The Heavy Bowling Ball (c+b jets) probes of sQGP

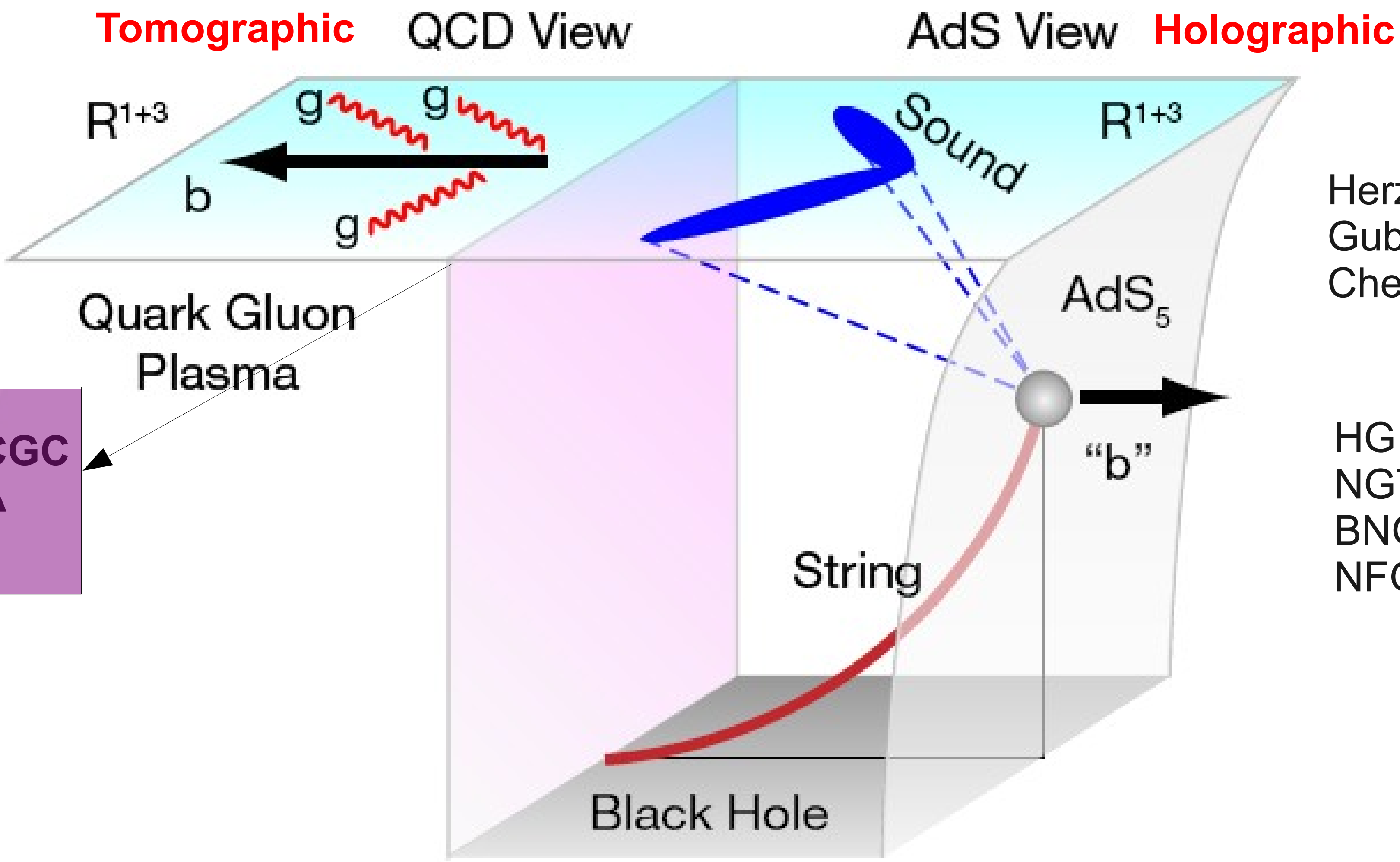
A QM12 Post Mortem

M. Gyulassy , Columbia U

pQCD Tomography vs hQCD Holography
UV probes of ultra dense QGP Matter

M.Gyulassy
Physics **2**, 107 (2009)

GLV
DGLV
BDMPS
ASW
WHDG
ZLCPI
AMYHG
CUJET



Opacity of CGC GLASMA at LHC?

McV
KLN
BK
JMWLK
AM

Herzog ..
Gubser ..
Chesler ..

HG
NGT
BNGT
NFG

Can either paradigm account for both RHIC and LHC jet observables ?

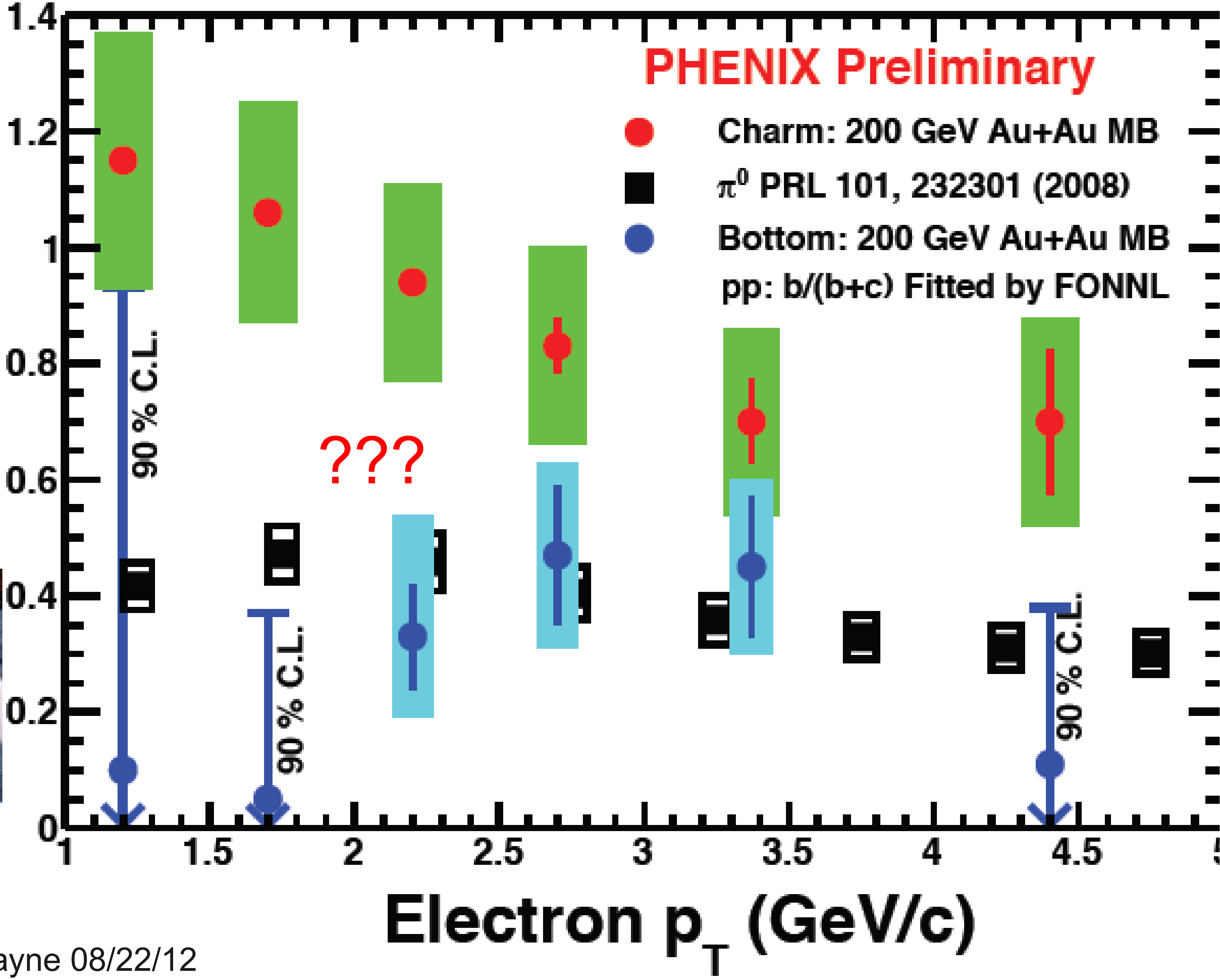
Does CGC initial state "cloud" jet tomography prospects at LHC ?

Prelude:

QM12 PHENIX Surprises

That Question our hard probe paradigms

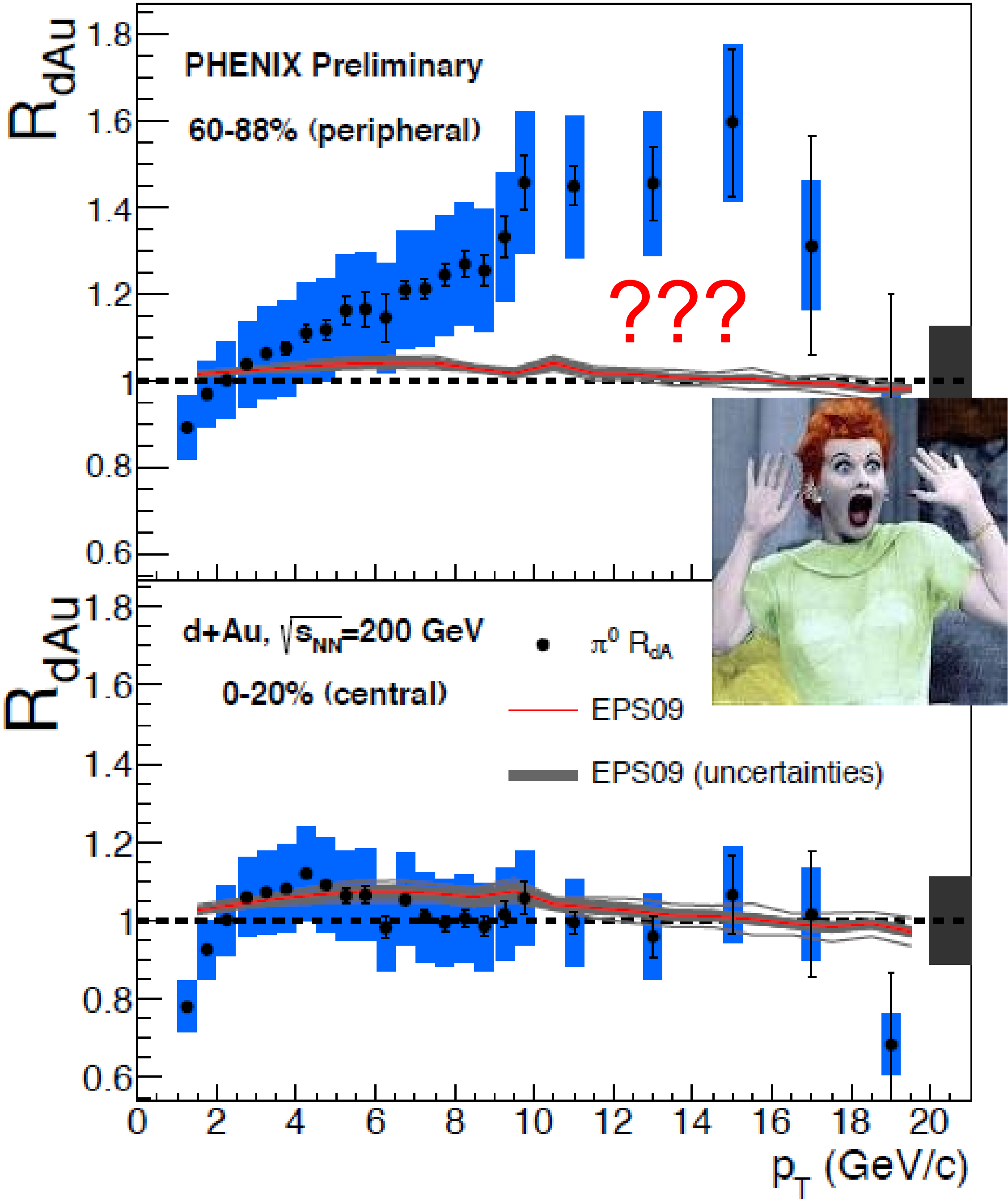
A first shock at QM12 by PHENIX (B->e/D->e) ($p_{T_e} < 3.5$) < 1 !!



MGyulassy Wayne 08/22/12

The PHENIX *Peripheral* DAu Shock (QM12)

- Mapping centrality dependence as integrated longitudinal density through the nucleus, using EPS09 + Glauber MC + PYTHIA (x,Q²)
- Using real PHENIX centrality distributions
- Leads also to only a weak centrality dependence
- Again, data is not matched in peripheral collisions
- It seems that T_A scaling does not work => different physics, beyond modified nPDFs

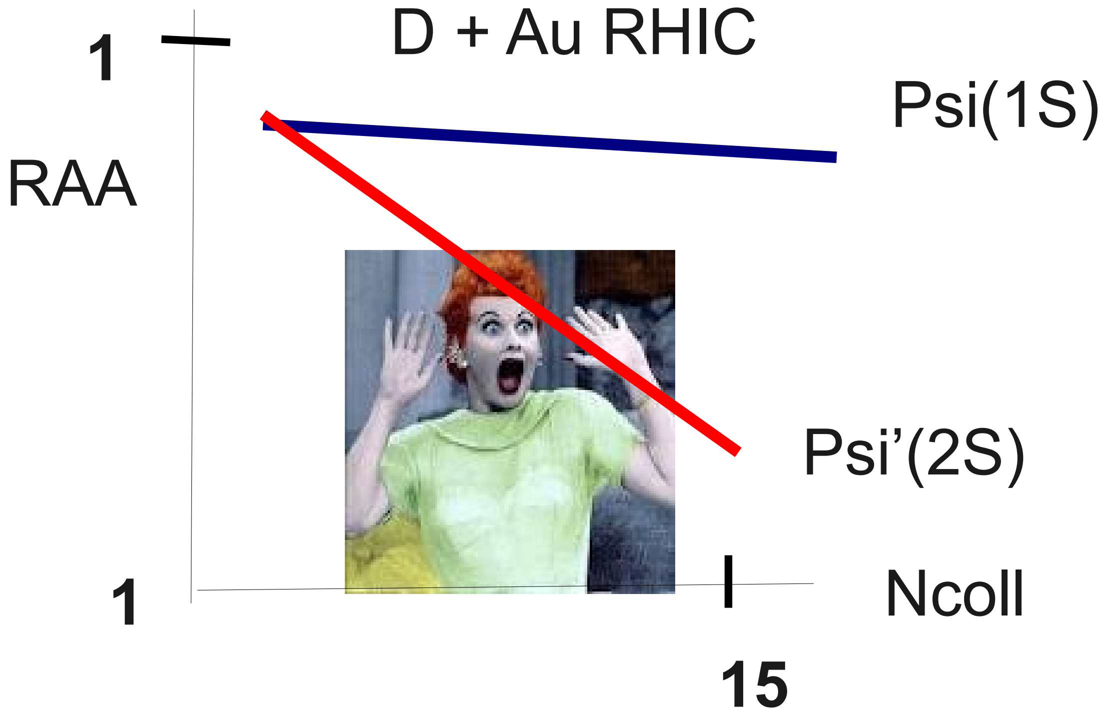


Ladies and Gents: Something is Rotten in the State of Denmark

YET Another Monkey Wrench Model: YAMOM

See Manuel Calderon's previous talk

PHENIX QM12
(Dau -> Psi' / Dau → Psi) → 0 as Ncoll increases to 15



IF the QM12 PHENIX prelim data go away by QM14,

Then we can go on quibling about JET details as at this meeting.

IF they survive, then our JET collab will need to find another direction

I assume here the former.

Idealized Dynamical Scenarios for Hard Probes Now under debate:

1) CGC: All Quenching / Anti Quenching Phenomena are <u>Initial State</u> Effects

2) pQCD: <u>Eikonal</u> elast and radiative Opacity expansion, Evolution Eqs,
eff Rate eqs., ...
Assumes QGP has quasiparton d.o.f.

3) hQCD: <u>Holographic</u> higher D= 5 ...10 Gravity dual / string models

4) npQCD: <u>Non-perturbative</u> jet-medium (e.g., mag monopole gas SL model)

5) eff Transport:: non equilibrium parton transport , non extensive Tsallis/Levy
Power law tails beyond Bulk Hydro

6) Hybrid phenomenology: YAJEM, JEWEL, Polytrop, FP , ...

