Спектроскопия очарованных мезонов и барионов

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*THE REAL SCIENCE

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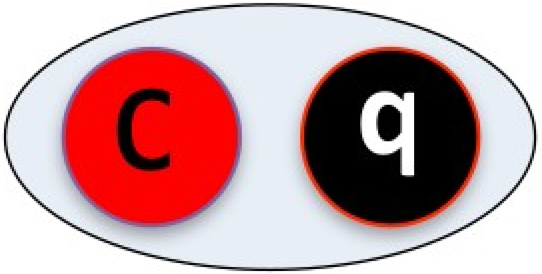
Open charm spectroscopy



-Heavy and light quark system – strong interacting «atom»

-Can be described in different models:
HQET, relativized quark model etc.

What can be studied

-Spectroscopy

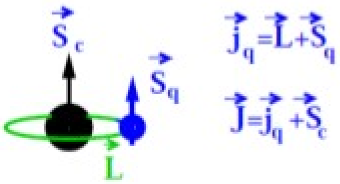
-Production cross section, formfactors

-Decay modes

-Fragmentation study

Excited states

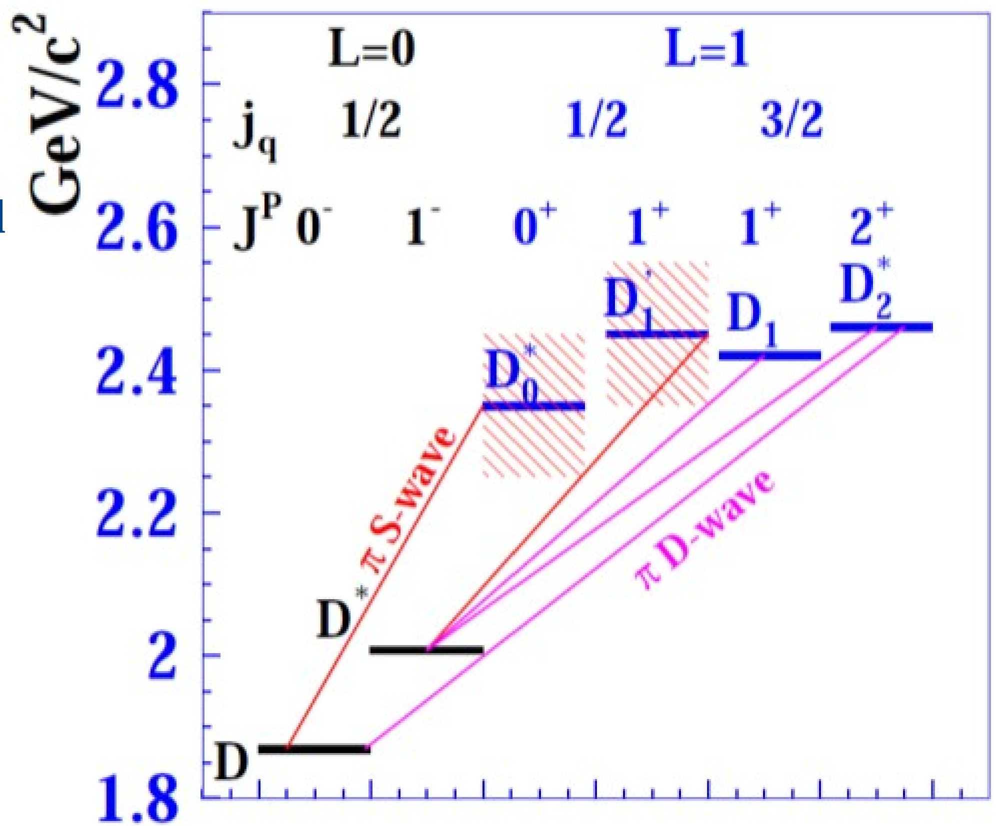
-In infinite heavy quark mass limit meson property is characterized by light quark wave function



