MC & Tools: summary

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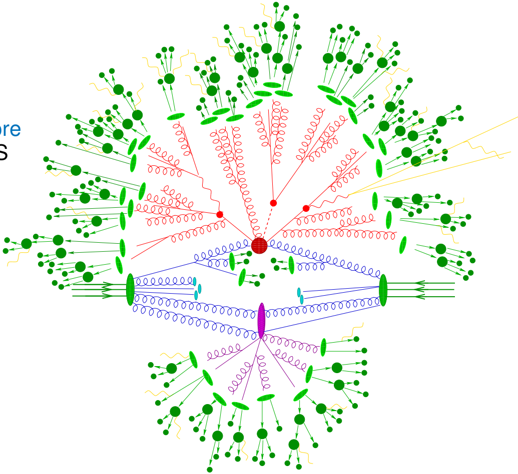
CERN & LAPTh Annecy

“Physics at TeV colliders” 2017
Les Houches, 14 June 2017

outline

- precision measurements: estimate uncertainties induced by our limited understanding of some aspects of fully-differential event generation
- identify where better modeling is more urgent, or where matching ME vs PS needs be improved
- comparison among different state-of-the-art tools and, where possible, higher logarithmic resummed (and matched) result:
  - ⇒ ultimate goal: move towards a better assessment of "theory uncertainties" for event generators
- studies involving MCs also in other subgroups...

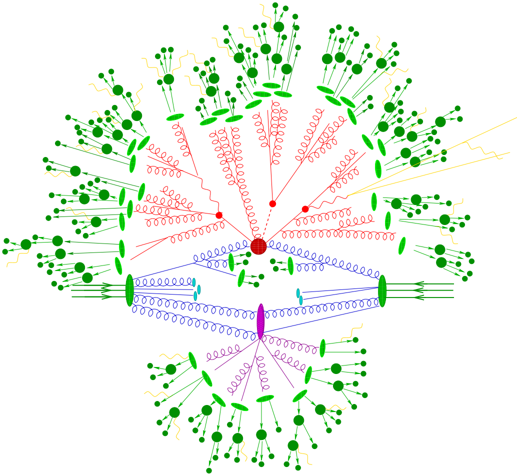


[sherpa's artistic view]

outline

1. heavy-flavours in initial and final state
2. resonance-aware NLO+PS
3. perturbative uncertainties & dedicated comparison among different event generators
4. tuning vs. scale variation
5. vector boson scattering

improvements of LHE format



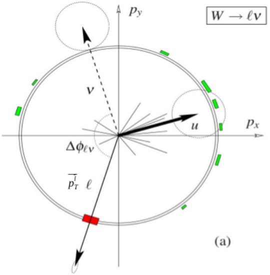
[sherpa's artistic view]

heavy flavour in the initial state

- W-mass extraction

Measurement strategy

- Event representation



- Main signature : final state lepton (electron or muon) : $\vec{p}_T^{\,l}$
- Recoil : sum of "everything else" reconstructed in the calorimeters; a measure of $p_T^{W,Z}$

$$\vec{u}_T = \sum_i \vec{E}_{T,i}$$ + useful projections (see later). No explicit jet reconstruction!

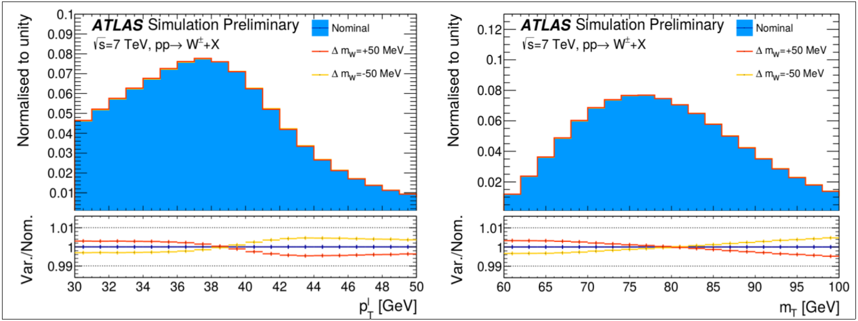
- Derived quantities : $\vec{p}_T^{\,\mathrm{miss}} = -\left(\vec{p}_T^{\,\ell} + \vec{u}_T\right)$ $\quad m_T = \sqrt{2 p_T^\ell p_T^{\mathrm{miss}} (1 - \cos\Delta\phi)}$

