aMC@NLO and top pair production at LC

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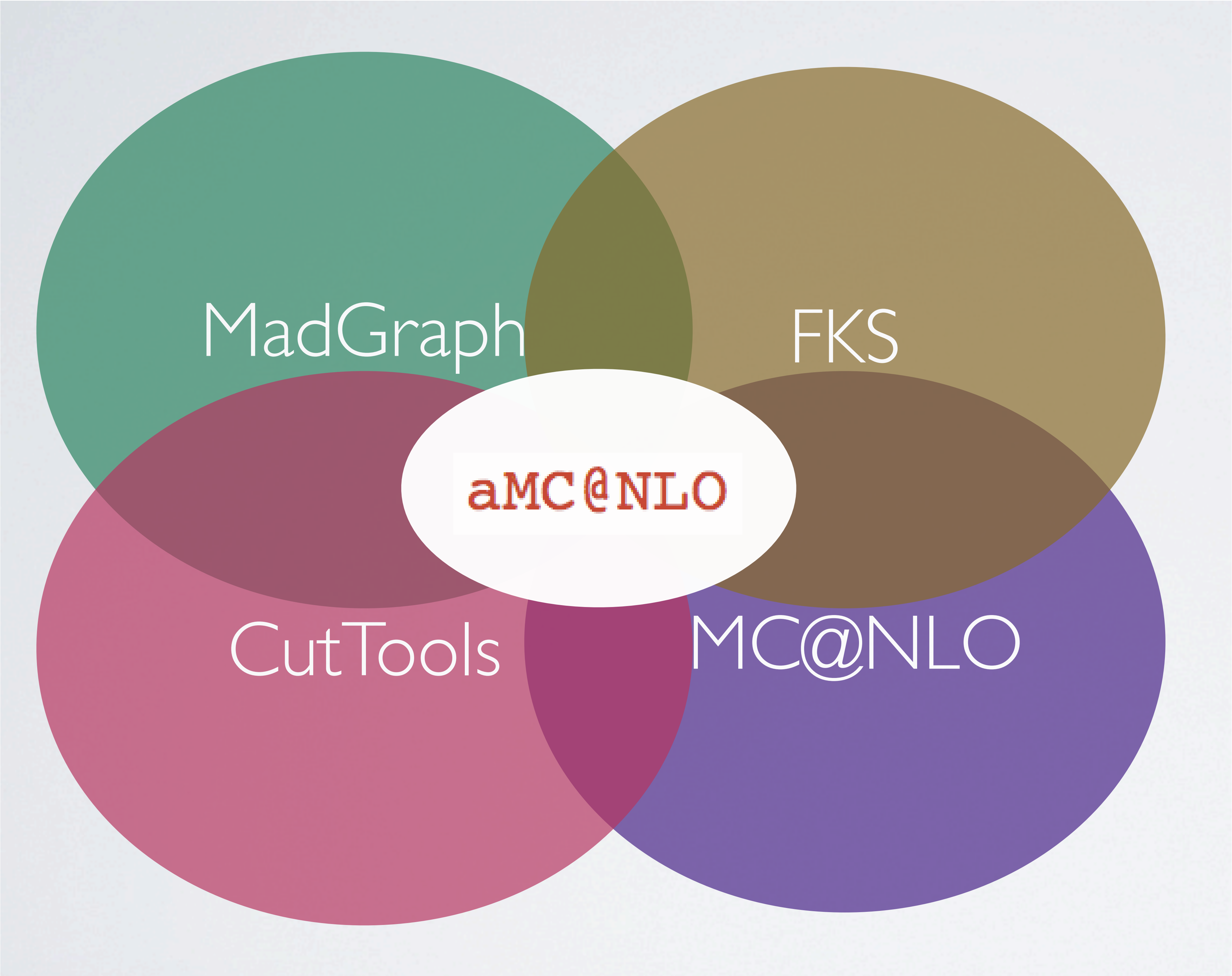
for the MadGraph/aMC@NLO team

Full list of contributors:
http://amcatnlo.web.cern.ch/amcatnlo/people.htm

Plan of the Talk

- aMC@NLO
  - ➡ MadLoop
  - ➡ MadFKS
  - ➡ NLO+PS
- MadSpin
- DEMO
- top pair production at LC
- Conclusion

aMC@NLO: A Joint Venture



aMC@NLO

- Why automation?
  - ➡ Time: Less tools, means more time for physics
  - ➡ Robust: Easier to test, to trust
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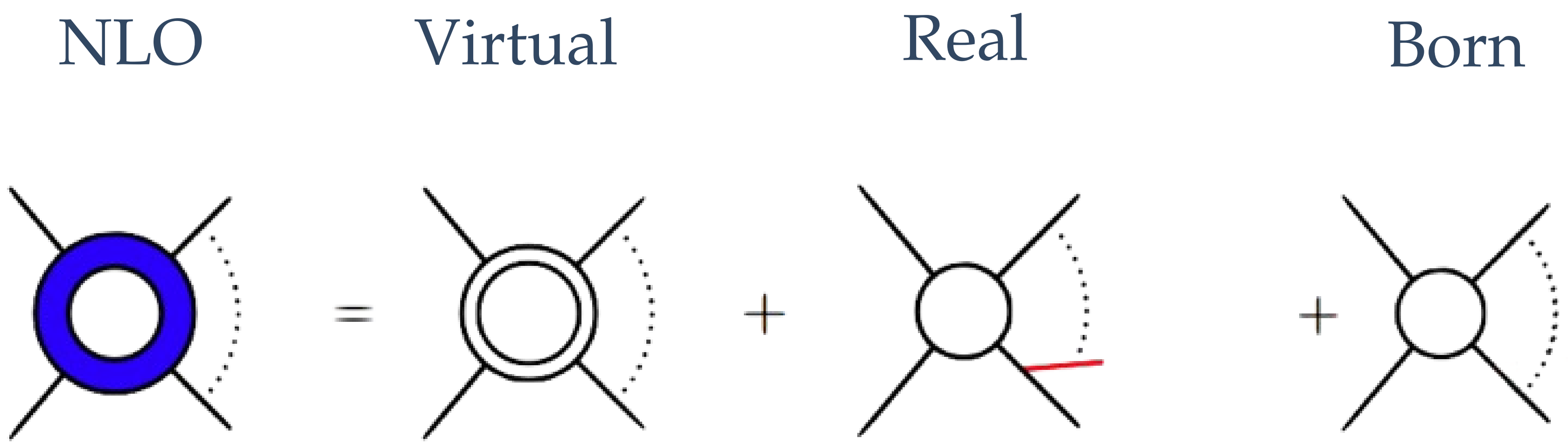
  - ➡ Reduction of the theoretical uncertainty
- Why matched to the PS?
  - ➡ Parton are not an detector observables
  - ➡ Matching cure some fix-order ill behaved observables

NLO Basics



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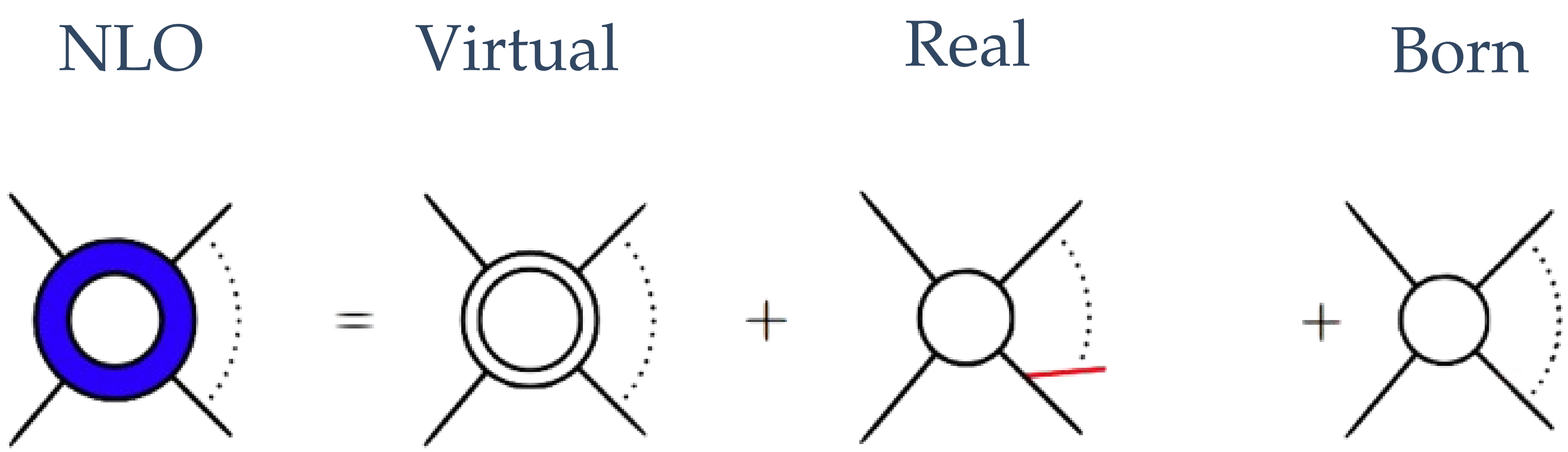

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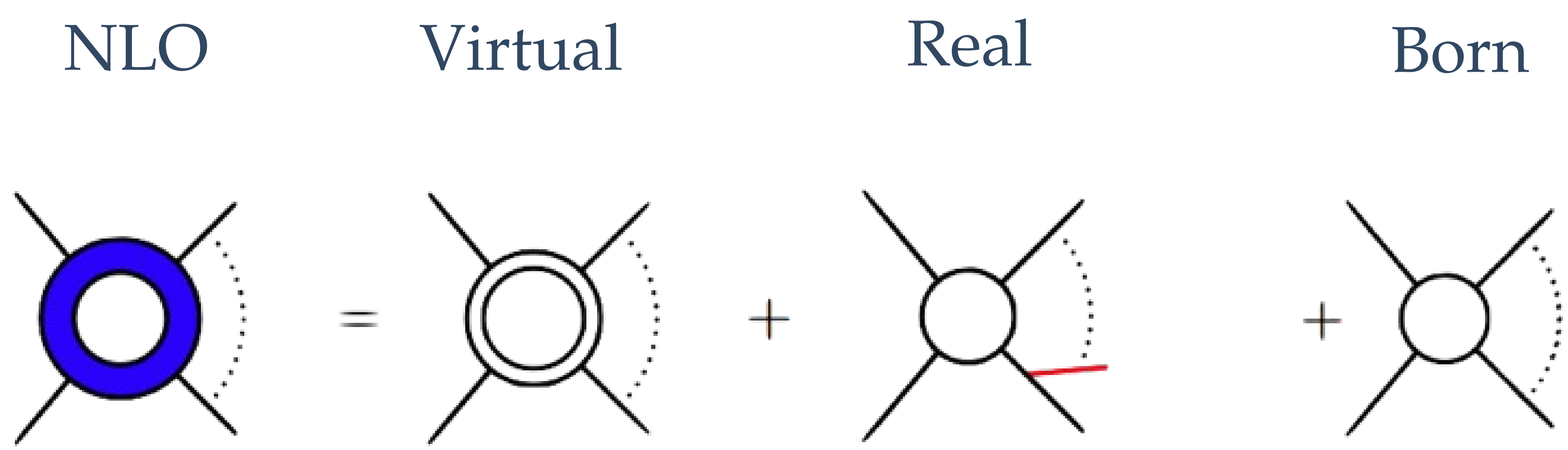

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MadLoop MadFKS MadGraph

MADLOOP

The virtual

OPP Reduction

- decomposition to scalar integrals
  works at the level of the integrals

$$\mathcal{M}^{\text{1-loop}} = \sum_{i_0<i_1<i_2<i_3} d_{i_0 i_1 i_2 i_3} \text{Box}_{i_0 i_1 i_2 i_3} + \sum_{i_0<i_1<i_2} c_{i_0 i_1 i_2} \text{Triangle}_{i_0 i_1 i_2} + \sum_{i_0<i_1} b_{i_0 i_1} \text{Bubble}_{i_0 i_1} + \sum_{i_0} a_{i_0} \text{Tadpole}_{i_0} + R + \mathcal{O}(\epsilon)$$

