Jet Tomo-graphy of wQGP via pQCD

Versus

Jet Corona-graphy of sQGP via AdS Holography

In A+A at RHIC and LHC

and
Possible implications for holographic baryon physics at FAIR

Miklos Gyulassy (Columbia University)

Tomo collabs: M. Plumer, M. Thoma, XN.Wang, P.Levai, I.Vitev, M.Djordjevic, A. Adil, W.Horowitz, S. Wicks, A. Buzzatti, A. Ficnar

Holo collabs: W.Horowitz, J. Noronha, G. Torrieri, B. Betz, A. Ficnar

Part 1: Speculations about Baryonic Holograms at FAIR

Part 2: Holo vs Tomo vs Corona -graphy of Jet Quenching

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Part 5: Overtime 1- Turbulent Initial Conditions with eta/s << 1
=> [Jet, Bulk Flow] $\neq$ 0

Part 6: Overtime 2: Demonic vs Angelic Flow Beyond Perfection at LHC
HRG CGC

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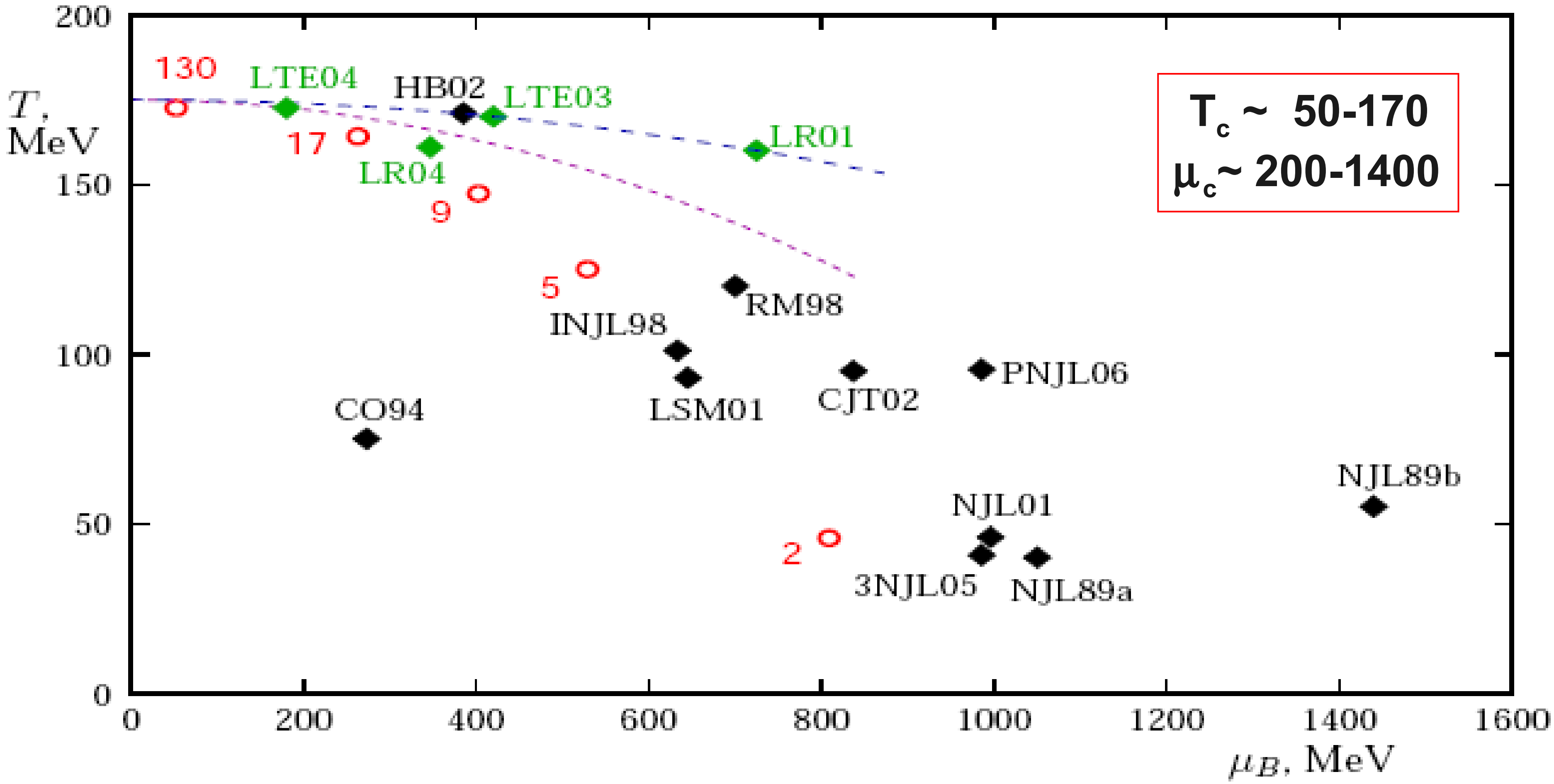
Theory of the QCD Critical End Point covers all possibilities

A high priority open problem for LOEWE HIC for FAIR



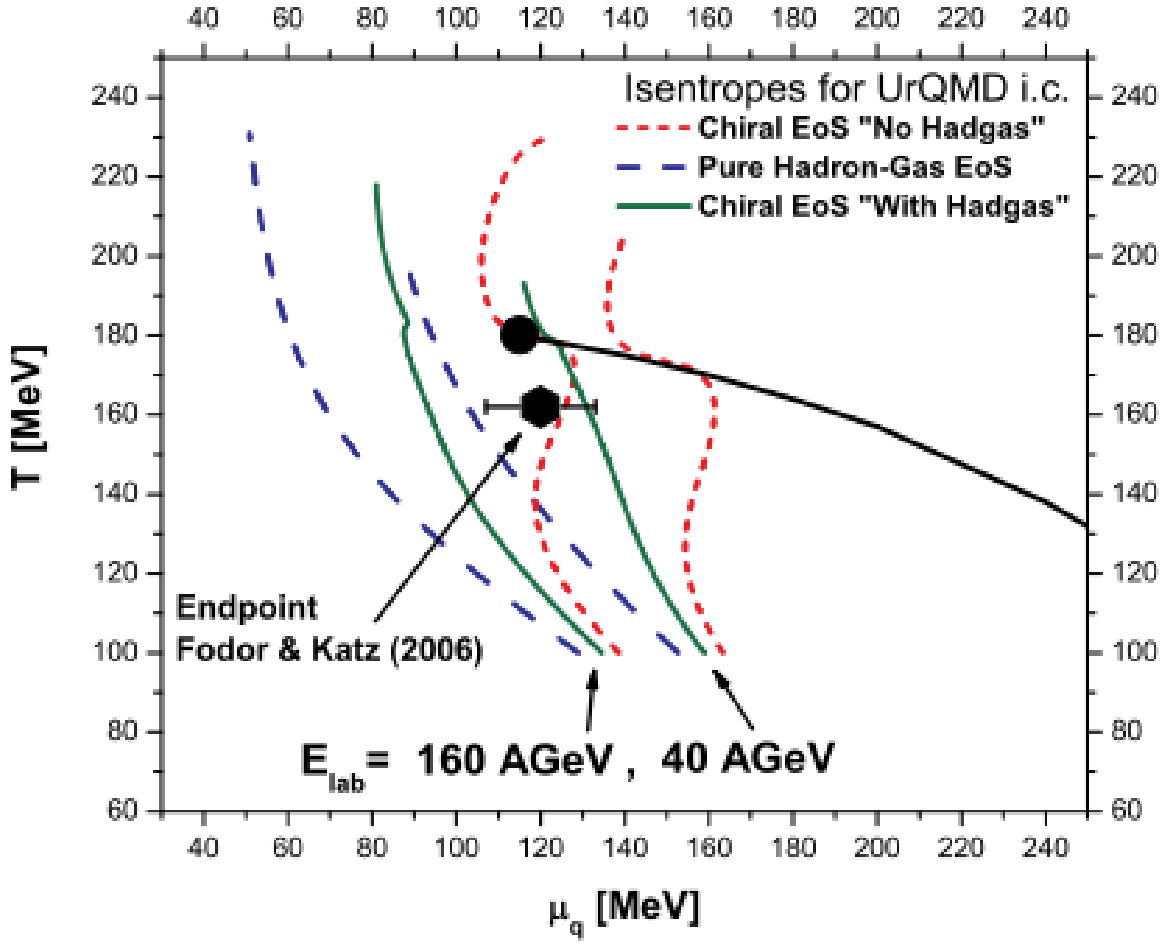
$T_c \sim$ 50-170
$\mu_c \sim$ 200-1400

Figure 4: Comparison of predictions for the location of the QCD critical point on the phase diagram. Black points are model predictions: NJLa89, NJLb89 – [12], CO94 – [13, 14], INJL98 – [15], RM98 – [16], LSM01, NJL01 – [17], HB02 – [18], CJT02 – [19], 3NJL05 – [20], PNJL06 – [21]. Green points are lattice predictions: LR01, LR04 – [22], LTE03 – [23], LTE04 – [24]. The two dashed lines are parabolas with slopes corresponding to lattice predictions of the slope $dT/d\mu_B^2$ of the transition line at $\mu_B = 0$ [23, 25]. The red circles are locations of the freezeout points for heavy ion collisions at corresponding center of mass energies per nucleon (indicated by labels in GeV) – Section 5.

M. Stephanov, Lattice QCD Review

(3+1)-Dimensional Hydrodynamic Expansion with a Critical Point from Realistic Initial Conditions

J. Steinheimer,[1] M. Bleicher,[1] H. Petersen,[1,2] S. Schramm,[1] H. Stöcker,[1,2,3] and D. Zschiesche[1]

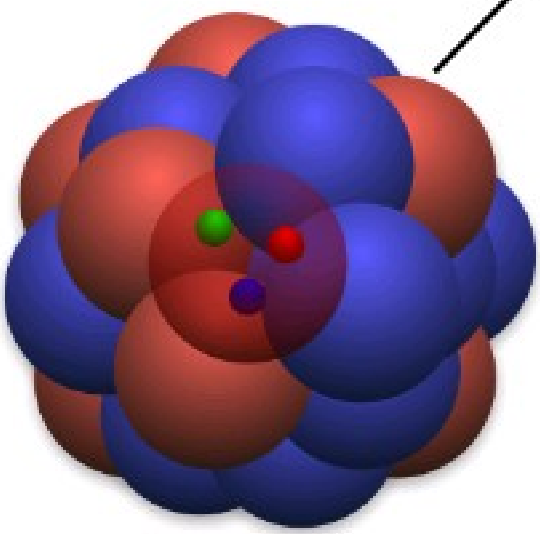


Dynamic (Isentropic) Path in A+A is sensitive to details of <u>Unknown</u> Equation of State P(T, μ)

- **And <u>UNKNOWN</u> Transport properties eta, zeta, kappa**

Evolving Ideas about Nuclear Matter

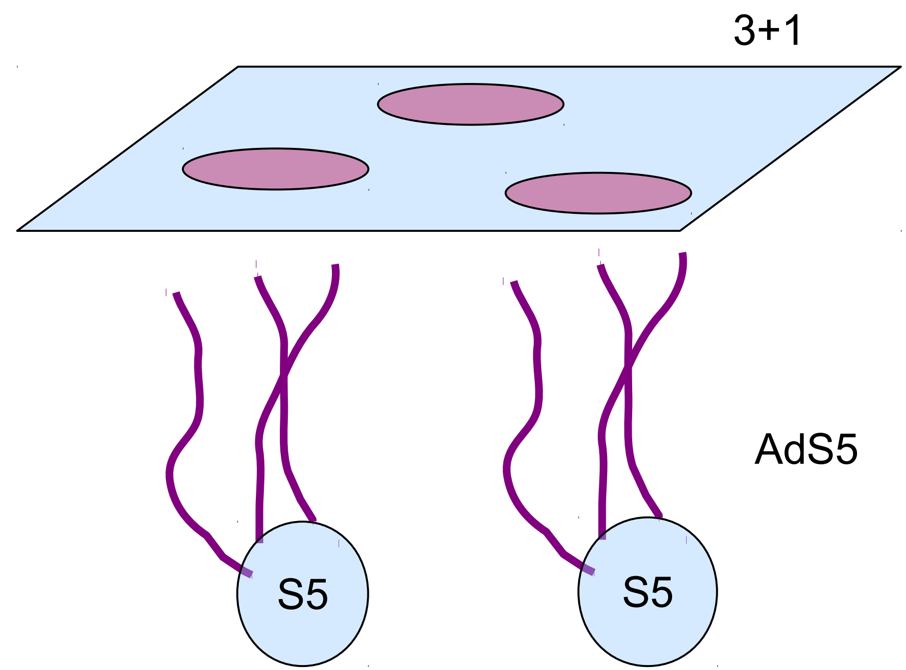
1932 Nucleus



Walecka
Hadro Dynamics

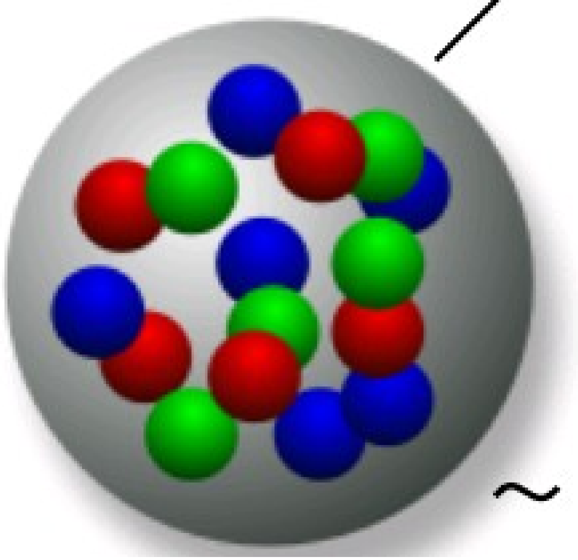
930 MeV/A

Witten 1989



10 D Stringy “Baryon Junction”
Holography

1974 Quark Bag

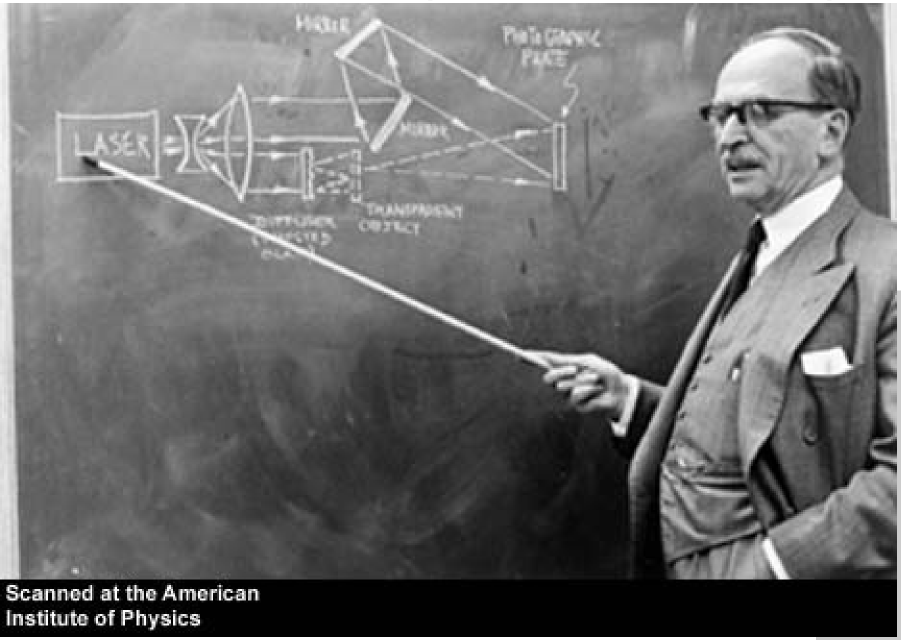


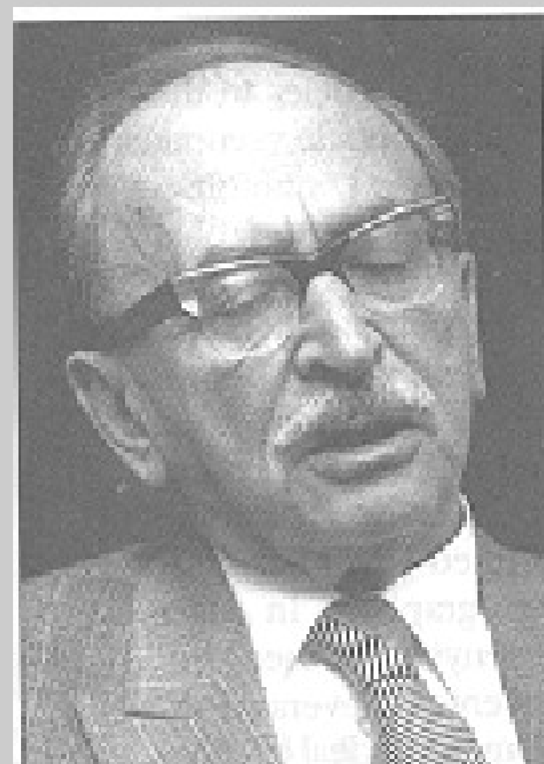
NJL
Quark Dynamics

~ $B/\rho + c\,\rho^{1/3} > 1.3$ GeV

Whole (holo) spatial picture (graf) using amplitude and phase (1949)

