Recent results from LHCb

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On behalf of the LHCb collaboration

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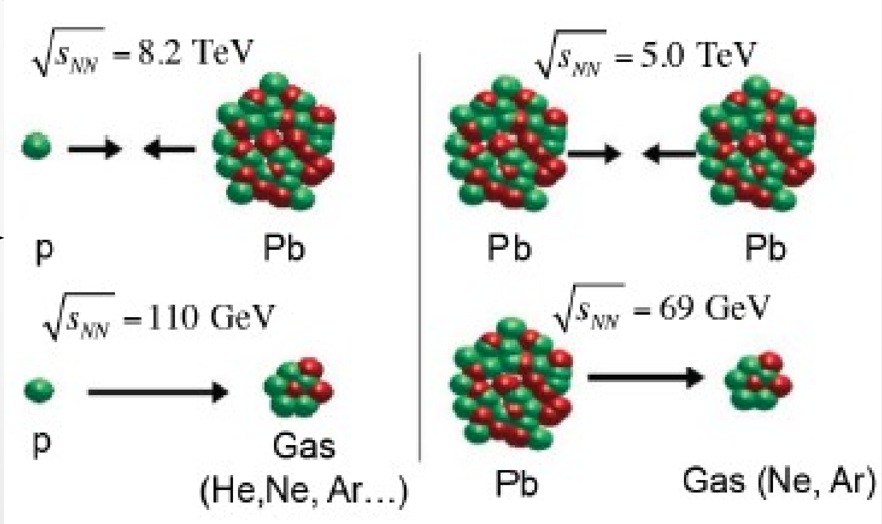
laboratório de partículas elementares
Universidade Federal do Rio de Janeiro

Outline

- **Physics program**
- **LHCb experiment**
- **Highlights of recent results**
  - **Mostly from Run I data, some analyses include ongoing Run II data**
- **Prospects**
- **Conclusion**

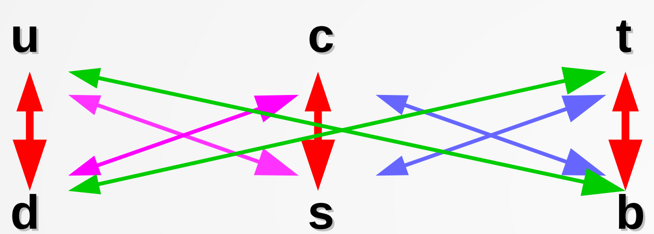
LHCb physics scope

- Main scope
  - Use heavy flavours (b,c) decays to probe New Physics indirectly
    - Deviations from Standard Model on cleanly-predicted observables
    - Constraints on New Physics parameters even if no detected sign
  - Precise measurements on weak couplings of quarks, “CKM physics”
    - Understand better EW CP violation, as an input to the cosmological puzzle
- Other topics are considered
  - Heavy Quarks production at pp collisions
  - Forward EW and QCD physics
  - Search for exotics
  - Heavy ion physics
  - ...



CKM picture: where we start...

Weak interaction couples quarks through elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix
Weak eigenstates are different from mass eigenstates = CKM matrix is not diagonal and may relate quarks of different generation



~1
~0.2
~ 0.04
~ 0.004-0.008

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Clear hierarchy in the couplings: the further from diagonal, the weaker

Unitarity imposes relations, among which $\sum_k V_{ik} V^*_{jk} = 0$

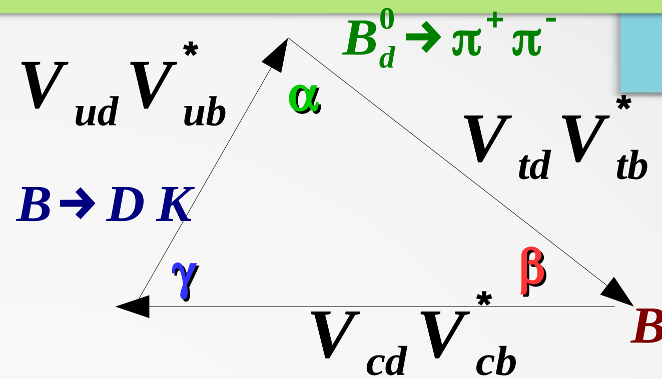
Elements forming sides (and angles) of 3 independent “unitarity” triangles, of which only a couple are of interest for heavy-flavour decays

...and where we stand

Most interesting relation:

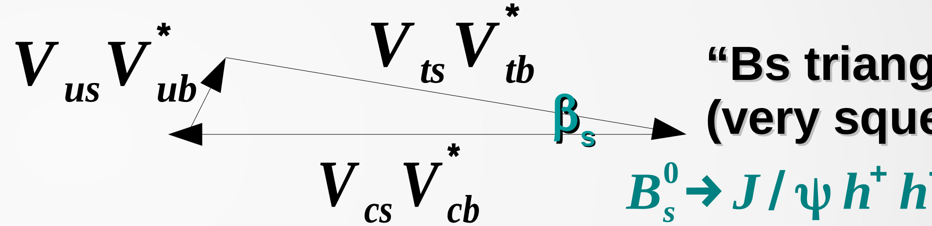
$$V_{ud}V_{ub}^{*}+V_{cd}V_{cb}^{*}+V_{td}V_{tb}^{*}=0$$

Sides usually measured in semileptonic decays and oscillation frequency, angles in CP asymmetries



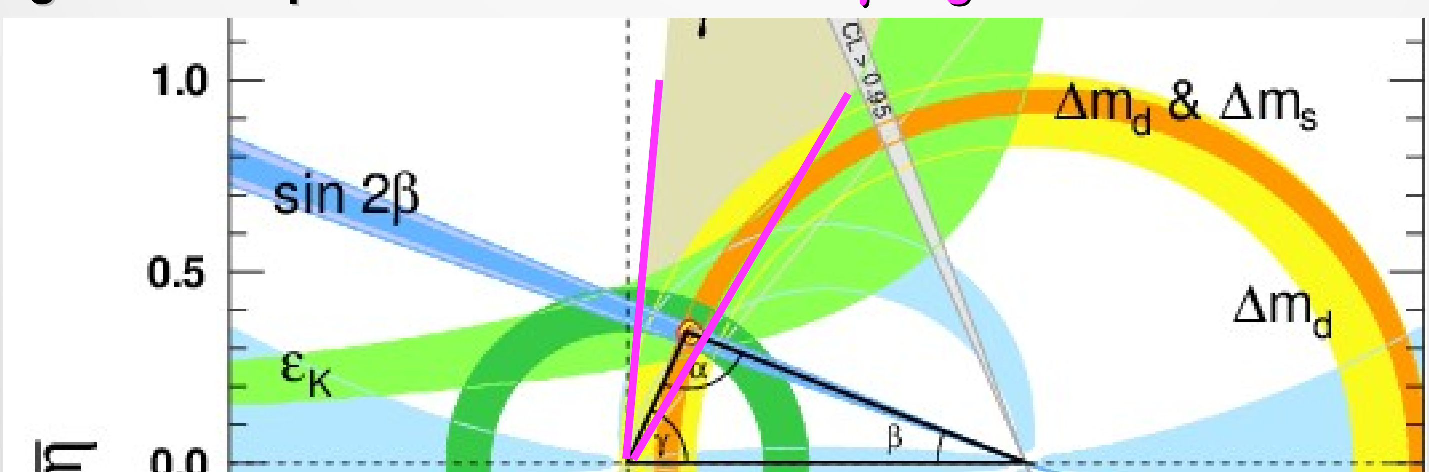
"Bd triangle"

$$V_{us}V_{ub}^{*}+V_{cs}V_{cb}^{*}+V_{ts}V_{tb}^{*}=0$$



"Bs triangle" (very squeezed)

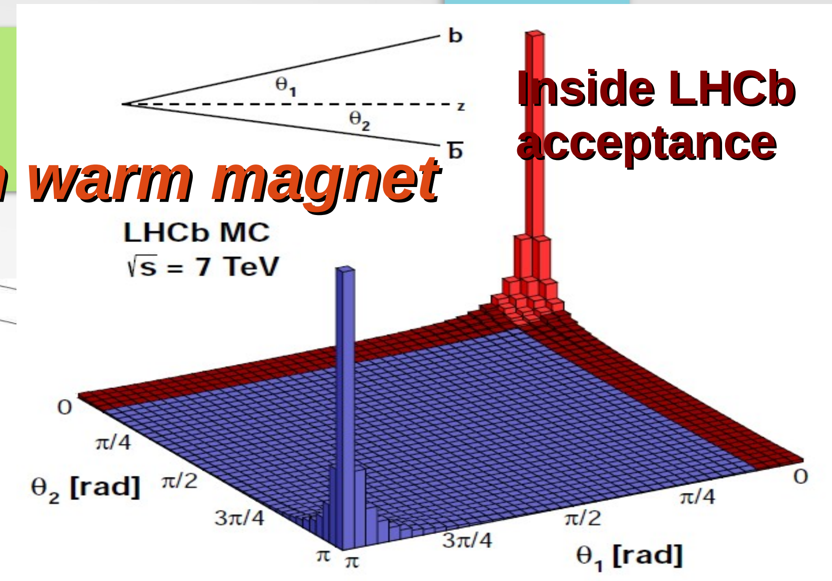
CKM picture verified but with higher precision, discrepancies could still arise, e.g. need for precise measurement of γ angle



CKM fitter Winter 14

LHCb detector

Forward single-arm spectrometer with warm magnet (possibility to inverse polarity)