[Ossola, Papadopoulos, Pittau 2006]

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- If we would know a similar relation at the **integrand** level, we would be able to manipulate the integrands and extract the coefficients without doing the integrals

$$
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$$N(l) = \sum_{i_0<i_1<i_2<i_3}^{m-1} \left[d_{i_0 i_1 i_2 i_3} + \tilde{d}_{i_0 i_1 i_2 i_3}(l) \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}_{i_0 i_1 i_2}(l) \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}_{i_0 i_1}(l) \right] \prod_{i \neq i_0, i_1}^{m-1} D_i + \sum_{i_0}^{m-1} \left[a_{i_0} + \tilde{a}_{i_0}(l) \right] \prod_{i \neq i_0}^{m-1} D_i + \tilde{P}(l) \prod_{i}^{m-1} D_i$$

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Spurious term

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Spurious term

- feed cut tools with numerator value and it returns the coeficients

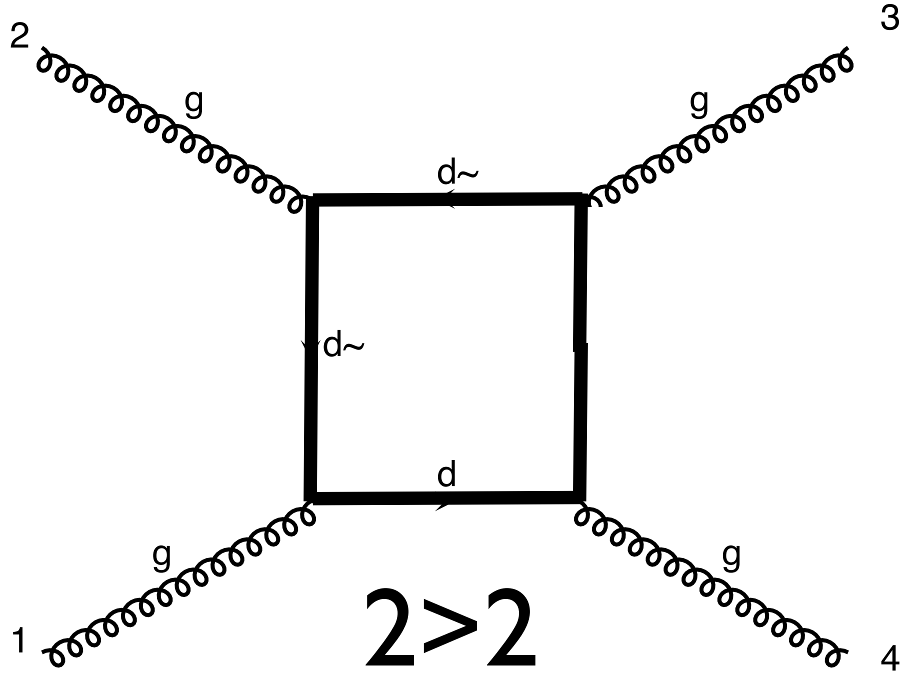
[Ossola, Papadopoulos, Pittau 2006]

OPP in a nutshell

- In OPP reduction we reduce the system at the integrand level.
- We can solve the system numerically: we only need a numerical function of the (numerator of) integrand. We can set-up a system of linear equations by choosing specific values for the loop momentum l, depending on the kinematics of the event
- OPP reduction is implemented in CutTools (publicly available). Given the integrand, CutTools provides all the coefficients in front of the scalar integrals and the R1 term
- The OPP reduction leads to numerical unstabilities whose origins are not well under control. Require quadruple precision.
- Analytic information is needed for the R2 term, but can be compute once and for all for a given model

MADLOOP

- Diagram Generation



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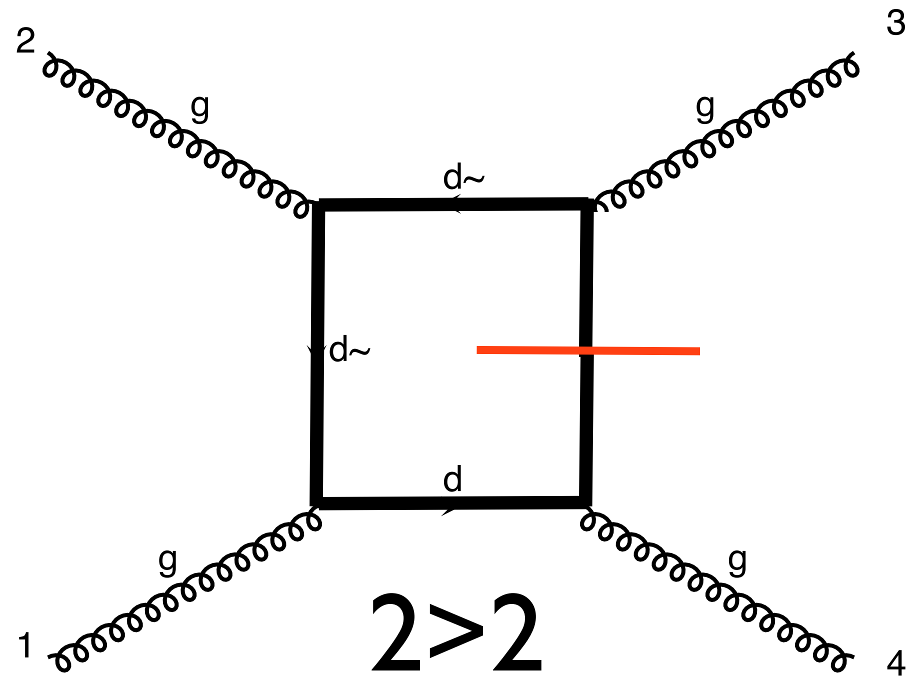

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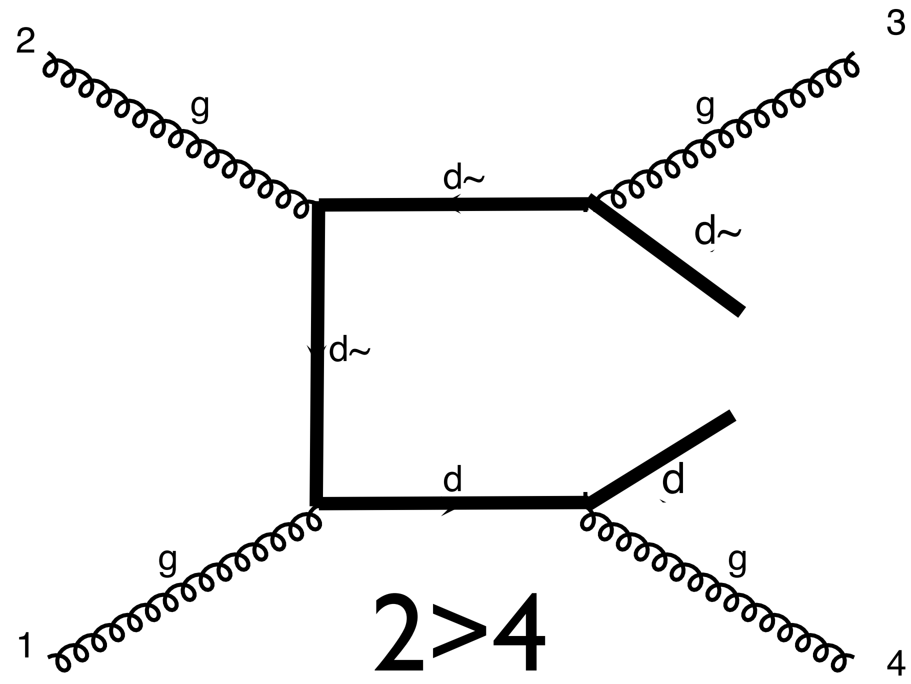
  - ➡ Need to filter result



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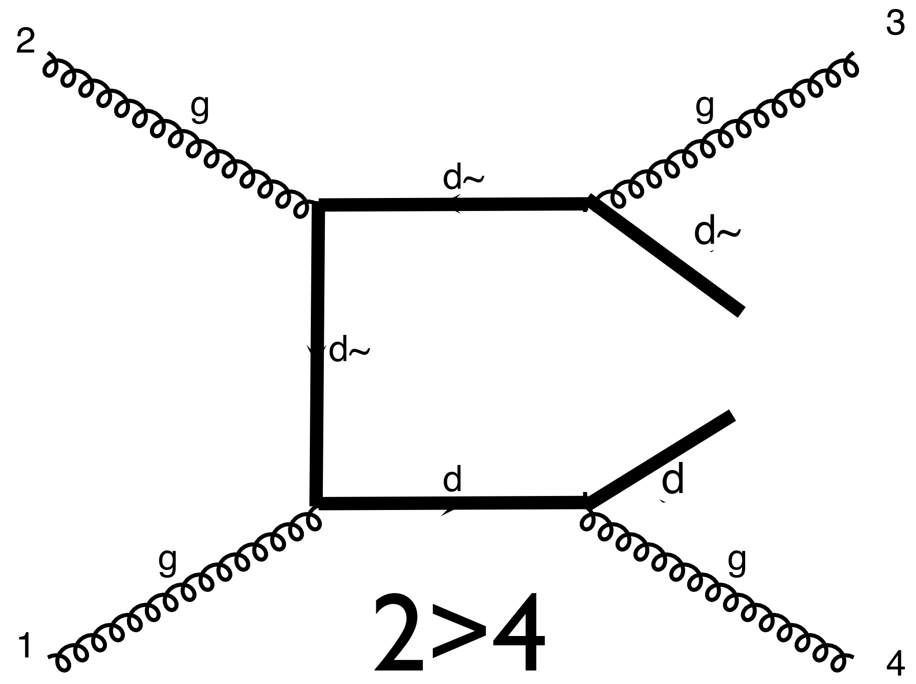
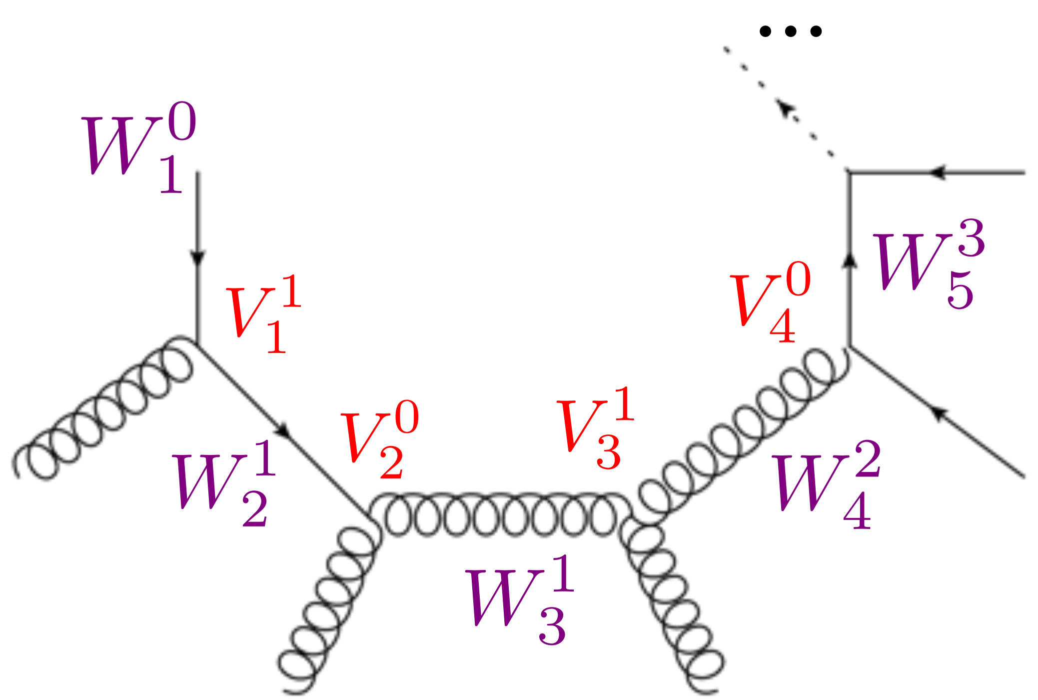


