MadGraph5_aMC@NLO

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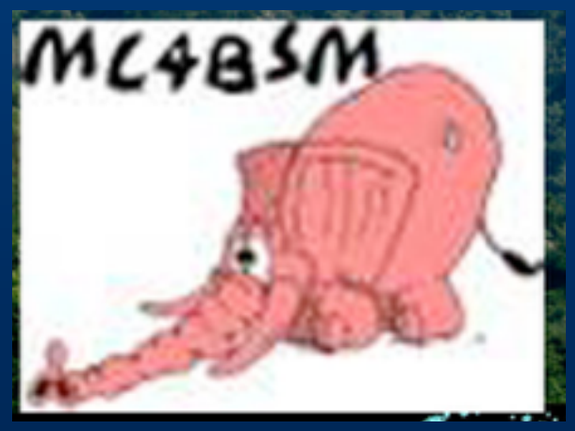

Plan

- What is MG5aMC?
- BSM support @ LO and NLO
- BSM re-weighting (LO and NLO)
- BSM tools and interface

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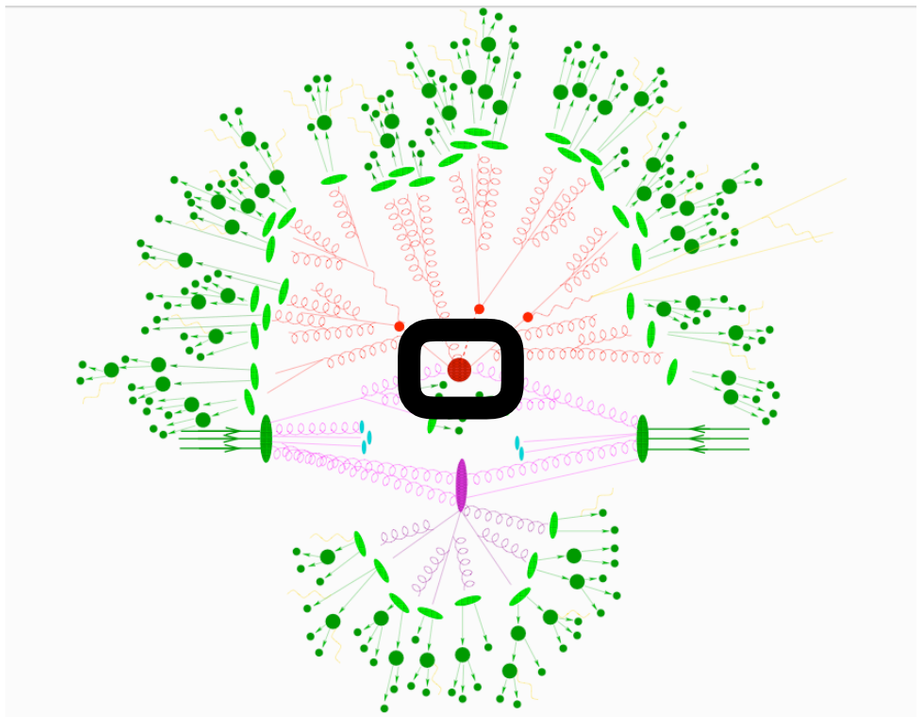
What it is?



- We simulate the high energy part of the collision
  - ➡ LO and NLO computation
- Cross-section and event generation
  - ➡ SM and BSM

Lagrangian

matrix-element

parton events

Showered events

hadronized events

Detector events

- Link theory with data
- Full Automation

What it is?

- This is a Framework of tools (MadSpin, MadWeight, ...)
- This is a matrix element provider (tree-level and one loop)

	Tree (SM)	Tree (BSM)	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	NLO (EW) (BSM)	Loop Induced (SM)	Loop Induced (BSM)
Fix Order	✓	✓	✓	✓	✓		✓	✓
+Parton Shower	✓	✓	✓	✓	✓		✓	✓
Merged Sample	✓	✓	✓		✓		✓	✓

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- What is MG5aMC?
- BSM support @ LO and NLO
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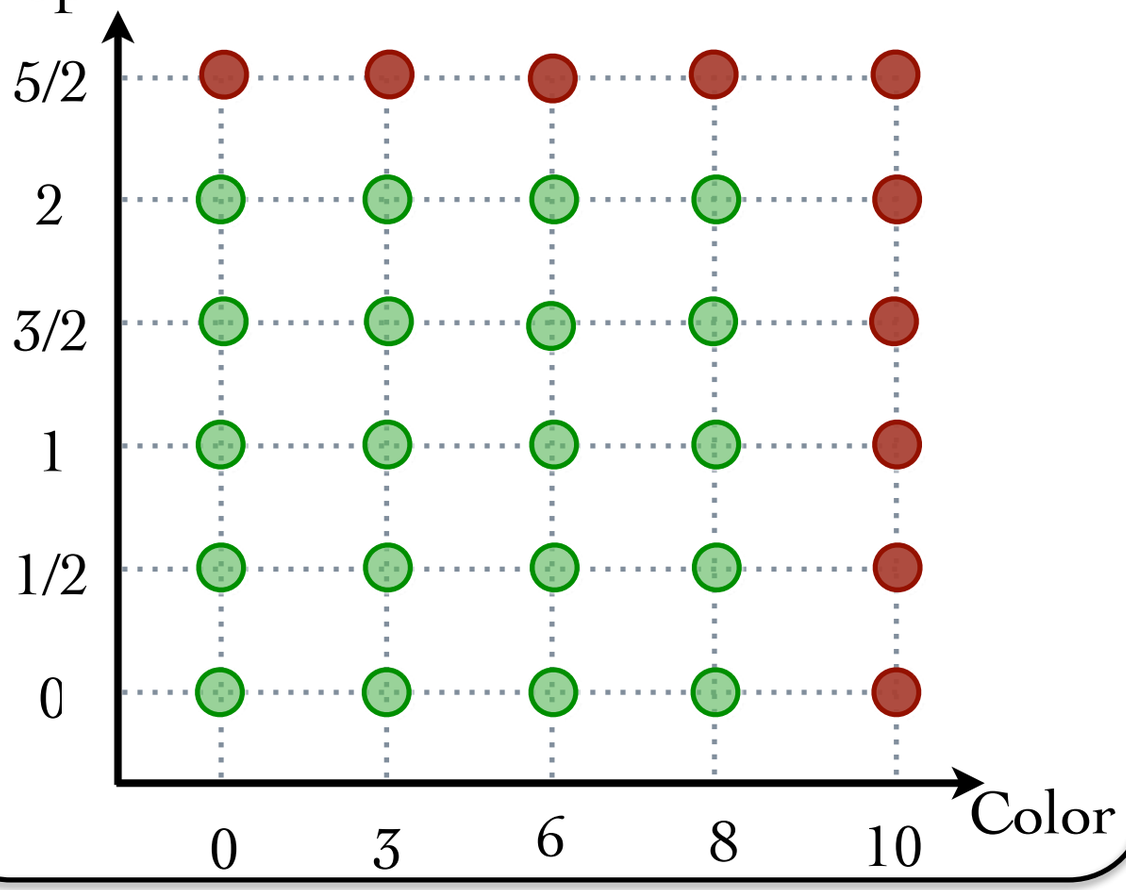
BSM Status @LO