2D plate contains complete 3D info via interference



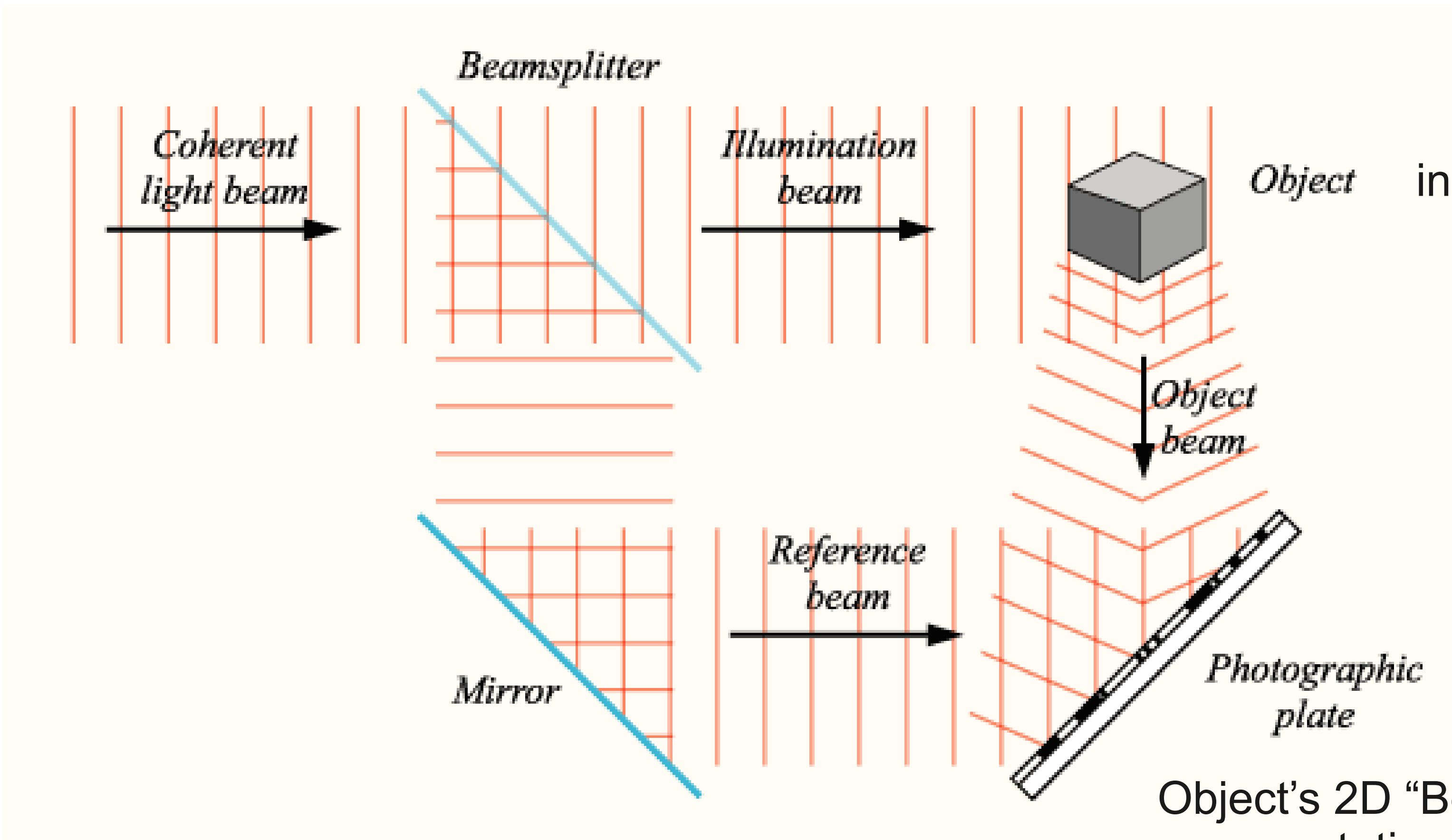


Dennis Gabor, the inventor of holography.
(5 June 1900, Budapest – 8 February 1979, London)

Gábor Dénes
Nobel Prize 1971
http://www.kfki.hu/fszemle/archivum/fsz9905/bor.html

Coherent Interfering reflected wave and reference waves recorded on 2D film
Encodes **phase** and **amplitude** information about the 3D objects in the “Bulk”

=> Classical Wave Holography

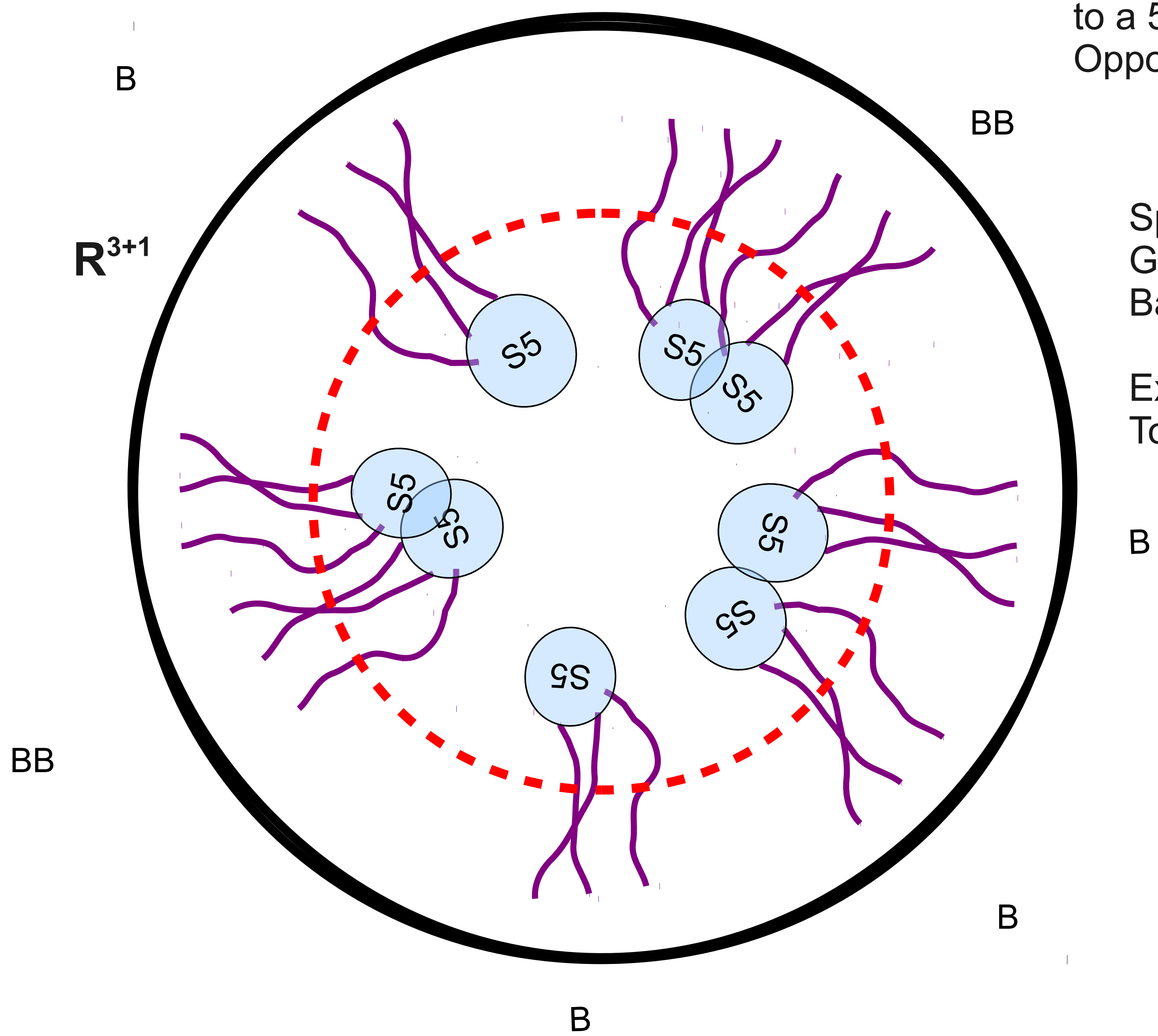


in the 3D “Bulk”

Object’s 2D “Boundary” representation

Dense Correlated Nuclear Matter in AdS/CFT

Every 5D "point"
In AdS5 attached
to a 5D ball with
Opposite curvature

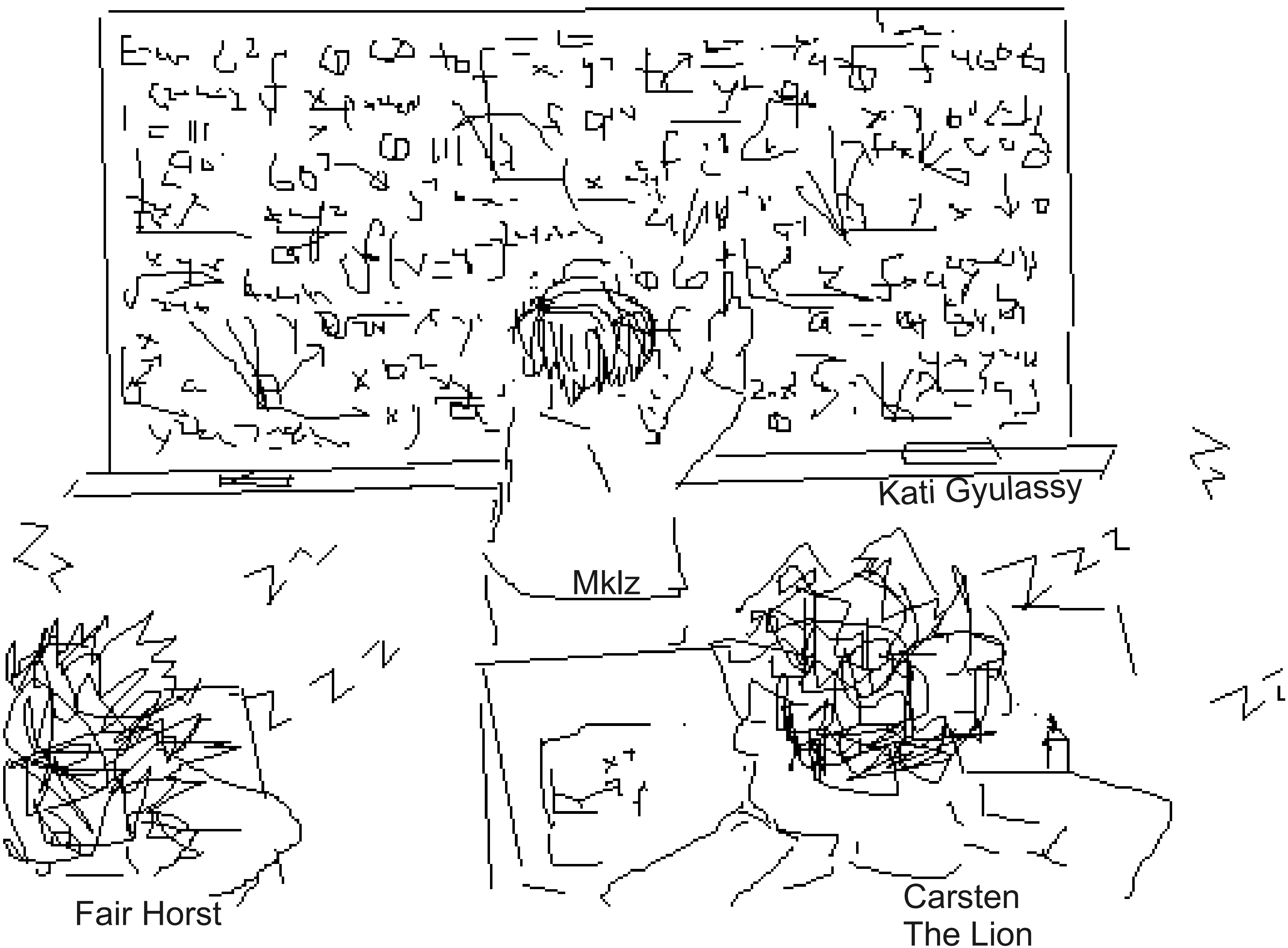


Speculative 10D
Geometry with
Baryon Junctions

Extrapolated down
To Nc=3 real world

What is the *non-conformal* dual geometry near the CEP ??

“Ah Ha! Baryons are 10D Junction Knots that FAIR can untie!”



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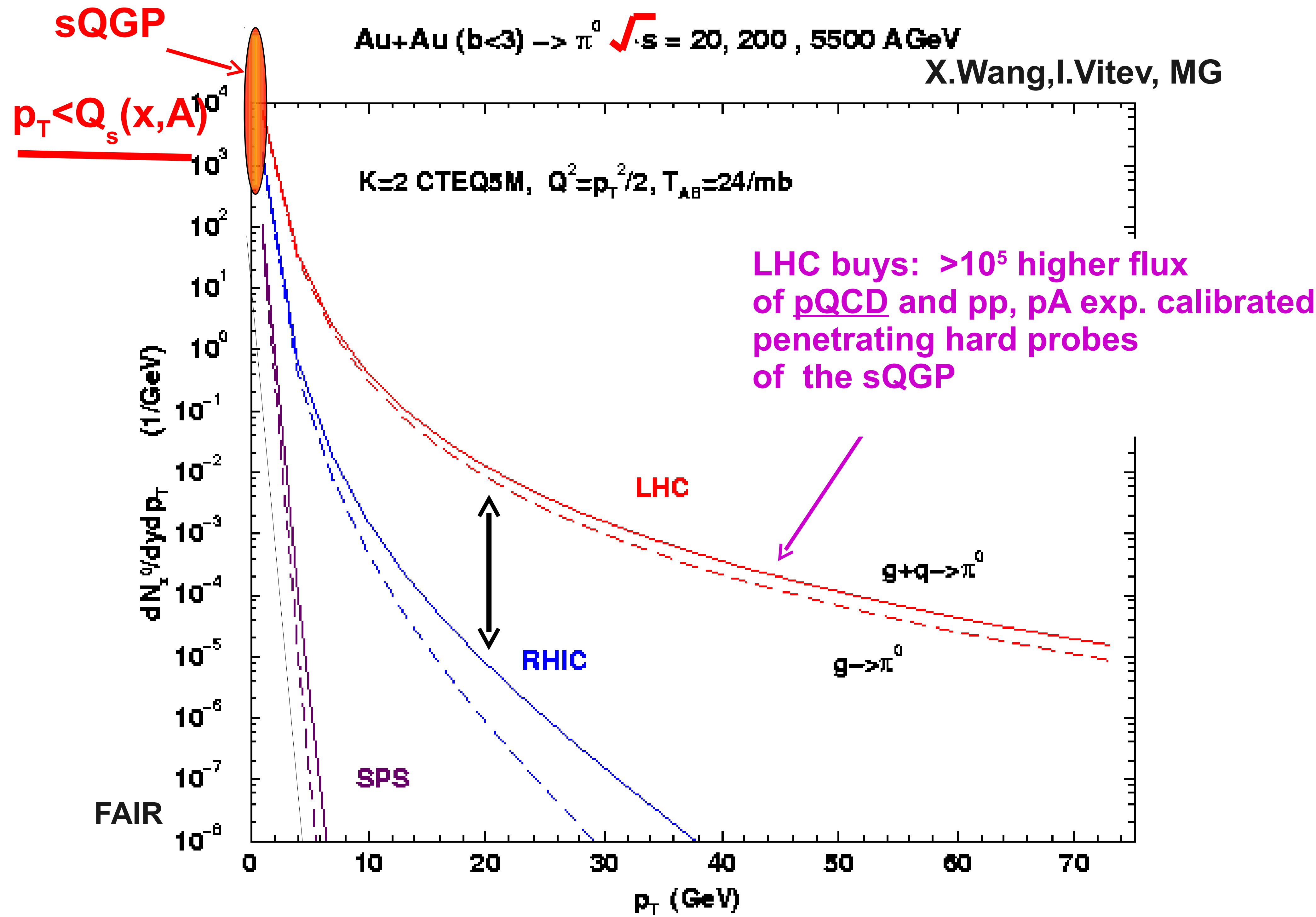
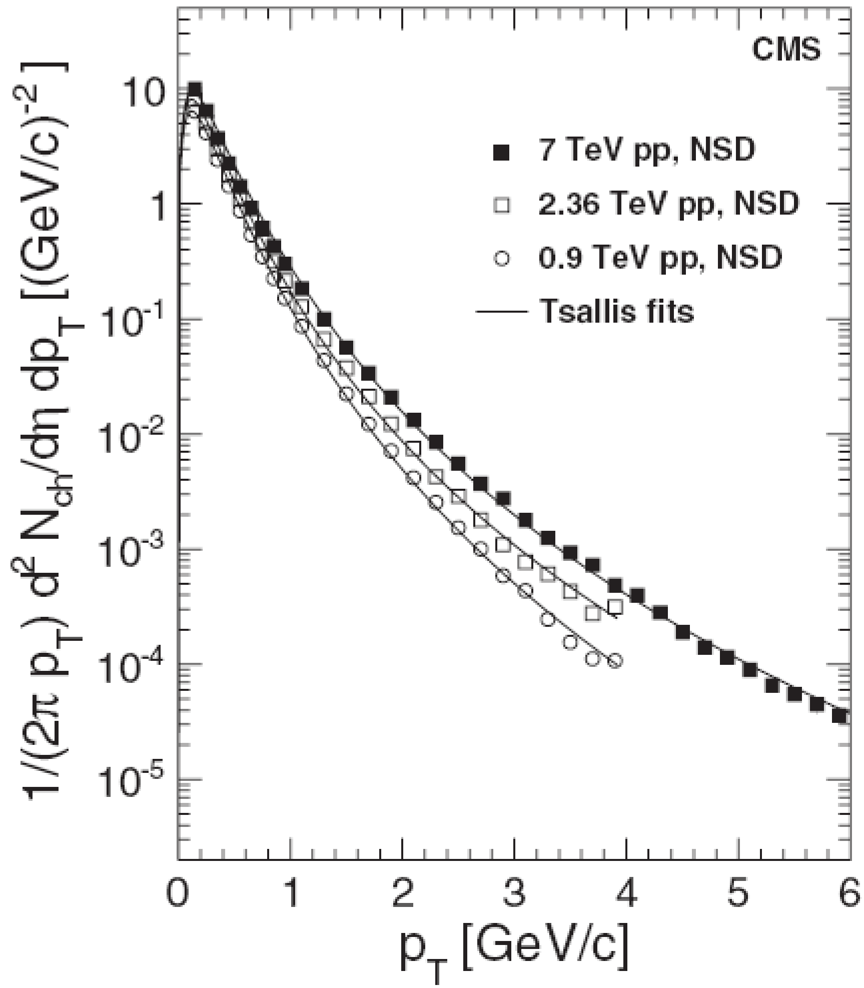


