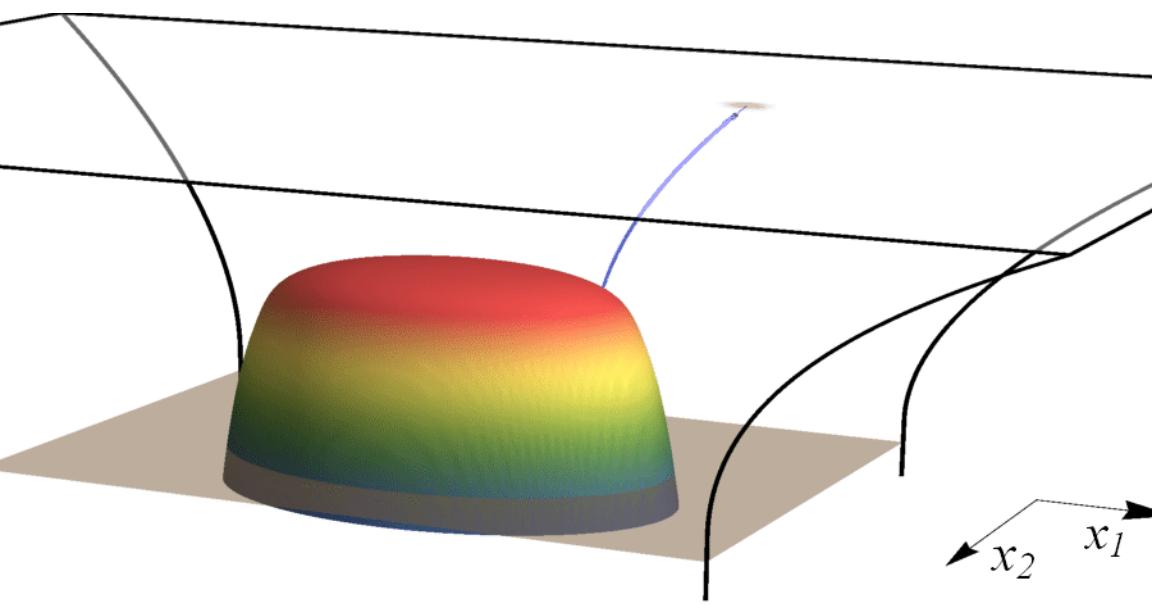




EVOLUTION OF THE JET OPENING ANGLE DISTRIBUTION IN HOLOGRAPHIC PLASMA

TRACKING ENERGIES AND ANGLES

with Jasmine Brewer, Krishna Rajagopal and Andrey Sadofyev
1602.04187 (PRL 116)



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Hard Probes
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(slowed down by 10^{23})