The Jet nuclear modification factor :

A+A
exp

$$\frac{d\sigma_a(p_f)}{dyd^2p_f} \equiv R^a_{AA}(p_f)\frac{d\sigma^0_a(p_f)}{dyd^2p_f}$$

p+p & nuclear geom
Exp and pQCD

$$= \left\langle \int \underbrace{d\epsilon P_a(\epsilon; p_i, \mathbf{x}, \phi)} \left(\frac{d^2p_i}{d^2p_f}\right)\frac{d\sigma^0_a(p_i)}{dyd^2p_i}\right\rangle_{\mathbf{x},\phi} .$$

geometry

Jet energy loss
theory

Prob of fractional energy loss $p_i = p_f/(1-\epsilon)$

$$\boxed{\begin{aligned} R^{q,g}_{AA}(P_f, \vec{x}_0, \phi) &= \frac{dN^{jet}_{QGP}(P_f)}{dyd\phi dP_f^2} \Big/ \frac{dN^{jet}_{vac}(P_f)}{dyd\phi dP_0^2} \\ &= \frac{dP_0^2}{dP_f^2}\frac{dN^{jet}_{vac}[P_0(P_f)]}{dyd\phi dP_0^2} \Big/ \frac{dN^{jet}_{vac}(P_f)}{dyd\phi dP_0^2} \end{aligned}}$$

$$v_n^\pi(N_{part}) = \frac{\int d\phi \cos\{n\,[\phi-\psi_n]\}\; R^\pi_{AA}(N_{part},\phi)}{\int d\phi\, R^\pi_{AA}(N_{part},\phi)}$$

Jet azimuthal
asymmetry

Dynamical Scenarios for Hard Probes:

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Perturbative (HTL,Eikonal) QCD Opacity series for indunced gluon radiation (DGLV 2005)

$$x\frac{dN^{(n)}}{dx\,d^2\mathbf{k}} = \frac{C_R\alpha_s}{\pi^2}\frac{1}{n!}\int\prod_{i=1}^{n}\left(d^2\mathbf{q}_i\,\frac{L}{\lambda_g(i)}\left[\bar{v}_i^2(\mathbf{q}_i)-\delta^2(\mathbf{q}_i)\right]\right)\times$$
$$\times\left(-2\,\tilde{\mathbf{C}}_{(1,\cdots,n)}\cdot\sum_{m=1}^{n}\tilde{\mathbf{B}}_{(m+1,\cdots,n)(m,\cdots,n)}\left[\cos\left(\sum_{k=2}^{m}\Omega_{(k,\cdots,n)}\Delta z_k\right)-\cos\left(\sum_{k=1}^{m}\Omega_{(k,\cdots,n)}\Delta z_k\right)\right]\right)$$

geom

Soft Radiation ($E \gg \omega, x \ll 1$)
Soft Scattering ($E \gg q, \omega \gg k_T$)

Opacity series expantion → $\left(\frac{L}{\lambda}\right)^n$

Radiation antenna → *Cascade terms*

$$\tilde{\mathbf{C}}_{(i_1 i_2\cdots i_m)} = \frac{(\mathbf{k}-\mathbf{q}_{i_1}-\mathbf{q}_{i_2}-\cdots-\mathbf{q}_{i_m})}{(\mathbf{k}-\mathbf{q}_{i_1}-\mathbf{q}_{i_2}-\cdots-\mathbf{q}_{i_m})^2+m_g^2+M^2x^2},$$

$$\tilde{\mathbf{B}}_{(i_1 i_2\cdots i_m)(j_1 j_2\cdots j_n)} = \tilde{\mathbf{C}}_{(i_1 i_2\cdots i_m)} - \tilde{\mathbf{C}}_{(j_1 j_2\cdots j_n)},$$

Gunion – Bertsch $\tilde{\mathbf{B}}_i = \tilde{\mathbf{H}} - \tilde{\mathbf{C}}_i\,,$

Hard $\tilde{\mathbf{H}} = \frac{\mathbf{k}}{\mathbf{k}^2+m_g^2+M^2x^2},$

Heavy Quark Mass

LPM effect →

$$\Omega_{(m,\cdots,n)} = \underbrace{\frac{(\mathbf{k}-\mathbf{q}_m-\cdots-\mathbf{q}_n)^2}{2xE}}_{\text{Inverse formation time}} + \underbrace{\frac{m_g^2+M^2x^2}{2xE}}_{\text{Mass effects}}$$

Scattering center distribution → $\Delta z_k = z_k - z_{k-1} \sim L/(n+1)$

Can now be computed via Monte Carlo CUJET1.0 up to n =1+… + 9 (A.Buzzatti,MG)

The famous Heavy quark “Dead Cone” in QCD

(Dokshitzer,Kharzeev)

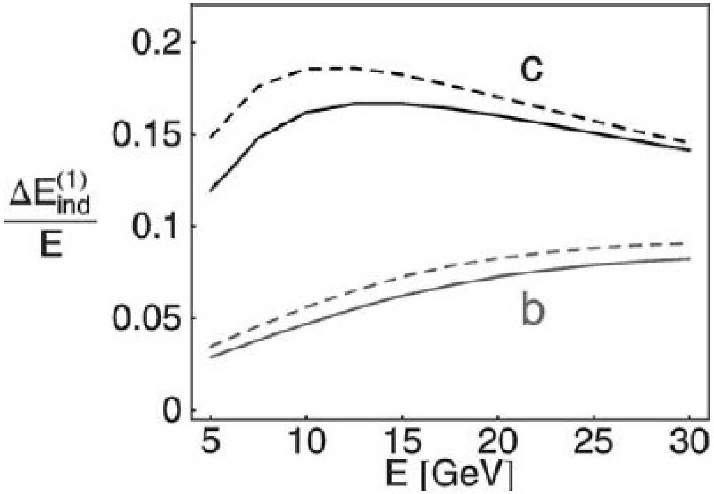
$$\omega \frac{dN_g^{(0)}}{d^3\vec{k}} \approx x \frac{dN_g^{(0)}}{dx\, d^2\vec{k}_\perp} \approx \frac{C_R \alpha_s}{\pi^2} \frac{\mathbf{k}^2}{(\mathbf{k}^2 + m_g^2 + x^2 M^2)^2}.$$

Eq. (9) clearly shows the depletion of radiation in the “dead cone” [29] at angles

$$\theta < \theta_c = \sqrt{m_g^2 + x^2 M^2}/(xE)$$

generalized to take into account also the Ter-Mikayelian dielectric dispersion in a QGP.

$$\frac{dE_{\text{ind}}^{(1)}}{dx} = \frac{C_R \alpha_S}{\pi} \frac{L}{\lambda} E \int \frac{d\mathbf{k}^2}{\mathbf{k}^2 + m_g^2 + M^2 x^2} \int \frac{d^2\mathbf{q}_1}{\pi} \frac{\mu^2}{(\mathbf{q}_1^2 + \mu^2)^2} \times 2 \frac{\mathbf{k} \cdot \mathbf{q}_1 (\mathbf{k} - \mathbf{q}_1)^2 + (m_g^2 + M^2 x^2)\mathbf{q}_1 \cdot (\mathbf{q}_1 - \mathbf{k})}{(\frac{4Ex}{L})^2 + ((\mathbf{k} - \mathbf{q}_1)^2 + M^2 x^2 + m_g^2)^2},$$



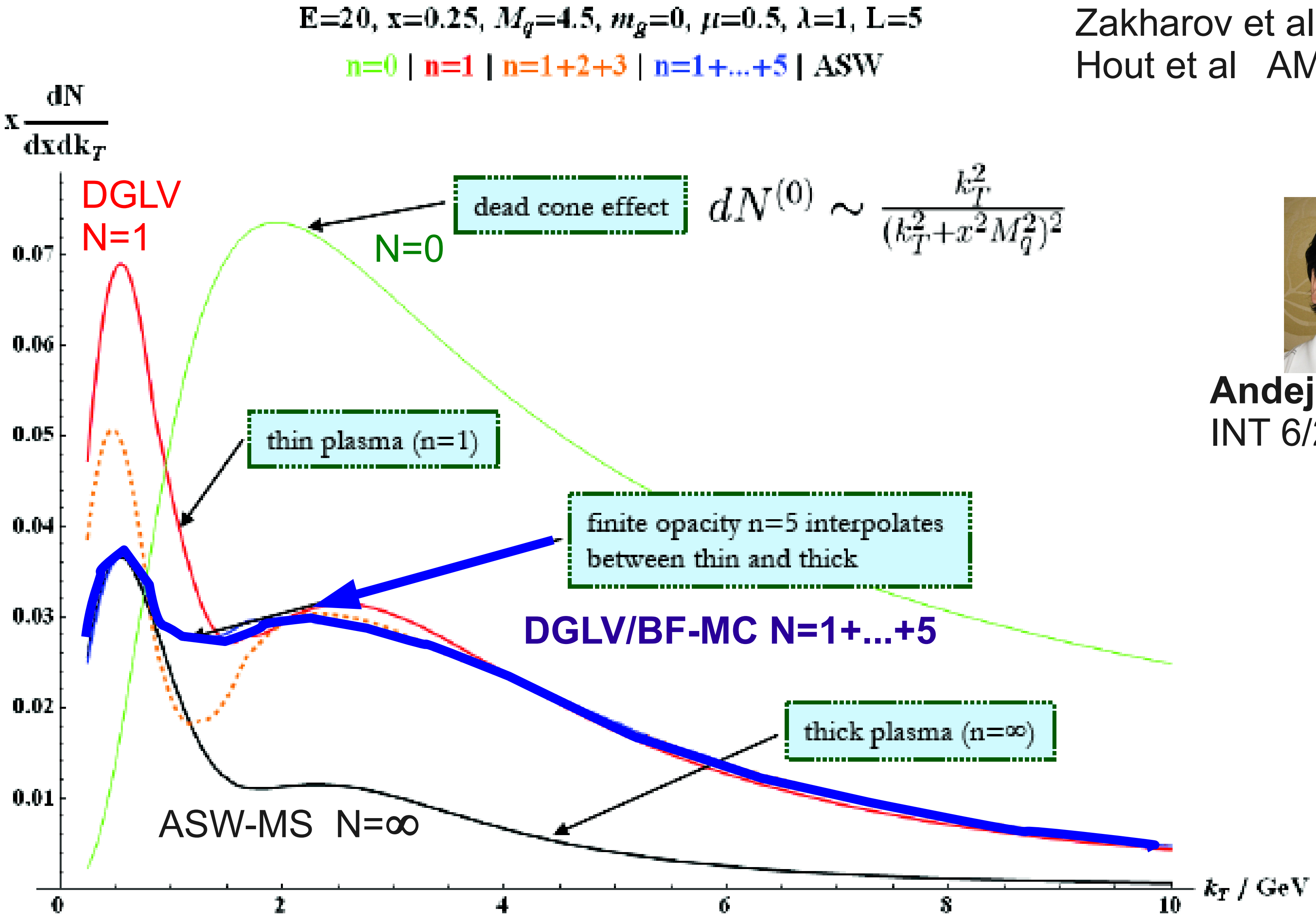
M. Djordjevic, M. Gyulassy / Nuclear Physics A 733 (2004) 265–298

Progress on numerical MC interpolation between N=1 and N = ∞

Buzzatti, Ficnar, Gyulassy, Wicks, to be published

DGLV vs ASW

See also:
Zakharov et al LCPI
Hout et al AMY-HG



$$dN^{(0)} \sim \frac{k_T^2}{(k_T^2+x^2M_q^2)^2}$$

Andej Ficnar
INT 6/25/10

Dynamical Scenarios for Hard Probes:

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Soft and Hard AdS/CFT Holography: J. Noronha, GTorrieri, MG, 0906.4099 [hep-ph]

Both *Bulk Flow* and *Jet observables* are predicted ***analytically*** by AdS – GB holography

$$\frac{S}{S_{SB}} \overset{*}{=} \frac{3}{4}\left(1+\lambda_{GB}+\frac{1}{8}\left(\frac{5\sqrt{\lambda_{tH}}}{16\,Nc^2}+\frac{15\,\mathrm{Zeta}[3]}{\lambda_{tH}^{3/2}}\right)\right)$$

$$\frac{\eta}{S} \overset{**}{=} \frac{1}{4\pi}\left(1-4\,\lambda_{GB}+\frac{5\sqrt{\lambda_{tH}}}{16\,Nc^2}+\frac{15\,\mathrm{Zeta}[3]}{\lambda_{tH}^{3/2}}\right)$$

$$\frac{dP}{dt} = -\mu_Q\,P \overset{***}{=} -\sqrt{\lambda_{tH}}\left(1+\frac{3\,\lambda_{GB}}{2}+\frac{15\,\mathrm{Zeta}[3]}{16\,\lambda_{tH}^{3/2}}\right)\frac{\pi\,T^2}{2\,M_Q}\,P$$

via simultaneous fit to

1) EOS via Lattice QCD experiment
2) Viscosity via AA Elliptic Flow
3) Relativistic Drag via Heavy Quark Jet Quenching
4) Jet+Bulk coupled 1+2+3 via associated two particle conical correlations

V2 vs RAA(e) fits $(\lambda_{tH}\,,\ \lambda_{GB}) \sim (\,7 \pm 1,\ 0. \pm 0.1)$

Heavy quark jet tomography of Pb + Pb at LHC: AdS/CFT drag or pQCD energy loss?

W.A. Horowitz [a,b,*], M. Gyulassy [a,b]

$$n_Q + 1 = -\frac{d}{d\log p_T}\log\left(\frac{d\sigma_Q}{dy\,dp_T}\right)$$

from pQCD ~ pp data

$$R^Q_{AA}(p_T) = \langle (1-\epsilon)^{n_Q} \rangle$$

$$R^Q_{AA}(p_T) = \frac{1-e^{n_Q\mu_Q L}}{n_Q\mu_Q L} \approx \frac{1}{n_Q\mu_Q L} \propto \text{M} \qquad (3)$$

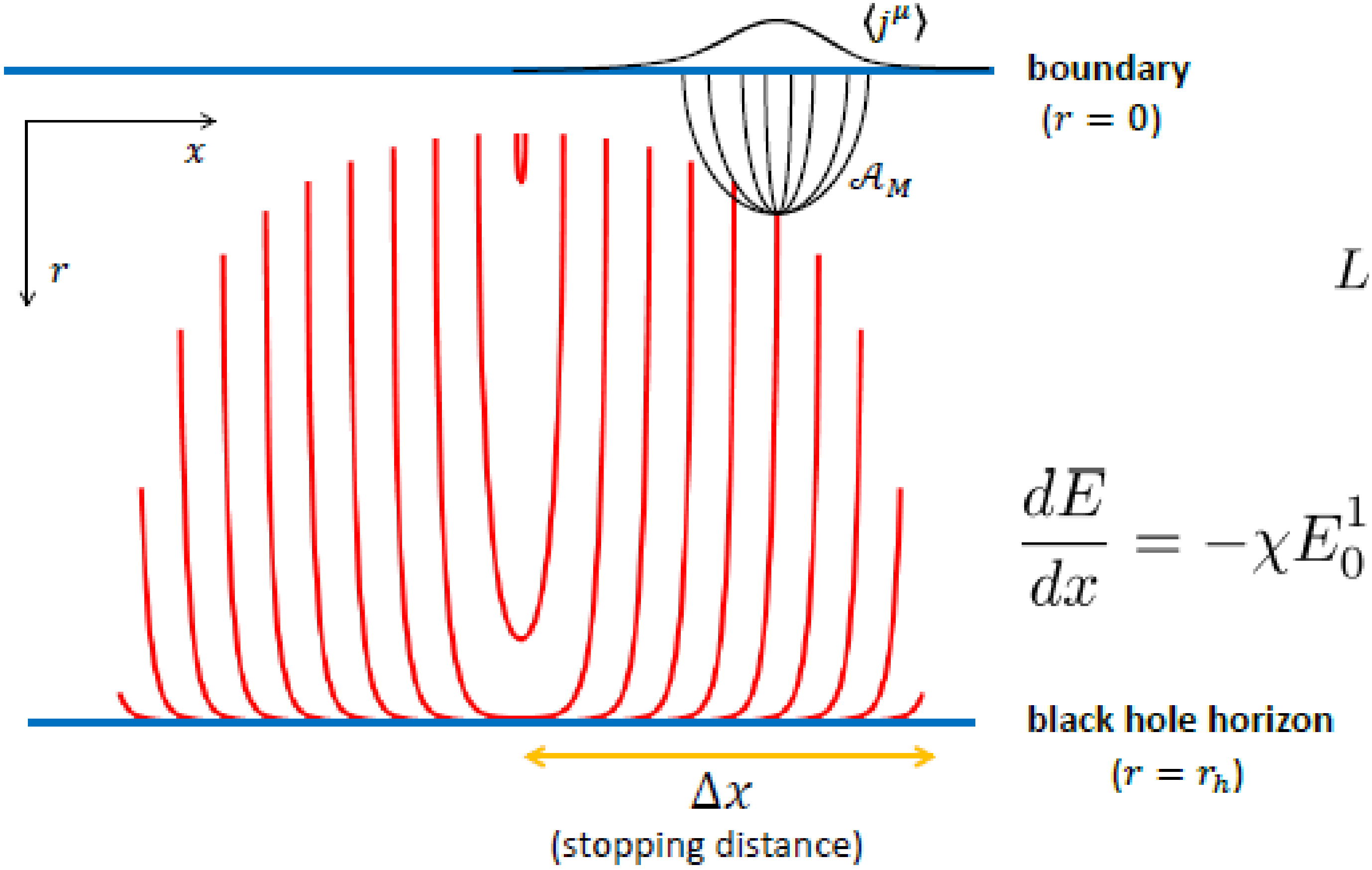
where the p_T dependence is carried entirely by the spectral index $n_Q(p_T)$.

Predicts Flat in pT RAA
Up to the D7 speed limit

$$\gamma_c = \left(1 + \frac{2M}{\sqrt{\lambda}T^*}\right)^2 \approx \frac{4M^2}{\lambda(T^*)^2}$$

Can falling strings in deformed AdS geometries account for the transparency of the sQGP at LHC?

Andrej Ficnar[1], Jorge Noronha[2] and Miklos Gyulassy[1]



$$L_s(E_0, T) = \frac{\kappa}{T}\left(\frac{E_0}{\sqrt{\lambda}T}\right)^{1/3}$$

$$\frac{dE}{dx} = -\chi E_0^{1/3} x^1 T^{8/3}, \quad \chi \equiv 2\lambda^{1/3}/\kappa^2$$

[3] A. Ficnar, arXiv:1201.1780 [hep-th]

Falling strings give similar dE/dx energy, path, density dependence
As pQCD tomography BUT the coupling is much larger

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abc or “Polytrop” Modelling of RAA

For pQCD
a ~ 1/3 , b~1

$$\frac{dP}{d\tau} = -\kappa P^a \tau^b T^{2-a+b}(x(\tau),\tau)$$

For Holographic
Falling Strings
(Chesler Yaffe)
Lstop ~ $E^{1/3}$
=> a = 1/3 , b=1
OR a = 0 , b=2

$$\frac{P(L)}{P(0)} = \left(1 - \kappa' \frac{(dN/dy)^{(2-a+b)/3}}{(LP(0))^{1-a}}\right)^{\frac{1}{1-a}}$$

With Bjorken 1 + 1 D expanding sQGP

For Holographic
String Drag
(Gubser, Herzog)
a = 1 , b=0

$$R_{AA}(p_f; s, A) = \frac{\partial p_0}{\partial p_f} \frac{d\sigma(p_0(p_f))/dp}{d\sigma(p_f)/dp}$$

$$\approx \left(1 + \kappa' \frac{(dN/dy)^{(2-a+b)/3}}{(Lp_f)^{1-a}}\right)^{\frac{a-n(p_f)}{1-a}}$$

(1-a)

Spectral index
From pQCD

$a \to 1$ $e^{-\chi}$

Fix κ’ by fit to one RHIC R(pf=10 GeV ,dNdy=1000) reference point.

