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New Heavy Quark Baryons

Michal Kreps

University of Karlsruhe

Why heavy baryon spectroscopy

- Heavy Quark mesons are QCD analog of "hydrogen atom"
  - $\longrightarrow$ Starts to be very sensitive test of various model in non-perturbative regime of QCD
  - $\longrightarrow$ Lot of information in charm sector
  - $\longrightarrow$ Bottom sector starts to speak up as well
- Heavy Quark baryon are next interesting laboratory
  - $\longrightarrow$ Heavy quark - light diquark is basic picture
  - $\longrightarrow$ Another sensitive test of models
  - $\longrightarrow$ Still many things to observe in charm sector
  - $\longrightarrow$ In bottom sector only Λ_b directly seen
- Discovery of new particles is exciting and fun

Where to study heavy baryons

- Everywhere where we produce them and have detector to detect them
- Current results come from

  $\longrightarrow$ B-factories (Belle, *BABAR*)

  - \+ Have large amount of data
  - \+ Clean environment
  - – Bound to charm sector

  $\longrightarrow$ Tevatron (CDF)

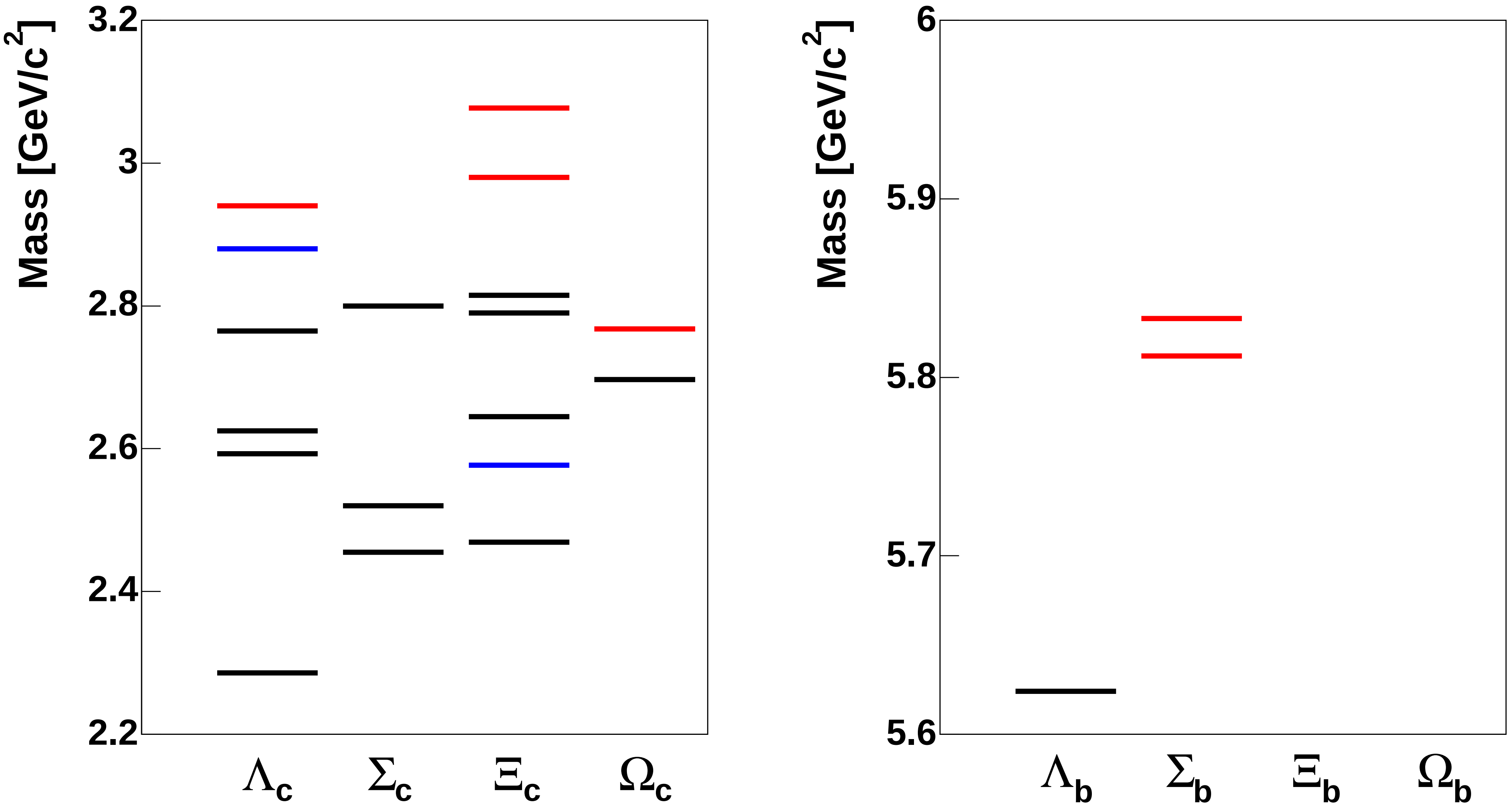
  - – Difficult environment from $p\bar{p}$ collisions
  - – Only now starts to have reasonable amount of data for b-baryons
  - \+ Can do all b-hadrons