High pT “hard” observables probe the “soft” sQGP

First moderate pT “non-extensive” fits at LHC in p+p



At 7 TeV
n=6.6
T=145 MeV

$$E\frac{d^3N_{\rm ch}}{dp^3} = \frac{1}{2\pi p_T}\,\frac{E}{p}\,\frac{d^2N_{\rm ch}}{d\eta\, dp_T} = C\frac{dN_{\rm ch}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

T. S. Biro´, G. Purcsel, and K. U¨ rmo¨ssy, Eur. Phys. J. A 40,325 (2009).

Low pT pion interferometric Corona-graphy

High pT QCD Jet Tomography

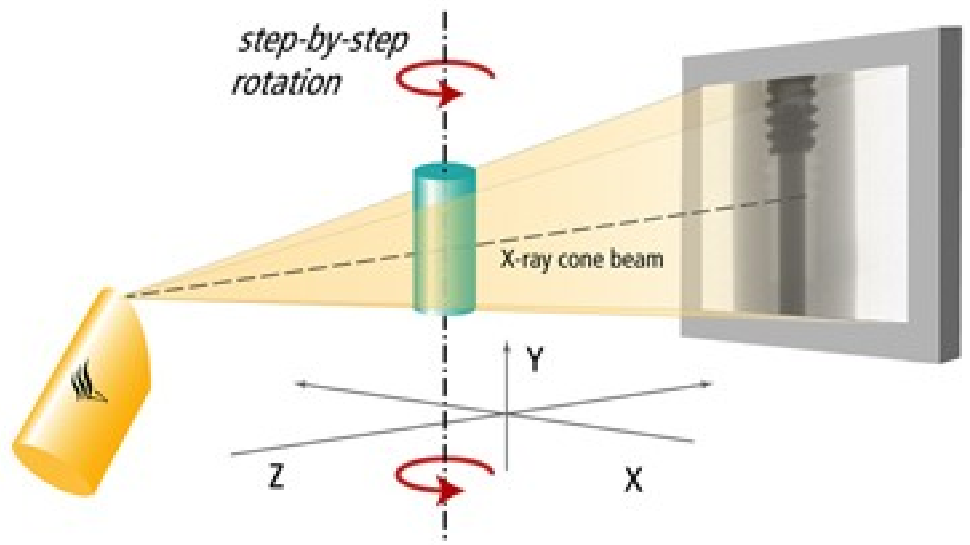
10D Heavy Jet Holographic duals

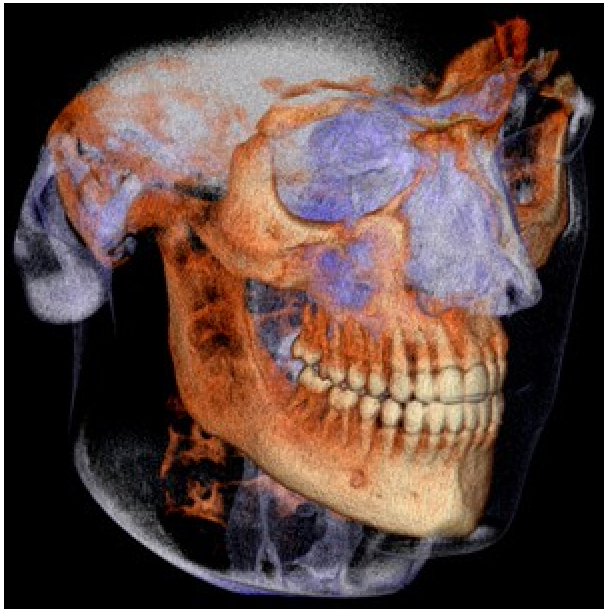
In contrast , Ideal **Volumetric Tomography** uses

1) Controlled initial flux of ***incoherent*** beam of ***penetrating probes***

2) a ***detailed dynamical theory*** of probe energy loss and differential scatt dN/dyd^2k_T

3) a cooperative ***(not too wiggly, i.e. non-fluctuating)*** patient





e.g, Cone-Beam Volumetric Tomography (CBVT)

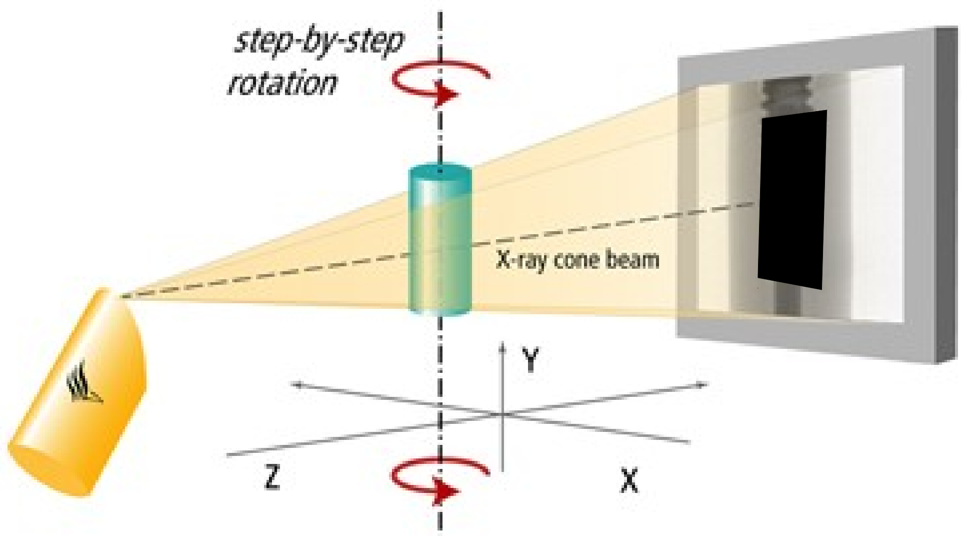
Low dose 3D x-ray tomography in action at your nearest dentist

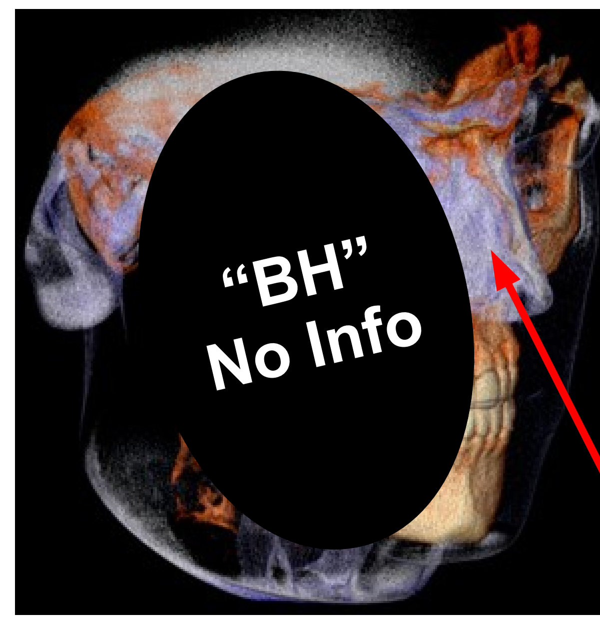
Only " Surface" Corona-graphy is possible when

1) Probe is ***strongly absorbed*** in the volume (*e.g. E+M from the sun)

2) We need ***detailed dynamical theory*** of **surface emmision** physics of
Moderate Opacity N<10 region between interior matter and the vacuum

3) A cooperative ***(not too wiggly, i.e fluctuating)*** patient/subject



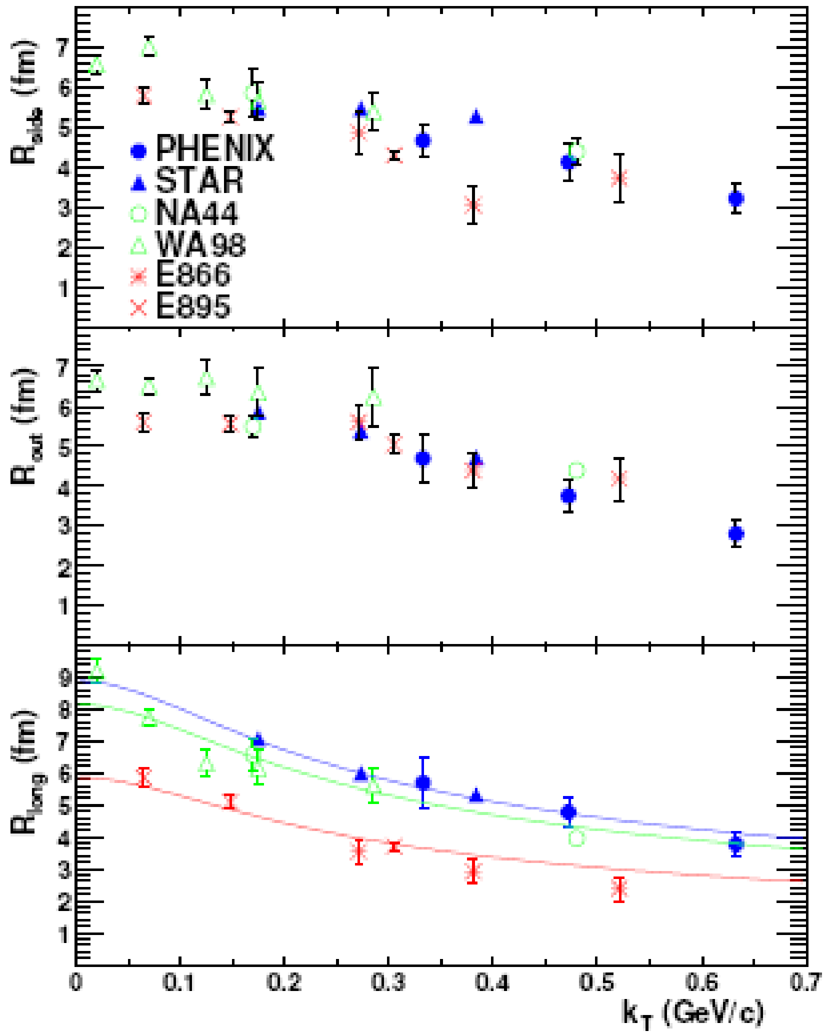


Cone-Beam Volumetric Tomography (CBVT)

Low dose 10 sec x-ray 3D tomograph

Only the
Boundary "Corona"
Surface layer
Can be imaged
In this case

Surprizing Pion Coronagraphy results from SPS- RHIC



HBT Interferometry of pion corona ruled out the "slowly burning QGP log" time delay signal that ***could have*** provided direct evidence For a 1st order QCD deconfinement transition.

Data consistent with Z.Fodor et al's Lattice QCD slow cross-over QCD "butter" transition

Regions of "homogeneity" are remarkably ***Independent*** of **Initial.Conditions**. vs s

APH N.S., Heavy Ion Physics 17/2–4 (2003) 261–270

(I.Lovas, J.Nemeth, J. Zimany 70th birthday fest)

HEAVY ION
PHYSICS
©Akadémiai Kiadó

Why Is the Null HBT Result at RHIC So Interesting?

M. Gyulassy[1] and D.H. Rischke[2]

Bose symmetrization induces an interference between pion amplitudes [15, 16]:

$$P_n(\mathbf{k}_1, \cdots, \mathbf{k}_n) \propto \left\langle \sum_\sigma \prod_{j=1}^{n} e^{i(k_j - k_{\sigma_j})\cdot x_j} \delta_\Delta(k_j, k_{\sigma_j}, p_j) \right\rangle , \qquad (1)$$

with the smoothed delta function given by

$$\delta_\Delta(k, k', p) = (2\pi\Delta p^2)^{-3/2} \exp\left(\frac{1}{2}\left[p - \frac{1}{2}(k + k')\right]^2 / \Delta p^2 + \frac{1}{2}(k - k')^2 \Delta x^2 \right) . \qquad (2)$$

The brackets $\langle \cdots \rangle$ denotes the ensemble average over the $7n$ pion *freeze-out* space coordinates $\{x_1, p_1, \cdots, x_n, p_n\}$. The smoothed delta function arises if Gaussian wavepackets are assumed. The widths Δx and Δp depend on details of the pion

2^{nd} Order (HBT) interferometry tries to invert **__6D__ (q,K)** Bose correlations to extract **__7D__ (dp$_{12}$, dr$_{12}$, dt$_{12}$) phasespace-time** freezeout "homogeneity" volume information

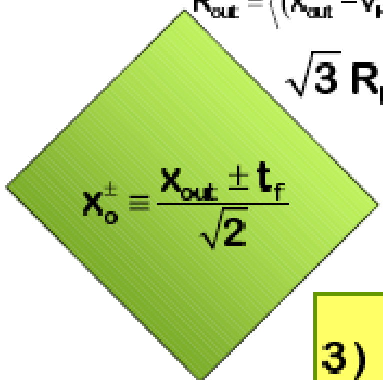
$$C(\mathbf{k}_1,\mathbf{k}_2) = C_2(\mathbf{q},\mathbf{K}) = 1 + \lambda \frac{\langle \cos(\mathbf{q}\cdot(\beta_{\mathbf{K}}(t_1-t_2)-(\mathbf{r}_1-\mathbf{r}_2))e^{-\mathbf{q}^2\Delta x^2}\delta^3_{\Delta p}(\mathbf{K}-\mathbf{p}_1)\delta^3_{\Delta p}(\mathbf{K}-\mathbf{p}_2)\rangle}{\langle\delta^3_{\Delta p}(\mathbf{k}_1-\mathbf{p}_1)\rangle\langle\delta^3_{\Delta p}(\mathbf{k}_2-\mathbf{p}_2)\rangle}$$

Degree of ***__Incoherence__*** → λ

Some Source Fits giving $R_{out}=R_{side}=R_K$

$$\frac{dN}{dx_{out}\,dt_f}$$

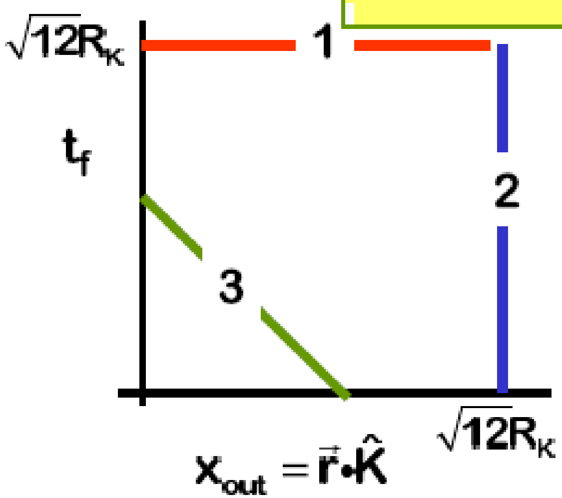
$$R^2_{out} = \langle (x_{out}-v_K t_f)^2\rangle - \langle (x_{out}-v_K t_f)\rangle^2 \approx \Delta(x_{out}-v_K t_f)^2$$

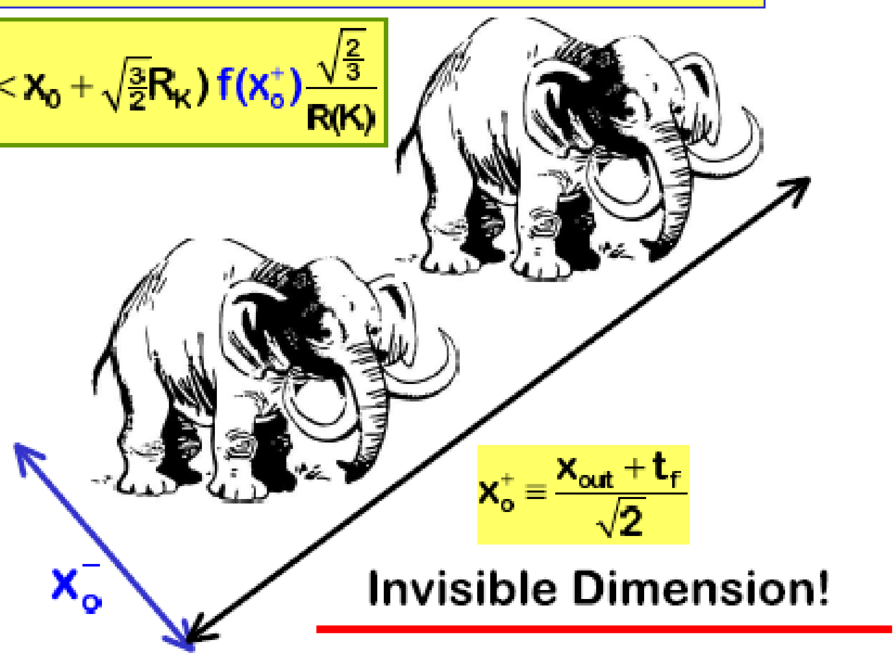


1) $\delta(t_f-\tau)\theta(x_0 < x_{out} < x_0 + \sqrt{12}R_K)\frac{1}{\sqrt{12}R_K}$

2) $\delta(x_{out}-x_0)\theta(\tau < t_f < \tau + \sqrt{12}R_K)\frac{1}{\sqrt{12}R_K}$

3) $\theta(x_0 < x_0^- < x_0 + \sqrt{\tfrac{3}{2}}R_K)\, f(x_0^+)\frac{\sqrt{\tfrac{2}{3}}}{R(K)}$





4) Herd of elephants Distributed along Light cone give *__Same__* C(q,K) !!

