QCD results from ATLAS

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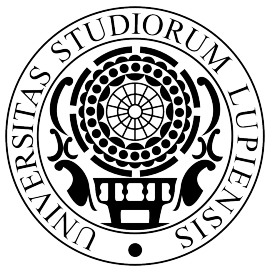
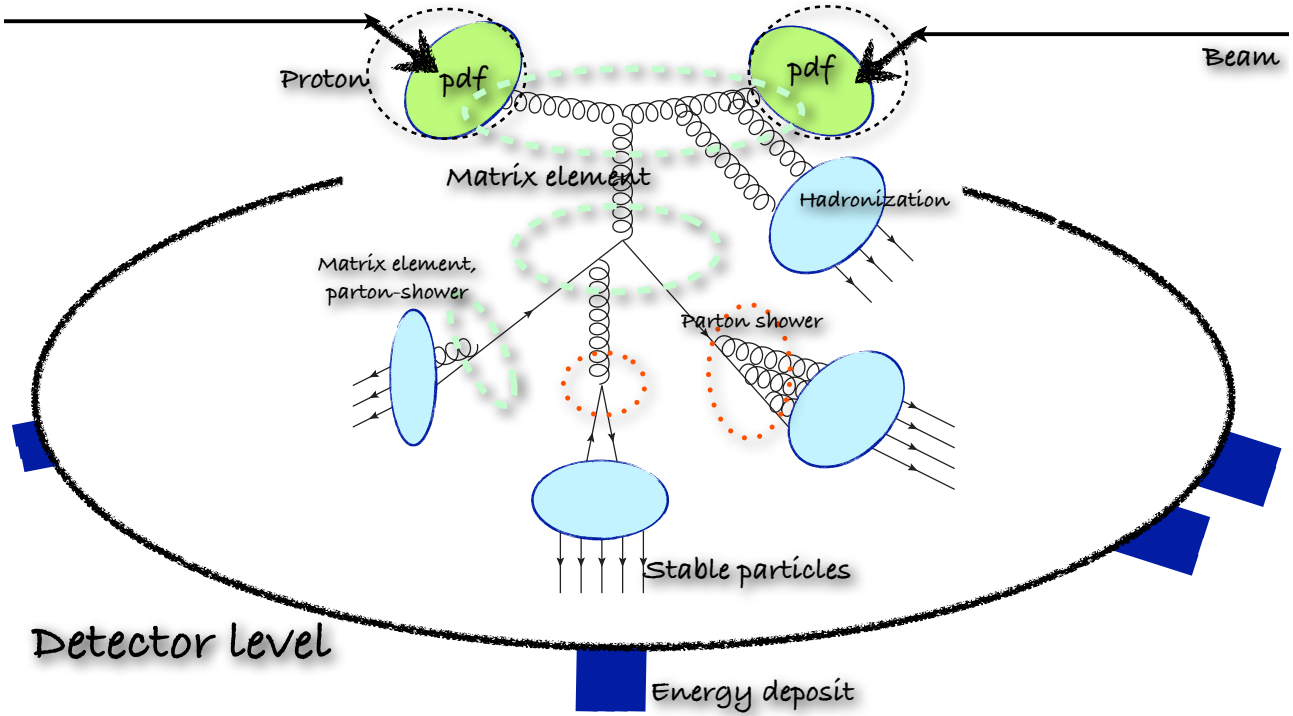


Introduction

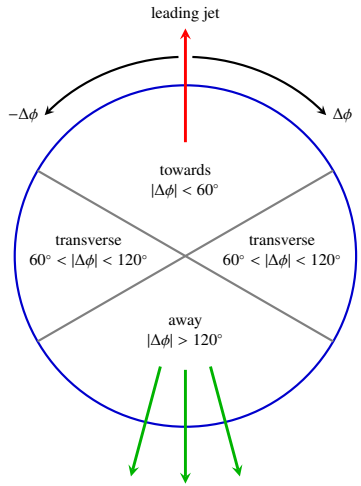
- Data compared to theory predictions at particle level.
  - Monte Carlo (MC) event generators based on matrix elements (ME) at low multiplicity in LO approximation ($2 \to 2$), eg. PYTHIA or HERWIG, on multileg ME (up to $2 \to 6$), eg. ALPGEN+HERWIG+JIMMY and SHERPA, or on NLO matrix elements, eg. MC@NLO+HERWIG+JIMMY.
  - Parton level predictions available up to NNLO QCD, eg. FEWZ, or at NLO with multileg ME (up to $2 \to 6$) calculation, BLACKHAT+SHERPA
  - **What kind of theory prediction is preferred by the data?**
  - Several parton distribution function (pdf) sets (eg. CT10, MSTW2008...) used in theory calculations.
    - **What can we learn about parton distribution functions with the LHC data?**

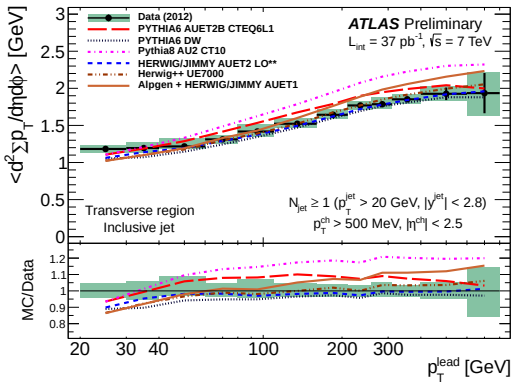


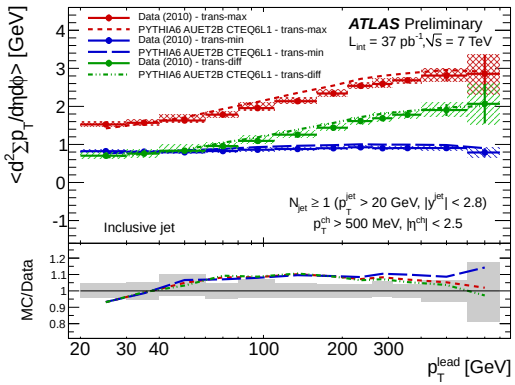
The underlying event in jet events

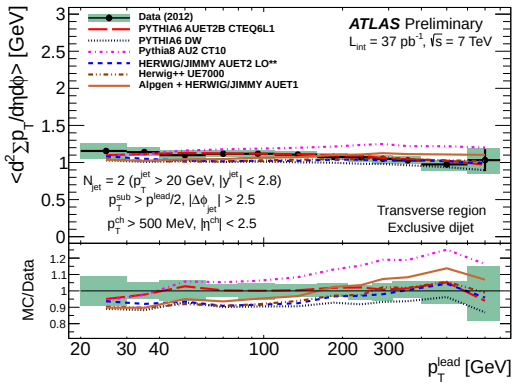
ATLAS-CONF-2012-164

- Study the UE as function of jet p_T (event hard scale).
- Define different azimuthal regions with respect to the leading jet.
  - Transverse region more sensitive to UE.
  - Separating further the transverse regions to improve the sensitivity to different UE components:
    - more active transverse region "transv-max";
    - less active transverse region "transv-min";
    - "transv-diff": difference between observables in "transv-max" and "transv-min"
- MC models (PYTHIA8, HERWIG++, different tunes of PYTHIA6 and HERWIG) reproduce approximately well the features observed in data.





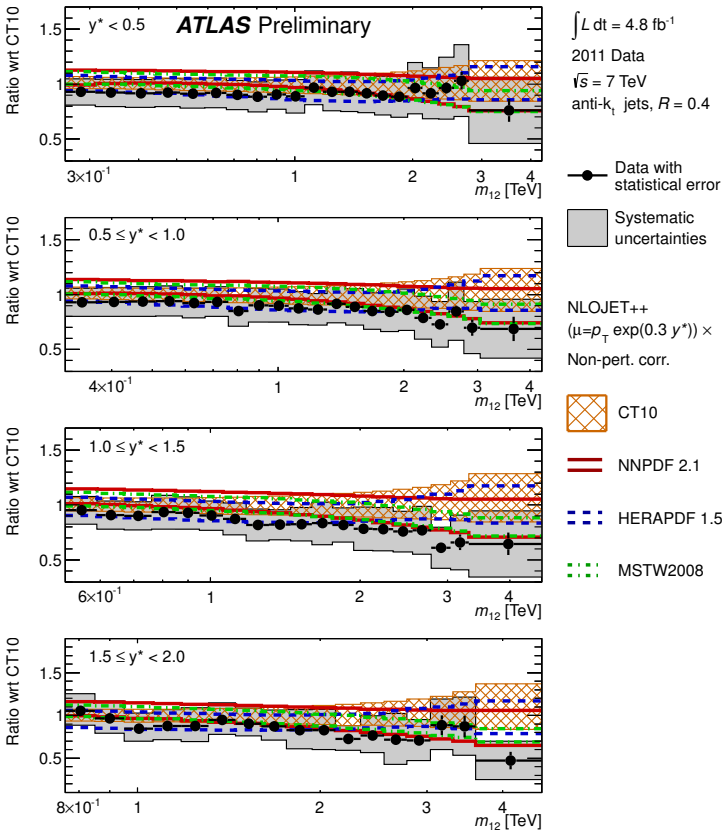


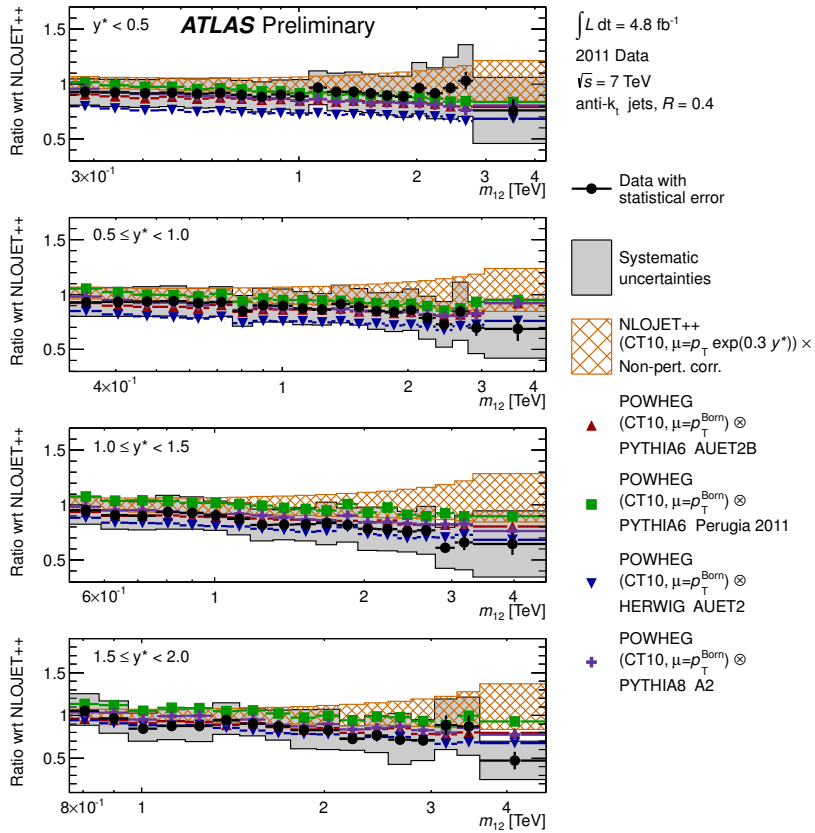


Dijet cross sections

ATLAS-CONF-2012-021

- Data compared to NLO QCD calculations (POWHEG, NLOJET++);
  - various pdf sets and parton shower (PS) models have been tested.
- Sizable experimental systematic uncertainties, ~ 10%-60%, dominated by jet-energy-scale uncertainty.