- Evaluation of the Numerator:
  - ➡ OpenLoops technique [S. Pozzorini & al.(2011)]

$$\mathcal{N}(l^\mu) = \sum_{r=0}^{r_{max}} C^{(r)}_{\mu_0\mu_1\cdots\mu_r} l^{\mu_0} l^{\mu_1} \ldots l^{\mu_r}$$



MADFKS

The real

FKS substraction

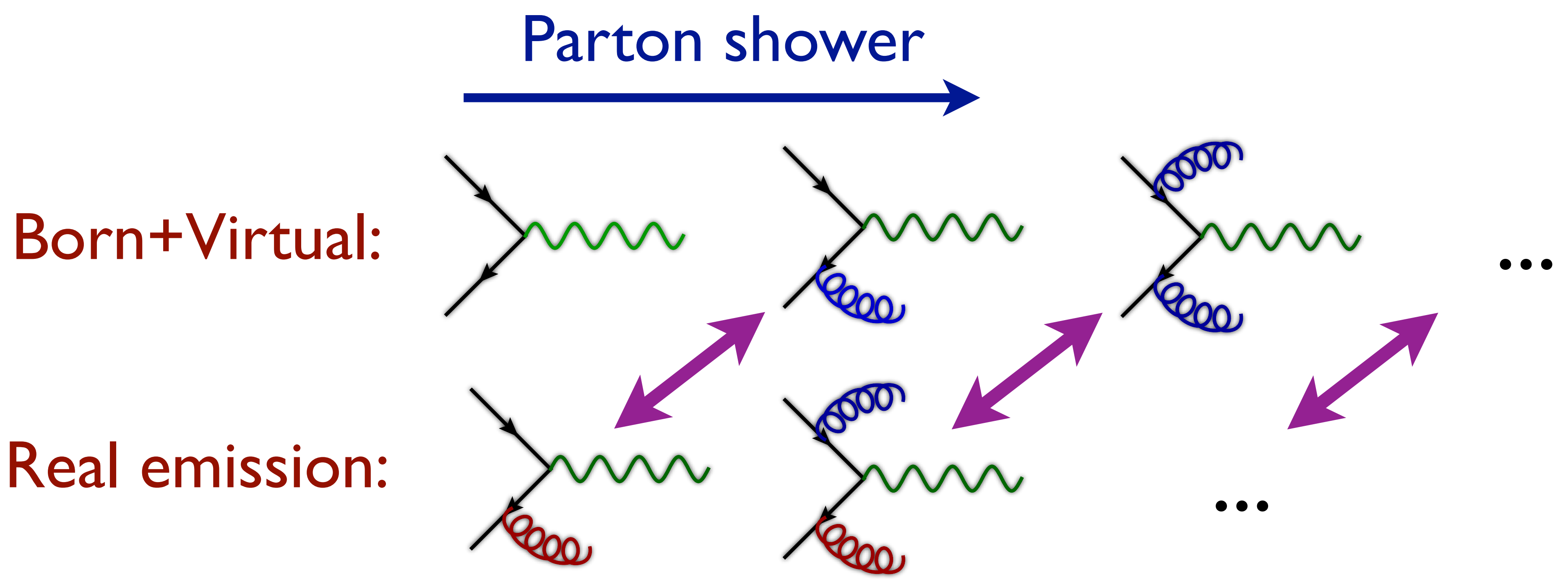
- Find parton pairs *i*, *j* that can give collinear singularities
- Split the phase space into regions with one collinear singularities
- Integrate them independently
  - ➡ with an adhoc PS parameterization
  - ➡ can be run in parallel
- # of contributions ~ n^2

[S. Frixione, Z Kunst, A Signer (1995)]

MC@NLO

Matching to the shower

Sources of double counting



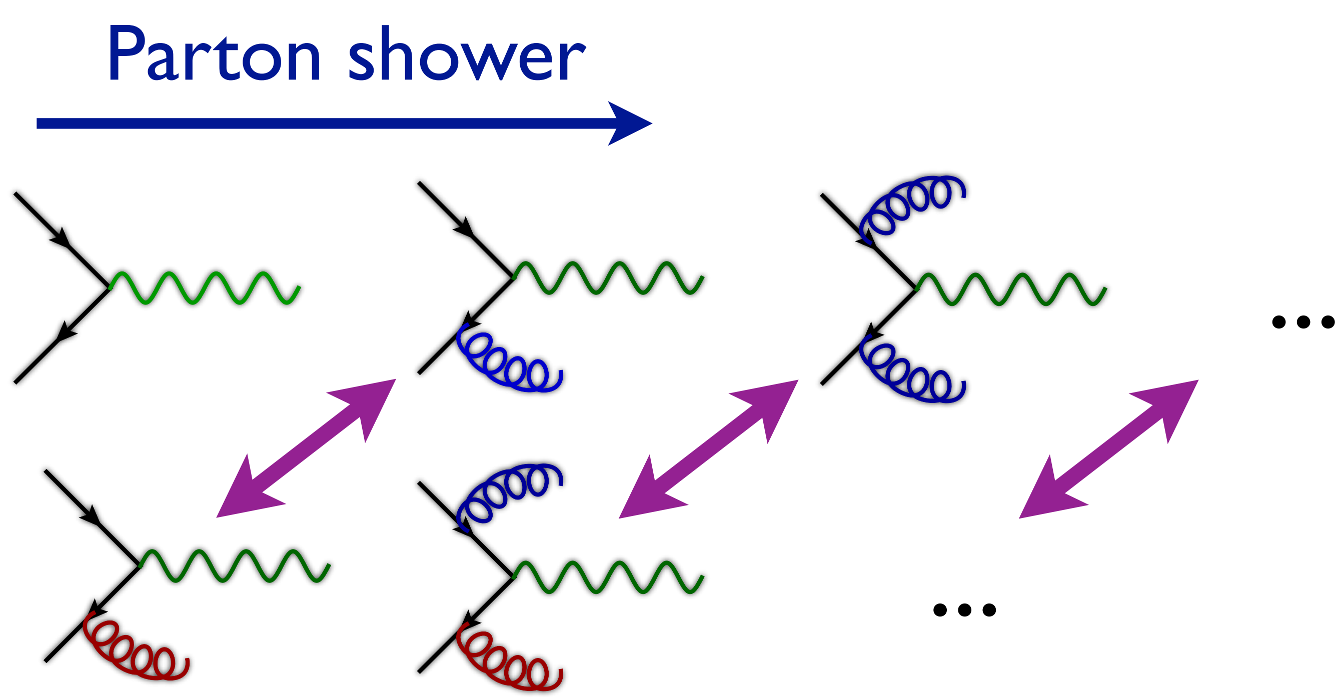
- There is double counting between the real emission matrix elements and the parton shower: the extra radiation can come from the matrix elements or the parton shower

- There is also an overlap between the virtual corrections and the Sudakov suppression in the zero-emission probability

MC@NLO procedure

Born+Virtual:

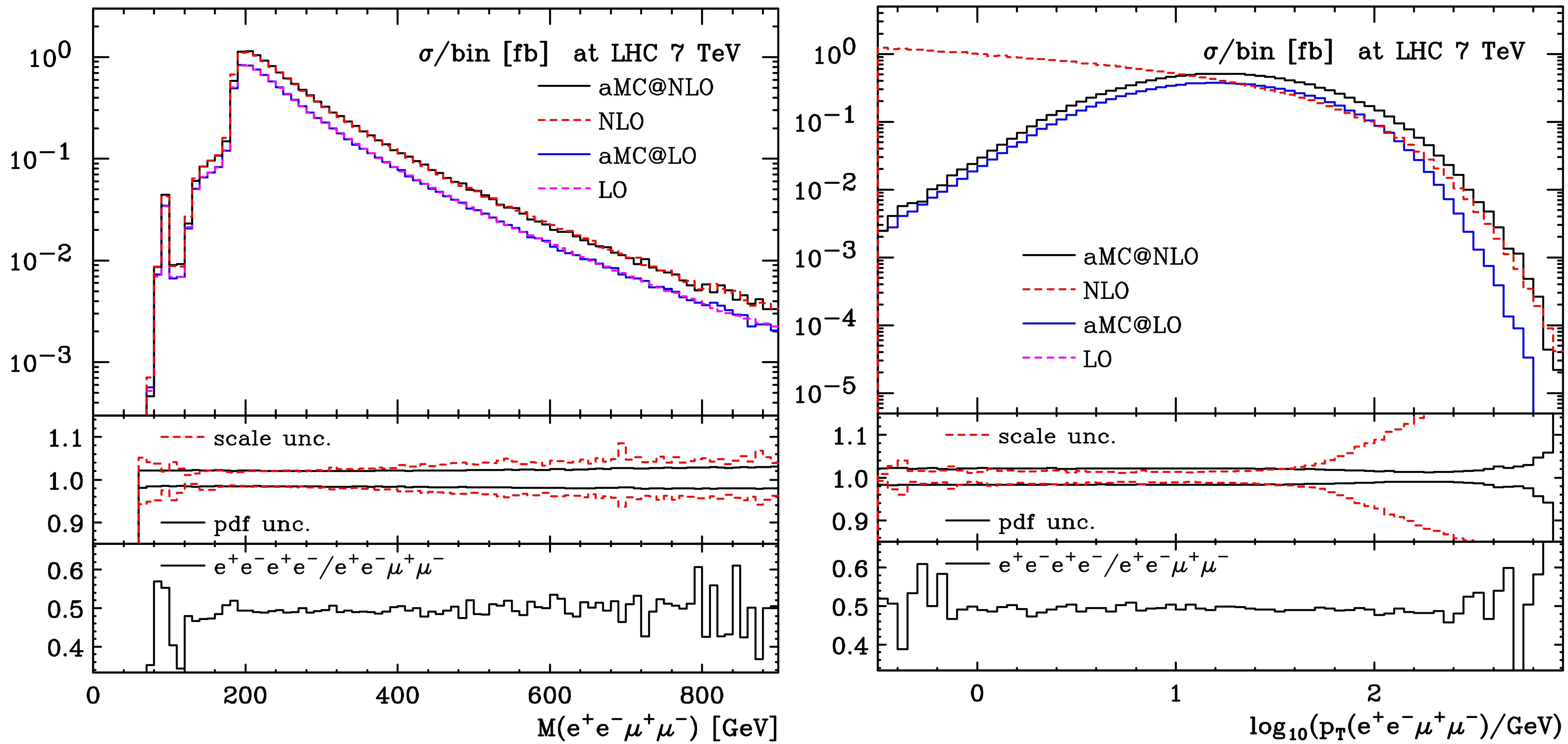
Real emission:



$$\frac{d\sigma_{\mathrm{NLOwPS}}}{dO} = \left[d\Phi_m\left(B + \int_{\mathrm{loop}} V + \int d\Phi_1 MC\right)\right] I_{\mathrm{MC}}^{(m)}(O) + \left[d\Phi_{m+1}(R - MC)\right] I_{\mathrm{MC}}^{(m+1)}(O)$$

- Double counting is explicitly removed by including the “shower subtraction terms”

Four-lepton production



- 4-lepton invariant mass is almost insensitive to parton shower effects. 4-lepton transverse momenta is extremely sensitive

[Frederix, Frixione, Hirschi, maltoni, Pittau & Torrielli (2011)]

results

- Errors are the MC integration uncertainty only
- Cuts on jets, γ*/Z decay products and photons, but no cuts on b quarks (their mass regulates the IR singularities)
- Efficient handling of exceptional phase-space points: their uncertainty always at least two orders of magnitude smaller than the integration uncertainty
- Running time: two weeks on ~150 node cluster leading to rather small integration uncertainties

	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

MadSpin

Decay with Full Spin correlation

[P. Artoisenet, R. Frederix, OM, R. RietKerk (2012)]

