Recent results and prospects for LHCb in SM physics involving W/Z/top

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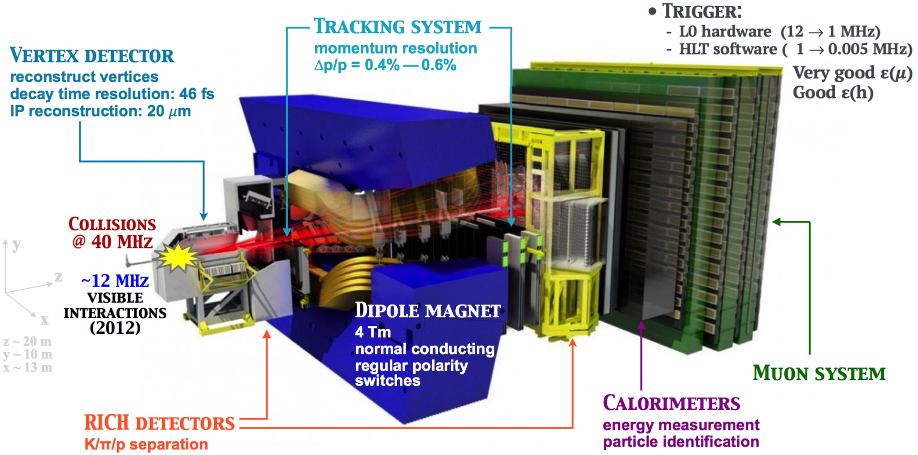
Rencontres de Blois, France Blois, 2019

Outline

LHCb experiment

Int. J. Mod. Phys. A 30 (2015) 1530022



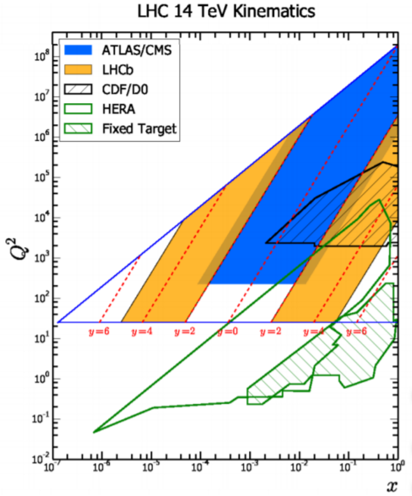
LHCb is a general purpose forward spectrometer ($2 < \eta < 5$) optimized to measure CP violation, rare decays involving B and D mesons, and searches for beyond Standard Model physics

LHCb experiment

- It offers a unique coverage complementary to ATLAS and CMS
- Probe Parton Density Function (PDFs) in a previously unexplored region of low x and high Q^2
- Luminosity collected:

Run I	3.2 fb^{-1}	7, 8 TeV	2010-2012
Run II	5.9 fb^{-1}	13 TeV	2015-2018

- Low number of pp interactions per bunch crossing 1.1-1.7
- Precise luminosity measurement (1-2%)



Recent results for LHCb in SM physics involving W/Z/top

Top Measurements

Top measurements

Phys. Lett. B 767 (2017) 110-120

Previous measurements in the forward region:

- First observation of the top in the forward region through the channel $t \to \mu + b$ (Phys. Rev. Lett. 115 (2015))
- Simultaneous measurement of $\mathrm{W} + b\bar{b}$, $\mathrm{W} + c\bar{c}$, and $t\bar{t}$ through the channel $t\bar{t} \to \ell b\bar{b}$ (Phys. Lett. B 767 (2017) 110-120)

