Search for long-lived particles, forward EWK and Top physics at LHCb

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CERN

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Outlook

Introduction

Displaced vertices searches

- Search for dark photons
- Search for massive long-lived particles decaying semileptonically
- Search for massive long-lived particles decaying to jet pairs

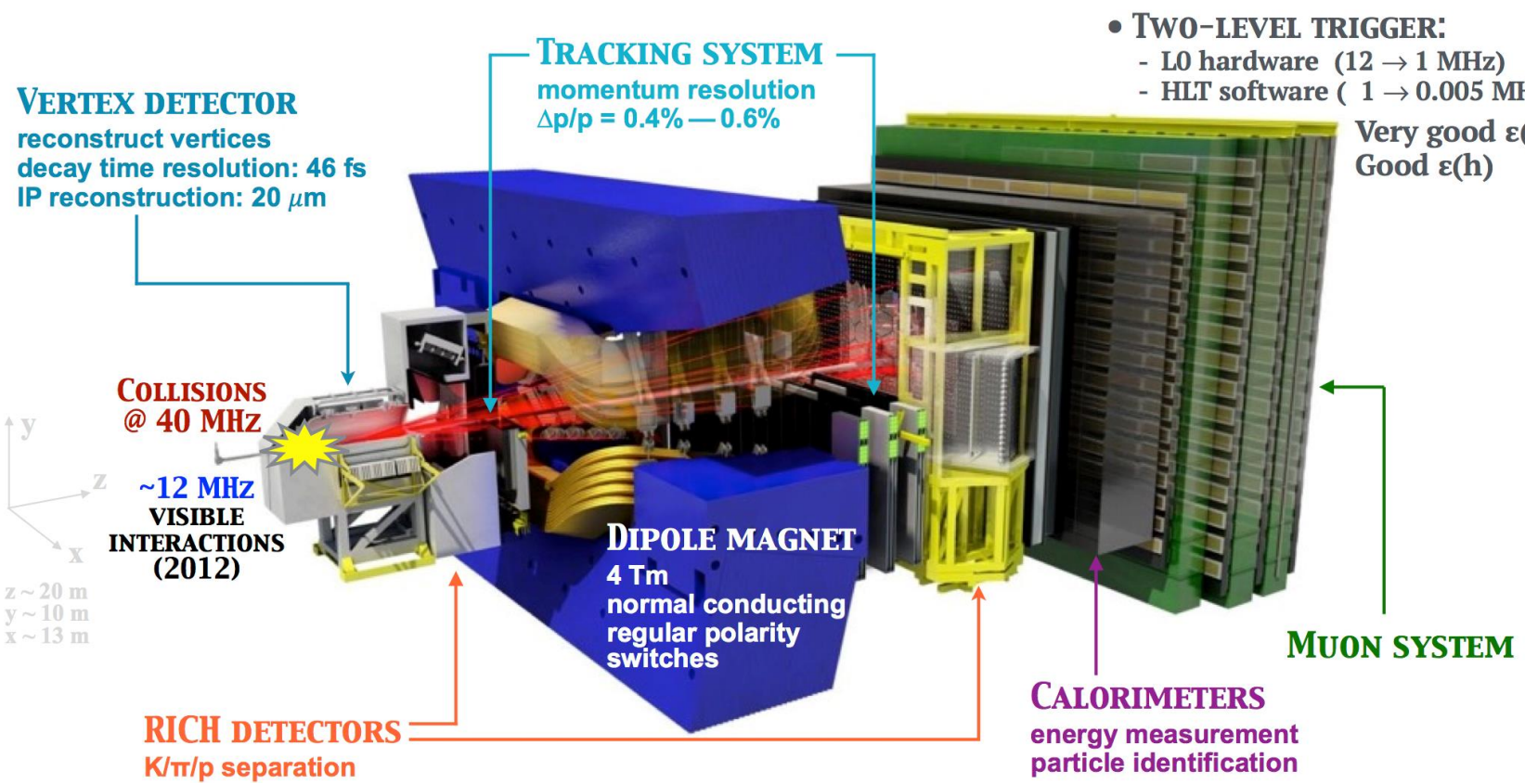
Forward electroweak and top physics

- First observation of Z($b\bar{b}$) in the forward region
- Measurement of $t\bar{t}$, $W + c\bar{c}$ and $W + b\bar{b}$ production cross-sections
- Measurement of the forward top pair production in the dilepton channel

Conclusion

LHCb experiment

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



Forward spectrometer $(2 < \eta < 5)$

- Designed to measure CP violation, rare decays involving B and D mesons and search for beyond Standard Model physics
- LHCb offers an unique coverage (Complementary to CMS and ATLAS)
- Low pile-up
- Excellent vertex reconstruction
  - for a primary vertex (PV) with 25 tracks:
    - $\sigma_{PV_z} = 71\ \mu\text{m}$
    - $\sigma_{PV_T} = 13\ \mu\text{m}$

Displaced vertices searches

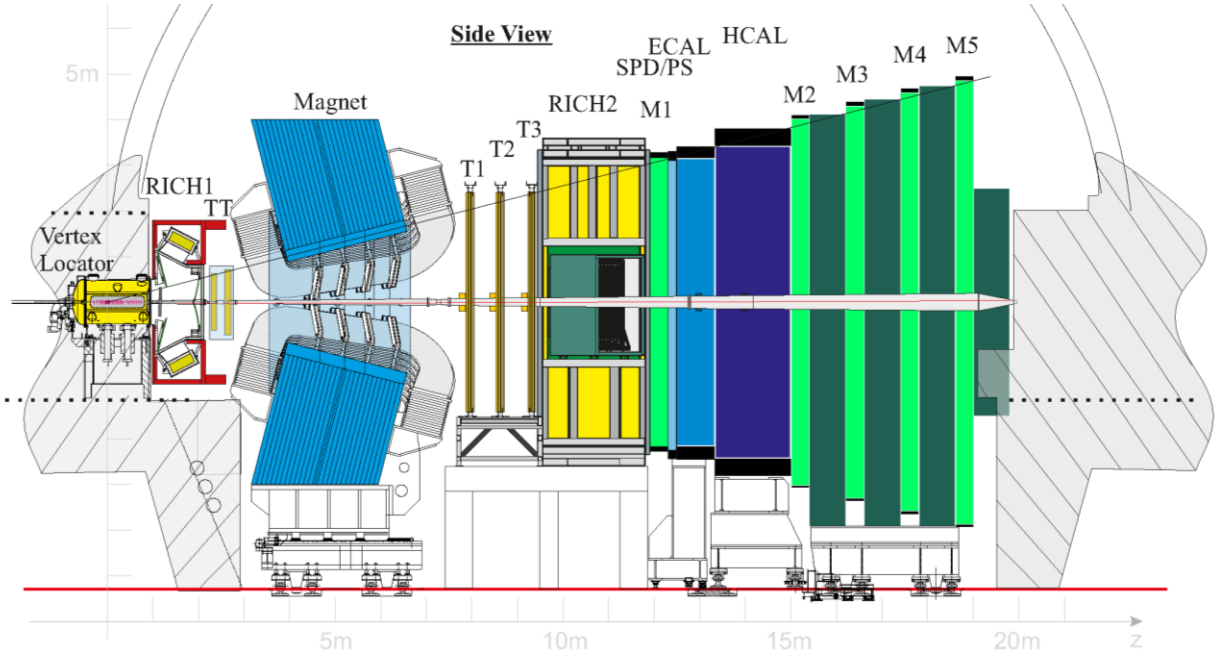
Displaced vertices reconstruction

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

- Displaced vertex is reconstructed using tracks
  - mass resolution might be improved using jets to associate the neutral energy to the vertex

- Inside the vertex locator (up to 50 cm):
  - Excellent vertex and track resolution
  - Background dominated by the material interactions 5 mm away from the beam (detailed geometry)

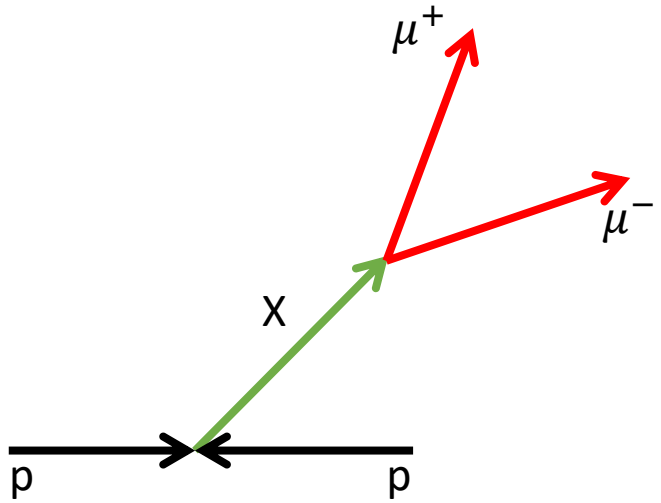
- Before the TT station (up to 2 m):
  - Track resolution is two times worse than VELO tracks (under study)



- More than 20 m (whole experiment):
  - Charged LLP signature (Eur. Phys. J. C (2015) 75: 595)
  - Proposal of a new subdetector Codex-b 25-35 m away (*Phys. Rev. D* 97 (2018) 015023)

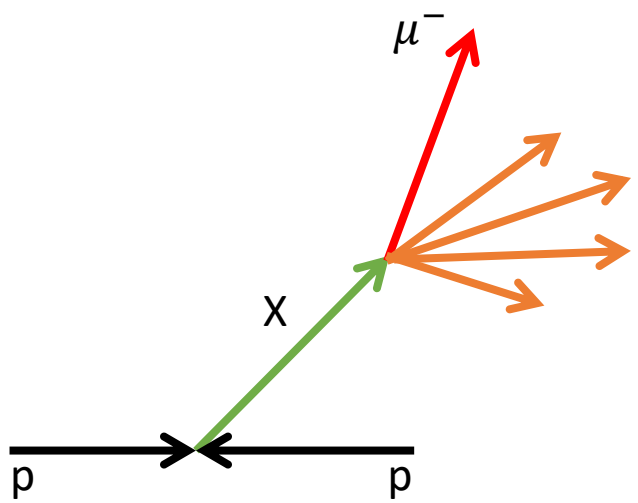
Displaced vertices reconstruction

Three examples will be covered in this talk:



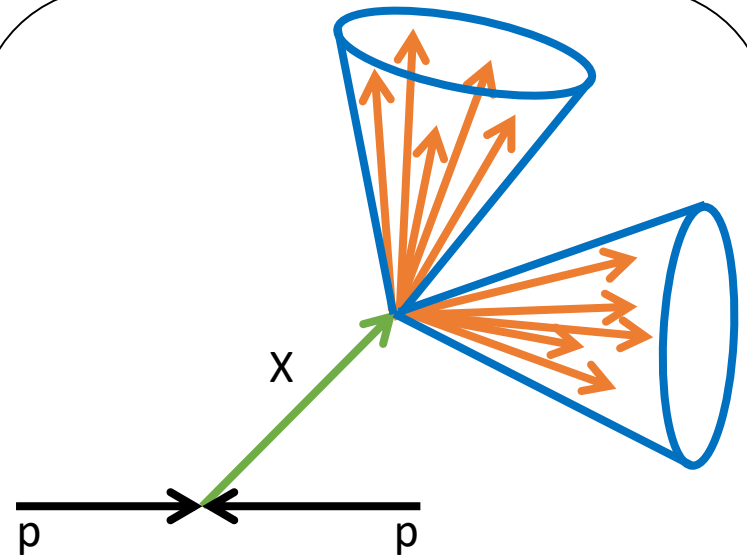
Dimuon displaced vertex

Search for dark photons produced in 13 TeV pp collisions
(*Phys. Rev. Lett.* 120 (2018) 061801)



Displaced vertex with a high p_T muon

Search for massive long-lived particles decaying semileptonically in the LHCb detector
(*Eur. Phys. J. C* 77 (2017) 224)



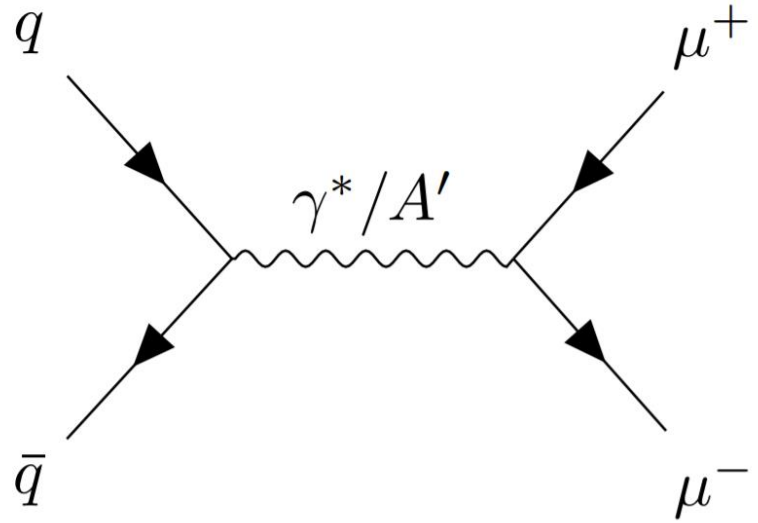
Displaced vertex with two jets

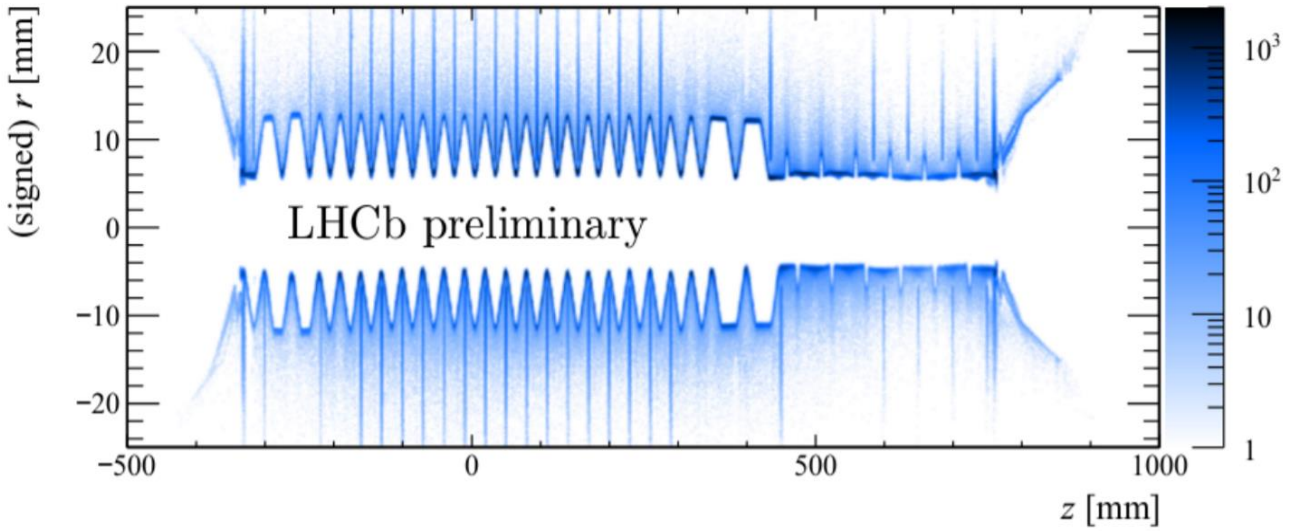
Search for massive long-lived particles decaying to jet pairs
(*Eur. Phys. J. C* 77 , 12 (2017) 812)

Dark photons search

Phys. Rev. Lett. 120 (2018) 061801

- Dark matter sector linked to Standard model particles via portals
- A massive dark photon (A') production is suppressed relative to the ordinary photon by a factor ϵ^2
- Search of prompt-like and long-lived dark photons using $A' \rightarrow \mu^+\mu^-$ (Similar to $\gamma^* \rightarrow \mu^+\mu^-$ decays)
- Selection:
  - Muons are required to be in the LHCb acceptance ($2 < \eta < 4.5$)
  - $p_T > 0.5\ (1.0)$ GeV, p > 10 (20) GeV for long-lived (prompt-like) search
  - A' is also required to have p_T above 1 GeV
  - Material interactions are vetoed

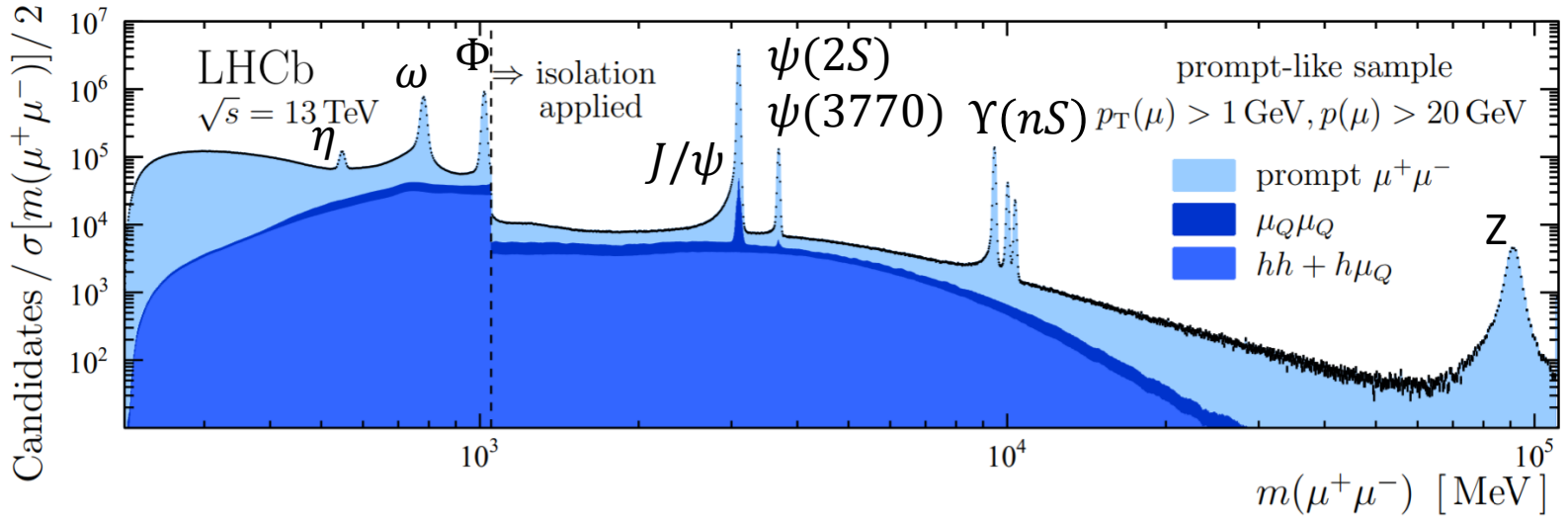


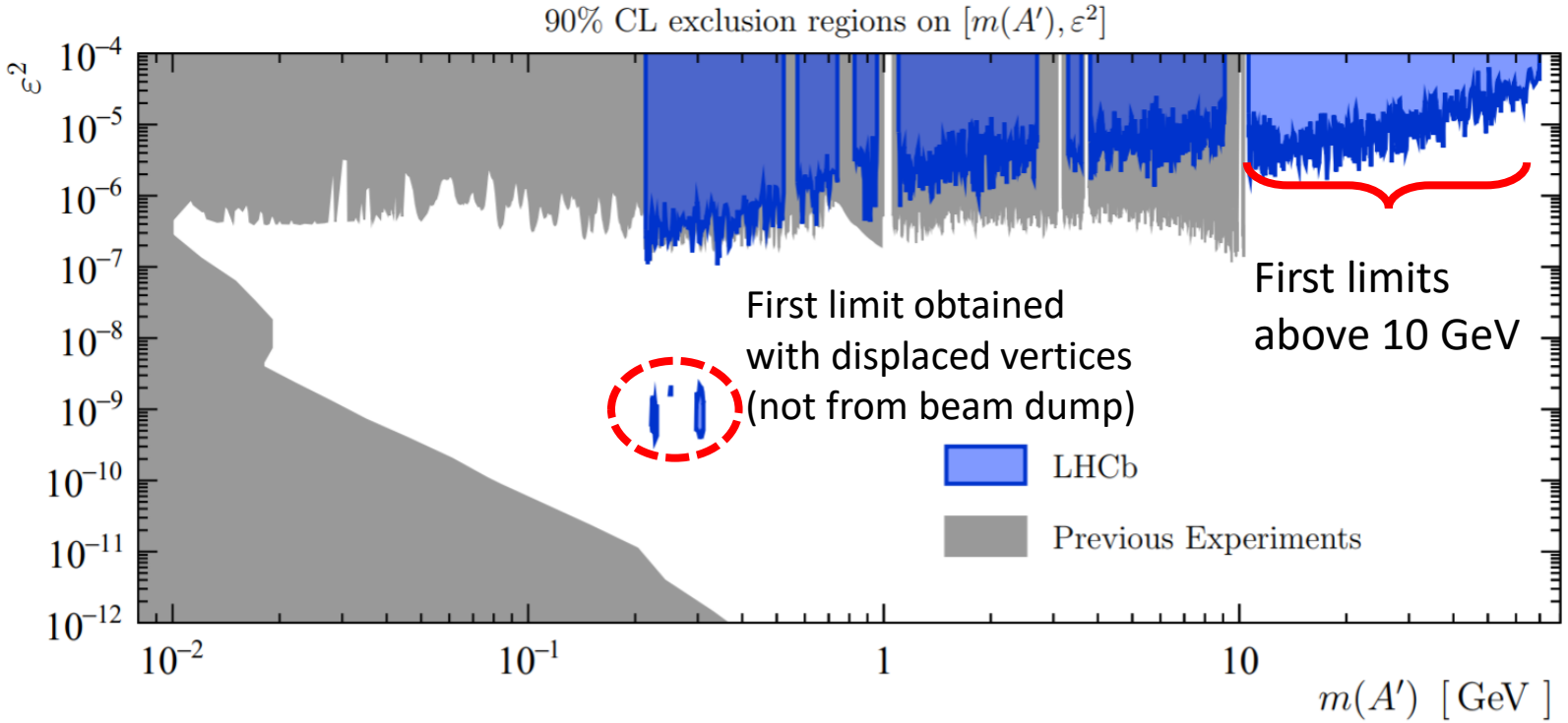


Dark photons search

Phys. Rev. Lett. 120 (2018) 061801

- Jet isolation requirement improves the sensitivity by up to factor 2 ($p_T(\mu)/p_T(jet) > 0.7$)
- Prompt-like search covers mass range up to 70 GeV
- Long-lived search is restricted to the low-mass region 214 GeV $< m(A') <$ 350 GeV
- Most stringent to date for the mass range 10.6 - 70.0 GeV
- First search to achieve enough sensitivity using displaced-vertex signature (not from beam dump)



