Direct Photons at LHC

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Kopeliovich, Rezaeian, Pirner and Ivan Schmidt, arXiv:0704.0642

Heavy Ion Collisions at the LHC Last Call for Predictions, CERN 2007

Direct photons production

- A powerful proble for the initial state of matter created in HIC
  direct photon R_{AA}, $v2$ and ... yet to be understood.
  However, the primary motivation, since 20 years ago...
- To extract information about the gluon density inside proton in conjunction with DIS.
  Nevermind, it has never happened!
- To allow for precision test of pQCD(few clean sub-processes)
  It has not yet achived either.

Sources of direct photons:

- 1: LO: Compton scattering process $q + q -> \bar{q} + \gamma$ and annihilation process : $q + \bar{q} -> g + \gamma$
- 3: NLO: Bremsstrahlung
- 4: NNLO: Jet fragmentation
- 5: pre-equilibrium photon, jet-photon conversion in presence of medium

Can one disentangle the sources of photons:
Not really! (which frame)

Direct photon productions and pQCD

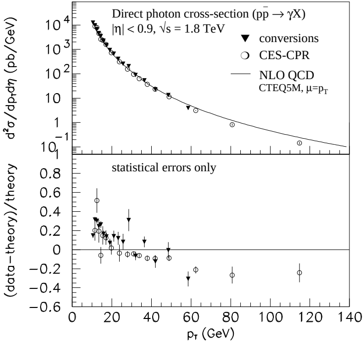
- Rumor:
  pQCD calculation describe photon production very well.
- Fact:
  Typically $20 - 30\%$ theoretical uncertainty due to the various choice of scale.
  Intrinsic uncertainties of NLO: the renormalization, factorization and fragmentation scale.
- Comparison with experiment: depending on energy the deviation is quite significant.

puzzel #1, low p_T problem

Two approaches:

- The data cannot be simultaneously fitted with a single set of scales and structure functions. Aurenche *et al*, 1998
- Take into account recoil corrections due to initial stat gluon radiation. Apanasevich *et al*, 1999
  $< k_T > \approx 1$ GeV for fixed tagert
  $< k_T > \approx 3 - 4$ GeV for Tevatron
  $< k_T > \approx 5 - 7$ GeV for LHC

puzzel #2, high p_T problem



- "We find that the shape of the cross section as a function of p_T is poorly described by next-to-leading-order QCD predictions, but agrees with previous CDF measurements"....CDF collaboration, PRD 70 (2004) 074008

- p_T distribution of photon bremsstrahlung in quark-nuclues intercations can be described in terms of the universal dipole cross section $\sigma^{q}_{q\bar{q}}(r;x)$: Kopeliovich, *et al* PRC 59 (1999) 1609

$$\frac{d\sigma^{qA}(q\to q\gamma)}{d(ln\alpha)d^2\vec{p}_T d^2b} = \frac{1}{(2\pi)^2}\sum_{in,f}\sum_{L,T}\int d^2\vec{r}_1 d^2\vec{r}_2 e^{i\vec{p}_T.(\vec{r}_1-\vec{r}_2)} \times \phi^{\star T,L}_{\gamma q}(\alpha,\vec{r}_1)\phi^{T,L}_{\gamma q}(\alpha,\vec{r}_2)\Sigma_\gamma(x,\vec{r}_1,\vec{r}_2,\alpha,b),$$

where

$$\Sigma_\gamma(x,\vec{r}_1,\vec{r}_2,\alpha,b) = 1 - e^{-\frac{1}{2}\sigma_{q\bar{q}}(x,\alpha r_1)T(b)} - e^{-\frac{1}{2}\sigma_{q\bar{q}}(x,\alpha r_2)T(b)} + e^{-\frac{1}{2}\sigma_{q\bar{q}}(x,\alpha(\vec{r}_1-\vec{r}_2))T(b)}.$$

$$\frac{d\sigma^{DY}(pp\to\gamma^\star X)}{dM^2 dx_F d^2\vec{p}_T} = \frac{\alpha_{em}}{3\pi M^2(x_1+x_2)}\int_{x_1}^{1}\frac{d\alpha}{\alpha}F_2^p(\frac{x_1}{\alpha},Q)\frac{d\sigma^{qN}(q\to q\gamma^\star)}{d(ln\alpha)d^2\vec{p}_T}$$

$$\frac{d\sigma^{\gamma}(pA\to\gamma X)}{dx_F d^2\vec{p}_T} = \frac{1}{x_1+x_2}\int_{x_1}^{1}\frac{d\alpha}{\alpha}F_2^p(\frac{x_1}{\alpha},Q)\times\frac{d\sigma^{qA}(q\to q\gamma)}{d(ln\alpha)d^2\vec{p}_T}.$$

Dipole parametrizations

- Golec-Biernat, Wusthoft (GBW) 1999:

$$\sigma_{q\bar{q}}(x,\vec{r}) = \sigma_0 \left(1 - e^{-r^2/R_0^2}\right),$$

it does not match with QCD evolution DGLAP at large value of Q^2. This failure can be clearly seen in the energy dependence of $\sigma_{tot}^{\gamma^\star p}$ for $Q^2 > 20$ GeV^2, where the the model predictions are below the data.