$t = 0.2 \text{ fm}/c$

Center for Theoretical Physics

OUTLINE

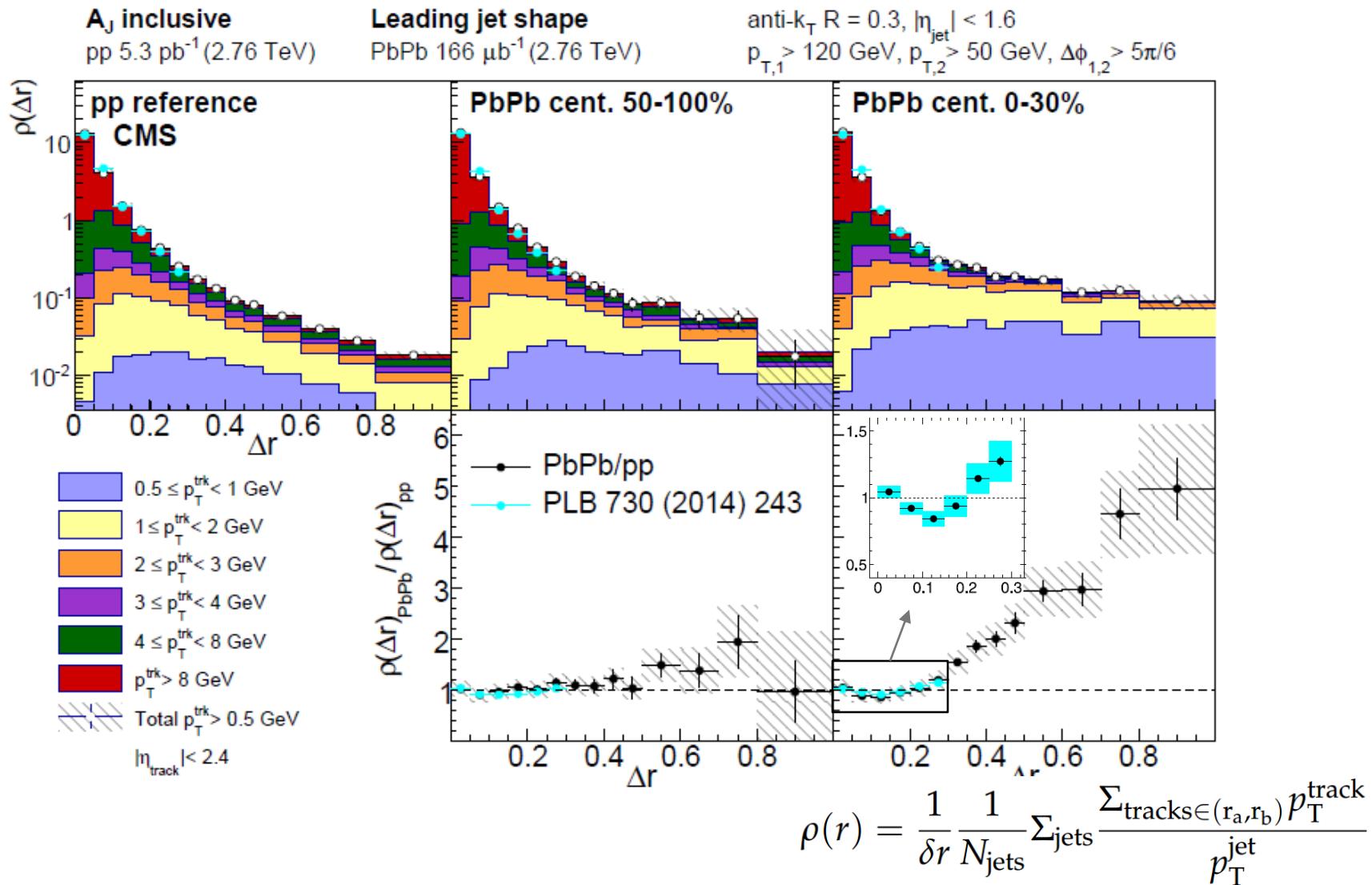
A simple model

- Jets as string, shooting a jet through a slab of plasma
- Construct model of null strings
- Evolve ensemble of jets: *initial* energy & angle from perturbative QCD
- Shoot ensemble through expanding and cooling black hole
- Extract influence QGP on jet opening angle distribution

A qualitative prediction

- Lose both very narrow and very wide jets

JET SHAPE MODIFICATIONS



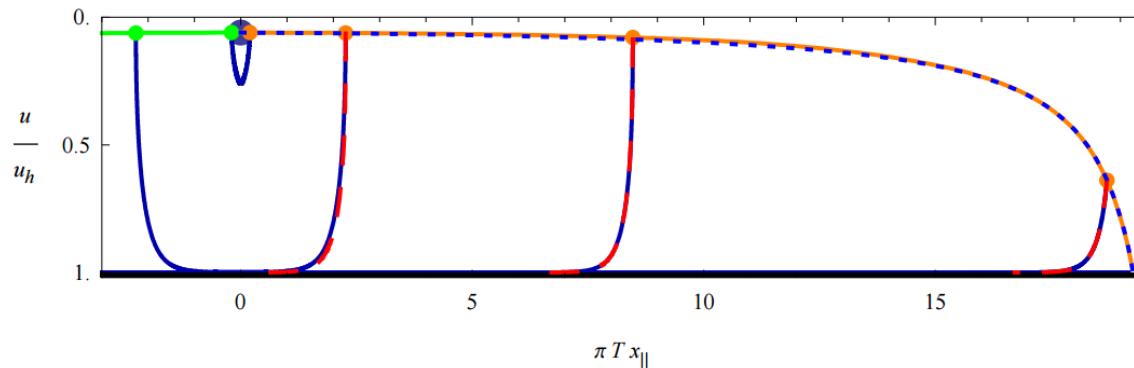
JET PRODUCTION

Typical philosophy:

- Jet is result of hard event, as prescribed in pQCD
- Energy loss, through soft modes, and non-perturbative

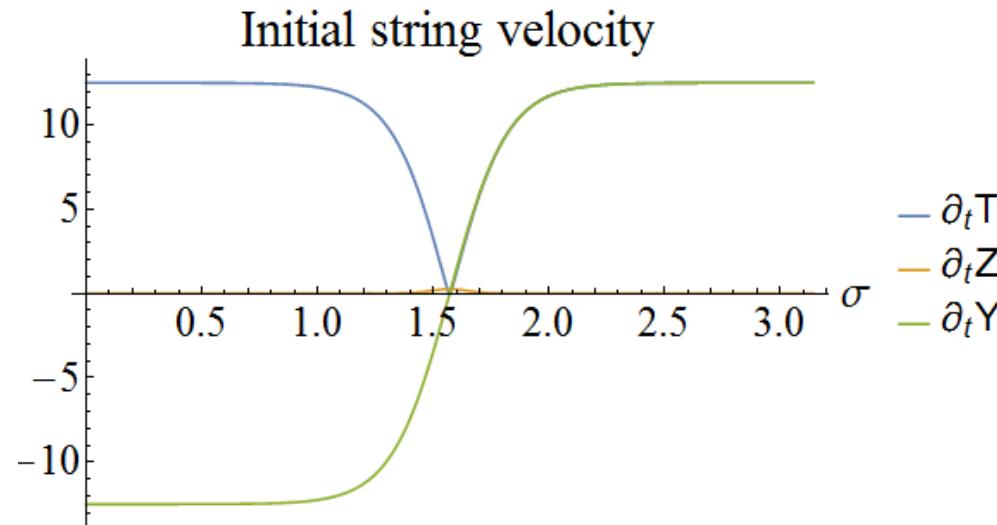
In AdS/CFT: jet = (classical) string

- Create string (quark-antiquark pair) with ‘jet-like’ properties
 - Problem: initial condition string is 2 functions (position, velocity)



A TYPICAL EXAMPLE

Try simulate string (regularised finite endpoint string):



