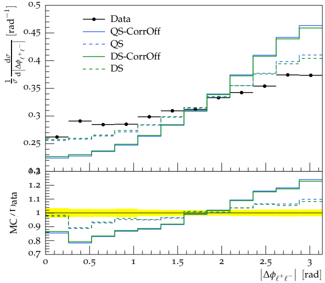
Monte Carlo and Tools

(Vitaliano Ciulli, Stefan Prestel, Emanuele Re)

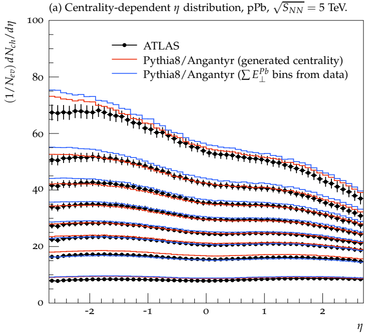
“Physics at TeV colliders” 2019

Les Houches, 11 June 2019

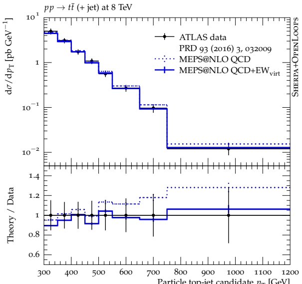
MC generators: last 2 years



Color, spin, higher orders – and theoretical concerns



Heavy ions, collective effects & the ridge



Electroweak matching, multi-jets, resonance-aware generators

(our) thoughts for possible studies this year

- Matching and merging
  - top-pair: modeling of top p_T
  - $t\bar{t}b\bar{b}$: what is the status?
- Parton showers: accuracy, uncertainties, EW effects
  - multiple scales and uncertainties (follow up from LH '17)
  - EW corrections: find observables that highlight effects? Is modelling sufficient, do we need EW showers?
- Vector-bosons scattering / fusion
  - follow up from LH '17, this time at NLO (QCD+EW?)
  - impact of matching on distributions? Impact of recoil strategy in shower Sudakovs?
- Computing and formats
  - Negative weights: define a good metric for "bad" behavior
  - New formats/tools? (Need of) improvements of time-honored LHA?
- ...

LH 2019: first steps

- Wednesday morning (June 12th): kick-off meetings (10h30 - 12h00)

- We'll keep the wikipage updated

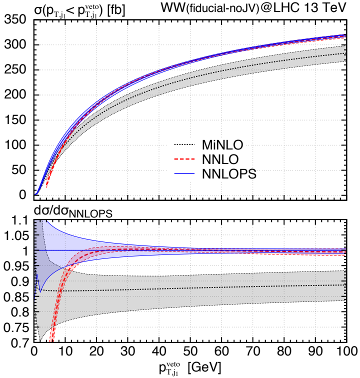
- we've prepared a slack workspace which we plan to use once the activities are defined a bit better: click here for up-to-date information and discussions

matching and merging

matching and merging: status and recent progress

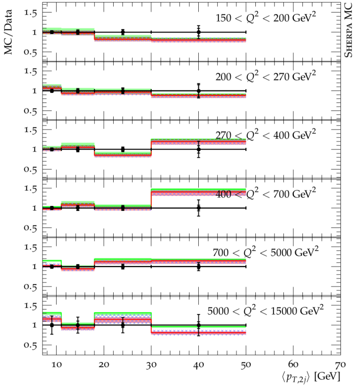
- for color-singlet production, NNLO+PS is understood, at least 3 methods available (`MiNLO`, `UNNLOPS`, `Geneva`). So far, not yet clear how to go beyond this.

