

The CASCADE MC event generator

H. Jung (DESY)

- Why another Monte Carlo event generator ?
- CASCADE
 - Basic idea
 - Status
 - Future plans
- Why to use another Monte Carlo event generator ?

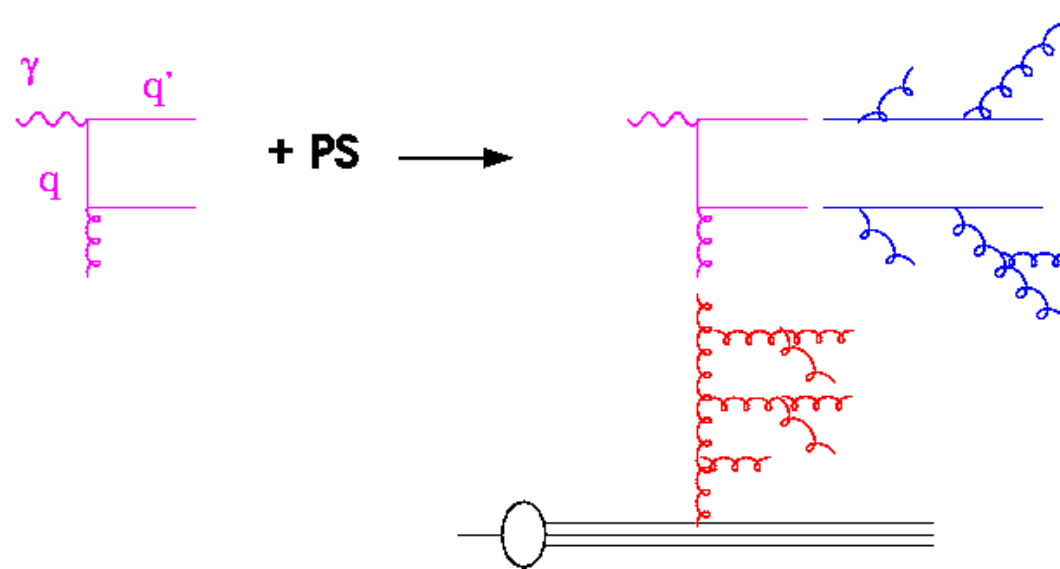
Why another Monte Carlo event generator ?

Why another Monte Carlo event generator ?

because existing ones are potentially

- inconsistent
- not sufficient

Inconsistency: example from HERA

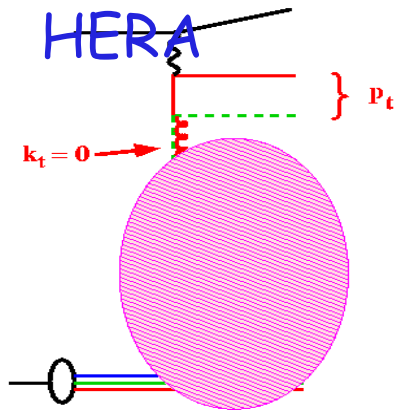


- **Collinear approach:** incoming/outgoing partons are on mass shell
 $(\gamma+q)^2 = q'^2, -Q^2 + x \gamma s = 0 \Rightarrow x = Q^2/(\gamma s)$
- **BUT** final state radiation:
 $(\gamma+q)^2 = q'^2, -Q^2 + x \gamma s = m^2 \Rightarrow x = (Q^2+m^2)/(\gamma s)$
- **AND** initial state radiation:
 $(\gamma+q)^2 = q'^2, -Q^2 + x \gamma s + q^2 = 0 \Rightarrow x = (Q^2-q^2)/(\gamma s)$
- **Collinear approach:** $q'^2 = q^2 = 0$, order by order
- Well known.... since years....
- NLO corrections... better treatment of kinematics... but still not all....

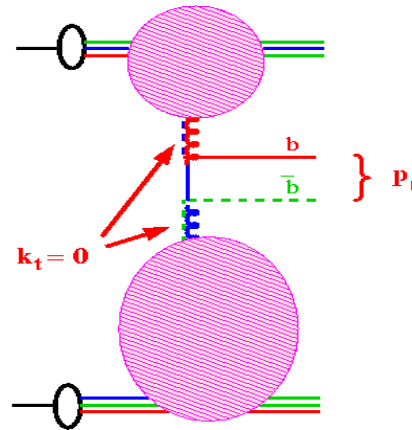
Problems in Collinear Approximation

J. Collins, H. Jung hep-ph/0508280

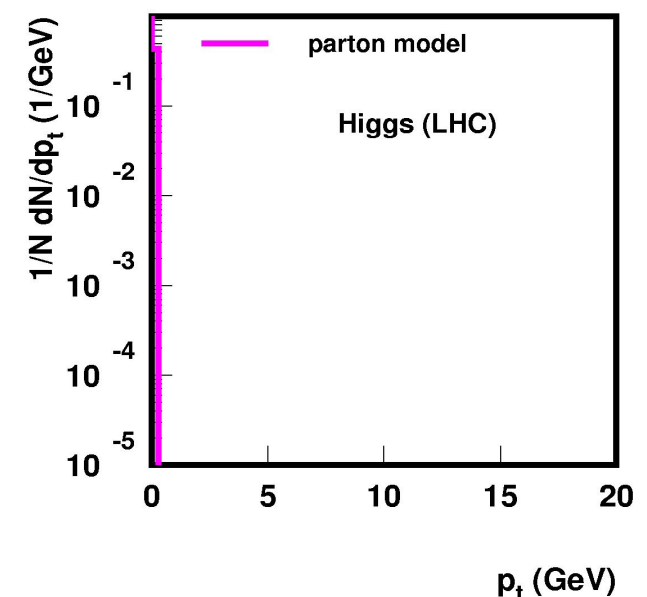
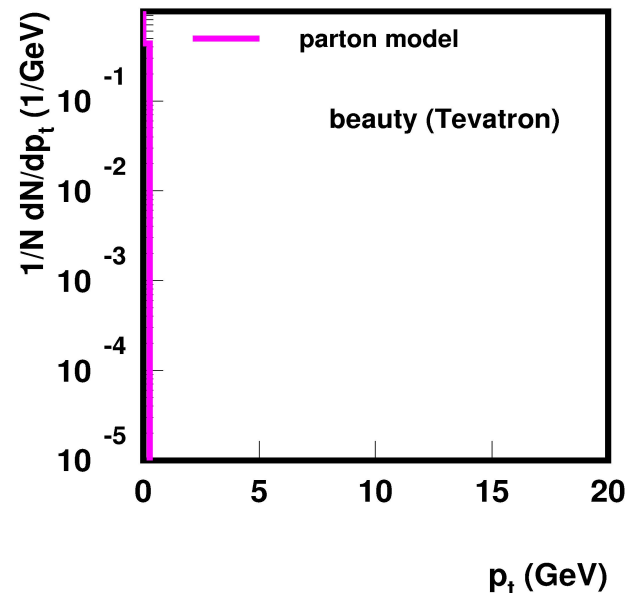
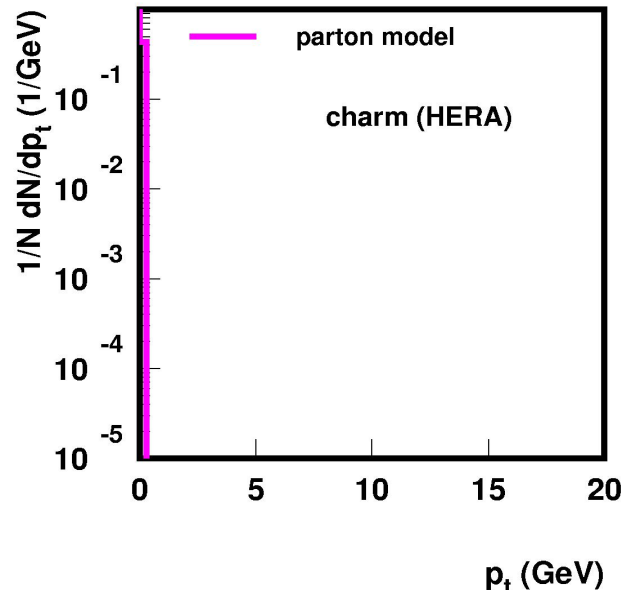
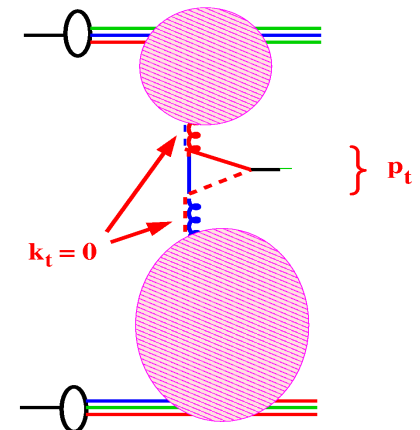
heavy quarks at