- GBW couple to DGLAP, Bartels *et al* 2002:

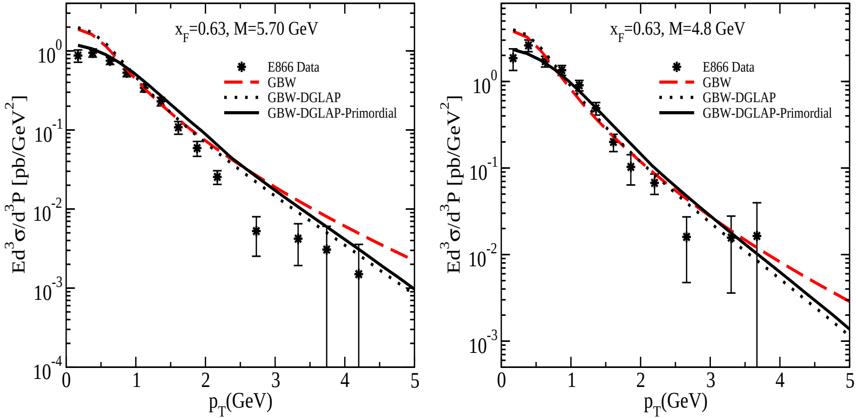
$$\sigma_{q\bar{q}}(x,\vec{r}) = \sigma_0 \left(1 - exp\left(-\frac{\pi^2 r^2 \alpha_s(\mu^2) xg(x,\mu^2)}{3\sigma_0}\right)\right),$$

where the scale μ^2 is related to the dipole size by

$$\mu^2 = \frac{C}{r^2} + \mu_0^2.$$

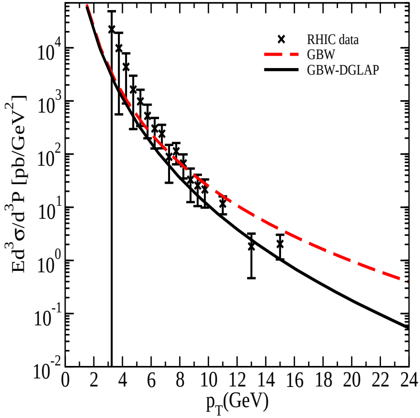
$$\frac{\partial xg(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi^2} \int_x^1 dz P_{gg}(z) \frac{x}{z} g(\frac{x}{z},\mu^2).$$

Dilepton spectrum in 800− GeV pp

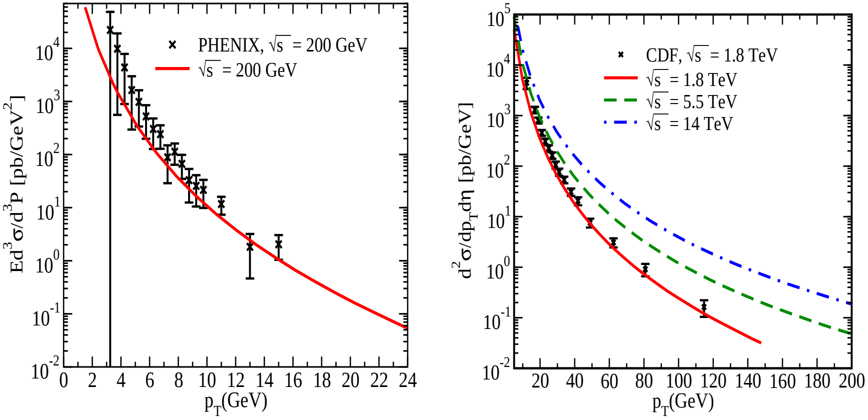


- constant primordial momentum $\langle k_0^2 \rangle = 0.4\text{GeV}^2$ is incorporated within the GBW-DGLAP dipole model (solid line)

