RECENT RESULTS IN PROMPT PHOTON PRODUCTION*

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An introduction is given to recent results in prompt photon production in different reactions.

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1. Introduction

Light played always a key role in the attempts to understand early states of hadronic matter. In early reports on the creation of the World [1], light provided clarity and structure. Nowadays, we can see the Universe back to some 10^5 years after the Big Bang by observation of light. In the microscopic world photons tell us about the original hard interactions through fire balls created in nucleus–nucleus collisions. Photons also give a rather clear message on partonic patterns, in contrast to quarks and gluons which are not directly observable. Only the last two points will be further discussed in this report.

Usually photons are called "prompt" (or "direct"), if they are coupling to interacting partons, in contrast to photons from hadron decays or photons emitted by leptons. Figs. 1 show examples of leading order (LO) graphs of prompt photon emissions in *ep* and hadron–hadron interactions. The *ep* interactions in Figs. 1(a) and (b) are called photoproduction, if the photon virtuality Q^2 is small, (typically $< 1\,\mathrm{GeV}^2$), which means in case of the HERA experiments [2,3] that the scattered electron stays in the beam pipe. The photon can interact directly (Fig. 1(a)) or fluctuate into a hadronic state, part of which interacts with the incident proton (Fig. 1(b)).

There is substantial interest in the observation of prompt photons as they are more directly related to partonic interactions than jets and sensitive to the gluon content of the interacting particles (resolved photon and proton,

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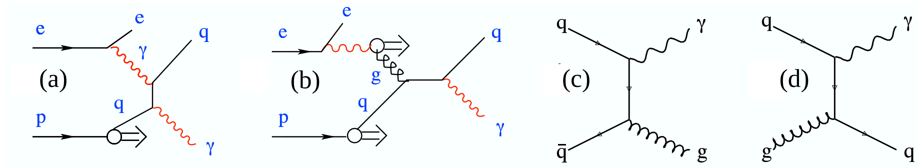

Fig. 1. Examples of LO graphs for prompt photon production in γp (a), (b) and hadron–hadron interactions (c), (d).

Figs. 1(b) and (d), respectively). They are an important background at searches at the LHC (*e.g.* Higgs $\rightarrow \gamma\gamma$), and as they are not strongly interacting, they help to disentangle in nucleus–nucleus collisions effects of initial or final state interactions, of a quark–gluon plasma or hadron gas.

Various calculations exist in next to leading order (NLO) perturbative QCD (pQCD) based on next to leading order (NLO) matrix elements and, in most cases, collinear parton densities (pdfs) of the interacting particles. In recent analyses also $k_{\rm t}$ factorised pdfs have been used [4] for γp and pp interactions. Further non-perturbative elements enter the calculations. Besides the γ's indicated in Figs. 1, there are γ's from fragmentation processes of quarks and gluons which are part of the calculated signal. Detailed comparisons with experimental data require also simulation of the hadronic final state. First, because photons may be measured together with jets instead of inclusively, and second, because some experiments require an isolation cone for the measured prompt photons.

TABLE I

Characteristic differences of experiments. The hadronic energies are in GeV, the distance from vertex to calorimeter in metres. The experiments exploiting explicit π^0 id, require no isolation cone R.

	reaction	had. energy	distance	yield/backgd	$R(\eta,\phi)$
H1/ZEUS	$\gamma p, ep$	200	1	shower analysis	1
D0	$p\bar{p}$	1960	1	shower analysis	0.4
CDF	$p\bar{p}$	1800	1	shower analysis	0.4
CDF	$p\bar{p}$	1800	1	γ conversions	0.4
E706	$pp, pN, \pi N$	31, 39	9	measure γ/π^0	–
WA98	Pb–Pb	17.3	22	measure γ/π^0	–
PHENIX	Au–Au	200	5	measure γ/π^0	–

Isolation of the prompt photon candidates is required in many experiments to cope with the large background of photons from π^0 and η decay which may not be resolved as single γ's in calorimetric measurements. The prompt photon signal is then determined by sophisticated shower shape analyses. Other experiments work without an explicit isolation condition and subtract measured π^0 and η yields[1].

In the following a few recent results of experiments with characteristics given in Table I will be shortly discussed.

2. Prompt photons in γp at HERA

Recent results from H1 on inclusive prompt photons show that NLO calculations [11, 12] describe the measured distributions well in shape, being however low by about 30% in normalisation, when corrections for hadronisation are applied using the leading order plus parton shower Monte Carlo (MC) programs of PYTHIA and HERWIG. The MC generators themselves are also low by a similar amount. A similar discrepancy was observed in $\gamma\gamma$ interactions by OPAL [5]. If a jet is required in addition to the prompt γ, the NLO description is good in various distributions (see the figures in Refs. [3, 13]). One may speculate, that here more LO like configurations are selected which may reduce the phase space for higher order emissions. See [13, 14] for first results in DIS.