WW @ NNLO+PS



[ER,Wiesemann,Zanderighi, '18]

DIS @ NNLO+PS

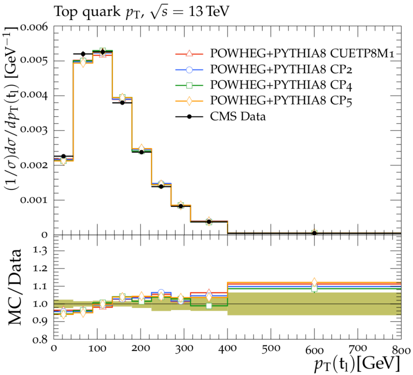


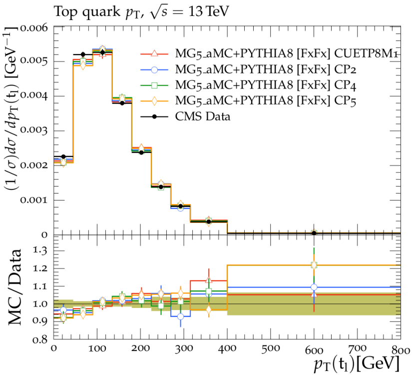
[Höche,Kuttimalai,Li, '18]

- for all other SM processes, NLO+PS (merging) is there, and used in several analyses
- overall they work reasonably well, with exceptions, some of them quite notable...

matching and merging: open issues

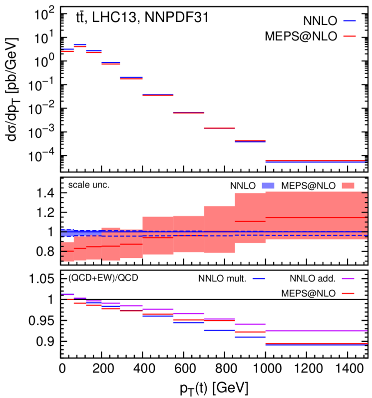
- long-standing discrepancies in description of inclusive $t\bar{t}$: *e.g.* top p_T



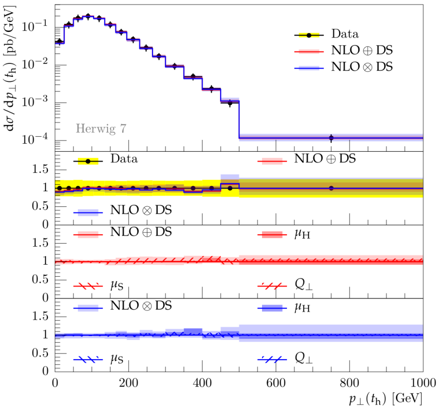


matching and merging: open issues

- long-standing discrepancies in description of inclusive $t\bar{t}$: *e.g.* top p_T
- (at least to me), not fully clear if this is understood: NNLO effect, scale choice, EW effects, MC-related issue, ATLAS vs. CMS...



[Czakon et al. '19]

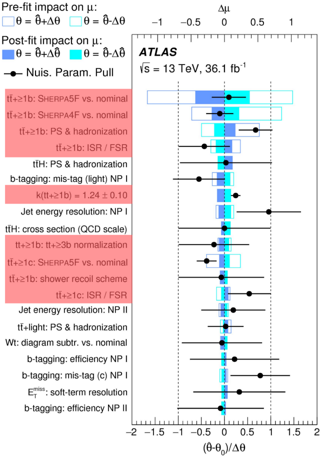


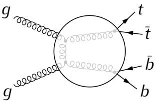
[Cormier at al - HW7, '18]

- can we make some progress here?

matching and merging: open issues

- $t\bar{t}H(\to b\bar{b})$ needs MC simulation of $t\bar{t}b\bar{b}$: MC modeling is the largest source of uncertainties

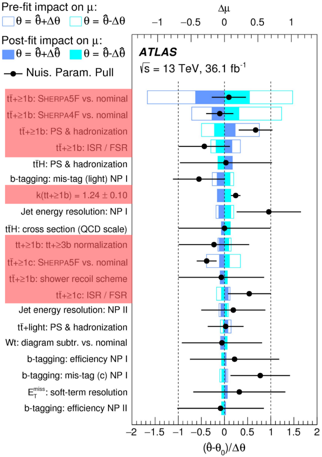


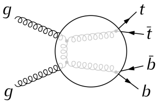


ongoing activities:

matching and merging: open issues

- $t\bar{t}H(\to b\bar{b})$ needs MC simulation of $t\bar{t}b\bar{b}$: MC modeling is the largest source of uncertainties

