

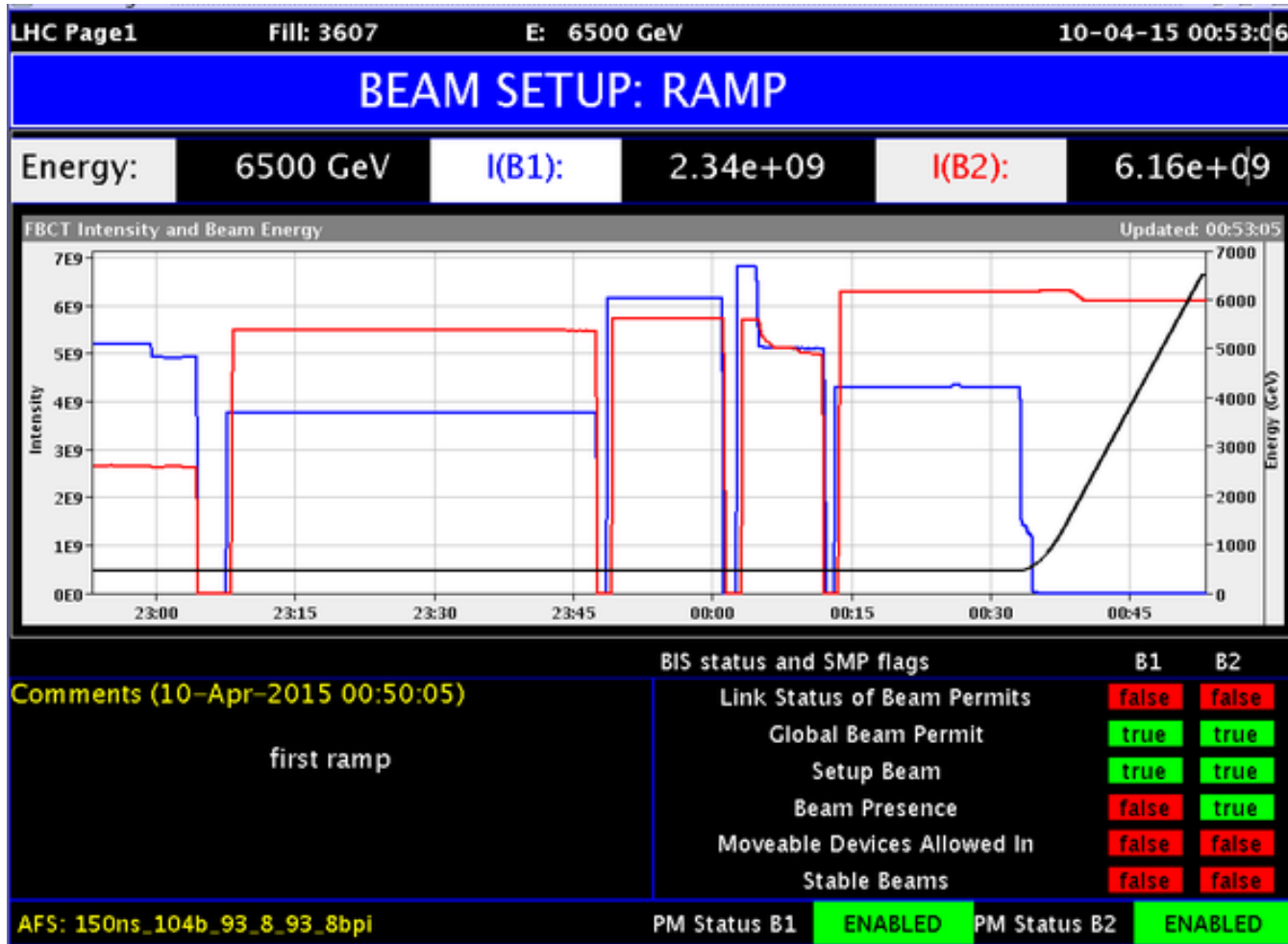
WP2 - Predictions and simulations of signal and background

Status & Visions (experiment)

Jon Butterworth

Freiburg, 15/4/2015

No experimental papers listed on Higgstools web pages.....



- Doesn't mean no progress...

Experimental Activities WP2

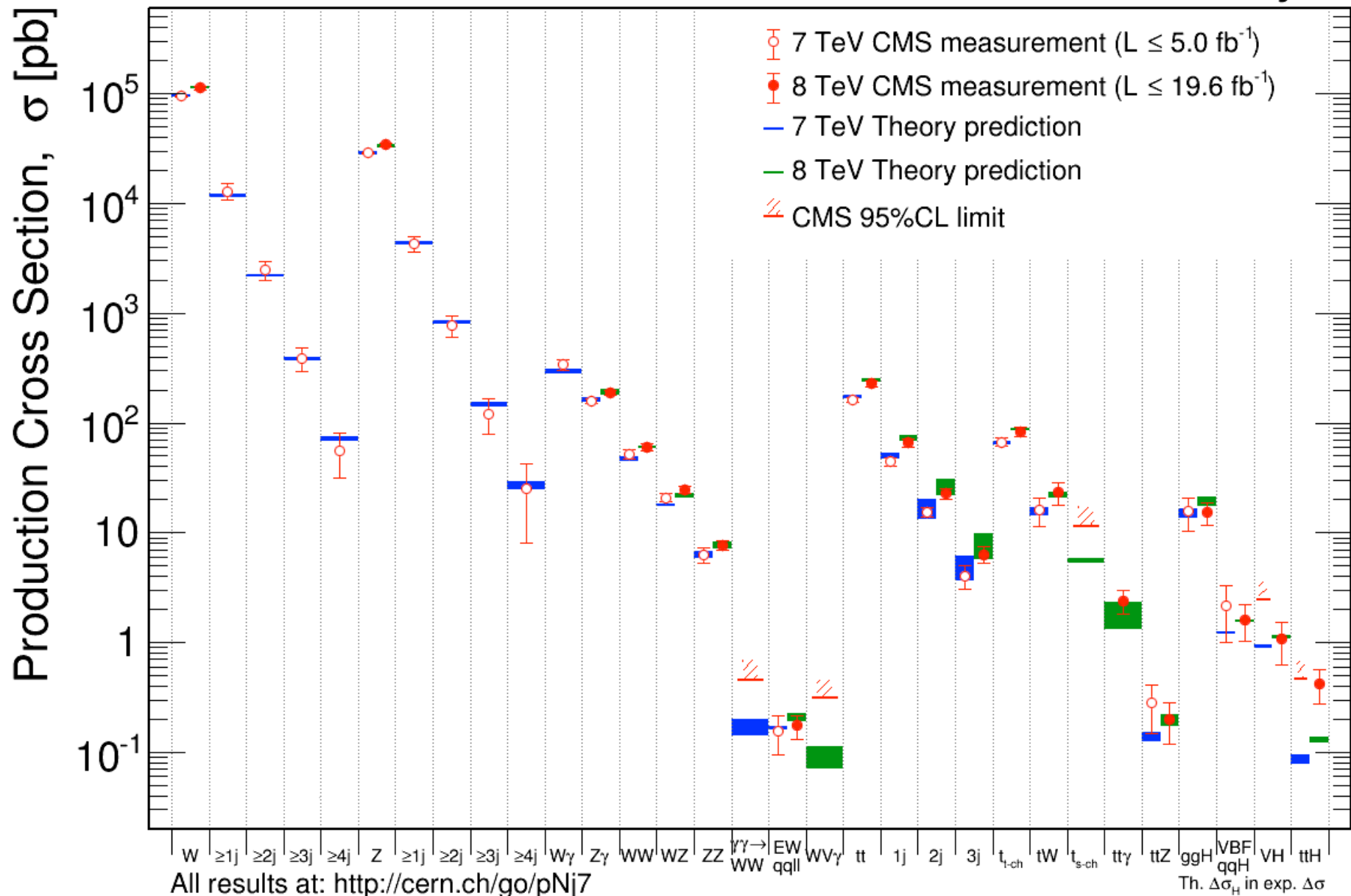
- Many contributions from HiggsTools members to preparations for Run II within the experiments, essential for implementing and testing best signal & background predictions, e.g.
 - Triggers
 - B-tagging
 - Jet and subjet calibration

