Study of jet energy loss and the LHC ALICE data

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12th Zimanyi Winter School
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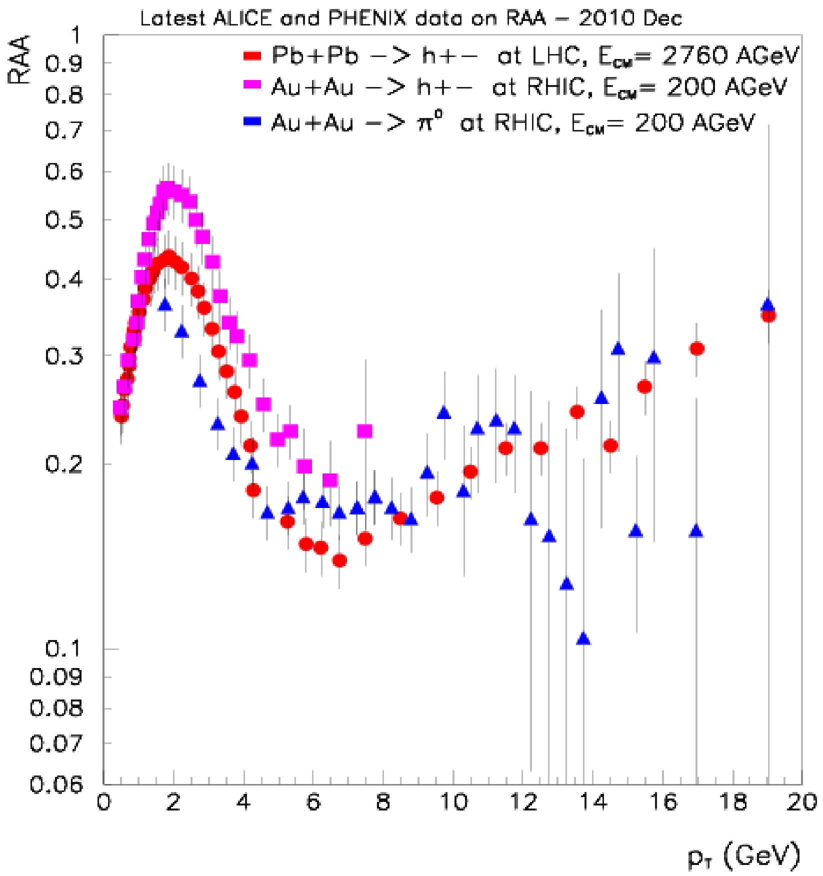
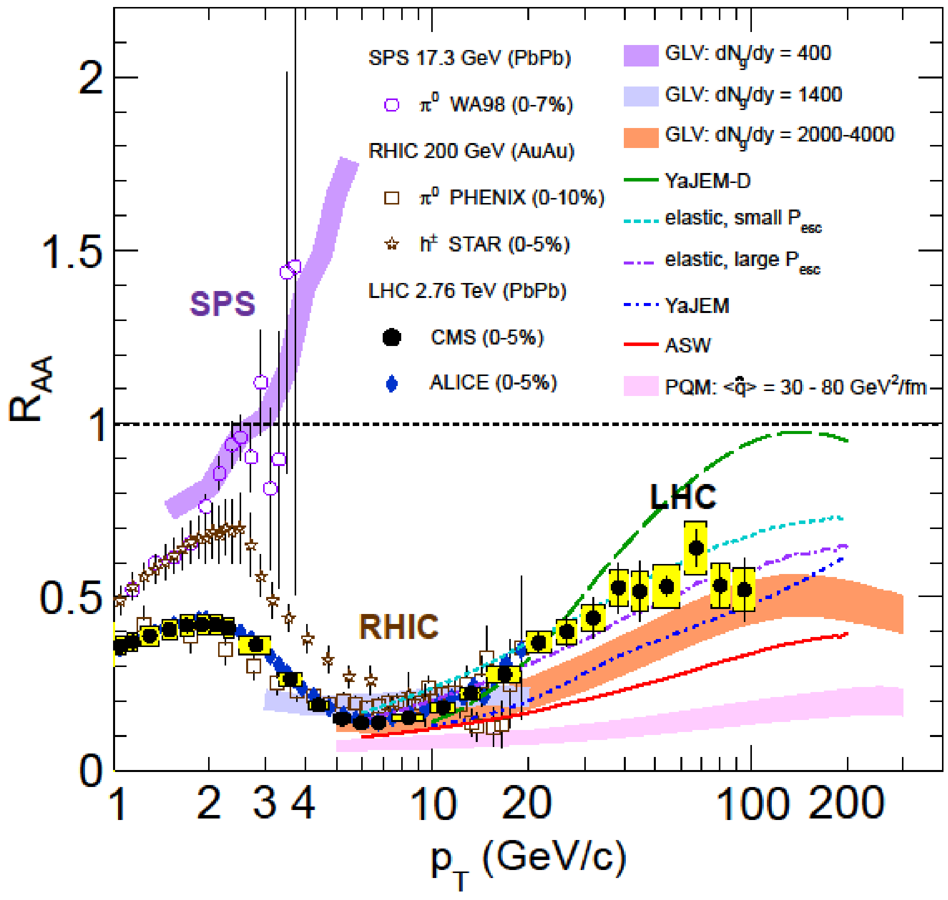
ICPAQGP'2010: New result on RAA in Pb+Pb at 2760 AGeV ALICE at LHC --- J. Schukraft





First glance:

RAA overlaps at RHIC and LHC !!!

Second glance in 2012: NOT!

(we have good microscope)

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    --- particle production, pQCD, jets, pp, pA
2. Jet energy loss
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    --- coherent gluon field and diquark coalescence
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1. Introduction

--- particle production, pQCD, jets, pp, pA

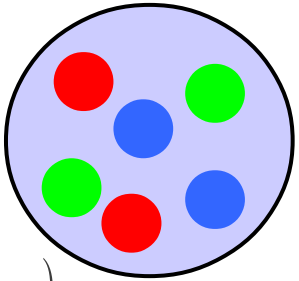
Particle production mechanisms in high energy HI collisions:

I. Dilute parton gas limit as initial condition + parton cascade:

PDF(p,n) +pQCD + Glauber + [Shad; Multisc; Quench; Fluct; ...]

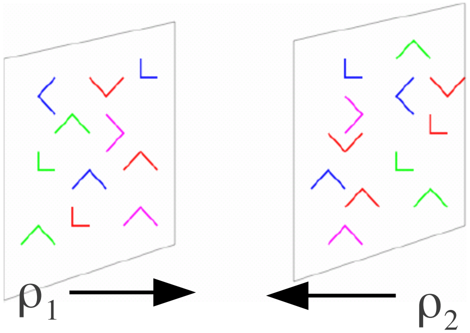
$$E_\pi \frac{d\sigma^{pp}}{d^3 p_\pi} = \int dx_1 \int dx_2 \int dz_c f_{a/p}(x_a, Q^2) f_{b/p}(x_b, Q^2) \frac{d\sigma}{d\hat{t}} \frac{D_c^\pi(z_c)}{\pi z_c^2}$$

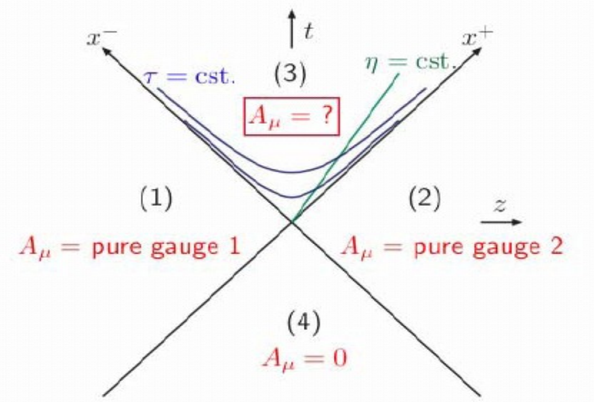
$$E_\pi \frac{d\sigma^{AB}}{d^3 p_\pi} = \int d^2 b\, d^2 r\ \ t_A(\vec{r}) t_B(|\vec{b} - \vec{r}|)\ \ E_\pi \frac{d\sigma^{pp}}{d^3 p_\pi} \otimes S(\ldots) \otimes M(\ldots) \otimes Q(\ldots) \otimes F(\ldots)$$

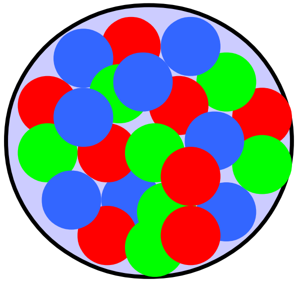


Dilute gas

II. Dense gluon matter limit as initial condition + hydro:







CGC: high density gluons

CGC initial condition:

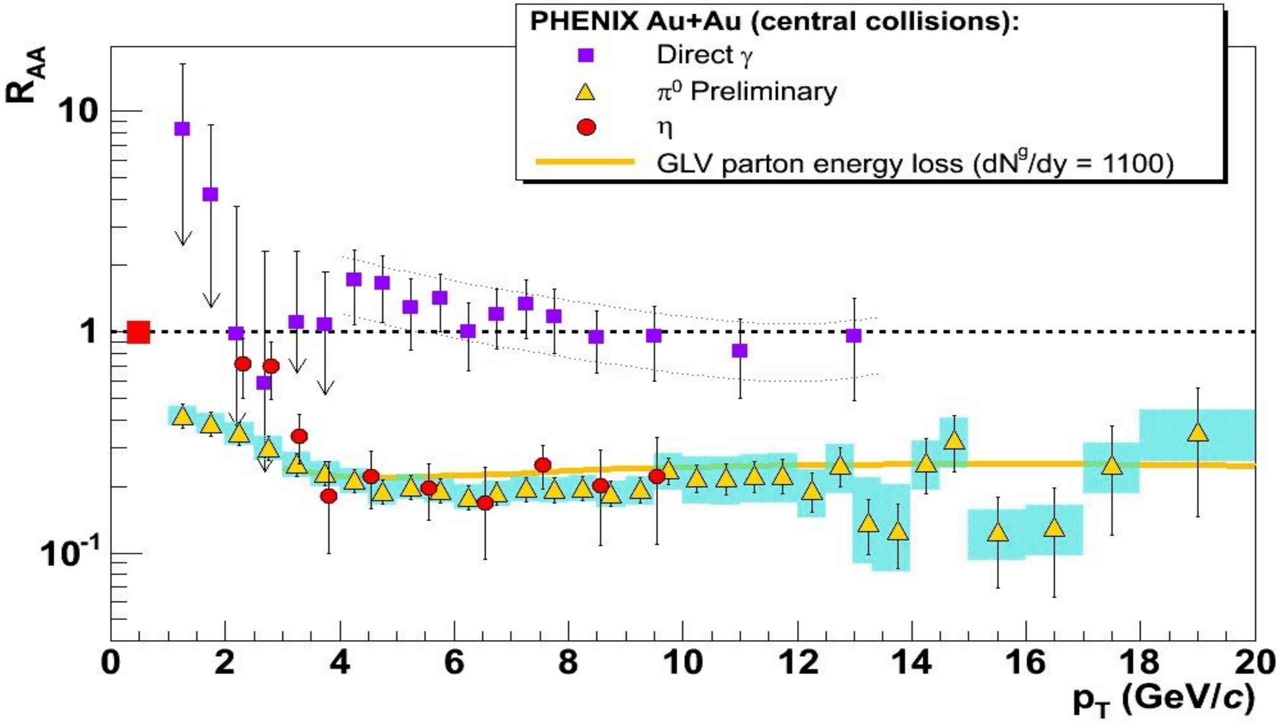
$$J^\mu = \delta^{\mu +}\delta(x^-)\rho_1(\mathbf{x}_T) + \delta^{\mu -}\delta(x^+)\rho_2(\mathbf{x}_T)$$

where $-D_i \alpha^i_{(m)} = \rho_{(m)}(\mathbf{x}_\perp).$ and α_1, α_2 gluon fields of nuclei

Successful applications of I and II:

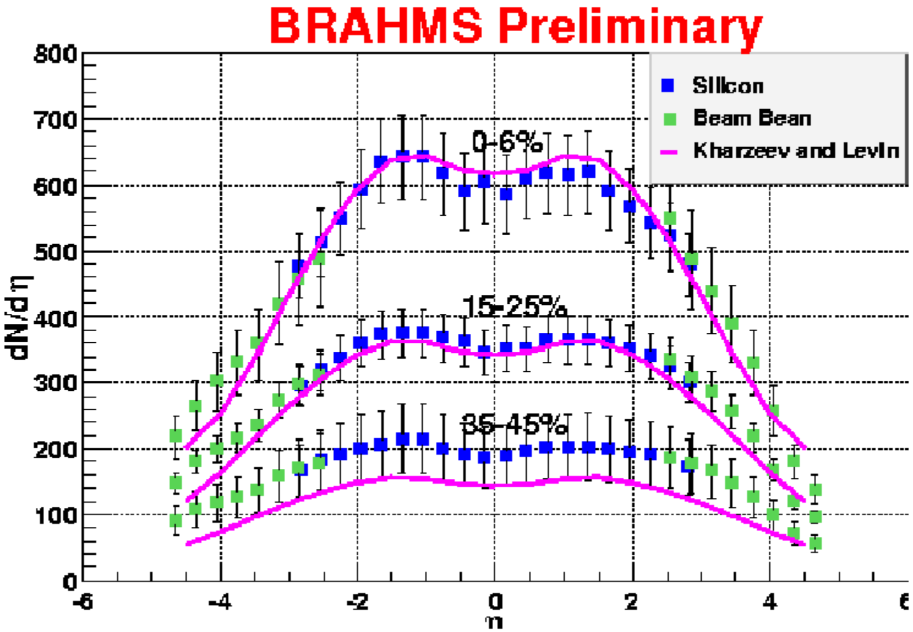
I. pQCD model:

- --- hard probes
- --- high-p_T physics
- --- jets
- --- h-h correlations
- --- ...

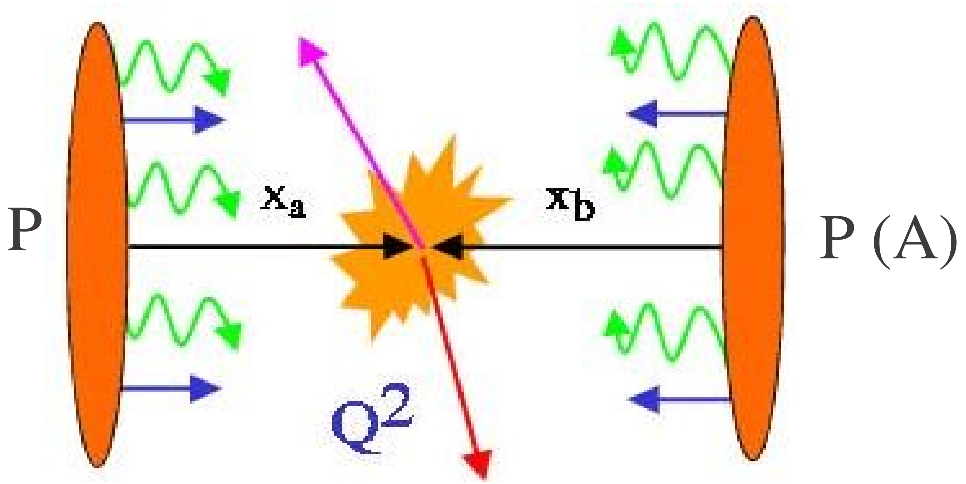


II. CGC model:

- --- soft physics
- --- multiplicities
- --- centrality dependence
- --- E_T production
- --- rapidity distributions
- --- ...



DILUTE PARTON GAS LIMIT: Jets in pp and in pA collisions:



Jet production in pp collision
("in vacuum"):
↣ pQCD description

Jet production in pA collision (" in cold dilute matter")

↣ modified PQCD description:
- **--- SHADOWING inside A**
- **--- MULTISCATTERING/BROADENING penetrating A and the "cold matter"**
- **--- ENERGY LOSS penetrating the "cold dilute matter"**

Can we separate these mechanisms?

Can we determine them separately during theoretical data analysis ?

We could learn a lot from high precision RHIC and LHC data on dAu & pPb!

Hard physics: pion production in pp collision at high-p_T

Perturbative QCD calculations in LO/NLO for p+p ➡ π + X process with finite - k_T

NLO : M. Aversa et al. NPB327,105; P. Chiappetta et al. NPB412,3; P. Aurenche et al. NPB399,34; ...)

+ intrinsic kT: G. Papp, P. Levai, G.G. Barnaföldi, G. Fai, hep-ph/0212249, EPJC33(2004)609

$$E_\pi \frac{d\sigma^{pp}}{d^3 p_\pi} = \frac{1}{S}\sum_{abc}\int_{VW/z_c}^{1-(1-V)/z_c} \frac{dv}{v(1-v)} \int_{VW/vz_c}^{1} \frac{dw}{w}\int^{1} dz_c$$

$$\int d^2\mathbf{k}_{Ta}\int d^2\mathbf{k}_{Tb}\; f_{a/p}(x_a,\mathbf{k}_{Ta},Q^2)\; f_{b/p}(x_b,\mathbf{k}_{Tb},Q^2)$$

$$\left[\frac{d\sigma^{BORN}}{dv}\delta(1-w)+\frac{\alpha_s(Q_R)}{\pi}K_{ab,c}(s,v,w,Q,Q_R,Q_F)\right]\frac{D_c^\pi(z_c)}{\pi z_c^2}$$

An approximation for the unintegrated parton distribution functions (PDFs) :

$$f_{a/p}(x_a,\mathbf{k}_{Ta},Q^2) = f_{a/p}(x_a,Q^2)\;\; g(\mathbf{k}_{Ta})$$

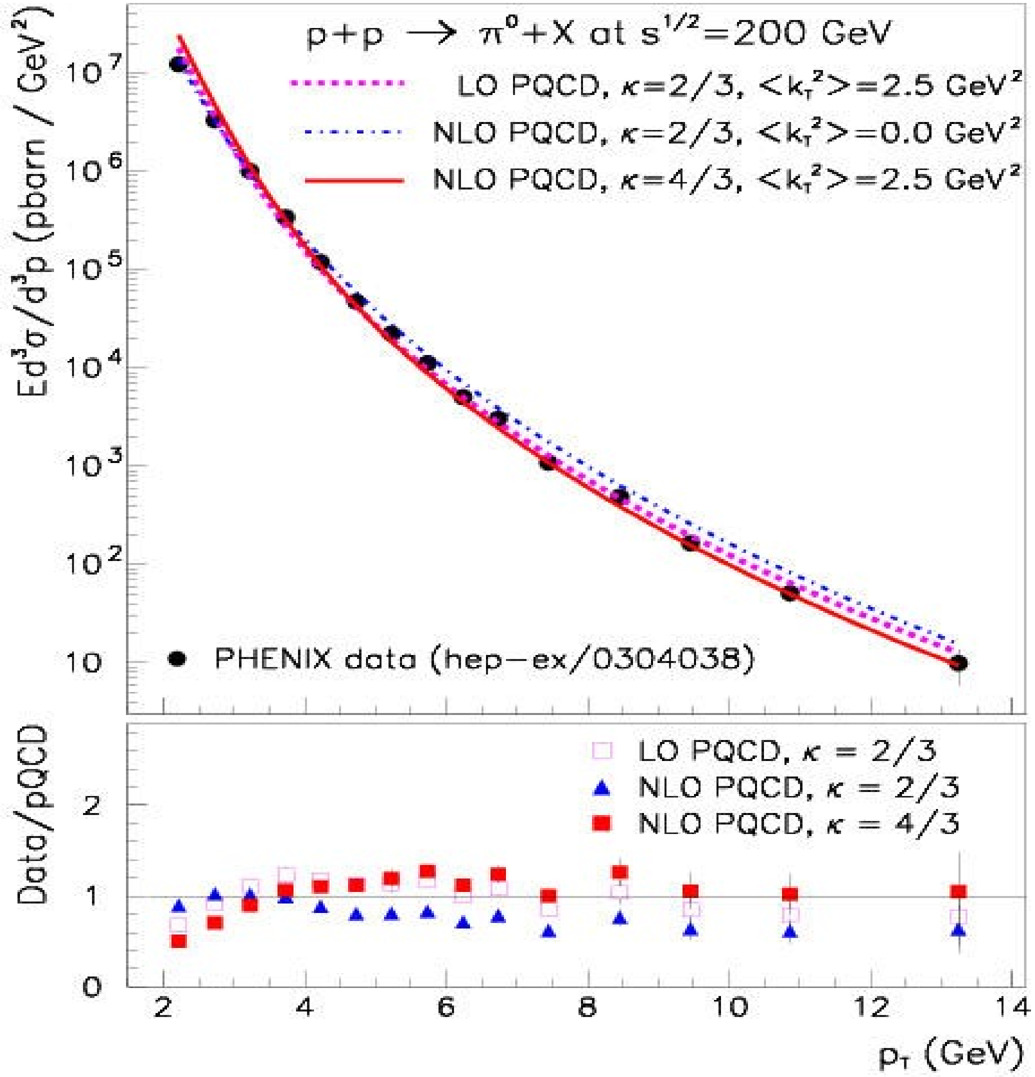
Where we use gaussian

$$g(\mathbf{k}_{Ta}) = \frac{1}{\pi\langle k_T^2\rangle} e^{-k_T^2/\langle k_T^2\rangle}$$

