Holographic jet shapes and their evolution in strongly coupled plasma

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In collaboration with

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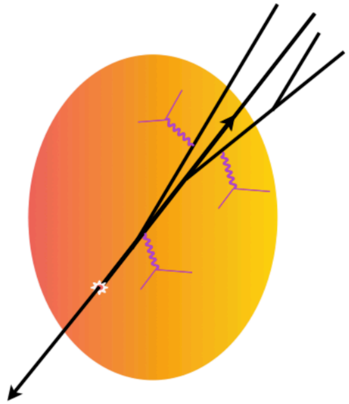
Goal: understand parton energy loss in QGP

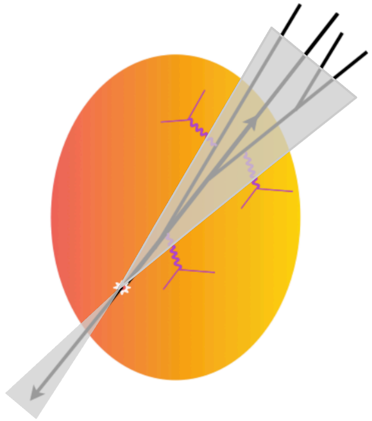
- Jet modification observables

Modeling jets in QGP

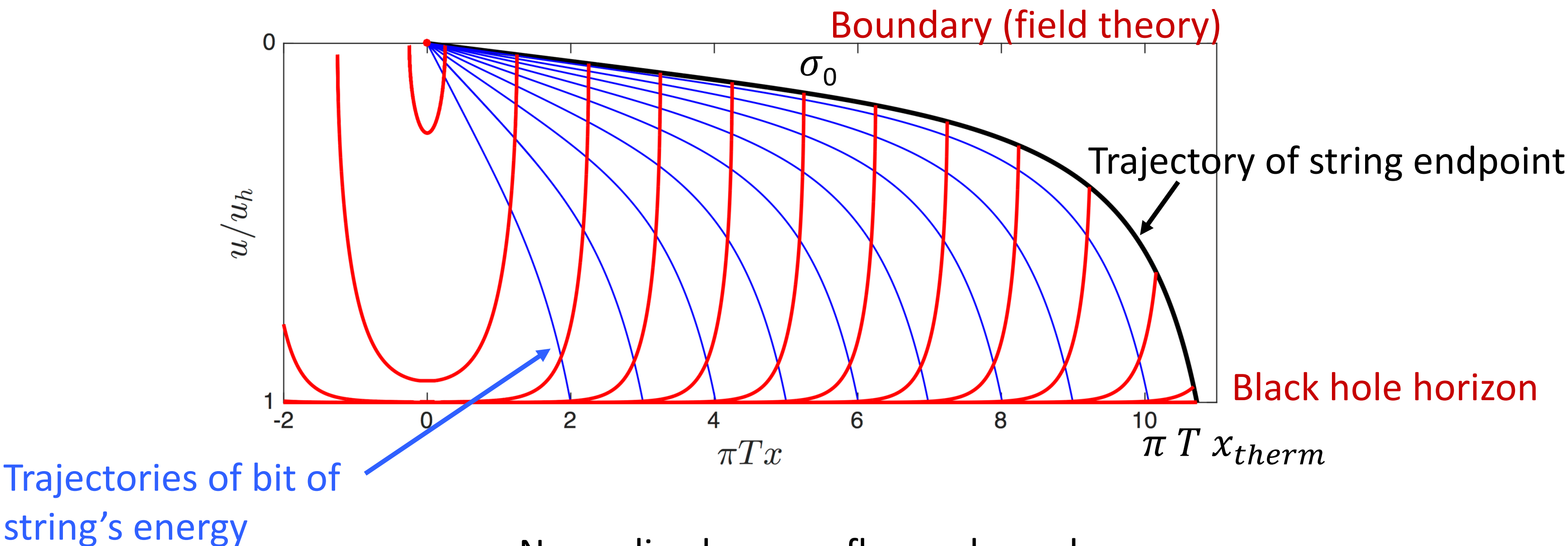
- Use jets in holography to model jets in QCD
- Different from the hybrid model discussed earlier



