Simulation of BSM Physics (II)

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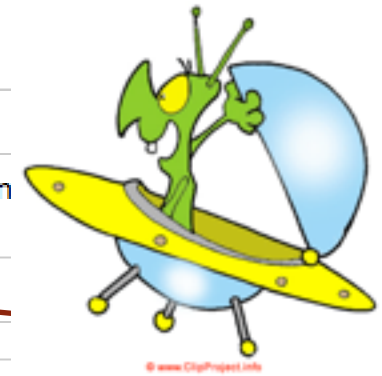
Plan

- Today:
  - ➡ Effective Field Theory
  - ➡ Width computation
  - ➡ Narrow width approximation (decay-chain)
  - ➡ Mass Production
  - ➡ ReCasting

Which Model?

Available models

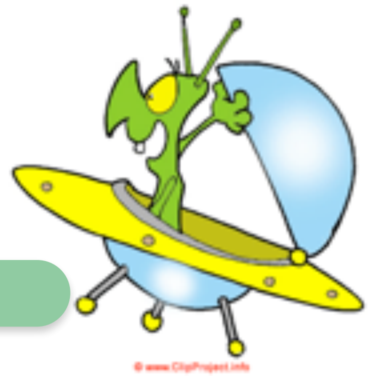


Standard Model	The SM implementation of FeynRules, included into the distribution of the FeynRules package.
Simple extensions of the SM (18)	Several models based on the SM that include one or more additional particles, like a 4th generation, a secon doublet or additional colored scalars.
Supersymmetric Models (5)	Various supersymmetric extensions of the SM, including the MSSM, the NMSSM and many more.
Extra-dimensi	
Strongly coupl theories (8)	
Miscellaneous	

Model	Short Description	Contact	Status
Axigluon model	The SM plus a scalar gluon field.	S. Krastanov	**Available**
DY SM extension	The SM plus new spin-0, -1, and -2 bosons that contribute to Drell-Yan production of leptons at the LHC.	N. Christensen	**Available**
FCNC Higgs interactions	The SM plus higher-dimensional flavor changing Higgs interactions.	S. Krastanov	**Available**
Fourth generation model	A fourth generation model including a t' and a b'	C. Duhr	**Available**
General 2HDM	The most general 2HDM, including all flavor violation and mixing terms.	C. Duhr, M. Herquet	**Available**
Hidden Abelian Higgs Model	A Z' model where the Z' interacts with the SM through mixings, leading to very small non-SM like Z' couplings.	C. Duhr	**Available**
HiggsCharacterisation	The model file for the spin/parity characterisation of a 125 GeV resonance.	P. de Aquino, K. Mawatari	**Available**
Higgs effective theory	An add-on for the SM implementation containing the dimension 5 gluon fusion operator.	C. Duhr	**Available**
Higgs Effective Lagrangian	Higgs effective Lagrangian including operators up-to dimension 6.	A. Alloul, B. Fuks and V. Sanz	**Available**
Hill Model	A model with an unusual extension of the SM Higgs sector.	P. de Aquino, C. Duhr	**Available**
Inert Doublet Model	A model with an additional complex scalar SU(2)L doublet and an unbroken Z2 symmetry under which all SM particles are even while the extra doublet is odd.	A. Goudelis, B. Herrmann, O. Stal	**Available**
Minimal Zp models	The minimal Z' extension of the SM.	L. Basso	**Available**
Monotops	The SM plus monotop effective Lagrangian.	B. Fuks	**Available**
Sextet diquarks	The SM plus sextet diquark scalars.	J. Alwall, C. Duhr	**Available**
Standard model + Scalars	The SM, together with a set of singlet scalar particles coupling only to the SM Higgs, and allowing it to decay invisibly into this new scalar sector.	C. Duhr	**Available**
Triplet diquarks	The SM plus triplet diquark scalars.	J. Alwall, C. Duhr	**Available**
Type III See-Saw Model	The SM, including neutrino masses coming from a type III See-Saw mechanism.	C. Biggio, F. Bonnet	**Available**
VLQ	The SM, plus vector-like quarks, in a model-independent framework.	M. Buchkremer, G. Cacciapaglia, A. Deandrea, L. Panizzi	**Available**
Wprime	The SM a new spin-1 W' boson.	J. Donini, B. Fuks	**Available**

Which Model?

Available models



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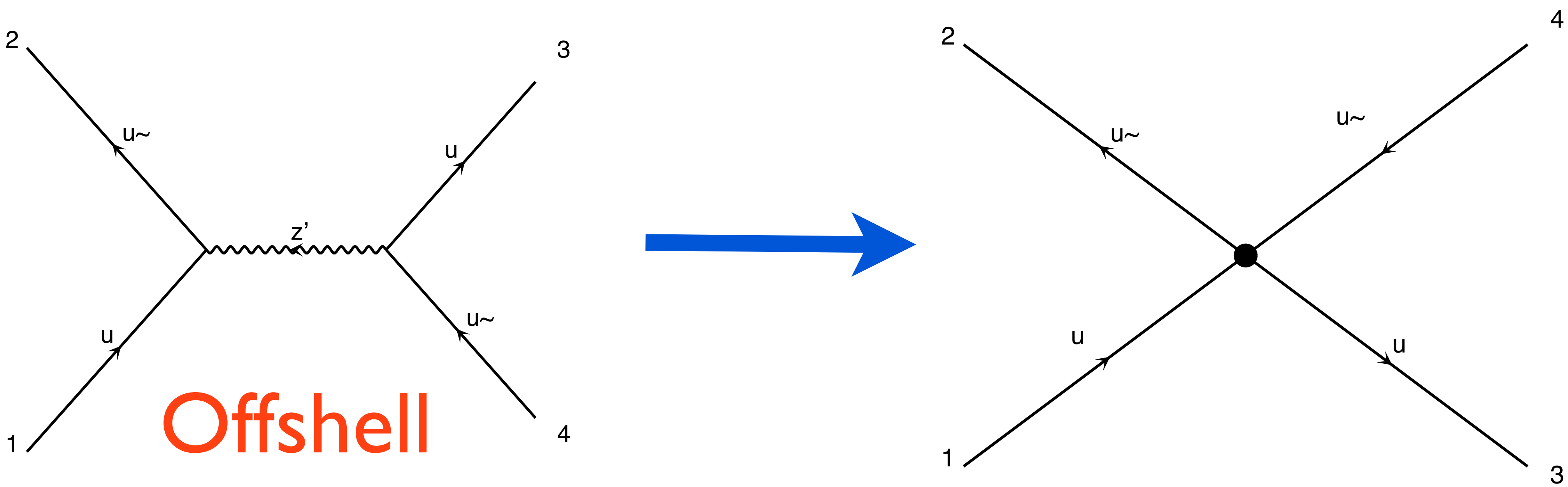
Supersymmetric Models (5)	Various supersymmetric extensions of the SM, including the MSSM, the NMSSM and many more.
Extra-dimensional Models (4)	Extensions of the SM including KK excitations of the SM particles.
Strongly coupled and effective field theories (8)	Including Technicolor, Little Higgs, as well as SM higher-dimensional operators, vector-like quarks.
Miscellaneous (0)	

Effective Operator

- New Physics at (too?) High Energy



Offshell

$$M_{Z'} \gg \sqrt{\hat{S}}$$

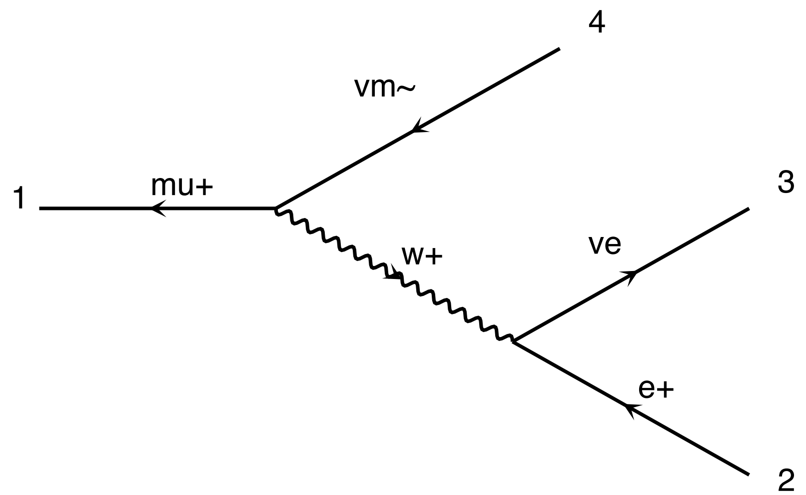
Effective Vertex

☞ Additional terms in the Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cancel{\frac{1}{\Lambda^4}\mathcal{L}_8} + \ldots$$

Fermi Theory

- The muon decay can (and was) be described by a Dimension 6 operator



$$\frac{G_F}{\sqrt{2}} \left(\bar{\nu}_l \gamma_\mu (1-\gamma_5) l\right) \left(\bar{l} \gamma^\mu (1-\gamma_5) \nu_l\right)$$

Dimension 6: $\frac{G_F}{\sqrt{2}} = \frac{c_F}{\Lambda_F^2}$

- This corresponds to the first term of the propagator Taylor expansion

Dimension 8

$$\frac{1}{p^2 - M_W^2} = -\frac{1}{M_W^2} - \frac{p^2}{M_W^4} + \dots$$

Effective Field Theory

$$\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

Type	Name	Dimension
Bosons	$H\,, G\,, W\,,\ B$	1
Fermion	L, Q, l_R, u_R, d_R	3/2
Covariant derivative	D^μ	1
Strength tensor	$F^{\mu\nu}$	2

Effective Field Theory

$$\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

The number of possible Operators are huge

- 59 Dimension 6 Operators If
  - ☞ Preserve the SM gauge symmetries
  - ☞ Preserve B-L accidental symmetries
  - ☞ We consider only one flavour

- Only One Dimension 5 Operator:

$$\frac{1}{\Lambda}\epsilon_{ij}\epsilon_{kl}H^j H^l \bar{L}^{ci}_R L^k_L$$

Give a mass to the neutrino

$$\mathcal{L} = \mathcal{L}^{SM} + \sum \frac{c_i}{\Lambda^2}\mathcal{O}_i + \mathscr{O}\left(\frac{1}{\Lambda^4}\right)$$

Th. error

Dimension 8

- Smaller effects or larger errors for higher dimension operators

$$\mathcal{L} = \mathcal{L}^{SM} + \sum \frac{c_i}{\Lambda^2}\mathcal{O}_i^6 + \sum \frac{d_i}{\Lambda^4}\mathcal{O}_i^8 + \mathcal{O}\left(\Lambda^{-6}\right)$$

