ACCURATE, AUTOMATIC, AUGMENTING MC'S FOR THE LHC

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NEW PHYSICS SEARCHES

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New Physics

Non-resonant	Resonant

NEW PHYSICS SEARCHES

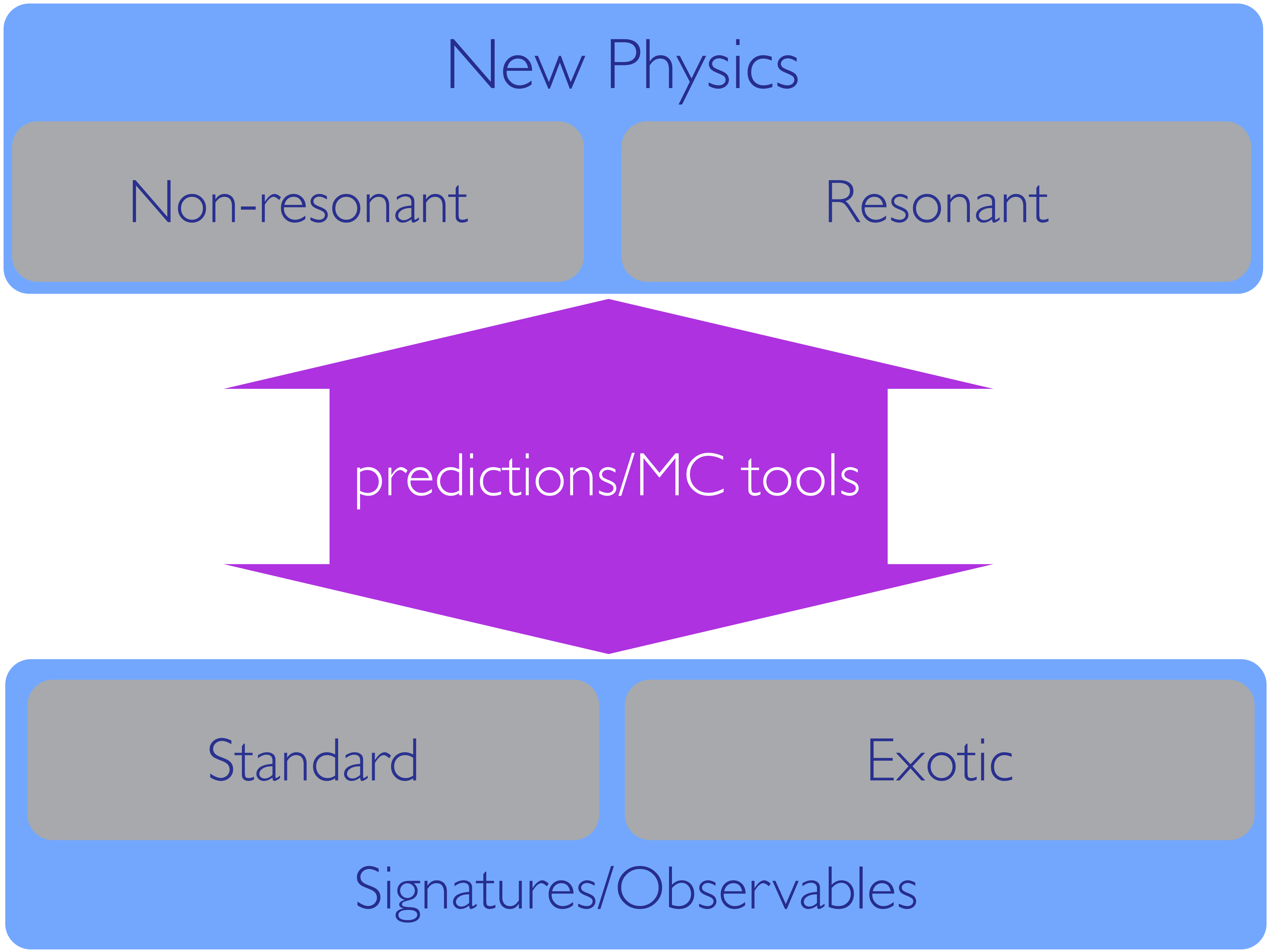
New Physics

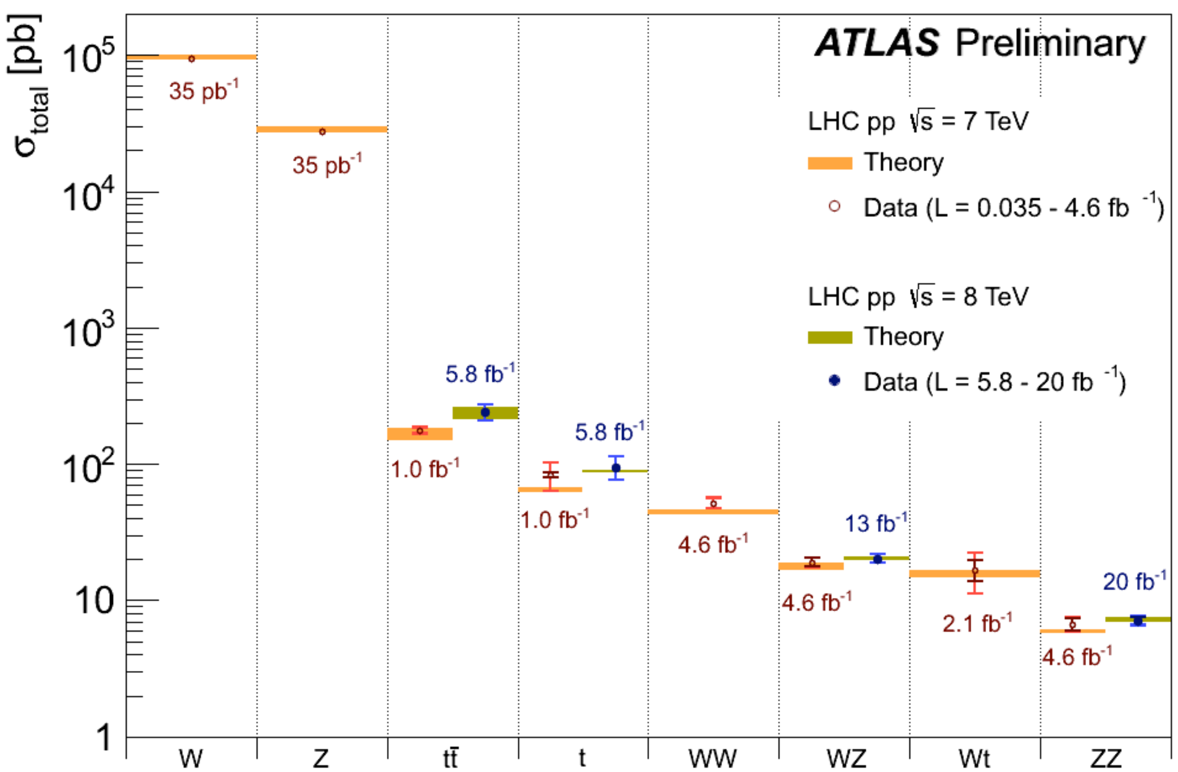
Non-resonant	Resonant

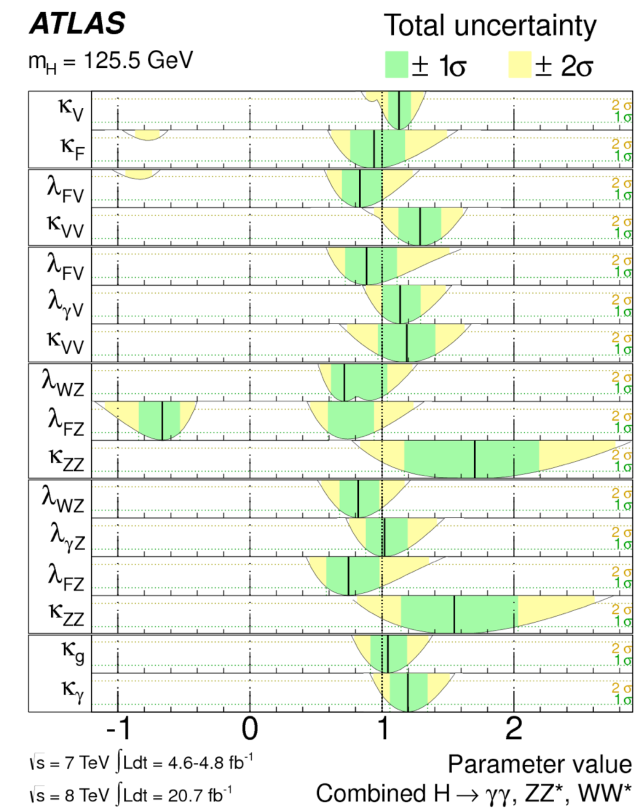
Standard	Exotic

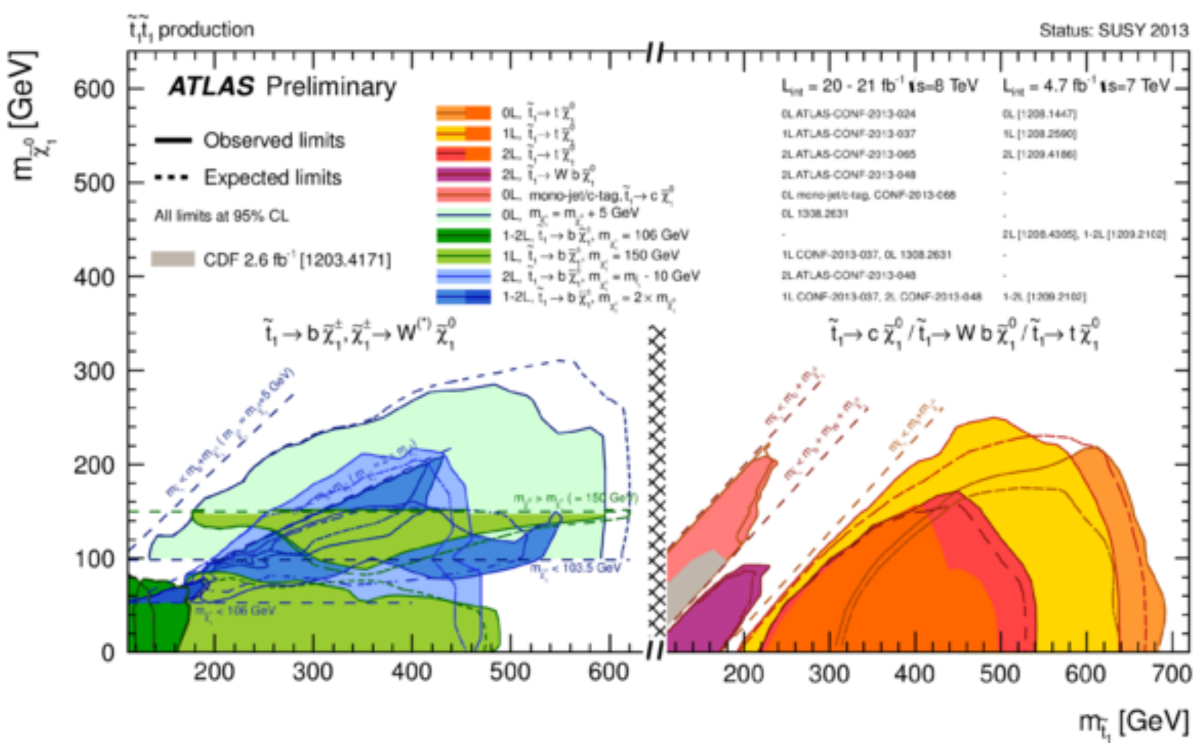
Signatures/Observables

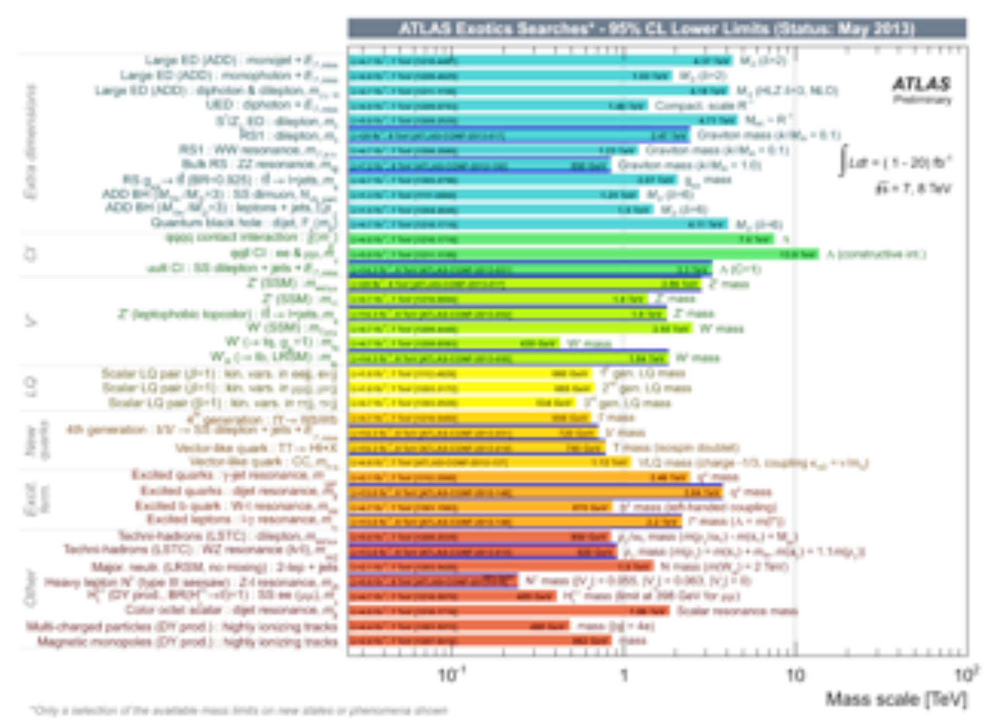
NEW PHYSICS SEARCHES

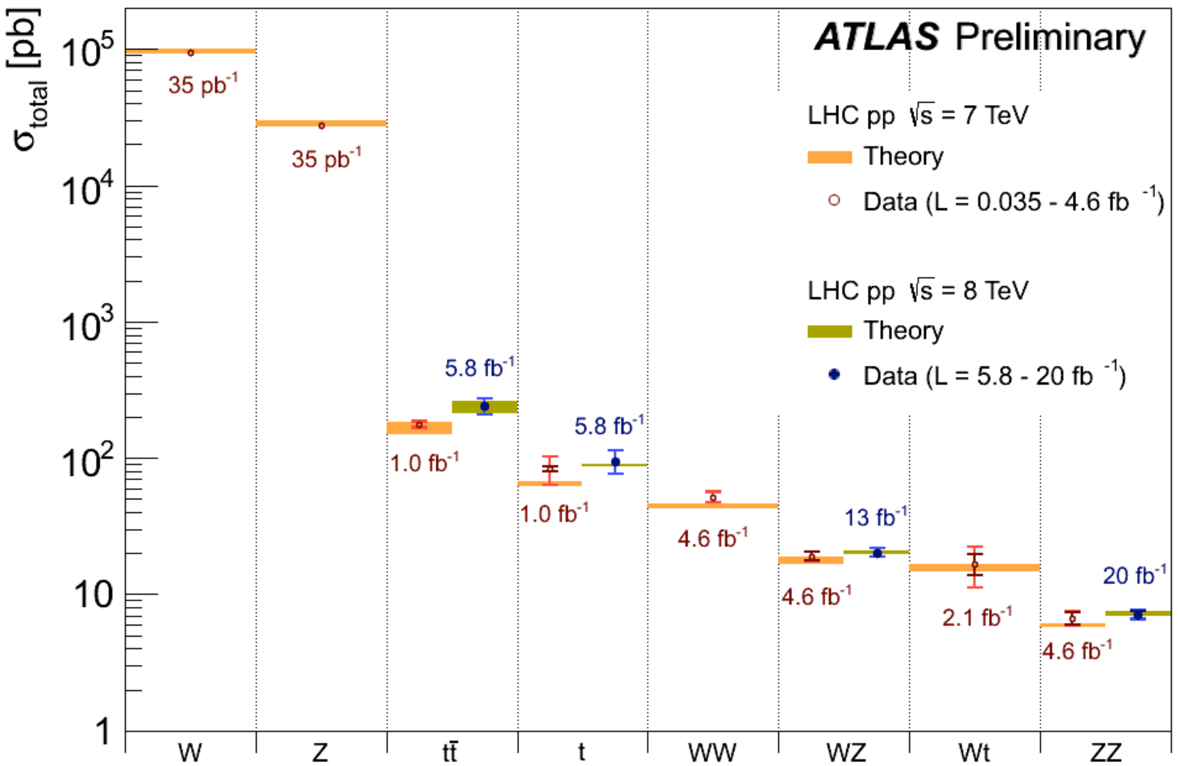


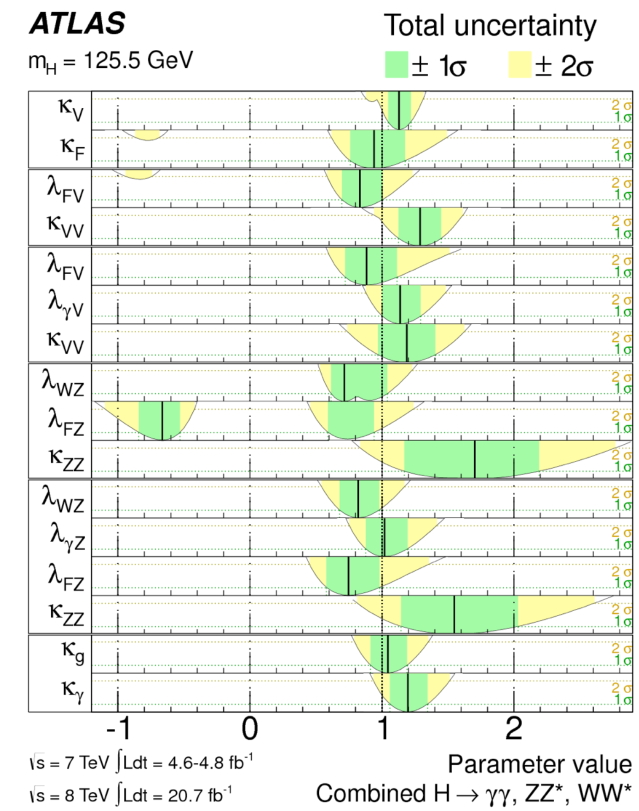

ATLAS Preliminary
LHC pp √s = 7 TeV
Theory
Data (L = 0.035 - 4.6 fb⁻¹)
LHC pp √s = 8 TeV
Theory
Data (L = 5.8 - 20 fb⁻¹)
σtotal [pb]
35 pb⁻¹
35 pb⁻¹
1.0 fb⁻¹
5.8 fb⁻¹
1.0 fb⁻¹
5.8 fb⁻¹
4.6 fb⁻¹
4.6 fb⁻¹
13 fb⁻¹
2.1 fb⁻¹
4.6 fb⁻¹
20 fb⁻¹
W
Z
tt̄
t
WW
WZ
Wt
ZZ


ATLAS
mH = 125.5 GeV
Total uncertainty
± 1σ
± 2σ
κV
κF
λFV
κVV
λFV
λγV
κVV
λWZ
λFZ
κZZ
λWZ
λγZ
λFZ
κZZ
κg
κγ
√s = 7 TeV ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 20.7 fb⁻¹
Parameter value
Combined H → γγ, ZZ*, WW*

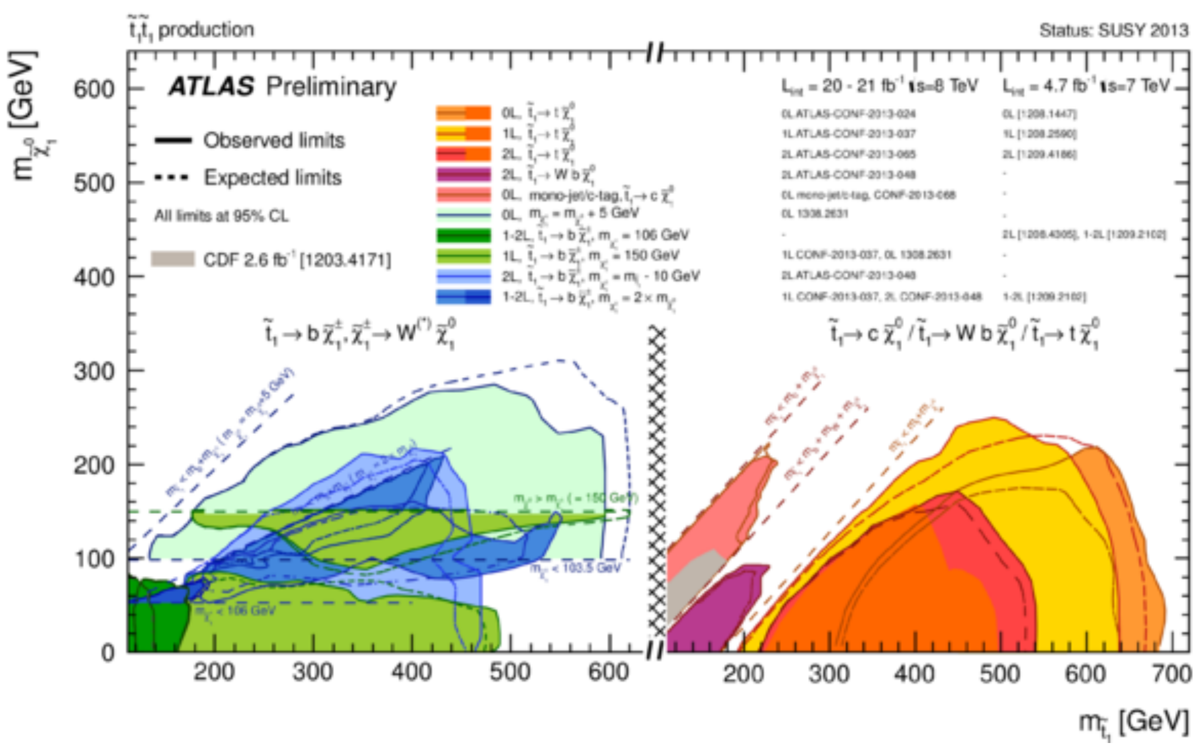

t̃1t̃1 production
Status: SUSY 2013
ATLAS Preliminary
Observed limits
Expected limits
All limits at 95% CL
CDF 2.6 fb⁻¹ [1203.4171]
Lint = 20 - 21 fb⁻¹ √s=8 TeV
Lint = 4.7 fb⁻¹ √s=7 TeV
t̃1 → b χ̃±1, χ̃±1 → W(*) χ̃01
t̃1 → c χ̃01 / t̃1 → W b χ̃01 / t̃1 → t χ̃01
m χ̃01 [GeV]
m t̃1 [GeV]


ATLAS Exotics Searches* - 95% CL Lower Limits (Status: May 2013)
ATLAS
Preliminary
Mass scale [TeV]





No sign of new physics (so far)!




MC developer

WHY HAPPY?

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- **Accuracy:** accurate simulations for both SM and BSM are a must.

...SO
HOW WE (USED TO) MAKE PREDICTIONS AT HADRON COLLIDERS?

LHC MASTER FORMULA

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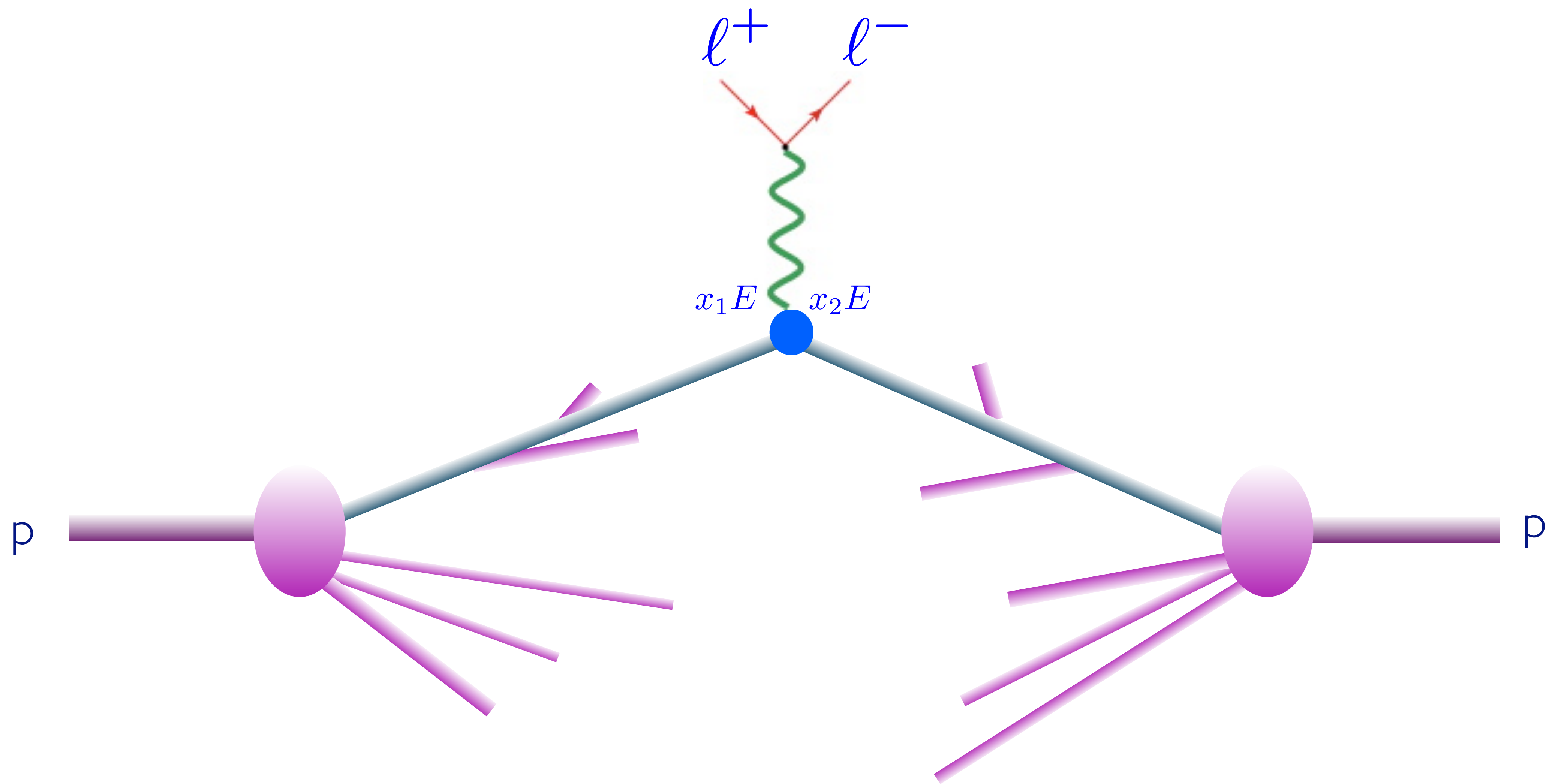

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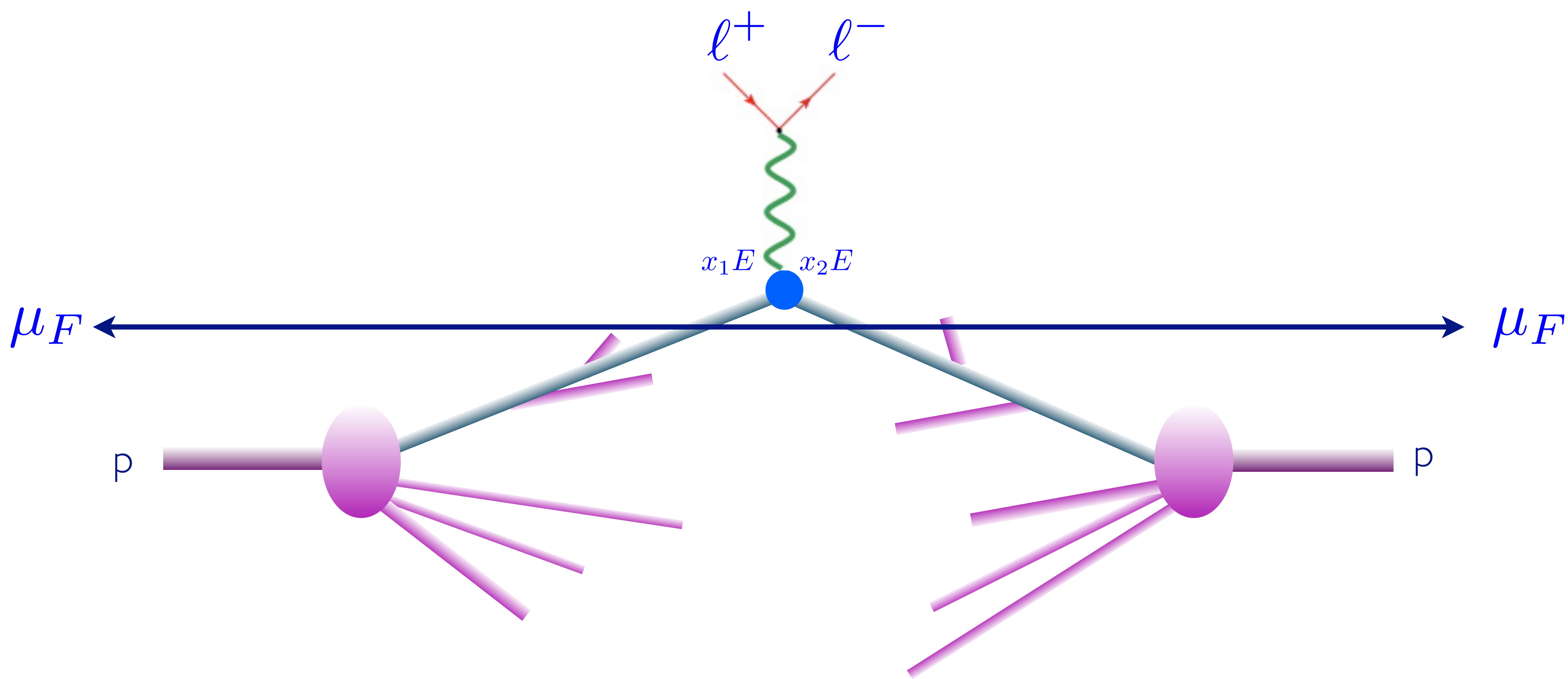

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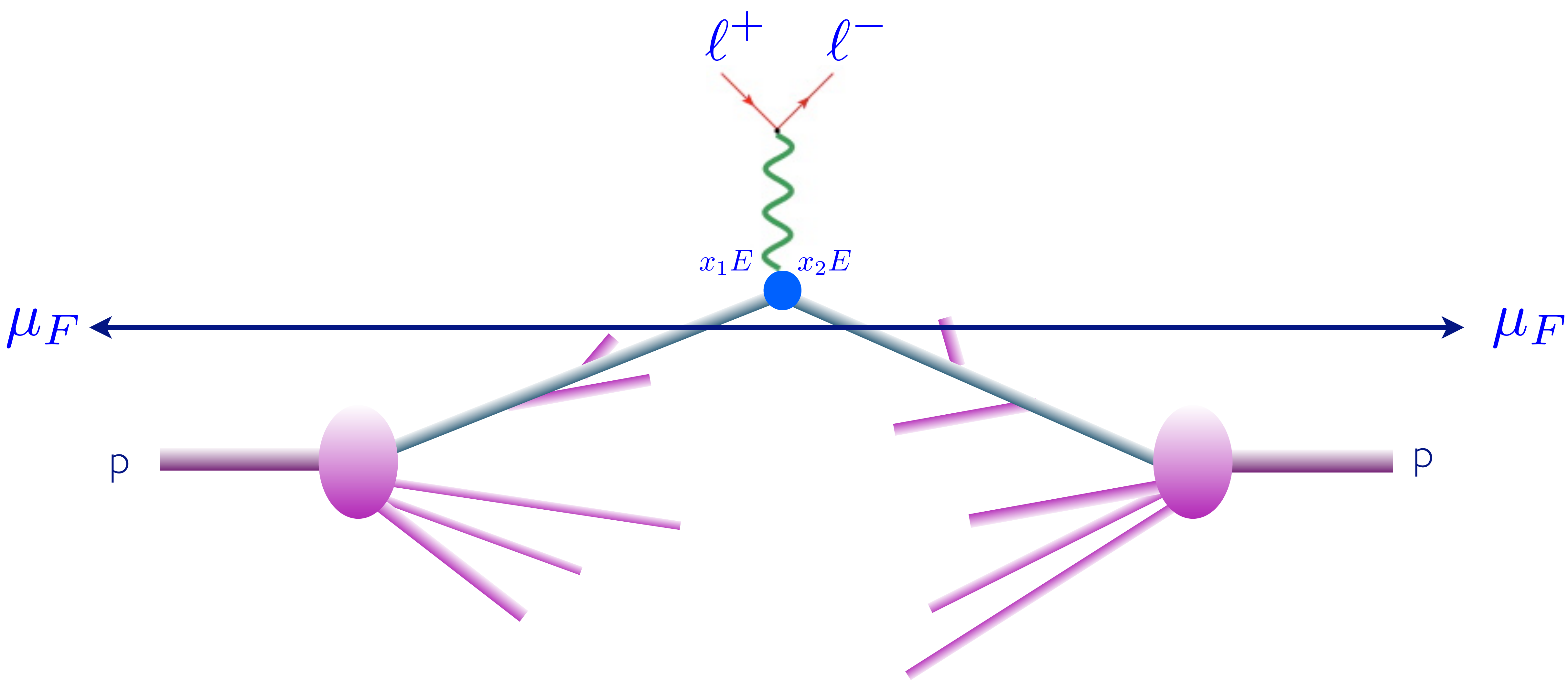

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab\to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2})$$

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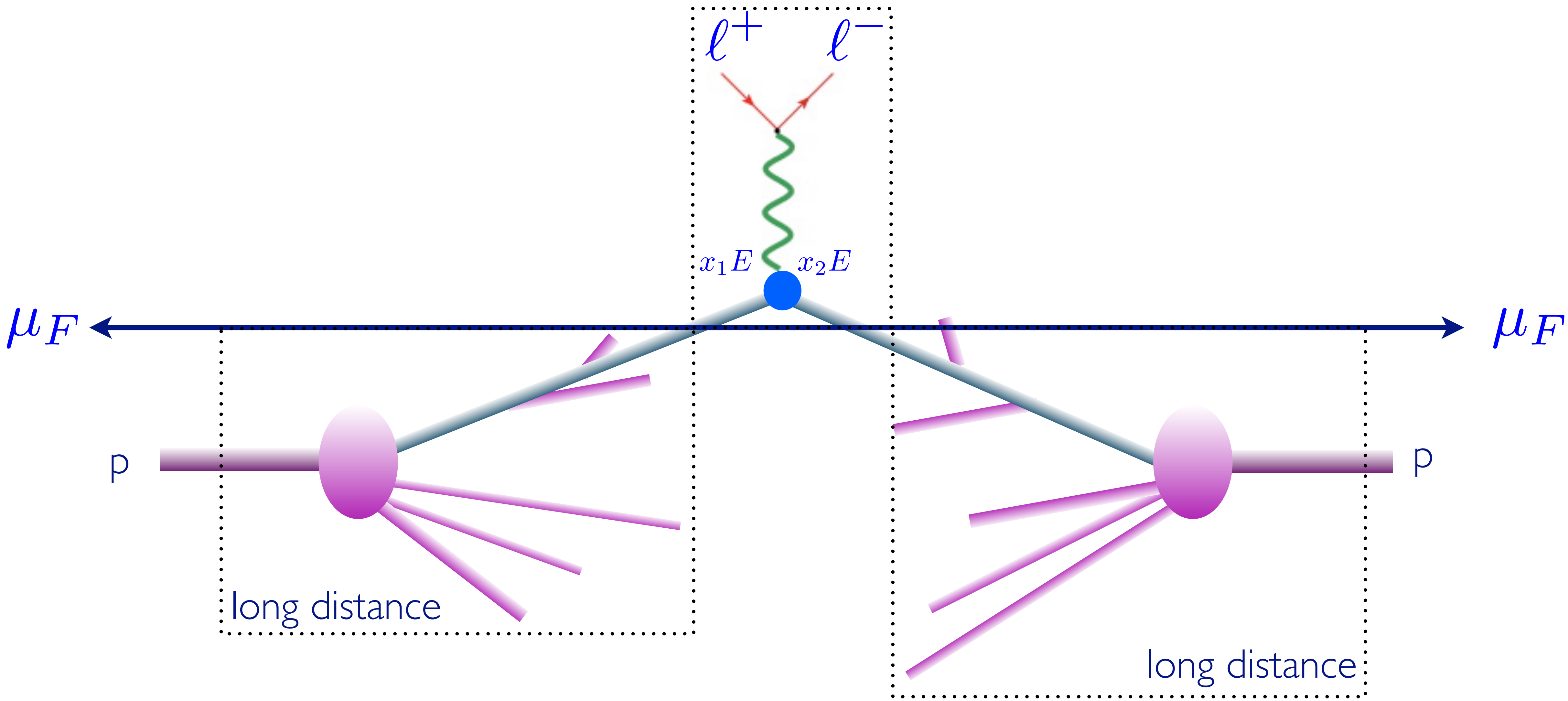

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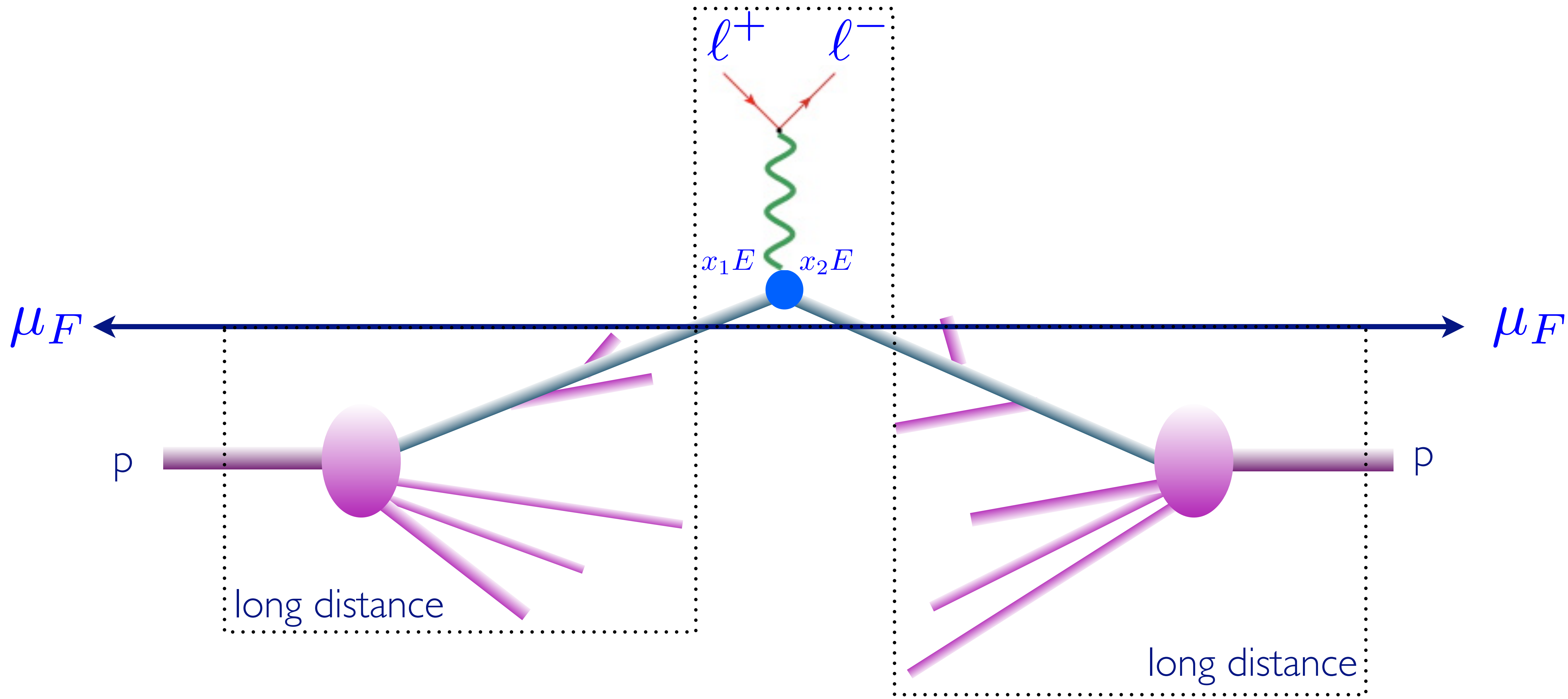

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Pheno/Th exploit this formula to provide accurate and flexible predictions from a given model (SM, MSSM,...)

HOW WE (USED TO) MAKE PREDICTIONS?

First way:

- For low multiplicity include higher order terms in our fixed-order calculations (LO→NLO→NNLO...)
  ⇒ $$\hat{\sigma}_{ab\to X} = \sigma_0 + \alpha_S \sigma_1 + \alpha_S^2 \sigma_2 + \dots$$

TH

- For high multiplicity use the tree-level results

Comments:

1. The theoretical errors systematically decrease.
2. Pure theoretical point of view.
3. A lot of new techniques and universal algorithms have been developed.
4. Final description only in terms of partons and calculation of IR safe observables ⇒ not directly useful for simulations

NLO BASICS

NLO contributions have three parts

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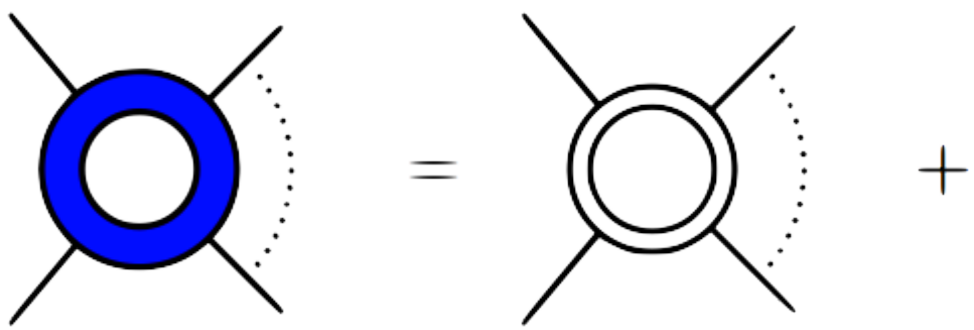
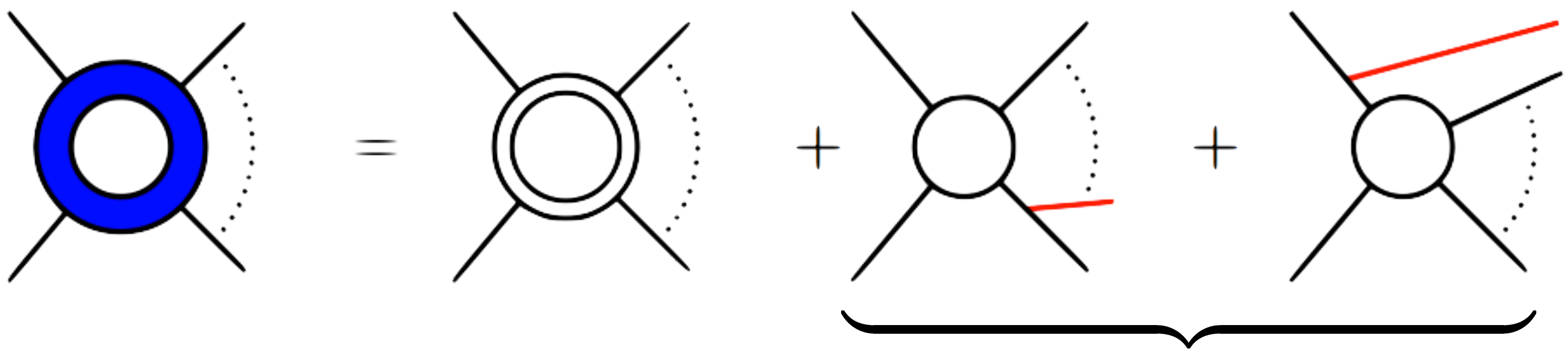


$$\sigma^{\rm NLO} = \int_m d^{(d)}\sigma^V +$$

Virtual part

NLO BASICS

NLO contributions have three parts



$$\sigma^{\text{NLO}} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R +$$

Virtual part

Real emission part

NLO BASICS

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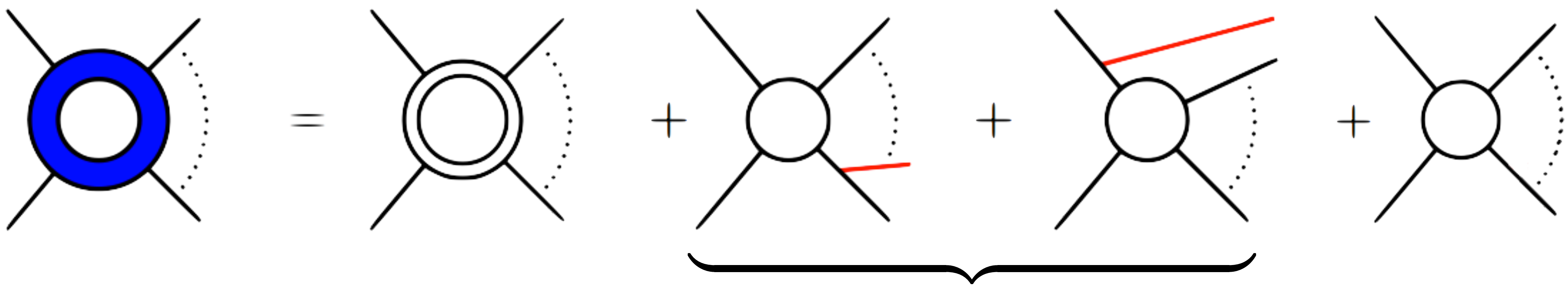

$$\sigma^{\mathrm{NLO}} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R + \int_m d^{(4)}\sigma^B$$

Virtual part — Real emission part — Born

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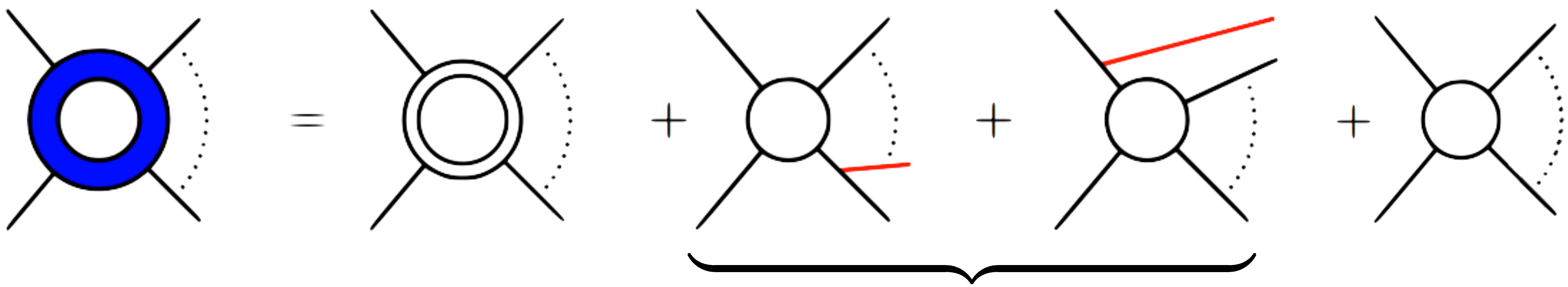

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- Loops have been for long the bottleneck of NLO computations
- Virtuals and Reals are each divergent and subtraction scheme need to be used (Dipoles, FKS, Antenna's)
- A lot of work is necessary for each computation

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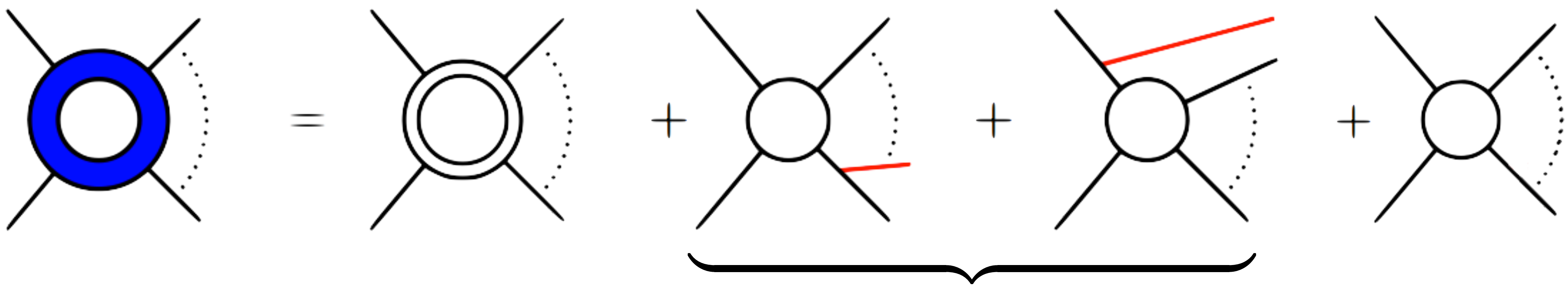

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The cost of a new prediction at NLO used to exceed 100k€.

