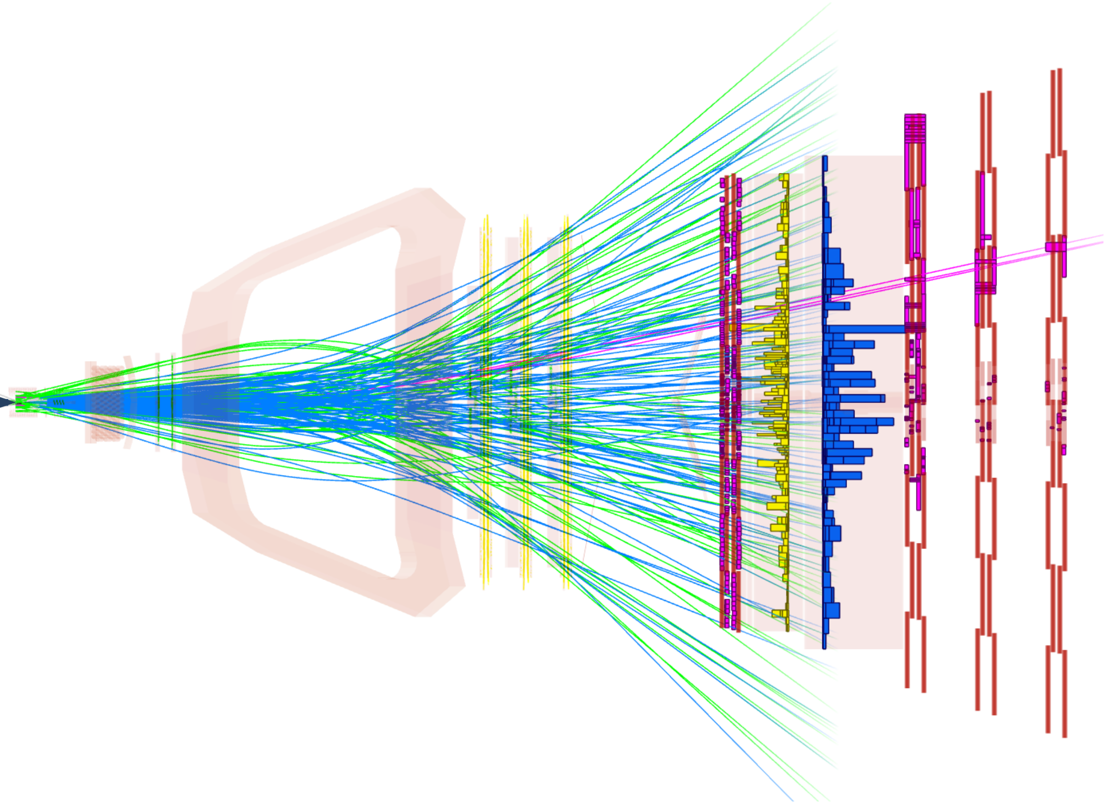
Implications 2018

Results from Top & EW



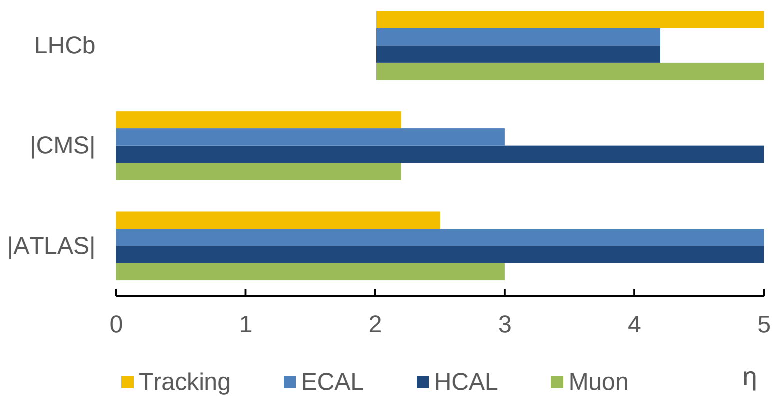
James V Mead *on behalf of the LHCb collaboration*

Overview

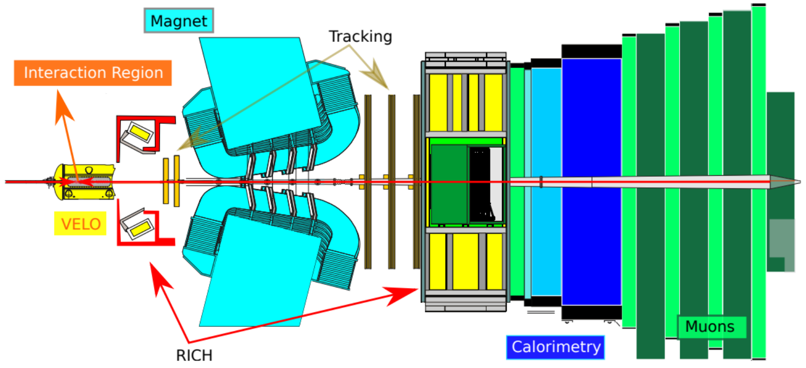
- LHCb – the forward GPD
- Top physics – Run I
- Top physics – Run II
- EW results – Run II
- EW results – Run I
- Future prospects

Forward GPD

- Unique forward region coverage
- Excellent vertex resolution for jet flavour tagging
- Low pile-up environment (1→2 interaction pbc.)