Direct photon productions at RHIC and Tevatron for *pp*

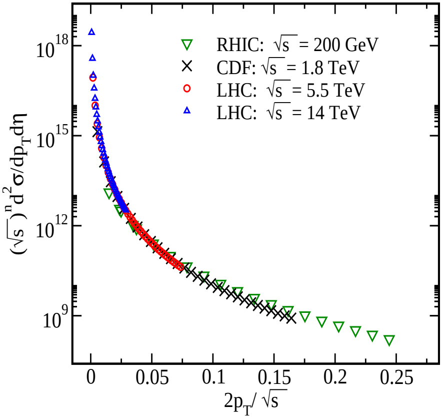


Direct photon productions at RHIC and LHC



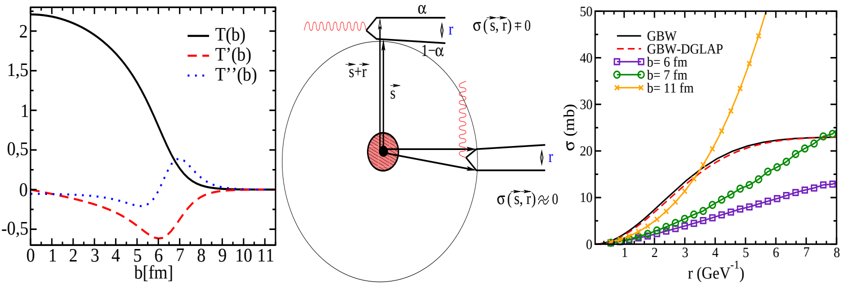
- Neither *K*-factor, nor higher twist corrections, no quark-to-photon fragmentation function are to be added.

Direct photon productions and scaling



- $d^2\sigma/dp_T d\eta \approx (s/s_0)^{-n/2} F(x_T)$, prediction: n=3.2

Elliptic flow and dipole orientation

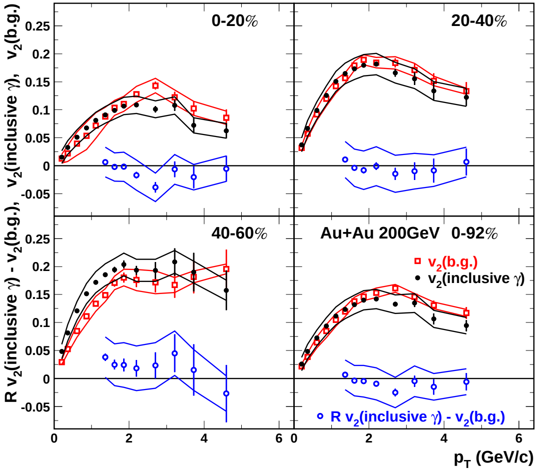


- The origion of elliptic anisotropy: rescatterings and shape of the system

- The key function which describes the effect of multiple interactions is eikonal exponential, $\exp(-\frac{1}{2}\sigma^{q}_{q\bar{q}}(r)\,T_A(b))$ which arises in the Glauber formalism as an approximation to the convolution of cross section and nuclear thickness function:

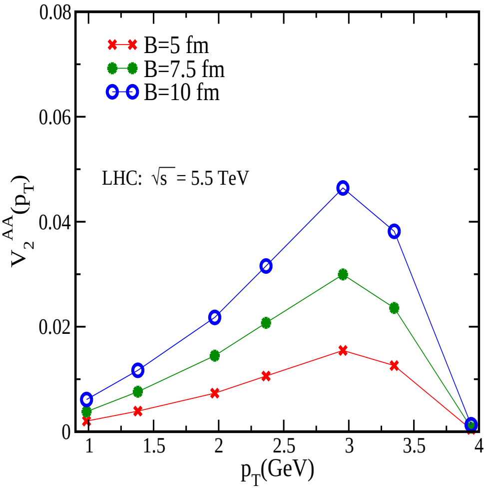
$$\sigma^{q}_{q\bar{q}}(r)\,T_A(b) \approx \int d^2\vec{s}\sigma^{q}_{q\bar{q}}(\vec{r},\vec{s})\,T_A(\vec{b}+\vec{s}).$$

Direct photon Elliptic flow at RHIC: data



PHENIX collaboration, PRL. 96 (2006) 032302

Direct photon Elliptic flow for *AA* at LHC, preliminary results



Summary and outlook

- direct photon production and DY dilepton pair production processes can be described within the same color dipole approach without any free parameters.
- in the dipole approach there is no ambiguity in defining the intrinsic transverse momentum. Such a purely non-perturbative primordial momentum improves the results in the case of dilepton pair production, but does not play a significant role for direct photon production at the given experimental range of p_T.
- color dipole formulation coupled to the DGLAP evolution provides a better description of data at large transverse momentum compared to the GBW dipole model.
- Direct photon at both RHIC and LHC flow, $v2 > 0$.