Particle transverse momentum distributions in p-p collisions at $\sqrt{S_{NN}}$= 0.9TeV

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Outline of Presentation:

- Introduction.
- Rapidity.
- Invariant yield Freeze-Out.
- Unified Statistical Thermal Freeze-Out Model (USTFM).
- Resonance Decay Contributions.
- Fitting Procedure.
- Results and Discussion.
- Conclusion.
- References.

Introduction:

- For the study of Mid-rapidity space transverse momentum spectra of hadrons (p, K^+, K^0_S, φ, Λ, and ($\Xi+\bar{\Xi}$)) and the available rapidity distributions of Strange hadrons (K^0_S, (Λ +Λ̄ ,($\Xi+\bar{\Xi}$)) USTFM has been used.
- Using Model calculations provides Thermal Freeze-Out Condition.
- Shows transparency in p-p collisions at LHC.

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- Incorporates longitudinal as well as transverse hydrodynamic flow.
- Heavy decay contributions are taken into account.
- Imposed the criteria of exact strangeness conservation.

Rapidity

- This defines the longitudinal motion for a particle of mass m moving along z-axis.

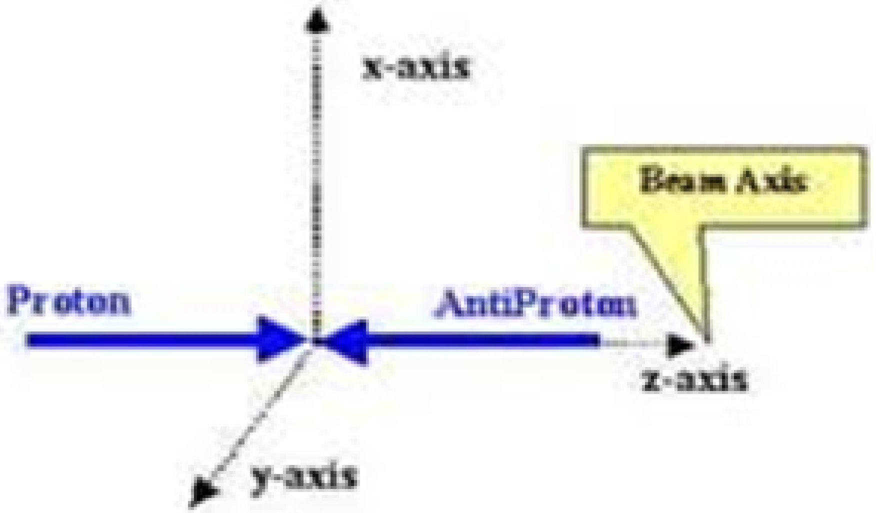
$$y = \frac{1}{2}\ln\left(\frac{E + p_z}{E - p_z}\right)$$

- It is a dimensionless quantity and can be +ve or −ve.
- It has simple properties under the change of frame of reference.
- In non-relativistic case, rapidity y = longitudinal velocity β.
- The rapidity is useful as momentum, since rapidity differences are Lorentz invariant

$$dy' = y_2' - y_1' = y_2 - y_1 = dy$$

- Energy and momentum in terms of rapidity are

$$E = m_T \cosh(y) \qquad p_Z = m_T \sinh(y)$$

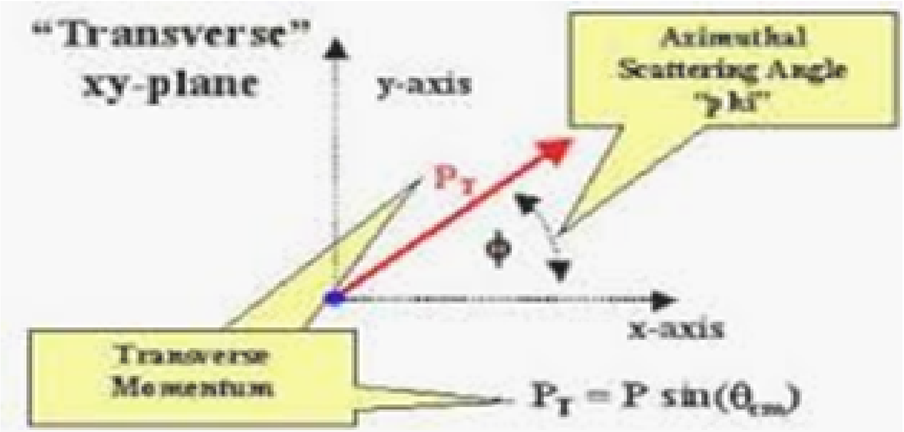


Invariant Yield and Freeze-Out

- **Number of particles produced per event, N, per unit of Lorentz-invariant momentum space.**

