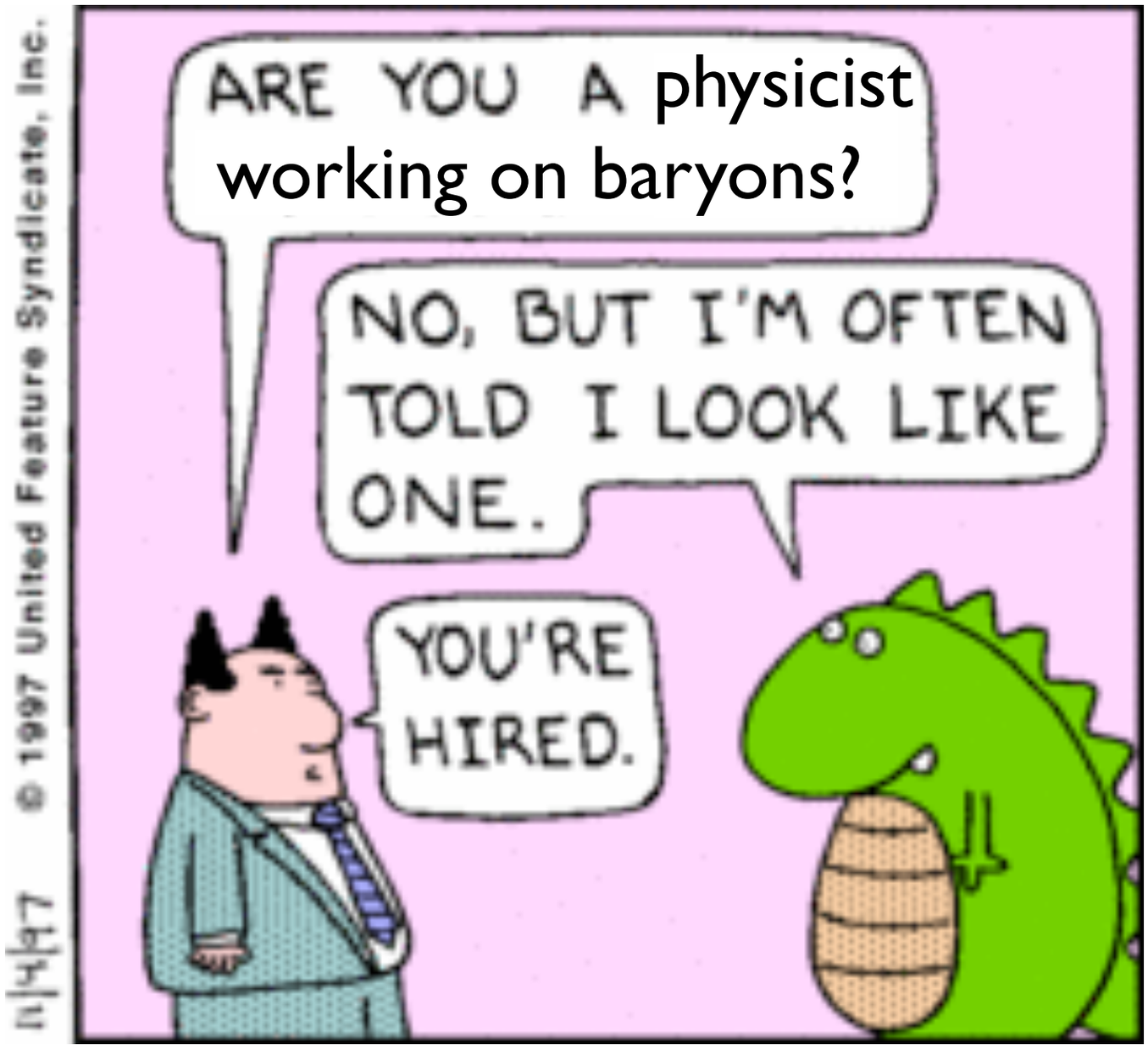
Prospects for charmed baryons

Mat Charles (Oxford)

Why I am giving this talk



Apologies to Scott Adams

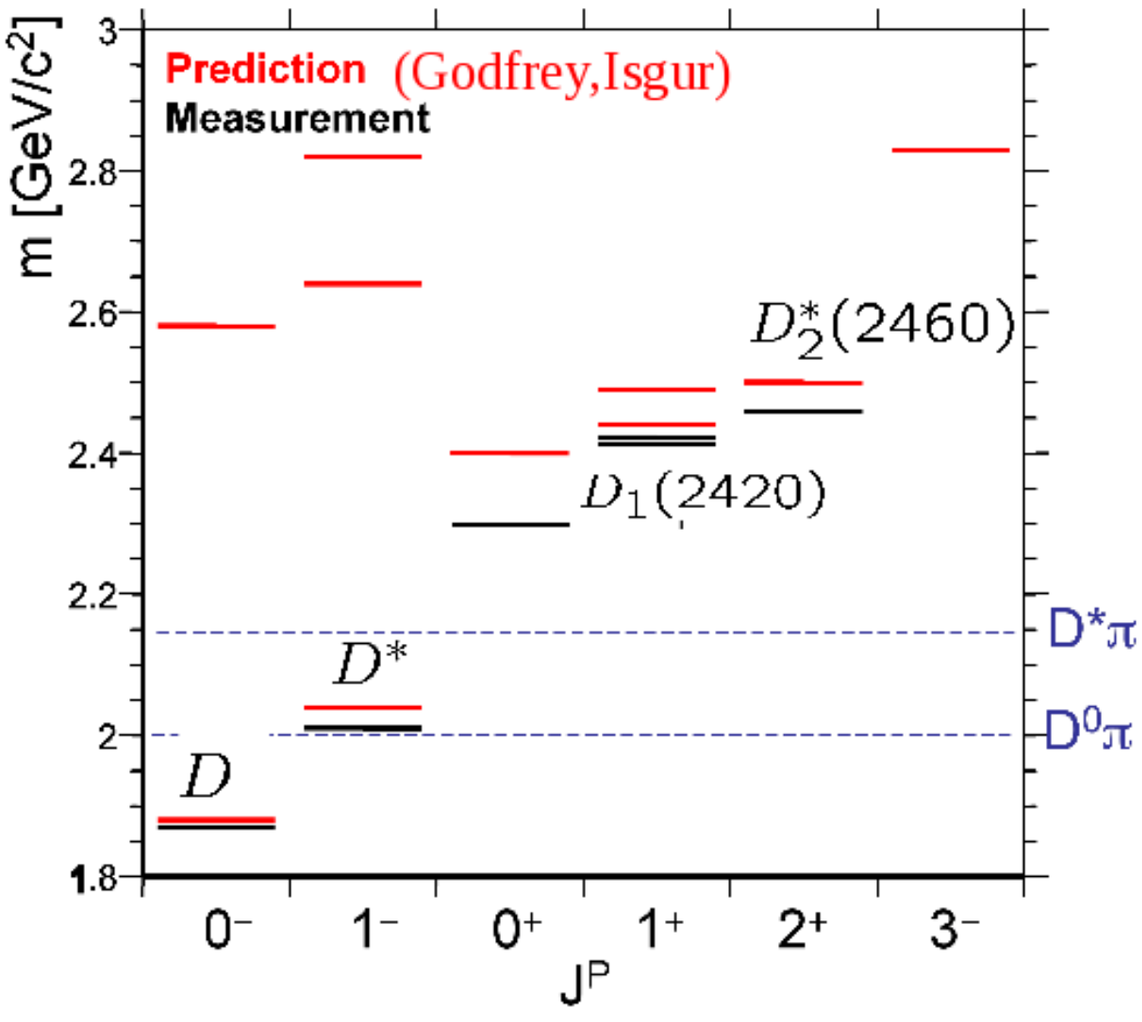
In this talk

- Focus is on "prospects" rather than "status"
- Main topics:
  - Spectroscopy of singly charmed baryons
  - Doubly charmed baryons
  - Implications for b baryons
- Afterthoughts