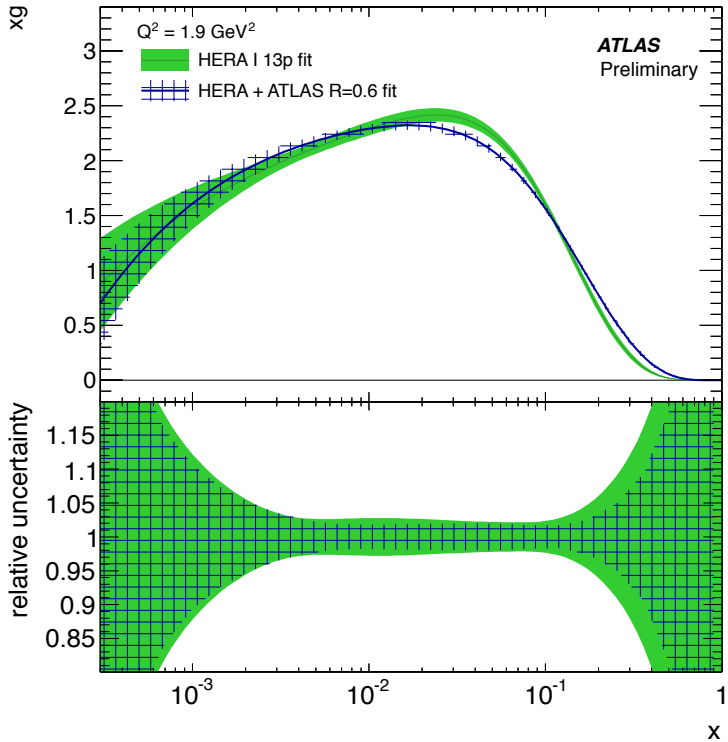


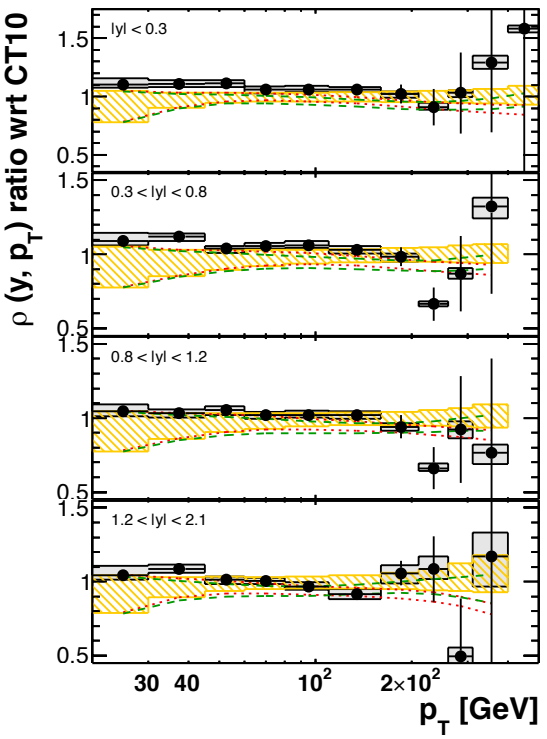


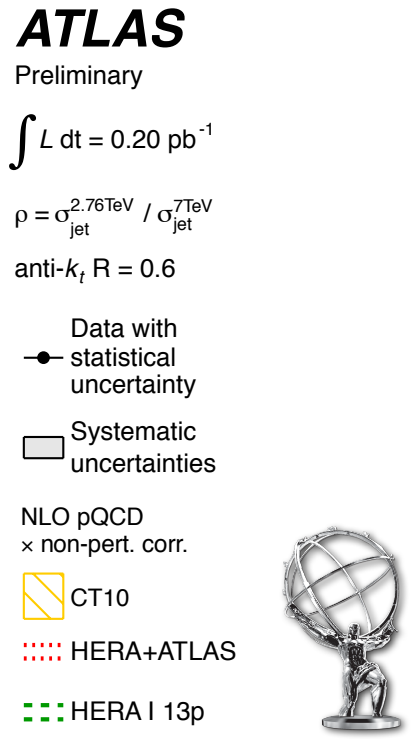
Ratio of inclusive jet cross section at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7$ TeV

ATLAS-CONF-2012-128

- Measuring $\rho(y, p_T) = \left(\frac{2.76\ TeV}{7\ TeV}\right)^3 \cdot \frac{\sigma^{(2.76\ TeV)}(y,p_T)}{\sigma^{(7\ TeV)}(y,p_T)}$
- Exploiting the partial cancellation of correlated systematic uncertainties (**jet-energy-scale!**) in cross section ratios.
- **Experimental uncertainties typically smaller than the theoretical uncertainties.**
  - ATLAS data sensitive at intermediate-high Bjorken-x: reduced uncertainty almost in the full x range.



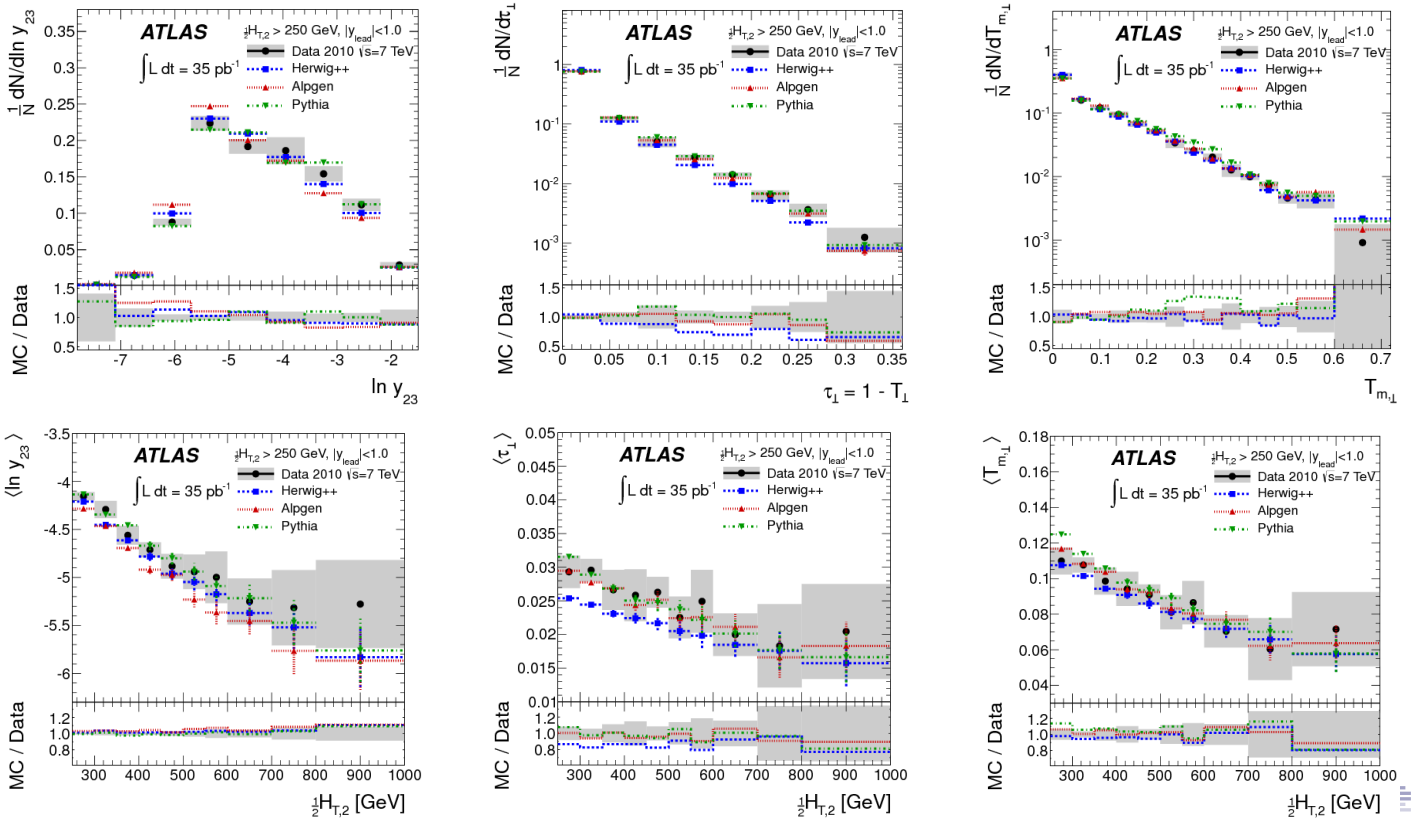




Event shapes at large momentum transfer

Eur. Phys. J. C 72 (2012) 2211

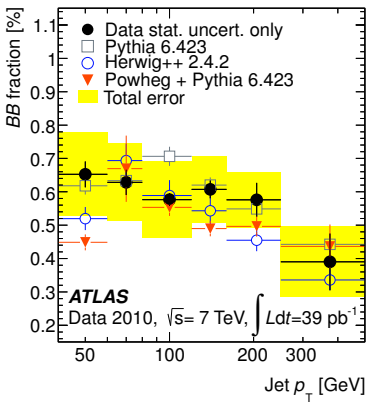
- Study of multijet topology using event shapes: third-jet resolution parameter (y_{23}), event thrust ($T_\perp$), thrust minor ($T_{m,\perp}$).
  - Dependence on the event hard scale (mean p_T of the two leading jets, $\frac{1}{2}H_{T,2}$) also investigated.
- Reasonable description of data provided by LO MC generators (ALPGEN, PYTHIA6, HERWIG++).

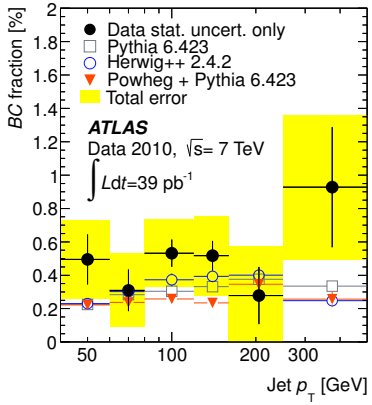


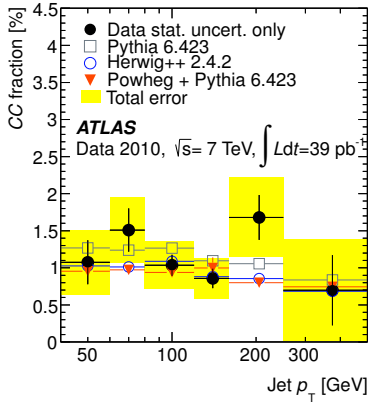
More exclusive measurement: flavour composition of dijet events

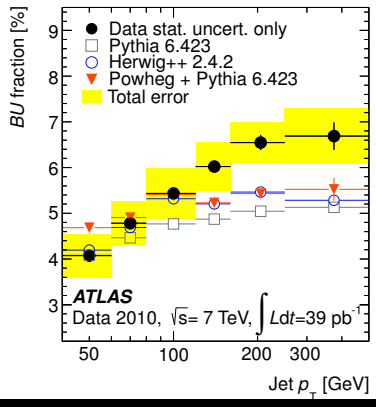
Eur. Phys. J. C 73 (2013) 2301

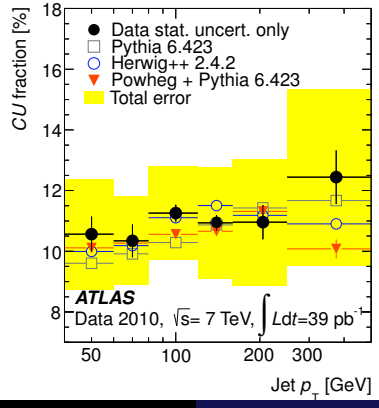
- Extract the flavor composition in di-jet events: bottom-bottom (BB), charm-charm (CC), light-light (UU), bottom-charm (BC), bottom-light (BU), charm-light (CU);
  - no b-tagging requirements.
- Compare data to LO generators (PYTHIA6, HERWIG++) and NLO predictions (POWHEG);
  - significant data-MC disagreement in the BU fraction.