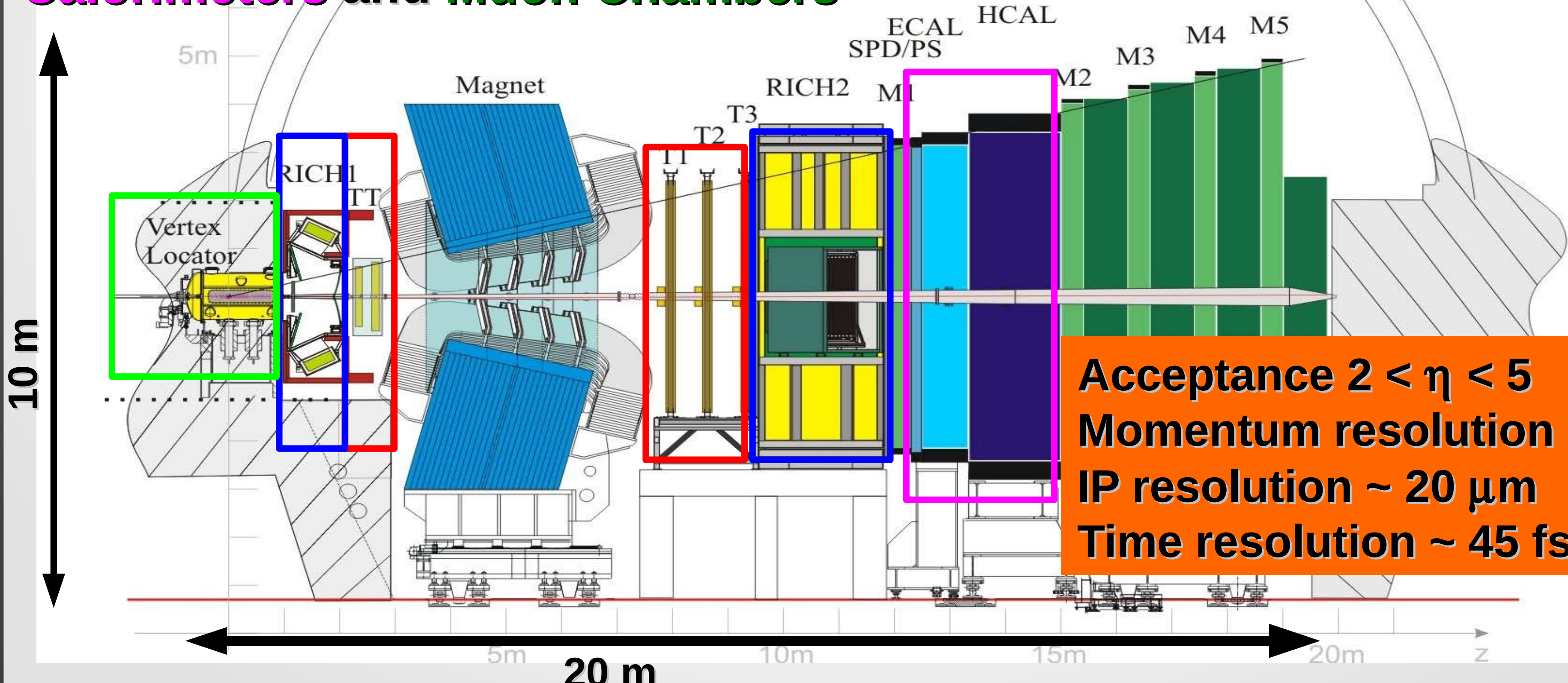
Optimize for b and c hadron studies

Vertexing

Tracking stations

Particle ID Ring Imaging Cherenkov

Calorimeters and Muon Chambers



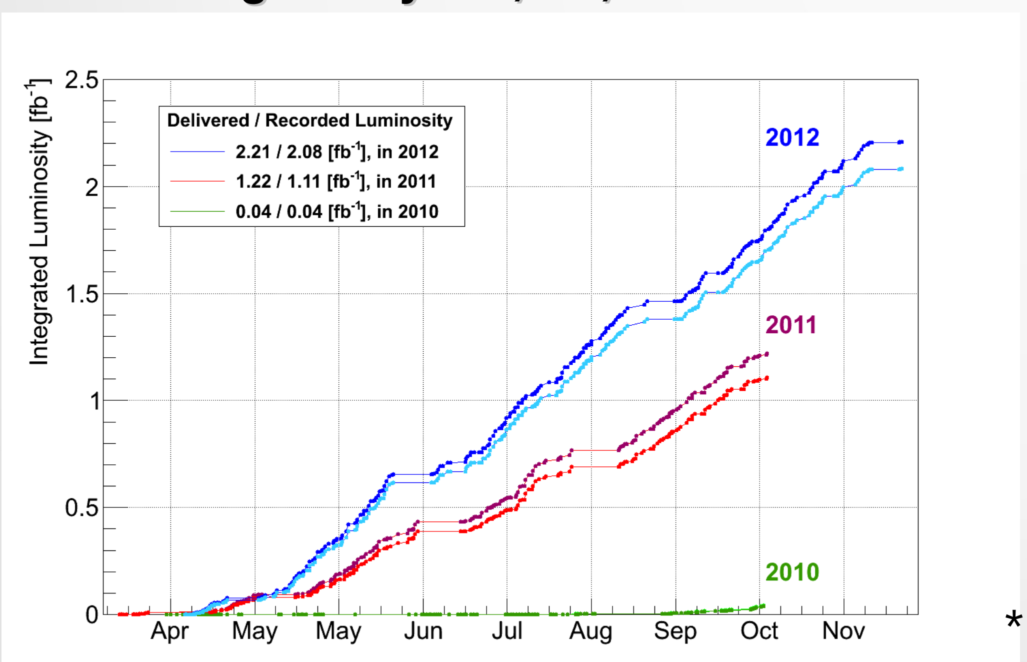
Acceptance 2 < η < 5
Momentum resolution ~ 0.5%
IP resolution ~ 20 μm
Time resolution ~ 45 fs

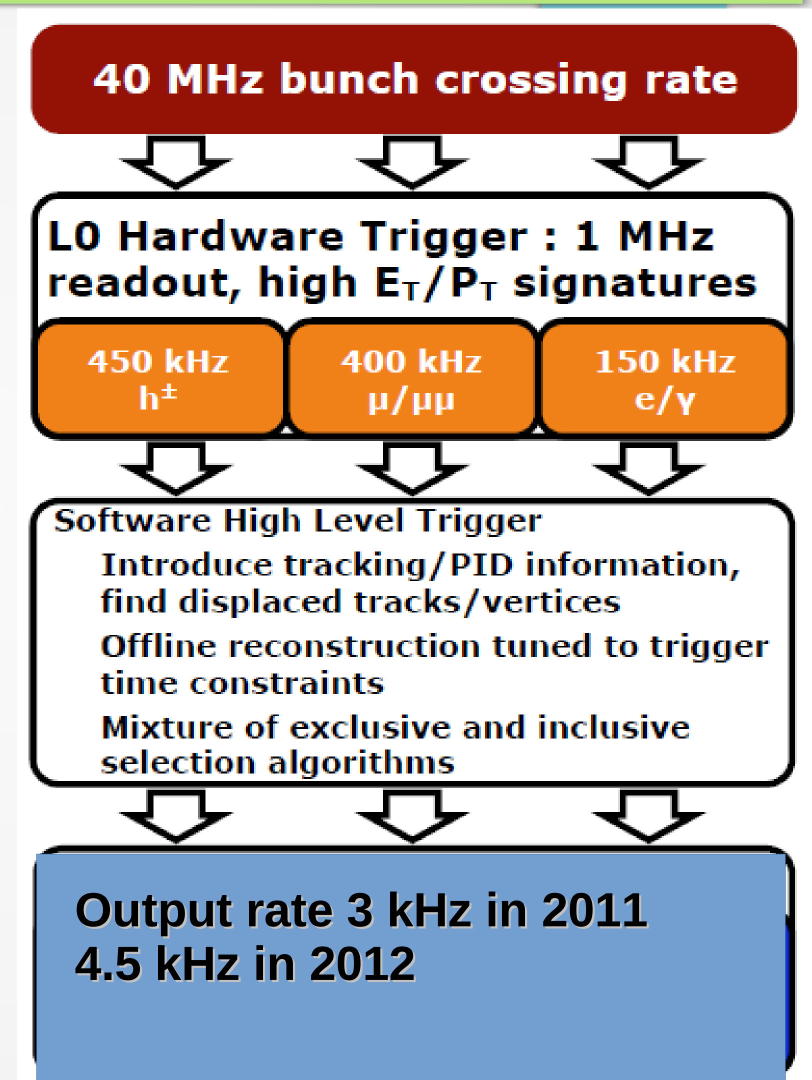
LHCb data (2011+2012) – Run I

10^{11} protons per bunch colliding at 7 (2011) and 8 (2012) TeV

Luminosity at IP8 (LHCb): 2-4 x 10^{32} cm^{-2} s^{-1}
About 1500 charged particles produced at each pp collision

$\sigma(b\bar{b})$ ~ 75 µb @ 7 TeV* in LHCb acceptance
~ 40% B+, 40% B0, ~ 10% Bs
Remaining b baryons, Bc, etc...



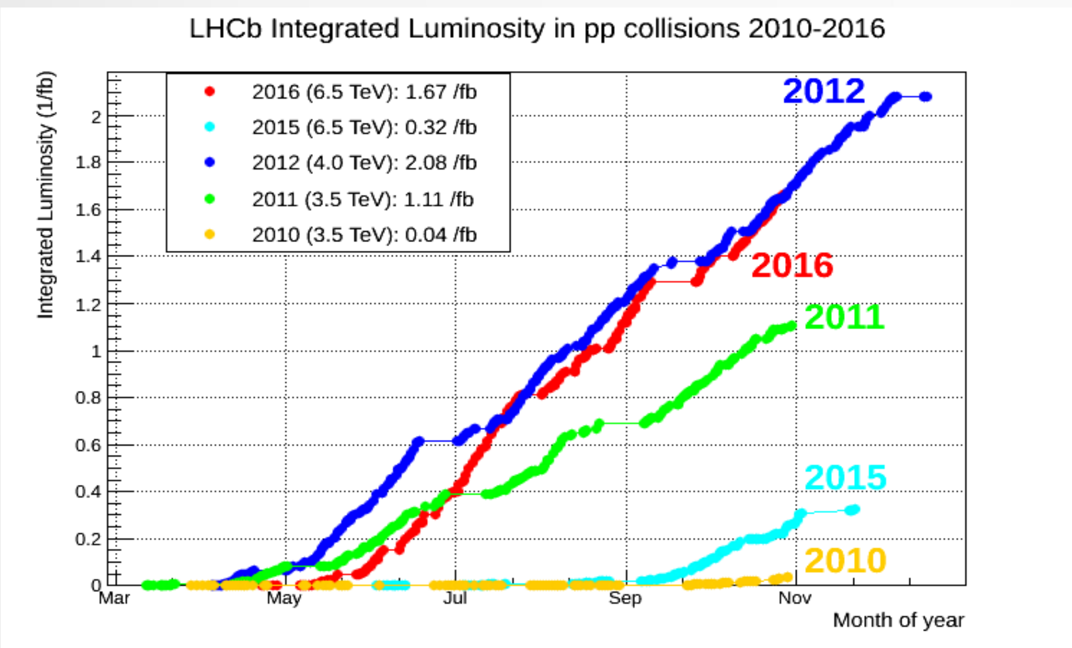


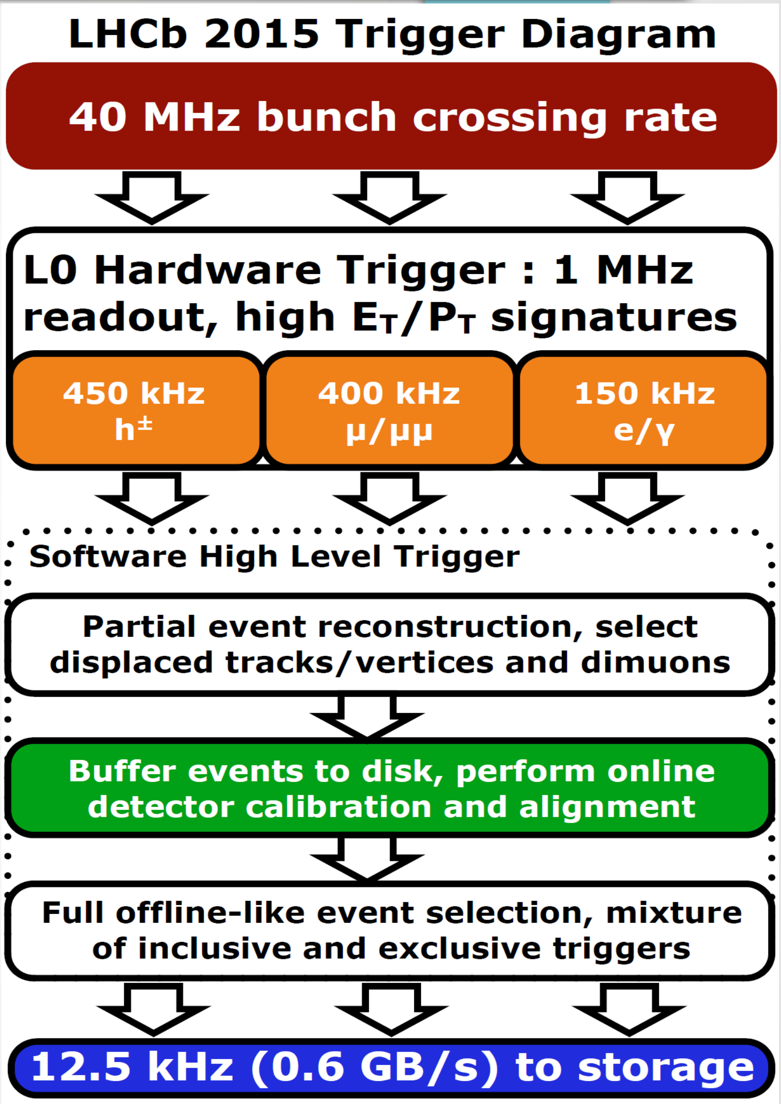
* *J. High Energy Phys.08 (2013) 117*

LHCb data (2015+2016) – ongoing Run II

Bunch colliding at 13 TeV

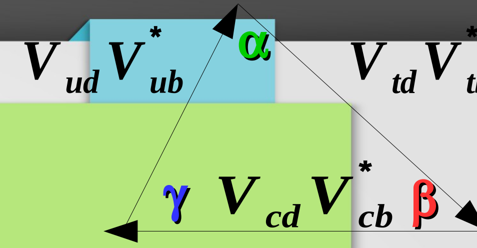
$\sigma(b\bar{b})$ ~ 165 μb @ 13 TeV* in LHCb acceptance
About 2.3 times the value @ 7-8 TeV



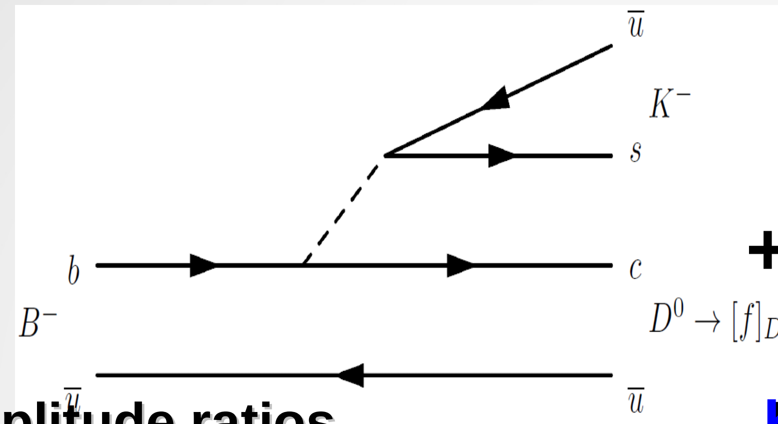


** LHCb-PAPER-2016-031*

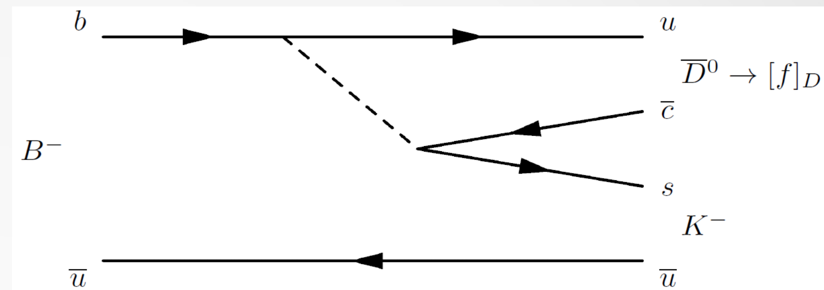
γ angle from $B \to DK^{(*)}(h,hh)$ decays



