Open Charm Production in p + p and Pb + Pb collisions at the LHC*

J. Barrette, V. Topor Pop, C. Gale
McGill University

M. Gyulassy
Columbia University

M. Petrovici
National Institute for Physics, Bucharest

* Work supported by NSERC, the US Department of Energy, and by the Romanian Authority for Scientific Research

Introduction

- We have shown in previous works that data on particle productions in p+p and heavy-ion collisions are consistent with the presence of enhanced strong longitudinal color electric field (in addition to other dynamical effects e.g. shadowing, quenching..).
- Here we will extend this work to the production of open prompt charm mesons (as well as beauty mesons).
- This work is done in the framework of the HIJING/BB_{bar} v2.0 model

HIJING/BB$_{bar}$

- Our calculations used the HIJING/BB V2.0 model based on string phenomenology.
- In the string phenomenology, strong longitudinal fields (flux tubes) decay into new ones by quark anti-quark ($q\bar{q}$) or diquark anti-diquark (qq-qq) pair production that subsequently hadronizes to produce the observed hadrons.
- Due to confinement, the color of these strings is restricted to a small area in transverse space.
- With increasing energy of the colliding particles, the number of strings grows and they start to overlap. This will introduce a possible dependence of particle production on the energy density (or multiplicity).

In the Schwinger mechanism for static field the probability of pair creation is given by

$$\frac{dN}{dtd^3x} = \frac{\kappa^2}{4\pi^3}\exp(-\pi m^2/\kappa)$$

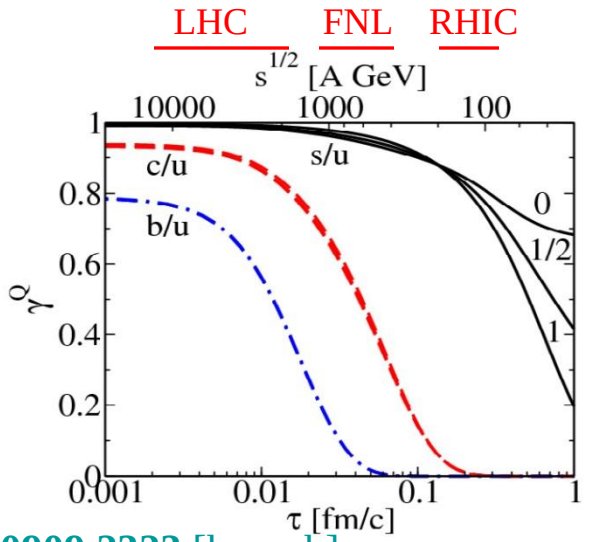
$$\kappa = eE \approx 1GeV/\ fm$$

Gives a ratio of production rate (e.g. heavy quark to light quark)

$$\gamma^Q = \frac{P(Q\bar{Q})}{P(s\bar{s})} = \exp(-\pi(m_Q{}^2 - m_q{}^2)/\kappa)$$

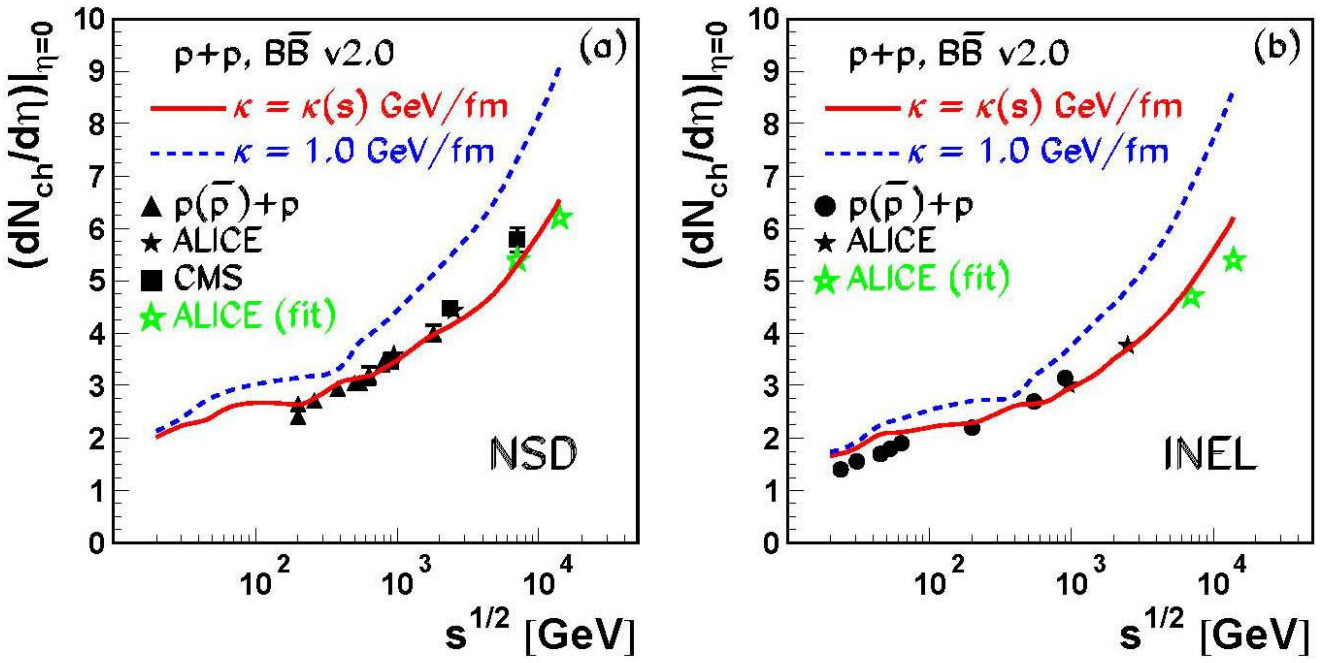
Reaction dynamics induced a strong time dependence of the strong color field that can be described by an effective string tension (κ_{eff})