LOOP TECHNIQUES

modified by the speaker

BEST EXAMPLE: MCFM

Downloadable general purpose NLO code [Campbell, Ellis, Williams+collaborators]

Final state	Notes	Reference
W/Z		
diboson (W/Z/γ)	photon fragmentation, anomalous couplings	hep-ph/9905386, arXiv:1105.0020
Wbb	massless b-quark massive b quark	hep-ph/9810489 arXiv:1011.6647
Zbb	massless b-quark	hep-ph/0006304
W/Z+1 jet		
W/Z+2 jets		hep-ph/0202176, hep-ph/0308195
Wc	massive c-quark	hep-ph/0506289
Zb	5-flavour scheme	hep-ph/0312024
Zb+jet	5-flavour scheme	hep-ph/0510362

Final state	Notes	Reference
H (gluon fusion)		
H+1 jet (g.f.)	effective coupling	
H+2 jets (g.f.)	effective coupling	hep-ph/0608194, arXiv:1001.4495
WH/ZH		
H (WBF)		hep-ph/0403194
Hb	5-flavour scheme	hep-ph/0204093
t	s- and t-channel (5F), top decay included	hep-ph/0408158
t	t-channel (4F)	arXiv:0903.0005, arXiv:0907.3933
Wt	5-flavour scheme	hep-ph/0506289
top pairs	top decay included	

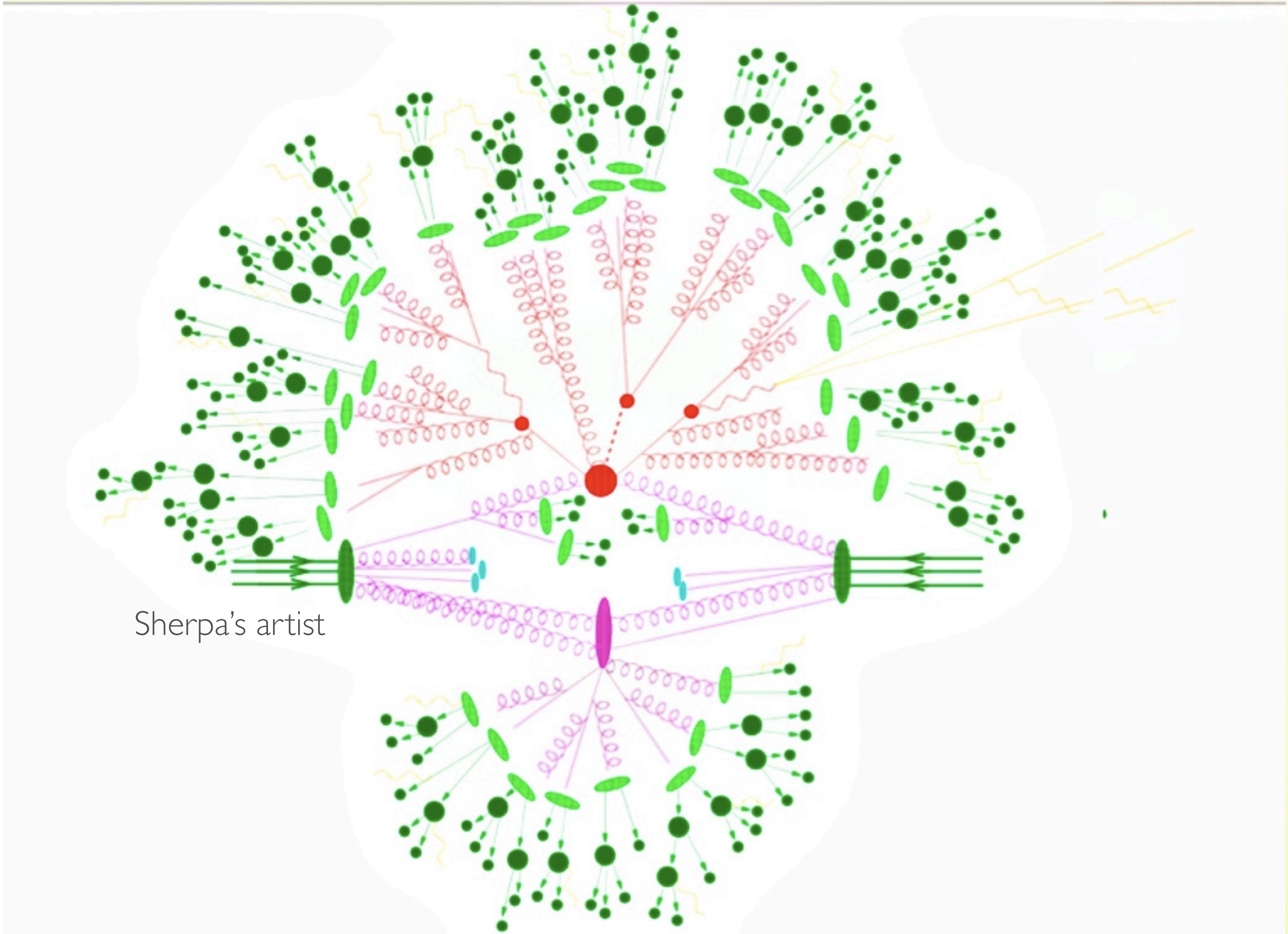
☞ + recent additions, overall 30+ processes

☞ First results implemented in 1998 ...this is 13 years worth of work of several people **(~5M$)**

☞ Cross sections and parton-level distributions at NLO are provided

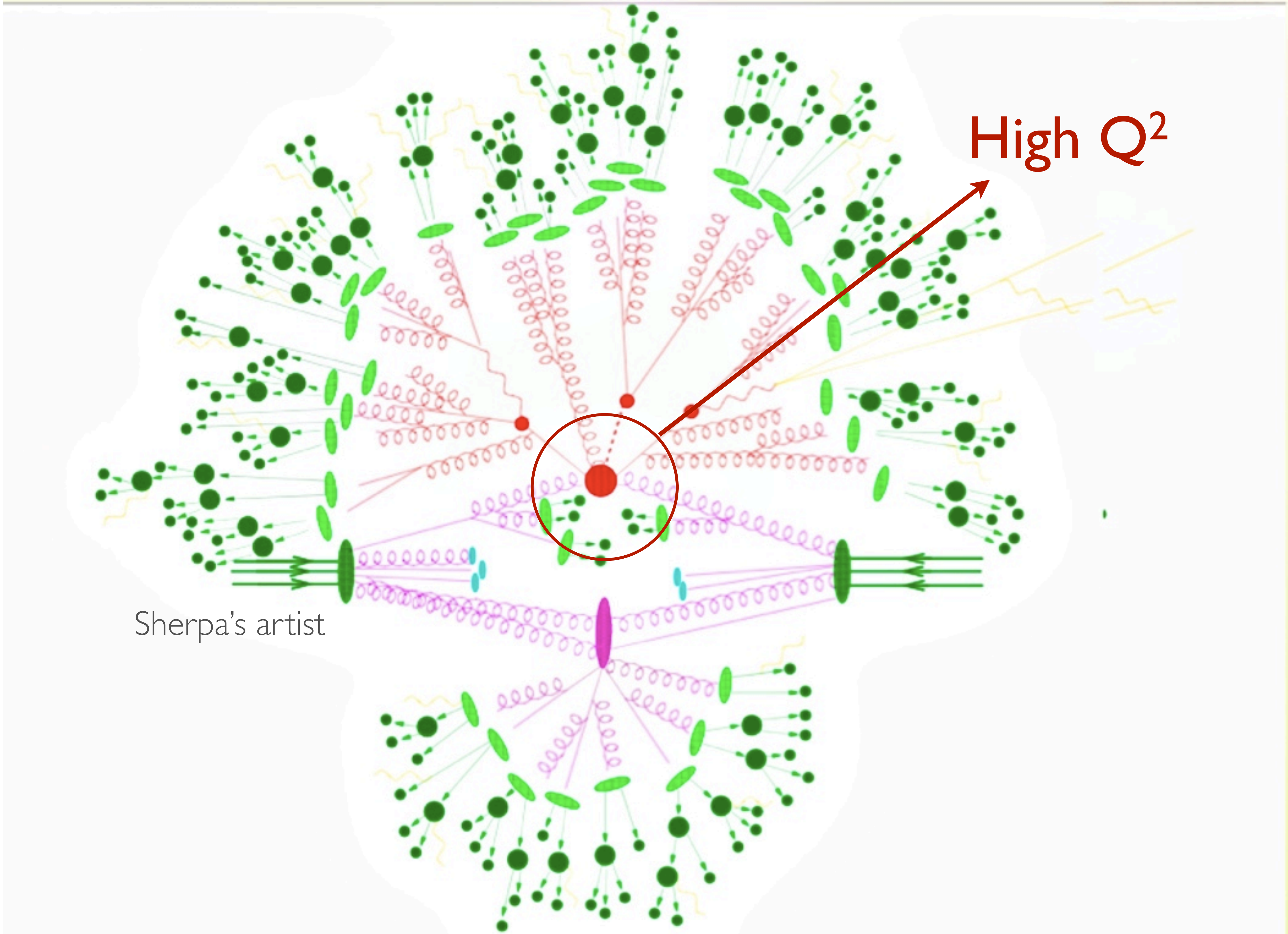
☞ One framework, however, each process implemented by hand.

Events at hadron colliders



Sherpa's artist

Events at hadron colliders



HOW WE (USED TO) MAKE PREDICTIONS?

Second way:

- Describe final states with high multiplicities starting from 2 → 1 or 2 → 2 procs, using parton showers, and then an hadronization model.

EXP

Comments:

1. Fully exclusive final state description for detector simulations
2. Normalization is very uncertain
3. Very crude kinematic distributions for multi-parton final states
4. Improvements are only at the model level.

most known and used : PYTHIA, HERWIG, SHERPA

SM STATUS 10 YEARS AGO

pp→ n particles

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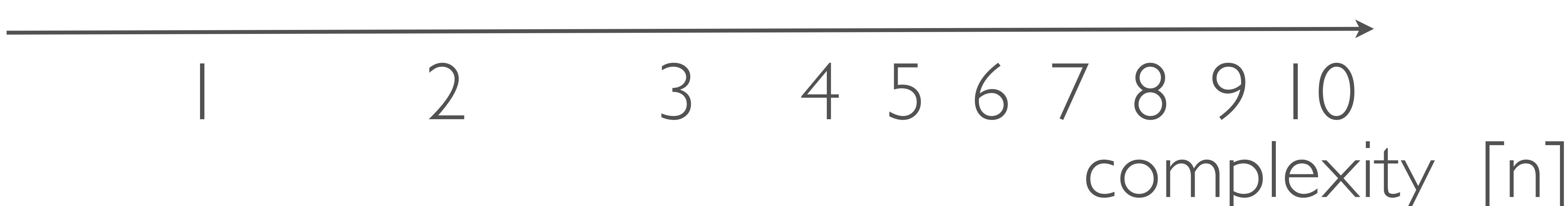

SM STATUS 10 YEARS AGO

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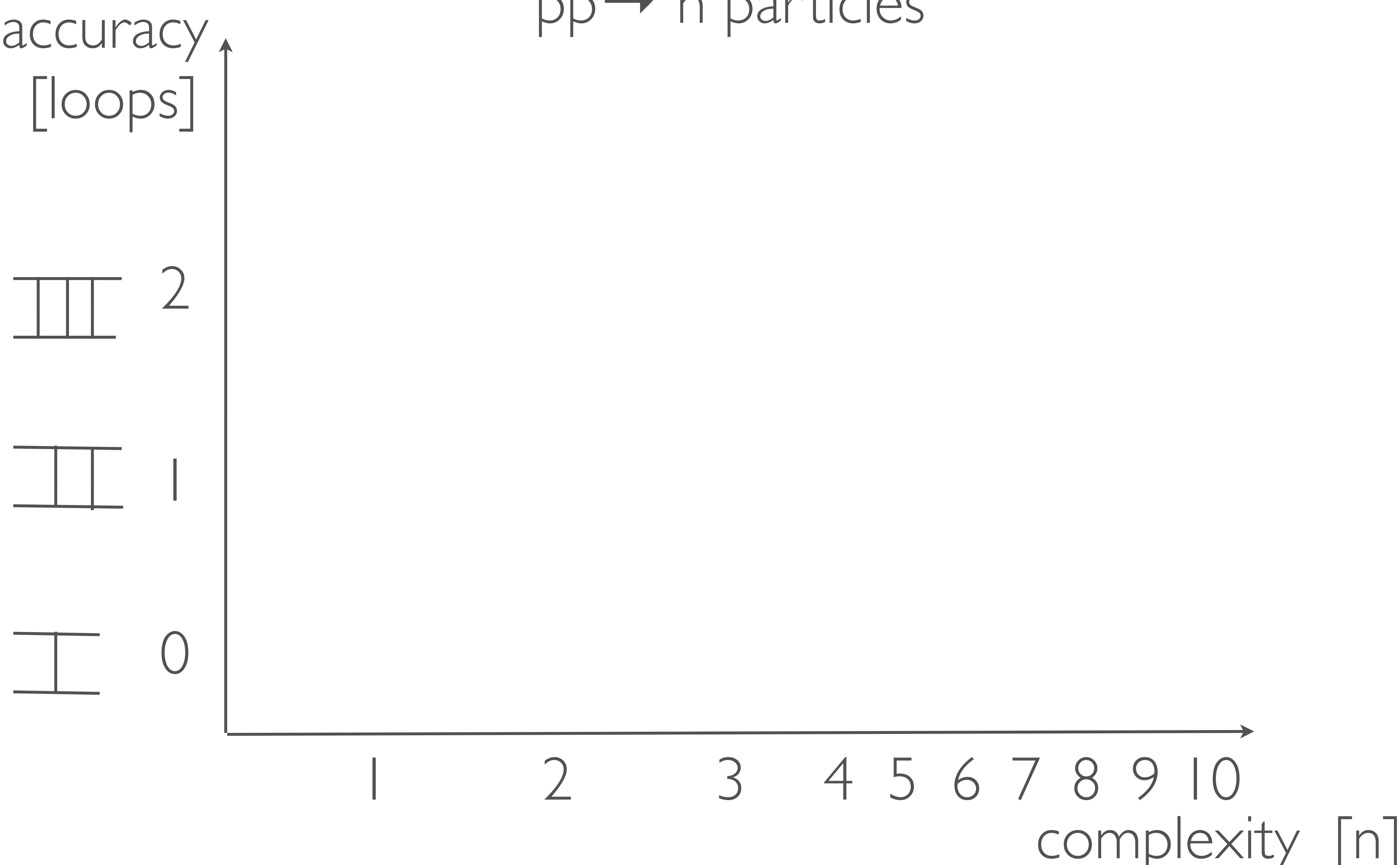

SM STATUS 10 YEARS AGO

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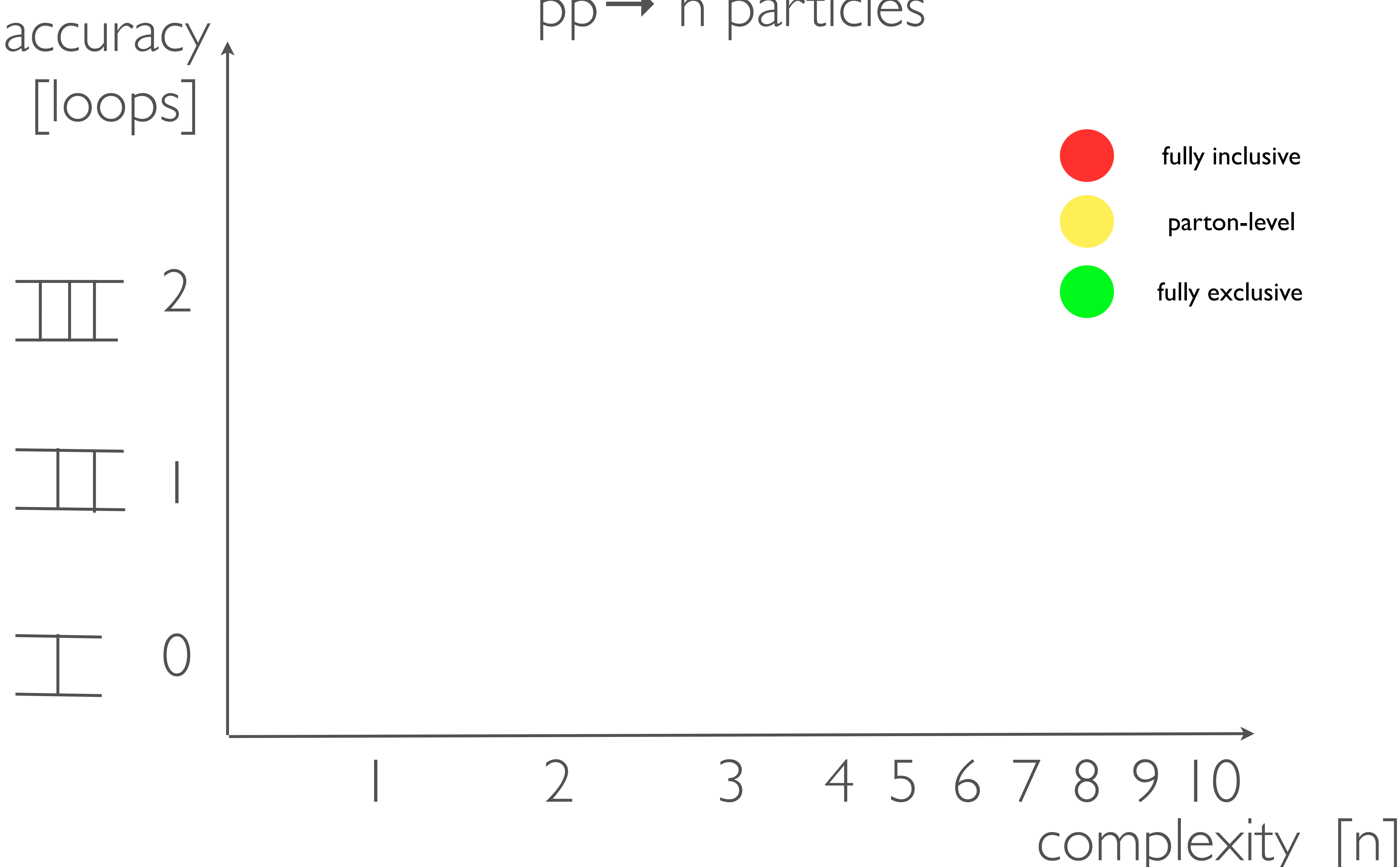
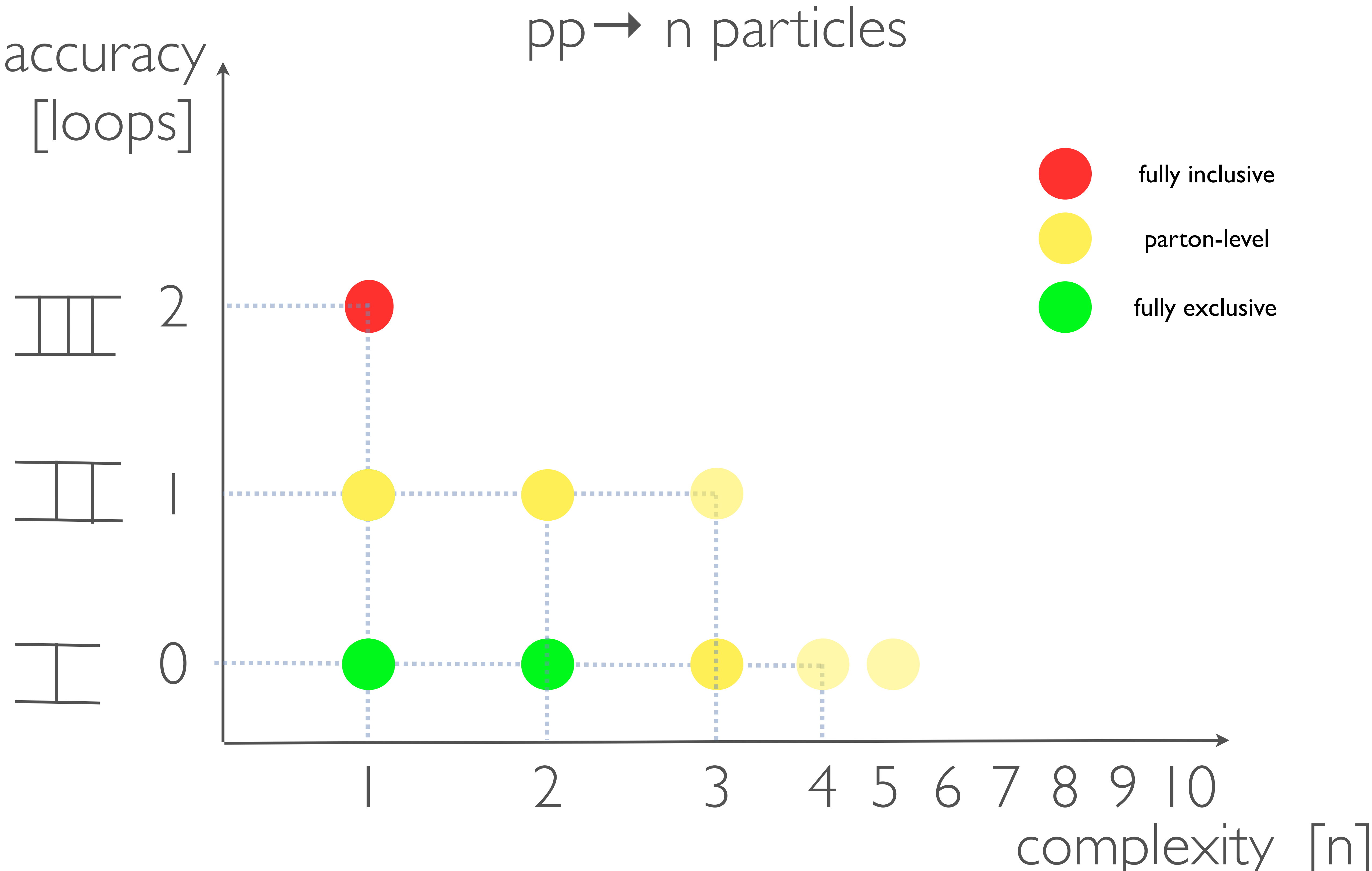
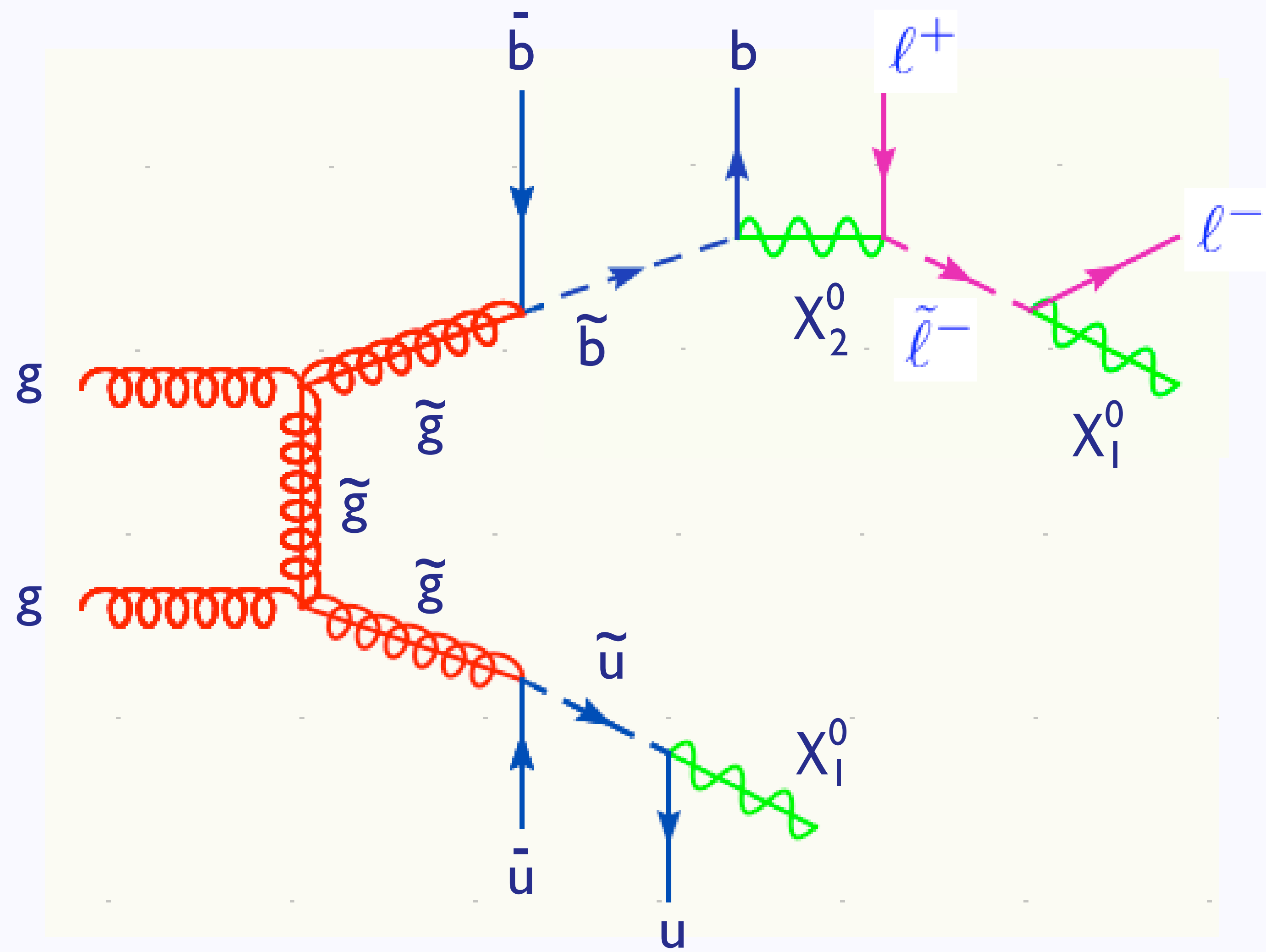


SM STATUS 10 YEARS AGO

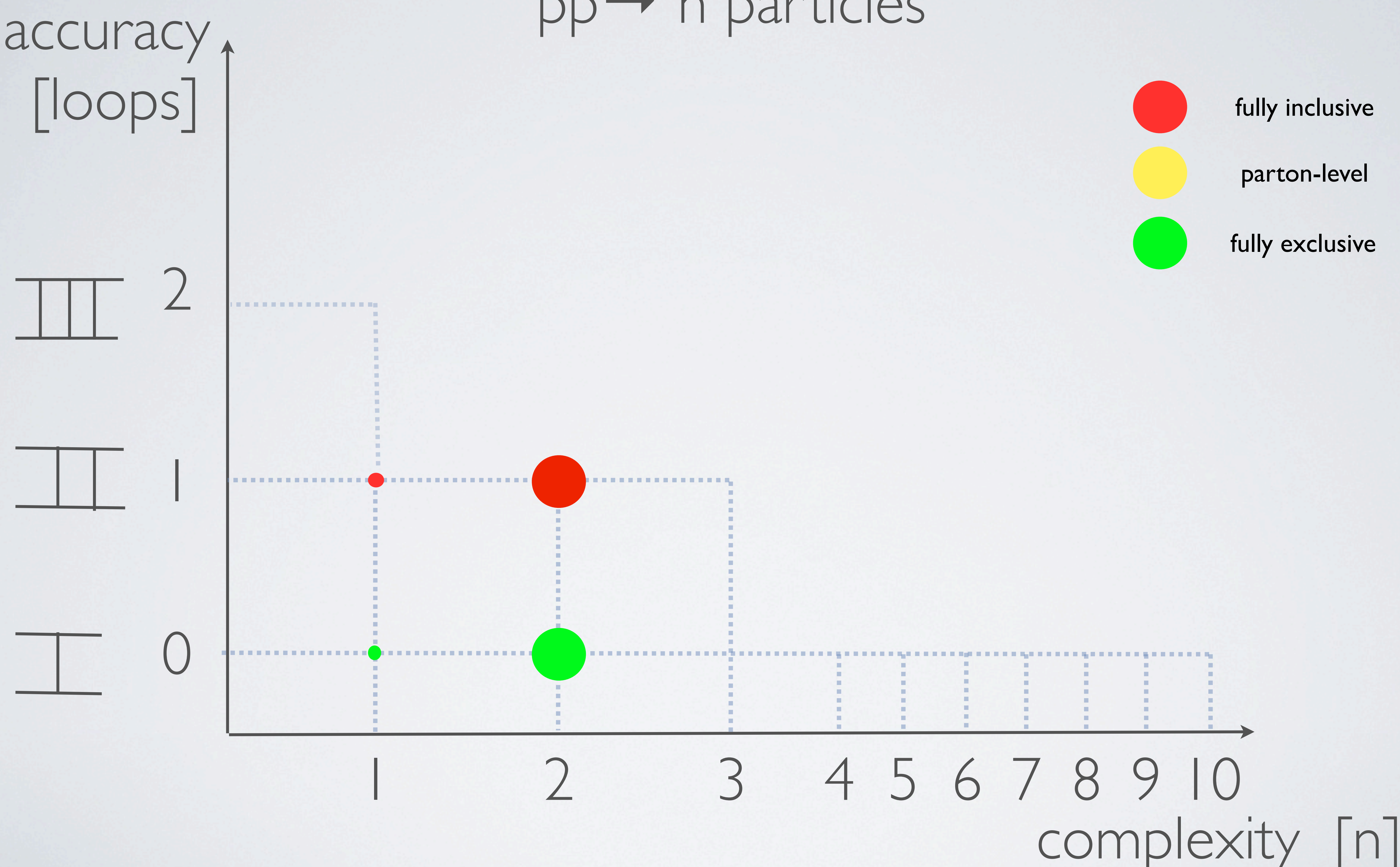


WHAT ABOUT NEW PHYSICS?



BSM (=SUSY)STATUS 10 YEARS AGO

pp→ n particles



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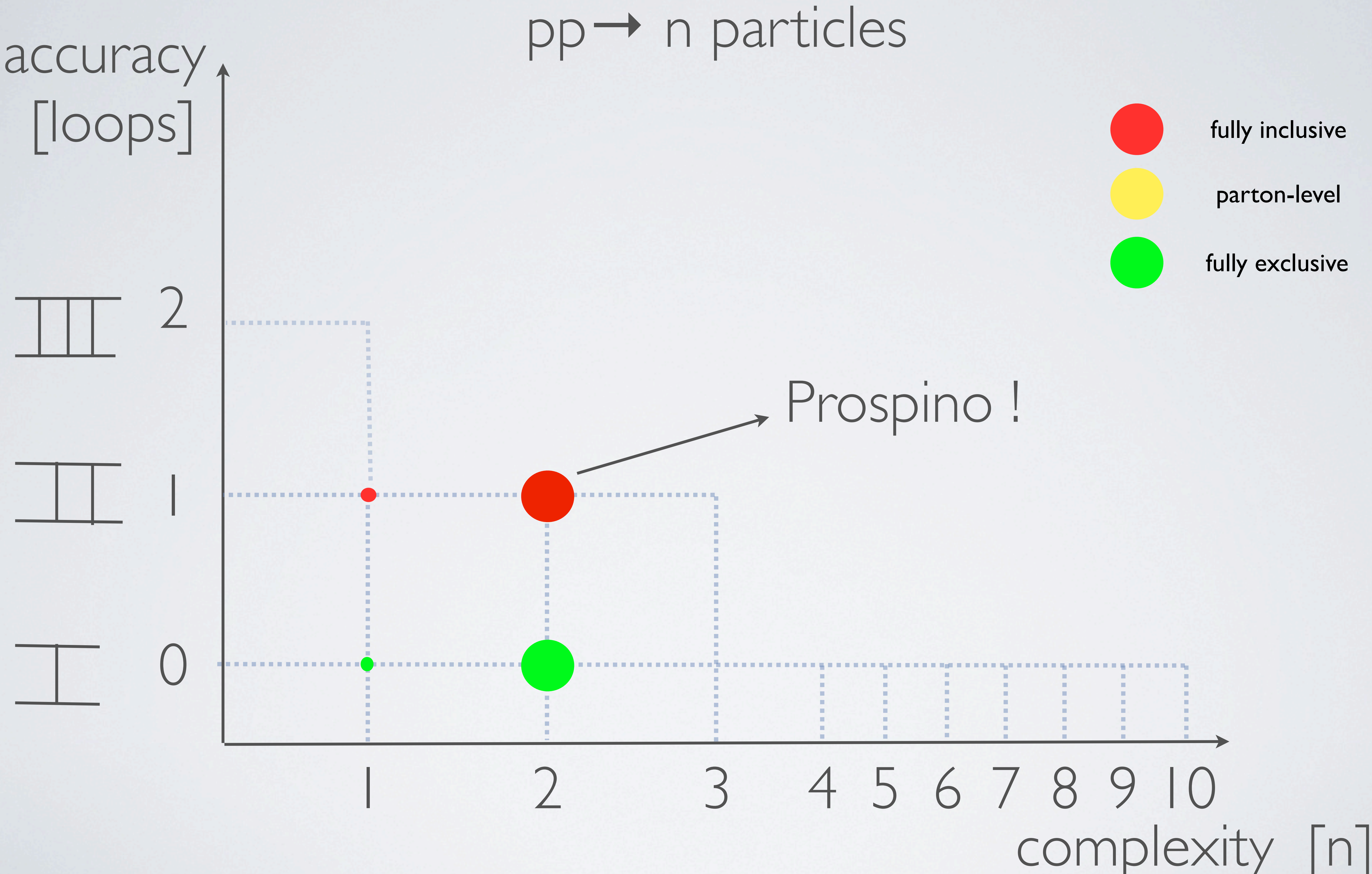

TH/EXP INTERACTIONS ANTE LHC

TH

Idea

TH/EXP INTERACTIONS ANTE LHC

TH

Idea

Lagrangian

Feyn. Rules

Amplitudes

x secs

↓

Paper

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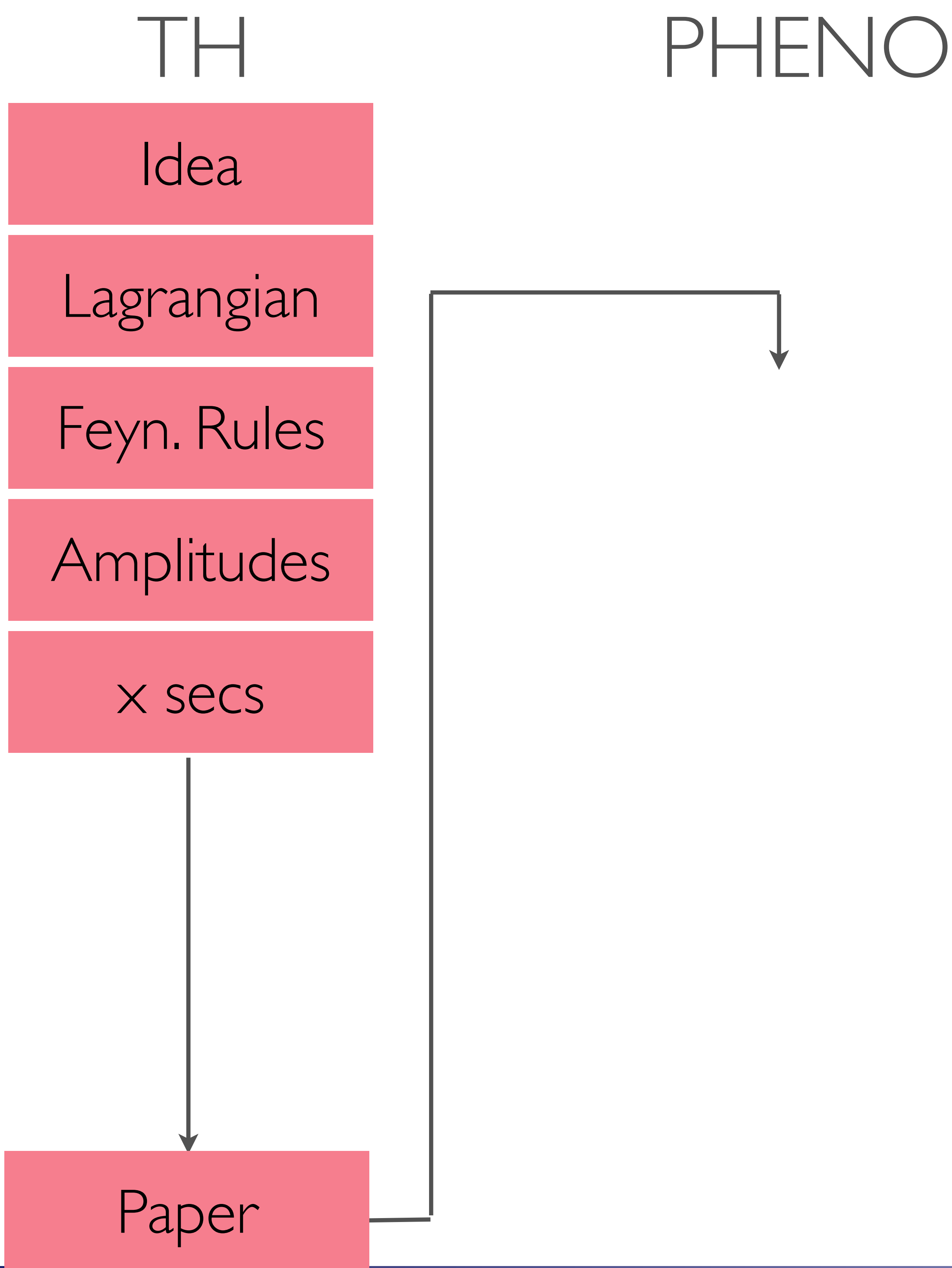

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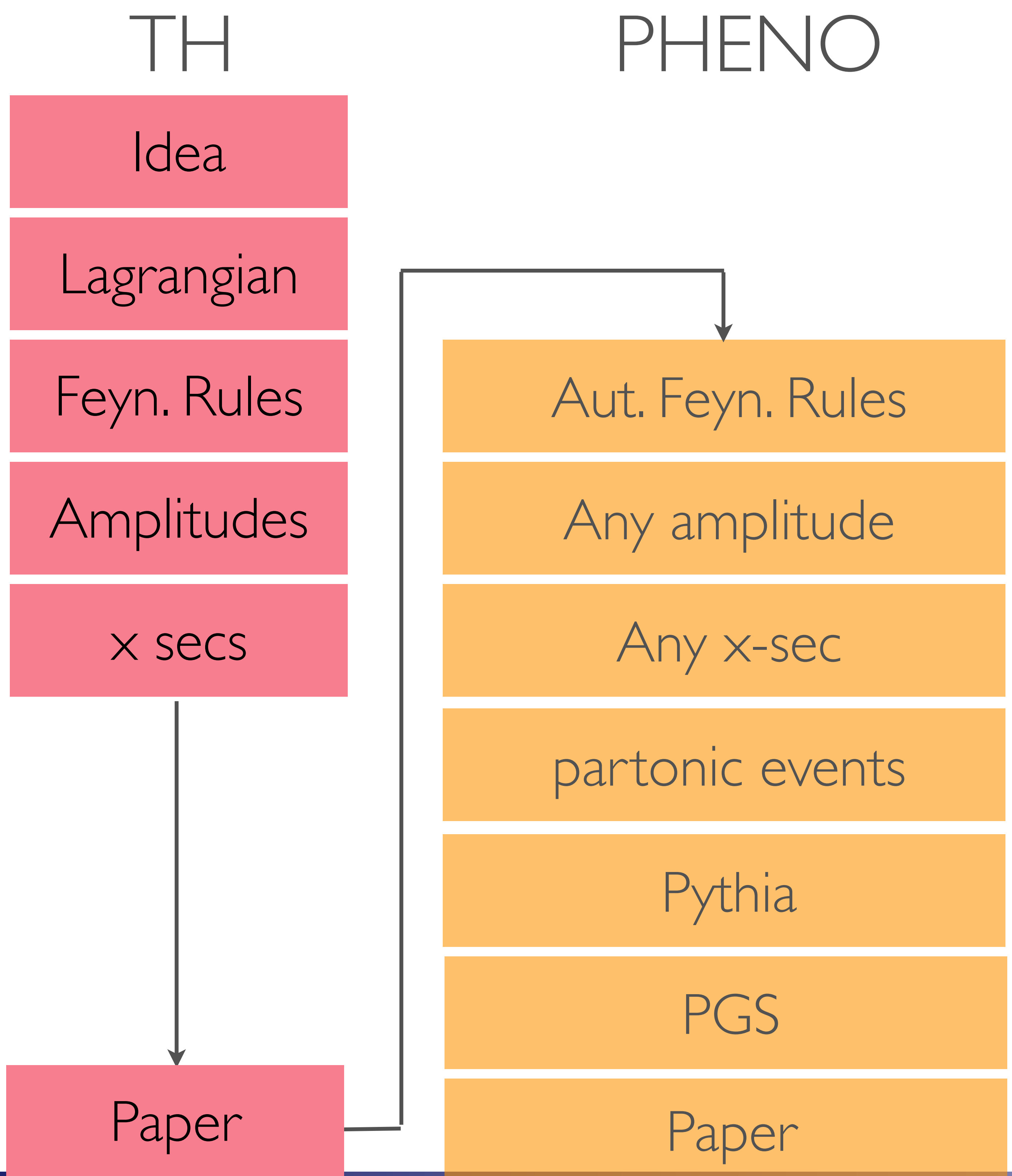

TH/EXP INTERACTIONS ANTE LHC

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TH/EXP INTERACTIONS ANTE LHC

TH | PHENO | EXP

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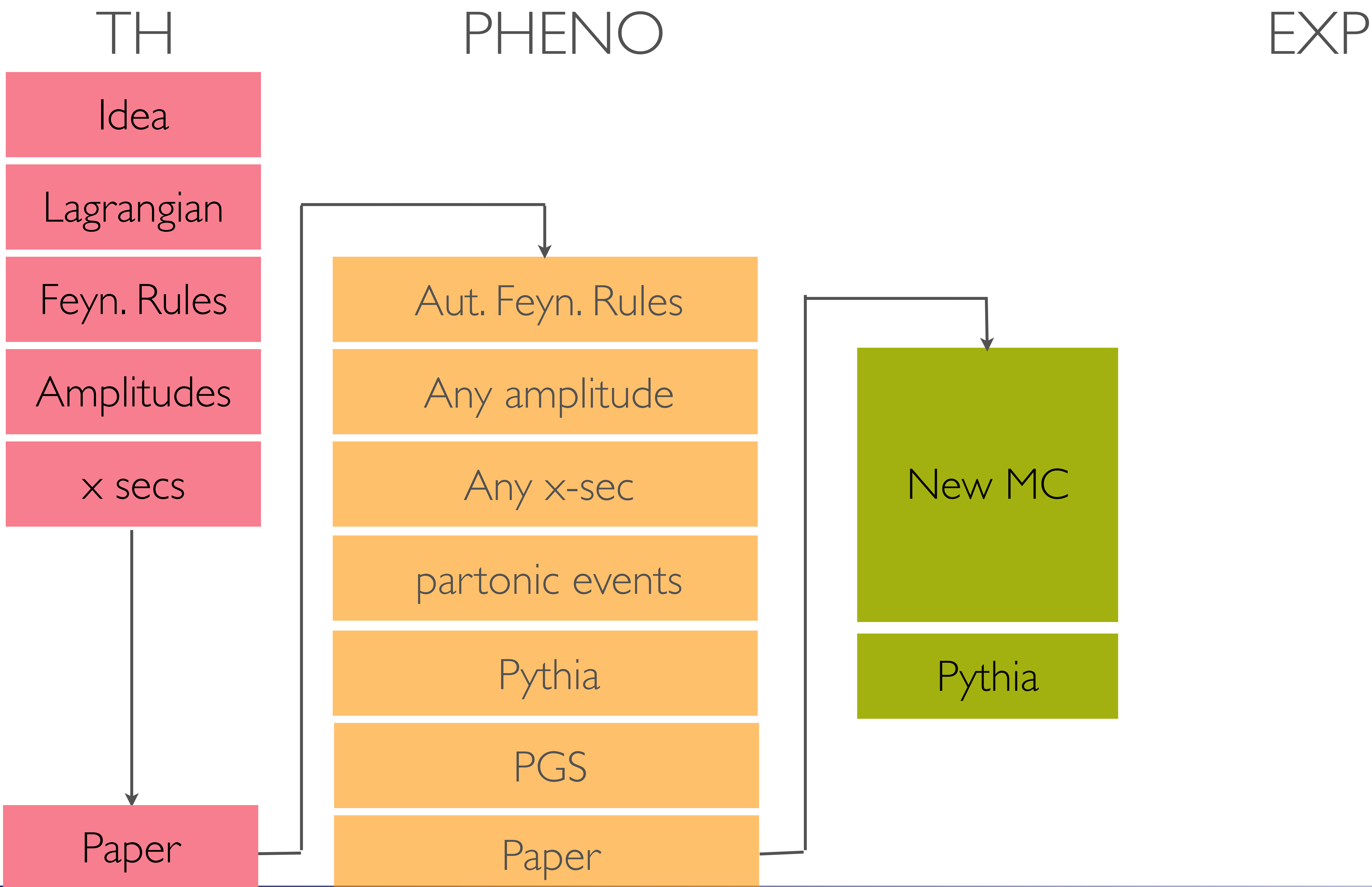

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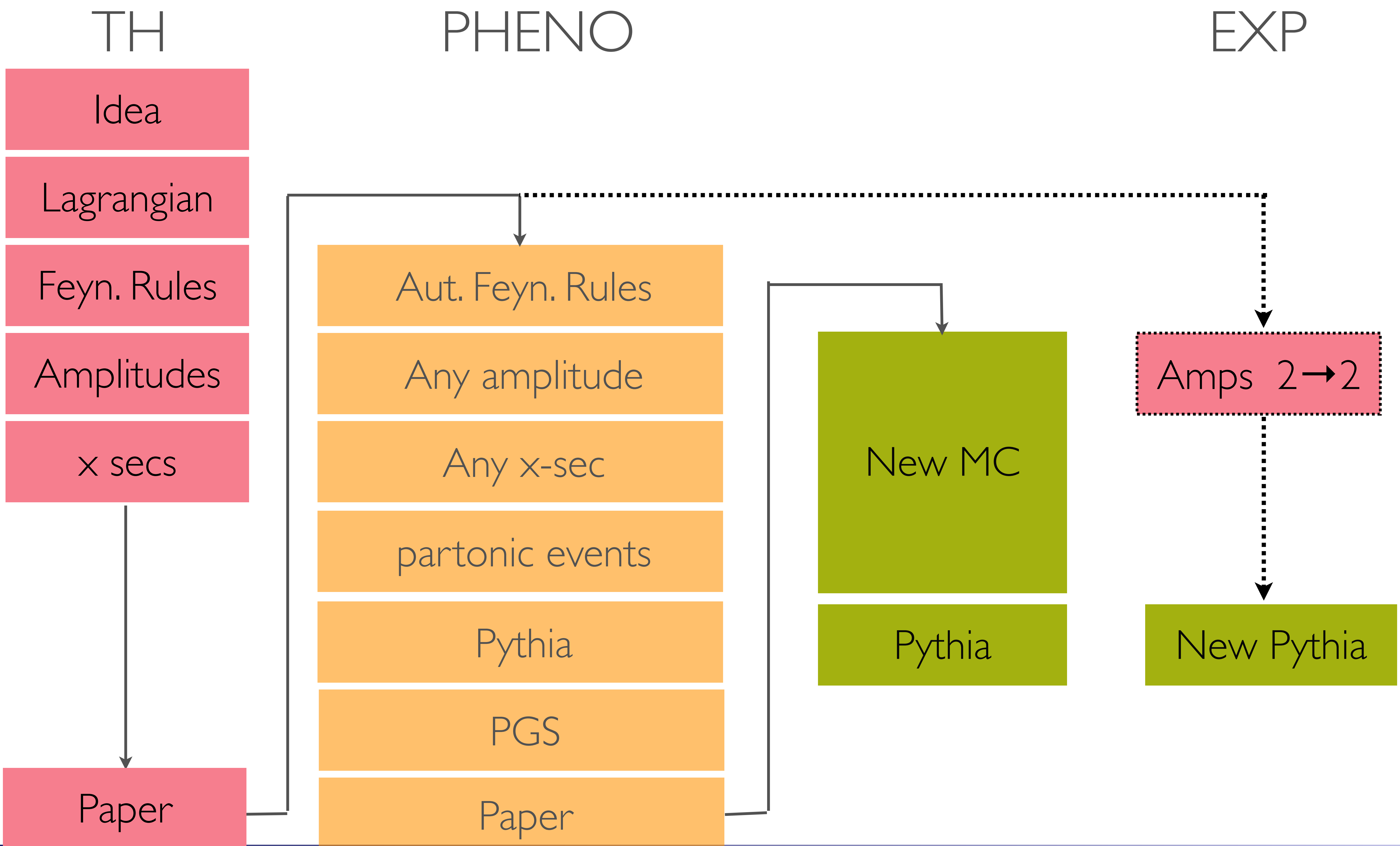

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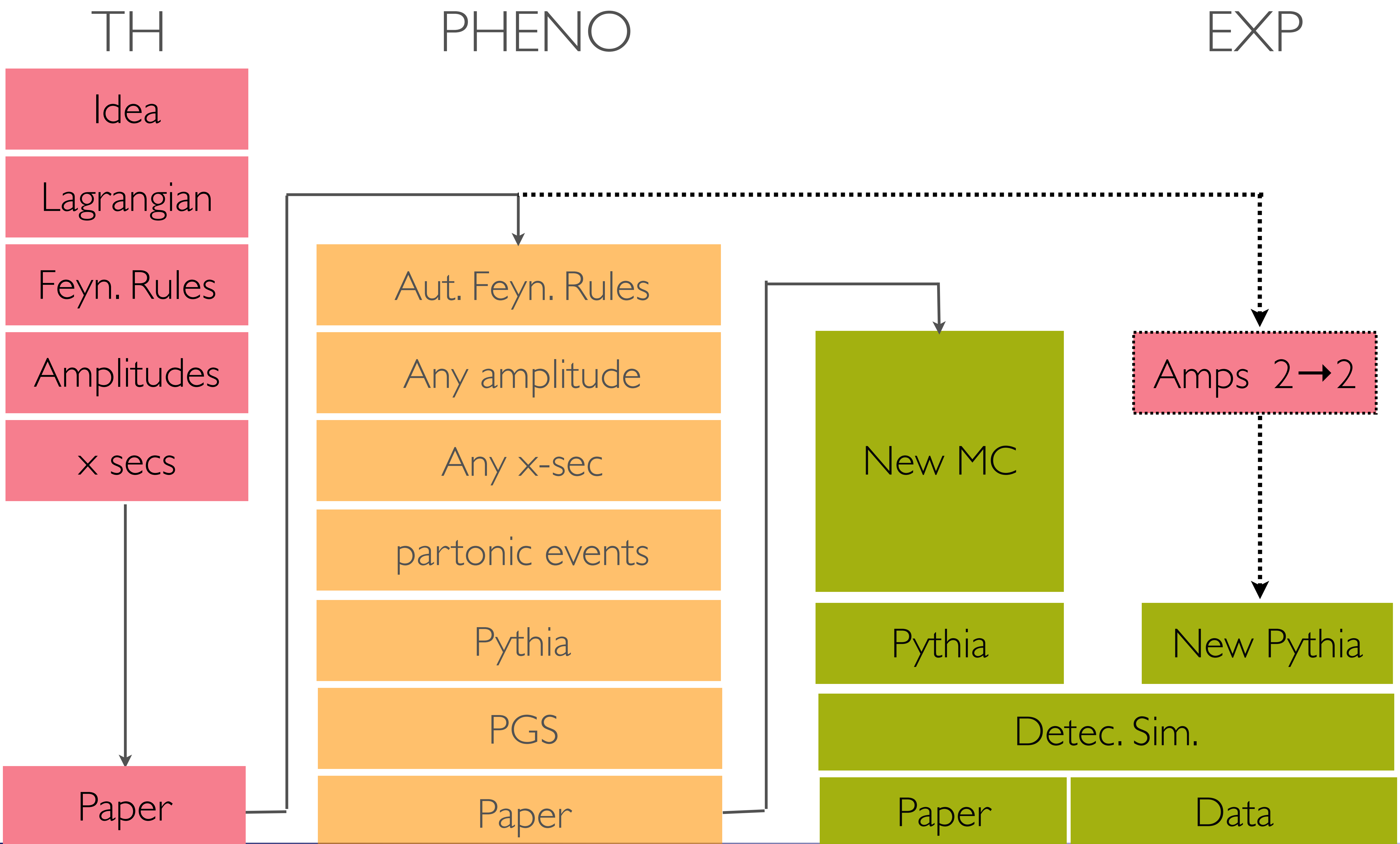

BSM TH/EXP INTERACTIONS : THE OLD WAY

- Workload is tripled!
- Long delays due to localized expertise and error prone. Painful validations are necessary at each step.
- It leads to a proliferation of private MC tools/sample productions impossible to maintain, document and reproduce on the mid- and long- term.
- Just publications is a very inefficient way of communicating between TH/PHENO/EXP.

