QCD and NLL-PS

CPP 2001, Tokyo, 2001.11.28-30

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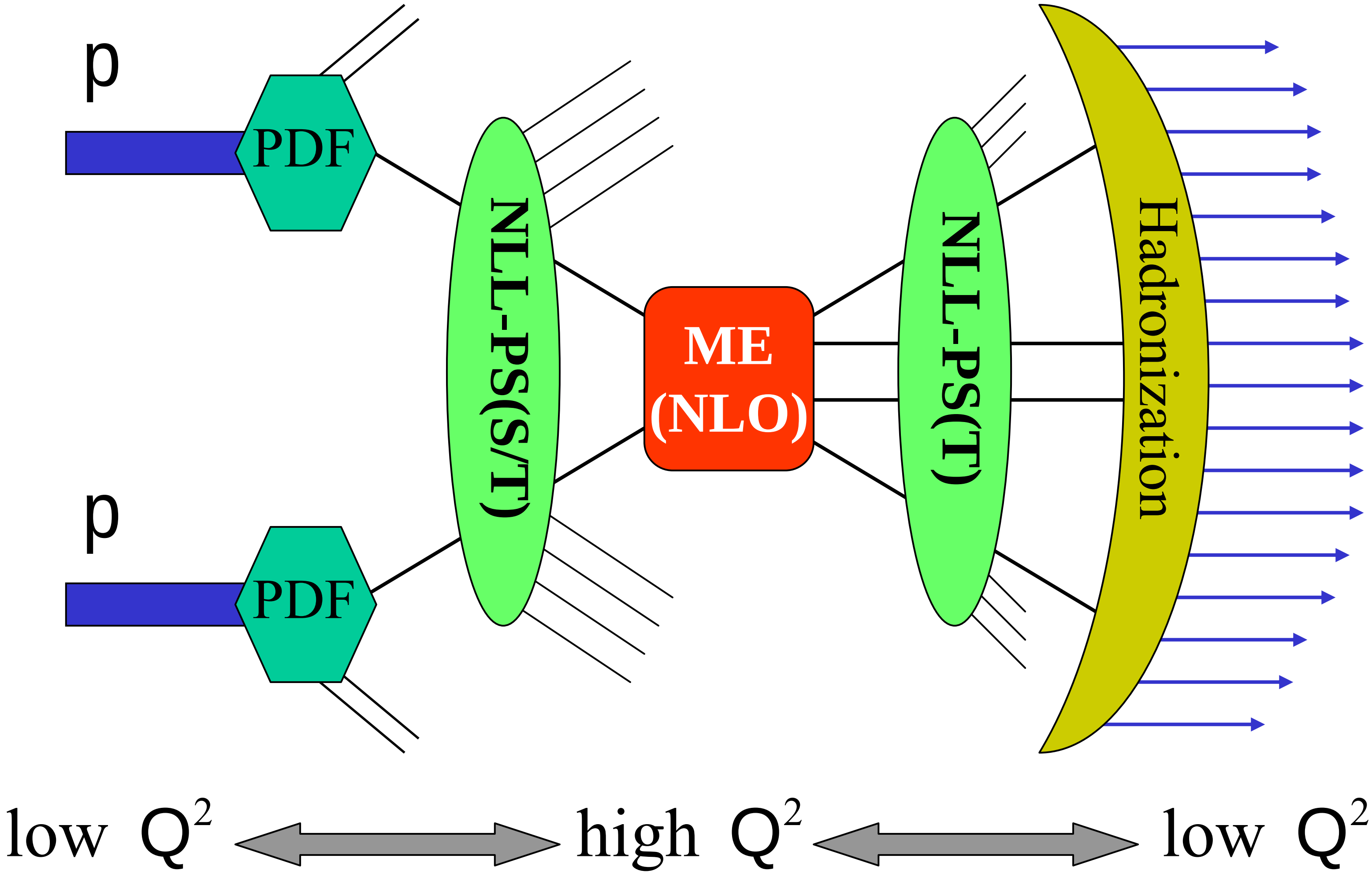
followed by Kurihara's talk


p
PDF
p
PDF
NLL-PS(S/T)
ME
(NLO)
NLL-PS(T)
Hadronization
low Q2
high Q2
low Q2

QCD

low Q^2 $\longleftrightarrow$ high Q^2

empirical model
soft physics

pert.QCD
reliable theoretical
prediction

RGE

try to use maximum
information of pert.QCD

The Art of Pert.QCD

- Many detailed theoretical predictions in literatures: LO, NLO, NNLO,…
  for cross sections, shape parameters, distribution functions, …
- The required stage is to construct event generators(EG) which are consistent with these predictions.
- EG: {4-vectors, weights}

parton shower (PS)

- old wisdom of QCD
  Konishi Ukawa Veneziano (1979)
  Odorico (1980)
- systematic summation of large log’s
  in physical gauge (e.g. axial gauge)
  interference diagrams = subdominant
  → stochastic (classical) branching
- naturally connect large/small Q^2

Proposed Strategy in PS-NLL

To construct EG, we are to go beyond the exact prediction of pert.QCD.