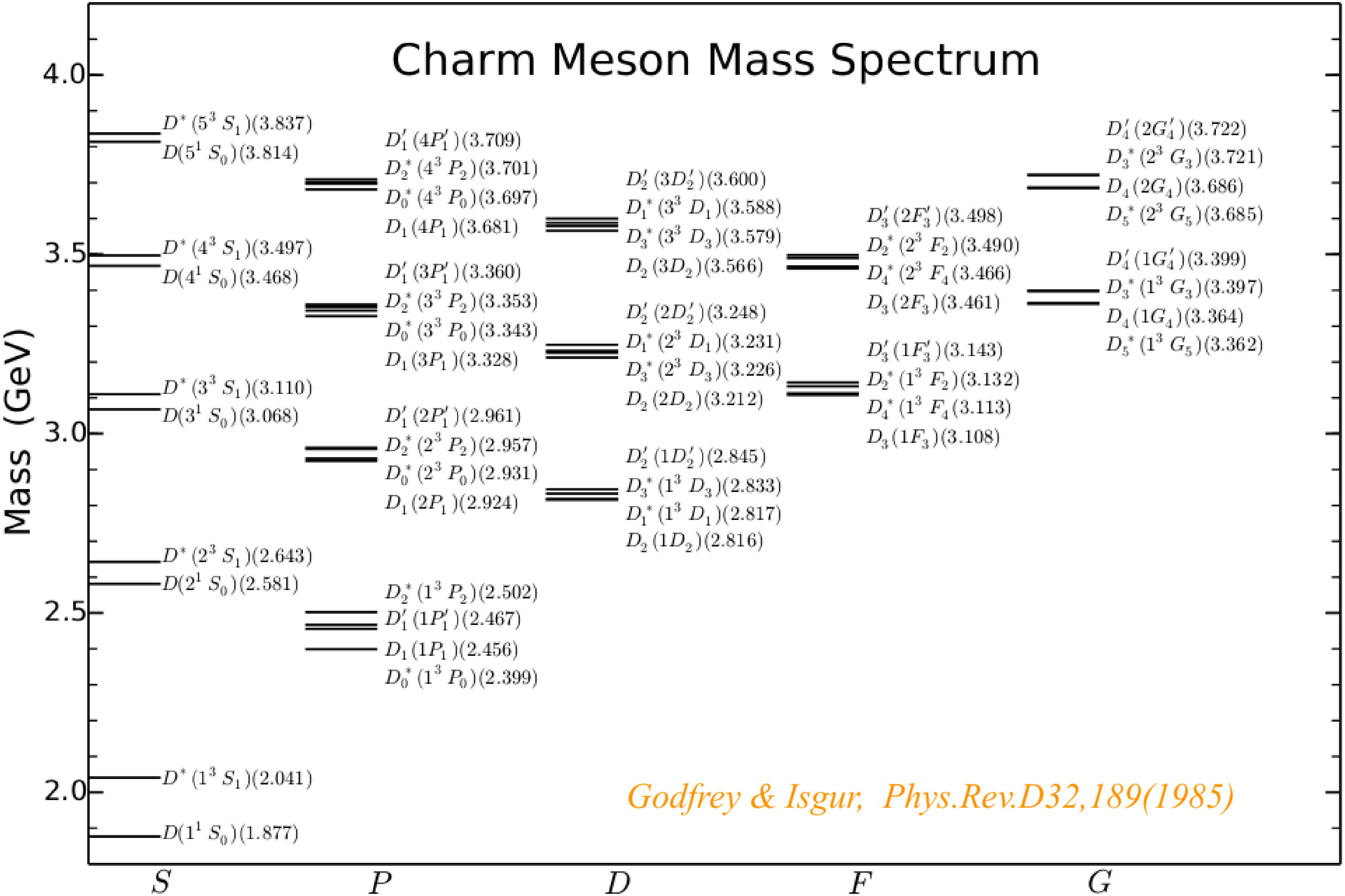
«good» quantum numbers

J_q – light quark total momentum
J – total momentum of meson

For finite mass of c-quark observed states is quantum mixture of states



Predicted excited stetes



Recently observed excited stetes

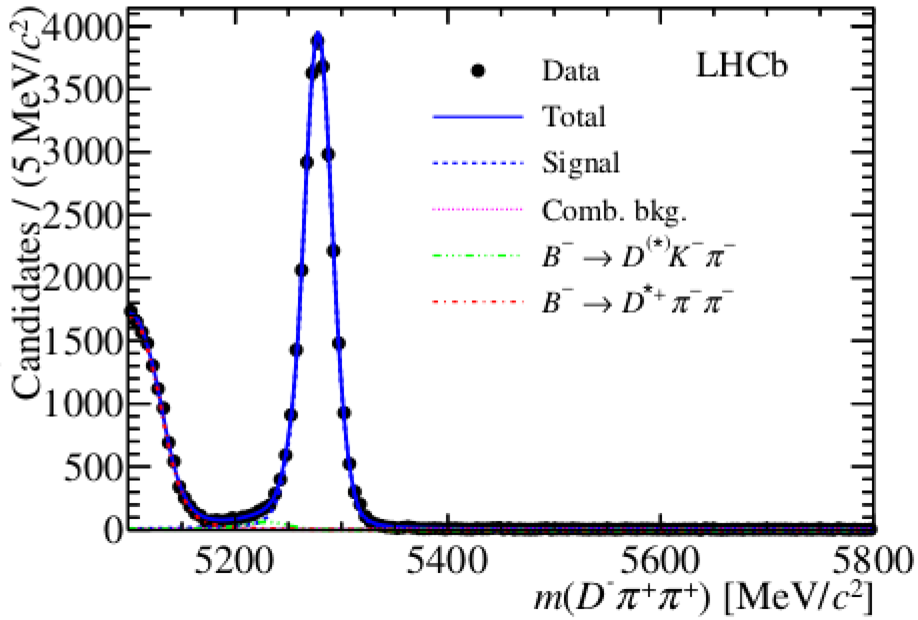
State	J^P	Observed Decays	Mass (MeV)	Width (MeV)	References
$D_J(2550)^0$	0^-	$D^{*+}\pi^-$	$2539.4 \pm 4.5 \pm 6.8$	$130 \pm 12 \pm 13$	BaBar [2]
$D_J(2580)^0$		$D^{*+}\pi^-$	$2579.5 \pm 3.4 \pm 3.5$	$177.5 \pm 17.8 \pm 46.0$	LHCb [11]
$D_J^*(2600)^0$		$D^+\pi^-$	$2608.7 \pm 2.4 \pm 2.5$	$93 \pm 6 \pm 13$	BaBar [2]
				$\Gamma(\to D^+\pi^-)/\Gamma(\to D^{*+}\pi^-) = 0.32 \pm 0.02 \pm 0.09$	BaBar [2]
$D_J^*(2650)^0$		$D^{*+}\pi^-$	$2649.2 \pm 3.5 \pm 3.5$	$140.2 \pm 17.1 \pm 18.6$	LHCb [11]
$D_J(2750)^0$		$D^{*+}\pi^-$	$2752.4 \pm 1.7 \pm 2.7$	$71 \pm 6 \pm 11$	BaBar [2]
$D_J(2740)^0$		$D^{*+}\pi^-$	$2737.0 \pm 3.5 \pm 11.2$	$73.2 \pm 13.4 \pm 25.0$	LHCb [11]
$D_J^*(2760)^0$		$D^{*+}\pi^-$	$2761.1 \pm 5.1 \pm 6.5$	$74.4 \pm 3.4 \pm 37.0$	LHCb [11]
		$D^+\pi^-$	$2760.1 \pm 1.1 \pm 3.7$	$74.4 \pm 3.4 \pm 19.1$	LHCb [11]
		$D^+\pi^-$	$2763.3 \pm 2.3 \pm 2.3$	$60.9 \pm 5.1 \pm 3.6$	BaBar [2]
				$\Gamma(\to D^+\pi^-)/\Gamma(\to D^{*+}\pi^-) = 0.42 \pm 0.05 \pm 0.11$	BaBar [2]
$D_J^*(2760)^+$		$D^0\pi^+$	$2771.7 \pm 1.7 \pm 3.8$	$66.7 \pm 6.6 \pm 10.5$	LHCb [11]
$D_1^*(2760)^0$	1^-	$D^+\pi^-$	$2781 \pm 18 \pm 11 \pm 6$	$177 \pm 32 \pm 20 \pm 7$	LHCb [9]
$D_3^*(2760)^-$	3^-	$\bar{D}^0\pi^-$	$2798 \pm 7 \pm 1 \pm 7$	$105 \pm 18 \pm 6 \pm 23$	LHCb [10] [a]
$D_J(3000)^0$		$D^{*+}\pi^-$	2971.8 ± 8.7	188.1 ± 44.8	LHCb [11]
$D_J^*(3000)^0$		$D^+\pi^-$	3008.1 ± 4.0	110.5 ± 11.5	LHCb [11]

