Status and Plans of the QCD (Jets & EW bosons) Group

Vieri Candelise
Università di Trieste & INFN Trieste

on behalf of the LHC Electroweak: Jets & EW Bosons Working Group

CERN, 18/12/2019
The “EWWG2”: Jets & EW bosons Group

**Conveners Team**

**ATLAS**: Eram Rizvi, Ben Nachman  
**CMS**: Vieri Candelise, Hannes Jung  
**LHCb**: Stephen Farry, Will Barter  
**Theory**: Marek Schoenherr

**QCD ~ Jets & EW bosons**

**Subgroups' twiki pages**

- **WG 1**: Drell-Yan physics and EW precision measurements  
- **WG 2**: Jets and EW bosons subgroup  
- **WG 3**: EW multi-boson production

**When we meet:** Every 2nd Tuesday at 4pm on Vydio

**Our Twiki page:** [https://twiki.cern.ch/twiki/bin/view/LHCPhysics/EWWG2](https://twiki.cern.ch/twiki/bin/view/LHCPhysics/EWWG2)

**Our meeting page:** [https://indico.cern.ch/category/3290/](https://indico.cern.ch/category/3290/)
### Main Ongoing Activities

- **Benchmark Comparisons**: historically the main task of the EW-VJ group, aiming for theory/data comparisons of selected processes (e.g. V+jets), observables and given predictions between ATLAS, CMS, LHCb at 7/8/13 TeV. Collect and understand the mis-modellings and discrepancies observed.

- **RIVET and HEP infos**: well advanced topic where we aim to set a common strategy (format) about the storage and usage of uncertainty infos (correlations, tables…) across experiments.

- **Jet Substructure**: define common strategy on observables, ranges and binning definitions across experiment, collect and improve RIVET routines, measurements...
RIVET Library

Crucial and Essential for our group is the collection of RIVET routines to be used for comparisons

we have a “library” of RIVET routines for V+Jets -like measurements

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCPublicResultsWithJets

we always encourage and advertise analyzers in our experiments meetings to update and send us their routines (but this is often the bottleneck for us!)

W/Z+jets

<table>
<thead>
<tr>
<th>Rivet Routine</th>
<th>Process</th>
<th>Data Set</th>
<th>arXiv</th>
<th>Routine status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS_2015_11310737</td>
<td>Z + jets</td>
<td>7TeV 2015</td>
<td>1408.3104</td>
<td>public</td>
</tr>
<tr>
<td>CMS_2014_11303894</td>
<td>W + jets</td>
<td>7TeV 2014</td>
<td>1406.7533</td>
<td>public</td>
</tr>
<tr>
<td>CMS_2016_11491953</td>
<td>W + jets</td>
<td>8TeV 2017</td>
<td>1610.04222</td>
<td>public</td>
</tr>
<tr>
<td>CMS_2017_11610623</td>
<td>W + jets</td>
<td>13TeV 2017</td>
<td>1707.0579</td>
<td>public</td>
</tr>
<tr>
<td>CMS_xxxx_xxxxxxxx</td>
<td>Z + jets</td>
<td>13TeV 2018</td>
<td>1804.05252</td>
<td>in preparation</td>
</tr>
<tr>
<td>CMS_xxxx_xxxxxxxx</td>
<td>Z + jets</td>
<td>8TeV 2017</td>
<td>1611.03844</td>
<td>in preparation</td>
</tr>
<tr>
<td>ATLAS_2013_11230812</td>
<td>Z + jets</td>
<td>7TeV 2011</td>
<td>1304.7098</td>
<td>public</td>
</tr>
<tr>
<td>ATLAS_2017_11514251</td>
<td>Z + jets</td>
<td>13TeV 2015</td>
<td>1702.05725</td>
<td>public</td>
</tr>
<tr>
<td>ATLAS_2012_11083318</td>
<td>W + jets</td>
<td>7TeV 2010</td>
<td>1201.1276</td>
<td>public</td>
</tr>
<tr>
<td>ATLAS_2014_11319490</td>
<td>W + jets</td>
<td>7TeV 2011</td>
<td>1409.8639</td>
<td>public</td>
</tr>
<tr>
<td>ATLAS_xxxx_xxxxxxxx</td>
<td>W(-&gt;ev) + jets</td>
<td>8TeV 2012</td>
<td>1711.03296</td>
<td>in preparation</td>
</tr>
<tr>
<td>LHCb_2014_11262703</td>
<td>Z(-&gt;mumu)+jets</td>
<td>7 TeV 2011</td>
<td>1310.8197</td>
<td>public</td>
</tr>
<tr>
<td>LHCb_xxxx_xxxxxxxx</td>
<td>W/Z(-&gt;mu(mu))+jets</td>
<td>8 TeV 2012</td>
<td>1605.00951</td>
<td>in preparation</td>
</tr>
</tbody>
</table>
News from the Group
New proposals: PDFs benchmarking