Status

- No additional progress on this front since 2014
- Basically any BSM model is cover @LO
- Input UFO model (See FeynRules talk)



Lorentz

- Use HELAS routine
  - created by ALOHA
- Basically any lorentz structure is supported
  - some limit on 4-fermion with majorana

BSM Status @NLO

	Yes	No
FeyRules +MadLoop	*General CTs (UV&R2); Fermion-flow violation; Majorana particles; Non-renormalized opt; Spin-2 particles; Finite renormalization;*	*Complex-Mass Scheme; Corrections other than QCD; Four-fermion operators; General color repres; Spin-3/2 particle; others ?*
MadFKS +MC@NLO	*General Soft CTs; Restricted Coll. CTs; Restricted MC CTs; Color can be 1,3,8; Reweighting for aS;*	*On-shell subtraction; General Coll./MC CTs; General color; General Reweighting; Corrections other than QCD; others ?*

BSM Status @NLO

Slide copy from huasheng

	Yes	No
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- Still limited for the moment. But moving forward

Example of BSM

Slide copy from huasheng

- Colored particle production
  - Colored scalar pair production — Degrande, Fuks, Hirschi, Proudom, HSS (PRD'15)
  - Supersymmetric QCD — Degrande, Fuks, Hirschi, Proudom, HSS (PLB'16)
  - Vector-like quark pair production — Les Houches 2015 (1605.02684) ; Fuks, HSS (to appear)
  - MSSM — Degrande, Fuks, Goncalves-Netto, Hirschi, Lopez-Val, Mawatari, Pagani, Proudom, HSS, Zaro (in preparation)
- BSM Higgs production
  - Higgs characterisation model — Artoisenet et al. (JHEP'13); Maltoni, Mawatari, Zaro (EPJC'14); Demartin, Maltoni, Mawatari, Page, Zaro (EPJC'14); Demartin, Maltoni, Mawatari, Zaro (EPJC'15)
  - Two-Higgs-Doublet Model — Degrande (CPC'15); Degrande, Ubiali, Wiesemann, Zaro (JHEP'15)
  - Georgi-Machacek model — Degrande, Hartling, Logan, Peterson, Zaro (PRD'16)
- Spin-2 particle production — Das, Degrande, Hirschi, Maltoni, HSS (1605.09359)
- Dark matter collider production
  - s-channel mediator
    - spin 0 or 1 mediator — Mattelaer Vryonidou (EPJC'15); Backovic, Kramer, Maltoni, Martini, Mawatari, Pellen (EPJC'15); Neubert, Wang, Zhang (JHEP'16); Arina et al. (1605.09242)
    - spin 2 mediator — Das, Degrande, Hirschi, Maltoni, Mawatari, HSS (in preparation)
  - t-channel mediator — Fuks, Hirschi, Mattelaer et al. (in preparation)
- SM effective field theory
  - Top FCNC processes — Degrande, Maltoni, Wang, Zhang (PRD'15); Durieux, Maltoni, Zhang (PRD'15)
  - ttbarZ/gamma production — Bylund, Maltoni, Tsinikos, Vryonidou, Zhang (JHEP'16)
  - Single-top production — Zhang (PRL'16)
  - Top pair production via chromomagnetic dipole momenta — Franzosi, Zhang (15)
- Other colorless particle production
  - Heavy neutrino production — Degrande, Mattelaer, Ruiz, Tumer (1602.06957)

Plan

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BSM Re-Weighting

Re-weighting are everywhere

- scale and pdf uncertainties (available both for LO and NLO computation)
- loop induced processes
- matching/merging
- experimental re-weighting

BSM Re-weighting

- Change the events weights of a LHEF for various BSM theories.
- Re-use the same parton shower and detector simulation