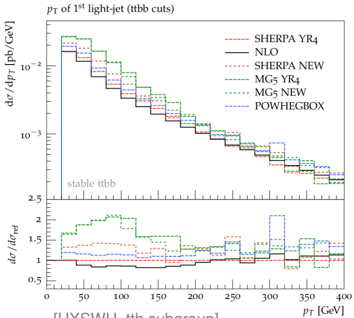




ongoing activities:

1. $t\bar{t}b\bar{b}$ at NLO+PS in the 4FS

   - large NLO perturbative uncertainties (20-30 %) + large discrepancies among different generators $\to$ matching systematic + PS effects (recoils)
   - tuned comparison ongoing in HXSWG, final outcome not yet clear



[HXSWH, tth subgroup]

matching and merging: open issues

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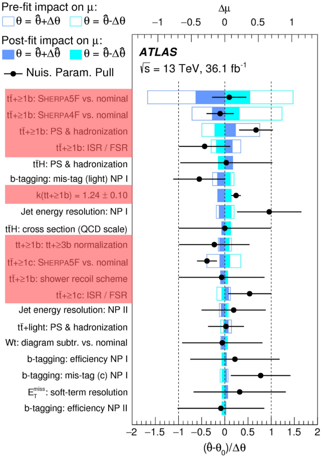
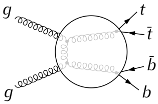
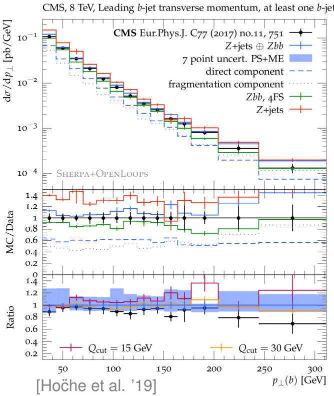




ongoing activities:

1. $t\bar{t}b\bar{b}$ at NLO+PS in the 4FS
2. merging in a variable flavour number scheme
   - 2 samples: tt+jets MEPS@NLO + $ttbb$ 4FS NLO+PS, overlap removal based on full PS history
   - worked out for $Z + b\bar{b}$, ongoing for $t\bar{t}b\bar{b}$



[Hoĉhe et al. ’19]

matching and merging: open issues

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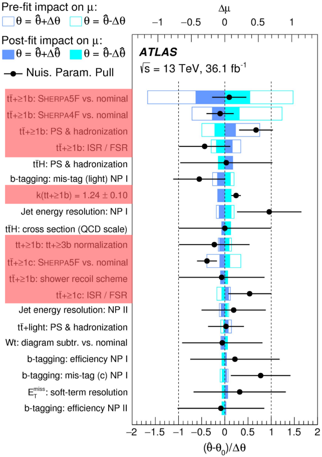

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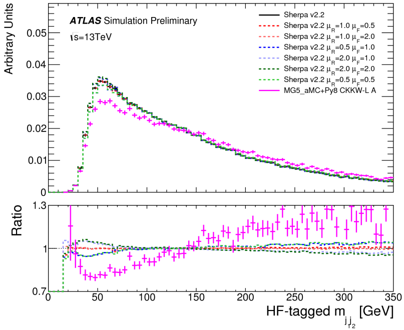


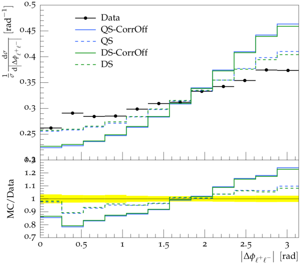
- V+HF in the VH signal region might also suffer from large MC uncertainties
- LH: studies on these fronts (with Higgs WG)?

parton showers

parton showers: status and recent progress

improving, or going beyond, existing shower algorithms:

- color correlations, spin correlations
  [Plätzer et al. // Prestel,Isaacson // Bellm // Webster,Richardson // Nagy,Soper '18-'19]



- first steps and tests towards evolution at next order [Höche,Prestel et al. '17-]

- dedicated studies to determine the actual logarithmic accuracy
  [Höche,Reichelt,Siegert '17, Dasgupta et al. '18, Bewick et al. '19]

