

# BSM Tools: Theory

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# Outline



- Evolution of the Tools Group
- Event Generation
- Recasting and Analysis
- Other tools
- Overlap with the 1st session.

## Evolution of the Tools Group



- There have been huge developments in the tools over the last ten years.
- Particularly in event generation but also in other tools.
- The things that are interesting/important now are very different to those in early Les Houches meetings.

## Event Generation



- Lots of developments.
- Mainly aimed at improving simulation of SM processes, after all the most important thing even for BSM.
- However a lot of improvements for BSM physics as well.

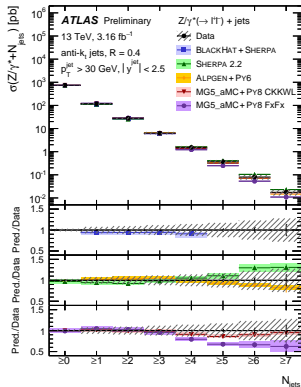
## Progress: Higher Orders

- Focus of event generator development has been the inclusion of additional hard emissions and higher-order corrections.
- Multiple emissions at LO, CKKW (Catani, Krauss, Kuhn and Webber JHEP 0111 (2001) 063) and numerous variants.
- Matching to NLO (NLO normalisation and 1st emission)
  - MC@NLO (Frixione, Webber JHEP 0206 (2002) 029)
  - POWHEG (Nason JHEP 0411 (2004) 040)
  - KrkNLO (S. Jadach, et. al. JHEP 1510 (2015) 052)
- Merging at NLO (NLO normalisation for multiple emissions)
  - MINLO (Hamilton, Nason, (+Zanderighi) JHEP 1006 (2010) 039, JHEP 1210 (2012) 155)
  - FxFx Frederix, Frixione JHEP 1212 (2012) 061
  - Sherpa (Höche, Krauss, Schonherr, Siebert JHEP 1304 (2013) 027)
  - UMEPS (Lönnblad, Prestel JHEP 1303 (2013) 166)
  - Herwig 7.1 (Bellm et.al. arXiv:1705.06700, Plätzer JHEP 1308 (2013) 114) + ...
- 1st processes at NNLO (Hamilton, Nason, Oleari, Zanderighi JHEP 1305 (2013) 082),  
...

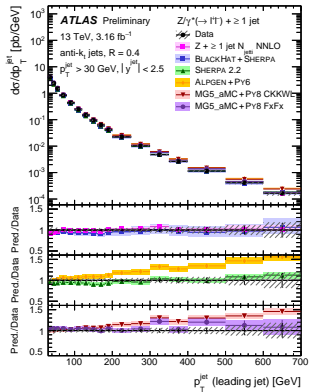
## Progress: New Algorithms

- Motivated by matching/merging development of new parton-shower algorithms
  - **Improved AO** (Gieseke, Stephens, Webber JHEP 0312 (2003) 045)
  - **PYTHIA  $p_T$**  (Sjöstrand, Skands, Eur.Phys.J. C39 (2005) 129-154)
  - **Catani-Seymour based SHERPA** (Schumann, Krauss JHEP 0803 (2008) 038),  
**Herwig** (Plätzer, Gieseke JHEP 1101 (2011) 024)
  - **Antenna Based** (Giele, Kosower, Skands Phys.Rev. D78 (2008) 014026)
  - **DIRE** (Höche, Prestel Eur.Phys.J. C75 (2015))
  - **GenEvA** (Bauer, Tackmann, Thaler JHEP 0812 (2008) 010)
- These developments have been possible due to improved understanding of QCD, automation of NLO calculations, and faster computers.

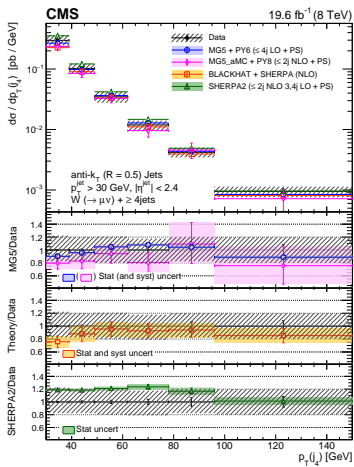
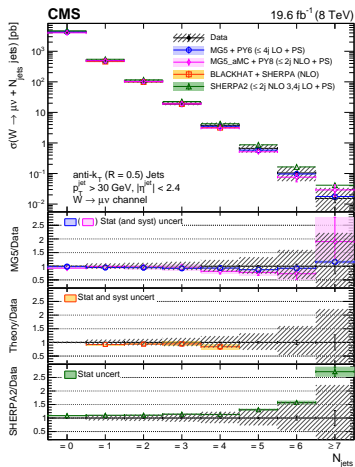
## ATLAS Z+jets