$$E\frac{d^3N}{d^3p} = \frac{d^3N}{2\pi p_T dp_T dy}$$

- **The Invariant spectrum is the core measurement of this work. All results presented later on will be derived from invariant spectra of various hadrons.**



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Hadrons decouple from the rest of the system.
Particle production processes stop.
Hadrons stream freely to their respective detectors.
Particle ratios and particle spectra freeze.

Chemical Freeze-out:

Inelastic collisions cease.
Particle number is fixed.
Characterized by chemical freeze-out temperature and chemical potential.
Information given by the particle ratios and their rapidity distributions.

Kinetic Freeze-out:

Elastic collisions cease.
Particle energy and momenta are fixed.
Characterized by kinetic freeze-out temperature and collective flow.
Information given by the transverse momentum distributions.

Unified Statistical Thermal Freeze-Out Model (USTFM)

- The system formed at freeze-out is assumed to be in thermo-chemical equilibrium.
- Fireballs moving along the beam axis with monotonically increasing fireball rapidities y_0.
- The momentum distributions of hadrons are characterized by the Lorentz-invariant Cooper-Frye formula:

$$E\frac{d^3n}{d^3P} = \frac{g}{(2\pi)^3}\int f\left(\frac{p^\mu u^\mu}{T}, \lambda\right) p^\mu d\Sigma_{\mu.}$$

Where Σ_f represents freeze-out surface. Fugacity $\lambda = exp(\mu/T)$.

- Also $E\frac{d^3N}{d^3p} = E'\frac{d^3N}{d^3p'}$ where $E'\frac{d^3N}{d^3p'} \sim \frac{E'}{e^{\left(\frac{E'-\mu}{T}\right)} \pm 1}$ is the quantum distribution function.
- Chemical Potential $\mu = a + by_0{}^2$

$$E' = \gamma(E - \vec{p}.\vec{\beta}) \qquad \vec{p}.\vec{\beta} = p_T\beta_T + p_z\beta_z$$

