

Black Holes and Fireballs at the LHC

MPP Munich, 30-7-2013

Anastasios Taliotis
Vrije Universiteit Brussel

arXiv:1212.0528; published in JHEP

Outline

- Review Shockwave collisions in GR
- Trapped surface analysis, an elementary introduction
- ~~• Flat backgrounds, applications to BHs production at the LHC and extra dimensions~~
- AdS backgrounds and applications to QGP production at the LHC
- Summary/conclusions/take home message

Review Shockwave collisions

- Studied by many authors in both backgrounds

[Ads:,Albacete,Kovcegov,Taliotis;Romatscke,Mateos-Solana-van der Schee, ,Heller,Janik,Peschanski,Wu, Chesler,Yaffe..., Flat:'t Hooft,D'Eath, Payne,Giddings,Tomaras,Taliotis, Herdeiro et.al...]

- Single shock wave geometry

Essential formulas

- Restricted SO(3) invariant shocks:

$$ds^2 = \frac{-2dx^+ dx^- + dx_{\perp}^2 + EG_5 z \phi(q(z, x_{\perp})) \delta(x^-) (dx^-)^2}{z^2 / L^2}$$

$$q = \frac{x_{\perp}^2 + (z - z_0)^2}{4zz_0}$$

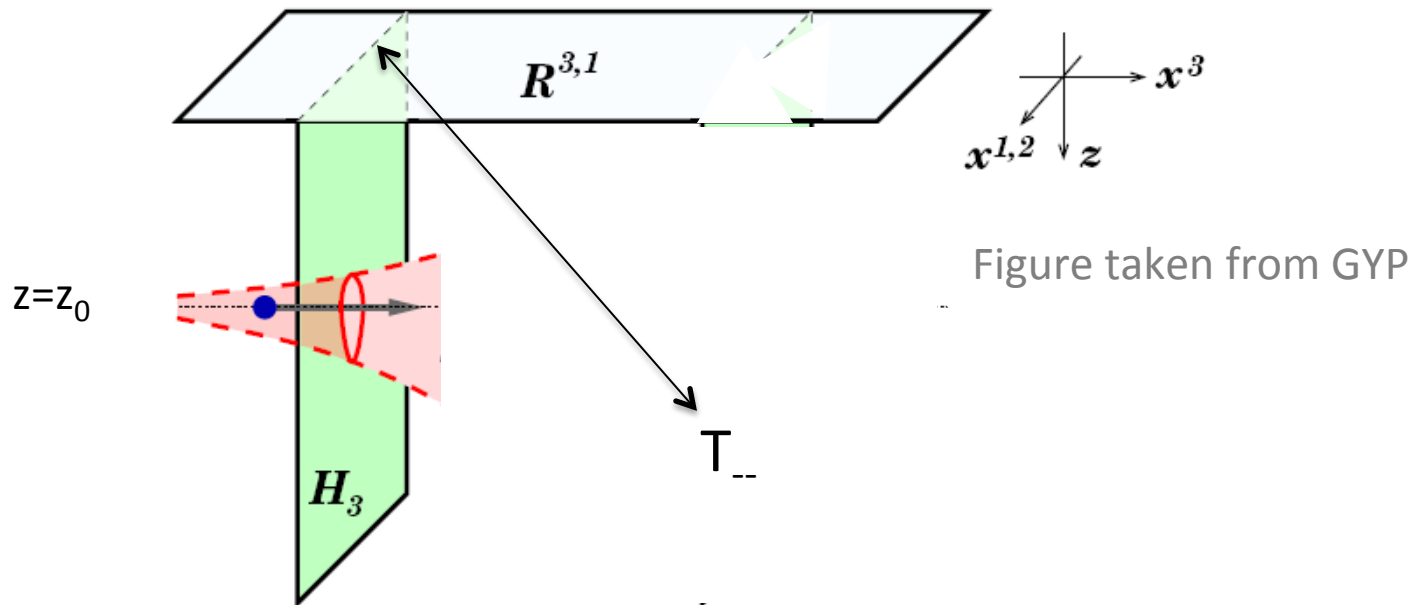
$$R_{--} + \frac{4}{L^2} g_{--} \sim \delta(x^-) \nabla_q^2 \phi = 8\pi G_5 J_{--} = EG_5 \rho(q) \delta(x^-)$$

- z_0 estimates the center of ρ in the 5th dimension.
- z_0 is also the width of $T_{\mu\nu}$ in gauge theory side. Although expected, NOT trivial to show this for any ρ .