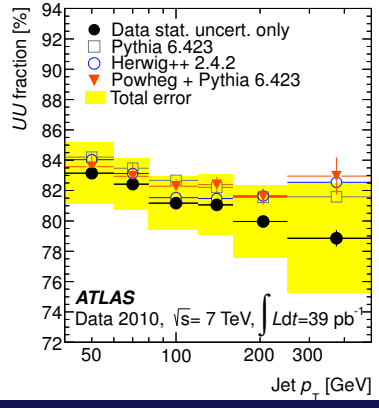








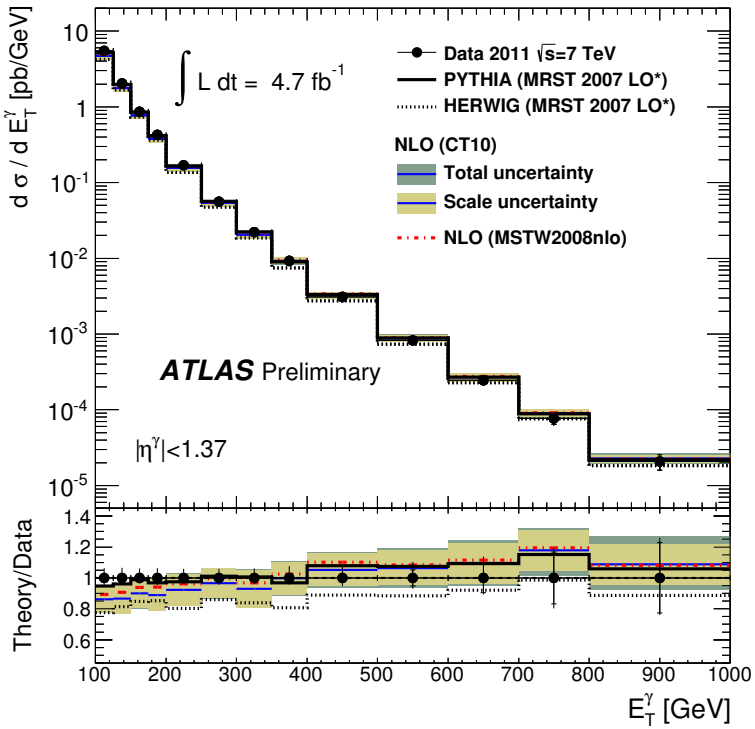


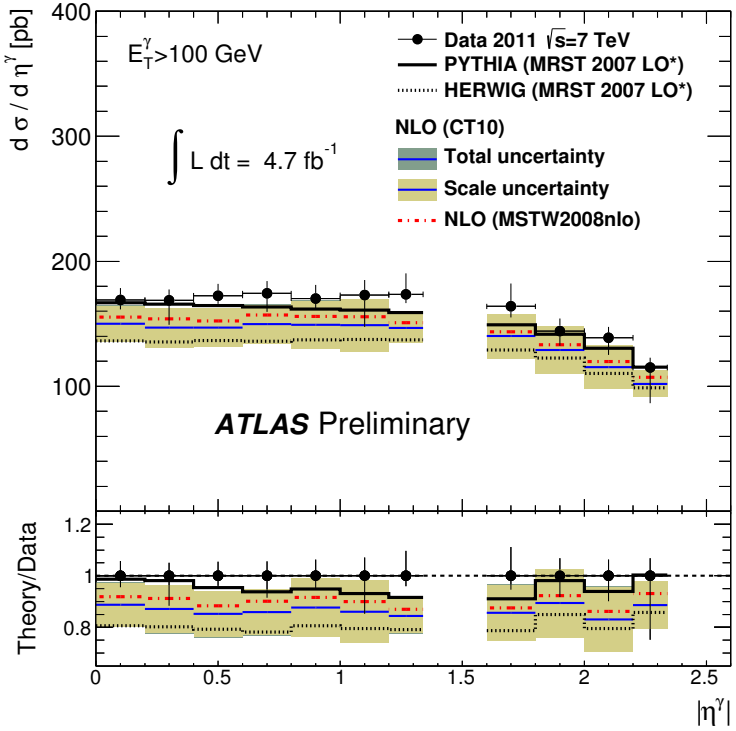


Inclusive cross sections of isolated prompt photons

ATLAS-CONF-2013-022

- Measured E_T^γ and $|\eta^\gamma|$ distributions for isolated photon production.
- Distributions well described by LO (PYTHIA, HERWIG) and NLO (JETPHOX) QCD predictions,
  - but cross section at low E_T^γ, slightly underestimated by all the predictions.

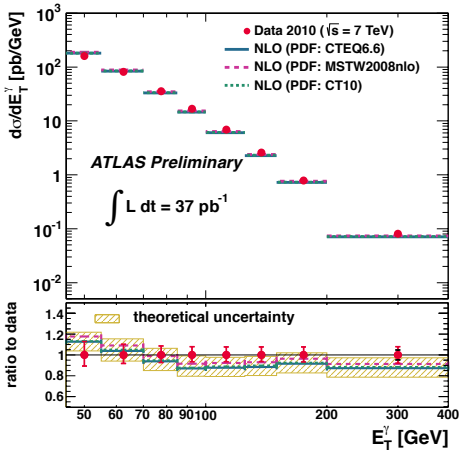


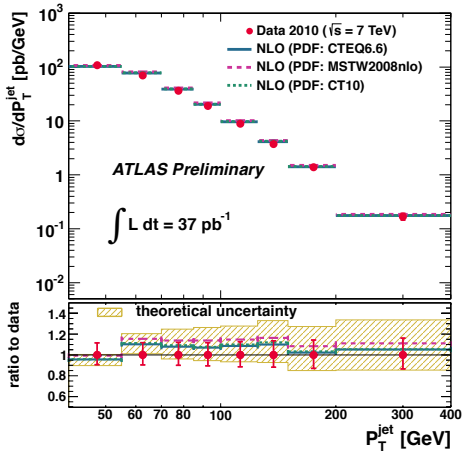


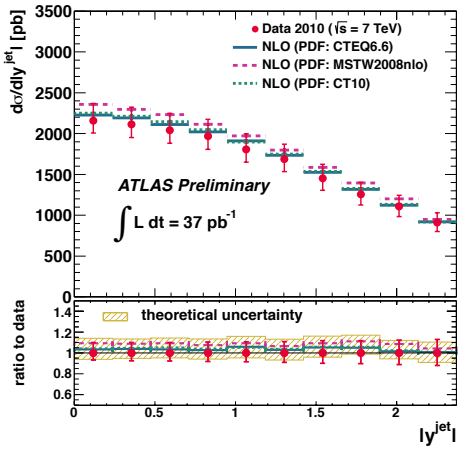
Dynamics of isolated-photon and jet production

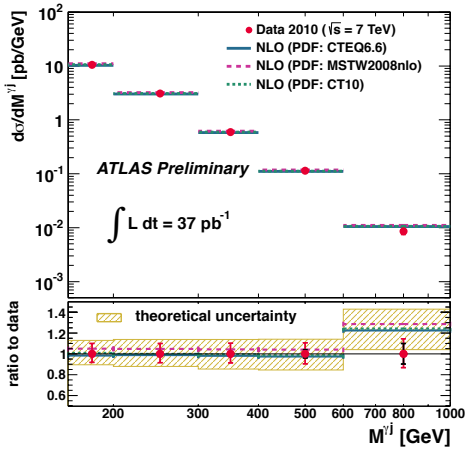
ATLAS-CONF-2013-023

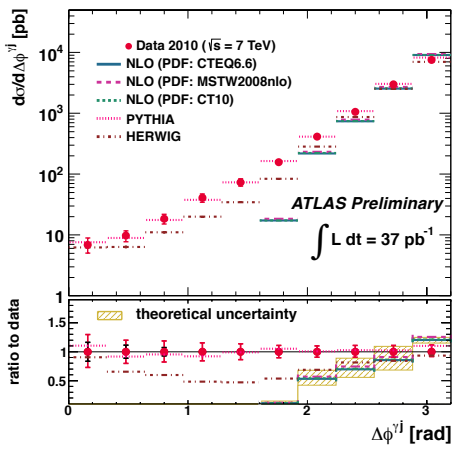
- Several distributions have been measured, including γ-jet angular correlations.
- Data is well described by NLO QCD calculation (JETPHOX) but $|\Delta\phi^{\gamma j}|$, better reproduced by LO Monte Carlo (PYTHIA).

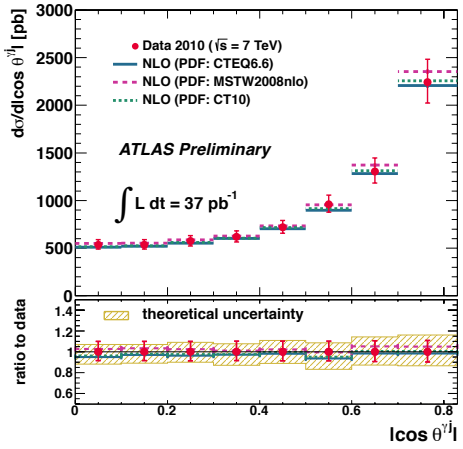








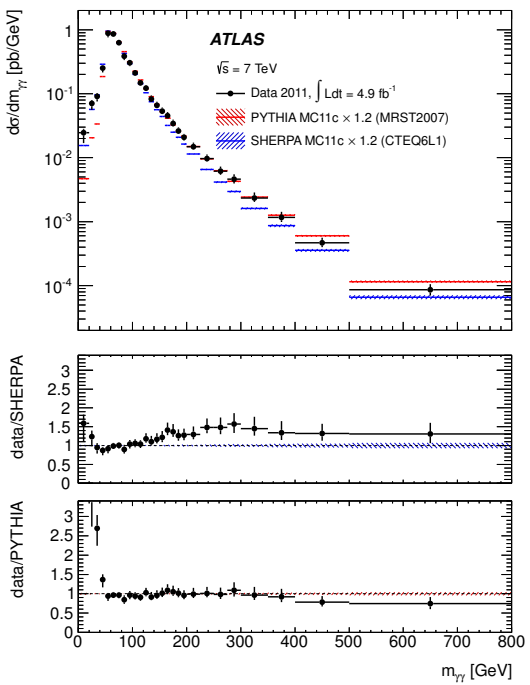


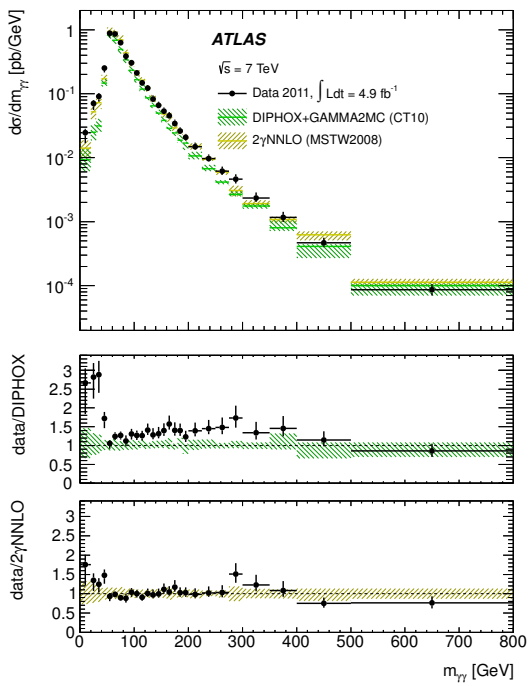


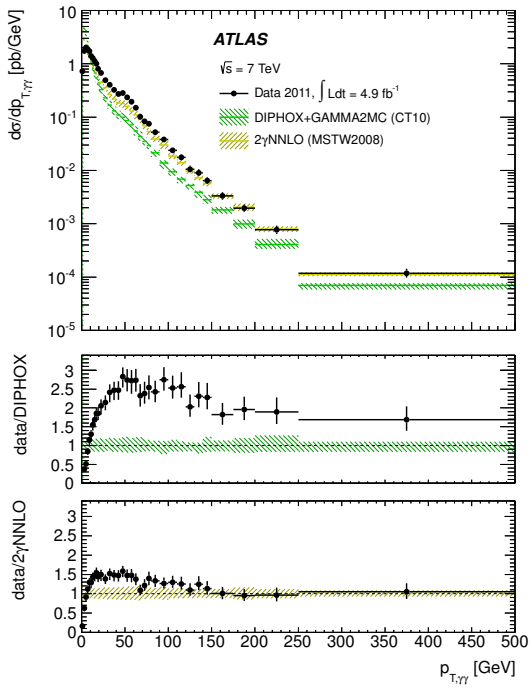
Measurement of isolated photon pairs cross section

JHEP **1301 (2013) 086**

- Isolated photon pair cross section as function of $m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, $\cos(\theta^*_{\gamma\gamma})$ (cosine of polar angle of the photon pair in the Collins-Soper di-photon rest frame).
- Data compared to NNLO (2γNNLO), NLO (DIPHOX) calculations and LO MC generators (PYTHIA, SHERPA).
  - Good description of data is achieved with NNLO calculation.

