(a)MC@NLO status report

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on behalf of

the aMC@NLO collaboration:

P.Artoisenet, R. Frederix, S. Frixione, F. Maltoni, O. Mattelaer, R. Pittau, P.Torrielli, V. Hirschi

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Matching NLO computations with parton showers

- Why NLO + PS?
  - Reliable predictions of rates
  - Reliable estimate of uncertainties (scale & PDF)
  - Better theoretical accuracy, less need of fine tuning
  - Realistic description of the final state
  - Better understanding of data
  - Steep increase in complexity (in particular for higher multiplicities)

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Ask a computer to do the hard job
Automation!

Matching in MC@NLO

- Use suitable counterterms to avoid double counting the emission from shower and ME, keeping the correct rate at order α_s:

$$\frac{d\sigma_{MC@NLO}}{dO} = \left(\mathcal{B} + \mathcal{V} + \int d\Phi_1 MC\right) d\Phi_n \; I^n_{MC}(O) + (\mathcal{R} - MC)\, d\Phi_n \, d\Phi_1 \; I^{n+1}_{MC}(O)$$

S-events H-events

- MC depends on the PSMC's Sudakov:

$$MC = \left| \frac{\partial\left(t^{MC}, z^{MC}, \phi\right)}{\partial \Phi_1} \right| \frac{1}{t^{MC}} \frac{\alpha_s}{2\pi} \frac{1}{2\pi} P\left(z^{MC}\right) \mathcal{B}$$

- Available for Herwig6, Pythia6 (virtuality-ordered), Herwig++ (Pythia 8 in progress)
- MC acts as local counterterm
- Some weights can be negative (unweighting up to sign)
  - Only affects statistics

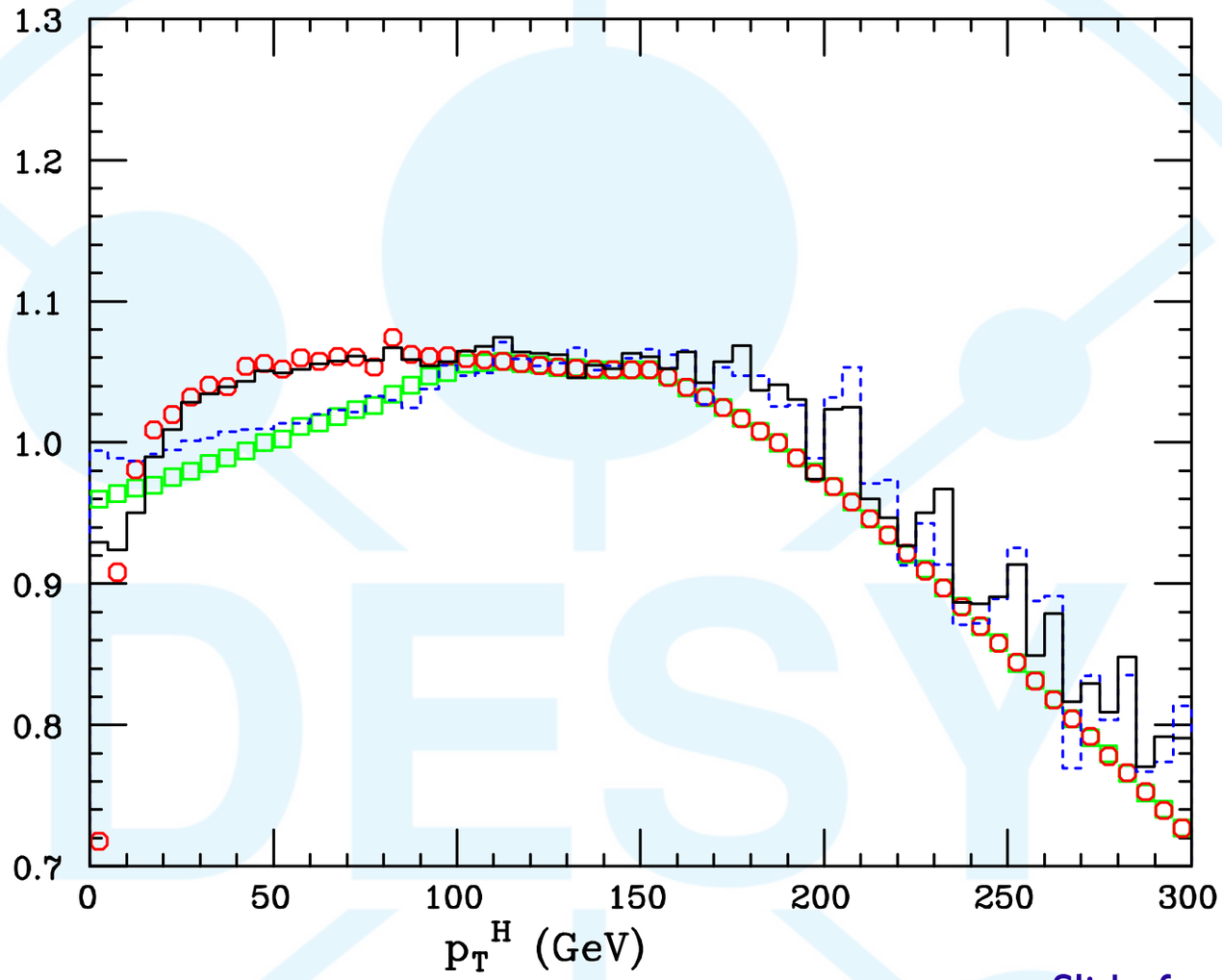
News from MC@NLO (without the "a"): gg>H

- ≤ v4.07 only HEFT available (born with exact m_t dependence)
- v4.08 (06/12) real+virtual ME with exact m_t, m_b dependence
- v4.10 (07/13) allows user to follow the Grazzini and Sargsyan prescription

arXiv:1306.0581

- Different resummation scales (Q_i in HRes, shower scale in MC@NLO) for top and bottom contributions
  - ~ m_b for bottom loops
  - ~ m_H for top loops
- Two runs have to be performed, and the results combined

MC@NLO vs HRES



Slide from S.Frixione

histograms: MC@NLO symbols: HRes

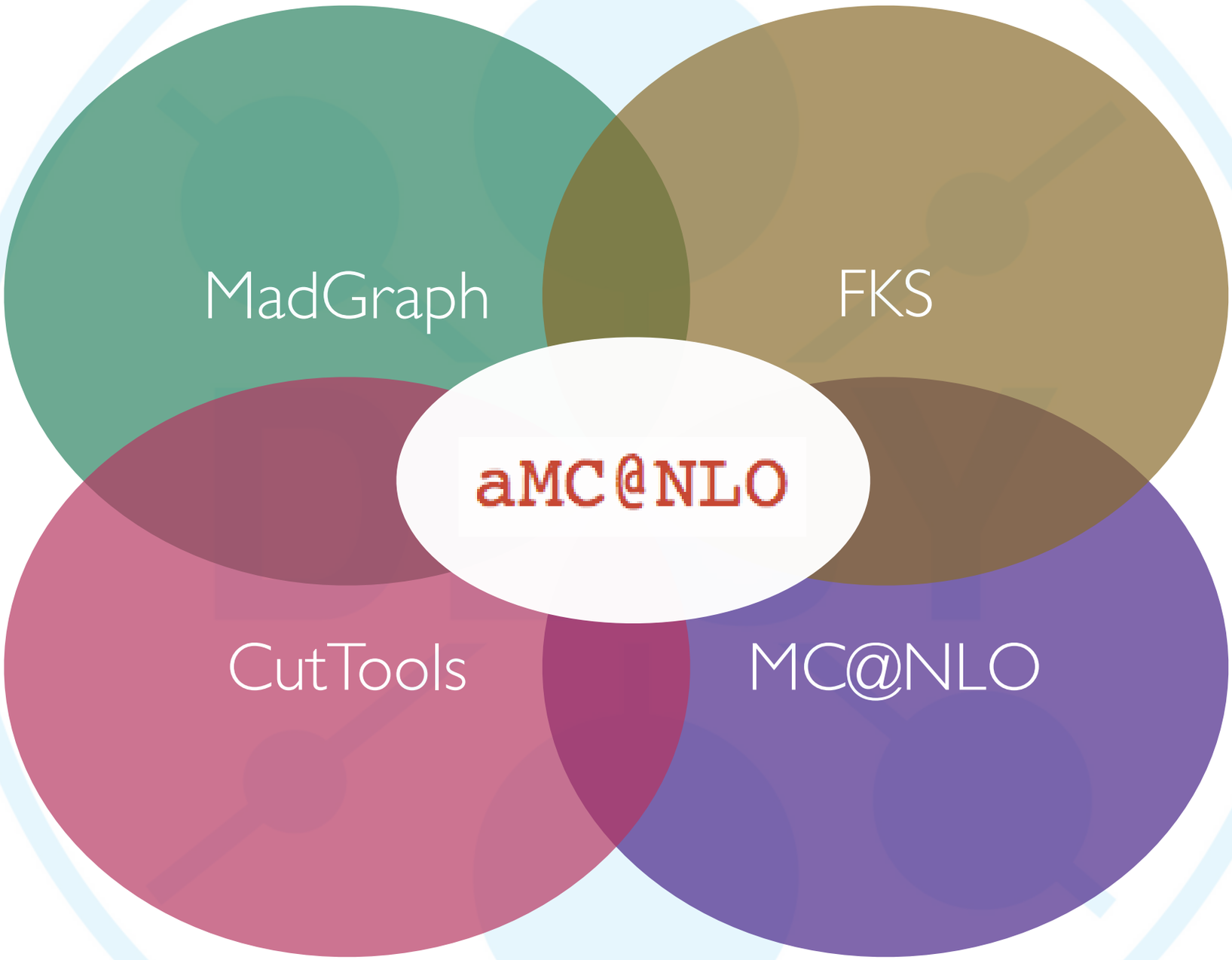
solid and circles: $Q_2 = \mathcal{O}(m_b)$ dashed and boxes: $Q_2 = \mathcal{O}(m_H)$

