Top Physics at LHCb

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on behalf of the LHCb collaboration

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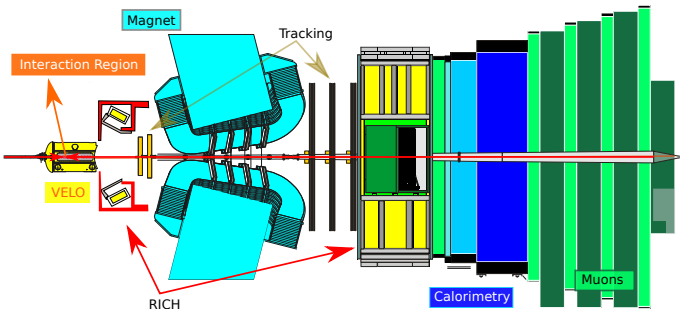
introduction

optimised to study decays of heavy flavour hadrons

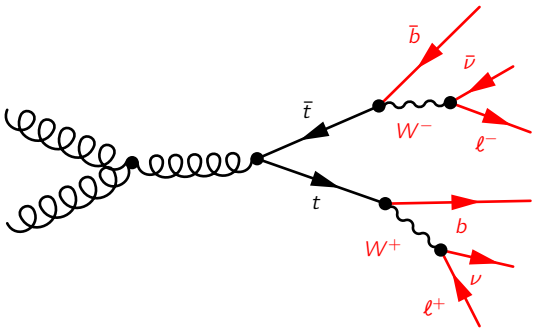
- fully instrumented between $2.0 \leq \eta \leq 5.0$
- excellent tracking, vertexing and PID capabilities
- average pile-up ~ 2

pp datasets		
Year	Energy	Lumi
2011	7 TeV	1.0 fb^{-1}
2012	8 TeV	2.0 fb^{-1}
2015-2018	13 TeV	6.0 fb^{-1}

see talk by Katharina Mueller



detecting tops at LHCb



how do we reconstruct top quarks at LHCb?

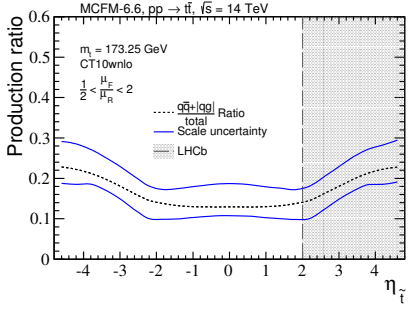
- low acceptance - focus on partial reconstruction of top final states
  - identify by the presence of as little as two reconstructed objects (≥ 1 lepton)
  - triggered using single lepton triggers
  - leptons (jets) in range $2.0 < \eta < 4.5$ ($2.2 < \eta < 4.2$)
  - jets tagged using secondary vertex tagger, with further separation provided by 2D BDT [*JINST* (2015) 10:P06013]
- no access to E_T^{miss}

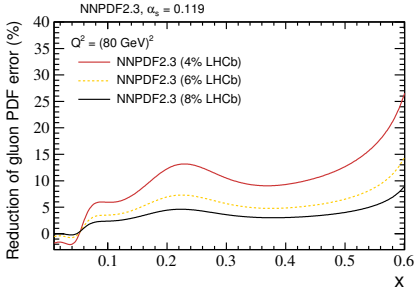
three measurements of top production performed by LHCb

- μb, $\ell b\bar{b}$, μeb

top quarks in the forward region [*JHEP* (2014) 02:p. 126]

LHCb uniquely explores top quark production in the forward region of *pp* collisions





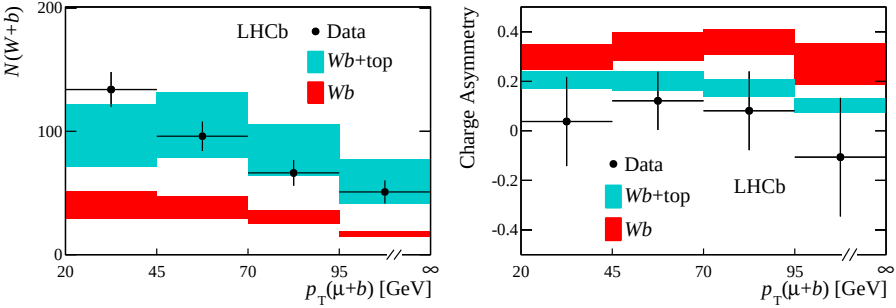
- test of differential predictions
- reduced gg contribution to top production in the forward region
  - increased $t\bar{t}$ asymmetry