$$\gamma^Q{}_\infty(\kappa^Q{}_{eff}) = \gamma^Q(\tau)$$



P. Levai, V. Skokov, e-Print: **arXiv:0909.2323** [hep-ph]

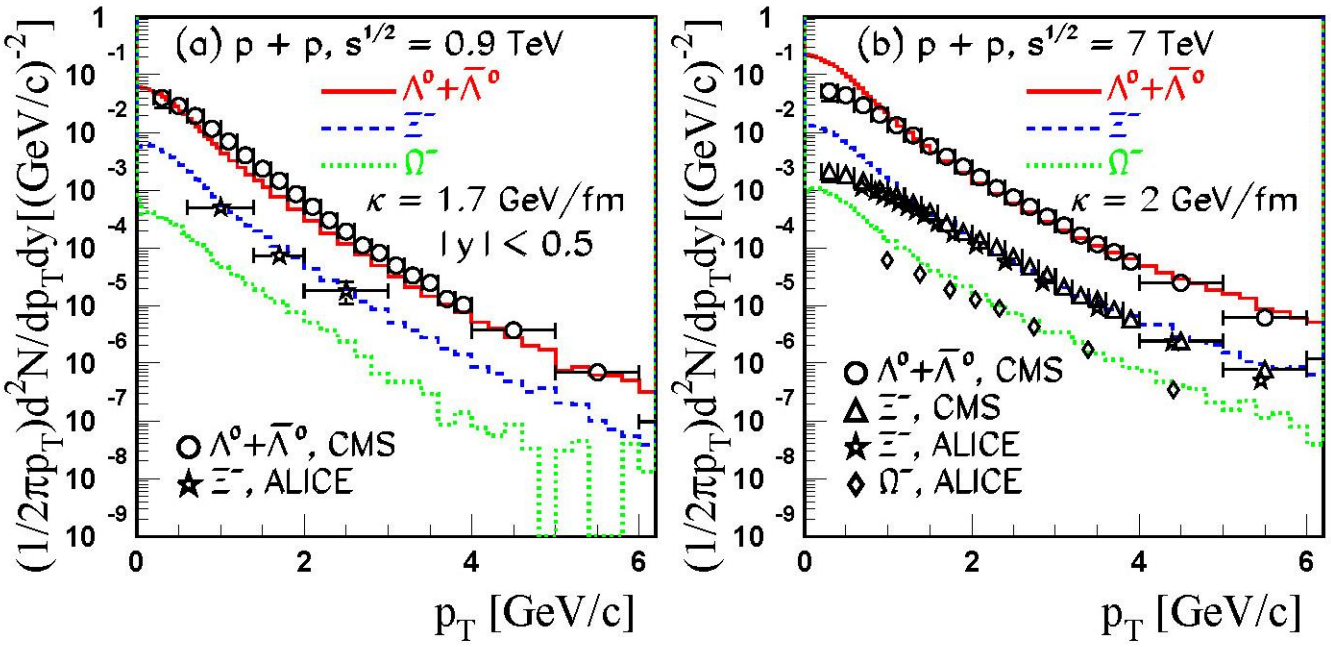
Charged-Particle Central Pseudorapidity Density



$$\kappa(s) = \kappa_0 (s/s_0)^{0.06} \quad with\ s_0 = 1GeV^2 and\ \kappa_0 = 1GeV/fm$$

