CMS ridge effect at LHC as a manifestation of bremsstralung

of gluons off quarks accelerated in a strong color field

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The recently reported effect of long-range near-side angular correlations at LHC occurs for large multiplicities of particles with $1\,GeV\ < p_T\ < \ 3\,GeV$. *In the talk (based mostly on our work (1)) we propose a simple qualitative mechanism which corresponds to gluon bremsstralung of quarks moving with acceleration defined by the string tension. The smallness of azimuth angle difference* $\Delta\phi$ *along with large* $\Delta\eta$ *at large multiplicities in this interval of* p_T *are natural in the mechanism. The mechanism predicts also bremsstralung photons with mean values of* $p_T \approx 2.9GeV * 2.5/m_u(MeV)$ *and* $0.72\,GeV * 5/m_d(MeV)$.

1. B.A. Arbuzov, E.E. Boos and V.I. Savrin, Eur. Phys. J. C 71: 1730 (2011); arXiv:1104.1283(hep-ph)

The well-known classical expression for dipole electromagnetic radiation of electric charge e moving with acceleration being parallel to velocity of the motion (17)

$$\frac{dE}{dt} = \frac{2\,\alpha\, w^2}{3}; \qquad (1)$$

For strongly interacting quarks we change (1) for the following relation

$$\frac{dE}{dt} = \frac{\alpha_s}{9}\left(\frac{A^2}{m}\right)^2; \qquad (2)$$

where acceleration $w = A^2/m$ with A and m being

the string tension and a light quark mass.

$$m_u = 2.5\,MeV;\; m_d = 5\,MeV;\; A = 420\,MeV; \qquad (3)$$

where light quark masses are chosen to be in the middle of interval of their possible values: $1.7\,MeV < m_u < 3.3\,MeV$; $4.1\,MeV < m_d < 5.8\,MeV$ ***(18).***

$$\frac{\Delta E}{\Delta t} = \frac{\alpha_s}{9}\left(\frac{A^2}{m}\right)^2; \qquad (4)$$

$$\Delta E\,\Delta t = 1. \qquad (5)$$

$$\Delta E\,=\,\sqrt{\frac{\alpha_s}{9}}\,\frac{A^2}{m}\,. \tag{6}$$

Then we use the standard one loop expression for α_s at scale ΔE

$$\alpha_s(\Delta E)\,=\,\frac{12\pi}{(33-2N_f)\,\ln\left(\frac{\Delta E^2}{\Lambda^2_{QCD}}\right)}\,; \tag{7}$$

$$\Delta E_u\,\approx\,11.2\,GeV\,;\quad \Delta E_d\,\approx\,5.6\,GeV\,. \tag{8}$$

First of all let us consider an explanation of large differences in pseudo-rapidity $\Delta\eta$ along with small differences in azimuth angle $\Delta\phi$. Here we are to take into account both quarks constituting the extended object (a cigar). Namely let "the cigar" be produced with some overall momentum k while its position remains being (almost) parallel to the line of $p\,p$ collision. Such situation is presented in Fig.1.

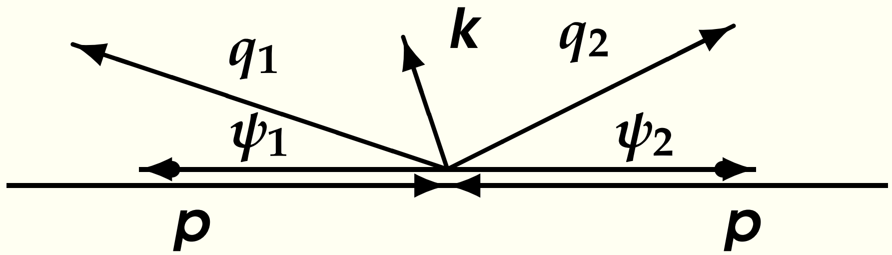

Fig.1 The string moving with momentum k from the point of collision of two protons, ψ_1, ψ_2 are angles in Eq. (9) and q_1, q_2 are momenta of the quarks.

