Les Houches studies on MC modeling

Carlo Pandini (*summarizing* Les Houches discussions from many people)

16th Workshop of the LHC Higgs Cross Section Working Group

Cern, 16-18 October 2019

Introduction and outline

From 1999 to 2019..
20 years of LH!

https://phystev.cnrs.fr/index.php
https://phystev.cnrs.fr/wiki/2019:programme

Very specific "hands-on" workshop structure

- almost no scheduled talks / presentations
- theorists + experimentalists together in the same room
- list of topics built together before and during the workshop
- goal: well-defined "Les Houches projects" to study specific topics (summarized in the LH proceedings)
- two 10-day sessions: SM and BSM

Very informal structure: by nature impossible to cover every discussion in a short summary

*People not attending the workshop are encouraged to participate to the LH projects before/during/**after** the workshop: if interested please get in contact to contribute!*

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- goal:
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Summarizing Les Houches discussion not simple

(some material from July HXSWG parton-shower meeting: first summary from E. Re)

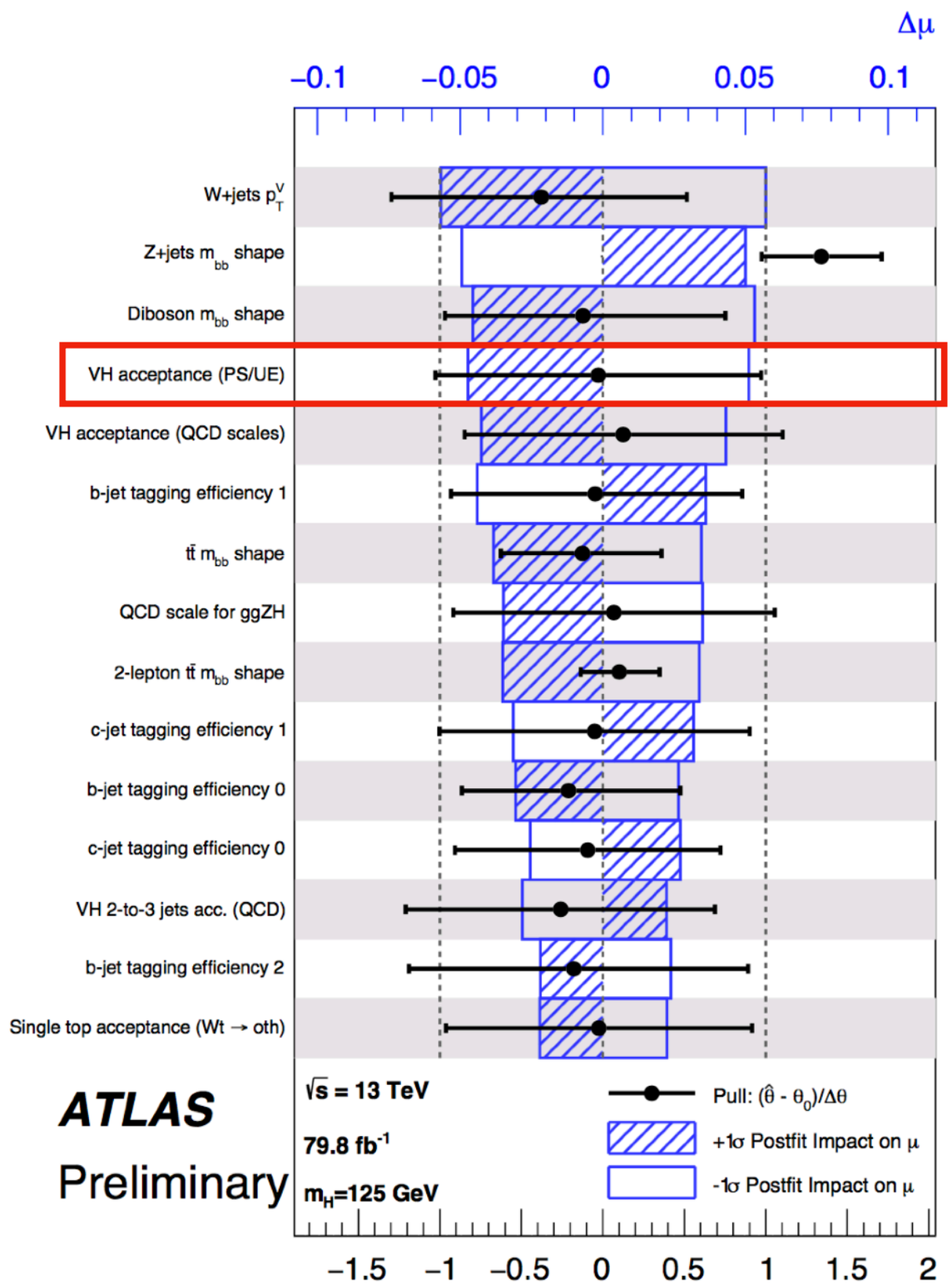
(some personal bias from an ATLAS-experimental view)

Very informal structure: by nature impossible to cover every discussion in a short summary