$s^{1/2}$	$\kappa(s)$
100	1.74
1000	2.3
10000	3.0

V. Topor Pop et Al. Phys. Rev. C83 024902 (2011)

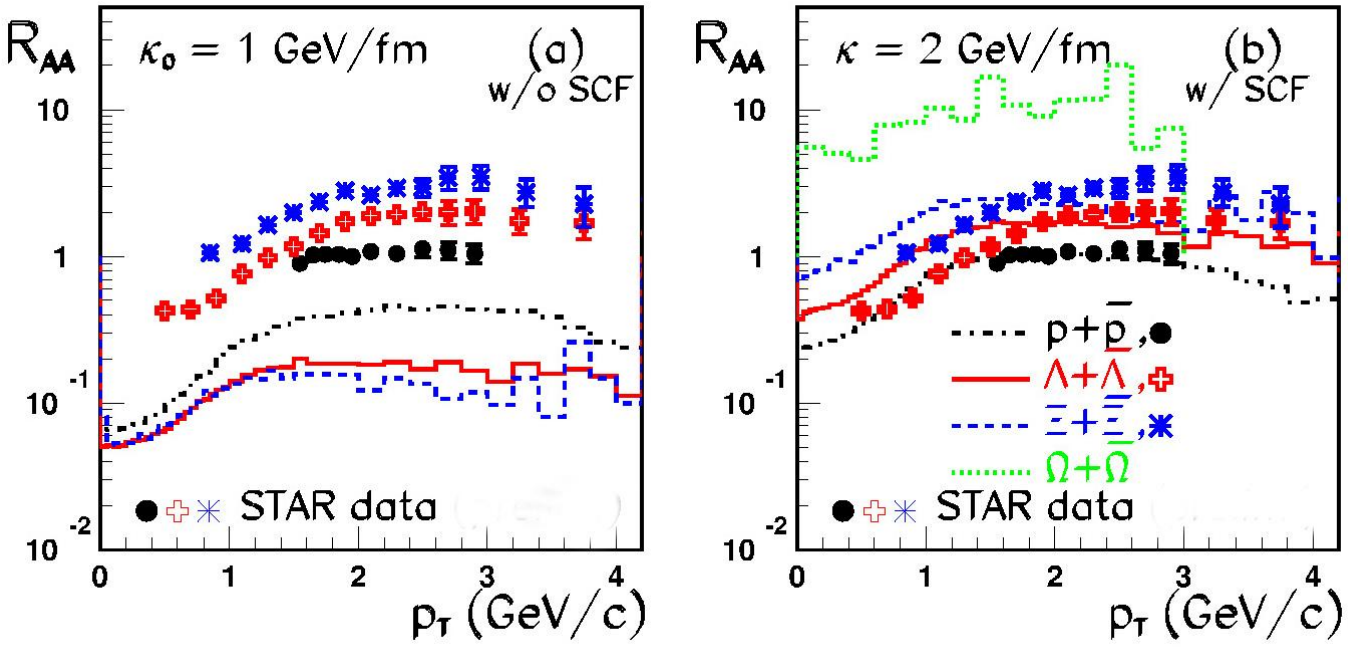


A good description of strange hadrons spectra is obtained if we consider a decrease of the exponent from 0.06 to 0.04 (i.e $\kappa(s) = \kappa_0(s/s_0)^{0.04}$), resulting in a value of string tension κ= 2 GeV/fm at 7 TeV (vs 2.8). This modification leads to a relatively small decrease of roughly 15% in the entropy of the system still consistent with data.

V. Topor Pop et al. Phys Rev. C86 (2012) 044902

Nuclear Modification Factor in Au+Au at RHIC

A similar increased value of string tension is needed to reproduce the NMR for particle production at RHIC



$$R_{AA}(p_T) = \frac{d^2N_{AA}/dydp_T}{< N_{coll} > d^2N_{pp}/dydp_T}$$

V. ToporPop, M. Gyulassy, J.B., C. Gale, Phys. Rev. C72,054901 (2005)

Summary of Input

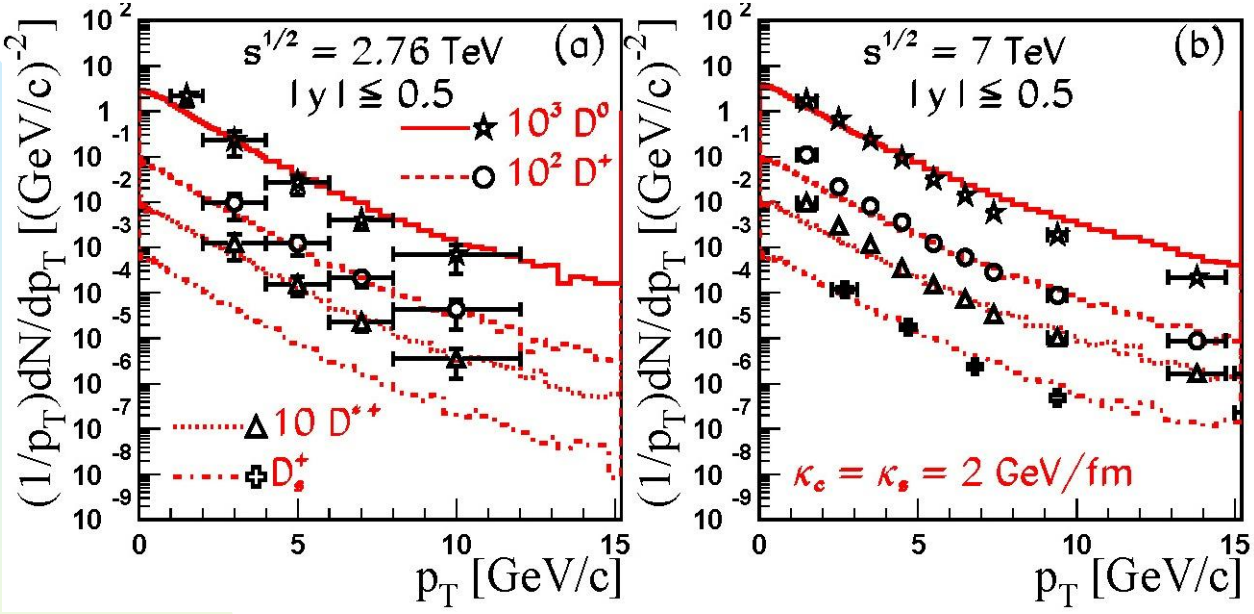
- We thus introduce an energy and mass dependence string tension
  $\kappa(s,A) = \kappa_0 (s/s_0)^{0.04} A^{0167}$ Gev/fm
- The nucleon-nucleon (NN) collisions at high energy can be divided into soft and hard processes. The separation between these two processes is characterized by a cut-off parameter p_0. Below p_0 the interaction is considered non-perturbative, and characterized by a cross section σ_{soft}.
- The inclusive jet cross section σ_{jet} at leading order (LO) is

