MCFM status

Francesco Tramontano

CERN Theory Group

Overview

- MCFM: http://mcfm.fnal.gov (v5.7, Jan. 2010 ☆)

  J.M. Campbell, R.K. Ellis (main authors)
  R. Frederix, F. Maltoni, F. Tramontano, S. Willenbrock

- Next-to-leading order parton-level predictions.
- Cross sections and differential distributions.
- Standard Model processes involving
  vector boson+jets, top quarks, Higgs.
- Decays of unstable particles included (mostly), maintaining
  spin correlations.

Overview: W/Z+jets

Final state	Notes	Reference
W/Z		
diboson	anomalous couplings	hep-ph/9905386
Wbb	massless b-quark	hep-ph/9810489
Zbb	massless b-quark	hep-ph/0006304
W/Z+1 jet		
W/Z+2 jets		hep-ph/0202176, hep-ph/0308195
Wc	massive c-quark	hep-ph/0506289
Zb	5-flavour scheme	hep-ph/0312024
Zb+jet	5-flavour scheme	hep-ph/0510362

Overview: Top and Higgs

Final state	Notes	Reference
H (g.f.)		
H+1 jet (g.f.)	effective coupling	
H+2 jets (g.f.)	☆ effective coupling	hep-ph/0608194, arXiv:1001.4495
WH/ZH		
H via WBF		hep-ph/0403194
Hb	5-flavour scheme	hep-ph/0204093
t	s- and t-channel (5F), top decay included	hep-ph/0408158
t	☆ t-channel (4F)	arXiv:0903.0005, arXiv:0907.3933
Wt	5-flavour scheme	hep-ph/0506289
top pairs	no top decay	

Overview: other calculations

Final state	Notes	Reference
Wb+jet	complicated procedure, private version only	hep-ph/0611348, arXiv:0809.3003
WW+jet	semi-numerical virtual amplitudes; private	arXiv:0710.1832
J/ψ and Y(singlet)	private version only, could be made available	hep-ph/0703113, arXiv:0806.3282
J/ψ (photo-prod. in DIS)	private version only, could be made available	arXiv:0901.4352

- LO calculations of related processes (above+1 jet).
- Select other processes at LO (e.g. ttH).

MCFM usage

- Code controlled by text file input.DAT .
- Choice of final state, basic parameters, quark masses (☆).
- Other (electroweak) inputs specified at compile time, src/User/mdata.f .

```
'5.7'           [file version number]

[Flags to specify the mode in which MCFM is run]
.false.         [evtgen]
.false.         [creatent]
.false.         [skipnt]
.false.         [dswhisto]

[General options to specify the process and execution]
1               [nproc]
'lord'          [part 'lord','real' or 'virt','tota']
'test'          ['runstring']
14000d0         [sqrts in GeV]
+1              [ih1 =1 for proton and -1 for antiproton]
+1              [ih2 =1 for proton and -1 for antiproton]
120d0           [hmass]
80d0            [scale:QCD scale choice]
80d0            [facscale:QCD fac_scale choice]
.false.         [dynamicscale]
.false.         [zerowidth]
.true.          [removebr]
10              [itmx1, number of iterations for pre-conditioning]
20000           [ncall1]
10              [itmx2, number of iterations for final run]
20000           [ncall2]
1089            [ij]
.false.         [dryrun]
.true.          [Qflag]
.true.          [Gflag]

[Heavy quark masses]
172.5d0         [top mass]
4.75d0          [bottom mass]
1.5d0           [charm mass]

[Pdf selection]
'cteq6l1'       [pdlabel]
4               [NGROUP, see PDFLIB]
46              [NSET - see PDFLIB]
cteq6mE.LHgrid  [LHAPDF group]
-1              [LHAPDF set]

[Jet definition and event cuts]
0d0             [m34min]
14000d0         [m34max]
0d0             [m56min]
14000d0         [m56max]
.true.          [inclusive]
'ktal'          [algorithm]
15d0            [ptjet_min]
0d0             [|etajet|_min]
2d0             [|etajet|_max]
0.7d0           [Rcut_jet]
.false.         [makecuts]
```

Brief calculational details

- Code generates three types of event:

  (a)virtual (loop) diagrams (LO kinematics)

  (b)real radiation diagrams (LO + 1 parton)

  (c)real counter-events (LO kinematics)

- The counter-events are Catani-Seymour dipoles, one for each type of collinear singularity;
  - can be many for colour-rich processes (e.g. 24 for W/Z/H + 2 jets).
- Many weighted events, with large cancellations between events of types (b) and (c).