heavy quarks in



Higgs in pp



➔ NLO corrections will be very large for these LO processes

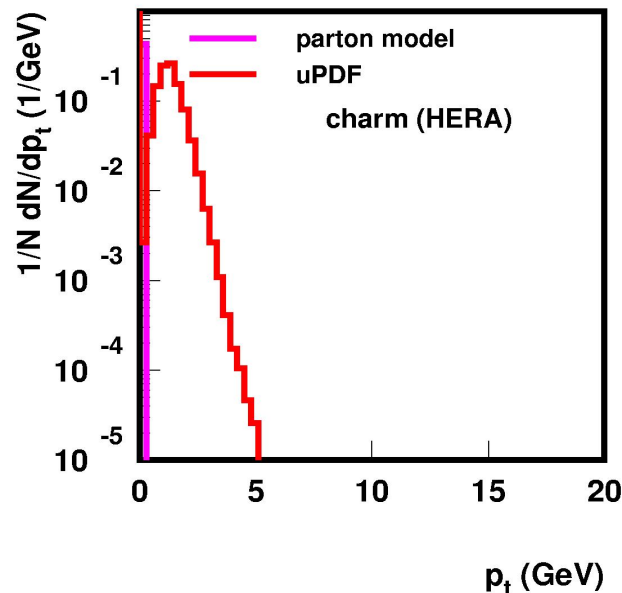
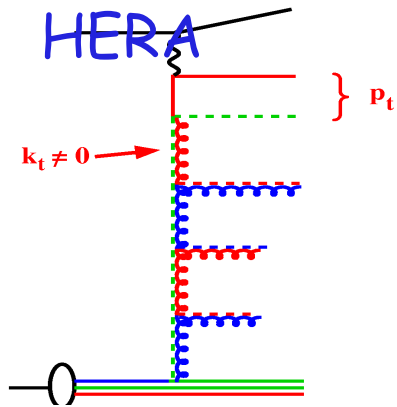
**Why another
Monte Carlo event generator ?**

**because we can do
much better ...**

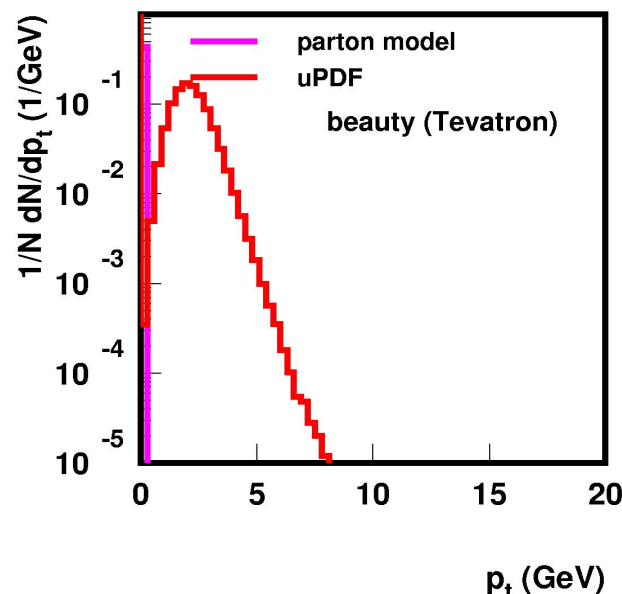
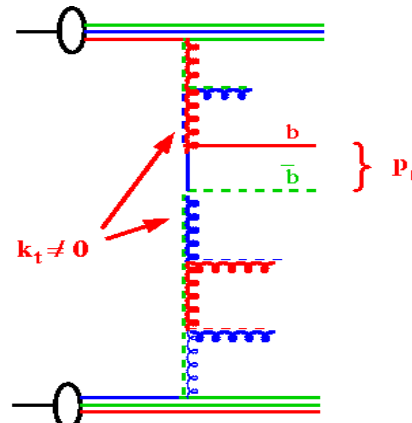
Doing much better with uPDFs ...

J. Collins, H. Jung hep-ph/0508280

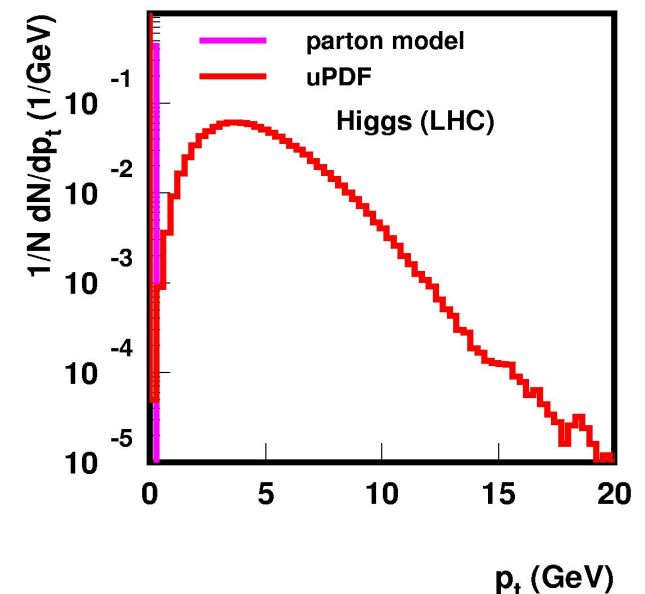
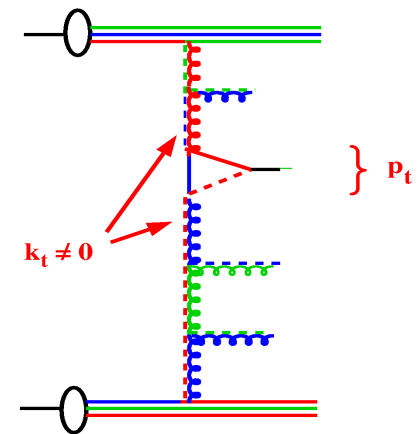
heavy quarks at



heavy quarks in

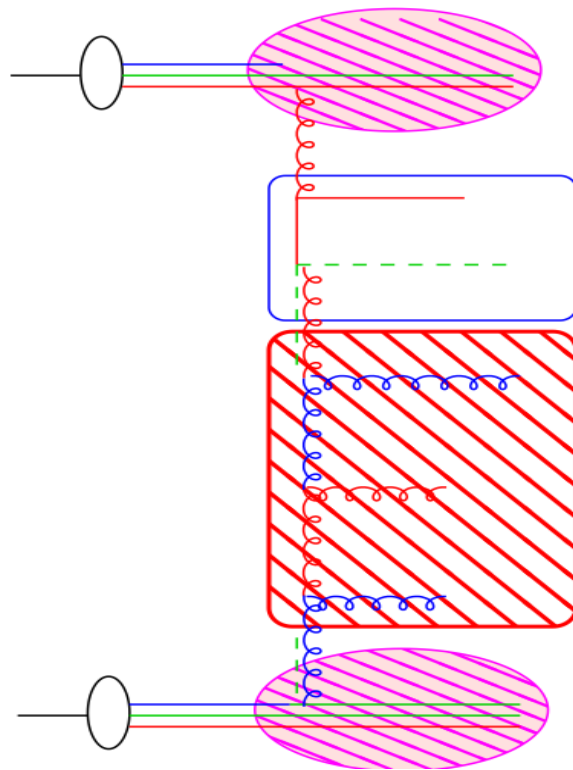


Higgs in pp



→ doing kinematics correct at LO, reduces NLO corrections ... **NEED**

CASCADE - basic idea

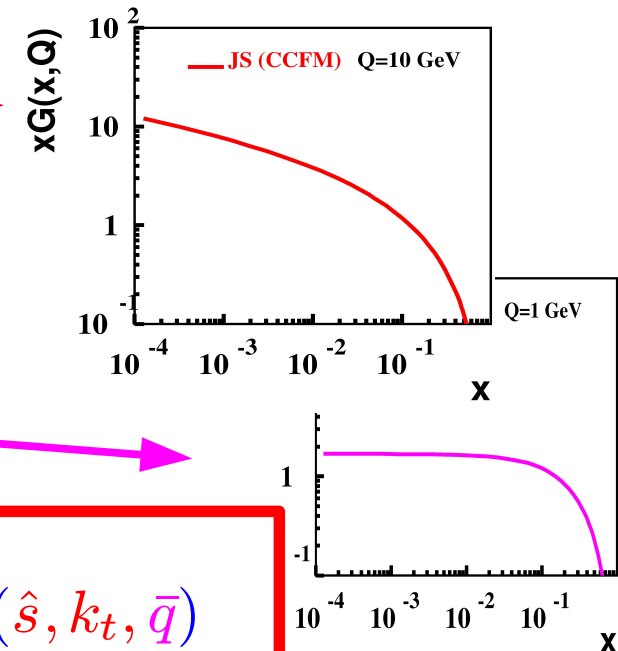


matrix element

evolution of parton cascade:

$$\tilde{P} = \bar{\alpha}_s \left(\frac{1}{1-z} + \frac{1}{z} + \dots \right)$$

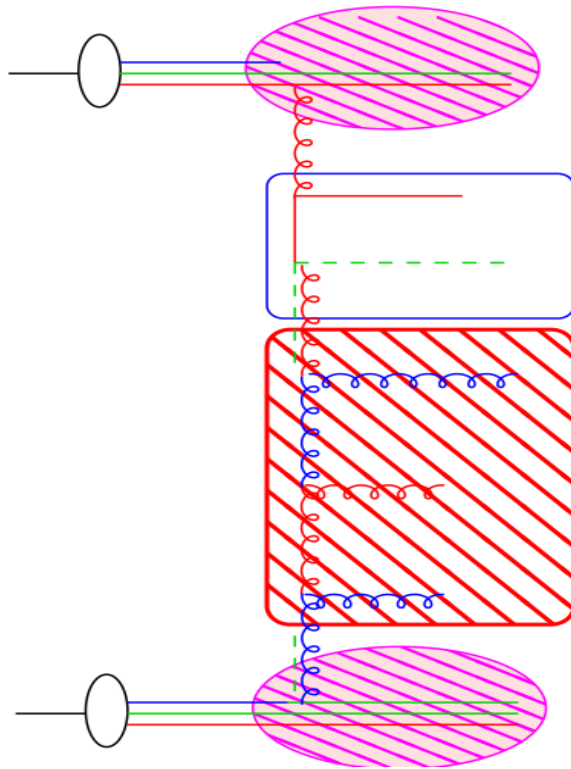
initial distribution
~ flat



$$\begin{aligned} \sigma(pp \rightarrow q\bar{q} + X) &= \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2 k_{t1} d^2 k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q}) \\ &\quad \times x_{g1} \mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2} \mathcal{A}(x_{g2}, k_{t2}, \bar{q}) \\ \int d^2 k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) &= x_g G(x_g, Q^2) \text{ if } \hat{\sigma} = \hat{\sigma}(\hat{s}, 0, \bar{q}) \end{aligned}$$

CASCADE - C C F M evolution

atani iafaloni iorani archesini



matrix element
off shell

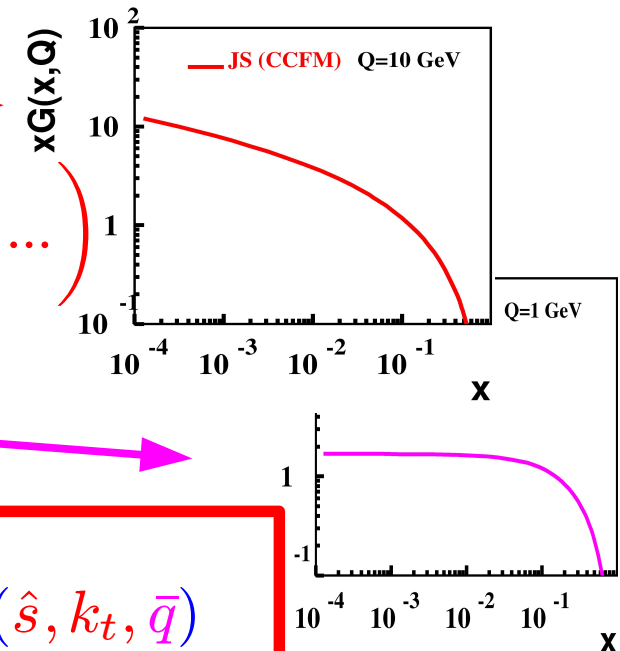
evolution of parton
cascade:

$$\tilde{P} = \bar{\alpha}_s \left(\frac{1}{1-z} + \frac{1}{z} \Delta_{ns} + \dots \right)$$

initial distribution
~ flat

CCFM (all loops)

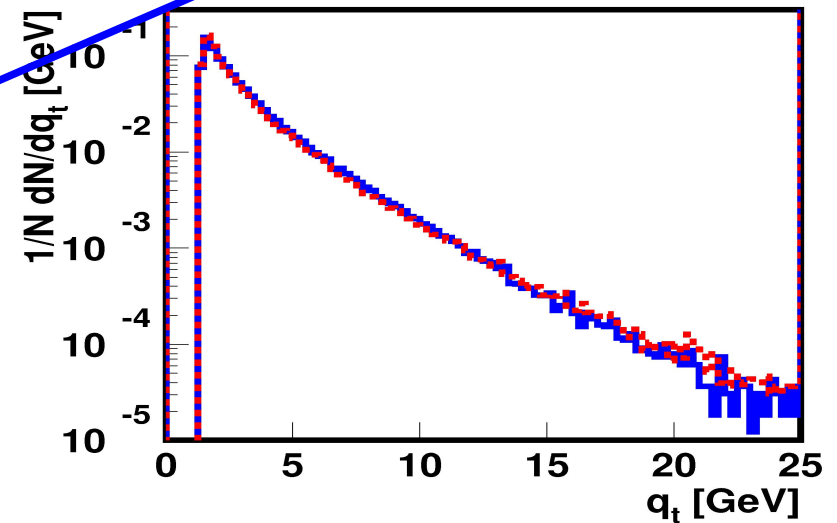
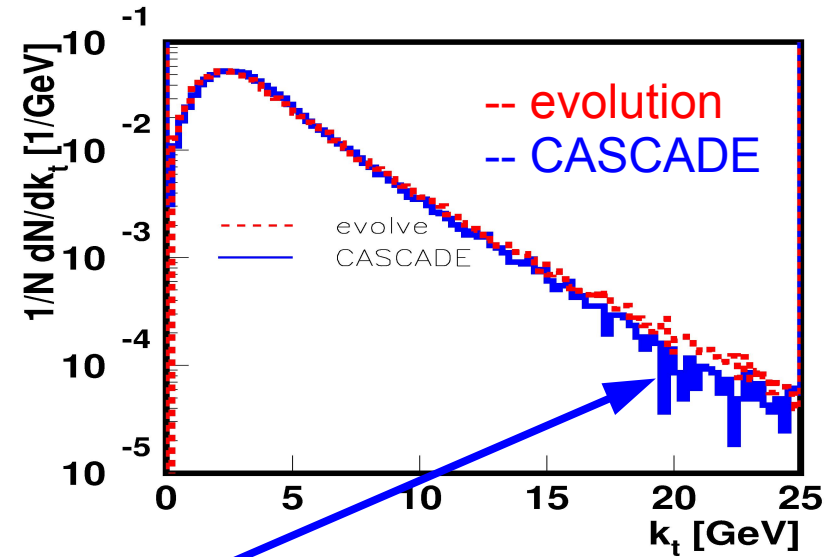
- angular ordering
- non - Sudakov Δ_{ns}



$$\begin{aligned} \sigma(pp \rightarrow q\bar{q} + X) &= \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2 k_{t1} d^2 k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q}) \\ &\quad \times x_{g1} \mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2} \mathcal{A}(x_{g2}, k_{t2}, \bar{q}) \\ \int d^2 k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) &\simeq x_g G(x_g, Q^2) \end{aligned}$$

Advantage of explicit uPDFs

- DGLAP evolution equations:
 - only inclusive predictions
 - no information on emitted partons
- CCFM treats explicitly
 - partons emitted during cascade
 - color coherence
 - energy momentum conservation
- best to implement in MC generator
 - compare **evolution** and **parton shower**



BUT need determination of

uPDF fit to inclusive HERA data

- fit parameters of starting distribution

$$x g(x, \mu_0^2) = N x^{-B_g} \cdot (1-x)^4$$

- using F_2 data

(H1 Eur. Phys. J. C21 (2001) 33-61, DESY 00-181)

