Automated NLO calculations for top quark observables at hadron colliders

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Max-Planck-Institut für Physik
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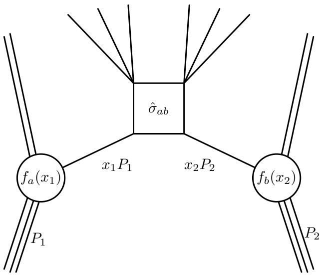
Overview

1. QCD processes at hadron colliders
2. Calculation of virtual corrections
3. GoSam and Sherpa
4. The process $pp \to W^+W^-b\bar{b}$ at NLO
5. The observable m_{lb}
6. Results

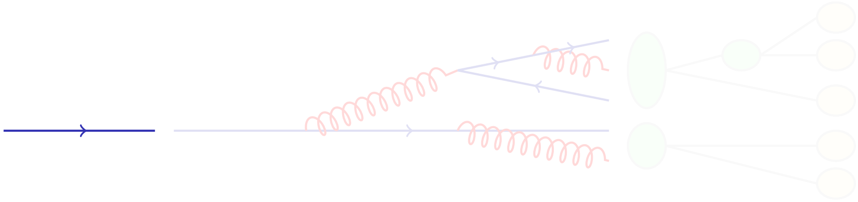
QCD processes at hadron colliders



- Factorization of short and long distance physics
- Scattering of hadrons which are bound states of quarks and gluons
- Parton distribution functions $f_a(x)$ have to be measured
- Partonic cross section $\hat{\sigma}_{ab}$ can be calculated perturbatively

$$d\sigma(P_1, P_2) = \sum_{a,b} \int dx_1\, dx_2\, f_a(x_1)\, f_b(x_2)\, d\hat{\sigma}_{ab}(x_1 P_1, x_2 P_2)$$

Parton shower and hadronization



Parton level

Final state contains only particles generated by the hard scattering.

Shower level

Additional gluons and quark pairs due to soft and collinear emissions.

Hadron level

Coloured particles in the final state are clustered into hadrons which subsequently decay to stable particles.

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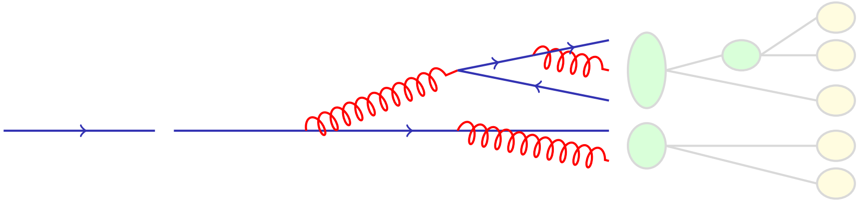

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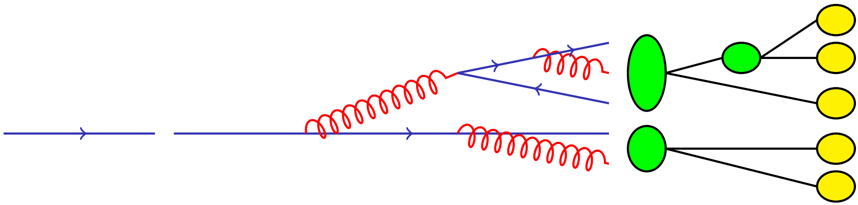

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The partonic cross section

Perturbative expansion in α_S

$$d\hat{\sigma}_{ab} = \alpha_S^k(\mu) \sum_{m=0}^{\infty} d\hat{\sigma}_{ab}^{(m)}(\mu)\, \alpha_S^m(\mu)$$

NLO cross section

$$\sigma^{NLO} = \int_N d\sigma^B + \int_N d\sigma^V + \int_{N+1} d\sigma^R$$

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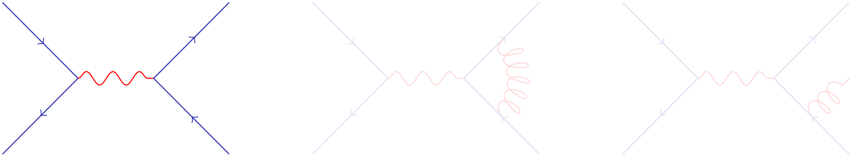

