Scaling behaviour of the p_T spectra for identified hadrons in pp collisions

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[W. C. Zhang, J. Phys. G, **43**, 015003, 2016]

Outline

- Introduction
- Method to search for the scaling behaviour
- Scaling behaviour of identified π, K and p
- Colour string percolation model
- Conclusions

Introduction

- One of the most important observations in high energy collisions is the p_T spectra for different species of final state particles.
- From the spectra, we can learn a lot about the regularities of the particle productions
- In many studies, searching for a scaling behaviour of the p_T spectra is helpful to reveal these regularities.

Introduction

- Bjorken scaling in DIS

PDFs depend not on the energy of DIS but on the ratio of the energy to the momentum transfer in the scattering.

[J. D. Bjorken and E. A. Paschos, Phys. Rev. 185, 1975, 1969.]

- KNO (Koba-Nielsen-Olesen) scaling

The multiplicity distributions P_n collapse on a universal scaling curve when presented as a function of $z = n/\langle n \rangle$: $\Psi(z) = \langle n \rangle P_n$

[Z. Koba, H. B. Nielsen and P. Olesen, Nucl. Phys. B 40, 317, 1972.]

Introduction

- Scaling behaviour in the pion p_T spectra with different centralities at midrapidity in Au+Au collisions at RHIC.

[R. C. Hwa and C. B. Yang, Phys. Rev. Lett. 90, 212301, 2003]

- This scaling behaviour of pions was also found in noncentral regions in Au+Au and d+Au collisions.

[L. L. Zhu and C. B. Yang, Phys. Rev. C 75, 044904, 2007]

- An analogous scaling behaviour in the proton and anti-proton p_T spectra with different centralities at midrapidity in Au+Au collisions.

[W. C. Zhang et al. Phys. Rev. C 76, 044910, 2007]

Introduction

- Recently, we observed a scaling behaviour in the p_T spectra of inclusive charged hadrons in $pp(p\bar{p})$ collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 (0.63,1.8 and 1.96) TeV.

[W. C. Zhang, C. B. Yang, J. Phys. G, **41**, 105006, 2014]

- In this talk, we will show the scaling behaviour in the p_T spectra of identified pions, kaons and protons in pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV.

[W. C. Zhang, J. Phys. G, **43**, 015003, 2016]

Introduction

- These identified charged hadron p_T spectra were published by the ALICE collaboration.

[Eur. Phys. J. C, 71, 1655, 2011]
[Phys. Lett. B, 736, 196, 2014]
[Eur. Phys. J. C, 75, 226, 2015]

- π: $(\pi^+ + \pi^-)/2$, K: $(K^+ + K^-)/2$, p: $(p+\bar{p})/2$
- The p_T coverage for pions:

0.9 TeV: 0.1-2.6 GeV/ c

2.76 TeV： 0.1-20.0GeV/ c ← The largest coverage

7 TeV: 0.1-3.0 GeV/ c

Method to search for the scaling behaviour

- Take the pion p_T spectra as an example
- Define $z = p_T/K$ and $\Phi(z) = A \cdot (2\pi p_T)^{-1} d^2N/dp_T dy|_{p_T=Kz}$
- By choosing proper K and A, the scaled p_T spectra at different energies can be put into one curve.
- Here, we set K and A for the collisions at 2.76 TeV to be 1.
- For the collisions at 0.9 and 7 TeV, K and A are determined by the quality factor (QF) method.

Method to search for the scaling behaviour

- QF is defined as

$$QF(K,A) = \left[\sum_i \frac{(v^i - v^{i-1})^2}{(u^i - u^{i-1})^2 + \varepsilon^2} \right]^{-1}$$

$$v^i = \log(A \bullet (2\pi p_T^i)^{-1} d^2N^i / dp_T^i\, dy^i)$$

$$u^i = p_T^i / K$$

ε=0.01

- Before entering the QF formula, (u^i, v^i) has been rescaled so that $0 \le u^i, v^i \le 1$, and u^i are ordered.
- Two successive data points being close in u and far in v will give a large contribution to the sum in QF.

Method to search for the scaling behaviour

- As a result, a set of data points with a small sum (thus a large QF) is expected to lie close to a unique curve.
- For the scaling parameters at 0.9 (7) TeV, we utilize the data points at 0.9 (7) and 2.76 TeV to determine them.
- The best set of (K, A) for 0.9 (7) TeV is chosen to be the one which globally maximizes the QF.

