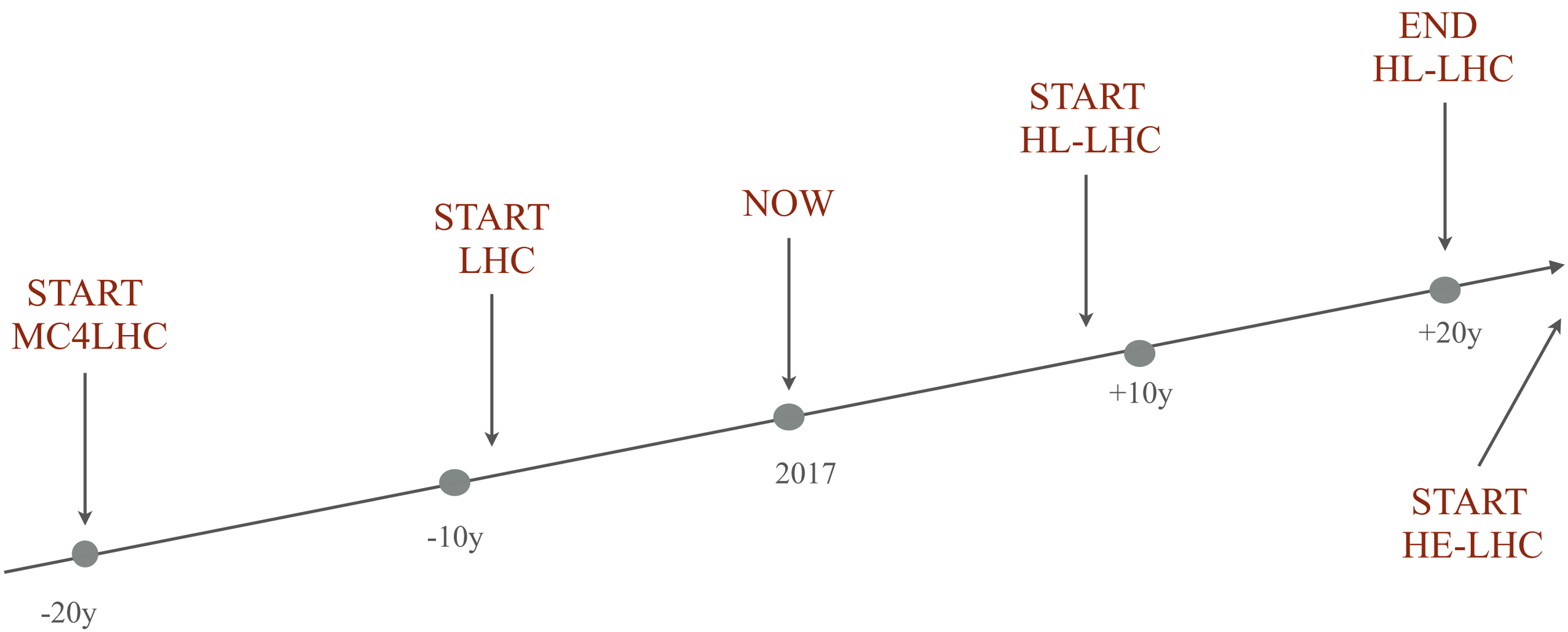
MC Challenges at high lumi/energy - LHC

Fabio Maltoni
Centre for Cosmology, Particle Physics and Phenomenology (CP3)
Université catholique de Louvain

Main question

Will our MCs be up to the challenges
of the HL-LHC in ten years from now?

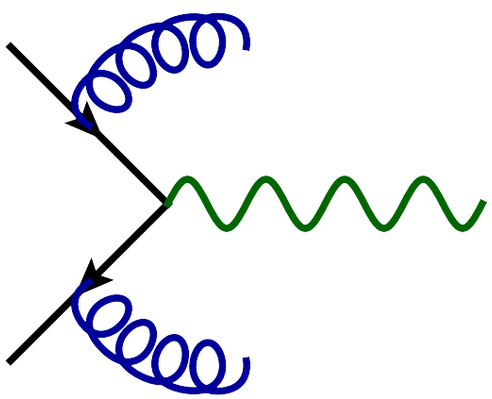
Half-way of the MC4LHC activity



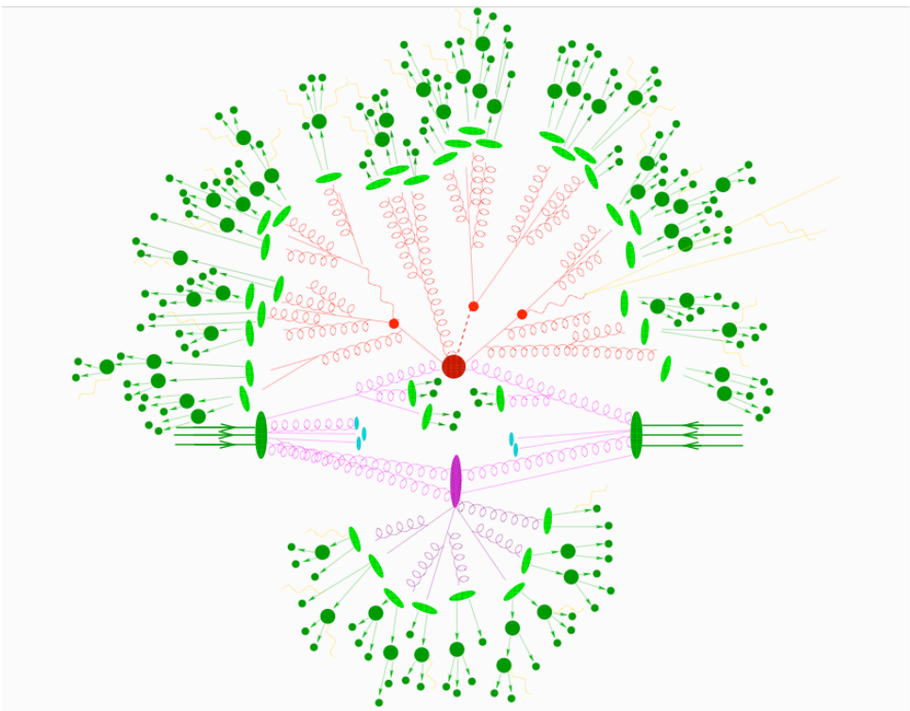
MC4LHC community got together and started to get ready 10 years in advance…
good moment to start planning and identifying the most important challenges!

Predictive Monte Carlo Generators

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

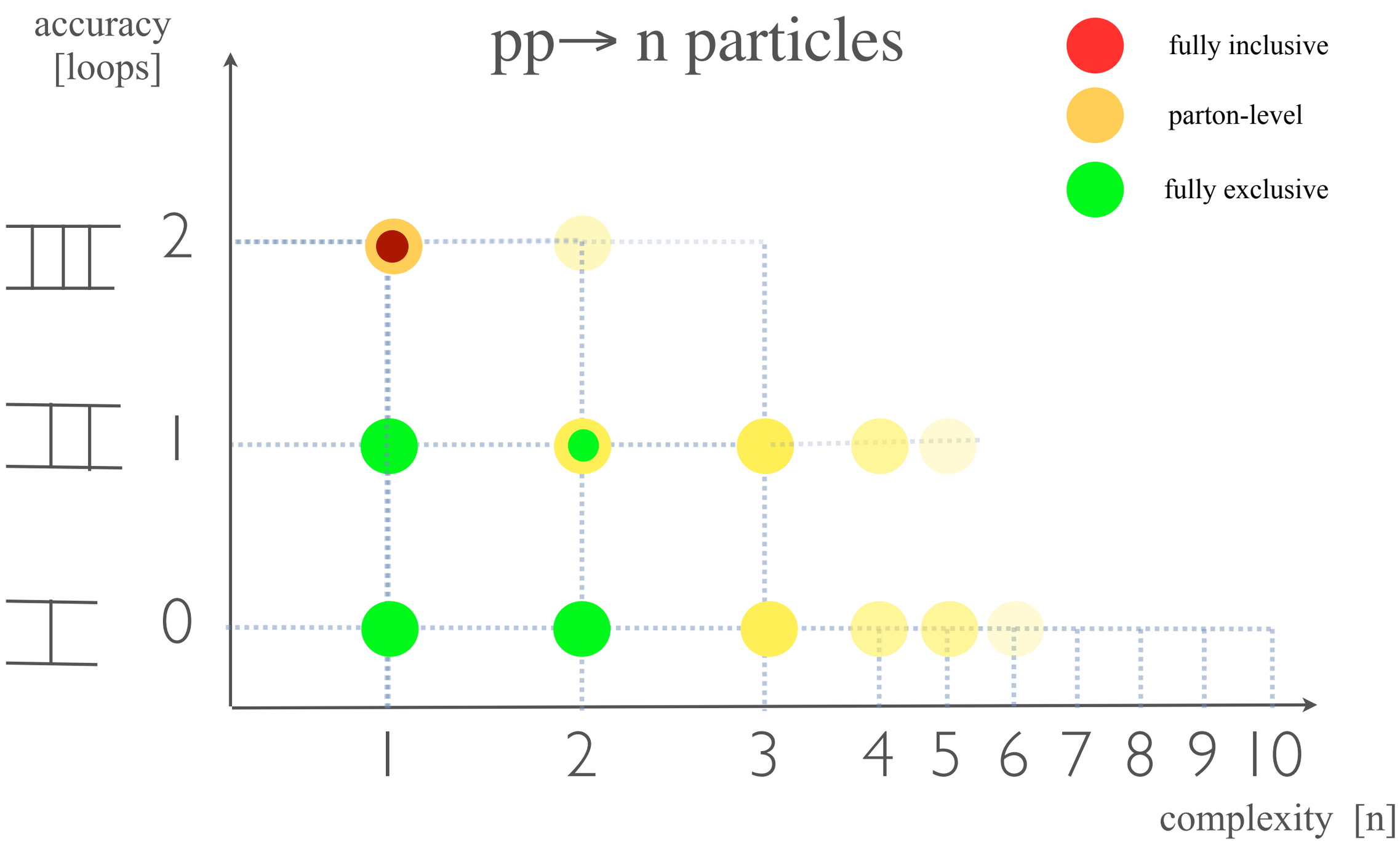


High Q^2

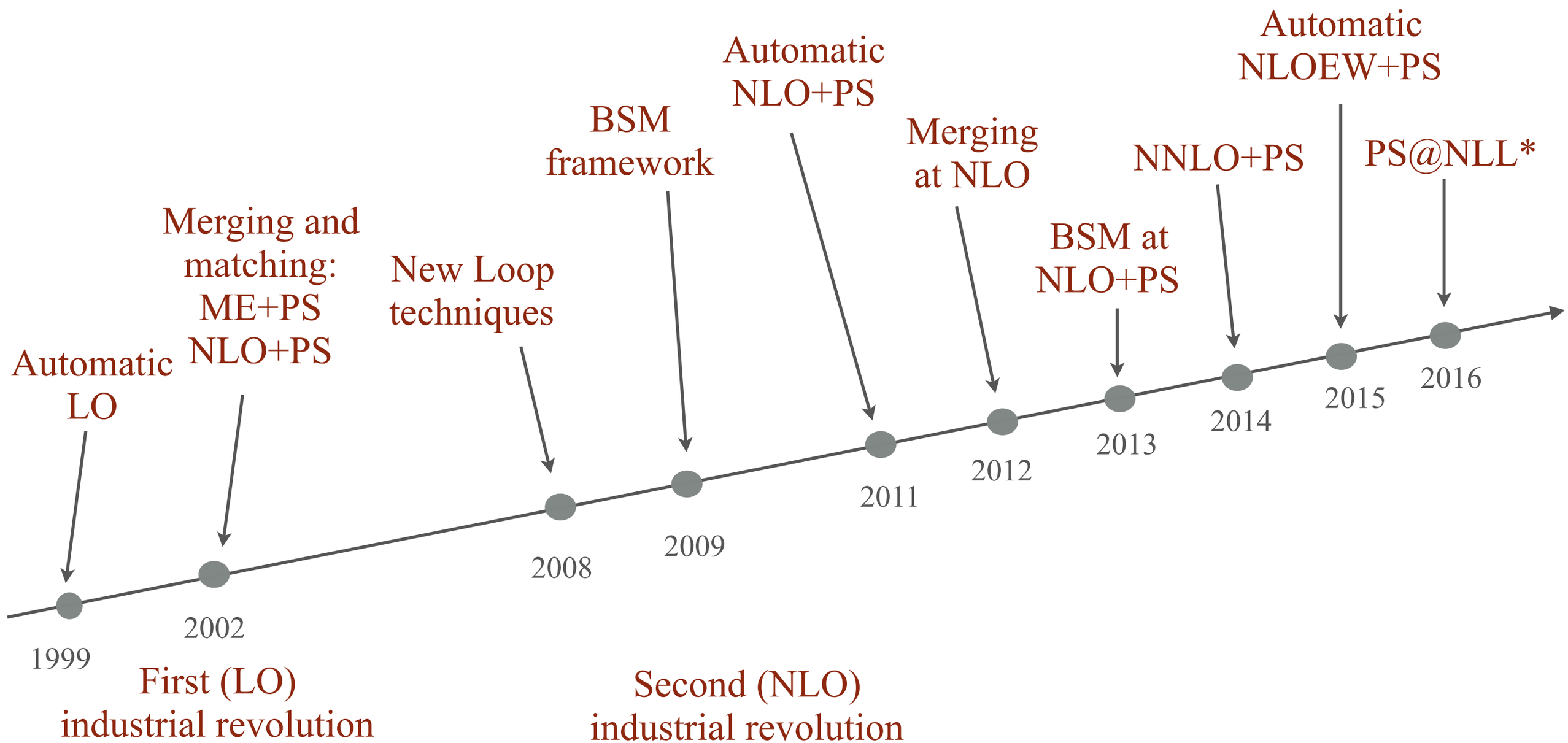


A **predictive** MC associates an history to short-distance events obtained from a parton-level (at least) next-to-leading order calculation i) avoiding double counting, ii) keeping the formal fixed-order accuracy, iii) resumming collinear and soft enhanced effects, iv) deconstructing PDF and FF probabilities and v) providing hadronisation and an UE.