(see dedicated talk later today!)

- Evaluating the correlations between PDF sets for the first time

- LHC measurements correlated through PDFs

- Motivations: sin2 θW, mW, αS, data/theory comparisons

---

**Proposed procedure**

→ Proposal to evaluate correlations between PDF sets, originating from common experimental inputs, using coherently-generated pseudo-experiments

→ Use the xFitter framework to generate pseudo-experiments fluctuating the statistical and systematic experimental uncertainties, taking into account correlations, for an inclusive sample of data (covering all the data used for the various PDF fits)

→ For each generated pseudo-experiment, select the data points used by each PDF fitting group and re-do the corresponding fit (Only the nominal fit has to be determined at this stage, not the eigenvectors)

(After validation and cross-checks – see next slides)

→ Use the ensemble of fitted pseudo-experiments to determine correlations between the uncertainties of various PDF sets

→ For $V+jets$: compare quantitatively theoretical predictions for various cross sections, using different PDFs
New Forum Topics: Jet Measurements in ALICE

Inclusive jet reconstruction at 5.02 TeV in pp and PbPb collisions with ALICE

Eliane Epple and James Mulligan

Tue 5. Nov 2019

First ALICE talk in our LHCEW Jets & EW bosons working meeting!

- many interesting jets results from a different physics perspective in ALICE
- we are including ALICE in our LHCEW team
- in contact to engage two co-conveners

“Measurements of inclusive jet spectra in pp and central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV” based on arxiv.org/pdf/1909.09718.pdf

https://indico.cern.ch/event/860687/contributions/3624865/attachments/1939413/3215108/LHC-EW_WG.pdf

very interesting discussion during the meeting
Inclusive jet measurements in pp are a very useful probe for many purposes!

- At small radii they are useful to guide resummation techniques
- Measurements of different jet radii are important to disentangle non-perturbative effects (UE+Hadronization)
- At large radii they are useful to be part of common PDFs and $\alpha_s$ fits

\[
R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{1}{N_{\text{event}}} \left. \frac{d^2 N}{dp_T d\eta} \right|_{AA}
\]
\[
\left. \frac{d^2 \sigma}{dp_T d\eta} \right|_{pp}
\]
New Forum Topics: Color Flow with Jet Pull

- Jets carry colour, and are thus colour connected to other colour-charged objects

\[ \vec{r}_i = \sum_{i \in \text{jet } a} \frac{p_{t_i}}{p_t} |\vec{r}_i| \]

\[ \vec{r}_i = (y_i - y_a, \phi_i - \phi_a) \]

- Particles created during hadronization should be concentrated along angular region spanned by the colour connected partons

Reinhild Yvonne Peters (ATLAS)
Simone Marzani et al. (Theory)


- Pairing of connection depends on nature of decaying particles

not IRC safe!
New Forum Topics: Color Flow with Jet Pull

- look at “safe” projections of the jet pull vector
- resummation of the pull magnitude (qT-like)
- safe projections

IRC safe! we can combine fixed-order and resummed prediction in the standard way

\[ pp \rightarrow H(\rightarrow bb\bar{b}) + Z(\rightarrow l^+l^-) \]

IRC safe projections will open the way for more studies and comparisons in our group!