Method to search for the scaling behaviour

Pions

$\sqrt{s}$ (TeV)	K	A
0.9	0.93 ± 0.04	1.11 ± 0.14
2.76	1	1
7	1.06 ± 0.02	0.89 ± 0.07

Kaons

$\sqrt{s}$ (TeV)	K	A
0.9	0.913 ± 0.007	1.05 ± 0.01
2.76	1	1
7	1.14 ± 0.04	1.05 ± 0.14

Protons

$\sqrt{s}$ (TeV)	K	A
0.9	0.926 ± 0.001	1.08 ± 0.02
2.76	1	1
7	1.108 ± 0.006	1.04 ± 0.02

Scaling behaviour of identified π, K and p

- Tsallis distributions to parameterize the spectra at 2.76 TeV

$$\Phi(z) = C_q \left[1 - (1-q)\frac{\sqrt{m^2 + z^2} - m}{z_0}\right]^{\frac{1}{1-q}}$$

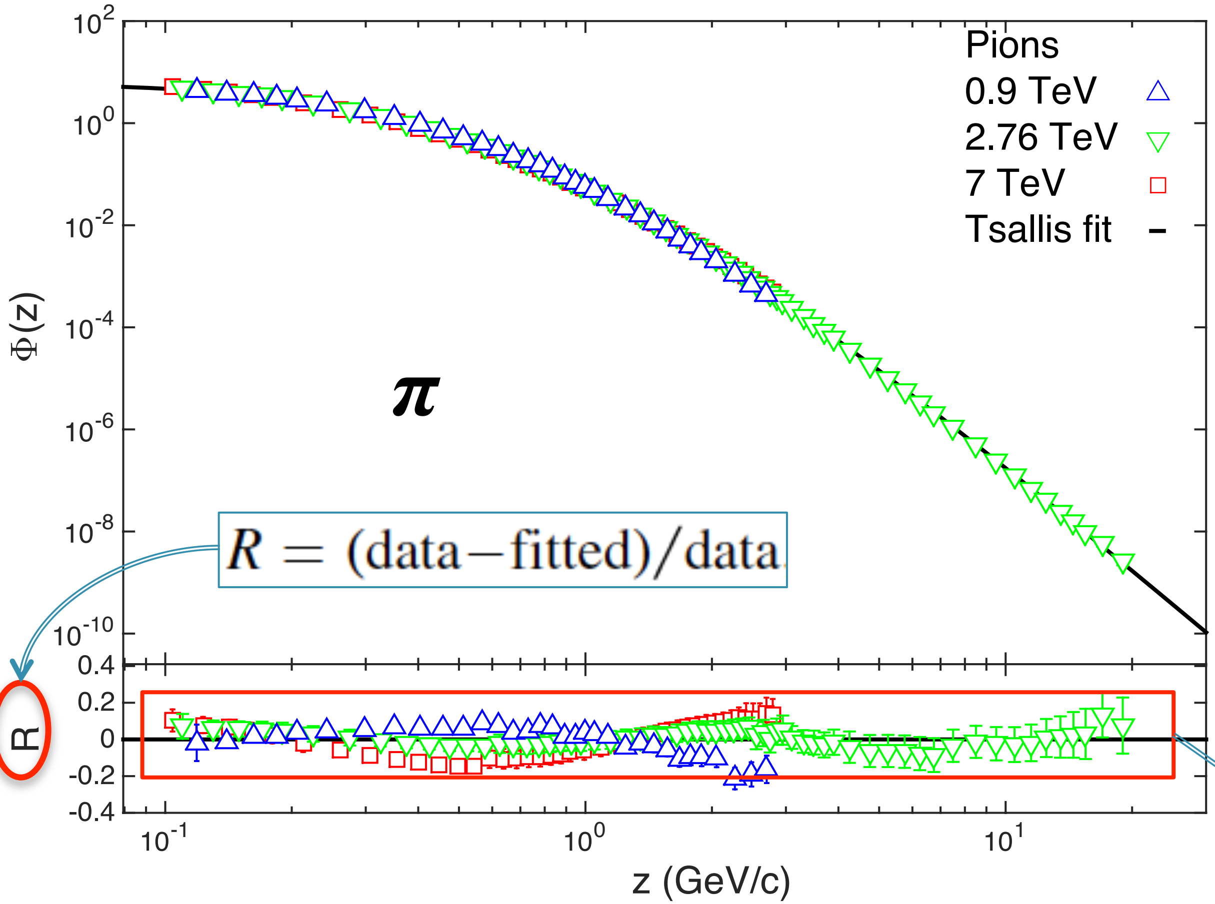
Fit parameters: C_q, q, z_0

The mass of π, K, p

0.1(0.1 and 0.1) GeV/c at 2.76 TeV

0.14(0.494 and 0.938) GeV/c^2

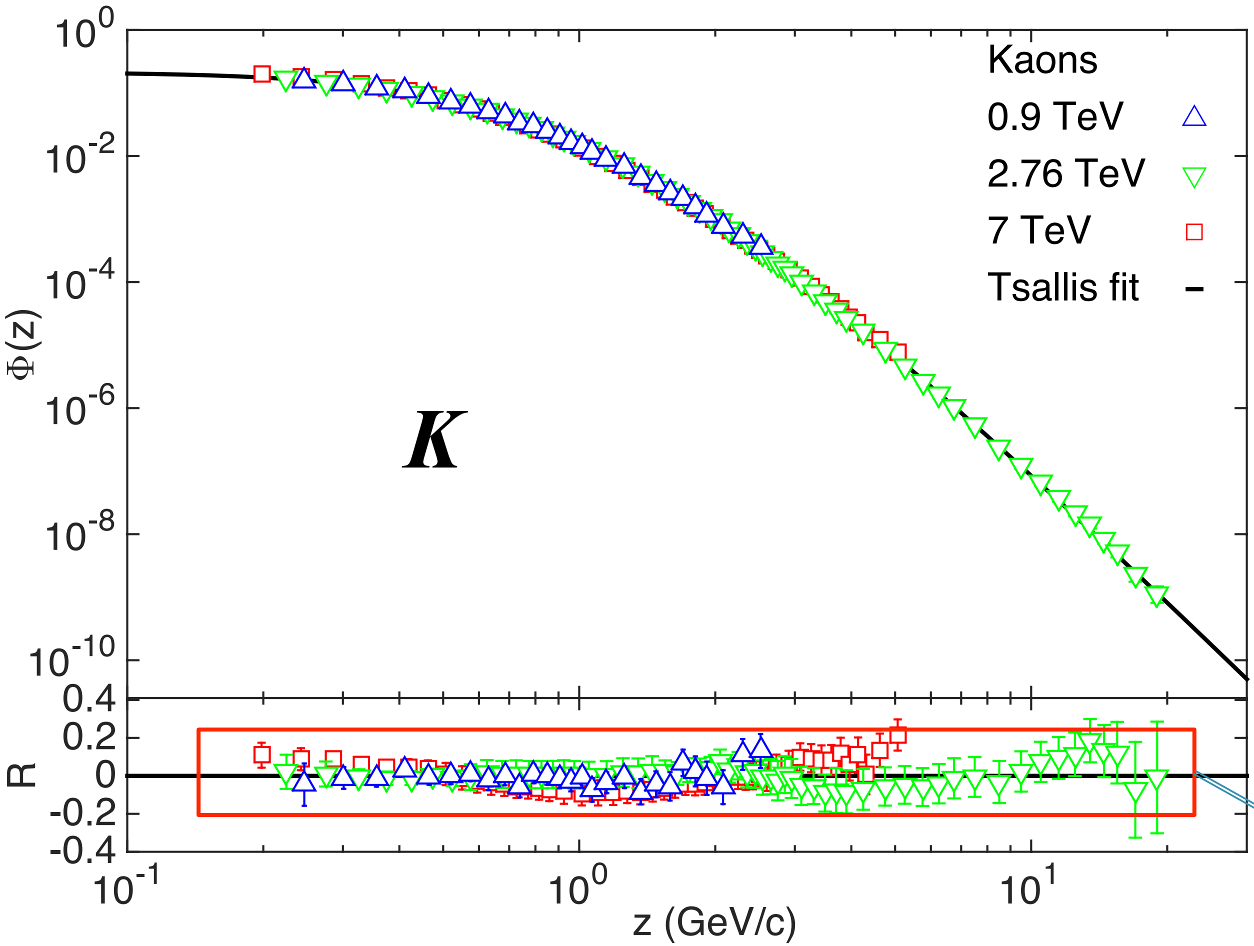
Scaling behaviour of identified π, K and p



	Pions
C_q	6.01 ± 0.08
q	1.1416 ± 0.0007
z_0 (GeV/c)	0.1308 ± 0.0008
χ^2/dof	0.49

agreement is within 20%.