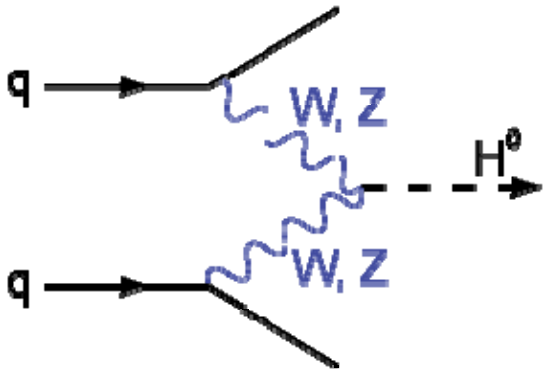
Jet algorithm

- Choice of three algorithms:

  cone (seedless cone),
  ktal (k_T algorithm)
  ankt (k_T algorithm ☆)

```
[Jet definition and event cuts]
0d0             [m34min]
14000d0         [m34max]
0d0             [m56min]
14000d0         [m56max]
.true.          [inclusive]
'ktal'          [algorithm]
15d0            [ptjet_min]
0d0             [|etajet|_min]
2d0             [|etajet|_max]
0.7d0           [Rcut_jet]
```

- When it makes sense, one can also choose none to avoid jet cuts altogether, e.g.



weak boson fusion: no singularity associated with jets becoming soft or collinear

PDF selection

```
[Pdf selection]
'cteq6l1'          [pdlabel]
4                  [NGROUP, see PDFLIB]
46                 [NSET - see PDFLIB]
cteq6mE.LHgrid     [LHAPDF group]
-1                 [LHAPDF set]
```

- Many recent PDF fits implemented natively (set using pdlabel).
- Can link to LHAPDF library via makefile.
  - access to other PDF sets (e.g. NNPDF), chosen by LHAPDF group.
  - for fits with multiple member sets, choose individual member with LHAPDF set.
  - the value -1 determines, for suitable sets, the estimated PDF uncertainty, *in a single run*.

Sample uncertainty output

- Additional output lists cross section obtained with each member uncertainty set.
- In addition, estimates PDF uncertainty with a given prescription:

$$\Delta\sigma_{\mathrm{PDF}+} = \sqrt{\sum_i \left(\max\left[\sigma(set_{+i}) - \sigma(set_0), \sigma(set_{-i}) - \sigma(set_0), 0\right]\right)^2}$$