Directly observed states

Listed in PDG 2006

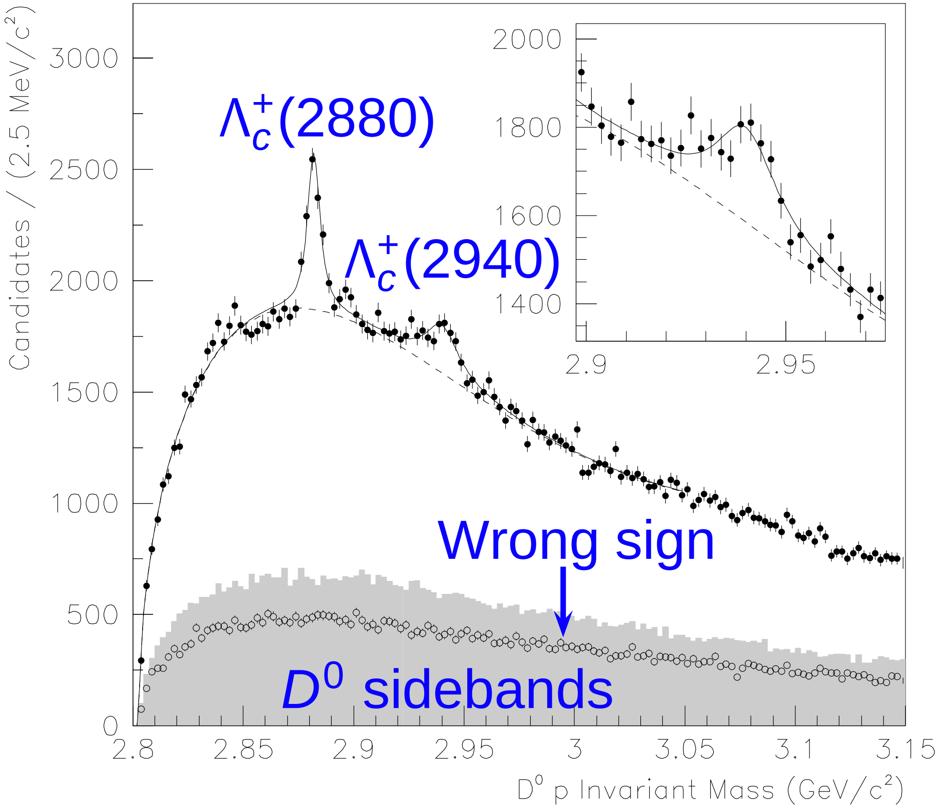
Listed in PDG 2006, but new results

Not in PDG 2006, covered here

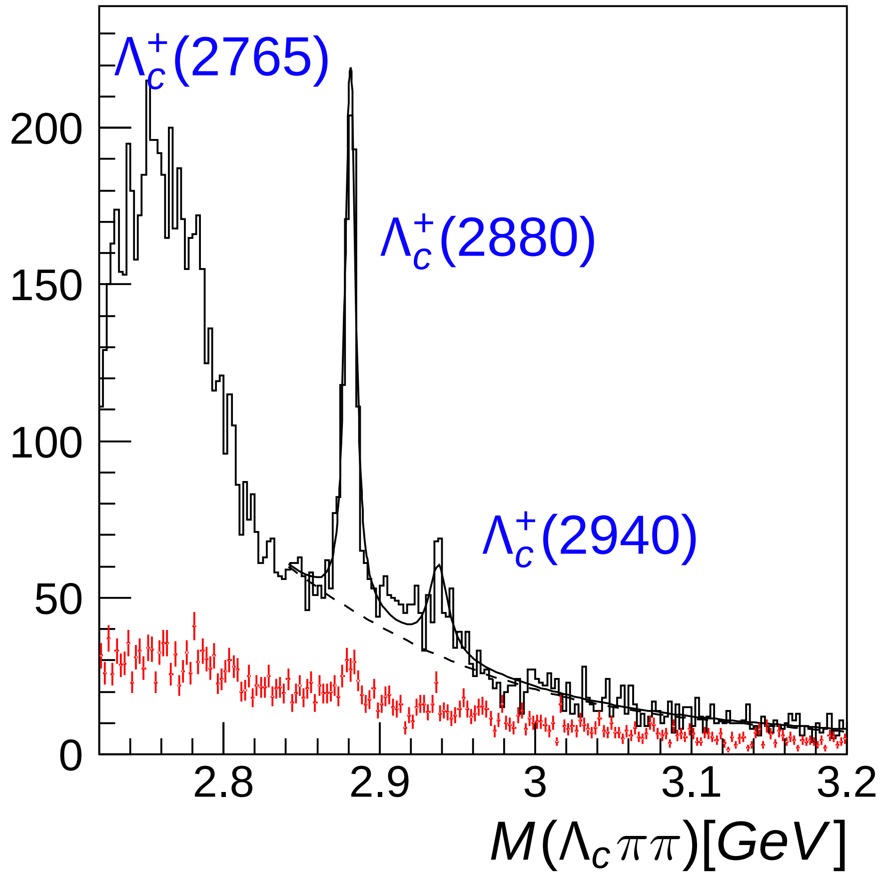


$\Lambda_c^+(2880)$, $\Lambda_c^+(2940)$

- 287 fb^{-1} of data
- $p\,D^0$ final state
- $D^0 \to K\pi$, $D^0 \to K\pi\pi\pi$
- PRL 98, 012001 (2007)



- 553 fb^{-1} of data
- Confirmation in $\Lambda_c^+\pi^+\pi^-$
- $\Lambda_c^+\pi^\pm$ consistent with $\Sigma_c(2455)$
- hep-ex/0608043