Horowitz,MG, NPA872(2011); B.Betz, MG PRC84 (2011), PRC86 (2012)

DGVW, Phys.Lett.B632:81-86,2006

(radiative loss only)

Interpretation of
Heavy Jet Quenching data
via nonphotonic e- is
Complicated by

1) Production b/c uncertainty

2) uncertain b->B->e, c->D->e
Fragmentation chain

3) b vs c Quenching dynamics
PQCD vs AdS/CFT

Future tagged b and c
Jet quench data
At both RHIC and LHC

Will be essential to solve
puzzle

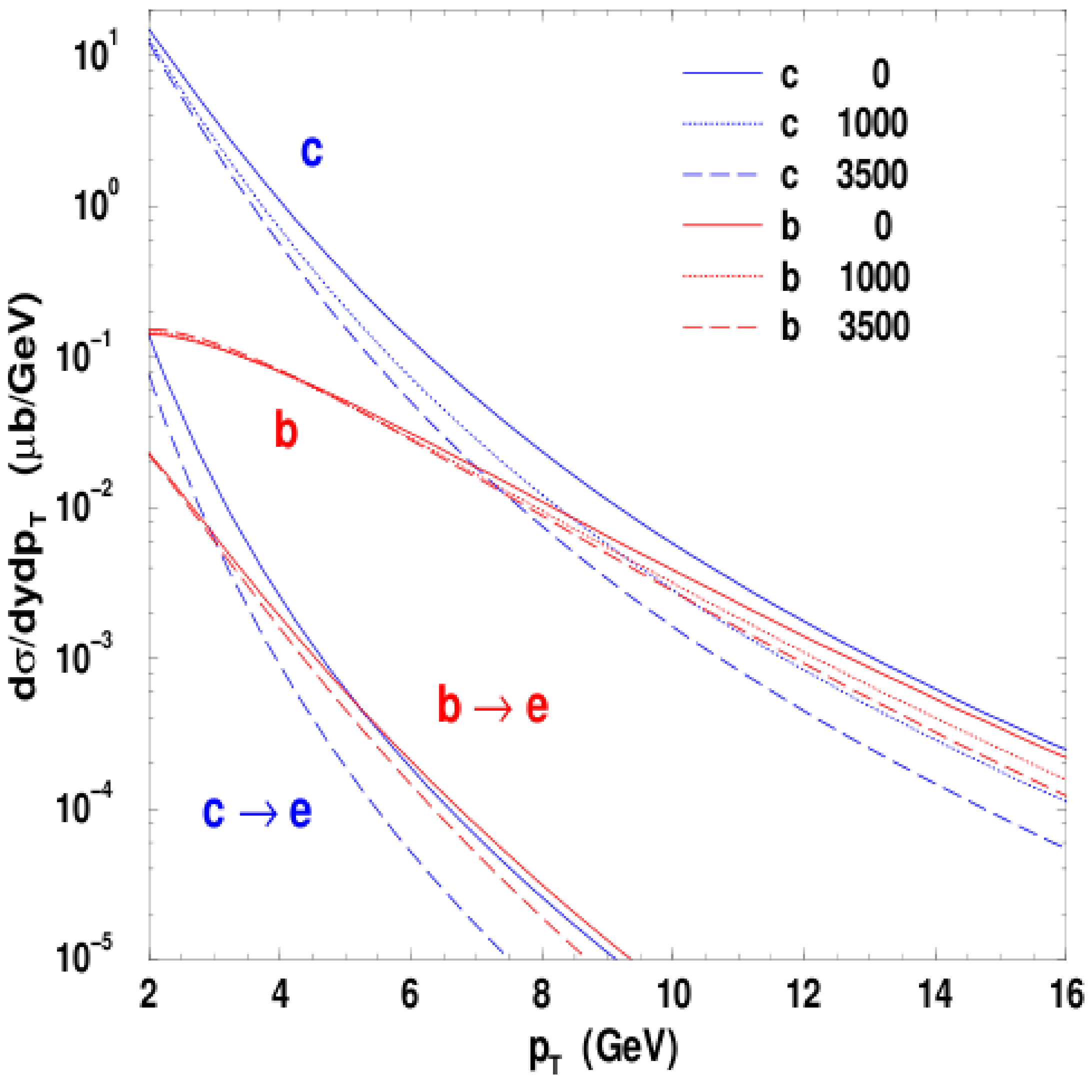
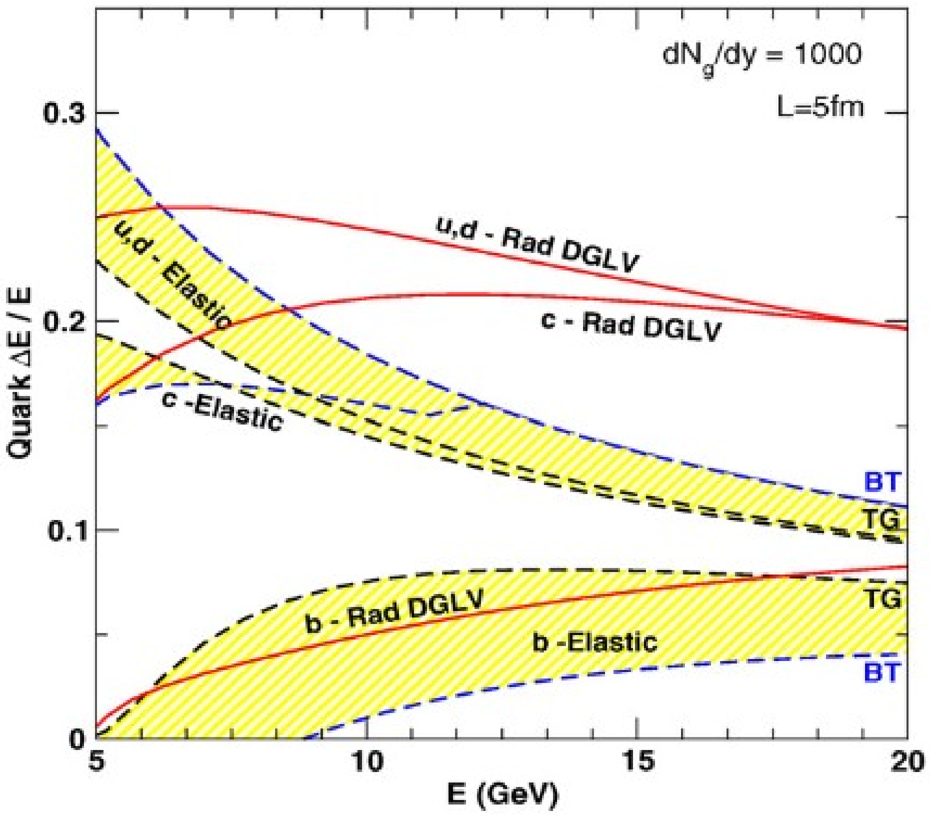


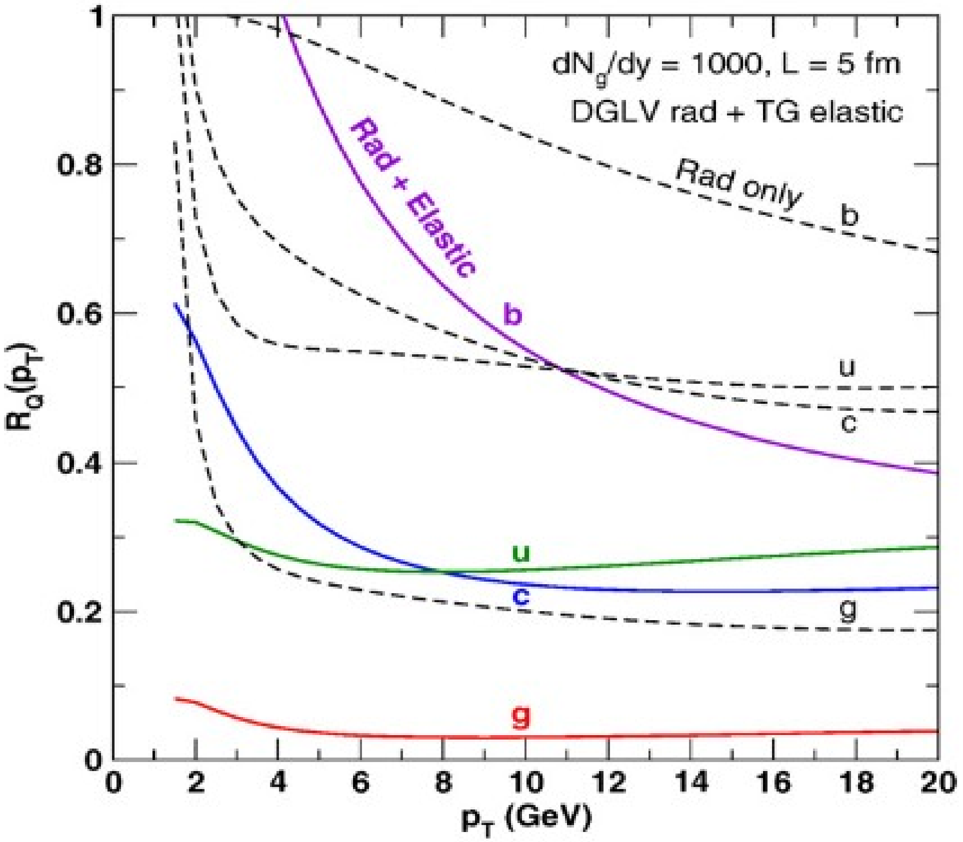
FIG. 1: The differential cross section (per nucleon pair) of charm (upper blue) and bottom (upper red) quarks calculated to NLO in QCD [34] compared to single electron distributions calculated with the fragmentation and decay scheme of Ref. [34]. The solid, dotted and long dashed curves show the effect of DGLV heavy quark quenching with initial rapidity densities of $dN_g/dy = 0, 1000,$ and 3500, respectively.

$$P(E_i \to E_i - \Delta_{\rm rad} - \Delta_{\rm el}) = \int \frac{d\phi}{2\pi} \int \frac{d^2\vec{x}_\perp}{N_{\rm bin}(b)} T_{AA}(\vec{x}_\perp, \vec{b}) \otimes P_{\rm rad}\big(\Delta_{\rm rad}; L(\vec{x}_\perp, \phi)\big) \otimes P_{\rm el}\big(\Delta_{\rm el}; L(\vec{x}_\perp, \phi)\big).$$

S. Wicks et al. / Nuclear Physics A 784 (2007) 426–442

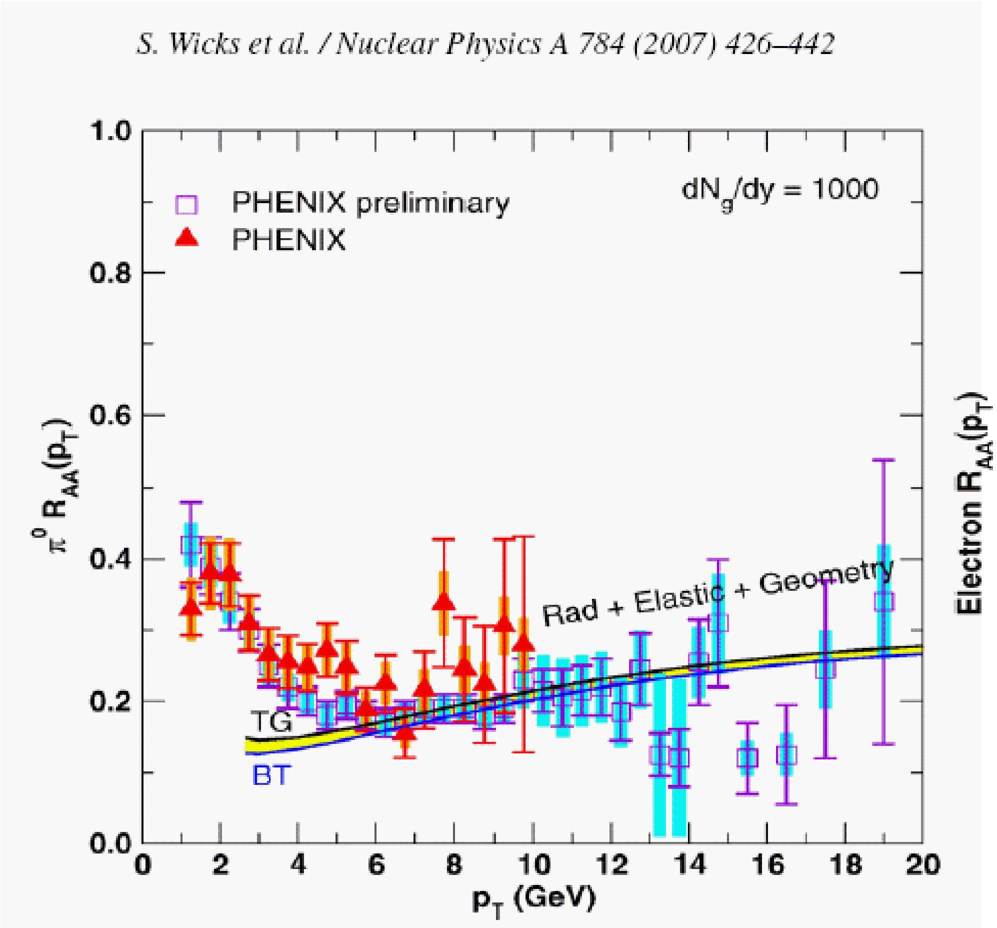


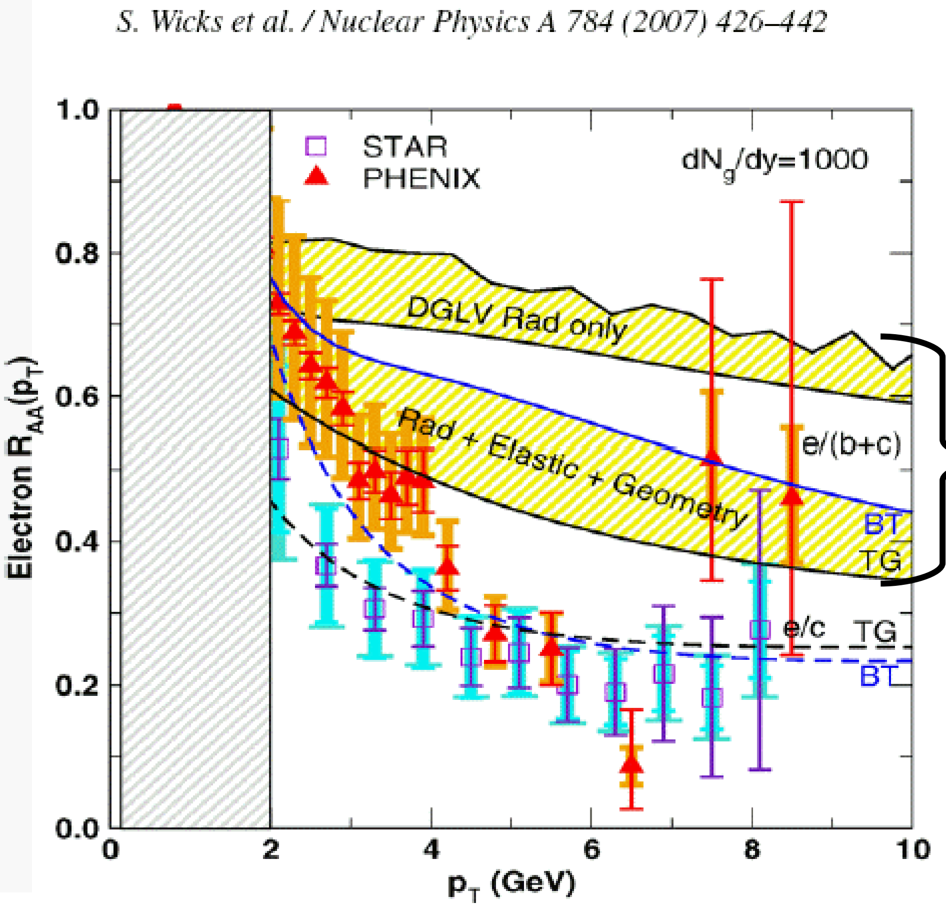
S. Wicks et al. / Nuclear Physics A 784 (2007) 426–442



In pQCD paradigm both Radiative and Elastic Energy loss are ***Mass dependent***
and DE(bottom) << DE(g, u, s, and even c ~ u)