ATLAS-CONF-2016-046



# CMS $W$ +jets



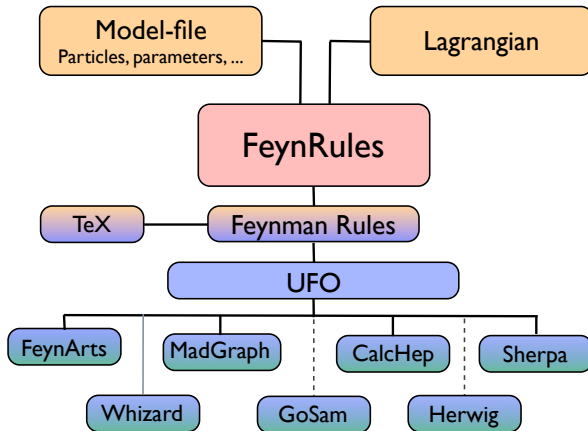
CMS PRD 95 (2017) 052002



## BSM Physics

- Historically implementing specific models in PYTHIA/HERWIG/MadGraph.
- Major development **FeynRules** and other tools which allow the Feynman rules to be computed from the Lagrangian and outputted in the **UFO** format.
- The major event generators and ME programs can read the UFO and calculate hard processes, decays etc..
- Now extended to NLO.
- Also developments in other tools for spectrum calculations (mainly in SUSY) and decays.
- Are there still models we can't simulate reliably?

# FEYNRULES



## Communication and Accords



- Les Houches has had a major impact in agreeing standard and accords for communication between the different tools.
- Are there other things we need to agree?
- Only works with the agreement of the affected parties.

## Reinterpretation/Recasting

- Now a lot of tools to do this ATOM, Contour, CheckMATE, FastLim, Gambit, . . .
- Other tools to analyse events Rivet, MadAnalysis, ..
- Is there work to do here on these tools?
- For the last 2–3 LH there have been efforts for an accord.
- Seems to be more a discord, needs consensus and buy-in by all the effected parties.

## Tools Related Issues From Session 1

There are some topics which have a tools element where there's possibility for overlap with the 1st session.

- Jet-Substructure, lot of work in the first session, mainly for QCD ( $\alpha_S$  determination) and Higgs. Applications to BSM?
- Application of Quark-Gluon tagging to BSM?
- Higgs template cross sections
- Backgrounds. 1st session mainly interested in measurement of SM processes, but as background also important for BSM and for tools in how we simulate them.

# Jet Substructure



taken from Jesse Thaler's summary of session 1.

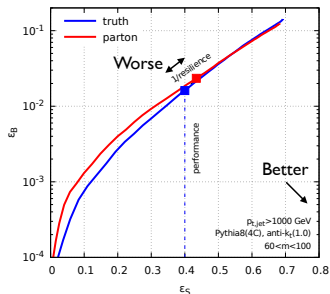
- 2-Prong Jet Substructure Resilience
- Extracting the Strong Coupling Constant
- Uses for Quark/Gluon Tagging
- Advanced Observables for Parton Showers

## 2-prong

## ROC Curves

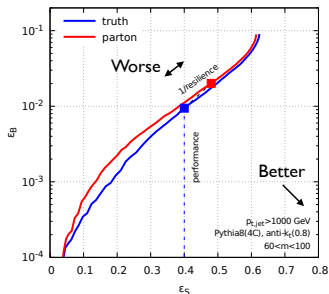
 $parton \Rightarrow particle, p_T > 1 \text{ TeV}$ 

## ATLAS-like



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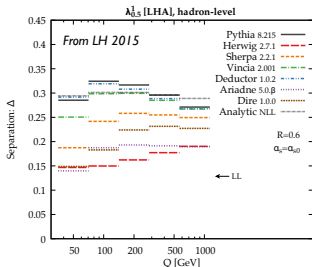
## CMS-like



BSM Tools: Theory

# Quark-Gluon tagging

## New Opportunities for I-Prong Tagging



Assuming progress on  
parton shower modeling  
by LH 2019...

...what physics analyses  
might benefit from  
quark/gluon tagging?

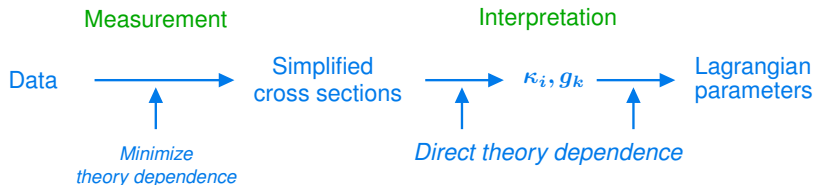
E.g.: dark matter mono-tagged-jet plus MET, quark-rich gluino cascade decays, pileup jet mitigation, double subjet tagging in boosted hadronic  $W/Z$ , constrain parton showers using LEP data, resolving combinatorics in  $t\bar{t}$  + jet, forward jet tagging in VBF/VBS, constraining PDFs with (N)NLO interplay, disentangle box/triangle graphs in high  $p_T$  Higgs, initial-state tagging using jet vetoes, ...



# Higgs Template Cross Sections

taken from Kerstin Tackmann's summary of session 1.

## Introduction: simplified template cross sections.



### Goals

- Decouple the measurements and the interpretation
  - ★ Run1  $\mu$  measurements fold theory predictions and uncertainties directly into the measurements
- Minimize the theoretical uncertainties in the measurements
- Allow for interpretation with more/different model assumptions/BSM scenarios than provided by the experiments

## Projects for Les Houches



- Are there models/signals which we can't simulate?
- Reinterpretation tools and discussion.
- Simulation of backgrounds and jet structure based signals.
- Long Live Particles.
- EFT/precision approach to new physics searches.
- DM specific issues.

# Projects for Les Houches



- Go home and do QCD.