$$\sigma_{jet} = \int_{p_0^2}^{s/4} dp_T^2 dy_1 dy_2 \frac{1}{2} \frac{d\sigma_{jet}}{dp_T^2 dy_1 dy_2}, \text{where,}$$

$$\frac{d\sigma_{jet}}{dp_T^2 dy_1 dy_2} = K \sum_{a,b} x_1 f_a(x_1, p_T^2) x_2 f_b(x_2, p_T^2) \frac{d\sigma^{ab}(\hat{s}, \hat{t}, \hat{u})}{d\hat{t}}$$

  - σ_{ab} is the parton-parton cross section and $f_a(x, p_T^2)$ is the parton distribution functions (PDF).
- For heavy-ion collisions: the coherent interaction becomes important and an energy and mass dependent cut-off value $p_0(s) = 0.416\ A^{0.128}\ (\sqrt{s_{NN}})^{0.191}$ GeV/c is introduced. (see Topor Pop et al. Phys Rev C 84 (2011) 044909)
- In addition the calculations take also into consideration shadowing effects as in HIJING (Wang, Phys Rep (1997)), introducing a shadowing factor $S_{a/A}(x, r)$ for the PDF, $f_{a/A}(x,Q^2) = S_{a/A}(x,Q^2) A f_{a/n}$.

Open charm production in p+p collisions

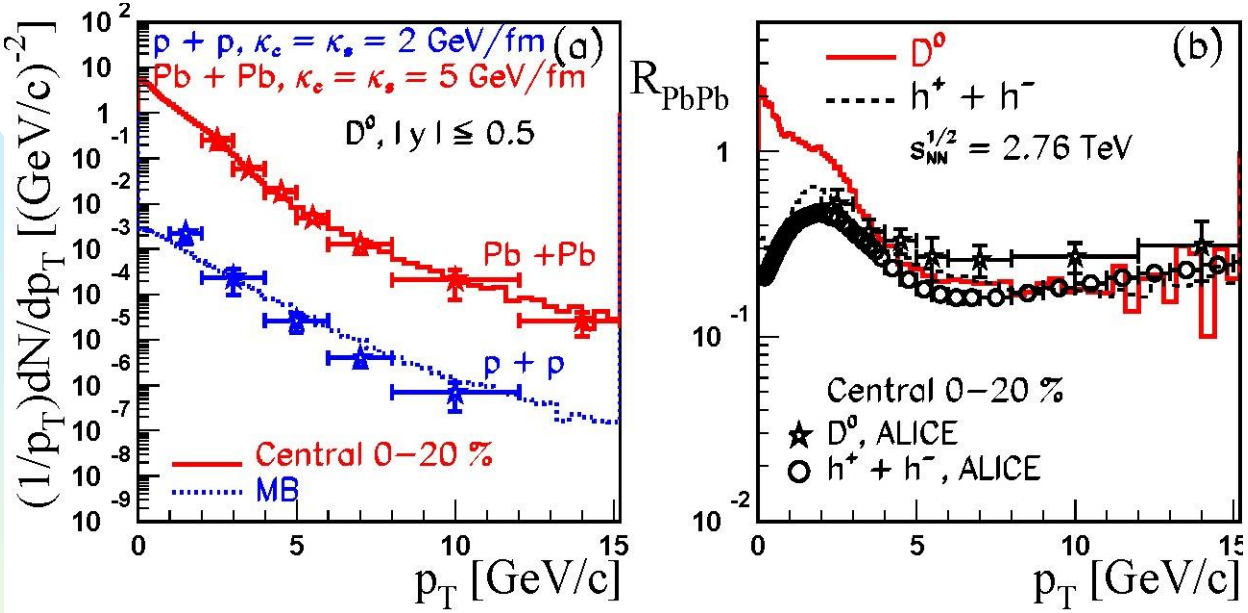


With $\kappa \approx$ 2GeV/fm the experimental spectra well described (but predict spectra a bit too soft)

Note: Error on data at 2.76TeV too large to use as a baseline. We use calculated spectra as baseline to calculate nuclear modification factor

