Soft photon radiation in hadronic collisions: color dipole description

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Abstract:

The Low theorem, proven only for diffractive photon radiation, cannot be extended to inelastic hadronic collisions with multi-particle production. Comparison with incorrect calculations led to the so-called soft-photon puzzle. We describe soft photon production within the color-dipole approach. The required quark distribution in the colliding hadrons at a soft scale is calculated employing the popular quark-gluon string model (QGSM). The dipole cross section is parametrized and fitted to HERA DIS data at low Q^2. Our results are in good accord with data on low-k_T photon yield in pp inelastic collisions.

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Challenge

- We want to describe p_T distribution of direct photons
- Considering scale $Q^2 = p_T^2$, at low p_T we are:
  - Out of perturbative QCD, i.e. no QCD parton model
  - Below minimal Q_0^2 used by most od PDFs parametrization
- We can use the **Color dipole model**
  - No limitation on low Q^2 or p_T
  - We need projectile proton quark distribution…
- Solution: Quark-Gluon String Model (QGSM) or Dual Parton Model inspired quark distribution
  - Regge-based model
  - The production of a particle corresponds to the cut-pomeron pole contribution in the elastic scattering amplitude

QGSM references:

A. B. Kaidalov, Phys. Atom. Nucl. 66 (2003) 1994–2016.

Color dipole model approach

- Invariant cross section

$$E\frac{d^3\sigma}{d^3p} = K(s,y,p_T)\int_{x_1}^{1} \frac{d\alpha}{\alpha^2} f^{(n)}_{q/p}\left(\frac{x_1}{\alpha}\right)\frac{d^3\sigma^{qp\to\gamma X}}{d(\ln\alpha)d^2p_T}$$

kinematic factors

quark distribution from QGSM of PDF

Standard quark-nucleon interaction within color dipole model

- Quark-target interaction

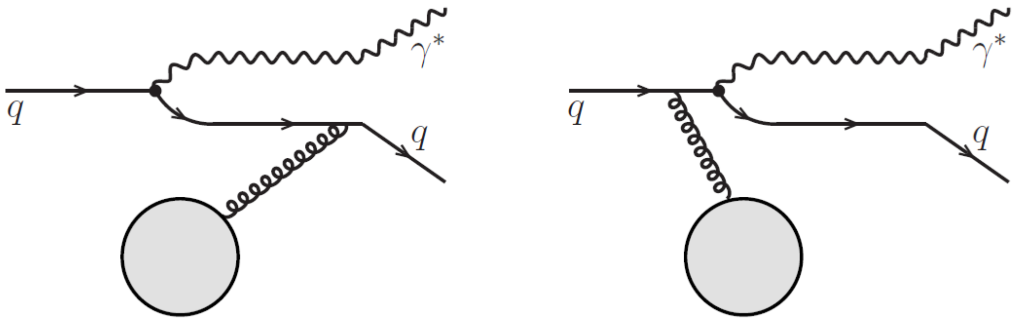
$$\frac{d^3\sigma^{(qN\to\gamma X)}}{d(\ln\alpha)d^2p_T} = \frac{1}{(2\pi)^2}\int d^2\rho_1\, d^2\rho_2\, e^{i\vec{p}_T(\vec{\rho}_1-\vec{\rho}_2)}\Psi^*_{\gamma^* q}(\alpha,\vec{\rho}_2)\Psi_{\gamma^* q}(\alpha,\vec{\rho}_1)\sigma_\gamma(\vec{\rho}_1,\vec{\rho}_2,\alpha)$$

