Highlights from the LHCb experiment

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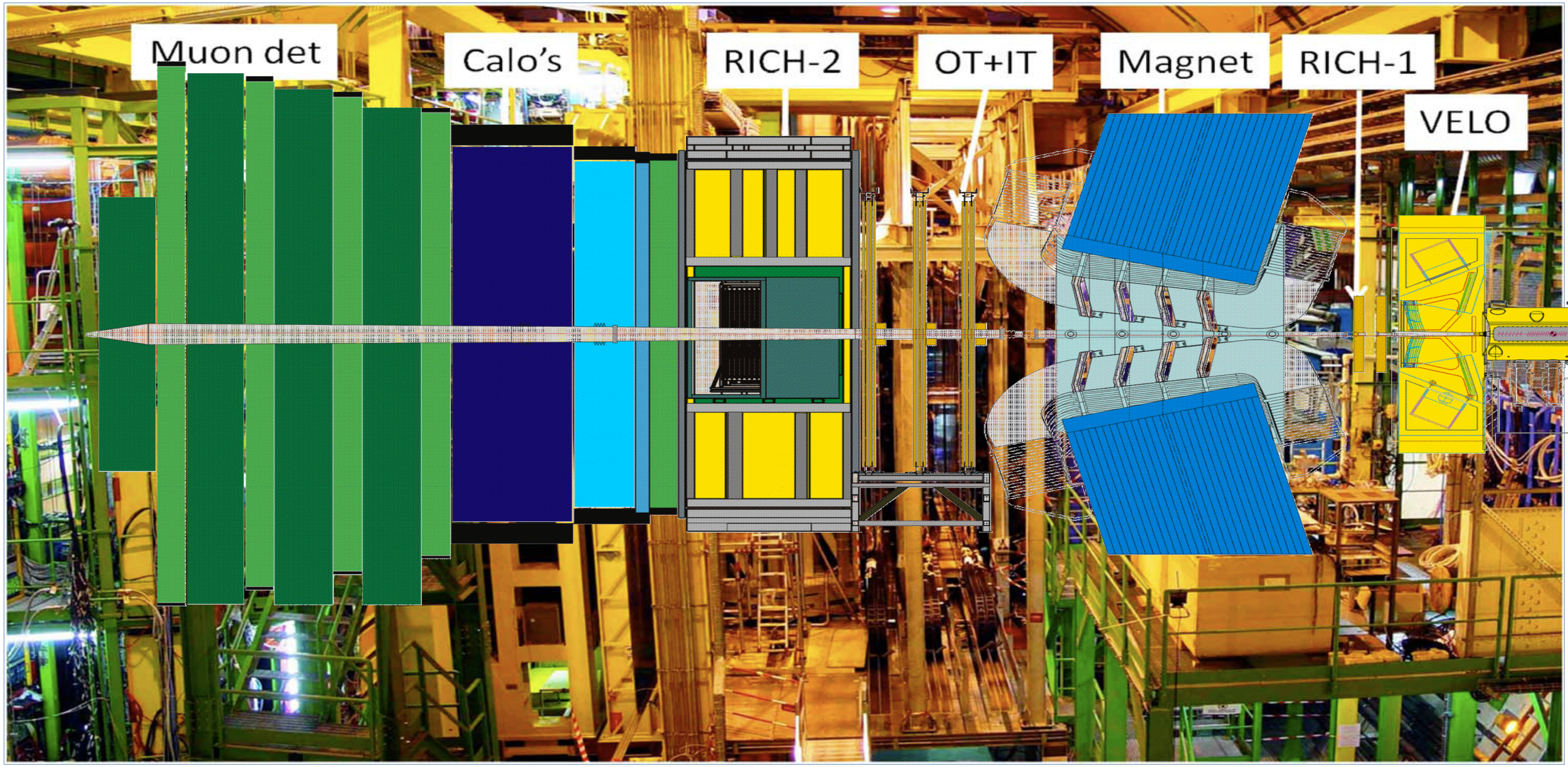
On behalf of the LHCb collaboration

EPS 11 July 2017

The LHCb experiment

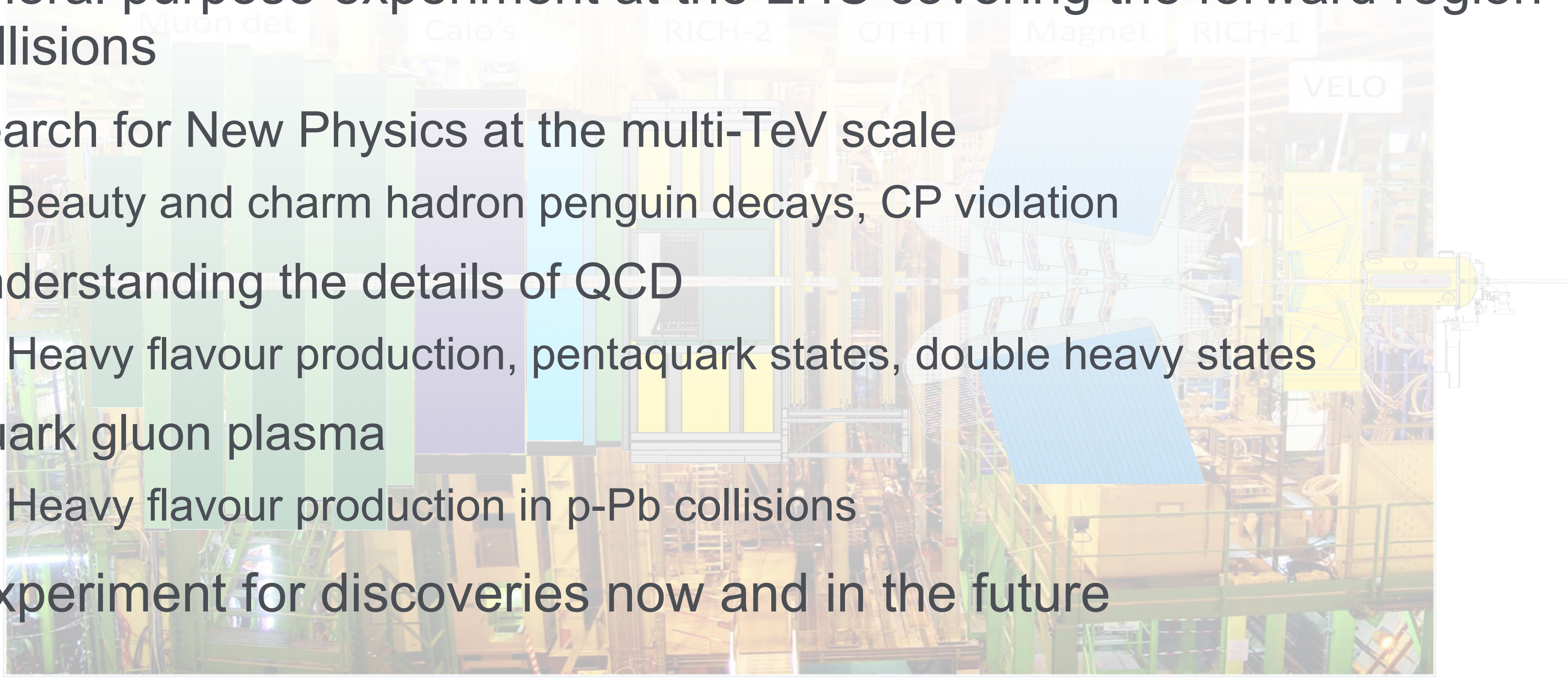


The LHCb experiment

A general purpose experiment at the LHC covering the forward region of collisions

- Search for New Physics at the multi-TeV scale
  - Beauty and charm hadron penguin decays, CP violation
- Understanding the details of QCD
  - Heavy flavour production, pentaquark states, double heavy states
- Quark gluon plasma
  - Heavy flavour production in p-Pb collisions

An experiment for discoveries now and in the future



Indirect searches for New Physics

We are used to the concept that heavy particles are influencing physics at lower energies

- Radioactive decays are mediated by the W boson
- Neutrino scattering is controlled by exchange of Z bosons
- B–$\overline{B}$ oscillations depend on top quark mass

Performing precision measurements makes us sensitive to even higher mass scales

- In B-decays this gives sensitivity to new physics at masses up to ~50 TeV

Lepton non-universality

Lepton universality in the gauge sector is one of the key features of the Standard Model

Decays with electrons, muons and taus should all be identical

- The only difference for decays with electrons, muons and taus is from their mass
- Effect of this is easy to correct for in predictions

Discovery of lepton flavour non-universality is a key signature of New Physics

Unfortunately the identification of leptons is anything but universal!