1	10%	1%	0.1%
1	0%	10%	3%

- Extra assumptions if first order does not vanishes
- Less convergence
  - ➡ more problem with unitarity

Effective Field Theory

$$\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

- Only few Operators for one process and different effects

Weak Boson production

Conserving CP

$$\mathcal{O}_{WWW} = \mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W_{\rho}^{\mu}]$$
$$\mathcal{O}_{W} = (D_\mu\Phi)^\dagger W^{\mu\nu}(D_\nu\Phi)$$
$$\mathcal{O}_{B} = (D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi)$$

Not Conserving CP

$$\mathcal{O}_{\tilde{W}WW} = \mathrm{Tr}[\tilde{W}_{\mu\nu}W^{\nu\rho}W_{\rho}^{\mu}]$$
$$\mathcal{O}_{\tilde{W}} = (D_\mu\Phi)^\dagger \tilde{W}^{\mu\nu}(D_\nu\Phi)$$

Benchmark

- After having choose the model of interests you need to choose a benchmark

SUSY Case

- Low Energy spectrum is calculable from High energy spectra.
- Based on the RGE
- Example:
  - ➡ SoftSUSY
  - ➡ FlexibleSUSY

EFT

- Free parameter
- Check the constraint on the parameter

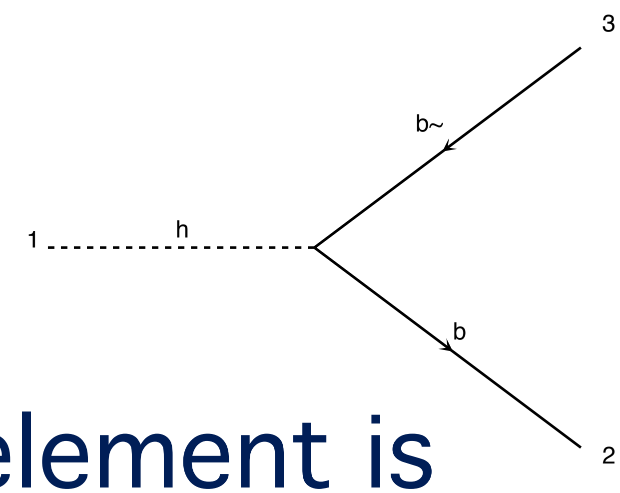
What about the width?

- Need to be (re-)computed for each phase-space.
- Need partial-width

2-body decay

2 body decay

$$\Gamma = \frac{1}{2MS}\int d\Phi_2|\mathcal{M}|^2$$



- By Lorentz Invariance the matrix element is constant over the phase-space.

$$\Gamma = \frac{\sqrt{\lambda(M^2,m_1^2,m_2^2)}|\mathcal{M}|^2}{16\pi S M^3}$$

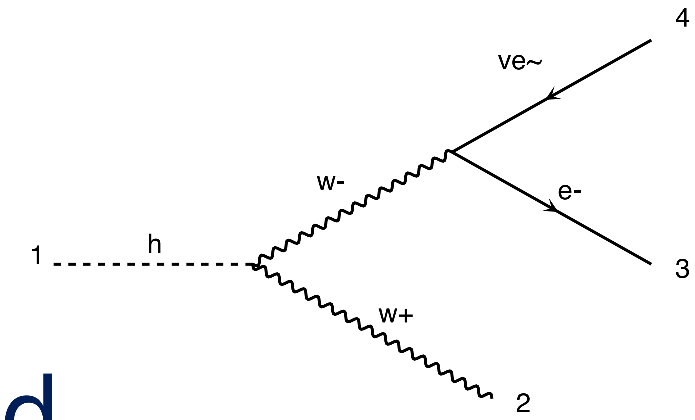
$$\lambda(M^2,m_1^2,m_2^2) = \left(M^2 - m_1^2 - m_2^2\right)^2 - 4m_1^2m_2^2$$

- Calculable analytically by FeynRules
  - ➡ formula present in the UFO model.

```
Decay_t = Decay(name = 'Decay_t',
                particle = P.t,
                partial_widths = {(P.W__plus__,P.d):'((MT**2 - MW**2)*((3*CKM3x1*ee**2*MT**2*complexconjugate(CKM3x1))/(2.*s
                                  (P.W__plus__,P.s):'((MT**2 - MW**2)*((3*CKM3x2*ee**2*MT**2*complexconjugate(CKM3x2))/(2.*s
                                  (P.W__plus__,P.b):'(((3*CKM3x3*ee**2*MB**2*complexconjugate(CKM3x3))/(2.*sw**2) + (3*CKM3x
```

N Body Decay

3(and more)-body Decay



- Analytical Formula too complicated
  - ➡ Especially in a spectrum independent way
  - Numerical integration
- Need to remove double counting with 2-body
- Typically LO computation
  - Remove radiation diagram

Example of code

- Herwig / Bridge / MadWidth

MadWidth

hep-ph/1402.1178

2-body
- Use FeynRules formula (instateneous)

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

Relevant?

No → DONE

Maybe ↓

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

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

Relevant?

No → DONE

Yes? ↓

Numerical Integration

Speed

Speed comparison

Model	FeynRules Two-body	Bridge Two-body	MadWidth Default	Bridge Three-body
HEFT model	0.6 s	60s	40s	114 s
SPS1a MSSM scenario	12 s	13min 43s	84 s	1h47

- 100 times faster for 2body decay
- 3 to 75 times faster for 3body decay

Input

```
DECAY 2000011 Auto #  wsl4
DECAY 2000013 Auto #  wsl5
DECAY 2000015 Auto #  wsl6
```

Output

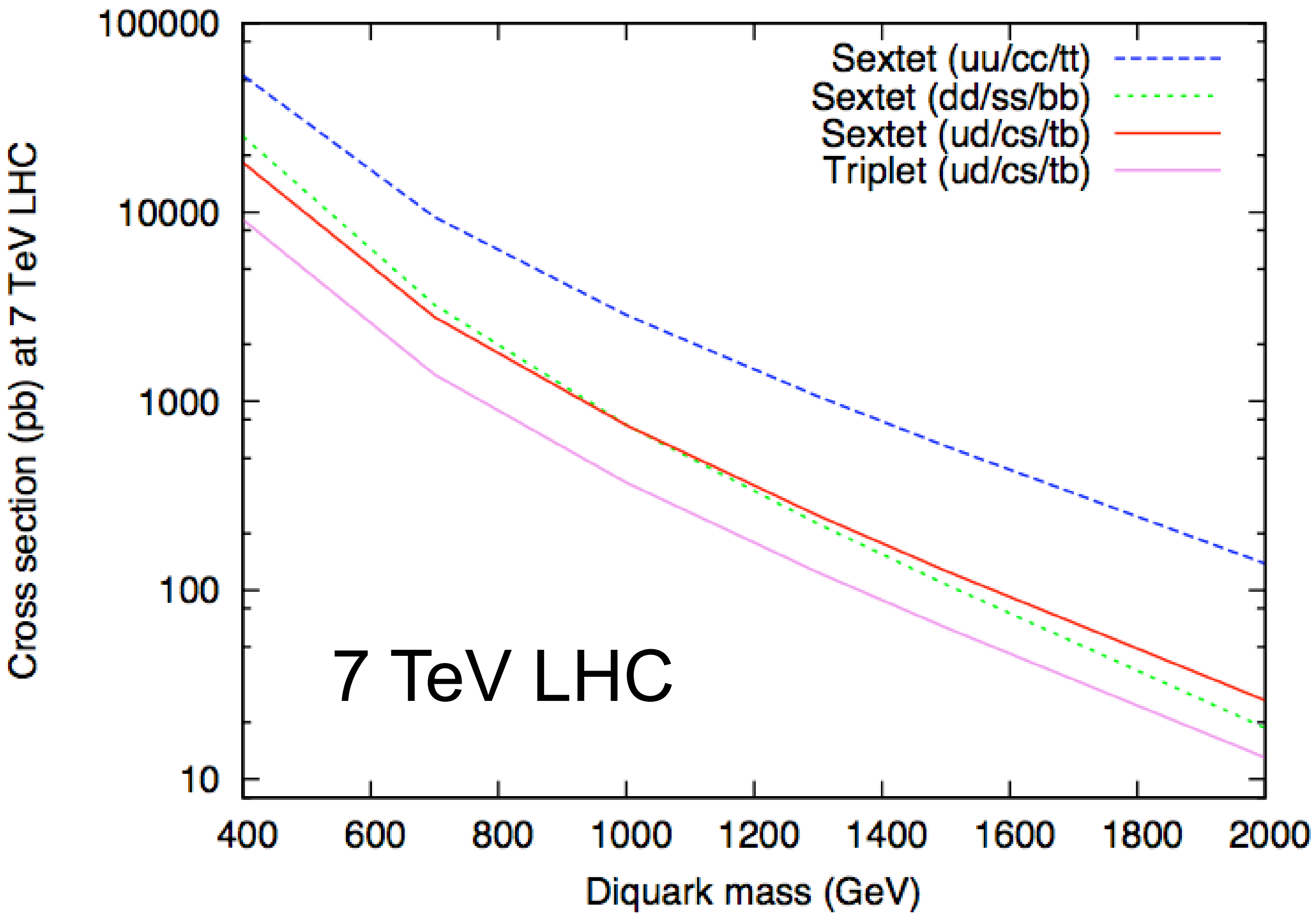
```
DECAY   25    1.844415e-02
#  BR                NDA  ID1     I
    7.587771e-01     2    -5   5 #
    1.214531e-01     2    -4   4 #
    9.108578e-02     2    -15   15
    5.920576e-03     2    -4   6 #
    5.920576e-03     2    -6   4 #
    4.858342e-03     2    -3   3 #
    4.070016e-03     3    -24   -5
    4.069040e-03     3    -6   5   2
```

