Experimental Summary
MC&Tools, Resummation, Jets, ML

Alexander Grohsjean

Thanks a lot for all the help in preparing the slides to Baris, Betsy, Chris, Jennifer, Josh and Sapta!

3 Continued/ 2 newly started projects …

- LHC tune
- parton shower and hadronization uncertainties
- jet substructure

- vector boson polarization
- tops at threshold

Tuning Studies: Snapshot

- Ongoing efforts in Pythia, Sherpa and Herwig to update the tunes
- No agreed uncertainty estimation method from MC authors

- Latest LHC tunes:
  a. ATLAS:
     - Pythia A14 Tunes are over ten years old
  b. CMS:
     - Comprehensive Pythia (CPx) and Herwig tunes (CHx)
  c. several shortcomings identified -> update with recent LHC data desirable

Pythia Tuning Team

1. LEP / ee Tuning Convenor: PZS
- 1a: Perturbative aspects (event shapes, jet rates, matching & merging)
- 1b: Inclusive fragmentation
- 1c: Flavour composition & particle correlations

2. HERA / DIS Tuning Convenor: Ilkka Helenius

3. LHC / pp Tuning Convenor: Christian Preuss
- 3a: Perturbative aspects (Drell-Yan pT, jet rates & shapes, matching & merging)
- 3b: UE in hard processes (inclusive jets, DY, top)
- 3c: Min-Bias / Nonperturbative / Collective phenomena

4. Cosmic rays, forward physics, beam remnants, total XS Convenor: Torbjörn Sjöstrand

5. For **all** of the above: **methodologies** & **reproducibility** Convenor: Leif Lönnblad
- Tuning parameter groups, observables & weights, goodness of fit, uncertainties, variations
- Overlaps and interplays (eg DIS ↔ VBF, total XS ↔ min-bias, ee jets ↔ pp jets, …)

Peter Skands

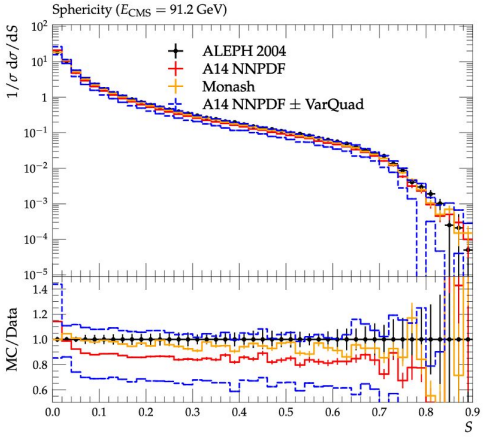
Qs of Interest:

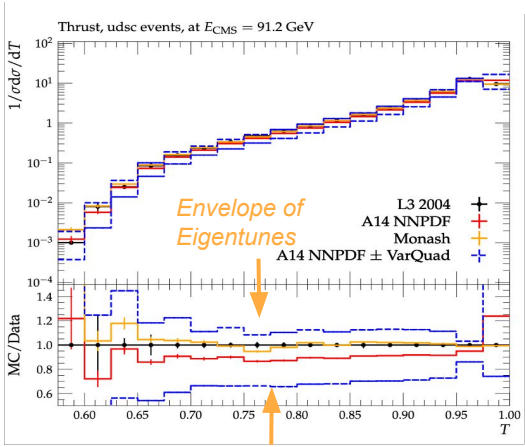
1. Tune universality: Hadronisation between LEP <-> LHC, ME accuracy,...
2. Ingredients of a tune: minimum requests from MC tuning efforts
3. Common tunes across different event generators?
4. Sufficient uncertainty prescription

Tuning Studies: A14 and Monash

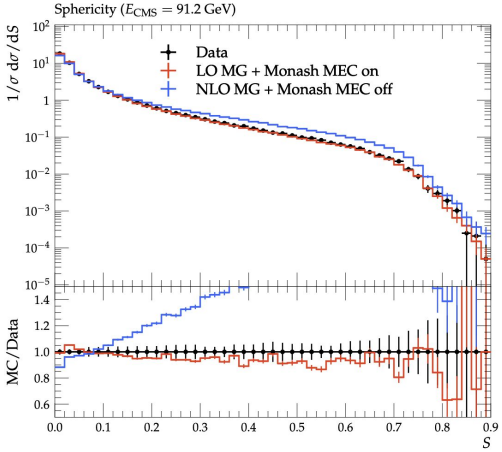
Baris Tuncay

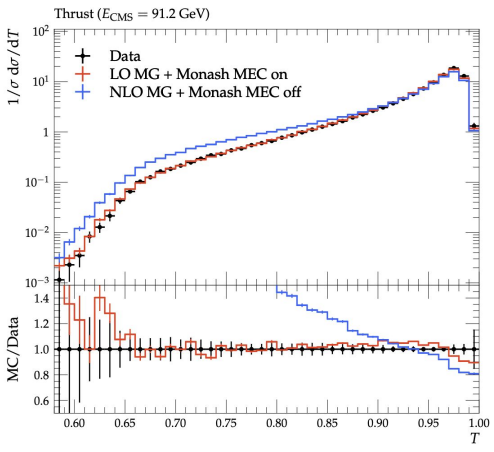
- "BSM tune" (Andy Buckley)
- description of LEP jet shapes worsened by the modification of FSR alpha$_s$ (red line)
- data covered within the uncertainties of the tune (blue band)