$$x < 0.05 \quad Q^2 > 5 \text{ GeV}^2$$

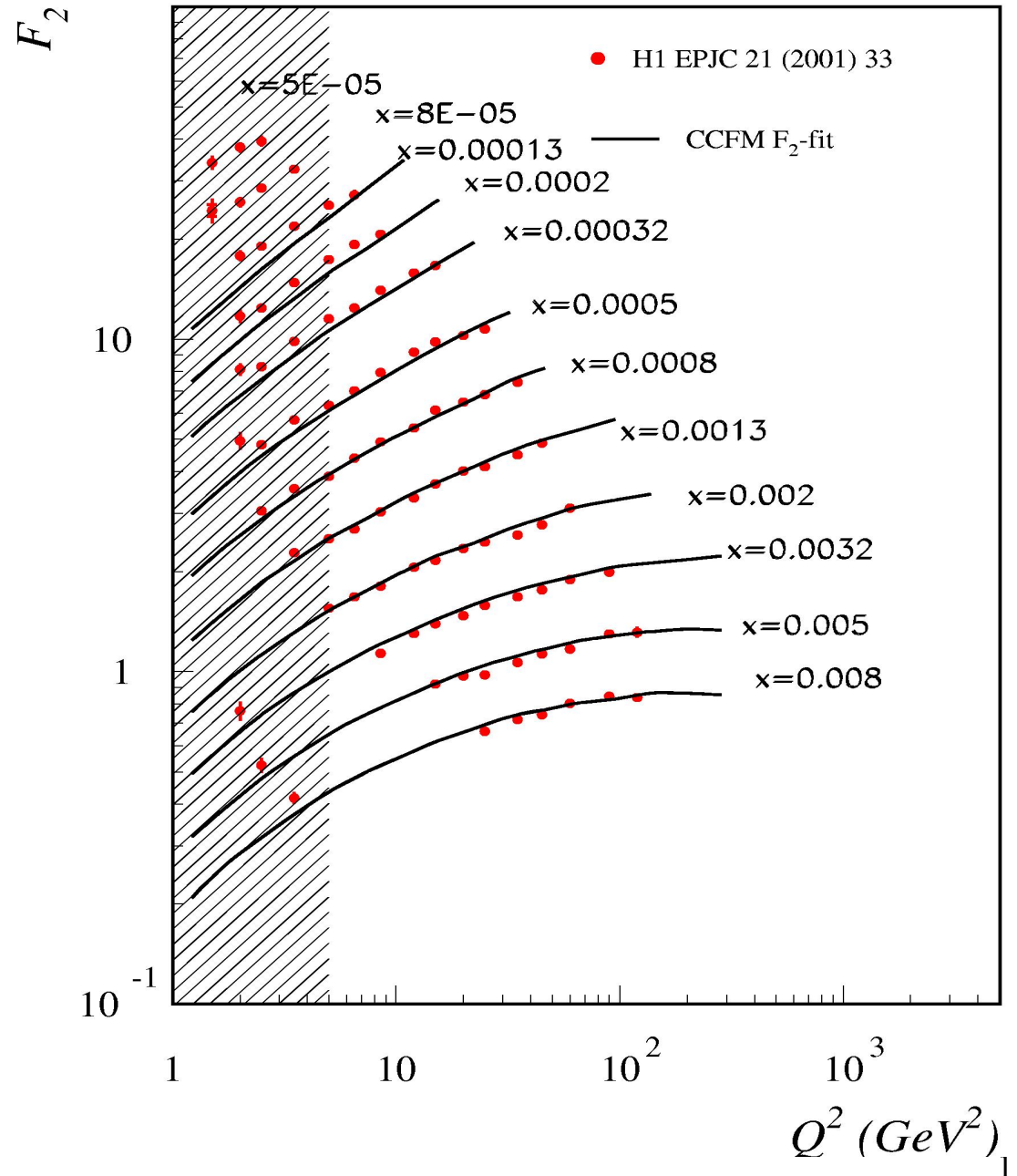
- parameters: $\mu_r^2 = p_t^2 + m_{q,Q}^2$

$$m_q = 250 \text{ MeV}, m_c = 1.5 \text{ GeV}$$

- Fit (only stat+uncorr):

$$\frac{\chi^2}{\text{ndf}} = \frac{111.8}{61} = 1.83$$

→ similar to NLO DGLAP fits (~1.5)



CASCADE MC event generator

- gluon induced processes included
 - ep: $\gamma g^* \rightarrow q\bar{q}$, $\gamma^* g^* \rightarrow Q\bar{Q}$, $\gamma g^* \rightarrow J/\psi g$ at HERA tested well !!!
 - pp: $g^* g^* \rightarrow q\bar{q}$, $g^* g^* \rightarrow Q\bar{Q}$, $g^* g^* \rightarrow h$ HQ at TeVatron tested !!!
- initial state parton shower,
backward evolution, according to
CCFM
- final state PS
- p-remnant treatment
- Hadronization
- full PYTHIA final state PS &
remnant treatment $t\bar{t}$ included
- appli

NEW:
using LHA interface to
PYTHIA/HERWIG
for
- final state PS
- p-remnant
- hadronization

use CASCADE in ep and pp

CASCADE for LHC

- Extension of CASCADE towards a multipurpose event generator applying k_{\perp} -factorization
- Inclusion of new processes ... matrix element calculations needed ...
- Extension of "CASCADE" collaboration:
M. Deak, K. Kutak,
J. Bartels, F. Schwennsen,
S. Baranov, A. Kotikov,
A. Lipatov, N. Zotov

- New processes (calculations done recently)

$$pp \rightarrow W^{\pm} + jets + X$$

$$pp \rightarrow Z^0 + jets + X$$

$$pp \rightarrow \gamma + jets + X$$

- New processes to come:

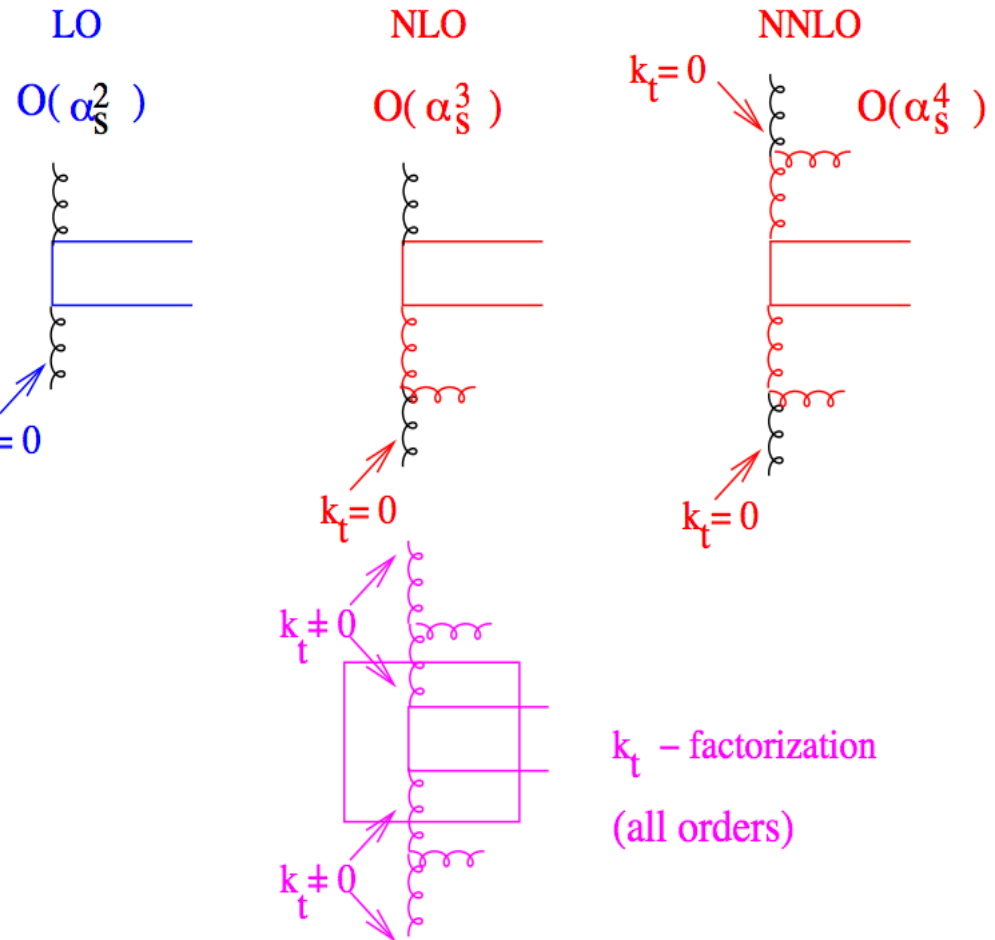
$$pp \rightarrow jets + X$$

$$pp \rightarrow \gamma + \gamma + X$$

Why another Monte Carlo event generator ?

