Production of $K^{-}p$ and $K^{+}\bar{p}$ bound states in pp collisions and interpretation of $\Lambda(1405)$

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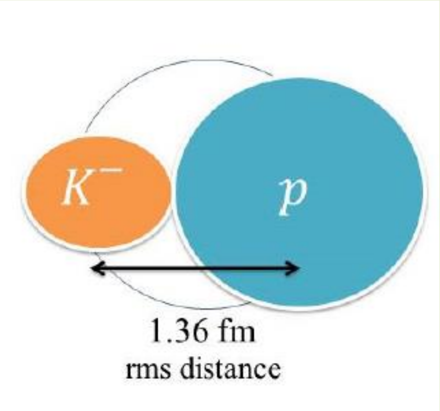
- Conclusion

Introduction

$\bar{K}N$ interaction supports the $\Lambda(1405)$ as a bound state of $K^{-}p$



[Yamazaki, Akaishi et al, Phys. Lett. B 587, 167 (2004) ; Phys. Rev. C 65, 044005 (2002); Phys. Lett. B 535, 70 (2002)], Phys. Rev. C 76, 045201 (2007)]

Interpretation of $\Lambda(1405)$ as lower I = 1 exited state has been problematic because of its low mass and the large mass difference from the higher I = 1 exited state, $\Lambda(1520)$

Predicted by Loering et al., in relativistic quark model, the two Λ states of $J^P = \frac{1}{2}^{-}$ and $\frac{3}{2}^{-}$ with roughly degenerated mass around 1520 MeV

[Loering et al , Eur. Phys. J. A10, 395 (2001); Eur. Phys. J. A10, 447 (2001)]

$J^P = \frac{1}{2}^-$	$J^P = \frac{3}{2}^-$	Δm	prediction
$\Lambda_c(2595)$	$\Lambda_c(2625)$	≈30 MeV	33±1
$\Lambda(1405)$	$\Lambda(1520)$	≈110 MeV	112±5

[N. Isgur, Phys.Rev. D 62, 014025 (2000)]

The udQ I = 1 excited baryons are treated as meson-like states in which the ud quark pair is compact and Q is far from the center-of-mass of the ud cluster.

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The physical nature of the $\Lambda(1405)$ is still not clear

In this work

- the PACIAE model (a parton and hadron cascade model) is used to simulate the production of charged particles, K^+, K^-, p and $\bar{p}$ in pp collisions at 0.9 TeV
- The simulated yield of charged particles from PACIAE is compared with the ALICE experimental data in order to fix the model parameters
- The DCPC model is employed to study the production of K^-p and $K^+\bar{p}$ clusters