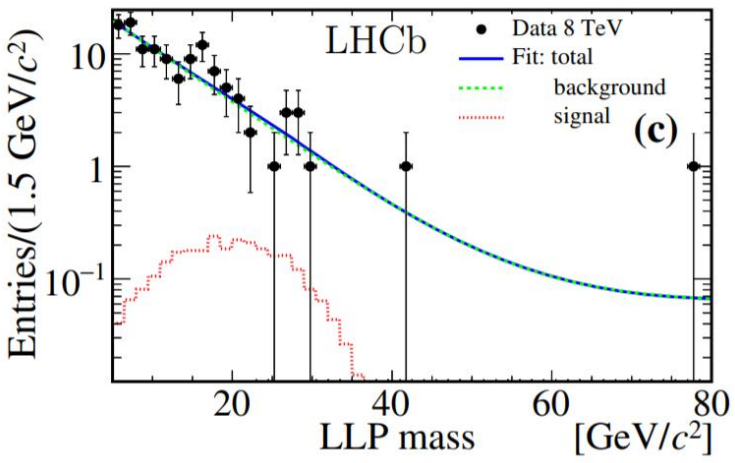


Search for massive long-lived particles decaying semileptonically

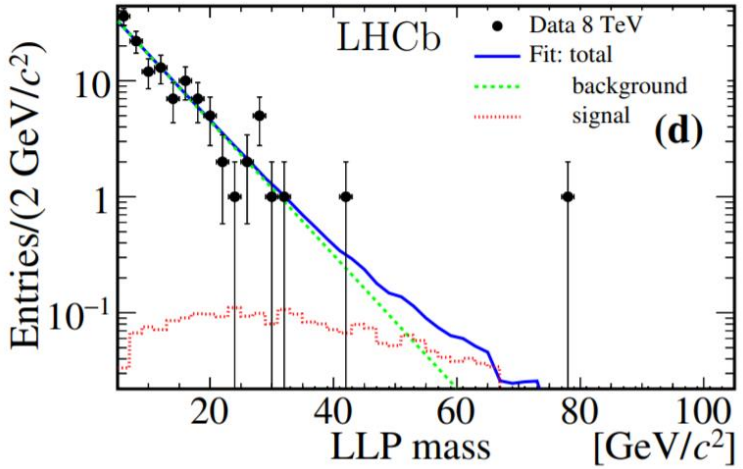
[Eur. Phys. J. C 77 (2017) 224]

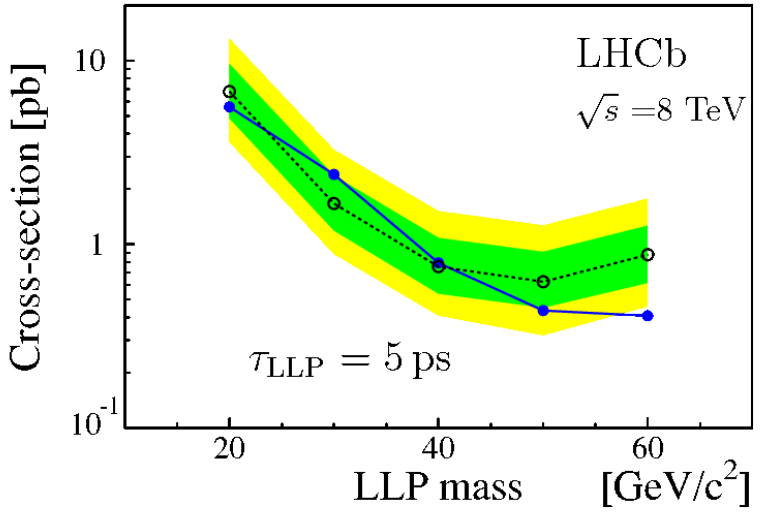
- Benchmark model: MSSM mSUGRA with R-parity violation
- The neutralino is a long-lived particle that decays via $X_1^0 \rightarrow lq'\bar{q}$
- High multiplicity displaced vertex reconstruction with one associated high p_T muon
- Lifetime between 5-100 ps (up to 30 cm flight distance in average) and masses between 20-80 GeV
- Data driven method to extract the background shape based on the muon isolation
- Limits at 95% CL were set on the cross section times branching fractions

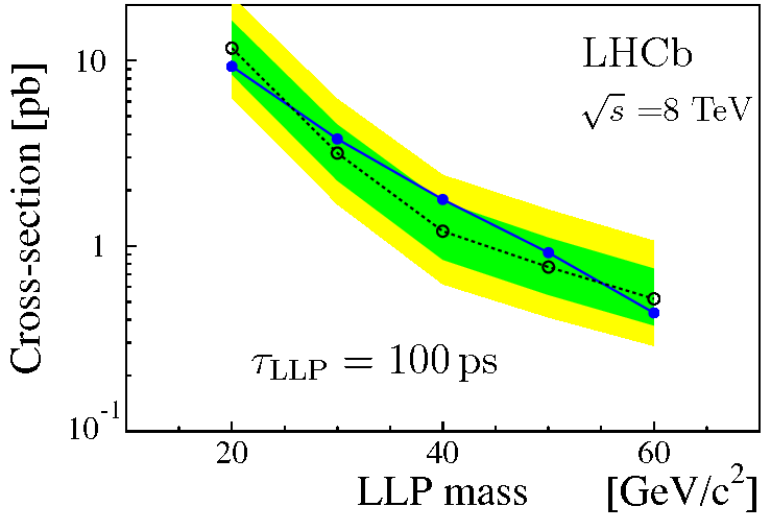
m_{LLP} = 38 GeV τ = 5 ps



m_{LLP} = 98 GeV τ = 10 ps



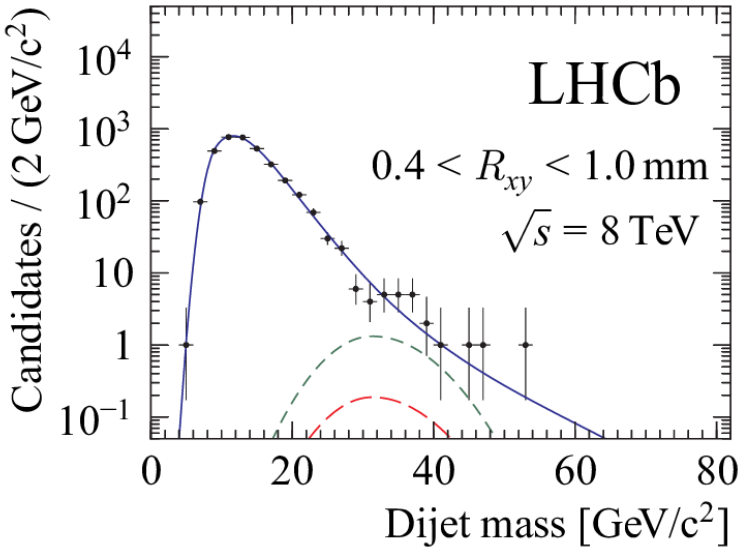


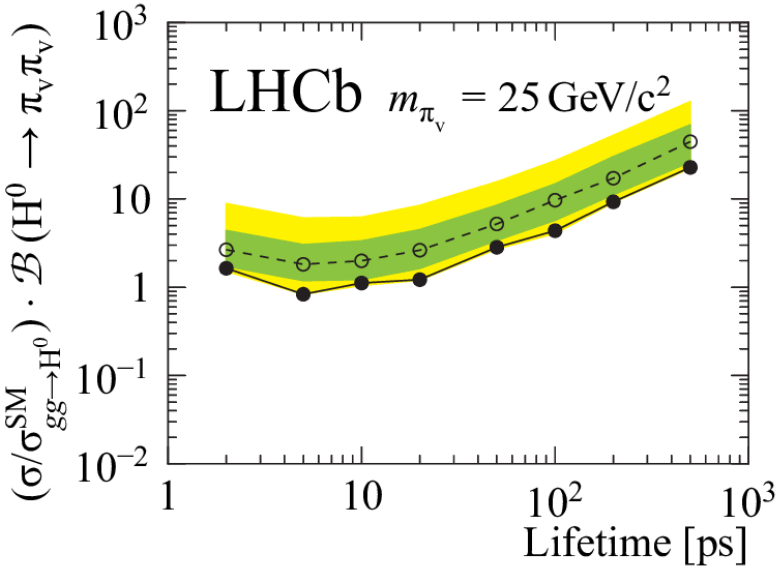


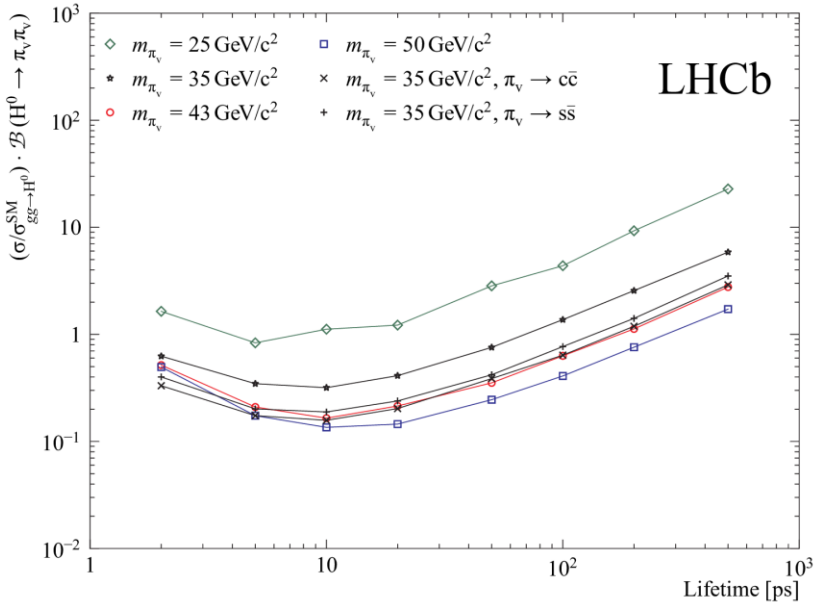
Search for massive long-lived particles decaying to jet pairs

