中国地质大学
China University of Geosciences

Study on Ω_c^0 States Decaying to $\Xi_c^+ K^-$ in pp collisions at $\sqrt{s} = 7$ and 13 TeV

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Outline

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- **Observation of New Ω_c^0 States**
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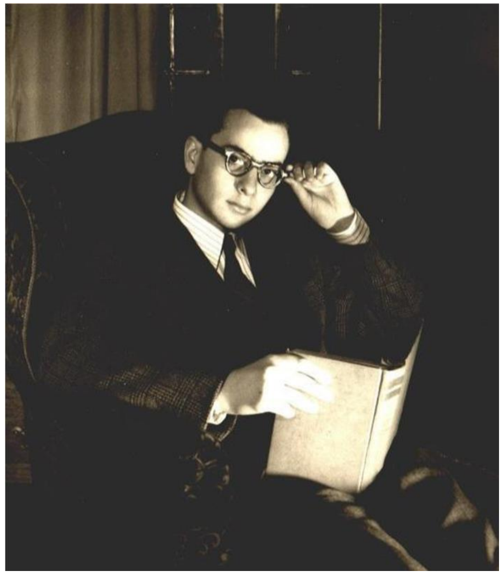
Introduction



Phys. Lett. 8 (1964) 214-215

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A SCHEMATIC MODEL OF BARYONS AND MESONS *

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If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just **1** and **8**.

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING
II *)

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CERN---Geneva

ABSTRACT

Both mesons and baryons are constructed from a set of three fundamental particles called aces. The aces break up into an isospin doublet and singlet. Each ace carries baryon number 1/3 and is fractionally charged. SU_3 (but not the Eightfold Way) is adopted as a higher symmetry for the strong interactions. The breaking of this symmetry is assumed to be universal, being due to mass differences among the aces. Extensive space-time and group theoretic structure is then predicted for both mesons and baryons, in agreement with existing experimental information. Quantitative speculations are presented concerning resonances that have not as yet been definitively classified into representations of SU_3. A weak interaction theory based on right and left handed aces is used to predict rates for $|\Delta S| = 1$ baryon leptonic decays. An experimental search for the aces is suggested.

*) Version I is CERN preprint 8182/TH.401, Jan. 17, 1964.

**) This work was supported by the U.S. Air Force Office of Scientific Research and the National Academy of Sciences - National Research Council.

8419/TH.412
21 February 1964

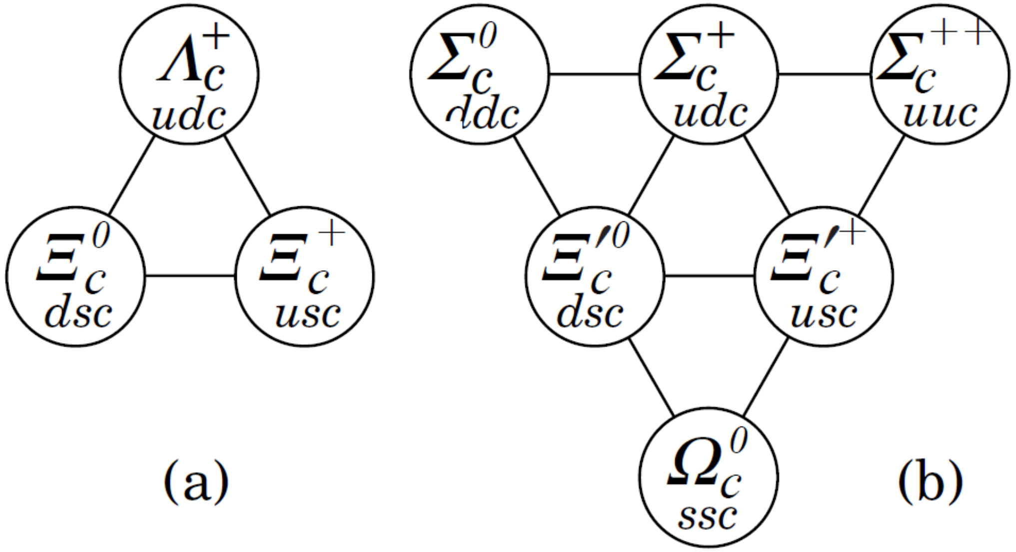
8419/TH.412
21/ February 1964

Introduction

The Categorizations of hadrons:

- Hadron
  - Conventional QM states
    - Meson : $q\bar{q}$, $Q\bar{q}$, $Q\bar{Q}$
    - Baryon : qqq, Qqq, QQq, ...
  - Exotic states
    - Molecular state
    - Hybrid meson
    - Glueball
    - Tetraquark
    - Pentaquark
    - $\cdots$

Observation of new Ω_c^0 states



PRL **118,** 182001 (2017) PHYSICAL REVIEW LETTERS week ending 5 MAY 2017

Observation of Five New Narrow Ω_c^0 States Decaying to $\Xi_c^+ K^-$

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(LHCb Collaboration)

(Received 14 March 2017; published 2 May 2017)

The $\Xi_c^+ K^-$ mass spectrum is studied with a sample of pp collision data corresponding to an integrated luminosity of 3.3 fb^{-1}, collected by the LHCb experiment. The Ξ_c^+ is reconstructed in the decay mode $pK^-\pi^+$. Five new, narrow excited Ω_c^0 states are observed: the $\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3066)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$. Measurements of their masses and widths are reported.

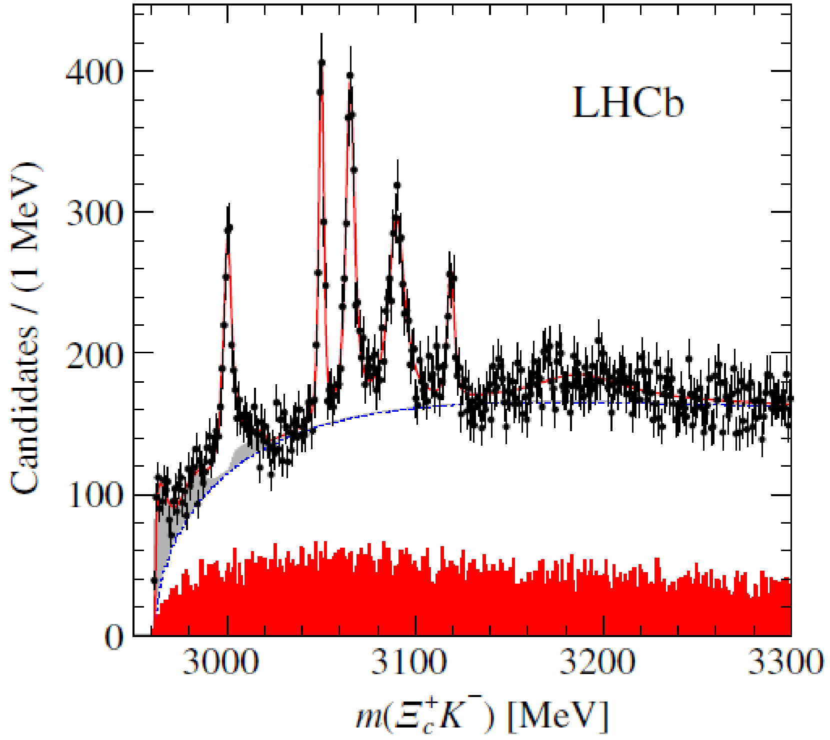
DOI: 10.1103/PhysRevLett.118.182001

The spectroscopy of singly charmed baryons cqq' is intricate. With three quarks and numerous degrees of freedom, many states are expected. At the same time, the large mass difference between the charm quark and the light quarks provides a natural way to understand the spectrum by using the symmetries provided by the heavy quark effective theory (HQET) [1,2]. In recent years, considerable improvements have been made in the predictions of the properties of these heavy baryons [3–14]. In many of these models, the heavy quark interacts with a (qq') diquark, which is treated as a single object. These models predict seven states in the mass range 2.9–3.2 GeV (natural units are used throughout this Letter), some of them narrow. Other models make use of lattice QCD