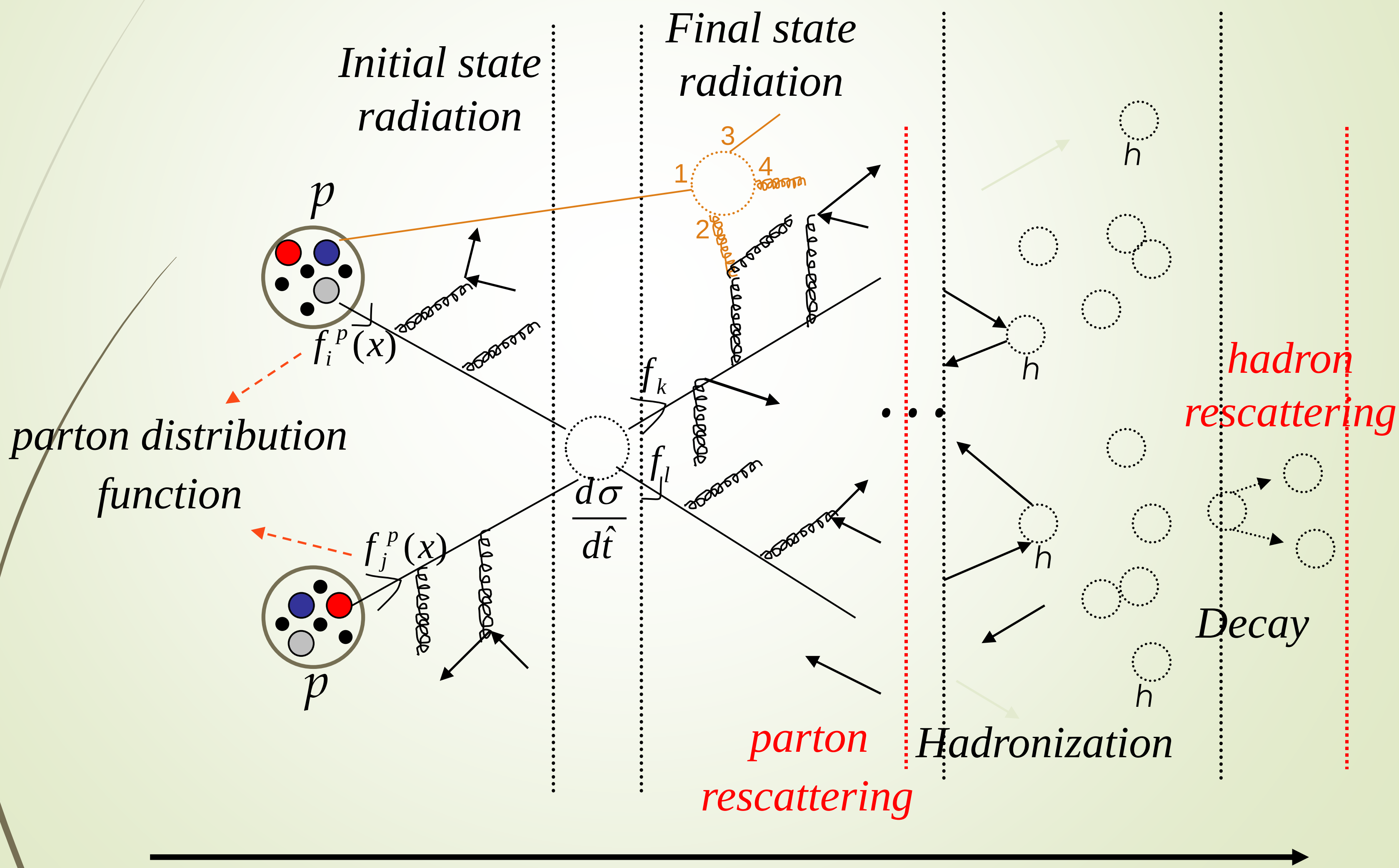
Brief introduction for PACIAE model

PACIAE, parton and hadron cascade model, is based on PYTHIA model for both p+p and A+A collisions. The model is updated based on PYTHIA 6.4.

[B. H. Sa et al., Computer Physics Communications 183, 333 (2012)]

DYNAMIC SIMULATION (PYTHIA,PACIAE)

Sketch for pp dynamic simulation



Charged particles production in PACIAE model

Yield of kaons and proton and antiproton in pp collisions at 0.9 TeV with $|y| < 0.5$

Particle type	ALICE data	PACIAE
K^+	0.183 ± 0.004	0.176
K^-	0.182 ± 0.004	0.171
p	0.083 ± 0.002	0.078
$\bar{p}$	0.079 ± 0.002	0.076

ALICE data are taken from Eur. Phys. J. C71, 1655 (2011) & Eur. Phys. J. C75, 226 (2015)

Yield of Kp cluster in DCPC model

Dynamically constrained phase space coalescence model (DCPC)