The Heavy Quark Jet Puzzle : the second thorn in pQCD Tomography


S. Wicks et al. / Nuclear Physics A 784 (2007) 426–442


S. Wicks et al. / Nuclear Physics A 784 (2007) 426–442

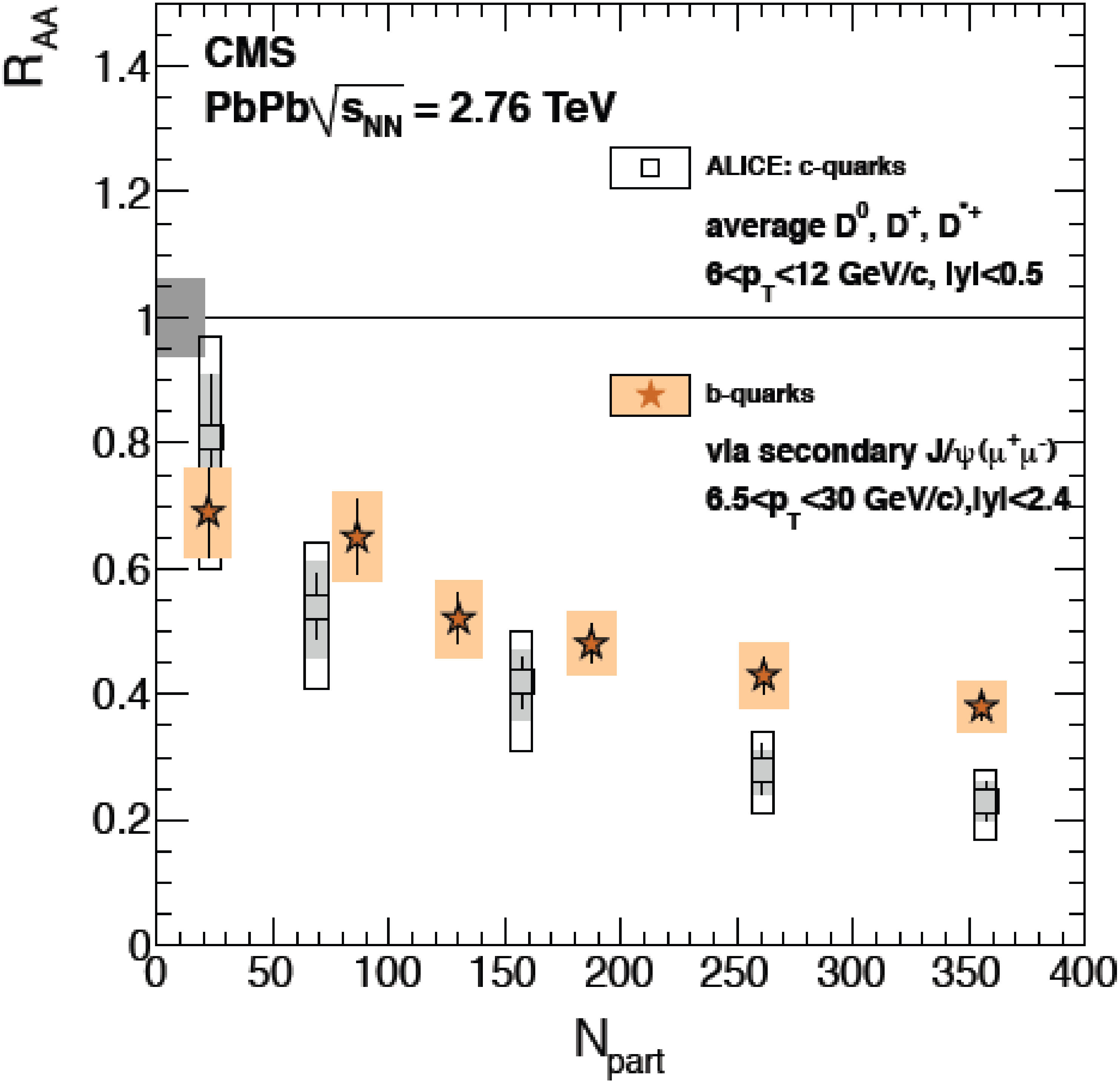
(c+b)->e

c->e only

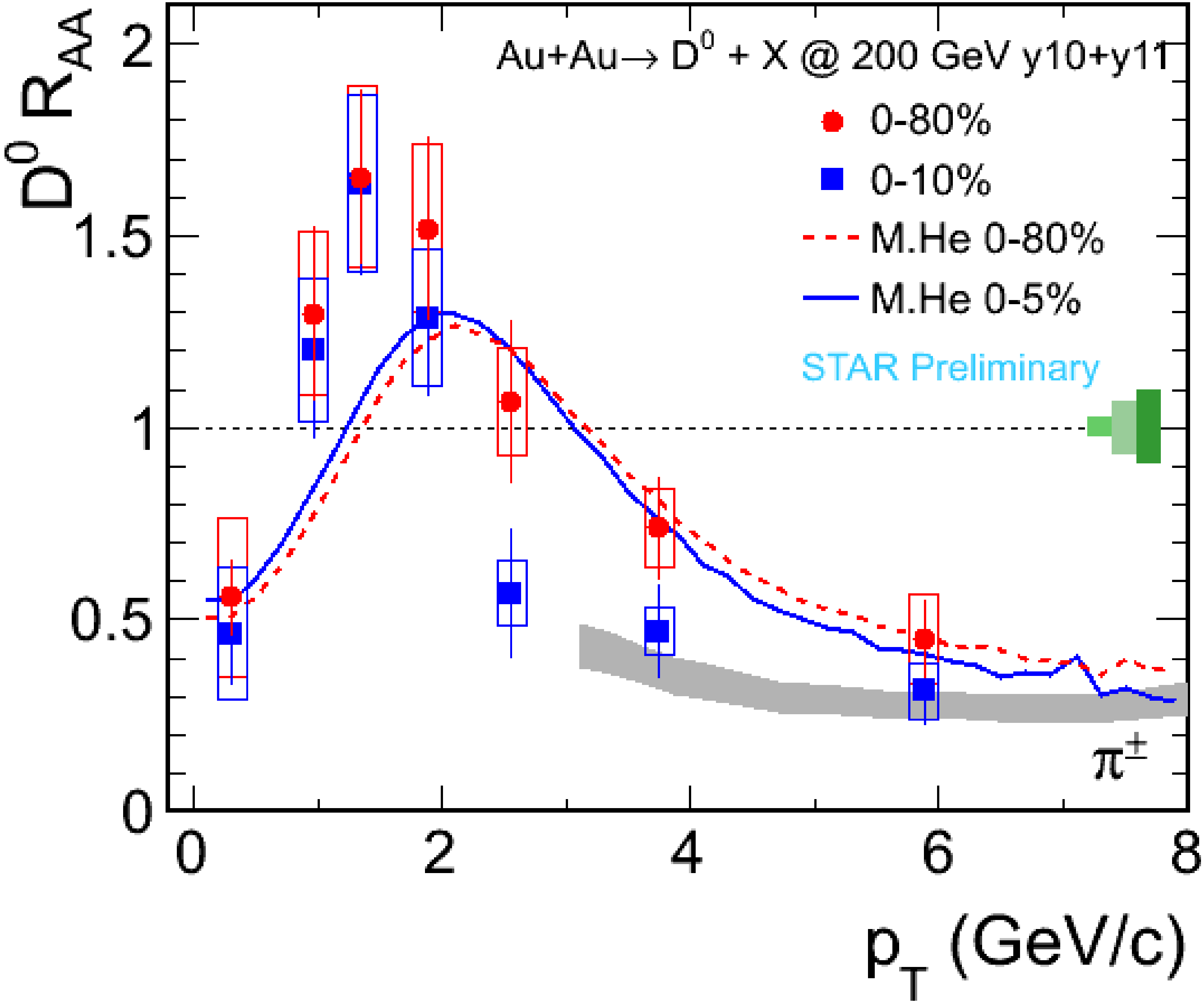
Does the *inferred* bottom quark jet data rule out the pQCD HTL paradigm ?

How can a relativistic “bowling ball” (bottom quark) stop in a T=300 MeV QGP ???

For pT>6 GeV the more “Natural” Mass Hierchy was Observed at LHC



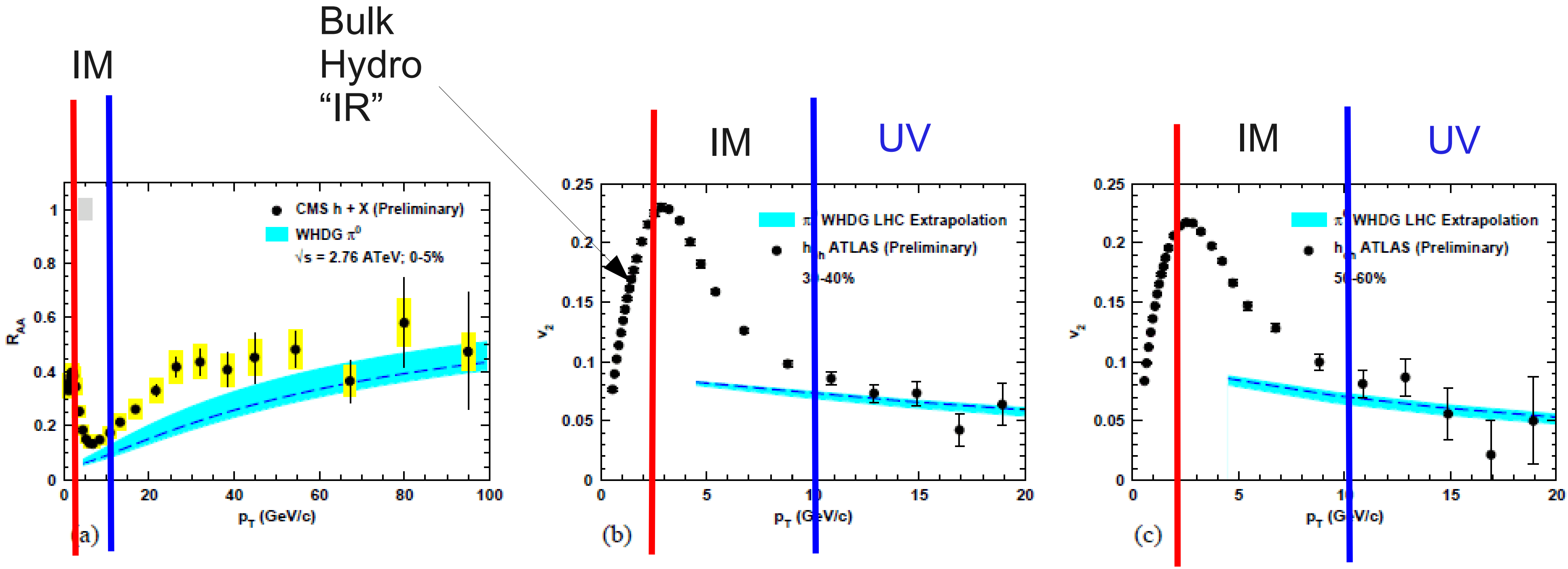
Is STAR QM12 D quenching RAA~ 0.5 pT < 4 GeV consistent with new PHENIX RAA(D->e)~ 1 ?



Consistency of Heavy Quark with Light Quark Jet Tomography at LHC

RHIC constrained fixed
coupling WHDG
W.Horowitz, MG 2011

Modulo pT~30 “bump” works well in “UV” pT>10 GeV domain



Bulk
Hydro
“IR”

IM

IM

UV

IM

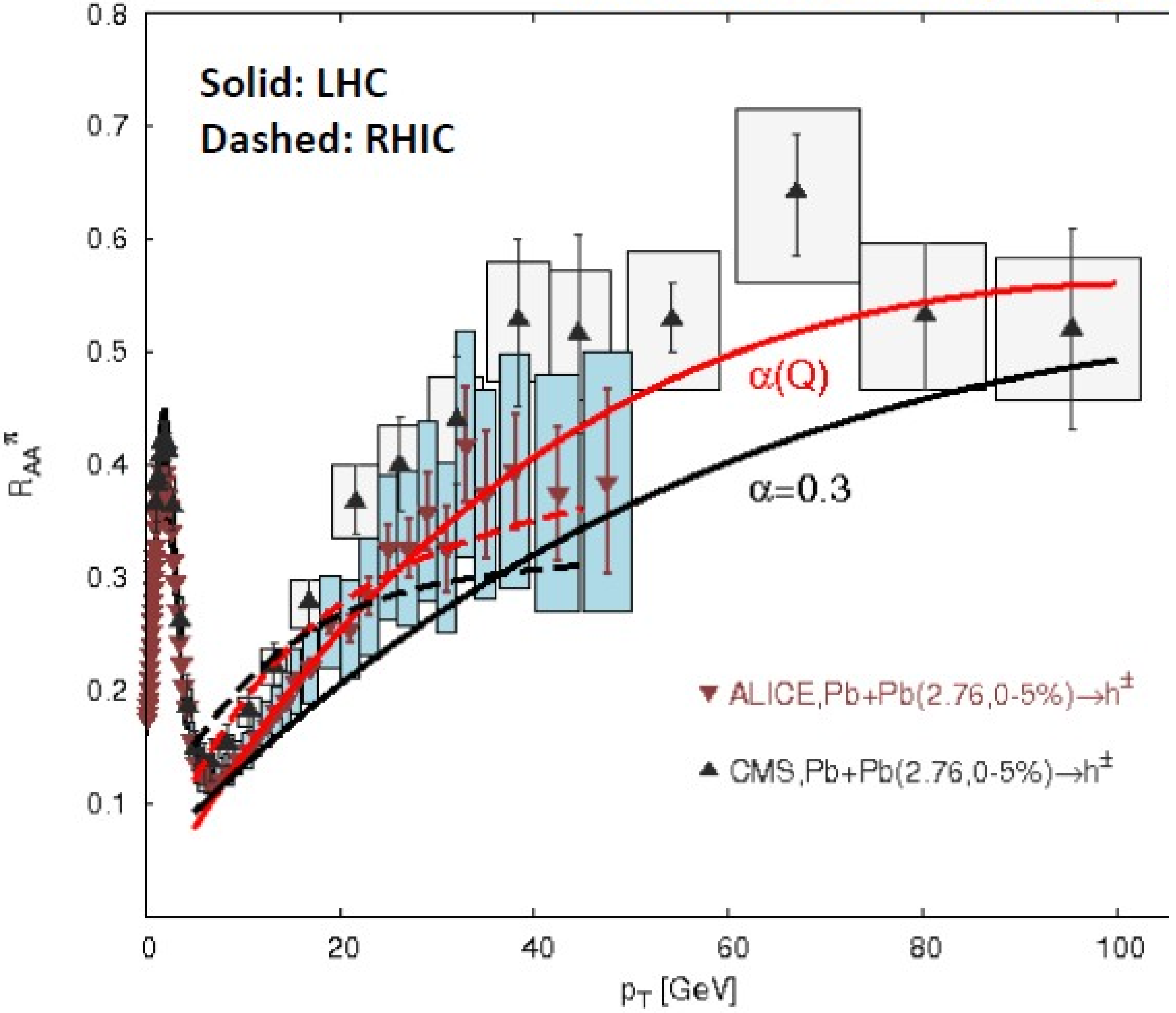
UV

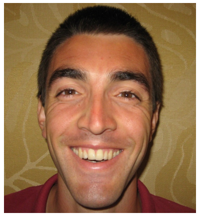
FIGURE 1. (a) Constrained $R_{AA}^{\pi^0}(p_T)$ predictions from the WHDG energy loss model [2, 3] compared to preliminary CMS $R_{AA}^{h+X}(p_T)$ data [12] at $\sqrt{s} = 2.76$ ATeV for 0-5% central collisions at LHC. Constrained $v_2^{\pi^0}(p_T)$ predictions from WHDG compared to preliminary ATLAS $v_2^{h^\pm}(p_T)$ data [13] at $\sqrt{s} = 2.76$ ATeV for (b) 30-40% and (c) 50-60% collisions at LHC. In (a)-(c) the dashed blue line (cyan band) corresponds to the zero-parameter LHC prediction from WHDG for the best-fit constraint (1-σ uncertainty on the best-fit constraint) to RHIC data.

Intermediate “IM” 2 < pT<10 GeV interpolates between Hydro pT<2 and Hard UV pT>10

Running coupling (CUJET1.0 , A.Buzzatti, MG 2012) resolves LHC Surprising Transparency puzzle

See also B. Betz and M. Gyulassy, arXiv:1201.02181

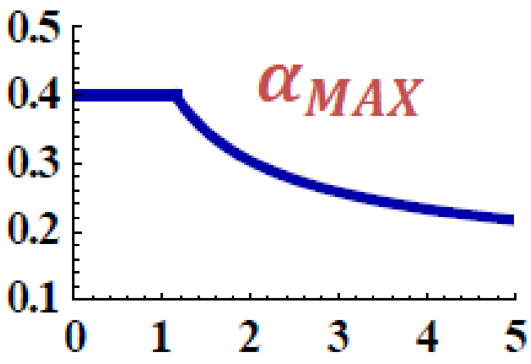




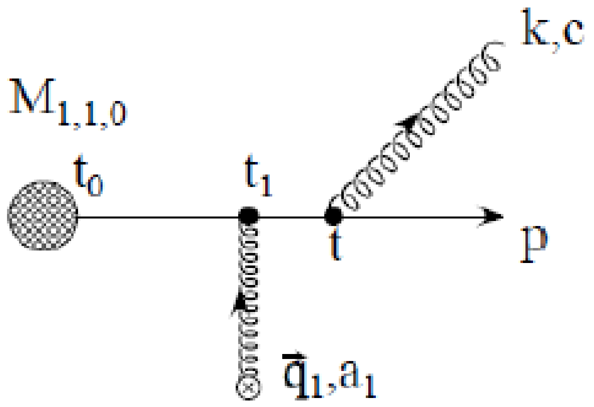
- **Introduce one-loop alpha running** (rc-CUJET)

$$\alpha_s(Q^2) = \frac{2\pi}{9}\frac{1}{Log\left[{}^{Q}/_{\Lambda}\right]}$$

B. G. Zakharov, JETP Lett. 88 (2008) 781-786



- $$Radiative = \begin{cases} \alpha(q^2)^2 \\ \alpha\left(\frac{k_\perp^2}{x(1-x)}\right) \\ \mu = g\left(\alpha(2T^2)\right)T \end{cases}$$



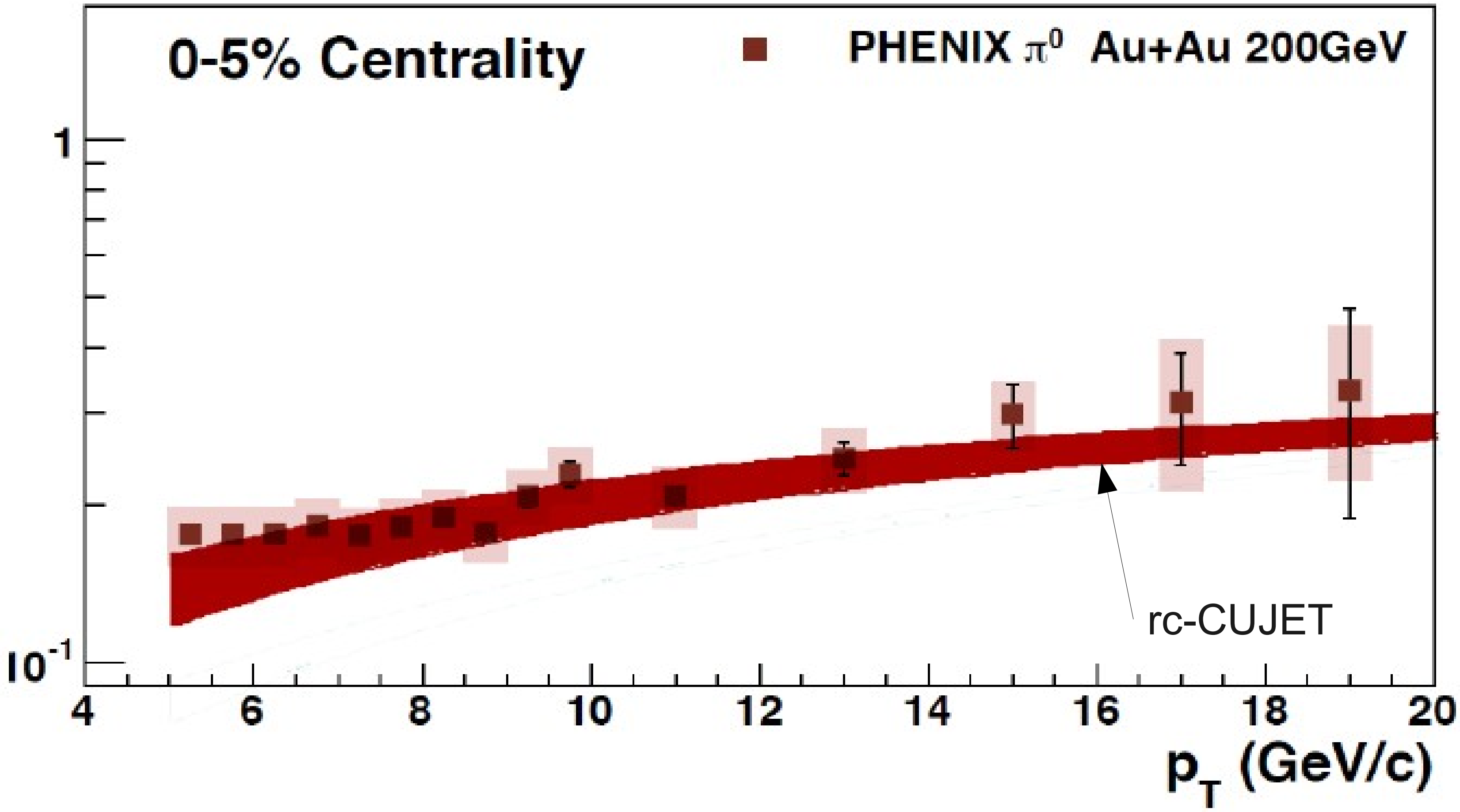
- $$Elastic = \begin{cases} \alpha(ET) \\ \alpha(\mu^2) \end{cases}$$

