Progress in automated Next-to-Leading-Order calculations

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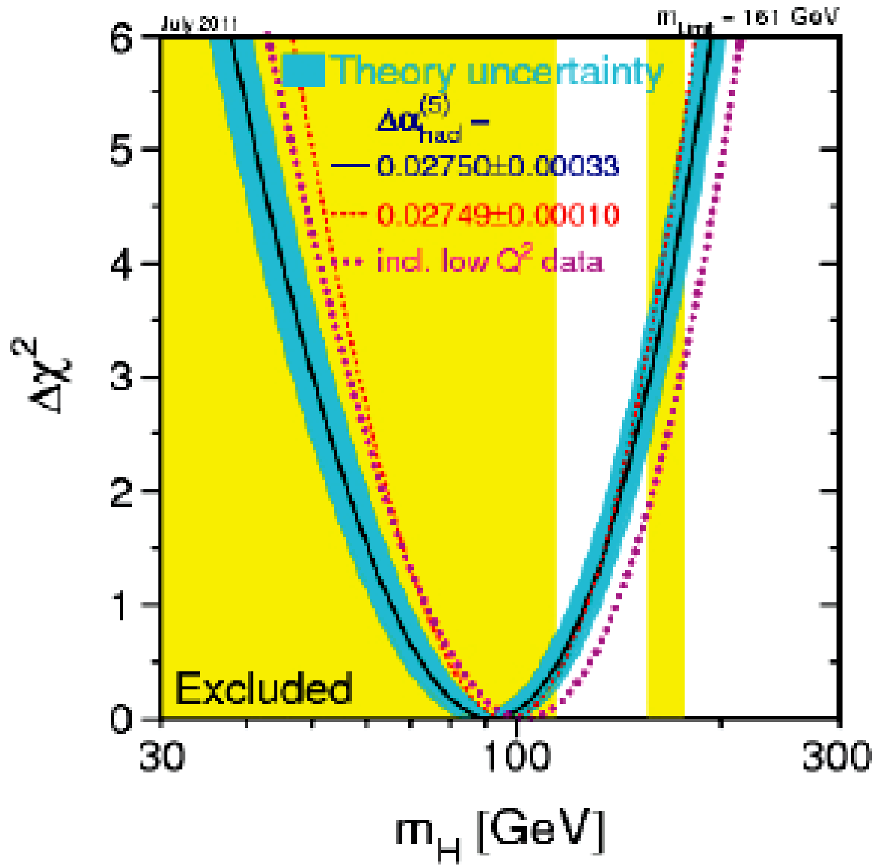
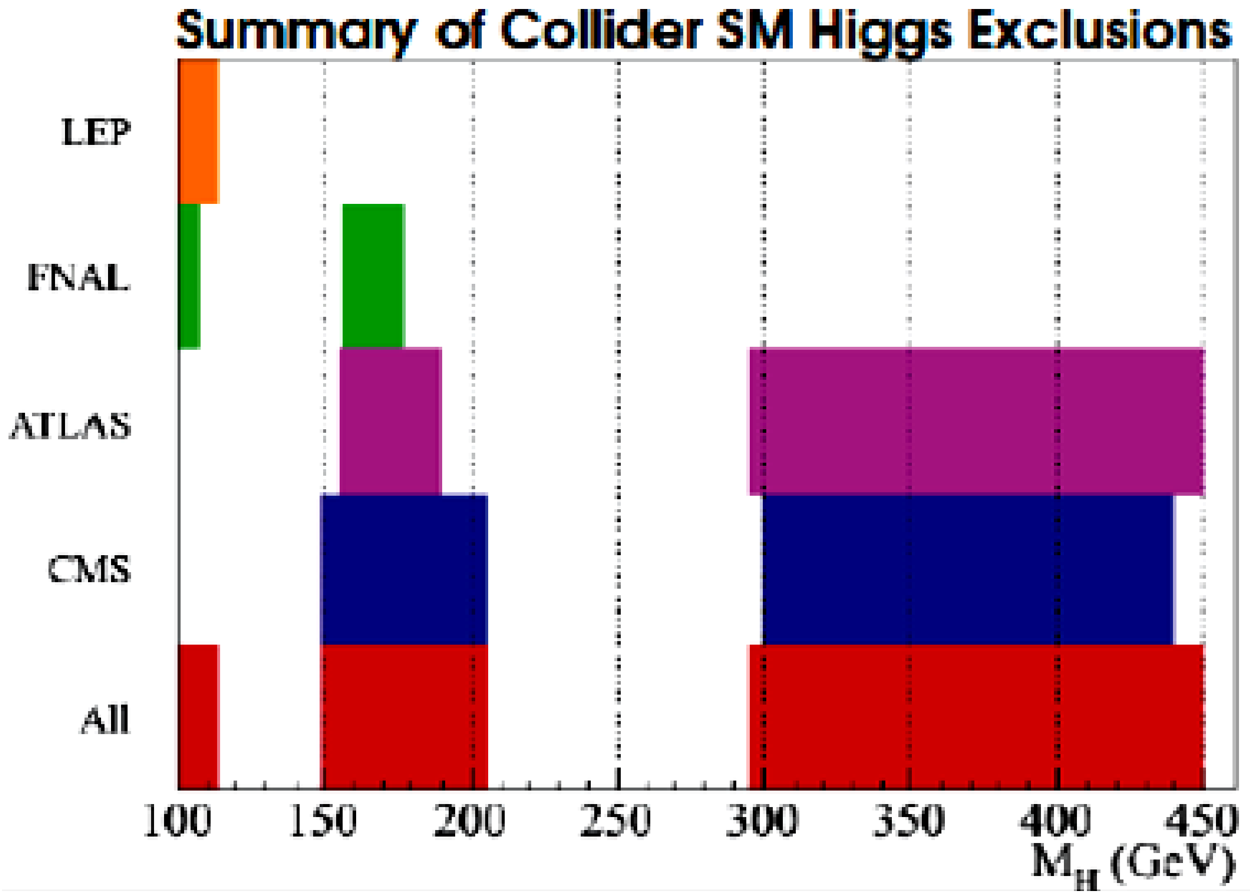
Higgs boson hunting

- The Higgs boson is an essential ingredient of the SM but it has not been observed yet
- Radiative corrections are sensitive to the Higgs boson mass
- Taking into account the LEP limit and the precision electroweak limit:



$$m_H < 185 \text{ GeV} \quad \text{at } 95\ \% \text{ CL}$$

Where we are now: result of the Higgs exclusion plot

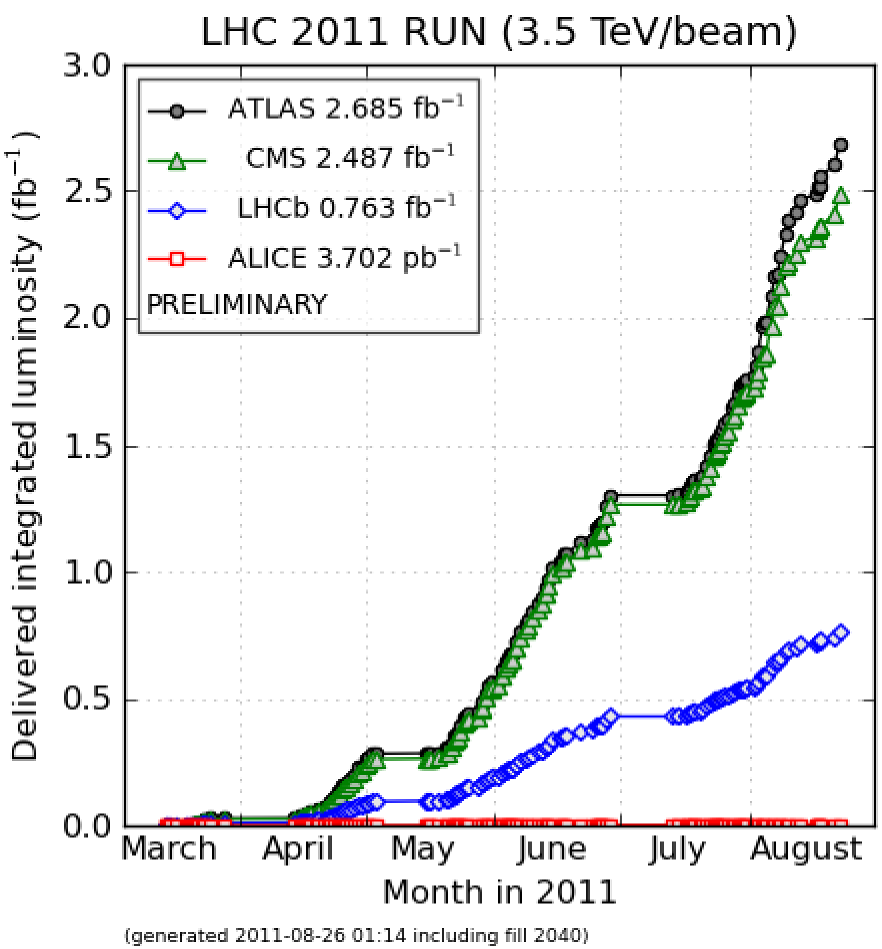


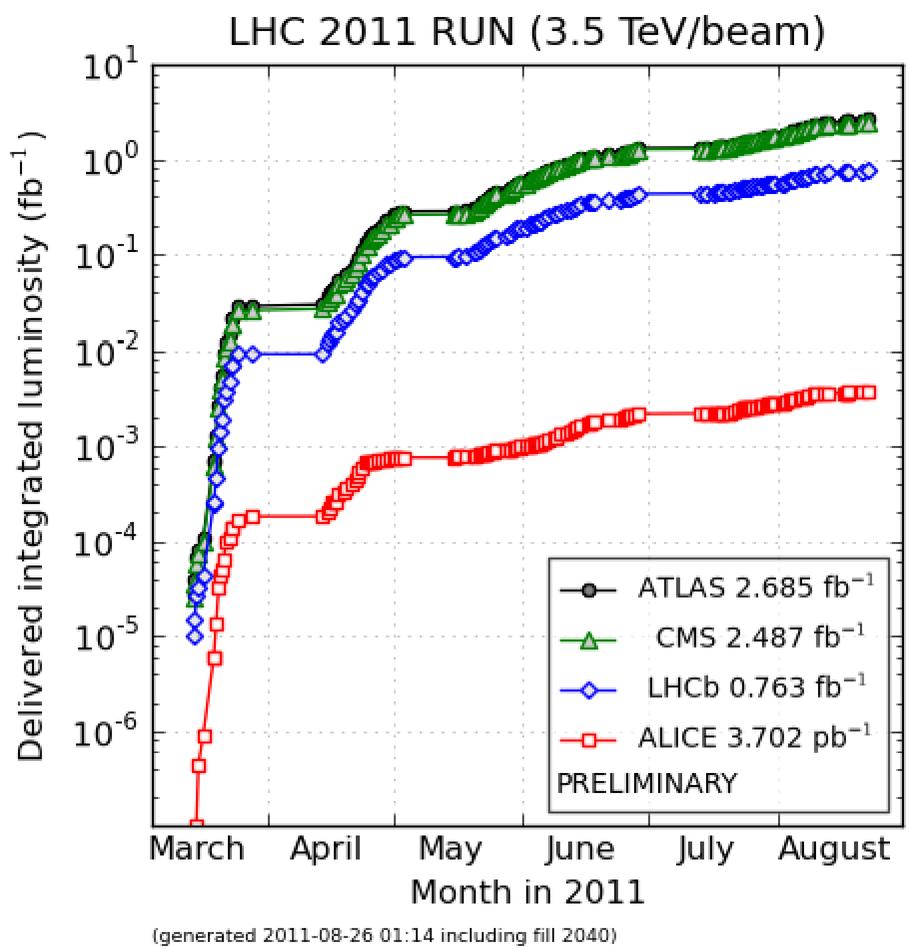
Taken from Massimiliano Grazzini

LHC luminosity plots

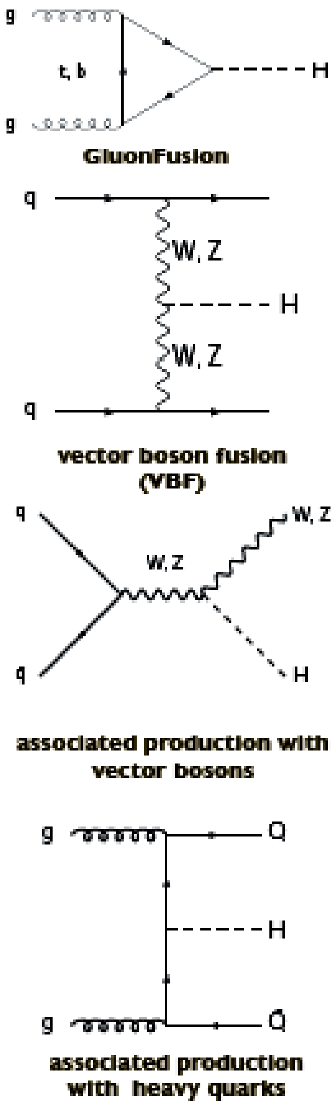
News and many details on the LHC operation can be found at:

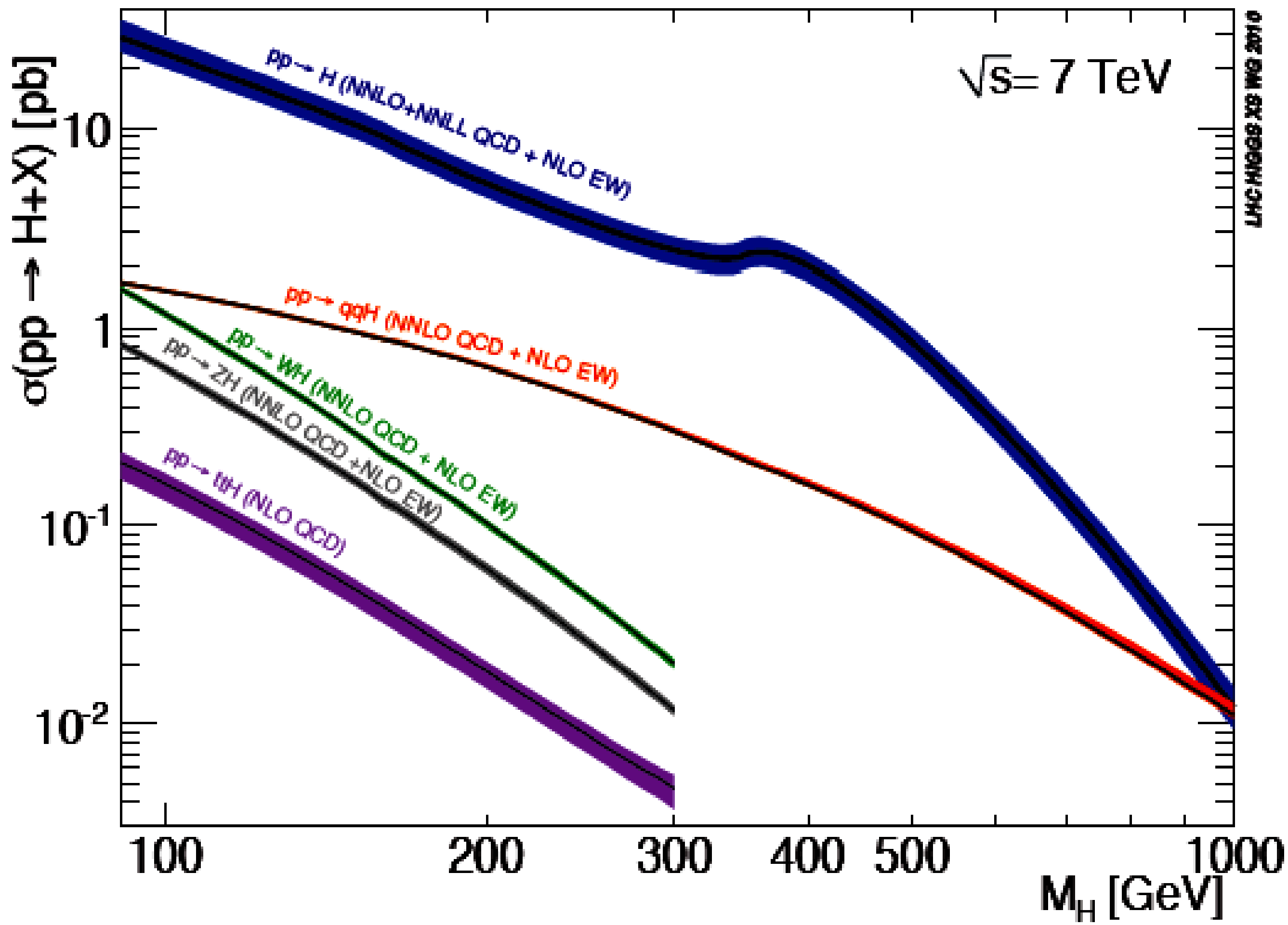
http://lpcc.web.cern.ch





Higgs production inclusive cross sections



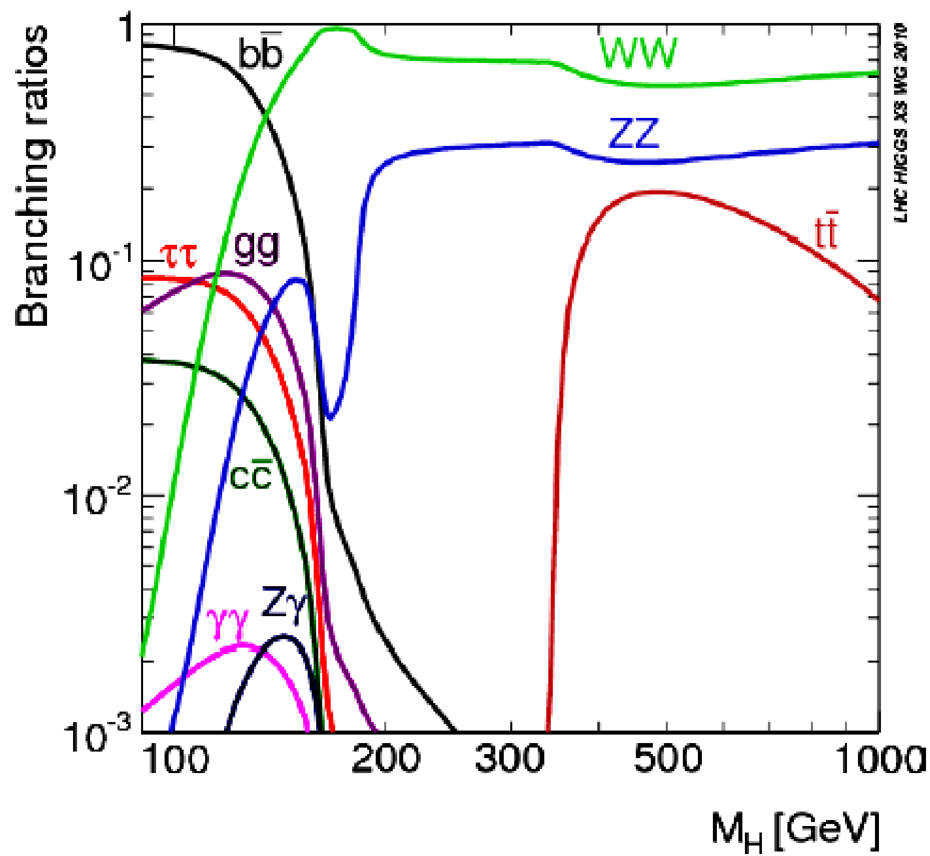


High energy & high luminosity make discovery possible but through very challenging researches:

- Many backgrounds hard to disentangle and not all known with NLO accuracy
- Pile-up, Underlying events…
- Need of predictions made through flexible tools

Many predictions made with Leading Order tools

- Tuned with data
- Many very flexible tools on the market
- Parton shower resummation



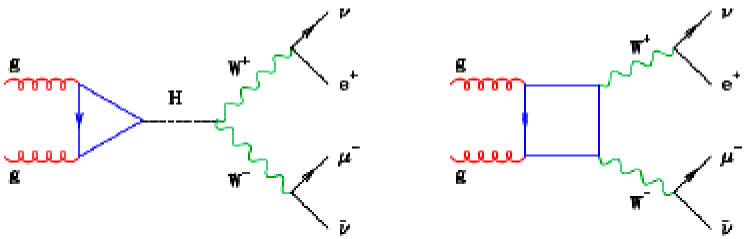
With NLO computations:

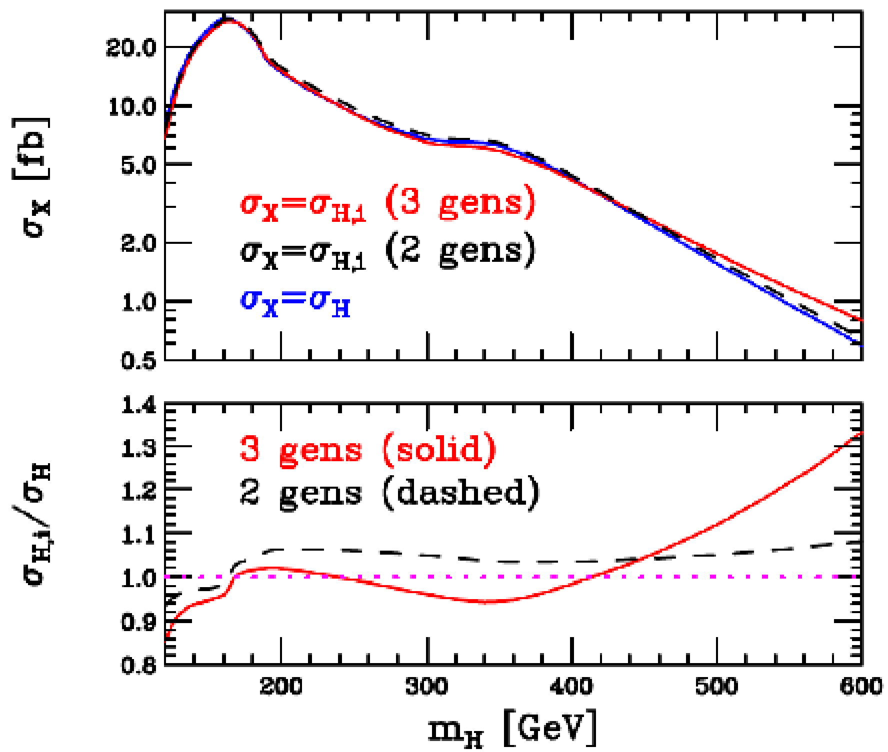
- Much more precise predictions on total rates
- Jet structure better under control
- More reliable theoretical error related to the scale dependence
- PDF's uncertainty

NNLO is still very hard

- Only 3 fully differential computations available for hadron colliders:
  - ggH [Anastasiou, Melnikov, Petriello (2005) Catani, Grazzini (2007), Grazzini (2008)]
  - Drell-Yan [Melnikov, Petriello (2006), Cieri et al (2009), Gravin et al (2010)]
  - WH [Ferrera, Grazzini, FT (2011)]

Signal-Background and Signal-Signal interferences starts to be addressed





$$\sigma_B \longrightarrow |\mathcal{A}_{\text{box}}|^2 \,, \qquad \mathcal{A}_{\text{box}} = 2\mathcal{A}_{\text{massless}} + \mathcal{A}_{\text{massive}} \,,$$

$$\sigma_H \longrightarrow |\mathcal{A}_{\text{Higgs}}|^2 \,,$$

$$\sigma_i \longrightarrow 2\text{Re}\left(\mathcal{A}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right) \,,$$

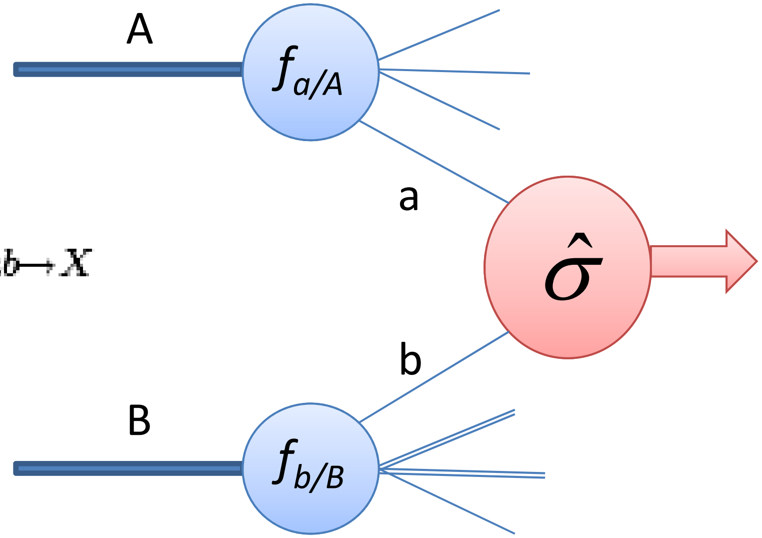
$$\sigma_{H,i} = \sigma_H + \sigma_i \,.$$

$$\delta\sigma_i = \frac{(\hat{s}-m_H^2)}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2}\,\Re\mathrm{e}\left\{2\widetilde{\mathcal{A}}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right\} + \frac{m_H\Gamma_H}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2}\,\Im\mathrm{m}\left\{2\widetilde{\mathcal{A}}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right\}$$

Binoth, Ciccolini, Kauer, Kramer hep-ph/0503094/0611170
Campbell, Ellis, Williams 1107.5569

Hard interaction: factorization formula

$$\sigma_{AB} = \int dx_a dx_b\, f_{a/A}(x_a, Q^2) f_{b/B}(x_b, Q^2)\, \hat{\sigma}_{ab\to X}$$



Two ingredients needed:

- Parton Distribution functions
  - from experiments, evolution from theory

- Short distance coefficients as an expansion in α_S
  - from theory

General method for NLO parton level MC

- The ingredients for a NLO prediction are:

  - ✓ Tree graphs for the lowest order
  - ✓ Tree graphs for the real radiation with an additional parton
  - ✓ One loop correction to the Born level process

- The Born approximation involve m partons in the final state

$$\sigma^{LO} = \int_m d\sigma^B$$

- At NLO we have the real cross section $d\sigma^R$ with m+1 partons in the final state and the one-loop correction $d\sigma^V$ to the process with m partons in the final state

$$\sigma^{NLO} \equiv \int d\sigma^{NLO} = \int_{m+1} d\sigma^R + \int_m d\sigma^V$$

- The two integrals are separately divergent although their sum is finite

Solution: subtraction method [Ellis, Ross, Terrano]

- The general idea consists of the use of the identity

$$d\sigma^{NLO} = \left[d\sigma^R - d\sigma^A\right] + d\sigma^A + d\sigma^V$$

- Where $d\sigma^A$ is a proper approximation of $d\sigma^R$ such as to have the same singular behavior point-by-point as $d\sigma^R$ itself.

$$\sigma^{NLO} = \int_{m+1} \left[d\sigma^R - d\sigma^A\right] + \int_{m+1} d\sigma^A + \int_m d\sigma^V$$

- Further $d\sigma^A$ can be chosen in such a way to be analytically integrable over the extra parton degrees of freedom. Adding it back to the virtual correction we form a finite m parton integrand

$$\sigma^{NLO} = \int_{m+1} \left[d\sigma^R - d\sigma^A\right] + \int_m \left[d\sigma^A + d\sigma^V\right]$$

Existing NLO tools:

Public codes containing hard-coded processes and setup to produce phenomenological results (integration, jet algorithms, plotting facilities, ..., interface to PS-MC)

- ✓ MCFM [Campbell, Ellis, Williams]
- ✓ VBF@NLO [K.Arnold et al]
- ✓ ...