- can provide constraints on gluon PDF at higher-x than central region
  - up to 20-30% reduction possible at large-x

current measurements

μb - Run 1

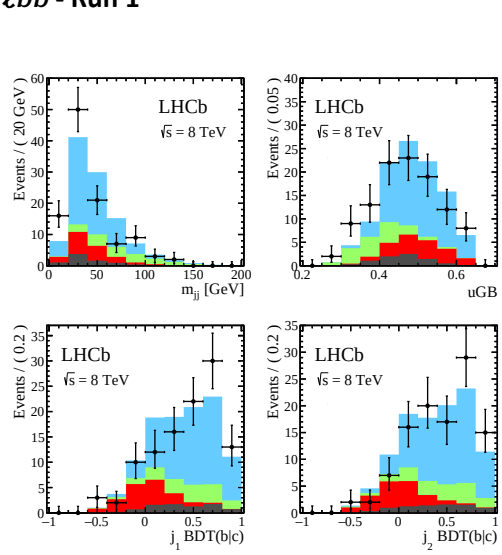
[*Phys. Rev. Lett.* (2015) 115:p. 112001]



- first measurement of top production performed using 3 fb^{-1} of data at 7 and 8 TeV in μb final state
  - most statistically accessible final state
  - cannot distinguish between single top and $t\bar{t}$ production
- combined measurement of single top and top pair production at 7 and 8 TeV ($\sim 75\% t\bar{t}$)
- total signal yield of 220 ± 39
- measurement precision $\sim 20\%$, statistically limited

$\ell b\bar{b}$ - Run 1

[*Phys. Lett.* (2017) B767:pp. 110–120]

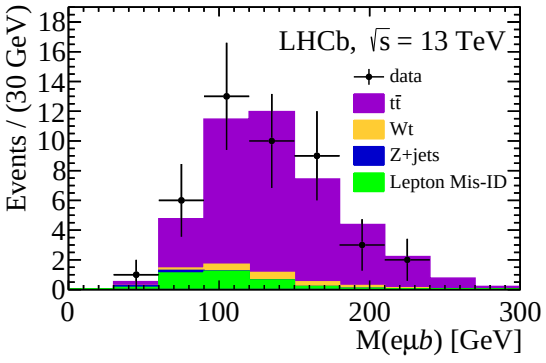


- measurement of $t\bar{t}$ production performed in $\ell b\bar{b}$ final state using 2 fb^{-1} at 8 TeV
  - use both leptons and muon final states
  - simultaneous measurement of $t\bar{t}$, Wbb and Wcc production
- 4-dimensional fit used to extract signal components
- $t\bar{t}$ signal observed with significance of 4.9σ
- measurement precision $\sim 40\%$
  - similar contributions from statistical and systematic sources

top production in the μeb channel

[*JHEP* (2018) 08:p. 174]

- factor of 10 increase in forward $t\bar{t}$ cross-section in Run 2 of the LHC
- can make measurements in the dilepton final state
  - extra lepton gives higher purity final state
- analysis based on data collected in 2015 and 2016 $\sim 2\,\text{fb}^{-1}$

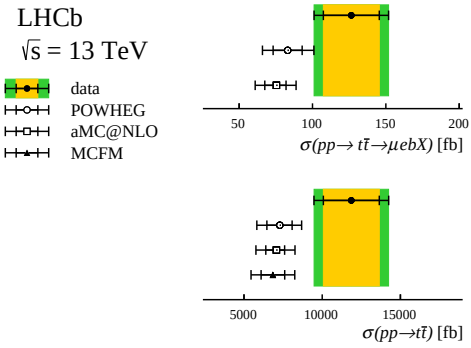


- a total of **44** candidates selected with a purity of $\sim 87\%$
- dominant background from lepton mis-identification
- also contributions from Zj and Wt
- measurement precision $\sim 20\%$

μeb results

[*JHEP* (2018) 08:p. 174]

- measurements compared to predictions in measurement fiducial region (top)
- extrapolated to top quark level (below)
  - $2.0 < y^t < 5.0$
- results compared to POWHEG and aMCatNLO
- compatible with SM predictions



systematic uncertainties

- dominant systematic uncertainties on top measurements due to **jet tagging**, **purity determination** and **luminosity**