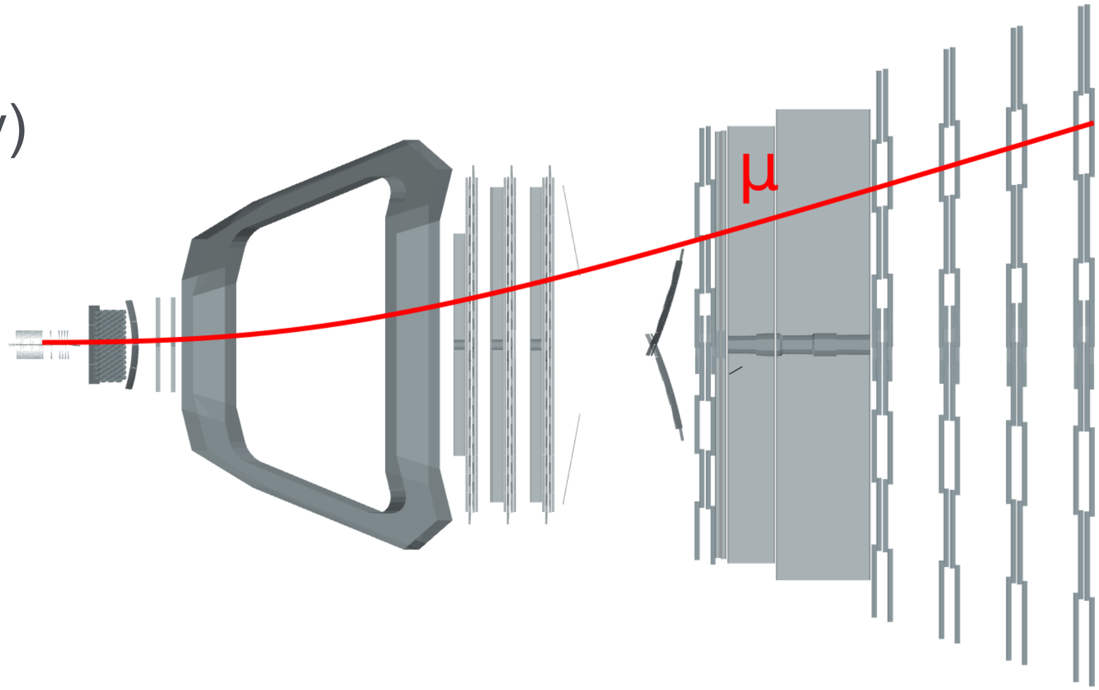
Muon identification

Muons are the perfect particles for identification

No radiation (as they are heavy)

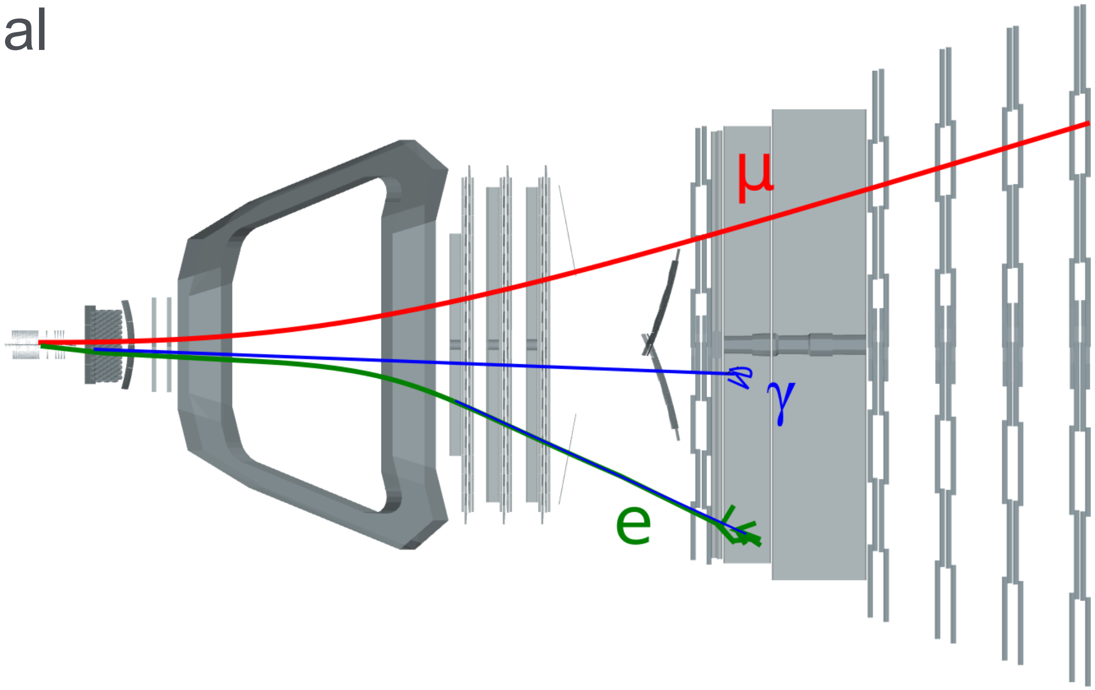
They are stable within a particle physics detector

No strong interaction so they are the only charged particles passing through absorber



Electron identification

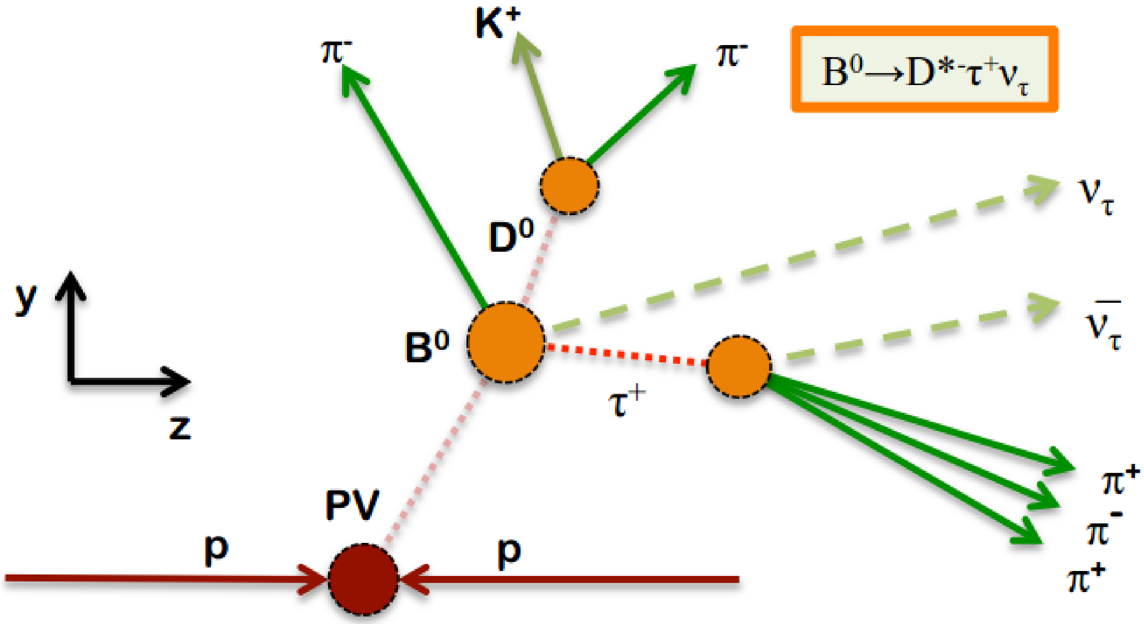
- Electrons are very light
  - When they pass through material they emit bremsstrahlung
    - Curvature in magnetic field will measure too low momentum
  - Photons can convert and fake electrons
- Bremsstrahlung recovery can (partially) fix this



Tau identification

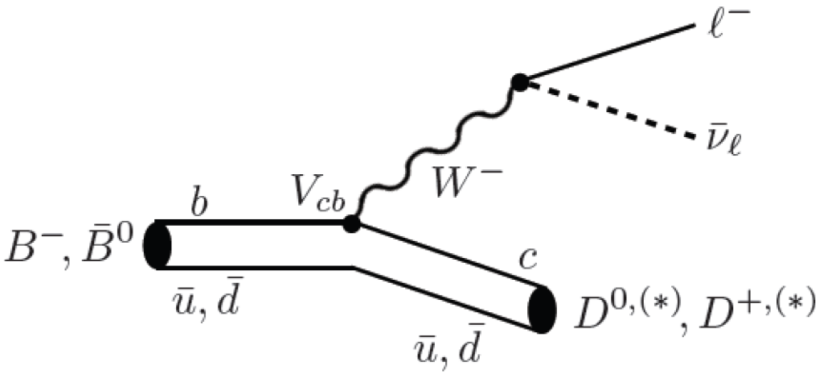
The identification of a tau lepton is really hard

- A short lifetime of 10^{-12} s means we only see decay products
- Hadronic decays with pions and a neutrino
- Semileptonic decay, $\tau \rightarrow \mu \bar{\nu} \nu$ has just one track and two neutrinos
- Mass and lifetime very similar to D_s which has very similar decays



Semileptonic decays

In the SM, the decay $B^0 \to D^{*-} l^+ \nu$ proceed through a tree level decay



$$\frac{d\Gamma^{SM}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)}{dq^2} = \underbrace{\frac{G_F^2\,|V_{cb}|^2\,|p^*_{D^{(*)}}|\,q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\ell^2}{q^2}\right)^2}_{\text{universal and phase space factors}}$$

$$\times \underbrace{\left[(|H_+|^2+|H_-|^2+|H_0|^2)\left(1+\frac{m_\ell^2}{2q^2}\right)+\frac{3m_\ell^2}{2q^2}|H_s|^2\right]}_{\text{hadronic effects}}.$$

$$R(D^*) = \frac{BF(B \to D^* \tau \nu)}{BF(B \to D^* \mu \nu)} \overset{\text{SM}}{=} 0.252 \pm 0.003$$

