Proton-to-pion ratio for the near-side jet in pp and AA collisions at RHIC and LHC energies

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Quark Matter 2008 Conference
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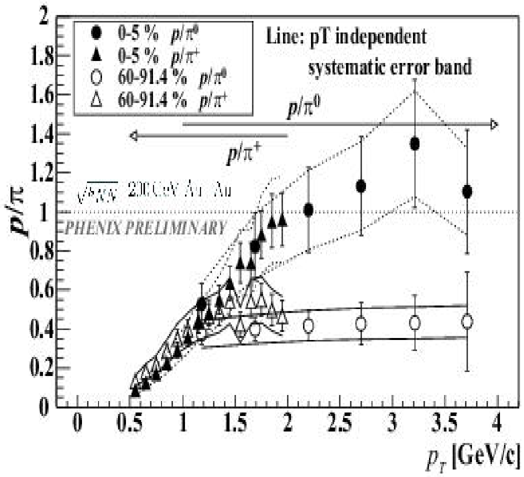
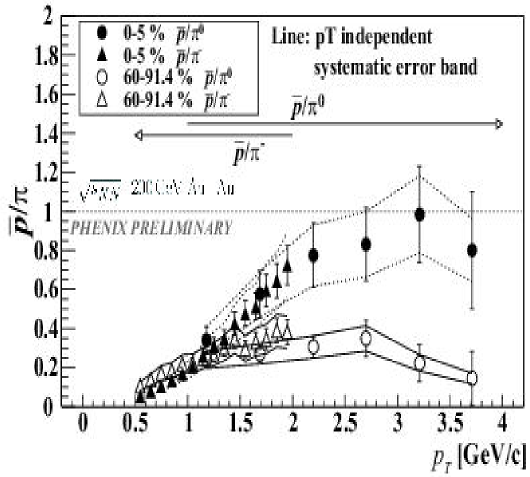
QM02: First results from RHIC at √s = 130 and 200 A GeV -- $p/\pi^+, \bar{p}/\pi^-$

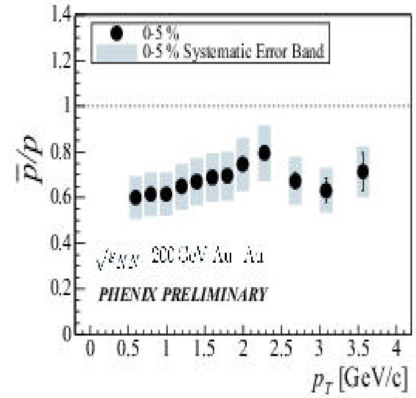
PHENIX Coll., T. Sakaguchi, NPA715(2003)757.

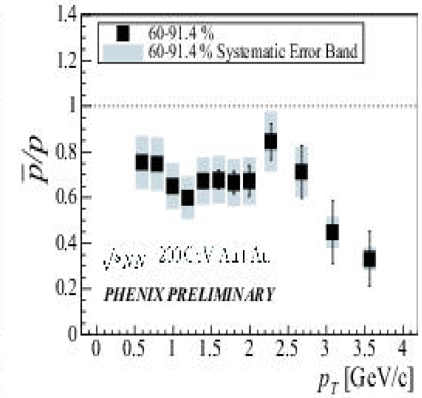
$$N(\bar{p}) > N(\pi^-)!!!$$

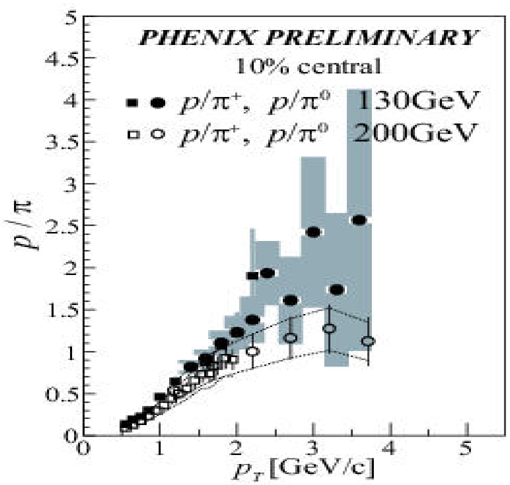


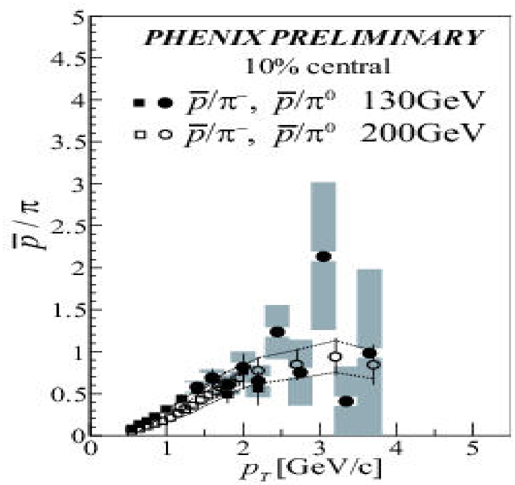


Anomalous antiproton (proton) production ??









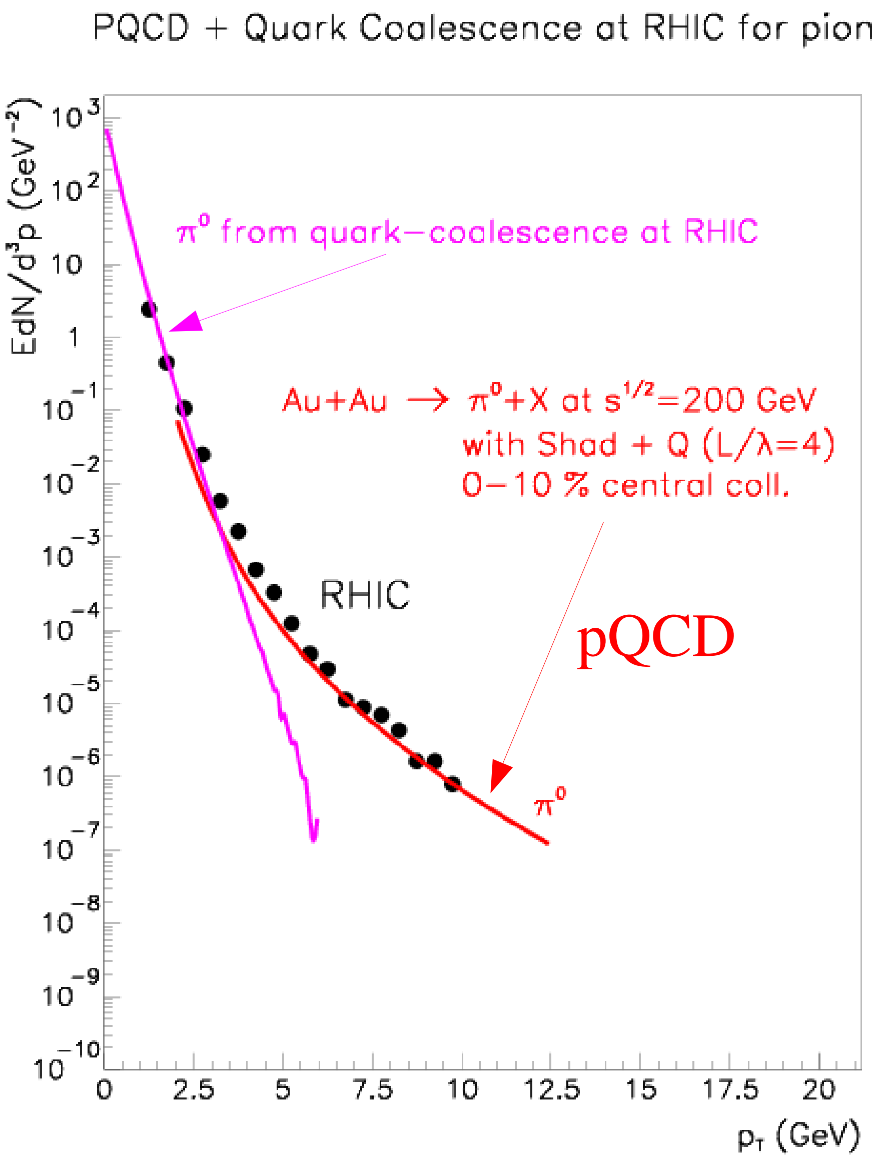
The birth of "intermediate p_T-region"

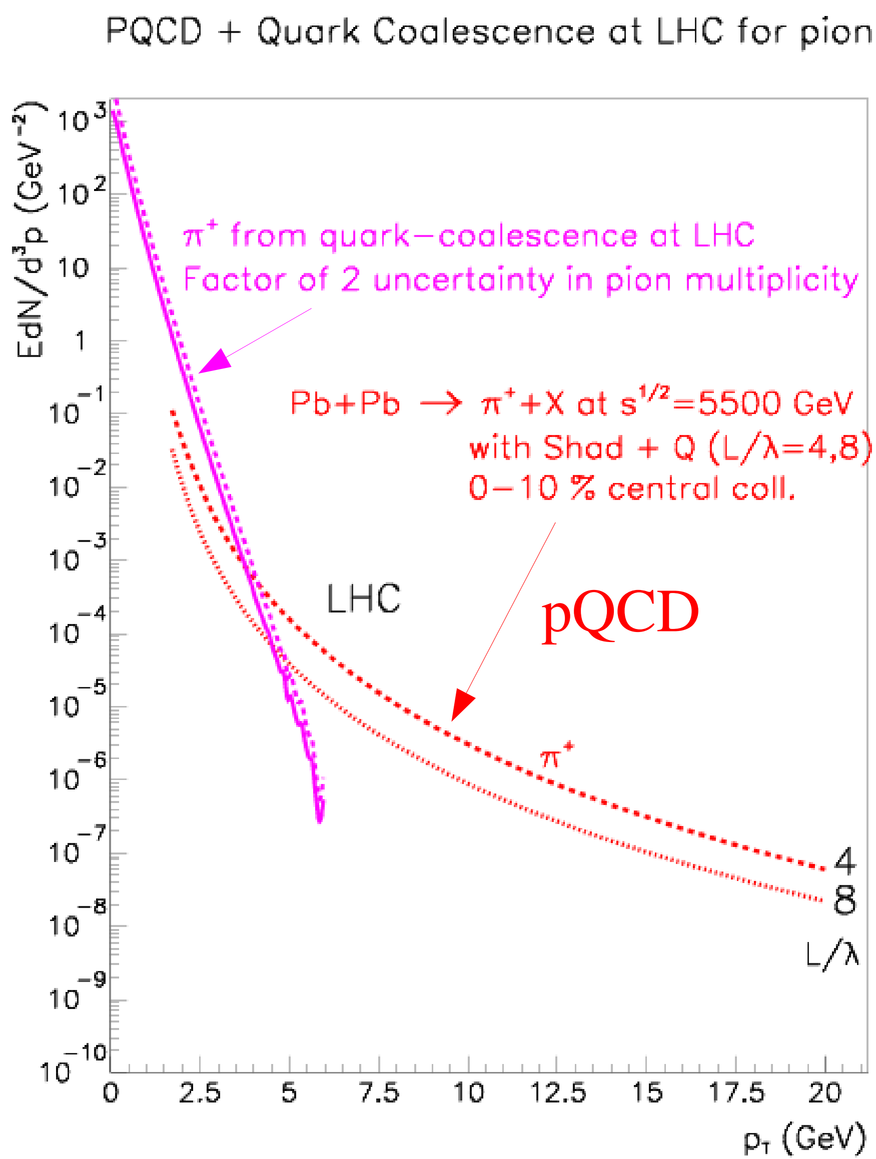
Quark coalescence/recombination
(Hwa & Yang; Greco et al; Friese et al.)
See Rudy Hwa's plenary talk !!!