$$E = m_T Coshy \qquad p_z = m_T Sinhy$$

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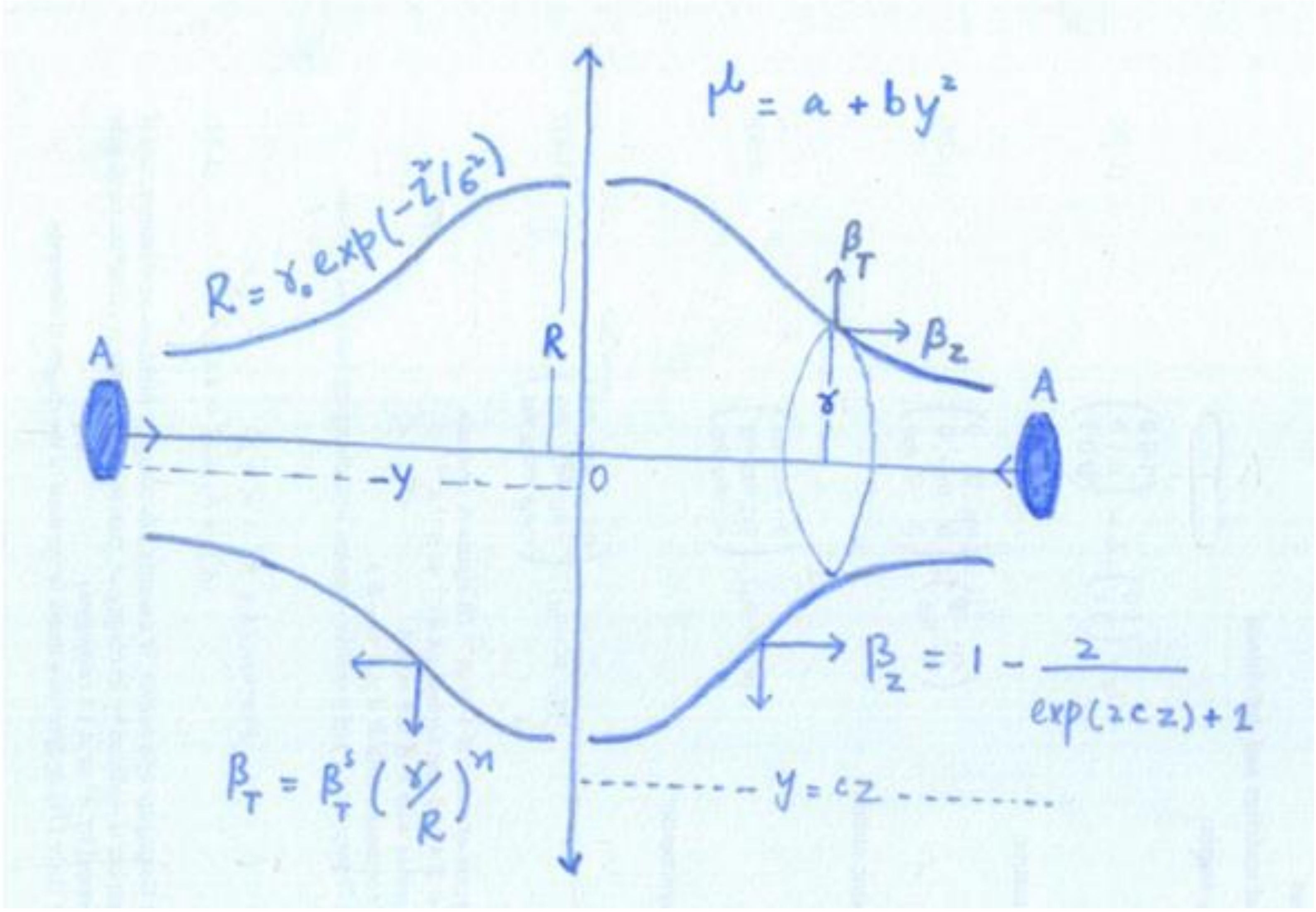

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- We have incorporated both the transverse as well as longitudinal flow.

- The transverse (or radial) velocity component of the hadronic fluid varies with the transverse coordinate r as : $\beta_T(r) = \beta_T^S (r/R)^n$ where R is the Transverse radius of the fireball which decreases with the z coordinate of the system as: $R = r_0 \exp(-|z|^2/\sigma^2)$

- The fluid's surface transverse expansion velocity is fixed as: $\beta_T^s = \beta_T^0 \sqrt{1-\beta_z^2}$

- The longitudinal velocity component is: $\beta_z(z) = 1 - \dfrac{2}{\exp(2cz)+1}$

- Also we ensure that net particle velocity must satisfy: $\beta(r,z) = \sqrt{\beta_T^2 + \beta_z^2} < 1$

- Finally an integral over the physical volume of the system (using cylindrical coordinate system) is performed to obtain the net hadronic yield:

$$E\frac{d^3N}{d^3p} = \frac{g}{(2\pi)^2}\int_{-\infty}^{\infty}\int_0^R \lambda E' e^{\left(-\frac{E'}{T}\right)} r\, dr\, dz$$

This is the thermal (primordial) yield.

Resonance decay contributions

- The spectrum of a given decay product of a given parent hadron in the rest frame of the fireball can be written as :

$$K^0(1270) \rightarrow K^+(892)\pi^-$$

$$K^+(892) \rightarrow K^+(493)\pi^0$$

$$\frac{d^3 n^{decay}}{d^3 p} = \frac{1}{2pE}\left(\frac{m_h}{p^*}\right)\int_{E_-}^{E_+} dE_h E_h \left(\frac{d^3 n_h}{d^3 p_h}\right)$$

The two body decay kinematics gives the *product* hadron momentum and energy in the "rest frame of the *decaying hadron*" as

$$p^* = (E^{*2} - m^2)^{1/2} \qquad E^* = \frac{m_h^2 - m_j^2 + m^2}{2m_h}$$

The limits of integration are : $E_\pm = \left(\frac{m_h}{m^2}\right)(EE^* \pm pp^*)$