QCD

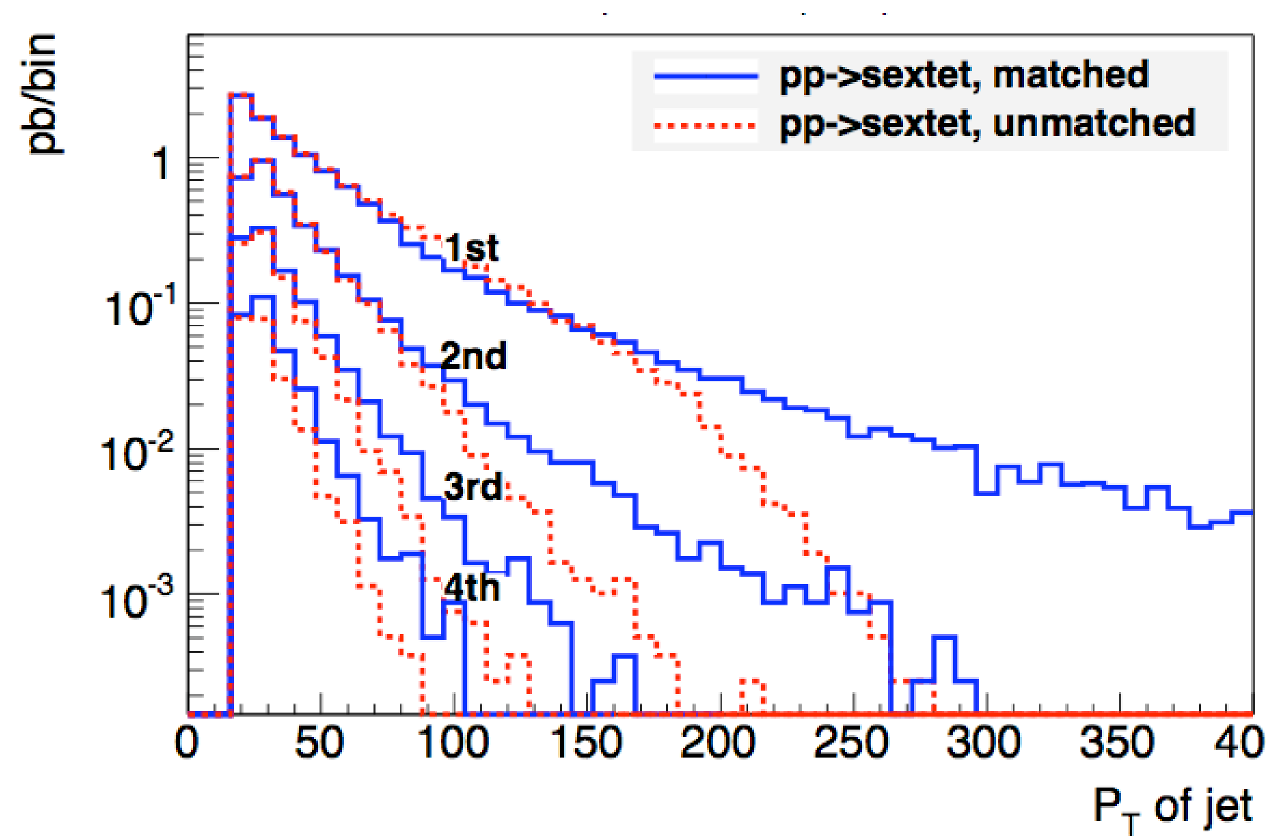
- Need to be handle in a specific way
  - ➡ provide additional information for the shower
- Handling the color algebra to rewrite it in a product of δ_{ij} (i.e color flow)

color	disponibility
1	✓
3	✓
ϵ_{ijk}	✓
6	✓
8	✓
10	Whizard

Color sextet and ε^{ijk} implementations



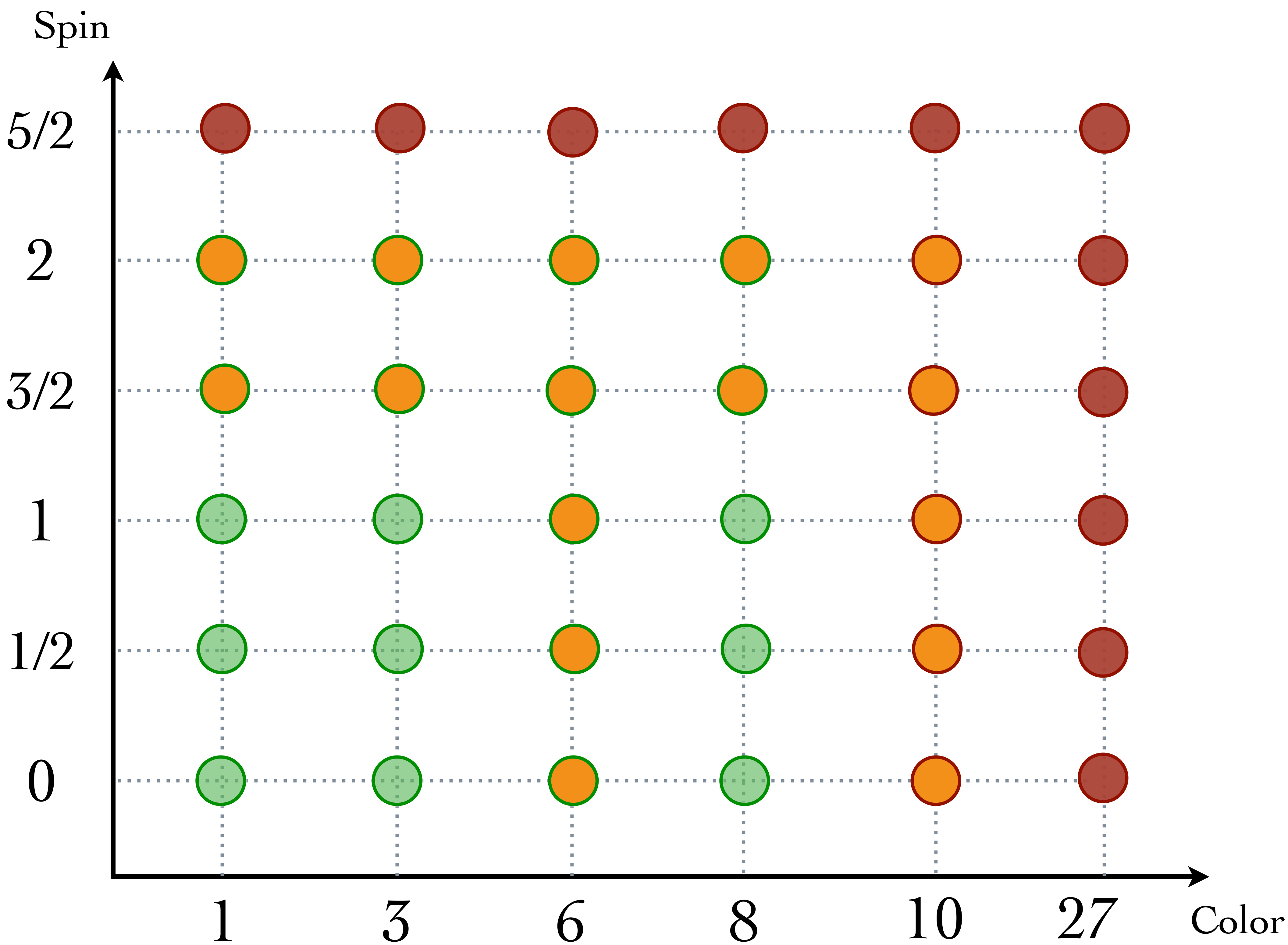
Diquark cross sections with coupling 0.01



Jet p_T:s, fully matched

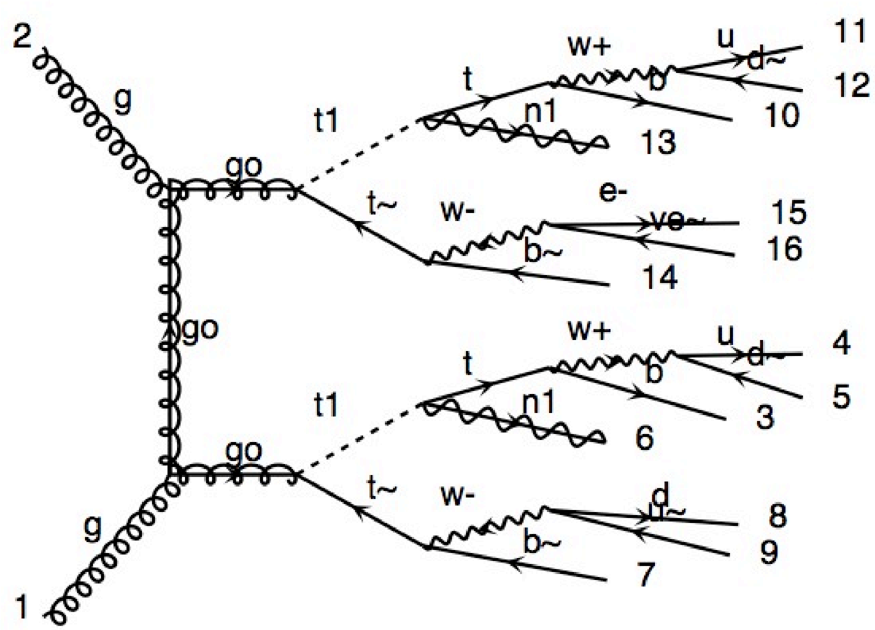
pp → D + 0,1,2 jets

Spin-Color

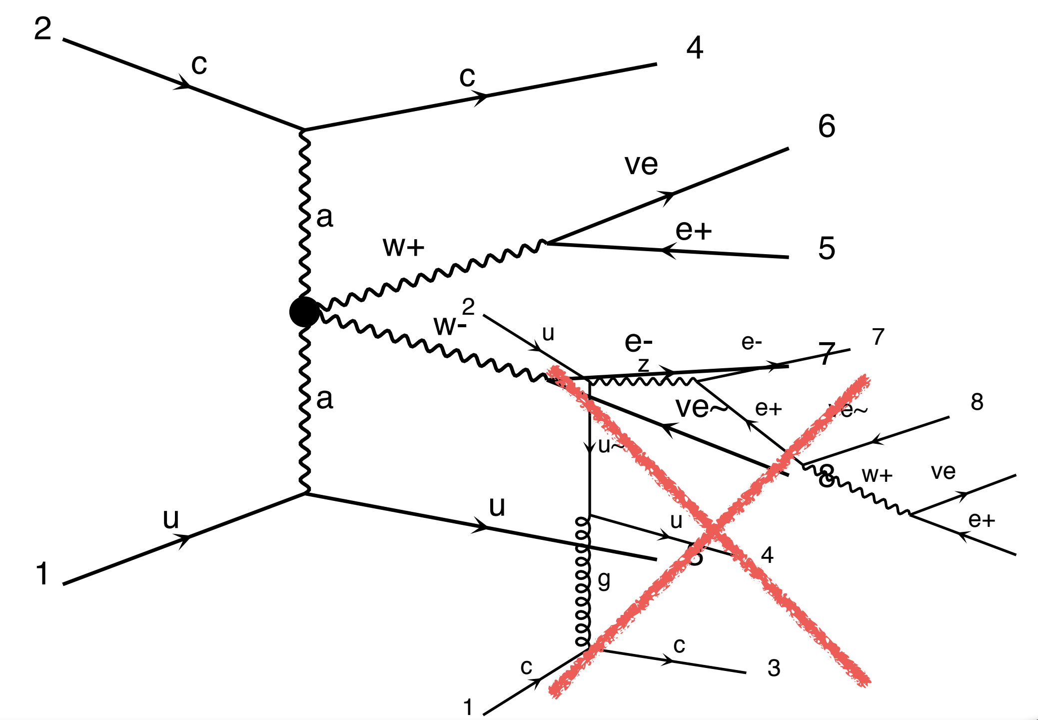


Decay

SUSY Case



EFT Case



Problem

- Process complicated to have the full process
  - ➡Including off-shell contribution

Solution

- Only keep on-shell contribution

Narrow-Width Approx.