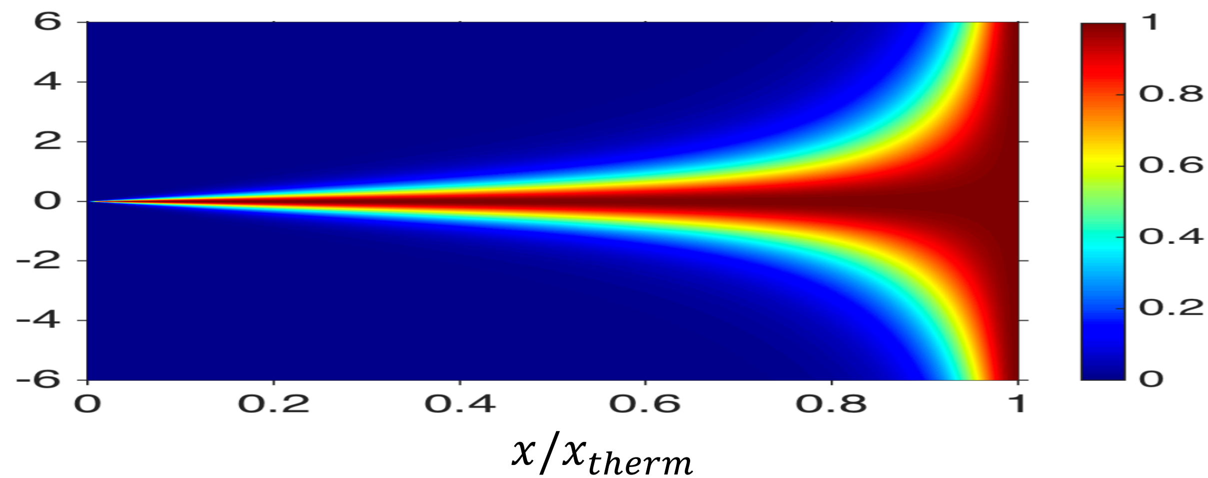
Hybrid model



This work



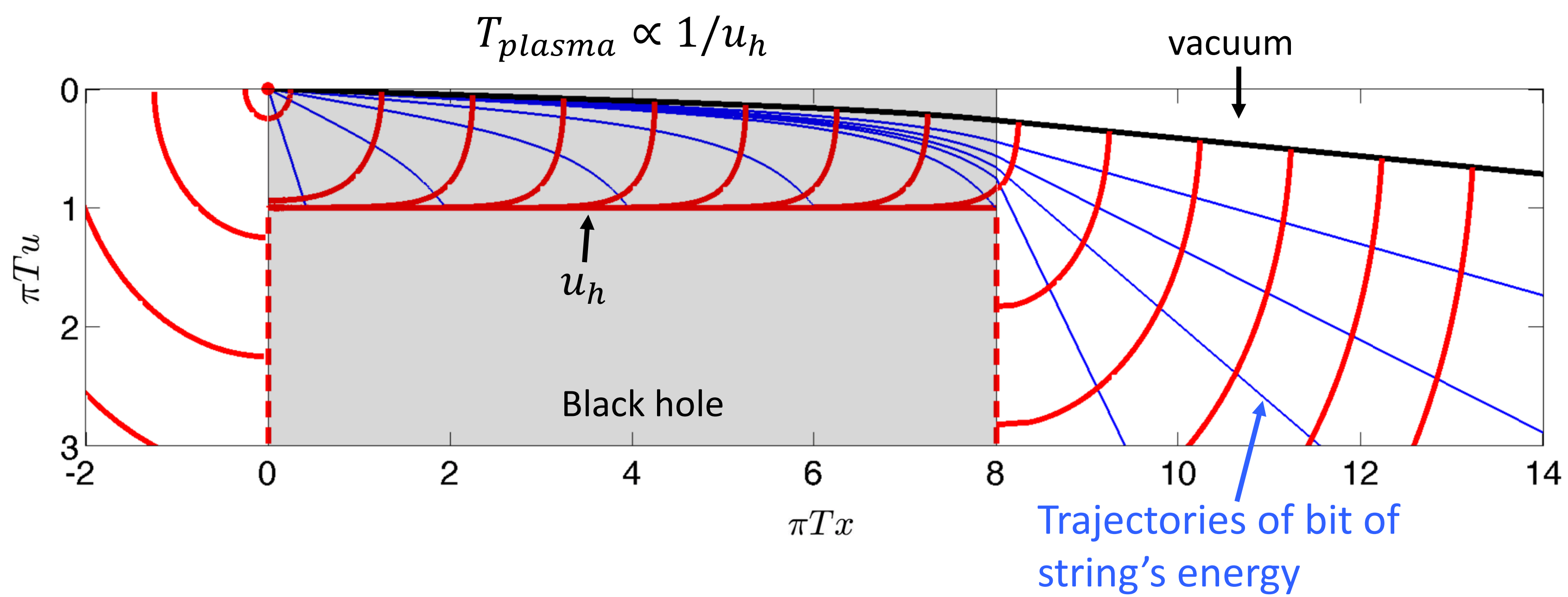
Normalized energy flux on boundary



(figures: Chesler & Rajagopal 1511.07567)

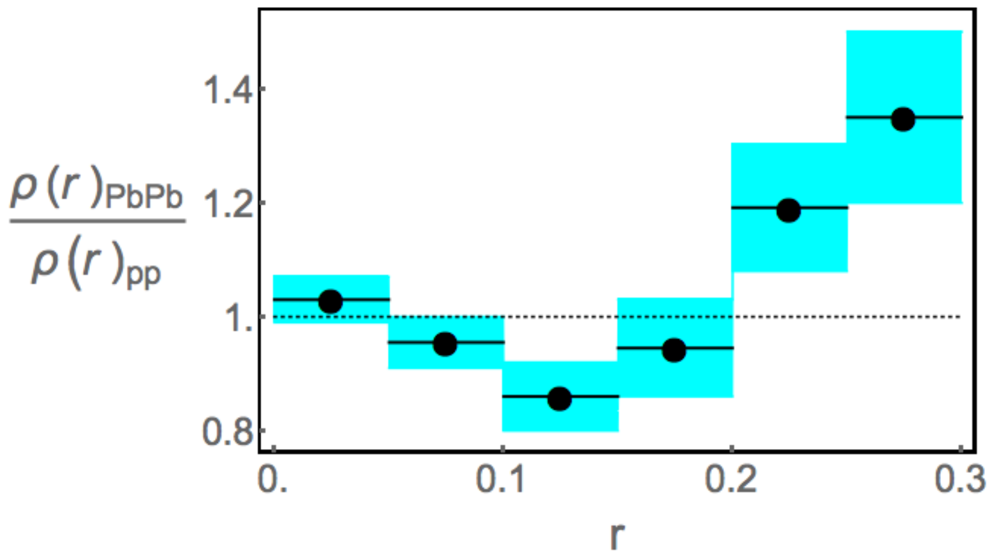
Holographic jets in plasma always get wider

