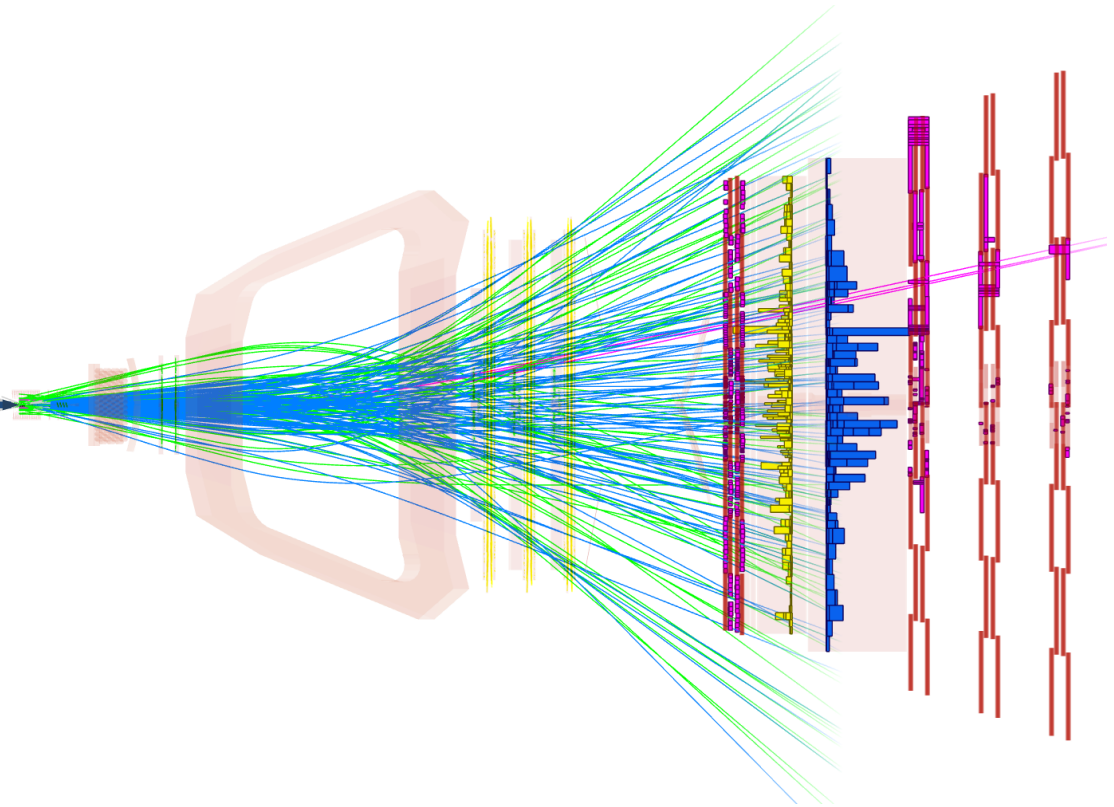
UNIVERSITY OF LIVERPOOL

TOP 2018

Tops in the forward region

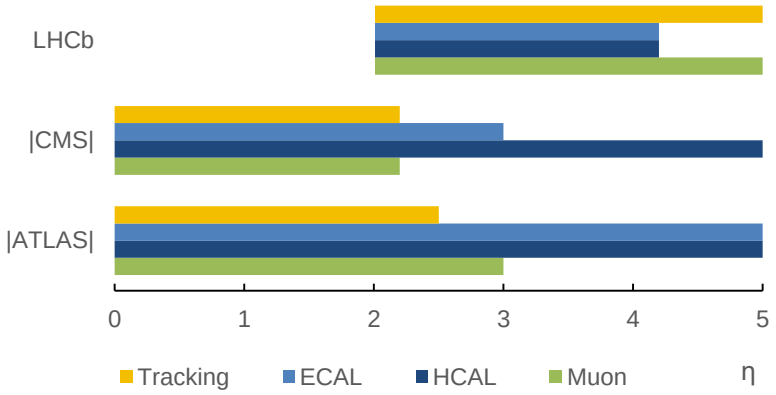


Overview

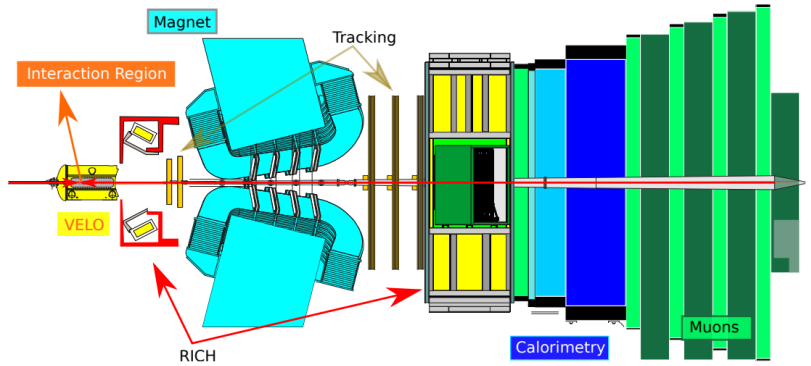
- LHCb as a general purpose detector
- Forward region top physics
- Run I results
- Run II results
- More to come

Forward GPD

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



- Low acceptance (< 4% solid angle)
- Low luminosity compared to ATLAS/CMS
- Dependent on partial reconstruction (no missing E_T)