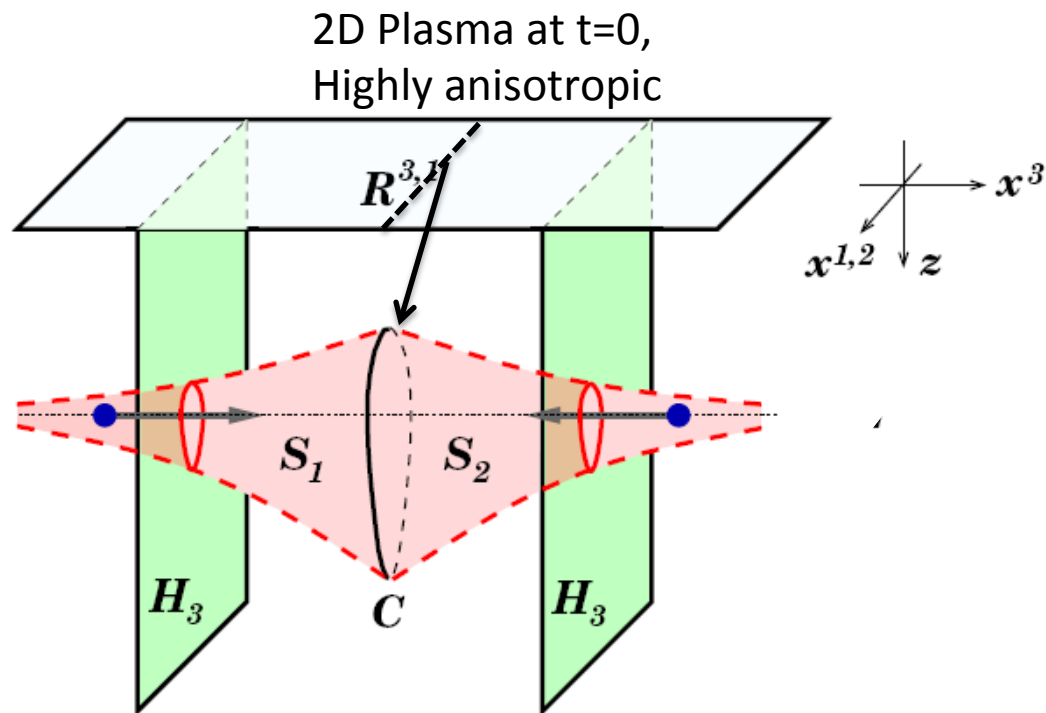
- What does this describe in gauge theory?

Can show $g_{--} |_{\text{bdry}} \sim T_{--}$. Since $g_{--} |_{\text{bdry}} \sim f(x_{\text{perp}})\delta(x^-)$

It implies that this geometry describes a thin fast glueball along x^- having a transverse profile .



- Superimpose two shocks: Add another one along the opposite direction
- Shocks talk each other at $x_- > 0, x_+ > 0$



Introduction to TS

Important Clarifications

- What this method does not do: does NOT provide info for $g_{\mu\nu}$ on future LC
- What this method can do: provides a suggestion that a BH is formed by reducing to unusual BV problem. In what follows we will assume that a BH is always formed.
- TS yields a lower bound on entropy production $S_{\text{trap}} \leq S_{\text{prod}}$

[Giddings, Eardly, Nastase, Kung, Gubser, Yarom, Pufu, Kovchegov, Shuryak, Lin, Kiritsis, Taliotis, Aref'eva, Bagrov, Joukovskaya, Veneziano, Alvarez-Gaume, Gomez, Vera, Tavanfar, Vazquez-Mozo, Romatske...]

Trapped surface analysis introduction (D=4, flat backgrounds)

If there is a function ψ and some curve C s.t.

$$\nabla_{\perp}^2(\psi - \varphi) = 0 \quad \psi|_C = 0, \quad \nabla_{\perp}\psi \cdot \nabla_{\perp}\psi|_C = 1$$

then there exists a trapped surface and it is enclosed inside the curve C .

