“From Quarks and Gluons to Hadrons and Nuclei”
Erice-Sicily, 16-24 September 2011

Hadron Production in Jets at LHC

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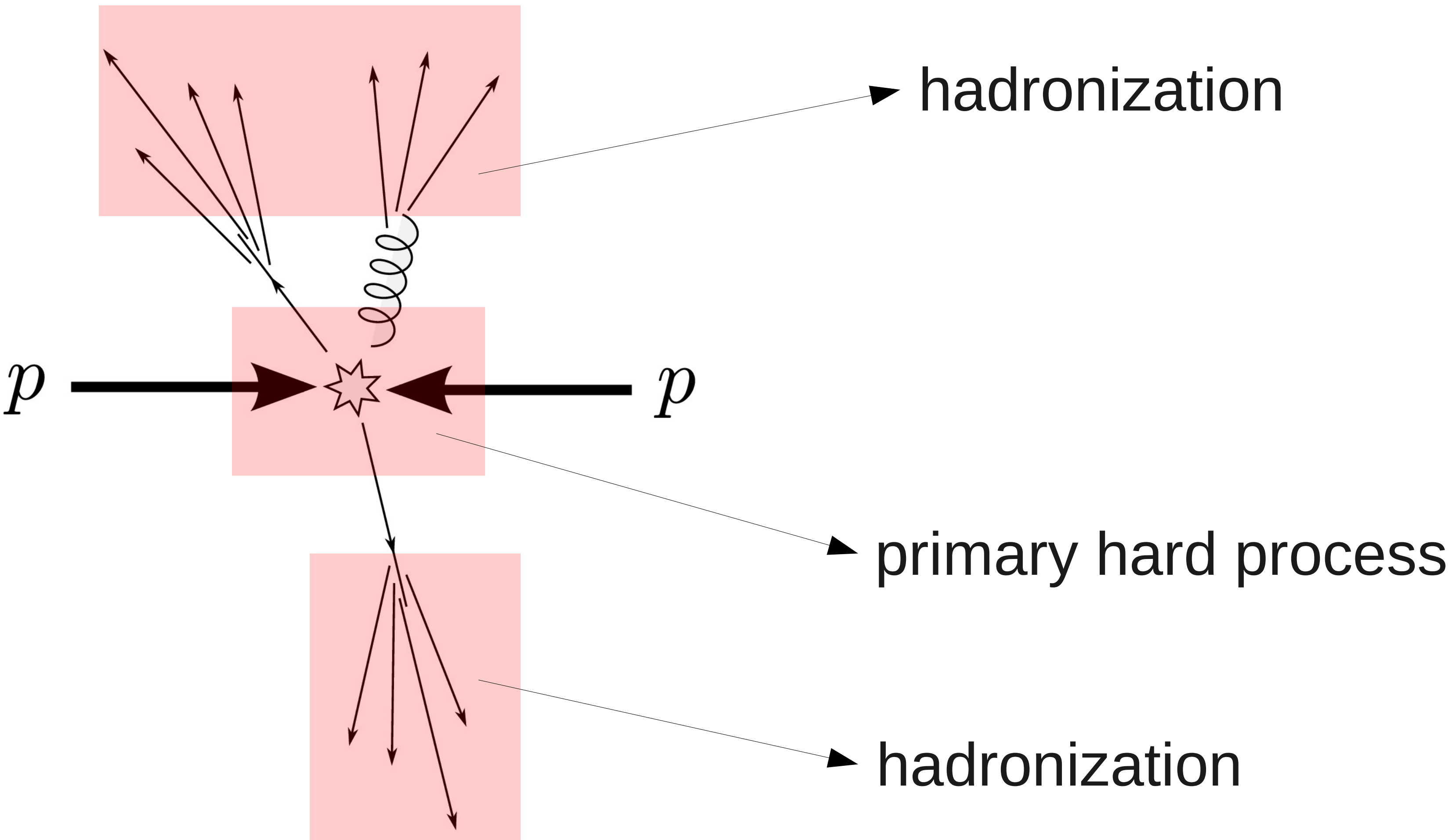
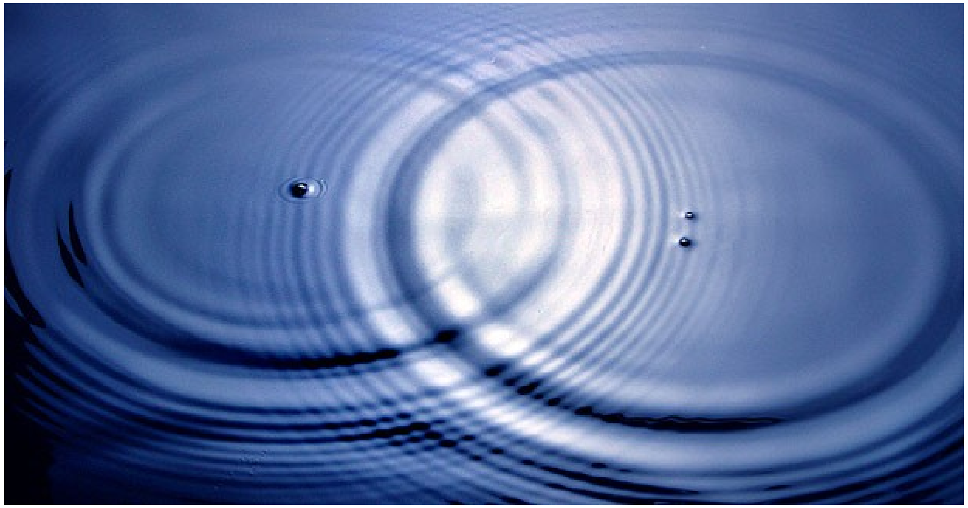
A hard process at LHC



