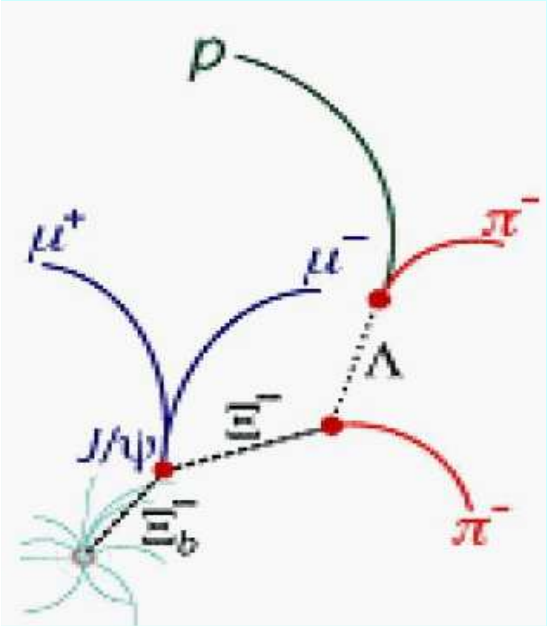
The Charm and Beauty of the Lochness Monster at LHC

M. Gyulassy (FIAS & Columbia)

In memory of Professor József Zimányi
who enjoyed strangeness, charm ,and beauty in
baryonic matter in all forms and shapes



Csontvari : Zarandok 1907

Last year I
almost beat Jozso
to the “Source”

But John Harris
and Dirk Rischke
pulled me back
and let him get there

First!

Today we celebrate
his life and his physics

by looking forward
into possibilities
and opportunities
of the future

Outline:

1. Baryons, Junctions, and the perfect *udscbt* di-baryon.
2. Combining three ideas in

   heavy quark jet tomography

   * and the recent attack of RHIC electrons
3. Charm and beauty as a AdS_5 Lochness monster at the LHC

A June 2007 present from D0/FNAL: charm-tagged strange-beauty Baryon Ξ_s^-

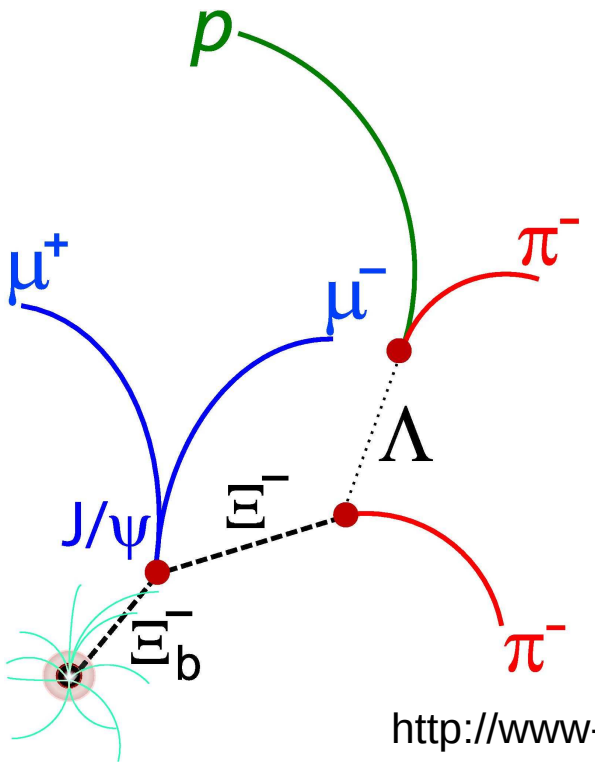
(Jozso would have really loved this one !)

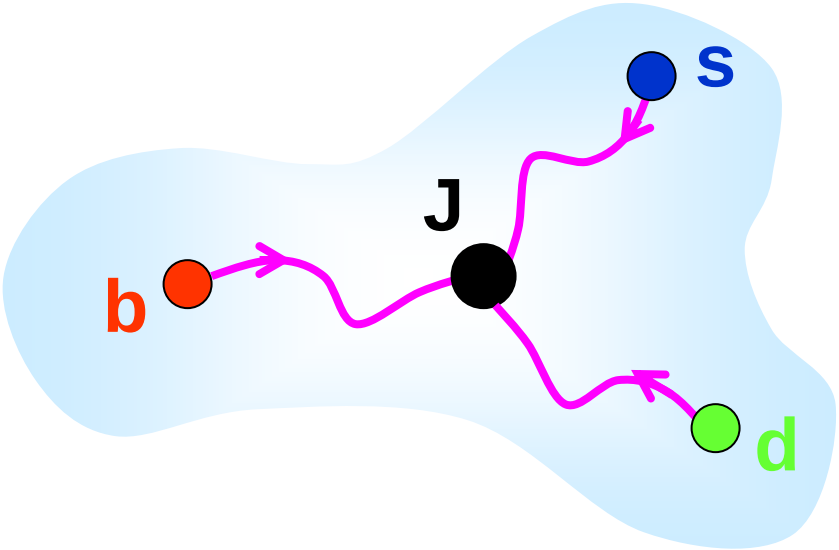
$$\Xi_s(x) = \int dx_1 dx_2 dx_3 \; b^i(x_1) s^j(x_2) d^k(x_3) \, J_{ijk}(x \mid x_1, x_2, x_3)$$

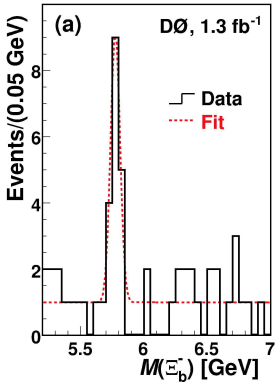
Bound by a baryon junction $J_{i,j,k}(x \mid x_1, x_2, x_3) = \varepsilon^{i'j'k'} U_{i'i}(x, x_1) U_{j'j}(x, x_2) U_{k'k}(x, x_3)$

Mass=5.774±0.019 GeV/c^2

Lifetime ~ 10^{-12} sec (mm)







15 events / 10^{12}

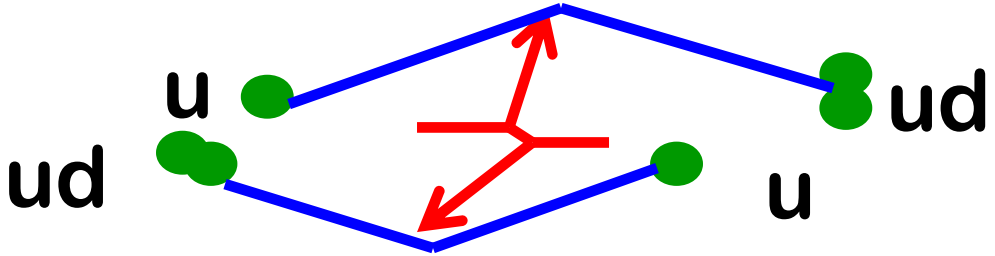
http://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B07F/