Experimental Activities WP2

- Contributions also to experiment/theory comparison infrastructure
 - Rivet, and internal packages in ATLAS/CMS
 - Integration of the latest MC programmes and predictions
- Exploitation of Run I data to validate, test (and sometimes tune) the predictions →

Mar 2015

CMS Preliminary



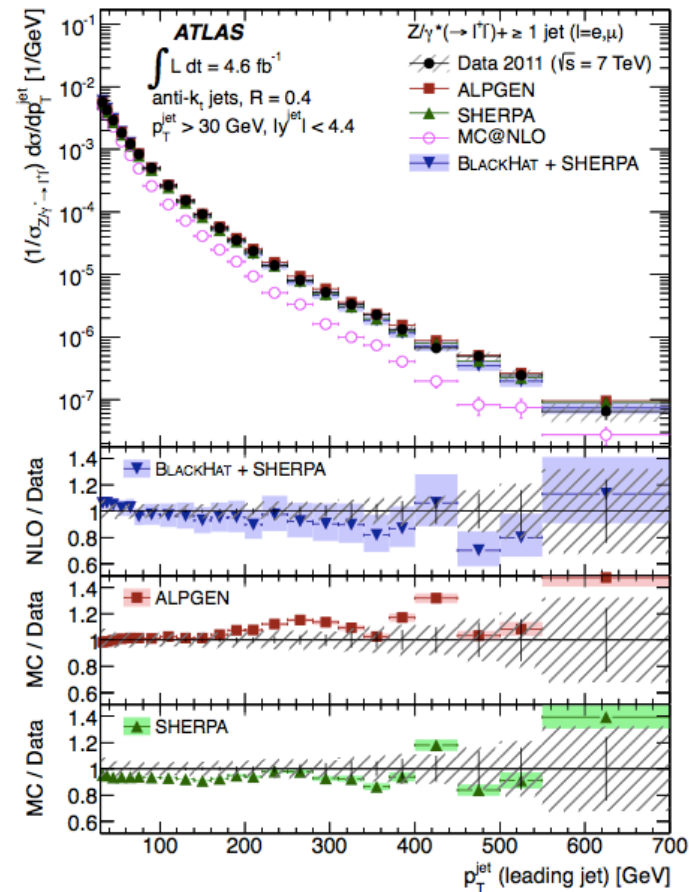
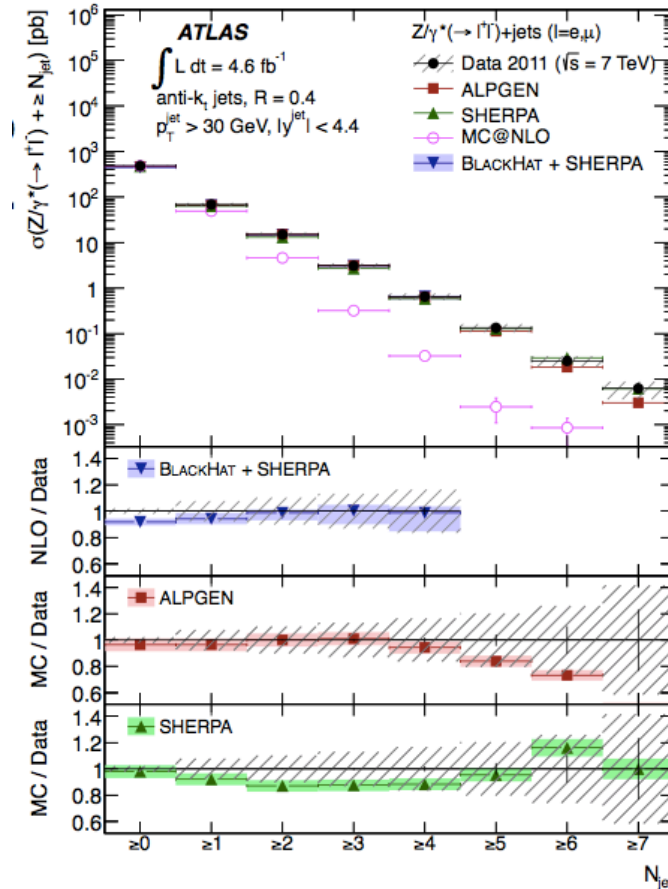


Backgrounds as evaluated in experiments

- Often described as “data driven”
 - Control regions/inversion of cuts
 - Still usually requires interpolation, even extrapolation, which requires decent theory input
 - In any case, demonstrating a precision understanding of Standard Model is essential for confidence in new discoveries.
 - *(See for example talk tomorrow from Inês Ochoa on VH , $H \rightarrow bb$ backgrounds)*
- Focus on fiducial and differential measurements
 - Minimise model dependence/circularity
 - Meet theory at the “final-state particle level”

e.g Z+jets

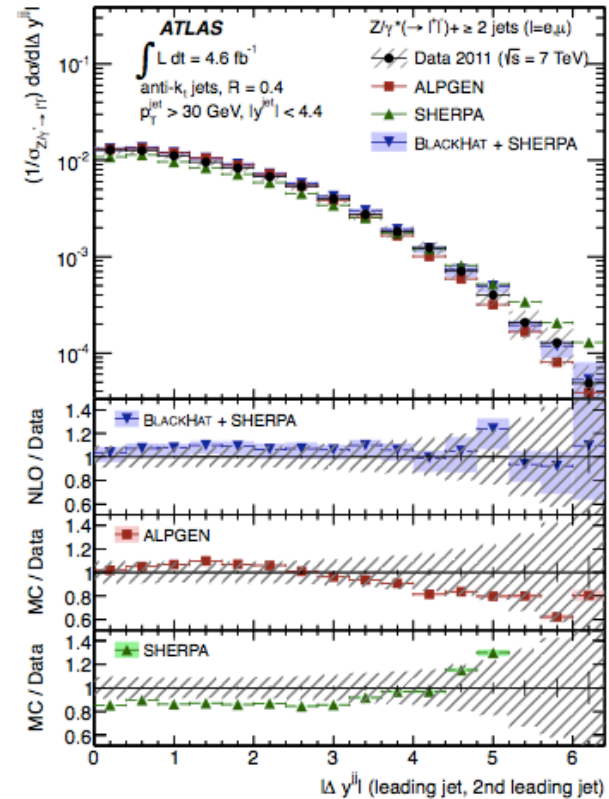
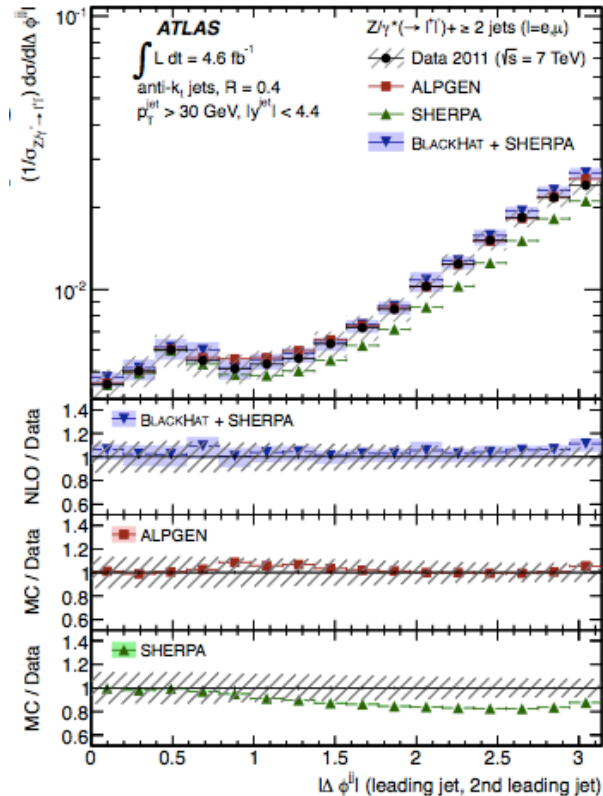
- Few backgrounds, multiple scales, high statistics “workhorse” for validation & tuning
- Sherpa & Alpgen, up to 5 jets in ME, matched to parton shower, plus hadronisation & underlying event