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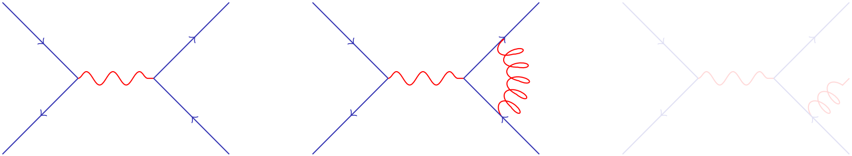

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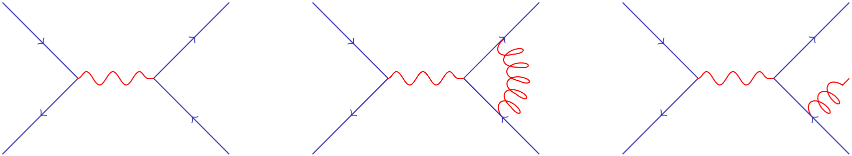
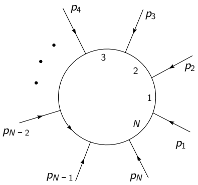


Infrared subtraction

- Virtual and real part diverge separately in the infrared limit
- The sum of both is finite
- Introduce subtraction terms which locally cancel the divergences:

$$\sigma^{NLO} = \int_N d\sigma^B + \int_N \underbrace{\left[d\sigma^V + \int_1 d\sigma^A \right]}_{\text{poles cancel after 1D integration}} + \int_{N+1} \underbrace{\left[d\sigma^R - d\sigma^A \right]}_{\text{finite}}$$

Calculation of virtual corrections



$$\mathcal{M}_N = \int d^D q \frac{N(q)}{D_1(q)...D_N(q)}$$

with

$$N(q) = C_0 + C_1^{\mu_1} q_{\mu_1} + C_2^{\mu_1 \mu_2} q_{\mu_1} q_{\mu_2} + ...$$

$$D_i(q) = (q + \sum_{k=1}^{i} p_k)^2 - m_i^2$$

$\mathcal{M}_N$ can be expanded in a basis of scalar master integrals:

$\mathcal{M}_N = d$ $+ c$ $+ b$ $+ a$ $+ \mathcal{R}$

Master integrals are known.

Different approaches to amplitude reduction: Passarino-Veltman reduction Passarino, Veltman (1979), OPP method Ossola, Papadopoulos, Pittau (2007), ...

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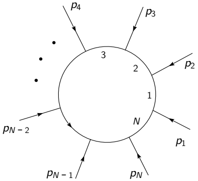

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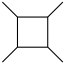
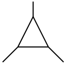
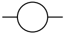
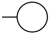
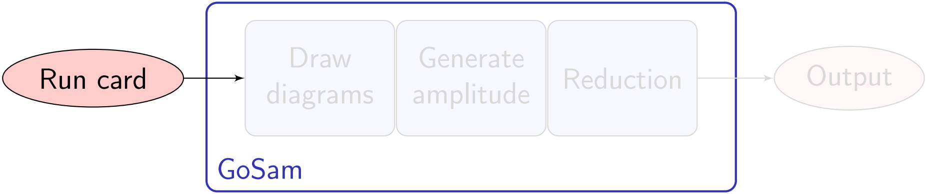
$\mathcal{M}_N = d$  $+ c$  $+ b$  $+ a$  $+ \mathcal{R}$

Master integrals are known.

Different approaches to amplitude reduction: Passarino-Veltman reduction Passarino, Veltman (1979), OPP method Ossola, Papadopoulos, Pittau (2007), ...