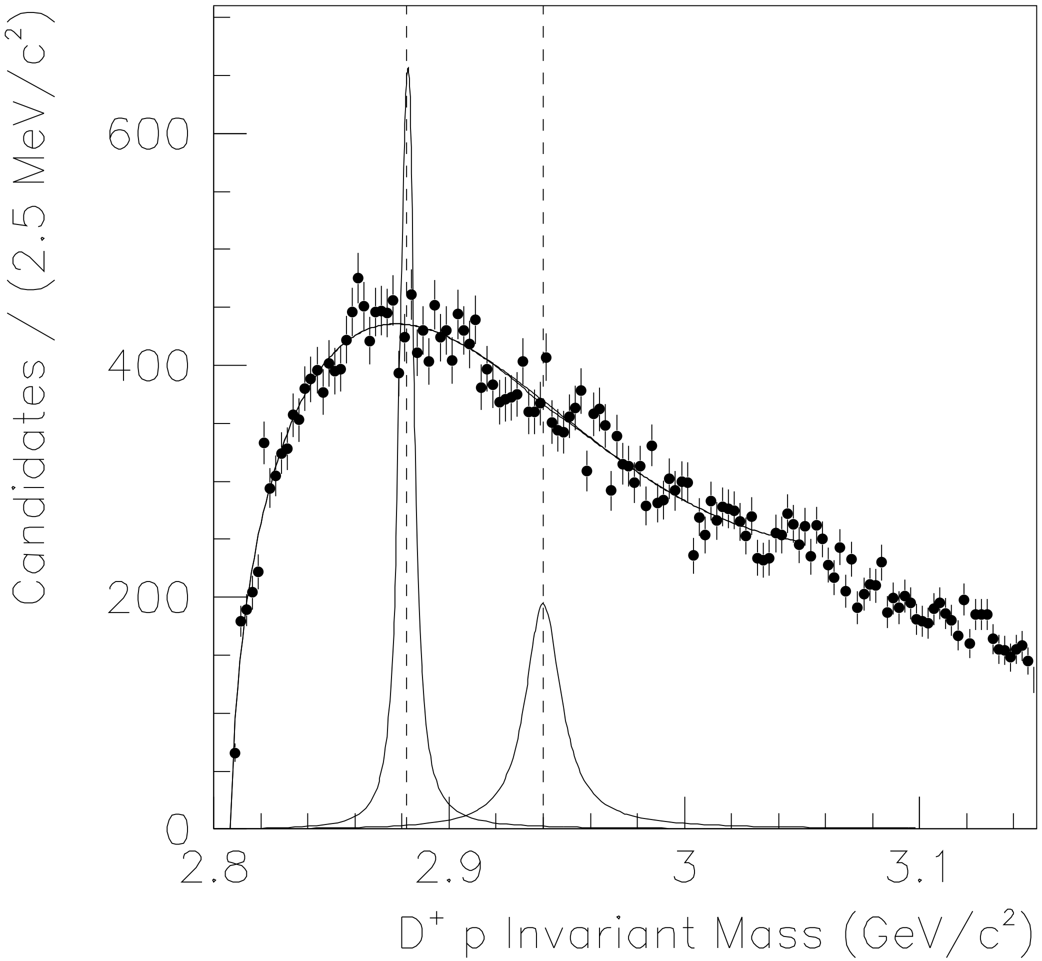
$\Lambda_c^+(2880)$, $\Lambda_c^+(2940)$

- $\Lambda_c(2880)$ known state, but pD^0 decay is new
- $\Lambda_c(2940)$ observed for the first time
- Significance $7.5\,\sigma$ at *BABAR* and $6.2\,\sigma$ at Belle
- Mass and width consistent between experiments

	State	Mass [MeV$/c^2$]	Width [MeV$/c^2$]
BABAR	$\Lambda_c(2880)$	$2882 \pm 0.1 \pm 0.5$	$5.8 \pm 1.5 \pm 1.1$
Belle	$\Lambda_c(2880)$	$2881.2 \pm 0.2 \pm 0.4$	$5.5 \pm 0.7 \pm 1.1$
BABAR	$\Lambda_c(2940)$	$2939.8 \pm 1.3 \pm 1.0$	$17.5 \pm 5.2 \pm 5.9$
Belle	$\Lambda_c(2940)$	$2938.0 \pm 1.3^{+2.0}_{-4.0}$	$13\,^{+8}_{-5}\,^{+27}_{-7}$

- To learn more, both experiments do further studies
  - $\rightarrow$ *BABAR* checks isospin partners
  - $\rightarrow$ Belle studies resonant substructure of decay and angular distributions