- Use interfering amplitudes in tree-level $B \to DK^{(*)}(h,hh)$ decays

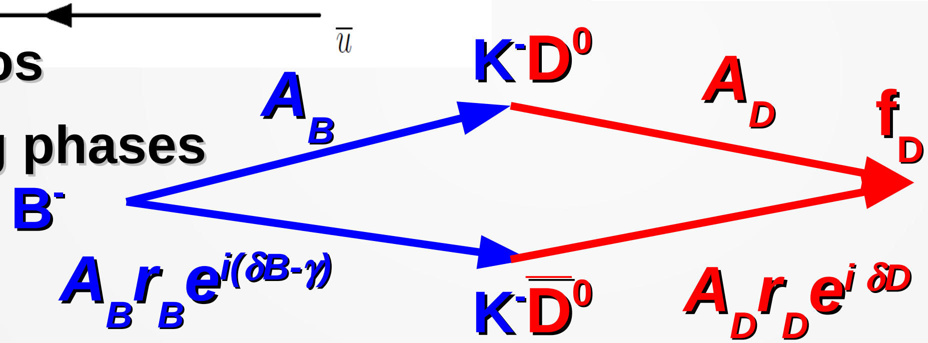


+



r_i: amplitude ratios

δ_i: relative strong phases



<u>In general</u>: r_D and f_D used as external inputs (e.g. from CLEO-c data)

- Fits use ratios of allowed/suppressed BF + asymmetries
- For multibody D decays, dilution factor due to δ_D variation across phase space
- Compare to γ from loop diagrams: mismatch? BSM particles in the loop?
- Combine LHCb analyses to make averages

γ from $B \to DK$, different techniques

- f_D = CP eigenstates, $D^0 \to K^+K^-$, $\pi^+\pi^-$, $K_S\pi^0$
  - Gronau, London, Wyler (GLW) 1991
- f_D = flavour states: $D^0 \to K^+\pi^-$, $K^-\pi^+$
  - Atwood, Dunietz, Soni (ADS) 1997
- f_D = multibody final states (variation of δ_D over phase space)
  - $K_Sh^+h^-$ Giri, Grossman, Soffer, Zupan 2003; Poluektov 2004 (GGSZ-P)
  - $K^\pm\pi^{-/+}\pi^+\pi^-$, multibody ADS
  - $K_SK^\pm\pi^{-/+}$, GLS
- Some variants involving neutrals, B^0 and Bs

Observables: charge asymmetries and BF ratios of suppressed/favoured D decays (applies for self-tagging decays)

γ from trees

Case of $D^0 \to K^- \pi^+$ (Cabibbo Allowed), $D^0 \to K^+ \pi^-$ (double Cabibbo Suppressed)

$$R_h^{\pm} = \frac{\Gamma\left(B^{\pm} \to D_{DCS} h^{\pm}\right)}{\Gamma\left(B^{\pm} \to D_{CA} h^{\pm}\right)} = \frac{r_B^2 + r_D^2 + 2 r_B r_D \cos\left(\delta_B + \delta_D \pm \gamma\right)}{1 + \left(r_B r_D\right)^2 + 2 r_B r_D \cos\left(\delta_B - \delta_D \pm \gamma\right)}$$

For multibody decays, must take into account the interference term between the two amplitudes in the D meson phase space, using a coherence factor κ_D

PRD68 (2003) 033003, arXiv:hep-ph/0304085

$$2 r_B r_D \cos\left(\delta_B + \delta_D \pm \gamma\right) \to 2 r_B r_D \kappa_D \cos\left(\delta_B + \delta_D \pm \gamma\right)$$

γ from B → DK in LHCb

- **Many channels under study in LHCb**
  - **Using either CP, flavour, or multibody final states of D**

B decay	D decay	Method	Ref.	Status since last combination [28]
$B^+ \to Dh^+$	$D \to h^+h^-$	GLW/ADS	[44]	Updated to $3\,\mathrm{fb}^{-1}$
$B^+ \to Dh^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[44]	Updated to $3\,\mathrm{fb}^{-1}$
$B^+ \to Dh^+$	$D \to h^+h^-\pi^0$	GLW/ADS	[45]	New
$B^+ \to DK^+$	$D \to K_\mathrm{S}^0 h^+h^-$	GGSZ	[46]	As before
$B^+ \to DK^+$	$D \to K_\mathrm{S}^0 K^-\pi^+$	GLS	[47]	As before
$B^+ \to Dh^+\pi^-\pi^+$	$D \to h^+h^-$	GLW/ADS	[48]	New
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS	[49]	As before
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz	[50]	New
$B^0 \to DK^{*0}$	$D \to K_\mathrm{S}^0\pi^+\pi^-$	GGSZ	[51]	New
$B_s^0 \to D_s^\mp K^\pm$	$D_s^+ \to h^+h^-\pi^+$	TD	[52]	As before

arXiv:1611.03076

γ combination of results

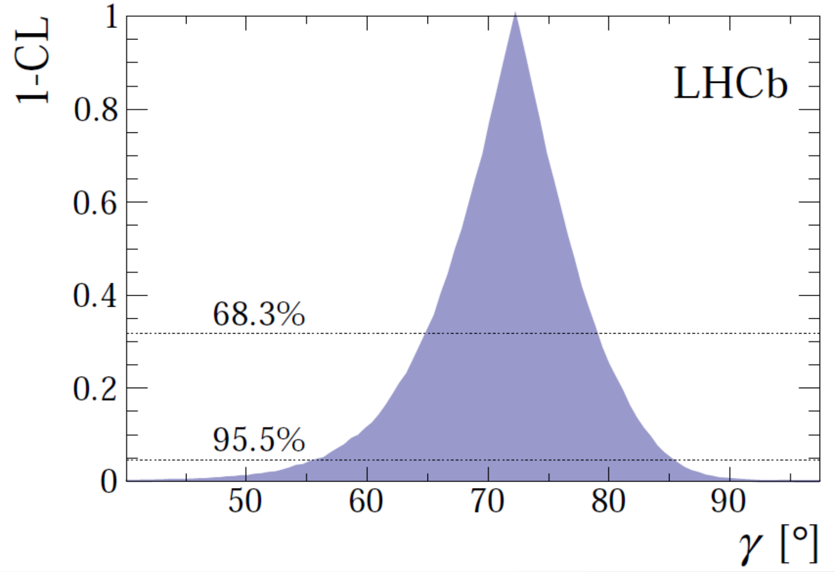
LHCb-PAPER-2016-032, arXiv:1611.03076
submitted to JHEP

NEW

Combination of analyses :

- $B^+ \to DK^+$
  - PLB760 (2016) 117, PRD91 (2015) 112014, JHEP 10 (2014) 097, PLB733 (2014) 36
- $B^0 \to DK^{*0}$
  - PRD90 (2014) 112002, JHEP 08 (2016) 137
- $B^0 \to DK\pi$
  - PRD93 (2016) 112018
- $B^+ \to DK^+\pi\pi$
  - PRD92 (2015) 112005,
- Time dependent $B_s \to D_s K^+$
  - JHEP 11 (2014) 060

$$\gamma = (72.2\,^{+6.8}_{-7.3})^\circ$$

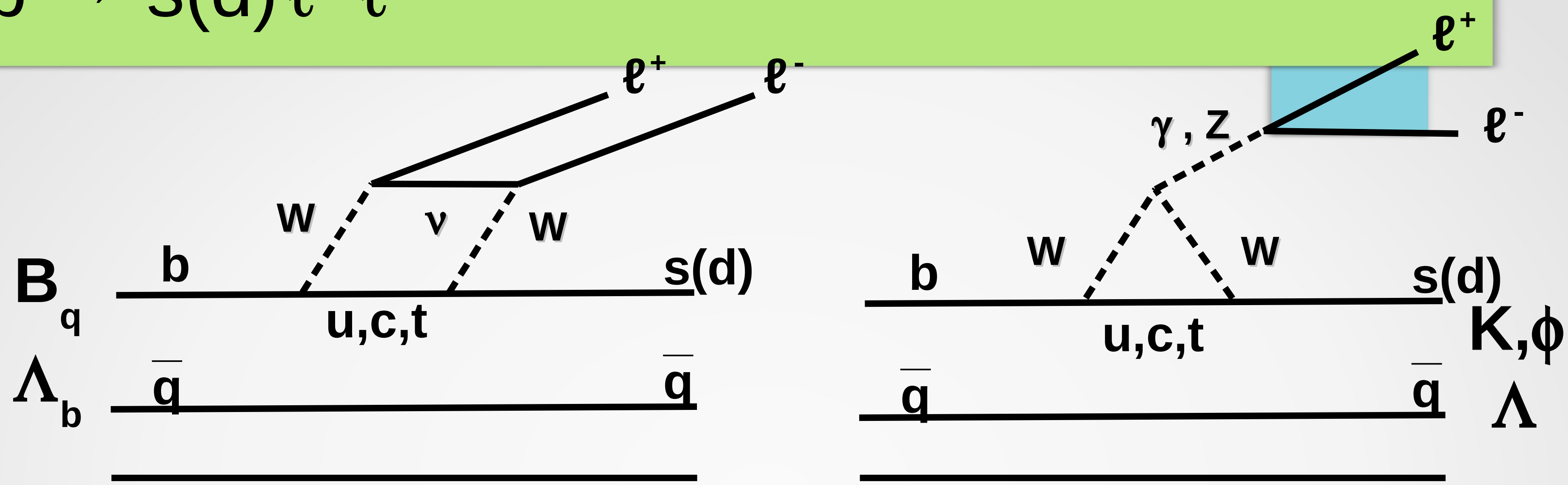


LHCb result dominates the world average

Rare (loop) decays

- Weak/Electromagnetic box diagrams $b \rightarrow s(d)\ell^+\ell^-$
- Observation of $B^0 \rightarrow K^+K^-$

$b \to s(d)\ell^+\ell^-$



New physics can intervene in the loops/boxes

Can be probed through the analysis of the dynamics of the decays

Or testing, e.g., lepton universality $b \to s\, e^+e^- / b \to s\mu^+\mu^-$

Dynamics for $B^0 \to K^{*0}\mu^+\mu^-$, $B_s \to \phi\mu^+\mu^-$

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_l\,\mathrm{d}\cos\theta_K\,\mathrm{d}\Phi} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-\boxed{F_\mathrm{L}})\sin^2\theta_K + \boxed{F_\mathrm{L}}\cos^2\theta_K$$
$$+\tfrac{1}{4}(1-\boxed{F_\mathrm{L}})\sin^2\theta_K\cos 2\theta_l - \boxed{F_\mathrm{L}}\cos^2\theta_K\cos 2\theta_l$$
$$+ S_3\sin^2\theta_K\sin^2\theta_l\cos 2\Phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\Phi$$
$$+ \boxed{A_5}\sin 2\theta_K\sin\theta_l\cos\Phi + \boxed{A_6}\sin^2\theta_K\cos\theta_l$$
$$+ S_7\sin 2\theta_K\sin\theta_l\sin\Phi + A_8\sin 2\theta_K\sin 2\theta_l\sin\Phi$$
$$+ A_9\sin^2\theta_K\sin^2\theta_l\sin 2\Phi\Big].$$

$q^2 = \mu^+\mu^-$ invariant mass squared

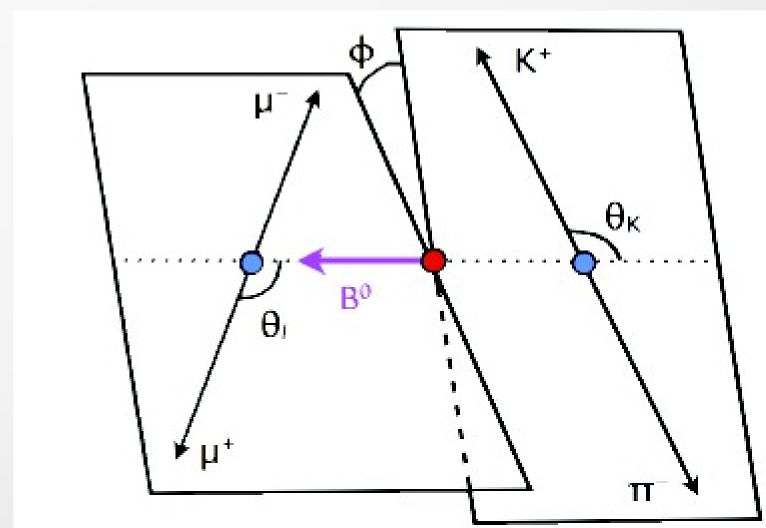
Formula slightly different between K* (self-tagging) and ϕ