- Example: Let the shock $\phi = EG_4 \text{Log}(kx_{\perp})$ ala AS
- Then $\psi = EG_4 \text{Log}(x_{\perp}/EG_4)$ and $C : x_{\perp;C} = EG_4$
- And $S = A/4G_4 \sim \int d^2x_{\perp} \sim E^2 G_4$ [Giddings & Eardley, 2002]

AdS Backgrounds and QGP

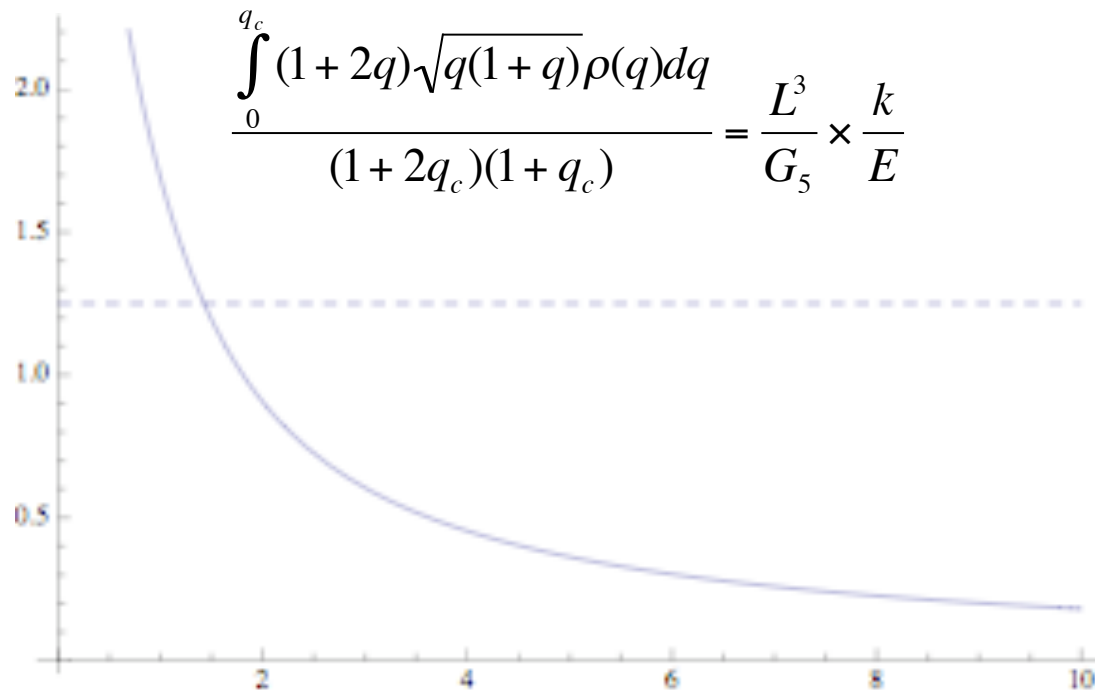
Trapped Surface Condition

$$\frac{\int_0^{q_c} (1+2q)\sqrt{q(1+q)}\rho(q)dq}{(1+2q_c)(1+q_c)} = \frac{L^3}{G_5} \times \frac{k}{E}$$

- Where $k \equiv 1/z_0$ (the transverse scale if the colliding glue-ball in the QFT side). Note the dimensionless parameter controlling the TS: E/k Vs $E \times k$ in flat backgrounds. Interesting!!
- We will classify ρ 's under the assumptions
 - (i) ρ is positive definite
 - (ii) ρ is integrable. (i)+(ii) \Rightarrow 3+1 cases
 - (iii) $(q\rho(q))' = 0$ has at most one root in $(0, \infty) \Rightarrow$ 3 cases
- The 3 cases depend on how ρ behaves at small q 's!

