Spectra of Identified Hadrons in Pb-Pb collisions at LHC

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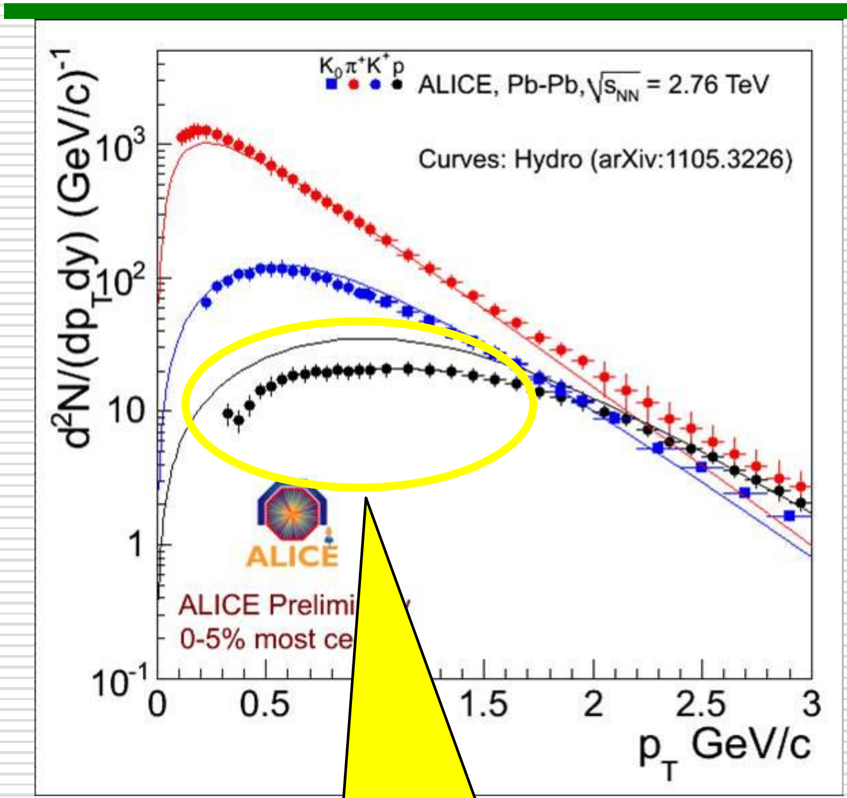
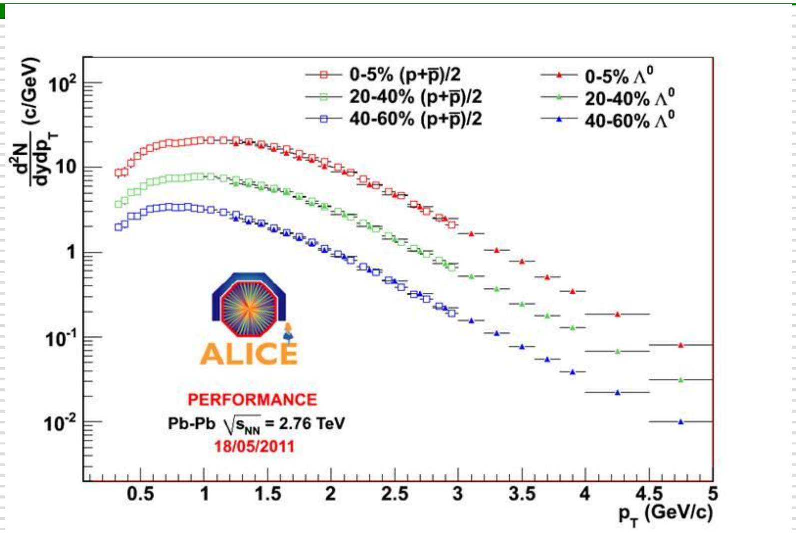
Outline

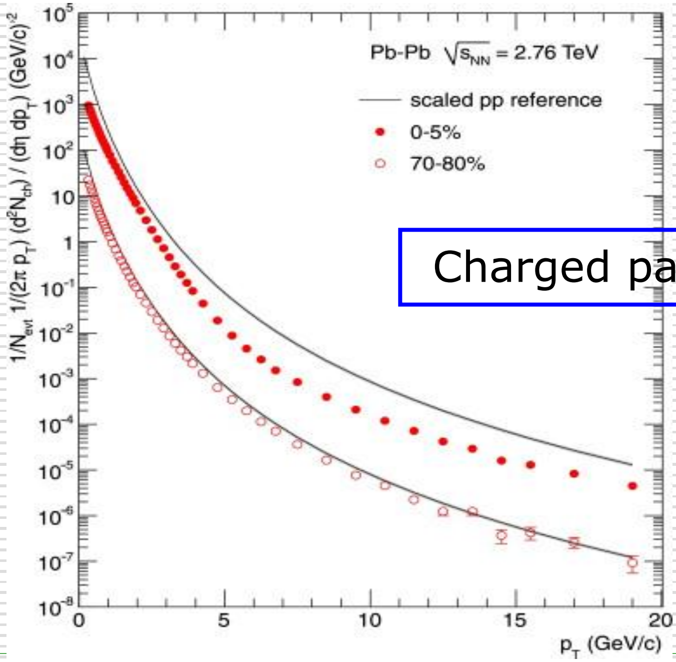
- Motivation
- Physics ideas of the recombination model
- Applications to Pb-Pb collisions
- Summary & outlook