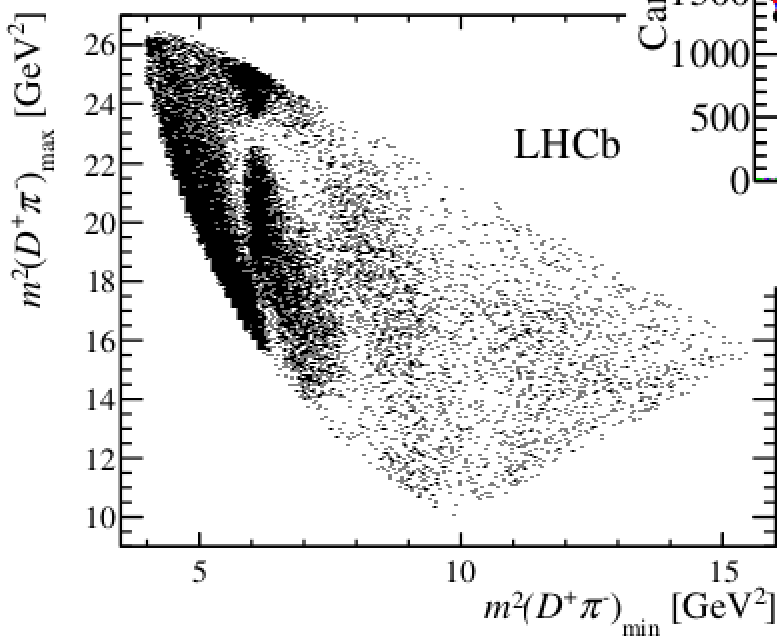
$B^- \to D^+\pi^-\pi^-$

Dalitz analysis of $27\,956 \pm 195$ $B^- \to D^+\pi^-\pi^-$ decays

- Signal purity $\sim$98.5%

Full $3\,\mathrm{fb}^{-1}$ of LHCb Run 1 data.





Identical pions ordered by magnitude of $m^2(D^+\pi^-)$
$m^2(D^+\pi^-)_{\min}$, $m^2(D^+\pi^-)_{\max}$

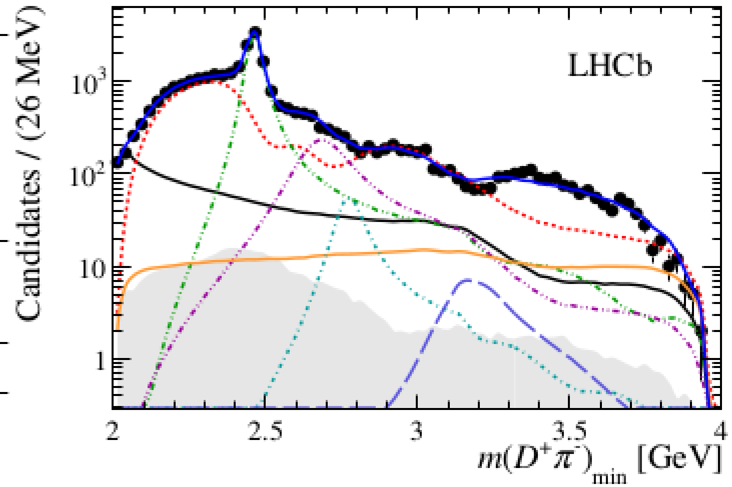
$B^- \to D^+\pi^-\pi^-$

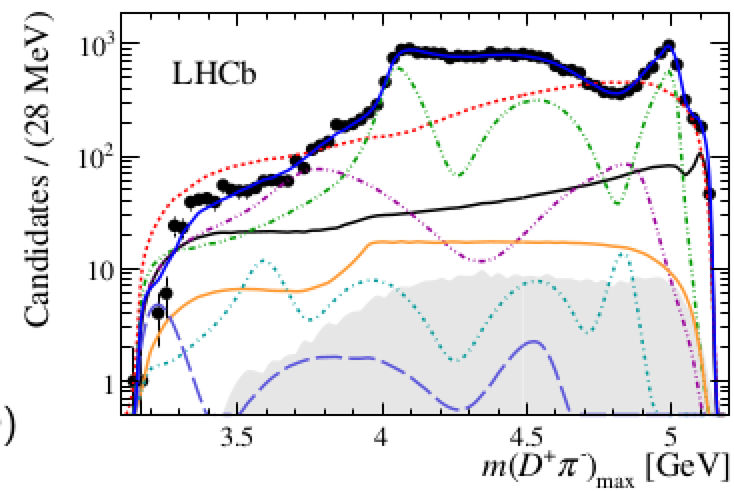
Resonance	Fit fraction (%)
$D_2^*(2460)^0$	$35.69 \pm 0.62 \pm 1.37 \pm 0.89$
$D_1^*(2680)^0$	$8.32 \pm 0.62 \pm 0.69 \pm 1.79$
$D_3^*(2760)^0$	$1.01 \pm 0.13 \pm 0.13 \pm 0.25$
$D_2^*(3000)^0$	$0.23 \pm 0.07 \pm 0.07 \pm 0.08$
$D_v^*(2007)^0$	$10.79 \pm 0.68 \pm 0.74 \pm 2.34$
B_v^*	$2.69 \pm 1.01 \pm 1.43 \pm 1.61$
Total S-wave	$56.96 \pm 0.78 \pm 0.62 \pm 0.87$

Resonance parameters (MeV)	
$D_2^*(2460)^0$	$m = 2463.7 \pm 0.4 \pm 0.4 \pm 0.6$
	$\Gamma = 47.0 \pm 0.8 \pm 0.9 \pm 0.3$
$D_1^*(2680)^0$	$m = 2681.1 \pm 5.6 \pm 4.9 \pm 13.1$
	$\Gamma = 186.7 \pm 8.5 \pm 8.6 \pm 8.2$
$D_3^*(2760)^0$	$m = 2775.5 \pm 4.5 \pm 4.5 \pm 4.7$
	$\Gamma = 95.3 \pm 9.6 \pm 7.9 \pm 33.1$
$D_2^*(3000)^0$	$m = 3214 \pm 29 \pm 33 \pm 36$
	$\Gamma = 186 \pm 38 \pm 34 \pm 63$

First observations of $D_3^*(2760)^0$, $D_2^*(3000)^0$

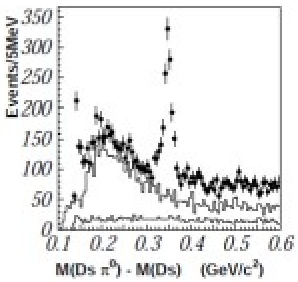
- Parameters of $D_3^*(2760)^0$ with $D_J^*(2760)$ observed in inclusive analysis.



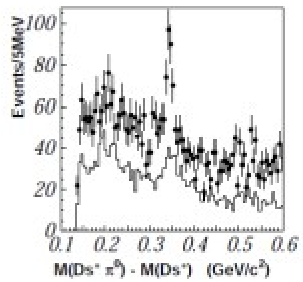


Спектроскопия D_{sJ}.