[Eur. Phys. J. C 77 , 12 (2017) 812]

- Benchmark model: Hidden valley
- Search for SM-like $H^0 \to \pi_V \pi_V$ where $\pi_V \to q\bar{q}$ (q=b, c or s)
- High multiplicity displaced vertex with two jets
- Anti-kt jet reconstruction with R=0.7
- 0.62 fb^{-1}(1.38 fb^{-1}) at 7 TeV (8 TeV)
- Explored several masses (25 – 50 GeV/c2) and lifetimes (2 – 500 ps) of the π_V
- Plan to analyse the Run II data and go to lower π_V masses

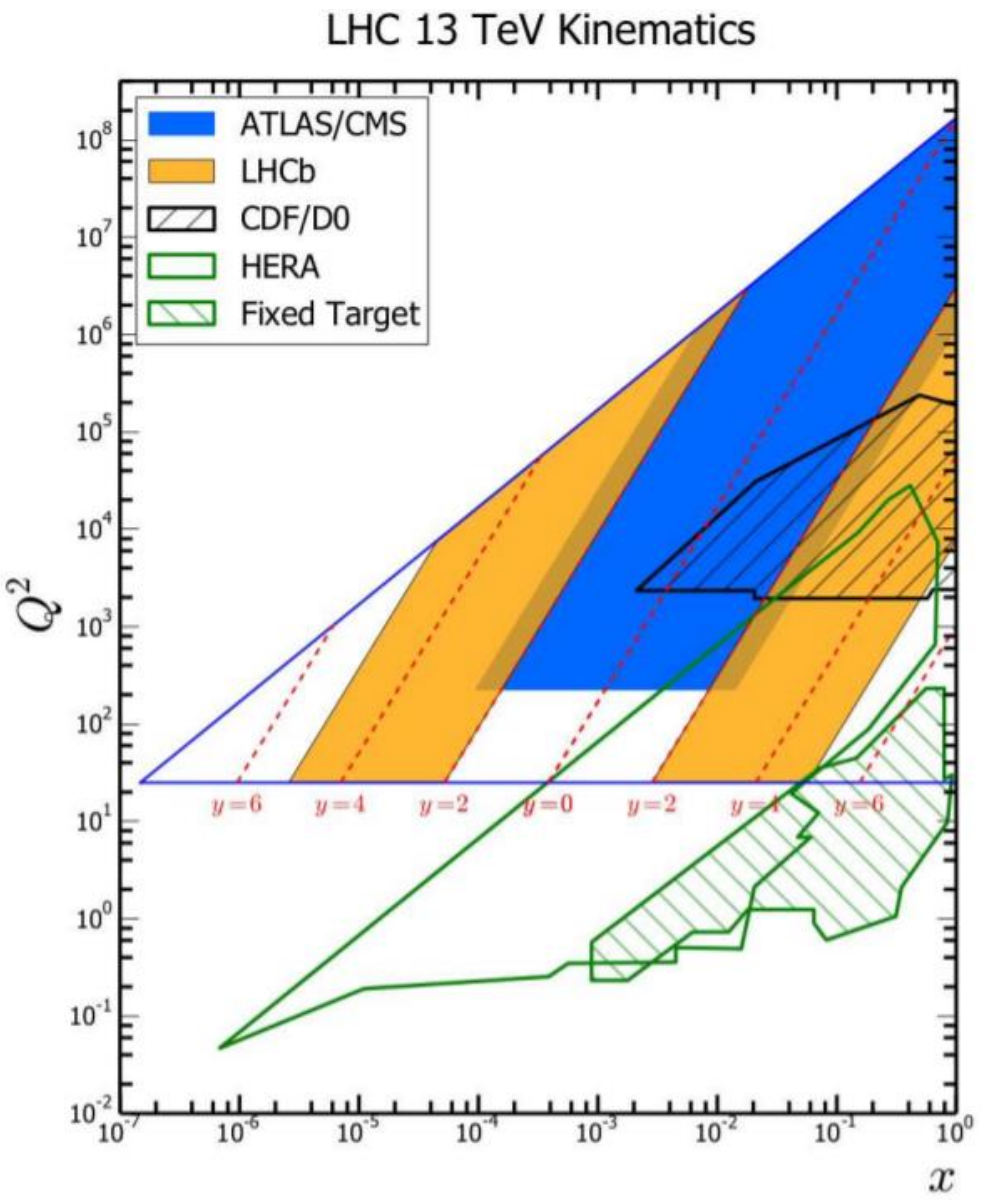






Forward electroweak and top physics

Electroweak and top measurements at LHCb

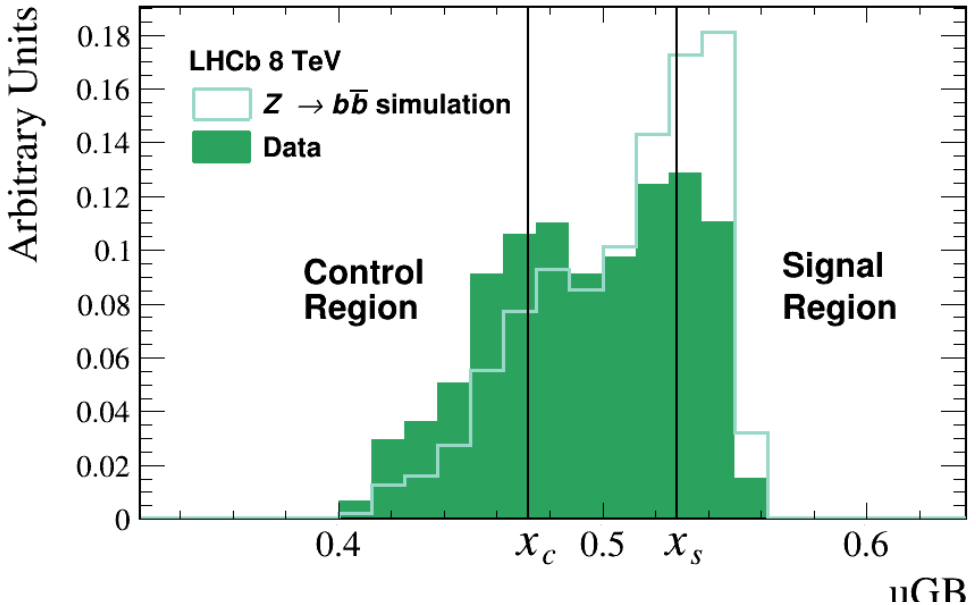


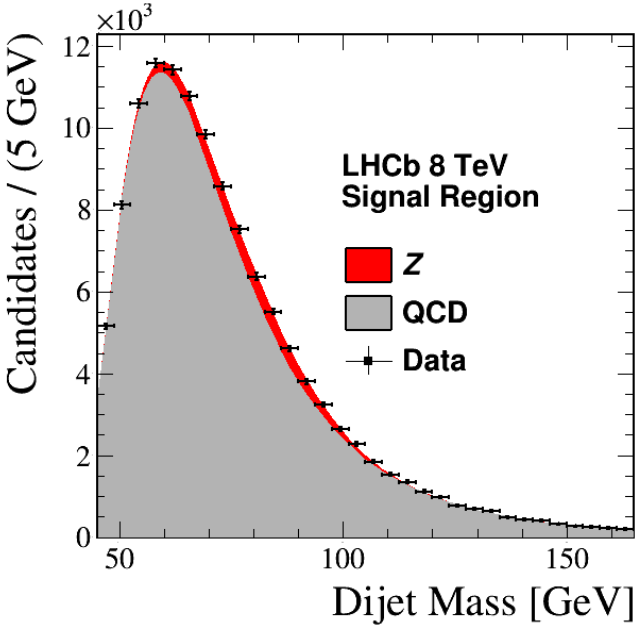
- LHCb offers an unique coverage complementary to CMS and ATLAS
- Probe Parton Density Function (PDFs) in an previously unexplored region of low x and high Q^2
- Important tests for pQCD
- Understanding of important backgrounds for Standard Model measurements and beyond Standard Model searches
- Many measurements already performed:
  - Z/W [*JHEP* 09 (2016) 136, *JHEP* 10 (2016) 030, *Eur. Phys. J. C* 75 (2015) 152, *JHEP* 12 (2014) 079, *JHEP* 11 (2015) 190, *JHEP* 08 (2015) 039, *JHEP* 01 (2014) 033, *JHEP* 02 (2013) 106, *JHEP* 01 (2013) 111, *JHEP* 06 (2012) 058]
  - Z/W+jet [*JHEP* 05 (2016) 131]
  - Z+b [*JHEP* 01 (2015) 064]
  - Z+D [JHEP(2014)091]
  - W+b/c [*Phys. Rev. D* 92 (2015) 052001]
  - **$Z(b\bar{b})$ [*Phys. Lett. B* 776 (2018) 430-439]**
  - **$t\bar{t}, W+b\bar{b}, W+c\bar{c}$ [*Phys. Lett. B* 767 (2017) 110-120]**
  - Single top [Phys.Rev.Lett. 115 (2015) no.11, 112001]
  - **$t\bar{t}$ in dilepton channel [in preparation LHCb-PAPER-2017-050]**

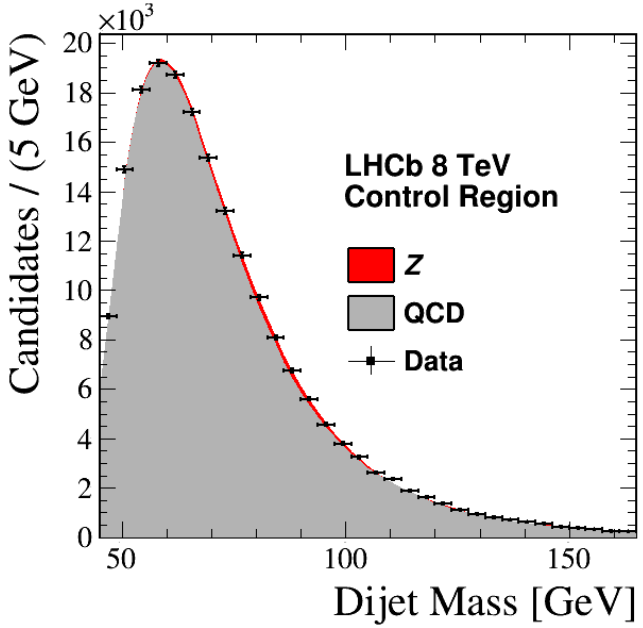
First observation of forward $Z \rightarrow b\bar{b}$ in pp collisions at $\sqrt{s}$ = 8 TeV

