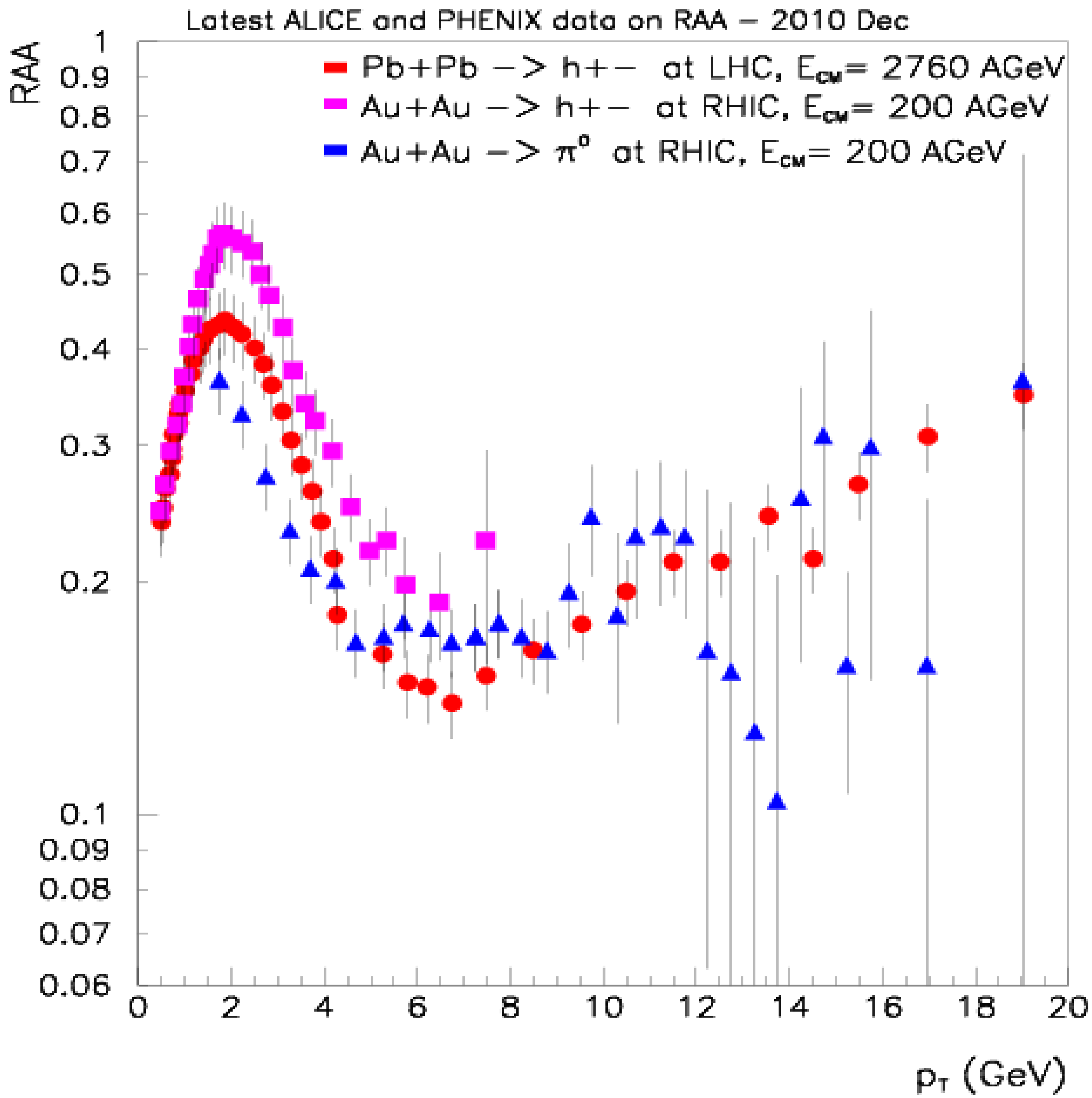
Jet energy loss studies in PbPb collisions at LHC energies

Péter Lévai (KFKI RMKI, Budapest, Hungary)
and
Attila Pásztor (ELTE, Budapest, Hungary)

6th Int. Workshop on High-pT Physics at LHC
4 April 2011, Utrecht

ALICE: New result on RAA in Pb+Pb at 2.76 ATeV (not the final one)

Phys. Lett. B696 (2011) 30. (new pp in 03/11)



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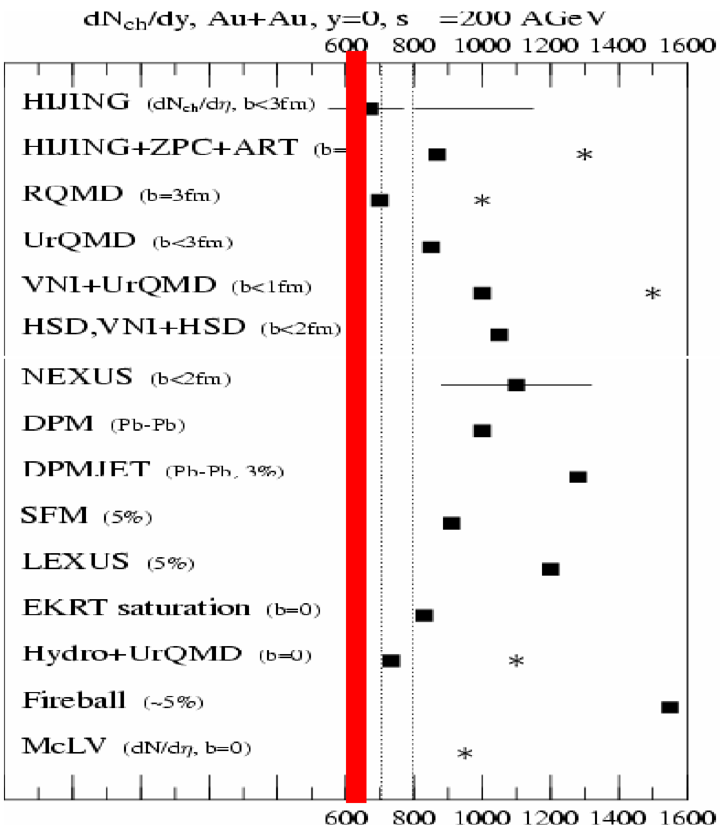
1. Introduction

--- particle production

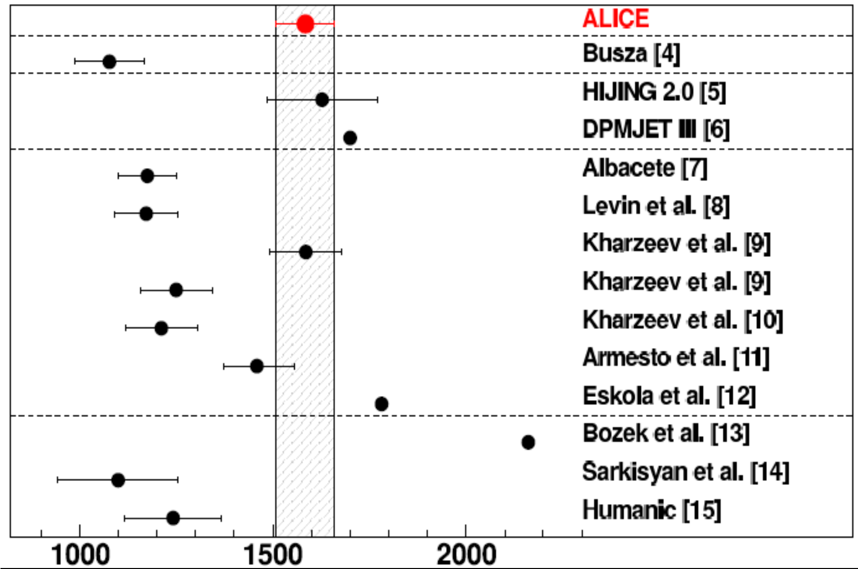
--- pQCD description for high-pT

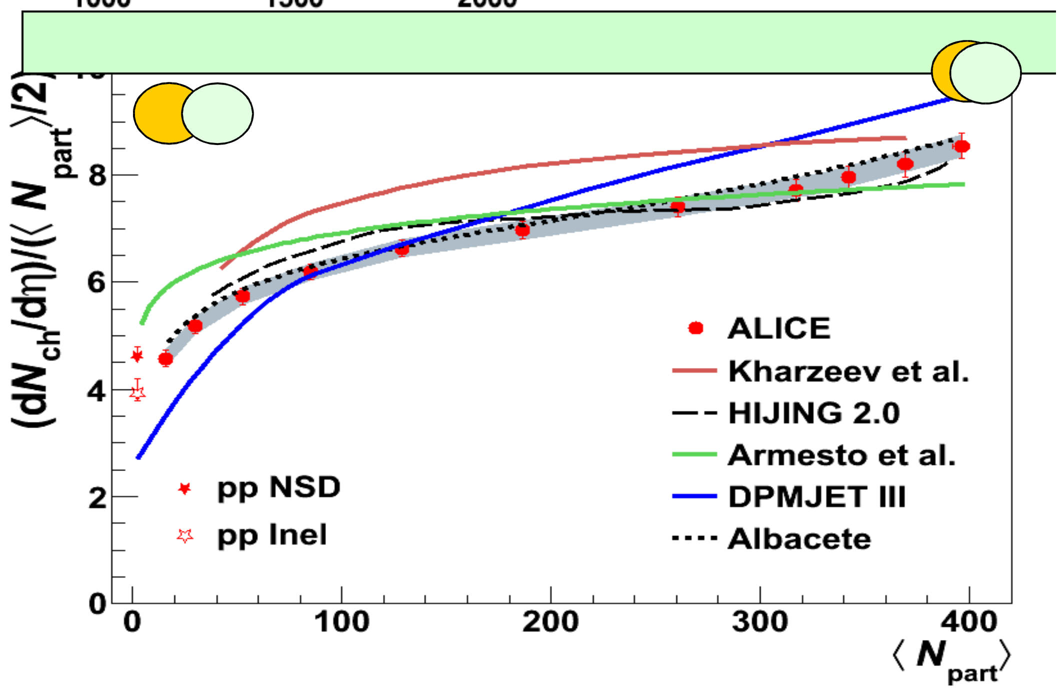
Experimental data on particle multiplicities at RHIC and LHC (2.2x)

RHIC



LHC (arXiv:1011.3916, PRL)





HIJING 2.0: two components

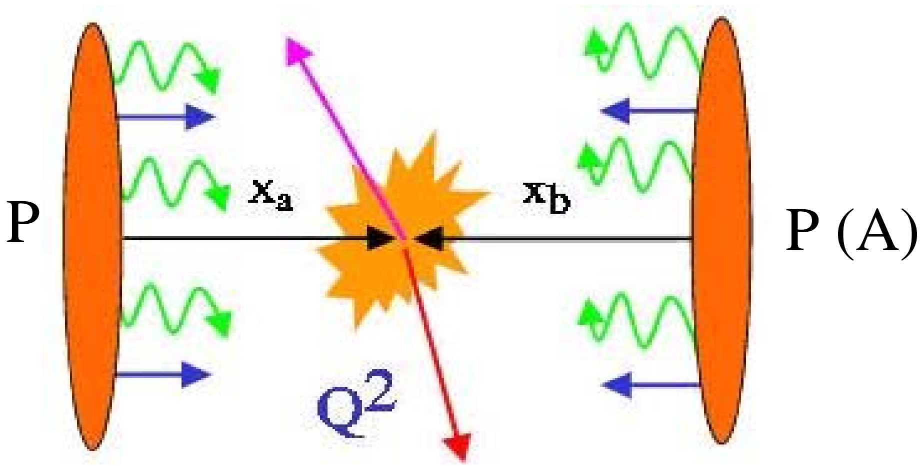
Soft: string physics for $p<p_0$

Hard: pQCD with GRV PDF

and b-dep. shadowing

(arXiv:1011.5907 [nucl-th])

Jets (high p_T probes) in pp and AA collisions:



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

Jet production in AA collision (" in hot matter")

➣ modified PQCD description:
- **--- SHADOWING inside A**
- **--- MULTISCATTERING/BROADENING penetrating A**
- **--- ENERGY LOSS penetrating the "hot matter"**

Can we separate these mechanisms?

Can we determine them separately during theoretical data analysis ?

We could learn a lot from high precision RHIC data !

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

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

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

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

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

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

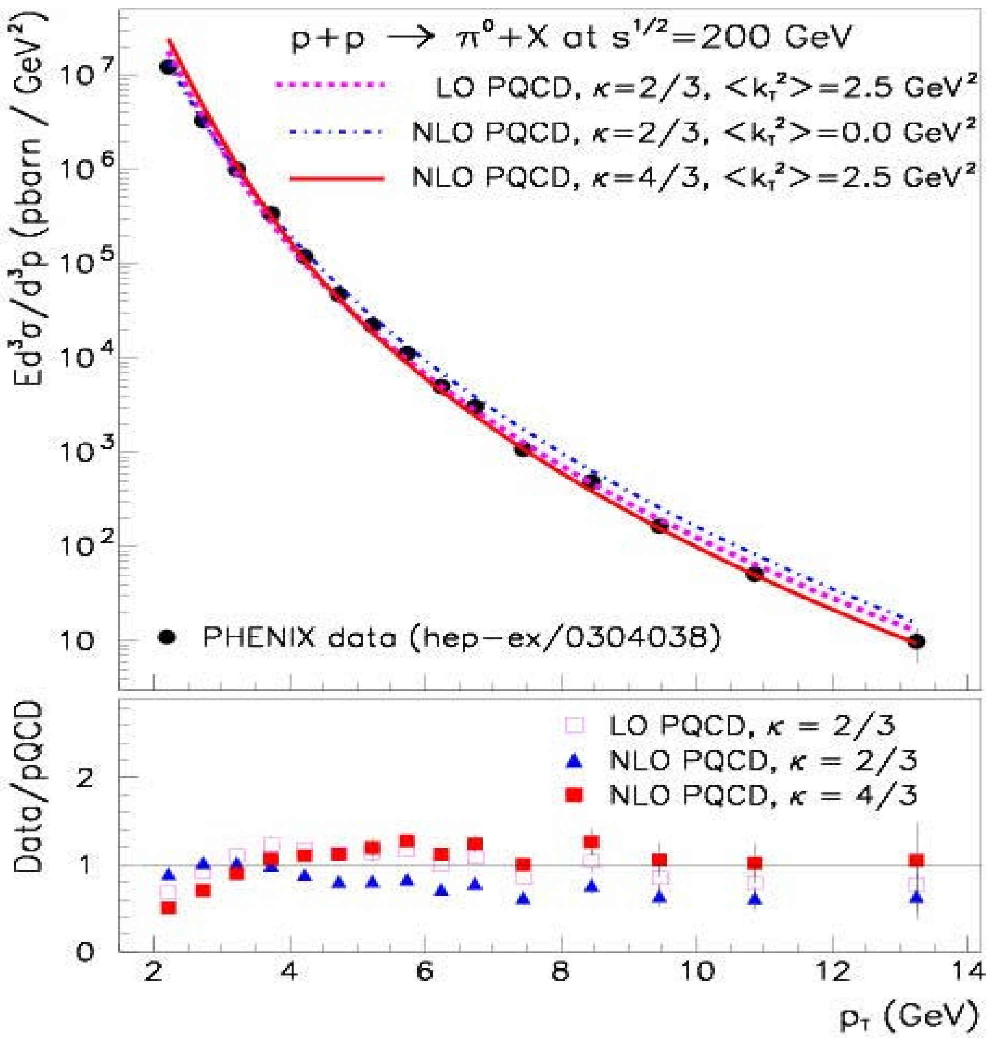
Where we use gaussian

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

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.

Hard physics: pion production in AA 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

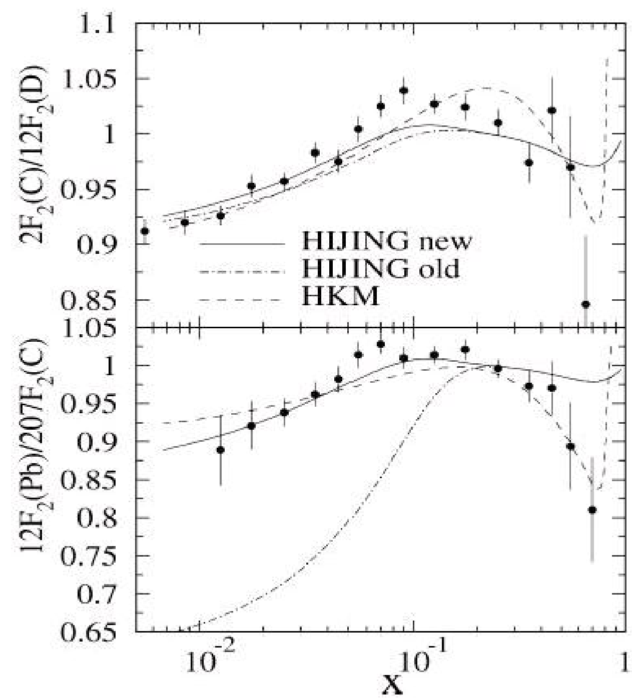


Fig. 2. Ratio of nuclear structure functions as measured in DIS. Solid lines are the new HIJING parameterization (Eq. (8)), dashed lines are the HKM parameterization [32] and dot-dashed lines are the old HIJING parameterization [16]. The data are from Ref. [30].