$\Lambda_c^+(2880), \Lambda_c^+(2940)$



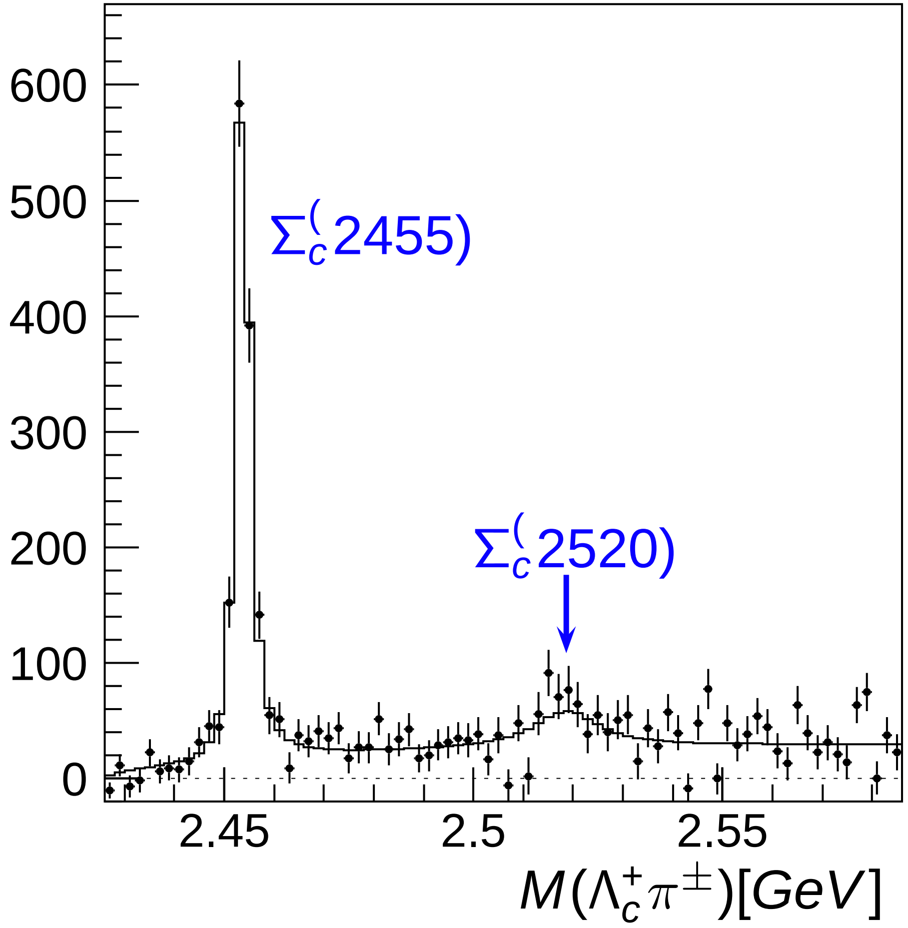
Curves same rate as pD^0

- $\rightarrow$ If $\Sigma_c \Rightarrow$ also $\Sigma_c^{++} \rightarrow D^+p$
  $D^+ \rightarrow K\pi\pi$
- $\rightarrow$ No resonant structure seen
- $\Rightarrow$ Both states are Λ_c's
- 3 Λ_c states predicted $\approx$ 2940 MeV$/c^2$
  $J^P = (1/2)^+, (1/2)^-, (3/2)^-$
  Migura et al, Eur.Phys.J. A28 (2006) 41
- The $\Lambda_c(2880)^+$ is near a predicted $(3/2)^-$ state.
- Details PRL 98, 012001 (2007)