Reinhild Yvonne Peters (ATLAS)
Simone Marzani et al. (Theory)

https://indico.cern.ch/event/867229/contributions/3654610/attachments/1962563/3262413/marzani_EWjets_meeting.pdf
Status of Projects
Benchmark Comparisons

**Purpose:** collect RIVET routines of SM processes involving jets and W/Z bosons in the LHC experiments and perform data/MC comparisons at several $\sqrt{s}$. Understand the different definitions and descriptions of the physics and try to quantify the compatibility.

**Status: Available RIVET routines**

**V+Jets and V+ HF**

- W+jets ATLAS, 7 TeV, 4.6 fb-1 [Figures](#)
- W+jets ATLAS, 7 TeV, 36 pb-1 [Figures](#)
- W+jets CMS, 7 TeV, 5 fb-1 [Figures](#)
- Z+ b jets ATLAS, 7 TeV, 4.6 fb-1 [Figures](#)
- Z+jets ATLAS, 7 TeV, 4.6 fb-1 [Figures](#)
- Z+jets CMS, 7 TeV, 4.9 fb-1 [Figures](#)
- Forward Z+jets, LCHb, 7 TeV [Figures](#)
- W+jets CMS, 8 TeV, 19.6 fb-1 [Figures](#)
- Z+b(b) CMS, 8 TeV, 19.8 fb-1 [Figures](#)
- Z+jets ATLAS, 13 TeV, 3.16 fb-1 [Figures](#)
- W+jets CMS, 13 TeV, 2.2 fb-1 [Figures](#)

**Inclusive and dijets**

- Inclusive jet, ATLAS, 7 TeV, 4.5 fb-1 [Figures](#)
- High-mass dijet cross section, ATLAS, 7 TeV, 4.5 fb-1 [Figures](#)
- Inclusive jet and dijet cross sections, ATLAS, 7 TeV, 36 pb-1 [Figures](#)
- Inclusive and dijet cross-sections of b-jets, ATLAS, 7 TeV, 34 pb-1 [Figures](#)
- Jet-pT and dijet mass, CMS, 7 TeV, 5 fb-1 [Figures](#)
- Inclusive b-jets, CMS, 7 TeV [Figures](#)
- Measurement of the inclusive jet cross-section, CMS, 7 TeV, 34 pb-1 [Figures](#)

**LHCb**

so far only Z+jets @ 7 TeV

**What I would ask Santa**

- manpower to work on BC!!
- more (updated) RIVET routines!!

**Benchmark Comparisons**

**Purpose:** collect RIVET routines of SM processes involving jets and W/Z bosons in the LHC experiments and perform data/MC comparisons at several $\sqrt{s}$. Understand the different definitions and descriptions of the physics and try to quantify the compatibility.

**Status: Generators**

<table>
<thead>
<tr>
<th><strong>POWHEG+PYTHIA8</strong></th>
<th>7 TeV</th>
<th>8 TeV</th>
<th>13 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>dijet <strong>POWHEG</strong></td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>$W + 2j$ <strong>POWHEG MiNLO</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$Z + 2j$ <strong>POWHEG MiNLO</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>SHERPA</strong></th>
<th>7 TeV</th>
<th>8 TeV</th>
<th>13 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>dijet S-<strong>Mc@NLO</strong></td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>$W + 0, 1, 2j@NLO + 3, 4, 5j@LO$</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$Z + 0, 1, 2j@NLO + 3, 4j@LO$</td>
<td>x</td>
<td>x</td>
<td>✓</td>
</tr>
</tbody>
</table>

**HERWIG7 + MADGRAPH + OPENLOOPS**
in the process of finalising the setups

---

## Benchmark Comparisons

### Modelling and Theory Comparisons: Plans of the Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>POWHEG</strong></td>
<td></td>
</tr>
<tr>
<td>DIJET</td>
<td>effect of MPI (MPI on/off) compare with different hdamp</td>
</tr>
<tr>
<td>TRIJET</td>
<td>comparisons with MiNLO, role of hdamp</td>
</tr>
<tr>
<td><strong>MC@NLO</strong></td>
<td></td>
</tr>
<tr>
<td>DIJET</td>
<td>NLO comparisons, effect of MPI (MPI on/off) different merging scales</td>
</tr>
<tr>
<td>2+3+4 Jets</td>
<td>NLO comparisons different merging scales</td>
</tr>
<tr>
<td><strong>SHERPA</strong></td>
<td></td>
</tr>
<tr>
<td>DIJET</td>
<td>NLO comparisons, effect of MPI (MPI on/off) different merging scales</td>
</tr>
<tr>
<td>2+3+4 Jets</td>
<td>NLO comparisons different merging scales, PS on/off</td>
</tr>
</tbody>
</table>

| V+Jets | detailed NLO+PS studies with agreed PDF set (NNPDF31?) and Tune (CP5?) |