Experimental data



Harder spectrum, flatter p



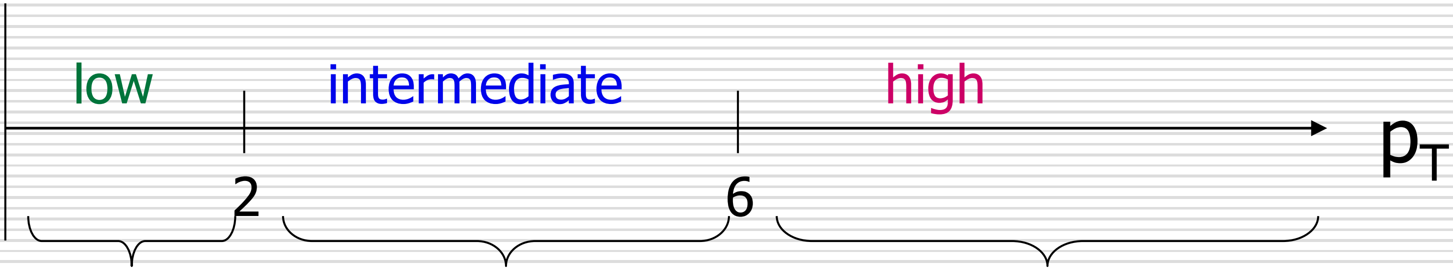


Charged particles

M.Floris, QM11, arXiv:1108.3257

ALICE, PLB696 (2011) 30-39

Transverse momentum spectra



hydro

no rigorous theoretical framework

pQCD

That is where abundant experimental data exist.

At intermediate p_T recombination model has been successful.

Recombination model

- Hadrons are formed by combining quarks.
- Gluons are first converted to q and qbar before hadronization.
- Fragmentation is interpreted as a quark recombination process.
- The model is successful in explaining the particle production at RHIC in central and forward directions.
- ***LHC?***

Basic formulas

p_T distributions of π and p

Recombination functions

Hwa, Phys. Rev. D (1980).

$$p^0\frac{dN^M}{dp_T} = \int \frac{dp_1}{p_1}\frac{dp_2}{p_2} F_{q_1\bar{q}_2}(p_1,p_2) R^M_{q_1,\bar{q}_2}(p_1,p_2,p_T)$$

$$p^0\frac{dN^B}{dp_T} = \int \left[\prod_{i=1}^{3} \frac{dp_i}{p_i}\right] F_{q_1q_2q_3}(p_1,p_2,p_3) R^B_{q_1,q_2,q_3}(p_1,p_2,p_3,p_T)$$

Parton distributions

T : thermal parton

S : shower parton

fragmentation

$$F_{q_1\bar{q}_2} = TT + TS + (SS)^{1j} + \cancel{(SS)^{2j}}$$

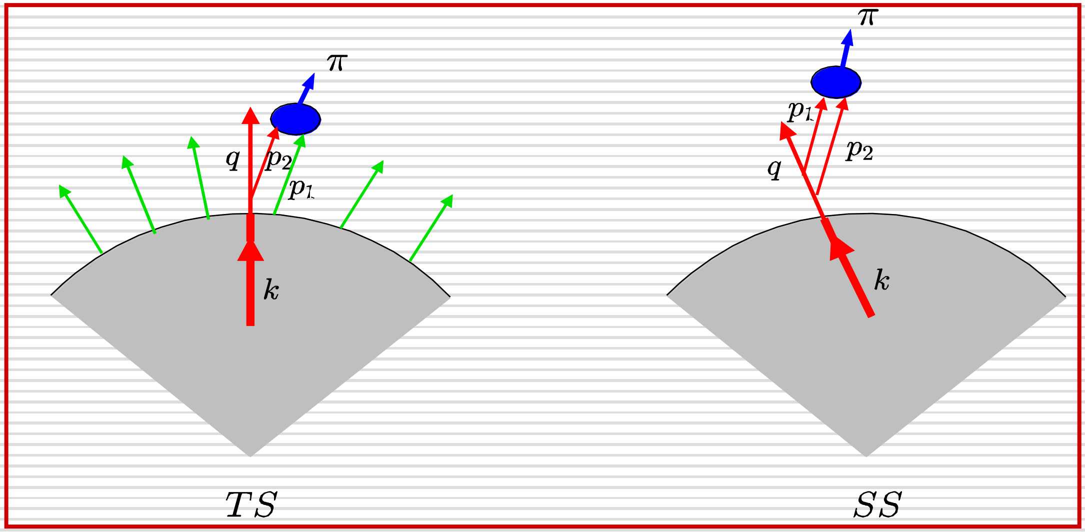
$$F_{q_1q_2q_3} = TTT + TTS + T(SS)^{1j} + (SSS)^{1j} + \cancel{T(SS)^{2j} + ((SS)^{1j}S)^{2j} + (SSS)^{3j}}$$