$\Lambda_c^+(2880)$

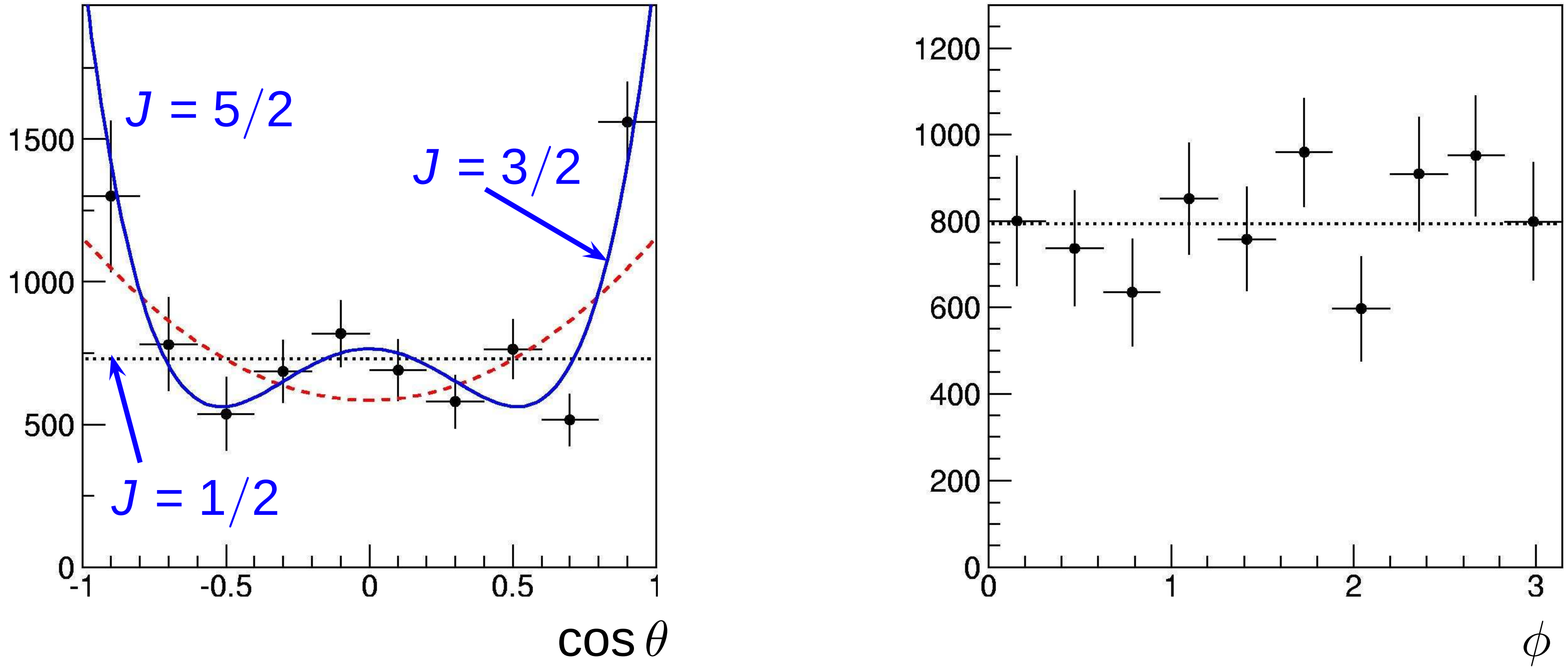
Fit $\Lambda_c(2880)$ yield in bins of $M(\Lambda_c^+\pi^\pm)$

Details: hep-ex/0608043



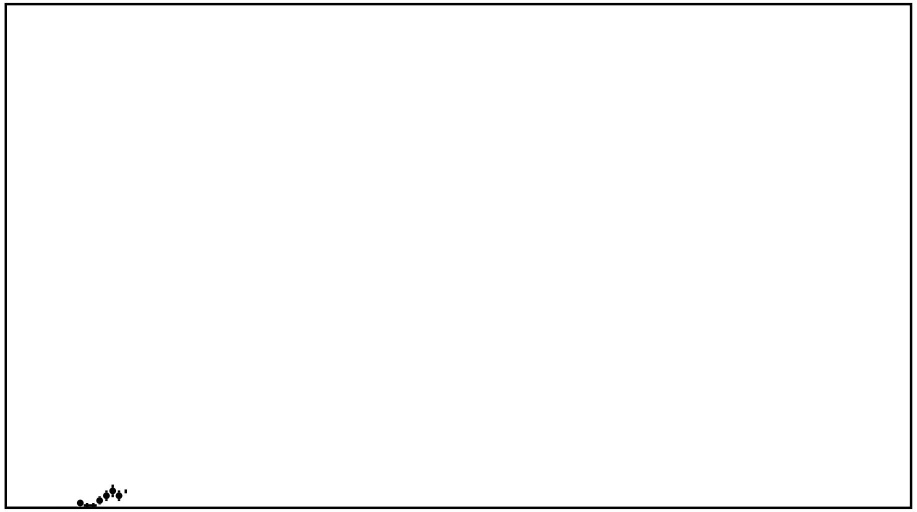
- Significance of $\Lambda_c(2880) \to \Sigma_c(2520)\pi$ 3σ with syst.
- $\Gamma(\Sigma_c(2455)\pi)/\Gamma(\Lambda_c\pi\pi) = 40.4 \pm 2.1 \pm 1.4\%$
- $\Gamma(\Sigma_c(2520)\pi)/\Gamma(\Lambda_c\pi\pi) = 9.1 \pm 2.5 \pm 1.0\%$
- $\Gamma(\Sigma_c(2520)\pi)/\Gamma(\Sigma_c(2455)\pi) = 22.5 \pm 6.2 \pm 2.5\%$