Jet quenching + quark coal. overlap
5 years of activity

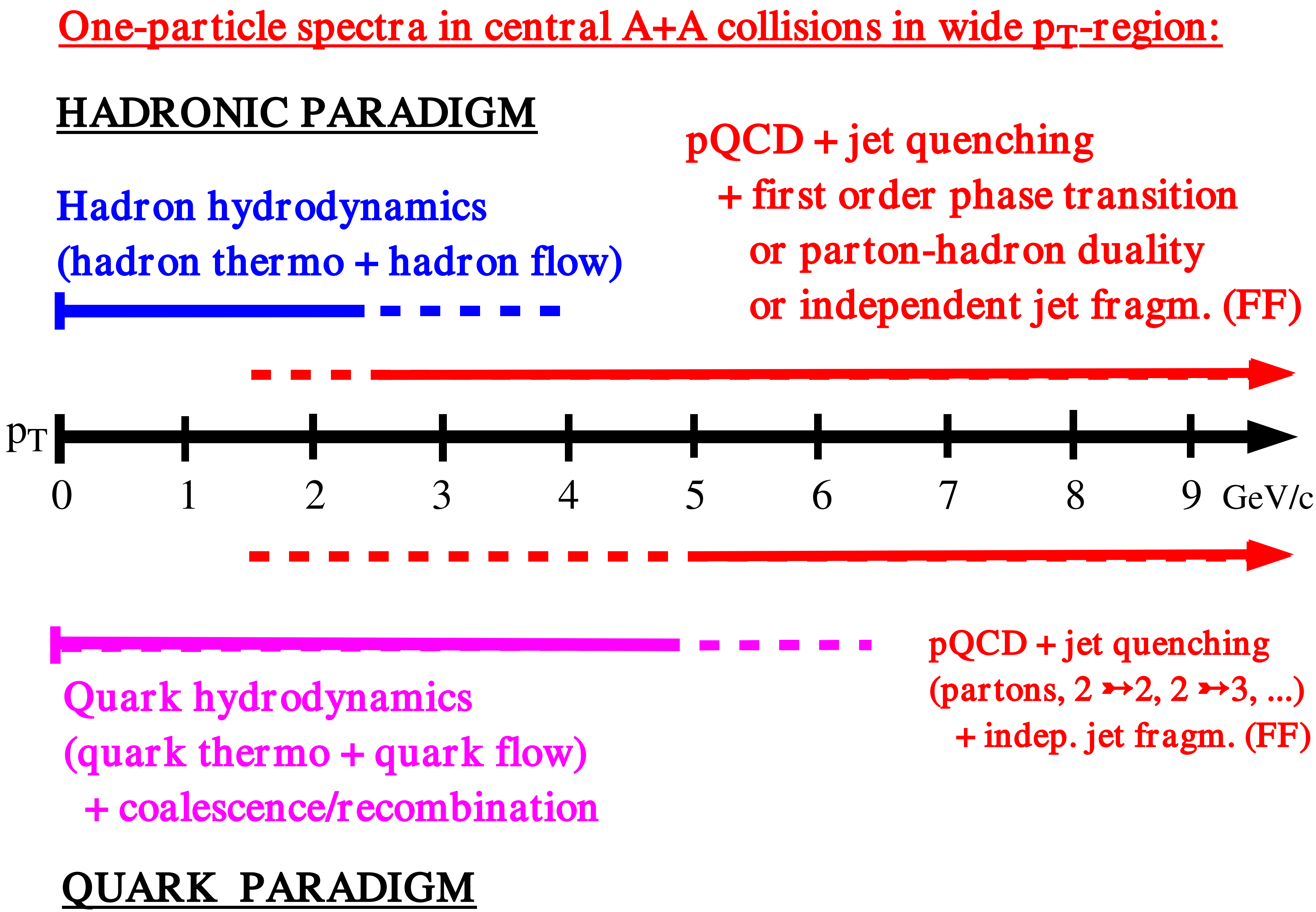
Early theoretical results (2005) for pions at RHIC and LHC

(Scaled up RHIC result for coalescence, v_T=0.6.)





Overlap at p_T = 2.5 - 3 GeV (RHIC) **at 4 ± 1 GeV at LHC**


One-particle spectra in central A+A collisions in wide p_T-region:
HADRONIC PARADIGM
Hadron hydrodynamics
(hadron thermo + hadron flow)
pQCD + jet quenching
+ first order phase transition
or parton-hadron duality
or independent jet fragm. (FF)
p_T
0
1
2
3
4
5
6
7
8
9
GeV/c
pQCD + jet quenching
(partons, 2 → 2, 2 → 3, ...)
+ indep. jet fragm. (FF)
Quark hydrodynamics
(quark thermo + quark flow)
+ coalescence/recombination
QUARK PARADIGM

One-particle spectra in central A+A collisions in wide p_T-region:

Proton/pion (B/M) anomaly:

excellent tool to investigate the overlap between the RECO and pQCD region

RECO details

very phenomenological (so far)

pQCD details

pp baseline (LO, NLO, intrinsic-kT, Sudakov-terms, ...)

fragmentation functions (KKP, AKP, ...; proton, Λ, Ξ, ...)

quenching mechanisms:

--- volume or surface effect

--- radiative and/or collisional energy loss

--- gluons and quarks in hot matter

Many open questions: two-particle correlations may help to answer

Two-particle correlations in pp, pA, AA collisions in wide p_T-region:

1. $\frac{v_2}{n_q}(\frac{E_T}{n_q})$ scaling strongly supports quark RE/CO
   quark number scaling (QNS) at lower pT
   [QNS-breaking at higher pT means pQCD/FF domin.]

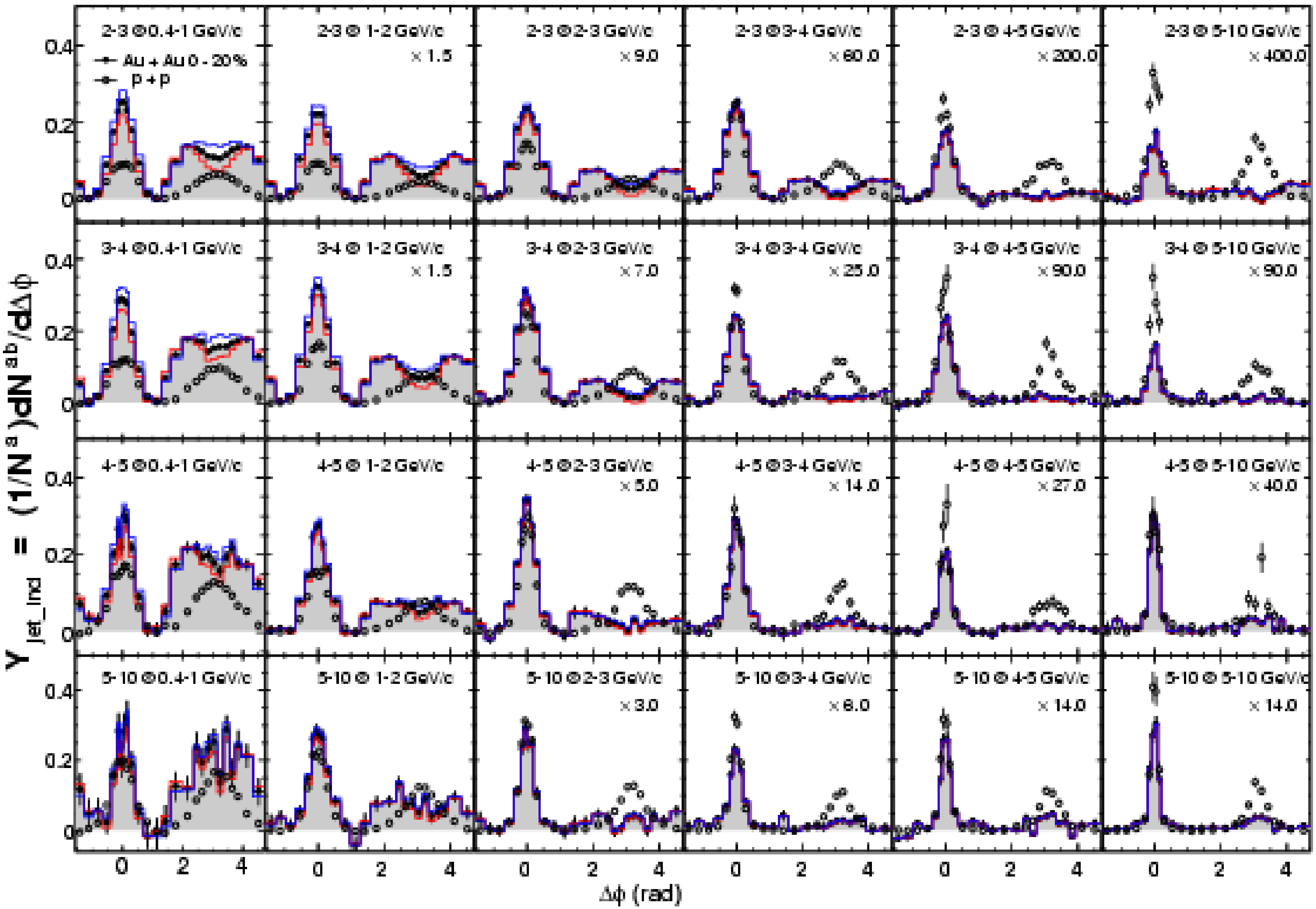
2. Near-side correlations:
   measurable modifications in pp ↣ dAu ↣ AuAu
   indicate in-matter effects for jets ➤➤➤➤ RIDGEOLOGY
   systematic analysis can be performed

3. Away-side correlations:
   strong modifications in pp ↣ dAu ↣ AuAu
   --- double bump structure, Mach-cones, ...
   --- jet-suppression, jet-reapperance, ...
   new ideas are constructed for explanations

Jet-Ridge-Bump: mutual understanding ➤➤ e.g. proton/pion ratio ?

QM08: Latest results from PHENIX at RHIC energy at √s = 200 A GeV

Hadron-hadron correlations A. Adare et al., arXive: 0801.4545 [hep-ex]



QM08: Latest results from PHENIX at RHIC energy at √s = 200 A GeV

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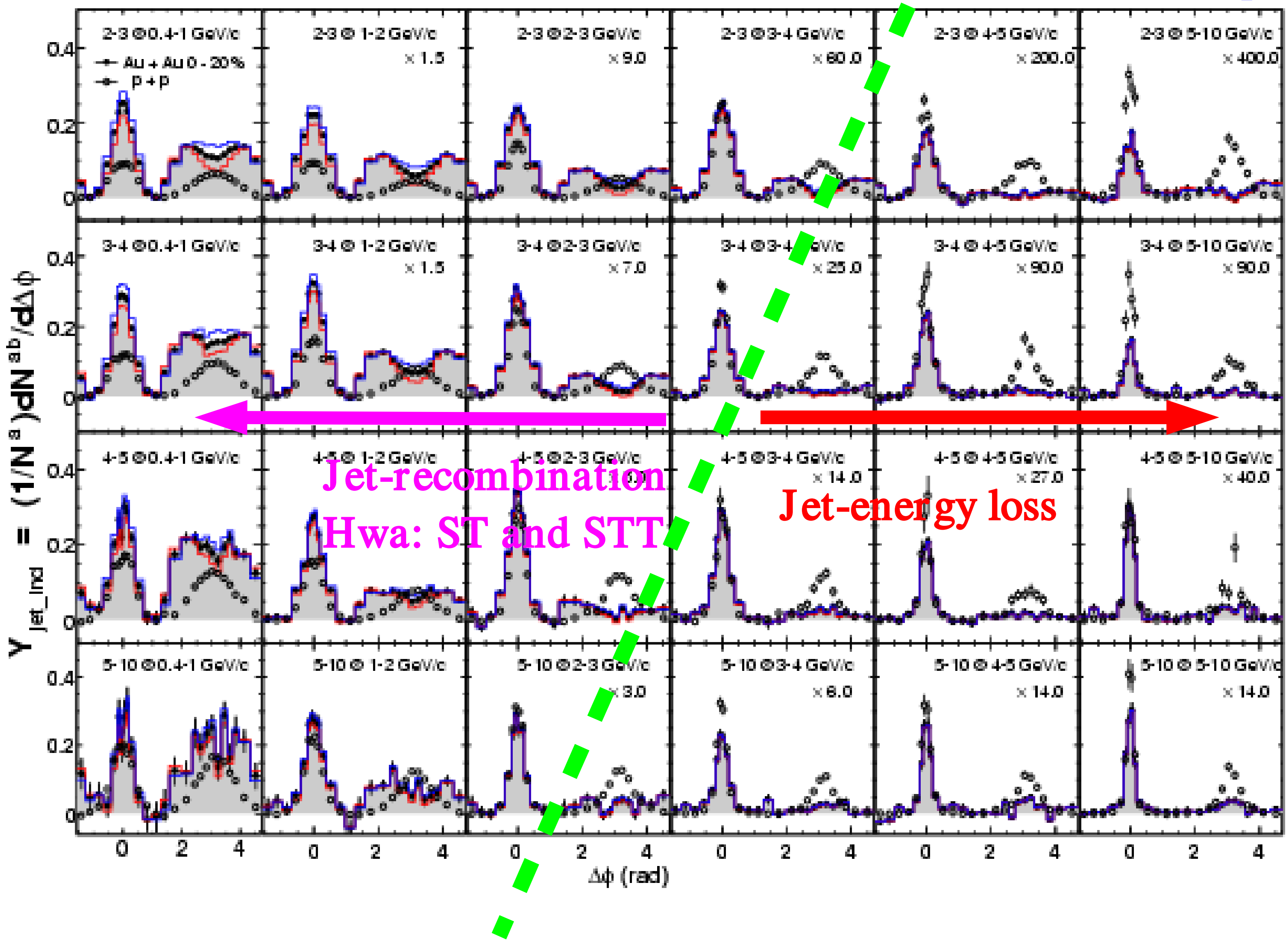
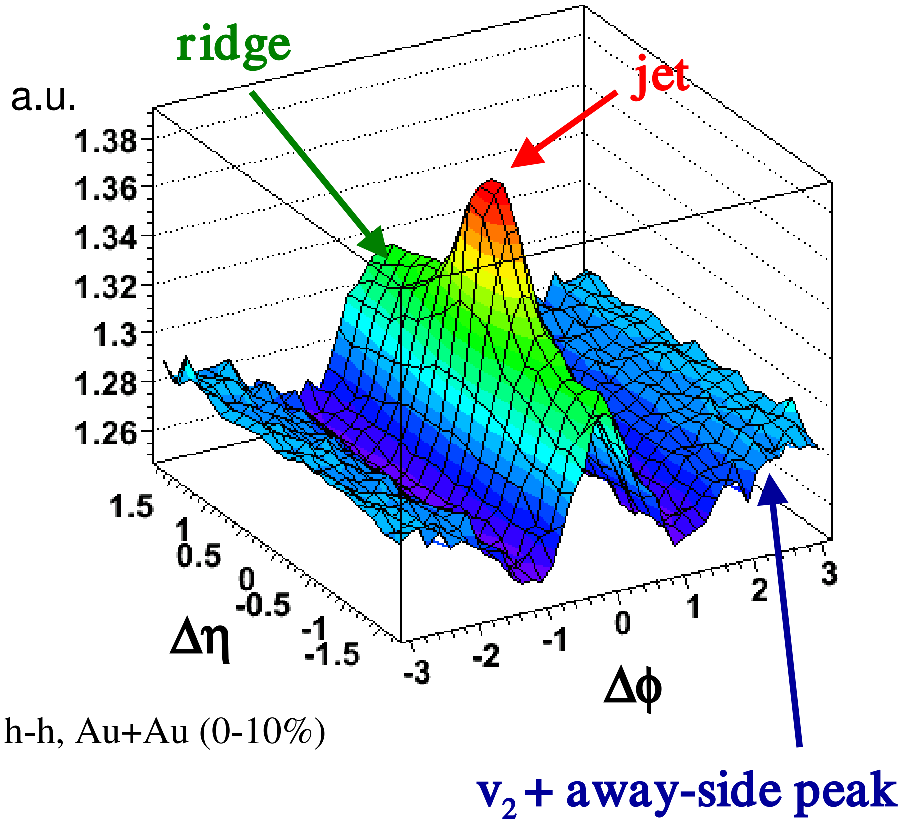