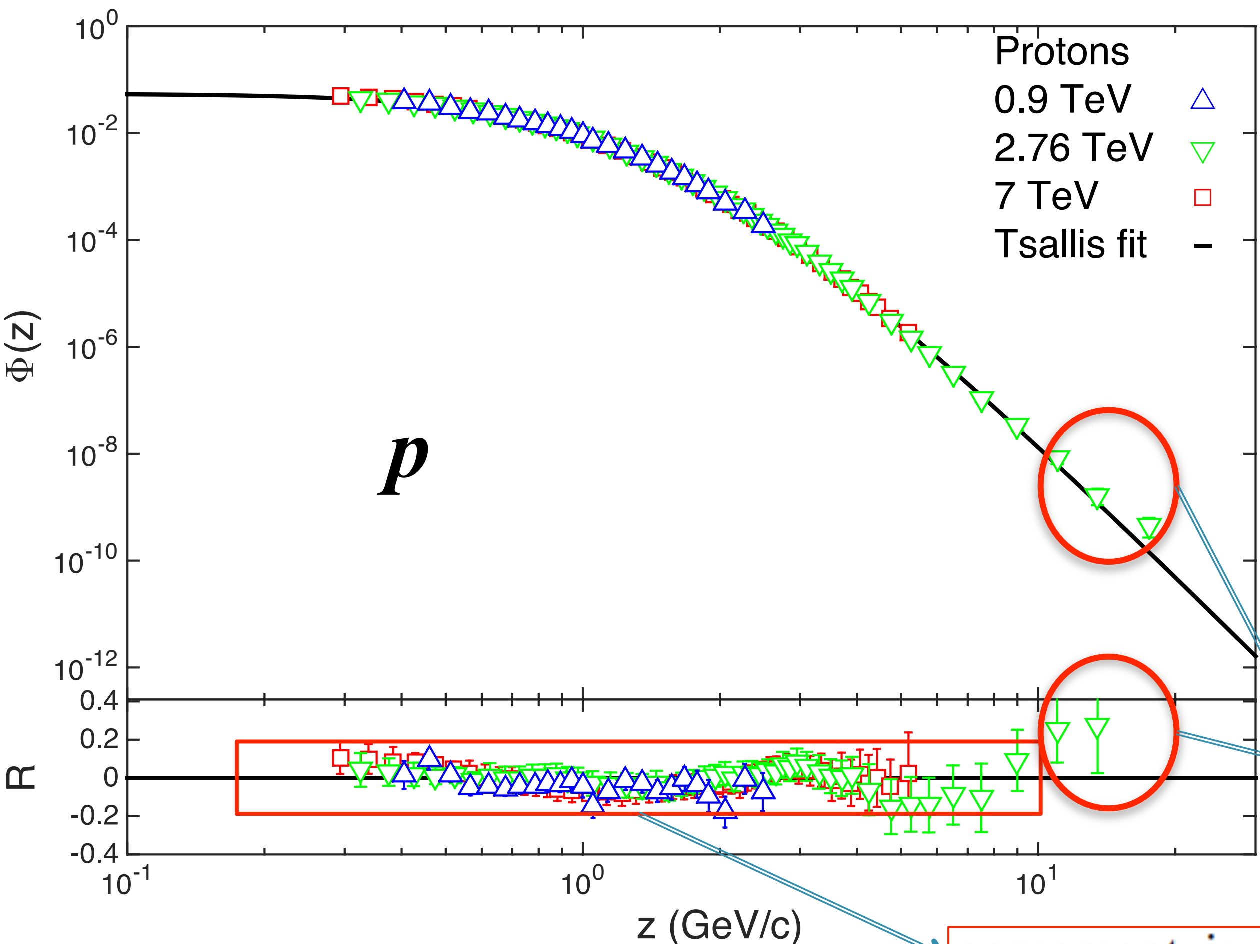
Scaling behaviour of identified π, K and p



	Kaons
C_q	0.214 ± 0.002
q	1.1402 ± 0.0004
z_0 (GeV/c)	0.193 ± 0.001
χ^2/dof	0.23

agreement is within 20%.

Scaling behaviour of identified π, K and p



	Protons
C_q	0.0546 ± 0.0008
q	1.115 ± 0.002
z_0 (GeV/c)	0.220 ± 0.002
χ^2/dof	0.40

The yield and exp. errors have the same order.

agreement is within 20%.

Colour string percolation model

- Colour strings are stretched between the partons of protons in pp collisions.
- These strings then decay into new ones with the emission of $q\bar{q}$ pairs.
- Identified hadrons are produced through the hadronization of these new strings.