Baris Tuncay



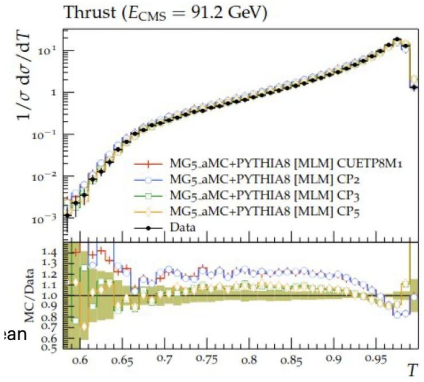


- initial studies at Les Houches 2025
  - comparison of Pythia's Monash tune (LO with MEC https://arxiv.org/pdf/2308.06389)
  - MC@NLO setup (no MEC to prevent double counting)

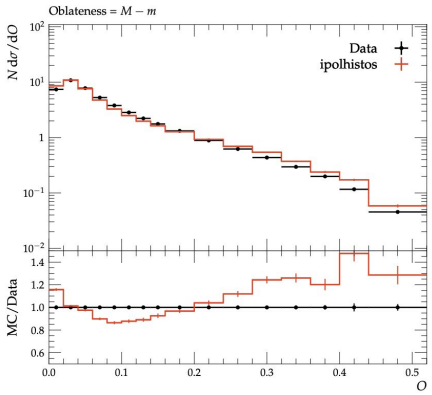
-> changes in jet shapes (to be understood)

Tuning Studies: (Prelim.) Hadronisation and FSR from LEP

- CPx tunes (pure UE tunes) provide reasonable description of LEP data for small alphas (0.118)



Baris Tuncay



➢ Slight improvement wrt the starting point

- use MC@NLO + Pythia setup to tune hadronisation parameters + $alpha_s$

```
StringPT_sigma 0.25 0.40
StringPT_enhancedFraction 0.0 0.02
StringPT_enhancedWidth 1.7 2.3
StringZ_aLund  0.55 0.80
StringZ_bLund  0.75 1.15
StringZ_aExtraSquark 0.0 0.15
StringZ_aExtraDiquark 0.75 1.15
StringZ_rFactC 1.12 1.55
StringZ_rFactB 0.85 1.15
TimeShower_alphaSvalue 0.117 0.137
TimeShower_pTmin 0.40 0.60
```

L3_2004_I652683
ALEPH_1991_I319520
ALEPH_2004_I636645
ALEPH_1999_I507422
ALEPH_2000_I507531
DELPHI_1996_I424112
DELPHI_2000_I524694
OPAL_1997_I421978
SLD_2002_I582951

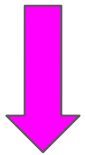
Jet rates, event shapes, charged multiplicity @ Z mass pole
500 samples, 100k events

- ➢ alphaS goes down
- ➢ Still some work to do to get the weights right and understand the interplay of the parameters
- ➢ Move to flavour-dependent hadronisation parameters

StringPT_sigma	0.318484
StringPT_enhancedFraction	0.013583
StringPT_enhancedWidth	1.998376
StringZ_aLund	0.781940
StringZ_bLund	0.856783
StringZ_aExtraSquark	0.114096
StringZ_aExtraDiquark	1.084901
StringZ_rFactC	1.308579
StringZ_rFactB	0.975819
TimeShower_alphaSvalue	0.123452
TimeShower_pTmin	0.400044

Tuning Studies: Next Steps

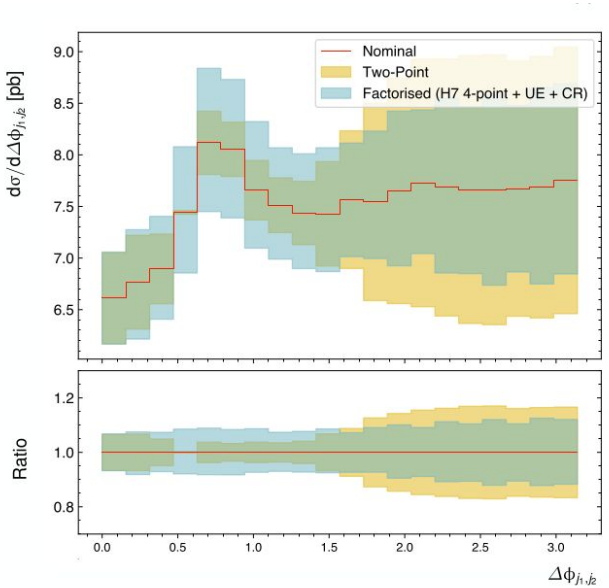
- MC@NLO + Pythia/Vincia tune: Baris, Chris, Miha -> *Global LHC tune (?), Matching effects*
- LO Pythia Hadronisation Tune from LEP vs LHC (e.g. Lund jet plane measurements): Matt, Jennifer -> *LHC Jets Tune: Hadronisation universality*
- Possible Herwig Tune: Betsy, Josh -> *Global LHC tune (?), Common tunes between MC generators*
- Uncertainty Prescriptions: All above + Alexander, Andrzej, Miha, Pratixan, James
- Tuning ingredient wishlist for future tunes