Conventional no Junction Dynamics

Soft Strings + Hard pQCD

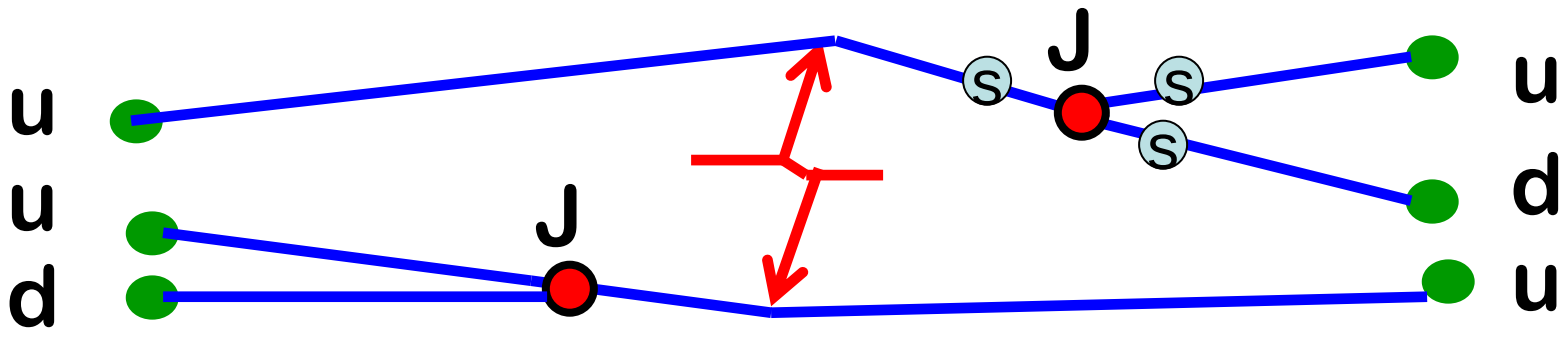
HIJING 1.38

FRITIOF 7.3



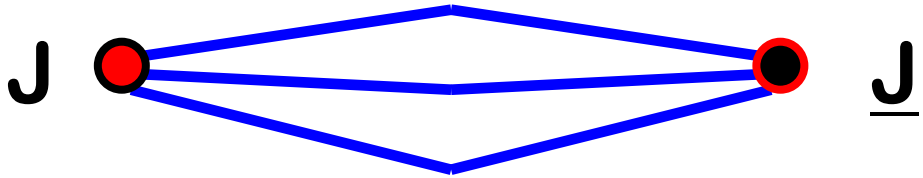
Hijing BB̲ model of Junction Production

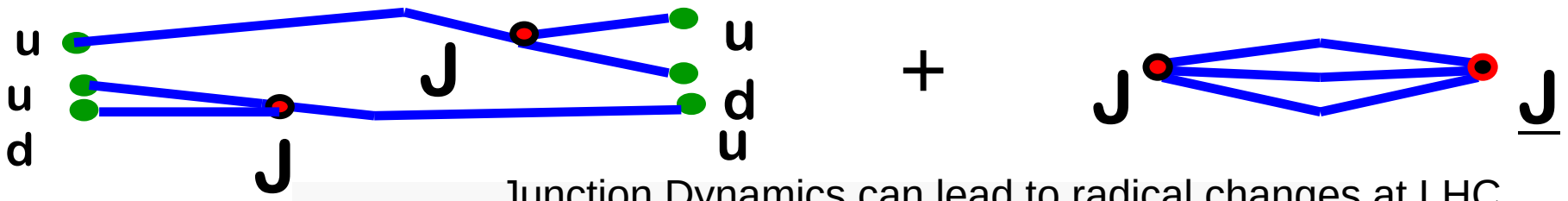
2 Valence Baryon Junctions + 1 Junction-anti Junction



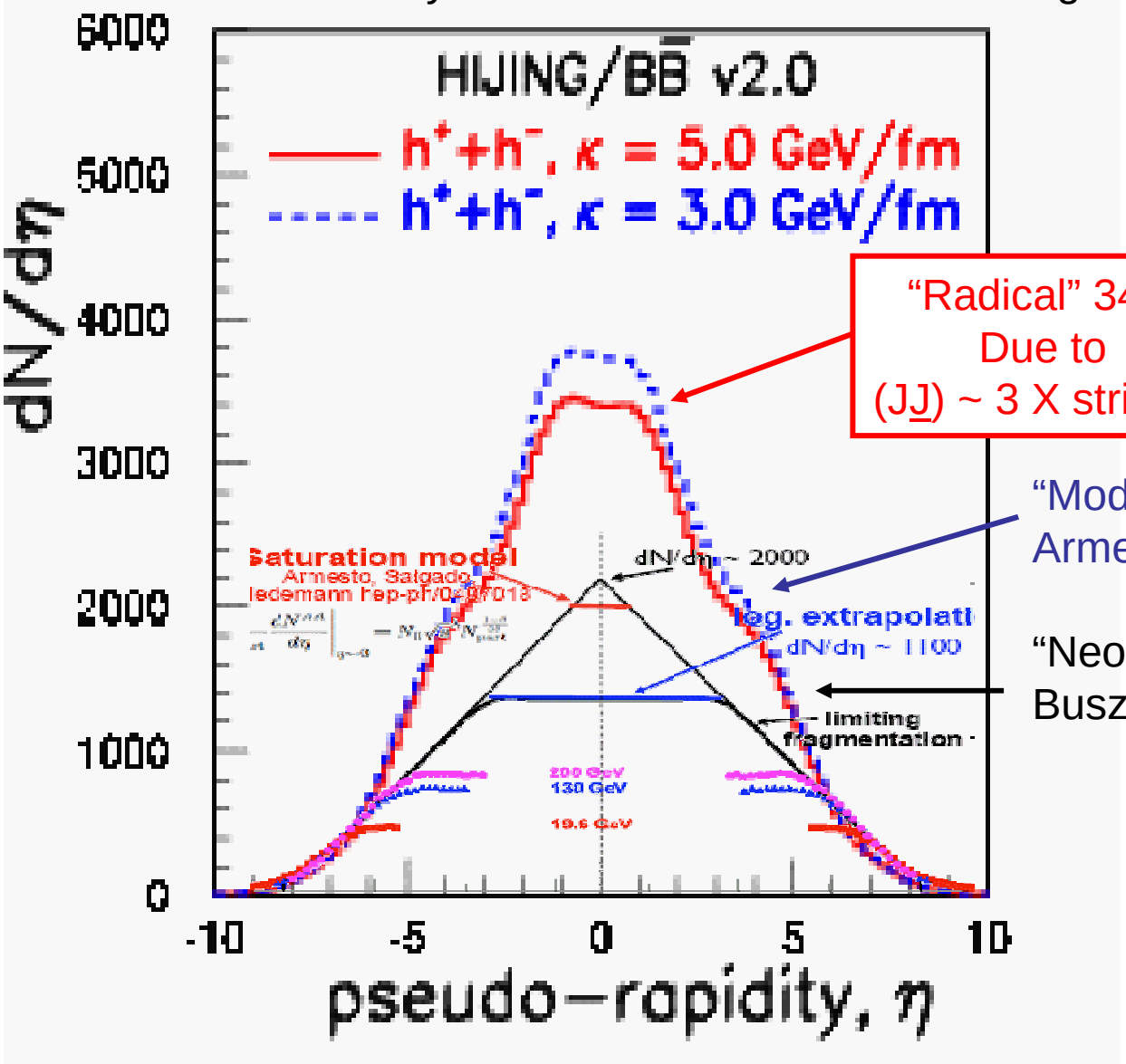
HIJING-BB̲ 2.0

Topor et al





Junction Dynamics can lead to radical changes at LHC



"Radical" 3400
Due to
(JJ) ~ 3 X strings !

"Moderate": 2000
Armesto et al 04

"Neocon": 1100
Busza 04

Topor et al

Hijing BB2.0 predictions for LHC
Topor Pop et al hep-ph/**0705.2705**

~ 100 J+$\underline{J}$

Our predictions for the LHC multiplicities, are summarized below, assuming $\kappa = 5$ GeV/fm ($\kappa = 3$ GeV/fm):

$dN_{ch}/d\eta = 3409\,(3735)$ $\quad dE_T/d\eta = 5805\,(5815)$

$dN^{\pi^\pm}/dy = 1043\,(1247)$ $\quad dN^{K^+}/dy = 264\,(313)$

$dN^{p}/dy = 206\,(186)$ $\quad dN^{\bar{p}}/dy = 203.2\,(183.3)$

$dN^{B-\overline{B}}/dy = 6.00\,(4.97)$

Our model predicts ≈ 17.0 produced charged hadrons per participant pair in central (0-5%) Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV. This value is higher than those obtained by requiring that both limiting fragmentation and the trapezoidal shape of the pseudo-rapidity distribution persist at the LHC (Wiedemann, 07).