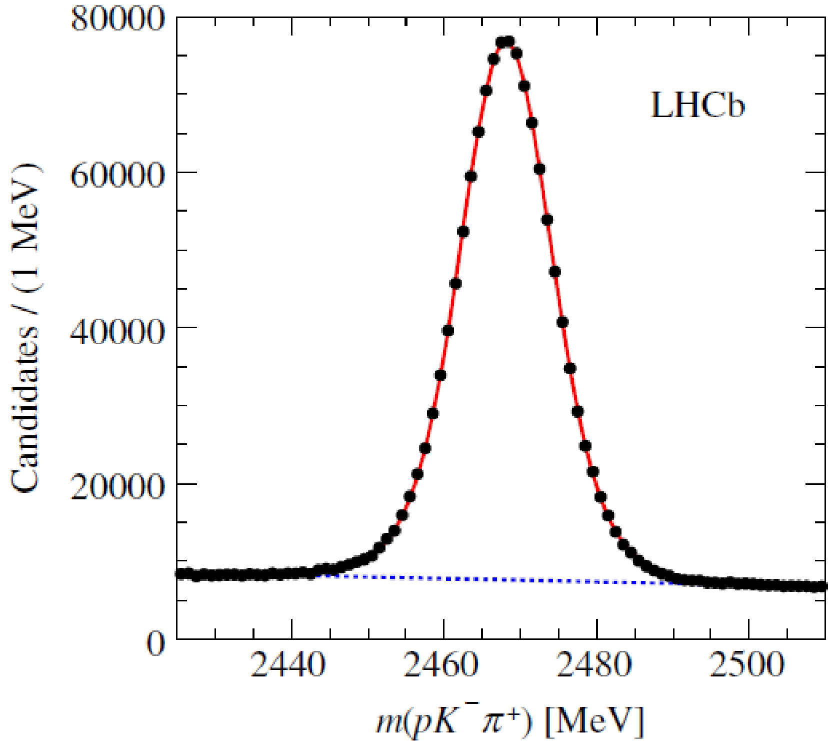
of 1.0, 2.0, and 0.3 fb^{-1} at center-of-mass energies of 7, 8, and 13 TeV, respectively, recorded by the LHCb experiment. The LHCb detector is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks, and is described in detail in Refs. [19,20]. Hadron identification is provided by two ring-imaging Cherenkov detectors [21], a calorimeter system, and a muon detector. The online event selection is performed by a trigger, which consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction [22]. Simulated events are produced with the software packages described in Refs. [23–28].

Observation of new Ω_c^0 states

PRL 118 182001 (2017)



Distribution of the reconstructed invariant mass $m(\Xi_c^+ K^-)$for all candidates passing the likelihood ratio selection



The Distribution of the reconstructed invariant mass $m(pK^-\pi^+)$ for all candidates in the inclusive Ξ_c^+ sample passing the likelihood ratio selection.