[Chen, Yan et al., Phys. Rev. C85, 024907 (2012); Phys. Rev. C86, 054910 (2012); J. Phys. G41, 115102 (2014)]

$$Y_{K^-p} = \int \cdots \int \delta_{12} \frac{d\vec{q}_1 d\vec{p}_1 d\vec{q}_2 d\vec{p}_2}{h^6},$$

with

$$\delta_{12} = \begin{cases} 1 & if \;\; 1 \equiv K^-, 2 \equiv p, \\ & m_\Lambda - \Delta m \leq m_{inv} \leq m_\Lambda + \Delta m, \\ & q_{12} \leq D_0 \\ 0 & \text{otherwise} \end{cases}$$

$$m_{inv} = \left[\left(E_{K^-} + E_p\right)^2 - \left(\vec{p}_{K^-} + \vec{p}_p\right)^2 \right]^{1/2}$$

$$E_{K^-} = \sqrt{\vec{p}_{K^-}^{\,2} + m_{K^-}^2}$$

$$E_p = \sqrt{\vec{p}_p^{\,2} + m_p^2}$$

m_Λ : mass of $\Lambda(1405)$

Δm : the mass uncertainty

D_0 : Kp rms distance of 1.36 fm

[Yamazaki, & Akaishi, Phys. Rev. C76, 045201 (2007)]

m_K, m_p: effective mass

Effective mass of K^+, K^-, p and $\bar{p}$

Particle type	m_0 (GeV)	m (GeV)
K^+	0.493	0.513
K^-	0.493	0.393
p	0.983	0.750
$\bar{p}$	0.983	0.850

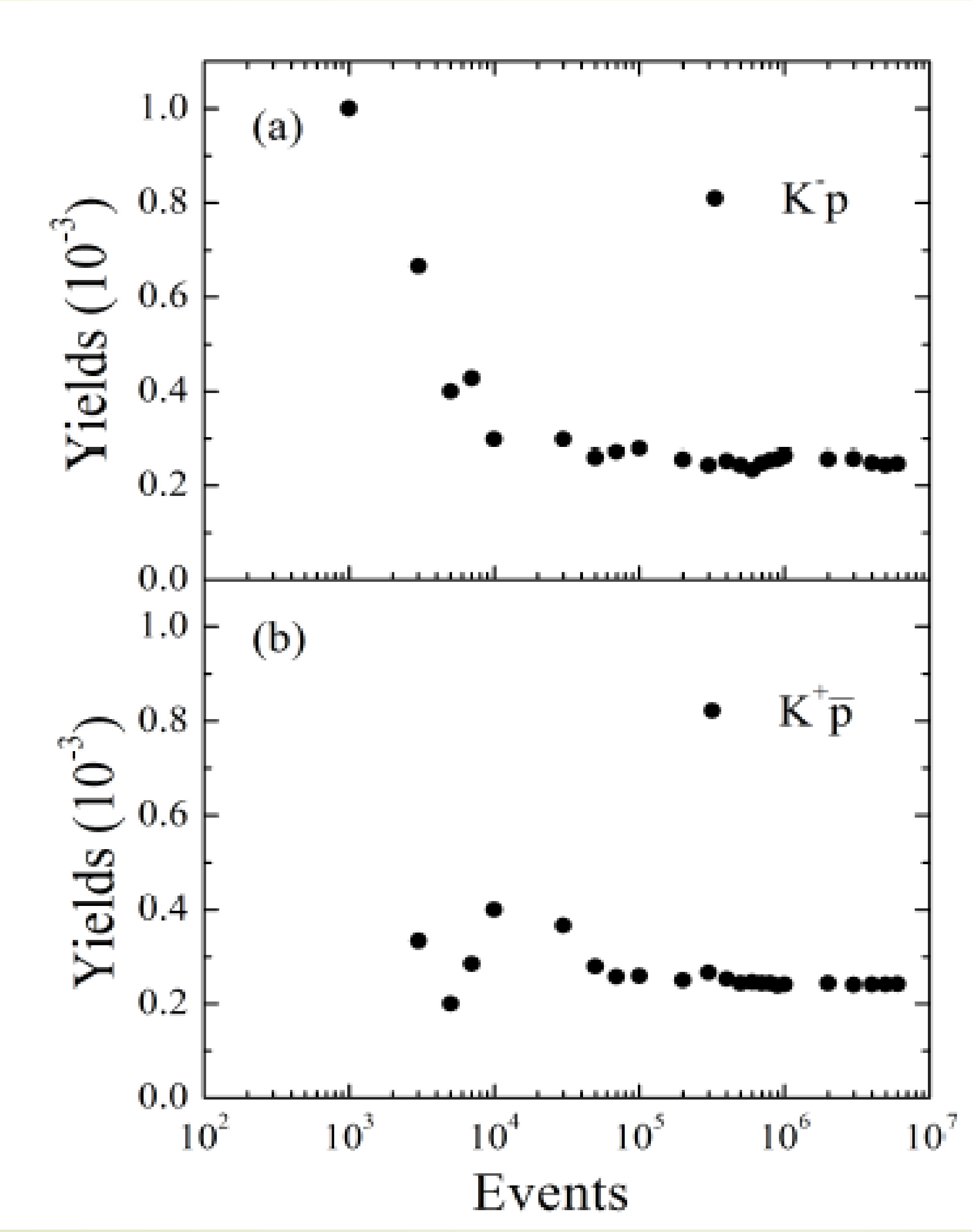
- $m_{K^-} = m_0 + 0.02$
- $m_{K^+} = m_0 - 0.01$