Baryon junctions *may* be produced Profusely at LHC

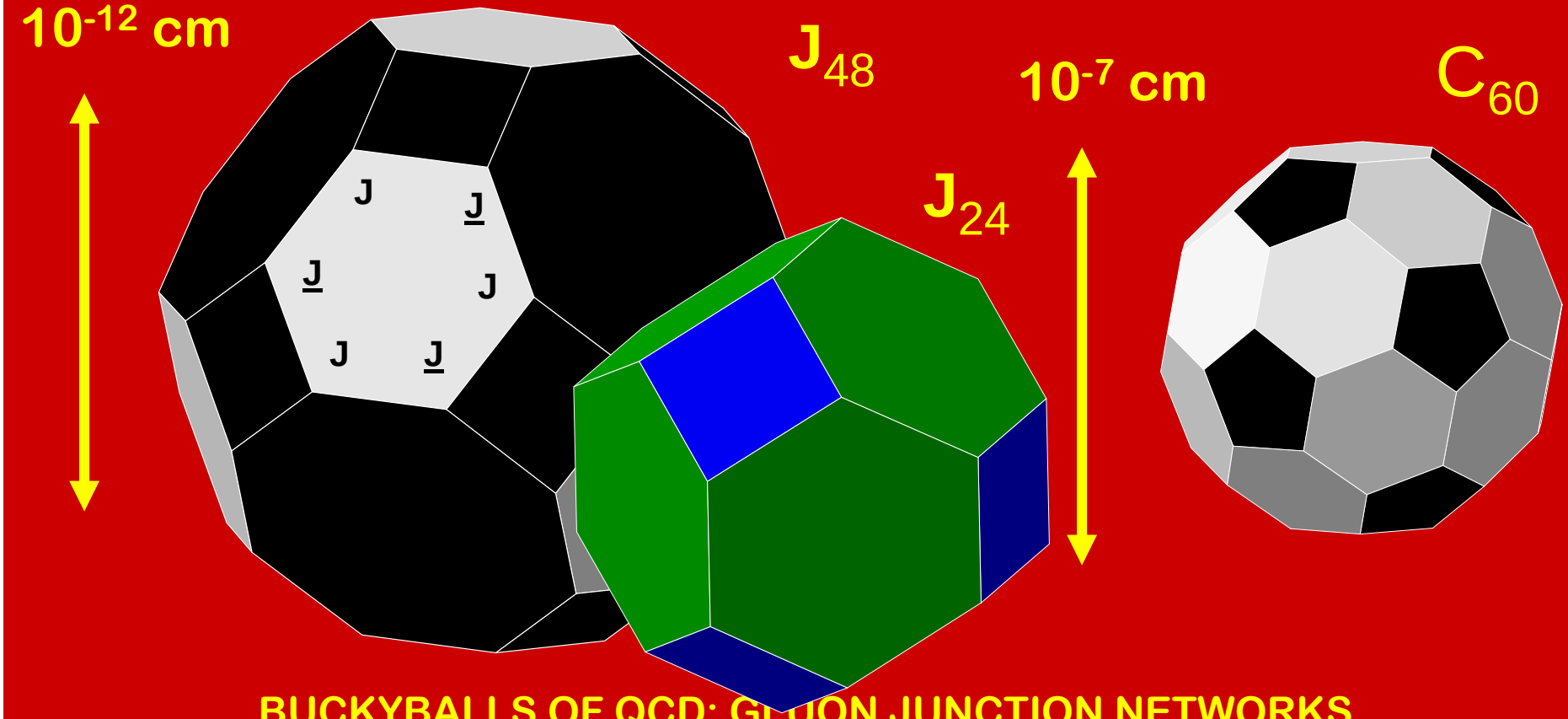
$$> 2 \times \left(\frac{dN^{p,\bar{p}}}{dy} \right)_{pQCD}$$

Eskola 07

Opens a way to explore more Exotic multibaryon systems

Baryon Junctions could lead to Femto Fullerines:

Possible Possible Gluon Buckey Balls: QCD cousins of C_{60}



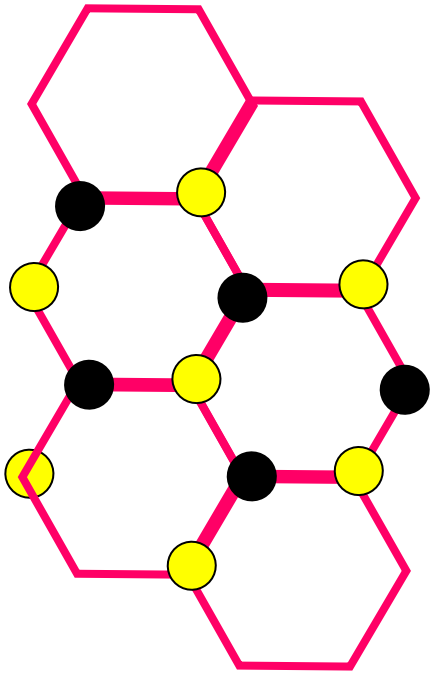
BUCKYBALLS OF QCD: GLUON JUNCTION NETWORKS.

T. Csorgo , M. Gyulassy, D. Kharzeev

Feb 2001, hep-ph/0102282

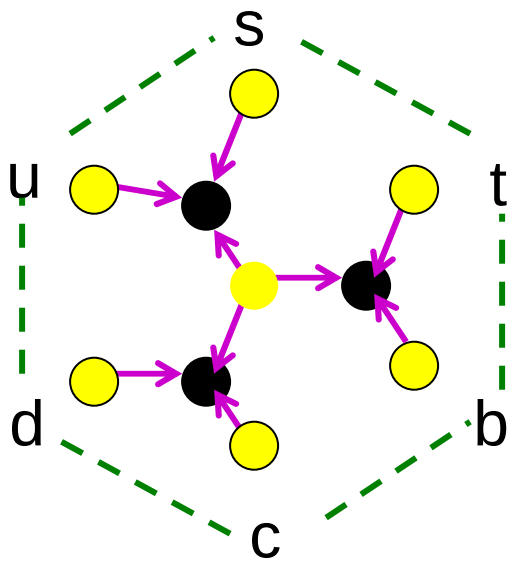
Some of the Things to Look for in the Ashes of Pb+Pb

From Gluon Junction
"Graphite"



To The Perfectly Exotic
All Family Di-Baryon

$$us\bar{J}tb\bar{J}dc\bar{J}J$$

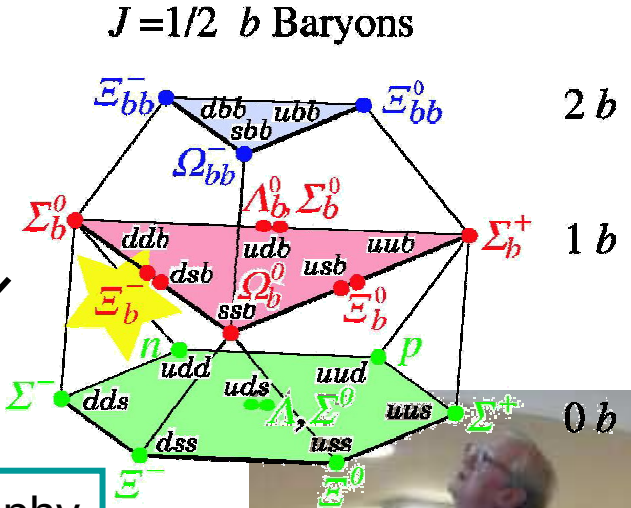


Baryon junction structures should be looked
for in the rubble of PbPb at LHC

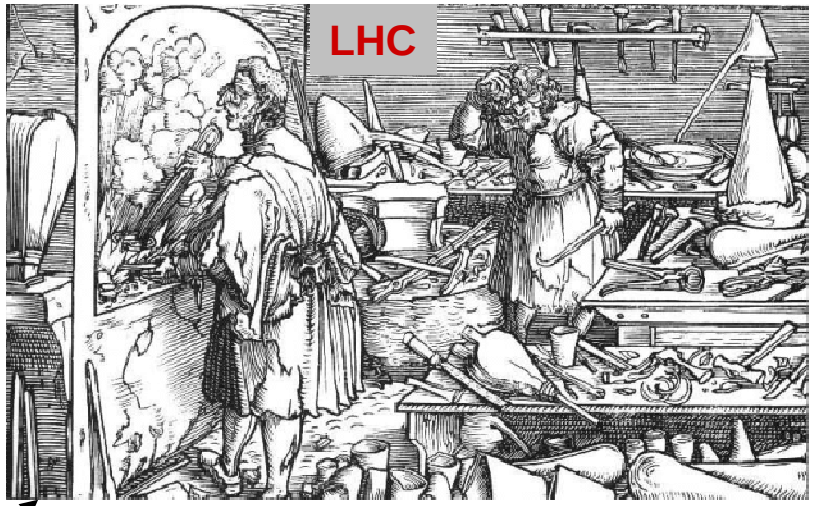
Part II: Combining Three Different Ideas

