QCD Radiation

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ep Interaction with High E_T, KEK

QCD study at HERA

- HERA: The collider between e^+e^- and quark, gluon- beams.
- Structure Functions: Unveil internal structure of nucleons . Good place to test QCD (Home ground).
- Decay products of heavy (new) particles include QCD jets with high rate.
- Sometimes the signal can be masked by QCD multi-jet channels.

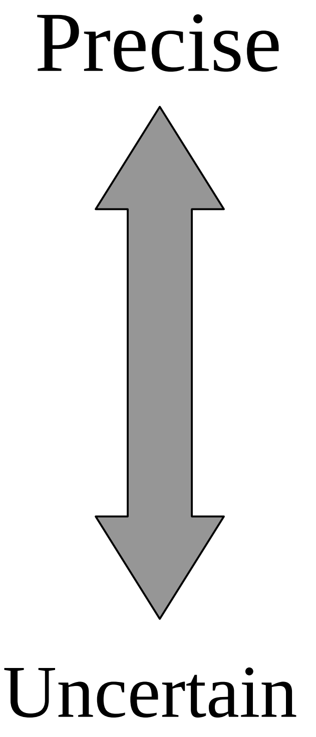
Dirty side of QCD

(= *cannot be controlled by pert.-QCD*)

- *Soft* components, spectators, forward jets ..
- *Multiple* scatterings
- Hadronization (old belief = it affects small in higher energy ?)

Theoretical outputs.
(or what do you need ?)

- Predictions by pert.-QCD.
- Models based on pert.-QCD.
- Models inspired by QCD.
- Phenomenological Models.



Basic proposal

- Try to use the information from pert.-QCD as much as possible.

High Q^2 Hard collision of partons

↕ parton shower method <== RGE

Low Q^2 Hadronization

- Where should we 'cut' ?

High P_T gluon radiation

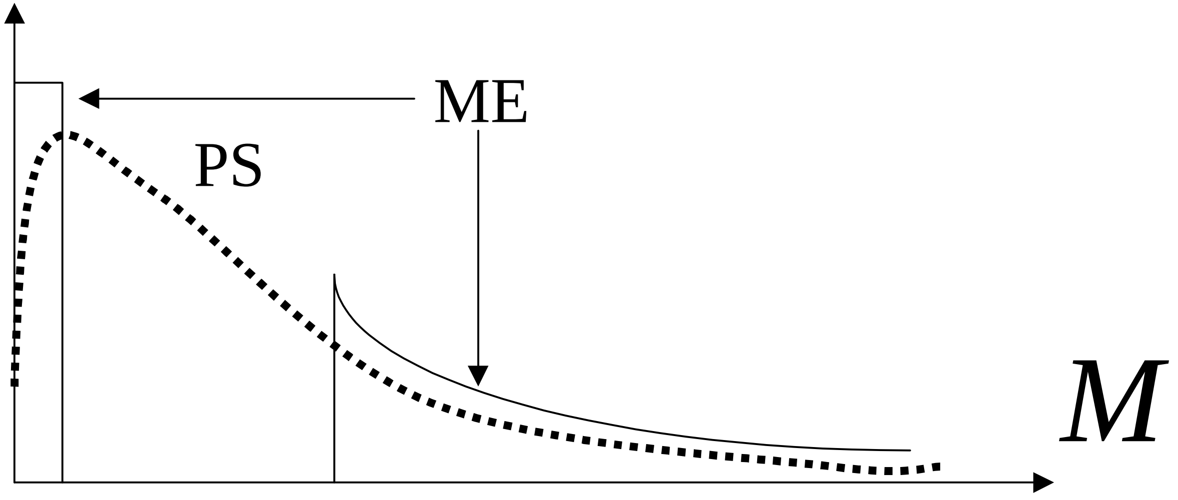
$$ep \rightarrow q(jet) + g(jet) + X$$

2 methods

- Matrix element for the hard collision
- Radiation by parton shower

Matrix element

- Matrix elements --> discontinuity problem (separate 1j/2j/3j… by y-cut)



QCD Parton Shower

- Monte Carlo Model based on pert.-QCD using RGE method
- Systematic summation of collinear log's