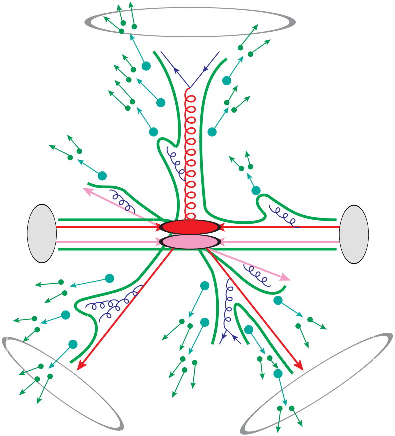
Observable	$\mathrm{NLL}_{\ln\Sigma}$ discrepancy
$1-T$	$0.116^{+0.004}_{-0.004}\,\bar{\alpha}^3 L^3$
vector p_t sum	$-0.349^{+0.003}_{-0.003}\,\bar{\alpha}^3 L^3$
B_T	$-0.0167335\,\bar{\alpha}^2 L^2$
y_3^{cam}	$-0.18277\,\bar{\alpha}^2 L^2$
FC_1	$-0.066934\,\bar{\alpha}^2 L^2$

- evolution at the amplitue level
  [Angeles et al. '18] [Nagy,Soper '17-'18]

  - all the above quite difficult: some "easier" idea that could be interesting to explore here...

general purpose generators: study of uncertainties

General-Purpose event generators cover many different phenomena through different models for



hard scattering

radiation cascade

multiparton interactions

hadronization and decay

Each model contains parameters

& smooth matching introduces more.

Some (inter)dependences studied already. . .

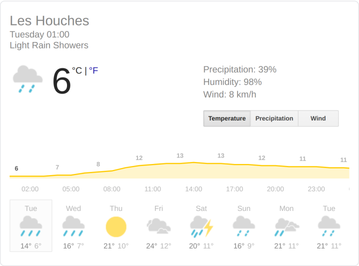
but we're far from there yet.

general purpose generators: study of uncertainties

- LH is a good place for these studies

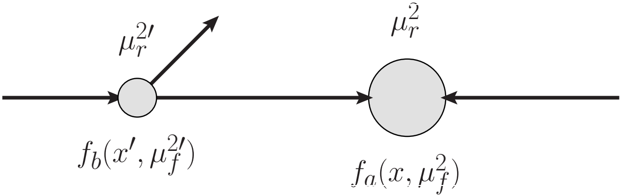
general purpose generators: study of uncertainties

- LH is a good place for these studies
- aren't these the studies usually kept for a "rainy day"?



general purpose generators: study of uncertainties

- LH is a good place for these studies



LH17

- ◇ $\mu_r^{2\prime}$ variations in different shower algorithms
- ◇ $\mu_r^{2\prime}$ variations vs. hadronization tuning.
- ◇ $\alpha_s(m_z)$ variations vs. PDF choices

Ideas for this time?

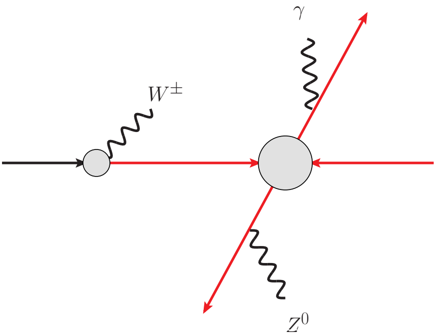
- ◇ PDF unfolding in different ISR algorithms?
- ◇ $\mu_r^{2\prime}$-$\mu_f^{2\prime}$ correlation?
- ◇ $\mu_f^{2\prime}$ vs. PDF member variations?
- ◇ $\mu_r^{2\prime}$ variations vs. MPI tuning?

EW effects in event generators

EW effects are typically important at high energy & high precision.

Status at fixed-order is quite advanced; EW corrections in PS start to be implemented (*e.g.* in `Sherpa`, $t\bar{t}$+jets, '18).

full EW shower evolution missing (but progress made *e.g.* on PDFs)

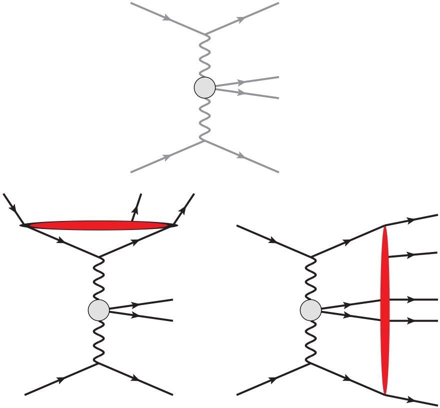


Possible points to discuss in LH:

- *Status of EW effects in GPMCs satisfactory?*
- *EW evolution needed?*
- *Killer observables?*

NLO+PS & recoils: vector boson scattering

Vector-boson scattering will be a crucial process in the future.