e.g Z+jets

- Generally very good agreement, some discrepancies in detail (e.g. jet angular variables)

arXiv:1309.7098



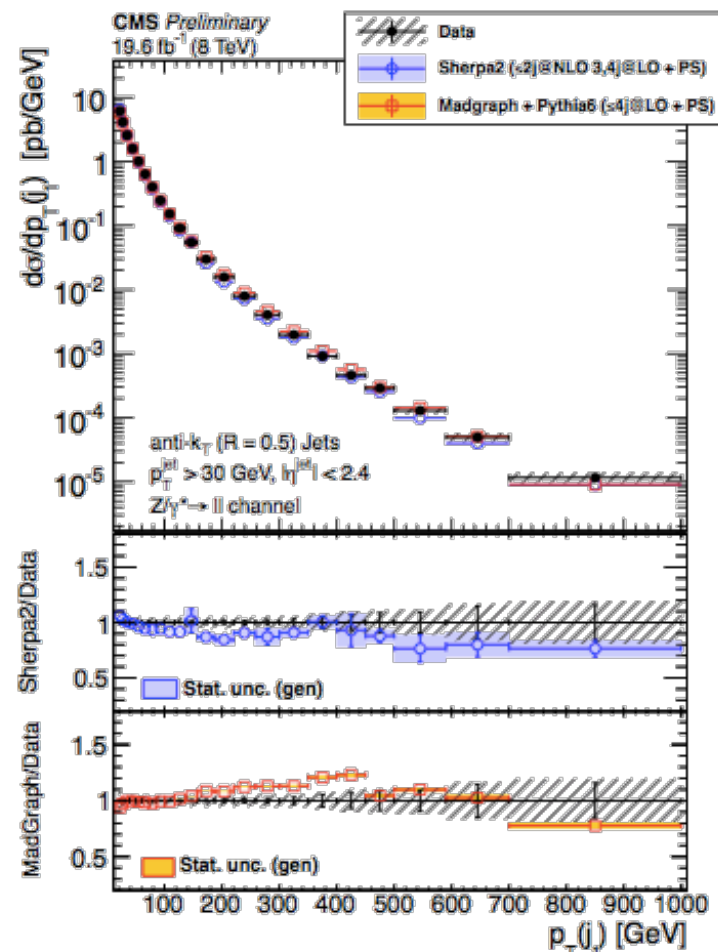
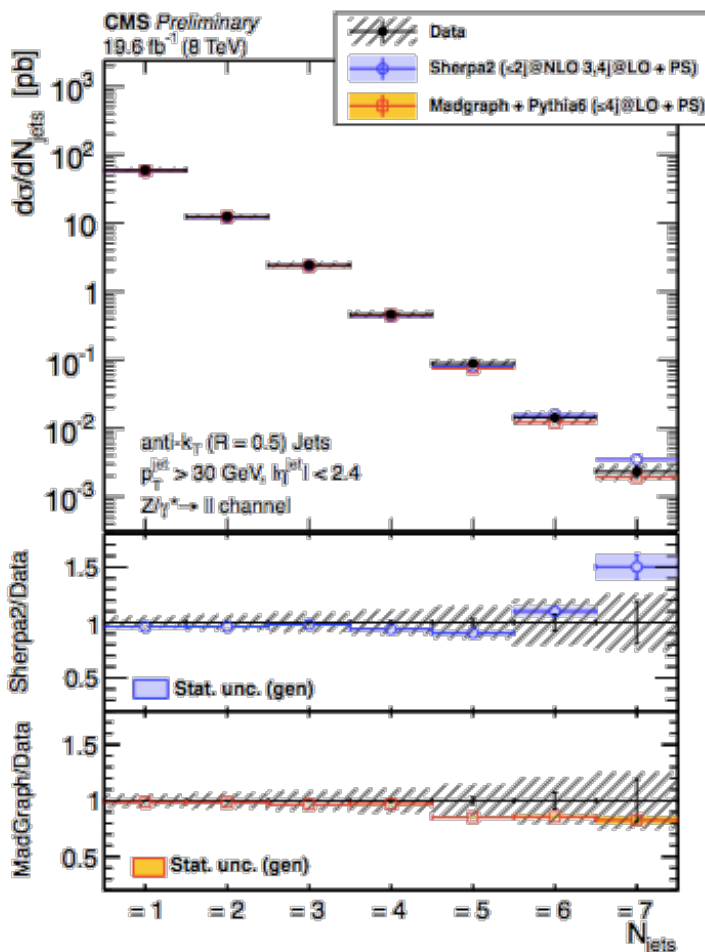


- ▶ The CMS equivalent now at $\sqrt{s}=8$ TeV.
- ▶ Very similar measurement but with significantly higher stats and more stringent constraints on MCs. (Unfortunately no di-jet kinematic plots)

- ▶ Sherpa models the data well except perhaps excess at low jet pT

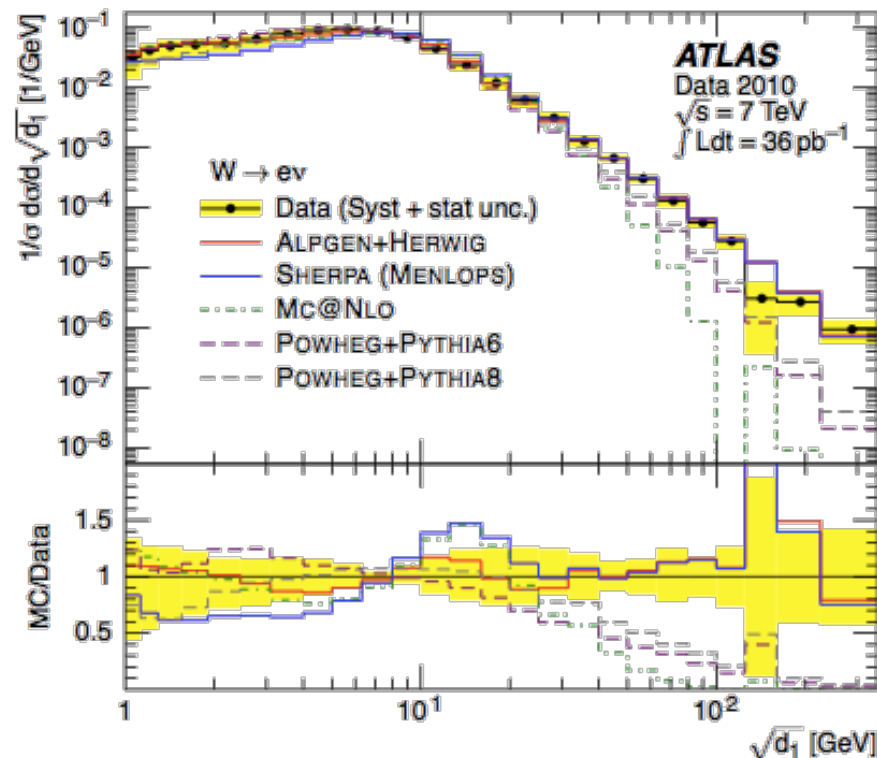
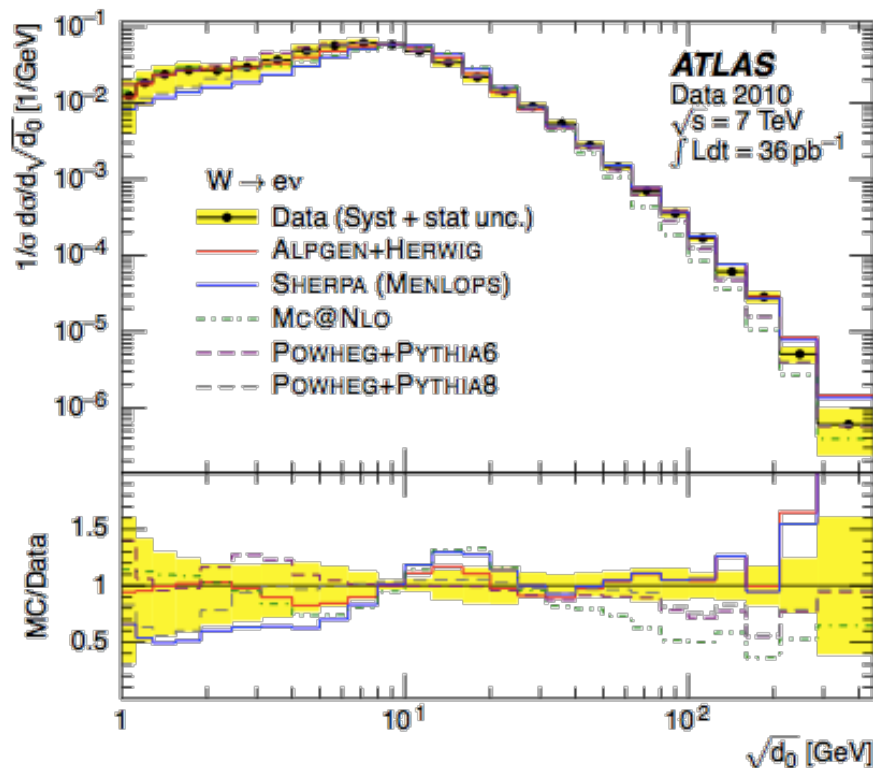
- ▶ Tune will help this in new version?

