Top Physics Prospects at LHCb

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LHC Top WG Meeting

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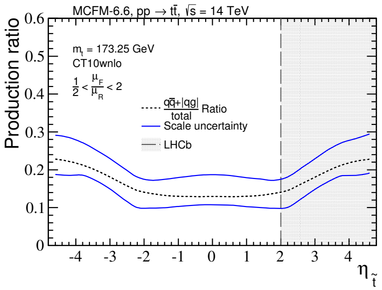
top physics at LHCb

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

- access larger values of Bjorken x
- increased contribution from quark-initiated production relative to central region
- test of perturbative QCD in unexplored region
- can provide unique constraints on gluon PDF at large-x

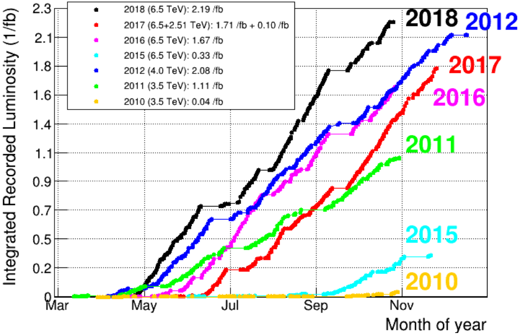


[*JHEP* (2014) 02:p. 126]

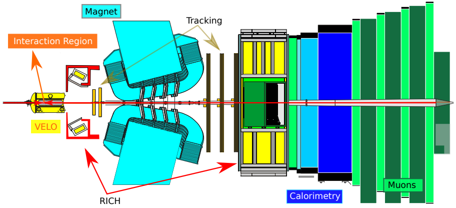
LHCb - running conditions

detector optimised to study decays of heavy flavour hadrons

- excellent vertex locator for b-tagging
- low pile-up environment (~ 2)
- low data-taking rate compared to ATLAS/CMS
- collected 3 fb^{-1} of data in Run 1 at 7 and 8 TeV
  - low cross-section for $t\bar{t}$ production
- collected 6 fb^{-1} in Run 2 at 13 TeV
  - factor 10 increase in $t\bar{t}$ yield



detecting tops at LHCb



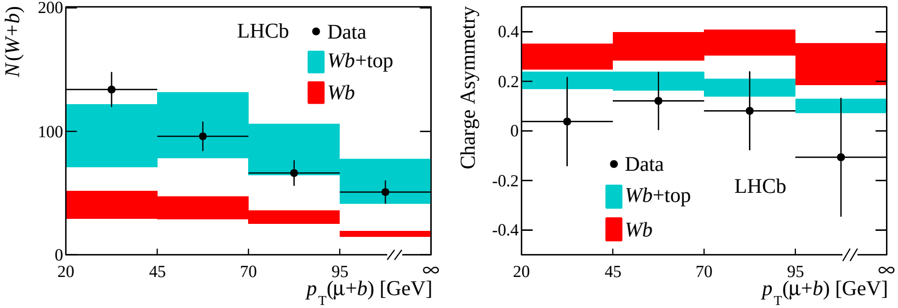
how do we reconstruct top quarks at LHCb?

- 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
- no access to E_T^{miss}