Fed into the LHC MC Working Group

PS/Had Uncertainties - Status before Les Houches 2025

- target:
  avoid convoluted, ad-hoc comparison
  between two generators,
  e.g. Powheg+Pythia vs Powheg+Herwig
- factorized approach (e.g. alternative parton shower and hadronization models)
  within a single generator
- starting point: Powheg + Herwig7
  - QTilde/Angular-ordered shower, Cluster hadronisation
  - QTilde/Angular-ordered shower, Lund-string hadronisation
  - Dipole shower, Cluster hadronisation
  - Dipole shower, Lund-string hadronisation

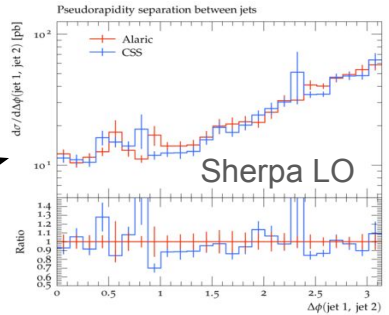


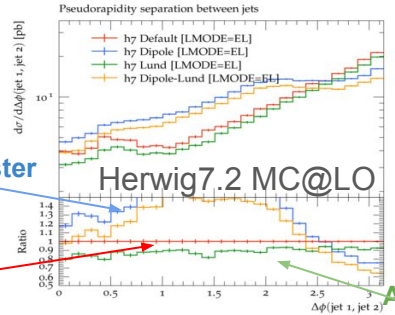
PS/Had Uncertainties - Progress at LH25

- Daniel started to look at Sherpa CSS vs ALARIC (at LO, Z+jet)
  - less difference in angular variables compared to dipole vs. angular ordered

- taking advantage of recent model update of Lund hadronisation in H7 including color reconnection and tune
  - compared Z+jet at LO Herwig cluster/Lund models (with updates) from Pratixan to ATLAS studies (w/o updates)

- Studies from Baris on Pythia8 nominal vs VINCIA
  - Missing tune? Further studies needed…

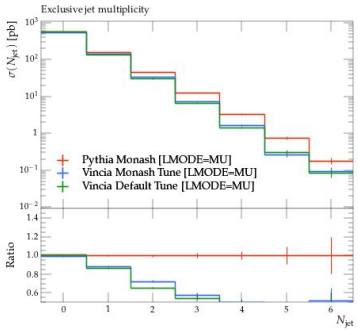


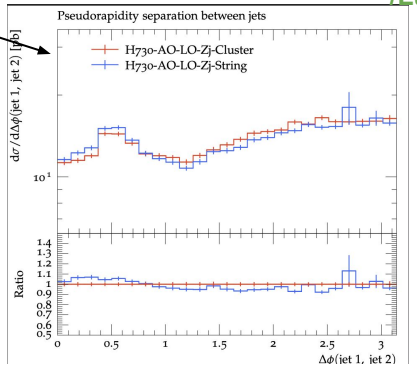


Dipole/cluster

Angular

Angular /Lund





PS/Had Uncertainties | Open questions

- Is factorisation of PS/Had effects really agreed?! (in contradiction to previous LH… 😅)
- Is it reasonable to derive uncertainties from one generator and apply to another?
- Does a full algorithmic PS variation need to include different ordering?
  - angular-ordered vs p_T-ordered ?
  - Would two p_T-ordered showers e.g. CSS and ALARIC *not* constitute a full variation?
- How consistently tuned are all the setups that we currently have?

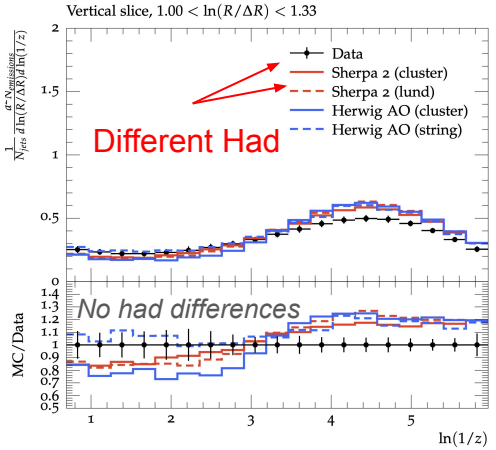
PS/Had Uncertainties | Follow-up LH25 projects

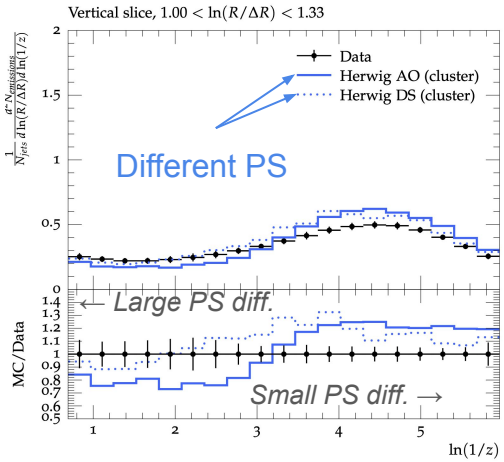
- Extension of existing studies
  - Define list of Rivet routines/observables which target specific aspects of the modelling - PS/Had/MPI
  - Update PS/Had studies using Sherpa
  - Add studies from Pythia8 nominal vs VINCIA
  - Add studies with Herwig7 updated Lund model - CR included and tune
  - Look at shower/hadronisation variations in e.g. Herwig at NNLO

