LUND UNIVERSITY

Theoretical Particle Physics in Lund

- QCD phenomenology

  Event generators: Gösta Gustafson, Torbjörn Sjöstrand, Leif Lönnblad, Malin Sjödahl, Stefan Prestel, Jesper Roy Christiansen, Christian Bierlich

  Diffraction, color singlet exchange, factorization: Gösta Gustafson, Johan Rathsman, Roman Pasechnik

  Low energy QCD phenomenology, flavor physics: Johan Bijnens, Johan Relefors

- BSM and cosmology

  Johan Rathsman, Roman Pasechnik, Thomas Rössler, Denis Karateev

Stockholm
Nov 27 2012
Malin Sjödahl

High energy QCD: Event generators

PYTHIA

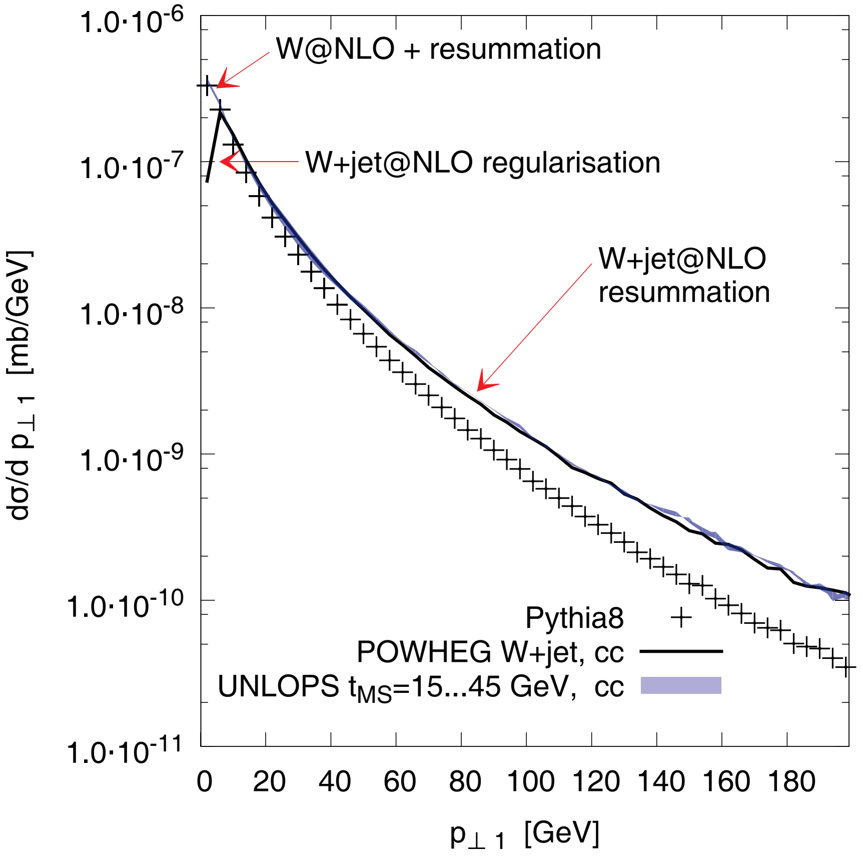
- Torbjörn Sjöstrand
  Transition to PYTHIA 8 in C++
- Jesper Roy Christiansen working on $W^{\pm}/Z$ radiation in PYTHIA

NLO - parton shower matching

- Leif Lönnblad and Stefan Prestel
  To accurately describe data at LHC we would like to calculate the hard process at NLO and then combine this with parton showers.

  This is tricky, one has to take care not to double count singular regions of phase space. Also necessary to merge showers with different number of emissions, done in PYTHIA.