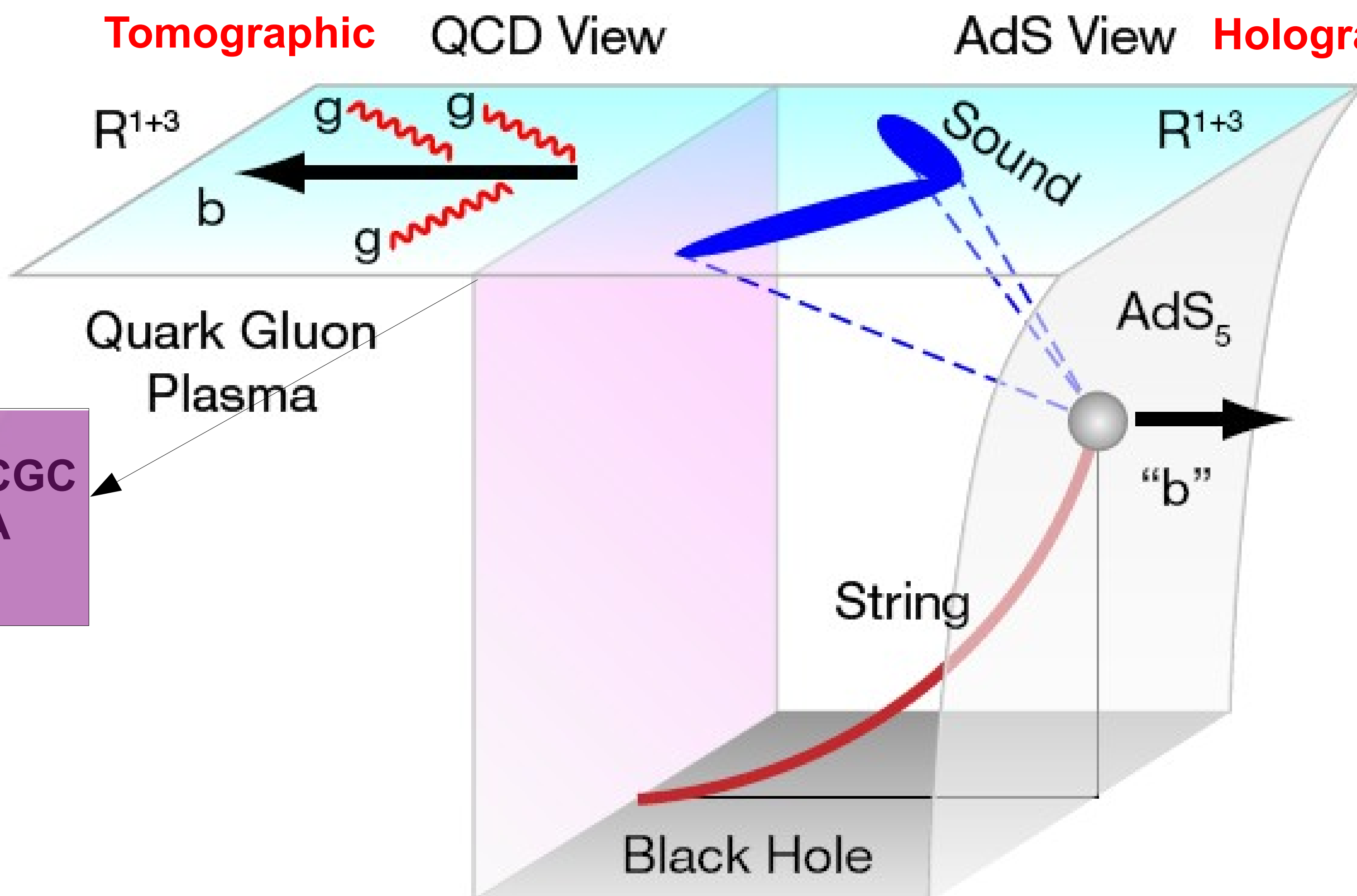
Fig. 3. The invisble HBT $x_0^+ \propto \mathbf{v_T}\cdot\mathbf{r} + t$ dimension! Beware of elephant herds.

pQCD Tomography vs hQCD Holography

Getting to the bottom of the heavy quark jet puzzle

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

DGLV
BDMPS
WHDG
BFGW
ZLCPI
AMYHG
HT



Herzog ..
Gubser ..

Opacity of CGC GLASMA at LHC?

HG
NGT
BNGT
NF

McV
KLN
BK
JMWLK
AM

Which paradigm can resolve the bottom quark puzzle ?

Will CGC saturation at LHC cloud jet tomography ?

DGLV Theory of Mass M Quark Jet radiation + thermal glue dispersion general n-th order in opacity induced gluon radiation

$$x\frac{dN^{(n)}}{dx\,d^2\mathbf{k}} = \frac{C_R\alpha_s}{\pi^2}\frac{1}{n!}\int\prod_{i=1}^{n}\left(d^2\mathbf{q}_i\,\frac{L}{\lambda_g(i)}\left[\bar{v}_i^2(\mathbf{q}_i)-\delta^2(\mathbf{q}_i)\right]\right)$$

$$\times\left(-2\tilde{\mathbf{C}}_{(1,\dots,n)}\sum_{m=1}^{n}\tilde{\mathbf{B}}_{(m+1,\dots,n)(m,\dots,n)}\right.$$

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

Formation Time QCD LPM Effect

$$\left.\times\left[\cos\left(\sum_{k=2}^{m}\Omega_{(k,\dots,n)}\Delta z_k\right)-\cos\left(\sum_{k=1}^{m}\Omega_{(k,\dots,n)}\Delta z_k\right)\right]\right)$$

$$\omega_{(m,\dots,n)} = \frac{(\mathbf{k}-\mathbf{q}_m-\cdots-\mathbf{q}_n)^2}{2xE} \to \Omega_{(m,\dots,n)} \equiv \omega_{(m,\dots,n)} + \frac{m_g^2+M^2x^2}{2xE}.$$

Current elements "Dead Cones"

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

$$\tilde{\mathbf{C}}_{(i_1i_2,\dots,i_m)} = \frac{(\mathbf{k}-\mathbf{q}_{i_1}-\mathbf{q}_{i_2}-\cdots-\mathbf{q}_{i_m})}{(\mathbf{k}-\mathbf{q}_{i_1}-\mathbf{q}_{i_2}-\cdots-\mathbf{q}_{i_m})^2+m_g^2+M^2x^2}$$

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

$$\tilde{\mathbf{B}}_{(i_1i_2,\dots,i_m)(j_1j_2,\dots,j_n)} = \tilde{\mathbf{C}}_{(i_1i_2,\dots,j_m)}-\tilde{\mathbf{C}}_{(j_1j_2,\dots,j_n)}.$$

The quenched spectra of partons, hadrons, and leptons are calculated as in [11] from the generic pQCD convolution

$$\frac{E\, d^3\sigma(e)}{dp^3} = \frac{E_i\, d^3\sigma(Q)}{dp_i^3} \otimes P(E_i \to E_f) \otimes D(Q \to H_Q) \otimes f(H_Q \to e), \qquad (1)$$

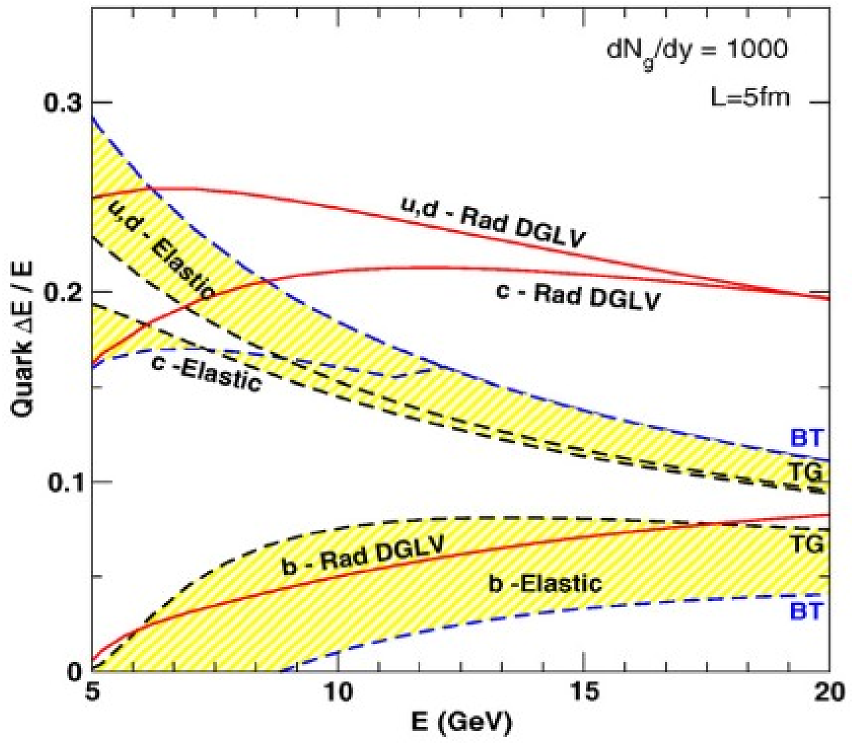
$$P(E_i \to E_i - \Delta_{\rm rad} - \Delta_{\rm el}) = \int \frac{d\phi}{2\pi} \int \frac{d^2\vec{x}_\perp}{N_{\rm bin}(b)} T_{AA}(\vec{x}_\perp, \vec{b}) \otimes P_{\rm rad}\big(\Delta_{\rm rad}; L(\vec{x}_\perp, \phi)\big) \otimes P_{\rm el}\big(\Delta_{\rm el}; L(\vec{x}_\perp, \phi)\big).$$

$$R_Q^{\rm II}(p_T, L_Q) \equiv \left\langle \left(1 - \epsilon_Q^r(L_Q)\right)^n \left(1 - \epsilon_Q^e(L_Q)\right)^n \right\rangle_{\Delta E}$$

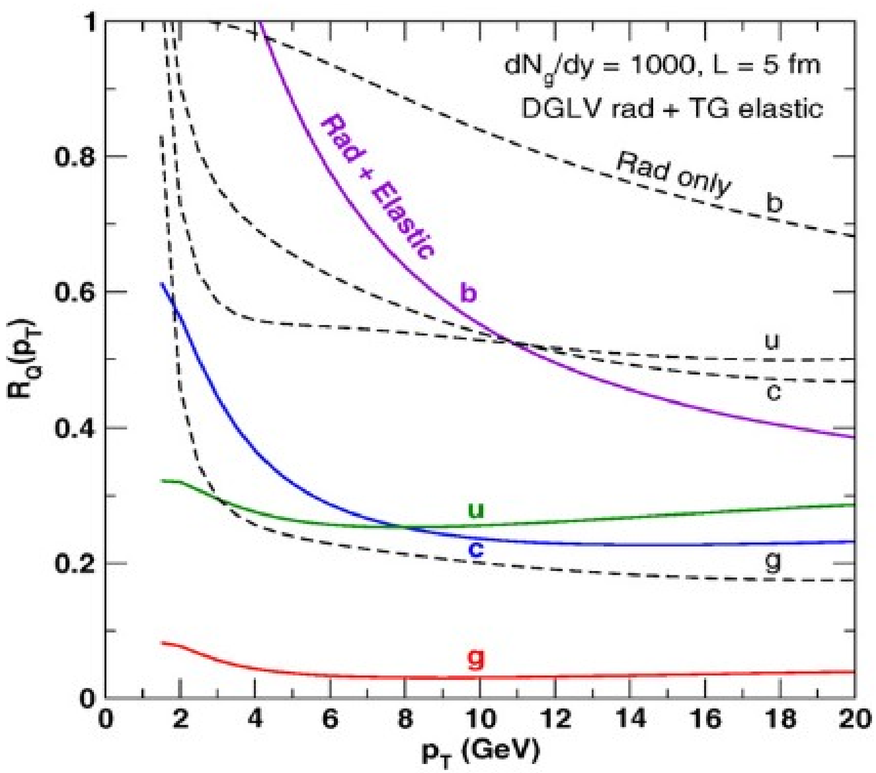
Assumes hadronization *in vacuum*

Open question: effects of HRG T<Tc ?.

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

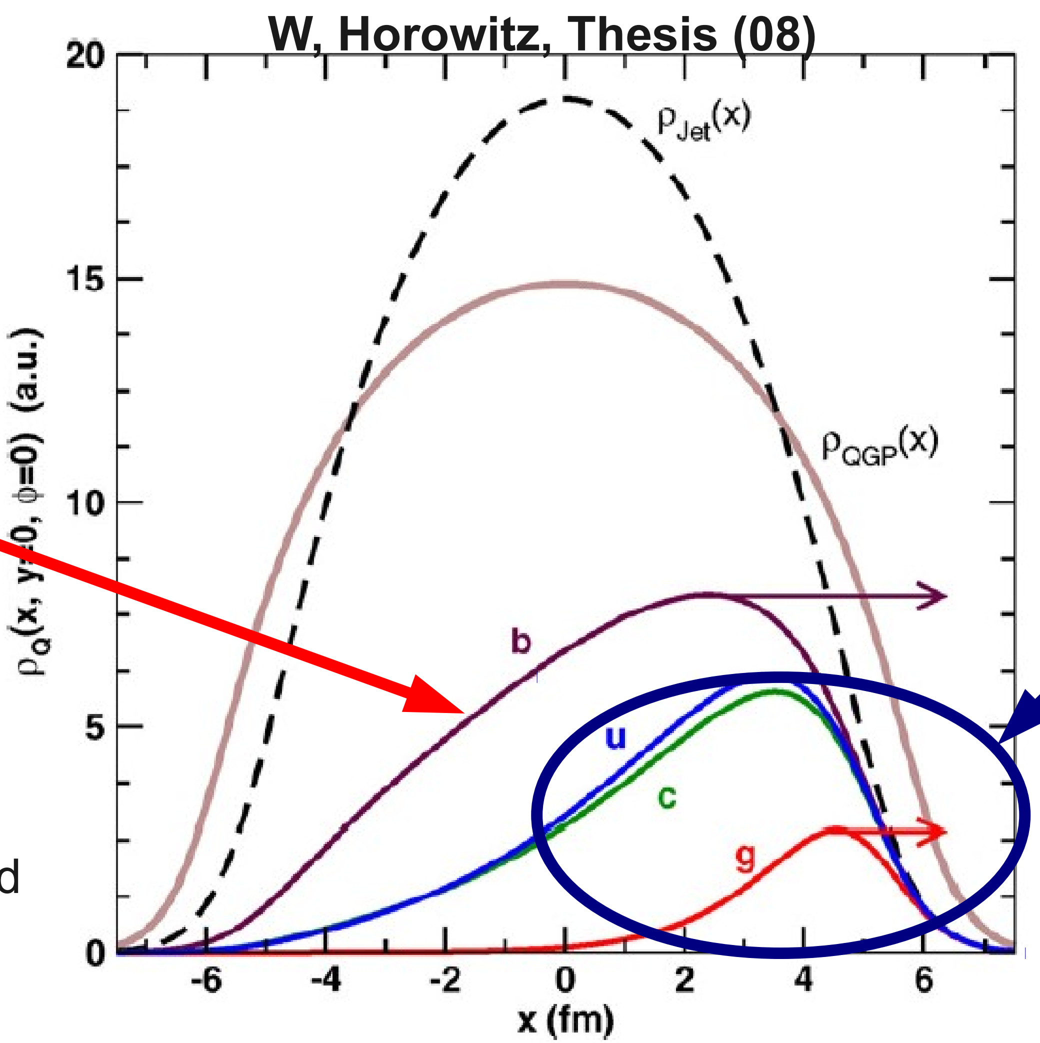


S. Wicks et al. / Nuclear Physics A 784 (2007) 426–442



Why Jet Tomo-graphy evolved into Jet Corona-graphy

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



At RHIC pT < 20
Bottom quarks are
the only <u>Volumetric</u>
pQCD Probes
of HTL-wQGP

g,u,d,s,c jets
Useful only to
Probe the "Corona"
***Even* at $\alpha_s \sim 0.3$**