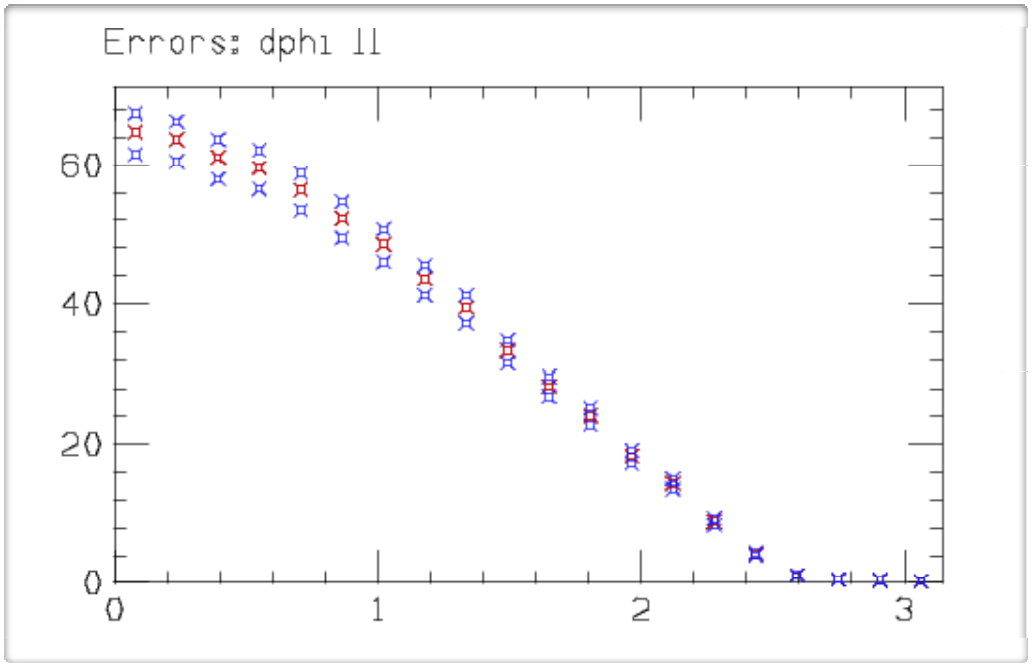
- Here, CTEQ6.6 (44 sets), used to compute $H \rightarrow WW$ via gluon fusion for m_H=170GeV at 14 TeV LHC (with some cuts).

```
* ---------------- SUMMARY ---------------- *
*                                           *
*           HEPDATA prescription            *
*     (see, for example Eqn. (43) of        *
*      J.Campbell, J.Huston, W.J.Stirling,  *
*      Rep. Prog. Phys. 70 (2007) 89)       *
*                                           *
*      Minimum value        94.735 fb       *
*      Central value        97.854 fb       *
*      Maximum value       100.315 fb       *
*                                           *
*   Err estimate +/-         4.714 fb       *
*      +ve direction         4.256 fb       *
*      -ve direction         5.198 fb       *
*   Fractional error         0.048          *
*                                           *
```

Sample distribution uncertainty

- PDF uncertainty in a distribution requires one-line addition to plotting routine, nplotter.f .
- e.g. opening angle between leptons in transverse plane.

```
call bookplot(n,tag,'dphi_ll',dphi_ll,wt,wt2,
                0d0,3.142d0,0.1571d0,'lin')
call ebookplot(n,tag,dphi_ll,wt)
```



- default plot shown
- additional output file produced, containing histograms for each uncertainty set

Output options

- Default behaviour is to accumulate histograms internally; output to a file at the end of the run.

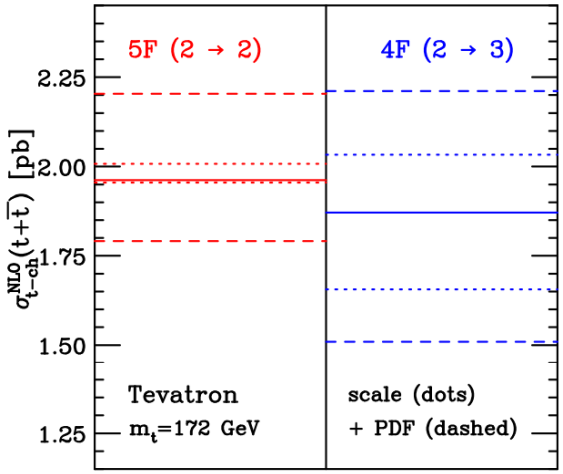
```
[Flags to specify the mode in which MCFM is run]
.false.         [evtgen]
.false.         [creatent]
.false.         [skipnt]
.false.         [dswhisto]
```