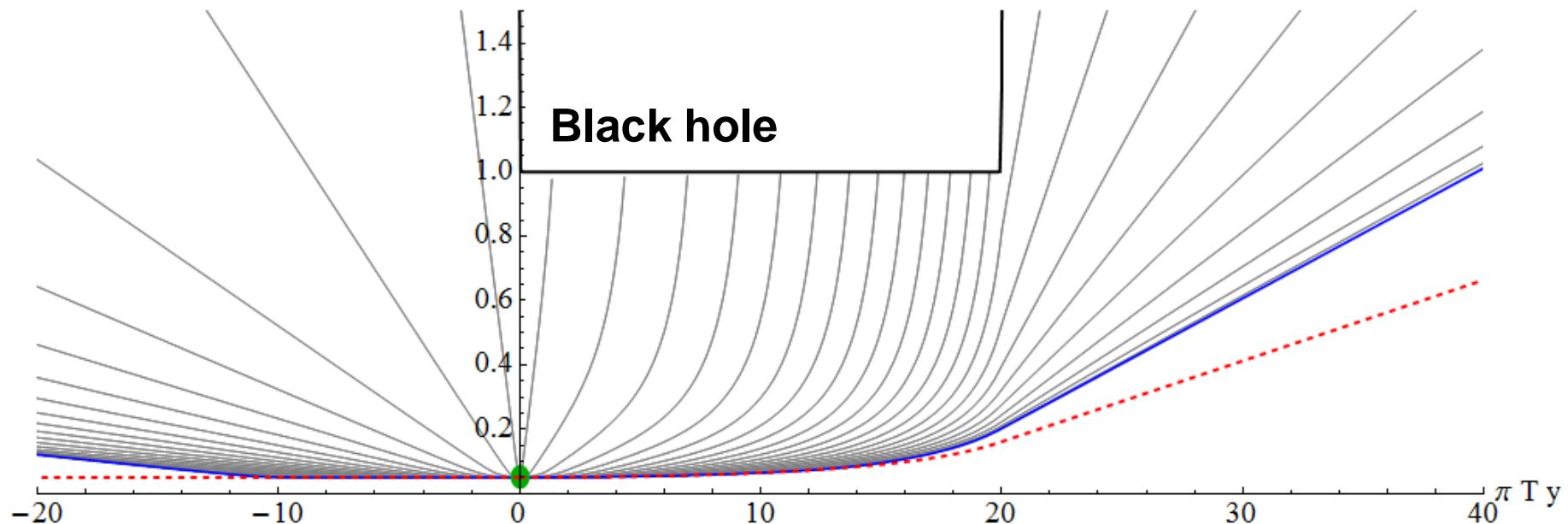
Shoot through slab of plasma (or dynamic spacetime)

- constant 300 MeV plasma, length 4fm, create at edge
- Little bit of freedom: start at 5% from boundary-horizon distance
- `t Hooft coupling 5.5, gives jet energy of 1.6 TeV

STRING EVOLUTION

Constant σ slices string world sheet

z/z_h

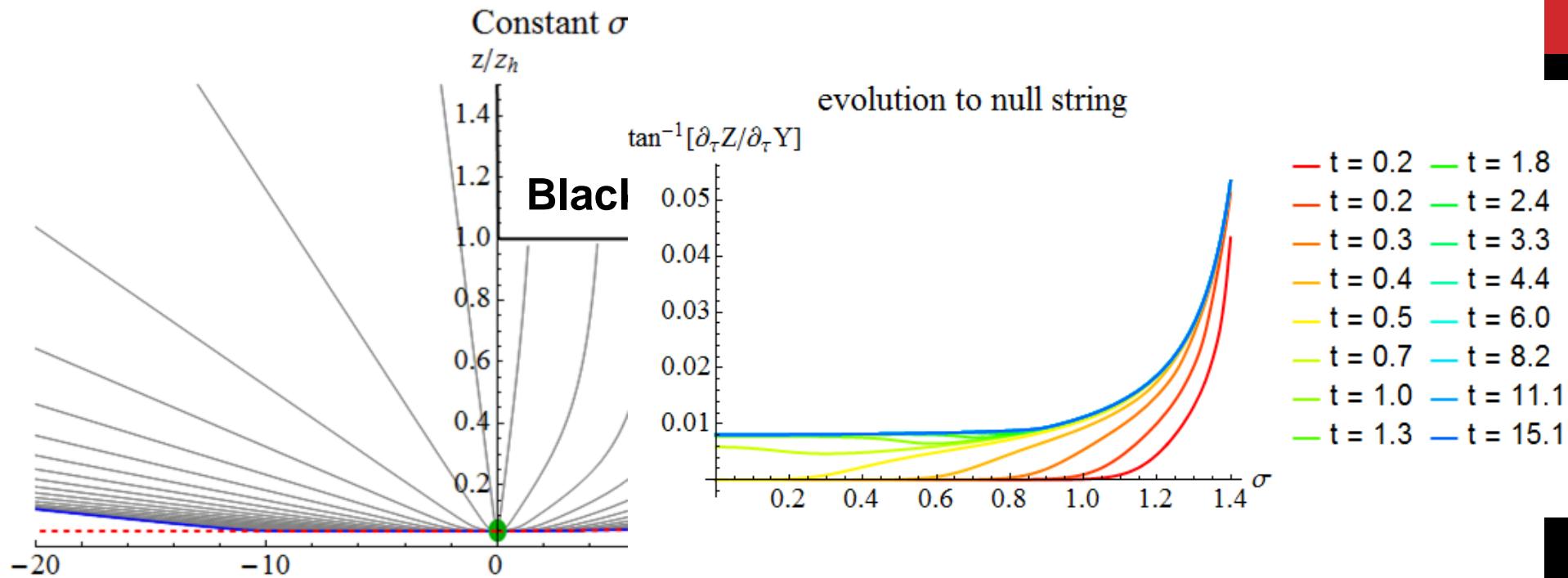


String endpoint (blue) follows null trajectory initially (red dashed)

String endpoints change direction when energy vanishes

- ‘Snapback’: especially relevant when string is moving upwards

TOWARDS A SIMPLER MODEL



After a while the string becomes a null string (1 fm/c should be ok?)