- Access new kinematic regions
- Complementary phase space to ATLAS/CMS
- Constrain PDF uncertainties at low/high-x



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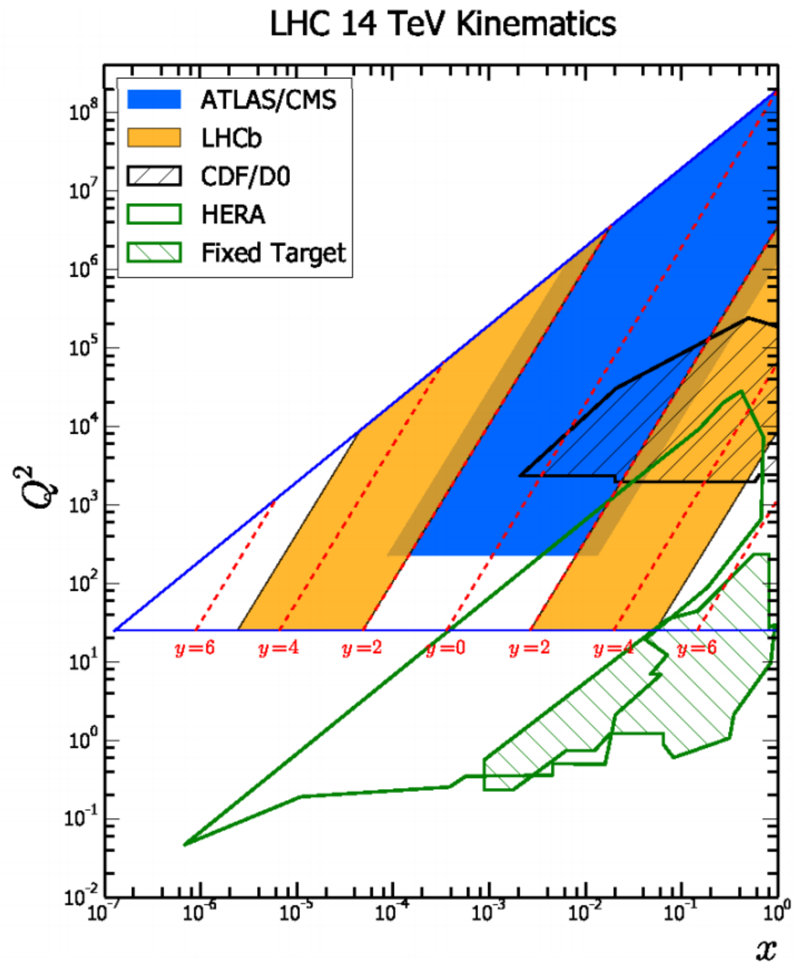
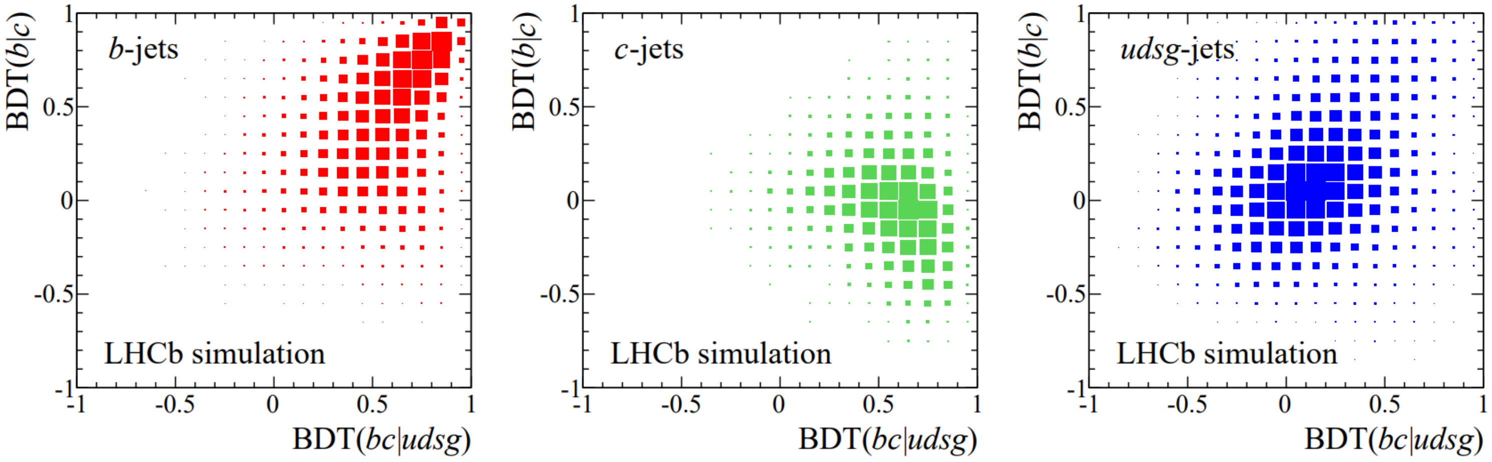
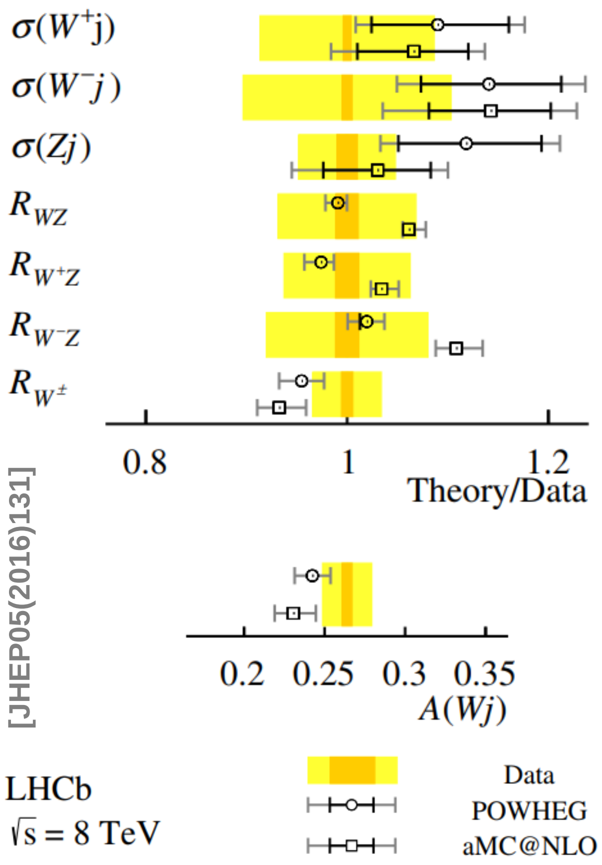