Note: not tuned comparison, still results are consistent

Both codes use an additive matching approach

aMC@NLO

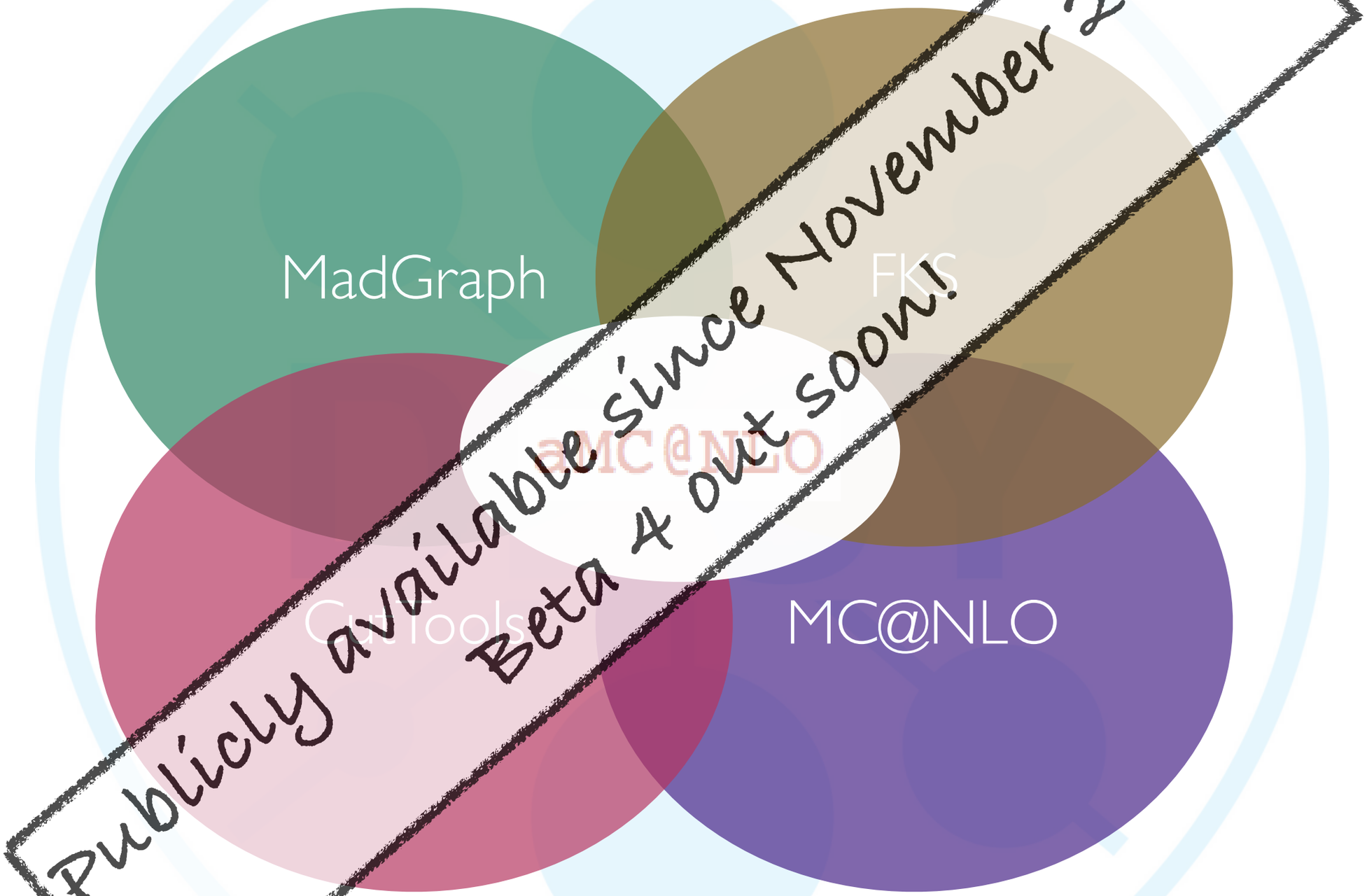
aMC@NLO



All in one code!

no external dependencies apart for FastJet and LHAPDF (optional)

aMC@NLO



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Full automation (and extreme simplicity)

- Start the MG5/aMC@NLO shell

```
$./bin/mg5
```

- Generate the process

```
> generate p p > t t~ h [QCD]
```

- Write the code

```
> output my_tth_nlo
```

- Launch the event generation/fixed order computation

```
> launch
```

Physics applications (since last year)

- Spin correlations in *ttH*
- *t*-channel Single top with off shell/non resonant effects
- Drell-Yan/Diboson production in ADD theories
- Matching systematics in VBF
- Higgs Characterization framework

Spin correlations in ttH

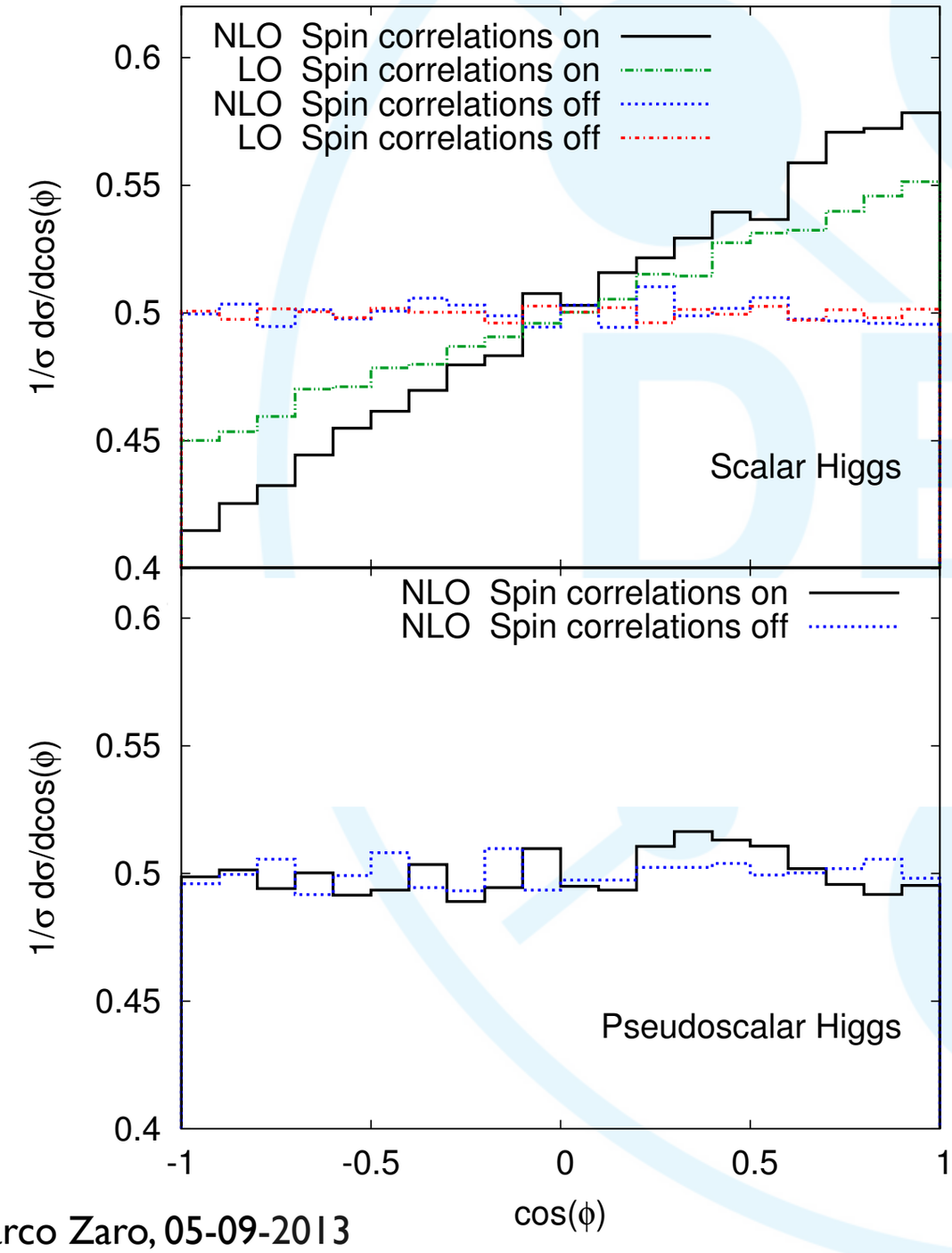
P. Artoisenet, R. Frederix, O. Mattelaer, R. Rietkerk, arXiv:1212.3460 + YR3