- A Boltzmann type distribution for the massive decaying hadron in the local rest frame of the hadronic fluid element leads to the following final expression for the invariant cross section of the product hadron:

$$E'\frac{d^3N}{d^3p'} = \frac{1}{2p'}\left\{\frac{m_h}{p^*}\right\}\lambda_h g_h e^{-\alpha\theta E'E^*}\left\{\frac{\alpha}{\theta}\left[E'E^* Sinh(\alpha\theta p'p^*) - p'p^* Cosh(\alpha\theta p'p^*)\right] + T^2 Sinh(\alpha\theta p'p^*)\right\}$$

where $\alpha = m_h/m^2$ and $\theta = 1/T$

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- $$\left\{E\frac{d^3N}{d^3p}\right\}_{total} = \left\{E\frac{d^3N}{d^3p}\right\}_{premordial} + \left\{\sum_j \frac{Ed^3N}{d^3p} * B.R_{j\to h}\right\}$$

  Transverse momentum distribution

- $$\frac{dN}{dy} = \int (E\frac{d^3n}{d^3p})dp_T$$ **Rapidity distribution**

Fitting procedure

Minimization of χ^2 per degree of freedom

$$\chi^2 = \sum_i \frac{(R_i^{exp} - R_i^{theor})^2}{\epsilon_i^2}$$

Centre of mass energies studied

9.2 GeV, 62.4 GeV, 130.0 GeV, 200.0 GeV, 0.9 TeV, 2.76 TeV, 5.02 TeV, 7.0 TeV

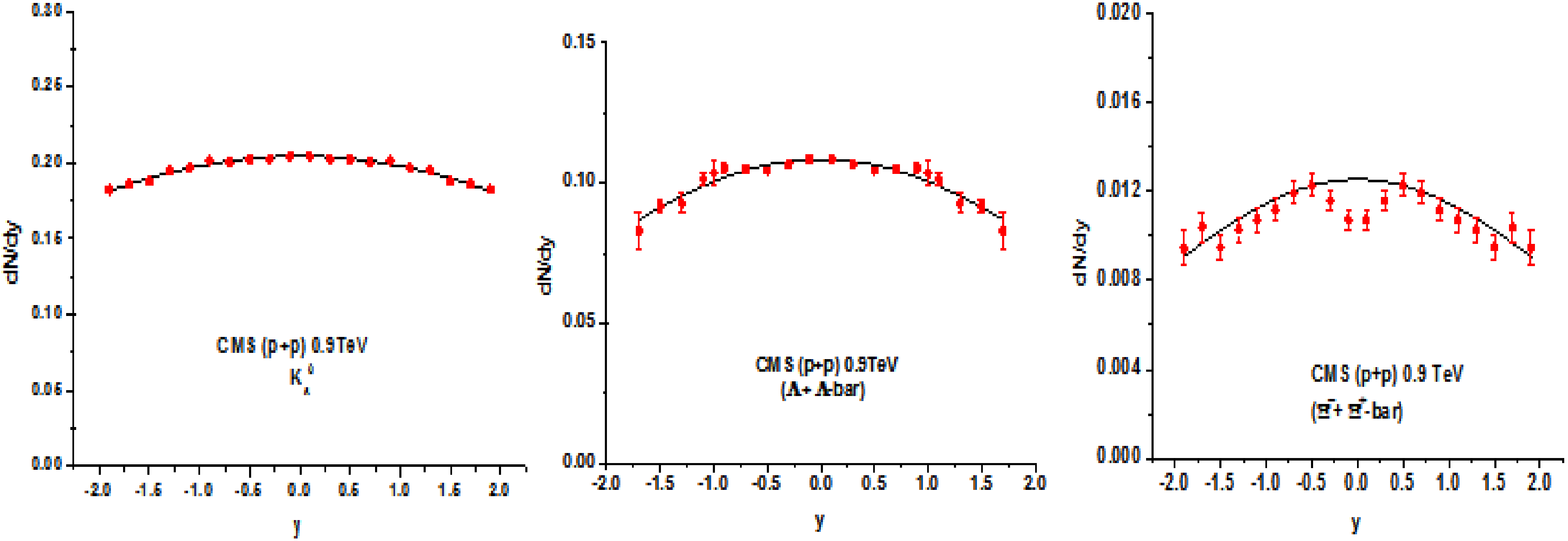
S.P.S . ...RHIC.................. ....LHC....................