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

- First measurement of Z(b$\bar{\text{b}}$) in the forward region
- Fiducial selection: $\mathrm{p_T} > 20$ GeV, $2.2 < \eta < 4.2$ and $45\ \mathrm{GeV} < \mathrm{m\_jj} < 165\ \mathrm{GeV}$
- A third jet is required to reduce the contribution from QCD multijets
- uGB BDT (*J. Instrum.* 10 (2015) T03002) is used to separate signal from background based on $\Delta\eta(\mathrm{b}-\mathrm{jets})$, p_T of the third jet and $\Delta\phi(\mathrm{Z}, \mathrm{third\ jet})$
- Simultaneous fit in the signal region and control region



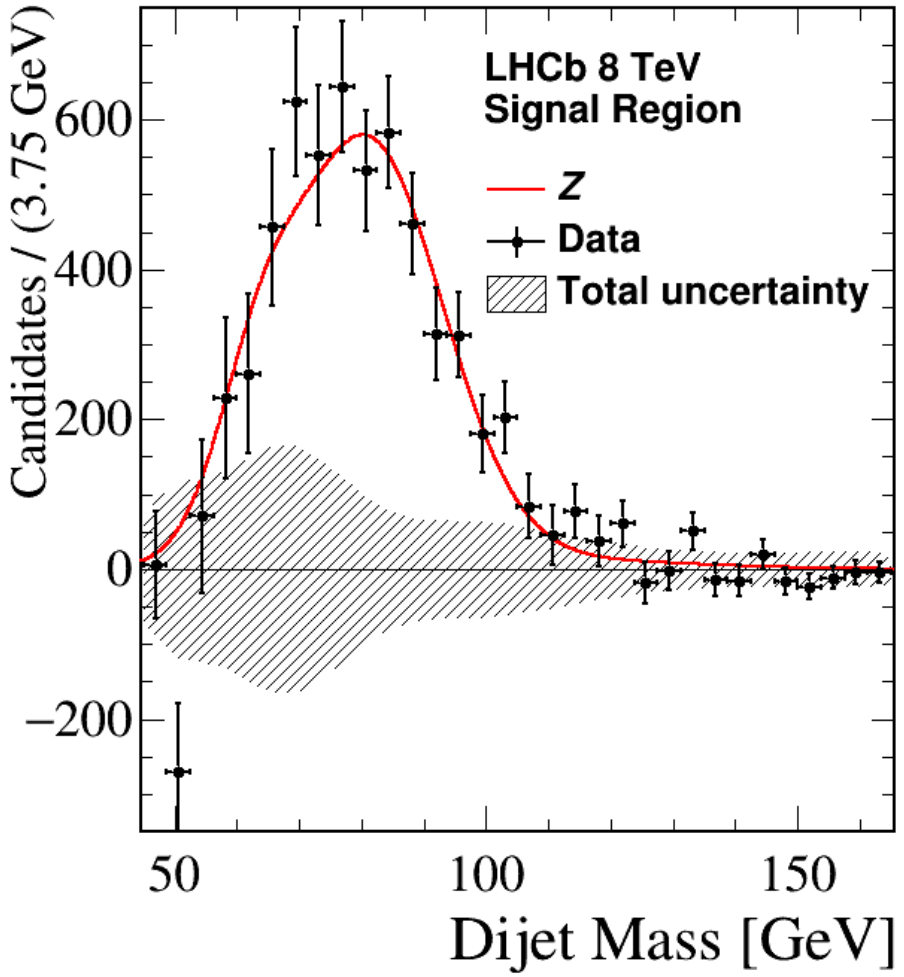




First observation of forward $Z \rightarrow b\bar{b}$ in pp collisions at $\sqrt{s}$ = 8 TeV

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

- The jet energy correction is also calculated during the fit
- The Z mass peak is at around 80 GeV
- The systematic uncertainty is dominated by the heavy flavour tagging efficiency (~17%)



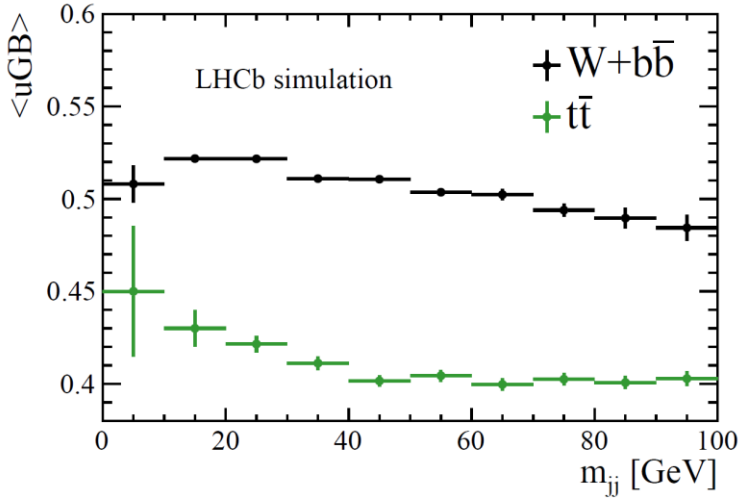
- The measurement is agreement with the aMC@NLO NNPDF3.0:
  - $\sigma_{measurement}(pp \rightarrow Z)\mathcal{B}(Z \rightarrow b\bar{b}) = 332 \pm 46 \pm 59$ pb
  - $\sigma_{aMC@NLO}(pp \rightarrow Z)\mathcal{B}(Z \rightarrow b\bar{b}) = 272^{+9}_{-12}(scale) \pm 5\ (PDF)$ pb

Measurement of forward $t\bar{t}$, $W + b\bar{b}$ and $W + c\bar{c}$ production cross-sections at $\sqrt{s}$ = 8 TeV

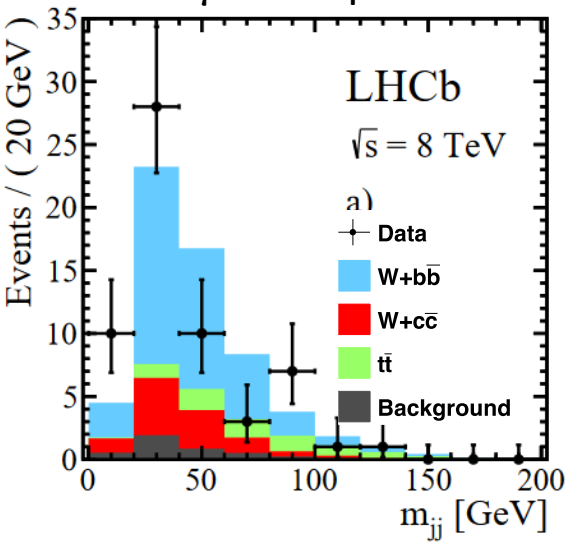
Phys. Lett. B 767 (2017) 110-120

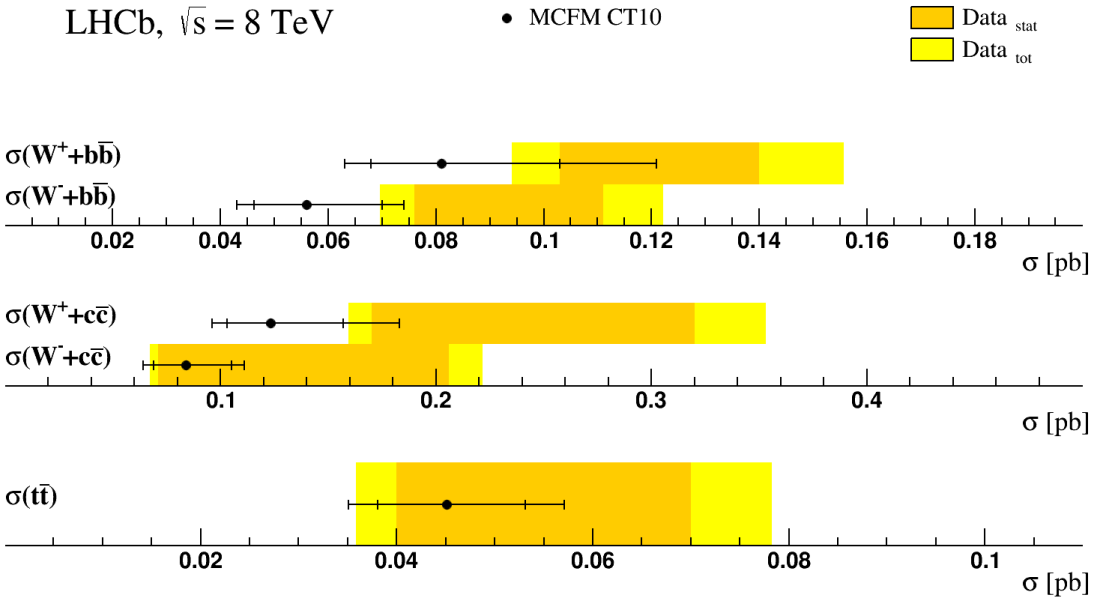
- Novel measurement of the $W + c\bar{c}$ production
- Selection:
  - $W(\mu\nu_\mu)$ or $W(e\nu_e)$
  - $p_T^l > 20$ GeV, $\mathbf{12.5\ GeV < p_T^j < 100\ GeV}$
  - $2.2 < \eta^j < 4.2$, $2.0 < \eta^\mu < 4.5$ ($\mathbf{2.0 < \eta^e < 4.25}$)
  - Isolated leptons and jets ($\Delta R > 0.5$)
- Backgrounds: Z+b/c, single top, QCD, ...
- 4D simultaneous fit for μ^+, μ^-, e^+ and e^- using:
  - $BDT_{b|c}$ for both jets
  - Dijet mass (m_{jj})
  - Uniform Gradient boosting BDT (uGB) to separate $t\bar{t}$ and $W + b\bar{b}$ (J. Instrum. 10 (2015) T03002)

Good agreement with MCFM NLO prediction with PDF CT10
Showering and hadronization using Pythia 8