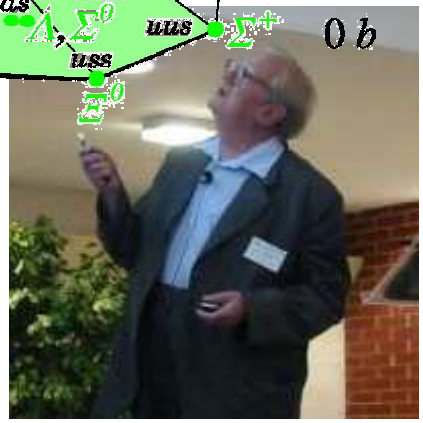
$$N_{\rm M}(\vec{R},\vec{r},\vec{p}) = N_{\rm M}(\vec{r},\vec{r},\vec{p})\ \exp\left(-\int_{\vec{r}}^{\vec{R}(\vec{r},\vec{p}_0)} {\rm d}l'\mu_{\rm M}(\vec{r}\,',p)\right)$$

Ψ,ϕ,ρ Tomography

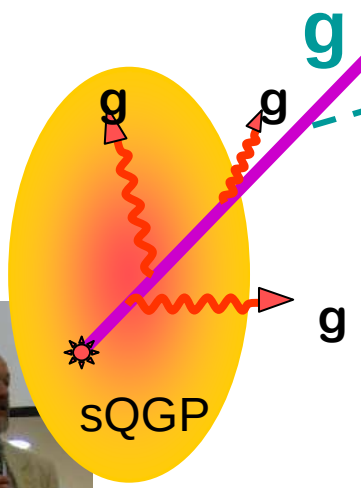


Heavy Quark Jet Tomography



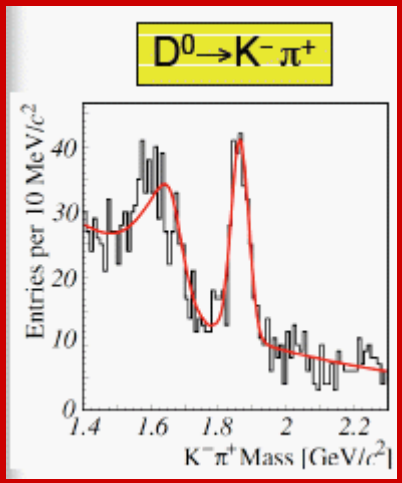


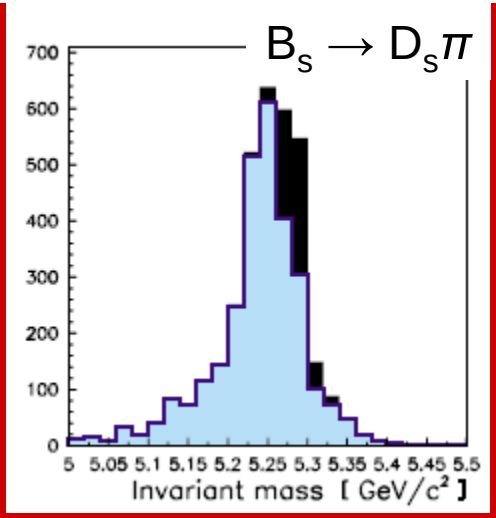
$b^i\ c^j\ s^k$ nuclei



Jet Quenching

Open Charm





Strange Beauty

The Loch Ness Monster (or hoax)

Is this the AdS_5 Brachistochrone Floating between a D3 Black brane and our D7 Probe brane? Or just a Toy model?

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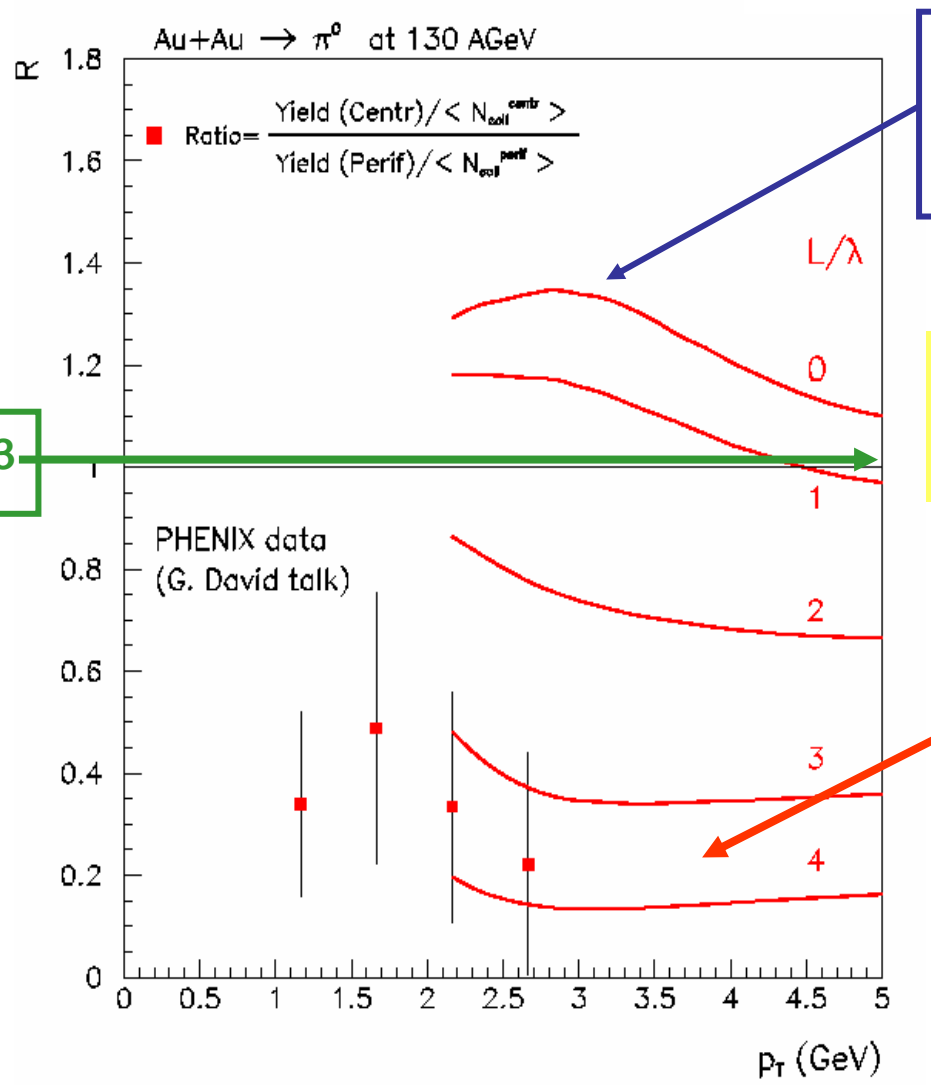
Első RHIC Plazma Sűrűség Mérése Jet Elnyomásával

P.Lévai, I. Vitev, G. Fai, G. Papp, M.Gyulassy (QM01)

$R^{\pi^0}_{AuAu}$



Cronin Effektus

(p+p→ π^0)X $A^{4/3}$

Plazma Opacity

$L/\lambda_g = \int dz\, \sigma_g(z)\rho_g(z)$

dE_{GLV}/dx Quench

(First determination of the high opacity of the QGP at RHIC)

Comparing Heavy Quark Jet Tomography at RHIC and LHC

pQCD predicts heavy quark production spectral index $\frac{d\sigma^Q}{dp_\perp} \propto p_\perp^{-n_Q-1}$

$$n_Q(p_\perp)+1 = -\frac{d\log\left(d\sigma_{QCD}^{pp\to Q}/dp_T dy\right)}{d\log p_\perp}$$

Nuclear modification factor

$$R_{AA}^Q(p_\perp) \sim \left(1-\frac{\Delta E^Q(p_\perp,L|\rho_g)}{p_\perp}\right)^{n_Q(p_\perp)}$$