- ▶ MG5+Py6 is somewhat harder than the data as seen elsewhere.





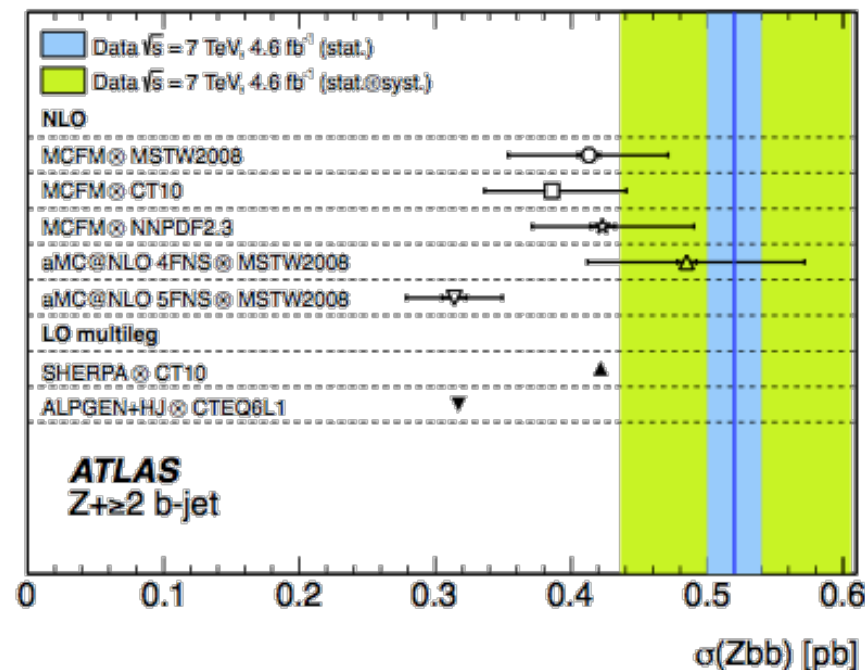
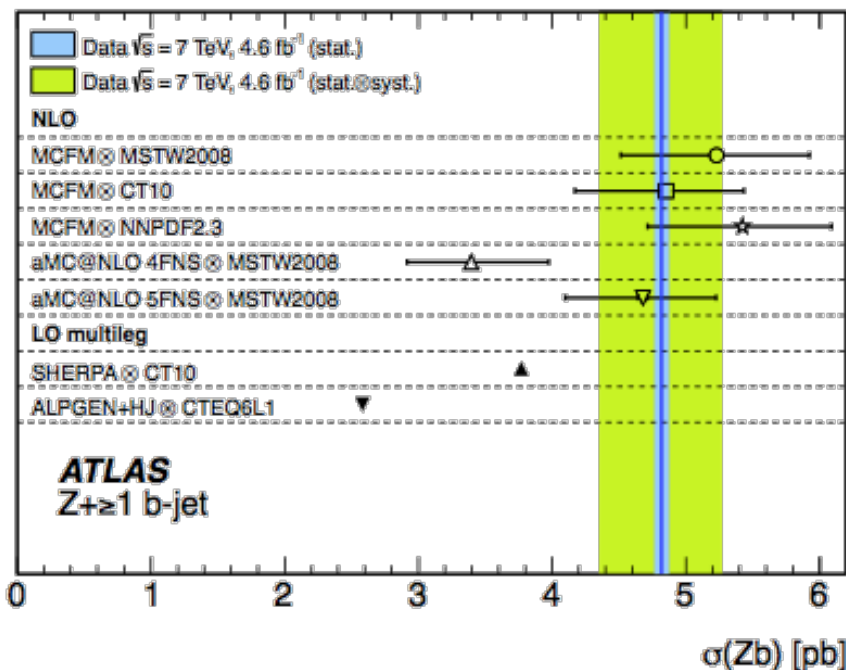
- ▶ Measurement of the kT-splitting scale - the scale at which as N-jet process would become an N+1-jet process
- ▶ This is particularly useful as it is often a key metric for validating ME+PS merging/matching schemes.
- ▶ Can help constrain merging scale uncertainties.



- Similar advantages to Z + jets, but also
 - Probes extra scale (b mass. Kinematics and cross sections for massive vs massless)
 - More directly tests key backgrounds for common Higgs and top decays
 - Special attention to $g \rightarrow bb$ background in boosted topologies (*e.g. HiggTools work ongoing on $g \rightarrow bb$ in $t\bar{t}bb$ from Tim Wolf, Netherlands node*)



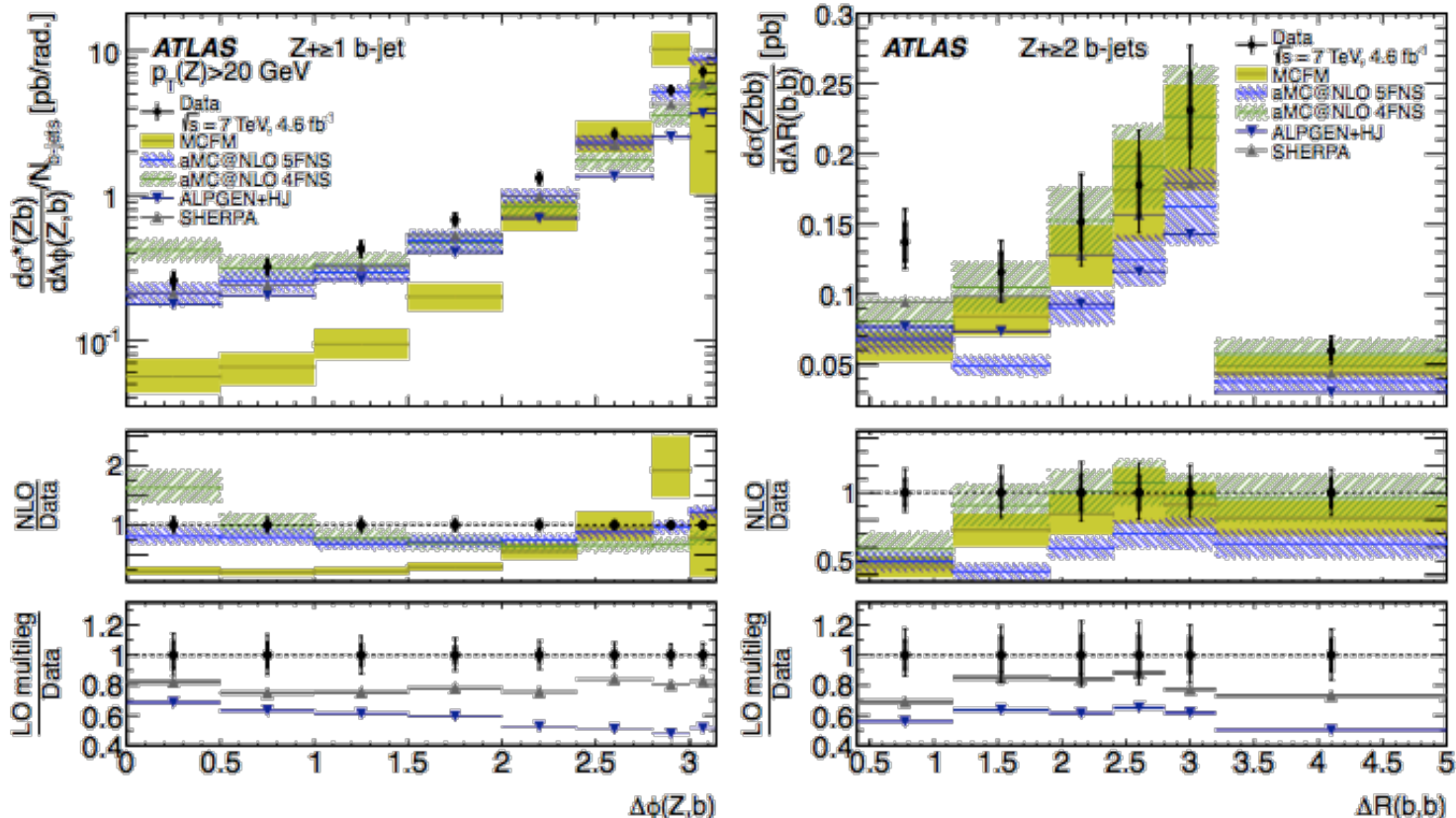
- ▶ Inclusive and differential measurements of Z+b-jet production.
 - ▶ **Z+≥1 b-jet** - More stats
 - ▶ **Z+≥2 b-jets** - Angular correlations but lower stats.
- ▶ As expected 5-flavour scheme reproduces Z+b cross section better and 4-flavour scheme reproduces the Z+bb cross section.