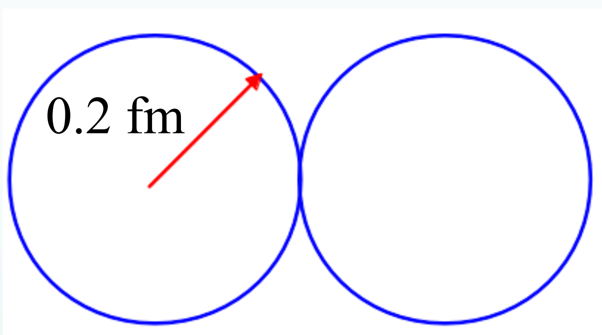
[L. Cunqueiro et al, Eur. Phys. J. C, 53, 585–9, 2008]

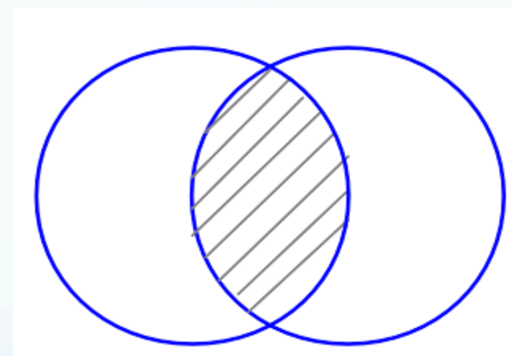
[J. Dias de Deus J et al, Eur. Phys. J. C, 41 229–41, 2005]

Colour string percolation model

- These strings are viewed as small areas in the transverse plane.
- When there are n strings, they start to overlap and form

clusters with transverse areas of S_{n}.





get in touch, $S_n = nS_1$, $nS_1/S_n = 1$

maximumly overlap, $S_n = S_1$, $nS_1/S_n = n$

degree of string overlap

$$\langle p_T^2 \rangle_{ni} = \sqrt{nS_1 / S_n}\, \langle p_T^2 \rangle_{1i}$$

Colour string percolation model

- The p_T spectra of identified particles produced in pp collisions:

$$\frac{d^2N}{2\pi p_T dp_T dy} = C\int_0^{\infty} W(x) f(x, p_T) dx$$

normalization const.