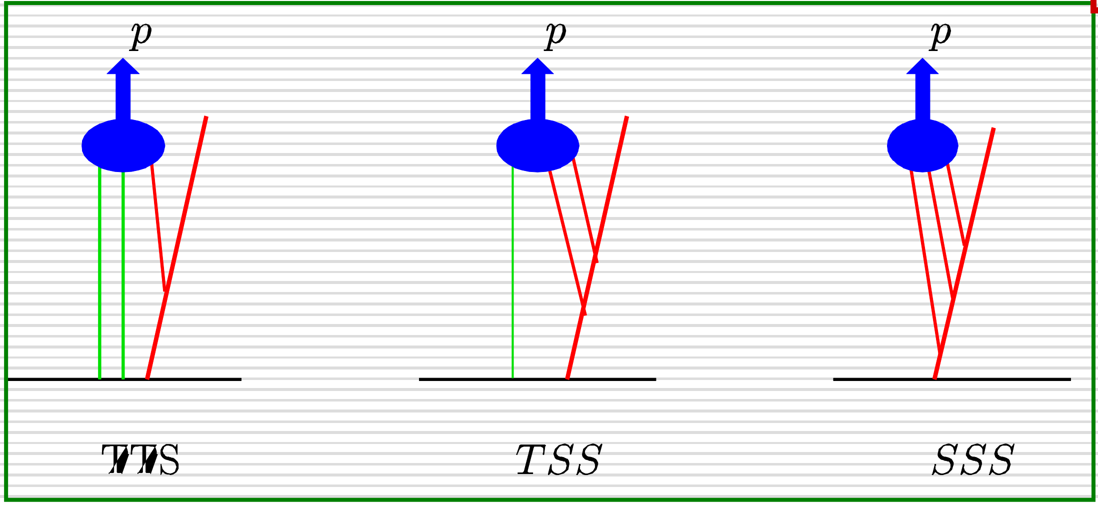
For $p_T < 5$ GeV/c, only need to consider 1-jet contribution.

Soft components

Thermal and shower partons can also recombine

Parton distributions





Thermal partons:

$$\mathcal{T}(p_1) = C p_1 e^{-p_1/T}$$

Shower partons:

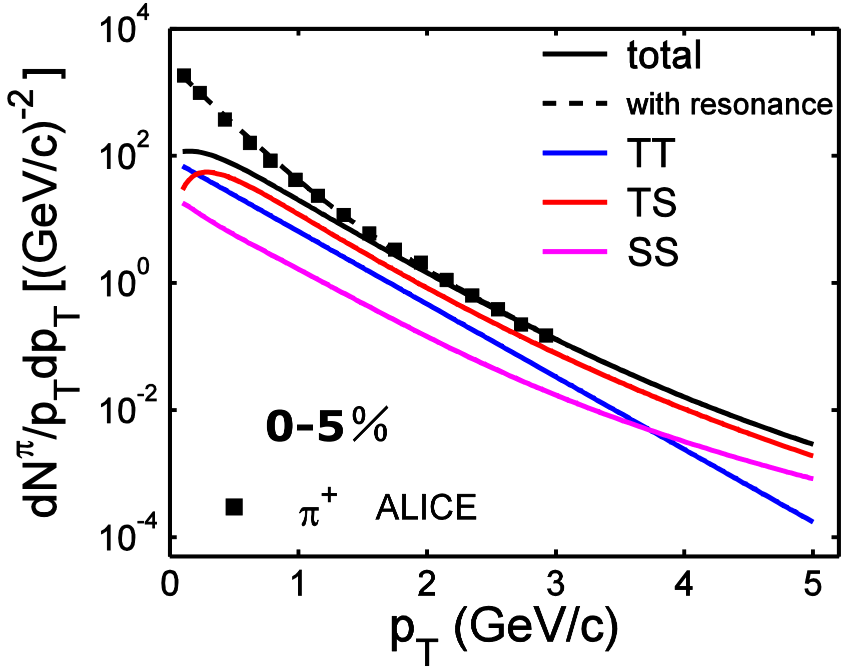
$$\mathcal{S}^q(p_2,\kappa) = \int \frac{dq}{q} \sum_i \bar{F}_i(q,\kappa) S_i^q(p_2/q)$$