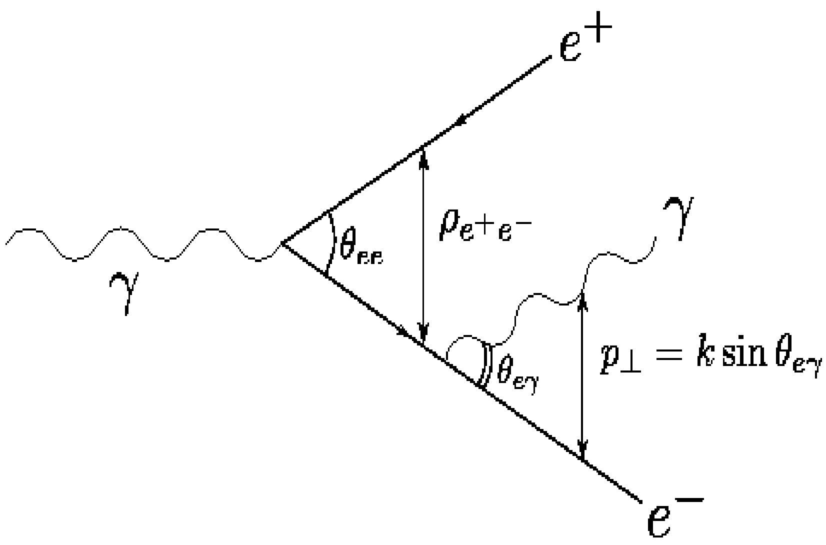
Waves and obstacles: size is important



Wavelength is smaller or comparable with the size of an obstacle:
obstacle shape plays important role in dynamics

Wavelength is larger than the size of an obstacle:
obstacle shape is irrelevant

QED: the essence of coherence



- To which extent e^+ and e^- independently emit gamma's?