- ✓ MC@NLO [Frixione et al]
- ✓ POWHEG [Alioli et al]

Frameworks for merging of NLO computations with Parton Shower

Full simulations of events with reliable normalization and precise description of hard emission

The dream is to have a fully automatic and flexible tool able to generate any process at NLO accuracy within one framework

Transition: the NLO REVOLUTION

Collection of pre-coded processes => generation of process by the user "on the fly"

Automated codes under construction by several groups (see later):

We are almost there, the magic word is INTERFACE

INGREDIENTS FOR NLO AUTOMATIC COMPUTATIONS

- ❑ Born & Real radiation: tree level matrix element

- ✓ Many tools available on the market, too many to mention all of them:

GRACE	SHERPA
HELAS/MADGRAPH/MADEVENT	HELAC/PHEGAS
WHIZARD	CompHep
….	

- ❑ Subtractions: automated in several programs:

- ✓ MadDipole [Frederix, Greiner, Gehrmann]

- ✓ AutoDipole (SuperAutoDipole) [Hasegawa, Moch, Uwer]

- ✓ Dipoles in SHERPA [Gleisberg, Krauss]

- ✓ HELAC-DIPOLES [Czakon, Papadopoulos, Worek]

- ✓ MadFKS [Frederix, Frixione] (still not public)

Complications in one loop computations (increase with the number of legs)

- **Numerical integration** of the matrix elements on a bigger phase space
  - ➢ Optimized phase space generators
  - ➢ New methods to generate faster real matrix elements

- **Computation** of the **virtual** matrix element
  - ➢ Tremendous progress in the last few years

The dream of fully automated virtual computation is not new !

- some combined tools available since many years by T.Hahn:

FeynArts/FormCalc/LoopTools

- useful to perform computations
- but also for numerical comparisons with independent computations
- Diagram based computation

- PV reduction, but even unitarity based reduction program interfaced
- Code generation
- Scalar integrals

see talk on Monday

NEW DEVELOPMENTS IN ONE LOOP COMPUTATIONS

- Pioneering works:

  - Improvements in the computation of tensor integrals
    Binoth et al GOLEM95
    Denner & Dittmaier

  - Application of unitarity to the computation of one loop amplitudes
    Bern, Dixon, Kosower
    Britto, Cachazo, Feng

  - Reduction at the integrand level
    Ossola, Papadopoulos, Pittau
    Ellis, Giele, Kunszt, Melnikov

One loop virtual corrections: state of the art

Analytic calculations:

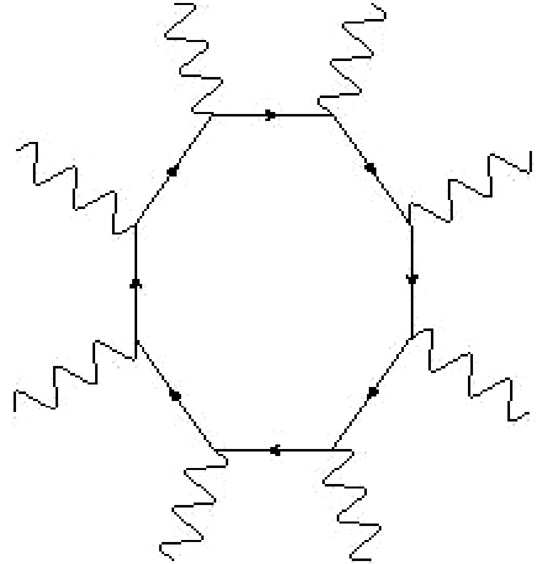
- W/Z/γ+ 2jets Bern et al (1998)
- H + 2jets (eff. coupling)
  Badger, Berger, Campbell, Del Duca, Dixon, Ellis, Glover, Mastrolia, Risager, Sofianatos, Williams (2006-2009)
- W/Zbb with massive b quark
  Febres Cordero, Reina, Wackeroth (2006,2008)

  Wbb with massive b quark
  Badger, Campbell, Ellis (2011)

Numerical calculations:

- EW corr. e+e- > 4 fermions
  Denner and Dittmaier (2005)
- W+W- 1jet (2007)
  Dittmaier et al, Campbell et al, Binoth et al
- pp > W + 3jets Ellis et al, Berger et al (2009)
- pp > Z + 3jets Berger et al (2009)
- pp > ttbb (2009)
  Bredenstein et al, Bevilacqua et al
- pp > tt +2jets Czakon et al (2010)
- pp > 4b Binoth et al (2010),
  Greiner et al (2011)
- pp > W + 4jets Berger et al (2010)
- pp > W+W- bb by Denner et al and
  Bevilacqua et al (2011)
- pp > W+W+/W+W- 2jets Melia et al (2011)
- pp > Z + 4jets Ita et al (2011)

Any amplitude:



$$\mathcal{A}_n = \int d^d\bar{q}\ A(\bar{q},\epsilon)\ ,$$

$$A(\bar{q},\epsilon) = \frac{\mathcal{N}(\bar{q},\epsilon)}{\bar{D}_0\bar{D}_1\cdots\bar{D}_{n-1}}\ ,$$

$$\bar{D}_i = (\bar{q}+p_i)^2 - m_i^2 = (q+p_i)^2 - m_i^2 - \mu^2,$$

$$\mathcal{N}(\bar{q},\epsilon) = N_0(\bar{q}) + \epsilon N_1(\bar{q}) + \epsilon^2 N_2(\bar{q}).$$

$$\bar{\not{q}} = \not{q} + \not{\mu} \qquad \bar{q}^2 = q^2 - \mu^2$$

- We collect over all the loop propagators
- In the following we will assume to work in dred, i.e. no explicit epsilon terms in the numerator; optimal for numerical implementations!
- Any amplitude can be expressed as a linear combination of scalar integrals: boxes, triangles, bubbles, tadpoles plus rational terms

simple integrals: numerator is 1

$$\int A = \sum_{i_0<i_1<i_2<i_3}^{m-1} d(i_0 i_1 i_2 i_3) D_0(i_0 i_1 i_2 i_3) + \sum_{i_0<i_1<i_2}^{m-1} c(i_0 i_1 i_2) C_0(i_0 i_1 i_2)$$
$$+ \sum_{i_0<i_1}^{m-1} b(i_0 i_1) B_0(i_0 i_1) + \sum_{i_0}^{m-1} a(i_0) A_0(i_0) + \text{rational terms}$$

integrals with μ^2 in the numerator

OPP integrand decomposition: 4-dim

- At integrand level the structure is enriched by polynomial terms that integrate to zero (I multiplied with all the propagators)

$$N(q) = \sum_{i_0<i_1<i_2<i_3}^{m-1} \left[d(i_0 i_1 i_2 i_3) + \tilde{d}(q; i_0 i_1 i_2 i_3)\right] \prod_{i\neq i_0,i_1,i_2,i_3}^{m-1} D_i + \sum_{i_0<i_1<i_2}^{m-1} \left[c(i_0 i_1 i_2) + \tilde{c}(q; i_0 i_1 i_2)\right] \prod_{i\neq i_0,i_1,i_2}^{m-1} D_i$$
$$+ \sum_{i_0<i_1}^{m-1} \left[b(i_0 i_1) + \tilde{b}(q; i_0 i_1)\right] \prod_{i\neq i_0,i_1}^{m-1} D_i + \sum_{i_0}^{m-1} \left[a(i_0) + \tilde{a}(q; i_0)\right] \prod_{i\neq i_0}^{m-1} D_i$$

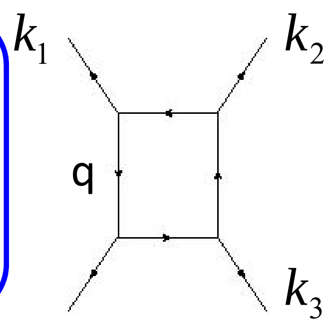
- A choice of q fulfilling 4-ple cut condition: $D_{i0} = D_{i_1} = D_{i_2} = D_{i_3} = 0$ will single out just one polynomial

$$\Delta_{i_0 i_1 i_2 i_3} = \left[d(i_0 i_1 i_2 i_3) + \tilde{d}(q; i_0 i_1 i_2 i_3)\right]$$