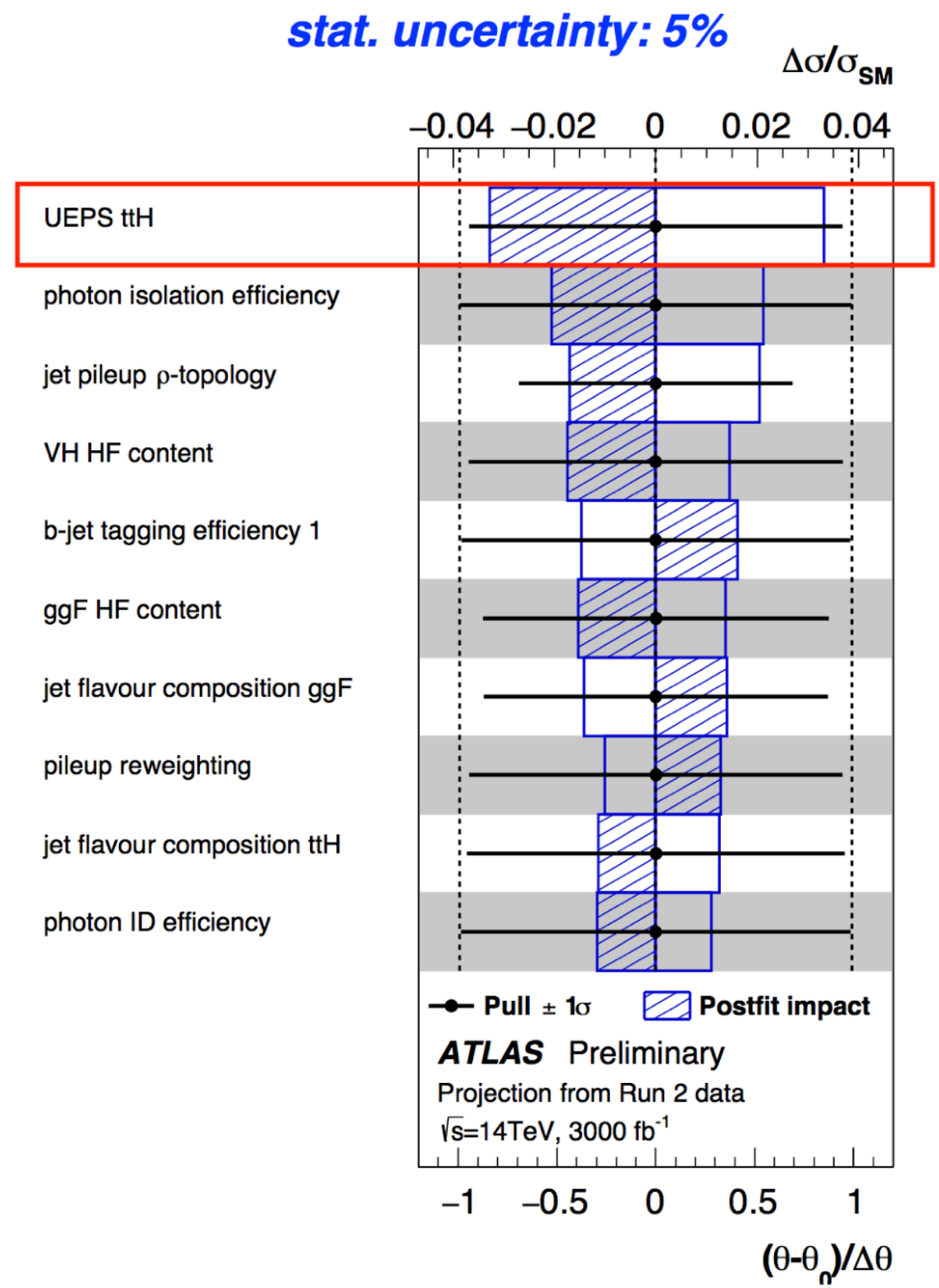
https://phystev.cnrs.fr/wiki/2019:start

Parton-shower modeling in experimental analyses

VHbb: ATLAS 80/fb



ttHyy: ATLAS 3000 fb^{-1}



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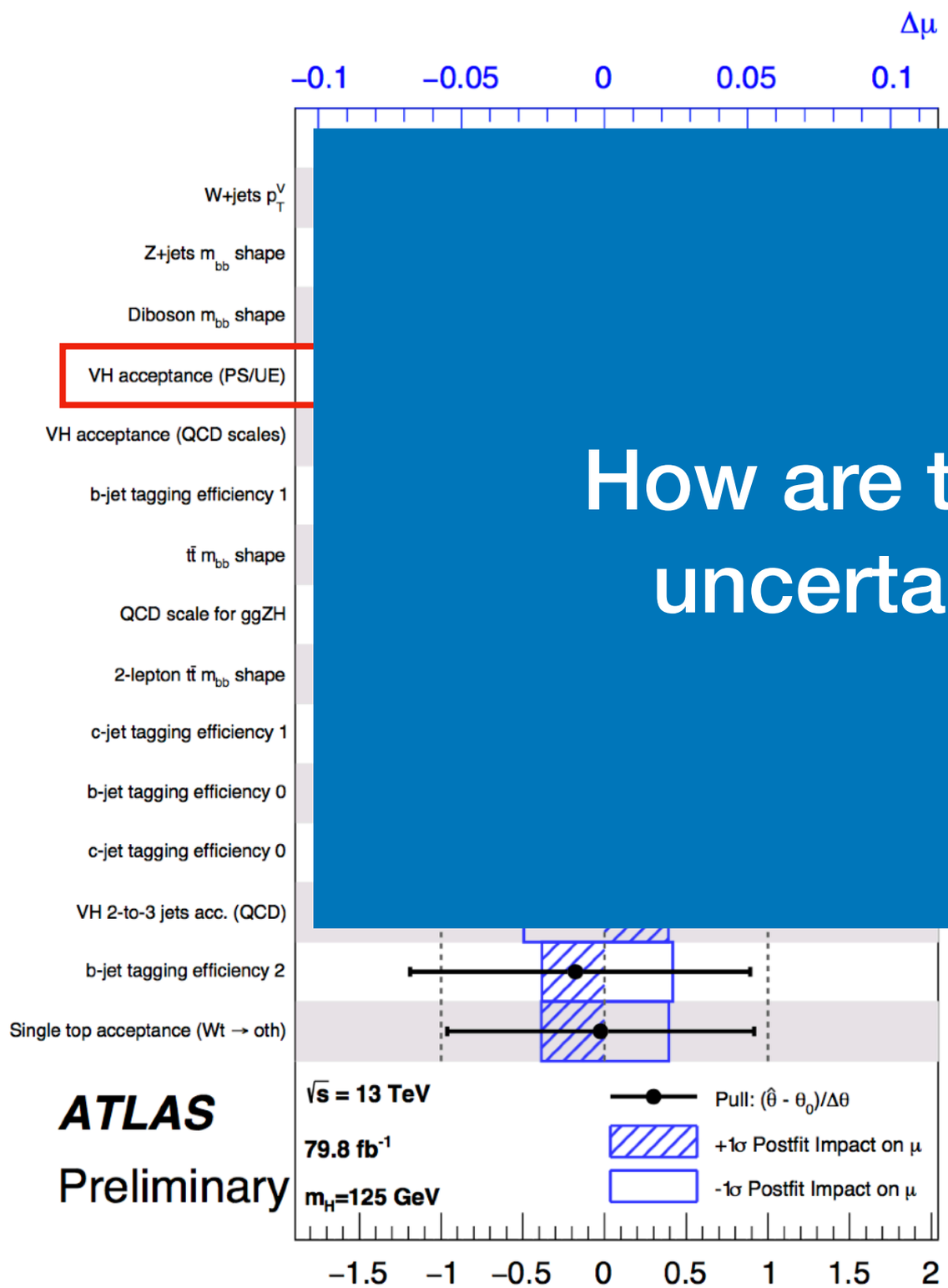
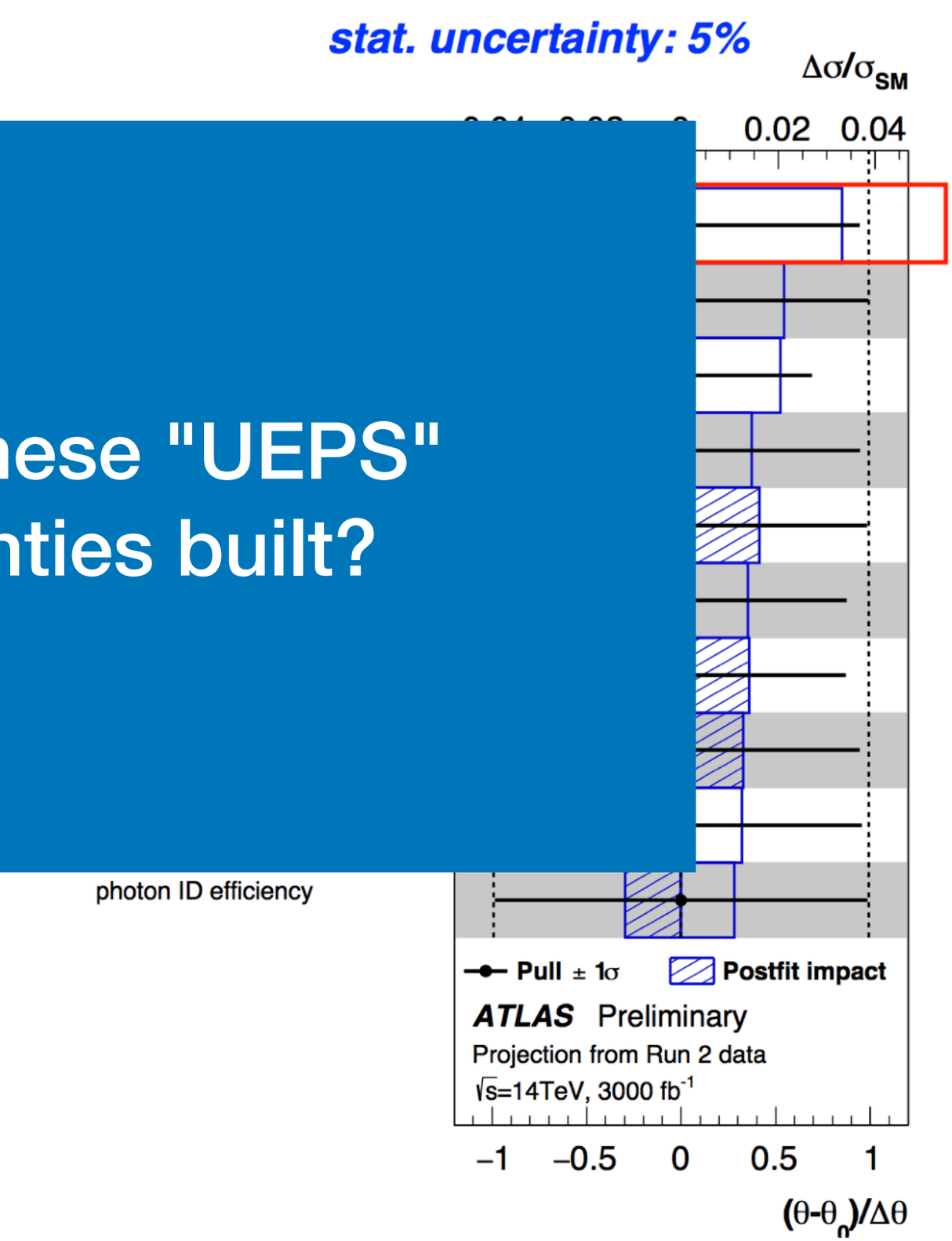


ttHyy: ATLAS 3000 fb^{-1}



How are these "UEPS" uncertainties built?

Ingredient 1: tune variations AZNLO

AZNLO: *designed for the Powheg+Pythia8 NLO+PS generator, and provide a very good description of ISR in the low and medium p_T region*

Measurements of the $Z/\gamma*$ boson transverse momentum distribution (and ϕ^*_η angular correlation) in pp collisions at $\sqrt{s}$ = 7 TeV

JHEP, 09:145, 2014

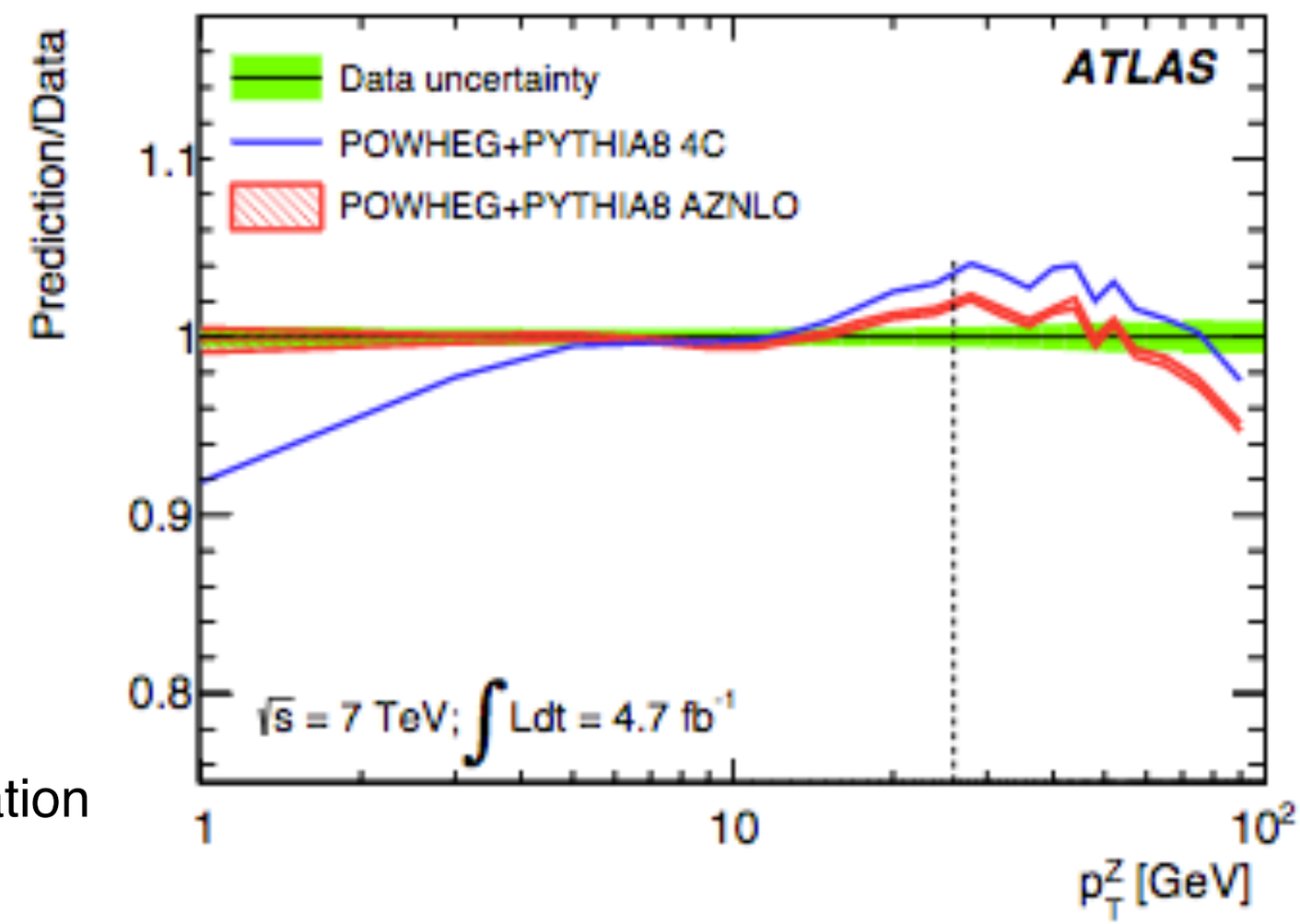
1211.6899

Strategy for the Powheg+Pythia8 tune → tunes performed for **$p_T(Z)$<26GeV** and ϕ^*_η<0.29 (best description of the tuning parameters)