- Some energy lost, some escapes



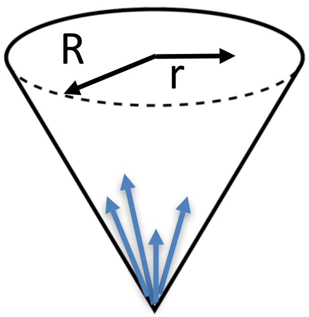
(figure: Chesler & Rajagopal 1402.6756)

Near jet axis, jets in plasma actually get narrower!



CMS: [1310.0878v2]

p_T^{jet} > 100 GeV
0.3<$|\eta^{jet}|$<2
Anti-k_T R=0.3
0-10% centrality



- Need to consider an ensemble of jets

Constructing an ensemble of jets

- Distribution of initial jet energies $\sim E^{-6}$
- Distribution of jet opening angles calculated in pQCD

[Larkoski, Marzani, Soyez, Thaler 1402.2657]

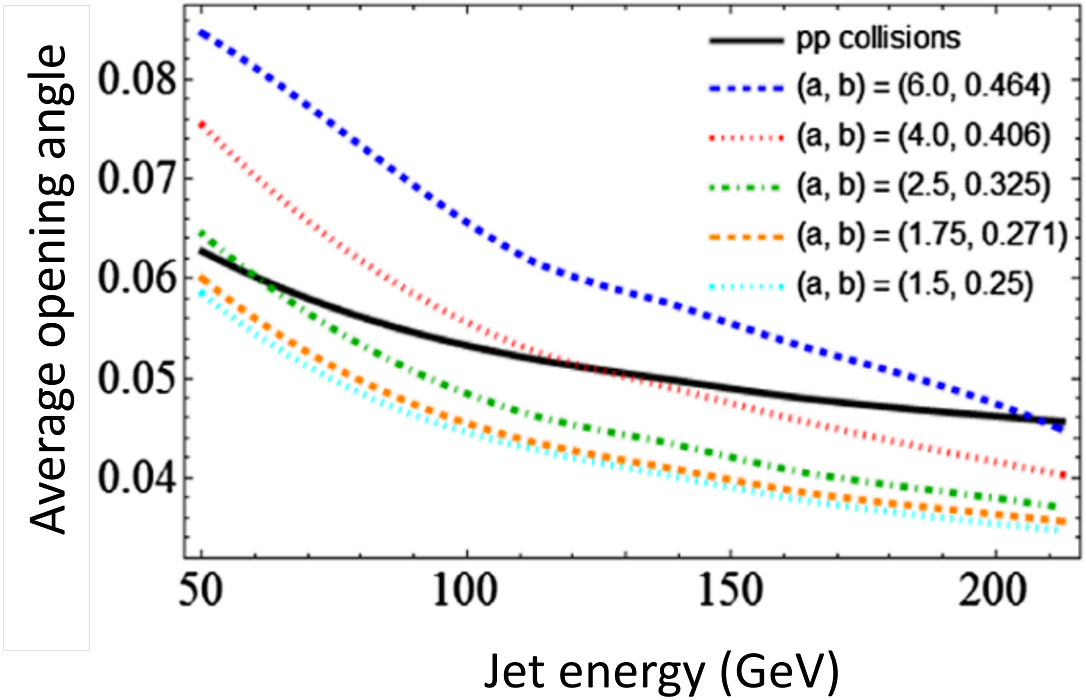
$$C_1^{(1)} = \sum_{hadrons\ i,j} z_i z_j \frac{|\theta_{ij}|}{R} \sim \text{ jet width}$$

Two free model parameters

- $C_1^{(1)} = a\,\sigma_0$ jet width $\sim$ holographic opening angle
- $T_{SYM} = b\,T_{QCD}$

Individual jets widen in holography, but *ensemble* of jets may narrow or widen

Rajagopal, Sadofyev, and van der Schee
PRL 116, 211603 (2016)