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OK?

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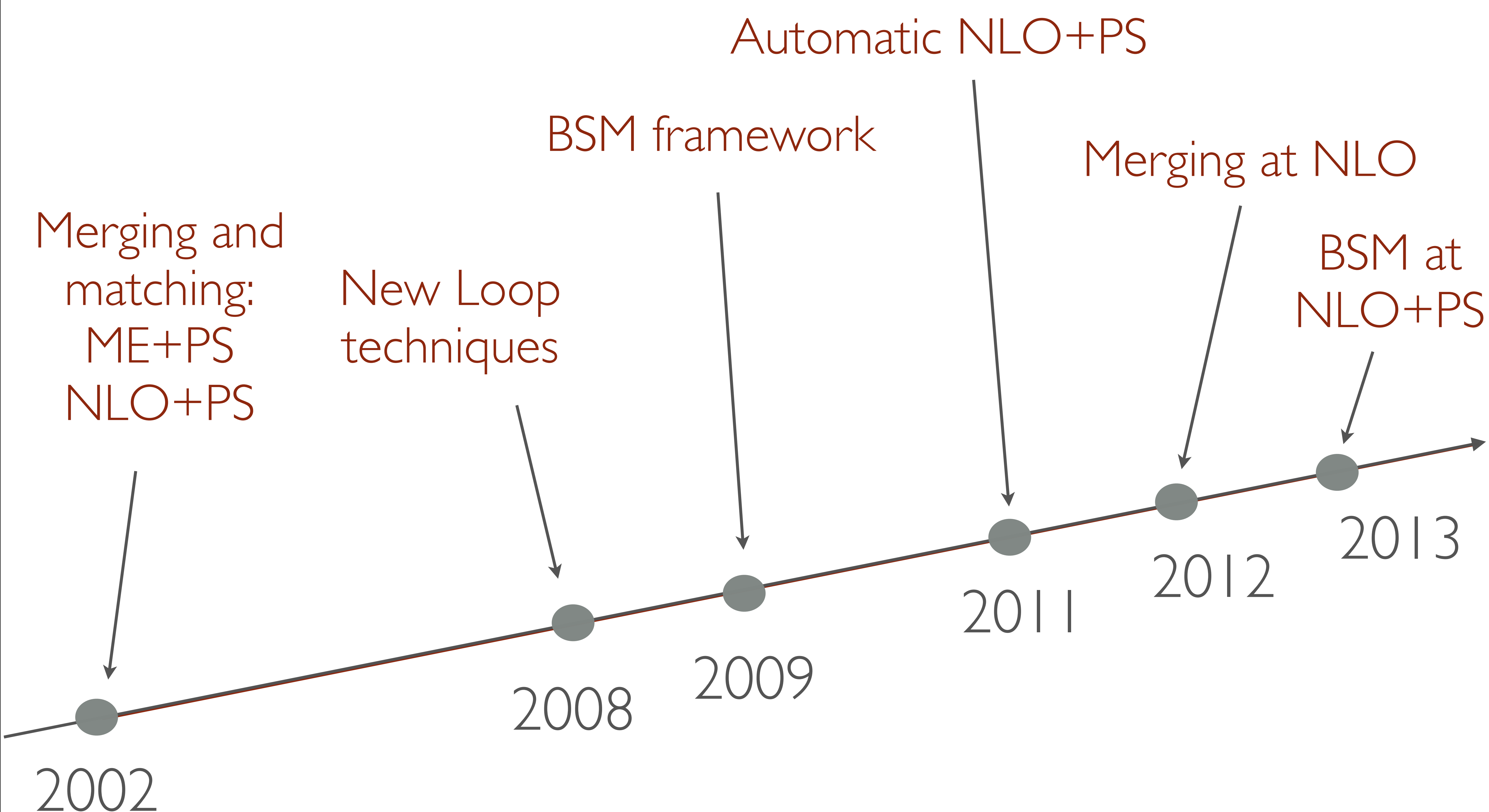
OK?

PREDICTIVE MC (SIMPLIFIED) PROGRESS



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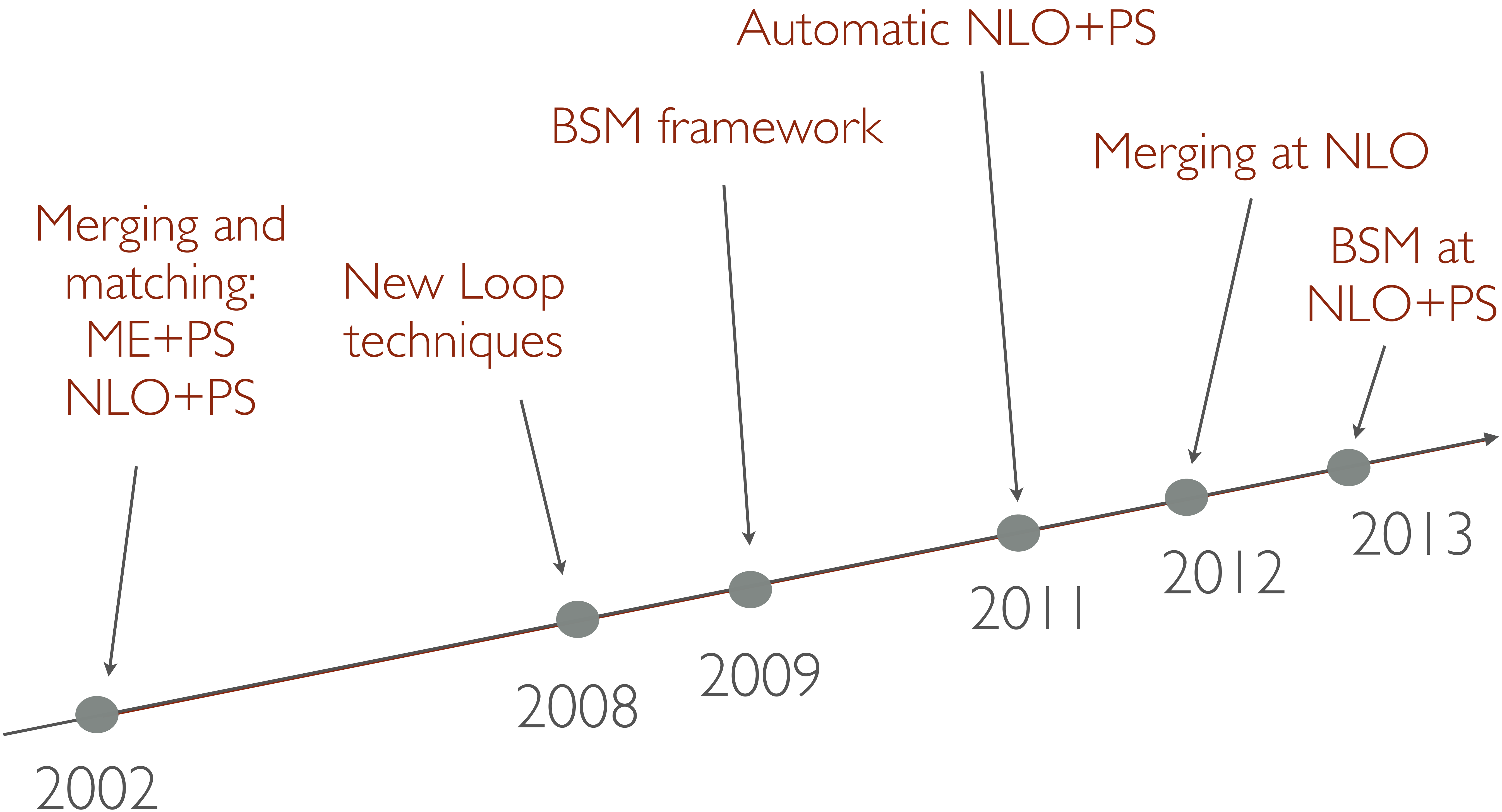
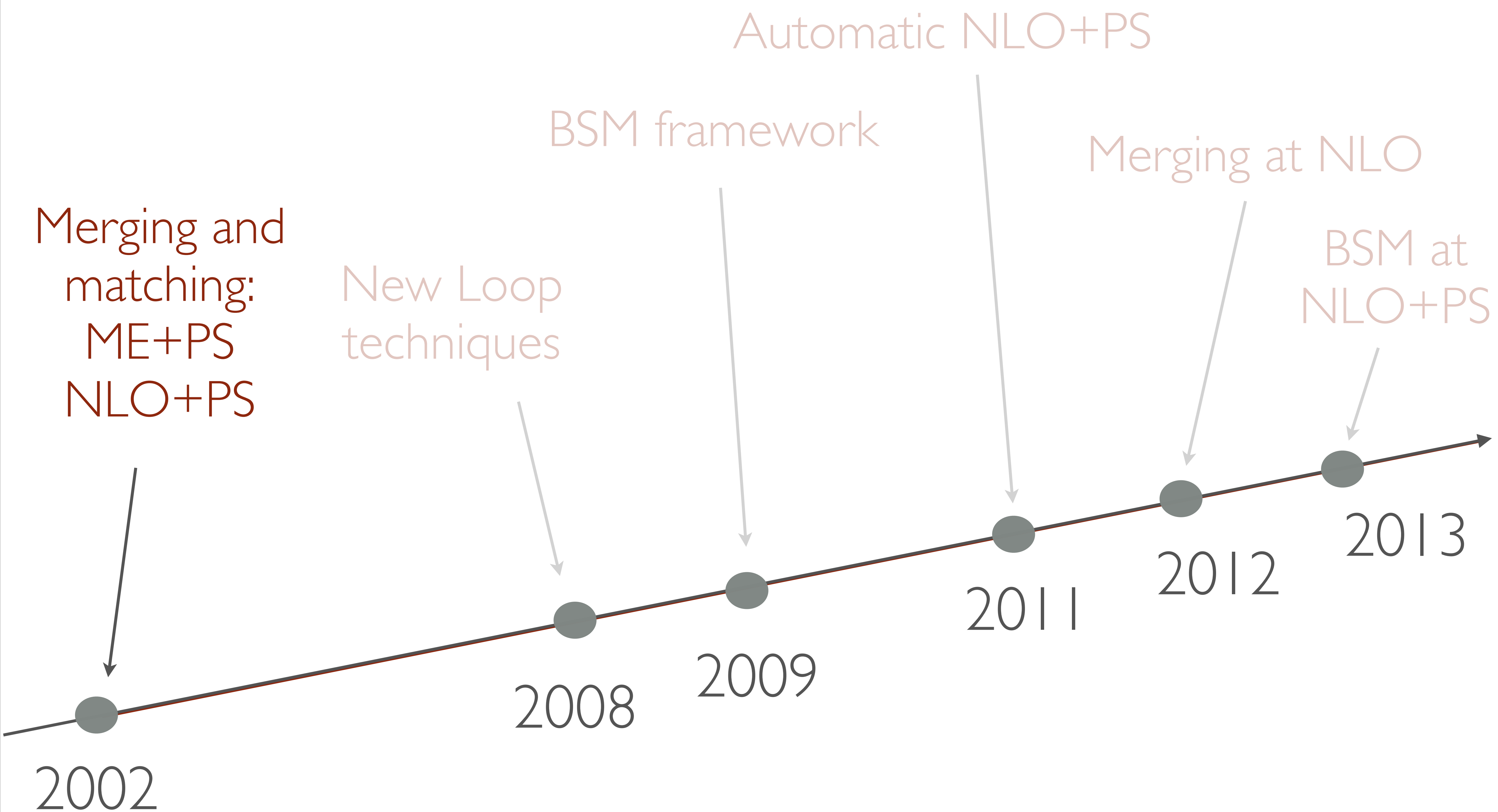


PREDICTIVE MC (SIMPLIFIED) PROGRESS



ME WITH PS

[Mangano]
[Catani, Krauss, Kuhn, Webber]
[Frixione, Nason, Webber]

Matrix Element

1. parton-level description
2. fixed order calculation
3. quantum interference exact
4. valid when partons are hard and well separated
5. needed for multi-jet description

Shower MC

1. hadron-level description
2. resums large logs
3. quantum interference through angular ordering
4. valid when partons are collinear and/or soft
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Approaches are complementary: merge them!

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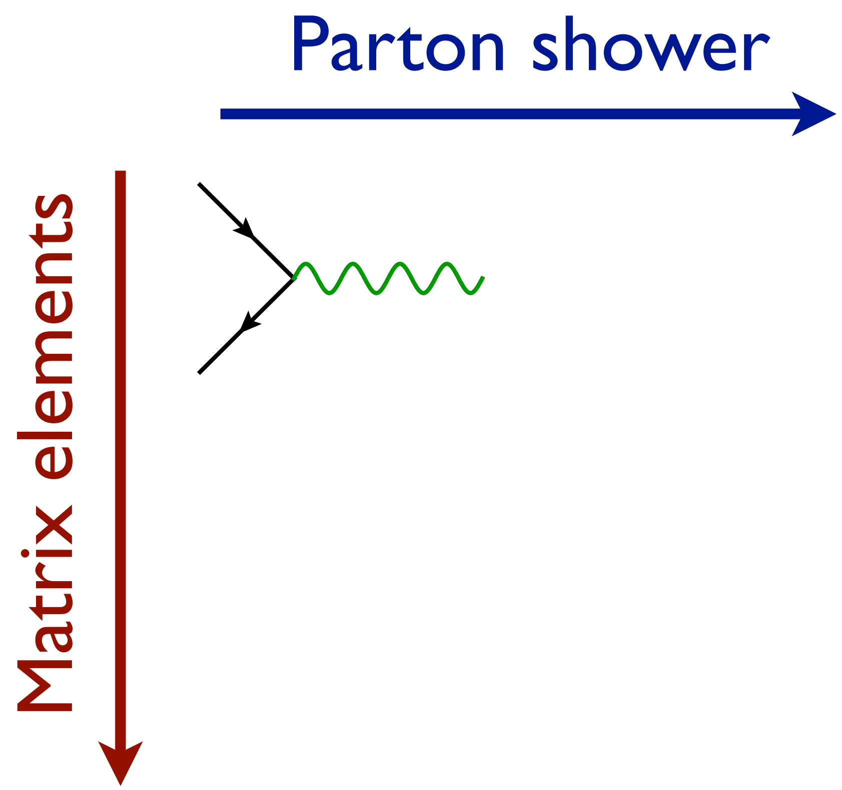
Approaches are complementary: merge them!

Difficulty: avoid double counting

Merging fixed order with PS



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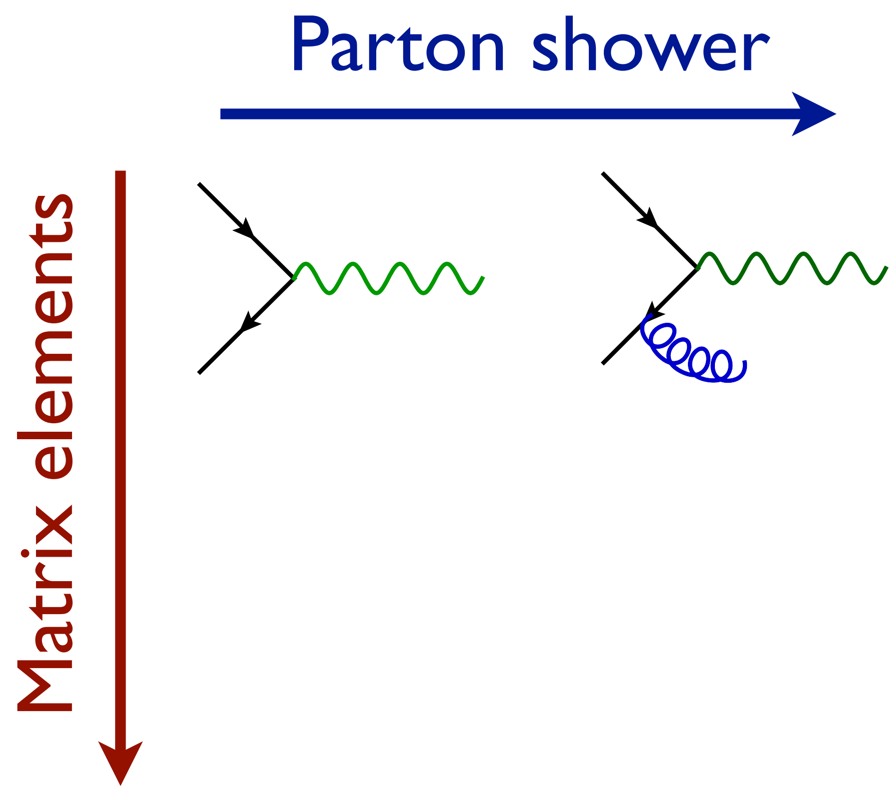

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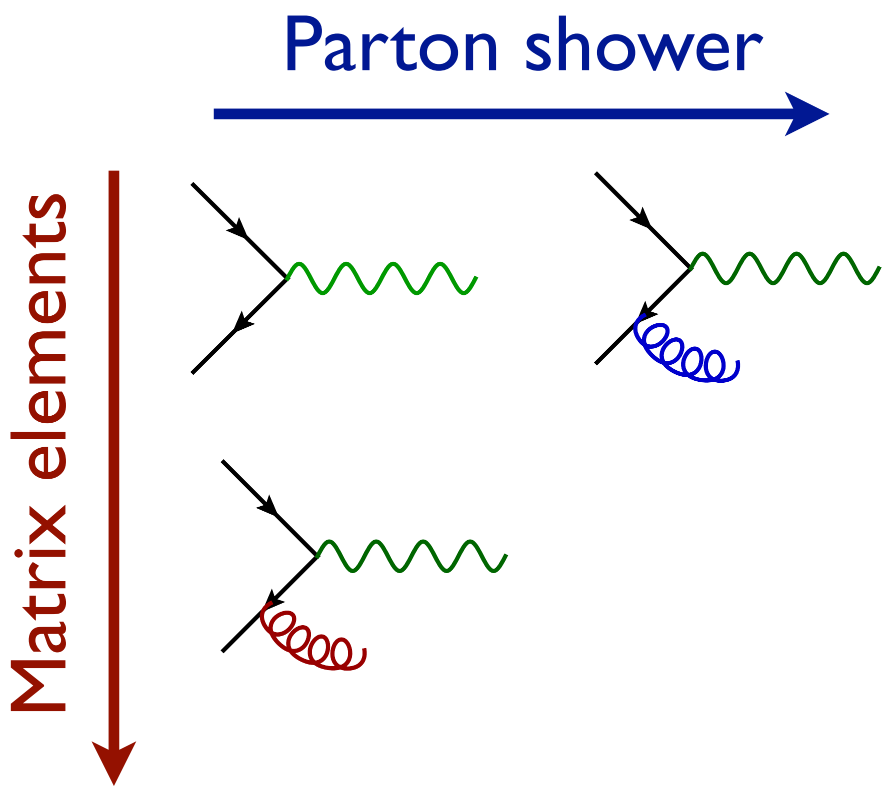

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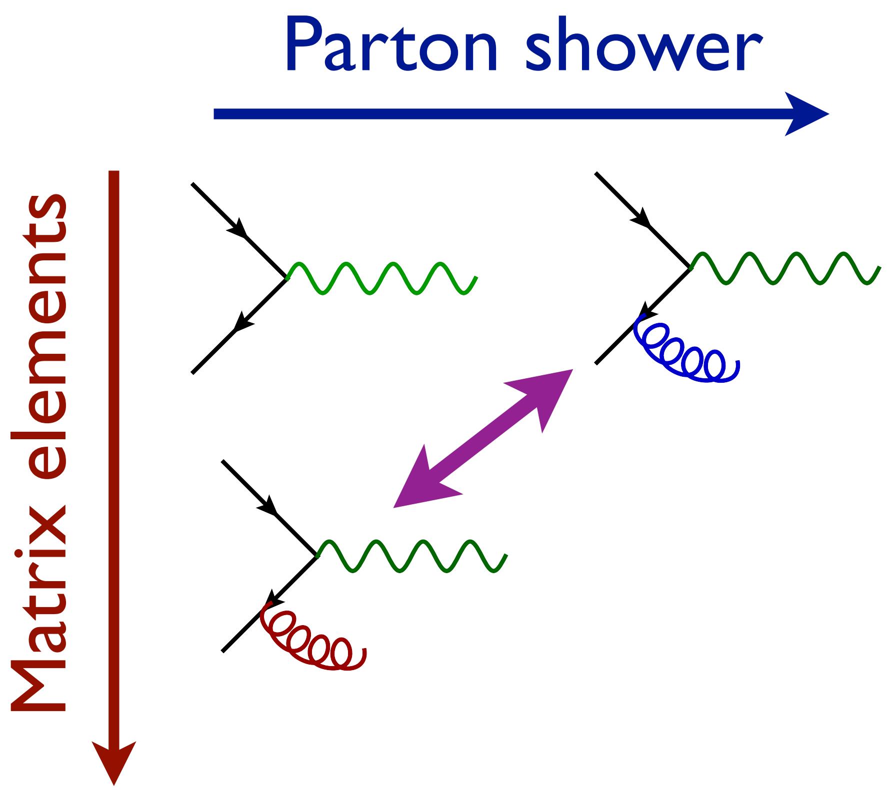

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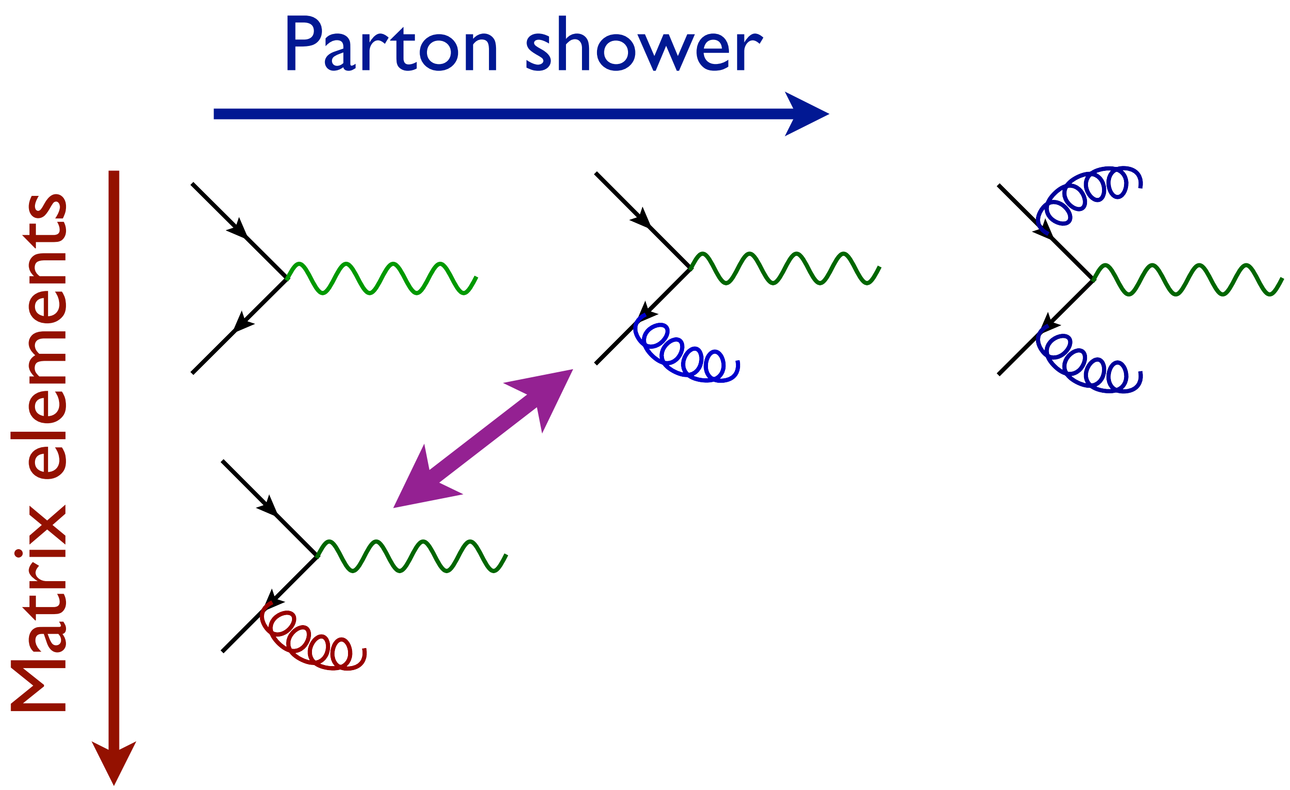

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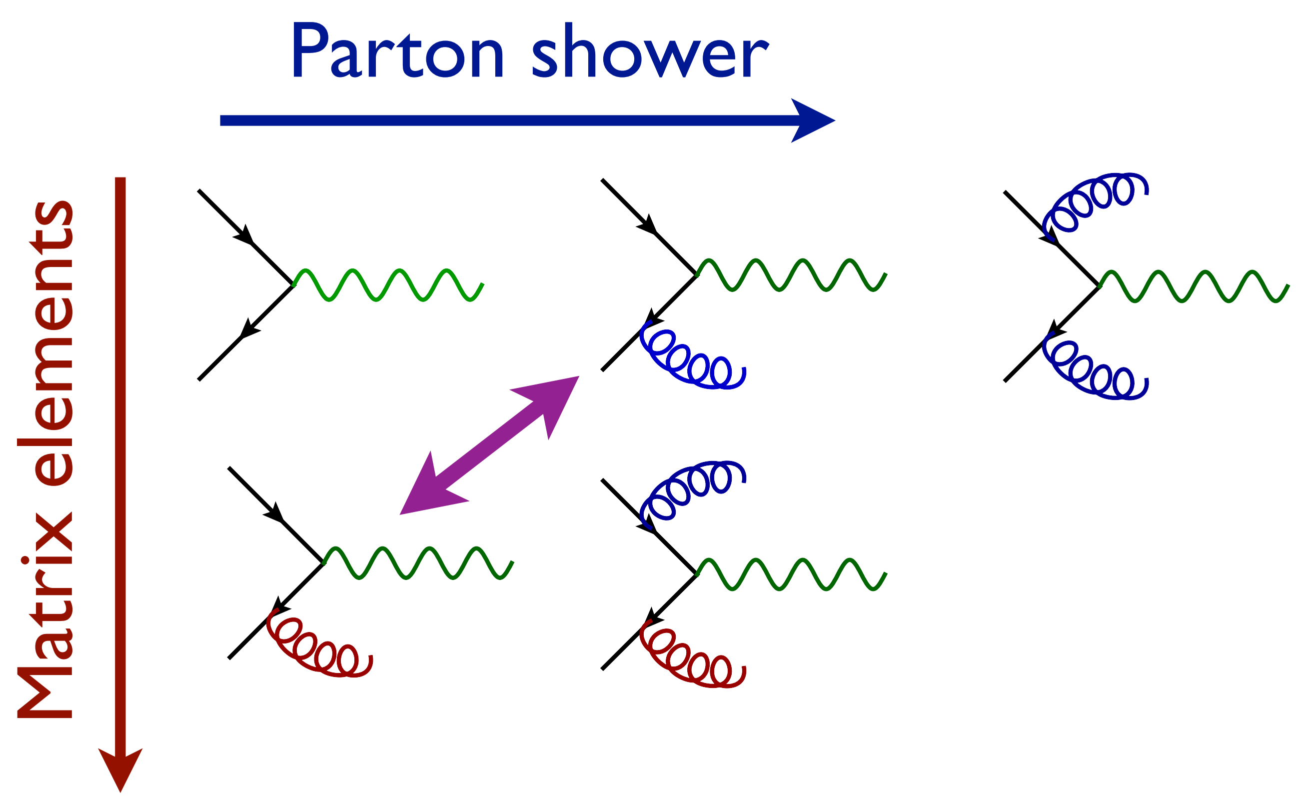

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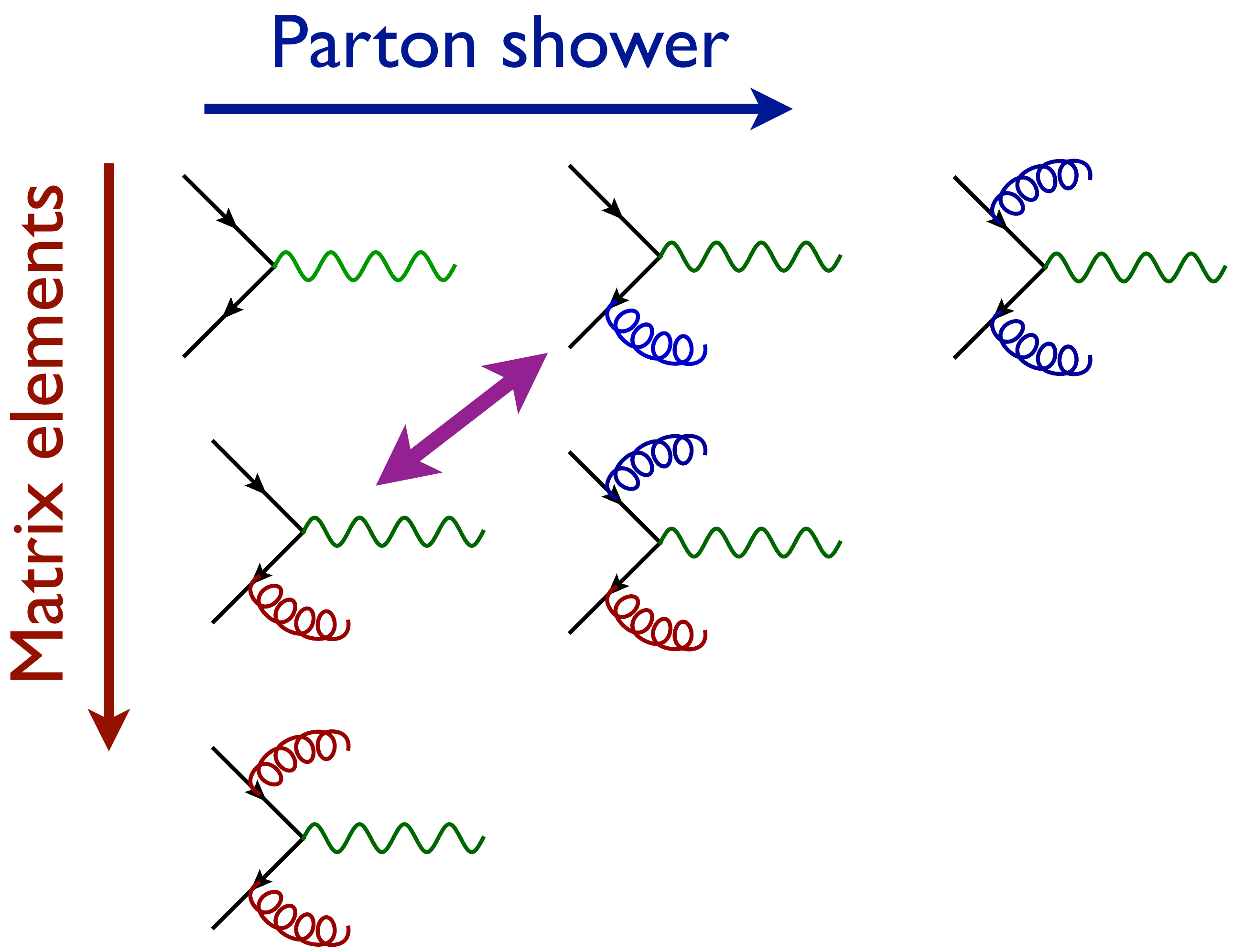

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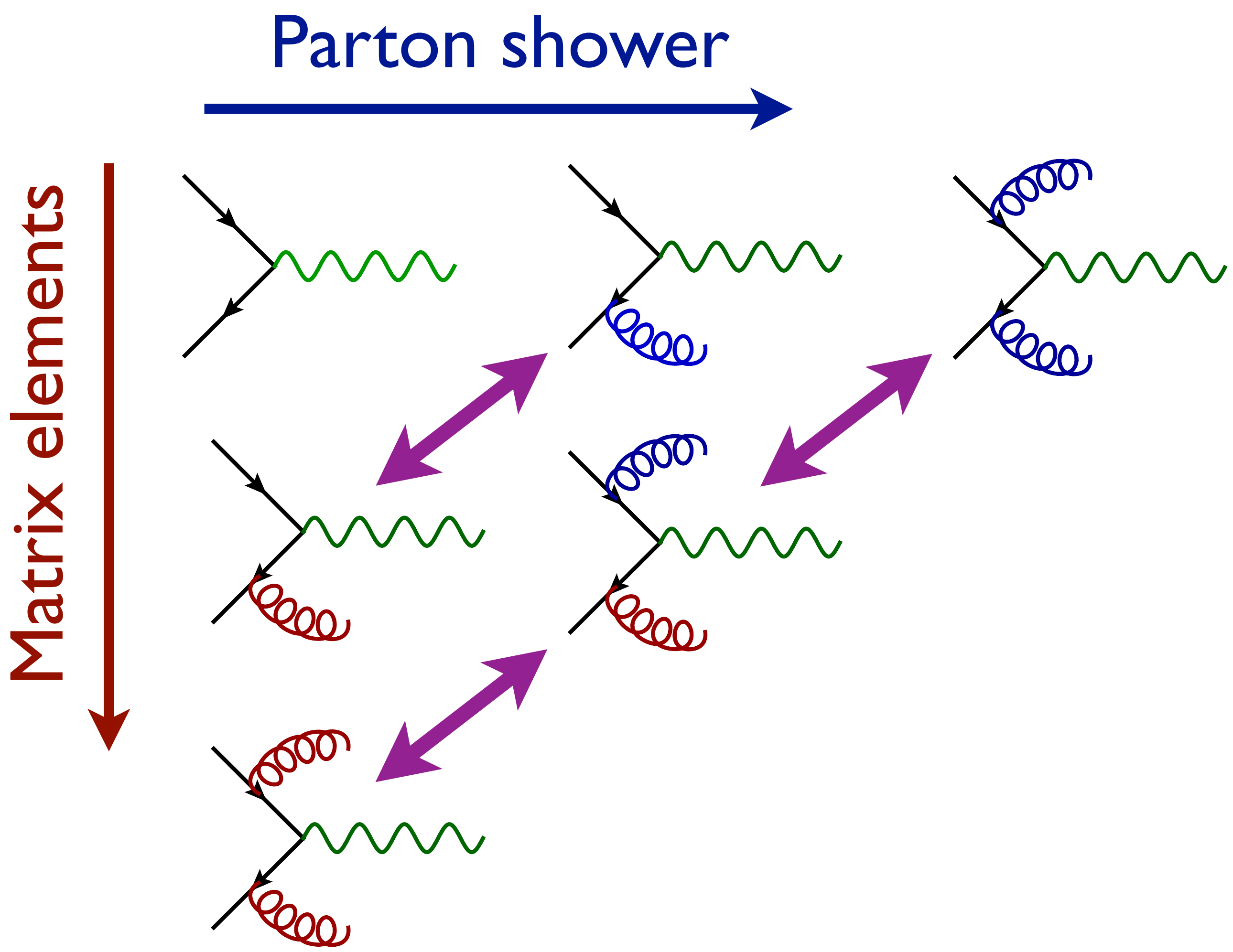

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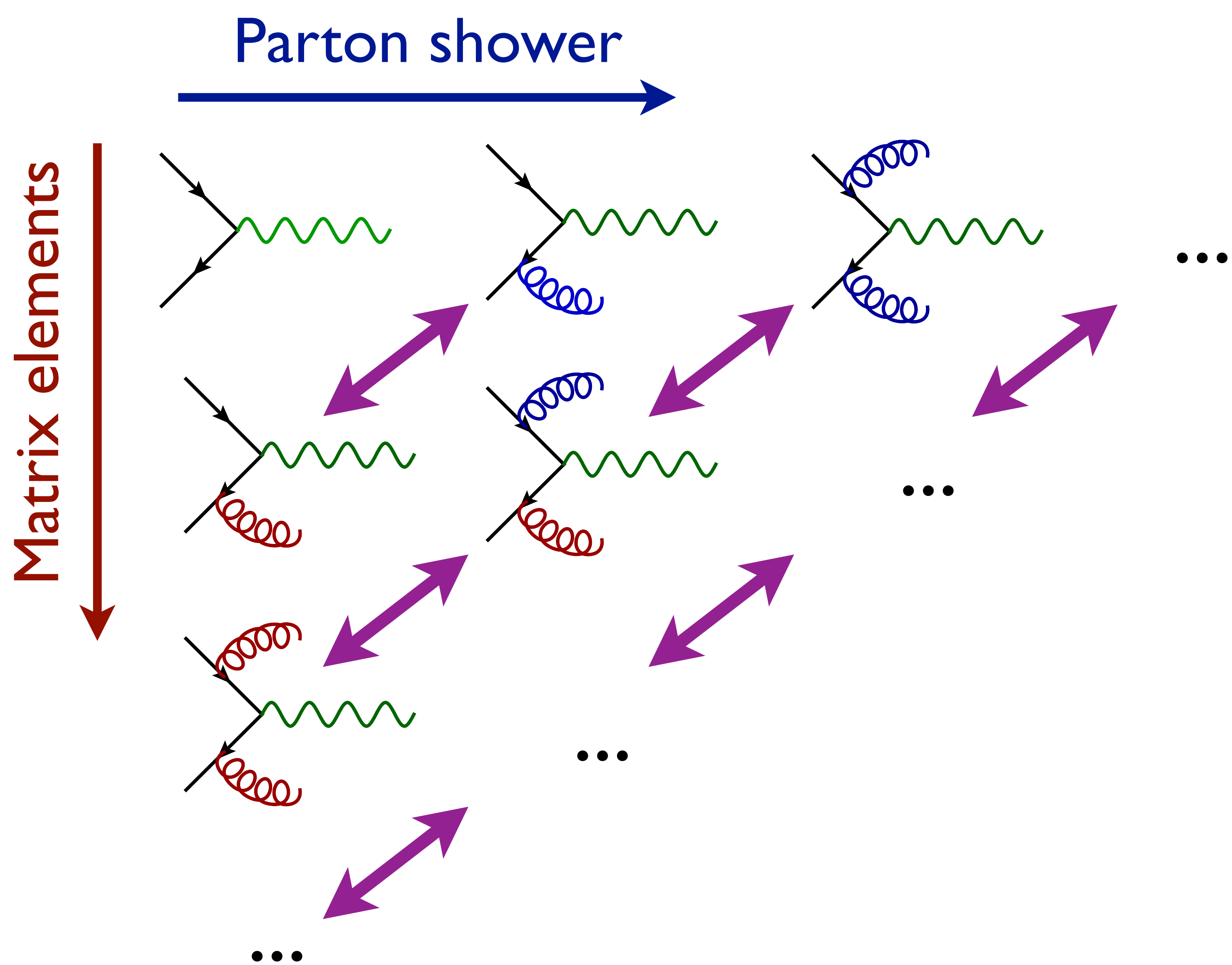

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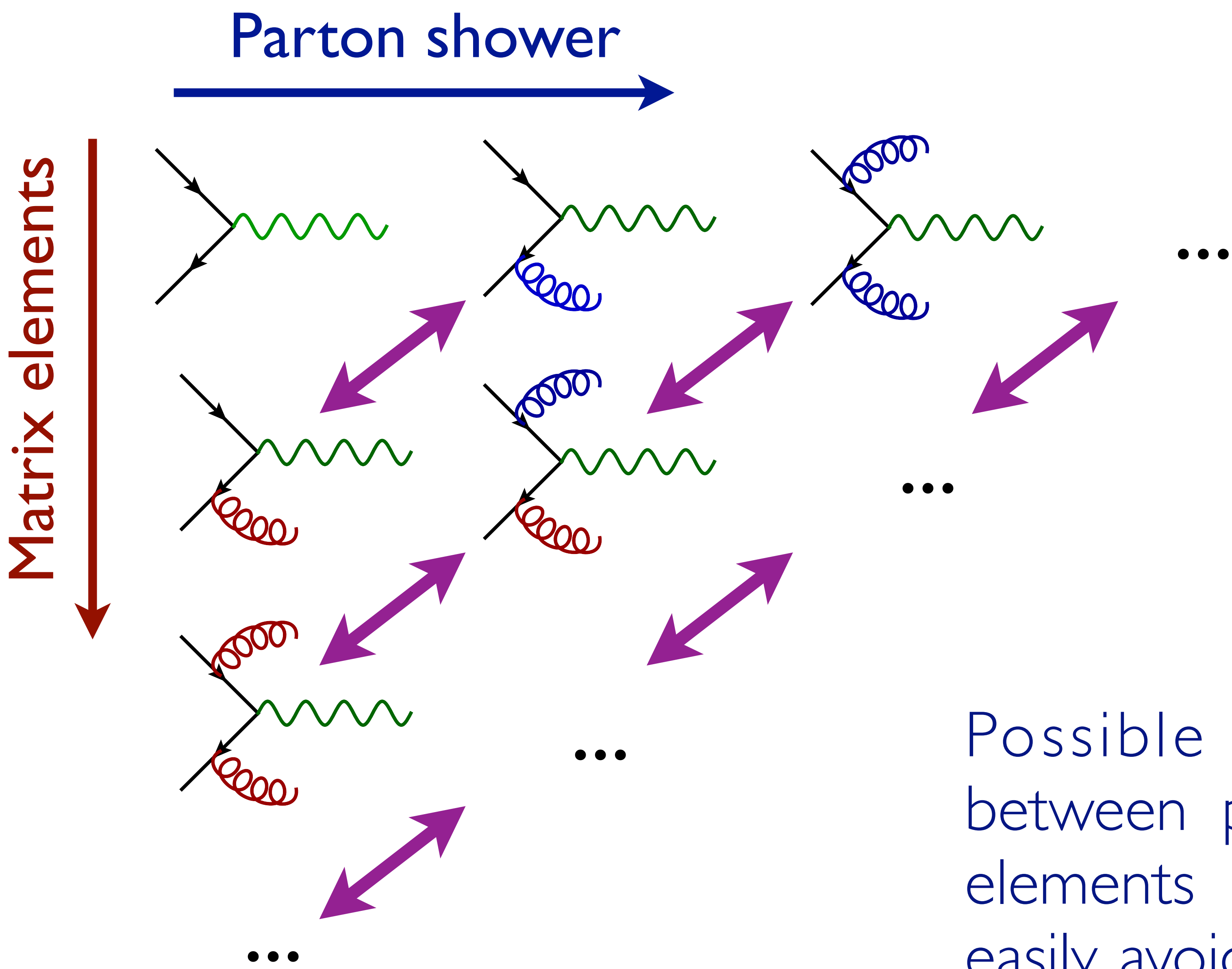

