Status of MadLoop/aMC@NLO

Roberto Pittau

Departamento de Física Teórica y del Cosmos
Universidad de Granada

LCWS11-Granada, September 29, 2011

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1. MadLoop

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1. MadLoop
2. aMC@NLO
3. Selected Physics Results

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A typical $2 \to m$ process at NLO

$$\sigma^{NLO} = \int_m d\sigma^B + \int_m \left(d\sigma^V + \int_1 d\sigma^A \right) + \int_{m+1} \left(d\sigma^R - d\sigma^A \right)$$

1. $d\sigma^B$ is the Born cross section
2. $d\sigma^V$ is the Virtual correction (loop diagrams)
3. $d\sigma^R$ is the Real correction (gluons or photons)
4. $d\sigma^A$ and $\int_1 d\sigma^A$ are *unintegrated* and *integrated* counterterms (allowing to compute the Real part in 4 dimensions)

The Virtual corrections

The decomposition of ANY one-loop amplitude in terms of KNOWN scalar one-loop functions

$$
\begin{aligned}
A \;=\; & \sum_{i_0<i_1<i_2<i_3}^{m-1} d(i_0 i_1 i_2 i_3) \int d^n\bar{q}\, \frac{1}{\bar{D}_{i_0}\bar{D}_{i_1}\bar{D}_{i_2}\bar{D}_{i_3}} \\
& + \sum_{i_0<i_1<i_2}^{m-1} c(i_0 i_1 i_2) \int d^n\bar{q}\, \frac{1}{\bar{D}_{i_0}\bar{D}_{i_1}\bar{D}_{i_2}} \\
& + \sum_{i_0<i_1}^{m-1} b(i_0 i_1) \int d^n\bar{q}\, \frac{1}{\bar{D}_{i_0}\bar{D}_{i_1}} \\
& + \sum_{i_0}^{m-1} a(i_0) \int d^n\bar{q}\, \frac{1}{\bar{D}_{i_0}} + R
\end{aligned}
$$

The problem is getting the set $\mathcal{S} = \left\{ \begin{array}{lll} d(i_0 i_1 i_2 i_3), & c(i_0 i_1 i_2), & \\ b(i_0 i_1), & a(i_0), & R \end{array} \right.$

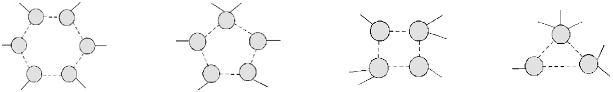
The OPP Method and CutTools (Ossola, Papadopoulos, Pittau, 2007)

Working at the *integrand* level

$$A = \int d^n \bar{q} \; \mathcal{A}(q)$$

- For example, in the case of $2 \rightarrow 4$

$$\mathcal{A}(q) = \sum \underbrace{\frac{N_i^{(6)}(q)}{\bar{D}_{i_0}\bar{D}_{i_1}\cdots\bar{D}_{i_5}}} + \underbrace{\frac{N_i^{(5)}(q)}{\bar{D}_{i_0}\bar{D}_{i_1}\cdots\bar{D}_{i_4}}} + \underbrace{\frac{N_i^{(4)}(q)}{\bar{D}_{i_0}\bar{D}_{i_1}\cdots\bar{D}_{i_3}}} + \underbrace{\frac{N_i^{(3)}(q)}{\bar{D}_{i_0}\bar{D}_{i_1}\bar{D}_{i_2}}} + \cdots$$



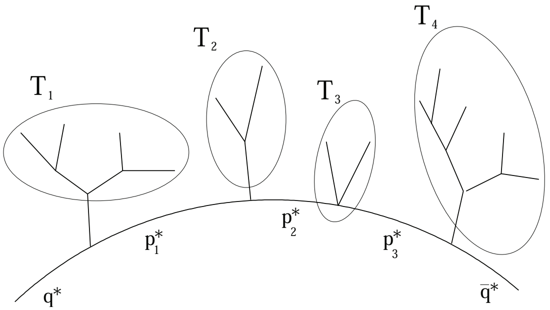
The coefficients are obtained *numerically* by sampling the numerators $N_i(q)$. The algorithm is implemented in the *public* code `CutTools` and it is *independent* of the number of external legs. $N_i(q)$ are *tree-level like* objects $\Rightarrow$

MadGraph can compute them!