At RHIC in pT~ 10-30 GeV

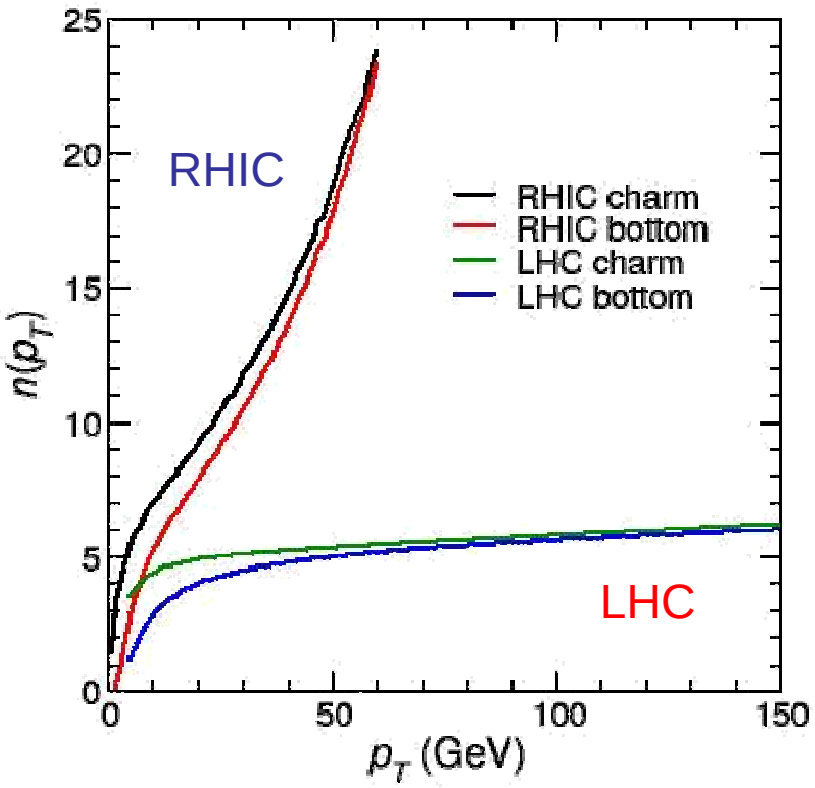
$$n_c \sim 7-12 \quad n_b \sim 5-11$$

$$n_c \neq n_b \neq const$$

At LHC in pT~ 20-100 GeV

$$n_c \approx n_b \approx 5 \approx const$$

y=0

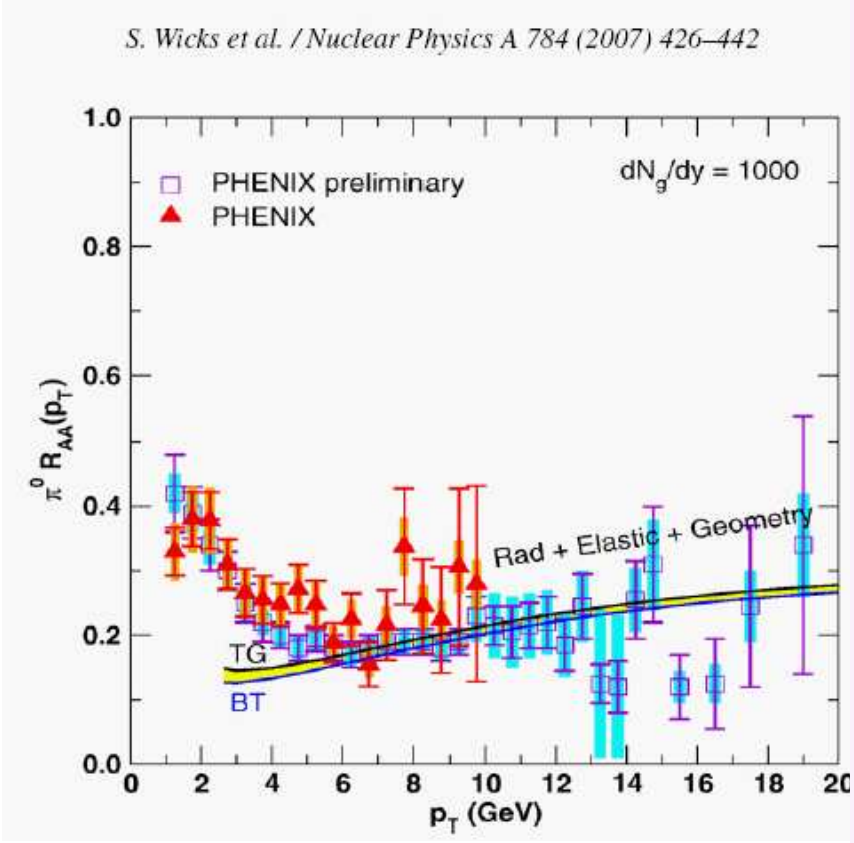


LHC easier to test predicted p_T,L dependence of $\Delta E^{c,b}(p_T,L|\rho_g)$ of pQCD vs AdS/CFT

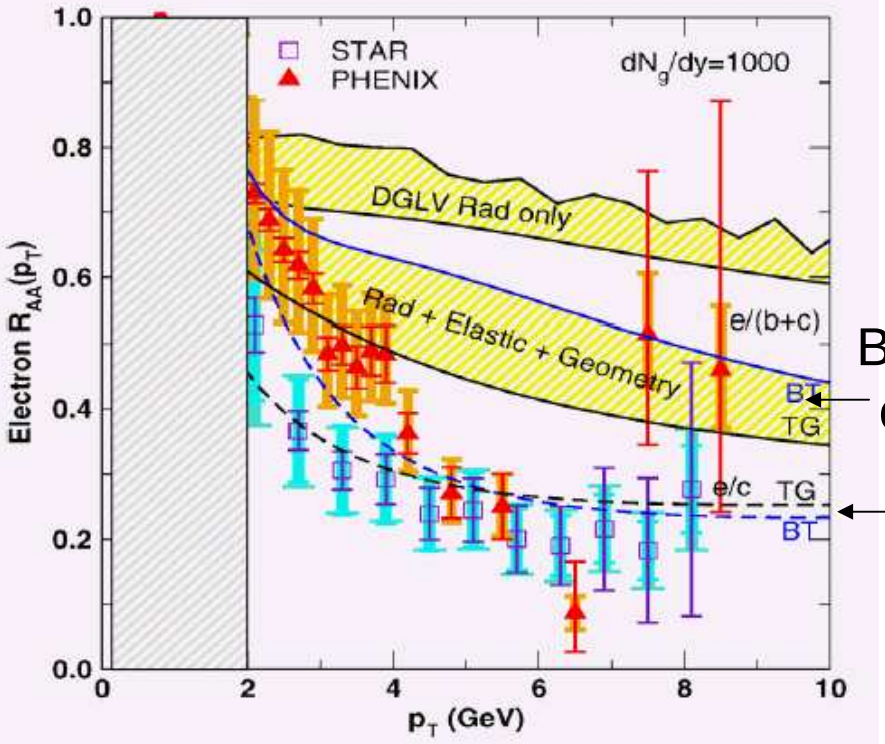
Horowitz, Gyulassy: nucl-th/**0706.2336** and to be published **Gyulassy 13/∞**

WHDG **nucl-th/0512076**

includes elastic and radiative en loss plus geometric path fluctuations



The Heavy Quark Quench Anomaly



Both c+b

c only

Electron data seem to rule out pQCD HQ dynamics *unless* b production is much smaller than NLO predicts (i.e. RHIC is charming but not beautiful)

To falsify pQCD mechanisms need RHIC and LHC data that resolves identified c and b jets seperately!

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The Heavy Quark Puzzle 2007: PHENIX collab, **Phys.Rev.Lett.98:172301,2007**