Hard physics: pion production in AA 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

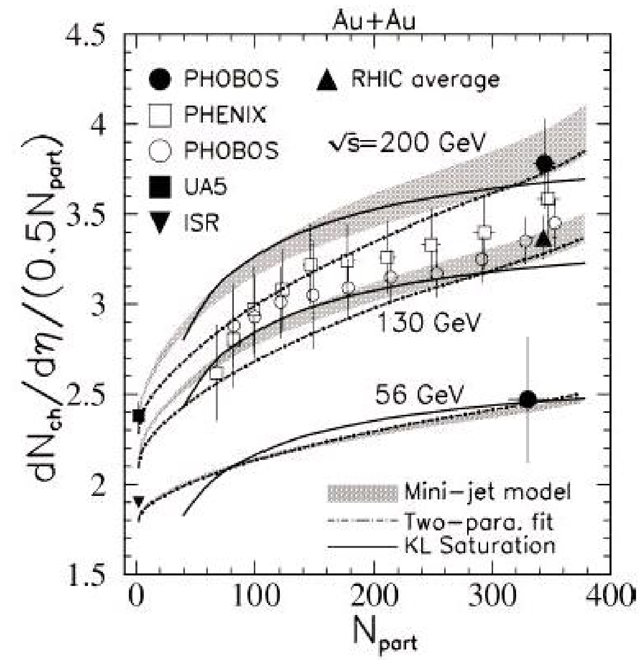
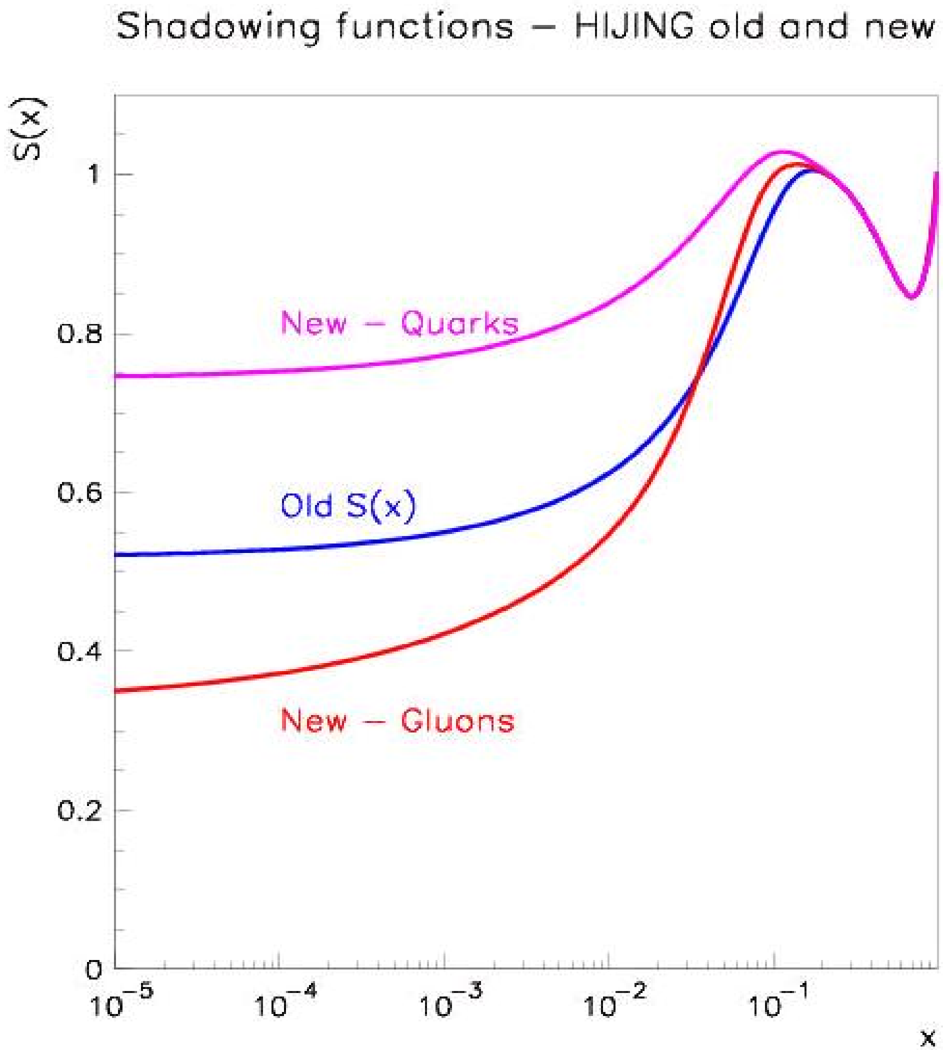


Fig. 4. The charged hadron central rapidity density per participant nucleon pair as a function of the averaged number of participants from the two-component model (shaded lines), two-parameter fit (Eq. (11)) (dot-dashed lines) and parton saturation model [9] as compared to experimental data [3,5,20,21].

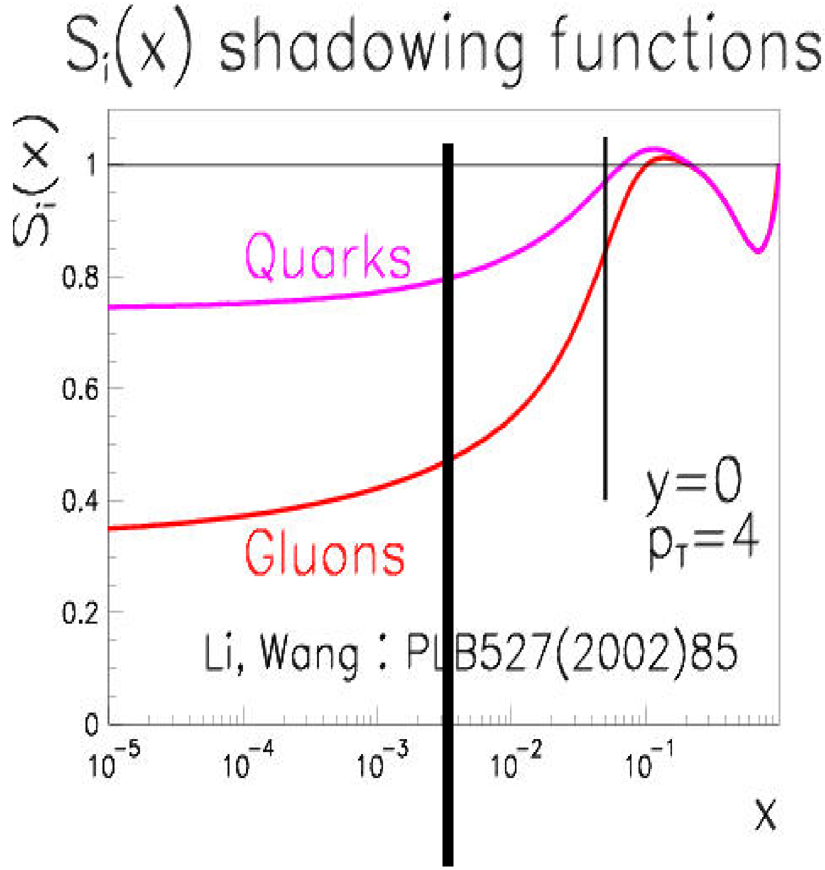
Shadowing effect:

S(x): shadowing function



X → 0 : S(x) is small

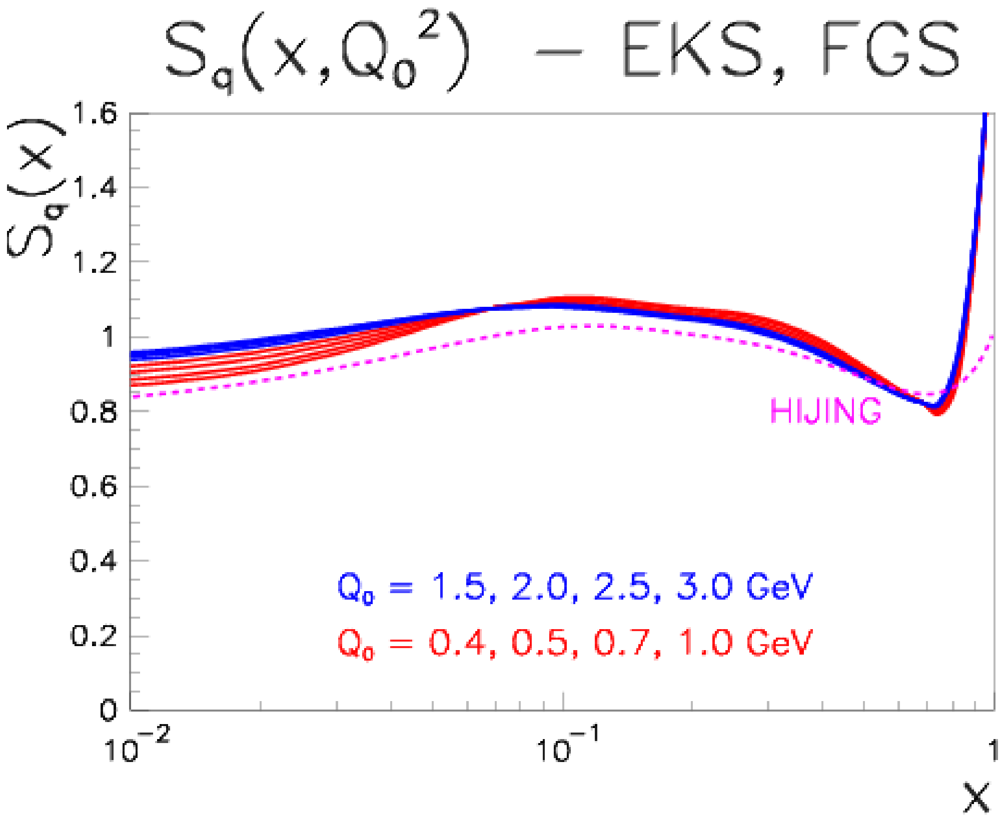
S(x) at y=0, p_T=4 GeV at RHIC



y=0, p_T=4 GeV

$s^{1/2}$=2760 GeV

EKS99 shadowing function with enhanced antishadowing



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

EPJ C9, 61 (1999)

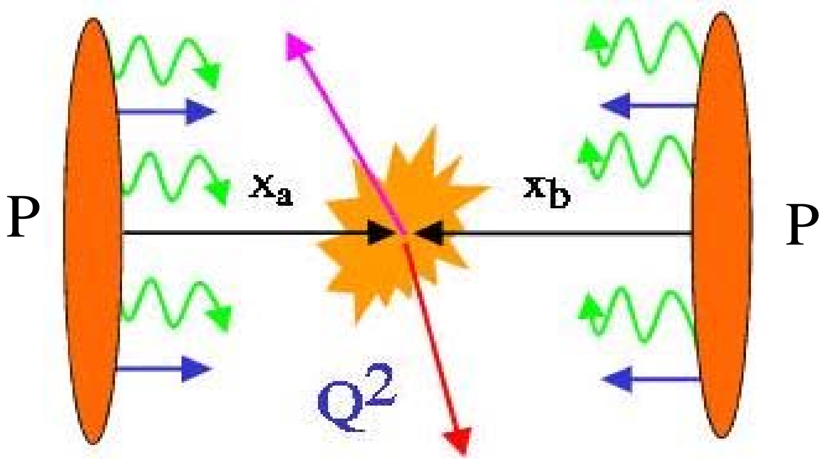
EKS: antishadowing effect for valence quarks

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

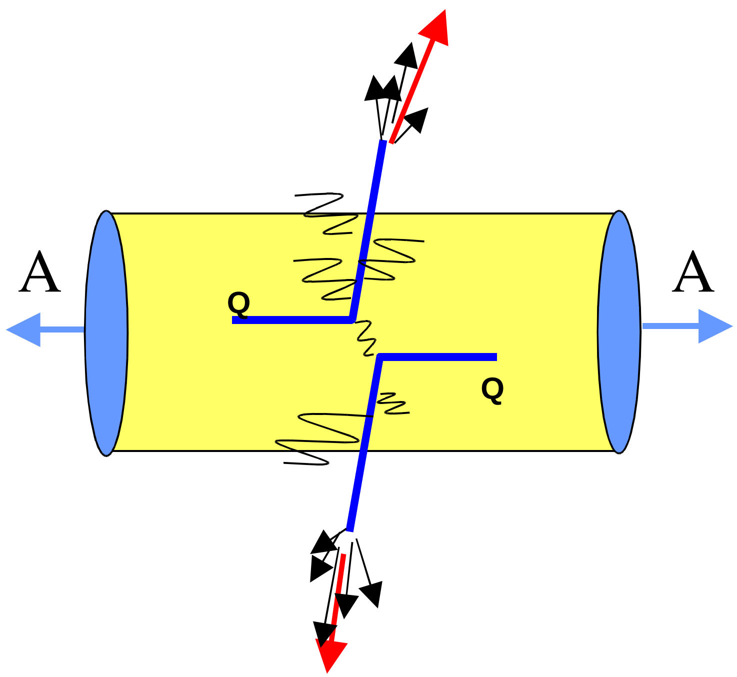
2. Jet energy loss

--- mechanism, description

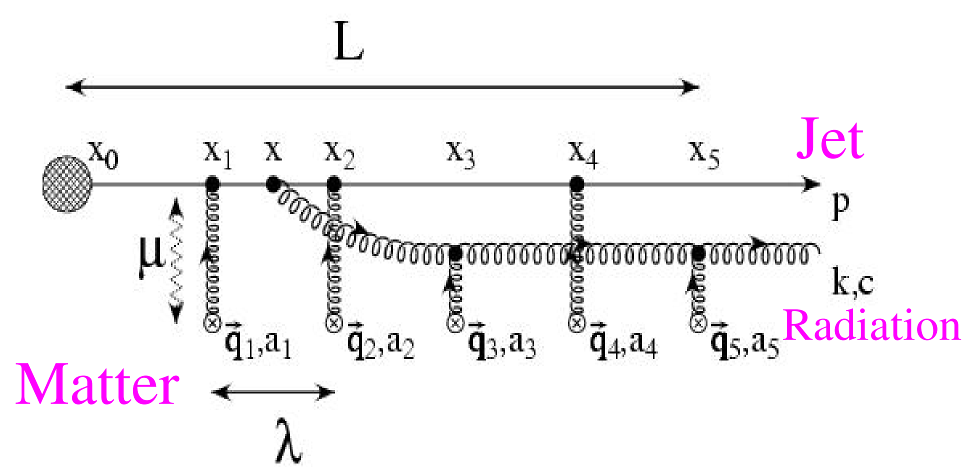
Jets in pp and in AA collisions:



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

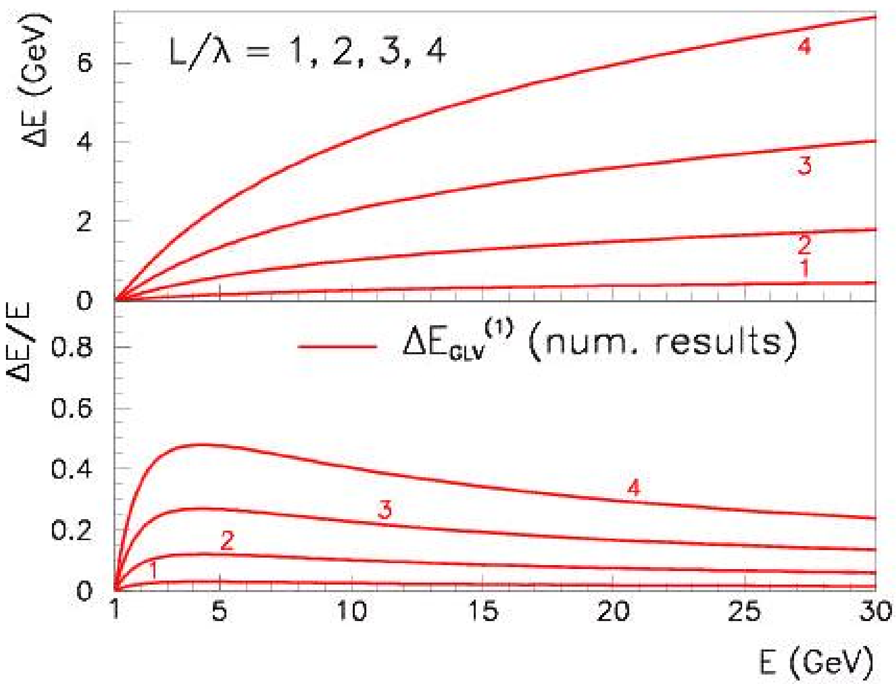


'Jet-quenching' : induced jet energy loss --- in thin colored matter

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

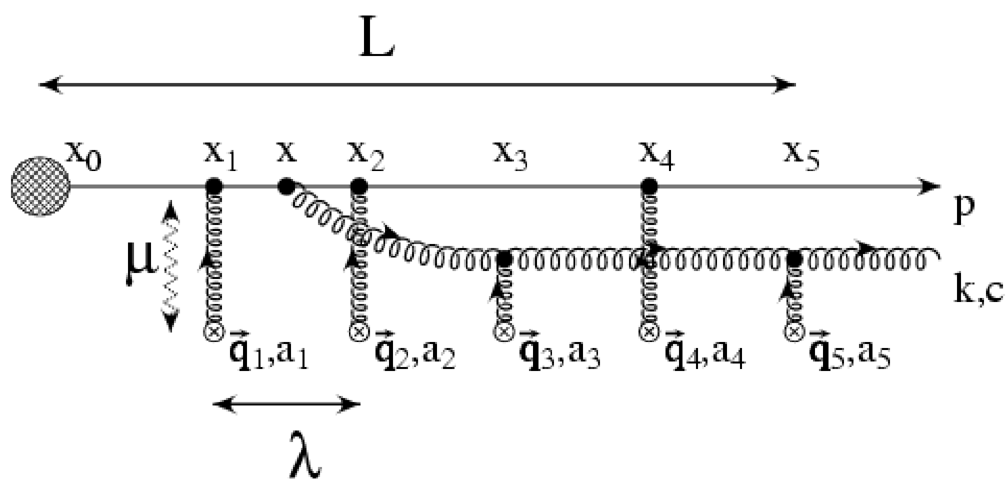
Induced jet energy loss --- agreements and disagreements:

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:

1. Averaged opacity ↣ time dependent color density:

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

2. 1-DIM Bjorken expansion:

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

3. Energy loss as the function of rapidity density:

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

3. Results at RHIC energies

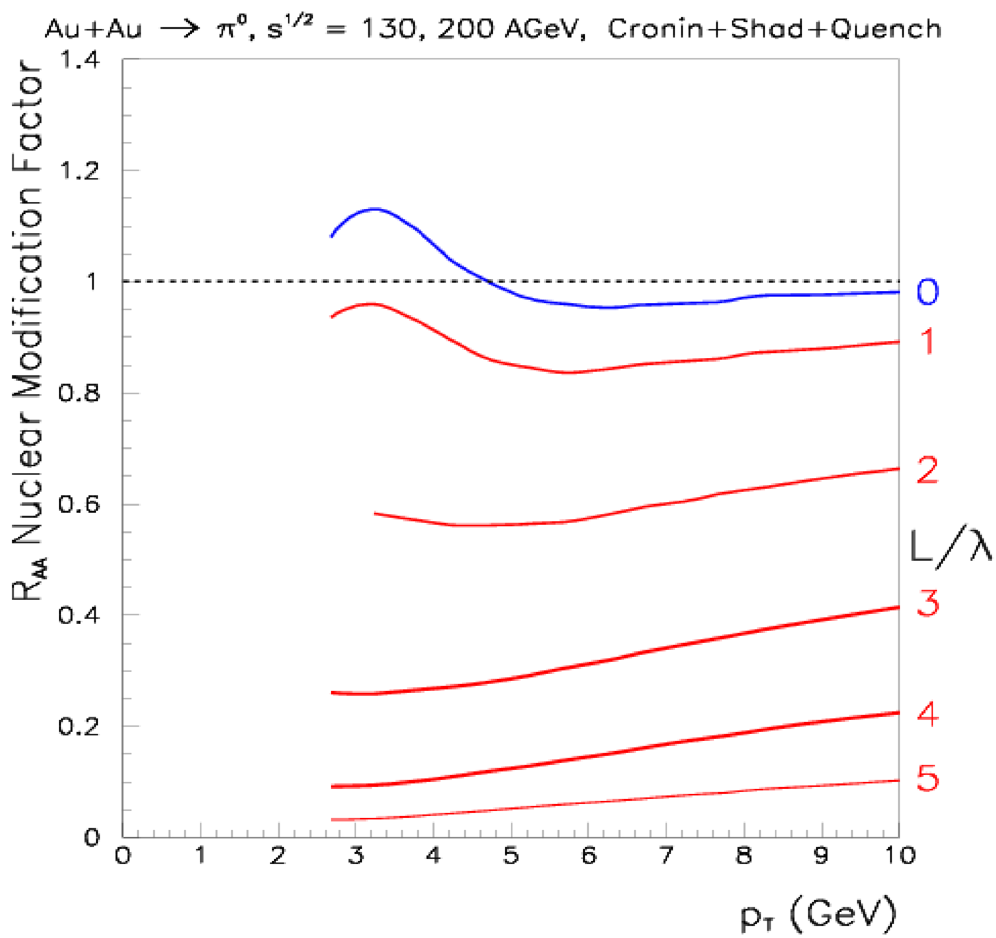
--- answers and new questions

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, ...

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



RHIC
200 A GeV
(130 A GeV)

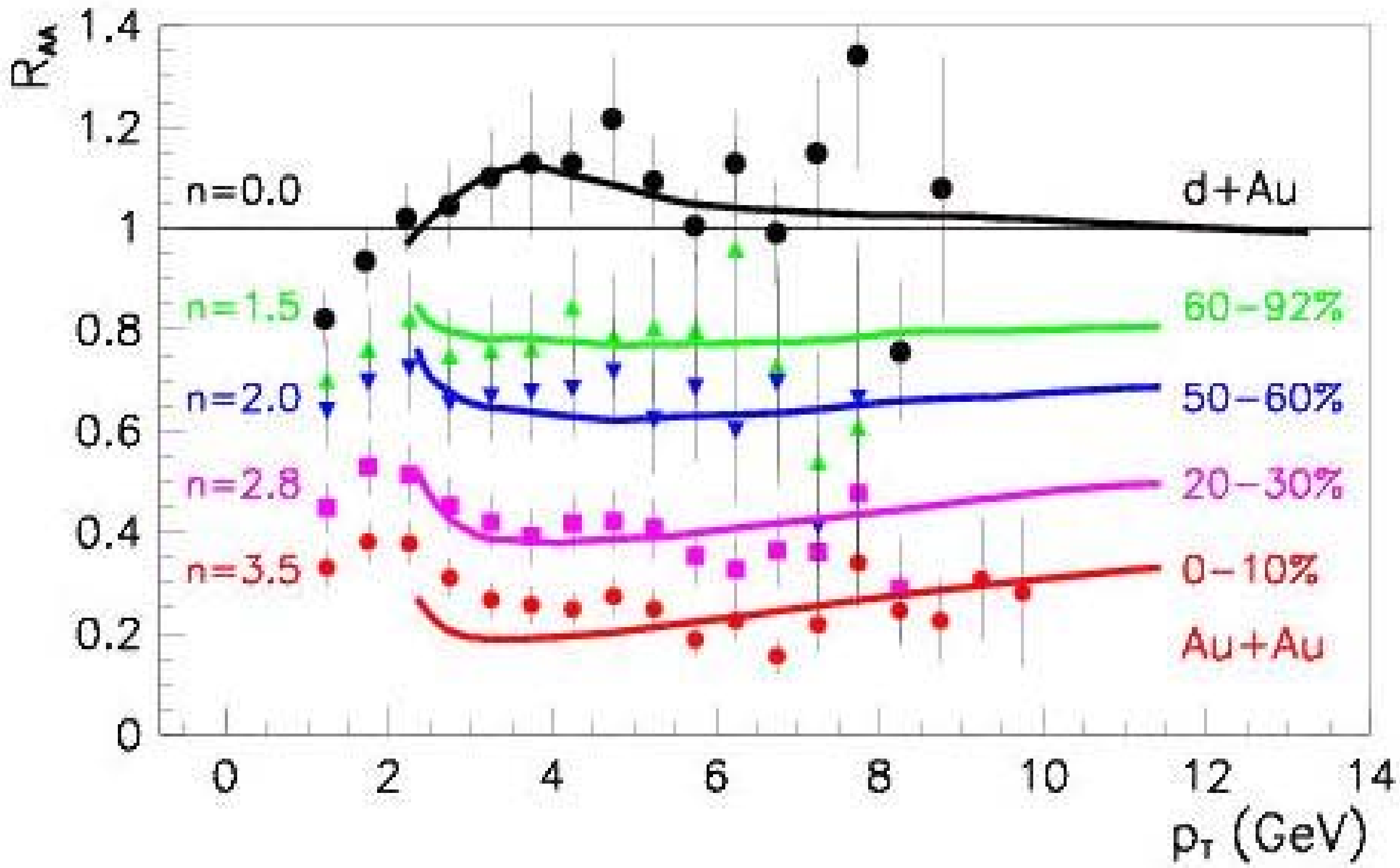
Au+Au

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, ...

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



RHIC
200 GeV/N

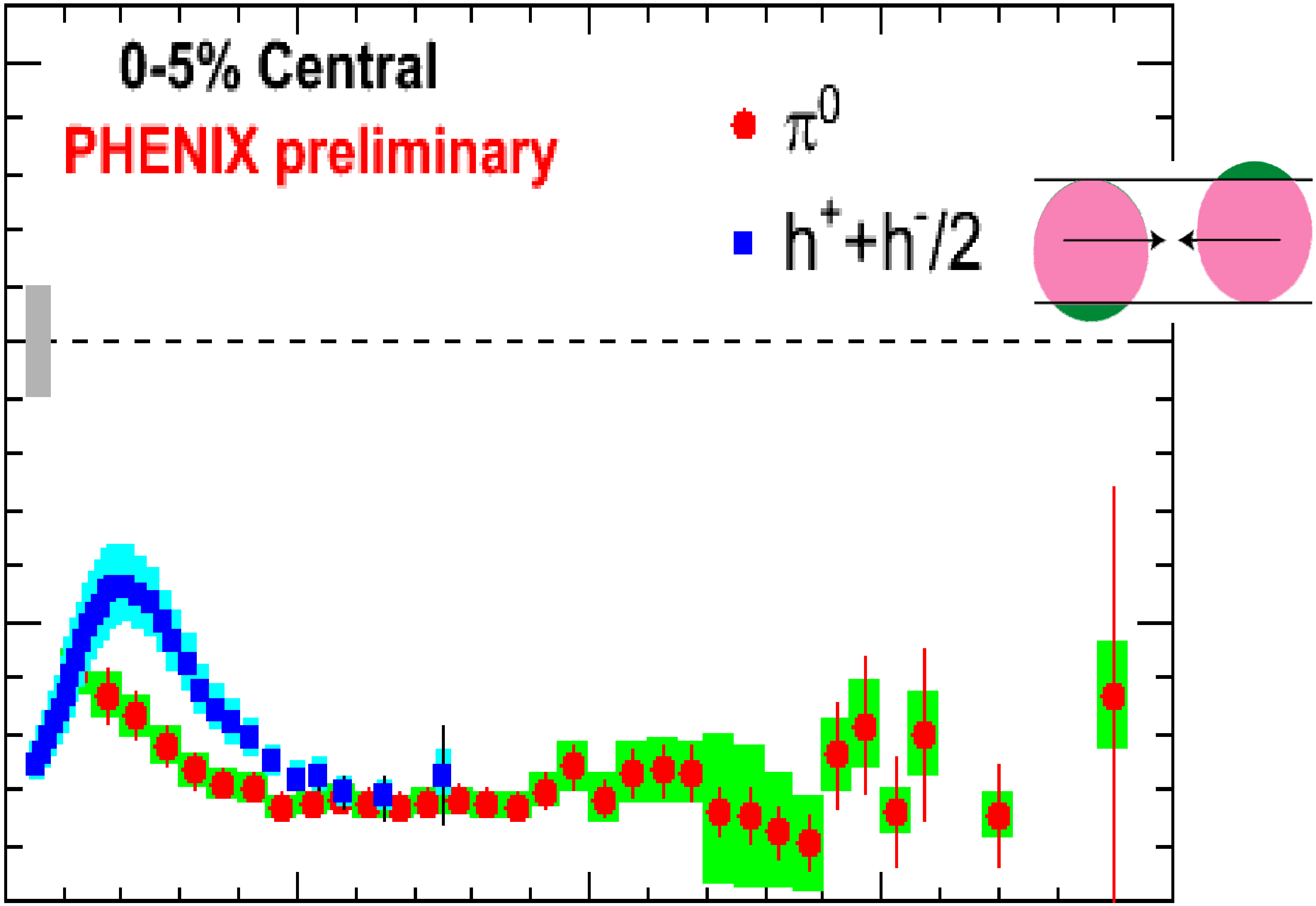
d+Au

Au+Au

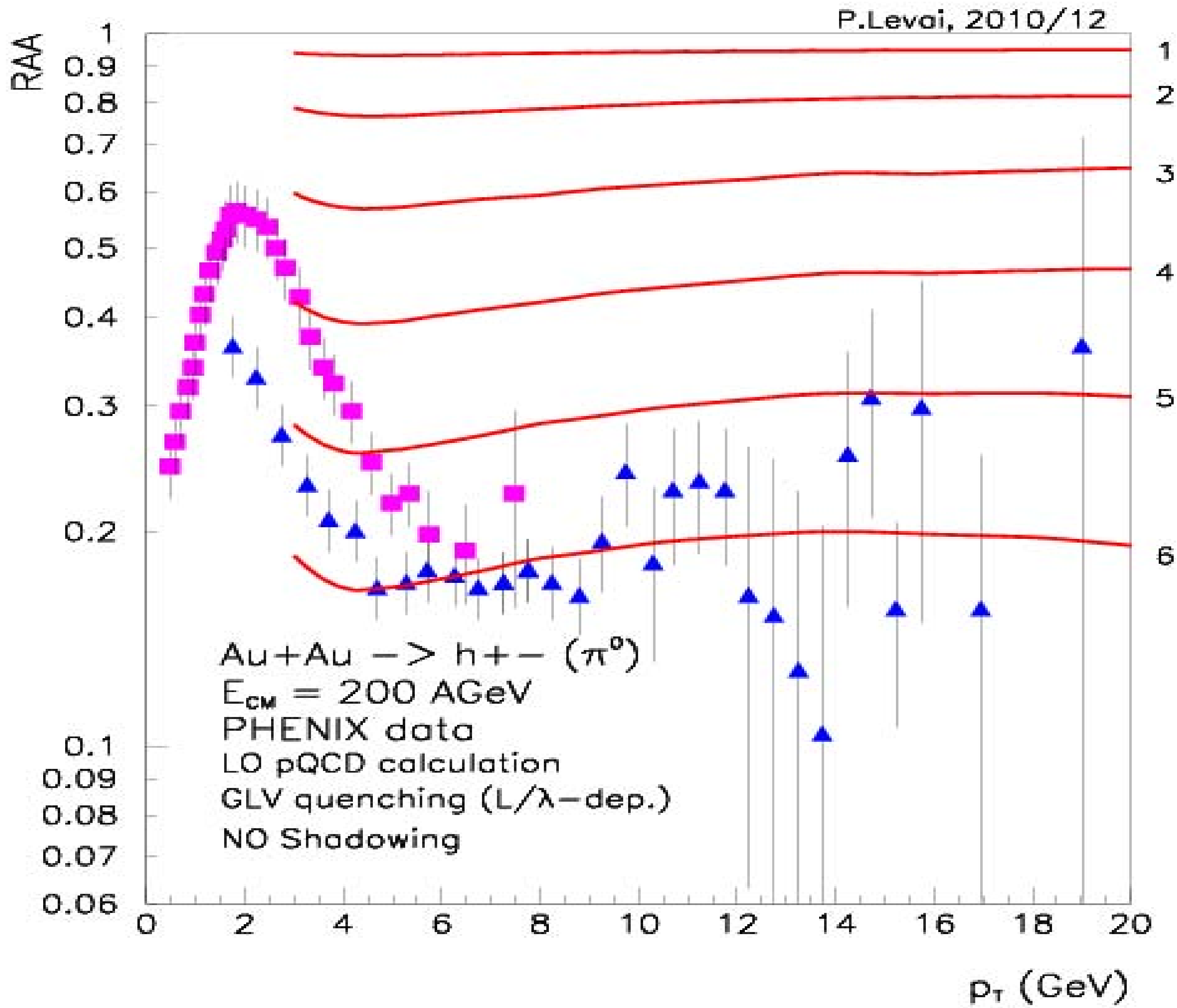
$\eta = 0$

G.G. Barnaföldi, PL, EPJ, 2006

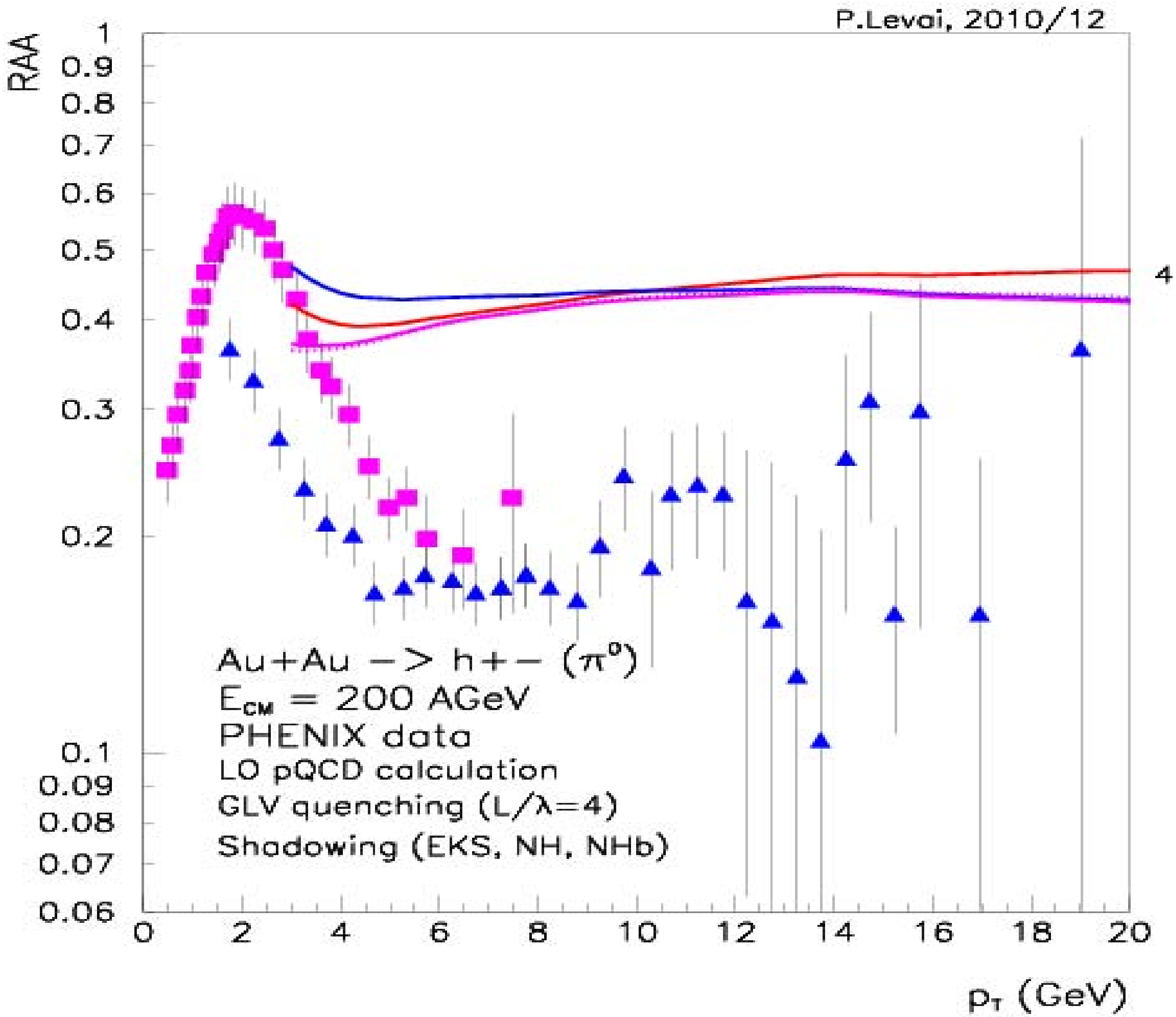
Most central Au+Au collisions (5%) at RHIC 200 AGeV