$$\boxed{\bar{F}_i(q,\kappa) = k(q)^2 f_i(k(q))}, k(q) = \kappa q$$

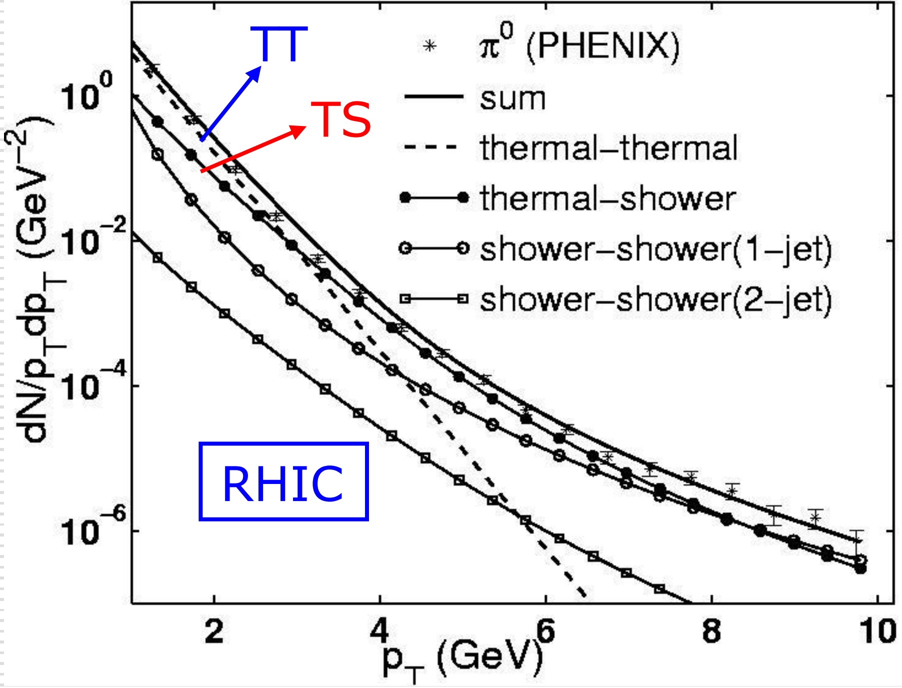
- From k→q: Momentum degradation in the medium.
- κ^{-1} is the momentum fraction of a parton retained after going through the medium.

πproduction in Pb-Pb collisions at 2.76 TeV

Hwa&Zhu, 1109.6300

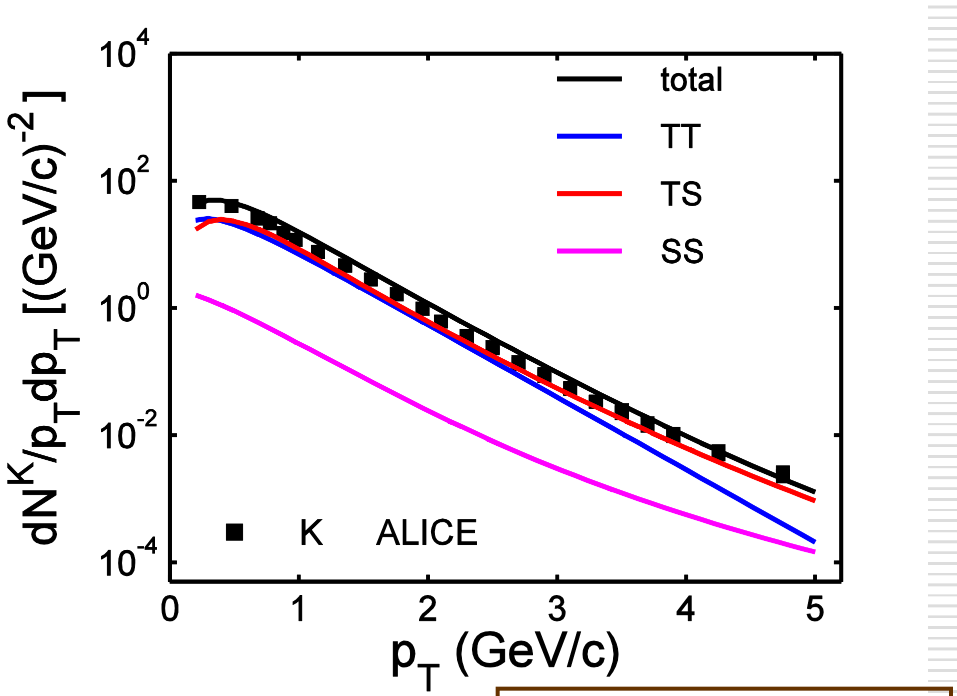


Hwa&Yang, PRC70,024905(2004)

