Wrap-up

Vincenzo Vagnoni
INFN Bologna

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INFN Bologna

Petition to abolish summary talks

- Don't be shy → pass by the secretariat before leaving
- All together we can stop the shameful abuse of summary speakers!

Standard disclaimer…

- Obviously it is impossible to give in 45 minutes (hopefully) a full summary of a week of talks → focusing on highlights
- Nevertheless, ended up with ~110 slides…
  - Several slides have been moved to the extended material after the conclusions
- If your topic of interest is not even there, then it's my fault, my bias, lack of time, or simply… I didn't understand. Sorry!

Setting the scene

- We know nowadays that the Standard Model (of particle physics) works beautifully up to an energy scale of a few hundred GeV
- However, there are compelling reason to state that it is incomplete, e.g.
  - Missing dark matter candidate
  - *CP* violation for dynamical generation of the BAU is largely insufficient
- As well as more fundamental reasons, such as
  - Why three families of quarks and leptons?
  - Why the masses of fundamental particles span several orders of magnitude?
  - How to accommodate gravity into the global quantum picture?

Setting the scene

- We know nowadays that the Standard Model (of particle physics) works beautifully up to an energy scale of a few hundred GeV

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M. Neubert

Strumia dixit: we are lost in space-time

We understand why we do not understand flavour.

LHC told us that the Higgs is not what most theorists expected.

Abandoning prejudices can lead to new ideas, e.g. fundamental composite H.
Maybe new ideas for flavour? Or new physics needed to make progress.

R_K? R_D? Data please.

A. Strumia

Flavour physics in a nutshell

- Classic broad-range measurements
  - CKM physics and rare decays
- Measurements in specific sectors where anomalies are emerging in recent years
  - Lepton-flavour universality in $b \to s\ell^+\ell^-$ transitions, and related $b \to s\ell^+\ell^-$ picture of decay rates
  - Lepton-flavour universality in semileptonic *b*-hadron decays
- Heavy flavour production, spectroscopy and properties
  - While primarily looking for BSM physics, flavour physics is also a unique laboratory to better understand QCD in the low-energy regime

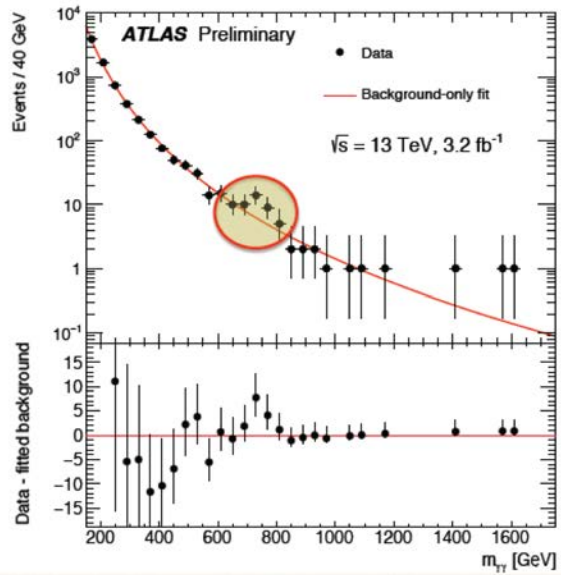
M. Neubert

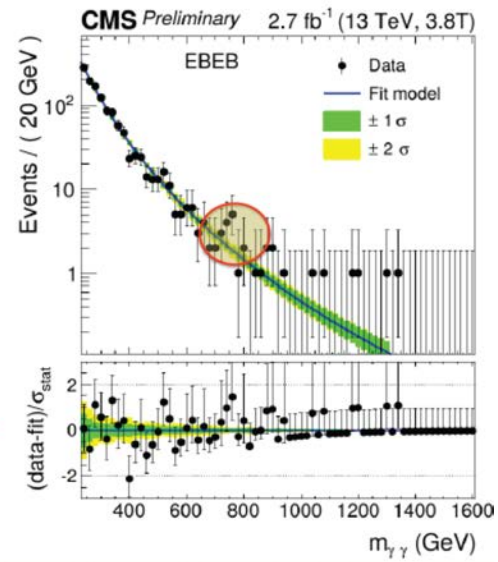
B flavour anomalies

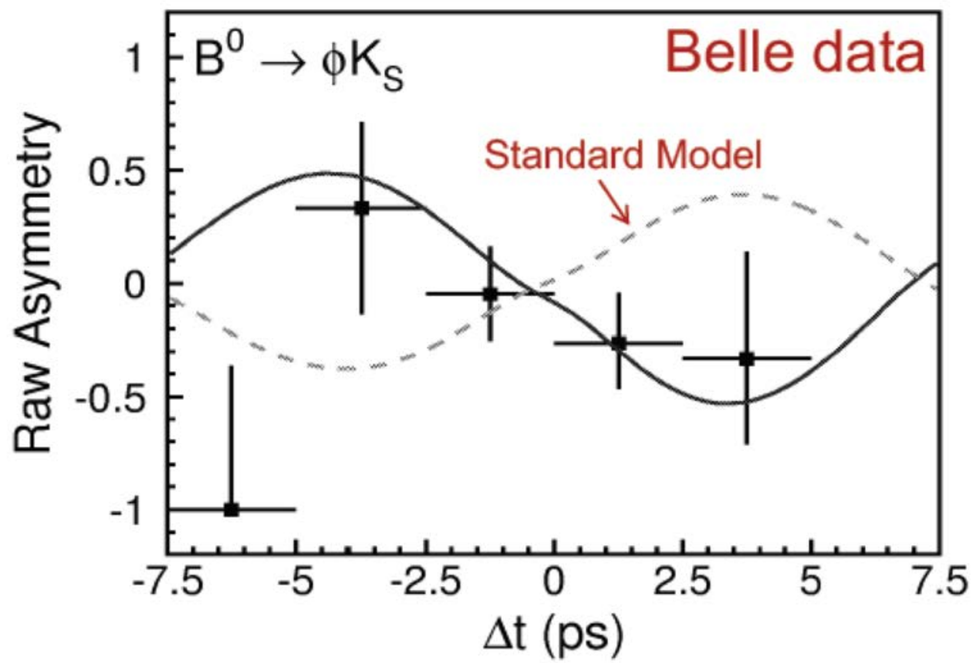
	b→clν	b→sll
Observables	R_D, R_{D^*}	R_K, R_{K^*}, angular distributions
SM	tree level, CKM favored	one-loop FCNC, GIM suppressed
LFU violation	τ vs. e/μ	μ vs. e
Caveats	τ reconstruction difficult, oldest experiment (BaBar) shows largest effect	electron reconstruction difficult at LHCb, so far no confirmation by another experiment
Benefits	Solid theory	Solid theory for $R_{K^{(*)}}$, some caveats for P_5'

Coeff.	best fit	1σ	2σ	pull
C_9^{NP}	-1.21	$[-1.41, -1.00]$	$[-1.61, -0.77]$	5.2σ
C_9'	$+0.19$	$[-0.01, +0.40]$	$[-0.22, +0.60]$	0.9σ
C_{10}^{NP}	$+0.79$	$[+0.55, +1.05]$	$[+0.32, +1.31]$	3.4σ
C_{10}'	-0.10	$[-0.26, +0.07]$	$[-0.42, +0.24]$	0.6σ
$C_9^{NP} = C_{10}^{NP}$	-0.30	$[-0.50, -0.08]$	$[-0.69, +0.18]$	1.3σ
$C_9^{NP} = -C_{10}^{NP}$	-0.67	$[-0.83, -0.52]$	$[-0.99, -0.38]$	4.8σ
$C_9' = C_{10}'$	$+0.06$	$[-0.18, +0.30]$	$[-0.42, +0.55]$	0.3σ
$C_9' = -C_{10}'$	$+0.08$	$[-0.02, +0.18]$	$[-0.12, +0.28]$	0.8σ
C_9^{NP}, C_{10}^{NP}	$(-1.15, +0.26)$	—	—	5.0σ
C_9^{NP}, C_9'	$(-1.25, +0.59)$	—	—	5.3σ
C_9^{NP}, C_{10}'	$(-1.34, -0.39)$	—	—	5.4σ
C_9', C_{10}^{NP}	$(+0.25, +0.83)$	—	—	3.2σ
C_9', C_{10}'	$(+0.23, +0.04)$	—	—	0.5σ
C_{10}^{NP}, C_{10}'	$(+0.79, -0.05)$	—	—	3.0σ

Matthias dixit: don’t get too excited!







M. Neubert

And in fact we are not too excited…

- Studies of CP violation are an important part of the flavour program
  - Determining precisely SM inputs (CKM parameters)
  - Search for new physics through sensitivity for new CP violating phases
- Non-leptonic B decays are key players
  - Large data sets from B-factories and LHCb-run I, many observables
  - Already impressive experimental uncertainties
- Foresee unprecedented precision for LHCb upgrade and Belle II
  - Challenges theorists to keep up

K. Vos

Still a lot to do with CP violation (here in beauty)

- Extraction of γ from $B \to DK$ is theoretically clean
  - Impressive 1° precision in the upgrade era expected
  - Will play an increasingly important role as input parameter
- Penguin polution in ϕ_s determinations under control
- Penguin dominated $B_s \to KK$ offers additional probe of ϕ_s
  - Requires analyses of $B_s^0 \to K^- \ell^+ \nu_\ell$
- $B \to \pi K$ decays remain puzzling $\to$ good prospects
  - Improved CP asymmetries in $B_d \to \pi^0 K_S$ needed
  - Crucial to distinguish New Physics from QCD effects
- Three-body decays still offer many interesting avenues to explore
  - Study QCDF in $B^0 \to D^- \pi^+ \pi^0$

K. Vos

CP violation in beauty

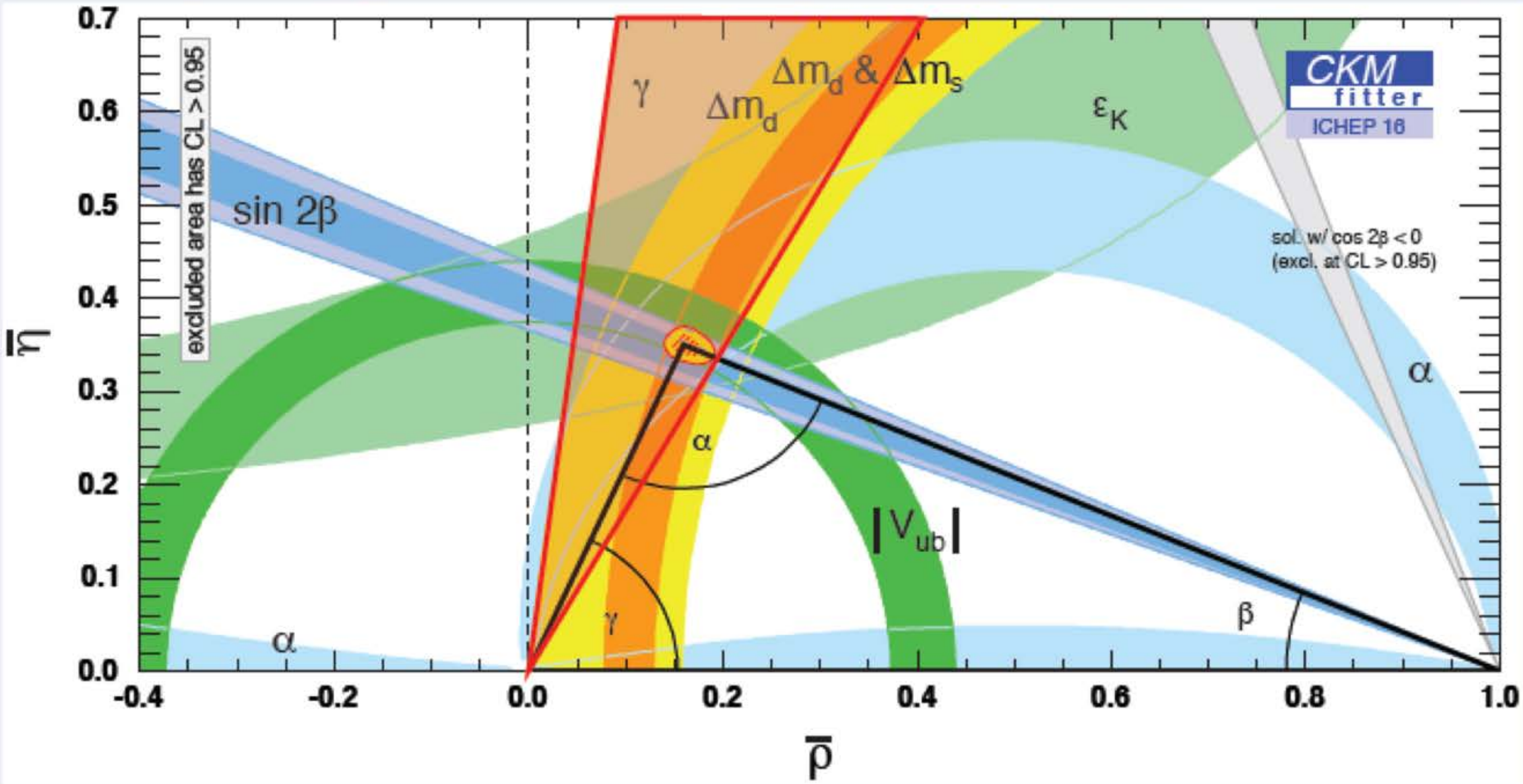
Tree-level determination of γ

- Angle γ is the *least well known* CKM constraint (*although now only just*)
  - **SM benchmark** - only CKM angle accessible at **tree level**