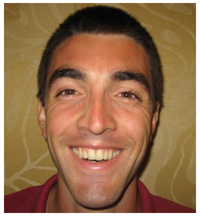
S. Peigne and A. Peshier, Phys.Rev. D77 (2008) 114017

Running coupling (rc-CUJET , A.Buzzatti, MG 2012) resolves LHC Surprising Transparency puzzle consistent with new RHIC data

PHENIX Collaboration

New data shown at QM12

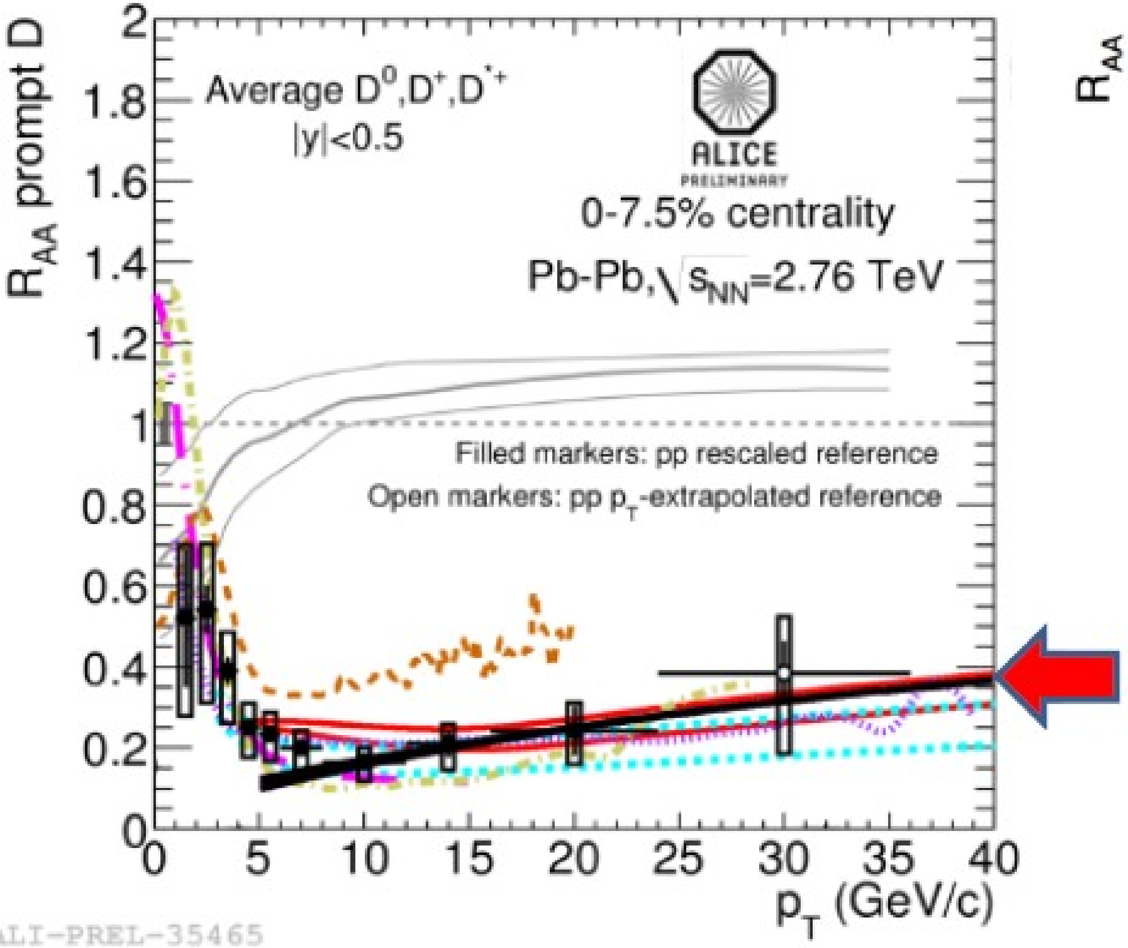




ALICE and CMS Heavy Flavors QM12

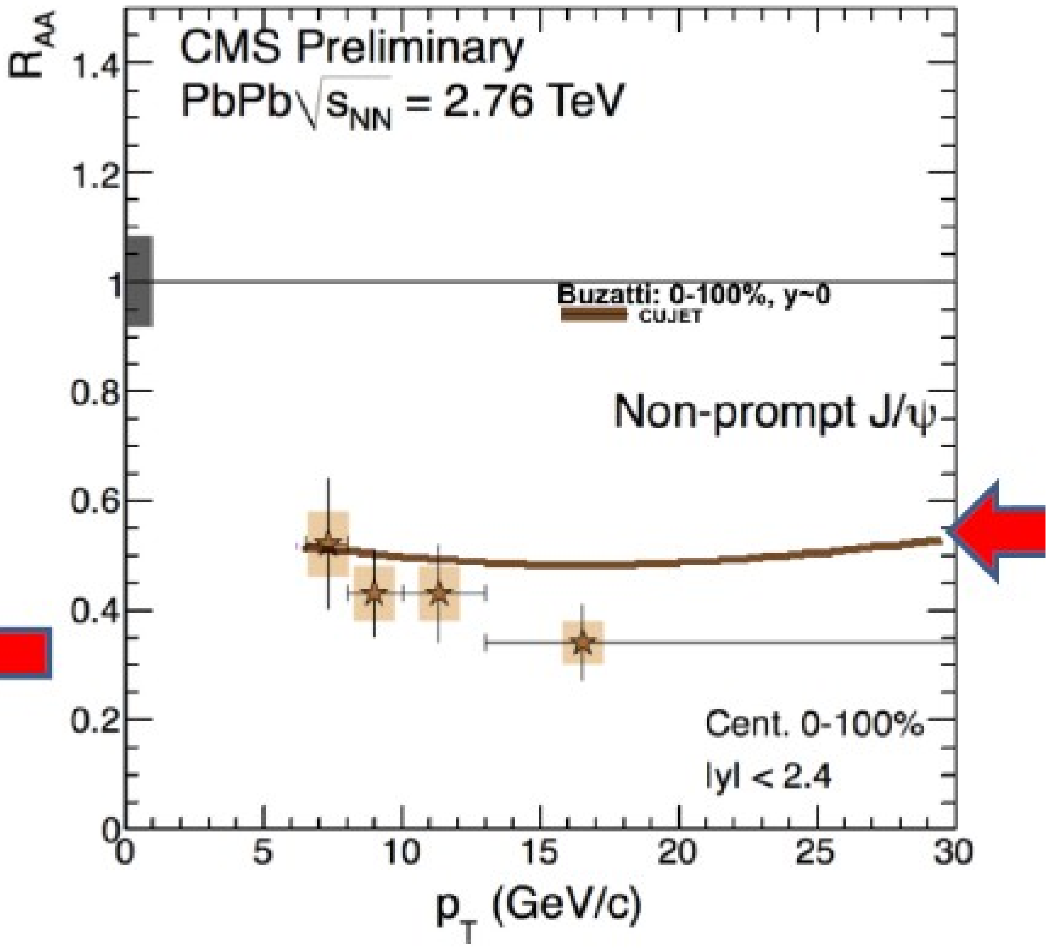
Compared to rc-CUJET predictions

ALICE Collaboration



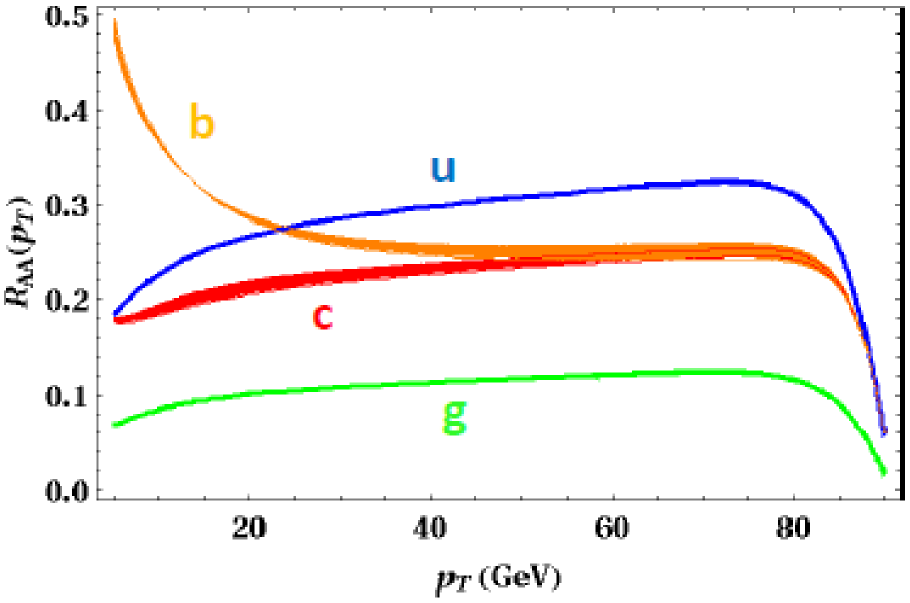
CMS Collaboration

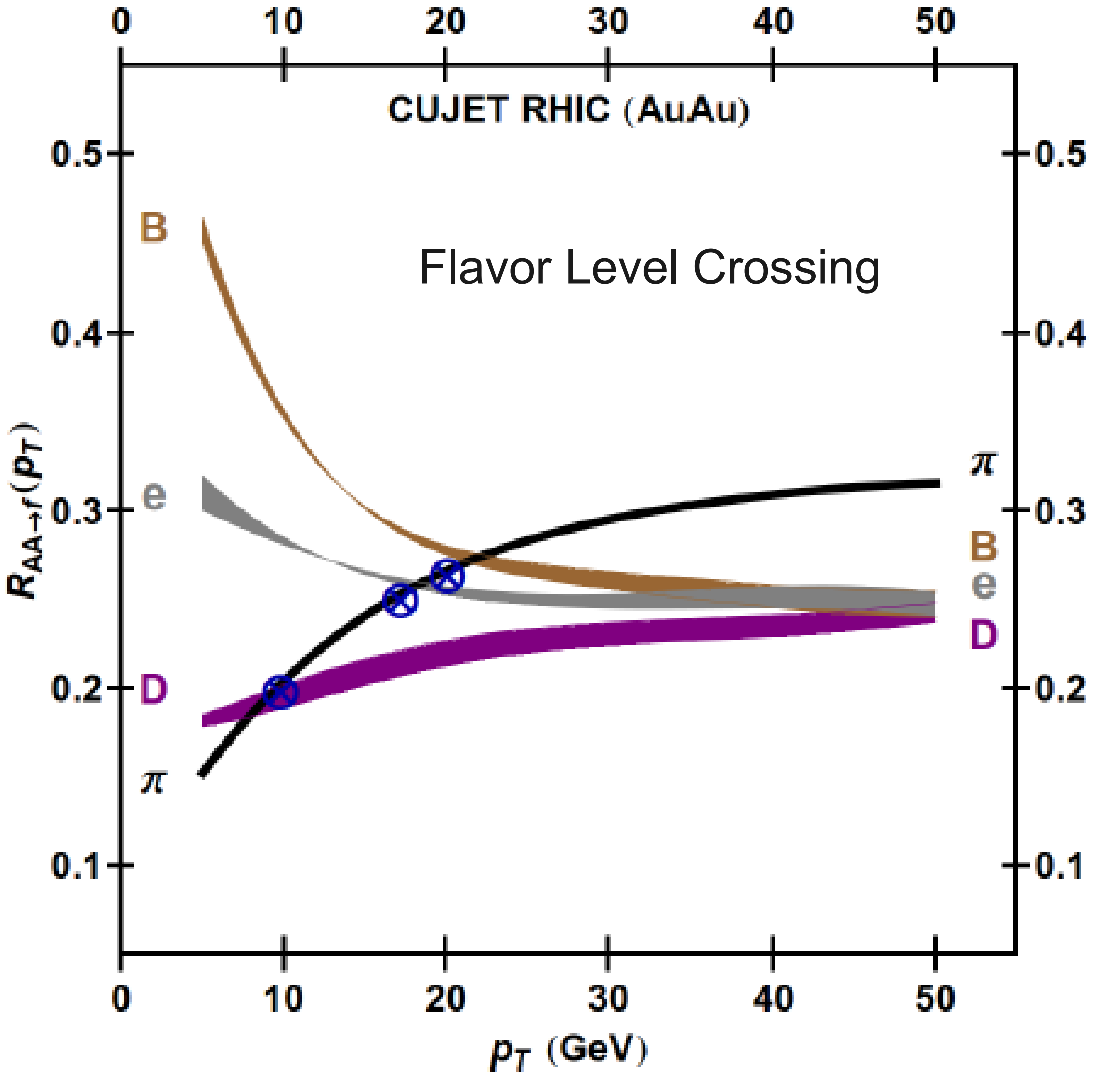
CMS-PAS HIN-12-014



RHIC Results

$0-5\%\ centrality, dNdy = 1000, \alpha_s = 0.3, \tau_0 = 1fm/c$





Inversion of R_{AA} flavor hierarchy at sufficiently high p_t

But **Incompatible** with QM12 PHENIX b->e/c->e << 1 prelim data

AB and M. Gyulassy, Phys. Rev. Lett. 108, 0223101 (2012)

Jet Flavor Tomography at LHC with CUJET

Parameters constrained by LHC
$dNdy = 2200$

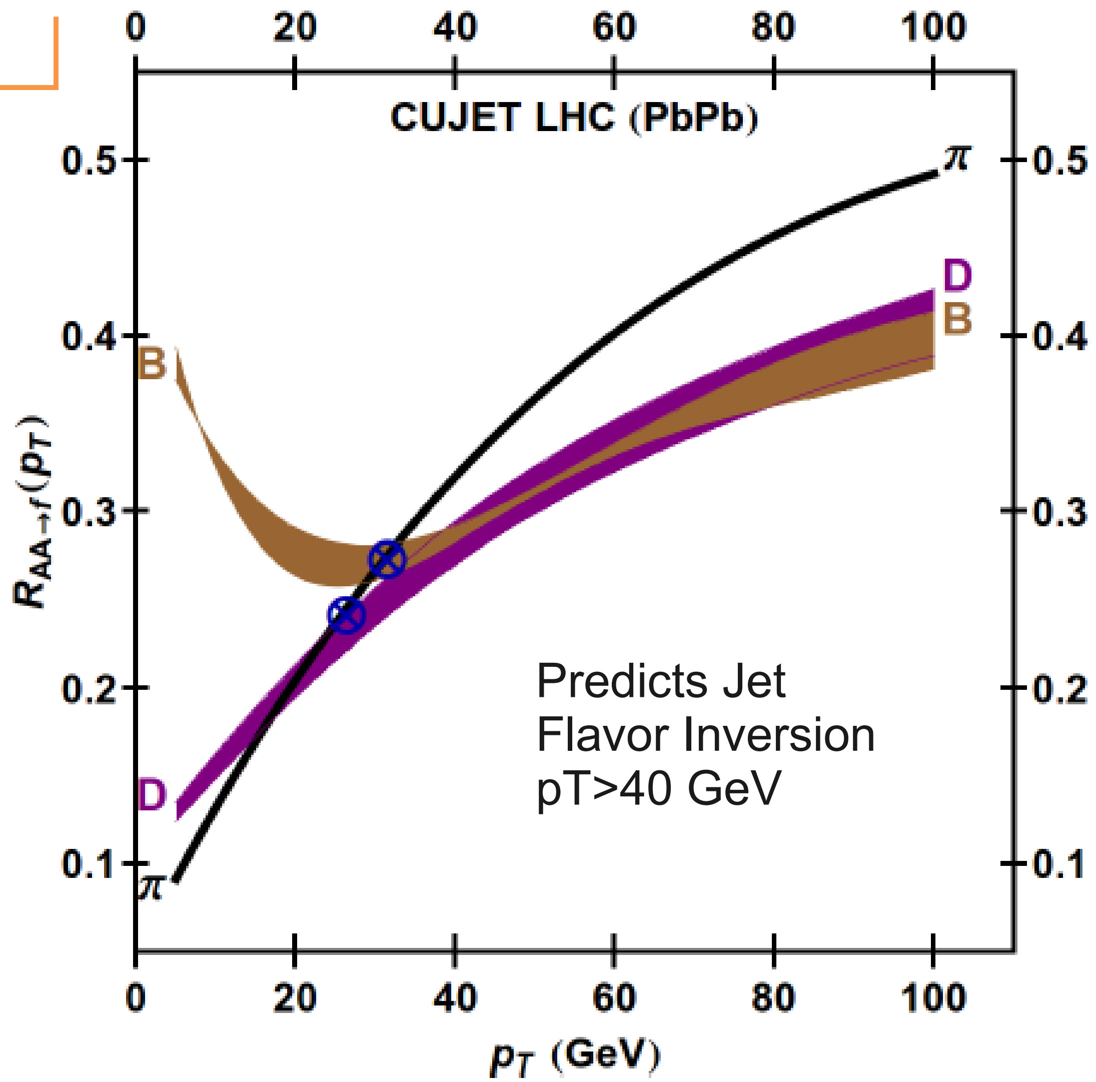
Competing effect between Energy loss ordering…