[slide from talk by M. Boonekamp, December '16]

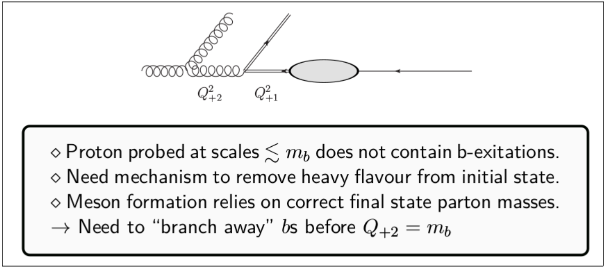
- fit predictions to Z data, apply to W

heavy flavour in the initial state

- sensitive final state distributions: $p_{T,\ell}, m_T, p_{T,miss}$



heavy flavour in the initial state



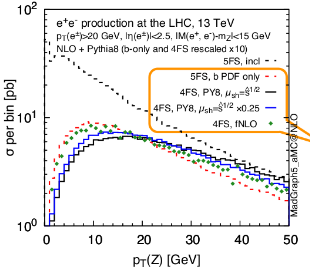
[from S. Prestel introductory talk at LH]

- in a PS generator, approximations (and modelling) are needed
- each generator adopt, in general,‘ different choices

heavy flavour in the initial state

- heavy-quark initiated processes have a non-negligible contribution

b-initiated contribution to Z pT in various approximations:



M. Zaro

Flavour decomposition of the 5FS cross section

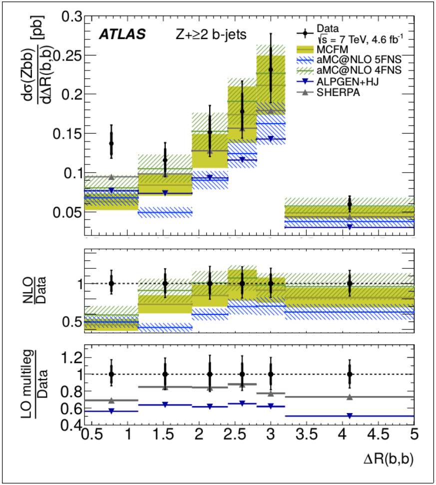
initial state quark	cross section (pb)	%
u	374.44 ± 0.62	35.0
d	391.15 ± 0.63	36.5
c	91.44 ± 0.34	8.6
s	170.43 ± 0.45	15.9
b	43.13 ± 0.26	4.0
total	1070.58 ± 0.86	100.0

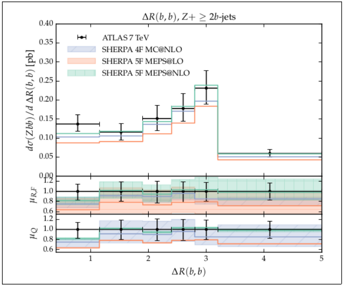
[slide from M. Zaro talk in Louvain, March '17]

★ study how different ways of implementing flavour excitation (spacelike $g \to Q\bar{Q}$) affect the $p_{T,Z}$ and $p_{T,W}$ shape, and the leptonic distributions

heavy flavour in the final state

- for $Vb\bar{b}$, the agreement MC/theory has improved, thanks to the availability of better tools





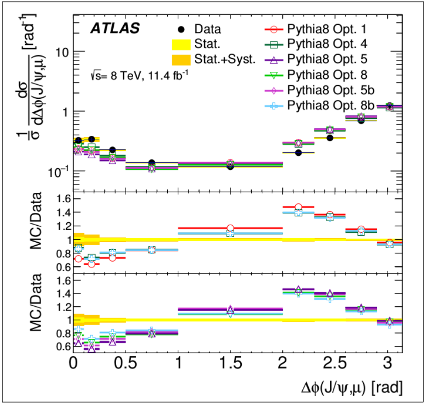
[Krauss, Napoletano, Schumann '16]