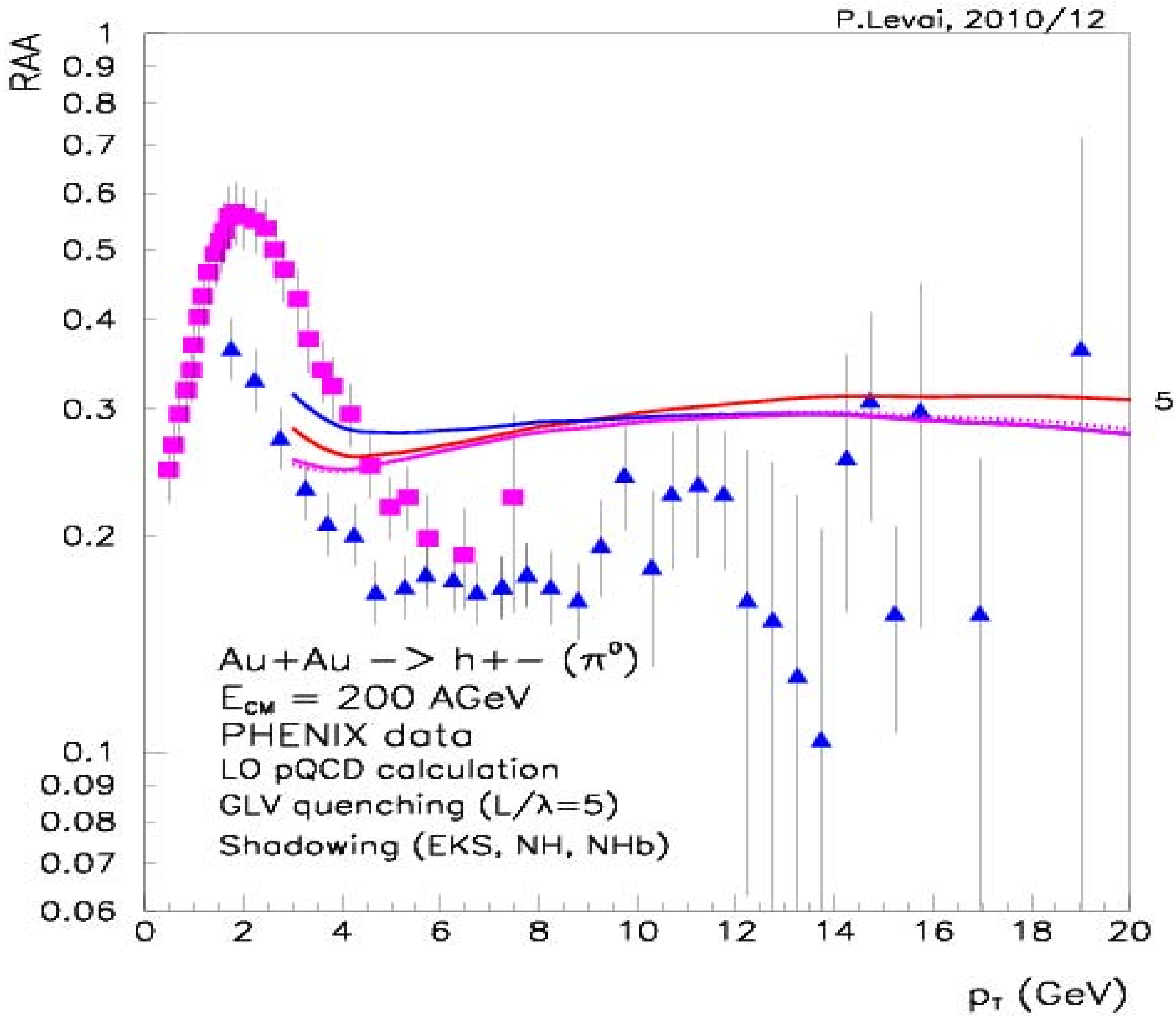
Most central Au+Au collisions (5%) at RHIC 200 AGeV
"Quenching only"



Most central Au+Au collisions (5%) at RHIC 200 AGeV
"Quenching at L/λ=4 + Shadowing"

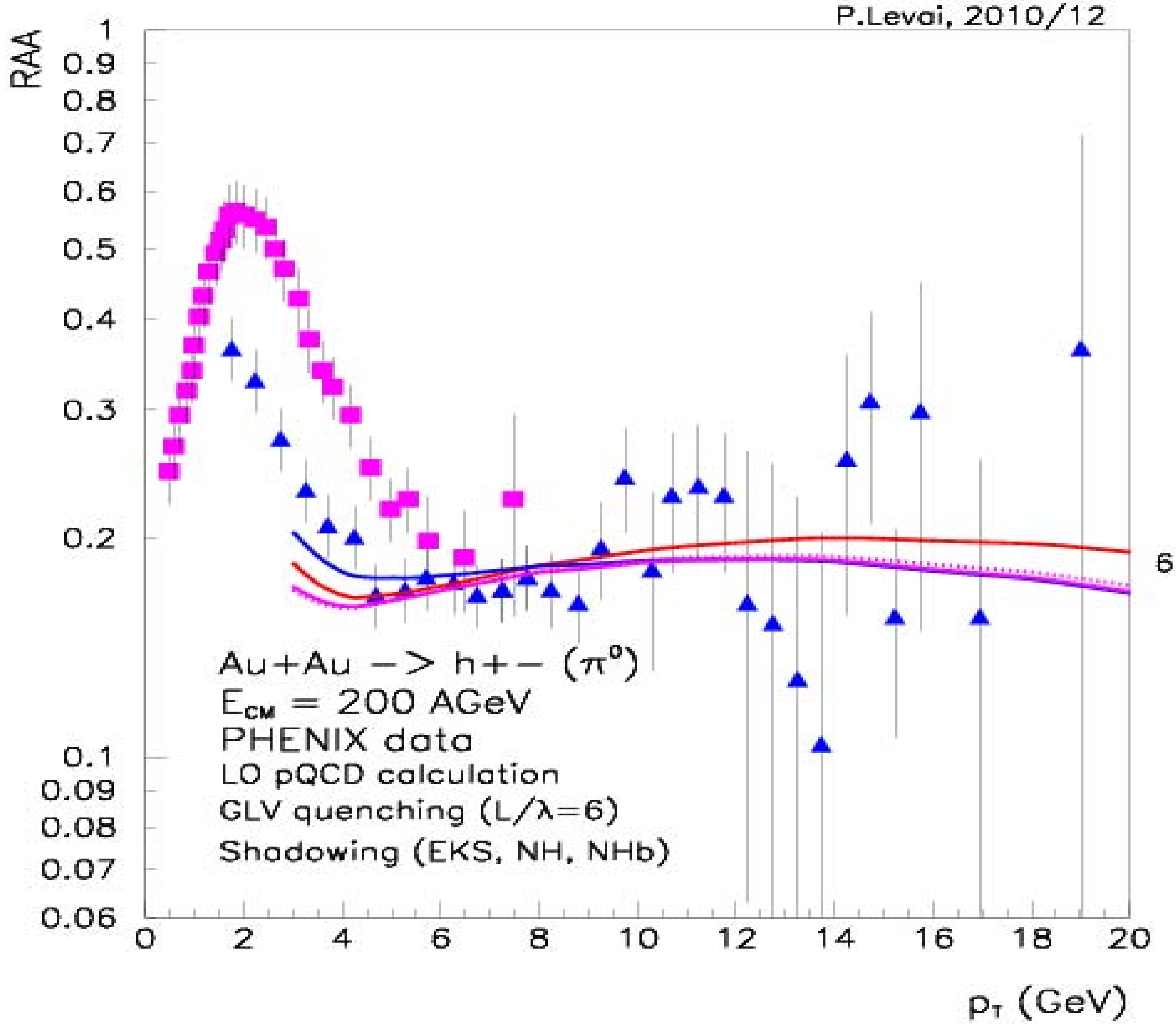


Most central Au+Au collisions (5%) at RHIC 200 AGeV
"Quenching at L/λ=5 + Shadowing"



Most central Au+Au collisions (5%) at RHIC 200 AGeV

"Quenching at L/λ=6 + Shadowing"



Shadowing: small effect at RHIC

Conclusion from light quark quenching at RHIC energy:

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

Shadowing has small influence

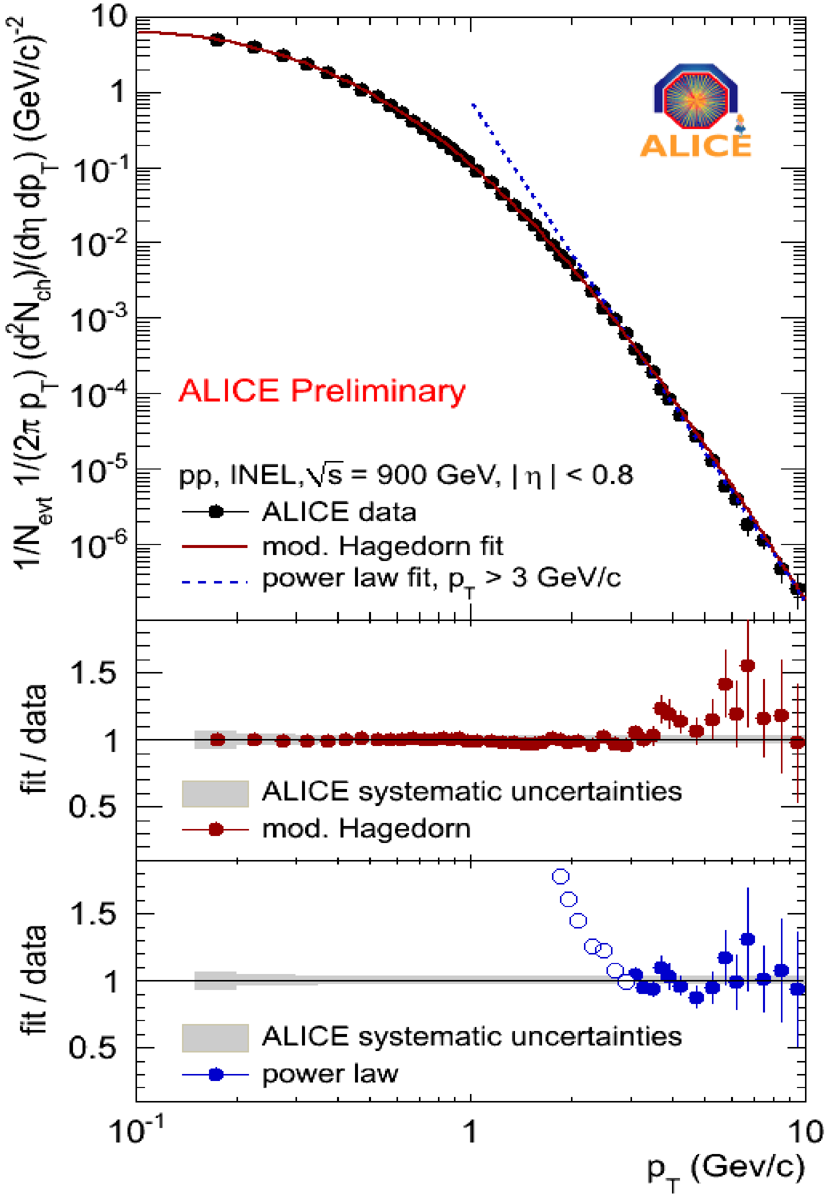
4. Results at LHC energies

--- new answers and new questions

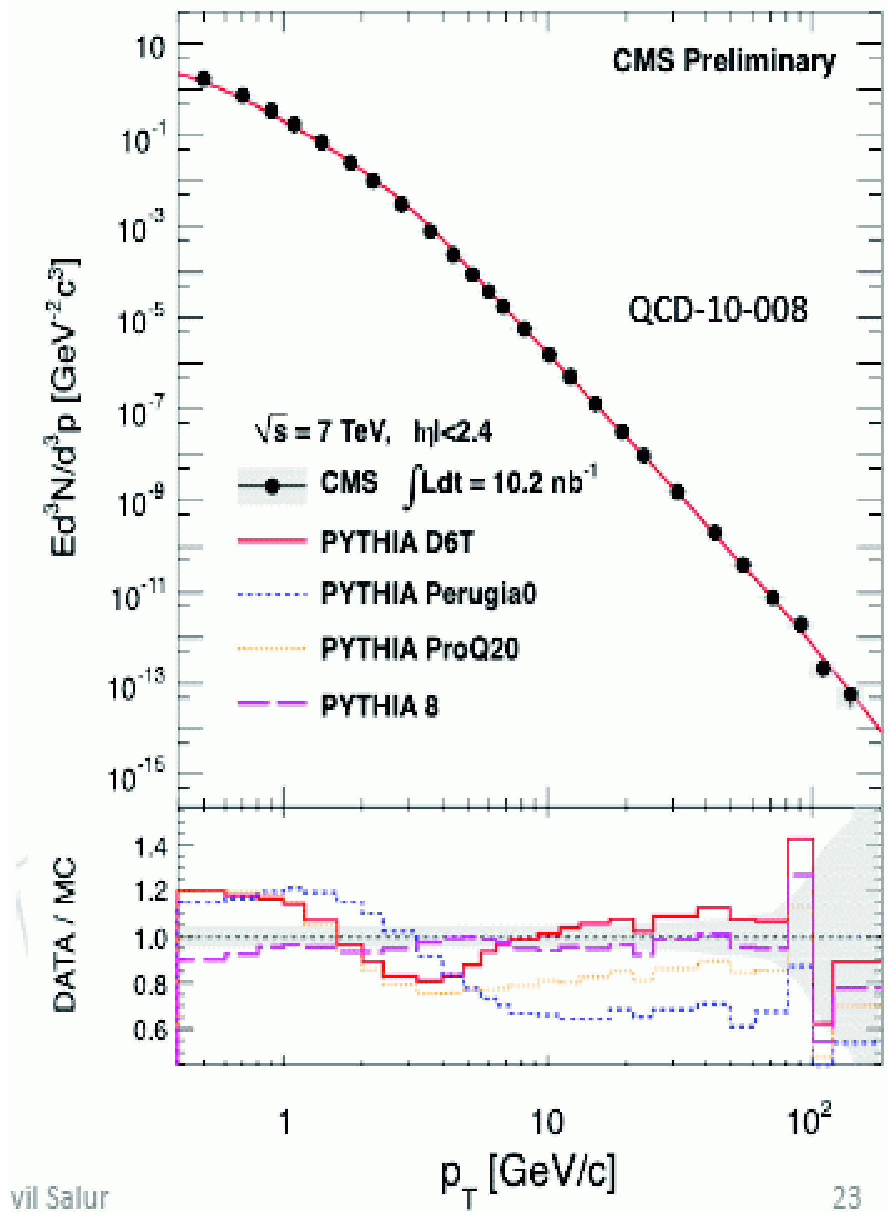
But at first: pp at 7 TeV

How good is our pQCD desription ?

