arXiv:1311.0836v1 [hep-ph] 4 Nov 2013

New Regimes of Stringy (Holographic) Pomeron and High Multiplicity pp and pA Collisions

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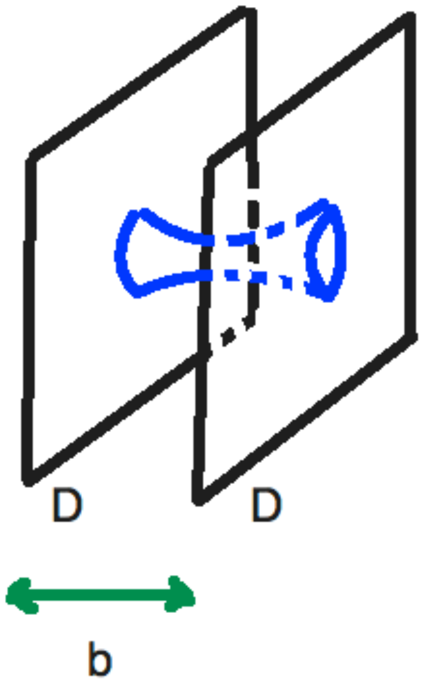


Two historic views on the Pomeron

$$\frac{d\sigma}{dt} \sim s^{\alpha(t)}$$

Prehistoric: Regge, Pomeranchuk, Gribov

$$\alpha(t) = \alpha(0) + \alpha' t + \ldots$$

intercept +string scale

1960's: Veneziano dual resonance amplitude => appearance of strings

1970's QCD Gribov,Lipatov => gluon ladders => BFKL

So, do we have two different Pomerons, soft (strongly coupled) and hard (weakly coupled)?

small digression: few (more exotic) non-perturbative Pomerons

- Kharzeev-Levin 2000: gluon ladder but with **sigma rungs**
- Shuryak-Zahed 2000: **instanton vertices, sphaleron rungs**
- **Polchinski-Strassler 2002:** **AdS/CFT Pomeron, basically graviton exchange** $\alpha(0) = 2 - O(1/\lambda^{1/2})$

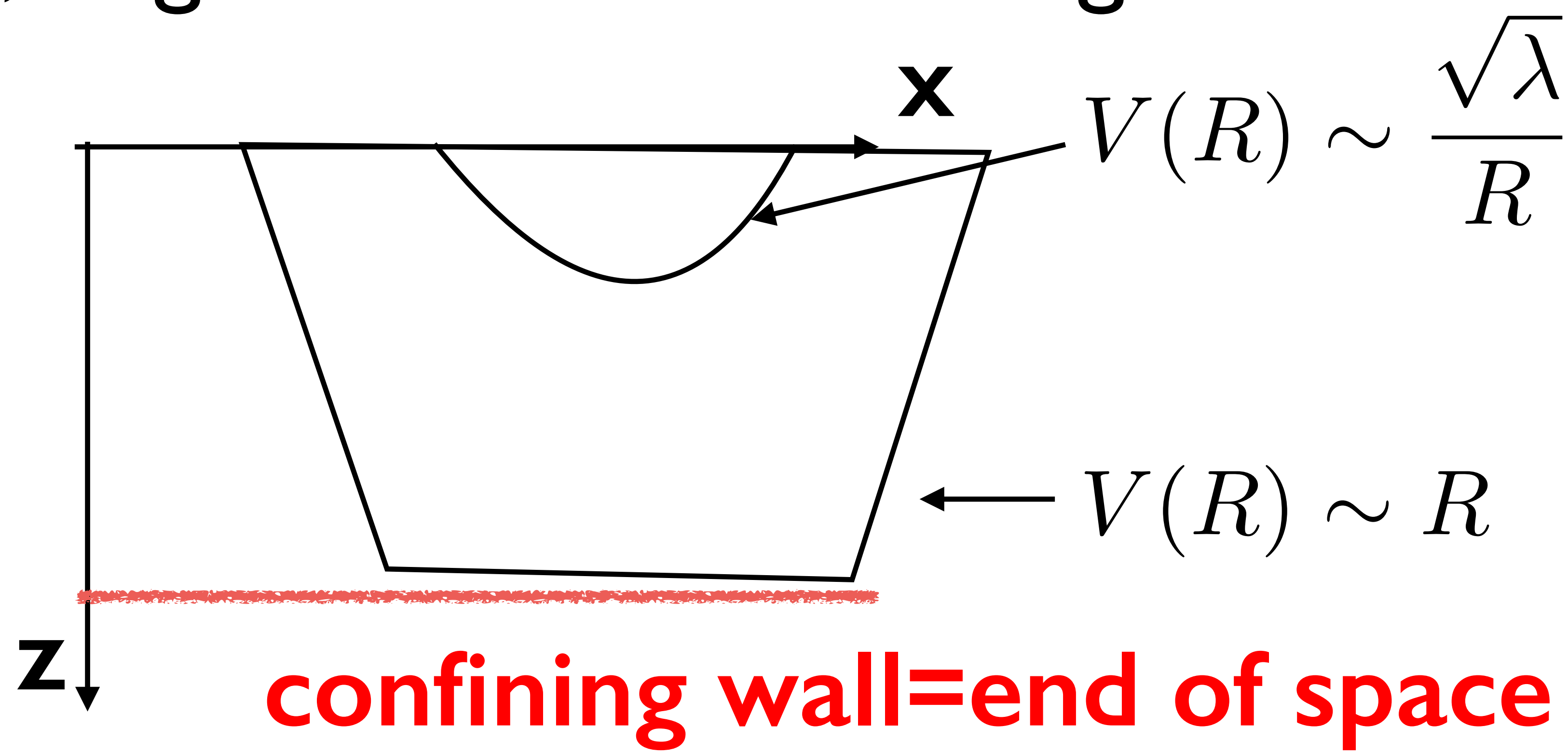
Holographic Pomeron based on AdS/QCD

- the answer to the question is No:
- Only one Pomeron because the gauge description on the boundary is **dual to** string description in the bulk. Weak and strong coupling are its limits
- Concrete model of this type has been worked out by Zahed et al (Stoffers,Basar, Kharzeev): I will call it **Z+**
- **Our main statement: as a function of b there are three distinct regimes: subcritical, near-critical and supercritical!**

AdS/QCD

- Holographic down-to-top model
- 5-th curved coordinate z=1/r
- z=>0, large r is UV=> conformal
- r=>0, large z is IR => confining wall

Maldacena pending strings



reproduces many things including correct Regge trajectories

Holographic Pomeron and the Schwinger Mechanism

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(Dated: April 18, 2012)

Contains the basic calculation of the string amplitude

Euclid-Minkowski relation

$$\theta \to -i\chi$$

Wilson Line correlator

$$\frac{1}{-2is}\mathcal{T}(\theta,q) \approx \int d^2b\; e^{iq_\perp\cdot b} \times\Big\langle\, (\mathbf{W}(-\theta/2,-b/2)-\mathbf{1})\,(\mathbf{W}(\theta/2,b/2,)-\mathbf{1})\,\Big\rangle = \int d^2b\; e^{iq_\perp\cdot b}\,\Big\langle \mathbf{W}(-\theta/2,-b/2)\mathbf{W}(\theta/2,b/2)-\mathbf{1}\Big\rangle$$

holographic setting in 5d

$$ds^2 = \frac{dz^2}{z^2 f(z)} + \frac{dx\cdot dx}{z^2}$$

string "tube" quantization by Polyakov action

$$\mathbf{WW} = g_s^2\int_0^\infty \frac{dT}{2T}\,\mathbf{K}(T)\,,$$

where

$$\mathbf{K}(T) = \int_{\mathrm{T}} d[x]\, e^{-\mathbf{S}[x]+\mathrm{ghosts}}\,,$$

$$\mathbf{S} = \frac{\sigma_T}{2}\int_0^T d\tau \int_0^1 d\sigma\,\left(\dot{x}^\mu\dot{x}_\mu + x'^\mu x'_\mu\right)\,,$$

the “tube”

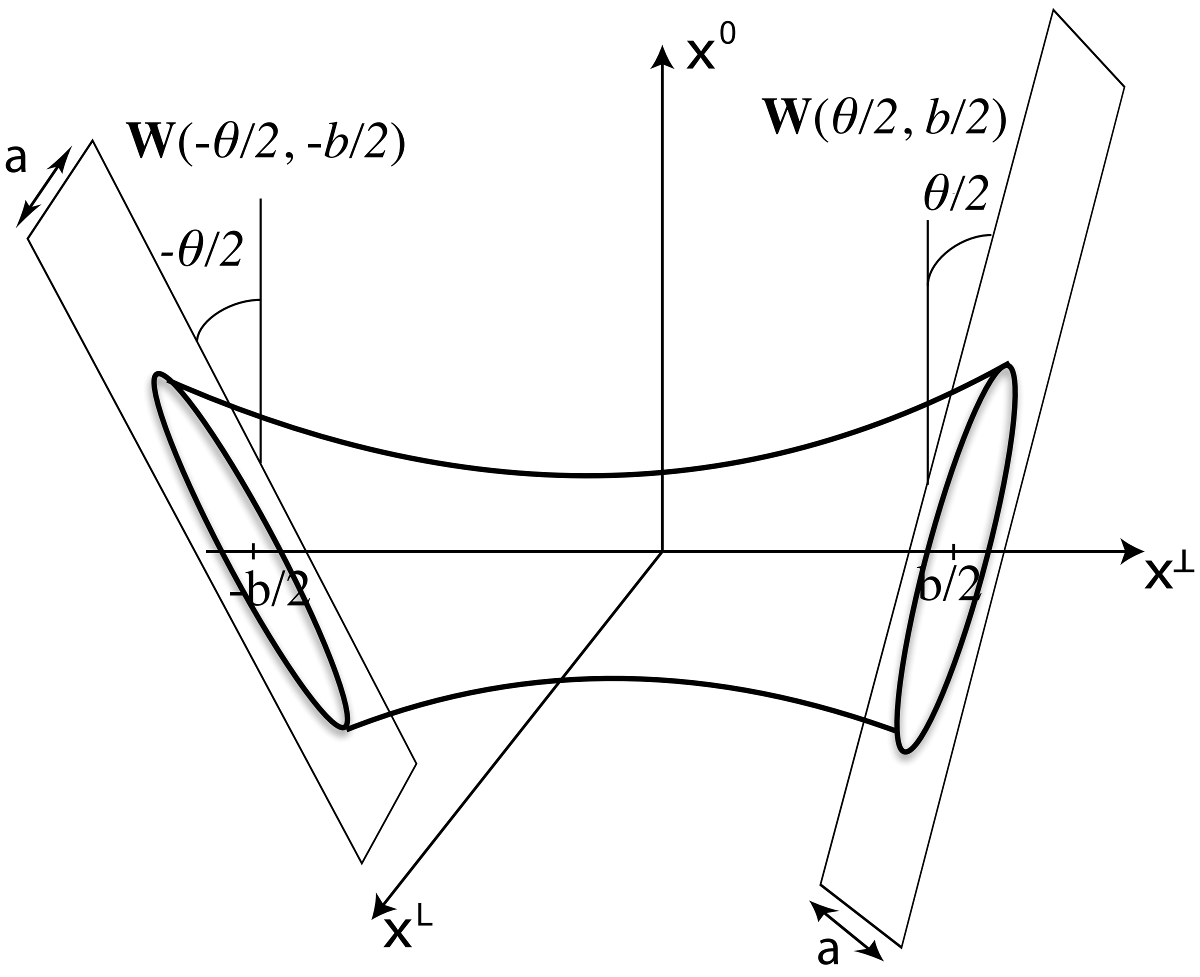


FIG. 1: Dipole-dipole scattering configuration in Euclidean space. The dipoles have size a and are b apart. The dipoles are tilted by $\pm\theta/2$ (Euclidean rapidity) in the longitudinal $x_0 x_L$ plane.