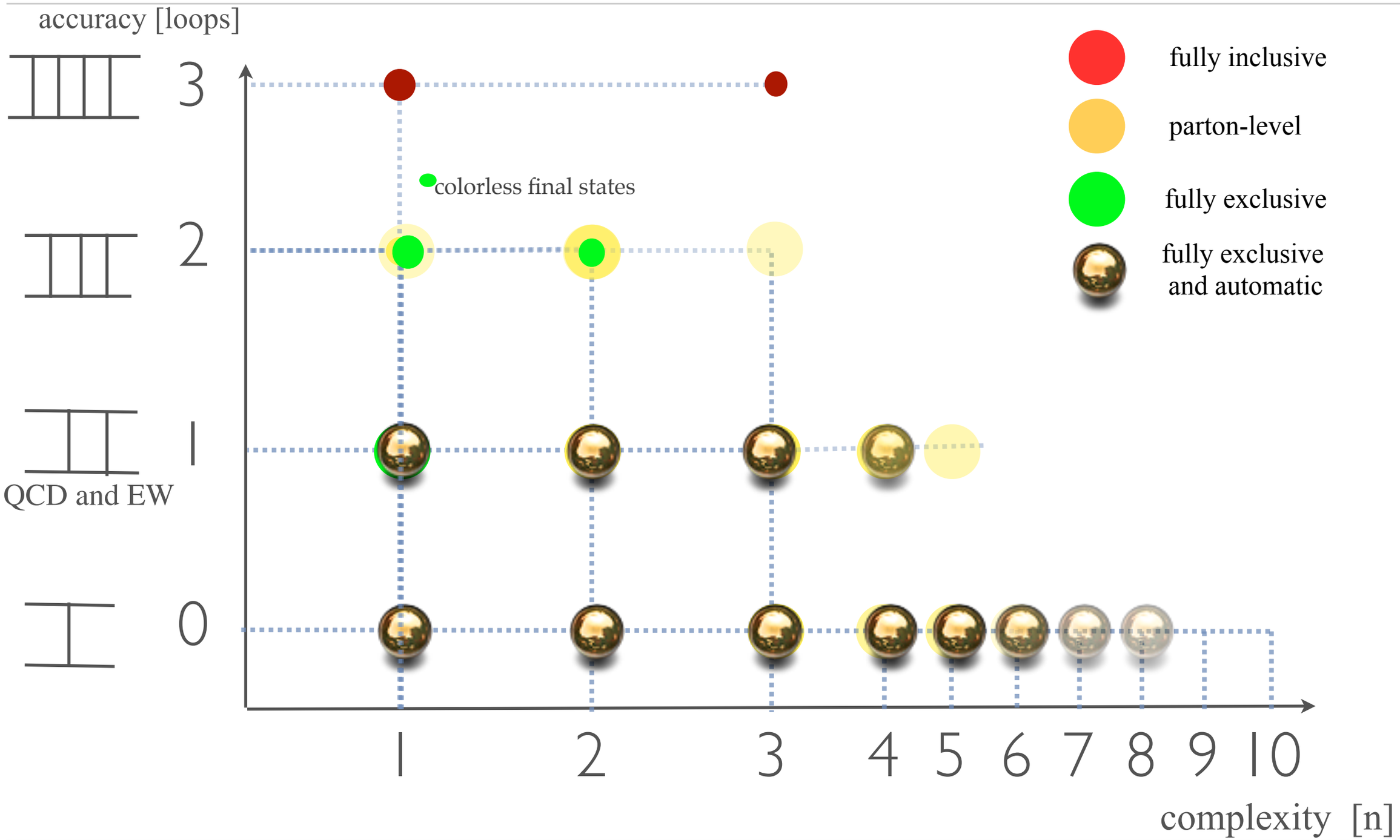
20 years ago


pp→ n particles
accuracy [loops]
2
1
0
1
2
3
4
5
6
7
8
9
10
complexity [n]
fully inclusive
parton-level
fully exclusive

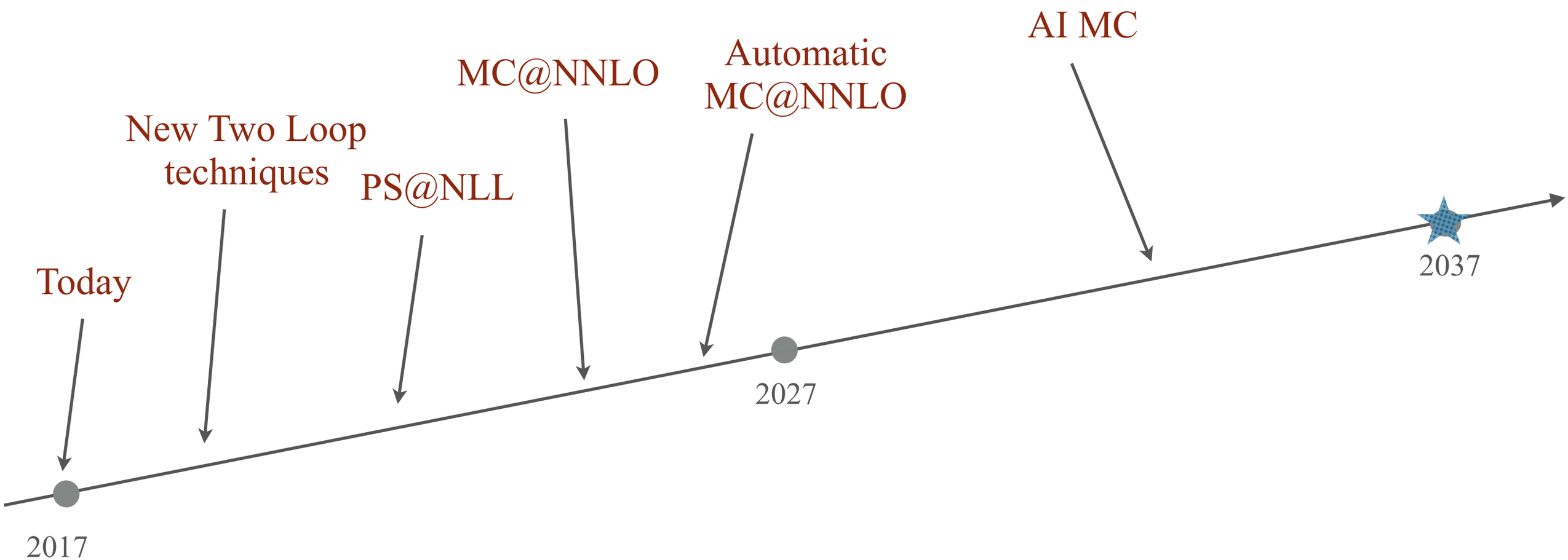
Progress in the past 20 years



Present 2017

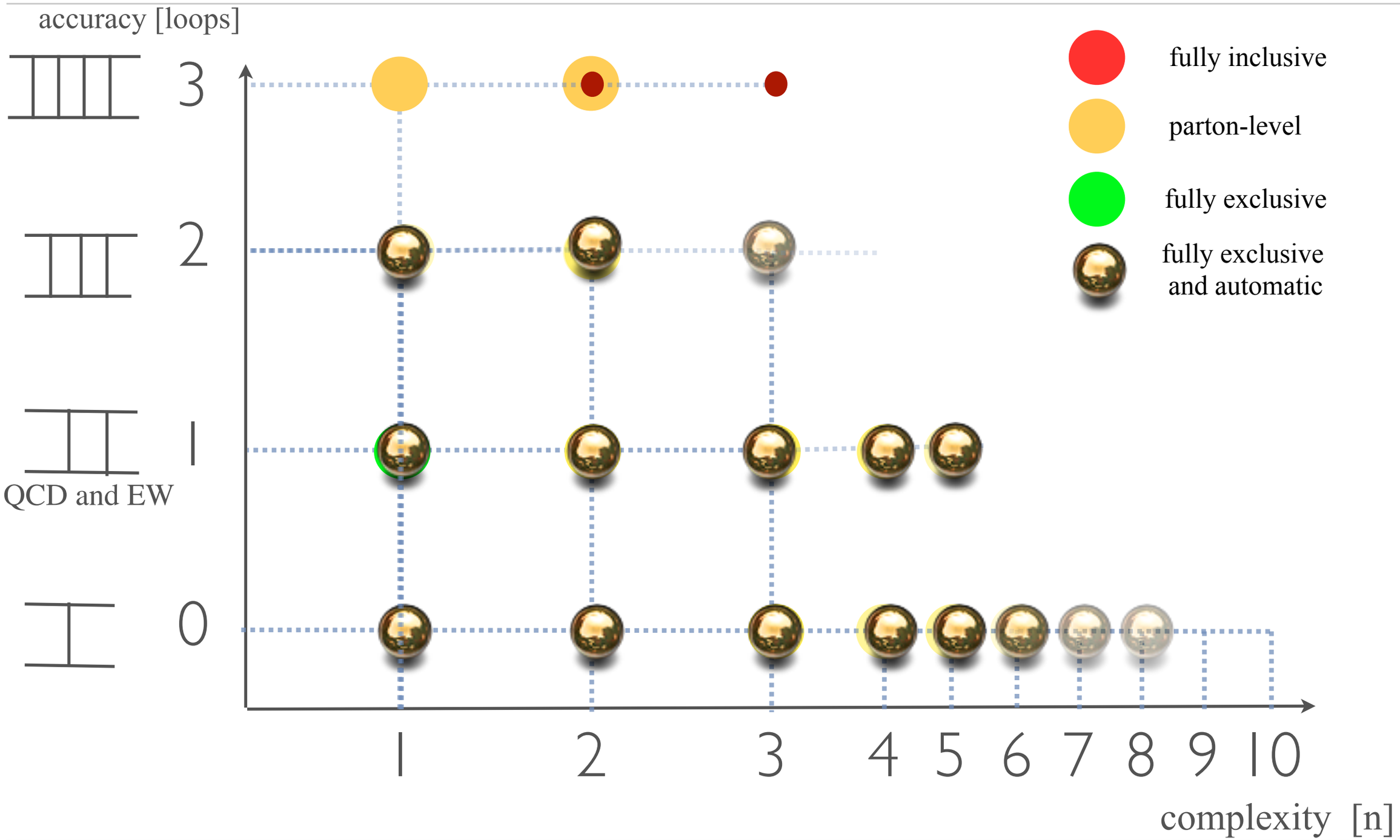


It's hard to make predictions, especially about **The Future**



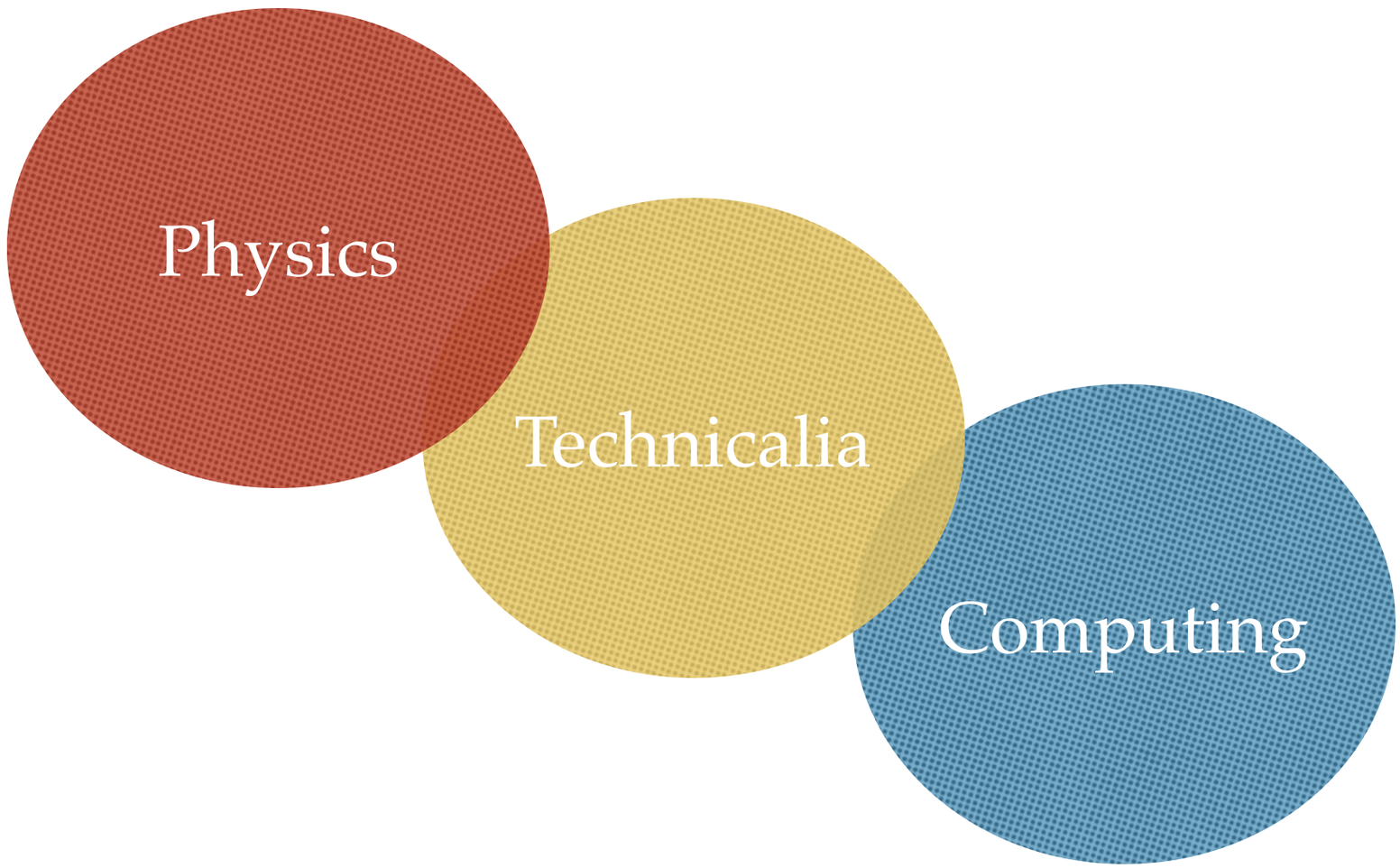
Third (NNLO)
industrial revolution

The future (2027 circa)