M. Kenzie

Current Status

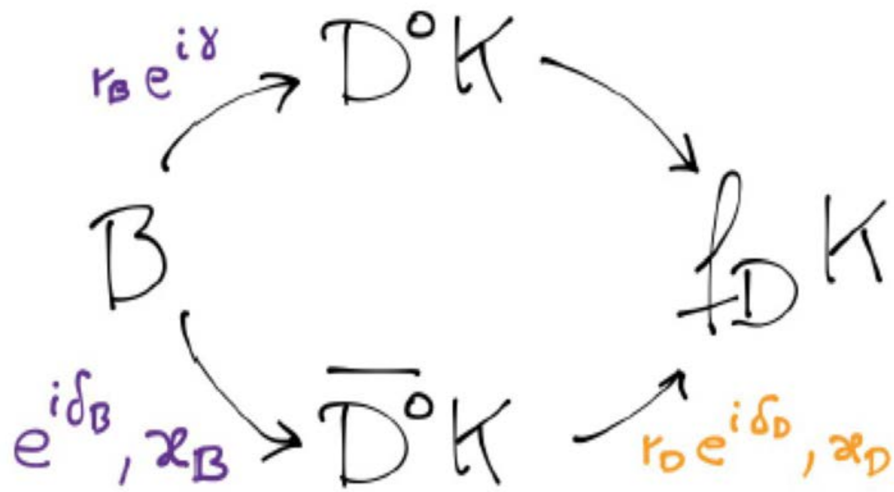
Direct: $\gamma = (73.5^{+4.3}_{-5.0})^\circ$ **Indirect:** $\gamma = (65.3^{+1.0}_{-2.5})^\circ$ **Pre-LHCb:** $\gamma = (73^{+22}_{-25})^\circ$



Many different ways, all very important

Categorise decays sensitive to γ depending on the $\overset{(-)}{D}{}^0 \to f$ final state

Optimal sensitivity is only acheived when combining them all together



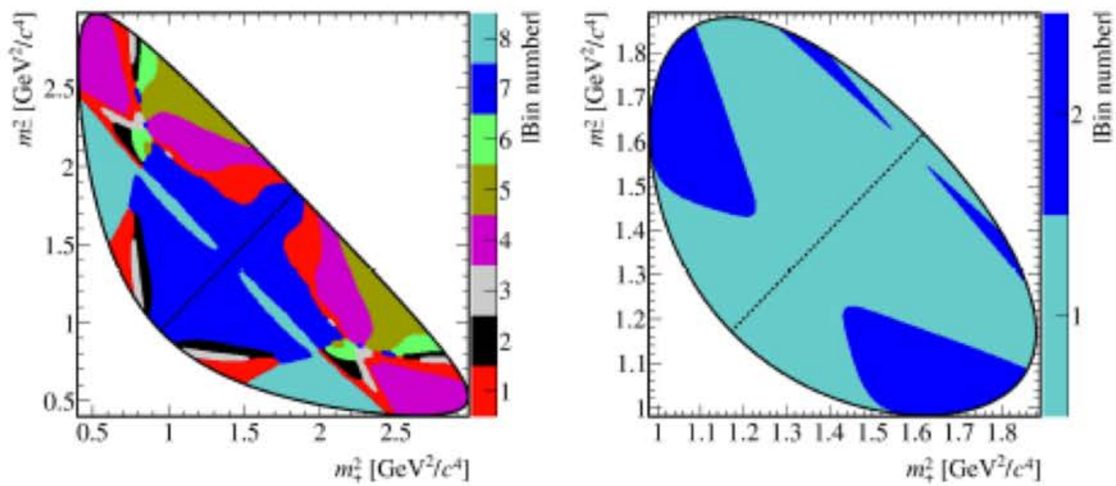
- GLW
  - CP eigenstates e.g. $D \to KK$, $D \to \pi\pi$
  - [Phys. Lett. B253 (1991) 483]
  - [Phys. Lett. B265 (1991) 172]
- ADS
  - CF or DCS decays e.g. $D \to K\pi$
  - [Phys. Rev. D63 (2001) 036005]
  - [Phys. Rev. Lett. 78 (1997) 3257]
- GGSZ
  - 3-body final states e.g. $D \to K^0_S\pi\pi$
  - [Phys. Rev. D68 (2003) 054018]
- TD (Time-dependent)
  - Interference between mixing and decay e.g. $B^0_s \to D^-_s K^+$ [phase is $(\gamma - 2\beta_s)$]
  - Penguin free measurement of ϕ_s?
- Dalitz
  - Look at 3-body B decays with D^0 or $\overline{D}^0$ in the final state, e.g. $B^0 \to \overline{D}^0 K^+\pi^-$
  - [Phys. Rev. D79 (2009) 051301]

M. Kenzie

One recent example

[LHCb-PAPER-2018-017]

- NEW LHCb paper with Run 2 data
- Consider both $D \to K_S^0 \pi\pi$ and $D \to K_S^0 KK$ decays
- Divide up the Dalitz space into $2N$ symmetric bins chosen to optimise sensitivity to γ



Decay amplitude is a superposition of supressed and favoured contributions

$$A_B(m_-^2, m_+^2) \propto A_D(m_-^2, m_+^2) + r_B e^{i(\delta_B - \gamma)} A_{\overline{D}}(m_-^2, m_+^2)$$

Expected number of B^+ (B^-) events in bin i

- $x_\pm + iy_\pm = r_B e^{i(\delta_B \pm \gamma)}$

$$N_{\pm i}^+ = h_{B^+} \left[F_{\mp i} + (x_+^2 + y_+^2) F_{\pm i} + 2\sqrt{F_i F_{-i}} (x_+ c_{\pm i} - y_+ s_{\pm i}) \right]$$

$$N_{\pm i}^- = h_{B^-} \left[F_{\pm i} + (x_-^2 + y_-^2)] F_{\mp i} + 2\sqrt{F_i F_{-i}} (x_- c_{\pm i} - y_- s_{\pm i}) \right]$$

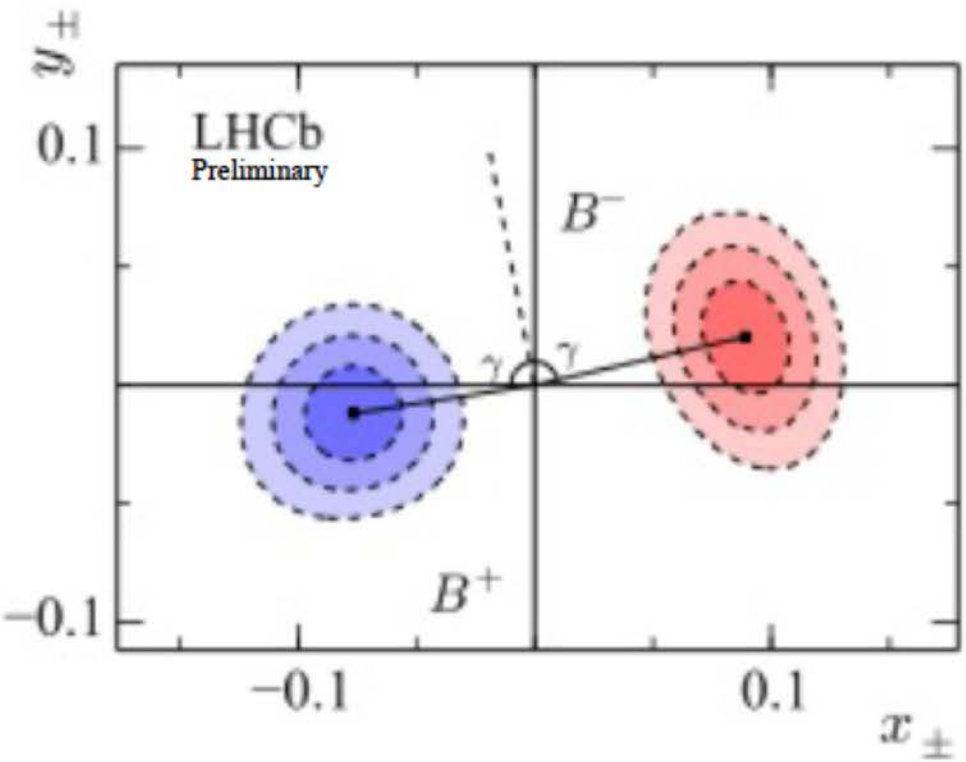
- $N_{\pm i}^\pm$ - events in each bin
- $F_{\pm i}$ - from $B \to D^{*\pm} \mu^\mp \nu_\mu X$
- c_i, s_i - from CLEO-c (QC $D^0 \overline{D}^0$) measurements
- $h_{B\pm}$ - overall normalisation

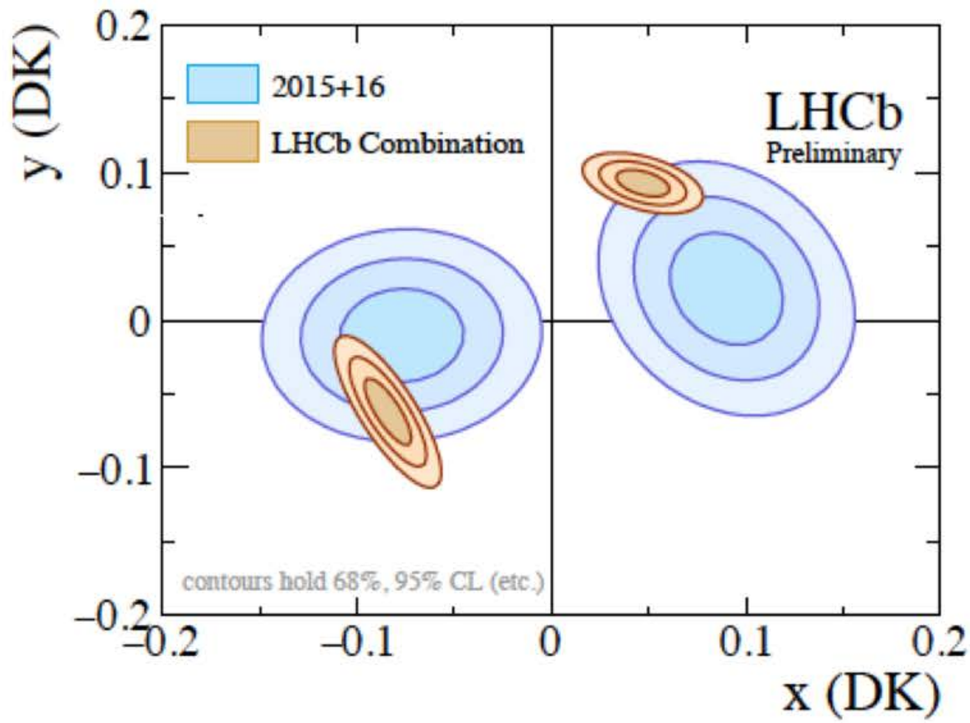
M. Kenzie

One recent example cont'd

[LHCb-PAPER-2018-017]