$\tilde{d}$ can **only** be of the type $q.p$

where $p = \varepsilon_{\alpha\beta\gamma} k_1^{\alpha} k_2^{\beta} k_3^{\gamma}$

[proof in OPP 2007]



- Once fitted such polynomial we can subtract it from both sides and repeat the game with another multiple cut condition -> recursive solution

- For each phase space point the only requirement for the reduction is the knowledge of the numerical value of the numerator function N for a small set of values of the loop momentum variable, solutions of the multiple cut conditions

Extension to D-dim

- fix a parametric form for the loop momentum in terms of a linear combination of four known 4-vectors e_i suitably chosen

$$\bar{\not{q}} = \not{q} + \not{\mu} \qquad \bar{q}^2 = q^2 - \mu^2 \qquad q = x_1 e_1 + x_2 e_2 + x_3 e_3 + x_4 e_4$$

the vanishing term (spurious term in the OPP terminology) are then polynomials of x_i and $\boldsymbol{\mu^2}$

- The problem is to fit the coefficients in the polynomials Δ

$$N(\bar{q}) = \sum_{i<<m}^{n-1} \Delta_{ijk\ell m}(\bar{q}) \prod_{h\neq i,j,k,\ell,m}^{n-1} \bar{D}_h + \sum_{i<<\ell}^{n-1} \Delta_{ijk\ell}(\bar{q}) \prod_{h\neq i,j,k,\ell}^{n-1} \bar{D}_h + \\ + \sum_{i<<k}^{n-1} \Delta_{ijk}(\bar{q}) \prod_{h\neq i,j,k}^{n-1} \bar{D}_h + \sum_{i<j}^{n-1} \Delta_{ij}(\bar{q}) \prod_{h\neq i,j}^{n-1} \bar{D}_h + \sum_{i}^{n-1} \Delta_{i}(\bar{q}) \prod_{h\neq i}^{n-1} \bar{D}_h$$

✓ Example: 3-ple cut residue

$$\Delta_{ijk}(\bar{q}) = c_{3,0}^{(ijk)} \boxed{+ c_{3,7}^{(ijk)} \mu^2} - \left((c_{3,1}^{(ijk)} \boxed{+ c_{3,8}^{(ijk)} \mu^2}) x_4 + (c_{3,4}^{(ijk)} \boxed{+ c_{3,9}^{(ijk)} \mu^2}) x_3 \right) (e_1 \cdot e_2) + \\ + \left(c_{3,2}^{(ijk)} x_4^2 + c_{3,5}^{(ijk)} x_3^2 \right) (e_1 \cdot e_2)^2 - \left(c_{3,3}^{(ijk)} x_4^3 + c_{3,6}^{(ijk)} x_3^3 \right) (e_1 \cdot e_2)^3 \ .$$

✓ with the 3 cut conditions: $D_i = D_j = D_k = 0$ one fixes x_1, x_2 and the product $x_3 x_4$

Amplitudes & Master Integrals

$$\mathcal{A}_n = \sum_{i<j<k<\ell}^{n-1} \left\{ c_{4,0}^{(ijk\ell)} I_{ijk\ell}^{(d)} + \frac{(d-2)(d-4)}{4} c_{4,4}^{(ijk\ell)} I_{ijk\ell}^{(d+4)} \right\}$$
$$+ \sum_{i<j<k}^{n-1} \left\{ c_{3,0}^{(ijk)} I_{ijk}^{(d)} - \frac{(d-4)}{2} c_{3,7}^{(ijk)} I_{ijk}^{(d+2)} \right\}$$
$$+ \sum_{i<j}^{n-1} \left\{ c_{2,0}^{(ij)} I_{ij}^{(d)} + c_{2,1}^{(ij)} J_{ij}^{(d)} + c_{2,2}^{(ij)} K_{ij}^{(d)} - \frac{(d-4)}{2} c_{2,9}^{(ij)} I_{ij}^{(d+2)} \right\}$$
$$+ \sum_{i}^{n-1} c_{1,0}^{(i)} I_i^{(d)}$$

$$\int d^d\bar{q} \frac{\bar{q}\cdot e_2}{\bar{D}_i \bar{D}_j} = J_{ij}^{(d)}$$
$$\int d^d\bar{q} \frac{(\bar{q}\cdot e_2)^2}{\bar{D}_i \bar{D}_j} = K_{ij}^{(d)}$$

The sources of rational terms are the integrals with μ^2 powers in the numerator

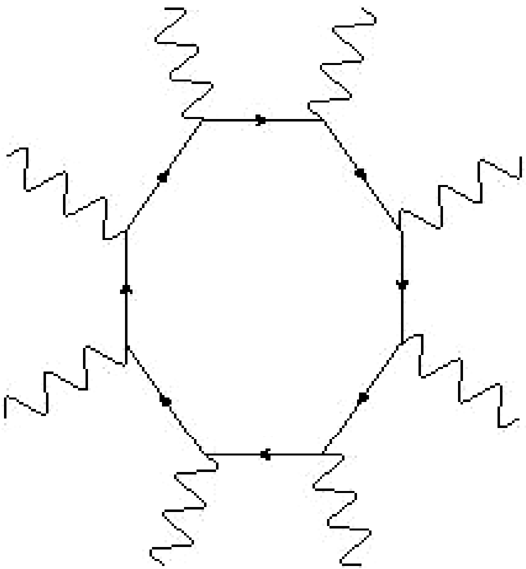
They are generated by the reduction algorithm, but could also be present ab initio in the numerator function as a consequence of the algebraic manipulations

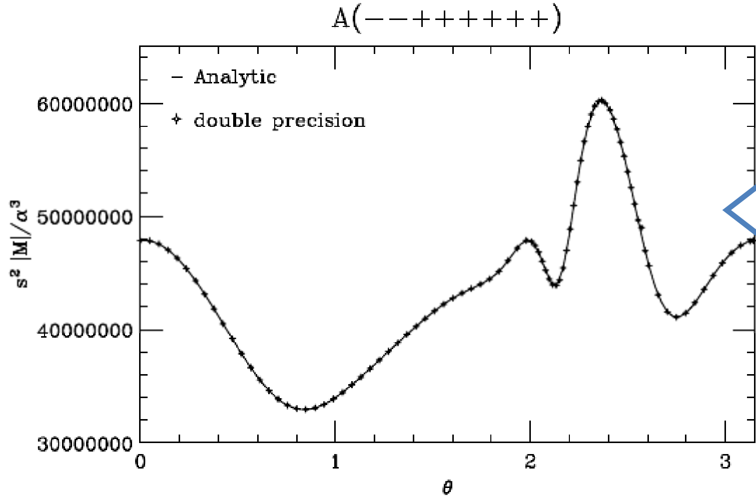
$$\int d^d\bar{q} \frac{\mu^2}{\bar{D}_i \bar{D}_j} = -\frac{(d-4)}{2} I_{ij}^{(d+2)}$$
$$\int d^d\bar{q} \frac{\mu^4}{\bar{D}_i \bar{D}_j \bar{D}_k \bar{D}_\ell} = \frac{(d-2)(d-4)}{4} I_{ijk\ell}^{(d+4)}$$
$$\int d^d\bar{q} \frac{\mu^2}{\bar{D}_i \bar{D}_j \bar{D}_k} = -\frac{(d-4)}{2} I_{ijk}^{(d+2)}$$

8-photons

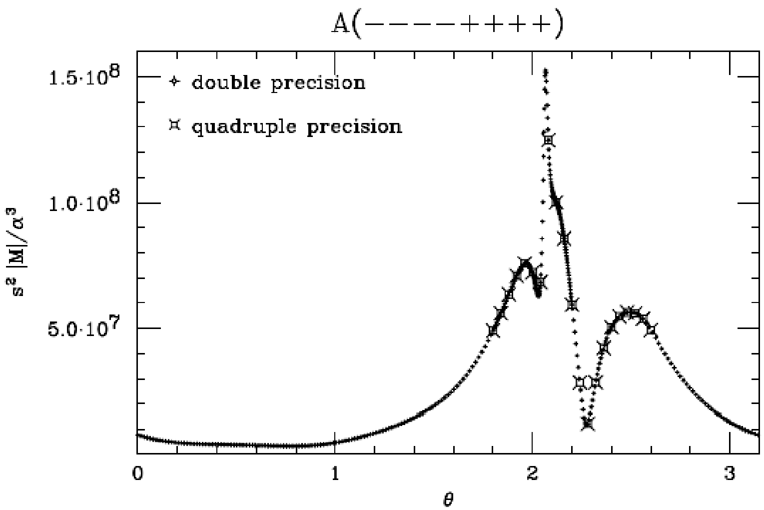
- imeth ='diag'
- **nleg = 8, rank = 8**
- 5040 permutations, only **2520 relevant diagrams**
- sampling set as in Gong et al (2008)