Results and Discussion

Particle	*a* (MeV)	*b* (MeV)	σ(fm)
K_s^0	1.88 ± 0.07	3.70 ± 0.05	5.40 ± 0.02
$(\Lambda + \overline{\Lambda})$	1.35 ± 1.10	3.55 ± 0.09	4.70 ± 0.04
$\Xi^- + \Xi^+$	1.0 ± 0.30	3.45 ± 0.09	4.40 ± 0.03

Table.1 Values of a, b and σ obtained from fitting the rapidity distributions of K_s^0, $(\Lambda + \overline{\Lambda})$ and $(\Xi^- + \overline{\Xi}^-)$, respectively, at $\sqrt{s_{NN}} = 0.9$ TeV.

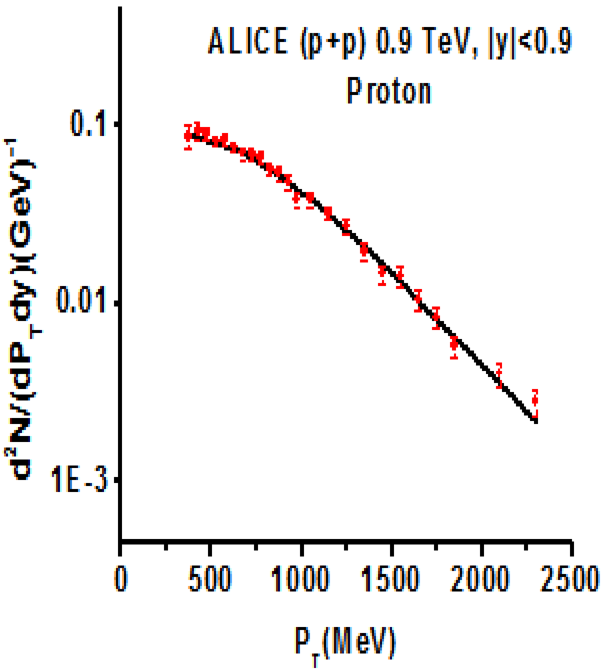
Rapidity distribution of K_s^0, $(\Lambda + \bar{\Lambda})$, $\bar{\Lambda}/\Lambda$ and $(\Xi^- + \overline{\Xi^+})$ at $\sqrt{s_{NN}}$=0.9 TeV.