LO

Re-Weighting

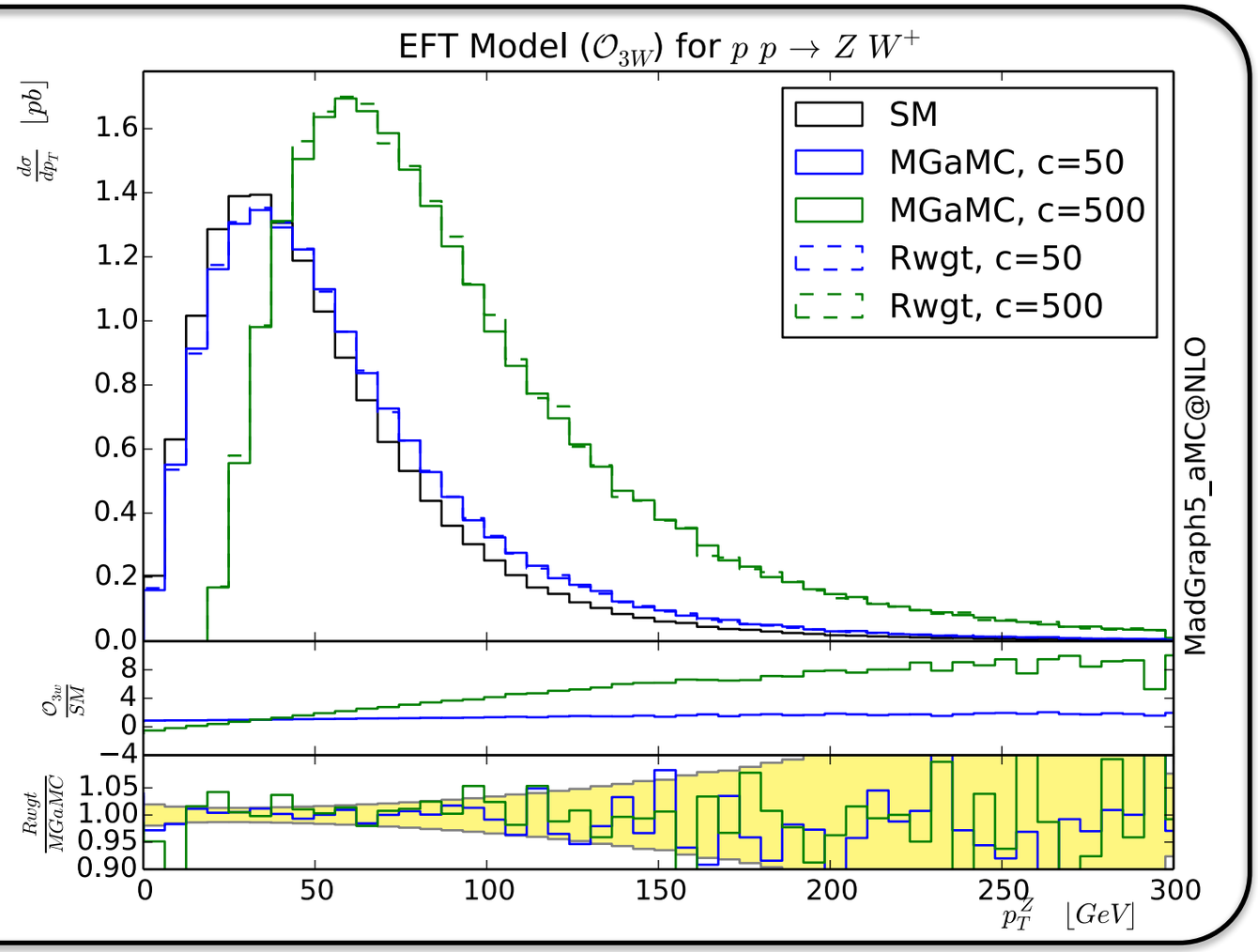
1404.7129
1607.00763

- Change the weight of the events

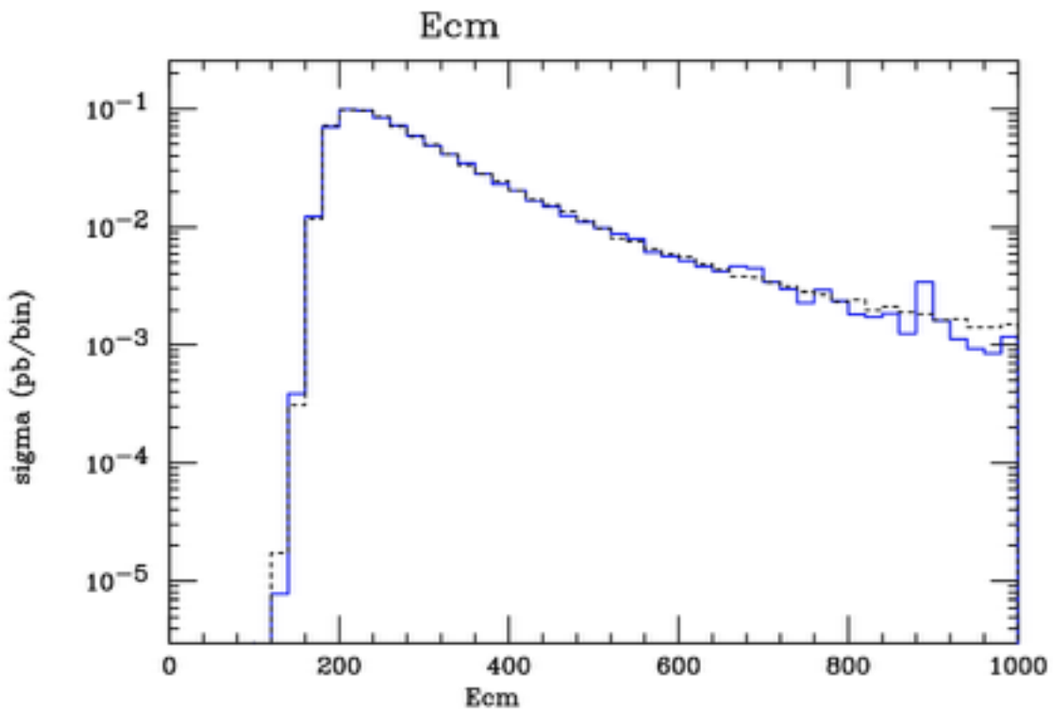
$$W_{new} = \frac{|M_{new}|^2}{|M_{old}|^2} * W_{old}$$

EFT Case

$$\mathcal{O}_{3W} = Tr\left[W_{\mu\nu}W^{\nu\rho}W_{\rho}{}^{\mu}\right]$$



Re-Weighting Limitation



$$\Delta\sigma_{new} = \frac{\sigma_{new}}{\sigma_{old}}\Delta\sigma_{new} + \mathrm{Var}_{wgt}\,\sigma_{old}$$

- statistical uncertainty can be enhanced by the re-weighting
- better to have wgt<1

- You need to have the same phase-space (more exactly a subset)
- Mass scan are possible only in special case
  - only for internal propagator
  - for small mass variation (order of the width)

Caution

LHE Additional information

Helicity

- Partial helicity distribution are not correct with the full re-weighting
- Solution $W_{new} = \frac{|M^h_{new}|^2}{|M^h_{orig}|^2} W_{orig},$

Now the default (@LO)

Leading color information

- modify the shower so not suitable.

