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 ?

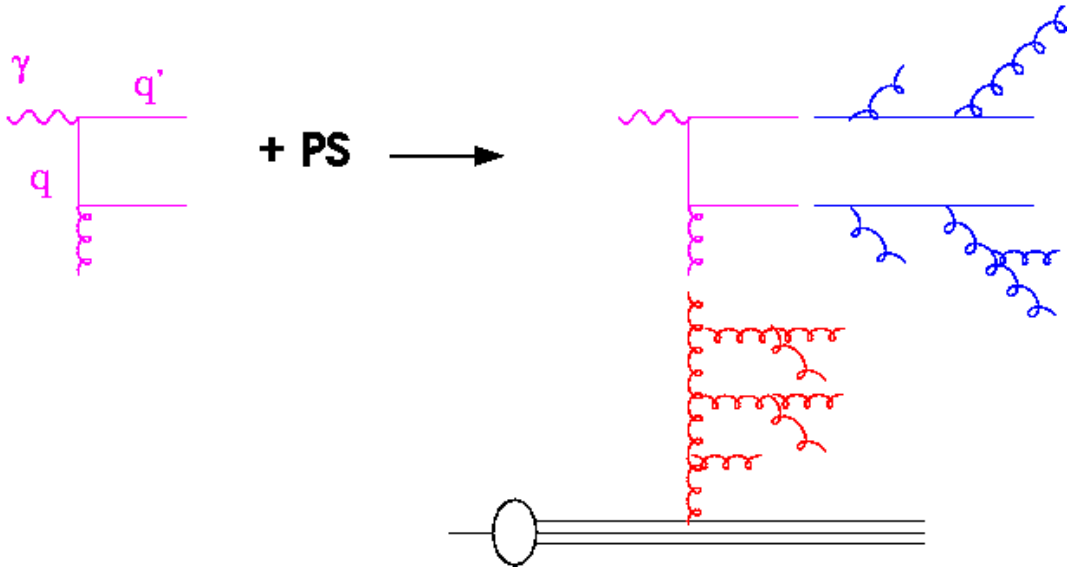
Why another Monte Carlo event generator ?

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

  $(\gamma+q)^2 = q'^2$, $-Q^2 + x\,y\,s = 0$ ➔ $x = Q^2/(ys)$

- **BUT** final state radiation:

  $(\gamma+q)^2 = q'^2$, $-Q^2 + x\,y\,s = m^2$ ➔ $x = (Q^2+m^2)/(ys)$

- **AND** initial state radiation:

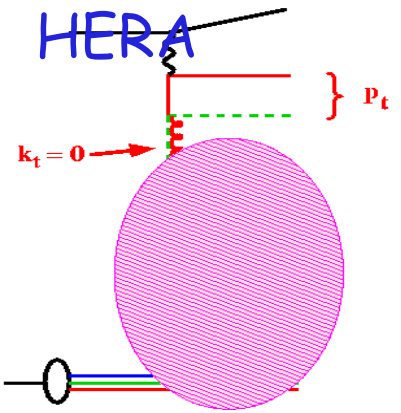
  $(\gamma+q)^2 = q'^2$, $-Q^2 + x\,y\,s + q^2 = 0$ ➔ $x = (Q^2-q^2)/(ys)$

- **Collinear approach: $q'^2 = q^2 = 0$, order by order ....**
- Well known.... since years....
- NLO corrections... better treatment of kinematics... but still not all....

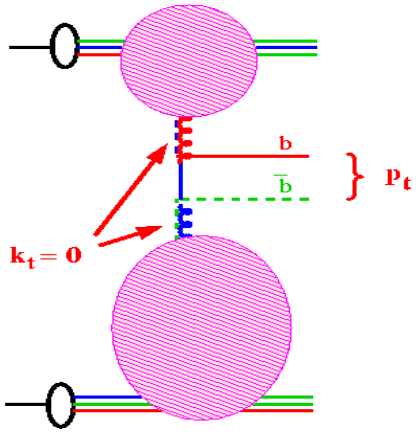
Problems in Collinear Approximation

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

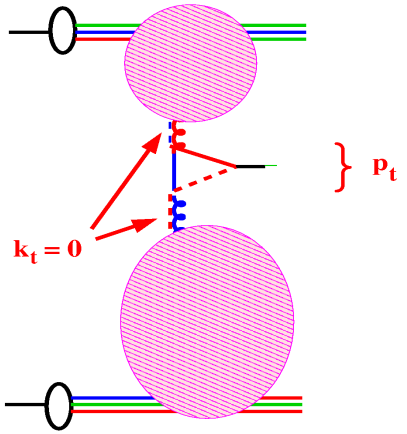
heavy quarks at HERA

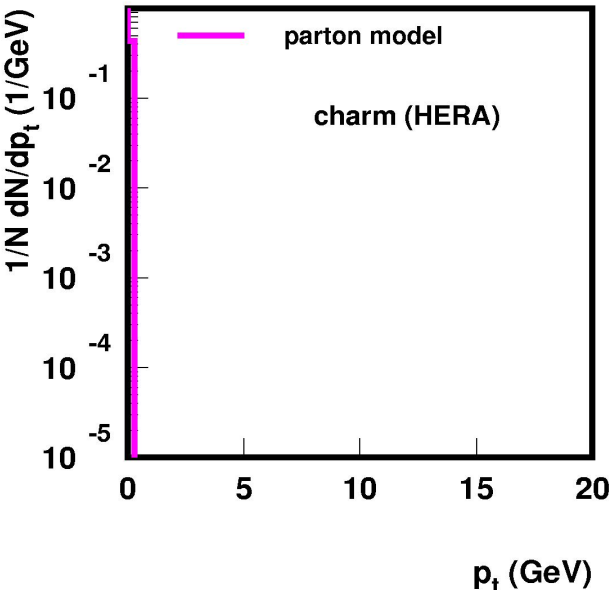


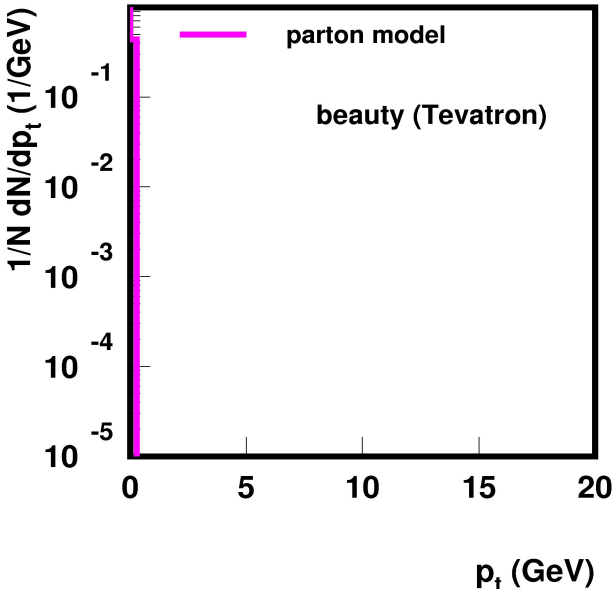
heavy quarks in

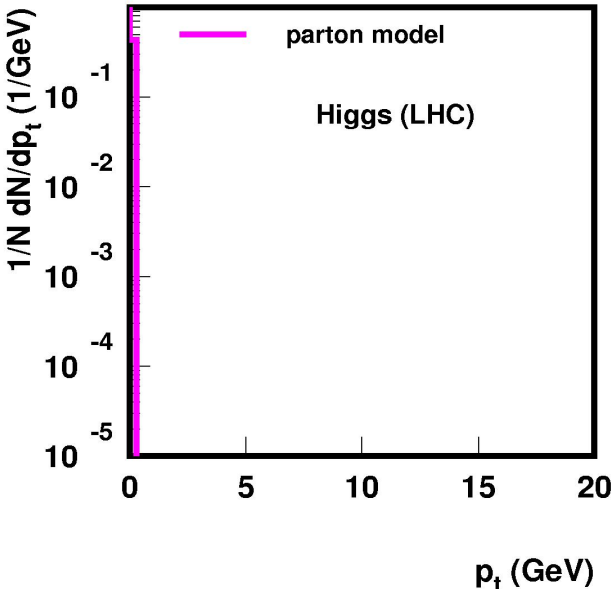


Higgs in pp









➔ NLO corrections will be very large for these LO processes .....