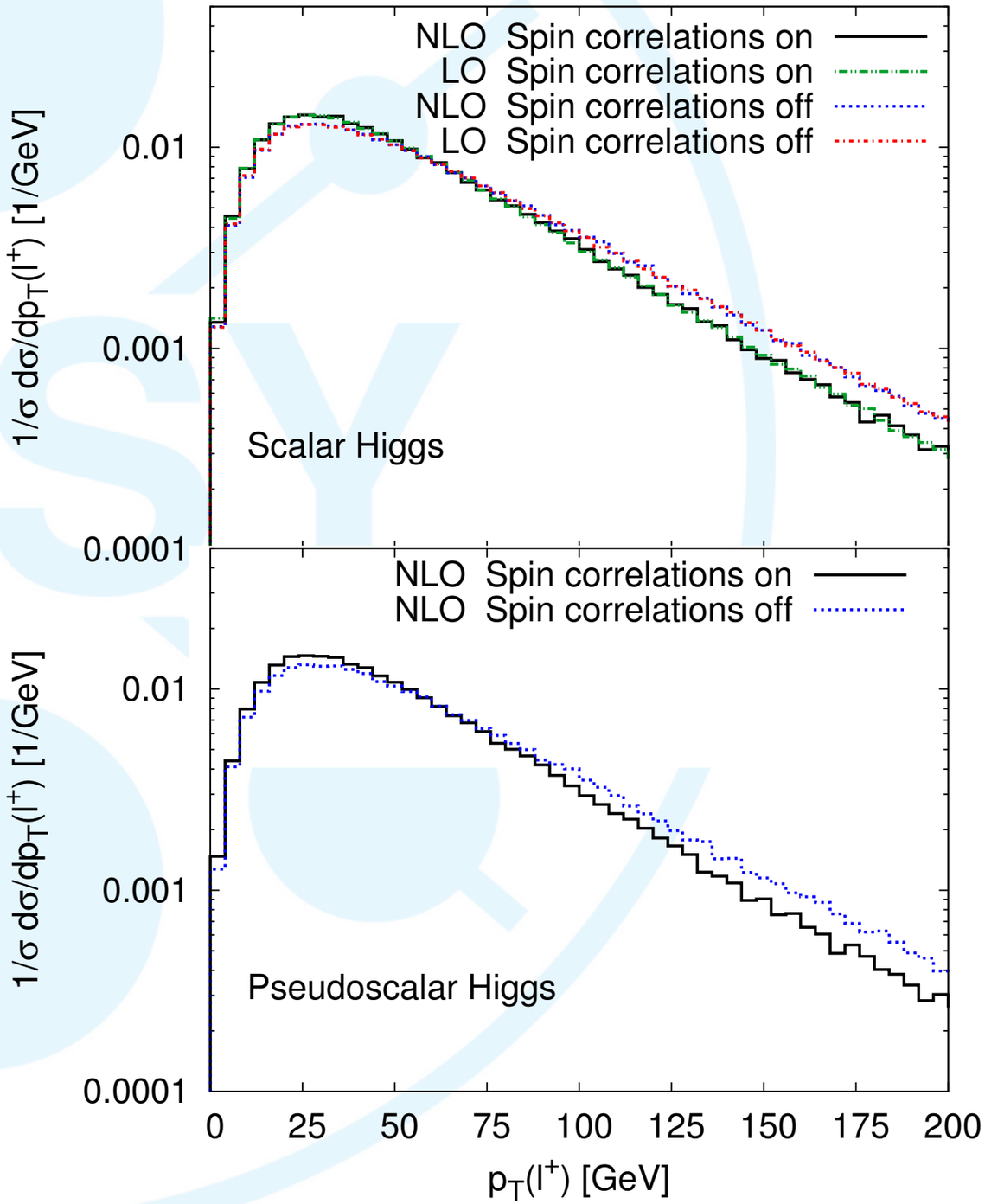
- MadSpin allows the user to perform the decay of an event sample into an arbitrary final state, keeping spin correlations
- Based on the method by Frixione, Laenen, Motylinski, Webber: arXiv:hep-ph/0702198
  - Read the (undecayed) event
  - Generate MEs for production (P) and production+decay (P+D)
  - Generate decay kinematics until

$$|M_{P+D}|^2 / |M_P|^2 > \mathrm{Rand}() \ \max\left(|\mathrm{M_{P+D}}|^2 / |\mathrm{M_P}|^2\right)$$

  - Write the decayed event
- Use *n*(+1)-body tree-level MEs for S(H) events
- Keep NLO accuracy for production-related observables
- Include all spin correlations
  - Effects of genuine loop origin are not accounted for (typically small)

Spin correlations in ttH: results





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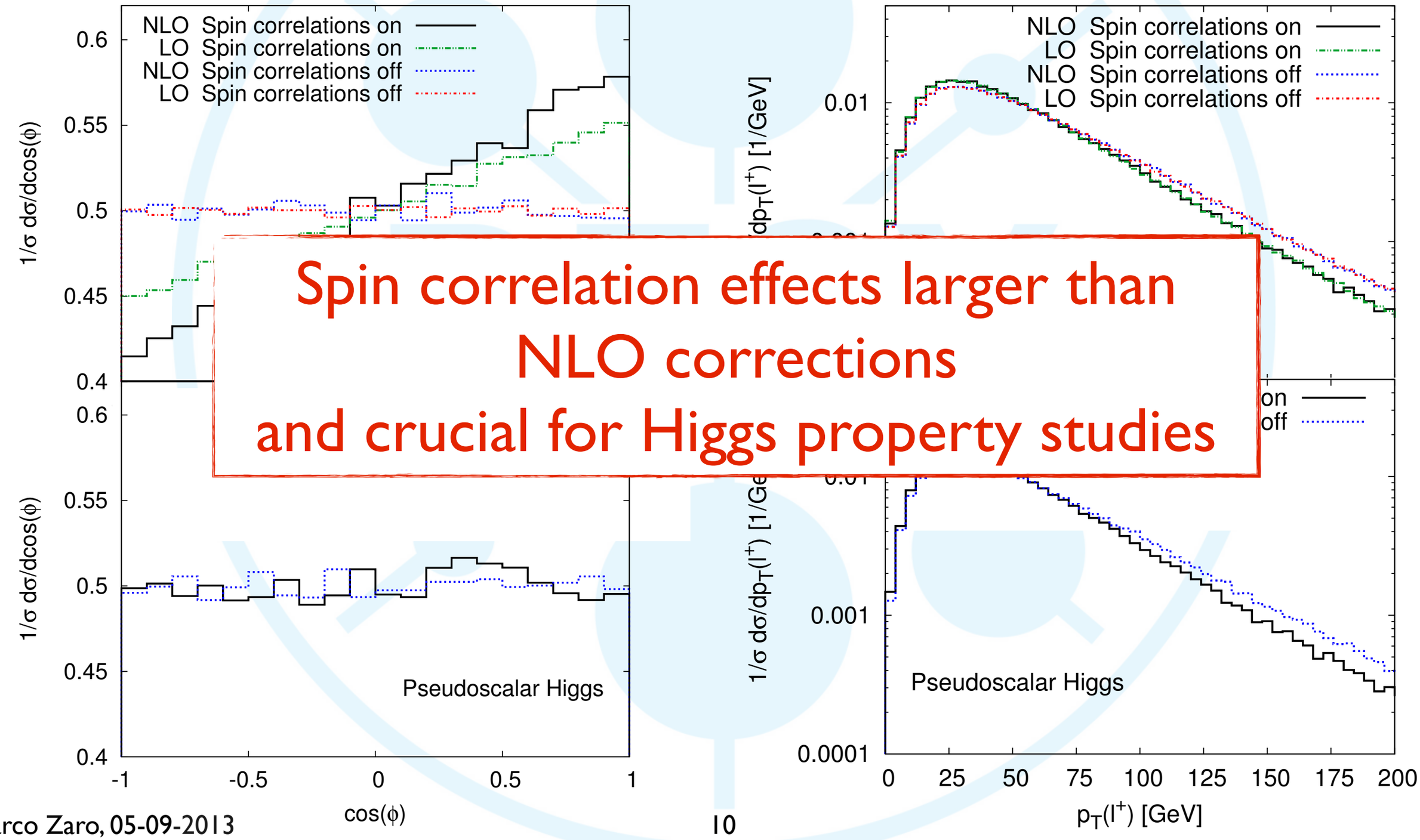

Spin correlation effects larger than NLO corrections and crucial for Higgs property studies

t-channel single top with off-shell and non resonant contributions

A. S. Papanastasiou, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, arXiv:1305.7088

P.Falgari, P.Mellor, A.Signer, arXiv:1007.0893
P.Falgari, F.Giannuzzi, P.Mellor, A.Signer, arXiv:1102.5267

t-channel single top with off-shell and non resonant contributions

A. S. Papanastasiou, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, arXiv:1305.7088

- First computation which consistently includes non resonant effects
- Compare with other approaches
  - Narrow width approximation (NWA)
  - Effective theory (ET, P.Falgari, P.Mellor, A.Signer, arXiv:1007.0893 P.Falgari, F.Giannuzzi, P.Mellor, A.Signer, arXiv:1102.5267)