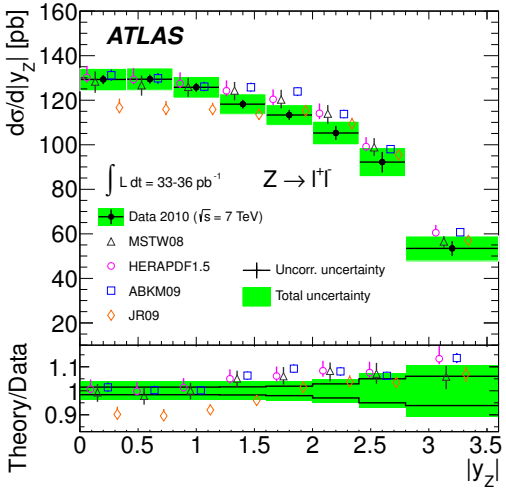


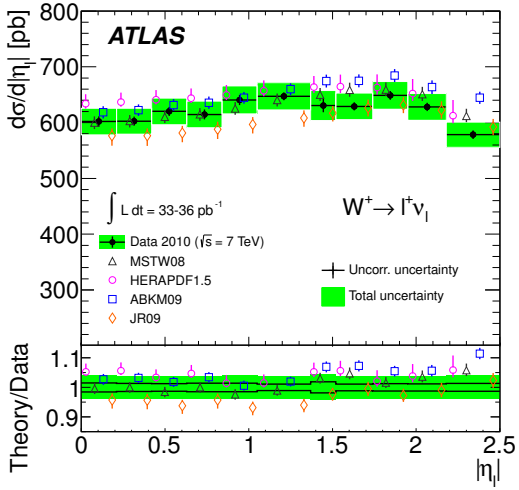


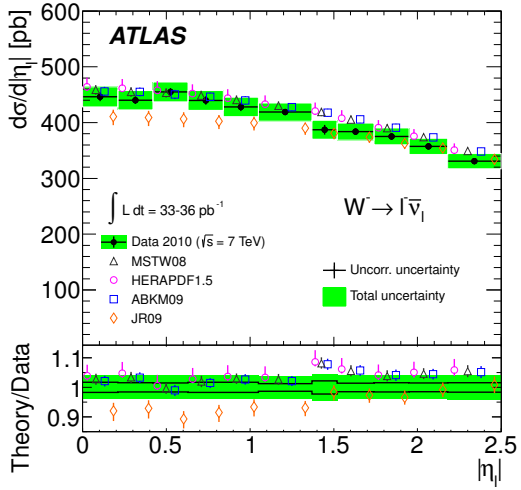


Measurement of the inclusive $W^{\pm}$ and Z/γ^* cross sections

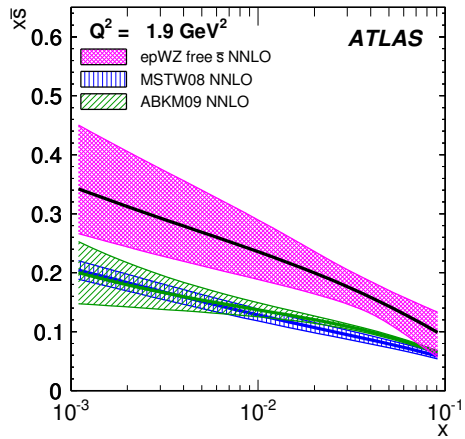
Phys. Rev. D 85 (2012) 072004 *and* *Phys. Rev. D* 85 (2012) 072004







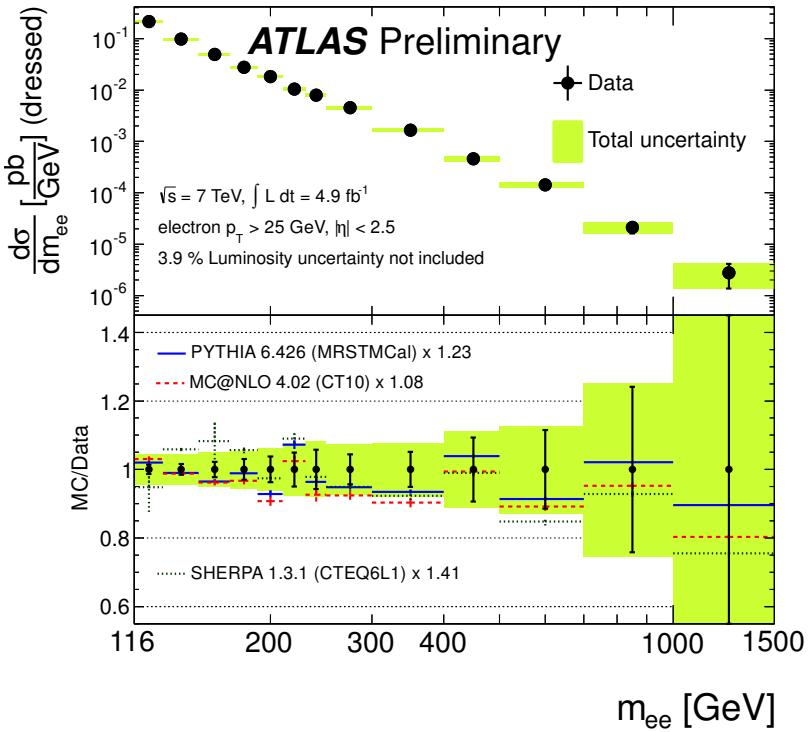
- Precise measurement of $W^{\pm}$ and Z/γ^* production;
  - experimental uncertainties at per-cent level.
- Significant spread in NNLO (FEWZ,DYNNLO) theory predictions evaluated with different pdf sets.
- **Fit to the strange quark pdf using the ATLAS data.**

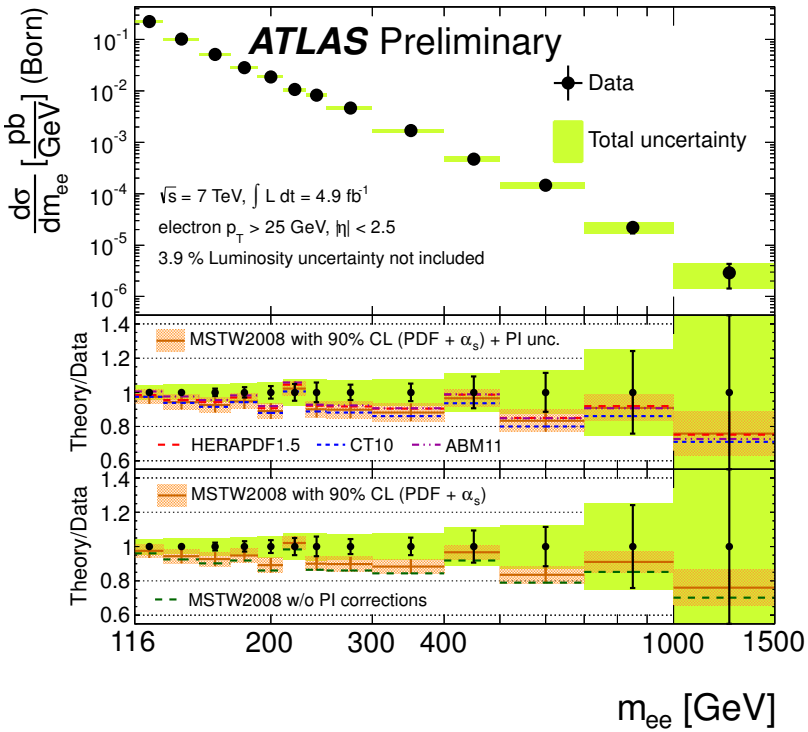


High-mass Drell-Yan differential cross section

ATLAS-CONF-2012-159

- Expected to increase the sensitivity to parton distribution functions in the high Bjorken-x region with increasing m_{ee}.
- Theory predictions, NNLO QCD (FEWZ) corrected for NLO EW effects, match well the data.
  - Photon induced (PI) lepton pair production ($\gamma\gamma \to \ell^+\ell^-$) is included.
- Statistical uncertainties dominates above 400 GeV.

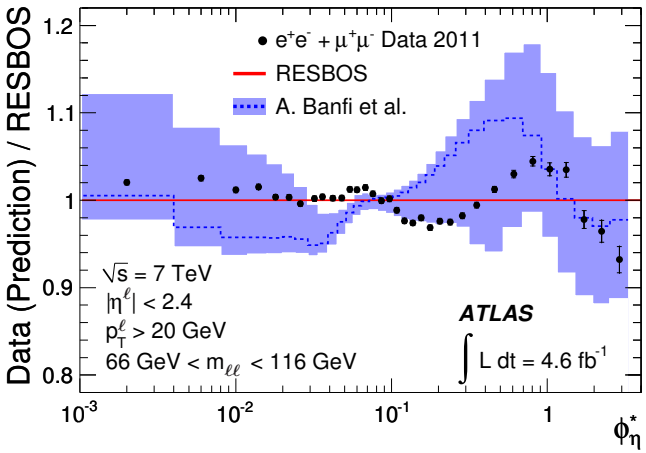


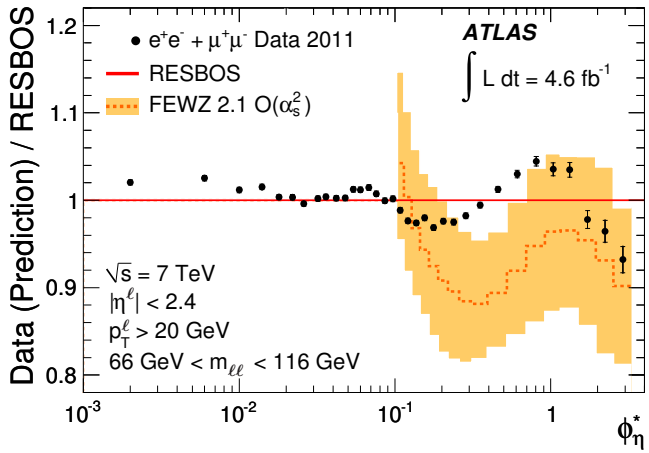


Angular correlations in Drell-Yan lepton pairs to probe Z/γ^* boson transverse momentum

ArXiv:1211.6899 [hep-ex]

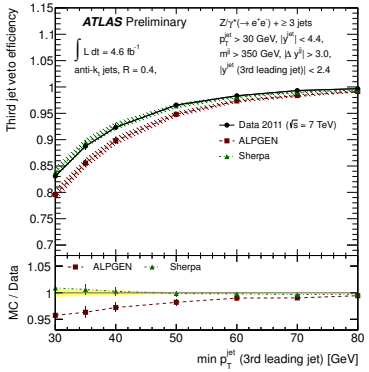
- Exploit the lepton angular correlation to study QCD radiation in Drell-Yan production.
- Measure distribution of ϕ^*_η angle: $\boxed{\phi^*_\eta = \tan(\phi_{acop}/2)\sin(\theta^*_\eta)}$.
  - $\phi_{acop} = \pi - \Delta\phi(\ell^+,\ell^-)$, $\cos(\theta^*_\eta) = \tanh\left[\frac{(\eta(\ell^-)-\eta(\ell^+))}{2}\right]$.
- ϕ^*_η is correlated to Z-p_T but has better resolution at very low transverse momentum (purity of $\gtrsim 85\%$).
- Compare ϕ^*_η spectrum to NLO+NNLL (ResBos, A. Banfi, et al. Phys. Lett. B **715** (2012) 152), NNLO (Fewz), and several MC generators.
- **Experimental uncertainties (dominated by statistic) typically one order of magnitude smaller than theory uncertainties.**

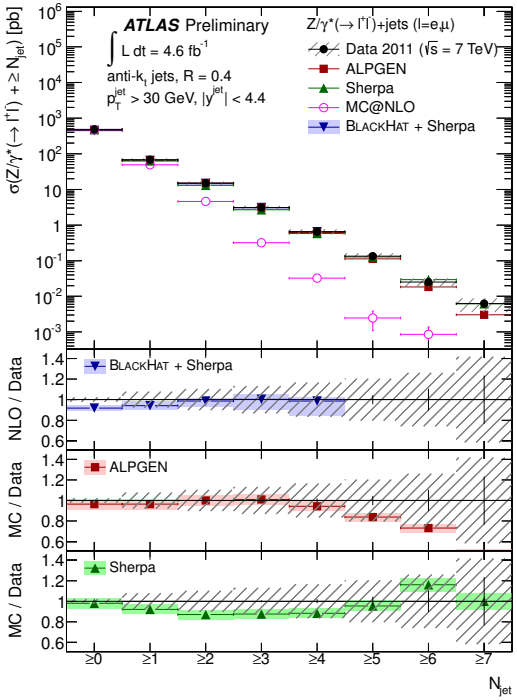


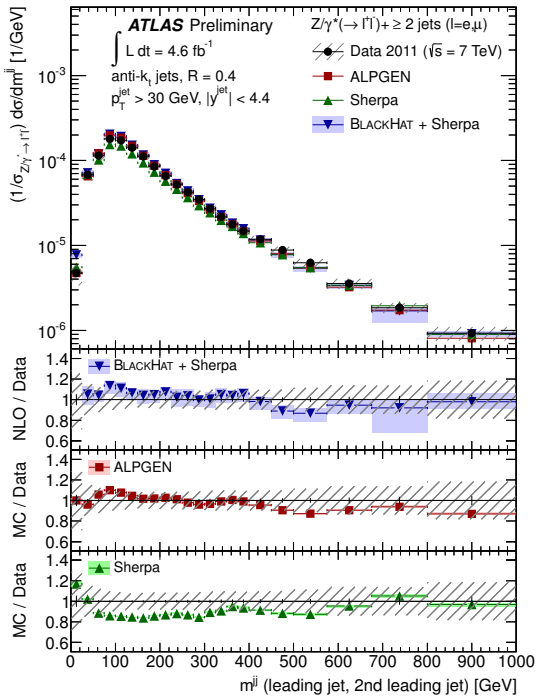


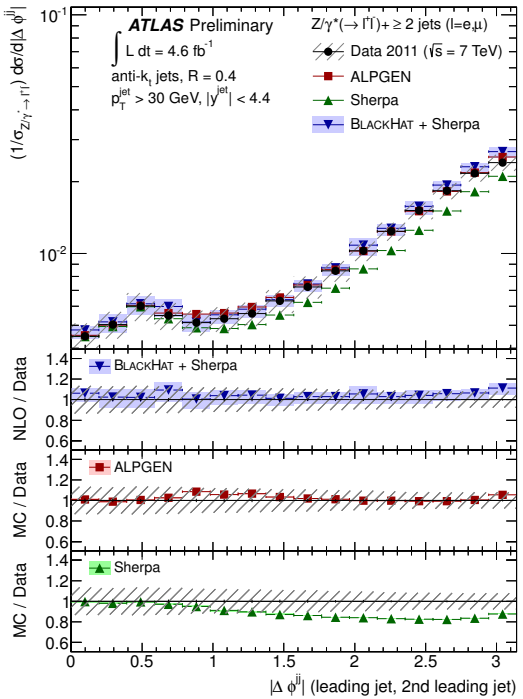
Study of jets produced in association with a Z/γ^* boson

- Several particle level distributions analyzed.
- Good agreement between data and LO multileg (ALPGEN, SHERPA) and NLO multileg (BLACKHAT+SHERPA) calculations is observed.
- Vector-boson-fusion topologies also studied.