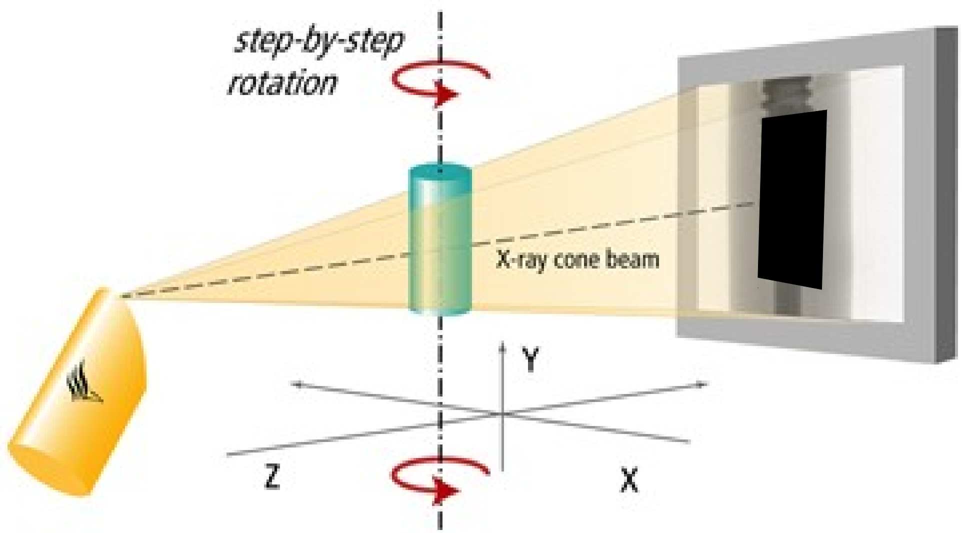
Secondary EM probes
q->q + γ + e + μ
Also give bulk info
But dynamic background
Needs better control

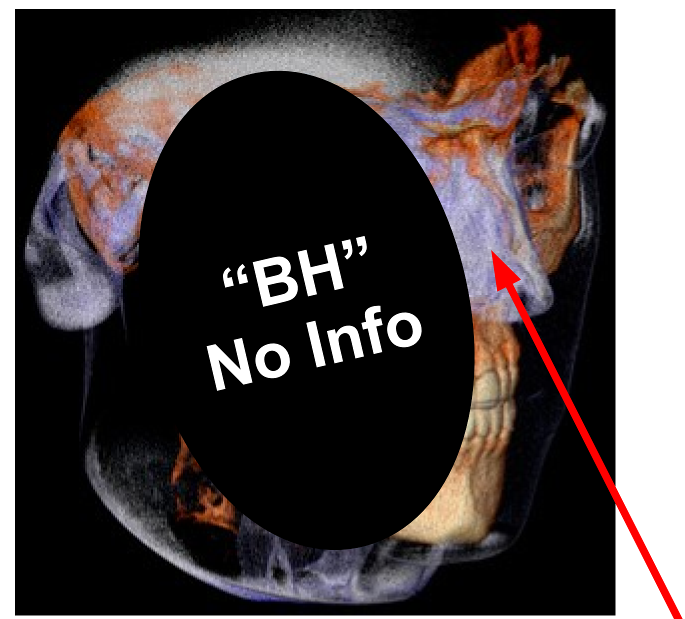
Recall Only " Surface" Corona-graphy is possible when

1) Probe is ***strongly absorbed*** in the volume (**RAA~0.2** << 1 at RHIC)

2) We now have ***detailed dynamical theory*** (DGLV-BFW-MC) of
Moderate Opacity N<10 jet quenching

3) But is sQGP ***not too wiggly, i.e fluctuating ??***



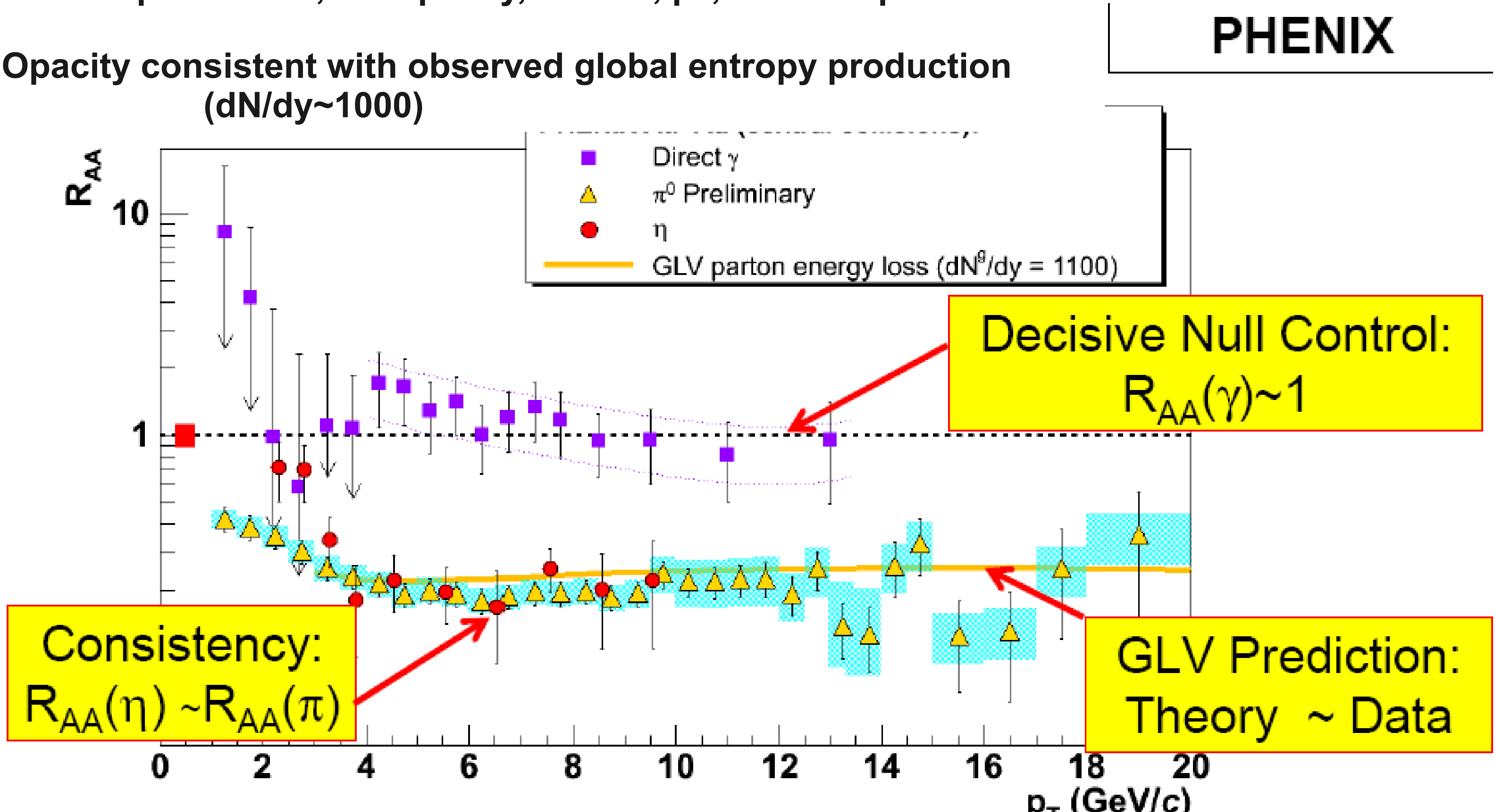


Only the
"Corona"
Can be imaged
In this case

Light quark/gluon jet tomography pQCD theory passed many key

RHIC exp. tests: A, Multiplicity, Ebeam, pT, flavor dependence

Opacity consistent with observed global entropy production (dN/dy~1000)



Suppression is very strong (R_{AA}=0.2!) and flat up to 20 GeV/c

Common suppression for π^0 and η; it is at partonic level

$\varepsilon > 15$ GeV/fm^3; $dN_g/dy > 1000$

Ivan Vitev, MG, PRL89 (02)

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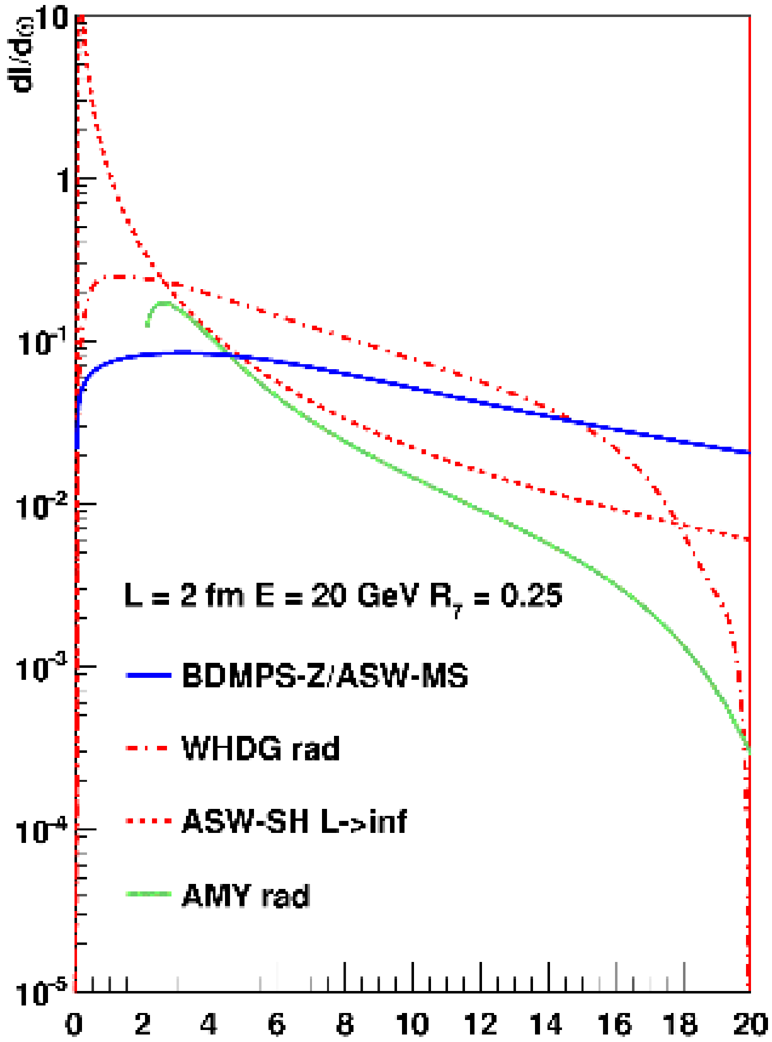
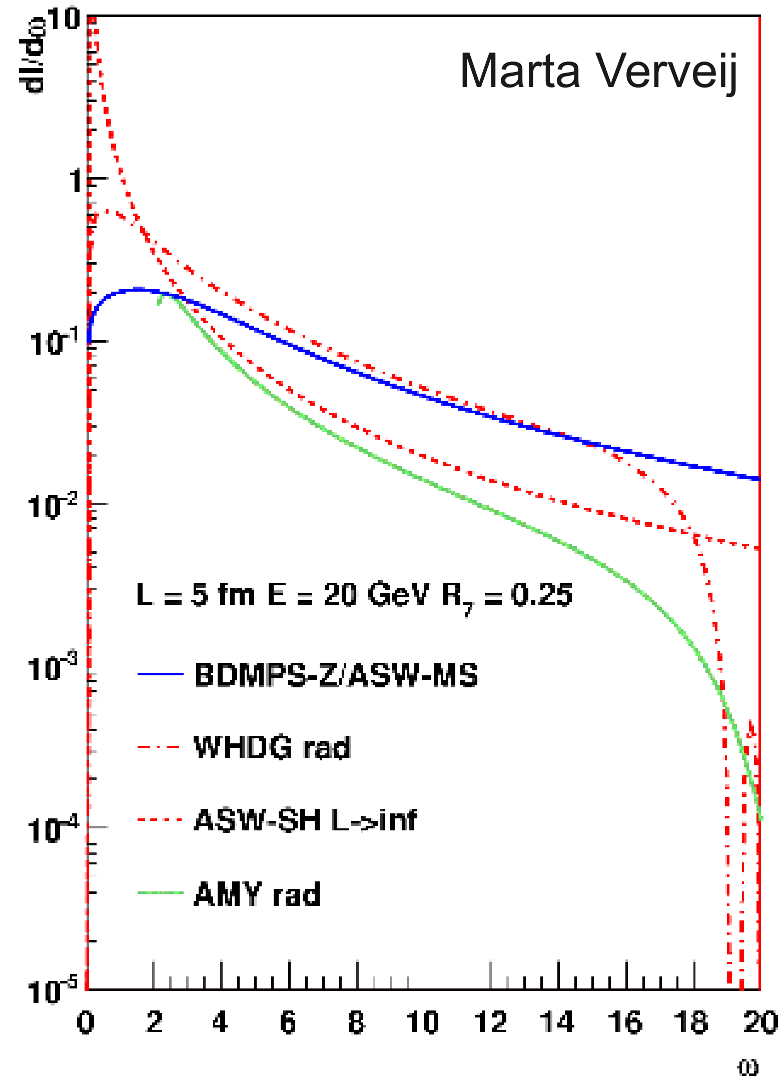
Previously many different, *apparently* inconsistent "tomographic solutions" could account for same RAA(pT) data





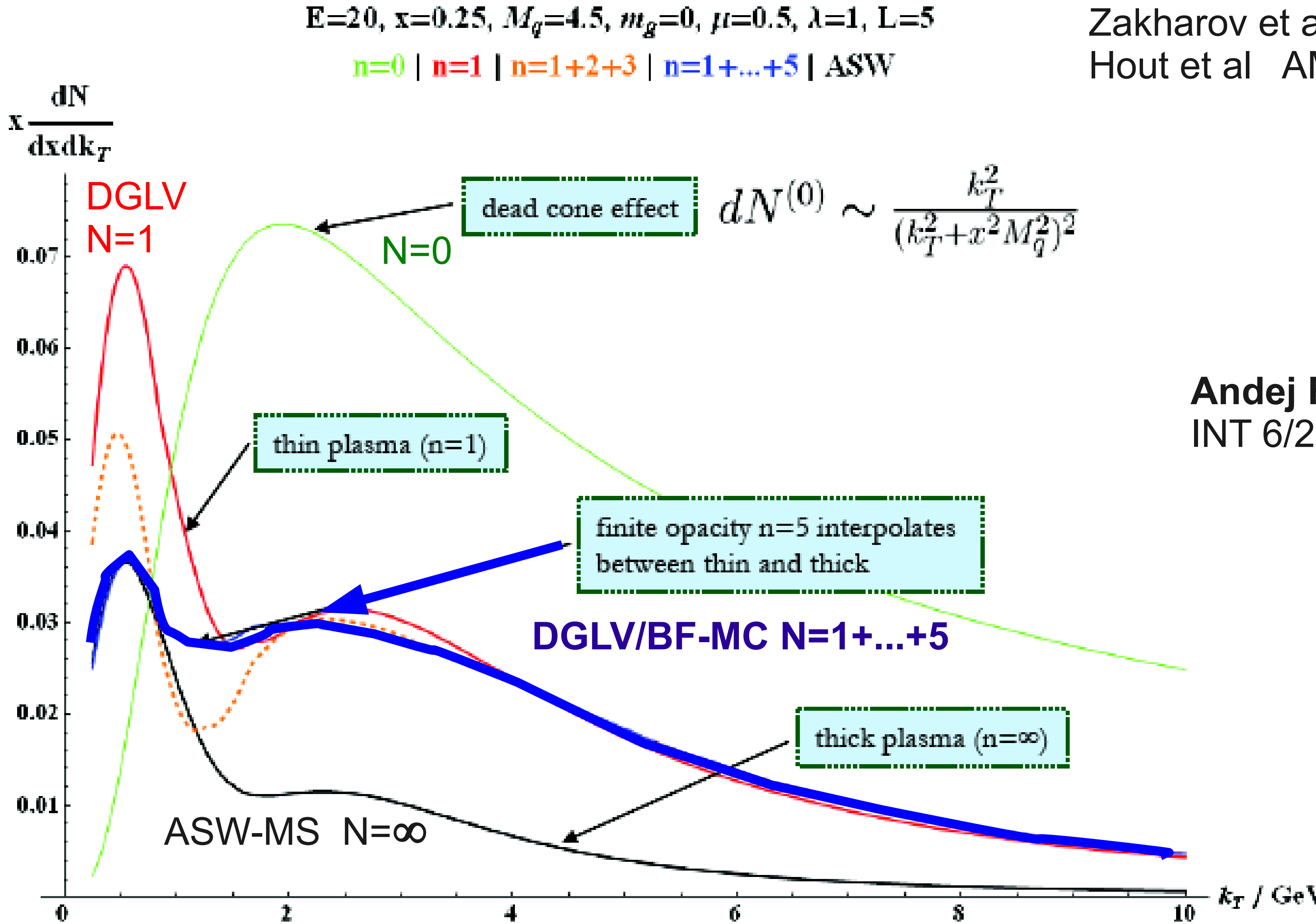
However, unlike in HBT case, improved MC based theory can resolve differences.
DOE/JET collab project aims to quantify this