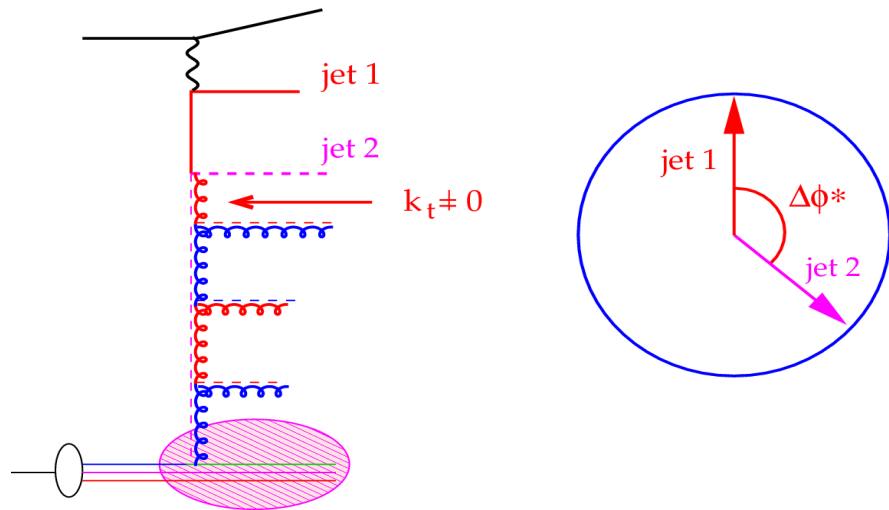
CASCADE and NLO calculations

- fit of uPDF to inclusive structure functions / x-sections used to determine normalization
 - includes "all-orders" !!!!
- off-shell matrix element simulation
 - part of real NLO corrections
 - study of scale dependence
 - compare to coll. NLO calculations
 - check with benchmark x-sections



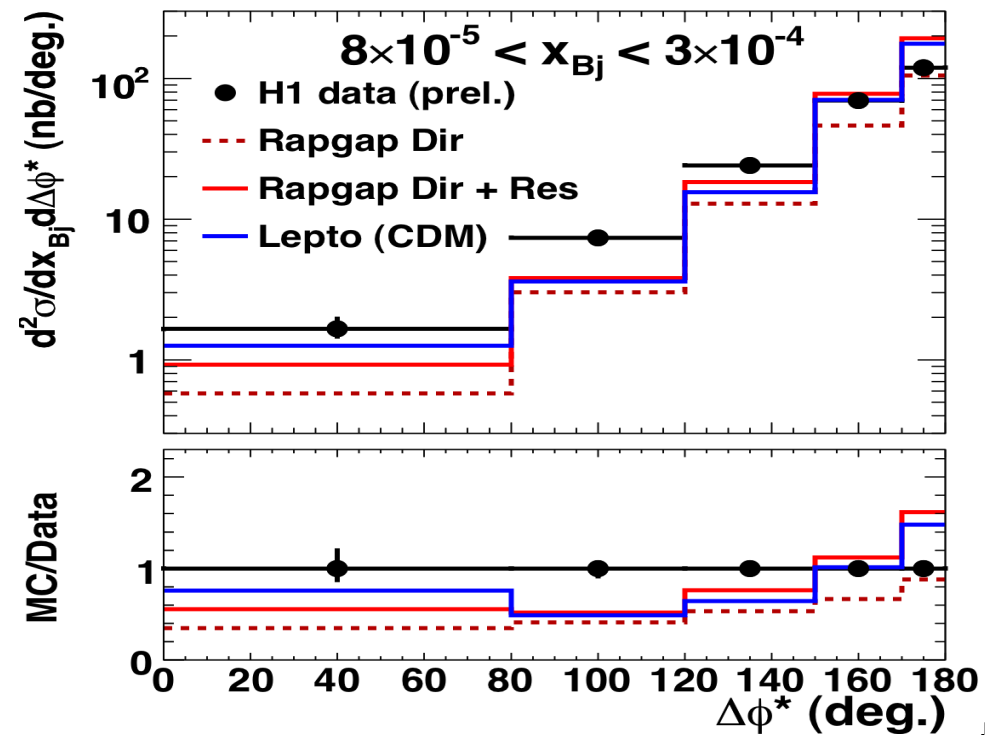
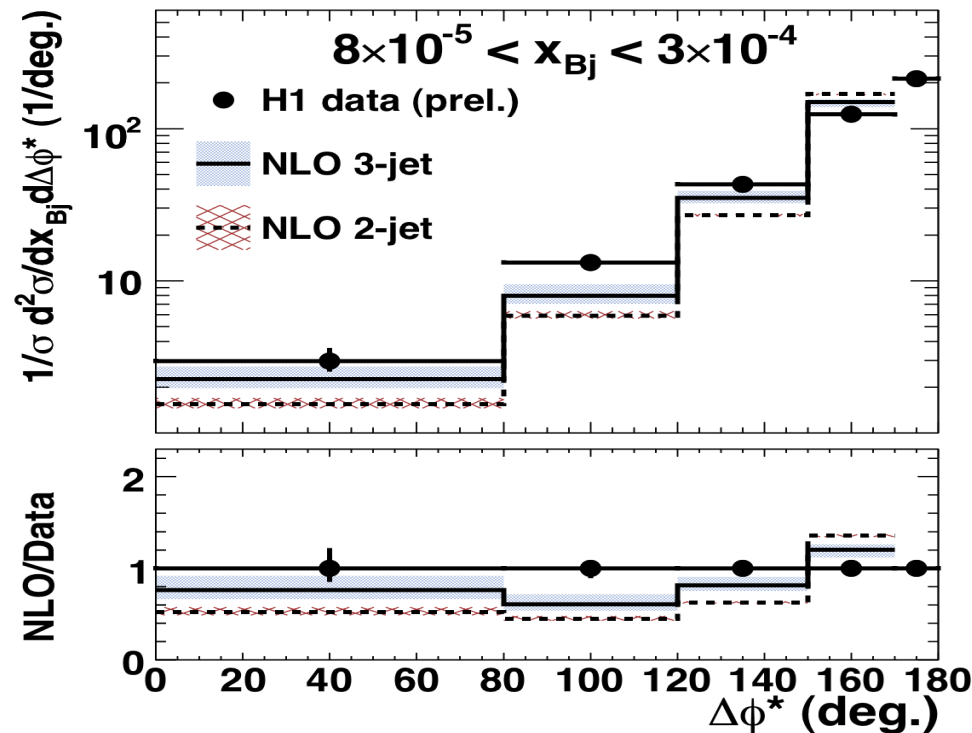
uPDFs are **THE** important ingredient
for **CASCADE** ...

The problem with NLO ...



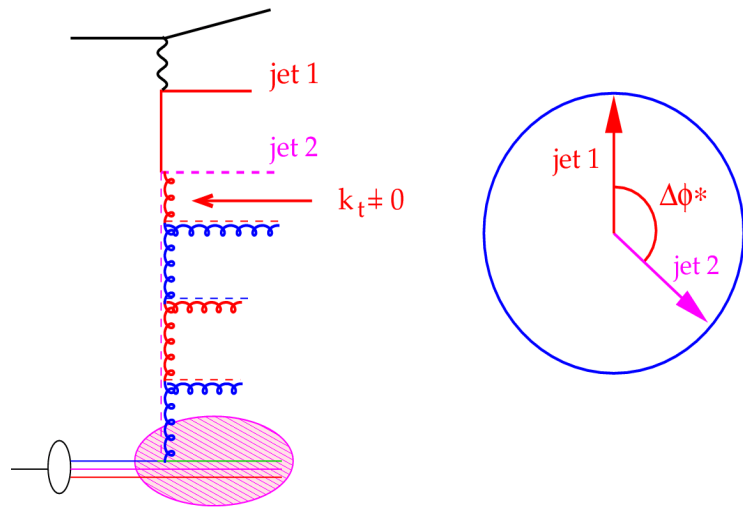
- H1 prel data $5 < Q^2 < 100 \text{ GeV}^2$
 $-1 < \eta < 2.5$
 $E_T > 5 \text{ GeV}$

→ None of the calculations can describe measurements !!!