- **If cut horizontally, it describes production of a pair of open strings**
- **If cut vertically, it describes an exchange by a closed string**
- **string fluctuations are include mode-by-mode**

$$\frac{1}{-2is}\mathcal{T}(s,t) \approx \frac{\pi^2 g_s^2 a^2}{2}\sum_{k=1}^{k_{\max}}\sum_{n=0}^{\infty}\frac{(-1)^k}{k}\left(\frac{k\pi}{\ln s}\right)^{D_\perp/2-1} \times d(n)\, s^{-2n/k+D_\perp/12k+\alpha' t/2k}, \qquad (70)$$

k=1 in SU(3), n is excitation

The previous literature focuses on what we call the "cold" regime of the string

$$\mathbf{b} \gg \beta \gg \tilde{\beta}_H \qquad (17)$$

where the former inequality follows from large collision energy (14) and the latter implies that the string is nearly straight, with small effective excitations (small effective T). The meaning of

We will now review the Pomeron results in this setting. The amplitude of the elastic dipole-dipole scattering reads [2–4]

$$\frac{1}{-2is}\mathcal{T}(s,t;k) \approx g_s^2 \int d^2\mathbf{b}\, e^{iq\cdot\mathbf{b}}\, \mathbf{K}_T(\beta,\mathbf{b};k) \qquad (15)$$

$$\mathbf{K}_T(\beta,\mathbf{b};1) = \left(\frac{\beta}{4\pi^2\mathbf{b}}\right)^{D_\perp/2}$$

$$\times e^{-\sigma\beta\mathbf{b}\left(1-(\tilde{\beta}_H/\beta)^2/2\right)}$$

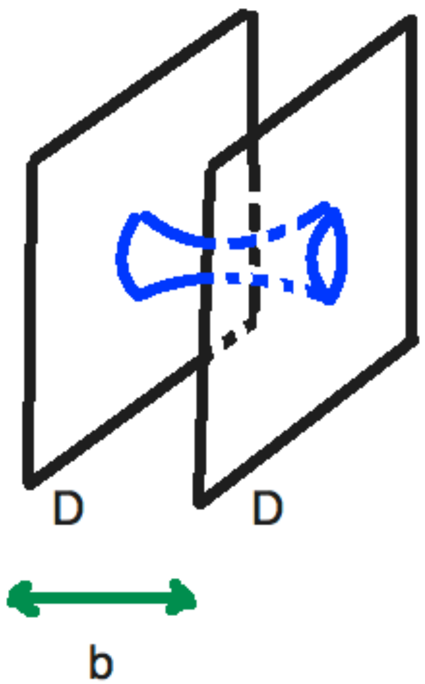
$$\times \sum_{n=0..\infty} d(n) exp(-2\chi n)$$

classical action b^2
vibrations b-independent

Linear Regge trajectories, daughters shifted by 2 down

$$\beta = \frac{1}{T} = \frac{2\pi\mathbf{b}}{\chi}$$

$$\chi = log(s)$$



As we mentioned, the expression (18) has been derived in [4] from the semiclassical approach to a Polyakov string, but (to leading order in $1/\lambda$) it can alternatively be derived from a diffusion equation

$$\left(\partial_\chi + \mathbf{D}_k\left(\mathbf{M}_0^2 - \nabla_{\mathbf{b}}^2\right)\right)\mathbf{K}_T = 0 \qquad (20)$$

where the rapidity χ interval is the time and the diffusion happens in the (curved) transverse space with the diffusion constant $\mathbf{D}_k = \alpha'/2k = l_s^2/k$. This diffusion (20) is nothing else but the Gribov diffusion of the Pomeron, leading on average to an impact parameter $\langle \mathbf{b}^2 \rangle = \mathbf{D}_k\chi$ for close Pomeron strings. If the "mother dipoles"

connection to Gribov diffusion

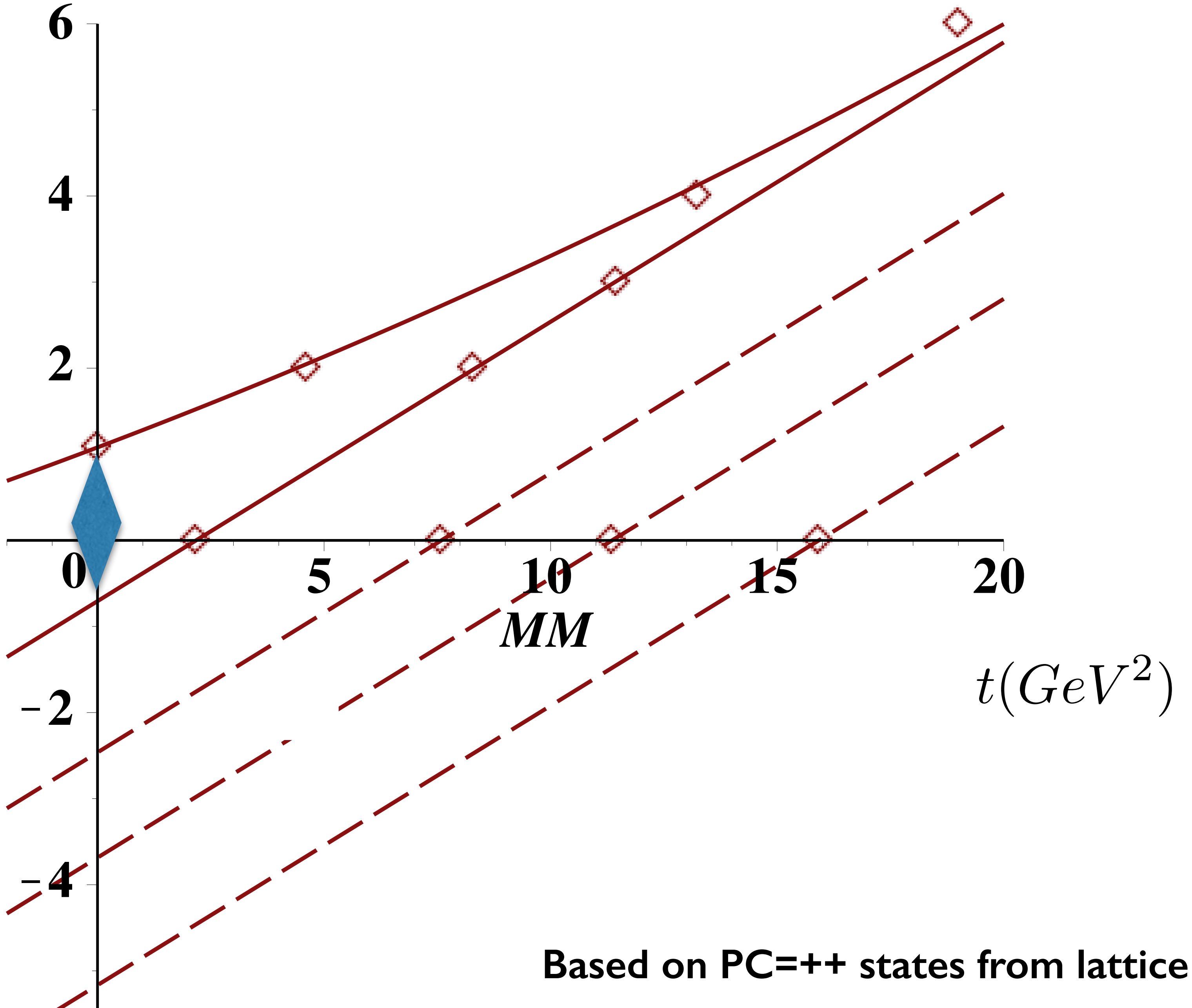
an update

closed string => glueball reggeons

Pomeron =>

$\Delta\alpha_1 = \alpha_P(0) - \alpha_{D1}(0) \approx 2.0$

1st daughter

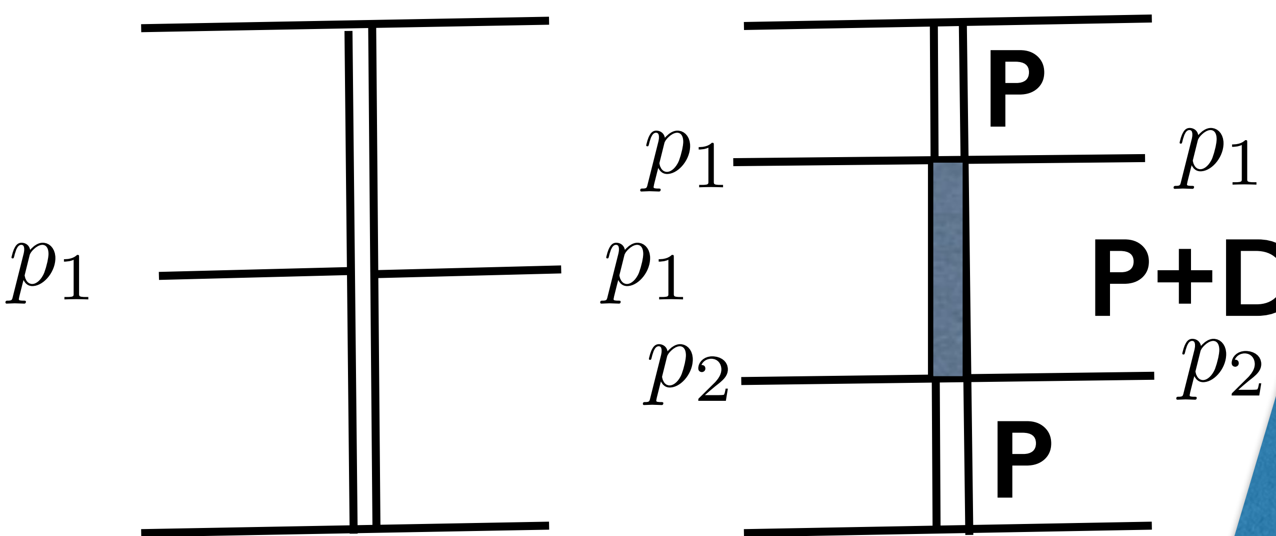


Daughter trajectories must be multiply degenerate because string number of states grows exponentially

Based on PC=++ states from lattice study

Harvey Meyer, hep-lat 0508002

one and 2 particle spectra: Kancheli-Mueller diagrams



A.H. Mueller, Phys. Rev. D 23, 2963 (1970).
O.V. Kancheli, JETP Lett. 11, 267 (1970).