- ▶ Inclusive and differential measurements of Z+b-jet production.
 - ▶ **Z+≥1 b-jet** - More stats
 - ▶ **Z+≥2 b-jets** - Angular correlations but lower stats.
- ▶ As expected 5-flavour scheme reproduces Z+b cross section better and 4-flavour scheme reproduces the Z+bb cross section.

arXiv:1407.3643
 arXiv:1109.1403



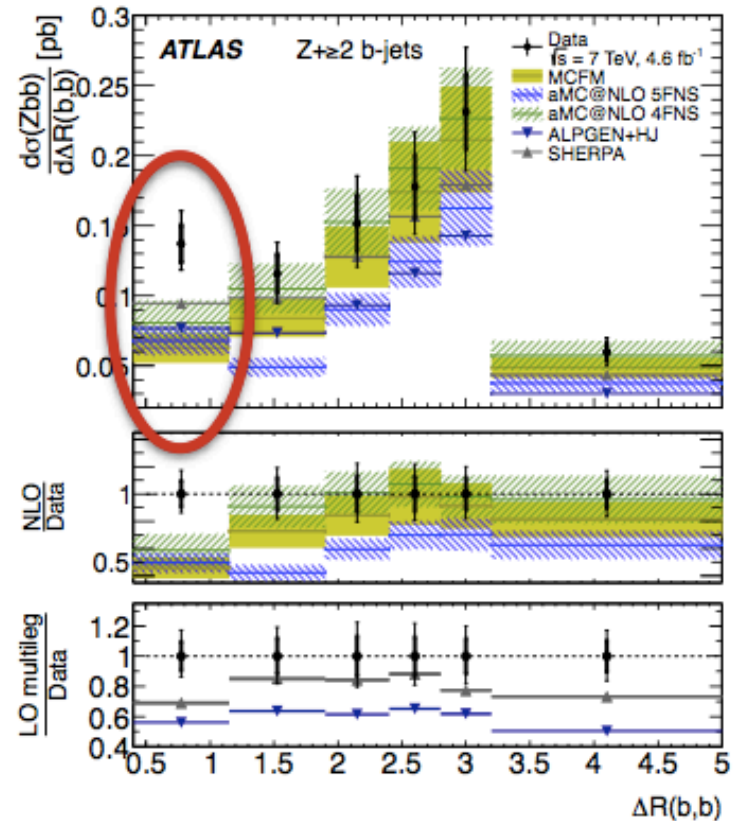
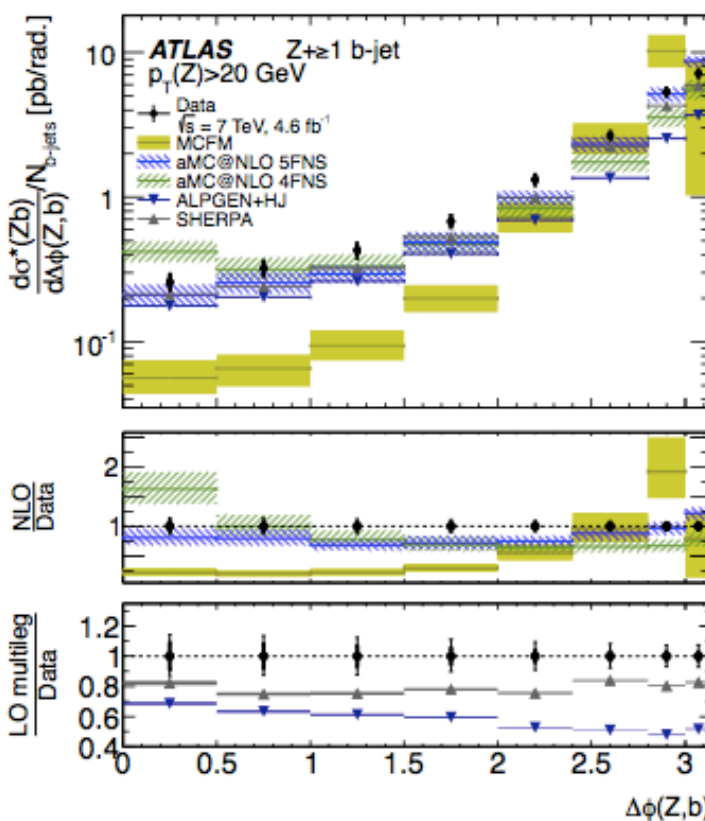


- ▶ Inclusive and differential measurements of Z+b-jet production.
 - ▶ **Z+≥1 b-jet** - More stats
 - ▶ **Z+≥2 b-jets** - Angular correlations but lower stats.
- ▶ As expected 5-flavour scheme reproduces Z+b cross section better and 4-flavour scheme reproduces the Z+bb cross section.