The width of the gaussian distribution for intrinsic-kT

Hard physics: pion production in pp collision at high-p_T

Perturbative QCD calculations in LO and NLO for pp --- including intrinsic- k_T



LO:

$$Q = \kappa\, p_T / z_c,\quad Q_F = \kappa\, p_T$$

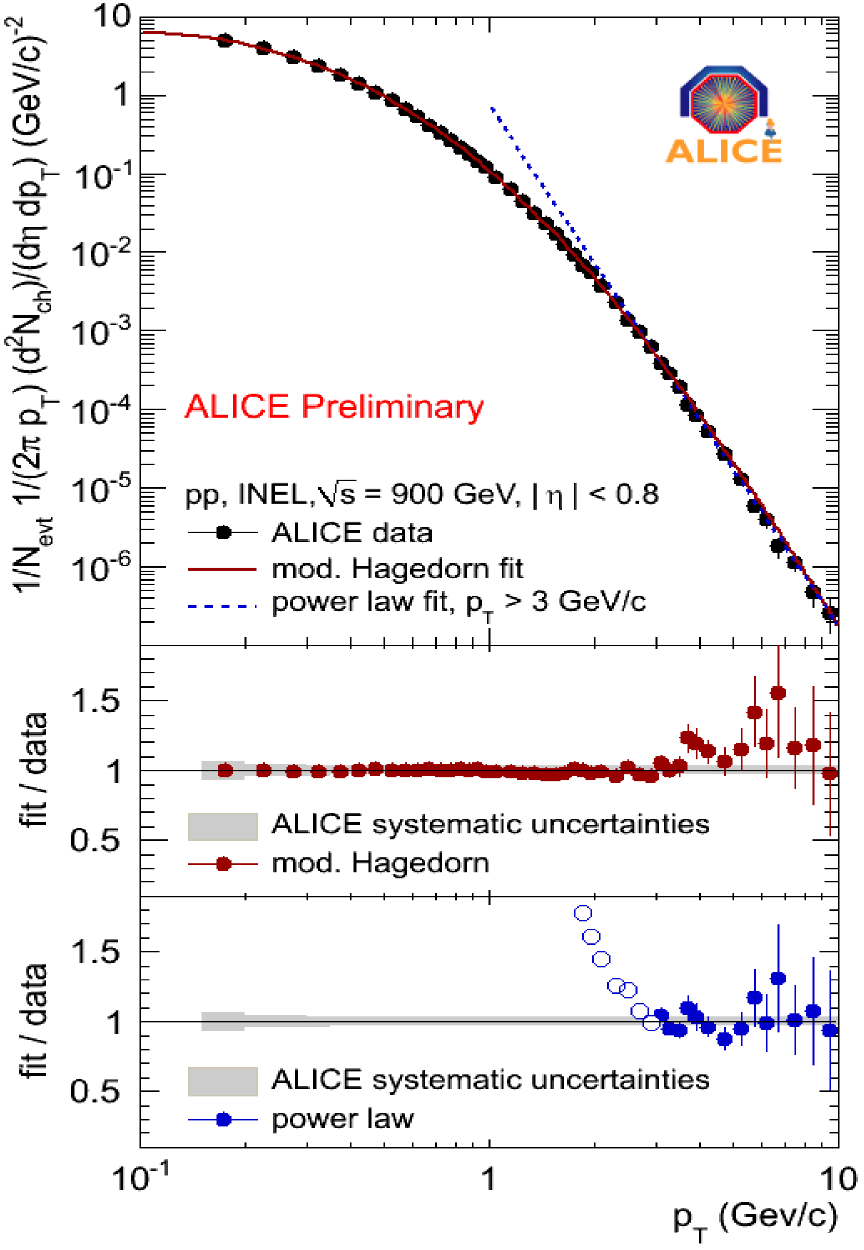
NLO:

$$Q = Q_R = \kappa\, p_T / z_c,\quad Q_F = \kappa\, p_T$$

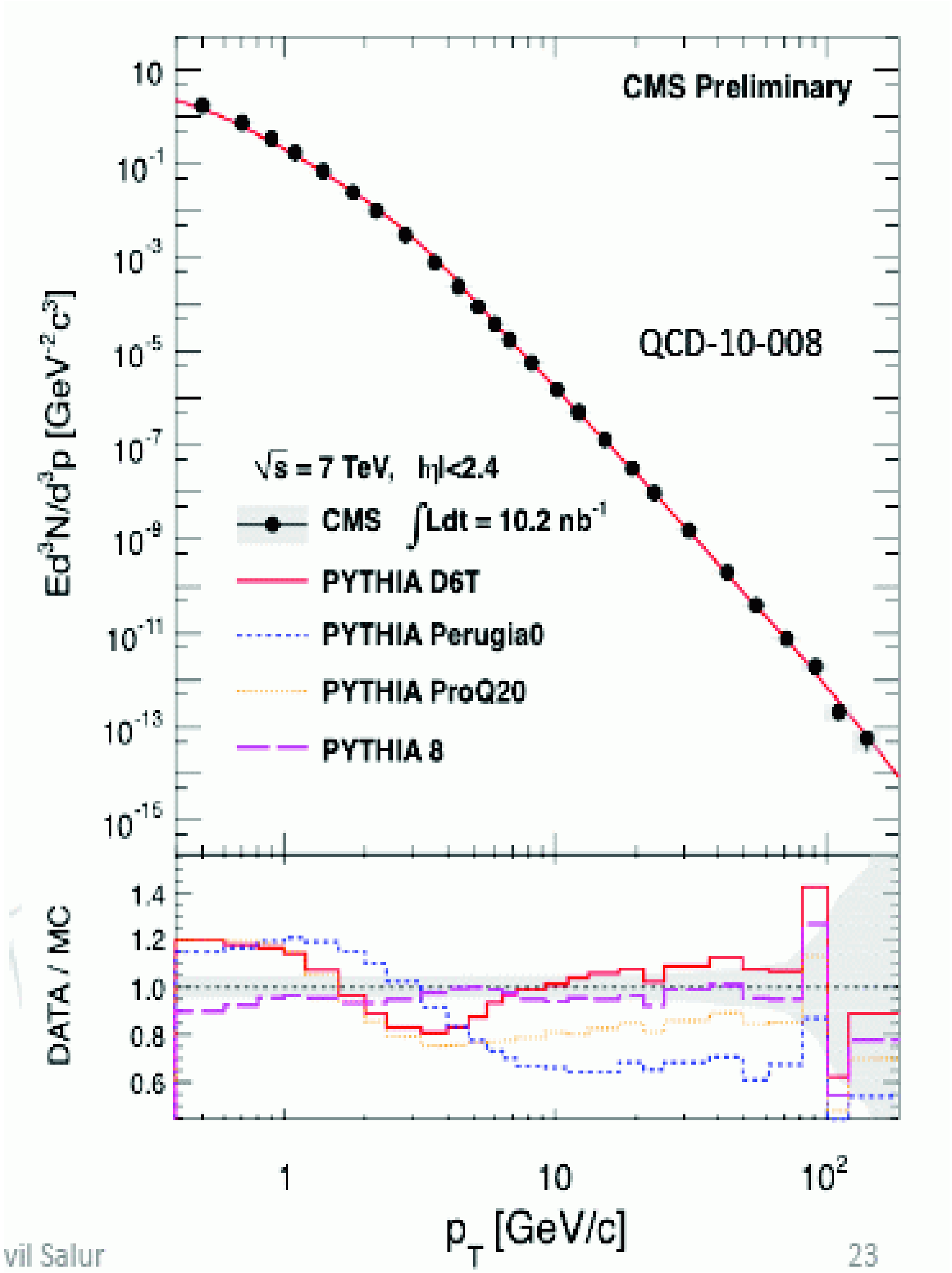
All descriptions with kT are approx. good enough for 3 GeV < pT < 15 GeV.

Y. Zhang, G. Fai, G. Papp,
G.G. Barnaföldi, P.L.:
PRC 65 (2002) 034903.
G.G. Barnaföldi et al.
EPJ C33 (2004) 609.

Charged hadron production in pp collisions in the high-pT region :

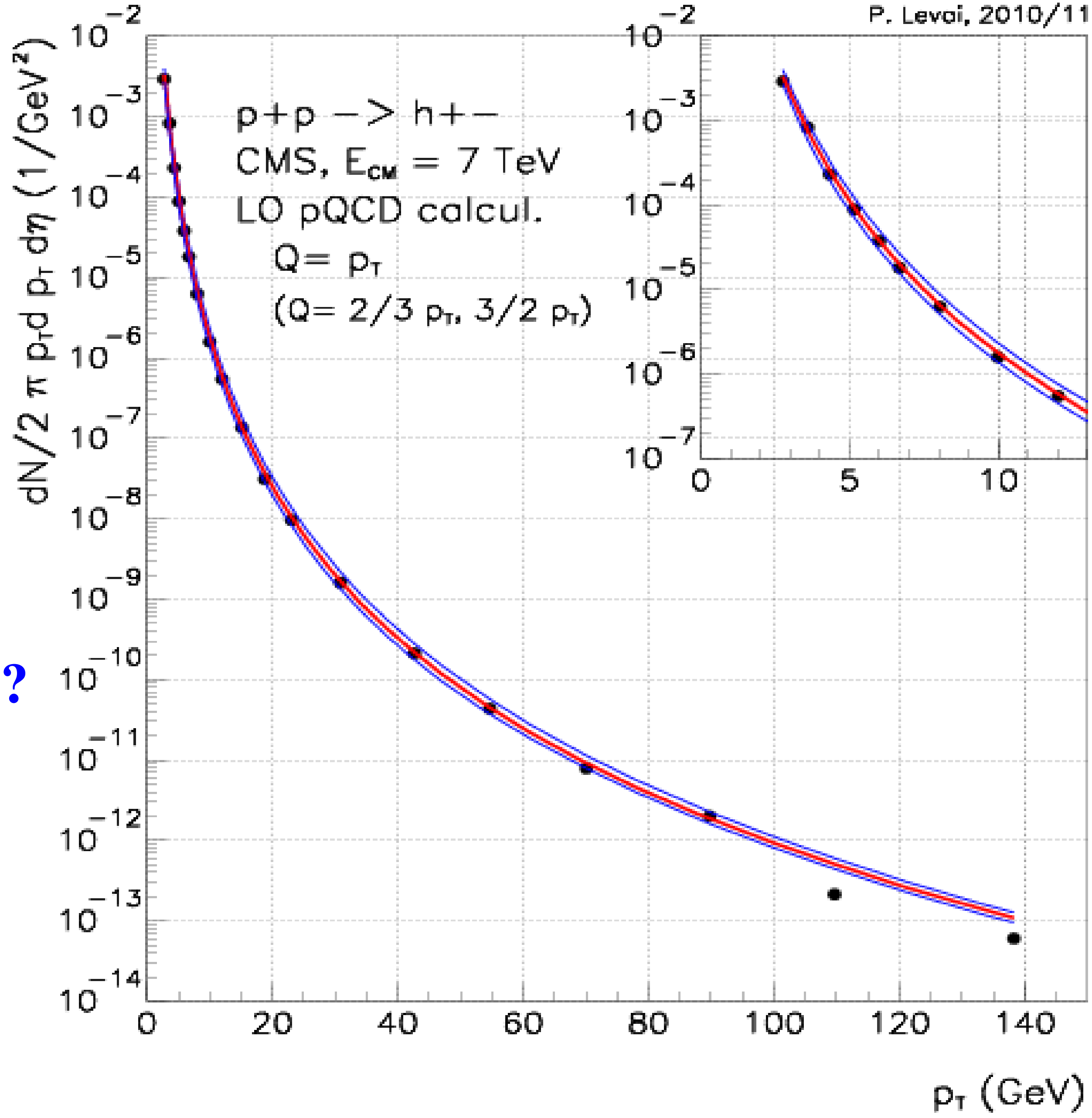


LHC ALICE (Prag'10)



LHC CMS (Prag'10)

Charged hadron production in pp collisions at 7 TeV – CMS data LO pQCD



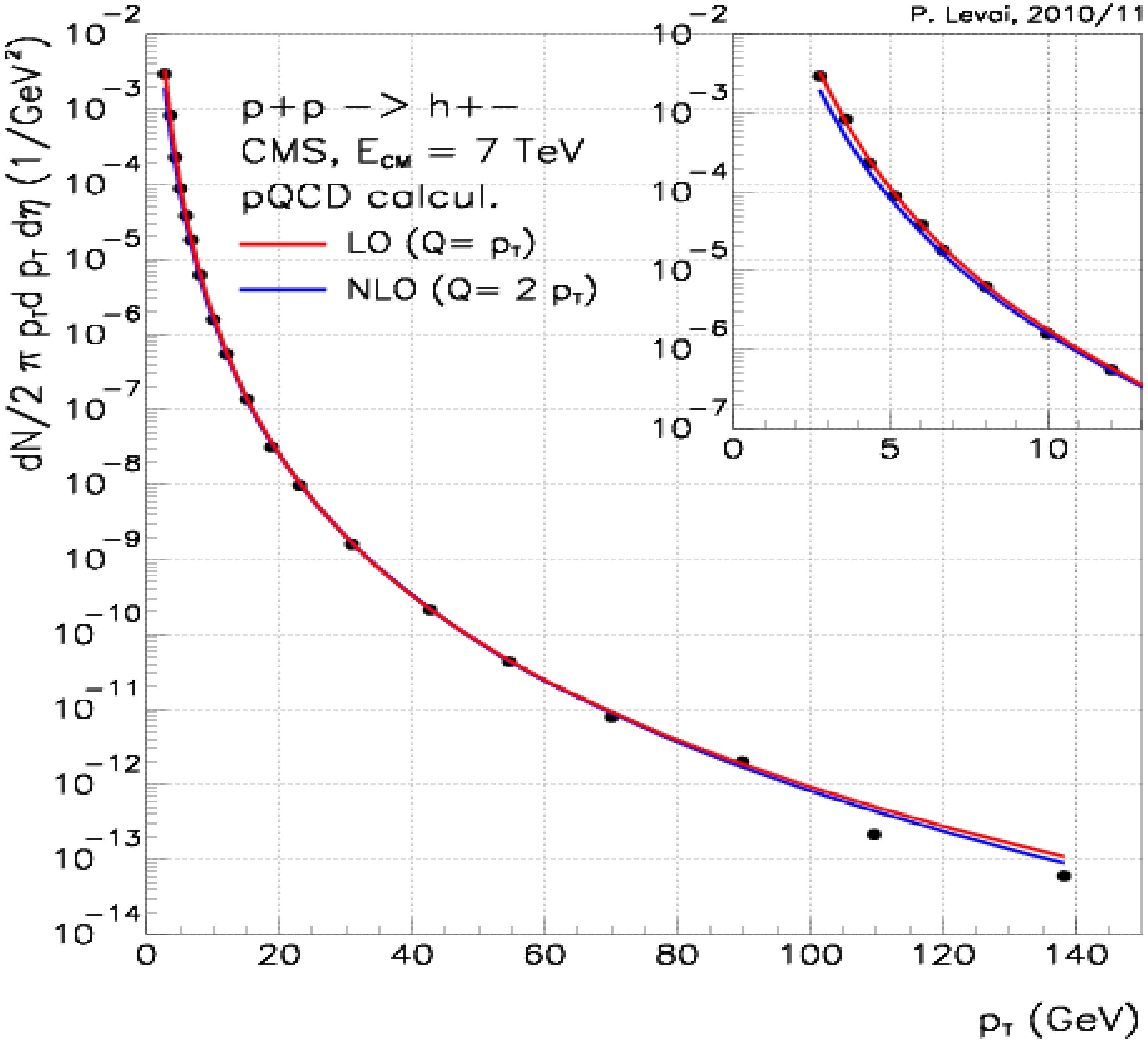
No need for intrinsic-kT !!??

(Neither at TEVATRON !)

Charged hadron production in pp collisions at 7 TeV – CMS data NLO pQCD

LO and NLO descriptions are equally good ! (Scale difference)

We will use our pQCD frame at 2.36 ATeV.



Hard physics: pion production in dAu collision at high-p_T

Perturbative QCD calculations in LO and NLO for pp + CRONIN + SHADOWING:

SHADOWING : "New-Hijing" parametrization, **Li & Wang, PLB527 (2002) 85.**

$$f_{a/A}(x_a,Q^2) = A\ S_a^A(x_a,Q^2)\ f_{a/N}(x_a,Q^2)$$

Shadowing function for quarks:

$$S_q^A = 1.0 + 1.19\log^{1/6}A\,(x^3 - 1.12\,x^2 + 0.21\,x) -$$

$$- s_q(A^{1/3}-1)^{0.6}(1-3.5\sqrt{x})\exp(-x^2/0.01)$$

Shadowing function for gluons:

$$S_g^A = 1.0 + 1.19\log^{1/6}A\,(x^3 - 1.2\,x^2 + 0.21\,x) -$$

$$- s_g(A^{1/3}-1)^{0.6}(1-1.5\,x^{0.35})\exp(-x^2/0.004)$$

88 S.-Y. Li, X.-N. Wang / Physics L

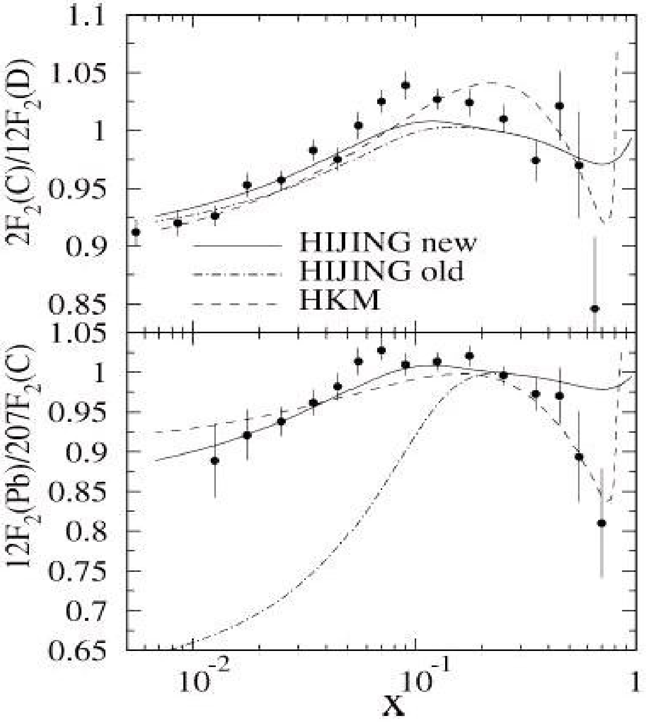


Fig. 2. Ratio of nuclear structure functions as measured in DIS. Solid lines are the new HIJING parameterization (Eq. (8)), dashed lines are the HKM parameterization [32] and dot-dashed lines are the old HIJING parameterization [16]. The data are from Ref. [30].