The tuning only varies the ISR shower cut-off and the primordial k_T in Pythia8

	POWHEG+PYTHIA8
Tune Name	AZNLO
Primordial k_T [GeV]	1.75 ± 0.03
ISR $\alpha_S^{ISR}(m_Z)$	0.118 (fixed)
ISR cut-off [GeV]	1.92 ± 0.12
χ^2_{min}/dof	46.0/33

Tuned predictions agree with the measured XS within 2% for $p_T(Z)$<50GeV



"Eigentune variations":

covering ISR/primordial-k_T variations + ren. scale variations for FSR, and MPI cut-off

- VAR1,VAR2: eigentune diagonalization
- MPIUp, MPIDown
- FSRUp, FSRDown

Ingredient 1: tune variations AZNLO

AZNLO: ... *ator, and provide a v... n p_T region*

EP, 09:145, 2014

1211.6899

Strategy for th... ϕ^*_η<0.29 ...ters)

The tuning onl... and the... essentially co... - not affec... (pl...

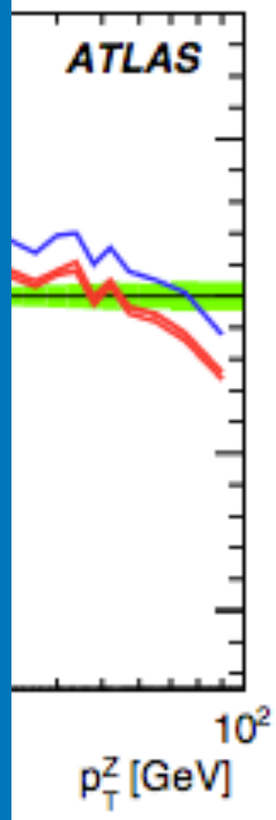
Tuned predict... XS with...

"Eigentune va...

only covering ISR/p... ren. scale variations... paramaters are rec... UE/PS/MPI uncerta...

AZNLO tune	primordial k_T	ISR cut-off
central	1.749	1.924
eigentune 1+	1.719	1.919
eigentune 1-	1.780	1.928
eigentune 2+	1.762	1.844
eigentune 2-	1.737	2.004

- *UE uncertainty:* Variation of the MPI Cut-off : between 1.91 to 2.05
- *FSR uncertainty:* Variation of the renormalization scale: 0.5 to 2



Ingredient 2: parton-shower model

Pythia8: *transverse momentum ordered (ISR, FSR, MPI)*
Lund String model (hadronization)
Herwig7: *angular ordered*
Cluster Model (hadronization)
(different evolution variable)

} *Pythia8 vs Herwig7 encodes many differences / **not** a complete summary*

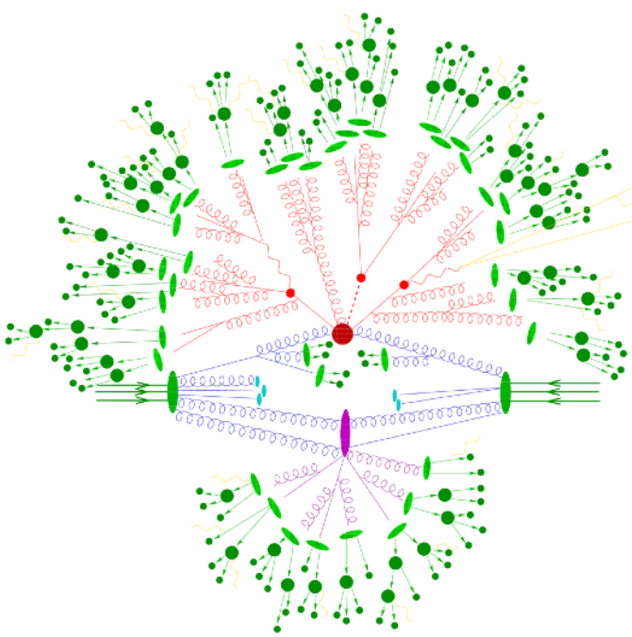
UEPS uncertainty model for Higgs signals:

process	Nominal generator generator	alternative PS generator	additional unc.
ggH	Powheg (NNLOPS) + Pythia 8 (AZNLO)	Powheg (NNLOPS) + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
VBF	Powheg + Pythia 8 (AZNLO)	Powheg + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
VH	Powheg (MINLO) + Pythia 8 (AZNLO)	Powheg (MINLO) + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
ttH	Powheg + Pythia 8 (A14)	aMC@NLO + Herwig++(UEEE5) VS aMC@NLO + Pythia 8 (A14)	

Parton shower modeling and MC variations

Longstanding discussion of "UEPS" uncertainties: ongoing since many LHs, topic of debates within HXSWG ... hard to find contact point between TH and EXP views

TH view: intricate combination of fine detail effects



Multi-purpose MC+PS generators

hard scattering

radiation cascade

multiparton interactions

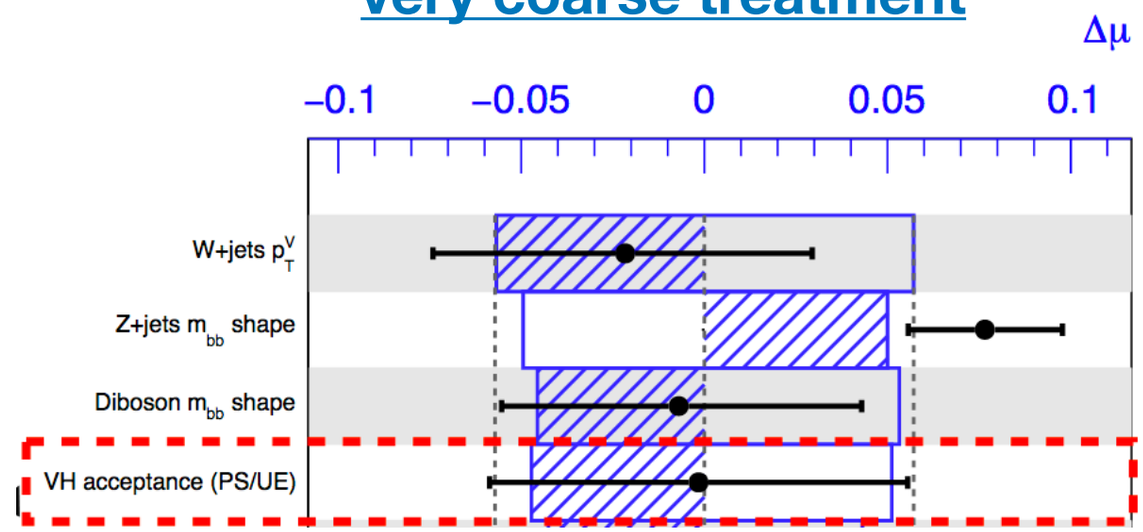
hadronization and decay

- each model contains parameters
- matching of different models (for different QCD regimes) introduces additional parameters: interdependencies and correlations!
- some parameter **variations** are studied in TH, though far from complete

Far from an agreement on how to define a **MC uncertainty**

Hard to define what is a **PS uncertainty**

Experimental analysis: very coarse treatment



"UEPS uncertainty" mostly from Pythia8 / Herwig7

[clearly 2-point/model comparison is very far from detailed studies of MC parameter variations]

Tools available to be more sophisticated (PS weights) but not much experience using them

***Experimental wishes*: motivated by large unc. (we are doing this wrong and seeing large effects): which param. variations should we consider? which physics effects are covered?**

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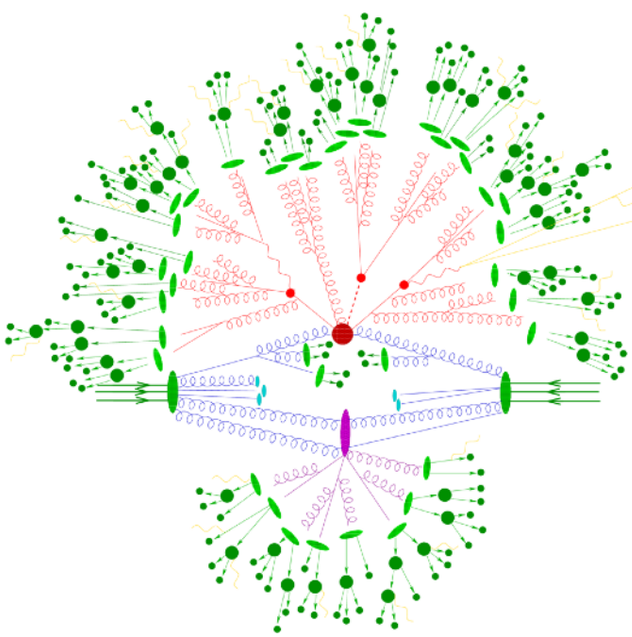