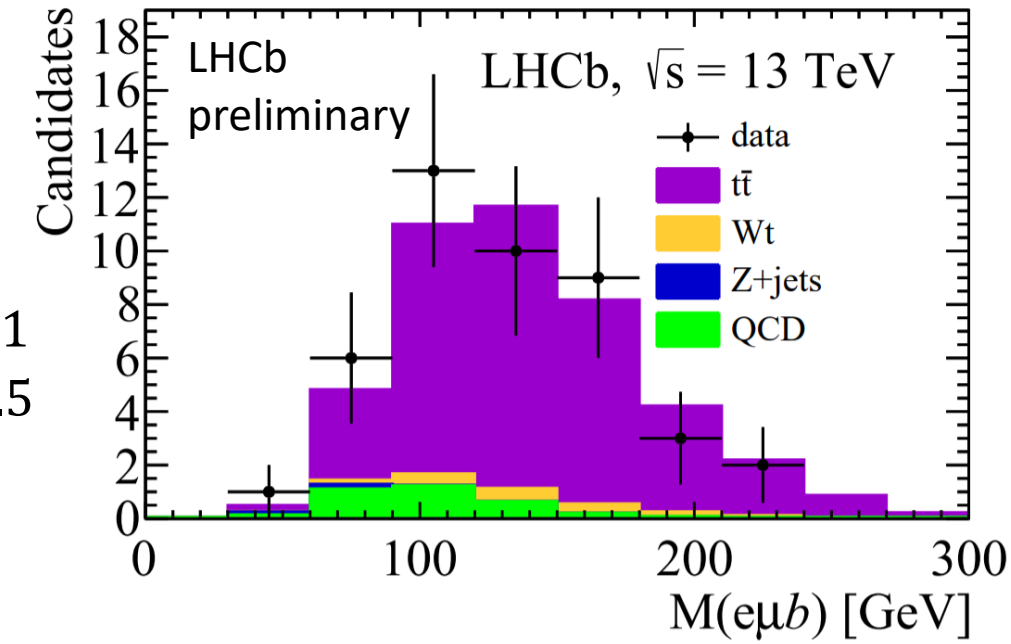
μ^+ sample



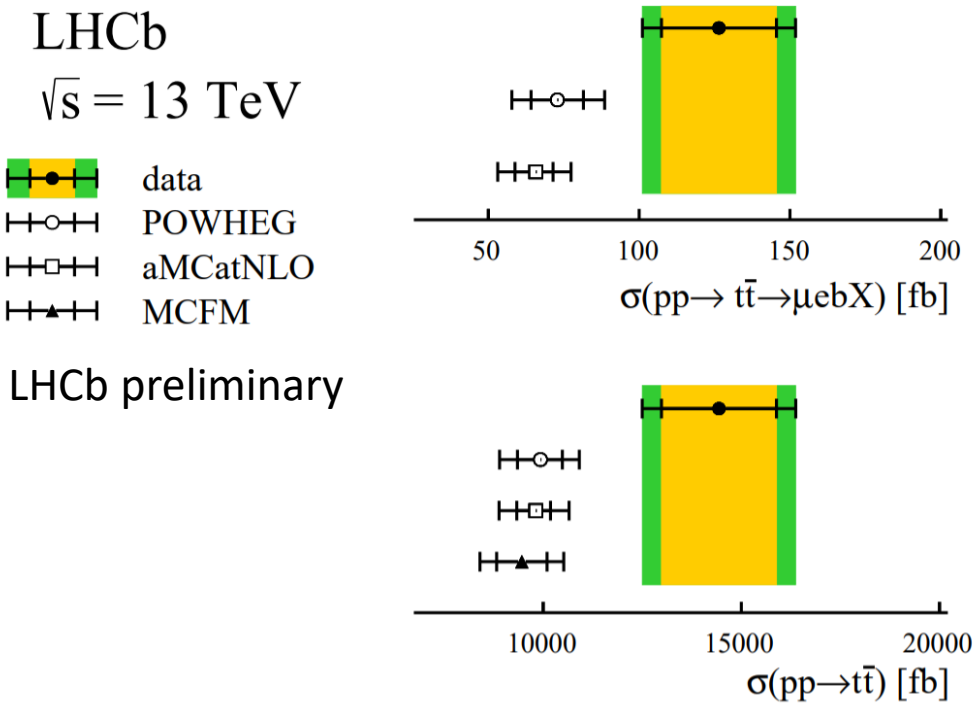


Measurement of forward top pair production in the dilepton channel in pp collisions at $\sqrt{s}$ = 13 TeV

paper in preparation (LHCb-PAPER-2017-050)



- Top quark measurement in the μeb final state
- Fiducial selection:
  - $p_T(l) > 20$ GeV , $2.0 < \eta(l) < 4.5$ and $\Delta R(l,l) > 0.1$
  - $p_T(b_{jet}) > 20$ GeV, $2.2 < \eta(b_{jet}) < 4.2$ and $\Delta R(l, b_{jet}) > 0.5$



LHCb preliminary

- High purity selection (~87%)
- Systematic uncertainty is dominated by the b-jet tagging
- The measurement is compatible with the predictions obtained using POWHEG, aMC@NLO and MCFM
- Potential to be the highest precision $t\bar{t}$ measurement at LHCb after the Upgrade

Conclusion

- The LHCb is a general purpose forward detector that provides an unique opportunity for analyses in the forward region complementary to CMS and ATLAS acceptance

- After the detector upgrade in 2020, the trigger will be fully implemented in the software level (more flexibility) and accumulate at least $50\ \mathrm{fb}^{-1}$ of data

- More talks about LHCb measurements at the Flavour physics section

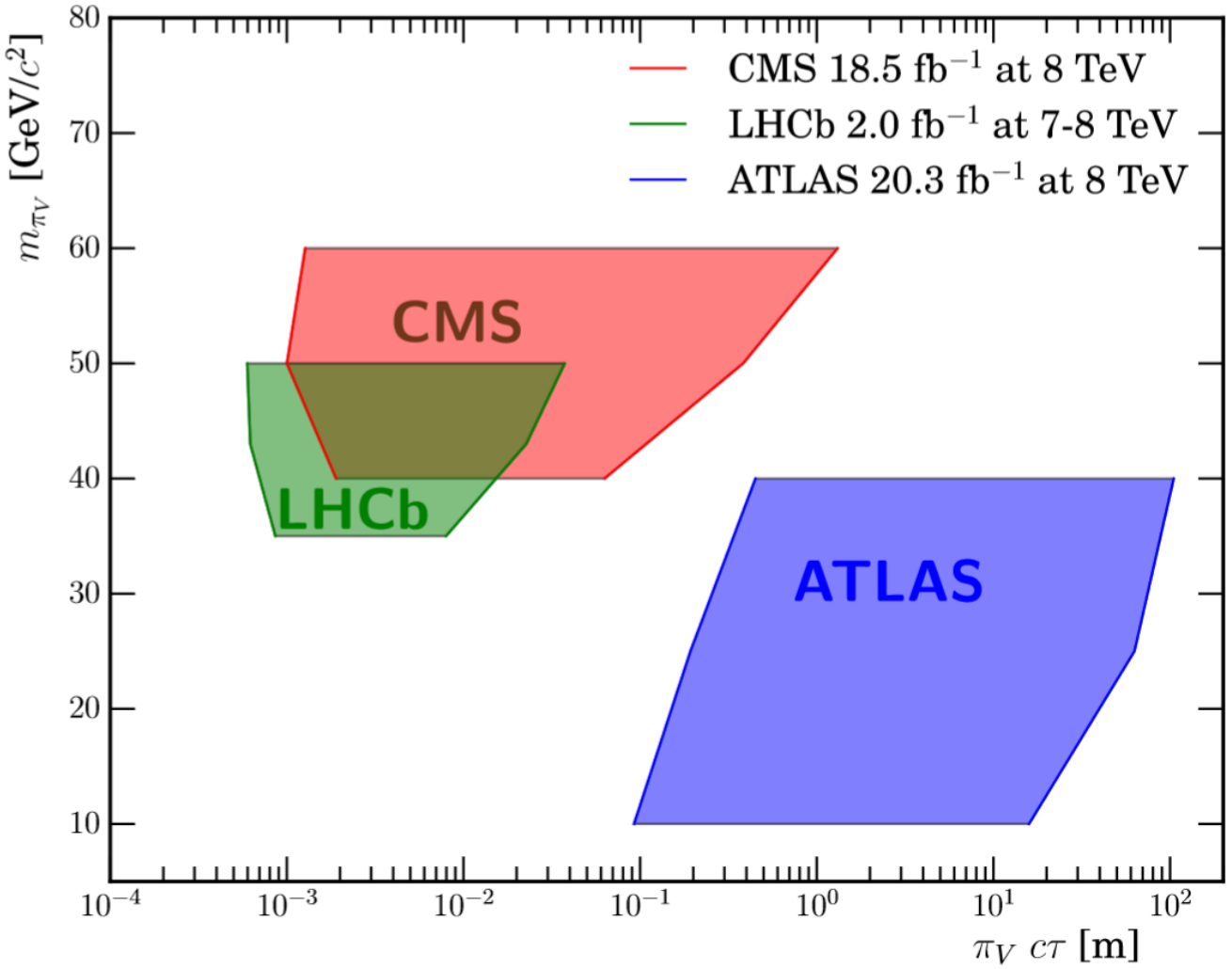
Thank you for your attention!

Backup slides

Search for massive long-lived particles decaying to jet pairs

Eur. Phys. J. C 77 , 12 (2017) 812

- Comparison of the exclusion regions using Run I data
- B($H^0 \rightarrow \pi_V \pi_V$) > 50% is excluded at 95% C.L. is shown
- CMS 18.5 fb−1 [PRD 91 (2015) 012007]
- ATLAS 20.3 fb−1 [PRD 92 (2015) 012010] [PLB 743 (2015) 15-34]
- new 13 TeV results from CMS not included in the recast [CMS-PAS-EXO-16-003]