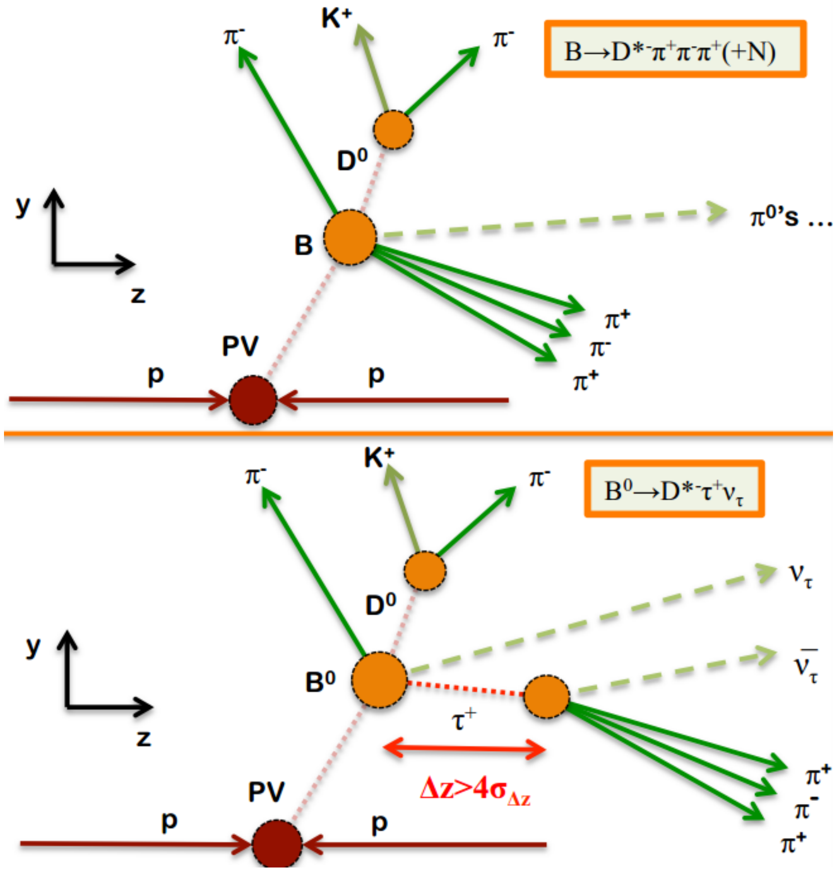
Semileptonic decays

Latest measurement from LHCb look at $\tau \to \pi^+ \pi^- \pi^+ \nu$ final states

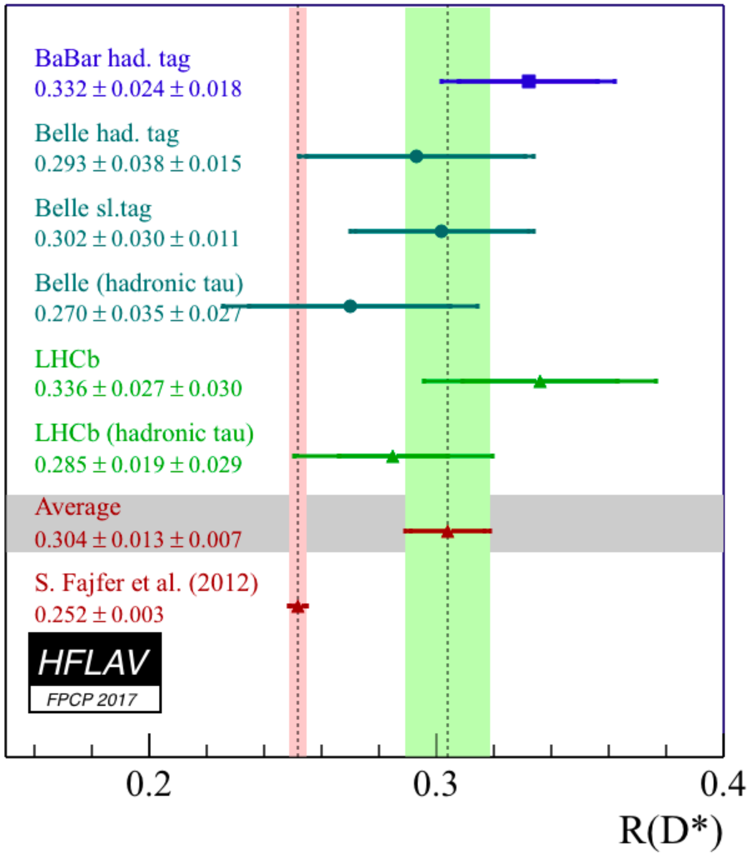
Normalisation done though a very similar known final state

$$R(D^*) = K_{had}(D^*) \times \frac{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{BR(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

$$K_{had}(D^*) = \frac{BR(B^0 \to D^{*-}\tau^+\nu_\tau)}{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}$$



Semileptonic decays



New LHCb measurement gives

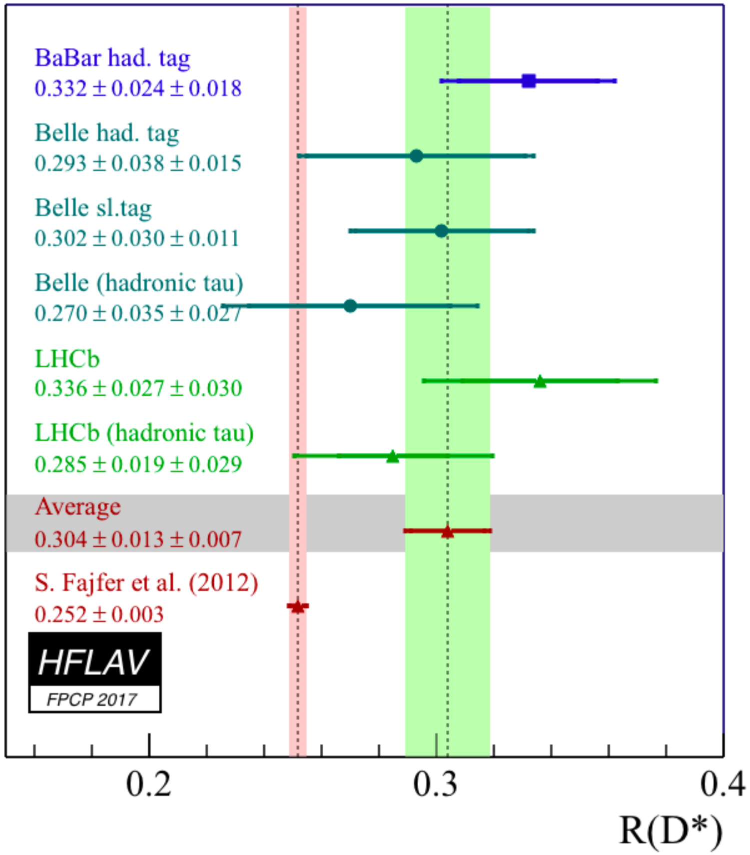
R(D*)=0.285±0.019(stat)±0.025(syst)