Data from Alice Collaboration

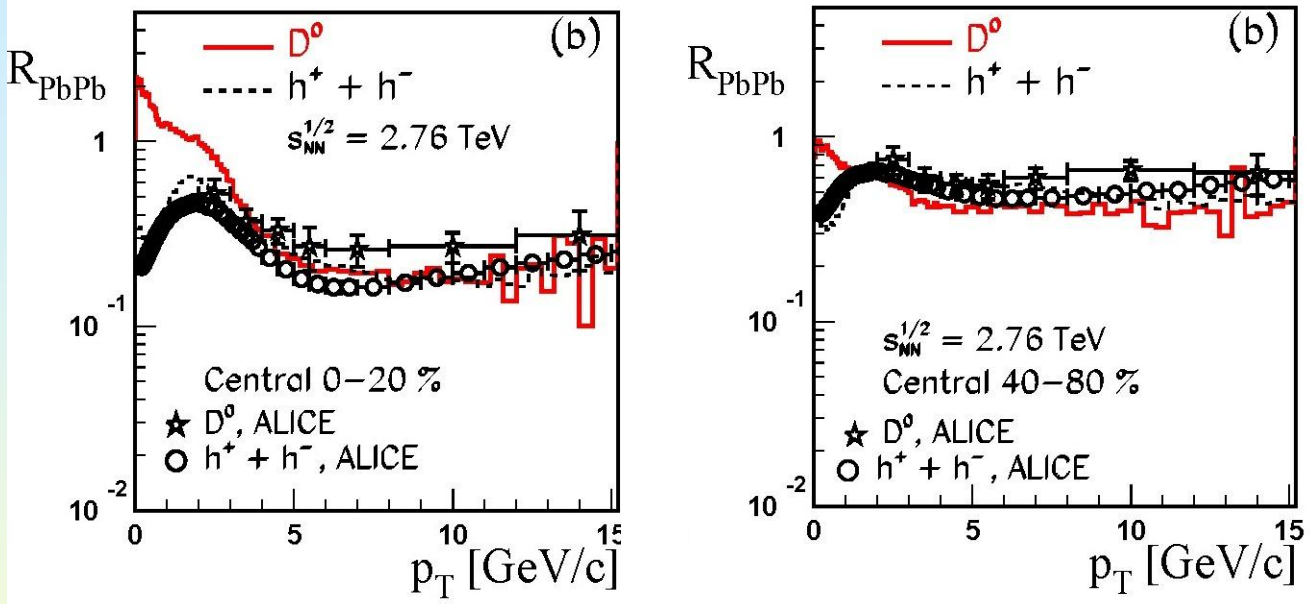
Open Charm Production in Pb+Pb at $\sqrt{S^{NN}}$=2.76 TeV



At high P_t, D_o show similar suppression as charged hadrons (a factor of ≈4) well described by larger κ

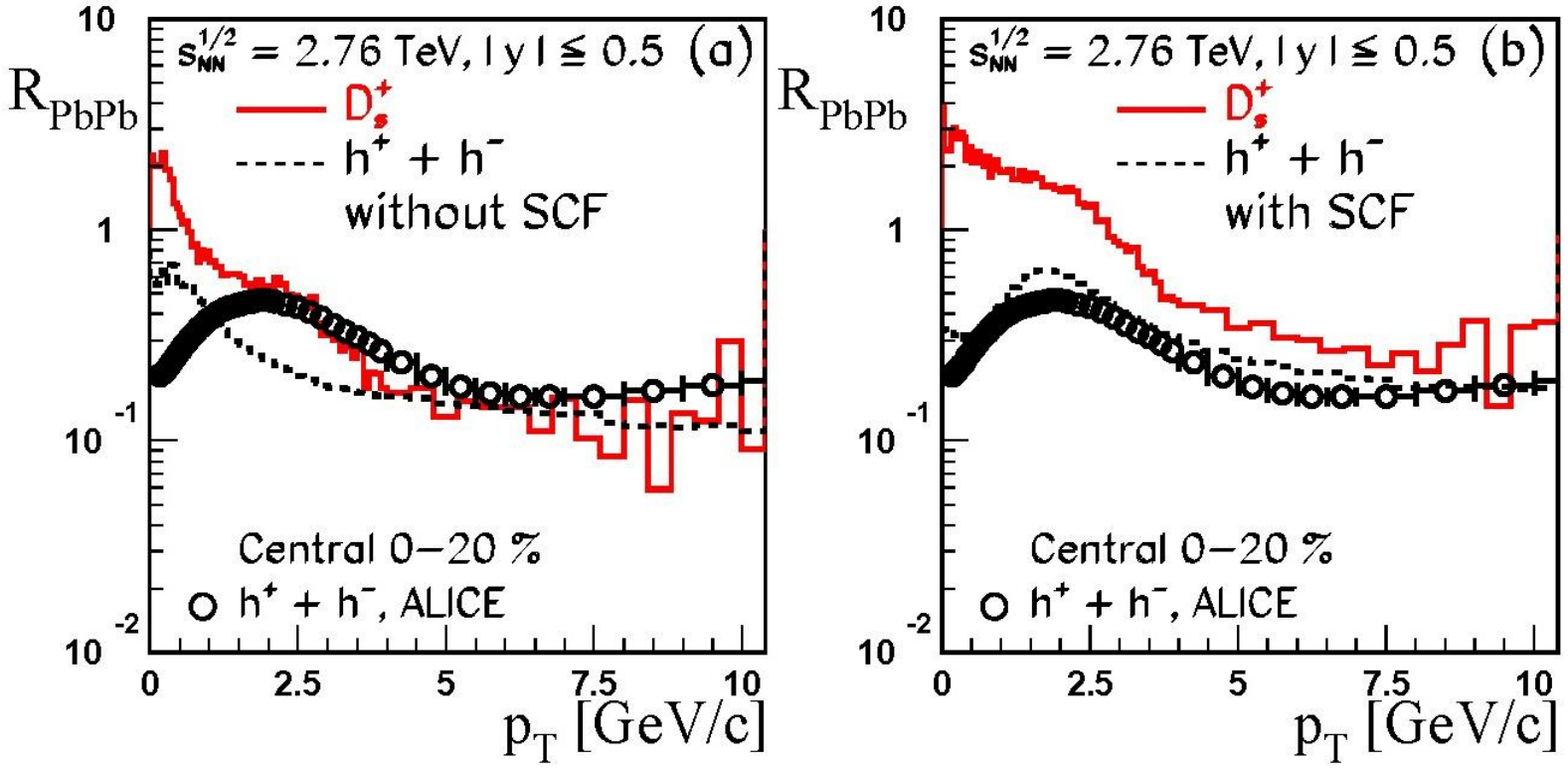
A strong difference appears at low Pt. A challenge to experimentalists