Intermediate particle

- modify the shower so not suitable.

NLO Re-Weighting

Naive LO like

- MC@NLO

$$d\sigma^{(\mathbb{H})} = d\sigma^{R} - d\sigma^{MC},$$
$$d\sigma^{(\mathbb{S})} = d\sigma^{MC} + \sum_{\alpha=S,C,SC} d\sigma^{\alpha},$$

- Reweight by multiplicities

$$W^{(\mathbb{S})}_{new} = \frac{\mathcal{B}^{new}}{\mathcal{B}^{orig}} W^{\mathbb{S}}_{orig},$$
$$W^{(\mathbb{H})}_{new} = \frac{\mathcal{R}^{new}}{\mathcal{R}^{orig}} W^{\mathbb{H}}_{orig}.$$

- REPOLO method

NLO method

- tracks the dependencies in the various matrix-elements (born, virtual, real)

$$d\sigma^{\alpha} = f_1(x_1,\mu_F) f_2(x_2,\mu_F) \Big[\mathcal{W}^{\alpha}_0 + \mathcal{W}^{\alpha}_F \log\left(\mu_F/Q\right)^2 + \mathcal{W}^{\alpha}_R \log\left(\mu_R/Q\right)^2 \Big] d\chi^{\alpha},$$

$$\mathcal{W}^{\alpha}_{\beta} = \mathcal{B} * \mathcal{C}^{\alpha}_{\beta,B} + \mathcal{B}_{CC} * \mathcal{C}^{\alpha}_{\beta,B_{CC}} + \mathcal{V} * \mathcal{C}^{\alpha}_{\beta,V} + \mathcal{R} * \mathcal{C}^{\alpha}_{\beta,R}$$

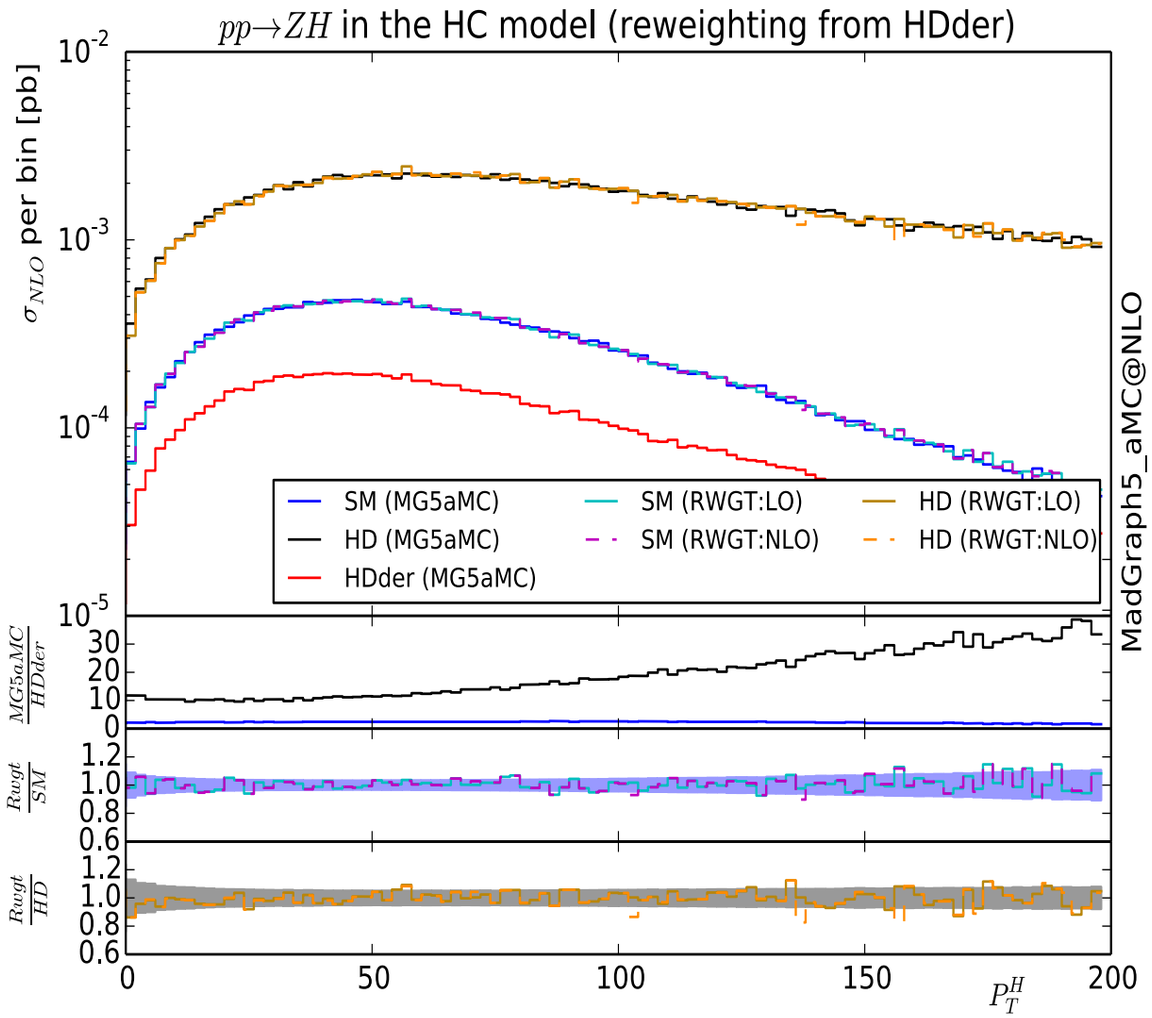
- re-weight each part according to the associated matrix-element
- compute the weight