Parton shower and hadronization studies for jet substructure

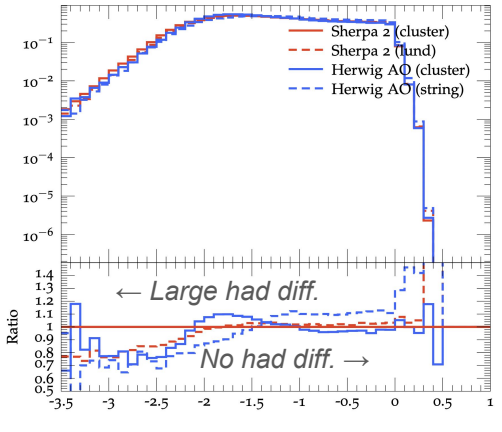
- At LH23, tried to find observables for pp collisions that are sensitive to specific changes in the modeling
- Found some observables that are primarily impacted by PS, but typically some mixing between PS and hadronization effects
- This year, focusing on exploring e^+e^- observables
  - Trying to explore similar questions in a cleaner environment, and with more PS predictions
  - Exploring dependency of different tuning parameters on these distributions
  - Discussed interaction with heavy flavor jet modeling

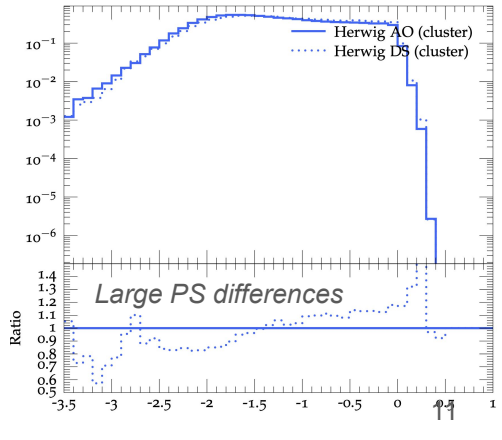
Lund jet plane





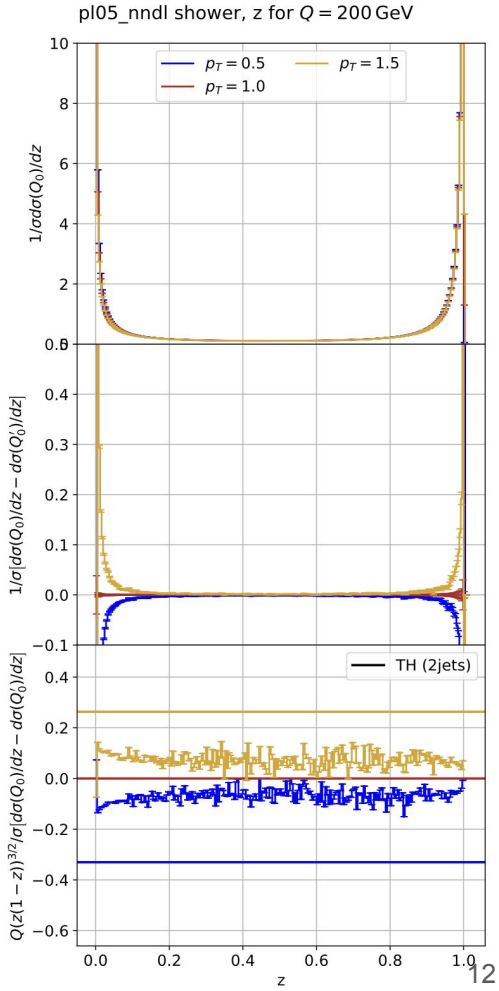
EEC2P





Parton shower and hadronization studies for jet substructure - Progress LH25

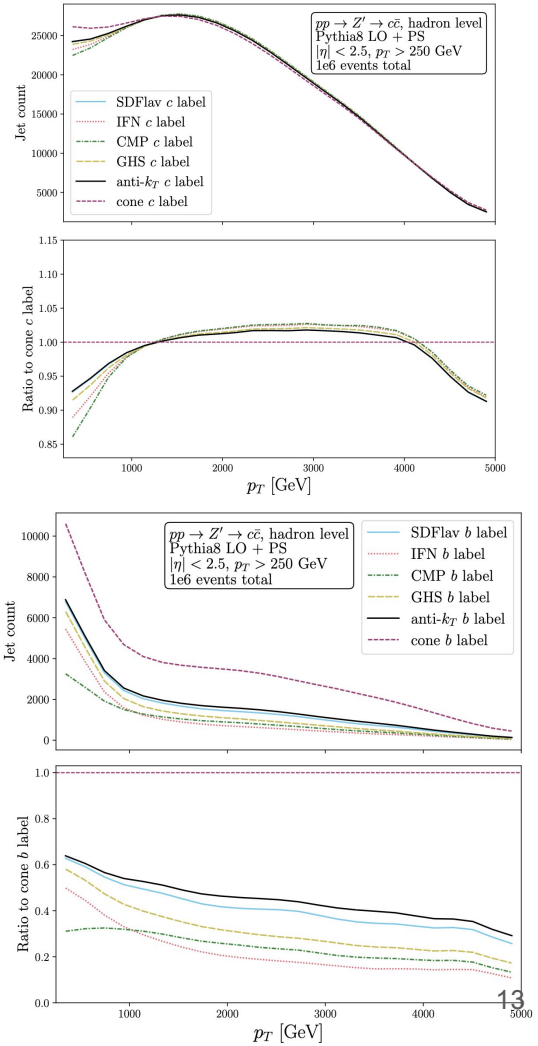
- Exploring a wide range of different observables for e^+e^-
  - Scanning wider range of energies than just LEP
- Created Rivet routines to enable comparison across a wide range of PS and hadronization models
- Results still being produced and analyzed, but will inform what observables can be measured, and what we can learn from these
  - Plan to take many of these lessons and apply to LHC data
  - Discussions of complementarity of these different measurements
- Other potential studies: sensitivity of variable-radius jet reconstruction on PS effects
  - Rivet routine in progress, hope to compare behavior of multiple algorithms