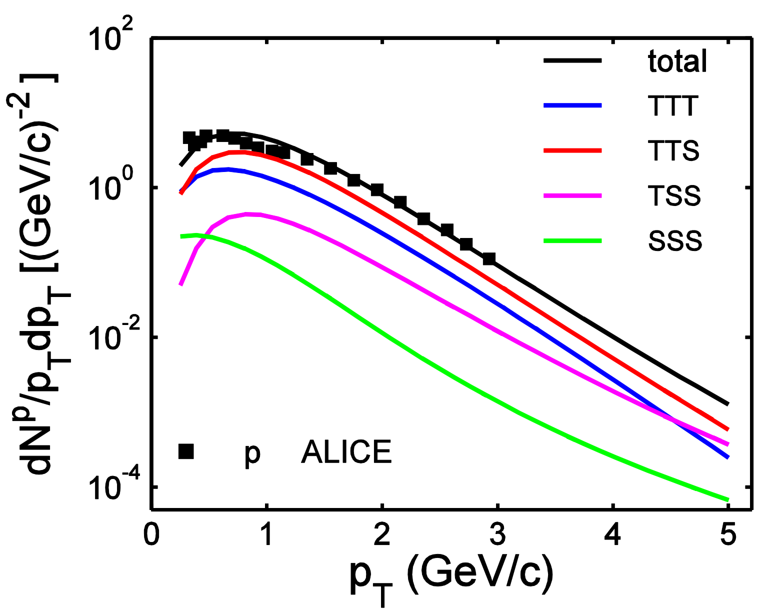


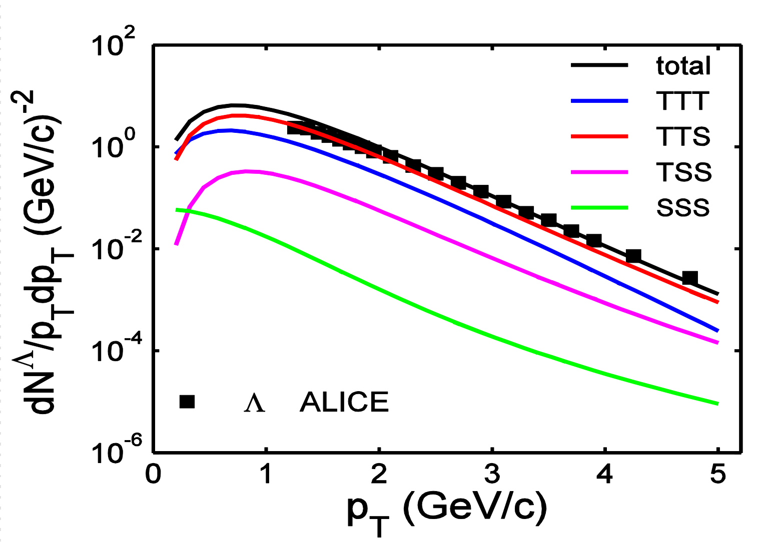
- Our calculation for pions is reliable above p_T~1.5 GeV/c.
- At LHC minijets are pervasive and their effects dominate the spectra at the low and intermediate p_T range.
- TS is found to be more than TT at LHC for p_T as low as 0.5, whereas at RHIC the cross over is between 3 and 4. That is the new finding at LHC.

K/p/Λspectra (0-5% Central)