- Keep the prediction of pert.QCD.
- Matching with NLO matrix element
- Positiveness of branching (if possible)
- LL>NLL (if possible)

Example(1) PDF, NS

$$\frac{d}{dt} f(x, Q^2) = \frac{\alpha_s(t)}{2\pi} \int_x^1 \frac{dy}{y} P(y) f(x/y, Q^2)$$

$$P(x) = P^{(0)}(x) + \frac{\alpha_s(t)}{2\pi} P^{(1)}(x) + \cdots \qquad P^{(0)} = C_F \frac{1+x^2}{1-x}$$

Fit by
experimental data

$$f(x, \boxed{Q_0{}^2})$$

←given

3 levels of MC

- Simple MC to solve DGLAP-eq.
- MC as branching process
- realistic MC as EG for incoming parton

MC to solve DGLAP

$$\frac{d}{dt} f(x,Q^2) = \frac{\alpha_s(t)}{2\pi} \int_x^1 \frac{dy}{y} P(y) f(x/y, Q^2)$$

$$\Longrightarrow \quad \Pi(Q_2^2, Q_1^2) = \exp\left[- \int_{Q_1^2}^{Q_2^2} \frac{dK^2}{K^2} \frac{\alpha_s(t_K)}{2\pi} \int_0^{1-\varepsilon} P(x)dx \right]$$

Non-branching probability from Q_1^2 to Q_2^2

MC to determine *($-K^2$, x)* at each branching

MC to solve DGLAP

- step.1 choose x_0 by initial distribution $f(x,Q_0^2)$
- step.2 determine branch $-K^2$ by $\Pi\ (Q^2, Q_0^2)$, x_j by $P(x)$, repeat until $-K^2 > Q_{max}^2$
- step.3 register $x = x_0 \times x_1 \times x_2 \times \ldots$ as the x at Q^2
- This should agree with exact PDF Q^2-dep.

MC to solve DGLAP

$$\Pi(Q_2^2, Q_1^2) = \exp\left[-\int_{Q_1^2}^{Q_2^2} \frac{dK^2}{K^2} \frac{\alpha_s(t_K)}{2\pi} \int_0^{1-\varepsilon} P(x)dx \right]$$