μb[*Phys. Rev. Lett.* (2015) 115:p. 112001]

source	uncertainty
GEC	2%
templates	5%
jet reconstruction	2%
SV-tag BDT templates	5%
b-tag efficiency	10%
trigger & μ selection	2%†
jet energy	5%†
$W \to \tau \to \mu$	1%†
luminosity	1–2%†
Total	14%
Theory	10%

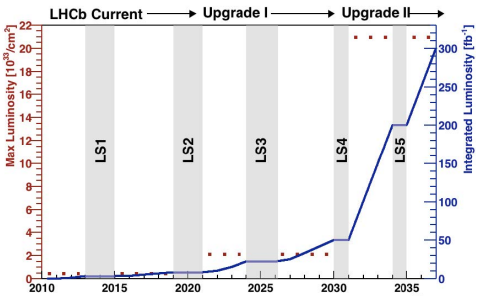
$\mu e b$ [*JHEP* (2018) 08:p. 174]

Source	%
trigger	2.0
muon tracking	1.1
electron tracking	2.8
muon id	0.8
electron id	1.3
jet reconstruction	1.6
jet tagging	10.0
selection	4.0
background	6.3
acceptance	0.5
total	12.7
luminosity	3.9

prospects

LHCb Upgrades

[1808.08865 [hep-ex]]



Upgrade 1

- collect > 50 fb^{-1}
- moving to fully software level trigger
- factor 5 increase in instantaneous luminosity -> increased pile-up

Upgrade 2

- collect > 300 fb^{-1}
- expect improved performance for high p_T electrons
- higher pile-up ($\sim$50) will be a challenge for jet reconstruction
- ATLAS and CMS detectors will also have increased forward coverage in HL-LHC
  - complementary measurements

statistical precision and expected yields

[1808.08865 [hep-ex]]

- projections for top quark physics in upgrade presented in [1808.08865 [hep-ex]]
  - improvements in tagging efficiency, selection, use of electrons assumed

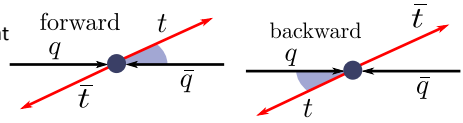
final state	current	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}	$< x >$
ℓb	220	54k	117k	830k	0.295
$\ell b\bar{b}$	24	8k	17k	130k	0.368
$\mu e b$	38	1k	2k	12k	0.348
$\mu e b\bar{b}$	-	120	260	1.5k	0.415

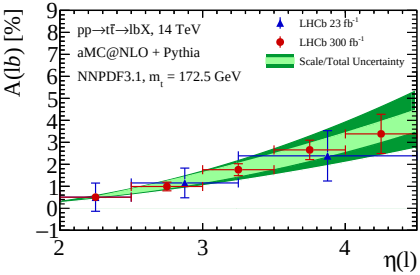
- all three measurements performed so far at LHCb have been statistically limited at the level of 15-20%
- analysis ongoing with full Run 2 dataset
  - differential measurements in $\ell b(\bar{b})$ channels will be made with stat uncertainty of a few percent
  - inclusive measurement in dilepton channel with stat precision $\sim 7\%$
- upgrades will bring significant boost in statistical precision

asymmetry

[1902.04070 [hep-ph]]

- measurements of $t\bar{t}$ asymmetry of interest since discrepancies seen at Tevatron in $p\bar{p}$ collisions
  - diluted by symmetric gluon-gluon fusion at the LHC
- the forward region offers unique possibilities for measuring the $t\bar{t}$ asymmetry
  - increased contribution from quark-initiated production in the forward region
- projections for $t\bar{t}$ asymmetry as a function of lepton pseudorapidity
  - two luminosity scenarios - end of Run 3 and HL-LHC
- statistically, SM $t\bar{t}$ asymmetry accessible with full HL-LHC dataset
- final state will also receive contributions from single top and $Wb(\bar{b})$ background
  - good knowledge of backgrounds required to measure $t\bar{t}$ asymmetry





conclusion and outlook

- LHCb provides unique measurements of top production in forward region
- current measurements using Run 1 data and early Run 2 data
- full Run 2 dataset being analysed
  - measurements will be no longer be limited by statistics
- LHCb upgrades will provide large sample of forward top quarks and sensitivity to the $t\bar{t}$ asymmetry
- looking forward to more top physics!

backup