Generation of one-loop amplitudes from tree amplitudes

- Given the fact that MadLoop is based on the MadGraph framework, it is clear that the most economic way of generating one-loop amplitudes is that of exploiting as much as possible the capabilities of the latter code to constructing tree-level quantities to be used as an input in `CutTools`
- One-loop amplitudes for $2 \to n$ processes can be constructed by sewing tree-level $2 \to n+2$ amplitudes discarding one-loop diagrams in excess (*diagram filtering*)
- Two diagrams must be considered equivalent if they are identical up to a cyclic permutation, or to mirror symmetry, or to a cyclic permutation plus mirror symmetry

$\Longrightarrow$



Example of L-cut Diagram, identified with the string

$$q^\star\, T_1\, p_1^\star\, T_2\, p_2^\star\, T_3\, p_3^\star\, T_4\, q^\star$$

The following 2 strings are equivalent:

$$p_1^\star\, T_2\, p_2^\star\, T_3\, p_3^\star\, T_4\, q^\star\, T_1\, p_1^\star \qquad q^\star\, T_4\, p_3^\star\, T_3\, p_2^\star\, T_2\, p_1^\star\, T_1\, q^\star$$

- It is easy to convince oneself that when computing QCD corrections the L-cut processes one needs to consider correspond to the following choices of the L-cut particles:

$$(q^\star, \bar{q}^\star) = (g, g) \quad \text{gluons}, \quad (1)$$
$$= (u, \bar{u}); (d, \bar{d}); \ldots (Q, \bar{Q}) \quad \text{quarks}, \quad (2)$$
$$= (\eta, \bar{\eta}) \quad \text{ghosts}. \quad (3)$$

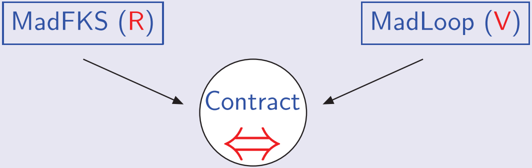
- To conclude, thanks to OPP, tree level programs can be transformed into one-loop generators:

That's MadLoop

NEW! Available soon on-line to check Virtuals for user's defined processes and PS points

The Real Corrections + Parton Shower

A Les Houches Accord to merge Real (R) and Virtual (V) parts



Binoth *et al.* Comput.Phys.Commun.181:1612-1622,2010.

MC@NLO (PS) ⇒

A completely automatic NLO tool = aMC@NLO

- MadLoop[(1)]+MadFKS[(2)]+MC@NLO[(3)]

They are independent modules, they will become PUBLICLY AVAILABLE within MadGraph5 [(4)]

(1) Hirschi, Frederix, Frixione, Garzelli, Maltoni, R.P. arXiv:1103.0621[hep-ph] (One-loop part, NEW! also external)

(2) Frederix, Frixione, Maltoni, Stelzer JHEP 0910:003,2009 (Real radiation)

(3) Frixione, Webber JHEP 0206 (2002) 029 (Parton Shower)

(4) http://madgraph.phys.ucl.ac.be/ (Main framework)

http://amcatnlo.cern.ch

aMC@NLO web page

The project

Home
People
Contact
News

MC Tools
(registration needed)