▶ Discrepancy at low $\Delta R(b,b)$

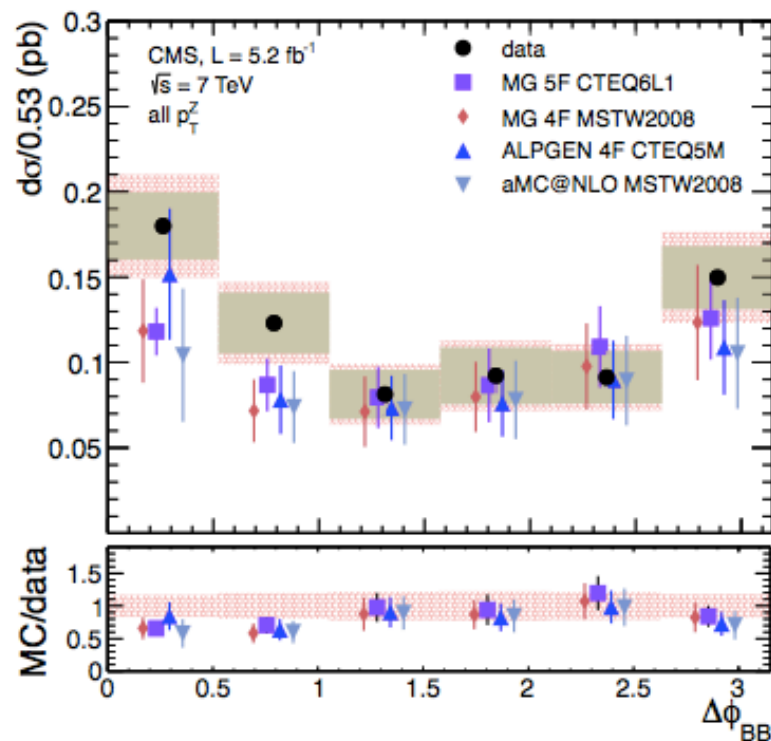
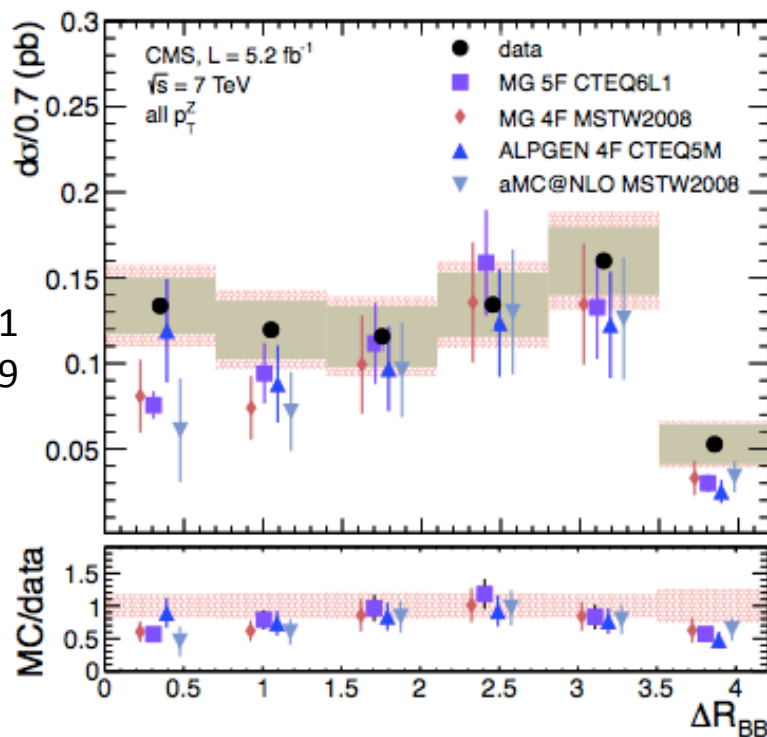
- ▶ only Alpgen reproduces shape here.

▶ No sensitivity to most interesting area at very low $\Delta R(b,b)$ due to jet radius.





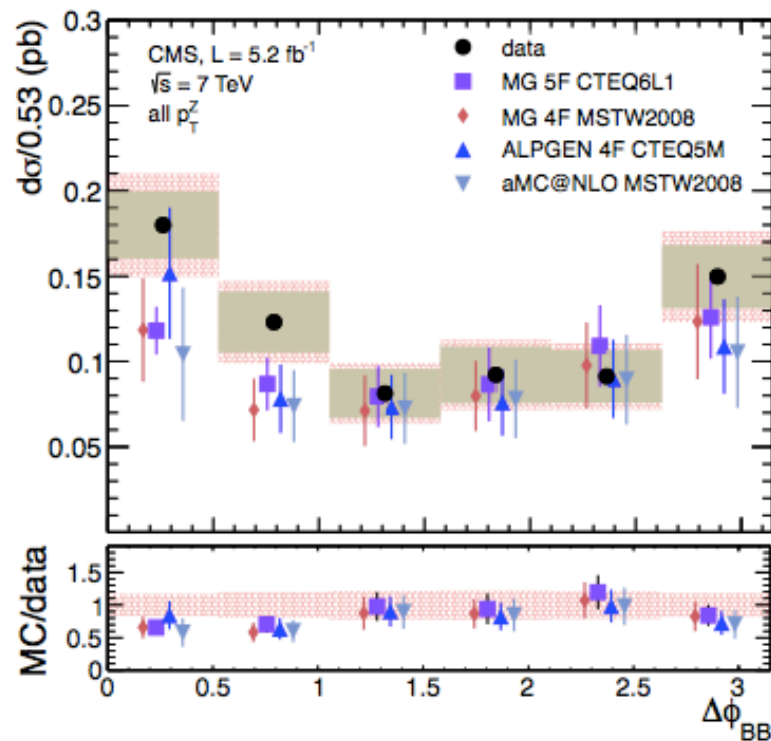
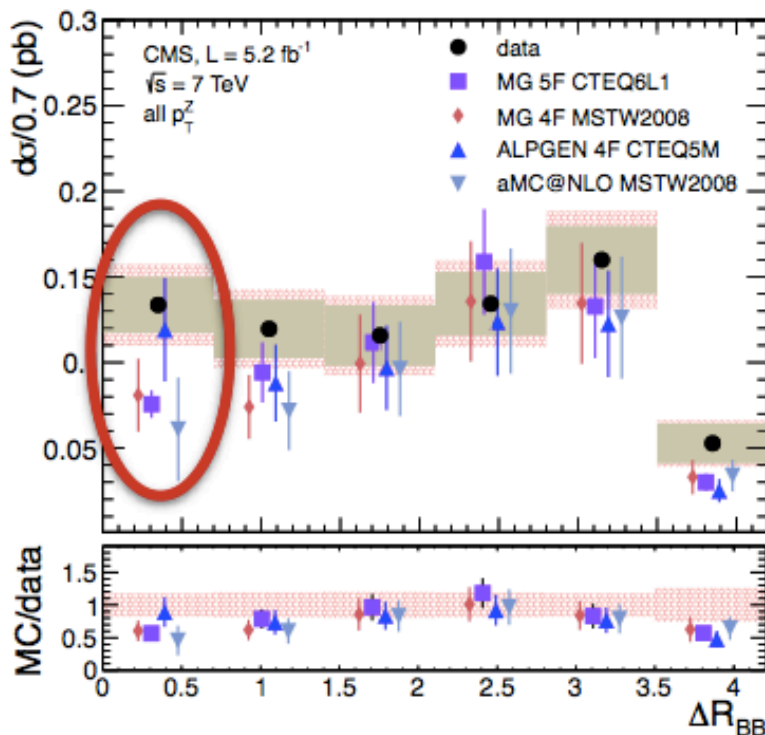
- ▶ Reconstitutes B-hadrons rather than jets
 - ▶ Inclusive vertex finder (non-jet-seeded b-tagging)
- ▶ Very nice measurement which allows access to very low $\Delta R(B,B)$
- ▶ Very statistics limited - but still see low $\Delta R(B,B)$ discrepancy.