Then velocities of quarks are not parallel to the direction of acceleration, but constitute some angles ψ_1, ψ_2 with this direction in laboratory reference frame. When a velocity and an acceleration are not parallel $\mathbf{v}\,\mathbf{w} = v\,w\cos\psi$ and there are two accelerated quarks we have the following angular distribution (17)

$$\frac{dE}{dt'} = \frac{\alpha_s}{24\,\pi}\left(\frac{A^2}{m}\right)^2 \times$$

$$\left(\Phi(\psi_1,\theta,\phi,v_1) + \Phi(\psi_2,\theta,\phi,v_2)\right) d\,\Omega; \qquad (9)$$

$$\Phi(\psi,\theta,\phi,v) = \frac{X + v^2 Y}{Z^5}$$

$$X = \sin^2\theta - 2v\sin\psi\sin\theta\cos\phi$$

$$Y = \cos^2\theta\sin^2\psi + \sin^2\theta\sin^2\psi\cos^2\phi$$

$$Z = 1 - v(\cos\psi\cos\theta + \sin\psi\sin\theta\cos\phi);$$

where t' is a time with account of a retardation (17),

ψ_1, ψ_2 are respectively angles for the first and the second quark. From Fig.2, Fig.3 we see that $\Delta\eta$ may be quite significant while $\Delta\phi$ is small. One should note that the peaks in Fig.2 and Fig.3 become narrower with increasing of speed and with increasing of ψ. Emphasize that the effect of a peak around $\phi = 0$ is connected with transverse movement of "the cigar" (Fig. 1). The more is transverse momentum k, i.e. angles ψ_i, the narrower becomes the distribution in ϕ.

$$\frac{dE(\eta)}{dt'} = \frac{\alpha_s}{24\,\pi}\left(\frac{A^2}{m}\right)^2 \Phi(\eta)\,\frac{d\,\eta}{\cosh^2\eta};$$

$$\Phi(\eta) = \int_{-\pi}^{\pi} \Phi_{12}(\psi_i, v_i, \theta, \phi)_{\cos\theta = \frac{\sinh\eta}{\cosh\eta}}\, d\phi\,; \qquad (10)$$

$$\frac{dE(\phi)}{dt'} = \frac{\alpha_s}{24\,\pi}\left(\frac{A^2}{m}\right)^2 \Phi(\phi)\,d\phi\,;$$

$$\Phi(\phi) = \int_0^{\pi} \Phi_{12}(\psi_i, v_i, \theta, \phi)\, \sin\theta\, d\,\theta; \qquad (11)$$