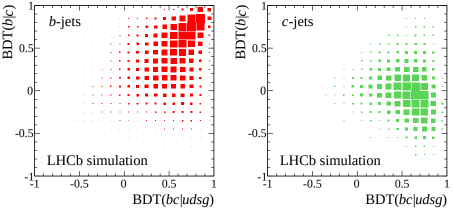
Channel $t\bar{t} \to e\mu b$

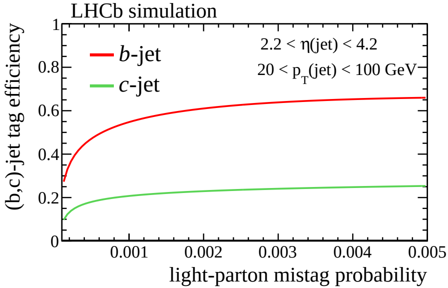
- Only possible due to an increase in production of a factor $\sim$10 with respect to Run I (8 TeV $\to$ 13 TeV)
- Second lepton with different flavour suppresses contribution from $\mathrm{W} + b\bar{b}$, $\mathrm{Z} + b\bar{b}$ and QCD background
- Analysis performed with the data collected in 2015 and 2016 ($\sim 2\mathrm{fb}^{-1}$)
- Fiducial region:
  - $p_T(\ell) > 20 GeV$ and $2.0 < \eta(\ell) < 4.5$ (prompt)
  - $\Delta R(\ell, jet) > 0.5$ and $\Delta(\mu, e) > 0.1$

Jet reconstruction and tagging

JINST 10 (2015) P06013

- Inputs are defined using the particle flow algorithm based on tracks, metastable particles (like K_s^0 and Λ) and calorimeter objects
- Anti-kt clustering algorithm with R=0.5
- Jet tagging is based on the secondary vertex reconstruction inside the jet with Booster Decision Tree discrimination
- Efficiency of about 65% (25%) for identification of b-jets (c-jets) with misidentification for light jets of 0.3%

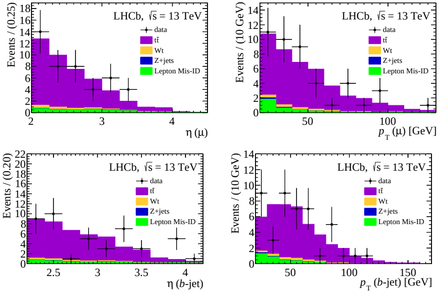


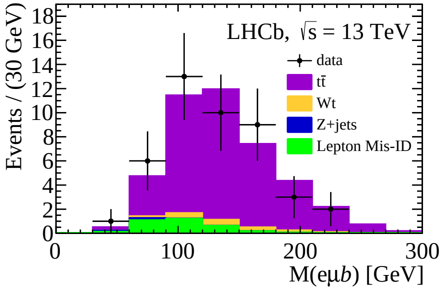


Channel $t\bar{t} \to e\mu b$

Phys. Lett. B 767 (2017) 110-120

Kinematic variables for the μ and b-jet





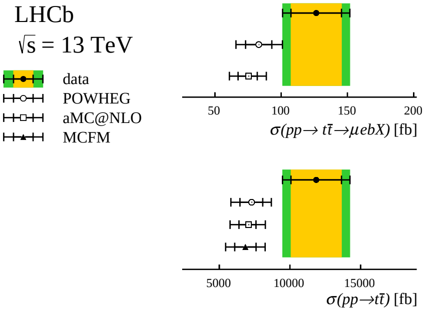
- QCD background shape taken from Data
- $\mathrm{Z} + jet$, $\mathrm{W} + t$ and $t\bar{t}$ shapes obtained from simulation
- $t\bar{t}$ normalized to the data after background subtraction

- Good agreement for the kinematic variables and $\mathrm{M}(e\mu b)$
- High purity ($\sim 87\%$)

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

Phys. Lett. B 767 (2017) 110-120

Systematic uncertainty	%
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/W measurements

Channel $Z \to \ell\ell$ ($\ell = e$ or μ)

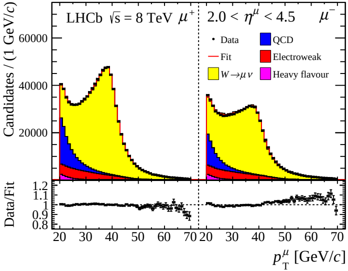
Selection:

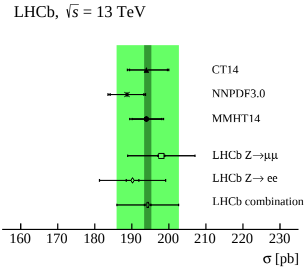
- $p_T(\ell) > 20$ GeV
- $2.0 < \eta(\ell) < 4.5$
- 60 GeV$< m_{\mu\mu} <$120 GeV (Z candidates only)
- Isolation requirement to reduce QCD base on a cone with $\Delta R < 0.5$ where $\Delta R = \sqrt{\eta^2 + \phi^2}$ (W candidates only)

High Z boson purity:

- Dimuon - $99.2 \pm 0.2)$%
- Dielectron - $92.2 \pm 0.5)$%

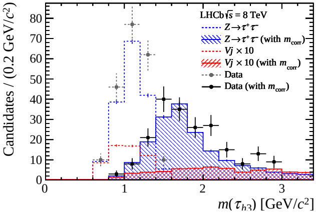
Good agreement with the model predictions and simulations

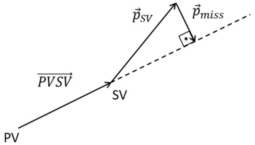




Channel $Z \to \tau\tau$

- $\tau\tau$ reconstructed via $\ell\ell$, ℓh or ℓhhh
- 58% of all $Z \to \tau\tau$ modes
- first time high-p_T tau reconstructed via 3-prong decay mode
- Back-to-back in ϕ ($|\Delta\phi(\tau,\tau)| > 2.7$)
- τ isolation requirement reduces contribution from QCD
- leptonic mode
  - At least one high p_T lepton ($p_T(\ell) > 20$ GeV)
  - unbalanced p_T between the two leptons due to the neutrinos
- hadrons
  - vertex information of h_3 allow a better mass estimation (m_{corr})
  - h_1 impact parameter minimum requirement reduces the prompt contributions

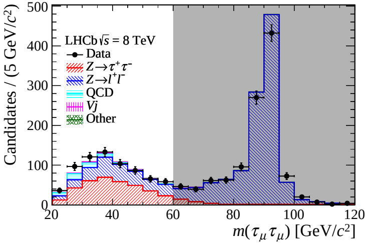


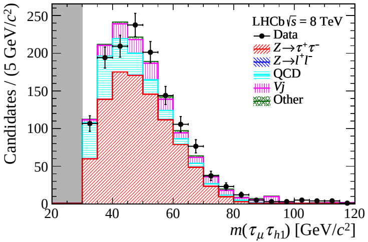


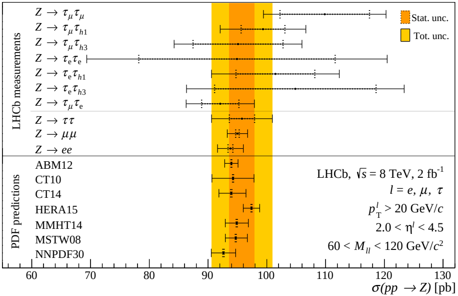
$$m_{corr} = \sqrt{M_{SV}^2 + \vec{p}_{miss} \cdot \vec{p}_{miss}} + |\vec{p}_{miss}|$$

Channel $Z \to \tau\tau$

JHEP 09 (2018) 159





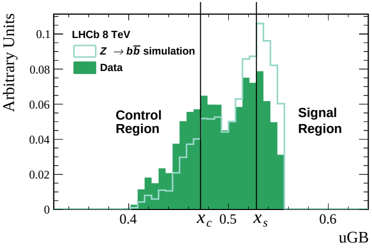


- Measurement in agreement with NNLO predictions and the lepton universality
- Dominated by the systematic uncertainty (Selection and reconstruction efficiencies, and background estimation)

