Conference Summary

Rather a collection of impressions from the conference.

04/10/2019 — Beauty in Ljubljana

Patrick Koppenburg

Adria airways

Train


Metz
Karlsruhe
Stuttgart
Ingolstadt
Nancy
Strasbourg
Ulm
Augsburg
Munich
Freiburg im Breisgau
Colmar
Konstanz
Kempten
Friedrichshafen
Garmisch-Partenkirchen
Basel
St Gallen
Innsbruck
Dijon
Besançon
Liechtenstein
Lucerne
Bern
Switzerland
Graz
Klagenfurt
Villach
Lausanne
Bolzano
Bozen
Mâcon
Maribor
Geneva
Chamonix
Trento
Udine
Slovenia
Lyon
Chambéry
Parc national de la Vanoise
Grenoble
Rijeka
Croatia
Valence
Parma
Parc national des Écrins
Gap
Parc national du Mercantour
Zadar
SCHLAFWAGEN

Questions

Chris Quigg

Unstable doubly heavy tetraquarks

Resonances in "wrong-sign" (double flavor) combinations DD, DB, BB?

$J^P = 1^+ \mathcal{T}^{\{cc\}++}_{[\bar{d}\bar{s}]}(4156) \to D^+ D_s^{*+}$: *prima facie evidence* for non-$q\bar{q}$ level

Double charge / double charm

(New kind of resonance: no attractive force at the meson–meson level.)

Also, $1^+ \mathcal{T}^{\{bb\}}_{\{\bar{q}_k \bar{q}_l\}}(10681)^{0,-,--}$, $\mathcal{Q} = +78$ MeV $1^+ \mathcal{T}^{\{bc\}}_{[\bar{u}\bar{d}]}(7272)^0$, $\mathcal{Q} = +82$ MeV

$0^+ \mathcal{T}^{[bc]}_{[\bar{u}\bar{d}]}(7229)^0$, $\mathcal{Q} = +83$ MeV $1^+ \mathcal{T}^{\{cc\}}_{[\bar{u}\bar{d}]}(3978)^+$, $\mathcal{Q} = +102$ MeV

Aside: ${}^3D_3$ and ${}^3F_4$ $c\bar{c}$ mesons still to be found in $D\bar{D}$, etc.

Homework for experiment

*T*1. Look for double-flavor resonances near threshold.

*T*2. Measure cross sections for final states containing 4 heavies: $Q_i \bar{Q}_i Q_j \bar{Q}_j$.

*T*3. Discover and determine masses of doubly-heavy baryons.
needed to implement HQS calculation of tetraquark masses
intrinsic interest in these states:
compare heavy–light mesons, possible core excitations
Resolve Ξ_{cc} uncertainty (SELEX/LHCb)

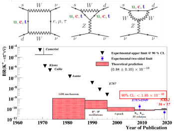
*T*4. Find stable tetraquarks through weak decays. Lifetime: $\sim \frac{1}{3}$ ps ??

Flavor: the problem of identity (continued)

Parameters of the Standard Model

3	Coupling parameters, α_s, α_{em}, $\sin^2\theta_W$
2	Parameters of the Higgs potential
1	Vacuum phase (QCD)
6	Quark masses
3	Quark mixing angles
1	CP-violating phase
3	Charged-lepton masses
3	Neutrino masses
3	Leptonic mixing angles
1	Leptonic CP-violating phase (+ Majorana phases?)
26^+	Arbitrary parameters

$K^+ \to \pi^+ \nu\bar{\nu}$ search and observation



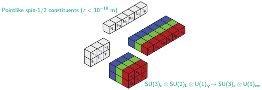
Searches for flavor-changing neutral currents

F6. Where are flavor-changing neutral currents in quark transitions? In the standard model, these are absent at tree level and highly suppressed by the Glashow–Iliopoulos–Maiani mechanism. They arise generically in proposals for physics beyond the standard model, and need to be controlled. And yet we have made no sightings!
Why not? $B_{s,d} \to \mu^+\mu^-$, $K^+ \to \pi^+\nu\bar{\nu}$, ...

F7. Can we detect flavor-violating decays $H(125) \to \tau^\pm\mu^\mp$, ...?

F8. How well can we test the standard-model correlation among $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$, $\mathcal{B}(B_s \to \mu^+\mu^-)$, and the quark-mixing matrix parameter γ?

Have we found the "periodic table" of elementary particles?



F9. What do generations mean? Is there a family symmetry?

F10. Why are there three families of quarks and leptons? (Is it so?)

F11. Are there new species of quarks and leptons? exotic charges?

More questions concerning the problem of identity

F12. Is there any link to a dark sector?

F13. What will resolve the disparate values of $|V_{ub}|$ and $|V_{cb}|$ measured in inclusive and exclusive decays?

F14. Is the 3×3 (CKM) quark-mixing matrix unitary?

F15. Why is isospin a good symmetry? What does it mean?

F16. Can we find evidence for charged-lepton flavor violation?

F17. Will we establish and diagnose a break in the SM?

F18. Do flavor parameters *mean* anything at all?
Contrast the landscape perspective.

F19. If flavor parameters have meaning (beyond engineering information), what is the meta-question?

The top quark touches many topics in particle physics

*t*1. How well can we constrain V_{tb} in single-top production, ...?

*t*2. How well can we constrain the top-quark lifetime? How free is t?
Recent ATLAS: $\Gamma(t) = 1.9 \pm 0.5$ GeV (SM 1.32 GeV)

*t*3. Are there $t\bar{t}$ resonances?

*t*4. Can we find evidence of flavor-changing top decays $t \to (Z, \gamma)(c, u)$?

Questions about EWSB and the Higgs Sector

*H*1. Is $H(125)$ the only member of its clan? Might there be others—charged or neutral—at higher or lower masses?

*H*2. Does $H(125)$ fully account for electroweak symmetry breaking? Does it match standard-model branching fractions to gauge bosons? Are absolute couplings to W and Z as expected in the standard model?

*H*3. Are all production rates as expected? Any surprise sources of $H(125)$?

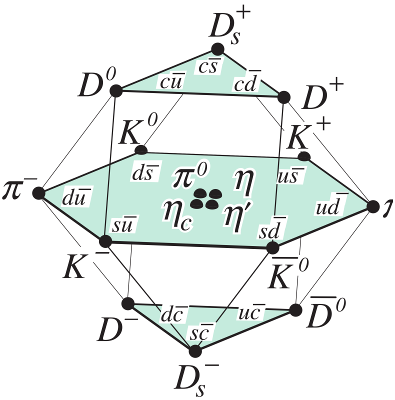
*H*4. What accounts for the immense range of fermion masses?

*H*5. Is the Higgs field the only source of fermion masses?
Are fermion couplings proportional to fermion masses? $\mu^+\mu^-$ soon?
How can we detect $H \to c\bar{c}$? e^+e^-?? (basis of chemistry)

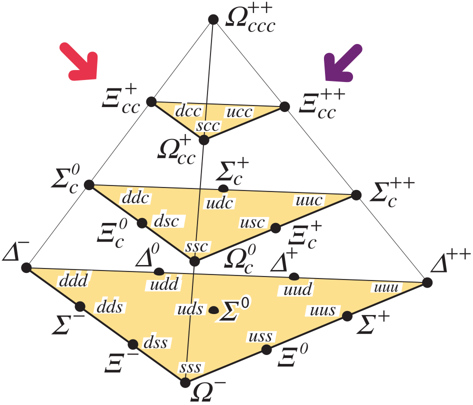
*H*6. What role does the Higgs field play in generating neutrino masses?

Charm baryons

Bound states with d,u,s,c quarks

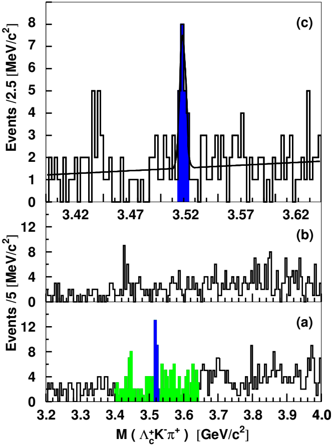


The meson 4-quark multiplet



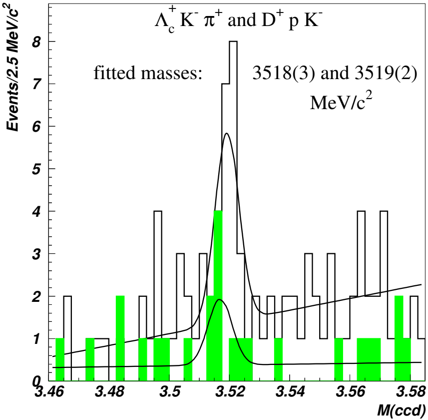
The baryon 4-quark multiplet

Observation of Ξ_{cc}^{+} baryon at SELEX



$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$: 6.3$\sigma$ at 3519 $\pm$ 1 MeV/c^2

[PRL 89 (2002) 112001]



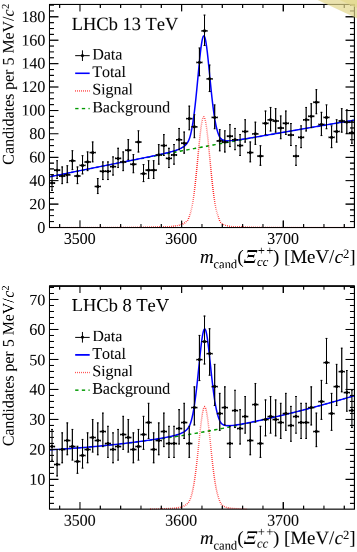
$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ and $D^{+} p K^{-}$: 4.8σ at 3518 $\pm$ 3 MeV/c^2

[PLB628 18 (2005)]

Observation of the Ξ_{cc}^{++} baryon

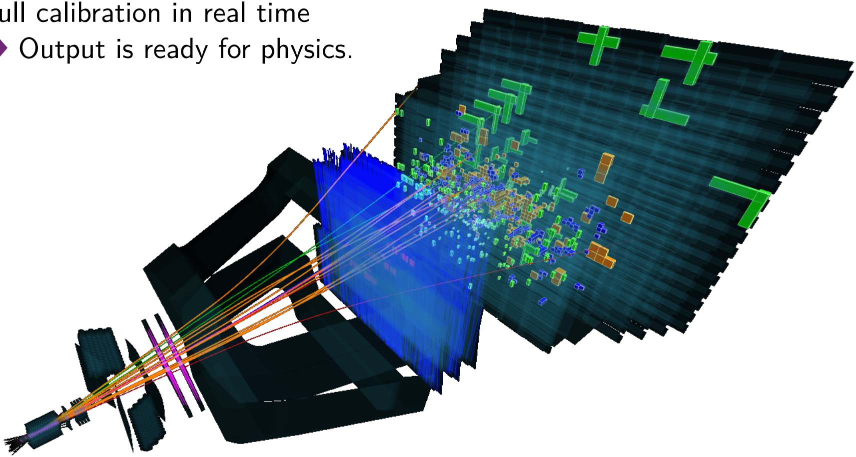
Two double-charm baryons expected: Ξ_{cc}^{+} (ccd) and Ξ_{cc}^{++} (ccu)

- Ξ_{cc}^{+} reported by SELEX in 2002 and 2004 [PRL 89 112001] [PLB628 18]
  - $m = 3518.7 \pm 1.7$ MeV$/c^2$
- We use 2016 13 TeV TURBO data to reconstruct $\Lambda_c^+ \to pK^-\pi^+$ and $\Xi_{cc}^{++} \to \Lambda_c^+ K^-\pi^+\pi^+$.
- Fit returns 12σ significance and $m = 3621.40 \pm 0.72 \pm 0.27 \pm 0.14(\Lambda_c^+)$ MeV$/c^2$.
  - ✔ Confirmed in 2012 8 TeV data
    - Mass 100 MeV$/c^2$ more than the SELEX state. Too much for isospin-splitting.



TURBO

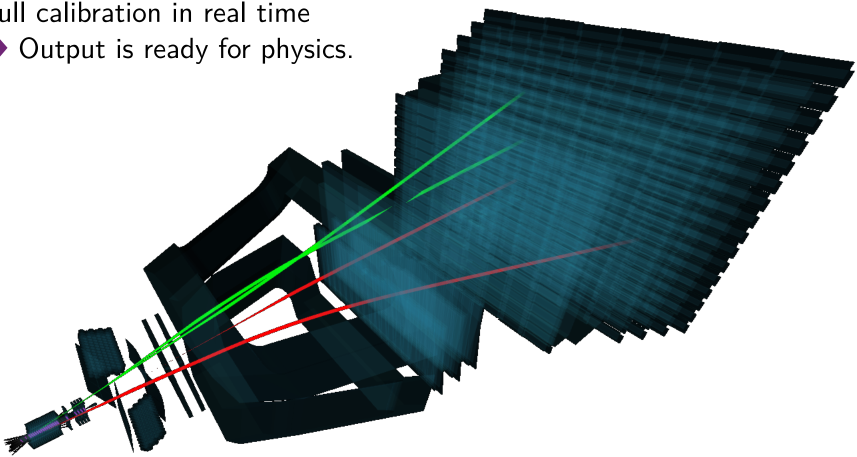
Full calibration in real time
➜ Output is ready for physics.



Plenty of collision events discarded, while the interesting are kept.

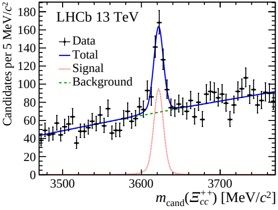
TURBO

Full calibration in real time
➜ Output is ready for physics.



TURBO++ stores only the needed information
➜ Huge savings in time and cost

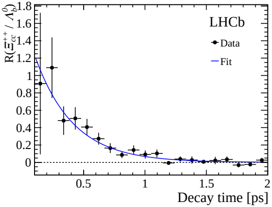
What we know about the Ξ_{cc}^{++} baryon



It is seen in

$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$

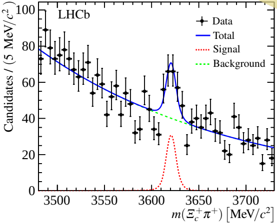
[PRL 119 (2017) 112001]



Its lifetime is

$256 \,^{+\,24}_{-\,22} \pm 14$ fs

[PRL 121 (2018) 052002]



It decays to $\Xi_c^+ \pi^-$

[PRL 121 (2018) 162002],

$m = 3621.24 \pm 0.65 \pm 0.31\,\text{MeV}/c^2$

- It is not seen in $D^+ p K^- \pi^+$ [arXiv:1905.02421]
- Its production at $\sqrt{s} = 13$ TeV is [LHCb-PAPER-2019-035] (prel.)

$$\frac{\sigma(\Xi_{cc}^{++}) \times \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}{\sigma(\Lambda_c^+)} = (2.22 \pm 0.27 \pm 0.29) \times 10^{-4}$$

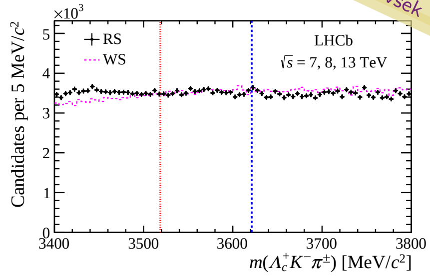
[LHCb, arXiv:1909.12273]

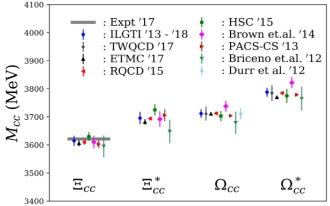
SEARCH FOR THE Ξ_{cc}^{+} BARYON

Matt Needham
Sasa Prelovsek

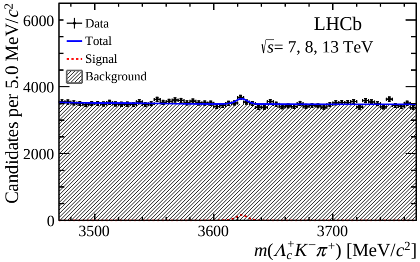
Looking for the Ξ_{cc}^{+} state, seen by SELEX

- Nothing at the SELEX mass ($3519\,\text{MeV}/c^2$)
- Small bump near the Ξ_{cc}^{++} mass ($3621\,\text{MeV}/c^2$) but not significant (2.7σ)
  - ➜ Is this the isospin partner of the Ξ_{cc}^{++}?

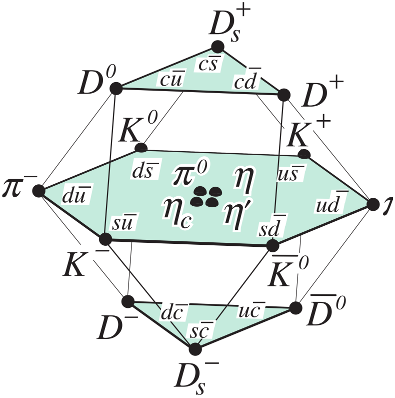




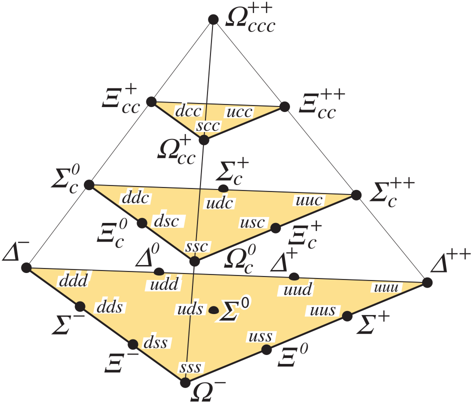
[M. Padmanath, arXiv:1905.09651]



BOUND STATES WITH d,u,s,c QUARKS

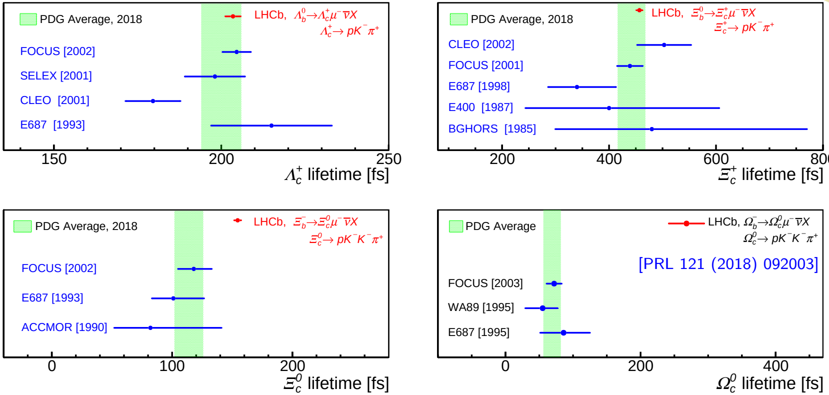


The meson 4-quark multiplet



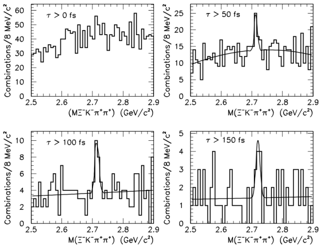
The baryon 4-quark multiplet

Lifetimes of the Λ_c^+, Ξ_c^0, and Ξ_c^+ baryons



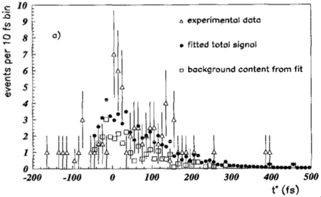
All lifetimes are more precise than the PDG average. The Λ_c^+ and Ξ_c^+ lifetimes are consistent, while the Ξ_c^0 and Ω_c^0 [PRL 121 (2018) 092003] are larger than previous measurements.