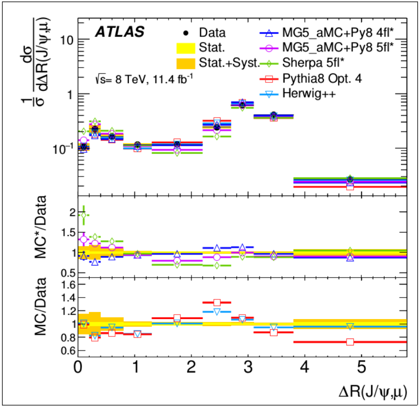
- however, not always possible to completely rely on ME corrections

heavy flavour in the final state

- understanding and improving the parton-shower modelling of $g \to b\bar{b}$ remains an open problem (at least theoretically), and new measurements are important to make progress.

$$pp \to B(J/\Psi(\mu\mu) + X)B(\mu + Y)$$



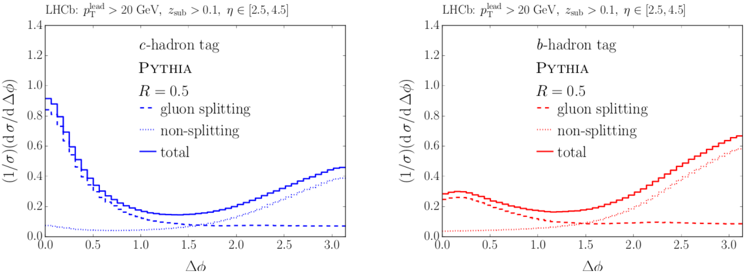


[ATLAS ’17: (arXiv:1705.03374)]

- aim: enhance the region we want to understand better

heavy flavour in the final state

- Can we find observables that inform parton shower developments and improvements?



[Ilten et al. '17]

★ possible project: assess if using new jet-algorithms (and jet-substructure techniques) can help in exposing differences among different MC choices

- if that is the case: motivation to look further into an experimental measurement

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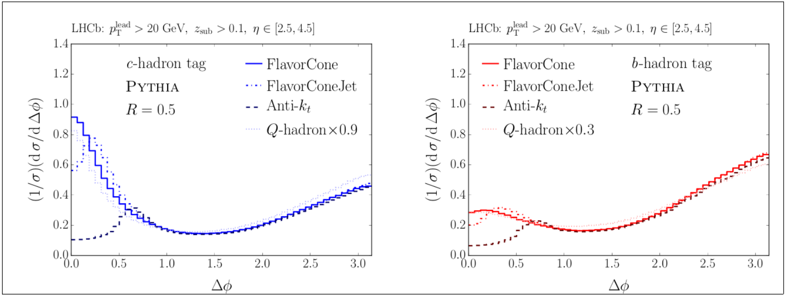

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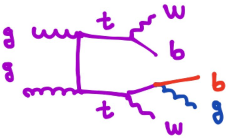
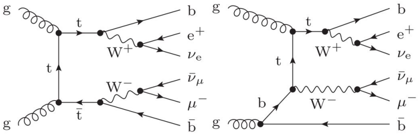
$pp \to W^+W^-b\bar{b}$ at the LHC

★ measurement of the top-mass: at the LHC likely to be achieved from combination of different strategies: total x-section, $t\bar{t}$ + jet, leptonic spectra, $b\ell$ endpoint and distribution,...
[see *e.g.* TOP LHC Working Group]



- some techniques rely on looking into the kinematics of visible particles from top-decay
- important that simulations are as accurate as possible, and associated uncertainties are quantified

★ $t\bar{t}$ vs. tW: by including decays with massive b, unified treatment of $t\bar{t}$ and tW:



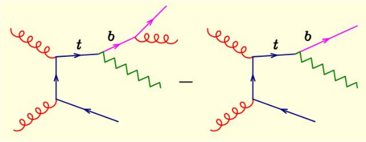
- “ $t\bar{t}$ ” $\to WWbb$: 2 resolved b-jets
- “ Wt ” $\to WWb$: veto on second b-jet
- arbitrary cuts on the other objects

★ jet-vetoes: used in many searches where $t\bar{t}$ is a background (*e.g.* $H \to W^+W^-$):

- vetoes can also act on decay products (*e.g.* b-jet veto)

NLO+PS & intermediate resonances

The problem, in a nutshell:



$$d\sigma = d\Phi_{\rm rad}\bar{B}(\Phi_B)\frac{R(\Phi_B,\Phi_{\rm rad})}{B(\Phi_B)} \times \exp\left[-\int \frac{R(\Phi_B,\Phi_{\rm rad})}{B(\Phi_B)} d\Phi_{\rm rad}\right]$$

- $\Phi_B \to (\Phi_B, \Phi_{\rm rad})$ mapping doesn't preserve virtuality
  $\Rightarrow R/B$ can become large also far from collinear singularity, but it shouldn't
- POWHEG radiation should have a well-defined resonance assignment, otherwise the shower will not preserve invariant masses, distorting the BW shape.
  - need to define a resonance history. However a full $WWbb$ computation contains non-doubly-resonant terms, interferences,...