$$\Delta E(light) \approx \Delta E(c) > \Delta E(b)$$

…and pp Production spectra

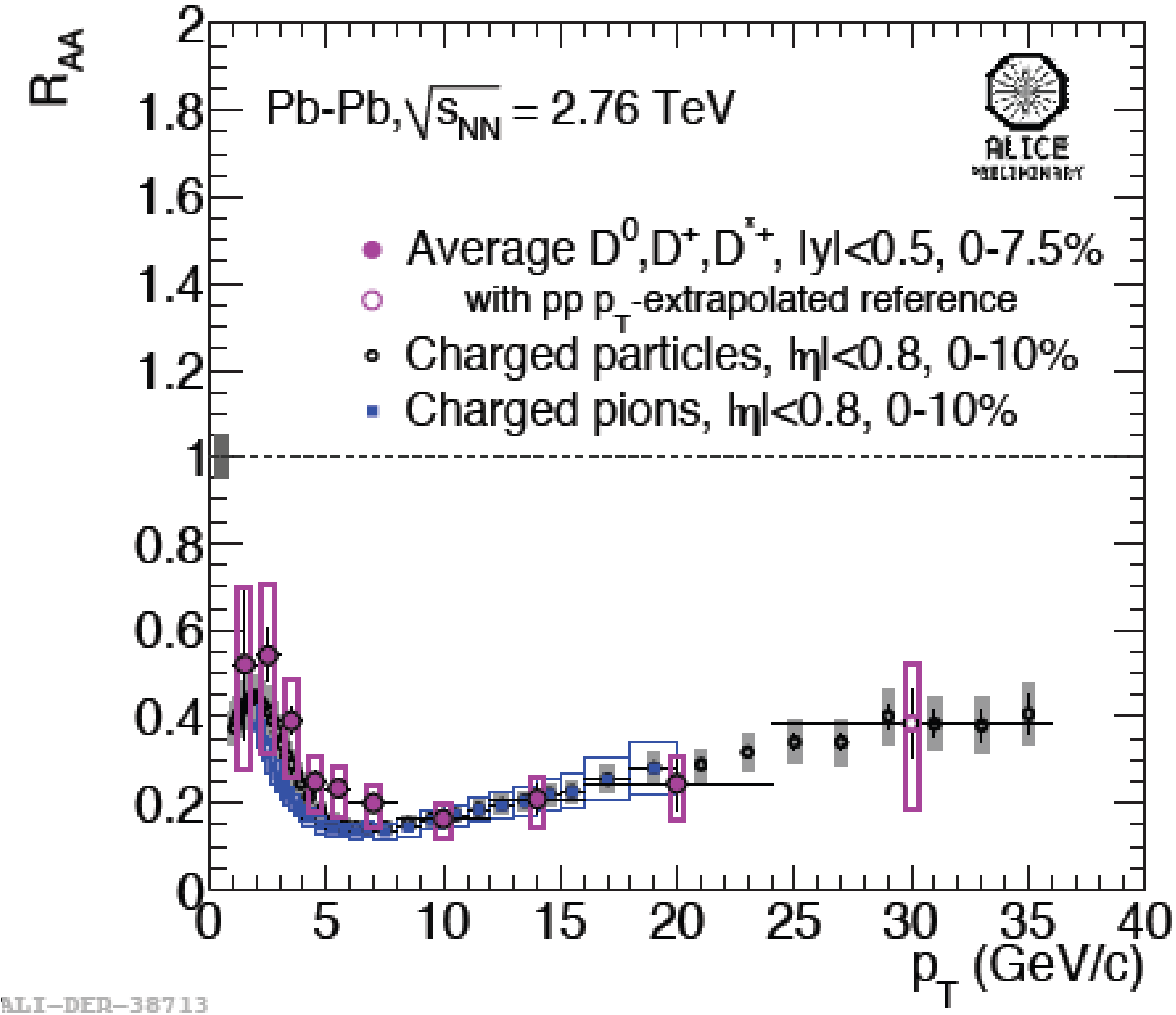
$$d\sigma(c,b)\, harder\ than\ d\sigma(light)$$

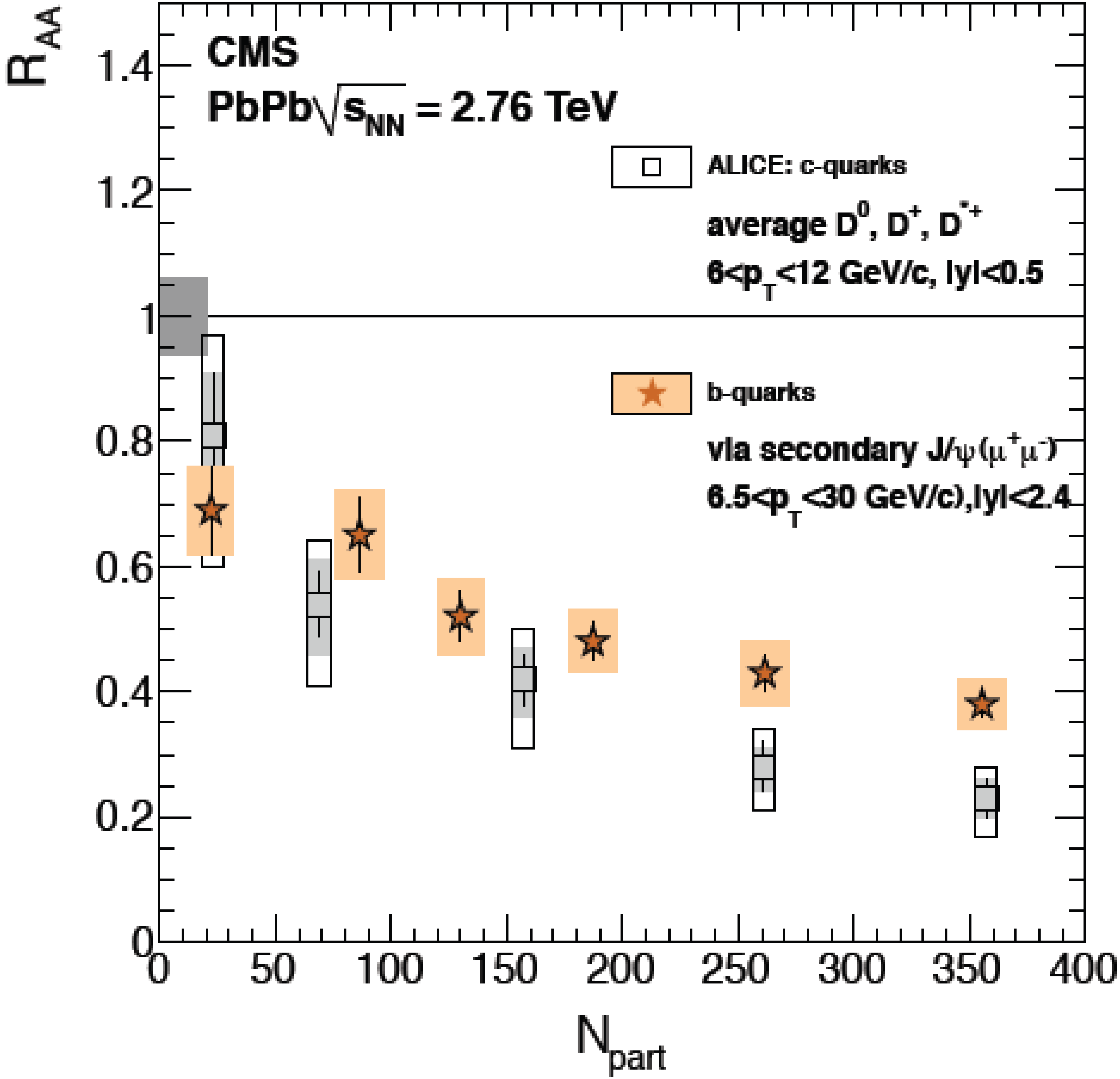
$$RAA \sim (1 - \Delta E/E)^{n-2}$$



Predicts Jet Flavor Inversion pT>40 GeV

AB and M. Gyulassy, Phys. Rev. Lett. 108, 0223101 (2012)


R_AA
Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE PRELIMINARY
Average D^0,D^+,D^{*+}, |y|<0.5, 0-7.5%
with pp p_T-extrapolated reference
Charged particles, |η|<0.8, 0-10%
Charged pions, |η|<0.8, 0-10%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
5
10
15
20
25
30
35
40
p_T (GeV/c)
ALI-DER-38713


CMS
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE: c-quarks
average D^0, D^+, D^{*+}
$6<p_T<12$ GeV/c, |y|<0.5
b-quarks
via secondary $J/\psi(\mu^+\mu^-)$
$6.5<p_T<30$ GeV/c), |y|<2.4
R_{AA}
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
50
100
150
200
250
300
350
400
N_{part}

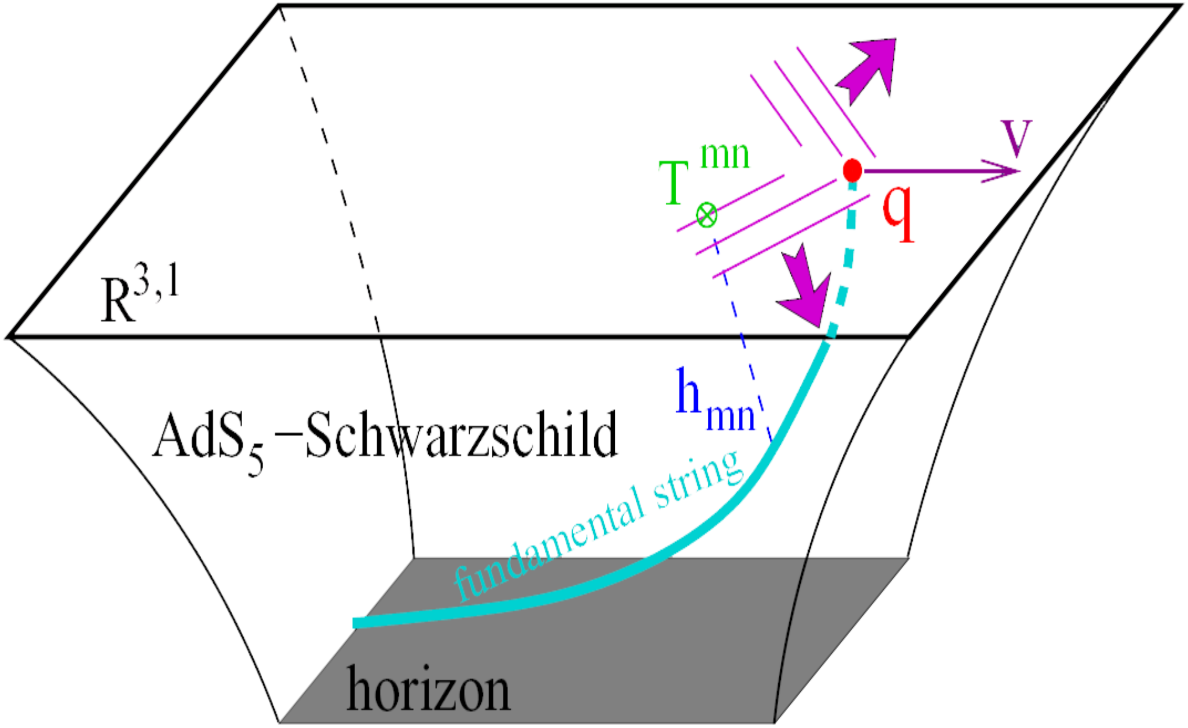
Can holographic AdS/CFTJet Models survive heavy quark jet measurements at RHIC and LHC?

J Friess, S Gubser, G Michalogiorgakis, S Pufu, Phys Rev **D75** (2007)

$dp_T/dt = - \mu\, p_T$

$\mu = \pi\lambda^{1/2}\, T^2/2M$

$p_T(t) = p_0\, e^{-\mu t}$

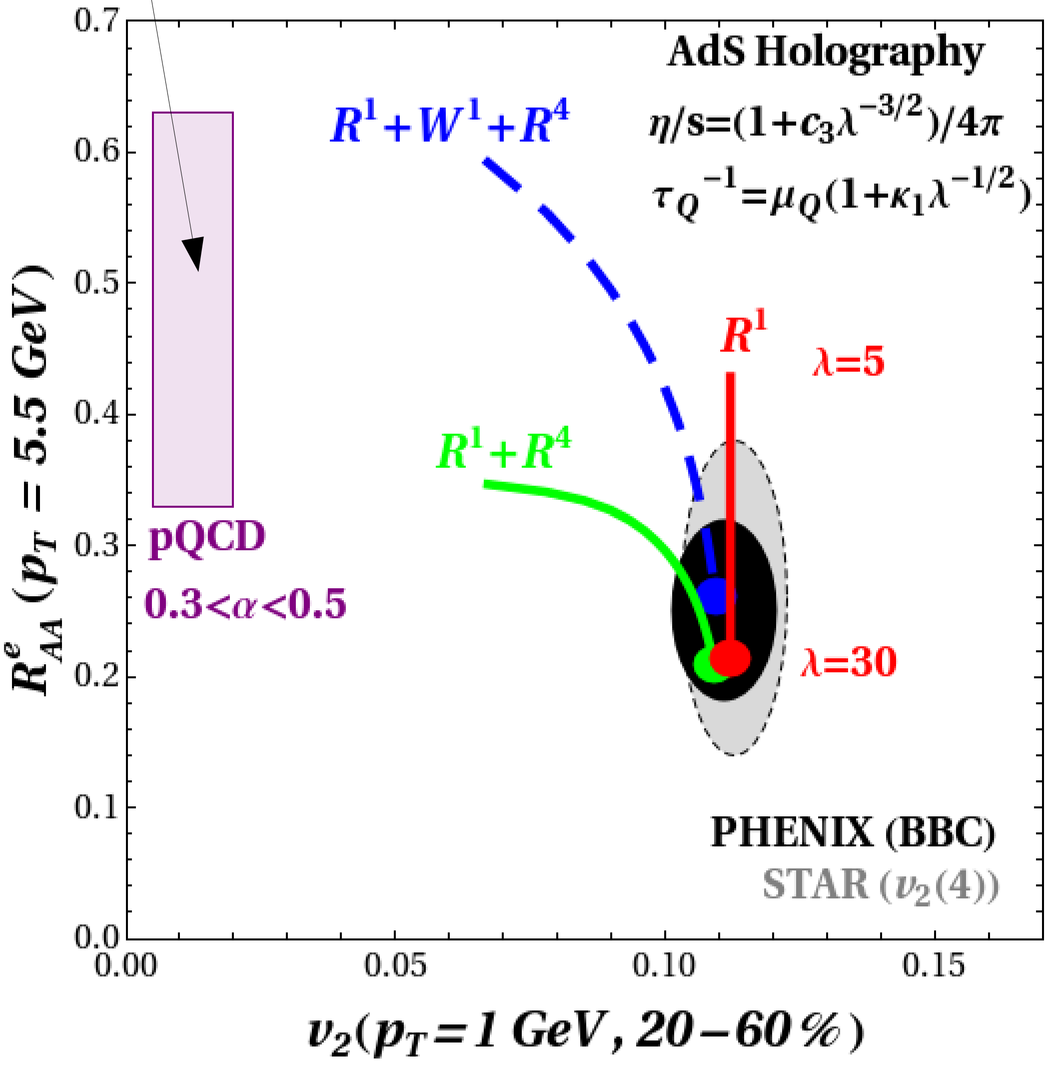


Stop distance

$L_s = (2M/\pi T^2)/\, \lambda^{1/2}\, \mathrm{Log}(p_0) \rightarrow 0$ for $\lambda >> 1$

Conformal Holography of Bulk Elliptic Flow and Heavy Quark Quenching
J. Noronha, MG, G. Torrieri PRC82 (2010)

(pQCD predicts too large viscosity => too small v2, and too weak heavy quark energy loss)

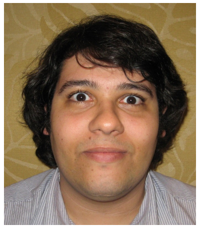


Ideal conformal N=4 SYM
AdS/CFT holography with

Is consistent with *both* IR bulk v2(1 GeV)
as well as heavy quark RAAe(5.5 Gev)