Two-particle correlations: ΔΦΔη

J. Putschke, J.Phys.G34:S679-684,2007

p_T^{trig}=3-6 GeV/c, 1.5 GeV/c <p_T^{assoc}< p_T^{trig}



- The azimuth angle correlations are extended to Δη
- At near-side the „ridge" appears
- High p_T partons interact with the hot background matter

Armesto et al, PRL 93 (2004)
Majumder et al, hep-ph/0611035
Chiu & Hwa Phys. Rev. C72:034903,2005
S.A. Voloshin, Nucl. Phys. A749, 287 (2005)

- Particle composition (B/M ratio, ...):
  - Peak in AuAu: pp-like
  - Ridge in AuAu: different
- QM'08 Poster #218 C.H CHEN (PHENIX)
  --- ridge is softer than hard scattering (pp)
  --- away shoulder is softer than ridge

Reference: bulk pion and proton production
initial thermal quark distributions (gluons have decayed)
quark coalescence at low-p_T and intermediate-p_T
(MICOR results for RHIC and LHC --- Csizmadia, L.P.)

Near-side:

Jet-peak: pQCD with jet-fragmentation

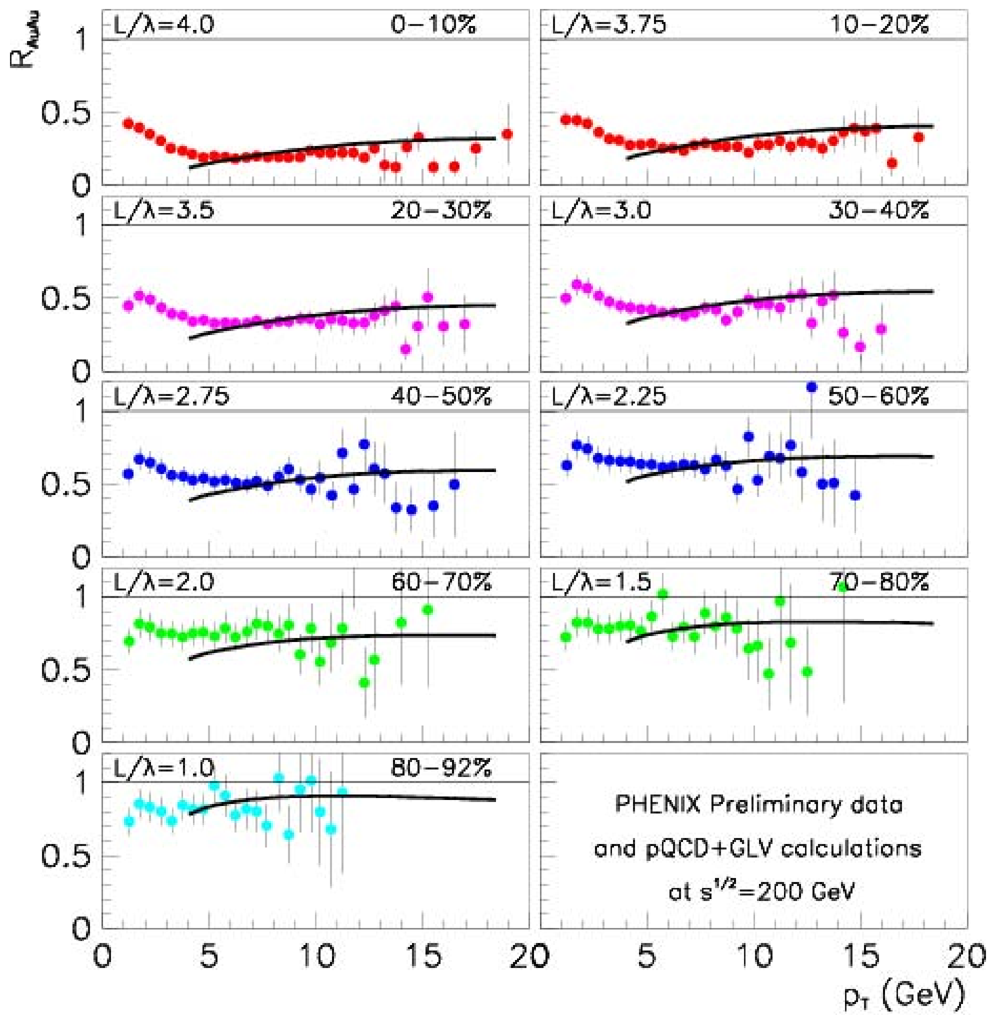
Ridge: ST: shower quark distribution + thermal (anti)quark
STT (or SST) for baryon production

Away-side (just for first approximation):

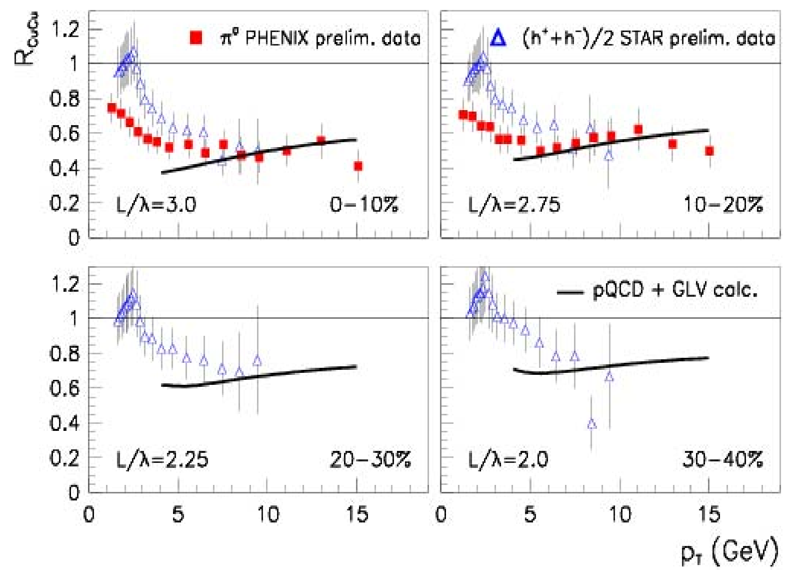
Bump: TT: thermal quark + thermal antiquark for pion
STT + TTT for baryon production

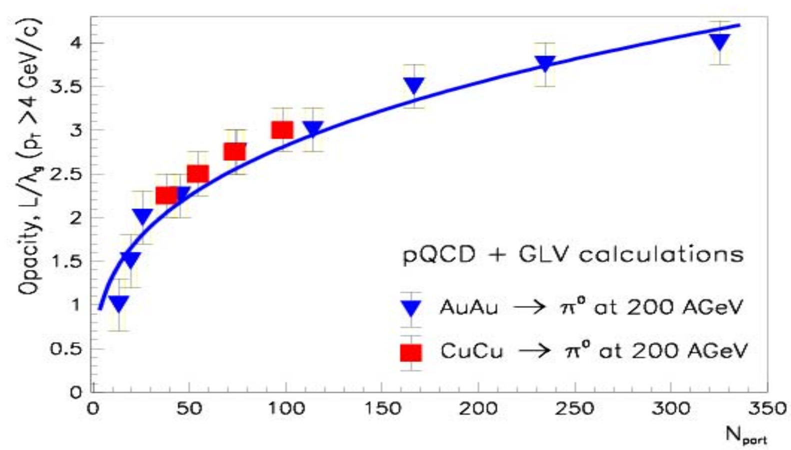
Bulk pion production at high-p_T at 200 AGeV ($p_T > 5$ GeV)

Au + Au collisions (opacities)



Cu+Cu collisions (opacities)