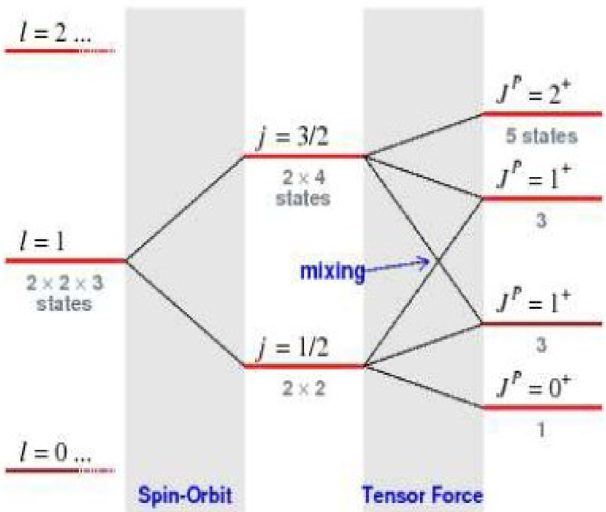
$D_{s0}^{*+}(2317) \to D_s^+\pi^0$

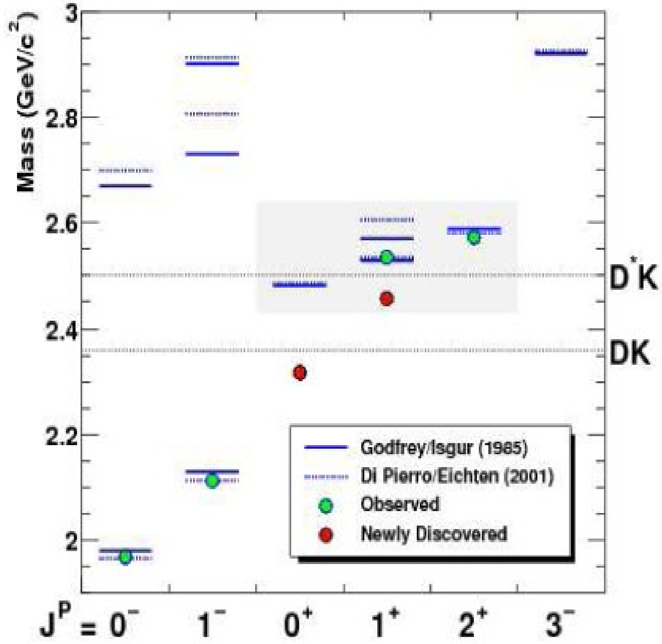


$D_{s1}^{+}(2460) \to D_s^{+*}\pi^0$



P-wave multiplet



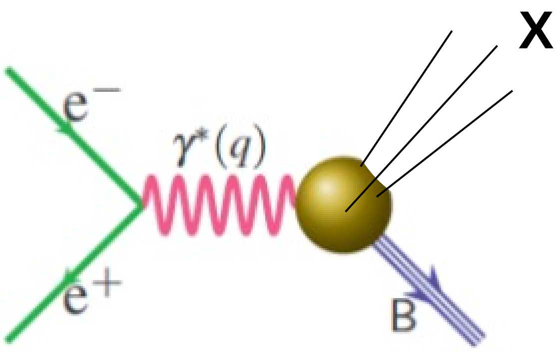


Figures: Courtesy of David Williams

Ожидалось что состояния $j = 1/2$ имеют массу $M > M_{D^{(*)}} + M_K$ и большую ширину. **(220 MeV)**

Production

-Inclusive production

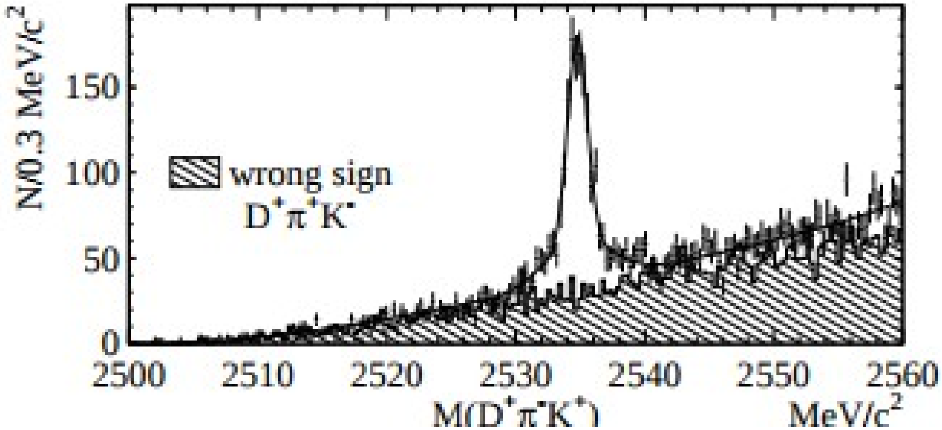


-Production and study of exclusive states DDπ, D*Dπ, D*D*π, D_sK...

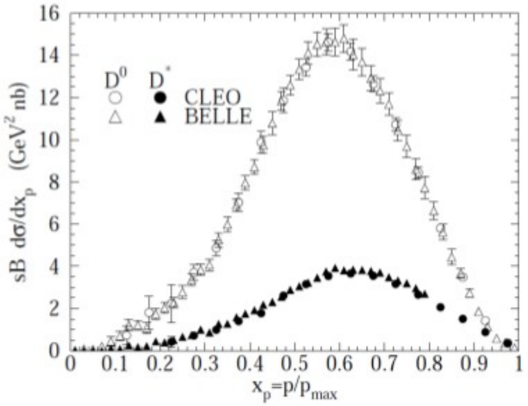
Inclusive production

-Larger statistic

-study of spectroscopy and decay of narrow states



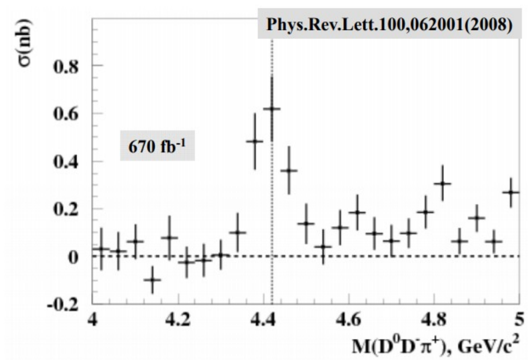
-study of fragmentation
and polarization of produced states