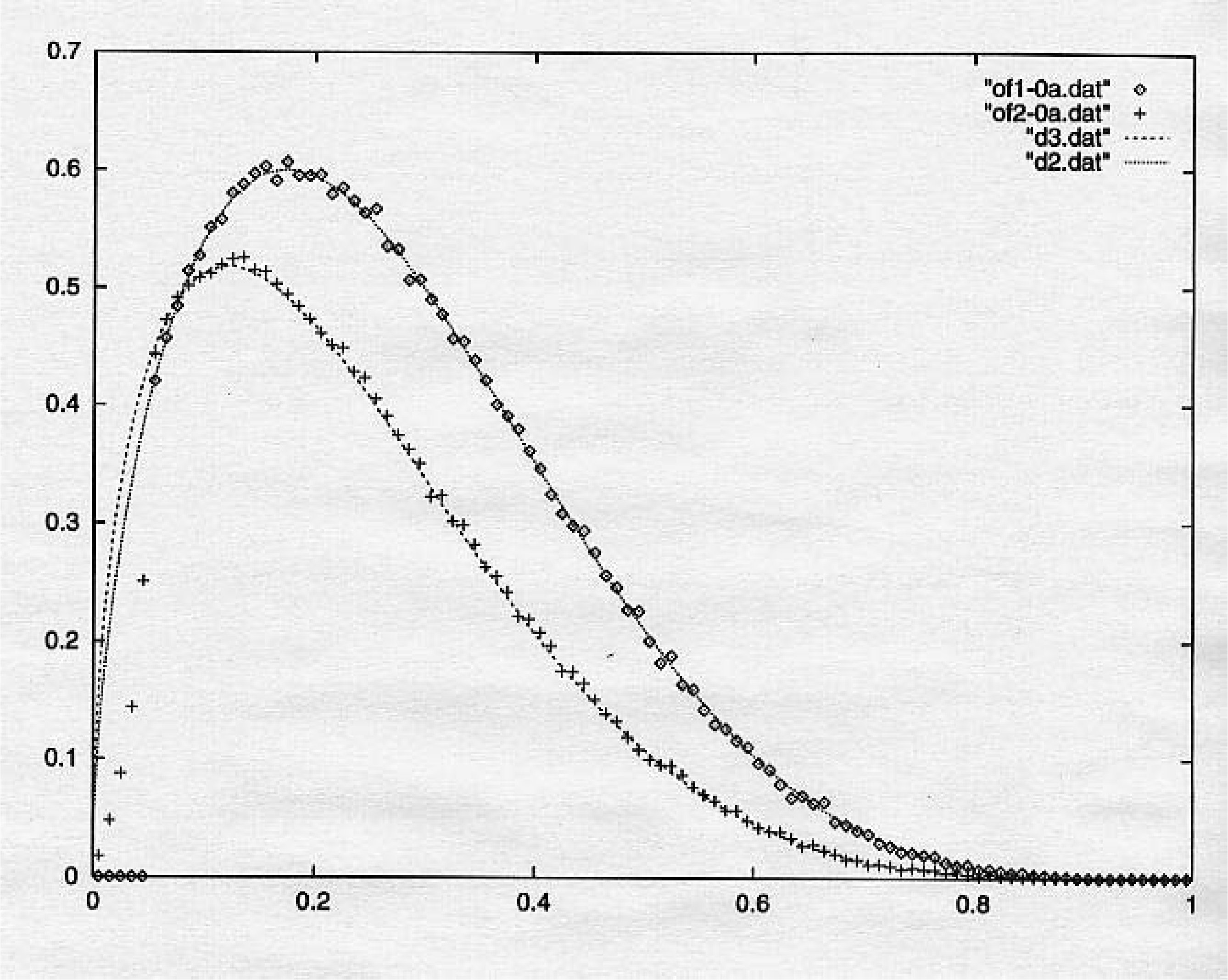
equivalent

QCD prediction

$$\exp\left[-\int_{\alpha(\mu)}^{\alpha(Q)} \frac{d\alpha}{2\alpha} \frac{\gamma_n(\alpha)}{\beta(\alpha)/g} \right]$$

MRS99(mode-1) u-valence

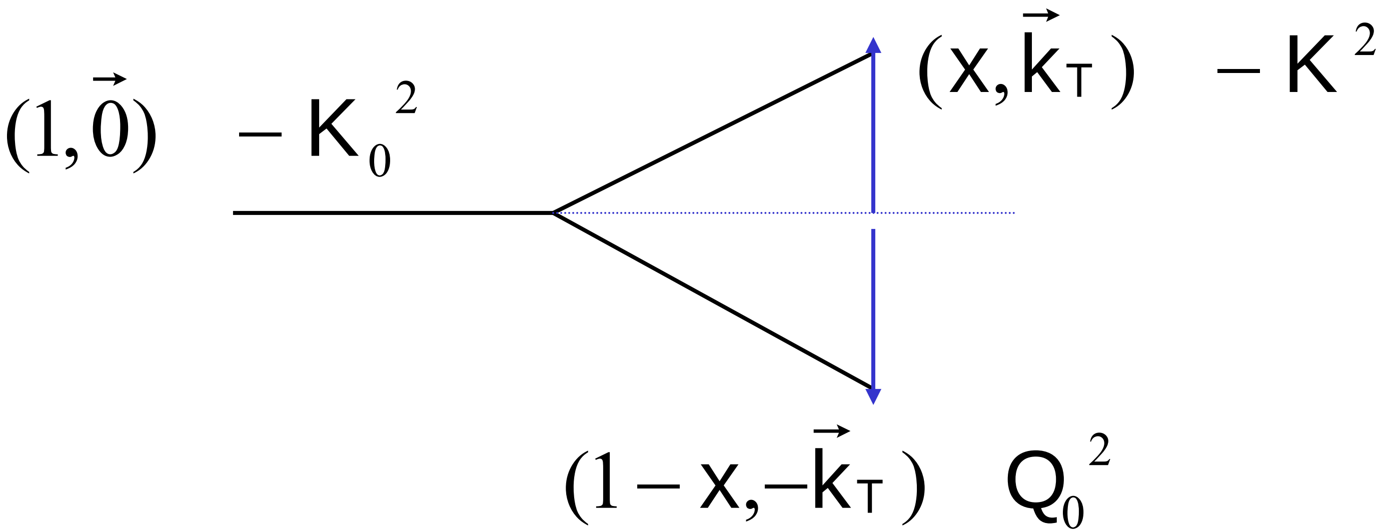
$Q^2 = 25\mathrm{GeV}^2 \rightarrow 10^4\,\mathrm{GeV}^2$