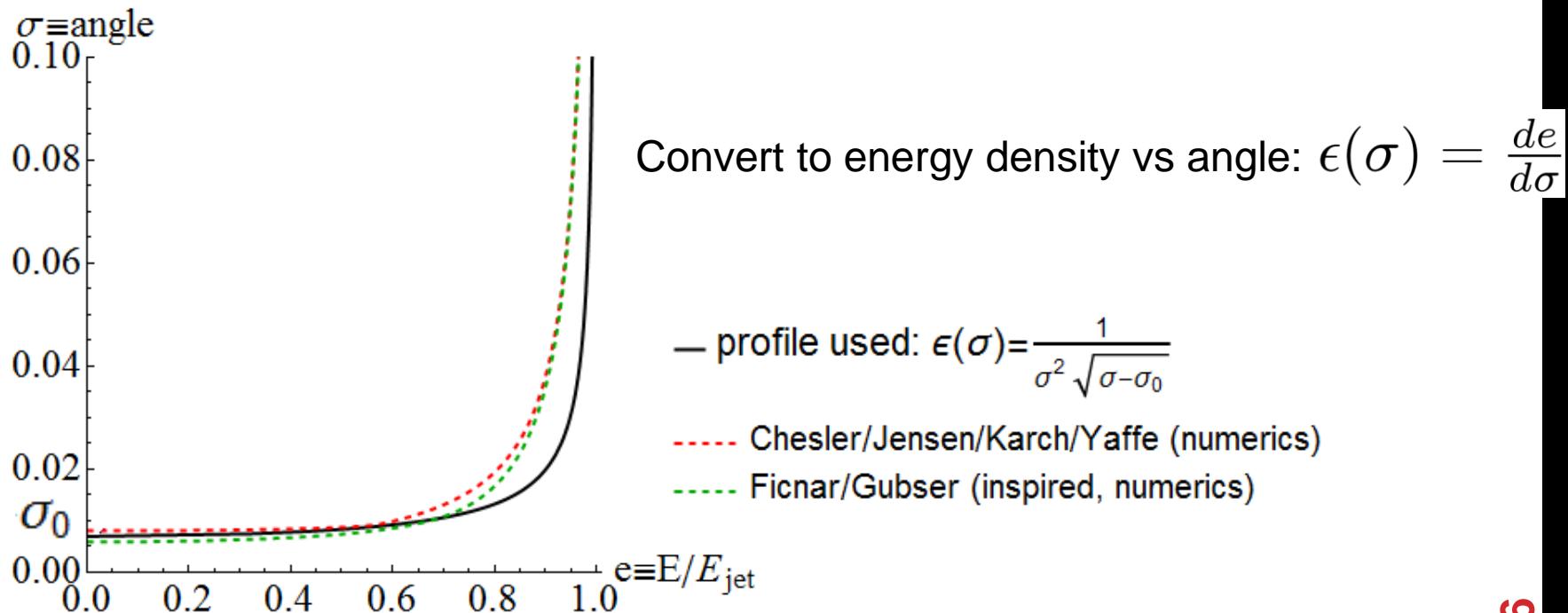
Evolution of string = independent evolution of null string segments

- Need to know where which string bit goes with how much energy

INITIAL/VACUUM ENERGY PROFILE

Need to specify energy along string (change of coordinate)

- Angle endpoint is positive constant, gives jet width
- Open string boundary condition: $\partial_\sigma X^\mu|_{\sigma=0} = 0$
- Try reasonable profile, perhaps inspired by string numerics

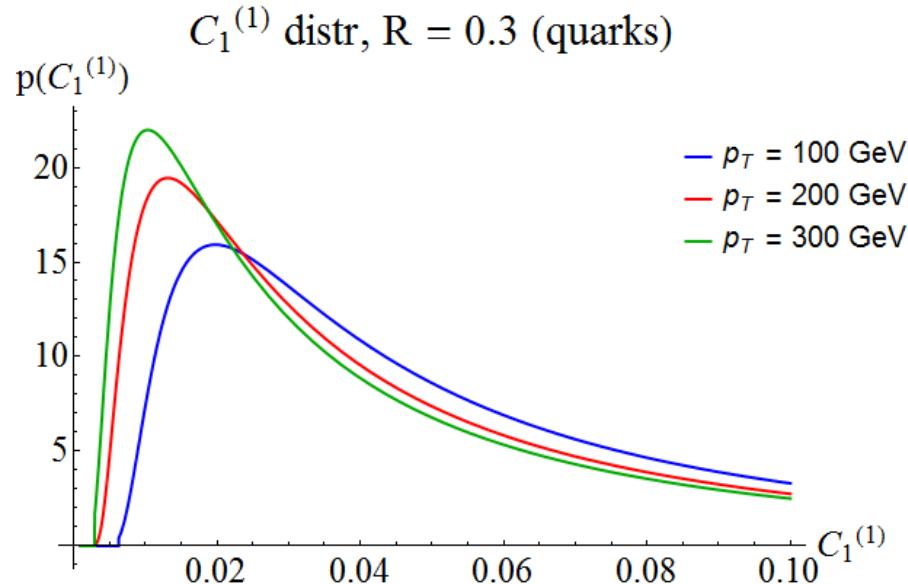


INITIAL CONDITIONS WITH JET WIDTHS

Initial conditions in literature: minimize energy loss

Would like to mimic distribution of real QCD jets

- Extra motivation: how is distribution affected by QGP?
- Take from pQCD (compares well with PYTHIA)