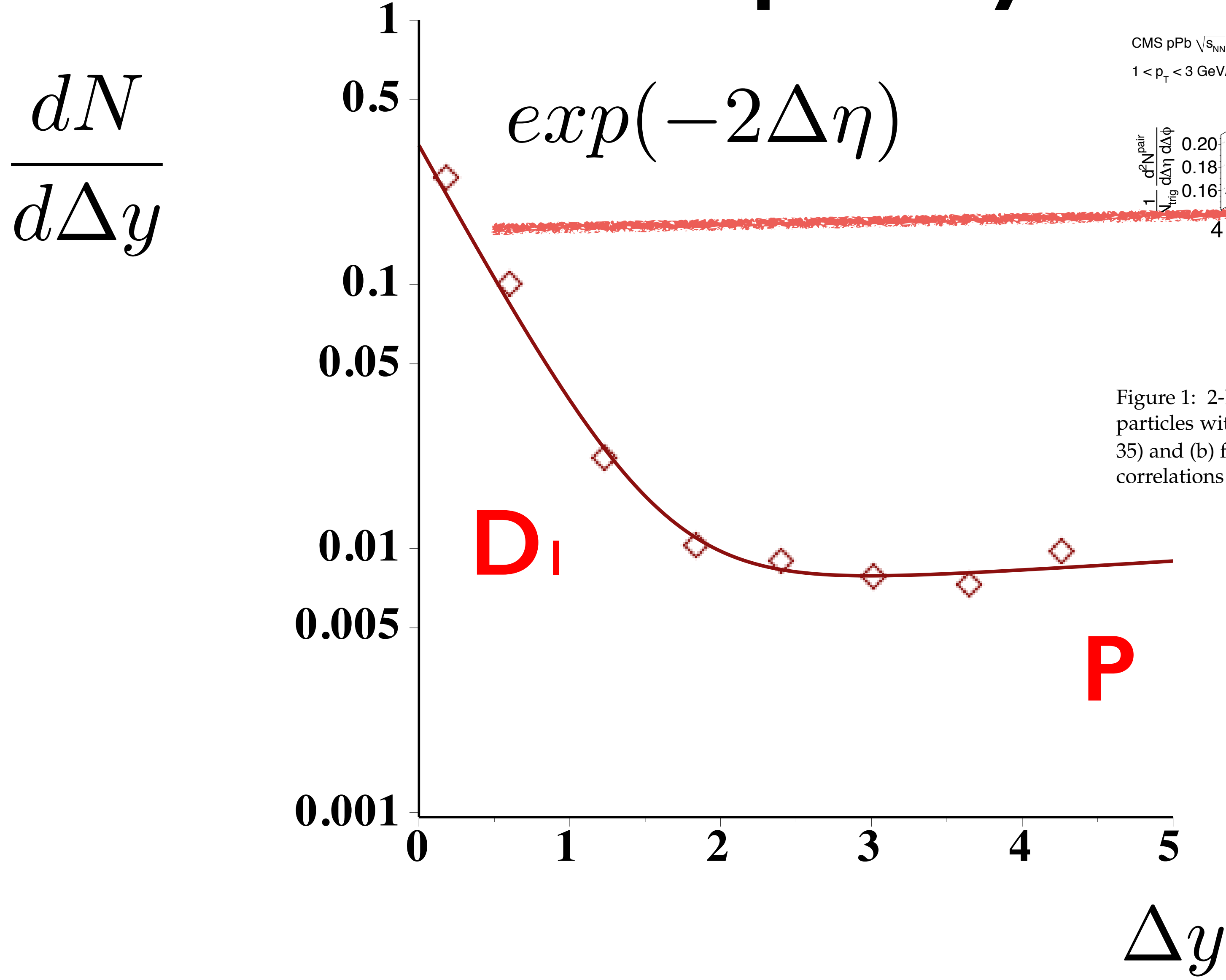
P+D1+...

$$\frac{dN}{d\Delta y} = C_P e^{-\Delta y(1-\alpha_P(0))} + C_{P'} e^{\Delta y(-\Delta\alpha_1)} + \dots$$

≈ 0.1 $\qquad$ ≈ 2

we thank Dima Kharzeev who reminded us of it

CMS correlation function does contain small rapidity correlation



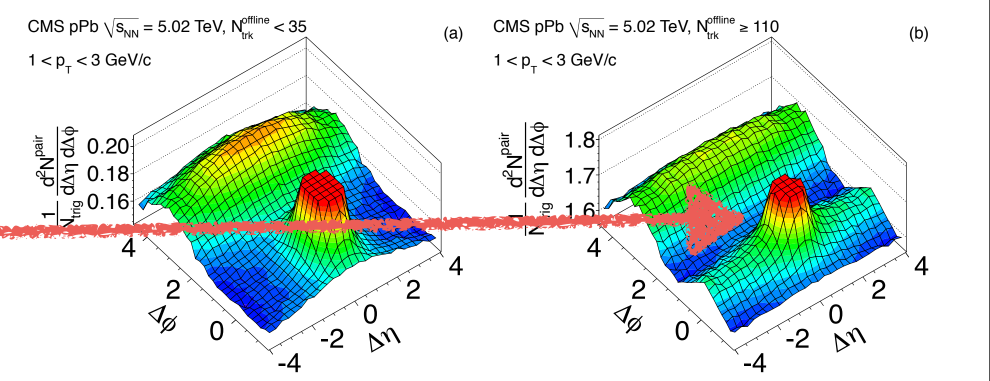


Figure 1: 2-D two-particle correlation functions for 5.02 TeV pPb collisions for pairs of char particles with $1 < p_T < 3\,\text{GeV}/c$. Results are shown (a) for low-multiplicity events (N_{trk}^{offlin} 35) and (b) for a high-multiplicity selection ($N_{trk}^{offline} \geq 110$). The sharp near-side peaks fron correlations have been truncated to better illustrate the structure outside that region.

Note: a cluster is there, with or without ridge

It was interpreted as jet, but we interpret is as a "string ball" cluster. Note it is seen for medium p_t=1-3 GeV.

fluctuations of flat membrane and a tube are different

- The (T=0) potential <W> is linear at large b and Coulombic (pQCD) at small b : yet **transition is smooth**
- **The tube has a periodic variable => quantization formally the same as the (Matsubara) thermal formalism => thus we expect thermal-like behavior with a nontrivial transition to pQCD regime**

New Regimes of Stringy (Holographic) Pomeron

1. A "cold" regime, with low string excitations;
2. A "near-critical" or "HPS regime", in which strings indefinitely increase their energy and entropy, but not their free energy / pressure;
3. An "explosive regime", in which the string occupies large portion of space and generates sufficient pressure for hydrodynamical explosion.

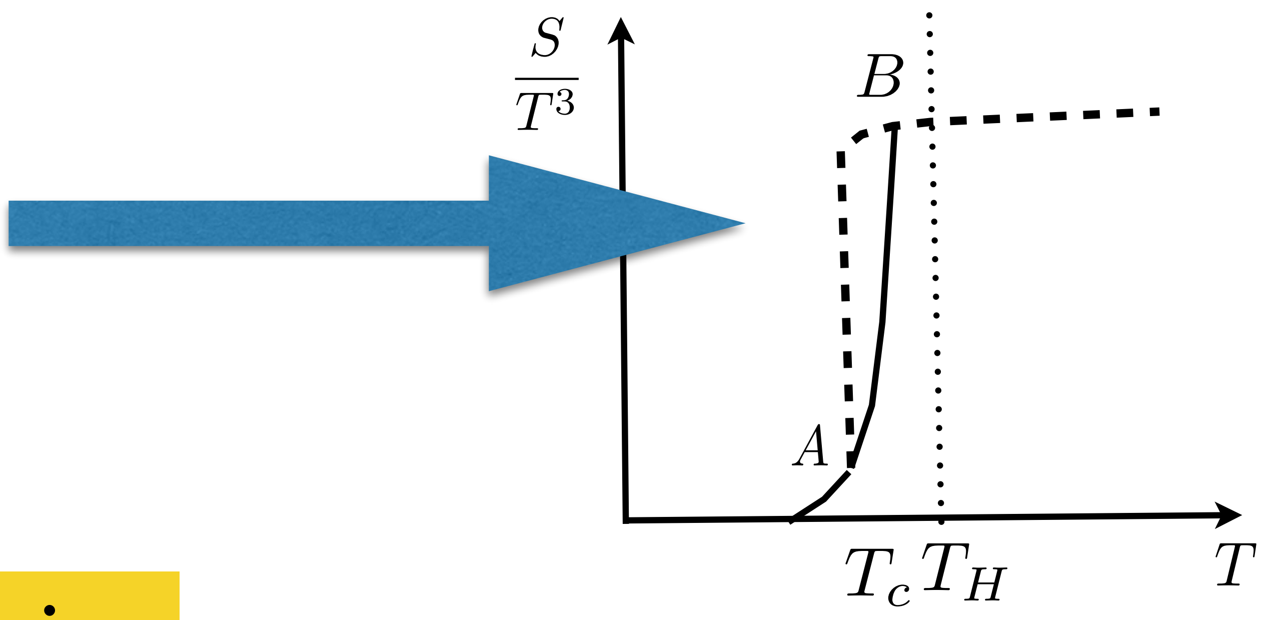


FIG. 3: (Color on-line) Schematic temperature dependence of the entropy density. The dashed line represents equilibrium gluodynamics with a first order transition at $T = T_c$. The solid line between points A and B represents the expected behavior of a single string approaching its Hagedorn temperature T_H.