three measurements of top production performed by LHCb so far

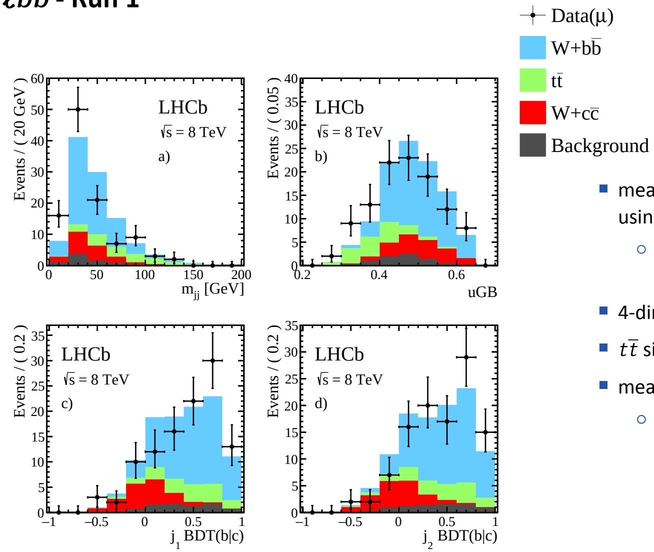
μb - Run 1

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

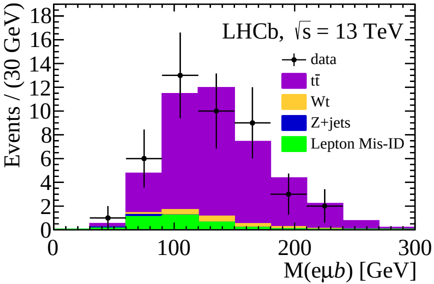


- first measurement of top production performed using 3 fb^{-1} of data at 7 and 8 TeV in μb final state
  - most statistically accessible final state
  - cannot distinguish between single top and $t\bar{t}$ production
- combined measurement of single top and top pair production at 7 and 8 TeV ($\sim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

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



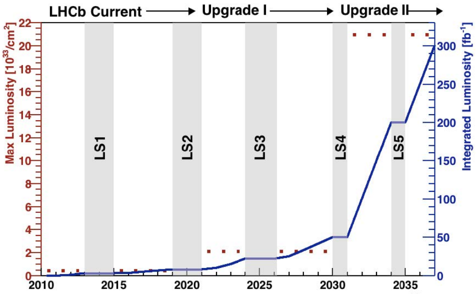
- measurement of $t\bar{t}$ production performed in $\ell b\bar{b}$ final state using 2 fb^{-1} at 8 TeV
  - simultaneous measurement of $t\bar{t}$, Wbb and Wcc production
- 4-dimensional fit used to extract signal components
- $t\bar{t}$ signal observed with significance of 4.9σ
- measurement precision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



first run 2 measurement made using μeb final state

- offers highest purity
- out of statistical reach in Run 1, possible with boost in stats coming from increase in $\sqrt{s}$
- analysis based on data collected in 2015 and 2016 $\sim$ 2 fb^{-1}
- measurement based on sample of **44** candidates with purity $\sim$ 87%
- dominant background due to lepton misidentification
- measurement precision $\sim$ 20%, stat. limited

LHCb Upgrades



LHCb is currently preparing for Upgrade 1

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

LHCb can participate in HL-LHC with 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
- proposal to replace hadronic calorimeter with muon shielding
  - need to evaluate impact on jet resolution
- ATLAS and CMS detectors will also have increased forward coverage in HL-LHC
  - complementary measurements

statistical precision and expected yields

[1808.08865]

- projections of event yields for upgrade, where improvements in tagging efficiency, selection, use of electrons etc.. is 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%
- currently 6 fb^{-1} of 13 TeV data from Run 2 available and being analysed
    - differential measurements in $\ell b(b)$ channels can be made with stat uncertainty of a few percent
    - inclusive measurement in dilepton channel with stat precision $\sim 7\%$
- clear that we will be systematics limited

systematic uncertainties

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

μb[1808.08865]

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%

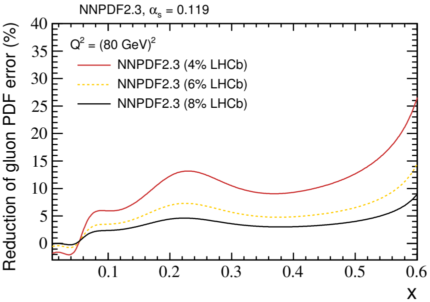
μeb [*JHEP* (2018) 08:p. 174]