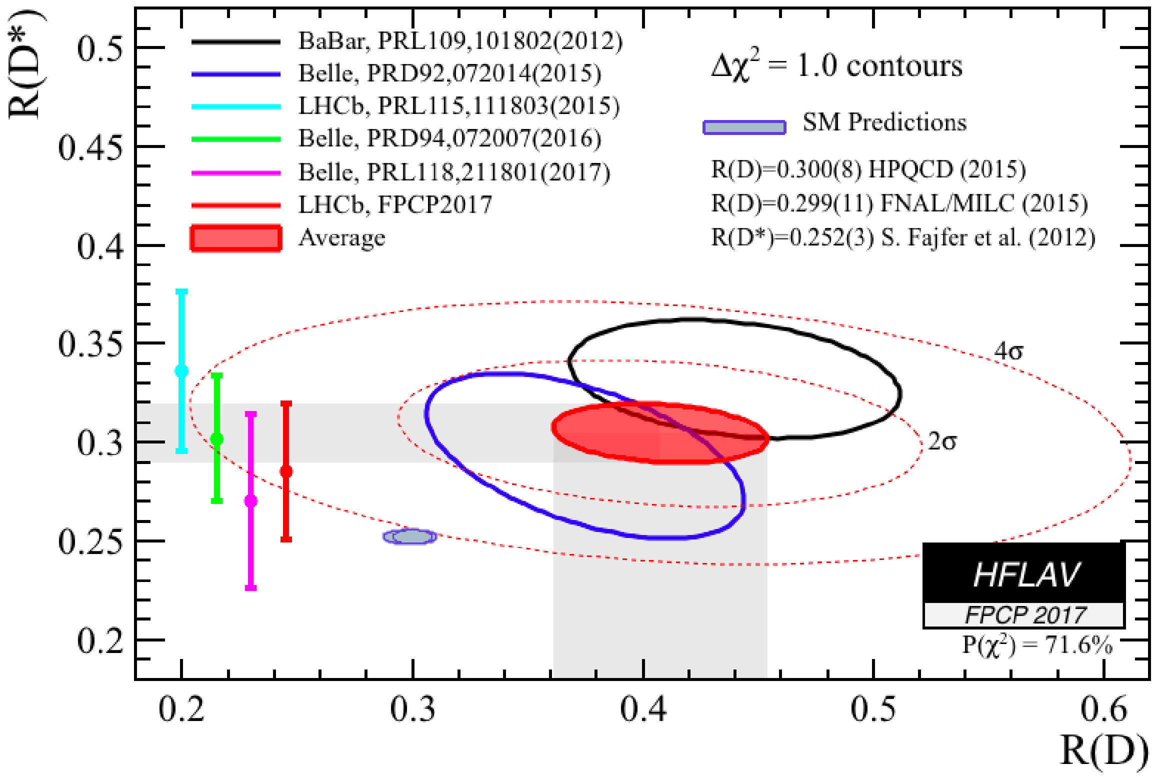
LHCb-PAPER-2017-027

Compatible with SM expectation

but also fully supporting previous measurements of high value

Semileptonic decays



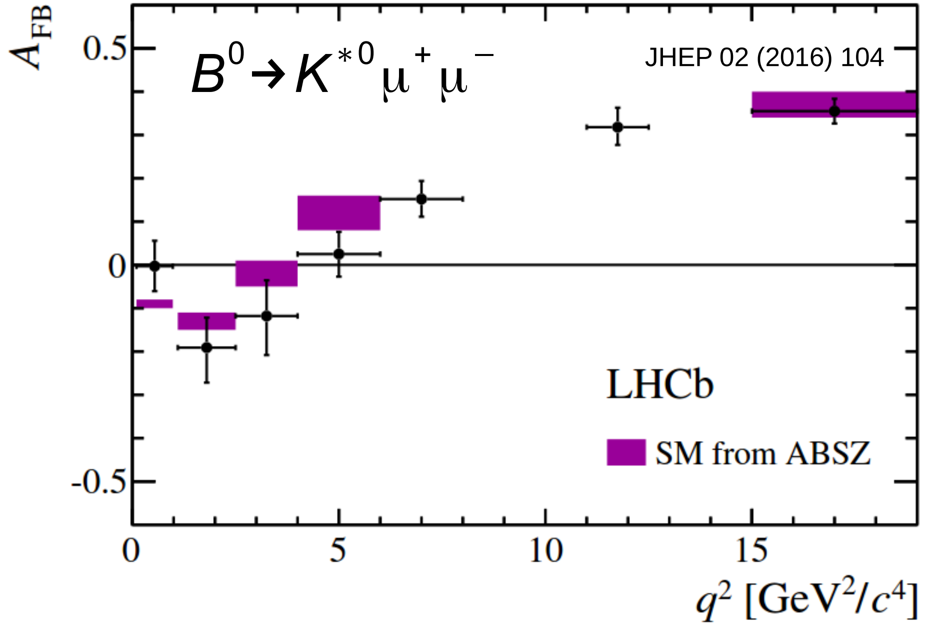


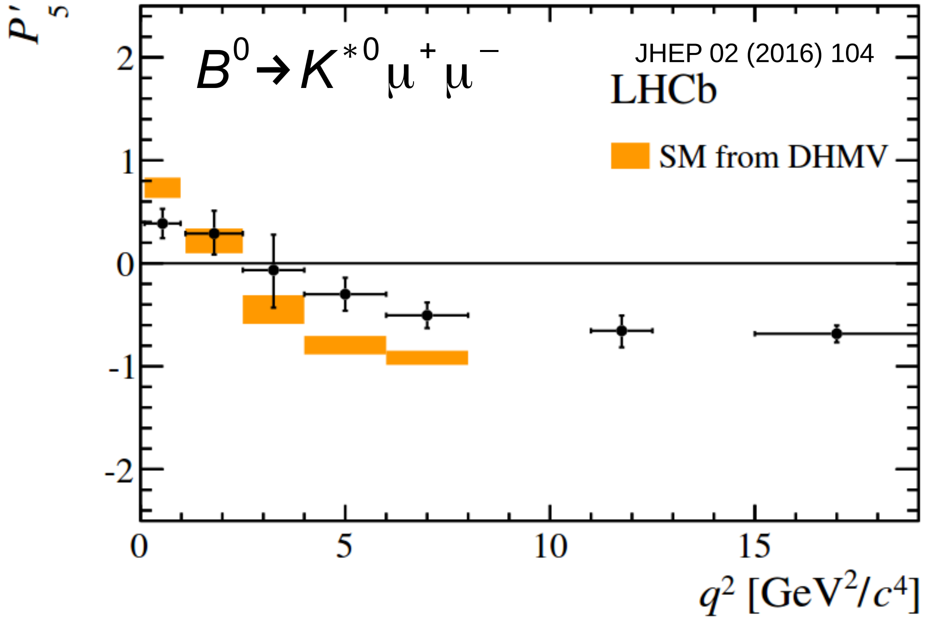
Results are internally consistent and 4σ from SM prediction

Multiple tensions

In electroweak penguin decays there are many more tensions

Branching fractions, **angular observables**

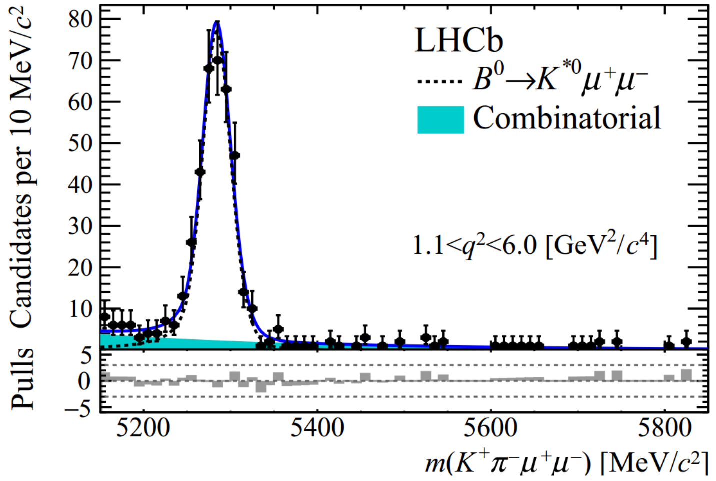




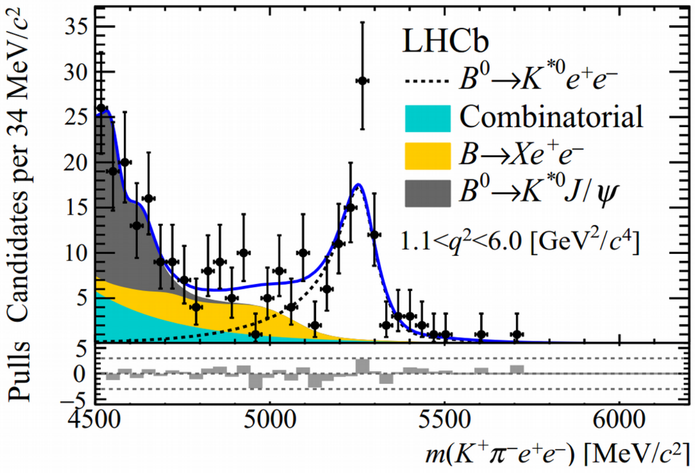
Multiple tensions

In electroweak penguin decays there are many more tensions

- Branching fractions, angular observables, **lepton non-universality**
  - Compare $B^0 \to K^{*0}\mu^+\mu^-$ with $B^0 \to K^{*0}e^+e^-$
  - Measure double ratio with respect to $B^0 \to K^{*0}J/\psi$ to minimise uncertainty from lepton identification



ArXiv:1705.05802



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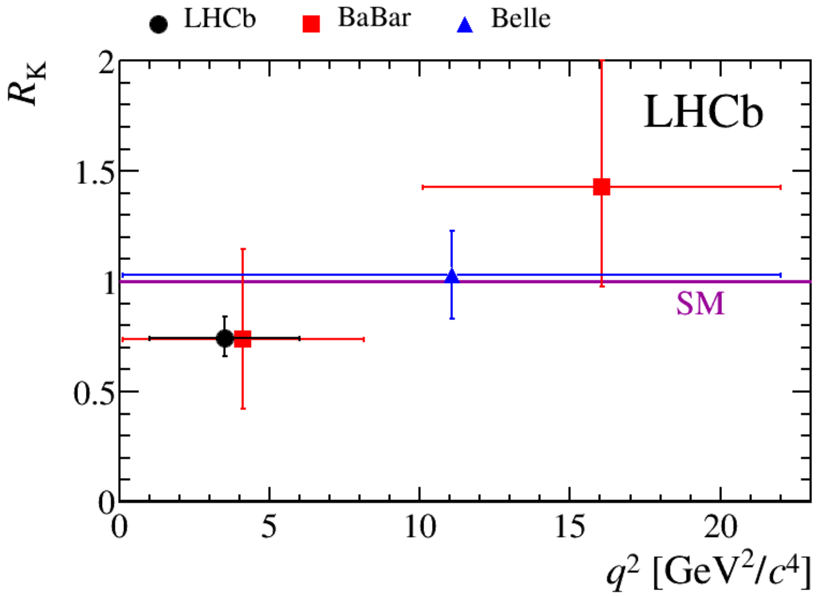
Phys. Rev. Lett. 113 (2014) 151601



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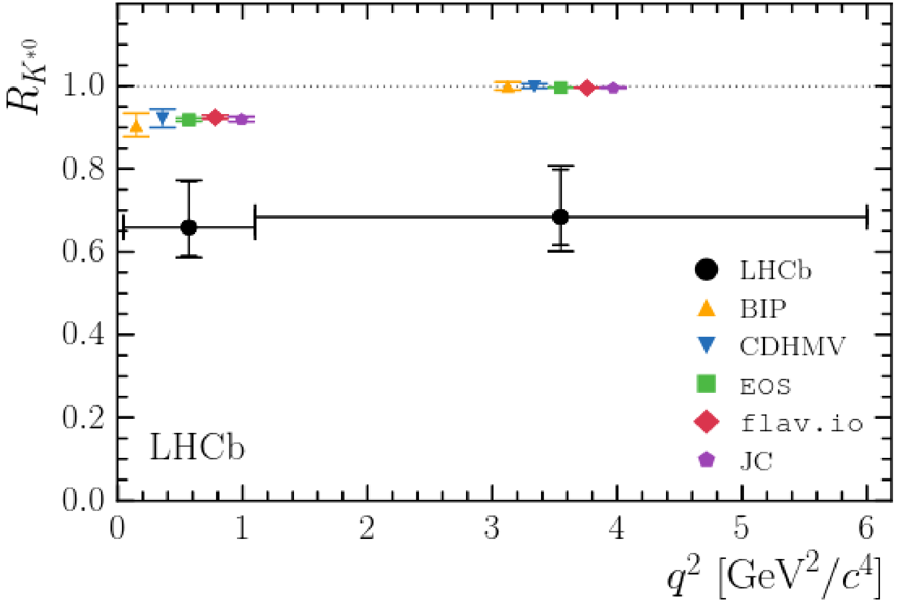