- We can go further and compute the full jet shape

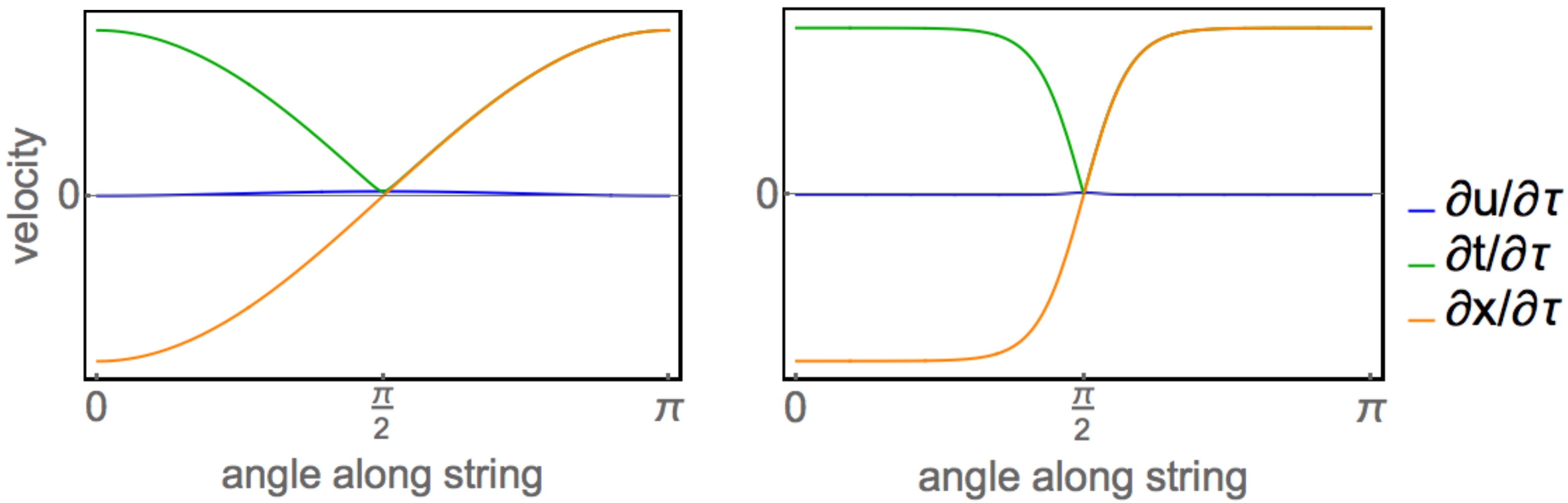
Outline of Key Results

- Predict the jet shape from real string dynamics in holography
- We predict modification to pp observables by expanding, cooling droplet of plasma
  - Presented here: jet shape modification, dijet asymmetry
- Advertisement: What can we get by including 3-jet events in holography?