- If the wavelength of the photon is larger than the transverse separation of $e^+ e^-$, it cannot resolve the internal structure of the pair and probes only the electric charge, i.e. is effectively emitted by the chargeless object -> emission suppressed

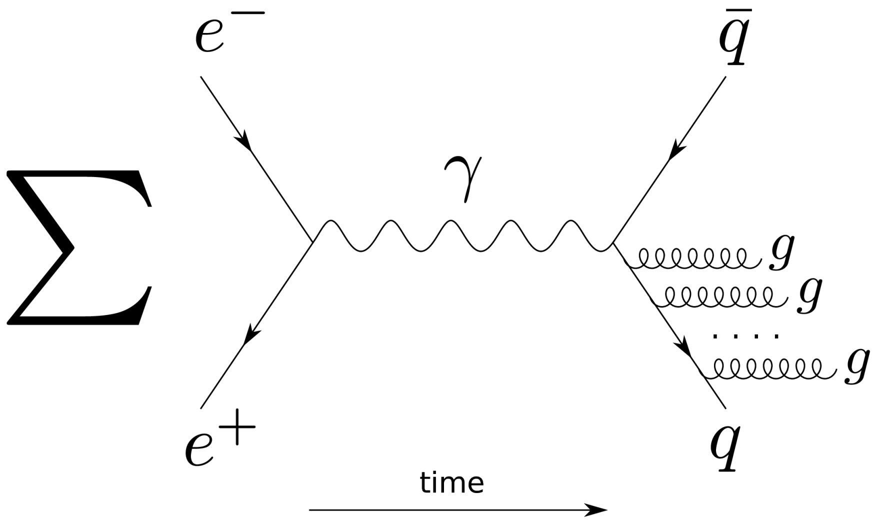
$$\lambda_{\perp\gamma} = \frac{1}{p_\perp} = \frac{1}{k\Theta_{e\gamma}} \; ; \qquad \rho_{e^+e^-} = \lambda_{\perp\gamma}\frac{\Theta_{ee}}{\Theta_{e\gamma}}$$

$$\rho_{e^+e^-} \ll \lambda_{\perp\gamma}, \quad \text{when} \quad \frac{\Theta_{ee}}{\Theta_{e\gamma}} \ll 1$$

The emission at large angles is suppressed (Chudakov effect)

A.E. Chudakov. *Izv. Akad. Nauk SSSR*, Ser. Fiz., 19:650, 1955.

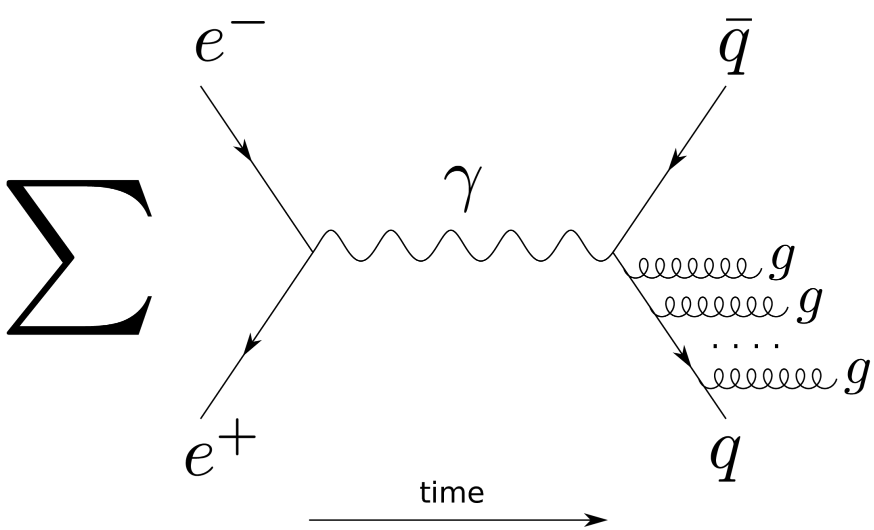
QCD: soft hadron production in e^+e^-



$$\xrightarrow{p_T \longrightarrow 0} \quad C_F \cdot \frac{\alpha_s(p_T)}{p_T^2}$$

Soft gluons are emitted coherently. Due to their large wavelength soft gluons do not resolve the structure of $q\bar{q}$ pair and see only the total color charge.