(simple)

NLL-PS

MC with branching



$$k_T^2 = -x(1-x)K_0^2 + (1-x)K^2 - xQ_0^2 > 0$$

MC with branching

$$-K_0^2 \ll -K^2 \quad \Rightarrow \quad x < 1 - \frac{Q_0^2}{-K^2}$$

$$\varepsilon = \frac{Q_0^2}{-K^2}$$

$$\Pi(Q_2^2, Q_1^2) = \exp\left[-\int_{Q_1^2}^{Q_2^2} \frac{dK^2}{K^2} \frac{\alpha_s(t_K)}{2\pi} \int_0^{1-\varepsilon} P(x)dx \right]$$

By this, *f(x,Q²)* receives some modification.

MC with branching

$$\varepsilon = \frac{Q_0^2}{-K^2}$$

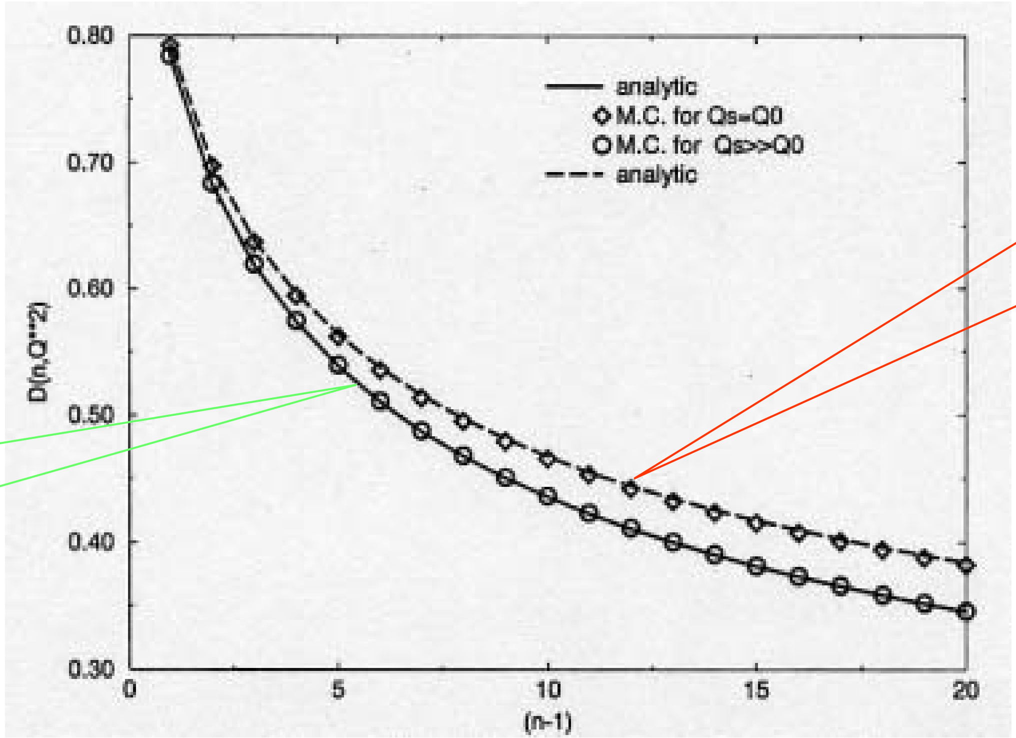
New correction term appears to keep the pert.QCD prediction.

$$\mathrm{P}(\mathrm{x})$$

$$\Downarrow$$

$$\mathrm{P}(\mathrm{x}) - (\beta_0 / 2)\alpha_{\mathrm{s}}(\mathrm{Q}_0^2)\log(1-\mathrm{x})\mathrm{P}(\mathrm{x})$$

moments of the SF



PS with K^2 dependent cut

PS with small cut

T.Munehisa, LL (α =0.05)