Solving full string equations of motion

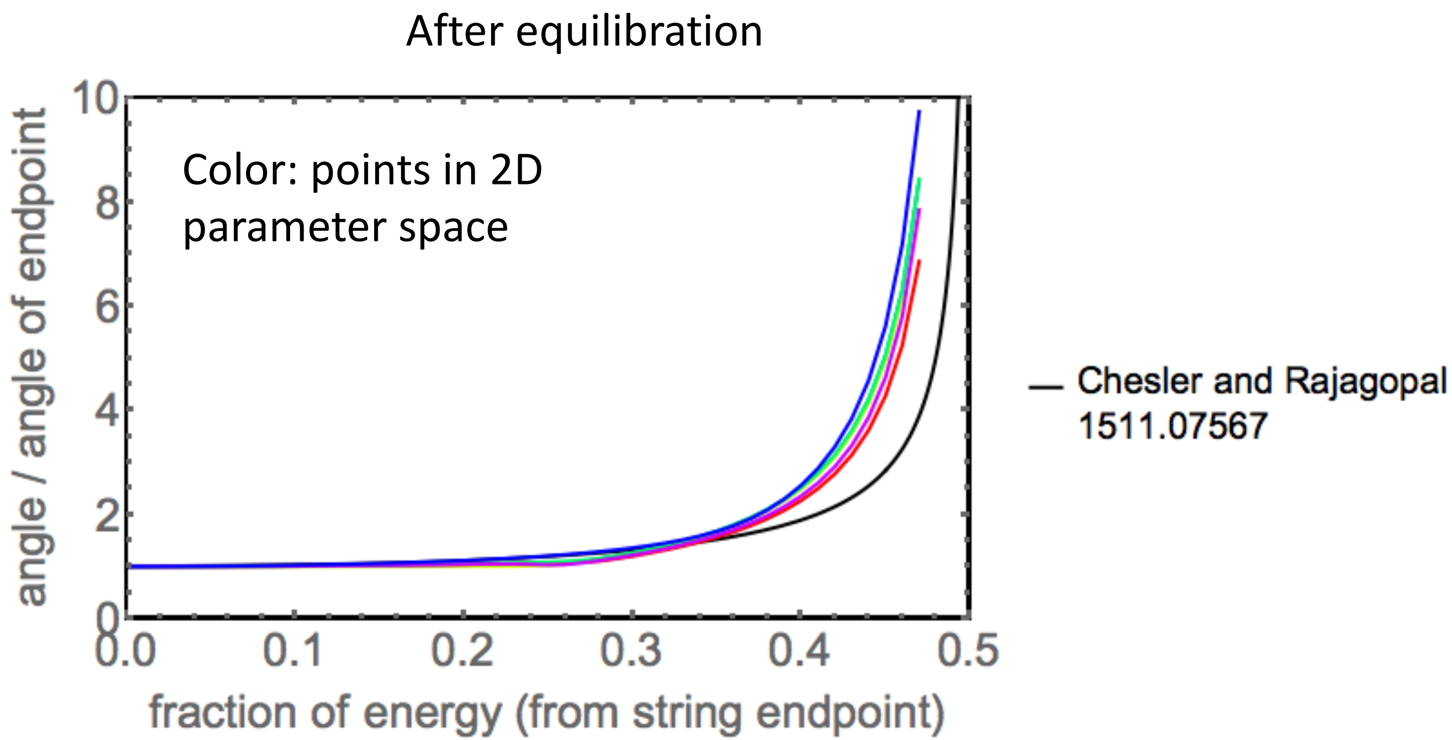
- Freedom to specify initial conditions

Example velocity initial conditions



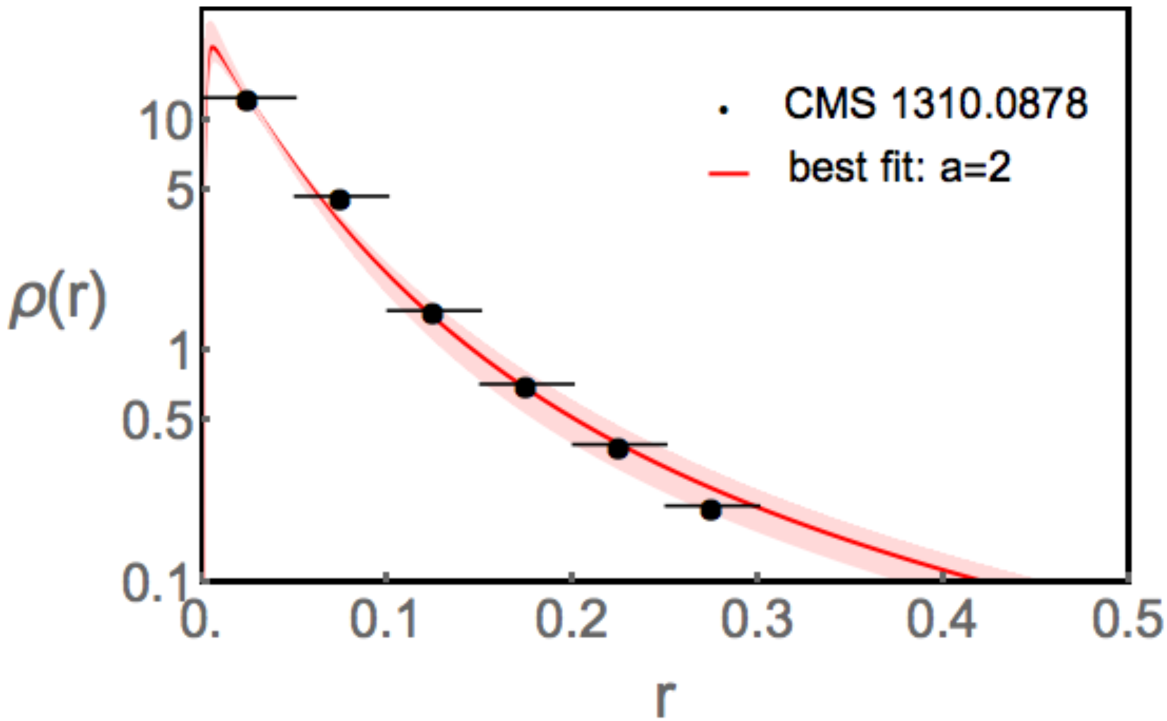
See e.g. [0810.1985]