- Perform CP-fit to determine $x_\pm$ and $y_\pm$
- Combine with Run 1 analysis to determine $\gamma = (80^{+10}_{-9})^\circ$





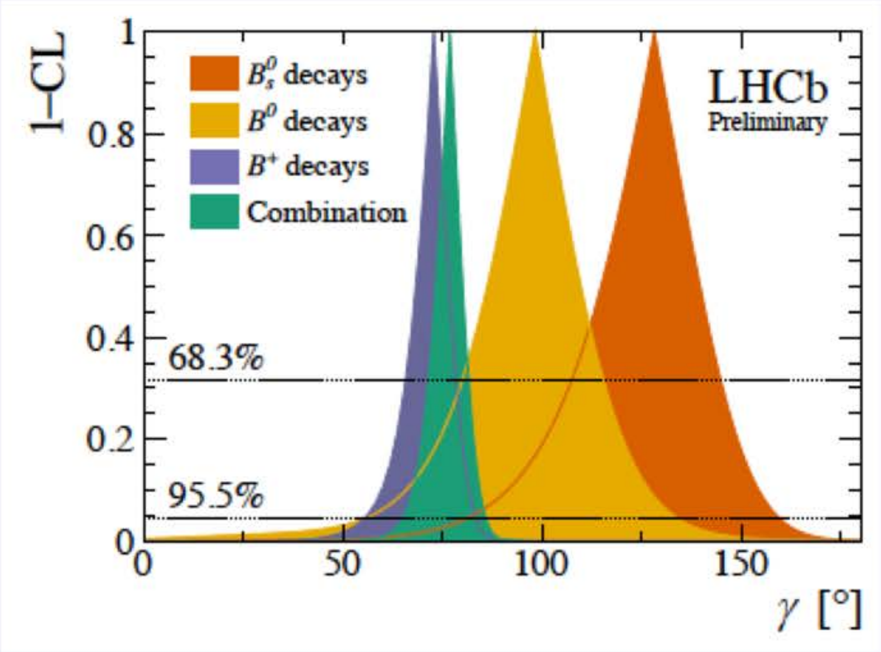
- Most precise determination of γ from a single channel!

M. Kenzie

Overall status with γ

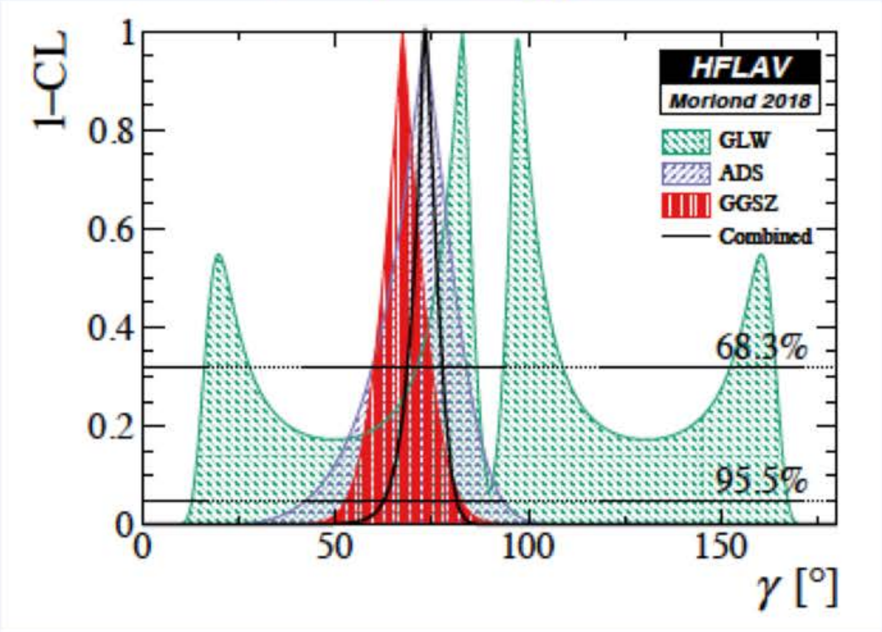
LHCb Average - [LHCb-CONF-2018-002]

$$\gamma = (74.0^{+5.0}_{-5.8})^\circ$$



World Average (HFLAV) - [Spring update]

$$\gamma = (73.5^{+4.2}_{-5.1})^\circ$$



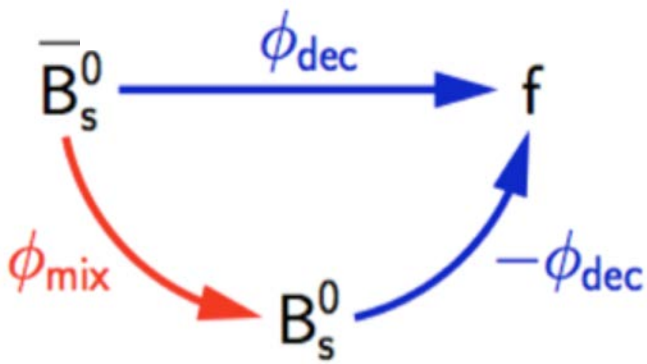
Indirect constraints are: $\gamma = (65.3^{+1.0}_{-2.5})^\circ$ $(\sim 2\sigma)$

Comparison between B_s^0 and B^+ initial states $\sim 2\sigma$

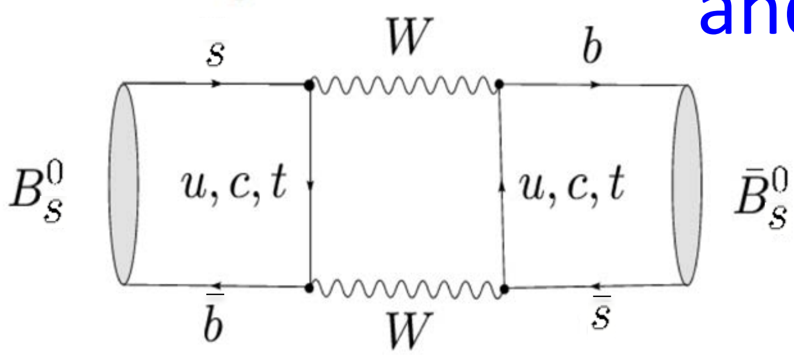
Don’t get excited either, but keep an eye…

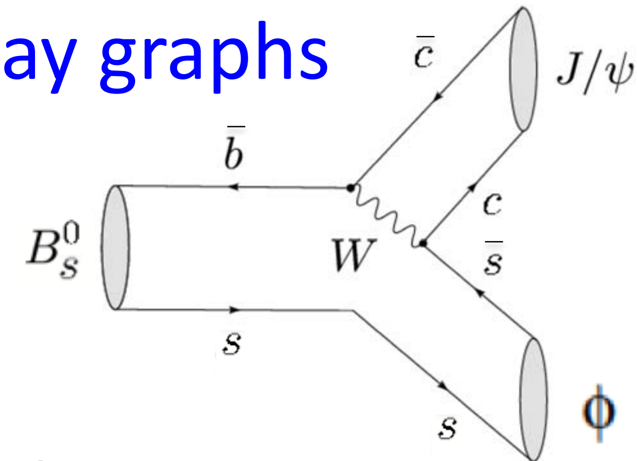
M. Kenzie

ϕ_s from $b \to c\bar{c}s$ transitions



- Golden mode $B_s \to J/\psi\phi$ proceeds (mostly) via a $b \to c\bar{c}s$ tree diagram
- Interference between B_s mixing and decay graphs

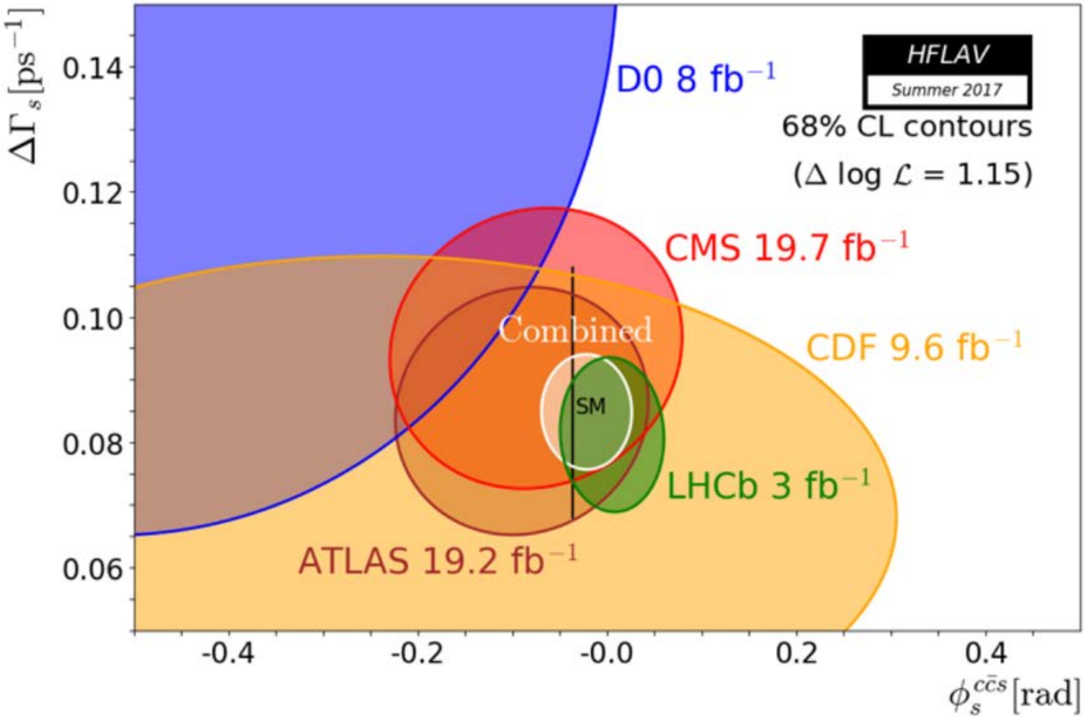




- Measures the phase-difference ϕ_s between the two diagrams, precisely predicted from global CKM fits in the SM to be $\phi_s = -2\lambda^2\eta = -37.4 \pm 0.7$ mrad → can be altered by new physics
  - But also affected by small pollution of sub-leading SM amplitudes that must be taken under control via subsidiary measurements

G. Cowan

ϕ_s from $b \to c\bar{c}s$ transitions cont'd



- Dominant contributions by LHCb, ATLAS and CMS
- Latest HFLAV world average
  - $\phi_s = -21 \pm 31$ mrad
- Still compatible with the SM at the present level of precision