Hagedorn-Polyakov-Susskind regime

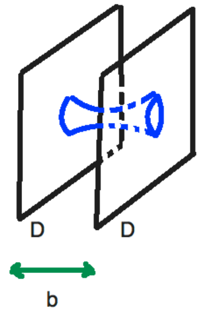
stringy excitations grows with an excitation energy *exponentially*. To see this, imagine a d-dimensional lattice with spacing a and draw all possible strings of length L/a making all possible turns (except going backward) at each site, that is

$$N(E) \approx (2d-1)^{L/a} = e^{E(L)/T_H} \tag{5}$$

where in the last term we changed length into energy using the string tension $E(L) = \sigma_T L$ and defined

$$T_H = \frac{\sigma_T a}{\ln(2d-1)} \tag{6}$$

As T=>T$_H$ the entropy and energy grow, but not free energy (pressure) as F=E-TS and two terms cance



QUANTUM FLUCTUATIONS OF QCD STRINGS

The temperature and the entropy

Although the scattering amplitudes involve string dynamics at zero temperature, the ensuing formula resemble those of a thermodynamical string. The reason stems from the string membrane exchanged as shown in Fig. 1 which is quantized on a circle making it formally identical to the thermal Matsubara formalism. Furthermore, the effective string temperature depends on the world-sheet coordinate $0 \leq \sigma_W \leq 1$ [4]

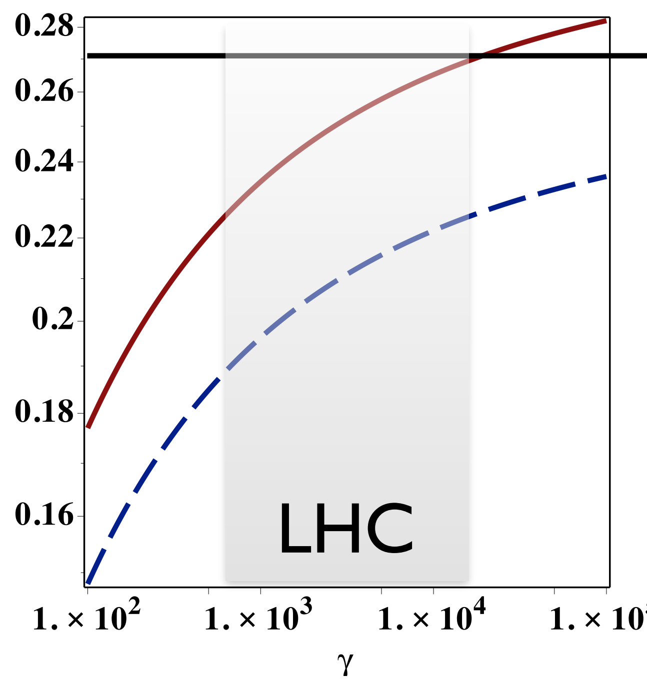
$$T(\sigma_W) = \frac{\chi}{2\pi \mathbf{b}} \frac{1}{\cosh(\chi(\sigma_W - 1/2))} \qquad (33)$$

with its highest value at the center or $T(1/2) \equiv T = \chi/2\pi\mathbf{b}$. It is instructive to focus on the actual effective temperature values, corresponding to LHC collisions. For that we define a typical impact parameter $\mathbf{b}_{\text{eff}}$ for pp collisions at energy s as

$$\mathbf{b}_{\text{eff}}(s) = \sqrt{\frac{\sigma_P(s)}{\pi F_{\text{gray}}}} \qquad (34)$$

where $\sigma_P(s)$ is the ***average*** t of the total pp and $\bar{\text{p}}$p cross section [50], and $F_{\text{gray}} < 1$ is

We think the value to compare is



$T_c \approx 0.27\,\text{GeV}$

of SU(3) gluodynamics

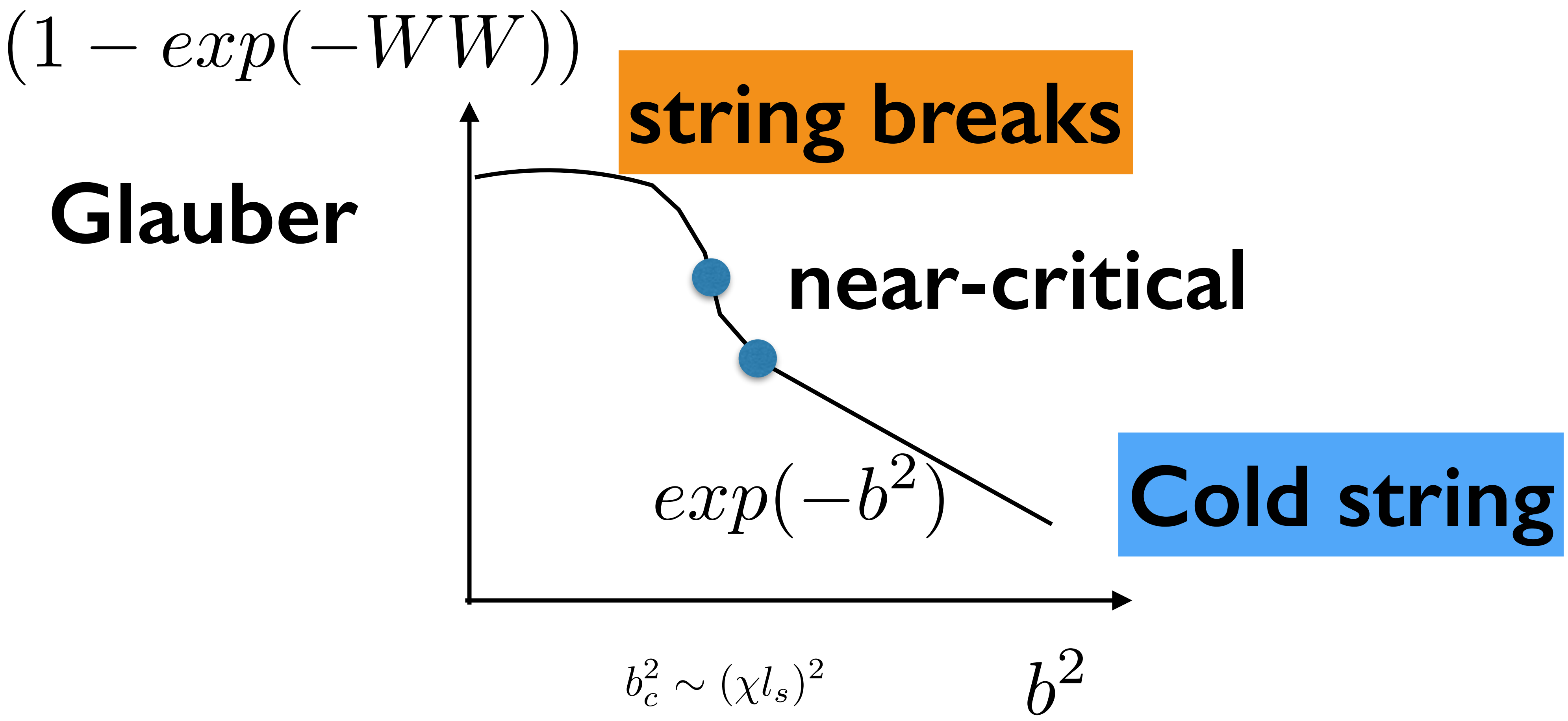
FIG. 4: (Color on-line) The effective string temperature T_{eff} (GeV) versus the c.m. beam gamma factor γ, solid for black disc estimate $F_{\text{gray}} = 1$ and dashed for gray factor $F_{\text{gray}} = 0.7$. As argued in the text, its value is to be compared to the effective Hagedorn temperature $\tilde{T}_H$.

$$D_\perp \to \tilde{D}_\perp = D_\perp \left(1 - \frac{3(D_\perp - 1)^2}{2kD_\perp\sqrt{\lambda}}\right)$$

This translates to a higher effective Hagedorn temperature $\tilde{T}_H > T_H$ through (10) with

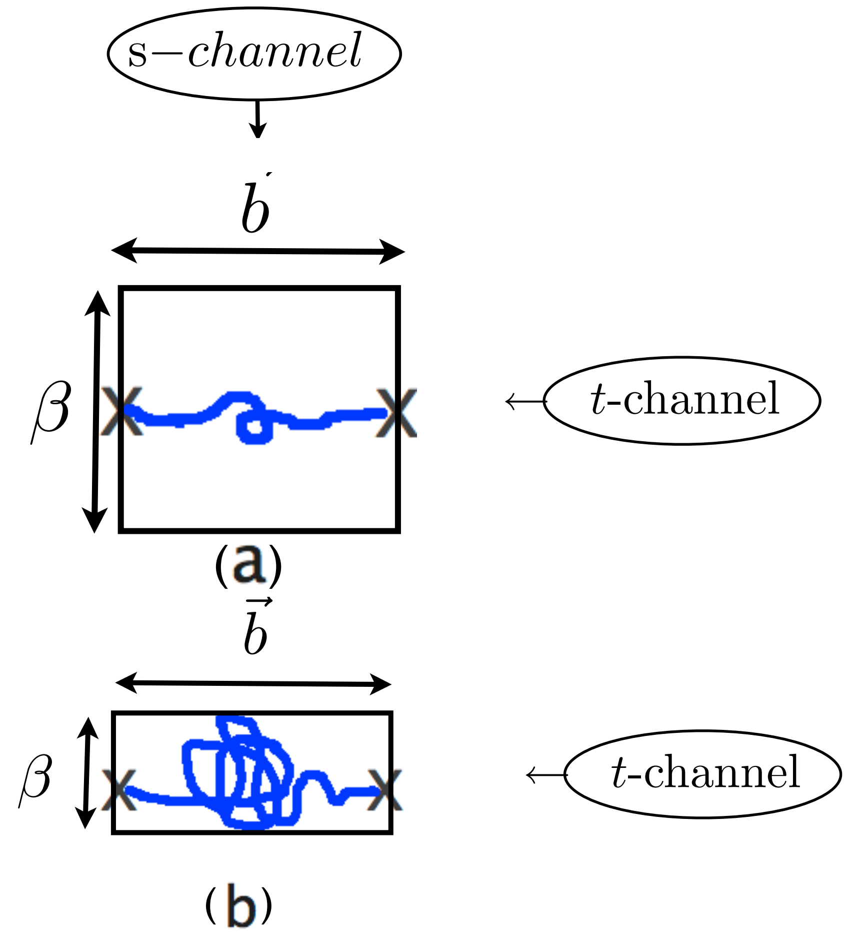
$$T_H^2 \to \tilde{T}_H^2 = \frac{3}{\tilde{D}_\perp}\frac{\sigma_T}{2\pi} \approx 1.8\, T_H^2 \qquad (36)$$

Can new regimes be seen in the elastic amplitude?



After integration over b and dipole sizes, can one still be able to see it in T(t) ?

Here is our 1st observation:
the middle of a string develops a **"string ball"**



cold

near-critical

perhaps observable as high multiplicity cluster near mid-rapidity

the near-critical Pomeron

One can re-sum "Luscher terms" in the potential

$$V(R) = \sqrt{\sigma_T^2 R^2 - const}$$

The re-summed result follows the paper of Arvis [38], which obtained the potential induced by the Nambu-Goto string. The result obtains the square root (which will play an important role in what follows)

$$\mathbf{K}_T(\beta, \mathbf{b}; 1) \approx \left(\frac{\beta}{4\pi^2 \mathbf{b}}\right)^{D_\perp/2} e^{-\sigma\beta\mathbf{b}\left(1-\tilde{\beta}_H^2/\beta^2\right)^{1/2}}$$

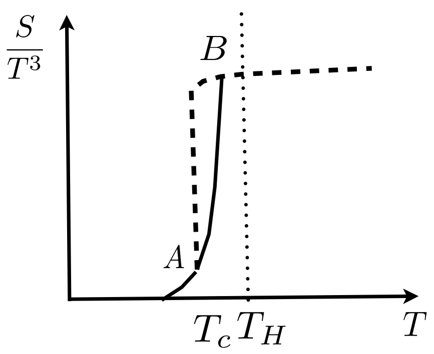
but the results get clearly inapplicable as root argument changes sign

Compare to "cold" one, in which it is a small correction

$$\mathbf{K}_T(\beta, \mathbf{b}; 1) \approx \left(\frac{\beta}{4\pi^2 \mathbf{b}}\right)^{D_\perp/2} e^{-\sigma\beta\mathbf{b}\left(1-\tilde{\beta}_H^2/2\beta^2\right)}$$

Can one figure out what to do when T>TH and argument of the sqrt <0?

from stringy to perturbative world



String theorists worked out the regime at T= or >T_H.