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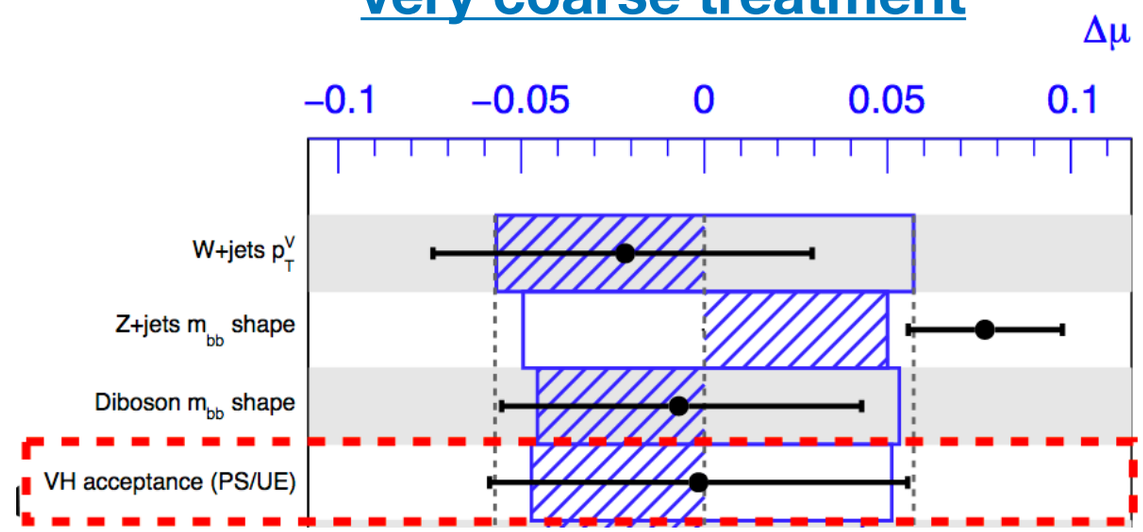

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[clearly 2-point/model comparison is very far from detailed studies of MC parameter variations]

Tools available to be more sophisticated (PS weights) but not much experience using them

***Theory perspective*: treatment of these uncertainties in experimental analyses often not very transparent / documented**

Hard to fully understand the meaning of "UEPS" parameters

Parton shower modeling and MC variations

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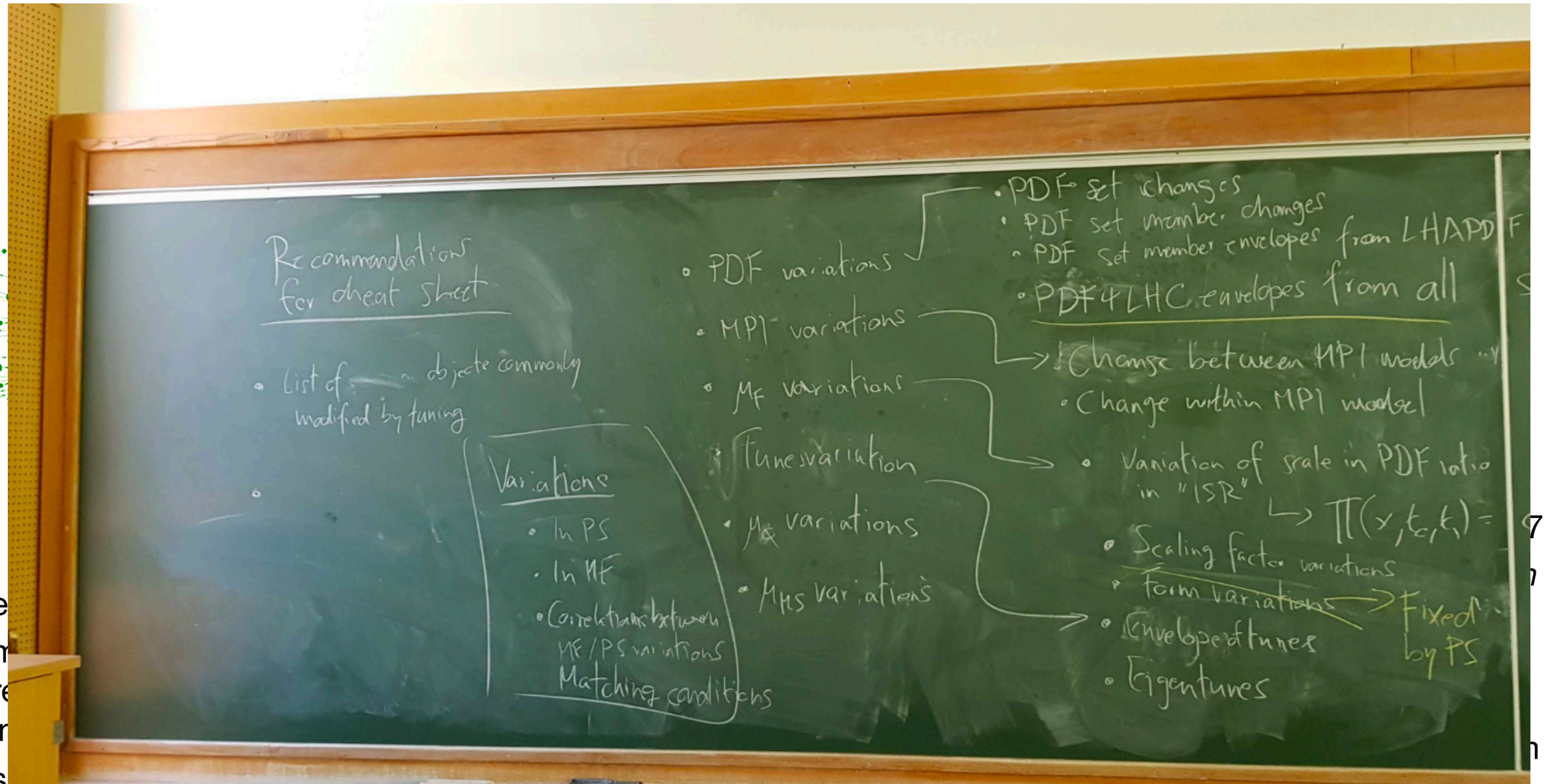

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Far from an agreement on how to define a **MC uncertainty**

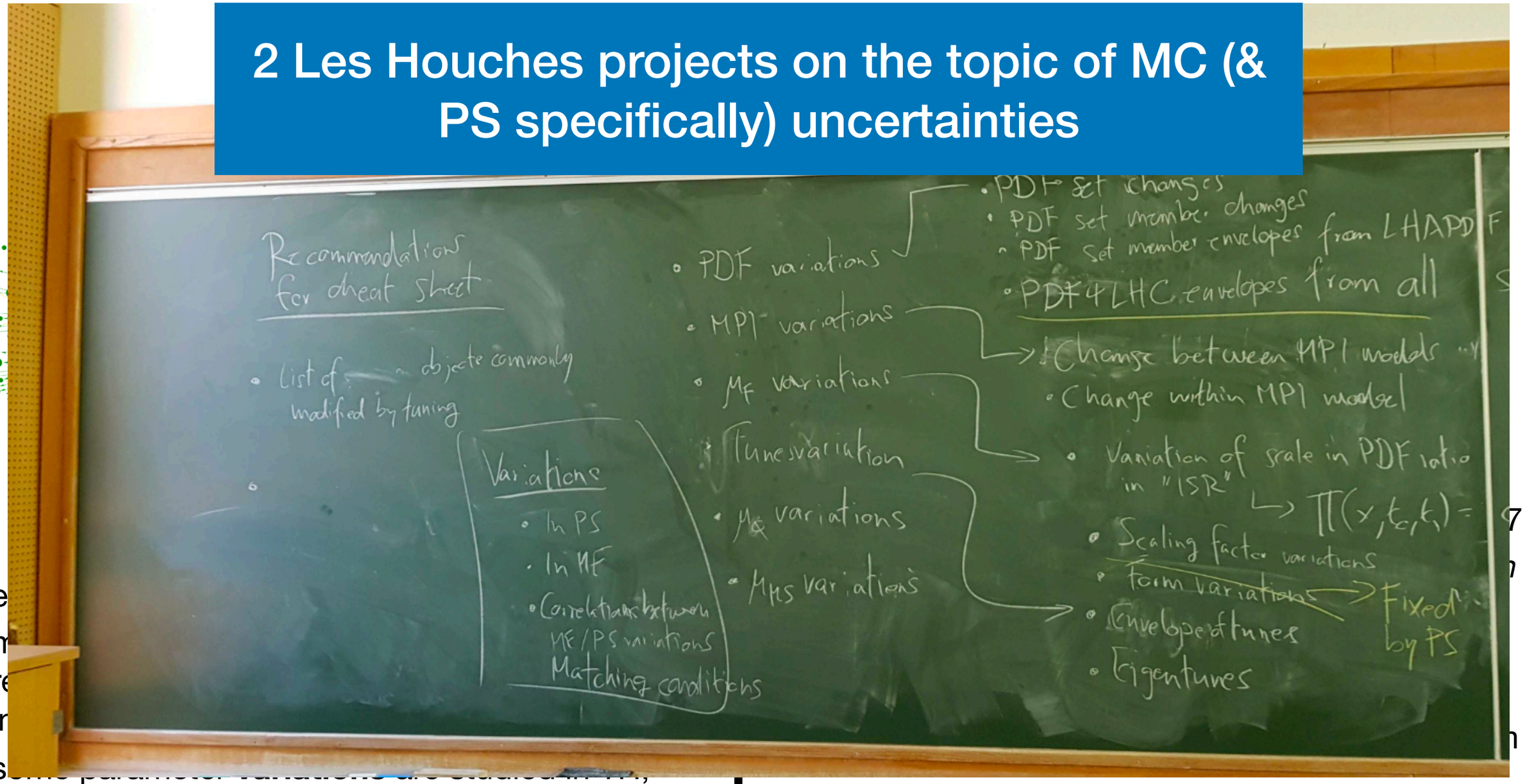
Hard to define what is a **PS uncertainty**

Discussions starting from clear exp. need (we are doing this wrong and seeing large effects) but often lost in treatment of fine TH details

Parton shower modeling and MC variations

Longstanding discussion of "UEPS" uncertainties: ongoing since many LHs, topic of debates within HXSWG ... hard to find contact point between TH and EXP views