Centrality Dependence of NMF



As expected the less suppression is observed for more peripheral collisions an effect well described by the model

Production of D_s charmed mesons

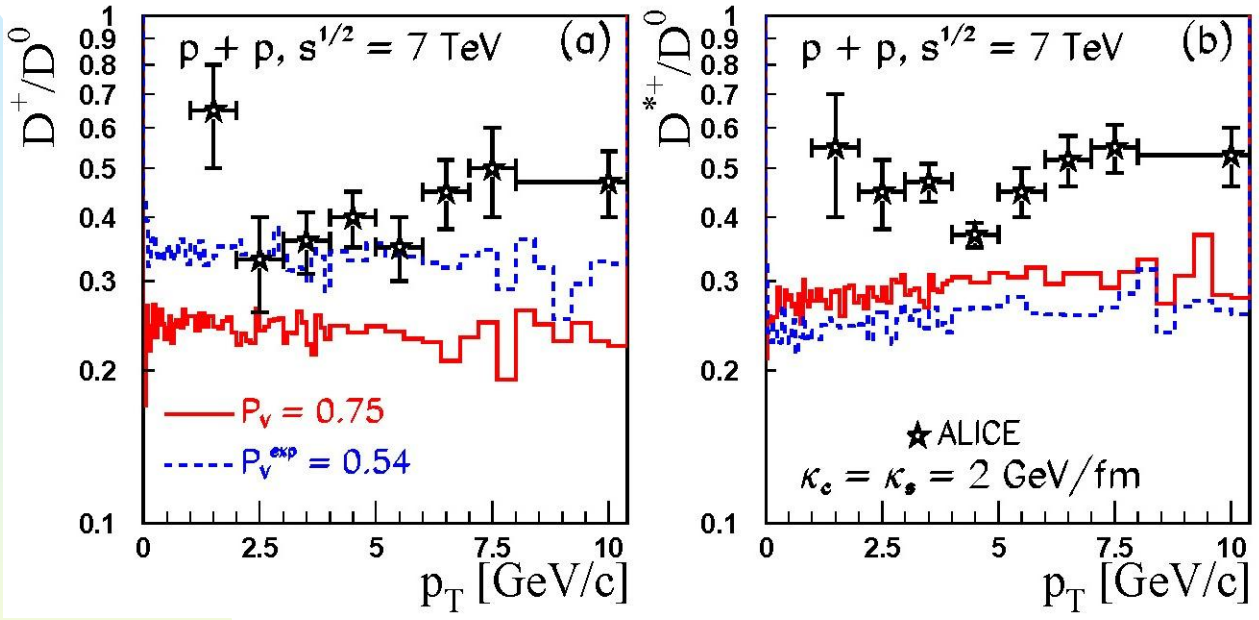


Data on charged hadrons consistent with SCF effects

Some effects also predicted for D_s+ with strong difference at low Pt

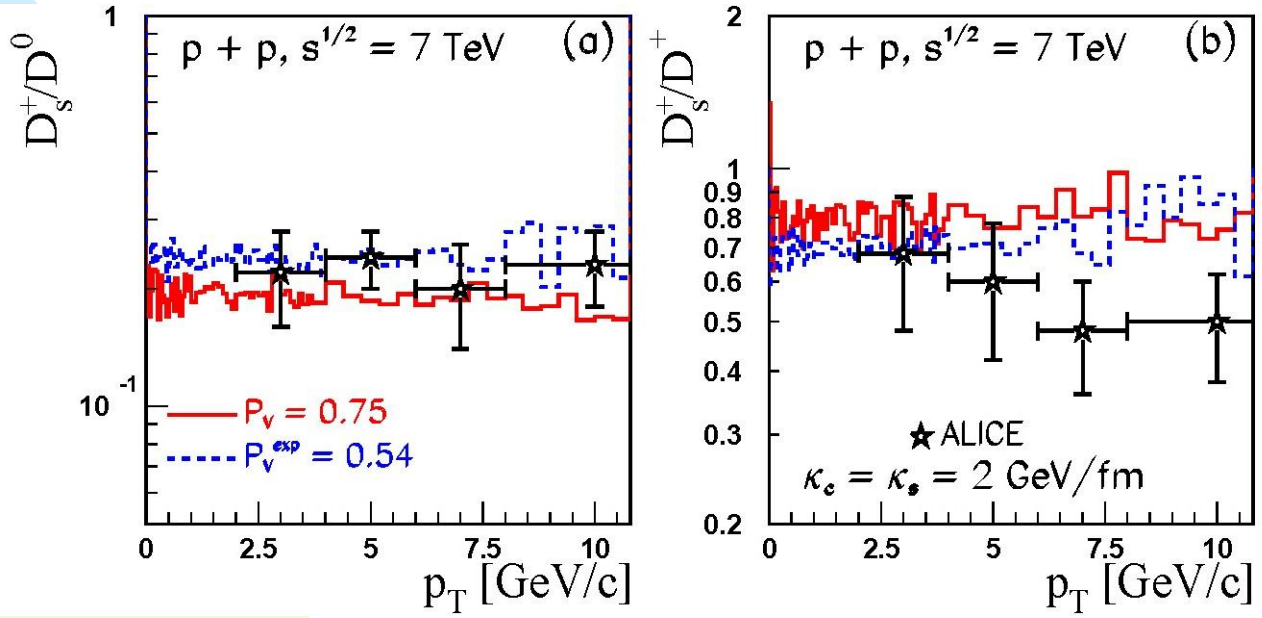
Very preliminary data compatible with observed h suppression but still inconclusive.