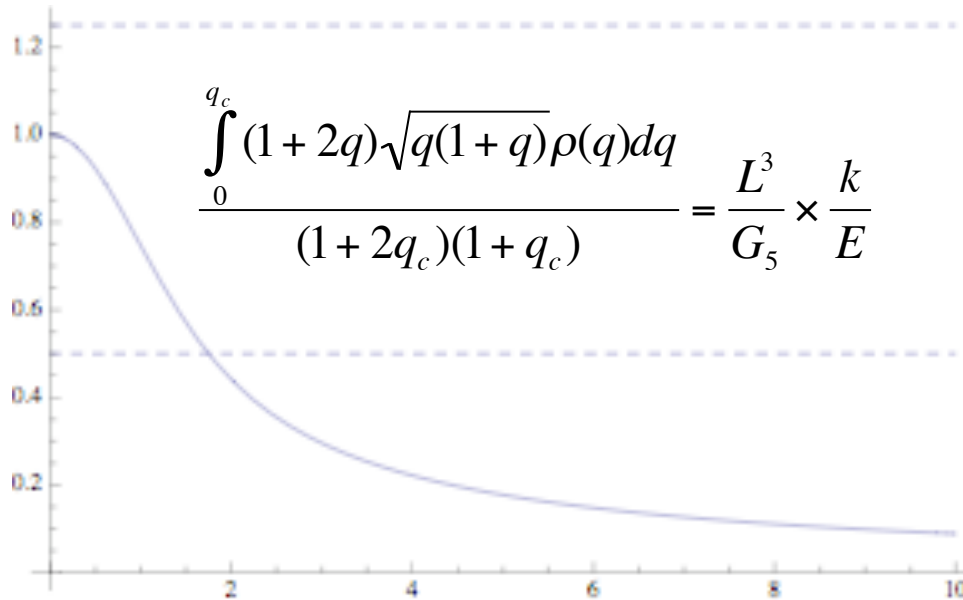
Case I. Always a single TS

- Case I.: $\rho \sim 1/q^n$ +sub-leading, $q \ll 1$, $3/2 > n > 1/2$.
(always a single TS)



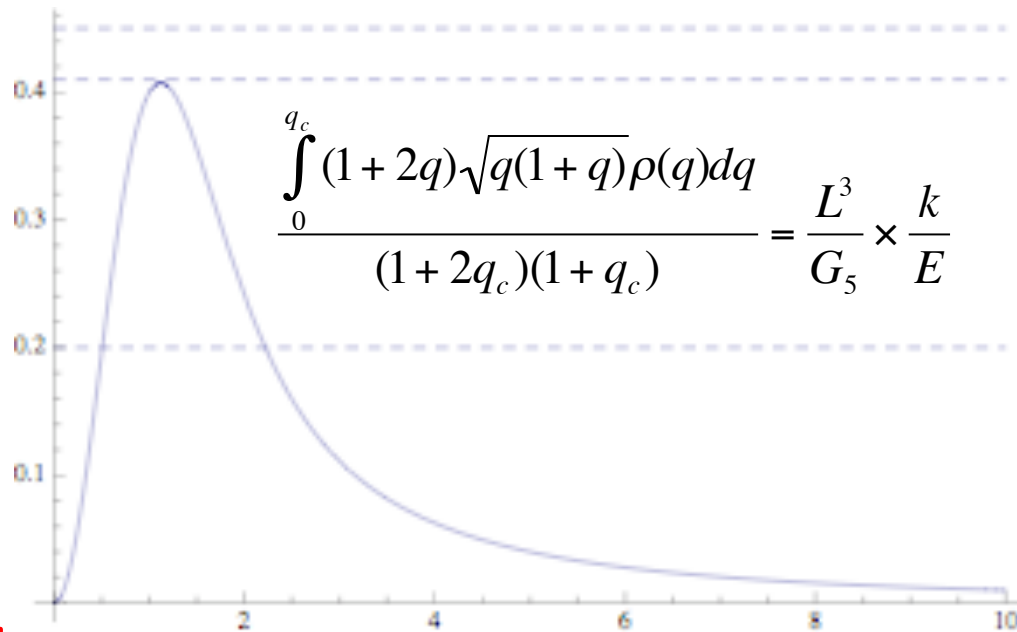
Case II. A marginal case: A single TS for sufficiently large E / k

- $\rho \sim 1/\sqrt{q}$ +sub-leading, $q \ll 1$ (a single TS if $E \gg k$).