Two constant modes of string excitation become a complex scalar field which develops VEV — a disorder parameter

$$m^2 \sim \beta^2 - \beta_H^2 < 0$$

strings break

$$< \chi^+\chi(0)\chi^+\chi(b) >= |\chi|^4 + e^{-b\sqrt{|\beta_H^2 - \beta^2|}}$$

Selfgravitating fundamental strings
Gary T. Horowitz , Joseph Polchinski
Phys.Rev. D57 (1998) 2557-2563
hep-th/9707170

In string language it means that a black hole is formed which can hide one end of a fundamental string

Diffractive and deeply virtual Compton scattering in holographic QCD

Alexander Stoffers and Ismail Zahed

$$\frac{d\sigma_{ap\to cp}}{dt}(\chi,|t|) = \frac{1}{16\pi s^2}|\mathcal{T}(\chi,|t|)|^2 \quad (2)$$

$$= \frac{1}{4\pi}\left|i\int d\mathbf{b}_\perp \int du \int du'\ e^{iq_\perp\cdot\mathbf{b}_\perp}\ |\psi_{ab}(u)|^2|\psi_p(u')|^2\ (1-e^{\mathbf{WW}})\right|^2 \quad (3)$$

$$= \frac{\pi}{4}\left|i\int\ d|\mathbf{b}_\perp|^2 \int du \int du'\ J_0(\sqrt{|\mathbf{b}_\perp|^2|t|})\ |\psi_{ab}(u)|^2|\psi_p(u')|^2\ (1-e^{\mathbf{WW}})\right|^2 \quad (4)$$

$$\mathbf{WW} \approx -\frac{g_s^2}{4}\,(2\pi\alpha')^{3/2}\,zz'\ \mathbf{N}(\chi,z,z',\mathbf{b}_\perp)\ .$$

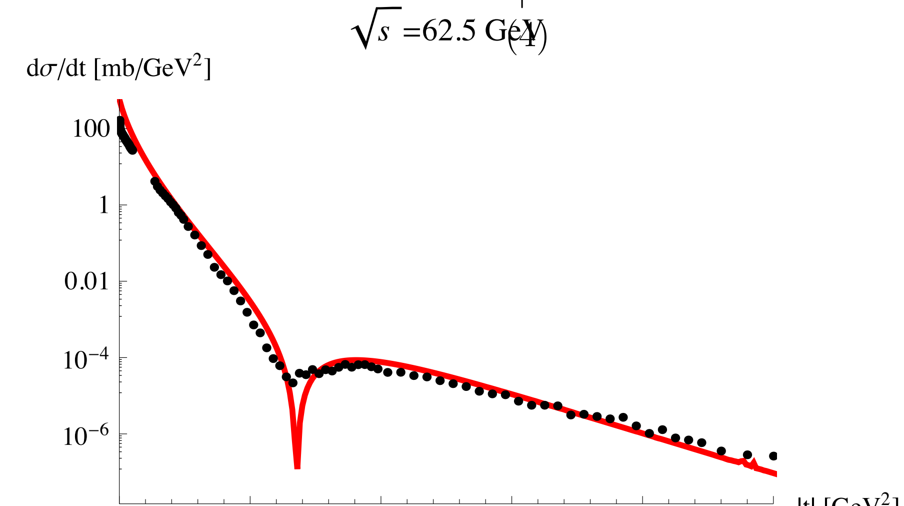
$$\mathbf{N}(\chi,\mathbf{b}_\perp,z,z') = \frac{1}{zz'}\,\Delta(\chi,\xi) + \frac{z}{z'z_0^2}\,\Delta(\chi,\xi_*)\ ,$$

and the heat kernel Δ in the background (6) is given by

$$\Delta_\perp(\chi,\xi) = \frac{e^{(\alpha_{\mathbf{P}}-1)\chi}}{(4\pi\mathbf{D}\chi)^{3/2}}\frac{\xi e^{-\frac{\xi^2}{4\mathbf{D}\chi}}}{\sinh(\xi)}\ ,$$

with the chordal distances ($u = -\ln(z/z_0)$)

$$\cosh\xi = \cosh(u'-u) + \frac{1}{2}\mathbf{b}_\perp^2\, e^{u'+u}$$
$$\cosh\xi_* = \cosh(u'+u) + \frac{1}{2}\mathbf{b}_\perp^2\, e^{u'-u}\ .$$



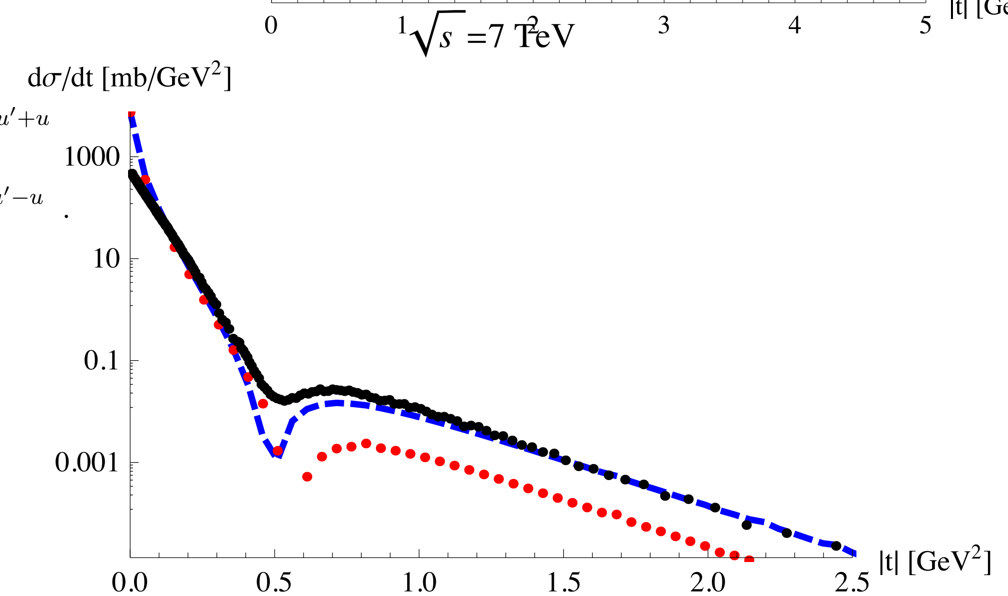


Figure 3: Differential pp cross section. Black dots: data from the TOTEM experiment at LHC, [59]. Dashed blue line and red dots: holographic result. See text.

the energy dependence is not very good because of approximation

$$\psi_p(u) = \delta(u - u_0)$$

Supercritical (explosive) regime

The onset is expected when the entropy becomes as large as that of the gluons, which corresponds to

$$s \approx N_c^2 \tilde{T}_H^3 \tag{46}$$

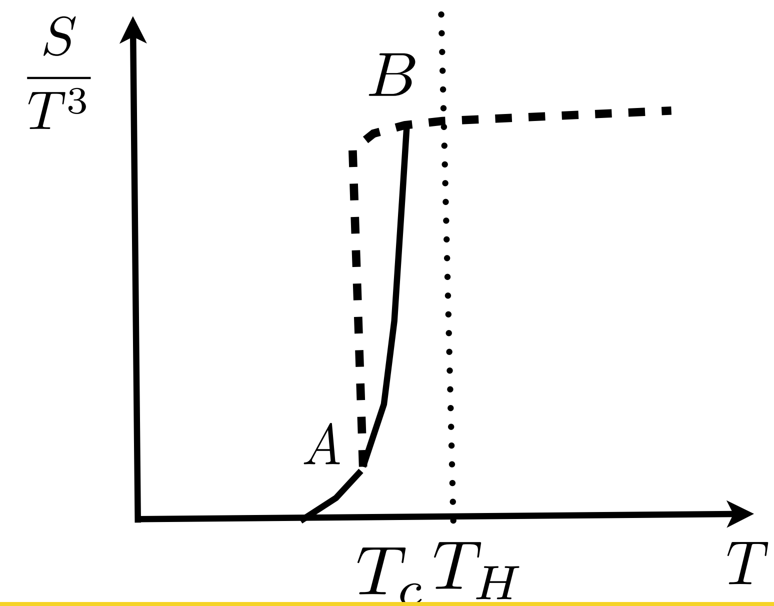
The estimate of the probability of this to happen in LHC pp events can be done using

$$\frac{\Delta\beta}{\tilde{\beta}_H} = \frac{\tilde{T}_H}{T} - 1 = \mathcal{O}\left(\frac{1}{N_c}\right) \tag{47}$$

For near critical strings we have (47) and $g_s \approx 1/N_c$. At LHC, $\chi \approx 10$ so using (45) we find

$$\frac{\sigma_{NC}}{\sigma_{MB}} \approx 10^{-5} \tag{48}$$

which is comparable to the probability of the high multiplicity events in which the CMS collaboration discovered the "ridge" phenomenon.



The appearance of QGP pressure leads to hydro explosion, which we discuss in a separate paper

High Multiplicity pp and pA Collisions: Hydrodynamics at its Edge and
Edward Shuryak, Ismail Zahed (SUNY, Stony Brook). Jan 2013.
Published in **Phys.Rev. C88 (2013) 044915** ; **arXiv:1301.4470**

the first discovery at LHC

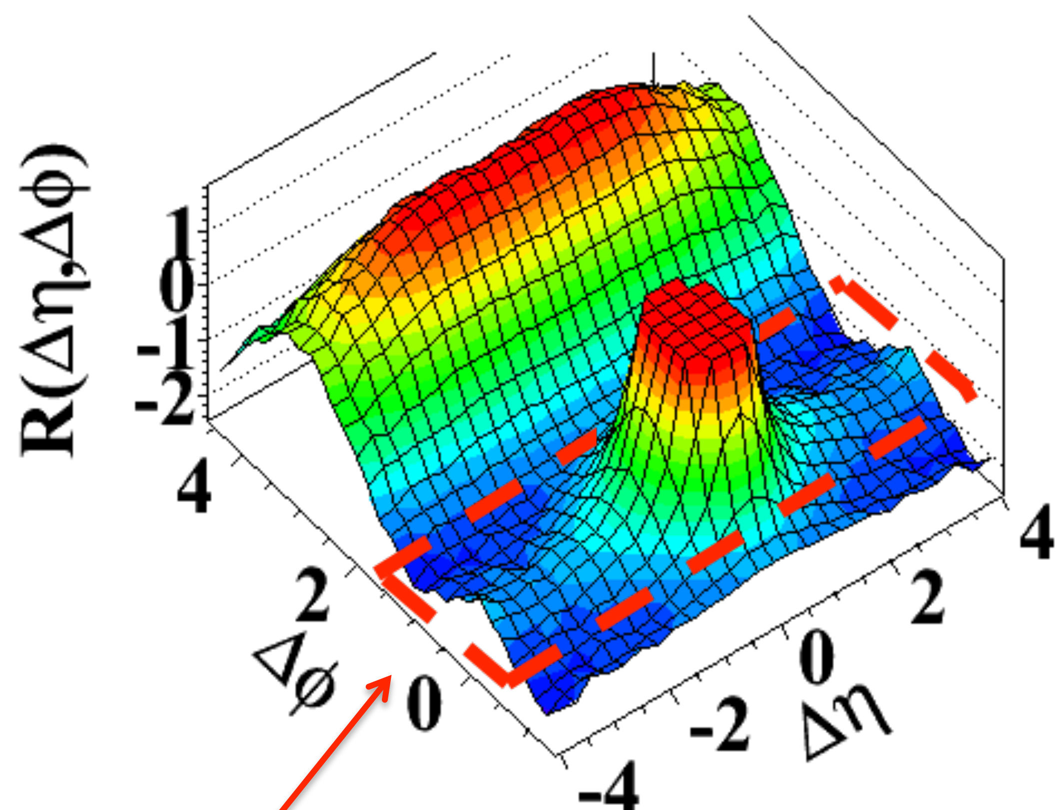
Opportunity of studying novel QCD phenomena opened up by the LHC