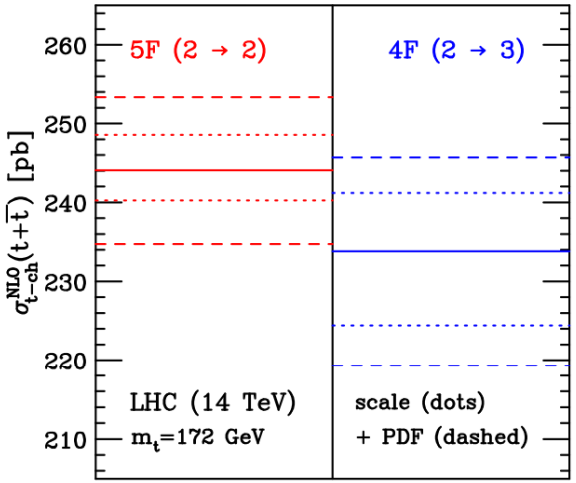
- Alternatively, can write event n-tuples.
  - ROOT n-tuples via FROOT interface (P. Nadolsky).
  - events are written after jet clustering, so changes to jet definition in processing do not make sense.
  - still allows greater flexibility for plotting observables of interest and re-binning.
  - weights for different PDF uncert. sets included too.

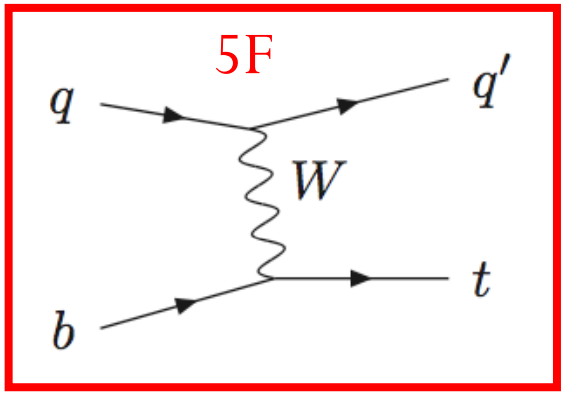
Single top predictions ☆

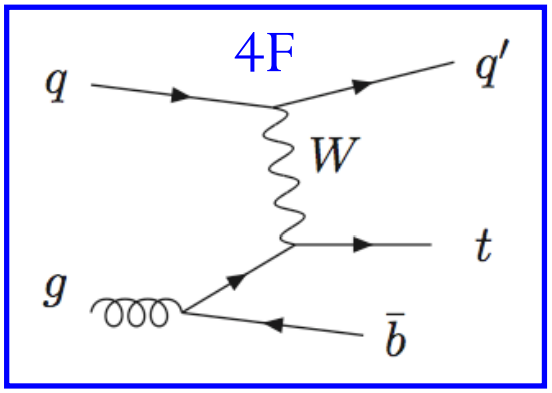
- Systematic analysis of t-channel single top in both 4- and 5-flavour schemes (at NLO).