- *Fixed-order calculations at impressive precision.*
  NLO matching possible/available
  - ...
  - WZ: NLO QCD+NLO EW [Denner et al. '19]
  - WW: NLO EW + PS [Chiesa et al. '19]
- *Is NLO matching fool-proof?*
- *Does parton shower recoil strategy deform results significantly?*

Possible study in LH: Comparison of calculations matched to PS, especially to understand deformation of fixed-order results by parton showers!

vector boson scattering

VBS results

channel	ATLAS		CMS	
$W^{\pm}W^{\pm}$	8,13 TeV	6.9 (4.6) σ	8,13 TeV	5.5 (5.7) σ
WZ	8,13 TeV	5.7 (3.3) σ	13 TeV	1.9 (2.7) σ
$Z\gamma$	8 TeV	2.0 (1.8) σ	8 TeV	3.0 (2.1) σ
$W\gamma$	-	-	8 TeV	2.7 (1.5) σ
ZZ fully leptonic	-	-	13 TeV	2.7 (1.6) σ
WV semi-leptonic	8 TeV	anomalous couplings	13 TeV	anomalous couplings

Results comparison

Some differences observed for WZ in the signal strengths:

Process	Experiment	Obs. (fb)	Pred. (fb)	Obs. ratio	Region
EW WZjj	ATLAS	$0.57^{+0.16}_{-0.14}$	$0.321^{+0.13}_{-0.11}$	$1.77^{+0.49}_{-0.43}$	ATLAS SR
	CMS	—	$1.25^{+0.13}_{-0.11}$	$0.82^{+0.51}_{-0.43}$	CMS tight SR
WZjj (EW+QCD)	ATLAS	$1.68^{+0.25}_{-0.25}$	$2.15^{+0.65}_{-0.44}$	0.78	ATLAS SR
	CMS	$3.18^{+0.71}_{-0.63}$	$3.27^{+0.42}_{-0.35}$	$0.98^{+0.22}_{-0.20}$	CMS tight SR
QCD WZjj	ATLAS	—	—	$0.56^{+0.16}_{-0.16}$	ATLAS CR
	CMS	—	$18.6^{+0.31}_{-0.25}$	~1.02	CMS tight CR

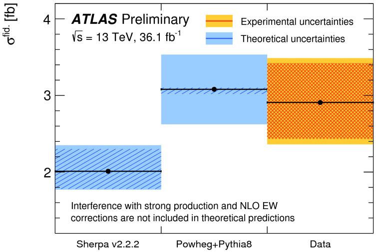
Kenneth Long - SM@LHC 2019

Fiducial regions however not easily comparable

MC predictions can differ significantly

Not clear if difference comes from data or MC!

same sign WW



MC generators used

	Wγ CMS	ZZ CMS	WZ ATLAS	WZ CMS	WV ATLAS
EW	MG5 LO k_F=1.2 VBFNLO	MG5 LO	Sherpa NLO +jets	MG5 LO	Whizard LO
QCD	MG5 LO + MLM	MG5 NLO + FxFx	Sherpa NLO +jets	MG5 LO + MLM	Whizard LO
aQGC	MG5 LO	MG5 LO + ME reweigh		MG5 LO + ME reweigh	Sherpa LO + NLO XS
interf.	Neglected	Neglected	syst. (2%)	negligible	Neglected

	ssWW ATLAS	ssWW CMS	Zγ ATLAS	Zγ CMS
EW	Sherpa LO +MEPS	MG5 LO	Sherpa LO NLO XS VBFNLO	MG5 LO kFactor 1.1
QCD	Sherpa LO +MEPS	MG5 LO	Sherpa LO	MG5 LO + MLM
aQGC		MG5 LO	MG5 LO	MG5 LO
interf.	syst. (6%)	syst. (few %)	syst. (~10%)	syst. (~11%)