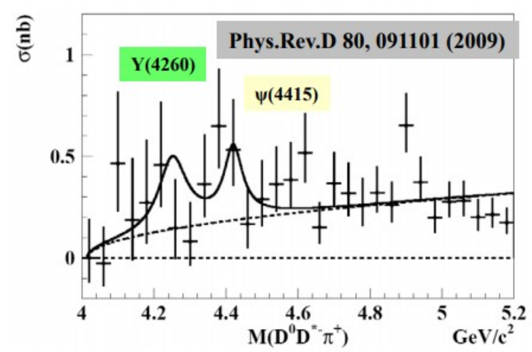
Exclusive states production

$e^+e^- \rightarrow D^0D^-\pi^+$, $D^+D^-\pi^0$, $D^0D^0\pi^0$

Cross section of $e^+e^- \rightarrow D^0D^-\pi^+$



Cross section of $e^+e^- \rightarrow D^0D^{*-}\pi^+$



For 1 ab^{-1}

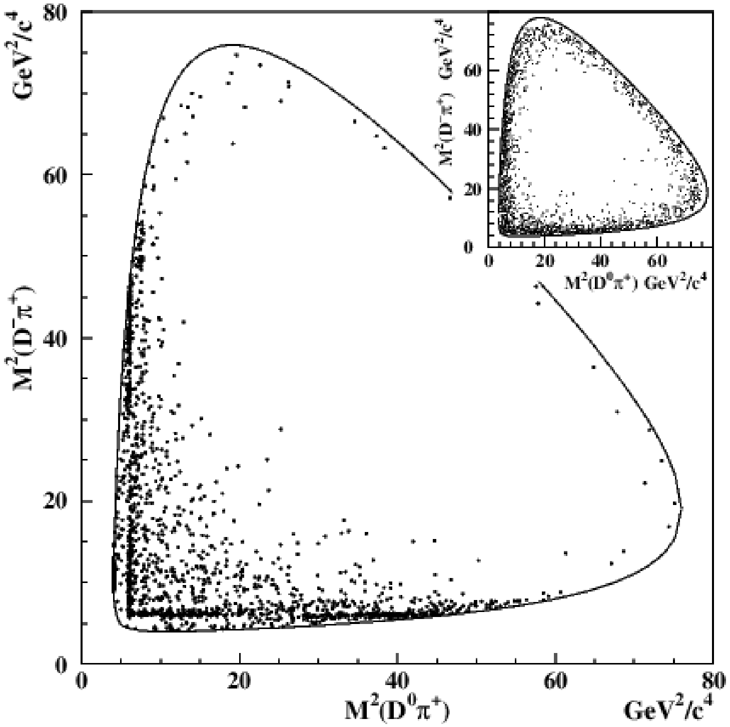
$DD\pi$	**6×10^8**	**2×10^6**
$D^*D\pi$	**6.5×10^8**	**10^6**

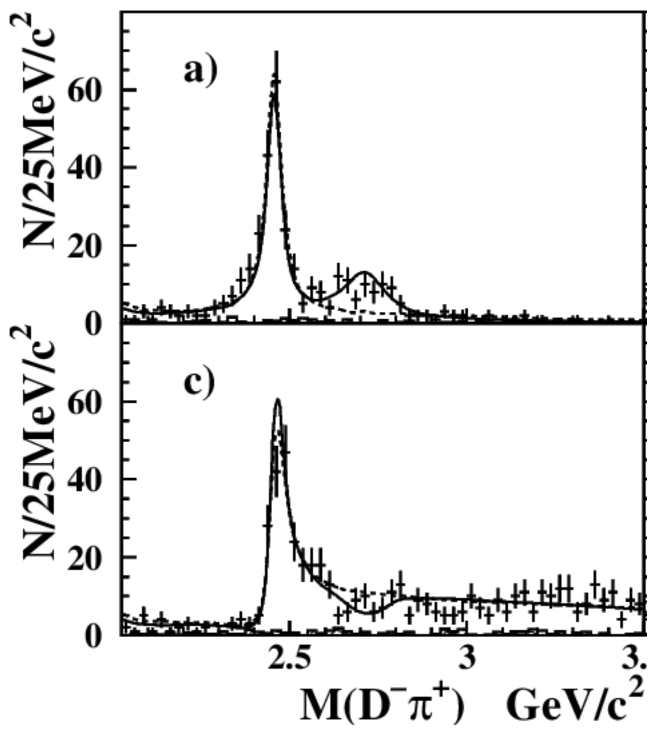
Exclusive states production

$e^+e^- \to D^0 D^- \pi^+$, $D^+ D^- \pi^0$, $D^0 D^0 \pi^0$

-Coherent state: 2 Dalitz variables+θ,ψ

Preliminary results of Belle 0.67 ab^{-1}





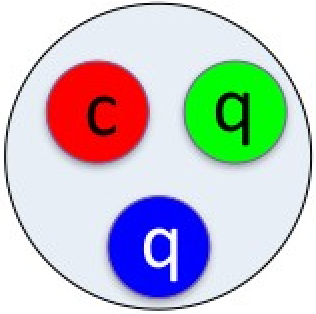
What to study at cτ factory

-D spectroscopy – hard competition with B-factory and LHCb**

-Study of decay modes with π^0,γ (advantage against LHCb)

-Detailed study of exclusive D(*)D(*)π modes

-Fragmentation, formfactors...



Charm barions

$$\Lambda_c^+ = udc,\quad \Sigma_c^{++} = uuc,\quad \Sigma_c^+ = udc,\quad \Sigma_c^0 = ddc,$$
$$\Xi_c^+ = usc,\quad \Xi_c^0 = dsc,\quad \Omega_c^0 = ssc$$

3 spin-1/2 QF-assymetric states (Λ^+_c , $\Xi^{+,0}_c$)

6 spin-1/2 QF-symmetric states ($\Sigma_c^{++,+,0}$, $\Xi'^{+0}_{c'}$, Ω^0_c),

6 spin-3/2 symmetric states ($\Sigma^{*++,+,0}_c$, $\Xi^{*+,0}_c$, Ω_c)

All 15 states were observed. There are 63 P-vawe exitations.

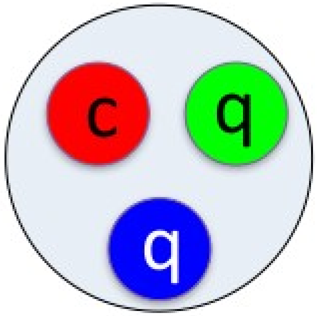
Double charm barions:

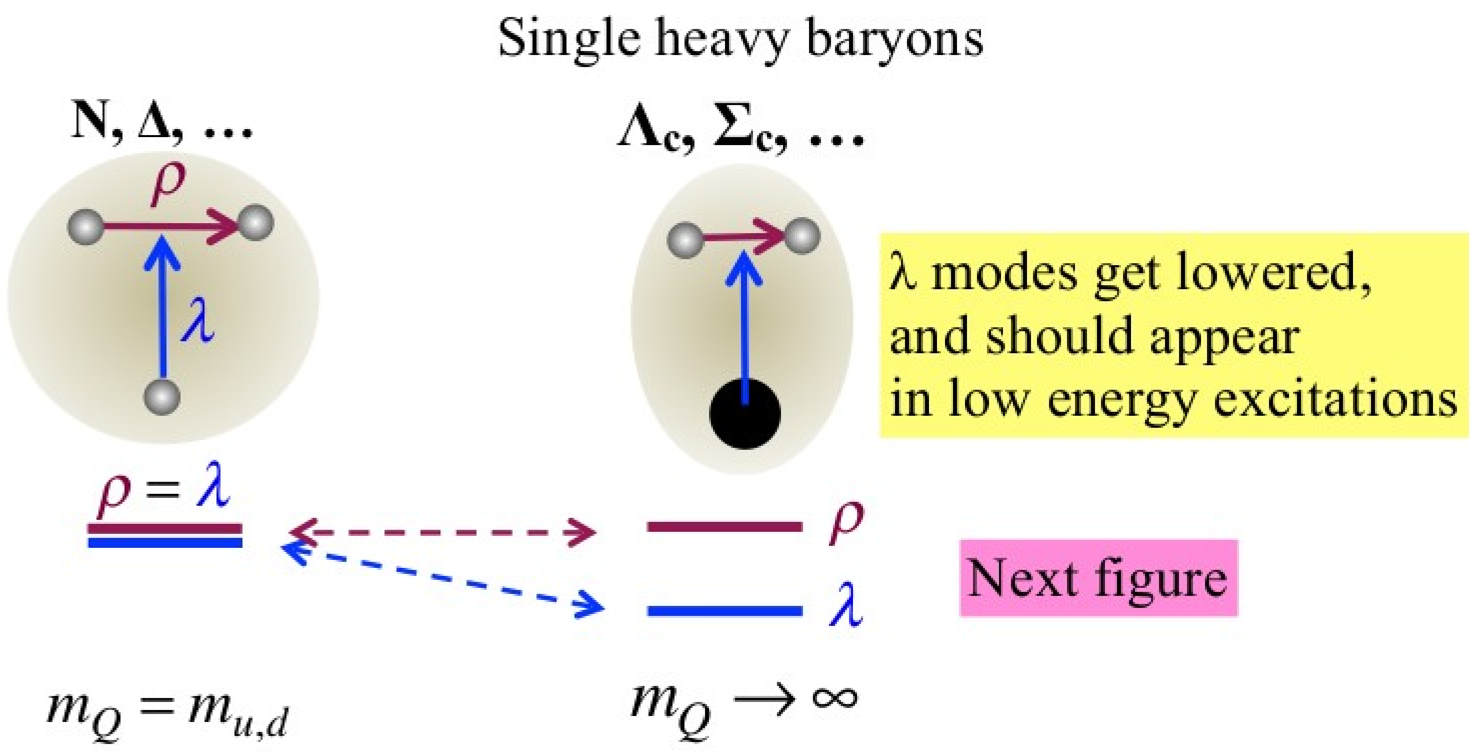
3 spin ½ $\Xi^{+,++}_{cc,}$ Ω^+_{cc}

3 spin 3/2 $\Xi^{*+,++}_{cc,}$ Ω^{*+}_{cc}

Triple charm Ω^{*++}_{ccc}

Charm barions





Charm barion spectroscopy

Quark Model Calculations

Yoshida, Hiyama, Hosaka, Oka, Phys.Rev. D92 (2015) no.11, 114029

$$H = \frac{p_1^2}{2m_q} + \frac{p_2^2}{2m_q} + \frac{p_3^2}{2M_Q} - \frac{P^2}{2M_{tot}}$$

$$+ V_{conf}(HO) + V_{spin-spin}(Color - magnetic) + \ldots$$

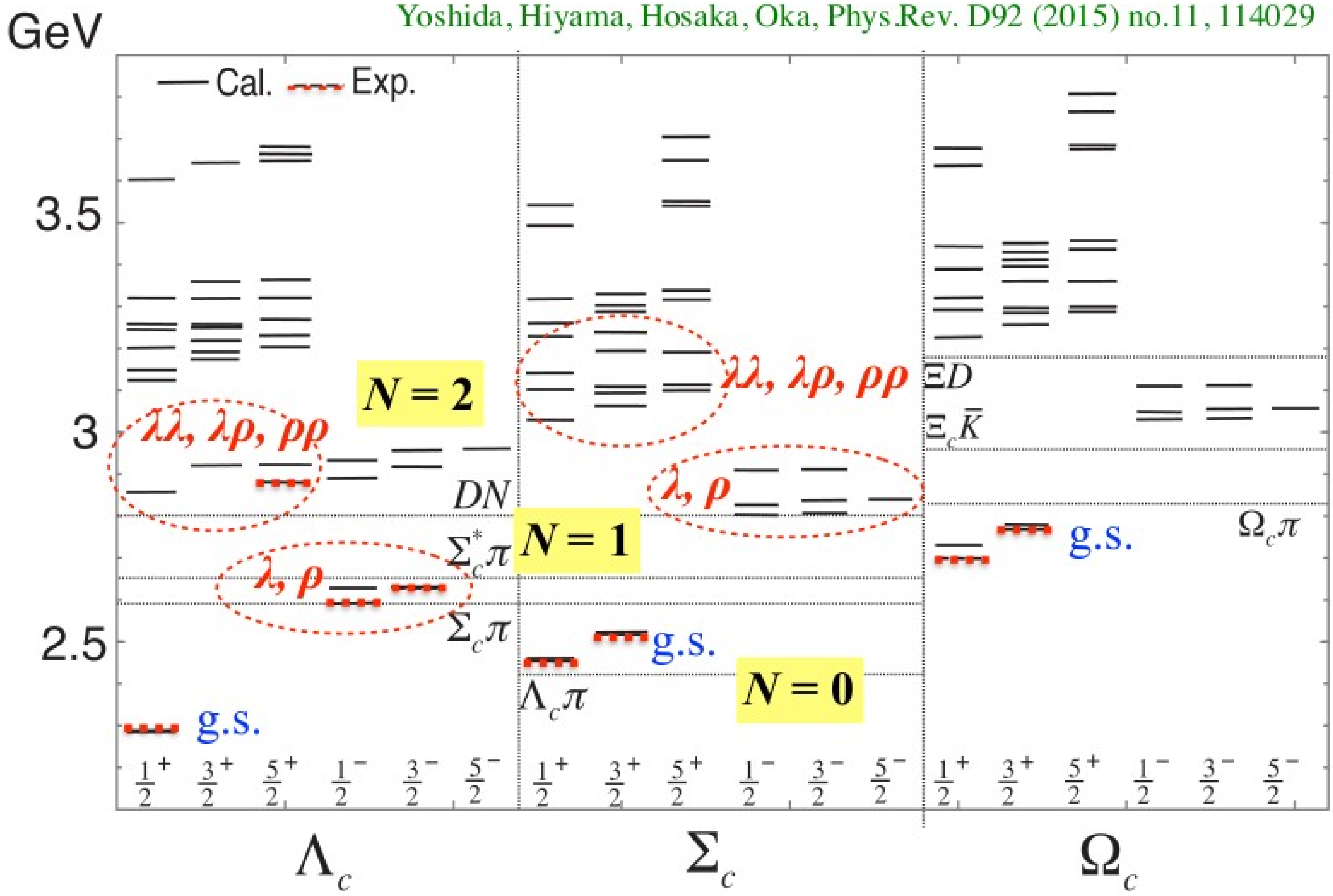
Wave function: (**Brown muck**) ✖ (Charm quark)