$$\Phi_{12}(\psi_i, v_i, \theta, \phi) = \Phi(\psi_1, \theta, \phi, v_1) +$$

$$\Phi(\psi_2, \theta, \phi, v_2).$$

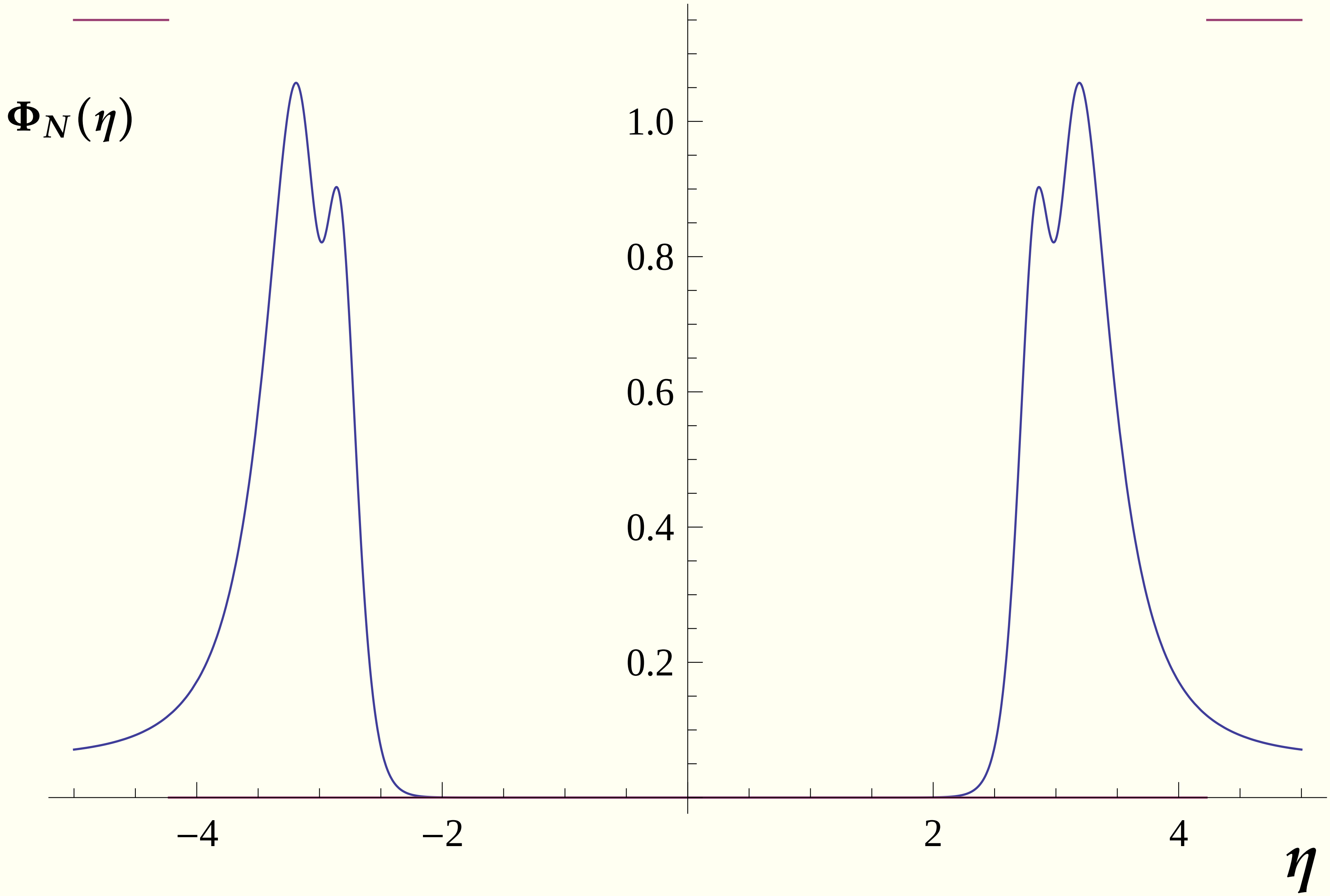

Fig. 2. Behavior of $\Phi_N(\eta)$, $v = 0.999$, $\psi_1 = 0.1$, $\psi_2 = \pi - 0.1$, $-5 < \eta < 5$.