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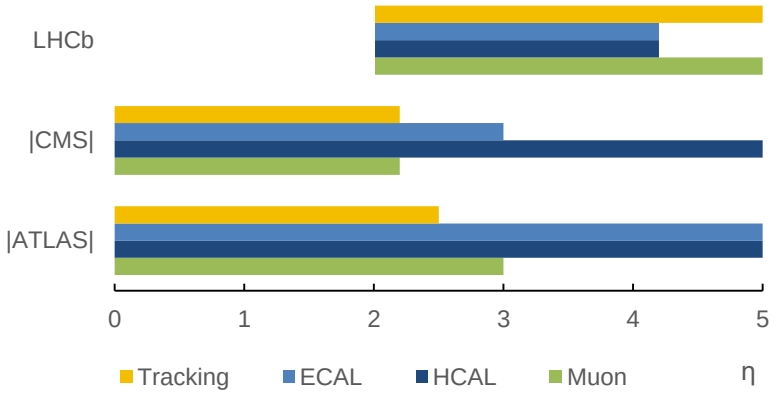

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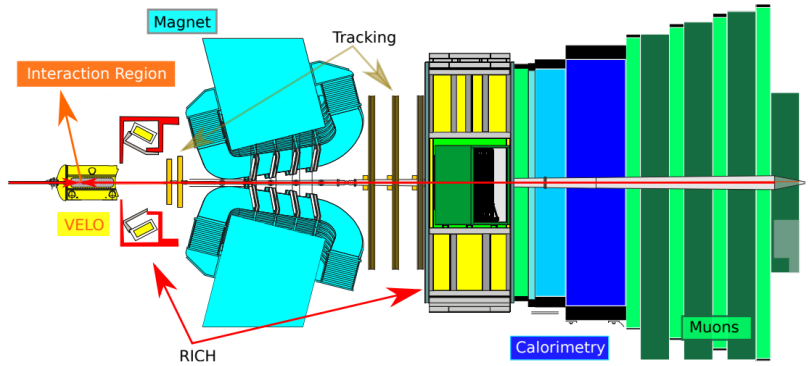
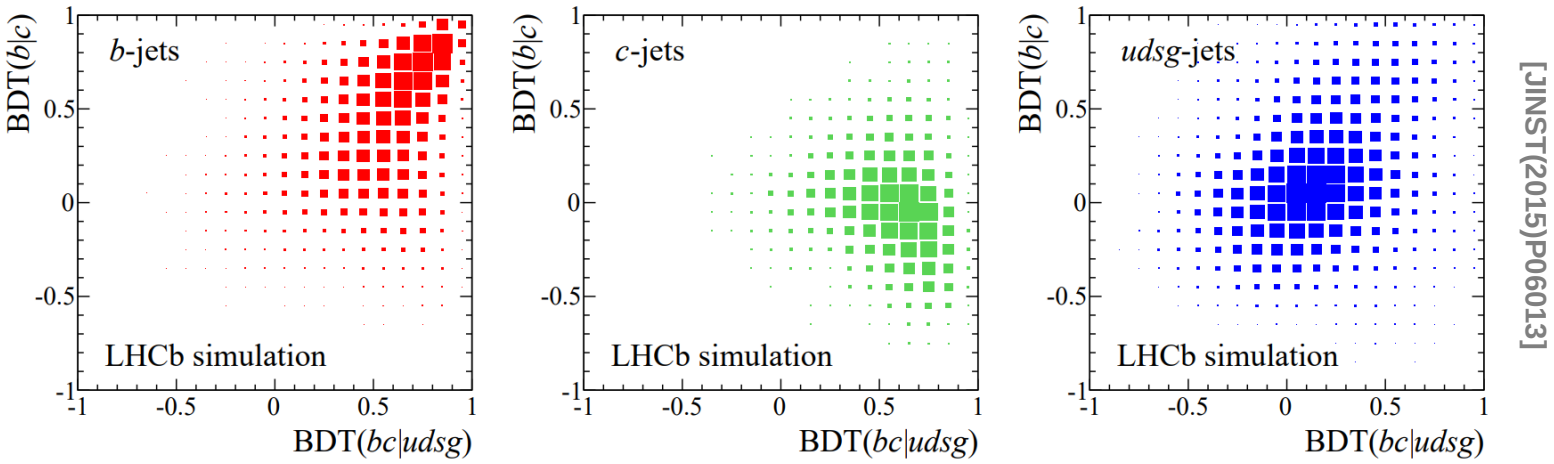
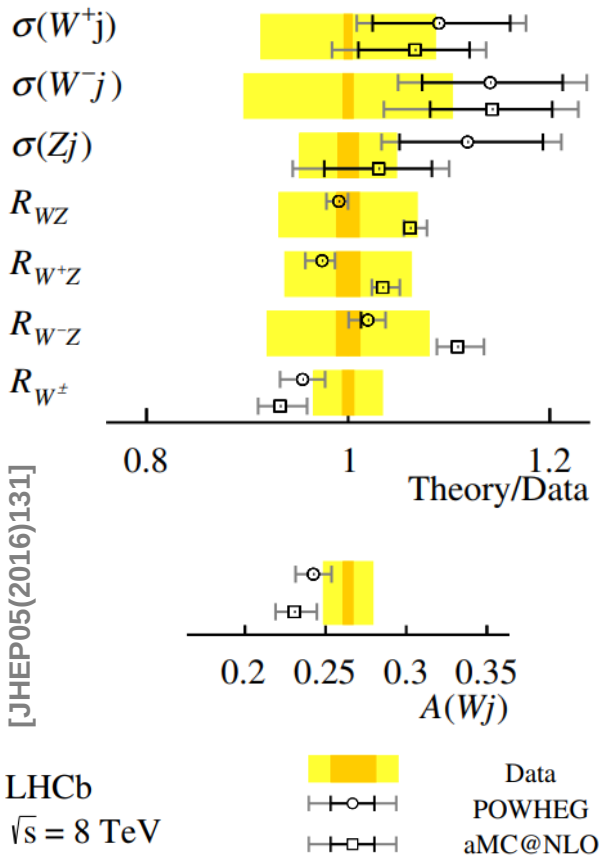