Possible double counting between partons from matrix elements and parton shower easily avoided by applying a cut in phase space

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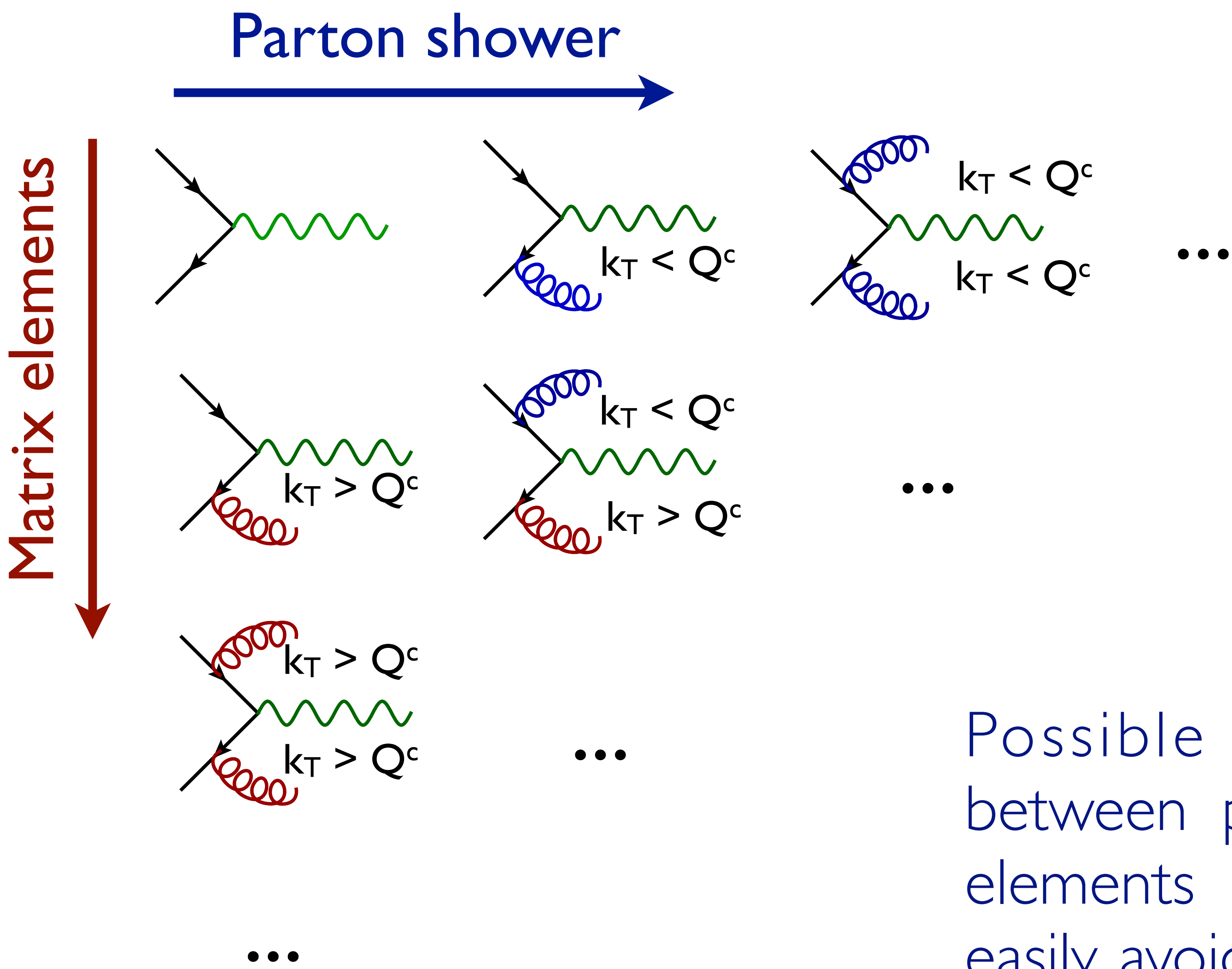

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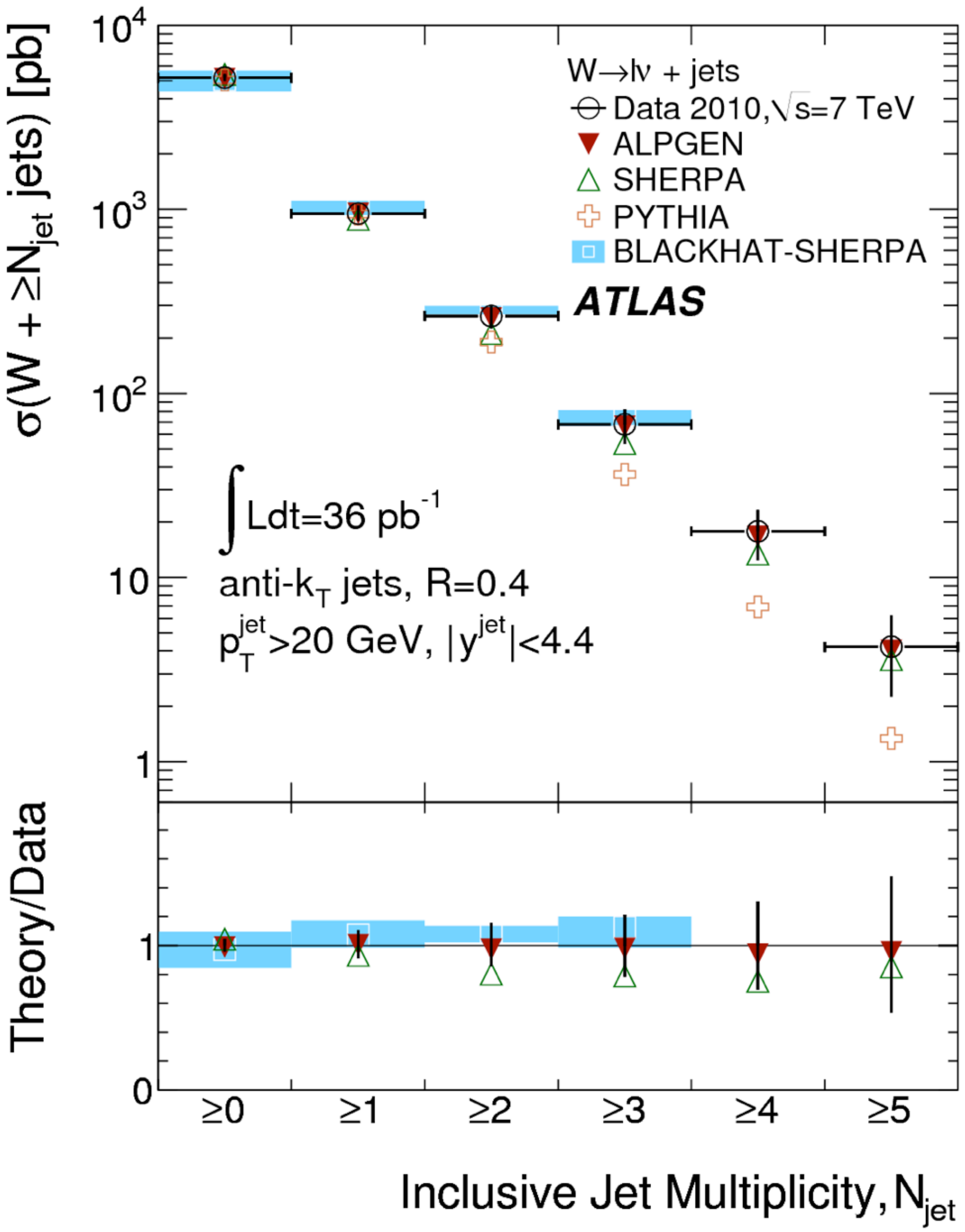
V+JETS AT THE LHC



Working amazingly well!

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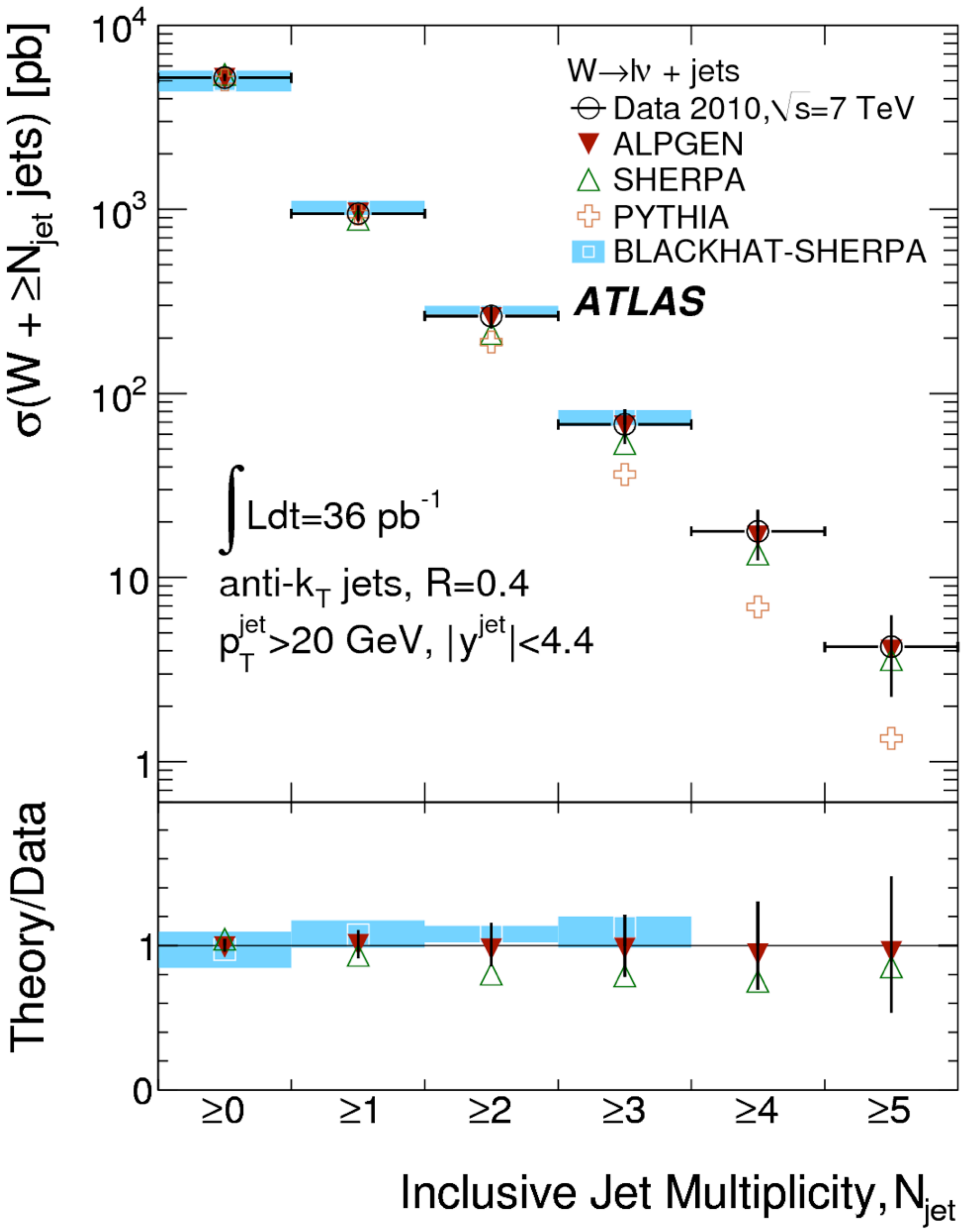

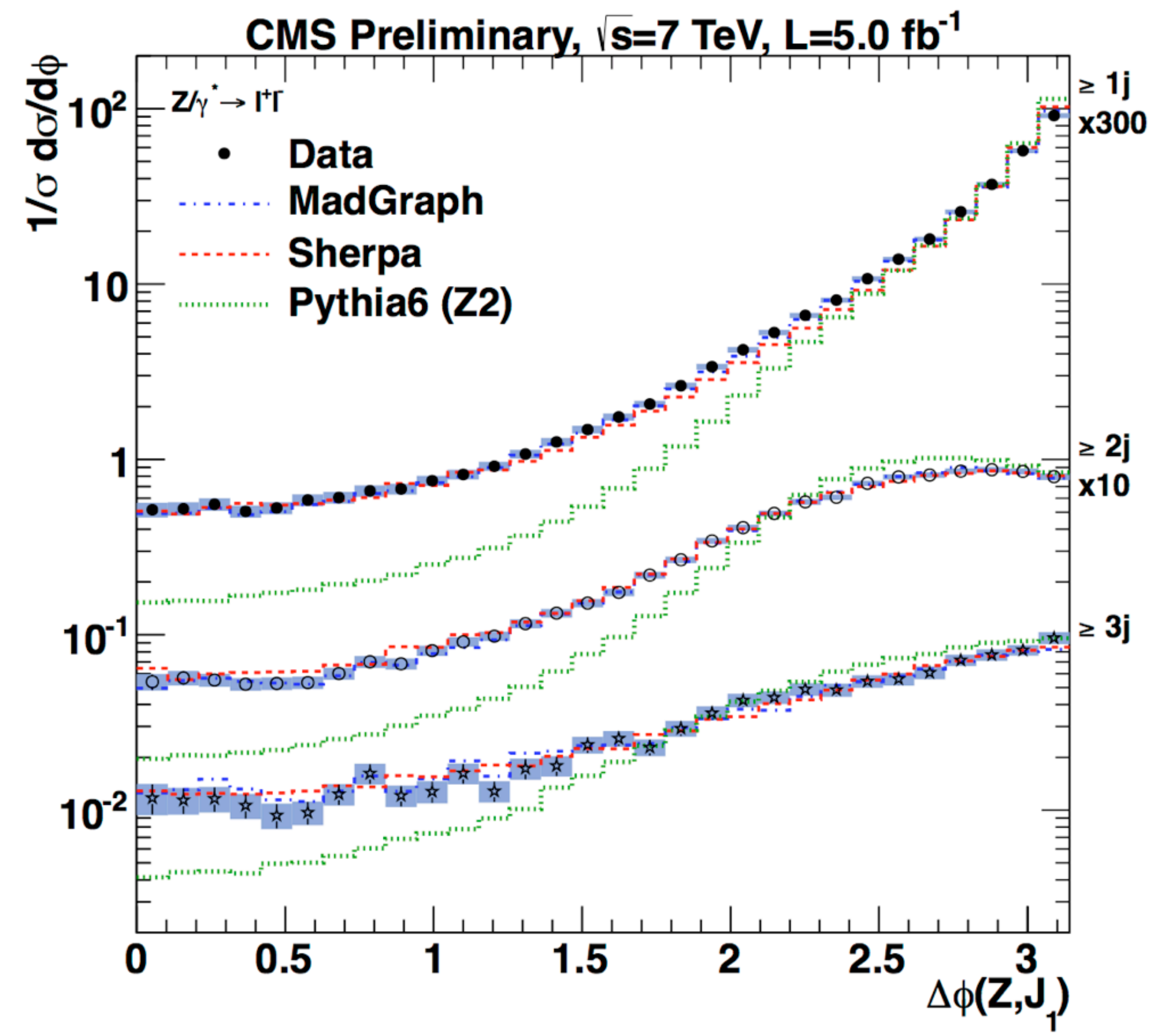

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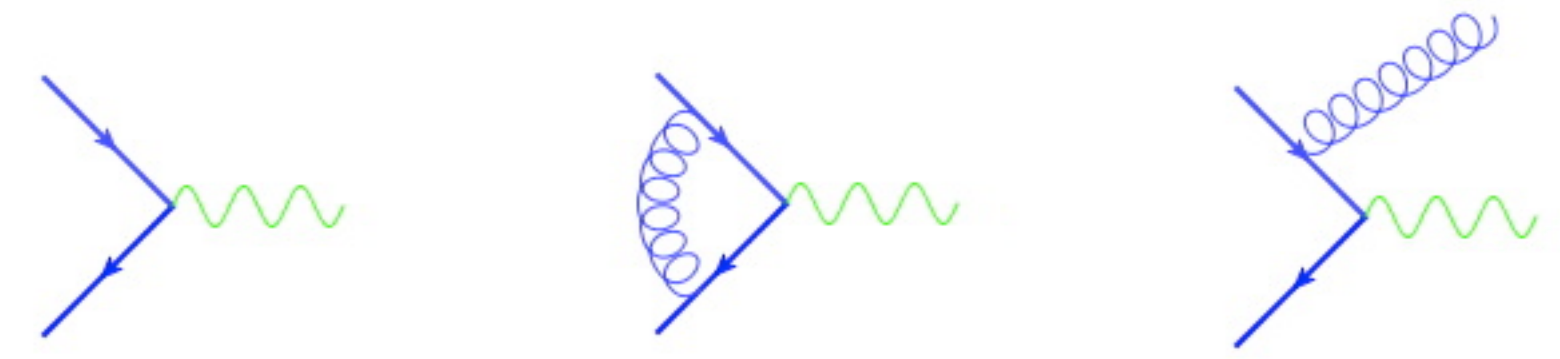
WHAT ABOUT NLO?



$$d\sigma^{\mathrm{NLOwPS}}_{\mathrm{NAIVE}} = \left[d\Phi_B(B(\Phi_B) + V + S^{\mathrm{int}}_{\mathrm{ct}})\right] I^n_{\mathrm{MC}} + \left[d\Phi_B d\Phi_{R|B}(R - S_{ct})\right] I^{n+1}_{\mathrm{MC}}$$

This simple approach does not work:

- Instability: weights associated to I^n_{MC} and I^{n+1}_{MC} are divergent pointwise (infinite weights).

- Double counting: $d\sigma^{naive}_{NLOwPS}$ expanded at NLO does not coincide with NLO rate. Some configurations are dealt with by both the NLO and the PSMC.

Currently, two solutions available

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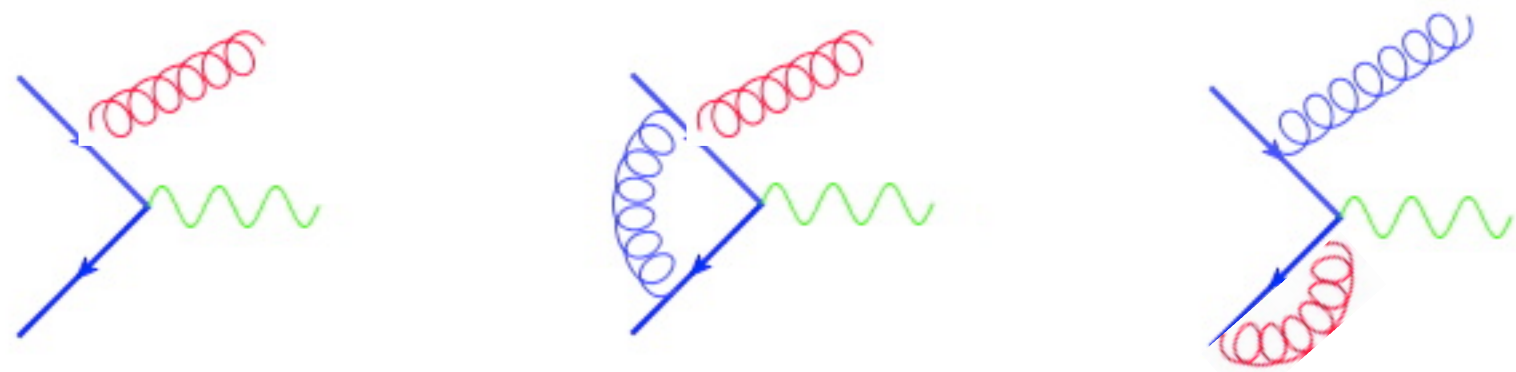

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NLO+PS IN A NUTSHELL

$$d\sigma^{\text{NLO+PS}} = d\Phi_B \bar{B}^s(\Phi_B) \left[\Delta^s(p_\perp^{\min}) + d\Phi_{R|B} \frac{R^s(\Phi_R)}{B(\Phi_B)} \Delta^s(p_T(\Phi)) \right] + d\Phi_R R^f(\Phi_R)$$

integrates to 1 (unitarity)

with

$$\bar{B}^s = B(\Phi_B) + \left[V(\Phi_B) + \int d\Phi_{R|B} R^s(\Phi_{R|B}) \right]$$

Full cross section (if F=1) at fixed Born kinematics

$$R(\Phi_R) = R^s(\Phi_R) + R^f(\Phi_R)$$

This formula is valid both for both MC@NLO and POWHEG

MC@NLO: $R^s(\Phi) = P(\Phi_{R|B})\, B(\Phi_B)$

Needs exact mapping $(\Phi_B, \Phi_R) \to \Phi$

POWHEG: $R^s(\Phi) = F R(\Phi)\,, R^f(\Phi) = (1-F) R(\Phi)$

F=1 = Exponentiates the Real.
It can be damped by hand.

MC@NLO AND POWHEG

MC@NLO AND POWHEG

MC@NLO

[Frixione, Webber, 2002;
Frixione, Nason, Webber, 2003]

- Matches NLO to HERWIG and HERWIG++ angular-ordered PS.
- Some events have negative weights.
- Large and well tested library of processes.

- Now available also for Pythia8, HW++ [Torrielli, Frixione, 1002.4293]
- Now automatized [Frederix, Frixione, Torrielli]
- Available in aMC@NLO (see later) and also in SHERPA

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POWHEG

[Nason 2004;
Frixione, Nason, Oleari, 2007]

- Is independent* of the PS. It can be interfaced to PYTHIA and HERWIG
- Generates only* positive unit weights.

- Can use existing NLO results via the POWHEG-Box [Aioli, Nason, Oleari, Re et al. 2009]

AUTOMATION

AUTOMATION

GENIUS: 1% INSPIRATION AND 99% PERSPIRATION.

[Thomas Edison]

Automation

Genius: 1% inspiration and 99% perspiration.

[Thomas Edison]

True, but perspiration can be automated!

AUTOMATION

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- **COST SAVING**

  Trade human time and expertise spent on computing one process at the time with time on physics and pheno.

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  Programs are modular and computations based on elements that can be systematically and extensively checked. Trust can be easily built.

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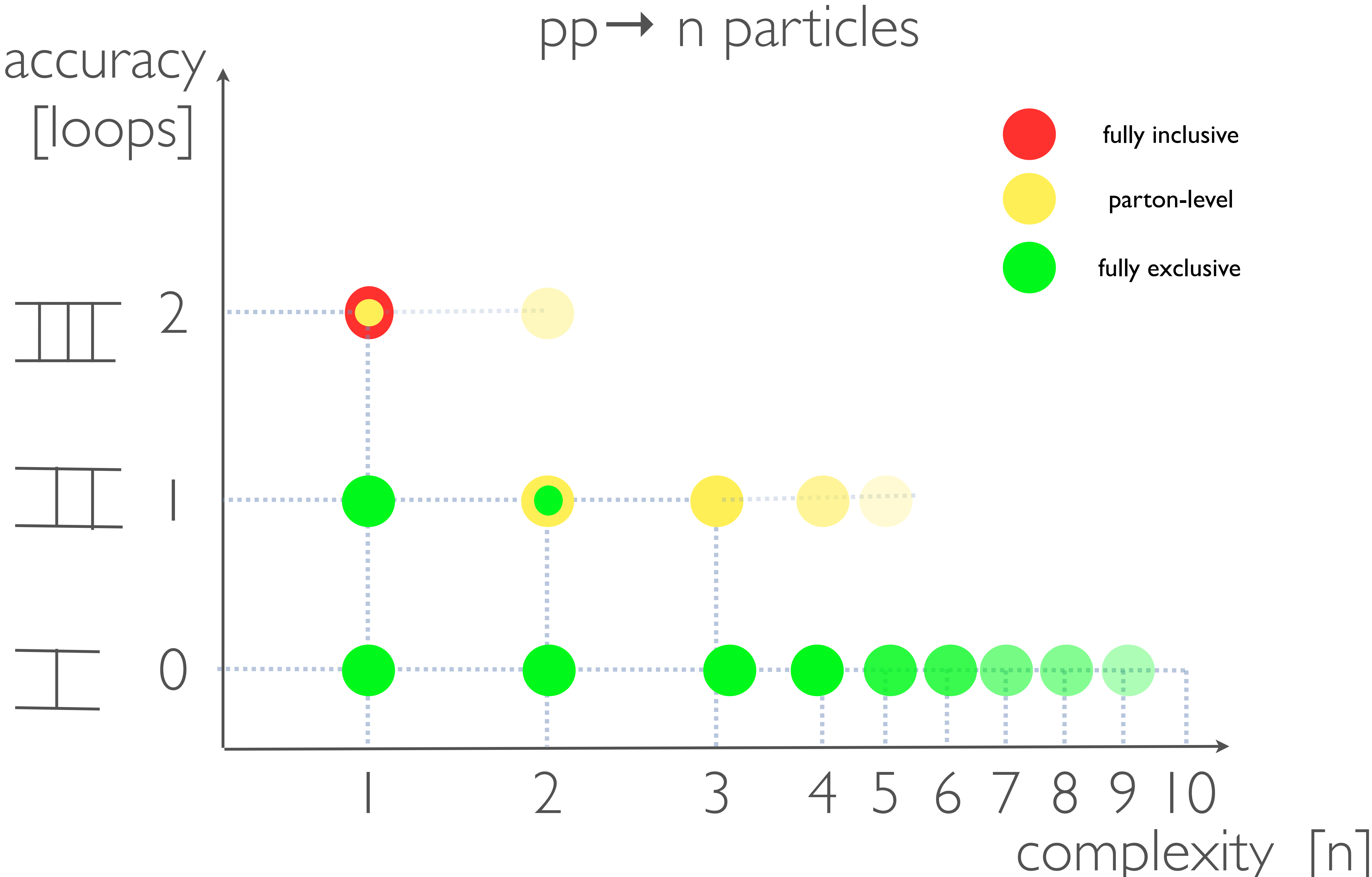
Programs are modular and computations based on elements that can be systematically and extensively checked. Trust can be easily built.

Wide accessibility

One framework for all. Available to everybody for an unlimited set of applications for all. Augmented TH/EXP collaboration.

AUTOMATION

SM STATUS ANTE LHC



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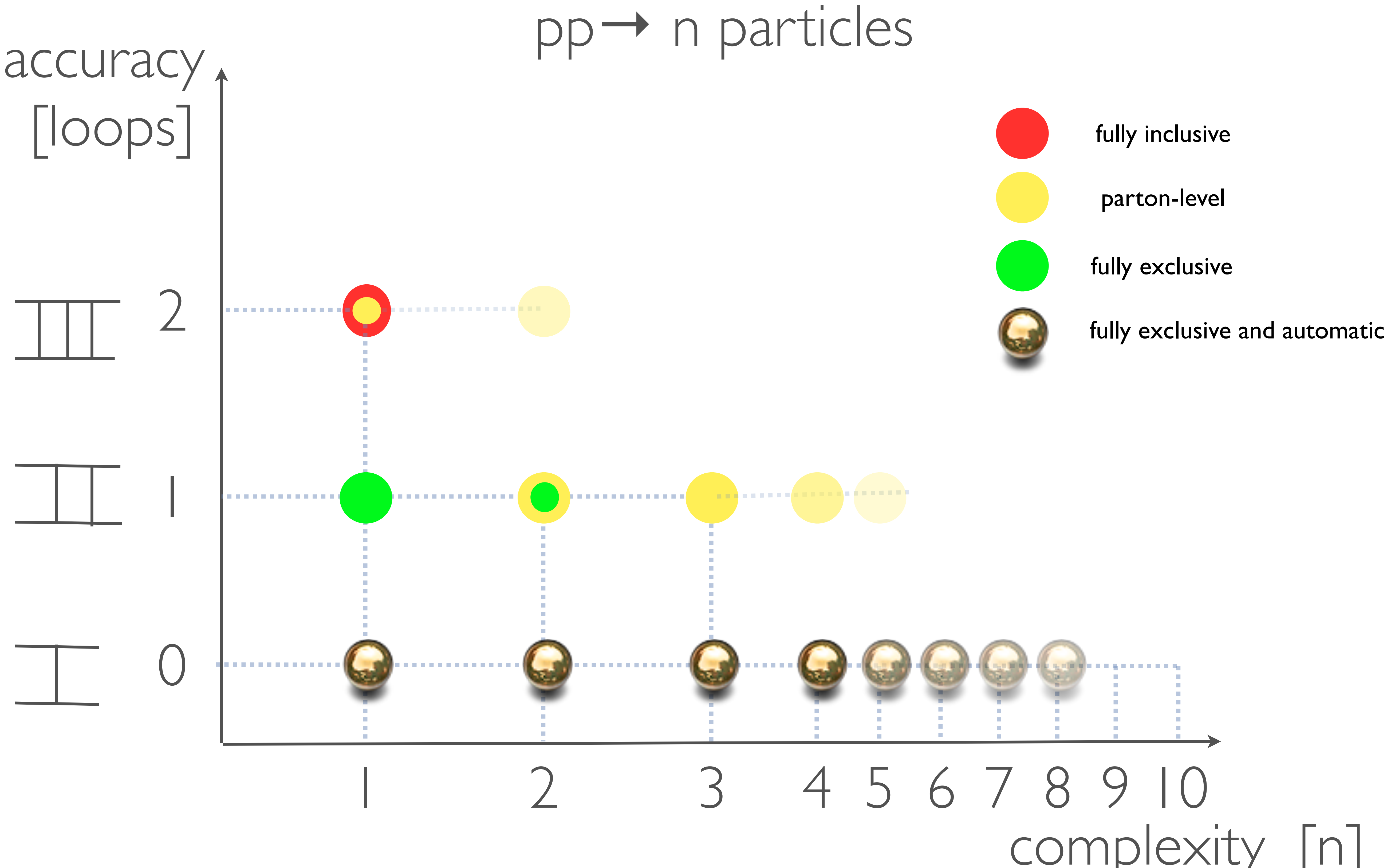
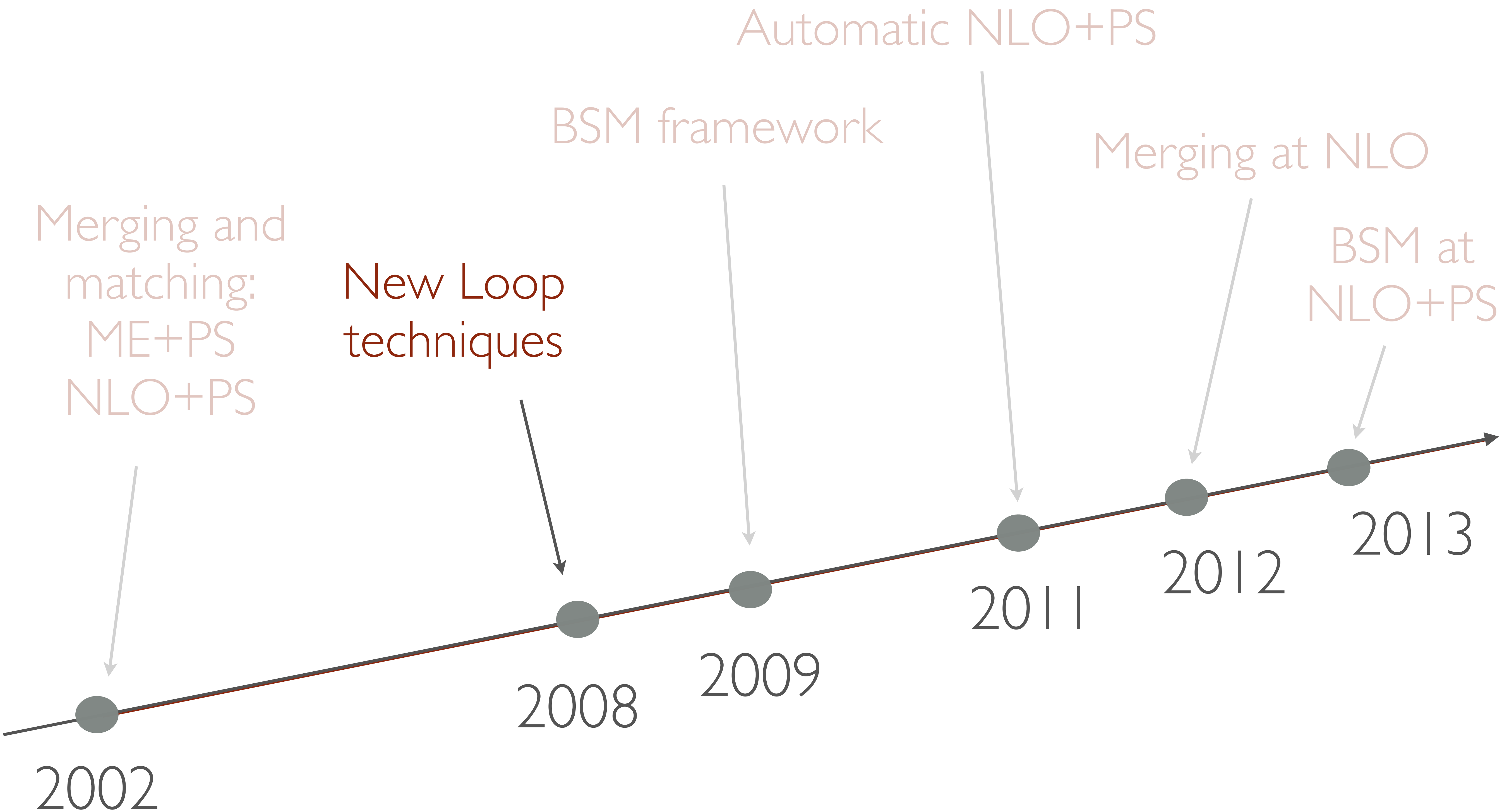


PREDICTIVE MC (SIMPLIFIED) PROGRESS



NEW LOOP TECHNIQUES

For the calculation of one-loop matrix elements, several methods are now established :

- Generalized Unitarity (ex. BlackHat, Rocket,...)

[Bern, Dixon, Dunbar, Kosower, hep-ph/9403226 + ...; Ellis, Giele, Kunszt 0708.2398, +Melnikov 0806.3467]

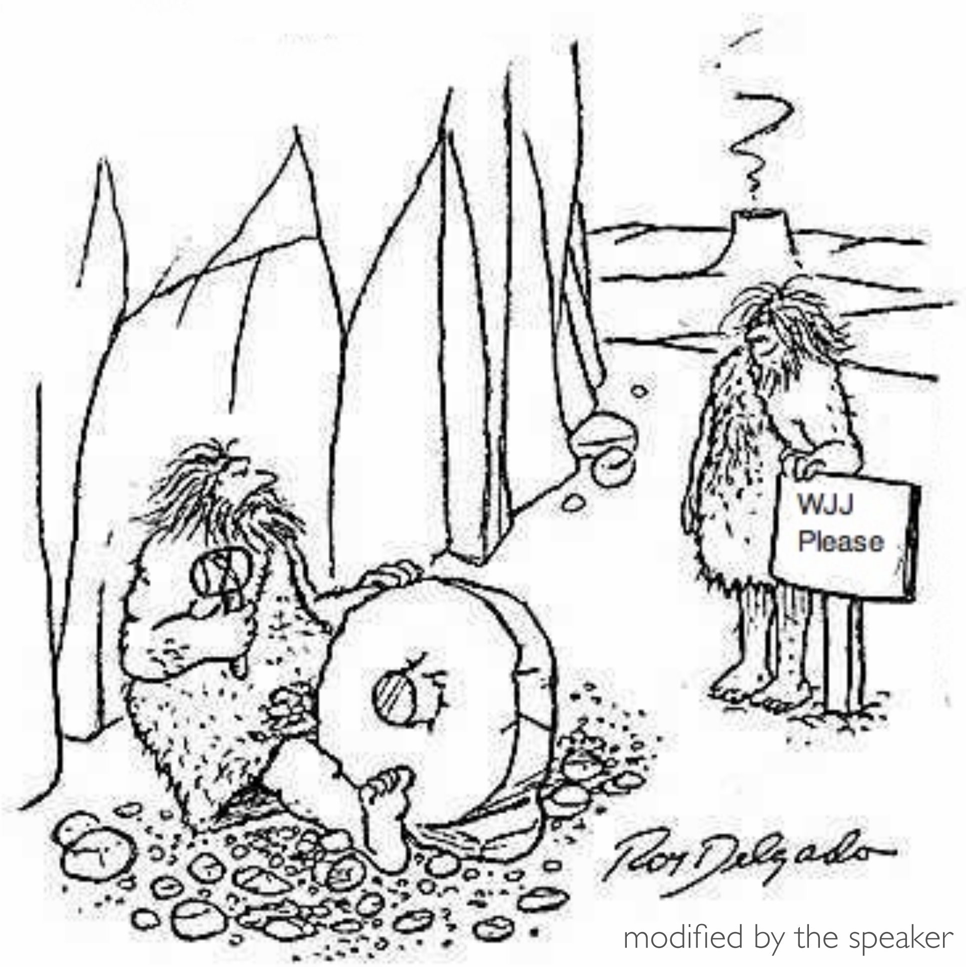
- Integrand Reduction (ex. CutTools, Samurai)

[Ossola, Papadopolulos, Pittau, hep-ph/0609007; del Aguila, Pittau, hep-ph/0404120; Mastrolia, Ossola, Reiter, Tramontano, 1006.0710]

- Tensor Reduction (ex. Golem, GoSam)

[Passarino, Veltman, 1979; Denner, Dittmaier, hep-ph/0509141, Binoth, Guillet, Heinrivh, Pilon, Reiter 0810.0092]

Predictions at NLO



modified by the speaker

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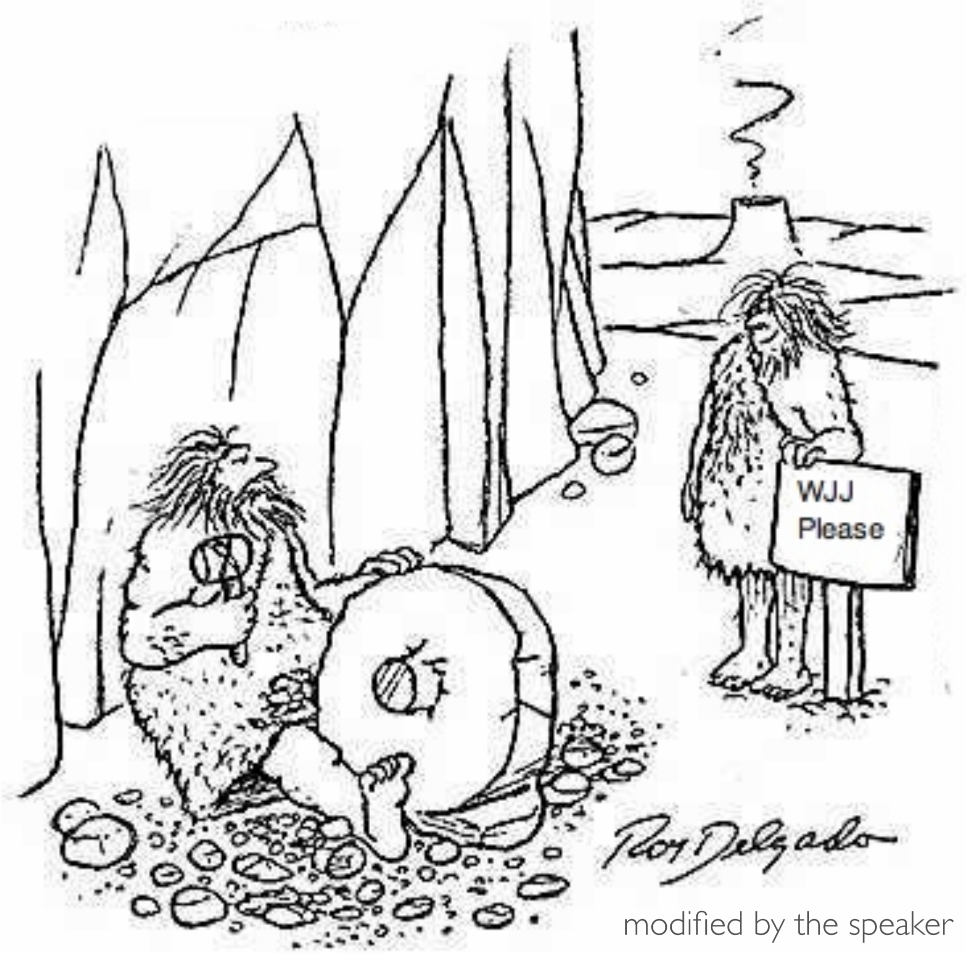

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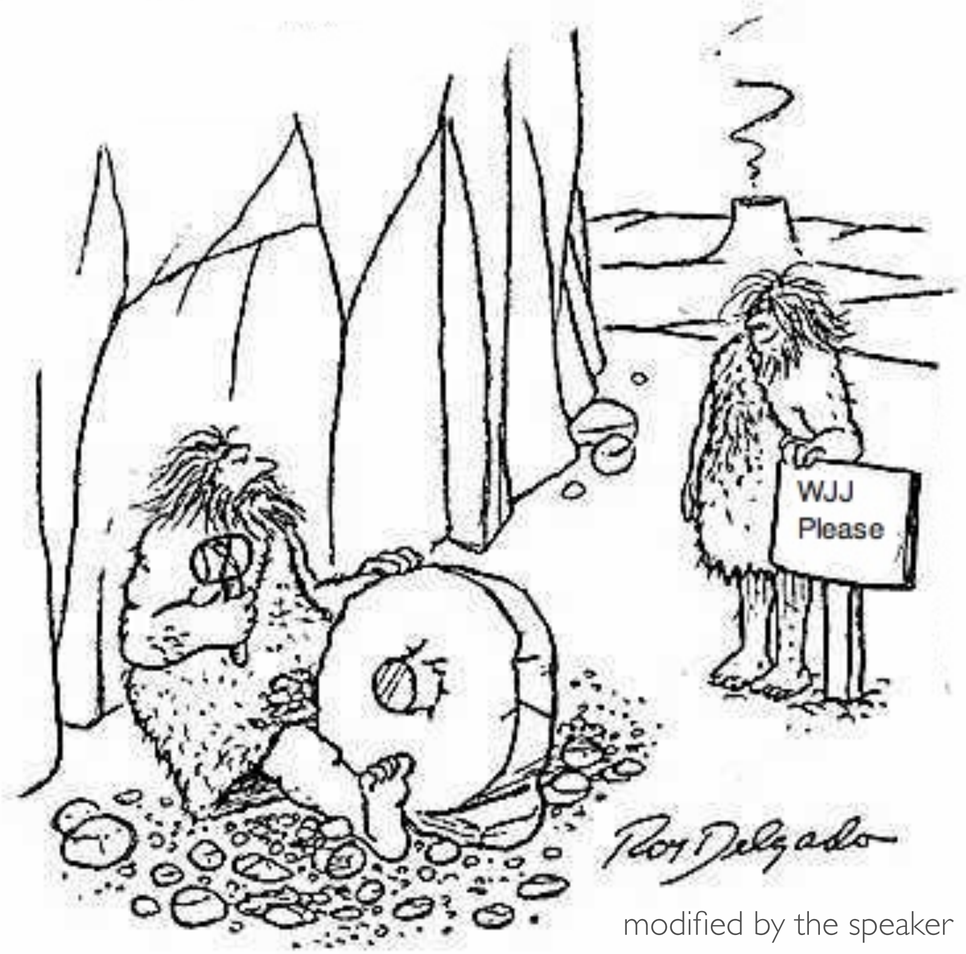

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Integrand Reduction
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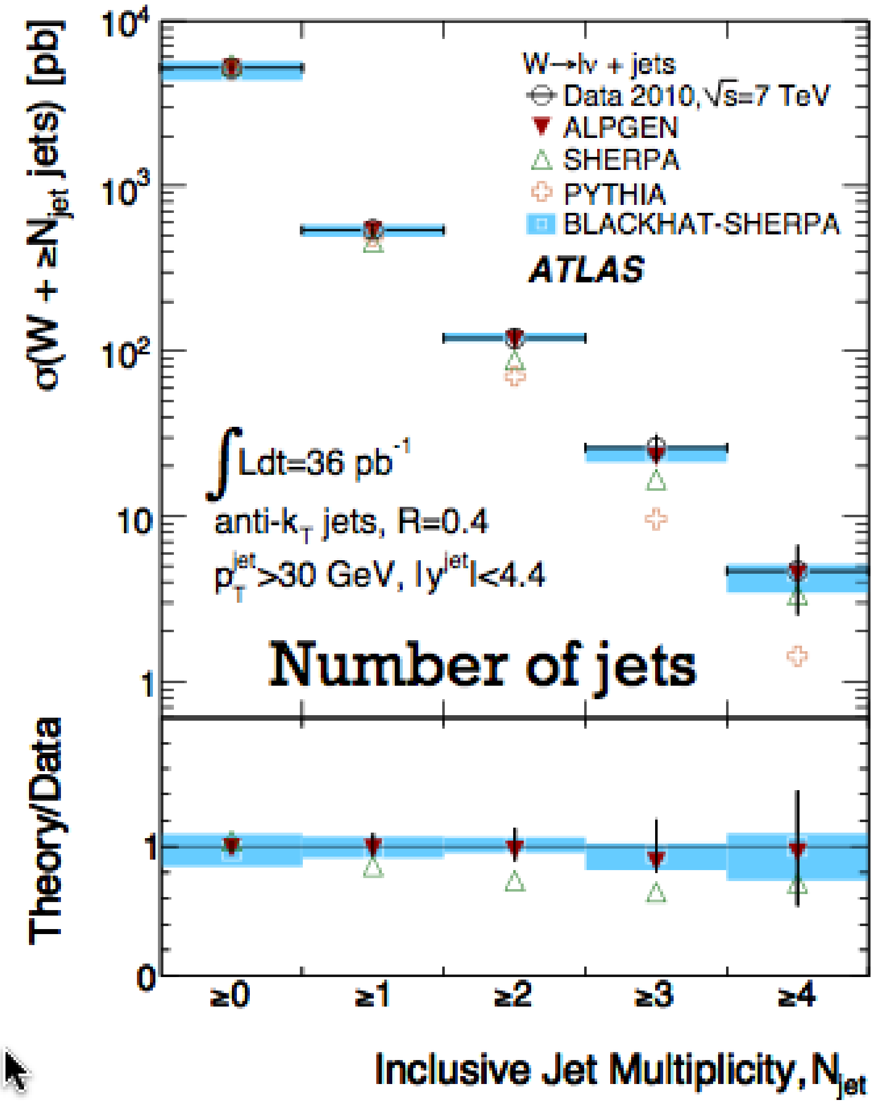
Thanks to new amazing results, some of them inspired by string theory developments, now the computation of loops has been extended to high-multiplicity processes or/and automated.