Ma et al., Phys. Lett. B 604, 170 (2004)

- $m_p = 0.8m_0$
- $m_{\bar{p}} = 0.9m_0$

Gaitanos & Kaskulov, Nucl. Phys. A 940, 181 (2015)

$K^{-}p$ and $K^{+}\overline{p}$ yields as a function of number of events in pp collision at 0.9 TeV.



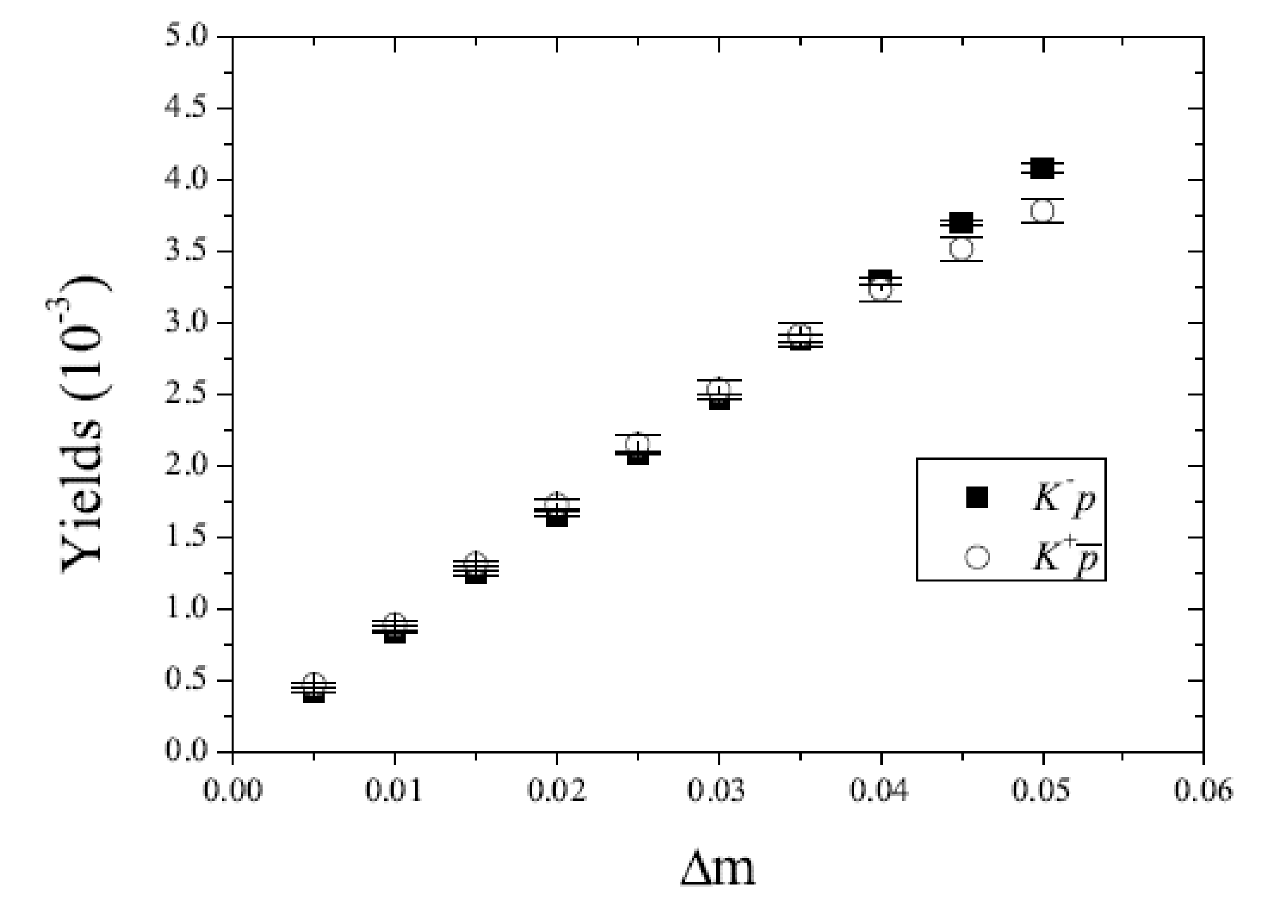
Yields tends to be stable when the number of events is larger than 10^6