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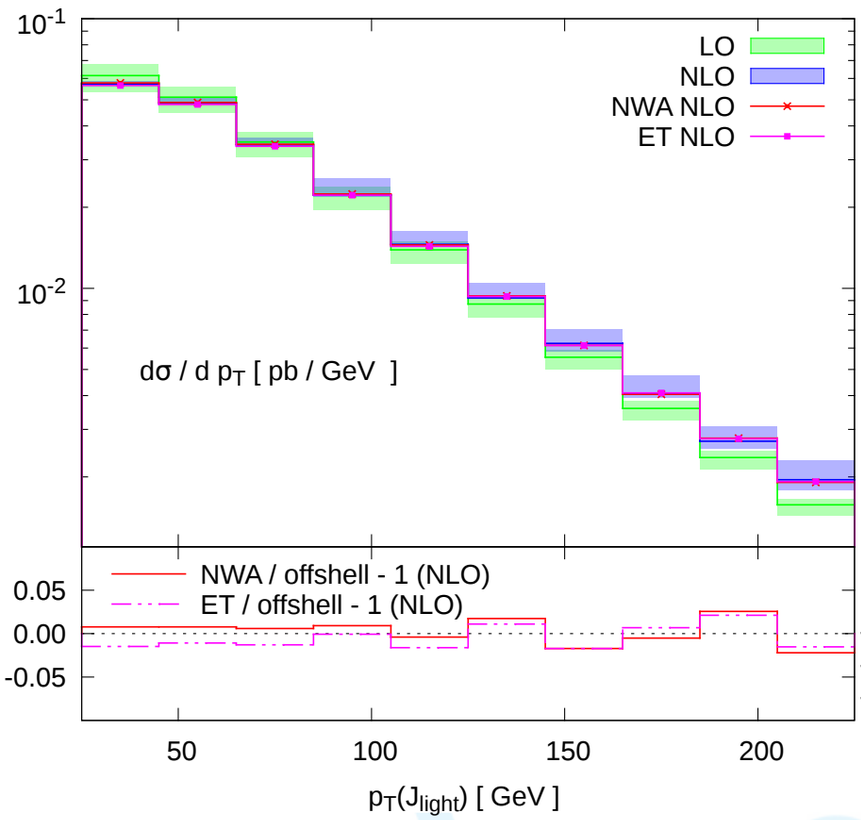
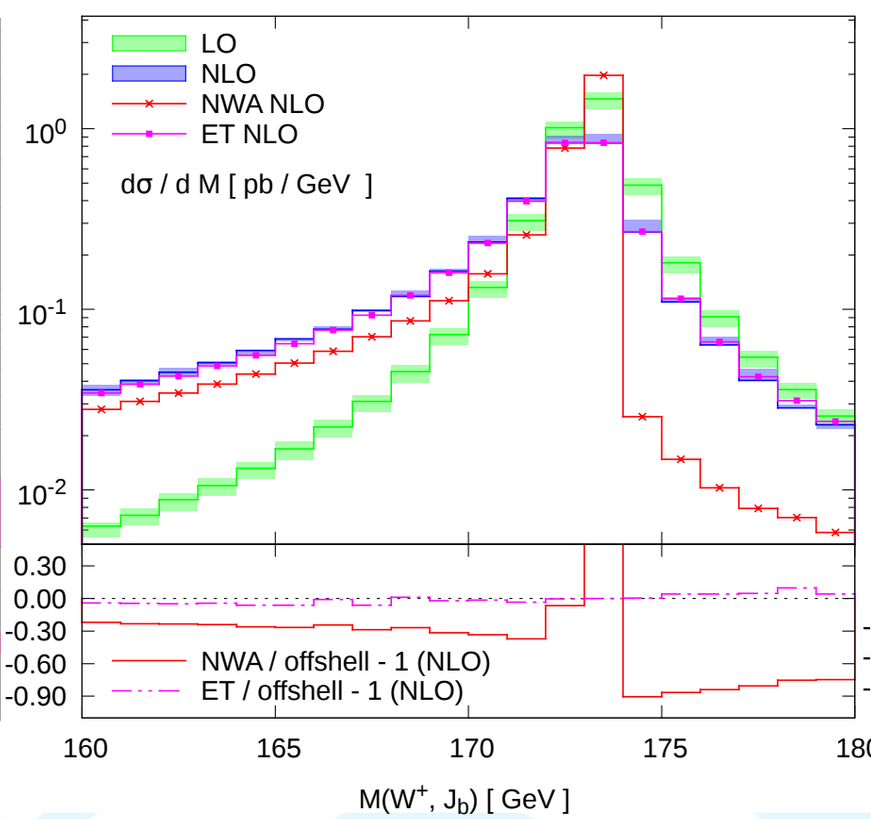
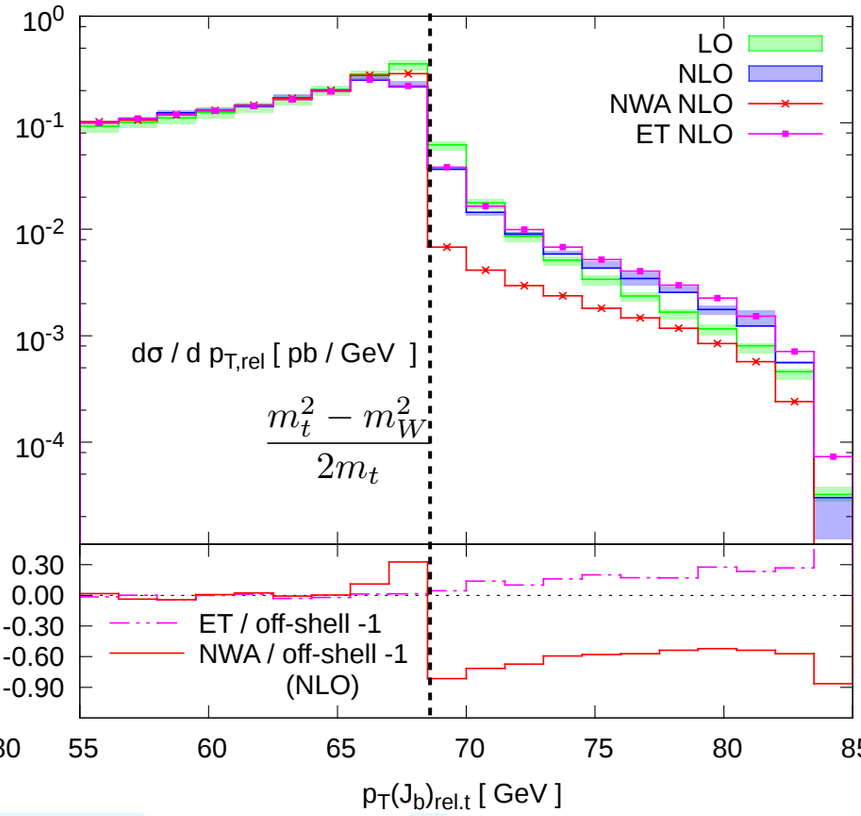




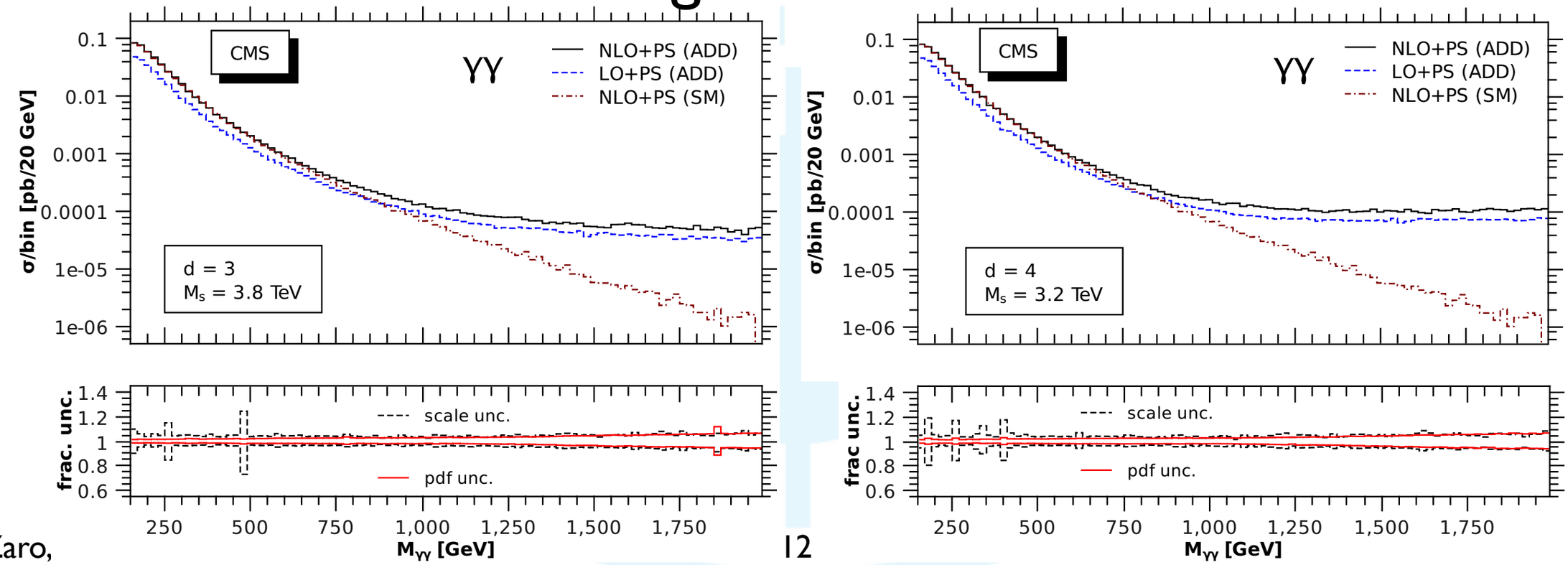


- Approaches agree on observables not sensitive to the reconstructed top mass
- NWA cannot catch effects above the top peak
- (Smaller) differences with ET approach far from the peak