Old Ω_c^0 lifetime measurements



WA89: $55 {}^{+13}_{-11} {}^{+18}_{-23}$ fs

[Phys.Lett. B358 (1995) 151, arXiv:hep-ex/9507004]



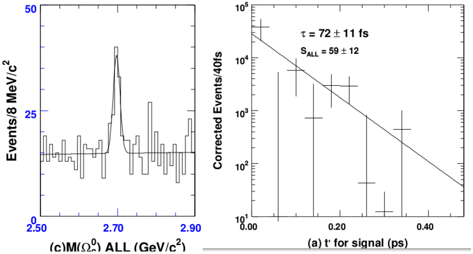
E687: $86 {}^{+27}_{-20} \pm 28$ fs

[Phys.Lett. B357 (1995) 678]

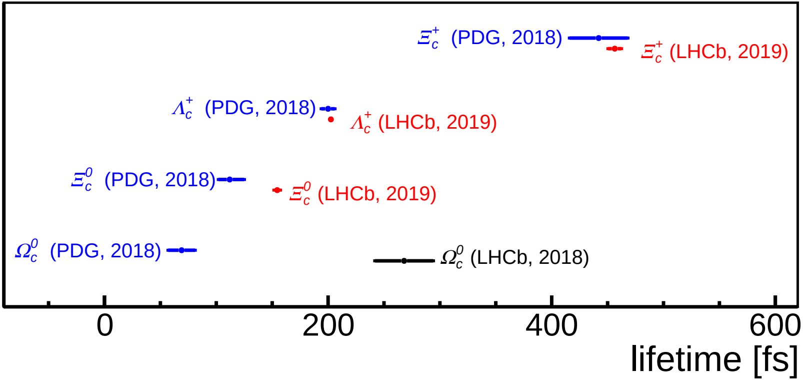
PDG: 69 ± 12 fs

FOCUS measures $72 \pm 11 \pm 11$ ps with 64 ± 14 baryons

[Phys.Lett. B561 (2003) 41, arXiv:hep-ex/0302033]



Lifetimes of the Λ_c^+, Ξ_c^0, and Ξ_c^+ baryons



Hierarchy of charmed baryon lifetimes.

Spectroscopy

New charmonium state in $D\bar{D}$

Using $D\bar{D}$ combinations in the full $9\,\text{fb}^{-1}$ 2011–18 data sample.

X(3842): New charmonium seen in D^+D^- and $D^0\bar{D}^0$! Could be spin-3 $\psi_3(1^3D_3)$

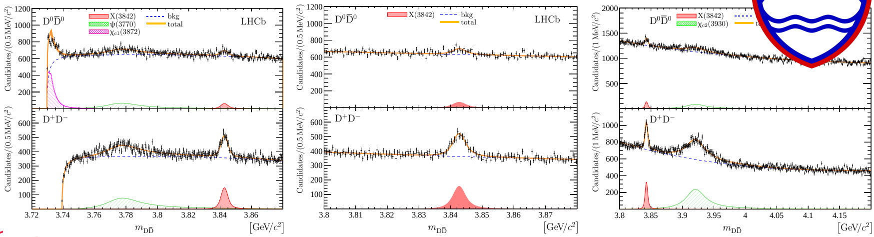
$m = 3842.71 \pm 0.16 \pm 0.12\,\text{MeV}/c^2$, $\Gamma = 2.79 \pm 0.51 \pm 0.35\,\text{MeV}$.

χ_{c2}(3930): First seen in hadroproduction.

$m = 3921.9 \pm 0.6 \pm 0.2\,\text{MeV}/c^2$, $\Gamma = 36.6 \pm 1.9 \pm 0.9\,\text{MeV}$.

ψ(3770): First seen in prompt hadroproduction.

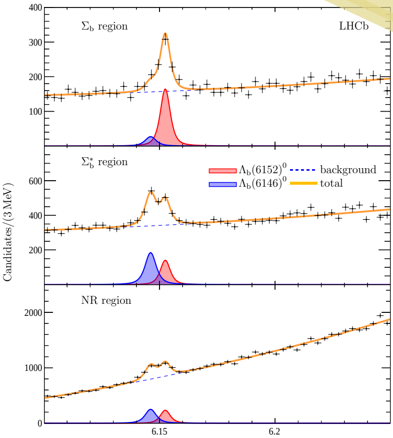
$m = 3778.1 \pm 0.7 \pm 0.6\,\text{MeV}/c^2$.



New baryons in $\Lambda_b^0\pi^+\pi^-$

Combine 890k $\Lambda_b^0 \to \Lambda_c^+\pi^-$ and 218k $\Lambda_b^0 \to J/\psi\, pK^-$ from $9\,\text{fb}^{-1}$ 2011–18 data with two pions.

- Clear peak seen at $6149.6 \pm 0.3\,\text{MeV}/c^2$
- Further split depending in $\Lambda_b^0\pi^\pm$ mass compatibe with Σ_b, $\Sigma_b{}^*$ or neither (only one pion can be compatible).
- Best fit: two narrow peaks (widths of 3 ± 1 and 2 ± 1 MeV)



$m(\Lambda_b(6146)^0) = 6146.18 \pm 0.33 \pm 0.22 \pm 0.16\,\text{MeV}/$

$m(\Lambda_b(6152)^0) = 6152.51 \pm 0.26 \pm 0.22 \pm 0.16\,\text{MeV}/$

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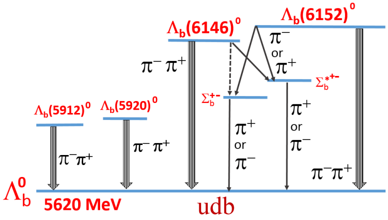


- The $\Lambda_b(6152)^0$ decays to $\Sigma_b{}^\pm\pi^\mp$ and $\Sigma_b^{*\pm}\pi^\mp$.
- The $\Lambda_b(6136)^0$ decays only to $\Sigma_b^{*\pm}\pi^\mp$

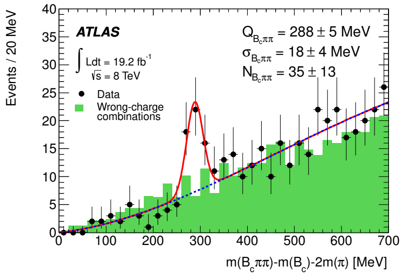
➜ Likely to be $J^P = \frac{3}{2}^+$ and $J^P = \frac{5}{2}^+$. Could also be excited $\Sigma_b{}^0$.

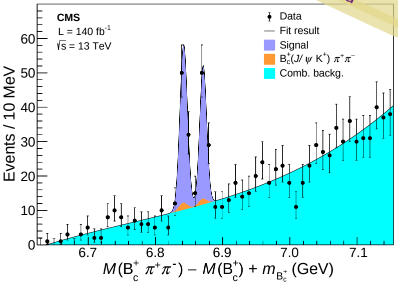
The tale of the two camels

Leonardo Cristella

Dromedary and Bactrian Camel

$B_c^{(*)}(2S)^+$ at the LHC

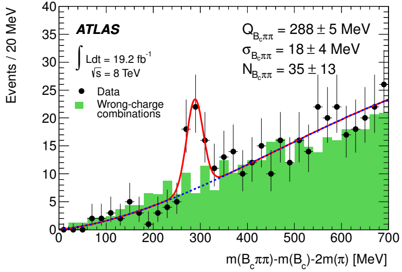


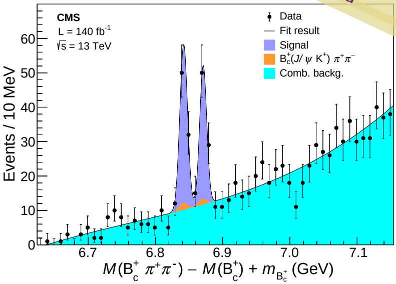


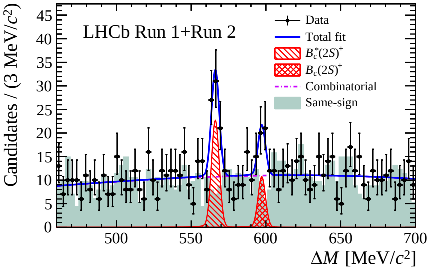
CMS [CMS, PRL 122 (2019) 132001]
ATLAS [ATLAS, PRL 113 (2014) 212004]

$B_c^{(*)}(2S)^+$ at the LHC

Leonardo Cristella







CMS [CMS, PRL 122 (2019) 132001]

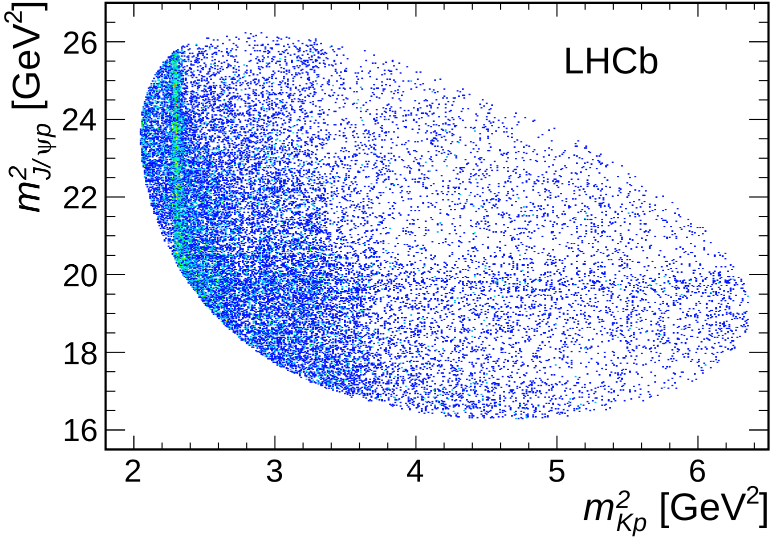
ATLAS [ATLAS, PRL 113 (2014) 212004]

LHCb [PRL 122 (2019) 232001]

[LHCb, Phys. Rev. Lett. 115 (2015) 072001, arXiv:1507.03414]

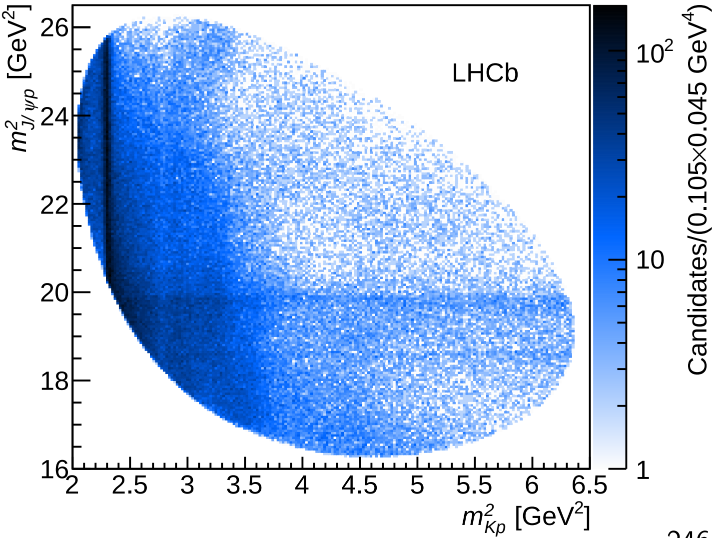
Observation of two pentaquarks

Liming Zhang



[LHCb, Phys. Rev. Lett. 122 (2019) 222001, arXiv:1904.03947]

Observation of narrow pentaquarks



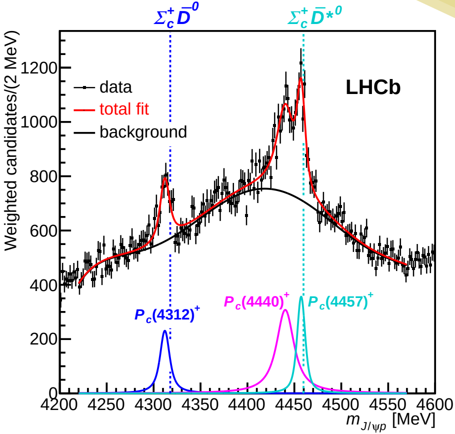
246 000 Λ_b^0

Observation of narrow pentaquarks

Liming Zhang

Three states are observed:

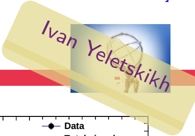
- $P_c(4312)^+$ $\Gamma \sim 10\,\text{MeV}$ (7σ), which we could not see with $3\,\text{fb}^{-1}$
- $P_c(4440)^+$ $\Gamma \sim 20\,\text{MeV}$ and
- $P_c(4457)^+$ $\Gamma \sim 6\,\text{MeV}$. The significance of the 2-peak structure is 5.4σ
- ✗ No sensitivity to the wide $P_c(4380)^+$

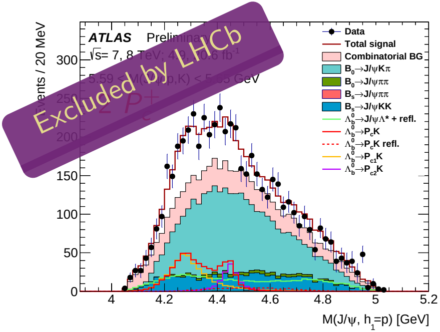


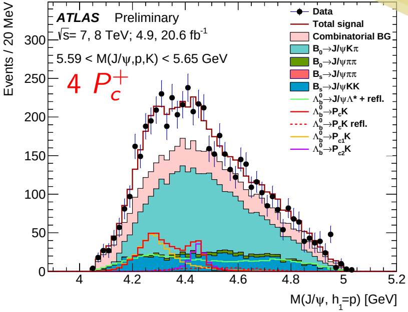
It is striking that the $P_c(4312)^+$ and the $P_c(4457)^+$ sit at the $\Sigma_c D$ and $\Sigma_c D^*$ thresholds

[ATLAS-CONF-2019-048]

P_c^+ states at ATLAS

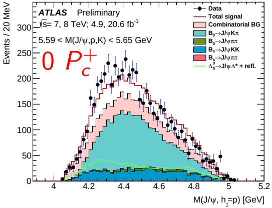






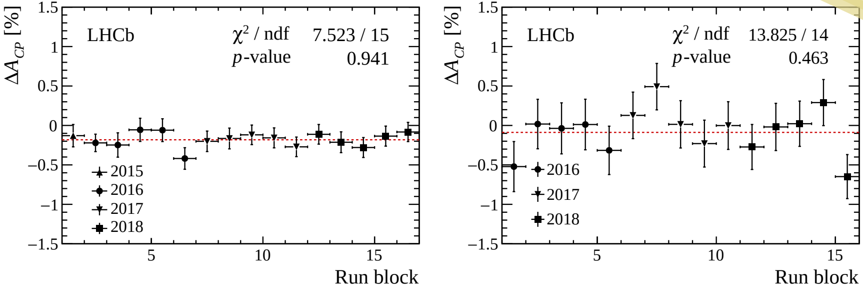
With Run 1 data, ATLAS find 2270 ± 300 $\Lambda_b^0 \to J/\psi\, pK^-$ decays

- Good fits with LHCb states of [PRL 115 (2015) 072001] and [PRL 122 (2019) 222001]
- Fit with only Λ is not ($p \sim 9 \times 10^{-3}$)



CP violation

ΔA_{CP} RESULTS



π-tagged: $(-18.2 \pm 3.2 \pm 0.9) \times 10^{-4}$

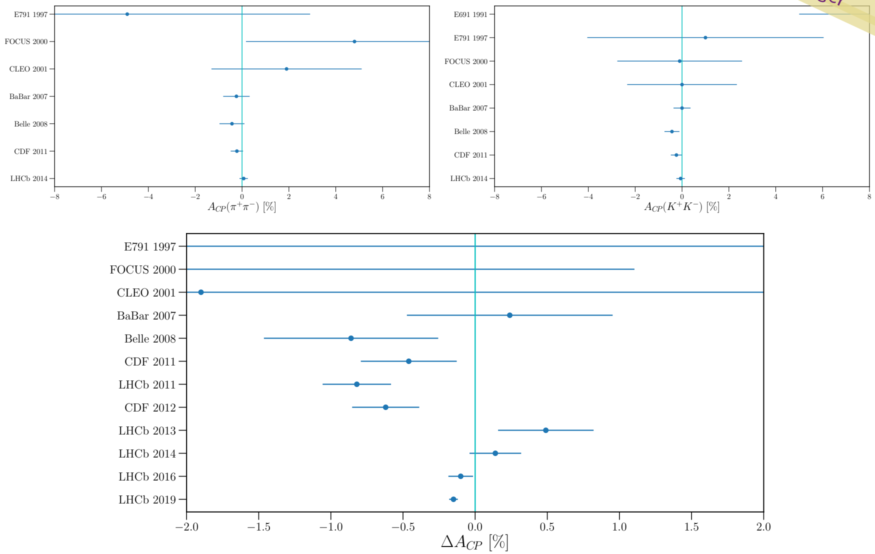
μ-tagged: $(-9 \pm 8 \pm 5) \times 10^{-4}$

Combining with Run-1 results $(-10 \pm 8 \pm 3) \times 10^{-4}$ [PRL 116 (2016) 191601] and $(+14 \pm 16 \pm 8) \times 10^{-4}$ [JHEP 07 (2014) 041]:

$$\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4} \qquad (5.3\sigma)$$

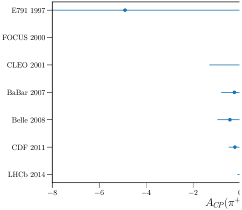
ΔA_{CP} History

Maxime Schubiger



ΔA_{CP} History

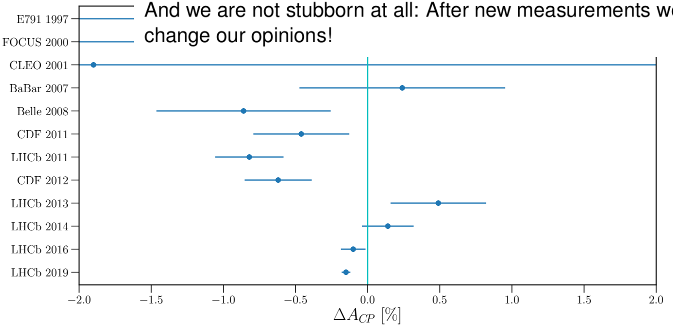
Ulrich Nierste



The theory community has delivered a perfect service to the experimental colleagues:
Every measurement hinting at some non-zero CP asymmetry was successfully postdicted offering interpretations both

- within the Standard Model
  and
- as evidence for new physics!

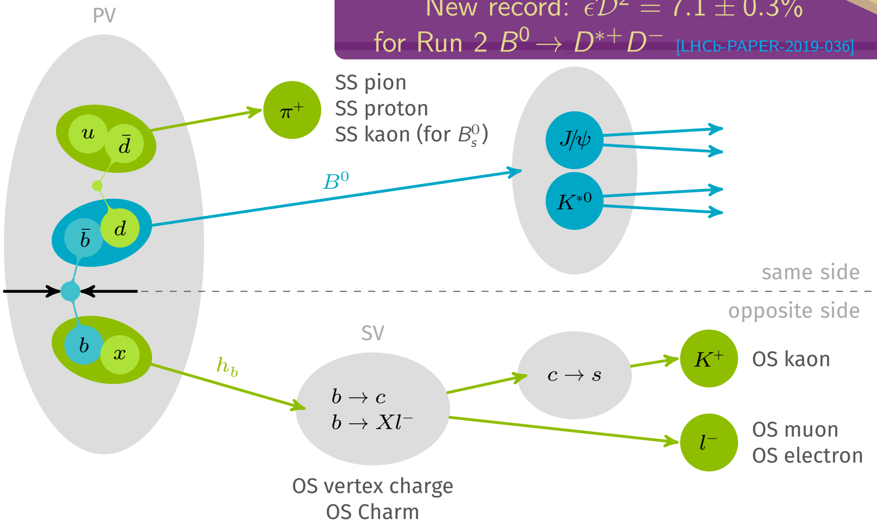
And we are not stubborn at all: After new measurements we eagerly change our opinions!