$q \to q\gamma$ wave function

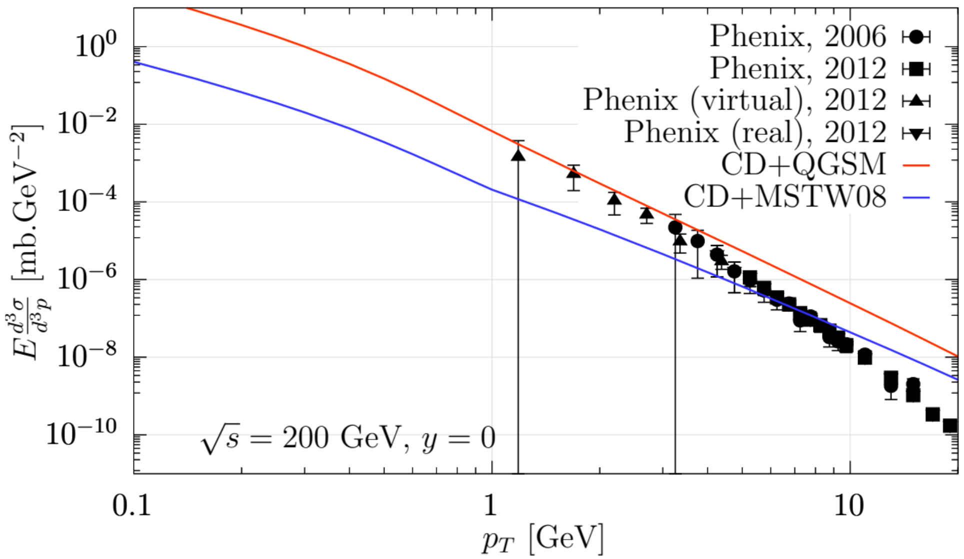
Dipole cross section

- Quark distribution
  - High p_T - standard PDF
  - Low p_T - QGSM inspired quark distribution

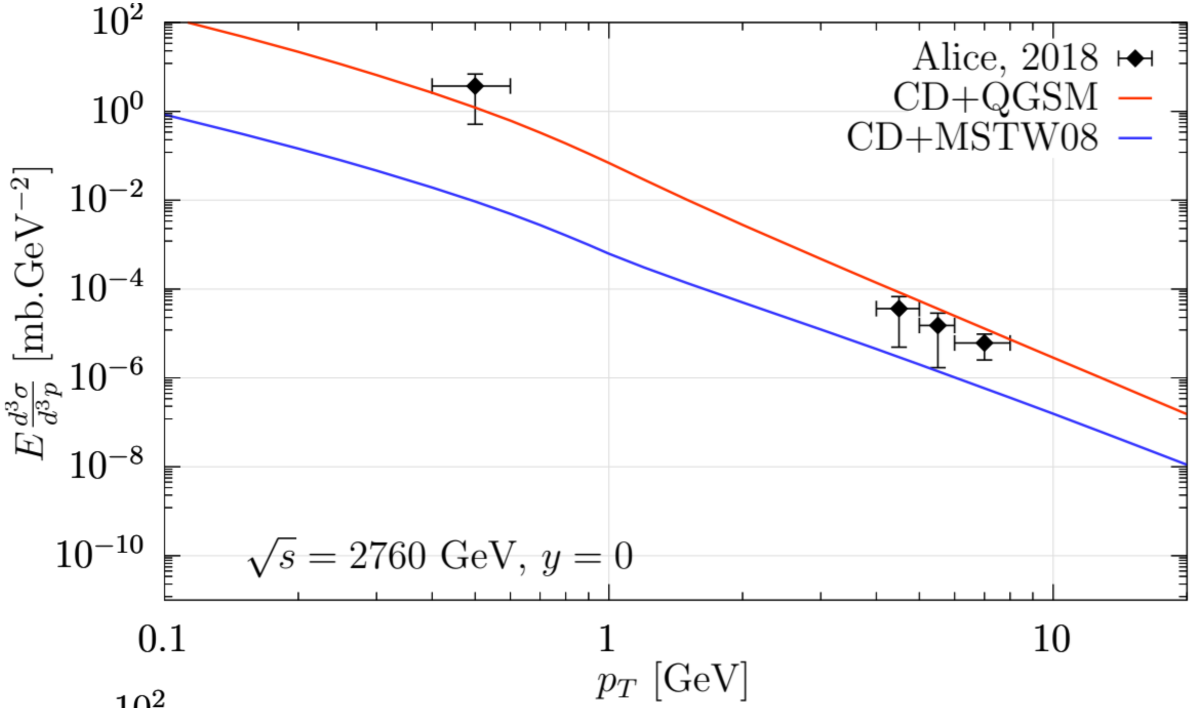
$$x f^{(n)}_{u_v/p}(x) = C_u x^{-\alpha_R}(1-x)^{\alpha_R-2\alpha_B+n-1}$$