Theory

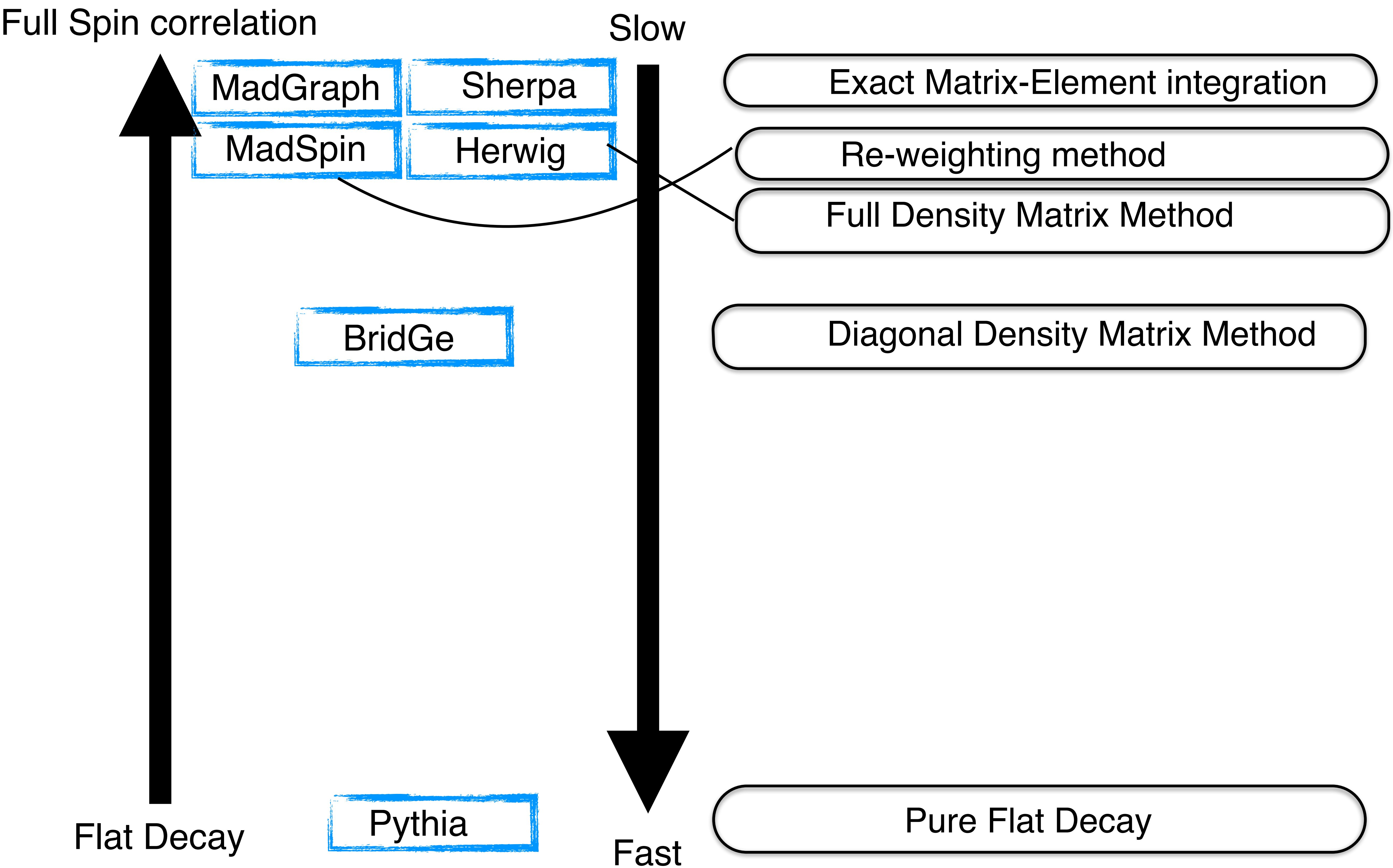
$$\int dq^2 \left| \frac{1}{q^2 - M^2 - iM\Gamma} \right|^2 \approx \frac{\pi}{M\Gamma} \delta(q^2 - M^2)$$

$$\sigma_{full} = \sigma_{prod} * (BR + \mathcal{O}(\frac{\Gamma}{M}))$$

Comment

- This is an Approximation!
- This force the particle to be on-shell!
    - Recover by re-introducing the Breit-wigner up-to a cut-off

Spin-correlation



MadSpin

[Artoisenet, OM et al. 1212.3460]

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

offshell	spin	unweighted
No	No	YES

One Event

- smear the mass
- flat decay

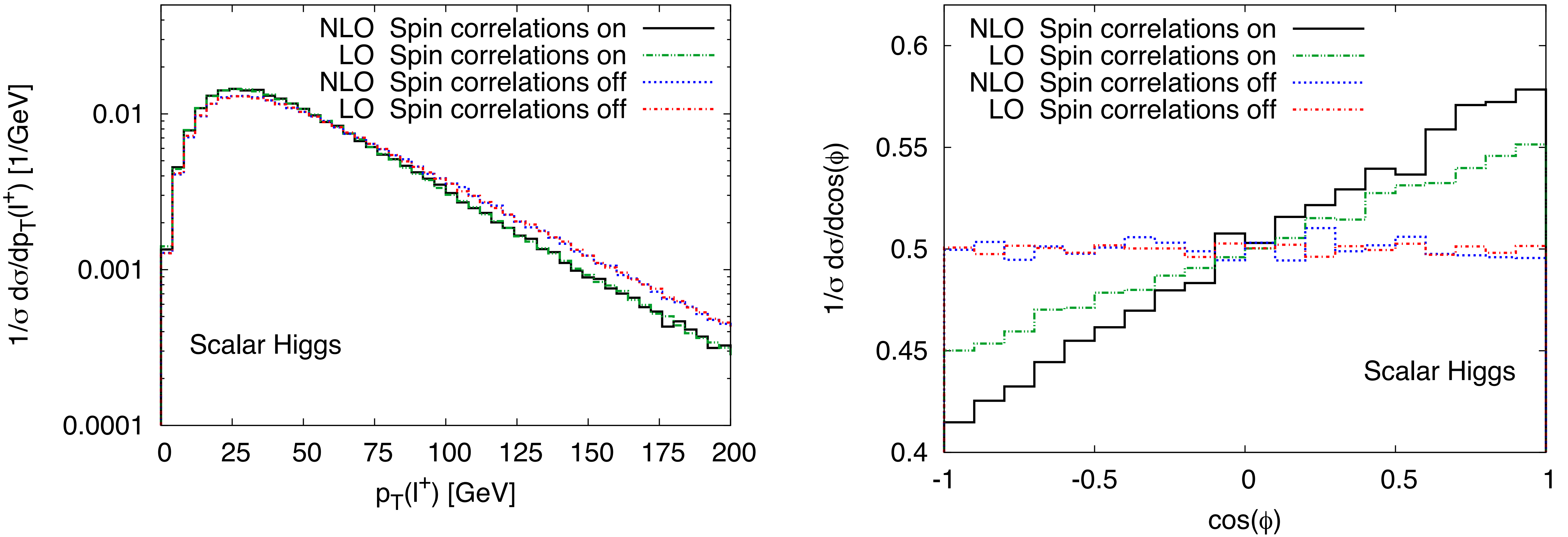
Decay Events

- re-weight by $|M_{LO}^{P+D}|^2/|M^{P_{LO}}|^2$

Decay Events II

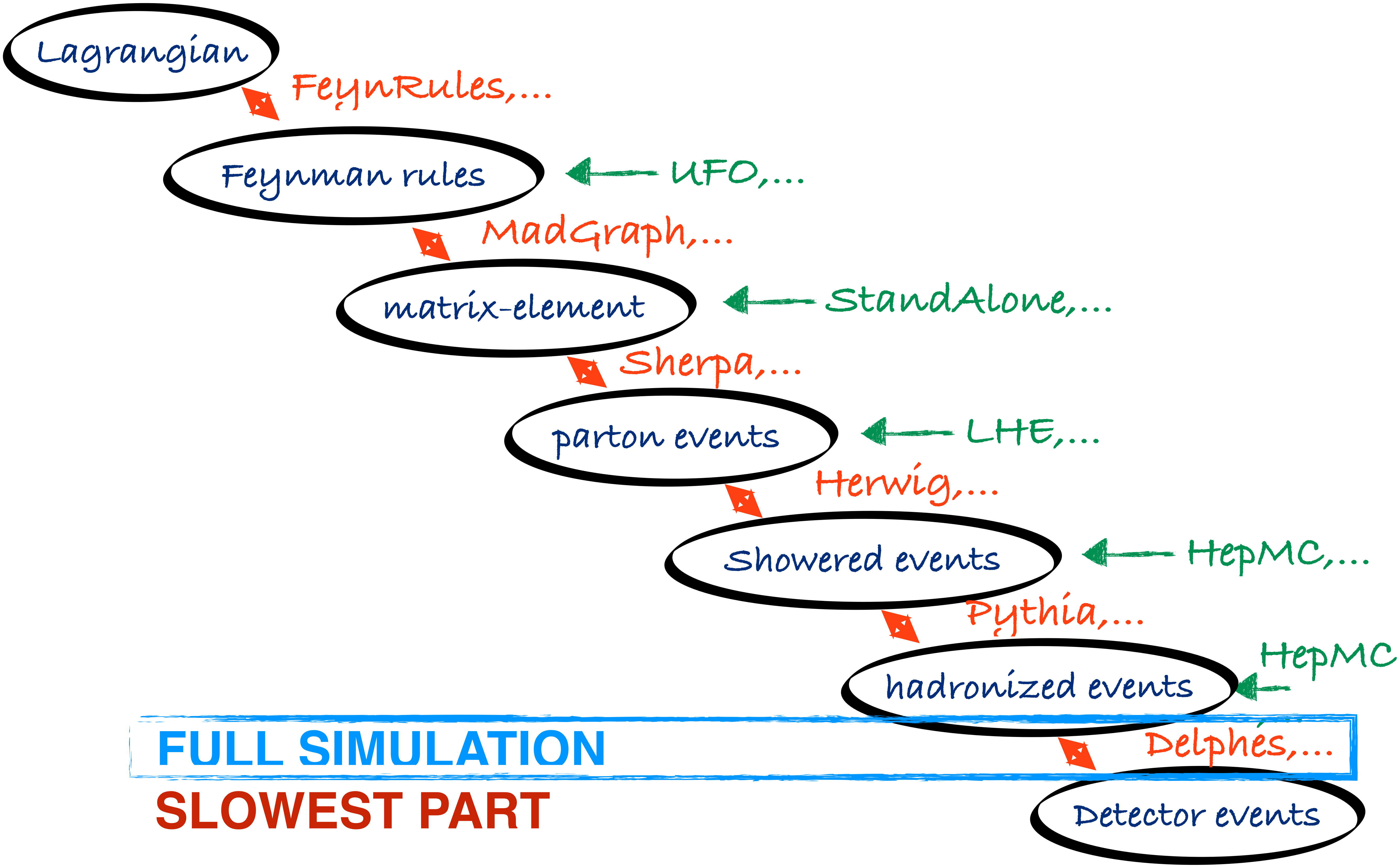
- accept/reject method
- reject the decay not the event