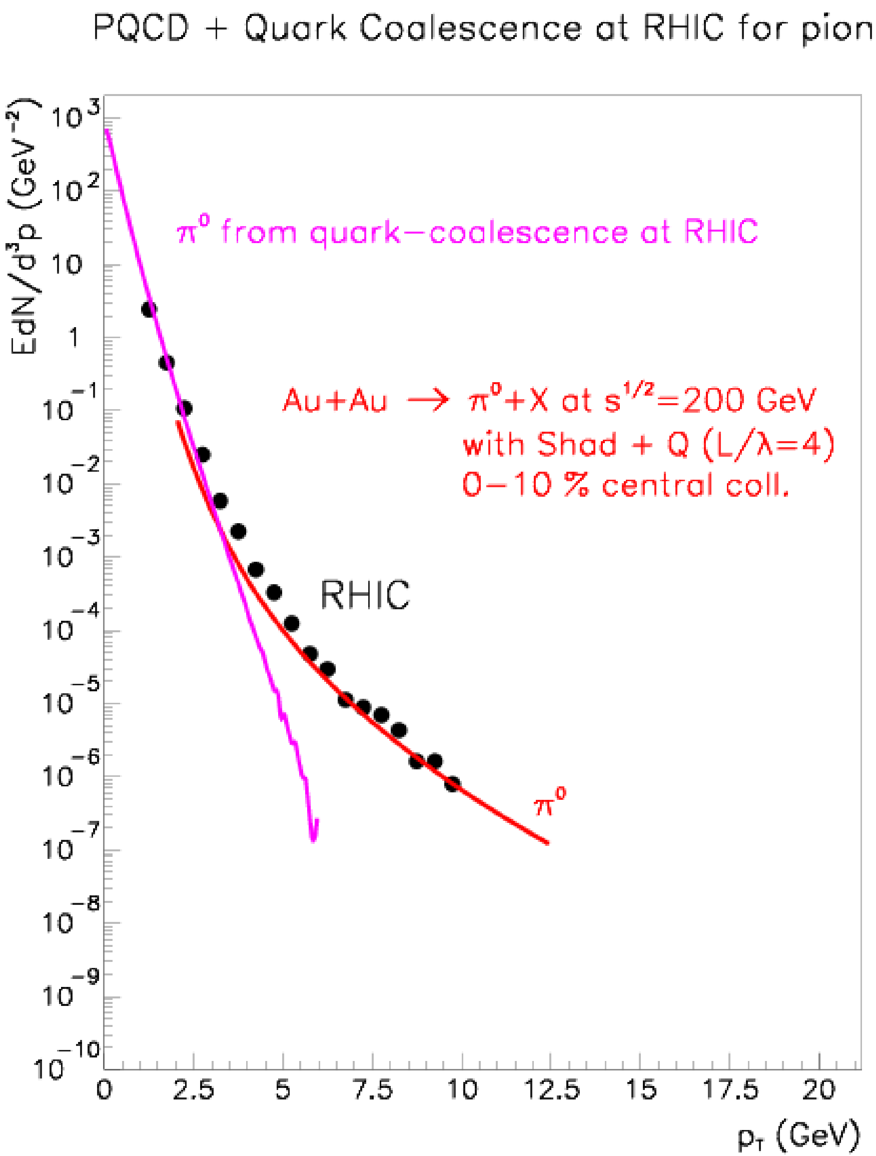


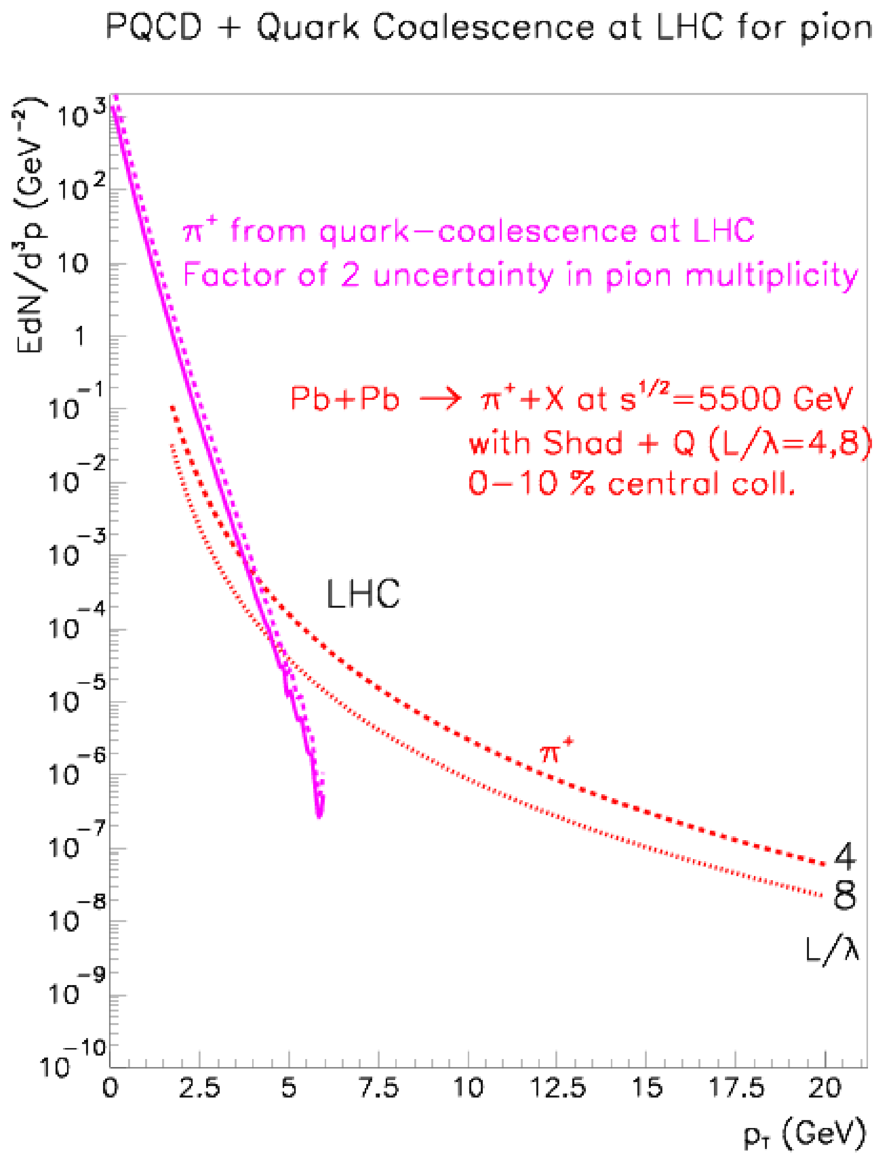
Jet energy loss: volume effect ⇔ $L / \lambda \propto (N_{part})^{1/3}$

G.G. Barnafoldi et al., Eur. Phys. J C33 (2004) S603.

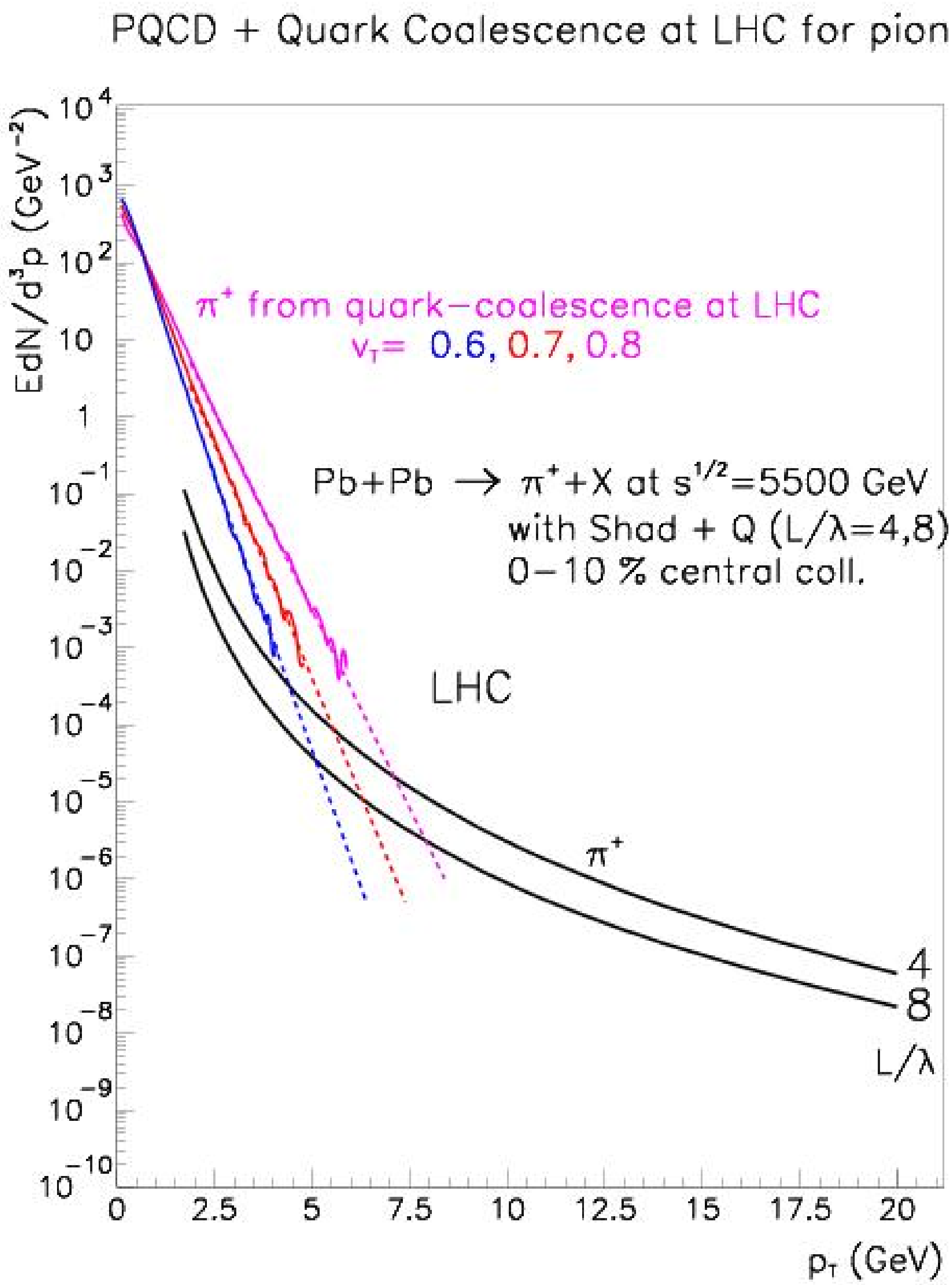
Bulk Pions at RHIC and LHC

(Scaled up RHIC result for coalescence, v_T=0.6.)





Overlap at p_T = 2.5 - 3 GeV (RHIC) at 4 ± 1 GeV at LHC



Bulk pions at LHC:
(latest calculation)

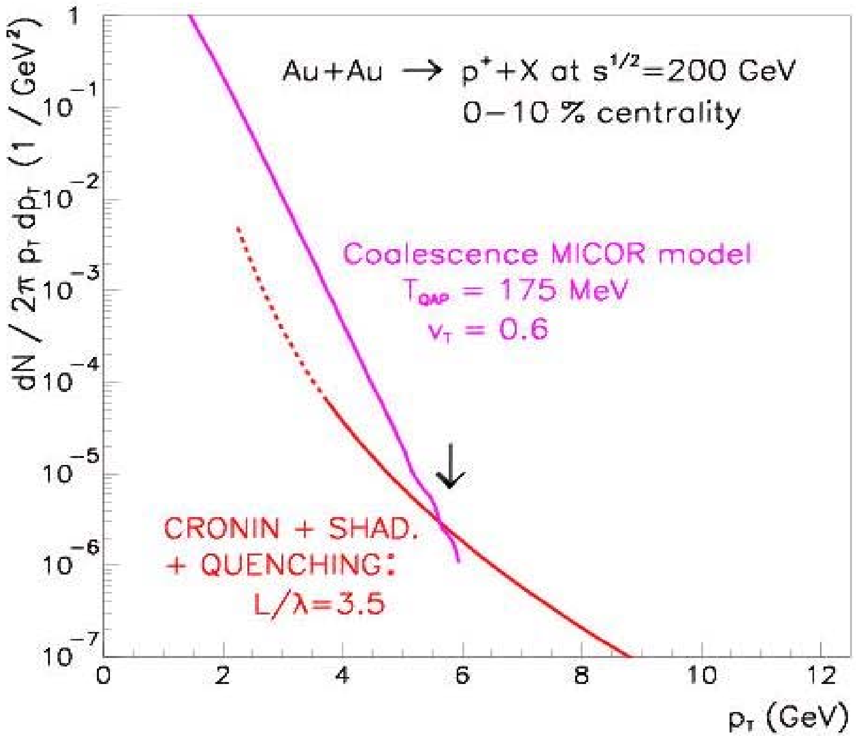
dN/dy (π^+, y=0) = 631
dN/dy (h^-, y=0) = 816

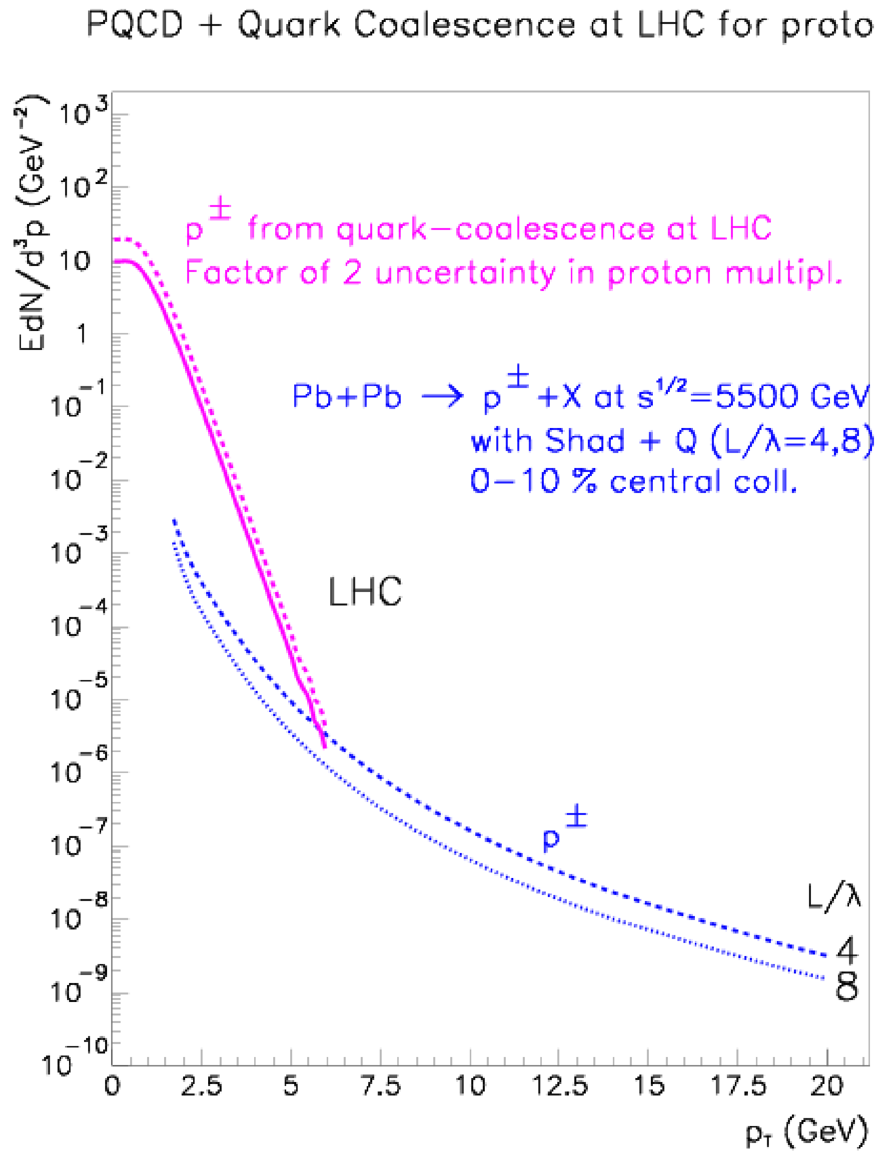
v_T=0.6, 0.7, 0.8

Uncertainty from the transverse flow.