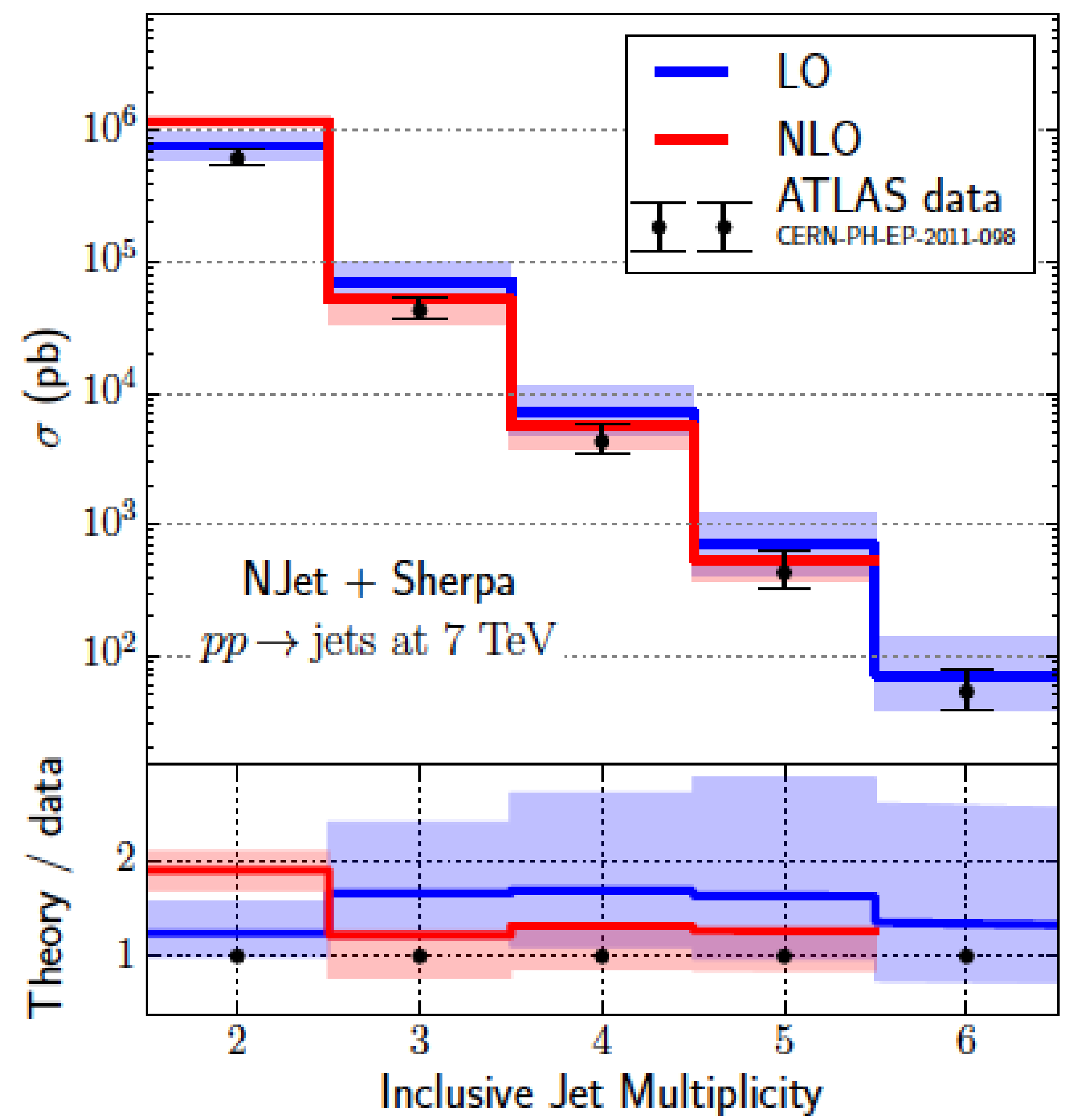
THE RACEHORSES

W+5 jets



[Bern et al., 1304.1253]

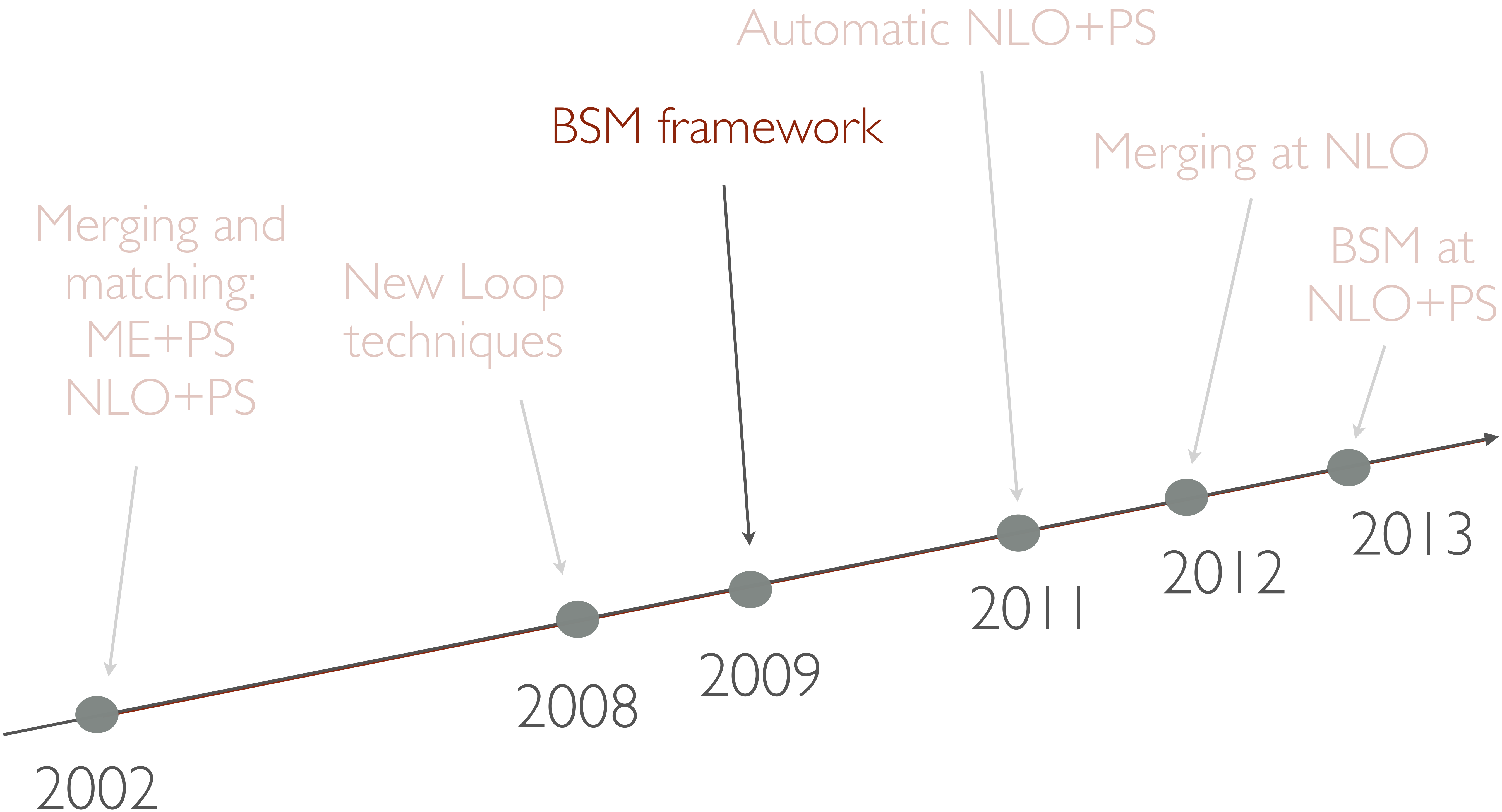
5 jets



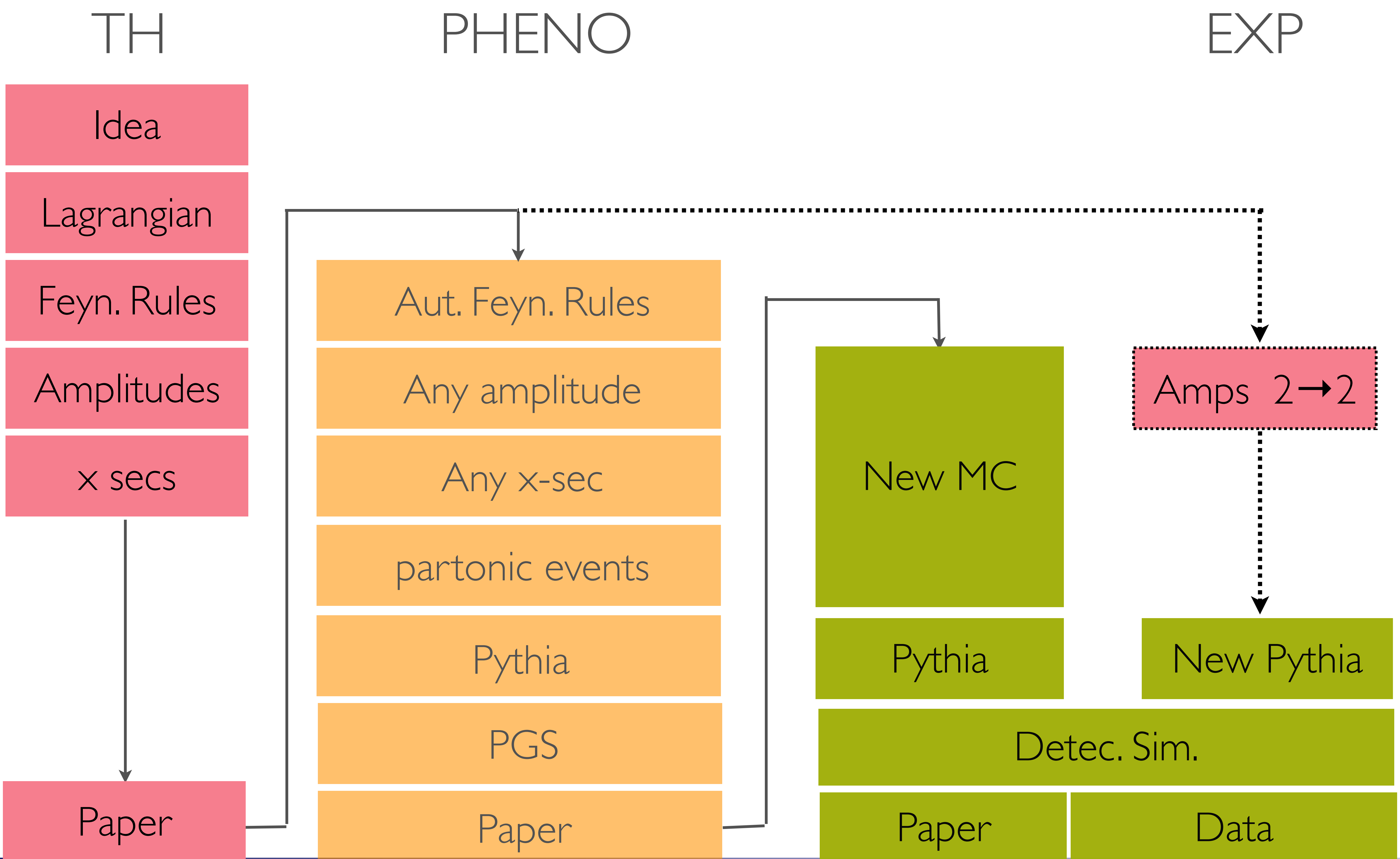
[Badger et al. 1309.6585]

Tuesday 24 June 2014

PREDICTIVE MC (SIMPLIFIED) PROGRESS



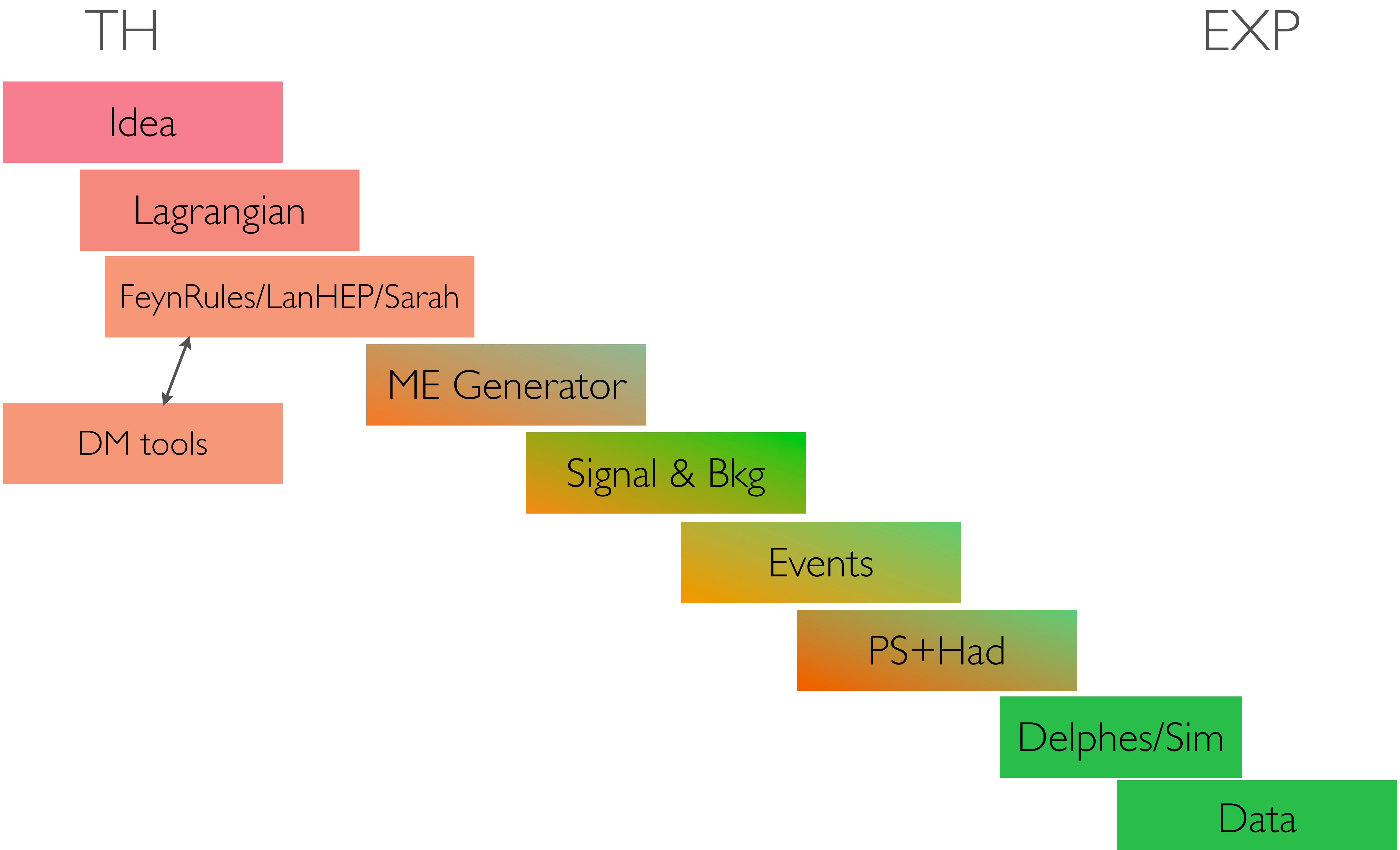
BSM TH/EXP INTERACTIONS : THE OLD WAY



BSM TH/EXP INTERACTIONS : THE OLD WAY

TH	PHENO	EXP
Idea		
Lagrangian		
	Aut. Feyn. Rules	
	Any amplitude	
	Any x-sec	
	partonic events	
		Pythia
		Detec. Sim.
		Data

BSM TH/EXP INTERACTIONS AUGMENTED



BSM TH/EXP INTERACTIONS AUGMENTED

TH

EXP

- One path for all
- Physics and software validations streamlined
- Robust and efficient Th/Exp communication
- It works top-down and bottom-up

Idea

Lagrangian

FeynRules/LanHEP/Sarah ↔ DM tools

ME Generator

Signal & Bkg

Events

PS+Had

Delphes/Sim

Data

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Events

PS+Had

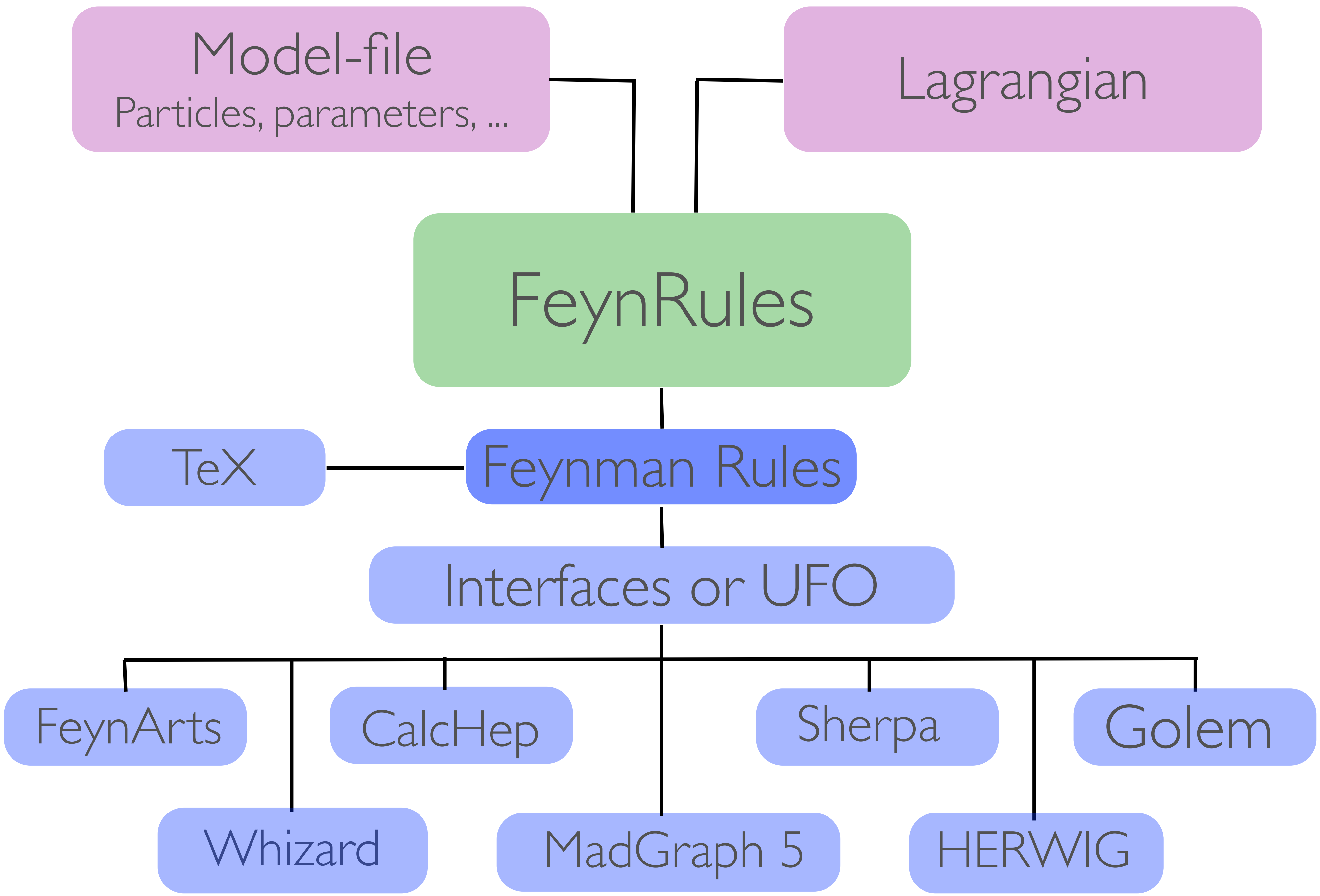
Delphes/Sim

Data

Complete automatization LO (and now NLO) calculations available, including merging with the parton shower in multi-jet final states, for SM as well as for BSM physics.

THE FEYNRULES PROJECT

[Alloul, Christensen, Degrande, Duhr, Fuks]



THE FEYNRULES PROJECT

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 second Higgs doublet or additional colored scalars.
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)	

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Strongly ... theories	
Miscellan...	

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**

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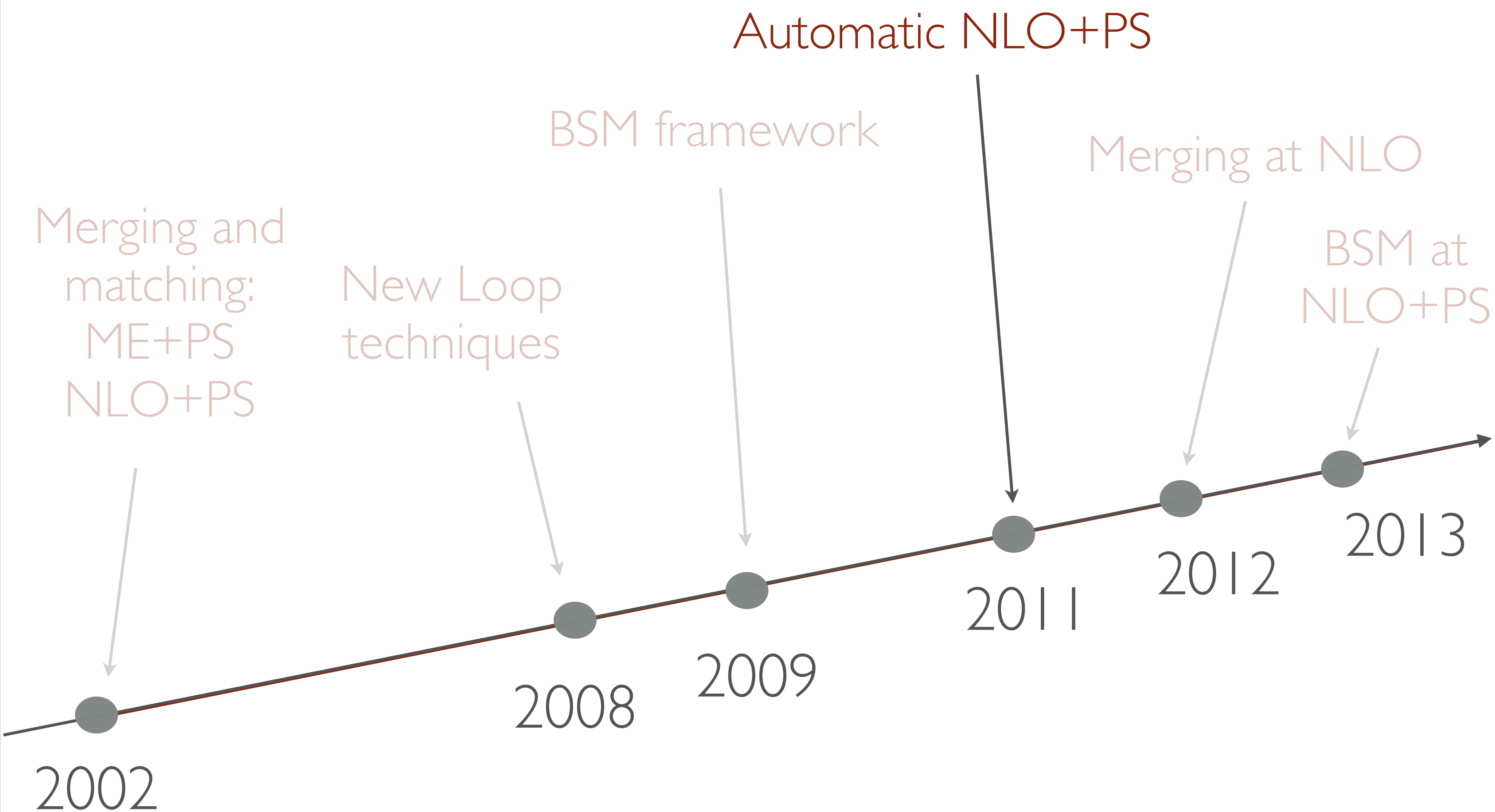

NEW CODES FOR AUTOMATIC LOOP AMPLITUDES

- MadLoop : Hirschi et al., **1103.0621,** based on MadGraph + CutTools
- HELAC-NLO : Bevilacqua et al. , **1110.1499**, based on HELAC + CutTools
- GoSam : Cullen et al. , **1111.6534** , based on QGRAF+SAMURAI+Golem
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Limitations on applications (i.e. number of external partons or BSM) are systematically and quickly overcome:
"the wave function of the automatic loop effort has collapsed!"

NEW NLO+PS FRAMEWORKS

- **POWHEG-BOX** and applications: Alioli et al, 1002.2581, 1009.2450, 1009.5594, 1012.3380, 1102.4846, 1105.4488, 1107.5051, 1108.0909:

  Framework which allows to promote a standard NLO calculation into a MC at NLO generator. Very popular choice. More than ~20 processes implemented in the last two years. Similar in spirit to MCFM.

- **NEW SHERPA** Hoeche et al, 1008.5399, 1009.1127, 1111.1220 :

  Flexible framework having both MC@NLO and POWHEG methods based on CS dipoles, needs virtuals. Fully automatic except for virtuals.

- **HERWIG++** D'Errico et Richardson 1106.2983,1106.3939, Hamilton et al. 0806.0290, 0903.4345, 1004.1764, 1009.5391:

  POWHEG method, several processes implemented. Need the NLO elements.

- **POWHEL** Papadopoulous, Garzelli, Kardos Trocsanyi, 1108.0387,1111.1444:

  HELAC-NLO + POWHEG-Box

MadGraph5_aMC@NLO

Suppose now you are interested in multi-lepton backgrounds to SUSY. You might want to check:

[Alwall et al. 1405.0301]

```
./bin/mg5_aMC
> generate p p > t t~ W+ W- [QCD]
> output ttww
> launch
```

where heavy states can then be decayed by MadSpin keeping spin correlations.

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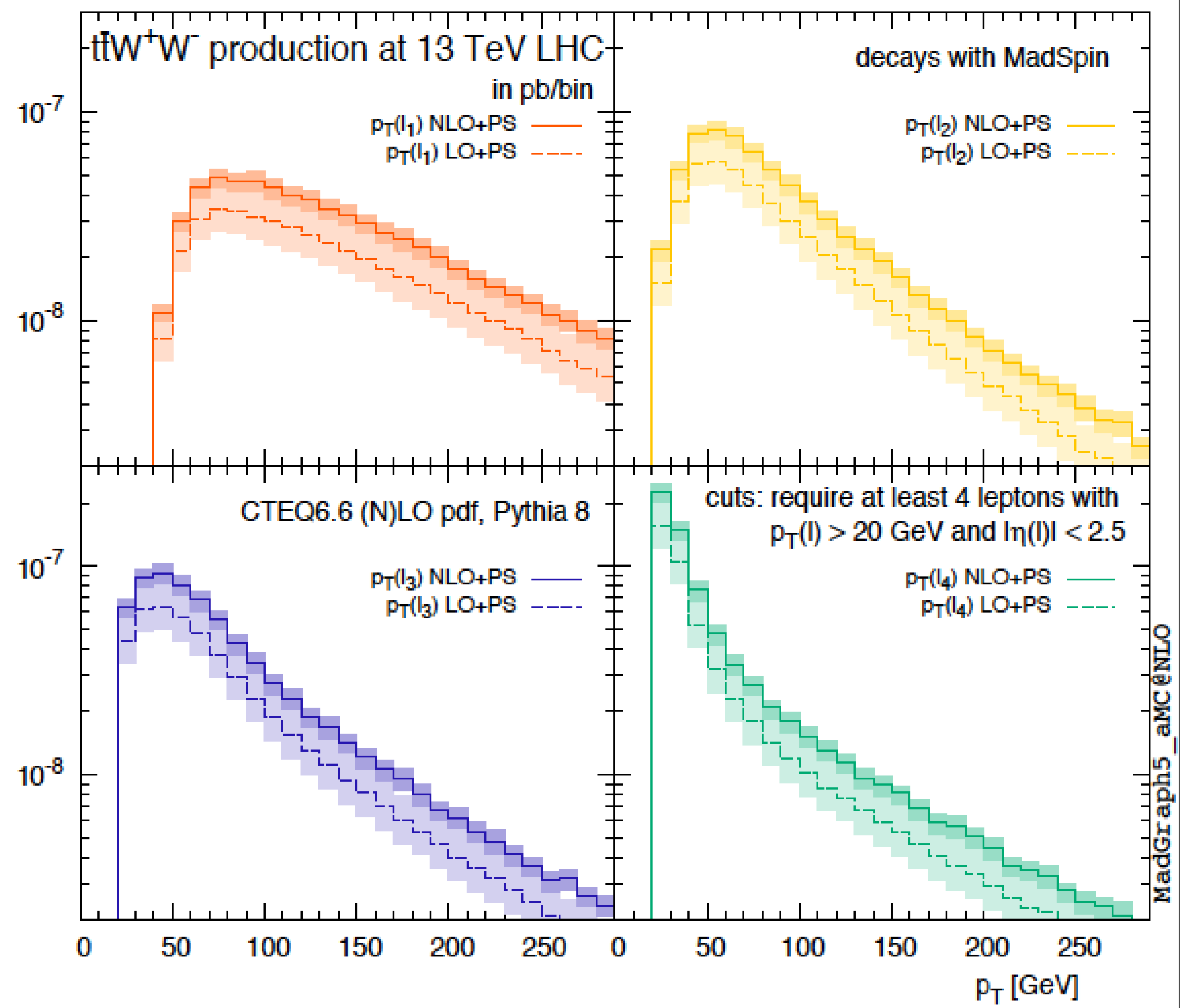

