QCD radiation in the production of heavy colored particles at the LHC

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26/03/09 - NIKHEF - TH seminar
Outline

• Introduction

• Jet matching/merging

• Detailed study of matching impact
Heavy particles and QCD radiations

- LHC: a QCD machine!

- Radiation: not part of the “main” process but could be important
  - additional jets
  - transverse boost

- Trustable MC simulation is crucial for shape prediction, final state definitions, ...

- SM: ttbar+jets, W/Z+jets,...

- Beyond the SM: new strongly interacting particles?
Matrix Element vs Parton Showers for multi-jets events

- **Matrix-Element**
  - Needed for multi-jet description
  - A limited number of partons
  - Valid when partons are well separated in the phase-space

- **Parton Showers**
  - Needed for realistic studies
  - Any number of partons
  - Valid when partons are collinear/softs

- We need both approaches to simulate physics from high scale down to hadronization scale (~1 GeV)
- What happens if ME and PS are used without control?

- Example: $tt + 2$ partons vs $tt + 1$ partons

**2 partons (collinear)**

2 partons

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$1$ parton + no hard radiation

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$1$ parton + $1$ hard radiation

**ME and PS overlap**

⇒ If you add all multiplicities: wrong cross-section.
To avoid overlap: one parton $\Leftrightarrow$ one jet (except for highest multiplicity sample)

- ME: scale$>\$jet definition
- PS: scale$<\$jet definition

$\Rightarrow$ define a cutoff (different definitions are possible) to separate ME and PS phase-spaces and use a matching technique
What is available on the market?

**Showering**
- HERWIG
- PYTHIA
- ARIADNE
- SHERPA

**ME Generators**
- ALPGEN
- HELAC
- MG/ME
- AMEGIC++
- ...

**Matching Schemes**
- MLM
  - Event Rejection based
  - Cone or Kt

- CKKW
  - Sudakov Reweighting
  - Shower veto
  - Kt clustering
• CKKW (reweighting method)  

  - Control the showers: no additional resolvable radiation  
    ⇒ 1 parton gives 1 jet (no double counting)  
    ⇒ reweight event/event by the probability of having no  
      resolvable emission (Sudakov form factor)  

• MLM (not reweight, but reject)  

  - No control of the showers, but match jets (PS level) with  
    partons (ME level): rejection method  

• Three versions: MLM (Mangano), Kt MLM (Mrenna, Alwall),  
  Shower-kt (Alwall).
Does it work?

- A real test of Kt MLM: W+ jets at Tevatron

- Possibility of a theoretical validation for most of SM processes: $t\bar{t}$bar, $W/Z$, photon+jets,... we come to that in a while...

[MG Team]
Matching in BSM? One step forward...

- Additional difficulty: double counting due to resonances

Example: $\tilde{q}\tilde{q}jj$
Matching in BSM? One step forward...

- Additional difficulty: double counting due to resonances

Example: $\tilde{g}\tilde{g}jj$

If Go's on resonance:

double counting with

with $go \to dr+q$ in pythia
Matching in BSM? One step forward...

- Additional difficulty: double counting due to resonances

Example: $\tilde{q}\tilde{q}jj$

If Go's on resonance:

double counting with

$\text{with } \text{go} \rightarrow \text{dr} + q \text{ in pythia}$
Matching in BSM? One step forward...

- Additional difficulty: double counting due to resonances

Example: \( \tilde{q}\tilde{q}jj \)

If Go's on resonance:
- double counting with

\[ \text{with } \text{go} \rightarrow \text{dr}+q \text{ in pythia} \]
Matching in BSM? One step forward...

- Additional difficulty: double counting due to resonances

Example: \( \widetilde{q}\widetilde{q}jj \)

If Go’s on resonance:
double counting with

with \( \text{go} \rightarrow \text{dr} + q \) in pythia

OK!
First time this is possible!
How to control the matched simulation?

- Differential jet rates \((N+1 \rightarrow N)\): scale at which and events passes from a \(N+1\) to a \(N\) jet configuration while clustered.

Determined by ME

Determined by PS

Transition from PS to ME regime is smooth

Log(Differential Jet Rate \(2 \rightarrow 1\))

- Transition from PS to ME regime is smooth
Detailed study of the matching impact

 ISR

 Physical cases

J. Alwall, SdV, F. Maltoni. JHEP 0902:017
Sensitivity to showers

- Matching implies that jets kinematics are ruled by ME calculations above the cutoff
  
  - ⇒ physical distributions at large Pt should be less sensitive to shower parametrization:

  - Shower evolution variable: $Q^2, P_T^2, \ldots$

  - Starting scales: from low values ("wimpy") to high values ("power") showers...

  - additional tunes...

The IS radiation in Pythia only

- Case of gluino production done “a la Pythia“ (2→2): Pt distribution of extra-jets
The IS radiation with ME + Pythia

- Case where gluinos are produced with ME calculation with up to 2 jets with MG/ME (2→2,3,4)
~SPS1a → gluinos~600 GeV
squarks~560 GeV
neutralino~100 GeV

Shape prediction

\[ g \rightarrow \tilde{g} \rightarrow \tilde{d}_L \rightarrow j \rightarrow j \rightarrow \chi^0 \]

hard

soft

Hard
• The classical case illustrated @ SPS1a: $2 \rightarrow 2$
The classical case illustrated @ SPS1a (2→2,3,4)
The false gluino case

- Let's say nature produces squark pairs at 600 GeV

Conclusion: we don’t have only squarks!
Let's say nature produces squark pairs at 600 GeV

Unmatched qq + 25% qg: fits “data”

Unmatched qg, Mg = 700 GeV

Mis-interpretation: presence of gluinos!
The degenerate case

- If $m_{\tilde{g}} \sim m_{LSP}$:
  - Jets from gluinos are soft
  - small MET
- $\Rightarrow$ gluinos “disappear”!
- impact of matching is huge since jets are almost exclusively ISR
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Summary

- To simulate multi-jets events inclusive samples, need a matching technique

- Matching in SUSY possible after solving double counting arising from the presence of resonances

- Sensitivity of extra-jet kinematics to showers parametrization is strongly reduced

- Eliminates some major problems for critical cases

J. Alwall, SdV, F. Maltoni. JHEP 0902:017
Thanks for your attention! 😊
Back-up slides
Tree-level+PS vs NLO calculations

G. Salam, M. Rubin

SDV, F. Maltoni
Kt-MLM in more details

- Main steps are
  - With MadEvent: generate events with a minimal distance in the phase-space between the partons
  - Perform showering using Pythia
  - Match each jet with a parton using the cutoff as maximal distance (except for highest multiplicity events)
    - if \( N(jet) \neq N(parton) \rightarrow \text{reject} \)
  - For clustering algos, the distance definition is \( Kt \) instead of Cone (MLM [Mangano])
Validation [SdV, P.Demin]

- MatchChecker: [http://cp3wks05.fynu.ucl.ac.be/twiki/bin/view/Software/MatchChecker](http://cp3wks05.fynu.ucl.ac.be/twiki/bin/view/Software/MatchChecker)

- Draw differential jet rates, kinematic, MET, Ht
  - with detailed contribution of each multiplicity
  - in comparison plots if more than one production

- Produces a rootfile with all global histos for further use

- Produces a complete report with everything inside