Jet performance

- Inputs from ParticleFlow, anti-k_T clustered R = 0.5
- Energy resolution ~ 10-15%, fake rate < 1%
- *b*-tag efficiency ~ 65%, flavour mistag ~ 0.3%



[JINST(2015)P06013]



[JHEP05(2016)131]

Results

Run I

7 & 8 TeV

- $t \rightarrow \mu + b$

8 TeV

- $t\bar{t},\ W + b\bar{b}\ /\ c\bar{c}$
- $Z \rightarrow \tau\bar{\tau}$
- $Z \rightarrow b\bar{b}$

Run II

13 TeV

- $t\bar{t} \rightarrow \mu e + jet$
- $Z \rightarrow \mu\bar{\mu}\ /\ e\bar{e}$

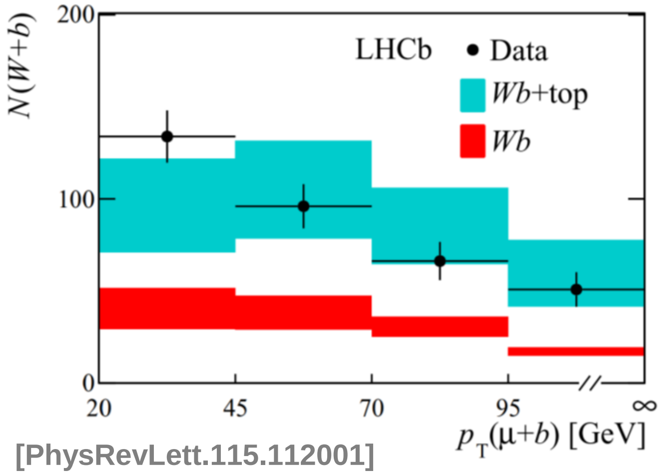
- $W / Z + jet$
- $t \rightarrow \mu + b$
- $A_{\eta}^{t\bar{t}}$ … WIP

Prospects

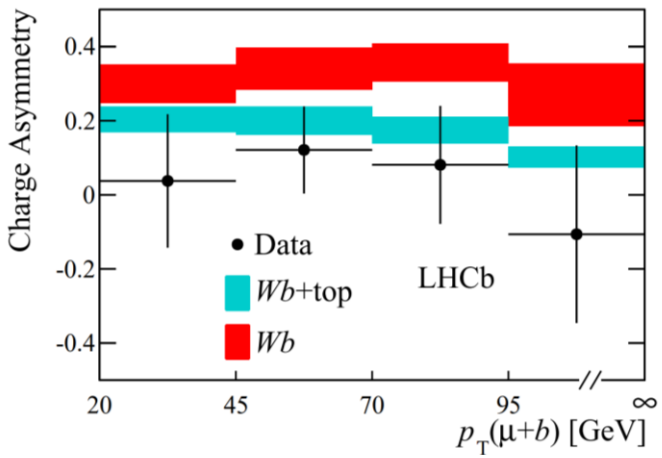
- $A_{\eta}^{t\bar{t}}$
- m_W
- $\sin^2 \theta_W^{eff}$

$t \rightarrow \mu + b$

- EW vs QCD fit to muon isolation provides *W*+jet yield
  - Data driven template of QCD multi-jet background
  - 2D fit to flavor BDTs provides *W*+*b*-tag yield
- Top yield and charge asymmetry extracted
  - *Wb* subtraction using simulated *Wb*/*Wj* normalised to data
- Precision ~ 24%
  - Dominated by SV-tag efficiency
  - 5.4σ observation, first in the forward region!
  - Consistent with NLO SM predictions



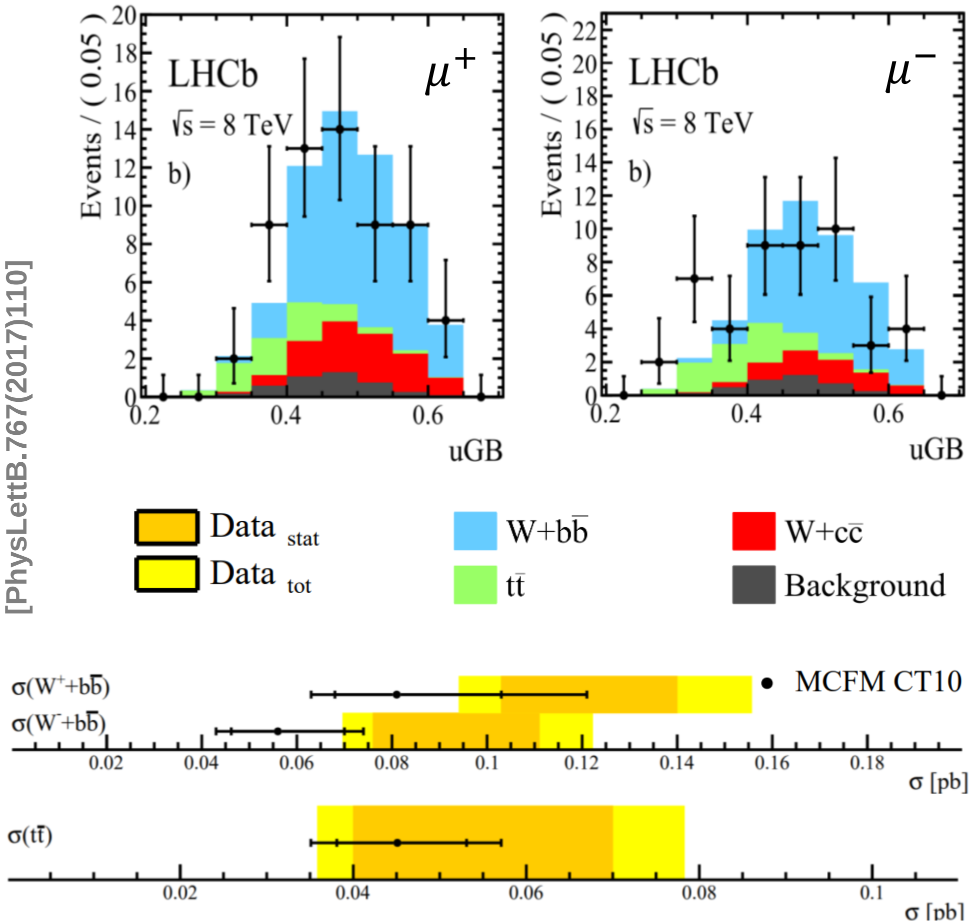
[PhysRevLett.115.112001]