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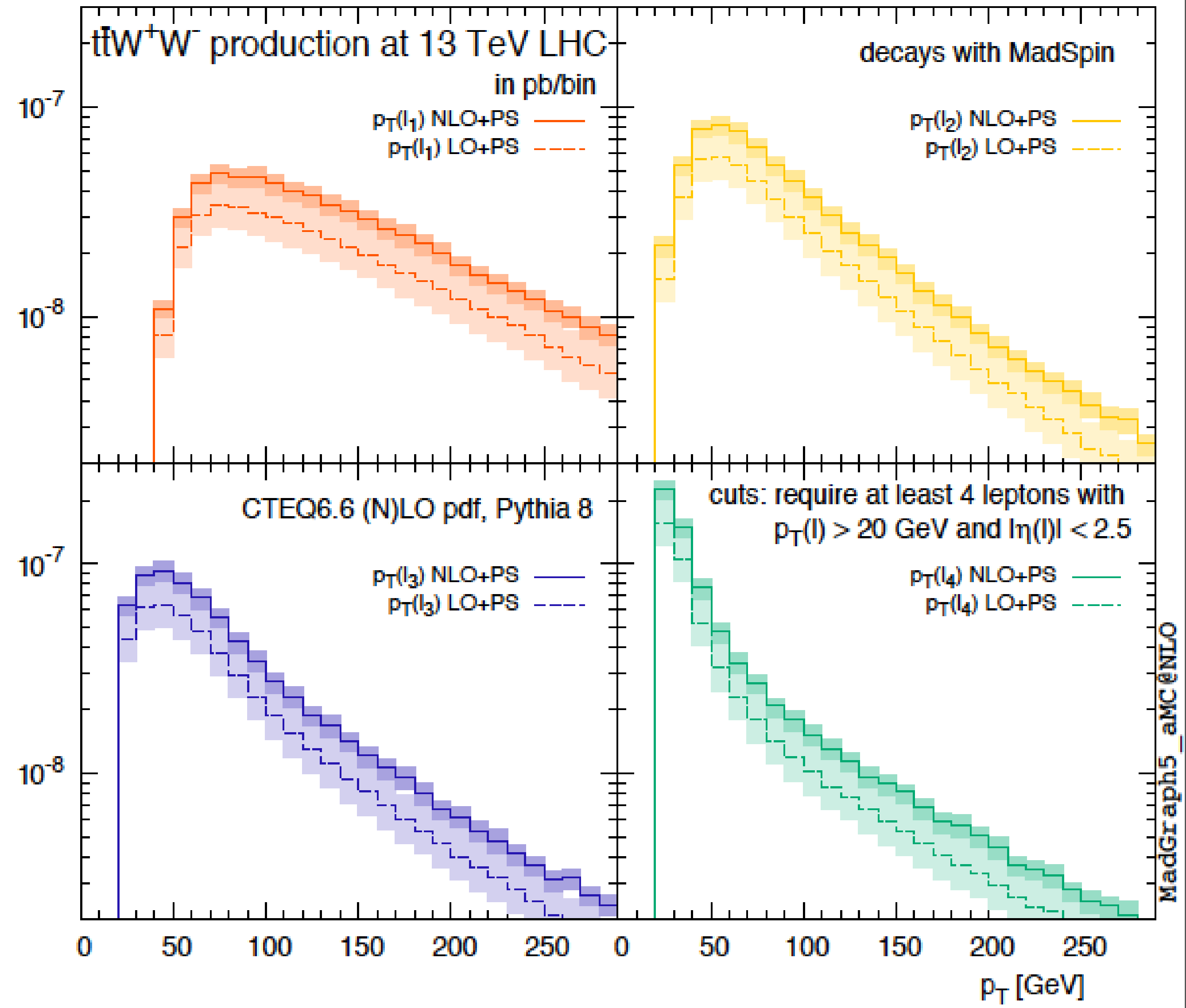
```

where heavy states can then be decayed by MadSpin keeping spin correlations.

Uncertainties from scale variation and pdfs **are automatically computed** (at no extra cost) and associated to each of the **unweighted events** (=any distribution will have the corresponding uncertainty band)

[Alwall et al. 1405.0301]



AUTOMATIC NLO IN SM (2014)

Process		Syntax	LO 13 TeV	LO unc.	NLO 13 TeV	NLO unc.
Vector boson +jets						
a.1	$pp \to W^{\pm}$	p p > wpm	$1.375 \pm 0.002 \cdot 10^{5}$	+15.4% +2.0% / −16.6% −1.6%	$1.773 \pm 0.007 \cdot 10^{5}$	+5.2% +1.9% / −9.4% −1.6%
a.2	$pp \to W^{\pm}j$	p p > wpm j	$2.045 \pm 0.001 \cdot 10^{4}$	+19.7% +1.4% / −17.2% −1.1%	$2.843 \pm 0.010 \cdot 10^{4}$	+5.9% +1.3% / −8.0% −1.1%
a.3	$pp \to W^{\pm}jj$	p p > wpm j j	$6.805 \pm 0.015 \cdot 10^{3}$	+24.5% +0.8% / −18.6% −0.7%	$7.786 \pm 0.030 \cdot 10^{3}$	+2.4% +0.9% / −6.0% −0.8%
a.4	$pp \to W^{\pm}jjj$	p p > wpm j j j	$1.821 \pm 0.002 \cdot 10^{3}$	+41.0% +0.5% / −27.1% −0.5%	$2.005 \pm 0.008 \cdot 10^{3}$	+0.9% +0.6% / −6.7% −0.5%
a.5	$pp \to Z$	p p > z	$4.248 \pm 0.005 \cdot 10^{4}$	+14.6% +2.0% / −15.8% −1.6%	$5.410 \pm 0.022 \cdot 10^{4}$	+4.6% +1.9% / −8.6% −1.5%
a.6	$pp \to Zj$	p p > z j	$7.209 \pm 0.005 \cdot 10^{3}$	+19.3% +1.2% / −17.0% −1.0%	$9.742 \pm 0.035 \cdot 10^{3}$	+5.8% +1.2% / −7.8% −1.0%
a.7	$pp \to Zjj$	p p > z j j	$2.348 \pm 0.006 \cdot 10^{3}$	+24.3% +0.6% / −18.5% −0.6%	$2.665 \pm 0.010 \cdot 10^{3}$	+2.5% +0.7% / −6.0% −0.7%
a.8	$pp \to Zjjj$	p p > z j j j	$6.314 \pm 0.008 \cdot 10^{2}$	+40.8% +0.5% / −27.0% −0.5%	$6.996 \pm 0.028 \cdot 10^{2}$	+1.1% +0.5% / −6.8% −0.5%
a.9	$pp \to \gamma j$	p p > a j	$1.964 \pm 0.001 \cdot 10^{4}$	+31.2% +1.7% / −26.0% −1.8%	$5.218 \pm 0.025 \cdot 10^{4}$	+24.5% +1.4% / −21.4% −1.6%
a.10	$pp \to \gamma jj$	p p > a j j	$7.815 \pm 0.008 \cdot 10^{3}$	+32.8% +0.9% / −24.2% −1.2%	$1.004 \pm 0.004 \cdot 10^{4}$	+5.9% +0.8% / −10.9% −1.2%

Process		Syntax	LO 13 TeV	LO unc.	NLO 13 TeV	NLO unc.
Three vector bosons +jet						
c.1	$pp \to W^+W^-W^{\pm}$ (4f)	p p > w+ w- wpm	$1.307 \pm 0.003 \cdot 10^{-1}$	+0.0% +2.0% / −0.3% −1.5%	$2.109 \pm 0.006 \cdot 10^{-1}$	+5.1% +1.6% / −4.1% −1.2%
c.2	$pp \to ZW^+W^-$ (4f)	p p > z w+ w-	$9.658 \pm 0.065 \cdot 10^{-2}$	+0.8% +2.1% / −1.1% −1.6%	$1.679 \pm 0.005 \cdot 10^{-1}$	+6.3% +1.6% / −5.1% −1.2%
c.3	$pp \to ZZW^{\pm}$	p p > z z wpm	$2.996 \pm 0.016 \cdot 10^{-2}$	+1.0% +2.0% / −1.4% −1.6%	$5.550 \pm 0.020 \cdot 10^{-2}$	+6.8% +1.5% / −5.5% −1.1%
c.4	$pp \to ZZZ$	p p > z z z	$1.085 \pm 0.002 \cdot 10^{-2}$	+0.0% +1.9% / −0.5% −1.5%	$1.417 \pm 0.005 \cdot 10^{-2}$	+2.7% +1.9% / −2.1% −1.5%
c.5	$pp \to \gamma W^+W^-$ (4f)	p p > a w+ w-	$1.427 \pm 0.011 \cdot 10^{-1}$	+1.9% +2.0% / −2.6% −1.5%	$2.581 \pm 0.008 \cdot 10^{-1}$	+5.4% +1.4% / −4.3% −1.1%
c.6	$pp \to \gamma\gamma W^{\pm}$	p p > a a wpm	$2.681 \pm 0.007 \cdot 10^{-2}$	+4.4% +1.9% / −5.6% −1.6%	$8.251 \pm 0.032 \cdot 10^{-2}$	+7.6% +1.0% / −7.0% −1.0%
c.7	$pp \to \gamma ZW^{\pm}$	p p > a z wpm	$4.994 \pm 0.011 \cdot 10^{-2}$	+0.8% +1.9% / −1.4% −1.6%	$1.117 \pm 0.004 \cdot 10^{-1}$	+7.2% +1.2% / −5.9% −0.9%
c.8	$pp \to \gamma ZZ$	p p > a z z	$2.318 \pm 0.004 \cdot 10^{-2}$	+2.0% +1.9% / −2.8% −1.5%	$2.177 \pm 0.015 \cdot 10^{-2}$	+3.1% +1.8% / −2.9% −1.4%
c.9	$pp \to \gamma\gamma Z$	p p > a a z	$3.077 \pm 0.008 \cdot 10^{-2}$	+5.7% +1.9%	$4.571 \pm 0.017 \cdot 10^{-2}$	+4.2% +1.7%
c.10	$pp \to \gamma\gamma\gamma$	p p > a a a	$1.269 \pm 0.003 \cdot 10^{-2}$	+9.8% +2.0% / −11.0% −1.8%	$3.441 \pm 0.012 \cdot 10^{-2}$	+11.8% +1.4% / −11.6% −1.5%

Process		Syntax	LO 13 TeV	LO unc.
Vector-boson pair +jets				
b.1	$pp \to W^+W^-$ (4f)	p p > w+ w-	$7.355 \pm 0.005 \cdot 10^{1}$	+5.0% / −6.1%
b.2	$pp \to ZZ$	p p > z z	$1.097 \pm 0.002 \cdot 10^{1}$	+4.5% +1.9% / −5.6%
b.3	$pp \to ZW^{\pm}$	p p > z wpm	$2.777 \pm 0.003 \cdot 10^{1}$	+3.6% +2.0% / −4.7%
b.4	$pp \to \gamma\gamma$	p p > a a	$2.510 \pm 0.002 \cdot 10^{1}$	+22.1% +2.4% / −22.4% −2.1%
b.5	$pp \to \gamma Z$	p p > a z	$2.523 \pm 0.004 \cdot 10^{1}$	+9.9% / −11.2% −1.6%
b.6	$pp \to \gamma W^{\pm}$	p p > a wpm	$2.954 \pm 0.005 \cdot 10^{1}$	+9.5% / −11.0% −1.7%
b.7	$pp \to W^+W^-j$ (4f)	p p > w+ w- j	$2.865 \pm 0.003 \cdot 10^{1}$	+11.6% / −10.0% −0.8%
b.8	$pp \to ZZj$	p p > z z j	$3.662 \pm 0.003 \cdot 10^{0}$	+10.9% / −9.3% −0.8%
b.9	$pp \to ZW^{\pm}j$	p p > z wpm j	$1.605 \pm 0.005 \cdot 10^{1}$	+11.6% / −10.0%
b.10	$pp \to \gamma\gamma j$	p p > a a j	$1.022 \pm 0.001 \cdot 10^{1}$	+20.3% / −17.7%
b.11*	$pp \to \gamma Zj$	p p > a z j	$8.310 \pm 0.017 \cdot 10^{0}$	+14.5% +1.0% / −12.8%
b.12*	$pp \to \gamma W^{\pm}j$	p p > a wpm j	$2.546 \pm 0.010 \cdot 10^{1}$	+13.7% +0.9% / −12.1%
b.13	$pp \to W^+W^+jj$	p p > w+ w+ j j	$1.484 \pm 0.006 \cdot 10^{-1}$	+25.4% +2.1% / −18.9%
b.14	$pp \to W^-W^-jj$	p p > w- w- j j	$6.752 \pm 0.007 \cdot 10^{-2}$	+25.4% +2.4% / −18.9% −1.7%
b.15	$pp \to W^+W^-jj$ (4f)	p p > w+ w- j j	$1.144 \pm 0.002 \cdot 10^{1}$	+27.2% +0.7% / −19.9% −0.5%
b.16	$pp \to ZZjj$	p p > z z j j	[illegible]	+26.6% +0.7% / −19.6% −0.6%
b.17	$pp \to ZW^{\pm}jj$	p p > z wpm j j	[illegible]	+26.7% +0.7% / −19.7% −0.5%
b.18	$pp \to \gamma\gamma jj$	p p > a a j j	[illegible]	+26.2% +0.6% / −19.8% −1.0%
b.19*	$pp \to \gamma Zjj$	p p > a z j j	[illegible]	
b.20*	$pp \to \gamma W^{\pm}jj$	p p > a wpm j j	[illegible]	

Process		Syntax	LO 13 TeV	LO unc.	NLO 13 TeV	NLO unc.
Heavy quarks and jets						
d.1	$pp \to jj$	p p > j j	$1.162 \pm 0.001 \cdot 10^{6}$	+24.9% +0.8% / −18.8% −0.9%	$1.580 \pm 0.007 \cdot 10^{6}$	+8.4% +0.7% / −9.0% −0.9%
d.2	$pp \to jjj$	p p > j j j	$8.940 \pm 0.021 \cdot 10^{4}$	+43.8% +1.2% / −28.4% −1.4%	$7.791 \pm 0.037 \cdot 10^{4}$	+2.1% +1.1% / −23.2% −1.3%
d.3	$pp \to b\bar{b}$	p p > b b~	$3.743 \pm 0.004 \cdot 10^{3}$	+25.2% +1.5% / −18.9% −1.8%	$6.438 \pm 0.028 \cdot 10^{3}$	+15.9% +1.5% / −13.3% −1.7%
d.4*	$pp \to b\bar{b}j$	p p > b b~ j	$1.050 \pm 0.002 \cdot 10^{3}$	+44.1% +1.6% / −28.5% −1.8%	$1.327 \pm 0.007 \cdot 10^{3}$	+6.8% +1.5% / −11.6% −1.8%
d.5*	$pp \to b\bar{b}jj$	p p > b b~ j j	$1.852 \pm 0.006 \cdot 10^{2}$	+61.8% +2.1% / −35.6% −2.4%	$2.471 \pm 0.012 \cdot 10^{2}$	+8.2% +2.0% / −16.4% −2.3%
d.6	$pp \to b\bar{b}b\bar{b}$	p p > b b~ b b~	$5.050 \pm 0.007 \cdot 10^{-1}$	+61.7% +2.9% / −35.6% −3.4%	$8.736 \pm 0.034 \cdot 10^{-1}$	+20.9% +2.9% / −22.0% −3.4%
d.7	$pp \to t\bar{t}$	p p > t t~	$4.584 \pm 0.003 \cdot 10^{2}$	+29.0% +1.8% / −21.1% −2.0%	$6.741 \pm 0.023 \cdot 10^{2}$	+9.8% +1.8% / −10.9% −2.1%
d.8	$pp \to t\bar{t}j$	p p > t t~ j	$3.135 \pm 0.002 \cdot 10^{2}$	+45.1% +2.2% / −29.0% −2.5%	$4.106 \pm 0.015 \cdot 10^{2}$	+8.1% +2.1% / −12.2% −2.5%
d.9	$pp \to t\bar{t}jj$	p p > t t~ j j	$1.361 \pm 0.001 \cdot 10^{2}$	+61.4% +2.6% / −35.6% −3.0%	$1.795 \pm 0.006 \cdot 10^{2}$	+9.3% +2.4% / −16.1% −2.9%
d.10	$pp \to t\bar{t}t\bar{t}$	p p > t t~ t t~	$4.505 \pm 0.005 \cdot 10^{-3}$	+63.8% +5.4% / −36.5% −5.7%	$9.201 \pm 0.028 \cdot 10^{-3}$	+30.8% +5.5% / −25.6% −5.9%
d.11	$pp \to t\bar{t}b\bar{b}$	p p > t t~ b b~	$6.119 \pm 0.004 \cdot 10^{0}$	+62.1% +2.9% / −35.7% −3.5%	$1.452 \pm 0.005 \cdot 10^{1}$	+37.6% +2.9% / −27.5% −3.5%

Process		Syntax	LO 13 TeV	LO unc.	NLO 13 TeV	NLO unc.
Single-top						
f.1	$pp \to tj$ (t-channel)	p p > tt j $$ w+ w-	$1.520 \pm 0.001 \cdot 10^{2}$	+9.4% +0.4% / −11.9% −0.6%	$1.563 \pm 0.005 \cdot 10^{2}$	+1.4% +0.4% / −1.8% −0.6%
f.2	$pp \to t\gamma j$ (t-channel)	p p > tt a j $$ w+ w-	$9.956 \pm 0.014 \cdot 10^{-1}$	+6.4% +0.9% / −8.8% −1.0%	$1.017 \pm 0.003 \cdot 10^{0}$	+1.3% +0.8% / −1.2% −0.9%
f.3	$pp \to tZj$ (t-channel)	p p > tt z j $$ w+ w-	$6.967 \pm 0.007 \cdot 10^{-1}$	+3.5% +0.9% / −5.5% −1.0%	$6.993 \pm 0.021 \cdot 10^{-1}$	+1.6% +0.9% / −1.1% −1.0%
f.4	$pp \to tbj$ (t-channel)	p p > tt bb j $$ w+ w-	$1.003 \pm 0.000 \cdot 10^{2}$	+13.8% +0.4% / −11.5% −0.5%	$1.319 \pm 0.003 \cdot 10^{2}$	+5.8% +0.4% / −5.2% −0.5%
f.5*	$pp \to tbj\gamma$ (t-channel)	p p > tt bb j a $$ w+ w-	$6.293 \pm 0.006 \cdot 10^{-1}$	+16.8% +0.8% / −13.5% −0.9%	$8.612 \pm 0.025 \cdot 10^{-1}$	+6.2% +0.8% / −6.6% −0.9%
f.6*	$pp \to tbjZ$ (t-channel)	p p > tt bb j z $$ w+ w-	$3.934 \pm 0.002 \cdot 10^{-1}$	+18.7% +1.0% / −14.7% −0.9%	$5.657 \pm 0.014 \cdot 10^{-1}$	+7.7% +0.9% / −7.9% −0.9%
f.7	$pp \to tb$ (s-channel)	p p > w+ > t b~, p p > w- > t~ b	$7.489 \pm 0.007 \cdot 10^{0}$	+3.5% +1.9% / −4.4% −1.4%	$1.001 \pm 0.004 \cdot 10^{1}$	+3.7% +1.9% / −3.9% −1.5%
f.8*	$pp \to tb\gamma$ (s-channel)	p p > w+ > t b~ a, p p > w- > t~ b a	$1.490 \pm 0.001 \cdot 10^{-2}$	+1.2% +1.9% / −1.8% −1.5%	$1.952 \pm 0.007 \cdot 10^{-2}$	+2.6% +1.7% / −2.3% −1.4%
f.9*	$pp \to tbZ$ (s-channel)	p p > w+ > t b~ z, p p > w- > t~ b z	$1.072 \pm 0.001 \cdot 10^{-2}$	+1.3% +2.0% / −1.5% −1.6%	$1.539 \pm 0.005 \cdot 10^{-2}$	+3.9% +1.9% / −3.2% −1.5%

Process		Syntax	LO 13 TeV	LO unc.	NLO 13 TeV	NLO unc.
Heavy quarks+vector bosons						
e.1	$pp \to W^{\pm}b\bar{b}$	p p > wpm b b~	$3.074 \pm 0.002 \cdot 10^{2}$	+42.3% +2.0% / −29.2% −1.6%	$8.162 \pm 0.034 \cdot 10^{2}$	+29.8% +1.5% / −23.6% −1.2%
e.2	$pp \to Zb\bar{b}$	p p > z b b~	$6.993 \pm 0.003 \cdot 10^{2}$	+33.5% +1.0% / −24.4% −1.4%	$1.235 \pm 0.004 \cdot 10^{3}$	+19.9% +1.0% / −17.4% −1.4%
e.3	$pp \to \gamma b\bar{b}$	p p > a b b~	$1.731 \pm 0.001 \cdot 10^{3}$	+51.9% +1.6% / −34.8% −2.1%	$4.171 \pm 0.015 \cdot 10^{3}$	+33.7% +1.4% / −27.1% −1.9%
e.4*	$pp \to W^{\pm}b\bar{b}j$	p p > wpm b b~ j	$1.861 \pm 0.003 \cdot 10^{2}$	+42.5% +0.7% / −27.7% −0.7%	$3.957 \pm 0.013 \cdot 10^{2}$	+27.0% +0.7% / −21.0% −0.6%
e.5*	$pp \to Zb\bar{b}j$	p p > z b b~ j	$1.604 \pm 0.001 \cdot 10^{2}$	+42.4% +0.9% / −27.6% −1.1%	$2.805 \pm 0.009 \cdot 10^{2}$	+21.0% +0.8% / −17.6% −1.0%
e.6*	$pp \to \gamma b\bar{b}j$	p p > a b b~ j	$7.812 \pm 0.017 \cdot 10^{2}$	+51.2% +1.0% / −32.0% −1.5%	$1.233 \pm 0.004 \cdot 10^{3}$	+18.9% +1.0% / −19.9% −1.5%
e.7	$pp \to t\bar{t}W^{\pm}$	p p > t t~ wpm	$3.777 \pm 0.003 \cdot 10^{-1}$	+23.9% +2.1% / −18.0% −1.6%	$5.662 \pm 0.021 \cdot 10^{-1}$	+11.2% +1.7% / −10.6% −1.3%
e.8	$pp \to t\bar{t}Z$	p p > t t~ z	$5.273 \pm 0.004 \cdot 10^{-1}$	+30.5% +1.8% / −21.8% −2.1%	$7.598 \pm 0.026 \cdot 10^{-1}$	+9.7% +1.9% / −11.1% −2.2%
e.9	$pp \to t\bar{t}\gamma$	p p > t t~ a	$1.204 \pm 0.001 \cdot 10^{0}$	+29.6% +1.6% / −21.3% −1.8%	$1.744 \pm 0.005 \cdot 10^{0}$	+9.8% +1.7% / −11.0% −2.0%
e.10*	$pp \to t\bar{t}W^{\pm}j$	p p > t t~ wpm j	$2.352 \pm 0.002 \cdot 10^{-1}$	+40.9% +1.3% / −27.1%	$3.404 \pm 0.011 \cdot 10^{-1}$	+11.2% +1.2% / −14.0% −0.9%