Observation of new Ω_c^0 states

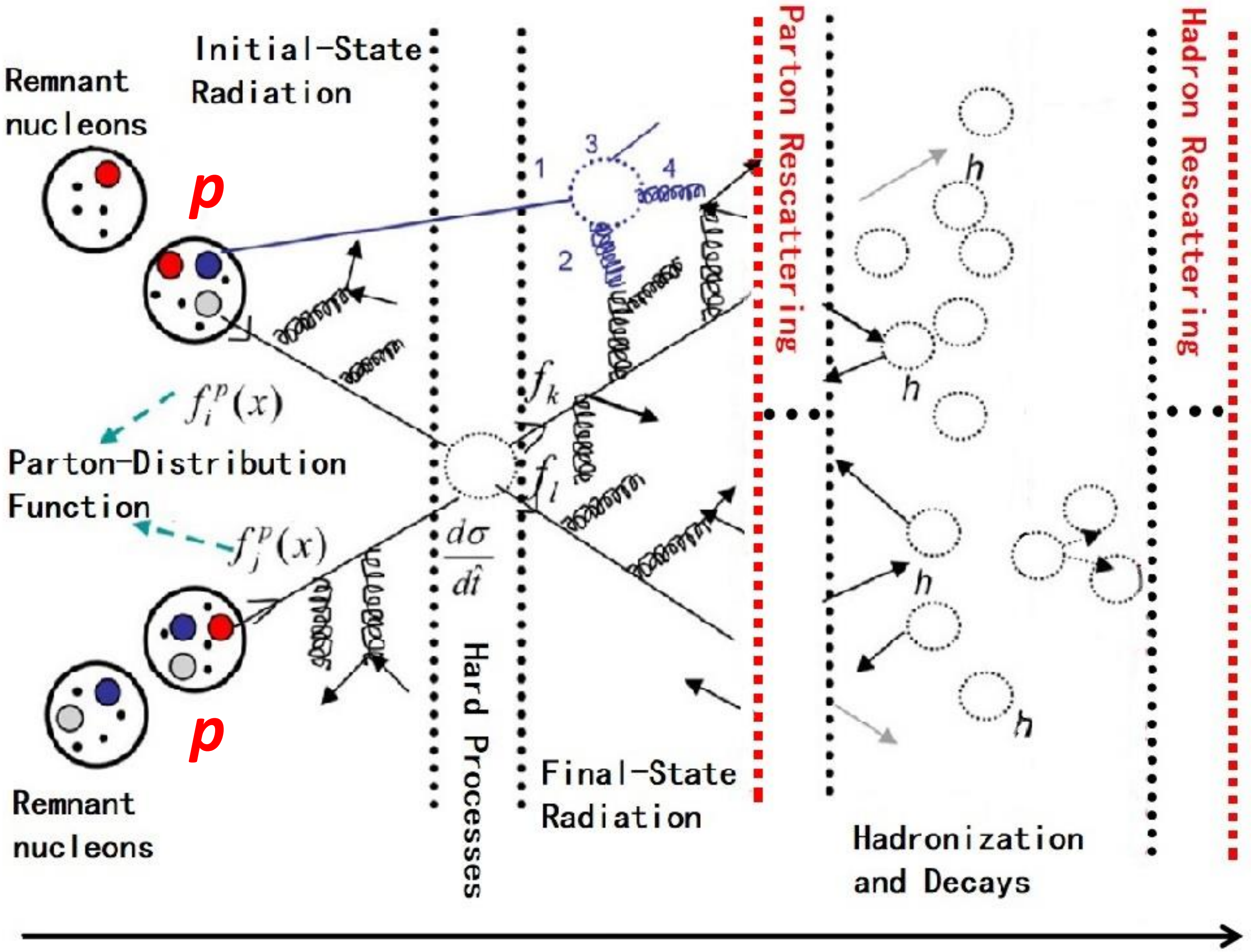
Results of the fit to $m(\Xi_c^+ K^-)$ for the mass, width, yield, and significance for each resonance.

PRL 118 182001 (2017)

Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$	$970 \pm 60 \pm 20$	20.4
		<1.2 MeV, 95% C.L.		
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	$480 \pm 70 \pm 30$	10.4
		<2.6 MeV, 95% C.L.		
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	
$\Omega_c(3066)^0_{\mathrm{fd}}$			$700 \pm 40 \pm 140$	
$\Omega_c(3090)^0_{\mathrm{fd}}$			$220 \pm 60 \pm 90$	
$\Omega_c(3119)^0_{\mathrm{fd}}$			$190 \pm 70 \pm 20$	

parton and hadron cascade model

Computer Physics Communications, 183, 333-346 (2012).



PACIAE 2.0a :The structure of dynamics in nucleon-nucleon collision.

Hadron rescattering: $\pi, K, p, n, \rho(w), \Delta, \Lambda, \Sigma, \Xi, \Omega, J/\Psi$ and their antiparticles.

Dynamically constrained phase space coalescence model

Phys. Rev. C 86, 054910 (2012).
Phys. Rev. C 85, 024907 (2012).