Exp.	Mode	Dataset	$\phi_s^{c\bar{c}s}$	$\Delta\Gamma_s$ (ps^{-1})	Ref.
CDF	$J/\psi\phi$	9.6 fb^{-1}	$[-0.60, +0.12]$, 68% CL	$+0.068 \pm 0.026 \pm 0.009$	[2]
D0	$J/\psi\phi$	8.0 fb^{-1}	$-0.55^{+0.38}_{-0.36}$	$+0.163^{+0.065}_{-0.064}$	[3]
ATLAS	$J/\psi\phi$	4.9 fb^{-1}	$+0.12 \pm 0.25 \pm 0.05$	$+0.053 \pm 0.021 \pm 0.010$	[4]
ATLAS	$J/\psi\phi$	14.3 fb^{-1}	$-0.110 \pm 0.082 \pm 0.042$	$+0.101 \pm 0.013 \pm 0.007$	[5]
ATLAS	above 2 combined		$-0.090 \pm 0.078 \pm 0.041$	$+0.085 \pm 0.011 \pm 0.007$	[5]
CMS	$J/\psi\phi$	19.7 fb^{-1}	$-0.075 \pm 0.097 \pm 0.031$	$+0.095 \pm 0.013 \pm 0.007$	[6]
LHCb	$J/\psi K^+K^-$	3.0 fb^{-1}	$-0.058 \pm 0.049 \pm 0.006$	$+0.0805 \pm 0.0091 \pm 0.0032$	[7]
LHCb	$J/\psi\pi^+\pi^-$	3.0 fb^{-1}	$+0.070 \pm 0.068 \pm 0.008$	—	[8]
LHCb	$J/\psi K^+K^{-\,a}$	3.0 fb^{-1}	$+0.119 \pm 0.107 \pm 0.034$	$+0.066 \pm 0.018 \pm 0.010$	[9]
LHCb	above 3 combined		$+0.001 \pm 0.037$(tot)	$+0.0813 \pm 0.0073 \pm 0.0036$	[9]
LHCb	$\psi(2S)\phi$	3.0 fb^{-1}	$+0.23^{+0.29}_{-0.28} \pm 0.02$	$+0.066^{+0.41}_{-0.44} \pm 0.007$	[10]
LHCb	$D_s^+D_s^-$	3.0 fb^{-1}	$+0.02 \pm 0.17 \pm 0.02$	—	[11]
All combined			-0.021 ± 0.031	$+0.085 \pm 0.006$	

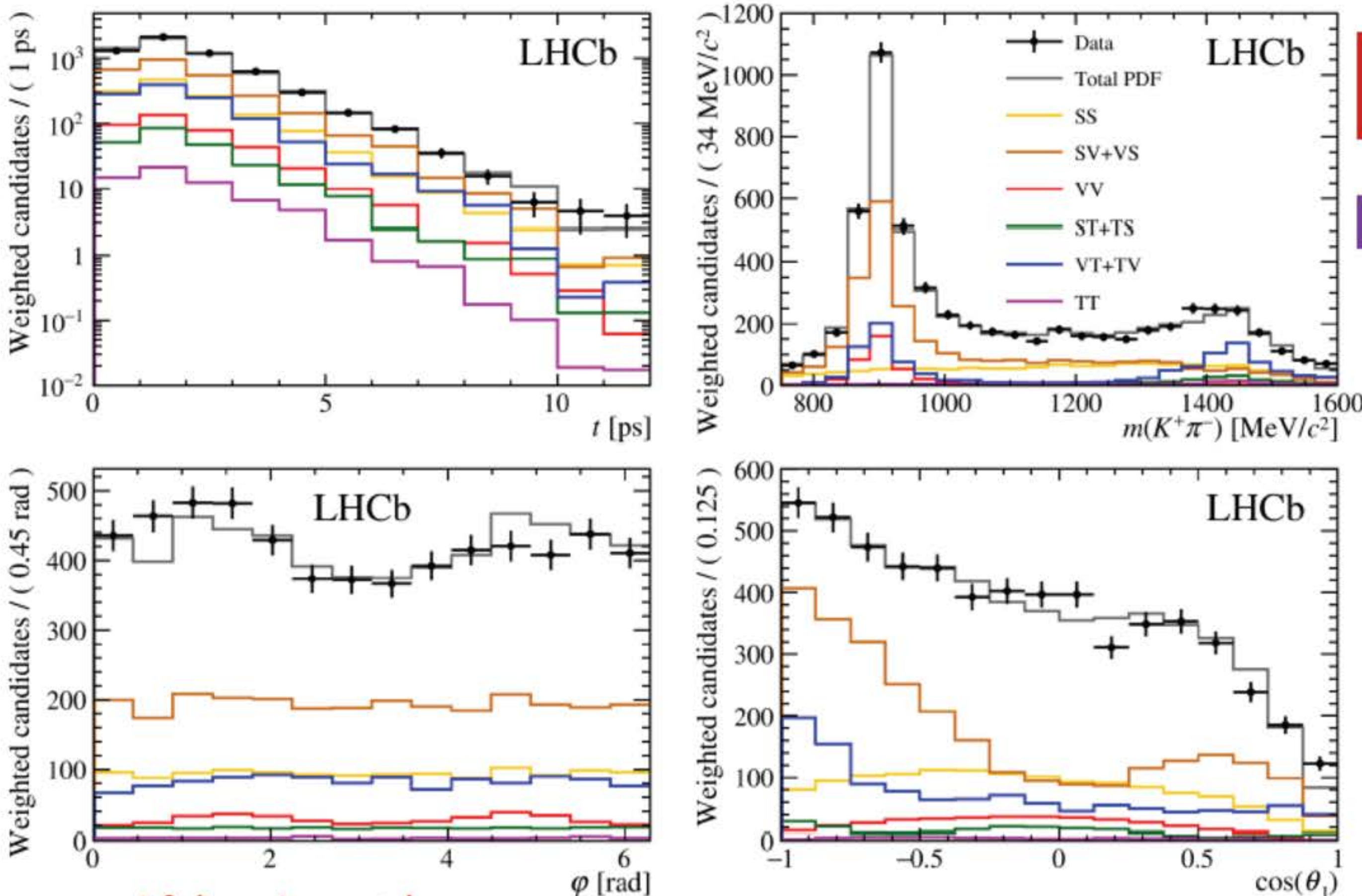
[a] $m(K^+K^-) > 1.05$ GeV/c^2.

See HFLAV page for the list of references https://hflav.web.cern.ch

Other ϕ_s's

$\phi_s^{d\bar{d}}$ from $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$

[JHEP 03 (2018) 140]



+ 2 dimensions not shown

Parameter	Value
Common parameters	
$\phi_s^{d\bar{d}}$ [rad]	$-0.10 \pm 0.13 \pm 0.14$
$\lvert\lambda\rvert$	$1.035 \pm 0.034 \pm 0.089$
Vector/Vector (VV)	
f^{VV}	$0.067 \pm 0.004 \pm 0.024$
f_L^{VV}	$0.208 \pm 0.032 \pm 0.046$
$f_\parallel^{VV}$	$0.297 \pm 0.029 \pm 0.042$
$\delta_\parallel^{VV}$ [rad]	$2.40 \pm 0.11 \pm 0.33$
$\delta_\perp^{VV}$ [rad]	$2.62 \pm 0.26 \pm 0.64$
Scalar/Vector (SV and VS)	
f^{SV}	$0.329 \pm 0.015 \pm 0.071$
f^{VS}	$0.133 \pm 0.013 \pm 0.065$
δ^{SV} [rad]	$-1.31 \pm 0.10 \pm 0.35$
δ^{VS} [rad]	$1.86 \pm 0.11 \pm 0.41$
Scalar/Scalar (SS)	
f^{SS}	$0.225 \pm 0.010 \pm 0.069$
δ^{SS} [rad]	$1.07 \pm 0.10 \pm 0.40$
Scalar/Tensor (ST and TS)	
f^{ST}	$0.014 \pm 0.006 \pm 0.031$
f^{TS}	$0.025 \pm 0.007 \pm 0.033$
δ^{ST} [rad]	$-2.3 \pm 0.4 \pm 1.7$
δ^{TS} [rad]	$-0.10 \pm 0.26 \pm 0.82$

First CPV results

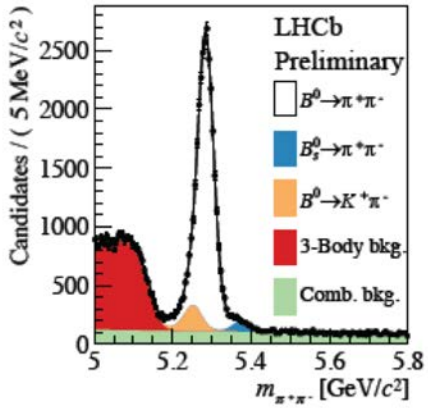
Small longitudinal VV fraction

+ other results for fractions/phases of other Q2B amplitudes

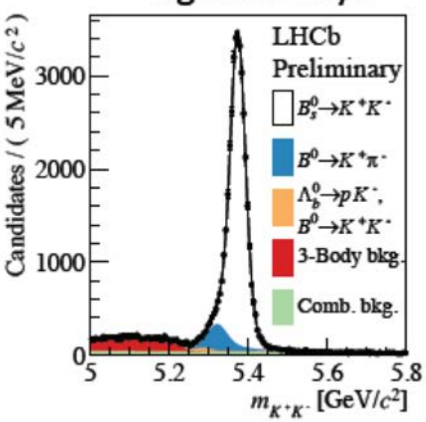
Systematic uncertainty dominated by modelling the angular efficiency from simulation

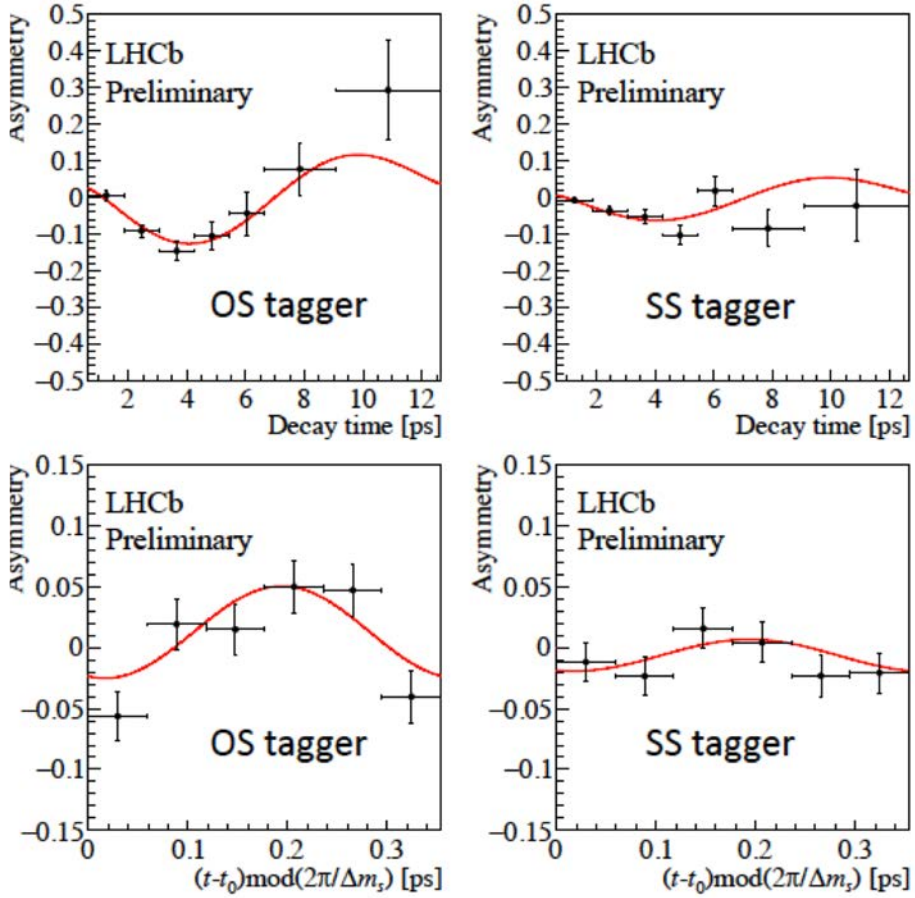
CP violation in $B^0_{(s)} \rightarrow h^+h^-$