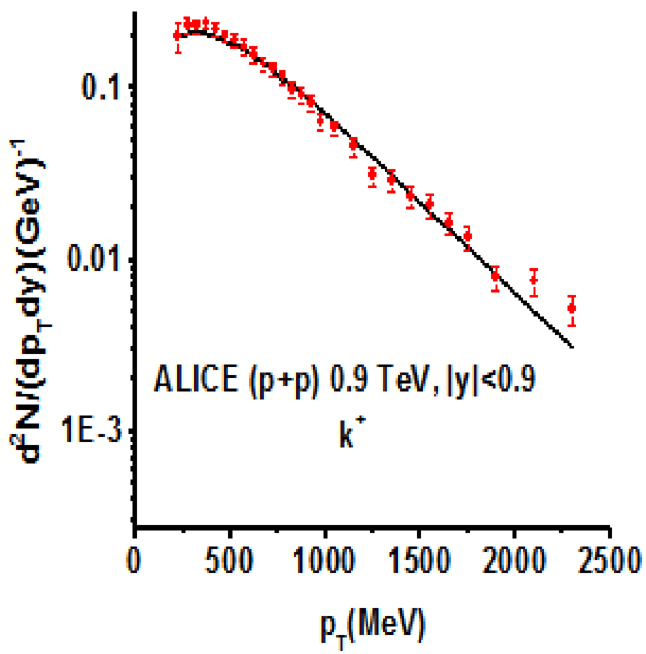


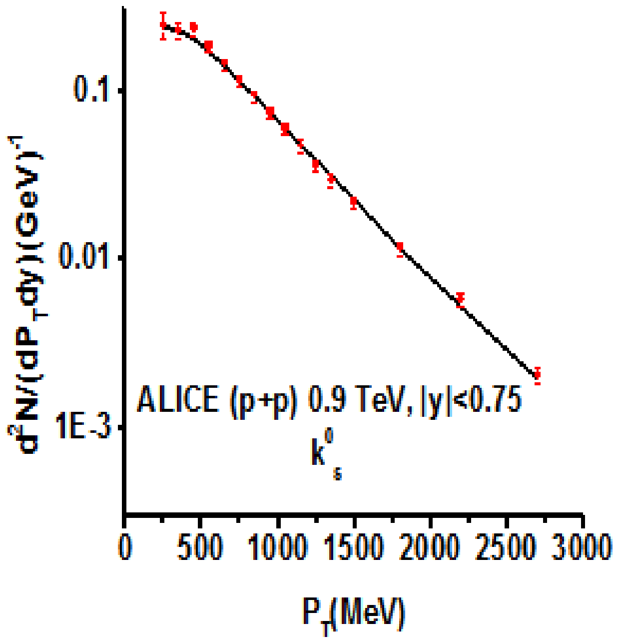
Freeze-Out parameters of various hadrons along with their corresponding χ^2/dof , produced at √SNN=0.9TeV

Particle	T (MeV)	β_T^0	n	χ^2/dof
K^+	173.0 ± 1.0	0.58 ± 0.01	1.20 ± 0.10	1.18
K_s^0	174.0 ± 2.0	0.55 ± 0.01	1.04 ± 0.10	0.63
p	172.0 ± 1.0	0.56 ± 0.01	1.10 ± 0.06	0.65
ϕ	175.0 ± 2.0	0.52 ± 0.02	1.0 ± 0.12	0.25
Λ	175.0 ± 2.0	0.51 ± 0.01	1.02 ± 0.08	0.70
$(\Xi^- + \Xi^-)$	176.0 ± 2.0	0.49 ± 0.02	1.02 ± 0.11	0.91

Transverse momentum spectrum of (p, K^+, K^0_S, ϕ, Λ, and ($\Xi+\overline{\Xi}$))