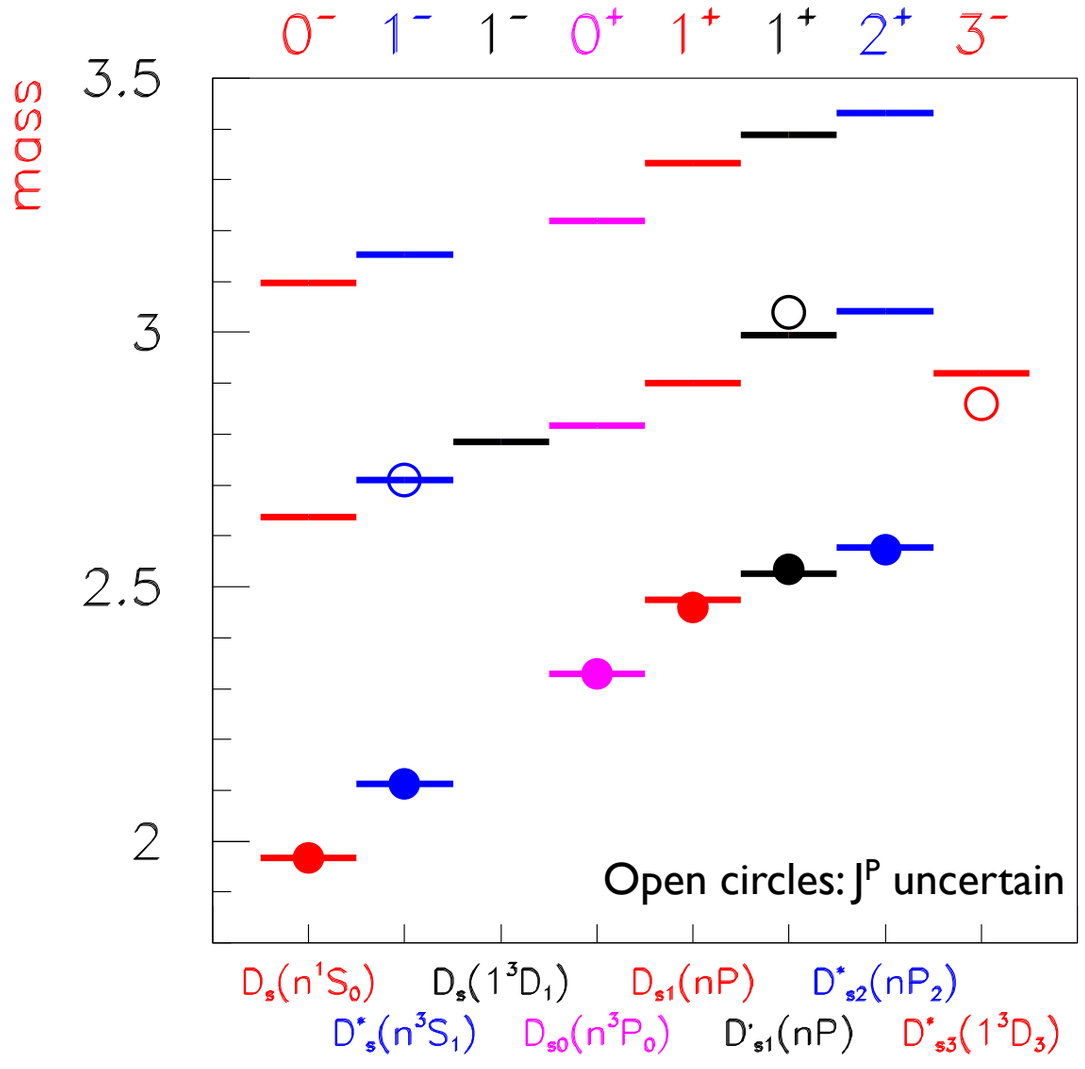
Background: Charm meson spectroscopy

From Antimo Palano's talk on open charm meson spectroscopy at EuroFlavour 2009:

D mesons



D_s mesons

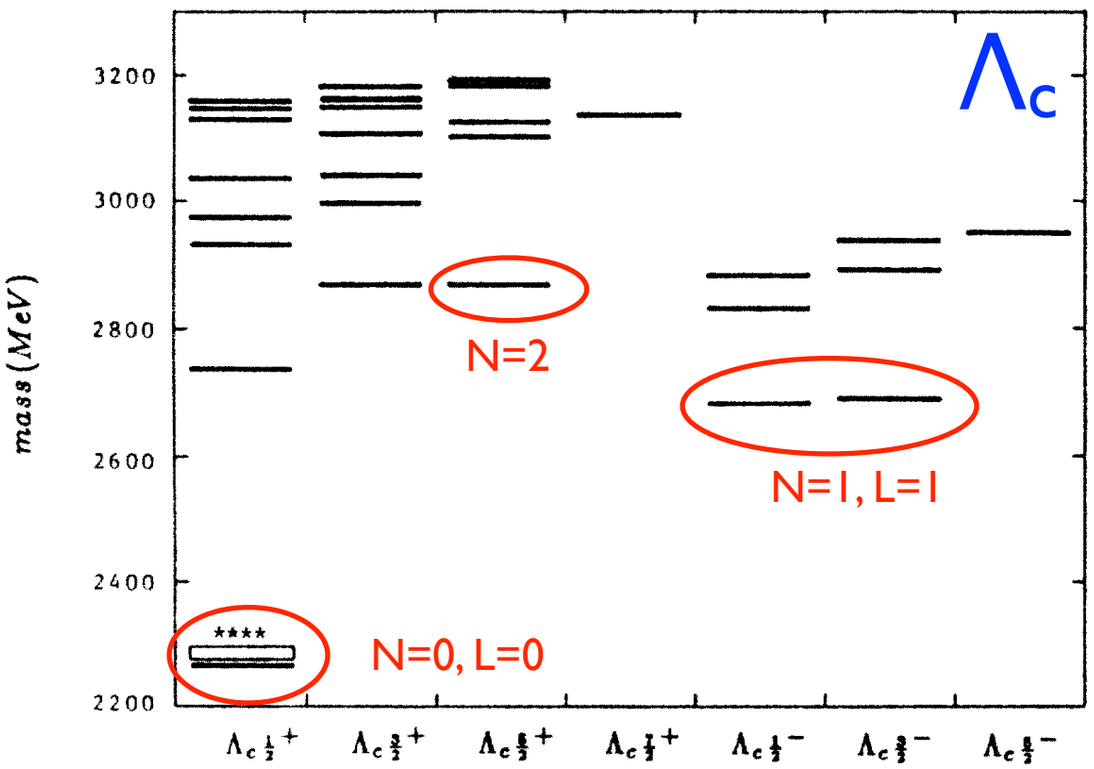


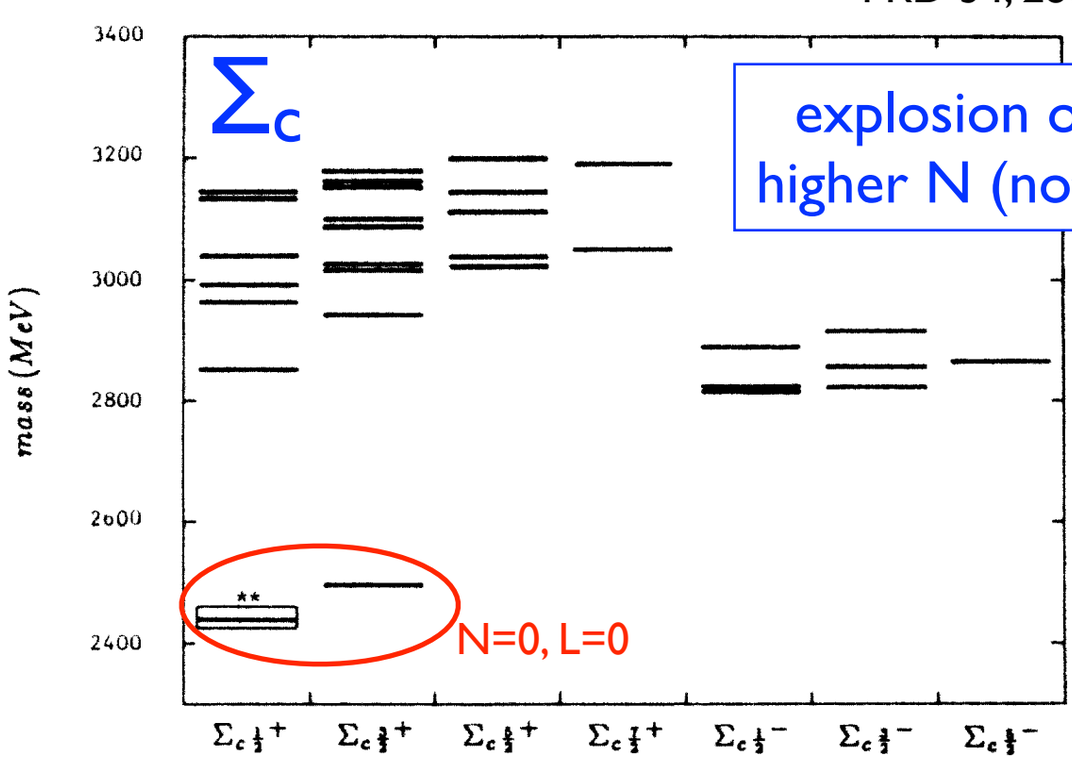
- n=0 states trivial.
- n=L=1 states accounted for, broadly understood.
- Less known about radially excited states, but tractable pattern

Charm baryon spectroscopy (Λ_c and Σ_c)

Prediction from Capstick & Isgur (1986) up to N=2:

PRD 34, 2809 (1986)





explosion of states at higher N (not observed)

Red circles: observed states where we have fairly solid idea of J^P assignment.

States known experimentally:

State	Assumed J^P	Status
Λ_c	$^1/_2$ +	****
$\Lambda_c(2595)$	$^3/_2$ −	***
$\Lambda_c(2625)$	$^3/_2$ −	***
$\Lambda_c(2880)$	$^5/_2$ +	***
$\Lambda_c(2940)$	?	***

State	Assumed J^P	Status
$\Sigma_c(2455)$	$^1/_2$ +	****
$\Sigma_c(2520)$	$^3/_2$ +	***
$\Sigma_c(2800)$	?	***
Λ_c / $\Sigma_c(2765)$	?	*

J^P now measured!

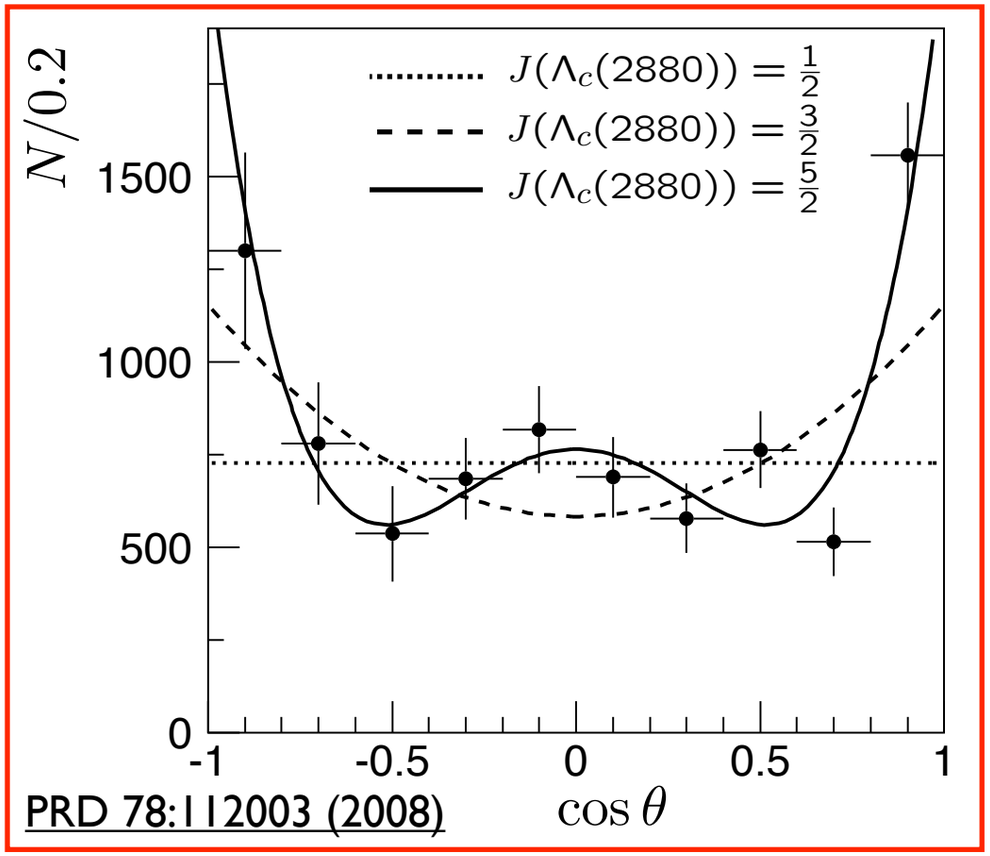
Spectroscopy of singly charmed baryons

- Well-understood for ground & low-lying states
  - Heroic work by CLEO here
- Two problems for higher states:
  - We only know of a handful -- many missing
    - Some, esp. higher excitations, hard to produce at e^+e^- B-factories
    - Some will be broad & hard to see
    - ... and surely some where we didn't look in the right final state yet
  - Identification: very few have measured quantum numbers
- Good news: LHCb can help on both counts
  - 1 year of nominal running $\approx 2\ fb^{-1} \approx 10^{13}$ ccbar pairs
  - Main challenge, as ever, is triggering