Jet shape determined by distribution of energy along string after equilibration



Single-parameter fit to jet shape in proton-proton

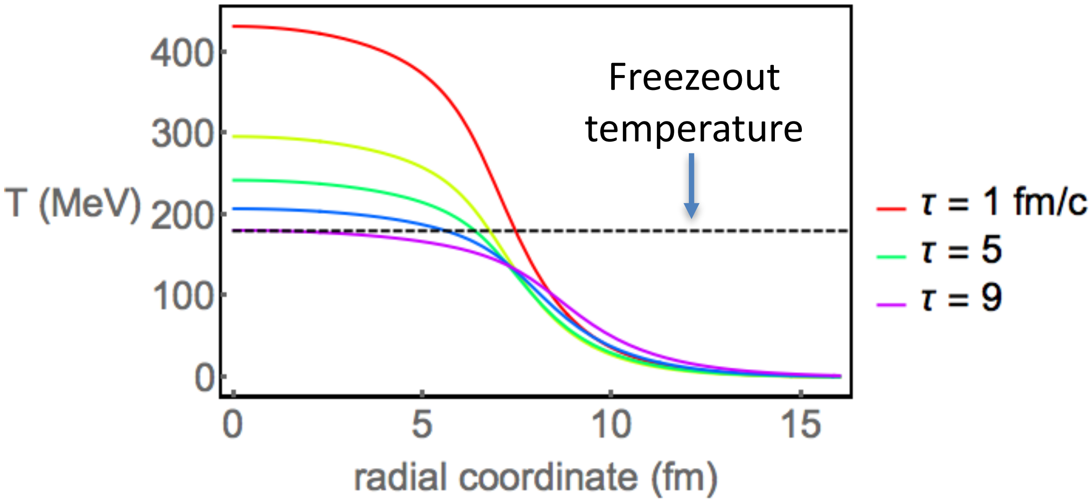
- constrains free parameter a



$p_T^{jet} > 100$ GeV
$0.3<|\eta^{jet}|<2$
Anti-k_T R=0.3

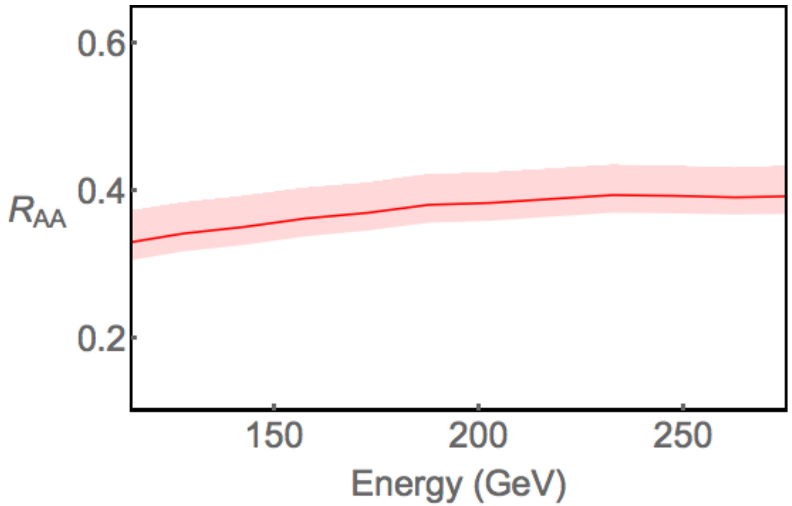
Simplified Model of Plasma Evolution

(See PRL 116, 211603 for details)

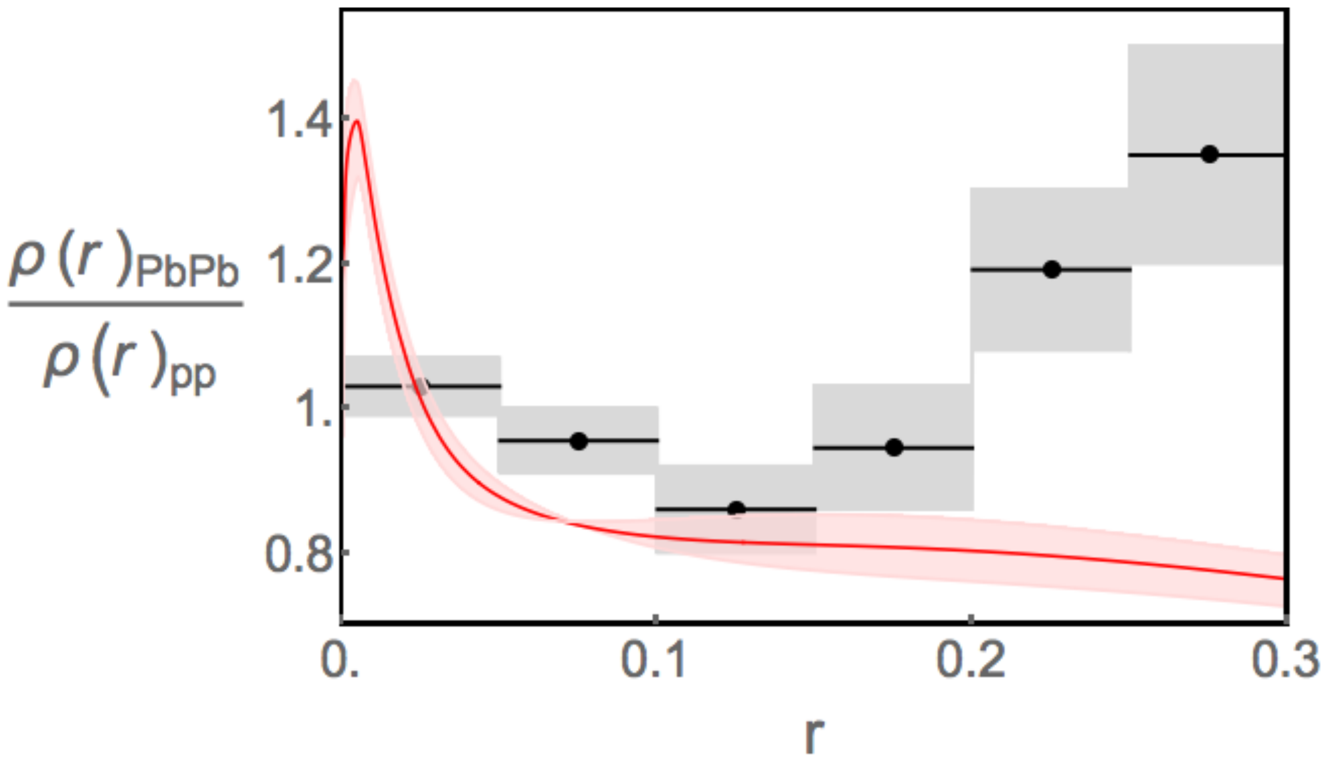


Fit free parameter b from R_{AA}

Shown: b=0.203



Jet shape modification



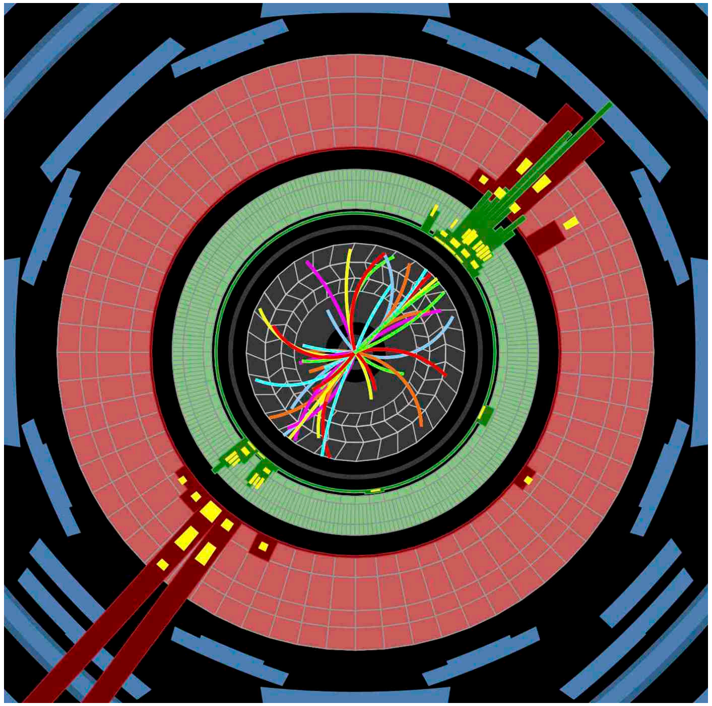
p_T^{jet} > 100 GeV
0.3<|η^{jet}|<2
Anti-k_T R=0.3
0-10% centrality