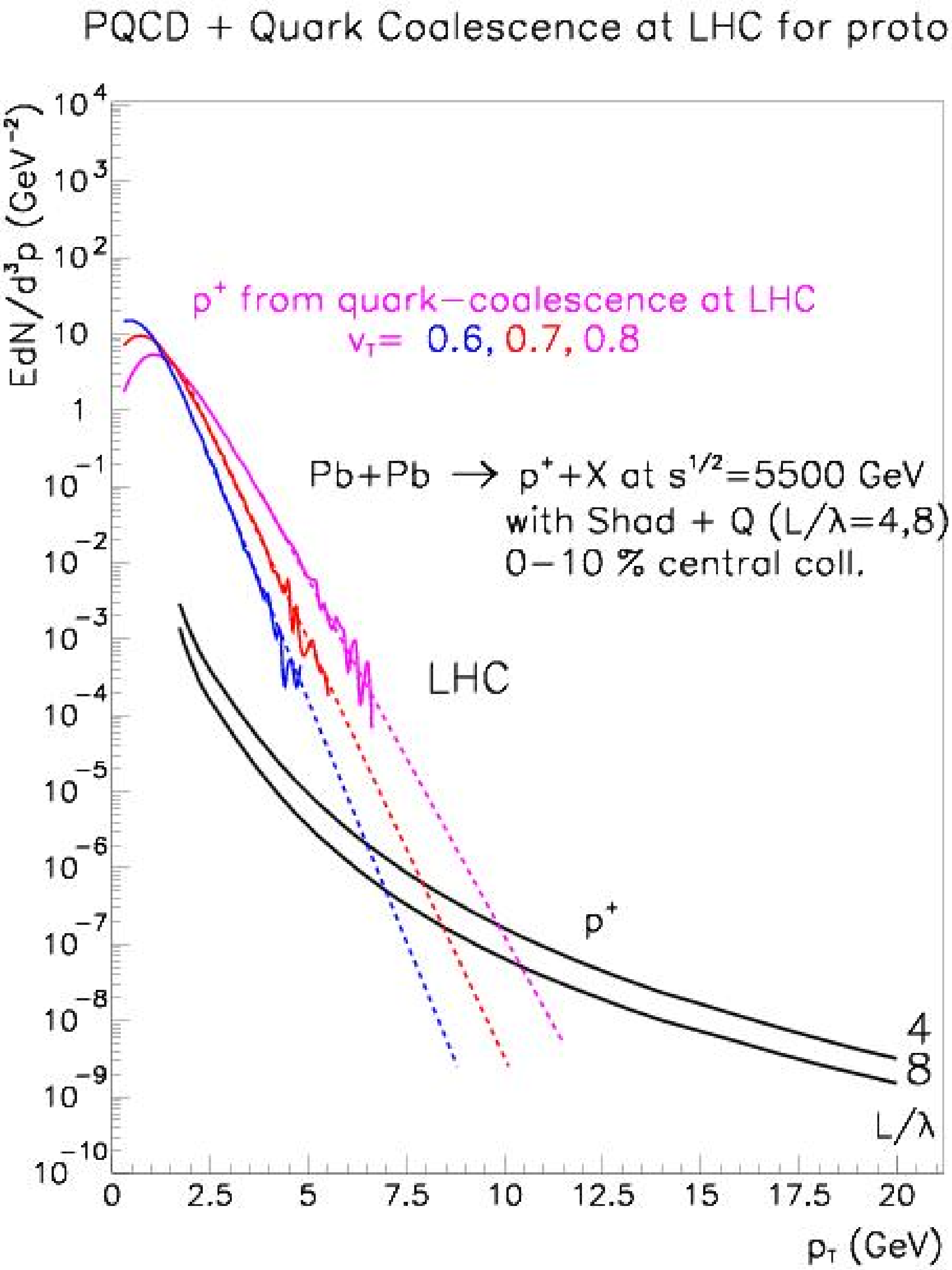
Bulk protons at RHIC and LHC

(Scaled up RHIC result for coalescence, v_T=0.6.)





Overlap at p_T = 5 - 6 GeV (RHIC) at 6± 1 GeV at LHC

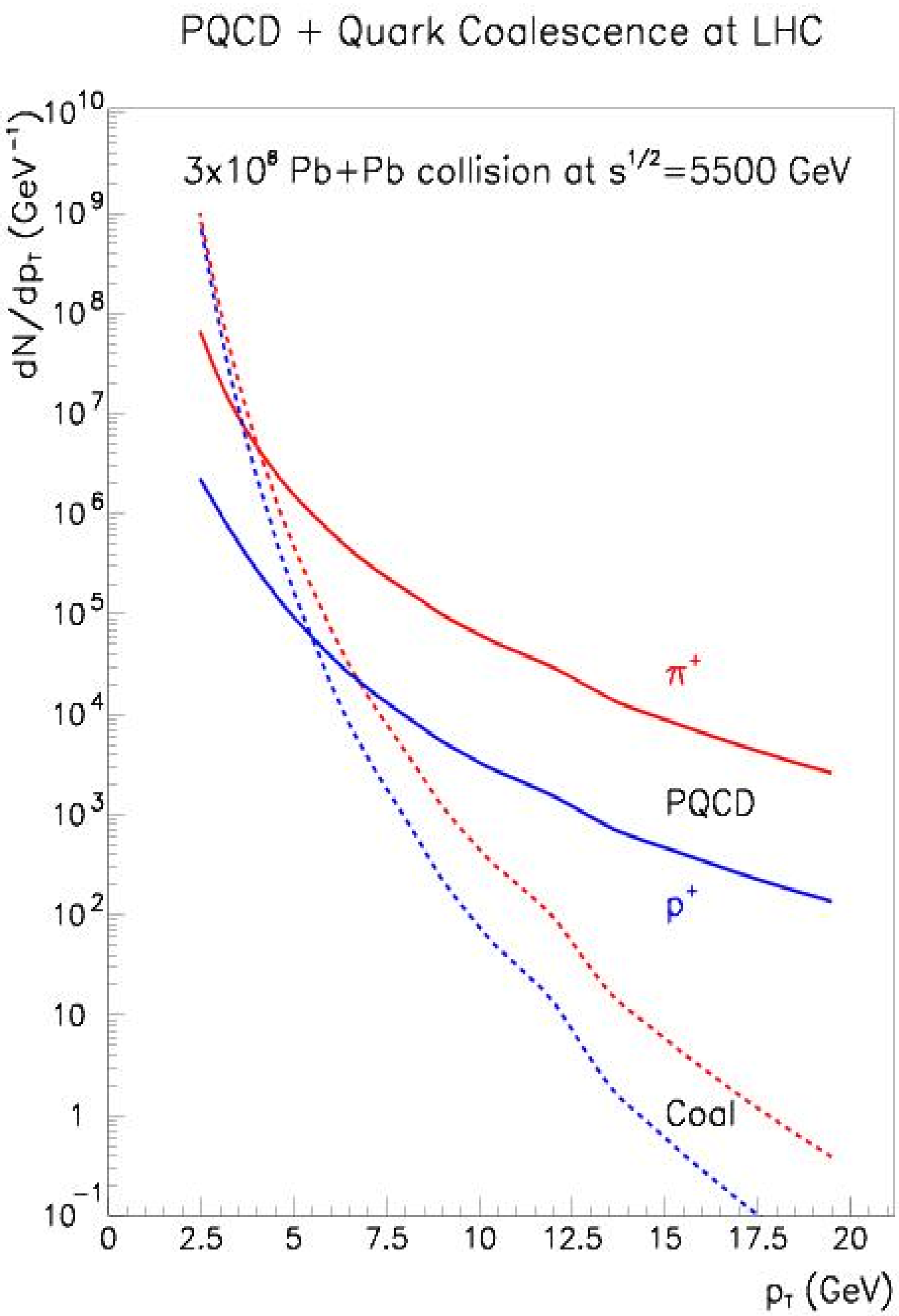


Bulk protons at LHC:
(latest calculation)

dN/dy (p^+, y=0) = 68.6
dN/dy (h^-, y=0) = 816

v_T=0.6, 0.7, 0.8

Uncertainty from the transverse flow.



"1 year" at LHC: absolute yields for bulk pion and proton (v_T=0.7)

What are the wanted proton/pion ratios ?

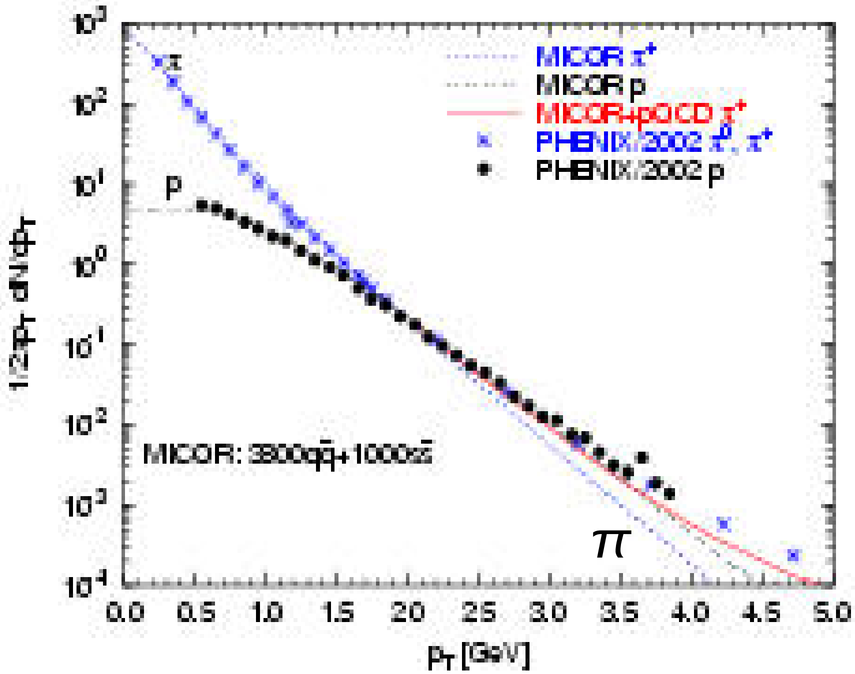
Quark coalescence at low-p_T: MICOR + pQCD model

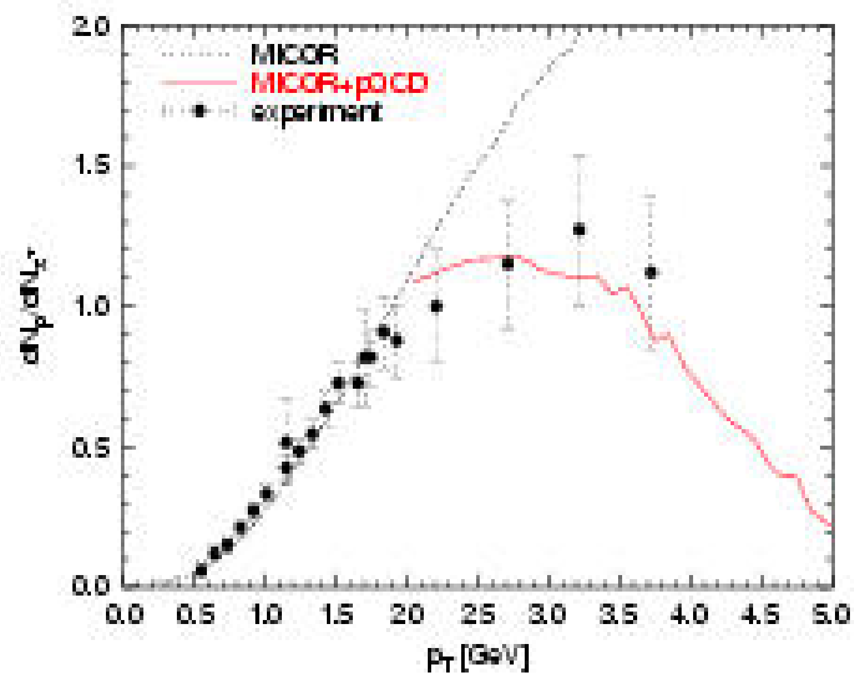
Bulk proton/pion ratio

P. Csizmadia, P.L. '03

MICOR model : quark-coalescence (0 < p_T < 4-5 GeV)