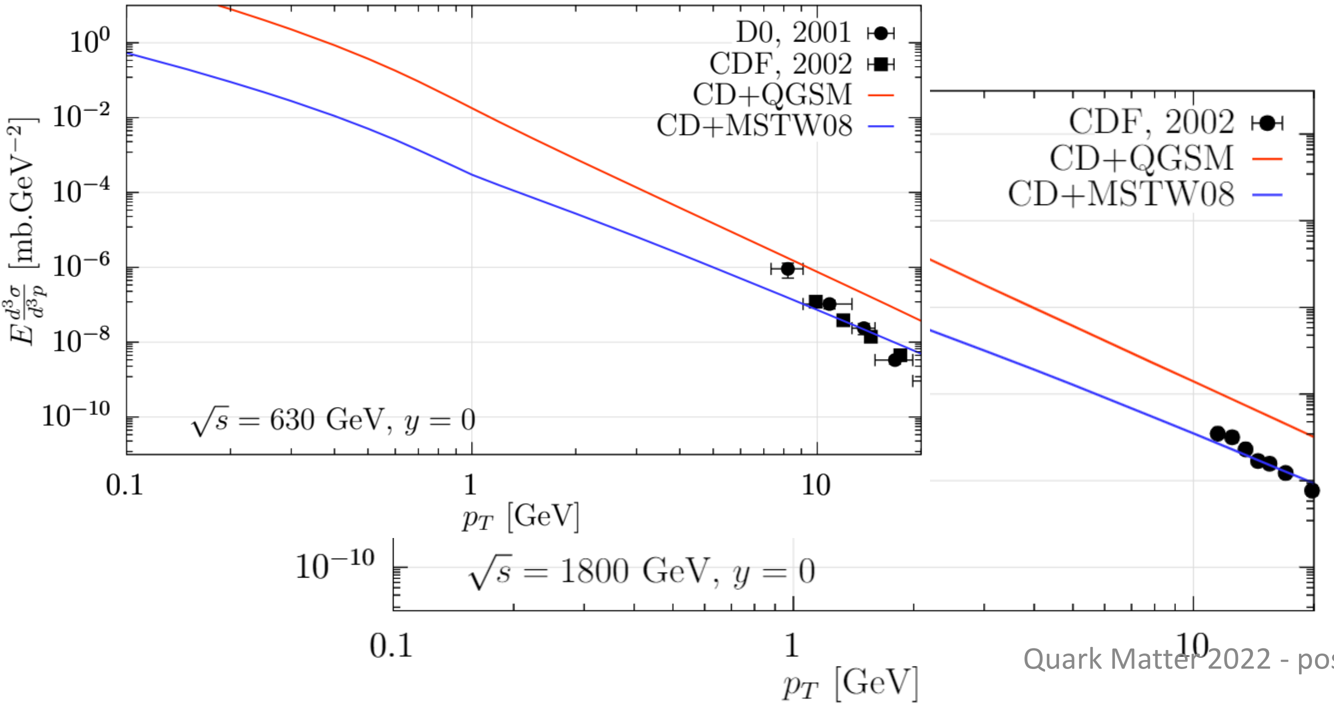
Results



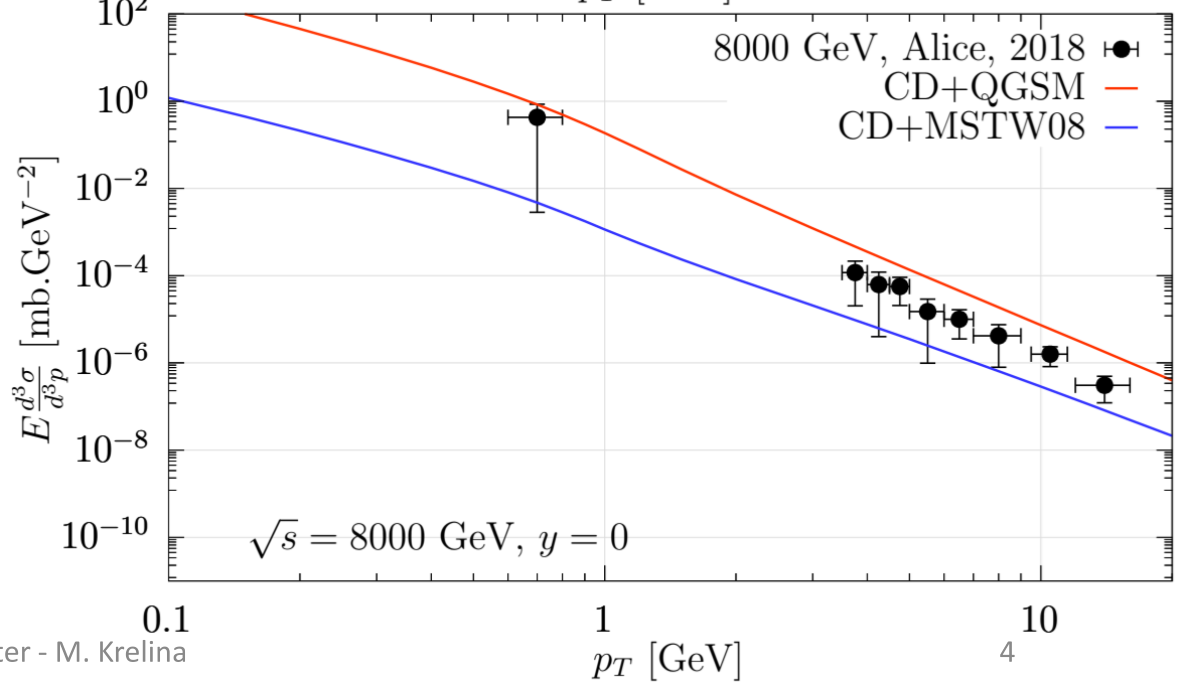
Phenix, 2006
Phenix, 2012
Phenix (virtual), 2012
Phenix (real), 2012
CD+QGSM
CD+MSTW08
$\sqrt{s} = 200$ GeV, $y = 0$
$E\frac{d^3\sigma}{d^3p}$ [mb.GeV^{-2}]
p_T [GeV]



Alice, 2018
CD+QGSM
CD+MSTW08
$\sqrt{s} = 2760$ GeV, $y = 0$
$E\frac{d^3\sigma}{d^3p}$ [mb.GeV^{-2}]
p_T [GeV]



D0, 2001
CDF, 2002
CD+QGSM
CD+MSTW08
$\sqrt{s} = 630$ GeV, $y = 0$
$E\frac{d^3\sigma}{d^3p}$ [mb.GeV^{-2}]
p_T [GeV]
CDF, 2002
CD+QGSM
CD+MSTW08
$\sqrt{s} = 1800$ GeV, $y = 0$
p_T [GeV]



8000 GeV, Alice, 2018
CD+QGSM
CD+MSTW08
$\sqrt{s} = 8000$ GeV, $y = 0$
$E\frac{d^3\sigma}{d^3p}$ [mb.GeV^{-2}]
p_T [GeV]

Conclusions

- Color dipole model – an ideal tool to describe low and high p_T
  - However, different quark distribution for low and high p_T needed
- Novel approach to low p_T quark distribution – inspired by QGSM
- We reached reasonable description of experimental data

Outlook

- Describe data on soft photons from WA102
- Study limits and creating form factor of QGSM quark distribution to PDFs
- Parallel theoretical work on misuse of Low's theorem (B. Kopeliovich)
- Can we explain low-p_T direct photons excess in *Pb-Pb* collisions?