### 1. Benchmark comparison

1. done for Powheg for V+jets for jets measurements for 7 TeV, 8 TeV and 13 TeV
2. done for Sherpa jets for 7 TeV
3. Herwig7 first results on Z+jets are done
4. Sherpa for 13 TeV Z+jets in the making

Benchmark Comparisons

Examples: Z+Jets @ 7 TeV

\[ \sigma(Z/\gamma^* \rightarrow ll + N_{\text{jet}}) \] [pb]

CMS $\sqrt{s} = 7$ TeV $L_{\text{int}} = 4.9$ fb$^{-1}

<table>
<thead>
<tr>
<th>MC/Data</th>
<th>Data</th>
<th>PH-cutep8m1-MPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
<td>1.6</td>
</tr>
<tr>
<td>6</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>7</td>
<td>1.9</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Inclusive jet multiplicity

\[ \sigma(Z/\gamma^* \rightarrow \ell^+ \ell^- + \geq N_{\text{jet}}) \] [pb]

<table>
<thead>
<tr>
<th>MC/Data</th>
<th>Data</th>
<th>PH-cutep8m1-MPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>1</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>7</td>
<td>1.6</td>
<td>1.7</td>
</tr>
</tbody>
</table>

one of the few cases where we have same energy, observables and plot for at least 2 experiments!

Benchmark Comparisons

Examples: Z+Jets & W+Jets @ 13 TeV

Z → ℓ⁺ ℓ⁻, dressed level

CMS Z+jets


(missing RIVET routines!)
Benchmark Comparisons

Examples: $Z+bb @ 8 \text{ TeV}$

Data PH-cuet8m1-\text{M}

CMS, 8 TeV, Leading b jet transverse momentum, at least two b jet

CMS, 8 TeV, DeltaPhi$_{Zb}$, at least one b jet

CMS $Z+(>2)\text{b}$

CMS $Z+(>1)\text{b}$


worst situation is with $V+HF$, missing RIVET at 7/8/13 TeV for many analyses
Benchmark Comparisons

Examples: Forward Z+jets (LHCb) @ 7 TeV

\[ \frac{1}{\sigma d\sigma / dp_T^{jet}}, p_T^{jet} > 10 \text{ GeV} \]

Data
PH-cutep8m1-MPI

MC/Data


(need more RIVET routines from LHCb!)
HEPData Recommendations

- Are we routinely storing enough information on HEPData to efficiently re-use the measurements we make at the LHC?
  --> Not always! **small policy shifts can boost impact of analyses**

- Discussions over past year (see Dec 18, Feb 19, July 19) resulted in attempt to **formalise recommendations and document them in a note** to be agreed between LHC experiments
  - Give **recommendations on conventions to follow** depending on what level of re-interpretation is needed

- Recommendations discussed in dedicated presentations to experiments
  - ATLAS (SM, HDBS, PMG groups) Oct-Dec 2019
  - CMS (Generator Group) Late Oct 2019
  - LHCb (QEE Group) Nov 2019
  - ALICE : planned discussion in Jan 2019

Louie Corpe
HEPData Recommendations

- Identify different levels of recommendations, depending on the analysis type and how re-interpretatable it needs to be:
  
  **Best case** - aims to provide maximal information for reinterpretations. Should be gold standard for precision measurements

  **Scenario A - Maximum Re-interpretability**
  **Scenario B - Approximate Re-interpretability**
  **Scenario C - Minimum Requirements for Analysis Preservation**

  Bare minimum for a search to be re-interpretable

  Closest to current situation. Plenty of information published. Not necessarily enough for strict combinations... but good enough for many analyses (especially searches)