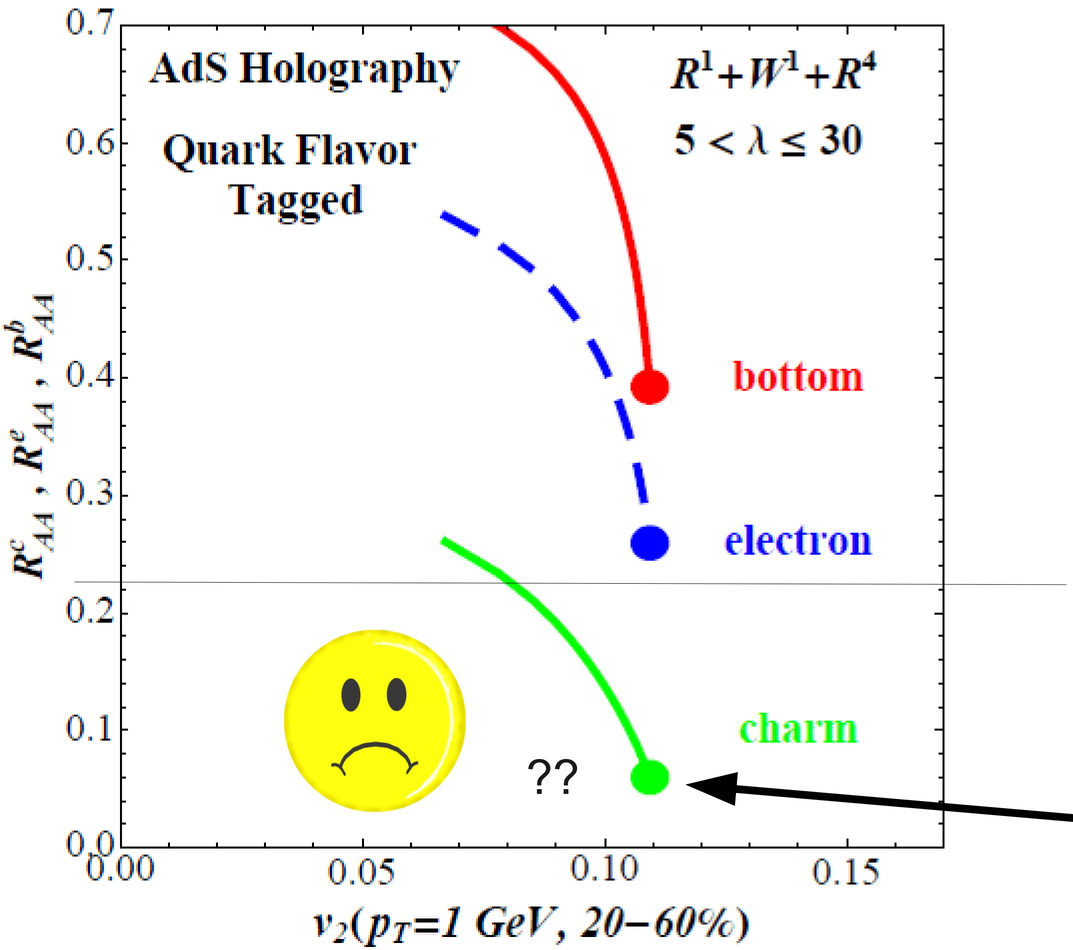
With "reasonably large" t'Hooft coupling
Lambda ~ 20-30

Surprising robust to higher gradient R^4
And world sheet fluctuation corrections



But AdS string drag predictions for B and D identified tomography
make easy to falsify target at RHIC and LHC (but requires heavy flavor identification)

Woops



Pion RAA

FIG. 2. (Color online) The predicted correlation between identified heavy quark jet quenching, R^Q_{AA}, and soft elliptic flow, $v_2(p_T = 1\ \mathrm{GeV})$, based on approximate $R^1 + W^1 + R^4$ conformal holography that includes leading order worldsheet fluctuations and quartic curvature corrections via Eqs. (2-

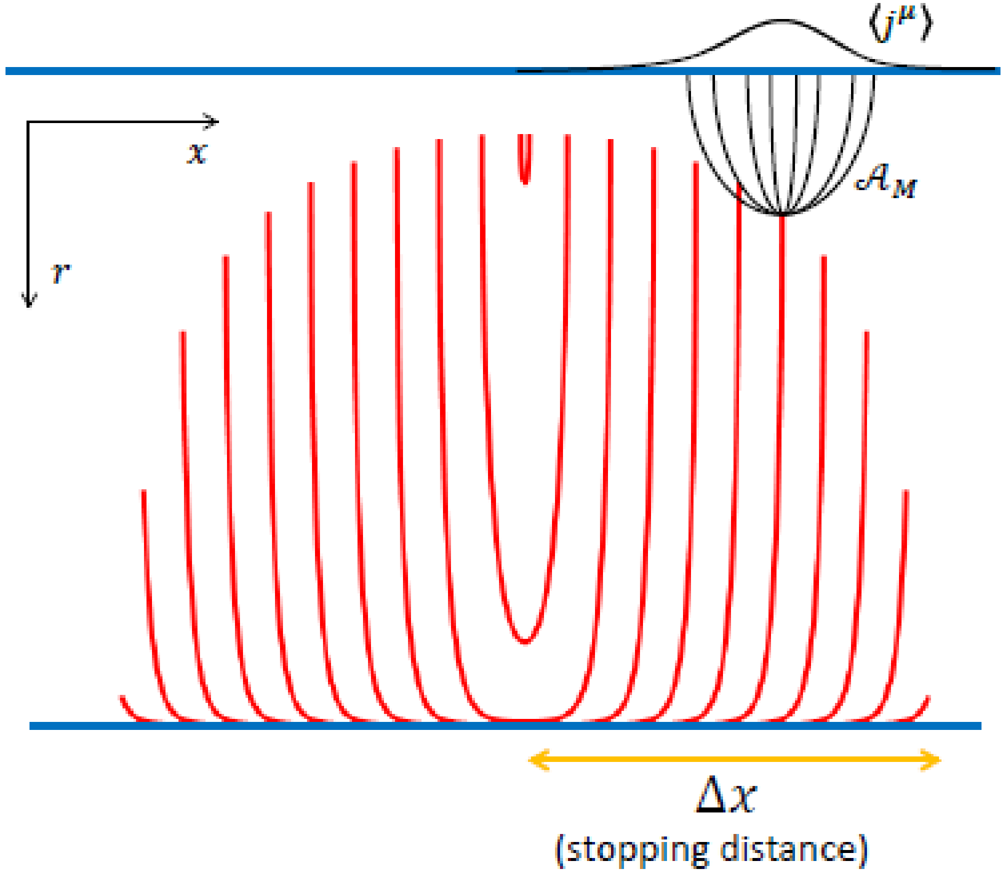
The price
for electrons
quenching
is very high
in conformal
AdS string
drag !

Predicts
RAA(charm)
Much Less
than
RAA(pion) !

QM12 data rule out this scenario

Can falling strings in deformed AdS geometries account for the transparency of the sQGP at LHC?

Andrej Ficnar[1], Jorge Noronha[2] and Miklos Gyulassy[1]



boundary
$(r = 0)$

black hole horizon
$(r = r_h)$

$$L_s(E_0, T) = \frac{\kappa}{T}\left(\frac{E_0}{\sqrt{\lambda}T}\right)^{1/3}$$

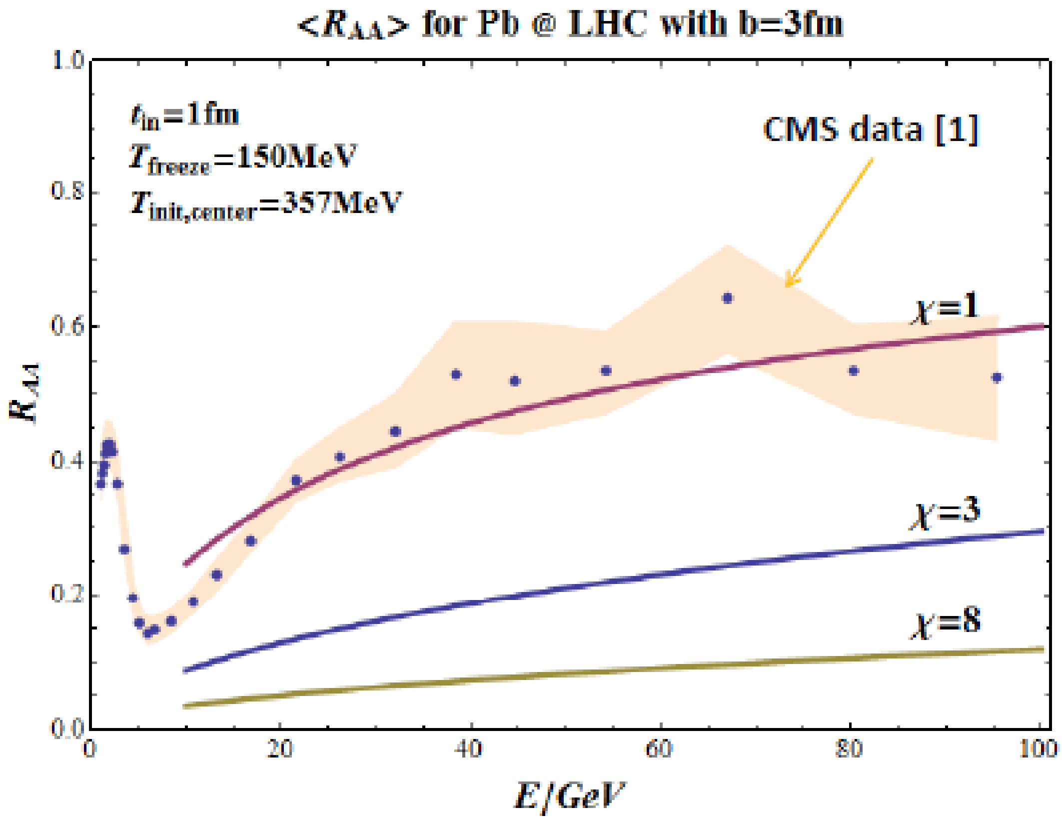
$$\frac{dE}{dx} = -\chi E_0^{1/3} x^1 T^{8/3}, \quad \chi \equiv 2\lambda^{1/3}/\kappa^2$$

[3] A. Ficnar, arXiv:1201.1780 [hep-th]

Falling strings give similar dE/dx energy, path, density dependence
As pQCD tomography BUT the coupling is much larger

A. Ficnar, J. Noronha and M. Gyulassy, to appear

$$\chi \equiv 2\lambda^{1/3}/\kappa^2$$



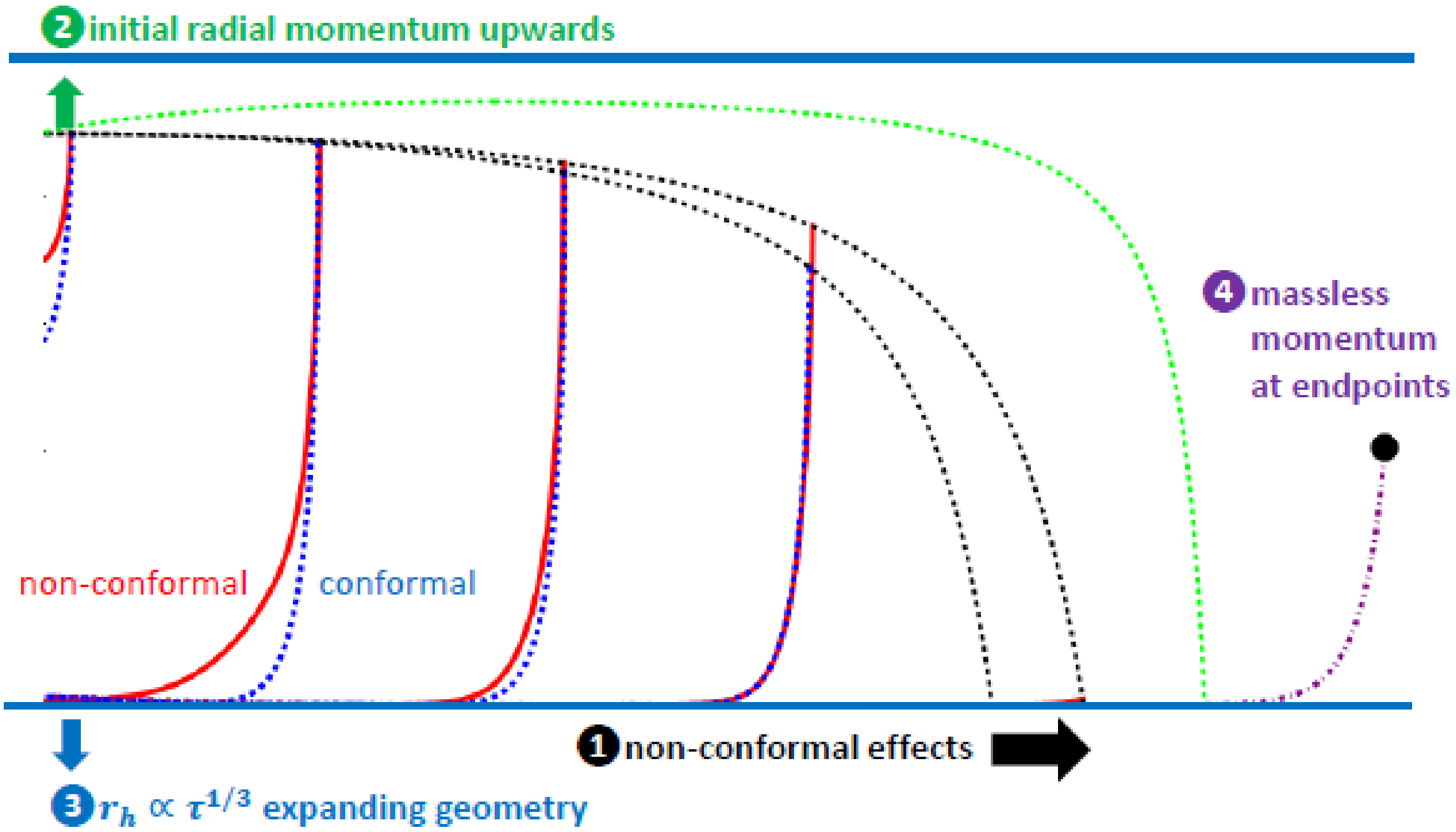
λ=0.002

"Opps"

λ=1

Using $\kappa \approx 0.5$ [2] and an unphysically small $\lambda = 1$, we obtain a minimal value of $\chi \approx 8$. Such a high value of χ gives an R_{AA} of a rather low magnitude, indicating strong quenching. Using even lower values of χ, we see that R_{AA} actually has the correct qualitative behavior as displayed by the LHC data [1]. This suggests that the main problem here could be simply in the magnitude the uenching.

A. Ficnar : Future hQCD AdS deformations to explore



Interpolation model between
Extreme different dynamical energy loss

$$\boxed{\frac{dP}{d\tau}(\vec{x}_0,\phi,\tau) = -\kappa P^a(\tau)\,\tau^z\,T^{c=2-a+z}[\vec{x}_\perp(\tau),\tau,b]}$$

generalized from
Jia's survival model

J. Jia et al., PRC 82 (2010), 024902

$$R_{AA}^{q,g}(P_f,\vec{x}_0,\phi) = \frac{g_0[P_0(P_f)]}{g_0(P_f)}\frac{dP_0^2}{dP_f^2}$$

pQCD

$$P_0(P_f) = \left[P_f^{1-a} + K\int_{\tau_0}^{\tau_f}\tau^z T^c[\vec{x}_\perp(\tau),\tau]d\tau\right]^{1/(1-a)}$$

$$K = (1-a)\kappa C_2$$

CGC-like, deformed Glauber

in. cond. (dcgc1.2):

B.Betz et al., PRC 86, 024903 (2012)

$$x \rightarrow s_x x, \quad y \rightarrow s_y y$$

$$s_x = \sqrt{\frac{\langle x^2\rangle_{\rm CGC}}{\langle x^2\rangle_{\rm Gl}}}, \quad s_y = \sqrt{\frac{\langle y^2\rangle_{\rm CGC}}{\langle y^2\rangle_{\rm Gl}}}$$

with the assumption

$$\epsilon_{\rm CGC} = f\cdot\epsilon_{\rm Gl} \qquad f = 1.2\pm0.1$$

Jet-energy and path-length

dependencies (4 main scenarios):

a	z	c	in. cond.
0	1	3	Glauber
1/3	1	8/3	Glauber dcgc1.2
1	2	3	"Jia" dcgc1.2

see A. Ficnar QM'12 Poster

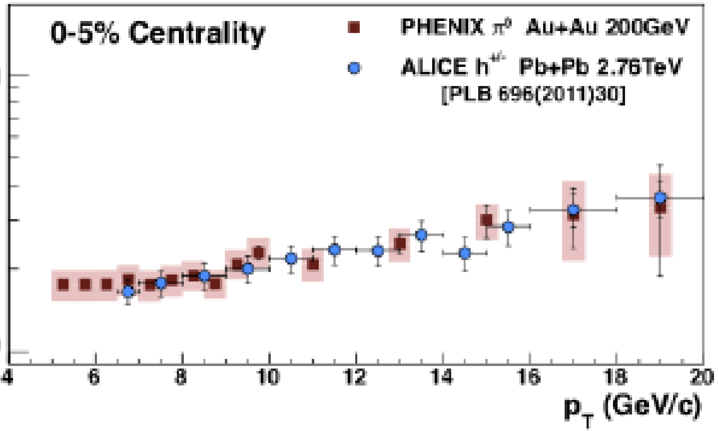
A. Ficnar, arXiv: 1201.1780

pure binary collisions for a=1

J. Jia et al., PRC 82 (2010), 024902

B.Betz, MG. PRC84(11),PRC86(12)

$R_{AA}(p_T)$ at RHIC



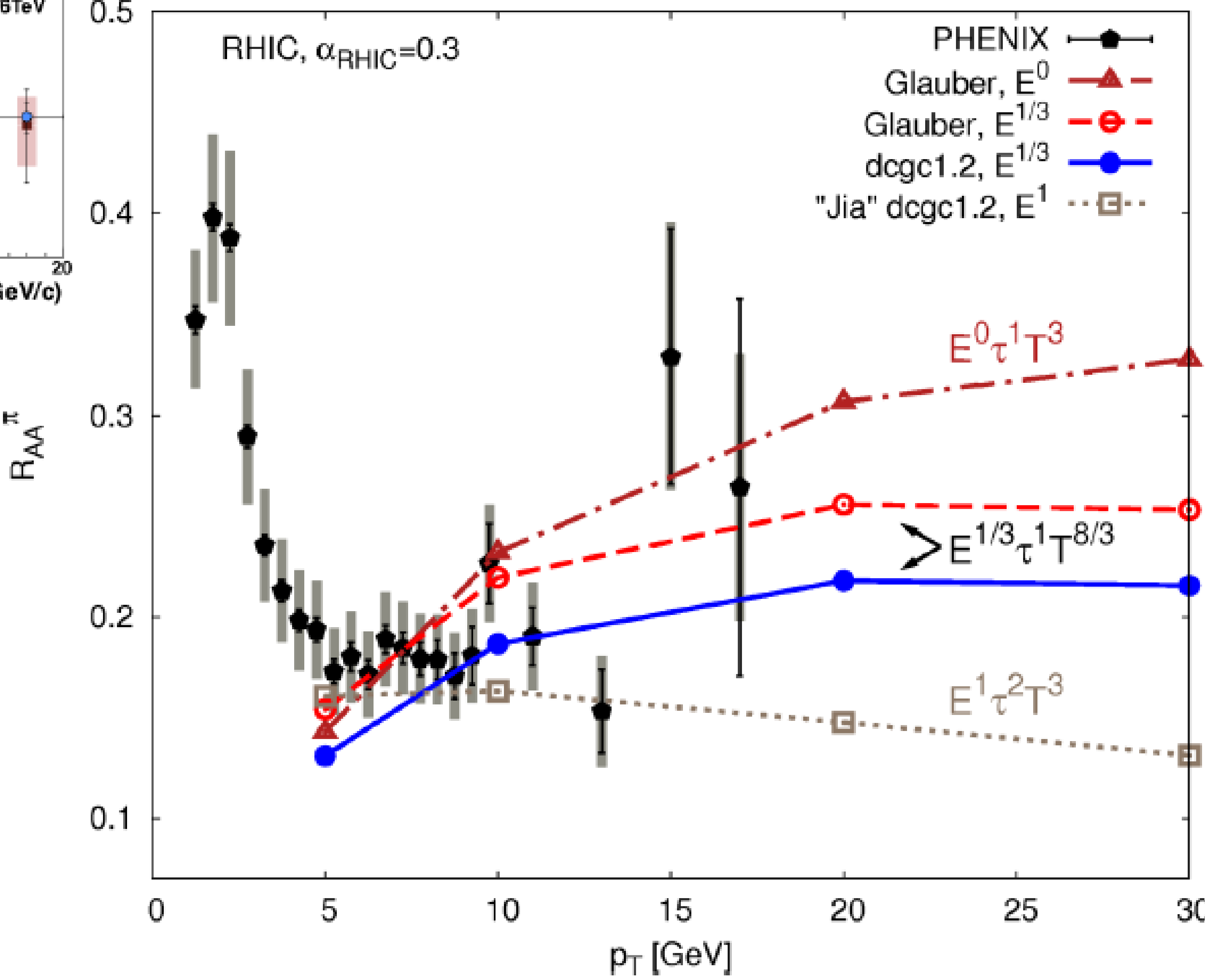
PHENIX Overview Talk, QM 12

– $a = 0$ and $a = 1/3$ energy exponents are consistent with data within error bars