$t\bar{t} \to l + b\bar{b}$

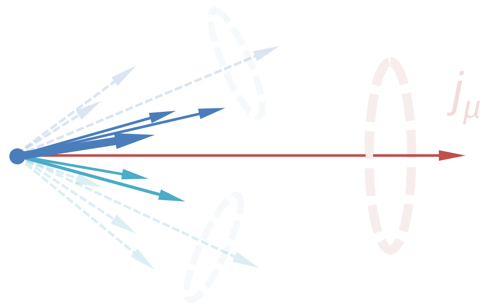
- ᴜGB is an MVA output
  - Trained to separate *W*→*bb*, *W*→*cc* & $t\bar{t}$
  - Uniform boosting minimises m_{jj} correlation
- 4D fit to m_{jj}, BDT(*b*|*c*) for both jets, ᴜGB
  - Split samples by lepton charge and flavor
- Precision ~ 40%
  - Suffers from systematics and low stats
  - 4.9σ significance $t\bar{t}$ production
  - Systematics to improve with larger data set

[PhysLettB.767(2017)110]



$t\bar{t} \to \mu e + b$

- ***Method***
  - 10 fold increase in $t\bar{t}$ cross-section with Run II energy
  - Highly pure channel now viable with ~ 2 fb^{-1} of 13 TeV data



- ***Selection***
  - Two leptons: p_T (μ,e) > 20 GeV/c, 2.0 < η < 4.5
  - HF jet: p_T > 20 GeV/c, 2.2 < η < 4.2
  - ΔR(l,j) > 0.5, ΔR(μ,e) > 0.1

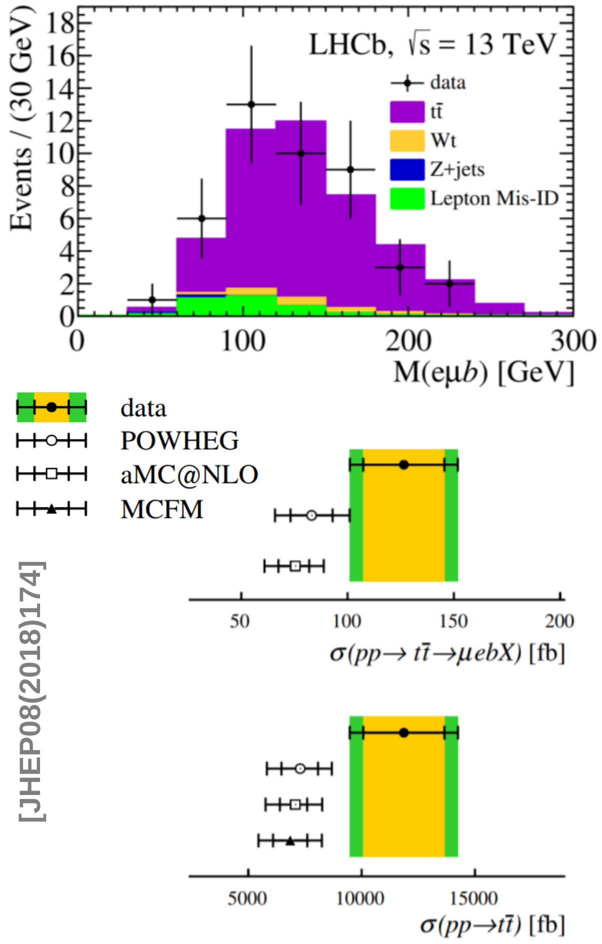
- ***Prompt & isolated leptons***
  - IP < 0.04mm, p_T (j_l) > 5 GeV/c

$d\sigma$(fb)	7 TeV			8 TeV			14 TeV		
lb	285	±	52	504	±	94	4366	±	663
lbj	97	±	21	198	±	35	2335	±	323
lbb	32	±	6	65	±	12	870	±	116
$lbbj$	10	±	2	26	±	4	487	±	76
l^+l^-	44	±	9	79	±	15	635	±	109
l^+l^-b	19	±	4	39	±	8	417	±	79

[LHCb-PUB-2013-009]

$t\bar{t} \rightarrow \mu e + b$

- Statistically limited but ~ 90% pure channel
  - Complementary to Run I measurements
- Background subtraction, $t\bar{t}$ normalised to remaining data
  - Lepton mis-ID shape from data QCD, W/Z+jet
  - *Zj*, *Wt* & $t\bar{t}$ from simulation
- Precision ~ 23%
  - Dominated by jet tag efficiency and QCD background
  - Good agreement in p_T and η for *μ* and *e*
  - Consistent with SM



[JHEP08(2018)174]

Results

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- $t \to \mu + b$

8 TeV

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- $Z \to \tau\bar{\tau}$
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Run II

13 TeV

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- $Z \to \mu\bar{\mu}\ /\ e\bar{e}$