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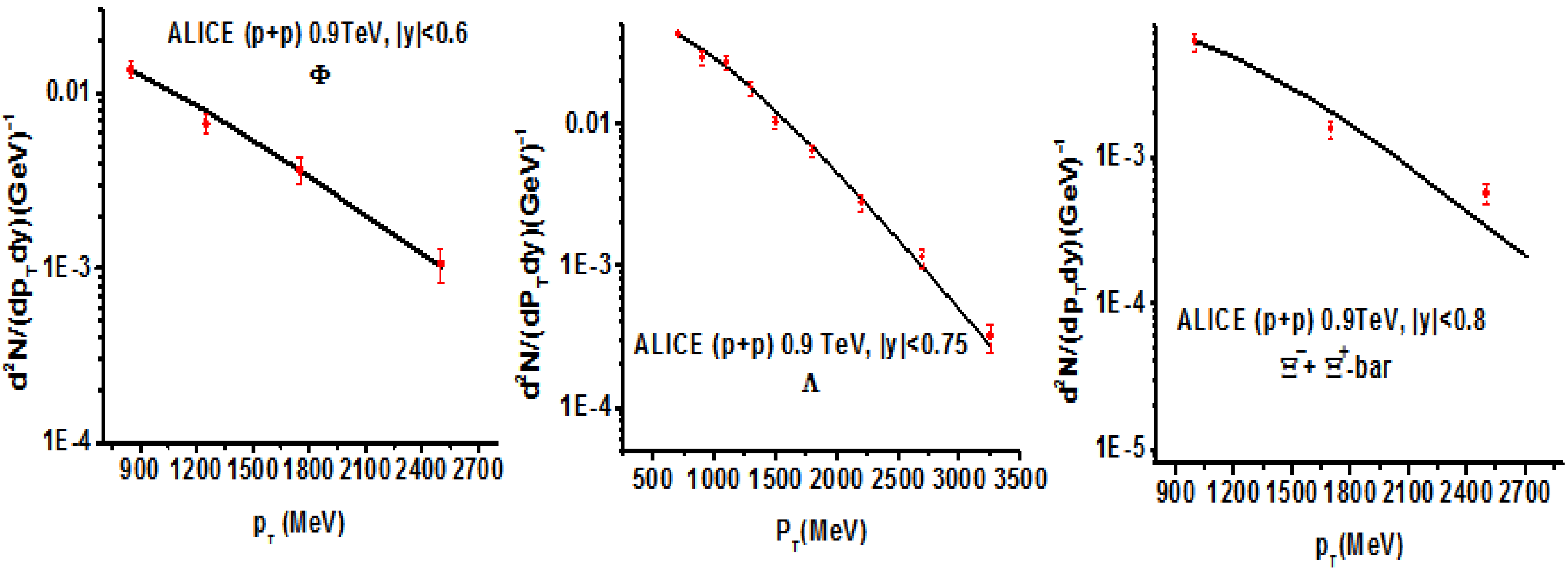
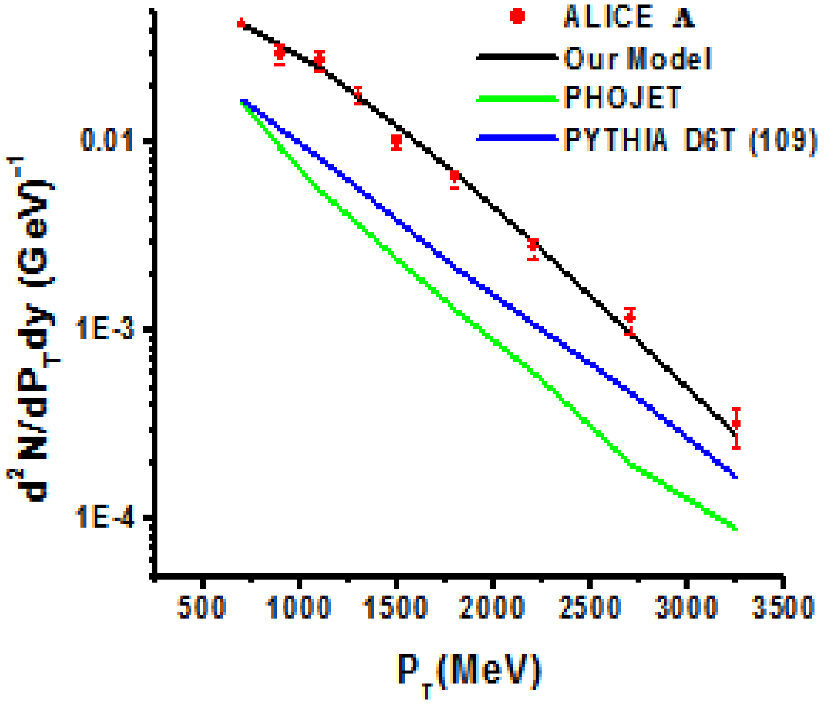
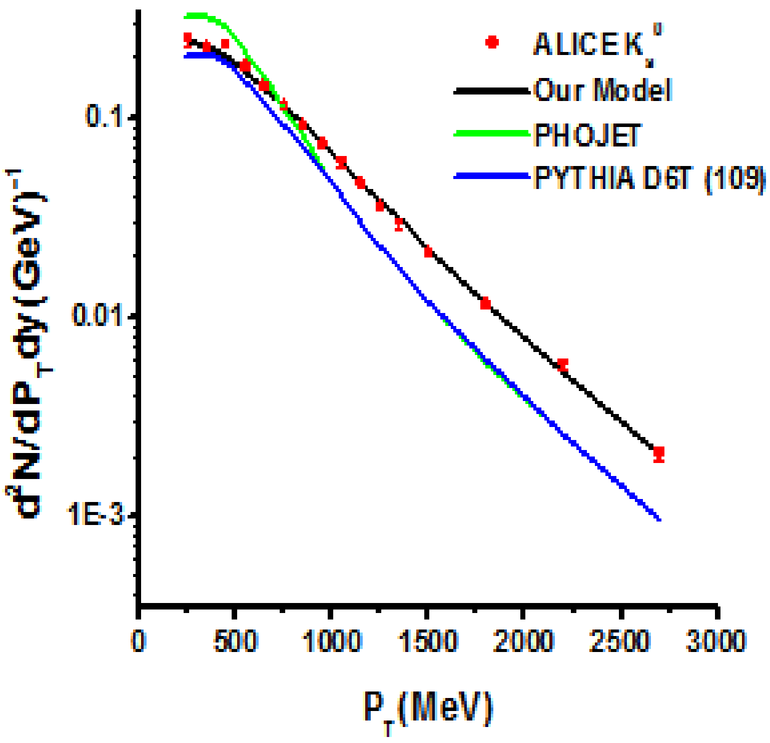