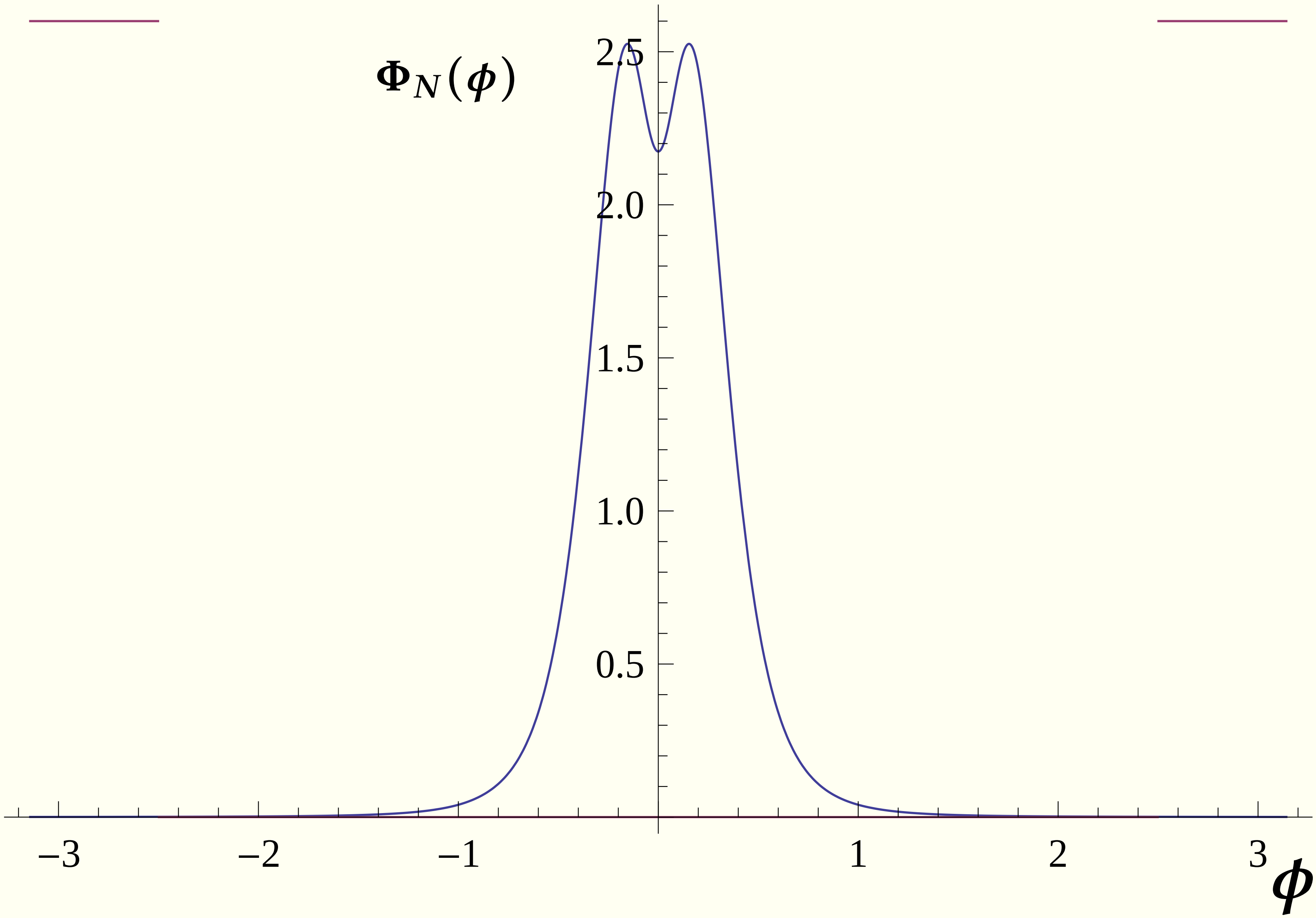

Fig. 3. Behavior of $\Phi_N(\phi)$, $v = 0.999$, $\psi_1 = 0.1$, $\psi_2 = \pi - 0.1$, $-\pi < \phi < \pi$.

Now let us consider properties of gluon radiation of a single quark.

$$\frac{dE}{dt'} = \frac{\alpha_s}{24\,\pi}\left(\frac{A^2}{m}\right)^2 \frac{\sin^2\theta'}{(1 - v\cos\theta')^5}\,d\,\Omega\, =$$

$$\frac{\alpha_s}{24\,\pi}\left(\frac{A^2}{m}\right)^2 \Phi_0(\theta')\,d\,\Omega; \qquad (12)$$

$$\Phi_0(\theta') = \Phi(0, \theta', \phi, v)\,;$$

where v is a velocity of a quark, θ' is a polar angle and $d\Omega = \sin\theta' d\theta'\, d\phi$. Using angular distribution of the radiation (12) we estimate the mean p_T of the radiated gluon

$$< p_T^g > = \frac{\Delta E}{\sqrt{1-v^2}} \frac{I_1}{I_2}; \quad I_2 = \int \Phi_0(\theta')\, d\Omega;$$

$$I_1 = \int \Phi_0(\theta')\, A(v,\theta') \sin\theta'\, d\Omega; \tag{13}$$

$$A(v,\theta') = 1 + \frac{\cos\theta'\,(1-v^2) - v\sin^2\theta'}{1 - v^2\cos^2\theta'};$$

where $\Phi_0(\theta')$ *is defined in (12). Calculating integrals in (13) with the aid of the following relation valid for* $v \to 1$ *and* $\rho > \frac{\mu}{2}$

$$\int_0^\pi \frac{\sin^{\mu-1}\theta d\theta}{(1-v\,\cos\theta)^\rho} = \frac{2^{\mu-\rho}\Gamma\left(\frac{\mu}{2}\right)\Gamma\left(\frac{1}{2}\right)\Gamma(2\rho-\mu)}{(1-v^2)^{\rho-\mu/2}\Gamma(\nu)\Gamma\left(\frac{1-\mu}{2}+\rho\right)};$$

we obtain for quark u and d respectively with $v \to 1$

$$< p_T^g(u) > = \frac{9\,\pi\,\Delta\,E_u}{32} \approx 9.9\,GeV\,;$$
$$< p_T^g(d) > = \frac{9\,\pi\,\Delta\,E_d}{32} \approx 4.95\,GeV\,. \qquad (14)$$

Then we estimate the multiplicity for gluon energy in an accompanying reference frame (8) by the following expression valid in the region of few GeV for charged multiplicity (19)

$$< N_{ch} > = a + b\,\ln\sqrt{s}\,;$$
$$a = -0.43 \pm 0.09\,; \quad b = 2.75 \pm 0.06\,. \qquad (15)$$