- $W / Z + jet$
- $t \to \mu + b$
- $A_\eta^{t\bar{t}}$ … *WIP*

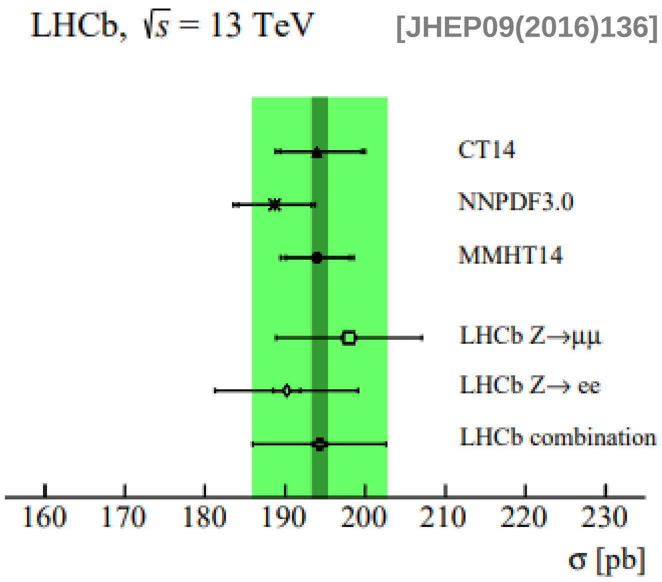
Prospects

- $A_\eta^{t\bar{t}}$
- m_W
- $\sin^2 \theta_W^{eff}$

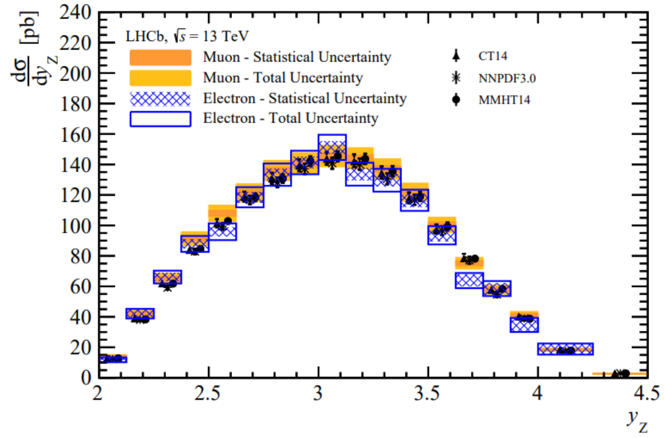
- ***Method***
  - Lower x accessible through 13 TeV data, $L_{int} = 294 \pm 11\ pb^{-1}$
  - Measured in terms of Z rapidity (SM test) and p_T & ϕ^*_η (QCD modelling)
- ***Angular variable, ϕ^*_η***
  - $\phi^*_\eta \equiv \tan(\phi_{acop}/2) / \cosh(\Delta\eta_{ll}/2)$, where $\phi_{acop} \equiv \pi - \Delta\phi_{ll}$
  - Probes same physics as p_T with better experimental resolution
- ***Selection***
  - Opposite sign leptons: $2.0 < \eta < 4.5$
  - $p_T\ (\mu,e) > 20$ GeV/c, $60 < m_{\mu\mu} < 120$ GeV/c^2, $m_{ee} > 40$ GeV/c^2

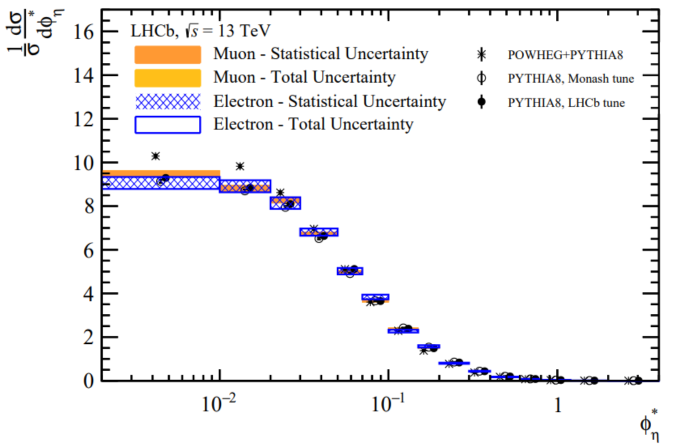
$Z \to \mu\bar{\mu}$ / $e\bar{e}$

- Backgrounds: HF-decay, mis-ID hadrons, $Z\to \tau\tau$, *tt*, *WW*
  - *μμ*: HF-decay, estimate from un-isolated region
  - *ee*: mis-ID hadrons, estimate from same-sign region
- High purity samples
  - $\rho_{\mu\mu} = (99.2 \pm 0.2)\%$
  - $\rho_{ee} = (92.2 \pm 0.5)\%$
- Consistent with σ_Z predictions
  - Uncertainty dominated by preliminary Run II Luminosity measurement



[JHEP09(2016)136]