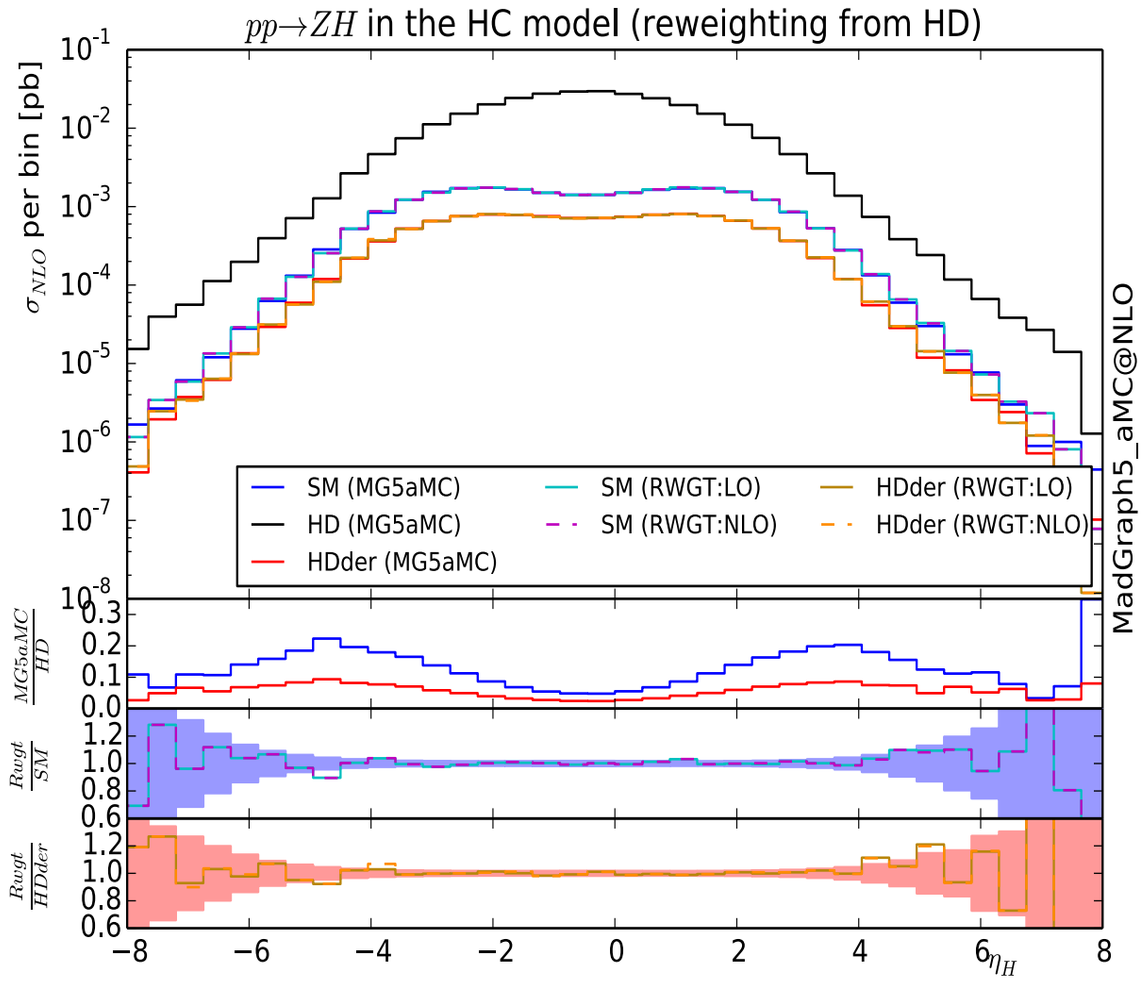
NLO Re-Weighting

EFT Example

$$\mathcal{L}_{HD} = -\frac{1}{4}\frac{1}{\Lambda}\kappa_{HWW} Z_{\mu\nu} Z^{\mu\nu} H$$

$$\mathcal{L}_{HDder} = -\frac{1}{\Lambda}\kappa_{H\partial Z} Z_\nu \partial_\mu Z^{\mu\nu} H + (-\frac{1}{\Lambda}\kappa_{H\partial W} W^+_\nu \partial_\mu W^{-\mu\nu} H + h.c.)\,,$$





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BSM Tools

BSM Related Tools

- MadSpin
- Automatic width computation
- MadDM

MadSpin

- Decay events with full spin-correlation
- LO decay but working for NLO generation
- keep off-shell effects
- cross-section computed in NWA

MadSpin

[Artoisenet, OM et al. 1212.3460]

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

One Event

offshell	spin	unweighted
No	No	YES

MadSpin

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offshell	spin	unweighted
No	No	YES