F_L: fraction of longitudinal polarization of K*/ϕ

$A_6 \sim A_{FB}$ = forward-backward asymmetry of the dimuon system

$A_5 = S_5$ in the case of K*

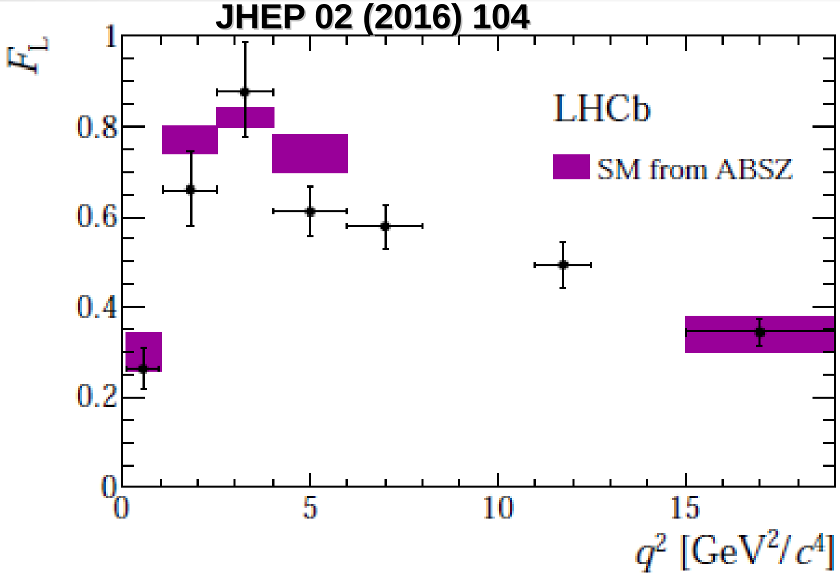
They depend on B →K*/ϕ form factors and Wilson Coefficients of the OPE

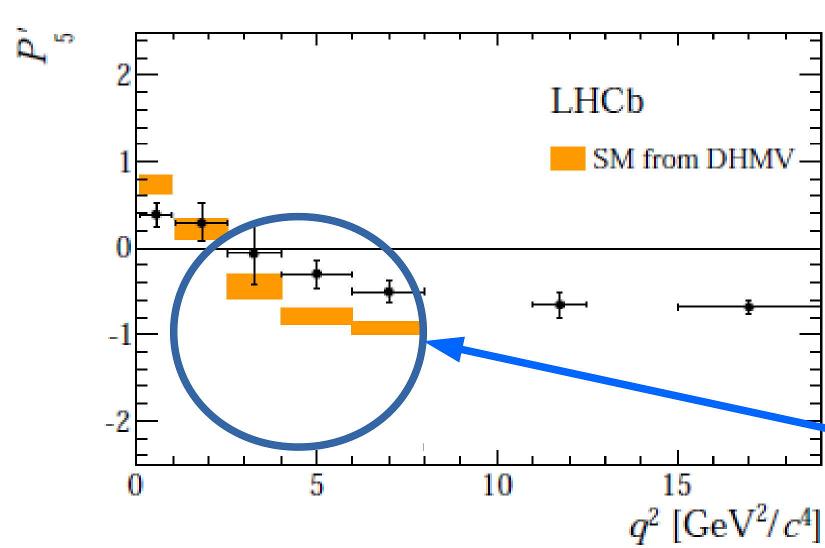


$B \rightarrow X\,\mu^+\mu^-$ results

$B^0 \rightarrow K^{*0}\mu^+\mu^-$

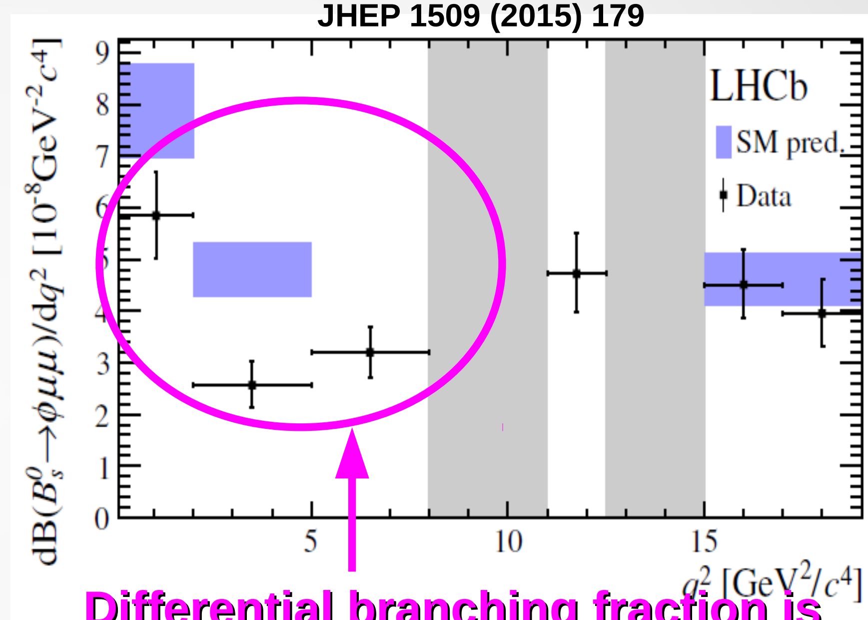
JHEP 02 (2016) 104





$B_s \rightarrow \phi\mu^+\mu^-$

JHEP 1509 (2015) 179



Differential branching fraction is 3.1σ below SM prediction in the lower q half, no discrepancy for the angular variables with this statistics

$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

Form-factor independent

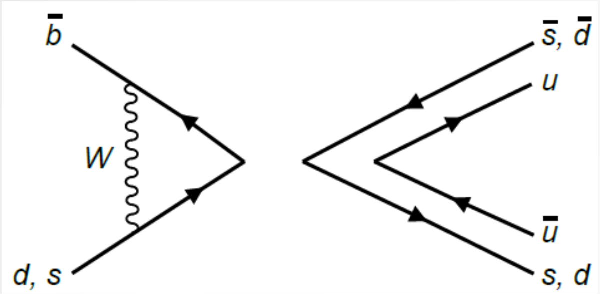
3.7σ combined difference with SM

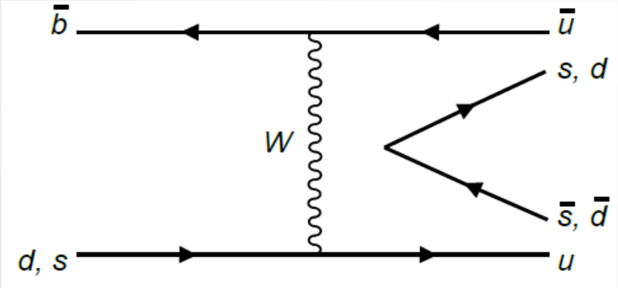
Observation of $B^0 \to K^+K^-$

arXiv:1610.08288
submitted to PRL

$B_s^0 \to K^+K^-$ can proceed through a penguin

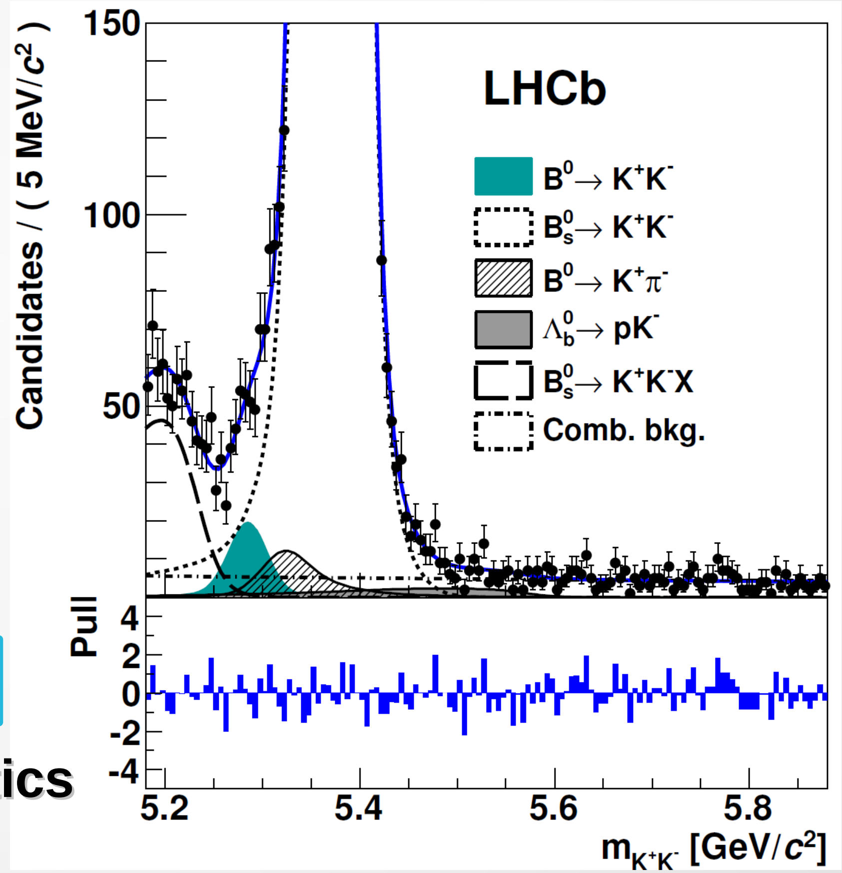
$B^0 \to K^+K^-$: annihilation or W exchange only





$$\boxed{N(B^0 \to K^+K^-) = 201 \pm 33 \pm 14}$$

Significance : 5.8σ including systematics

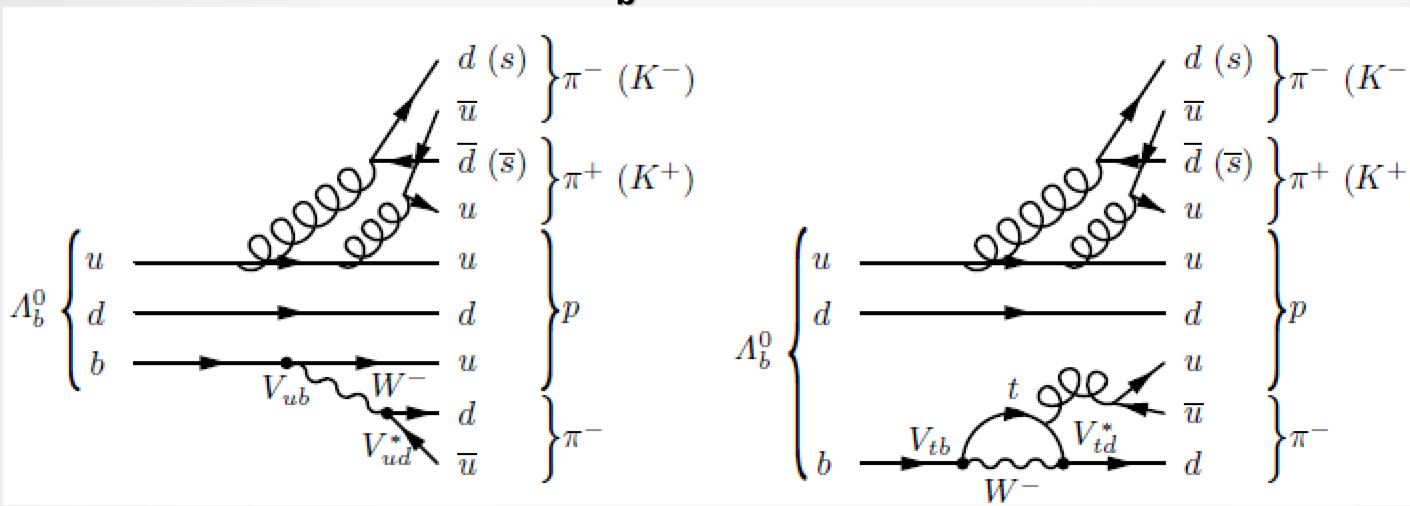


$$\boxed{\mathcal{B}(B^0 \to K^+K^-) = (7.80 \pm 1.27 \pm 0.81 \pm 0.21) \times 10^{-8}}$$

CP violation in baryon decays

arXiv:1609.05216
Submitted to Nature

CPV seen in B and K decays, never in baryons
Search for direct CPV in $\Lambda_b \to p\pi hh$ decays



Look at triple scalar products

$$C_{\widehat{T}} = \vec{p}_p \cdot (\vec{p}_{h_1^-} \times \vec{p}_{h_2^+})$$

$$\overline{C}_{\widehat{T}} = \vec{p}_{\overline{p}} \cdot (\vec{p}_{h_1^+} \times \vec{p}_{h_2^-})$$

$$A_{\widehat{T}}(C_{\widehat{T}}) = \frac{N(C_{\widehat{T}} > 0) - N(C_{\widehat{T}} < 0)}{N(C_{\widehat{T}} > 0) + N(C_{\widehat{T}} < 0)}$$

$$\overline{A}_{\widehat{T}}(\overline{C}_{\widehat{T}}) = \frac{\overline{N}(-\overline{C}_{\widehat{T}} > 0) - \overline{N}(-\overline{C}_{\widehat{T}} < 0)}{\overline{N}(-\overline{C}_{\widehat{T}} > 0) + \overline{N}(-\overline{C}_{\widehat{T}} < 0)}$$