Identifying states

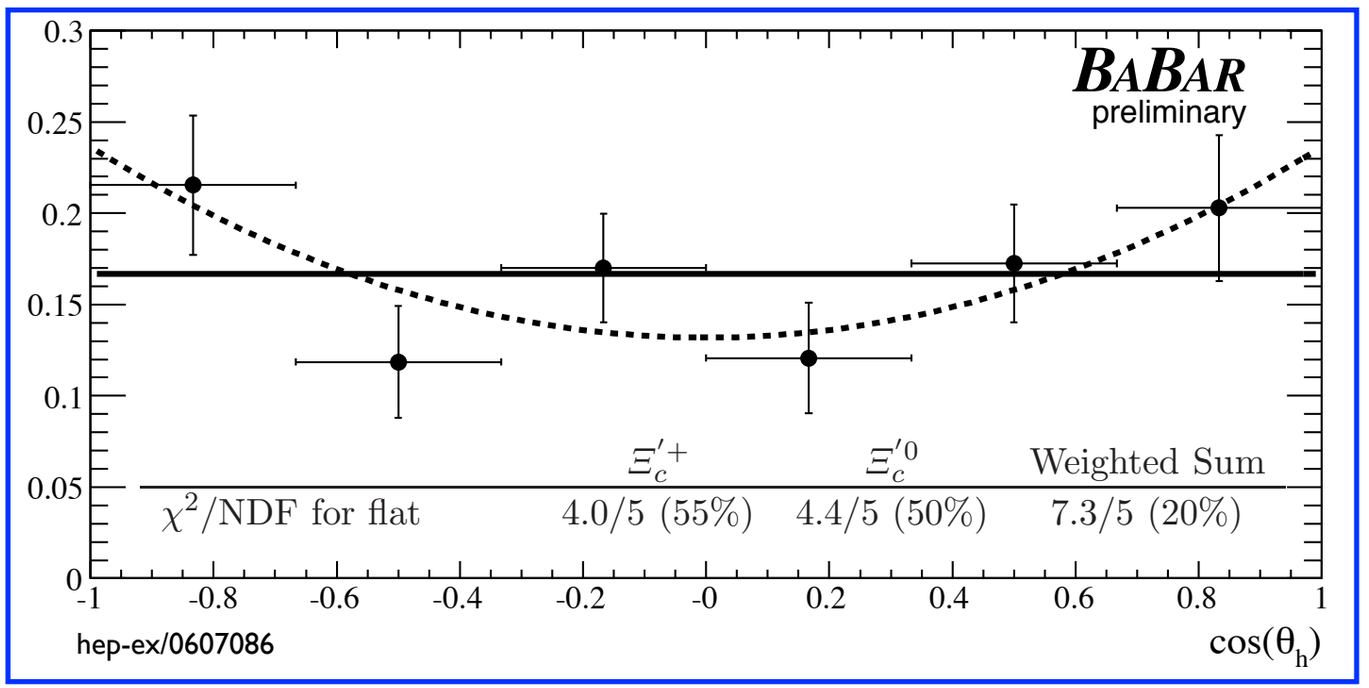
- Measuring J^P of inclusively-produced states is hard because you don't know how spin states are populated.
- Sometimes it works out, e.g. Belle's angular analysis of $\Lambda_c(2880)^+ \to \Sigma_c(2455)^0\,(\Lambda_c^+\,\pi^-)\,\pi^+$
- ... but if angular distribution comes out flat, e.g. Babar's analysis of $\Xi'_c{}^0 \to \Xi_c^0\,(\Xi^-\,\pi^+)\,\gamma$, can't really exclude anything.

Belle $\Lambda_c(2880)^+ \to \Sigma_c(2455)^0\,\pi^+$



PRD 78:112003 (2008)