Hard physics: pion production in dAu collision at high-p_T

Perturbative QCD calculations in LO and NLO for pp + CRONIN + SHADOWING:

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$$- s_g (A^{1/3} - 1)^{0.6} (1 - 1.5\,x^{0.35}) \exp(-x^2/0.004)$$

+ *b* impact parameter dependence:

$$s_i(\boldsymbol{b}) = s_i \frac{5}{3} (1 - b^2/R_A^2)$$

Re-weightening

S.-Y. Li, X.-N. Wang / Physics L

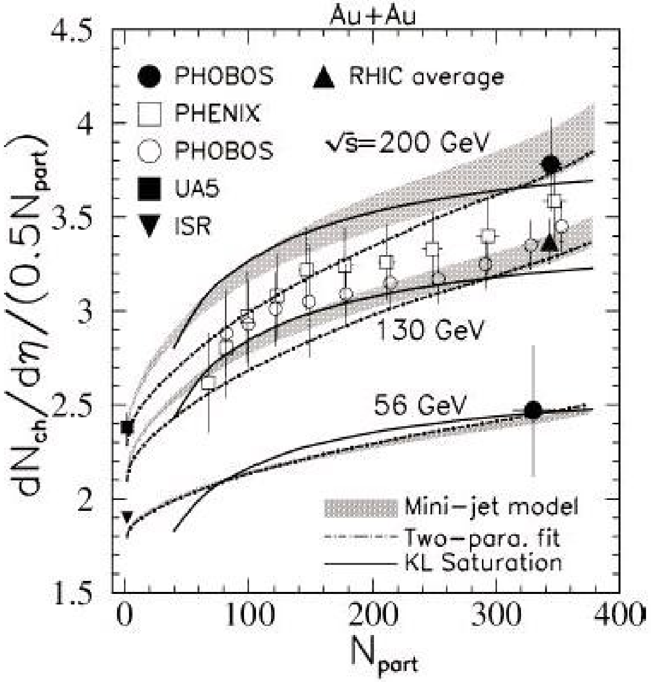
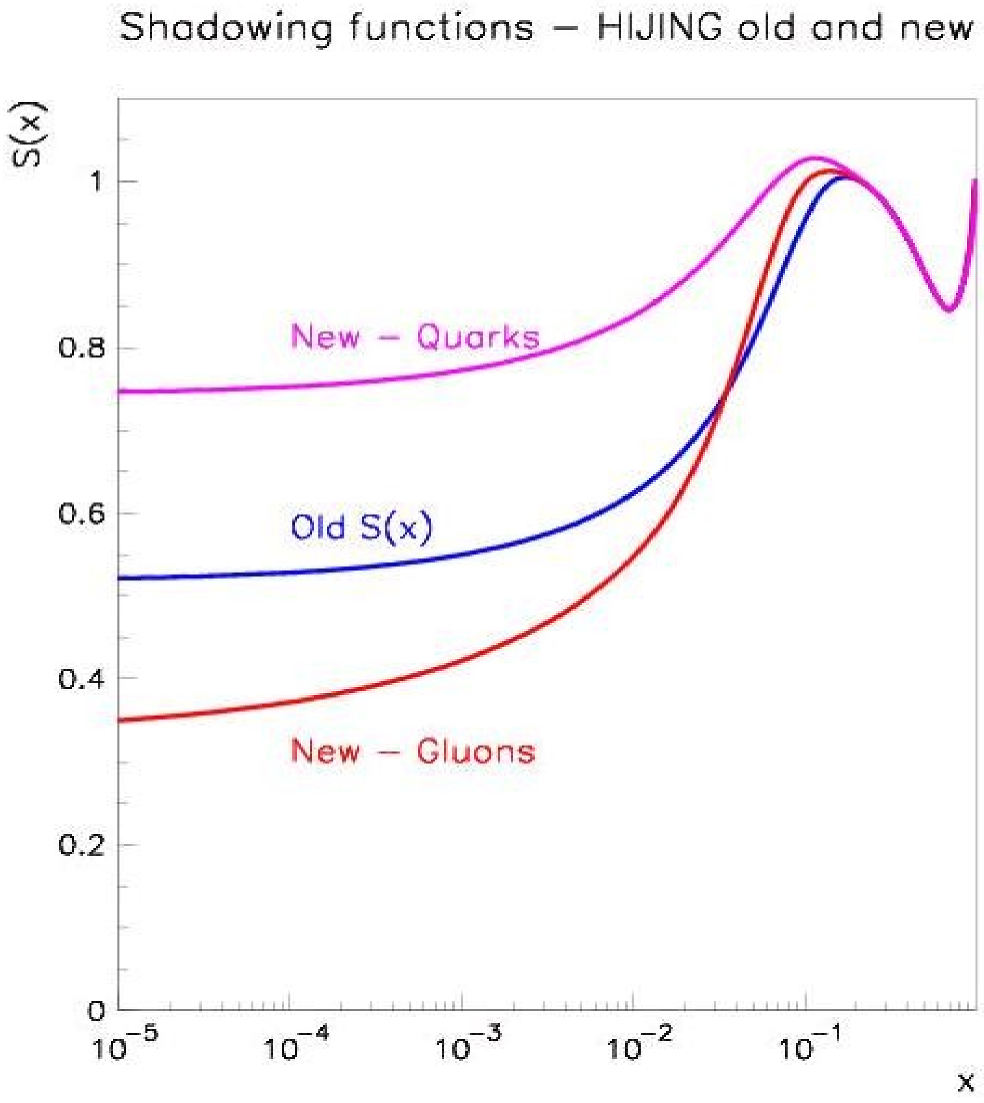


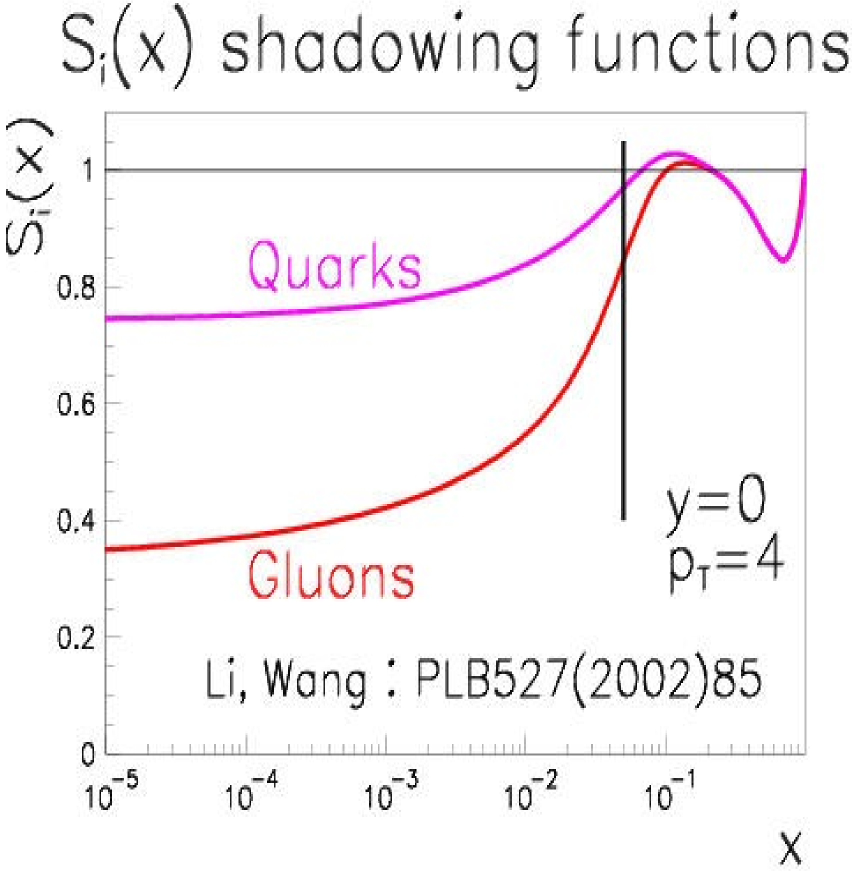
Fig. 4. The charged hadron central rapidity density per participant nucleon pair as a function of the averaged number of participants from the two-component model (shaded lines), two-parameter fit (Eq. (11)) (dot-dashed lines) and parton saturation model [9] as compared to experimental data [3,5,20,21].

Shadowing effect in dAu collisions:

S(x): shadowing function

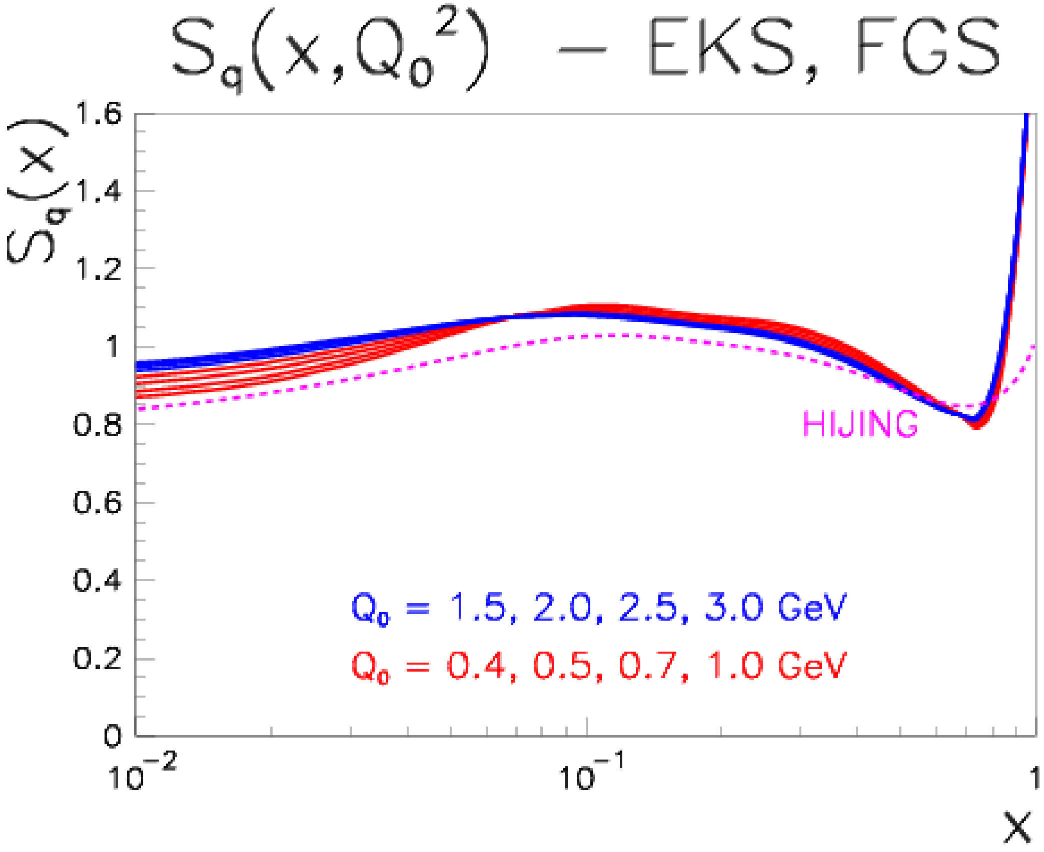
S(x) at y=0 & p_T = 4 GeV





$X \rightarrow 0$: S(x) is small

EKS99 shadowing function with enhanced antishadowing



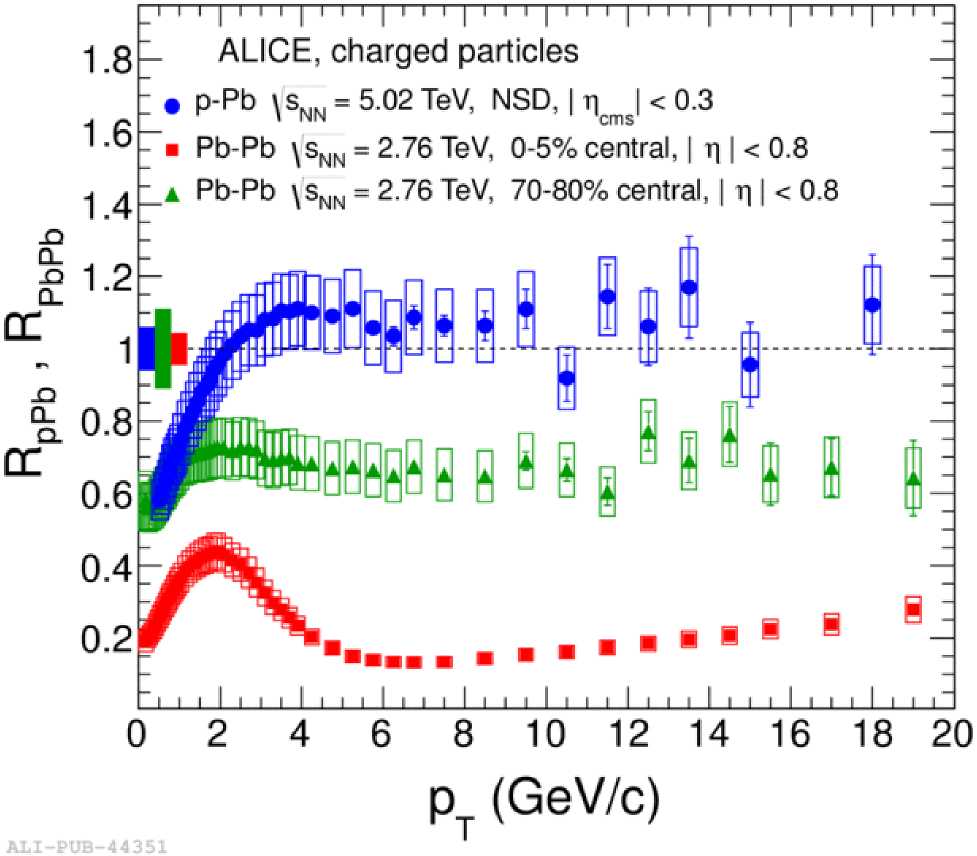
K.J. Eskola,
V.J. Kolhinen,
C.A. Salgado

EPJ C9, 61 (1999)

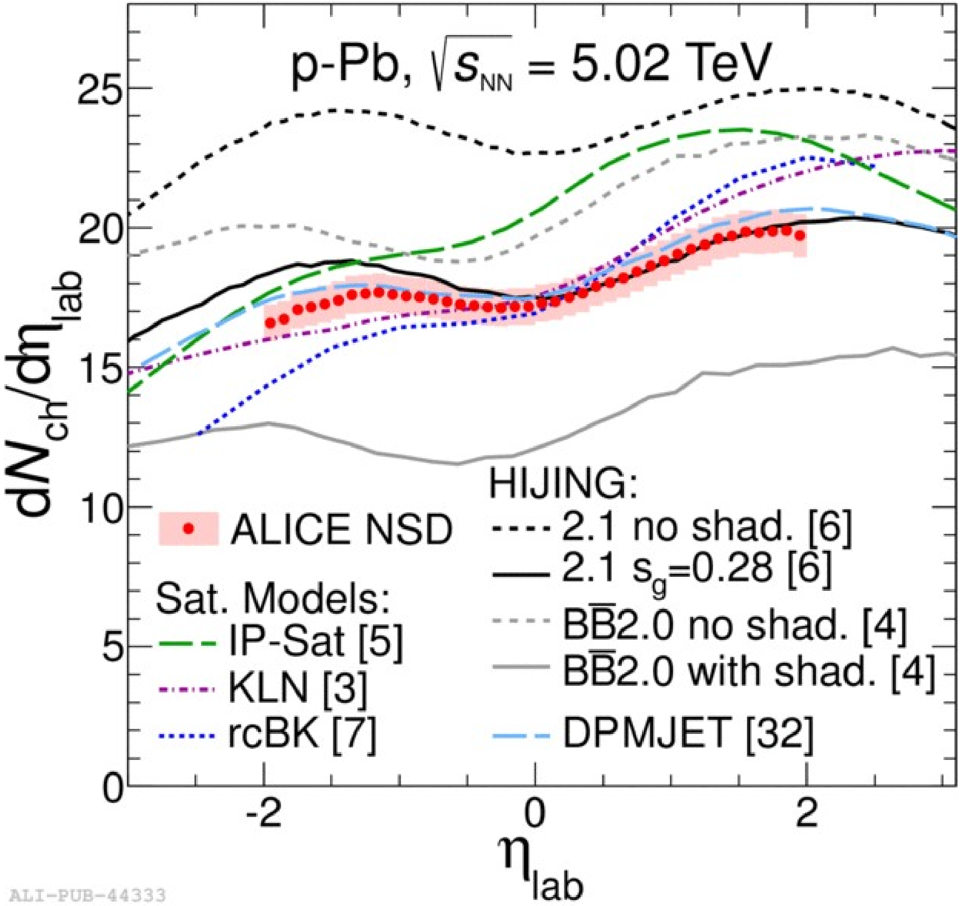
EKS: antishadowing effect for valence quarks

stronger than HIJING
at large-x
weaker than HIJING
at small-x

Results at LHC in pPb collisions at (s_NN)^ ½ = 5.02 TeV:



ALI-PUB-44351



ALI-PUB-44333

Shadowing effects are there, but they can be neglected in R_pA

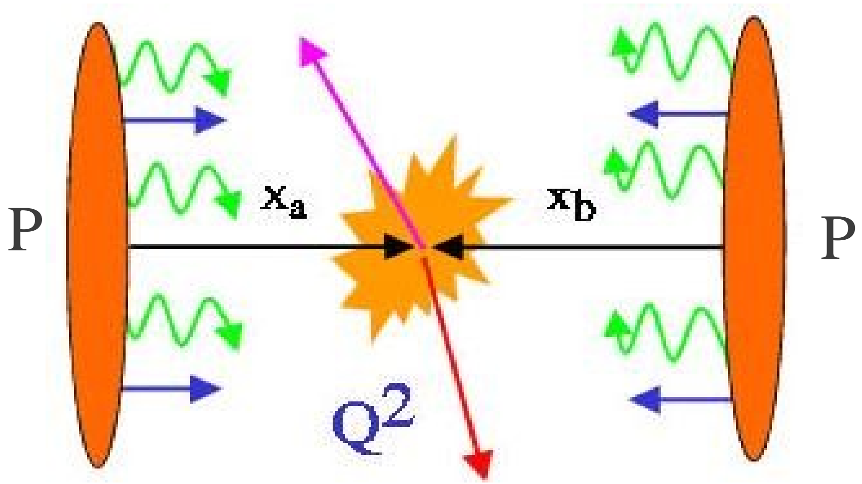
→ in R_AA ?? My answer: YES, neglect it.

ALICE: arXiv: 1210.4520 and arXiv: 1210.3615

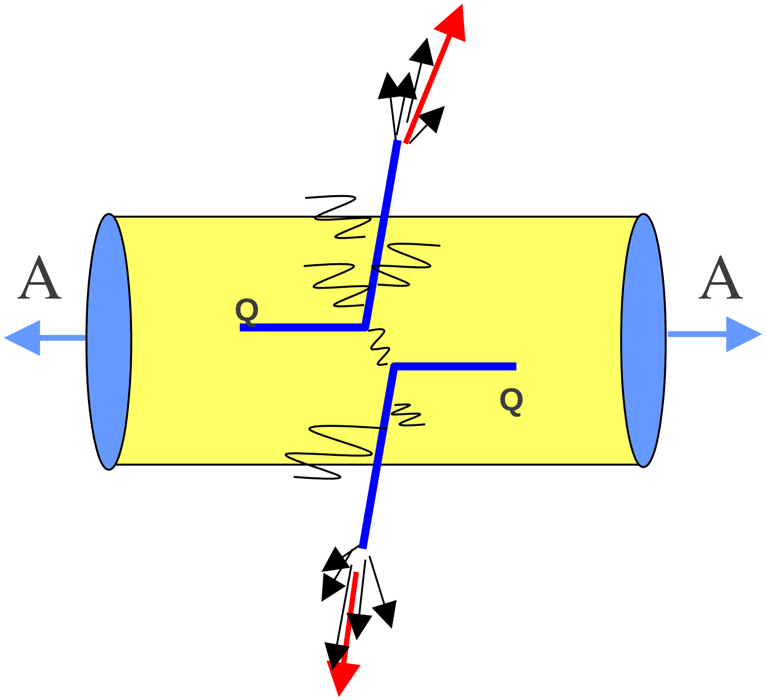
2. Jet energy loss

--- mechanism, description

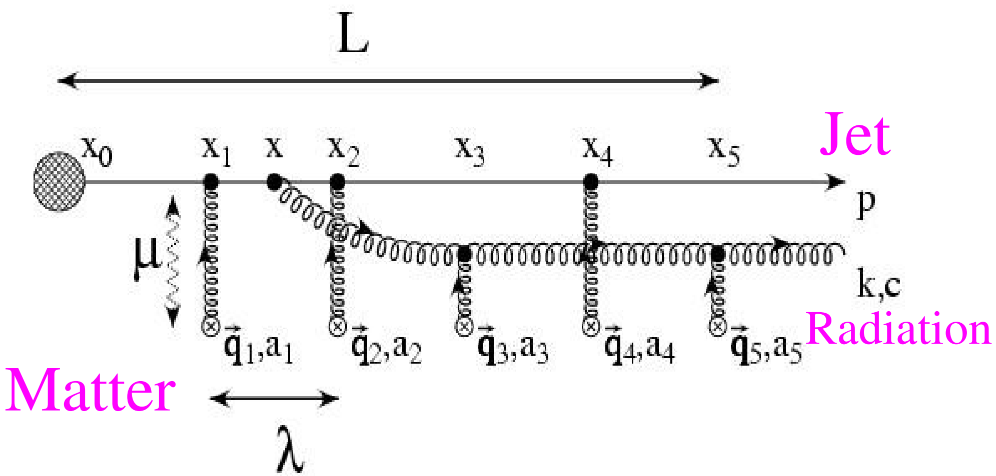
Jets in pp and in AA collisions:



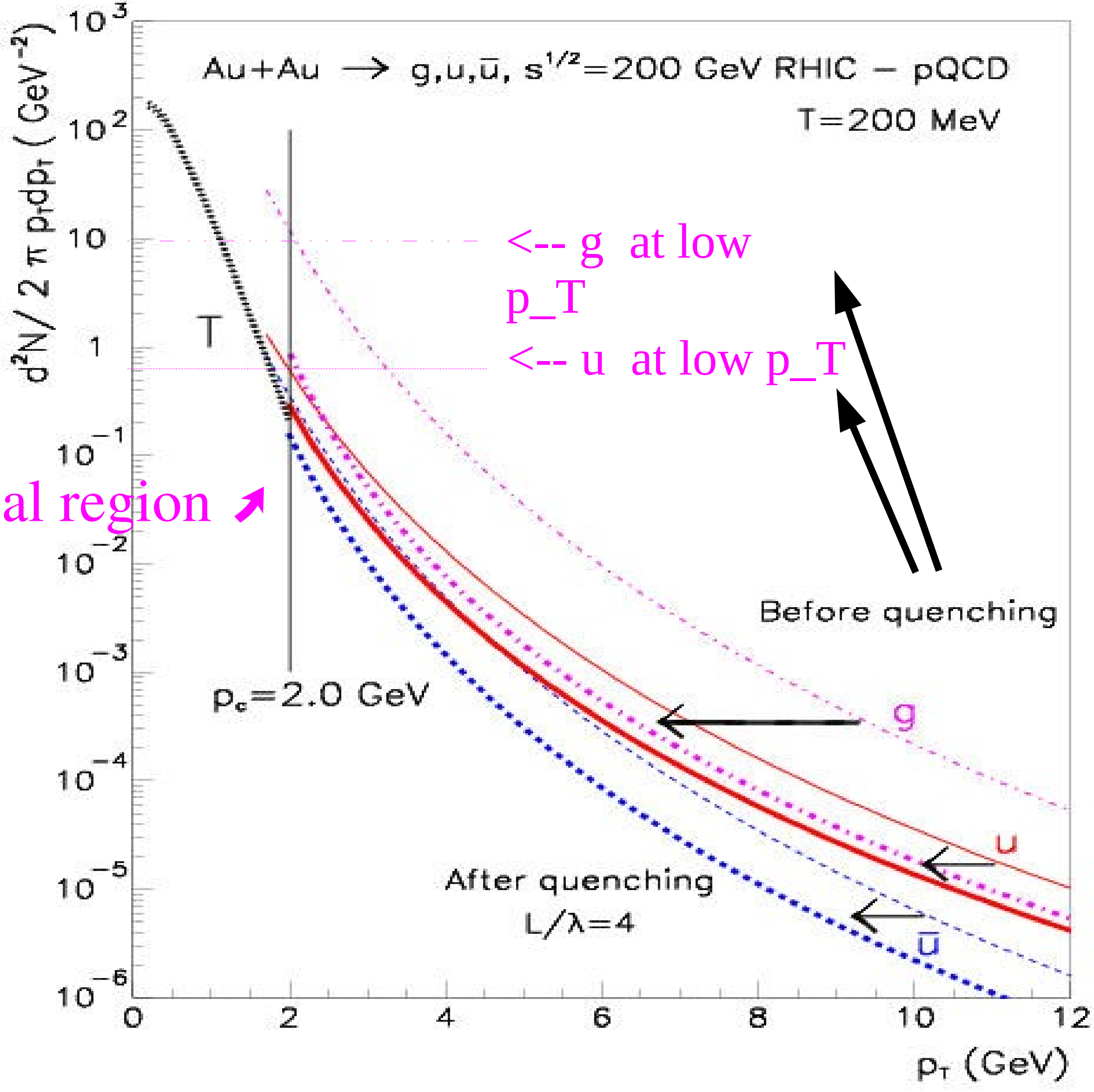
Jet production in pp collision
(in vacuum):
➣ pQCD description



Jet production and propagation
in AA collision (inside hot dense matter)
➣ induced gluon radiation in a
modified pQCD description
JET-TOMOGRAPHY



Initial parton distributions before and after quenching



<-- g at low p_T

<-- u at low p_T

Critical region ↗

Before quenching:

AuAu spectra

≡ binary scaled pp spectra

primary partons ➡

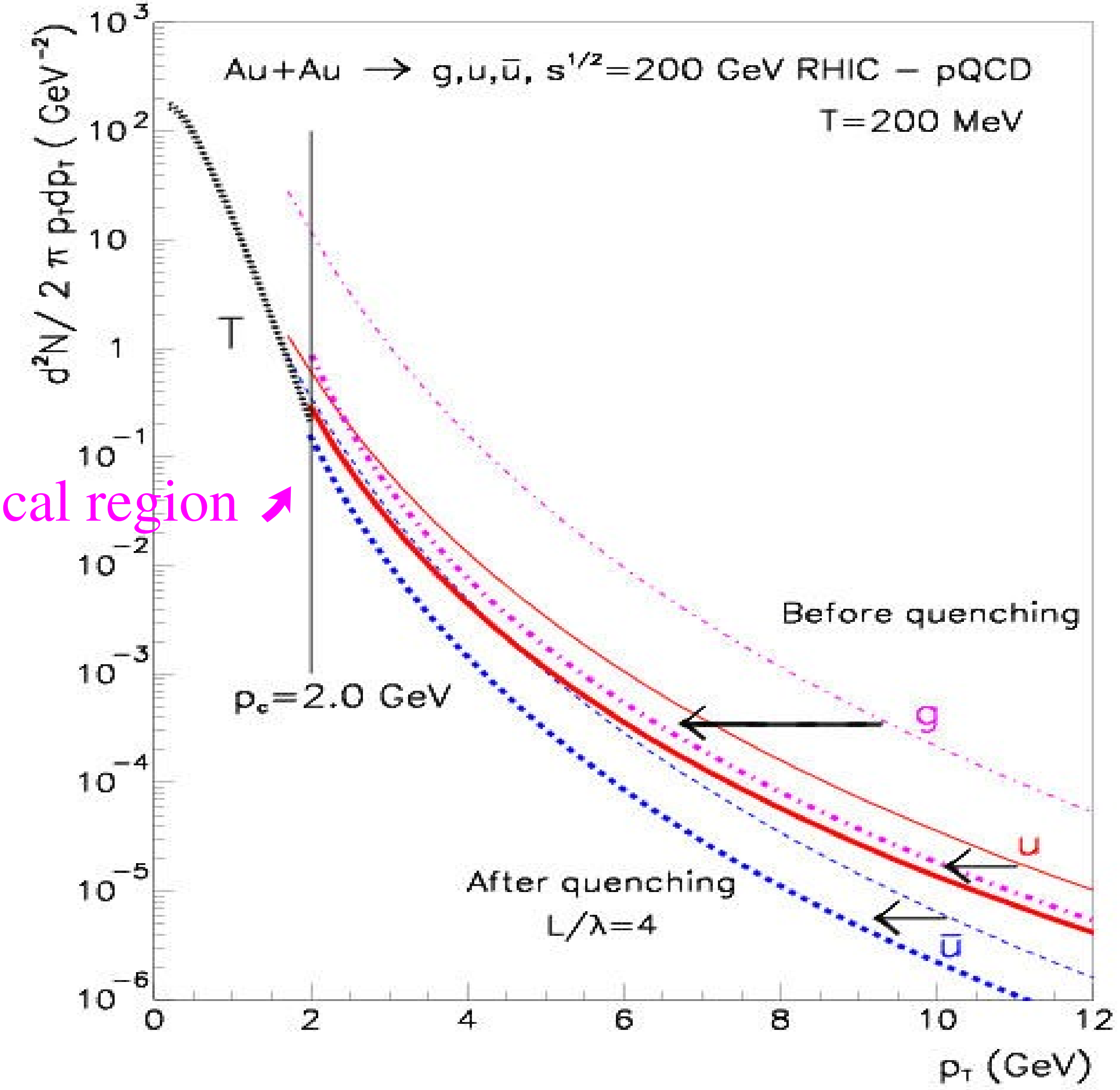
p_T > p_c : polinomial

p_T < p_c : suppressed or saturated

p_T > p_c :

80 % of dE_T/dy (y=0)

Initial parton distributions before and after quenching



Critical region ↗

After quenching:

radiated gluons →

thermal bath (T=200 MeV)

≡ **hot dense matter formation**

dE_T/dy (y=0) = 570 GeV

80 % is soft (p_T < p_c)

20 % is hard (p_T > p_c)

Modification in parton spectra is shifted to smaller hadronic p_T in case of independent jet fragmentation.

JET-QUENCHING

⇩ ⇩ ⇩ ⇩

SUPPRESSION in HADRON SPECTRA

A+A collision ↣ induced jet energy loss : thick plasma $L >> \lambda$

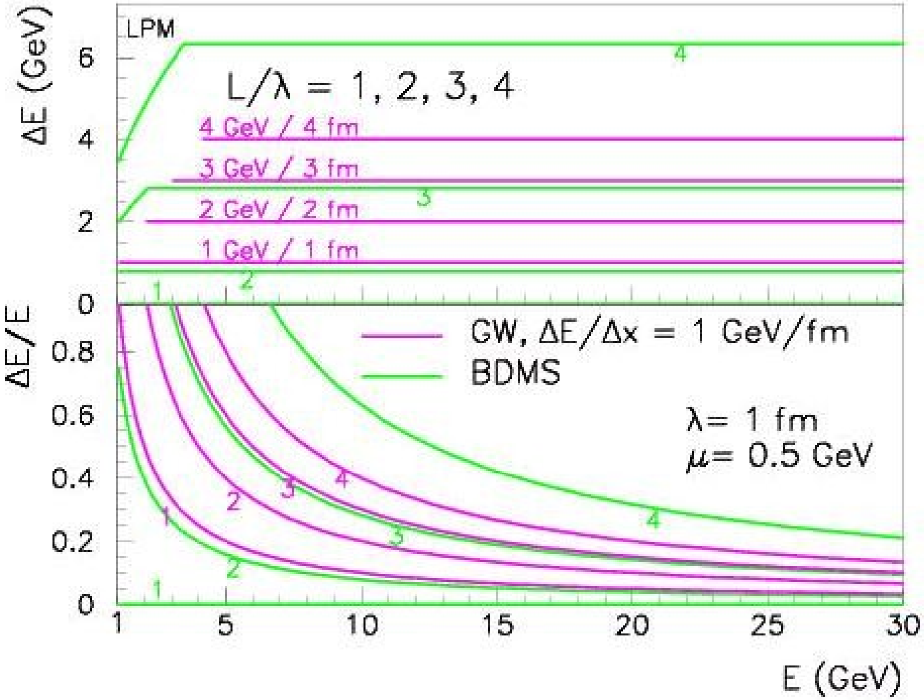
QED analogy (Gyulassy-Wang): 1-2 GeV/fm B. Betz: dE/dx = c E^0

Time ordered pQCD diagrams in infinite matter limit

large number of very soft interaction ($L \gg \lambda_g$)

(energy loss ➞ diffusion equation)

BDMS 97-98, Zakharov 96-98



$$\Delta E_{BDMS} \approx \frac{C_R \alpha_s}{4} \frac{L^2 \mu^2}{\lambda_g} \log \frac{L}{\lambda_g}$$

E-independent ΔE energy loss

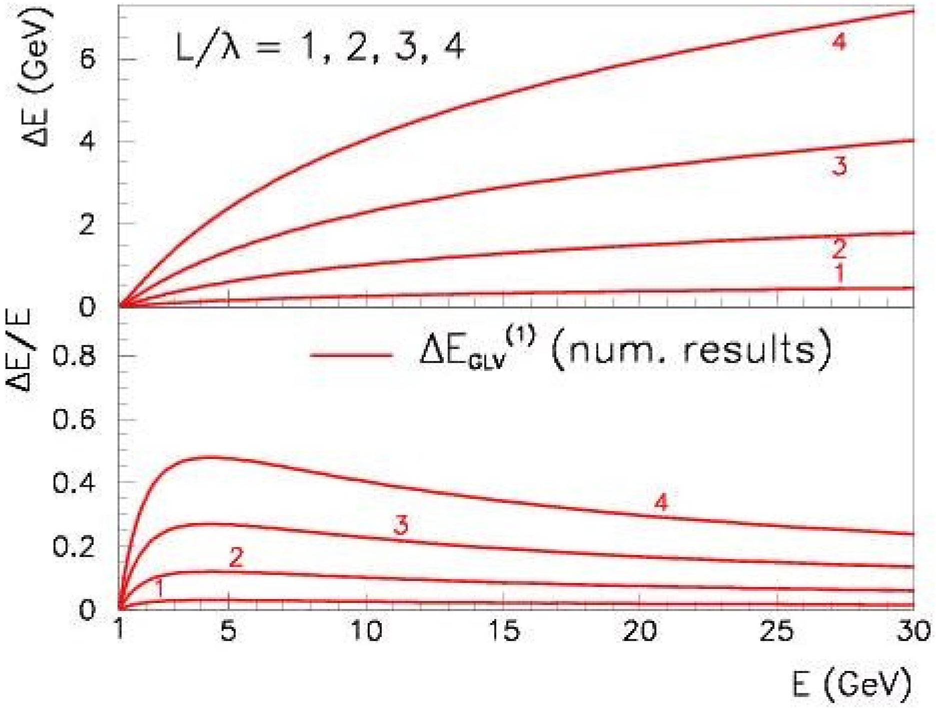
Strong E-dependence of ΔE/E
in the window
3 < E < 10 GeV

'Jet-quenching' : induced jet energy loss --- in thin colored matter

M. Gyulassy, P. Levai, I. Vitev,
PRL85,5535(2000), NPB594,371(2001)

GLV: time-ordered pQCD (Feyman diagrams)
+ OPACITY expansion (N = 1,2,3, ...)
+ kinematical cuts

$$\Delta E_{GLV} \approx \frac{C_R \alpha_s}{N(E)} \frac{L^2 \mu^2}{\lambda_g} \log \frac{E}{\mu}$$



E-dependent ΔE energy loss

E-independent ΔE/E
in the window
3 < E < 10-15 GeV

$$L/\lambda \rightarrow \int \tau \rho(\tau) d\tau$$

Opacity ↣ Density

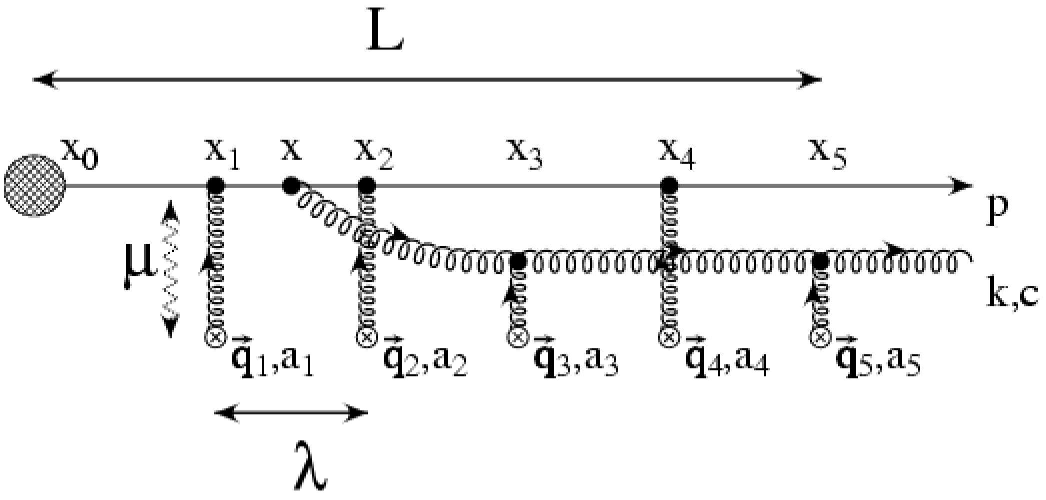
Induced jet energy loss --- agreements and disagreements:

BDMS, GW, GLV, Zakharov, Wiedemann, Salgado, ...

1. $\Delta E_{loss} \sim L^2$ **non-abelian nature**

2. $\Delta E_{loss} \sim \hat{q}$ **transport coefficient:** $\hat{q} \approx \mu^2/\lambda \approx \int d^2 q_T \, q_T^2 \, d\sigma/dq_T^2$

3. $\Delta E_{loss} = C_R \alpha_S \hat{q} L^2 F[\ldots]$ **where F[...] depends on theories**



Coherence & Interference

Induced jet energy loss in expanding matter: D. Molnar (Wuhan)

1. Averaged opacity ↣ time dependent color density:

$$1/\lambda_{col} = \sigma_{el}\rho_{col} \to \frac{9/2\pi\alpha_S^2}{\mu^2}\,\frac{2}{L^2}\int_0^L \tau\rho_{col}(\tau)\,d\tau$$

2. 1-DIM Bjorken expansion:

$$\to \frac{9/2\pi\alpha_S^2}{\mu^2}\,\frac{2}{L^2}\,\frac{1}{A_T}\,\frac{dN^{col}}{dy}\,L$$

3. Energy loss with rapidity density:

$$\Delta E_{GLV}^{\mathrm{1DIM}} \approx \frac{9C_R\pi\alpha_s^3}{4}\,\frac{1}{A_T}\,\frac{dN^{col}}{dy}\,L\,\log\frac{2E}{\mu^2 L}$$

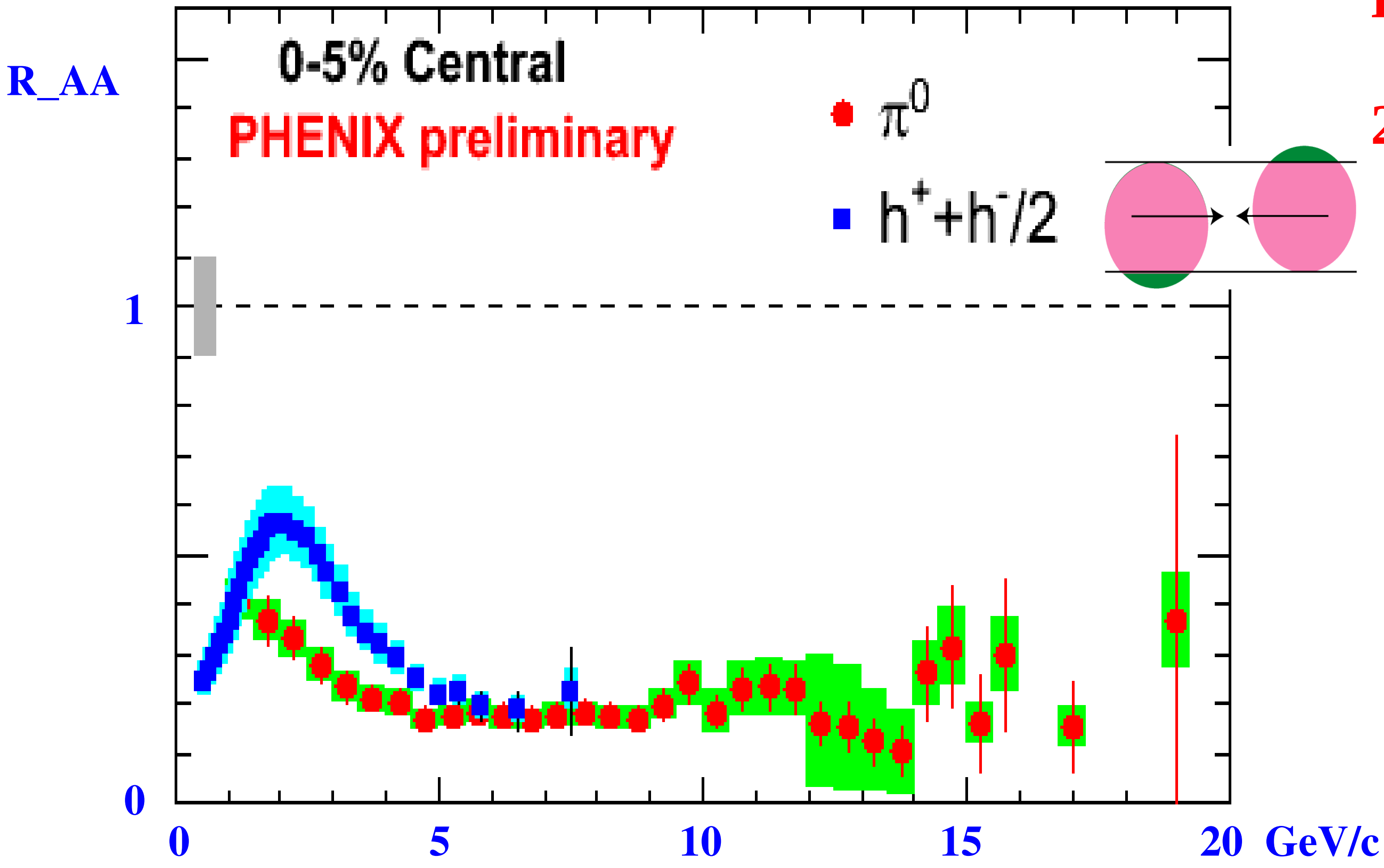
3. Data vs. Theory at RHIC and LHC energies
--- answers and new questions

Hard physics: pion production in AA collision at high- p_T

Perturbative QCD calculations in NLO for heavy ion collisions:

geometrical overlap + shadowing, multiscattring, jet-quenching, ...