[LHCb, Eur. Phys. J. C77 (2017) 238, arXiv:1610.06019]

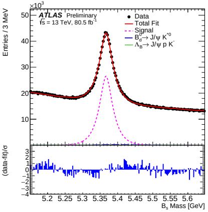
Flavour Tagging at the LHC

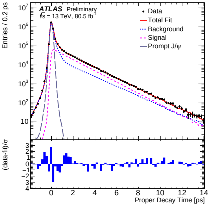
New record: $\epsilon\mathcal{D}^2 = 7.1 \pm 0.3\%$
for Run 2 $B^0 \to D^{*+} D^-$ [LHCb-PAPER-2019-036]

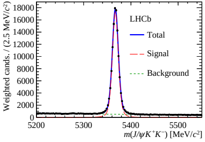


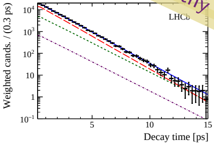
φ_s at ATLAS and LHCb

Katya Govorkova, Radek Novotný





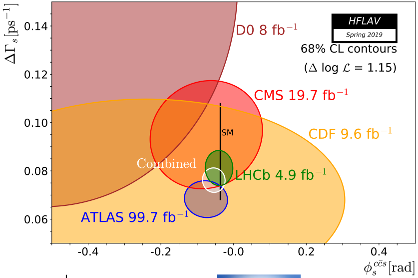


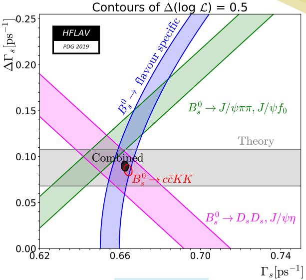


$N(B_s^0)$	**477 240** $\pm$ 760	117 000
$\sigma(\tau)$	69 fs	**45.54** $\pm$ 0.04 $\pm$ 0.05 fs
$\epsilon\mathcal{D}^2$	1.65 $\pm$ 0.01%	**4.73** $\pm$ 0.34%
φ_s	$-0.068 \pm$ **0.038** $\pm$ 0.018 rad	$-0.083 \pm$ 0.041 $\pm$ **0.006** rad
$\Delta\Gamma_s$	0.067 $\pm$ **0.005** $\pm$ 0.002 ps^{-1}	0.077 $\pm$ **0.008** $\pm$ 0.003 ps^{-1}
Γ_s	0.669 $\pm$ **0.001** $\pm$ **0.001**	0.6542 $\pm$ 0.024 $\pm$ 0.015 ps^{-1}

φ_s at ATLAS and LHCb

Katya Govorkova, Radek Novotný





$N(B_s^0)$	**477 240** $\pm$ 760	117 000
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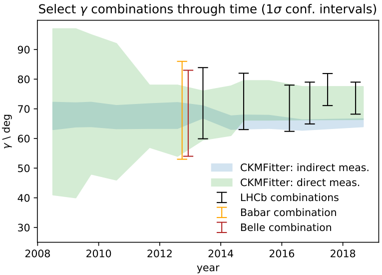
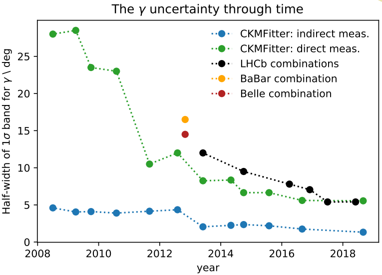
$\epsilon\mathcal{D}^2$	1.65 $\pm$ 0.01%	**4.73** $\pm$ 0.34%
φ_s	$-0.076 \pm 0.034 \pm 0.019$ rad	$-0.090 \pm$ **0.032** rad
$\Delta\Gamma_s$	$0.068 \pm$ **0.004** ± 0.003 ps^{-1}	0.0784 ± 0.0062 ps^{-1}
Γ_s	$0.669 \pm$ **0.001** $\pm$ **0.001** ps^{-1}	0.6570 ± 0.0023 ps^{-1}

THE ANGLE γ

Mikkel Bjørn





The precision on direct measurements of γ is slowly approaching that of the CKM fits

BaBar [Derkach, arXiv:1301.3283], Belle [Trabelsi, arXiv:1301.2033], CKMfitter [ckmfitter.in2p3.fr], LHCb [LHCb-CONF-2018-002]

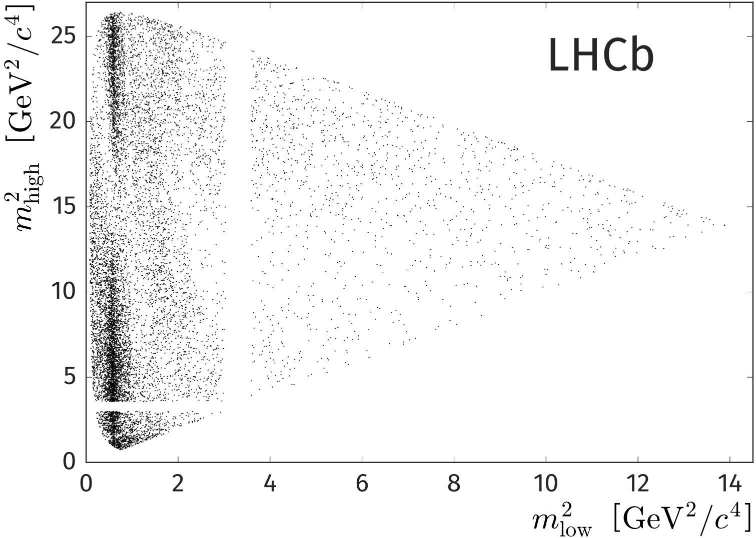
The angle γ

	Measurements in latest LHCb γ combination [LHCb-CONF-2018-002]							
	$3\ \text{fb}^{-1}$ Run 1 dataset • Includes $2\ \text{fb}^{-1}$ 15+16 data • Not in combination yet							
	B-decay mode	$B^+ \to DK^+$	$B^+ \to D^*K^+$		$B^+ \to DK^0_S\pi^+$	$B^0 \to DK^+\pi^-$		$B^+ \to DK^+\pi^+\pi^-$
	D-decay mode		Part. reco.	Full reco.	DK^{*+}-res.	DK^{*0}-res.	Dalitz-method	
GLW	h^+h^-	PLB.777(18)16	PLB.777(18)16		JHEP.17(17)156	JHEP.08(19)41	PRD.93(16)112018	PRD.92(15)112005
GLW	$\pi^+\pi^-\pi^+\pi^-$	PLB.760(16)117			JHEP.17(17)156	JHEP.08(19)41		
GLW	$h^+h^-\pi^0$	PRD.91(25)112014						
ADS	$K^\pm\pi^\mp$	PLB.760(16)117			JHEP.17(17)156	PRD.90(14)112002 JHEP.08(19)41		PRD.92(15)112005
ADS	$K^\pm\pi^\mp\pi^+\pi^-$	PLB.760(16)117			JHEP.17(17)156	JHEP.08(19)41		
ADS	$K^\pm\pi^\mp\pi^0$	PRD.91(25)112014						
GGSZ	$K^0_S h^+h^-$	JHEP.10(14)97 JHEP.08(18)176				MD: JHEP.08(16)137		
GLS	$K^0_S K^+\pi^-$	PLB.733(14)36						
Time-dependent		Time dependent measurements with $B^0_s \to D^\mp_s K^\pm$ [JHEP.03(18)59] and $B^0 \to D^\mp\pi^\pm$ [JHEP.06(18)84] decays						

Good news: Most LHCb measurements still to be done (or to be updated)

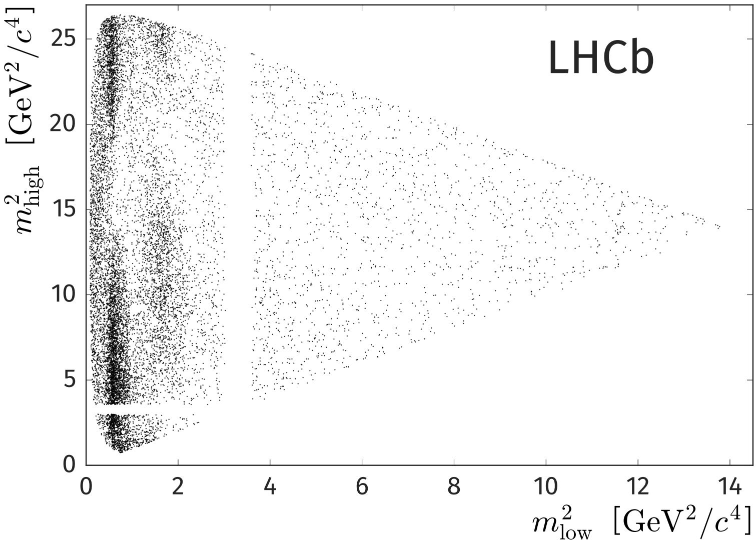
$B^+ \to \pi^+\pi^-\pi^+$ AMPLITUDE ANALYSIS

Daniel O'Hanlon

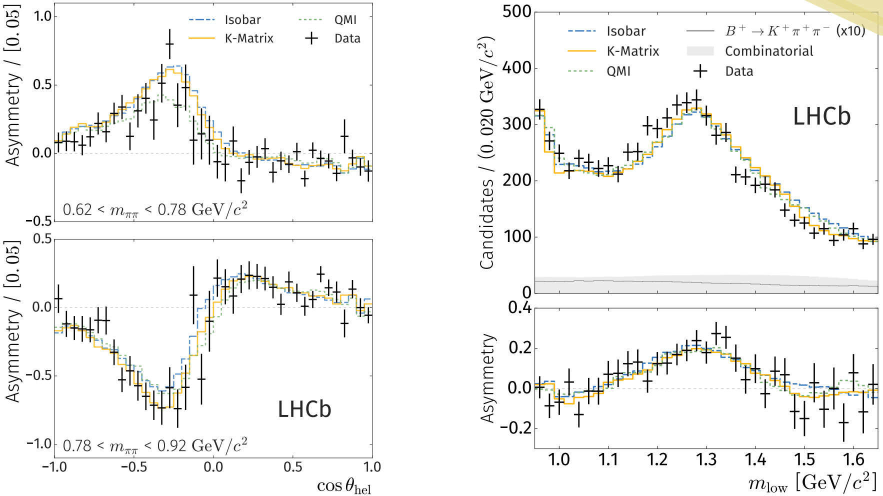


$B^+ \to \pi^+\pi^-\pi^+$ AMPLITUDE ANALYSIS

Daniel O'Hanlon

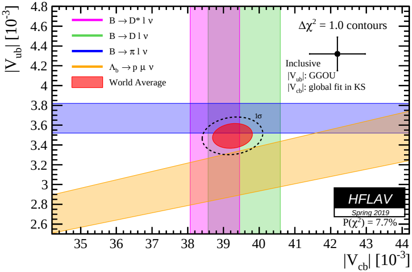


$B^+ \to \pi^+\pi^-\pi^+$ AMPLITUDE ANALYSIS

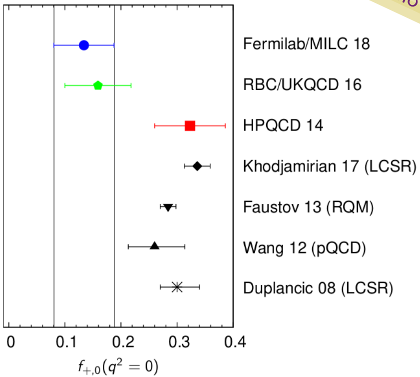


Large *CP* asymmetries seen in interference of S-wave with ρ^0 (left) and in $f_2(1270)$ region (right).

V_{ub}



V_{ub} vs V_{cb} from [HFlav]

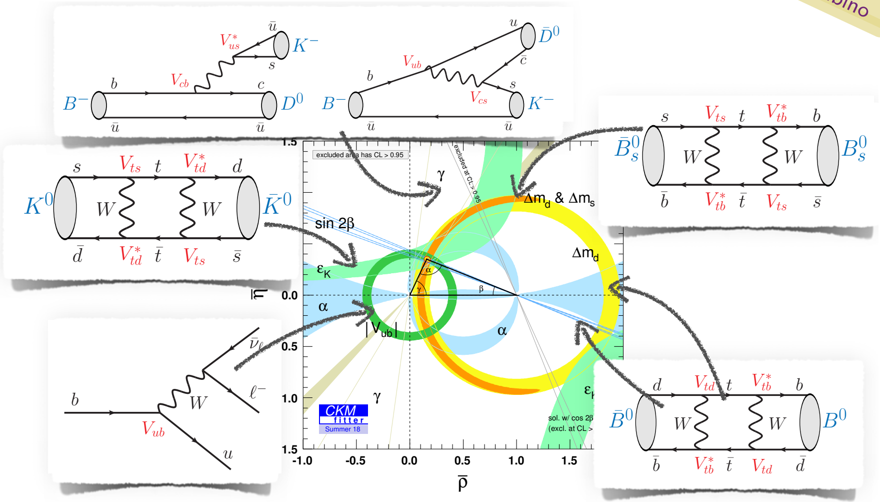


$B_s^0 \to K^- \ell^+ \nu$ form factor calculations

[Jure Zupan, arXiv:1903.05062]

CKM fit constraints

Oliver Witzel
Paolo Gambino

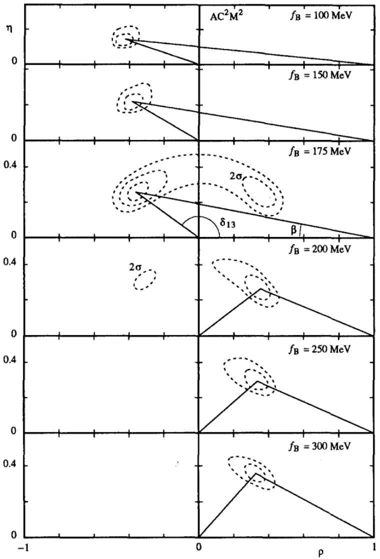


The Unitarity Triangle in 1992

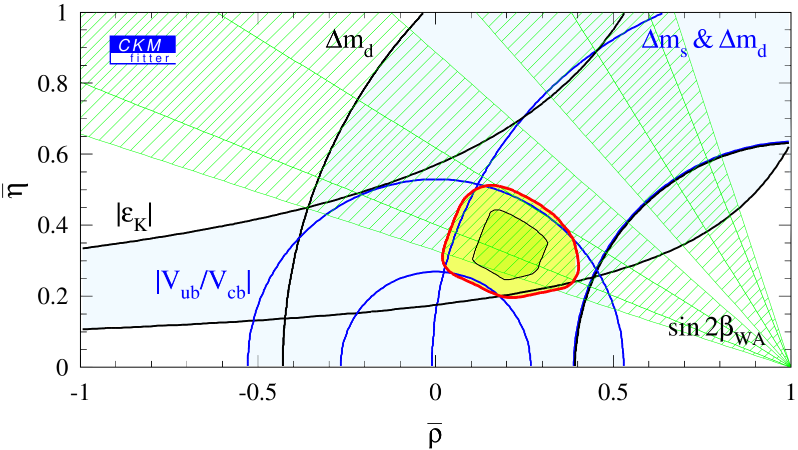
Inputs: $|V_{ub}|/|V_{cb}|$ from ARGUS [PLB255 (1991) 297] and CLEO [PLP 64 (1990) 16] (model-dependent), ϵ_K, B^0 oscillations from ARGUS [PLB 192 (1987) 245] and CLEO [PRL 62 (1989) 2233], and the t mass $m_t > 89\,\text{GeV}/c^2$ (95%) from CDF.

- Today the value of f_B is about 225 MeV. In 1992, much smaller values were considered likely.

Status at first Beauty in 1993, in Liblice, Czech Republic



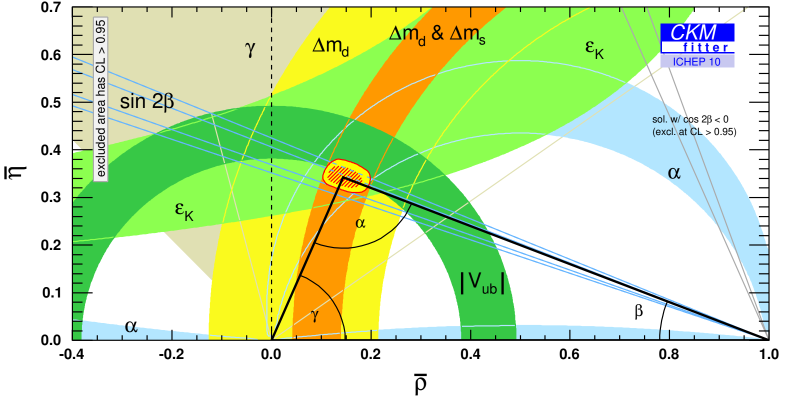
The Unitarity Triangle in 2001



First measurement of $\sin 2\beta$

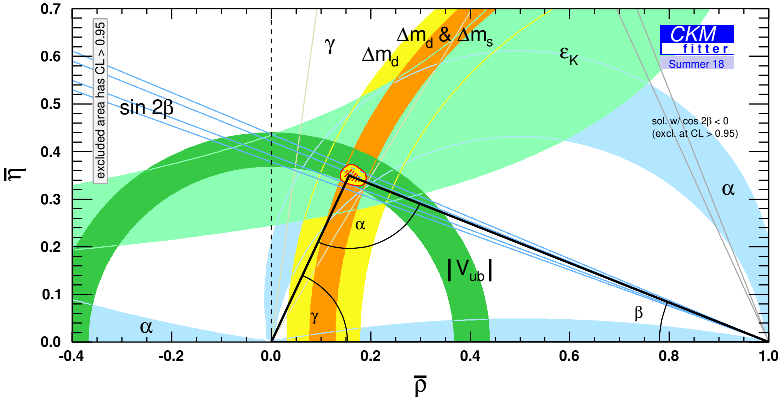
[CKMFitter]

The Unitarity Triangle in 2010



Constraints on Δm_s

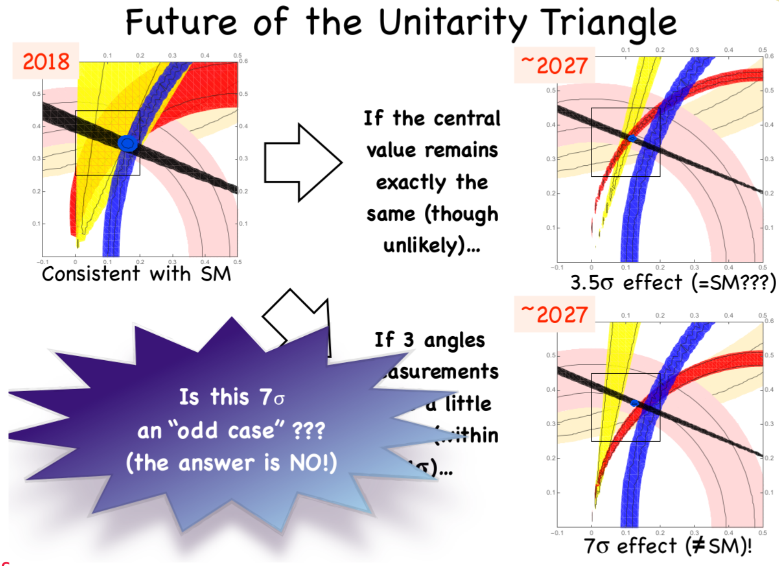
The Unitarity Triangle in 2018



The CKM matrix still holds!