$$C_1^{(\alpha)} \equiv \sum_{i,j} z_i z_j \left(\frac{|\theta_{ij}|}{R} \right)^\alpha$$

z_i : fraction of jet energy

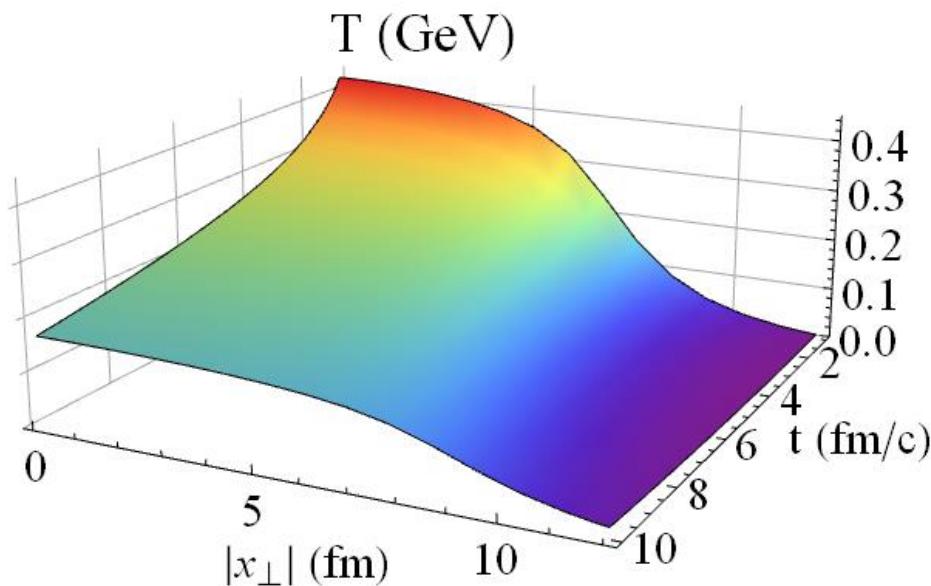
θ_{ij} : angle between particle i and j

R : jet radius parameter

Link opening angle $C_1^{(1)}$ to AdS angle: $C_1^{(1)} = a \sigma_0$ (**a is free**)

MORE SIMPLIFICATIONS

Simple semi-analytic hydrodynamic temperature profile:



$$T(\tau, \vec{x}_\perp) = b \left[\frac{dN_{\text{ch}}}{dy} \frac{1}{N_{\text{part}}} \frac{\rho_{\text{part}}(\vec{x}_\perp/r_{\text{bl}}(\tau))}{\tau r_{\text{bl}}(\tau)^2} \right]^{1/3},$$

$$r_{\text{bl}}(\tau) \equiv \sqrt{1 + (v_T \tau / R)^2}$$

(b measures N_{ch} per S , given EOS)

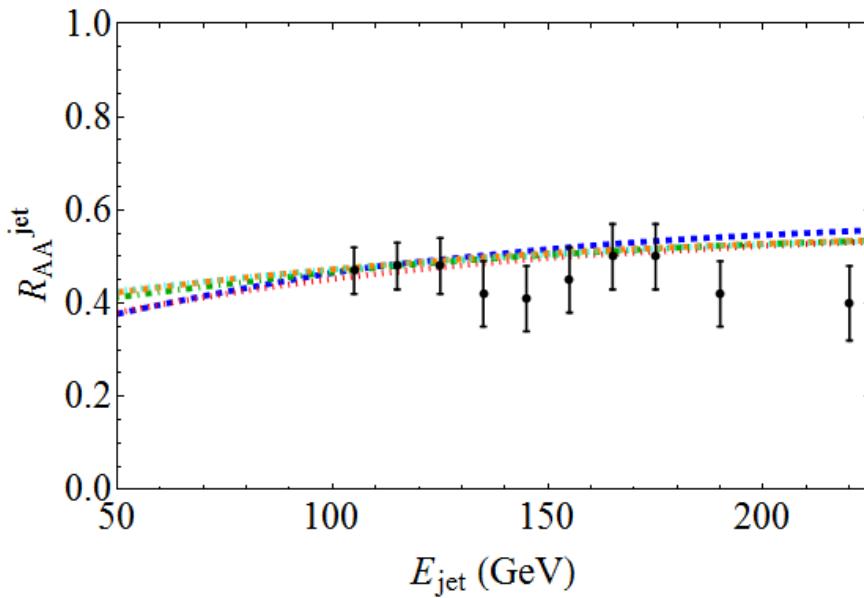
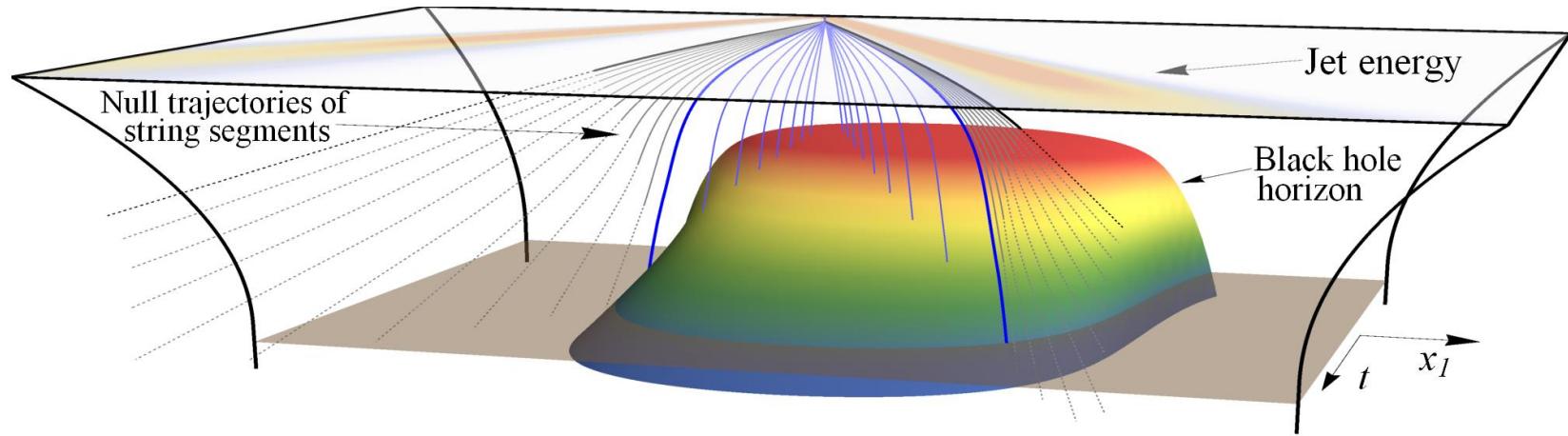
Neglect initial dynamics (1 fm/c) + hadronization + confinement