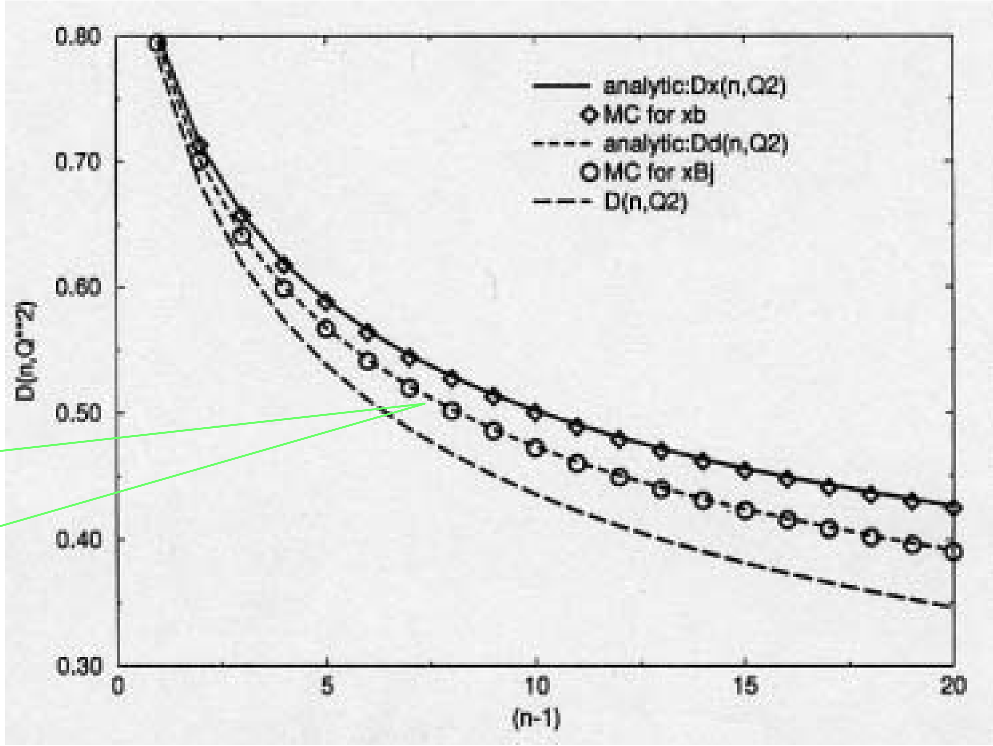
MC as EG

required items

- determine 4-vectors from $(-K^2, x)$
  ϕ chosen at random
  → change ‘direction of parton’ ?
- What is the observed x_{Bj} ?
  (Off-shell partons enter the collision.)

more correction terms

moments of the SF



PS for x_{Bj}

$x_{Bj} = x(1-t)$

T.Munehisa, LL (α =0.05)

Example(2) PDF, siglet

$\mathrm{P}(x)$ Singular at x=0

$$\exp\left[-\int \frac{dK^2}{K^2}\frac{\alpha_s(K^2)}{2\pi}\int_0^{1-\varepsilon} P(x)dx\right]$$

1) Introduce cutoff

2) evolution of $x\, f(x,Q^2)$ …
Momentum Conservation

Study by H.Tanaka

siglet, *xf(x)* evolution

$$\frac{d}{dt} f_q(x,t) = \frac{\alpha_s(t)}{2\pi} \int_x^1 \left[P_{qq}(y) f_q(x/y,t) + P_{qg}(y) f_g(x/y,t) \right] \frac{dy}{y}$$

$$\frac{d}{dt} f_g(x,t) = \frac{\alpha_s(t)}{2\pi} \int_x^1 \left[P_{gq}(y) f_q(x/y,t) + P_{gg}(y) f_g(x/y,t) \right] \frac{dy}{y}$$