Results: NLO - parton shower matching



Transverse momentum of hardest jet for $W^{\pm}$ + jets

Dipsy

- Gösta Gustafson, Leif Lönnblad and Christoffer Flensburg (former PhD student)
  Small x event generator based on the BFKL equation, includes saturation
  Applicable to e, p, and nucleus scattering, used for studying correlations, exclusive events and diffraction
  Work continued by Christian Bierlich for nucleus-nucleus

Subleading N_c effects

- Malin Sjödahl
  N_c suppressed terms in parton showers and fixed order calculations

Diffraction, QCD factorization, color singlet exchange mechanism

- Gösta Gustafson, Leif Lönnblad,
  diffraction based on the optical theorem (DIPSY)
- Roman Pasechnik,
  Diffractive gauge boson production and issues with QCD factorization
- Johan Rathsman and Roman Pasechnik et al.,
  diffractive W-production as a test of color singlet exchange mechanism

Low energy QCD

- Hans Bijnens,
  Chiral perturbation theory,
  Low energy effective field theory for QCD, expanding in momentum and mass/energy
  Higher order corrections from leading logarithmic contributions of form $(m^2_{\text{meson}} \log(m^2_{\text{meson}}/\mu^2_{\text{renorm}}))^n$ - an attempt to improve the accuracy in chiral perturbation theory
  Hadronic corrections to muon anomalous magnetic moment with Johan Relefors

Beyond the standard model and cosmology

- Johan Rathsman and Thomas Rössler,
  Light charged Higgs bosons in the NMSSM
- Johan Rathsman, Hans Bijnens and Jie Lu (former PhD student),
  Effects of flavor changing neutral currents from the renormalization group evolution
- Roman Pasechnik, Johan Rathsman and Denis Karateev,
  Grand unified theories based on $SU(3)_C \otimes SU(3)_L \otimes SU(3)_R$
- Roman Pasechnik,
  Higgs sector in bosonic technicolor models
  Cosmological constant from QCD vacuum in quasi-classical gravity

Funding and international networks

- Activity largely sponsored by VR, 50% of Johan Bijnens, Johan Rathsman and Leif Lönnblad, 75% of Malin Sjödahl. We (Torbjörn Sjöstrand) also have group contract from VR
- Torbjörn Sjöstrand and Roman Pasechnik and current PhD students funded by Lund University
- MCnet 2013-2016
  European union funded Marie Curie research and training network for Monte Carlo event generators
- HadronPhysics 2012-2014

Treating $N_c = 3 \neq \infty$

- An $N_c = 3 \neq \infty$ parton showers
  with Simon Plätzer
  JHEP 07 (2012) 042, arXiv:1201.0260
- ColorFull - a C++ package for parton showers and fixed order calculations in SU(N_c)
  Work in progress
- Orthogonal bases for $SU(N_c)$ color space
  with Stefan Keppeler
  JHEP09(2012)124, arXiv:1207.0609
- ColorMath - a Mathematica package for color summed calculations in SU(N_c)
  arXiv:1211.2099

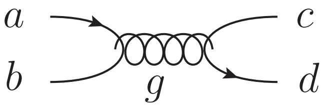
The color space

- We never observe individual colors $\rightarrow$ we are only interested in color summed quantities
- For given external partons, the color space is a finite dimensional vector space equipped with a scalar product