Neutral particles $\longrightarrow$ factor $\frac{3}{2}$. Mean multiplicity:

$$u: \sqrt{s} = 4.15\, GeV; \quad < N > = 5.2;$$
$$d: \sqrt{s} = 3.37\, GeV; \quad < N > = 4.3. \tag{16}$$

Estimate for transverse momenta of hadrons

$$p_T = p_T^g / N$$

$$u: 1.3\, GeV < p_T < 3.0\, GeV;$$
$$d: 0.8\, GeV < p_T < 2.0\, GeV. \tag{17}$$

Average angular spread for gluons

$$< \Delta\bar{\theta} > \simeq \frac{< p_T^g > \sqrt{N_g}}{< E_g > N_g}; \tag{18}$$

Small multiplicity $\to \Delta\bar{\theta}$ increases $\to$ the effect disappears.

$$< \Delta\bar{\theta} > \simeq \frac{2 < p_T^g > \sqrt{N_g}}{\sqrt{x_1 x_2 s}}; \tag{19}$$

where x_1, x_2 are values of x for quark in the first proton and the anti-quark in the second one.
Number of radiated gluons N_g depends on angle ψ

and velocity v. Using again formulas from (17) we have the following estimate

$$N_g = \frac{\sqrt{x_1 x_2 s}}{2\Delta E\sqrt{1+\frac{\sin^2\psi}{(1-v^2)}}}. \tag{20}$$

For example with $\psi = 0.1$ and $v = 0.999$, average $\Delta E = (\Delta E_u + \Delta E_d)/2 = 8.4\,GeV$, $\sqrt{s} = 7\,TeV$ (2) and with average of the product $< x_1\, x_2 > \approx 0.01$ (see, e.g. (20) and references therein) we have $N_g \simeq 17$. Now in our interpretation one bremsstralung gluon gives average number of charged hadrons $N_{ch} \approx 3.2$. Bearing in mind, that our quasi-classical estimate

corresponds to non-coherent production of gluons, with $N_g \approx 17$ we estimate total number of charged particles produced by a quark $N^q_{ch} = 54$ that gives just multiplicity ≥ 100 for two radiating quarks.

Now with $N_g = 17$, $\sqrt{s} = 7\,TeV$, average $< p^g_T >= 7.4\,GeV$ and $< x_1\,x_2 >= 0.01$ we have from (19)

$$< \Delta\bar{\theta} > \approx \; 0.09\,; \qquad (21)$$

This angular spread actually gives widening of distributions in η and ϕ.

Widening of the ridge with $\sqrt{s}$ decreasing.

$\sqrt{s} = 0.9\,TeV \rightarrow < \Delta\bar{\theta} > = 0.8 \rightarrow$ *vanishing of the effect.*

Thus, one can conclude the simple mechanism of gluon bremsstralung off quarks moving in a strong colour field describes qualitatively the CMS ridge effect. Of course, a real situation could be much more involved. In particular, other colour configurations, as was pointed out in various studies (see, for example, (13)), may play a significant role. Our consideration based on simple quasi-classical estimations shows that constituting string configurations may lead to basic features of the

ridge effect, namely, correlations in particular kinematic region at very high multiplicities. Obviously, in order to show more accurate properties of proposed mechanism one should elaborate in more detail corresponding model and develop corresponding event generator to perform more realistic simulations.

The accelerated quarks radiate photons as well.

Mean p_T:

$$\left(\frac{2e}{3}\right): \; p_T \approx 2.9\,GeV \times \frac{2.5}{m_u(MeV)};$$
$$\left(\frac{e}{3}\right): \; p_T \approx 0.72\,GeV \times \frac{5}{m_d(MeV)}. \tag{22}$$

$\longrightarrow$ ***information on masses of light quarks m_u, m_d.***

Recent data from ATLAS (21) (1107.0581 (hep-ex)):

Single photon E_T distributions show unexpected fluctuation at $E_T \simeq 5\,GeV \longrightarrow m_u \simeq 1.45\,MeV$.