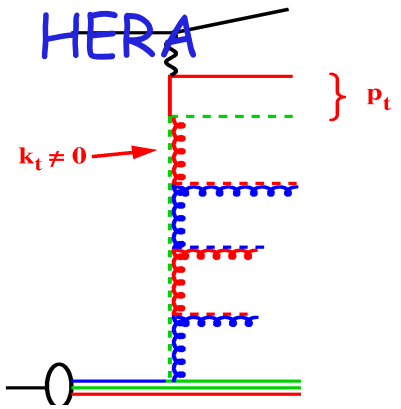
Why another Monte Carlo event generator ?

because we can do much better ...

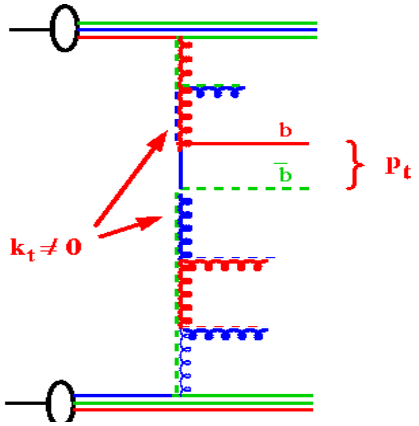
Doing much better with uPDFs ...

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

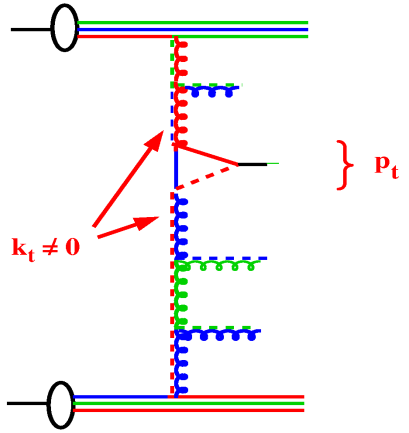
heavy quarks at HERA

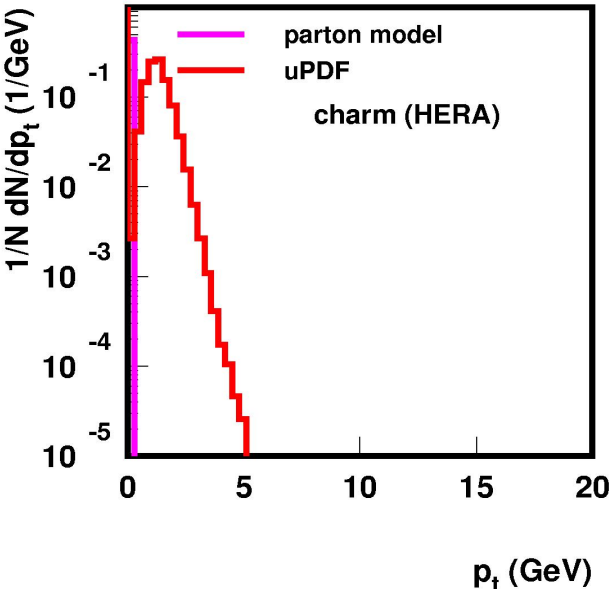


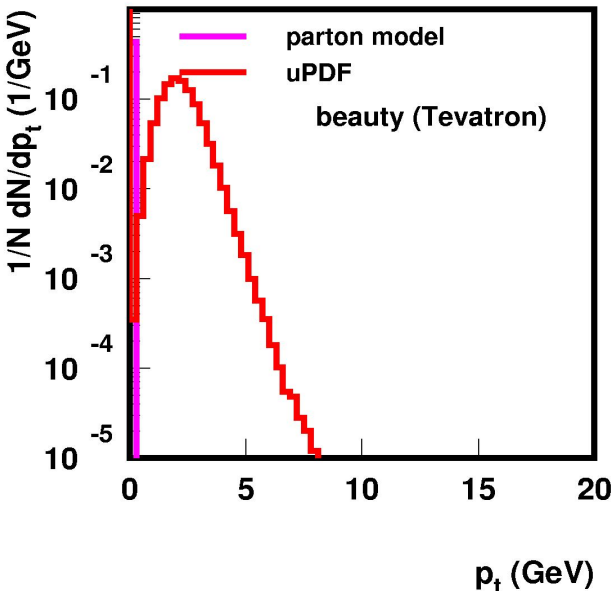
heavy quarks in

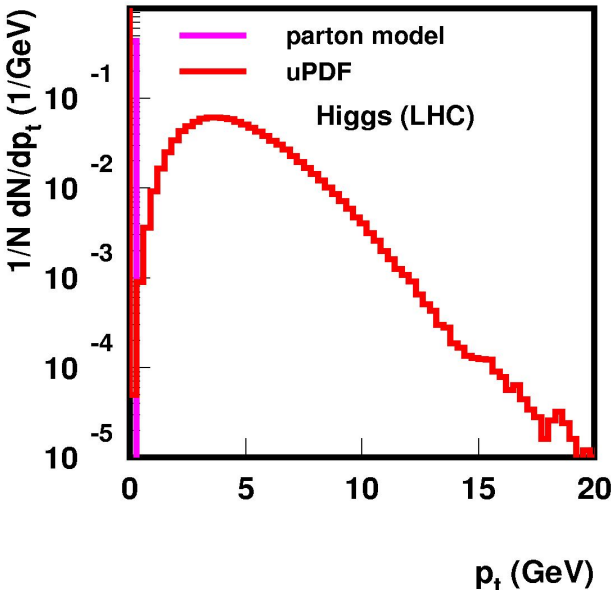


Higgs in pp



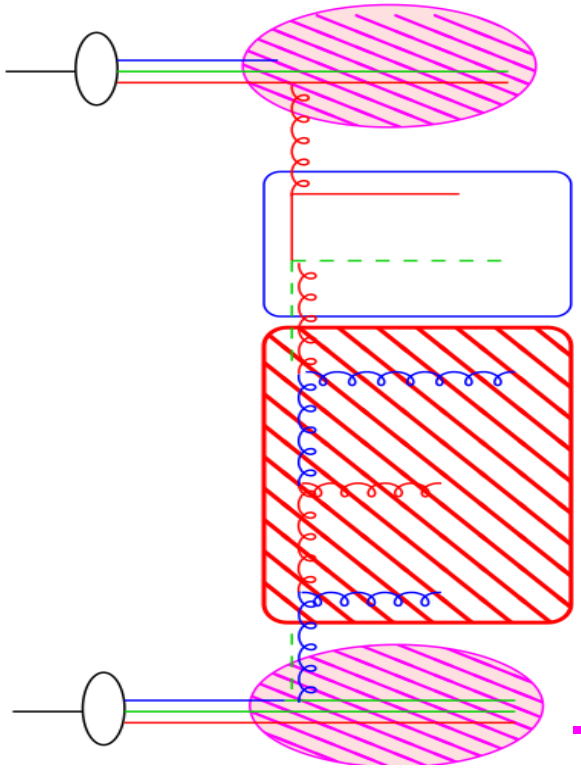






➔ doing kinematics correct at LO, reduces NLO corrections ... NEED uPDFs !!!!