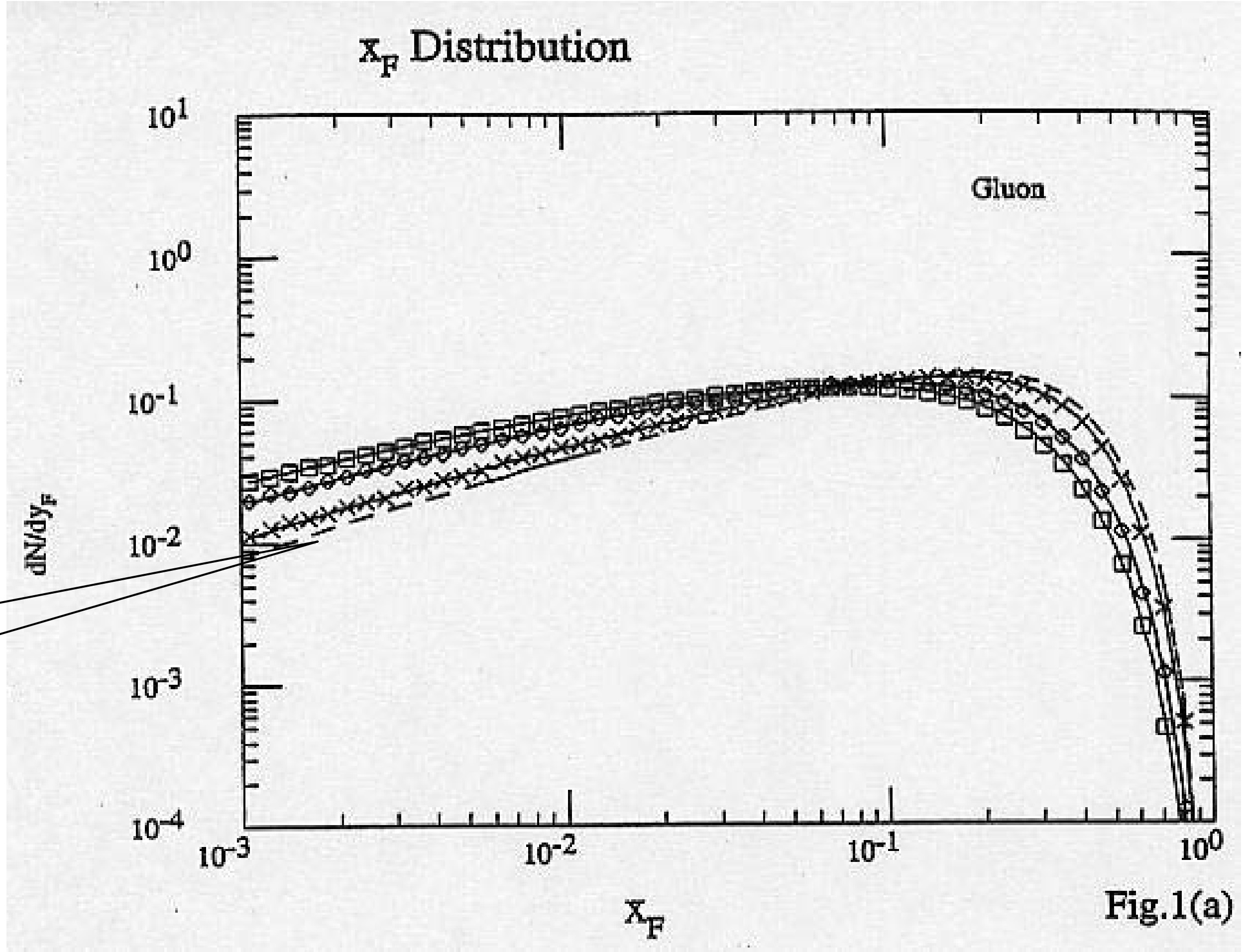
$$\boxed{x f(x,t) \quad \Rightarrow \quad F(x,t)}$$

$$\frac{d}{dt} F_q(x,t) = \frac{\alpha_s(t)}{2\pi} \int_x^1 \left[\underline{yP_{qq}(y)} F_q(x/y,t) + \underline{yP_{qg}(y)} F_g(x/y,t) \right] \frac{dy}{y}$$

$$\frac{d}{dt} F_g(x,t) = \frac{\alpha_s(t)}{2\pi} \int_x^1 \left[\underline{yP_{gq}(y)} F_q(x/y,t) + \underline{yP_{gg}(y)} F_g(x/y,t) \right] \frac{dy}{y}$$

gluon
(GRV98)