https://arxiv.org/abs/2506.13449

Flavor algorithms

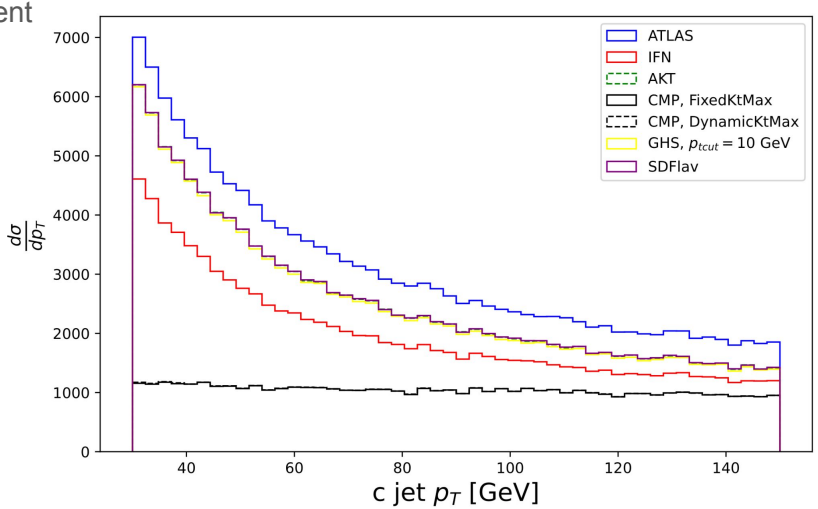
- Studies of new IRC safe definitions of jet flavor are focused on *theoretical comparisons*
- Flavor label will interact with experimental b(c)-tagging algorithms by changing what jets are used for the target of the training
  - Can see large differences in the labeling, particularly at low and high p_T
- LH25: focused on characterizing experimental impact of these algorithms



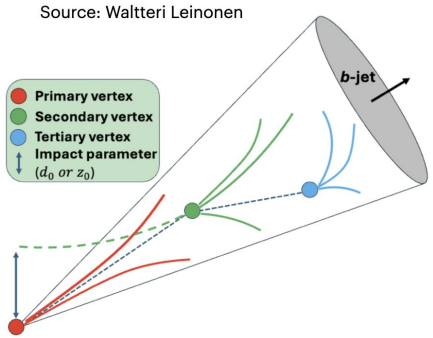
Flavor algorithms

Radek Grabarczyk

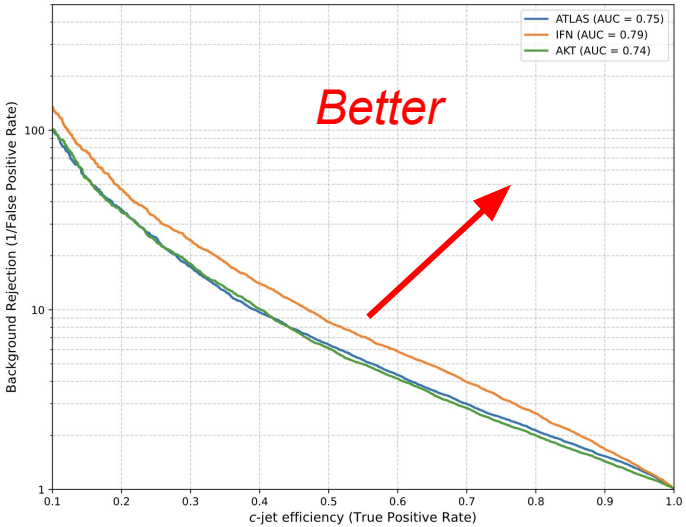
- Using a high-mass Z' sample ($m_{Z'}$ = 4 TeV), but looking at low-p_T c-jets (from QCD emissions in the event)
- Most algorithms behave similarly
  - IFN is more aggressive than the other algorithms, which is consistent with other results
- CMP has an entirely different shape for the number of tagged c-jets
  - CMP has some sensitivity to the overall scale of the event
- **Follow-up**: how do these algorithms generalize across different topologies?
  - Plan to train tagger on these samples, and apply it to other topologies (e.g. much lower Z' mass)
    - *Not fully realistic, but can help determine if further considerations are needed on training sets based on these algorithms*
- **Follow-up**: How are these labels correlated?
  - Would multiple output nodes (one per algorithm) improve our ability to identify b-jets?
  - Would it be possible to observe these differences in an actual measurement, or are most of these algorithms roughly similar within our uncertainties?