$$< A, B >= \sum_{a,b,c,\ldots} (A_{a,b,c,\ldots})^* B_{a,b,c,\ldots}$$

Example: If

$$A = \sum_g (t^g)^a{}_b (t^g)^c{}_d = \sum_g$$

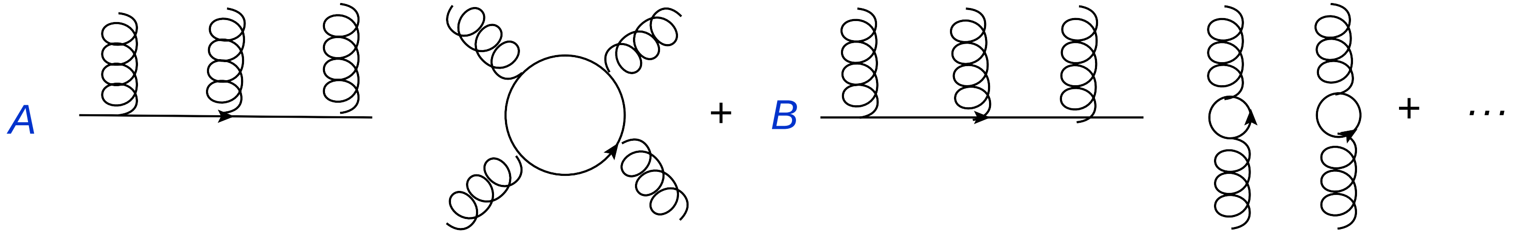


,

then $< A|A >= \sum_{a,b,c,d,g,h} (t^g)^b{}_a (t^g)^d{}_c (t^h)^a{}_b (t^h)^c{}_d$

- We may use any basis (spanning set)

- In general an amplitude can be written as linear combination of different color structures, like



- This is the kind of "trace bases" used in ColorFull for the SU(3) parton shower, and in most NLO calculations

An $N_c = 3$ parton shower

In collaboration with Simon Plätzer (DESY)

JHEP 07 (2012) 042, arXiv:1201.0260

- Traditional parton showers such as PYTHIA treats the three colors of nature as infinitely many
- We correct each emission by keeping all terms in an $1/N_c$ expansion
- So far we have studies a LEP-like setting, for which we find small deviations for standard observables
- Now we are working on hadron colliders

ColorFull

For the purpose of treating a general QCD color structure I have written a C++ color algebra code, ColorFull, which:

- Is used in the color shower with Simon Plätzer and in a Higgs + 3 jets at NLO project
- automatically creates a "trace basis" for any number and kind of partons, and to any order in α_{s}
- describes the effect of gluon emission
- ... and gluon exchange
- squares color amplitudes
- is planned to be published separately

However...

- The type of “basis” used for the color shower (and most NLO calculations) is non-orthogonal and overcomplete
  (for more than N_c gluons plus $q\bar{q}$-pairs)
- ... and the number of used vectors grows as a factorial in
  $N_g + N_{q\bar{q}}$
  $\rightarrow$ when squaring amplitudes we run into a factorial square scaling
- Hard to go beyond $\sim$ 8 gluons plus $q\bar{q}$-pairs

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- Would be nice with minimal orthogonal basis

Orthogonal multiplet bases

In collaboration with Stefan Keppeler (Tübingen)

JHEP09(2012)124, arXiv:1207.0609

- The color space may be decomposed into irreducible representations, enumerated using Young tableaux multiplication
- The problem is to construct the corresponding projection operators and basis vectors, the Young tableaux operate with quark-units, but in nature we have gluons and anti-quarks as well
- To make a long story short...

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- To make a long story short...
- This is the problem we have solved: We know how to construct minimal orthogonal bases for the SU(N_c) color space
- This has the potential to very significantly speed up exact calculations in the color space of $SU(N_c)$

ColorMath - a Mathematica package for color summed calculations in SU(N_c)

arXiv:1211.2099

Easy to use Mathematica package for color summed calculations in QCD, $SU(N_c)$

In[1]:= `Get["/data/Documents/Annatjobb/Color/Mathematica/ColorMath0.90.m"]`

```
Version: 0.90 (November 8 2012), for Mathematica 7 and 8.

Author: Malin Sjodahl

For suggestions and bug reports contact malin.sjodahl@thep.lu.se.

If you use this package for research, please cite the ColorMath paper.
```

In[2]:= $\text{Amplitude} = T\, t^{\{g\}q1}{}_{q3}\, t^{\{g\}q4}{}_{q2} + S\, t^{\{g\}q1}{}_{q2}\, t^{\{g\}q4}{}_{q3};$