QCD: soft hadron production in e^+e^-



color factor
for gluon emission
from a quark

$$p_T \longrightarrow 0 \qquad C_F \cdot \frac{\alpha_s(p_T)}{p_T^2}$$

common p_T dependence,
(MLLA approximation)

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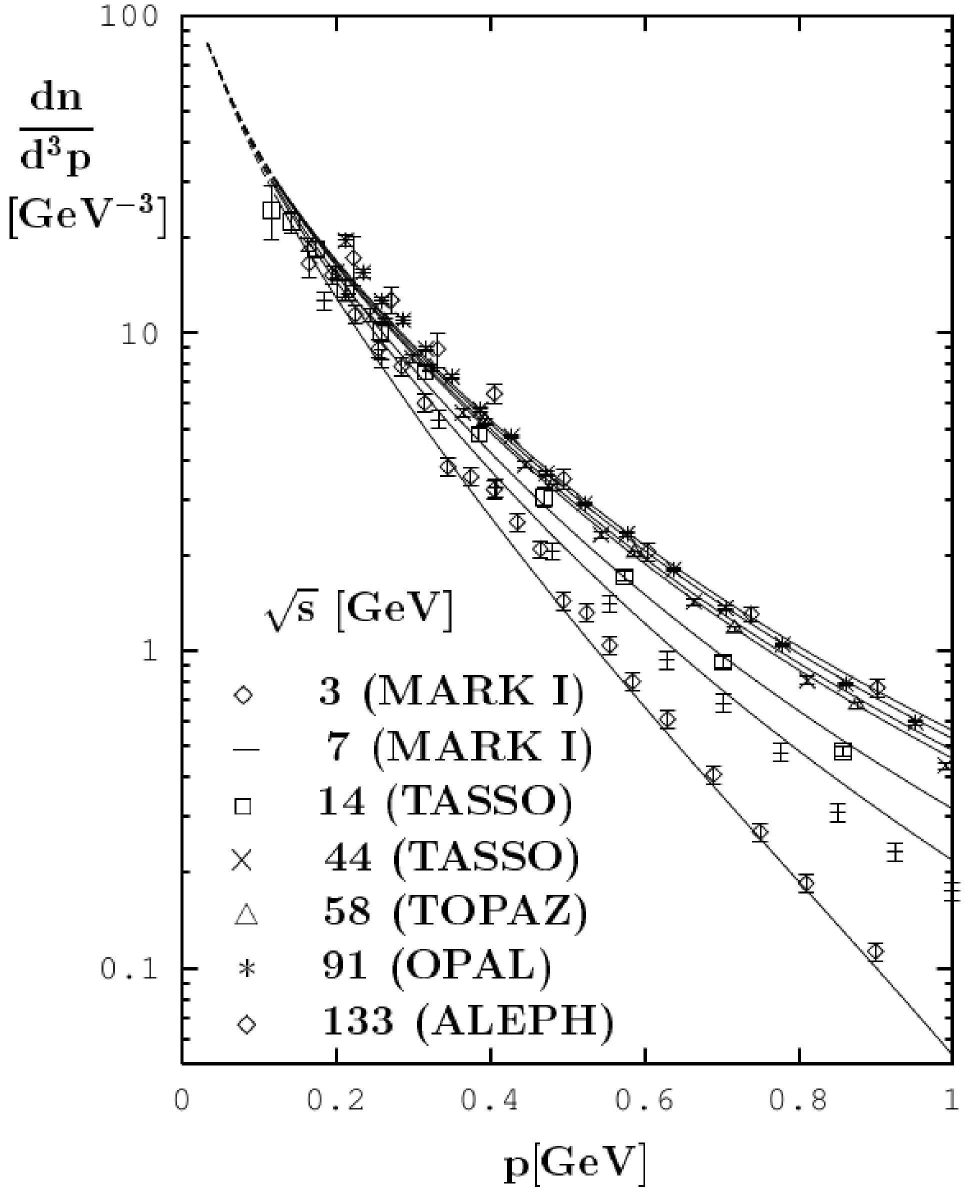
Soft hadron production in e^+e^-



n – inclusive particle densities of charged particles in e^+e^- annihilations for different collision energies

