Photon Total Cross-Sections

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April 8th, 2003
Photon 2003, Frascati

✦ Present predictions on $\gamma\gamma \rightarrow \text{hadrons}$
✦ Why predictions differ
✦ Which predictions to trust?
✦ A work program to reach stable predictions: Towards a QCD Description of the decrease and the increase of total cross-sections through Soft Gluon Summation (Bloch-Nordsieck Model) and Mini-jets

With A. de Roeck, R.M. Godbole, A. Grau and Y.N. Srivastava
With input from

A. Grau, G.P. and Y.N. Srivastava, PR D60 (1999) 114020
Present Predictions

Already at $\sqrt{s} = 500$ GeV
predictions differ by a factor 3
Why predictions differ?

1. There is no calculation from first principles but this would not necessarily be a deterrent from making correct predictions as the $pp/p\bar{p}$ case shows

2. All models for $\gamma\gamma$ do some degree of extrapolation from
   ♦ $pp/p\bar{p} \implies$ thus doubling the errors
   ♦ from $\gamma p \implies$ as there are differences among data at high energy

3. At low energies old $\gamma\gamma$ data have large errors and even LEP data probably have a 10% normalization error

4. Data do not reach a high enough energy to pinpoint how the cross-section rises (unlike the $pp/p\bar{p}$ case)
Which predictions to trust

\begin{itemize}
  \item \textbf{(a)} is the photon like a proton?

  Then models based on Gribov factorization

  \[
  \sigma_{\gamma\gamma} = \frac{\sigma_{\gamma p}^2}{\sigma_{pp/p}}
  \]

  or similar extensions

  \[ \Rightarrow \sigma_{\gamma\gamma}(\sqrt{s} = 1 \text{ TeV}) = 500 \div 700 \text{ nb} \]

  \item \textbf{(b)} QCD models \( \sigma_{jet} \Rightarrow \text{Eikonal Minijet Model} \)

  \[ \Rightarrow \sigma_{\gamma\gamma}(\sqrt{s} = 1 \text{ TeV}) = 1000 \div 1500 \text{ nb} \]

\end{itemize}

But it is time to get serious
**QCD vs. stable predictions**

A work program to reach stable predictions may be based on

- at low energy \( \Longrightarrow \) The photon is like a proton
- at high energy Minijets+Resummation
- low and high with a unified description

\[
\sigma_{\gamma\gamma}^{\gamma\gamma} = 2P_{\text{had}}^{\gamma\gamma} \int d^2 \vec{b} [1 - e^{-\chi(b,s)/2}]
\]

with

\[
\chi(b, s) = \frac{4}{9} \frac{[\chi_{pp} + \chi_{p\bar{p}}]_{\text{soft}}}{2} + A_{BN}(b, s, p_{t\text{min}}) \sigma_{\text{jets}}^{\gamma\gamma}(s, p_{t\text{min}})
\]

Resummation of soft gluons takes place through Fourier transform of resummed soft gluon transverse momentum distribution

\[
A_{BN}(b, s, p_{t\text{min}}) = \frac{e^{-h(b,s,p_{t\text{min}})}}{\int d^2 \vec{b} e^{-h(b,s,p_{t\text{min}})}}
\]

- first obtain soft eikonal from analogous QCD minijets+resummation for protons
- fix jet parameters from \( \gamma p \)
  - parton densities
  - \( p_{t\text{min}} \)
**Bloch-Nordsieck resummation**

Technically rather challenging

\[ h(b, s) = \int_{k_{\text{min}}}^{k_{\text{max}}} d^3 \bar{n}_{\text{gluons}}(k) \left[ 1 - e^{i k \cdot b} \right] \]

\[ k_{\text{max}} \rightarrow \text{average over densities} \uparrow \text{as } \sqrt{s} \uparrow \]

\[ k_{\text{min}} = 0 \text{ in principle but one needs a } \text{model for} \]

\[ \alpha_s(k_t) \text{ as } k_t \rightarrow 0 \]
Modelling for $\alpha_s$ in the infrared limit

We choose $\alpha_s$ from Nakamura, GP, Srivastava, Z.Phys.C21:243,1984 such that it is

- Integrable
  - but
- singular

- inspired by the Richardson potential for quarkonium bound states

$$\tilde{\alpha}_s(k_\perp^2) = \frac{12\pi}{(33 - 2N_f) \ln[1 + p(\frac{k_\perp}{\Lambda_{QCD}})^2 p]}$$

- for $K_\perp \gg \Lambda_{QCD}$ $\tilde{\alpha}_s \to \alpha_s^{AF}$
- for $K_\perp \ll \Lambda_{QCD}$ $\tilde{\alpha}_s \to (k_\perp^2)^{-p}$

If $p$ is smaller than 1 the integral can be done
Energy dependence in impact parameter $b$

The energy dependence which ultimately will soften the rise due to mini-jets comes from the maximum transverse momentum allowed to a single gluon.