$Q^2 = 10^1, 10^2, 10^3 \,\mathrm{GeV}^2$



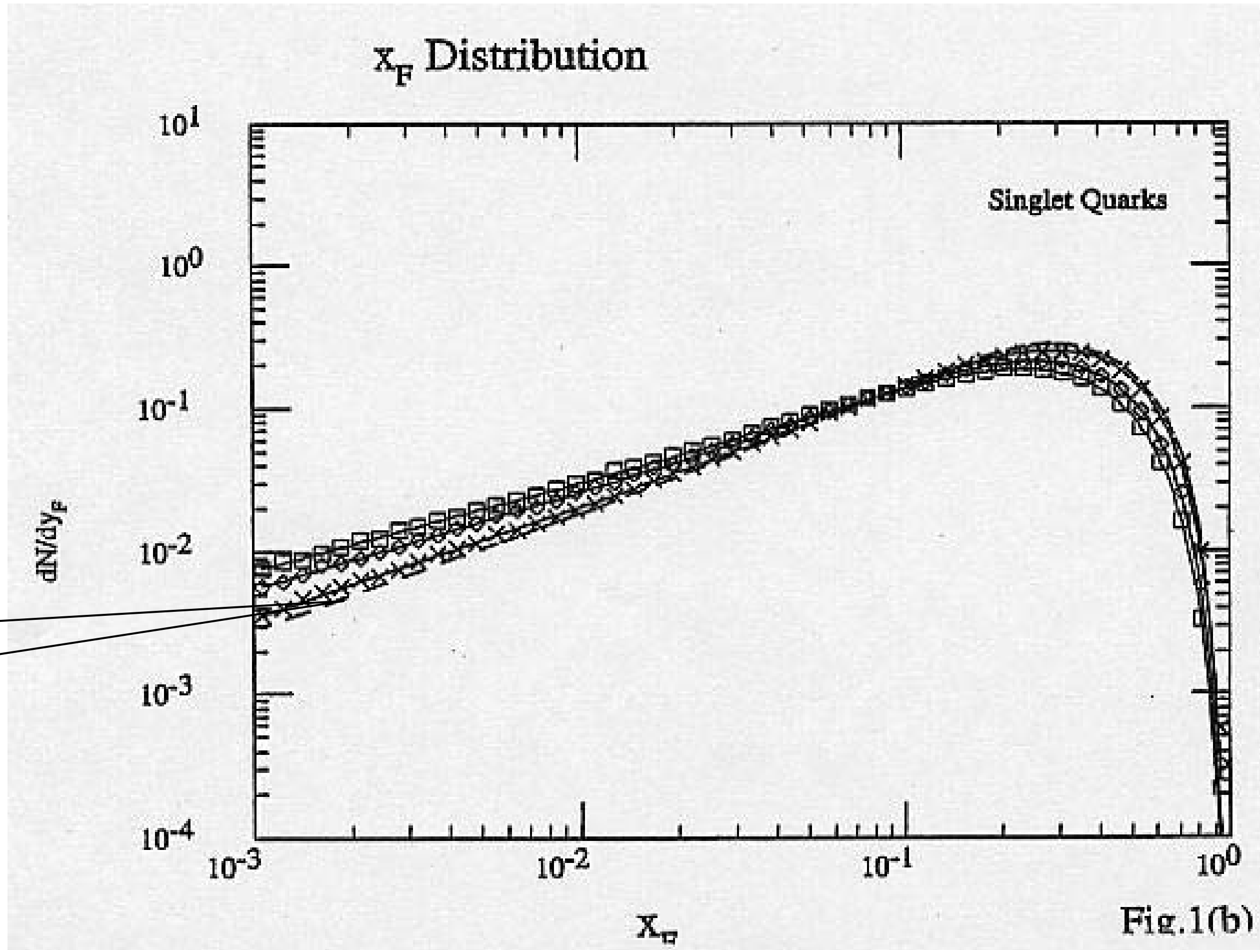
Input
5GeV^2

(simple)
NLL-PS

H.Tanaka

singlet quark
(GRV98)

$Q^2 = 10^1, 10^2, 10^3\,\mathrm{GeV}^2$

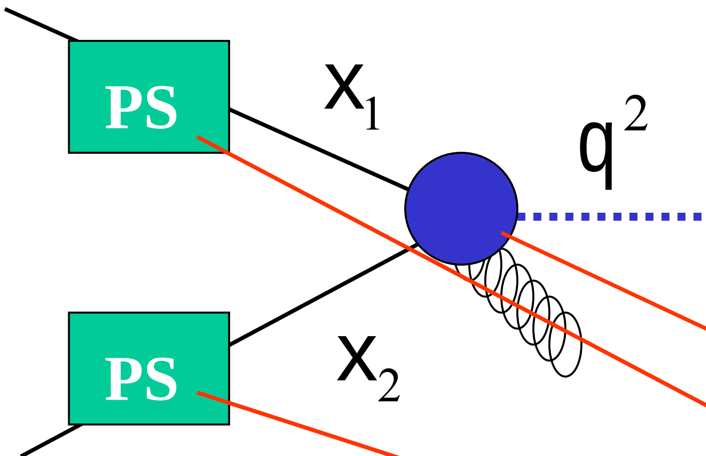


(simple)
NLL-PS

Input
$5\mathrm{GeV}^2$

H.Tanaka

Example(3) DY process



$$z = \frac{q^2}{s} = \frac{\tau}{x_1 x_2} \qquad \tau = \frac{q^2}{S}$$

$$\tau \frac{d\sigma}{d\tau} = \sigma_0(S) \int dx_1 dx_2 \frac{1}{x_1 x_2} D(x_1, q^2) D(x_2, q^2) C(z, q^2)$$

$$\int_0^1 \mathrm{d}\tau \frac{\mathrm{d}\sigma}{\mathrm{d}\tau}\tau^{\mathrm{n}} = \sigma_0(\mathrm{S})\mathrm{D_n D_n C_n} = \mathrm{F_n(q^2)}$$