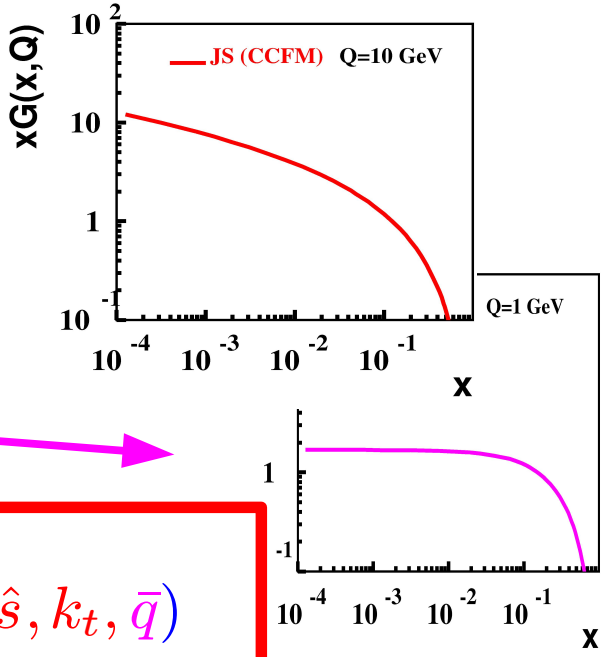
CASCADE - basic idea



matrix element

evolution of parton cascade:

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

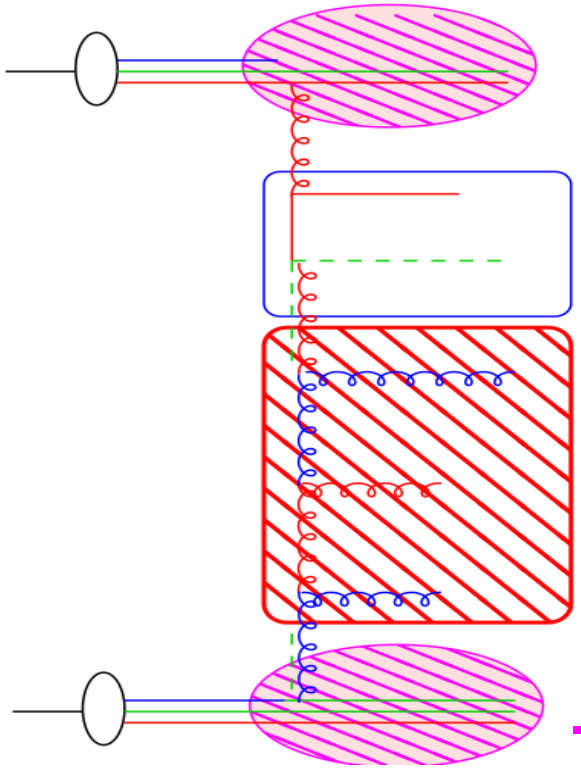


initial distribution ~ flat

$$\sigma(pp \to q\bar{q} + X) = \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2k_{t1} d^2k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q})$$
$$\times x_{g1}\mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2}\mathcal{A}(x_{g2}, k_{t2}, \bar{q})$$

$$\int d^2k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) = x_g G(x_g, Q^2) \text{ if } \hat{\sigma} = \hat{\sigma}(\hat{s}, 0, \bar{q})$$

CASCADE - $C_{atani}C_{iafaloni}F_{iorani}M_{archesini}$ evolution



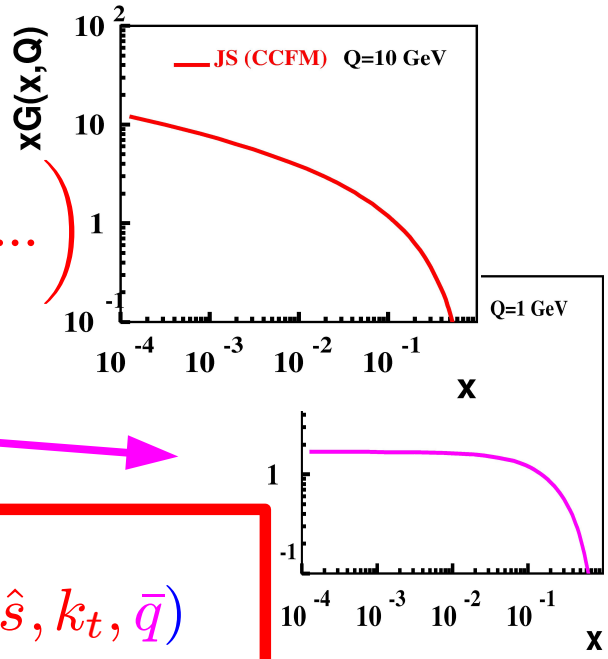
matrix element
off shell

CCFM (all loops)

- angular ordering
- non - Sudakov Δ_{ns}

evolution of parton cascade:

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



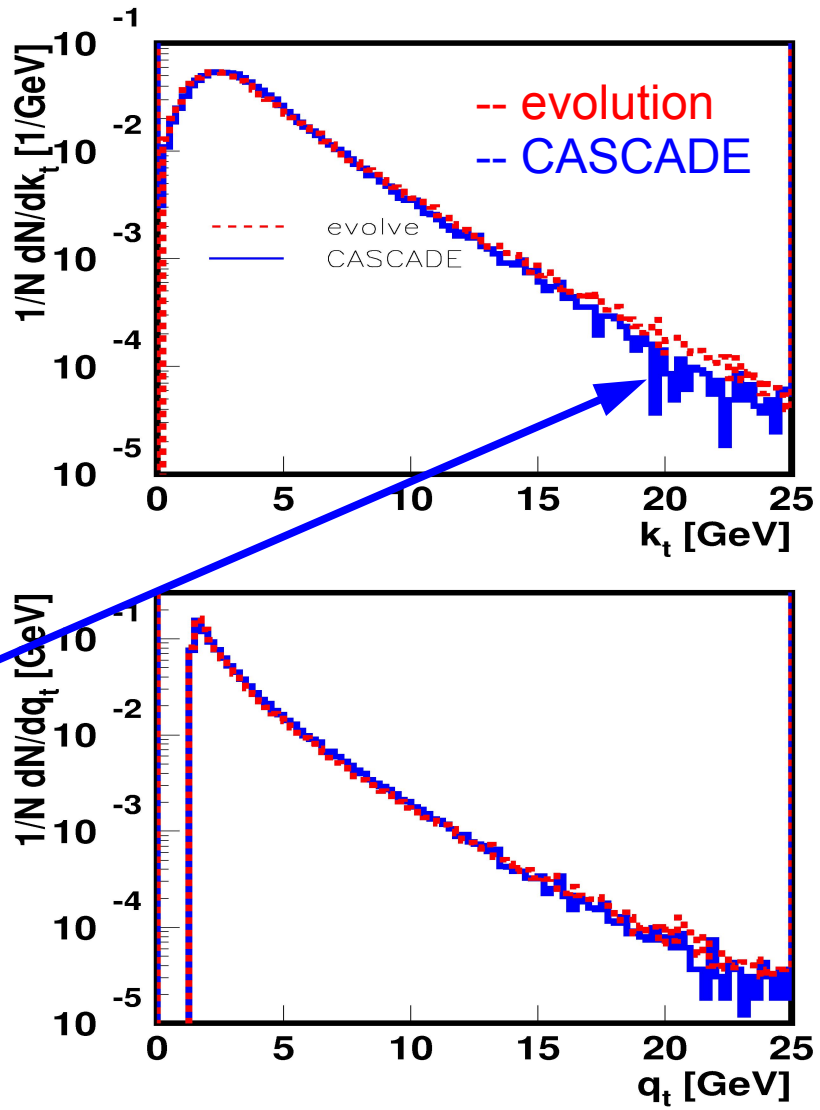
initial distribution
~ flat

$$\sigma(pp \to q\bar{q} + X) = \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2k_{t1} d^2k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q})$$
$$\times x_{g1}\mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2}\mathcal{A}(x_{g2}, k_{t2}, \bar{q})$$

$$\int d^2k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) \simeq x_g G(x_g, Q^2)$$