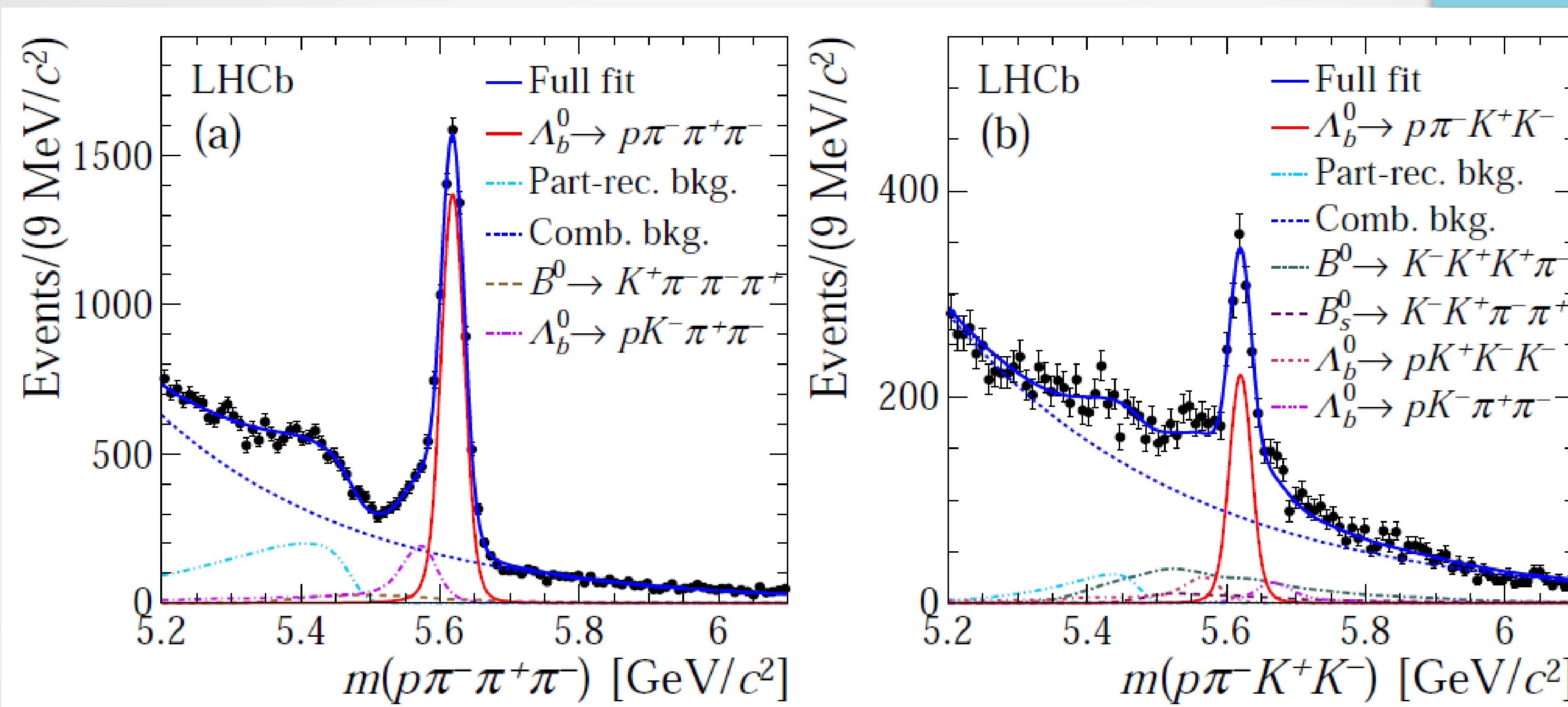
Observable measuring CPV :

$$a_{CP}^{\widehat{T}\text{-odd}} = \frac{1}{2}\left(A_{\widehat{T}} - \overline{A}_{\widehat{T}}\right)$$

$\Lambda_b \rightarrow p\pi hh$ signals and CP

arXiv:1609.05216
Submitted to Nature

First observation

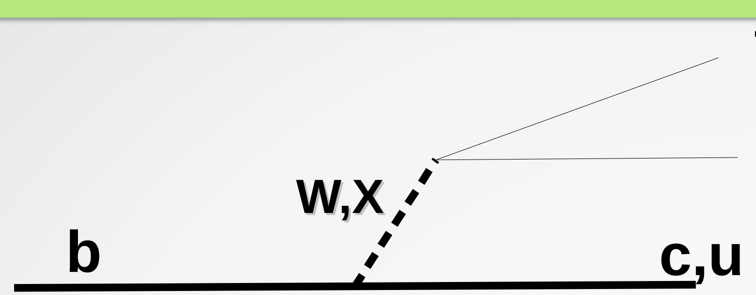


Overall 3.3σ CP violation found for $\Lambda_b \rightarrow p\pi\pi\pi$

First evidence of CP violation in baryon decays

No CP violation for $\Lambda_b \rightarrow p\pi KK$

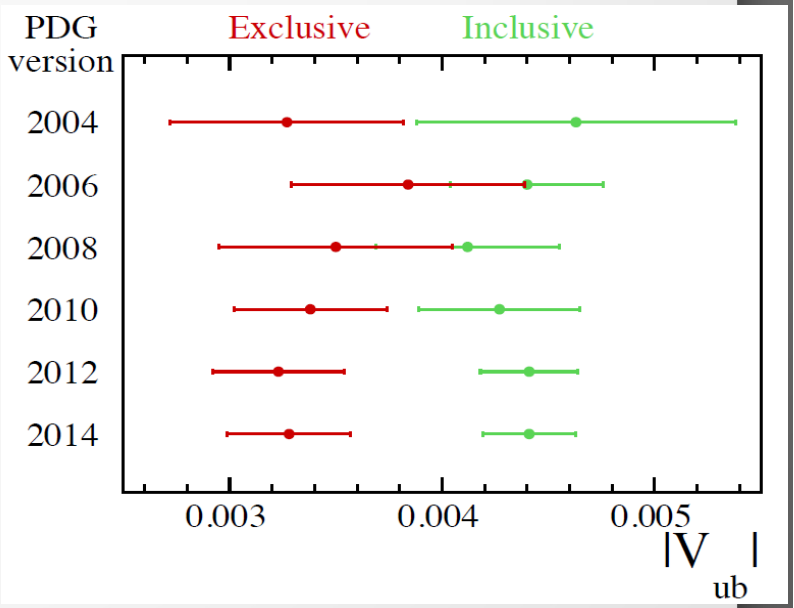
Semileptonics



Theoretically well-understood in the SM
Decays to light leptons well-measured by B factories
a) Not as good for τ lepton
b) Good way to extract V_{qb} CKM element

a) Any new (charged) intermediate boson/mediator would couples preferentially to τ: LHCb studied $B^0 \to D^{*+} \tau \nu$ / $B^0 \to D^{*+} \mu \nu$
(LHCb-PAPER-2015-025, arXiv:1506.08614)

b) Use of $b \to u \mu \nu$ to improve $|V_{ub}|$ (relative uncertainty still ~ 12-13%) + solve the tension between measurements from exclusive $B \to \pi \mu \nu$ and inclusive $B \to X_u \mu \nu$:
Use of $\Lambda_b \to p \mu \nu$ (LHCb-PAPER-2015-013, arXiv:1504.01568)



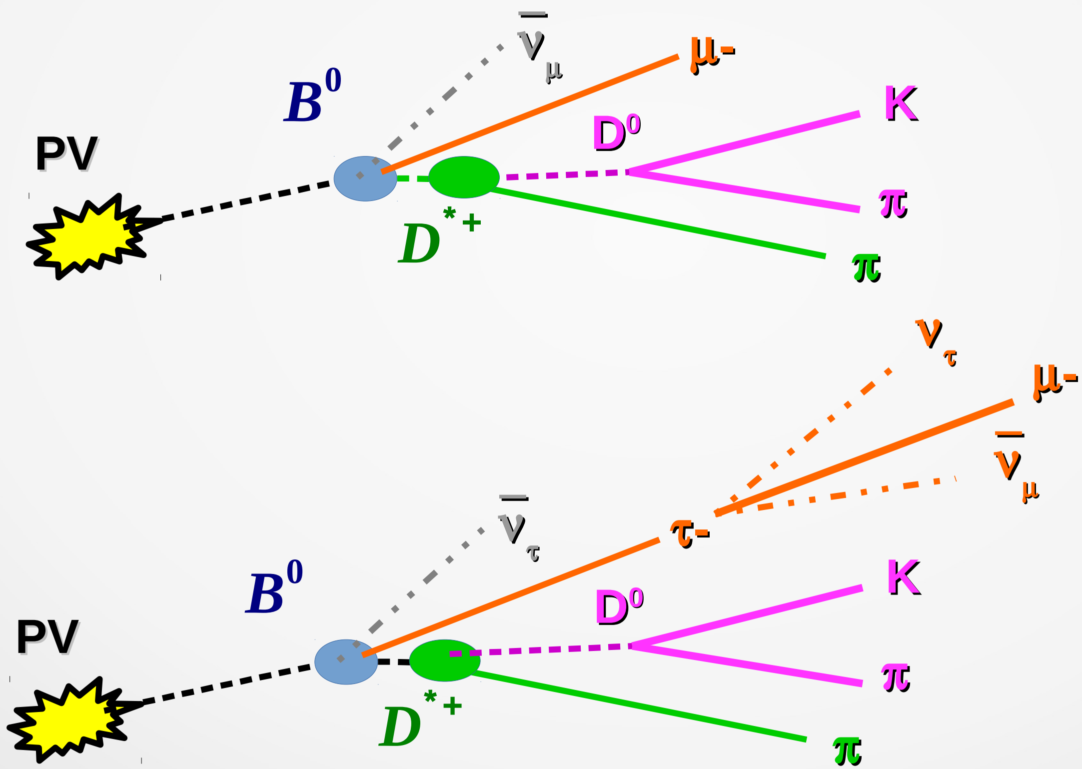
$\bar{B}^0 \rightarrow D^{*+}\,\tau^-\,\bar{\nu}_\tau$

Measure: $$R(D^*) \equiv \frac{\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\mu^-\bar{\nu}_\mu)}$$

Using τ decay:

$\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau$

= 0.252 in SM (PRD 85094025 (2012)), with very good precision



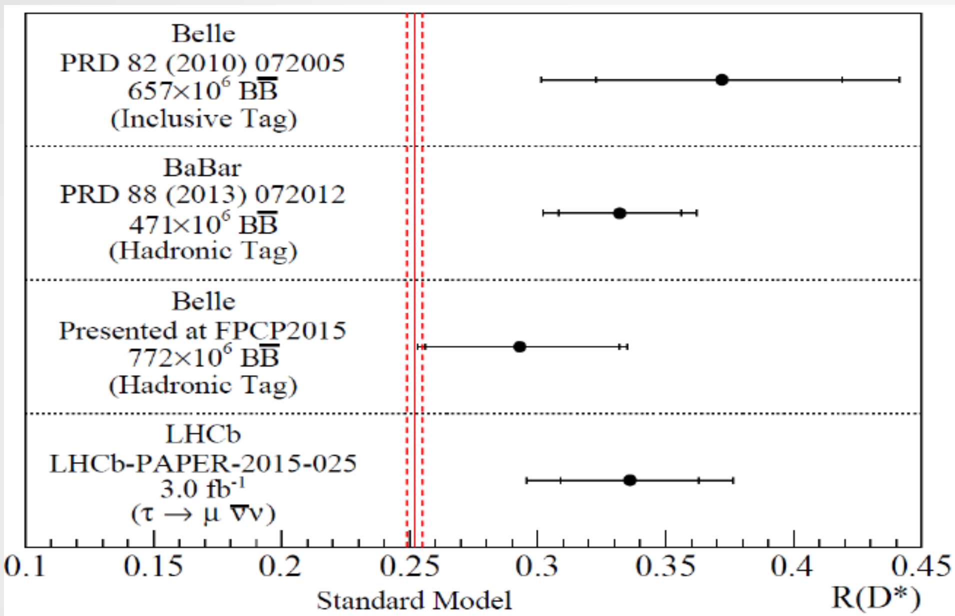
Very specific topologies + use of missing mass, muon energy and momentum transfer q

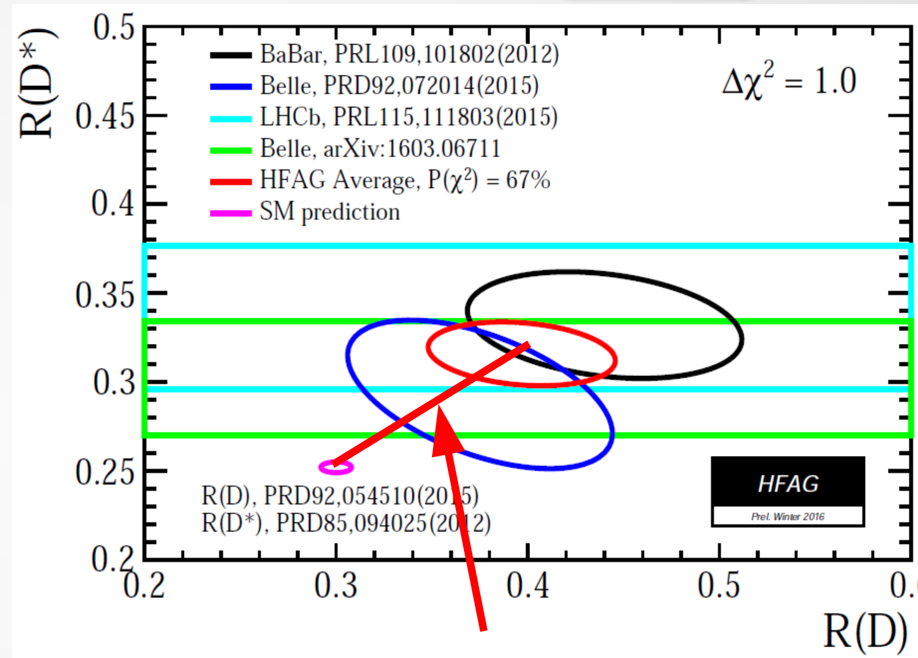
Ongoing effort for τ hadronic final state