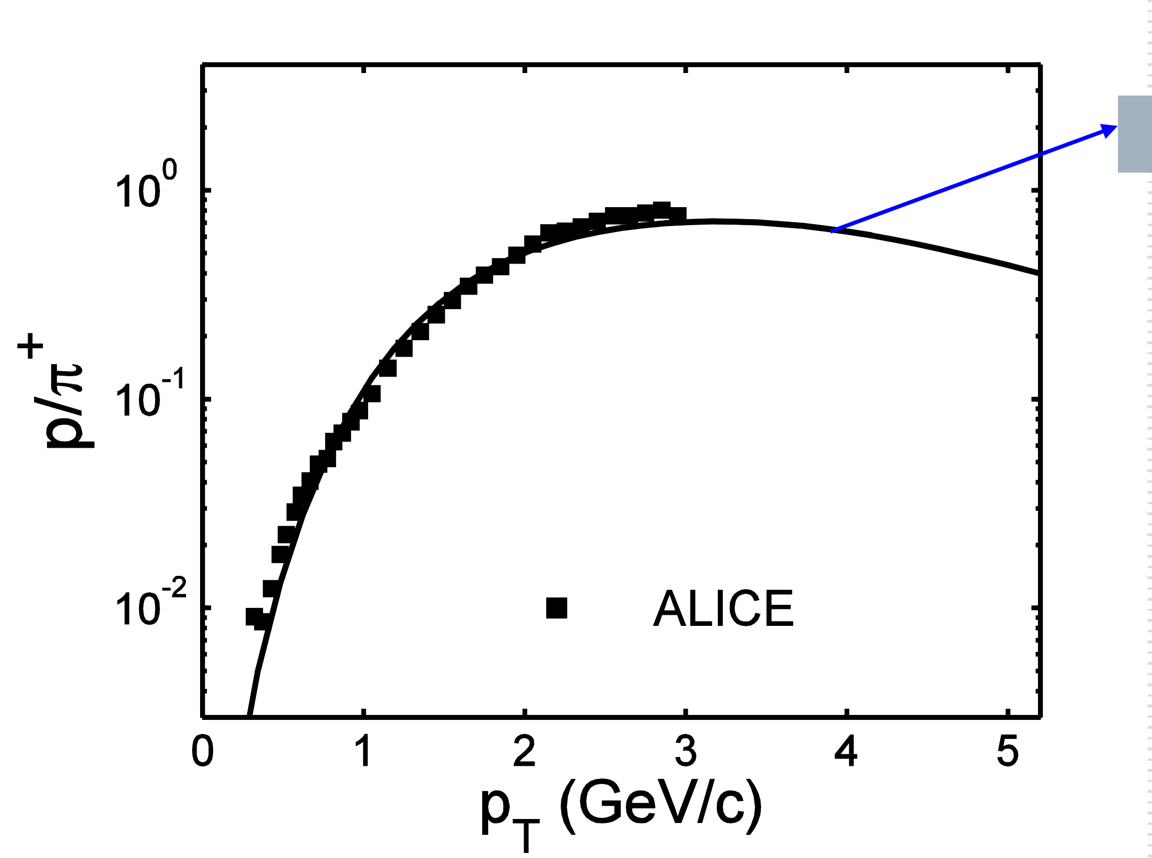
Hwa&Zhu, 1109.6300





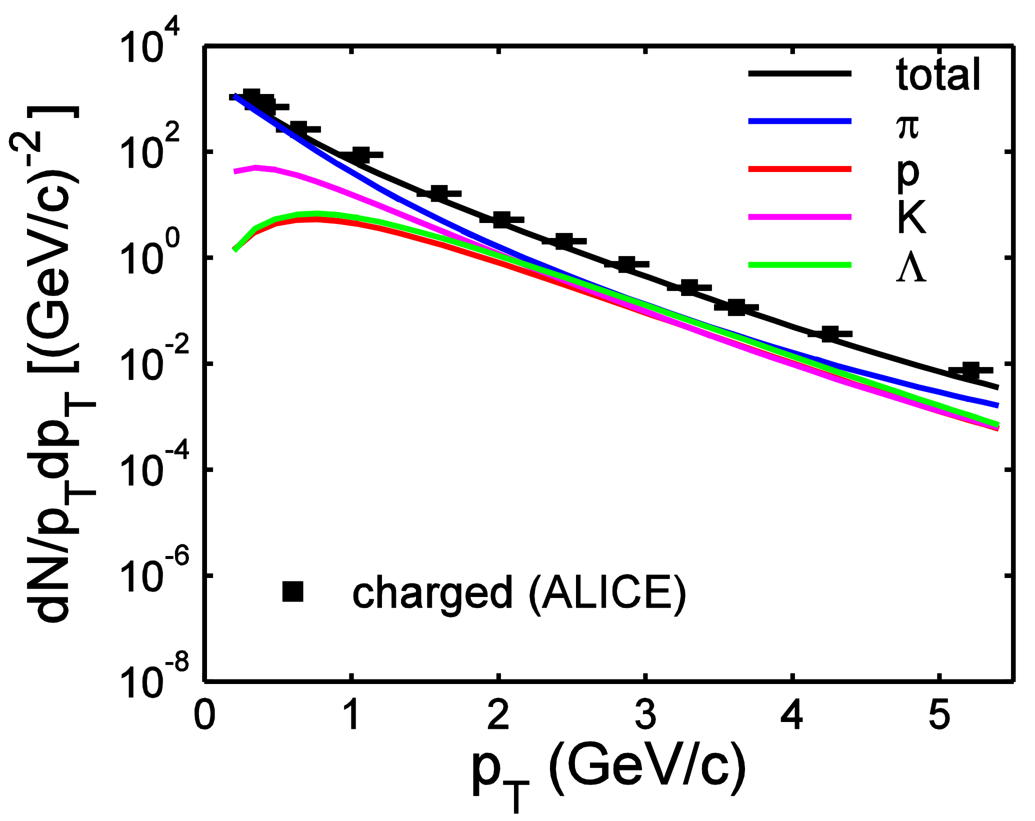
- T=0.38 for thermal partons is slightly higher than 0.32 at RHIC.
- κ=2.6 implies on average roughly $1-\kappa^{-1}$=60% of the initial parton energy is lost to the medium.

p/π⁺ ratio



Gentle falloff

Charged particle spectrum



- Regard Λ as representative of Σ^+.
- At p_T>5 GeV/c, we maybe have to consider the multi-jet contribution.