+ pert. QCD : + independent jet-fragment. (2 < p_T < 10 GeV)



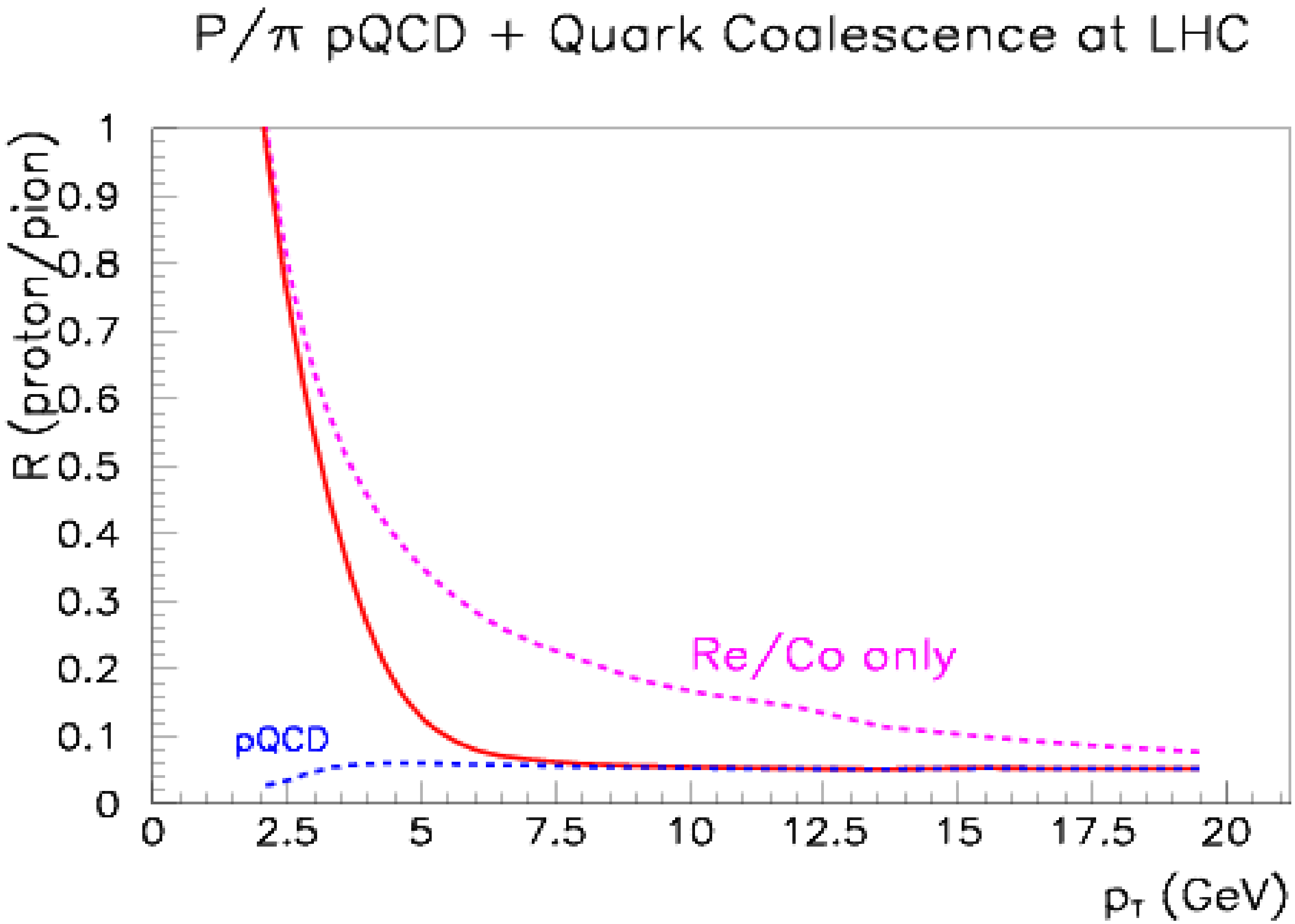


MICOR: pion yield is decreasing faster than proton yield with increasing p_T

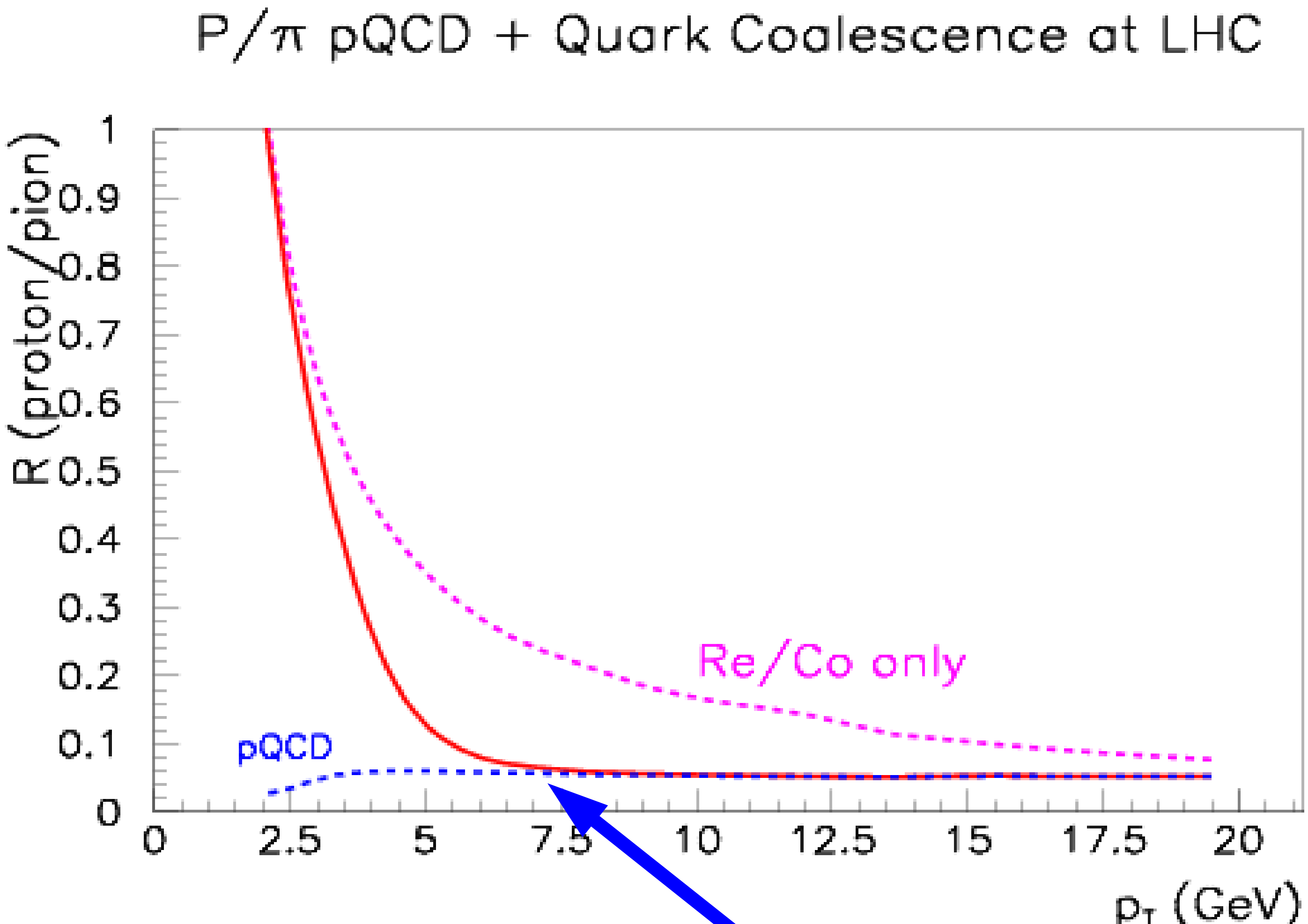
pQCD: FF pion yield is comparable with coal. yield, FF proton yield is negligible