Online MC generation
Codes Download
Compare with MadLoop
Event samples DB

Communication

Citations
Publications
Talks & Seminars
Events

Resources

Useful links
File Sharing

People contributing to the aMC@NLO project

Name	Affiliation	Main responsabilities/projects
Johan Alwall	FNAL, Batavia	MadGraph 5 : MadFKS and MadLoop
Pierre Artoisenet	Ohio State Univ., Columbus	MadGraph 5 : Decay package
Rikkert Frederix	ITP, Zurich	MadGraph, MadFKS, MadLoop
Stefano Frixione	CERN, Geneva and ITPP,EPFL, Lausanne	MadFKS, MadLoop, MC@NLO
Benjamin Fuks	IPHC, Strasbourg	SUSY and BSM loops
Valentin Hirschi	ITPP, EFPL, Lausanne	MadLoop
Fabio Maltoni	CP3, UCLouvain, Louvain-la-Neuve	MadGraph
Olivier Mattelaer	CP3, UCLouvain, Louvain-la-Neuve	MadGraph 5 and web tools
Roberto Pittau	Granada Univ. and CERN, Geneva	CutTools, Automatic R2, EW corrections
Guillame Serret	IPHC, Strasbourg	Automatic UV and R2 c.t.
Tim Stelzer	UIUC, Urbana	MadGraph
Paolo Torrielli	ITPP, EFPL, Lausanne	MC@NLO and SUSY loops
Marco Zaro	CP3, UCLouvain, Louvain-la-Neuve	MadGraph 5 : MadFKS

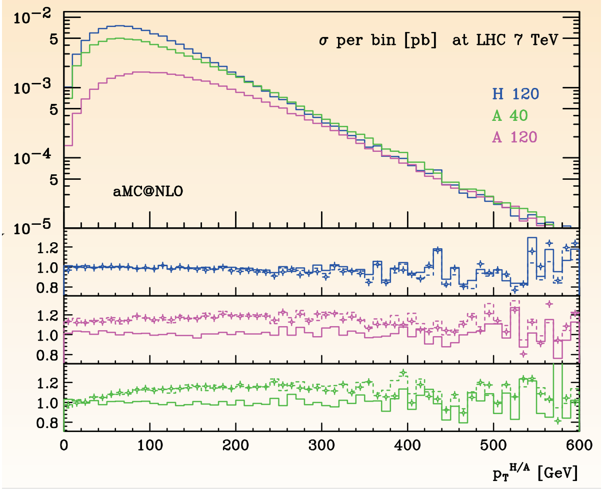
Results at Hadron Colliders

- Published-Results:
  - Partonic total Cross-sections (MadLoop+MadFKS): [Hirschi, Frederix, Frixione, Garzelli, Maltoni & RP, arXiv:1103.0621]
  - (pseudo-)scalar Higgs production in association with a top-antitop pair [Frederix, Frixione, Hirschi, Maltoni, RP & Torrielli, arXiv:1104.5613]
  - Vector boson production in association with a bottom-antibottom pair [Frederix, Frixione, Hirschi, Maltoni, RP & Torrielli, arXiv:1106.6019]

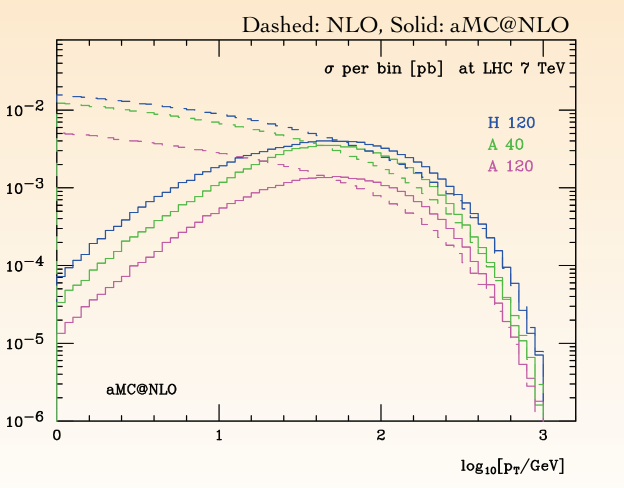
- Preliminary unpublished results (thanks to R. Frederix!):
  - W+2j production (Tevatron)
  - 4 charged lepton production