Start string at single point at boundary

- Distribute according to binary scaling and $(E_{\text{jet}}^{\text{init}})^{-6}$
- **Free parameter b :** to get reasonably energy loss ((coupling) $\mathcal{N} = 4 \neq \text{QCD}$)

RESULTS

Shooting about 50.000 jets through plasma

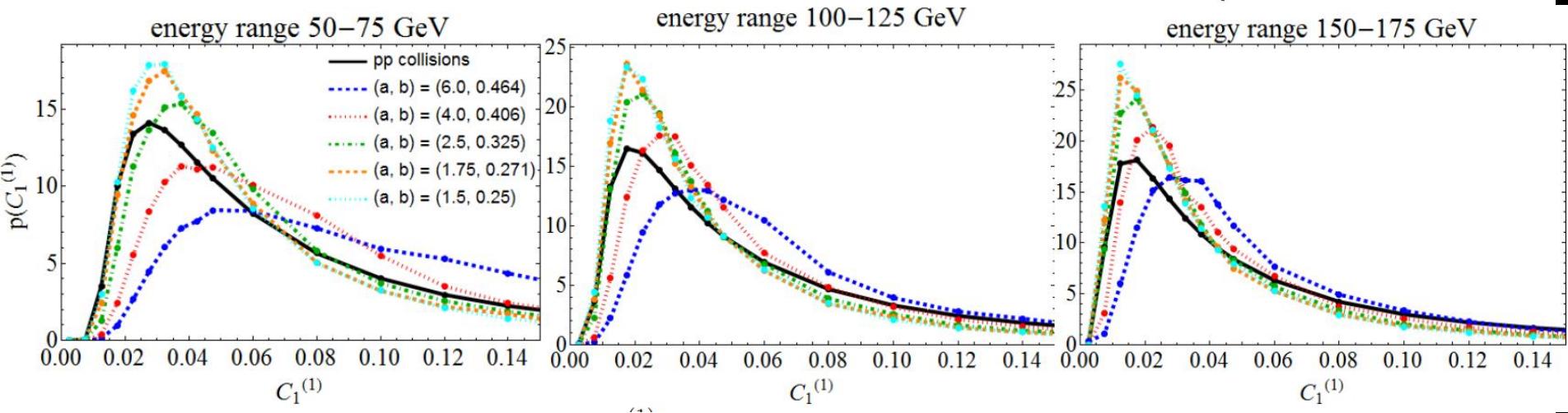
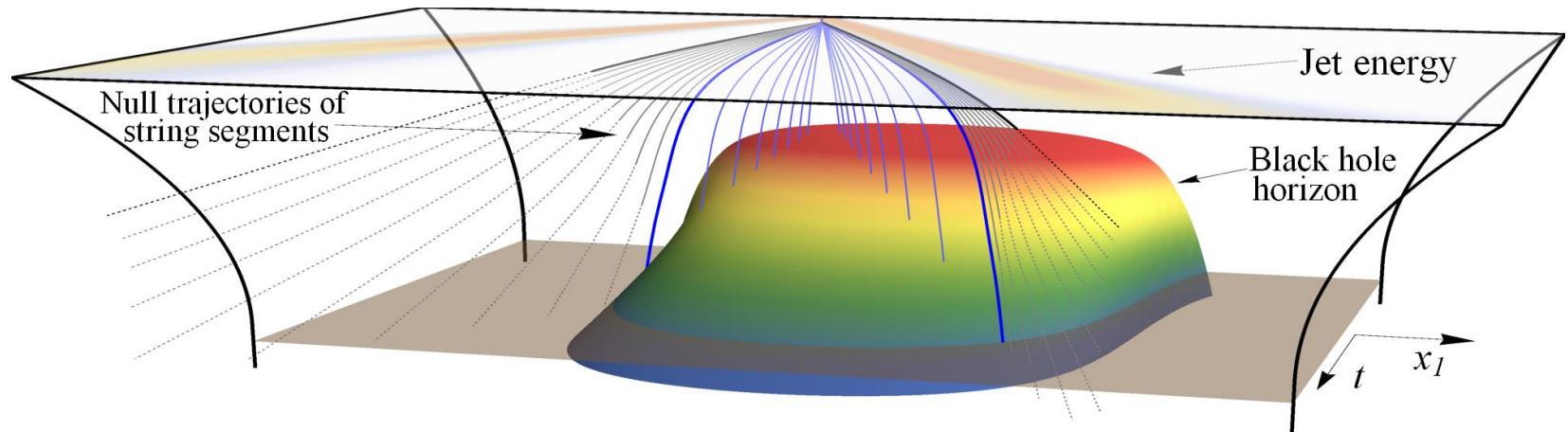