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)

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

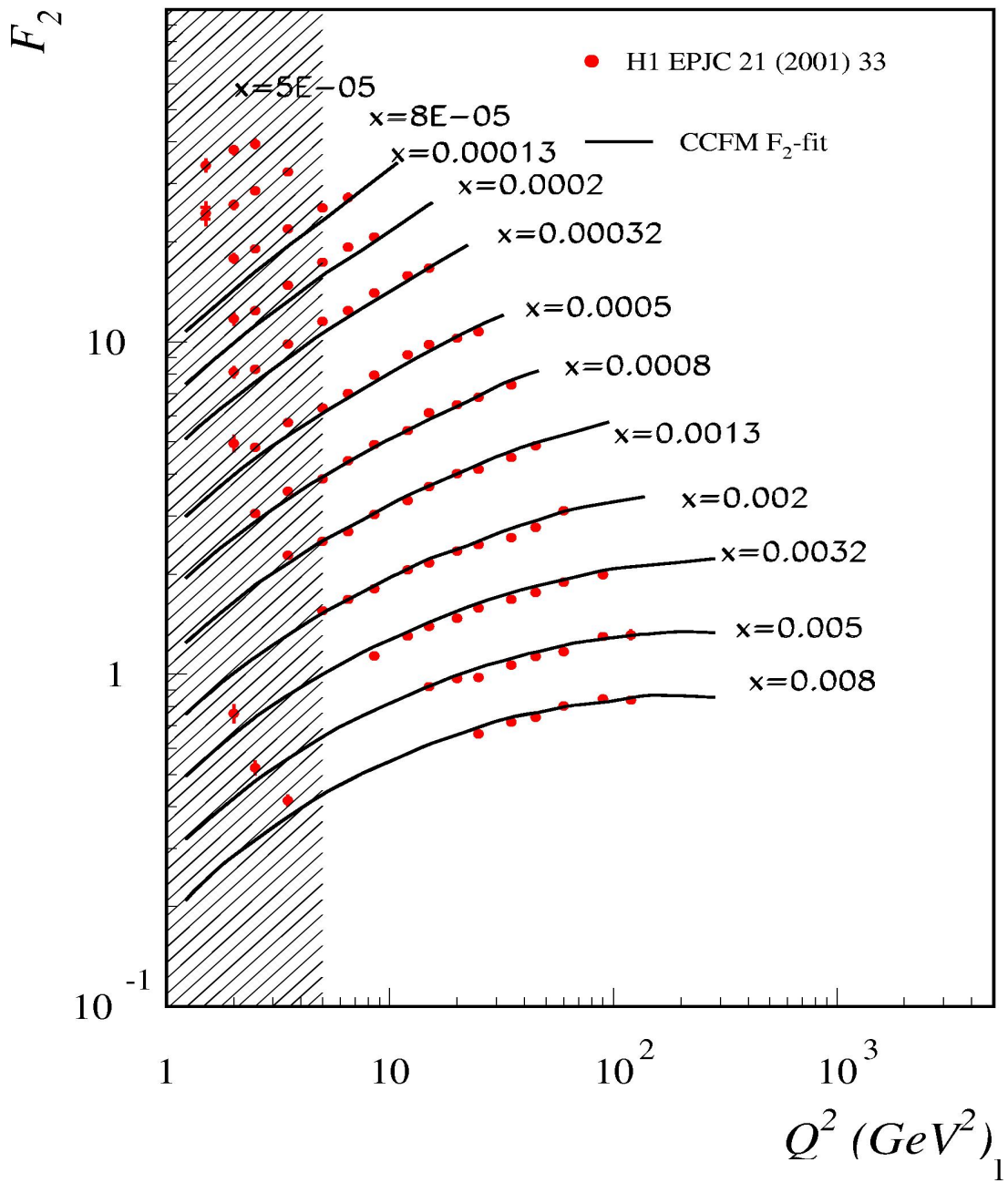
- parameters: $\mu_r^2 = p_t^2 + m_{q,Q}^2$

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

- Fit (only stat+uncorr):

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

➔ similar to NLO DGLAP fits (~1.5)



CASCADE MC event generator

- gluon induced processes included
  - ep: $\gamma g^* \to q\bar{q}$, $\gamma^* g^* \to Q\bar{Q}$, $\gamma g^* \to J/\psi g$ at HERA tested well !!!
  - pp: $g^* g^* \to q\bar{q}$, $g^* g^* \to Q\bar{Q}$, $g^* g^* \to h$ 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 included

➔ appli $t\bar{t}$

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_t-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)

$$pp \rightarrow W^{\pm} + jets + X$$
$$pp \rightarrow Z^0 + jets + X$$
$$pp \rightarrow \gamma + jets + X$$

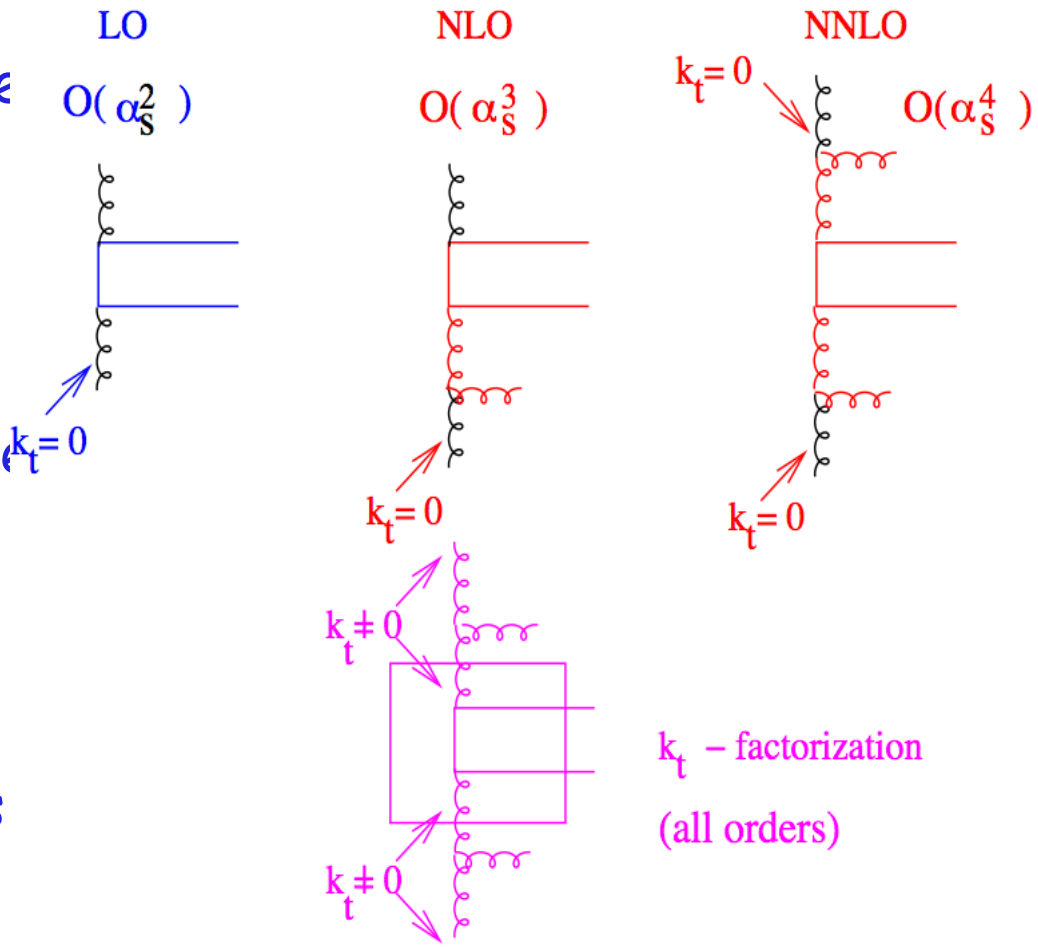
- New processes to come:

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

Why another Monte Carlo event generator ?