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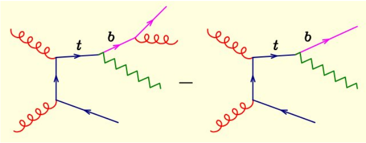

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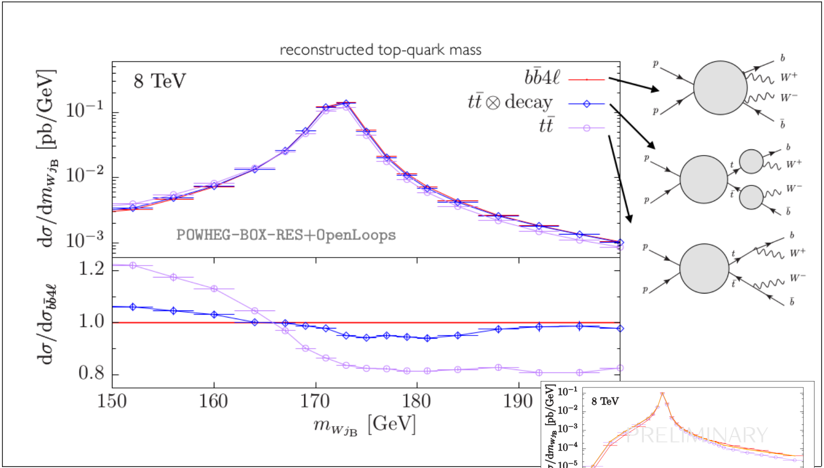
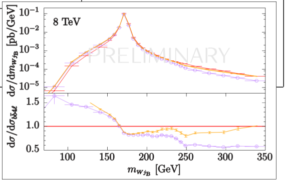
- Issues first addressed, for $pp \rightarrow b\bar{b} + 4$ leptons production, in the narrow-width approximation [Campbell,Ellis,Nason,ER '14]
- POWHEG BOX RES: general solution and new framework [Jezo,Nason '15]
  - applied to 4F t-channel single-top and $pp \rightarrow b\bar{b} + 4$ leptons (full exact NLO) [Jezo,Nason '15; Jezo,Lindert,Nason,Oleari,Pozzorini '16]
- in the MC@NLO matching scheme, 4-f t-channel single-top [Frederix et al. '16]

NLO+PS & intermediate resonances

- summary plot: [further studies and plots: J. Lindert talk at LHCP2017 and T. Jezo talk at the 4th CMS single-top WS]





NLO+PS & intermediate resonances

- ongoing pheno study on the impact on top mass extraction

  [Ferrario-Ravasio,Jezo,Nason,Oleari; in progress]

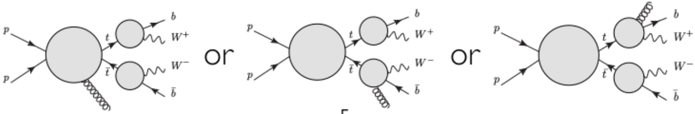
- in the context of the TOP LHC WG, this is a very active field, and we had a session with many of the people involved (TH, ATLAS and CMS)
  - discussed how to validate (and optimize) the use of these new tools (in ATLAS and CMS), in the context of the m_t extraction

★ possible activities:

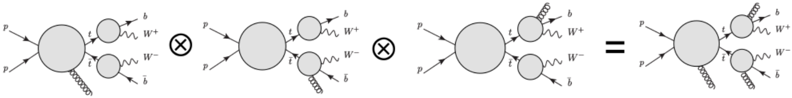
  - EXP study comparing matching to Pythia8 vs Herwig7
  - single-top t-channel: resonance-aware POWHEG vs. MC@NLO

interfacing (NLO) MEs with PS

- improvement of our tools often requires a more refined interface between ME and PS (at least in some cases)



$$\Longleftrightarrow \quad d\sigma = \bar{B}(\Phi_B)\, d\Phi_B \left[\Delta(q_{cut}) + \sum_{\alpha} \Delta(k_T^{\alpha}) \frac{R_{\alpha}(\Phi_{\alpha}(\Phi_B, \Phi_{rad}))}{B(\Phi_B)} d\Phi_{rad} \right]$$



$$\Longleftrightarrow \quad d\sigma = \bar{B}(\Phi_B)\, d\Phi_B \prod_{\alpha=\alpha_b, \alpha_{\bar{b}}, \alpha_{ISR}} \left[\Delta_{\alpha}(q_{cut}) + \Delta_{\alpha}(k_T^{\alpha}) \frac{R_{\alpha}(\Phi_{\alpha}(\Phi_B, \Phi_{rad}^{\alpha}))}{B(\Phi_B)} d\Phi_{rad}^{\alpha} \right]$$

[figures from J. Lindert talk at LHCP2017]

- more flexible interface: useful also new ideas being developed (multiple radiation), new MC's (like `Geneva`) or in view of future developments (e.g. interplay QED/QCD emissions)

interfacing (NLO) MEs with PS

Scales

It has been claimed that the shower starting/veto scales need to be more flexible. Something like that is already included in the Pythia8 which interprets eg. an attribute `pt_start_3="42"` in a `<scales>` tag as the starting scale of particle 3. These attributes are in addition to the `mups` defined in the current version together with `mur` and `muf`.

After discussions it was agreed that much of the complications of scale settings for individual particles must in any case be handled through specialized hooks into the parton shower, the interface of which is determined by the individual parton shower, with different implementations done by the respective matrix element providers. For this to work smoothly there is nevertheless a need to formalise the information that goes into the event file.

The suggestion is to allow subtags named `<scale>` with the content specifying a special scale in GeV. This tag can have a number of attributes:

- `stype` (mandatory) specifies the type of scale intended. The onle pr-defined value is `"veto"` for a veto scale for a parton shower emission. The variable in which this scale is defined depends on the ME generator that produced the event file. A PS generator reading the file must work out from the `<generator>` tag exactly in which kinematical variable to veto. In addition `stype` may correspond to a starting scale of the evolution for the PS, which again is different for different programs. It is up to the authors of the individual PS programs to specify the name to be used. One could e.g. imagine that Pythia8 decides to recognise `stype="pystart"`.
- `pos` specifies for which particle the scale applies, given by an integer where `"1"` is the first particle in the HEPEUP block. If more than one integer is given, it should be interpreted as specifying the emission from the first in a "dipole" connecting to any of the subsequent. If not specified this scale applies to all particles that do not have a specific `<scale>` tag.
- `etype` specifies the emission type for which the scale should be applied. This should be a list of integers corresponding to the PDG code of the emitted particle. Short-hands allowed are `"QCD"` corresponding to any quark or a gluon, and `"EW"` corresponding to any lepton or electro-weak gauge boson. If not supplied, the scale applies to any emission.

For any emission not matching a `<scale>` tag, the `mups` still applies, although whether this should be interpreted as a starting scale or a veto scale is not defined.

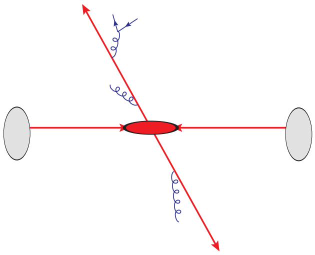
Splitting up the LHE file

★ plan: code and test what we agreed upon, using a relatively simple case

- document and share with all MC community, get feedbacks
- make sure that all will work smoothly when used by experimentalists
- might become a LHE v4

perturbative uncertainties in MC generators

Sources of uncertainty & correlations



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}

...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 $k_\perp$"

1. Parton showers "undo" PDF evolution.
2. Short-distance x-sections for matching assume certain PS settings.
3. Hadron p_Ts can be non-perturbative, or inherited from partons

perturbative uncertainties in MC generators

slide from S. Prestel talk at LH

Towards uncertainty recommendations?

Goal: Find consensus how to vary μ_f^H, μ_r^H and μ_q^{PS}.