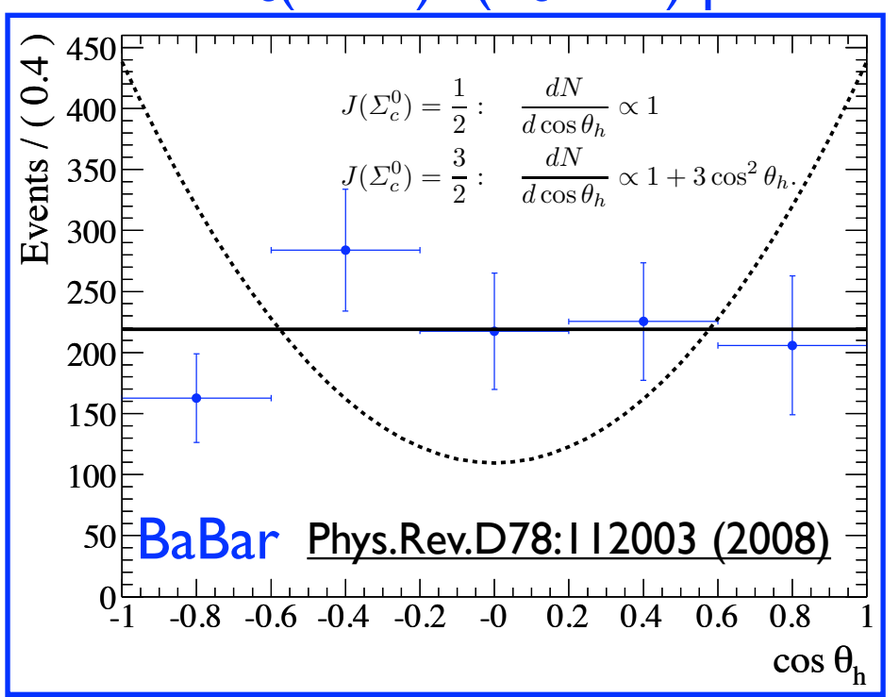
BaBar $\Xi'_c{}^0 \to \Xi_c^0\,\gamma$



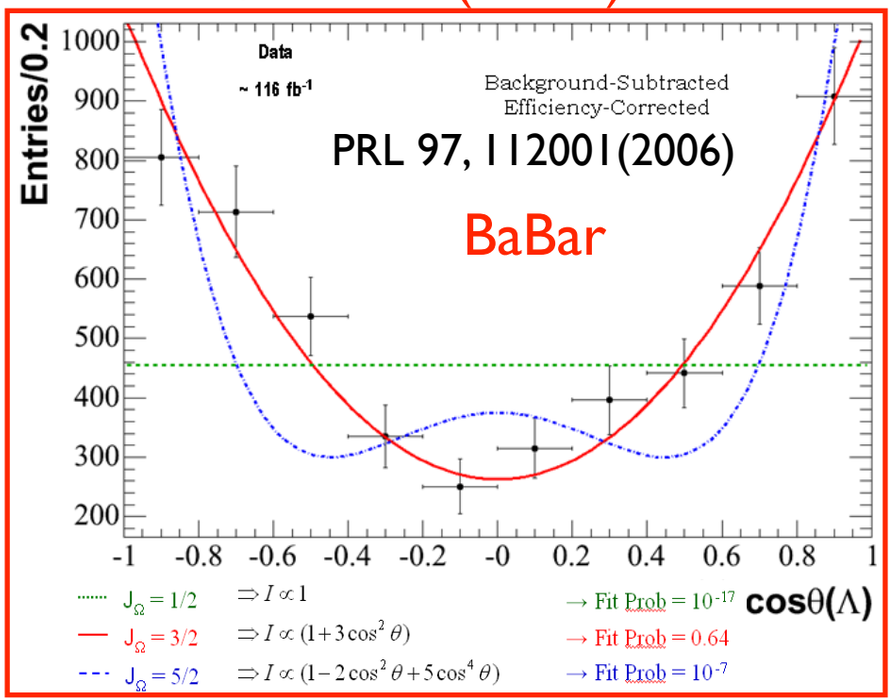
Identifying states

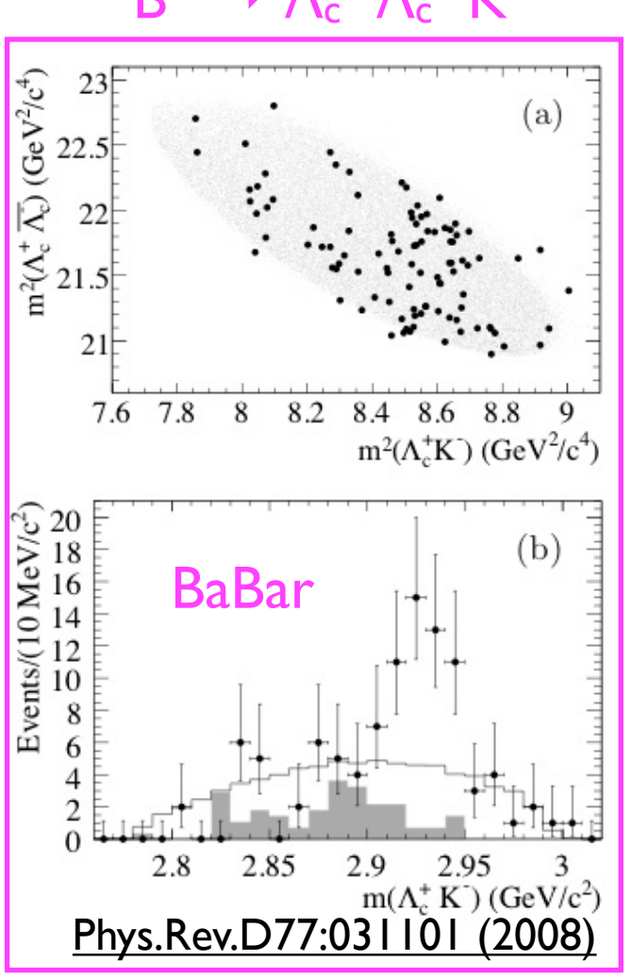
- More powerful: exclusive production from known initial state.
  - e.g. BABAR: Spin of $\Sigma_c(2455)$ from $B^- \to \Sigma_c(2455)^0\ (\Lambda_c^+ \pi-)$ pbar
  - e.g. BABAR: Spin of Ω^- from $\Xi_c^0 \to \Omega^-\ (\Lambda^0 K^-)\ K^+$
- ... but Belle & BABAR can't do these for higher excited states
  - B mesons don't like high-L decays to baryons with large J
  - Rates often marginal for B decays to baryons
- LHCb may be able to crack the problem open: $B^- \to \Lambda_c^+ \Lambda_c^- K^-$
  - Sheer statistics for modes like $B^- \to \Xi_c(2980)^0\ (\Lambda_c^+ K^-)\ \Lambda_c^-$
  - 3-body decays of B baryons, perhaps like: $\Lambda_b^0 \to \Sigma_c^*\ \pi$

$B^- \to \Sigma_c(2455)^0\ (\Lambda_c^+ \pi-)$ pbar



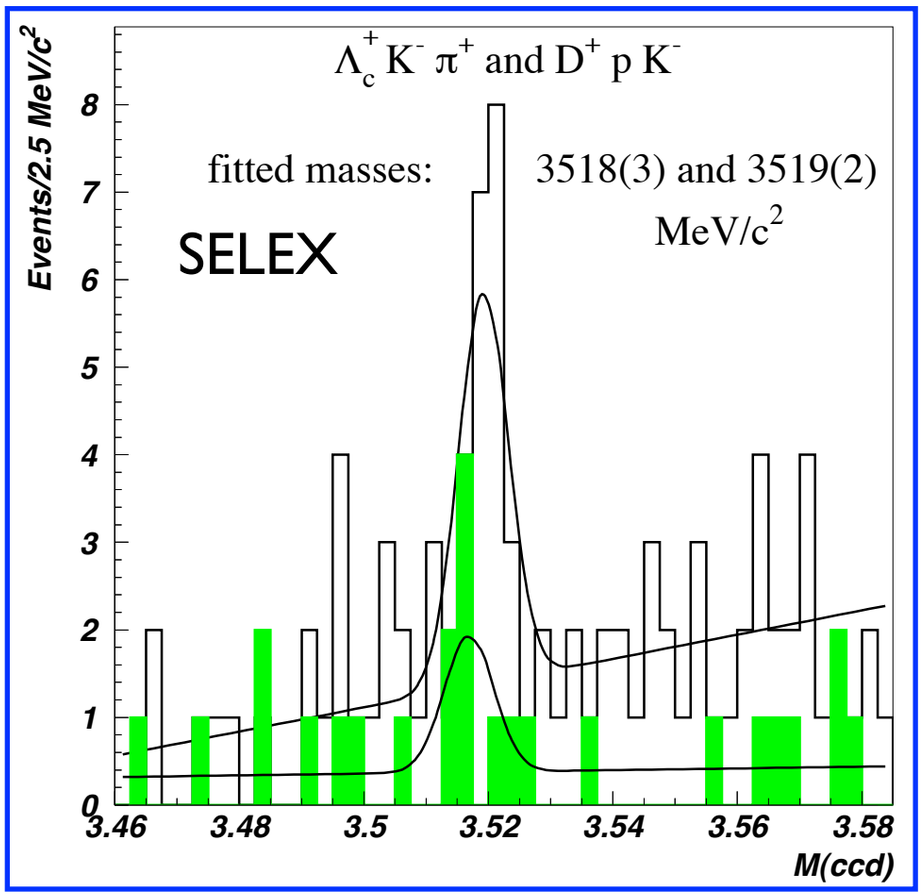
$\Xi_c^0 \to \Omega^-\ (\Lambda^0 K^-)\ K^+$