2 Les Houches projects on the topic of MC (& PS specifically) uncertainties



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Far from an agreement on how to define a **MC uncertainty**

Hard to define what is a **PS uncertainty**

Discussions starting from clear exp. need (we are doing this wrong and seeing large effects) but often lost in treatment of fine TH details

Theory compendium for MC variations

Discuss what **parameter variations are possible in General-Purpose MCs**:
this should help build an intuition on which of these variations can affect which measurements

Project #1: Theory Nomenclature for MC variations

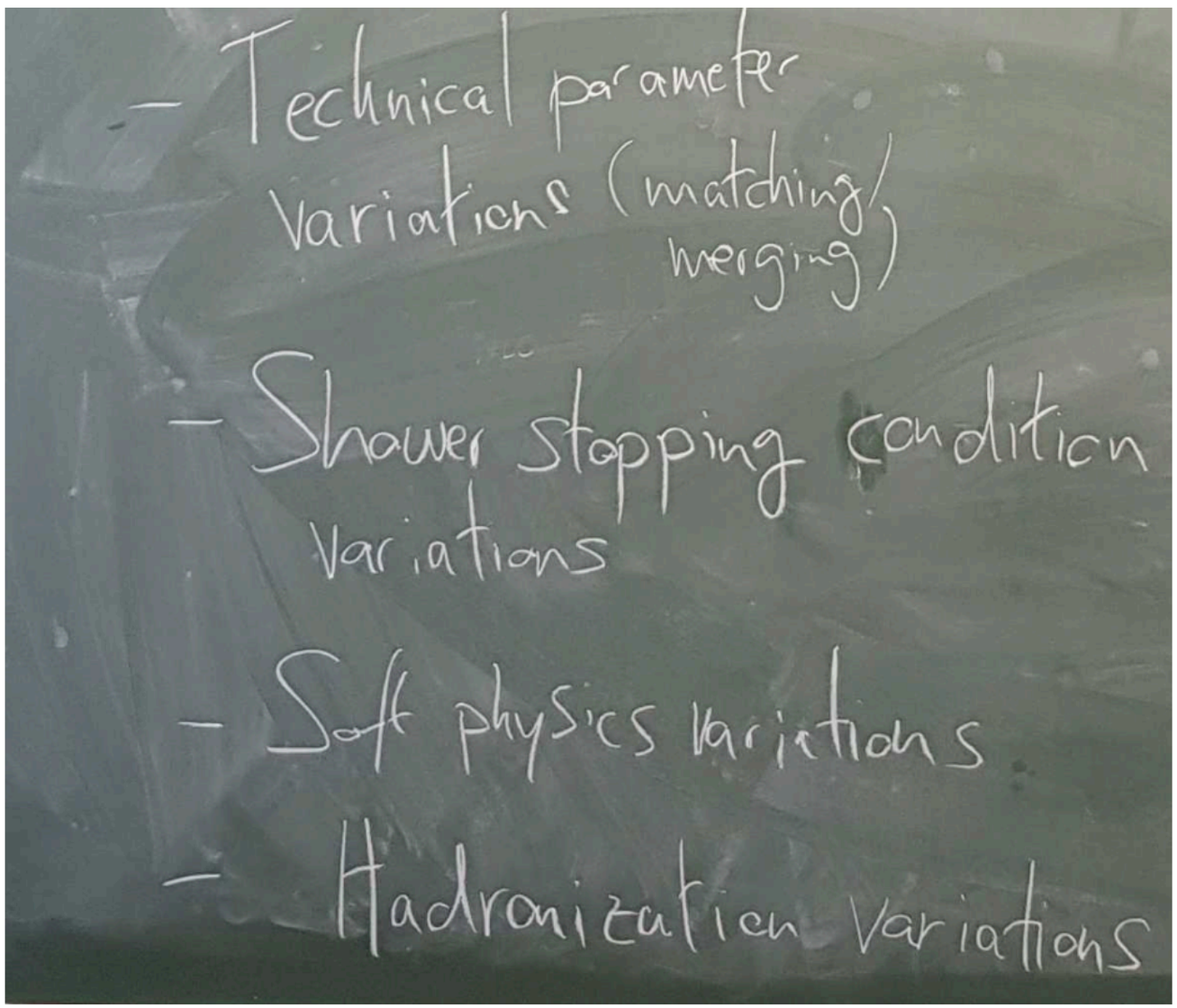
- comprehensive **list of parameter variations** in General Purpose MC+PS
- **common naming convention** for variations across different tools / codes
- exact interpretation of "variation X", and which phenomena it influences
- **correlation** scheme among variations
- constraints / suggested ranges / "good practices" for each variation
- examples of set of MC variations relevant for different cases (possibly with plots)
  (e.g. QED shower for bare leptons, hadronization for small-R jets, MPI for large-R jets, etc.)

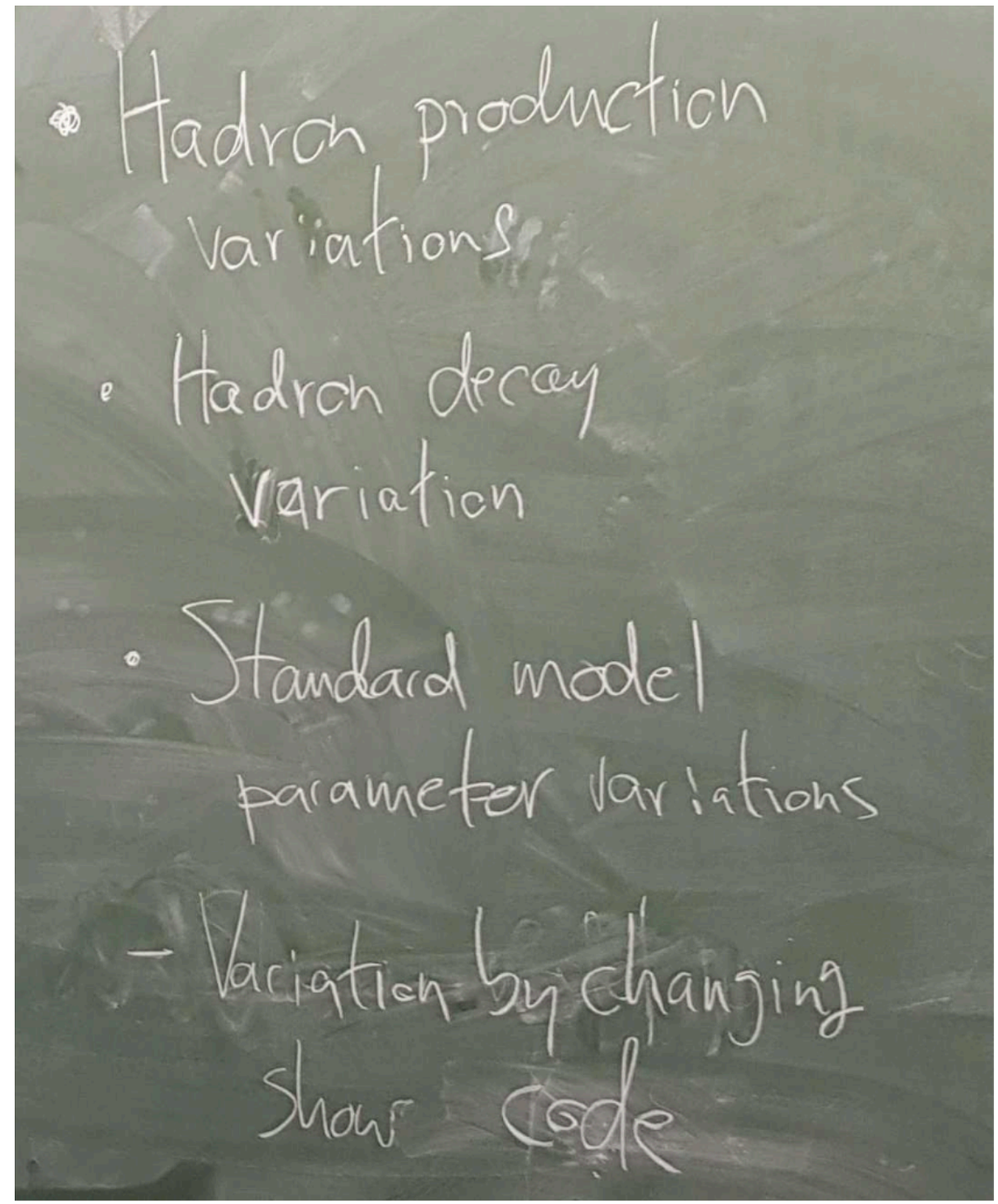
Key to include all MC developers: suggested to coordinate this project via MCNet

Feedback from the experimental side is also critical: especially considering what is ***technically feasible*** *with MC tools available in experimental collaboration / CPU constraints*

Theory compendium for MC variations

Some examples from the **Les Houches blackboards**: enumerating variations from f.o. and PS