Possible New Physics interpretations

- First of all the tensions are large
  - 30% effect against SM for taus in tree level decays
  - 25% effect against SM for muons in electroweak penguins
- Many constraints to consider
  - No signs of NP at CMS and ATLAS, push mass scale to above few TeV
  - Effect is small or absent in B-$\overline{B}$ oscillations
  - Proton decay, $\mu \to e$ conversion, $(g-2)_\mu$
- Explanation will tell us something fundamental about what **flavour** is
- The multiple 2-3σ effects all have potential to become 4-5σ in a few years

The indirect view

To enable a discovery of New Physics, we need to know the SM parameters

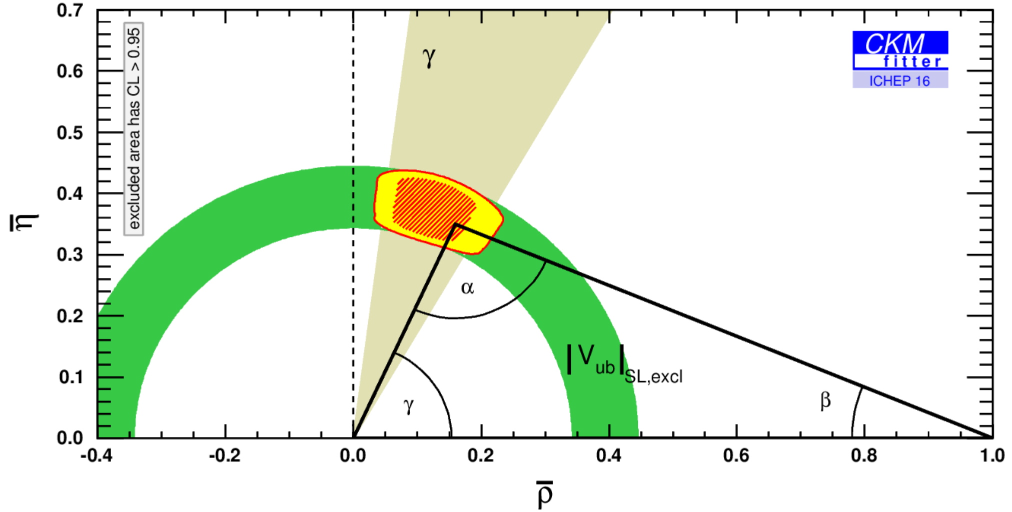
There are key measurements that we can improve

Improve SM parameters

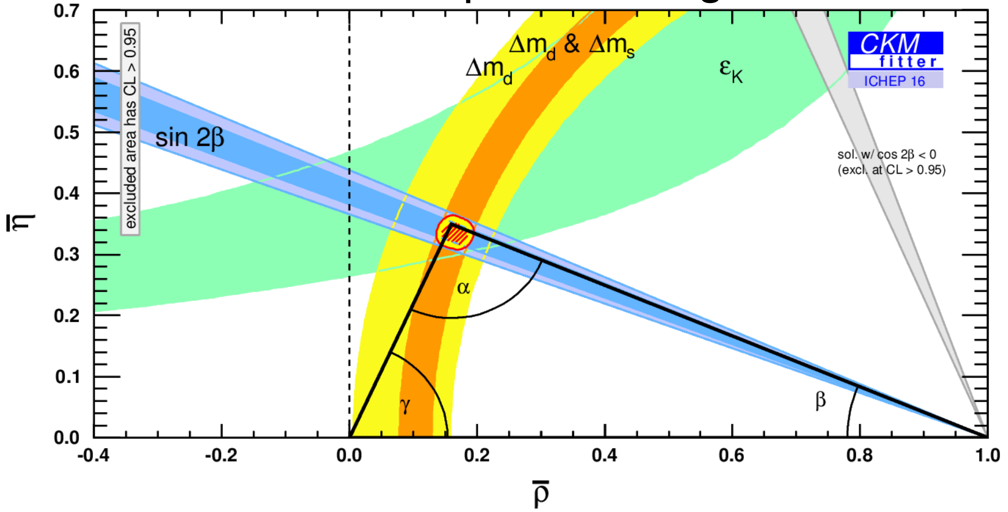
If there is no NP is flavour physics, the unitarity triangle should be the same in all measurements

- Comparing tree level decays and loop level decays is a way to look for inconsistencies

Tree level: small NP effect?



Loop level: Large NP effect?



New CKM angle γ measurement

The CKM angle γ is best measured in interference between b→c and b→u tree level decays

- From all Run-1 and 2 data a new measurement with $B^{\pm} \to (D^{*} \to D\pi^{0}/\gamma)K^{\pm}$
- Partial reconstruction of D^{*0} used
- Sensitivity to γ from $D^{0} \to K^{+}K^{-}$ and $D^{0} \to \pi^{+}\pi^{-}$ decay CP eigenstates

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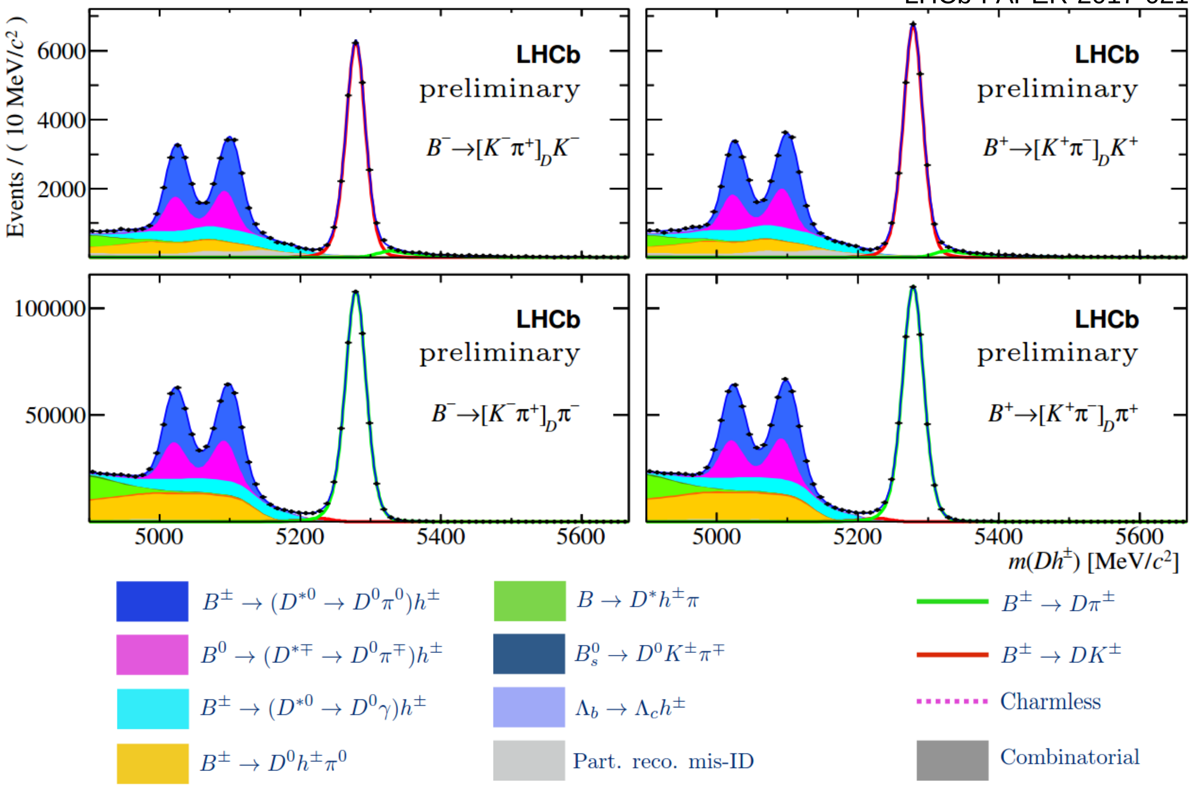