As the uncertainty principle

$$\Delta \vec{q} \, \Delta \vec{p} \geq h^3,$$

we can estimate the yield of a single particle by

$$Y_1 = \int_{H \leq E} \frac{d\vec{q}\, d\vec{p}}{h^3}.$$

Similarly, for the yield of N particles cluster

$$Y_N = \int \cdots \int_{H \leq E} \frac{d\vec{q_1}\, d\vec{p_1} \ldots d\vec{q_N}\, d\vec{p_N}}{h^{3N}}.$$

Equation must satisfy these constraint conditions:

$$\begin{cases} m_0 - \Delta m \leq m_{inv} \leq m_0 + \Delta m; \\ q_{ij} \leq D_0, (i \neq j; i, j = 1,2 \ldots N); \\ m_{inv} = \left[\left(\sum_{i=1}^{N} E_i \right)^2 - \left(\sum_{i=1}^{N} \vec{p}_i \right)^2 \right]^{1/2}. \end{cases}$$

Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$

- Determine the appropriate parameter to simulate the pp collision by PACIAE model:

The value of five important and specifical parameter in PACIAE modle

Parameter	K	β	$P(qq)/P(q)$	$P(s)/P(u)$	Gaussian width
Value	0.1 GeV	$0.58 GeV^{-2}$	0.10	0.42	0.36 GeV

The yield of Ξ_c^+ and K^- computed by PACIAE in mid-rapidity pp collisions at $\sqrt{s} = 7$ TeV

particles	PACIAE	Experiment data
K^-	0.286	0.286 ± 0.016
Ξ_c^+	7.40×10^{-5}	$7.47 \pm 0.14 \times 10^{-5}$

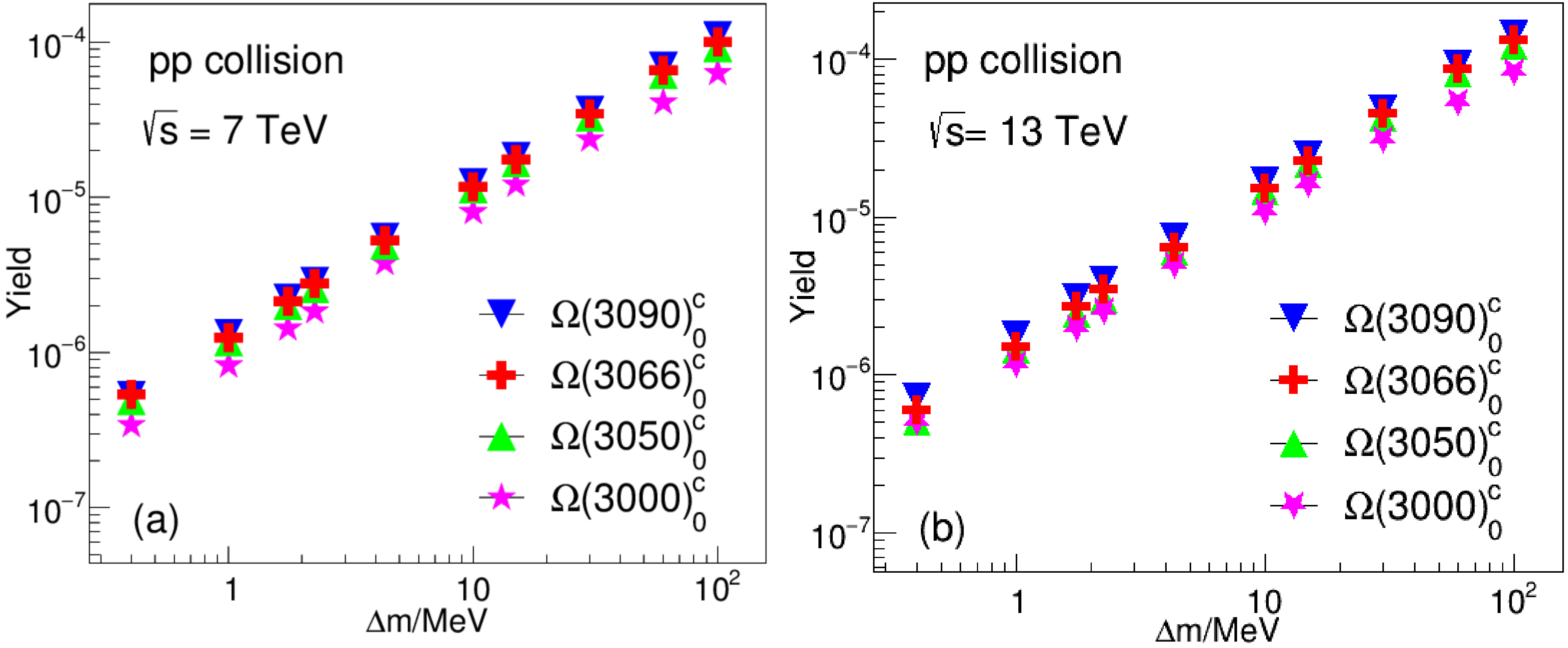
Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$