D mesons ratios (1)



Related to the parameter $P_V=V/(V + S)$

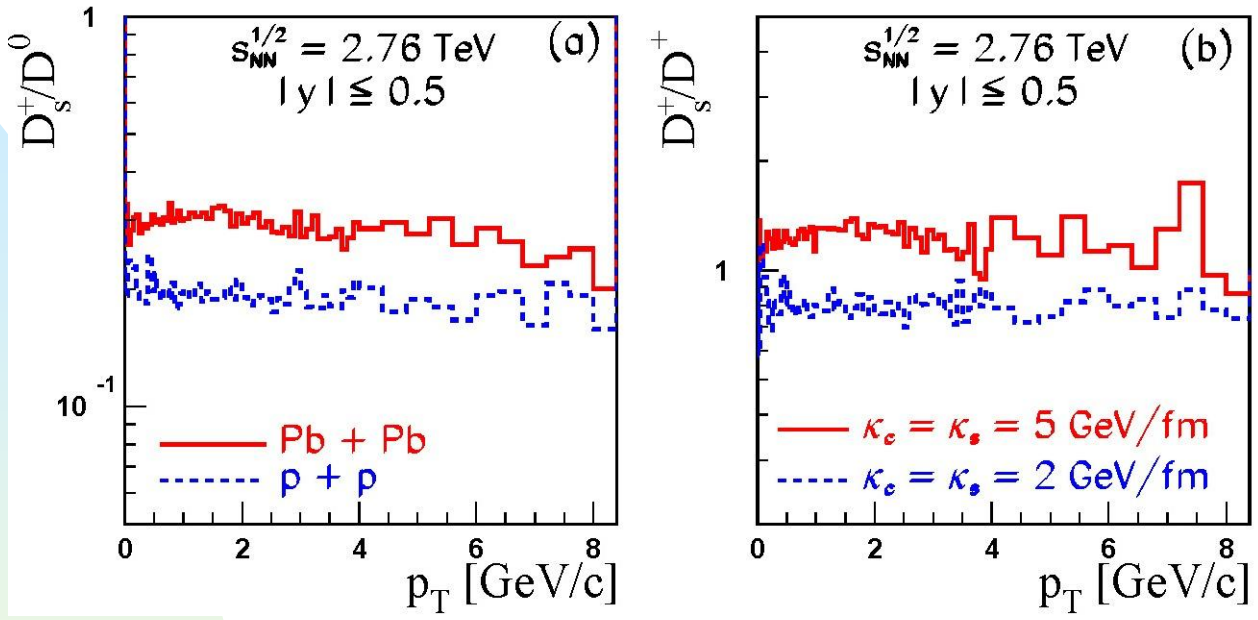
D mesons ratios (2)



Mainly determined by γ_s(s/u) suppression factor

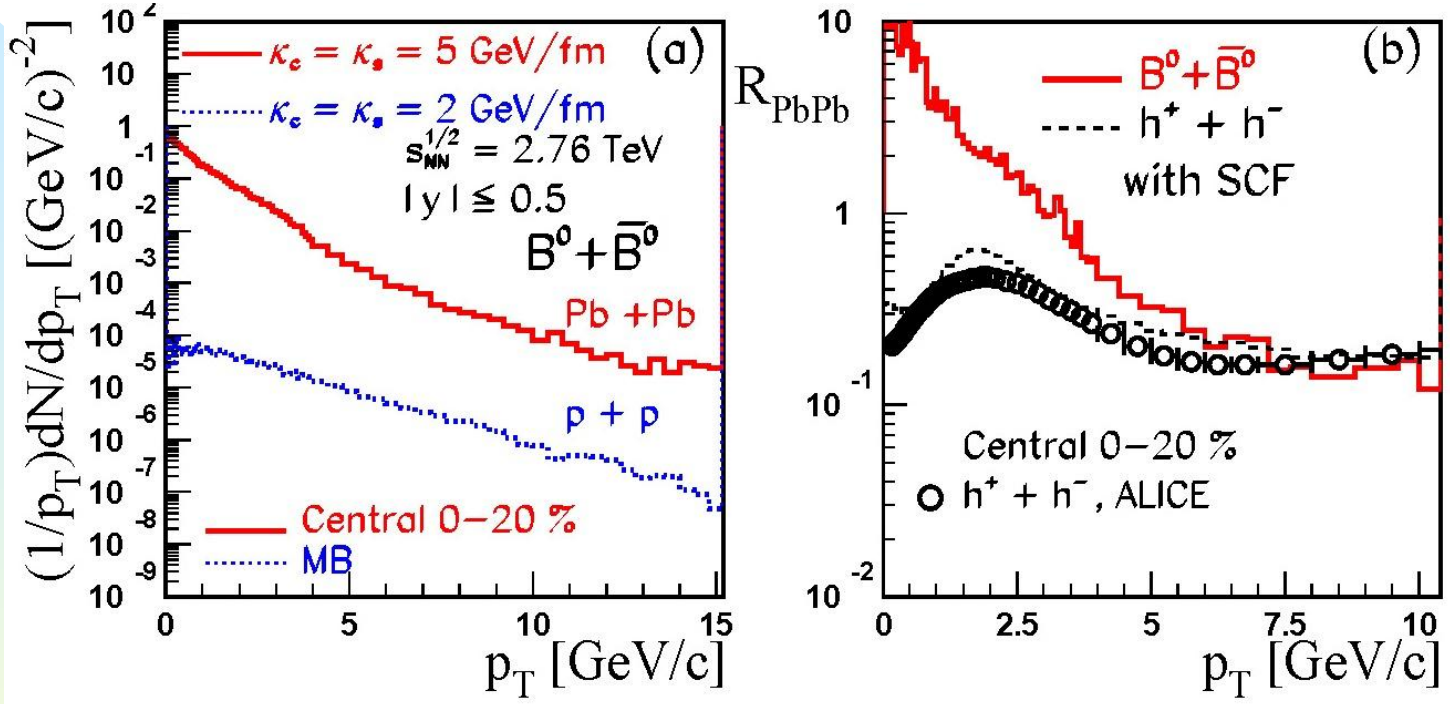
At 7 TeV we use γ_s(s/u) =0.45 consistent with experimental value ($0.31 \pm 0.08(\text{stat}) \pm 0.10(\text{sys})$)