DY/Diboson production in ADD theories

R. Frederix, M. K. Mandal, P. Mathews, V. Ravindran, S. Seth, P. Torrielli, MZ, arXiv:1209.6527
R. Frederix, M. K. Mandal, P. Mathews, V. Ravindran, S. Seth, arXiv:1307.7013

- Motivation: provide accurate predictions for Large Extra Dimensions searches (4+d, d=2→6)
- Study all possible final states (l^+l^-, ww, zz, γγ) keeping all spin correlations
- Look for kinematical regions of interest



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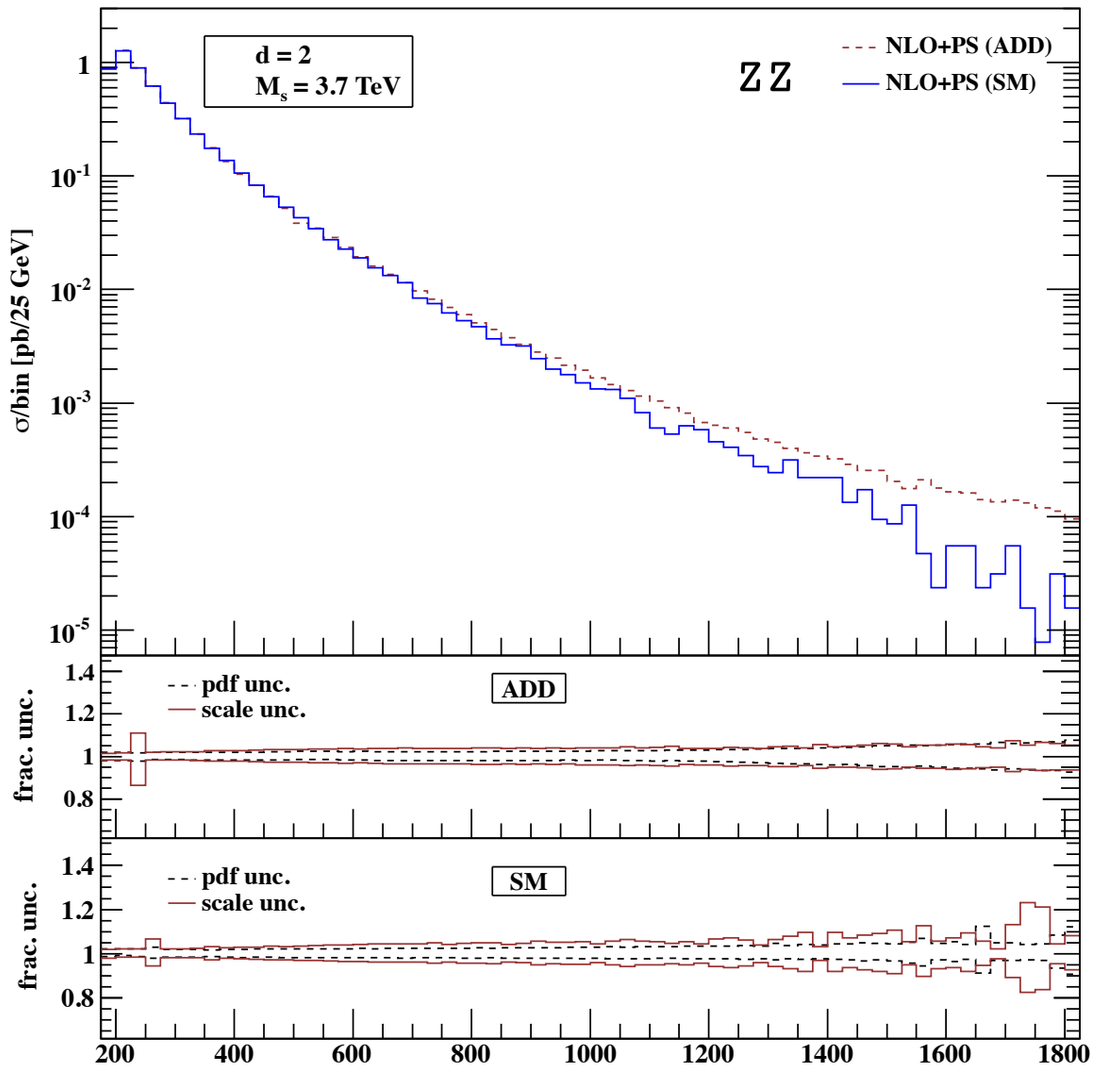
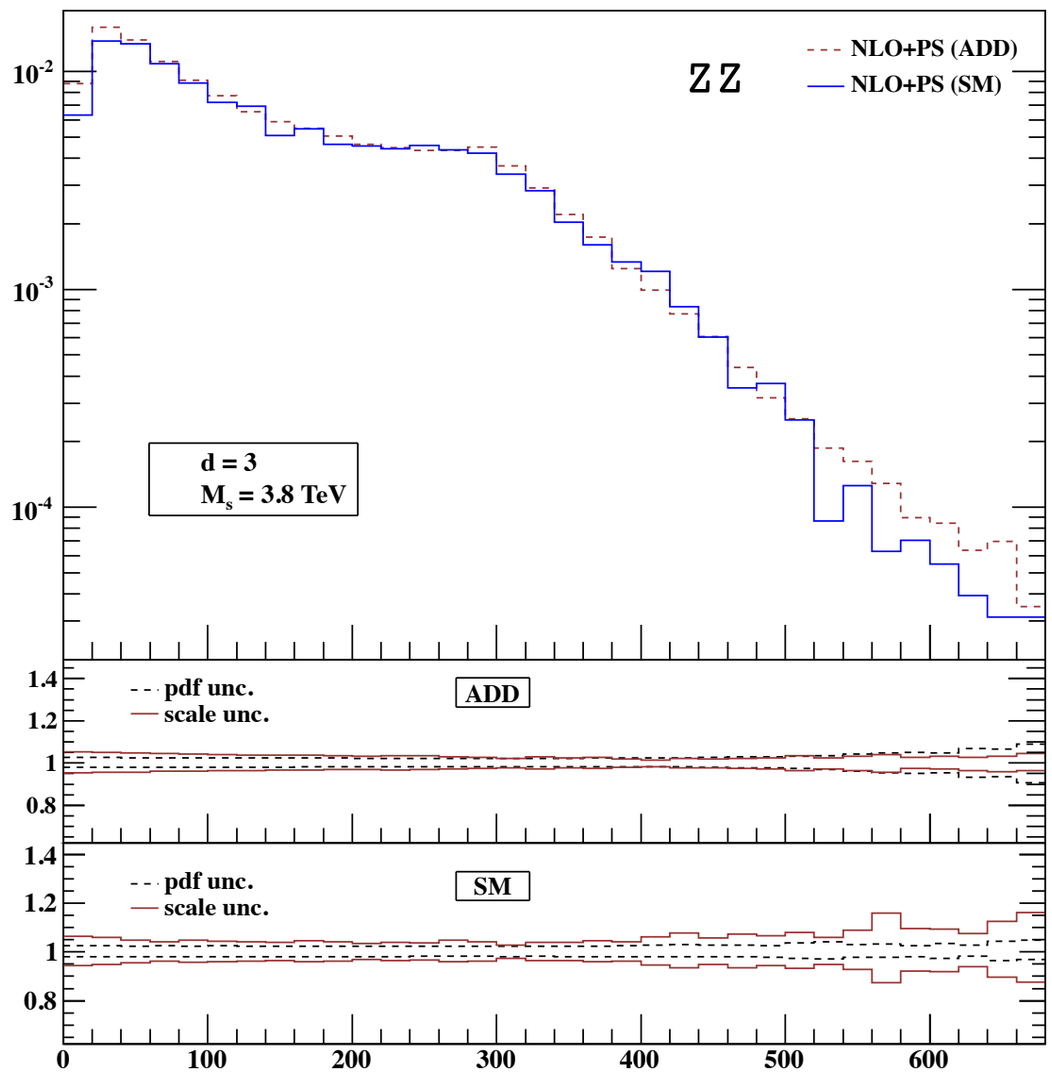