$$J = \underbrace{j}_{\text{Brown muck}} + \underbrace{\frac{1}{2}}_{\text{Charm quark}} = \underbrace{j \pm \frac{1}{2}}_{\text{HQ(LS) doublet}}$$

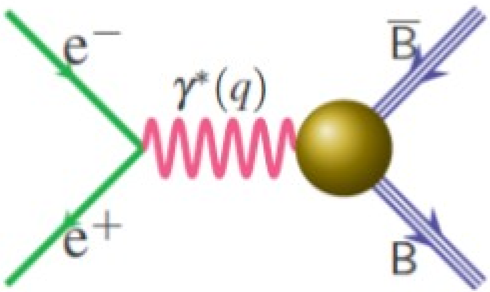
$$\Lambda_c(J^-;\lambda) = \left[\left[\psi_1(\vec{\lambda})\psi_0(\vec{\rho}), d^0 \right]^1, \chi_c \right]^{J=\frac{1}{2},\frac{3}{2}} \quad D^0 c$$

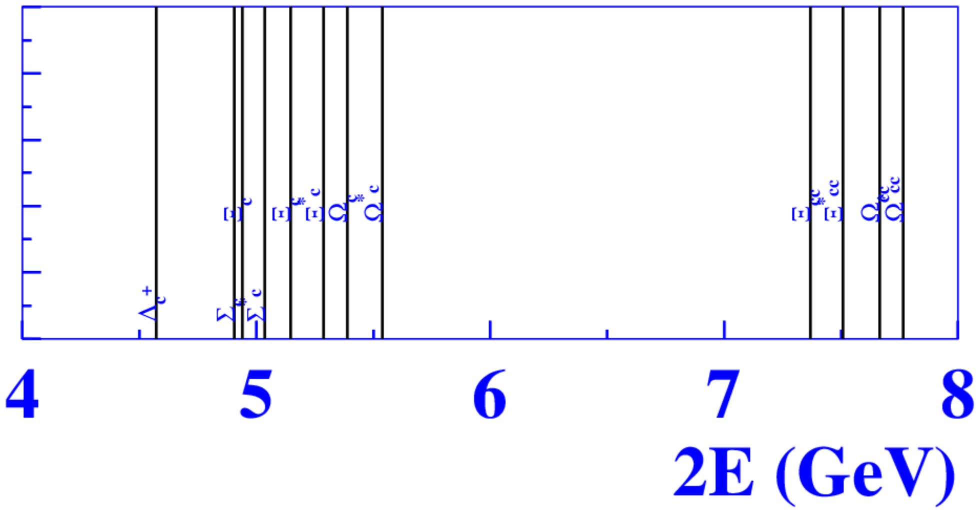
Charm barion spectroscopy

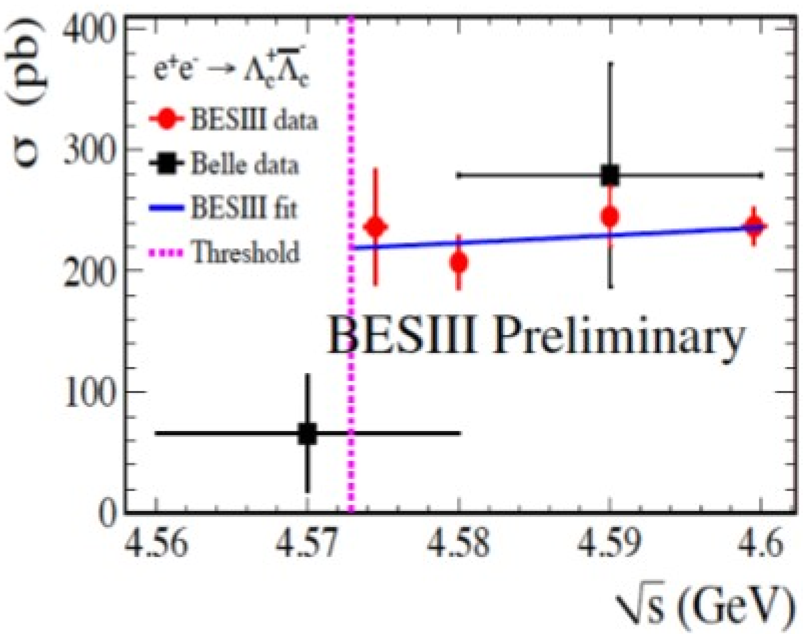
Yoshida, Hiyama, Hosaka, Oka, Phys.Rev. D92 (2015) no.11, 114029