uPDFs from di-jets: k_{\perp} -dependence

Hansson, Jung arXiv:0707.4276

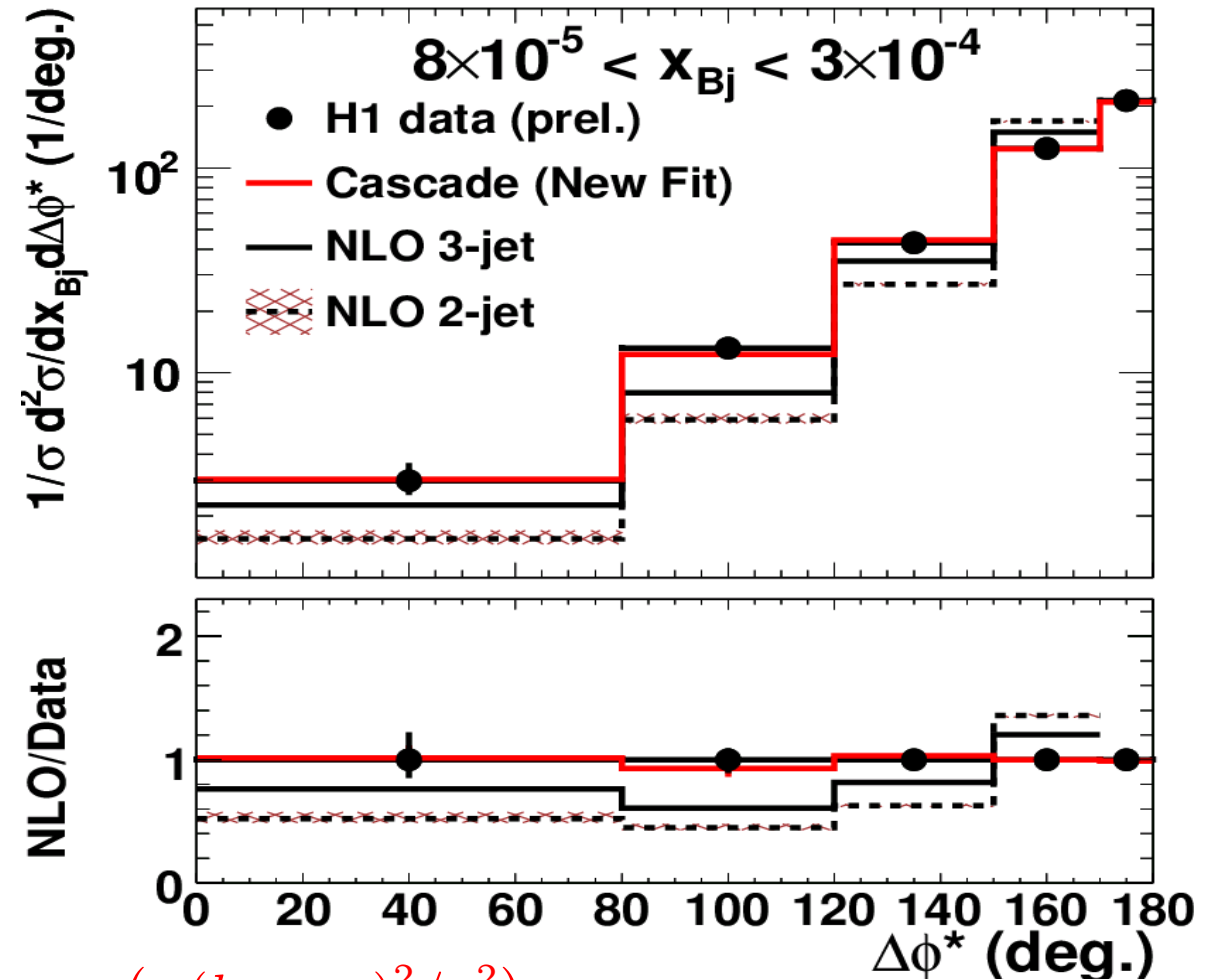


- H1 prel data
 $5 < Q^2 < 100 \text{ GeV}^2$
 $-1 < \eta < 2.5$
 $E_T > 5 \text{ GeV}$

- determine small k_{\perp} region with

$$x\mathcal{A}(x, \mu_0^2) = Nx^{-B_g} \cdot (1-x)^4 \cdot \exp\left(-\frac{(k_{t0} - \mu)^2}{\sigma^2}\right)$$

- large k_{\perp} from evolution



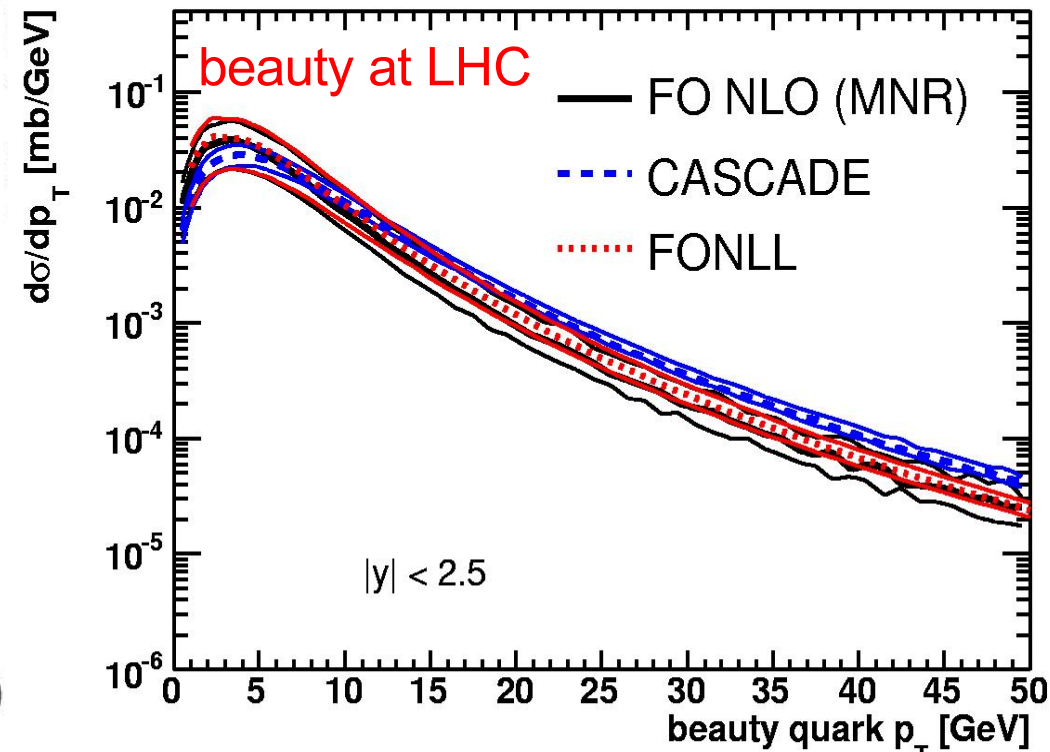
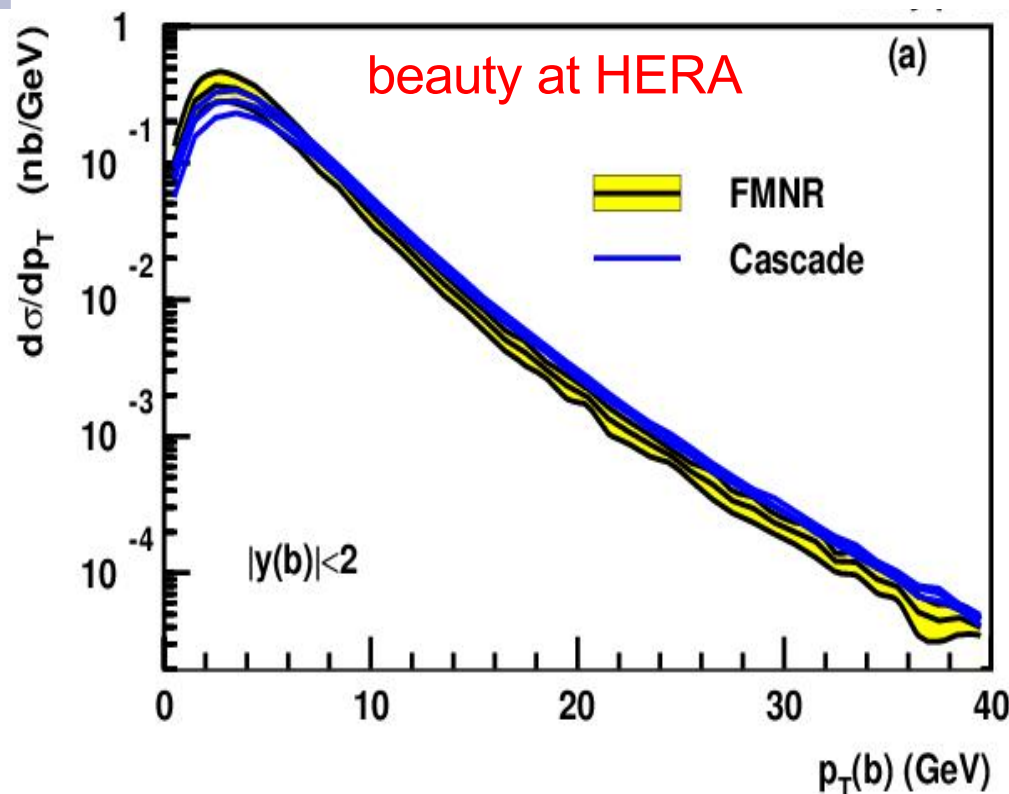
→ perfect description of shape and rate