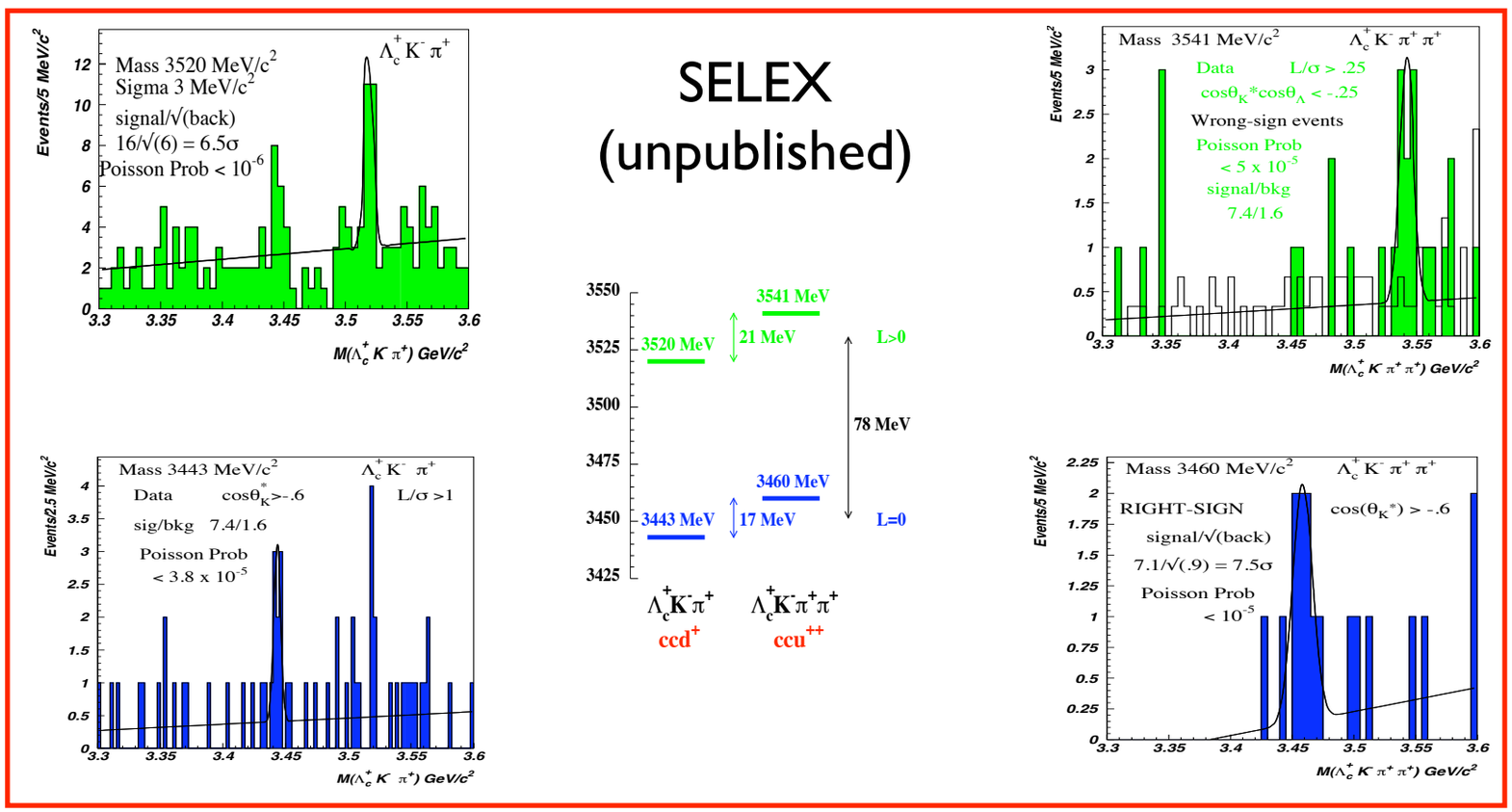


Doubly charmed baryons

- In 2002 and 2004, SELEX published results on a weakly-decaying Ξ_{cc}^+ at 3518 MeV/c^2
  - $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$: 15.9 events over background of 6.1 ± 0.5 => 6.3σ
  - $\Xi_{cc}^+ \to p D^+ K^-$: 5.62 events over background of 1.38 ± 0.13 => 4.8σ
  - ... and also unpublished results on 4 other claimed Ξ_{cc} states
- These observations have not been confirmed yet
  - Searches by BABAR, Belle, FOCUS.
  - SELEX used O(1600) Λ_c^+, FOCUS O(20k), BaBar+Belle O(1M)

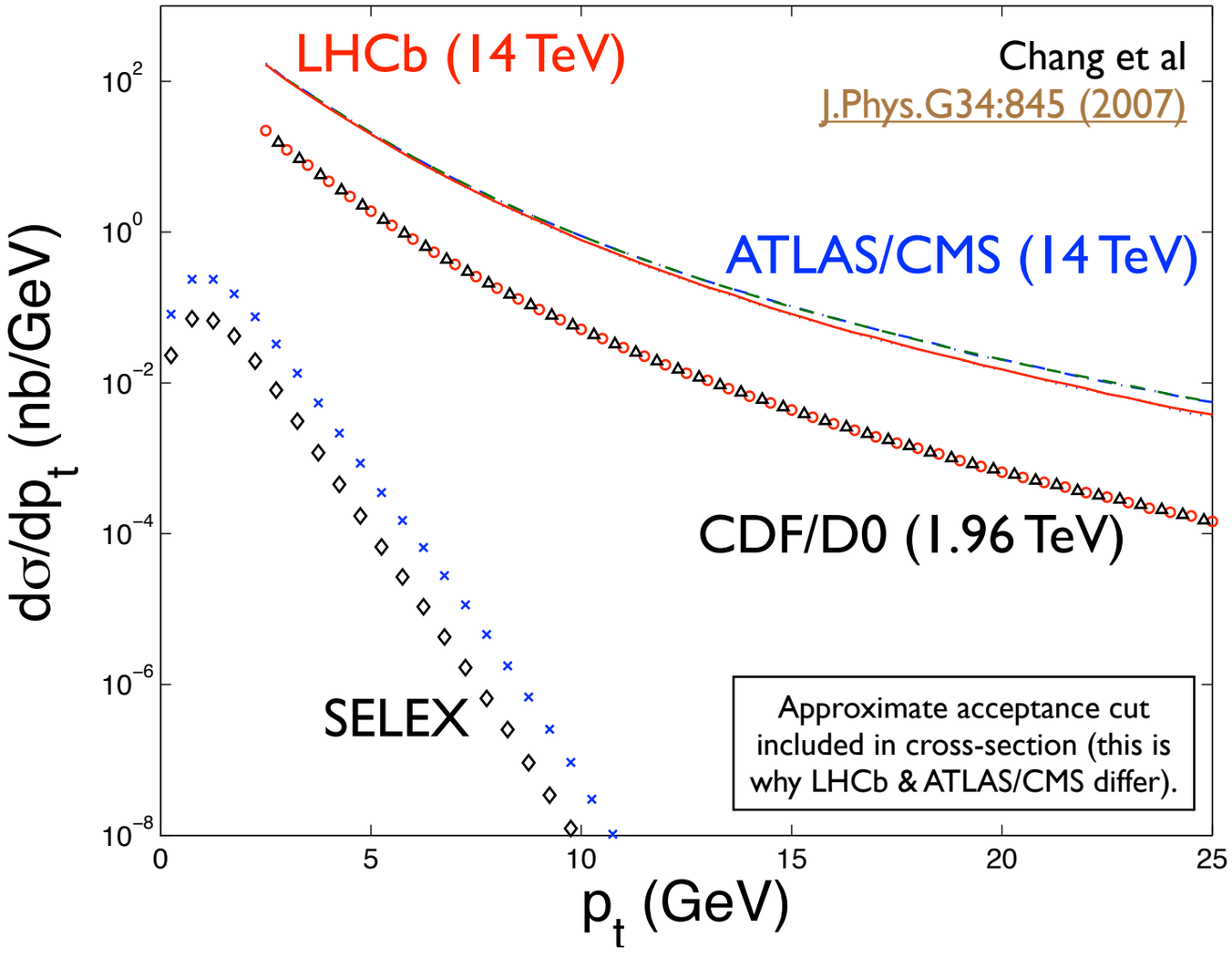


PRL 89:112001 (2002) and PLB 628:18 (2005)



Doubly charmed baryons

- Things have been quiet for a few years.
  - SELEX has no more data
  - Nobody else sees it, but can't rule out enhanced rate at SELEX
  - ... but serendipity: interesting spectrum of Ξ_c^* seen in same $\Lambda_c^+ K^- \pi^+$ final state by Belle & BABAR (but not SELEX)
- ... but resolution is in sight: LHCb should be able to observe the states and confirm or overturn the SELEX result.