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

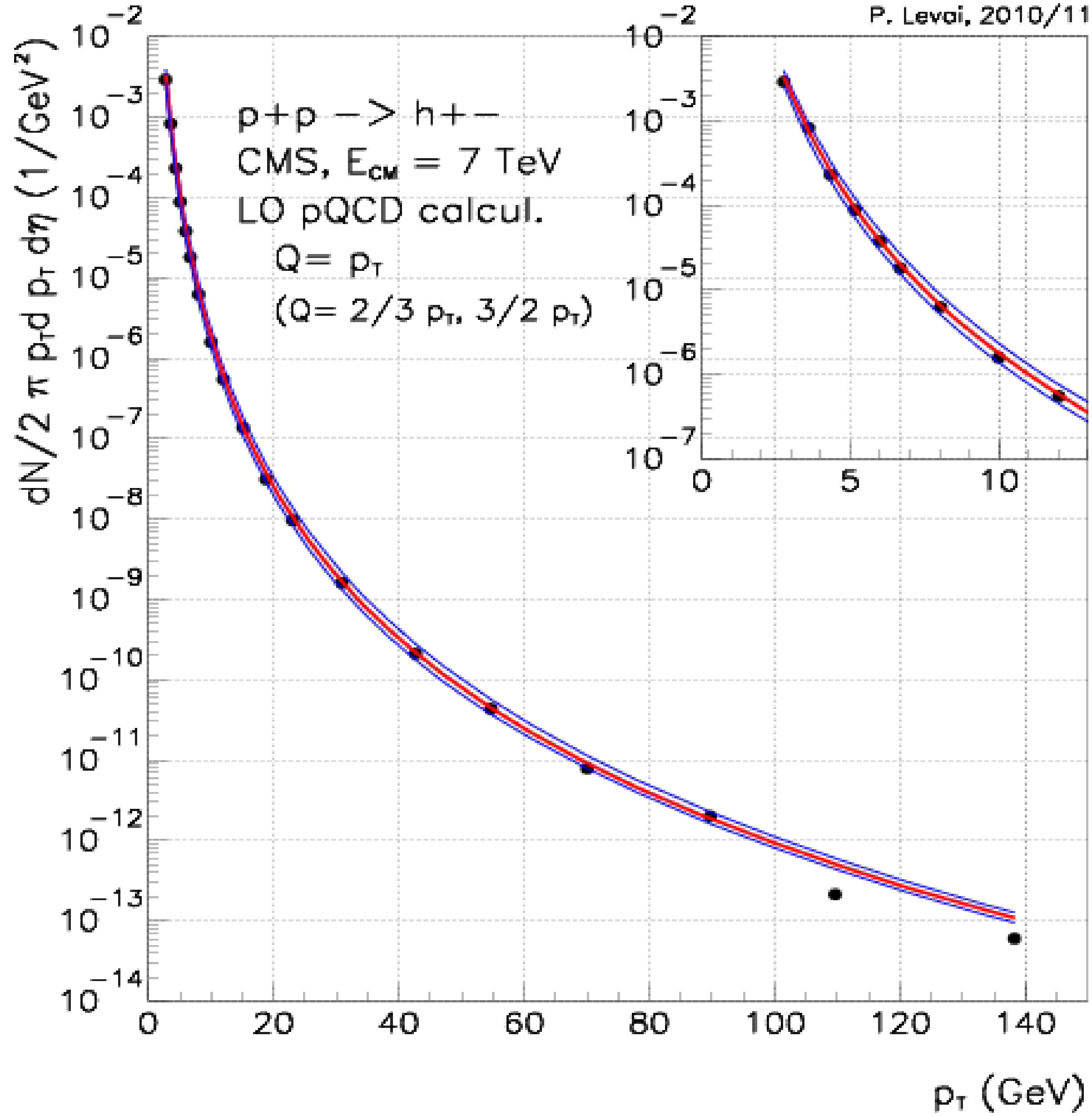


LHC ALICE (Prag'10)



LHC CMS (Prag'10)

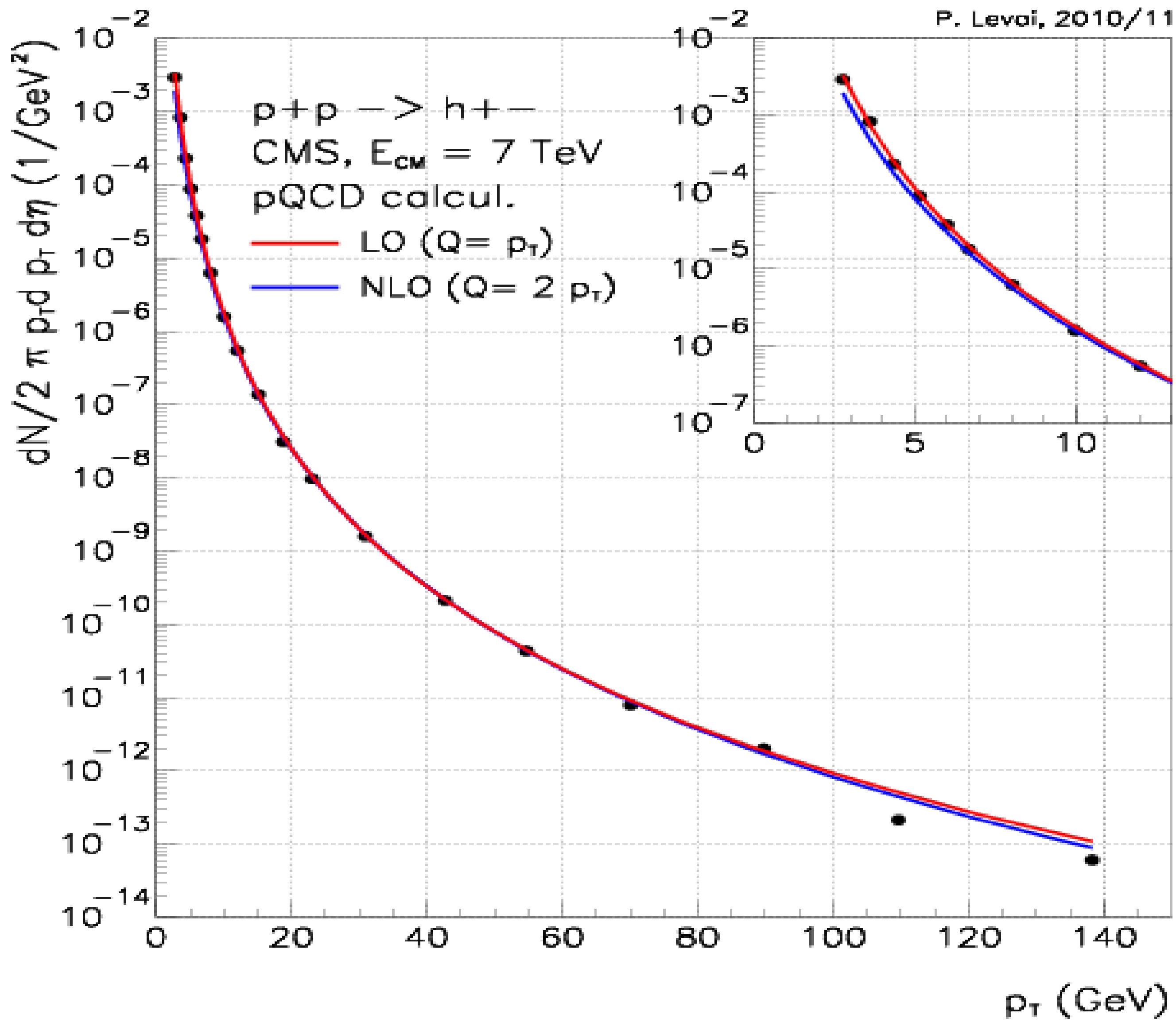
Charged hadron production in pp collisions at 7 TeV – CMS data LO pQCD



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

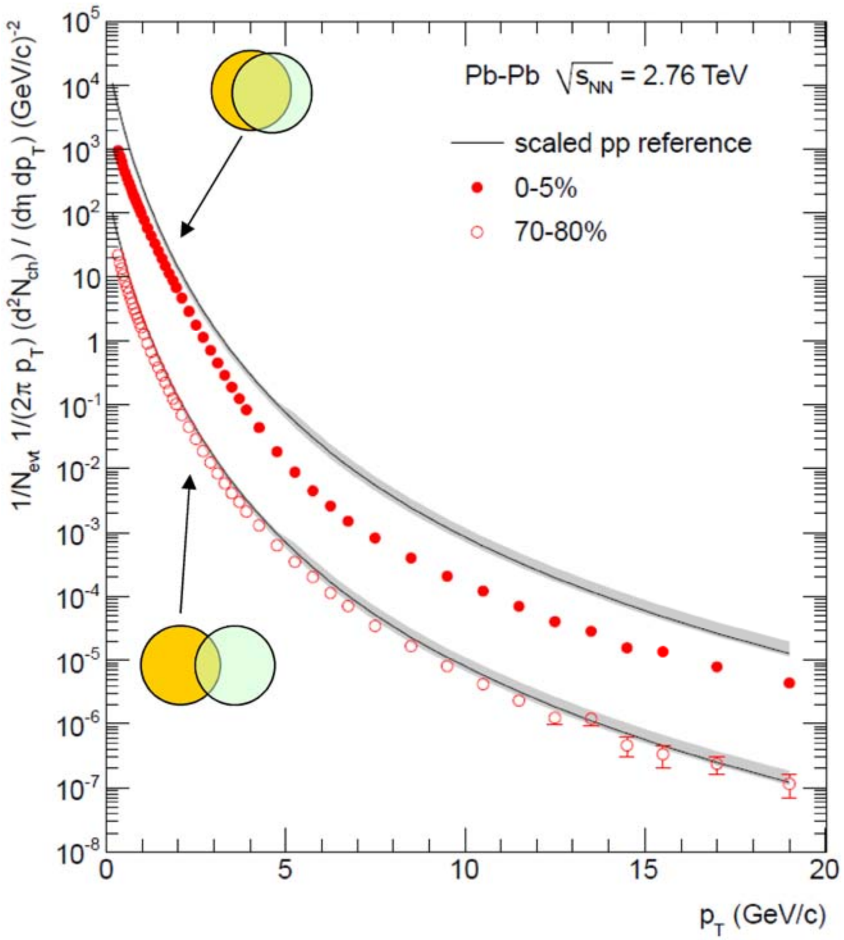
LO and NLO descriptions are equally good !
(Scale difference)

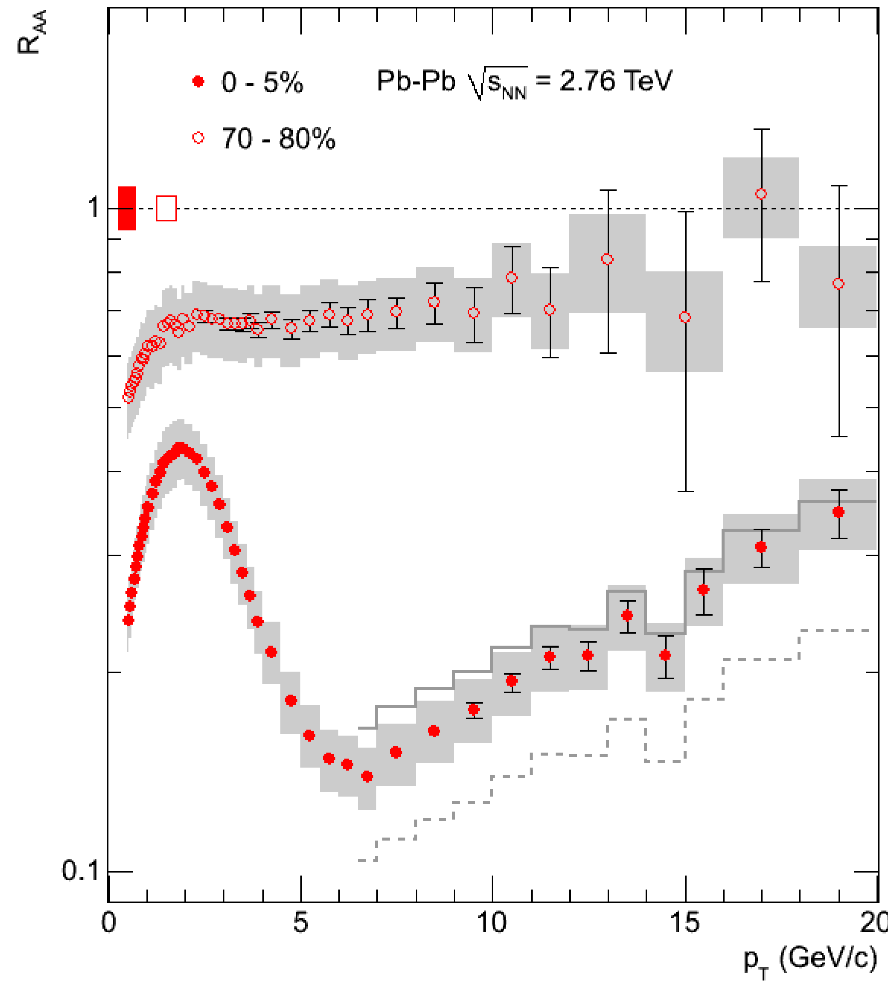
We will use our pQCD frame at 2.36 ATeV.



Charged hadron production in PbPb collision at 2.76ATeV --- new ALICE data --- (PLB 696, 30, 2011)

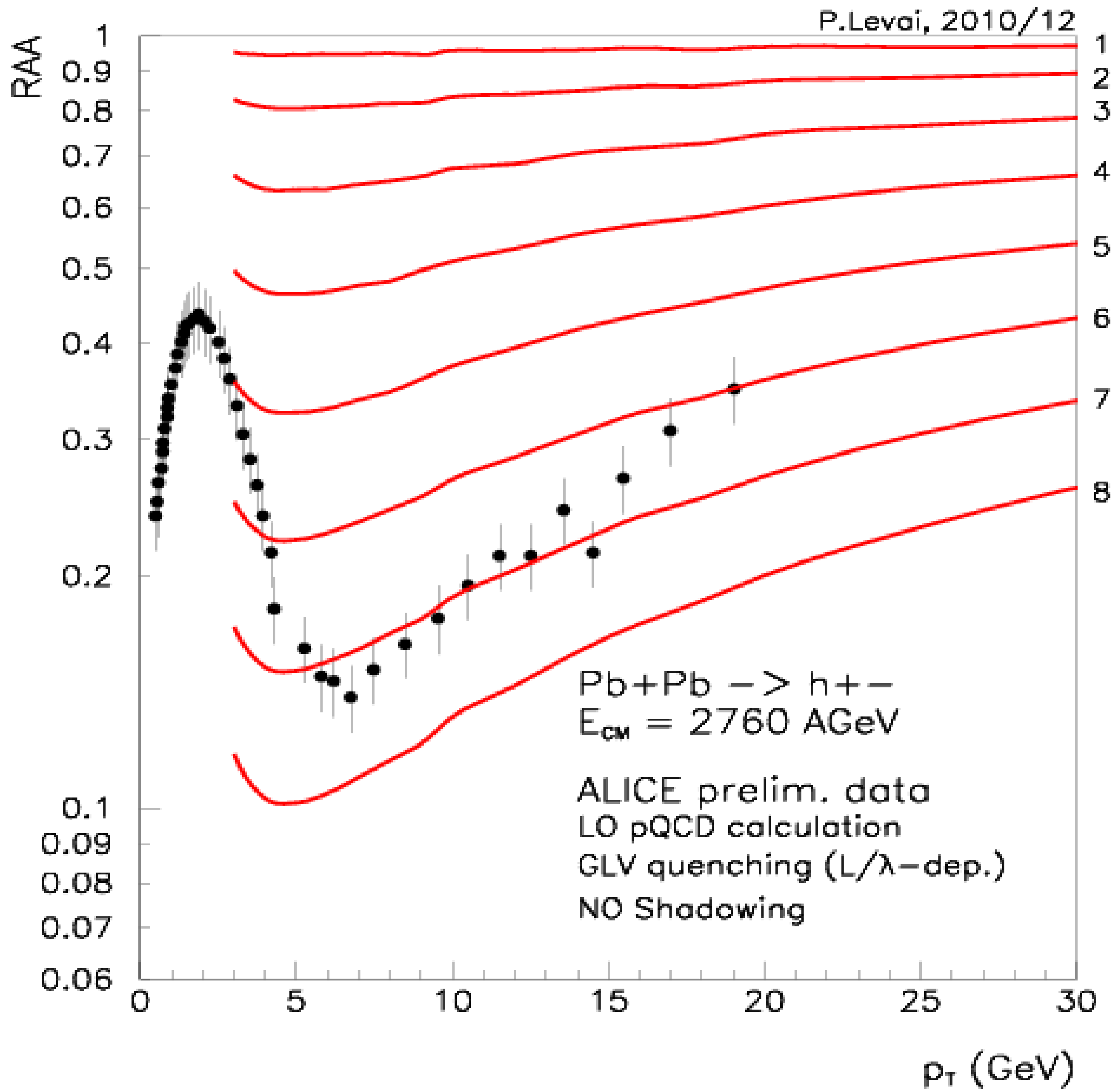
$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle\, (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T}$$