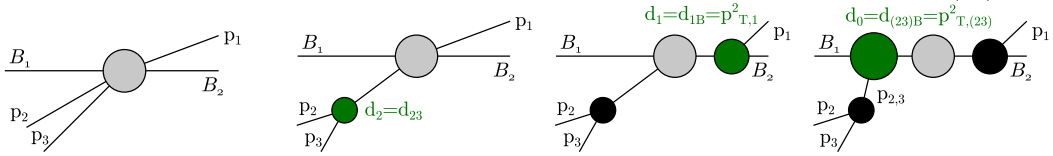
k_t splitting scales in $W \to \ell\nu$ events

ArXiv:1302.1415 [hep-ex]

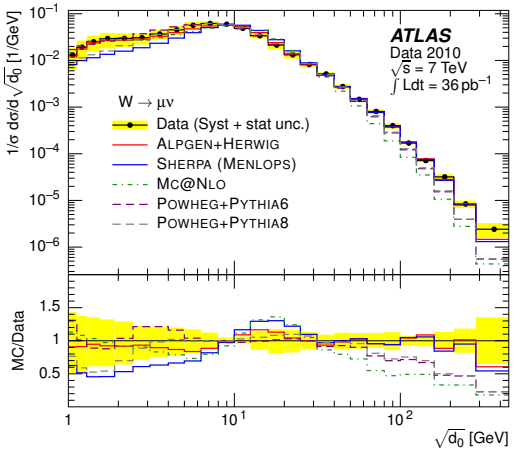
- Define splitting scales using the distance between constituents i, j and the beam B defined as:
  - $d_{i,j} = min(p_{Ti}^2, p_{Tj}^2)\,\Delta R_{ij}^2/R^2$, $d_{iB} = p_{Ti}^2$, $R = 0.6$ algorithm radius parameter;

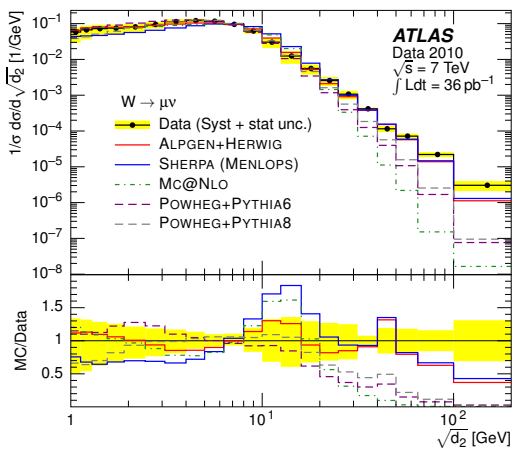
Paradigm: event with 3 k_T splitting scales

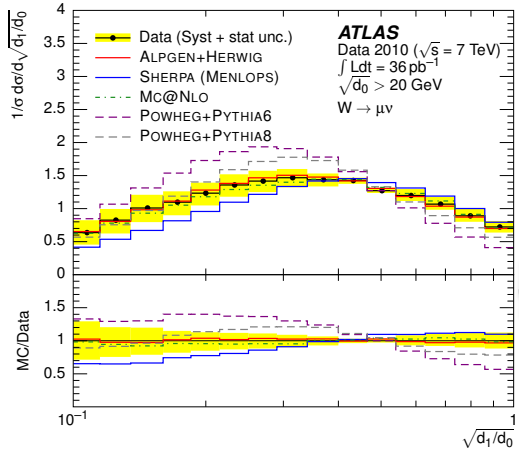
Input momentum $d_2 = d_{23}$ $d_1 = d_{1B}$ $d_0 = d_{(23)B}$



- Data compared to NLO QCD (MC@NLO, POWHEG), LO and NLO multi-leg MC event generators (ALPGEN, SHERPA).







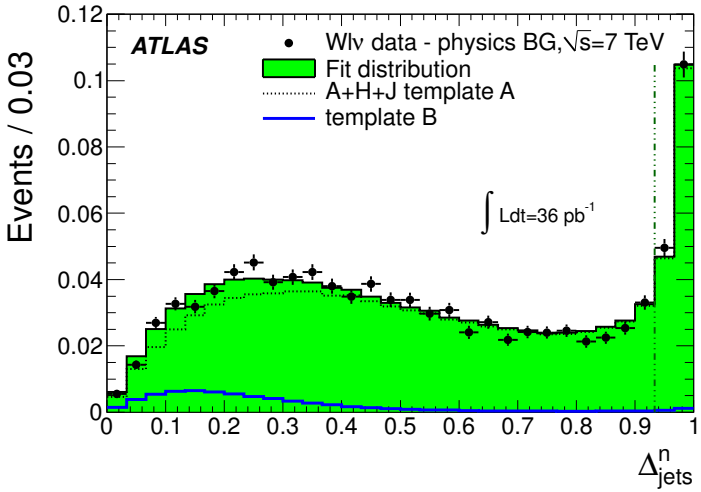
Hard double-parton interactions in W ($\to \ell\nu$) + 2 jets events

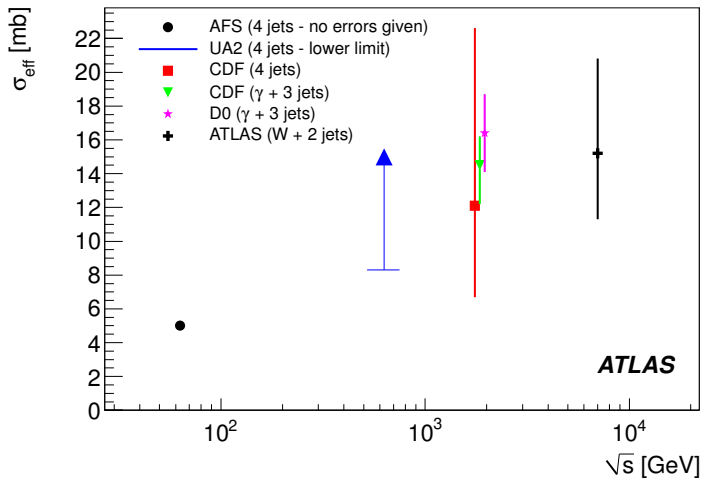
ArXiv:1301.6872

- Testing double-parton-interactions, DPI, in W+2jets measuring the fraction of DPI ($f_{DPI}^{(D)}$) and the effective parameter area (σ_{eff}).
  - The measurement procedure exploit the assumption of factorization of DPI dynamic.

$$f_{DPI}^{(D)} = \frac{N_{W(0j)+2j(DPI)}}{N_{W+2j}} \qquad \sigma_{eff} = \frac{N_{W(0j)}}{f_{DPI}^{(D)} N_{W+2j}} \cdot \frac{N_{2j}}{\mathcal{L}_{2j}\,\epsilon_{2j}}$$

- Extract from data $f_{DPI}^{(D)}$ by a fit to the distribution $\Delta_{jets}^{n} = \frac{\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2}}{|\vec{p}_T^{\,j1}| + |\vec{p}_T^{\,j2}|}$.
  - Δ_{jets}^{n} proved to be robust against jet-related systematics.
- No dependence on the CM energy has been observed for DPI.

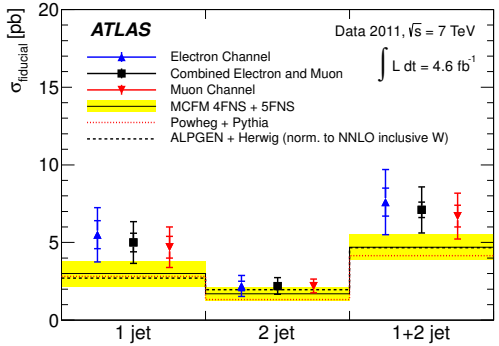


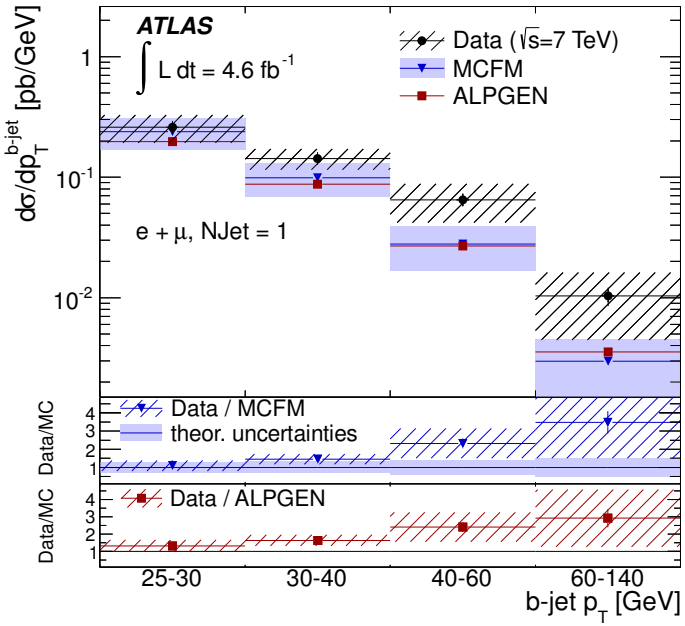


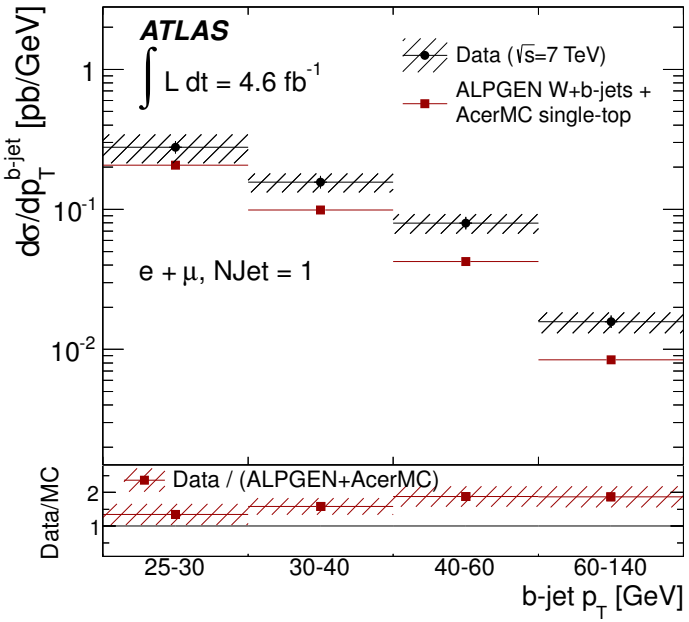
Cross-section for W boson production in association with b-jets

ArXiv:1302.2929 [hep-ex]

- Differential measurement in jet multiplicities and b-jet p_T.
  - Significant contribution from DPI (35%-20%).
- The single top contribution is treated alternatively as background and included in the signal definition.
- Data compared to NLO QCD (MCFM) and LO multi-leg predictions (ALPGEN).







Conclusions

- A plethora of measurements have been performed and detailed comparisons with the most advanced theory predictions have been provided.
- Significant work ongoing to fully exploit the 2011/2012 dataset; several interesting results to come in next months.
- To do with more data:
  - More detailed measurements of exclusive final states and exclusive topologies.
  - Measure gauge bosons and jets in extreme phase space regions.
  - Use the data for pdf fit and MC tunes.