LET'S BE OPTIMISTIC

Emi Kou



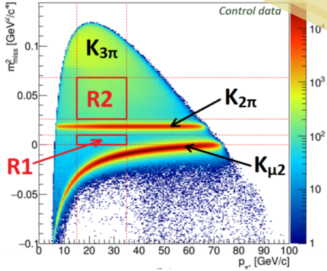
Rare Decays

Search for $K^+ \to \pi^+ \nu\bar{\nu}$ decays

Adding 2017 data

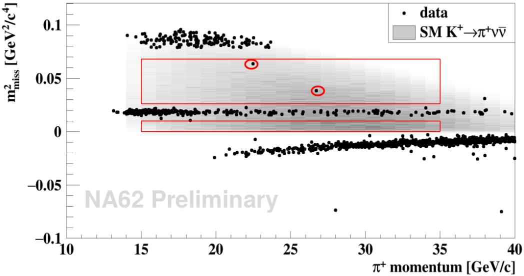
Find 2 more candidates in signal box. ➜ See 3 while expecting 1.65 ± 0.31 background ➜ Set 95% CL

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) < 2.4 \times 10^{-10}$$



Consistent with SM expectation $(8.4 \pm 1.0) \times 10^{-11}$ [Buras, Buttazzo, Girrbach, Knegjens, JHEP 1511 (2015) 033].

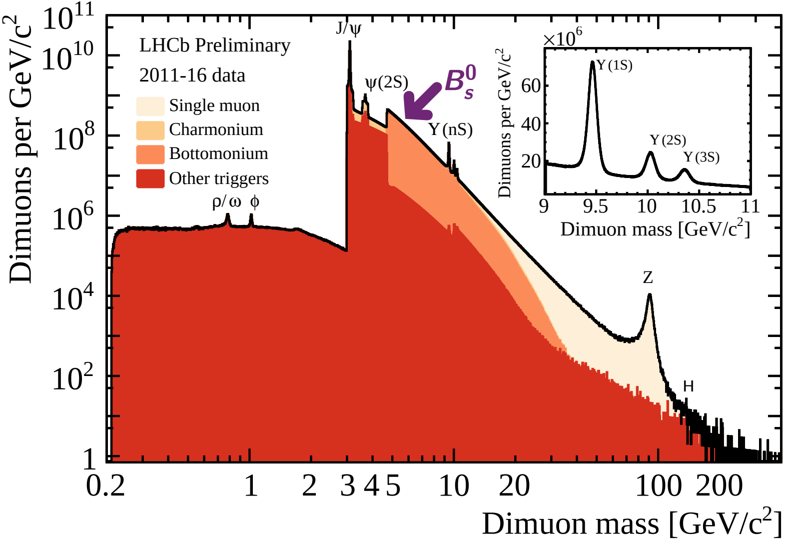
Single-event sensitivity: $(3.46 \pm 0.17) \times 10^{-11}$
➜ $\mathcal{B} = (5 \pm 7) \times 10^{-11}$



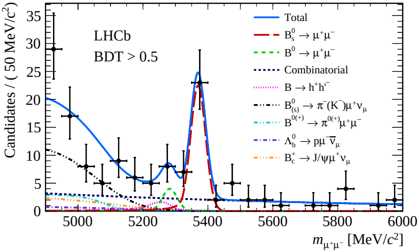
[LHCb, LHCb-CONF-2016-005]

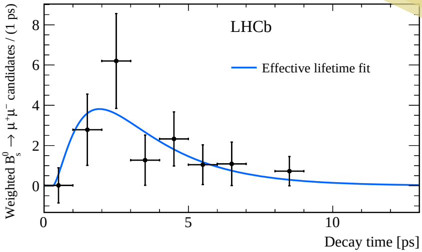
Dimuon mass distribution

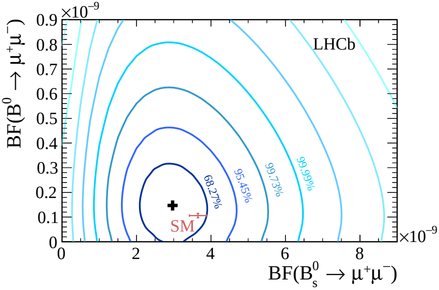
Zuzana Kučerová



Observation of the decay $B_s^0 \to \mu^+\mu^-$







With 2011–2016 LHCb data ($4.4\,\text{fb}^{-1}$):

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6\,^{+0.3}_{-0.2}) \times 10^{-9}$$

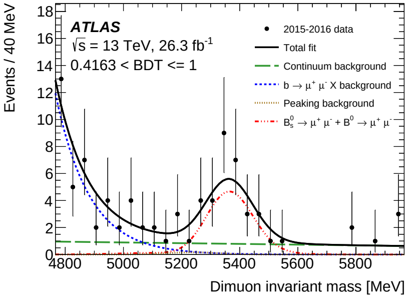
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.5\,^{+1.2}_{-1.0}\,^{+0.2}_{-0.1}) \times 10^{-10}$$

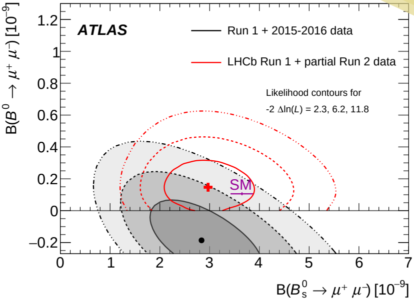
Effective limfetime:

$$\tau^{\text{eff}}_{B_s^0 \to \mu^+\mu^-} = 2.04 \pm 0.44 \pm 0.05 \text{ ps}$$

$B_s^0 \to \mu^+\mu^-$ at ATLAS

Wolfgang Walkowiak





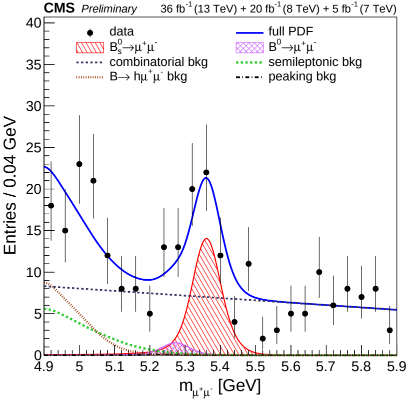
ATLAS now also see $B_s^0 \to \mu^+\mu^-$:

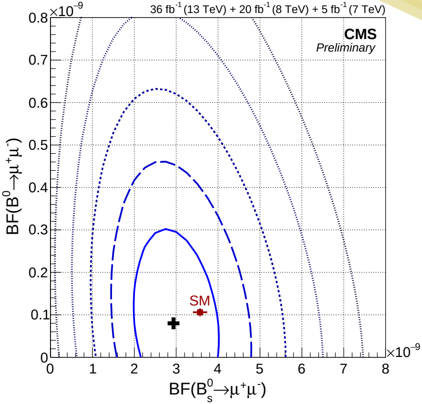
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.8\,^{+0.8}_{-0.7}) \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (-1.9 \pm 1.6) \times 10^{-10} < 2.1 \times 10^{-10} \text{ (95\% C.L.)}$$

Consistent with LHCb [PRL 118 (2017) 191801]

$B \to \mu^+\mu^-$ with 2011–16 data





$B_s^0 \to \mu^+\mu^-$ observed at 5.6σ. No significant $B^0 \to \mu^+\mu^-$

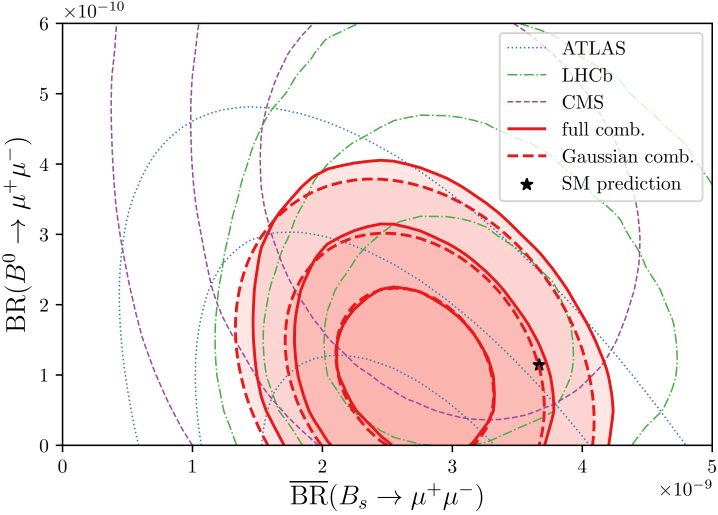
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(2.9\,^{+0.7}_{-0.6} \pm 0.2\right) \times 10^{-9}$$ ← Assumes SM τ_{eff}

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.6 \times 10^{-10} \text{ at } 95\%$$

[Aebischer et al., arXiv:1903.10434]

$B \to \mu^+\mu^-$ after Moriond 2019

David Straub

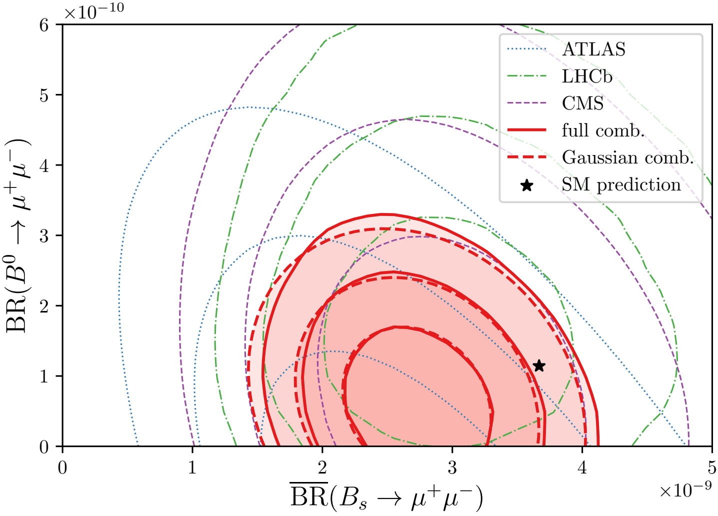


[CMS PRL 111 (2013) 101804] [PRL 118 (2017) 191801] [ATLAS JHEP 04 (2019) 098]

[Aebischer et al., arXiv:1903.10434]

$B \to \mu^+\mu^-$ after Summer 2019

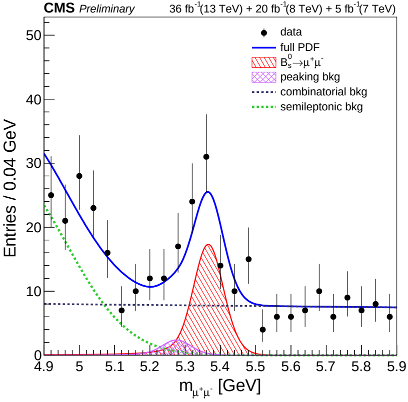
David Straub

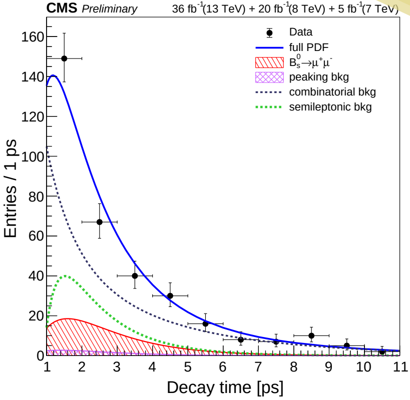


Thanks to David Straub for the updated plot

[PRL 118 (2017) 191801] [ATLAS JHEP 04 (2019) 098] [CMS-PAS-BPH-16-004]

$B \to \mu^+\mu^-$ with 2011–16 data

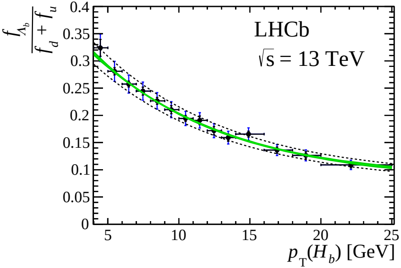


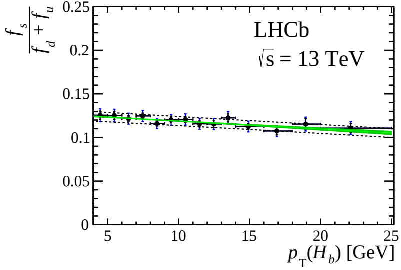


2D fit for signal and effective lifetime

$$\tau^{\text{eff}}_{B_s^0 \to \mu^+\mu^-} = 1.70\,^{+0.61}_{-0.44}\ \text{ps}$$

b fractions at 13 TeV





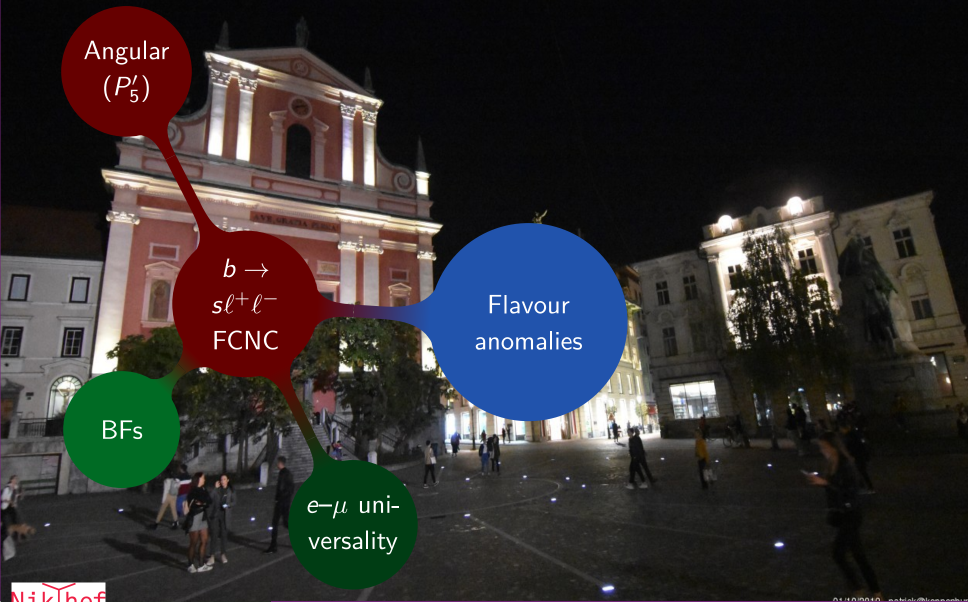
b-hadron fractions determined using semileptonic $b \to c\mu\nu$ decays

- Use corrected mass to infer neutrino momentum
- Get 14 M $D^0 X\mu^-\overline{\nu}$, 4.3 M $D^+ X\mu^-\overline{\nu}$, 0.8 M $D_s^+ X\mu^-\overline{\nu}$ and 1.8 M $\Lambda_c^+ X\mu^-\overline{\nu}$
- See p_T dependence of f_s and $f_{\Lambda_b^0}$

Averages:

$$\frac{f_s}{f_u + f_d} = 0.122 \pm 0.006$$
$$\frac{f_{\Lambda_b^0}}{f_u + f_d} = 0.259 \pm 0.018$$

Flavour Anomalies



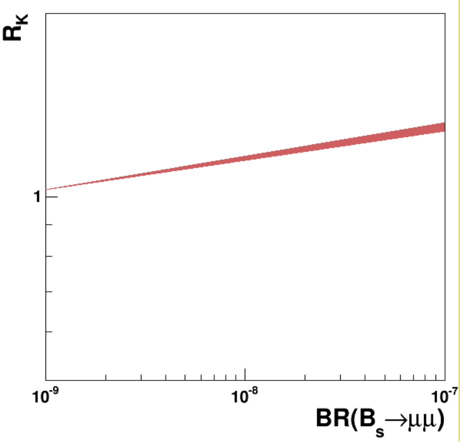
Lepton Universality in $b \to s\ell^+\ell^-$

$$R_X = \frac{\int_{q^2_{min}}^{q^2_{max}} dq^2 \frac{d\Gamma(B\to X\mu^+\mu^-)}{dq^2}}{\int_{q^2_{min}}^{q^2_{max}} dq^2 \frac{d\Gamma(B\to Xe^+e^-)}{dq^2}}$$

$$R_K - 1 \propto \mathcal{B}(B^0_s \to \mu^+\mu^-)$$

Assuming:

- Right-handed currents negligible
- (Pseudo-)scalar couplings $\propto m_\ell$,
- No *CP* phases beyond the SM

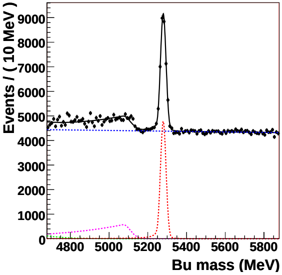


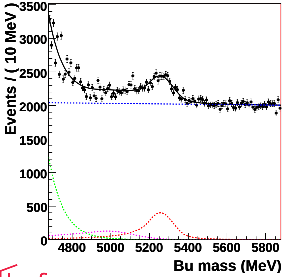
[Hiller & Krüger, PRD69 (2004) 074020]

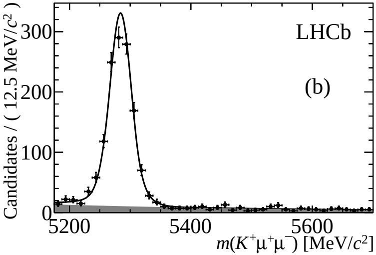
[LHCb, Phys. Rev. Lett. 113 (2014) 151601, arXiv:1406.6482]

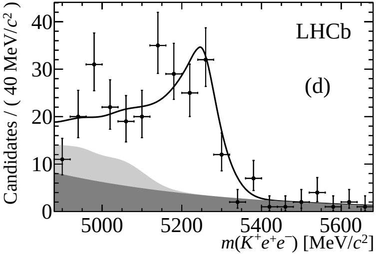
R_K History

[Note LHCb-2007-034]









Lepton Universality in $B^+ \to K^+\ell^+\ell^-$

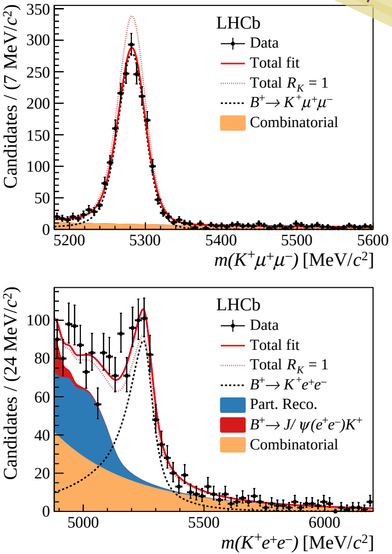
Christoph Langenbruch

- For $B^+ \to K^+\ell^+\ell^-$, the range $1.1 < q^2 < 6\,\text{GeV}^2/c^4$ is considered
- The fit gets 1943 ± 49 $B^+ \to K^+\mu^+\mu^-$ decays
- The $B^+ \to K^+e^+e^-$ fit gets a yield of 766 ± 48
- Systematic uncertainties arise from mass shapes, trigger & PID calibrations, input q^2 distributions