Summary & outlook

- First quantitative study for experimental data on the spectra of identified hadrons at LHC and shows applicability of the recombination model at LHC clearly.
- Shower partons from minijets play the important role in hadronization in the intermediate p_T region.
- Minijets are copiously produced, and are the non-flow component whose effects cannot be ignored even at low p_T.

- Examine the centrality dependence in the intermediate region.
- Multi-minijets contribution to hadron spectra at high $p_{T.}$
- Two-particle correlation.

Thank you!

backup

Shower parton

$$\mathcal{S}^q(p_2,\bar{\xi}) = \int \frac{dq}{q} \sum_i \bar{F}_i(q,\bar{\xi}) S_i^q(p_2/q)$$

For all centralities

$$\bar{F}_i(q,\bar{\xi}) = \int d\xi P(\xi,\phi,b) F_i(q,\xi)$$

After averaging over all creation points

$$F_i(q,\xi) \ = \int dk k f_i(k) G(k,q,\xi)$$

parton distribution at the surface

$$G(k,q,\xi) = q\delta(q - ke^{-\xi})$$

Momentum degradation function

Recombination model for fragmentation

$$xD(x) = \int \frac{dx_1}{x_1}\frac{dx_2}{x_2} F_{q\bar{q}}(x_1, x_2) R(x_1, x_2, x)$$

Fragmentation function known from fitting e+e- annihilation data

S π
V → π
G → π
S → K
G → K
→

Biennewies, Kniehl, Kramer
Kniehl, Kramer, Pötter

Recombination function known in the recombination model

Hwa, Phys. Rev. D (1980).

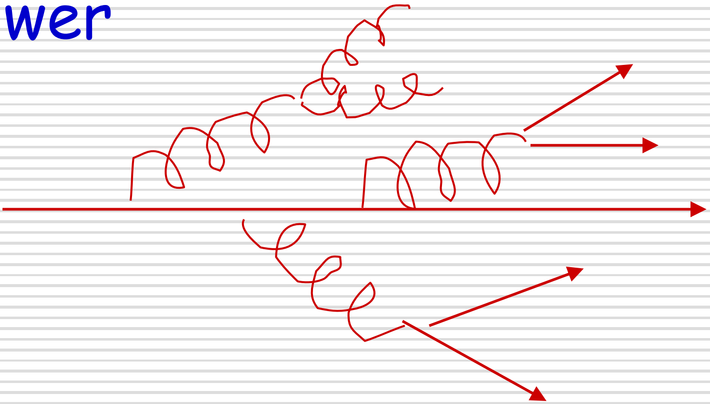
Shower parton distributions

$$S_i^j(x_1) \qquad \begin{aligned} j &= u, d, s, \bar{u}, \bar{d}, \bar{s} \\ i &= u, d, s, \bar{u}, \bar{d}, \bar{s}, g \end{aligned}$$

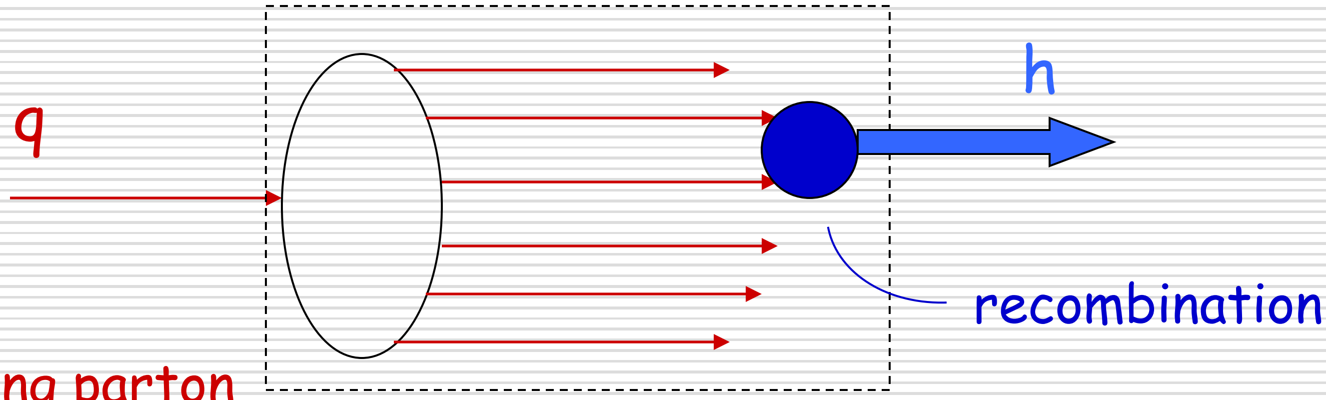
K, L, G, L_s, G_s

Hwa and Yang, PRC70,024904(2004)