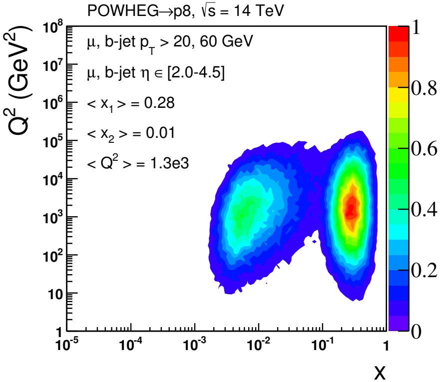
Source	%
trigger	2.0
muon tracking	1.1
electron tracking	2.8
muon id	0.8
electron id	1.3
jet reconstruction	1.6
jet tagging	10.0
selection	4.0
background	6.3
acceptance	0.5
total	12.7
luminosity	3.9

reducing systematic uncertainties

- **jet tagging:**
  - dominant systematic uncertainty on all measurements performed thus far
  - expect significant reduction for upcoming measurements
- **background modelling:**
  - Run 1 measurements benefit from improved signal-to-background ratio at 13 TeV.
  - Measurements in dilepton channel limited by size of control samples, will improve with more stats
- **luminosity:**
  - Run 1 measurements made with precision of 1-2%
  - Run 2 used preliminary calibration with precision of $\sim 4\%$
  - Final Run 2 calibration will be a similar precision to Run 1 measurements
- other systematic uncertainties should also reduce

what precision do we need?



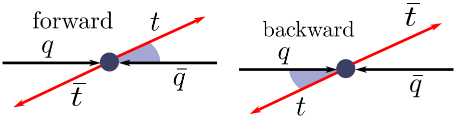


- precision of below 5% at LHCb will have significant impact on gluon PDF at large-x [*JHEP* (2014) 02:p. 126]
- dilepton channel will need upgrade statistics to reach this level
- ATLAS/CMS reach precision of up to $\sim$ 3%

cross-sections - what should we measure?

- LHCb covers only a small part of the full phase space
  - no extrapolation to 4π
- additionally, no E_T^{miss} and partial reconstruction means no top reconstruction
  - extrapolation to a "top fiducial region" is also a sizeable correction
  - introduces large theory uncertainty on measurements
- should we quote our results only at the level of the leptons and b-jets?
  - differential measurements v lepton,jet, lepton+jet kinematics?
  - difficult to compare with theory / other measurements?
  - can they then be used in PDF fitters?

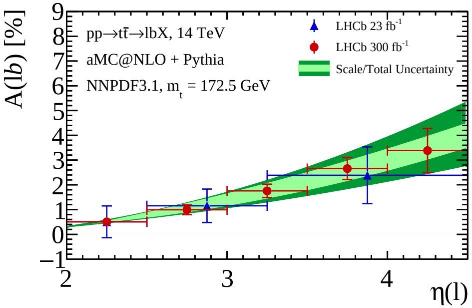
asymmetry (I)



- the forward region offers unique possibilities for measuring the $t\bar{t}$ asymmetry
  - less dilution from symmetric gluon-gluon fusion
- requires large statistics
  - SM asymmetry unlikely to be statistically accessible with dilepton mode even with upgrade datasets
  - focus on single lepton final states
- define asymmetry as $A(\Delta\eta) = \frac{N^{\ell^+ b}(\Delta\eta) - N^{\ell^- b}(\Delta\eta)}{N^{\ell^+ b}(\Delta\eta) + N^{\ell^- b}(\Delta\eta)}$ [*Phys. Rev. Lett.* (2011) 107:p. 082003]
  - cancellation of large number of systematic uncertainties

asymmetry (II)

- 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 background
    - competes with PDF asymmetries
    - knowledge of backgrounds will likely be limiting uncertainty on extraction of $t\bar{t}$ asymmetry
- first asymmetry measurement currently underway with Run 2 dataset



conclusion and outlook

- LHCb can provide unique measurements of top production in forward region
- work ongoing to analyse full Run 2 dataset
- measurements will be limited by systematic uncertainties
- improvements foreseen in tagging and background estimation
- also room for new ideas, observables etc...
- looking forward to more top physics!

backup