	Process	μ	n_{lf}	Cross section (pb) LO	NLO
a.1	$pp \to t\bar{t}$	m_{top}	5	123.76 ± 0.05	162.08 ± 0.12
a.2	$pp \to tj$	m_{top}	5	34.78 ± 0.03	41.03 ± 0.07
a.3	$pp \to tjj$	m_{top}	5	11.851 ± 0.006	13.71 ± 0.02
a.4	$pp \to t\bar{b}j$	$m_{top}/4$	4	25.62 ± 0.01	30.96 ± 0.06
a.5	$pp \to t\bar{b}jj$	$m_{top}/4$	4	8.195 ± 0.002	8.91 ± 0.01
b.1	$pp \to (W^+ \to)e^+\nu_e$	m_W	5	5072.5 ± 2.9	6146.2 ± 9.8
b.2	$pp \to (W^+ \to)e^+\nu_e\, j$	m_W	5	828.4 ± 0.8	1065.3 ± 1.8
b.3	$pp \to (W^+ \to)e^+\nu_e\, jj$	m_W	5	298.8 ± 0.4	300.3 ± 0.6
b.4	$pp \to (\gamma^*/Z \to)e^+e^-$	m_Z	5	1007.0 ± 0.1	1170.0 ± 2.4
b.5	$pp \to (\gamma^*/Z \to)e^+e^-\, j$	m_Z	5	156.11 ± 0.03	203.0 ± 0.2
b.6	$pp \to (\gamma^*/Z \to)e^+e^-\, jj$	m_Z	5	54.24 ± 0.02	56.69 ± 0.07
c.1	$pp \to (W^+ \to)e^+\nu_e b\bar{b}$	$m_W + 2m_b$	4	11.557 ± 0.005	22.95 ± 0.07
c.2	$pp \to (W^+ \to)e^+\nu_e t\bar{t}$	$m_W + 2m_{top}$	5	0.009415 ± 0.000003	0.01159 ± 0.00001
c.3	$pp \to (\gamma^*/Z \to)e^+e^- b\bar{b}$	$m_Z + 2m_b$	4	9.459 ± 0.004	15.31 ± 0.03
c.4	$pp \to (\gamma^*/Z \to)e^+e^- t\bar{t}$	$m_Z + 2m_{top}$	5	0.0035131 ± 0.0000004	0.004876 ± 0.000002
c.5	$pp \to \gamma t\bar{t}$	$2m_{top}$	5	0.2906 ± 0.0001	0.4169 ± 0.0003
d.1	$pp \to W^+W^-$	$2m_W$	4	29.976 ± 0.004	43.92 ± 0.03
d.2	$pp \to W^+W^-\, j$	$2m_W$	4	11.613 ± 0.002	15.174 ± 0.008
d.3	$pp \to W^+W^+\, jj$	$2m_W$	4	0.07048 ± 0.00004	0.1377 ± 0.0005
e.1	$pp \to HW^+$	$m_W + m_H$	5	0.3428 ± 0.0003	0.4455 ± 0.0003
e.2	$pp \to HW^+\, j$	$m_W + m_H$	5	0.1223 ± 0.0001	0.1501 ± 0.0002
e.3	$pp \to HZ$	$m_Z + m_H$	5	0.2781 ± 0.0001	0.3659 ± 0.0002
e.4	$pp \to HZ\, j$	$m_Z + m_H$	5	0.0988 ± 0.0001	0.1237 ± 0.0001
e.5	$pp \to Ht\bar{t}$	$m_{top} + m_H$	5	0.08896 ± 0.00001	0.09869 ± 0.00003
e.6	$pp \to Hb\bar{b}$	$m_b + m_H$	4	0.16510 ± 0.00009	0.2099 ± 0.0006
e.7	$pp \to Hjj$	m_H	5	1.104 ± 0.002	1.036 ± 0.002