Flavor algorithms



Radek Grabarczyk



- Using LundNet to tag jets based purely on their substructure (no B-hadron information)
  - The ATLAS algorithm is similar to AKT
  - IFN outperforms other methods, even though the flavor label includes information outside the jet
- Need more studies on the experimental implications of switching to these methods
  - Clear messaging to experimentalists about this sort of behavior will help the transition to the algorithms
- **Follow-up**: studies comparing performance on different processes and using multiple MC models
  - Want to test **stability** against modeling differences and **performance** for tagging

Polarized electroweak bosons

study interplay of EFT and polarization states of bosons

focus on WZ process

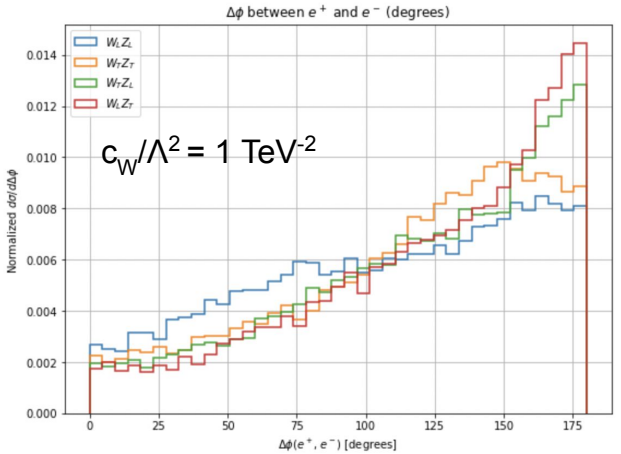
- WW: leptonic complicated due to presence of neutrinos
- ZZ: absence of s-channel diagram

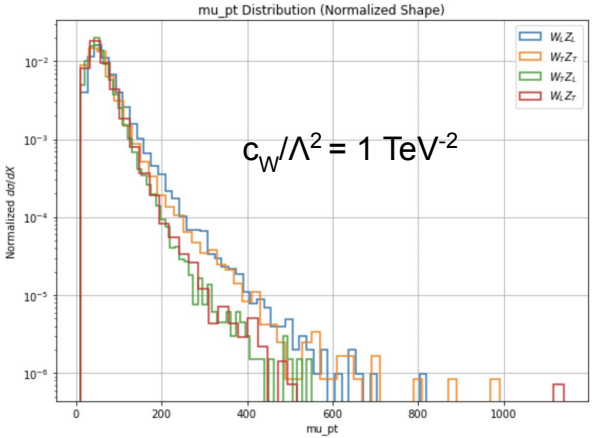
two setups to compare

- fixed order from Giovanni and Rene
- MC-based (5 flavor scheme, setup aligned to fixed order) factoring in parton shower and detector simulation
  - W→ l ν, Z→ l+ l- with $c_W/\Lambda^2 = 1\ \text{TeV}^{-2}$
  - all combinations of longitudinal and transverse states

plan to continue studies (also as part of the COMETA initiative)

ultimate goal: experimental analysis based on lessons learned and tools developed (NN-based discriminator)