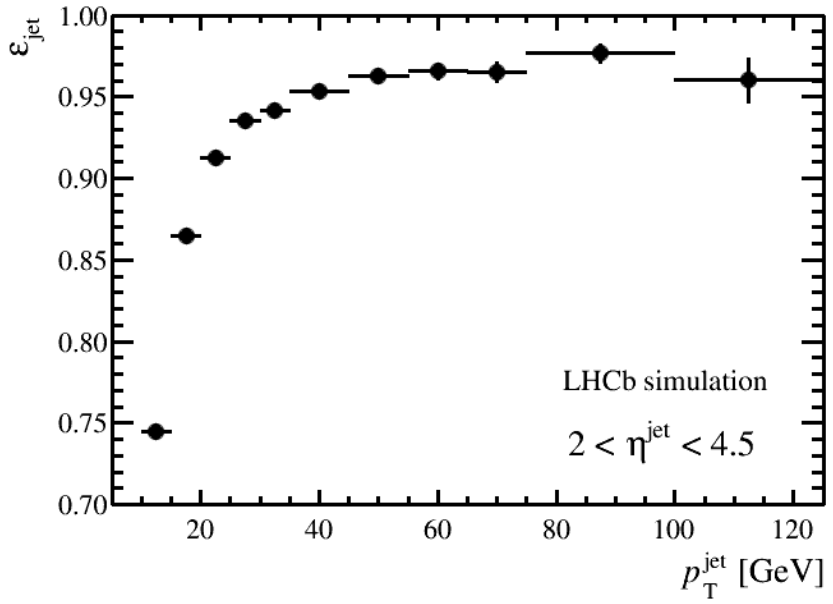


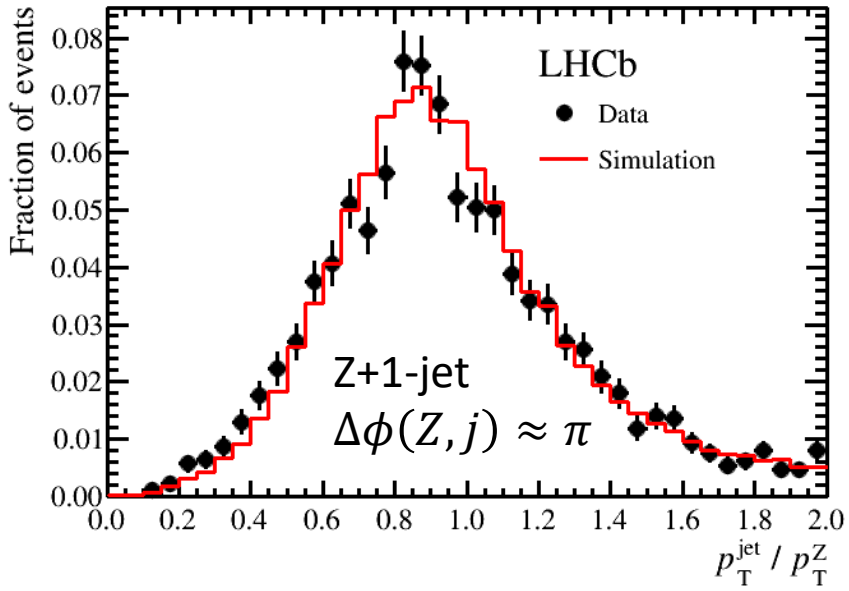
plot by M. Borsato

Jet reconstruction

- Particle flow algorithm
- Neutral recovery
  - Excess of energy in the calorimeter nearby a track is treated as an additional neutral particle
- Clustering algorithm: anti-kt with R=0.5
- Jet reconstruction efficiency is ~95% for high p_T jets after the quality criteria (jet identification)
- Jet energy resolution is $\sim 10 - 15\%$ for $10\ \mathrm{GeV} < p_T^j < 100\ \mathrm{GeV}$
- The jet energy is dominated by the tracks (charged particles)

J. High Energy Phys. 01 (2014) 033



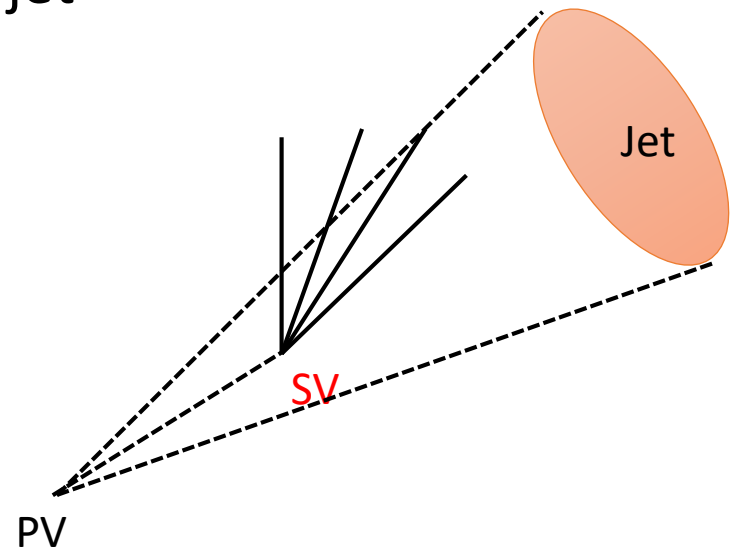


Tagging

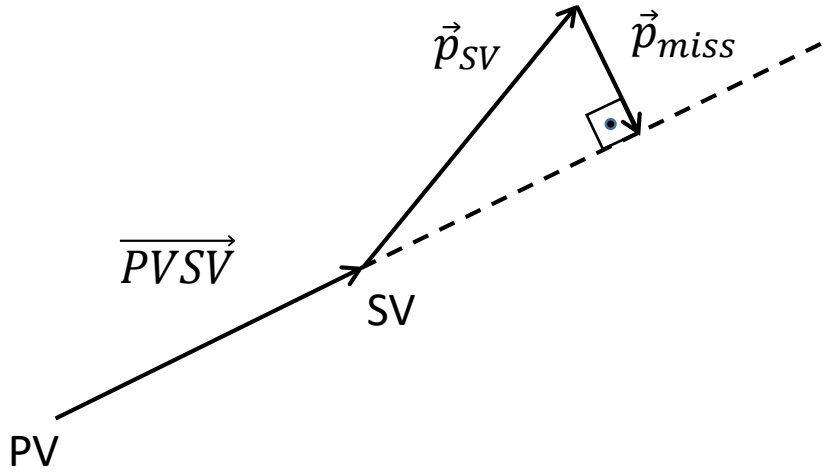
J. Instrum. 10 (2015) P06013

Two BDT responses

- Discrimination between heavy and light jets (BDT(bc|udgs))
- Discrimination between bottom and charm jets (BDT(b|c))
- The secondary vertex (SV) is required to be in the jet



- Several variables are used including:
  - The SV mass M
  - The SV corrected mass (M_{corr})
  - The flight distance χ^2
  - Fraction of jet p_T carried by the SV

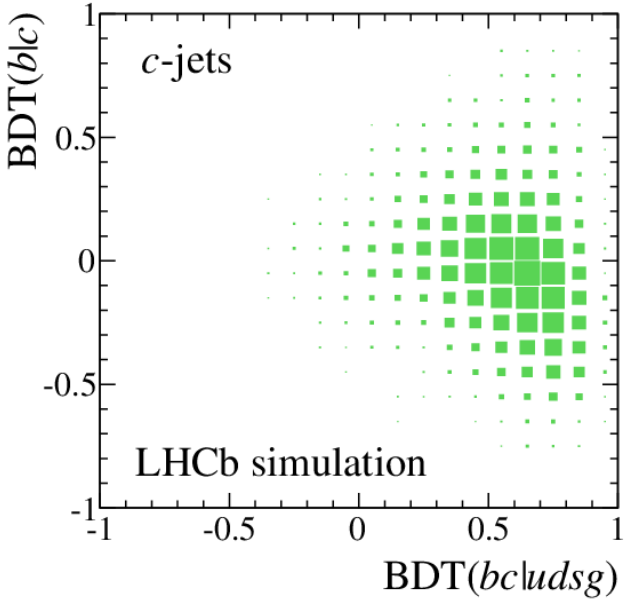


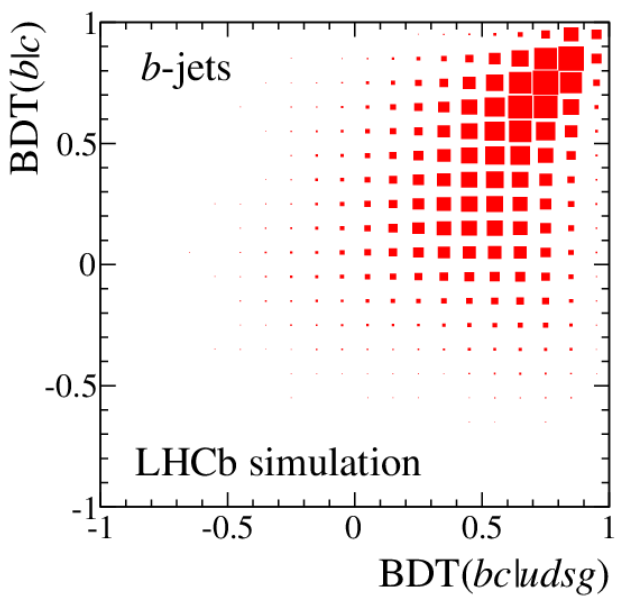
$$M_{corr} = \sqrt{M_{SV}^2 + \vec{p}_{miss}^{\,2}} + \vec{p}_{miss}$$

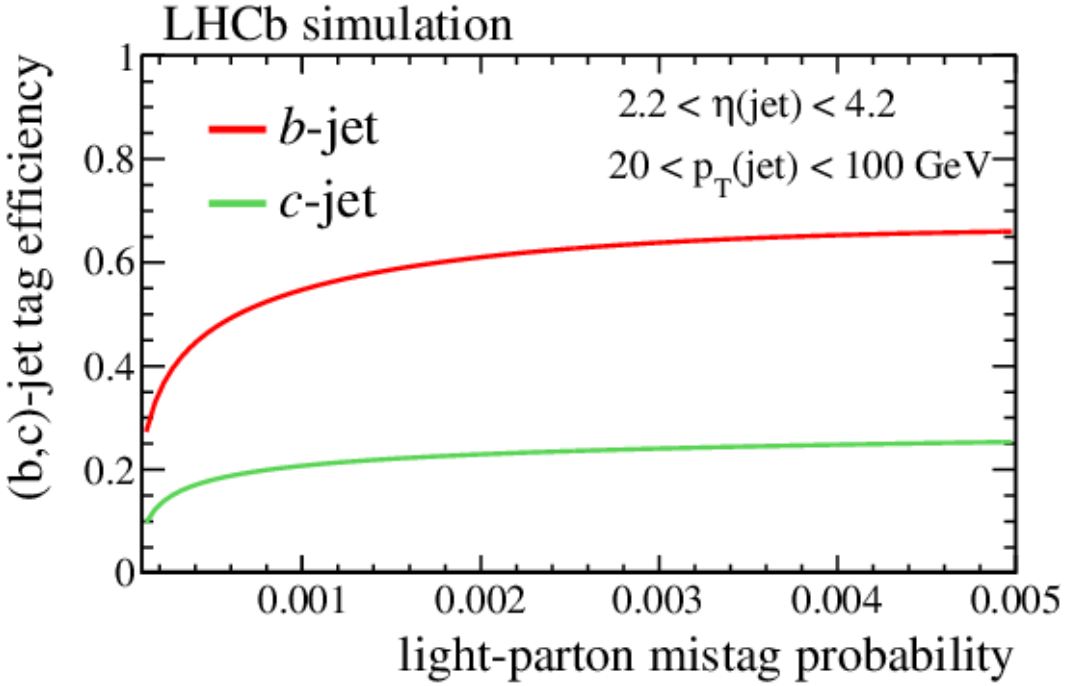
Tagging

J. Instrum. 10 (2015) P06013

- Powerful heavy quark tagging
- For jets with $20\ \text{GeV} < p_T^j < 100\ \text{GeV}$ and $2.2 < \eta^j < 4.2$:
  - Efficiency of b-jet tagging $\sim 65\%$
  - Efficiency of c-jet tagging $\sim 20\%$
  - Misidentification of a light-jet $\sim 0.3\%$