MC Challenges

We can organise the MC challenges in three wide classes:



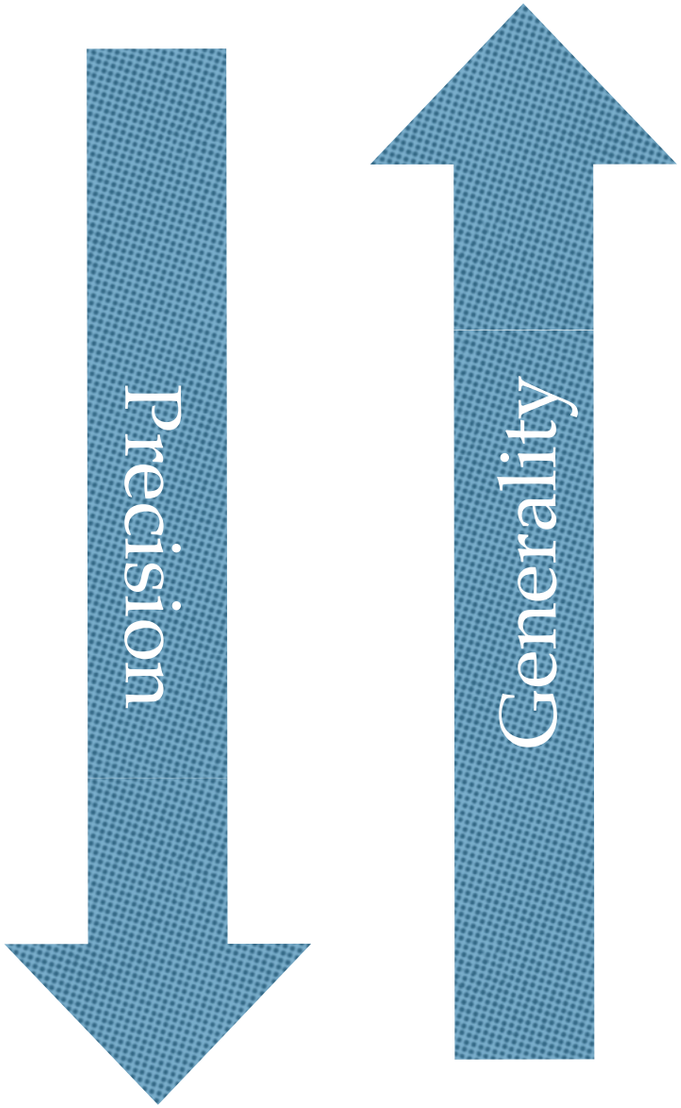
Physics Goals of the HL LHC

Physics

1. Search for new resonant states, speficic UV models or simplified ones, via non-SM final states or exotic signatures.

2. Search and quantification of deviations in the interactions among SM particles.

3. Precise determination of the fundamental parameters of the dim=4 SM Lagrangian, such as masses (m_h, m_W, m_t), and couplings.



Example #1: managing large rates

Physics

Process	inclusive	pt>X
ttbar	3G	150K (pt>1 TeV)
W	600G	200K (pt>1 TeV)
Z	200G	70K (pt>1 TeV)
H	150M	50K (pt>300 GeV)

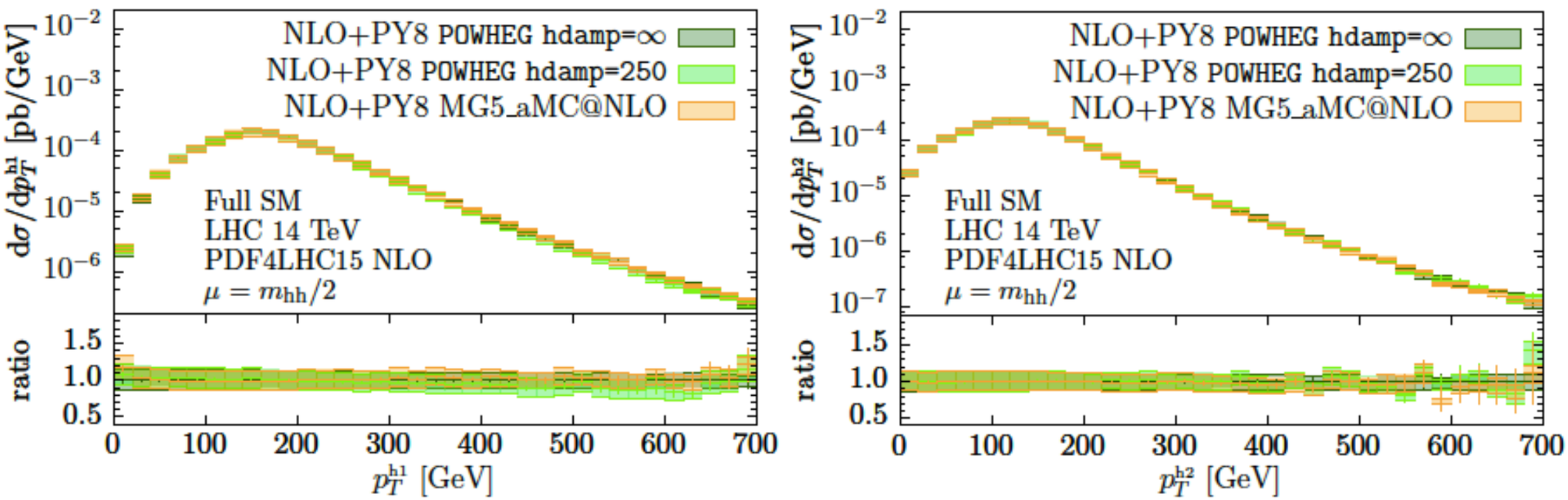
With 3 iab of luminosity expected at the end of the HL-LHC a large nuber of events for many interesting SM processes is expected in the bulk and a significant one also in the tails.

This will challenge our mass production schemes with diverging needs: accuracy and precision (expensive) vs large samples vs statistically signifcant tails.

Example #2: managing small signals

Physics

Based on the full NLO computation of [Borowka et al. 1604.06447 and 1608.04798], [Heinrich et al. 1703.09252] (including a cutting edge two-loop computation) have implemented it in POWHEG and MG5aMC. NLO is significant improvent over LO. Genuine NLO observales are rather stable. However, still uncertainties due to shower scale choices.



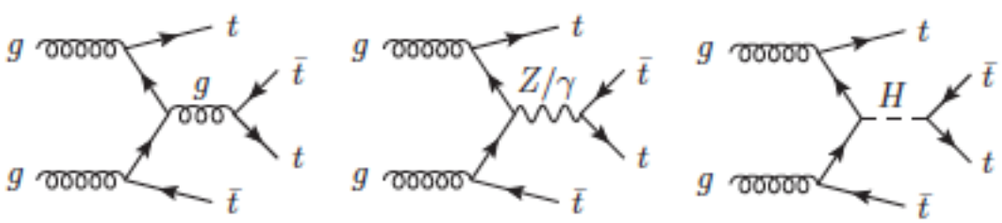
Many other gg loop induced processes contribute to important SM final states at the LHC for which we do not have **complete** NLO+PS calculations/implementations:

AA, AZ, ZZ, W+W-, HZ,..

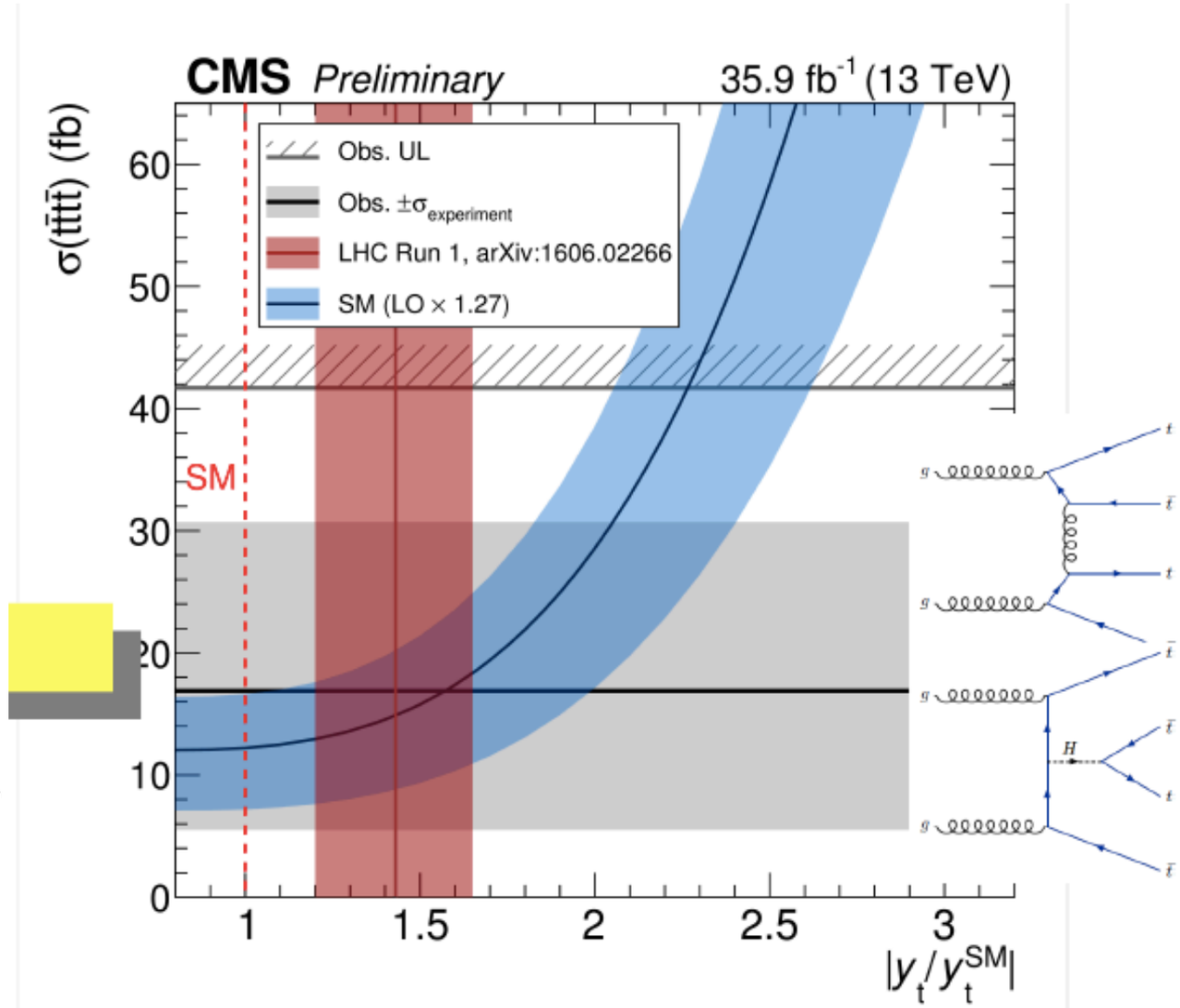
Example #3 : managing new ideas

Physics

Interesting suggestion to access the Yukawa y_t^4 coupling from tttt final state [Cao et al., 1602.01934]] already picked up by the CMS collaboration:



	8 TeV	14 TeV
$\sigma^{\rm SM}(t\bar{t}t\bar{t})_{g+Z/\gamma}$:	1.193 fb,	12.390 fb,
$\sigma^{\rm SM}(t\bar{t}t\bar{t})_{H}$:	0.166 fb,	1.477 fb,
$\sigma^{\rm SM}(t\bar{t}t\bar{t})_{\rm int}$:	−0.229 fb,	−2.060 fb.



Question is: is this result stable under radiative corrections?