$$n \sim C_F \cdot \frac{\alpha_s(p_T)}{p_T^2}$$

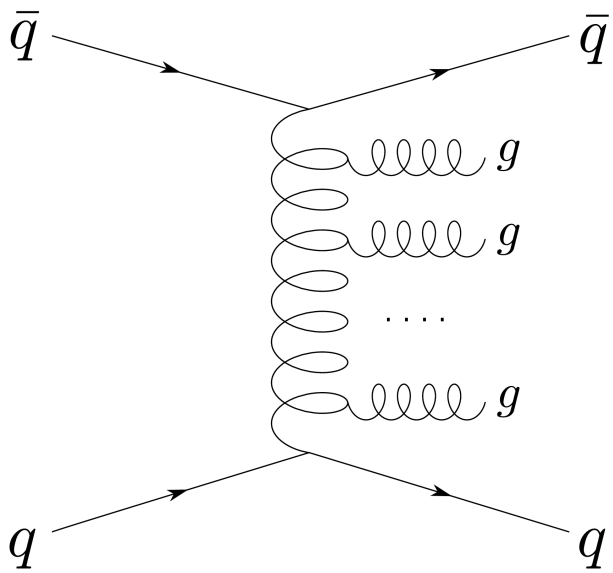
n does not depend on the collision energy in the limit $p_T \rightarrow 0$

This prediction is consistent with experimental data

Ochs, Acta Phys.Polon. B41 (2010)

Soft hadron production in pp

$$\sum$$

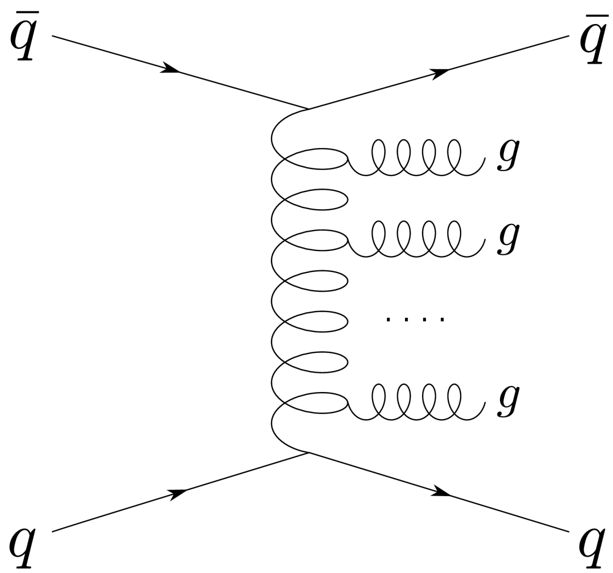


$$\xrightarrow{p_T \longrightarrow 0} \quad C_A \cdot \frac{\alpha_s(p_T)}{p_T^2}$$

The underlying physics of the minimum bias events is based on the collisions of two partons within the protons. The exchange of the t-channel gluon rearranges the incoming colors and leads to the radiation of the soft gluons from the effective color octet dipole.

Soft hadron production in pp

$$\sum$$



$$p_T \longrightarrow 0$$

color factor
for gluon emission
from a gluon

$$C_A \cdot \frac{\alpha_s(p_T)}{p_T^2}$$

common p_T dependence,
(MLLA approximation)

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More on soft hadron production in e^+e^- and pp collisions

In the $p_T \rightarrow 0$ limit:

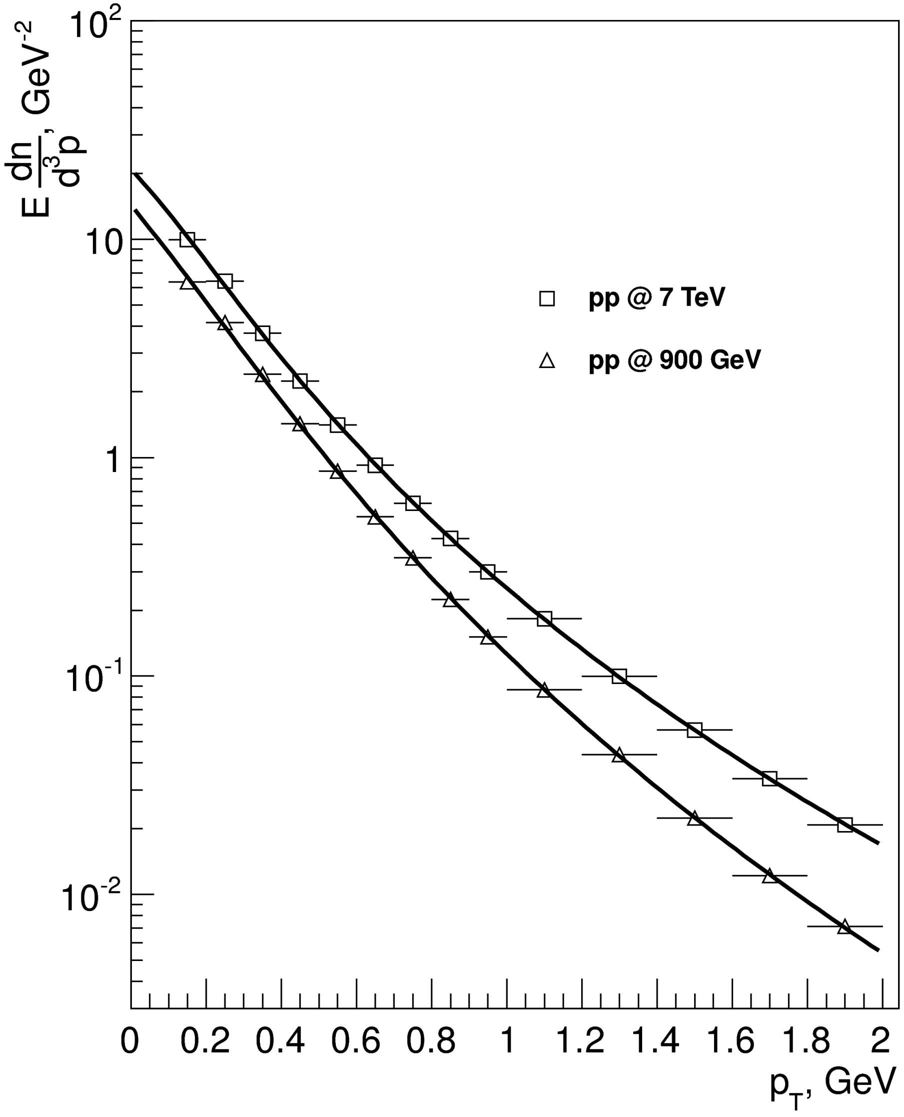
$$I_0^{pp} = E\frac{dn^{pp}}{d^3p} = \text{const} \sim C_A$$

$$I_0^{ee} = E\frac{dn^{ee}}{d^3p} = \text{const} \sim C_F$$

$$\frac{I_0^{pp}}{I_0^{ee}} = \frac{C_A}{C_F} = \frac{9}{4}$$

This prediction can be tested experimentally

CMS charged particle multiplicity



Fit extrapolation to p_T=0 point shows ~ 30% difference.

Errors for the extrapolation to p_T=0 are not shown.

ALICE experiment is designed for low p_T measurements and may provide more precise results.

Summary

- Inclusive soft particle spectra is independent of collision energy.