- (a, b) = (7.0, 0.464)
- (a, b) = (4.5, 0.406)
- (a, b) = (2.5, 0.325)
- .- (a, b) = (2.0, 0.271)
- ... (a, b) = (1.5, 0.25)

Naïve QCD: $a \sim 1.7$, $b \sim 0.78$

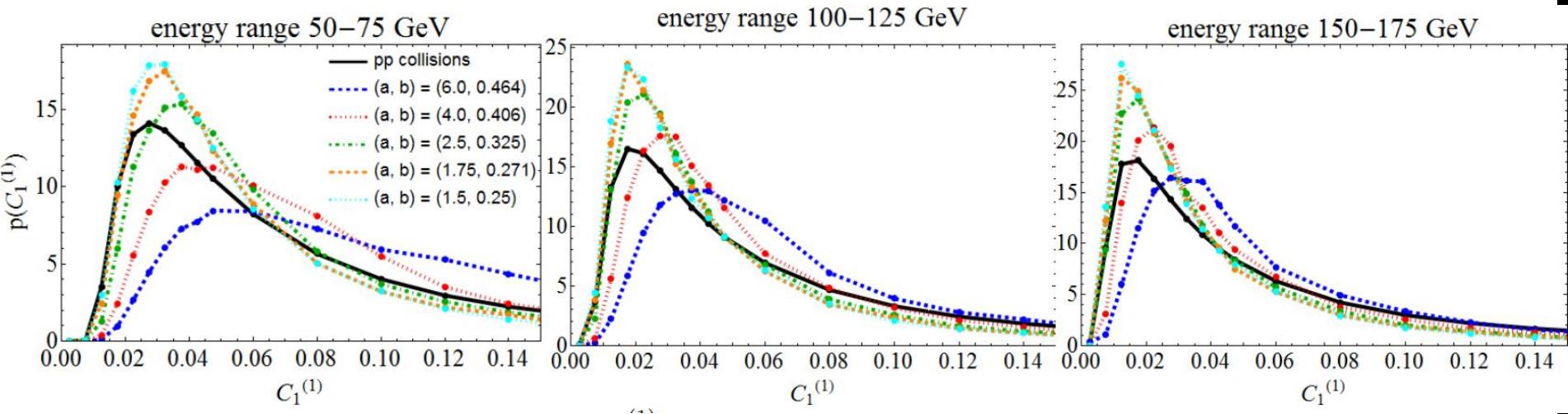
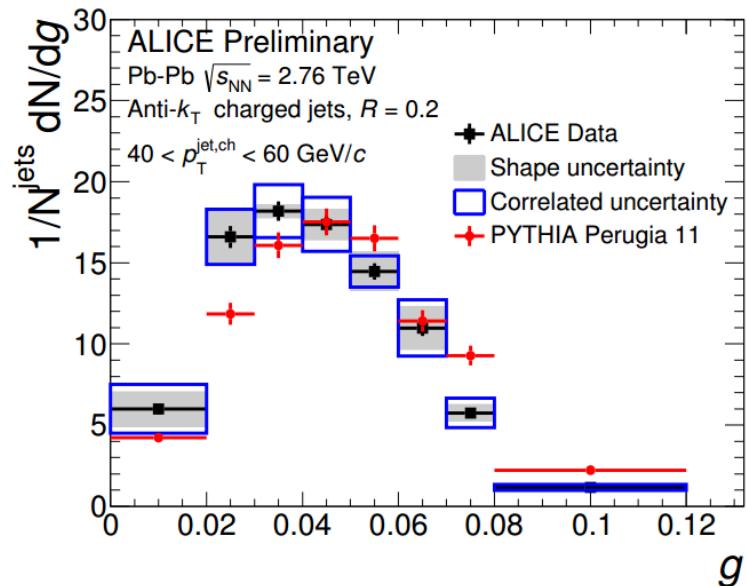
FIRST EFFECT: JETS WIDEN