Example #3 : managing new ideas

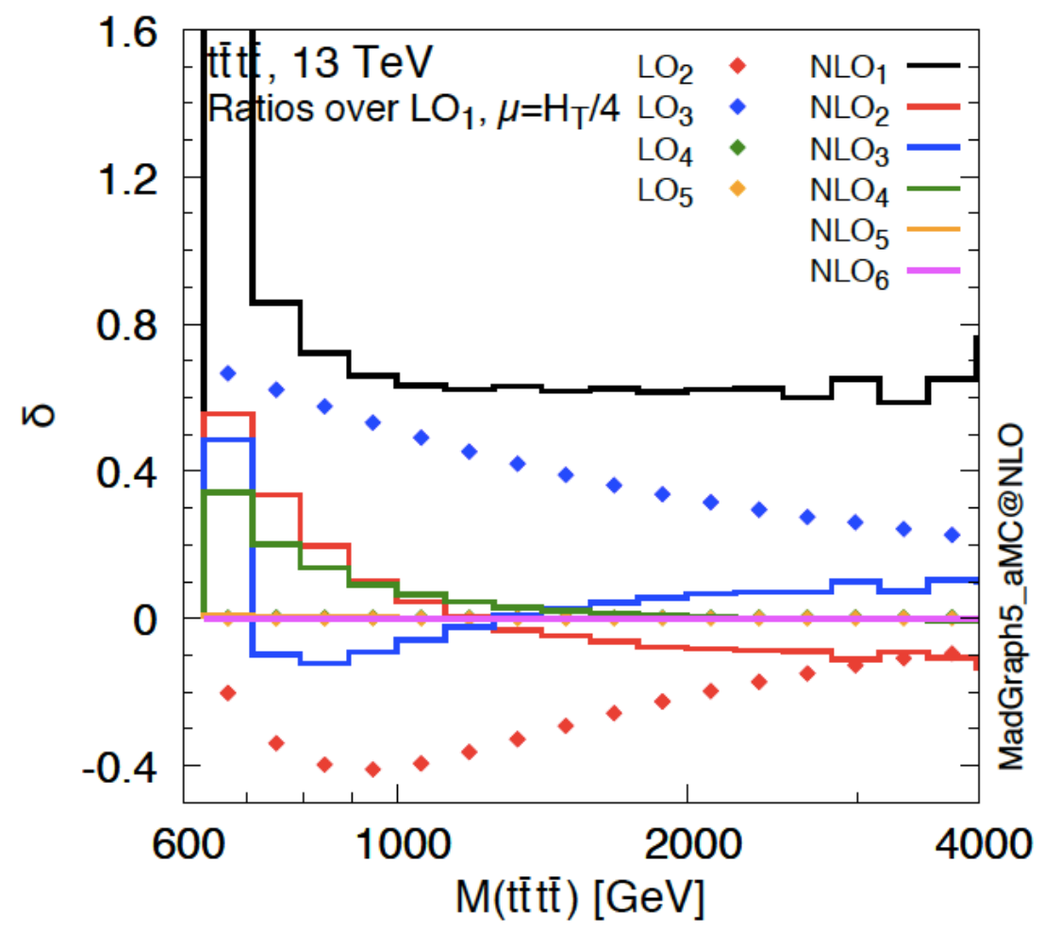
Physics

A recent calculation [Frederix, Pagani, Zaro, to appear] can help understand the issue by computing all higher-order terms and finding an unexpected pattern of cancellations.

$$\Sigma^{t\bar{t}t\bar{t}}_{\rm LO}(\alpha_s,\alpha) = \alpha_s^4\Sigma^{t\bar{t}t\bar{t}}_{4,0} + \alpha_s^3\alpha\Sigma^{t\bar{t}t\bar{t}}_{4,1} + \alpha_s^2\alpha^2\Sigma^{t\bar{t}t\bar{t}}_{4,2} + \alpha_s^3\alpha\Sigma^{t\bar{t}t\bar{t}}_{4,3} + \alpha^4\Sigma^{t\bar{t}t\bar{t}}_{4,4}$$
$$\equiv \Sigma_{\rm LO_1} + \Sigma_{\rm LO_2} + \Sigma_{\rm LO_3} + \Sigma_{\rm LO_4} + \Sigma_{\rm LO_5}\,.$$

$$\Sigma^{t\bar{t}t\bar{t}}_{\rm NLO}(\alpha_s,\alpha) = \alpha_s^5\Sigma^{t\bar{t}t\bar{t}}_{5,0} + \alpha_s^4\alpha^1\Sigma^{t\bar{t}t\bar{t}}_{5,1} + \alpha_s^3\alpha^2\Sigma^{t\bar{t}t\bar{t}}_{5,2} + \alpha_s^2\alpha^3\Sigma^{t\bar{t}t\bar{t}}_{5,3} + \alpha_s^1\alpha^4\Sigma^{t\bar{t}t\bar{t}}_{5,4} + \alpha^5\Sigma^{t\bar{t}t\bar{t}}_{5,5}$$
$$\equiv \Sigma_{\rm NLO_1} + \Sigma_{\rm NLO_2} + \Sigma_{\rm NLO_3} + \Sigma_{\rm NLO_4} + \Sigma_{\rm NLO_5} + \Sigma_{\rm NLO_6}\,.$$

$\delta[\%]$	$\mu = H_T/8$	$\mu = H_T/4$	$\mu = H_T/2$
$\rm LO_2$	-26.0	-28.3	-30.5
$\rm LO_3$	32.6	39.0	45.9
$\rm LO_4$	0.2	0.3	0.4
$\rm LO_5$	0.02	0.03	0.05
$\rm NLO_1$	14.0	62.7	103.5
$\rm NLO_2$	8.6	-3.3	-15.1
$\rm NLO_3$	-10.3	1.8	16.1
$\rm NLO_4$	2.3	2.8	3.6
$\rm NLO_5$	0.12	0.16	0.19
$\rm NLO_6$	< 0.01	< 0.01	< 0.01
$\rm NLO_2 + NLO_3$	-1.7	-1.6	0.9



MC Challenges : Physics

Physics

- (N)NLO+ fixed order precision & accuracy for QCD (tree-level and loop-induced)
- **NLO+PS for EW** and (two-loop) mixed QCD-EW corrections
- **Accuracy and precision of the PS resummation (NLL and more)**
- Modeling/measurements of non-perturbative effects (PDFs, fragmentation, UE)
- Bulk vs High-pT/boosted topologies
- Exclusive multi-jet final states at NLO
- **New Physics modeling : new particles and interactions**
- **Dedicated developments for specific high precision measurements of in the SM (m_W,m_t,..)**
- Dedicated developments for new phenomena (eg long-lived particles)
- …

Progress on PS@NLL

Physics

- Formulate parton-shower algorithm at NLO [Nagy,Soper] arXiv:1705.08093
  Naturally, NLO DGLAP evolution must be part of the full solution
- NLO DGLAP splitting kernels known since long
  [Curci,Furmanski,Petronzio] NPB175(1980)27, PLB97(1980)437
  [Floratos,Kounnas,Lacaze] NPB192(1981)417
- So far not implemented in parton showers because
  - Kernels are scheme dependent (easy)
  - Overlap with soft-gluon resummation (hard)
- Focus on purely collinear corrections ($\leftrightarrow$ B2) for a start
  - Redefine time-like Sudakovs to recover NLO DGLAP evolution
    [Jadach,Skrzypek] hep-ph/0312355
  - Negative NLO corrections require weighted veto algorithm
    [Schumann,Siegert,SH] arXiv:0912.3501, [Lönnblad] arXiv:1211.7204
  - Flavor changing splitting functions require $2 \to 4$ transitions
    [Prestel,SH] arXiv:1705.00742
- Flavor-changing case is simplest but requires all the technology

®StefanHoeche

Progress on PS@NLL

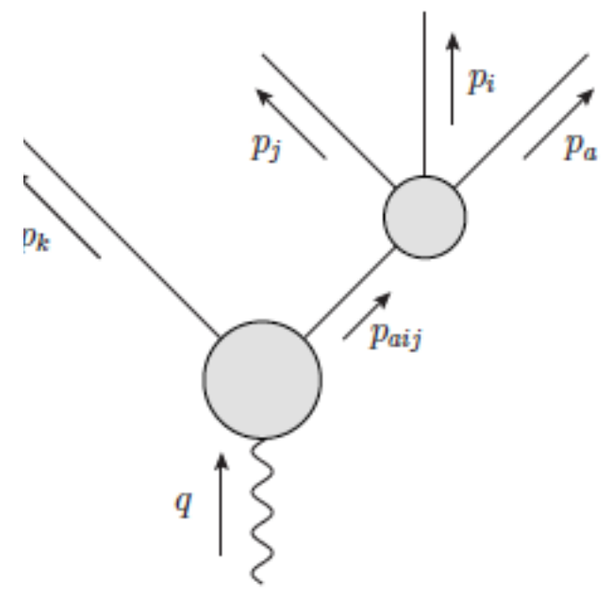
Physics

$$P_{qq'}(z) = \left(\mathbf{I} + \frac{1}{\varepsilon}\mathcal{P} - \mathcal{I}\right)_{qq'}(z) + \int \mathrm{d}\Phi_{+1}(\mathbf{R}-\mathbf{S})_{qq'}(z,\Phi_{+1})$$

where

$$\mathrm{I}_{qq'}(z) = \int \mathrm{d}\Phi_{+1} S_{qq'}(z,\Phi_{+1})\,, \qquad \mathcal{P}_{qq'}(z) = \int_z \frac{\mathrm{d}x}{x} P^{(0)}_{qg}(x) P^{(0)}_{gq}(z/x)$$

$$\mathcal{I}_{qq'}(z) = 2\int_z \frac{\mathrm{d}x}{x} C_F \left(\frac{1+(1-x)^2}{x}\ln(x(1-x)) + x\right) P_{gq}(z/x)$$



Basic layout of Dire [Prestel,SH] arXiv:1506.05057

- Dipole-like parton shower, kernels as close as possible to DGLAP
- Partial fraction soft eikonal à la Catani-Seymour, evolve in dipole-k_T
- Two independent implementations (Pythia & Sherpa)
- Cross-validation at particle level

New developments

- MC counterterms implemented in Amegic & Comix [SH]
- MC@NLO matching & NLO subtraction in Sherpa [SH]
- UNLOPS / MEPS@NLO merging in Pythia / Sherpa [Prestel,SH]
- Flavor-changing triple collinear splitting functions [Prestel,SH] arXiv:1507.00742
- NLO DGLAP kernels & 3-loop cusp [Krauss,Prestel,SH] arXiv:1507.00982

®StefanHoeche

Dedicated MC developments

Physics

POWHEG and MG5aMC

Resonance aware PS and NLO matching

WbWb → m_t

NLO QCD+EW corrections+PS (QCD and QED)

e+e-, eν → m_W

POWHEG

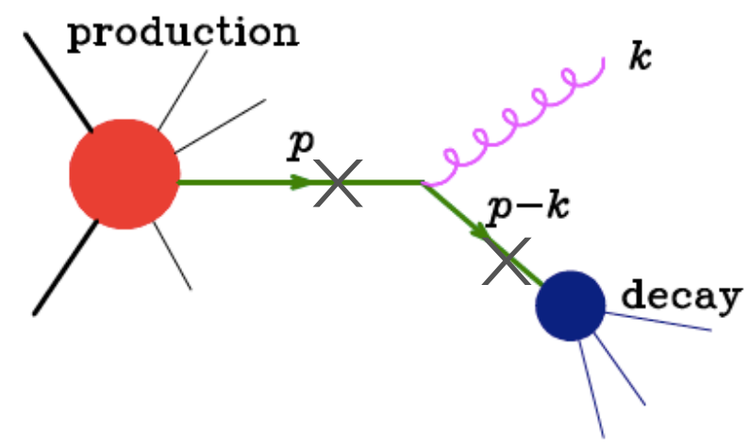
Other dedicated implementations/efforts (for example in b radiation) will be needed.

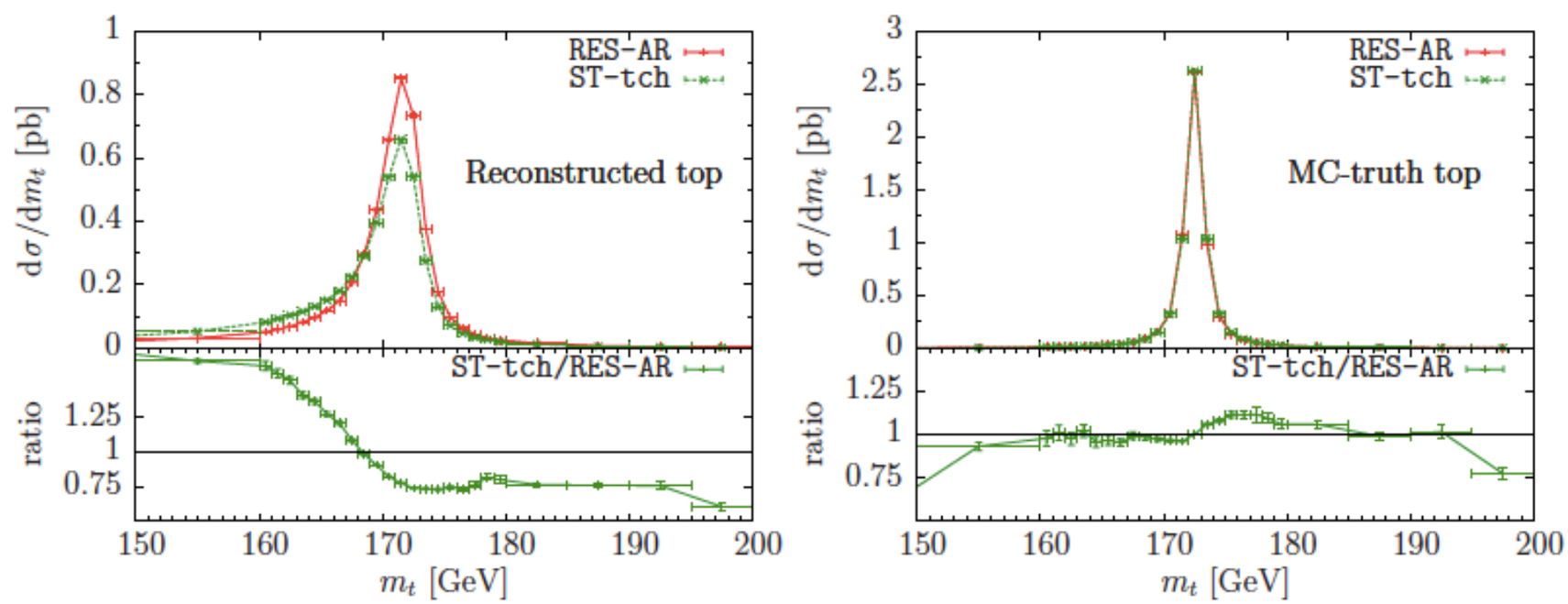
NLO+PS with intermediate resonances

Physics

[Jezo and Nason, 2015]

Amplitudes squared are expressed in terms of sum of contributions from the BW's. The cancellation between V and R happens only when $m_{bg}^2 \ll \Gamma_t E_{bg}$ A modified FKS method has been proposed that deals correctly with (spurious) double logs of Γ in POWHEG. Soft single logs Γ are left to cancel on their own in the B tilde function.