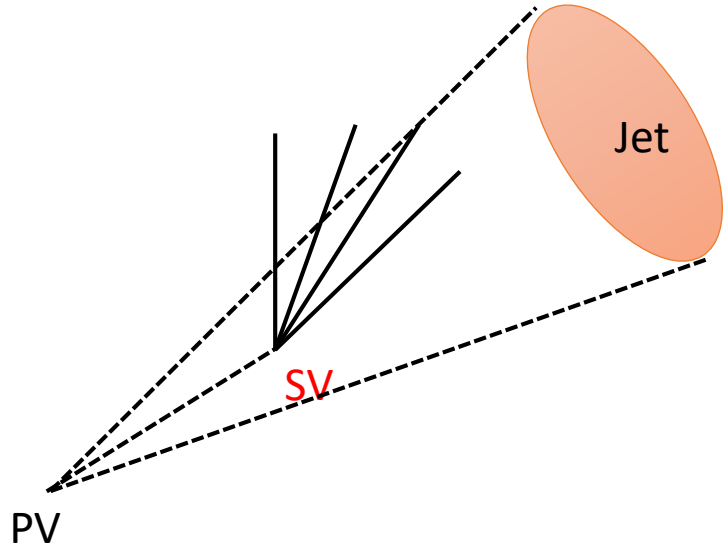


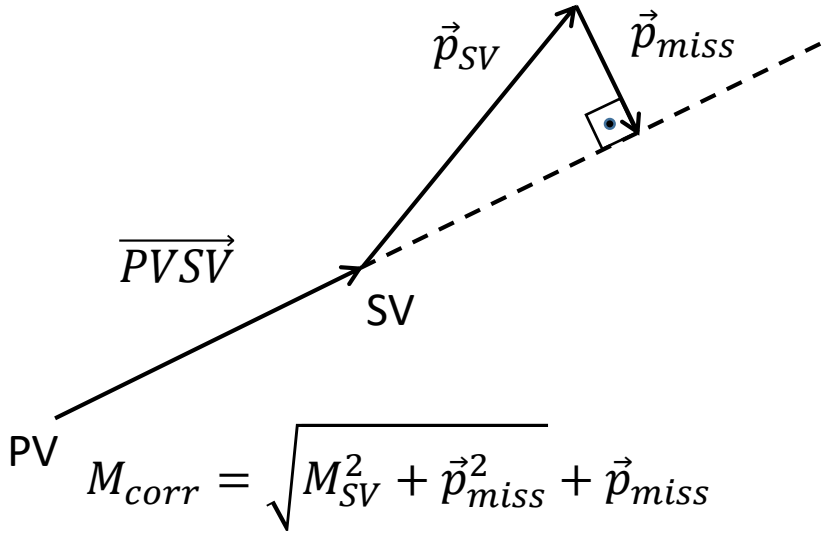
Identification of beauty and charm quark jets at LHCb

J. Instrum. 10 (2015) P06013

Variables used for the BDT(bc|udgs) and BDT(b|c):

- the SV mass M
- the SV corrected mass (M_{corr})
- the transverse flight distance of the two-track SV closest to the PV
- the fraction of the jet p_T carried by the SV
- ΔR between the SV and the jet
- the number of tracks in the SV
- The number of tracks in the jet ($\Delta R < 0.5$)
- the net charge of the tracks that form the SV
- The flight distance χ^2
- The sum of all SV track $\chi^2(IP)$

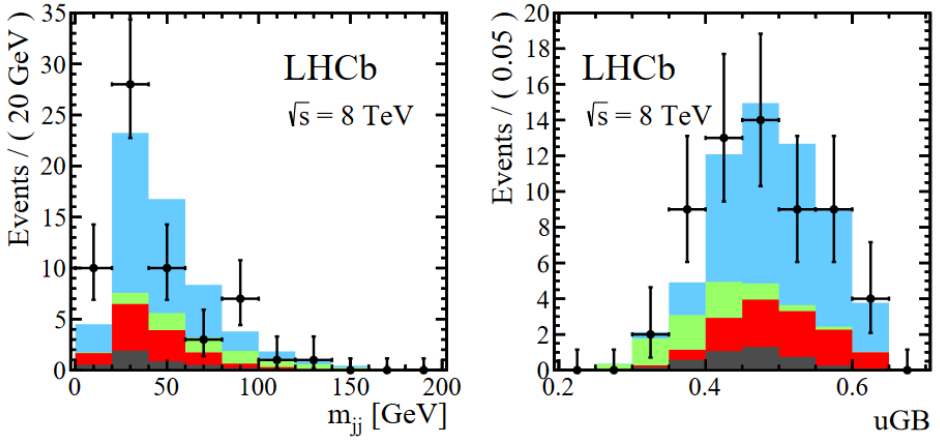




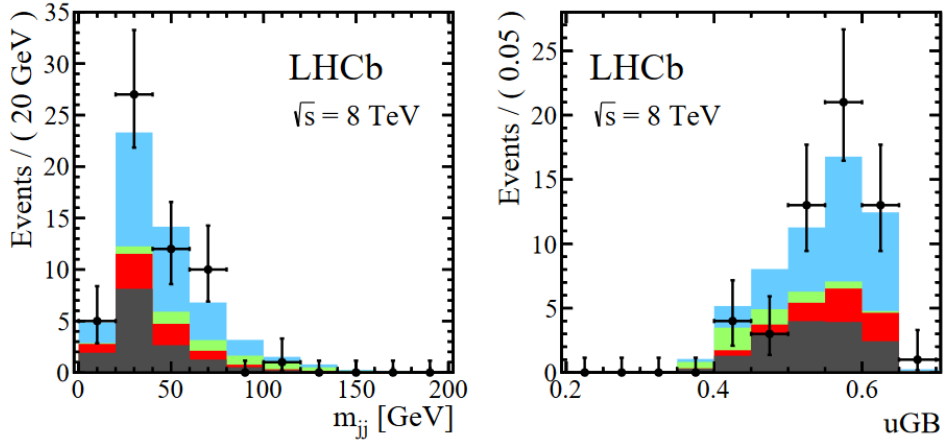
Measurement of the $t\bar{t}$, $W + b\bar{b}$ and $W + c\bar{c}$ production cross-section

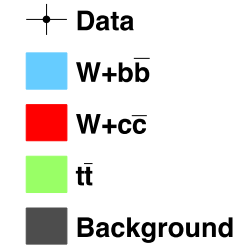
[Phys. Lett. B 767 (2017) 110-120]

μ^+ sample



e^+ sample

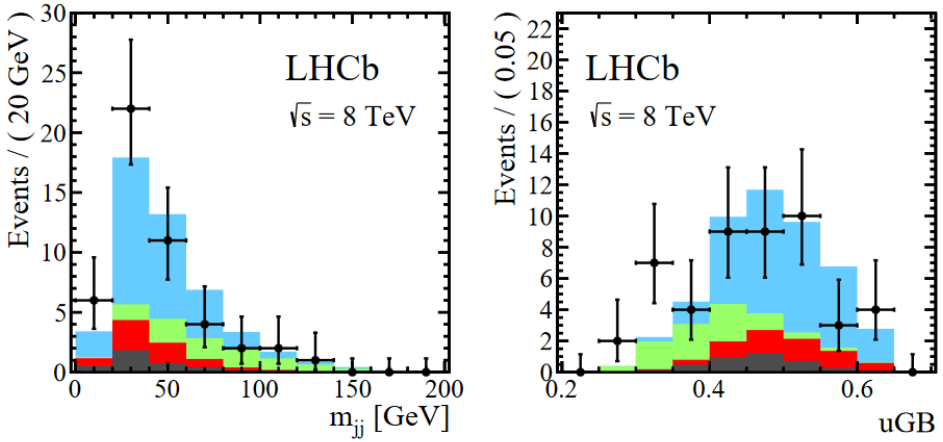




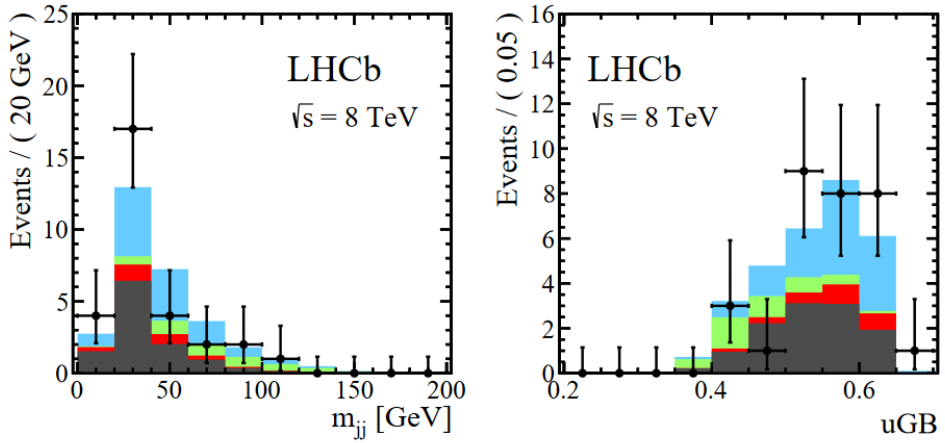
Measurement of the $t\bar{t}$, $W + b\bar{b}$ and $W + c\bar{c}$ production cross-section

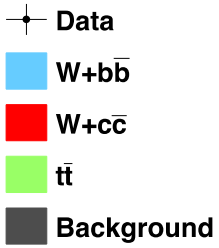
Phys. Lett. B 767 (2017) 110-120

μ^- sample



e^- sample

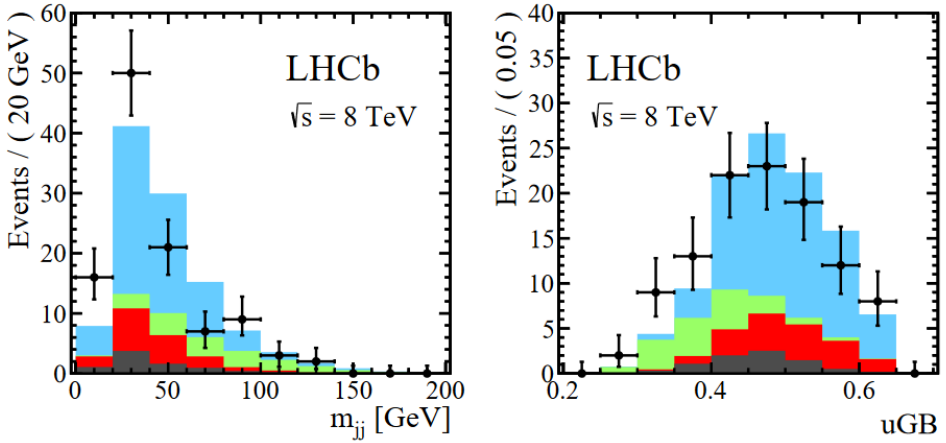




Measurement of the $t\bar{t}$, $W + b\bar{b}$ and $W + c\bar{c}$ production cross-section

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

μ sample merged



e sample merged