- Details in Louie’s dedicated talk on the subject.
- Headline changes:
  - Propose to always store breakdown of uncertainties on HEPData
  - Propose including SM Generator predictions as extra columns in tables
  - Encourage analysts to make Rivet routine at the same time as the paper
Goal #1: maintain a database of measurements, encourage HepData+Rivet routines, and common observable definitions/binnings

Work to do: ensure we have Rivet routines and HepData for our analyses. This is becoming more of a requirement in ATLAS and CMS, but is less so for LHCb and ALICE. We have recently added new routines from old(er) measurements to do MC comparisons with state-of-the-art PS MC setups.
**Goal #2**: study the impact of jet substructure measurements on FSR and NP PS MC tuning.

**Goal #3**: study the impact of jet substructure measurements on higher order effects in PS MCs.

---

**O(10+ GeV): Higher order showers**

There is an impressive effort by the MC community to include higher-order effects in parton showers.

Key question: what observables are sensitive to these innovations?

Attempt at LH17 to use jet substructure for probing the triple collinear splitting function ... without much luck. What about the **double soft** splitting?

---

**O(100 GeV): g \rightarrow bb**

- ATLAS data
- Vincia 2.2.05 +helicity shower and matrix element corrections

Low-stats indication: Vincia + ME corrections w/ helicity shower show same trend as data - prediction confirmed!

---

This was started as part of the jet working group at **Les Houches 2019**.
Conclusions & Future Plans

• The group is very active on several fronts. Main projects (benchmark comparisons) are moving slow because of lack of manpower and RIVET routines: we need to find a way to attract people from our experiment subgroups to join us!

• We recently had ALICE joining us and we plan to have more reports in the nex future; two LHCEW-J&EWB conveners to be appointed

• New proposals and ideas: PDF studies, new comparisons, color flow measurements have been developed, news in the next meetings!

• Recommendations of HEP data storage of uncertainties is now a document discussed within experiments subgroup

• Jet substructure precision group is active and we will have new results in the f meetings of 2020

we need to speed up activities, involve more people to have great results in 2020! stay tuned (… and enjoy your holidays)!
backup
New Forum Topics: Jet Measurements in ALICE

- Medium influence on jets
- Direct comparison to models with different jet energy loss mechanisms
- Constrain global fits of jet energy loss models to extract medium properties (e.g. q-hat)

Jet RAA shows strong suppression of jets in medium

Visible pT dependence of this effect

Models can describe the data qualitatively

some slight discrepancies this needs a closer look from the theory side

\[
R_{AA} = \left. \frac{1}{N_{\text{event}}} \frac{d^2 N}{d\eta d\phi} \right|_{\text{AA}} - \left. \frac{d^2 \sigma}{d\phi d\eta} \right|_{\text{pp}}
\]

Eliane Epple
James Mulligan

some highlights on PbPb
New proposals: full Run II designing measurements

Idea presented last year at the LHCEW workshop and discussed in Durham and at CERN

- Defining V+Jets measurements with the Run II sample such that they are comparable between (ATLAS, CMS, LHC, ALICE) experiments
- Agreement on observables, binning, systematic uncertainties and the format (ongoing)

**Systematics**: establish plan for evaluating correlations across experiments
**Combination**: understand when it is useful to combine

Perform quantitative comparisons between measurements

Next steps: identify datasets and test on pseudoexperiments timescale ~ short term work leading to some document
**Goal #2:** study the impact of jet substructure measurements on FSR and NP PS MC tuning.

This was started as part of the jet working group at Les Houches 2019.

---

**$O(\Lambda_{QCD})$: The low mass bump**

- Very sensitive to hadronization model.
- String/cluster only change in the NP region (i.e. name make sense)
- useful for tuning NP with LHC data?
- Pythia is qualitatively different at high(er) masses even though it agrees ~well in the NP region.

For the proceedings: show NP parameter variations within a model & compare with analytic predictions.

---

**$O(10 \text{ GeV})$: Tuning with jet substructure**

The work has just begun...

...but preliminary results indicate that multiple observables a can have a non-negligible impact on FSR parameters.

For the proceedings: complete a Les Houches jet substructure tune & determine sensitivity of individual measurements see jet pull in the backup
LHC Tune

? Maybe