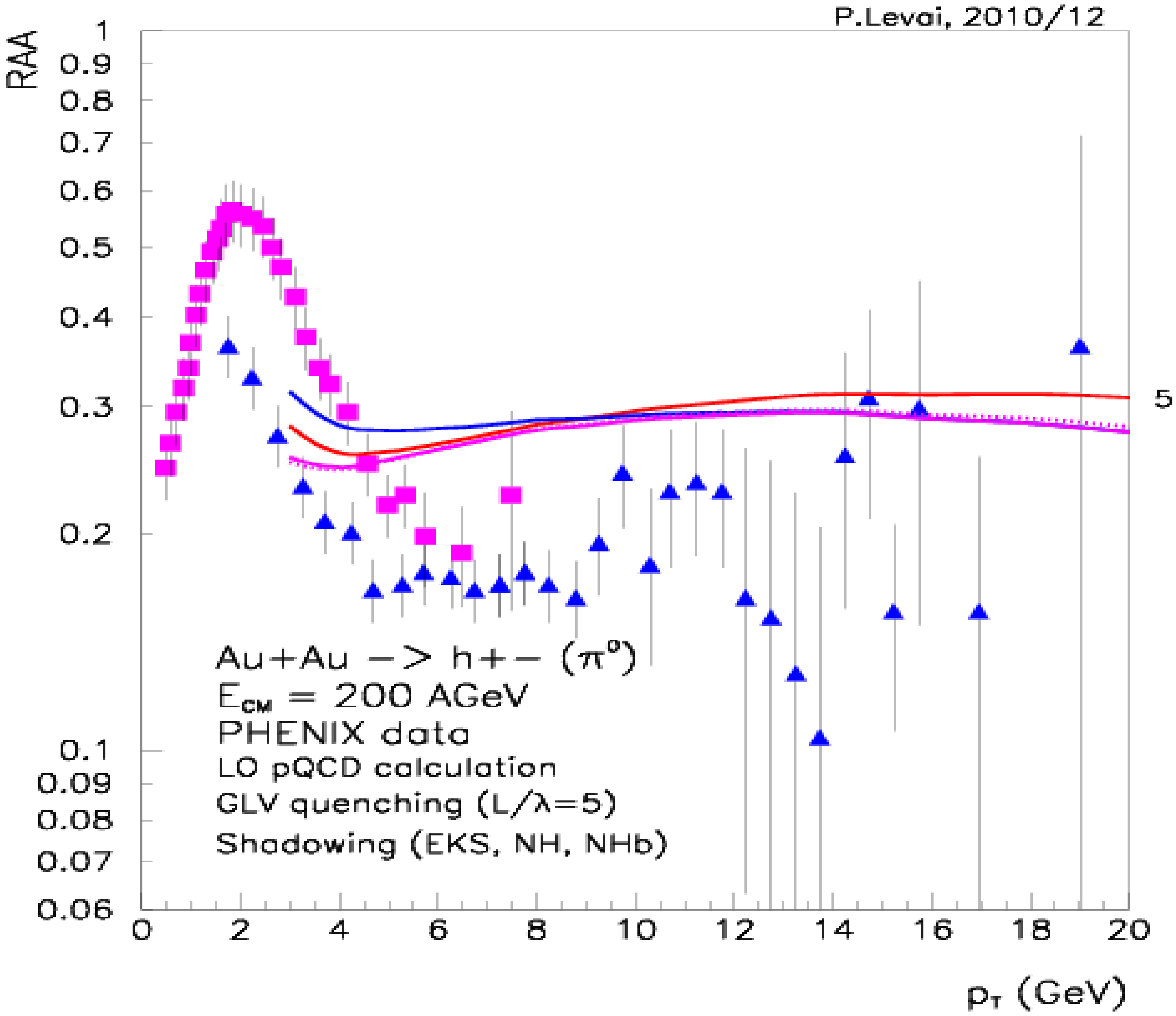
$$E_\pi \frac{d\sigma^{AB}}{d^3 p_\pi} = \int d^2 b\, d^2 r \;\; t_A(\vec{r})\, t_B(|\vec{b}-\vec{r}|) \;\; E_\pi \frac{d\sigma^{pp}}{d^3 p_\pi} \otimes S(...) \otimes M(...) \otimes Q(...)$$



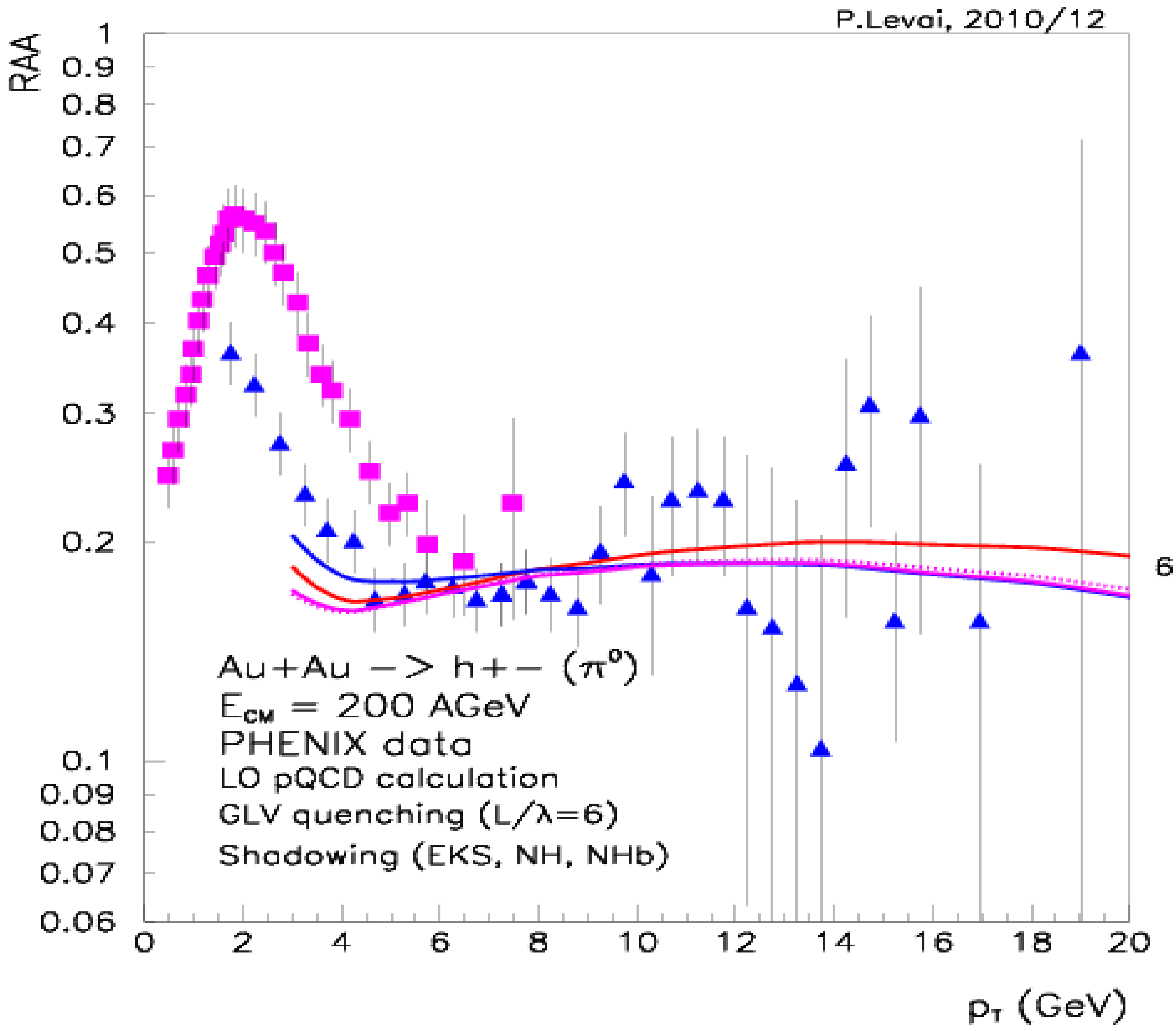
RHIC
data
200 A GeV

Au+Au

Most central Au+Au collisions (5%) at RHIC 200 AGeV
"Quenching at L/λ=5 + Shadowing"



Most central Au+Au collisions (5%) at RHIC 200 AGeV "Quenching at L/λ=6 + Shadowing"



Conclusion from light quark quenching at RHIC energy:

$L/\lambda = 5.5$ will describe RHIC data well

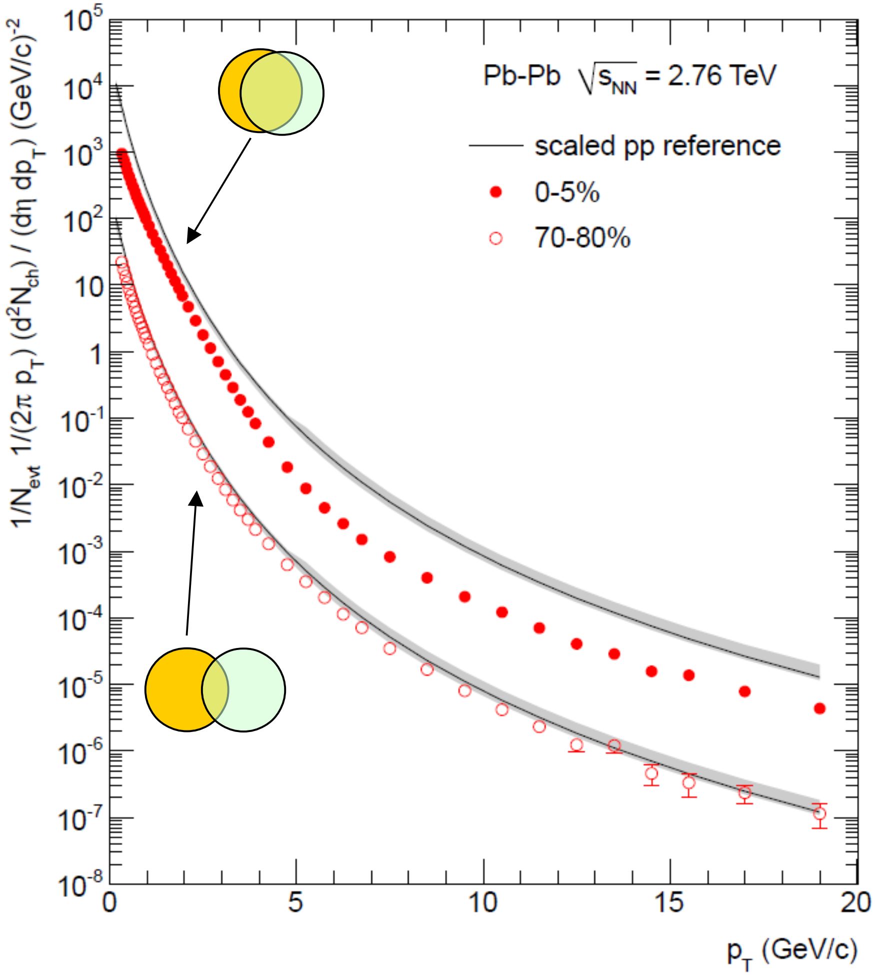
Shadowing has small influence

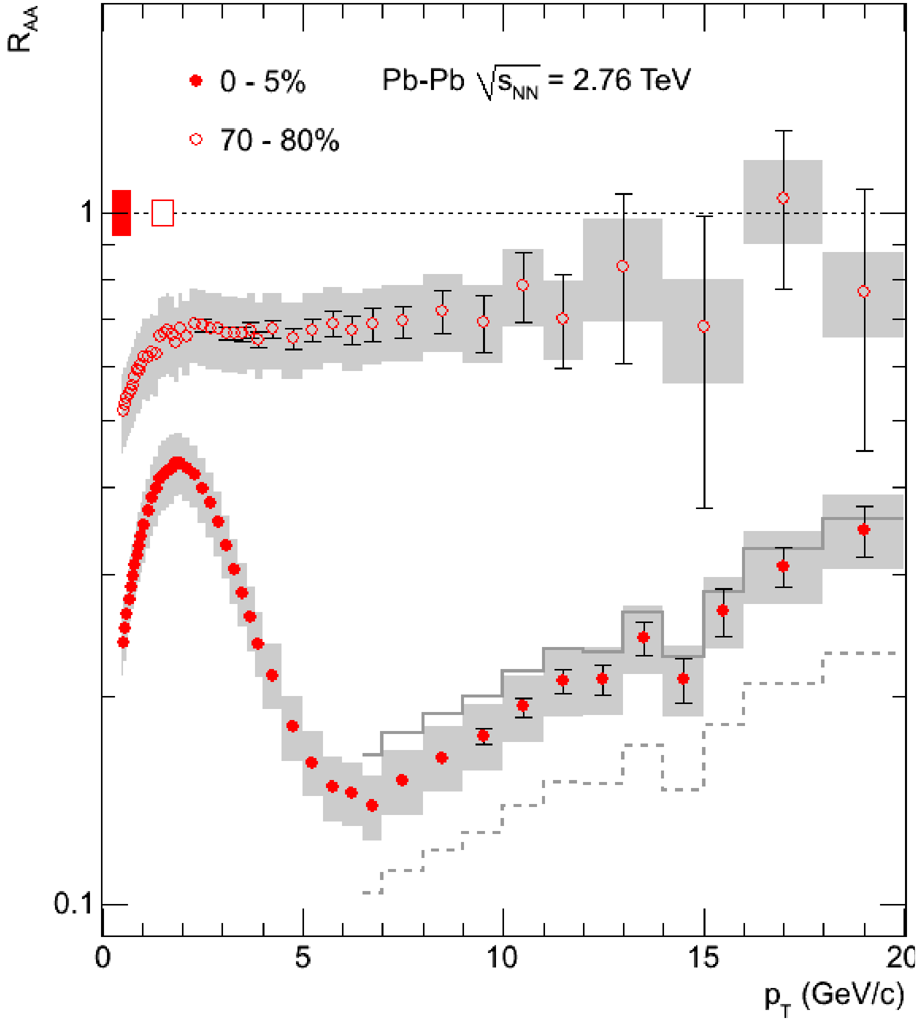
Results at LHC energies:

Pb+Pb at 2.76 ATeV

Charged hadron production in PbPb collision at 2.76ATeV --- first ALICE data --- (PLB696,30,2011)

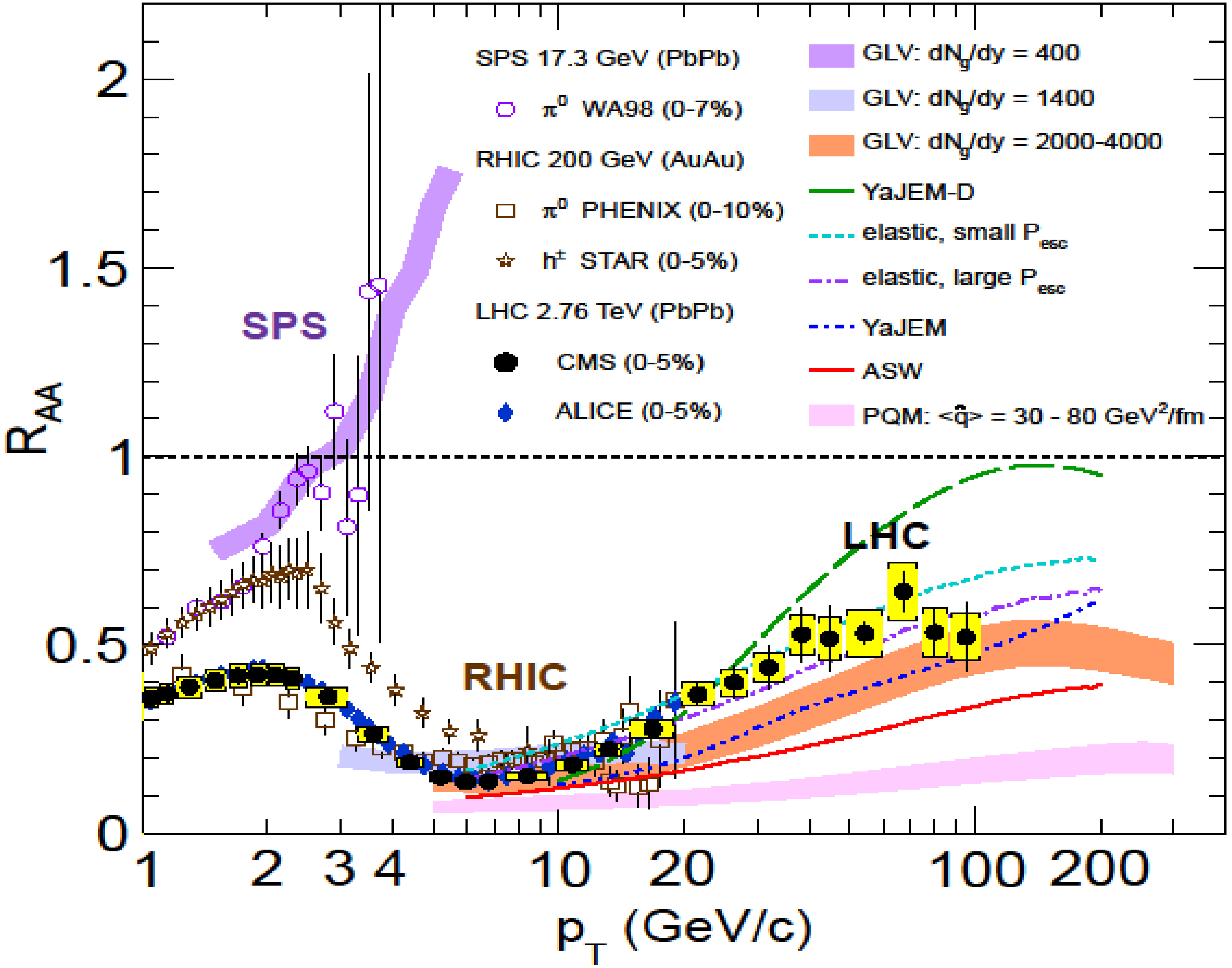
$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{\text{ch}}^{AA}/d\eta dp_T}{\langle N_{\text{coll}}\rangle\,(1/N_{evt}^{pp})\, d^2N_{\text{ch}}^{pp}/d\eta dp_T}$$





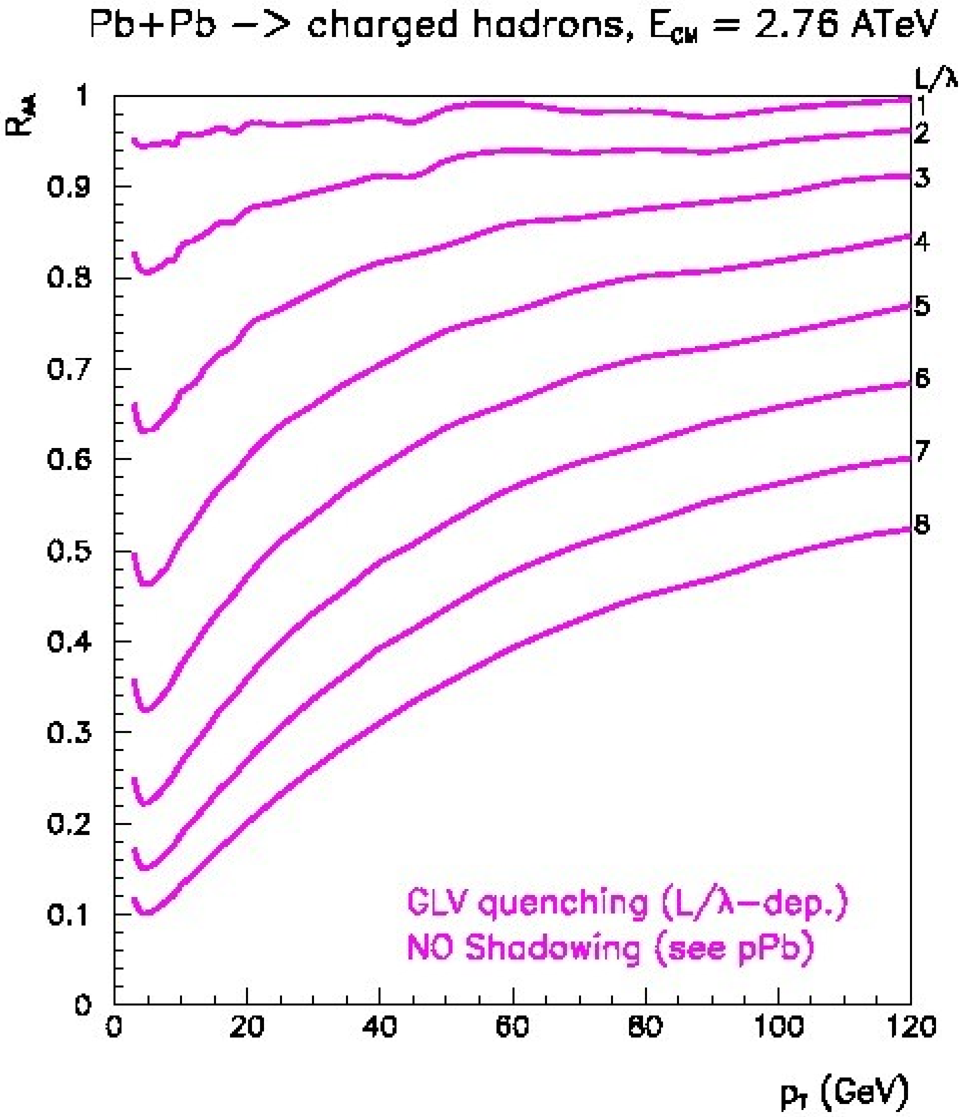
Most central Pb+Pb collisions (5%) at LHC 2.76 ATeV

Data from ALICE and CMS (EPJ C72, 1945,2012)