small p_T OK

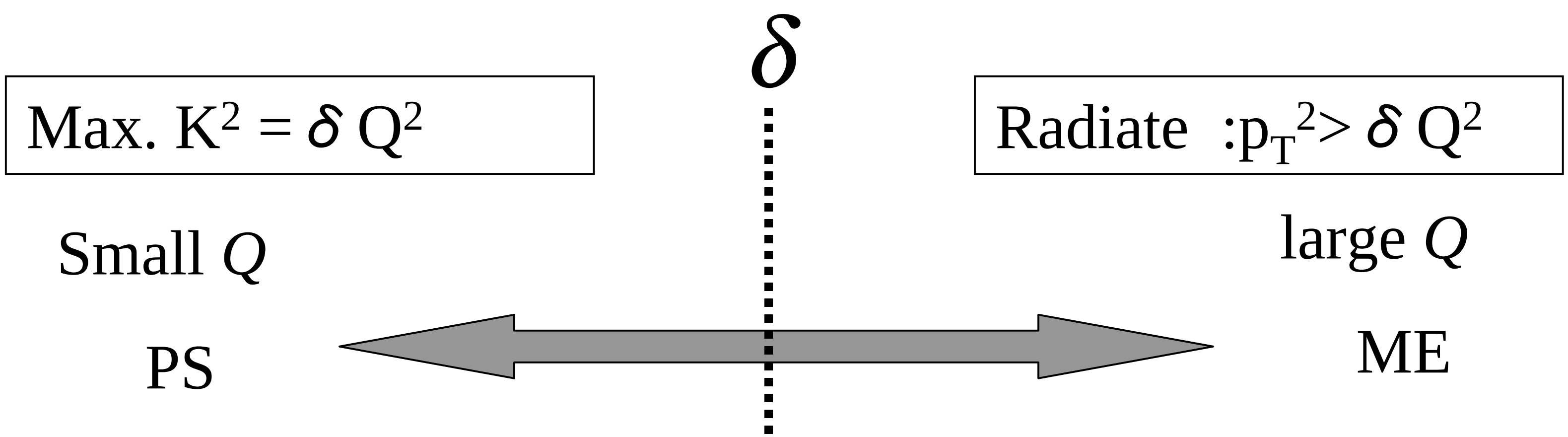
large p_T bad

$$\frac{dp_T^2}{p_T^2} \Rightarrow \log Q^2$$

Solution

- Mix the good points of ME and PS

- How ?



Prediction : independent of connection parameters

PDF:Scaling violation

$$q(x, Q^2), g(x, Q^2)$$

- Origin of scale dependence
  QCD correction: RGE --> PS
- In PS language, a quark loses momentum by gluon radiation : *x* --> smaller value
- PDF parametrization = by NLO QCD
  PS in LO : INCONSISTENCY !

NLO PS

$$\Pi(Q_1^2, Q_2^2) = \exp\left[-\int_{Q_1^2}^{Q_2^2}\int \frac{dK^2}{K^2}\frac{\alpha_s(K^2)}{2\pi} P(x)dx \right]$$

$$P(x) = P^{(0)}(x) + \frac{\alpha_s}{2\pi} P^{(1)}(x)$$

$$P^{(0)}(x) = C_F \frac{1+x^2}{1-x}$$

Known 20 years before

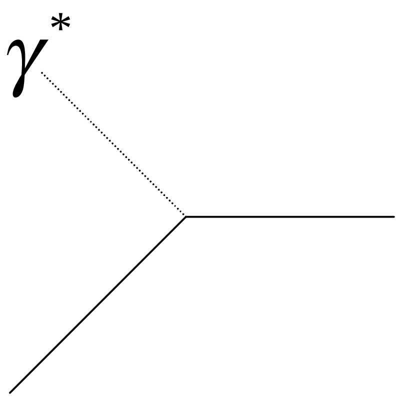
Q2-dep. of PDF will be the **output** of NLO-PS.

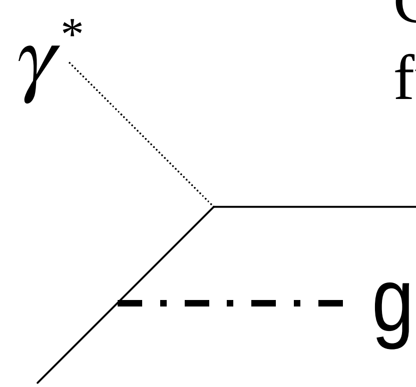
Hard ME into PS

$$\delta(1-x)$$

$$\frac{\alpha_s}{2\pi}C(x)$$

Coefficient function





Hard ME into PS(cont.)

$$\frac{\alpha_s}{2\pi} C(x)$$

Conventional one : BBDM ('78)