LHCb-PAPER-2015-025, arXiv:1506.08614

R(D*) result

$R(D^*) = 0.336 \pm 0.027 \pm 0.030$





Follows historical trend, above SM prediction by ~ 2.1σ

Combined R(D) and R(D*) gives 4σ discrepancy from SM

Future results to test lepton universality : $R(J/\Psi)$ from B_c, $R(\Lambda_c)$ from Λ_b, $R(D_s^{(*)})$ from B_s

Direct CPV measurement in $D^0 \to K^+K^-$

arXiv:1610.09476
LHCb-PAPER-2016-035
Submitted to PLB

The flavour (D^0 or $\overline{D}^0$) is kinematically determined in the chain $D^{*+} \to D^0\pi^+$ / $D^{*-} \to \overline{D}^0\pi^-$

$$A_{CP}(D^0 \to K^-K^+) \equiv \frac{\Gamma(D^0 \to K^-K^+) - \Gamma(\overline{D}^0 \to K^-K^+)}{\Gamma(D^0 \to K^-K^+) + \Gamma(\overline{D}^0 \to K^-K^+)}$$

In practice :

Production asymmetry

$$A_{CP}(D^0 \to K^-K^+) = A_{\rm raw}(D^0 \to K^-K^+) - A_P(D^{*+}) - A_D(\pi_s^+)$$

Slow pion detection asymmetry

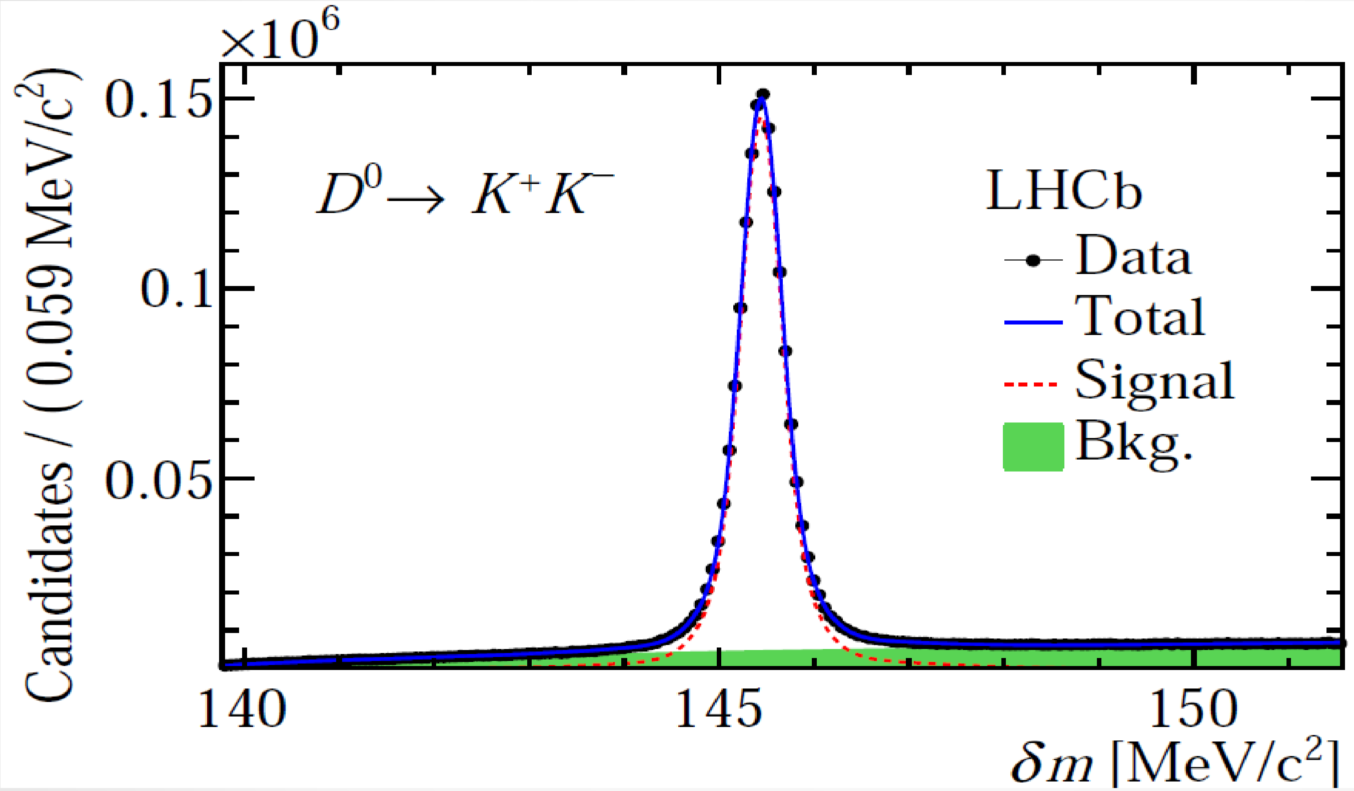
$A_P(D^{*+}) + A_D(\pi_s^+)$ **is measured using the raw asymmetries of the decays**

$D^0 \to K^-\pi^+$ $\quad D^+ \to K^-\pi^+\pi^+$ $\quad D^+ \to \overline{K}^0\pi^+$

and $A_D(\overline{K}^0)$ **which is known to be small and under control**

Fit to $\delta m \equiv m(h^+h^-\pi_s^+) - m(h^+h^-)$ $\quad h = K, \pi$

Direct CPV measurement in $D^0 \rightarrow K^+K^-$



$$A_{CP}(K^-K^+) = (0.14 \pm 0.15\,(\text{stat}) \pm 0.10\,(\text{syst}))\%$$

Combined LHCb value : $A_{CP}^{\text{comb}}(K^-K^+) = (0.04 \pm 0.12\,(\text{stat}) \pm 0.10\,(\text{syst}))\%$

Most precise single-experiment measurement

No CP violation in the charm sector !

Bc physics

- Unique hadron with two heavy quarks $Bc^+ = \bar{b}c$
- Decays through either charm or beauty quark
  - Decays could include lighter B mesons !
- Spectroscopy not very well known
  - About 10 measurements (8 upper limits!)
  - Limitation due to the lack of knowledge of the production $pp(\rightarrow b)\rightarrow Bc$ cross-section : measure products of branching fractions and cross-section ratios

LHCb pioneering work in Bc physics

Measured values of physical observables	Data
$\frac{Br(B_c\to J/\psi\pi^+\pi^-\pi^+)}{Br(B_c\to J/\psi\pi^+)} = 2.41 \pm 0.30 \pm 0.33$	$0.8\ \mathrm{fb}^{-1}$
$R_{c/u} \equiv \frac{\sigma(B_c)Br(B_c\to J/\psi\pi^+)}{\sigma(B_u)Br(B_u\to J/\psi K^+)} =$ **0.68±0.02 %**	**2 fb^{-1}**
$\frac{Br(B_c\to\psi(2S)\pi^+)}{Br(B_c\to J/\psi\pi^+)} = 0.250 \pm 0.068 \pm 0.014$	$1.0\ \mathrm{fb}^{-1}$
$R_{D_s/\pi} \equiv \frac{Br(B_c\to J/\psi D_s^+)}{Br(B_c\to J/\psi\pi^+)} = 2.90 \pm 0.57 \pm 0.24$	$3\ \mathrm{fb}^{-1}$
$R_{D_s^*/D_s} \equiv \frac{Br(B_c\to J/\psi D_s^{*+})}{Br(B_c\to J/\psi D_s^+)} = 2.37 \pm 0.56 \pm 0.10$	$3\ \mathrm{fb}^{-1}$
$f_{\pm\pm} \equiv \frac{Br_{\pm\pm}(B_c\to J/\psi D_s^{*+})}{Br(B_c\to J/\psi D_s^{*+})} = (52 \pm 20)\%$	$3\ \mathrm{fb}^{-1}$
$\frac{Br(B_c\to J/\psi K^+)}{Br(B_c\to J/\psi\pi^+)} =$ **0.079±0.007±0.003**	**3 fb^{-1}**
$\frac{\sigma(B_c)}{\sigma(B_s)} \times Br(B_c \to B_s\pi^+) = 2.37^{+0.37}_{-0.35} \cdot 10^{-3}$	$3\ \mathrm{fb}^{-1}$
$\frac{Br(B_c\to J/\psi K^+K^-\pi^+)}{Br(B_c\to J/\psi\pi^+)} = 0.53 \pm 0.10 \pm 0.05$	$3\ \mathrm{fb}^{-1}$

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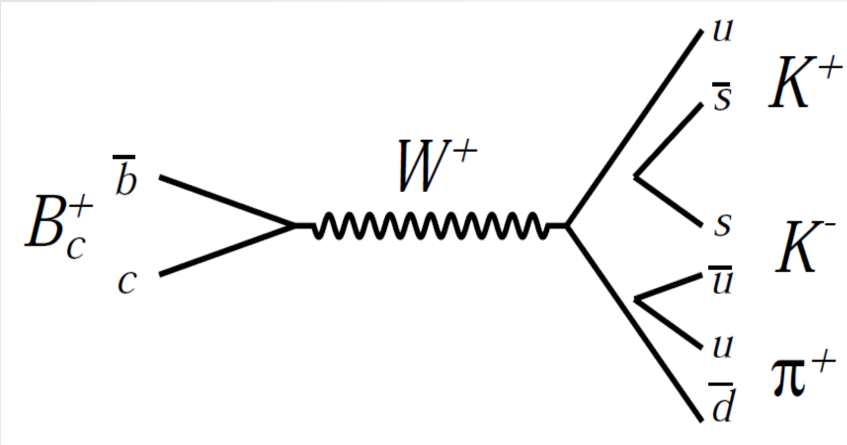
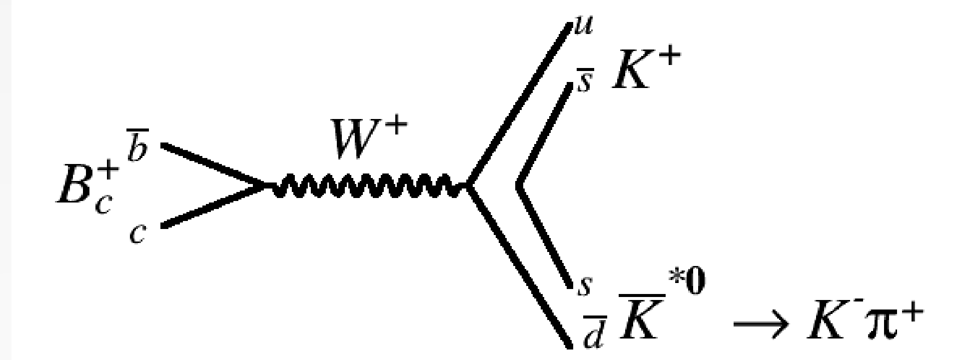
And many ongoing results and studies...