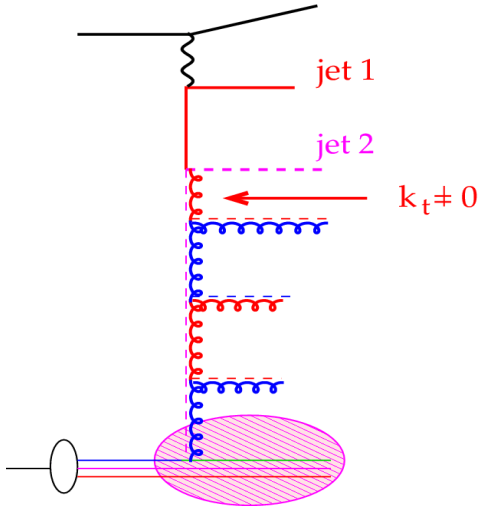
CASCADE and NLO calculations

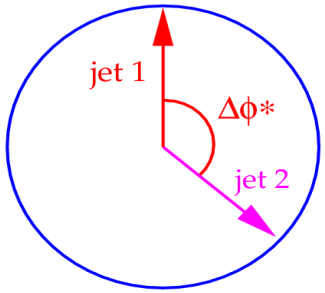
- fit of uPDF to inclusive structure functions /x-sections used to determine normalization
  - ➔ includes "all-orders" !!!!
- off-shell matrix element simulates part of real NLO corrections
  - ➔ study of scale dependence
  - ➔ compare to coll. NLO calculations
  - ➔ check with benchmark x-sections



uPDFs are THE important ingredient for CASCADE ...

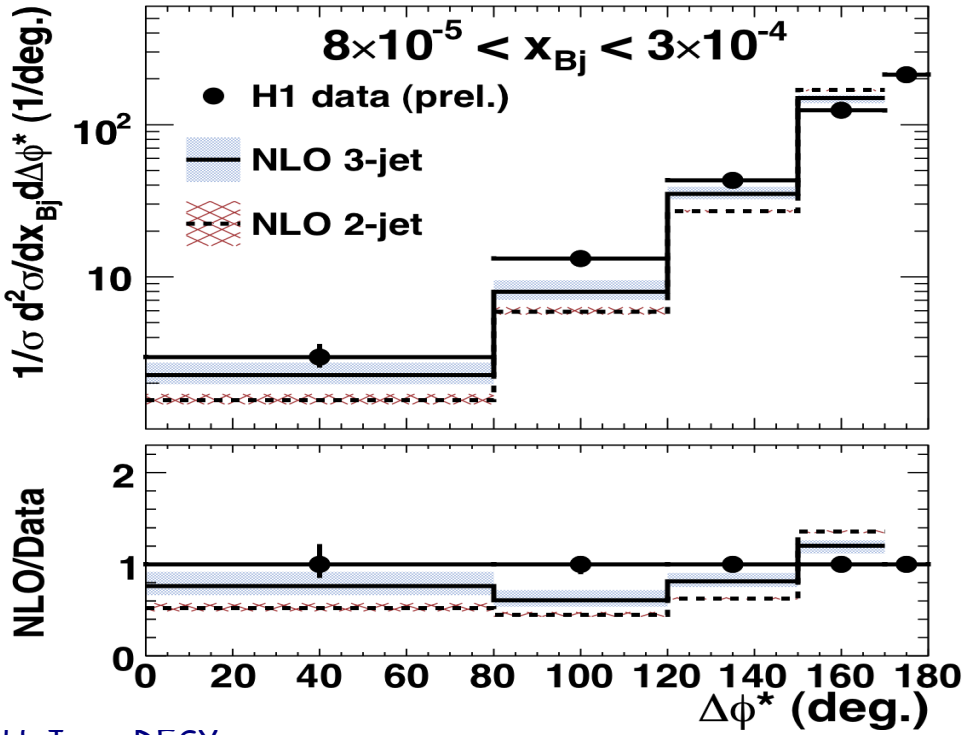
The problem with NLO ...

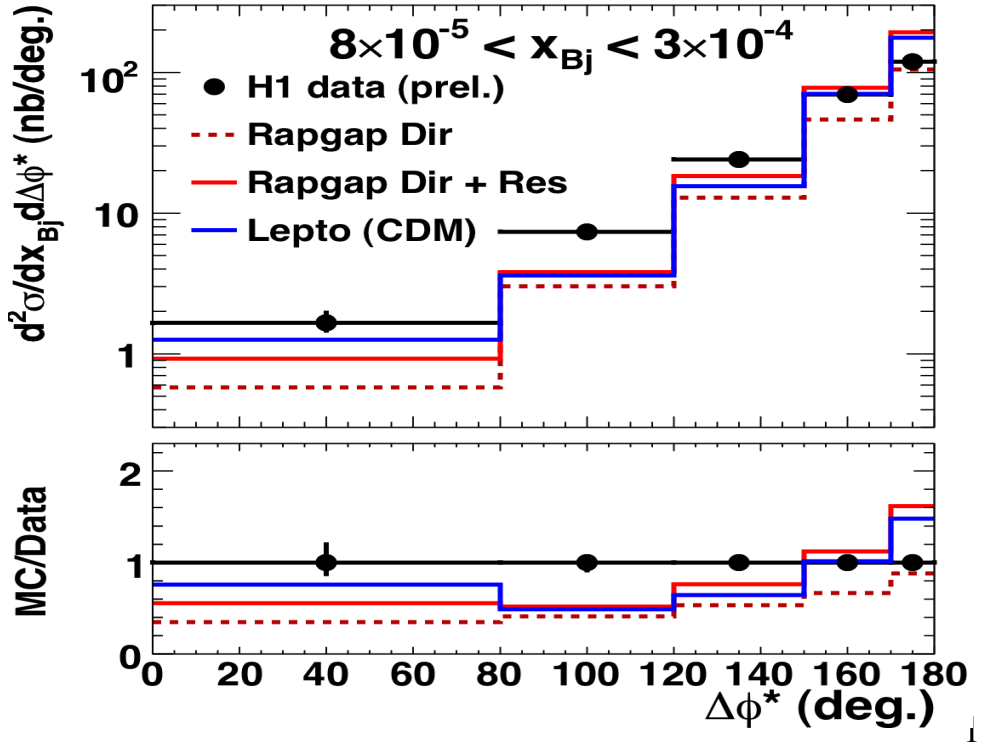




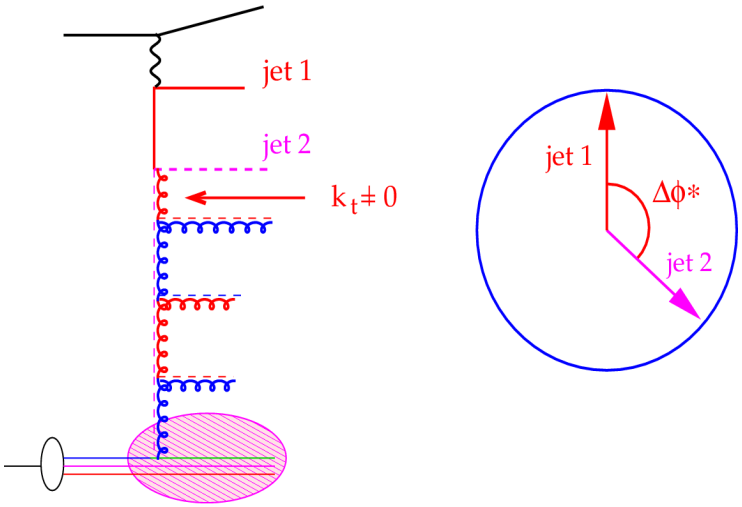
- H1 prel data $5 < Q^2 < 100\ \mathrm{GeV}^2$
  $-1 < \eta < 2.5$
  $E_T > 5\ \mathrm{GeV}$

➔ None of the calculations can describe measurements !!!