MadSpin

- WISH-LIST:
  - ➡ For a sample of events include the decay of unstable final states particles.
  - ➡ Keep full spin correlations and finite width effect
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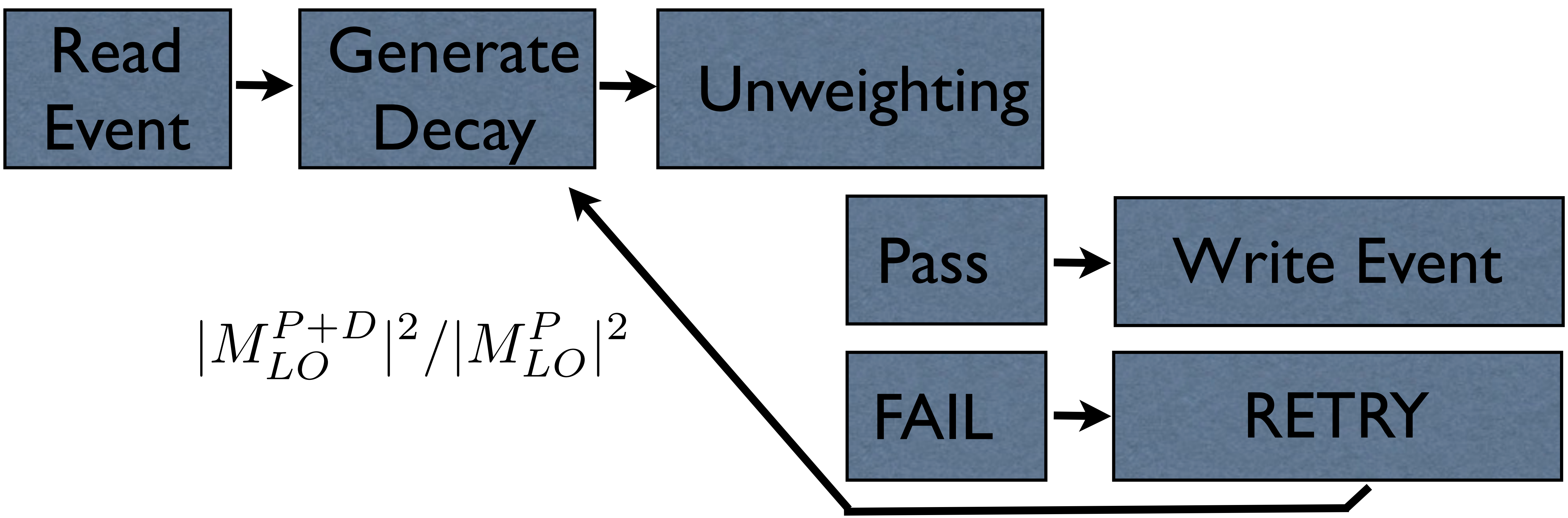
- Solution:

[Frixione, Leanen, Motylinski, Webber (2007)]



$$|M_{LO}^{P+D}|^2/|M_{LO}^{P}|^2$$

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  - ➡ Can be run in StandAlone

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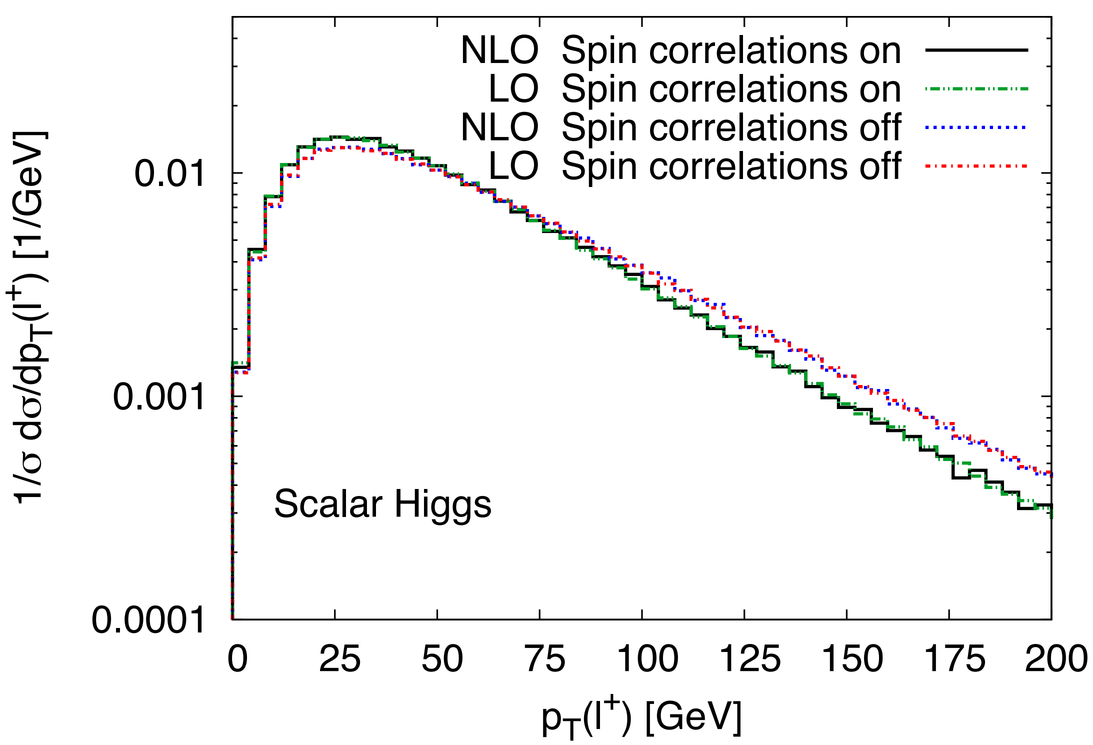
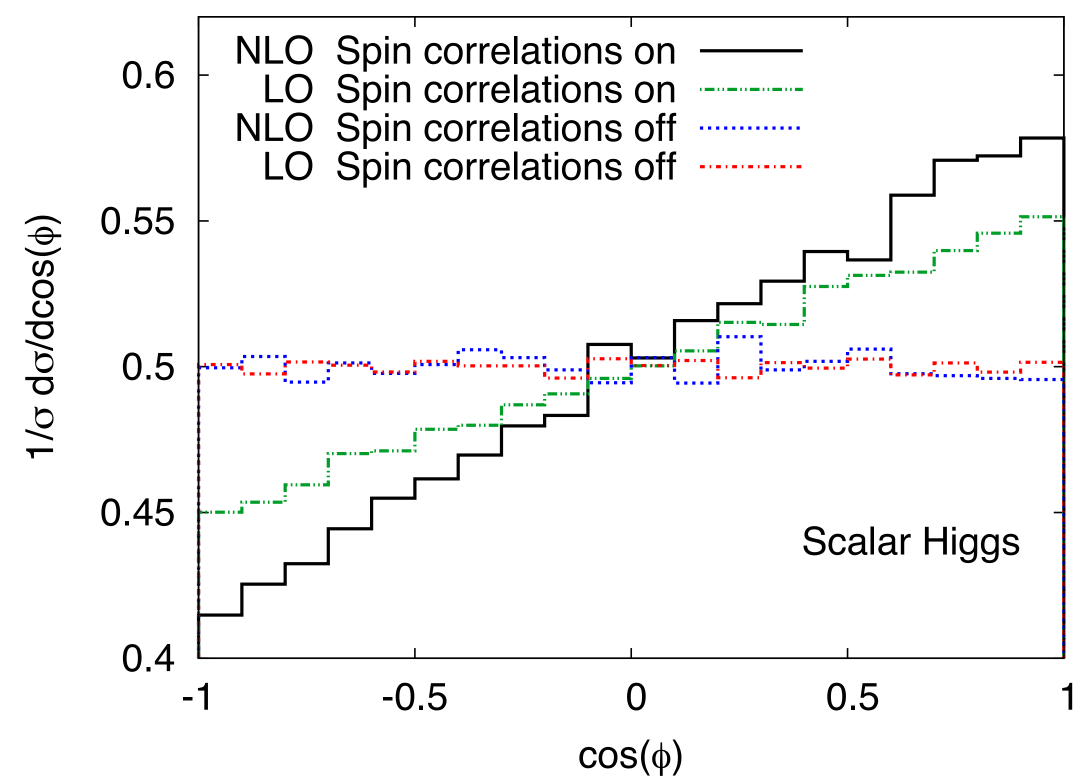
- Example t t~ h:



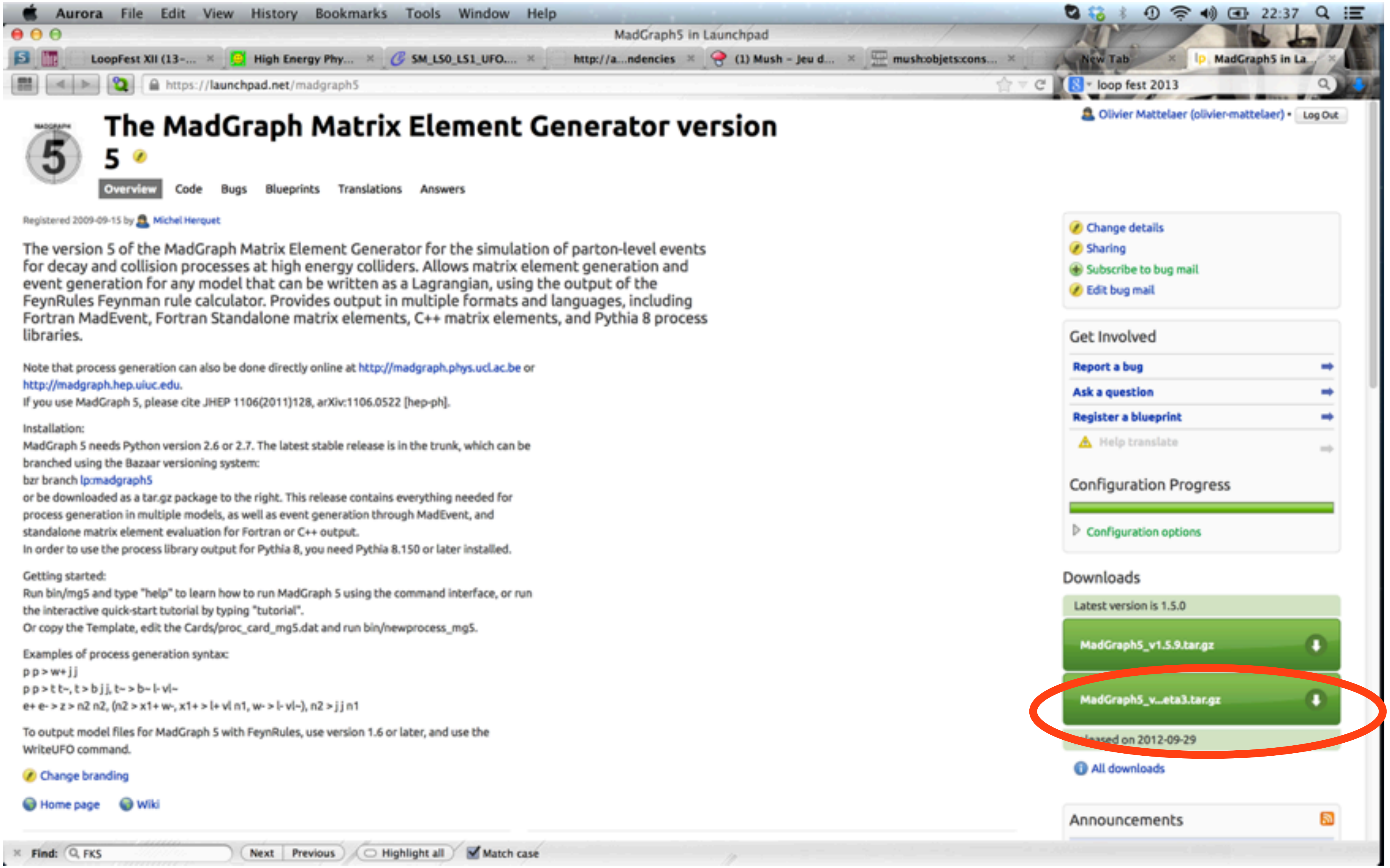


DEMO

Is it really automatic?