Case III. Two TS for sufficiently large E / k

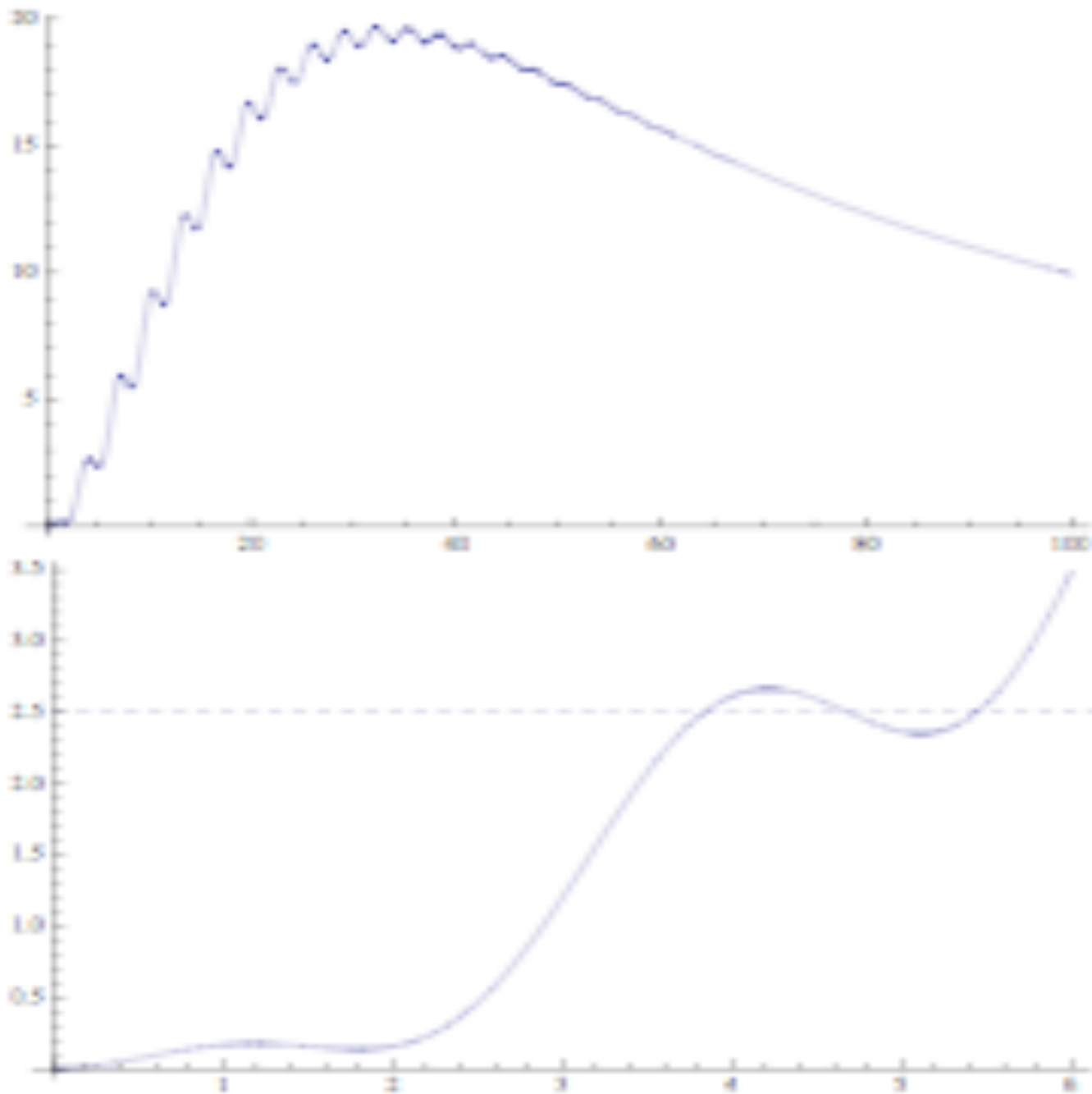
- Case III. $\rho \sim 1/q^n$ +sub-leading, $q \ll 1$, $n < 1/2$.
(2 co-eccentric TSs if $E \gg k$)



- “RN-like” scenario in the absence of charge

[Mureika,Nicoli,Spallucci;Taliotis]

Remove the
 $(x\rho(x))'=0$ has
a single root



Universal Results

Can show that any ρ :

- Yields a ϕ s.t. at $q \gg 1$ decays as $1/q^3$ as dictated by holographic renormalization considerations
[Skenderis, Papadimitriou, de Haro, Solodukhin,...].
- The TS, in the HE limit: $k/E \ll 1$, grows as $q_c^3 = E/k$ with k NOT dropping out.
- In the HE limit can show $S \sim q_c^2$ and so $S \sim (E/k)^{2/3}$.

