# Spin Polarisation in top pair with di-gamma production at NLO+PS

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Eur.Phys.J. C76 (2016) no.4, 221

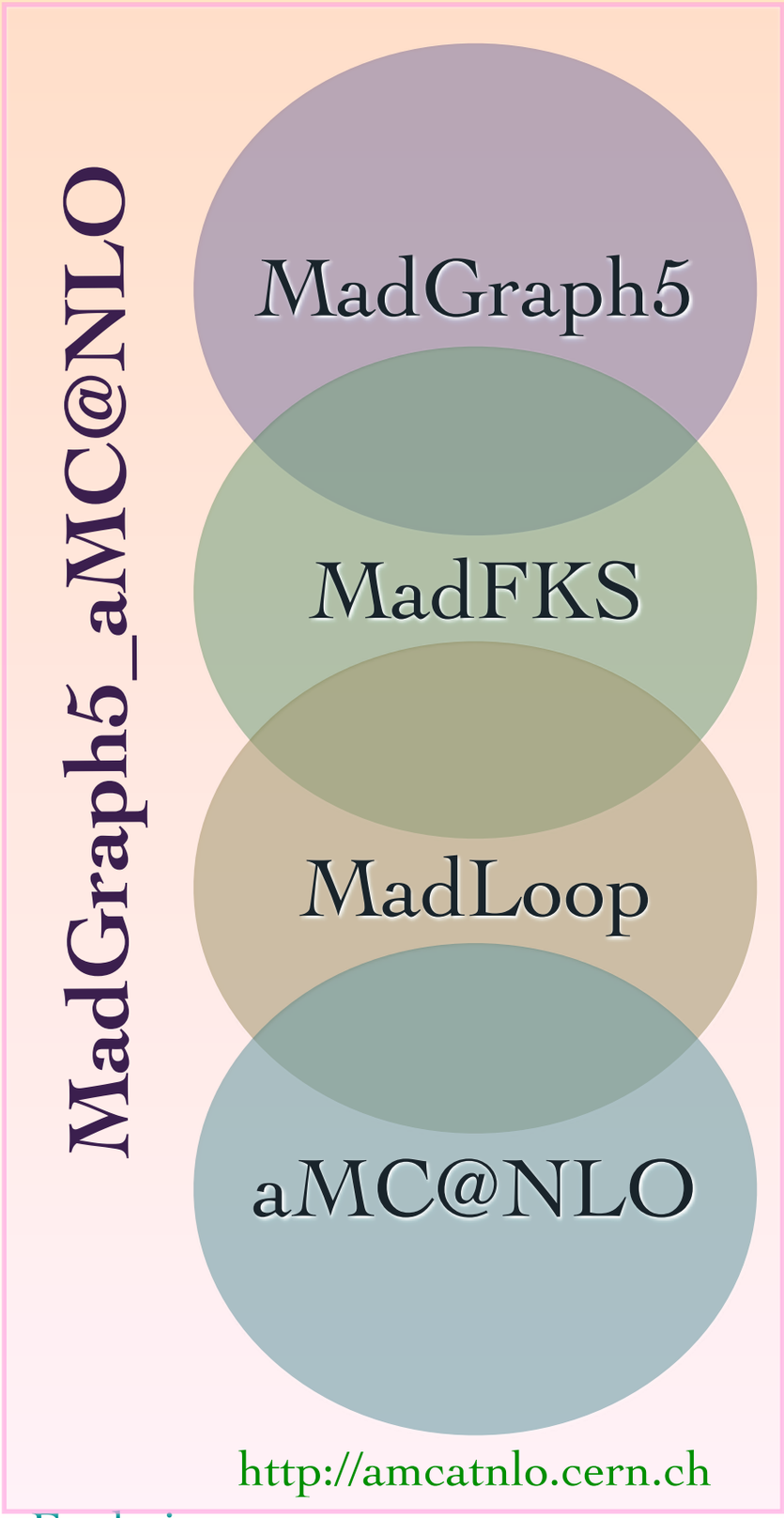
LHCP2016, Lund, Sweden, Jun. 13-18, 2016

# Motivation

- Interface between MadGraph5_aMC@NLO and GoSam
- Application to
  - signal: top pair + Higgs, with Higgs decaying to di-photon
  - irreducible, continuum background: top pair di-photon production

# MadGraph5_aMC@NLO

[Alwall, RF, Frixione, Hirschi, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Zaro]




- Modular structure:
  - Use MadGraph5 for LO and steering
  - MadFKS for factoring out Infrared singularities
  - MadLoop for the virtual corrections
  - aMC@NLO for matching to the parton shower

```
$ ./bin/mg5_aMC
MG5_aMC> generate p p > t t~ a a [QCD]
MG5_aMC> output my_NLO_ttaa_process