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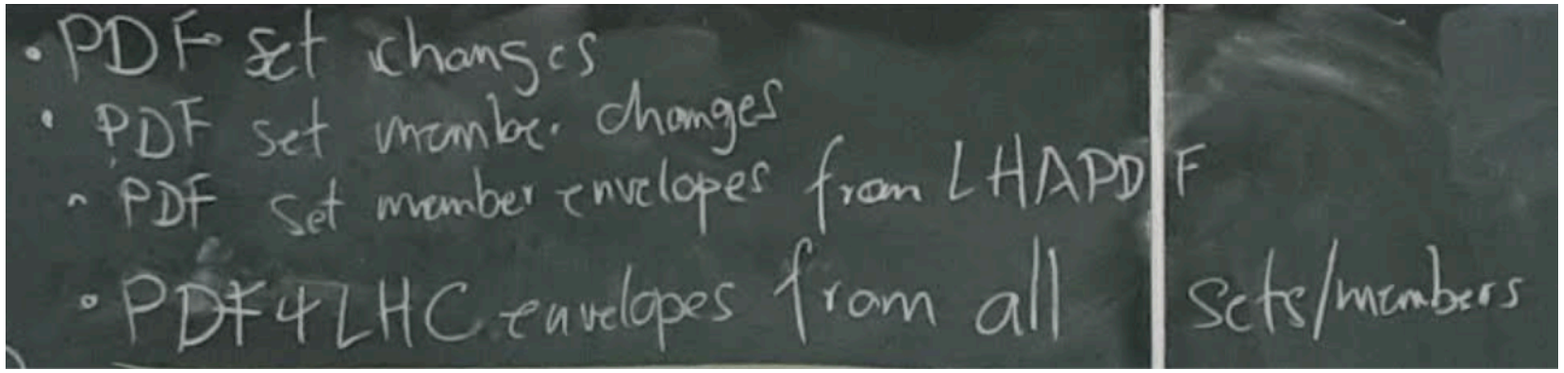
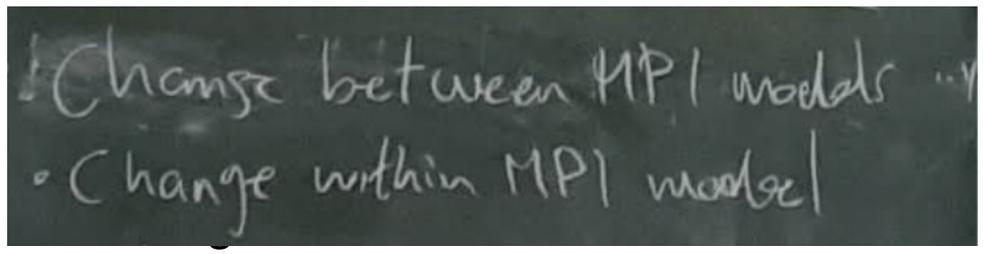
PDF variations



MPI variations



Tune variations

- Variation of typical tuning parameters in-between different tunes, given a list of parameters commonly modified by tuning.
- Envelope of different tunes
- Envelope/variation supplied together with one tune, e.g. eigentunes

Shower starting conditions

- muQ variations (short-hand for variation of shower starting conditions)
- Variation of functional form of starting conditions
- Variation of parameters of one form of starting conditions, e.g. of numerical value of shower starting scale or shower veto scale.

Ambitious project: #variations and handles from TH predictions easily "divergent"
(not mentioning here correlations between parameters!)

Case study of MC variations

Several possible case study to apply the above compendium have been discussed:
ttH very interesting and motivated by large unc. but more complex, VBF H, DY, ...
***Settled on ttbar**: standard candle with many measurements, good proxy for ttH, ...*

***Project #2: Case Study of MC variations** (trying to apply Project #1 to a useful case: **ttbar**)*

- ttbar case study, 2-3 observables to be selected
- consider different central setups ("N-points") of {FO/matching/merging accuracy), PS model, NP model}
- for each setup define envelope of MC variations (~based on Project #1)

1. **does it behave as expected?**
   (e.g. dependence on NP model in region dominated by hard physics, too large dependence on shower model, other signs of inconsistencies, ...)
2. **does it overlap across central setups? if not, can we understand if it's expected?**

Going towards properly defining what we call "UEPS" uncertainty (at least for one test case)

Continuation of what was done in LH15 (1605.04692):

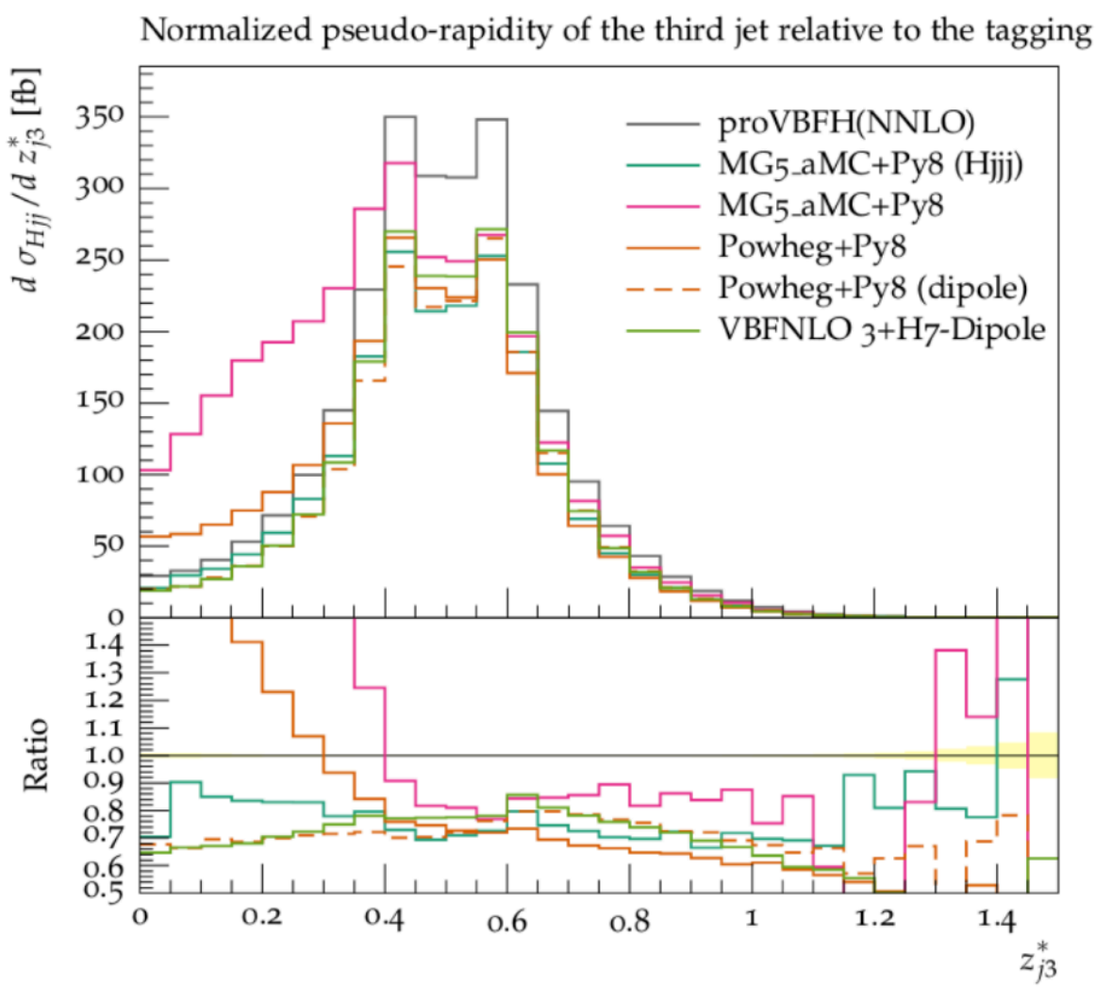
- higher accuracy in the ME part, better frameworks for “PS-reweighting”
- chosen $t\bar{t}$: NLO+PS not too computationally intensive, rich phenomenology, plenty of ATLAS/CMS studies with very similar setups, data and Rivet routines available, some TH studies already performed (e.g. HW7, 1810.06493)

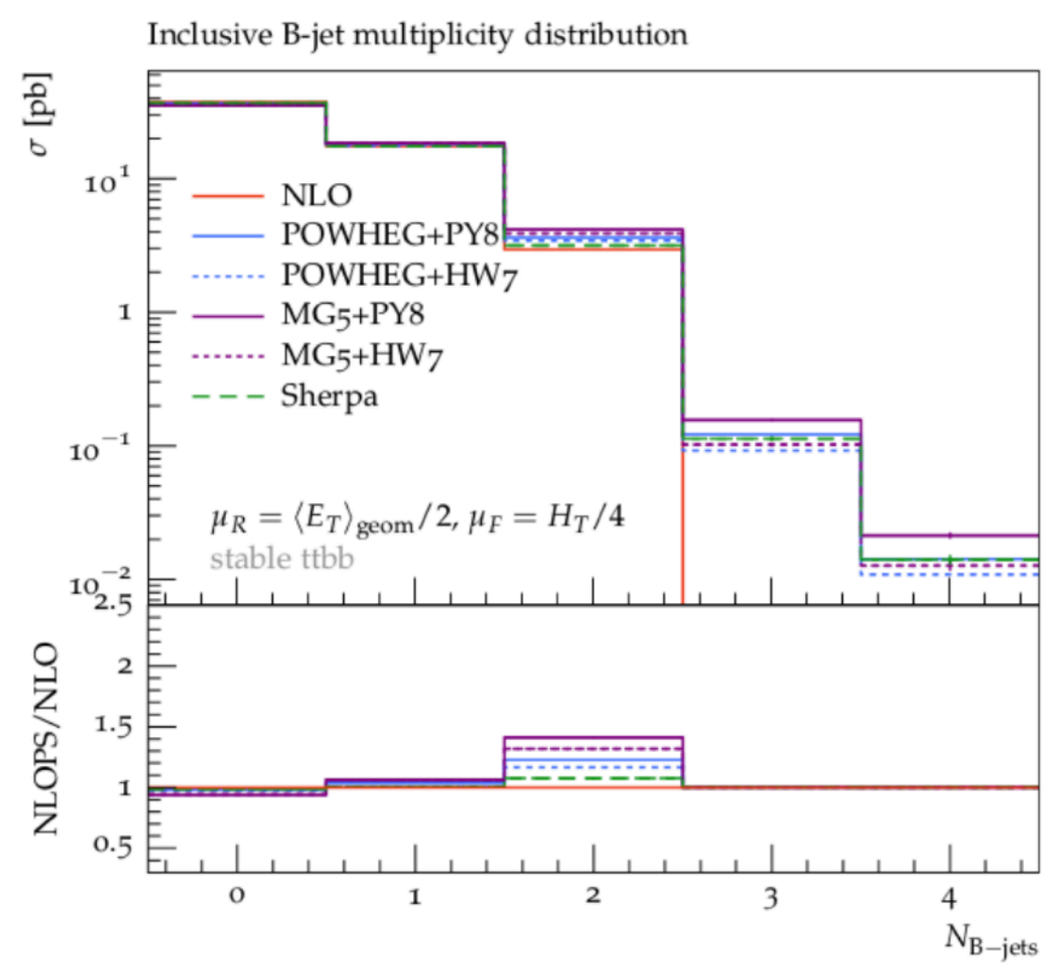
Interesting study for Higgs modeling as well: dedicated HXSWG WG1 meeting

Will to consider a "case study" project for an Higgs process (VBF?)