$$W(x) = \frac{\gamma}{\Gamma(k)}(\gamma x)^{k-1}\exp(-\gamma x)$$

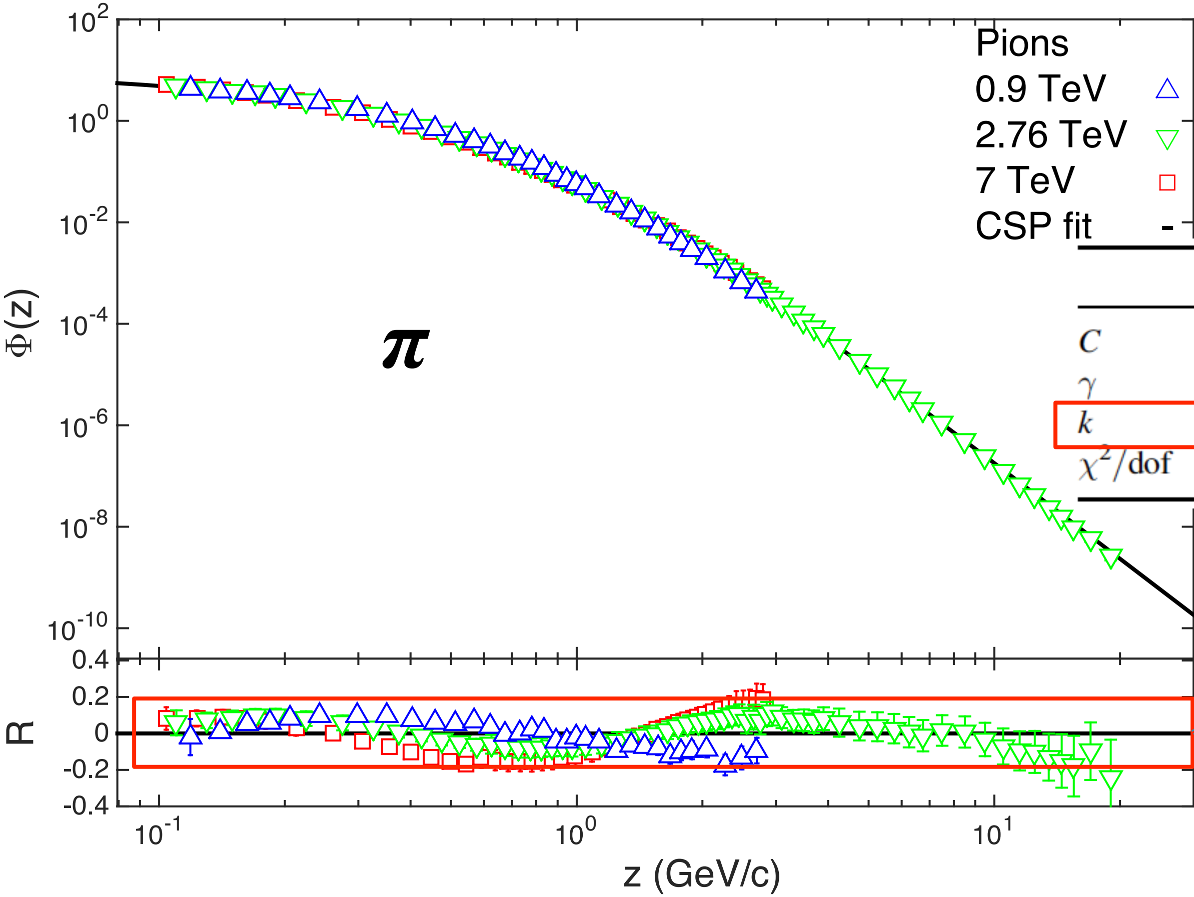
$$f(x, p_T) = \exp(-\sqrt{2x}\, p_T)$$

cluster size distribution, γ, k free para.

spectra produced by one cluster

Colour string percolation model

- The CSP model can describe the scaling behaviour presented in z well.



	Pions	Kaons	Protons
C	9.1 ± 0.2	0.53 ± 0.01	0.160 ± 0.007
γ	0.140 ± 0.003	0.342 ± 0.008	0.91 ± 0.07
k	3.15 ± 0.02	3.33 ± 0.02	5.0 ± 0.2
χ^2/dof	1.53	0.91	1.91

agreement is within 20%.

Colour string percolation model

- Under the transformation

$$x \to x' = \lambda x,\ \gamma \to \gamma' = \gamma/\lambda, p_T \to p_T' = p_T / \sqrt{\lambda}$$

$$W(x) = \frac{\gamma}{\Gamma(k)}(\gamma x)^{k-1} \exp(-\gamma x)$$

$$f(x, p_T) = \exp(-\sqrt{2x} p_T)$$

$$\frac{d^2 N}{2\pi p_T dp_T dy} = C \int_0^\infty W(x) f(x, p_T) dx$$

Invariant → The scaling behaviour we are looking for.

Colour string percolation model

- Compare the p_T` transformation in the CSP model $p'_T \to p'_T \sqrt{\lambda}$

with the one in the search for the scaling behaviour $p_T \to p_T / K$

$$K \sim 1/\sqrt{\lambda}$$

$$\lambda = \langle S_n / nS_1 \rangle^{1/2}$$

$$K \sim \langle nS_1 / S_n \rangle^{1/4}$$

J. Dias de Deus J and C. Pajares, Phys. Lett. B, 642, 455–8, 2006

- nS_1/S_n grows with energy, K should also increase with energy

Pions

$\sqrt{s}$ (TeV)	K	A
0.9	0.93 ± 0.04	1.11 ± 0.14
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Kaons

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That's indeed what we observed!

Summary

- We observed the scaling behaviour in the spectra of identified particles at 0.9, 2.76 and 7 TeV.
- This scaling behaviour is exhibited when $p_T \rightarrow z = p_T / K$.
- K is determined by the QF method.
- The scaling behaviour could be explained by the CSP model in a quantitative way.