Parton shower

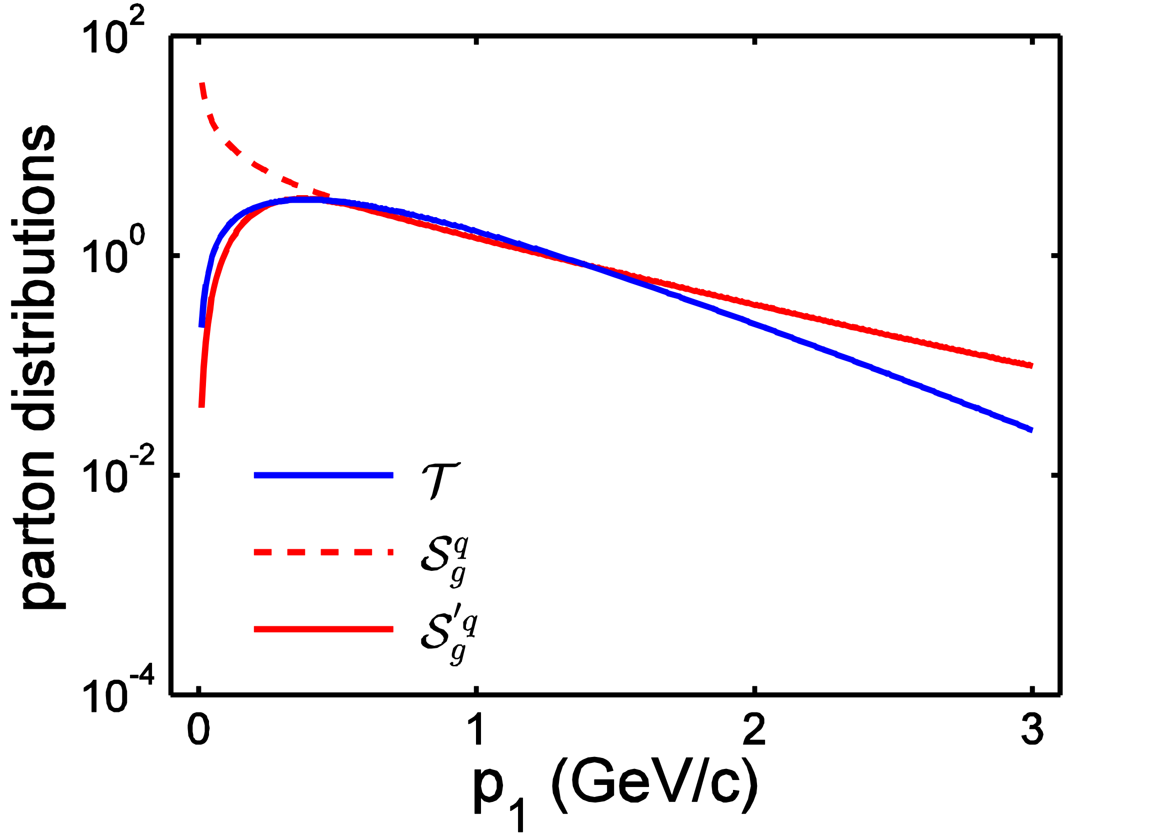


fragmentation



Initiating parton
(hard)

Parton shower
(soft)


10^2
10^0
10^{-2}
10^{-4}
parton distributions
0
1
2
3
p_1 (GeV/c)
$\mathcal{T}$
$\mathcal{S}_g^q$
$\mathcal{S}_g'^q$

Determining RFs

- R^{p} was determined from CTEQ
  - From the parton distributions in proton
  - $a=b=1.755$, $c=1.05$ at $Q^2=1\text{GeV}^2$
- R^{π} was determined from Drell-Yan processes
  - $a=b=0$
  - See Phys. Rev. C 66, 025204

Recombination functions

Given by the valon distribution of the hadrons

$$R^{\pi,K,\ldots}(y_1,y_2)=y_1y_2G_{Q_1Q_2}(y_1,y_2)$$

$$R^{p,n,\ldots}(y_1,y_2,y_3)=y_1y_2y_3G_{Q_1Q_2Q_3}(y_1,y_2,y_3)$$

$$G_{Q_1Q_2}(y_1,y_2)\propto y^a{}_1y^b{}_2\delta(y_1+y_2-1)$$

$$G_{Q_1Q_2Q_3}(y_1,y_2,y_3)\propto y_1{}^a y_2{}^b y_3{}^c\delta(y_1+y_2+y_3-1)$$

Different implementations

- Duke group etc:
  - ✓ 6-dimensional phase space
  - ✓ using Wigner function from density matrix
- Texas A&M/Budapest (Ko, Greco, Levai, Chen)
  - ✓ Monte Carlo implementation (with spatial overlap)
  - ✓ Soft and hard partons
  - ✓ Soft-hard coalescence allowed
- Ohio State (Lin, Molnar)
  - ✓ ReCo as a solution to the opacity puzzle