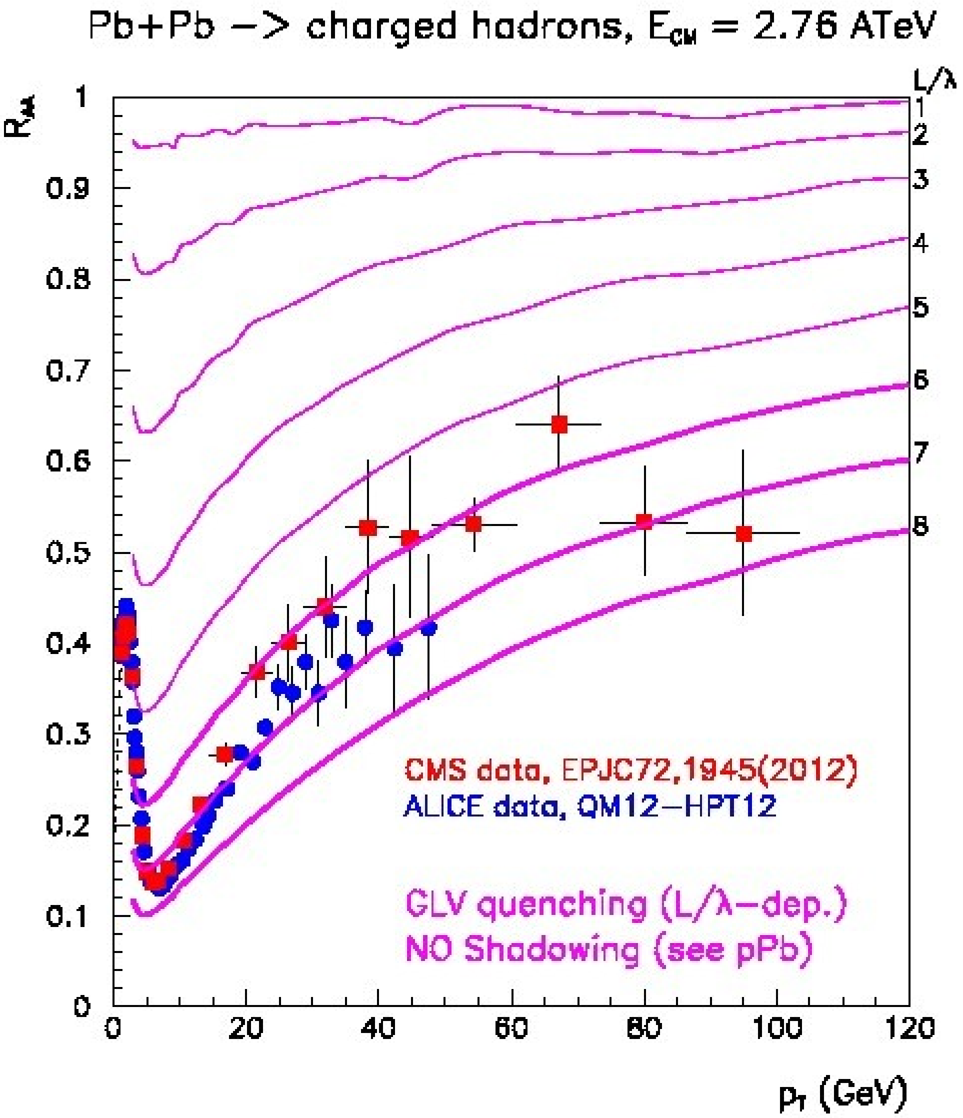


Most central Pb+Pb collisions (5%) at LHC 2.76 ATeV

Theory from GLV – energy loss only



Most central Pb+Pb collisions (5%) at LHC 2.76 ATeV
ALICE and CMS Data vs. Theory from GLV – energy loss only



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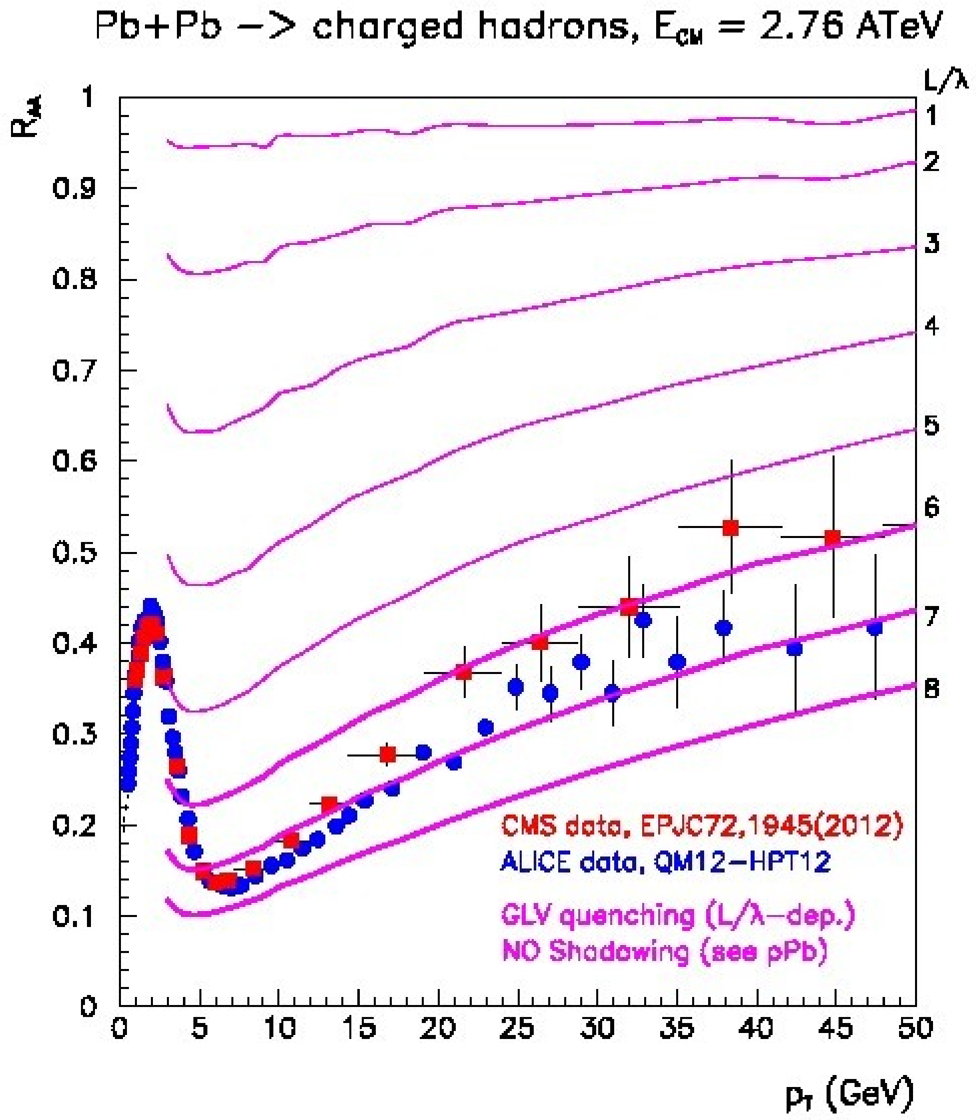


L/λ = 7 is needed

Conclusion from light quark quenching in PbPb collisions at 2760 AGeV LHC energy:

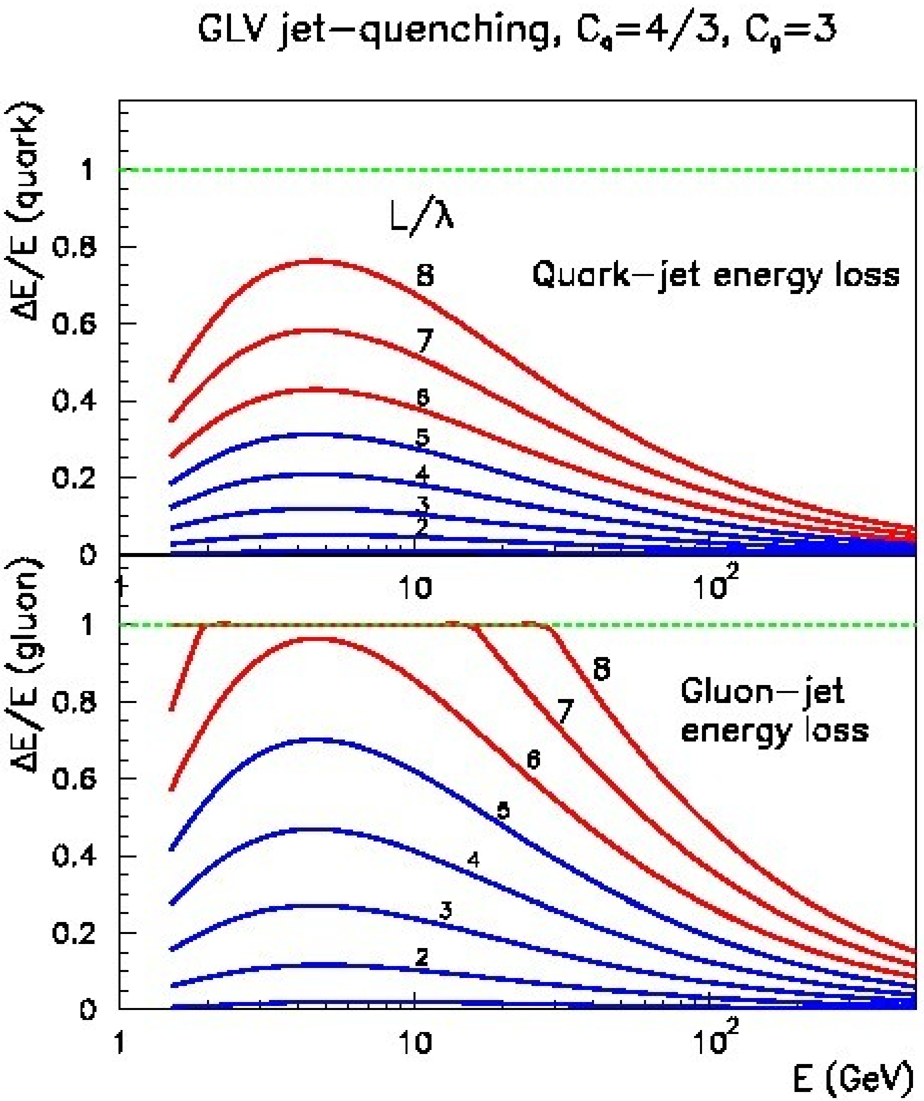
$L/\lambda = 7$ is needed without shadowing
(or with EKS shadowing)

This means 2x larger color density
at LHC energy w.r.t RHIC energy

What about the q and g details?

Jet energy loss for quark and gluon jets

ALICE and CMS Data vs. Theory from GLV – energy loss only



All gluon jet suffer quenching in the windows:

$L/\lambda = 7$

$2 < pT < 12$ GeV/c

$L/\lambda = 8$

$1 < pT < 20$ GeVc

What will happen with them?

1, Thermalization, QGP

2, Coherent gluon field & quark dominance

4. A new channel for extra proton production

--- coherent gluon field and diquark coalescence

A further (good) model for particle production:

III. Non-perturbative, non-asymptotic color transport:
“confined flux tube formation and breaking”

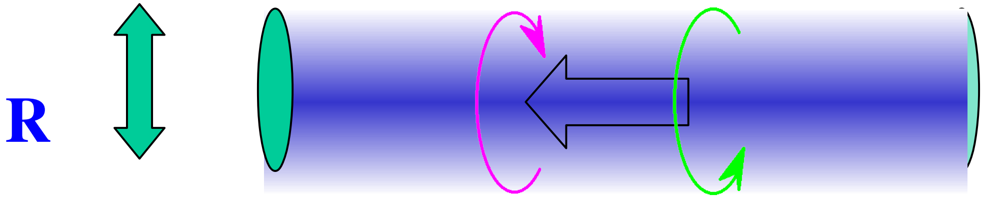
--- phenomenological approximations are known (string, rope)

--- phenomenology is applied successfully in string-based codes

--- FRITIOF, PYTHIA, HIJING 1.0/2.0 are using strings

--- URQMD, HIJING-BB is using ropes (melted strings)

--- good agreement with data at different energies



--- formal QCD-based equations are known (Heinz, Mrowczynski)

--- YM-field evolution in 3+1 dim, collision (Poschl, Müller)

--- lattice-QCD calculations have been started (Krasnitz, Lappi)

--- time-dependent strong fields, color kinetic eq. (Skokov, PL)

--- ...

A further model for particle production:

III. Non-perturbative, non-asymptotic color transport:
"pair-creation in strong fields"

--- strong (Abelian) static E field: Schwinger mechanism

probability of pair-creation:

$$P(p_T)\,d^2p_T = -\frac{eE}{4\pi^3}\ln\left(1-\exp\left[-\pi\frac{m^2+p_T^2}{eE}\right]\right)d^2p_T$$

integrated probability at mass m:

$$P_m = \frac{(eE)^2}{4\pi^3}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left[-\pi\frac{n\,m^2}{eE}\right]$$

ratio of production rates (e.g. strange to light)

$$\gamma_s = \frac{P(s\bar{s})}{P(q\bar{q})} = \exp\left[-\pi\frac{m_s^2-m_q^2}{eE}\right]$$

$$eE = 0.9\,GeV/fm$$

--- strong time dependent SU(N) color fields:

Kinetic Equation for the color Wigner function

A.V. Prozokevich, S.A. Smolyansky, S.V. Ilyin, hep-ph/0301169.

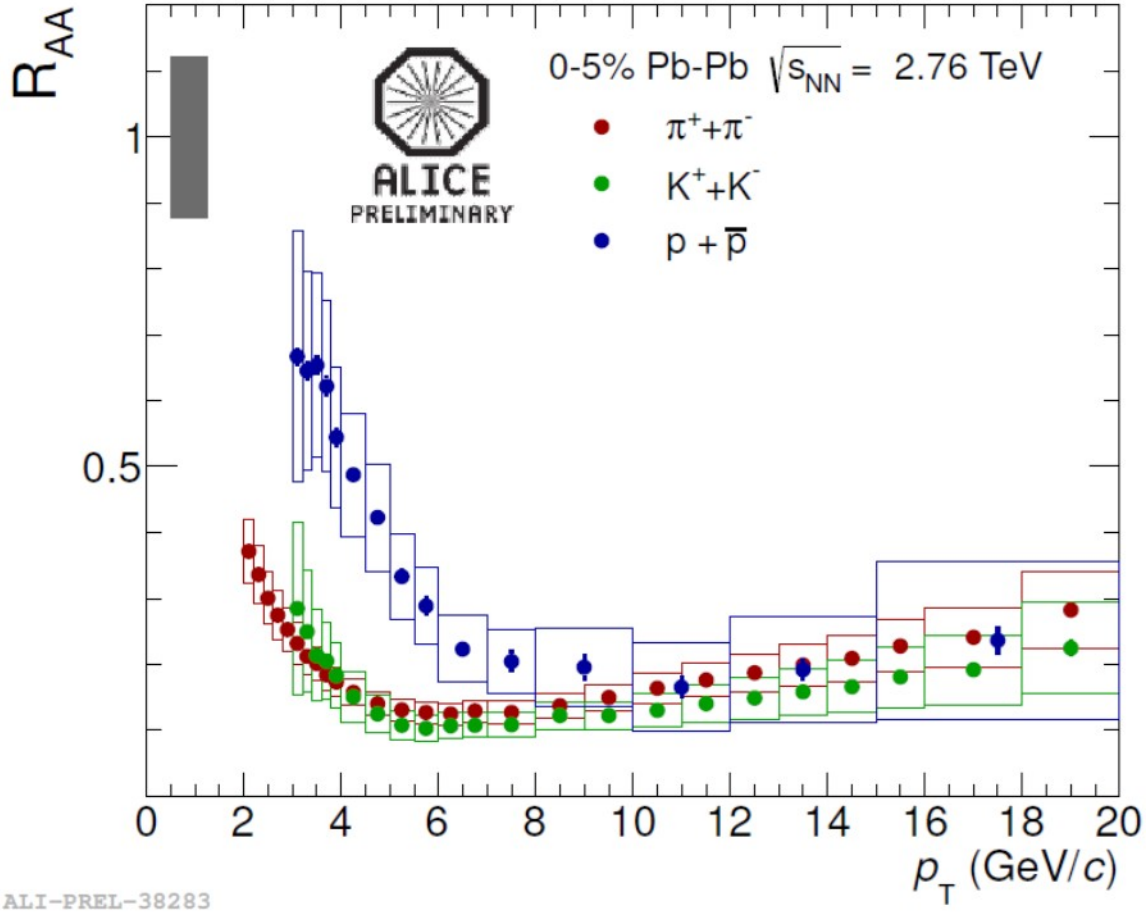
How could we decide between the two scenarios:

1, Gluon energy loss → thermal bath of QGP →
hadronization with quark coalescence

2, Gluon energy loss → coherent gluon field →
quark pair production from strong field →
quark-antiquark dominated plasma (QAP) →
hadronization with quark coalescence

Answer:
In 1: Thermal coalescence of quarks and antiquarks
In 2: Schwinger production of quark-antiquark pairs
and diquark-antidiquark pairs
Coalescence of (Schwinger) quark, antiquark
and diquark, anti-diquark
→ proton/pion ratio (R_AA) can be different !!!

New data from ALICE: R_AA of identified charged hadrons in PbPb



Theoretical investigations:

D. Berényi, A. Pasztor, V.V. Skokov, P.L.

J. Phys. G36 (2009) 064068; G38 (2011) 124155.

arXiv: 1208.0448

Kinetic equation for fermion pair production:

Wigner function: $W(k_{1,}k_{2,}k_3)$

Color decomposition: $W = W^s + W^a t^a, \quad where \quad a = 1, 2, \ldots, N_c^2 - 1$

Spinor decomposition: $W^{s;a} = a^{s;a} + b_\mu^{s;a}\gamma^\mu + c_{\mu\nu}^{s;a}\sigma^{\mu\nu} + d_\mu^{s;a}\gamma^\mu\gamma^5 + i\,e^{s;a}\gamma^5$

Color vector field (longit.): $A_\mu^a = (0, -\vec{A}) = (0, 0, 0, A_3^a)$

Kinetic equation for Wigner function:

$$\partial_t W + \frac{g}{8}\frac{\partial}{\partial k_i}\left(4\{W, F_{0,i}\} + 2\{F_{i\nu}, [W, \gamma^0\gamma^\nu]\} - [F_{i\nu}, \{W, \gamma^0\gamma^\nu\}]\right) =$$

$$= i\,k_i\{\gamma^0\gamma^i, W\} - i\,m[\gamma^0, W] + ig\left[A_i, [\gamma^0\gamma^i, W]\right].$$

for details see V.V. Skokov, PL: PRD71 (2005) 094010 for U(1)
PRD78 (2008) 054004 for SU(2)
in preparation for SU(3)

Distribution function for fermions with mass m:

$$f_f(\vec{k}, t) = \frac{m\,a^s(\vec{k}, t) + \vec{k}\,\vec{b}^s(\vec{k}, t)}{\omega(\vec{k})} + \frac{1}{2}$$

Time dependent external field, E(t) and neglected mass, m=0:

A, Pulse field (dotted):

$$E_{pulse}(t) = E_0\left[1 - \tanh^2(t/\delta)\right]$$

B, Constant field (dashed):

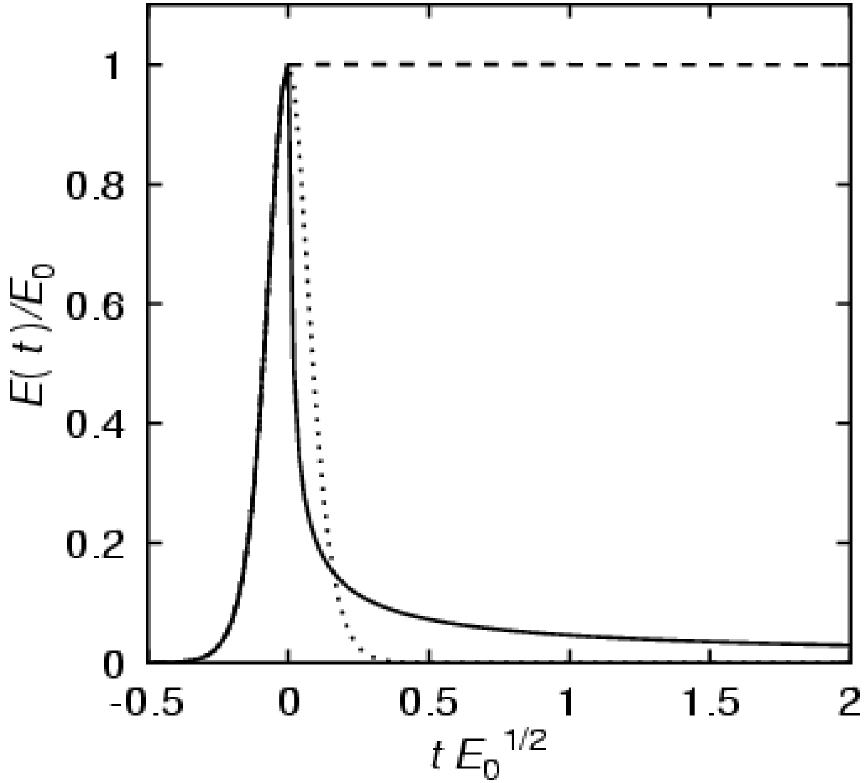
$$E_{const}(t) = E_{pulse}(t) \quad at \quad t<0$$

$$E_{const}(t) = E_0 \qquad at \quad t>0$$

C, Scaled field (solid):

$$E_{scaled}(t) = E_{pulse}(t) \quad at \quad t<0$$

$$E_{scaled}(t) = \frac{E_0}{(1+t/t_0)^{\kappa}} \quad at \quad t<0$$



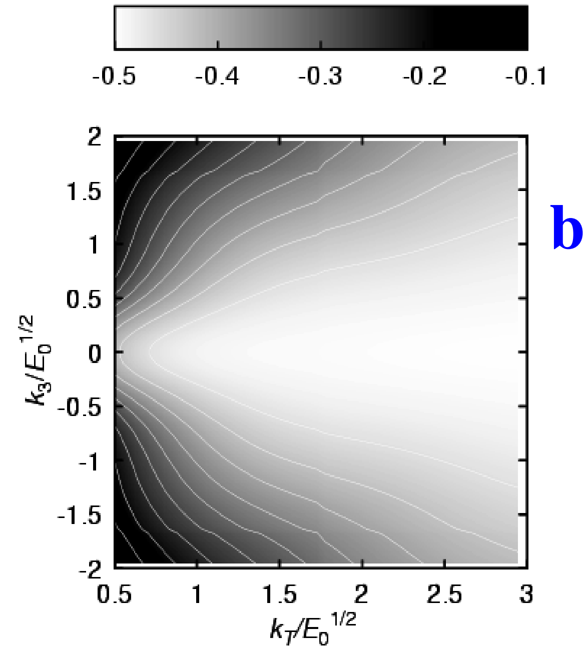
$$\delta = 0.1/E_0^{1/2} \quad at\ RHIC\ energy$$

$$\kappa = 2/3 \quad for\ scaled\ Bjorken\ expans$$

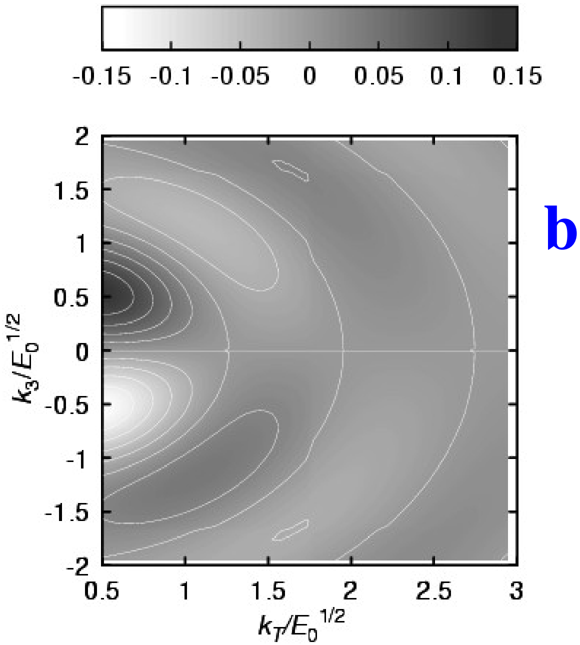
$$with \quad t_0 = 0.01/E_0^{1/2}$$

Numerical results (b^i) for the Bjorken expansion at $t= 2/\sqrt{E_0}$ in SU(2):