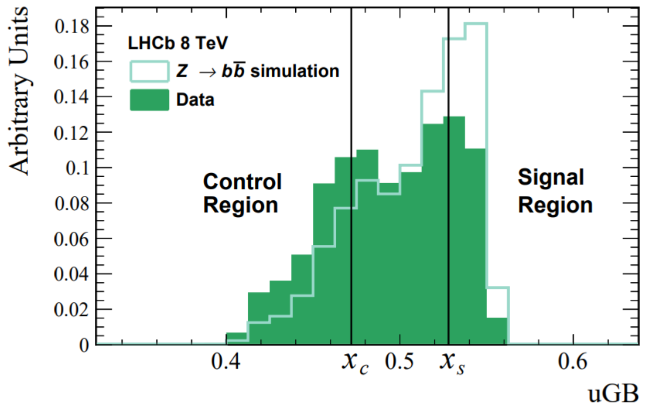




$Z \to b\bar{b}$

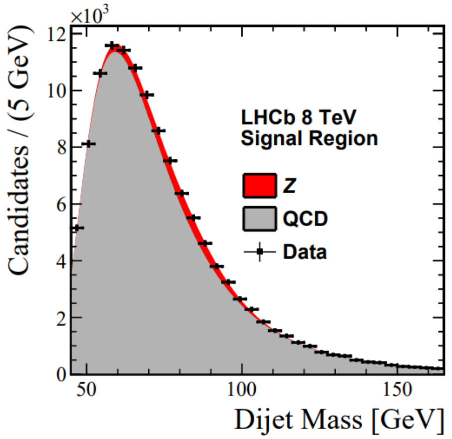
- ***Method***
  - First forward region measurement with ~ 2fb^{-1} at 8 TeV
  - Low trigger thresholds provide access to large invariant mass range
- ***Selection***
  - Two HF-jets: $p_T(j)$ > 20 GeV/c, $\Delta\phi^{jj}_{abs}$ > 2.5 rad, 45 < m_{jj} < 165 GeV/c^2
  - 'Balance' jet: $p_T(j_3)$ > 10 GeV/c, $p_T(\overrightarrow{Z_{jj}} + \overrightarrow{j_3})$ > 20 GeV/c
- ***uGB – BDT output***
  - m_{jj} correlation minimised using uniform gradient boosting
  - Input kinematics of 3-jet system to separate Z from QCD

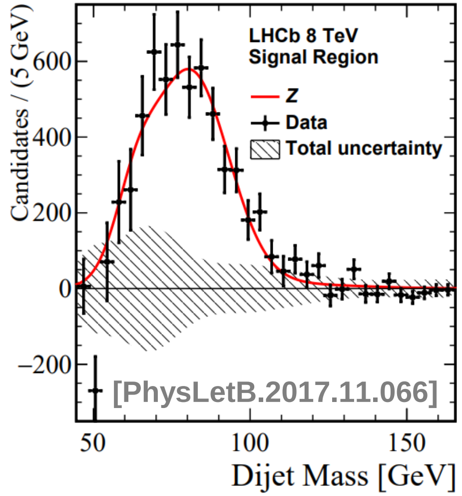
[PhysLetB.2017.11.066]



$Z \to b\bar{b}$

- Simultaneous fit to m_{jj} in signal and control regions
  - Signal $Z \to bb/cc$ shape taken from simulation
  - Dominant QCD modelled with Pearson IV distribution
  - Efficiencies from $Z \to \mu\mu +$ jet and simulation
- Residual jet energy scale factor, k_{JES}, included in fit
  - Consistent with unity, validating modelling & JECs from MC
- Precision σ_Z ~ 17.7%
  - Dominated by HF-tag efficiency uncertainty ~ 16.6%
  - Observation of $Z \to bb$ with 7.3σ significance





[PhysLetB.2017.11.066]

- ***Method***
  - First time 3-prong decay of high-p_T τ reconstruction at LHCb
  - $\tau\bar{\tau}$ reconstructed from ll, lh or $lhhh$ from ~ $2fb^{-1}$ at 8 TeV
- ***Selection***
  - $m(\tau\tau)_{ll} < 60$ GeV/c^2 $m(\tau\tau)_{lh_1,lh_3} > [20,30]$ GeV/c^2
  - $p_T(l)_{1,2} > [20,5]$ GeV/c, $p_T(h_1) > 10$ GeV/c, $p_T(h_3)_{1,n} > [6,1]$ GeV/c
  - $0.7 < m(h_3) < 1.5$ GeV/c^2, $m(h_3)_{corr} < 3$ GeV/c^2
- ***Isolation & separation***
  - $\hat{I}_{p_T} = p_T(\tau) / p_T(j_\tau)$, $\hat{I}_{p_T} > 0.9$
  - $\Delta\phi^{\tau\tau}_{abs} > 2.7$ rad

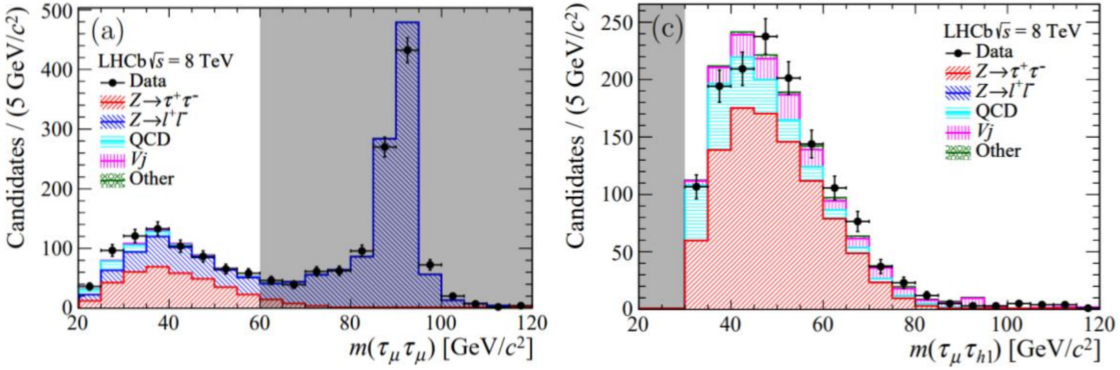
p_T asymmetry & imbalance

$0.1 < A^{ll}_{p_T}$, $0.1 < A^{\mu e}_{p_T} < 0.6$

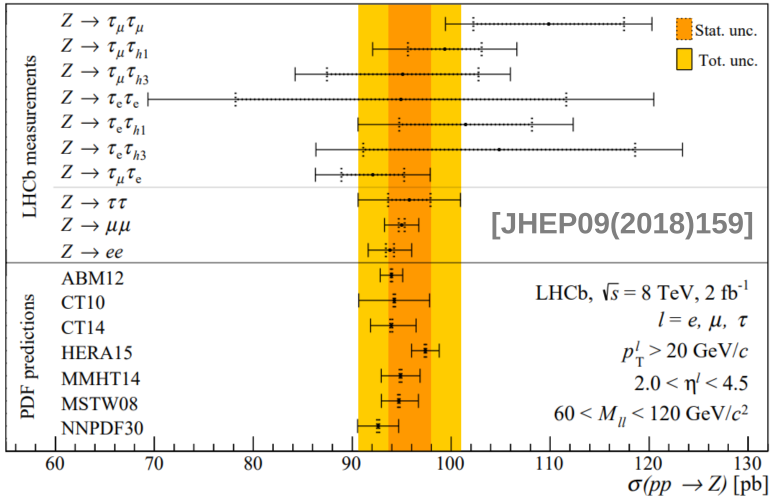
$p_T(h_3)_\Sigma > 12$ GeV/c

$Z \to \tau\bar{\tau}$

- Common fiducial $Z \to \mu\mu/ee$ comparison
  - $60 < m(\tau\tau) < 60$ GeV/c^2
  - $2.0 < \eta_\tau < 4.5$
  - $p_T(\tau) > 20$ GeV/c