$\Lambda_c^+(2880)$



- Fit $\Lambda_c(2880)$ mass distribution in angular bins and subtract non-resonant contribution
- χ^2/ndf.: 46.7/9 ($J = 1/2$); 35.1/8 ($J = 3/2$); 12.1/7 ($J = 5/2$)
- From χ^2 difference exclude $J = 1/2$ ($J = 3/2$) by 5.5 σ (4.8 σ)
- HQS expectations for $\Gamma(\Sigma_c(2520)\pi)/\Gamma(\Sigma_c(2455)\pi)$: 140% ($J^P = 5/2^-$) and 23 – 36% ($J^P = 5/2^+$)

$\Xi_c(2980)$, $\Xi_c(3077)$



Σ_b Fit result

- Mass differences (MeV/c^2)

$\rightarrow$ $m(\Sigma_b^-) - m(\Lambda_b) - m(\pi) =$
$55.9 \pm 1.0(\mathrm{stat}) \pm 0.1(\mathrm{sys})$

$\rightarrow$ $m(\Sigma_b^+) - m(\Lambda_b) - m(\pi) =$
$48.4^{+2.0}_{-2.3}(\mathrm{stat}) \pm 0.1(\mathrm{sys})$

$\rightarrow$ $m(\Sigma_b^*) - m(\Sigma_b) =$
$21.3^{+2.0}_{-1.9}(\mathrm{stat})^{+0.4}_{-0.2}(\mathrm{sys})$