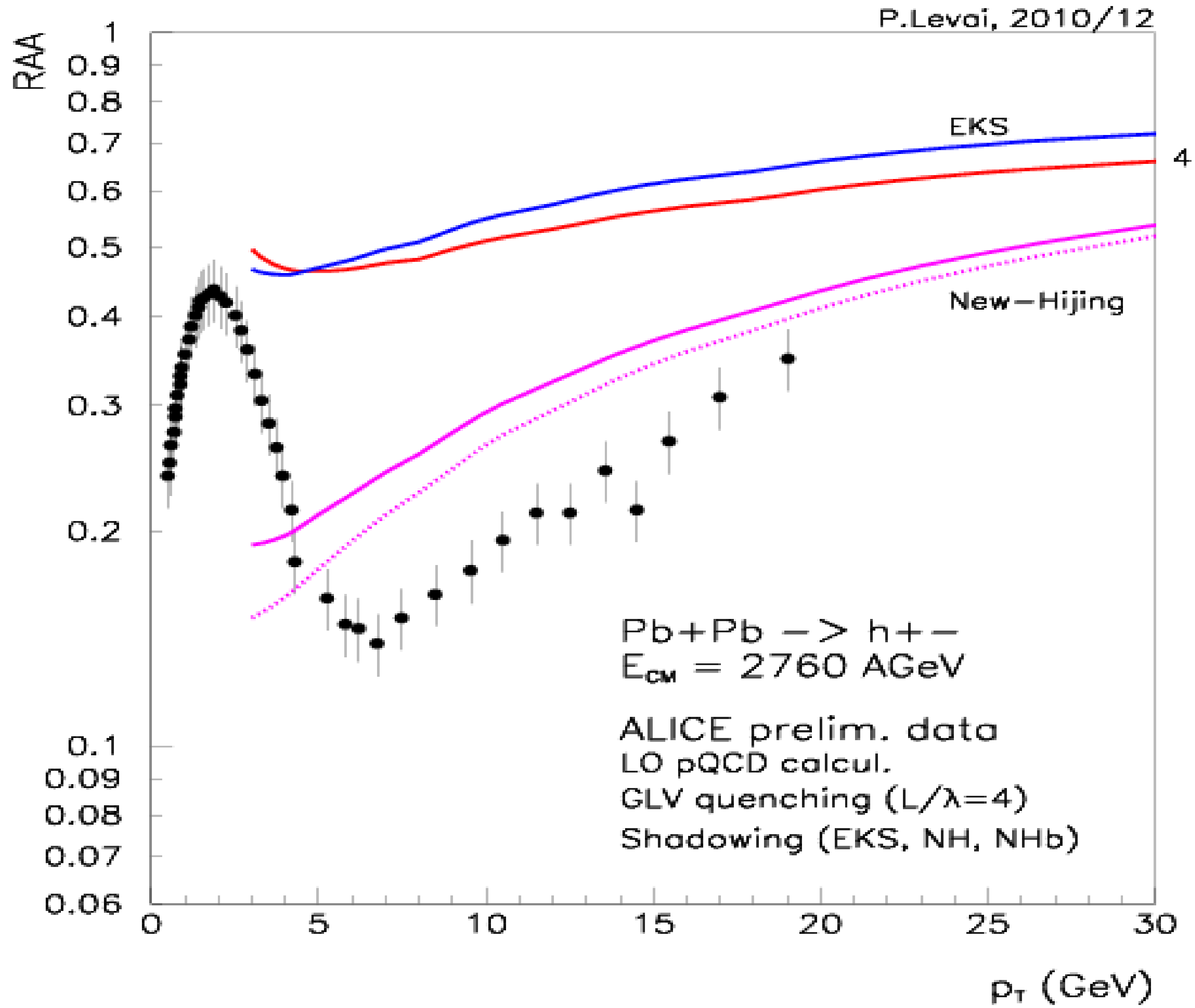


Most central Pb+Pb collisions (5%) at LHC 2.76 ATeV

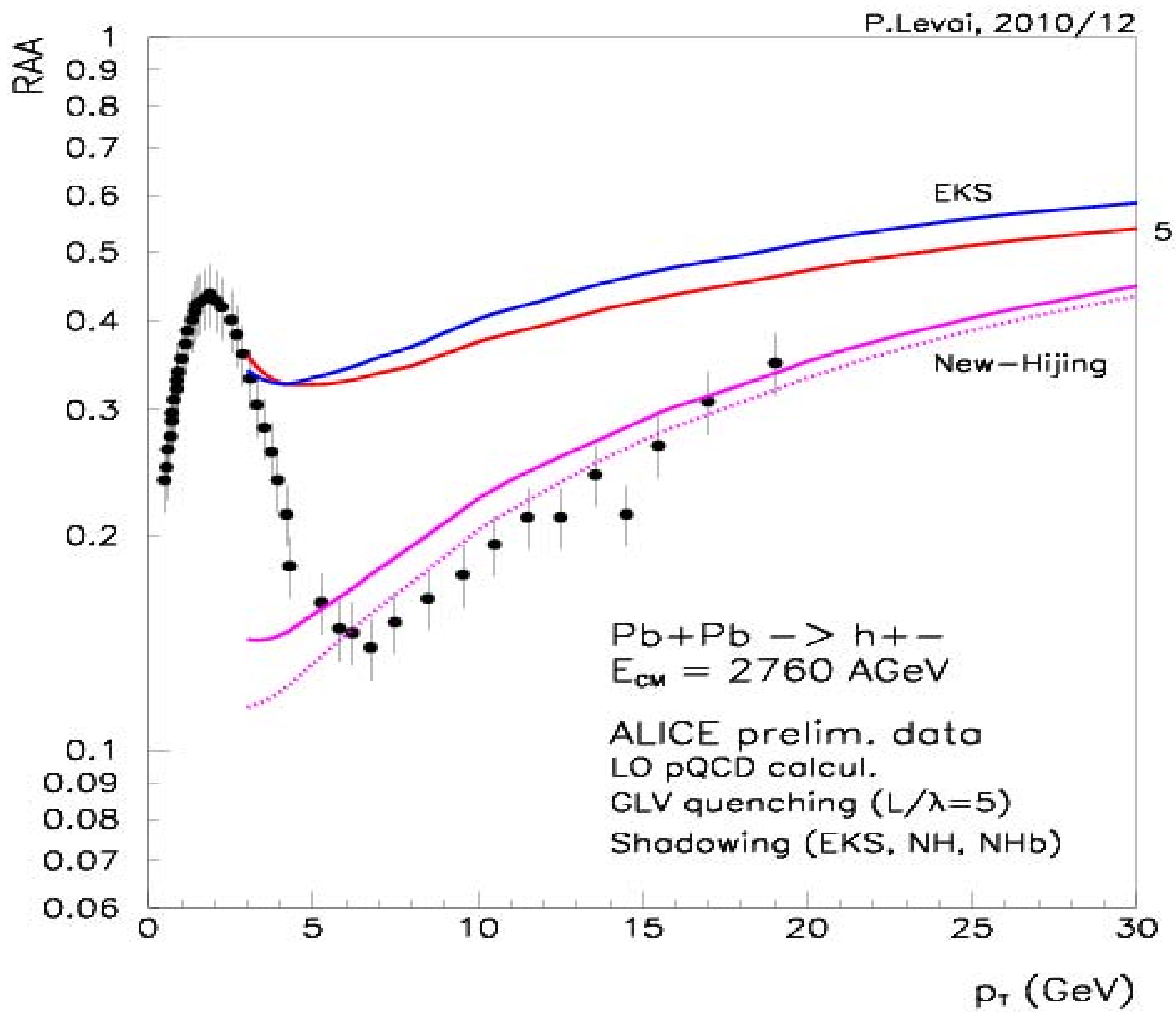
"Quenching only" - NOT FLAT at high-pT !!!! (p_T > 7 GeV)



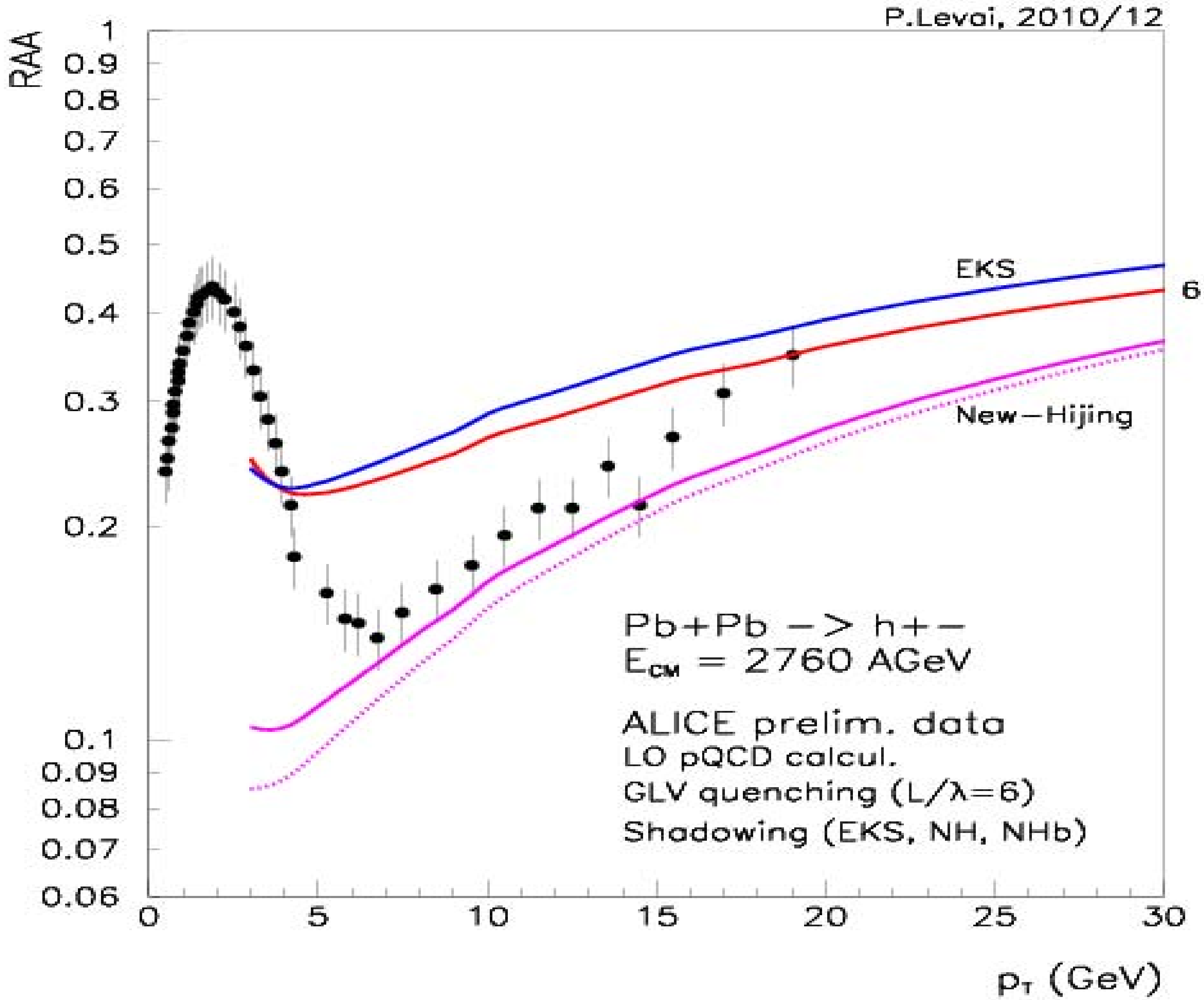
Most central Au+Au collisions (5%) at LHC 2.76 ATeV
"Quenching with L/λ=4 + Shadowing"



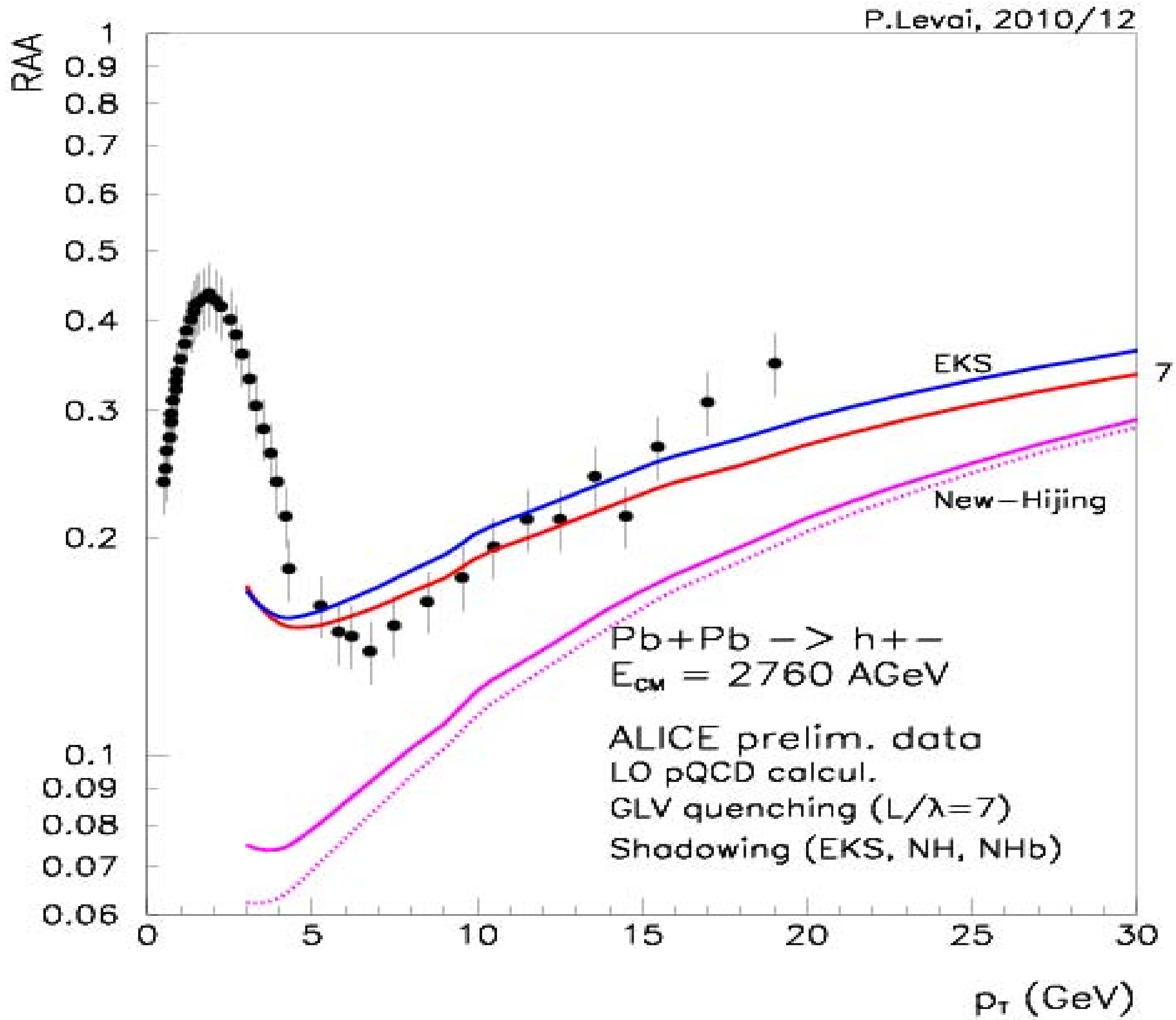
Most central Au+Au collisions (5%) at LHC 2.76 ATeV
“Quenching with L/λ=5 + Shadowing”



Most central Au+Au collisions (5%) at LHC 2.76 ATeV
"Quenching with L/λ=6 + Shadowing"



Most central Au+Au collisions (5%) at LHC 200 AGeV
"Quenching with L/λ=7 + Shadowing"



Conclusion from light quark quenching at LHC energy:

$L/\lambda = 5.5$ will describe LHC data well with New-Hijing shadowing functions

BUT: THIS IS THE SAME opacity, what was seen at RHIC !!!

or:

$L/\lambda = 7$ is needed with EKS shadowing

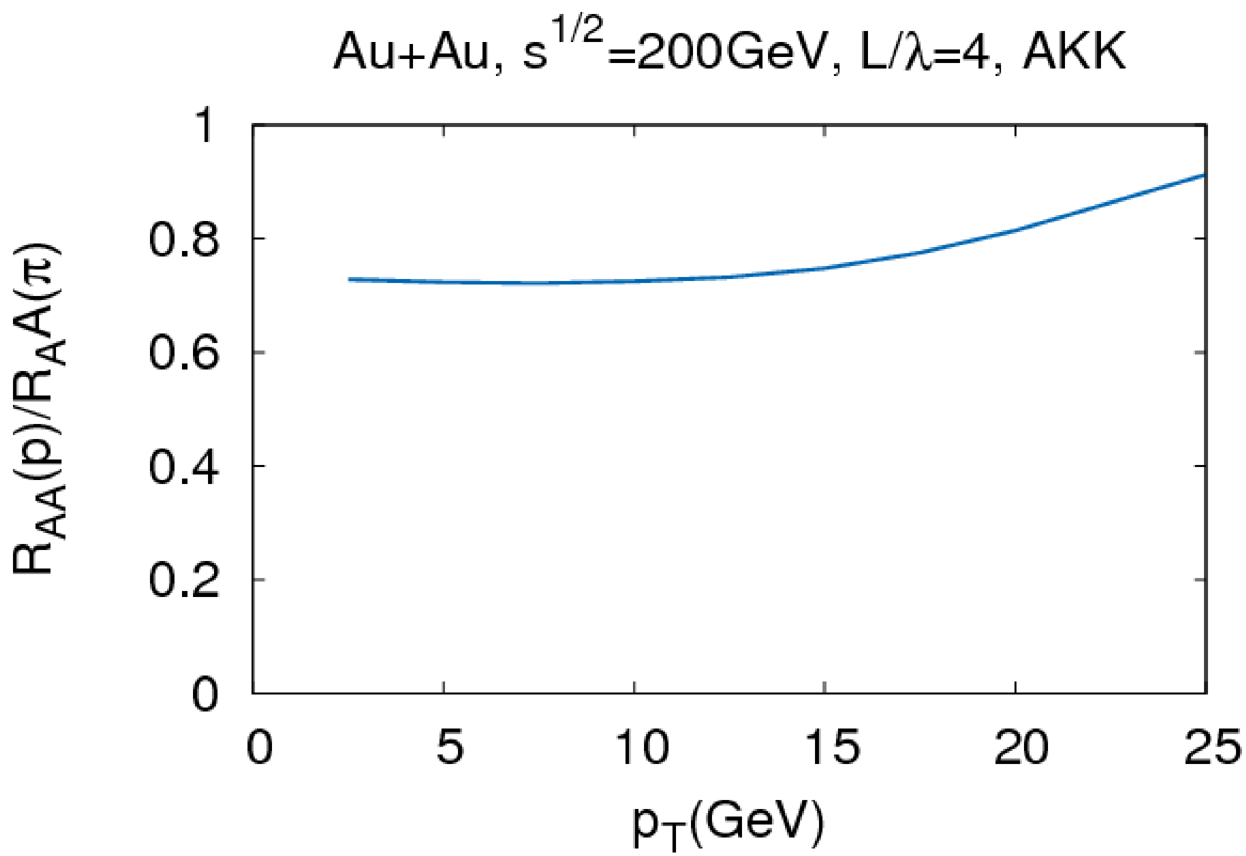
This means 2x larger color density at LHC energy w.r.t RHIC energy

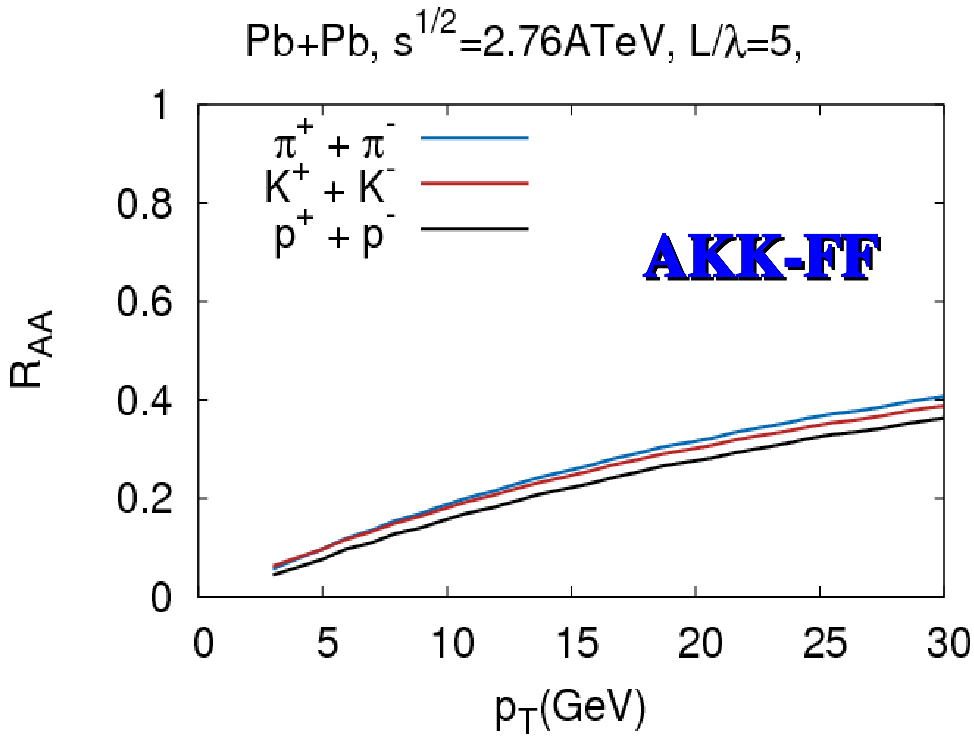
Ratio $(L/\lambda)^2$: $7^2/5.5^2 = 49/30 \approx 1.6$

5. Energy loss studies for identified hadron R_{AA}

Pásztor A, LP, 2011

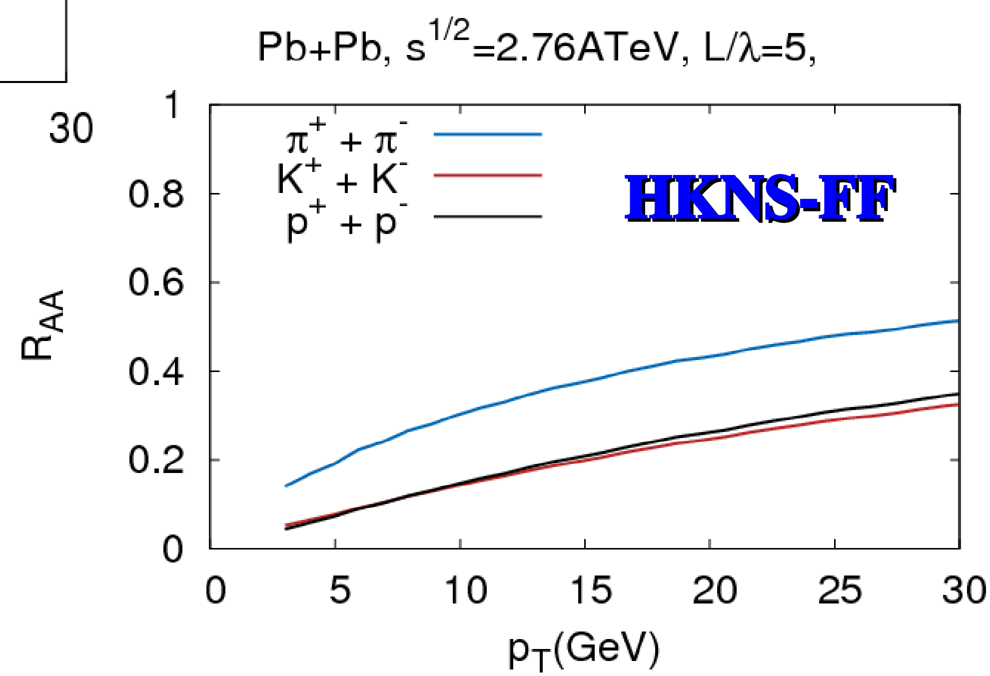
How large is the RAA nuclear modification factor for pion and proton ? What is the difference at RHIC?

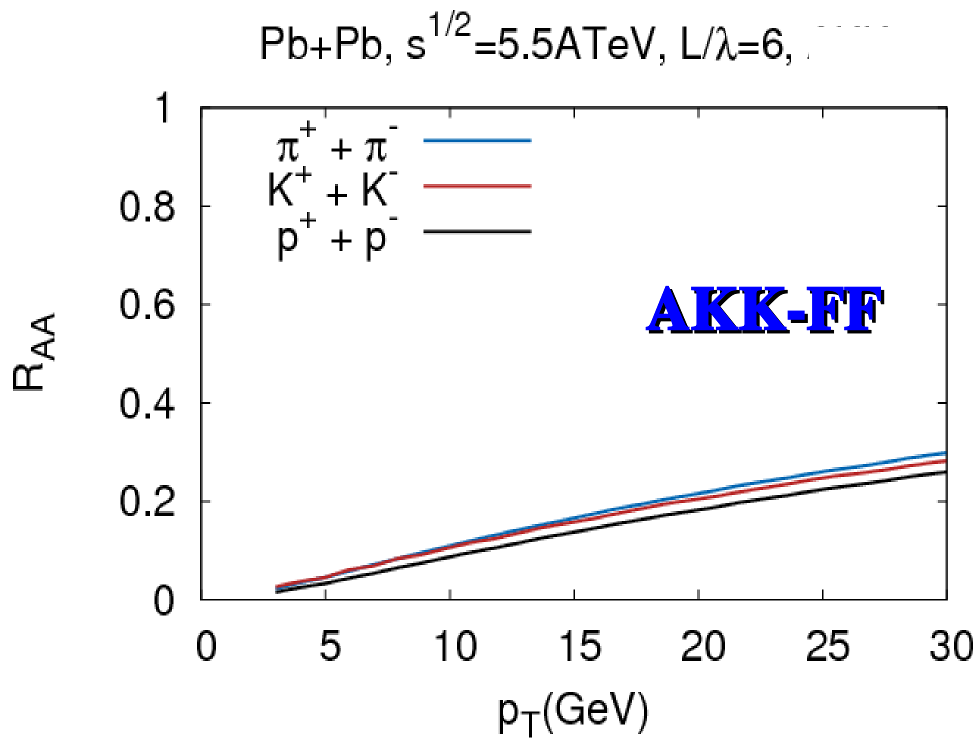




What is the difference at LHC at 2.76 ATeV?

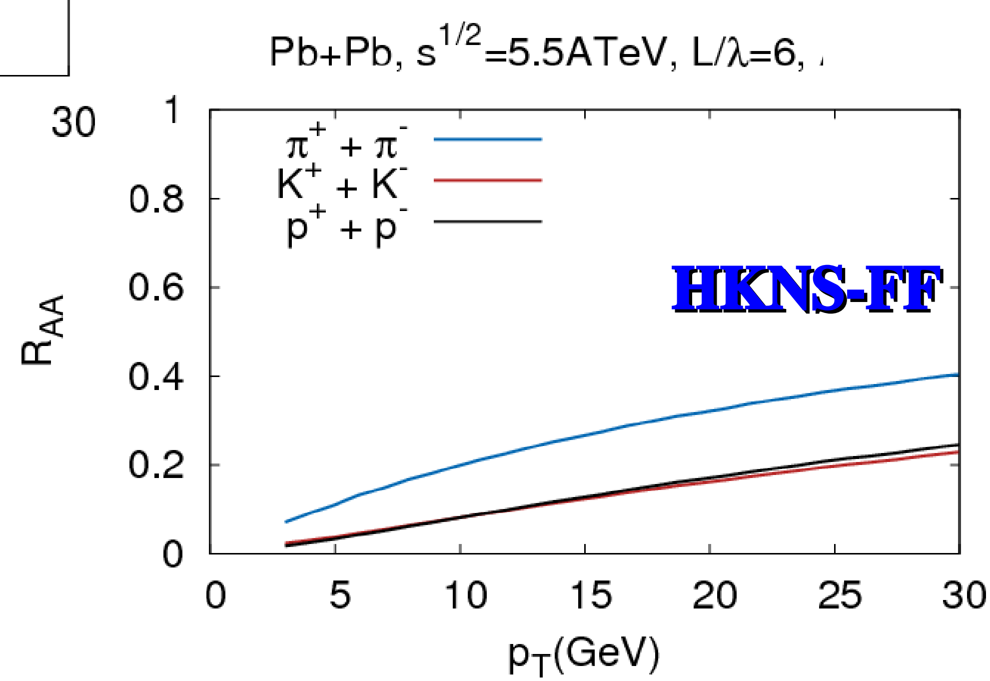
What is the dependence on the hadron flavour with different FF ?

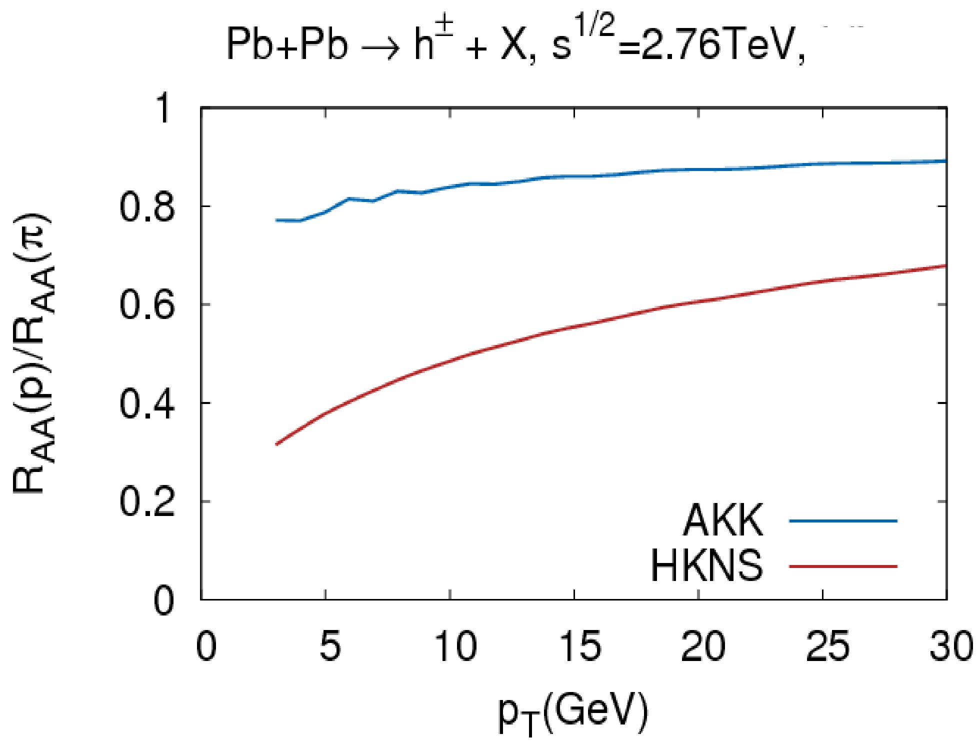




What is the difference at LHC at 5.5 ATeV?

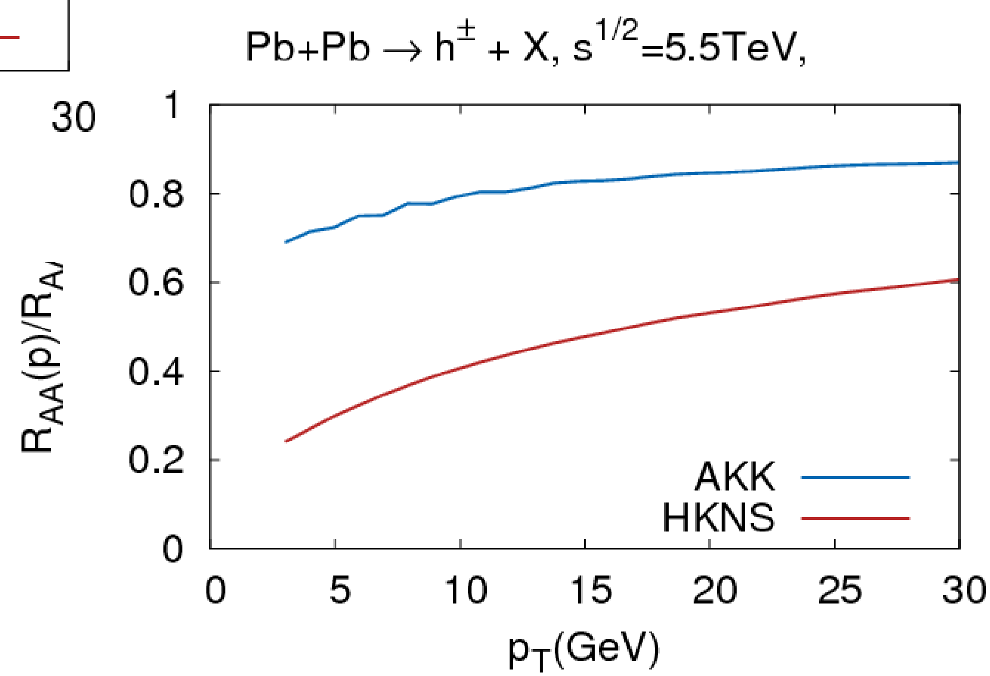
What is the dependence on the hadron flavour with different FF ?





What is the dependence on the FF-sets ?

Strong difference on the FF-sets !