Les Houches 2017 study

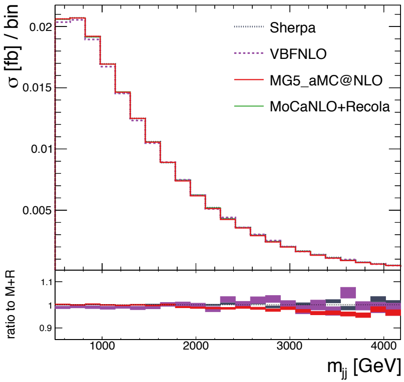
Comparison of EW WZ production at fixed order

Very good agreement but only after a careful tuning of inputs, scales and PDFs

More studies/comparisons of theory predictions for same sign WW:

ATLAS study of generators
ATL-PHYS-PUB-2019-004

A. Ballestrero et al. (VBSCan)
https://arxiv.org/abs/1803.07943



Which tools for the comparison?

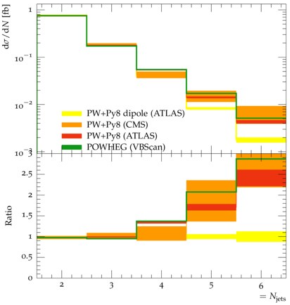
Both Les Houches and VBSCan comparison based on RIVET

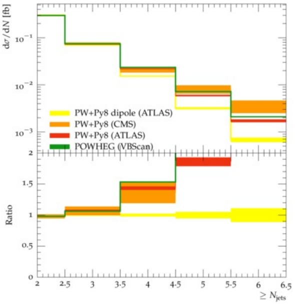
Routines available and being further developed (adding CR) here:

https://gitlab.cern.ch/lhcewkwg/lhcewkwg-multiboson/mc-comparison

Being used by LHCEWWG-MB to compare ATLAS and CMS generators setup: https://indico.cern.ch/event/826857/

e.g. number of jets in same sign WW with Powheg





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Ideas for a LH 2019 project

Technical comparison of generators/theory at NLO?

- the most recently available is NLO EW WZjj in Powheg (Jager, Karlberg, Sheller https://arxiv.org/abs/1812.05118)

Start looking at opposite sign WW?

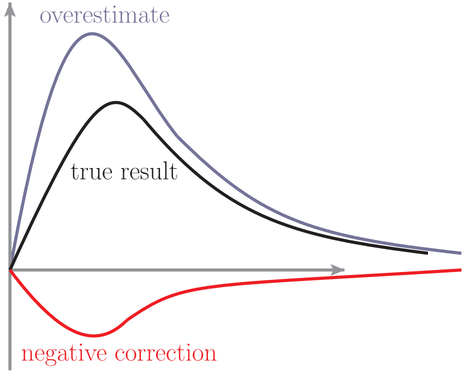
- Experimentally more challenging, but sooner or later will come…
- How about the theory side?

Use EFT to extract more informations/combine the results?

Something else?

tools & formats

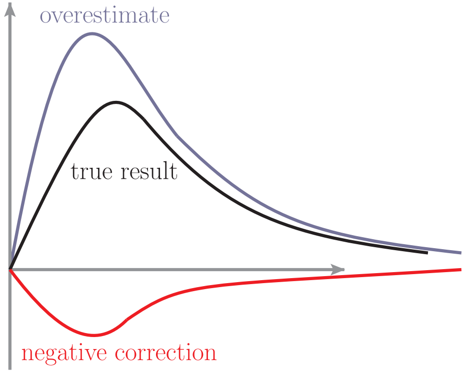
Negative weights, performance metrics



Weighted events are often unavoidable at some generation stage – *sometimes physics-related, mostly due to limited person power/money/recognition.*

Wildly fluctuating or negative weights complicate MC error assessment, and require more resources.

Negative weights, performance metrics



Weighted events are often unavoidable at some generation stage – *sometimes physics-related, mostly due to limited person power/money/recognition.*

Wildly fluctuating or negative weights complicate MC error assessment, and require more resources.