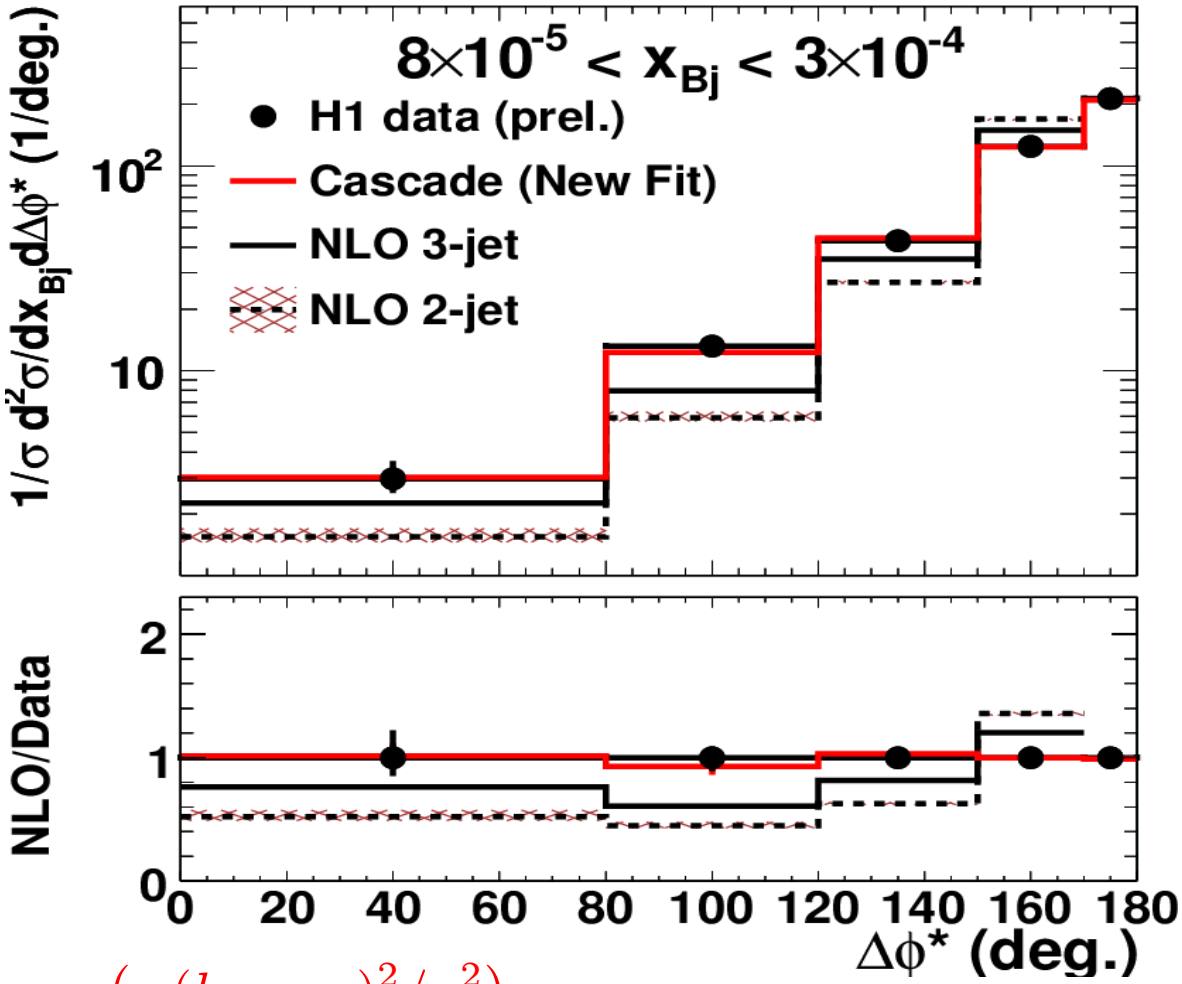




uPDFs from di-jets: k_t-dependence



Hansson, Jung arXiv:0707.4276



- H1 prel data

  $5 < Q^2 < 100\ \mathrm{GeV}^2$

  $-1 < \eta < 2.5$

  $E_T > 5\ \mathrm{GeV}$

- determine small k_t region with

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

- large k_t from evolution

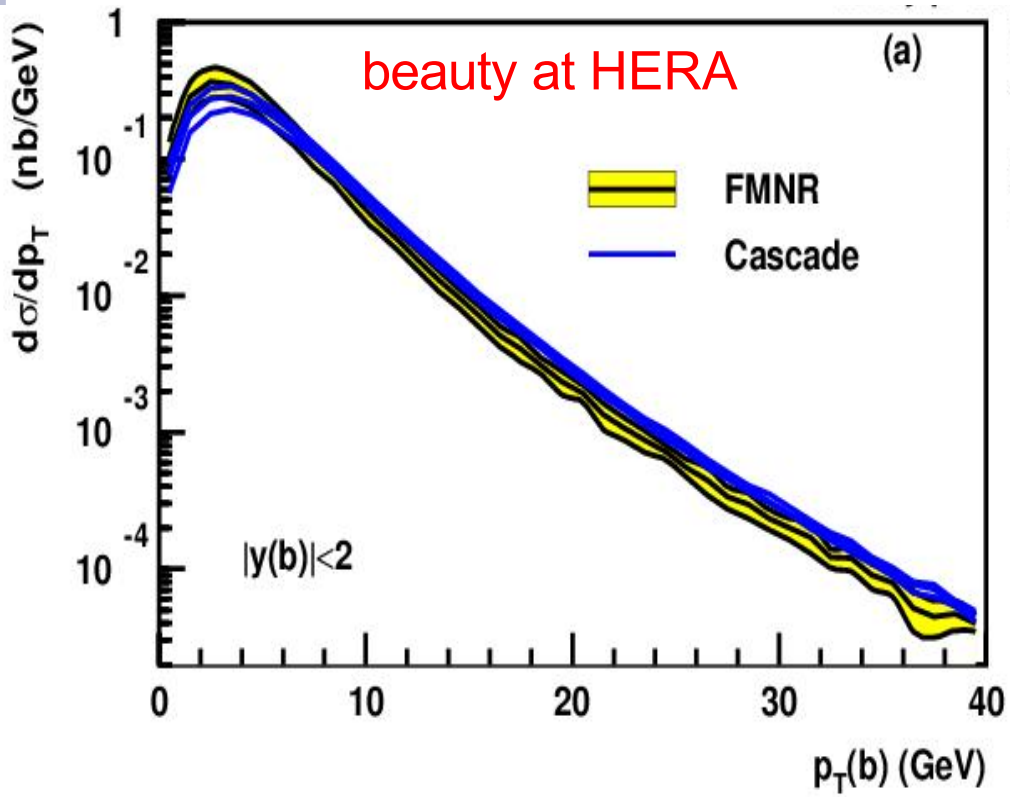
➔ perfect description of shape and rate

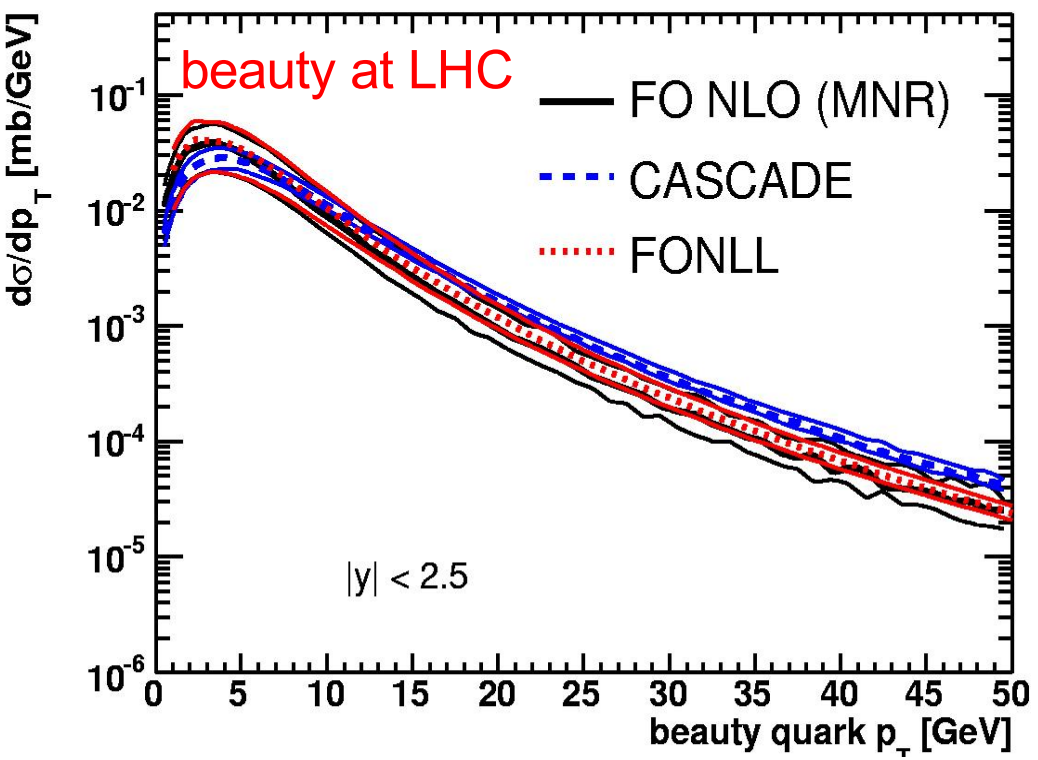