Our recent JET collab progress on numerical MC interpolation between N=1 and N=∞

Buzzatti, Ficnar, Gyulassy, Wicks, to be published

DGLV & ASW

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



Andej Ficnar
INT 6/25/10

With DGLV-BFW-MC we solved the qhat puzzle of why BDMS/ASW need such Unphysically high qhat ~ 10 GeV^2/fm

The qhat story relies on multisoft Gaussian diffusion without N=1 hard kT tails

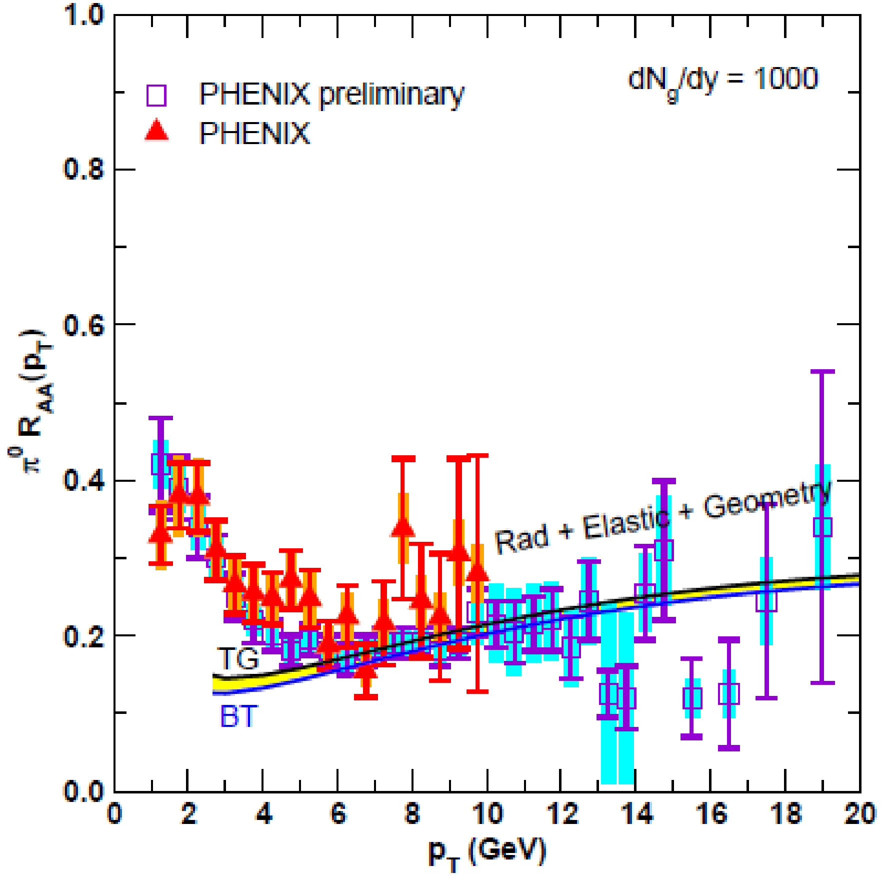
With Monte Carlo techniques we can now compute up to N=10
And interpolate smoothly between
N=1 that underestimates qhat and ASW N=2, … infty that overestimate qhat

We also found that that simple qhat scaling laws (Arnold) based on kinematics violating (pre-ASW) BDMS approximations do not apply in N<10 AA applications at RHIC or LHC

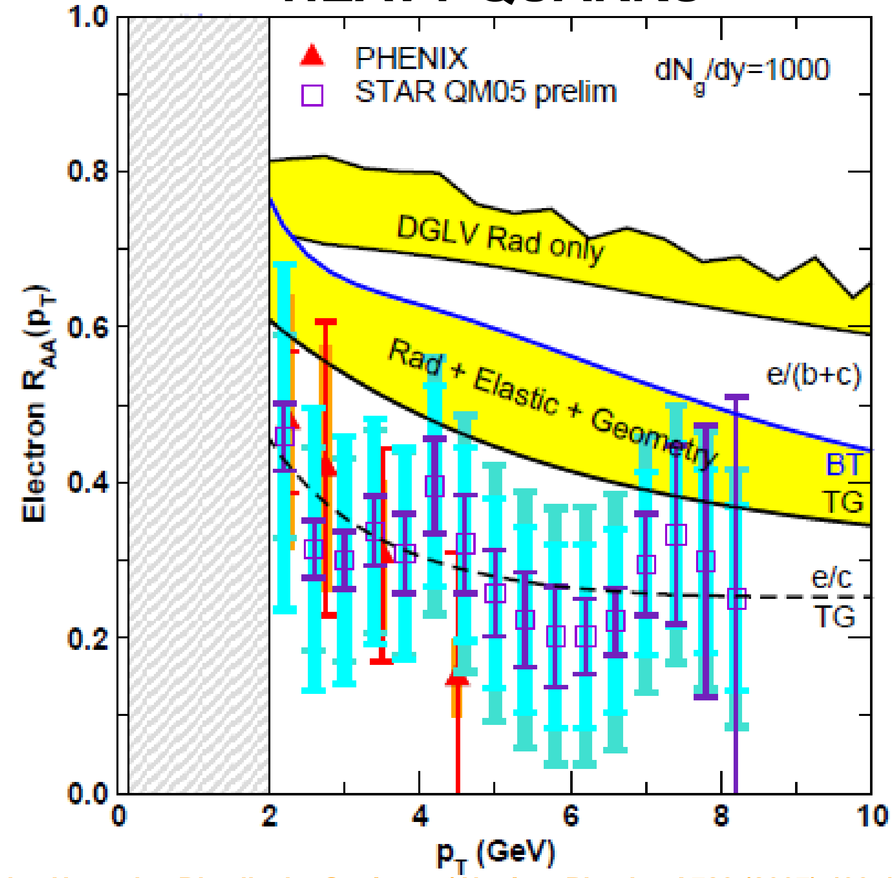
Most important result with DGLV-BFW-MC is that
Higher order opacity correlations with static GW do not solve Heavy Quark Jet Puzzle
Nor the high pT large v2 elliptic problem

The Heavy Quark Puzzle $R_{AA}(p_T, M_b)$

LIGHT QUARKS



HEAVY QUARKS



Wicks, Horowitz, Djordjevic, Gyulassy / Nuclear Physics A783 (2007) 493-496

DGLV/WHDG predictions falsified by PHENIX, STAR
Charm + Bottom → electron data in Au+Au 200AGeV RHIC

A bottom quark of 15 GeV does not stop in a 5 fm in pQDC with alpha~0.3.
Can moderate strong alpha ~0.5 extrapolations of pQCD explain BOTH ?
Will data force us to abandon the pQCD paradigm?

LHC with **identified** c and b Mesons up to 30 GeV will be critical
in search for a clean heavy quark tomographic window on the QGP - ***if it exists?***

Heavy Ion Collisions at the LHC - Last Call for Predictions **S.Wicks,** MG (07) 106

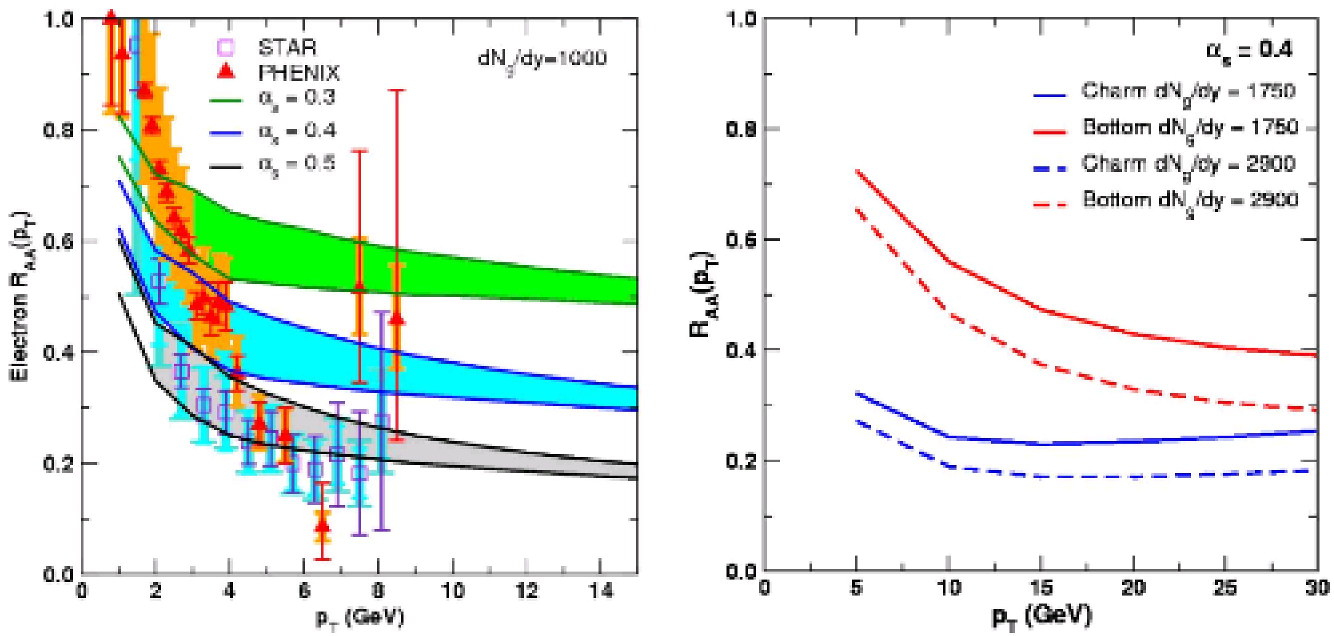


Figure 84: R_{AA} for observable products of heavy quark jets at RHIC (electrons - left) and two possible densities at the LHC (D and B mesons - right). There is considerable uncertainty in the perturbative production of c and b jets. This shows up in the results for electrons at RHIC in the large uncertainty band, ±0.1 or greater - as the ratio of c to b jets is very uncertain. However, the uncertainty in D and B meson R_{AA}s is small (approximately ±0.02) - the different slopes on the individual spectra have very little effect on the meson R_{AA} results.

M.Djordjevic,UHeinz, PRC77:(08), MD09
Aurenche (00), Zakharov (98)

Could ***dynamic*** HTL magnetic ***scattering*** + ***dynamic geometry*** help?

$$|V(q)|^2 = \left[\frac{\mu^2}{(q^2+\mu^2)^2}\right]_{\rm stat} \mapsto \left[\frac{\mu^2}{q^2(q^2+\mu^2)}\right]_{\rm dyn}$$

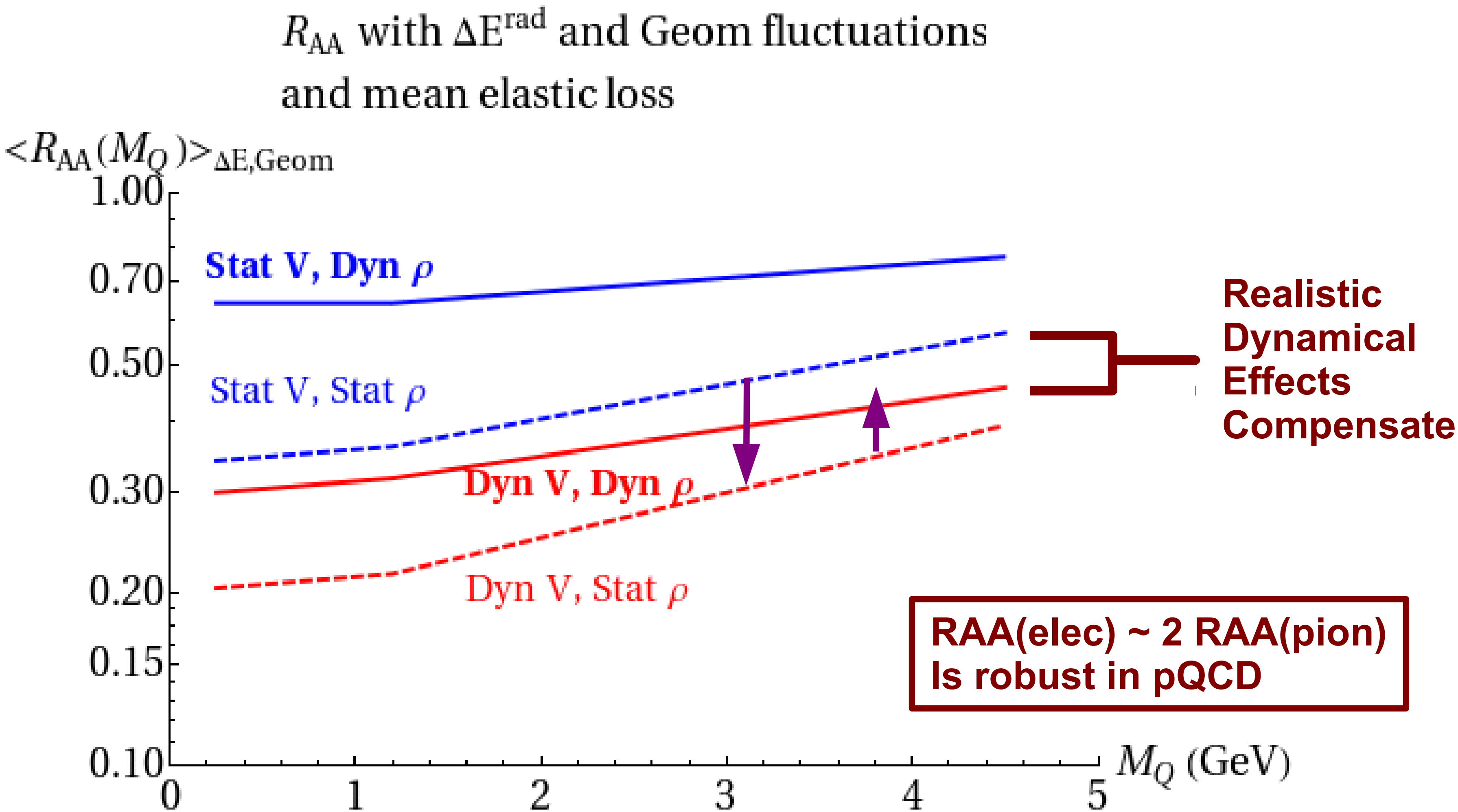
Static GW Model **NonStatic HTL Model**

$$\frac{\Delta E_{\rm dyn}}{E} = \frac{C_R\alpha_s}{\pi}\frac{L}{\lambda_{\rm dyn}}\int dx\,\frac{d^2k}{\pi}\frac{d^2q}{\pi}\frac{\mu^2}{q^2(q^2+\mu^2)}$$
$$\times 2\frac{k+q}{(k+q)^2+\chi}\cdot\left(\frac{k+q}{(k+q)^2+\chi}-\frac{k}{k^2+\chi}\right)\left(1-\frac{\sin(\frac{(k+q)^2+\chi}{xE^+}L)}{\frac{(k+q)^2+\chi}{xE^+}L}\right)$$

$$\chi \equiv M^2x^2 + m_g^2\ (1-x)$$ Heavy quark mass and thermal gluon mass effect

This was was answered by **A. Buzzatti** (LBL Jet Collab 6/19/10, INT 6/25/10)

A. Buzzatti, MG (10)



Dynamic magnetic scattering enhances _both_ light and heavy energy loss similarly

But Bj expansion + diffuse surface geometry reduce energy loss of both similarly

Two dynamical effects largely compensate each other and
Do _Not_ eliminate the heavy/light discrepancy with pQCD tomography