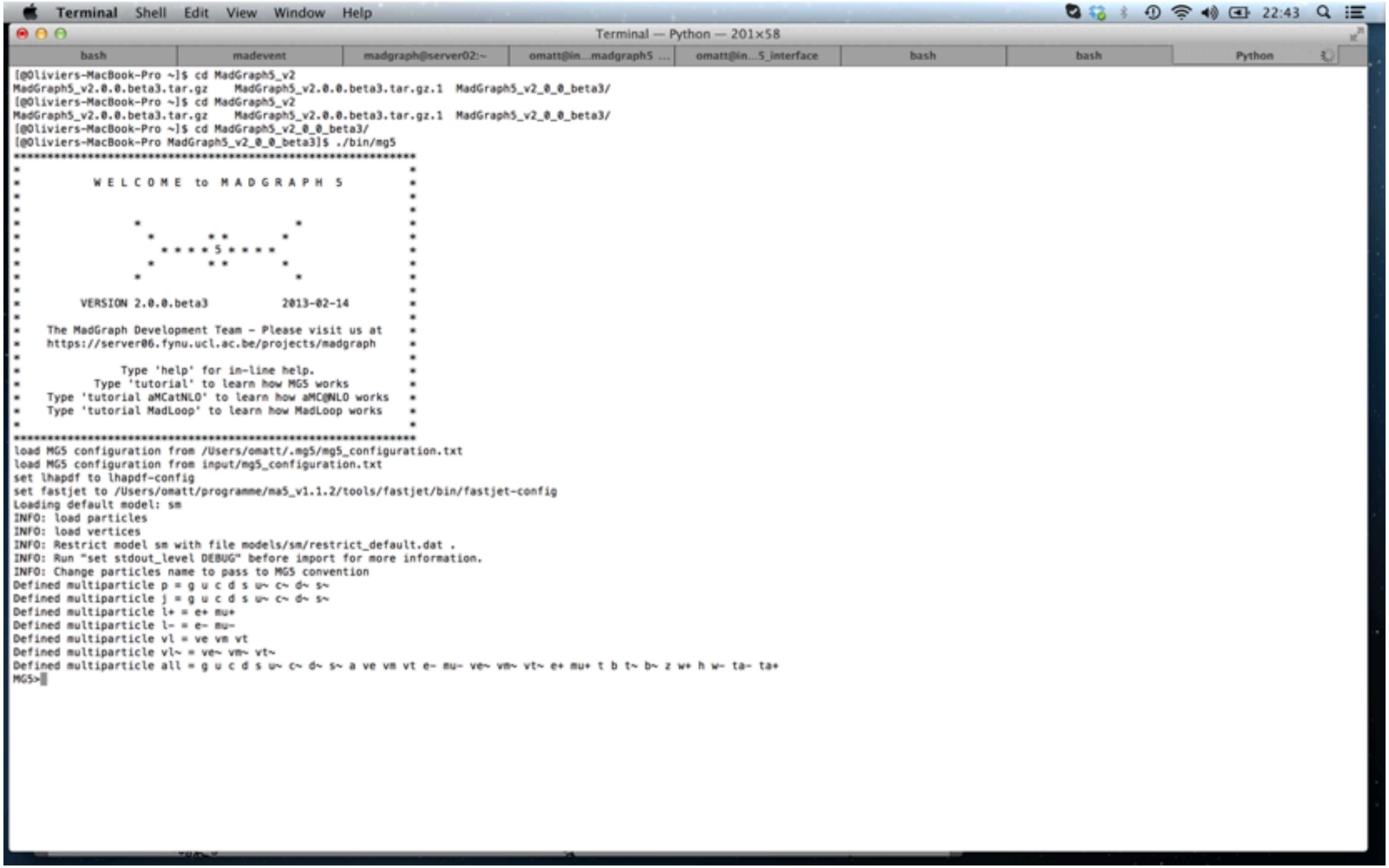
DEMO

- 1) Download the code



DEMO

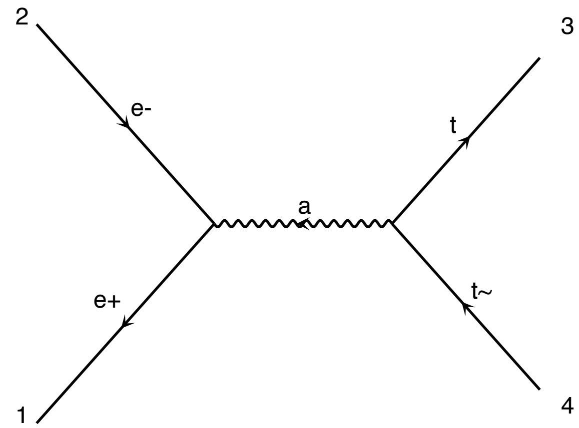
- launch the code [./bin/mg5]
  - ➡ Exactly like MG5 !!!



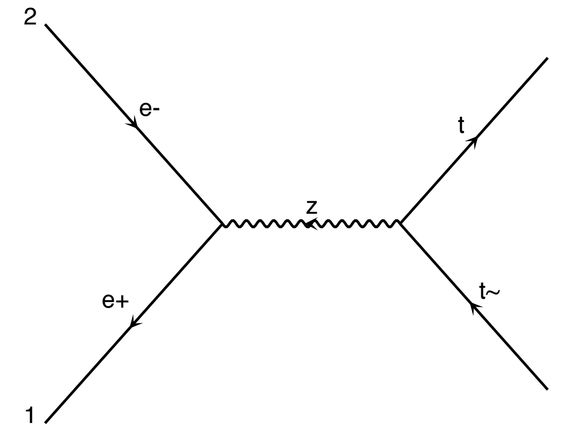
- You can enter ANY process!
  - ➡ add [QCD] for NLO functionalities
    - ✦ generate p p > t t~ [QCD]
    - ✦ generate p p > e+ e- mu+ mu- [QCD]
    - ✦ generate e+ e- > t t~ [QCD]

```
mg5>generate e+ e- > t t~ [QCD]
Switching from interface MG5 to aMC@NLO
The default sm model does not allow to generate loop processes. MG5 now loads 'loop_sm' instead.
 import model loop_sm
INFO: load particles
INFO: load vertices
INFO: Restrict model loop_sm with file models/loop_sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles l- / j / vl / l+ / p / vl~ unchanged
Defined multiparticle all = g gh gh~ d u s c d~ u~ s~ c~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+ b t b~ t~ z w+ h
INFO: Generating FKS-subtracted matrix elements for born process: e+ e- > t t~  [ QCD ]
INFO: Generating virtual matrix elements using MadLoop:
INFO: Generating virtual matrix element with MadLoop for process: e+ e- > t t~ [ QCD ]
INFO: Generated 1 subprocesses with 4 real emission diagrams, 2 born diagrams and 2 virtual diagrams
aMC@NLO>
```

- Born

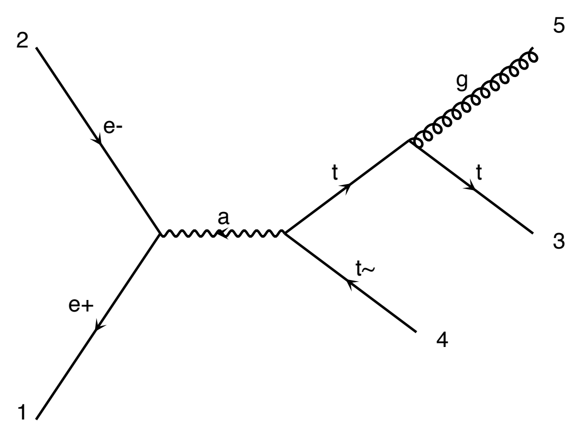


born diagram 1 QCD=0, QED=2

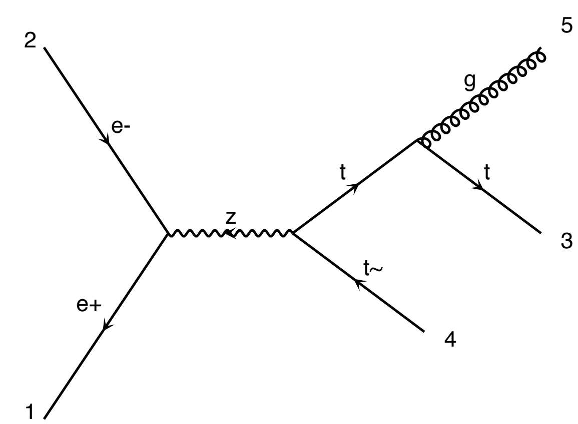


born diagram 2 QCD=0, QED=2

- real



real diagram 1 QCD=1, QED=2



real diagram 2 QCD=1, QED=2

- Virtual

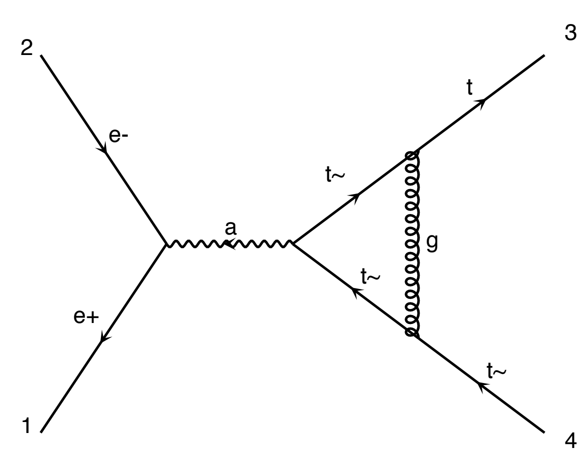


diagram 1 QCD=2, QED=2

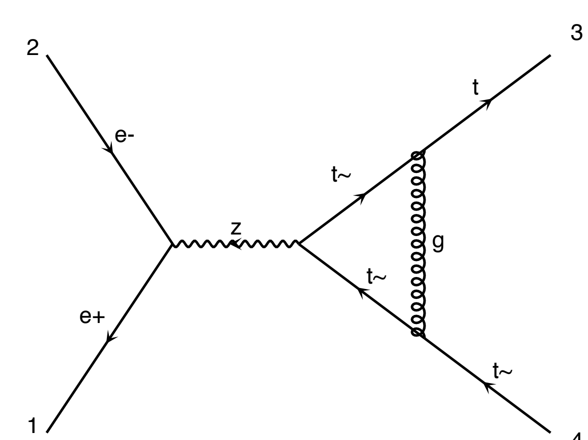


diagram 2 QCD=2, QED=2

- Create your aMC@NLO code
  - ➡ output PATH

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```
INFO: Writing out the aMC@NLO code, using optimized Loops
INFO: initialize a new directory: PROD_TT2
INFO: remove old information in PROD_TT2
INFO: Generating real emission matrix-elements...
INFO: Generating Helas calls for FKS process: e+ e- > t t~  [ QCD ]
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV2 routines
ALOHA: aloha creates FFV5 routines
INFO: Processing color information for process: e+ e- > t t~  [ QCD ]
INFO: Writing files in P0_epem_ttx
INFO: Creating files in directory V0_epem_ttx
INFO: Computing diagram color coefficients
INFO: Drawing loop Feynman diagrams for Process: e+ e- > t t~ [ QCD ]
INFO: Generating born Feynman diagrams for Process: e+ e- > t t~ [ QCD ]
History written to /Users/omatt/Documents/eclipse/2.0.0beta4/PROD_TT2/Cards/proc_card_mg5.dat
Export UFO model to MG4 format
ALOHA: aloha creates FFV2 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV4 routines
ALOHA: aloha creates FFV5 routines
ALOHA: aloha creates FFV2_5 routines
ALOHA: aloha creates FFV2_4 routines
INFO: Use Fortran compiler gfortran
INFO: Generate jpeg diagrams
INFO: Generate web pages
The option group_subprocesses is modified [Auto] but will not be written in the configuration files.
If you want to make this value the default for future session, you can run 'save options --all'
The option complex_mass_scheme is modified [False] but will not be written in the configuration files.
If you want to make this value the default for future session, you can run 'save options --all'
save configuration file to /Users/omatt/Documents/eclipse/2.0.0beta4/PROD_TT2/Cards/amcatnlo_configurat
Type "launch" to generate events from this process, or see
/Users/omatt/Documents/eclipse/2.0.0beta4/PROD_TT2/README
Run "open index.html" to see more information about this process.
```

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