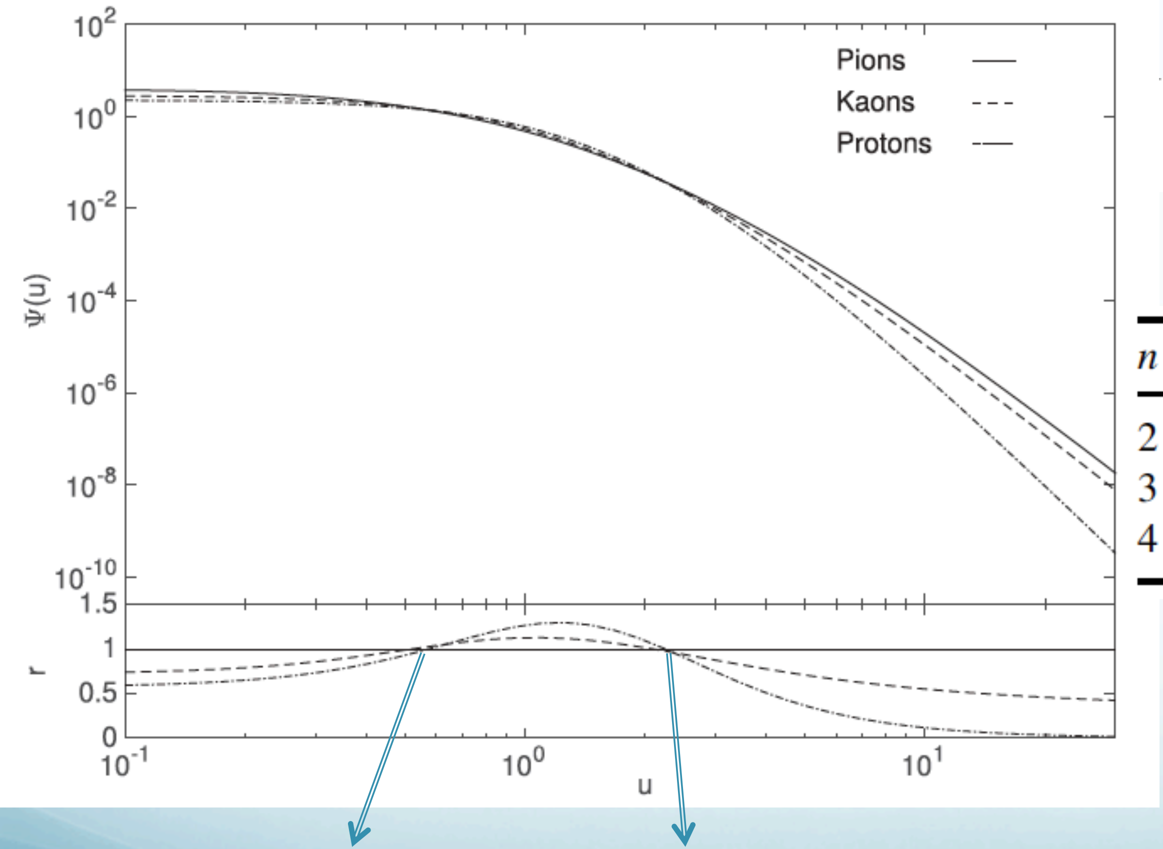
Thanks for your attention!

Back up slides

Scaling behaviours of identified π, K and p

- With different choices of K and A , the scaling functions $\Phi(z)$ are different.
- In order to get rid of this arbitrariness, we introduce another scaling variable, $u = z/\langle z \rangle = p_T/\langle p_T \rangle$, and the corresponding normalized scaling function $\Psi(u) = \langle z \rangle^2 \Phi(\langle z \rangle u) \Big/ \int_0^\infty \Phi(z) z dz$
- Here $\langle z \rangle = \int_0^\infty z\Phi(z) z dz \Big/ \int_0^\infty \Phi(z) z dz$