The result is

$$R_K = 0.846\,^{+\,0.060}_{-\,0.054}\,^{+\,0.016}_{-\,0.014}$$

(2.5σ from the SM)

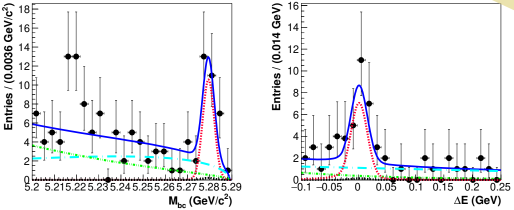


[Belle, arXiv:1908.01848]

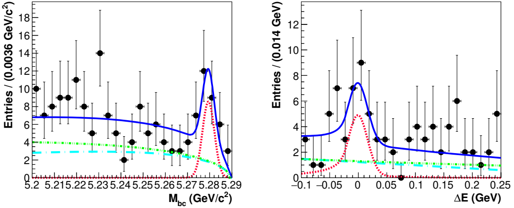
R_K at Belle

Using the full sample of 772×10^6 $B\overline{B}$ pairs Belle selects $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^0_S\ell^+\ell^-$ decays

- 137 ± 14 $B^+ \to K^+\mu^+\mu^-$ and 138 ± 15 $B^+ \to K^+e^+e^-$ decays found
- 27 ± 6 $B^0 \to K^0_S\mu^+\mu^-$ and 22 ± 7 $B^0 \to K^0_S e^+e^-$ decays found



$B^0 \to K^0_S\mu^+\mu^-$

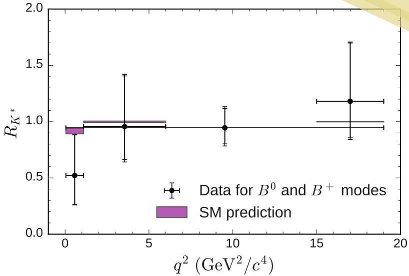


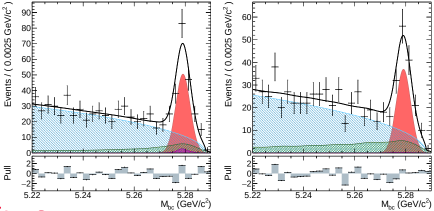
$B^0 \to K^0_S e^+e^-$

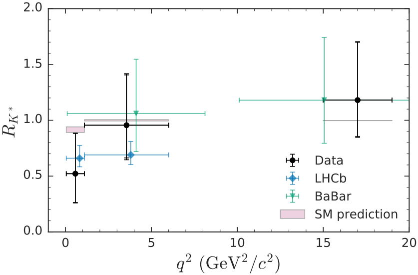
R_{K^*} at Belle

Using 711fb^{-1} data, Belle measure R_{K^*}

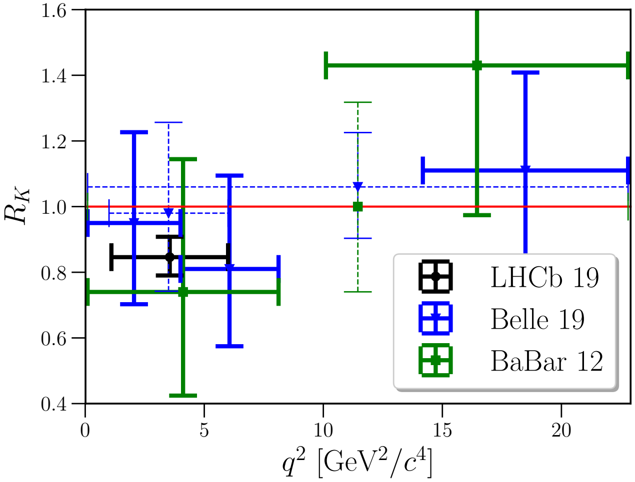
- Find 103 ± 13 $B \to K^* e^+ e^-$ and 140 ± 16 $B \to K^* \mu^+ \mu^-$ decays, adding B^0 and B^+
- Cross-check $r_{J/\psi} = 1.015 \pm 0.025 \pm 0.038$
- Combined result ➜





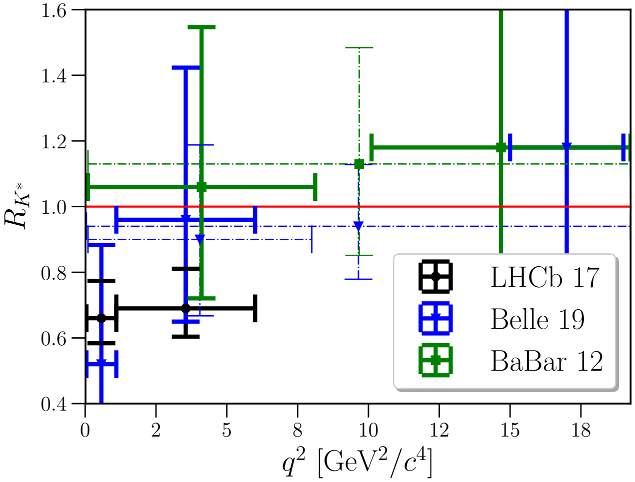


R_K



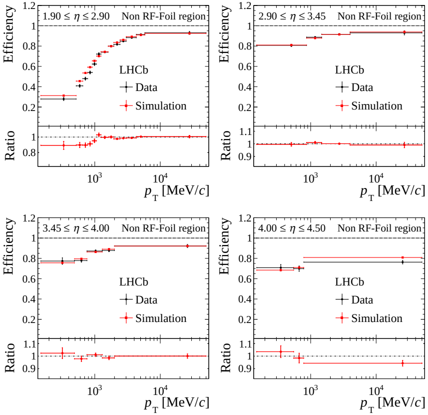
LHCb [PRL 122 (2019) 191801]. Belle [arXiv:1908.01848]. BaBar [PRD 86 (2012) 032012].

R_{K^*}



LHCb [JHEP 08 (2017) 055] . Belle [arXiv:1904.02440] . BaBar [PRD 86 (2012) 032012].

Electron Efficiency

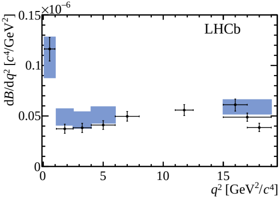


LHCb use $1.3\,\text{fb}^{-1}$ at $\sqrt{s} = 13\,\text{TeV}$ taken in 2017 with a dedicated trigger line.

- Reconstruct $B^+ \to J/\psi K^+$ with one electron (muon) and one velo track
- The reconstruction efficiency is well modeled by simulation.
- The average systematic uncertainty on the data/simulation ratio is 0.6% per track and varies over phase space.

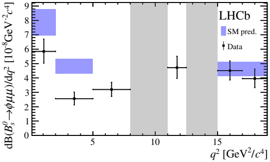
BFs too low in $b \to s\mu^+\mu^-$ decays?

Felix Kress
Christoph Langenbruch



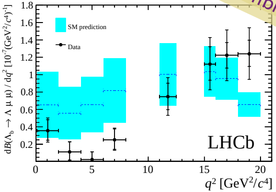
$B^0 \to K^{*0}\mu^+\mu^-$

[JHEP 11 (2016) 047]



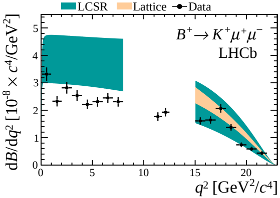
$B_s^0 \to \phi\mu^+\mu^-$

[JHEP 09 (2015) 179]



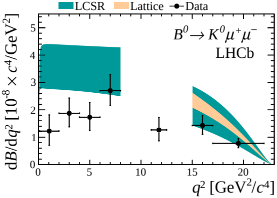
$\Lambda_b^0 \to \Lambda\mu^+\mu^-$

[JHEP 06 (2015) 115]



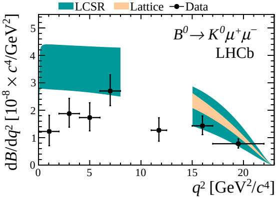
$B^+ \to K^+\mu^+\mu^-$

[JHEP 06 (2014) 133]



$B^0 \to K^0\mu^+\mu^-$

[JHEP 06 (2014) 133]

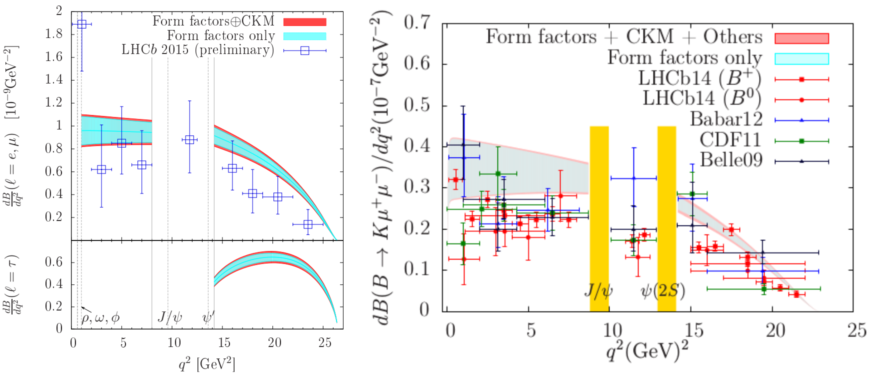


$B^+ \to K^{*+}\mu^+\mu^-$

[JHEP 06 (2014) 133]


Lattice
LHCb
LHCb
Sum Rules

$B \to h\ell^+\ell^-$ form factors from MILC

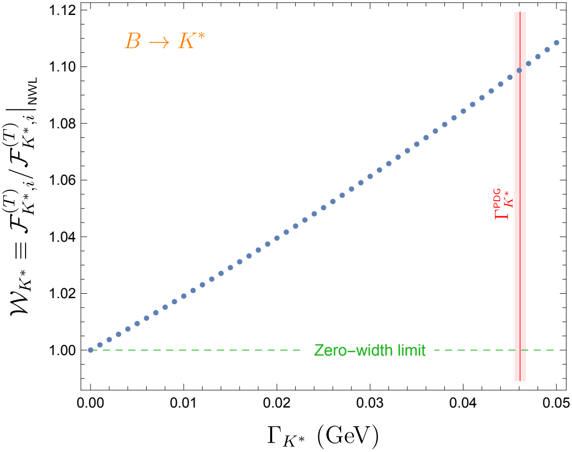


$B^+ \to \pi^+\ell^+\ell^-$ [JHEP 10 (2015) 034] and $B \to K\ell^+\ell^-$ [JHEP 06 (2014) 133] are all below the lattice computations.

[Descotes-Genon, Khodjamirian, Virto, arXiv:1908.02267]

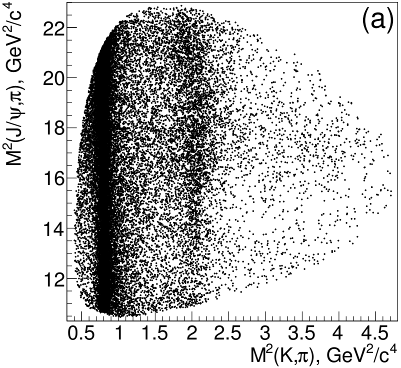
$B \to K\pi$ form factors applied to $B \to K^* \mu^+ \mu^-$

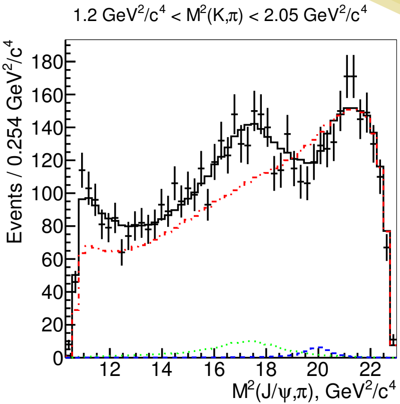
- Usually the $K^*(890)^0$ meson is assumed to be narrow. Corrections are $\mathcal{O}(\Gamma/m)$.



[Belle, PRD 90 112009 (2014), arXiv:1408.6457]

$Z_c(4200)^+$ in $\bar{B}^0 \to J/\psi K^- \pi^+$



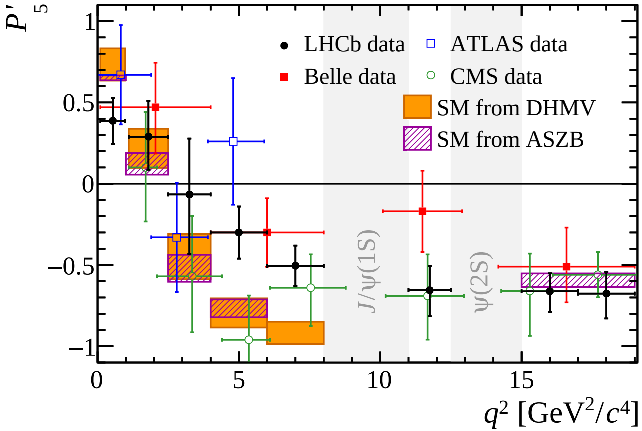


$K^*(890)^0$ and $K^*_{0,2}(1430)^0$ well visible

K^{*0} veto region: $Z_c(4200)^-$ very prominent. The $Z_c(4430)^-$ visible via interference.

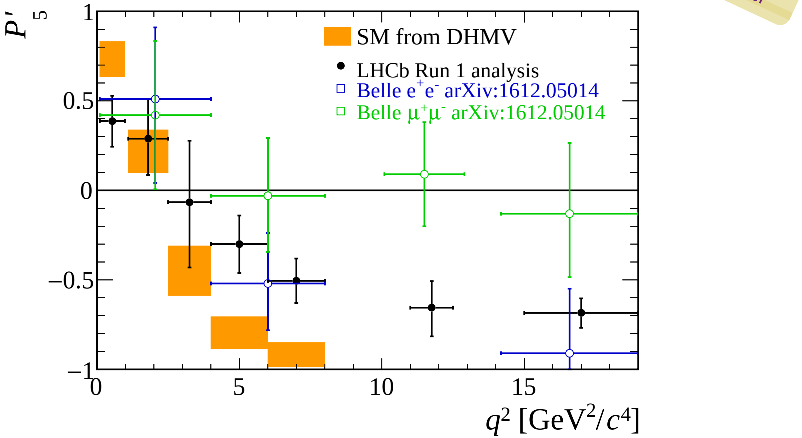
Confirmed model independently by LHCb [PRL 122 (2019) 152002]

All P'_5 measurements



LHCb [JHEP 02 (2016) 104], Belle [PRL 118 (2017) 111801]
CMS [PLB 781 (2018) 517], ATLAS [arXiv:1805.04000]

All P_5' measurements



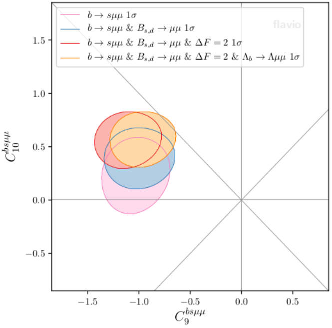
LHCb [JHEP 02 (2016) 104], Belle [PRL 118 (2017) 111801]

Fits

Other works from [Alok et al. 1903.09617] [Kowalska et al. 1903.10932] [D'amico et al. 1704.05438 updated] [Ciuchini et al. 1903.09632] with different settings, similar favoured NP scenarios

1D hyp	Algueró	Aebischer	Alok	Arbey	D'amico	Kowalska
$\mathcal{C}_{9\mu}^{\rm NP}$	5.6σ	5.9σ	6.2σ	5.3σ	6.5σ	4.7σ
$\mathcal{C}_{9\mu}^{\rm NP} = -\mathcal{C}_{10\mu}^{\rm NP}$	5.2σ	6.6σ	6.4σ	4.5σ	5.9σ	4.8σ
$\mathcal{C}_{9\mu}^{\rm NP} = -\mathcal{C}_{9'\mu}^{\rm NP}$	5.5σ	-	6.4σ	-	-	-

- NP hyps with significant pulls
- Right-handed currents interesting (due to R_K closer to 1)
- $\mathcal{C}_{9\mu}^{\rm NP} = -\mathcal{C}_{10\mu}^{\rm NP}$ favoured by [Aebischer et al.] as a combined effect of
  - $BR(B_s \to \mu\mu)$
  - $\Lambda_b \to \Lambda\mu\mu$ inputs
  - $\Delta m_{d,s}$ assuming no NP in $\Delta B = 2$ (not done in other fits)



B MIXING AND ANOMALIES

Avelino Vicente

$$\Delta M_s \equiv M_H^s - M_L^s = 2\left|\frac{G_F^2}{12\pi^2}\lambda_t^2 M_W^2 S_0(x_t) B f_{B_s}^2 M_{B_s}\hat{\eta}_B\right|$$

The experimental oscillation frequencies are [HFlav]

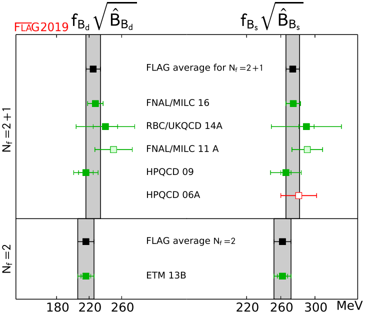
$$\Delta M_s^{\mathrm{Exp}} = (17.757 \pm 0.021)\ \mathrm{ps}^{-1} \qquad \Delta M_d^{\mathrm{Exp}} = (0.5064 \pm 0.0019)\ \mathrm{ps}^{-1}$$

But with latest lattice [FLAG] ([ETM] [HPQCD] [RBC/UKQCD] [MILC])

$$\Delta M_s^{\mathrm{FLAG}} = \left(20.1\,{}^{+1.2}_{-1.6}\right)\ \mathrm{ps}^{-1}$$

$$\Delta M_d^{\mathrm{FLAG}} = \left(0.582\,{}^{+0.049}_{-0.056}\right)\ \mathrm{ps}^{-1}$$

which is 1.5σ away. Could the same NP explain this and the B anomalies?