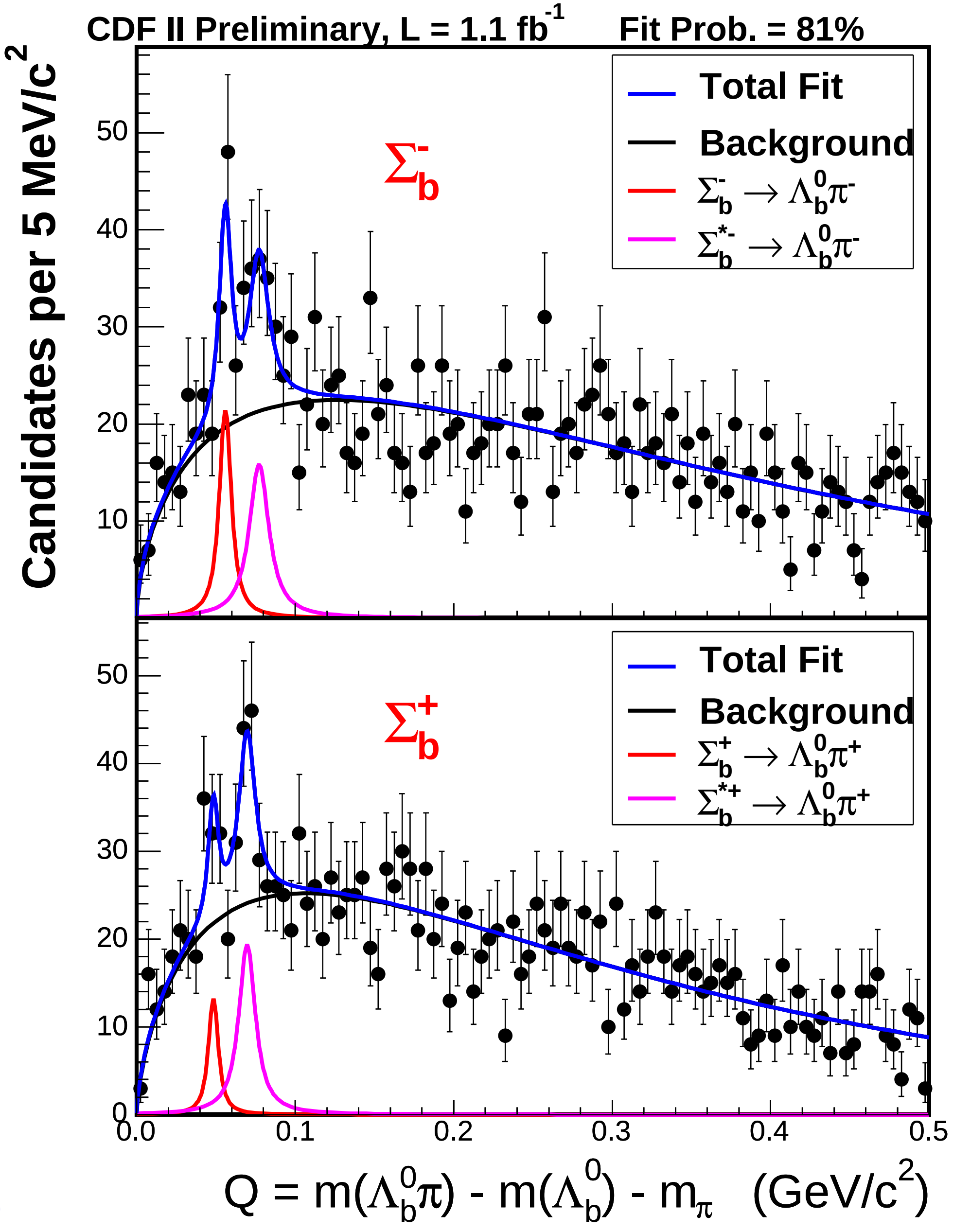
- Signal events

$\rightarrow$ $N(\Sigma_b^+) = 29^{+12.4}_{-11.6}(\mathrm{stat})^{+5.0}_{-3.4}(\mathrm{sys})$

$\rightarrow$ $N(\Sigma_b^-) = 60^{+14.8}_{-13.8}(\mathrm{stat})^{+8.4}_{-4.0}(\mathrm{sys})$

$\rightarrow$ $N(\Sigma_b^{*+}) = 74^{+17.2}_{-16.3}(\mathrm{stat})^{+10.3}_{-5.7}(\mathrm{sys})$

$\rightarrow$ $N(\Sigma_b^{*-}) = 74^{+18.2}_{-17.4}(\mathrm{stat})^{+15.6}_{-5.0}(\mathrm{sys})$



Σ_b Significance

- Repeat fit with alternative hypothesis
  - Single peak left out
  - Only one peak in each charge combination
  - No peak, pure background
- Derived from $\Delta(-\ln\mathcal{L})$

Hypothesis	$\Delta(-\ln\mathcal{L})$	Hypothesis	$\Delta(-\ln\mathcal{L})$
Null	44.7	No Σ_b^-	10.4
2 peaks	14.3	No Σ_b^+	1.1
		No Σ_b^{*-}	10.1
		No Σ_b^{*+}	9.8

$\Rightarrow$ Significance more than 5σ for 4 peaks

$\Rightarrow$ Evidence for three out of four individual peaks

Details at
http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-sigmab

Conclusions

- Last year very rich for Heavy Quark Baryons
- Several new baryon states in charm sector discovered
  $\Lambda_c^+(2940)$, $\Xi_c^{+,0}(2980)$, $\Xi_c^{+,0}(3077)$ and Ω_c^*
- Several refined measurements in charm sector
- Charged Σ_b states discovered in bottom sector

$\Rightarrow$ Our knowledge about Heavy Quark Baryons increased

$\longrightarrow$ I'm convinced this was not our last word on the topic