Comparison among the scaling functions of π, K and p



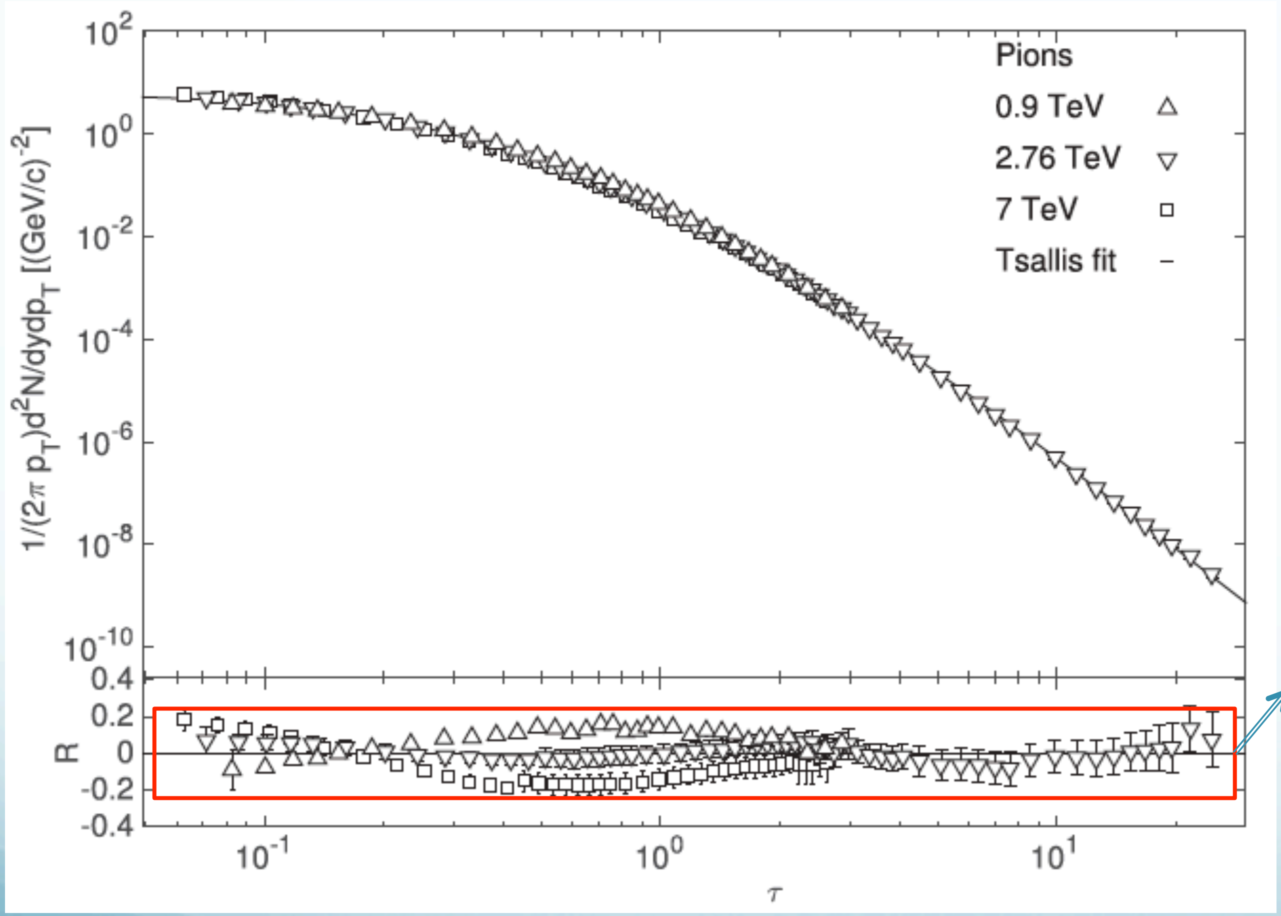
$$\langle p_T^n \rangle \Big/ \langle p_T \rangle^n = \int_0^\infty u^n \Psi(u) u \mathrm{d}u$$

n	Pions	Kaons	Protons
2	1.9 ± 0.2	1.7 ± 0.1	1.5 ± 0.2
3	6.5 ± 1.0	4.9 ± 0.3	3.3 ± 0.5
4	44.8 ± 8.2	26.8 ± 2.2	10.7 ± 2.2

u≈0.6

u≈2

Comparison to the scaling behaviour presented in τ



$$\tau = p_T / Q_0 (p_T / \sqrt{s})^{\lambda/2}$$

$$Q_0 = 1 \text{ GeV/c}$$

$$\lambda \approx 0.27.$$

agreement is within 20%.

Comparable!

Colour string percolation model

- The fragmentation function for the cluster is chosen as the Schwinger formula $f(\mathrm{x})=\exp(-p_{\mathrm{T}}^{2}\,x)$
- However, this function only describes the spectra well at the soft p_{T} region.
- In order to describe the spectra at the high p_{T} region as well, the Schwinger formula should be replaced by $f(x, p_T) = \exp(-\sqrt{2x}\,p_T)$

Colour string percolation model

- The rate of the K values increasing with energy for pions is different with the one for kaons or protons.
- The ratio between the values of K at different energies should be equal to the ratio between the values of $\langle p_T \rangle$ at different energies.

$$\langle p_T \rangle = \frac{\int_0^\infty \int_0^\infty W(x) f(x, p_T) p_T^2 \, dx dp_T}{\int_0^\infty \int_0^\infty W(x) f(x, p_T) p_T \, dx dp_T}$$

$f(x, p_T)$ are the same for pions (kaons or protons) at different energies.

The cluster's size distributions $W(x)$ are different for different particles.