$\sim$29k $B^0 \rightarrow \pi^+\pi^-$ signal decays



$\sim$37k $B_s^0 \rightarrow K^+K^-$ signal decays





LHCb-PAPER-2018-006

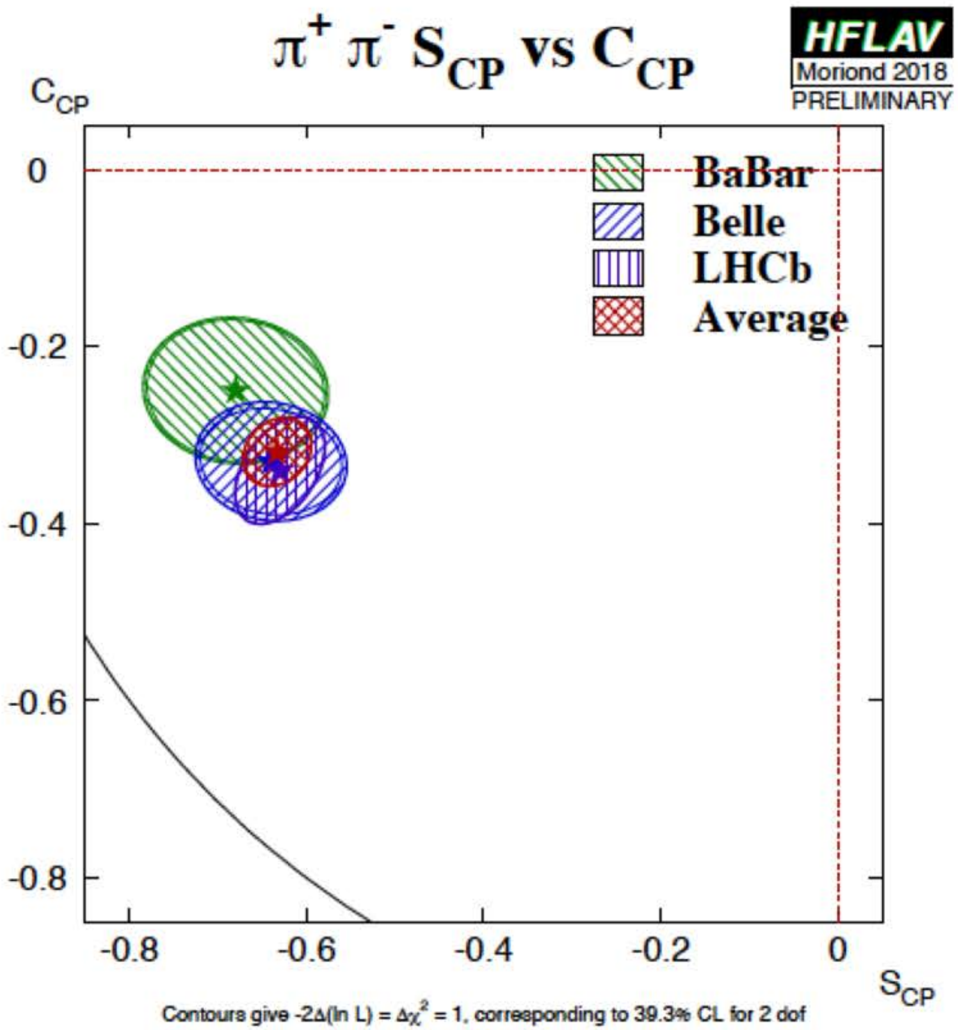
$$
\begin{aligned}
C_{\pi^+\pi^-} &= -0.34 \pm 0.06 \pm 0.01,\\
S_{\pi^+\pi^-} &= -0.63 \pm 0.05 \pm 0.01,\\
C_{K^+K^-} &= 0.20 \pm 0.06 \pm 0.02,\\
S_{K^+K^-} &= 0.18 \pm 0.06 \pm 0.02,\\
A^{\Delta\Gamma}_{K^+K^-} &= -0.79 \pm 0.07 \pm 0.10,\\
A^{B^0}_{CP} &= -0.084 \pm 0.004 \pm 0.003,\\
A^{B^0_s}_{CP} &= 0.213 \pm 0.015 \pm 0.007,
\end{aligned}
$$

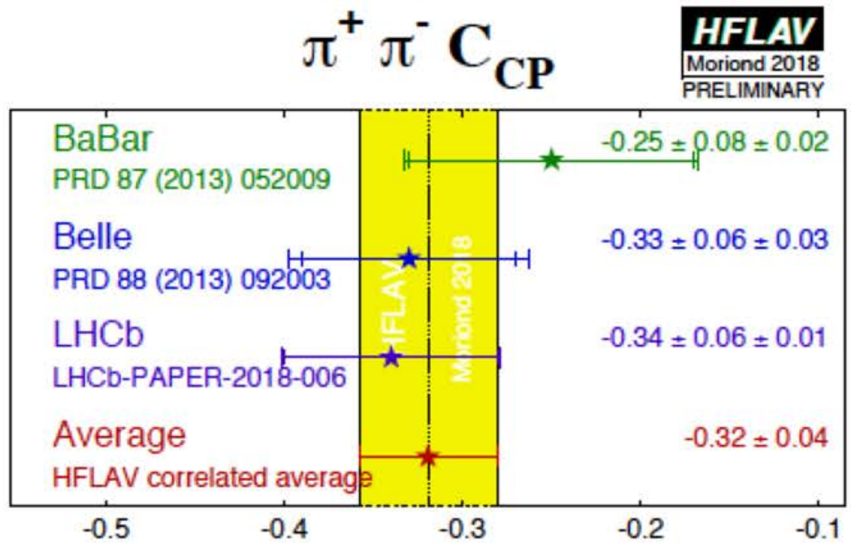
T. Latham

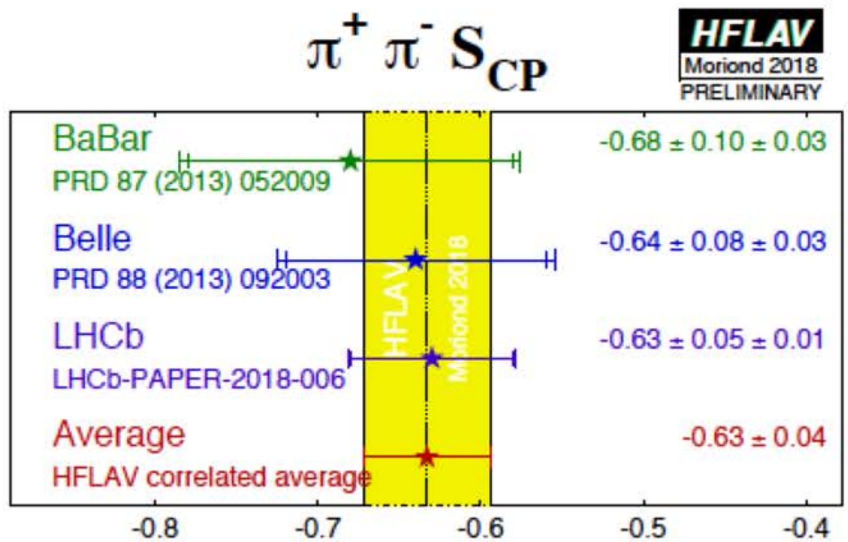
- Significant improvement ($\sim 2\times$ better precision) wrt previous results
- Most precise measurements from a single experiment
- First determination of $A^{\Delta\Gamma}_{KK}$
- Significance for $(C_{K^+K^-}, S_{K^+K^-}, A^{\Delta\Gamma}_{K^+K^-})$ to differ from $(0,0,-1)$ is determined to be 4σ
  - Strongest evidence of time-dependent CPV in B^0_s system to date

Overall status for *CP* violation in $B^0 \rightarrow \pi^+\pi^-$

Courtesy of the Heavy Flavour Averaging Group







T. Latham

Belle II prospects

The Belle II program

- large dataset ⊕ improved detector and physics software (flavor tagging, vertex reconstruction)
- unique possibilities for modes with final state with neutral particles

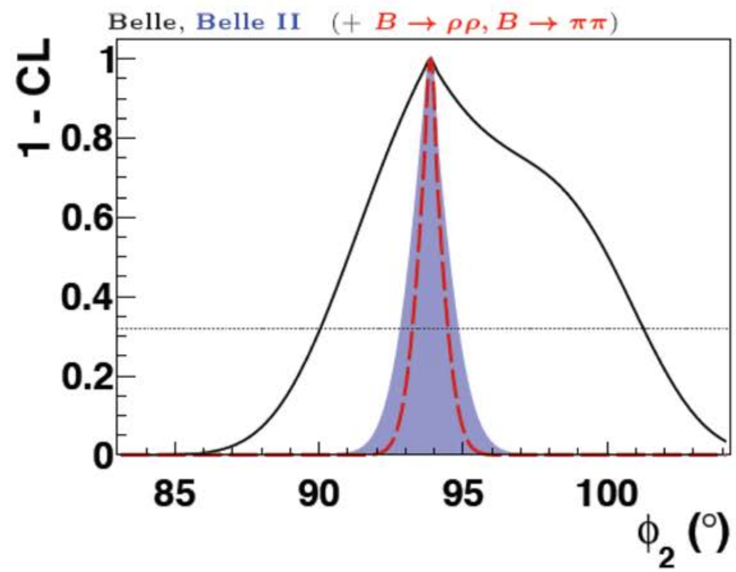
- $\sin(2\phi_1)$ will remain the most precise measurement on the UT parameters (precision level of penguin pollution)
- ϕ_2 determination will benefit of reduced errors and new inputs ($S_{\pi^0\pi^0}$, $B \to \rho\pi$ mode) for isospin analysis
- ϕ_3 measurement will reduce uncertainty of 1 order of magnitude, tough competition with LHCb
- other time dependent CP-violation analysis feasible @ Belle II ($B^0 \to K^\star(\to \pi^0 K_S^0)\gamma$)

ϕ_2 measurement: $B \to \pi\pi$

Isospin analysis input in $B \to \pi\pi$

	Value	Belle @ 0.8 ab^{-1}	Belle II @ 50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ [10^{-6}]	5.04	$\pm 0.21 \pm 0.18$ [2]	$\pm 0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ [10^{-6}]	1.31	$\pm 0.19 \pm 0.18$ [1]	$\pm 0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ [10^{-6}]	5.86	$\pm 0.26 \pm 0.38$ [2]	$\pm 0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm 0.06 \pm 0.03$ [3]	$\pm 0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm 0.08 \pm 0.03$ [3]	$\pm 0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm 0.36 \pm 0.12$ [1]	$\pm 0.03 \pm 0.01$
$S_{\pi^0\pi^0}$	—	—	$\pm 0.29 \pm 0.03$