Change of probability distributions of jet opening angle



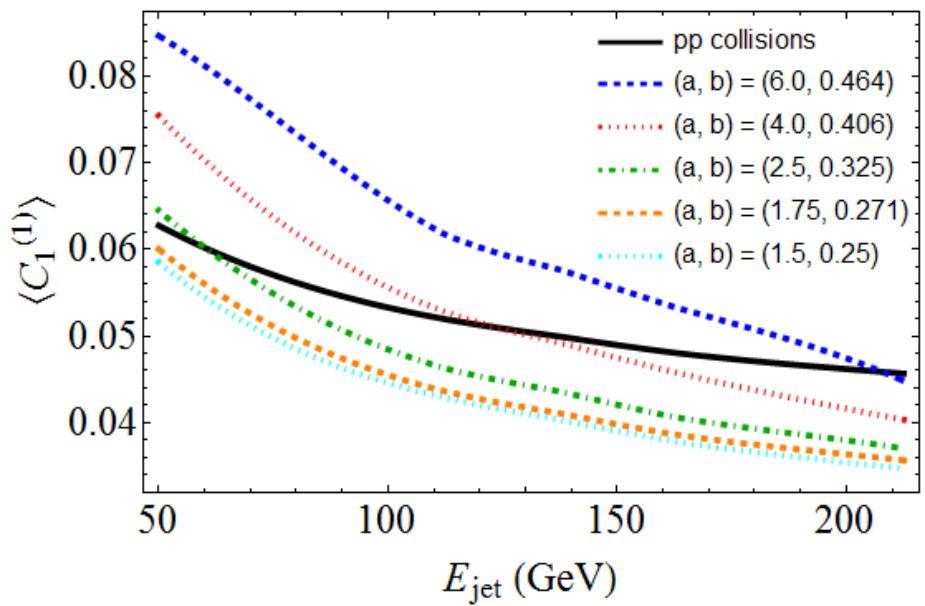
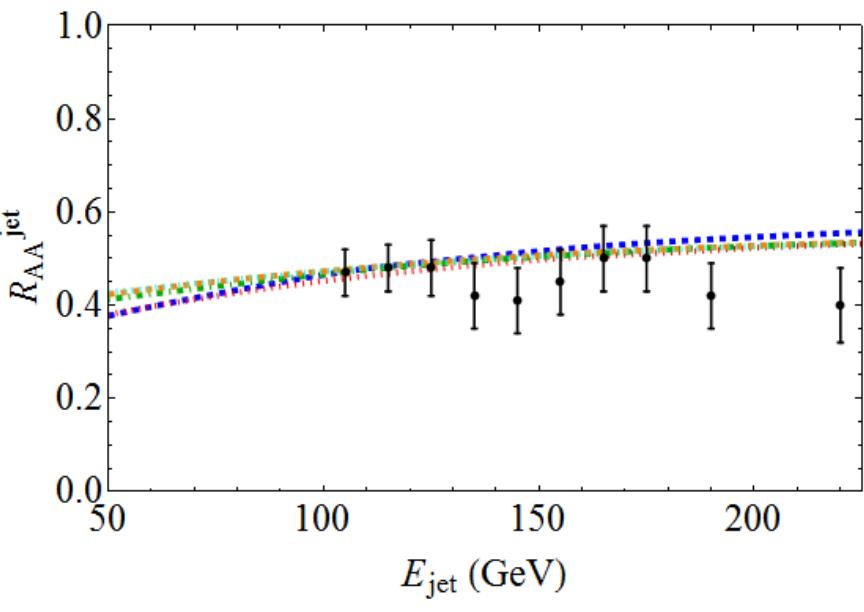
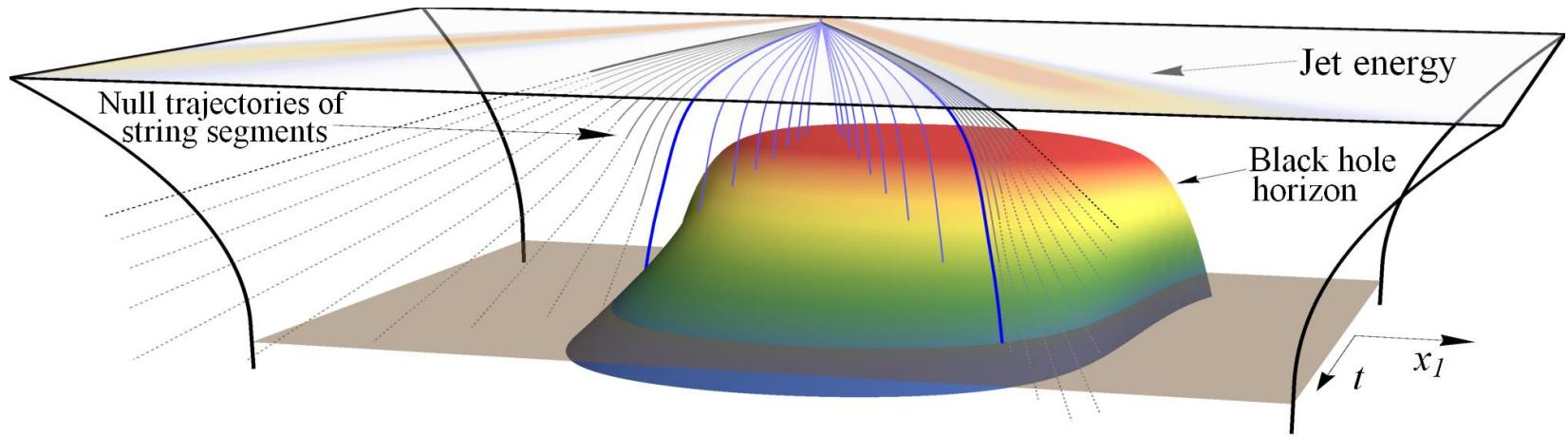
SECOND EFFECT: NARROWER JETS

- Energy distribution falls steeply ($\sim E^{-6}$)
- Wide jets lose (much) more energy
- → selection bias on narrow jets



UNCLEAR WHICH EFFECT DOMINATES

Average jet width can go up or go down (larger for lower energy)



DISCUSSION

Jets in holographic plasma

- Essential to take opening angle distribution in combination with energy
- Initial conditions should match those of proton-proton collisions

A qualitative prediction

- Each jet gets wider in plasma: narrowest jets are lost
- Wide jets lose more energy: widest jets also lost

How to compare N=4 SYM to QCD

- How are jets produced? pQCD? Confinement in IR/hadronization?
- Naïve comparison with $\lambda \approx 5.5$ seems to fail (?)

Outlook

- More quantitative comparisons with experiment,
e.g. dijets, off-central, more substructure, jet shape
- Real (finite endpoint) string dynamics? Match to null string?
- Finite coupling corrections in more realistic settings? Perhaps less fitting?