D mesons ratios (3)



If confirmed by data the enhancement in Pb+Pb collisions, the assumption of in medium increase of the effective string tension (or equivalently "in-medium mass modification" of charm quark) would be strongly supported

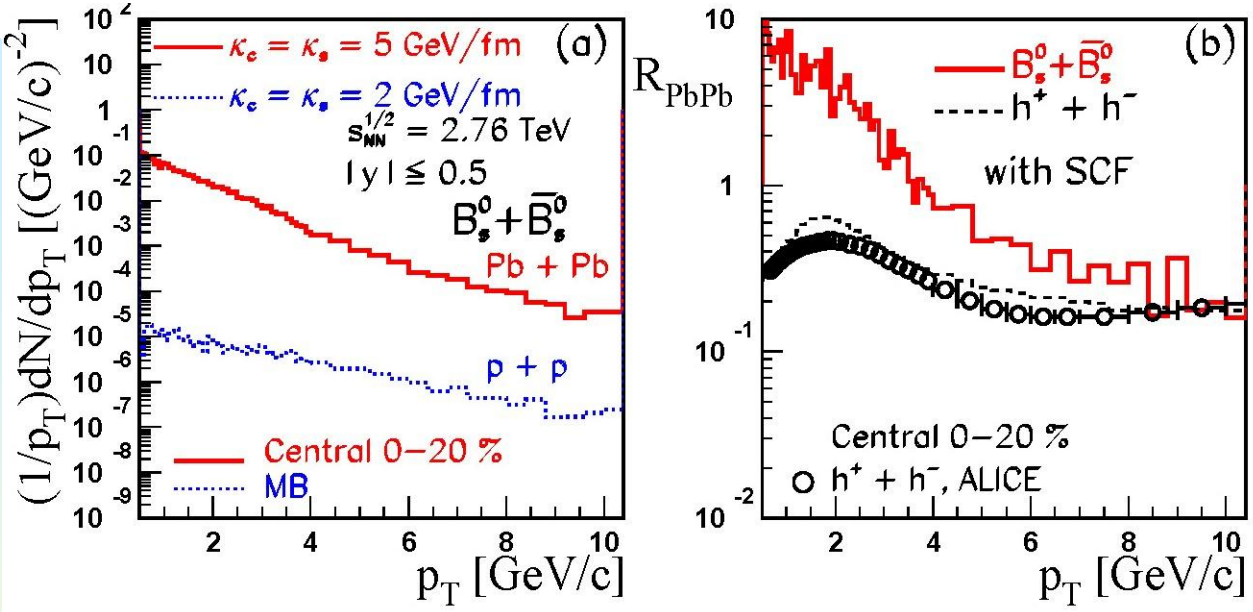
Predictions for b quark production (1)



The model predicts a strong bump (even an enhancement) at low p_t for B^0 mainly due to SCF effects

Such data could be used to check for possible flavor dependence of SCF effects.

Predictions for b quark production (2)



At moderate p_t the model predicts a kind of quark-mass hierarchy

$$R_{PbPb}^{\pi} < R_{PbPb}^{ch} < R_{PbPb}^{B0} < R_{PbP}^{Bs0}$$

Conclusions

- We studied influence of strong constant color electric field on open charmed mesons using a energy and energy dependence “effective” string tension.
- While still incomplete the early results on NMF or particle ratios are “well” explained by our approach
- However, more solid or quantitative conclusions called for more precise data (specially at low p_t).
- Caution and future: Our model is based on time-independent strength color field, a very simplistic picture. Models that would introduce time and space dependent mechanisms should be develop.