```
INFO: ***********************************************************
*                                                         *
*           W E L C O M E  to  M A D G R A P H  5         *
*                       a M C @ N L O                     *
*                                                         *
*                 *                       *               *
*                   *        * *        *                 *
*                     * * * * 5 * * * *                   *
*                   *        * *        *                 *
*                 *                       *               *
*                                                         *
*         VERSION 2.0.0.beta4           2013-06-22        *
*                                                         *
*    The MadGraph Development Team - Please visit us at   *
*                 http://amcatnlo.cern.ch                 *
*                                                         *
*               Type 'help' for in-line help.             *
*                                                         *
***********************************************************
INFO: load configuration from /Users/omatt/.mg5/mg5_configuration.txt
INFO: load configuration from /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_loop_sm_
INFO: load configuration from /Users/omatt/Documents/eclipse/2.0.0beta4/input/mg5_config
INFO: load configuration from /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_loop_sm_
set group_subprocesses Auto
set ignore_six_quark_processes False
set loop_optimized_output True
set gauge unitary
set complex_mass_scheme False
launch auto
The following switches determine which operations are executed:
 1 Perturbative order of the calculation:                              order=NLO
 2 Fixed order (no event generation and no MC@[N]LO matching):   fixed_order=OFF
 3 Shower the generated events:                                       shower=ON
 4 Decay particles with the MadSpin module:                         madspin=OFF
  Either type the switch number (1 to 4) to change its default setting,
  or set any switch explicitly (e.g. type 'order=LO' at the prompt)
  Type '0', 'auto', 'done' or just press enter when you are done.
 [0, 1, 2, 3, 4, auto, done, order=LO, order=NLO, ... ][60s to answer]
>
```

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

First Question:

```
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 2 Fixed order (no event generation and no MC@[N]LO matching):   fixed_order=OFF
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 4 Decay particles with the MadSpin module:                        madspin=OFF
  Either type the switch number (1 to 4) to change its default setting,
  or set any switch explicitly (e.g. type 'order=LO' at the prompt)
  Type '0', 'auto', 'done' or just press enter when you are done.
 [0, 1, 2, 3, 4, auto, done, order=LO, order=NLO, ... ][60s to answer]
>[timer stopped]
```

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

Second Question:

```
INFO: will run in mode: aMC@NLO
Do you want to edit a card (press enter to bypass editing)?
  1 / param     : param_card.dat
  2 / run       : run_card.dat
  3 / madspin   : madspin_card.dat
  4 / shower    : shower_card.dat
 you can also
   - enter the path to a valid card or banner.
   - use the 'set' command to modify a parameter directly.
     The set option works only for param_card and run_card.
     Type 'help set' for more information on this command.
 [0, done, 1, param, 2, run, 3, madspin, 4, enter path, ... ][60s to answer]
>
```

- each beam at 250 GeV

- The code runs:

```
INFO: For gauge cancellation, the width of 't' has been set to zero.
INFO: Compiling source...
INFO:           ...done, continuing with P* directories
INFO: Compiling directories...
INFO: Compiling on 8 cores
INFO:  Compiling P0_epem_ttx...
INFO:     P0_epem_ttx done.
INFO: Checking test output:
INFO: P0_epem_ttx
INFO:  Result for test_ME:
INFO:    Passed.
INFO:  Result for test_MC:
INFO:    Passed.
INFO:  Result for check_poles:
INFO:    Poles successfully cancel for 20 points over 20 (tolerance=1.0e-05)
INFO: Starting run
INFO: Using 8 cores
INFO: Cleaning previous results
INFO: Doing NLO matched to parton shower
INFO: Setting up grid
INFO:  Idle: 0,  Running: 2,  Completed: 2 [ current time: 17h19 ]
INFO:  Idle: 0,  Running: 1,  Completed: 3 [  1.2s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 4 [  1.3s  ]
INFO: Determining the number of unweighted events per channel

      Intermediate results:
      Random seed: 36
      Total cross-section:      6.232e-01 +- 4.2e-03 pb
      Total abs(cross-section): 7.010e-01 +- 2.5e-03 pb
```

Compilation

Check Poles cancelation

Integration

```
INFO: Computing upper envelope
INFO:  Idle: 0,  Running: 2,  Completed: 2 [ current time: 17h19 ]
INFO:  Idle: 0,  Running: 1,  Completed: 3 [  1.3s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 4 [  1.3s  ]
INFO: Updating the number of unweighted events per channel

      Intermediate results:
      Random seed: 36
      Total cross-section:      6.183e-01 +- 3.7e-03 pb
      Total abs(cross-section): 6.986e-01 +- 1.9e-03 pb
```

Integration

```
INFO: Generating events
INFO:  Idle: 0,  Running: 2,  Completed: 2 [ current time: 17h19 ]
INFO:  Idle: 0,  Running: 1,  Completed: 3 [  0.6s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 4 [  1.3s  ]
INFO:    Doing reweight
INFO:  Idle: 0,  Running: 1,  Completed: 3 [ current time: 17h19 ]
INFO:  Idle: 0,  Running: 0,  Completed: 4 [  0.74s  ]
INFO: Collecting events
INFO:
      Summary:
      Process e+ e- > t t~ [QCD]
      Run at l-l collider (250 + 250 GeV)
      Total cross-section: 6.183e-01 +- 3.7e-03 pb
      Ren. and fac. scale uncertainty: +1.0% -0.8%
      Number of events generated: 10000
      Parton shower to be used: HERWIG6
```

Events Generation

```
decay_events -from_cards
INFO: Running MadSpin
INFO: This functionality allows for the decay of resonances
INFO: in a .lhe file, keeping track of the spin correlation effets.
INFO: BE AWARE OF THE CURRENT LIMITATIONS:
INFO:   (1) Only a succession of 2 body decay are currently allowed
************************************************************
*                                                          *
*          W E L C O M E  to  M A D S P I N                *
*                                                          *
************************************************************
```

Top Decay