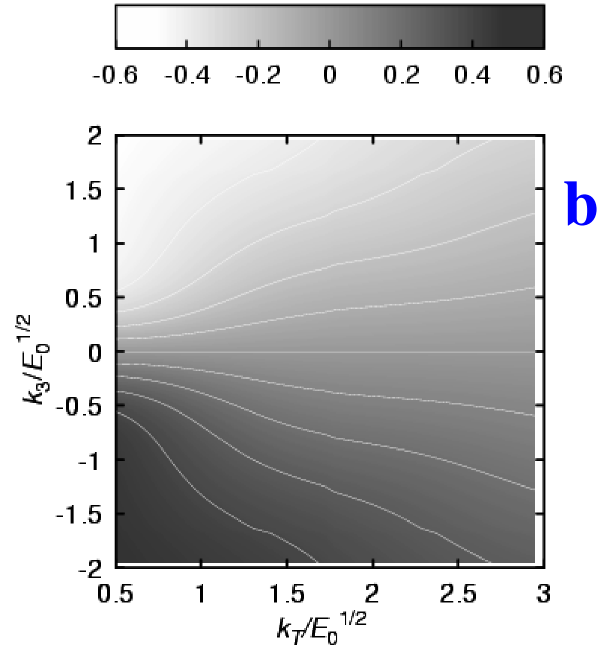
m = 0



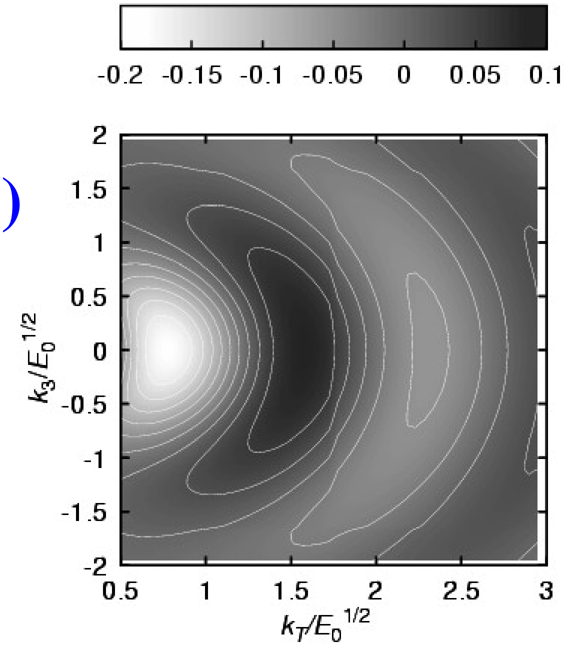
$b^s_T(k_T,k_3)$



$b^a_T(k_T,k_3)$

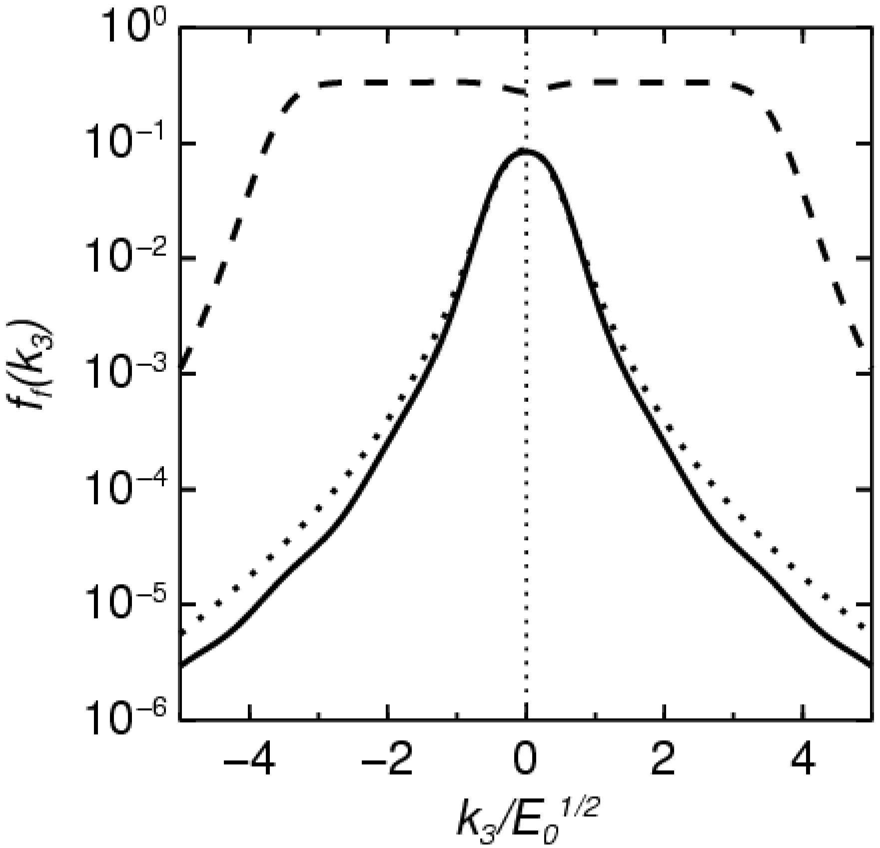


$b^s_3(k_T,k_3)$



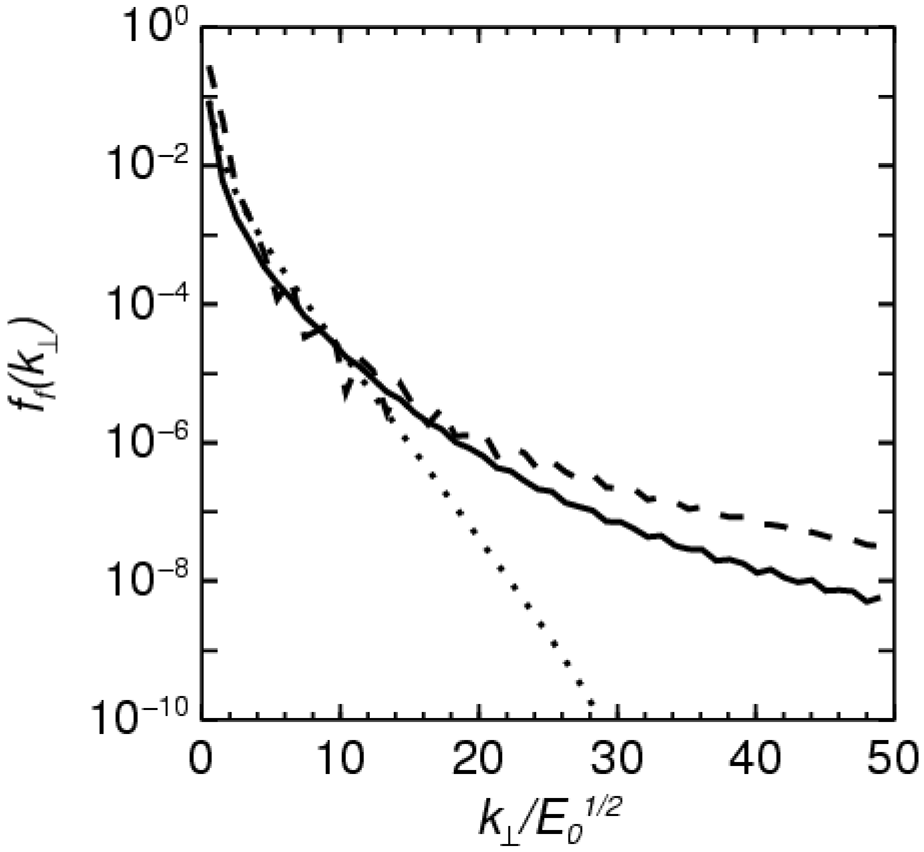
$b^a_3(k_T,k_3)$

Numerical results for fermion distributions at $t = 2/\sqrt{E_0}$ in SU(2):



$f_f(k_3)$: longitudinal mom. distr.

$k_T/\sqrt{E_0} = 0.5$



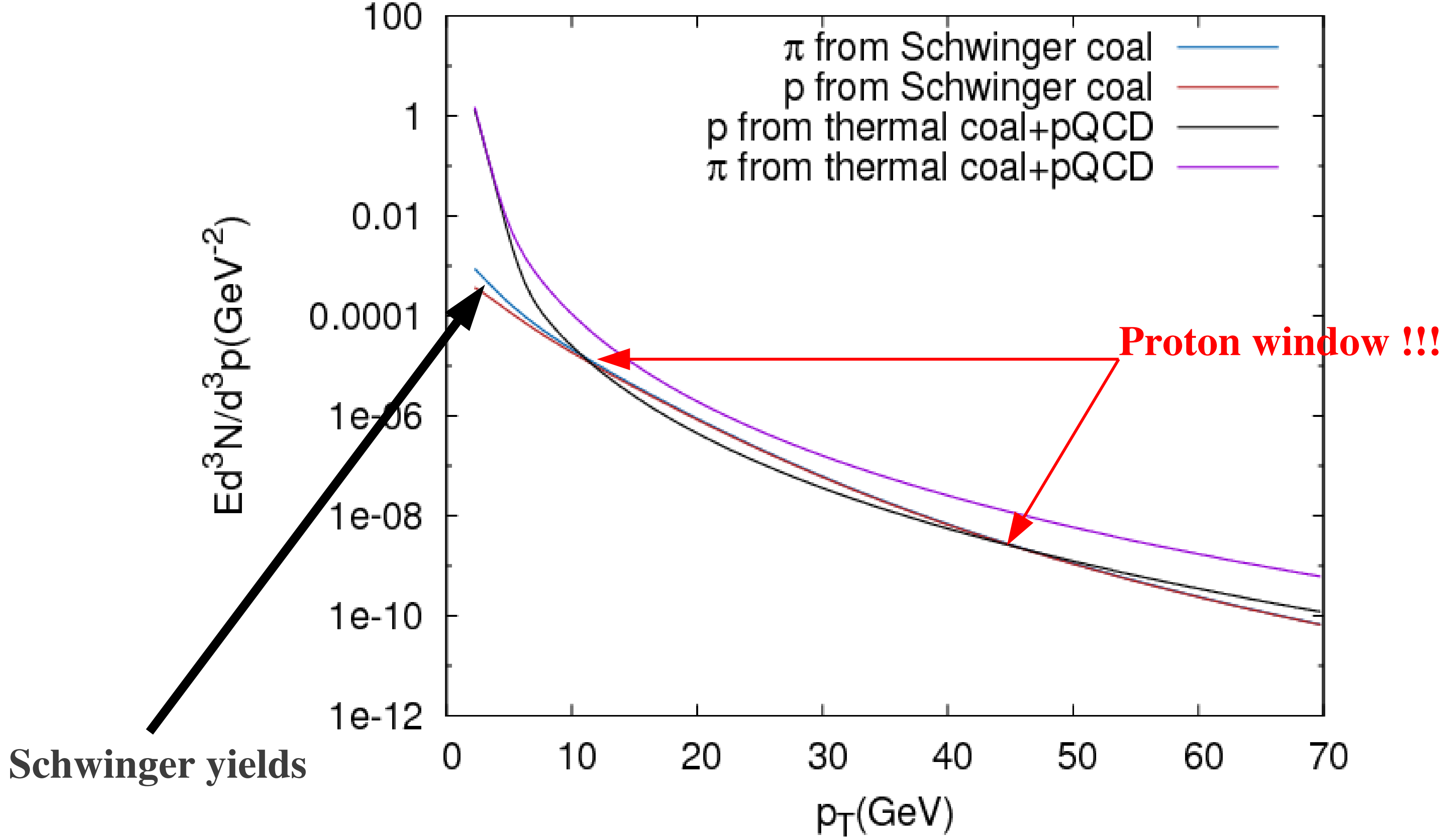
$f_f(k_T)$: transv. mom. distr.

$k_3 = 0$

⇒ exponential (pulse)

⇒ polinomial (scaled)

Tipical result: Proton and pion production from
jet fragmentation (FF)
coalescence of thermal quarks
coalescence of Schwinger quarks/diquarks

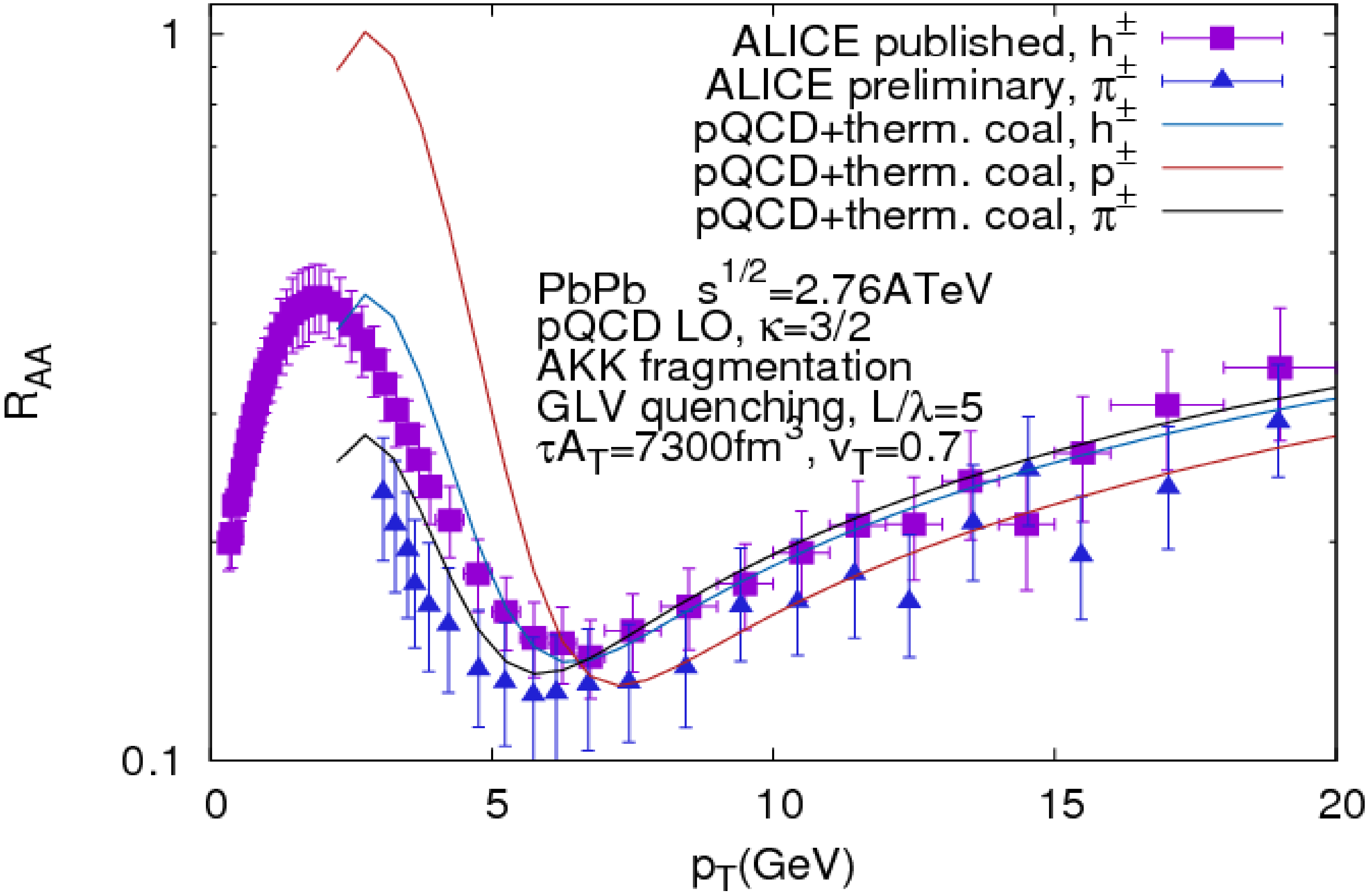


Proton window !!!

Schwinger yields

Latest calculations on charged hadron R_{AA} in Pb+Pb at 2.76 ATeV

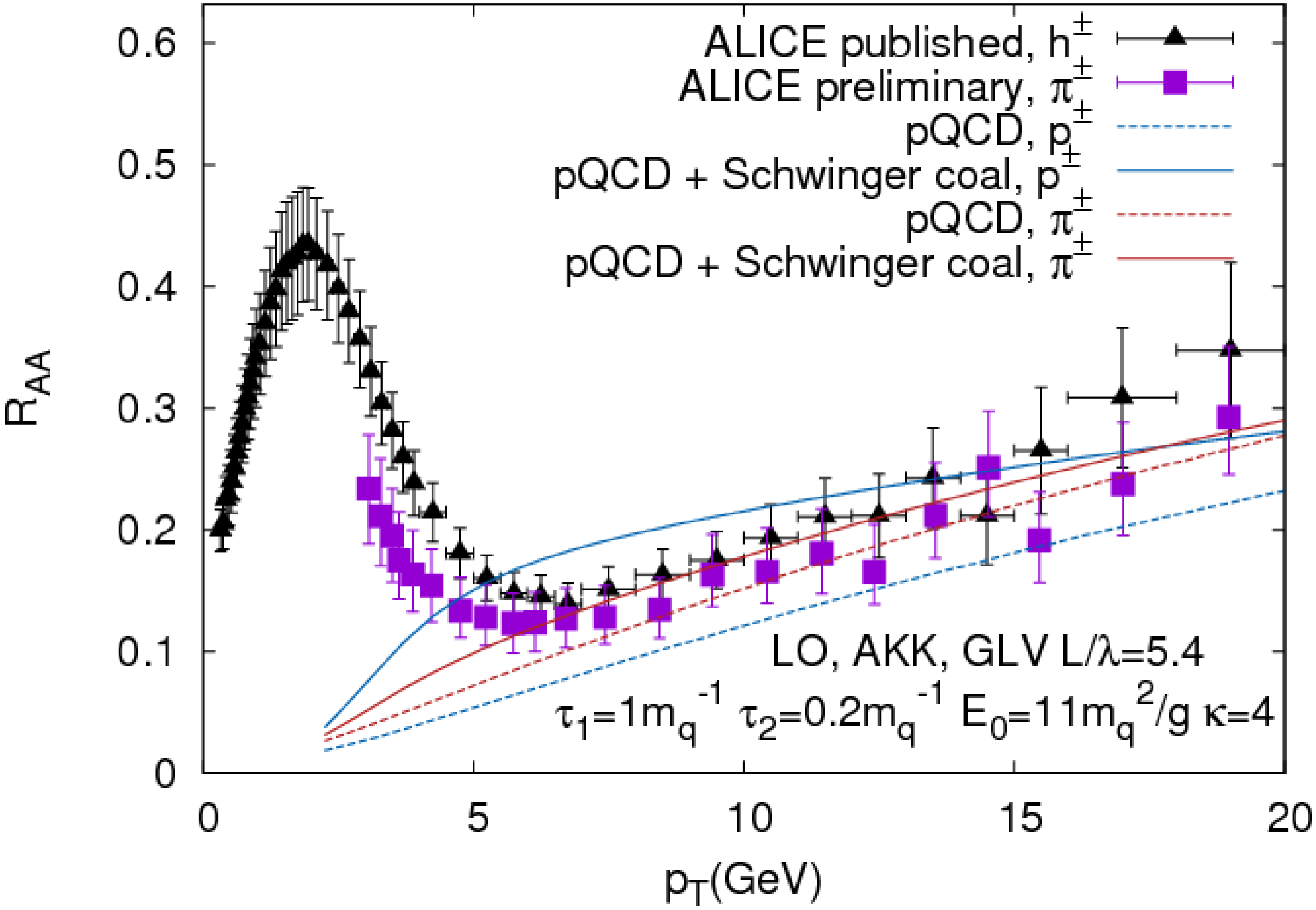
pQCD + Quenching + Thermal coalesc. P. Lévai et al. 2011



Latest calculations on charged hadron R_{AA} in Pb+Pb at 2.76 ATeV

pQCD + Quenching + Schwinger diquark coalesc.