MG5_aMC> launch
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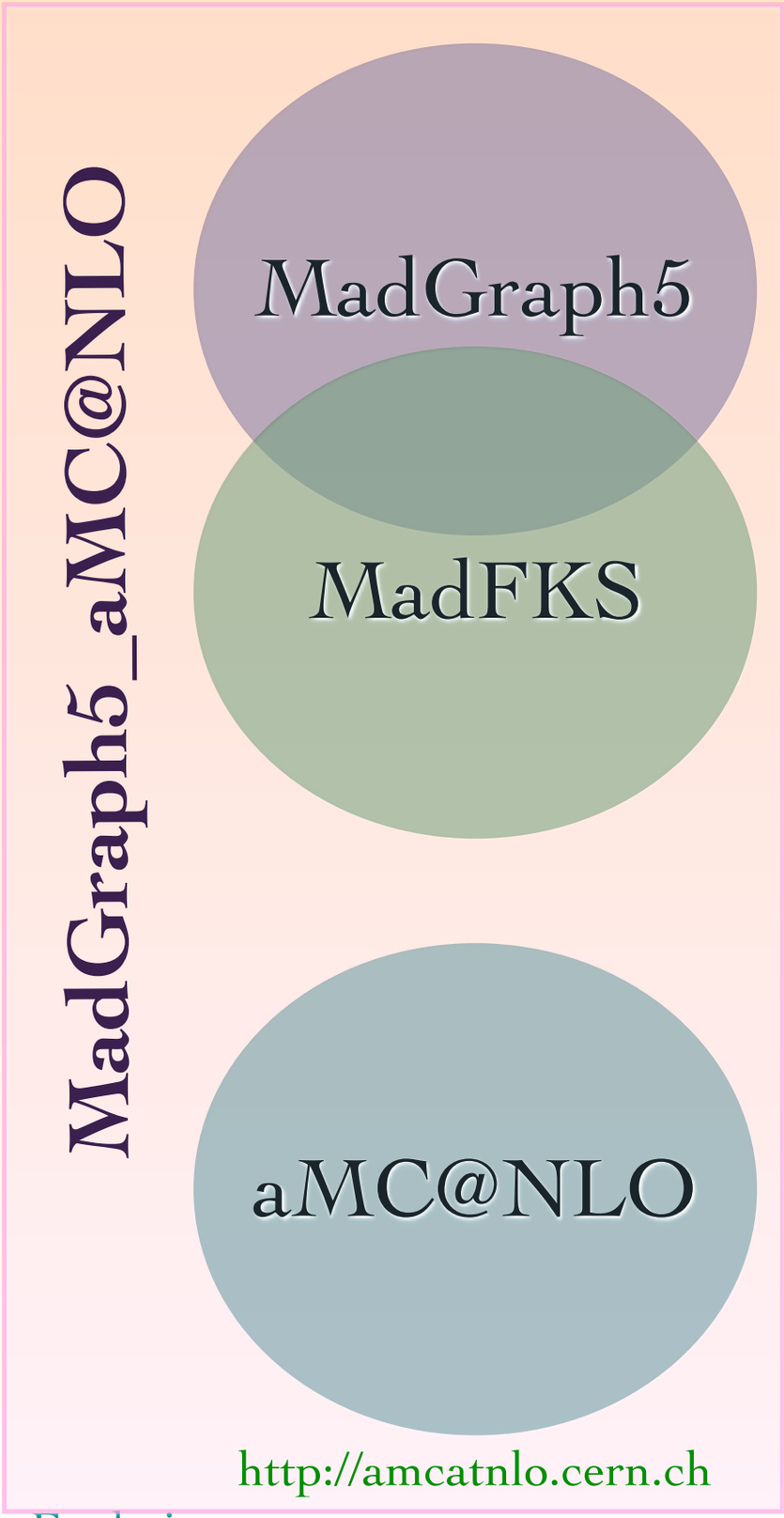


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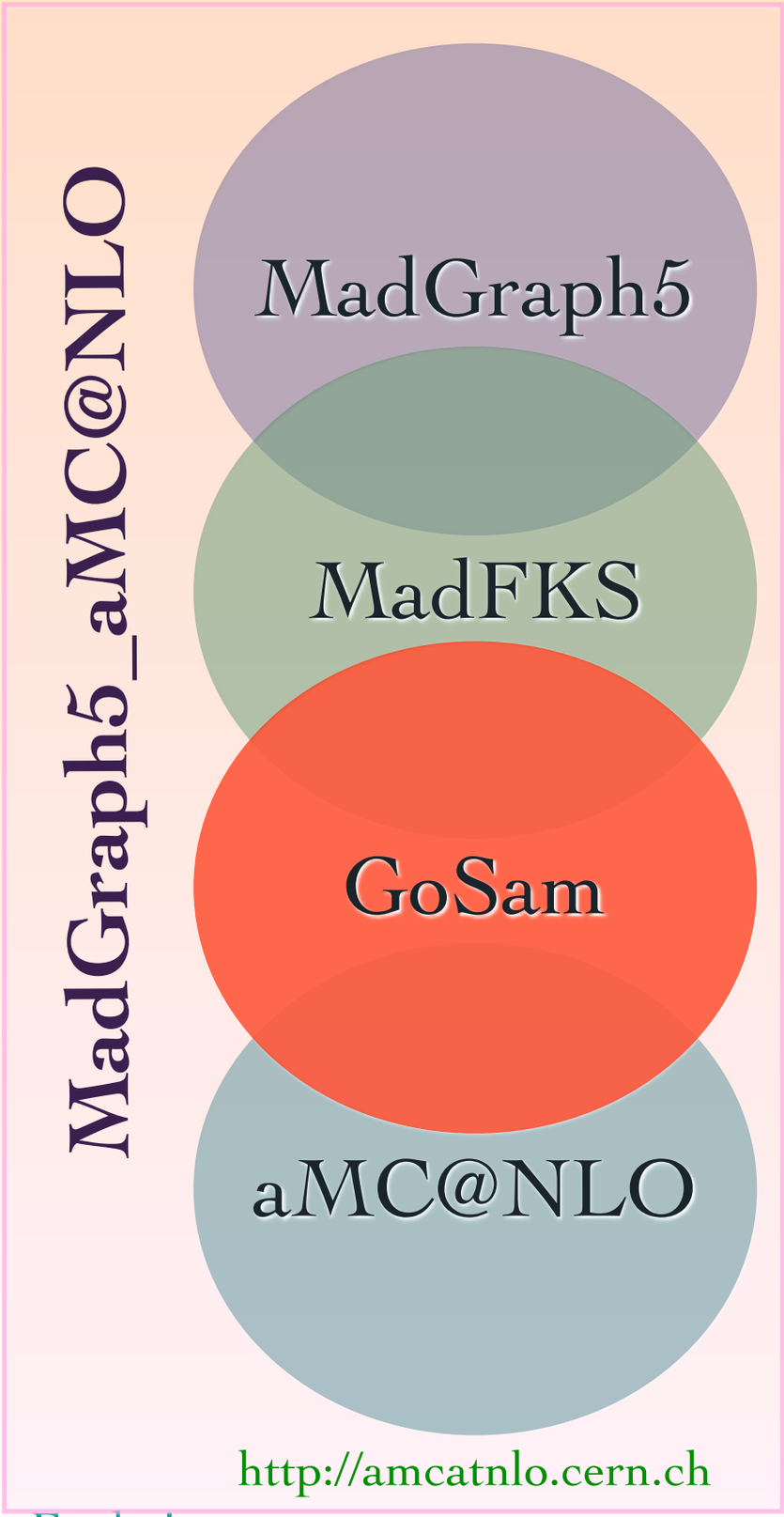


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# GoSam

http://gosam.hepforge.org

- Each tool has its own strengths and weaknesses
  - Availability
  - Speed
  - Stability
- Now possible to switch seamlessly between MadLoop and GoSam within MadGraph5_aMC@NLO
- Main difference between GoSam and MadLoop is that the former generates and computes **analytic expressions for the integrands**, while the latter uses a purely numerical approach

[Cullen, Van Deurzen, Greiner, Heinrich, Luisoni, Mastrolia, Mirabella, Ossola, Peraro, Schlenk, von Soden-Fraunhofen, Tramontano]

# Binoth-LesHouches interface

- The Binoth-Les Houches interface is used for the interplay between MG5_aMC and GoSam