Shift in the reconstructed top mass due to differences in the final state radiation treatment of the b quark. Implementation of WbWb available [Jezo et al. 2016]

EW corrections

Physics

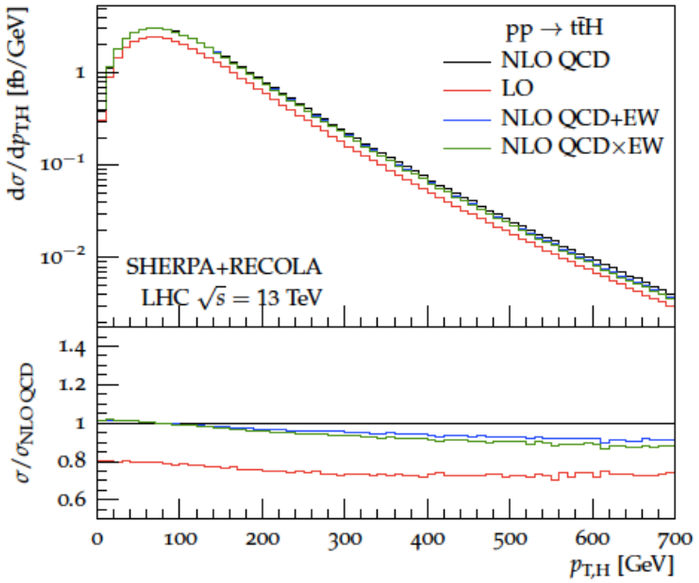
- The development of automatic NLO includes the possibility of computing EW corrections (including real/virtual photons) fully automatically nowadays.

- A few automatic tools and several non-trivial results exist:

  - MG5aMC
  - Sherpa+OpenLoops
  - Sherpa+Recola

giving consistent results. For example for ttH:

	SHERPA+RECOLA		MG5_AMC@NLO	SHERPA+OPENLOOPS
	$\sigma_{\rm EW}^{\rm NLO}$ [fb]	$\delta_{\rm EW}$[%]	$\delta_{\rm EW}$[%]	$\delta_{\rm EW}$[%]
inclusive	356.7(2)	−1.2(2)	−1.4	−1.4
$p_{\rm T,t/\bar{t}/H} > 200$ GeV	12.244(3)	−8.5(1)	−8.5	−8.4
$p_{\rm T,t/\bar{t}/H} > 400$ GeV	0.3435(3)	−14.1(2)	−13.9	−14.0
$p_{\rm T,H} > 500$ GeV	1.7798(9)	−11.7(1)	−11.6	−11.7
$\lvert y_{\rm t}\rvert > 2.5$	5.035(3)	0.3(2)	0.5	0.5



EW corrections

Physics

Full automation ⇒ a wide spectrum of processes is available [Frederix et al. 1711.XYWZ]

Process	Syntax	Cross section (pb) LO	Cross section (pb) NLO	δ_{EW} (%)
$pp \to e^+\nu_e$	p p > e+ ve QCD=0 QED=2 [QED]	$5.2499 \pm 0.0006 \cdot 10^3$	$5.2113 \pm 0.0006 \cdot 10^3$	-0.74 ± 0.02
$pp \to e^+\nu_e j$	p p > e+ ve j QCD=1 QED=2 [QED]	$9.1468 \pm 0.0012 \cdot 10^2$	$9.0449 \pm 0.0014 \cdot 10^2$	-1.11 ± 0.02
$pp \to e^+\nu_e jj$	p p > e+ ve j j QCD=2 QED=2 [QED]	$3.1557 \pm 0.0003 \cdot 10^2$	$3.0983 \pm 0.0006 \cdot 10^2$	-1.82 ± 0.02
$pp \to e^+e^-$	p p > e+ e- QCD=0 QED=2 [QED]	$7.5370 \pm 0.0009 \cdot 10^2$	$7.5004 \pm 0.0011 \cdot 10^2$	-0.49 ± 0.02
$pp \to e^+e^-j$	p p > e+ e- j QCD=1 QED=2 [QED]	$1.5059 \pm 0.0001 \cdot 10^2$	$1.4909 \pm 0.0002 \cdot 10^2$	-1.00 ± 0.02
$pp \to e^+e^-jj$	p p > e+ e- j j QCD=2 QED=2 [QED]	$5.1502 \pm 0.0004 \cdot 10^1$	$5.0482 \pm 0.0008 \cdot 10^1$	-1.98 ± 0.02
$pp \to e^+e^-\mu^+\mu^-$	p p > e+ e- mu+ mu- QCD=0 QED=4 [QED]	$1.2353 \pm 0.0001 \cdot 10^{-2}$	$1.1696 \pm 0.0003 \cdot 10^{-2}$	-5.32 ± 0.02
$pp \to e^+\nu_e\mu^-\bar{\nu}_\mu$	p p > e+ ve mu- vm~ QCD=0 QED=4 [QED]	$5.0649 \pm 0.0005 \cdot 10^{-1}$	$5.2511 \pm 0.0010 \cdot 10^{-1}$	$+3.68 \pm 0.02$
$pp \to He^+\nu_e$	p p > h e+ ve QCD=0 QED=3 [QED]	$6.7736 \pm 0.0001 \cdot 10^{-2}$	$6.4979 \pm 0.0009 \cdot 10^{-2}$	-4.07 ± 0.01
$pp \to He^+e^-$	p p > h e+ e- QCD=0 QED=3 [QED]	$1.4573 \pm 0.0001 \cdot 10^{-2}$	$1.3719 \pm 0.0002 \cdot 10^{-2}$	-5.86 ± 0.02
$pp \to Hjj$	p p > h j j QCD=0 QED=3 [QED]	$2.8270 \pm 0.0003 \cdot 10^0$	$2.7076 \pm 0.0004 \cdot 10^0$	-4.22 ± 0.02
$pp \to W^+W^-W^+$	p p > w+ w- w+ QCD=0 QED=3 [QED]	$8.2864 \pm 0.0005 \cdot 10^{-2}$	$8.8008 \pm 0.0013 \cdot 10^{-2}$	$+6.21 \pm 0.02$
$pp \to ZZW^+$	p p > z z w+ QCD=0 QED=3 [QED]	$1.9872 \pm 0.0001 \cdot 10^{-2}$	$2.0188 \pm 0.0003 \cdot 10^{-2}$	$+1.59 \pm 0.02$
$pp \to ZZZ$	p p > z z z QCD=0 QED=3 [QED]	$1.0763 \pm 0.0001 \cdot 10^{-2}$	$0.9743 \pm 0.0002 \cdot 10^{-2}$	-9.47 ± 0.02
$pp \to HZZ$	p p > h z z QCD=0 QED=3 [QED]	$2.1007 \pm 0.0003 \cdot 10^{-3}$	$1.9162 \pm 0.0003 \cdot 10^{-3}$	-8.78 ± 0.02
$pp \to HZW^+$	p p > h z w+ QCD=0 QED=3 [QED]	$2.4408 \pm 0.0000 \cdot 10^{-3}$	$2.4809 \pm 0.0005 \cdot 10^{-3}$	$+1.64 \pm 0.02$
$pp \to HHW^+$	p p > h h w+ QCD=0 QED=3 [QED]	$2.7827 \pm 0.0001 \cdot 10^{-4}$	$2.4259 \pm 0.0027 \cdot 10^{-4}$	-12.82 ± 0.10
$pp \to HHZ$	p p > h h z QCD=0 QED=3 [QED]	$2.6909 \pm 0.0003 \cdot 10^{-4}$	$2.3921 \pm 0.0003 \cdot 10^{-4}$	-11.10 ± 0.02
$pp \to t\bar{t}W^+$	p p > t t~ w+ QCD=2 QED=1 [QED]	$2.4108 \pm 0.0002 \cdot 10^{-1}$	$2.3013 \pm 0.0003 \cdot 10^{-1}$	-4.54 ± 0.02
$pp \to t\bar{t}Z$	p p > t t~ z QCD=2 QED=1 [QED]	$5.0456 \pm 0.0006 \cdot 10^{-1}$	$5.0025 \pm 0.0007 \cdot 10^{-1}$	-0.85 ± 0.02
$pp \to t\bar{t}H$	p p > t t~ h QCD=2 QED=1 [QED]	$3.4481 \pm 0.0004 \cdot 10^{-1}$	$3.5098 \pm 0.0005 \cdot 10^{-1}$	$+1.79 \pm 0.02$
$pp \to jjj$	p p > j j j QCD=3 QED=0 [QED]	$7.9644 \pm 0.0010 \cdot 10^6$	$7.9479 \pm 0.0020 \cdot 10^6$	-0.21 ± 0.03
$pp \to tj$	p p > t j QCD=0 QED=2 [QED]	$1.0618 \pm 0.0001 \cdot 10^2$	$1.0543 \pm 0.0002 \cdot 10^2$	-0.71 ± 0.02

MadGraph5_aMC@NLO

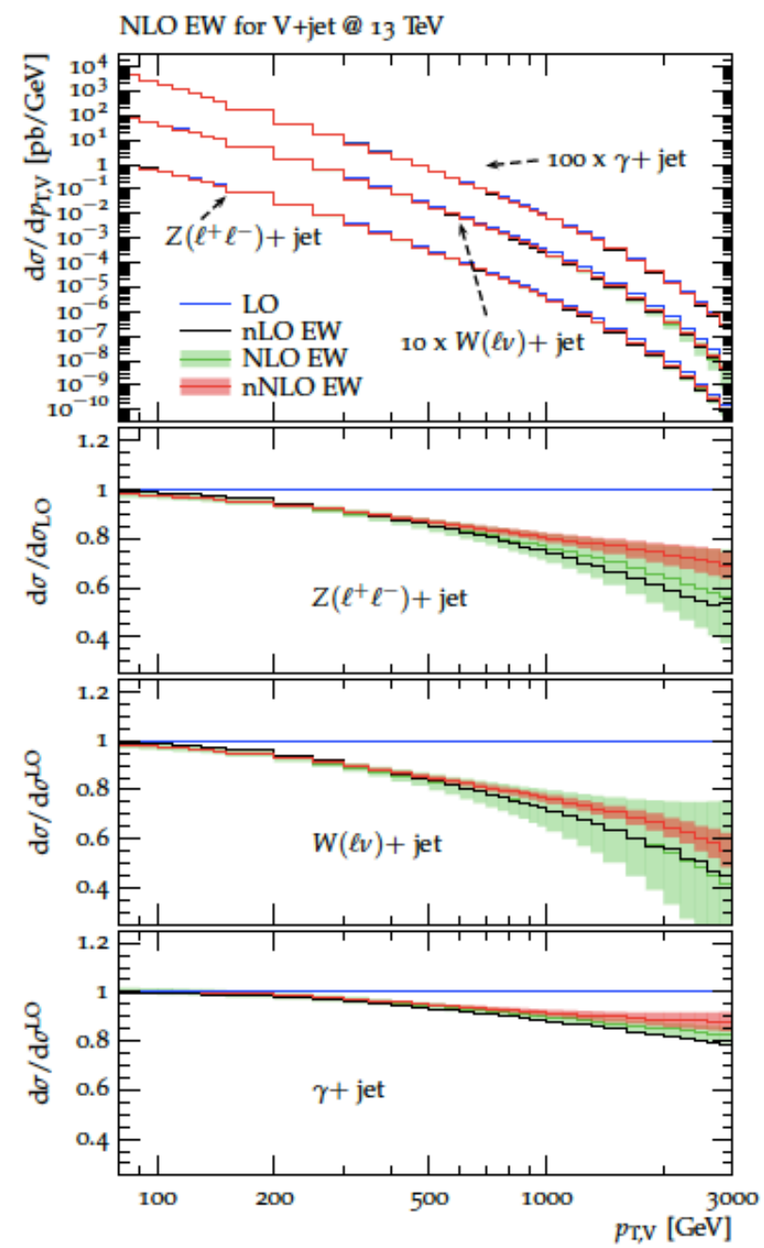
EW corrections

Physics

SM19 collab. 1705.04664

Considerations and open issues :

- Knowledge of EW corrections is typically essential in high-pT tails ⇒ affects the accuracy of the predictions
- Evidence that real weak-boson radiation is well described by fixed-order computations
- Matching with the PS not available yet in general (it is for DY in POWHEG for example) but no road-block
- Computation of mixed QCD-EW corrections will be needed to reliably assess uncertainties
- Other open questions?



BSM simulations

Physics

- Well-tested and proven easy and robust path to BSM simulations: FeynRules → UFO → Matrix Element generator (MG5aMC, Sherpa, HW7)→ LHEF → PS

- User-driven FeynRules Database of New Physics models continuosly updated and enriched

- NLO+PS for BSM brings additional complications:
  - Renormalization of the $\mathscr{L}_{\rm NP}$ needs to be performed and in case of use of numerical loop techniques the full set of counteterms is needed. Use NLOCT.
  - At NLO, processes mix with LO resonant contributions and in order to keep NLO accuracy in inclusive samples a MC friendly procedure to subtract real resonant diagrams must be in place (or a full off-shell computation should be available).
  - If non-renormalizable operators appear, such as in the EFT, higher-dimensional rank in the integrals appear as well as extra UV divergences and full mixing RGE are needed.

BSM simulations

Physics

Considerations and open issues :

- Most of the well-known NP signatures and simplified models can be achieved or are already available at NLO+PS with current technnology.
- Models giving exotic signatures (see current long-lived particle searches) might need dedicated efforts. This will always be the case. Should new physics models with special needs start to be addressed now?
- "Precision" new physics searches and interpretations (such as EFT) builds up on SM accurate and precise prediciction. Dedicated efforts to bring SMEFT to NLO accuracy in QCD. Systematic effort for EW corrections needed.
- Dark model searches (and the DMWG) are teaching us a lot on various MC issues too, such as the advantages of having common ATLAS and CMS NP samples.
- Fast and efficient parameter space scanning might become an issue.