P. Lévai et al. 2012



Latest calculations on charged hadron R_{AA} in Pb+Pb at 2.76 ATeV

pQCD + Quenching + (Thermal + Schwinger diquark) coalesc.

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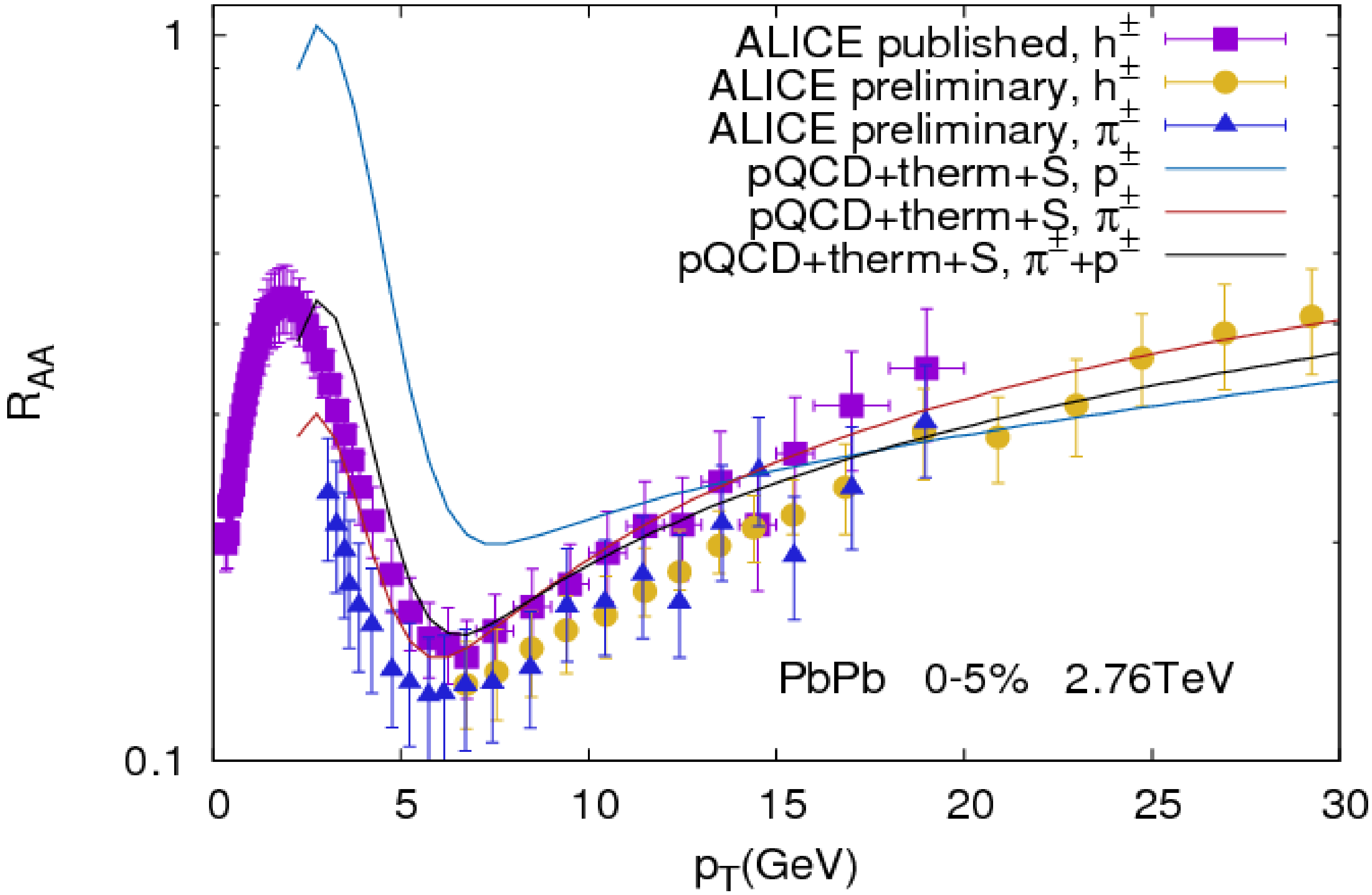
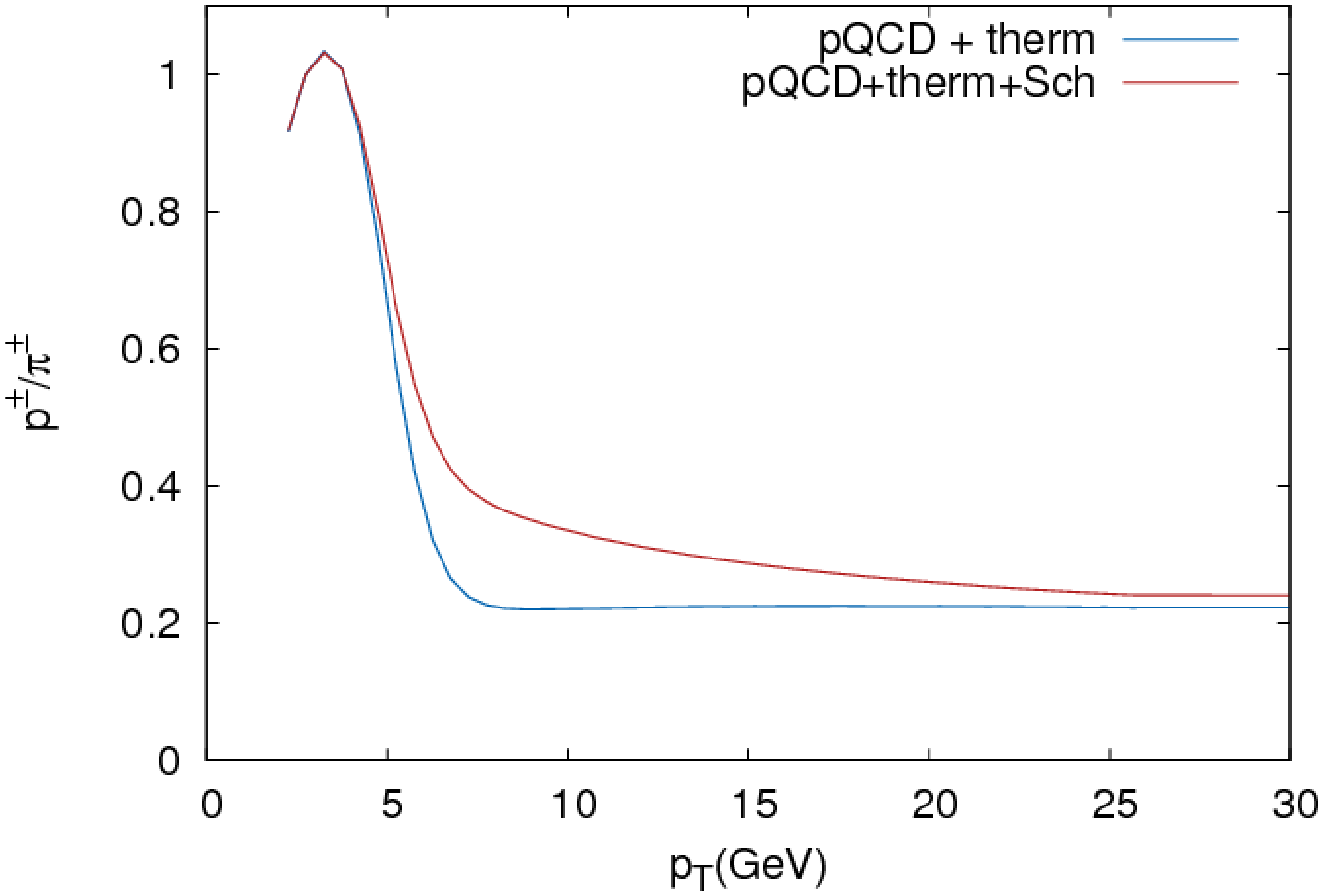


R_{AA}(p) > R_{AA}(pion) for $2 < p_T < 15$ GeV/c

Latest calculations on proton/pion ratio in Pb+Pb at 2.76 ATeV

pQCD + Quenching + (Thermal + Schwinger diquark) coalesc.

P. Lévai et al. 2012
ArXiv: 1208.0448



Extra proton yield at intermediate- and high-pT
In the window: 5 < pT < 20 GeV/c

Conclusions:

1. Jet energy loss is large at RHIC energies
and even larger at LHC energies.
Since R_pPb approx 1, then jet energy loss is needed.
In the window 5 < pT < 100 GeV seems to be all right.

2. Gluon energy loss is much larger, gluons will be quenched
at LHC energies in the window 5 < pT < 20 GeV.

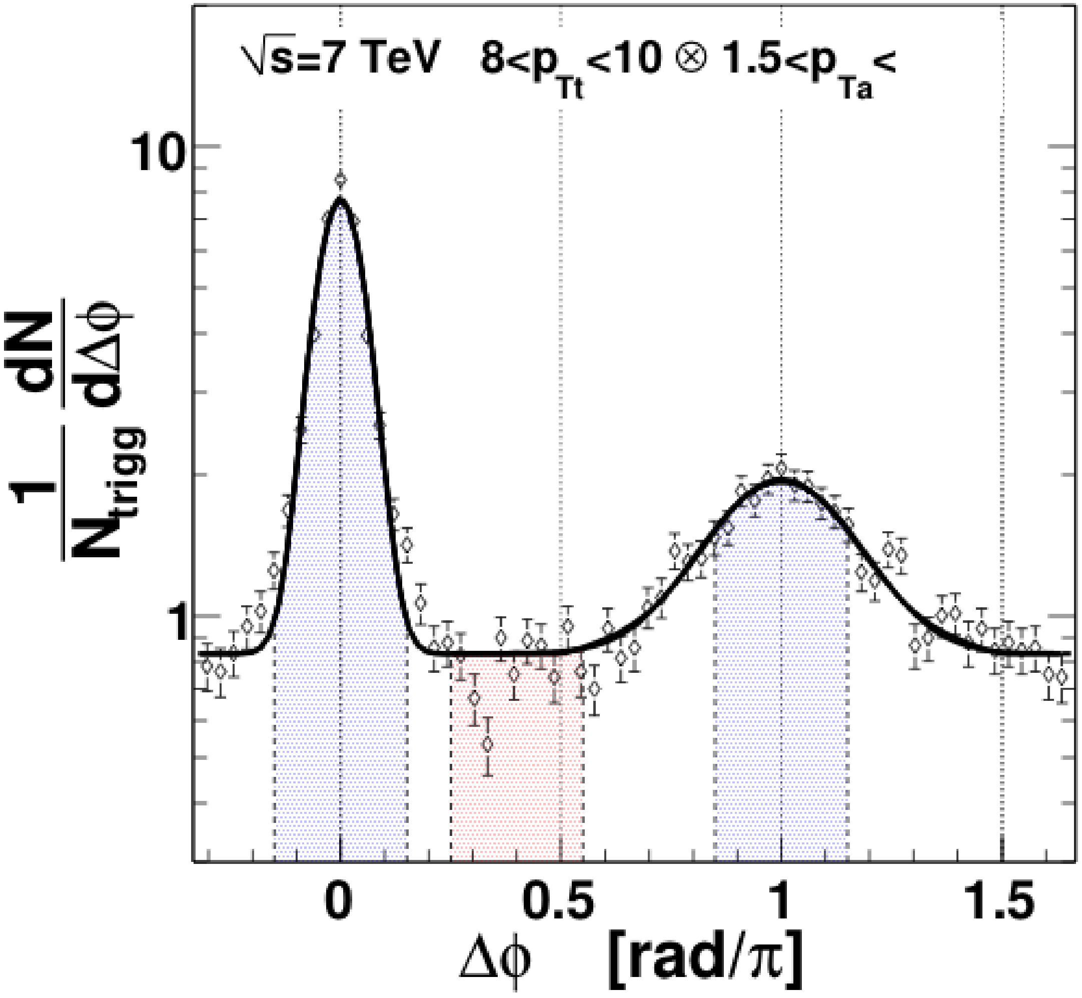
3. Showers can create a thermal bath (QGP)
or melting into a coherent gluon field
Which may appear in the early phase of the AA collision

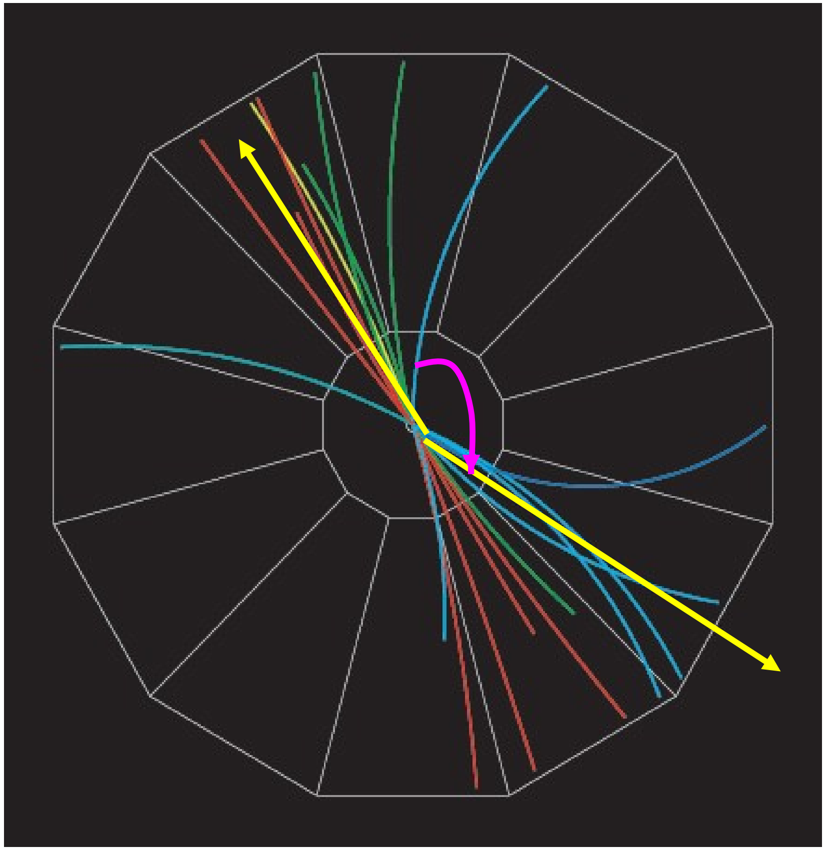
4. Baryon yields and baryon/meson ratios can decide
if coherent field appears or not.
(Extra diquark-antidiquark production and coalescence.)

Back-up slides on 2-particle correlations:

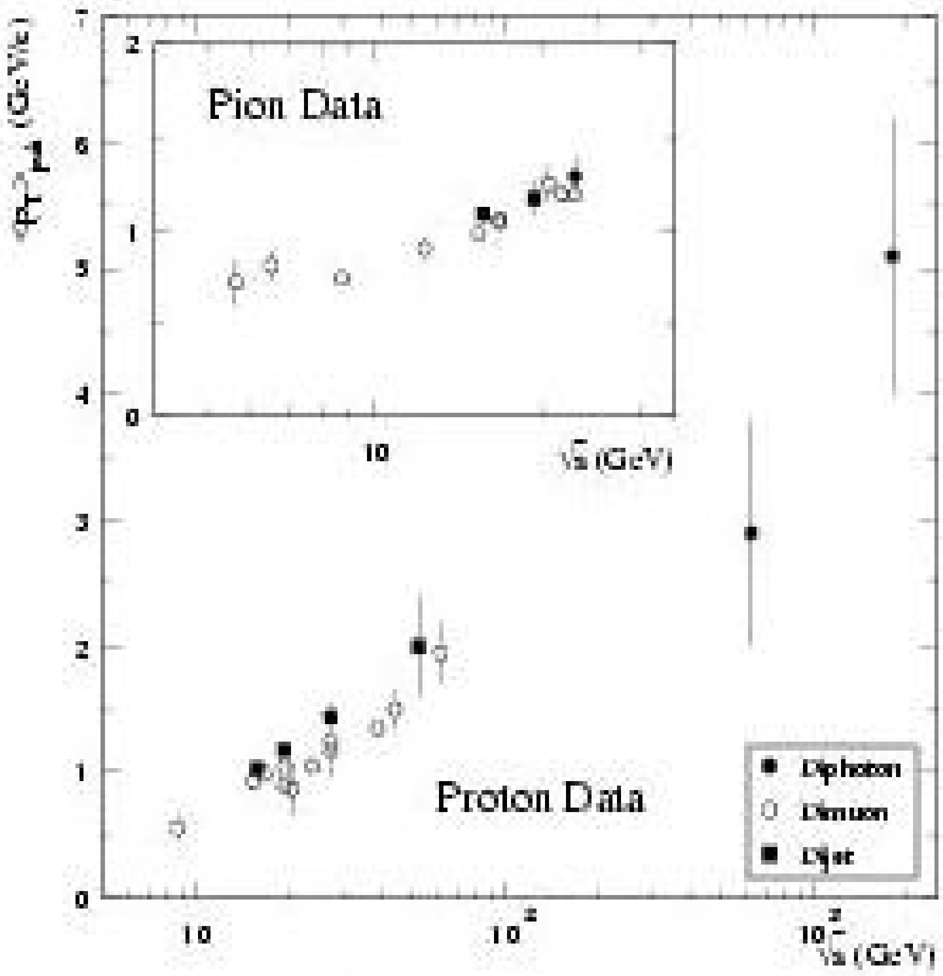
where is the kT-imbalance in the 1-particle spectra?????

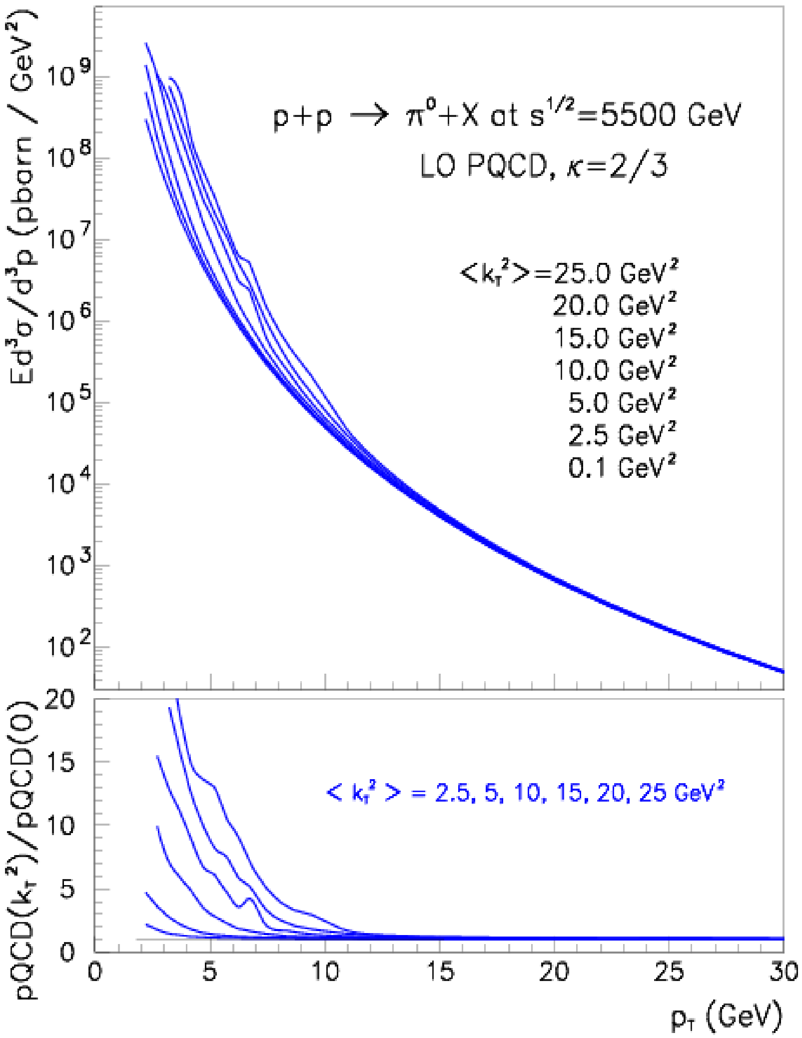
Why LO pQCD is working so nicely without intrinsic-kT ???


$\sqrt{s}$=7 TeV 8<p_{Tt}<10 ⊗ 1.5<p_{Ta}<
$\frac{1}{N_{trigg}}\frac{dN}{d\Delta\phi}$
10
1
0
0.5
1
1.5
$\Delta\phi$ [rad/π]



k_T-imbalance parameter --- extracted from 2-hadron correlation and applied in 1-particle distribution





But no room for intrinsic-k_T in CDF and CMS data !! ???