Jet performance

- 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]

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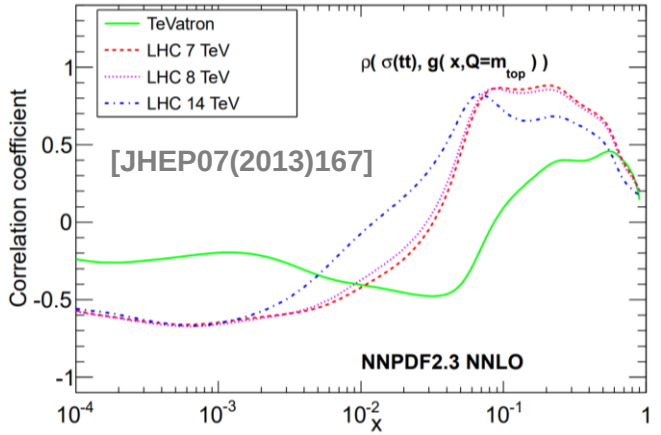
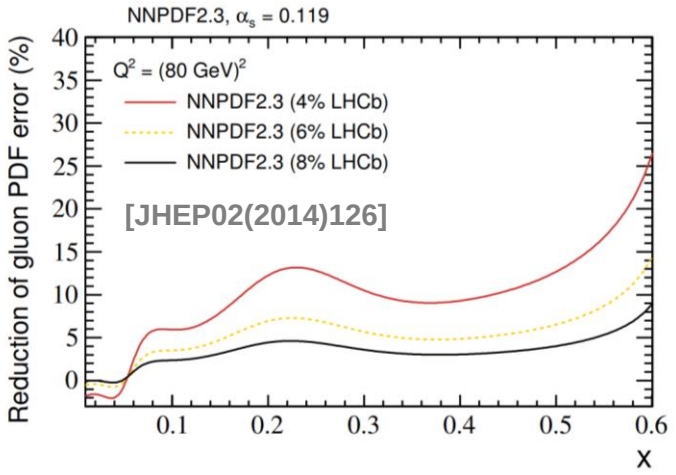
Access

- Gluon PDF is maximally correlated with $\sigma_{t\bar{t}}$ at high-x
- Tops naturally access high-x; forward tops, even higher
- Both differential top rapidity and inclusive $\sigma_{t\bar{t}}$ contribute

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

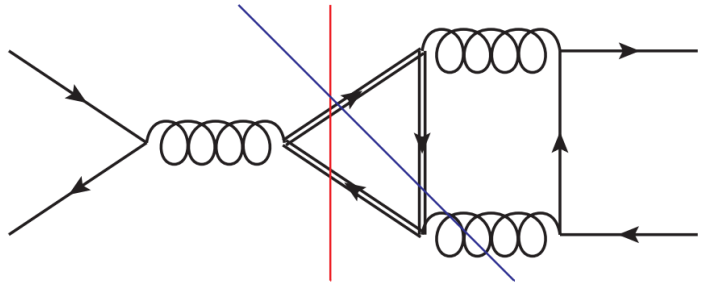
[LHCb-PUB-2013-009]