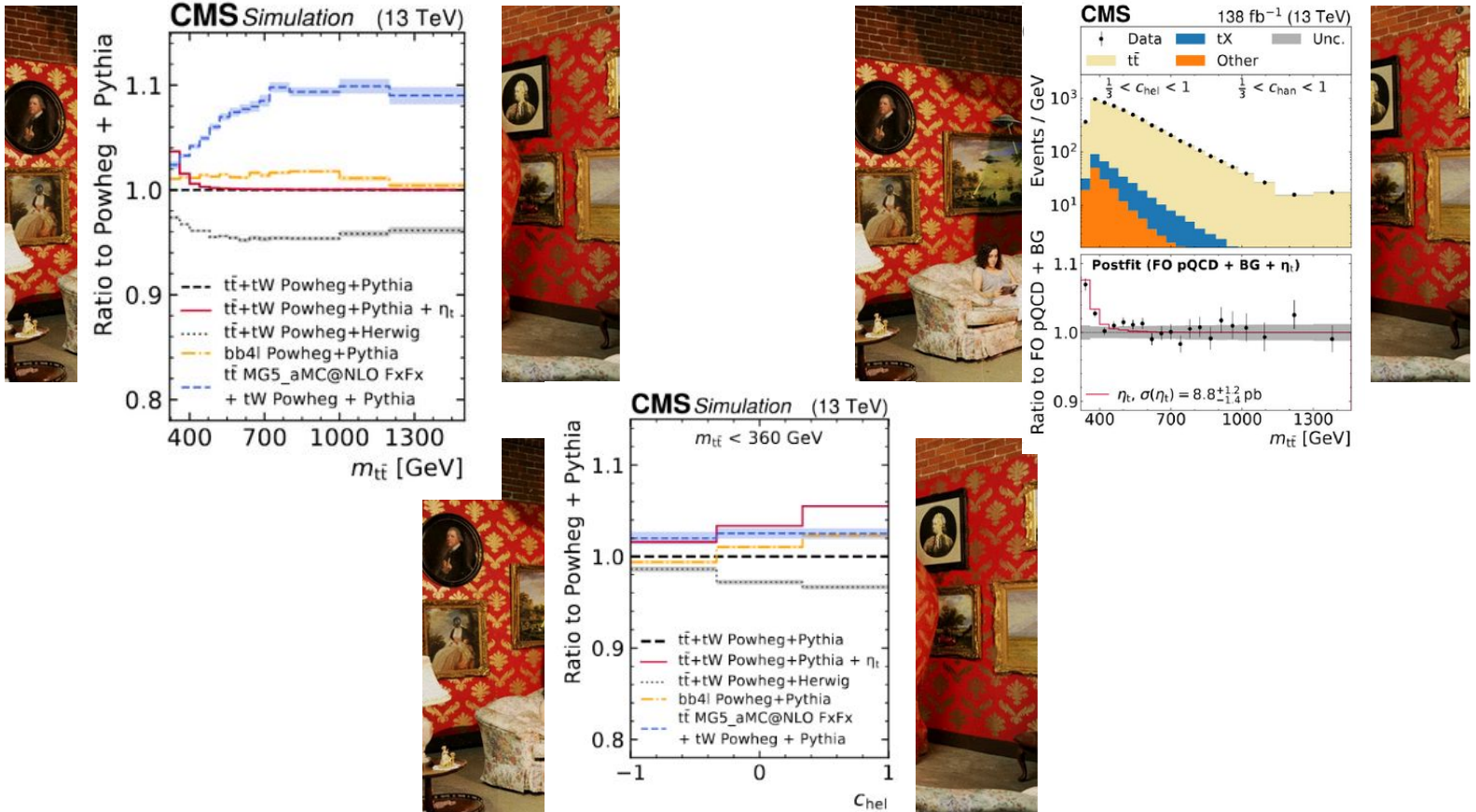


Maryam Bayat Makou, Saptaparna Bhattacharya, Miha Muskinja, Giovanni Pelliccioli, Rene Poncelet, Emanulele Re

Top at threshold

Top at threshold

Top at threshold



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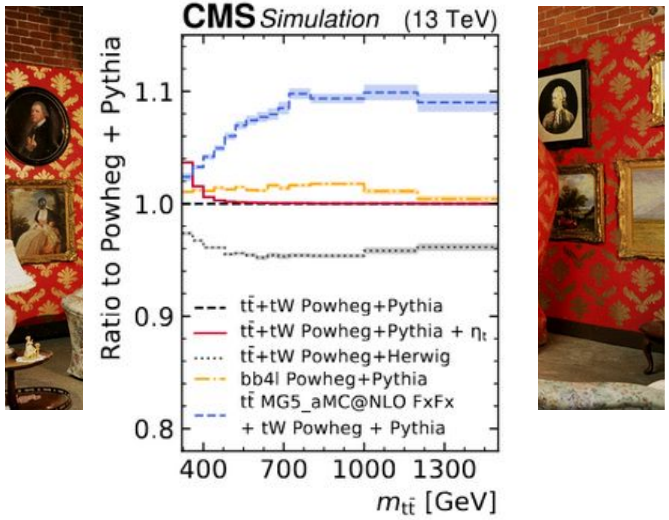


Les Houches Wishlist: bb4l at NNLO

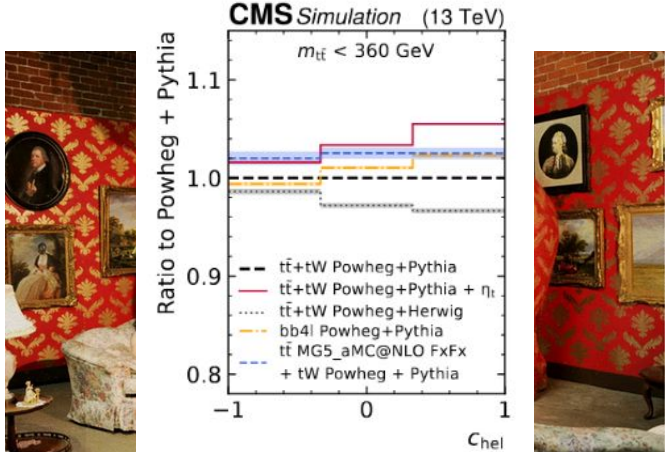
issues:

- bb4l only NLO accurate
- unclear how to apply knowledge from NNLO
- understanding bb4l predictions -> none-negligible differences between ATLAS and CMS with bb4l-dl version (recoil in PS?)

started work:

- detailed comparison of bb4l setups between ATLAS/CMS
- ongoing comparisons of matching

Top at threshold



issue:

- why are tt spins less correlated in H7 ?

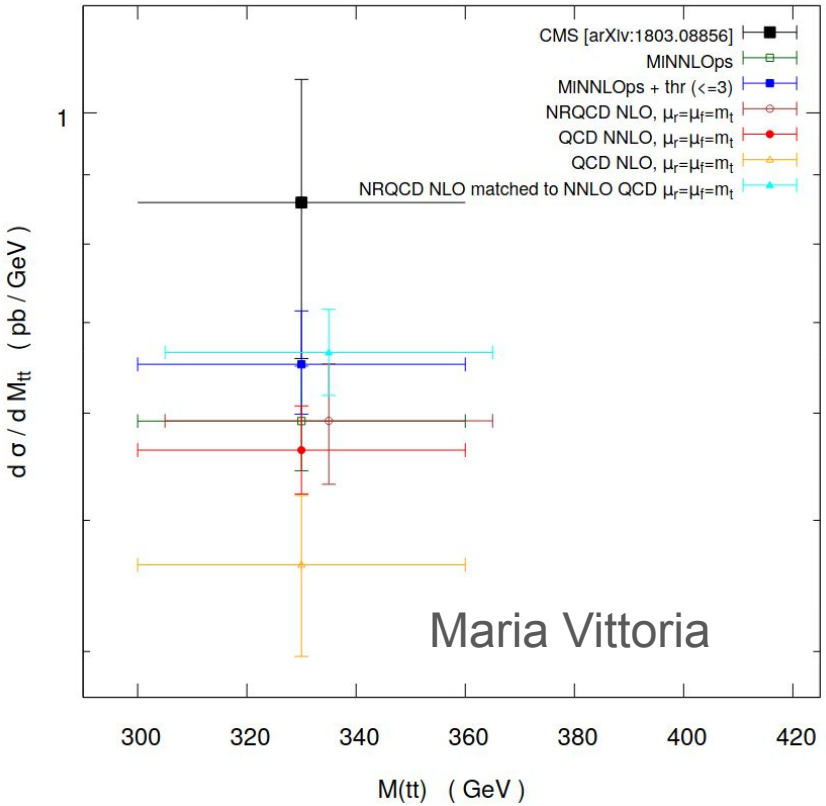
started work:

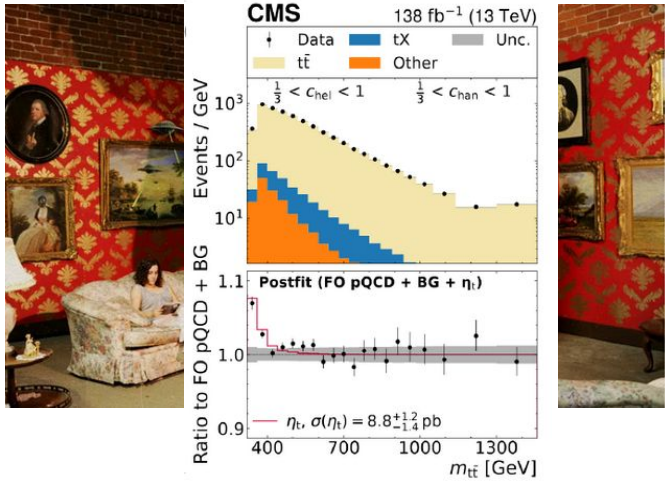
- treatment of spin in shower ? seems not to be the case
- observed difference between angular and dipole shower also in matched Powheg+Herwig setup? -> ongoing check by James

more work needed - thanks for all the help so far !

Top at threshold

Thanks to Emanuele, Andreas and Maria Vittoria!

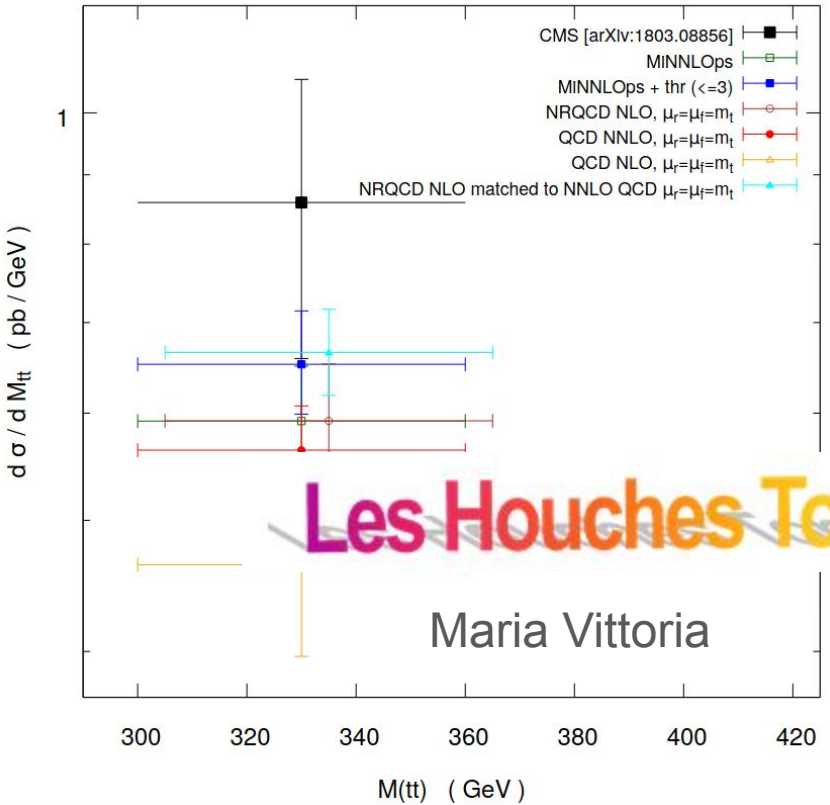


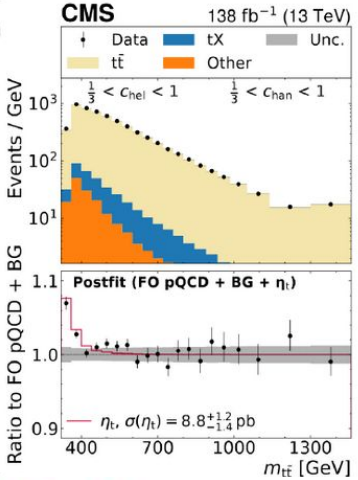


possible next steps:

- higher-order corrections to NRQCD predictions (Maria)
- inclusion of top width (Emanuele)

Top at threshold





Les Houches Toponium Follow-up

Maria Vittoria

Thanks to Alexandra, Baptiste and Laurids !

Summary

- LHC tune
- parton shower and hadronization uncertainties
- jet substructure
- vector boson polarization
- tops at threshold

Thanks to Emanuele for the invitation and a nice and extremely useful Les Houches 2025!