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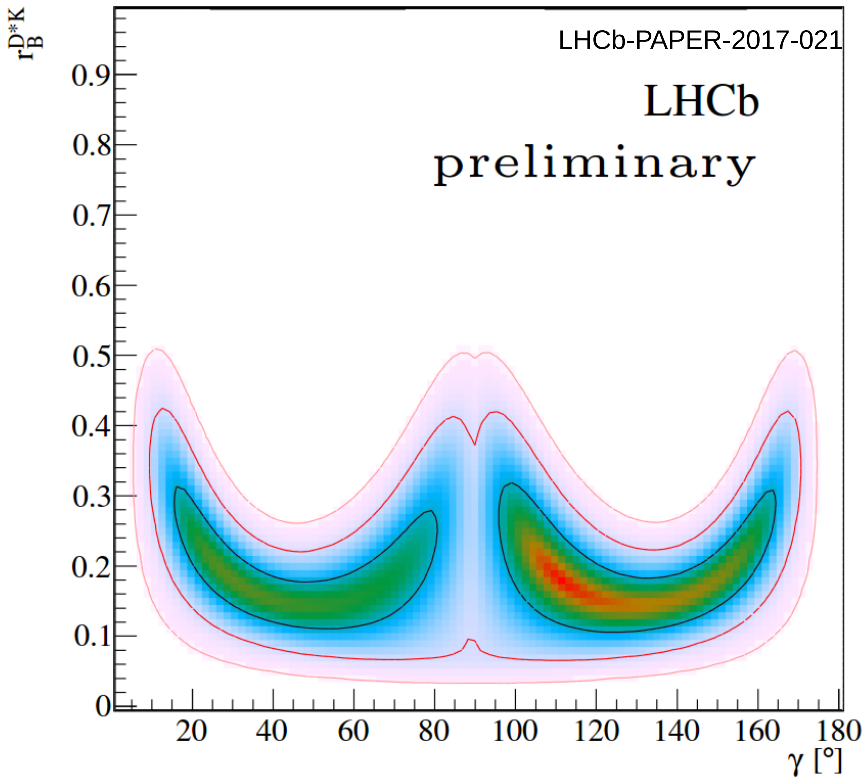
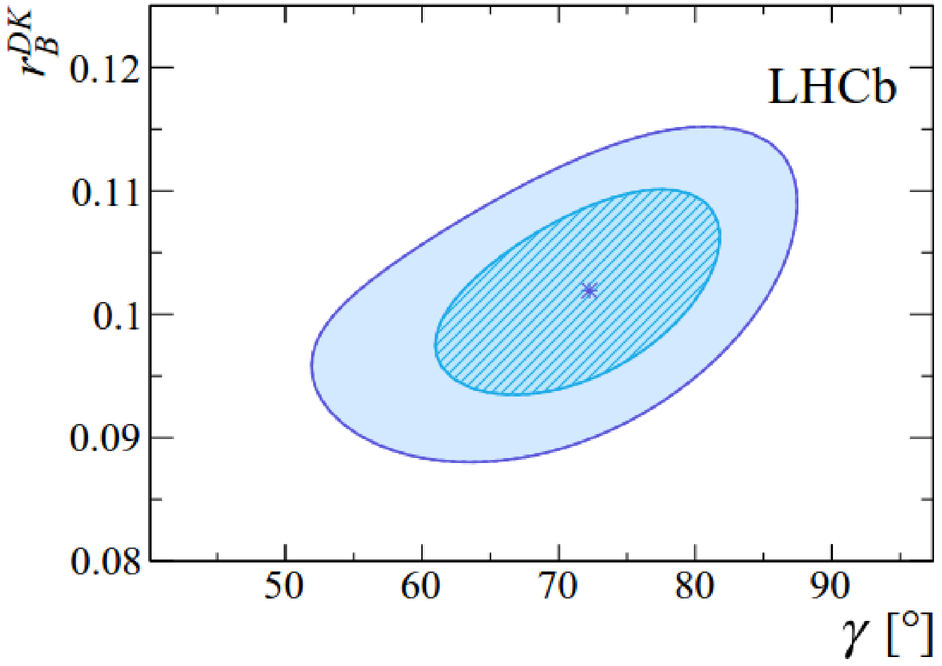
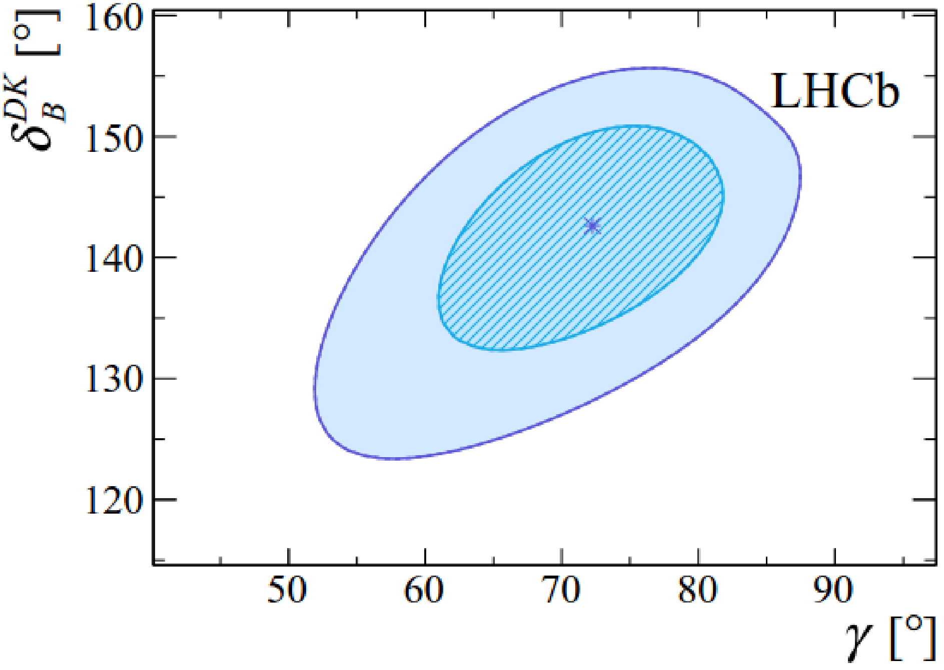


Global LHCb γ fit

The combined measurement of γ from last year gives $\gamma = \left(72.2^{+6.8}_{-7.3}\right)^o$