b=0.203

- Agrees qualitatively with data at small r
- Large r behavior – need wake

CMS: [1310.0878]

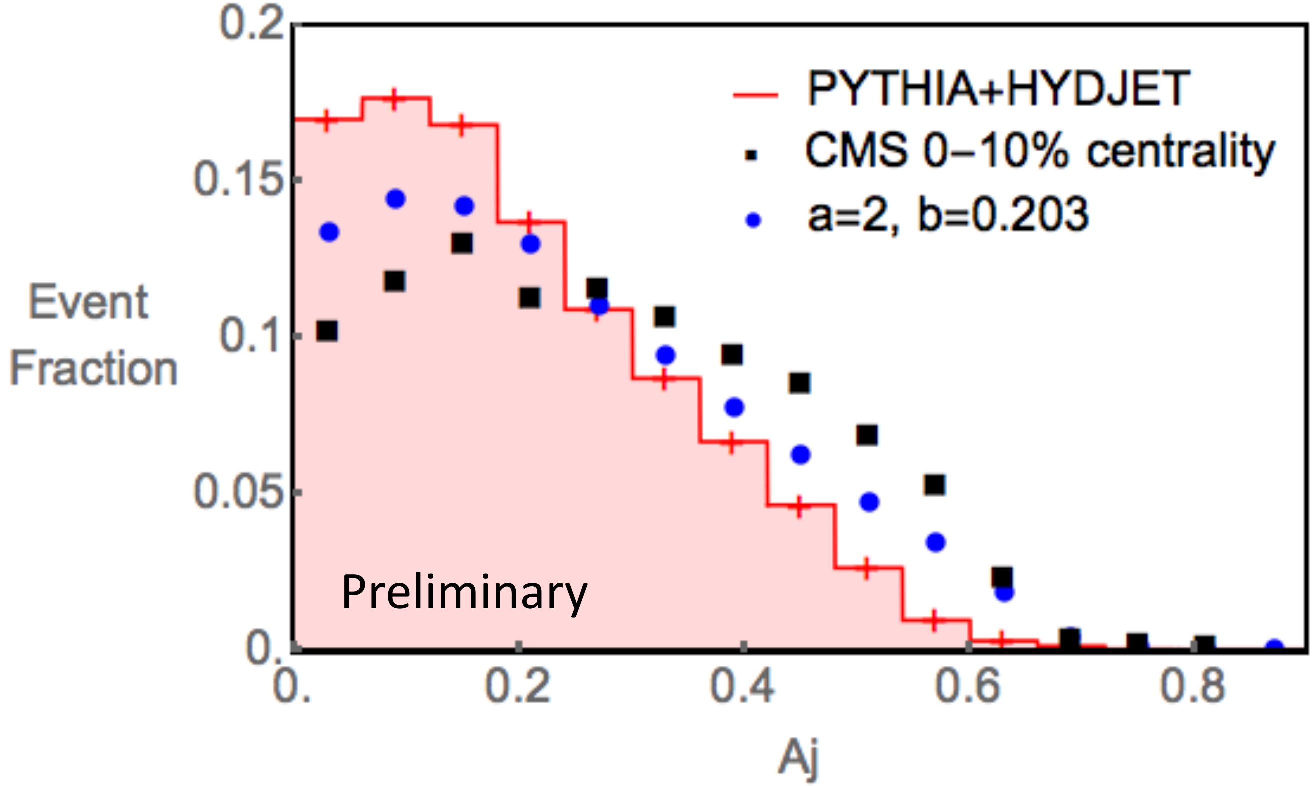
Dijet asymmetry in proton-proton



$$A_J = \frac{p_{T1} - p_{T2}}{p_{T1} + p_{T2}}$$

- Initial distributions of dijet asymmetry, angle between leading and subleading jets from PYTHIA+HYDJET [CMS 1202.5022]