```
#OLE_order written by MadGraph5_aMC@NLO

MatrixElementSquareType CHaveraged
CorrectionType          QCD
IRregularisation        CDR
AlphasPower             2
AlphaPower              2
NJetSymmetrizeFinal     Yes
ModelFile               ./param_card.dat
Parameters              alpha_s



# process
21 21 -> 22 22 6 -6
2 -2 -> 22 22 6 -6
1 -1 -> 22 22 6 -6
-2 2 -> 22 22 6 -6
-1 1 -> 22 22 6 -6
```

**Order file**

Generated by MG5_aMC and passed to GoSam. Contains information on processes that GoSam should generate

```
# vim: syntax=olp
#@OLP GoSam 2.0.0
#@IgnoreUnknown True
#@IgnoreCase False
#@SyntaxExtensions
MatrixElementSquareType CHaveraged | OK
CorrectionType QCD | OK
IRregularisation CDR | OK
AlphasPower 2 | OK
AlphaPower 2 | OK
NJetSymmetrizeFinal Yes | OK #Ignored by OLP
ModelFile ./param_card.dat | OK
Parameters alpha_s | OK
21 21 -> 22 22 6 -6 | 1 2
2 -2 -> 22 22 6 -6 | 1 0
1 -1 -> 22 22 6 -6 | 1 3
-2 2 -> 22 22 6 -6 | 1 1
-1 1 -> 22 22 6 -6 | 1 4
```

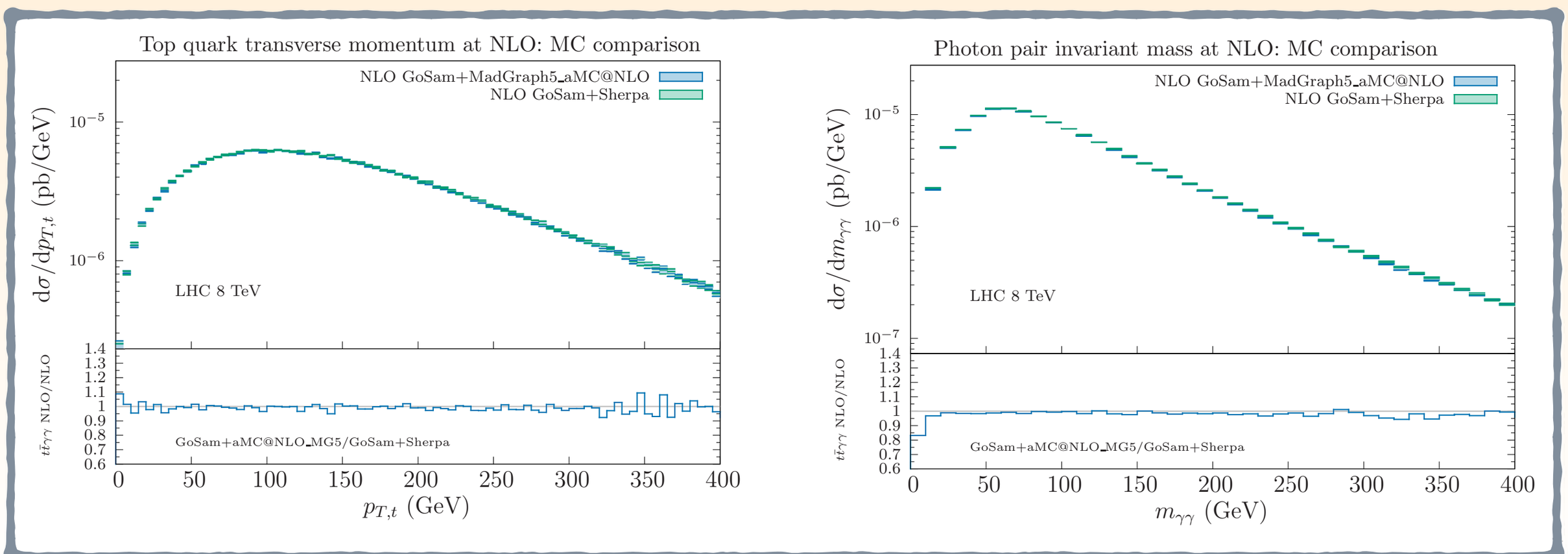
**Contract file**

GoSam returns if it understand the order file and assigns labels (to be used at run time) to each of the sub-processes

# Validation

- Many processes tested with the interface: at single phase-space points, total rates and diff. distributions
- For example top pairs + di-photon:

| $\sigma_{t\bar{t}\gamma\gamma}$, $\sqrt{s} = 8$ TeV | MG5_aMC + MadLoop | MG5_aMC + GoSam |
|---|---|---|
| LO [pb] | $1.0241 \pm 5.50 \cdot 10^{-4}$ | |
| NLO [pb] | $1.3507 \pm 5.85 \cdot 10^{-3}$ | $1.3432 \pm 5.16 \cdot 10^{-3}$ |



# Application

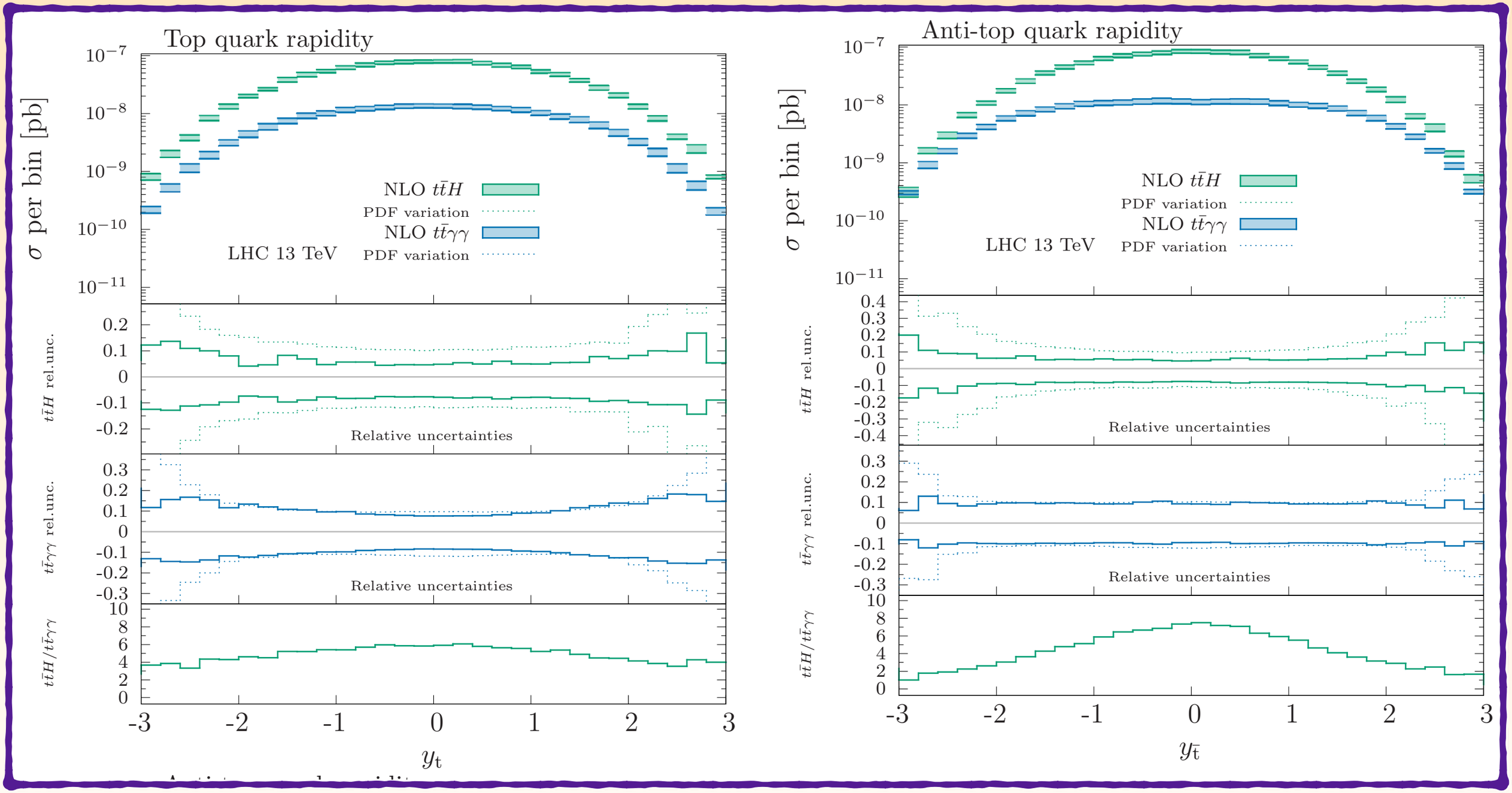
- As an application, we studied top pair production in association with a di-photon pair