Benchmarks: beauty at HERA and LHC

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)

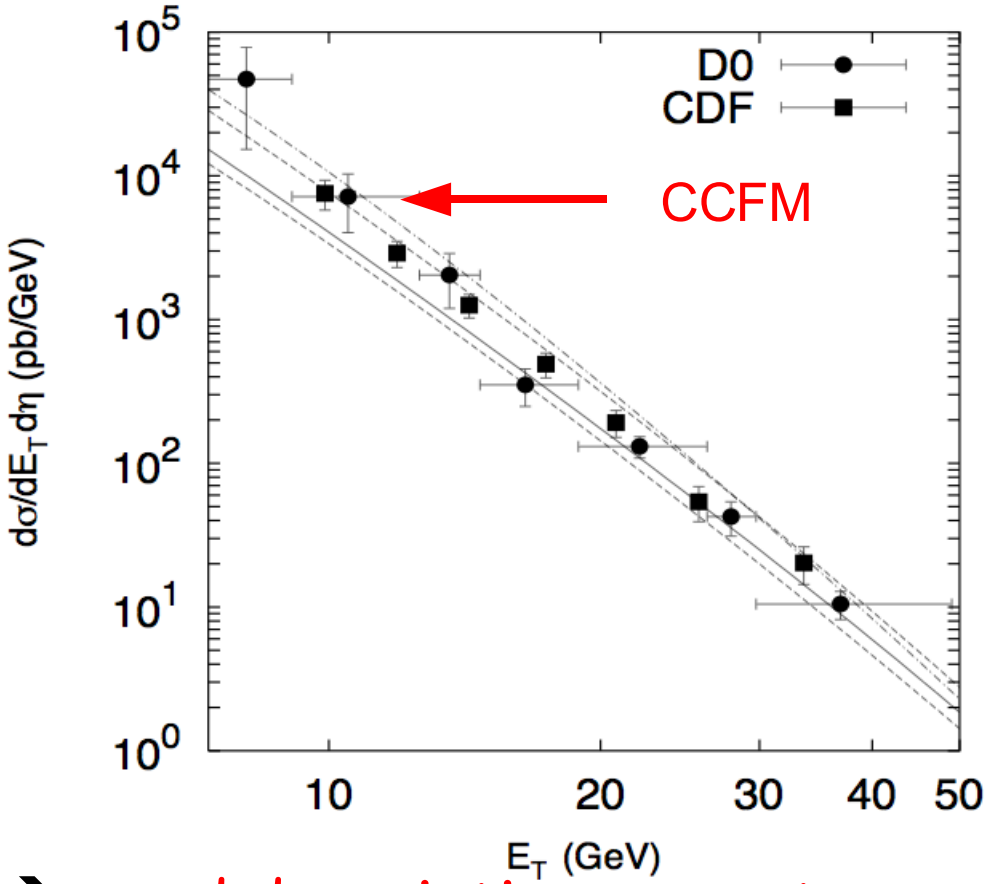




"Perfect" agreement of NLO(FMNR) calculation with CASCADE using uPDFs !!!

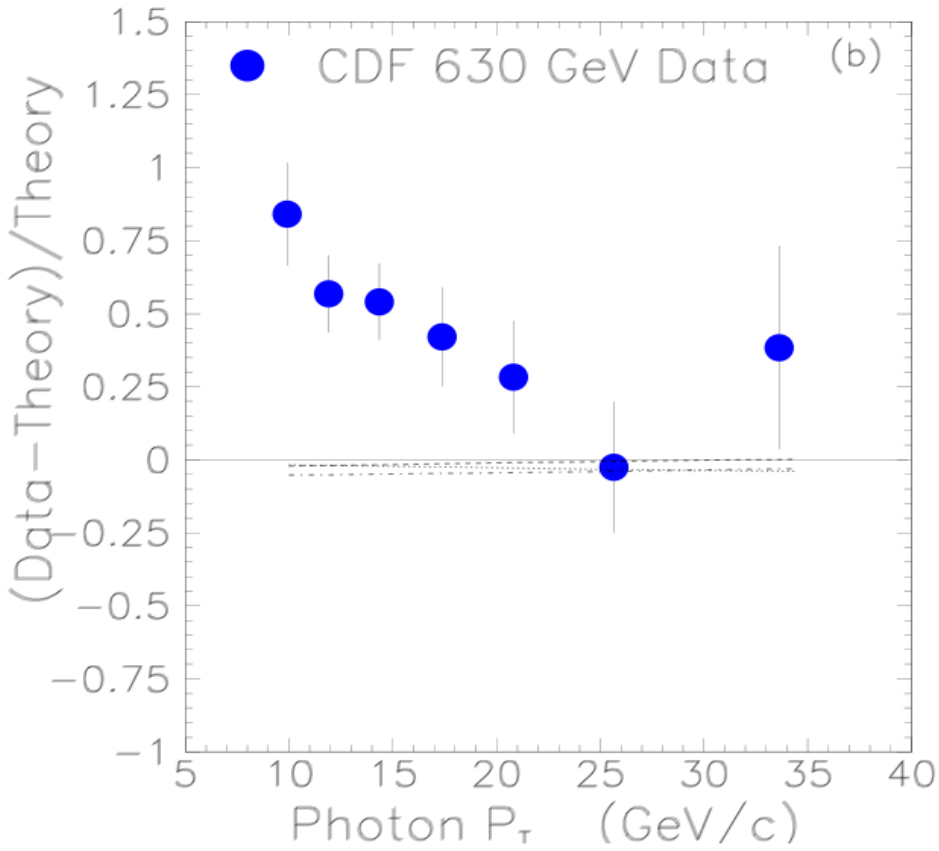
Prompt photons in pp

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



➔ good description even at lowest Et

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



➔ need 4 GeV intrinsic kt for lowest Et bins !!??!!