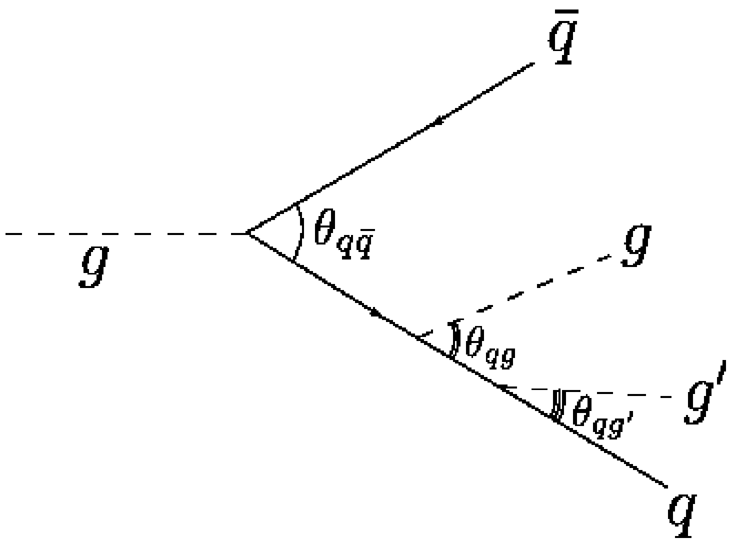
- The relative normalization of spectra in different processes is given by the color factors relevant for the minimal partonic process.

- Is there any new incoherent contributions in the new energy regime at LHC?

Backup

QCD: color coherence

- The same effect takes place in QCD where soft gluon radiation is governed by conserved color currents.



- On the one hand, the wavelength of the emitted gluon should be smaller than the hadronization scale R:

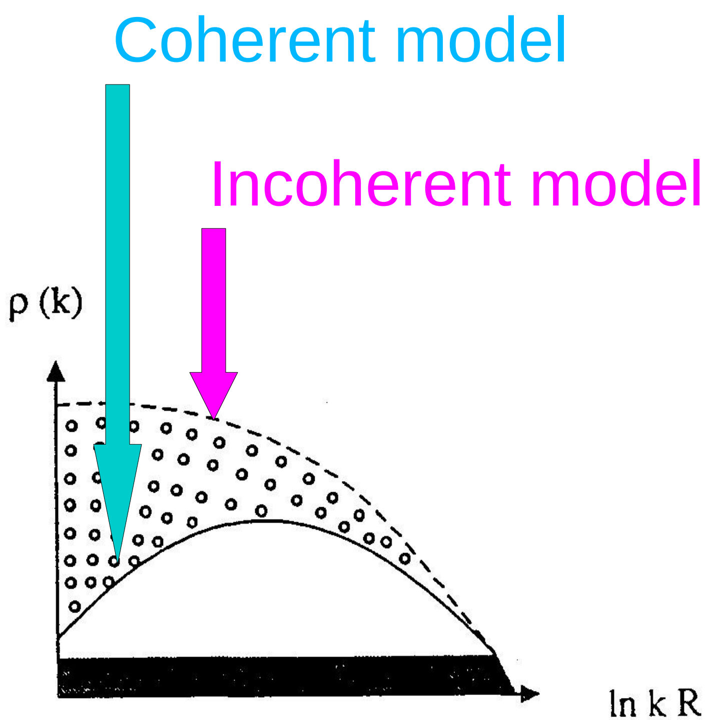
$$\lambda_{\perp g} = \frac{1}{k \sin \Theta_{qg}} > R \Rightarrow \Theta_{qg} > \frac{1}{kR}$$

- On the other hand, we have angular ordering:

$$\Theta_{qq} \ll \Theta_{qg} \ll \Theta_{qg'}$$

Yu.L. Dokshitzer, V.A. Khoze, A.H. Mueller, and S.I. Troyan. *Rev. Mod. Phys.*, 60:373, 1988.

What can we observe with color coherence?



Particle energy spectrum

$$\rho(k) \equiv \frac{dn}{d\ln k}$$

R – hadronization scale,
k – particle momentum

- Let us illustrate the influence of color coherence on particle spectra on a toy model
- The suppression of soft radiation follows from the angular ordering of partonic cascade and is a direct manifestation of the color coherence.
- This can be understood on kinematics ground as a result of two conflicting tendencies: due to the hadronization a slow particle is 'forced out' at large emission angle, on the contrary, the allowed decaying angle, after a few successive branching, is shrunk to small values.

Ya.I. Azimov, Yu.L. Dokshitzer, V.A. Khoze, and S.I. Troyan. *Z. Phys.*, C31:213, 1986.