Scale of new physics from B anomalies

[Di Luzio, Nardecchia, 2017]

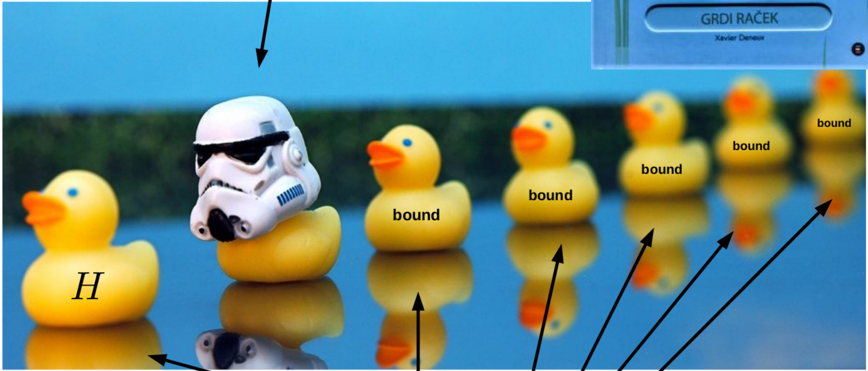
Notation:
$C_9 \equiv C_{9\mu}$

$$\underbrace{\frac{C_9^{\rm NP}}{\Lambda_{\rm NP}^2}}_{\rm NP} \sim 20\% \times \underbrace{\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} C_9^{\rm SM}}_{\rm SM}$$

Unsuppressed NP	$C_9^{\rm NP} = 1$	$\Rightarrow \Lambda_{\rm NP} \sim 30\,\text{TeV}$
CKM-suppressed NP	$C_9^{\rm NP} = \lvert V_{tb}V_{ts}^*\rvert$	$\Rightarrow \Lambda_{\rm NP} \sim 6\,\text{TeV}$
Loop-suppressed NP	$C_9^{\rm NP} = \frac{1}{16\pi^2}$	$\Rightarrow \Lambda_{\rm NP} \sim 2.5\,\text{TeV}$
CKM&loop-suppressed NP	$C_9^{\rm NP} = \frac{\lvert V_{tb}V_{ts}^*\rvert}{16\pi^2}$	$\Rightarrow \Lambda_{\rm NP} \sim 0.5\,\text{TeV}$

The ugly duckling

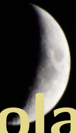
B-anomalies



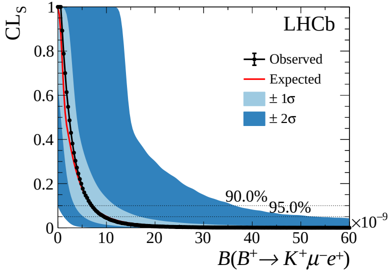
Other LHC results

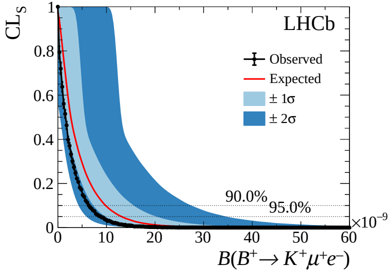
(+ the diphoton that should not be named)

Lepton Flavour Violation



Search for $B^+ \to K^+\mu^\pm e^\mp$





If lepton-universality is violated, lepton-number conservation may be too

- LHCb search for $B^+ \to K^+\mu^\pm e^\mp$ with Run 1 ($3\,\text{fb}^{-1}$) data
- After full (BDT) selection, combinatorial background dominates
- No signal found

Limits (90%) set as

$$\mathcal{B}(B^+ \to K^+\mu^+e^-) < 7.0 \times 10^{-9}$$
$$\mathcal{B}(B^+ \to K^+\mu^-e^+) < 6.4 \times 10^{-9}$$

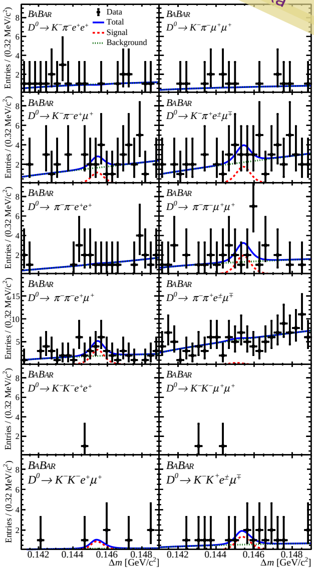
More than a factor 10 better than previous limit [BaBar, PRD73:092001,2006]

[BaBar, arXiv:1905.00608]

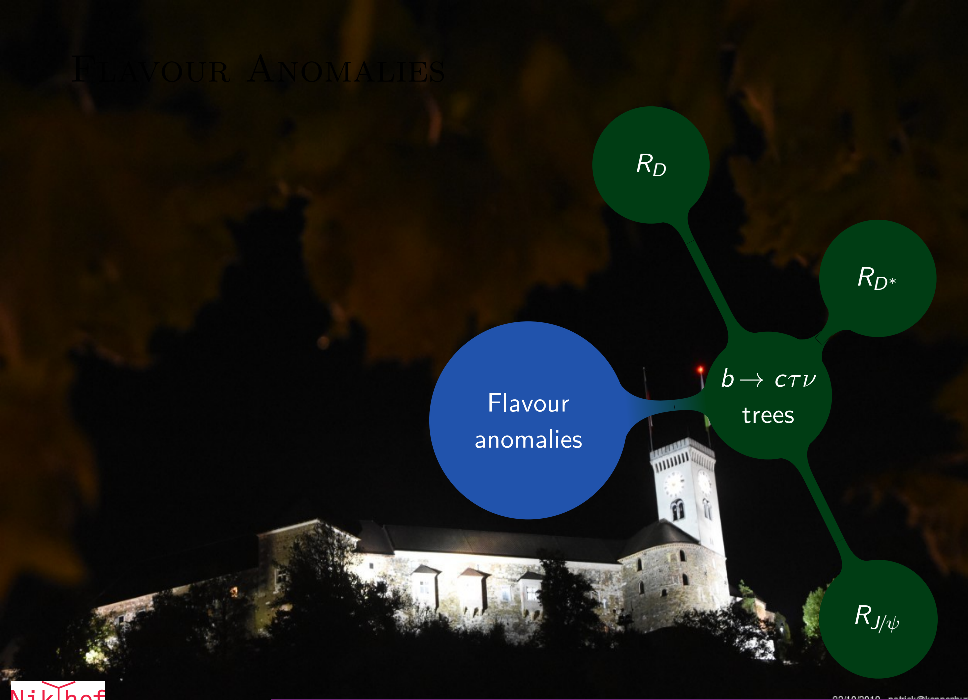
Search for Forbidden Decays

Jolanta Brodzicka

$D^0 \to$	N_{sig}	$\mathcal{B}$ and 90% U.L. ($\times 10^{-7}$)	
$\pi^-\pi^-e^+e^+$	$0.22 \pm 3.15 \pm 0.54$	$0.27 \pm 3.90 \pm 0.67$	< 9.1
$\pi^-\pi^-\mu^+\mu^+$	$6.69 \pm 4.88 \pm 0.80$	$7.40 \pm 5.40 \pm 0.91$	< 15.2
$\pi^-\pi^-e^+\mu^+$	$12.42 \pm 5.30 \pm 1.45$	$15.4 \pm 6.59 \pm 1.85$	< 30.6
$\pi^-\pi^+e^\pm\mu^\mp$	$1.37 \pm 6.15 \pm 1.28$	$1.55 \pm 6.97 \pm 1.45$	< 17.1
$K^-\pi^-e^+e^+$	$-0.23 \pm 0.97 \pm 1.28$	$-0.38 \pm 1.60 \pm 2.11$	< 5.0
$K^-\pi^-\mu^+\mu^+$	$-0.03 \pm 2.10 \pm 0.40$	$-0.05 \pm 3.34 \pm 0.64$	< 5.3
$K^-\pi^-e^+\mu^+$	$3.87 \pm 3.96 \pm 2.36$	$5.84 \pm 5.97 \pm 3.56$	< 21.0
$K^-\pi^+e^\pm\mu^\mp$	$2.52 \pm 4.60 \pm 1.35$	$3.62 \pm 6.61 \pm 1.95$	< 19.0
$K^-K^-e^+e^+$	$0.30 \pm 1.08 \pm 0.41$	$0.43 \pm 1.54 \pm 0.58$	< 3.4
$K^-K^-\mu^+\mu^+$	$-1.09 \pm 1.29 \pm 0.42$	$-0.81 \pm 0.96 \pm 0.32$	< 1.0
$K^-K^-e^+\mu^+$	$1.93 \pm 1.92 \pm 0.83$	$1.93 \pm 1.93 \pm 0.84$	< 5.8
$K^-K^+e^\pm\mu^\mp$	$4.09 \pm 3.00 \pm 1.59$	$3.93 \pm 2.89 \pm 1.45$	< 10.0



Flavour Anomalies



[Belle, arXiv:1904.08794]

R_D and R_{D^*} with a semileptonic tag

Hara Koji

Using 772 million $B\overline{B}$ pairs, a selileptonic opposite B tag and $\tau \to \mu\overline{\nu}\nu$, Belle measure

$$R(D) = 0.307 \pm 0.037 \pm 0.016$$
$$R(D^*) = 0.283 \pm 0.018 \pm 0.014$$

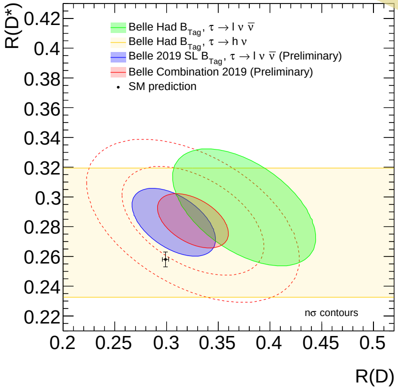
Using only muons:

$$R(D) = 0.373 \pm 0.068 \pm 0.030$$
$$R(D^*) = 0.245 \pm 0.035 \pm 0.020$$

Using only electrons:

$$R(D) = 0.281 \pm 0.042 \pm 0.017$$
$$R(D^*) = 0.304 \pm 0.022 \pm 0.016$$

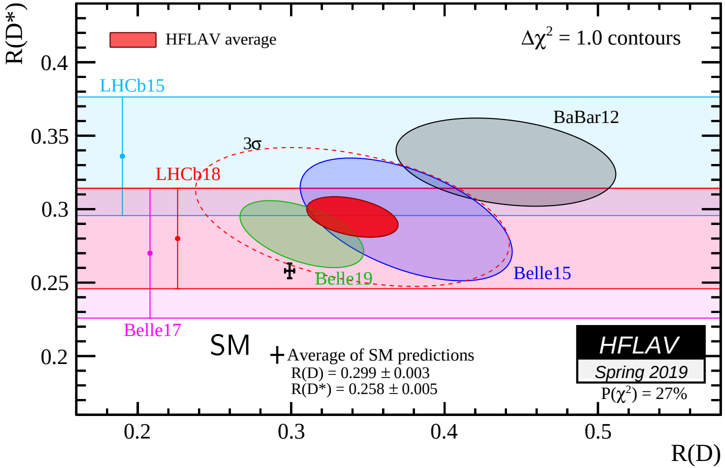
Probably the final word from Belle on $R(D^{(*)})$



Belle combination, with [PRD92 (2015) 072014] and [PRD 97 (2018) 012004]

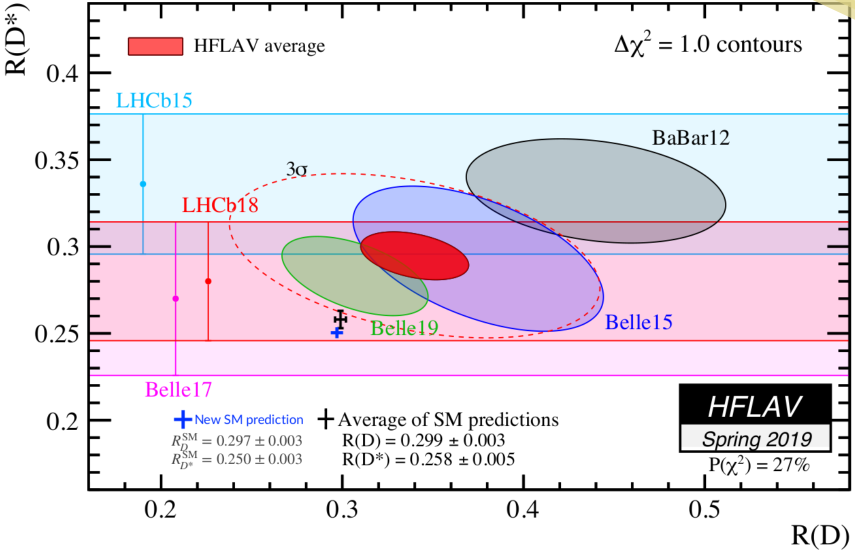
$B \to D^{(*)}\tau\nu$ HFLAV AVERAGE

HFLAV

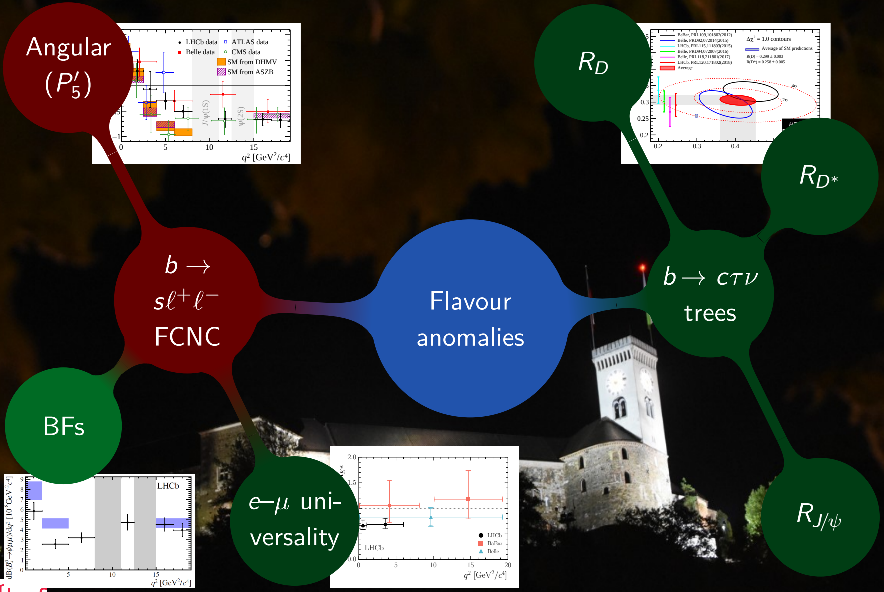


BABAR [PRL 109 101802 (2012)] [PRD 88 072012 (2013)] Belle [PRD 92 072014 (2015)] [PRL 118 211801 (2017)] [PRD 97 012004 (2018)] [arXiv:1904.08794] LHCb [PRL 115 (2015) 111803] [PRL 120 (2018) 171802]. Theory [FLAG EPJC77 (2017) 112], [Faijfer et al., PRD 85 094025 (2012)]

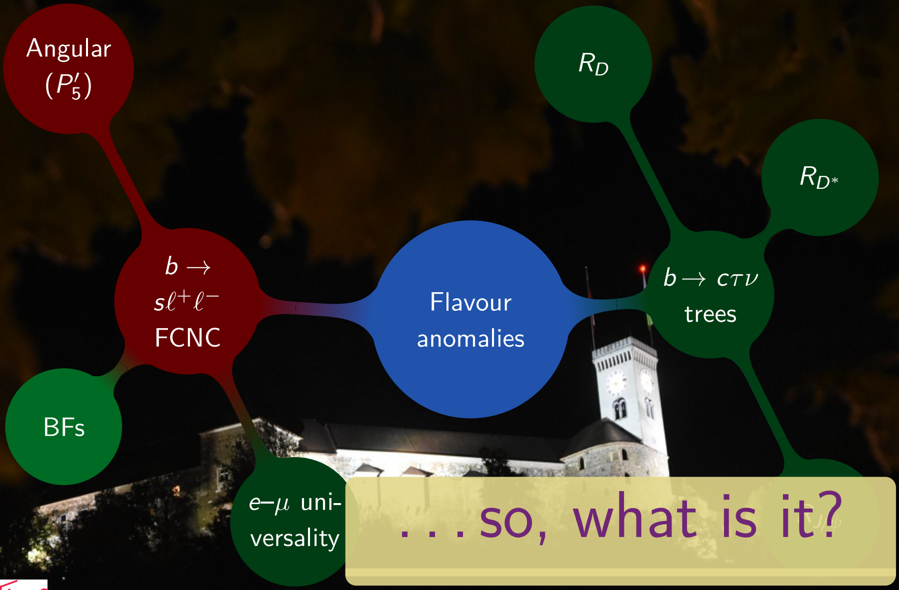
Or is is 3.9σ?



Flavour Anomalies

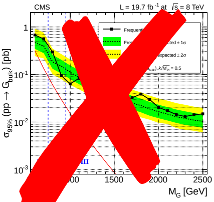


Flavour Anomalies

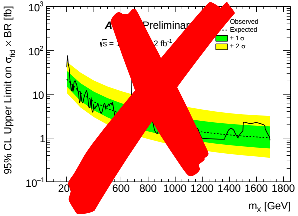


. . . so, what is it?

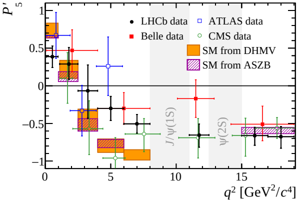
Are we already seeing New Physics?



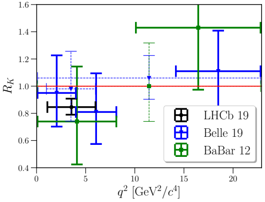
cess at 2 TeV [CMS, JHEP 08 (2014) 174]



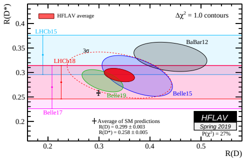
Excess at 750 GeV [ATLAS-CONF-2015-081]



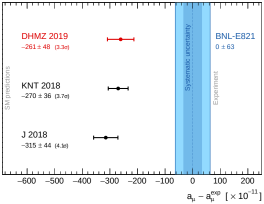
P_5' in $B \to K^* \mu^+ \mu^-$ [JHEP 02 (2016) 104]



Lepton universality [PRL 122 (2019) 191801] . . .



$b \to c\tau\nu$ [HFlav, arXiv:1909.12524]



Muon $g-2$ [Davier, Hoecker, Malaescu, Zhang]

There is a handful of intriguing 3–4σ anomalies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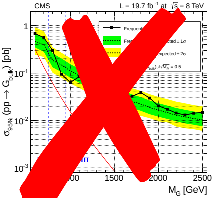
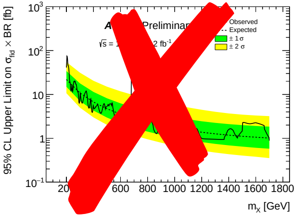
Meer DirkJan? Kijk op
veronicamagazine.nl
Mark Retera
TOK
KLEI
KLAP
KLAP
KLAP

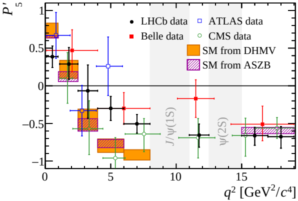
Are we already seeing New Physics?



cess at 2 TeV [CMS, JHEP 08 (2014) 174]

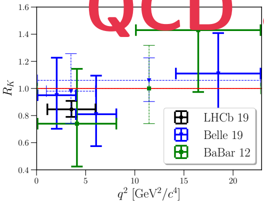


Excess at 750 GeV [ATLAS-CONF-2015-081]

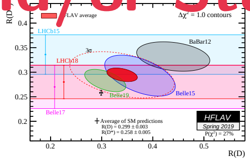


P'_5 in $B \to K^* \mu^+ \mu^-$ [JHEP 02 (2016) 104]

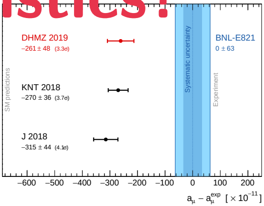
QCD and/or Statistics?



Lepton universality [PRL 122 (2019) 191801] . . .



$b \to c\tau\nu$ [HFlav, arXiv:1909.12524]



Muon $g-2$ [Davier, Hoecker, Malaescu, Zhang]


LIVE
The LHCb detector
breakyourownnews.com
BREAKING NEWS
DISCOVERY ANNOUCED IN TOKYO
9:54
BEAUTY DECAYS INDICATE YET UNKNOWN PARTICLES EXIST SAYS GUY WILKINSON

Flavour Anomalies

We need better precision in QCD.