In this work, 10^7 events are analyzed

$K^- p$ and $K^+ \overline{p}$ productions in pp collisions at 0.9 TeV

Δm	$K^- p$ (10^{-3})	$K^+ \bar{p}$ (10^{-3})
0.005	0.409 ± 0.005	0.464 ± 0.013
0.010	0.830 ± 0.008	0.887 ± 0.016
0.015	1.242 ± 0.013	1.312 ± 0.022
0.020	1.656 ± 0.018	1.727 ± 0.030
0.025	2.088 ± 0.013	2.147 ± 0.060
0.030	2.476 ± 0.016	2.530 ± 0.071
0.035	2.892 ± 0.022	2.911 ± 0.088
0.040	3.295 ± 0.030	3.236 ± 0.083
0.045	3.701 ± 0.024	3.519 ± 0.083
0.050	4.084 ± 0.029	3.784 ± 0.091

To see the relation between the yield per event and Δm, the data in this Table are plotted as shown in next slide



- the yields of $K^{-}p$ and $K^{+}\bar{p}$ increase linearly with increasing Δ*m*
- with the same Δm, the yields of $K^{-}p$ and $K^{+}\bar{p}$ are almost the same
- with Δm=0.02 GeV, the yields of $K^{-}p$ and $K^{+}\bar{p}$ are predicted to be (1.656 ± 0.018) x 10^{-3} and (1.727 ± 0.030) x 10^{-3}, respectively. Note that $\Delta m = \frac{\Gamma}{2}$ and decay width of Kp is 40 MeV [Dalitz & Tuan, Phys. Rev. Lett. 2, 425 (1959)]

Conclusions

- The PACIAE is used to simulate the charged particles (K^+,K^-, p and $\bar{p}$) in pp collision at 0.9 TeV

- These charged particles are then used as inputs to the DCPC model to construct the K^-p and $K^+\bar{p}$ clusters

- With the invariant mass in the rang of 1.405±0.02 GeV, the yields of K^-p and $K^+\bar{p}$ are predicted to be (1.656 ± 0.018) x 10^{-3} and (1.727 ± 0.030) x 10^{-3}, respectively

- The work indicates that the Λ(1405) and its antiparticle may be produced at almost the same rate in the pp collision at 0.9 TeV if the Λ(1405) is a K^-p bound state formed during the hadron rescattering period

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