$$q_{\text{max}}(\hat{s}) = \frac{\sqrt{\hat{s}}}{2}(1 - \frac{\hat{s}_{\text{jet}}}{\hat{s}})$$

with integration to be done over

- $\hat{s}$ the energy of the initial parton-parton subprocess
- the jet-jet invariant mass $\sqrt{\hat{s}_{\text{jet}}}$

Averaging over densities

$$\langle q_{\text{max}}(s) \rangle = \frac{\sqrt{s}}{2} \sum_{i,j} \frac{dx_1}{x_1} f_i/a(x_1) \int \frac{dx_2}{x_2} f_j/b(x_2) \sqrt{x_1 x_2} \int dz (1 - z)$$

$$\sum_{i,j} \frac{dx_1}{x_1} f_i/a(x_1) \int \frac{dx_2}{x_2} f_j/b(x_2) \int dz$$

with the lower limit of integration in the variable $z$ given by $z_{\text{min}} = 4p_{t_{\text{min}}}^2/(sx_1 x_2)$. 
Soft gluon emission and the intrinsic transverse momenta

\[
\sqrt{\langle k_t^2 \rangle_{\text{int}}} \quad (\text{GeV})
\]

\[
M \quad (\text{GeV})
\]

\[\Lambda = 0.3 \text{ GeV}\]
\[\Lambda = 0.2 \text{ GeV}\]
\[\Lambda = 0.1 \text{ GeV}\]
Soft Gluon Emission and Energy Dependence

The Bloch Nordsieck model

- is like EMM model with $\sigma_{jet}^{QCD}$ driving the rise

  and in addition

  Soft Gluon Emission from Initial State Valence Quarks in $k_t$-space to give impact parameter space distribution of colliding partons

- introduces energy dependence in the b-distribution of partons in the hadrons $\Rightarrow$ which depends on
  1. $p_{tmin}$
  2. parton densities

Two main results:

1. softening effect
2. dependence of hard scattering parameters is reduced

The softening effect happens

- as $\sqrt{s} \uparrow$ the phase space available for soft gluon emission also $\uparrow$
- the transverse momentum of the initial colliding pair due to soft gluon emission $\uparrow$
- more straggling of initial partons $\Rightarrow$ less probability for the collision
In the proton-proton and proton-antiproton fit with the Bloch-Nordsieck (BN) model, the eikonal takes the form

\[ n(b, s) = \sigma_{\text{soft}} A_{\text{BN}}^{\text{soft}} + \sigma_{\text{jet}} A_{\text{BN}}^{\text{jet}} \]

Soft gluon emission has here a twofold effect as the energy increases:

- with \( \sigma_{\text{soft}} \) constant or \( \downarrow \) \[ \sigma_{\text{soft}} A_{\text{BN}}^{\text{soft}} \downarrow \]

- with \( \sigma_{\text{jet}} \uparrow \) \[ \sigma_{\text{jet}} A_{\text{BN}}^{\text{jet}} \uparrow \] but not as much as without soft gluons
A good description is obtained with a soft part given by

$$\sigma_{soft}^{pp} = \sigma_0 A_{BN}^{soft}(b, s) \quad \sigma_0 = 48 \text{mb}$$

and

$$\sigma_{soft}^{p\bar{p}} = \sigma_0 (1 + \frac{2}{\sqrt{s}}) A_{BN}^{soft}(b, s)$$
Photoproduction data before HERA
ZEUS 96 Preliminary
H1 94
ZEUS 92 and 94
ZEUS BPC 95

with BN resummation

GRV $p_{\text{min}} = 1.4, 1.6, 1.8 \text{ GeV}$

Soft from pp soft eikonal times 2/3
Photoproduction data before HERA
ZEUS 96 Preliminary
H1 94
ZEUS 92 and 94
ZEUS BPC 95

GRS $p_{t\text{min}} = 1.2, 1.3, 1.4, 1.5$ GeV
Software from pp soft eikonal times 2/3

with BN resummation
Photoproduction data before HERA
ZEUS 96 Preliminary
H1 94
ZEUS 92 and 94
ZEUS BPC 95

with BN resummation

CJKL $p_{t_{\text{min}}}=1.6,1.8,2$ GeV (red)
Present Update for $\gamma\gamma$

Present update is done using following improvements

1. Soft part of the eikonal $n(b, s)$ directly from proton and antiproton processes $\rightarrow n_{soft}^{\gamma\gamma}(b, s)$ given by
$$\frac{4}{9} \frac{n_{soft}^{pp} + n_{soft}^{p\bar{p}}}{2}$$ using fit to protons,

2. soft resummation for hard scattering,

3. two types of densities

![Graph showing photon total cross-sections](image-url)
Aspen EMM and resummation

Phad constant = 1/240

GRS EMM \( p_{\text{min}} = 1.5 \) GeV \( k_0 = 0.4 \) \( A = 0 \)

GRS \( p_{\text{min}} = 1.32 \) GeV BN, soft from \( p/p\bar{p} \)

CJLK \( p_{\text{min}} = 1.6, 1.8, 2 \) GeV BN, soft from \( p/p\bar{p} \)

Aspen

LEP2-L3 189 GeV and 192-202 GeV

LEP2-OPAL 189 GeV

TPC

Desy 1984

Desy 1986