Flavour anomalies

QCD

Lattice

Sum rules

Flavour Anomalies

It could be new vector bosons (but beware of $B\overline{B}$ mixing)

Z', W'

Flavour anomalies

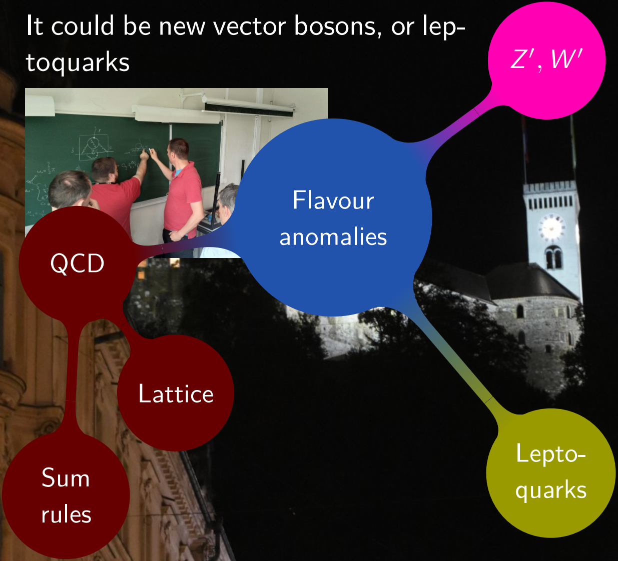
QCD

Lattice

Sum rules

Flavour Anomalies

It could be new vector bosons, or leptoquarks



Flavour Anomalies

Why is there no *CP* violation beyond the CKM matrix?

Flavour anomalies

Z', W'

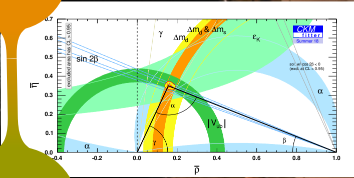
CPV?

Lepto-quarks

QCD

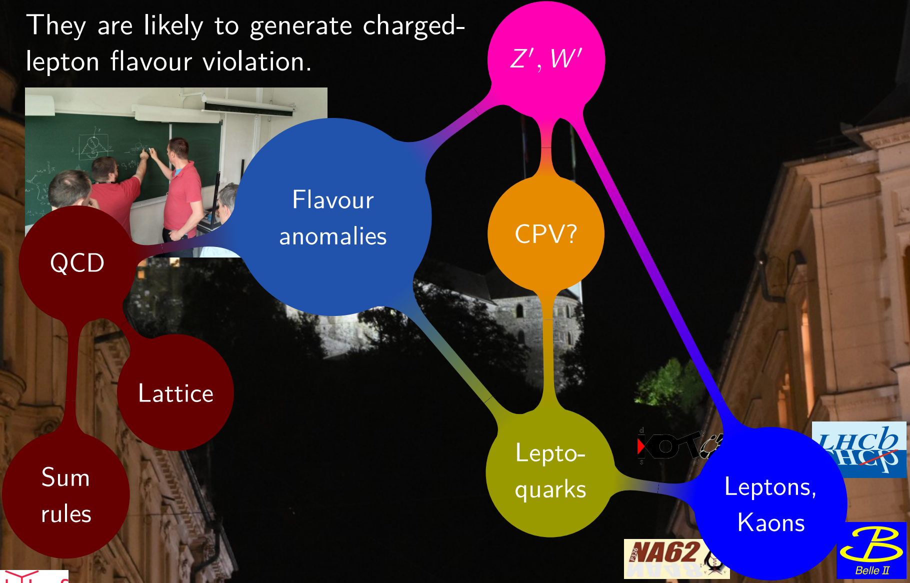
Lattice

Sum rules



Flavour Anomalies

They are likely to generate charged-lepton flavour violation.



Flavour Anomalies

Can we see the bosons or leptoquarks at ATLAS and CMS?

Flavour anomalies

QCD

Lattice

Sum rules

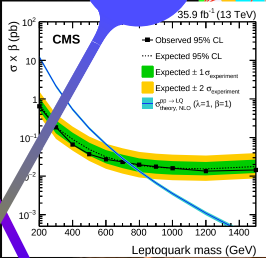
Z', W'

LHC

CPV?

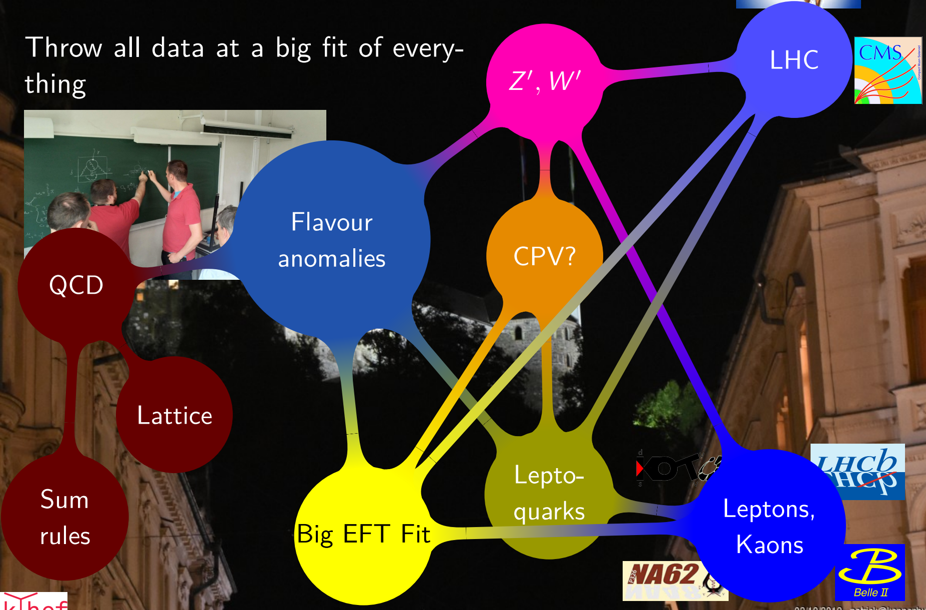
Lepto-quarks

Leptons, Kaons



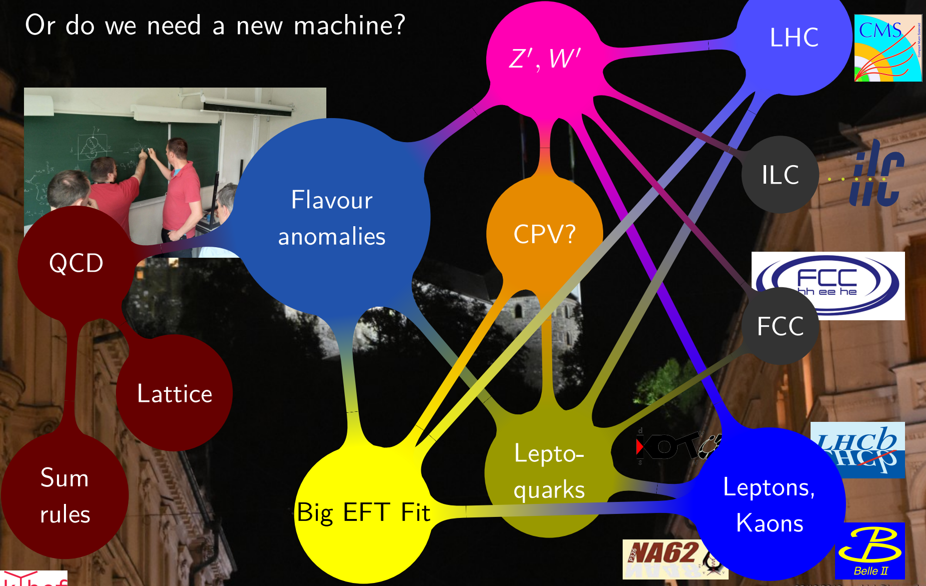
Flavour Anomalies

Throw all data at a big fit of everything



Flavour Anomalies

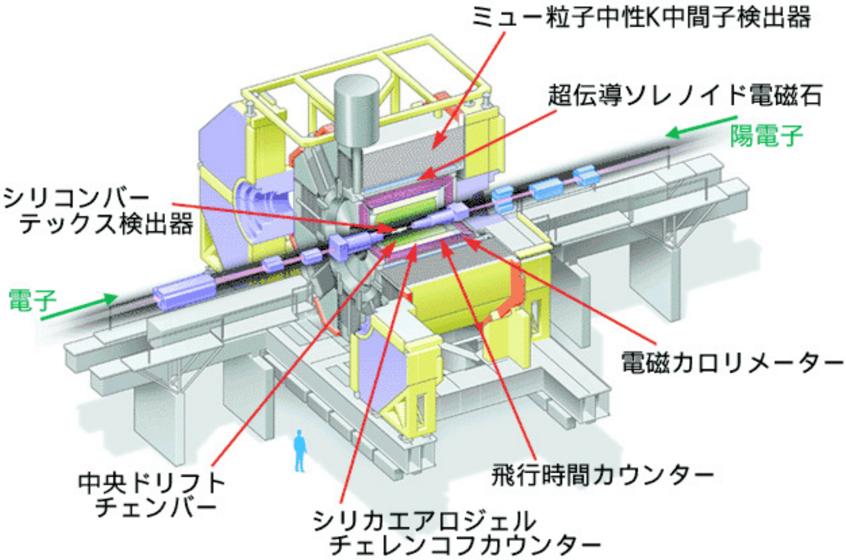
Or do we need a new machine?



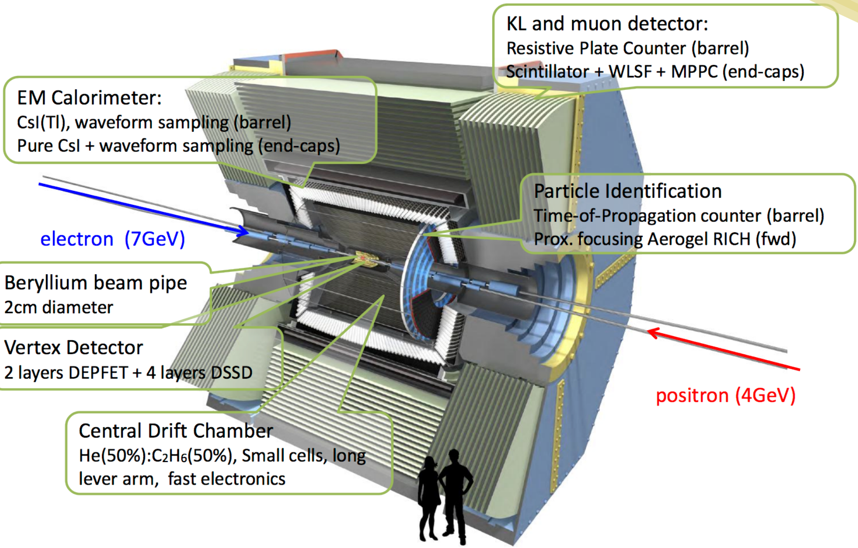
Outlook

[Belle, NIM A479 (2002) 117]

The Belle Experiment



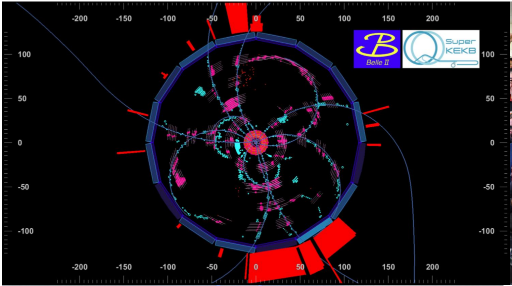
Belle II

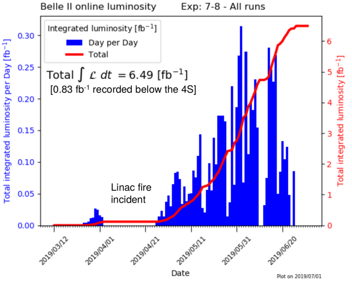


KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)
electron (7GeV)
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)
Beryllium beam pipe
2cm diameter
Vertex Detector
2 layers DEPFET + 4 layers DSSD
positron (4GeV)
Central Drift Chamber
He(50%):C2H6(50%), Small cells, long
lever arm, fast electronics

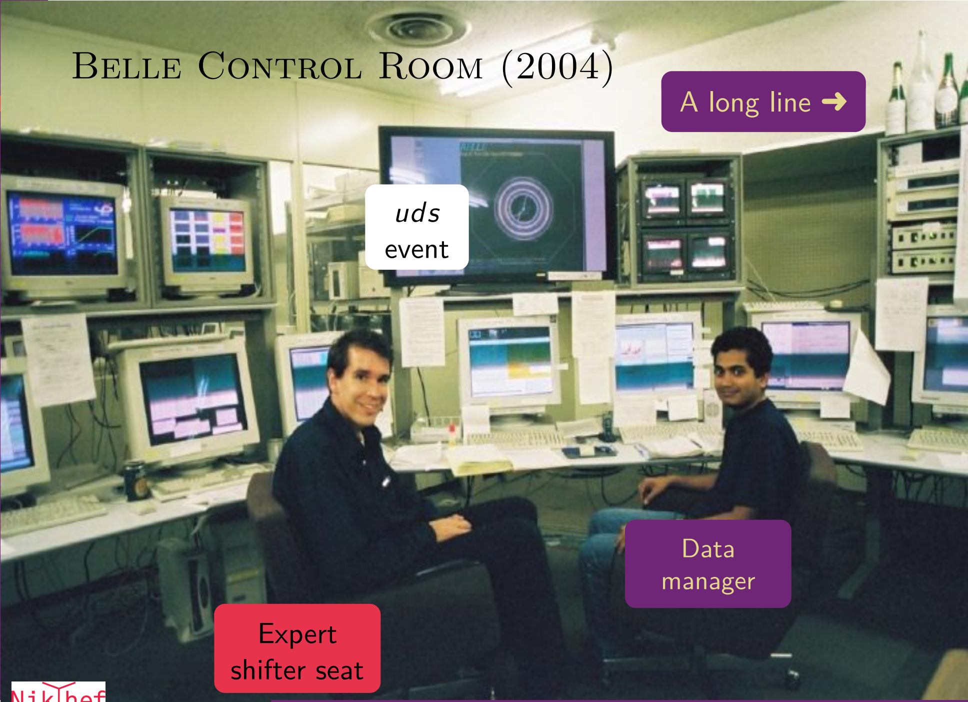
Gagan Mohanty

Belle II startup

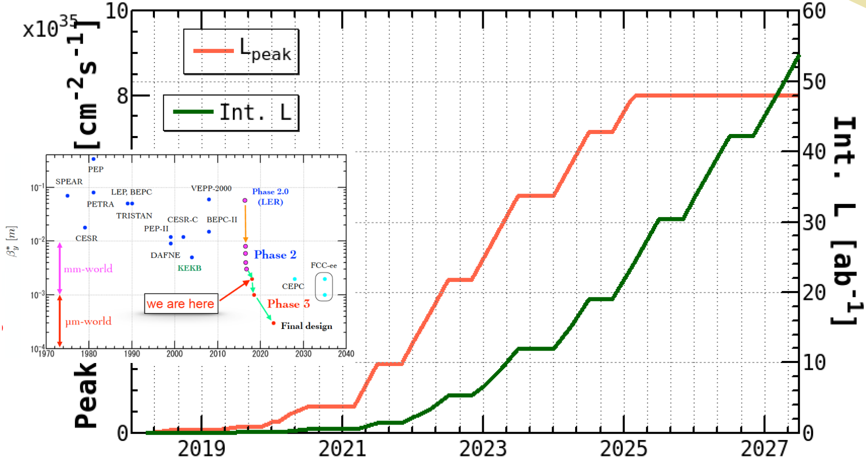




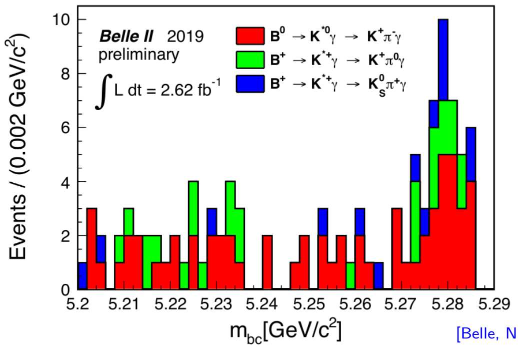
Belle Control Room (2004)

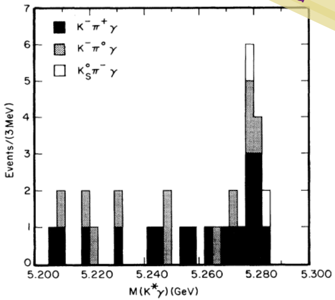


Belle II Schedule



Rare decays at Belle II

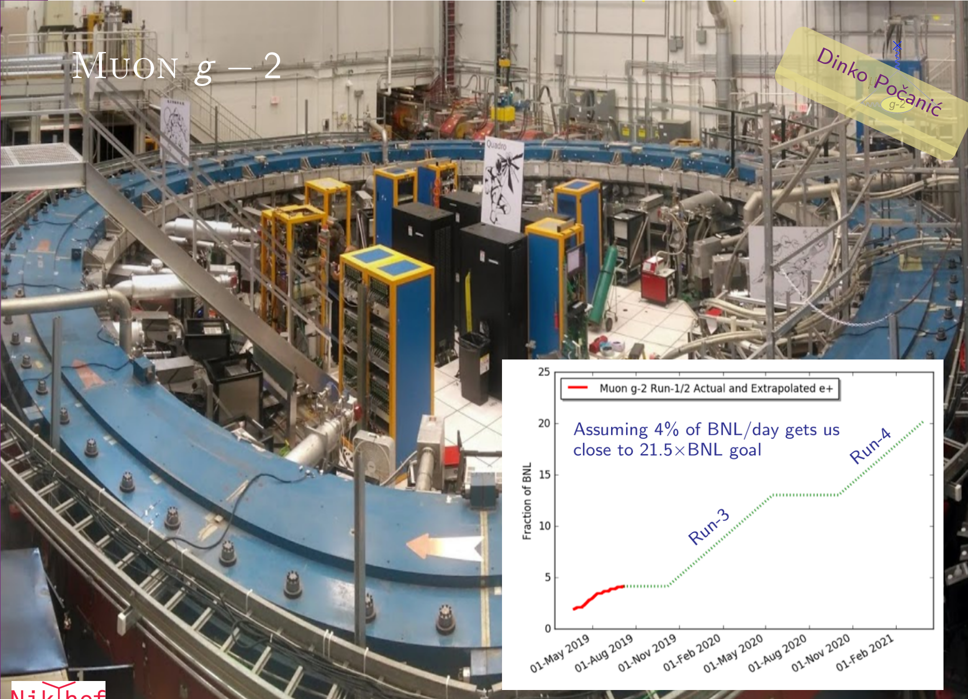




[Belle, NIM A479 (2002) 117][CLEO, PRL 71 (1993) 674]

	signal yield (statistics only)	significance
$B^0 \to K^{*0}(\to K^+\pi^-)\gamma$	19.1 ± 5.2	4.4 σ
$B^+ \to K^{*+}(\to K^+\pi^0)\gamma$	9.8 ± 3.4	3.7 σ
$B^+ \to K^{*+}(\to K^0_S\pi^+)\gamma$	6.6 ± 3.1	2.1 σ