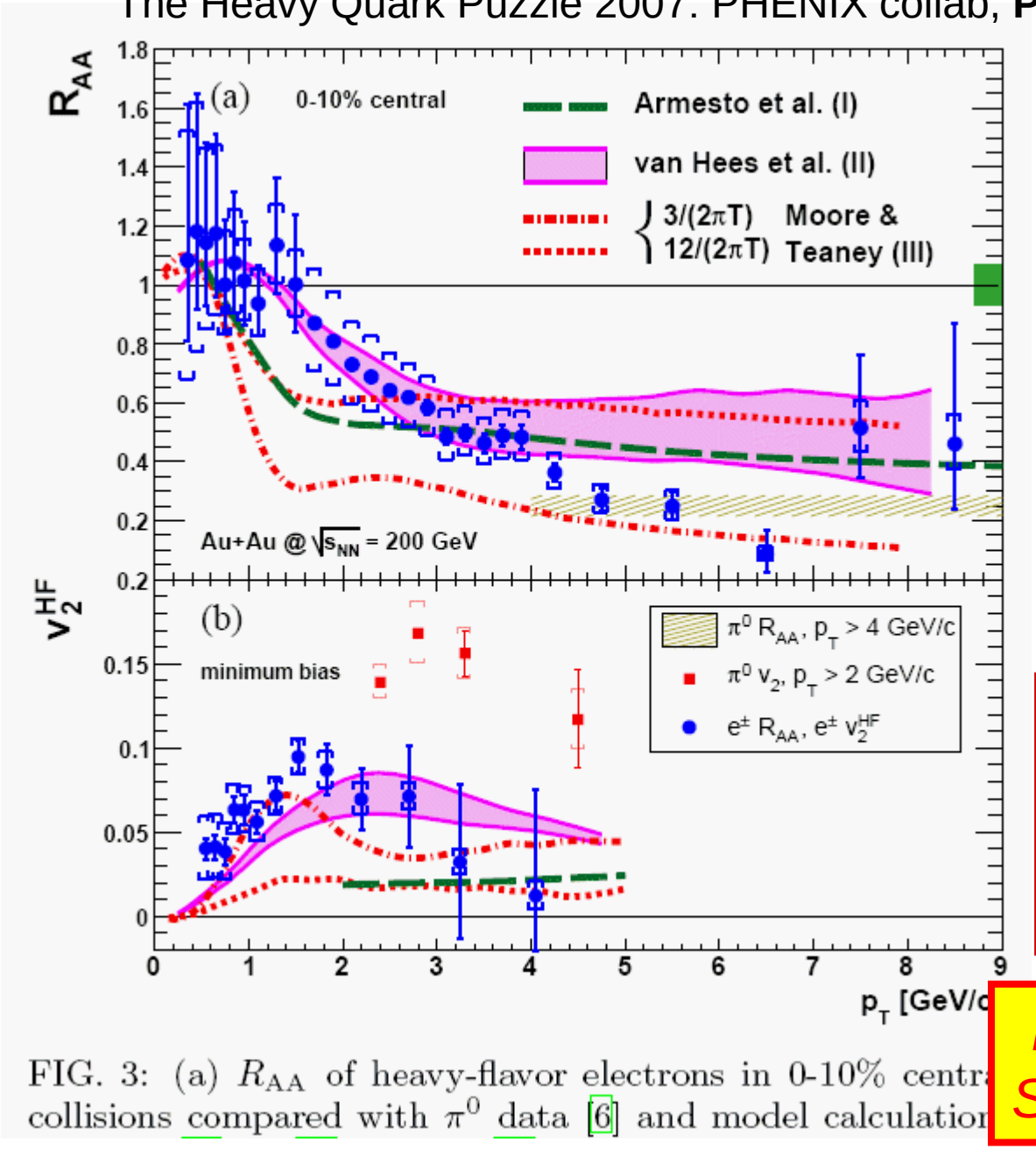

FIG. 3: (a) R_{AA} of heavy-flavor electrons in 0-10% centra collisions compared with π^0 data [6] and model calculation

"A perturbative QCD calculation with radiative energy loss can describe the measured RAA reasonably well using a large [very] transport coefficient

$$\hat{q} = \frac{\mu^2}{\lambda} = 14 \frac{\mathrm{GeV}^2}{\mathrm{fm}}$$

which leads to a consistent description of light hadron suppression as well v_2. This value would imply a strongly coupled medium."

However, WHDG predicted curves similar to AWS (not shown in Fig.3 here) using 7 times smaller $\hat{q} \sim 2$ by including elastic energy loss!

Note: No model explains Simultaneous R_{AA} and v_2 !

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Part 3: The AdS/CFT “Brachistochrone” predicts deviations from pQCD in Heavy Quark Jet Tomography

W.A. Horowitz and M. Gyulassy (FIAS Frankfurt & Columbia U.)

June 2007 e-Print: **arXiv:0706.2336** (LHC predictions)

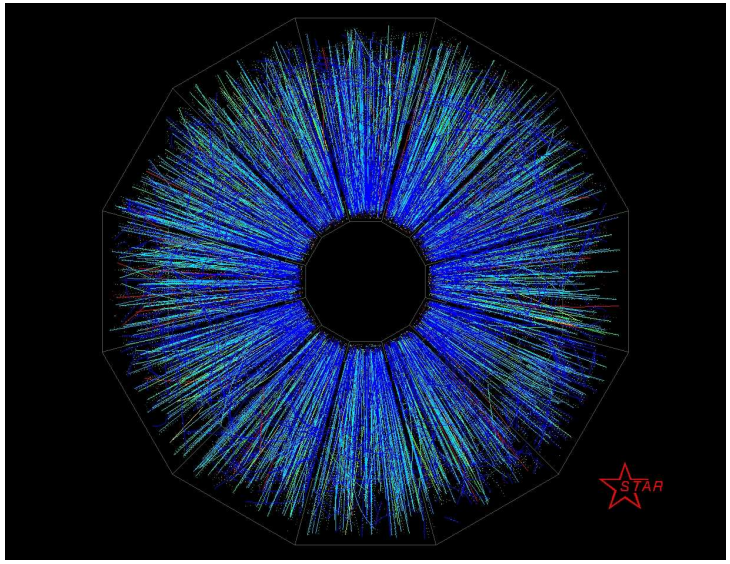
(RHIC predictions to be published)

Background Related work

1) WHDG: S. Wicks, W. Horowitz, M.Djordjevic , M. Gyulassy, **nucl-th/0512076; Nucl.Phys.A784:426-442,2007**.

2) DGVW: M. Djordjevic, M.Gyulassy, R. Vogt , S. Wicks , **nucl-th/0507019** ; **Phys.Lett.B632:81-86,2006**

Could an 5D Black Hole better approximate Quark Gluon Plasmas than QCD?



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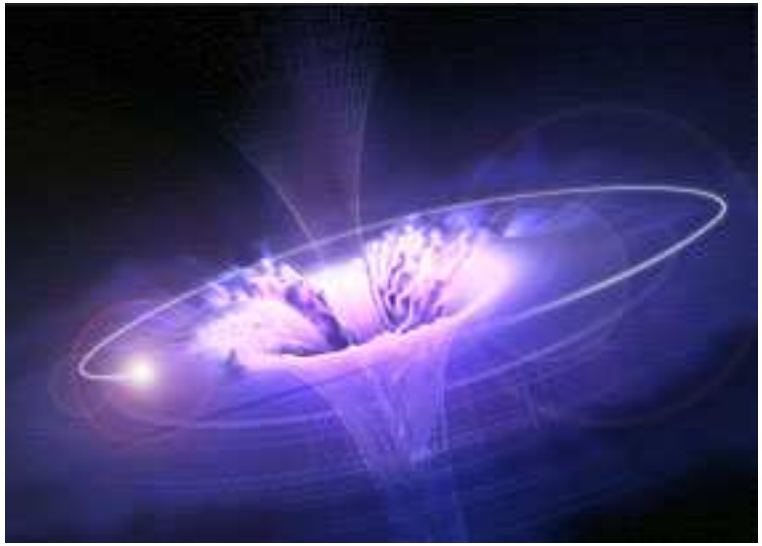
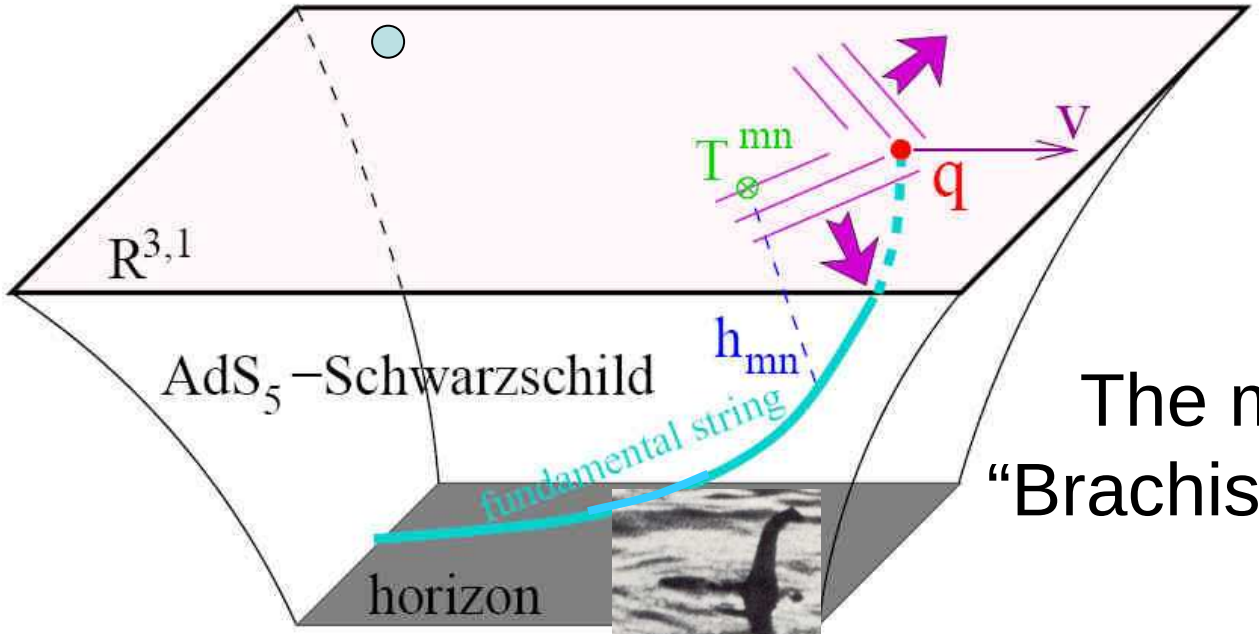