Desired feature captured

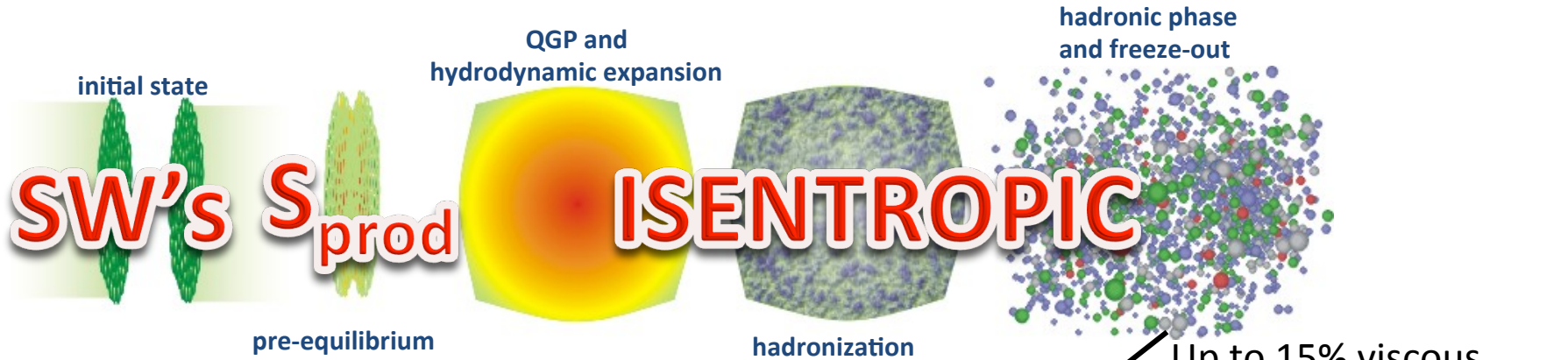
- Seen that a BH, hence QGP, may exist if $E \gg k$.
- But k is the transverse scale of the SE tensor in QFT; that is scale of colliding glue-balls.
- Tempted to identify k with Λ_{QCD}
- This would imply forming $\text{QGP} \Leftrightarrow E \gg \Lambda_{\text{QCD}}$
- Although expected, it is first time in literature such feature is described theoretically; in present context holographically.

Incorporating strong-weak coupling
physics and saturation scale: a
phenomenological approach

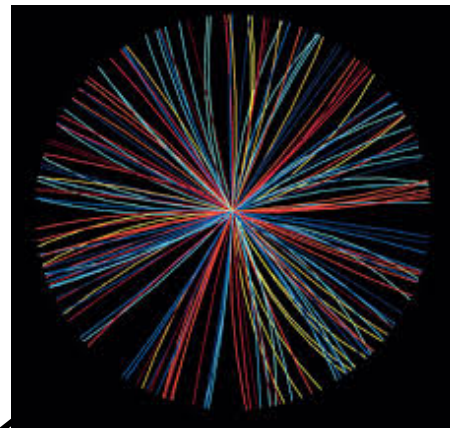
Attempting to fit RHIC and LHC data

- A phenomenological approach
- Relate S with total multiplicities N
- Use CGC model, in particular the saturation scale.
- Incorporate weak-strong coupling physics.

Multiplicities N_{ch}



Up to 15% viscous corrections; Heinz et al



$$N_{ch} = \sum_i N_{ch;i} = \sum_i \int \frac{d^3 N_{ch;i}}{dy d^2 p_T} dy d^2 p_T$$