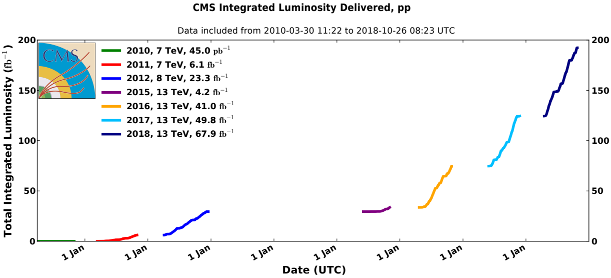
Muon $g-2$

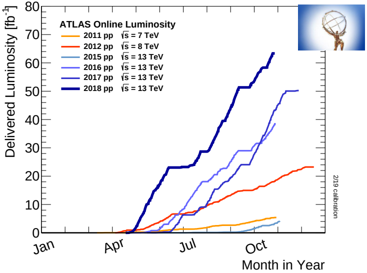

Dinko Počanić
Quadro
Muon g-2 Run-1/2 Actual and Extrapolated e+
Assuming 4% of BNL/day gets us close to 21.5×BNL goal
Run-3
Run-4
Fraction of BNL
0
5
10
15
20
25
01-May 2019
01-Aug 2019
01-Nov 2019
01-Feb 2020
01-May 2020
01-Aug 2020
01-Nov 2020
01-Feb 2021

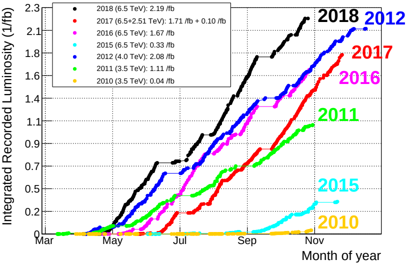
[Max Degtyarev (2019)]

LHC

Integrated Luminosity







PARKED B SAMPLE AT CMS

DAQ capacity exceeds computing capacity
→ park some data for later use

- CMS collected 10^{10} B events.
- Similar to LHCb's 2011 sample (caveats apply)

BROWN

What we Have on Tape

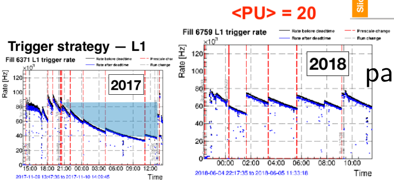
Greg Landsberg - Flavor Anomalies in CMS - Lyon September 2019

Slide 16

Mode	N_{2018}	f_B [17]	$\mathcal{B}$
Generic B hadrons			
B_d^0	4.99×10^9	0.4	1.0
$B^\pm$	4.99×10^9	0.4	1.0
B_s	1.56×10^9	0.1	1.0
b baryons	1.56×10^9	0.1	1.0
B_c	1.25×10^7	0.001	1.0
B hadrons total	1.25×10^{10}	1.0	1.0
Interesting B decays			
$B^0 \to K^* \ell^+ \ell^-$	3290	0.4	$\frac{2}{3} \times 9.9 \times 10^{-7}$ [14]
$B^\pm \to K^\pm \ell^+ \ell^-$	2250	0.4	4.51×10^{-7} [15]

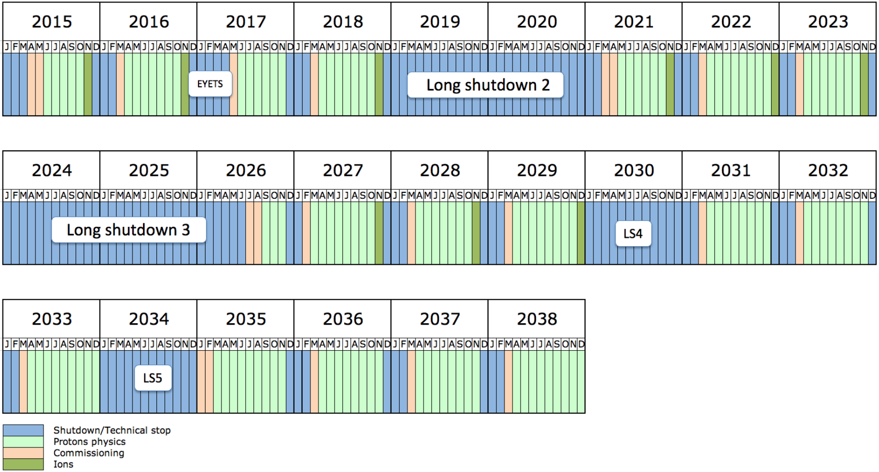
More than 20x the entire BaBar B sample collected in just 6 months!

For other physics, the integrated luminosity of this sample is ~50 fb^{-1}

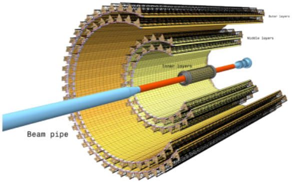


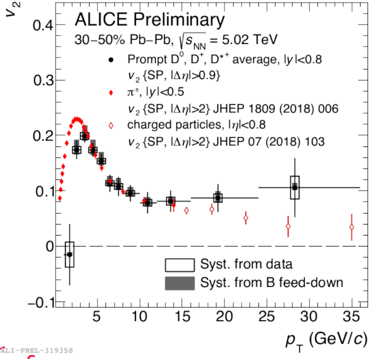
Approximate sample of b hadrons in parked sample **before** reconstruction and selection

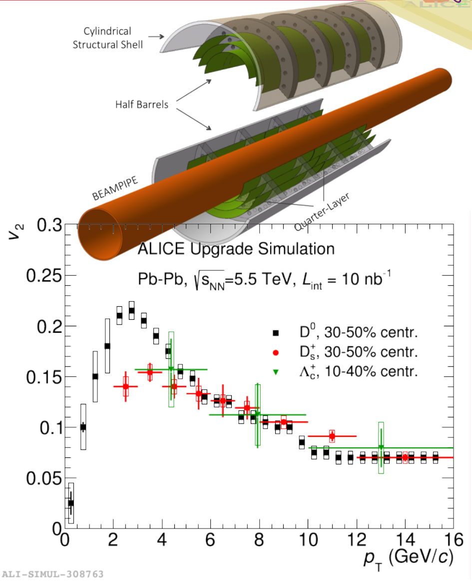
LHC schedule



ALICE Upgrades

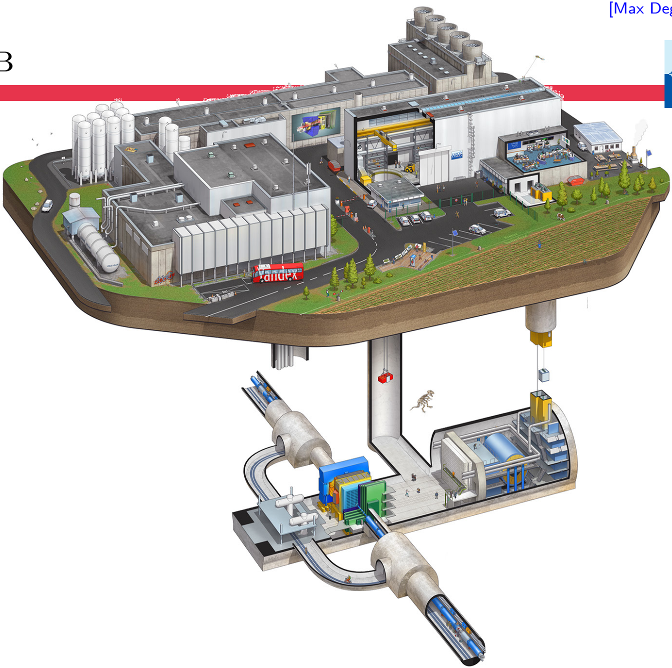






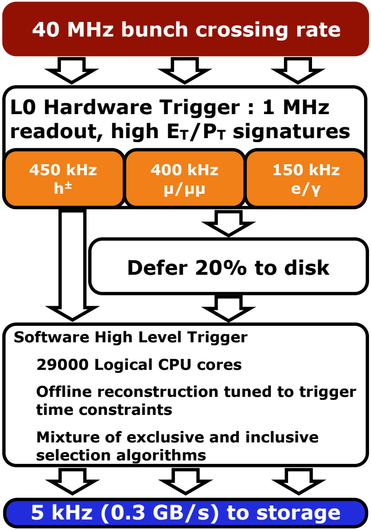
LHCb

[Max Degtyarev (2019)]

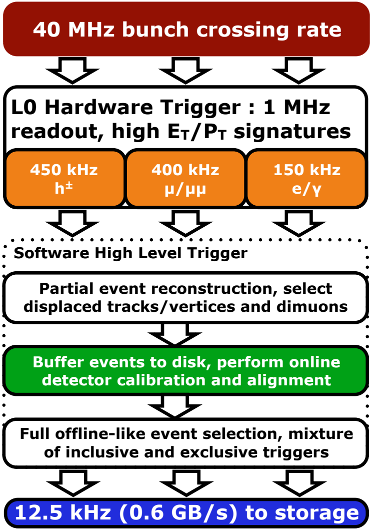


LHCb Trigger in Run 2

LHCb 2012 Trigger Diagram



LHCb 2015 Trigger Diagram



LHCb Trigger in Run 3

Sevda Esen

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

⇓ ⇓ ⇓

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz $h^{\pm}$	400 kHz $\mu/\mu\mu$	150 kHz e/γ

⇓ ⇓ ⇓

Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

⇓

Buffer events to disk, perform online detector calibration and alignment

⇓

Full offline-like event selection, mixture of inclusive and exclusive triggers

⇓ ⇓ ⇓

12.5 kHz (0.6 GB/s) to storage

→

LHCb Upgrade Trigger Diagram

30 MHz inelastic event rate (full rate event building)

⇓ ⇓ ⇓

Software High Level Trigger

Full event reconstruction, inclusive and exclusive kinematic/geometric selections

⇓

Buffer events to disk, perform online detector calibration and alignment

⇓

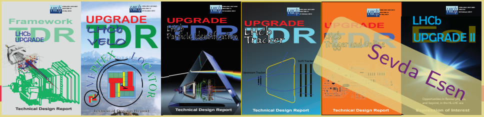
Add offline precision particle identification and track quality information to selections

Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

⇓ ⇓ ⇓

2-5 GB/s to storage

LHCb Upgrade



$\mathcal{L} = 2{\cdot}10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ requires some new detectors and 40 MHz read-out clock new electronics

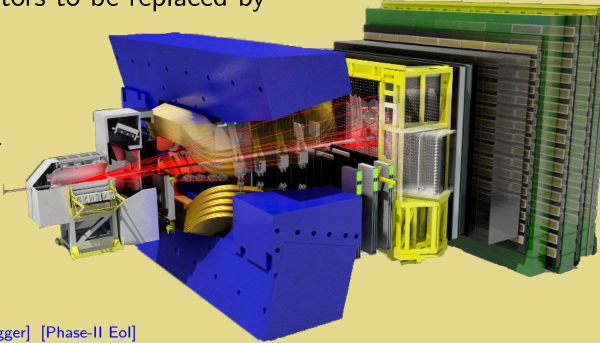
VELO: New pixel vertex detector

TRACKERS: New scintillating fibre tracker. The upstream tracker is also replaced

PID: Hybrid photodetectors to be replaced by multi-anode PMTs

➜ 50 fb^{-1} by Run 4.

✔ We are preparing another upgrade for Run 5 ➜ 300 fb^{-1}



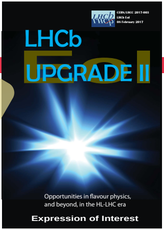
[Upgrade TDR] [Velo] [PID] [Sci-Fi] [Trigger] [Phase-II EoI]

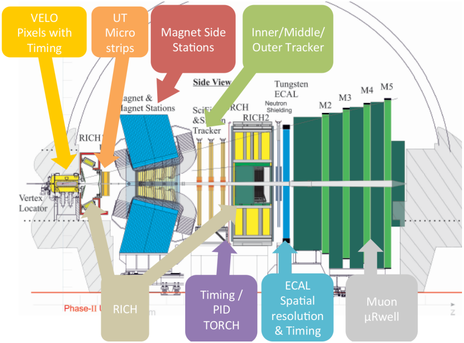

LHCb
DANGER
YCMM01
UX85

[CERN-LHCC-2017-003]

EoI for Phase-II Upgrade

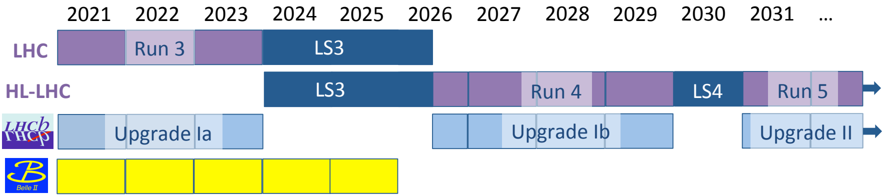
Sevda Esen





We have expressed an interest for a Phase-II upgrade [CERN-LHCC-2017-003] .

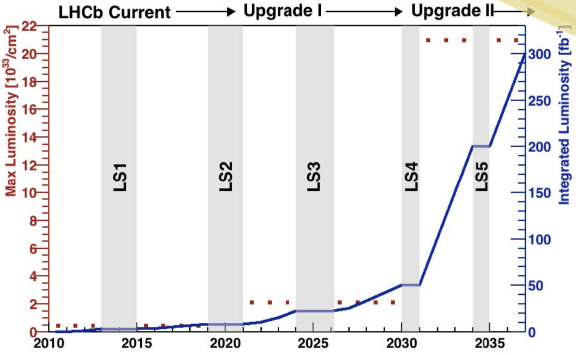
The physics case is [arXiv:1808.08865].



LHCb Phase-II Upgrade

The plan is to record 300 fb^{-1} by the end of Run 5.

1. EoI [CERN-LHCC-2017-003]
2. Physics case [LHCb, arXiv:1808.08865]
3. LHCC has approved LHCb to proceed to a framework TDR (2021)

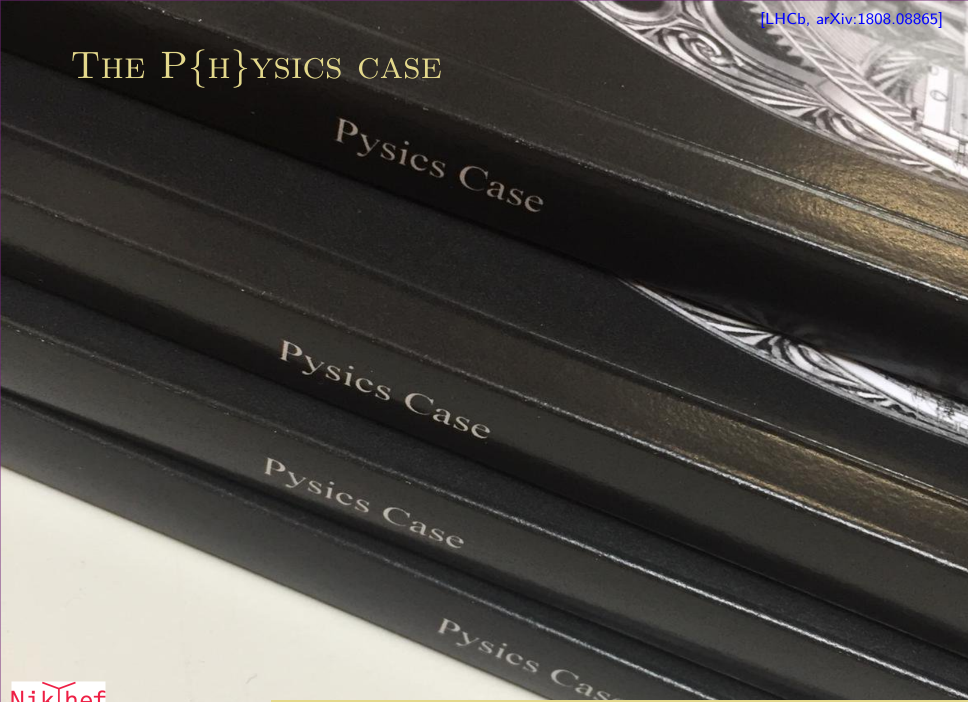


Join us at the open Upgrade-II meeting in Spring 2020 in Barcelona!

- Possibility to join as technical associate group.

[LHCb, arXiv:1808.08865]

The P{h}ysics case



Chris Quigg
Stéphane Monteil

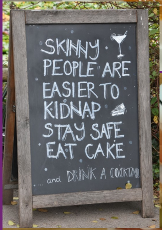
An exercise for all of us

How do *you* assess the scientific potential *for Beauty and in general* of

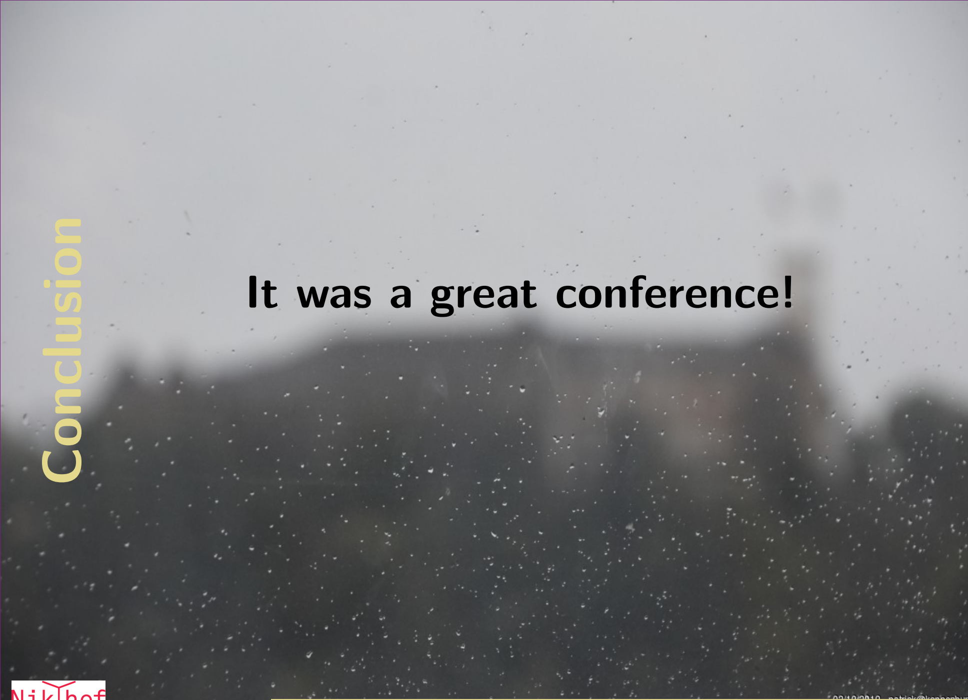
(a) The High-Luminosity LHC?
(b) The High-Energy LHC?
(c) A 100-TeV pp Collider (FCC-hh)?
(d) A 250-GeV ILC?
(e) A circular Higgs factory (FCC-ee or CEPC)?
(f) A 380-GeV CLIC?
(g) A $\mu^+\mu^- \to H$ Higgs factory?
(h) LHeC / FCC-eh? (or an electron–ion collider?)
(i) A muon-storage-ring neutrino factory?
(j) A multi-TeV muon collider?
(k) The instrument of your dreams?






SKINNY
PEOPLE ARE
EASIER TO
KIDNAP
STAY SAFE
EAT CAKE
and DRINK A COCKTAI

Conclusion

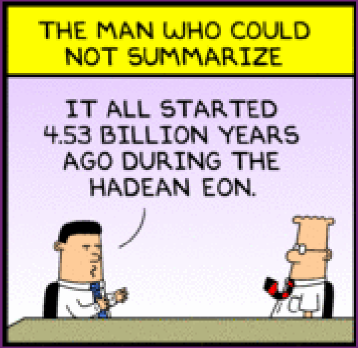


It was a great conference!

Conclusion

It was a great conference!

Thanks Ljubljana!


THE MAN WHO COULD NOT SUMMARIZE
IT ALL STARTED 4.53 BILLION YEARS AGO DURING THE HADEAN EON.

Backup