- Full list of Standard Model measurement: `https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults`.
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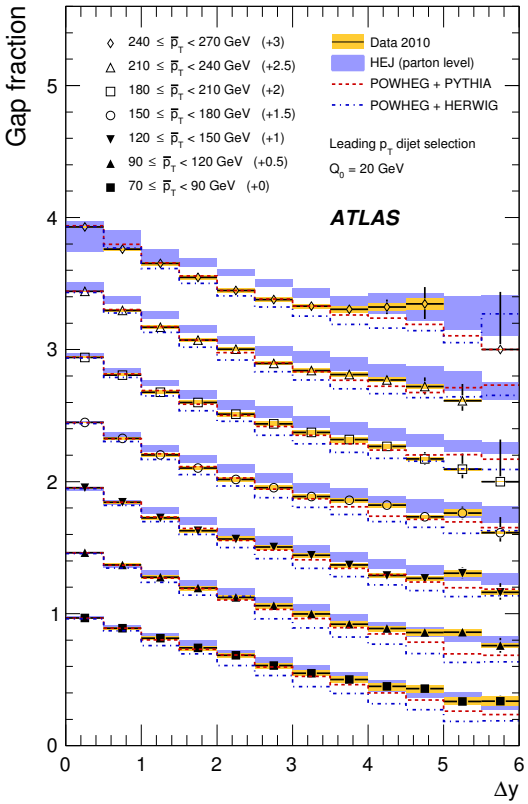
Thank you!

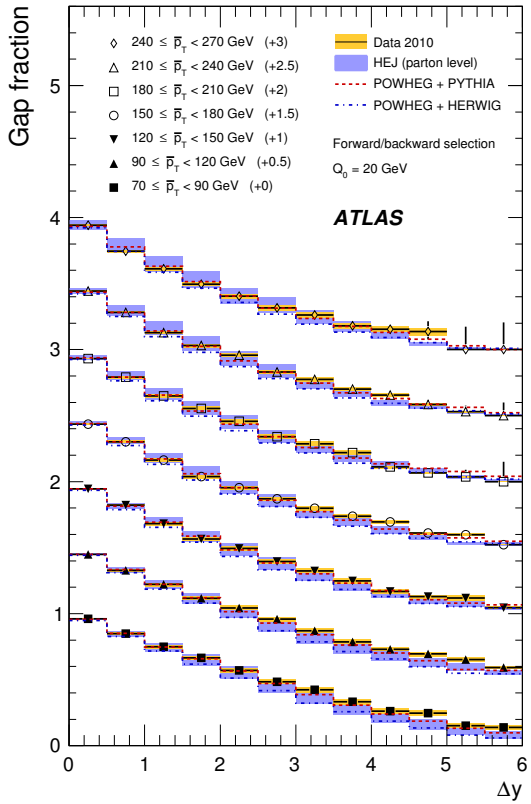
Backup

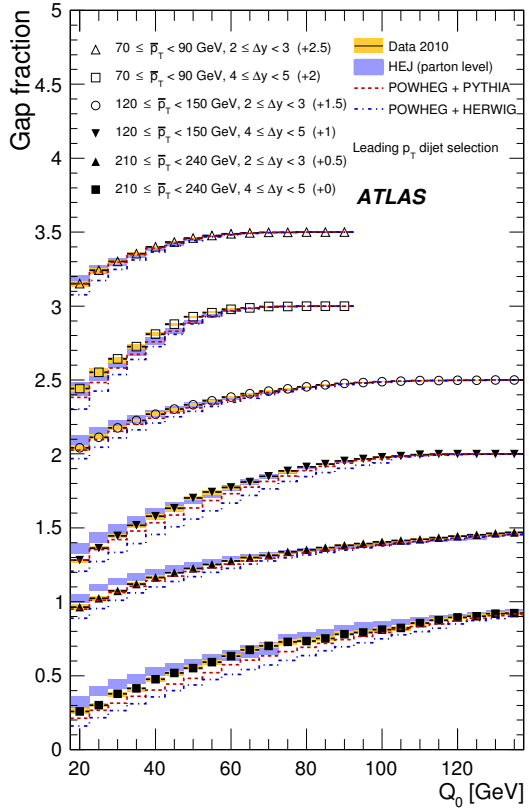
More exclusive measurement: dijet production with jet veto

JHEP **1109 (2011) 053**

- Gap fraction in dijets events: define the leading jets based on their rapidity gap ("forward/backward selection") or p_T ("leading p_T dijet selection").
- Compare data to NLO QCD calculation POWHEG and effective all order resummation (HEJ).
- **Uncertainty on data typically below the theory uncertainties.**
  - Significant spread among various theory predictions.



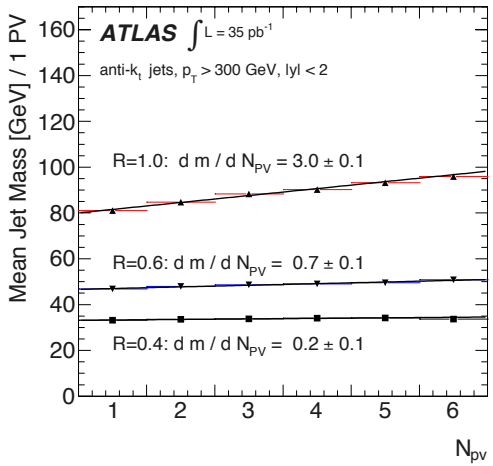


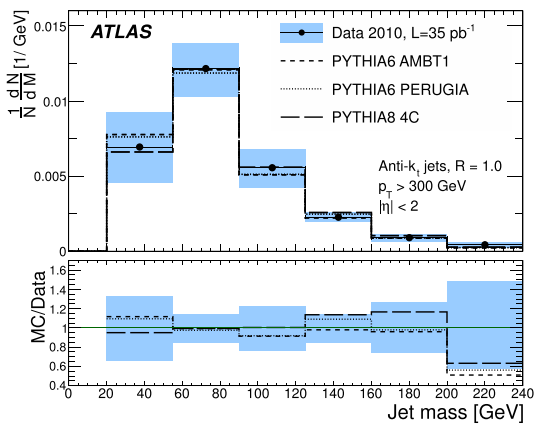


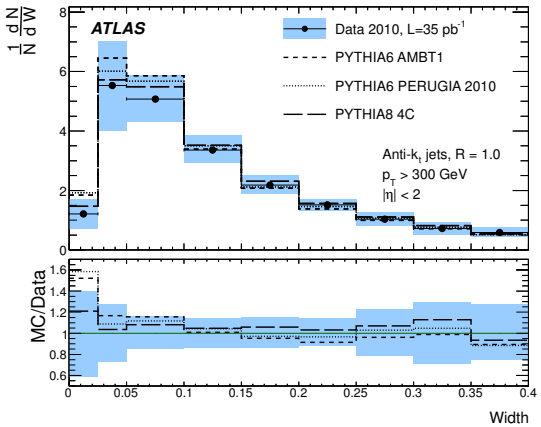
Proprierties of large-R anti-k_t jets

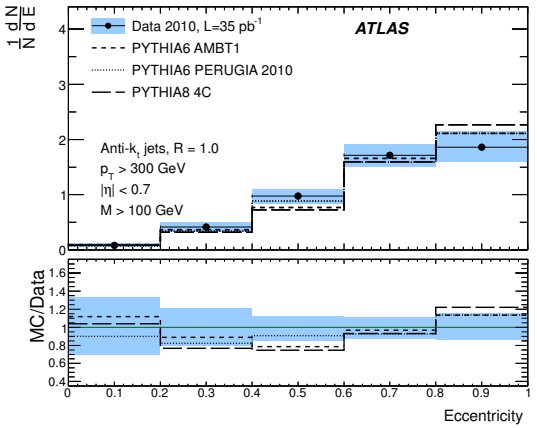
Phys. Rev. D 86 (2012) 072006 *and* *JHEP* 1205 (2012) 128

- Measured several proprierties of anti-k_t jets with radius $R = 0.4$-0.6-1.0 in boosted regime.
- Studied pile-up dependence.
  - Jet mass most sensitive to pile-up.
  - Correct for pile-up and UE.
- Compare data to Monte-Carlo with different parton showers and tunes (here shown Pythia6 and Pythia8).





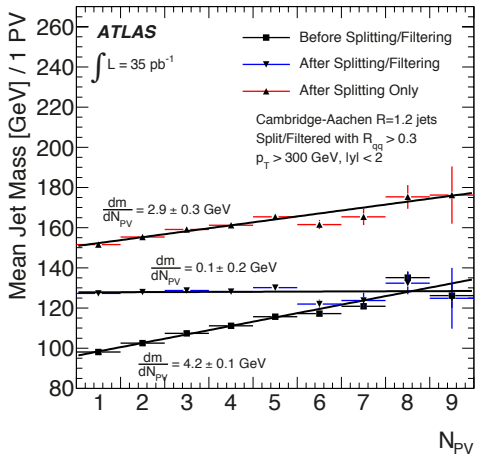


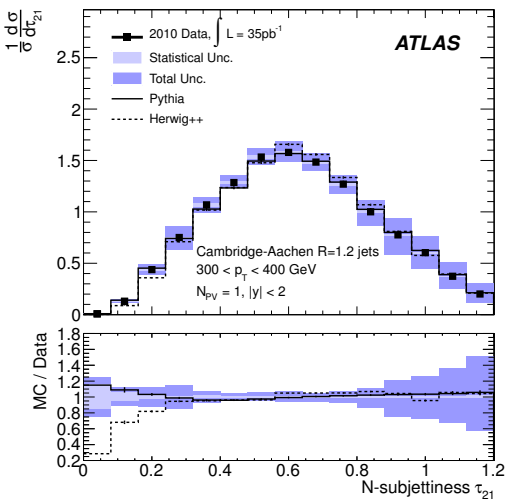


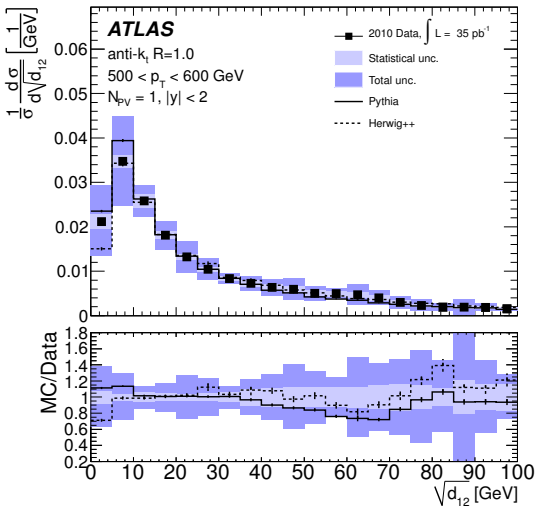
Properties of large-R Cambridge-Aachen jets

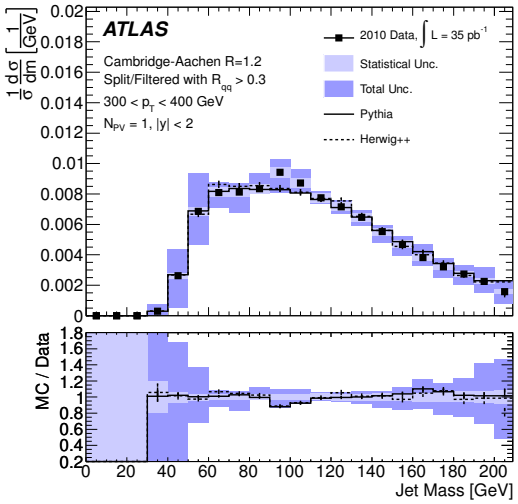
JHEP **1205 (2012) 128**

- Studied jet-substructure in Cambridge-Aachen jets with $R = 1.2$ measuring N-subjettiness, k_t splitting scales and jet mass.
- Splitting/Filtering procedure (J. M. Butterworth, et al., Phys. Rev. Lett. **100** (2008) 242001) reduce significantly pile-up effects,
  - **and is well modeled by LO MC generators** (Pythia6, Herwig++).