combination

$$P^{(1)}(x) - \beta_0 C(x)/2$$

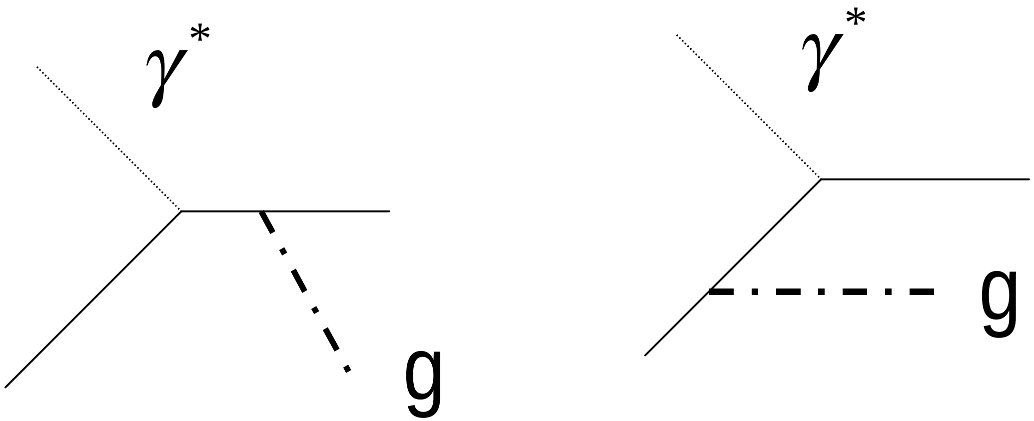
is invariant in any scheme

Change in *C(x)* is absorbed by the redefined $P^{(1)}(x)$

$C(x)$ by ME

$$\frac{\alpha_s}{2\pi}\frac{du}{-q^2}C_F x\left[-\frac{s}{u}-\frac{u}{s}+2q^2(s+u-q^2)\left(\frac{1}{su}-\frac{3}{(s-q^2)^2}\right)\right]$$

F_2 part



$C(x)$ correction to $P(x)$

Integrate for $\quad \dfrac{-q^2}{x} > |u| > \delta(-q^2)$

$$C'(x) = C_F\left[\frac{1+x^2}{1-x}\log\frac{1}{\delta x} + \left(\frac{-2x}{1-x} + 6x\right)(1-\delta x) + \frac{1}{2}\left(\frac{1}{1-x} - 6x\right)(1-\delta^2 x^2)\right]$$

Add a correction term to P function

$$P^{(1)}(x) \rightarrow P^{(1)}(x) + \Delta P(x)$$

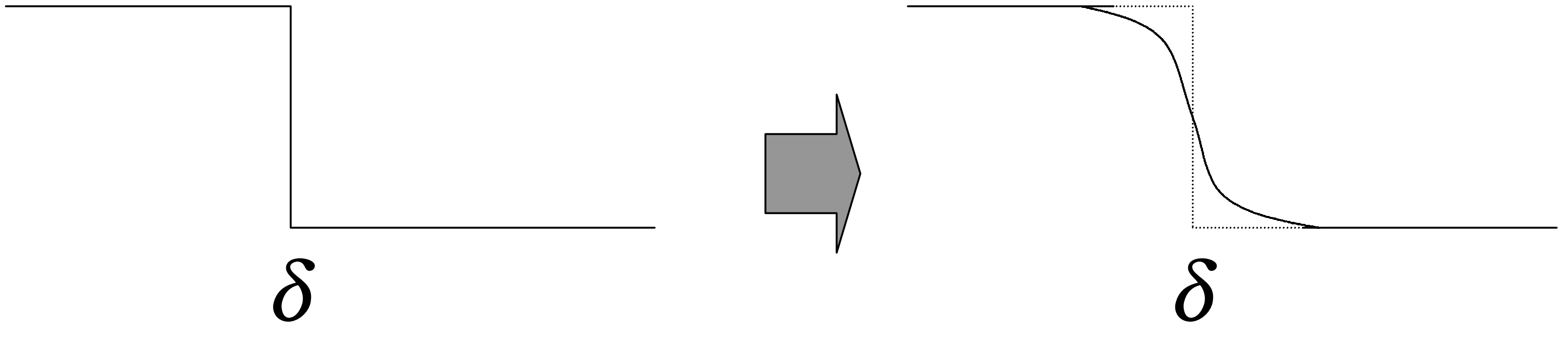
$$\Delta P(x) = (\beta_0/2)\big(C'(x) - C(x)\big)$$

Connection PS/ME

Step function connection is enough ?

Experience in e^+e^- case (NLLjet)
→slight cutoff dependence found

Smooth connection required



P(x) singularity(IR)

Modified *P(x)* includes singular term

$$P^{(0)}(x) \cdots \frac{1}{1-x}$$

$$\Delta P(x) \cdots C(x) \cdots \frac{-\log(1-x)}{1-x}$$

Breakdown of perturbation ?

CANCEL

Proper choice of the argument of α s

$$\alpha_s(Q^2) \Rightarrow \alpha_s(p_T{}^2) \approx \alpha_s((1-x)Q^2)$$

Proposed guiding principles

- Respect gold-plated pert.-QCD prediction for inclusive cross section : PS-Model should agree with it !
  → Avoid double counting
- Keep perturbation (or, kick out singular terms into NNLO)
  → NLO correction would be small ?

Summary

- **NLO** parton shower can provide :

* Natural introduction of hard gluon

* Consist treatment for QCD shower and Q^2 dependent PDF