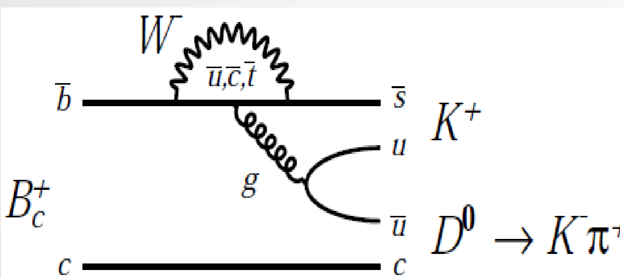
Search for Bc annihilation in the KKπ final state – Run I data only

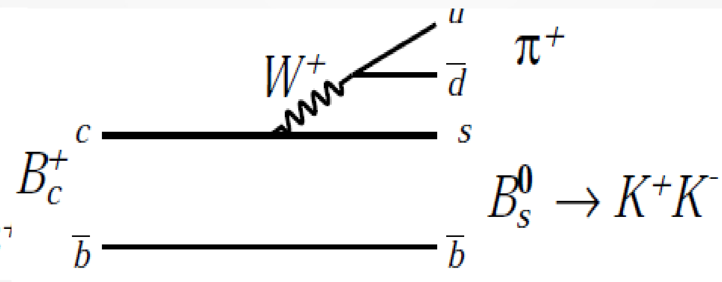
LHCb-PAPER-2016-022
arXiv:1607.06134
To be published in PRD-RC

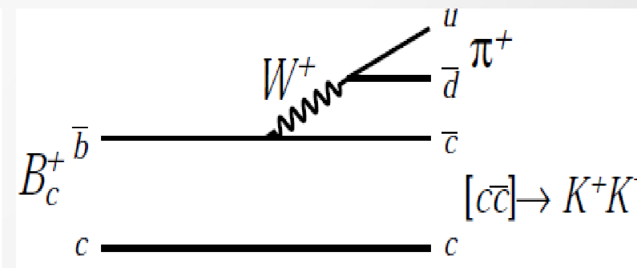




Other processes in the phase space :







Spectrum analysed in bins of Decision Tree classifier

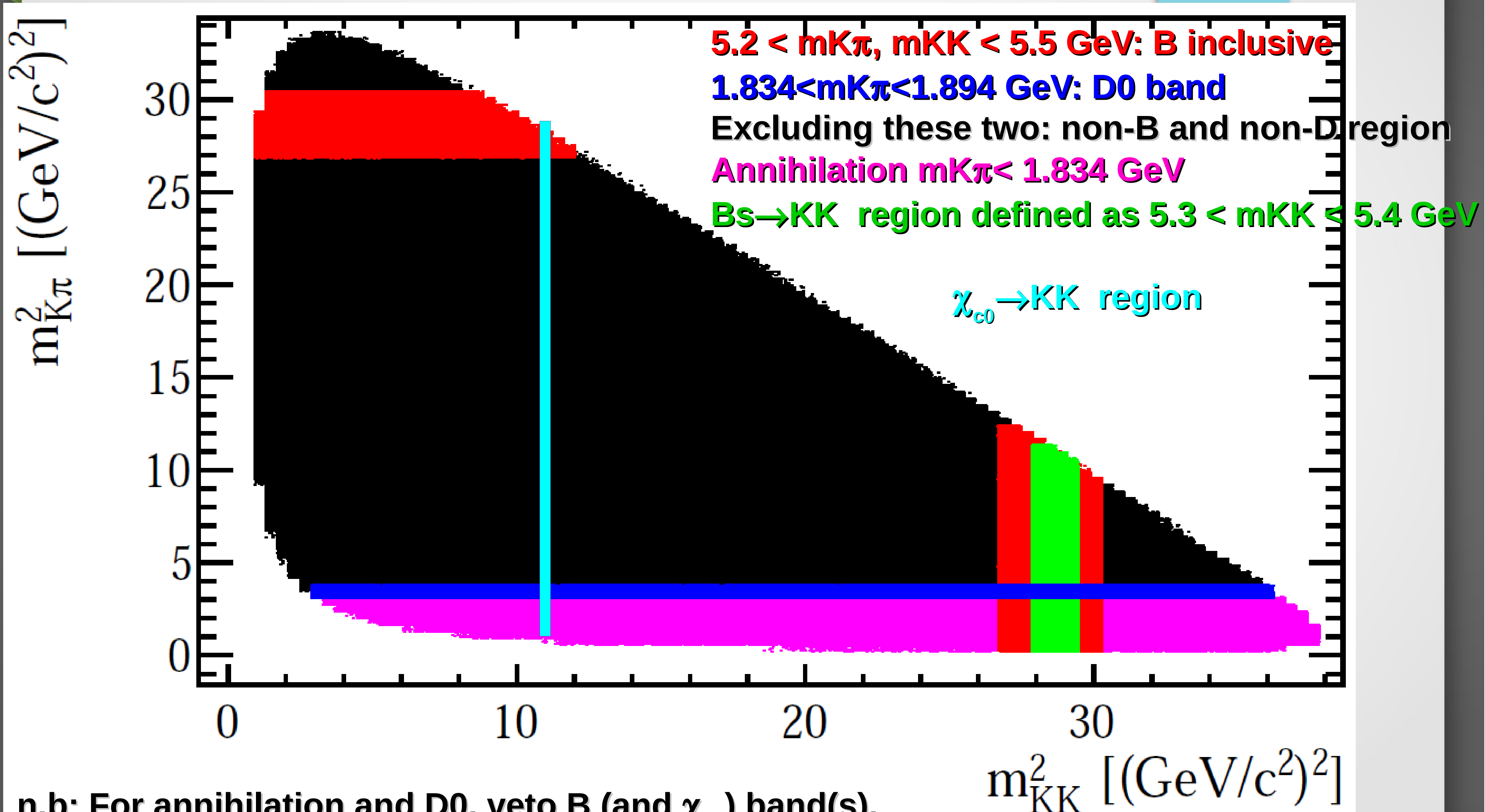
Normalizing channel :

$$B^+ \to \overline{D}^0(\to K^+K^-)\pi^+$$

Measured observable :

$$R_f \equiv \frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to f)$$

Fit Regions definition

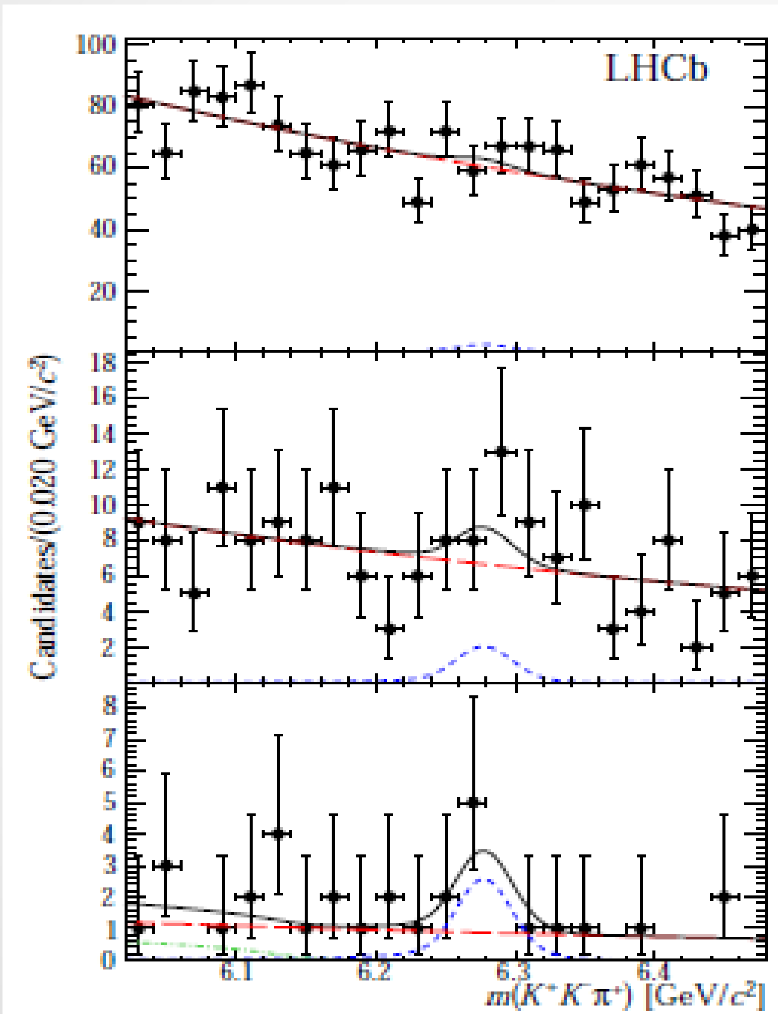


n.b: For annihilation and D0, veto B (and χ_{c0}) band(s), efficiency accounts for this.

Signal in annihilation region

Simultaneous fit to bins of Decision Tree Classifier

Increasing purity



~ 21±10 signal events
With a global significance of 2.4σ

Hint of annihilation signal ?

Adding Run II data will help to confirm

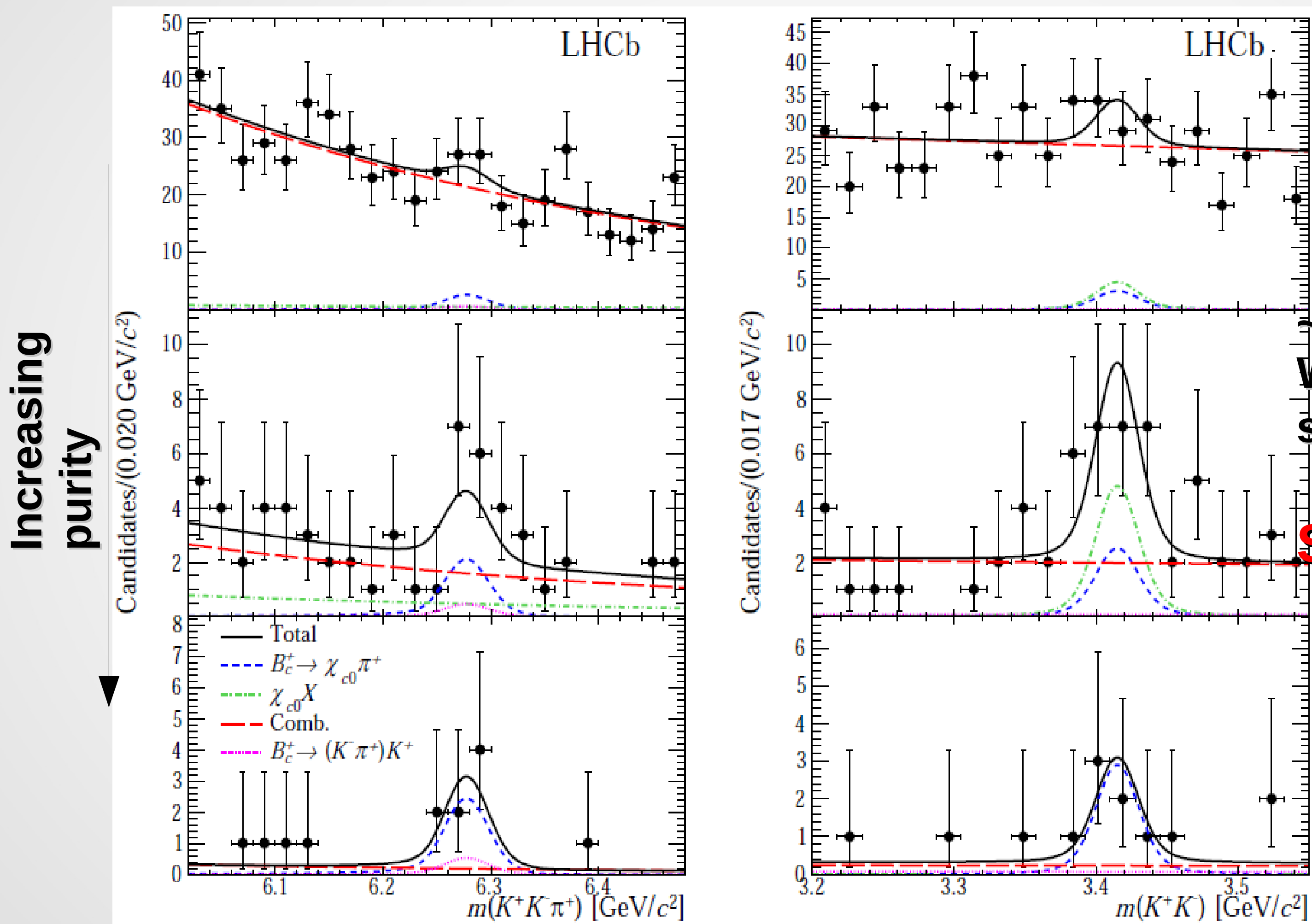
$$R_{\mathrm{an},KK\pi} = \left(8.0^{+4.4}_{-3.8}(\mathrm{stat}) \pm 0.6(\mathrm{syst})\right) \times 10^{-8}$$