```
INFO:    Estimating the maximum weight
INFO:    *****************************
INFO:      Probing the first 75 events
INFO:      with 400 phase space points
INFO:
INFO: Event 1/75 :  0.18s
INFO: Event 6/75 :  1s
INFO: Event 11/75 :  1.9s
INFO: Event 16/75 :  2.8s
INFO: Event 21/75 :  3.8s
INFO: Event 26/75 :  4.9s
INFO: Event 31/75 :  5.8s
INFO: Event 36/75 :  6.7s
INFO: Event 41/75 :  8s
INFO: Event 46/75 :  8.9s
INFO: Event 51/75 :  9.7s
INFO: Event 56/75 :  10.8s
INFO: Event 61/75 :  11.7s
INFO: Event 66/75 :  12.6s
INFO: Event 71/75 :  13.6s
INFO:
INFO: Decaying the events...
INFO: Event nb 1000  2.1s
INFO: Event nb 2000  3.8s
INFO: Event nb 3000  5.6s
INFO: Event nb 4000  7.3s
INFO: Event nb 5000  9.1s
INFO: Event nb 6000  10.8s
INFO: Event nb 7000  12.5s
INFO: Event nb 8000  14.4s
INFO: Event nb 9000  16.1s
INFO: Event nb 10000  17.9s
INFO: Total number of events written: 10000/10000
INFO: Average number of trial points per production event: 10.9322
INFO: Branching ratio to allowed decays: 1
INFO: Number of events with weights larger than max_weight: 0
INFO: Number of subprocesses 8
INFO: Number of failures when restoring the Monte Carlo masses: 1
INFO: Decayed events have been written in /Users/omatt/Documents/eclipse/2.0.
INFO: The decayed event file has been moved to the following location:
INFO: /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_loop_sm_16/Events/rur
INFO: MadSpin Done
INFO:    Prepairing MCatNLO run
INFO:    Compiling MCatNLO for HERWIG6...
INFO:                      ... done
INFO: Running MCatNLO in /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_lc
INFO: The file /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_loop_sm_16/E
It contains showered and hadronized events in the StdHEP format obtained show
cayed_1/events.lhe.gz with HERWIG6
quit
```

estimation of the maximum weight

adding decay event by event

Shower

DEMO

Is it really automatic?

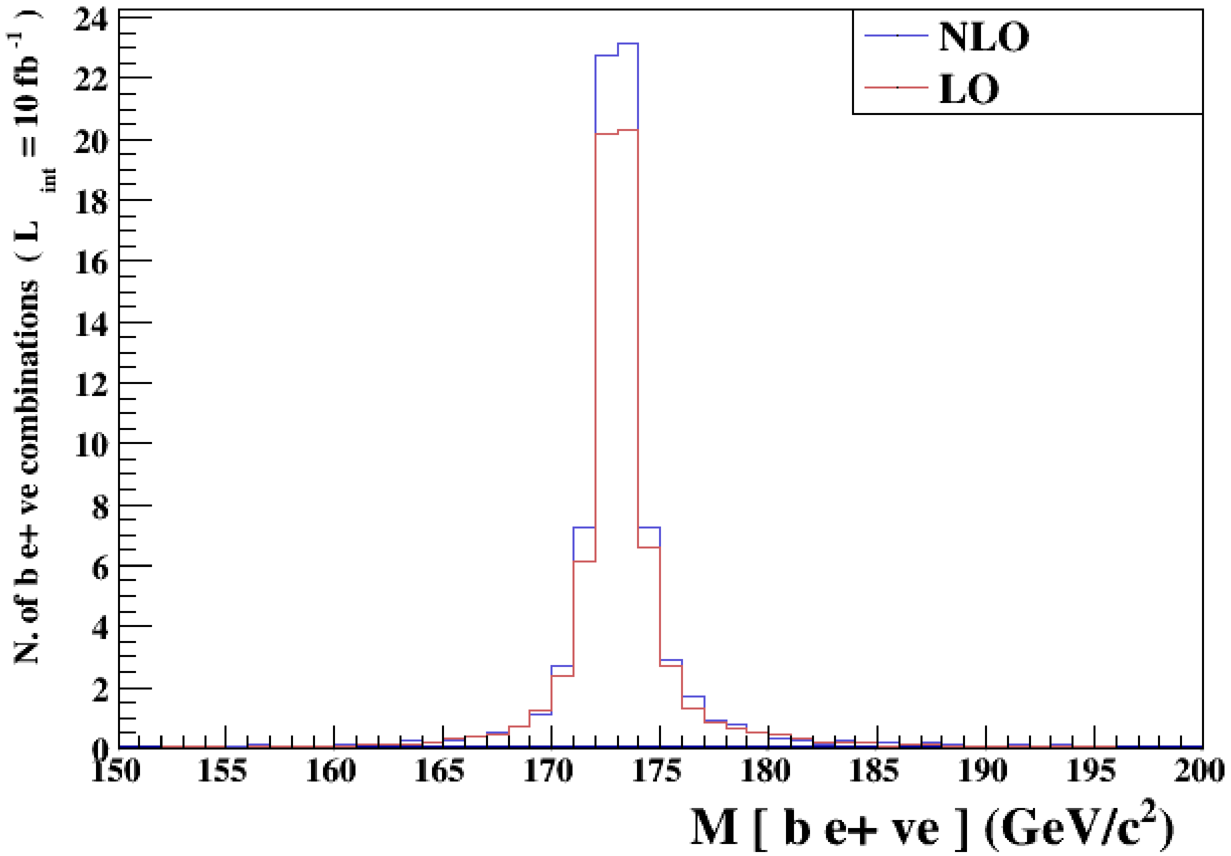
DEMO

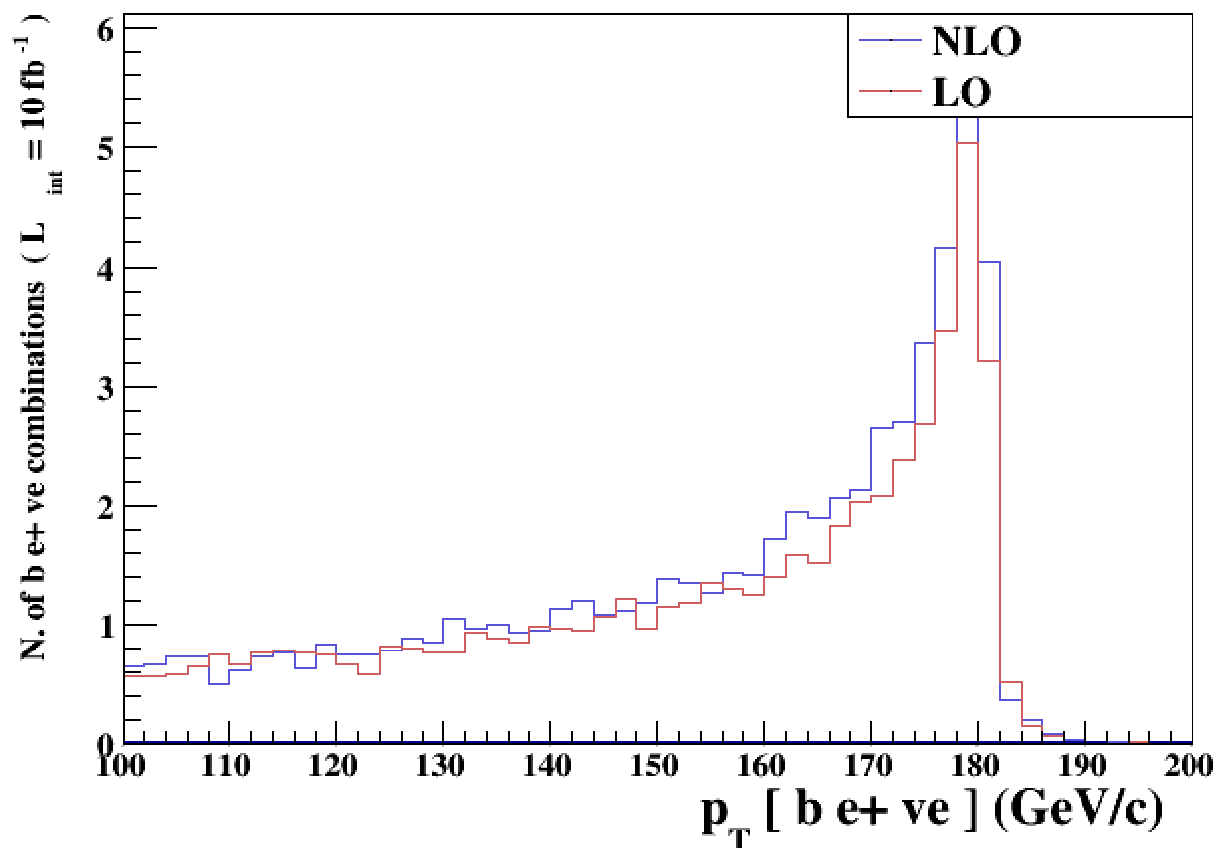
Is it really automatic?

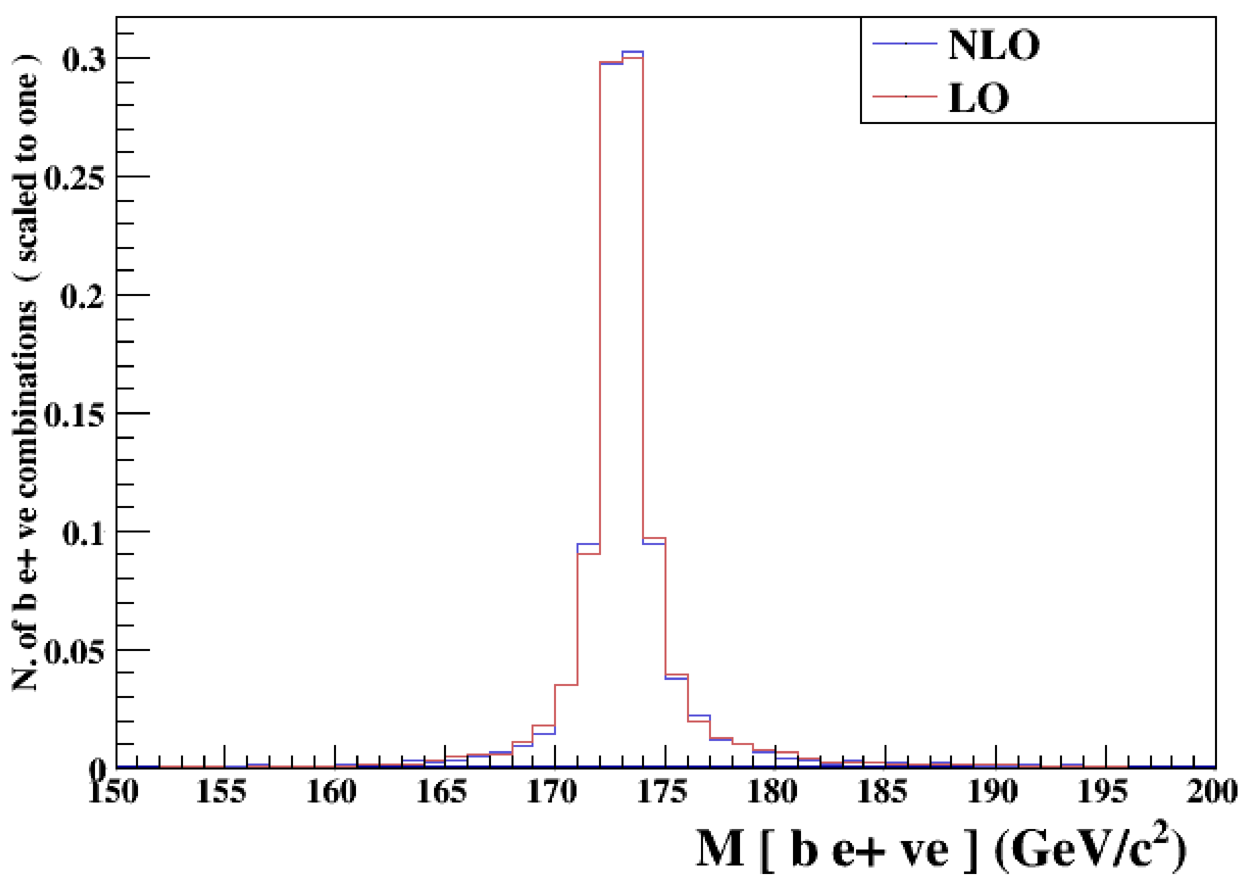
As much as LO!

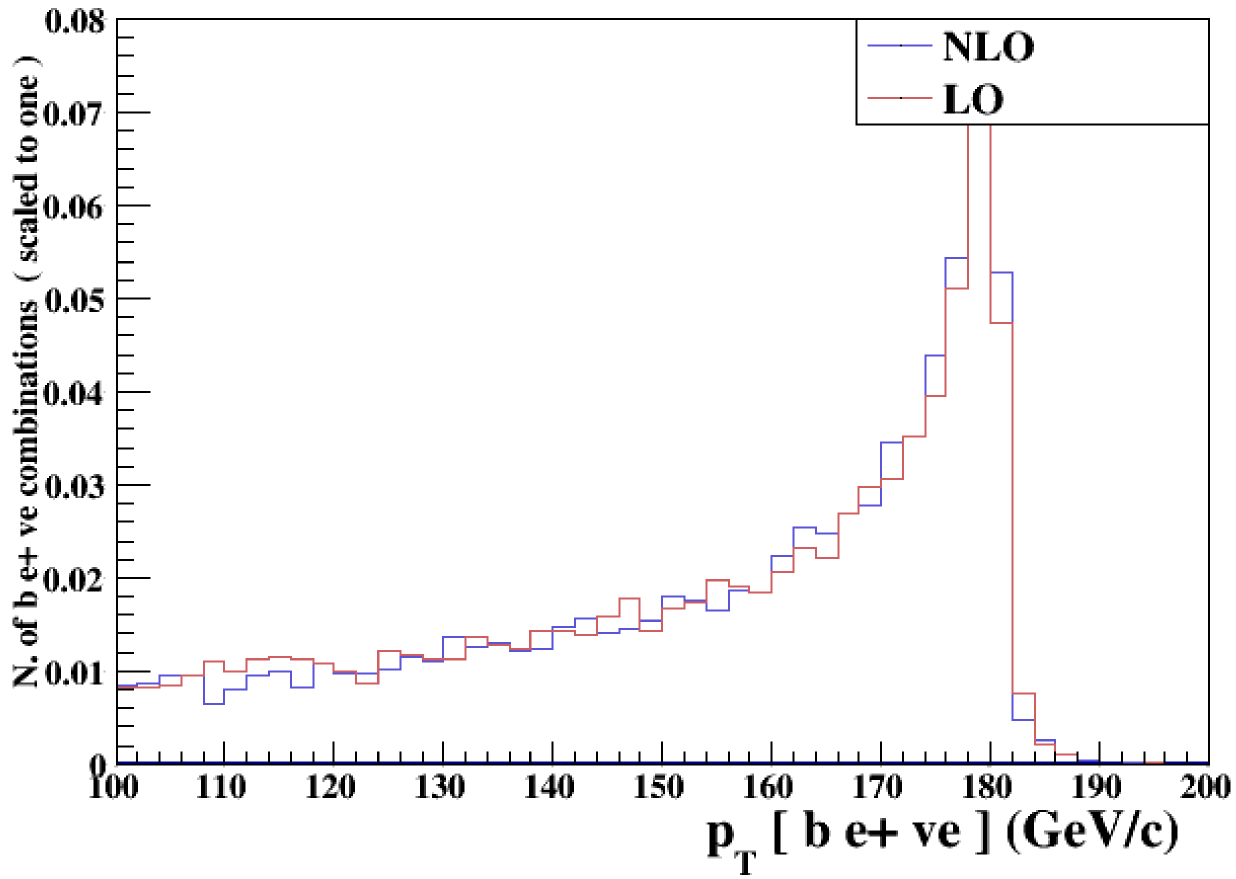
Top-quark pair production at ILC

Preliminary


NLO
LO
N. of b e+ ve combinations (L int = 10 fb -1)
M [b e+ ve] (GeV/c2)


NLO
LO
N. of b e+ ve combinations (L int = 10 fb -1)
pT [b e+ ve] (GeV/c)


NLO
LO
N. of b e+ ve combinations (scaled to one)
M [b e+ ve] (GeV/c2)


NLO
LO
N. of b e+ ve combinations (scaled to one)
pT [b e+ ve] (GeV/c)

Offshell effect at NLO

- Diagrams with unstable particles present in general an imaginary part in the Dyson-ressumed propagator:

$$P(p) = [p^2 - m_0^2 + Pi(p^2)]^{-1}$$