Case study of MC variations

- (to me) this approach seems suitable to highlight issues, if there (as done in the context of the HXSWG for VBF and $t\bar{t}H(\to b\bar{b})$).





- it should also clearly show that, unless unavoidable, it's not a good idea to estimate an uncertainty comparing a LO+PS vs. NLO+PS generator.
- it also seems to go towards what the EXP community is asking for.

(from E. Re)

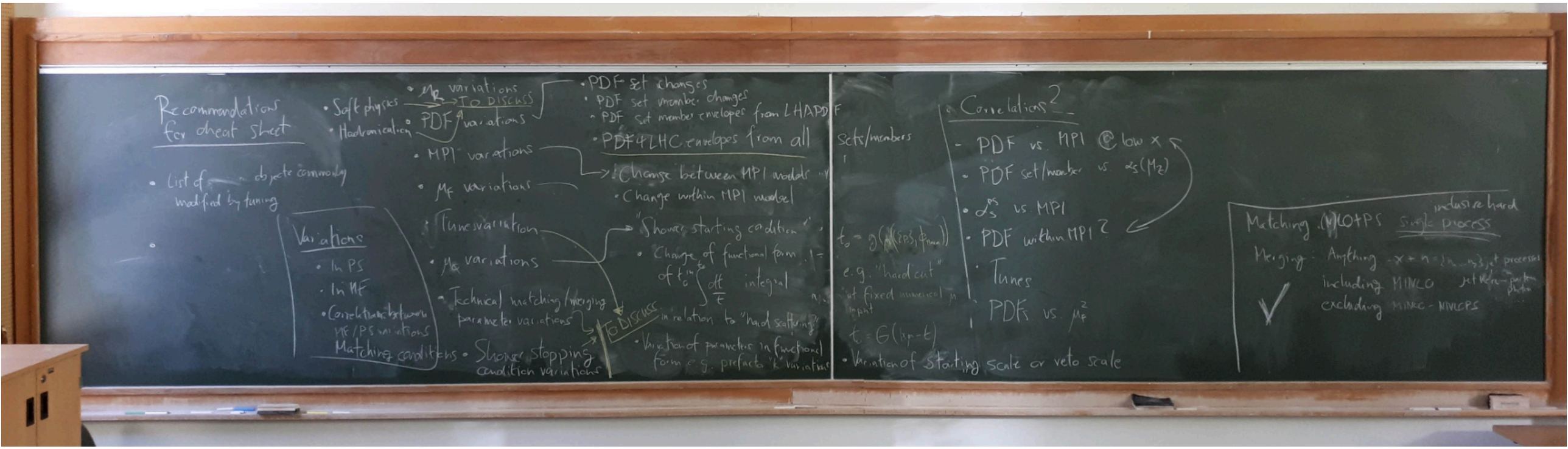
"Summary" of Les Houches discussions

As always lots of very interesting discussions on the topic of parton-shower modeling (and more generally MC uncertainties)

- discussion between TH and EXP: wish lists / what's feasible / how to improve ...
- 2 MC uncertainty projects from LH discussions: lots of interest in LH from MC developers and experimentalists
- not a lot of quantitative progress from LH until now: time to pick up the effort towards LH proceedings
- HXSWG and parton-shower modeling / uncertainties: several common points, we could for sure benefit from the LH results, and support them with Higgs studies

https://phystev.cnrs.fr/wiki/2019:start

BACK-UP


Recommendations for cheat sheet
• Soft physics
• Hadronization
• PDF variations
TO DISCUSS
• MPI variations
• μF variations
• Tunes variation
• μR variations
• Technical matching/merging parameter variations
• Shower stopping condition variations
• PDF set changes
• PDF set member changes
• PDF set member envelopes from LHAPDF
• PDF4LHC envelopes from all
• Change between MPI models
• Change within MPI model
"Shower starting condition"
• Change of functional form
integral
TO DISCUSS
in relation to "hard scattering"
• Variation of parameters in functional form e.g. prefacto "k" variations
• List of objects commonly modified by tuning
Variations
• In PS
• In MF
• Correlations between MF/PS variations
Matching conditions
sets/members
e.g. "hard cut"
• Variation of starting scale or veto scale
• Correlations?
- PDF vs. MPI @ low x
• PDF set/member vs. αs(MZ)
• αs vs. MPI
• PDF within MPI?
• Tunes
• PDFs vs. μF2
Matching (N)LO+PS
inclusive hard
single process
Merging: Anything
including MINLO
excluding MINLO - NNLOPS

Intermezzo: tune comparison

courtesy of C. Pandini

Parameter **A14**	Definition	Sampling range
`SigmaProcess:alphaSvalue`	The α_S value at scale $Q^2 = M_Z^2$	0.12 – 0.15
`SpaceShower:pT0Ref`	ISR p_T cutoff	0.75 – 2.5
`SpaceShower:pTmaxFudge`	Mult. factor on max ISR evolution scale	0.5 – 1.5
`SpaceShower:pTdampFudge`	Factorisation/renorm scale damping	1.0 – 1.5
`SpaceShower:alphaSvalue`	ISR α_S	0.10 – 0.15
`TimeShower:alphaSvalue`	FSR α_S	0.10 – 0.15
`BeamRemnants:primordialKThard`	Hard interaction primordial $k_\perp$	1.5 – 2.0
`MultipartonInteractions:pT0Ref`	MPI p_T cutoff	1.5 – 3.0
`MultipartonInteractions:alphaSvalue`	MPI α_S	0.10 – 0.15
`BeamRemnants:reconnectRange`	CR strength	1.0 – 10.0

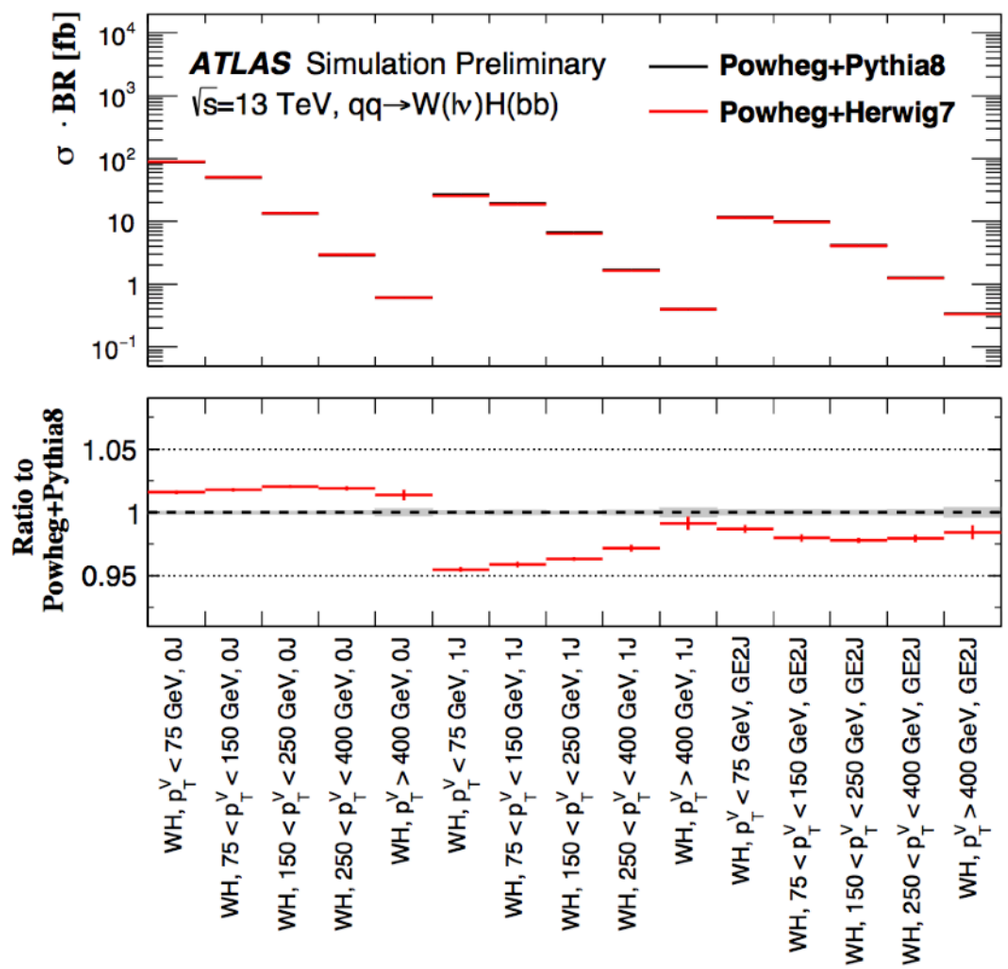
Generator Tune name	**AZNLO**	POWHEG+PYTHIA8 AZNLO
Base tune		4C
PYTHIA8 PARAMET		
primordial k_T	BeamRemnants:primordialKThar	1.75
ISR $\alpha_s^{ISR}(M_Z)$	SpaceShower:alphaSvalue	0.118
ISR cut-off	SpaceShower:pT0Ref	1.92
ISR α_s order	SpaceShower:alphaSorder	2
ISR limit	SpaceShower:pTmaxMatch	1
MPI cut-off	MultipartonInteractions:pT0Ref	2.00