One Event

- smear the mass
- flat decay

Decay Events

MadSpin

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One Event

- smear the mass
- flat decay

Decay Events

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YES	No	No

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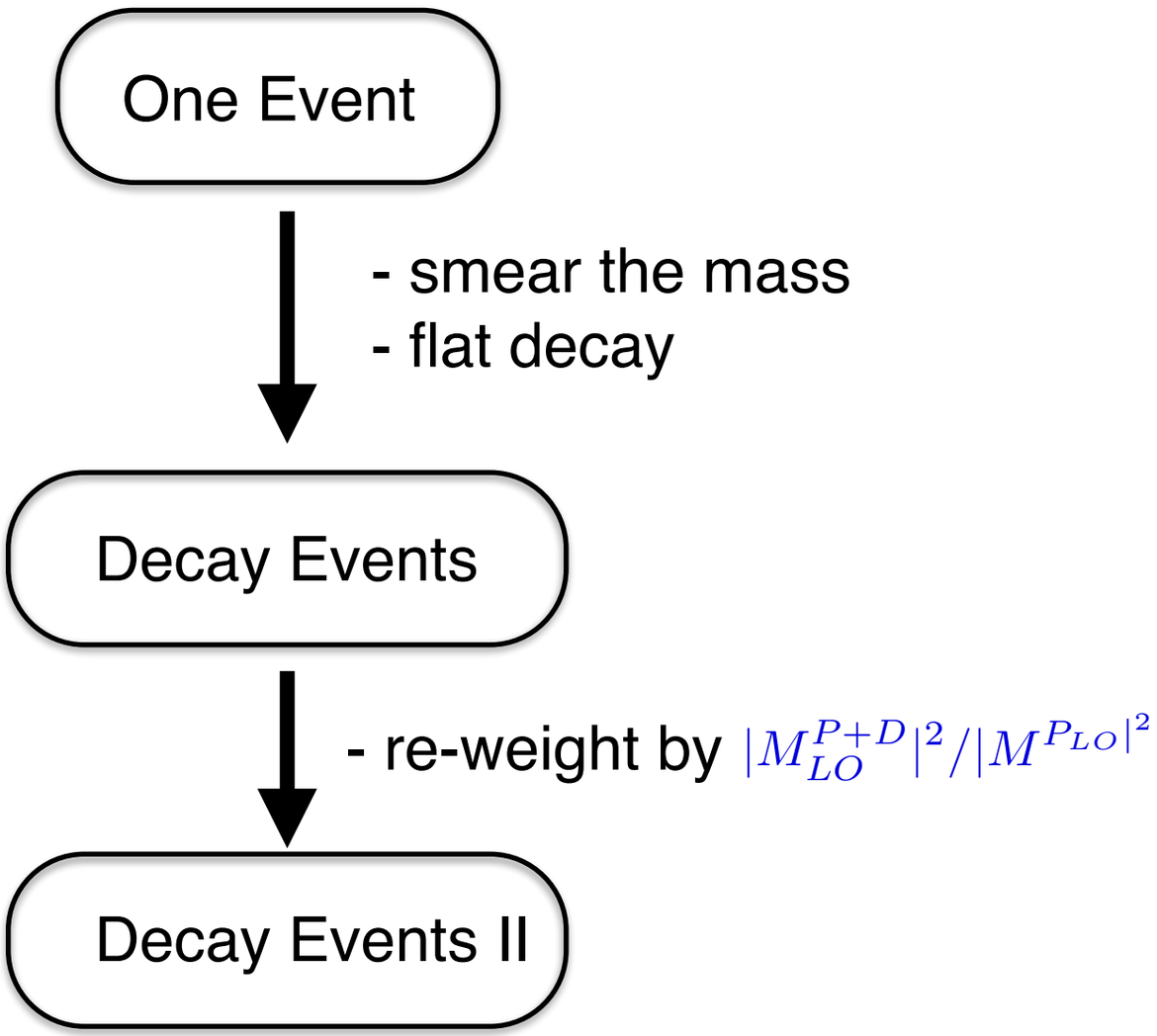

offshell	spin	unweighted
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YES	No	No

MadSpin

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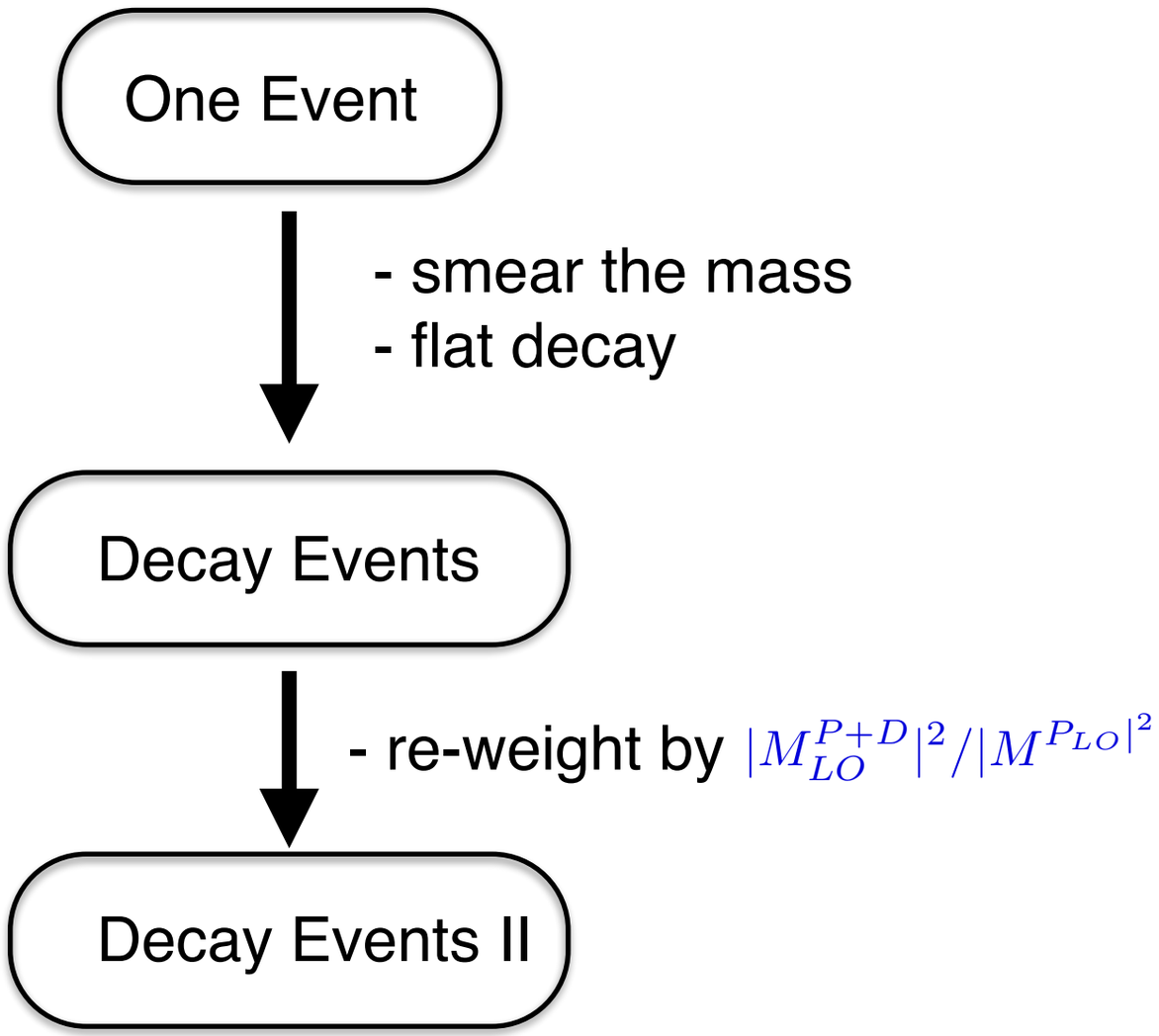

offshell	spin	unweighted
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YES	No	No
YES	YES	No