Compare to SM-based conservative range :

$$\sim [0.1, 1.7] \times 10^{-8}$$

Observation of Bc→ χ_{c0}(→KK)π

m(KKπ) **m(KK)**



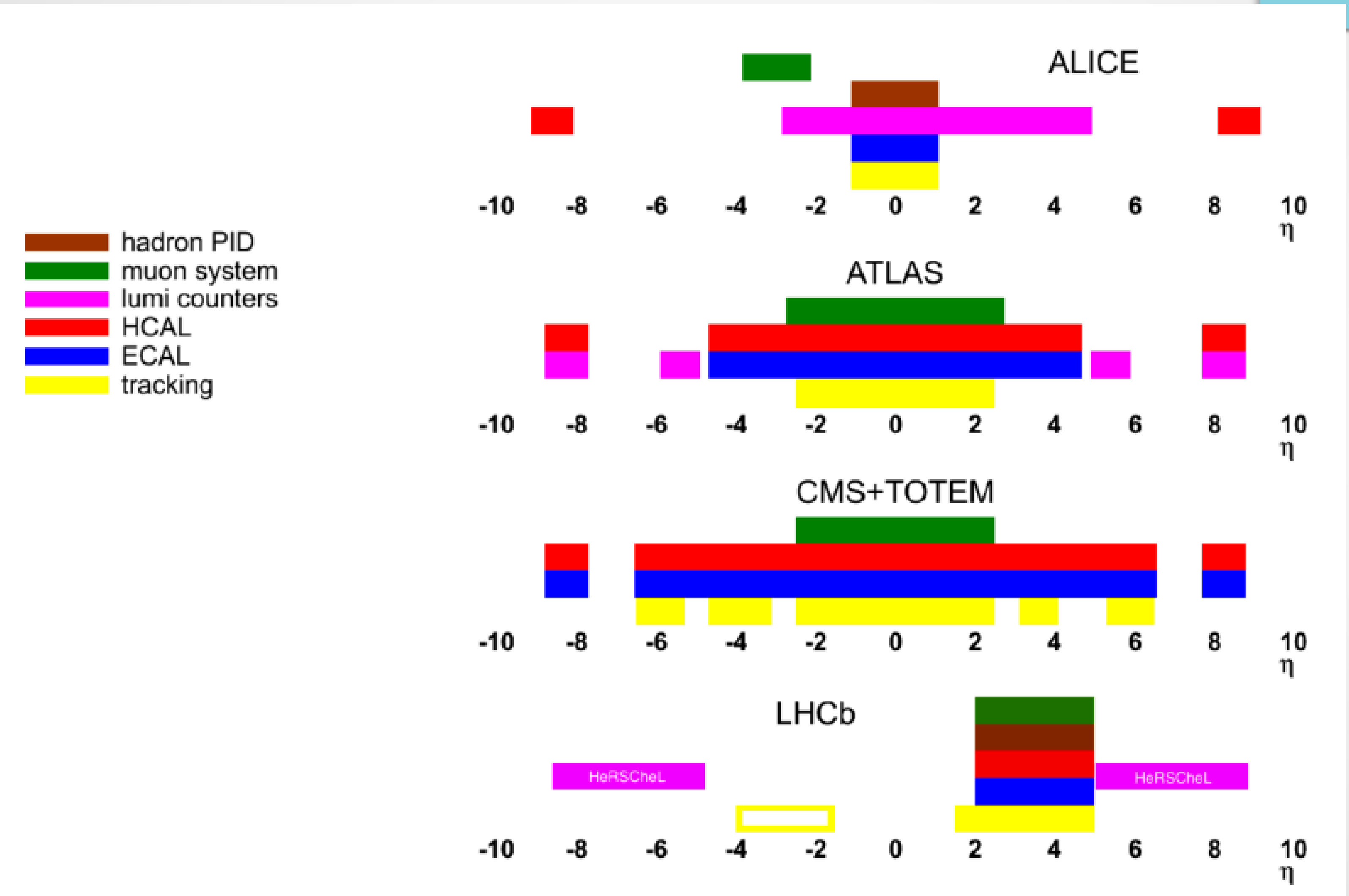
~ 21±6 signal events With a global significance of 4σ

Strong evidence

$$R_{\chi_{c0}\pi} = (9.8^{+3.4}_{-3.0}(\text{stat}) \pm 0.8(\text{syst})) \times 10^{-6}$$

Similar to (7.0±0.3)×10^{-6} for J/Ψπ

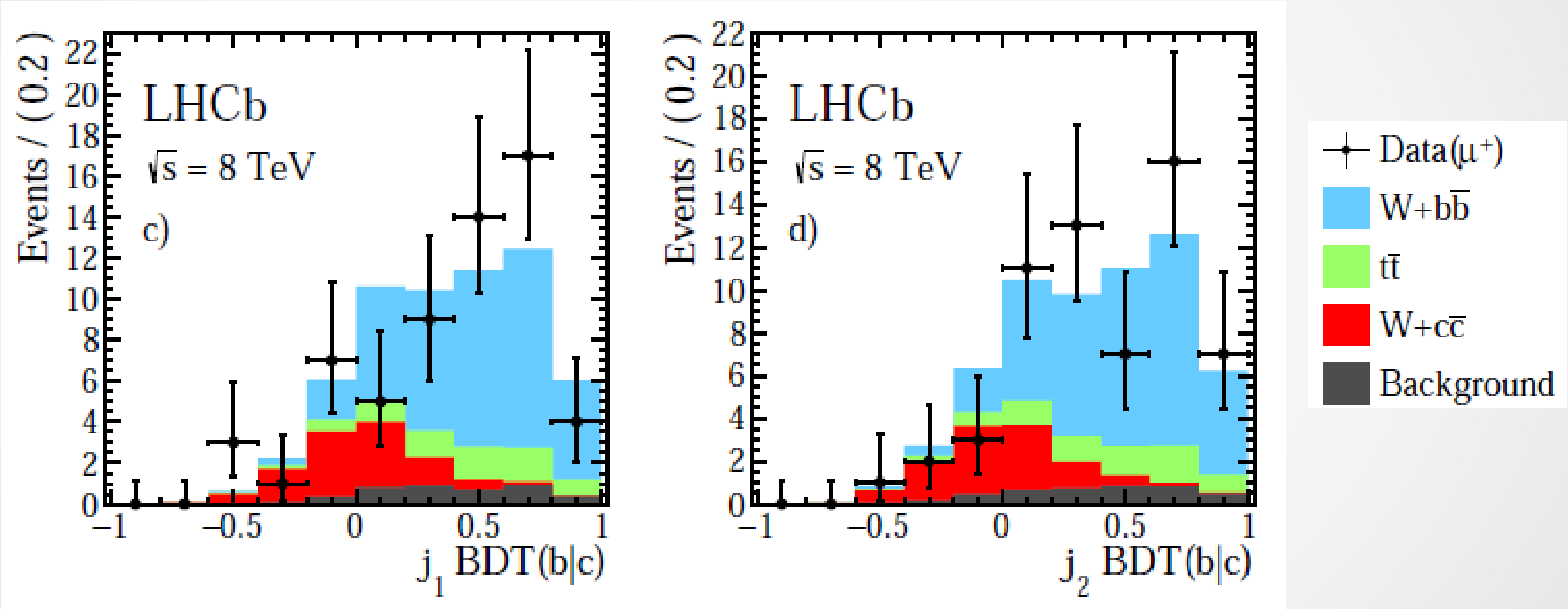
Forward physics



Forward physics, resolving W+b$\bar{b}$, W+c$\bar{c}$, t$\bar{t}$

LHCb-PAPER-2016-038
arXiv:1610.08142, submitted to PLB

W^+ ($\mu^+\nu$) + j1 j2 template fit



Analysis done for 4 samples $W^\pm$(μ/e ν) + j1 j2
Main background : Z($\mu\mu$/ee) + j1 j2

Results on W+b$\bar{b}$, W+c$\bar{c}$, t$\bar{t}$

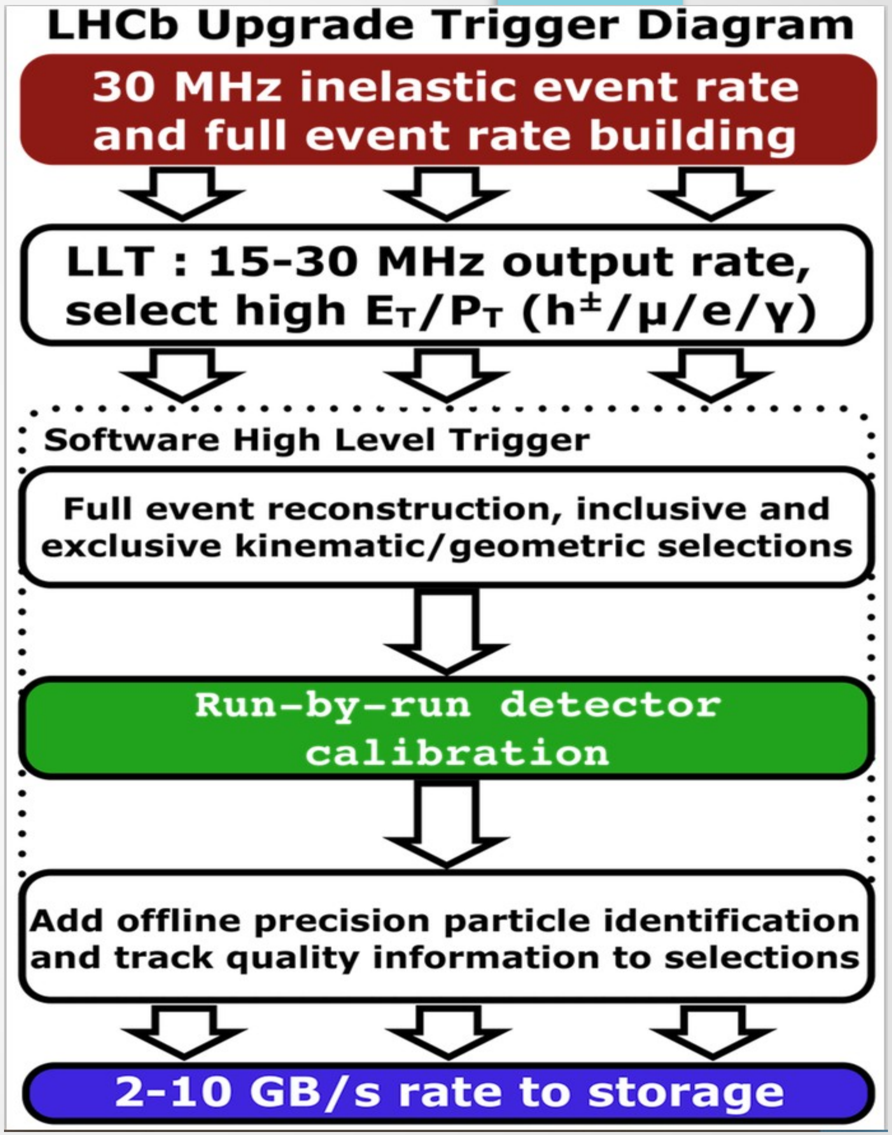
Signal	K	μ sample yields	e sample yields
$W^+ + b\bar{b}$	$1.49^{+0.23}_{-0.22}$	$45.5^{+6.9}_{-6.4}$	$20.5^{+3.1}_{-2.9}$
$W^- + b\bar{b}$	$1.67^{+0.33}_{-0.30}$	$28.7^{+5.6}_{-4.9}$	$12.1^{+2.3}_{-2.1}$
$W^+ + c\bar{c}$	$1.92^{+0.68}_{-0.58}$	$12.8^{+4.5}_{-3.9}$	$5.7^{+2.0}_{-1.7}$
$W^- + c\bar{c}$	$1.58^{+0.87}_{-0.73}$	$5.7^{+3.1}_{-2.6}$	$2.5^{+1.4}_{-1.2}$
$t\bar{t}$	$1.17^{+0.35}_{-0.31}$	$8.7^{+2.6}_{-2.3}$ (μ^+) $8.3^{+2.5}_{-2.2}$ (μ^-)	$3.7^{+1.1}_{-1.0}$ (e^+) $4.0^{+1.2}_{-1.1}$ (e^-)

Process	Expected [pb]	Observed [pb]	Significance
$W^+ + b\bar{b}$	$0.081\ ^{+0.022}_{-0.013}\ ^{+0.040}_{-0.018}$	$0.121\ ^{+0.019}_{-0.018}\ ^{+0.029}_{-0.020}$	7.1σ
$W^- + b\bar{b}$	$0.056\ ^{+0.014}_{-0.010}\ ^{+0.018}_{-0.013}$	$0.093\ ^{+0.018}_{-0.017}\ ^{+0.023}_{-0.016}$	5.6σ
$W^+ + c\bar{c}$	$0.123\ ^{+0.034}_{-0.020}\ ^{+0.060}_{-0.027}$	$0.24\ ^{+0.08}_{-0.07}\ ^{+0.08}_{-0.04}$	4.7σ
$W^- + c\bar{c}$	$0.084\ ^{+0.021}_{-0.015}\ ^{+0.027}_{-0.020}$	$0.133\ ^{+0.073}_{-0.062}\ ^{+0.050}_{-0.022}$	2.5σ
$t\bar{t}$	$0.045\ ^{+0.008}_{-0.007}\ ^{+0.012}_{-0.010}$	$0.05\ ^{+0.02}_{-0.01}\ ^{+0.02}_{-0.01}$	4.9σ

Still compatible with NLO SM-based predictions

Upgrade

- Planned during LS2 (2019-2020)
  - Prepare for acquisition of 50 fb^{-1}
- Detectors:
  - full upgrade of the tracking system
  - new RICH (Particle ID) detectors
  - Calorimeters and muon system: new electronics, more shielding, etc...
- Triggering: full software trigger
  - This removes the limitation of the L0 Hardware trigger (1 MHz)



Summary

- A big variety of results
  - A lot of recent results not shown : e.g., $B_s \to \phi\gamma$ polarisation (arXiv:1609.02032), $\Sigma \to p\mu\mu$ (LHCb-CONF-2016-013), etc...
  - Pushing the SM further in the corners and hunt for intervention of NP: e.g., persisting discrepancies in some observables of rare decays
  - Forward physics and Heavy Ion physics programs progressing as well
- Run II data taking is going on efficiently, 2 fb^{-1} of data already recorded with $\sigma(b\bar{b})(13\ \mathrm{TeV}) > 2 \times \sigma(b\bar{b})(7\text{-}8\ \mathrm{TeV})$
  - A lot of news should come with the analysis of the full Run I + 2015 + 2016 sample
- Preparation for upgrade is well advanced and most of the R&D phases are now achieved