- Main backgrounds incl. QCD / V + jet(s)
  - QCD with jet(s), *W* / *Z* + jets, *Z*→*bb*/*μμ*/*ee* from data
  - $t\bar{t}$, WW, ZZ and cross-feed taken from simulation



- Compatible with lepton-universality
  - Consistent with σ_{SM}, systematic uncertainty dominant

Results

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Prospects

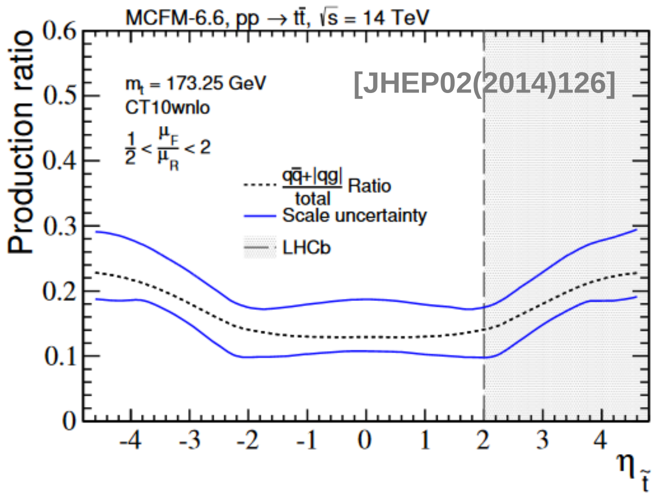
- $A_{\eta}^{t\bar{t}}$
- m_W
- $\sin^2 \theta_W^{eff}$

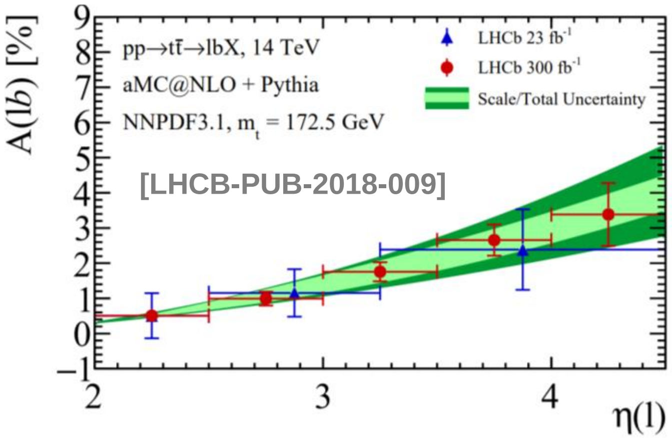
Future prospects

- ***Top asymmetry*** [LHCB-PUB-2018-009]
  - Current measurements consistent with SM and zero
  - Relative reduction of *gg* at LHCb increases asymmetry

  - Higher energies favour top over *Wb* background
  - Differential cross-section accessible with Run II data

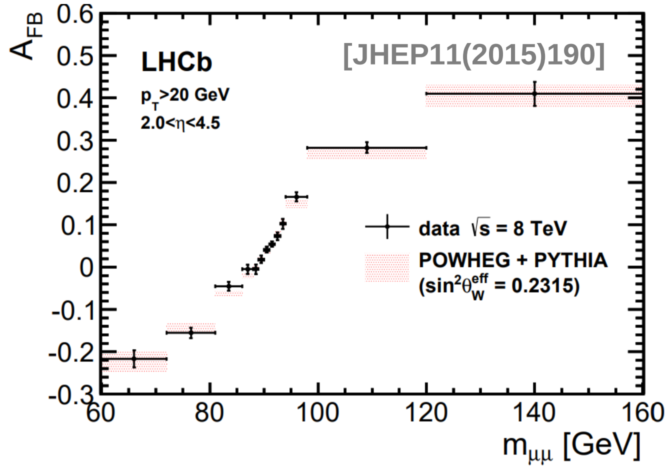
  - Potential for precision top studies with Run III data
  - Sub percent asymmetry precision for Run IV