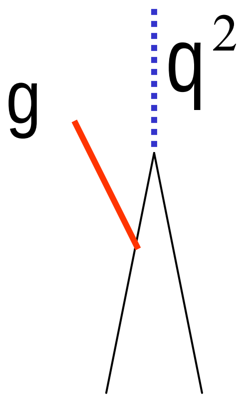
$$\mathrm{D_n} = \mathrm{A_n}\exp\left[-\int_{\alpha(\mu)}^{\alpha(\mathrm{Q})} \frac{\mathrm{d}\alpha}{2\alpha}\frac{\gamma_{\mathrm{n}}(\alpha)}{\beta(\alpha)/\mathrm{g}}\right] \qquad \mathrm{C_n} = 1 + \frac{\alpha}{4\pi}\mathrm{B_n}$$

$$\frac{\mathrm{F_n(q^2)}}{\mathrm{F_n(q_0^2)}} = \left(\frac{\alpha(\mathrm{q})}{\alpha(\mathrm{q_0})}\right)^{\gamma_{\mathrm{n}}^{(0)}/2\beta_0}\left(1 + \frac{\alpha(\mathrm{q})-\alpha(\mathrm{q_0})}{4\pi}\left\{\boxed{\mathrm{B_n} + 2\frac{\gamma_{\mathrm{n}}^{(1)}}{2\beta_0}} - 2\frac{\beta_1\gamma_{\mathrm{n}}^{(1)}}{2\beta_0{}^2}\right\}\right)$$

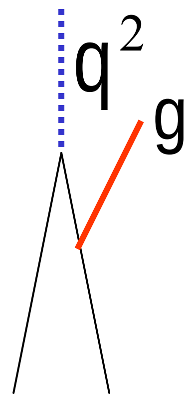
"scheme" dependence

$$\boxed{\mathrm{B} \to \mathrm{B}' \quad \Rightarrow \quad \gamma^{(1)} \to \gamma^{(1)\prime} = \gamma^{(1)} + \frac{\mathrm{B}-\mathrm{B}'}{\beta_0}}$$

Hard ME $$d\hat{\sigma} = Q_q^2 e^2 C_F g^2 \frac{2}{3}\left(\frac{t}{u}+\frac{u}{t}+2\frac{q^2 s}{tu}\right)$$



small *(-t)*



small *(-u)*

PS

$$\delta = (-t,-u)_{\min} / s$$

$$\int d\hat{\sigma} = \frac{Q_q^2}{3}\sigma_{\mu\mu}\frac{dq^2}{q^2}\frac{\alpha}{4\pi}B'(z)$$

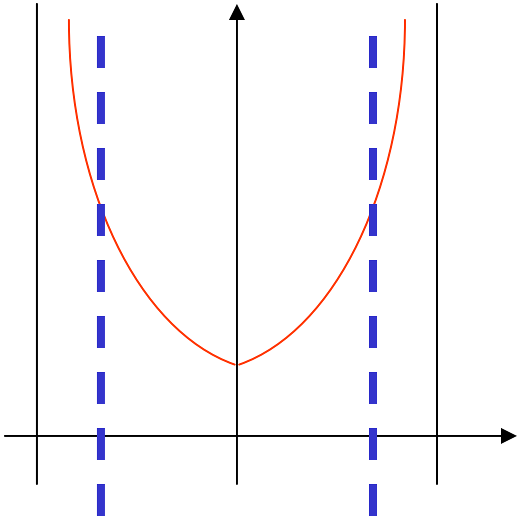
$$B'(z) = 4C_F\left[\frac{1+z^2}{1-z}(-\log(\delta/1-z)) - (1-z)\right]$$

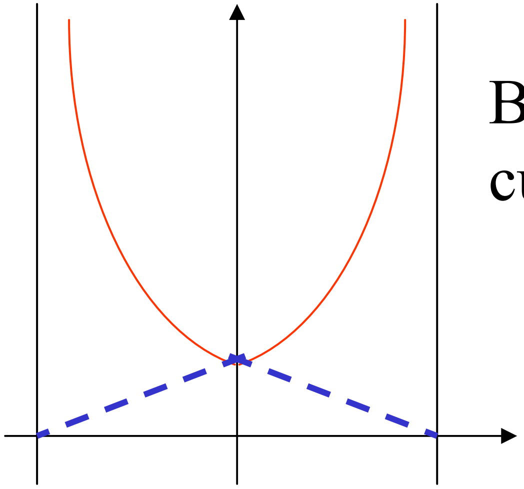
Modify (to avoid double counting)

$$\begin{cases} B(z) & \Rightarrow & B'(z) \\ (-K^2)_{\max} = q^2 & \Rightarrow & (-K^2)_{\max} = \delta q^2 \end{cases}$$

also modify P

shower





Better cut ?

EG:mixture of γ^* and $\gamma^* g$

(intermediate) conclusion

- NLO generator with NLL-PS
- Connection to NLO-ME
- Technical study and test

continue to the next talk….