If we find consensus, can we add μ_r^{PS} and μ_f^{PS} to the mix?

One possible way to find consensus could be to adopt conservative consistency conditions, e.g.:
◇ Backwards evolution of initial state showers allows only small differences of μ_f^H and μ_q^{PS}

perturbative uncertainties in MC generators

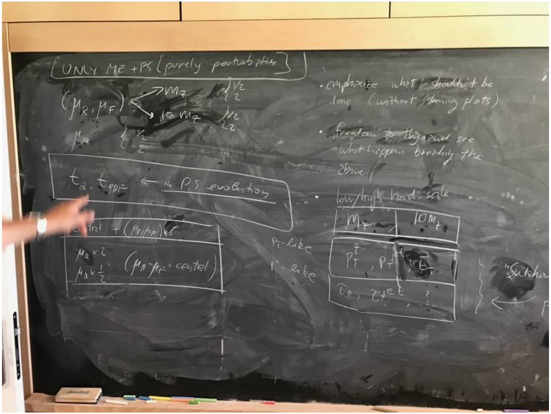
- probably we're not yet in the position of addressing this issue properly, for the scales entering the PS evolution
- but we all agree on the allowed variations for the other scales

★ plan: detailed comparison of several MC generators. We'll look into Drell-Yan:
  - more people can participate
  - try to look at several observables, without including non-perturbative effects
  - the agreed setup should allow to expose possible interesting features

- by having a comparison with analytic resummation (where available), hopefully we'll gain some insight on how to address the original question

perturbative uncertainties in MC generators

we have discussed...



...and agreed...

$\Rightarrow$ so hopefully this will be done

perturbative uncertainties in MC generators

...and of course extra studies aimed at studying effects on varying PS scales and other inputs are welcome

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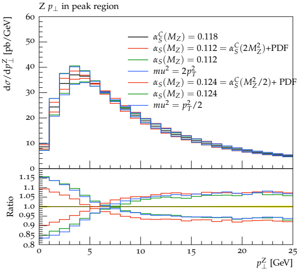


PRELIMINARY plots with Herwig7 from J. Bellm

Procedure:

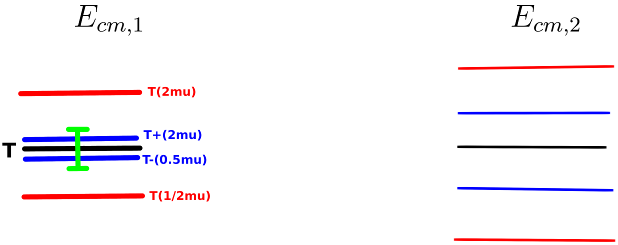
- choose a central value of α_S^C at a given scale μ.
- vary $\alpha_S(\mu^2) \rightarrow (\alpha_S(2\mu^2), \alpha_S(1/2\mu^2))$
- Use the “new/varied” values of α_S as $\alpha_S(\mu)$
- Change the PDF sets to match the “new/varied” $\alpha_S(\mu)$
- Get red lines.

Otherwise:

- change only the α_S values $\rightarrow$ green lines.
- change the scale t_R that the shower uses to emit by 2 or 1/2. $\rightarrow$ blue lines.

Tunes and scale variations

★ what happens when tunes are used to other energies



- interplay between tuning (of PS perturbative parameters) and scale variations. Need to introduce scale uncertanties in tunes?
- tune on $\mathcal{O}_1, ..., \mathcal{O}_n$ at $E_{cm,1}$, see results at $E_{cm,2}$. Are they consistent?
- at E_1: tune on $\mathcal{O}_1, ..., \mathcal{O}_k$, see predictions for other observables $\mathcal{O}_{k+1}, ..., \mathcal{O}_n$

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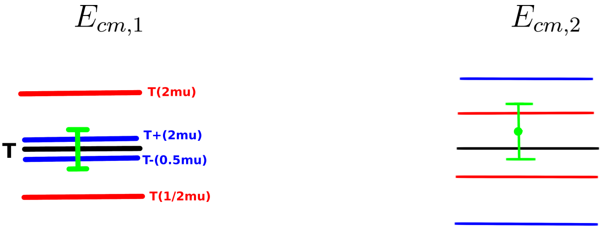