ALICE (p+p) 0.9TeV, |y|<0.6
Φ
0.01
1E-3
1E-4
900 1200 1500 1800 2100 2400 2700
p_T (MeV)
d²N/(dp_T dy)(GeV)⁻¹
ALICE (p+p) 0.9 TeV, |y|<0.75
Λ
0.01
1E-3
1E-4
500 1000 1500 2000 2500 3000 3500
P_T(MeV)
d²N/(dP_T dy)(GeV)⁻¹
ALICE (p+p) 0.9TeV, |y|<0.8
Ξ⁻ + Ξ⁺-bar
1E-3
1E-4
1E-5
900 1200 1500 1800 2100 2400 2700
p_T(MeV)
d²N/(dp_T dy)(GeV)⁻¹

Comparison of our Model results with PHOJET and PYTHIA D6T (109) calculations





Conclusion

- The transverse momentum spectra of the hadrons and the rapidity distribution of the strange hadrons are fitted quite well by using our model USTFM.
- A very small observed value of the mid rapidity chemical potential indicates the effects of almost complete nuclear transparency in pp collusions at LHC.
- The spectra are compared with the predictions from PYTHIA and PHOJET event generators and it is found that a better fit is obtained by using our model.

References

- [1] M. I. Gorenstein, M. S. Tsai, and Shin Nan Yang, *Phys. Rev. C* 51 (1995) 1465
- [2] S. Uddin et al, *J. Phys.G* 39, (2012) 015012
- [3] F. Becattini and U. Heinz, *Z. Phys. C* 76, (1997) 269
- [4] J. Cleymans et al., *proceedings of science*. arXiv:1107.0450v1 [hep-ph] (2011)
- [5] F. Becattini et al. *Eur. Phys. J.* C 66 (2010) 377
- [6] Kraus I, Cleymans J and Oeschler H. et al. *Phys. Rev.* C 79 (2009) 014901.
- [7] Kun jiang et al., arXiv: 1312.4230v1 [nucl-ex] (2013).
- [8] L. Van Hove *Phys. Lett.* B 118, (1982)138
- [9] P. Levai and B. Muller *Phys. Rev. Lett.* 67, (1991) 1519.
- [10] T. Alexopoulos et al., *Phys. Lett.* B 528, (2002) 43.
- [11] R.M. Weiner *Int.J.Mod.Phys E* 15, (2006) 37.
- [12] K. Alpgard et al., UA5 Collab.,
- *Phys. Lett.* B107, (1981) 310
- [13] G. Arnison et al., UA1 Collab., *Phys. Lett.* B107, (1981) 320

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- [14] P. Ghosh et al., J. Phys. G: Nucl. Part. Phys. 41 (2014) 035106
- [15] S. Uddin et al., *Advances in High energy physics*, 2015, Article ID 154853, 7 pages (2015)
- [16] S. Uddin et al., *Modern Physics Letters A*, Vol. 30, No. 33 (2015) 1550167 (11 pages)
- [17] S. Uddin et al., *Nuclear Physics A* 934 (2015) 121–132
- [18] Riyaz Ahmed Bhat et al., *Nuclear Physics A*, Volume 935, (2015) Pages 43-51
- [19] Inam-ul Bashir et al., *Int. Journal of Mod. Phys. A*, Vol. 30 (2015) 1550139 (11 pages) [20] Inam-ul Bashir et al., *Journal of Experimental and Theoretical Physics, 2015, Vol. 121, No. 2, pp. 206–211*
- [21] V. Khachatryan et al., (CMS
- Collab.), *JHEP* 05 (2011) 064
- [22] A. Andronic, P. Braun- Munzinger, J Stachel, *Nucl. Phys.A*, 772 (2006) 167-199
- [23]E. Abbas et al, (ALICE Collab.), *Eur. Phys. J*. C73 (2013) 2496
- [24] K. Aamodt *et al*, (ALICE Collab.), arXiv:1101.4110v3 [hep-ex] (2011)
- [25] Andre Mischke *et al*., (ALICE Collab.), Identified charged hadrons and strange particle production in 900 GeV proton- proton collisions with the ALICE experiment.(2010)

Thank you