[1]: arXiv:1705.02083, [2]: PRD 87(3) 031103, [2]: PRD 88(9) 092003



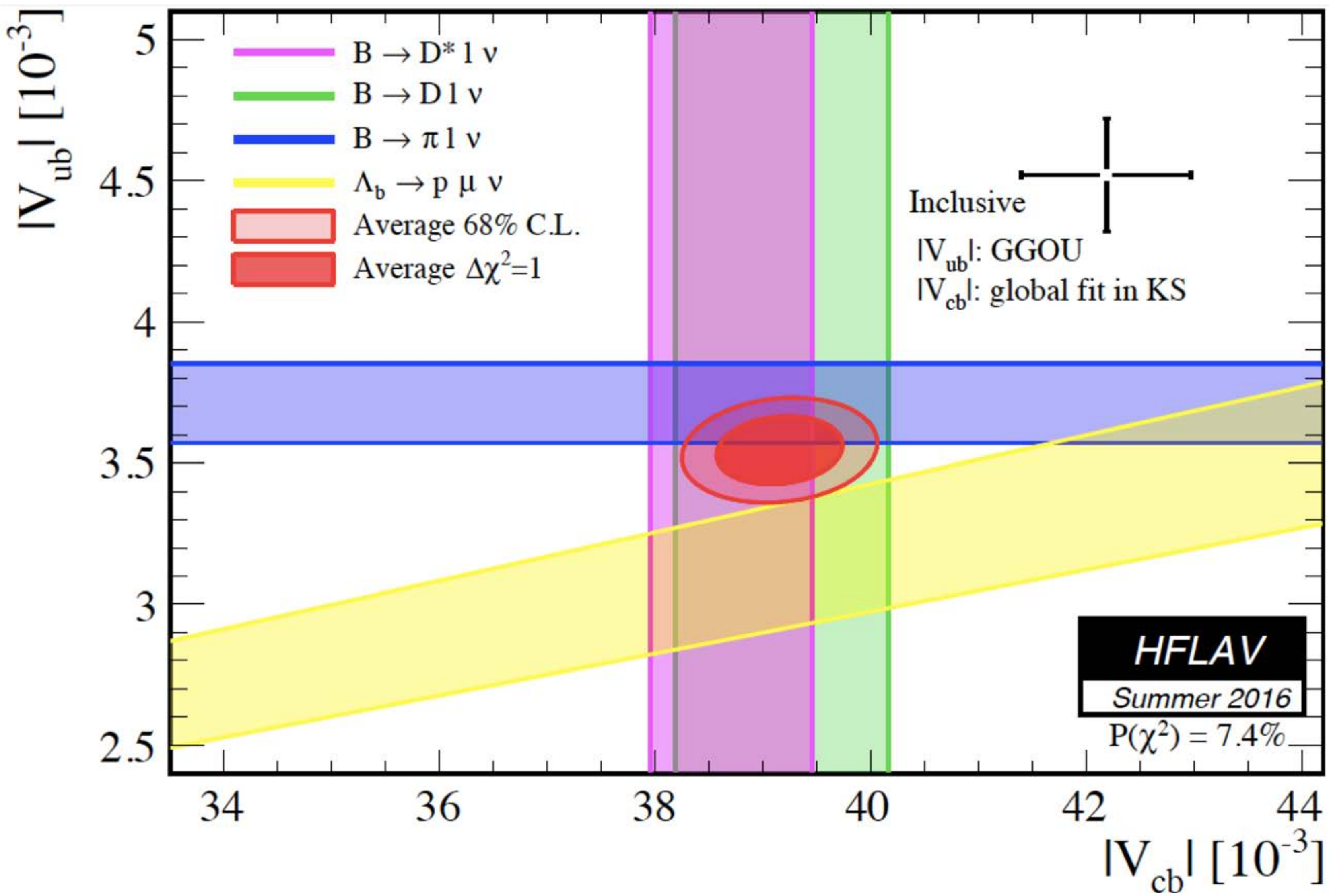
All $B \to hh$ inputs

$\Delta\phi_{2,hh}^{exp}|_{1\sigma} \sim 0.6°$

A. Mordá

Semileptonics

Long standing $|V_{ub}|/|V_{cb}|$ inclusive vs exclusive conundrum



F. Simonetto

Recent development: refitting Belle distribution

O. Sumensari

Results of new Belle angular analysis of $\bar{B} \to D^* \ell \bar{\nu}$ [1702.01521] revealed that $|V_{cb}|^{\rm excl}$ depends on parametrization of form factors:

$$h_{A_1}(w) = h_{A_1}(1)\left[1 + 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right]$$

$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$

$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$$

BGL gives $R_2(1)$ larger than HQET by more than 2σ

[Bigi et al. 2017], [Grinstein et al. 2017].

$$|V_{cb}|^{\rm excl}_{\rm CLN} = (38.2 \pm 1.5) \times 10^{-3} \qquad |V_{cb}|^{\rm excl}_{\rm BGL} = (41.7^{+2.0}_{-2.1}) \times 10^{-3}$$

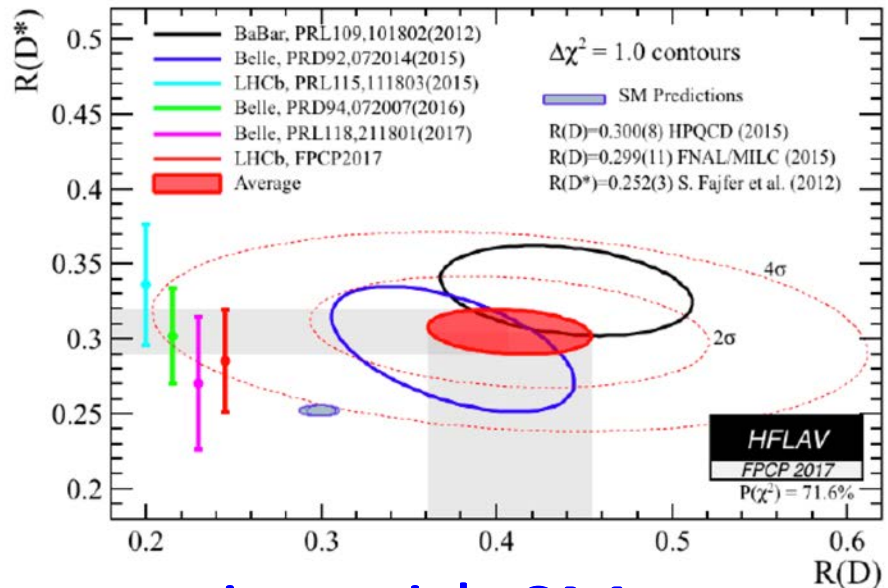
$$|V_{cb}|^{\rm incl}_{1S} = (42.0 \pm 0.5) \times 10^{-3} \qquad |V_{cb}|^{\rm incl}_{\rm kin} = (42.2 \pm 0.8) \times 10^{-3}$$

Both fits (using CLN or BGL) are good $\Rightarrow$ Inconclusive!

$\Rightarrow$ Belle-II will remedy the situation.

Way out: $|V_{cb}|$ from LQCD & Belle-II data at small recoil values.

Another headache for theory



F. Simonetto, P. Owen

- If we admit new physics competing with SM at tree level, should we revisit everything?

- SM prediction for R_D is robust (LQCD). Hadronic uncertainties entering R_{D^*} need to be better understood, but anomalies persist.
  More LQCD input necessary.
- Several viable New Physics scenarios can accommodate $R_{D^{(*)}}$.
  More exp. info. is needed: ang. distributions, other LFUV ratios etc.
- Building a model to simultaneously explain $R_{K^{(*)}}$ and $R_{D^{(*)}}$ remains a very challenging task.
  Data driven model building!

O. Sumensari

R(D*) with 3-prong τ decay

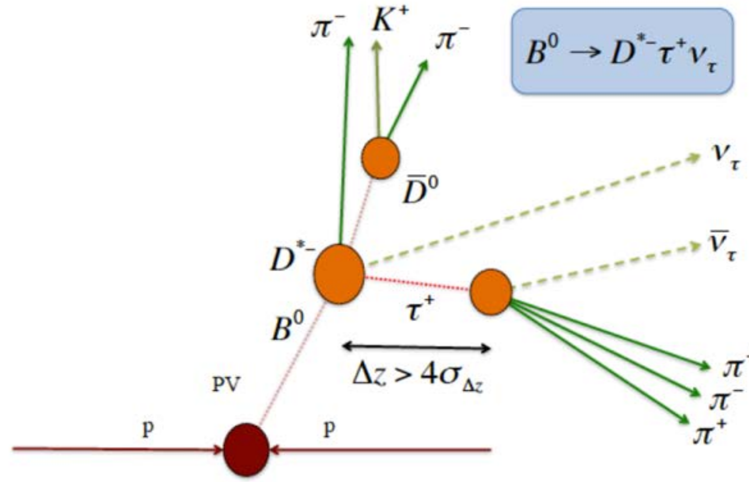
PRL 120 (2018) 171802
PRD 97 (2018) 072013

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

Normalisation done through a very similar known final state

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

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



P. Owen

$$\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau) = (1.40 \pm 0.09 \pm 0.12 \pm 0.10)\% \quad \mathcal{R}(D^{*-}) = 0.286 \pm 0.019 \pm 0.025 \pm 0.021$$

- LHCb can also perform measurements with other *b* hadrons
  - Recent determination of R(J/ψ) = BF($B_c \to J/\psi\tau\nu$) / BF($B_c \to J/\psi\mu\nu$) at about 2σ from the SM PRL 120 (2018) 121801
- Results from the R(J/ψ) measurement demonstrate possibility to measure form factor parameters for Bc decays

  → 20,000 normalization decays in Run 1 with selection designed for τ

M. Rudolph

Heavy hadron production and properties

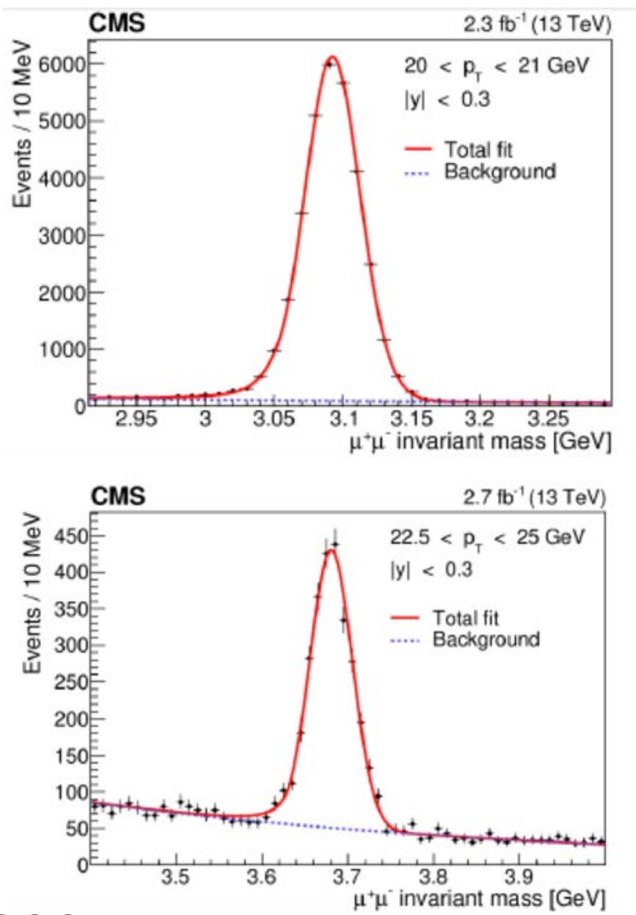
Quarkonia production cross-section

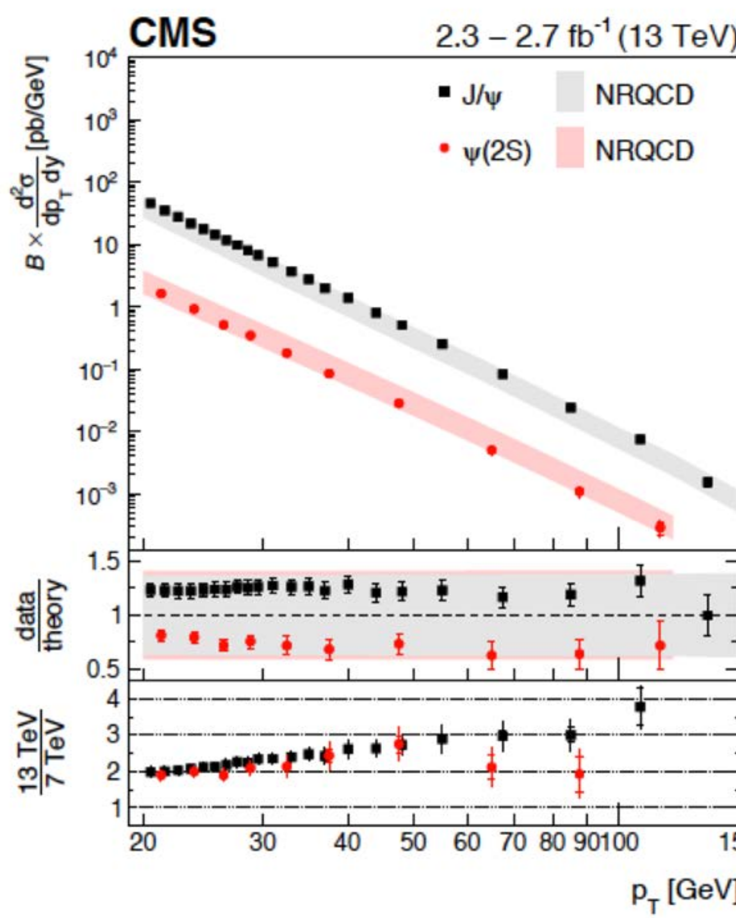
J/ψ , $\psi(2S)$, $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