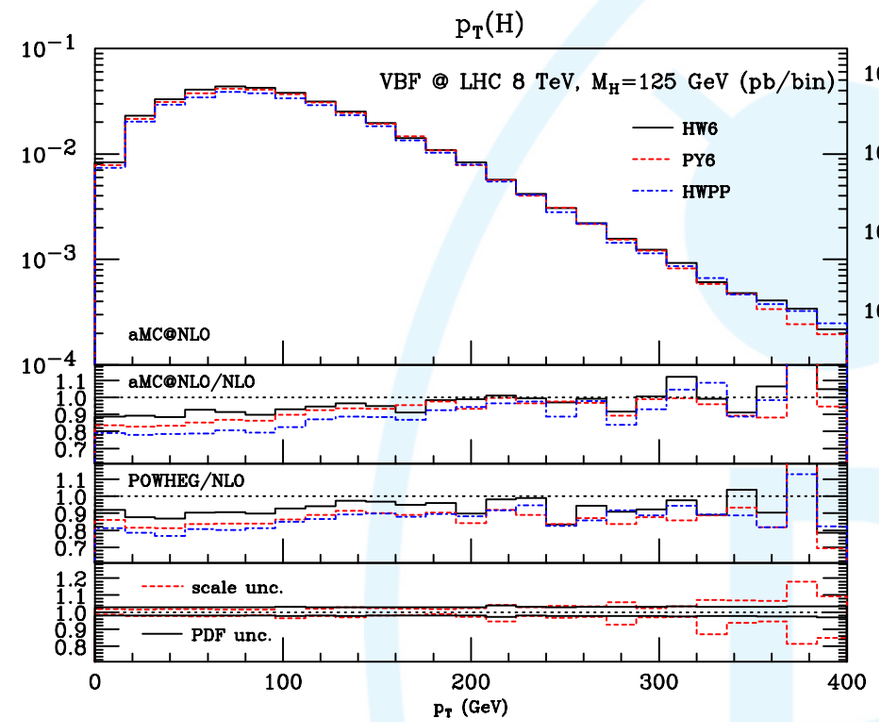
Matching systematics in VBF

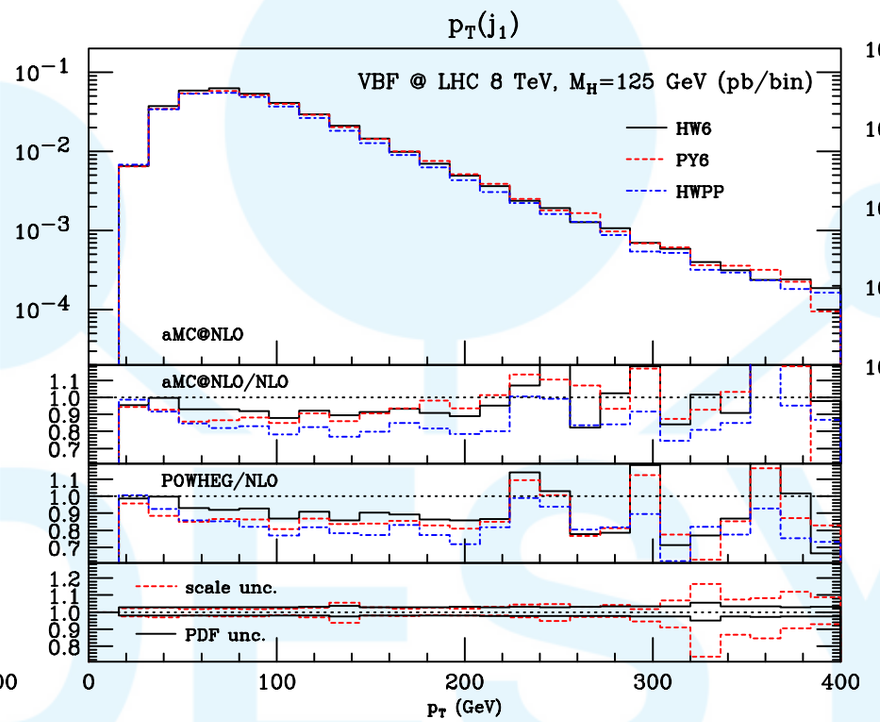
S. Frixione, P. Torrielli, MZ, arXiv:1304.7927 + YR3

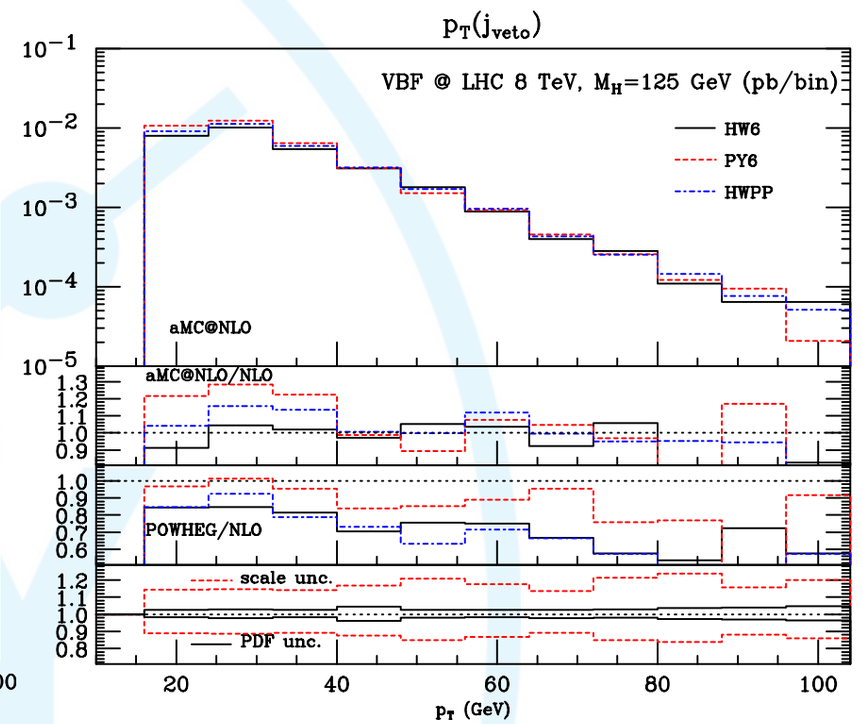
- Try to assess possible systematics related to the parton shower and/or matching method
- Compare aMC@NLO and POWHEG, with different PS
- VBF cuts:
  - ≥2 jet, anti-kt, $\Delta R=0.5$, $P^T > 20$ GeV, $|\Delta y| < 4.5$
  - $M(jj) > 600$ GeV, $|\Delta y(jj)| > 4$
- PS affects total x-sect after cuts (is it a tune effect?)
  - Effects much larger than theoretical uncertainties

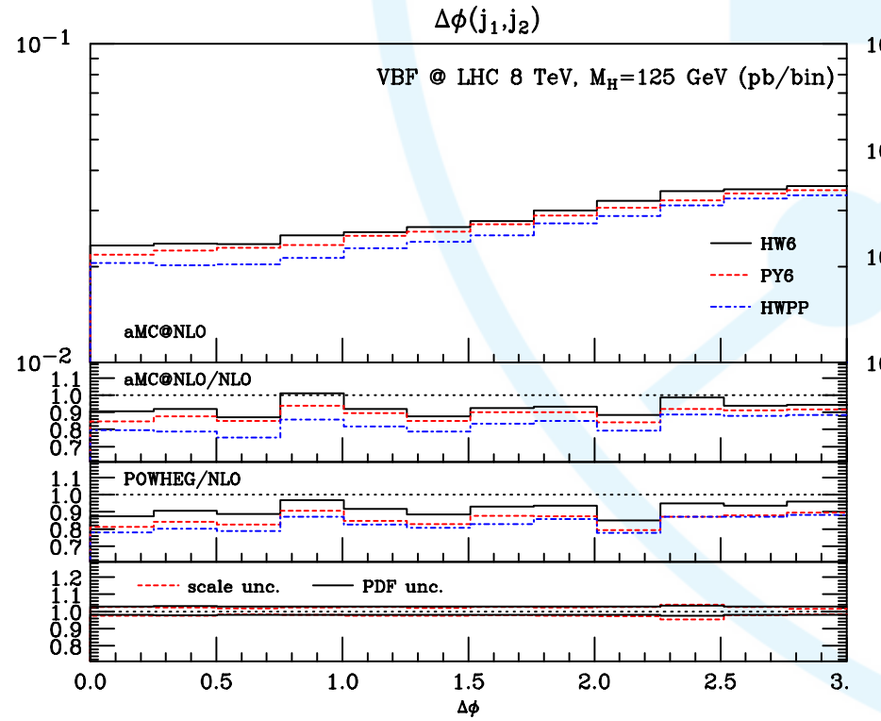
	HERWIG6	PYTHIA6	HERWIG++
aMC@NLO	0.93	0.89	0.83
POWHEG	0.92	0.86	0.83