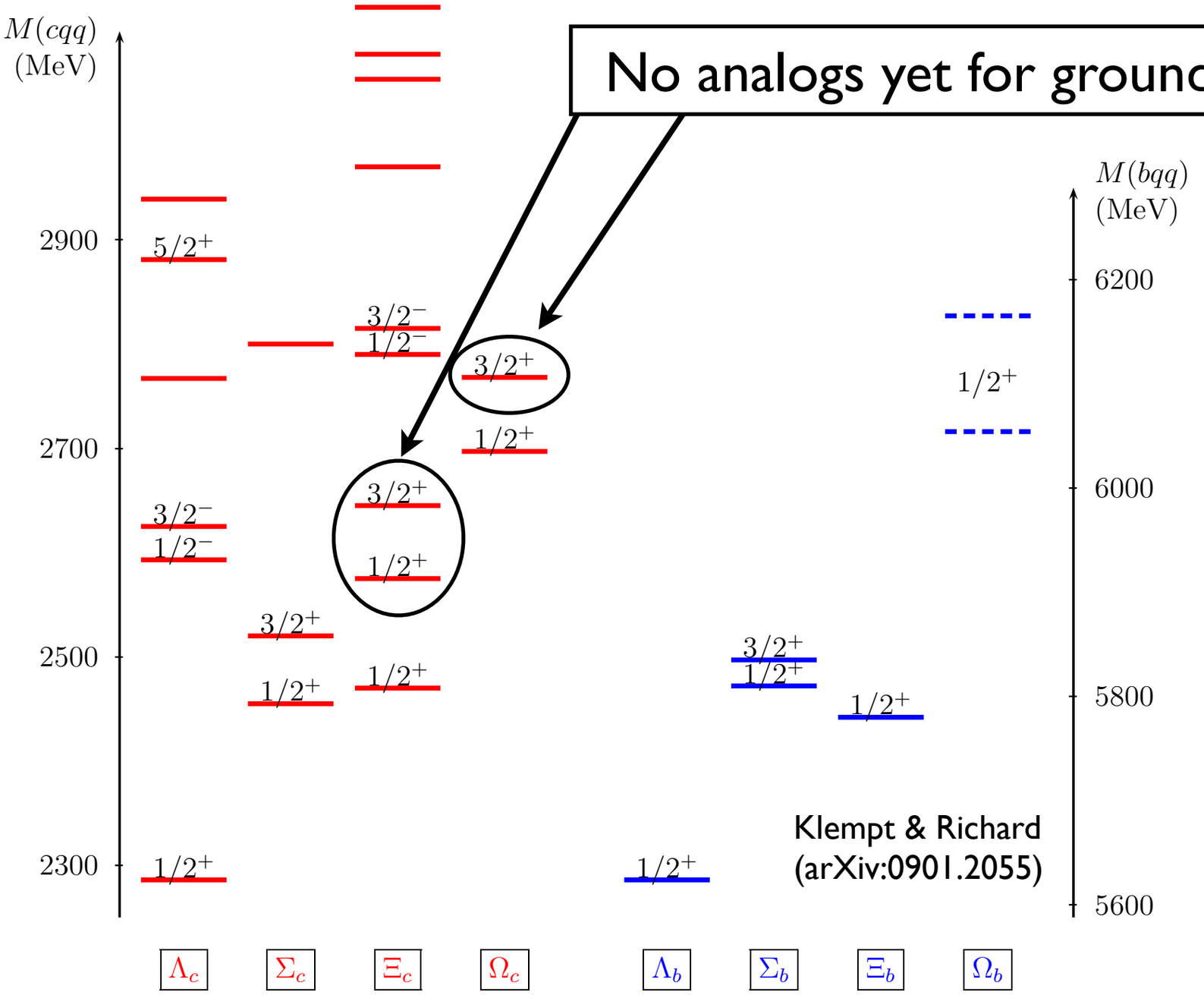


Theory estimates of cross-section vary a lot:

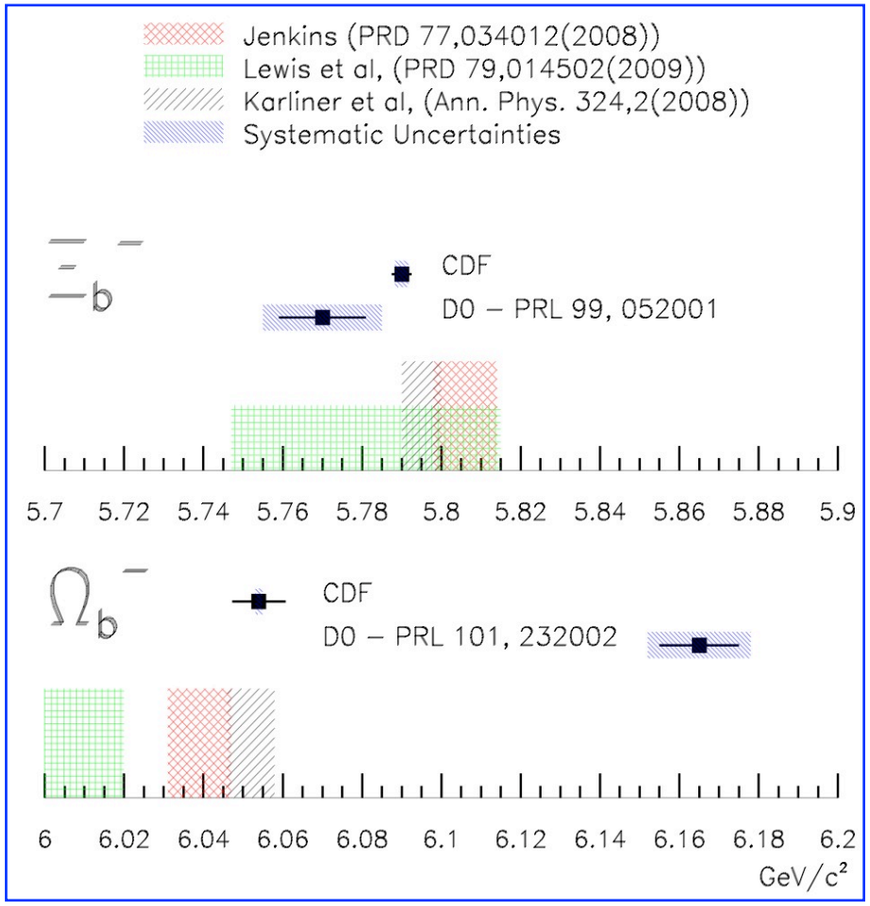
Paper	σ at Tevatron ($\sqrt{s}$=1.96 TeV)	σ at LHC ($\sqrt{s}$=14 TeV)	Ratio
Kiselev & Likhoded (incl. Ξ_{cc}^*) Phys.Usp. 45:455 (2002)	12 nb	122 nb	10.2
Ma & Si Phys.Lett. B568:135 (2003)	130 nb	1800 nb	13.8
Chang et al (with acceptance cuts and requiring p_T > 4 GeV) J.Phys.G34:845 (2007)	5.5 nb	61 nb	11.0

Depending on σ, BF, and trigger, LHCb might need anywhere from 100 pb^{-1} to 2 fb^{-1} to observe the state.