$\mathcal{L} = 2.3 - 2.7\ \text{fb}^{-1}$, $|y_{\mu^+\mu^-}| < 1.2$, $p_{T,\mu^+\mu^-}$ up to 120 GeV PLB 780 (2018) 251

Double-differential cross-section,
vs. transverse momentum and rapidity

$$\mathcal{B}(Q\bar{Q} \to \mu^+\mu^-) \cdot \frac{d^2\sigma(pp \to Q\bar{Q}X)}{dp_T dy} = \frac{N_{Q\bar{Q}}(p_T, y)}{\mathcal{L} \cdot \Delta p_T \cdot \Delta y} \cdot \langle \frac{1}{A(p_T, y) \cdot \epsilon(p_T, y)} \rangle$$





P. Ronchese

Quarkonia production cross-section

cont'd

J/ψ , $\psi(2S)$, $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

$\mathcal{L} = 2.3 - 2.7$ fb^{-1} , $|y_{\mu^+\mu^-}| < 1.2$, $p_{T,\mu^+\mu^-}$ up to 120 GeV PLB 780 (2018) 251

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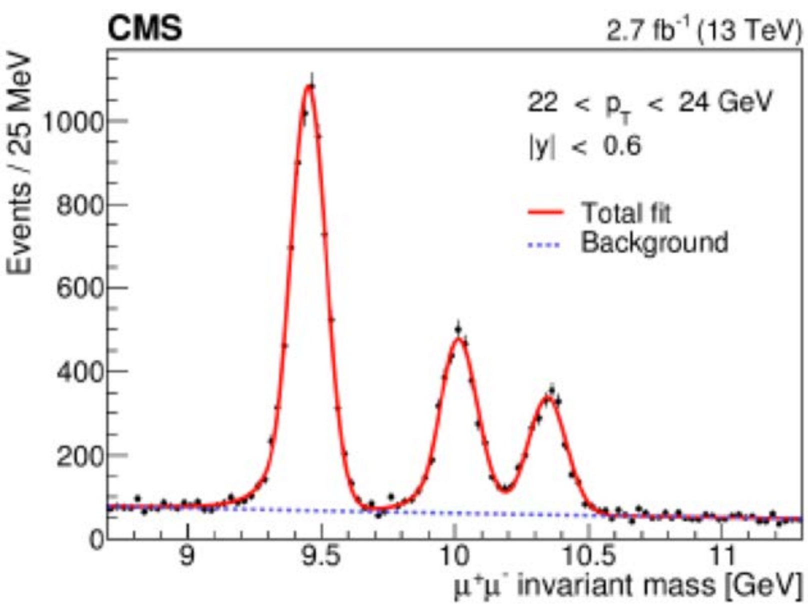
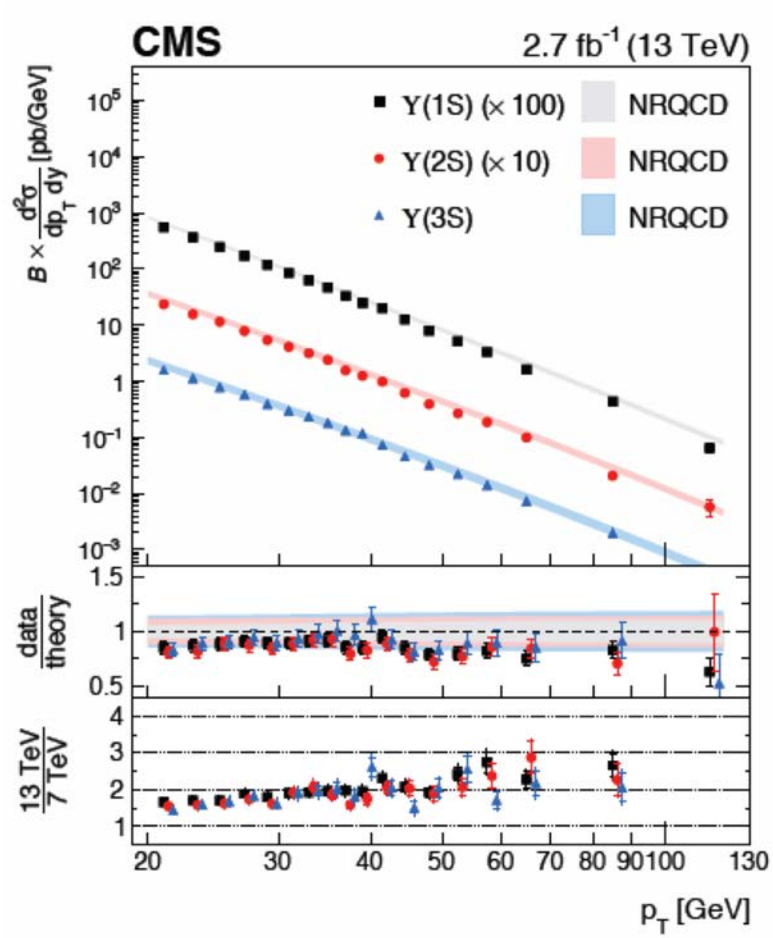


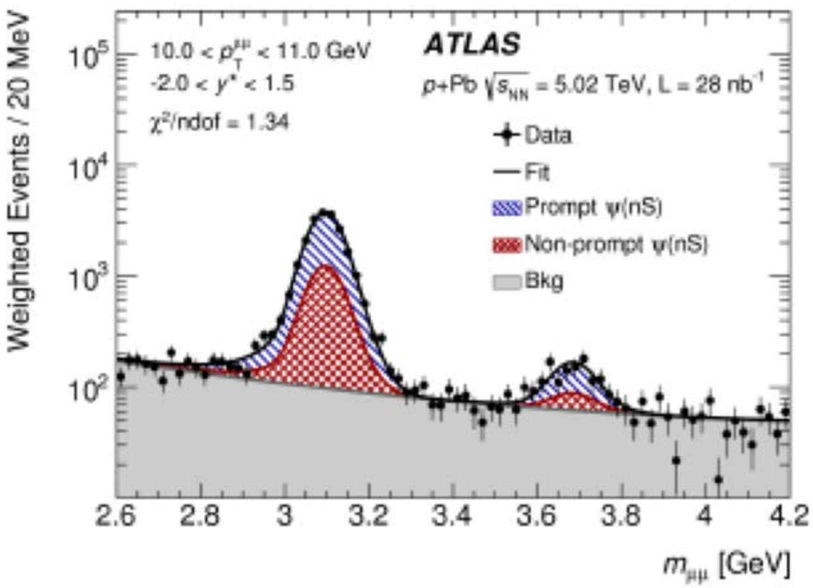


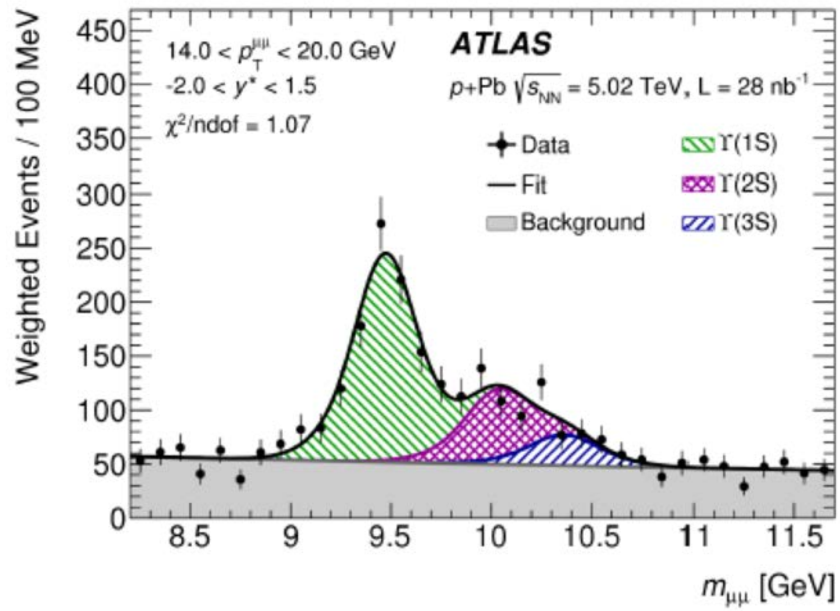
P. Ronchese

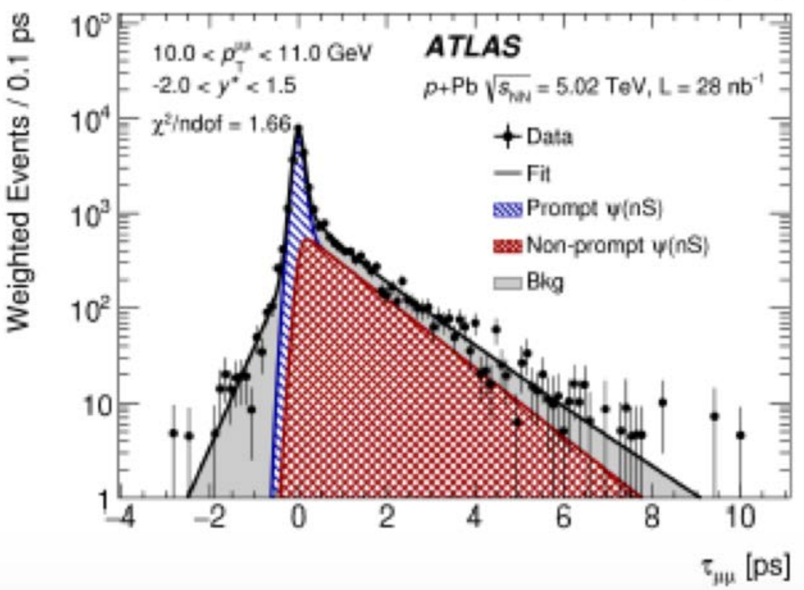
Quarkonium production in *p*Pb collisions