Arxiv:1402.1521
 Arxiv:1310.1349

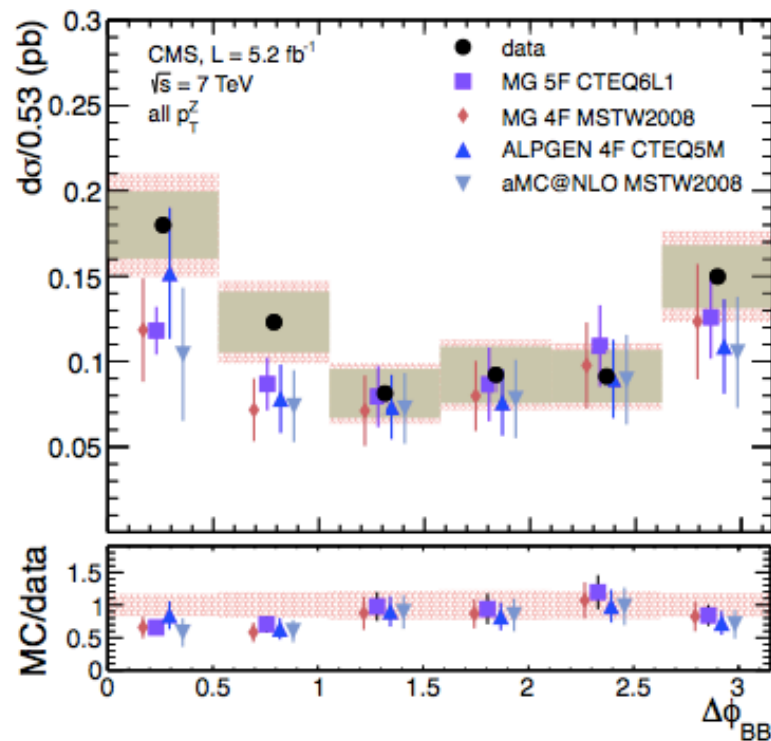
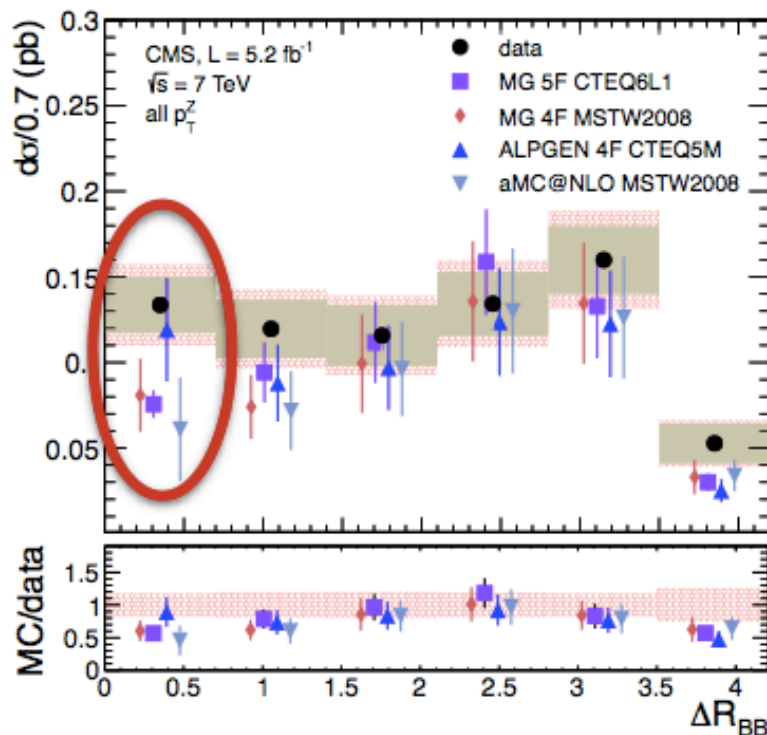


- ▶ Reconstitutes B-hadrons rather than jets
 - ▶ Inclusive vertex finder (non-jet-seeded b-tagging)
- ▶ Very nice measurement which allows access to very low $\Delta R(B,B)$
- ▶ Very statistics limited - but still see low $\Delta R(B,B)$ discrepancy.





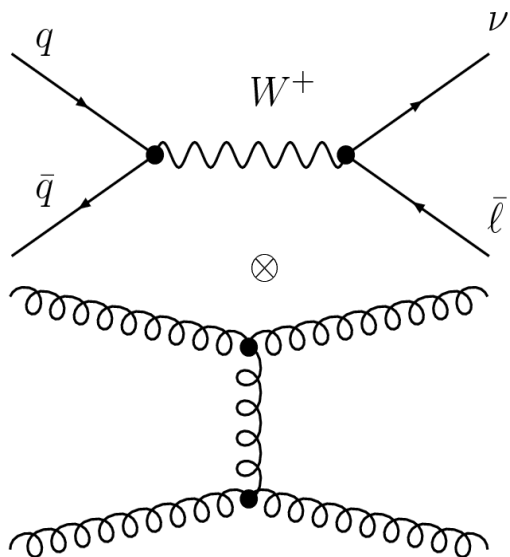
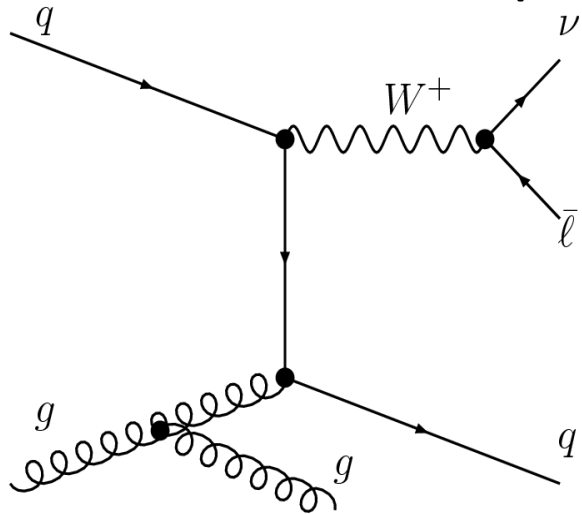
- ▶ Reconstitutes B-hadrons rather than jets
 - ▶ Inclusive vertex finder (non-jet-seeded b-tagging)
- ▶ Very nice measurement which allows access to very low $\Delta R(B,B)$
- ▶ Very statistics limited - but still see low $\Delta R(B,B)$ discrepancy.





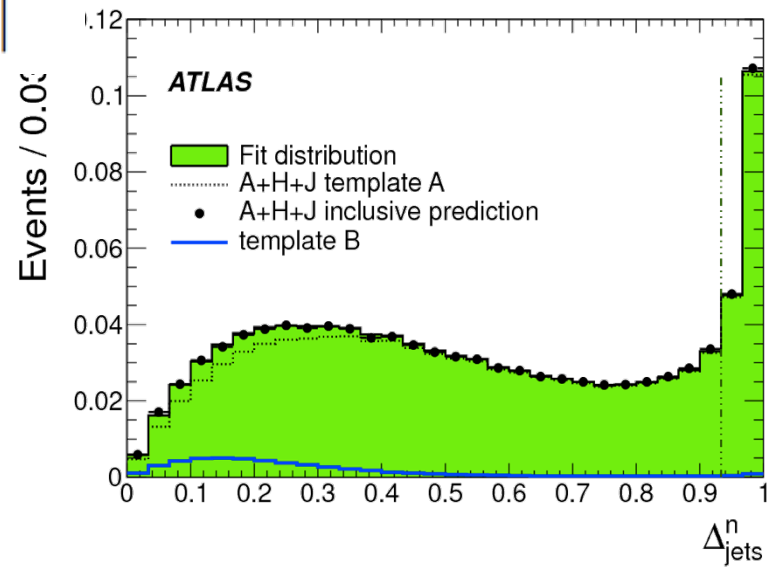
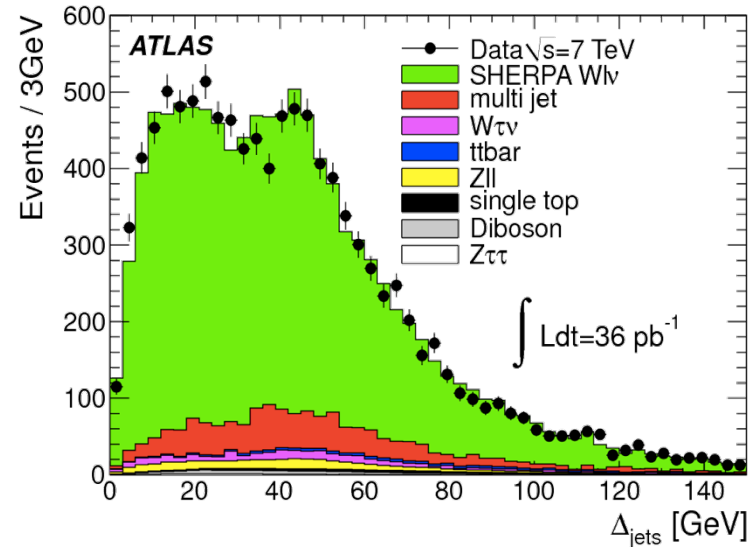
- Multiparton scattering
 - Definitely happens...
 - QCD motivated models, but lots of non-perturbative input (impact parameter distribution of partons, correlations...)
 - Pythia, Sherpa, Herwig all model it, and need it to describe underlying event
 - Potentially significant background to some rare event topologies (e.g. like-sign leptons)
 - Experimental constraints from e.g. W +dijets