3. Prompt photons in hadronic reactions

Notoriously, there are difficulties to describe prompt photon production in pQCD, particularly at fixed target energies. For example the high statistics data of the E706 collaboration [8] (see Fig. 2) at $\sqrt{s} = 32$ and 39 GeV are above NLO theory [15] by about a factor 2 at low $p_{\rm t}$. Agreement is reached by an *ad hoc* smearing by an intrinsic parton $k_{\rm t}$ of the protons $\gtrsim 1\,$GeV (see *e.g.* [16] for theoretical improvements by resummations). The deviations are smaller at high energies, but the CDF data [6] at $\sqrt{s} = 1.8\,$TeV show also steeper a $p_{\rm t}$ dependence than predicted [17]. It is interesting to note that more recent CDF results [18] which are based on photon conversions are consistent with the former calorimetric [6] measurements with quite different systematics. However, the preliminary D0 data [7, 19] from Tevatron Run 2 at $\sqrt{s} = 1.96\,$TeV are consistent with NLO theory [20] within errors. See [19] for di-photon results from CDF.

In nucleus–nucleus interactions, thermal photons are expected due to quark–gluon plasma (QGP) or, at even smaller $p_{\rm t}$, from a hadron gas. Fig. 3(a) shows the interpretation of the WA98 Pb–Pb data ($\sqrt{s_{NN}} = 17.3\,$GeV) in terms of a convolution [21] of such thermal photon emissions

[1] From the experimental data mentioned in this report, Refs. [2, 3, 5–7] belong to the first and Refs. [8–10] to the second group.

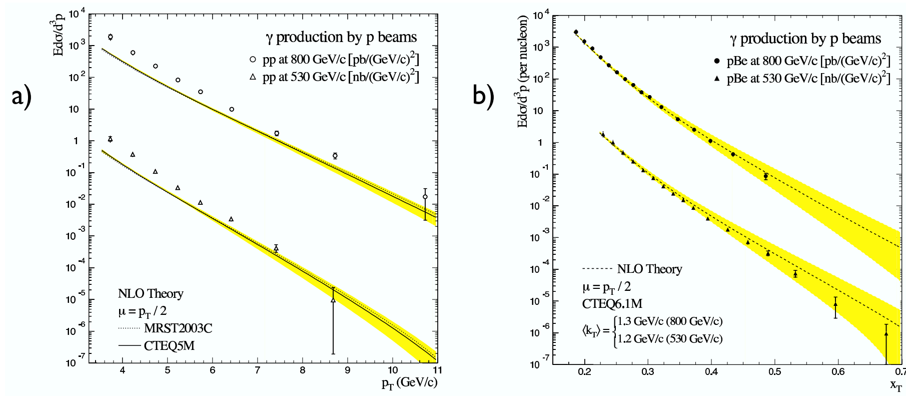

Fig. 2. E706 results compared with pQCD. (a) $pp \to \gamma X$ *versus* $p_{\rm t}$, (b) $p{\rm Be} \to \gamma X$ *versus* $x_{\rm t} = 2p_{\rm t}/\sqrt{s}$ with $k_{\rm t}$ smearing.

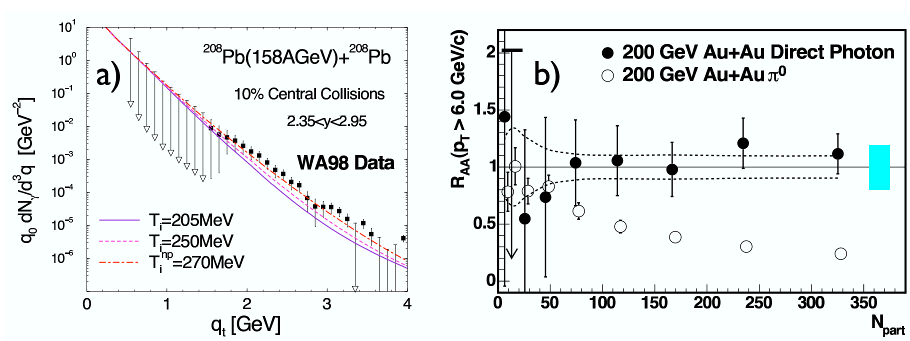

Fig. 3. (a) WA98 results described by QGP effects and pQCD. (b) PHENIX yields for γ and π^0 at $p_{\rm t} > 6\,{\rm GeV}$ *versus* the number of participating nucleons, scaled from Au–Au to NN.

with the pQCD treatment of nucleon–nucleon scattering. The high initial temperature of the plasma of 270 MeV is lowered to 205 MeV in other scenarios with additional $k_{\rm t}$ smearing. Definite conclusions are difficult to draw, due to the large background at low $p_{\rm t}$ and the lack of pPb data for a direct comparison.

Prompt photons in Au–Au collisions at the higher RHIC energies [10] ($\sqrt{s_{NN}} = 200\,{\rm GeV}$) are consistent with scaling from pp collisions (Fig. 3(b)), in remarkable contrast to the strongly interacting π^0s, showing that their suppression in collisions with many participating nucleons is a final state effect.

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