Channel $Z \to b\bar{b}$

Phys. Lett. B 776 (2018) 430-439

- First measurement of the $Z \to b\bar{b}$ in the forward region with $2fb^{-1}$
- Challenging reconstruction due to the large QCD background
- Balance jet ($jet_{balance}$) required to reduce the contribution from QCD multi-jet
- Selection:
  - $2.2 < \eta(b-jet) < 4.2$
  - $p_T(b-jet) > 20$ GeV
  - 45 GeV$< m_{jj} <$ 165 GeV
  - $|\Delta\phi(b-jet_1, b-jet_2)| > 2.5$
  - $p_T(jet_{balance}) > 10$ GeV
  - $p_T(\vec{Z}_{b\bar{b}} + \vec{jet}_{balance}) > 20$ GeV

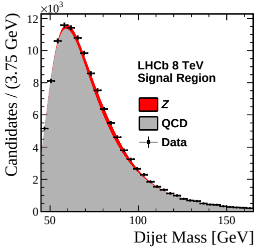


- uGB-BDT minimizes the correlation with m_{jj}
- inputs are based on the kinematic variables of the 3-jet system

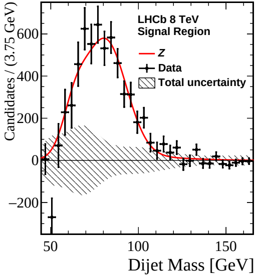
Channel $Z \to b\bar{b}$

Phys. Lett. B 776 (2018) 430-439

- Simultaneous fit of m_{jj} in the signal region and control region determines the $Z_{b\bar{b}}$ yield and jet energy scale factor
- Pearson IV distribution describes the QCD background



- Observation of the $Z \to b\bar{b}$ production with 6σ
- Systematic uncertainty dominated by the jet tagging ($\sim 17\%$)
- Cross-section is compatible with the prediciotn at NLO with aMC@NLO + Pythia
- jet energy scale is compatible with unity shows that the LHCb simulation describes well the b-jet energy



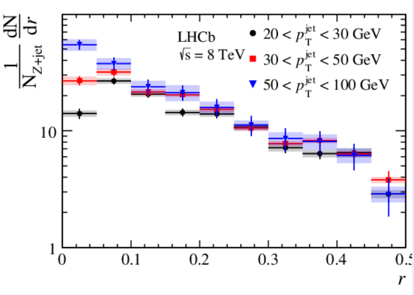
Charged Hadron production in Z-tagged jets

arXiv:1904.08878

Submitted to PRL

- First measurement of the jet hadronization in the forward region and in association with the Z boson
- The light-quark jets enhanced selection can provide information about the difference gluon and quark hadronization dynamics
- Selection:
  - Same Z boson used for Run II (see previous slides)
  - $p_T(jet) > 20$ GeV
  - $2.5 < \eta(jet) < 4.0$
  - $p_T(hadron) > 0.25$, $p(hadron) > 4$ GeV
  - $\Delta R(hadron, jet) < 0.5$
  - $|\Delta\phi(\mathrm{Z}, jet)| > 7\pi/8$

radial distance



$$r \equiv \sqrt{(\phi_{had} - \phi_{jet})^2 + (y_{had} - y_{jet})^2}$$

Charged Hadron production in Z-tagged jets

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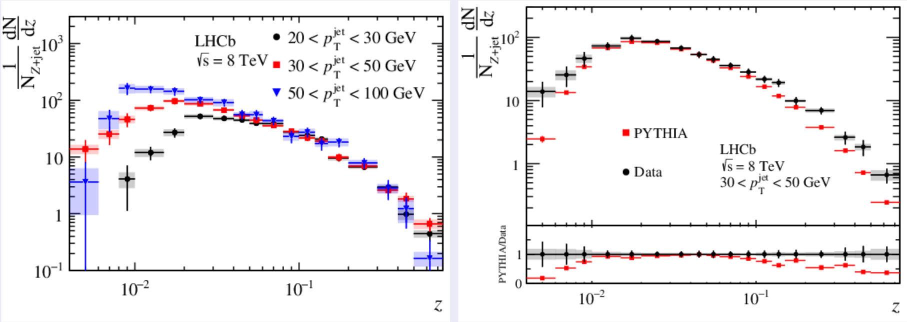
longitudinal momentum fraction ($z \equiv \vec{p}_{jet} \cdot \vec{p}_{hadron} / |\vec{p}_{jet}|^2$)

