$ threshold enhancement
- No sign of convincing structure in "exotic" combination
- More results to come soon.





Outlook and Conclusions

- Pentaquark searches at BaBar so far negative
  - No evidence so far of strange (Θ, Ξ_5, N_5) and charmed (Θ_c) pentaquarks in both exclusive B decays and inclusive searches in e^+e^-
  - Limits on Θ_5^+ and Ξ_5^{--} production cross sections lower than what's observed for non-exotic baryons
    - Pentaquarks not yet observed in e^+e^- annihilations…?
- However, the search continues!
  - New inclusive modes and techniques are being implemented
  - Many exclusive modes to be investigated
    - interesting physics in the exclusive modes apart from exotics