NLO/NNLO wishlist/ useage

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Start with the wishlist

- Began in 2005, added to in 2007 and 2009 (2011?)
  - only process 12 left among NLO
- Are there other motivated needs for NLO multi-parton final states?
  - from dedicated calculation or automatic calculation?
    - any reason to push beyond V +4 jets, for example?
  - one thing we promised to do at Les Houches is provide a table of the needed accuracy for each final state
    - i.e. what sorts of accuracy can we achieve experimentally?
    - are EW corrections necessary as well?
- In general, I think we have neglected the last point at the LHC
  - EW corrections for jet production ($\ln[p_T^2/m_W^2]$) possibly important

Process ($V \in \{Z, W, \gamma\}$)	Comments
Calculations completed since Les Houches 2005	
1. $pp \to VV$jet	WWjet completed by Dittmaier/Kallweit/Uwer [4, 5]; Campbell/Ellis/Zanderighi [6]. ZZjet completed by Binoth/Gleisberg/Karg/Kauer/Sanguinetti [7]
2. $pp \to$ Higgs+2jets	NLO QCD to the gg channel completed by Campbell/Ellis/Zanderighi [8]; NLO QCD+EW to the VBF channel completed by Ciccolini/Denner/Dittmaier [9, 10]
3. $pp \to VVV$	ZZZ completed by Lazopoulos/Melnikov/Petriello [11] and WWZ by Hankele/Zeppenfeld [12] (see also Binoth/Ossola/Papadopoulos/Pittau [13])
4. $pp \to t\bar{t}b\bar{b}$	relevant for $t\bar{t}H$ computed by Bredenstein/Denner/Dittmaier/Pozzorini [14, 15] and Bevilacqua/Czakon/Papadopoulos/Pittau/Worek [16]
5. $pp \to V$+3jets	calculated by the Blackhat/Sherpa [17] and Rocket [18] collaborations
Calculations remaining from Les Houches 2005	
6. $pp \to t\bar{t}$+2jets	relevant for $t\bar{t}H$ computed by Bevilacqua/Czakon/Papadopoulos/Worek [19]
7. $pp \to VV\,b\bar{b}$,	relevant for VBF $\to H \to VV$, $t\bar{t}H$
8. $pp \to VV$+2jets	relevant for VBF $\to H \to VV$ VBF contributions calculated by (Bozzi/)Jäger/Oleari/Zeppenfeld [20–22]
NLO calculations added to list in 2007	
9. $pp \to b\bar{b}b\bar{b}$	$q\bar{q}$ channel calculated by Golem collaboration [23]
NLO calculations added to list in 2009	
10. $pp \to V$+4 jets	top pair production, various new physics signatures
11. $pp \to Wb\bar{b}j$	top, new physics signatures
12. $pp \to t\bar{t}t\bar{t}$	various new physics signatures
Calculations beyond NLO added in 2007	
13. $gg \to W^*W^*\,\mathcal{O}(\alpha^2\alpha_s^3)$	backgrounds to Higgs
14. NNLO $pp \to t\bar{t}$	normalization of a benchmark process
15. NNLO to VBF and Z/γ+jet	Higgs couplings and SM benchmark
Calculations including electroweak effects	
16. NNLO QCD+NLO EW for W/Z	precision calculation of a SM benchmark

Start with the wishlist

- Should we move on to expanding the NNLO list?
  - only a few processes known at NNLO
    - Drell-Yan, Higgs production, γγ
  - People are close to finishing
    - inclusive jet production
    - tT production
  - People are working on
    - gg->WW (strong experimental desire for this)
    - VV
    - V+1 jet production
    - Higgs+1 jet production
    - any others?
- Again, EW effects may be competitive

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Start with the wishlist

- There's also the issue of how experimentalists can use these calculations
  - aMC@NLO: recently, W+2 jets was added to the program; but what is the learning curve to get to say W + 3,4 jets at NLO, or other cross sections not even currently known at NLO
  - are ntuples still useful for more immediate use?

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Calculations

- Once we have the calculations, how do we (experimentalists) use them?
- If a theoretical calculation is done, but it can not be used by any experimentalists, does it make a sound?
- We need public programs and/or public ntuples
- …as for example pioneered by MCFM

Example: Blackhat+Sherpa ntuples

NLO with BlackHat+Sherpa

NLO cross section

Born loop: lc and fmlc real

$$\sigma_n^{NLO} = \int_n \sigma_n^{tree} + \int_n \left(\sigma_n^{virt} + \Sigma_n^{sub}\right) + \int_{n+1} \left(\sigma_{n+1}^{real} - \sigma_{n+1}^{sub}\right)$$

vsub

BlackHat

so this is not Sherpa the parton shower, but Sherpa used as a (very efficient) fixed order matrix element generator

Sherpa

ROOT ntuples

- More complex to use than MCFM
  - no manual for example
  - and you don't produce the events yourself
  - my student Brian Martin and I are the beta users
- ntuples produced separately by Blackhat + Sherpa for
- No jet clustering has been performed; that's up to the user
  - a difference from MCFM, where the program has to be re-run for each jet size/algorithm
- What algorithms/jet sizes that can be run depends on how the files were generated
  - i.e. whether the right counter-events are present
- For the files on the right at 7 TeV (for W^+ + 3 jets), one can use kT, antikT, siscone (f=0.75) for jet sizes of 0.4, 0.5, 0.6 and 0.7

→

- bornLO (stands alone for pure LO comparisons; not to be added with other contributions below)
  - 20 files, 5M events/file, 780 MB/file
- Born
  - 18 files, 5M events/file, 750 MB/file
- loop-lc (leading color loop corrections)
  - 398 files, 100K events/file, 19 MB/file
- loop-fmlc (needed for full color loop corrections)
  - 399 files, 15K events/file, 3 MB/file
- real (real emission terms)
  - 169 files, 2.5 M event/file, 5 GB/file
- vsub (subtraction terms)
  - 18 files, 10M events/file, 2.8 GB/file

Predictions

- From Blackhat+Sherpa, we have ntuples (in same format) for W + 0,1,2, 3,4 jets
- Makes it easy to make plots for different jet multiplicities and/or combined jet multiplicities
  - including PDF uncertainties
  - including scale uncertainties
  - examining dependence on jet size/algorithm
- How can we make best use of the NLO matrix element information for these n-jet final states?
  - something like CKKW addition possible at NLO?

Choosing jet size

- Experimentally
  - in complex final states, such as W + n jets, it is useful to have jet sizes smaller so as to be able to resolve the n jet structure
  - this can also reduce the impact of pileup/underlying event
- Theoretically
  - hadronization effects become larger as R decreases
  - for small R, the ln R perturbative terms referred to previously can become noticeable
  - this restriction in the gluon phase space can affect the scale dependence, i.e. the scale uncertainty for an n-jet final state can depend on the jet size,

We can now easily change jet algorithms/sizes in the theory? Are we willing to do this in the data? If new physics is present at 7 TeV, it's pretty subtle. Should we develop a better perturbative understanding by varying the jet size/algorithm/etc?

…and now

- Discussion