- Mixing of different perturbative orders breaks gauge invariance. Fine cancellations spoiled, leading to enhanced violation of unitarity
- No pole cancelation at NLO for fix-width scheme
- Solution: Complex Mass-Scheme: $M \to \sqrt{M^2 - iM\Gamma}$,

$$c_W^2 = \frac{M_w^2 + iM_W\Gamma_W}{M_Z^2 + iM_Z\Gamma_Z}$$

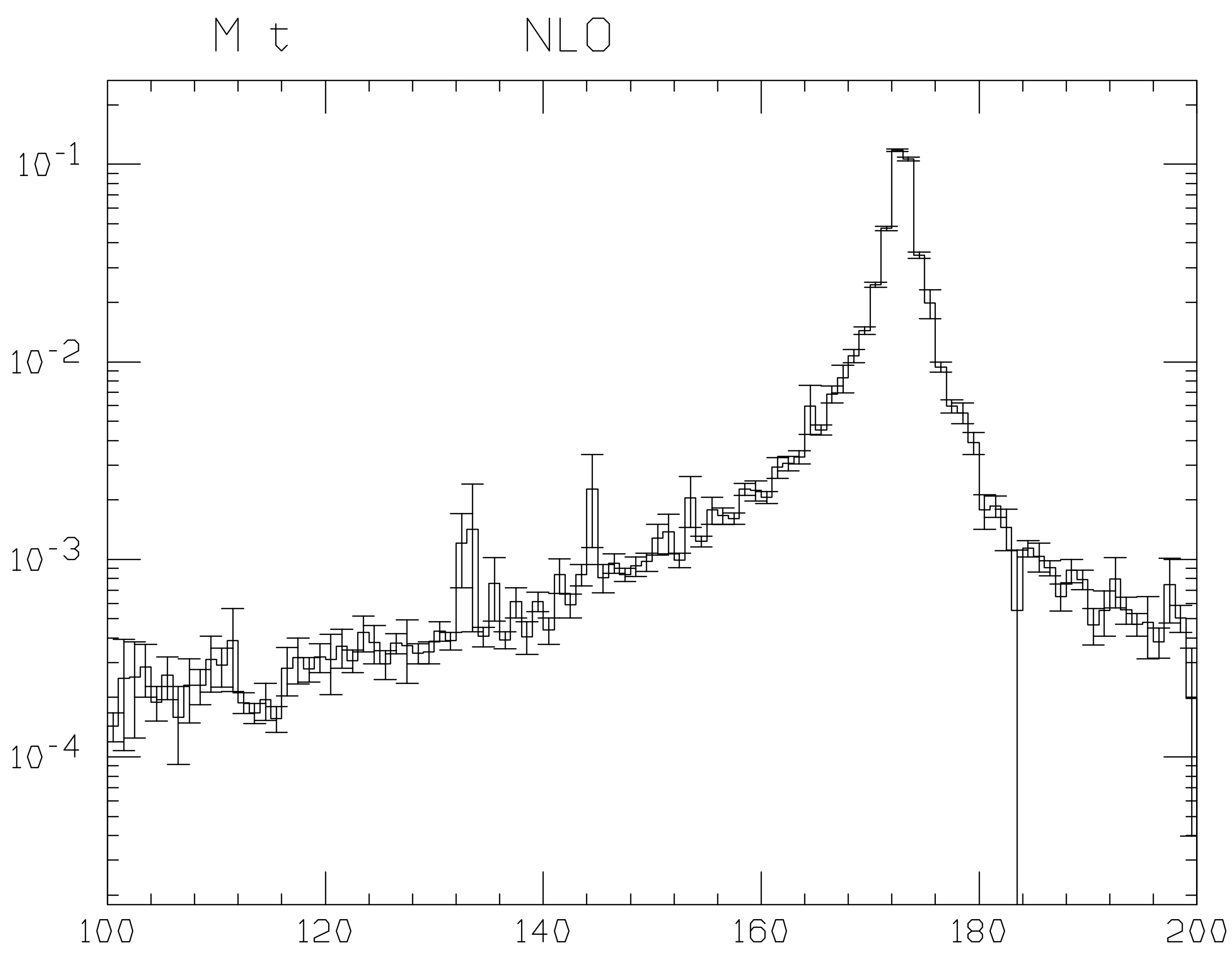
Gauge dependence at LO

$\lvert A\rvert^2$ - $\lvert$Feynman-unitary$\rvert$/unitary	complex mass	fixed width
$e^+e^- \to u\bar{u}d\bar{d}$	1.5334067678e-15	1.2312200197e-09
$u\bar{u} \to u\bar{u}d\bar{d}$	2.0862057616e-16	2.7696013365e-10
$u\bar{u} \to b\bar{b}e^+\nu_e\mu^-\nu_\mu$ (real Yuk)	1.7934842084e-06	2.2832833007e-05
"(complex Yuk)	8.5986902303e-16	2.2832833007e-05

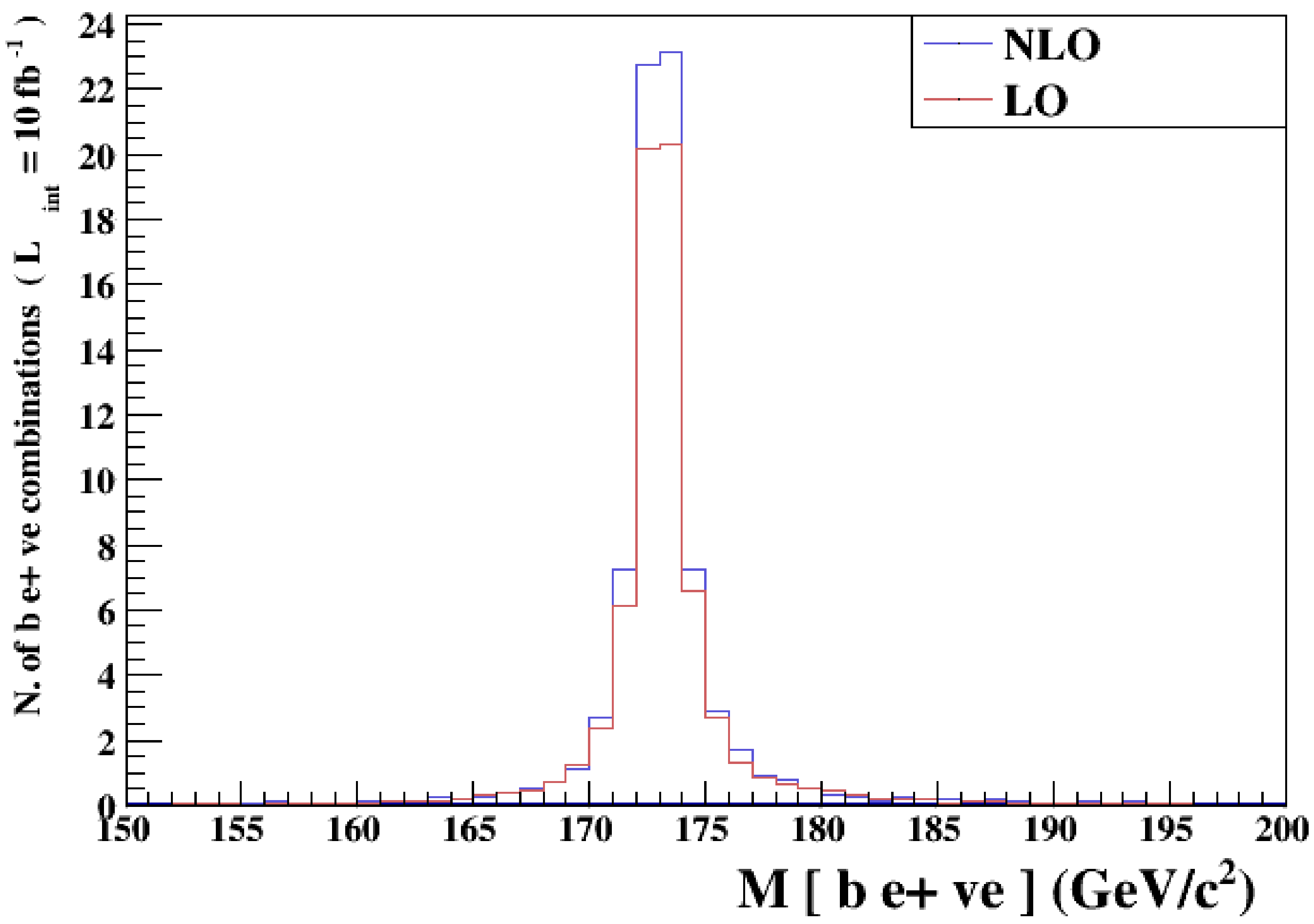
$\sigma(pb)$ for $gg \to b\bar{b}e^+\nu_e\mu^-\bar{\nu_\mu}$			
gauge - scheme	complex-mass	fix width	no width
feynman	1.796e-05 $\pm$ 2.3e-08	1.787e-05 $\pm$ 2.5e-08	
unitary	1.792e-05 $\pm$ 2.1e-08	1.778e-05 $\pm$ 2.4e-08	1.810e-05 $\pm$ 2.4e-08

Offshell effect at NLO

e+ e- > w+ w- b b~



e+ e- > t t~



Conclusion

- aMC@NLO is
  - ➡ public
  - ➡ automatic
  - ➡ flexible
- MadSpin
  - ➡ decay with full spin correlations
  - ➡ keep finite width effect
- complex-mass
- This is only the beginning of this Tool!

	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

Work in Progress in aMC@NLO

What to expect in the future

Perspectives

Perspectives

- FeynRules@NLO:

Perspectives

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  - ➡ NLO not only for the SM but for New Physics

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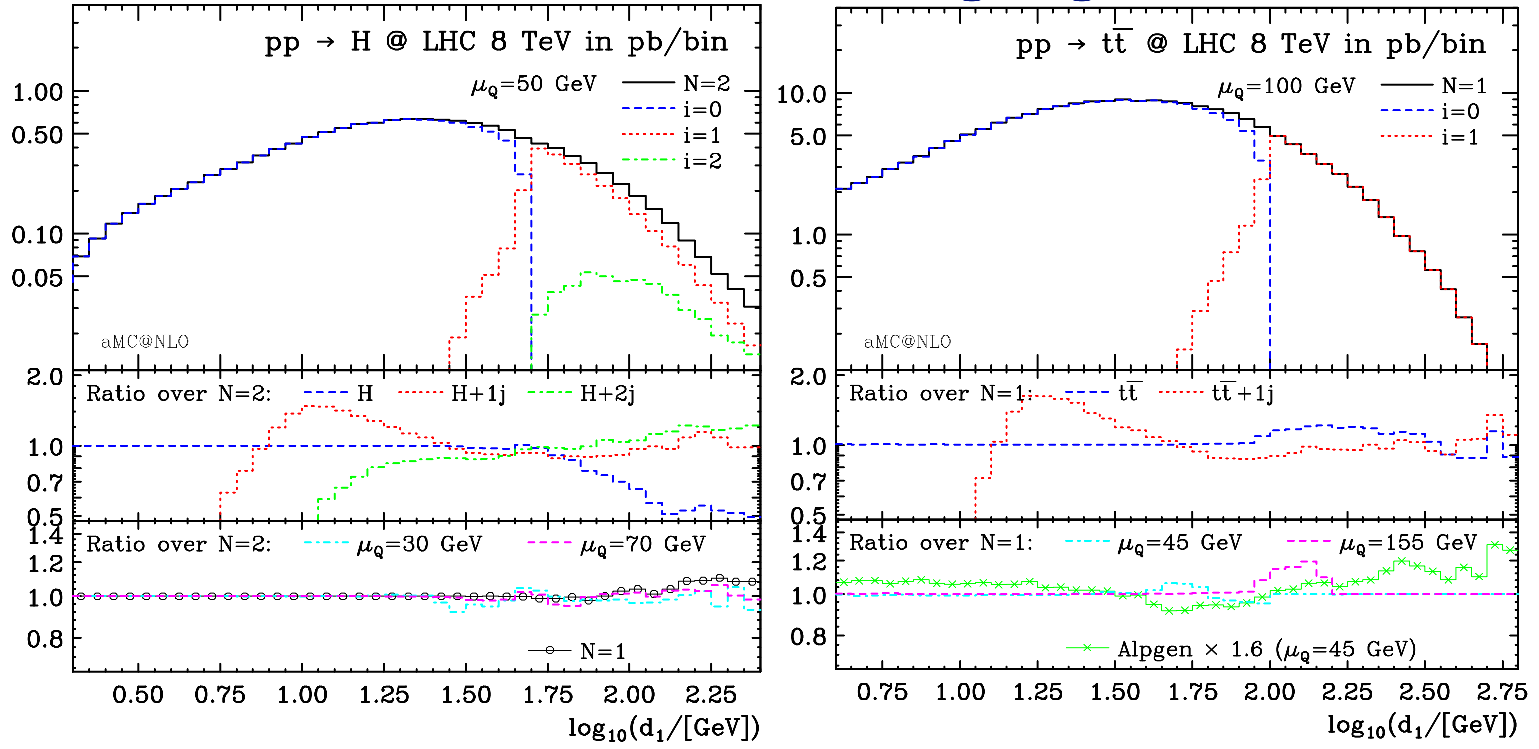

$0 \to 1$ rates in H^0 and $t\bar{t}$ production

Perspectives

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- Automation of loop-induced processes
- Interface to Pythia8
- Complex mass scheme

MC@NLO properties

- Good features of including the subtraction counter terms
  1. **Double counting avoided**: The rate expanded at NLO coincides with the total NLO cross section
  2. **Smooth matching**: MC@NLO coincides (in shape) with the parton shower in the soft/collinear region, while it agrees with the NLO in the hard region
  3. **Stability**: weights associated to different multiplicities are separately finite. The *MC* term has the same infrared behavior as the real emission (there is a subtlety for the soft divergence)
- Not so nice feature (for the developer):
  1. **Parton shower dependence**: the form of the *MC* terms depends on what the parton shower does exactly. Need special subtraction terms for each parton shower to which we want to match