The yield of $\Xi_c^+ K^-$ bound states($\Omega_c(X)^0$states) in the DCPC model can be calculated by

$$Y_{\Omega_c(X)^0} = \int_{H\leq E} \frac{dq_1 dP_1 dq_2 dP_2}{h^6} \delta_{12}$$

With $\delta_{12} = f(x) = \begin{cases} 1, & if \quad 1\equiv\Xi_c^+, 2\equiv K^- \\ & m_{\Omega_c(X)^0} - \Delta m \leq m_{inv} \leq m_{\Omega_c(X)^0} + \Delta m, \\ & q_{12} \leq D_0, \\ 0, & \text{otherwise} \end{cases}$

Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$



Distribution of the yields of the four narrow excited resonant Ω_c^0 states increase linearly with Δm , in pp collision at $\sqrt{s} = 7$ and 13 TeV

Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$

The yields of four new resonant Ω_c^0 states varies with Δm from 0.4 MeV to 100 MeV in pp collision at $\sqrt{s}$ = 7 and 13 TeV

Δm	$\sqrt{s}=7$ TeV				$\sqrt{s}=13$ TeV			
(MeV)	$\Omega_c(3000)^0$	$\Omega_c(3050)^0$	$\Omega_c(3066)^0$	$\Omega_c(3090)^0$	$\Omega_c(3000)^0$	$\Omega_c(3050)^0$	$\Omega_c(3066)^0$	$\Omega_c(3090)^0$
0.4	3.40×10^{-7}	4.87×10^{-7}	5.4×10^{-7}	5.30×10^{-7}	5.1×10^{-7}	5.06×10^{-7}	5.93×10^{-7}	7.20×10^{-7}
1	8.23×10^{-7}	1.17×10^{-6}	1.25×10^{-6}	1.33×10^{-6}	1.18×10^{-6}	1.44×10^{-6}	1.49×10^{-6}	1.77×10^{-6}
1.75	1.43×10^{-6}	2.00×10^{-6}	2.14×10^{-6}	2.25×10^{-6}	1.96×10^{-6}	2.44×10^{-6}	2.69×10^{-6}	3.10×10^{-6}
2.25	1.84×10^{-6}	2.58×10^{-6}	2.79×10^{-6}	2.88×10^{-6}	2.52×10^{-6}	3.02×10^{-6}	3.47×10^{-6}	3.93×10^{-6}
4.35	3.79×10^{-6}	4.91×10^{-6}	5.26×10^{-6}	5.53×10^{-6}	4.94×10^{-6}	6.04×10^{-6}	6.46×10^{-6}	7.40×10^{-6}
10	8.04×10^{-6}	1.13×10^{-5}	1.17×10^{-5}	1.24×10^{-5}	1.08×10^{-5}	1.45×10^{-5}	1.50×10^{-5}	1.68×10^{-5}
15	1.21×10^{-5}	1.67×10^{-5}	1.75×10^{-5}	1.83×10^{-5}	1.61×10^{-5}	2.14×10^{-5}	2.25×10^{-5}	2.47×10^{-5}
30	2.36×10^{-5}	3.27×10^{-5}	3.46×10^{-5}	3.64×10^{-5}	3.08×10^{-5}	4.22×10^{-5}	4.49×10^{-5}	4.80×10^{-5}
60	4.08×10^{-5}	6.19×10^{-5}	6.56×10^{-5}	6.99×10^{-5}	5.32×10^{-5}	8.11×10^{-5}	8.59×10^{-5}	9.15×10^{-5}
100	6.32×10^{-5}	9.19×10^{-5}	1.00×10^{-4}	1.10×10^{-4}	8.22×10^{-5}	1.20×10^{-4}	1.31×10^{-4}	1.42×10^{-4}

Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$

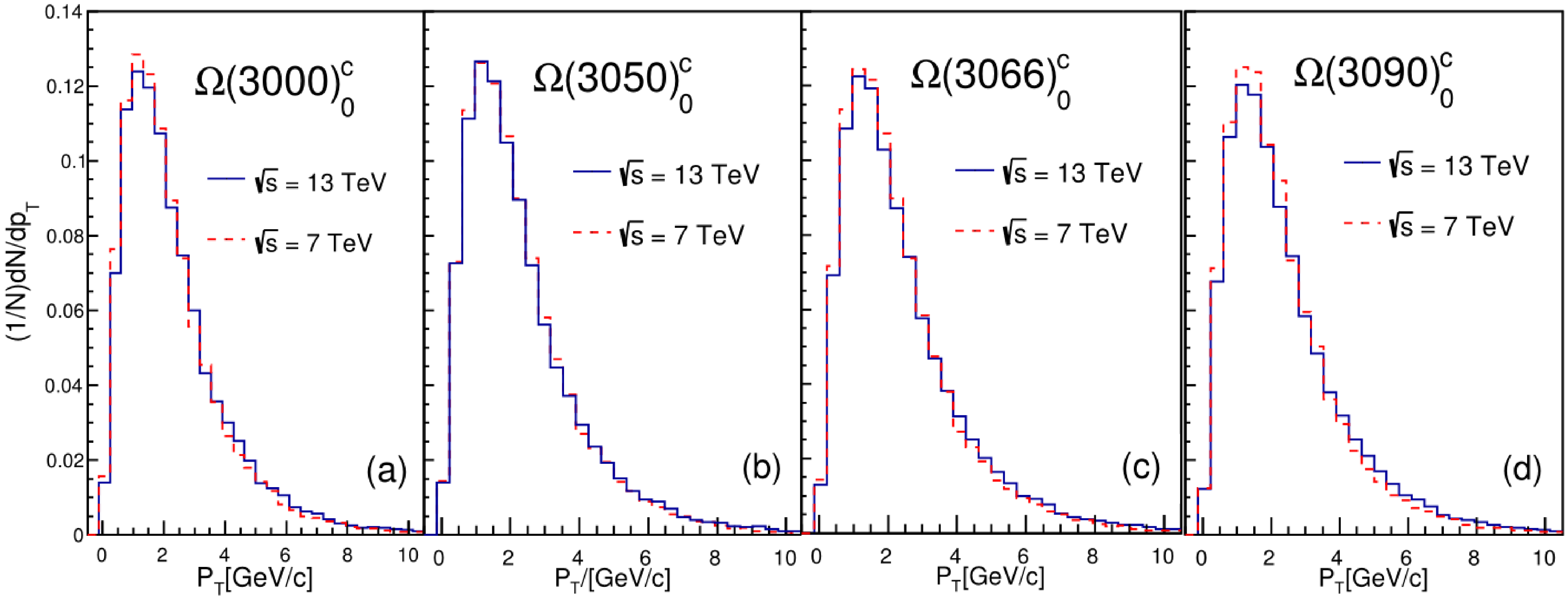
Tab I. The value of the four new excited resonant $\Omega_c(X)^0$ states in pp collision form LHCb collaboration.

$\Omega_c(X)^0$	Mass(MeV)	Γ(MeV)	Yield
$\Omega_c(3000)^0$	3000.4±0.2	4.5±0.6	1300±100
$\Omega_c(3050)^0$	3050.2±0.1	0.8±0.2	970±60
$\Omega_c(3066)^0$	3065.6±0.1	3.5±0.4	1740±100
$\Omega_c(3090)^0$	3090.2±0.3	8.7±1.0	2000±140

Tab II. The value of the four $\Omega_c(X)^0$ states in pp collision at $\sqrt{s} = 7$ and 13 TeV using PACIE and DCPC model, amusing $\Delta m = \Gamma/2$.