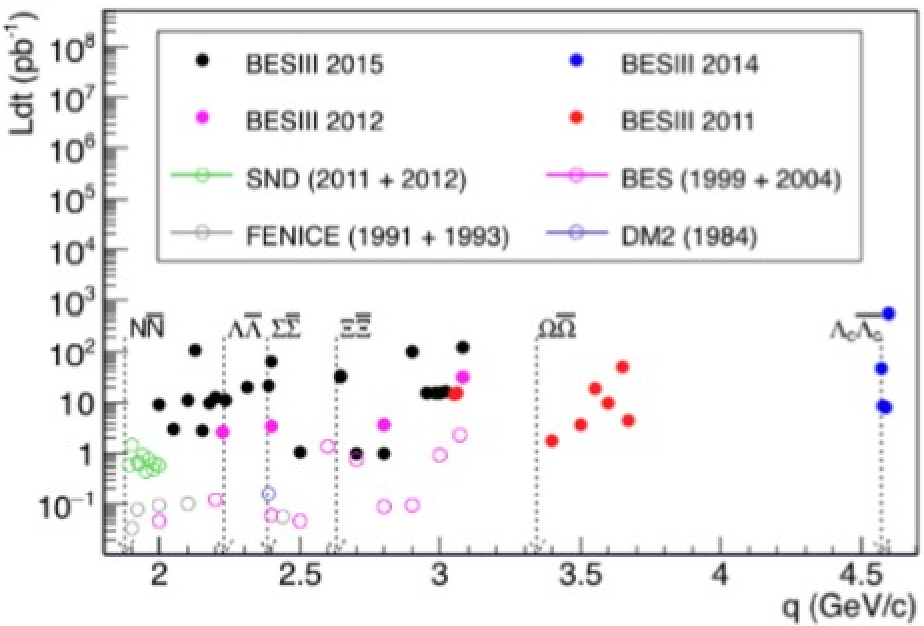


Charm barions formfactors









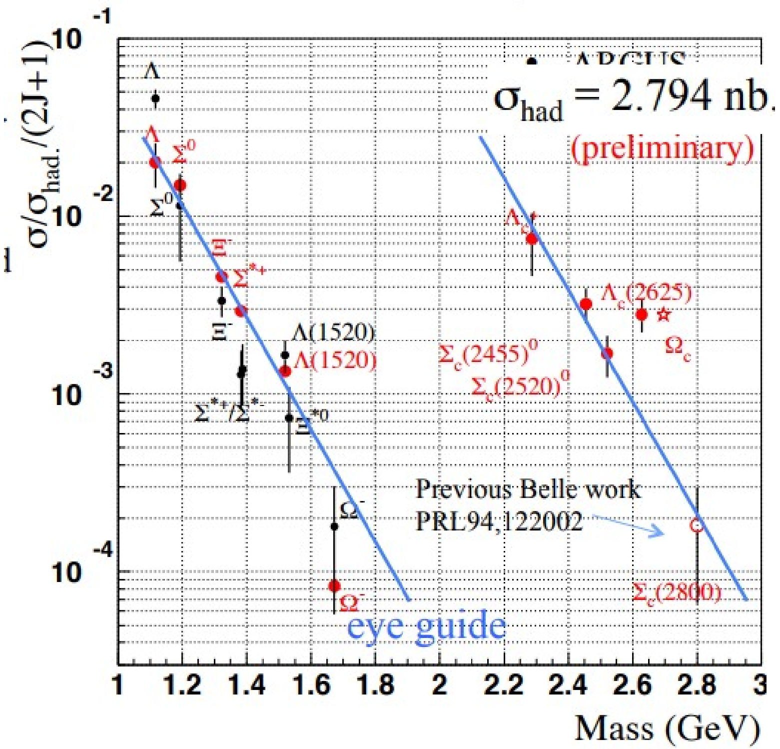
$e^+e^- \rightarrow \Lambda_c^+\Lambda_c^-$

For 1 ab^{-1} at threshold

2×10^8

Inclusive Λ_c production at Belle II 50 ab^{-1}

2×10^9



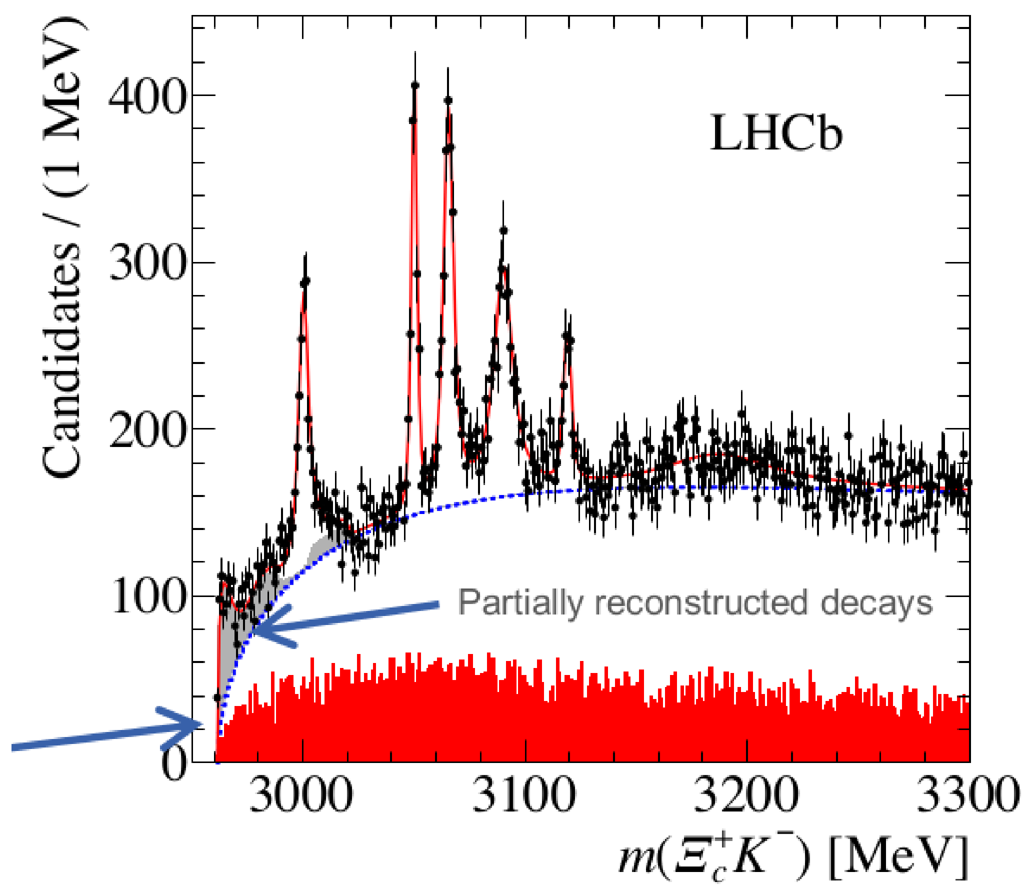
- LHCb study the $\Xi_c^+ K^-$ invariant mass spectrum

$$m(\Xi_c^+ K^-) = m([pK^-\pi^+]_{\Xi_c^+} K^-) - m([pK^-\pi^+]_{\Xi_c^+}) + m_{\Xi_c^+}$$

LHCb-PAPER-2017-002

- Ξ_c^+ candidates reconstructed in the $pK^-\pi^+$ final state
- 3.3 fb^{-1} data sample (Run 1 + 2015)

LHCb has huge power to study charm barions



What to study at cτ factory

-Spectroscopy of charm barions – hard competition with B-factory and LHCb

-Decay modes with π^0 advantage against LHCb

-Production crossection and probability of charmonium decay

-Formfactors study (higher energy is desirable)

Summary

-Open charm physics has many interesting topics to study

-Even after work of LHCb and Belle II charm factory has many interesting tasks:

- -study of cross section of charm hadrons production
- -study of the charmonia decays to open charm hadrons
- -study of barions formfactor
- -detailed study of exclusive D(*)D(*)π modes

Backup slides