In[3]:= `CSimplify[Amplitude Conjugate[Amplitude /. g→ g2]]`

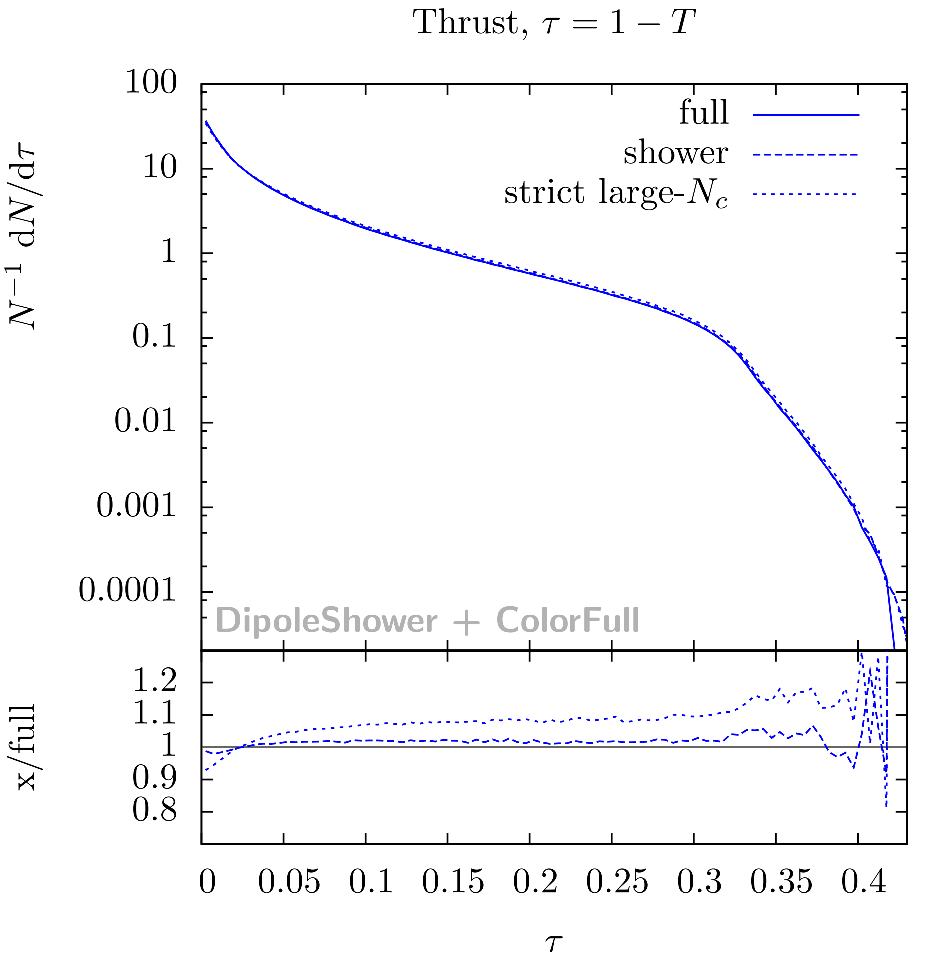
Out[3]= $$\frac{\left(-1+\mathrm{Nc}^2\right)\mathrm{TR}^2\,\left((\mathrm{Nc}\,S-T)\,\mathrm{Conjugate}[S]+(-S+\mathrm{Nc}\,T)\,\mathrm{Conjugate}[T]\right)}{\mathrm{Nc}}$$

The End

Thank you for your attention!