Maldecena *Conjecture*: when $N_c \to \infty$ and $g^2 N_c \to \infty$
In this limit, strongly coupled quantum conformal SYM in 4D is dual to classical weak gravity in the 5D curved space time AdS_5

Conformal SO(2,4) group of 4D SYM ~ Isometry SO(2,4) group of 5Dim AdS

3. Jet Quenching in AdS/CFT

You are here



The modern "Brachistochrone"

Figure 5: *In blue: the trailing string of an external quark (Herzog et al, 2006 [6]; Gubser 2006[7]). The dashed line shows classical propagation of a graviton from the string to the boundary, where its behavior can be translated into the stress-energy tensor* $\langle T_{mn} \rangle$ *of the boundary gauge theory.*

An analog of jet-quenching in AdS/CFT should involve a colored probe that we drag through the QGP, preferably at relativistic speeds. Readiest at hand are external quarks: strings with one end on the boundary.

Look for a Robust Signal insensitive to params to falsify AdS/CFT *or* pQCD for A+A jets

- $R_{AA} \sim (1-\varepsilon(p_T))^{n(p_T)}$ (where $p_T = (1-\varepsilon^Q)p_0$,i.e. $\varepsilon = 1 - p_T/p_0$)

1. Asymptotic pQCD fractional momentum loss for Heavy Quark:

$$\epsilon_{pQCD} \sim C\alpha_s^3 \frac{dN_g}{dy}\frac{L}{A_\perp}\frac{\log(p_\perp/M_Q)}{p_\perp}$$

DGLV,WHDG

2. String theory momentum loss of heavy Quark: **Gubser, Herzog et al**

$$\frac{d\log P_z}{d\tau} \equiv \mu = \frac{\pi\lambda T^2}{2M_Q} \qquad \epsilon_{AdS} \approx 1 - \exp\left[-\int_{\tau_0}^{L}\mu(\tau)\right]$$

  - Independent of p_T and stronger dependence on M_Q !!
  - T^2 dependence in exponent makes for a *very* sensitive probe

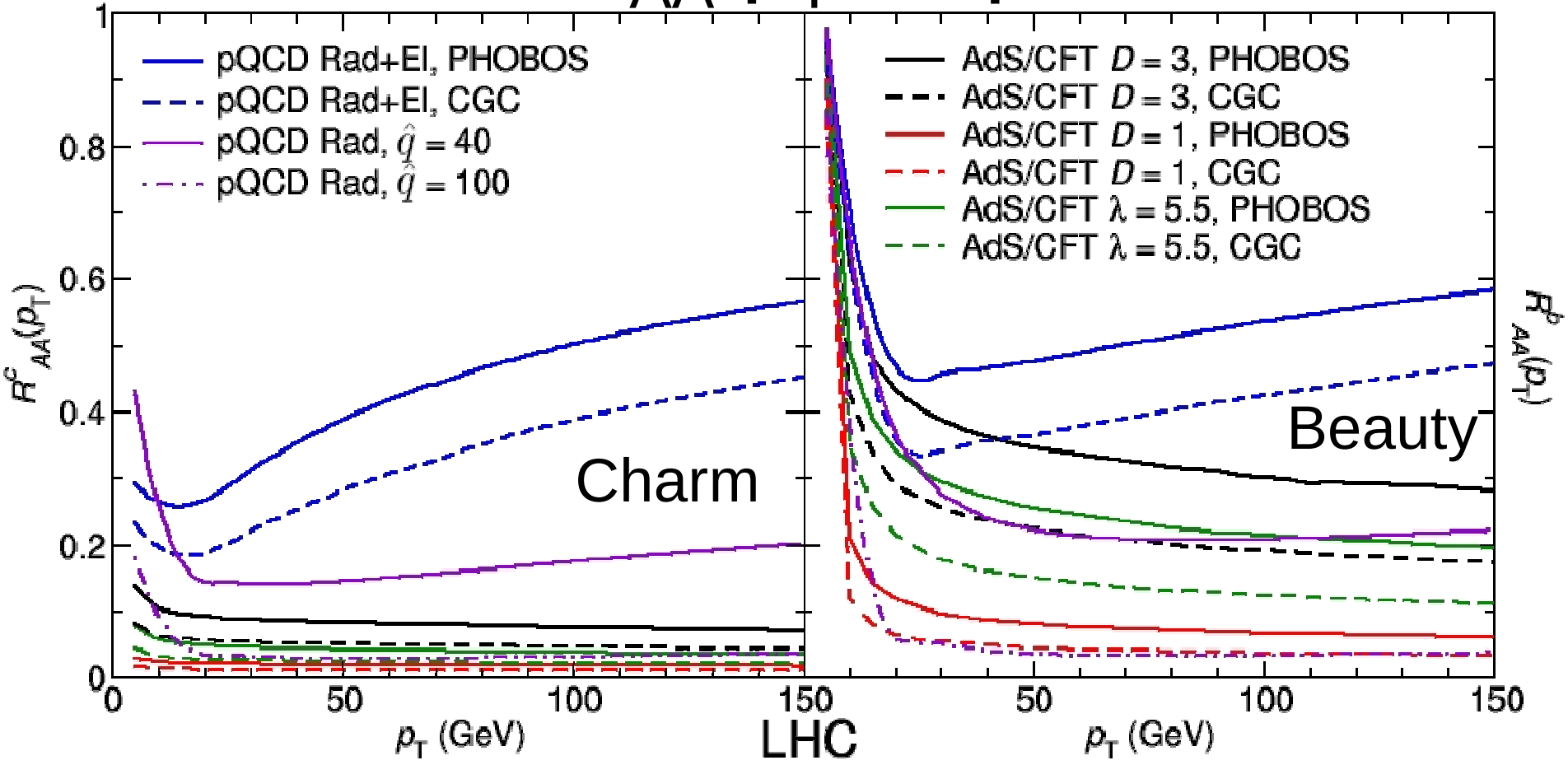
– We expect: ε_{pQCD} --> 0 vs ε_{AdS} ~ *indep* of p_T !

