The CASCADE and RAPGAP MCs

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- CASCADE
  - basic idea
  - applications - benchmarks
  - future plans

- RAPGAP
  - ideas
  - applications - benchmarks
  - future plans
BGF matrix element off shell

evolution of parton cascade:

\[ \tilde{P} = \bar{\alpha}_s \left( \frac{1}{1-z} + \frac{1}{z} \Delta_{n.s} + \ldots \right) \]

initial distribution ~ flat

\[ \sigma(ep \rightarrow e'q\bar{q}) = \int \frac{dy}{y} d^2 Q d\frac{x_g}{x_g} \int d^2 k_t \hat{\sigma}(\hat{s}, k_t, Q) x_g A(x_g, k_t, \bar{q}) \]

\[ \int d^2 k_t x_g A(x_g, k_t, \bar{q}) \approx x_g G(x_g, Q^2) \]
CASCADE MC generator

- DGLAP or CCFM
  ➔ 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
- need unintegrated parton densities
Processes included (gluon induced)

\[ \gamma g^* \rightarrow q\bar{q}, \quad \gamma g^* \rightarrow Q\bar{Q}, \quad \gamma g^* \rightarrow J/\psi g \]

\[ g^* g^* \rightarrow q\bar{q}, \quad g^* g^* \rightarrow Q\bar{Q}, \quad g^* g^* \rightarrow h \]

- initial state parton shower, backward evolution, according to CCFM
- final state PS
- p-remnant treatment
- hadronization

NEW:

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

CASCADE for ep and pp
CASCADEx and coll. NLO calcs

- 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
"Perfect" agreement of NLO(FMNR) calc with CASCADE on quark and hadron level for $x<0.01(y>2)$ !!!
Charm and Beauty at the LHC

Benchmarks at hadron level in central region

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

MNR band
FONLL band
CASCADE
VFNS

pp → D^+ X

|y| < 2.5

MNR band
FONLL band
CASCADE
VFNS

pp → B X

|y| < 2.5

CASCADE agrees well with MNR and FONLL for charm and beauty.
VFNS is larger for charm at small $p_t$ ...

All agree reasonably well ...But large uncertainties !!!
pt and phi correlations at LHC

- transverse momentum of quark-antiquark system \( p_T(Q\bar{Q}) \)
- azimuthal separation between two heavy quarks \( \Delta \phi(Q\bar{Q}) \)

from HERA-LHC proceedings 2005 O. Behnke et al, p 405

CASCADE has smaller uncertainties !!!
Phi correlations at HERA

- azimuthal separation between two heavy quarks $\Delta \phi (Q\bar{Q})$

watch out uncertainties in CASCADE and FMNR !!!
Features

- variation of renormalization scale
  - using uPDFs accordingly determined
  ➔ smaller uncertainty from theory
- various sets of uPDFs included (but only CCFM/KMR with parton shower):
  - CCFM
  - KMR
  - KMS
  - saturation model
  - derivative of integrated gluon
  - etc ...
- KMR prescription: one additional radiation ... useful for determination of hadronization corrections for NLO calcs
- full PYTHIA final state PS & remnant treatment included
  ➔ applicable for $t\bar{t}$ -production
Future Plans

- Multiple Interactions in $k_t$ factorization
  - connect MI with saturation and diffraction
  - including hard diffraction
- Inclusion of quarks in evolution
  - gluon in proton or coming from quark? issue on intrinsic $k_t$
  - is it gaussian or $1/k^2$
- Inclusion of other processes
  - W/Z production, prompt photons etc
**RAPGAP event generator**

- historically first version for hard diffraction in \( ep \)
  - Rapidity Gap events
  - including hard diffraction via 2-gluons and resolved pomeron
- including latest diffractive PDFs
- developed to full MC event generator for \( ep \) (including non – diffraction)
  - NOW also applicable for \( pp \)
  - including resolved virtual photons
- initial and final state parton showers (a la DGLAP)
- NOW:
  - final state PS, p-remnant treatment and hadronization a la PYTHIA/HERWIG
  - via LHA interface.
Future Plans for RAPGAP

- Multiple Interaction via PYTHIA also for DIS (resolved photoproduction)
- double diffraction also for $pp$
- double pomeron Higgs

⇒ Any other special processes for LHC needed?
Benchmark x-sections

- Compare parton level, visible D* and muon x – sections

reasonable agreement between NLO, RAPGAP and CASCADE
Conclusions

- **CASCADE**
  - alternative event simulation ($k_t$-factorization)
  - “reliable” predictions for gluon induced processes
  - future extensions:
    ➔ multiple interactions
    ➔ W/Z production
    ➔ prompt photons
    ➔ other processes?

- **RAPGAP**
  - simulation horse at HERA for diffraction and non-diffraction
  - future:
    ➔ Higgs (diffraction)
    ➔ others?

- **Feed back is very welcome**
- **Interesting to see applications to $pp$ !!!!!!!**