superposition: special structure in proton/pion ratio

Bulk proton/pion ratio at intermediate-p_T: MICOR + pQCD model

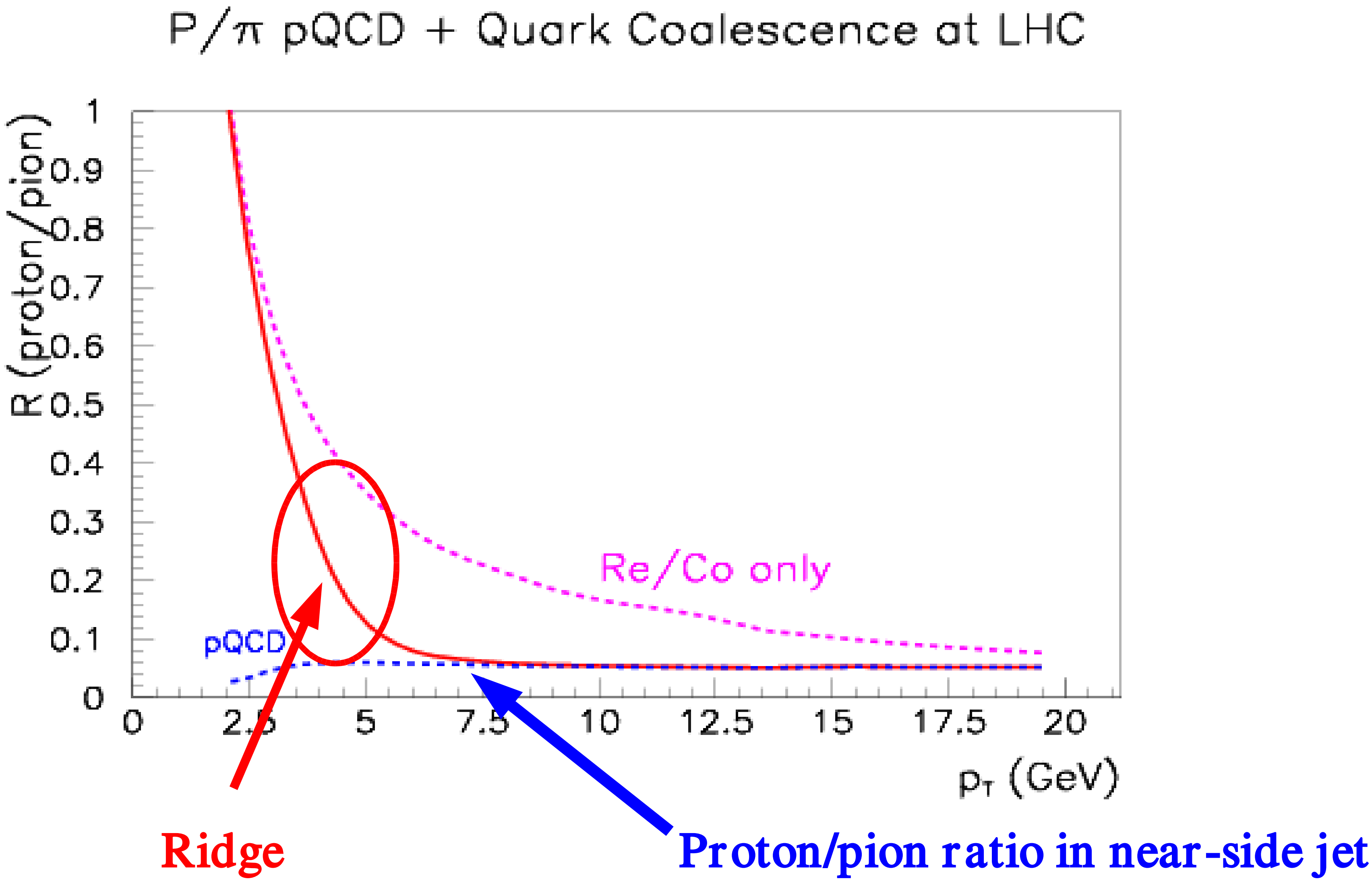


Jet proton/pion ratio at intermediate-p_T: pQCD model



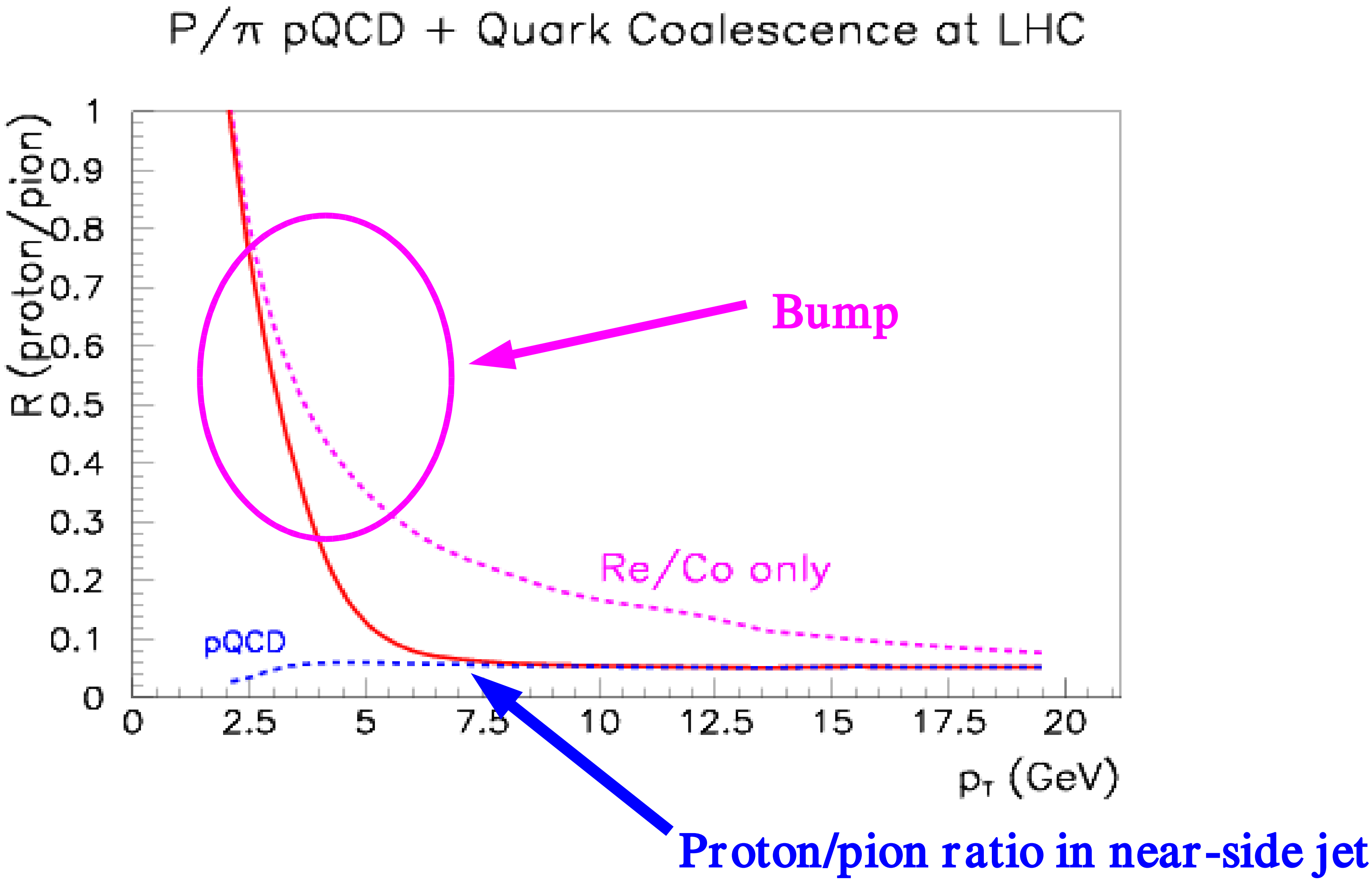
Proton/pion ratio in near-side jet

Ridge proton/pion ratio at intermediate-p_T: ReCo+pQCD model



Bump proton/pion ratio at intermediate-p_T:

ReCo+pQCD model



For precise calculation: meson production on the basis of RECO

V. Greco, C.M. Ko, P. Levai, PRL90 (2003) 202302.
PRC68 (2003) 034904.

Basic coalescence equation: $1 + 2 \to M$

$$\frac{dN_M}{d^3P_M} = g_M \int d^3r_a d^3r_b \frac{d^3p_1}{(2\pi)^3}\frac{d^3p_2}{(2\pi)^3} f_1^W(\vec{p}_1, \vec{r}_a)\, f_2^W(\vec{p}_2, \vec{r}_b) \cdot \delta^3(\vec{P}_M - \vec{p}_1 - \vec{p}_2)\, \mathcal{F}_M^W(\vec{r}_a - \vec{r}_b, \vec{p}_1 - \vec{p}_2)$$

f_i^W: the Wigner function of parton i $(\to dN_i/d^3p)$

$\mathcal{F}_M^W$: the Wigner function of the produced meson M $(\to$ box-like$)$

$$\mathcal{F}_M(\vec{r}_a - \vec{r}_b, \vec{p}_1 - \vec{p}_2) = \frac{1}{\Delta_p^3\,\Gamma_r^3}\frac{9\pi}{2}\Theta(\Delta_p - |\vec{p}_1 - \vec{p}_2|)\cdot\Theta(\Gamma_r - |\vec{r}_a - \vec{r}_b|)\,,$$

Δ_p: a sharp cutoff in the relative momenta

Γ_r: a correlation length in space (the size of the meson)

Longitudinally invariant coalescence rate:

$$\frac{dN_M}{d^2P_M} = \frac{g_M}{V}\frac{6\pi^2}{\Delta_p^3}\int d^2p_1\, d^2p_2 \frac{dN_1}{d^2p_1}\frac{dN_2}{d^2p_2}\delta^2(\vec{P}_{M,\perp} - \vec{p}_{1,\perp} - \vec{p}_{2,\perp})\,\Theta(\Delta_p - |\vec{p}_1 - \vec{p}_2|)\,.$$

Transverse explosion: comoving partons are able to coalesce, $\Phi_1 = \Phi_2$

$$\frac{dN_M}{2\pi P_{M,\perp} dP_{M,\perp}} = \frac{g_M}{V}\frac{6\pi^2}{\Delta_M^3}\int p_{1,\perp}dp_{1,\perp}\, p_{2,\perp}dp_{2,\perp}\frac{dN_1}{2\pi p_{1,\perp}dp_{1,\perp}}\frac{dN_2}{2\pi p_{2,\perp}dp_{2,\perp}} \cdot \frac{1}{P_{M,\perp}^2}\delta\left(1 - \frac{p_{1,\perp} + p_{2,\perp}}{P_{d,\perp}}\right)\Theta(\Delta_M - |p_{1,\perp} - p_{2,\perp}|)$$

R.C. Hwa & C.B. Yang,
PRC66 (2002) 064903.
R.J. Fries, B. Muller,
C. Nonaka, S.A. Bass,
PRL90 (2003) 202303.
PRC68 (2003) 044902.

Ridge: M=S+T:

f_1 : pQCD shower

f_2 : thermal

Baryon production on the basis of RECO

G. K. L. PRL90 (2003) 202302

Basic coalescence equation: $1 + 2 + 3 \longrightarrow B$

$$\frac{dN_B}{d^3P_B} = g_B \int d^3r_1\, d^3r_2\, d^3r_3 \frac{d^3p_1}{(2\pi)^3}\frac{d^3p_2}{(2\pi)^3}\frac{d^3p_3}{(2\pi)^3}\; f_1^W(\vec{p}_1,\vec{r}_1)\; f_2^W(\vec{p}_2,\vec{r}_2)\; f_3^W(\vec{p}_3,\vec{r}_3) \cdot \delta^3(\vec{P}_B - \vec{p}_1 - \vec{p}_2 - \vec{p}_3)\; \mathcal{F}_B^W(\vec{\rho},\vec{\lambda};\vec{q}_\rho,\vec{q}_\lambda)$$

f_i^W: the Wigner function of parton i $(\to dN_i/d^3p)$

$\mathcal{F}_B^W$: the Wigner function of the produced baryon B $(\to$ box-like$)$

$$\mathcal{F}_B(\vec{\rho},\vec{\lambda};\vec{q}_\rho,\vec{q}_\lambda) = \frac{1}{\Delta_\rho^3\,\Gamma_\rho^3}\frac{9\pi}{2}\,\Theta(\Delta_\rho - |\vec{q}_\rho|)\cdot\Theta(\Gamma_\rho - |\vec{\rho}|)\cdot \frac{1}{\Delta_\lambda^3\,\Gamma_\lambda^3}\frac{9\pi}{2}\,\Theta(\Delta_\lambda - |\vec{q}_\lambda|)\cdot\Theta(\Gamma_\lambda - |\vec{\lambda}|)\,.$$

$\Delta_\rho, \Delta_\lambda$: sharp cutoffs in the relative momenta

$\Gamma_\rho, \Gamma_\lambda$: correlation lengths in space ($\sim$ the size of the meson)

Longitudinally invariant coalescence rate:

$$\frac{dN_B}{d^2P_B} = \frac{g_B}{V^2}\frac{36\pi^4}{\Delta_\rho^3\,\Delta_\lambda^3}\int d^2p_1\, d^2p_2\, d^2p_3 \frac{dN_1}{d^2p_1}\frac{dN_2}{d^2p_2}\frac{dN_3}{d^2p_3} \cdot \delta^2(\vec{P}_{d,\perp} - \vec{p}_{1,\perp} - \vec{p}_{2,\perp} - \vec{p}_{3,\perp}) \cdot \Theta(\Delta_\rho - |\vec{q}_{\rho,\perp}|)\cdot\Theta(\Delta_\lambda - |\vec{q}_{\lambda,\perp}|)\,.$$

Transverse explosion: comoving partons are able to coalesce, $\Phi_1 = \Phi_2 = \Phi_3 = \Phi_B$

$$\frac{dN_B}{2\pi P_{B,\perp} dP_{B,\perp}} = \frac{g_B}{V^2}\frac{36\pi^4}{\Delta_B^6}\int p_{1,\perp}dp_{1,\perp}\; p_{2,\perp}dp_{2,\perp}\; p_{3,\perp}dp_{3,\perp} \prod_{i=1,2,3}\frac{dN_i}{2\pi p_{i,\perp}dp_{i,\perp}} \cdot \frac{1}{P_{B,\perp}^2}\,\delta\left(1 - \frac{p_{1,\perp}+p_{2,\perp}+p_{3,\perp}}{P_{B,\perp}}\right)\prod_{i=1,2,3}\Theta_i(\Delta_B - |p_{i,\perp} - p_{i+1,\perp}|)$$

Ridge: B = S+T+T

f_1 : pQCD shower

f_2 : thermal

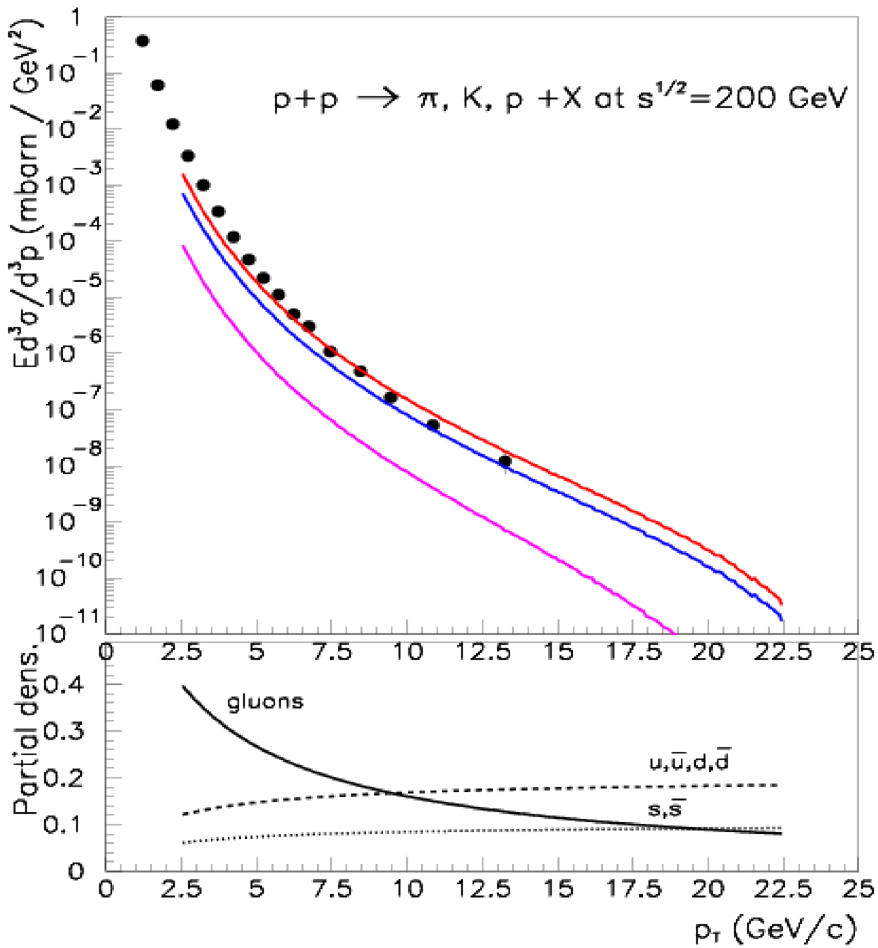
f_3 : thermal

But what are the "pQCD shower" distributions ???