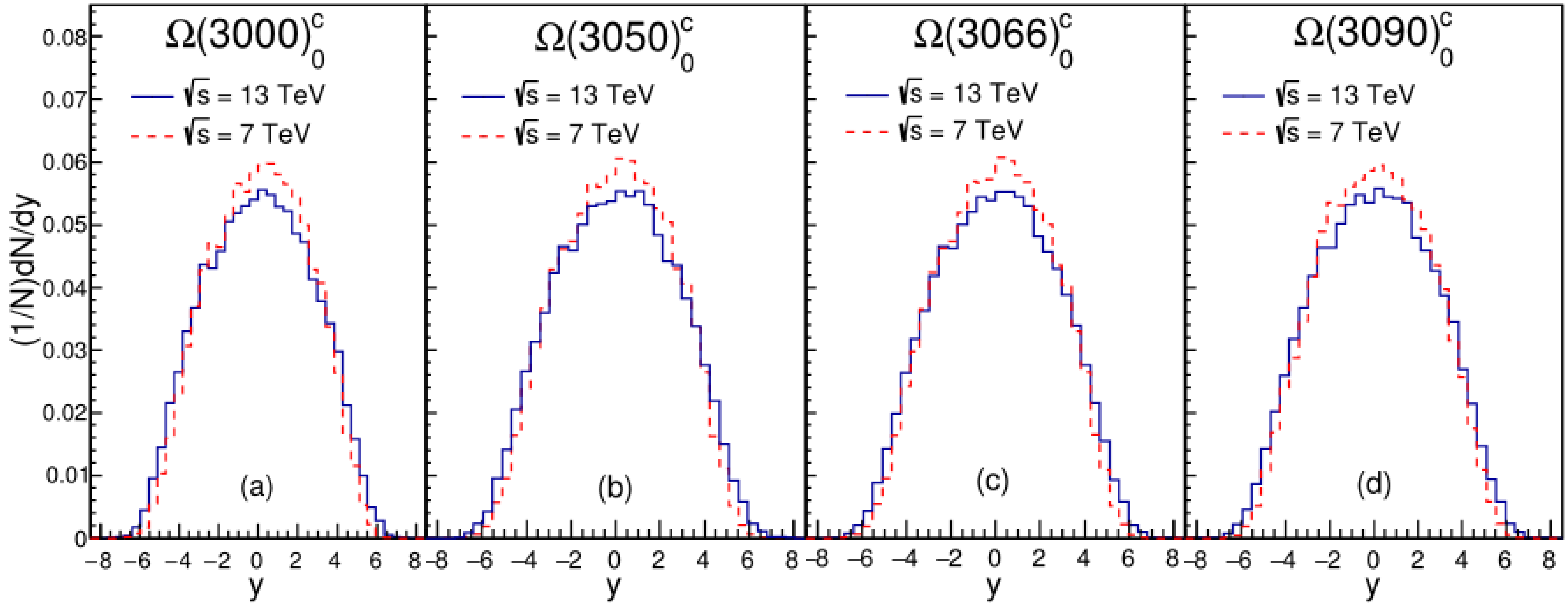
Resonance	Δm(MeV)	Yield(7 TeV)	Yield(13 TeV)
$\Omega_c(3000)^0$	2.25 ± 0.30	1.84×10^{-6}	2.52×10^{-6}
$\Omega_c(3050)^0$	0.40 ± 0.10	4.87×10^{-7}	5.06×10^{-7}
$\Omega_c(3066)^0$	1.75 ± 0.20	2.14×10^{-6}	2.69×10^{-6}
$\Omega_c(3090)^0$	4.35 ± 0.52	5.53×10^{-6}	7.40×10^{-6}

Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$



Transverse momentum distributions of the four excited resonant Ω_c^0 states

Study on $\Omega_c(X)^0$ States Decaying to $\Xi_c^+ K^-$



Rapidity distribution of the four resonant Ω_c^0 states

Summary

- Generate the pp collision at $\sqrt{s}=7$ and 13 TeV by PACIAE generator and study the $\Omega_c(X)^0$ during $\Omega_c^0 \to \Xi_c^+ K^-$ decay channel by DCPC.
- The yield per event of different $\Omega_c(X)^0$states are increase linearly with the Δm, and the yield at $\sqrt{s}=7$ TeV is bigger than it at $\sqrt{s}=13$ TeV .
- The Transverse momentum distributions or rapidity distribution of four different excited $\Omega_c(X)^0$states in pp collision at $\sqrt{s}=7$ and 13 TeV are similar.
- We are studying the pentaquarks and tetraquarks by PACIAE+DCPC model.

Thanks for your attention!