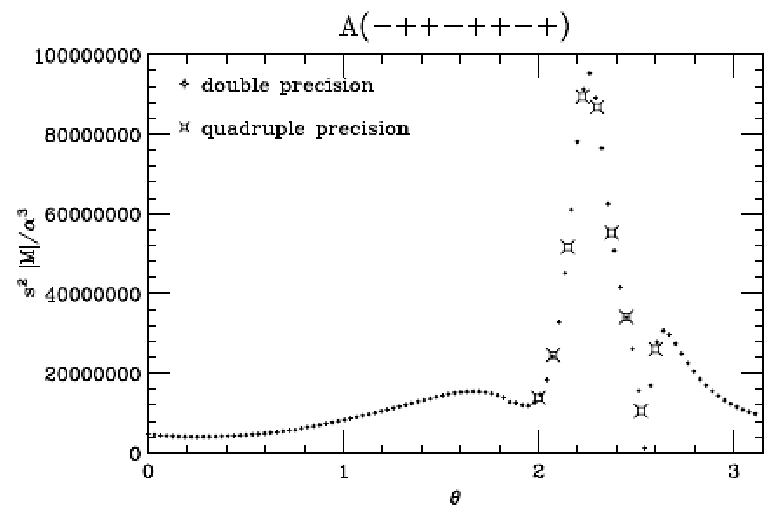
SAMURAI setup





MHV result numerically Checked vs. Mahlon (1993)





$$N(q,\mu^2) = -\mathrm{Tr}\left[\not{L}_0 \not{\epsilon}_1 \not{L}_1 \not{\epsilon}_2 \not{L}_2 \not{\epsilon}_3 \not{L}_3 \not{\epsilon}_4 \not{L}_4 \not{\epsilon}_5 \not{L}_5 \not{\epsilon}_6 \not{L}_6 \not{\epsilon}_7 \not{L}_7 \not{\epsilon}_8\right]$$

On-shell methods are quite flexible:

- Different implementations

  - Sewing tree level amplitudes

+ works with gauge invariant objects
- still not easy to automate the rational terms for general one loop amplitudes

Blackhat: Recursive bootstrap approach [Ita, Bern, Dixon, Febres Cordero, Kosower, Maitre]
Rocket: Tree level amplitudes in different dimensions [Ellis, Giele, Kunszt, Melnikov, Zanderighi]
Samurai: works with D-dimensional tree level amplitudes [Mastrolia, Ossola, Reiter, FT]

  - Diagrammatic approach:

    + contain all the information on the rational terms
    - single diagrams are not gauge invariant objects in general

    - Construction through the single cut:
      Helac-NLO [Bevilacqua, Czakon, Papadopoulos, Worek]
      MadLoop [Hirschi, Frederix, Frixione, Garzelli, Maltoni Pittau]

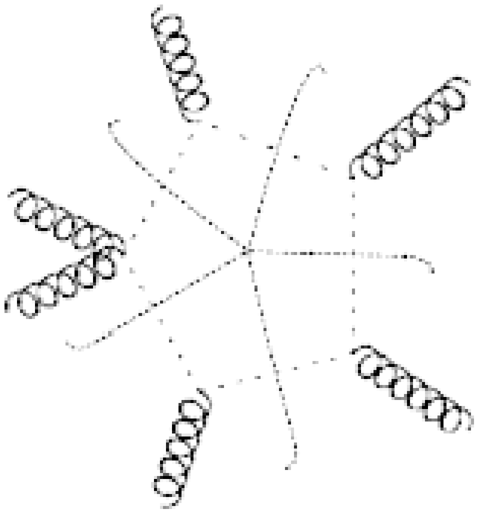
    - Fully algebraic method: **GoSam**
      [Cullen, Greiner, Heinrich, Luisoni, Mastrolia, Ossola, Reiter, FT]

5 and 6-gluons all plus helicity amplitude:

massive scalar loop

SAMURAI SETUP

- imeth='tree'
- nleg = 6, rank = 6



$$A_3^{\rm tree}(1_s;2^+;3_s)=\frac{[2|1|r_2\rangle}{\langle 2\,r_2\rangle}\ ,$$

$$A_4^{\rm tree}(1_s;2^+,3^+;4_s)=\frac{\mu^2\ [2\,3]}{\langle 2\,3\rangle(p_{12}^2-\mu^2)}\ ,$$

$$A_5^{\rm tree}(1_s;2^+,3^+,4^+;5_s)=\frac{\mu^2\ [2|1\ (2+3)|4]}{\langle 2\,3\rangle\langle 3\,4\rangle(p_{12}^2-\mu^2)(p_{45}^2-\mu^2)}\ ,$$

$$N(q,\mu^2)=A_4(L_1;1^+,2^+;-L_2)\times A_3(L_2;3^+;-L_3)\times A_3(L_3;4^+;-L_4)$$
$$\times A_3(L_4;5^+;-L_5)\times A_3(L_5;6^+;-L_1)$$

For this helicity choice the result is purely rational

numerically checked vs. S. Badger's table of results

More on the rational terms for the diagrammatic approach:

- Treatment strictly related the way the numerator function is furnished
  - Classified in two categories: R = R1 + R2

- R1 develops automatically performing the D-dimensional reduction of the tensors spanning the 4-dimensional part of the loop momentum

- R2 are present in the UV diagrams: bubbles, rank 2 and 3 triangles and rank4 boxes.

- At least two possibilities for R2 automatic computation:
  - for any fixed gauge theory calculate once and for all the contribution from all the diagrams that can generate R2 terms and define a set of tree level Feynman rules that give the R2 contribution for any process – **MadLoop approach**

  - Alternatively: construct the numerator function by implementing (few and universal) algebraic rules to get the R2 term on a diagram by diagram basis **GoSam approach**

App. of the GoSam code for the virtual computation

$u\bar{d} \rightarrow W^+(e^+\nu_e)b\bar{b}$

	Timings:	30min generation+compilation
2.27GHz gfortran –O2		7msec running a single ps-point

PS-point:

```
vecs(1,:)= (/ 76.0843499,   0.00000000,  0.00000000,  76.0843499 /)
vecs(2,:)= (/ 1998.03313,   0.00000000,  0.00000000, -1998.03313 /)
vecs(3,:)= (/ 955.016763,   50.0258080,  17.0602115, -953.553032 /)
vecs(4,:)= (/ 194.222790,   4.35888776,  39.0630650, -190.204020 /)
vecs(5,:)= (/ 468.235447,   208.221739,  40.6257851, -417.390852 /)
vecs(6,:)= (/ 456.642482,  -262.606435, -96.7490617, -360.800877 /)
```

Setup:

```
ren scale: = 80.0 GeV
        mb = 4.75 GeV
        mt = 172.5 GeV
       VUD = 0.975
    widthW = 2.1054GeV
        gs = 1
        MW = 80.398 GeV
        MZ = 91.1876 GeV
        GF = 0.0000116639 GeV^-2
```

b-quark massive everywhere but in the bubble contributing to the gluon vacuum polarization

NLO/LO/ason2pi results:

MCFM:

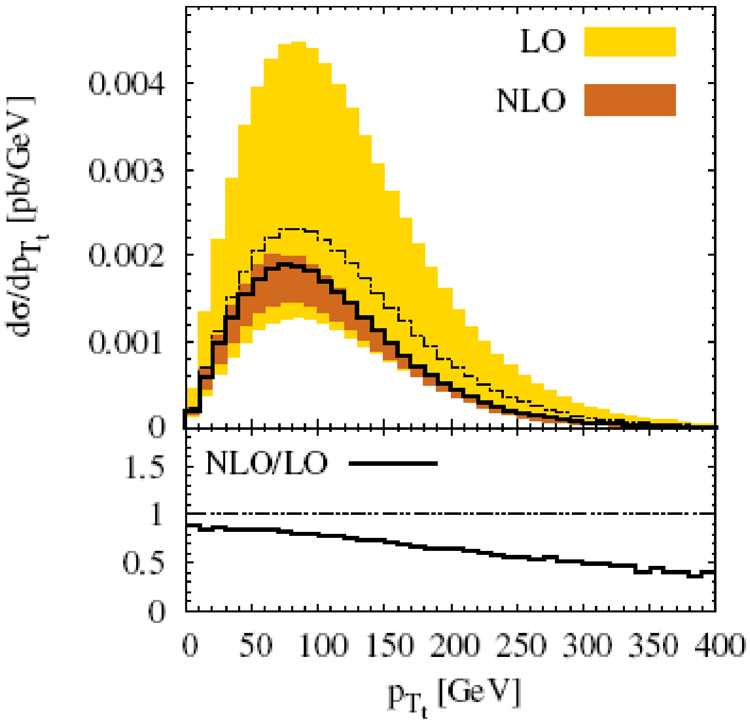
```
                LO:   1.8844347E-007
  NLO, finite par     41.217130
```