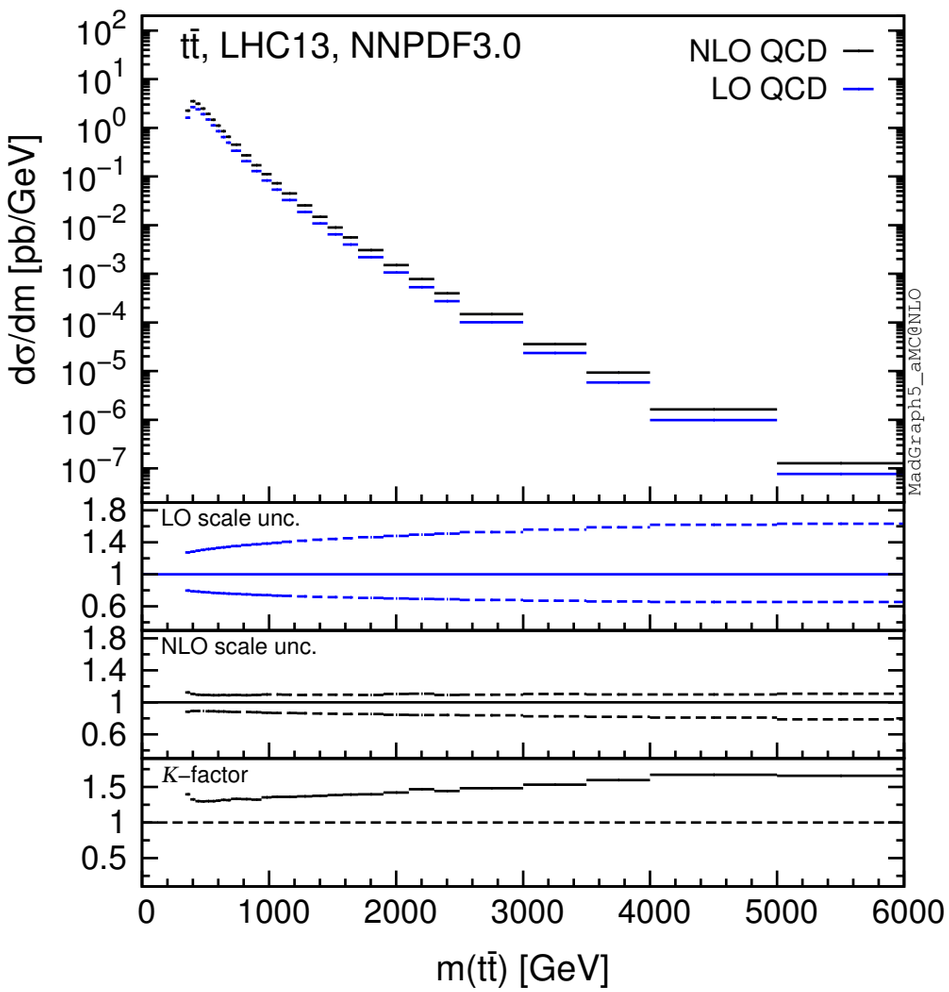
MC Challenges : Technicalia

Technicalia

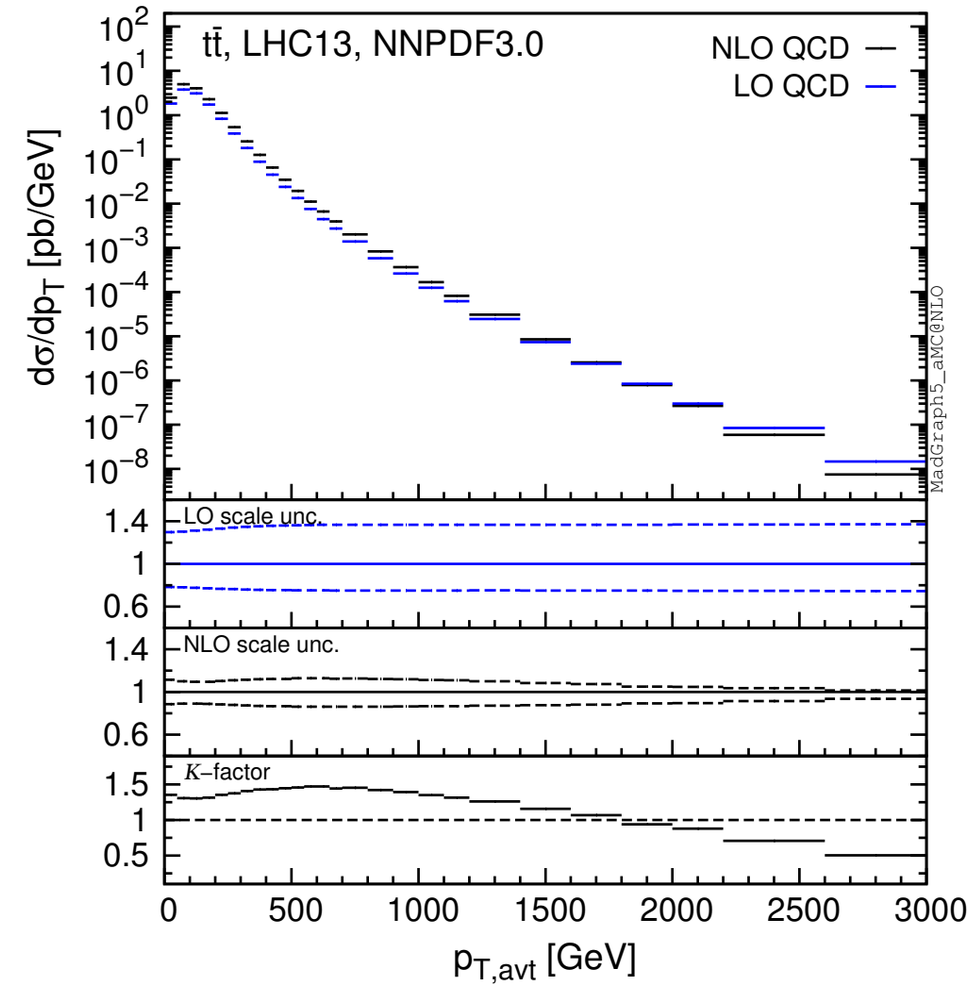
- **Efficient generation** for SM mass production (tails vs bulk)
- **Built-in event-by-event reliable estimation of the uncertainties**
- **New techniques and improved accuracy/precision imply negative weights**
- MVAs and New Analysis techniques
- **New Physics parameter scanning** (UV models, Simplified Models, EFT)
- Legacy and recasting tools
- …

Generating tails efficiently: bias functions

Technicalia



1 nb * 3000 fb-1 = 3 billions top pairs in the full dataset

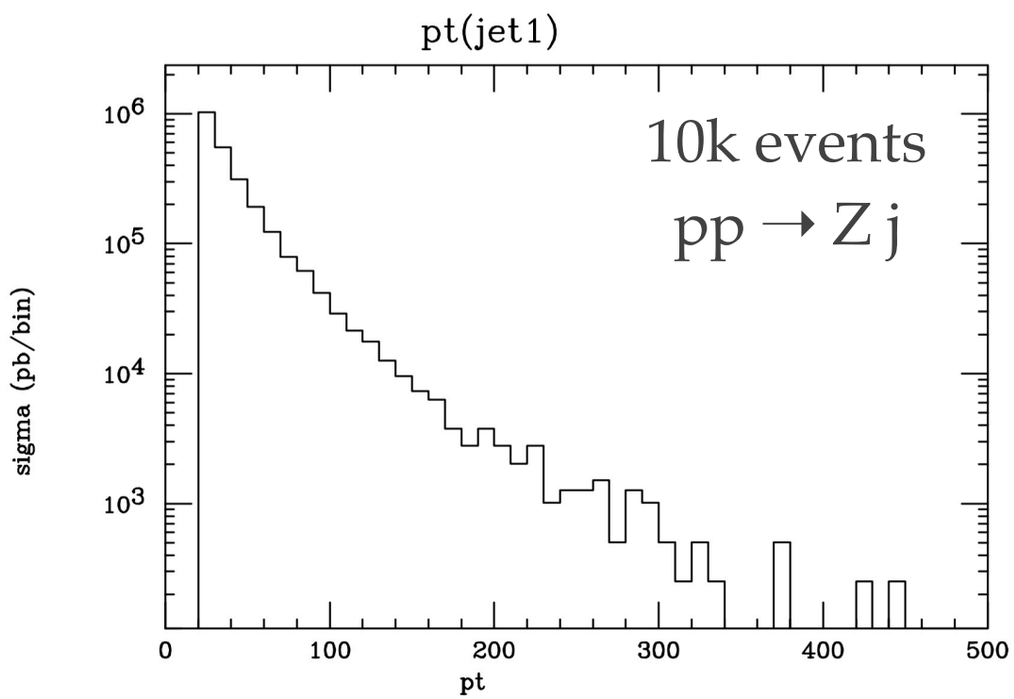


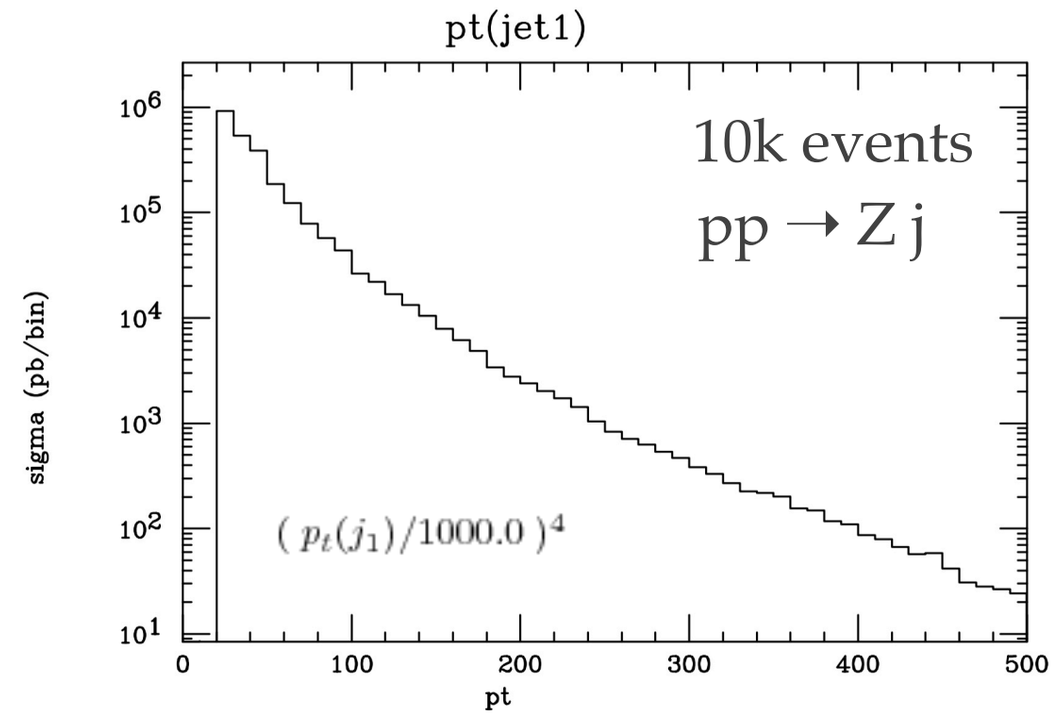
Usual technique used to generate samples over wide ranges, is to slice the phase space in n mutually excluding domains (like pt intervals) and make n independent generations.

Generating tails efficiently: bias functions

Technicalia

An alternative approach is to bias the event generation directly at the start, with a suitable function.

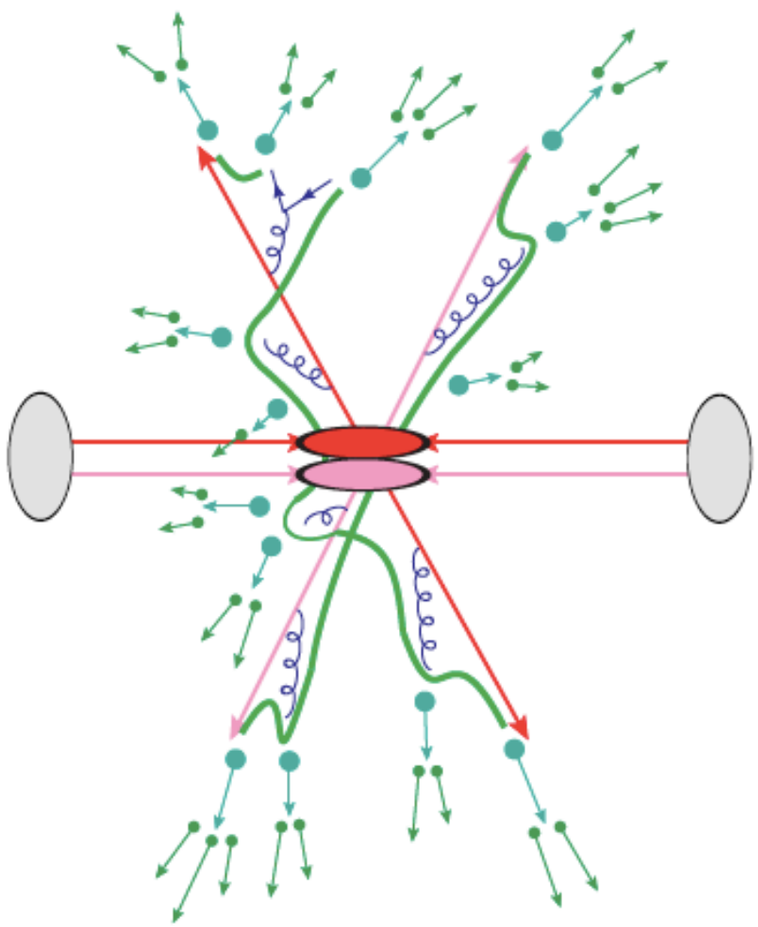




These two plots were both obtained from 10k events, but for the right-hand side one, the matrix elements have been biased by the quantity. Now available at NLO accuracy in MG5aMC [Frederix, Hirschi, Mattelaer, 2017] . See documentation HERE .

Do other MCs have similar features? Are they general enough for all needs?

Uncertainties



®StefanPrestel

Uncertainties:

Short-distance cross section:
μ_r^H, μ_f^H, PDF^H, α_s^H

Parton shower:
μ_q^{PS}, μ_r^{PS}, μ_f^{PS}, μ_{cut}^{PS}, PDF^{PS}, α_s^{PS}

Multiple interactions:
μ_q^{MPI}, PDF^{MPI}, α_s^{MPI} ...