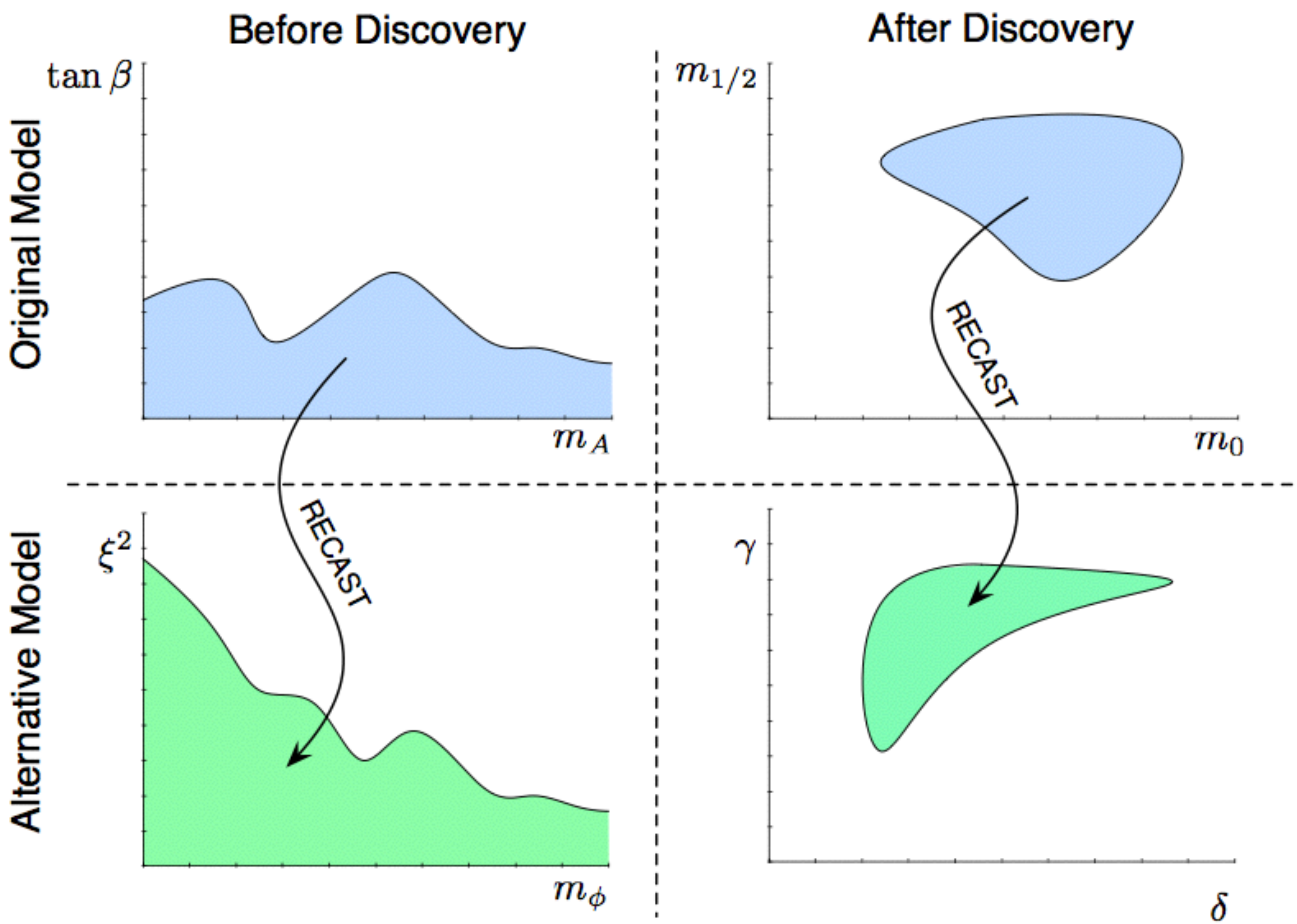
Final Sample



NLO Spin correlations on
LO Spin correlations on
NLO Spin correlations off
LO Spin correlations off
Scalar Higgs
0.01
0.001
0.0001
0 25 50 75 100 125 150 175 200
$p_T(l^+)$ [GeV]
$1/\sigma\ d\sigma/dp_T(l^+)$ [1/GeV]
NLO Spin correlations on
LO Spin correlations on
NLO Spin correlations off
LO Spin correlations off
Scalar Higgs
0.6
0.55
0.5
0.45
0.4
-1 -0.5 0 0.5 1
$\cos(\phi)$
$1/\sigma\ d\sigma/d\cos(\phi)$