Benchmarks: beauty at HERA and LHC

from Proceedings of the HERA-LHC workshop hep-ph/0601013

Cross sections at parton level in central region

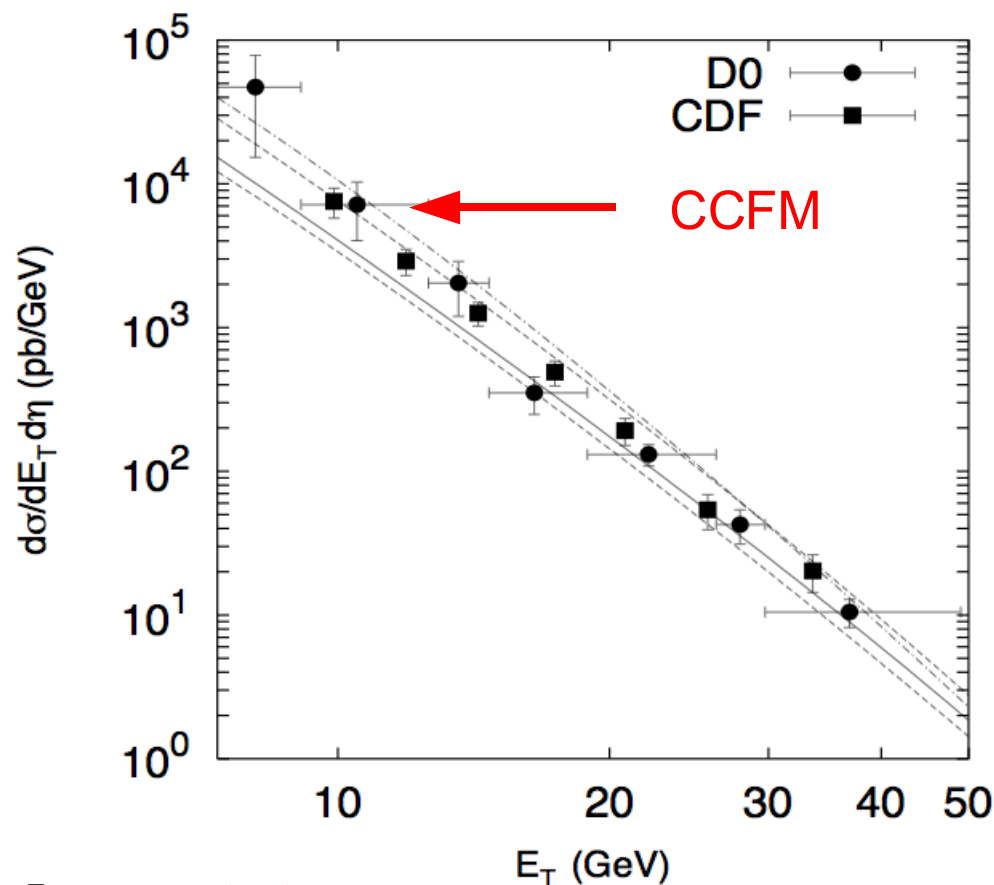
MNR (massive NLO) - FONLL (matched NLL) - CASCADE (uPDF)



➡ “Perfect” agreement of NLO(FMNR) calculation with CASCADE using uPDFs !!!

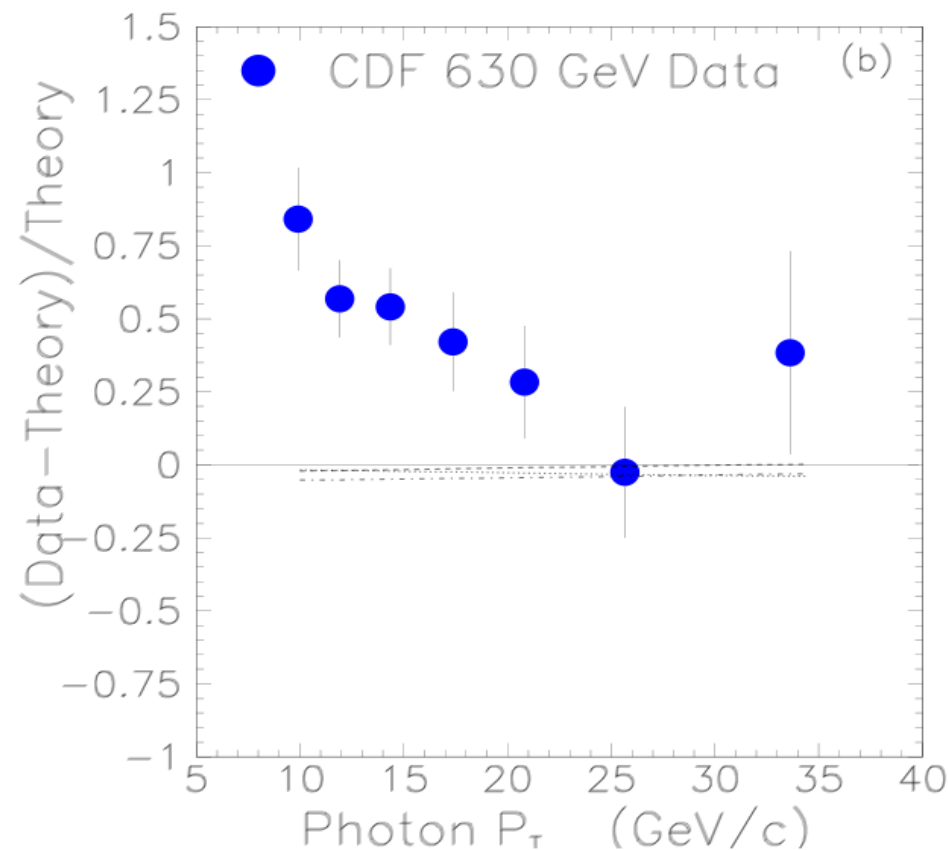
Prompt photons in pp

- Calculations done by Baranov, Lipatov, Zotov (hep-ph/0708.3560) implemented in *CASCADE*



→ good description even at lowest E_T

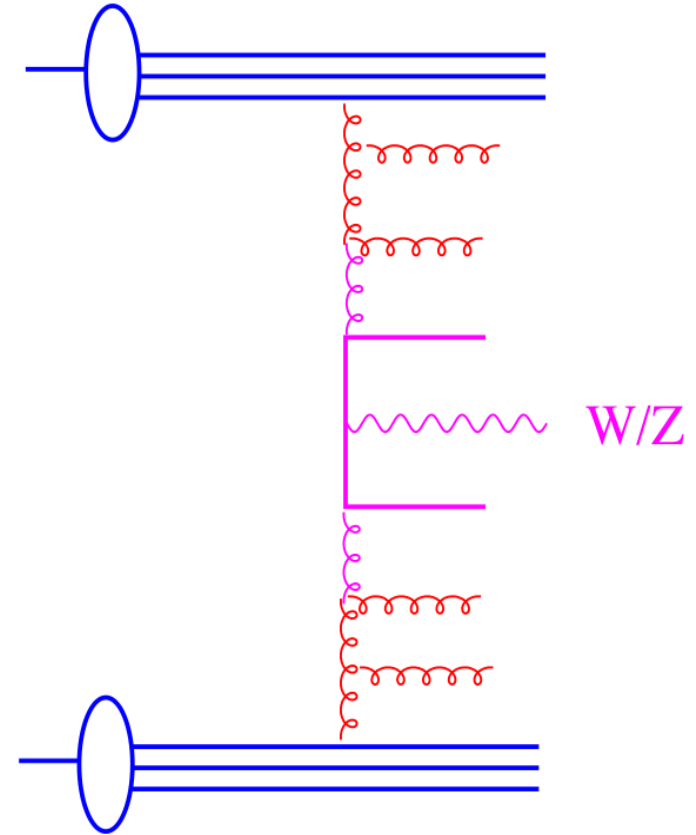
- Compare to collinear NLO result: (hep-ex/0201004)



→ need 4 GeV intrinsic k_T for lowest E_T bins !!??!!

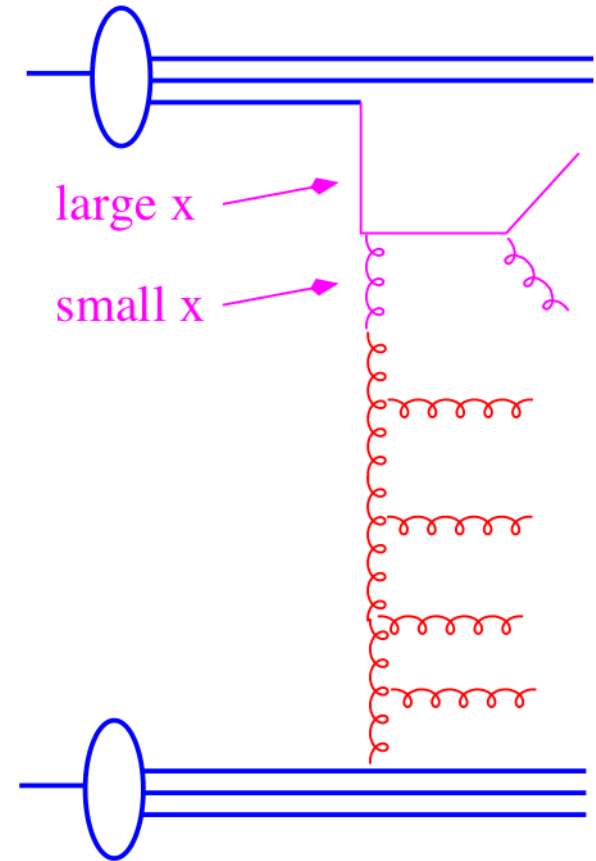
Z_0/W production in pp

- calculations performed: M. Deak, F. Schwennsen
$$gg \rightarrow Z_0/W^\pm + q + \bar{q}$$
$$gg \rightarrow Z_0/W^\pm + Q + \bar{Q}$$
- calculation now finished
will be presented by M. Deak in SFB meeting
today
- fully implemented in **CASCADE**
- allows comparison with collinear calculation, for the first time with W and Z