arXiv:0907.3933



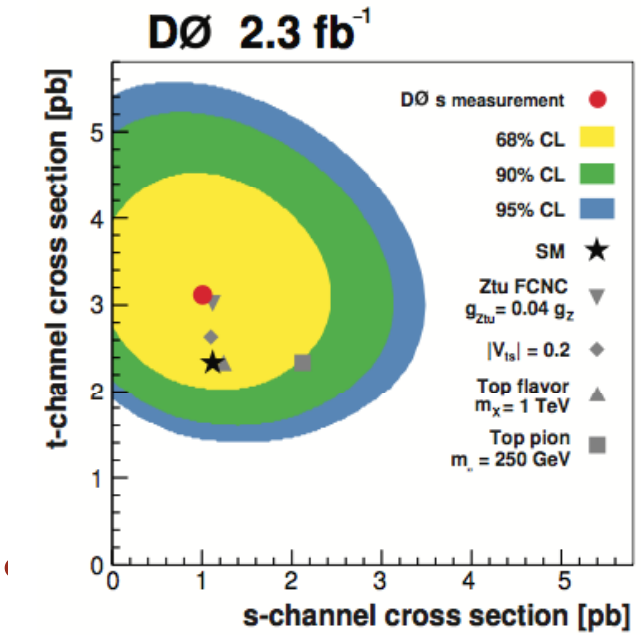


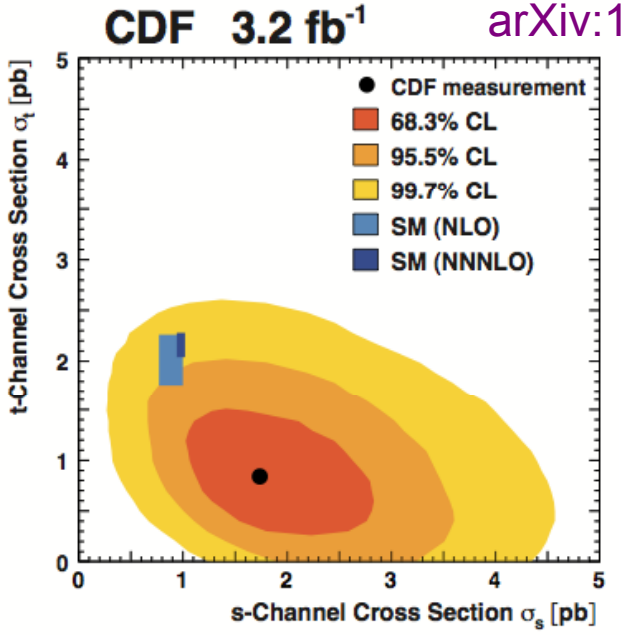




4F scheme

- The 4F scheme allows a modelling of the b p_T spectrum at NLO.
  - shape affects interpreted tagging efficiency and division into s- and t- channel processes.



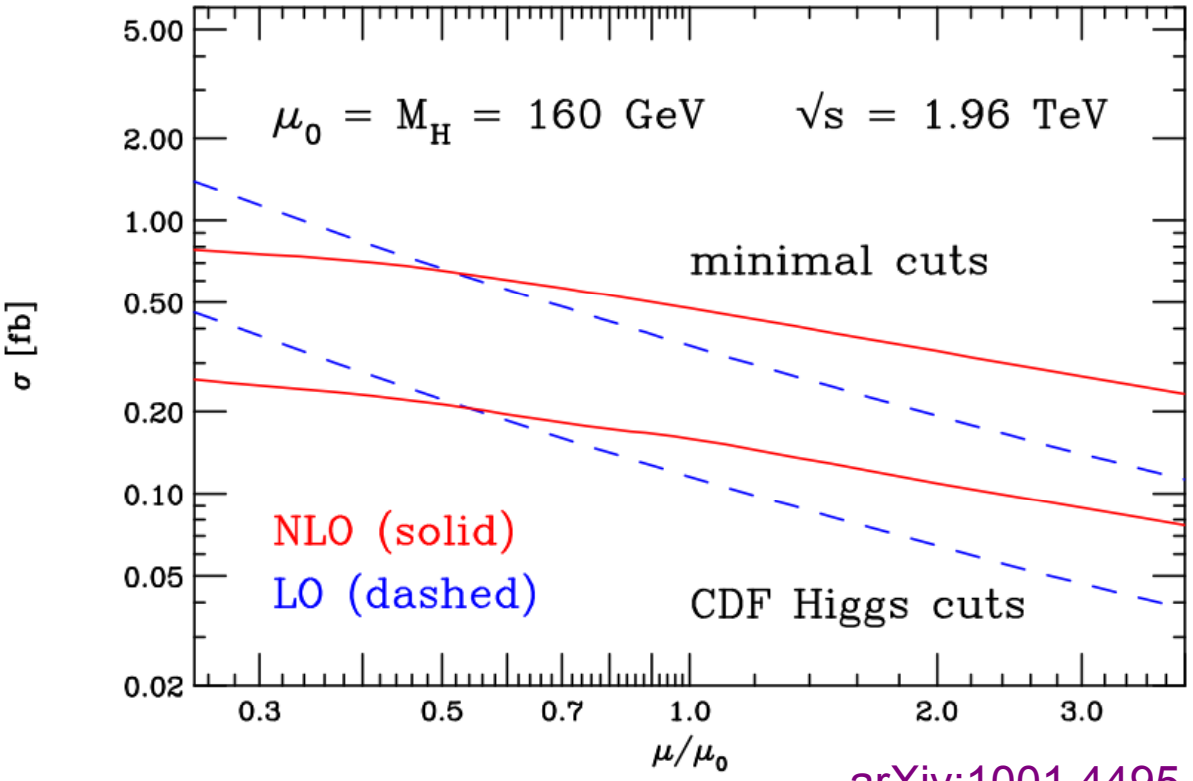


arXiv:1002.4167 [hep-ex]