BSM simulation





plot from arXiv:1010.2506v1

Scan

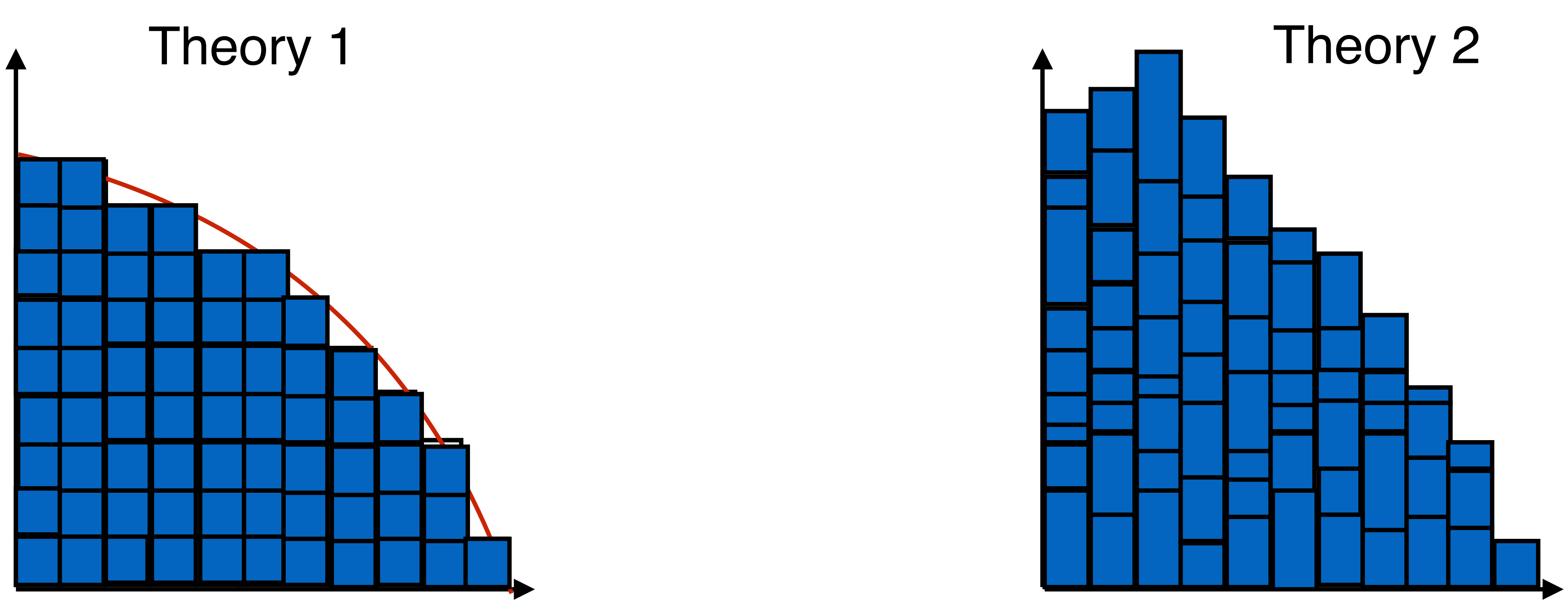
Idea

- Reuse the sample (Only one Full Sim)
- Change the weight of the events

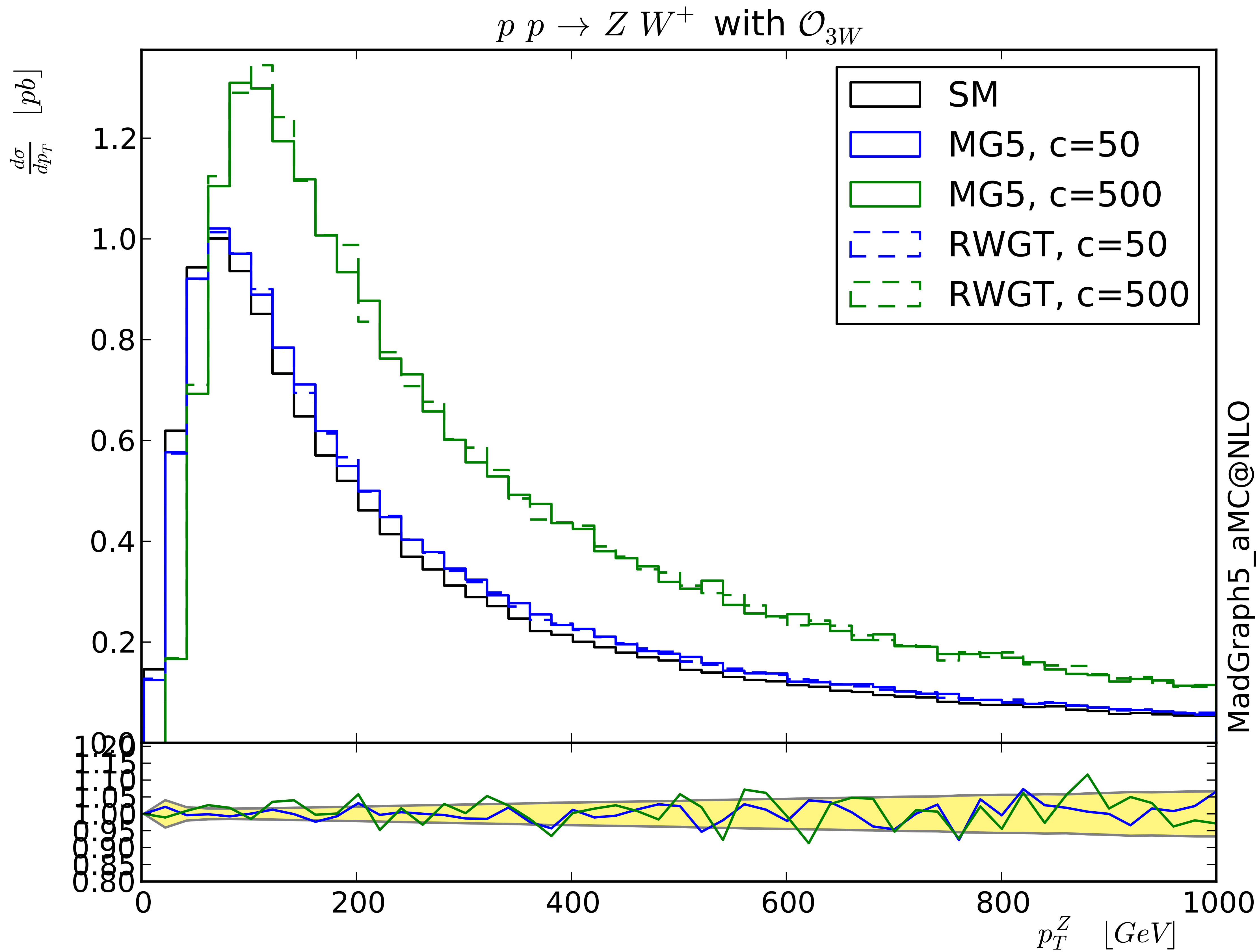
$$W_{new} = \frac{|M_{new}|^2}{|M_{old}|^2} * W_{old}$$

1405.0301

1404.7129



Examples HEFT



Systematics study

Theoretical Dependance

- the PDF set — 50 sets
- the renormalization/refactorization scale — 9 sets
- the matching scale — 3 sets

Idea

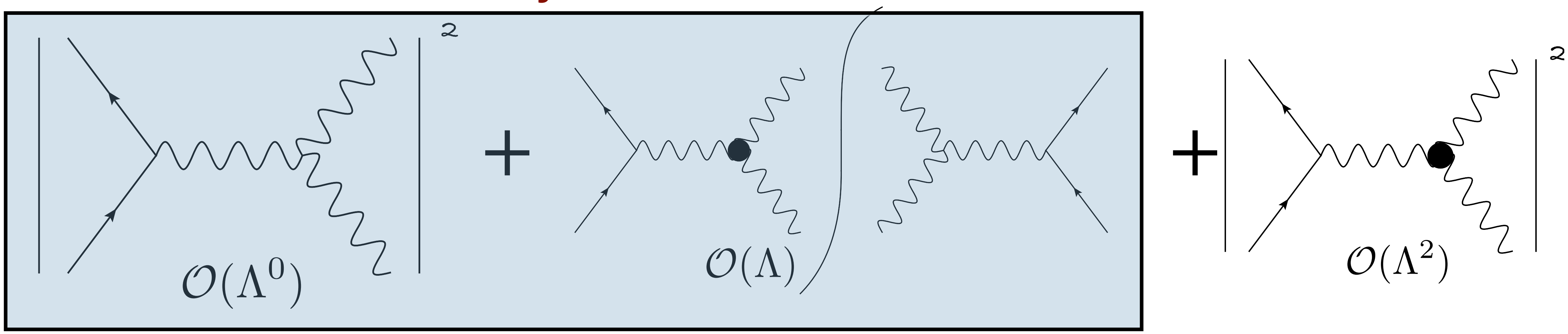
- Reweighting can also be used to study systematic uncertainty.

Implementation:

- Store additional information in the Event File
- Make the re-weighting on the flight

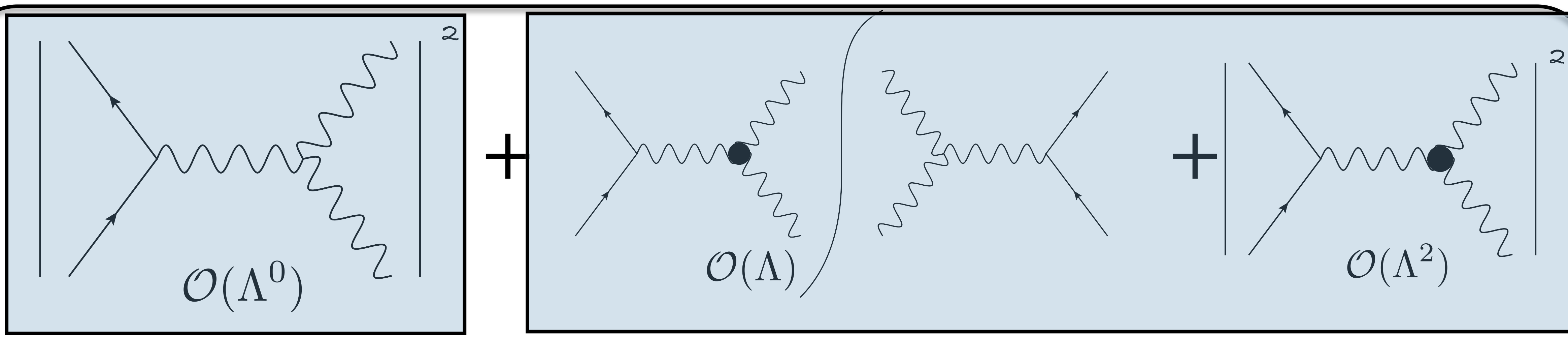
Non Definite positive

Effective Field Theory:



Signal

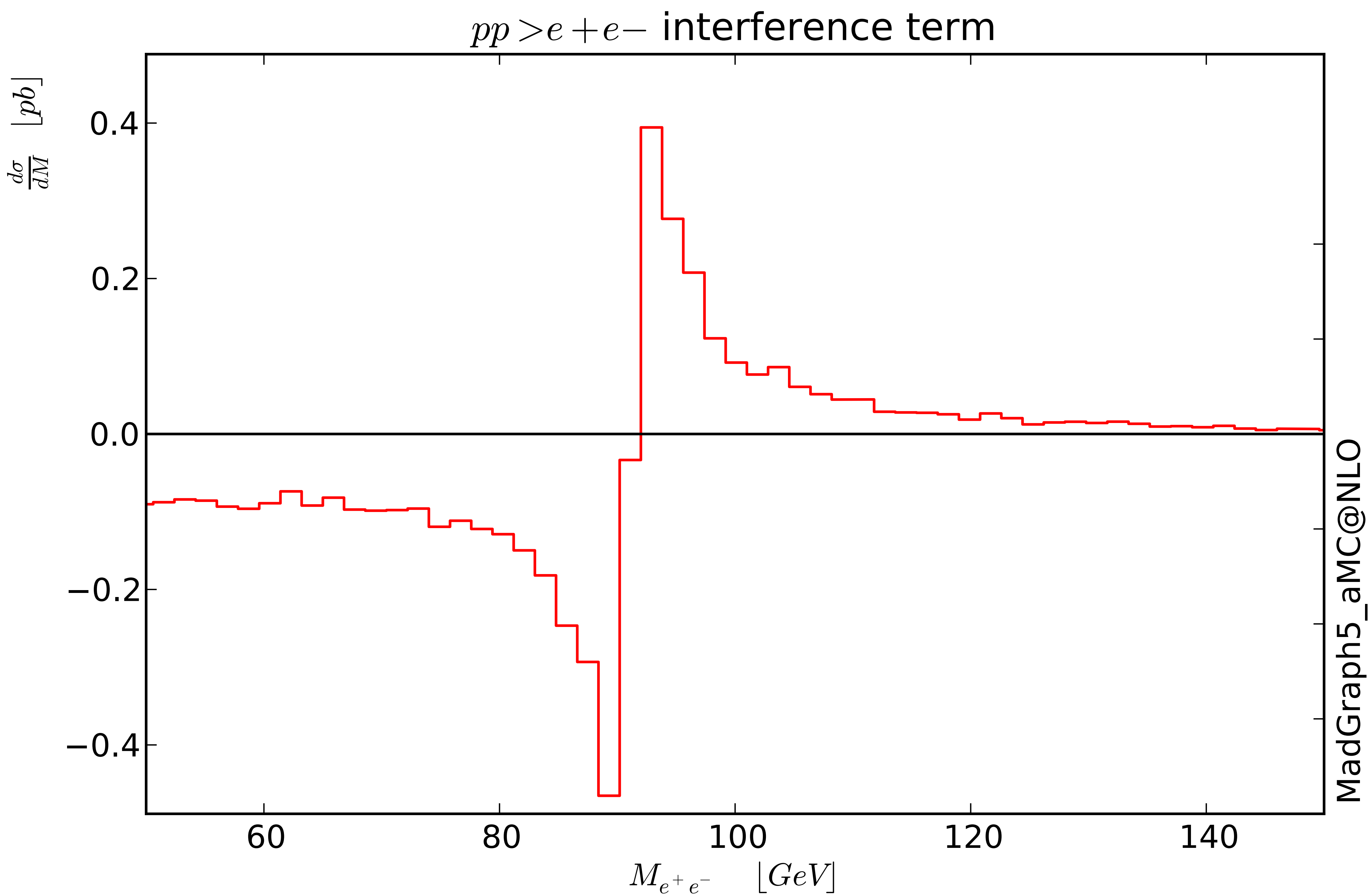
Equivalent to Dimension 8 contribution



SM
Model independent
Dominant

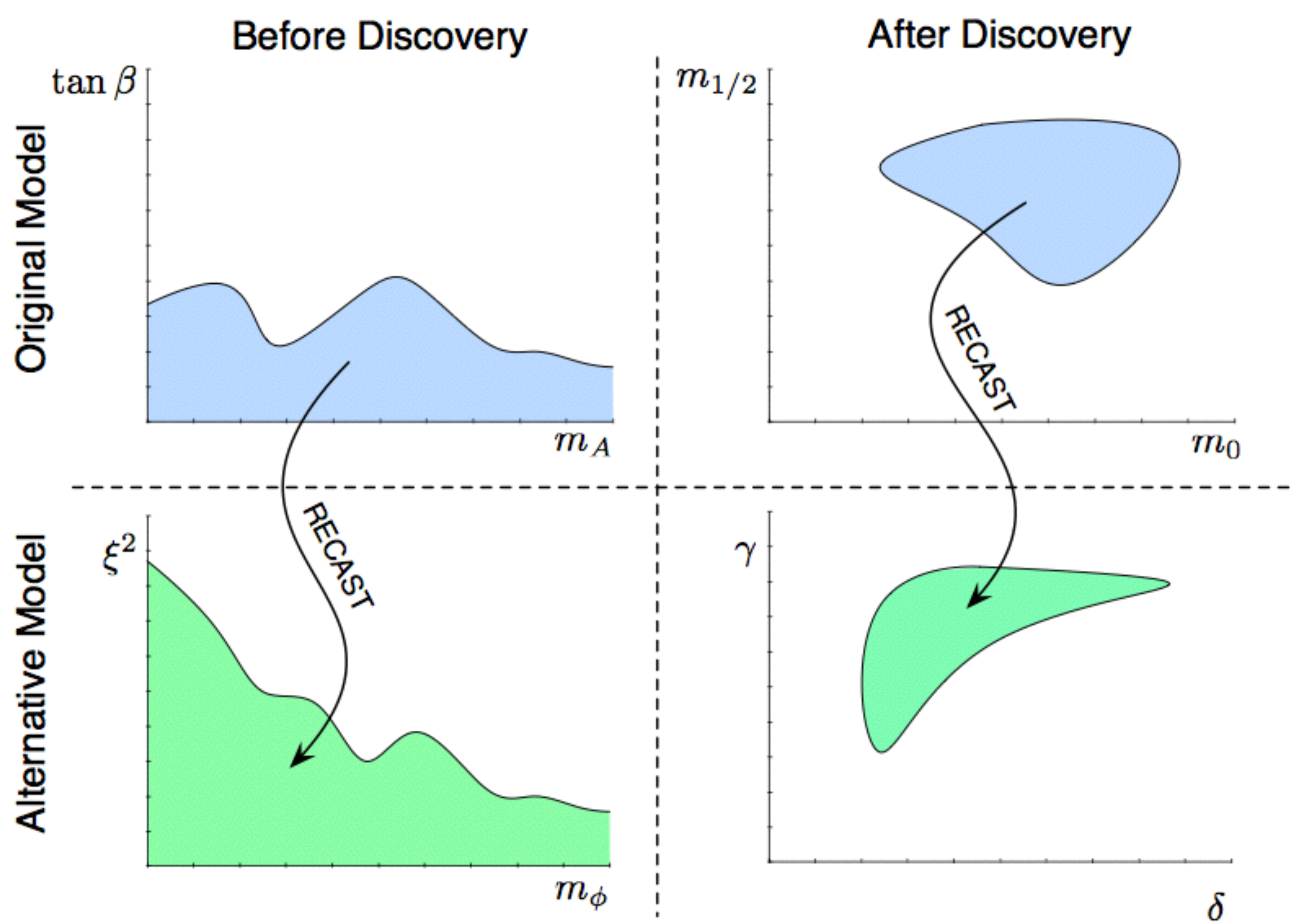
BSM
Model dependent
Sub-Dominant

Interference Plot



Re-Casting

- Same idea but at the analysis level



plot from arXiv:1010.2506v1

Why is it interesting

Experimentalist

- Your analysis will be reuse to exclude new model without extra work
- You might gain feedback about the analysis
- You will get cited

Theorist

- Want to check your analysis
- Is the BSM model exclude?
- Is the BSM reduces fluctuations?
- The closer they are from your work the better

What do we need?

- Simplified way to compare theory/data
- Need to be outside of experimental control area
- Automatic running

Working Flow

Input

- Event File
  - LHE
  - HEPMC

Detector Simulation →

Rivet Fork or Delphes Fork

- Detector like event

↓ Apply the selections

Examples of code

- MadAnalysis 5
- RECAST
- ATOM
- Checkmate

Output

- CL
- CutFlow
- Plots

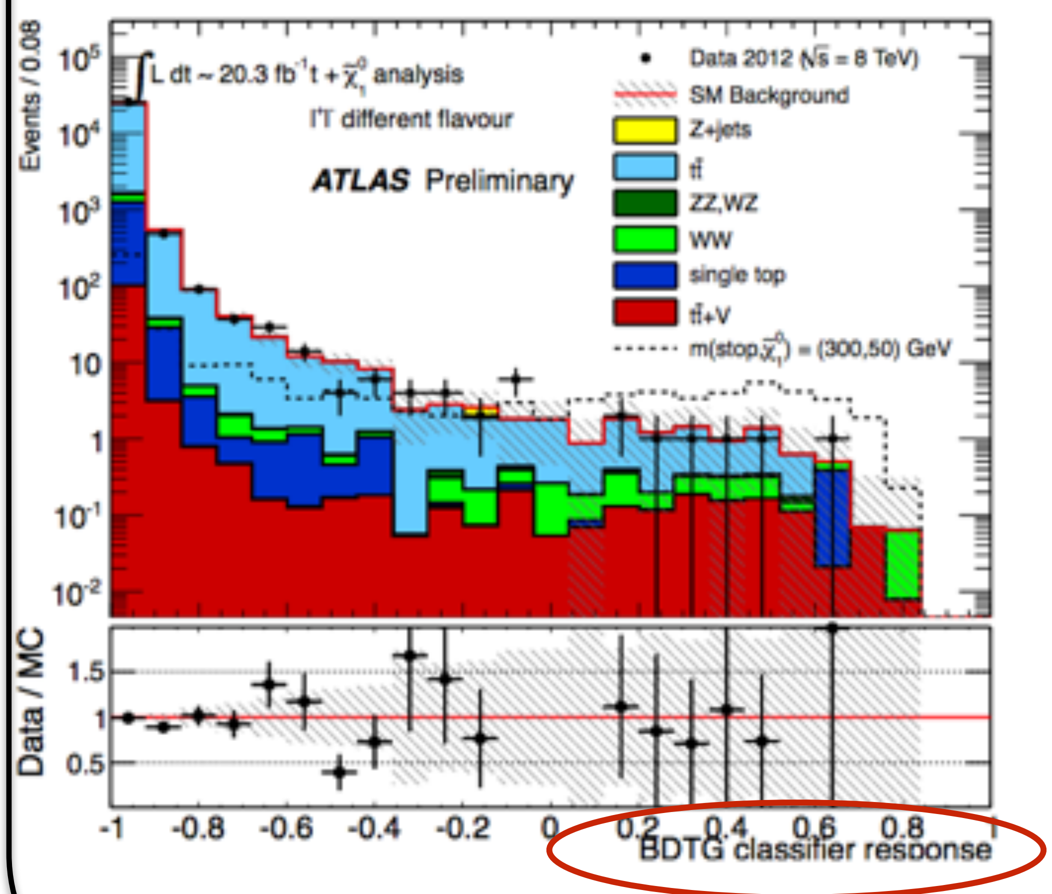
VALIDATION

ATOM Validation, from arXiv:1402.0492

#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom} ± Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$	$(\epsilon_{Atom}-\epsilon_{ATLAS})$/Stat
1	No cut	100.	100. ±		
2	Muon veto	75.1	79.8 ± 0.89	1.06	5.23
3	Electron veto	56.1	55.4 ± 0.74	0.99	−0.93
4	MET > 130	51.9	47.9 ± 0.69	0.92	−5.78
5	Jet multiplicity and pT	19.3	16.3 ± 0.4	0.84	−7.41
6	MET_track > 30	19.	16.2 ± 0.4	0.85	−6.99
7	delPhi(MET, MET_track) < pi/3	17.8	15.9 ± 0.4	0.89	−4.77
8	delPhi(jet, MET) > pi/5	15.2	14.6 ± 0.38	0.96	−1.5
9	Tau veto	13.3	13.5 ± 0.37	1.01	0.53
10	>= 2−bjet	5.8	5.9 ± 0.24	1.02	0.46
11	mT(bjet, MET) > 175	4.	3.8 ± 0.2	0.97	−0.67
12	80 < m^0_jjj < 270	3.5	3.4 ± 0.18	0.96	−0.7
13	80 < m^1_jjj < 270	2.1	2.2 ± 0.15	1.02	0.31
14	SR1: MET > 200	2.	2. ± 0.14	1.	0.05
15	SR2: MET > 300	1.5	1.6 ± 0.13	1.04	0.54
16	SR3: MET > 350	1.2	1.3 ± 0.11	1.05	0.55

Non cut based method

Boosted Decision Tree



ATLAS-CONF-2013-065

Matrix-Element method

- Use the BSM matrix-element to discriminate the signal for the background

$$\mathcal{P}(\boldsymbol{p}^{vis}|\alpha) = \frac{1}{\sigma_\alpha}\int d\Phi dx_1 dx_2 |M_\alpha(\boldsymbol{p})|^2 W(\boldsymbol{p},\boldsymbol{p}^{vis})$$

- Some study are too specialised to be recast

Types of Technique

Few assumptions

- Missing transverse momentum
- M_eff, H_T
- s Hat Min
- M_T
- M_TGEN
- M_T2 / M_CT
- M_T2 (with “kinks”)
- M_T2 / M_CT (parallel / perp)
- M_T2 / M_CT (“sub-system”)
- “Polynomial” constraints
- Multi-event polynomial constraints
- Whole dataset variables
- Cross section
- Max Likelihood / Matrix Element