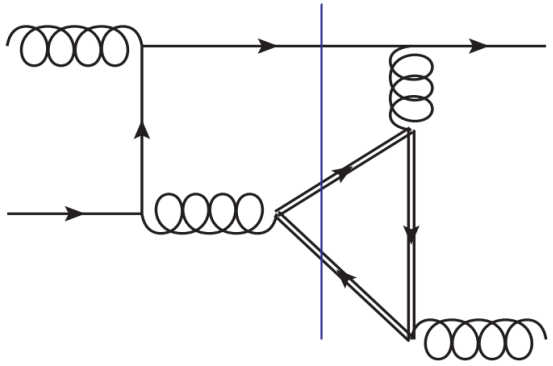


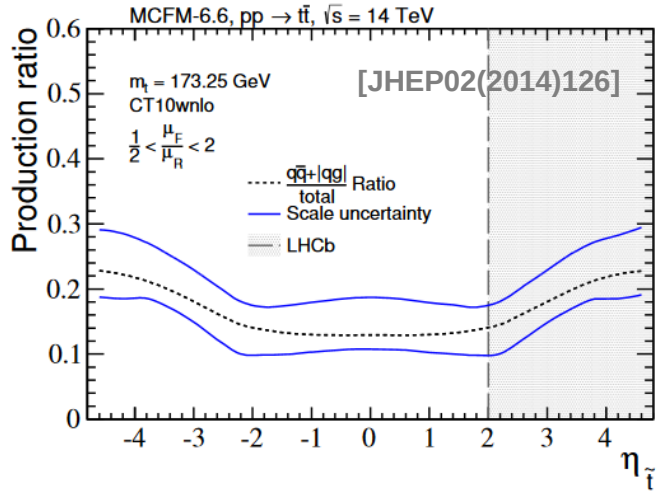


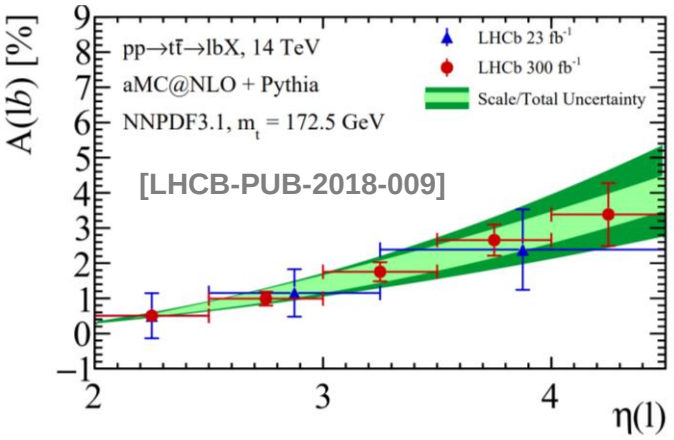
Sensitivity

- q content is increasing in forward region
- gg fusion relatively suppressed in forward region
- $q\bar{q}$ asymmetry maximised at high rapidities









Results

LHCb publication timeline

2018
- **Measurement of forward top pair production in the dilepton channel in pp collisions at √s=13 TeV**

2017
- **Measurement of the Z→bb cross-section in the forward region of pp collisions**
- **Updated search for long-lived particles decaying to jet pairs**
- **Study of J/ψ production in jets**
- Measurement of forward tt, W+bb and W+cc production in pp collisions at √s=8 TeV

2016
- Measurement of forward W and Z boson production in association with jets in pp collisions at √s=8 TeV

2015
- First observation of top quark production in the forward region
- Study of W boson production in association with beauty and charm
- Identification of beauty and charm quark jets at LHCb
- Search for long-lived particles decaying to jet pairs
- Measurement of the Z+b-jet cross-section in pp collisions at √s=7TeV in the forward region

2014
- First measurement of the charge asymmetry in beauty-quark pair production
- Study of forward Z+jet production in pp collisions at √s = 7 TeV

Overview

- LHCb as a general purpose detector
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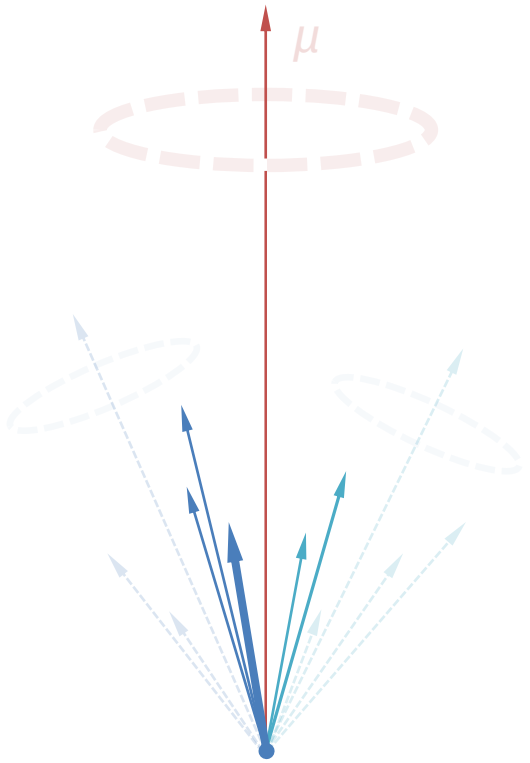
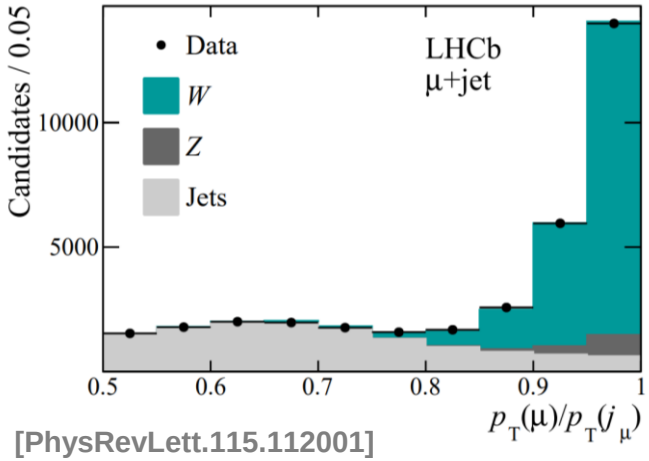
7,8 TeV $(\mu + b)$

- ***Method***
  - Partial reconstruction through high p_T muon and a *b*-jet
  - 3 fb^{-1} combined from 7 and 8 TeV data
- ***Selection***
  - Single muon: $p_T > 25$ GeV/c, $2.0 < \eta < 4.5$
  - HF-tagged jet: $50 < p_T < 100$ GeV/c, $2.2 < \eta < 4.2$
  - $\Delta R(\mu,j) > 0.5$, $p_T\,(\vec{j} + \overrightarrow{j_\mu}) > 20$ GeV/c
- ***Muon-jets***
  - High p_T muons are anti-k_T clustered into jet objects, j_μ