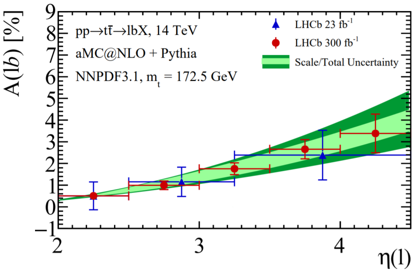


- Beginning of a broader hadronization research program at LHCb
- Based on particle identification (tracking, RICH, calorimetry), resonance production within jets (J/ψ, Φ, Υ), jet tagging and correlation with flavour identification

Prospects

Top Asymmetry

- Single particle asymmetry:
  $A^{lb} = \frac{N^{l^+b} - N^{l^-b}}{N^{l^+b} + N^{l^-b}}$
- Measurements during Run I and II with a precision of 20-40% limited by the available data samples
- Sub percent statistical precision cross-section and asymmetry in the ℓb and μeb final states in Run IV

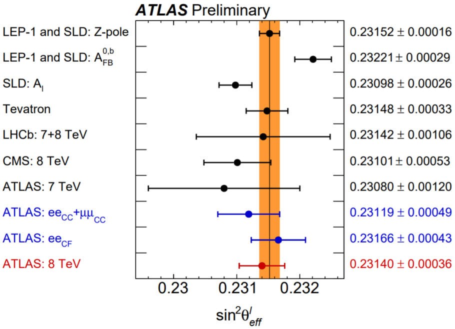


- High purity channel μeb will allow the most precise cross-section measurement in LHCb (total uncertainty of order of few percent) due to its unambiguous identification of $t\bar{t}$ events
- Inclusive cross-section at the percent level will allow a reduction of order of 20% on the gluon PDF uncertainty at large-x (JHEP 02 (2014) 126)

Effective weak mixing angle

LHCB-PUB-2018-009, JHEP 1511(2015) 190, ATL-CONF-2018-037

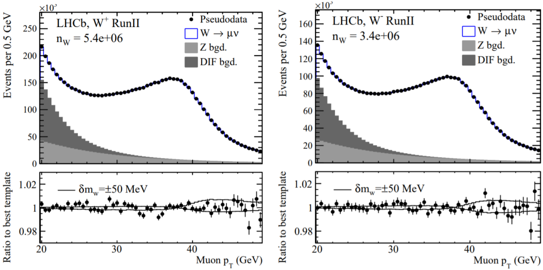
- Current measurement uncertainty is $\sim$ 6 times larger than the measurements from SLD and LEP
- The total uncertainty (100×10^{-5}) can be reduced by a factor ~ 8 (~ 20) by the end of Run IV (Run V)
- The full high lumi dataset will allow to probe the difference in the measurements from SLD and LEP



W boson mass

LHCB-PUB-2018-009, Eur. Phys. J. C75 (2015) 601

- LHCb can reduce the m_{W}^{LHC} uncertainty by 20-40% of the total uncertainty with the Run II data
- Softer W production implies a more direct relation between W mass and the lepton p_T spectrum



- ATLAS and CMS W mass measurements are limited by the theoretical uncertainties
- Upgrade II will allow a statistical precision of few MeV and a similarly precise measurement through $\mathrm{W}(e\nu)$

Conclusion

LHCb is a general purpose detector in the forward region

- Vast program of Top and W/Z measurements
- The top production measured on three final states which μeb final state provides clearest signature
- Several Vector boson decays already measured including $\mathrm{Z} \to \tau\tau$ and $\mathrm{Z} \to b\bar{b}$
- Beginning of a hadronization program at LHCb with the measurement of charged hadron production in Z-tagged jets
- More measurements to come with the full Run II data

Prospects

- Exciting prospects for the EW and Top physics
- LHCb will play an important role in the W mass and the effective weak mixing angle measurements at LHC

Thank you for your attention!