...correlated with:

μ_f^H with shower starting scale

μ_f^H, PDF^H with MPI

μ_q^{PS}/μ_f^H and PDF^{PS}/PDF^H

μ_r^{PS}/μ_r^H and α_s^{PS}/α_s^H for NLO+PS

μ_{cut}^{PS} with "string $p_\perp$" & "primordial $k_\perp$"

α_s^{MPI} and α_s^{PS}

α_s^{MPI} and "string tension"

Tough to describe all, let alone satisfactory uncertainty. Usual approach:

One set of scales $\oplus$ one PDF $\oplus$ one tune & uncorrelated uncertainties

Uncertainties: the power of reweighting

Technicalia

Goal:

Evaluate on the fly correlated and uncorrelated uncertainties (scales, PDF, parametric) on event-by-event basis by reweighting at no “extra” computing/storage cost.

Available Results:

aMC@NLO : Short distance scales + PDF uncertainties [2011]
POWHEG : Short distance scales + PDF uncertainties (available)
Sherpa: Short distance scales + PDF + Shower/alphas scale in PS [2015]
HW7: Shower/alphas scale in PS [2016] [2016]
Pythia8: Shower/alphas scale in PS [2016]

Uncertainties: the power of reweighting

Technicalia

reweighting the parton showers: α_S & PDF variations

[Bothmann et al. Eur. Phys. J. C **76** (2016) no.11, 590]

- shower Sudakov depends on α_S & PDFs

$\rightsquigarrow$ accept/reject probability

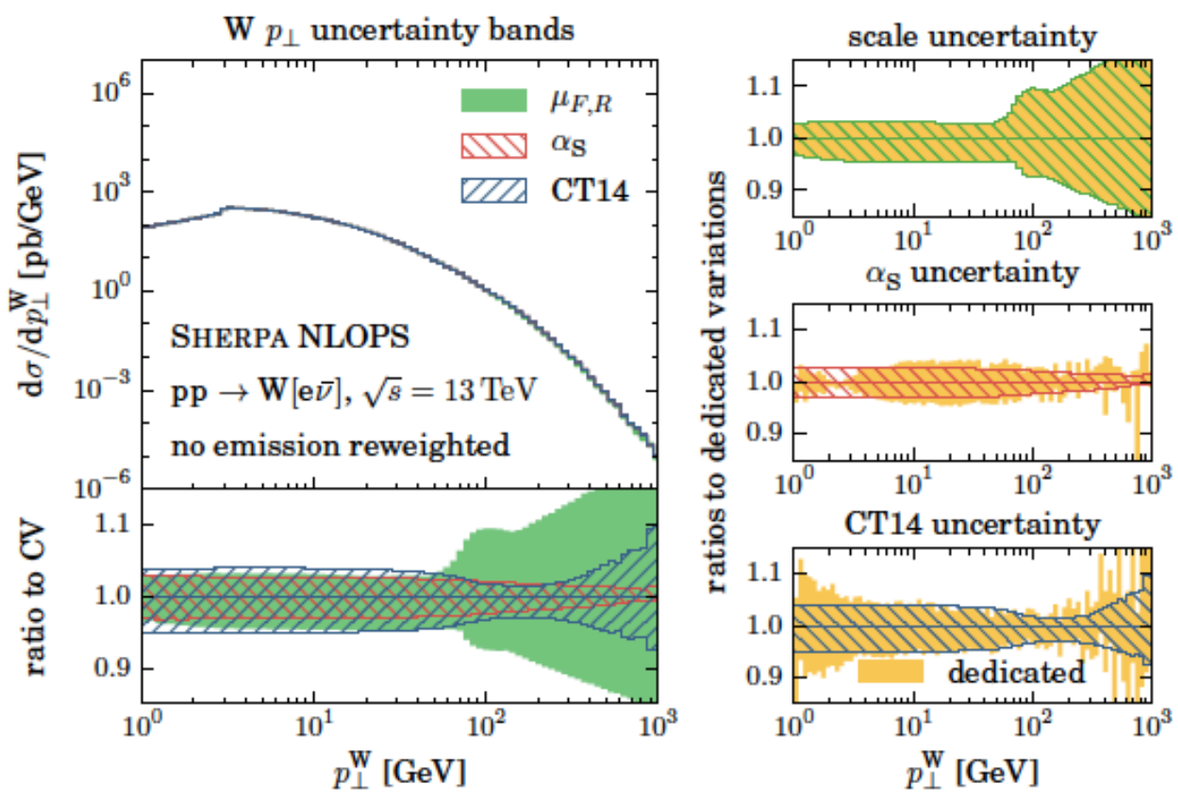
- need to reweight all acceptances/rejections

$P_{\rm acc} \to q\, P_{\rm acc}$

$P_{\rm rej} = 1 - P_{\rm acc} \to 1 - qP_{\rm acc}$

with $q \equiv \frac{\alpha_S'}{\alpha_S} \cdot \frac{f_a'(x/z)/f_b'(x)}{f_a(x/z)/f_b(x)}$

no shower emission reweighted



®SteffenSchumann

$\hookrightarrow$ on-the-fly evaluation of ME & PS α_S, PDF and scale uncertainties

$\hookrightarrow$ takes only factor of $\mathcal{O}(1)$ more time wrt to standard single run

Uncertainties: the power of reweighting

Technicalia

reweighting the parton showers: α_S & PDF variations

[Bothmann et al. Eur. Phys. J. C **76** (2016) no.11, 590]

- shower Sudakov depends on α_S & PDFs

$\rightsquigarrow$ accept/reject probability

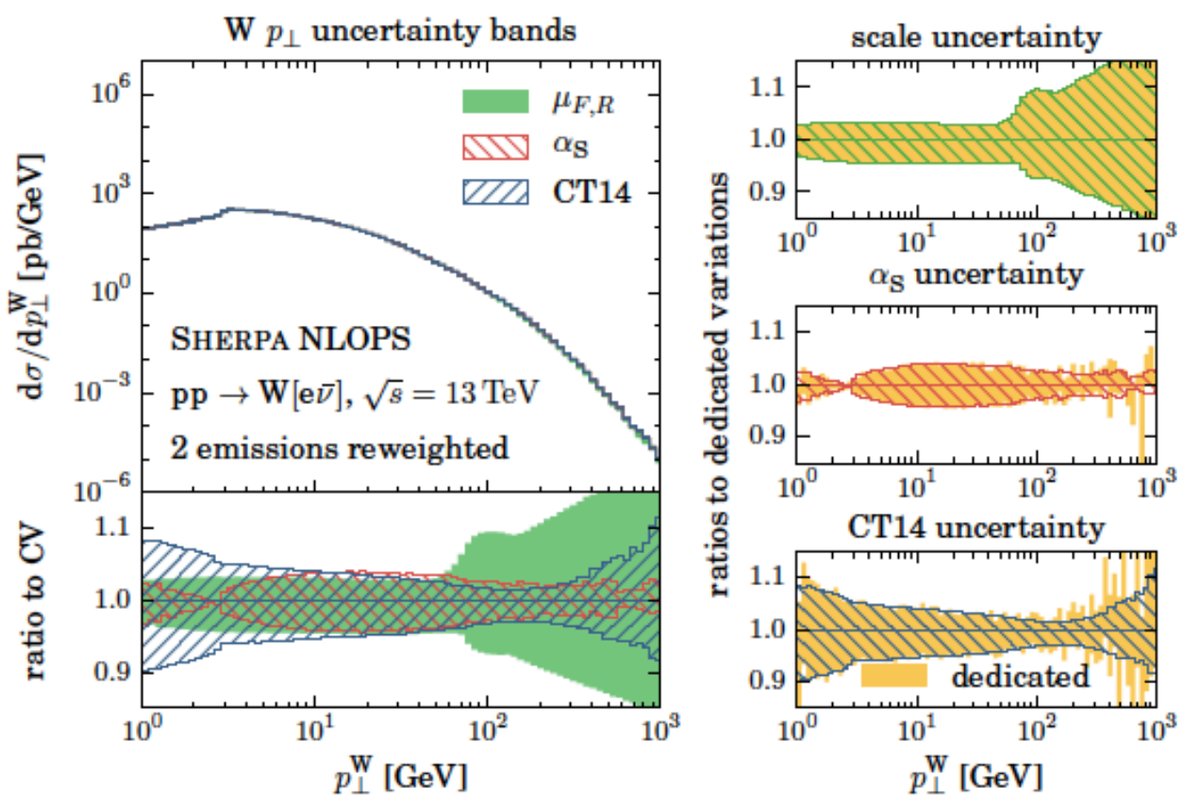
- need to reweight all acceptances/rejections

$$P_{\rm acc} \to q\, P_{\rm acc}$$

$$P_{\rm rej} = 1 - P_{\rm acc} \to 1 - qP_{\rm acc}$$

with $q \equiv \frac{\alpha_S'}{\alpha_S} \cdot \frac{f_a'(x/z)/f_b'(x)}{f_a(x/z)/f_b(x)}$

two shower emissions reweighted



®SteffenSchumann

$\hookrightarrow$ on-the-fly evaluation of ME & PS α_S, PDF and scale uncertainties

$\hookrightarrow$ takes only factor of $\mathcal{O}(1)$ more time wrt to standard single run

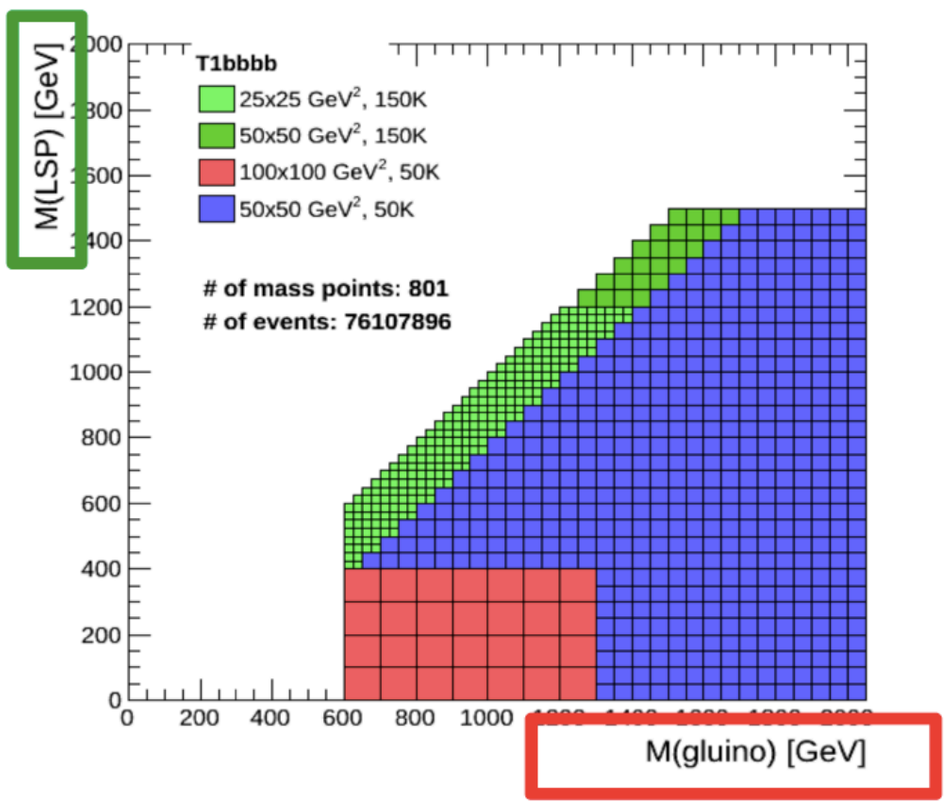
Aside: Negative weights

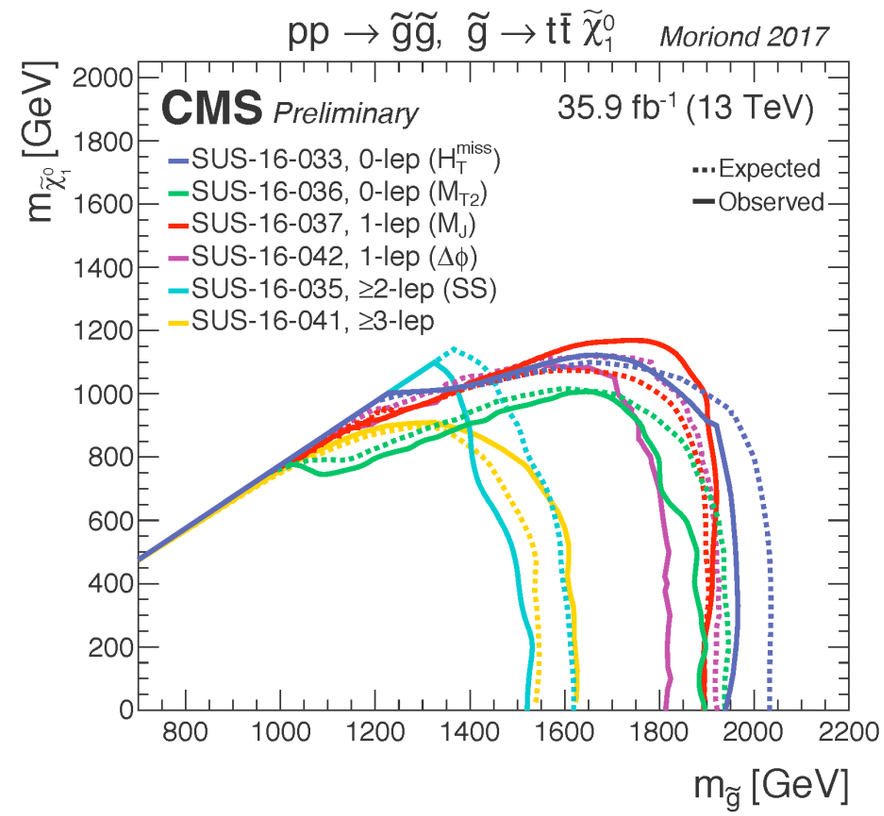
Technicalia

- Negative weighted events have become a common feature of many techniques. A blessing (opened the door to NLO+PS) and a curse at the same time.
- POWHEG has been constructed to reduce to a minimum the relevance of negative weights. However, MC@NLO (used in Sherpa and MG5aMC) method, ALL NLO merging techniques (FxFx, MENLOPS,MINLO) feature negative events.
- In some cases, the fraction of negative events can become prohibitive (>30-40%) for large scale MC productions.
- PS@NLL also features negative weights.
- Problem could become even more serious at NNLO+PS@NLL…

Q3 : Will this feature become a roadblock for mass production at the HL-LHC?