MadSpin

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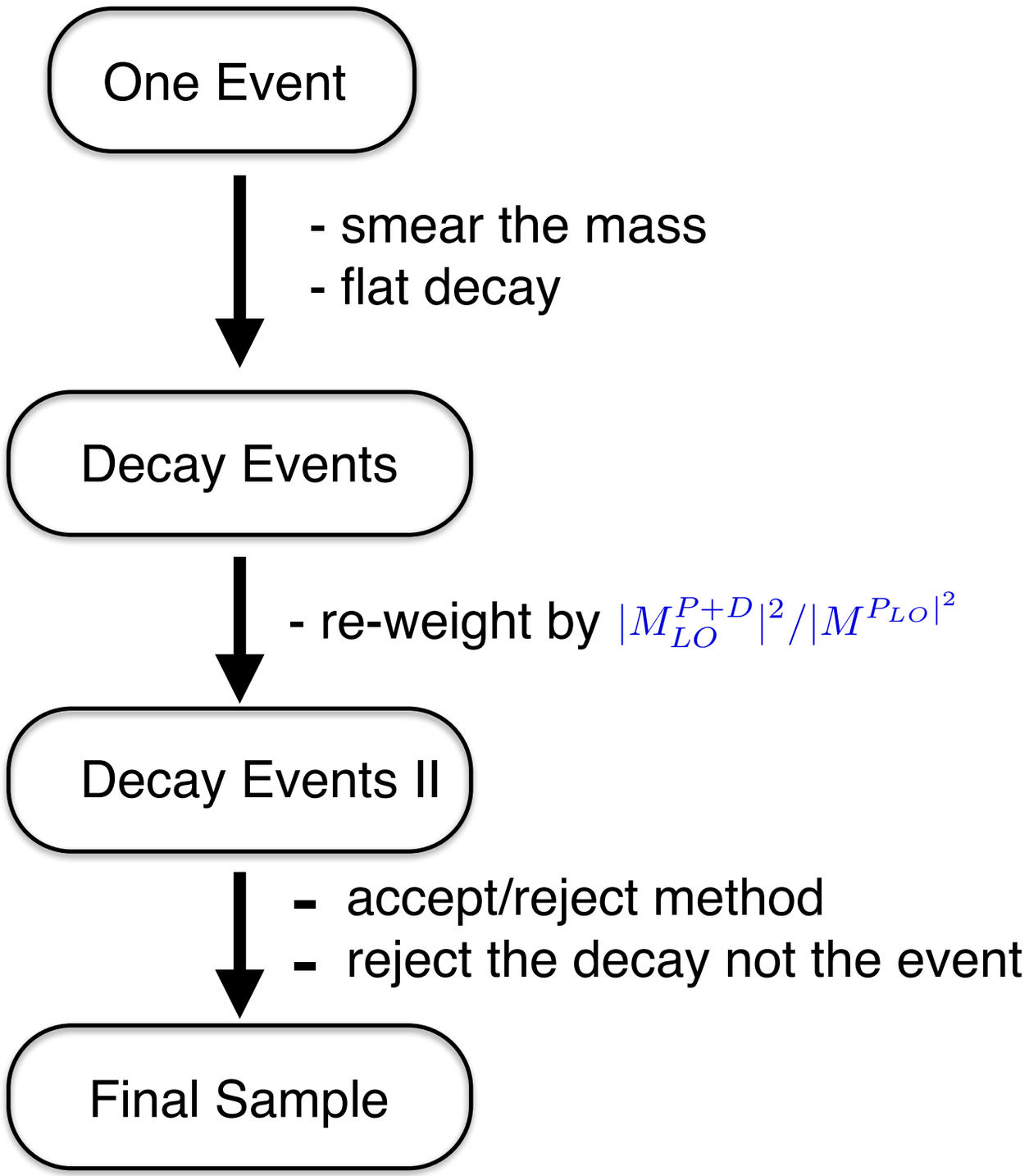

offshell	spin	unweighted
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YES	No	No
YES	YES	No

MadSpin

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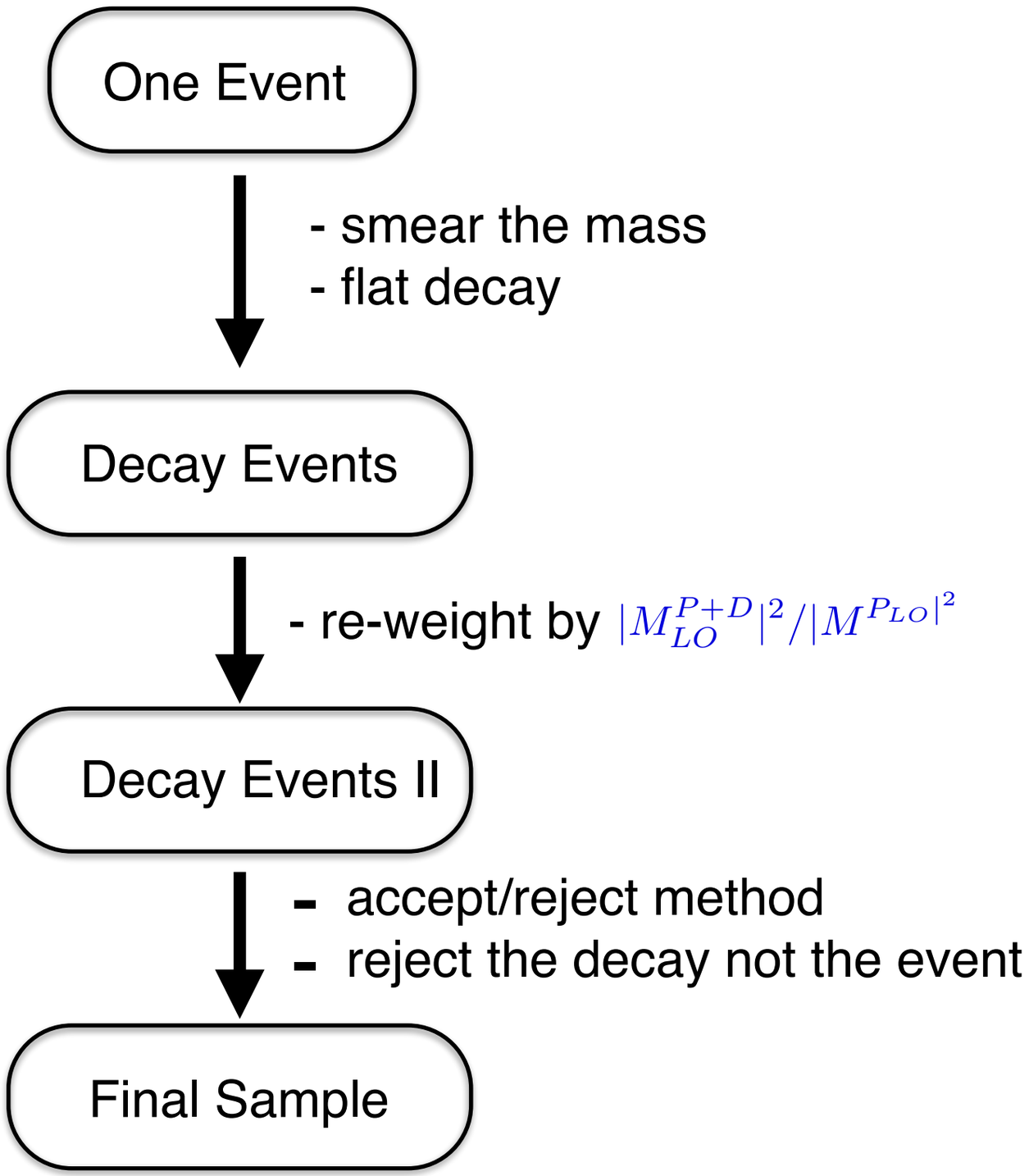