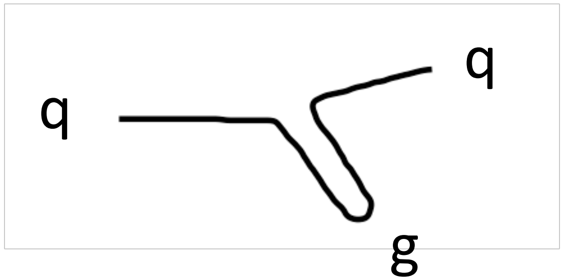
Dijet asymmetry modification

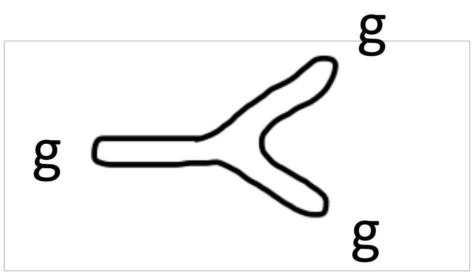


data points and PYTHIA+HYDJET: CMS 1202.5022

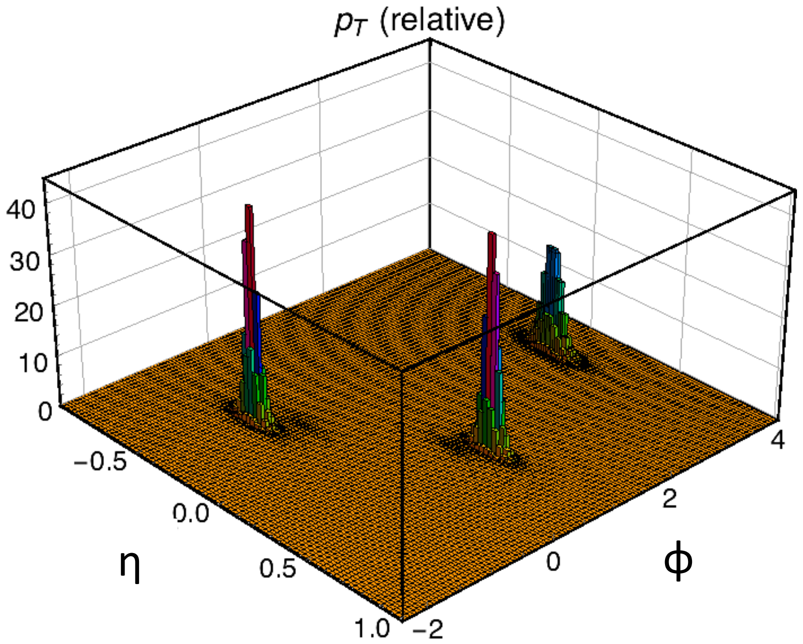
3-jet events in holography

(Work in progress)





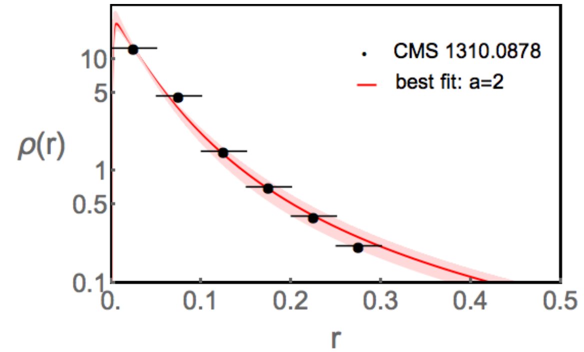
etc.



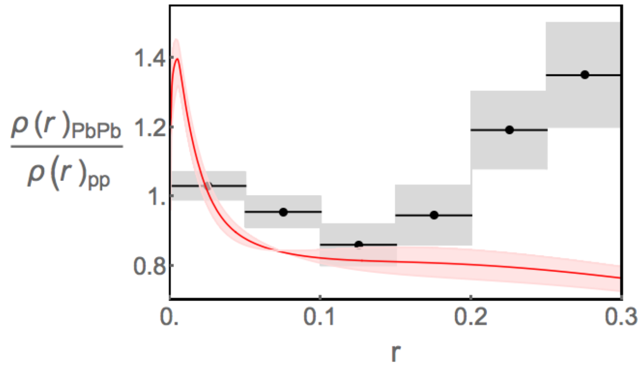
See also: Casalderrey-Solana and Ficnar 1512.00371

Main messages

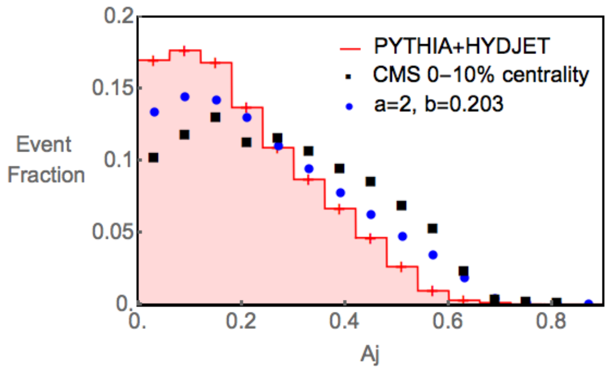
- Jet shape from full string dynamics



- Jet shape modification



- Dijet asymmetry modification



Back up Slides

$\mathcal{N}$=4 SYM and QCD

Why study $\mathcal{N}$=4 SYM?

- Quark gluon plasma is strongly coupled
- QCD is very hard at strong coupling
- QCD has no known gravity dual; $\mathcal{N}$=4 SYM does

N=4 SYM from classical gravity	QCD
$1/N_c^2 = 0$	$1/N_c^2 = 1/9$
Infinite coupling	Running coupling
Conformal	Approximately conformal for $T \gtrsim 2\,T_c$
$\eta/s = 1/4\pi \approx 0.08$	$\eta/s \approx 0.1$
No hadronization	Hadronization

lattice results suggest $1/N_c^2 = 1/9 \sim 1/N_c^2 = 0$

$\mathcal{N}$=4 SYM not asymptotically free

Similar hydrodynamics of plasma phases

No clear analog of jet reconstruction, jet substructure

Hope: Qualitative lessons about QCD plasma from $\mathcal{N}$=4 SYM

Modeling “Jets” in N=4 SYM