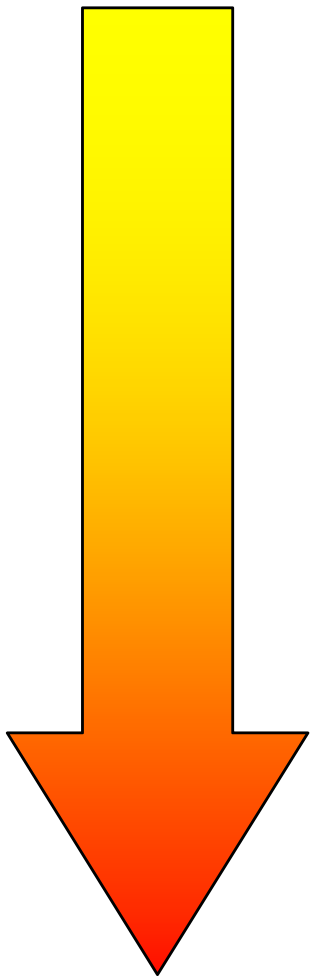
Many assumptions

Slide from Lester: arXiv:1004.2732

Types of Technique

Vague

conclusions



Specific

conclusions

- Missing transverse momentum
- M_eff, H_T
- s Hat Min
- M_T
- M_TGEN
- M_T2 / M_CT
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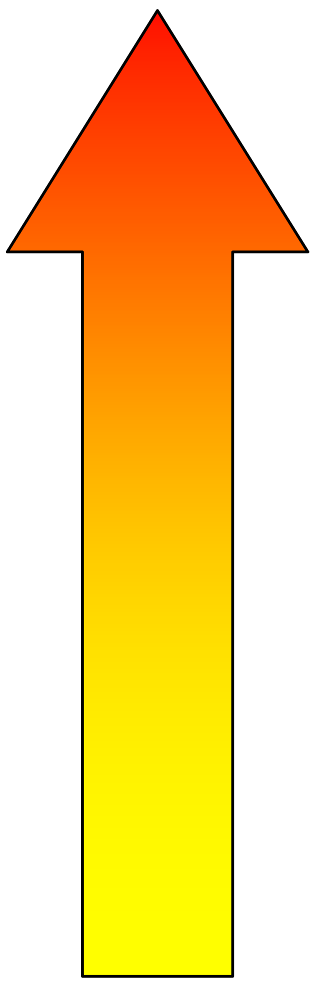
Types of Technique

Robust



Fragile

- Missing transverse momentum
- M_eff, H_T
- s Hat Min
- M_T
- M_TGEN
- M_T2 / M_CT
- M_T2 (with "kinks")
- M_T2 / M_CT (parallel / perp)
- M_T2 / M_CT ("sub-system")
- "Polynomial" constraints
- Multi-event polynomial constraints
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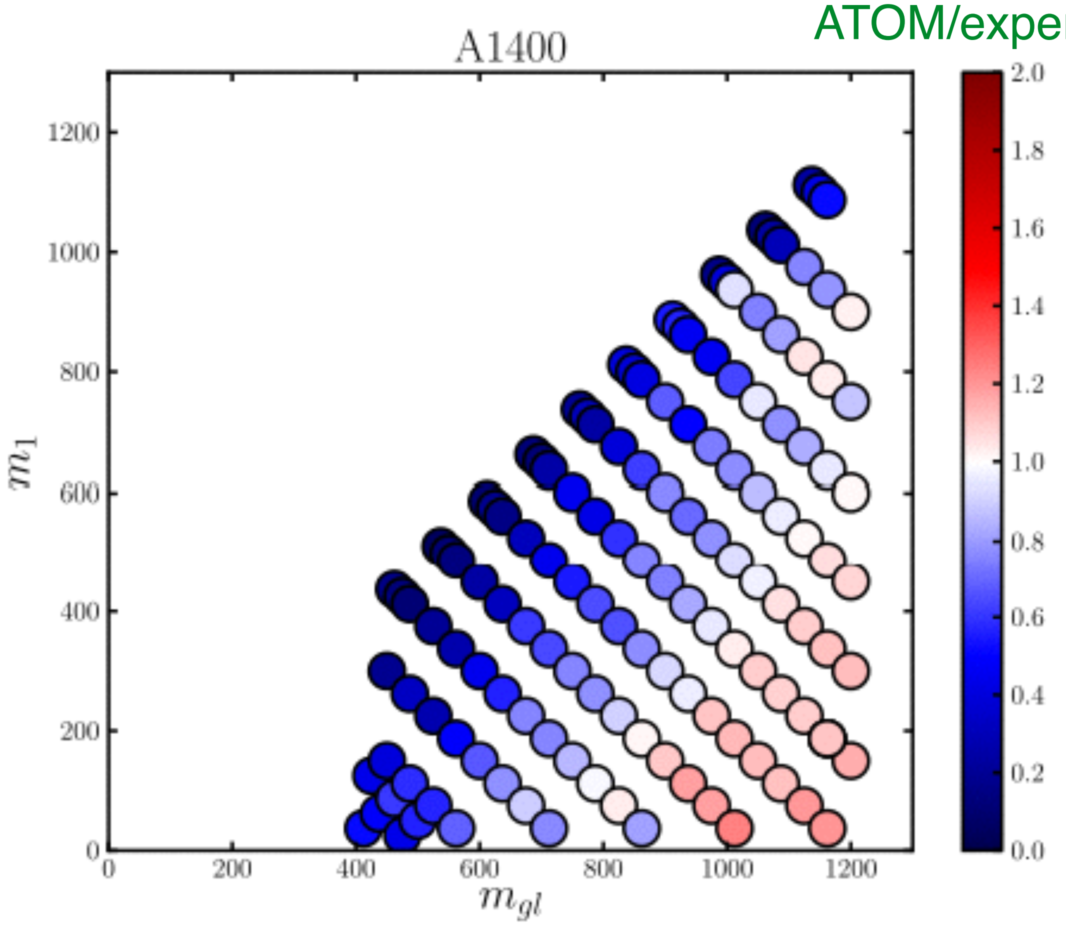
- Cross section
- Max Likelihood / Matrix Element

Slide from Lester: arXiv:1004.2732

Sensitivity to input

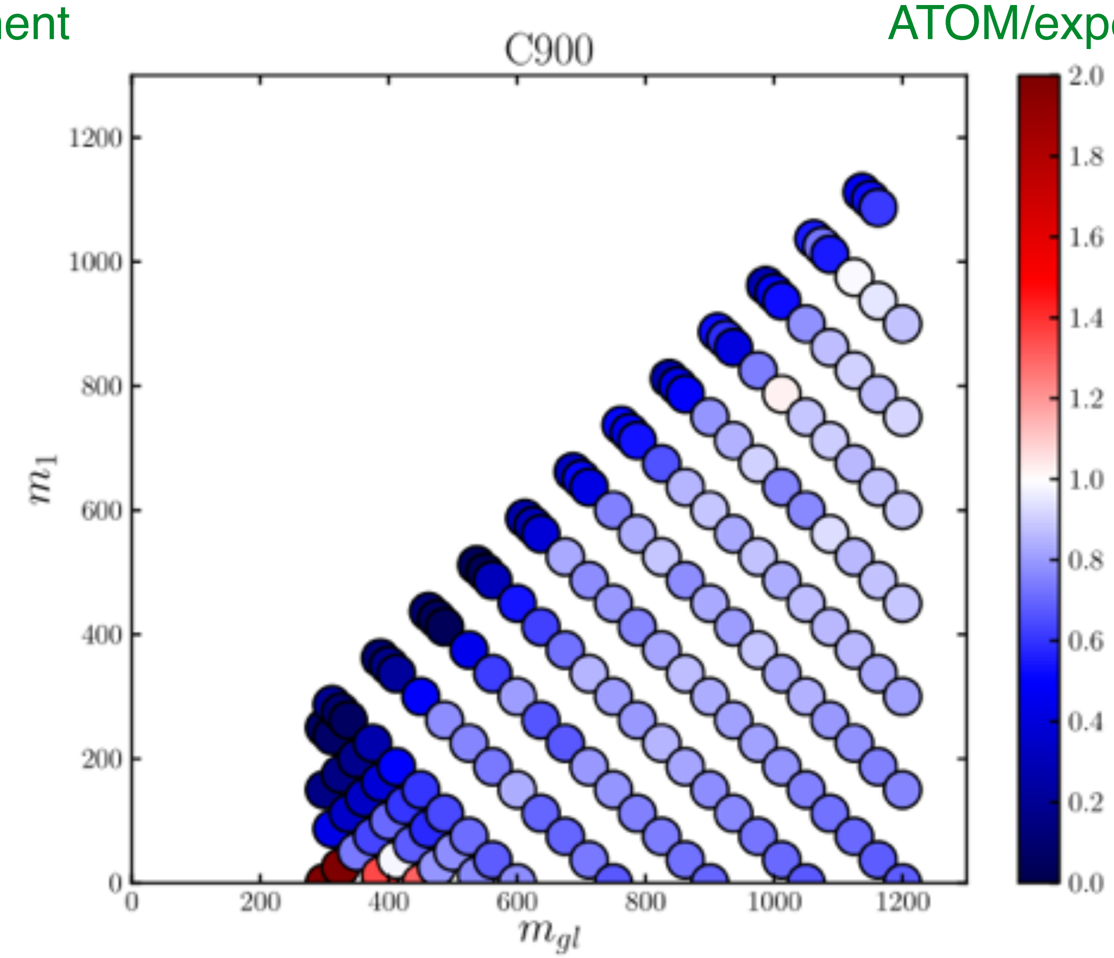
- QCD is everywhere!

unmatched



very bad close to deg. region

with ME/PS matching



~ 20% agreement

Code in inspire!

Information | Citations (3) | Files

Files are versioned, can be downloaded

MadAnalysis 5 implementation of CMS-SUS-13-011: search for stops in the single lepton final state at 8 TeV

DOI and citations

Dumont, Beranger (LPSC, Grenoble); Fuks, Benjamin (CERN); Wymant, Chris (Annecy, LAPTH)

Cite as: (2014) authors, http://doi.org/10.7484/INSPIREHEP.DATA.LR5T.2RR3

Description: This is the MadAnalysis 5 implementation of the CMS search for top-squark pair production in the single lepton final state with 19.5/fb at 8 TeV, to be used for re-interpretation studies. The C++ code contains extensive comments and can thus easily be used as a template for implementing other analyses.

Note: This analysis requires MINUIT libraries. Therefore, the line <LIBFLAGS += -lMinuit> should be added to the Makefile of the Build/ directory before compilation. More information how to use this code as well as a detailed validation summary are available at http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase

Cite as: Dumont, B., Fuks, B., Wymant, C. (2014) MadAnalysis 5 implementation of CMS-SUS-13-011: search for stops in the single lepton final state at 8 TeV. doi: 10.7484/INSPIREHEP.DATA.LR5T.2RR3

This dataset complements the following publication:
Toward a public analysis database for LHC new physics searches using MADANALYSIS 5

Record added 2014-06-19, last modified 2014-07-17

Conclusion

- BSM is now fully automated at LO
  - ➡ NLO is starting to be as well
- BSM is very large
  - ➡ various kind
  - ➡ various need
  - ➡ various way to generate
- It is your responsibility to use this wisely
  - ➡ You need to know the limitation of the tools