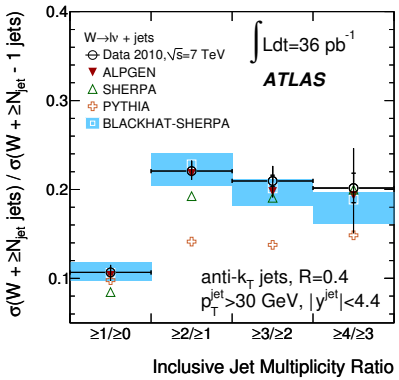


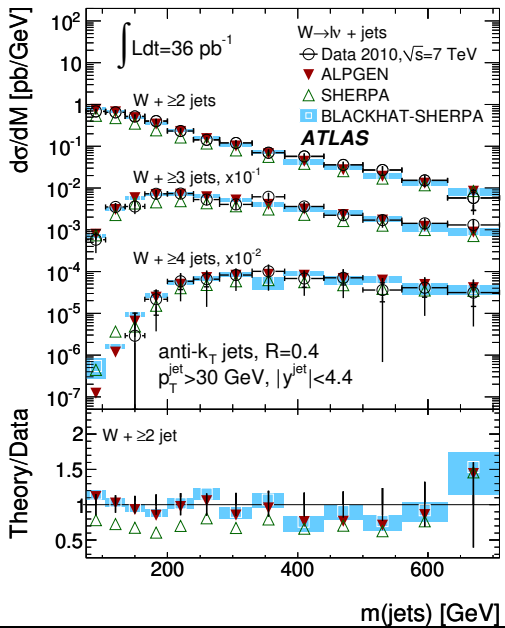


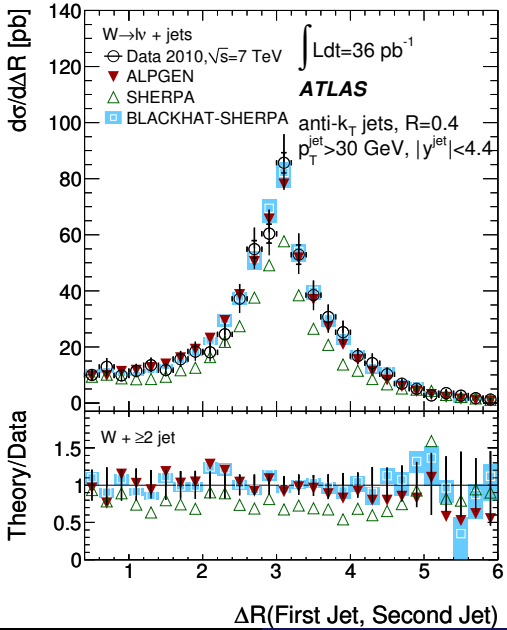
Study of jets produced in association with a W boson

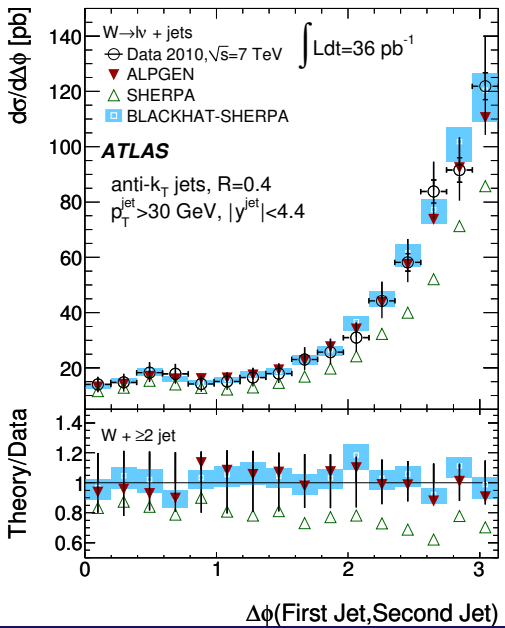
Phys. Rev. D 85 (2012) 092002

- Detailed study of jet production in association to W boson.
- Theory predictions: LO multileg (ALPGEN, SHERPA) NLO multileg (BLACKHAT+SHERPA) QCD calculation.
  - Need multileg calculation to properly describe the data.
- Dijet distributions shapes well predicted by theory.





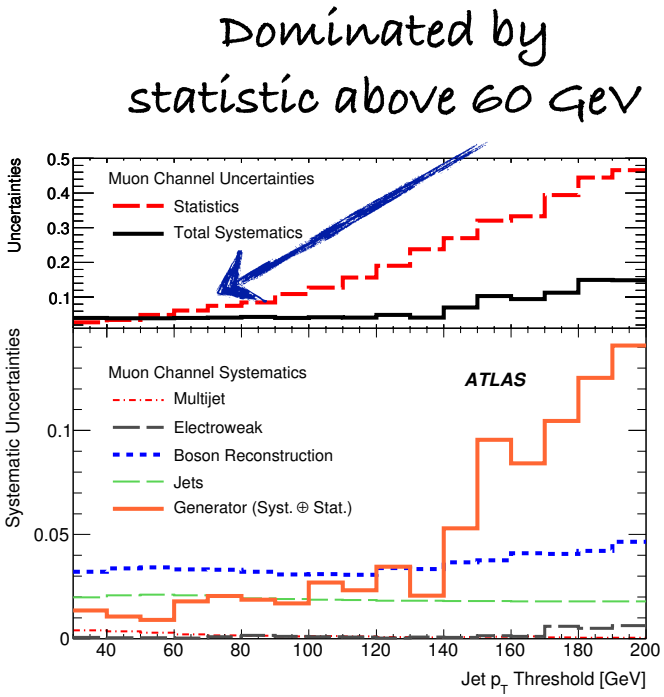


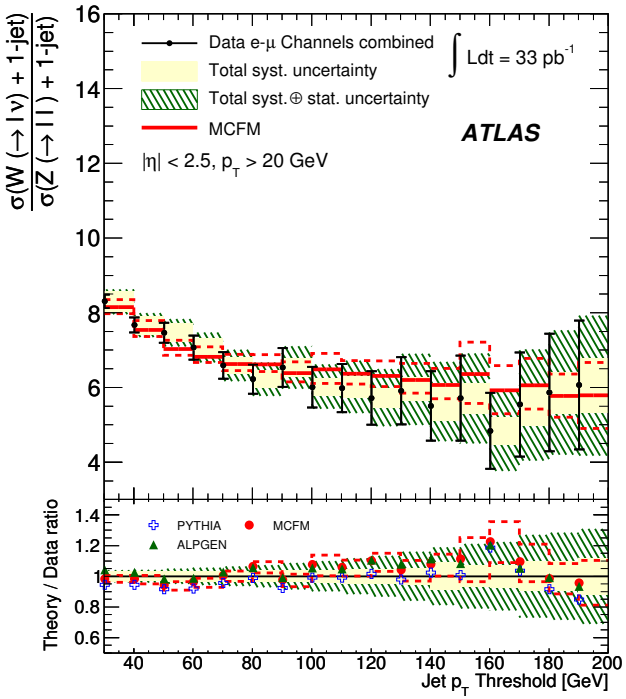


Ratio of the W and Z cross sections with exactly one associated jet

Phys. Lett. B 708 (2012) 221

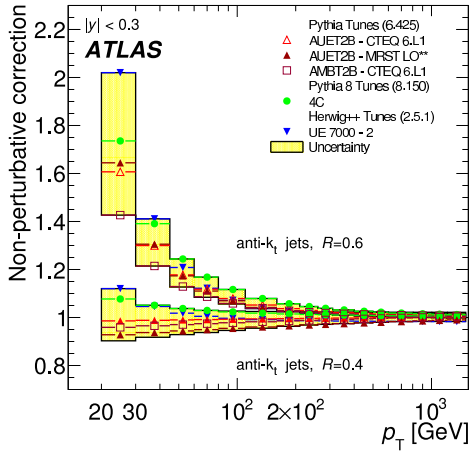
- Measured ratio of cross sections to minimize the experimental and theoretical uncertainties.
  - Systematic uncertainty down to 5% → will improve further (better detector knowledge, larger control samples, etc...)
- Using LO (PYTHIA) and LO multileg (ALPGEN) MC generators and NLO QCD (MCFM) predictions.
  - Data well described, also by LO Monte Carlo.

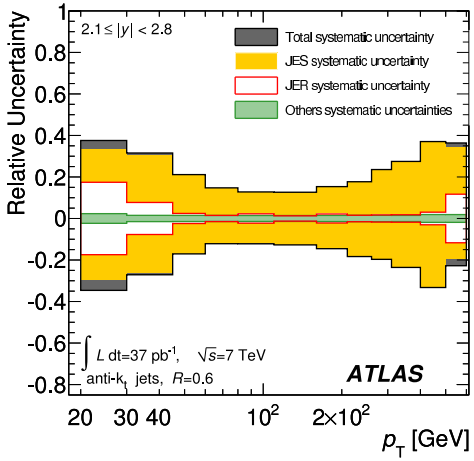


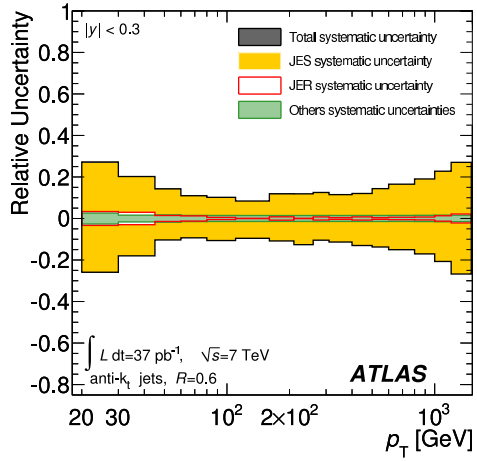


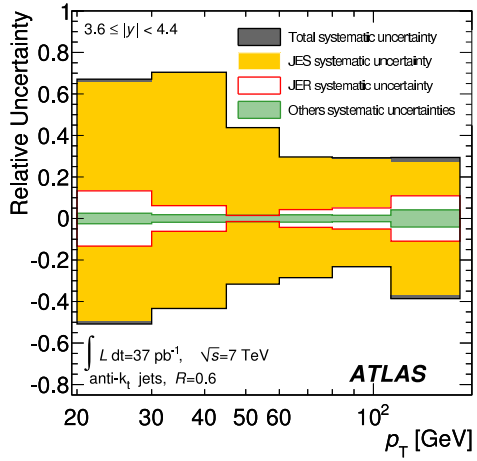
Inclusive jet and dijet cross sections

Phys. Rev. D 86 (2012) 014022



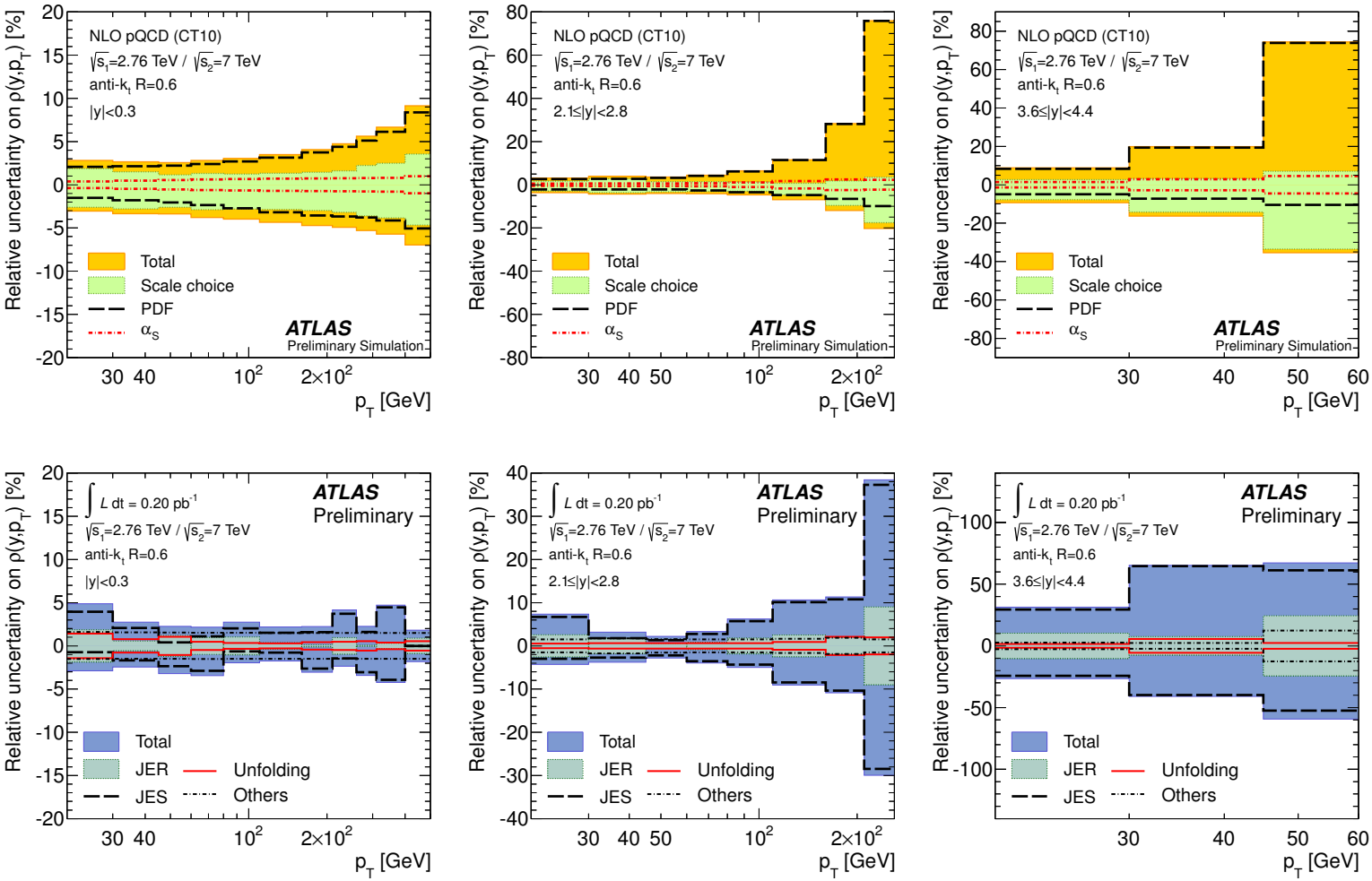






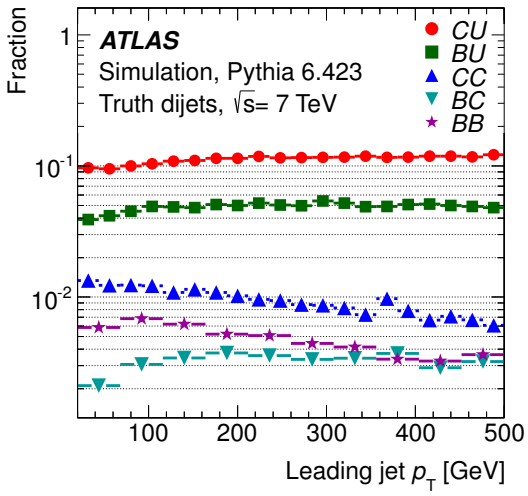
Inclusive jet cross section in pp collisions at $\sqrt{s} = 2.76$ TeV and comparison to the inclusive jet cross section at $\sqrt{s} = 7$ TeV