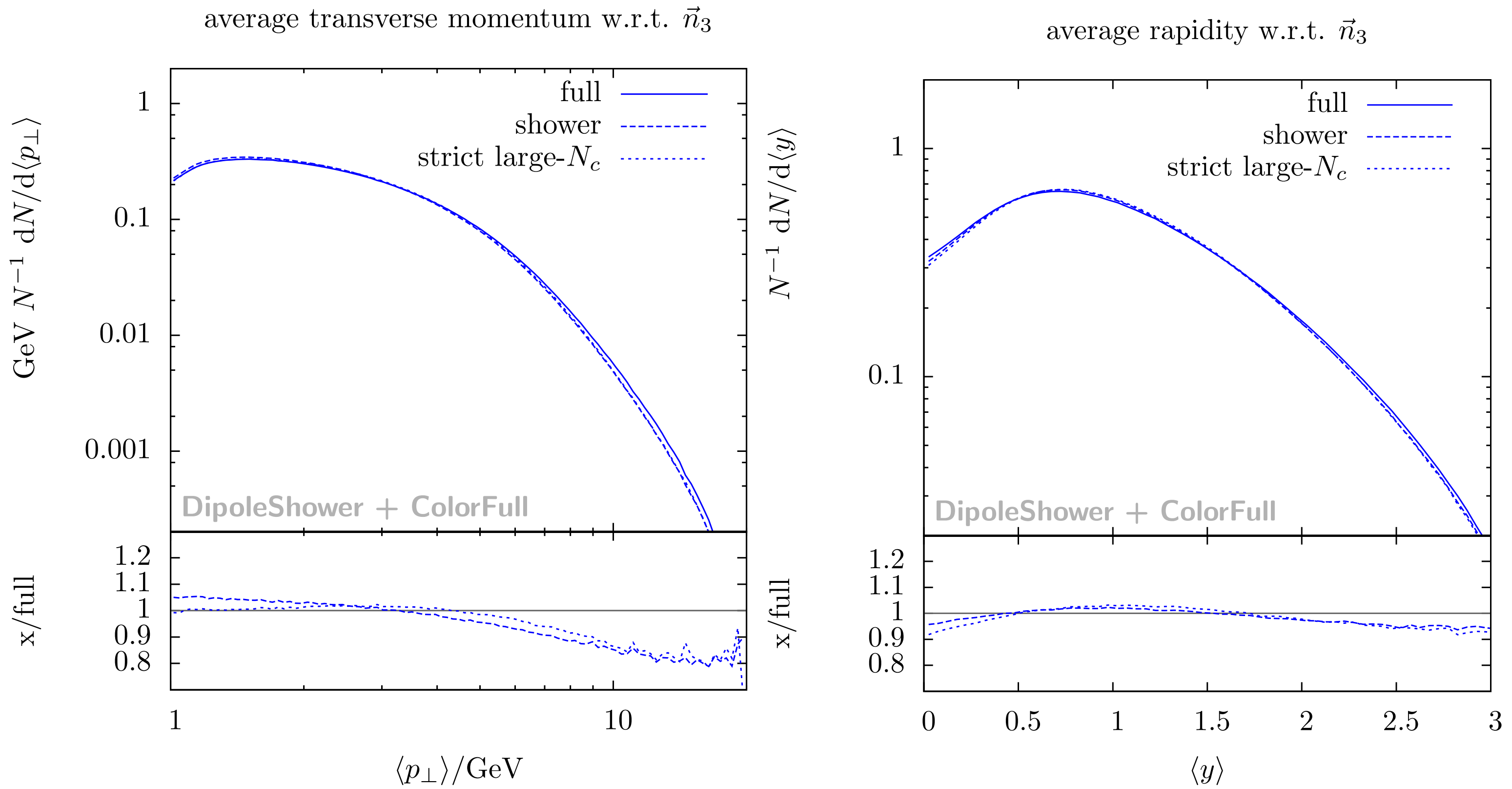
Backup: Thrust

For standard observables small effects, here thrust $T = \max_{\mathbf{n}} \frac{\sum_i |\mathbf{p_i} \cdot \mathbf{n}|}{\sum_i |\mathbf{p_i}|}$



Backup: Some tailored observables

For tailored observables we find larger differences



Average transverse momentum and rapidity of softer particles with respect to the thrust axis defined by the three hardest partons