Part 1: Speculations about Baryonic Holograms at FAIR

Part 2: Holo vs Tomo vs Corona -graphy of Jet Quenching

Part 3: JET collab update: DGLV-BFW-MC of the N<10 Corona

Part 4: Conformal Holography of Heavy Quark Jets and Bulk Elliptic Flow

Part 5: Overtime 1- Turbulent Initial Conditions with eta/s << 1
=> [Jet, Bulk Flow] $\neq$ 0

Part 6: Overtime 2: Demonic vs Angelic Flow Beyond Perfection at LHC
HRG CGC

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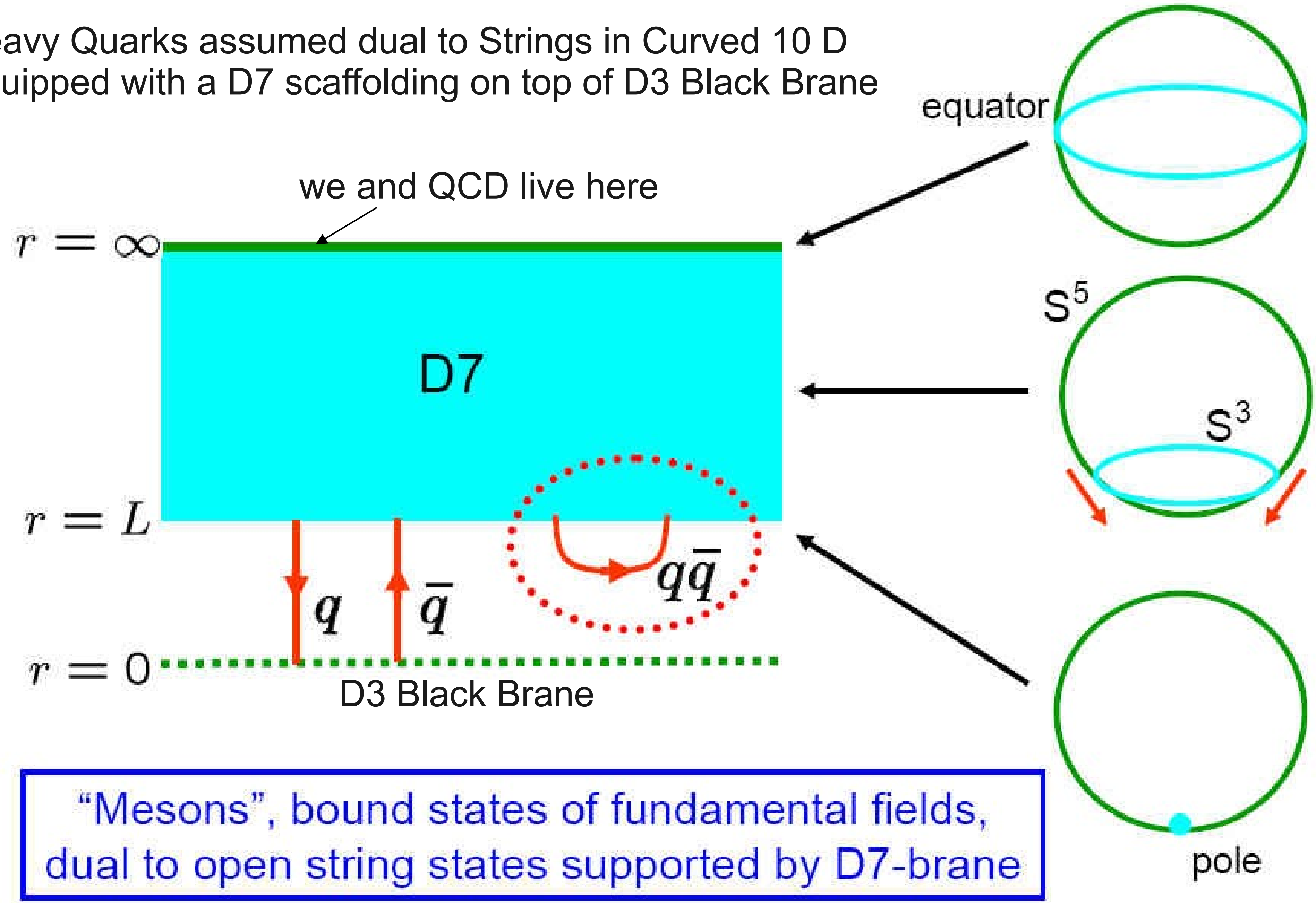
,

Heavy Quark dynamics in a Holographic AdS/CFT D7 Brane "setup"

Heavy Quarks assumed dual to Strings in Curved 10 D
Equipped with a D7 scaffolding on top of D3 Black Brane



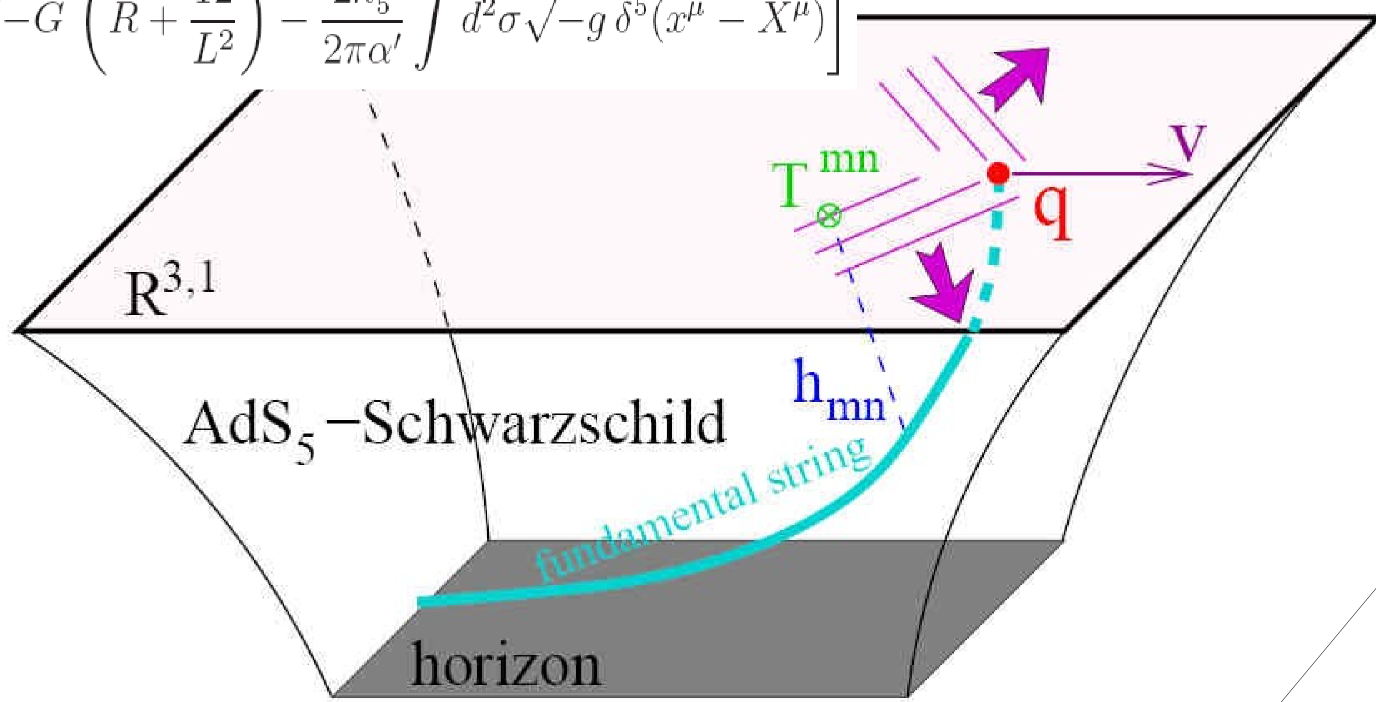
"Mesons", bound states of fundamental fields, dual to open string states supported by D7-brane

Myers KITP06

3. Jet Quenching in AdS/CFT

Gubser et al
Herzog et al

$$S = \frac{1}{2\kappa_5^2}\int d^5x\left[\sqrt{-G}\left(R+\frac{12}{L^2}\right) - \frac{2\kappa_5^2}{2\pi\alpha'}\int d^2\sigma\sqrt{-g}\,\delta^5(x^\mu - X^\mu)\right]$$



Very different from pQCD

$$\frac{dp_T}{dt} = -\mu_Q p_T = -\frac{\pi\sqrt{\lambda}(T^*)^2}{2M_Q}p_T, \qquad (1)$$

where T^* is the temperature of the SYM plasma as fixed by the Hawking temperature of the dual D3 black brane.

Conformal Holography : Nambu-Goto in an AdS5 + Black Brane background
"The 21st century Brachistochrone Problem"

$$g = \det g_{ab} = G_{\mu\nu}\partial_a X^\mu \partial_b X^\nu$$

$$S = \frac{1}{2\kappa_5^2}\int d^5x\left[\sqrt{-G}\left(R + \frac{12}{L^2}\right) - \frac{2\kappa_5^2}{2\pi\alpha'}\int d^2\sigma\sqrt{-g}\,\delta^5(x^\mu - X^\mu)\right]$$

stationary solution with curvature $\mathcal{R} = -12/L^2$. The t'Hooft coupling in the gauge theory is identified with L^2/α', where $\sqrt{\alpha'} = \ell_s$ is the fundamental 10d string length. The α' expansion in the gravity dual description is mapped into a series in $1/\sqrt{\lambda}$ in the gauge theory ← World-sheet fluctuations

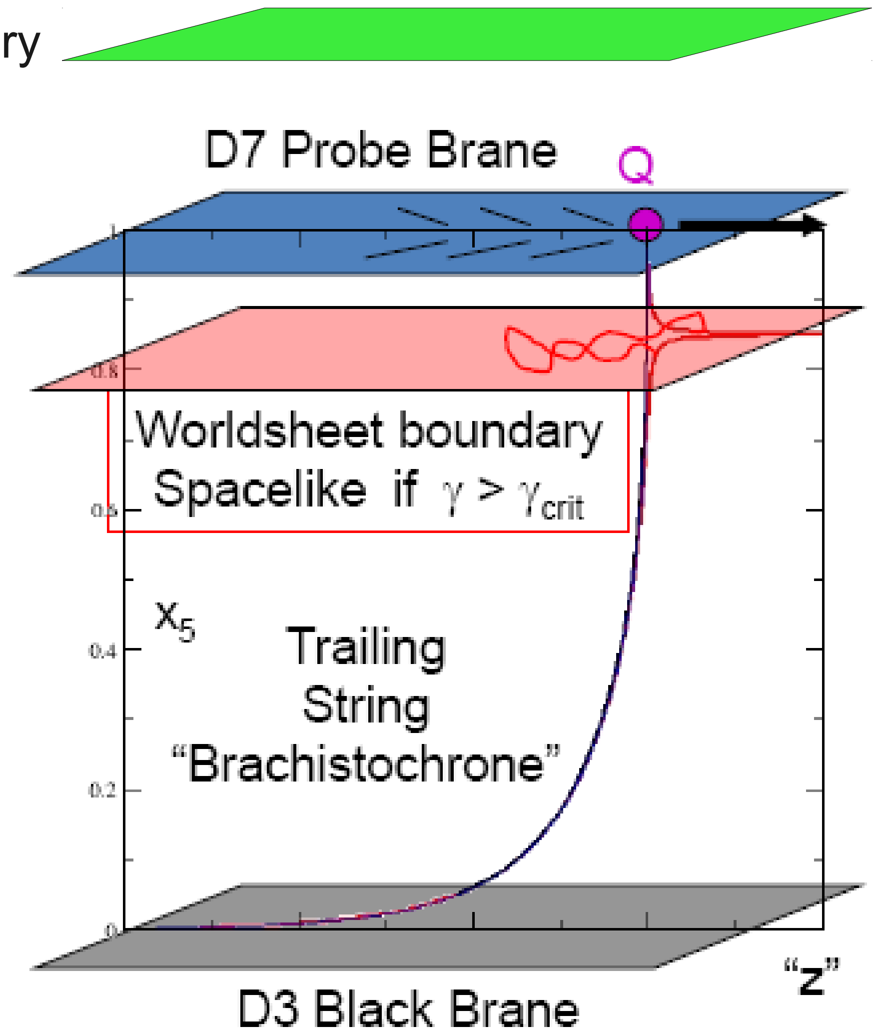
$$ds^2 = G_{00}(u)dt^2 + G_{xx}(u)d\vec{x}^{\,2} + G_{uu}(u)du^2 \qquad (5)$$

where see ref.[18] BH horizon

$$G_{00}(u) = -\frac{u^2}{L^2}\left(1 - \frac{u_h^4}{u^4}\right)(1 + O(\lambda^{-3/2})) \qquad (6)$$

$$G_{uu}(u) = \frac{L^2}{u^2}\left(1 - \frac{u_h^4}{u^4}\right)^{-1}(1 + O(\lambda^{-3/2}) \qquad (7)$$

and $G_{xx} = u^2/L^2(1 + O(\lambda^{-3/2})$. See ref.[18] also for the case of pure Gauss-Bonnet deformation of AdS.



Speed limit estimate for applicability of AdS drag

- $\gamma < \gamma_{crit} = (1 + 2M_q/\lambda^{1/2} T)^2$
  $\sim 4M_q^2/(\lambda T^2)$

Gubser 07 , Herzog et al 07

For $\lambda = 30$, M=4.5, T=0.2

$\gamma_{crit} \sim 70$

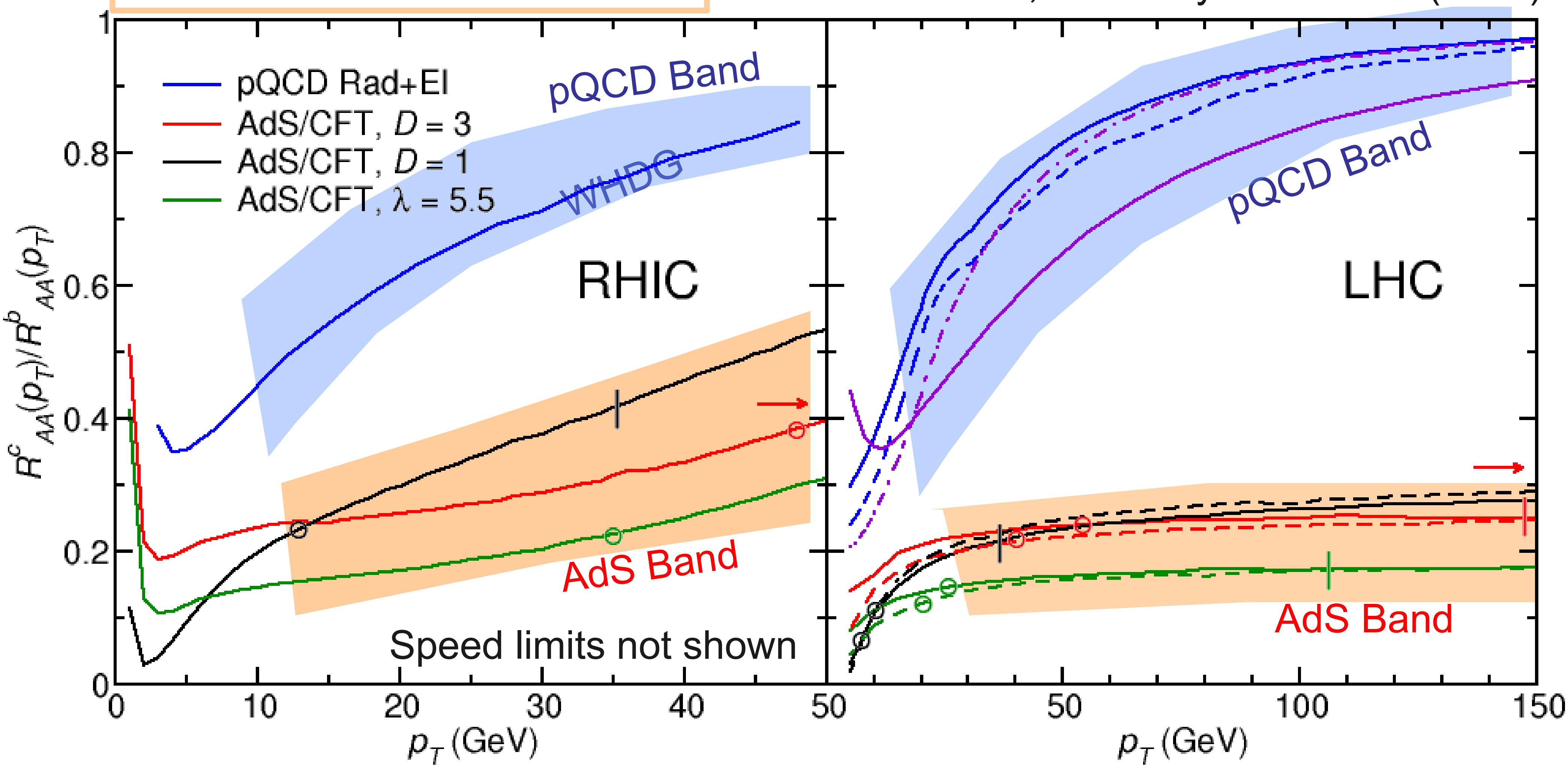
String is tachyonic (v > ***local*** speed of light) below apparent red horizon