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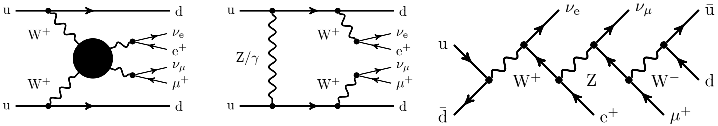
Vector Boson Scattering (VBS)

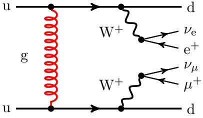
→ The LO is defined at order $\mathcal{O}\left(\alpha^6\right)$

Diagrams from Mathieu Pellen



VBS-like topology

- Background process: QCD-induced process



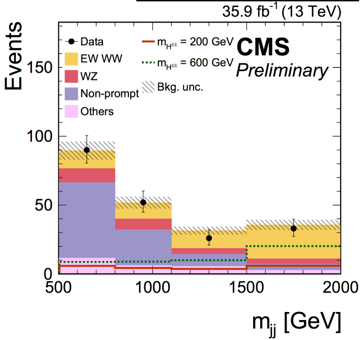
Interference usually small in VBF-like topology

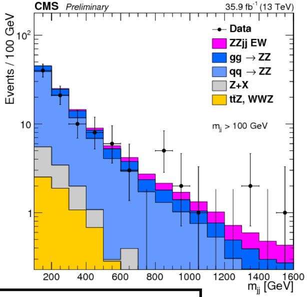
First results at Run II

- **pp → jjW±W±**
- First measurement with **> 5σ**
- Background: **non-prompt** and leptonic **WZ with one lepton lost**
- Unique from other VBS channels

- **pp → jjZZ**
- BDT training to optimize sensitivity
- Observed significance **2.7σ** (expected 1.6σ)
- Background **QCD-induced ZZ**

CMS-PAS-SMP-16-019





CMS-PAS-SMP-16-019

2

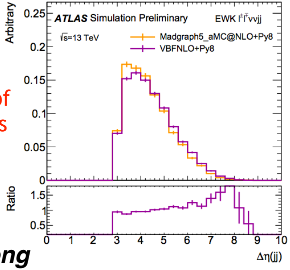
EWK Comparisons

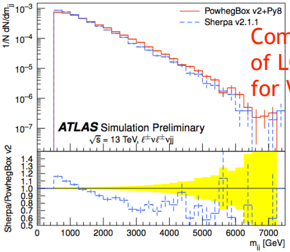
- For showered+hadronized events, differences in EWK processes aren't always within published (fixed order) uncertainties
  - Extensive comparisons published by ATLAS
- What does this tell us on how we should derive uncertainties?

ATL-PHYS-PUB-2017-005

		$VV+2j$	$VV+3j$	$VV+\geq 4j$
$VVjj = \ell^{\pm}\ell^{\mp}2\nu jj$	VBFNLO+PYTHIA8	LO	PS	PS
	MadGraph5_aMC@NLO+PYTHIA8	LO	PS	PS
$VVjj = \ell^{\pm}\ell^{\pm}2\nu jj$	Sherpa	LO	PS	PS
	PowhegBox+PYTHIA8	NLO	LO	PS

Comparison of LO generators for $W^{\pm}W^{\mp}jj$





(d) m_{jj}

Comparison of LO vs NLO for $W^{\pm}W^{\pm}jj$

Kenneth Long

Project outline

Processes to be studied:

- first: **pp → jj W^+Z → jj** $e^+\nu\mu^+\mu^-$
- then: **pp → jj W^+W^- → jj** $e^+\nu\mu^-\nu$

- assess **off-shell** and **interference** effects at LO (without PS) for different $\mathbf{\Delta\eta_{jj}}$ and $\mathbf{m_{jj}}$ cuts
- define **"signal"** (VBS topology) vs **"background"** (QCD-like topology) phase space regions
- assess to which precision **VBS-like approximation for NLO** calculation is reliable
  - neglected effects are similar those from off-shell
- study if by taking the **ratio of cross-sections** in "signal" and "background" regions some **theory uncertainties on QCD VVjj** production cancel out
- [**(optional)** check the size of VBS WW production as background to **VBS H→WW** production]

People: Kenneth, Mathieu, Vitaliano, Simon, Efe, Carlo, Reina, Marco…

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Thank you for your attention!