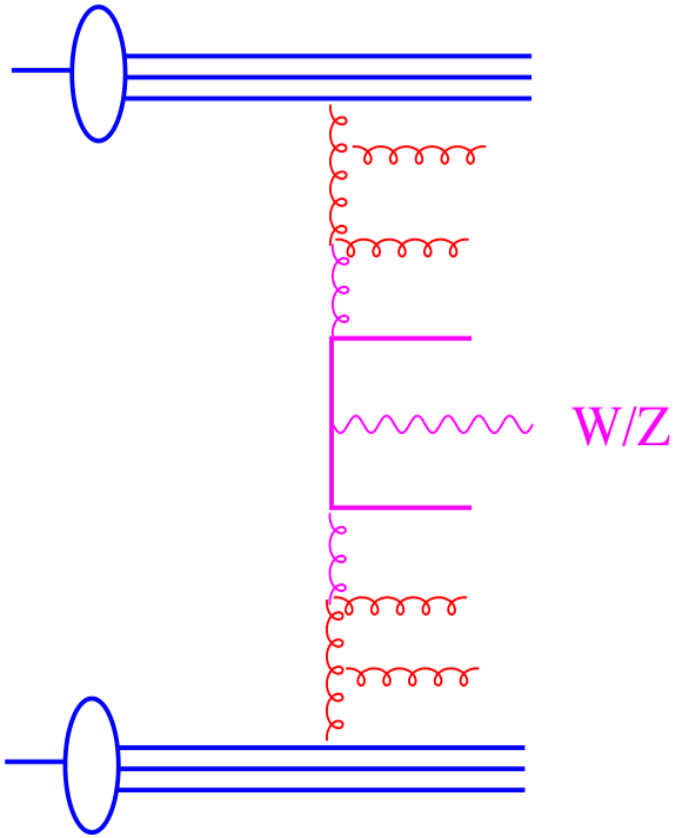
Z_0/W production in pp

- calculations performed: M. Deak, F. Schwennsen

$$gg \to Z_0/W^{\pm} + q + \bar{q}$$

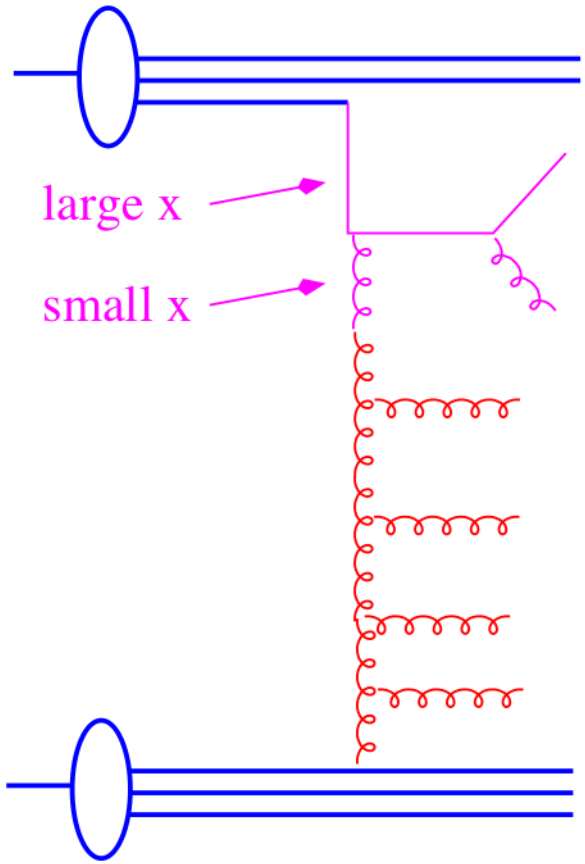
$$gg \to Z_0/W^{\pm} + Q + \bar{Q}$$

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



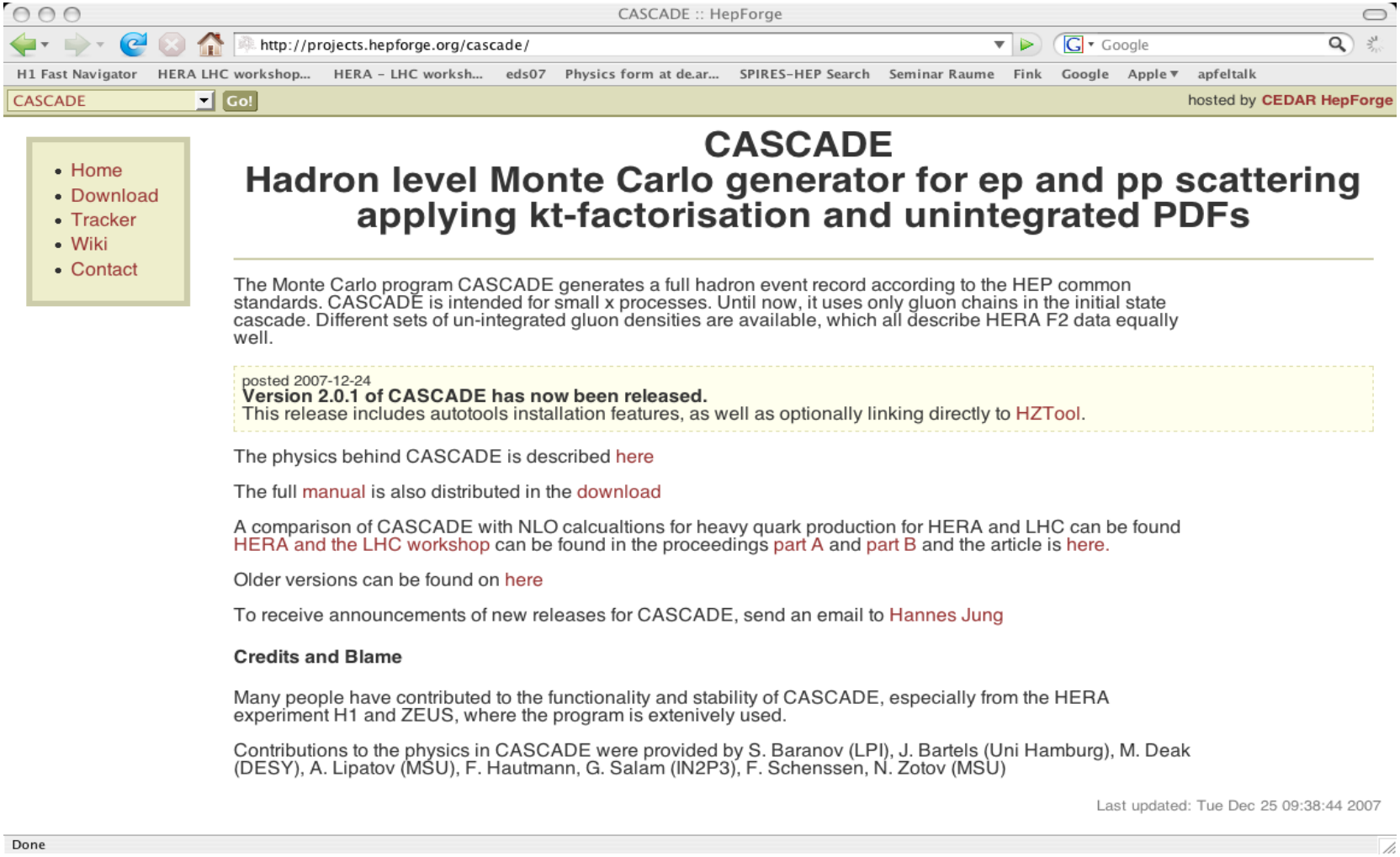
Where is CASCADE ?

- CASCADE home page:

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

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

- CASCADE also available in GENSER



Future plans

- physics
  - include $gg \to gg$ 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_t 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. D63 (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

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

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

➔ $\hat{\sigma}(\mathrm{LO}) \otimes \mathrm{PDF}(\mathrm{NLO})$ 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