⇒ Higher statistics measurements at RHIC with $5 < p_T < 30$ GeV are needed

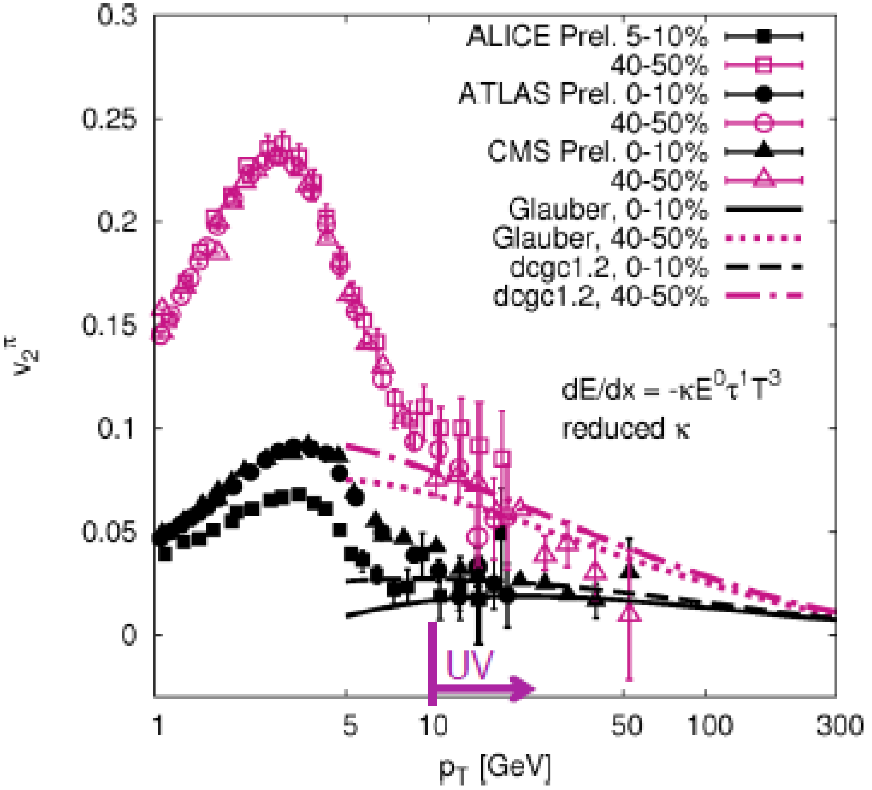
sPHENIX Upgrade Concept, arXiv:1207.6378

B.Betz et al., PRC **86**, 024903 (2012)

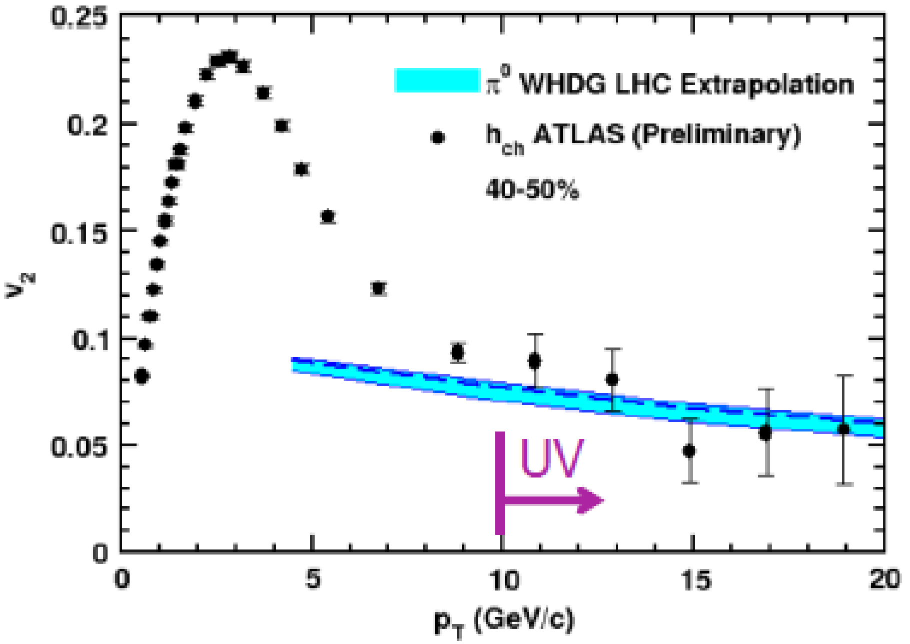


$v_2(p_T$, Centrality) at LHC

B.Betz et al., in preparation



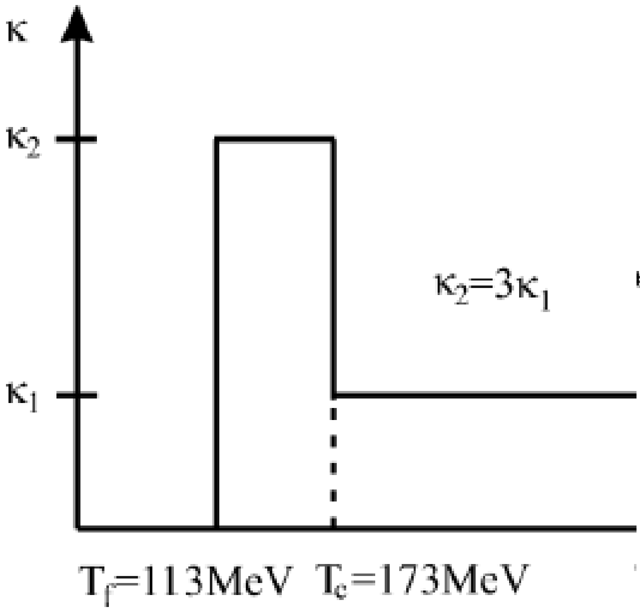
W. Horowitz et al., J. Phys. G **38**, 124064 (2011)



- Unlike the intermediate p_T, the deep ultraviolet p_T>10 GeV is much better explained by standard jet tomography at LHC
- For 1< p_T< 5 GeV, it is difficult to separate the jet contribution to v_2 from the high-p_T tails of the bulk QGP elliptic flow

⇒ Very high p_T>10 GeV v_2 is rather insensitive to 20% variations in the eccentricity between Glauber and CGC

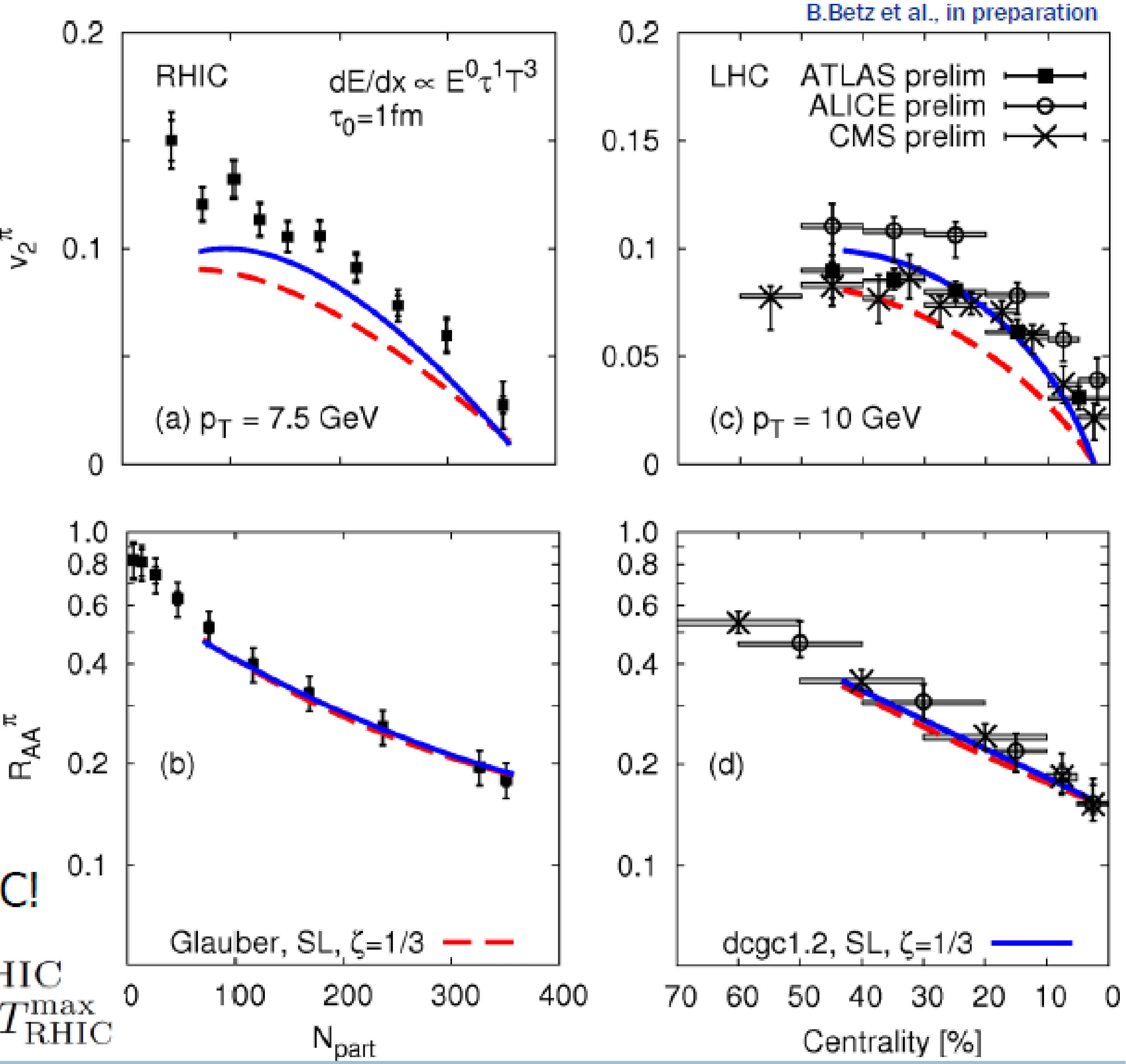
Temperature-dependent Coupling



J.Liao et al,. PRL **102** (2009) 202302

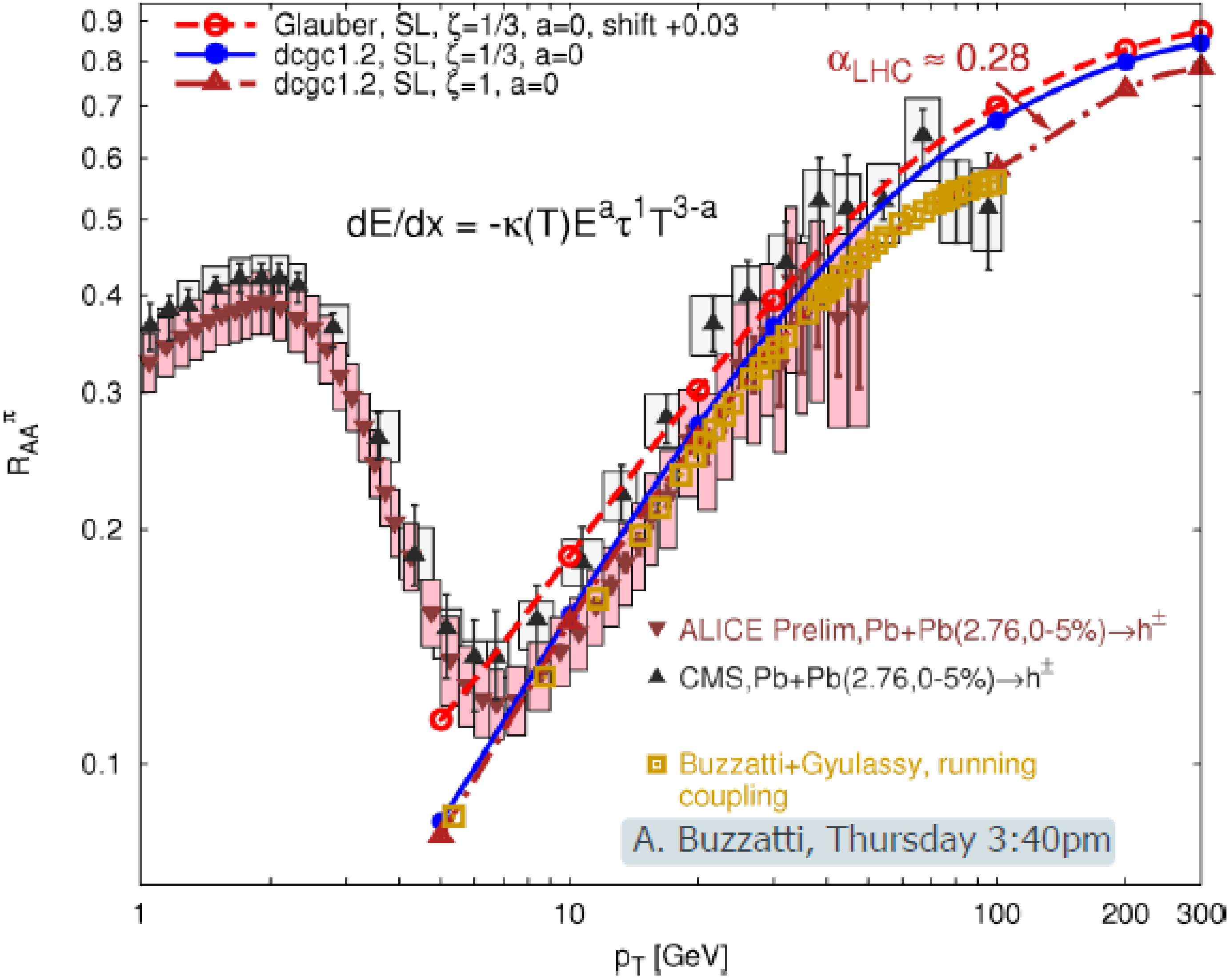
$$\boxed{\zeta = \kappa_1/\kappa_2}$$

- ⇒ Assumes the same κ(T) at RHIC and LHC!
- ⇒ $\mathrm{eff}\ \kappa_{\mathrm{LHC}} < \mathrm{eff}\ \kappa_{\mathrm{RHIC}}$ because $T^{\max}_{\mathrm{LHC}} \sim 1.3\ T^{\max}_{\mathrm{RHIC}}$

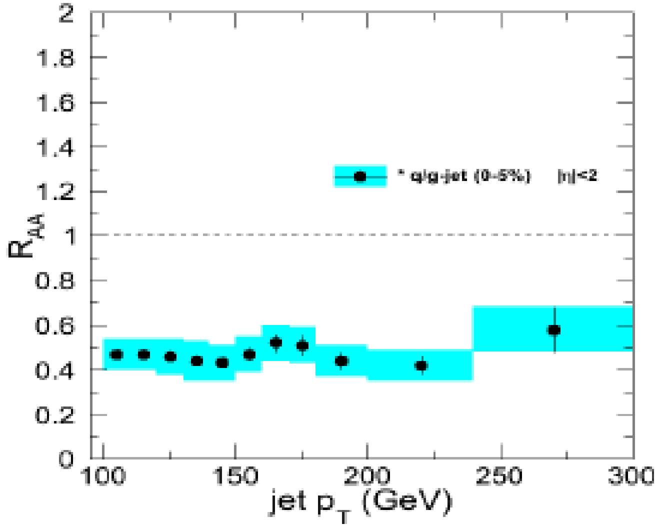


$R_{AA}(p_T)$ at LHC

B.Betz et al., in preparation



A. Buzzatti, Thursday 3:40pm



CMS Overview Talk, QM 12

→ Temperature-dependent and reduced couplings lead to similar $R_{AA}(p_T)$

→ Running coupling CUJET and SL a=0 ζ=1/3,1 all similar for p_T >10 GeV

Summary:

(1) Unexpected prelim D+Au data from PHENIX at RHIC
Difficult to reconcile with any of our present JET quench models

(2) Spectacular QM12 data from LHC confirm B > D > pi
Flavor Tomography beyond 7 GeV

(3) Running coupling CUJET solves LHC apparent
Transparency RAA puzzle consist with latest QM12 RHIC

(4) Holographic hQCD modelling based on conformal AdS
Ruled out by LHC for PT>10. Nonconformal generalized
Geometries must be tested

(5) Generic “Polytrop” dEdx model useful to interpolate between
Eikonal pQCD, AdS string drag, Holographic falling string,
And nonpertubative Tc enhanced models