JHEP 12 (2016) 087



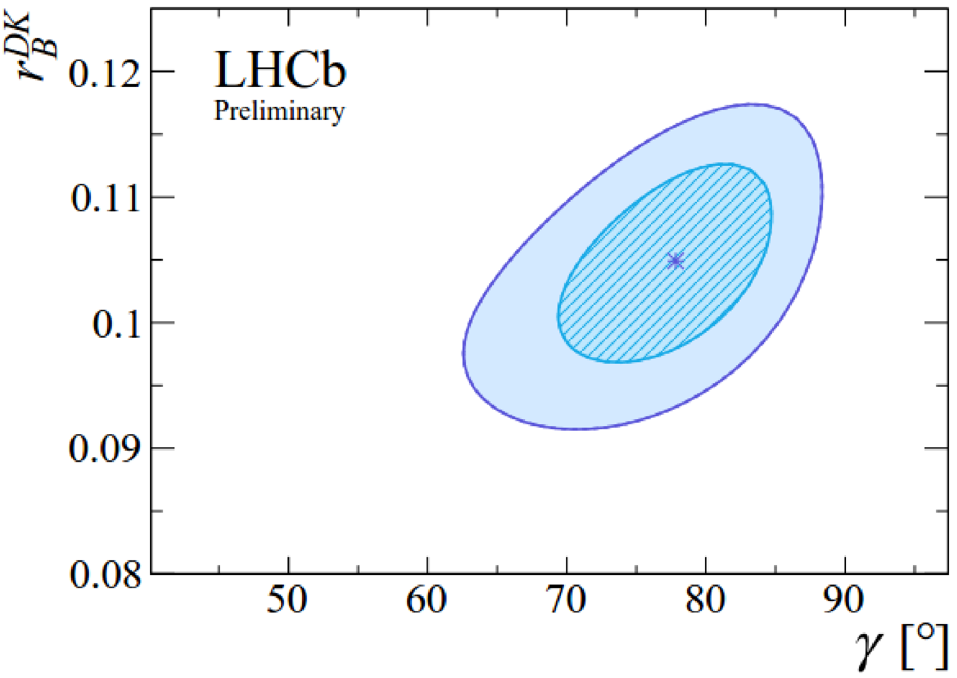


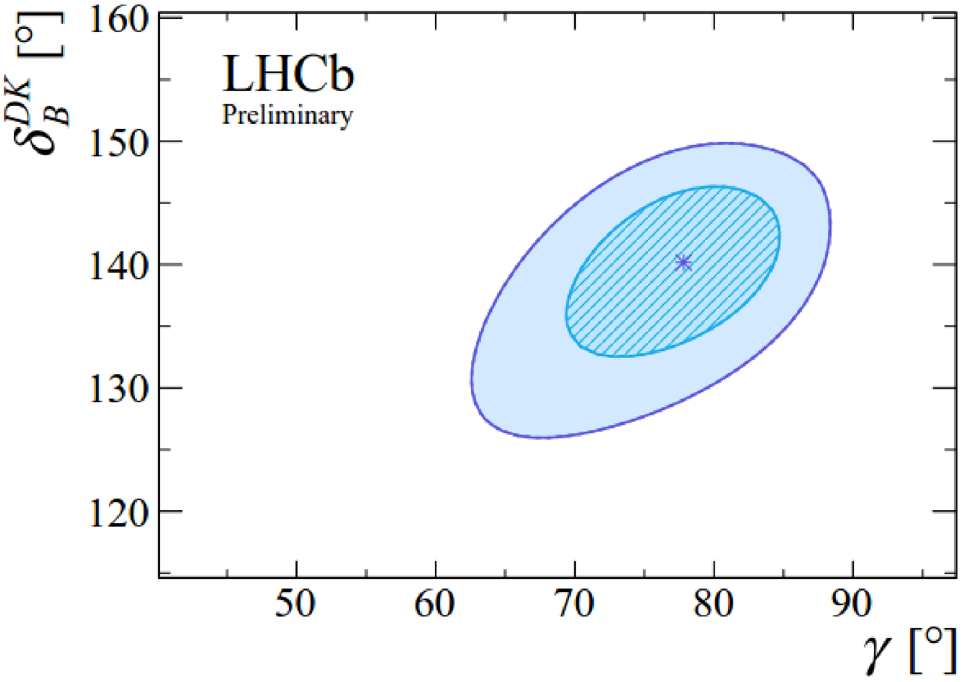
Global LHCb γ fit

All LHCb measurements combined gives $\gamma = (76.8\,^{+5.1}_{-5.7})^\circ$

Most precise from single experiment

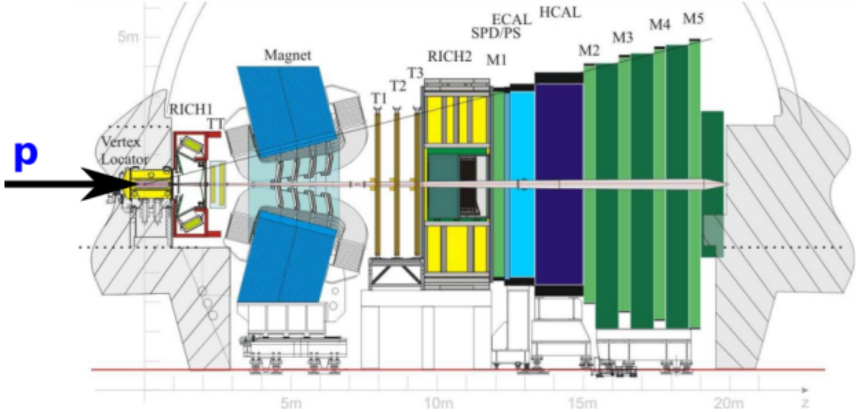
LHCb-CONF-2017-004





Heavy ion collisions

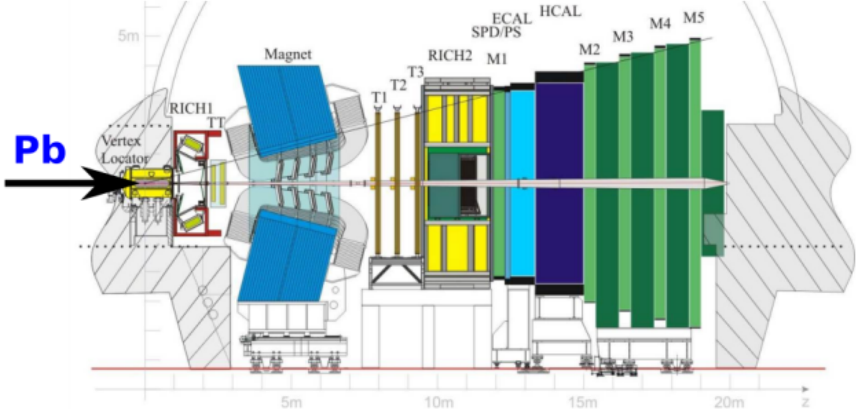
Data taken during 2016 p-Pb and Pb-p runs @ $\sqrt{s_{NN}} = 8.16$ TeV



Forward

$$1.5 < y^* < 4.5$$

$$y^* = y_{lab} - 0.465$$



Backward

$$-5.5 < y^* < -2.5$$

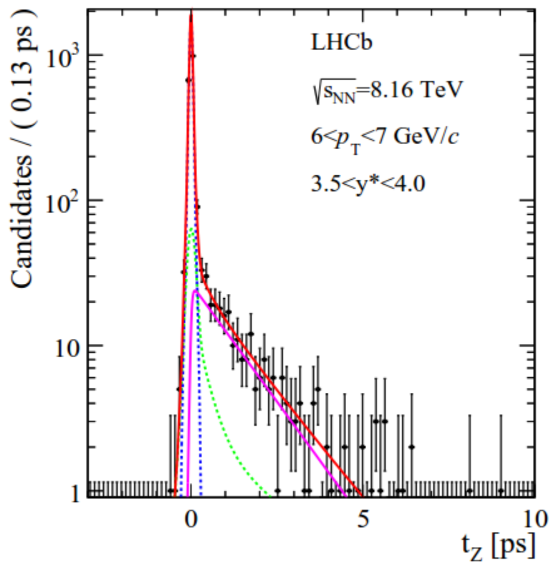
$$y^* = -(y_{lab} + 0.465)$$

Heavy ion collisions

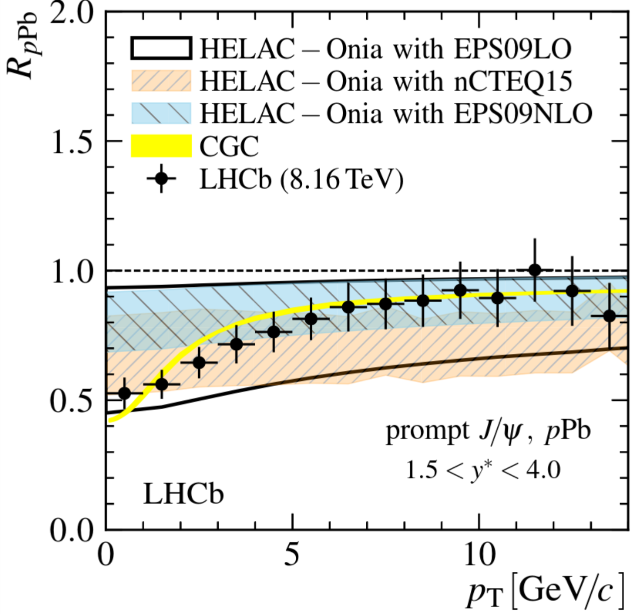
J/ψ **prompt** and non-prompt (from b-hadrons) cross section

Measure production relative to pp collisions (scaled by factor 208)

Effective lifetime

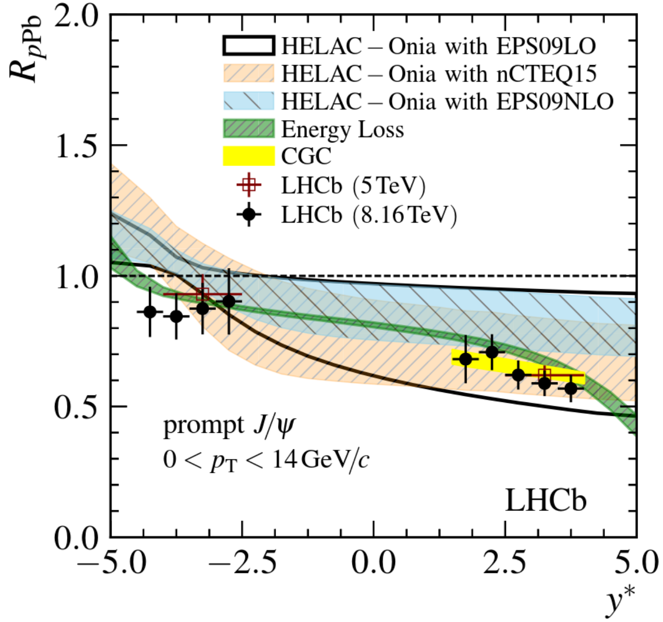


prompt



arXiv:1706.07122

prompt



Heavy ion collisions

J/ψ prompt and **non-prompt** (from b-hadrons) cross section

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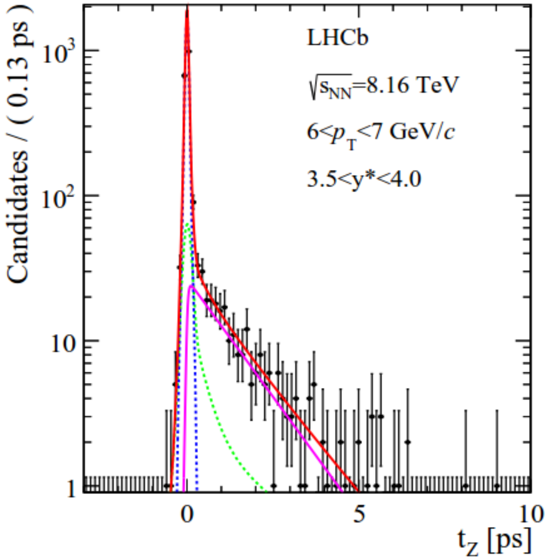
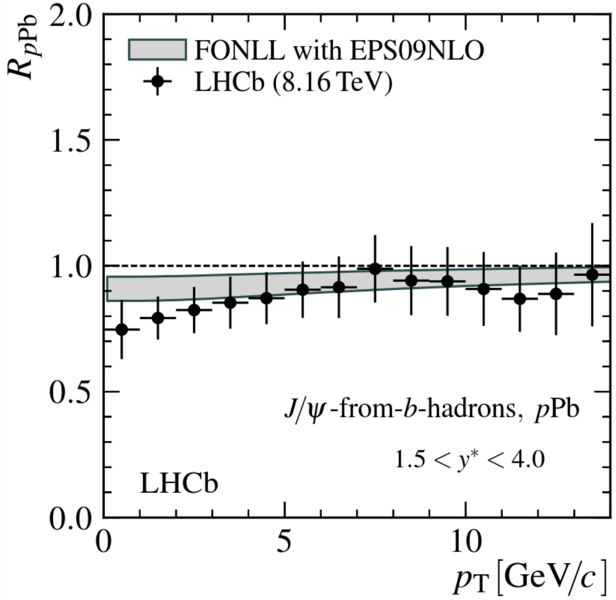
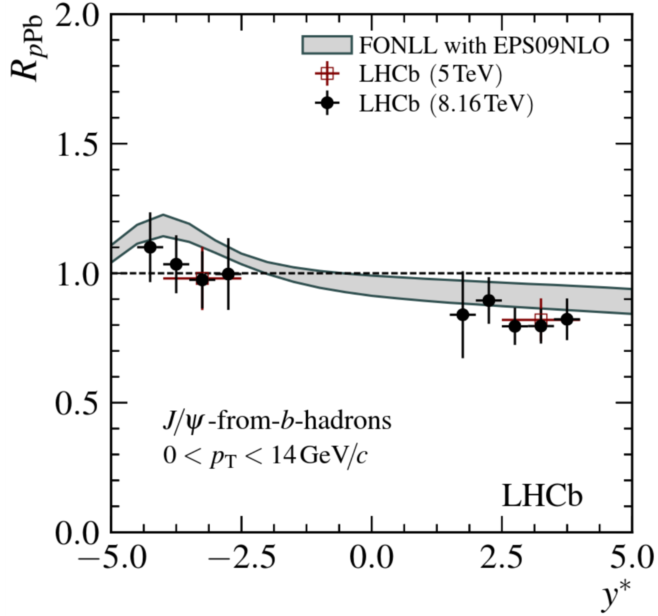