Higgs + 2 jets ☆

- Semi-numerical private code updated to use compact, analytic expressions for virtual amplitudes.

  (for refs. see e.g. arXiv:1001.1938)



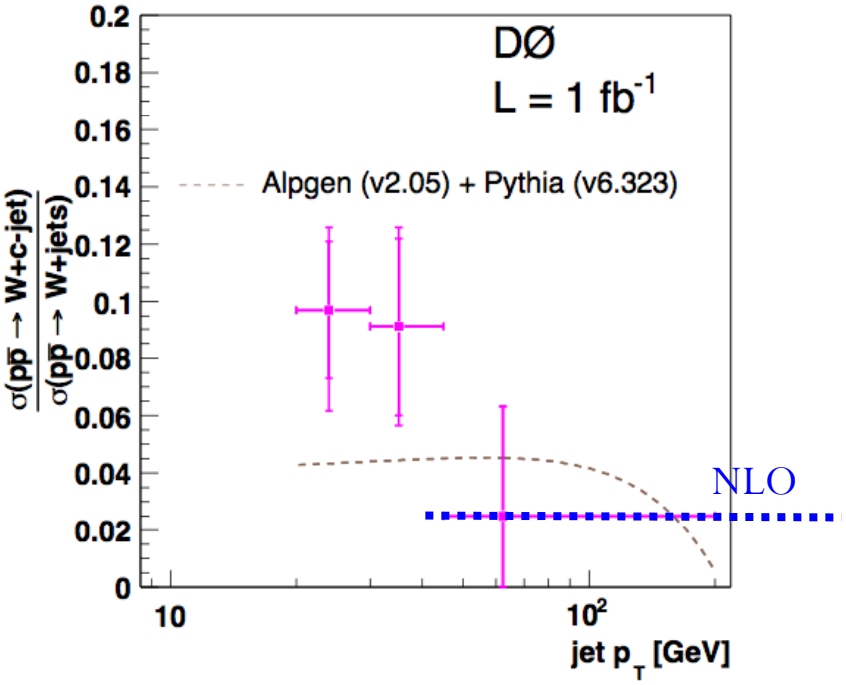
arXiv:1001.4495

- Much faster code, ~5ms per virtual point (2.66 Ghz iMac, gfortran, no opt.).
- Good enough to include in-situ decay $H \rightarrow WW^*$.

Heavy flavour

- Good agreement between (untagged) W/Z+jets data and theory.
- Tagged (c+b) jets less well understood;
  - many predictions @ NLO with MCFM.

arXiv:0803.2259 [hep-ex]



- E.g. W+c cross section measured by CDF consistent with NLO. arXiv:0711.2901 [hep-ex]
- Need more studies to understand shapes of dist'ns (backgrounds!).

Future user improvements

- Possible inclusion in the GENSER project.
- Improved interface with LHAPDF;
  - in particular, for sets with variable alpha-s.
- Improved ROOT n-tuple support, along the lines of Les Houches contribution;
  - in particular, pointers linking real and subtracted events, to enable proper statistical analysis.
- Interface to FastJet, for access to more algorithms;
  - already done for internal testing.

Future avenues

- The no. of final states for which virtual amplitudes might be available in compact analytic form (but are not at present) is by now rather small.
- Nevertheless, MCFM already contains a fairly extensive library of virtual amplitudes.
  - possibility of converting/documenting to suit Binoth Les Houches Accord on 1-loop amplitudes;
  - would also facilitate use in a NLO parton shower such as MC@NLO or POWHEG.