Improving mass scans

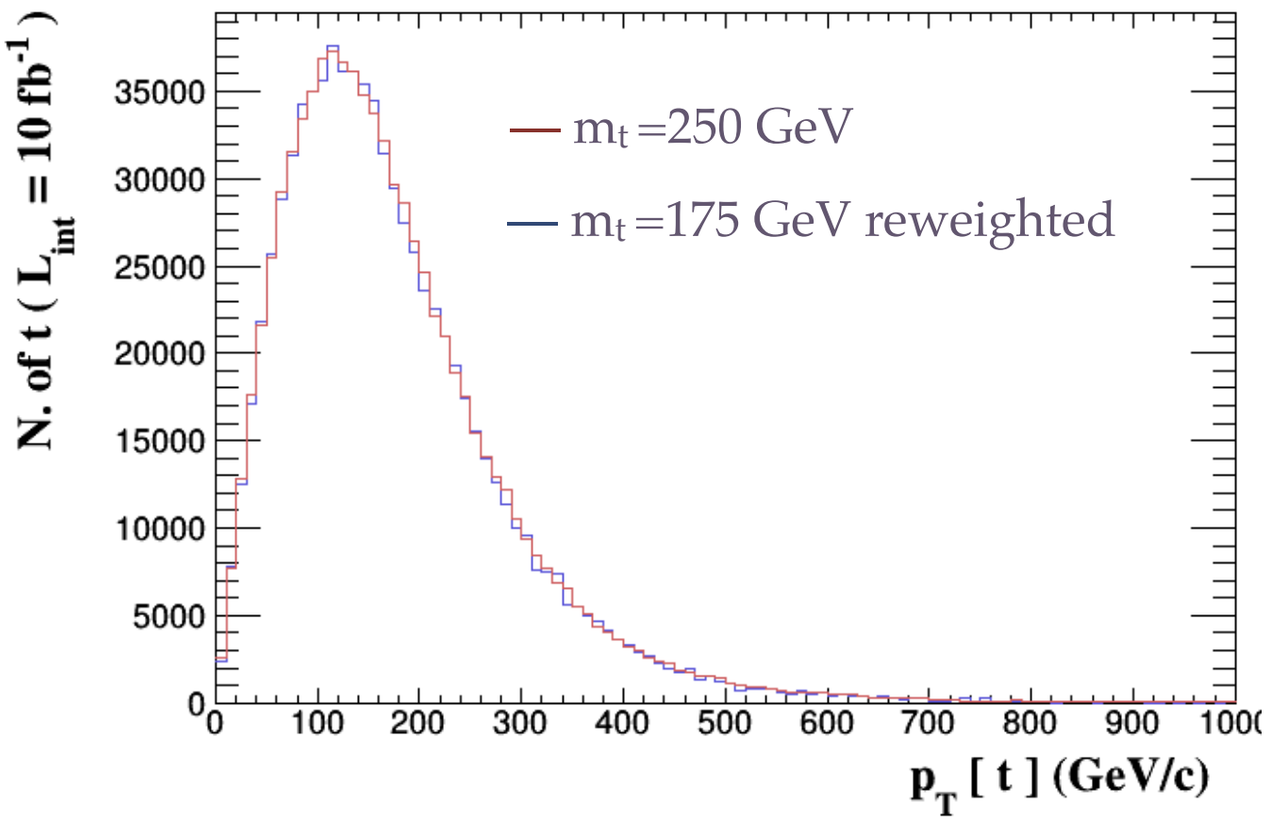


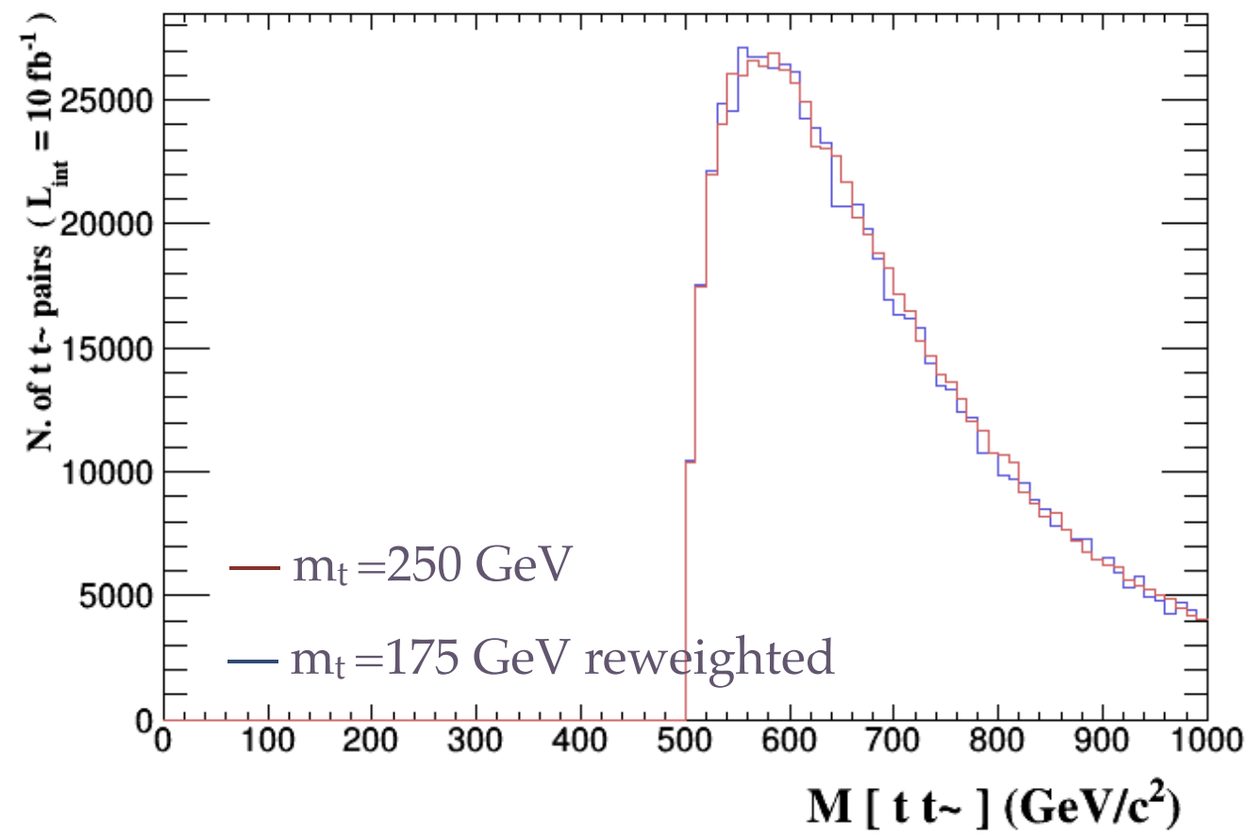


Possible improvement: reweight LHE events to different gluino masses.

Method: Use the conformal phase space mapping à la RAMBO [Kleiss, Stirling and Ellis, 1986] to generate weigthed samples with different masses [being explored by O. Mattelaer, 2017]

Improving mass scans





Reduces the number of LHE files/events needed and facilitates the book-keeping.

MC Challenges : Computing

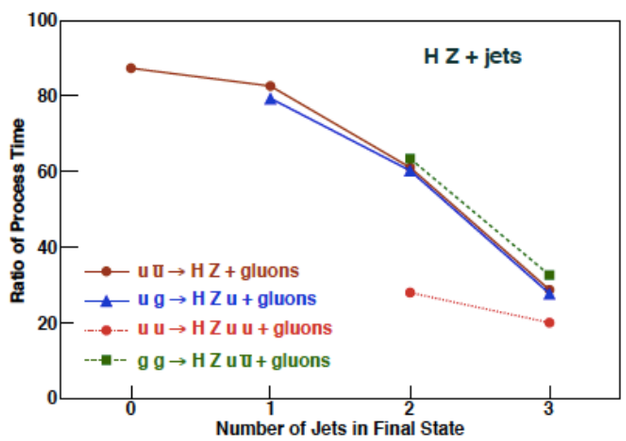
Computing

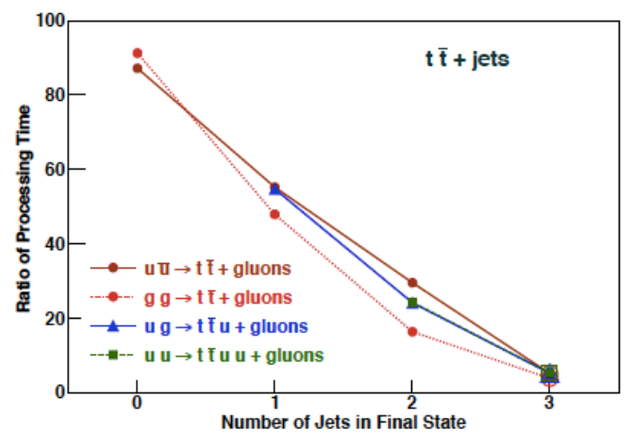
- Grid evolution
- **Exploitation of new computing architectures (MIP, GPU's, QC?)**
- **Exploitation of new ML techniques**
- Efficient storage and retrieval of samples (going beyond the LHE format?)
- Common New Physics MC samples for both experiments
- …

New architectures

Computing

MadGraph (LO) on GPU





[Hagiwara et al 200920092013]

Loss of gain when complexity increases.

Sherpa and MG5aMC on HPC

- First steps for usage of general-purpose MC on HPC made
- Good experience with fixed-order calculations, which always repeat the same, simple computational task
- Current best performance at $\sim 100 - 1000$ cores per job (different at different orders, NNLO requires $\mathcal{O}(10 - 100)$ more)
- Effort under way to design and write HPC-capable parton-level MC generator (recycling only algorithms)

- Unweighted particle-level event generation more intricate, as program flow and memory usage both unpredictable (MC!)
- We'd appreciate an increase in L2 cache much more than an increase in the number of vector units
- But can still work well with what industry is giving us, → No need to redesign particle-level part of simulation just combine with HPC-capable parton-level code when ready

Talk by ®StefanHoeche at CPAD

Overall, quite limited experience. Should we think about a MC optimal architecture?

Using DNN to integrate over phase space

Computing

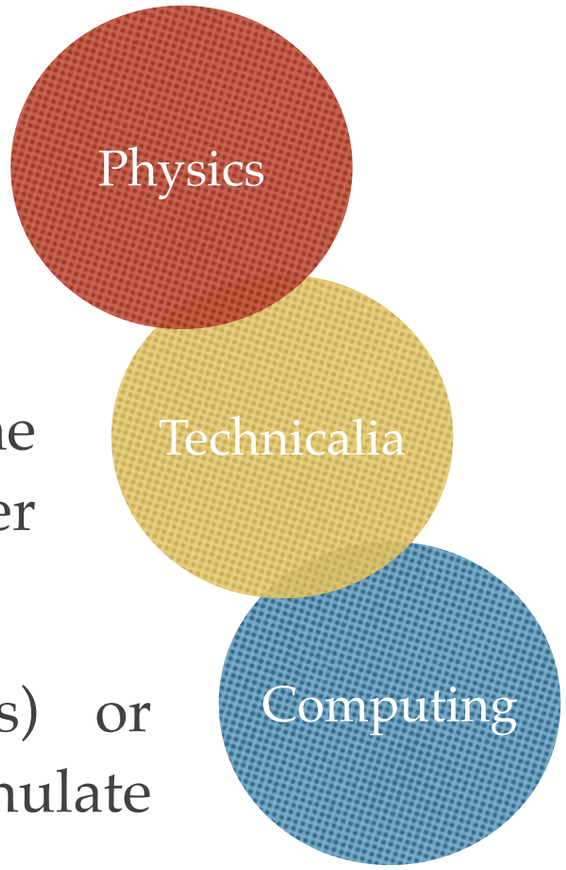
[J. Bendavid arXiv:1707.00028]

Algorithm	# of Func. Evals	$\sigma_w / < w >$	σ_I / I (2e6 add. evts)
VEGAS	300,000	2.820	$\pm 2.0 \times 10^{-3}$
Foam	3,855,289	0.319	$\pm 2.3 \times 10^{-4}$
Generative BDT	300,000	0.082	$\pm 5.8 \times 10^{-5}$
Generative BDT (staged)	300,000	0.077	$\pm 5.4 \times 10^{-5}$
Generative DNN	294,912	0.083	$\pm 5.9 \times 10^{-5}$
Generative DNN (staged)	294,912	0.030	$\pm 2.1 \times 10^{-5}$

Table 1. Performance comparison for integration of the 4-dimensional camel function between VEGAS, Foam, and the new BDT and DNN-based integration algorithms. The comparison shows the number of function evaluations required to train or construct grids for each algorithm, the resulting integration weight variance for further generated samples after training/grid construction, and the achievable integral precision with 2 million additional samples. The "staged" configurations refer to the case where integration is performed by sampling from the corresponding regression model, with the generative BDT or DNN used only to perform a secondary unweighting and integration of the regression approximation.

Conclusions and Outlook

- Challenges for the LHC will appear at three levels: Physics, Technicalia, Computing.



- From the physics point of view, a lot of progress is expected in hot topics such as NNLO computations in QCD and improving the shower accuracy to NLL. Expectations are high, yet breakthroughs will be necessary to achieve the goals.
- Event-by-event reweighting (LO and NLO) has imposed itself as the best way to maximise the information (from uncertanties to parameter scanning) contained in single samples and is already widely used.
- New computing technologies [hardware (parallel architectures) or software (ML,AI)] have the potential to change the way we simulate events at LHC and should be investigated.

Thanks

Thanks to all members of MCnet

Thanks to Stefan Hoeche, Stefan Prestel, Frank Krauss, Peter Skands, Olivier Mattelaer, Rikkert Frederix, Stefano Frixione, Davide Pagani, Marco Zaro, Hua-Sheng Shao

for providing me with key material and information