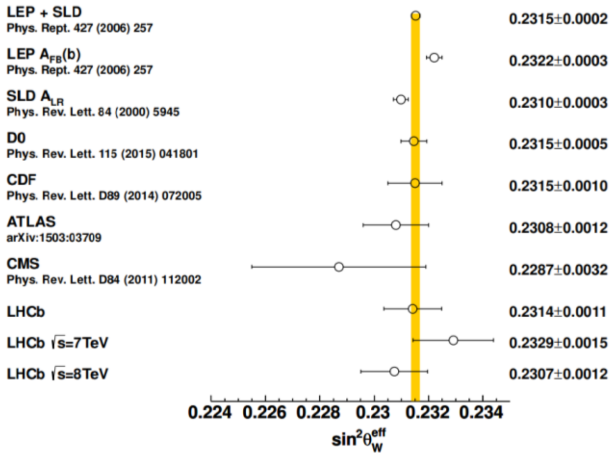




Future prospects

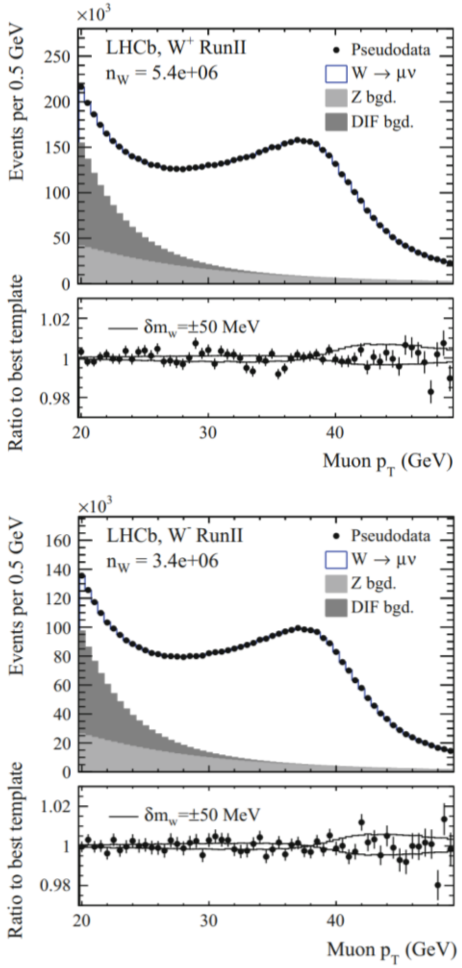
- ***Effective weak mixing angle*** [LHCB-PUB-2018-009]
  - Increased A_{FB}^{Z} in LHCb's higher rapidity acceptance
  - *Z* production theoretically constrained in forward region
  - Factor of 5 statistics increase with Run II data
  - Extend to analysis to *Z* angular coefficients
  - Factor of 20 projected by the end of Run III
  - Sufficient to probe LEP / SLD discrepancy





Future prospects

- ***W boson mass*** [LHCB-PUB-2018-009]
  - Tevatron results very statistically limited
  - LHCb to reduce m_W^{LHC} uncertainty by ~ 30% with Run II data
  - ATLAS dominated by theoretical uncertainties
  - Provides significant anti-correlation between PDFs
  - Closer relationship between m_W and charged lepton p_T
  - Run IV projected to reduce uncertainty to a few MeV



[epjc/s10052-015-3810-1]

Summary

- Looking towards differential top cross-sections
- Important constraints in sensitive forward region
- New methods and new measurements for Run I
- Run II results to benefit from full data & reduced δL
- New era of statistics driven precision at LHCb
- Exciting prospects and complementary program

$t \to \mu e + b$

- ***Summary of systematic uncertainties***
  - Relative uncertainties on $t\bar{t}$ cross-section measurement
  - % of measured σ in fiducial region of final state particles
    - Additional $t\bar{t}$ uncertainty from modelling extrapolating to tops

[LHCb-PAPER-2017-050]

Source	%
trigger	2.0
muon reconstruction	1.1
electron reconstruction	2.8
muon identification	0.8
electron identification	1.3
jet reconstruction	1.6
event selection	4.0
jet tagging	10.0
background	5.1
resolution factor	0.5
total	12.7

$Z \to \mu\bar{\mu}$ / $e\bar{e}$

- ***Summary of uncertainties***
  - Systematic dominated
  - Luminosity dominant systematic

[JHEP09(2016)136]

Source	$\Delta\sigma_Z^{\mu\mu}$ [%]	$\Delta\sigma_Z^{ee}$ [%]
Statistical	0.5	0.9
Reconstruction efficiencies	2.4	2.4
Purity	0.2	0.5
FSR	0.1	0.2
Total systematic (excl. lumi.)	2.4	2.5
Luminosity	3.9	3.9

- ***Summary of systematic uncertainties***
  - Uncertainty on HF-tag efficiency dominant
  - To reduce by factor of two with Run II studies

[PhysLetB.2017.11.066]

Systematic source	σ_Z [%]	k_{JES} [%]
Heavy-flavour tagging efficiency	16.6	0.5
Hardware trigger efficiency	1.9	–
GEC efficiency	1.7	–
Jet energy correction	2.7	0.3
Jet energy resolution	1.0	0.2
Jet identification efficiency	2.0	< 0.1
Balancing-jet selection efficiency	1.8	–
Signal model	2.0	0.3
QCD model	1.1	< 0.1
Transfer functions	1.5	0.8
R efficiencies ratio	0.3	< 0.1
Fit bias	2.1	–
Subdominant backgrounds ($t\bar{t}$, $W \to qq'$)	1.9	< 0.1
Final-state radiation	0.9	–
$f_{Z\to c\bar{c}}$ fraction	0.1	–
Luminosity	1.2	–
Total	17.7	1.1

$Z \to \tau\bar{\tau}$

- ***Summary of uncertainties***
  - Backgrounds dominant for $\tau_e\tau_e$
  - Mix of stat. and syst. generally

[JHEP09(2018)159]

	$\tau_\mu\tau_\mu$	$\tau_\mu\tau_{h1}$	$\tau_\mu\tau_{h3}$	$\tau_e\tau_e$	$\tau_e\tau_{h1}$	$\tau_e\tau_{h3}$	$\tau_\mu\tau_e$
Tau branching fractions product	0.5	0.3	0.5	0.5	0.3	0.5	0.3
PDF, acceptance, FSR	1.3	1.9	1.5	1.3	1.9	1.5	1.3
Reconstruction	2.1	3.1	5.6	4.5	5.4	7.0	2.7
Selection	5.0	3.5	4.7	5.7	3.5	5.1	3.9
Background estimation†	3.4	3.9	3.2	19.0	5.2	8.0	2.4
Systematic	6.4	6.2	8.0	20.3	8.4	11.8	5.2
Statistical†	6.9	3.8	8.1	17.6	6.6	13.1	3.4
Beam energy	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Luminosity	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Total	9.6	7.5	11.5	27.0	10.8	17.7	6.5