– Experimental constraints from e.g. W+dijets

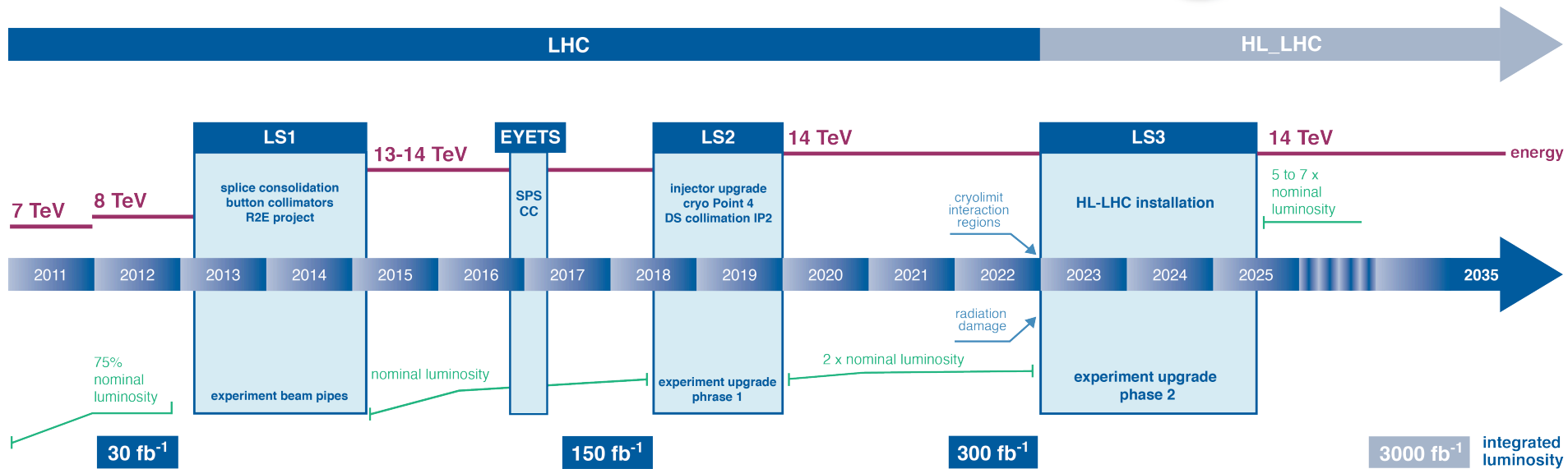


$$\Delta_{\text{jets}}^n = \frac{|\vec{p}_T^{J_1} + \vec{p}_T^{J_2}|}{|\vec{p}_T^{J_1}| + |\vec{p}_T^{J_2}|}$$

arXiv:1301.6872



LHC / HL-LHC Plan





- Have focused on boson+jets
 - Fiducial/differential measurements also important, and more becoming available, for $\gamma\gamma$ (including jets), **top** (including jet radiation patterns), **dibosons** (including regions where electroweak production is enhanced)...

The road ahead...

• Have focused on boson+jets

– Fiducial/differential measurements also important, and more becoming available, for $\gamma\gamma$ (including jets), top (including jet radiation patterns), $dibosons$ (including regions where electroweak production is enhanced)...

- CMS_2010_S8884919 – Measurement of the NSD charged particle multiplicity at $\sqrt{s} = 0.9, 2.36, \text{ and } 7 \text{ TeV}$ with the CMS detector.
- CMS_2011_S8941262 – Production cross-sections of muons from b hadron decays in pp collisions
- CMS_2011_S8950903 – Dijet azimuthal decorrelations in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2011_S8957746 – Event shapes
- CMS_2011_S9215166 – Measurement of dijet angular distributions and search for quark compositeness in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2011_S8973270 – B/\bar{B} angular correlations based on secondary vertex reconstruction in pp collisions
- CMS_2011_S8974280 – $K^*_S, \rho, \omega, \text{ and } \phi$ transverse momentum and rapidity spectra at 900 and 7000 GeV
- CMS_2011_S9086218 – Measurement of the inclusive jet cross-section in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2011_S9088458 – Measurement of ratio of the 3-jet over 2-jet cross section in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2011_S9120041 – Traditional leading jet UE measurement at $\sqrt{s} = 0.9$ and 7 TeV
- CMS_2011_S9215166 – Forward energy flow in MP and dijet events at 0.9 and 7 TeV
- CMS_2012_I1087342 – Measurement of forward and forward+central jets at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2012_I1090117 – Jet multiplicity distributions in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2012_I1102908 – Measurement of inclusive and exclusive dijet production ratio at large rapidity intervals at center-of-mass energy 7 TeV.
- CMS_2012_I1107658 – Measurement of the underlying event activity in the Drell-Yan process at a centre-of-mass energy of 7 TeV
- CMS_2012_I1184941 – Measurement of the differential cross section for inclusive dijet production as a function of ξ_i in 7 TeV proton-proton collisions.
- CMS_2012_I1193338 – Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2012_I941555 – Measurement of differential $Z/\gamma \rightarrow p_T$ and y
- CMS_2012_PAS_QCD_11_010 – Strange particle production in underlying events in proton-proton collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2013_I1209721 – Azimuthal correlations and event shapes in $Z + \text{jets}$ in pp collisions at 7 TeV
- CMS_2013_I1218372 – Study of the underlying event at forward rapidity in proton-proton collisions at the LHC
- CMS_2013_I1224539_DIJET – CMS jet mass measurement in dijet events
- CMS_2013_I1224539_WJET – CMS jet mass measurement in $W + \text{jet}$ events
- CMS_2013_I1224539_ZJET – CMS jet mass measurement in $Z + \text{jet}$ events
- CMS_2013_I1256943 – Cross-section and angular correlations in $Z + b$ -hadrons events at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2013_I1258128 – Rapidity distributions in exclusive $Z + \text{jet}$ and $\gamma + \text{jet}$ events in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2013_I1261026 – Jet and underlying event properties as a function of particle multiplicity
- CMS_2013_I1265659 – Probing color coherence effects in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2013_I1272853 – Study of observables sensitive to double parton scattering in $W + 2$ jets process in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2013_I1273574 – Studies of 4-jet production in proton-proton collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_2014_I1298810 – Ratios of jet p_T spectra, which relate to the ratios of inclusive, differential jet cross sections
- CMS_2014_I1303894 – Differential cross-section of $W + \text{jets}$ bosons + jets in pp collisions at $\sqrt{s} = 7 \text{ TeV}$
- CMS_QCD_10_024 – Pseudorapidity distributions of charged particles at $\sqrt{s} = 0.9$ and 7 TeV
- DO_1996_S3214044 – Topological distributions of inclusive three- and four-jet events

- Have focused on boson+jets
 - Fiducial/differential measurements also important, and more becoming available, for $\gamma\gamma$ (including jets), **top** (including jet radiation patterns), **dibosons** (including regions where electroweak production is enhanced)...
 - 8 TeV dataset still not fully measured & available in Rivet



- Have focused on boson+jets
 - Fiducial/differential measurements also important, and more becoming available, for $\gamma\gamma$ (including jets), **top** (including jet radiation patterns), **dibosons** (including regions where electroweak production is enhanced)...
 - 8 TeV dataset still not fully measured & available in Rivet
- Lots of work going on in the experiments and generator collaborations (including by HiggsTools members & ESRs) to make well-understood, up-to-date versions of MC generators available early in Run 2



- Have focused on boson+jets
 - Fiducial/differential measurements also important, and more becoming available, for $\gamma\gamma$ (including jets), **top** (including jet radiation patterns), **dibosons** (including regions where electroweak production is enhanced)...
 - 8 TeV dataset still not fully measured & available in Rivet
- Lots of work going on in the experiments and generator collaborations (including by HiggsTools members & ESRs) to make well-understood, up-to-date versions of MC generators available early in Run 2
- Well placed for strong HiggsTools contributions to the challenges of Run 2