e.11*	$pp \to t\bar{t}Zj$	p p > t t~ z j	$3.953 \pm 0.004 \cdot 10^{-1}$	+46.2% / −29.5%	$5.074 \pm 0.016 \cdot 10^{-1}$	+7.0% +2.5% / −12.3% −2.9%
e.12*	$pp \to t\bar{t}\gamma j$	p p > t t~ a j	$8.726 \pm 0.010 \cdot 10^{-1}$	+45.4% +2.3% / −29.1%	$1.135 \pm 0.004 \cdot 10^{0}$	+7.5% +2.2% / −12.2% −2.5%
e.13*	$pp \to t\bar{t}W^-W^+$ (4f)	p p > t t~ w+ w-	$6.675 \pm 0.006 \cdot 10^{-3}$	+30.9% / −21.9%	$9.904 \pm 0.026 \cdot 10^{-3}$	+10.9% +2.1% / −11.8% −2.1%
e.14*	$pp \to t\bar{t}W^{\pm}Z$	p p > t t~ wpm z	$2.404 \pm 0.002 \cdot 10^{-3}$	+26.6% +2.5% / −19.6%	$3.525 \pm 0.010 \cdot 10^{-3}$	+10.6% +2.3% / −10.8% −1.6%
e.15*	$pp \to t\bar{t}W^{\pm}\gamma$	p p > t t~ wpm a	$2.718 \pm 0.003 \cdot 10^{-3}$	+25.4% +2.3% / −18.9%	$3.927 \pm 0.013 \cdot 10^{-3}$	+10.3% +2.0% / −10.4% −1.5%
e.16*	$pp \to t\bar{t}ZZ$	p p > t t~ z z	$1.349 \pm 0.014 \cdot 10^{-3}$	+29.3% / −21.1%	$1.840 \pm 0.007 \cdot 10^{-3}$	+7.9% +1.7% / −9.9% −1.5%
e.17*	$pp \to t\bar{t}Z\gamma$	p p > t t~ z a	$2.548 \pm 0.003 \cdot 10^{-3}$	+30.1% +1.7% / −21.5%	$3.656 \pm 0.012 \cdot 10^{-3}$	+9.7% +1.8% / −11.0% −1.9%
e.18*	$pp \to t\bar{t}\gamma\gamma$	p p > t t~ a a	$3.272 \pm 0.006 \cdot 10^{-3}$	+28.4% / −20.6%	$4.402 \pm 0.015 \cdot 10^{-3}$	+7.8% +1.4% / −9.7% −1.4%

Process		Syntax	LO 13 TeV	LO unc.
Four vector bosons				
c.21*	$pp \to W^+W^-W^+W^-$ (4f)	p p > w+ w- w+ w-	[illegible]	−3.5% −1.7%
c.22*	$pp \to W^+W^-W^{\pm}Z$ (4f)	p p > w+ w- wpm z	[illegible]	−4.1% −1.8%
c.23*	$pp \to W^+W^-W^{\pm}\gamma$ (4f)	p p > w+ w- wpm a	[illegible]	−2.5% −1.7%
c.24*	$pp \to W^+W^-ZZ$ (4f)	p p > w+ w- z z	$4.320 \pm 0.013 \cdot 10^{-4}$	+4.4% +2.4% / −4.1% −1.7%
c.25*	$pp \to W^+W^-Z\gamma$ (4f)	p p > w+ w- z a	$8.403 \pm 0.016 \cdot 10^{-4}$	+3.0% +2.3% / −2.9% −1.7%
c.26*	$pp \to W^+W^-\gamma\gamma$ (4f)	p p > w+ w- a a	$5.198 \pm 0.012 \cdot 10^{-4}$	+0.6% +2.1% / −0.9% −1.6%
c.27*	$pp \to W^{\pm}ZZZ$	p p > wpm z z z	$5.862 \pm 0.010 \cdot 10^{-5}$	+5.1% +2.4% / −4.7% −1.8%
c.28*	$pp \to W^{\pm}ZZ\gamma$	p p > wpm z z a	$1.148 \pm 0.003 \cdot 10^{-4}$	+3.6% +2.2% / −3.5% −1.7%
c.29*	$pp \to W^{\pm}Z\gamma\gamma$	p p > wpm z a a	$1.054 \pm 0.004 \cdot 10^{-4}$	+1.7% +2.1% / −1.9% −1.7%
c.30*	$pp \to W^{\pm}\gamma\gamma\gamma$	p p > wpm a a a	$3.600 \pm 0.013 \cdot 10^{-5}$	+0.4% +2.0% / −1.0% −1.6%
c.31*	$pp \to ZZZZ$	p p > z z z z	$1.989 \pm 0.002 \cdot 10^{-5}$	+3.8% +2.2% / −3.6% −1.7%
c.32*	$pp \to ZZZ\gamma$	p p > z z z a	$3.945 \pm 0.007 \cdot 10^{-5}$	+1.9% +2.1% / −2.1% −1.6%
c.33*	$pp \to ZZ\gamma\gamma$	p p > z z a a	$5.513 \pm 0.017 \cdot 10^{-5}$	+0.0% +2.1% / −0.3% −1.6%
c.34*	$pp \to Z\gamma\gamma\gamma$	p p > z a a a	$4.790 \pm 0.012 \cdot 10^{-5}$	+2.3% +2.0% / −3.1% −1.6%
c.35*	$pp \to \gamma\gamma\gamma\gamma$	p p > a a a a	$1.594 \pm 0.004 \cdot 10^{-5}$	+4.7% +1.9% / −5.7% −1.7%

AUTOMATIC NLO IN SM (2014)

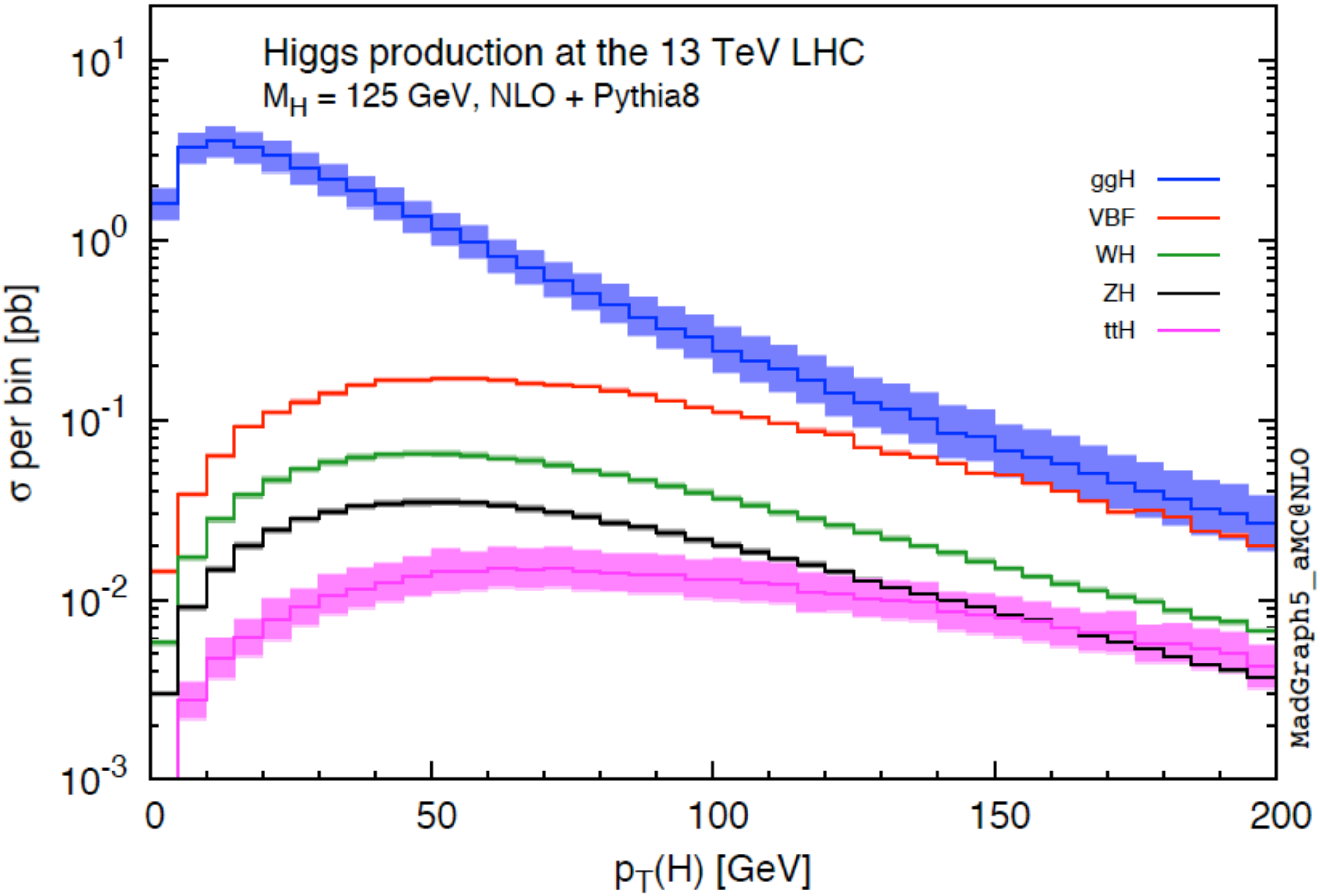
- Code tested producing by 150 process and corresponding cross sections at NLO in QCD.
- Most of all pp → 4 final state covered (not pp→4j and pp→H+3j)
- Differential NLO (QCD) and NLO+PS automatically available
- Uncertainties evaluated in the same run and on event-by-event basis

AUTOMATIC NLO IN SM (2014)

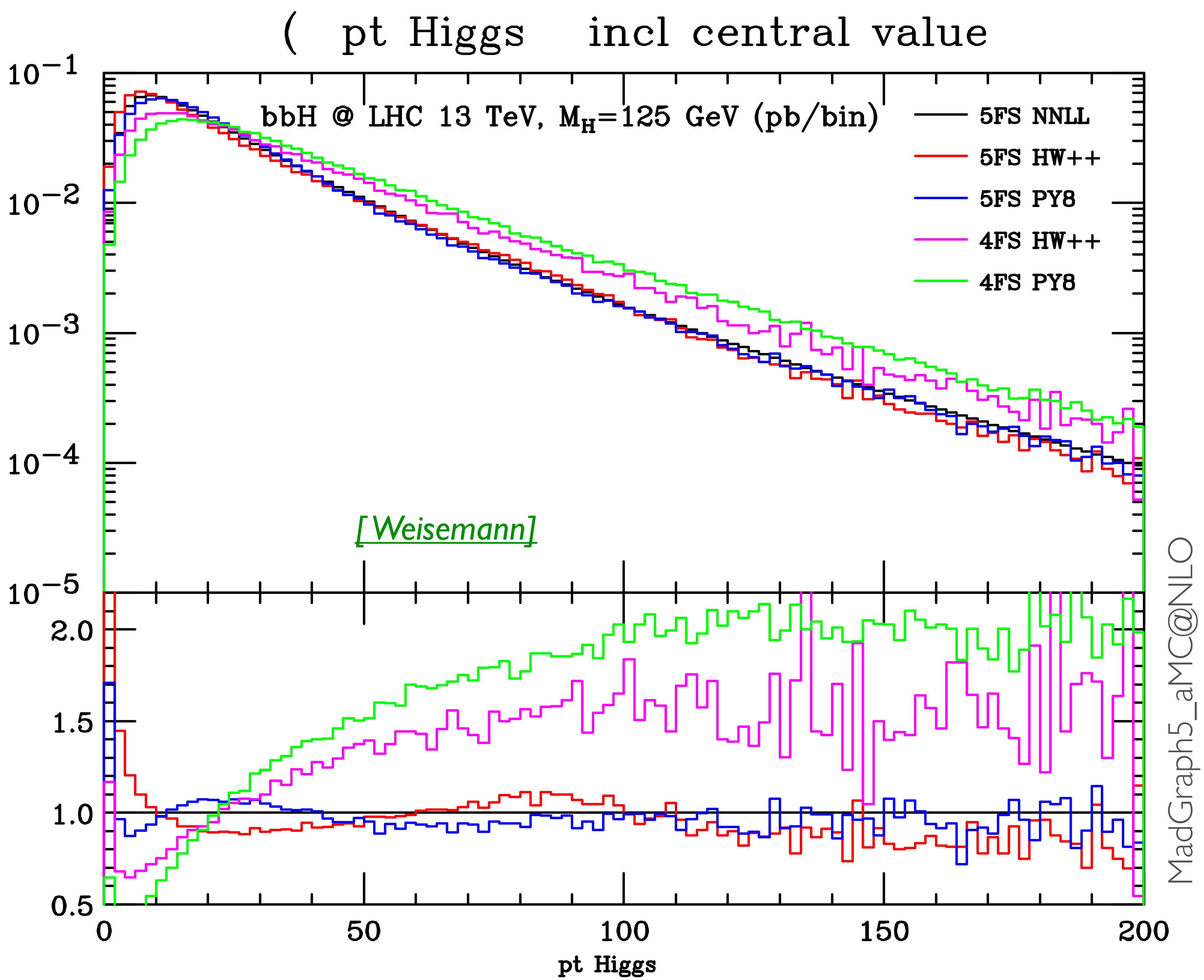
Process		Syntax	Cross section (pb) LO 13 TeV		Cross section (pb) NLO 13 TeV	
Single Higgs production						
g.1	$pp \to H$ (HEFT)	`p p > h`	$1.593 \pm 0.003 \cdot 10^{1}$	${}^{+34.8\%}_{-26.0\%}$ ${}^{+1.2\%}_{-1.7\%}$	$3.261 \pm 0.010 \cdot 10^{1}$	${}^{+20.2\%}_{-17.9\%}$ ${}^{+1.1\%}_{-1.6\%}$
g.2	$pp \to Hj$ (HEFT)	`p p > h j`	$8.367 \pm 0.003 \cdot 10^{0}$	${}^{+39.4\%}_{-26.4\%}$ ${}^{+1.2\%}_{-1.4\%}$	$1.422 \pm 0.006 \cdot 10^{1}$	${}^{+18.5\%}_{-16.6\%}$ ${}^{+1.1\%}_{-1.4\%}$
g.3	$pp \to Hjj$ (HEFT)	`p p > h j j`	$3.020 \pm 0.002 \cdot 10^{0}$	${}^{+59.1\%}_{-34.7\%}$ ${}^{+1.4\%}_{-1.7\%}$	$5.124 \pm 0.020 \cdot 10^{0}$	${}^{+20.7\%}_{-21.0\%}$ ${}^{+1.3\%}_{-1.5\%}$
g.4	$pp \to Hjj$ (VBF)	`p p > h j j $$ w+ w- z`	$1.987 \pm 0.002 \cdot 10^{0}$	${}^{+1.7\%}_{-2.0\%}$ ${}^{+1.9\%}_{-1.4\%}$	$1.900 \pm 0.006 \cdot 10^{0}$	${}^{+0.8\%}_{-0.9\%}$ ${}^{+2.0\%}_{-1.5\%}$
g.5	$pp \to Hjjj$ (VBF)	`p p > h j j j $$ w+ w- z`	$2.824 \pm 0.005 \cdot 10^{-1}$	${}^{+15.7\%}_{-12.7\%}$ ${}^{+1.5\%}_{-1.0\%}$	$3.085 \pm 0.010 \cdot 10^{-1}$	${}^{+2.0\%}_{-3.0\%}$ ${}^{+1.5\%}_{-1.1\%}$
g.6	$pp \to HW^{\pm}$	`p p > h wpm`	$1.195 \pm 0.002 \cdot 10^{0}$	${}^{+3.5\%}_{-4.5\%}$ ${}^{+1.9\%}_{-1.5\%}$	$1.419 \pm 0.005 \cdot 10^{0}$	${}^{+2.1\%}_{-2.6\%}$ ${}^{+1.9\%}_{-1.4\%}$
g.7	$pp \to HW^{\pm}j$	`p p > h wpm j`	$4.018 \pm 0.003 \cdot 10^{-1}$	${}^{+10.7\%}_{-9.3\%}$ ${}^{+1.2\%}_{-0.9\%}$	$4.842 \pm 0.017 \cdot 10^{-1}$	${}^{+3.6\%}_{-3.7\%}$ ${}^{+1.2\%}_{-1.0\%}$
g.8*	$pp \to HW^{\pm}jj$	`p p > h wpm j j`	$1.198 \pm 0.016 \cdot 10^{-1}$	${}^{+26.1\%}_{-19.4\%}$ ${}^{+0.8\%}_{-0.6\%}$	$1.574 \pm 0.014 \cdot 10^{-1}$	${}^{+5.0\%}_{-6.5\%}$ ${}^{+0.9\%}_{-0.6\%}$
g.9	$pp \to HZ$	`p p > h z`	$6.468 \pm 0.008 \cdot 10^{-1}$	${}^{+3.5\%}_{-4.5\%}$ ${}^{+1.9\%}_{-1.4\%}$	$7.674 \pm 0.027 \cdot 10^{-1}$	${}^{+2.0\%}_{-2.5\%}$ ${}^{+1.9\%}_{-1.4\%}$
g.10	$pp \to HZj$	`p p > h z j`	$2.225 \pm 0.001 \cdot 10^{-1}$	${}^{+10.6\%}_{-9.2\%}$ ${}^{+1.1\%}_{-0.8\%}$	$2.667 \pm 0.010 \cdot 10^{-1}$	${}^{+3.5\%}_{-3.6\%}$ ${}^{+1.1\%}_{-0.9\%}$
g.11*	$pp \to HZjj$	`p p > h z j j`	$7.262 \pm 0.012 \cdot 10^{-2}$	${}^{+26.2\%}_{-19.4\%}$ ${}^{+0.7\%}_{-0.6\%}$	$8.753 \pm 0.037 \cdot 10^{-2}$	${}^{+4.8\%}_{-6.3\%}$ ${}^{+0.7\%}_{-0.6\%}$
g.12*	$pp \to HW^{+}W^{-}$ (4f)	`p p > h w+ w-`	$8.325 \pm 0.139 \cdot 10^{-3}$	${}^{+0.0\%}_{-0.3\%}$ ${}^{+2.0\%}_{-1.6\%}$	$1.065 \pm 0.003 \cdot 10^{-2}$	${}^{+2.5\%}_{-1.9\%}$ ${}^{+2.0\%}_{-1.5\%}$
g.13*	$pp \to HW^{\pm}\gamma$	`p p > h wpm a`	$2.518 \pm 0.006 \cdot 10^{-3}$	${}^{+0.7\%}_{-1.4\%}$ ${}^{+1.9\%}_{-1.5\%}$	$3.309 \pm 0.011 \cdot 10^{-3}$	${}^{+2.7\%}_{-2.0\%}$ ${}^{+1.7\%}_{-1.4\%}$
g.14*	$pp \to HZW^{\pm}$	`p p > h z wpm`	$3.763 \pm 0.007 \cdot 10^{-3}$	${}^{+1.1\%}_{-1.5\%}$ ${}^{+2.0\%}_{-1.6\%}$	$5.292 \pm 0.015 \cdot 10^{-3}$	${}^{+3.9\%}_{-3.1\%}$ ${}^{+1.8\%}_{-1.4\%}$
g.15*	$pp \to HZZ$	`p p > h z z`	$2.093 \pm 0.003 \cdot 10^{-3}$	${}^{+0.1\%}_{-0.6\%}$ ${}^{+1.9\%}_{-1.5\%}$	$2.538 \pm 0.007 \cdot 10^{-3}$	${}^{+1.9\%}_{-1.4\%}$ ${}^{+2.0\%}_{-1.5\%}$
g.16	$pp \to Ht\bar{t}$	`p p > h t t~`	$3.579 \pm 0.003 \cdot 10^{-1}$	${}^{+30.0\%}_{-21.5\%}$ ${}^{+1.7\%}_{-2.0\%}$	$4.608 \pm 0.016 \cdot 10^{-1}$	${}^{+5.7\%}_{-9.0\%}$ ${}^{+2.0\%}_{-2.3\%}$
g.17	$pp \to Htj$	`p p > h tt j`	$4.994 \pm 0.005 \cdot 10^{-2}$	${}^{+2.4\%}_{-4.2\%}$ ${}^{+1.2\%}_{-1.3\%}$	$6.328 \pm 0.022 \cdot 10^{-2}$	${}^{+2.9\%}_{-1.8\%}$ ${}^{+1.5\%}_{-1.6\%}$
g.18	$pp \to Hb\bar{b}$ (4f)	`p p > h b b~`	$4.983 \pm 0.002 \cdot 10^{-1}$	${}^{+28.1\%}_{-21.0\%}$ ${}^{+1.5\%}_{-1.8\%}$	$6.085 \pm 0.026 \cdot 10^{-1}$	${}^{+7.3\%}_{-9.6\%}$ ${}^{+1.6\%}_{-2.0\%}$
g.19	$pp \to Ht\bar{t}j$	`p p > h t t~ j`	$2.674 \pm 0.041 \cdot 10^{-1}$	${}^{+45.6\%}_{-29.2\%}$ ${}^{+2.6\%}_{-2.9\%}$	$3.244 \pm 0.025 \cdot 10^{-1}$	${}^{+3.5\%}_{-8.7\%}$ ${}^{+2.5\%}_{-2.9\%}$
g.20*	$pp \to Hb\bar{b}j$ (4f)	`p p > h b b~ j`	$7.367 \pm 0.002 \cdot 10^{-2}$	${}^{+45.6\%}_{-29.1\%}$ ${}^{+1.8\%}_{-2.1\%}$	$9.034 \pm 0.032 \cdot 10^{-2}$	${}^{+7.9\%}_{-11.0\%}$ ${}^{+1.8\%}_{-2.2\%}$

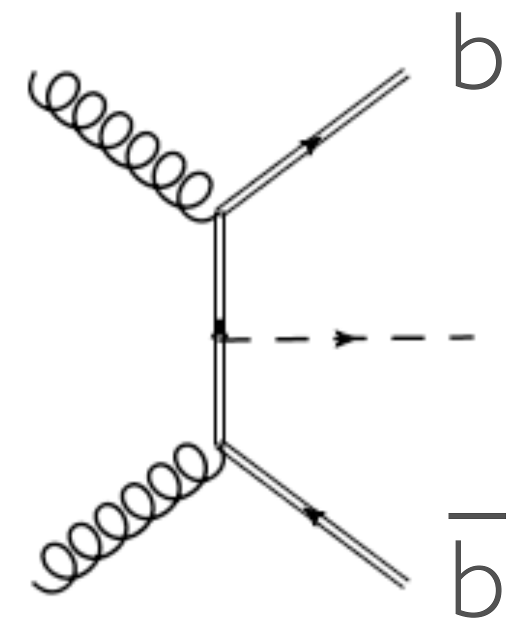
AUTOMATIC SINGLE HIGGS PRODUCTION

[Alwall et al. 1405.0301]



AUTOMATIC SINGLE HIGGS PRODUCTION





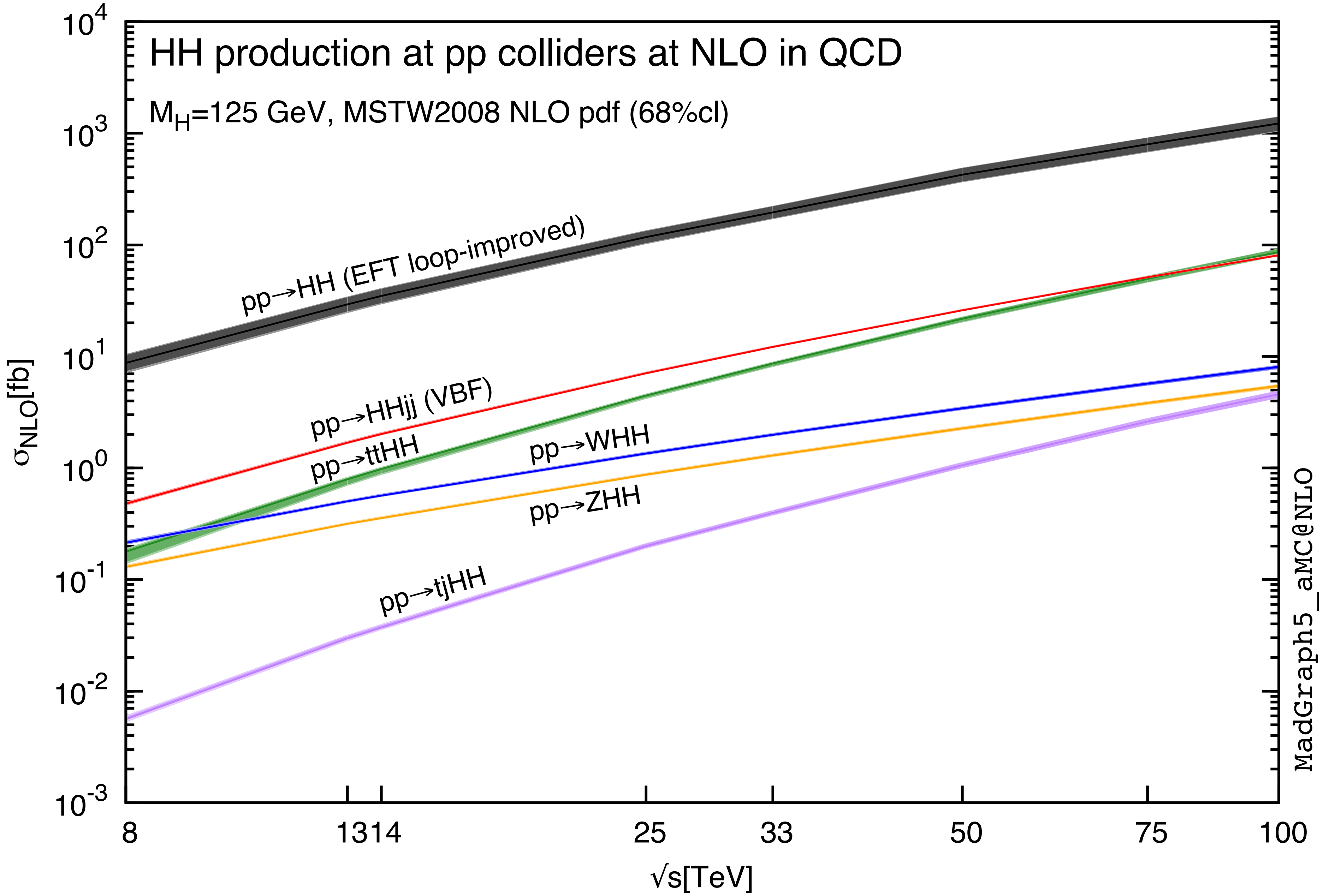
AUTOMATIC NLO IN SM (2014)

	Process Multiple Higgs production	Syntax	Cross section (pb) LO 13 TeV		NLO 13 TeV	
h.1	$pp \to HH$ (Loop improved)	`p p > h h`	$1.772 \pm 0.006 \cdot 10^{-2}$	$^{+29.5\%}_{-21.4\%}$ $^{+2.1\%}_{-2.6\%}$	$2.763 \pm 0.008 \cdot 10^{-2}$	$^{+11.4\%}_{-11.8\%}$ $^{+2.1\%}_{-2.6\%}$
h.2	$pp \to HHjj$ (VBF)	`p p > h h j j $$ w+ w- z`	$6.503 \pm 0.019 \cdot 10^{-4}$	$^{+7.2\%}_{-6.4\%}$ $^{+2.3\%}_{-1.6\%}$	$6.820 \pm 0.026 \cdot 10^{-4}$	$^{+0.8\%}_{-1.0\%}$ $^{+2.4\%}_{-1.7\%}$
h.3	$pp \to HHW^{\pm}$	`p p > h h wpm`	$4.303 \pm 0.005 \cdot 10^{-4}$	$^{+0.9\%}_{-1.3\%}$ $^{+2.0\%}_{-1.5\%}$	$5.002 \pm 0.014 \cdot 10^{-4}$	$^{+1.5\%}_{-1.2\%}$ $^{+2.0\%}_{-1.6\%}$
h.4*	$pp \to HHW^{\pm}j$	`p p > h h wpm j`	$1.922 \pm 0.002 \cdot 10^{-4}$	$^{+14.2\%}_{-11.7\%}$ $^{+1.5\%}_{-1.1\%}$	$2.218 \pm 0.009 \cdot 10^{-4}$	$^{+2.7\%}_{-3.3\%}$ $^{+1.6\%}_{-1.1\%}$
h.5*	$pp \to HHW^{\pm}\gamma$	`p p > h h wpm a`	$1.952 \pm 0.004 \cdot 10^{-6}$	$^{+3.0\%}_{-3.0\%}$ $^{+2.2\%}_{-1.6\%}$	$2.347 \pm 0.007 \cdot 10^{-6}$	$^{+2.4\%}_{-2.0\%}$ $^{+2.1\%}_{-1.6\%}$
h.6*	$pp \to HHHW^{\pm}$	`p p > h h h wpm`	$3.989 \pm 0.009 \cdot 10^{-7}$	$^{+3.9\%}_{-3.8\%}$ $^{+2.2\%}_{-1.7\%}$	$4.590 \pm 0.012 \cdot 10^{-7}$	$^{+1.8\%}_{-1.7\%}$ $^{+2.2\%}_{-1.7\%}$
h.7	$pp \to HHZ$	`p p > h h z`	$2.701 \pm 0.007 \cdot 10^{-4}$	$^{+0.9\%}_{-1.3\%}$ $^{+2.0\%}_{-1.5\%}$	$3.130 \pm 0.008 \cdot 10^{-4}$	$^{+1.6\%}_{-1.2\%}$ $^{+2.0\%}_{-1.5\%}$
h.8*	$pp \to HHZj$	`p p > h h z j`	$1.211 \pm 0.001 \cdot 10^{-4}$	$^{+14.1\%}_{-11.7\%}$ $^{+1.4\%}_{-1.1\%}$	$1.394 \pm 0.006 \cdot 10^{-4}$	$^{+2.7\%}_{-3.2\%}$ $^{+1.5\%}_{-1.1\%}$
h.9*	$pp \to HHZ\gamma$	`p p > h h z a`	$1.397 \pm 0.003 \cdot 10^{-6}$	$^{+2.4\%}_{-2.5\%}$ $^{+2.2\%}_{-1.7\%}$	$1.604 \pm 0.005 \cdot 10^{-6}$	$^{+1.7\%}_{-1.4\%}$ $^{+2.3\%}_{-1.7\%}$
h.10*	$pp \to HHHZ$	`p p > h h h z`	$2.735 \pm 0.006 \cdot 10^{-7}$	$^{+3.9\%}_{-3.7\%}$ $^{+2.2\%}_{-1.7\%}$	$3.154 \pm 0.007 \cdot 10^{-7}$	$^{+1.7\%}_{-1.6\%}$ $^{+2.2\%}_{-1.7\%}$
h.11*	$pp \to HHZZ$	`p p > h h z z`	$2.309 \pm 0.005 \cdot 10^{-6}$	$^{+3.9\%}_{-3.8\%}$ $^{+2.2\%}_{-1.7\%}$	$2.754 \pm 0.009 \cdot 10^{-6}$	$^{+2.3\%}_{-2.0\%}$ $^{+2.3\%}_{-1.7\%}$
h.12*	$pp \to HHZW^{\pm}$	`p p > h h z wpm`	$3.708 \pm 0.013 \cdot 10^{-6}$	$^{+4.8\%}_{-4.5\%}$ $^{+2.3\%}_{-1.7\%}$	$4.904 \pm 0.029 \cdot 10^{-6}$	$^{+3.7\%}_{-3.2\%}$ $^{+2.2\%}_{-1.6\%}$
h.13*	$pp \to HHW^{+}W^{-}$ (4f)	`p p > h h w+ w-`	$7.524 \pm 0.070 \cdot 10^{-6}$	$^{+3.5\%}_{-3.4\%}$ $^{+2.3\%}_{-1.7\%}$	$9.268 \pm 0.030 \cdot 10^{-6}$	$^{+2.3\%}_{-2.1\%}$ $^{+2.3\%}_{-1.7\%}$
h.14	$pp \to HHt\bar{t}$	`p p > h h t t~`	$6.756 \pm 0.007 \cdot 10^{-4}$	$^{+30.2\%}_{-21.6\%}$ $^{+1.8\%}_{-1.8\%}$	$7.301 \pm 0.024 \cdot 10^{-4}$	$^{+1.4\%}_{-5.7\%}$ $^{+2.2\%}_{-2.3\%}$
h.15	$pp \to HHtj$	`p p > h h tt j`	$1.844 \pm 0.008 \cdot 10^{-5}$	$^{+0.0\%}_{-0.6\%}$ $^{+1.8\%}_{-1.8\%}$	$2.444 \pm 0.009 \cdot 10^{-5}$	$^{+4.5\%}_{-3.1\%}$ $^{+2.8\%}_{-3.0\%}$

All channels here are possible at the NLO+PS for the first time.

[Frederix et al. 1401.7340]

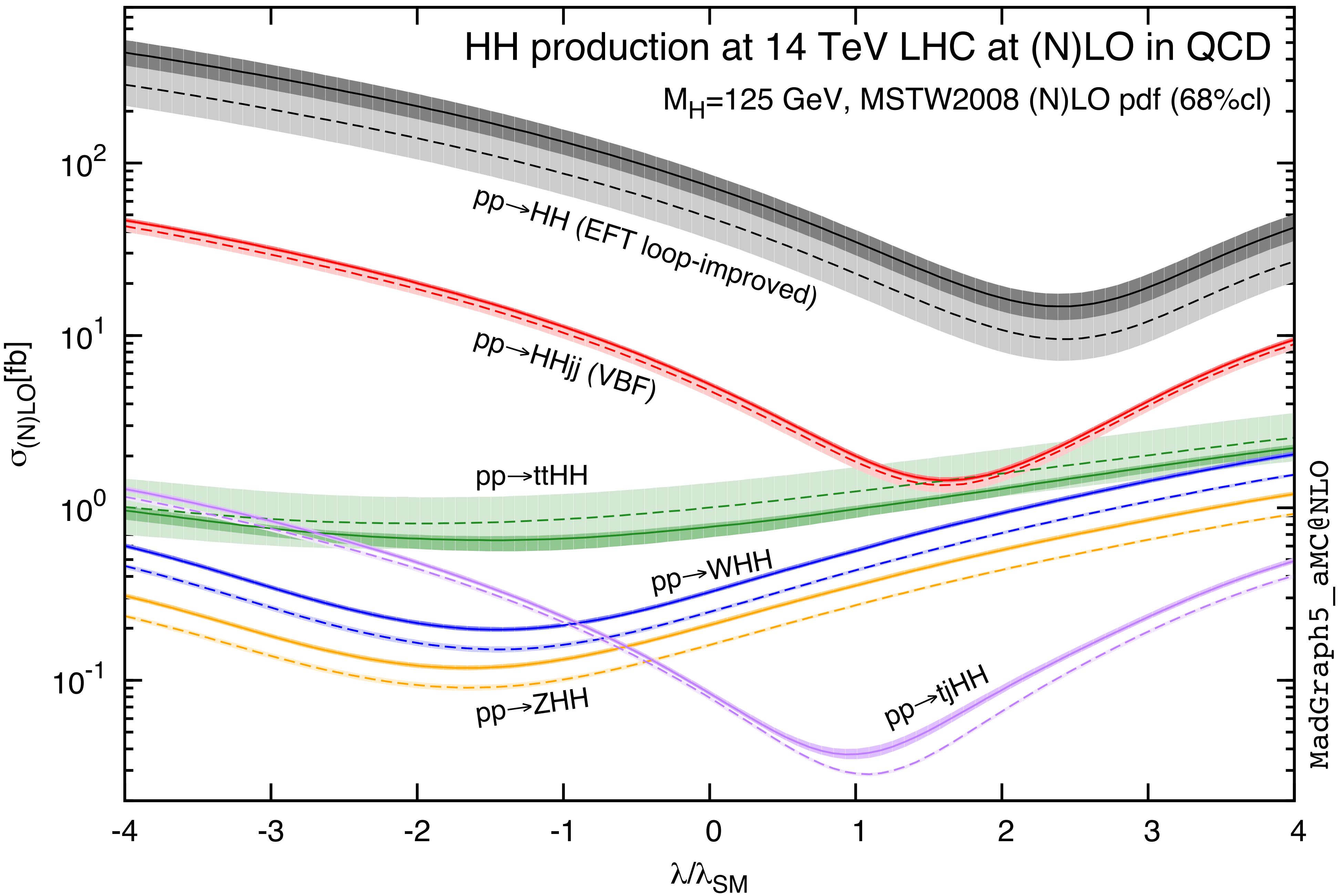
HH PRODUCTION AT PP COLLIDERS