Model: first FF step ↣ leading hadron spectra

remnant partons + one FF step ↣ associated hadrons

leading + associated ↣ final hadron spectra



This model can work:

pion, kaon, proton

one-particle spectra

Two-particle correlation:

(M-B, B-aB correlation)

Independent fragmentation:

no flavour,

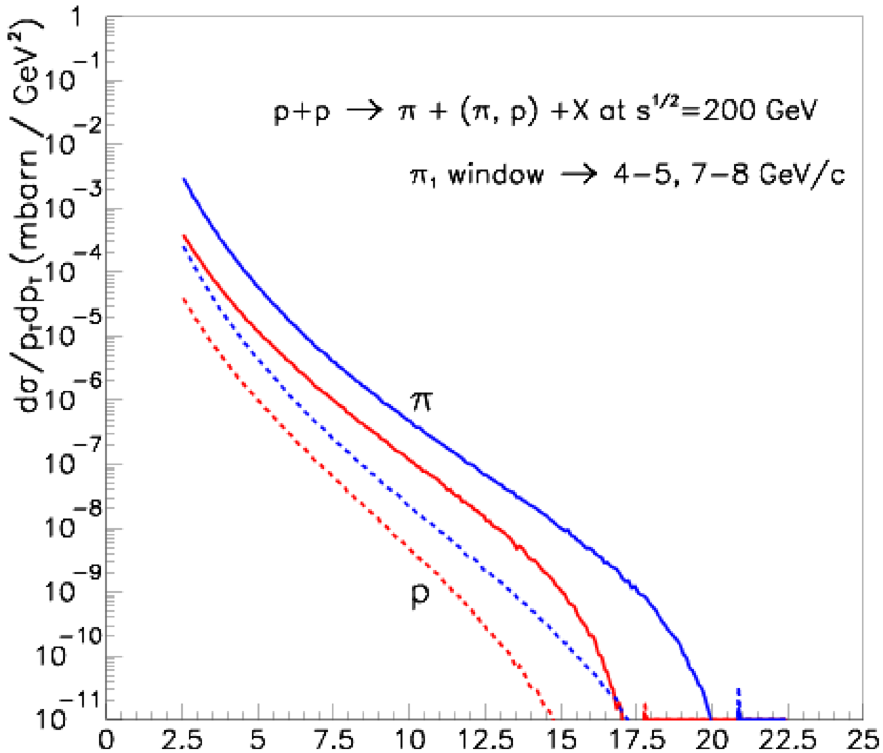
no charge,

no baryon-number

correlation

Near-side h-h correlation in p-p collision

Leading particle is pion in the pT windows: 4-5 GeV/c & 7-8 GeV/c



Momentum distribution for "associated" hadrons:

pions in windows 1 and 2
(full blue and red line)

protons in windows 1 and 2
(dashed blue and red line)

Further works are needed.
How to check it ?

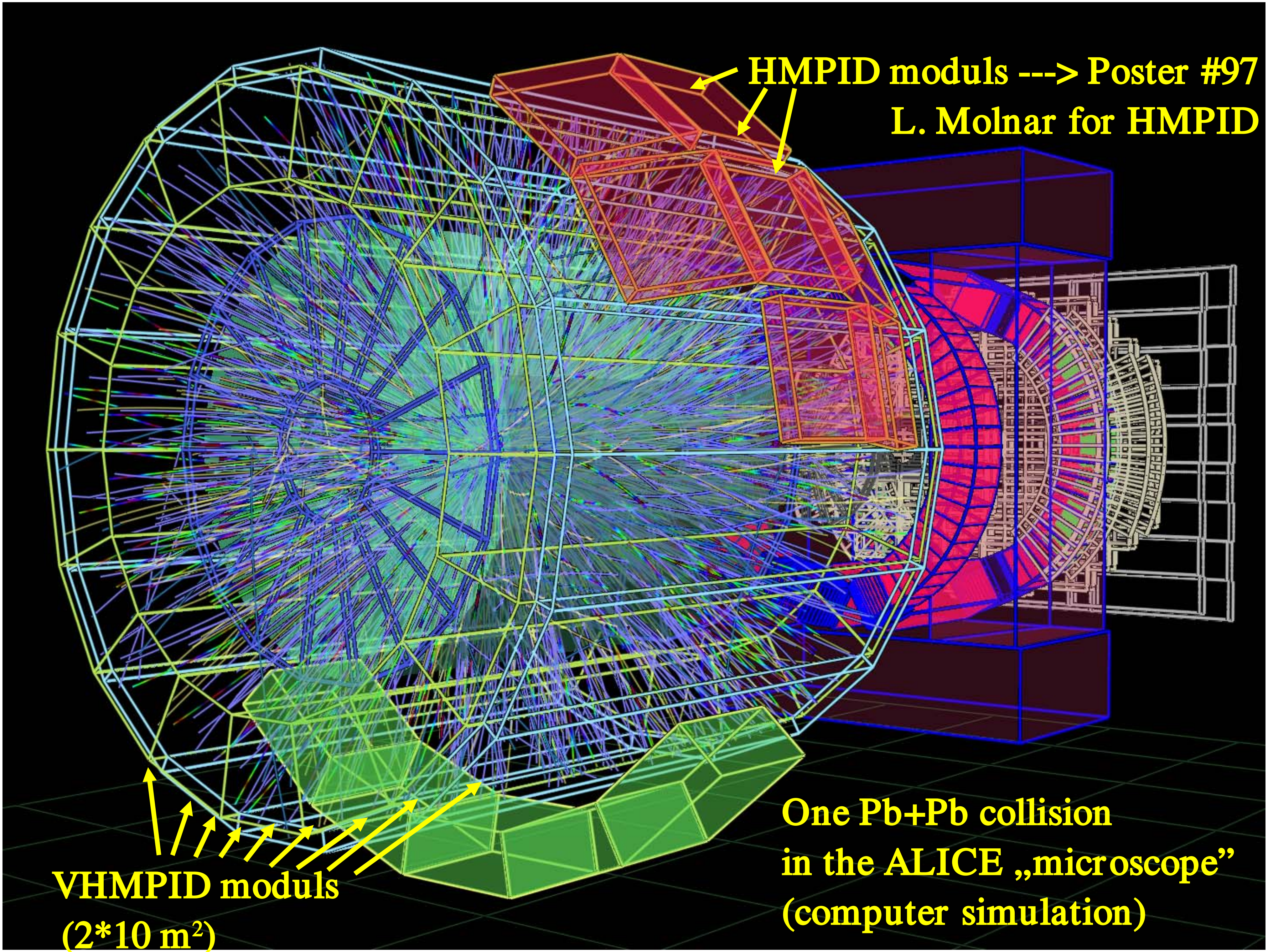
+ influence of quenching !!!

Why intermediate-pT region (p_T = 3-10 GeV/c) is important ?

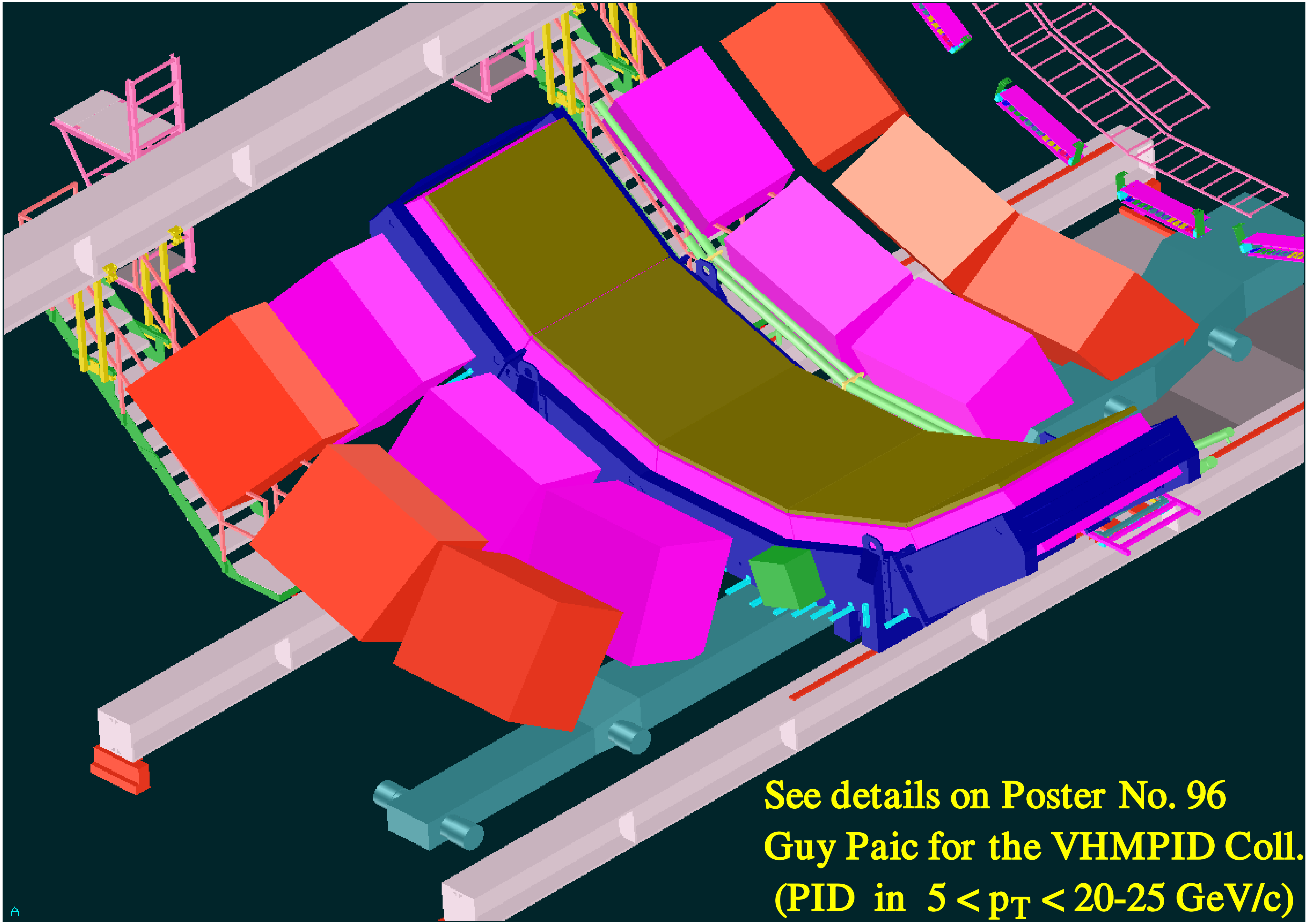
1. π, (K,) p yields in this p_T region (one-particle spectra)
   understanding RHIC data, proton/pion anomaly
   challenge for theory: soft + quark coalescence + pQCD
   particle production mechanisms
   deeper knowledge on FF
   jet energy loss, flavor dependence

2. Near-side hadron-hadron correlations (two-particle spectra)
   B-M (π-p) and B-B (p-$\bar{p}$) correlations at RHIC
   Parton-showers, dFFs ($D_B * D_M$, $D_B * D_{\bar{B}}$, or D_{BM}, ... ?)
   Triple-, 4-particle FFs ? In-matter modifications?
   Jet energy loss: volume or surface effect?

3. Only after the answers of the above problems:
   Away-side hadron-hadron correlations
   which is complicated, includes further effects:
   size; influence of k_T-imbalance; in-matter effects; ...


HMPID moduls ---> Poster #97
L. Molnar for HMPID
One Pb+Pb collision
in the ALICE „microscope"
(computer simulation)
VHMPID moduls
(2*10 m²)

Aim: 6+6 VHMPID moduls around the PHOS detector (kb. 2x10 m^2) – 2010/11



Conclusions:

1. Soft/hard overlap: intermediate -p_T region
   Precise measurement is the key point for understanding
   hadron production mechanisms;

2. Two-particle correlations:
   near-side correlation is simpler but not trivial.
   AuAu collisions vs pp collisions at RHIC-200:
   enhancement at lower-p_T and suppression at high-p_T;
   in-matter effects are seen in near-side correlations
   Quenching is volume effect !!!
3. Proton-pion anomaly in near-side correlations in Au+Au coll.
   in-matter effects in the ridge – challenging for theory

4. Surprise in the 5 < pT < 20 GeV/c region at LHC !!!??
   ➣ ➣ ALICE HMPID ➣➣➣ ALICE VHMPID detectors