These issues can be serious bottleneck for some analyses.

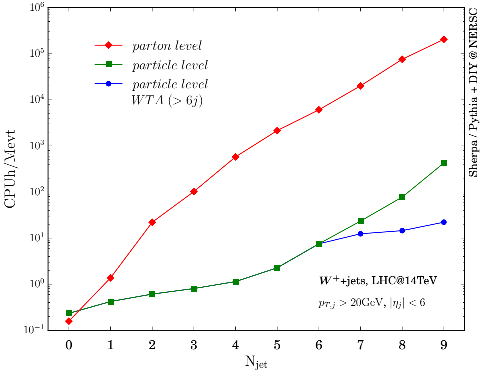
"*Event generators computing*" WS few months ago: find metric to define a "mutually acceptable level of weighting"?

- Fraction of negative-weight events :(
- Counter-event contribution to $d\sigma/d\mathcal{O}$ for reference $\mathcal{O}$?

High-Performance computing for the HL-LHC

In any case, HL-LHC may need better use of computing resources.

Example: (LO) merging at its limit



[Höche,Prestel,Schulz '19]

e.g. $W^{\pm} + 9$ jets at 14 TeV with $p_{\perp j} > 20$ GeV: $\sigma_{lo} \approx 0.5pb$

$\Rightarrow$ Usable for analyses

Computation time dominated by fixed-order – for now, but not forever.

Is regeneration an option? Can we avoid I/O bottlenecks?
For LH: can we find/discuss suitable technologies for the future?

Updates of LHA/LHEF?

Les Houches Event Format has allowed to decouple ME generators and GPMCs.
Bleeding-edge calculations may encourage updates.

Failed @ LH17 to agree on/implement suggested improvements.

Is it worth trying again? Should one make the format(s) also useful for other communities?

```
<event info="some non-standard attribute" npLO=" -1 " npNLO=" 0 ">
  4    81  1.000000E+00  2.779475E+02  7.861651E-03  1.084400E-01
  2  1  0  0  101    0  0.0000000000E+00  0.0000000000E+00  3.0163058970E+02  3.0163058970E+02  0.0
 -2  1  0  0    0  102  0.0000000000E+00  0.0000000000E+00 -2.9643457592E+02  2.9643457592E+02  0.0
  6  1  1  2  101    0 -1.3588865269E+02 -1.6715922432E+02  1.1286978960E+02  3.0000050129E+02  1.7
 -6  1  1  2    0  102  1.3588865269E+02  1.6715922432E+02 -1.0767377581E+02  2.9806466432E+02  1.7
<rwgt>
<wgt id="1001"> 0.50109E+02 </wgt>
<wgt id="1002"> 0.45746E+02 </wgt>
<wgt id="1003"> 0.52581E+02 </wgt>
</rwgt>
<scales muf="90.1" mur="90.2" mups="90.3" newscale="90.4"> comment </scales>
</event>
```

Legacy data

Which HEP data? [DPHEP arXiv:1205.4667]

- *Raw data (level 4): O(Petabyte)*
- *Analysis level data (level 3): sufficient for a complete re-analysis*
- *Simplified event level data (level 2): 4-vectors of detected particles*
- *Published data (level 1): for HEP, also available in HEPDATA*

Focusing on published data, how can we allow testing the SM and performing searches for New Physics spanning over different experimental analyses?

The MineHEP project by Univ. of Florence, in collaboration with IPPP Durham, as a first step in this direction, is trying to organise the already available information in HEPDATA to easily extract as much information as possible with a search engine

But other approaches are also possible/complementary (opendata, Rivet,…)

If people are interested, it is worth having a discussion on these items: feedback from this community is clearly most valuable!

No man is an island...

As usual, some projects will naturally overlap with the other working groups:

- New observables to test new showers $\rightarrow$ Jets WG
- Matching/merging crash tests with substructure $\rightarrow$ Jets WG
- GPMC Higgs modelling systematics $\rightarrow$ Higgs & SM WG
- ...

After all, we hope new ideas will come from you, that's what makes LH successful and useful!

Thanks for your attention!

First kick-off meetings tomorrow morning (June 12th).