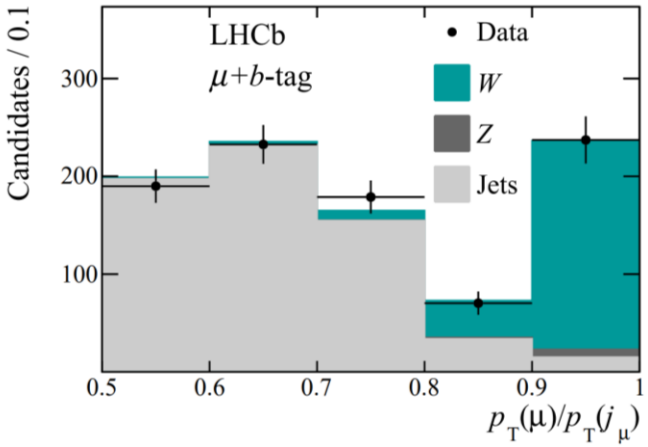


7,8 TeV $(\mu + b)$

- EW vs QCD fit to muon isolation provides *W*+jet yield
  - Isolation variable defined as $p_T(\mu) / p_T(j_\mu)$
  - Data driven template of QCD multi-jet background
  - BDTs' flavour fit provides *W*+*b*-tag yield per iso. bin
- 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!



[PhysRevLett.115.112001]



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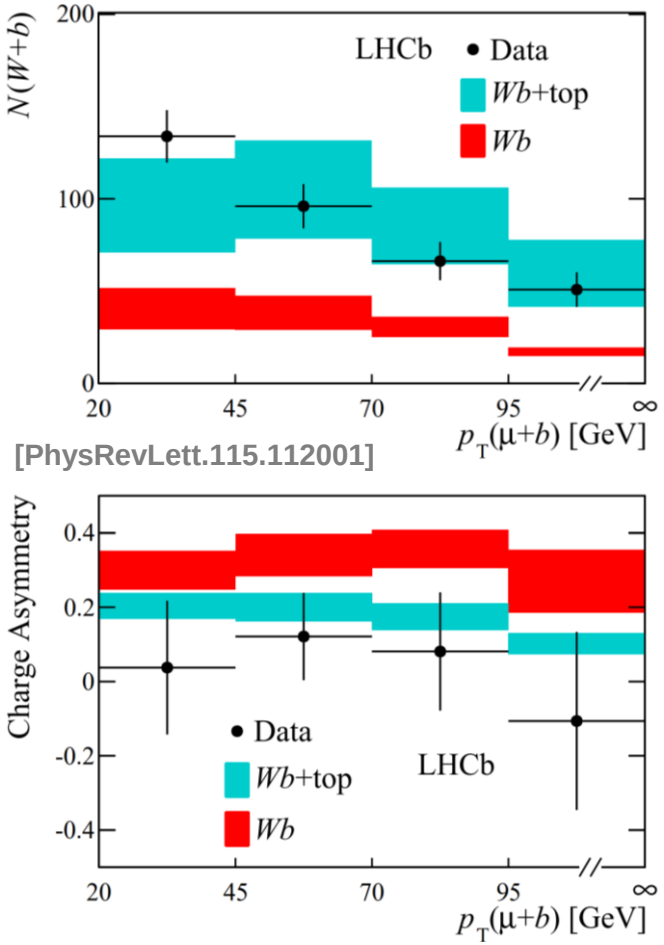


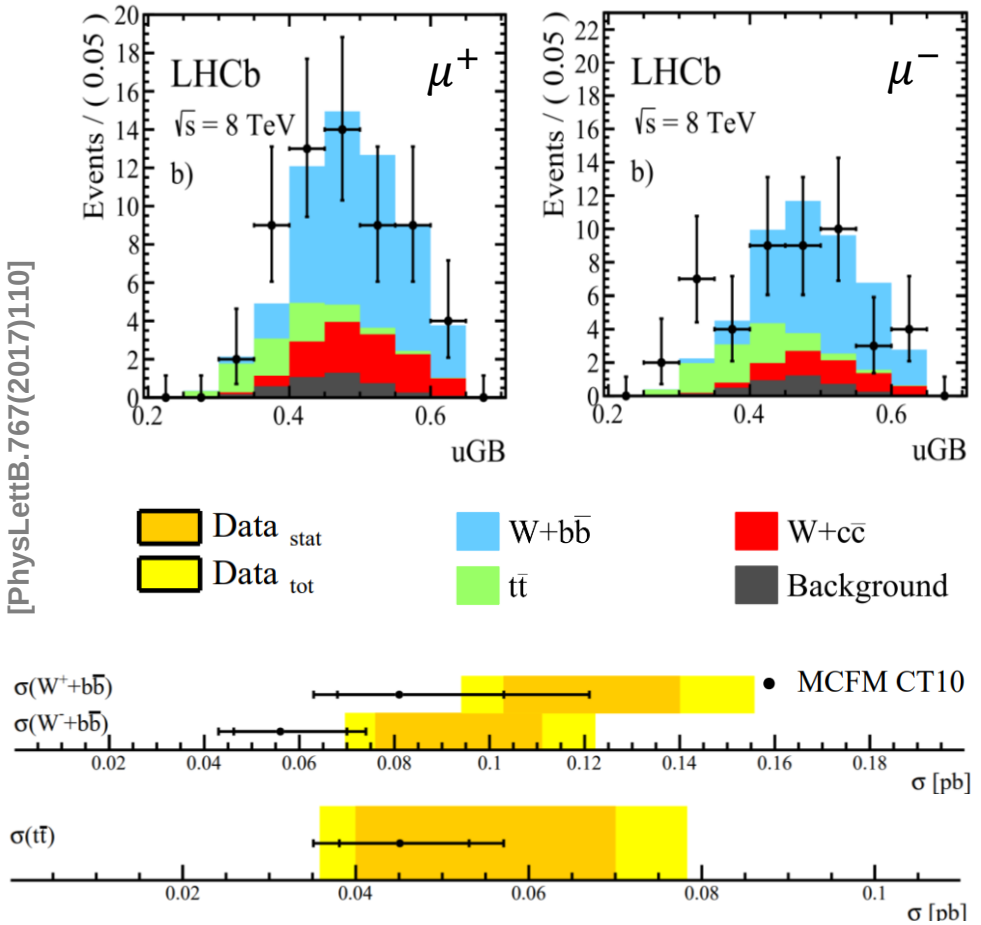
[PhysRevLett.115.112001]