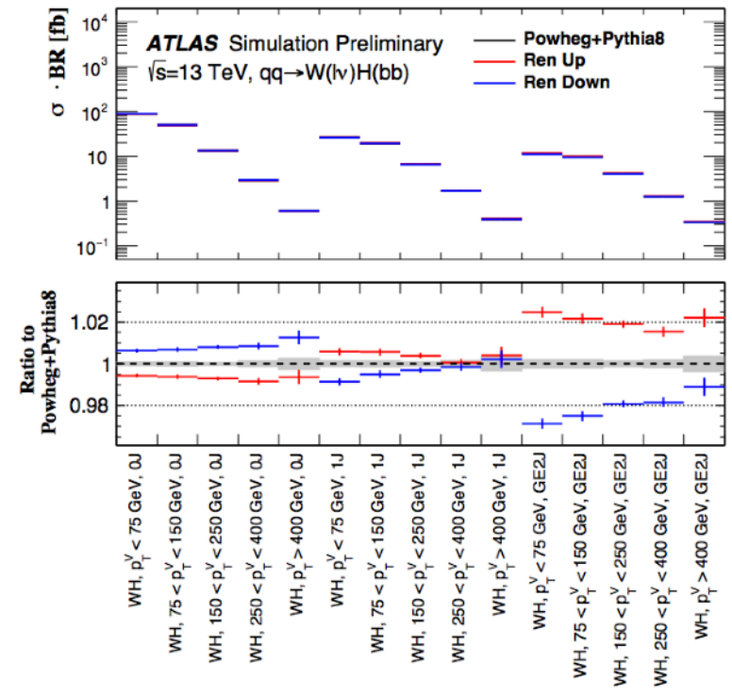
Herwig7 native tune H7-UE-MMHT
PS cutoff & hadronization

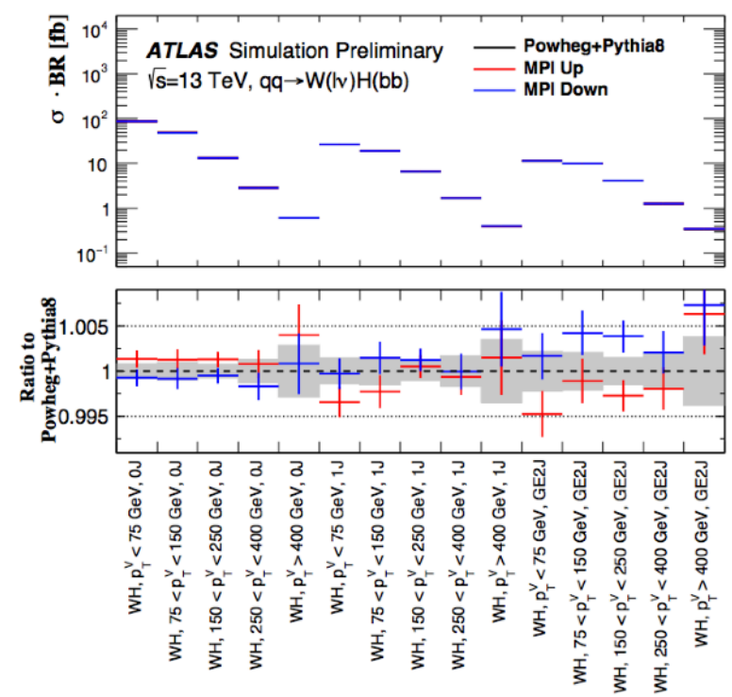
Parameter	H7-UE-MMHT
$p_{\perp,0}^{\min}$ **[MPI cutoff]**	4.39
b	0.366
μ^2/GeV^2	2.30
p_{disrupt}	0.798
p_{reco}	0.4276

- ***documented impact of PS variations on STXS bins:***
  - not used in the prediction since extra radiation already covered by higher order corrections (scale unc. have O(10%))

Var1 and Var2 have practically 0 effect on these observables: expected?







- ***mild trend in V p_T, larger effects in nJet:***
  - effects much larger for ggZH since pure LO (backUp)

UE / PS / MPI / HAD systematics

(main P/H differences)	Pythia	Herwig
PS algorithm	dipole-type pT ordered	angular-ordered
evolution variable	(closely related to) ~ pT	QTilde
hadronization	Lund string fragmentation	cluster model

A14

Parameter	Definition	Sampling range
`SigmaProcess:alphaSvalue`	The α_S value at scale $Q^2 = M_Z^2$	0.12 – 0.15
`SpaceShower:pT0Ref`	ISR p_T cutoff	0.75 – 2.5
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`TimeShower:alphaSvalue`	FSR α_S	0.10 – 0.15
`BeamRemnants:primordialKThard`	Hard interaction primordial $k_\perp$	1.5 – 2.0
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AZNLO

Generator Tune name		POWHEG+PYTHIA8 AZNLO
Base tune		4C
PYTHIA8 PARAMET		
primordial k_T	BeamRemnants:primordialKThar	1.75
ISR $\alpha_s^{ISR}(M_Z)$	SpaceShower:alphaSvalue	0.118
ISR cut-off	SpaceShower:pT0Ref	1.92
ISR α_s order	SpaceShower:alphaSorder	2
ISR limit	SpaceShower:pTmaxMatch	1
MPI cut-off	MultipartonInteractions:pT0Ref	2.00

Herwig7 native tune H7-UE-MMHT
PS cutoff & hadronization

Parameter	H7-UE-MMHT
$p_{\perp,0}^{\min}$ **[MPI cutoff]**	4.39
b	0.366
μ^2/GeV^2	2.30
p_{disrupt}	0.798
p_{reco}	0.4276

Higgs - uncertainties and variations

Two points to consider today: **(2) parton-shower/hadronization**

Current PMG "*recommendation*" is to look at both eigentune variations (AZNLO Powheg+Pythia tune) and Pythia/Herwig comparison

clear goal: avoid 2-point Pythia/Herwig comparison

parton-shower

Uncertainties currently in use:

- Parametric: α_s variations ⇒ eigentunes
- Non-parametric:
  - Angular vs Dipole
  - Evolution variable
  - Splitting kernels

  } Probed by 2-point comparisons e.g. Herwig vs Pythia

hadronization

Uncertainties currently in use:

- Non-parametric:
  - **Hadronisation**: string (Pythia, (Sherpa)) vs cluster (Herwig, (Sherpa))
- Parametric:
  - **MPI** parameters ⇒ **eigentunes** (well defined - no improvements expected in methodology)

- **Derive better defined "PS uncertainty"**
  - new PS (Herwig 7, Sherpa, Pythia 8) allow to switch between PS algorithms ⇒ disentangle perturbative and non-perturbative effects [6]
  - shower weights (Herwig 7, Sherpa, Pythia 8) covering perturbative PS uncertainties (scale, splitting kernels) being validated [7]

  ⇒ better definition of PS uncertainties: e.g. shower weights ⊕ MPI+CR eigentune

How to improve

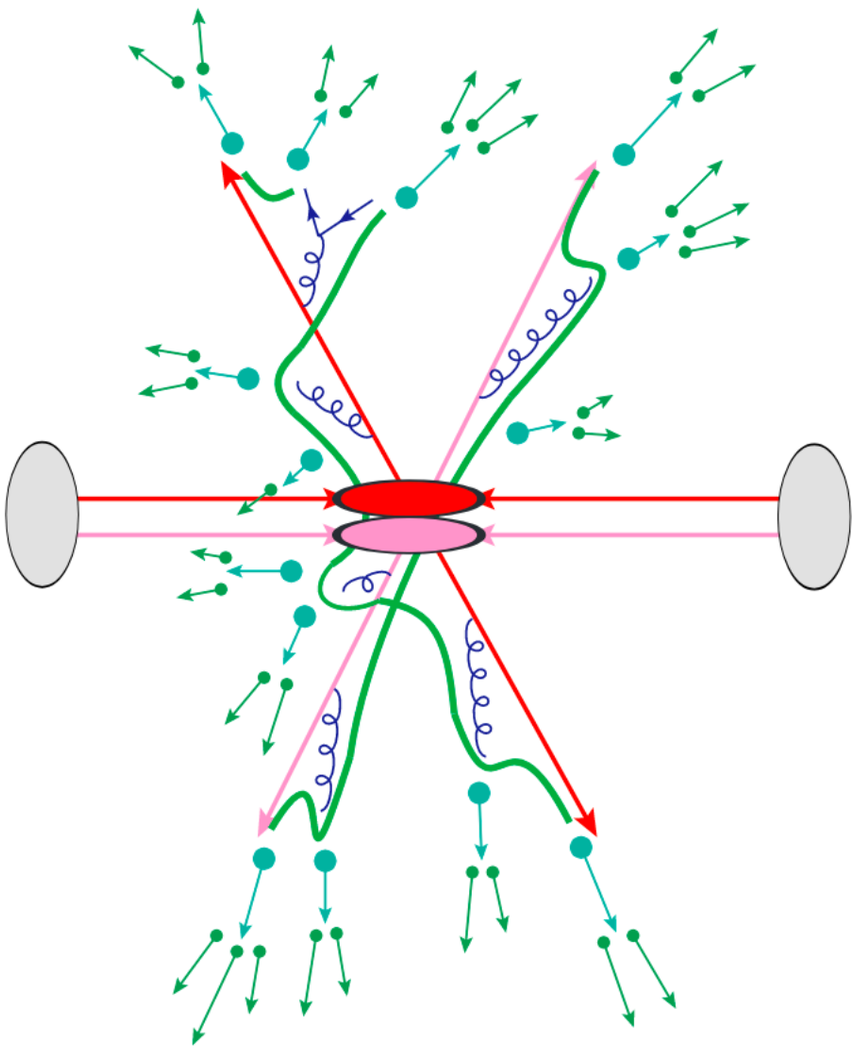
- **Derive parametrised hadronisation uncertainty**
  - Tune measurements sensitive to hadronisation parameters ⇒ **hadronisation eigentune**
- **Decouple hadronisation from other effects**
  - Use **in-house variation of hadronisation model** (e.g. Sherpa) to disentangle hadronisation effects

- **not yet fully clear how the weights are going to be used**
- no experience with new PS allowing switches between PS algorithms (e.g. Herwig7 paper)

No new "final recommendation": if/when this becomes an important effect for us - we need to consider the available tools

Interaction with TH/PMG very welcome: December 10-1 HXSWG General Assembly - **parallel session on PS uncertainties for Higgs modelling**

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}

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 $\mathrm{PDF}^{PS}/\mathrm{PDF}^H$

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