Two-particle Δη-Δϕ correlation

September, 2010

10^10$ per 10^10 events, but those cost 1000000$ each

pp N>110, $1<p_T<3$ GeV/c



Planar particle emission

Observation of long-range, near-side angular correlations in proton-proton collisions at the LHC

The CMS collaboration

ABSTRACT: Results on two-particle angular correlations for charged particles emitted in proton-proton collisions at center-of-mass energies of 0.9, 2.36, and 7 TeV are presented, using data collected with the CMS detector over a broad range of pseudorapidity (η) and azimuthal angle (ϕ). Short-range correlations in $\Delta\eta$, which are studied in minimum bias

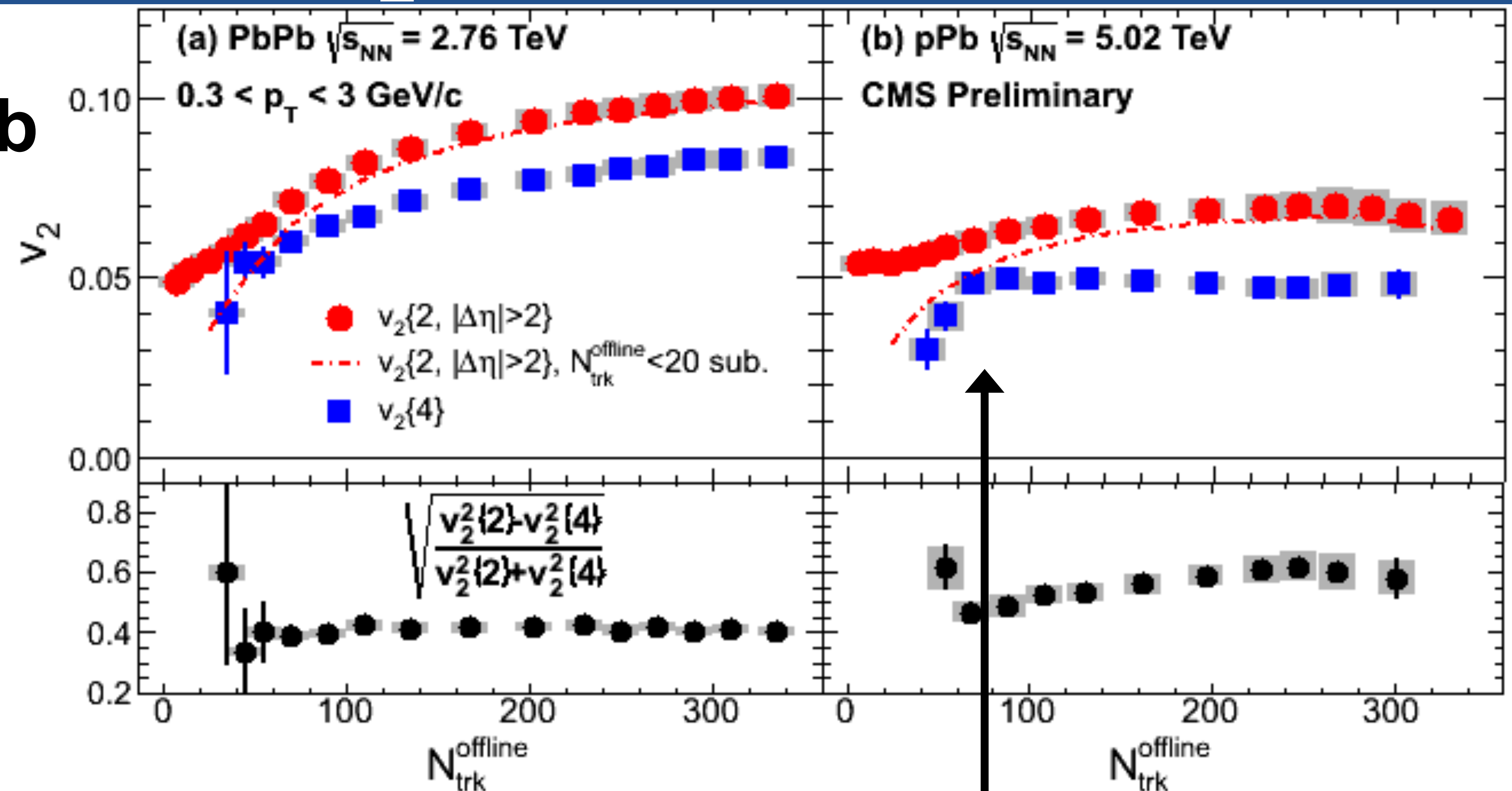
Unexpected ridge-like correlations in high multiplicity pp!

Not in minimum bias pp or pp MC models

CMS pPb: v2 from 2 and 4-particles

v_2 in pPb and PbPb

PbPb



pPb

2 and 4 are comparable: clear sign of collectivity **except at low multiplcity: fluctuations**

v_2 smaller in pPb than PbPb

$v_2\{4\}$ drops at low multiplicity

$$v_2\{2\} = \sqrt{< v_2 >^2 + \sigma_{v_2}^2}$$

$$v_2\{4\} = \sqrt{< v_2 >^2 - \sigma_{v_2}^2}$$

Which is the real end of hydro!

PHYSICAL REVIEW C **88**, 044915 (2013)

High-multiplicity *pp* and *pA* collisions: Hydrodynamics at its edge

Edward Shuryak and Ismail Zahed

We predicted the radial flow in pp/pA to be even stronger than in central AA

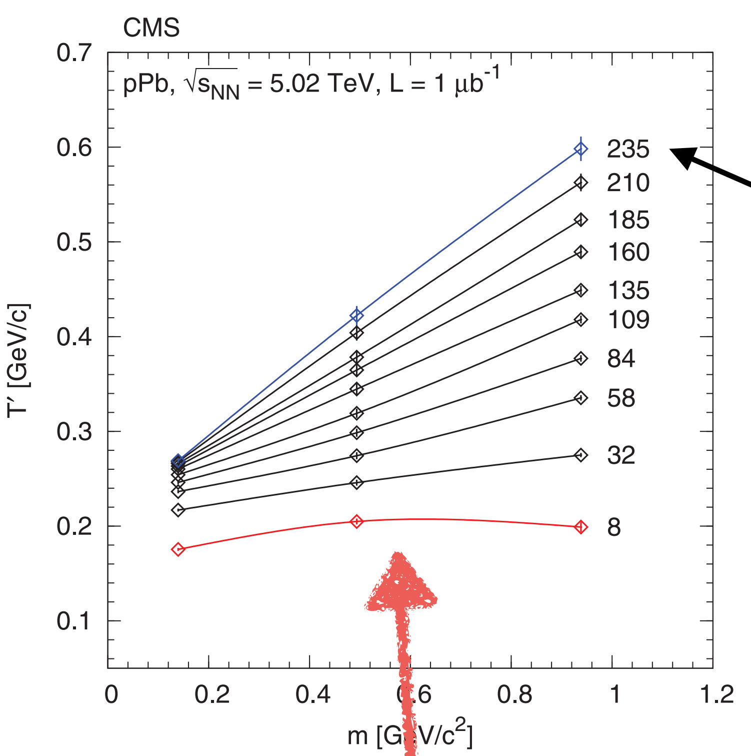


FIG. 8. (Color online) The slopes of the $m_\perp$ distribution T' (GeV) as a function of the particle mass, from [13]. The numbers on the right

No Mt scaling => not a large Qs in Glasma, but collective flow: p=m v

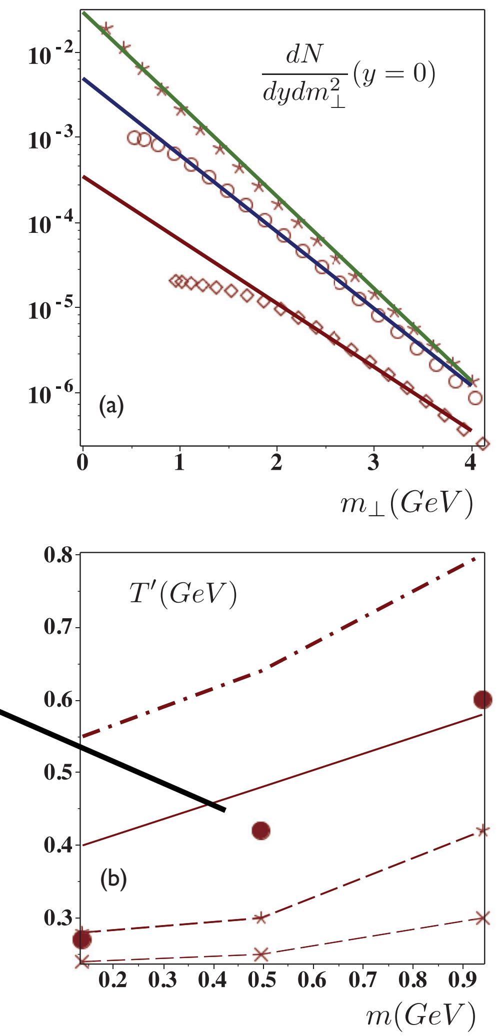


FIG. 9. (Color online) (a) A sample of spectra calculated for π, K, p, top-to-bottom, versus $m_\perp$ (GeV), together with fitted exponents.(b) Comparison of the experimental slopes $T'(m)$ versus the particle mass m (GeV). The solid circles are from the highest multiplicity bin data of Fig. 8, compared to the theoretical predictions. The solid and dash-dotted lines are our calculations for freeze-out temperatures $T_f = 0.17, 0.12$ GeV, respectively. The asterisk-marked dashed lines are for Epos LHC model, diagonal crosses on the dashed line are for AMTP model.