Total cross sections at NLO for the most relevant HH production channels

[Frederix et al. 1401.7340]

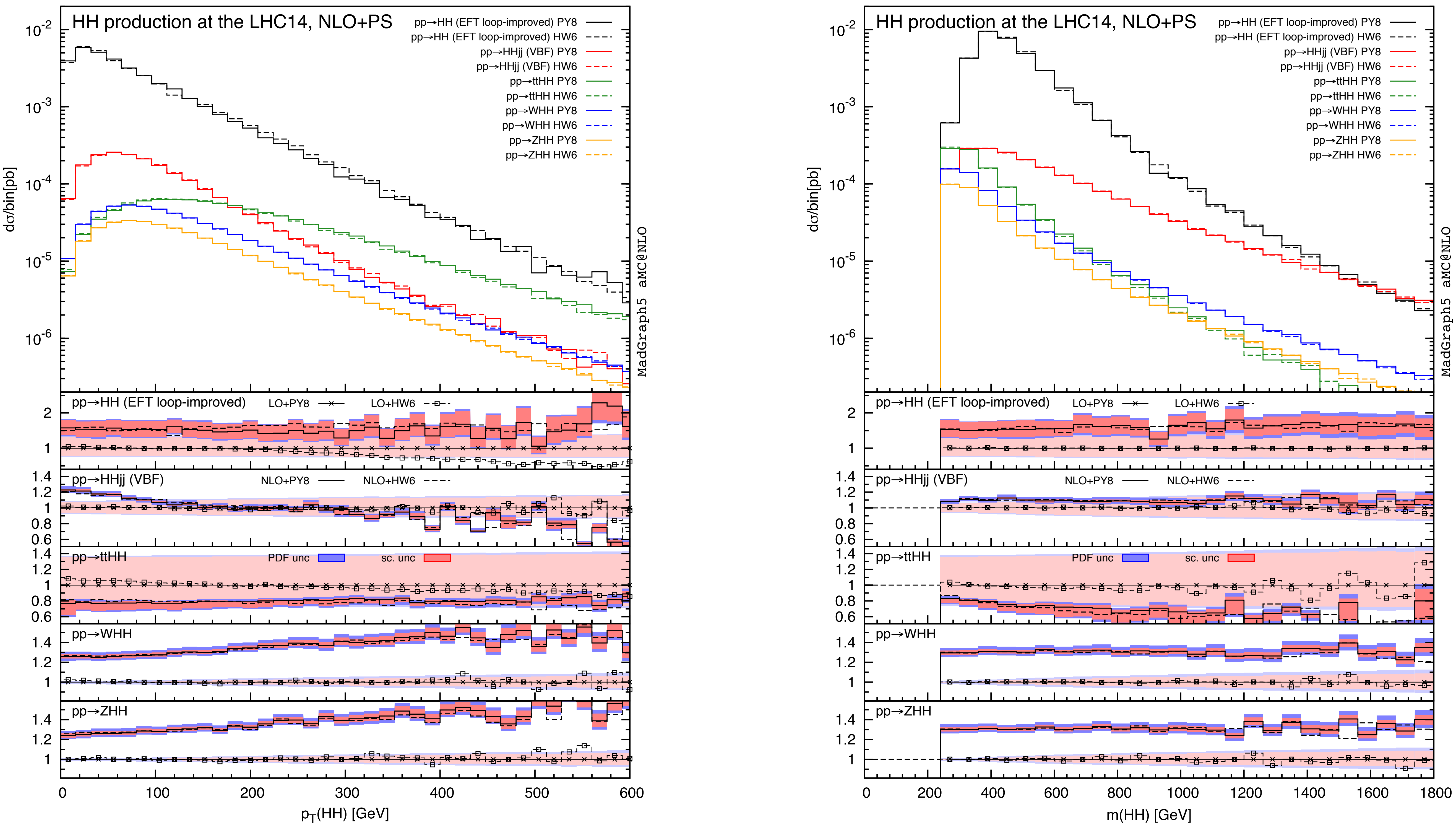
HH PRODUCTION AT PP COLLIDERS



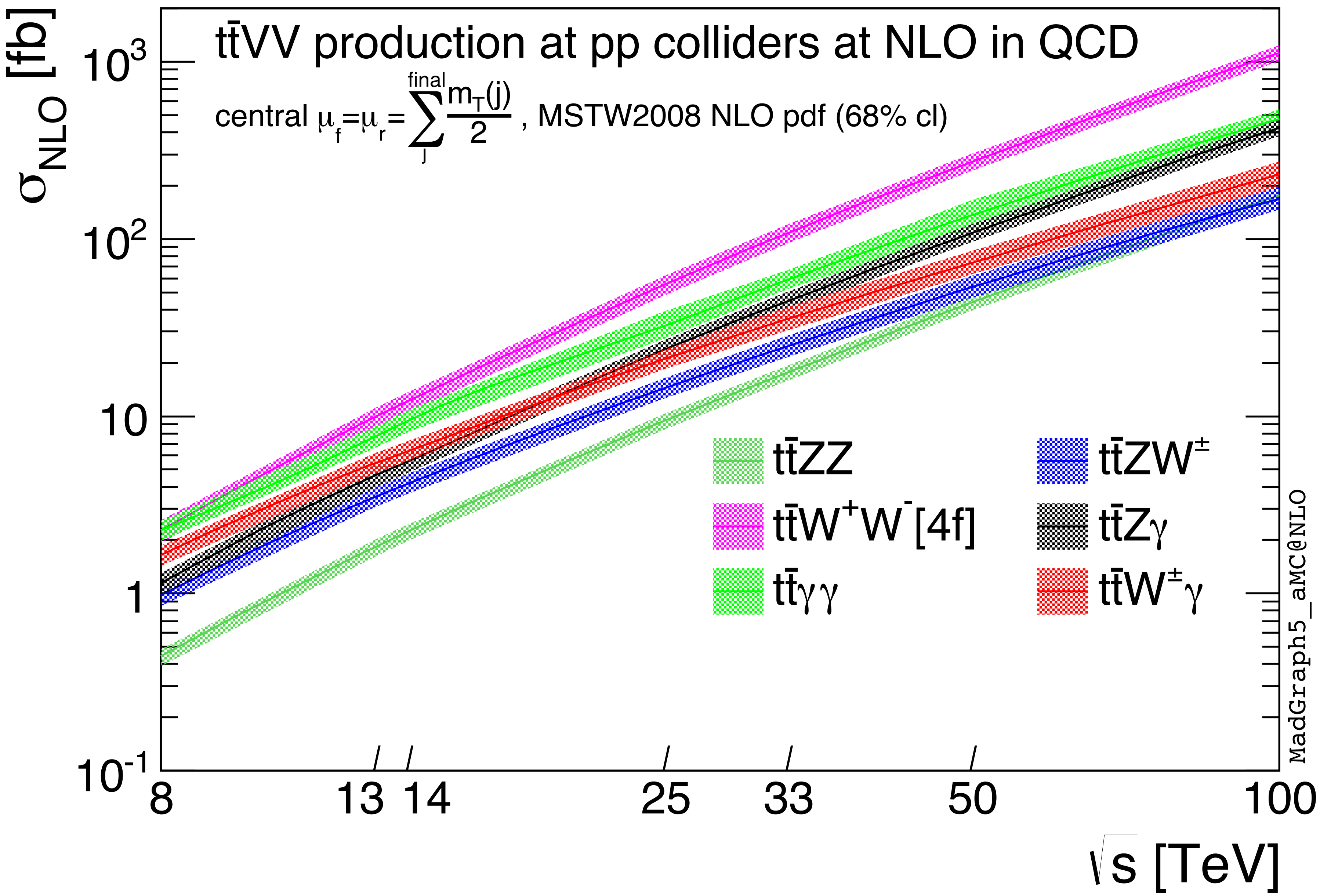
Trilinear coupling sensitivity

[Frederix et al. 1401.7340]

HH PRODUCTION AT PP COLLIDERS

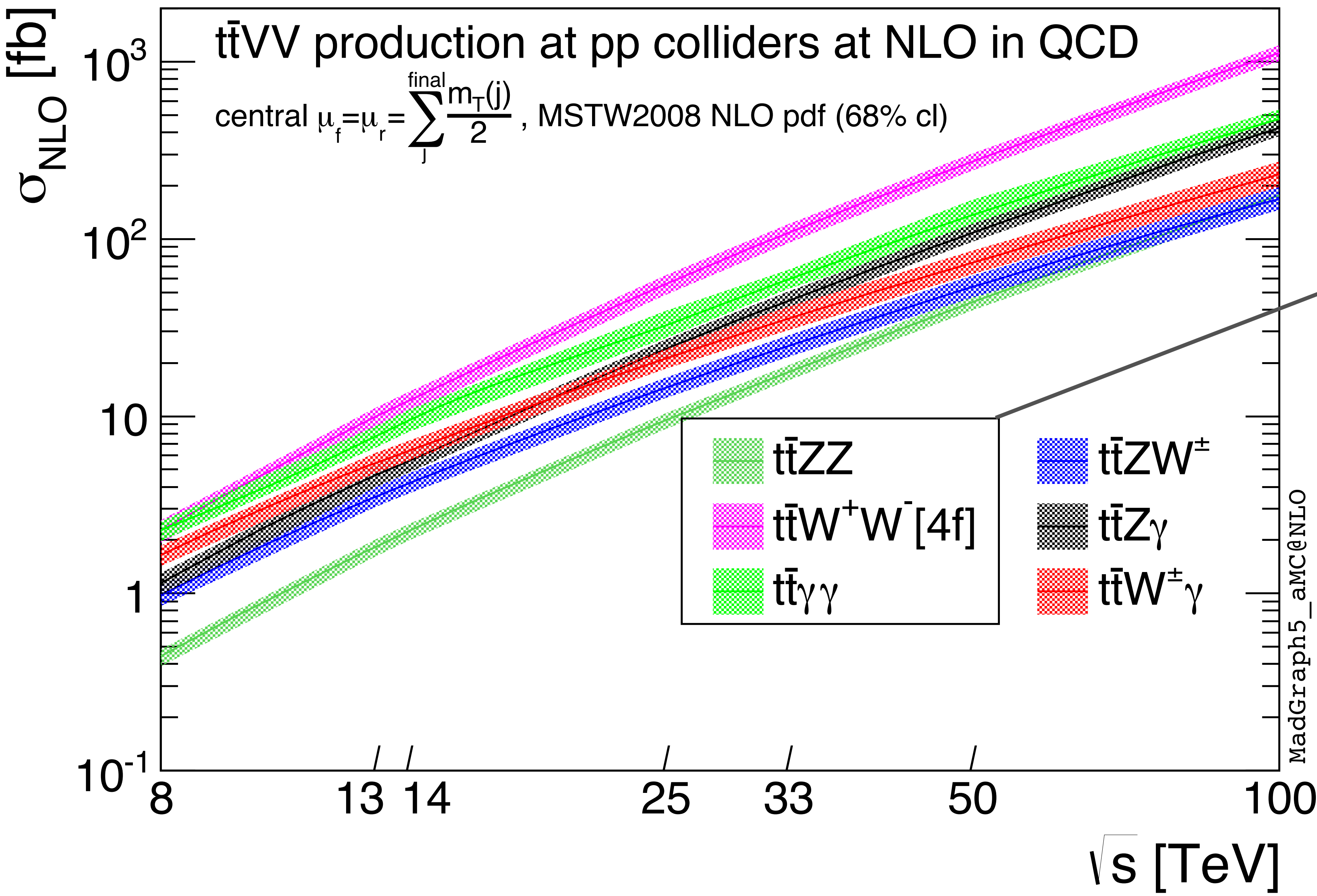


TTVV PRODUCTION AT PP COLLIDERS



[Tsinikos and Pagani, in progress]

TTVV PRODUCTION AT PP COLLIDERS

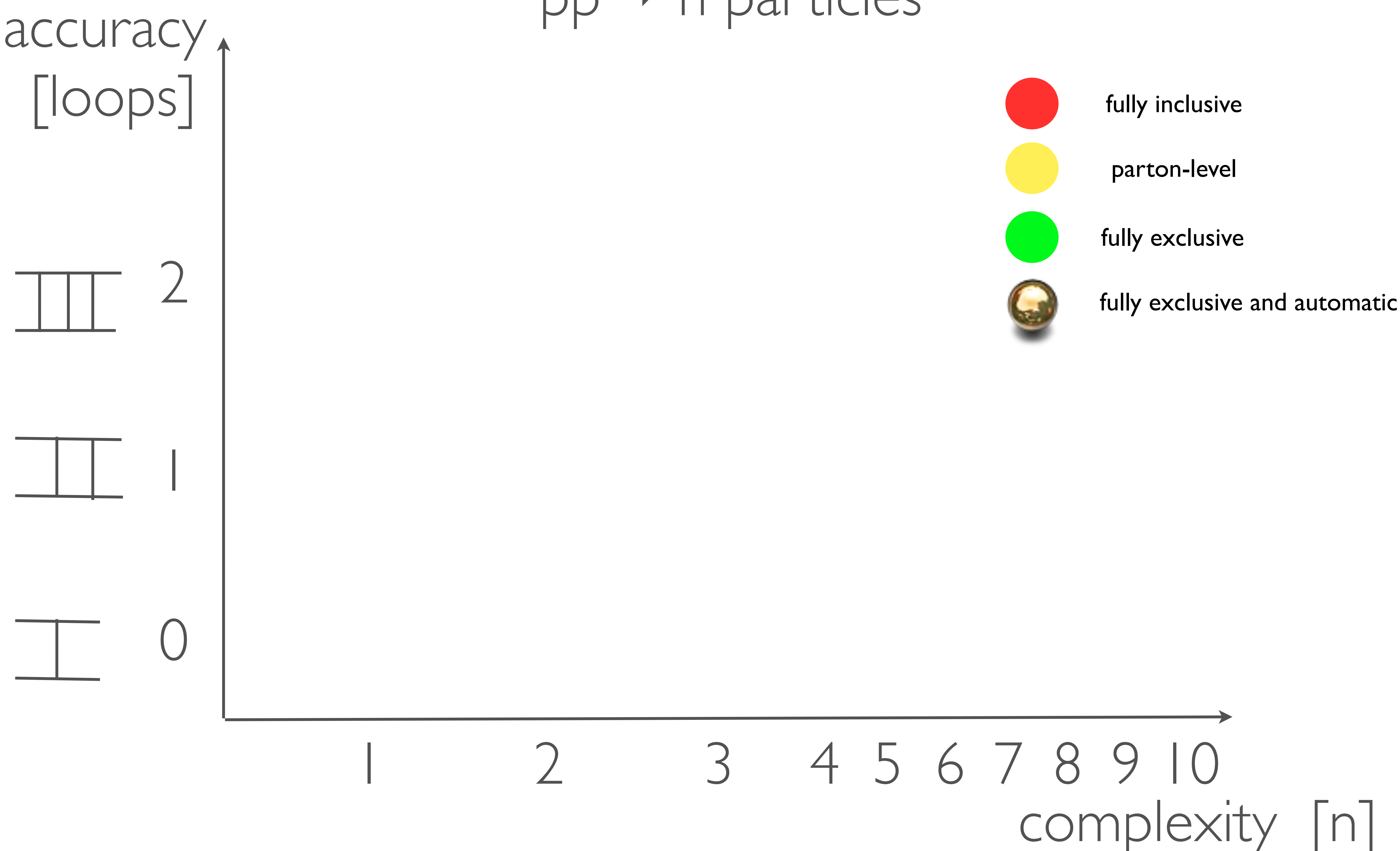


Irreducible backgrounds to ttH inclusive searchers

[Tsinikos and Pagani, in progress]

SM STATUS : XMAS 2013

pp→ n particles



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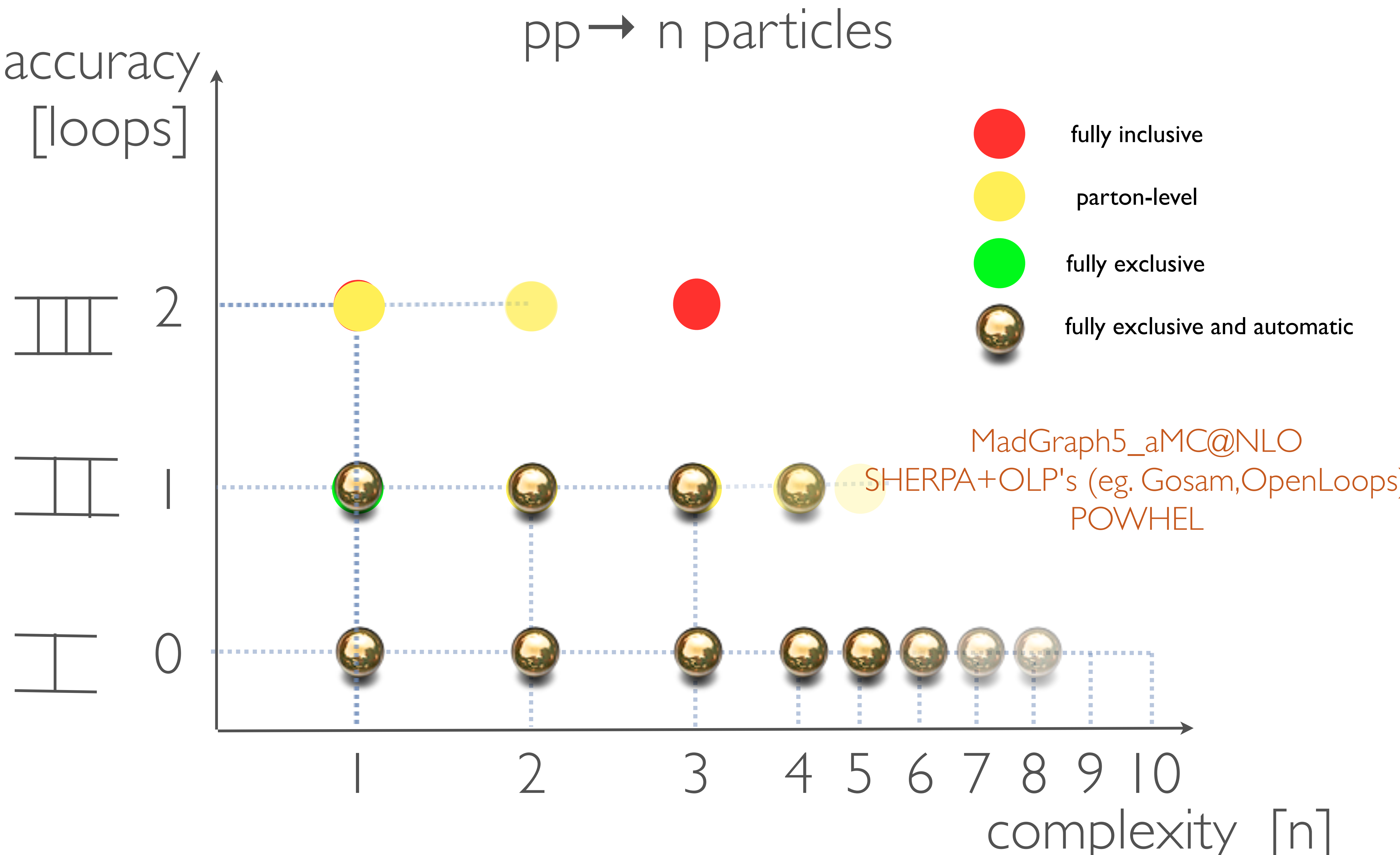


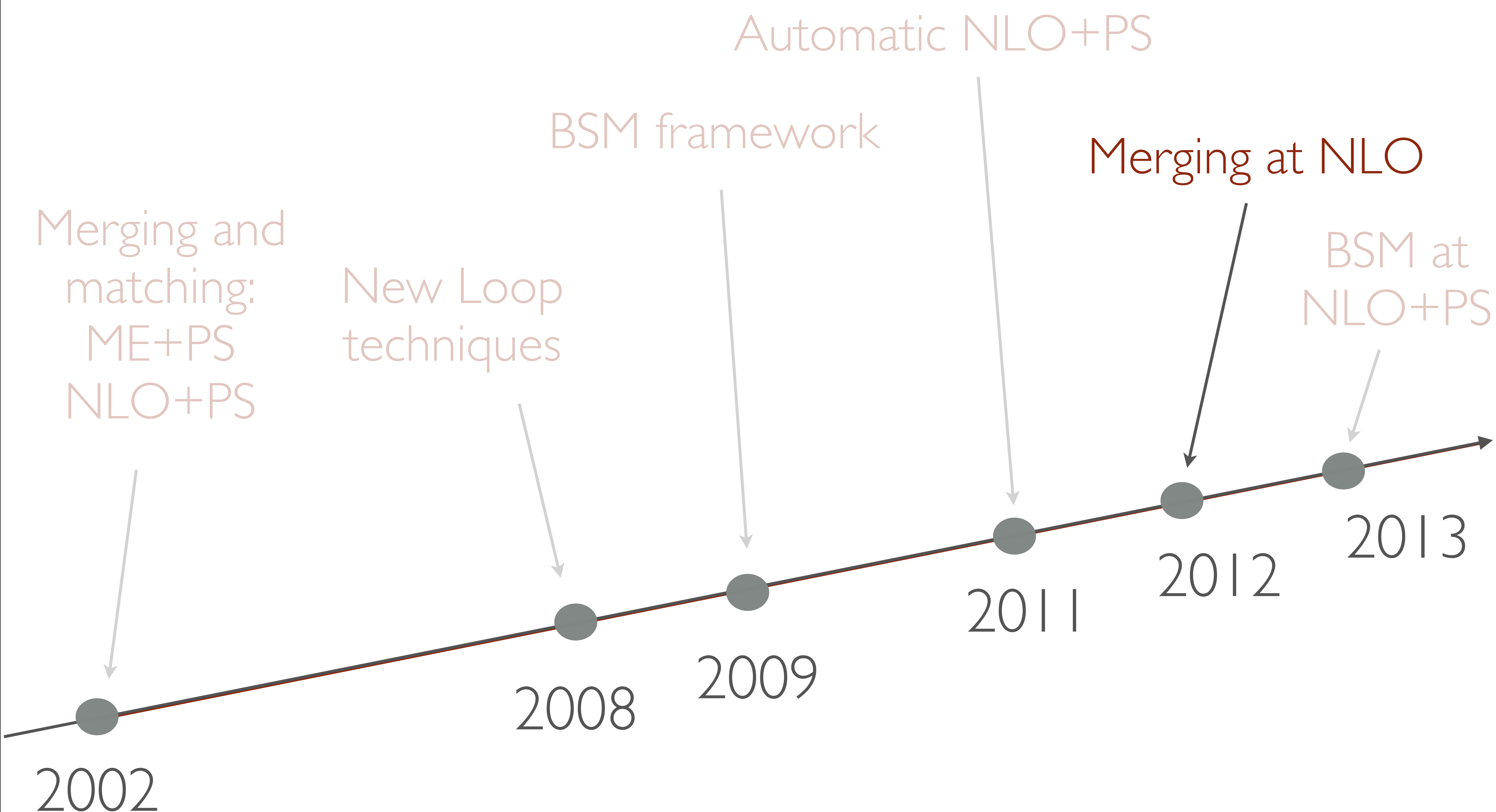
BOTTOM LINE

NNLO and NLO+PS stay to the LHC era

as

NLO and LO+PS stayed to the Tevatron era

PREDICTIVE MC (SIMPLIFIED) PROGRESS



MULTI-JET MERGING @ NLO

The problem consists in merging samples for S+0j, S+1j, S+2j, S+...j computed at NLO consistently without double counting (where S can be a Higgs, a ttbar pair, a W-boson, etc.)

Sherpa approach: Hoeche et al., 1207.5031

CKKW-L approach: Lavesson, Lonnblad, 0811.2912, Lonnblad, Prestel, 1211.4827-7278

Geneva approach : Alioli et al. 1212.4504 and see also 1311.0286 (with NNLO proposal)

FxFx approach (with MC@NLO) : Frederix and Frixione 1209.6215

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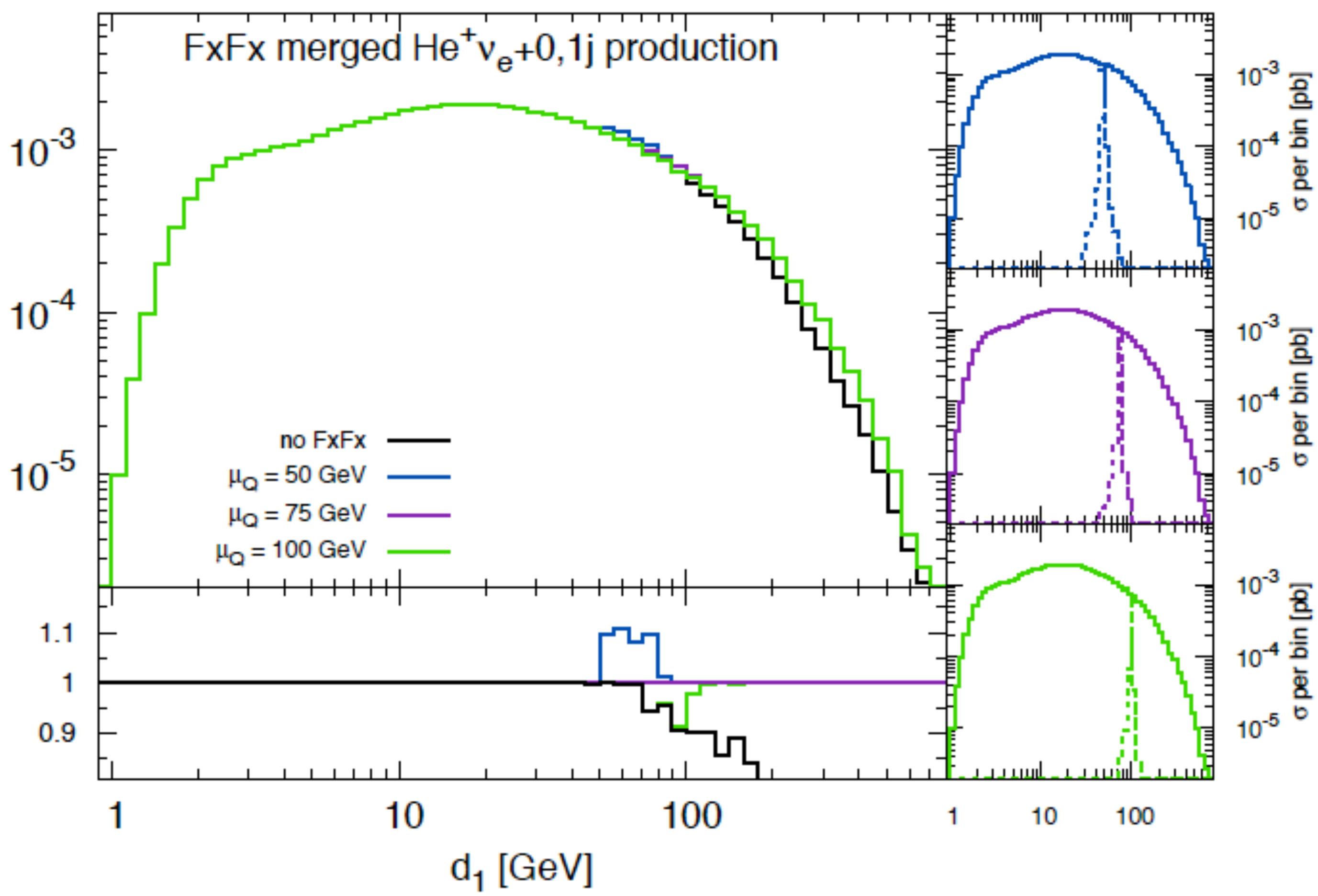
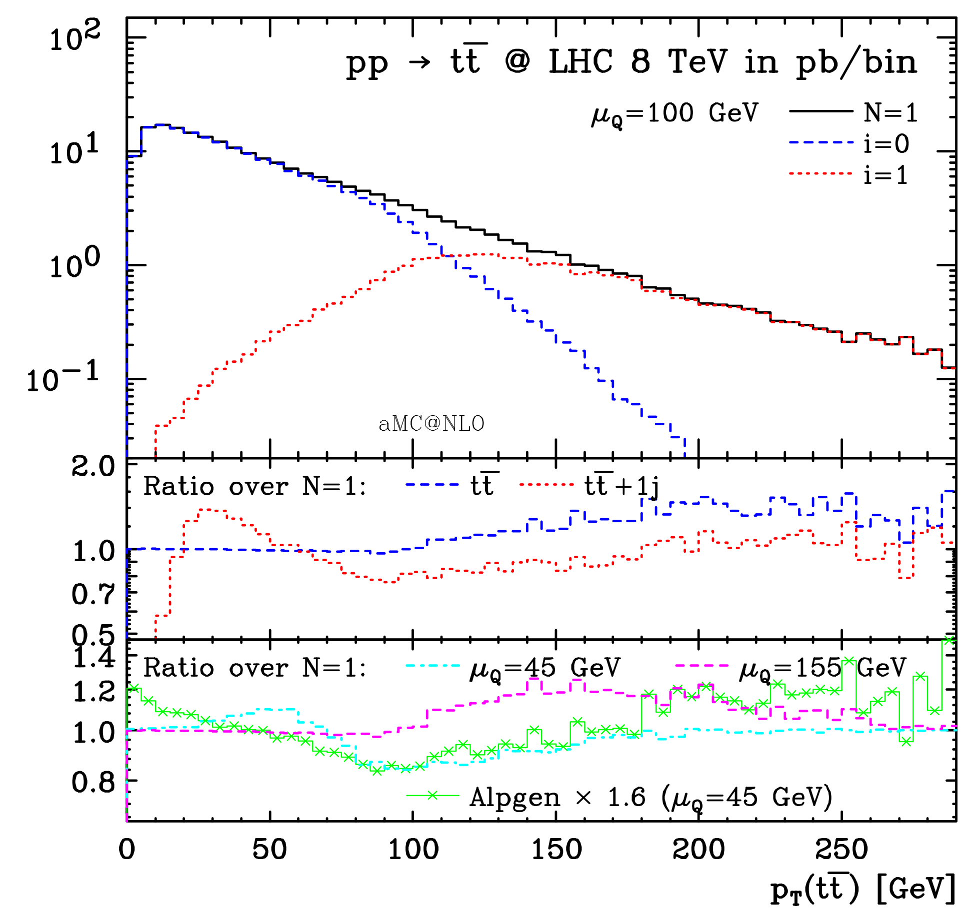
The wave function of the merging at NLO effort has collapsed in 2012

MULTI-JET MERGING @ NLO

[Frederix, Frixione, 1209.6215]



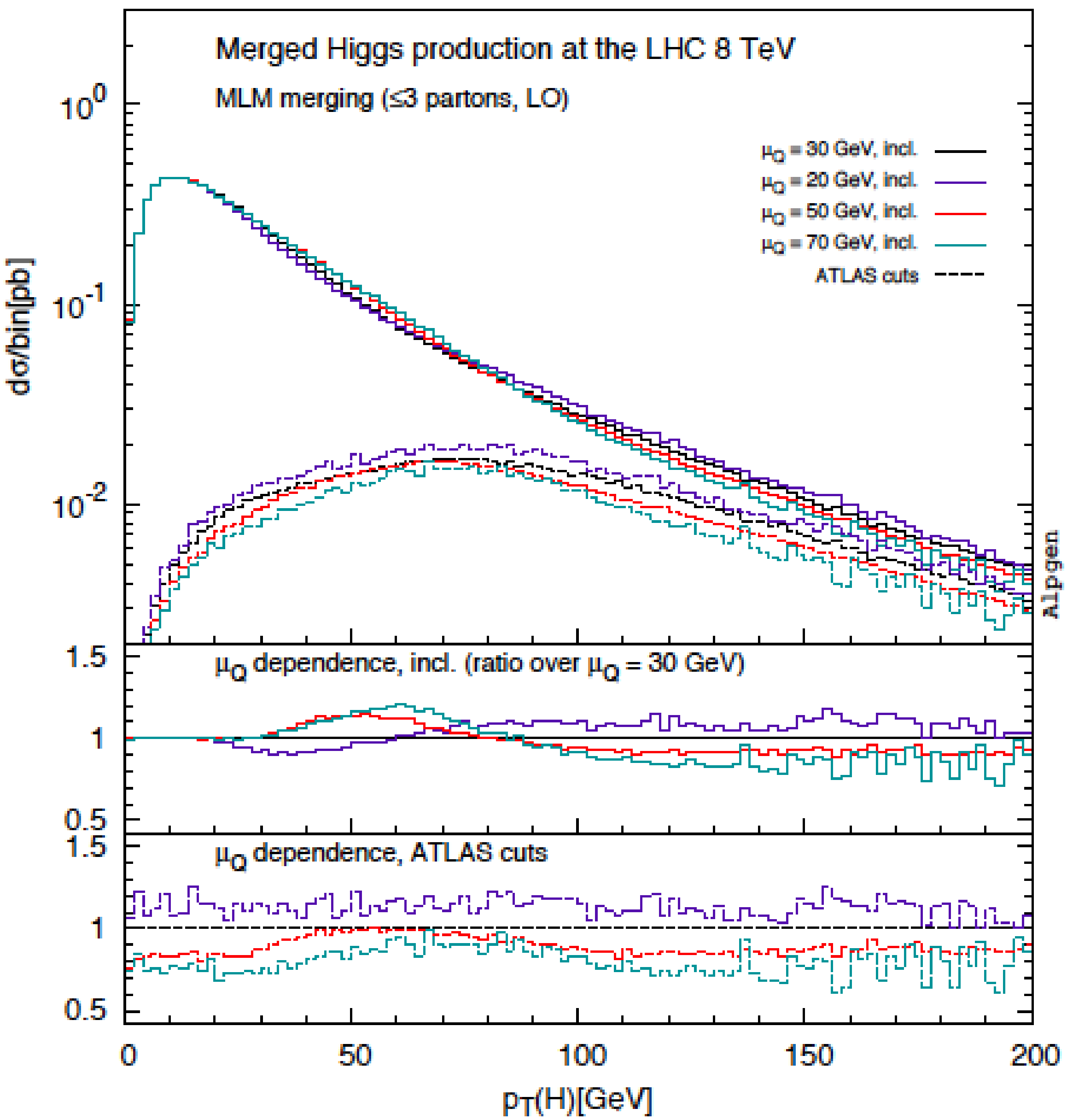


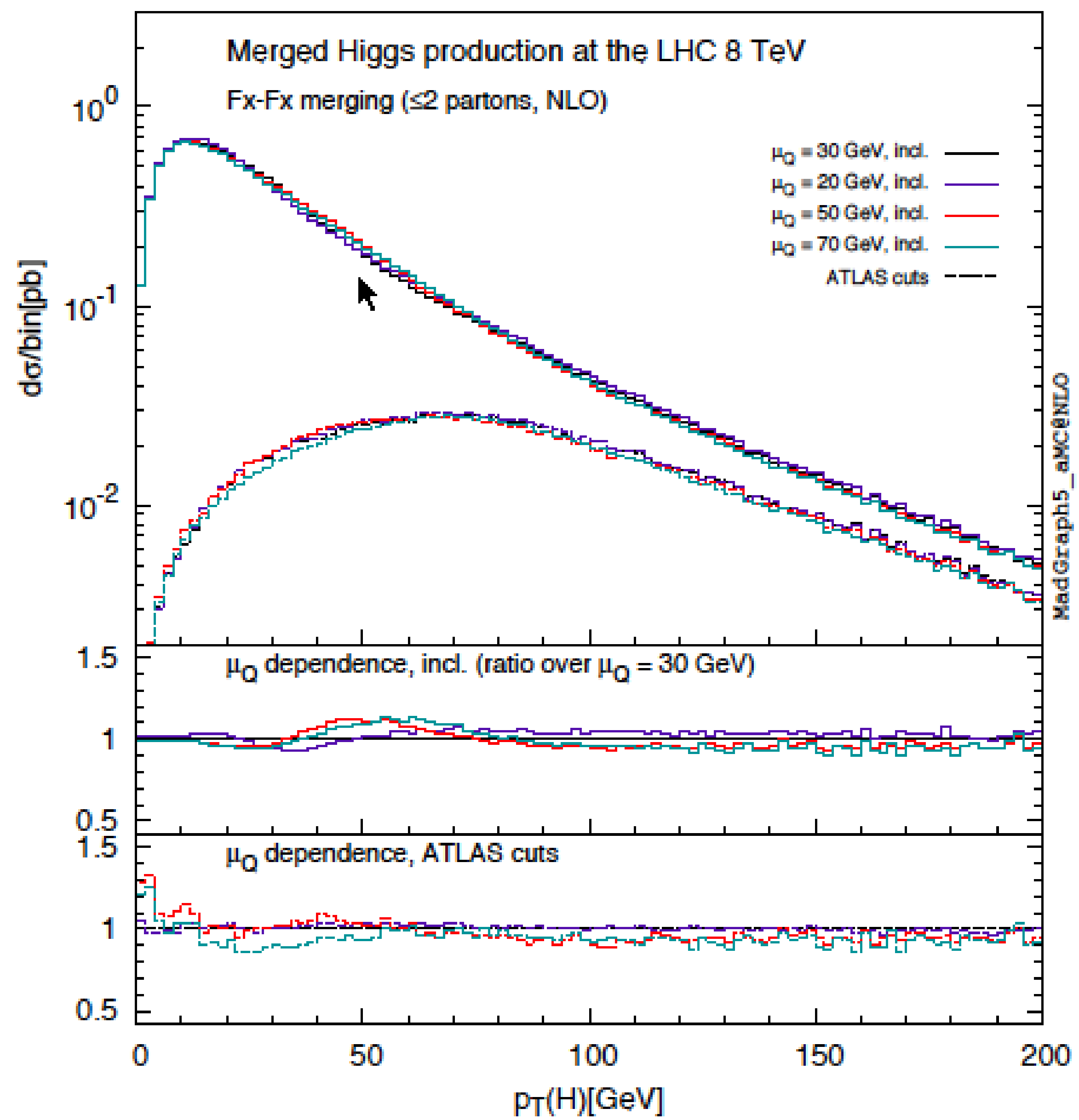
- Differential jet rates
- Matching up to 1 extra jet at NLO

- Differential jet rates
- Matching up to 1 extra jet at NLO

MULTI-JET MERGING @ NLO

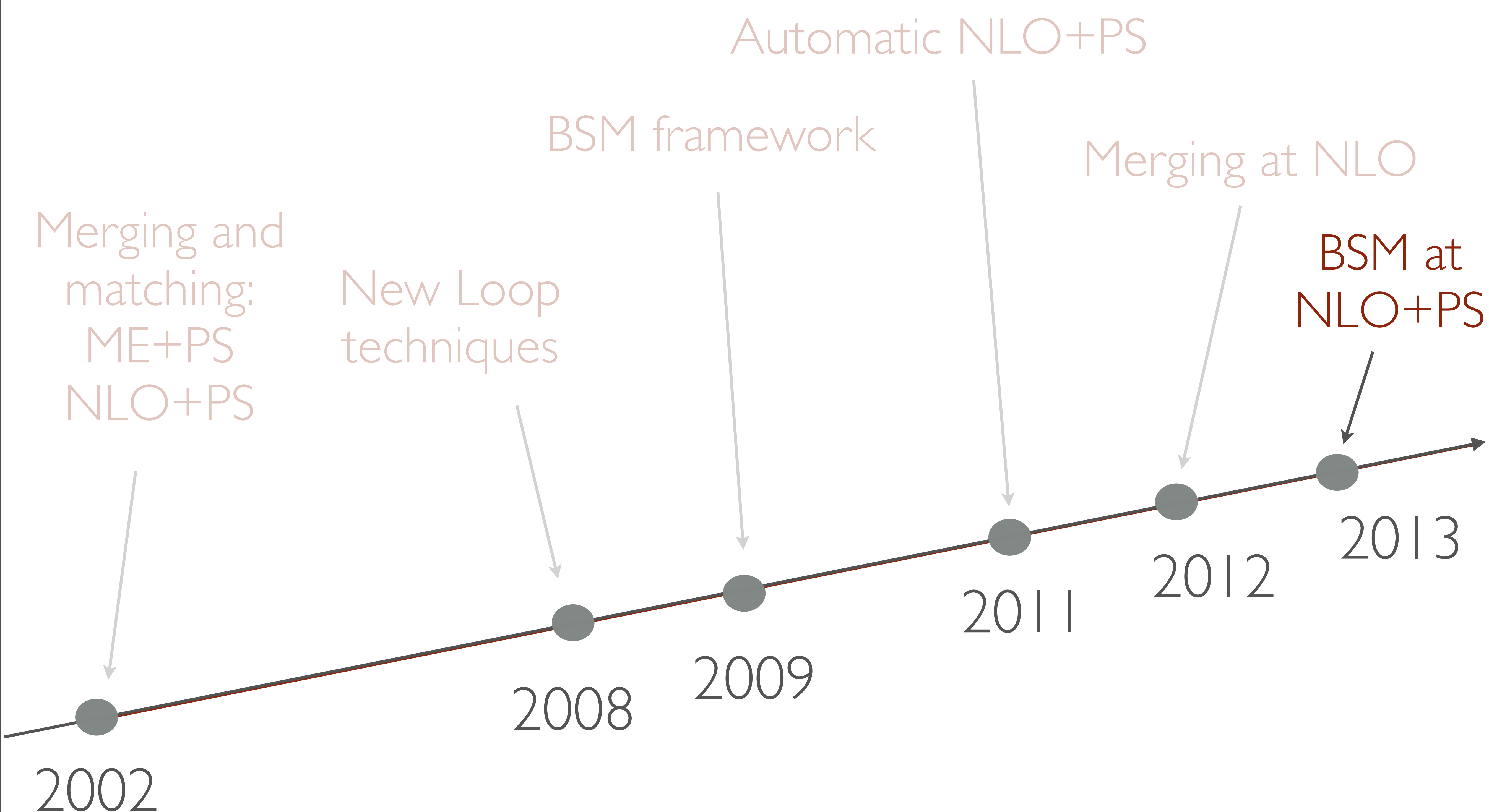
[Frederix, Frixione]



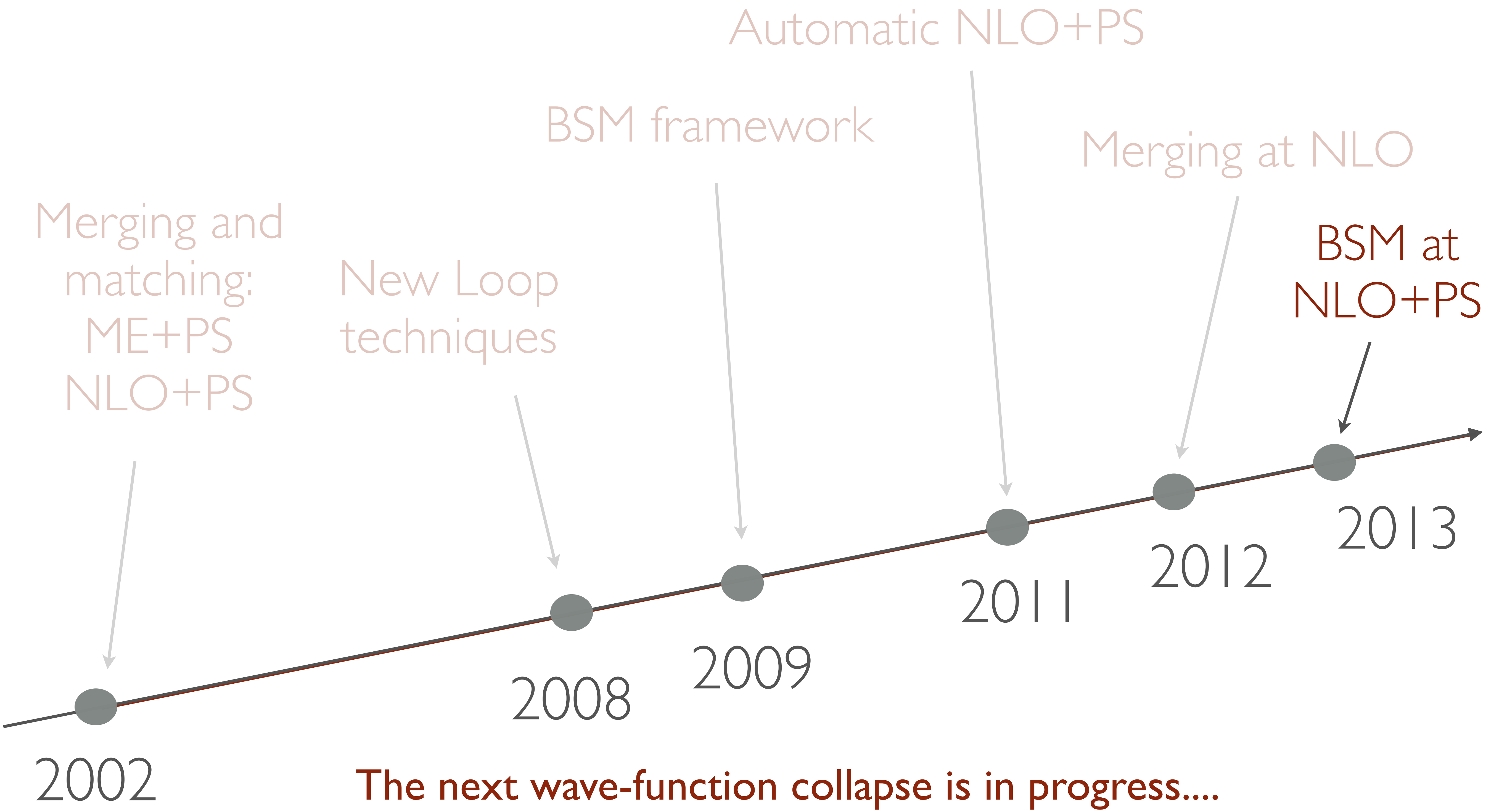


comparison LO (Alpgen) vs NLO merging (MadGraph5_aMC@NLO)

PREDICTIVE MC (SIMPLIFIED) PROGRESS

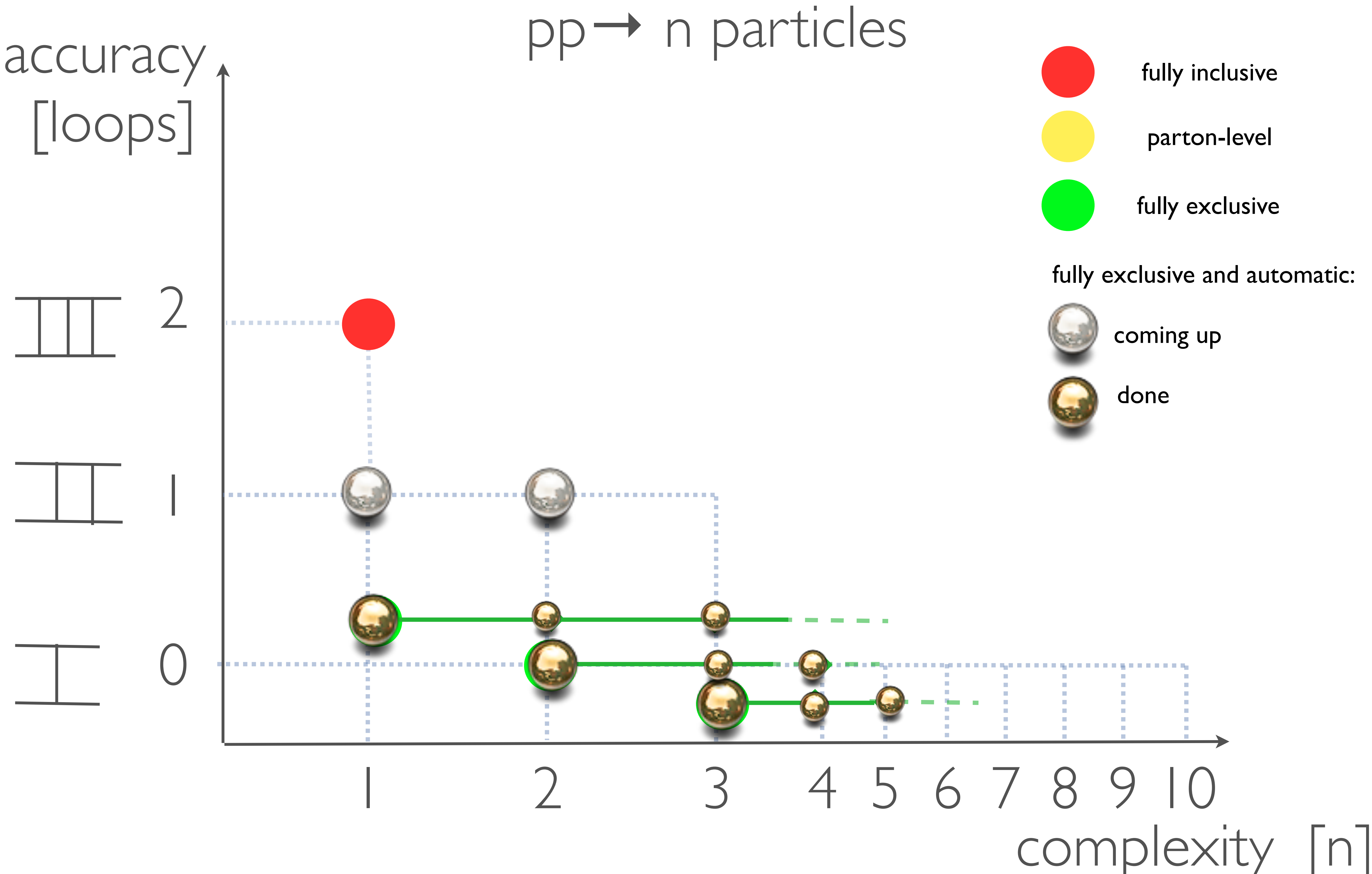


PREDICTIVE MC (SIMPLIFIED) PROGRESS



The next wave-function collapse is in progress....

BSM STATUS AND OUTLOOK



BSM Status and OUTLOOK

- Loops
  - UV (and R2) counterterms need to be calculated for each model once for all. This can now be achieved automatically by FeynRules+FeynArts+NLOCT . [Degrande 2014]
- Real corrections/matching/merging
  - Automatic resonant diagram subtraction (in progress)

2HDM available! SUSY being validated...

Top-Higgs EFT

Very few operators of dim-6 in top physics:

[Willenbrock and Zhang 2011, Aguilar-Saavedra 2011, Degrande et al. 2011]

CP-even

operator	process
$O_{\phi q}^{(3)} = i(\phi^+ \tau^I D_\mu \phi)(\bar{q}\gamma^\mu \tau^I q)$	top decay, single top
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W^I_{\mu\nu}$ (with real coefficient)	top decay, single top
$O_{qq}^{(1,3)} = (\bar{q}^i \gamma_\mu \tau^I q^j)(\bar{q}\gamma^\mu \tau^I q)$	single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi} G^A_{\mu\nu}$ (with real coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_G = f_{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$gg \to t\bar{t}$
$O_{\phi G} = \frac{1}{2}(\phi^+ \phi) G^A_{\mu\nu} G^{A\mu\nu}$	$gg \to t\bar{t}$
7 four-quark operators	$q\bar{q} \to t\bar{t}$

CP-odd

operator	process
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W^I_{\mu\nu}$ (with imaginary coefficient)	top decay, single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi} G^A_{\mu\nu}$ (with imaginary coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_{\tilde{G}} = f_{ABC} \tilde{G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$gg \to t\bar{t}$
$O_{\phi\tilde{G}} = \frac{1}{2}(\phi^+ \phi) \tilde{G}^A_{\mu\nu} G^{A\mu\nu}$	$gg \to t\bar{t}$

TOP-HIGGS : FLAVOR CONSERVING

Consider, for example, the following top-Higgs interactions:

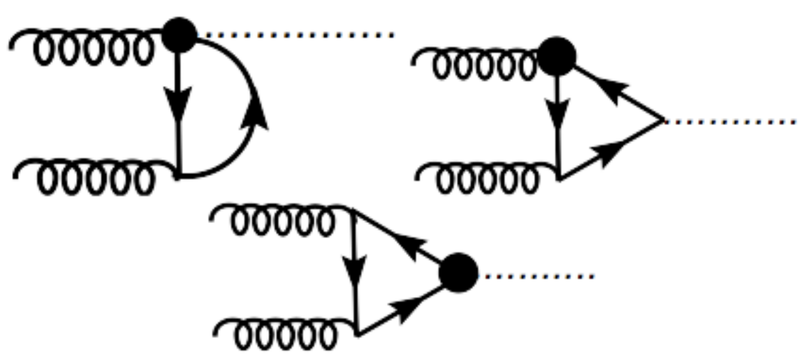
$$\mathcal{O}_{hg} = \left(\bar{Q}_L \sigma^{\mu\nu} T^a t_R\right) \tilde{\phi}\, G^a_{\mu\nu},$$

$$\mathcal{O}_{t\phi} = \left(\phi^\dagger \phi\right) \left(\bar{Q}_L t_R\right) \tilde{\phi}$$

$$\mathcal{O}_{G\phi} = \frac{1}{2}(\phi^\dagger \phi) G^a_{\mu\nu} G^{\mu\nu}_a$$

At NLO in QCD the first two operators mix: $\gamma = \frac{2\alpha_s}{\pi} \begin{pmatrix} \frac{1}{6} & 0 \\ -2 & -1 \end{pmatrix}$

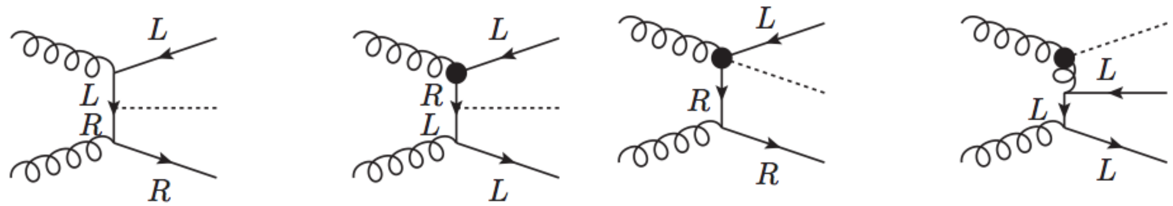
In addition, the third operator receives contributions from the first two at one loop:



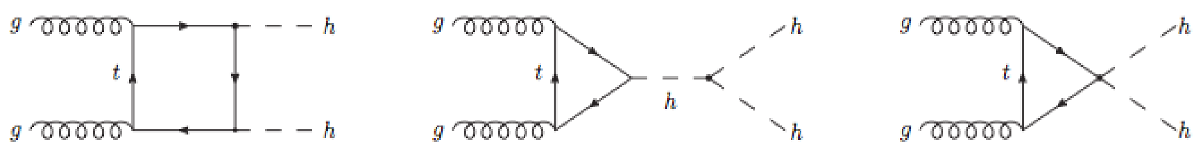
A meaningful analysis can only be made by considering them all!

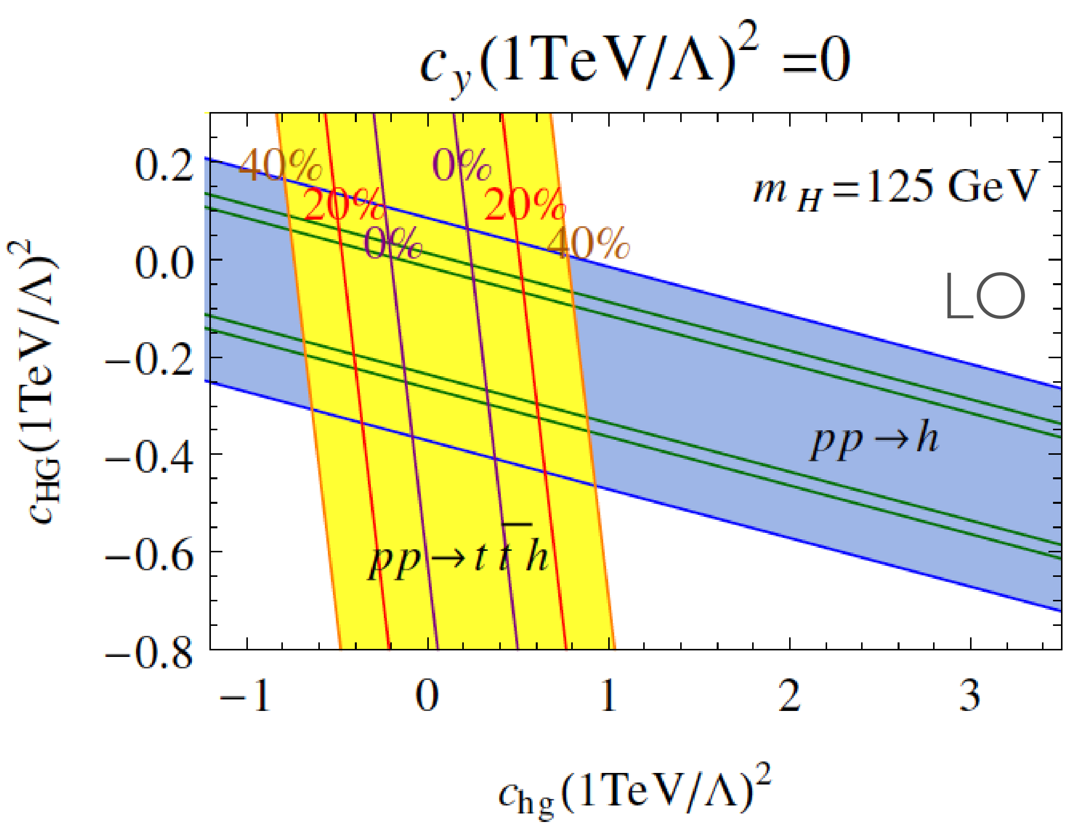
TOP-HIGGS : FLAVOR CONSERVING

$pp \to t\bar{t}h$

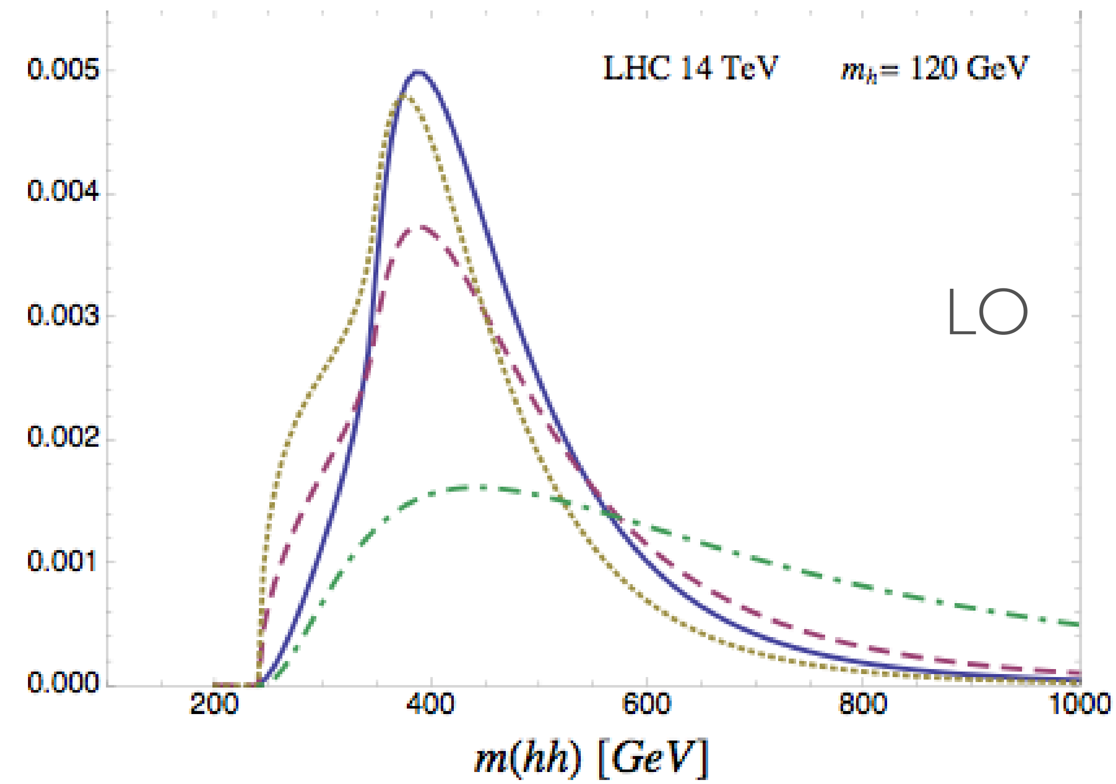


$pp \to hh$





[Degrande et al.]



[Contino et al. 2012]

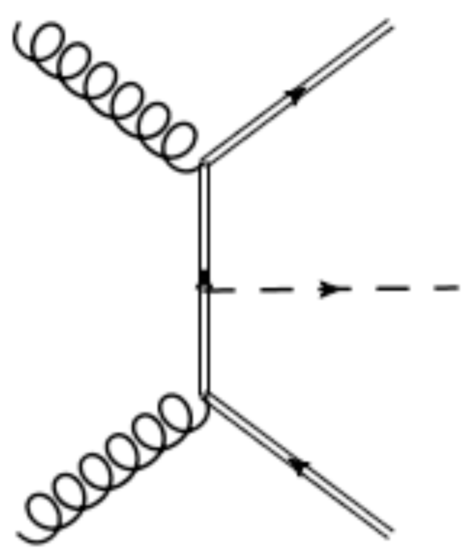
Still LO analyses ..to be upgraded to NLO

TOP-HIGGS : CP VIOLATION

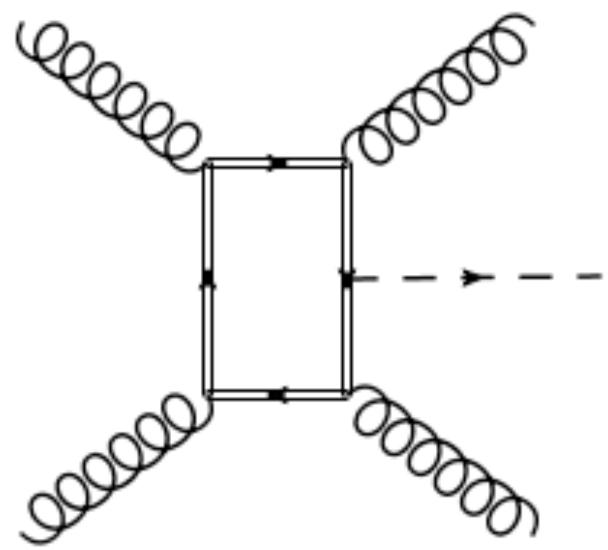
[Demartin et al., in preparation]

$$\mathcal{L}_0^t = -\bar{\psi}_t \big(c_\alpha \kappa_{Htt} g_{Htt} + i s_\alpha \kappa_{Att} g_{Att}\, \gamma_5 \big) \psi_t \, X_0$$

Two ways of directly accessing presence of CP-mixing in top-Higgs interactions at the LHC:



pp→ttH



pp→Hjj

Both possible at NLO+PS, (Hjj in the HEFT)

TOP-HIGGS : CP VIOLATION

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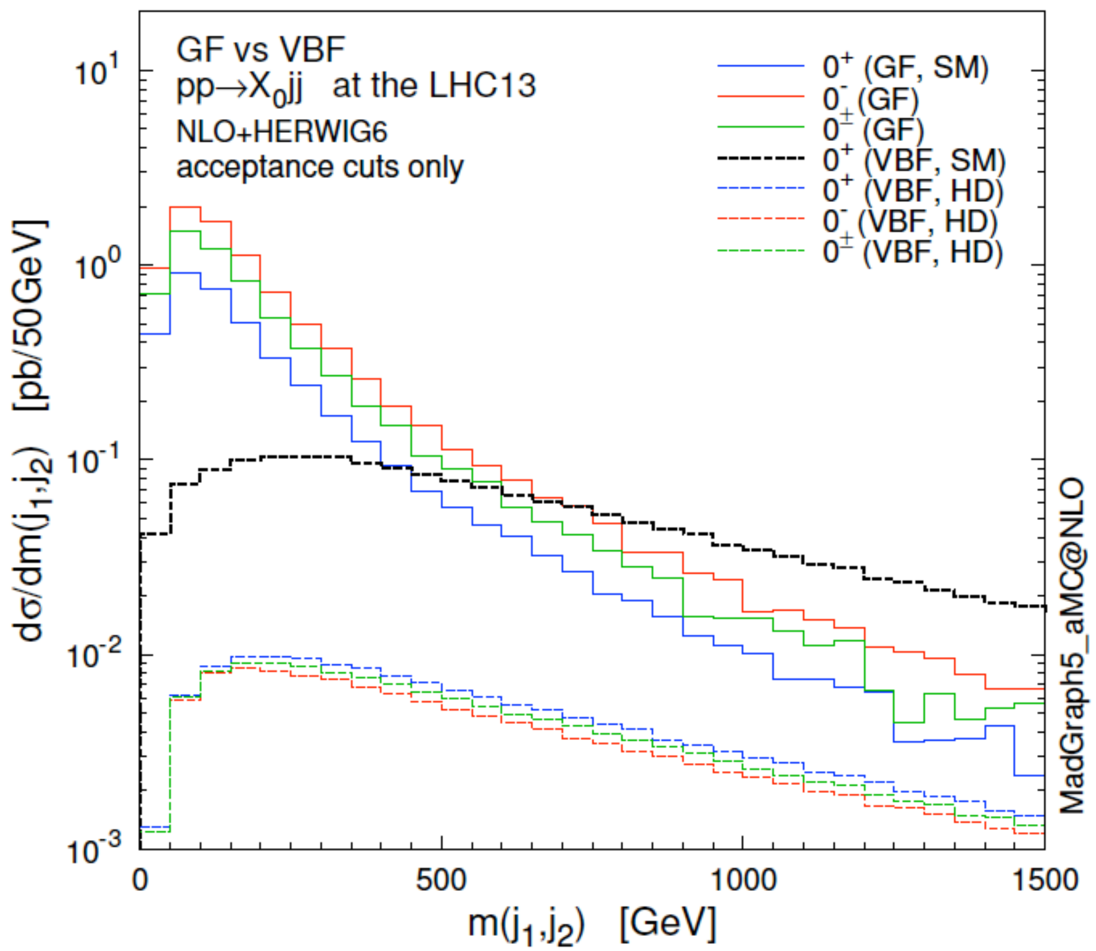
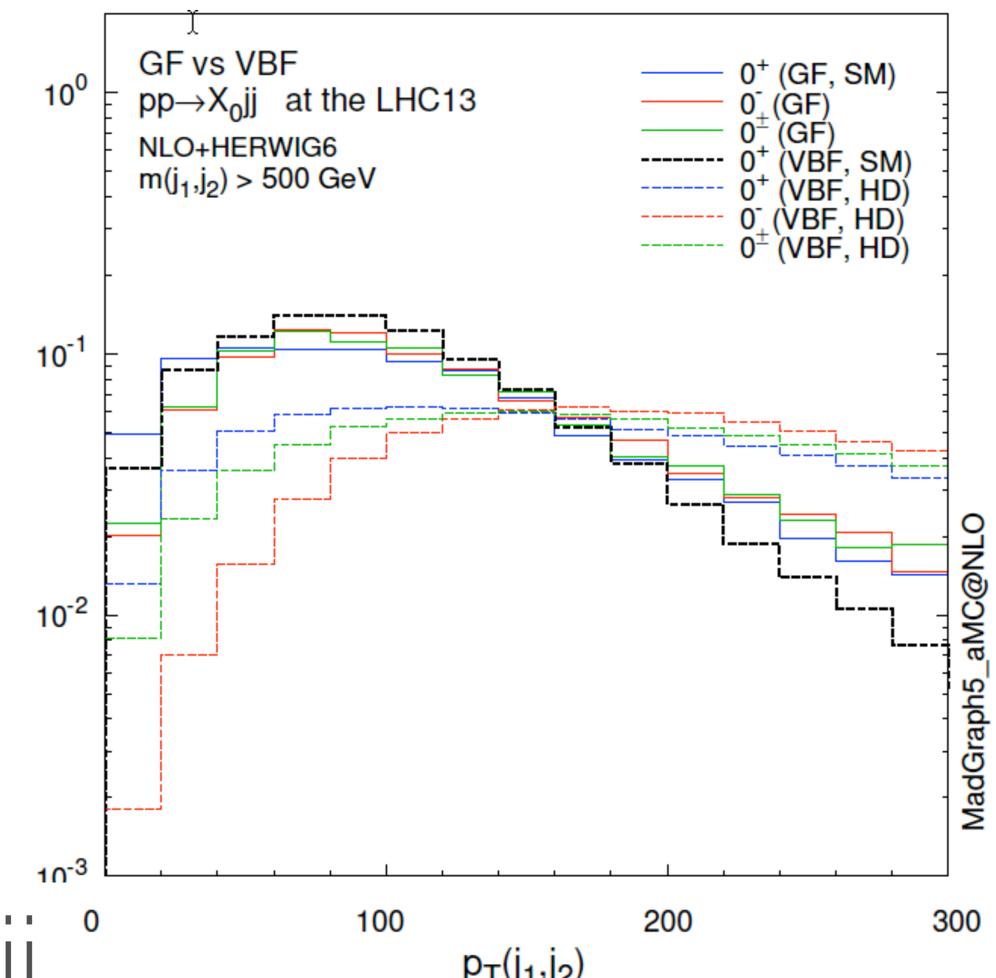
$$\mathcal{L}_0^{\rm loop} = -\frac{1}{4} \left[c_\alpha \kappa_{Hgg} g_{Hgg} \, G_{\mu\nu}^a G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg} \, G_{\mu\nu}^a \widetilde{G}^{a,\mu\nu} \right] X_0$$



pp→Hjj



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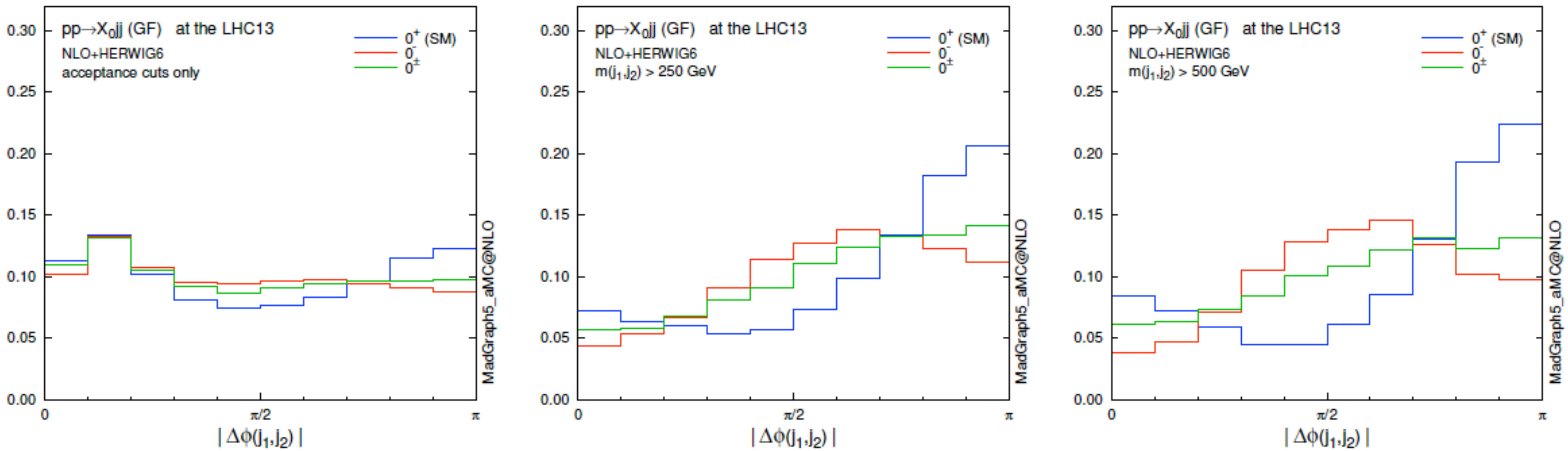
pp→Hjj



Delta(phi) among the jets is a sensitive variable as mjj increases.

TOP-HIGGS : CP VIOLATION

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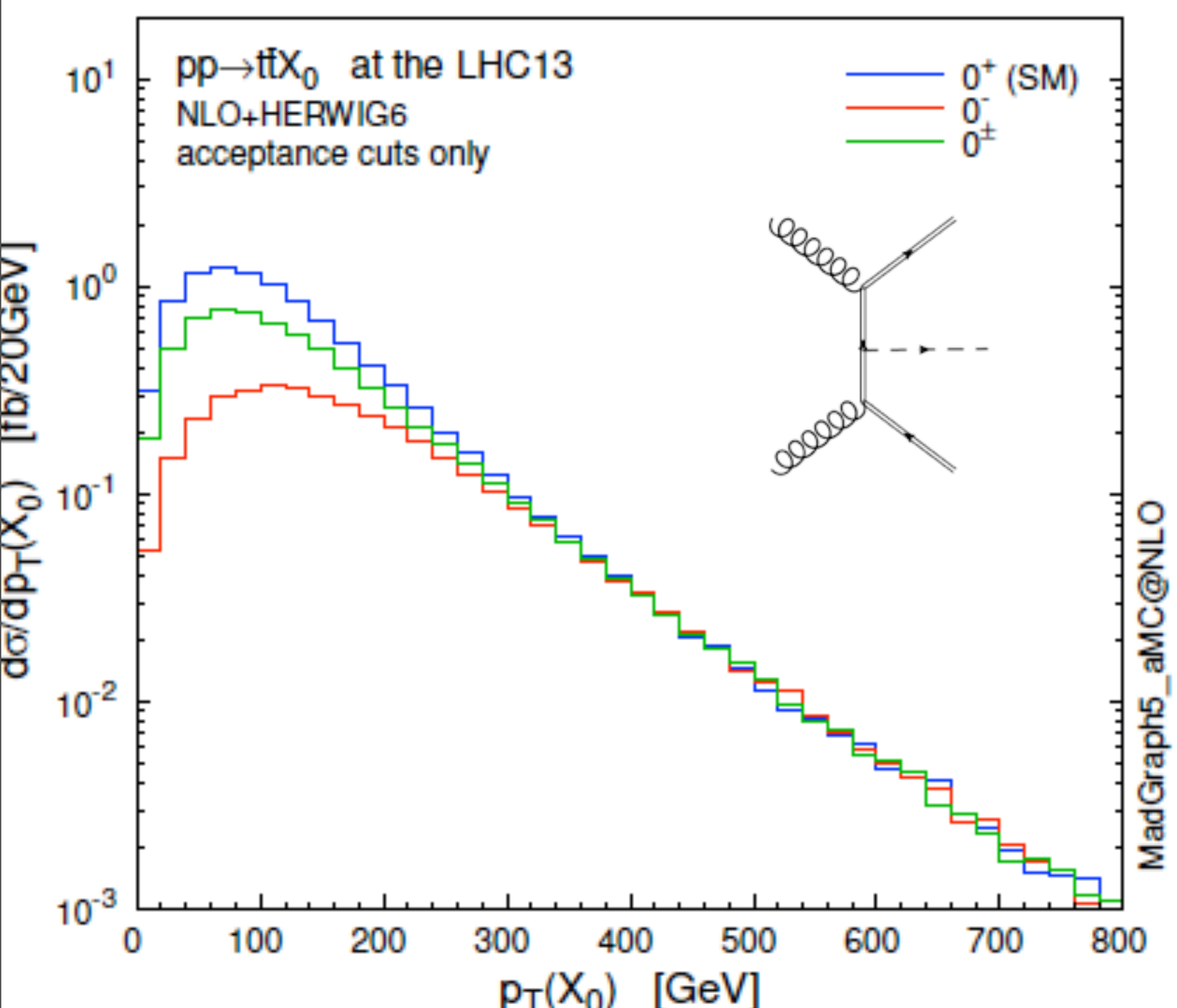
pp→ttH



At LO the two contributions add up incoherently.

At NLO in QCD CP-even and CP-odd amplitudes interfere.

At high Higgs pT shapes and normalization exactly equal (mt effects become subdominant)

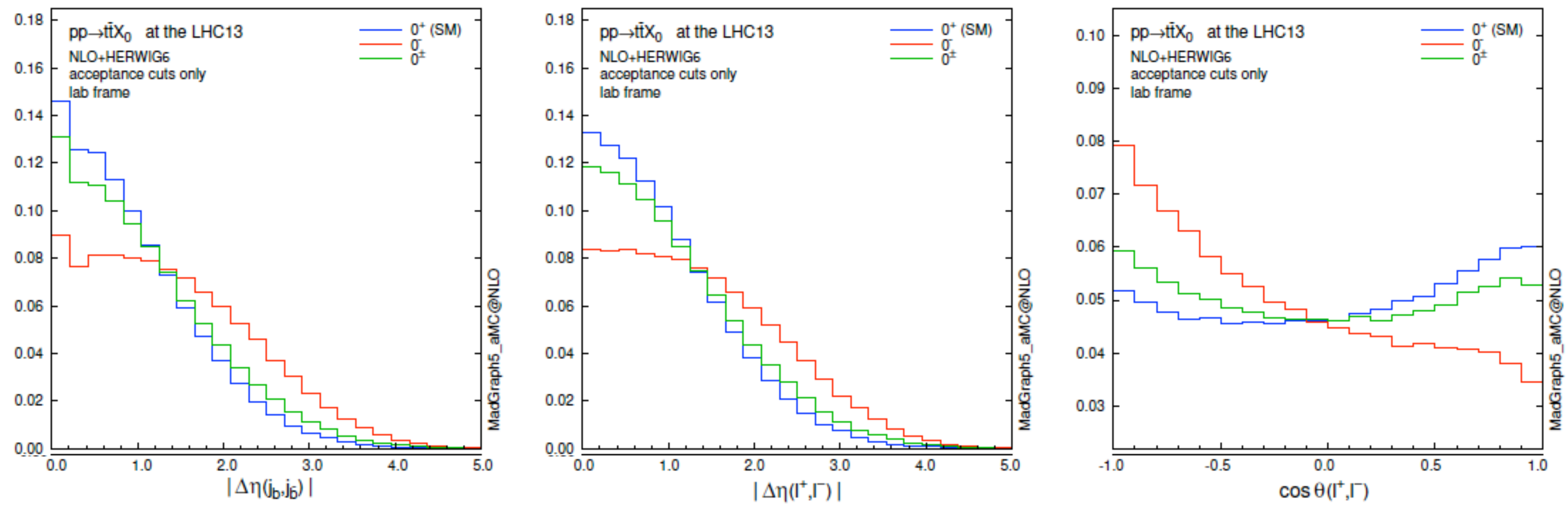
⇒ boosted analyses insensitive to CP?

TOP-HIGGS : CP VIOLATION

[Demartin et al., in preparation]

$$\mathcal{L}_0^t = -\bar{\psi}_t \left(c_\alpha \kappa_{Htt} g_{Htt} + i s_\alpha \kappa_{Att} g_{Att}\, \gamma_5 \right) \psi_t \, X_0$$

pp ➞ ttH



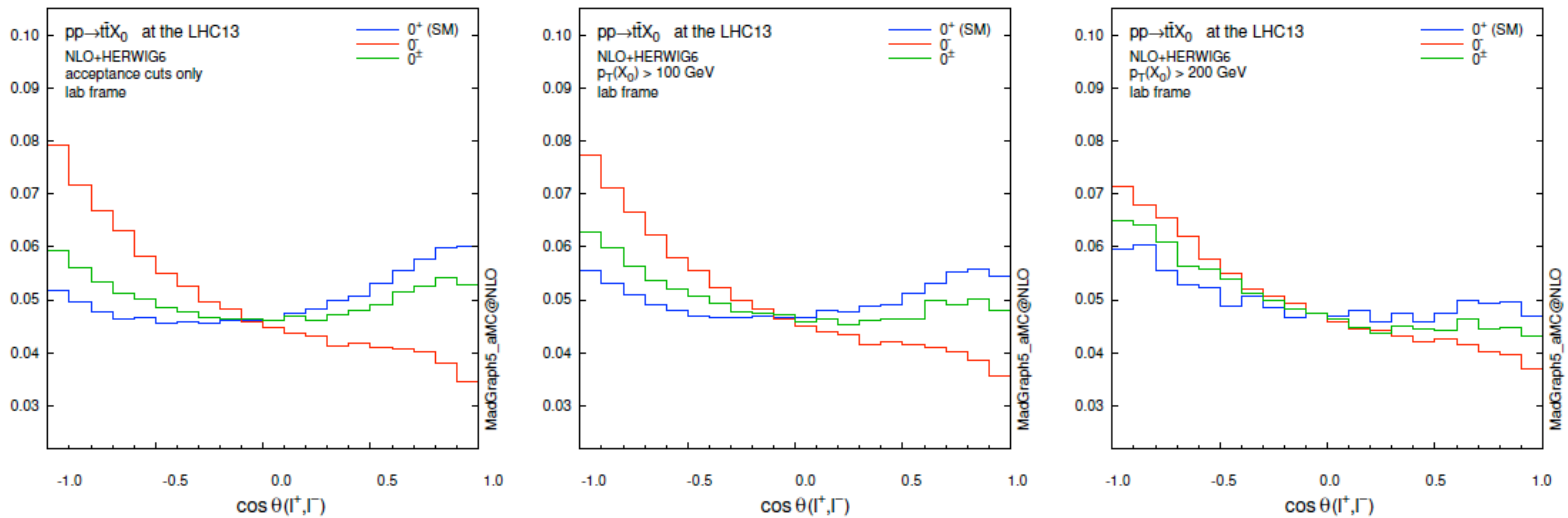
Angular variables between the daughters of the top sensitive to the CP-mixing.

TOP-HIGGS : CP VIOLATION

[Demartin et al., in preparation]

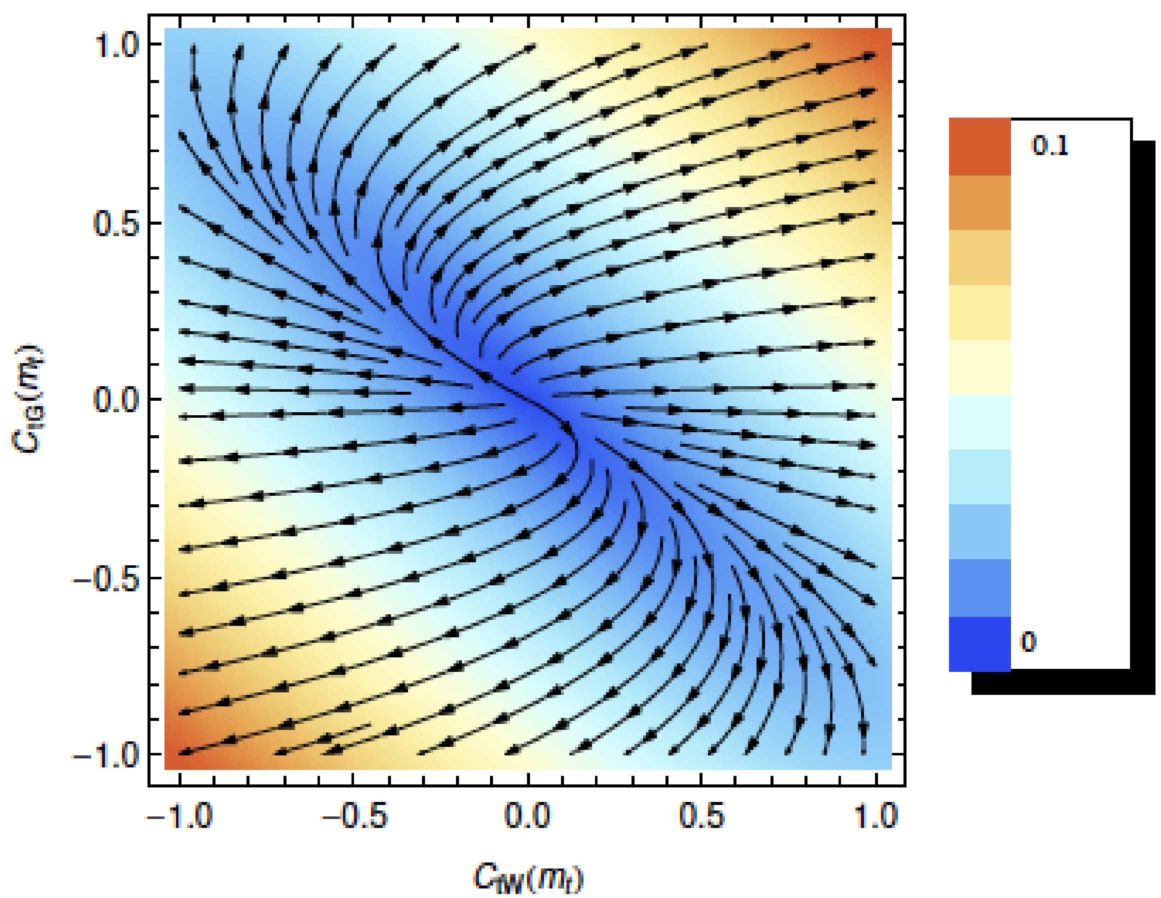
$$\mathcal{L}_0^t = -\bar{\psi}_t \big(c_\alpha \kappa_{Htt} g_{Htt} + i s_\alpha \kappa_{Att} g_{Att}\, \gamma_5 \big) \psi_t \, X_0$$

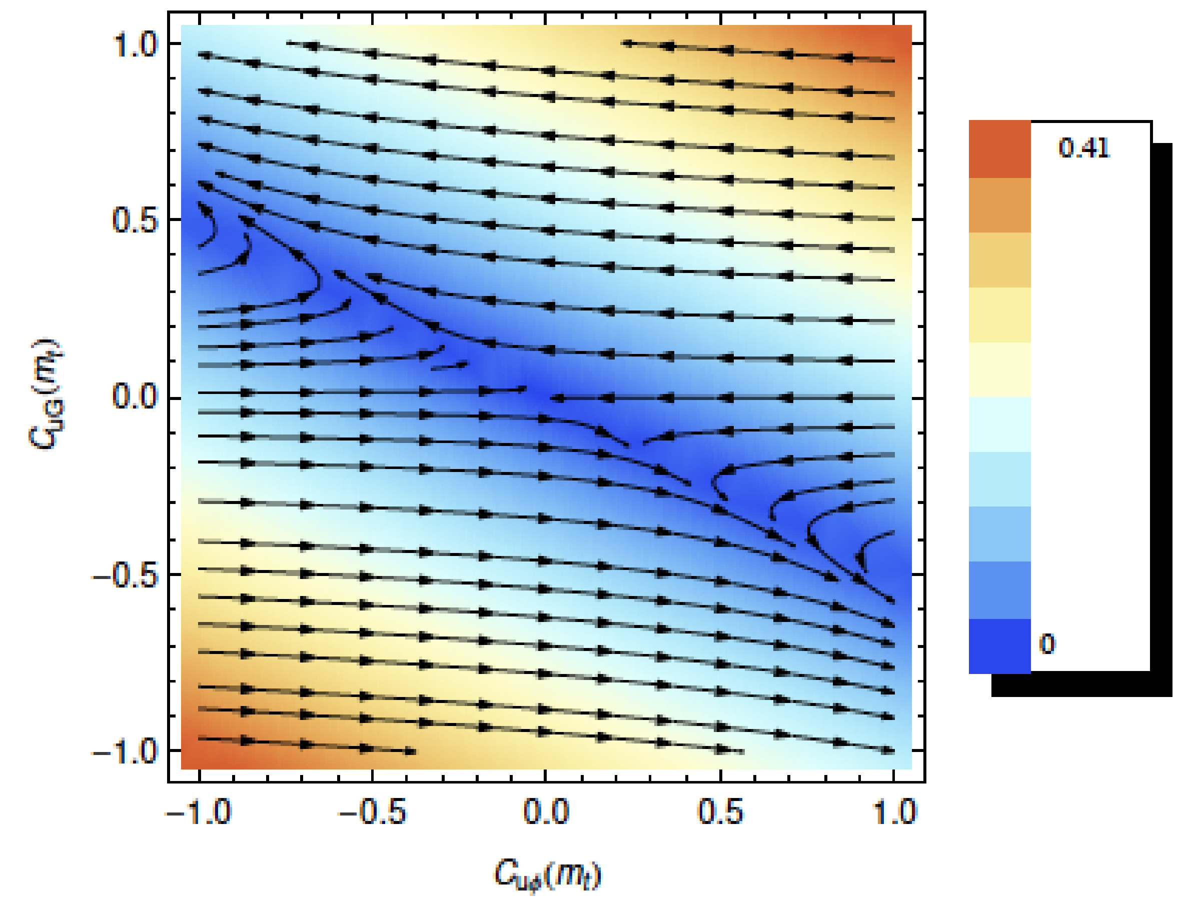
pp→ttH



CP-mixing sensitivity is maintained for the boosted case.

TOP-HIGGS : FLAVOR CHANGING





$$
\begin{aligned}
O_{tG} &= y_t g_s (\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\varphi} G^A_{\mu\nu} \\
O_{tW} &= y_t g_W (\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi} W^I_{\mu\nu} \\
O_{tB} &= y_t g_Y (\bar{Q}\sigma^{\mu\nu} t)\tilde{\varphi} B_{\mu\nu} \\
O_{t\varphi} &= -y_t^3 (\varphi^\dagger\varphi)(\bar{Q}t)\tilde{\varphi}\ .
\end{aligned}
\qquad
\gamma = \frac{2\alpha_s}{\pi}\begin{pmatrix} \frac{1}{6} & 0 & 0 & 0 \\ \frac{1}{3} & \frac{1}{3} & 0 & 0 \\ \frac{5}{9} & 0 & \frac{1}{3} & 0 \\ -4 & 0 & 0 & -1 \end{pmatrix}
$$

$$
\begin{aligned}
O^{(13)}_{uG} &= y_t g_s (\bar{q}\sigma^{\mu\nu}T^A t)\tilde{\varphi} G^A_{\mu\nu} \\
O^{(13)}_{uW} &= y_t g_W (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi} W^I_{\mu\nu} \\
O^{(13)}_{uB} &= y_t g_Y (\bar{q}\sigma^{\mu\nu} t)\tilde{\varphi} B_{\mu\nu} \\
O^{(13)}_{u\varphi} &= -y_t^3 (\varphi^\dagger\varphi)(\bar{q}t)\tilde{\varphi}\ .
\end{aligned}
\qquad
\gamma = \frac{2\alpha_s}{\pi}\begin{pmatrix} \frac{1}{6} & 0 & 0 & 0 \\ \frac{1}{3} & \frac{1}{3} & 0 & 0 \\ \frac{5}{9} & 0 & \frac{1}{3} & 0 \\ -2 & 0 & 0 & -1 \end{pmatrix}
$$

At $\mu = 1$ TeV: $C^{(13)}_{uG} = 1$, $C^{(13)}_{u\varphi} = 0$ $\Rightarrow$ At $\mu = 173$ GeV: $C^{(13)}_{uG} = 0.98$, $C^{(13)}_{u\varphi} = 0.23$

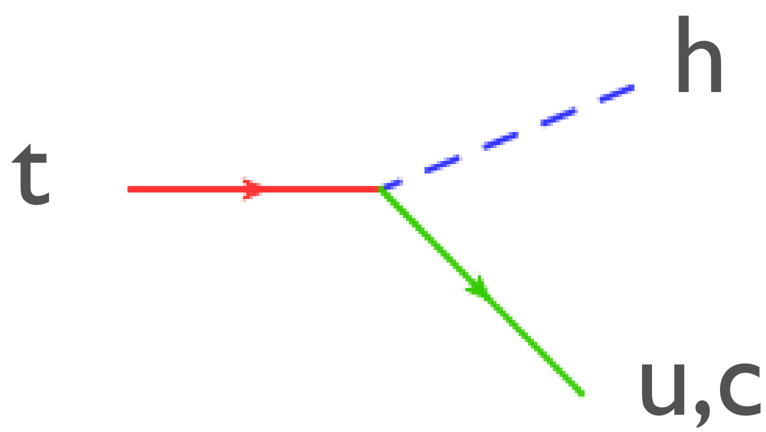
[Zhang, 2014]

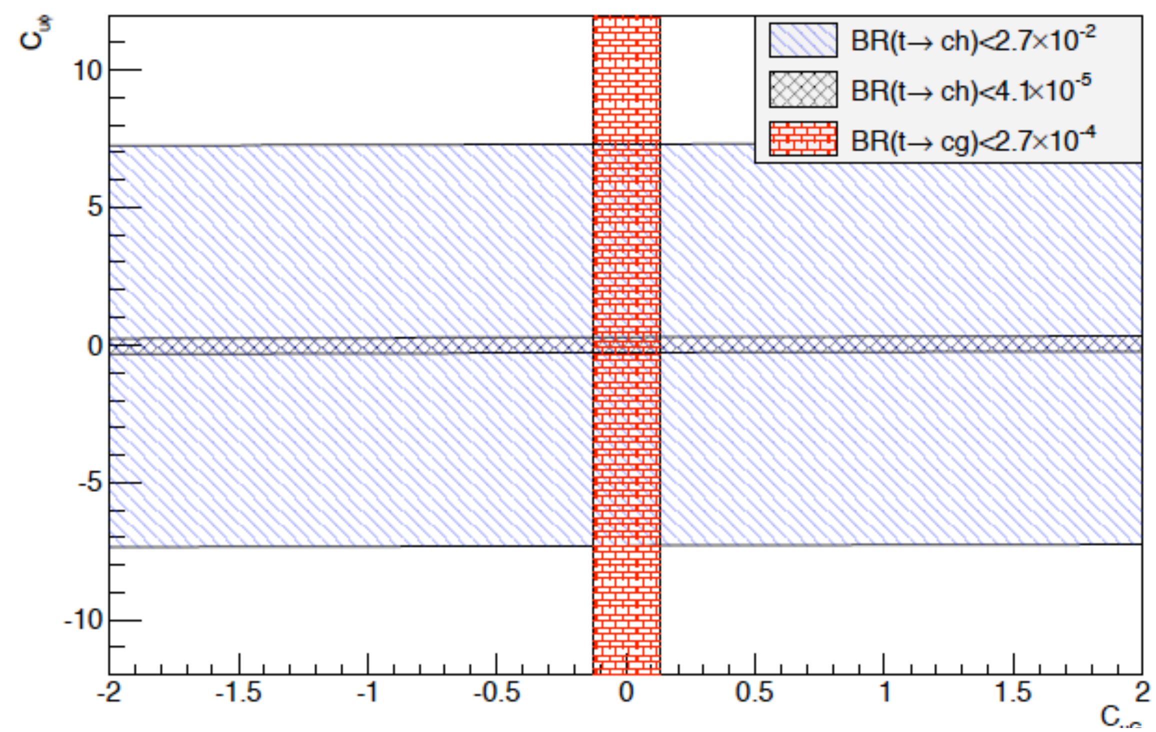
TOP-HIGGS : FLAVOR CHANGING

The study of FCNC couplings can bring new information:

[Drobnak, 2012 based on CMS and ATLAS results] [Kao et al. 2011 , Kai-Feng et al 2013] [Zhang FM, 2013]

For example:



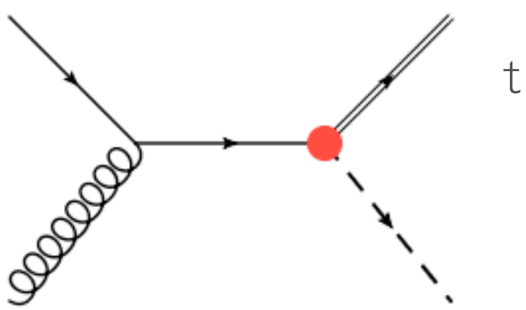


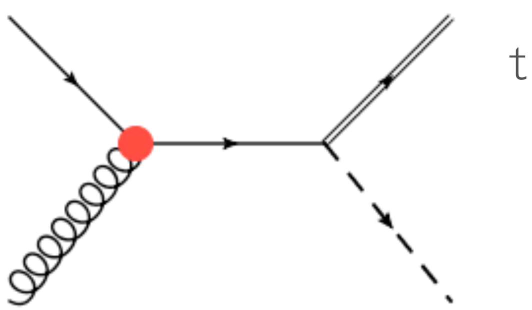
$$
\begin{aligned}
\Gamma^{(0)} =& 7.11 |C_{u\varphi}(\mu)|^2 \times 10^{-4}\,\mathrm{GeV}\,,\\
\Gamma^{(1)} =& \Bigg\{ \left[1.19 - 9.05 \log\left(\frac{m_t}{\mu}\right)\right] |C_{u\varphi}(\mu)|^2 \\
&- \left[3.26 + 18.1 \log\left(\frac{m_t}{\mu}\right)\right] \mathrm{Re} C_{uG}(\mu) C^*_{u\varphi}(\mu) \\
&+ 9.33 \times 10^{-5} |C_{uG}(\mu)|^2 \Bigg\} \times 10^{-4}\,\mathrm{GeV}\,.
\end{aligned}
$$

$$
\frac{\alpha_s \Gamma^{(1)}}{\Gamma_{(0)}} = 0.018 - 0.049 \frac{C_{uG}}{C_{u\varphi}}
$$

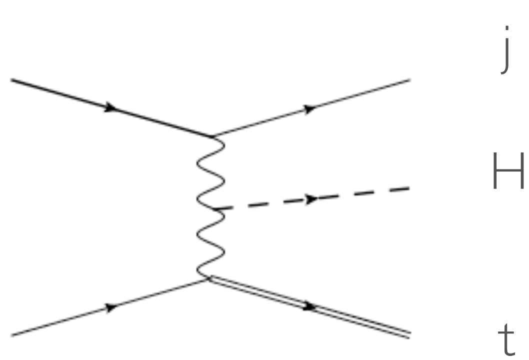
TOP-HIGGS : FLAVOR CHANGING

pp →tH





pp →tHj (SM)



Two contributions appear at LO:
one from $O_{u\varphi}$ and one from O_{uG}.

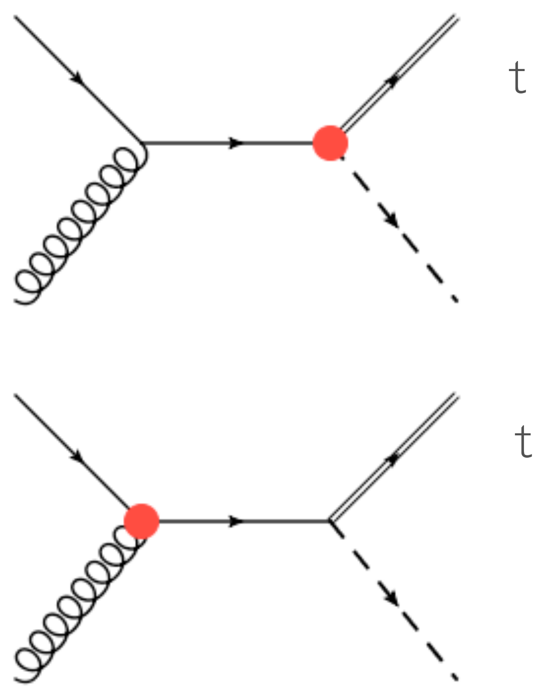
At NLO in QCD O_{uG} mixes with all the other operators so, unless it is artificially taken as zero, it has always to be included.

It also means that if a specific (arbitrary) choice of coefficient operators is made at high scales (where one can imagine a full theory to live) many operators become active when evolved to lower scales.

Only a global/fit approach on constraining such operators at the same time can be useful strategy and it has to be at least NLO in QCD.

TOP-HIGGS : FLAVOR CHANGING

pp →tH



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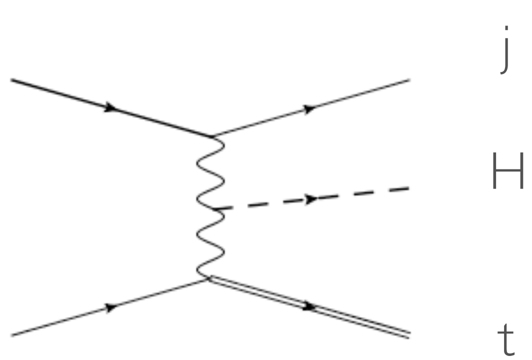

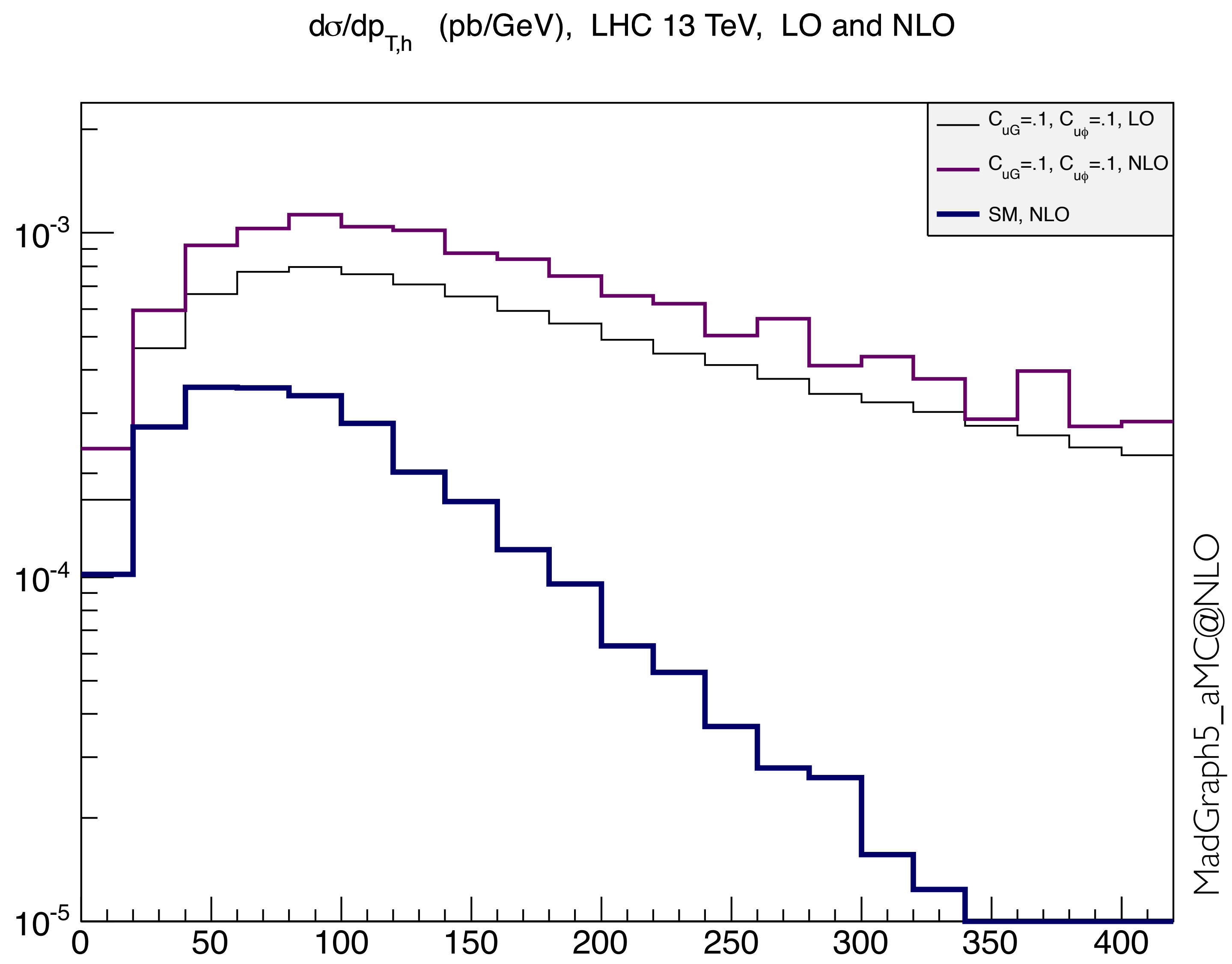

[Degrande, FM, Wang, Zhang]

CONCLUSIONS

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- Amazingly efficient, flexible and robust BSM simulation chain available and being continuously improved. Same level of sophistication as SM processes can be attained. Both top-down and bottom-up approaches included.
- **A**ugmented EXP/TH interactions in the new framework and not limited anymore by the burden of heavy/long and inefficient calculations...

Automation

Accurate

Augmented

AAA

Automation

Accurate

Augmented

AAA MONTECARLO FOR THE LHC

Free to Pheno