  - Both signal (resonant Higgs->di-photon) and background (continuum)
  - Include (semi-)leptonic top decays using MadSpin: keeps spin correlations
  - Events are showered with Pythia 8
- Selection cuts:
  - 2 isolated photons with $p_{T,\gamma} > 20 \text{ GeV}, \quad |\eta_\gamma| < 2.5, \quad 123 \text{ GeV} < m_{\gamma\gamma} < 129 \text{ GeV}$
  - 2 charged leptons $p_{T,l^\pm} > 10 \text{ GeV}, \quad |\eta_{l^\pm}| < 2.7$
  - 2 bottom jets (100% b-tagging efficiency) $\Delta R = 0.4, \quad p_{T,j} > 20 \text{ GeV}, \quad |\eta_j| < 4.7$
  - Use MC truth to select the "right" photons/leptons/b-jets and reconstruct the top quarks

# Fiducial cross section

| $\sqrt{s} = 13$ TeV | $pp \to t\bar{t}H,\ H \to \gamma\gamma$ | $pp \to t\bar{t}\gamma\gamma$ |
|---|---|---|
| LO [pb] | $8.84(2) \cdot 10^{-7}\ ^{+27\%}_{-20\%}\ ^{+10\%}_{-11\%}$ | $1.442(2) \cdot 10^{-7}\ ^{+25\%}_{-18\%}\ ^{+10\%}_{-12\%}$ |
| NLO [pb] | $11.77(5) \cdot 10^{-7}\ ^{+6\%}_{-8\%}\ ^{+11\%}_{-12\%}$ | $2.175(7) \cdot 10^{-7}\ ^{+10\%}_{-10\%}\ ^{+10\%}_{-11\%}$ |
| K-factor | 1.33(1) | 1.51(1) |

- With these simple cuts, signal is larger than background (but very tiny)
- Getting total cross section will already be very challenging
  - nevertheless, I'll focus in this talk on diff. distributions, which is not something that will be measured in the near future, but shows some interesting theoretical features

# T-TBAR CHARGE ASYMMETRY

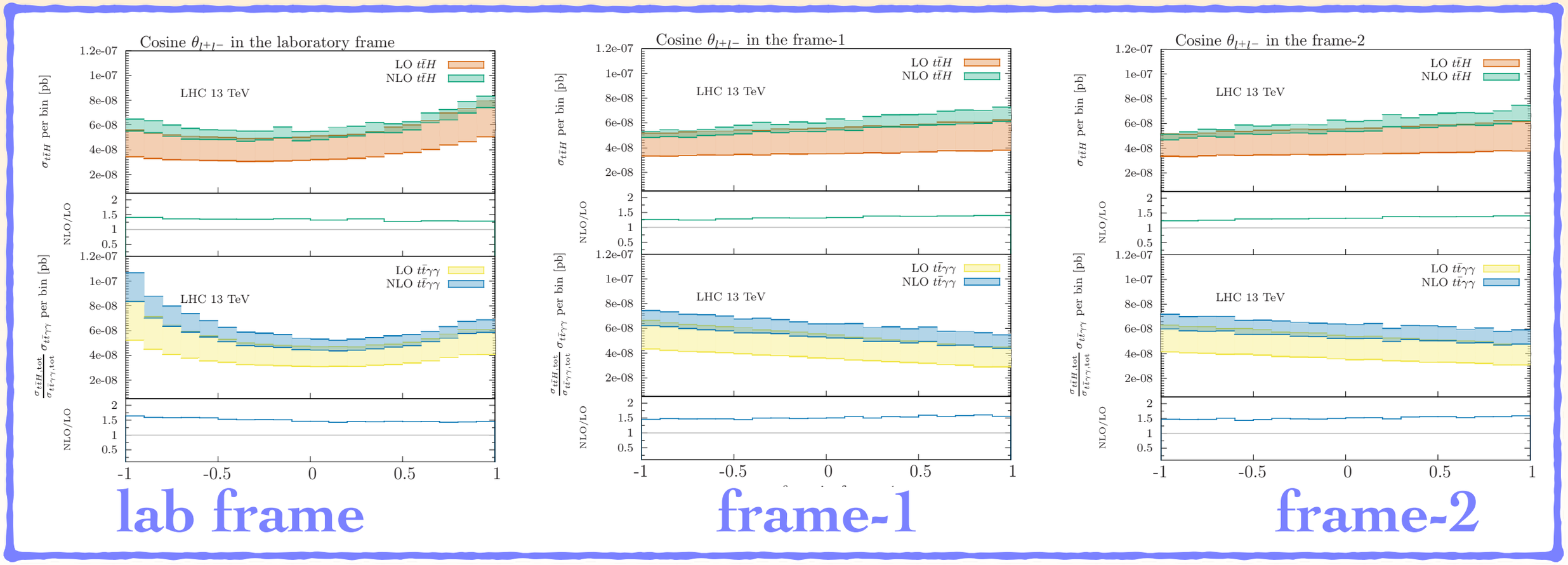



✦ Top and anti-top quark rapidities: clear sign of asymmetry for the background

# Spin polarisation

- Use leptons (from the top decays) as spin-analyser