8 TeV $(l + b\bar{b})$

- ***Method***
  - Simultaneous fit of *Wbb*, *Wcc* and $t\bar{t}$
  - ~ 2 fb^{-1} of 8 TeV data
- ***Selection***
  - Single lepton: p_T (μ,e) > (20,15) GeV/c, 2.0 < η < (4.5,4.25)
  - Two HF jets: 12.5 < p_T < 100 GeV/c, 2.2 < η < 4.2
  - ΔR(l,j) > 0.5, ΔR(j_1,j_2) > 0.5, p_T $(\vec{l} + \vec{j_1} + \vec{j_2})$ < 15 GeV/c
- ***Multivariate discriminant***
  - uGB trained to separate *Wbb*, *Wcc* and $t\bar{t}$

8 TeV $(l + b\bar{b})$

- uGB separates *lbb* components
  - Trained with pT, η, m_j, ΔR, $\cos(\theta_l)$
  - θ_l, scattering angle in di-jet rest frame
  - Uniform boosting minimises m_{jj} correlation
- 4D fit to m_{jj}, BDT(*b*|*c*) for both jets, uGB
  - Split samples by lepton charge and flavor
- Precision ~ 40%
  - Suffers from systematics and low stats
  - 4.9σ significance $t\bar{t}$ production



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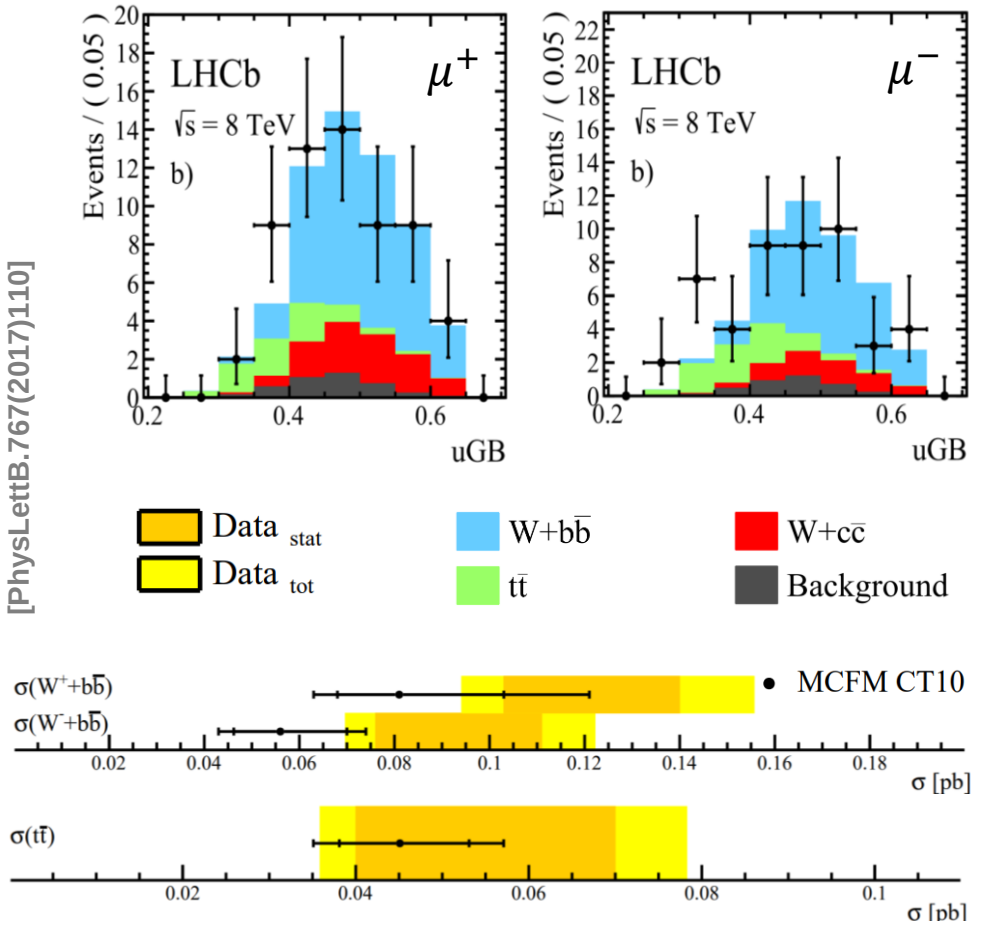