. THE STRING BALL AS AN EFFECTIVE BLACK HOLE

The near-critical string has a propagator (40) that behaves like a thermal ensemble with Unruh temperature $1/\beta_U$. Its free energy or pressure $\mathbf{F} = -\ln\mathbf{K}_T/\beta_U$ [2] are small

$$\mathbf{F}(\beta, \mathbf{b}) \approx k\sigma\,\mathbf{b}\left(1 - \frac{\tilde{\beta}_H^2}{\beta^2}\right)^{1/2} \quad (52)$$

but the energy and the entropy are very large

$$\mathbf{E} = \partial_{\beta_U}(\beta_U k\mathbf{F}) \approx k\sigma\mathbf{b}\left(1 - \frac{\tilde{\beta}_H^2}{\beta^2}\right)^{-1/2} \quad (53)$$

$$\mathbf{S} = \beta_U^2 \partial_{\beta_U}\mathbf{F} \approx (\tilde{\beta}_H^2/\beta)k\sigma\mathbf{b}\left(1 - \frac{\tilde{\beta}_H^2}{\beta^2}\right)^{-1/2}$$

For $\beta \approx \tilde{\beta}_H$ this coincides with the first law of thermodynamics for black-holes in Rindler coordinates as noted by Susskind [40]

$$\mathbf{S} \approx \beta_H\mathbf{E} = 2\pi\left(\mathbf{E}l_s\right) \quad (54)$$

F,p are small, E,S are large

The transverse area of the black-hole is the area of the diffusing string in rapidity

$$A_{BH} = 2\pi^2\left(\sqrt{\chi/k}\,l_s\right)^3 \quad (56)$$

in transverse $D_\perp = 3$ provided that the diffusion length in the z-direction is within the confining wall. As a result, we have the Bekenstein-Hawking type relation

$$\frac{\mathbf{S}_{BH}}{A_{BH}} \equiv \frac{1}{4G_5} \quad (57)$$

with an effective Newton constant

$$G_5 = \pi^2\left((\chi/k^3)(1 - \tilde{\beta}_H^2/\beta^2)\right)^{1/2} l_s^3 \quad (58)$$

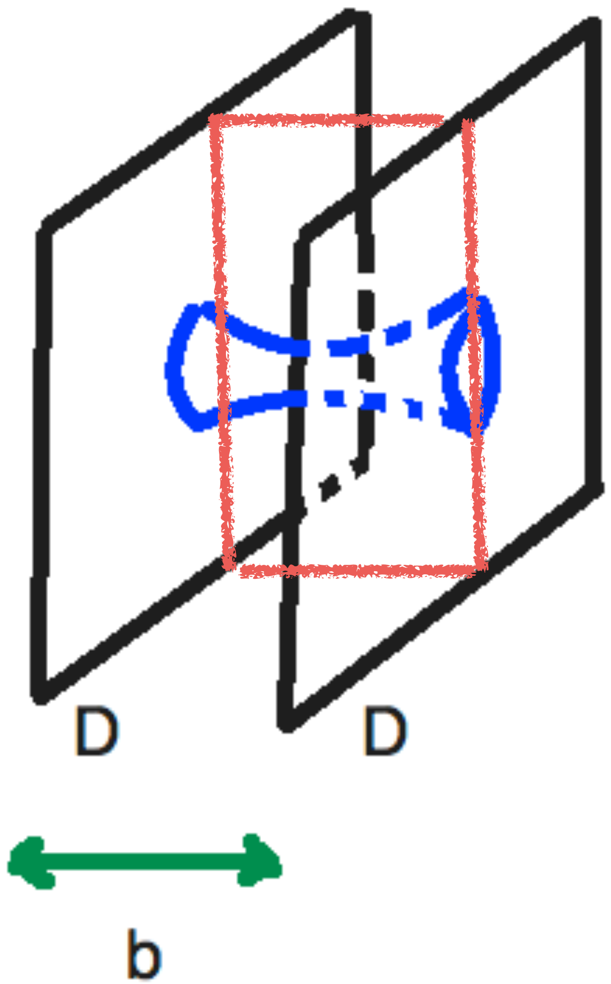
For a fundamental string, the Planck and string constants are related with G_5 through $G_5 = l_P^3 = g_s^2 l_s^3$. We recall in the large N_c counting $g_s^2 \approx 1/N_c^2$.

From tunneling (Euclidean) to Real time

Outlook

$$Im A_{elastic} \sim |A_{inelastic}|^2$$

The unitarity cut is shown by red

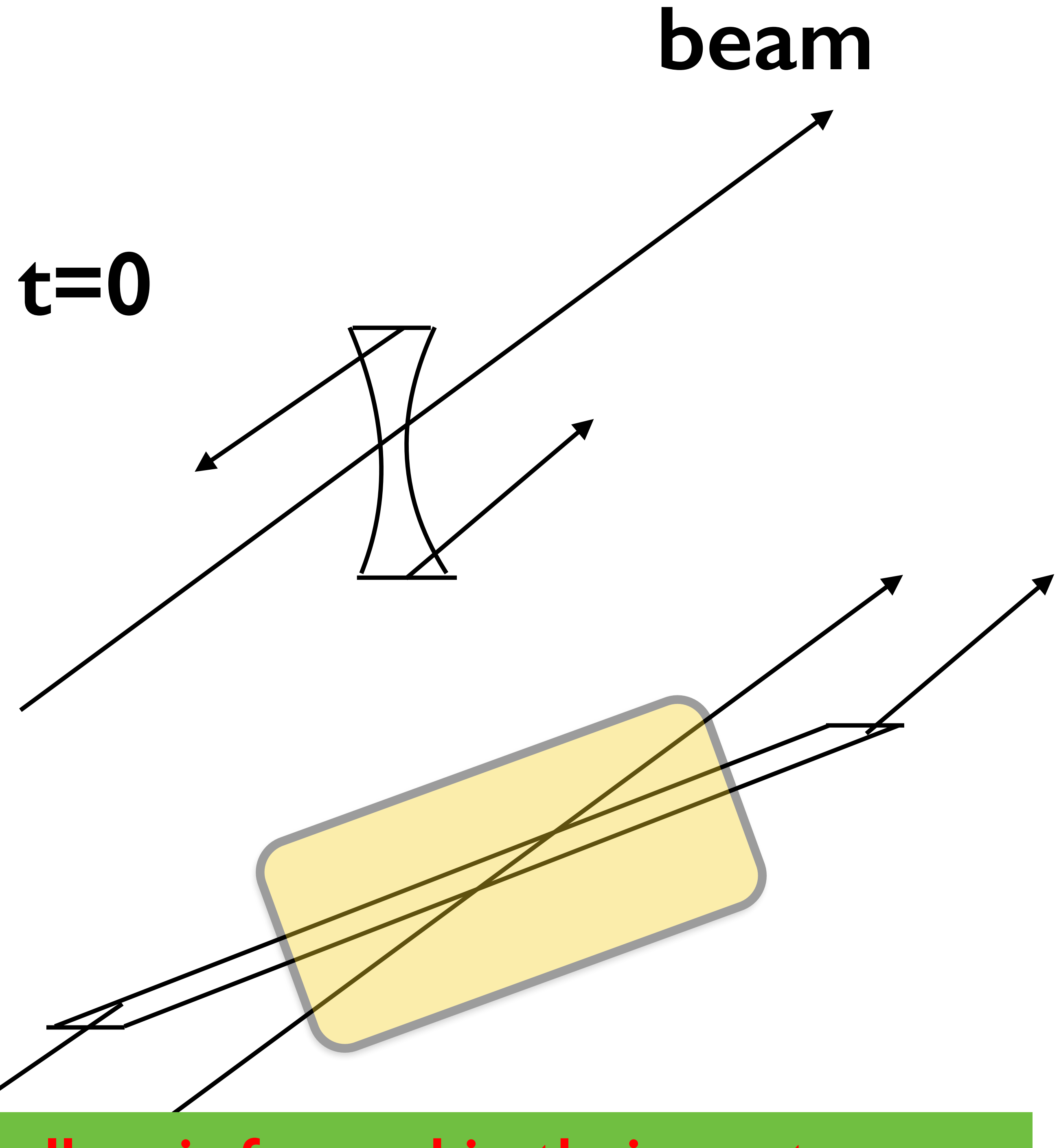


The picture includes (twice) the Euclidean part of the semicircular path (as in Schwinger process, in fact known from Sauter,1931)

The Minkowski part has exp(iS) so the probability=1

The end of E. path becomes the initial condition for the Minkowski part of the path

- at time zero strings are born transverse, in **b** direction
- then they are stretched along the beam direction



If the cluster — string ball — is formed in their center and it is heavy enough, a trapped surface appears: it creates string breaking, Hawking radiation etc

Hydro = falling in z under gravity

Gubser,Pufu and Yarom" Heavy ion collisions as that of two black holes

A significant leap forward had been done recently by Gubser, Pufu and Yarom [123], who proposed to look at heavy ion collision as a process of head-on collision of two point-like black holes, separated from the boundary by some depth L – tuned to the nuclear size of Au to be about 4 fm, see Fig.??. By using global AdS coordinates, these authors argued that (apart of obvious axial O(2) symmetry) this case has higher – namely O(3)– symmetry with the resulting black hole at the collision moment at its center, thus in certain coordinate

$$q = \frac{\vec{x}_\perp^2 + (z-L)^2}{4zL} \qquad (91)$$

the 3-d trapped surface C at the collision moment should be just a 3-sphere, at constant $q = q_c$. (Here $x_\perp$ are two coordinates transverse to the collision axes.) The picture of it is shown in Fig.29(b)

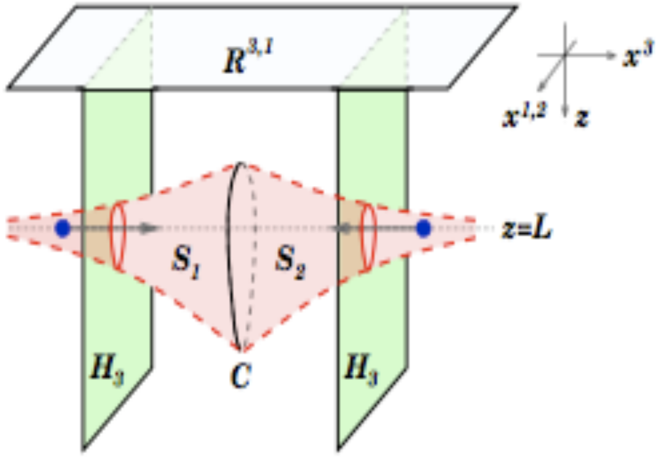
If so, one can find the radius at which it is the trapped null-surface and determine its energy and Bekenstein entropy. For large q_c these expressions are

$$E \approx \frac{4L^2 q_c^3}{G_5}, \; S \approx \frac{4\pi L^3 q_c^2}{G_5}, \qquad (92)$$

from which, eliminating q_c, the main result of the paper follows, namely that the entropy grows with the collision energy as

$$S \sim E^{2/3} \qquad (93)$$

Note that this power very much depends on the 5-dimentional gravity and is different from the 1950's prediction of Fermi and Landau (??) in which this power was 1/2 and (accidentally or not) fits the data better.