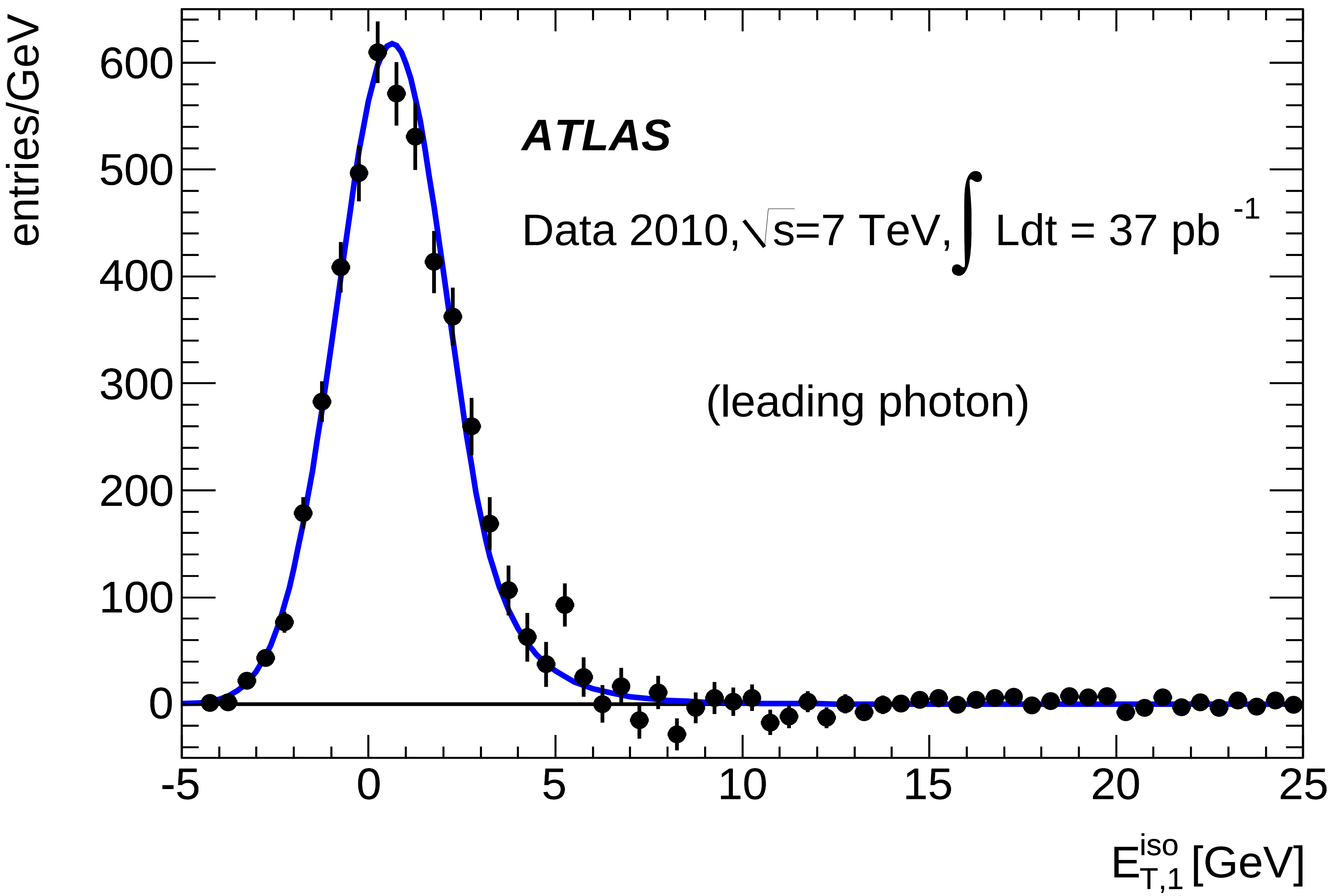

Fig. 4. Data driven signal isolation distribution for leading photon obtained usingthe photon candidates (solid circles) or extrapolated from electrons (continuous line)(extracted from (21) Fig. 2a).