Relating S with N_{ch}

- Since $N_{\text{CH}} \sim S_{\text{GT}} = \text{AdS/CFT} = S_{\text{ST}} > S_{\text{TS}}$. Numerical works [Hogg, Romatschke, Wu] show $S_{\text{ST}} = b S_{\text{TS}}$ where b is collision energy independent
- On the other hand, overall constants (gravity parameters s.t. G_5/L^3) must be fitted with data. Hence schematically work as

$$N_{\text{ch}} = (\text{fit } b) \times S_{\text{TS}}$$

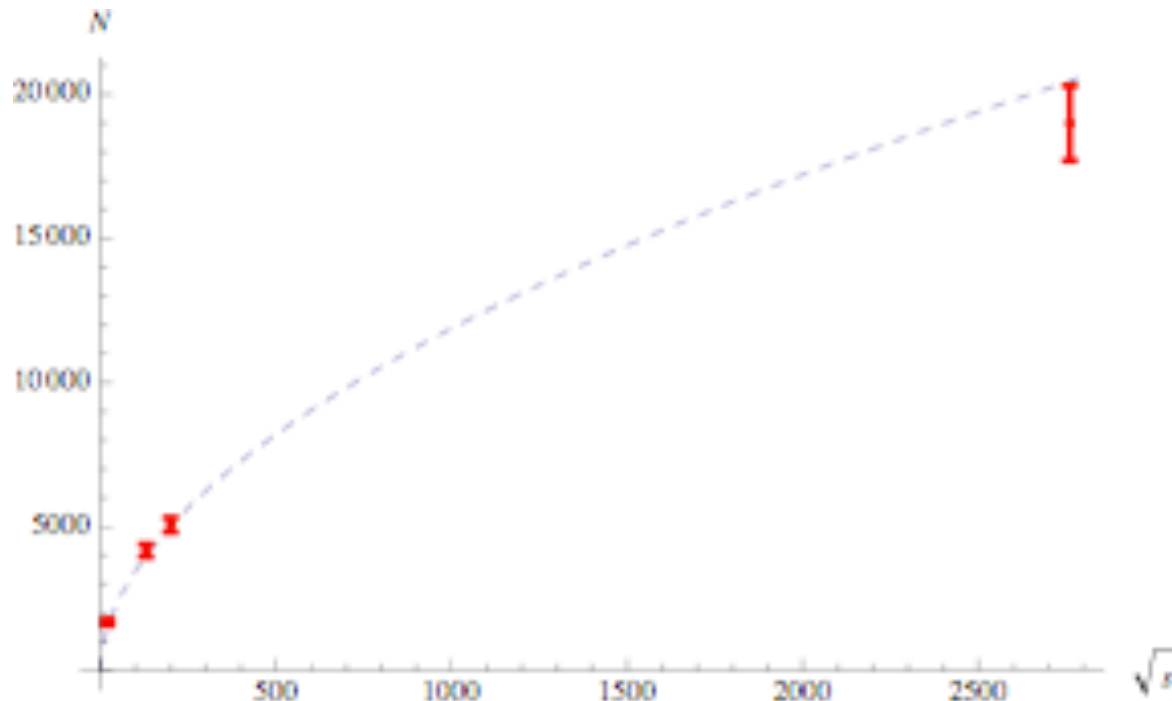
Connection with data

- Seen that $N_{\text{CH}} \sim S \sim (E/k)^{2/3}$
- k could generally be E dependent
- Take $k=Q_s(E)$ and use Q_s from pQCD results
- This means that the transverse scale of colliding ultra-fast pancakes is set by Q_s rather than Λ_{QCD} .

- Then $N \sim (E/Q_s(E))^{2/3} \sim (s/\Lambda_{\text{QCD}})^{1/3(1-\lambda)}$, $\lambda=[0.1,0.2]$
where $\lambda \sim 0.2$ for AA collisions

$$Q_s^2(s_{NN}) = (0.2 \text{ GeV})^2 A^{1/3} \left(\sqrt{s_{NN}} \right)^{2\lambda}$$

- Hence $N \sim (s/\Lambda_{\text{QCD}})^{0.26}$ and fit constant using the data.
Choosing the (s independent) constant 300 yields



Summary

- Gave an elementary intro to TS/review known results.
- Classified transversally symmetric distributions according to the TSs that can create (for flat and AdS backgrounds).
- Found universal results in both, the geometries at large distances and at the S in the HE limit.

Take home messages

- Applied to BHs at LHC: No ED \Rightarrow No BHs but ED \Rightarrow BHs open scenario (did not study this here).
- QGP \Leftrightarrow E \gg Λ_{QCD} . First time to be described theoretically.

Thank you