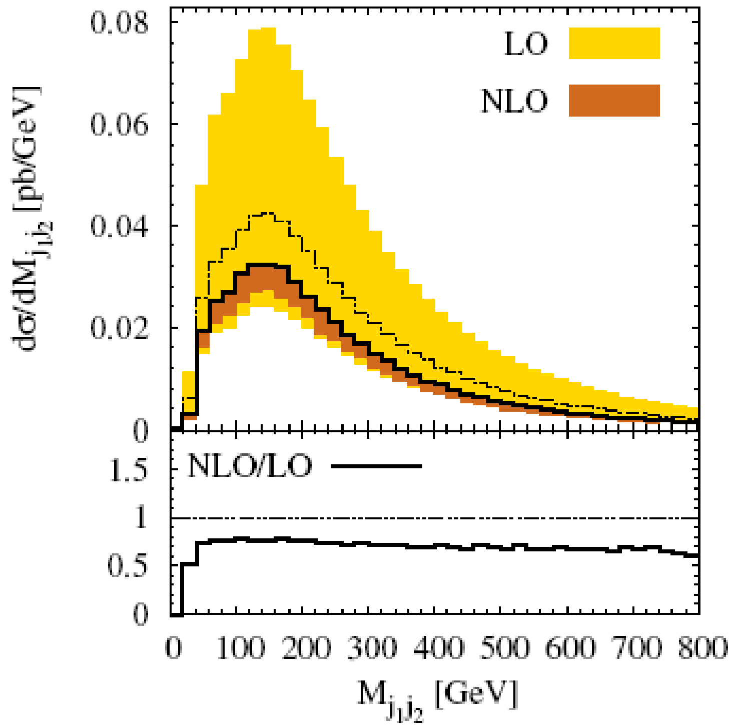
GOSAM:

```
#               LO:   1.8844347E-007
# NLO, finite par     41.217130
# NLO, single pol     26.603671
# NLO, double pol    -2.6666667
# IR,  single pol     26.603671
# IR,  double pol    -2.6666667
```

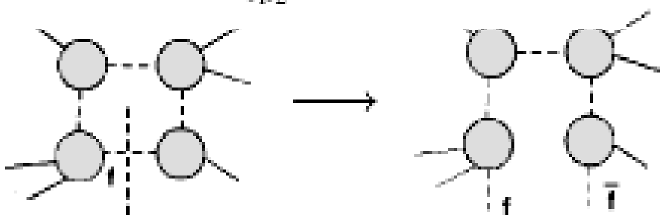
New recent physical results for 2 to 4 process

Study of $pp \to t\bar{t}jj$ with Helac-NLO
Bevilacqua, Czakon, Papadopoulos, Worek 1108.2851





Cut-construction through single cut



Sampling colour/helicity and re-weighting works

MadLoop(MadGraph+CutTools)+MadFKS

Hirschi, Frederix, Frixione, Garzelli, Maltoni and Pittau

	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

- Automation up to full integration at parton level
- Results obtained with 2 weeks of running on 200 machines
- but also NLOwPS processes with aMC@NLO

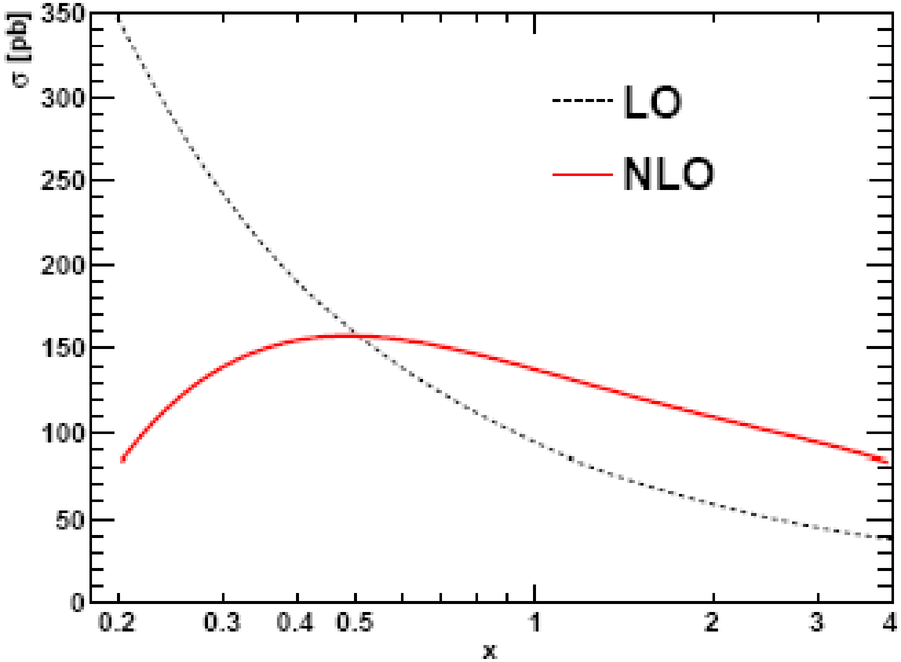
Frederix et al

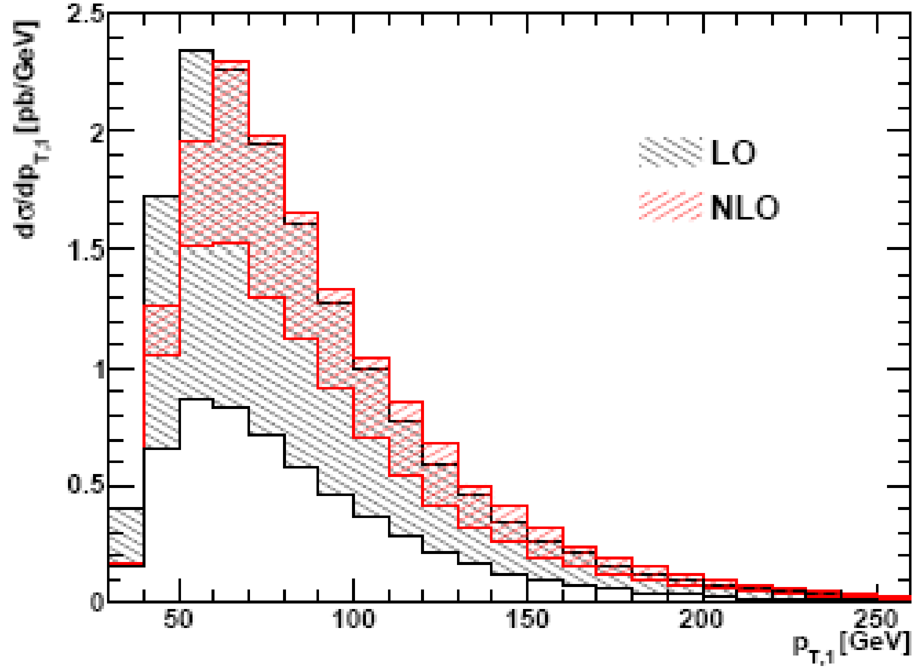
$pp \to ttH \,/\, ttA$ 1104.5613

$pp \to Wbb \,/\, Zbb$ 1106.6019

New recent physical results for 2 to 4 process at 1-loop

Study of $pp \to b\bar{b}b\bar{b}$
by Greiner, Guffanti, Reiter, Reuter 1105.3624