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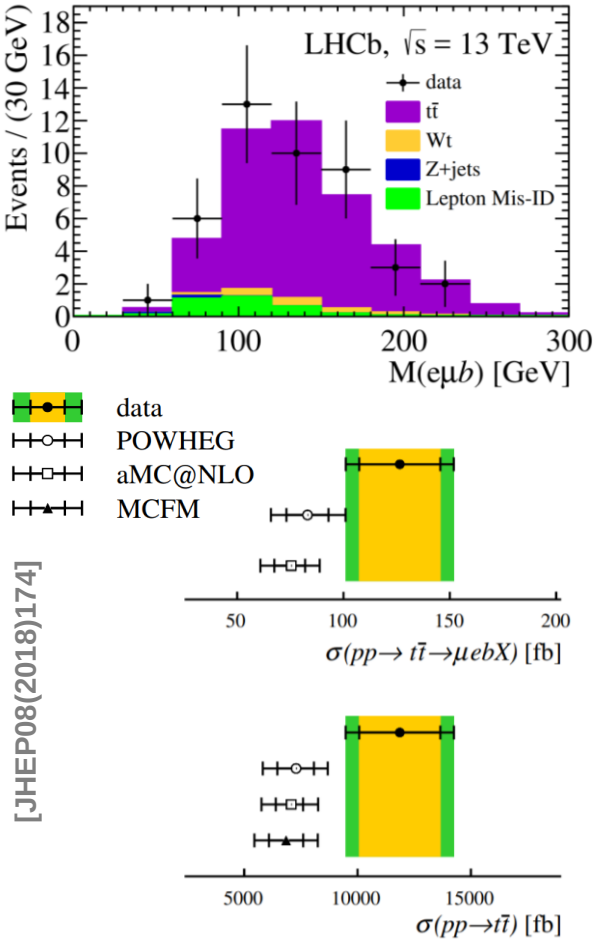
13 TeV $(\mu e + b)$

- ***Method***
  - 10x stats increase for $t\bar{t}$ with Run II energy
  - ~ 2 fb^{-1} of 13 TeV data, selection from highly pure channel now viable
- ***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

13 TeV $(\mu e + b)$

- Statistically limited but highly pure *llb* channel
  - Run II stats provide viable channel with ~ 90% purity
  - ‘Lepton mis-ID’ includes: QCD, W/Z+jet
- Background subtraction, $t\bar{t}$ normalised to remaining data
  - Lepton mis-ID shape from data; *Zj*, *Wt* & $t\bar{t}$ from simulation
  - Good agreement in p_T and η for μ and *e*
- Precision ~ 23%
  - Dominated by jet tag efficiency and QCD background
  - Consistent with SM



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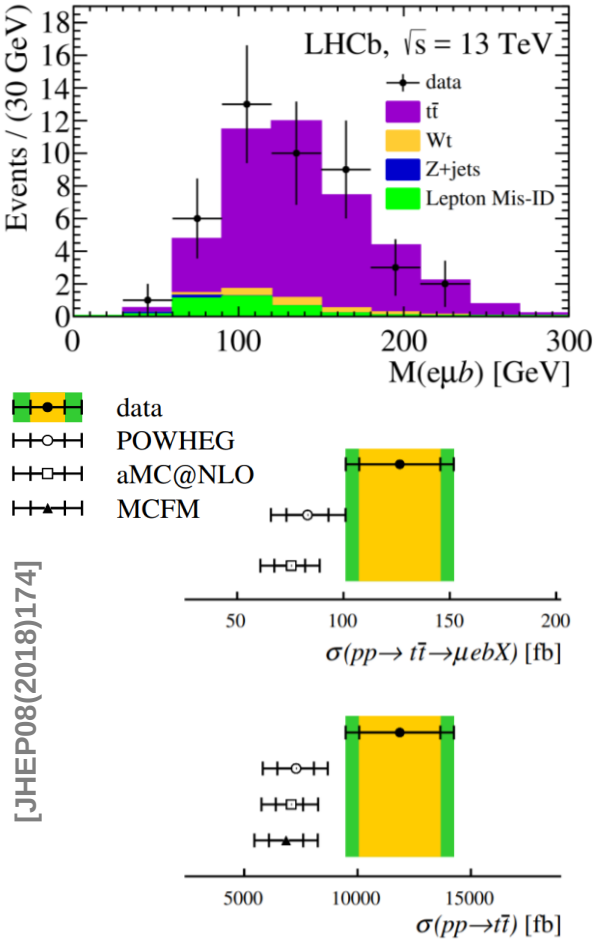

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Summary

- LHCb top data ready to contribute with more to come!
  - Run I - *lb* (3fb^{-1}), *lbb* (2 fb^{-1}), Run II - *llb* (2fb^{-1})
- 13 TeV - $\mu + b$ (6fb^{-1})
  - Top dσ/dη & asymmetry become accessible
- 13 TeV - $l + b\bar{b}$ (6fb^{-1})
  - Stats. dependant systematics diminish
- 13 TeV - $\mu e + b$ (6fb^{-1})
  - Alleviates remaining statistical limitations

Jan Kieseler
Tops in Run III

TOP 2018

thank you

7,8 TeV $(\mu + b)$

- ***Relative systematic uncertainties***
  - † denotes uncertainty applies only to cross-section
  - Only luminosity uncertainty dependant on √s
    - 2% at 7 TeV ; 1% at 8 TeV