As $\gamma \rightarrow \gamma_{crit}$ apparent red horizon goes above D7 probe brane
=> unstable string configurations dominate <=> strong off shell effects

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

PQCD vs pure Super AdS, λ_{GB}=0

W.Horowitz, MG: Phys.Lett.B666 (2008)



Bunching into a "pQCD band" vs a "AdS/CFT band" make this *Double* ratio of charm and bottom jet nuclear modification factors the ideal test of pQCD vs AdS/CFT gravity models of sQGP

Gubser, Klebanov, Tseytlin (98)
Gubser, PRD74 (06)
Buchel, Myers, Sinha, Paulos (08,09)

Kats, Petrov 07
Brigante 08
Maldacena Hoffman 08

AdS Holography Connects Thermo to Dissipation to Nonequilib dynamics

Noronha, Gyulassy, Torrieri, (2009),

With Phenomenological $R^2 \propto \lambda_{GB} \sim 1/N_c$ + $R^4 \propto \lambda^{-3/2}$ *pertubations* to R^1 (AdS_5)

$$\frac{\eta}{s} = \frac{1}{4\pi}\left(1 - 4\lambda_{GB} + 15\frac{\zeta(3)}{\lambda^{3/2}}\right)$$

$$\frac{s}{s_{SB}} = \frac{3}{4}\left(1 + \lambda_{GB} + \frac{15}{8}\frac{\zeta(3)}{\lambda^{3/2}}\right)$$

Heavy quark energy loss

$$\frac{dp}{dt} = -\frac{\sqrt{\lambda}\pi T^2}{2M_Q}\left(1 + \frac{3}{2}\lambda_{GB} + \frac{15}{16}\frac{\zeta(3)}{\lambda^{3/2}}\right)$$

* **New result J. Noronha**

To Predict

$$R^e_{AA} \times v_2$$

Main limitation is
that assumed conformal
invariance that does not hold T~ Tc

J.Noronha, G.Torrieri, MG (2009)

R_{AA}^{e} via AdS Holographic Corona-graphy

$$R^{Q}_{AA}(p_T,b) = \int_0^{2\pi} d\phi \int d^2\vec{x}_\perp \frac{T_{AA}(\vec{x}_\perp,b)}{2\pi N_{\rm bin}(b)} \times \exp\left[-n_Q(p_T)F_Q(\vec{x}_\perp,\phi)\right] \quad (14)$$

Corona factor
With spectral index

where $N_{\rm Bin}$ is the number of binary collisions and

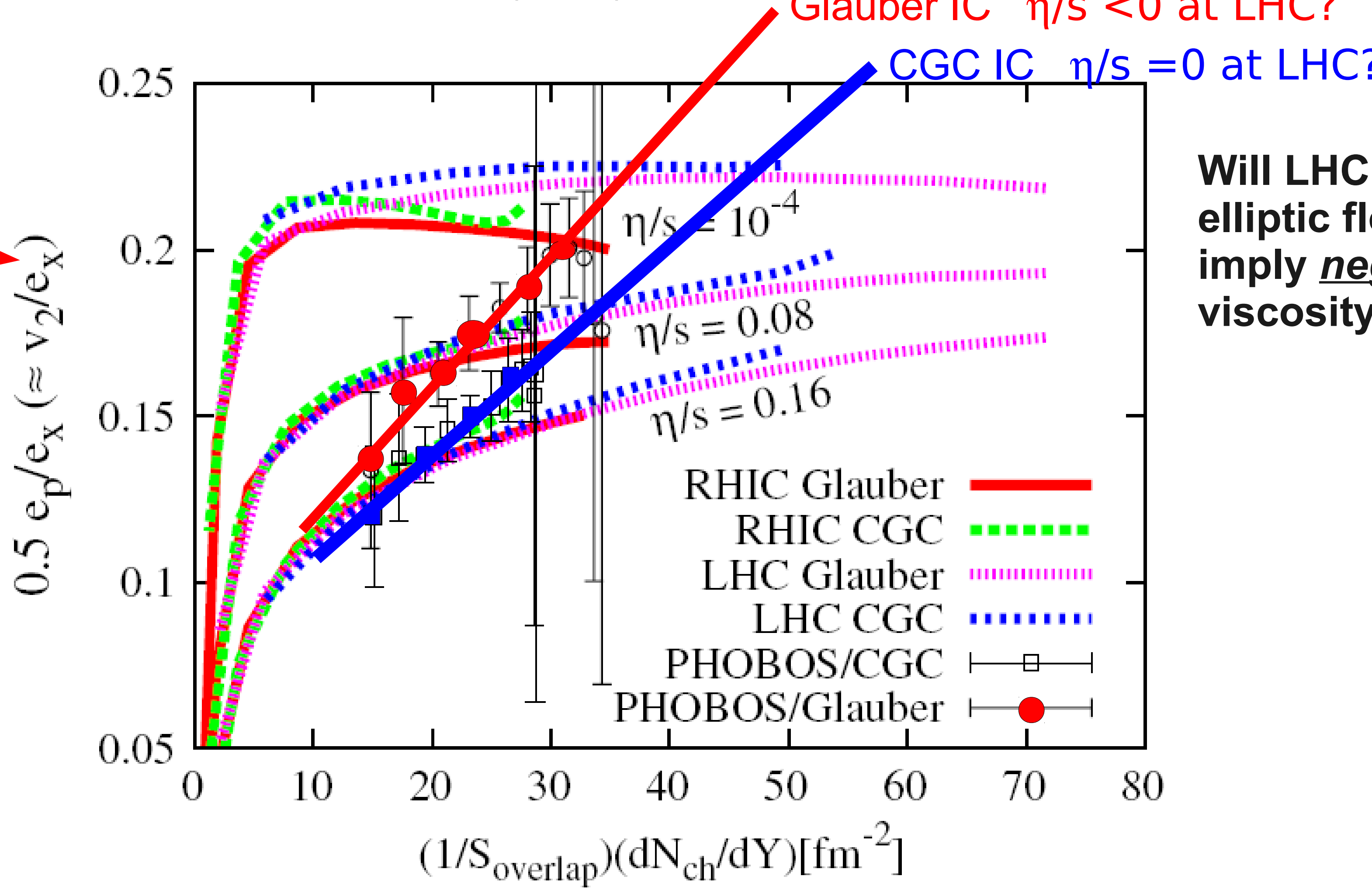
Fractional
Energy loss

$$F_Q(\vec{x}_\perp,\phi) = \sqrt{\lambda}\,\frac{\pi}{2M_Q}\left(1+\frac{3}{2}\lambda_{GB}+\frac{15}{16}\frac{\zeta(3)}{\lambda^{3/2}}\right) \times \int_{\tau_0}^{\infty} d\tau\, T^2(\vec{l},\tau)\,\theta(T(\vec{l},\tau)-T_f)\,. \quad (15)$$

M.Luzum, P.Romatschke:PRL103, 262302 (2009)

Beware!
e_x is a theory number

Same data / two different geom models



Will LHC elliptic flow imply *negative* viscosity??

FIG. 1 (color online). Anisotropy (3) divided by (1), as a function of initial entropy (4) divided by (2). Shown are results from hydrodynamic simulations for $\sqrt{s} = 200$ GeV Au + Au

We compute v2(lamda t'Hooft) at RHIC by fitting Luzum,Romatschke curves
For v2(eta/s)

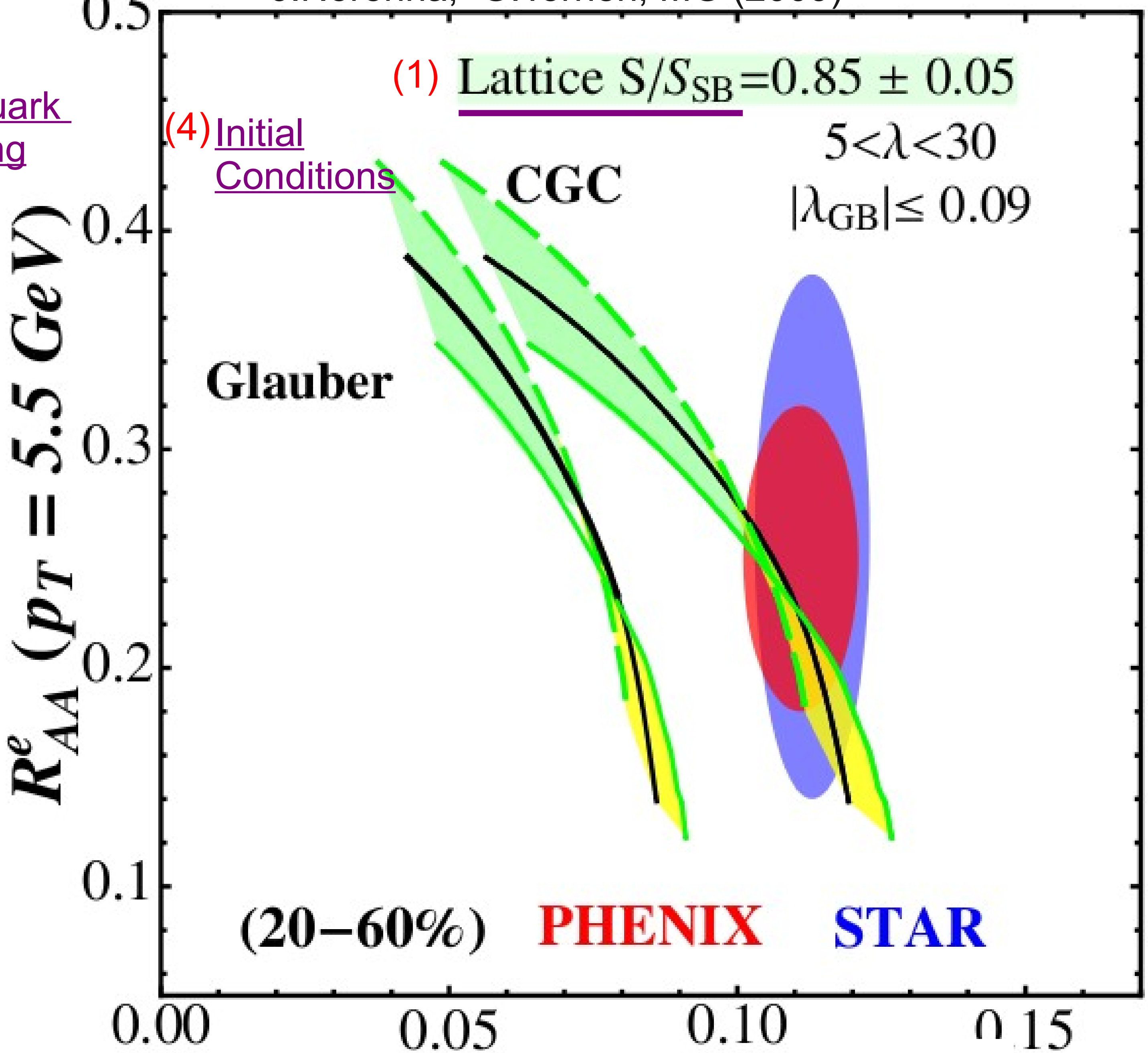
Correlation between Hard Jet and Soft Bulk observablesat RHIC via (AdS+GB) hQCD

J.Noronha, G.Torrieri, MG (2009)

(3) Heavy quark Jet quenching

(4) Initial Conditions

(1) Lattice S/S_{SB}=0.85 ± 0.05



(5) Heavy quark Jet induced collective flow

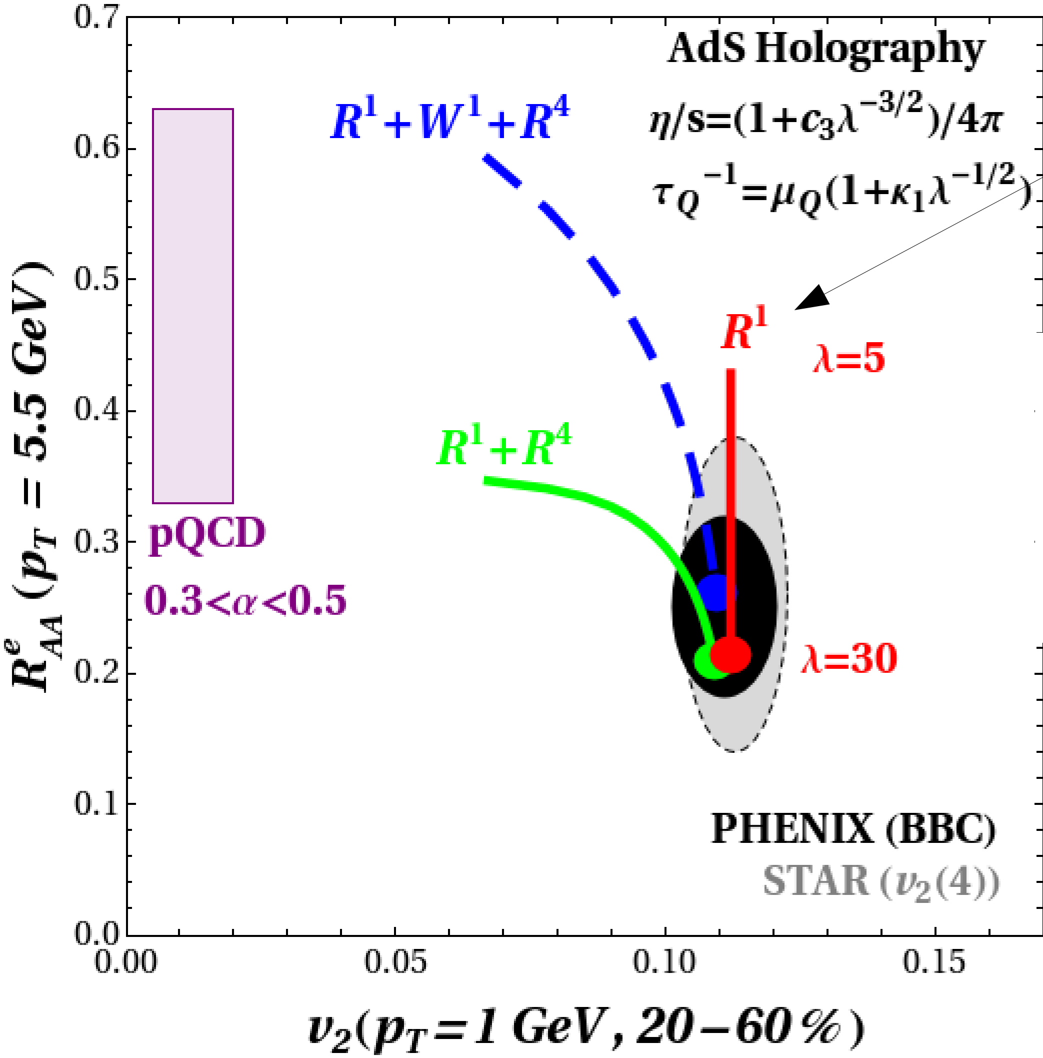
The Future

(2) Bulk Collective Flow $v_2(p_T = 1\ GeV, \eta/s)$ via Luzum, Romatschke PRC78 (08)

J.Noronha, G.Torrieri, MG (2009)

Unlike pQCD that predicts (P. Danielewicz, MG (85)) eta/s ~ 1 for wQGP

Conformal Holography predicts (KSS (02)) eta/s=1/4pi as seen in v2 for sQGP



Pure N=4 SYM
AdS/CFT
Einstein +Nambu-Goto
Action

-1.3 Chu,Huo,Ren (09)

$$\frac{d\ln E}{d\hat{x}} = -\frac{\sqrt{\lambda}}{2}\frac{T}{M_Q}\left[1+\frac{\kappa_1(1)}{\sqrt{\lambda}}+\frac{\kappa_2(1)}{\lambda}+\frac{1}{\lambda^{3/2}}\left(\frac{15}{16}\zeta(3)+\kappa_3(1)\right)+\frac{\kappa_4(1)}{\lambda^2}+\dots\right]$$

κ corrections correspond to fluctuations of the **string worldsheet** around its minimum area.

Remarkably robust correlation between Hard and Soft sQGP dynamics
Via a single lam ~ 20-30 t'Hooft parameter neglecting worlsheet fluc and string loop and GB deform

LHC will tell us 11/15/10 whether AdS holography (**hQCD**) extrapolated
Down to the critical QCD coupling alpha_c ~ 0.5 (Gribov)

can provide a more powerful approximate
A+A dynamical phenomenology than

standard **pQCD** extrapolated ***Upwards to*** the critical QCD alpha_c

Near Future RHIC with **b and c identified tomography**
Will provide a critical consistency control check of emerging pictures
Free of CGC ambiguities.

IF hQCD wins over pQCD approximations at RHIC and LHC,
then FAIR will have a very rich holographic future
in terms of 10D **non-conformal** baryon physics near
the sought after CEP (if that indeed exists)

Future theory development of Non-Conformal hQCD phenomenology is
urgently needed (J. Noronha, A.Ficnar)