– *frame-1*: the Lorentz boosts to bring $t$ and $\bar{t}$ separately at rest are defined with respect to the $t\bar{t}$-pair center-of-mass frame,
– *frame-2*: the Lorentz boosts to bring $t$ and $\bar{t}$ separately at rest are defined with respect to the lab-frame.



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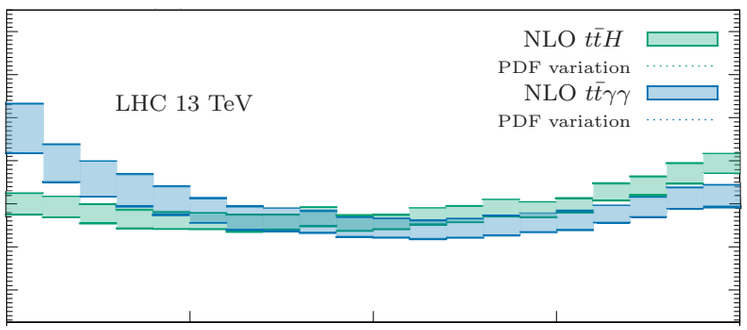
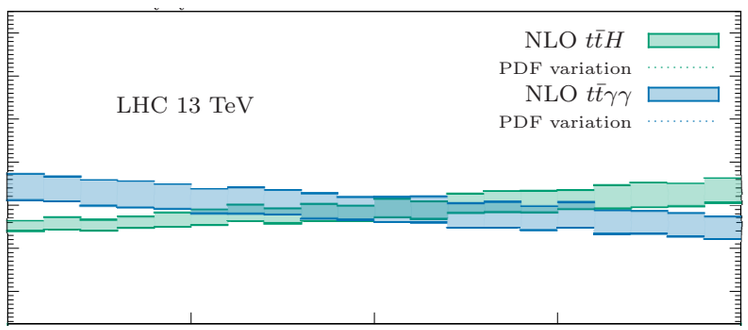
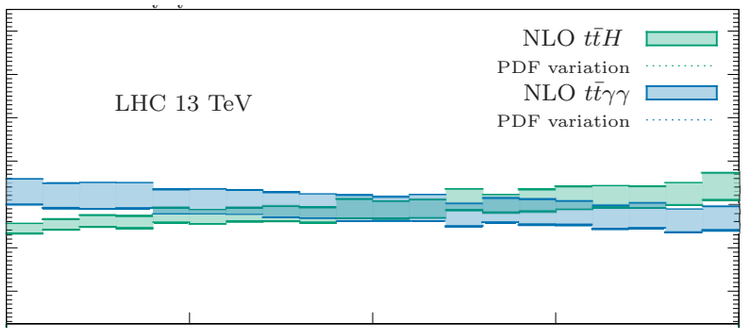



lab frame




frame-1




frame-2

# Conclusions

- New interface available between MadGraph5_aMC@NLO and GoSam
  - Allows for easy comparisons between MadLoop and GoSam
    - Availability
    - Speed
    - Stability
- Application to top pair production in association with a di-photon pair: Higgs signal versus continuum backgrounds
  - interesting features show
    - large top—anti-top asymmetry
    - spin correlations; largely independent from the frame