Theoretical conclusion (for today) :

1. pQCD model frame with jet quenching and nuclear shadowing is a very fruitful description at LHC energies

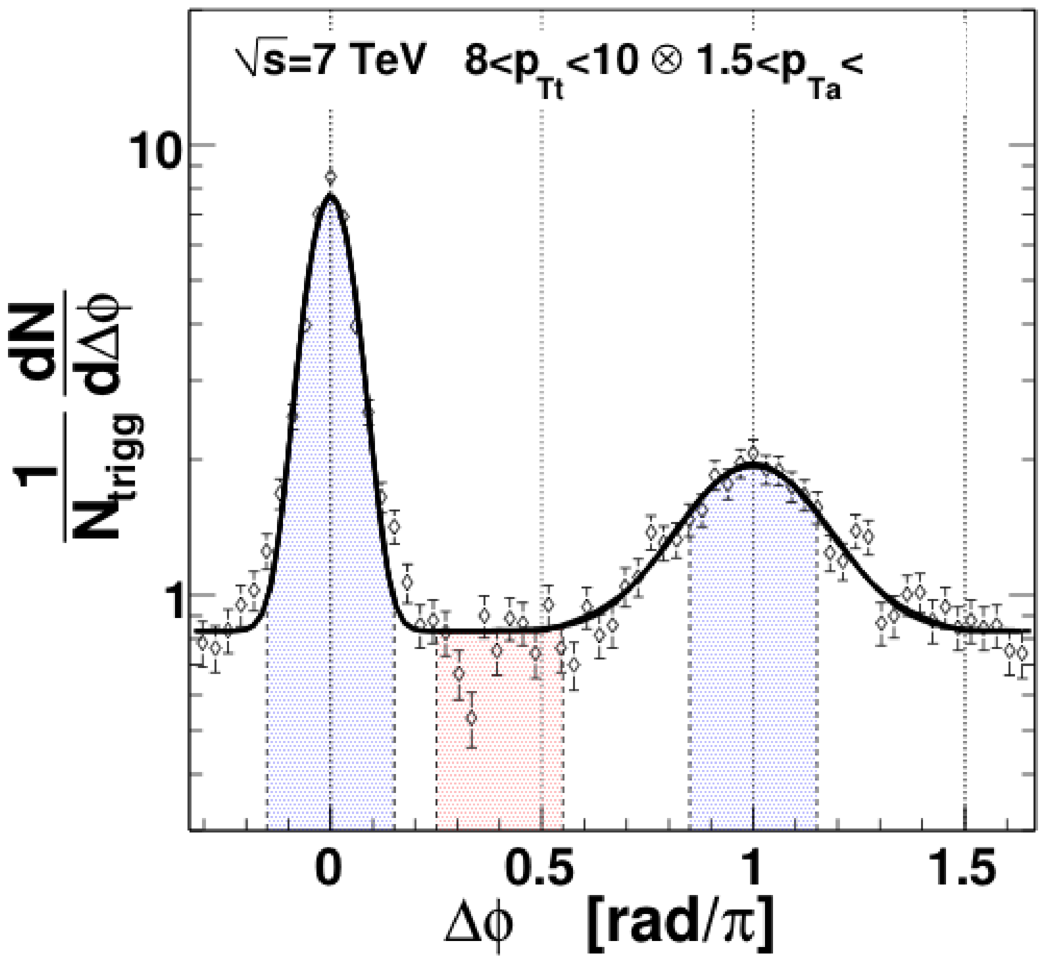
2. LHC data are very interesting, but final data are needed.

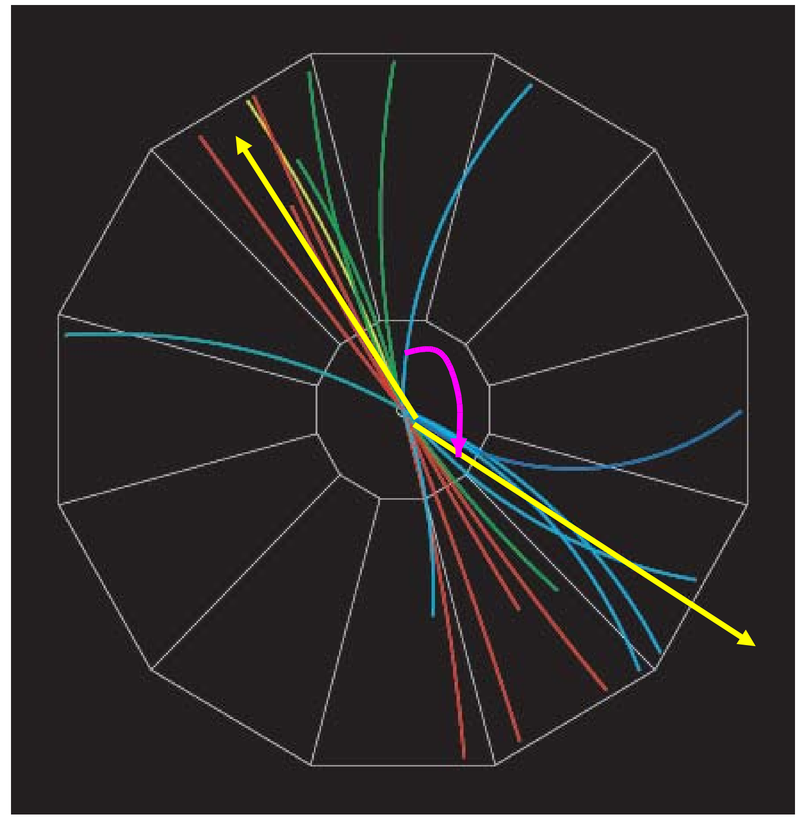
3. Looking forward to see further details
    - -- pi0 production at high-pT
    - -- identified charged hadrons at high-pT
    - -- charm quark energy loss !!!

Problems in 2-particle correlations:

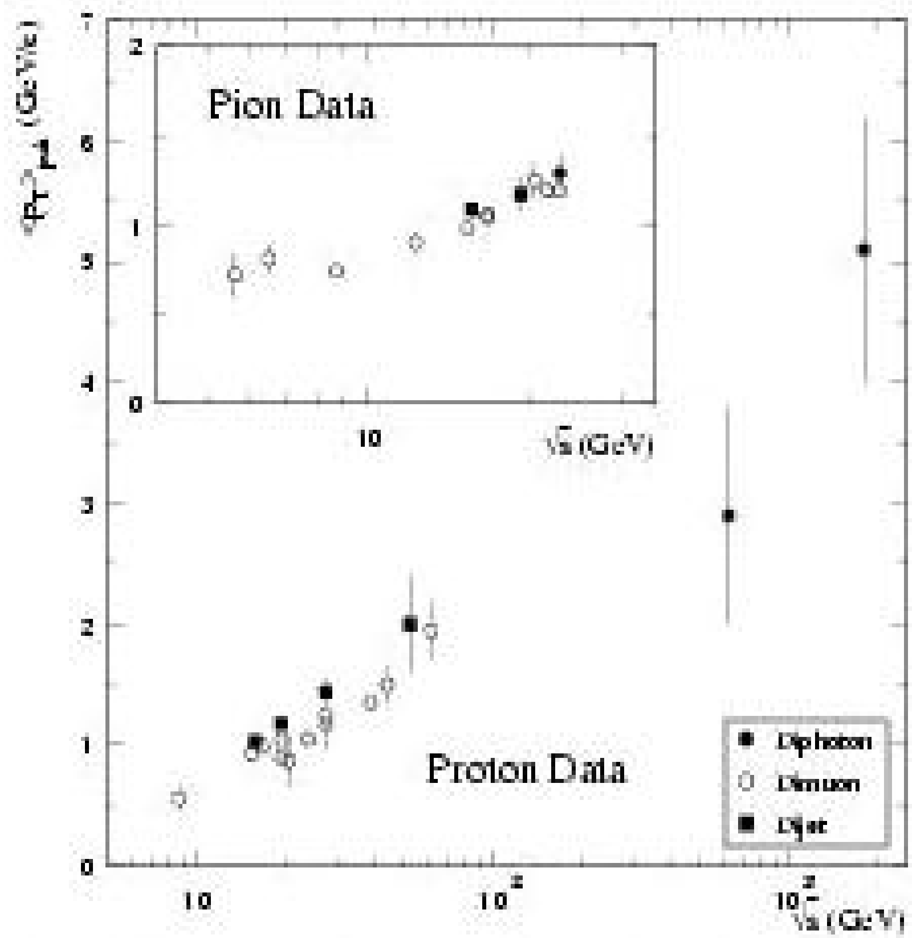
- where is the kT-imbalance in the 1-particle spectra?????

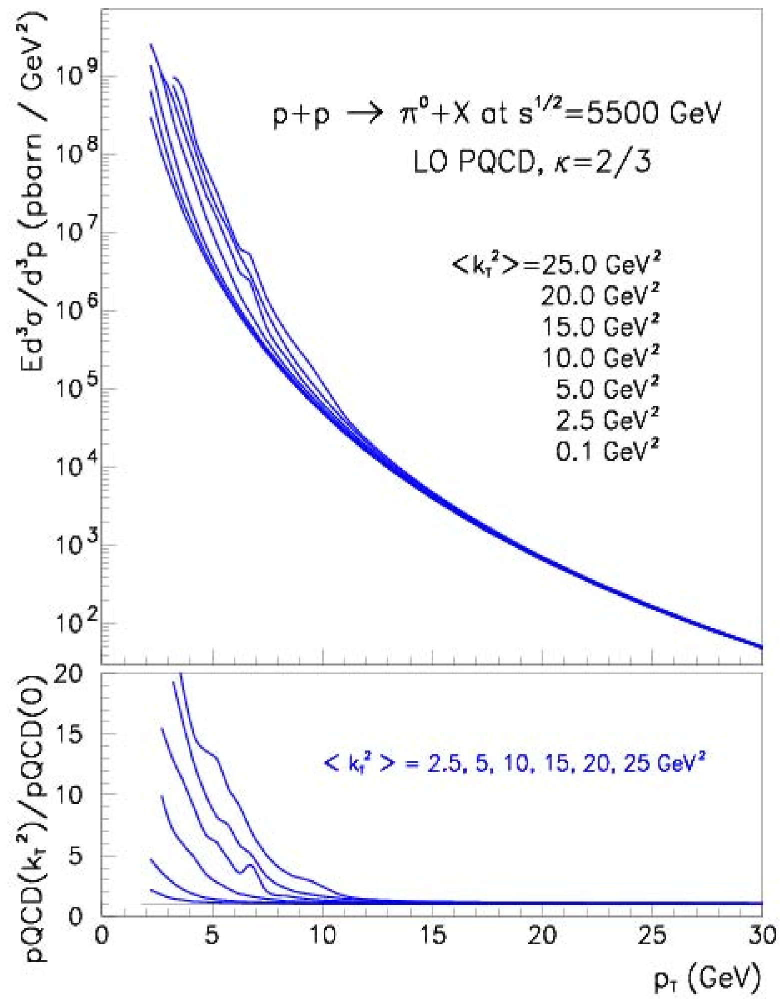
- why LO pQCD is working so well without intrinsic-kT ???


√s=7 TeV 8<p_Tt<10 ⊗ 1.5<p_Ta<
10
1
1/N_trigg dN/dΔφ
0
0.5
1
1.5
Δφ [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 !! ???

Experimental side: Particle identification at high-pT at LHC

1. LHC ALICE: TPC + TOF + ITS
   Statistically up to 40-50 GeV/c

2. LHC ALICE upgrade: VHMPID (track-by-track)
   Very High Momentum Particle Identification Detector
   RICH modul + Trigger modul
   Installation in 2015 (hopefully)

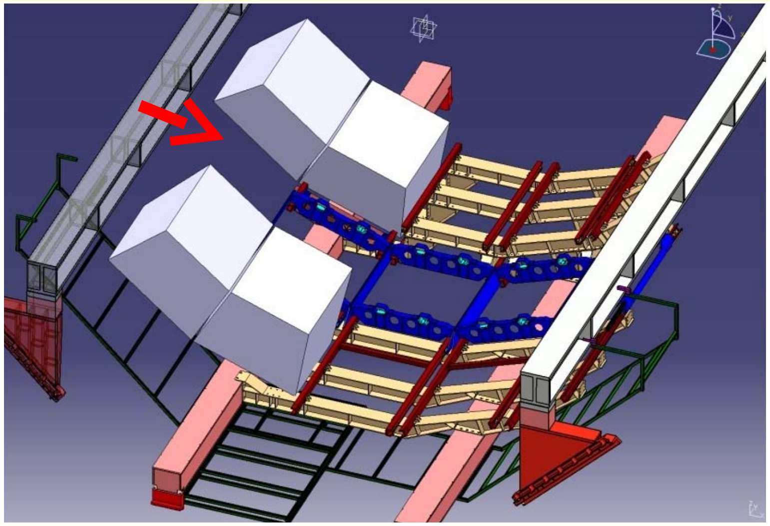
VHMPID mission: to identify charged hadrons track-by-track
up-to 25 GeV (C_4F_{10})
or at even higher momenta (CH_4)

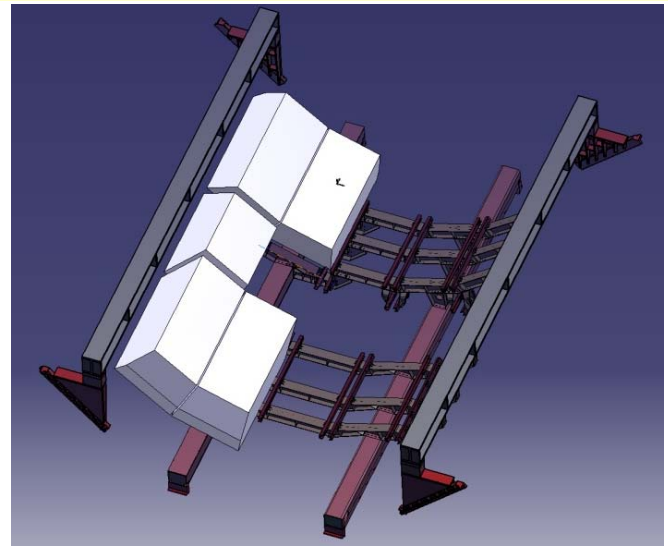
Talks at this Workshop:

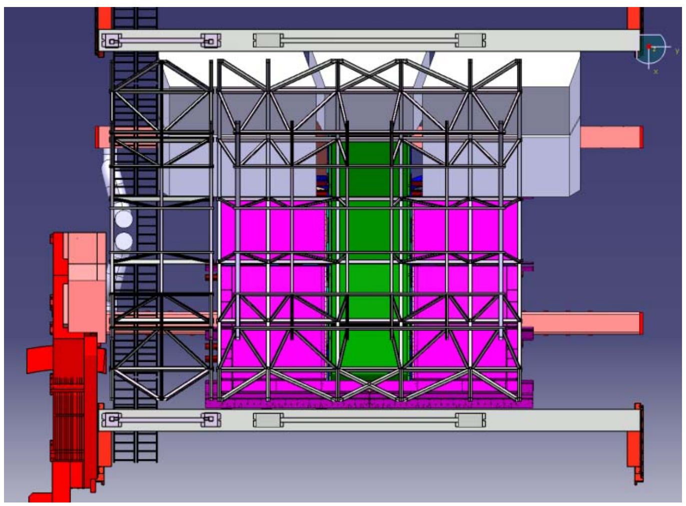
G. Hamar on Thursday at 15.00

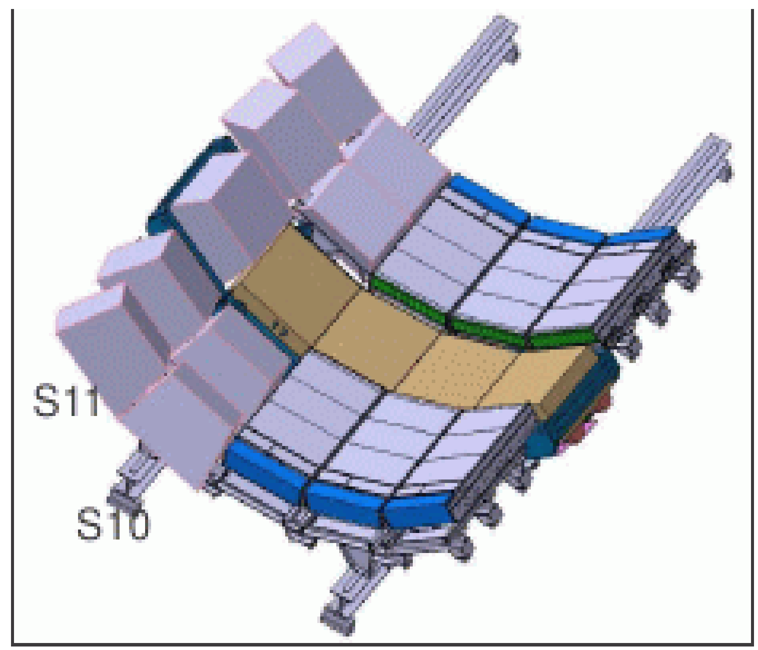
L. Boldizsar on Thursday at 15:30

VHMPID layout evolution (2009-2010)









The VHMPID collaboration

- **Instituto de Ciencias Nucleares Universidad Nacional Autonoma de Mexico, Mexico City, Mexico**

E. Cuautle,I. Dominguez, D. Mayani, A. Ortiz, G. Paic, V. Peskov

- **Instituto de Fsica Universidad Nacional Autonoma de Mexico, Mexico City, Mexico**

R. Alfaro

- **Benemerita Universidad Autonoma de Puebla, Puebla, Mexico**

M. Martinez, S. Vergara, A. Vargas

- **Universita' degli Studi di Bari and INFN Sezione di Bari, Bari, Italy**

G. De Cataldo, D. Di Bari, E. Nappi, C. Pastore, I. Sgura, G. Volpe

- **CERN, Geneva, Switzerland**

A. Di Mauro, P. Martinengo, L.Molnar, D. Perini, F. Piuz, J. Van Beelen

- **MTA KFKI RMKI, Research Institute for Particle and Nuclear Physics, Budapest, Hungary**

A. Agocs, G.G. Barnafoldi, G. Bencze, L. Boldizsar, E. Denes, Z. Fodor, E. Futo, G. Hamar, P. Levai, C. Lipusz, S. Pochybova

- **Eotvos University, Budapest, Hungary**

D. Varga

- **Chicago State University, Chicago, IL, USA**

E. Garcia

- **Yale University, New Haven, USA**

J. Harris, N. Smirnov

- **Pusan National University, Pusan, Korea**

In-Kwon Yoo, Changwook Son, Jungyu Yi