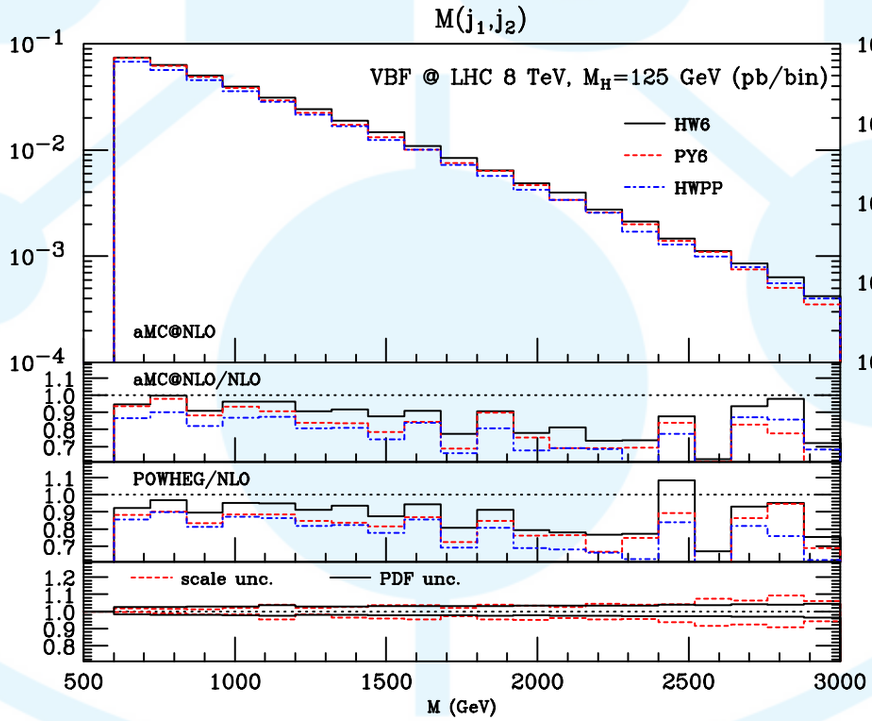
Matching systematics in VBF

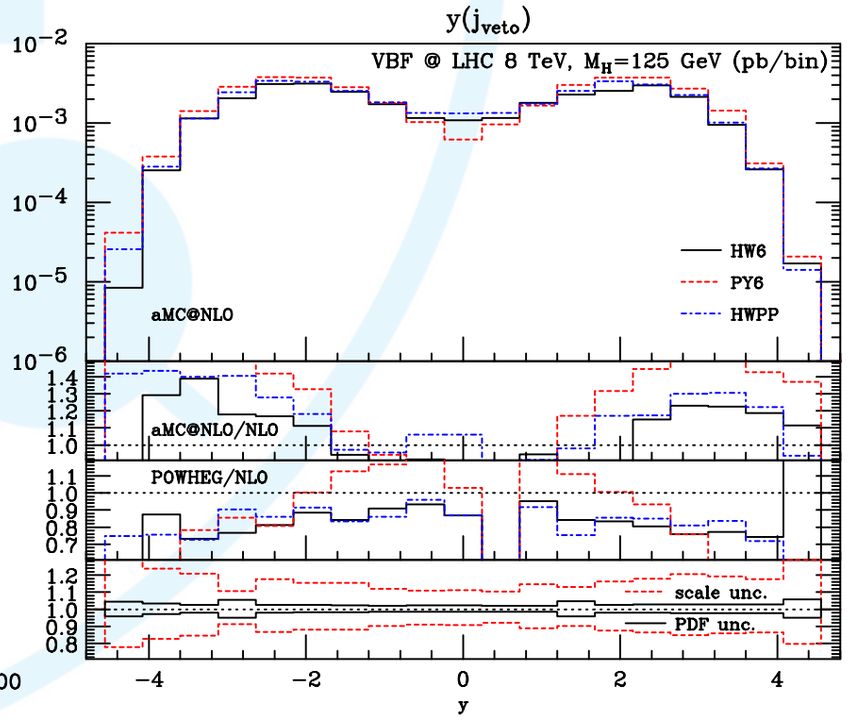












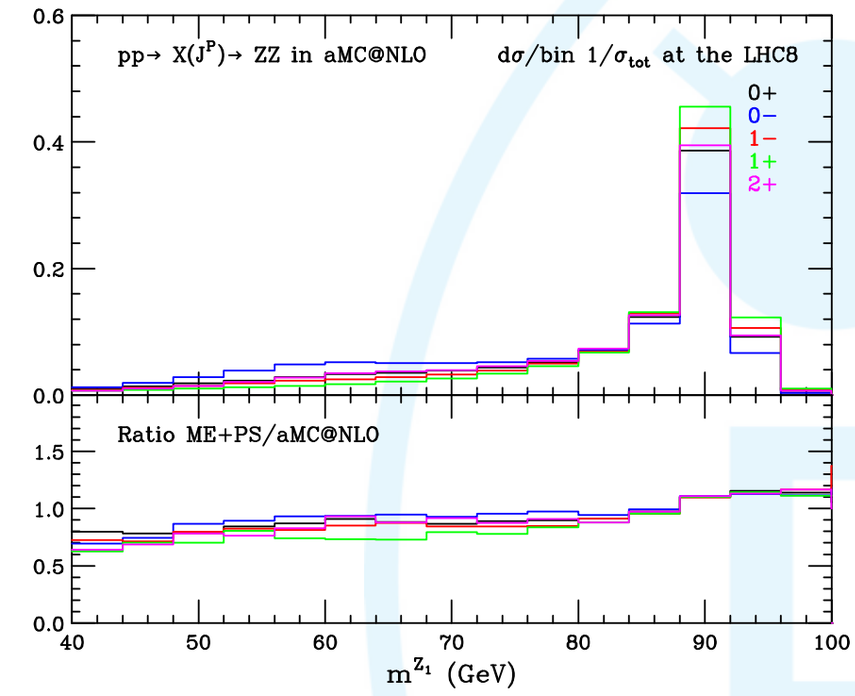
Higgs Characterization

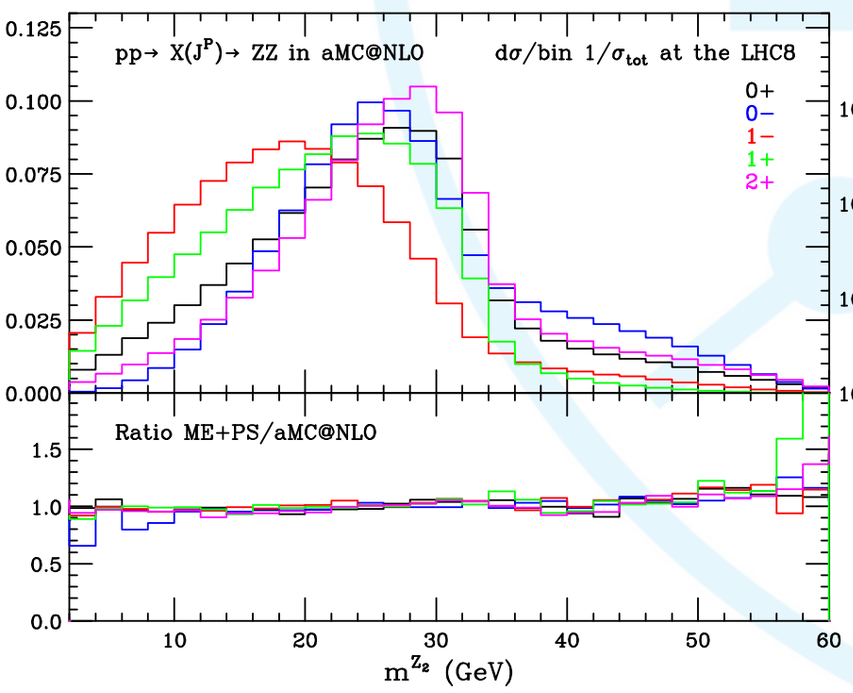
P. Artoisenet, P. de Aquino, F. Demartin, R. Frederix, S. Frixione, F. Maltoni, M. K. Mandal, P. Mathews, V. Ravindran, S. Seth, P. Torrielli, MZ, arXiv:1306.6464 + YR3

- Effective field theory approach
  - The "Higgs" is the first particle from NP
  - Agnostic on NP details (encoded in cutoff Λ)
- Keep lowest dimension operators for spin 0, 1, 2 hypotheses (CP +/- or mixed)
  - Validated against other approaches (e.g. JHU)
- Extra QCD radiation can be consistently incorporated (MLM or aMC@NLO)
- Study `zz`, `ww`, $\gamma\gamma$ final states, keeping all angular correlations

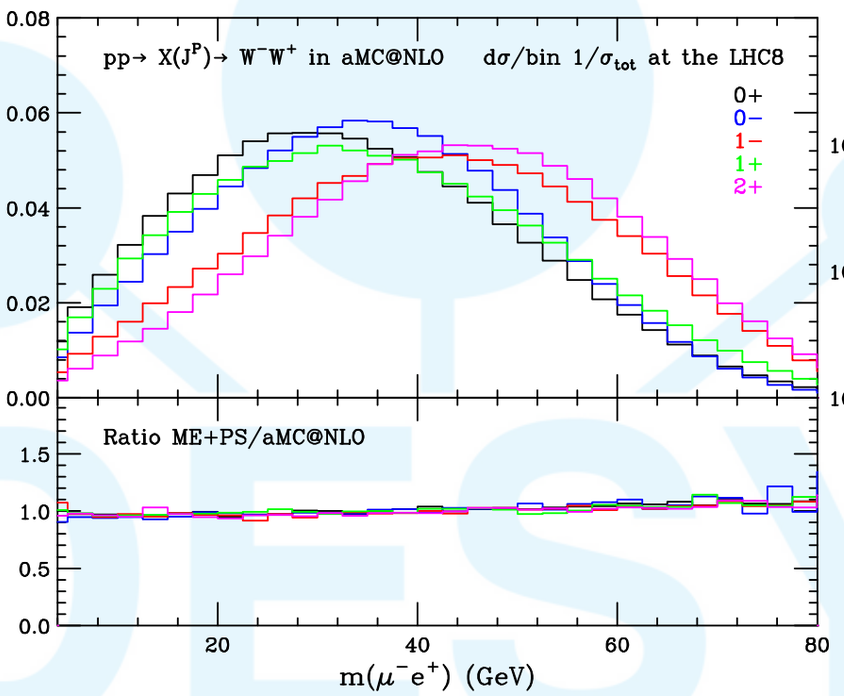
Results:

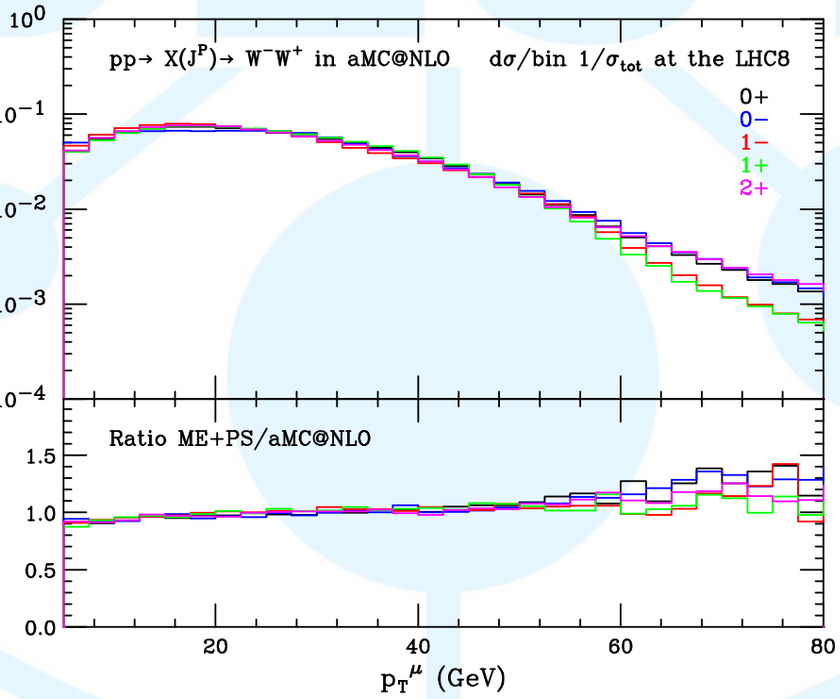
ZZ





WW





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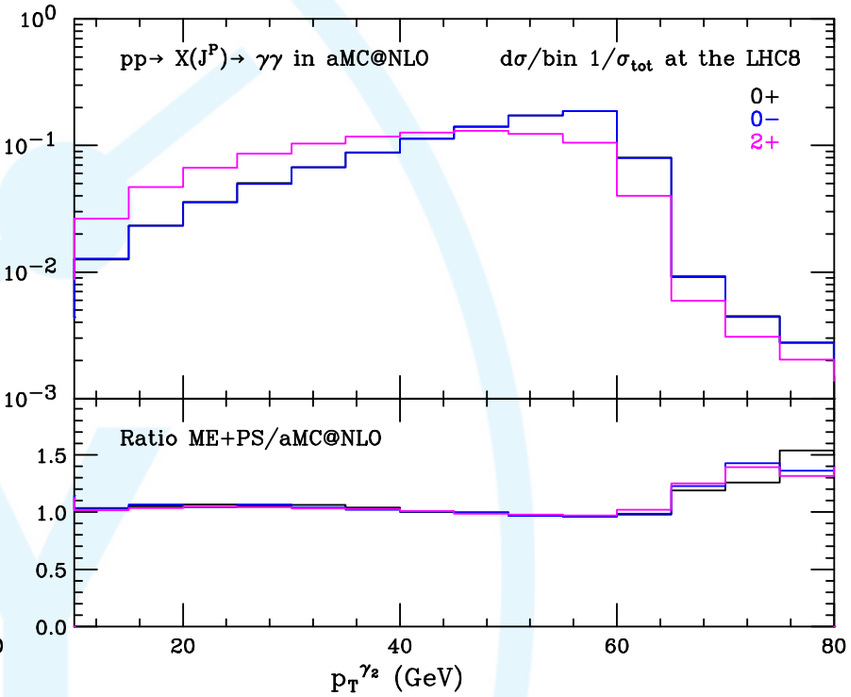

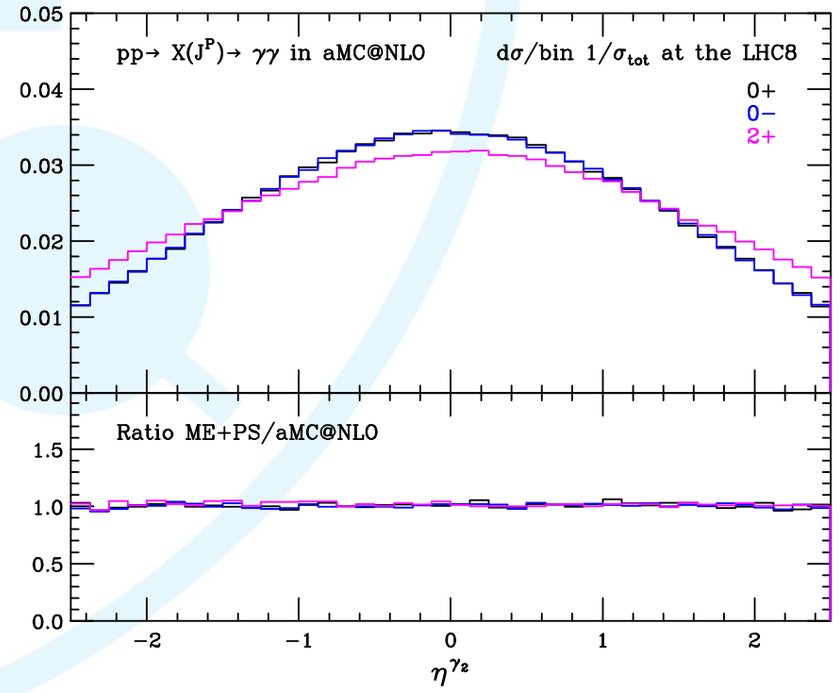

Non universal couplings to spin-2 resonances

- The production `p p > X2` is gluon-dominated (>90% at LO)
- One might be tempted to switch off the coupling to quarks
- This can be done (SU(3) gauge invariance ok), but there can be surprises...

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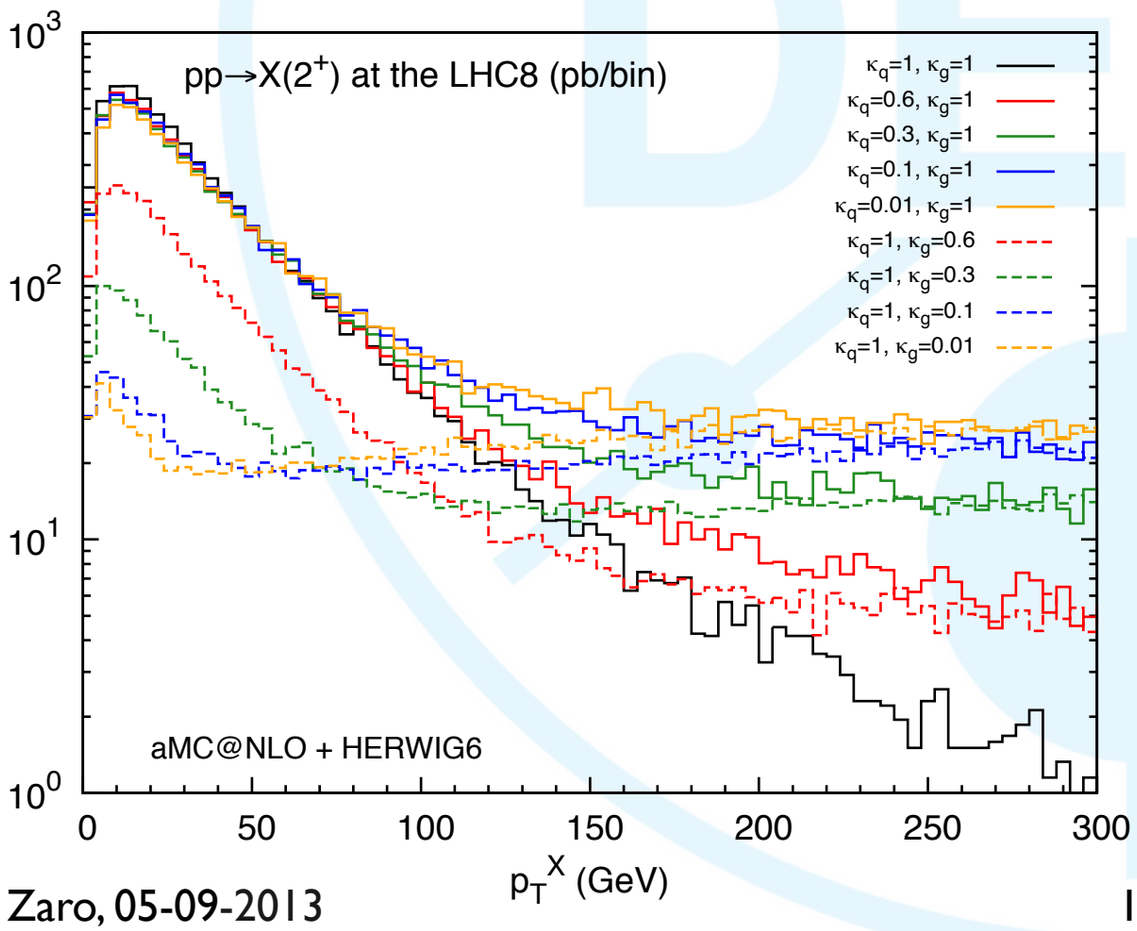

Unitarity-violating behavior in the p_T tail due to non conservation of gravitational current
Real emission ME explodes

Need $O(\alpha_s^3)$ to see this effect!
NLO or MEPS mandatory

Conclusions

- MC@NLO: v4.10 supports the Grazzini-Sargsyan resummation prescription for GF
- aMC@NLO: NLO computation (matched with PS) made easy!
  - Complete code with minimal dependencies
  - Further developments:
    - Interface with other OLP via the BLHA interface (e.g.GoSam)
    - Inclusion of the Fx-Fx merging @NLO
    - FeynRules @NLO
    - Automation of EW corrections
- More on http://amcatnlo.cern.ch