Higgs p_T in $Ht\bar{t}$ production

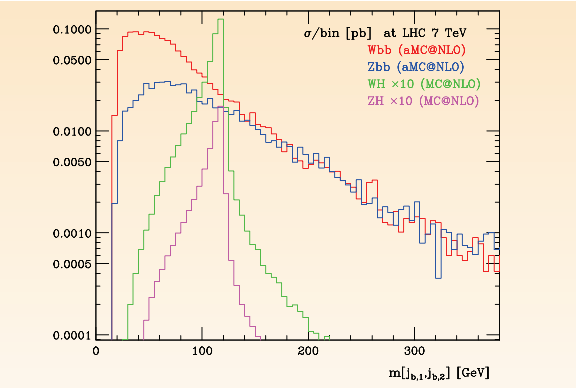


p_T of the $Ht\bar{t}$ system



Wbb, Zbb, WH and ZH at NLO

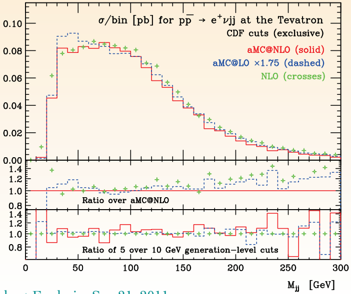
- Using aMC@NLO both signal and background for Vector boson production in association with a Higgs boson (with $H \to b\bar{b}$) can be produced at the same NLO accuracy, including showering and hadronization effects:

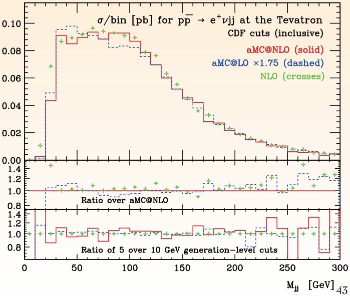


Wjj at the Tevatron

pp → Wjj
Dijet invariant mass

- Dijet invariant mass with/without jet veto
- This is the distribution in which CDF found an excess of events around 130-160 GeV
- No differences in shape between the 5 and 10 GeV generation level cuts
- No sign of enhancement over (N)LO or LOwPS in the mass range 130-160 GeV





Rikkert Frederix, Sep 21, 2011

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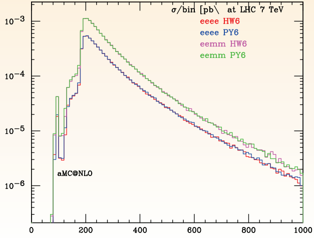
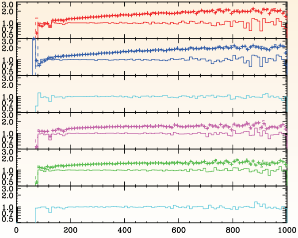
ZZ production

PP → ZZ → 4L

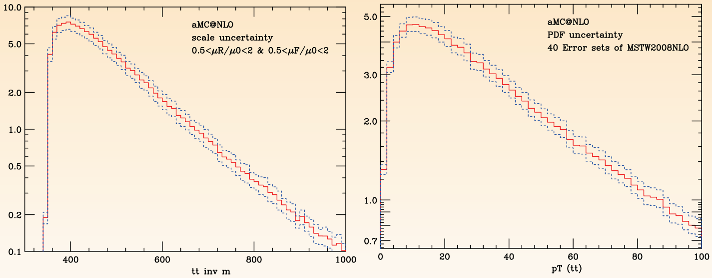
- Important background to heavy Higgs bosons
- NLO calculation includes Z/γ^* interference and single-resonant contributions, but no gg-induced (α_s^2) contributions
- First results using aMC@NLO with Pythia
- extremely stable predictions





NEW FEATURE: Extracting information to study uncertainties directly from the event files

Scale & PDF uncertainties example



- Top anti-top events
- Scale (left) and PDF (right) uncertainties

The Future (also in connection with ILC/CLIC)

- Automatic QCD NLO corrections to any, user defined, BSM theory
  (user friendly within the MadGraph framework)
- Automatic 1-loop EW corrections
  (the next level to prove whether the NLO revolution survives)
- Automatic 1-loop corrections to any renormalizable theory
  (for example SUSY, if survives LHC data)

Automation is not an option, but a necessity with the increasing level of complication

The theory community should be able to quickly provide accurate predictions for any New Physics Model

Thanks!