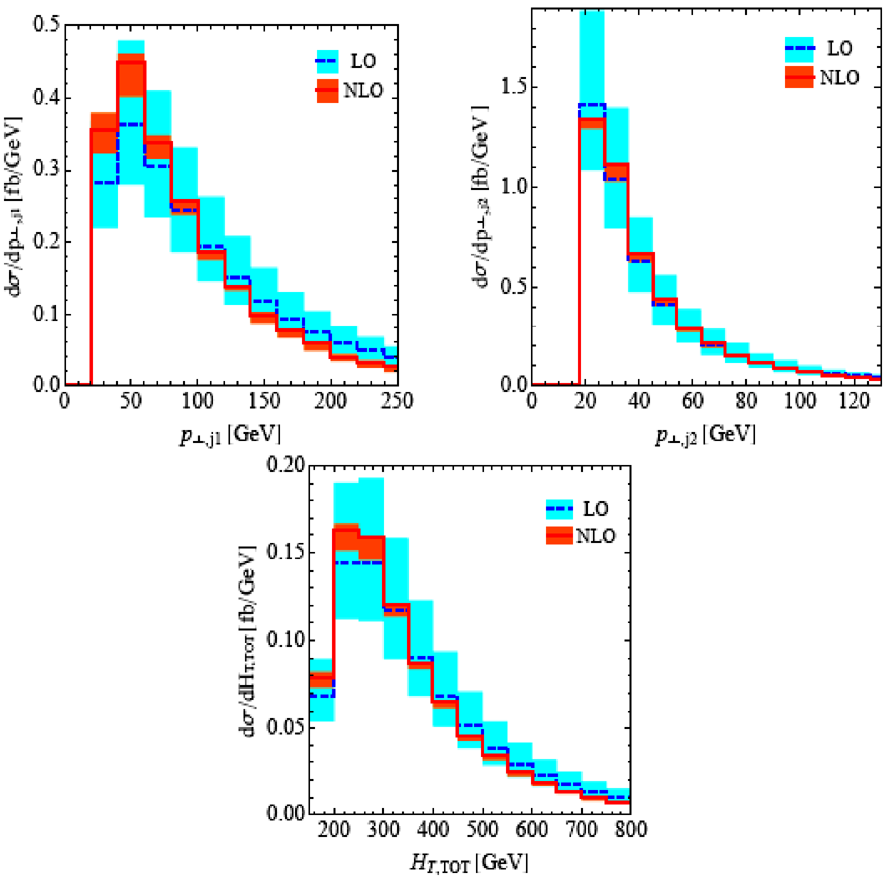


- ✓ Born & Real: MadGraph
- ✓ Subtractions: MadDipole
- ✓ Virtuals: GoSam

New recent physical results for one loop 2 to 4 process

pp → W+W-jj
by Melia, Melnikov, Rontsh, Zanderighi

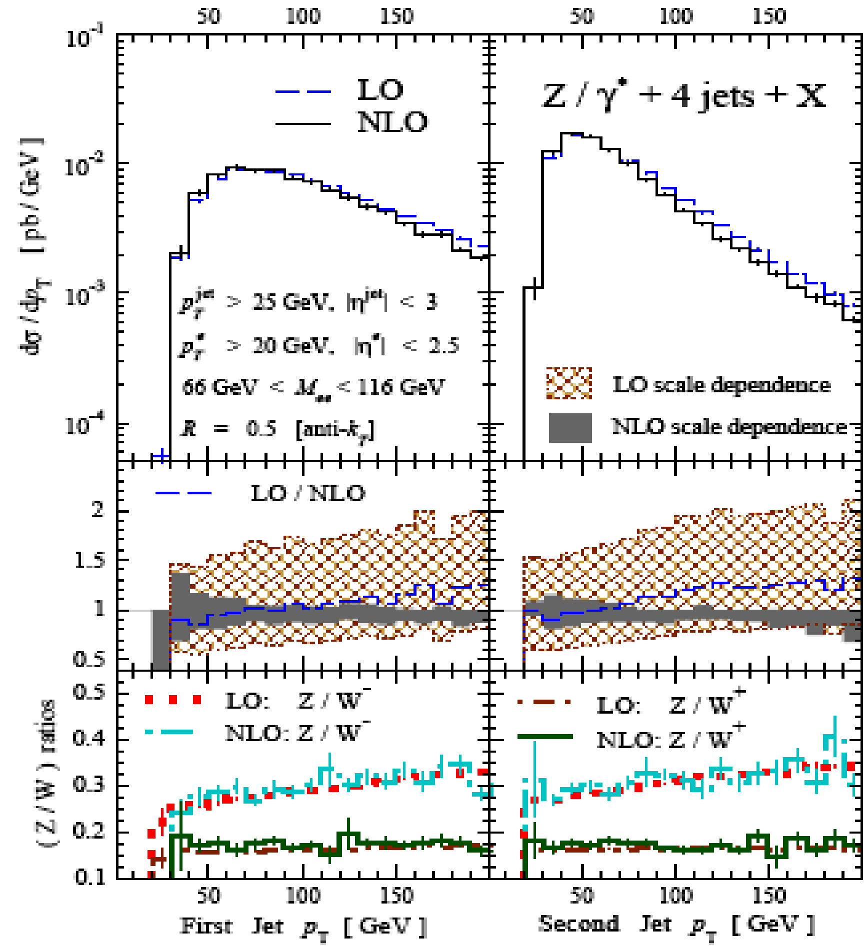
OPP/D-dimensional-unitarity EGKM+MCFM
1104.2327



New recent physical results for one loop 2 to 5 process !

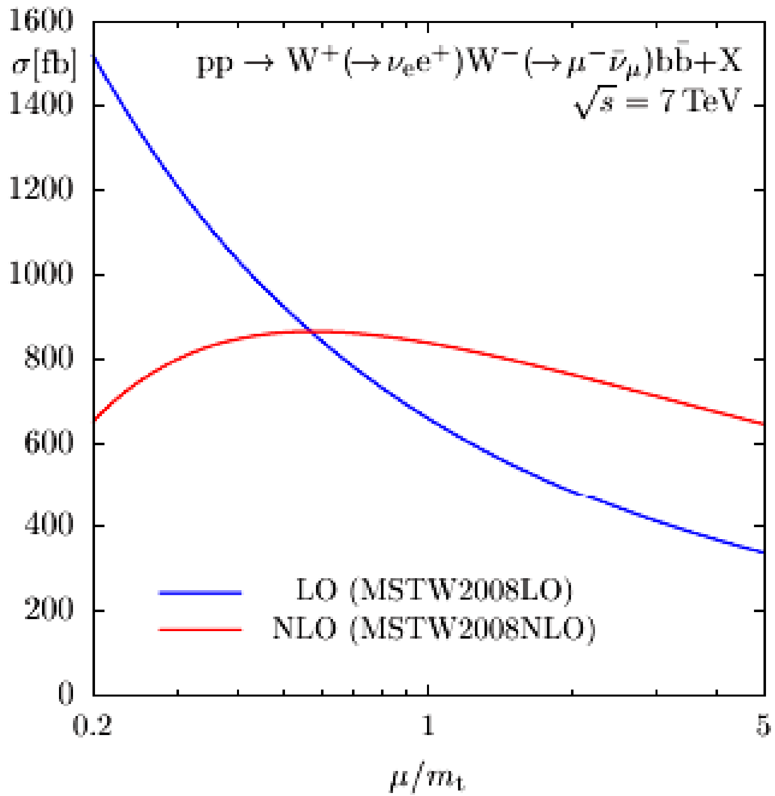
Z+4jets
by Ita, Bern, Dixon, Febres Cordero, Kosower, Maitre

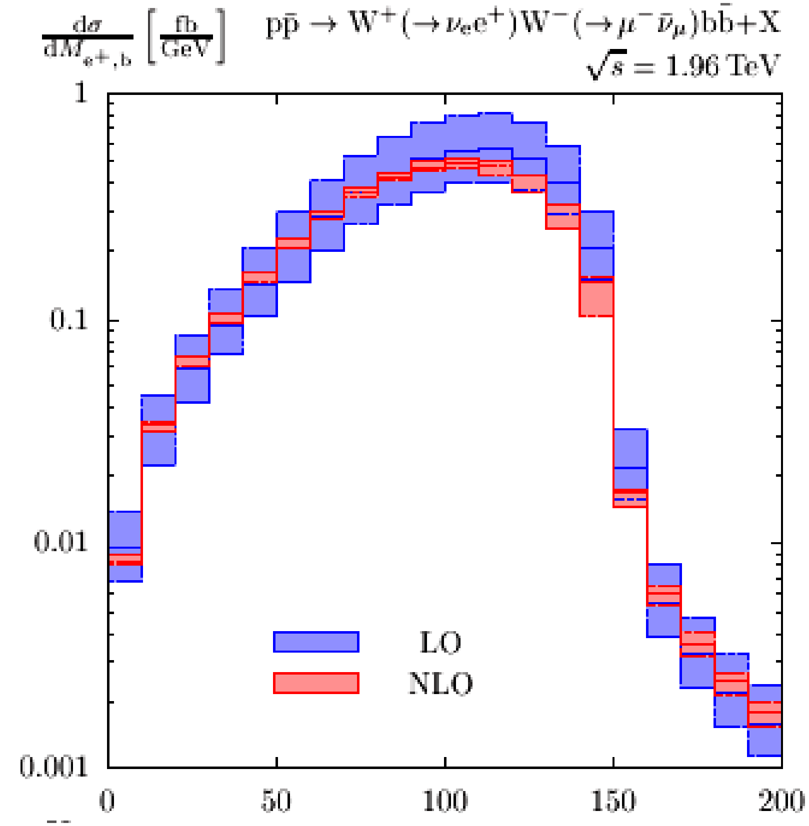
Blackhat+SHERPA 1108.2229



New recent physical results for one loop 2 to 4 process

$pp \to W^+W^-b\bar{b}$ by Denner, Dittmaier, Kallweit and Pozzorini





- Diagramatic approach
- Algebric reduction

- RECYCLING
- Numerical reduction of tensor integrals based on **Denner and Dittmaier NPB2006** (private code)

Conclusions

- **Full automation** for **NLO** computation is almost there !

- Private versions of codes already realize automation to a certain level
  Examples:
  Blackhat-Sherpa,
  HELAC-NLO (also interfaced with POWEHG),
  MadLoop+MadFKS (also interfaced with MC@NLO),
  GoSam+MadDipole (GoSam code also interfaced with Sherpa)

- **Progress** is coming **interfacing** different programs/tools

- The **GoSam** code for the virtual matrix elements will be released soon (see Gudrun Heinrich's talk)

- With perfect timing, extraordinarily powerful tools are being developed that hopefully will be of help to disentangle signal and backgrounds at the LHC:

stay tuned !