non-prompt



arXiv:1706.07122

non-prompt

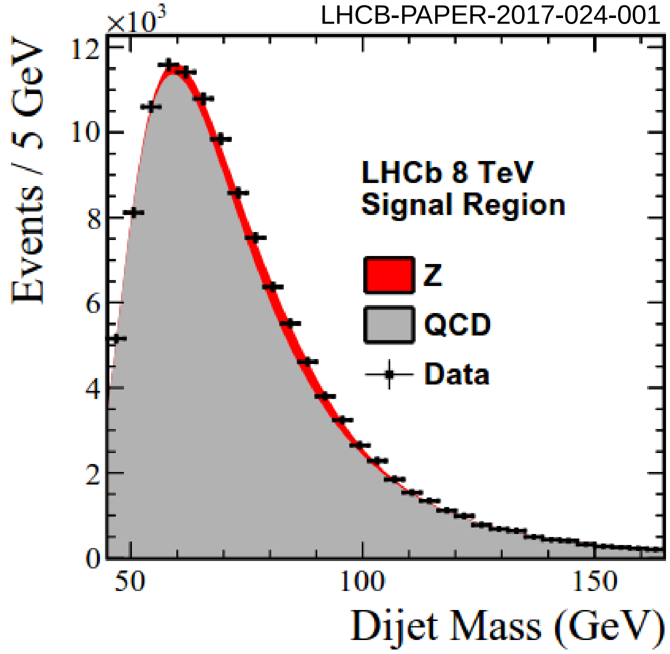


$Z \rightarrow b\bar{b}$

Looking at $pp \rightarrow (Z \rightarrow b\bar{b})j$ events

- Events with 3 jets, where two are b-tagged

$$\sigma(pp \rightarrow Z)\mathcal{B}(Z \rightarrow b\bar{b})$$
$$= 332 \pm 46(\text{stat.}) \pm 59(\text{syst.})\ \text{pb}$$



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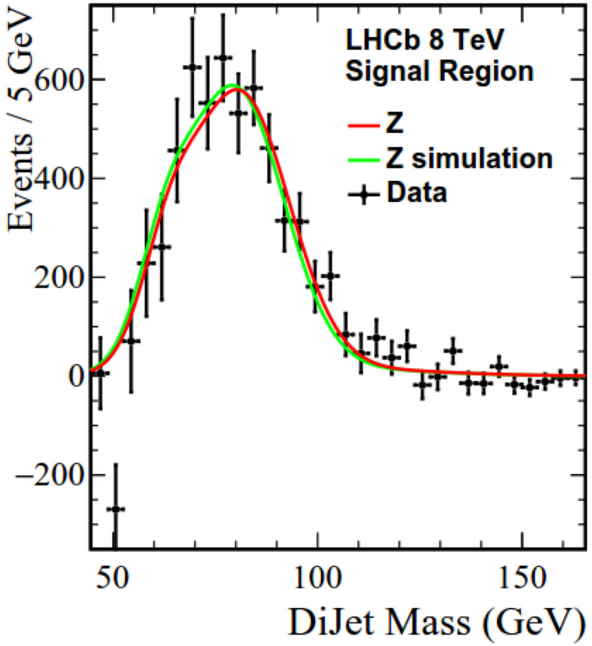
$$= 332 \pm 46(\mathrm{stat.}) \pm 59(\mathrm{syst.})\ \mathrm{pb}$$

Important measurement for future searches of heavy particles decaying to b-jets

LHCB-PAPER-2017-024-001

Background subtracted



The future of LHCb

The current detector configuration will be used until end of Run-2 (2018)

- ~ factor 5 on Run-1 yield

The LHCb upgrade will take data for 6 years from 2021

- ~ factor 25 in integrated luminosity
- Trigger will give additional factor 2 for many channels

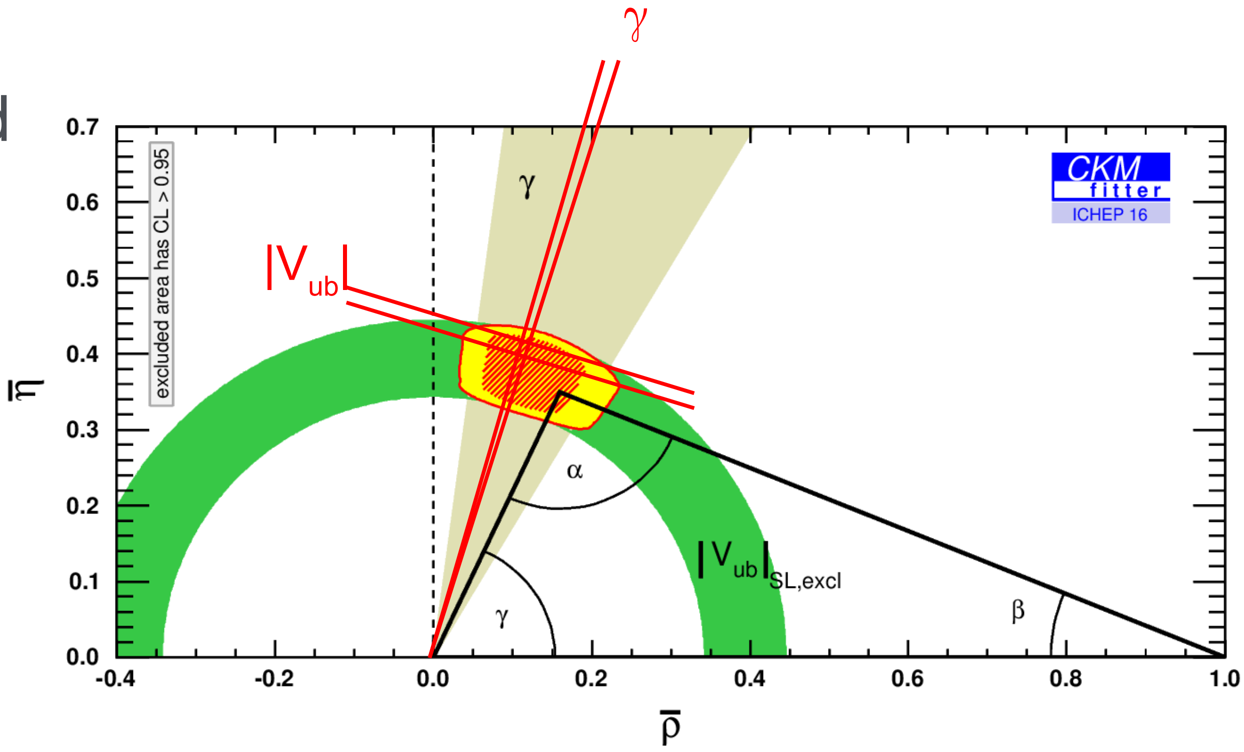
A proposed LHCb upgrade phase-II will take data after 2030

- ~ factor 200 in integrated luminosity

Improve γ and $|V_{ub}|$

The CKM angle γ will be improved to around 1° at end of upgrade phase 1, and to 0.4° at end of phase 2

Sets precise points to compare against $\Delta m_s/\Delta m_d$, penguin measurements and sin 2β



From null test to classification

If NP is there, we need to understand its properties

- $B^+ \to \pi^+\mu^+\mu^-$ BF compared to $B^+ \to K^+\mu^+\mu^-$
  - Can help us understand if NP observes minimal flavour violation
- Search for $B^+\to K^+e^+\mu^-$, $B^+\to K^+\tau^+\mu^-$
  - Is NP flavour diagonal in lepton sector?
- Test lepton universality in $b\to d$ transitions, $B\to \pi/\rho/p\bar{p}\ l^+l^-$
  - Does NP depend on quark sector?
- Measure $B^+\to p\bar{p}\tau^+\nu$ relative to $B^+\to p\bar{p}\mu^+\nu$
  - Does NP care about $b\to c$ vs. $b\to u$ transitions?

Conclusion

LHCb has a bright future

- Tensions on lepton flavour universality will be clear in a few years
- Classification of any New Physics possible in many different ways
- Heavy Ion physics programme has much to add
- Precision measurements of SM parameters