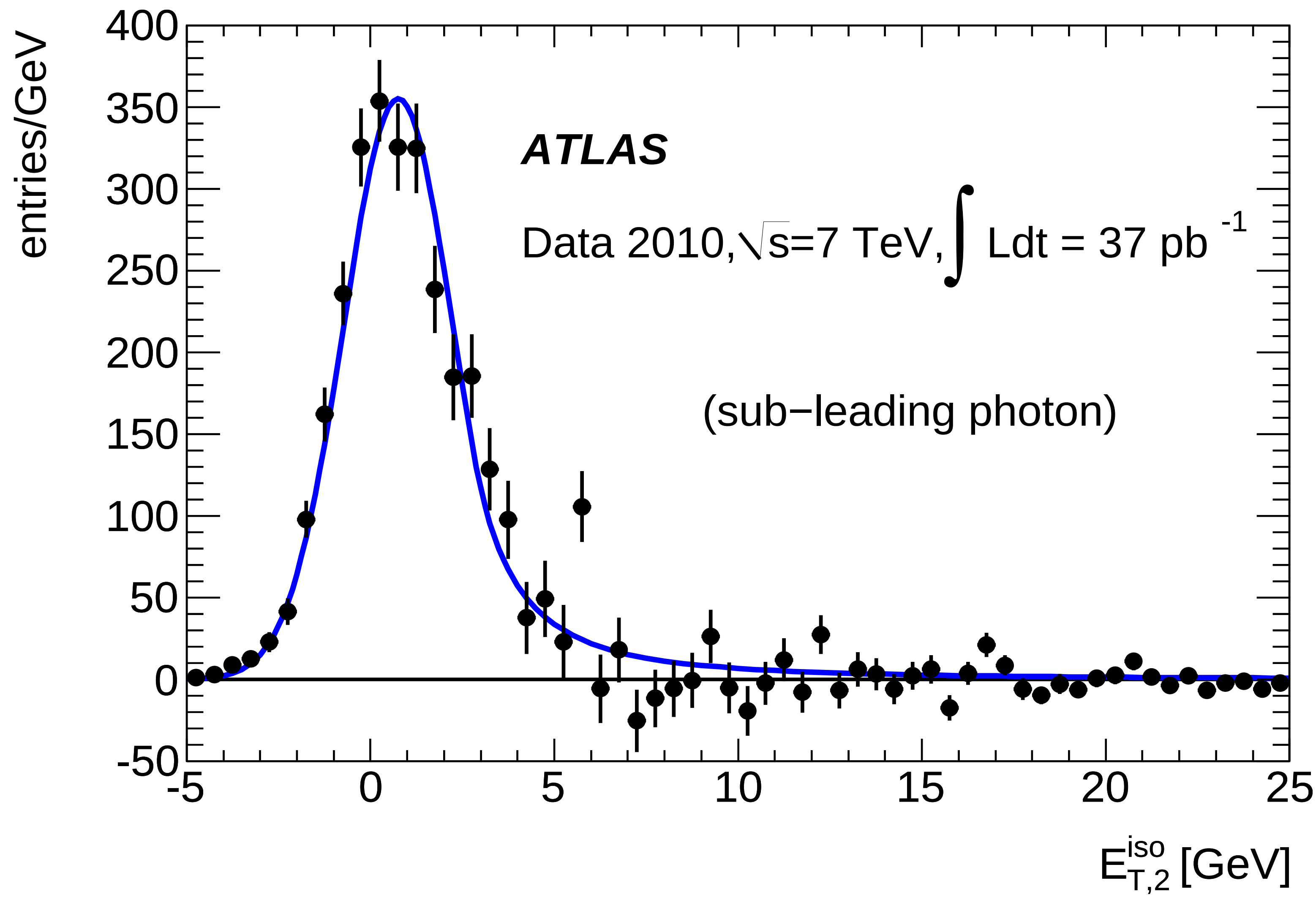

Fig. 5. Data driven signal isolation distribution for leading photon obtained usingthe photon candidates (solid circles) or extrapolated from electrons (continuous line)(extracted from (21) Fig. 2b).

RG evolution

$$m_u(E) = \frac{m_u(E_0)}{\left(1 + \frac{7\alpha_s(E_0)}{4\pi} \ln\left(\frac{E^2}{E_0^2}\right)\right)^{4/7}}; \quad E_0 = 2\,GeV. \quad (23)$$

$m_u(E_0) = 2.5\,MeV$ ***(3),*** $E = 300\,GeV$, $\alpha_s(E_0) = 0.3 \longrightarrow$ $m_u(E) = 1.425\,MeV \longrightarrow 5.1\,GeV$ ***spikes.***

Recent results of CMS for two photons (22) (1109.3310 (hep-ex)) also may serve as indications on behalf of the present mechanism – excess for small $\Delta\phi$ ***of the two photons. Just "CMS ridge effect" for photons.***

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