Including valence quarks

- including $qg \rightarrow qg$
- important for forward jets
- need unintegrated valence quarks
- transition to collinear case



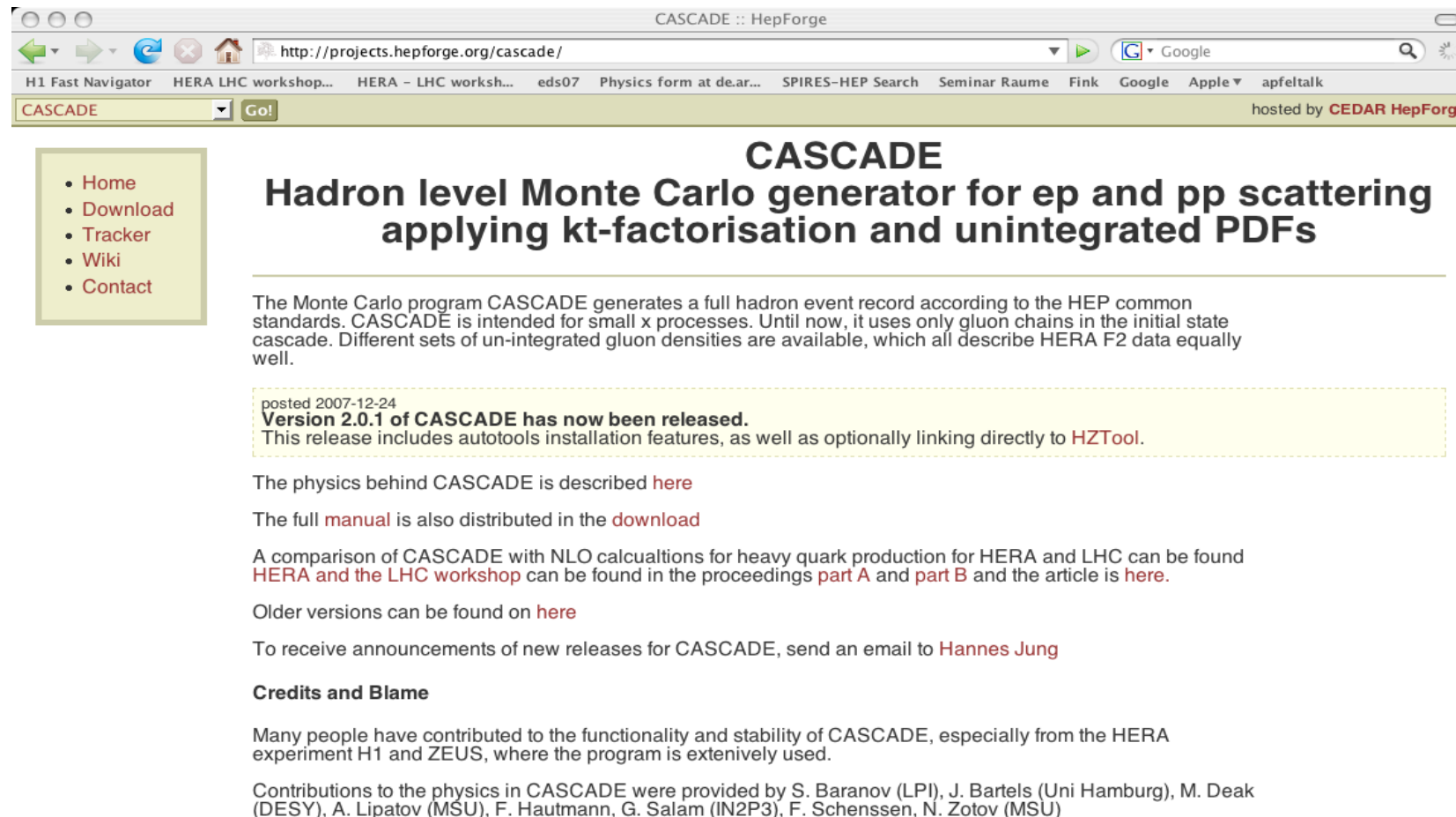
Where is CASCADE ?

- CASCADE home page:

<https://www.desy.de/~jung/cascade/welcome.html> or

<http://projects.hepforge.org/cascade/>

- CASCADE also available in GENSER



The screenshot shows a web browser window with the URL <http://projects.hepforge.org/cascade/>. The page title is "CASCADE :: HepForge". The main heading is "CASCADE Hadron level Monte Carlo generator for ep and pp scattering applying kt-factorisation and unintegrated PDFs". A sidebar on the left contains links: Home, Download, Tracker, Wiki, and Contact. The main content area includes a paragraph about the program, a yellow box announcing "Version 2.0.1 of CASCADE has now been released" with details about autotools and HZTool, and several links for more information, including a manual, workshop proceedings, and older versions. It also mentions contributors and a contact email for Hannes Jung.

CASCADE
Hadron level Monte Carlo generator for ep and pp scattering applying kt-factorisation and unintegrated PDFs

The Monte Carlo program CASCADE generates a full hadron event record according to the HEP common standards. CASCADE is intended for small x processes. Until now, it uses only gluon chains in the initial state cascade. Different sets of un-integrated gluon densities are available, which all describe HERA F2 data equally well.

posted 2007-12-24
Version 2.0.1 of CASCADE has now been released.
This release includes autotools installation features, as well as optionally linking directly to [HZTool](#).

The physics behind CASCADE is described [here](#)

The full [manual](#) is also distributed in the [download](#)

A comparison of CASCADE with NLO calculations for heavy quark production for HERA and LHC can be found [HERA and the LHC workshop](#) can be found in the proceedings [part A](#) and [part B](#) and the article is [here](#).

Older versions can be found on [here](#)

To receive announcements of new releases for CASCADE, send an email to [Hannes Jung](#)

Credits and Blame

Many people have contributed to the functionality and stability of CASCADE, especially from the HERA experiment H1 and ZEUS, where the program is extensively used.

Contributions to the physics in CASCADE were provided by S. Baranov (LPI), J. Bartels (Uni Hamburg), M. Deak (DESY), A. Lipatov (MSU), F. Hautmann, G. Salam (IN2P3), F. Schenksen, N. Zotov (MSU)

Last updated: Tue Dec 25 09:38:44 2007

Future plans

- physics
 - include $gg \rightarrow gg$ for jets
 - include approach in kt-factorisation for Multiple Interactions and UE
 - add more standard model processes
- technical side:
 - implementation into CMS and ATLAS software

Conclusions

- **CASCADE** has many advantages compare to other Monte Carlo event generators:
 - treats kinematics correct from the beginning
 - no difference between evolution and parton showering
 - agrees well with standard NLO calculations, where applicable !!!
 - includes naturally transition to small x via angular ordering in CCFM
- **CASCADE** for pp
 - applicable for standard high p_+ processes:
 - jets, heavy quarks, Higgs, W/Z
 - can be used like PYTHIA in experiment environment
 - inclusion of multi-parton scattering comes **next**

Doing better and easier with **CASCADE** !!!

Backup Slides

Other features of CASCADE

- various sets of uPDFs included (but only CCFM/KMR with parton shower):
 - CCFM
 - KMR (Kimber, Martin, Ryskin Phys. Rev. D 63 (2001) 114027)
 - KMS (Kwiecinski, Martin, Stasto Phys. Rev. D 56 (1997) 3991)
 - saturation model
 - derivative of integrated gluon
 -
 - Remember: consistent treatment only with uPDF
 - KMR prescription: one additional radiation ... useful for determination of hadronization corrections for NLO calculations
 - Features of CCFM uPDFs: variation of renormalization scale
 - using uPDFs accordingly determined
- smaller uncertainty from theory

Which PDFs to be used in MC's ?

arguments by T. Sjostrand

General purpose event generators

provide

$$\hat{\sigma}(\text{LO}) \otimes \text{PDF}(\text{LO}) \otimes \text{showers}$$

Each component separately is positive

BUT ...

- PDF fits using LO are bad
- no uncertainty estimate for LO PDFs
- Often NLO PDFs are used....

BUT

- PDFs are not physical observables ...
not necessarily positive
- $\hat{\sigma}(\text{LO}) \otimes \text{PDF}(\text{NLO})$ may be grap

- Different solutions proposed
 - determine new LO* PDFs by relaxing momentum sum rule
 - hack
 - use NLO PDFs for hard process, and LO PDFs for showering
 - hack
 - determine special PDFs: PDF4MC