GoSam

Cullen, Greiner, Heinrich, Luisoni, Mastrolia, Ossola, Reiter, Tramontano (2011)



- Run card contains process information and options
- Feynman diagram topologies are generated with QGRAF Nogueira (1993)
- Integrand is generated with FORM Vermaseren (1984 -) and Fortran code is produced
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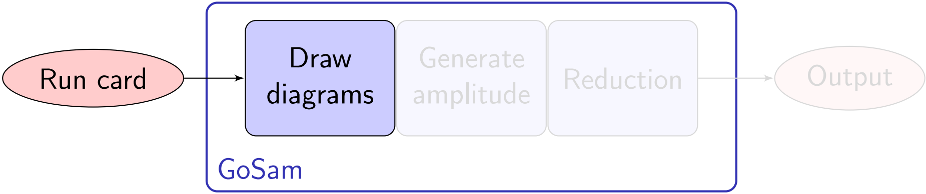

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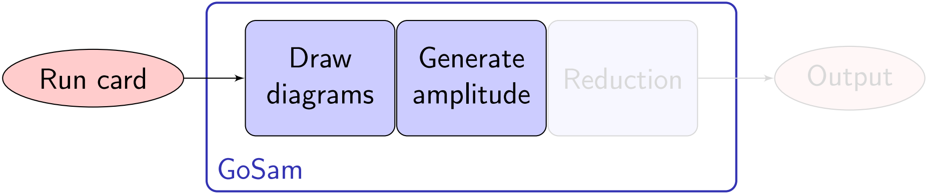

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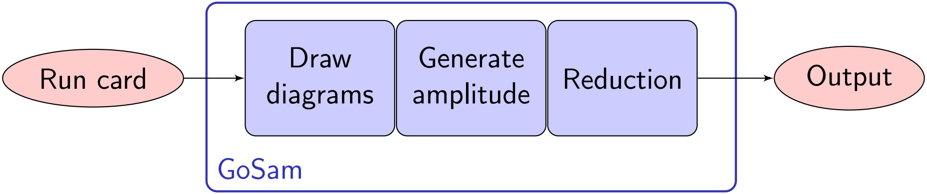

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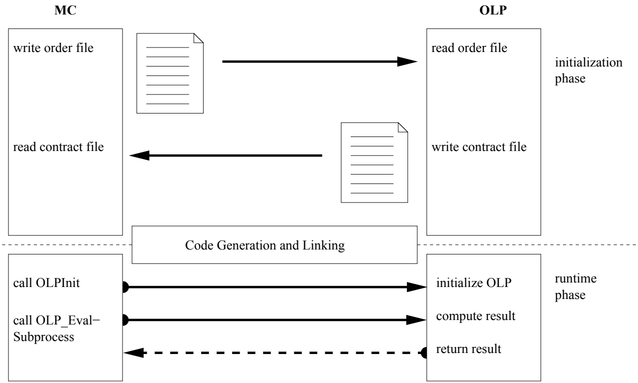
Sherpa

- Monte Carlo event generator
- Provides
  - Tree level matrix elements (Born and real part)
  - Implementation of Catani-Seymour dipole subtraction
  - Phase space integration
  - Parton shower
  - Hadronization
  - Hadron decays
- Event generation is possible at parton, shower and hadron level

Gleisberg, Hoeche, Krauss, Schoenherr, Schumann, Siegert, Winter

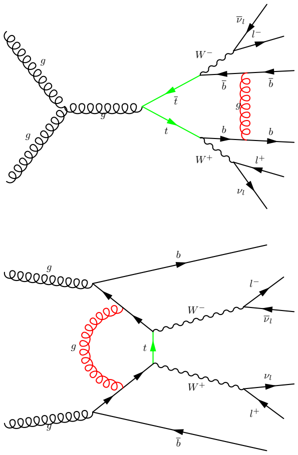
The Binoth Les Houches Accord



- Interface between Monte-Carlo program (MC) and one-loop provider (OLP)
- Divided in initialization and runtime phase
- The interface is implemented in GoSam and Sherpa

Binoth et al. (2010)

The process $pp \to W^+W^-b\bar{b}$



- Top quark pair production and decay including nonresonant contributions
- Both W bosons decay leptonically (dilepton channel)
- The approximation $m_b = 0$ is made
- First calculated at NLO by Denner, Dittmaier, Kallweit, Pozzorini (2011) and Bevilacqua, Czakon, van Hameren, Papadopoulos, Worek (2011)
- Previous top quark calculations were done under the assumption that production and decay factorize (Neglects contributions which are suppressed by powers of $\frac{\Gamma_t}{m_t} \sim 0.02$) Biswas, Melnikov, Schulze (2010)