B baryons



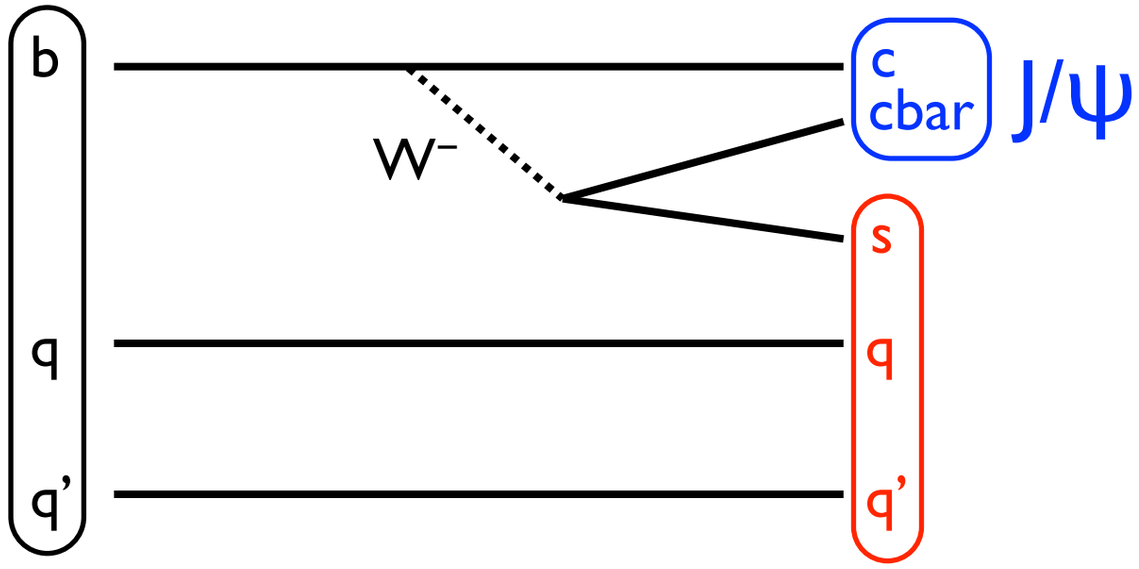
D0 and CDF disagree on Ω_b^- mass



- Most of the ground states now mapped out.
- Some isospin partners still missing (Σ_b^0, Σ_b^{*0}, Ξ_b^0)
- No excited states seen, but pattern should resemble charm

B baryons

- CDF & D0 use easily-triggered J/ψ → $\mu^+\mu^-$ modes:



Limited 2-body channels:

$\Omega_b^- \rightarrow J/\psi(\mu^+\mu^-)\ \Omega^-$

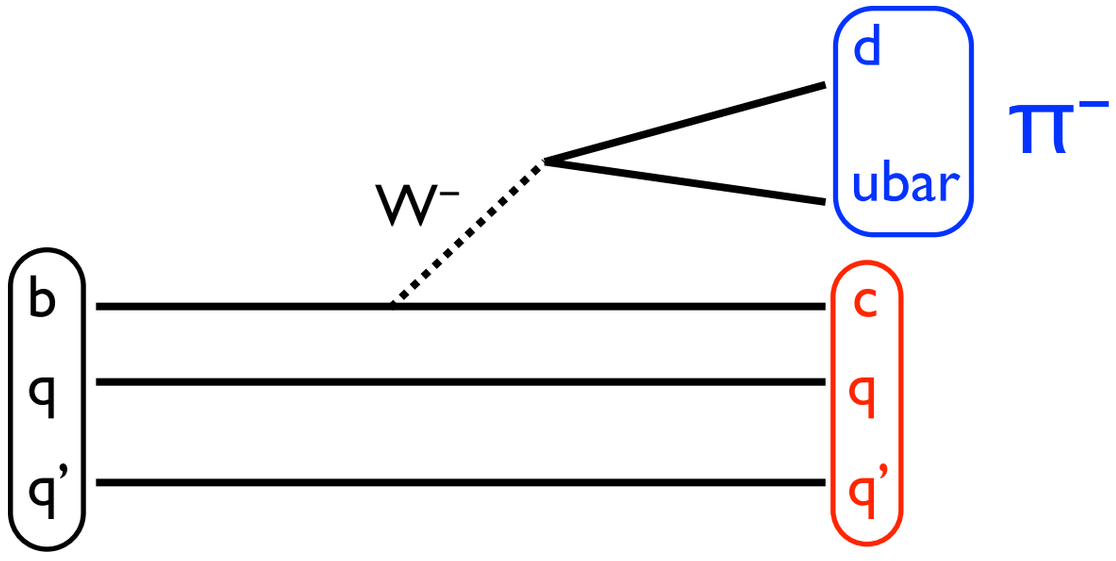
$\Xi_b^- \rightarrow J/\psi(\mu^+\mu^-)\ \Xi^-$

$\Lambda_b^0 \rightarrow J/\psi(\mu^+\mu^-)\ \Lambda^0$

Could also try 3-body, e.g.

$\Xi_b^0 \rightarrow J/\psi(\mu^+\mu^-)\ \Xi^-\ \pi^+$

- Alternative, requiring hadronic trigger: decays via c-baryons:



Many possibilities, e.g.

$\Omega_b^- \rightarrow \Omega_c^0\ \pi^-$

$\Omega_b^- \rightarrow \Xi_c^0\ K^-$

$\Xi_b^0 \rightarrow \Xi_c^+\ \pi^-$

$\Lambda_b^0 \rightarrow \Lambda_c^+\ \pi^-$

Note that this has similar final state and topology [but not charge] to doubly charmed baryon decays, e.g. $\Xi_{cc}^+ \rightarrow \Xi_c^0\ \pi^+$

CP violation?

- Searches for direct CP asymmetries in charmed baryon decays notoriously hard
  - Built-in proton/antiproton detection asymmetry
  - ... and also production asymmetry at hadronic machine
- ... but if direct CPV is large (>> 1%) it would be unambiguous
  - Seems very unlikely for any charm baryon decay
  - ... but what about b-baryons?
- Could look for asymmetry between Dalitz plots of baryon & antibaryon decays
  - e.g. SCS decays $\Lambda_c^+ \to p\, K^-\, K^+$ vs $\Lambda_c^- \to \text{pbar}\, K^-\, K^+$

Afterword

- Believe it or not, this was not an LHCb propaganda talk!
  - ... though I admit to a small bias
- LHCb has potential to be the next heavy baryon heavyweight
  - High luminosity (eventually)
  - High cross-sections
  - Forward region instrumented (down to 10 mrad, $\eta \sim 5$)
  - Large boost; excellent vertexing. PID, muon systems
- Two big challenges:
  - Triggering
  - Manpower! (baryons not considered sexy)