=> $dR_{AA}(p_T)/dp_T > 0$ in pQCD while $dR_{AA}(p_T)/dp_T < 0$ in AdS/CFT

Horowitz, Gyulassy: nucl-th/**0706.2336** and to be published

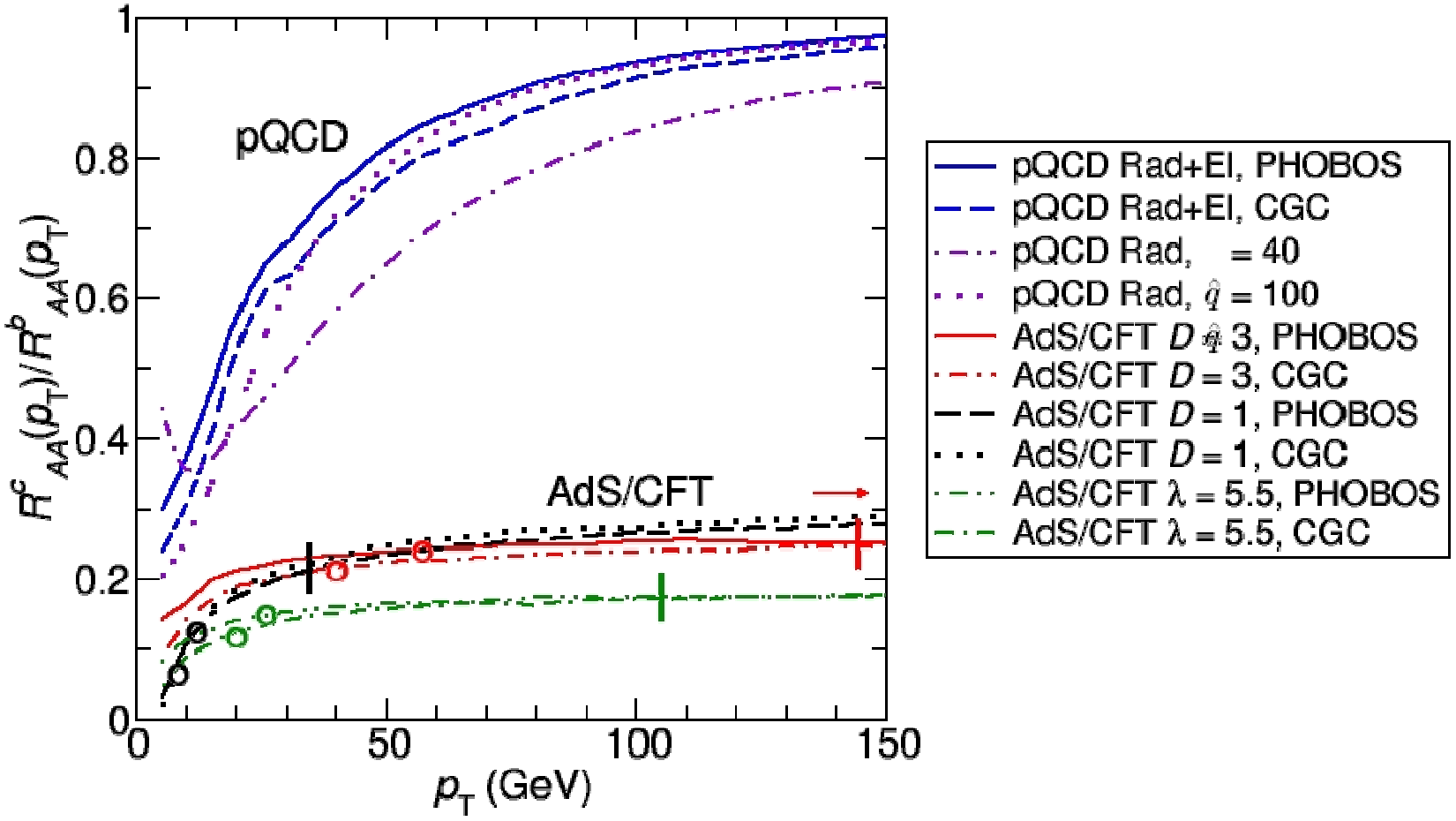
HG, nucl-th/0706.2336

LHC *c*, *b* R_{AA} p_T Dependence



- Absolute R^Q Predictions for LHC vary strongly with opacity and coupling parameters in both models. No fragility here.
- But with freedom to adjust params, hard to test pQCD vs AdS

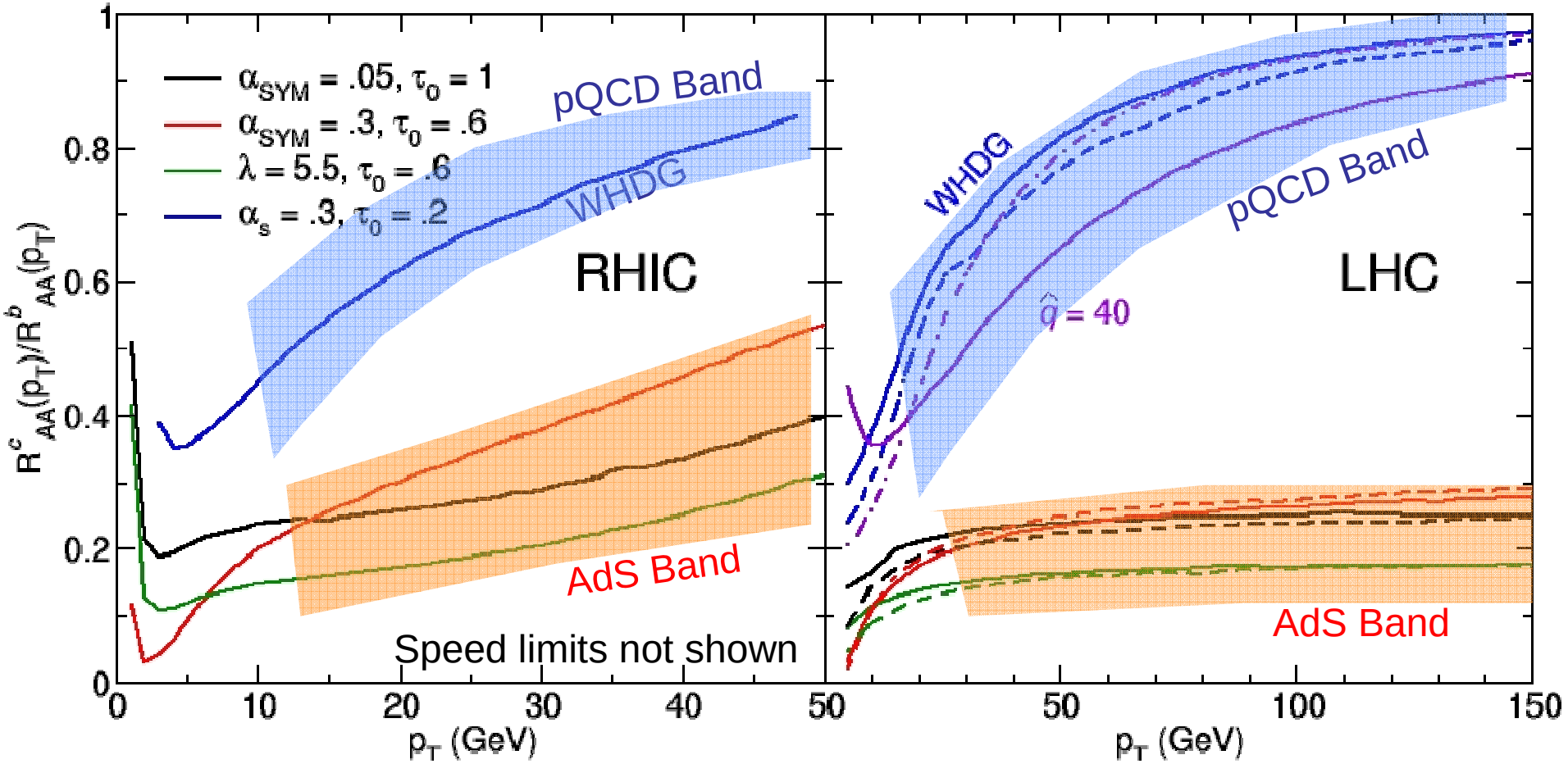
LHC $R^{cb} = R^{c}_{AA}(p_T)/R^{b}_{AA}(p_T)$ Predictions
pQCD vs AdS Heavy Quark Dynamics



- AdS O: speed limit at T_c , |: speed limit at $T(\tau_0)$
- AdS speed limits sensitive to all model parameters g^2N , τ_0, $T(\tau_0)$, dN/dy
- Note bunching of pQCD curves and bunching of AdS curves is robust

Horowitz, Gyulassy: nucl-th/**0706.2336** and to be published

$R^{cb} = R^{c}_{AA}(p_T)/R^{b}_{AA}(p_T)$



Bunching into "pQCD band" vs "AdS/CFT band" is less tight at RHIC
But qualitatively similar as to LHC

Horowitz, Gyulassy: nucl-th/**0706.2336** and to be published

Summary of Charm and Beauty of Physics with Jozso

1. Baryons: novel baryonic structures will appear with charm and beauty at LHC thanks to J and J

2. We still have to wait for indentified c and b to decide whether to abandon pQCD or to jump into the AdS black hole. *Quantitative* tests must be applied to both.

3. Identified Heavy Quark Jet Tomography will become a key tool. The double ratio of charm to bottom nuclear modification factors $R^{cb=}R^{c}/R^{b}$ is the most promising robust probe to falsify pQCD or to kill the AdS lochness monster of heavy quark jet dynamics

We will remember and miss Jozso’s guidance on our own dusty road to the furture

Munkacsi: Poros ut