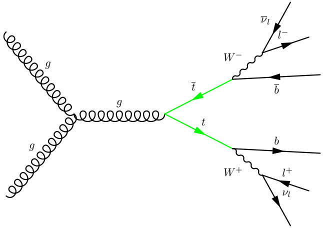
The process $pp \to W^+W^-b\bar{b}$

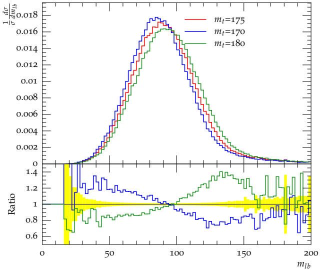
- Four subprocesses:

	Diagrams	Hel.	$t/PS[ms]$
$u\bar{u}$	$14+334$	4	93
$d\bar{d}$	$14+334$	4	94
$b\bar{b}$	$28+668$	4	218
gg	$31+1068$	8	1750

- Complex mass scheme for top quarks: $m_t^2 \to m_t^2 - im_t\Gamma_t$
- Fixed scale: $\mu_R = \mu_F = \frac{m_t}{2}$
- Dynamical scale: $\mu_R = \mu_F = H_T$ (Scalar sum over transverse momenta of final state particles)

Invariant mass of b-jet and lepton m_{lb}





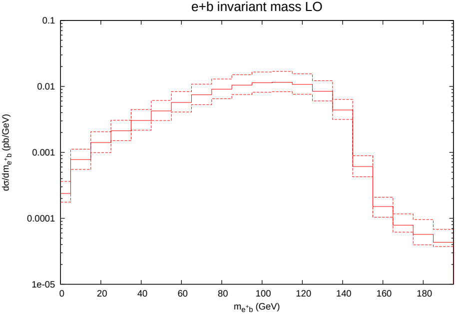
- Definition: $m_{lb} = (p_{\text{b-jet}} + p_l)^2$
- Hadron level calculation at leading order
- Distribution is sensitive to the value of the top quark mass
- Precision measurement of the top quark mass
- Collaboration with the ATLAS group at MPI

Comparison of LO results

Integrated cross section:

	Sherpa	[1207.5018]
σ_{LO} [fb]	922.187 ± 0.33918	922.22

Sherpa



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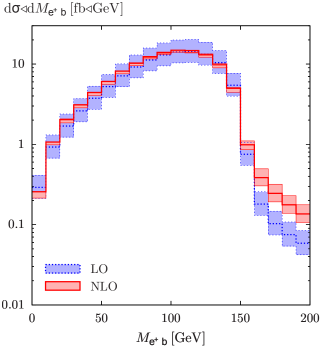

NLO comparison with arxiv:1207.5018

Comparison for one phase space point taken from arxiv:1207.5018 Denner, Dittmaier, Kallweit, Pozzorini (2012)

$$|\mathcal{M}|^2_{tree} = a_0$$

$$|\mathcal{M}|^2_{1-loop} \propto c_0 + \frac{c_{-1}}{\epsilon} + \frac{c_{-2}}{\epsilon^2} + \mathcal{O}(\epsilon)$$

$u\bar{u}$	GoSam	[1207.5018]
$a_0 \cdot 10^{-5}$	1.5688630692027**87**	1.568863069202805
c_0	0.34653097**9416799**	0.346530980271734
c_{-1}	−0.1030794160**242820**	−0.103079416107610
c_{-2}	−0.092962285192**48788**	−0.092962285192701**3**
gg		
$a_0 \cdot 10^{-5}$	4.5540531546279**02**	4.55405315462797**2**
c_0	0.57173966**03625836**	0.571739679133372
c_{-1}	−0.03212591**118591111**	−0.032125892699063
c_{-2}	−0.1510637134379**715**	−0.151063713437886**4**

NLO results

$u\bar{u}$ subprocess:

σ_{NLO} [fb]	gen. events
33.1299 ± 1.86794	1000000

Timings:

- Event generation: 2h 18min
- Integration of virtual part: 9h 33min
- Integration of real part: 12min

Full result:

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