offshell	spin	unweighted
No	No	YES
YES	No	No
YES	YES	No
YES	YES	YES

Width

hep-ph/1402.1178

2-body

- Use FeynRules formula (instateneous)

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Fast-Estimation of 3-body
- Only use 2-body decay and PS factor

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No

DONE

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Relevant?
- Maybe → Channel Generation
- No → DONE

Channel Generation
- Remove Sequence of 2-body/radiation diagram

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hep-ph/1402.1178

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Relevant?

No → DONE

Maybe

Channel Generation
- Remove Sequence of 2-body/radiation diagram

Estimation of 3-body
- Based on the diagram. Approx. PS/Matrix-Element

Relevant?

Width

hep-ph/1402.1178

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Relevant?
- Maybe
- No

Channel Generation
- Remove Sequence of 2-body/radiation diagram

DONE

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Relevant?
- No

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hep-ph/1402.1178

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Relevant?
- Maybe
- No

Channel Generation
- Remove Sequence of 2-body/radiation diagram

DONE

Estimation of 3-body
- Based on the diagram. Approx. PS/Matrix-Element

Relevant?
- No
- Yes?

Numerical Integration

Width

hep-ph/1402.1178

2-body
- Use FeynRules formula (instateneous)

Fast-Estimation of 4 body
- Only use 2-body decay and PS factor

Relevant?
- Maybe
- No

Channel Generation
- Remove Sequence of 2-body/radiation diagram

DONE

Estimation of 4 body
- Based on the diagram. Approx. PS/Matrix-Element

Relevant?
- No
- Yes?

Numerical Integration

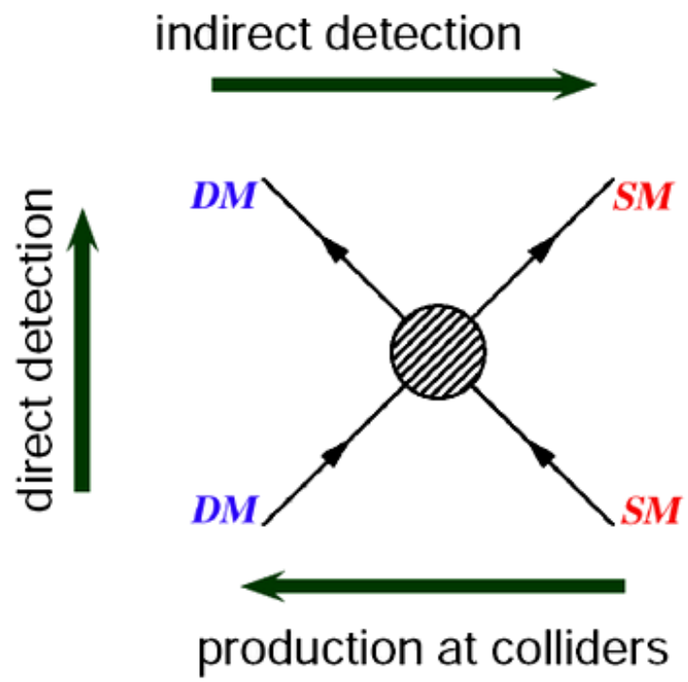
Tools

width Limitation

- Only LO
- No Loop Induced Decay
- Valid in Narrow-width approximation
- No hadronization effect

MadDM

- automatic determination of the DM candidate
- relic density computation
- direct and directional detection
- work in progress for indirect detection



Interface

Different type of linking

- output format
  - ➡ example: pythia8/Matchbox
- program run on generated event(LHEF)
  - ➡ example: shower program/detector simulation/plotting routine/...
  - ➡ program can be installed by MadGraph

How to add a new output?

- So far, need to be part of the main code
  - ➡Always available
  - ➡Annoying for maintenance

Interface

Development: Plugin output

- Allow new output type via PLUGIN module
  - ➡ example: Momenta / MadDM3.0
- Python module to install in “PLUGIN” directory
- Allow to define “output XXXX PATH” to work as YOU want
  - Abstract class, Documentation and example are available

Plugin can also

- Define new cluster class
- Define/Modify the user interface

CONCLUSION

- MadGraph5_aMC@NLO is committed to support BSM physics:
  - ➡ Full support of BSM@LO:
    - Basically any model supported
    - Many tools available
  - ➡ BSM@NLO is moving forward
    - Many publication
    - we are working to extend the possibility
- Plugin method should allow easier use of our generated matrix-element