No time is needed: trapped surface is there at time zero

On the critical condition in gravitational shock wave collision and heavy ion collisions
Shu Lin (Munich, Max Planck Inst.), Edward Shuryak (SUNY, Stony Brook). Nov 2010. 26 pp.

Grazing Collisions of Gravitational Shock Waves and Entropy Production in Heavy Ion Collision

Shu Lin[1], and Edward Shuryak[2] **arXiv 0902.1508**

The shock wave moving in $+x^3$ direction is given by:

$$ds^2 = L^2 \frac{-dudv + (dx^1)^2 + (dx^2)^2 + dz^2}{z^2} + L\frac{\Phi(x^1, x^2, z)}{z}\delta(u)du^2$$

with $\Phi(x^1, x^2, z)$ satisfies the following equation:

$$\left(\Box - \frac{3}{L^2}\right)\Phi = 16\pi G_5 J_{uu}$$

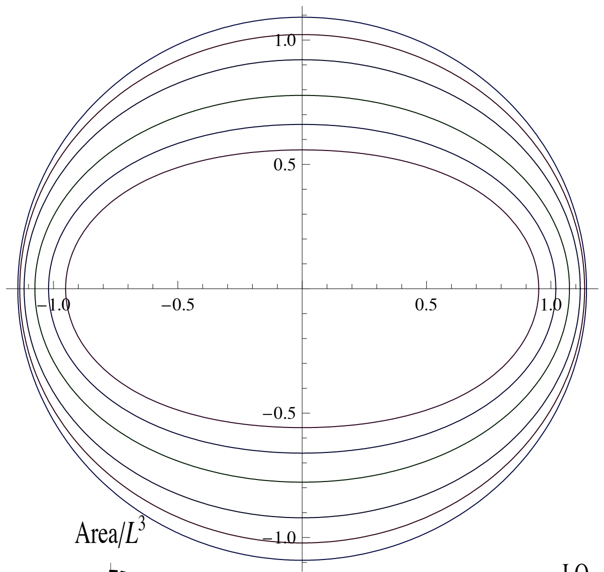
The vanishing of expansion gives the equation:

$$\left(\Box - \frac{3}{L^2}\right)(\Psi_1 - \Phi_1) = 0$$

$$\Psi_1|_{\mathcal{C}} = \Psi_2|_{\mathcal{C}} = 0$$

The boundary $\mathcal{C}$ should be chosen to satisfy the constraint:

$$\nabla\Psi_1 \cdot \nabla\Psi_2|_{\mathcal{C}} = 4$$



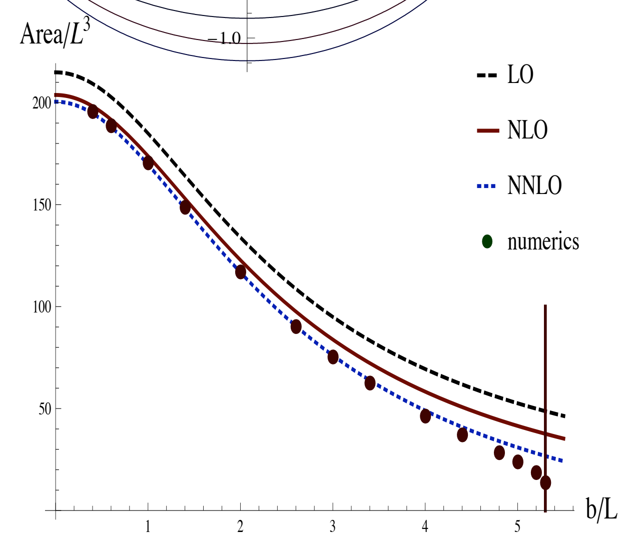


Figure 1: (Color online.) Comparisons between the numerics of [36] and the analytic formula (58). The black dashed curve represents the leading term in (58); the solid red curve corresponds to the first two terms in (58); the dotted blue curve represents the expression (58), which is correct up to a term of order $\mathcal{O}(1/\zeta^2)$; the green dots represent the numerical evaluations used in figure 3 of [36]; lastly, the vertical green line marks the place where, according to [36], the maximum impact parameter $b_{\max}/L$ occurs. We thank S. Lin and E. Shuryak for providing us with the results of their numerical evaluations.

The b.h. disappears at a particular b

See also Shuryak and Lin, **arXiv:1011.1918, for collision of two walls and Qs interpreted as the z coordinate of the walls**

summary

- A **single Pomeron,** but in 3 regimes
- it is stringy at large b and perturbative at small b
- with (crossover near-1st order) phase transition in between
- strongly fluctuating string => high multiplicity clusters, related to Pomeron daughters
- near-critical regime is thermodynamically dual to black hole
- **outlook: real-time part of the path.is B.H. really formed? (trapped surfaces…)**
- supercritical regime leads to QGP fireball and hydro explosion: **hydro description works**

seen in pA with few % probabiliy

Observation of long-range, near-side angular correlations in pPb collisions at the LHC

The CMS Collaboration*

high multiplicity trigger in pp reveals a ``ridge" which is also there in pPb

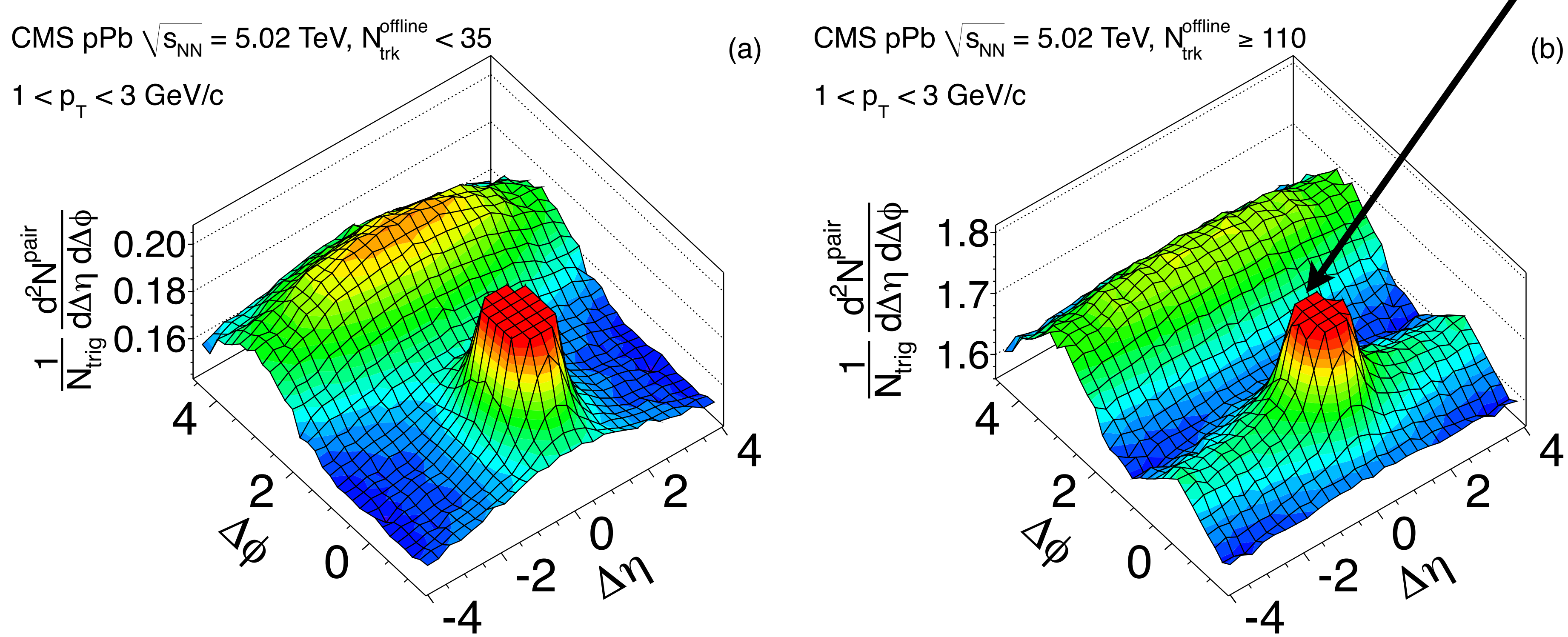


Figure 1: 2-D two-particle correlation functions for 5.02 TeV pPb collisions for pairs of charged particles with $1 < p_T < 3$ GeV/c. Results are shown (a) for low-multiplicity events ($N_{trk}^{offline} < 35$) and (b) for a high-multiplicity selection ($N_{trk}^{offline} \geq 110$). The sharp near-side peaks from jet correlations have been truncated to better illustrate the structure outside that region.

a string ball is dual to a black hole: viscosity

The correspondence is usually derived via the entropy

(=Hawking-Bekenstein)

But one can also calculate viscosity, which gives 1/4pi

although the calculation is stringy not BH. (And even if BH it is very different from that in AdS/CFT , not located in 5-th dimension, so were surprised)

Kubo

tensor. To assess the primordial viscosity, we follow [2] and write the needed expression on the streched horizon for the excited string

$$\eta_R = \lim_{\omega_R \to 0} \frac{A_R}{2\omega_R} \int_0^\infty d\tau e^{i\omega_R \tau} \mathbf{R}_{23,23}(\tau) \quad (87)$$

with A_R the area of the black-hole and τ a dimensionless Rindler time. The retarded commutator of the normal ordered transverse stress tensor for the Polyakov string on the Rindler horizon reads

$$\mathbf{R}_{23,23}(\tau) = \left\langle \left[T_\perp^{23}(\tau), T_\perp^{23}(0) \right] \right\rangle \quad (88)$$

with

$$T_\perp^{23}(\tau) = \frac{1}{2A_R} \sum_{n \neq 0} : a_n^2 a_n^3 : e^{-2in\tau} \quad (89)$$

and the canonical rules $\left[a_m^i, a_n^j\right] = m\delta_{m+n,0}\delta^{ij}$. The averaging in (88) is carried using the black-body spectrum as in (84). The result is

$$\eta_R = \lim_{\omega_R \to 0} \frac{A_R}{2\omega_R} \frac{\pi}{2A_R^2} \frac{(\omega_R/2)^2}{e^{\beta_R \omega_R/2} - 1} = \frac{1}{A_R} \frac{\pi}{8\beta_R} \quad (90)$$

We note the occurence of the Bekenstein-Hawking or Rindler temperature $\beta_{BH} = \beta_R$ in the thermal factor.

Combining (86) for the entropy to (90) yields the viscosity on the streched horizon

$$\frac{\eta_R}{\mathbf{S_R}/A_R} = \frac{1}{4\pi} \left(\frac{3}{D_\perp} \right) \equiv \frac{1}{4\pi} \quad (91)$$

fig for twisted tube