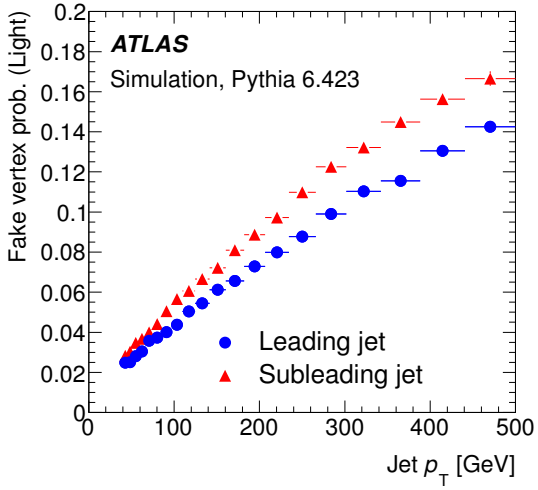
ATLAS-CONF-2012-128

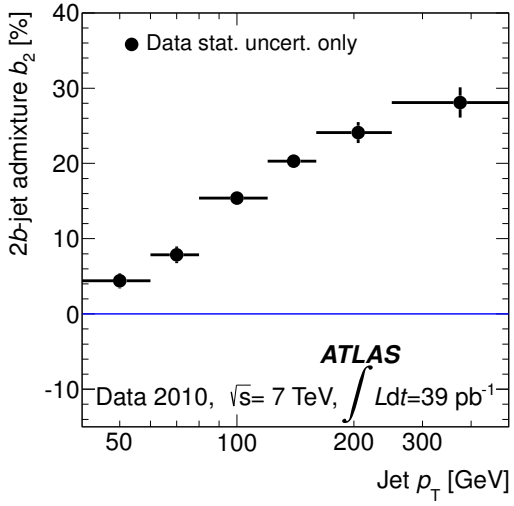


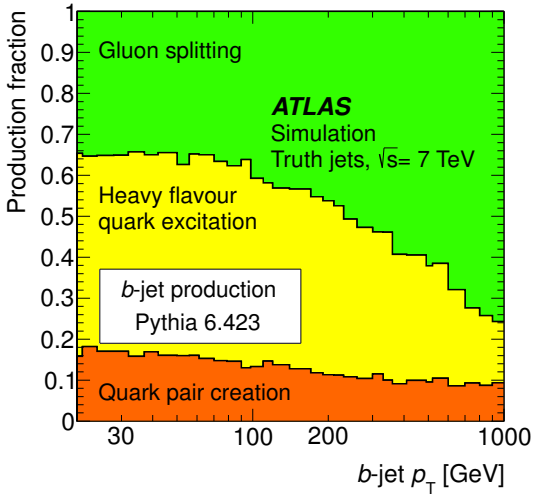
Flavour composition of dijet events: extra

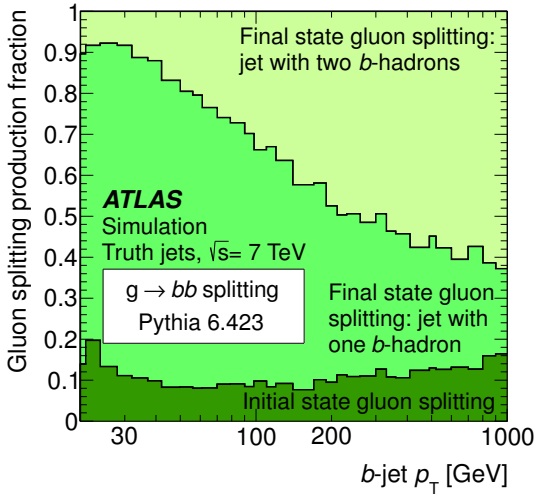
ArXiv:1210.0441 [hep-ex]





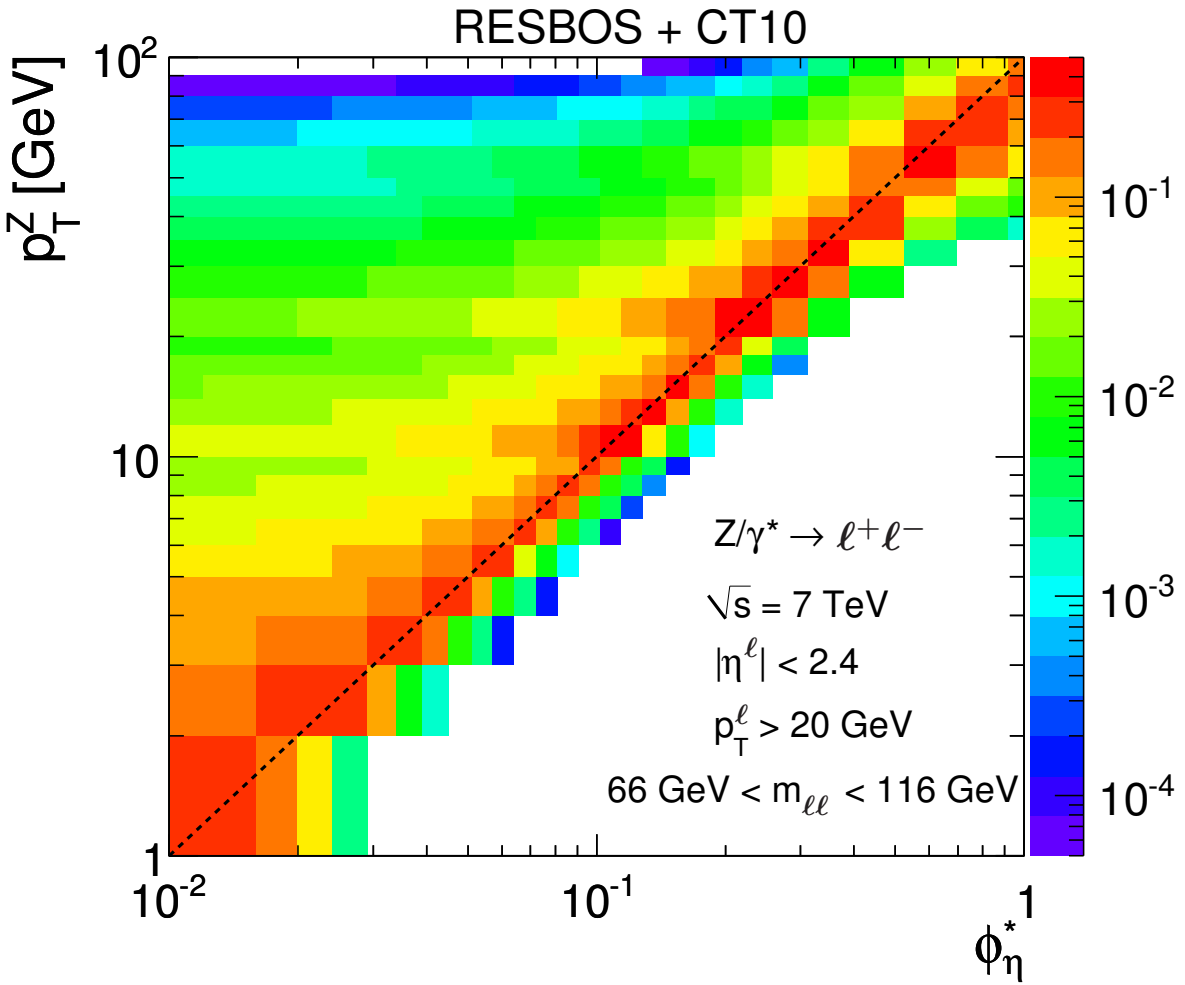






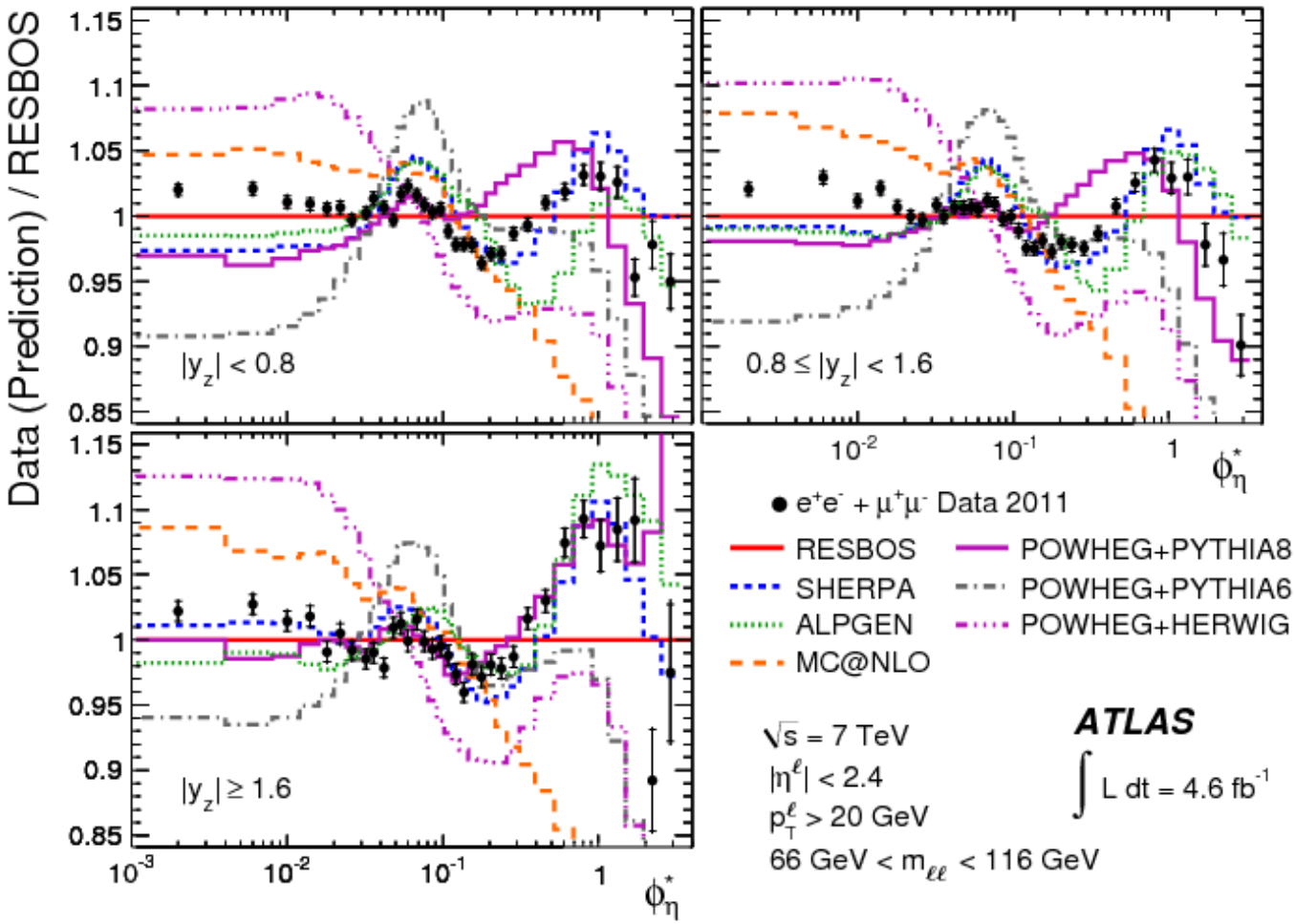
Angular correlations in Drell-Yan lepton pairs to probe Z/γ^* boson transverse momentum

ArXiv:1211.6899 [hep-ex]



Angular correlations in Drell-Yan lepton pairs to probe Z/γ^* boson transverse momentum

Phys. Lett. B 720 (2013) 32-51



Measurement of isolated photon pairs cross section

JHEP **1301 (2013) 086**