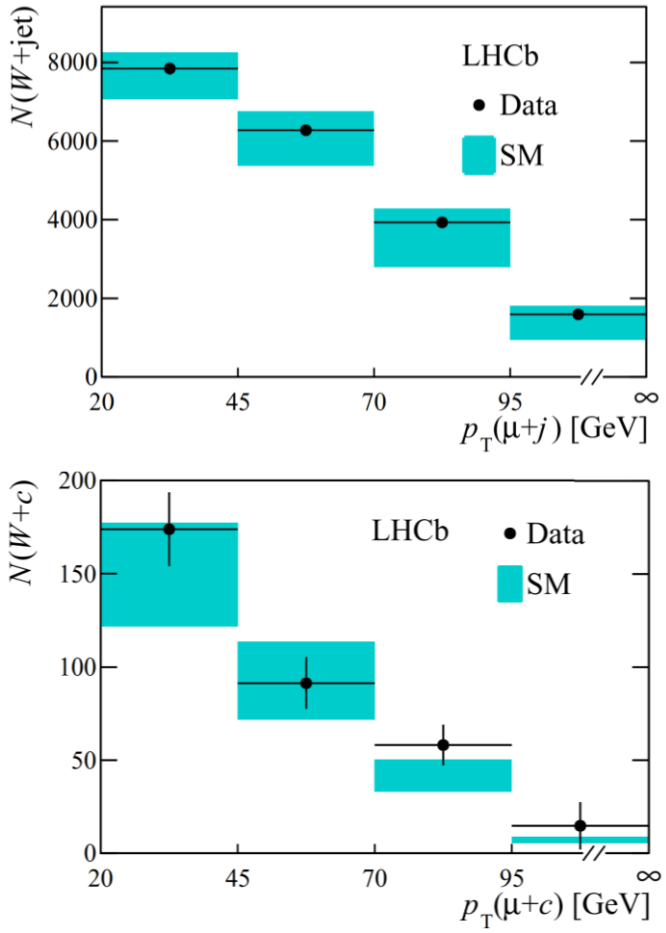
[PhysRevLett.115.112001]

source	uncertainty
GEC	2%
$p_{\mathrm{T}}(\mu)/p_{\mathrm{T}}(j_\mu)$ 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%

7,8 TeV $(\mu + b)$

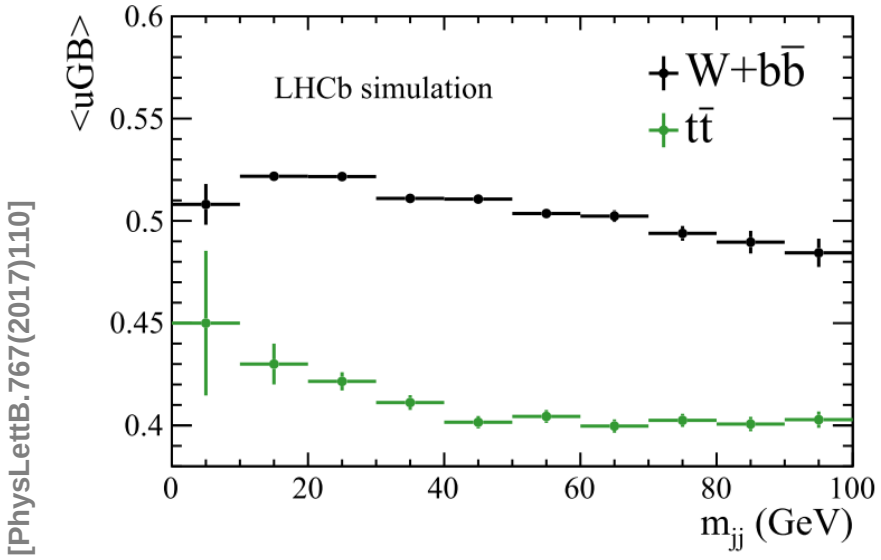
- ***Verification***
  - Top contribution insignificant to *W+c*
  - Di-boson also no meaningful contribution
    - Able to verify HF discrimination and analysis procedure

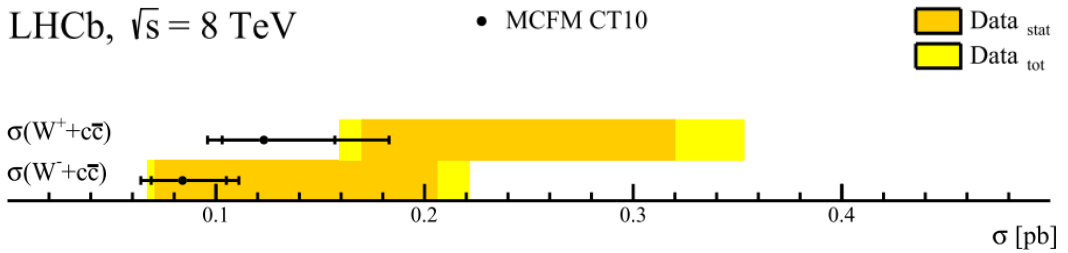
[PhysRevLett.115.112001]



8 TeV $(l + b\bar{b})$

- ***Uniform boosting techniques***
  - Minimised correlation to di-jet invariant mass
- ***W+cc cross section***
  - Provides limits for Higgs production





13 TeV $(\mu e + b)$

- ***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