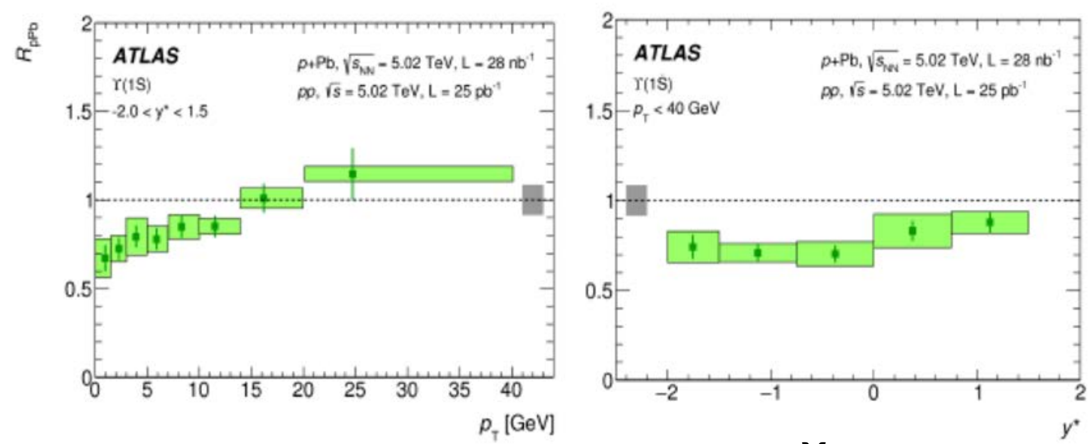
28 nb^{-1} *p*Pb at 5.02 TeV

EPJC 78 (2018) 171







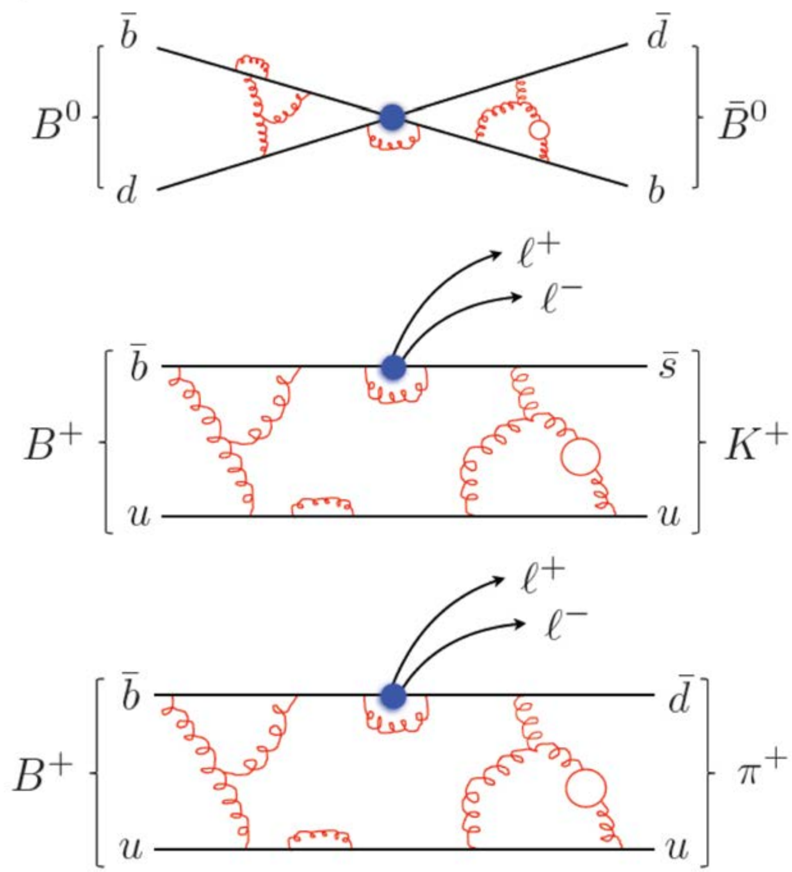


P. Řezníček

- Nuclear modification factor of Υ(1S) below 1 at pT < 15 GeV, compatible with 1 above; no y* dependence

Beautiful hadronic contributions to FCNCs via LQCD

- $B_{(s)} - \bar{B}_{(s)}$
  - state of the art $\Delta M_{d,s}$
  - work in progress on $\Delta\Gamma_s$
- $B \to K$
  - state of the art
  - restricted to large q^2
- $B \to \pi$
  - state of the art
  - work in progress, getting around the limitation



C. Bouchard

A practical example: Δm_d and Δm_s

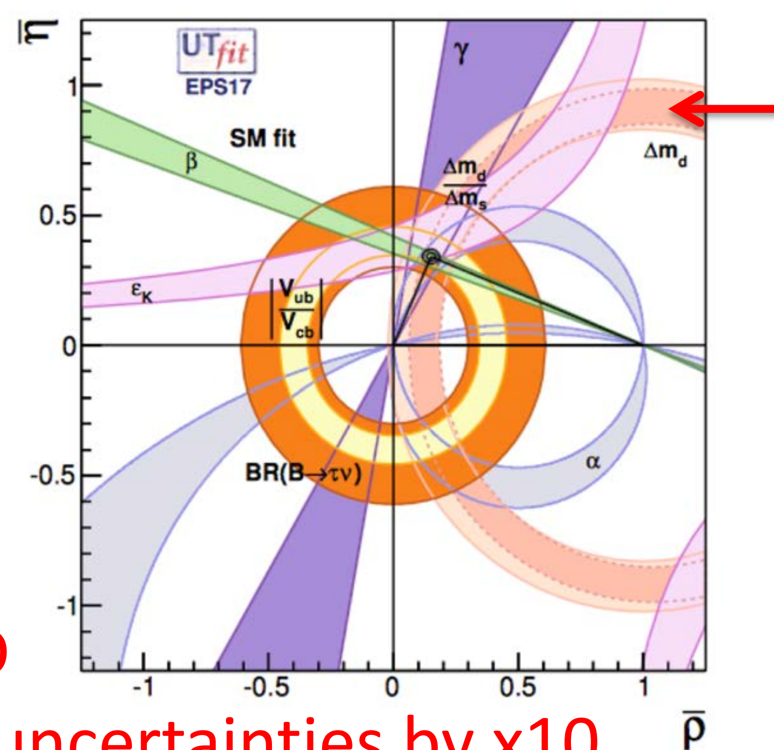
- Experimental precision has reached a remarkable level at the per mille level
  - $\Delta m_d = 0.5065 \pm 0.0019\ \mathrm{ps}^{-1}$
  - $\Delta m_s = 17.757 \pm 0.021\ \mathrm{ps}^{-1}$
- However, the interpretation requires inputs from LQCD

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_W^2\, \eta_c S(x_t)\, A^2\lambda^6\, [(1-\bar{\rho})^2 + \bar{\eta}^2]\, m_{B_d} f_{B_d}^2 \hat{B}_{B_d}$$

~7%

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d}^2 \hat{B}_{B_d}}{m_{B_s} f_{B_s}^2 \hat{B}_{B_s}} \left(\frac{\lambda}{1-\frac{\lambda^2}{2}}\right)^2 [(1-\bar{\rho})^2 + \bar{\eta}^2]$$

~4%



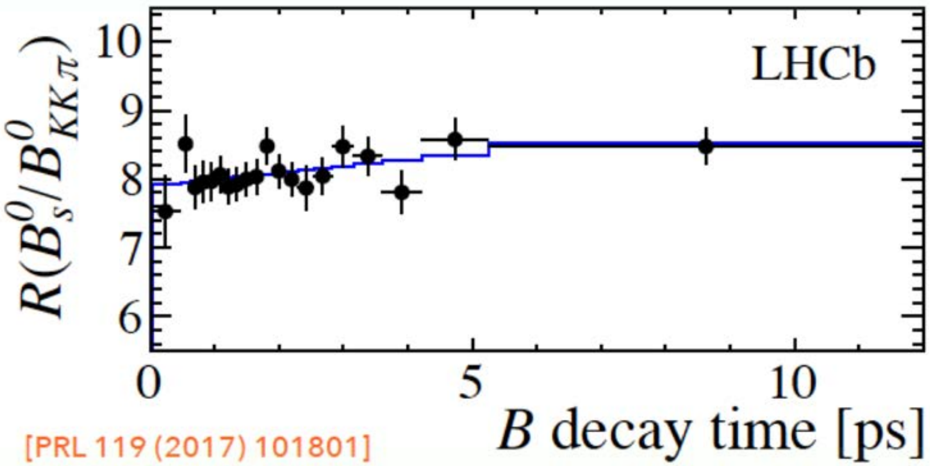
- The quest for precision with these constraints is now on LQCD
  - Need to sustain efforts from the LQCD community to reduce the theoretical uncertainties by x10

Precision measurement of B_s lifetime

M. Dorigo

- τ_s^{fs} from change in B_s^0 yield vs decay time, relative to the yield of B^0 decays **reconstructed in the same final state.**

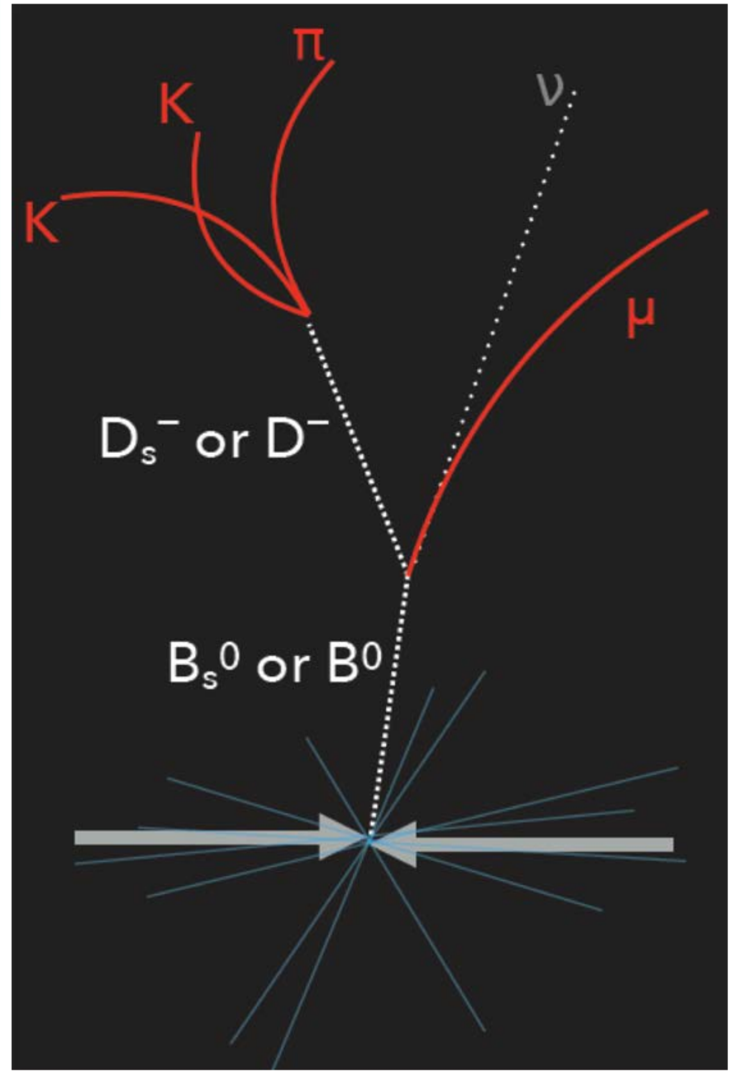
$$B^0_{(s)} \to D^-_{(s)} \mu^+ X \nu_\mu$$



[PRL 119 (2017) 101801]

$$\tau_s^{fs} = 1.547 \pm 0.013 \pm 0.010 \pm 0.004(\tau_{B^0})\ \text{ps}$$

15% better than world's best.
Halved the systematic of previous-best SL result.

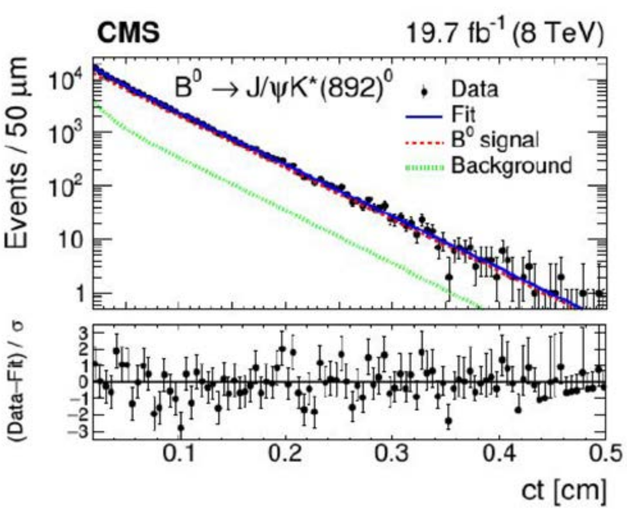


- Precision limited by the size of the reference sample
- Systematics dominated by the modelling in simulation of the signal

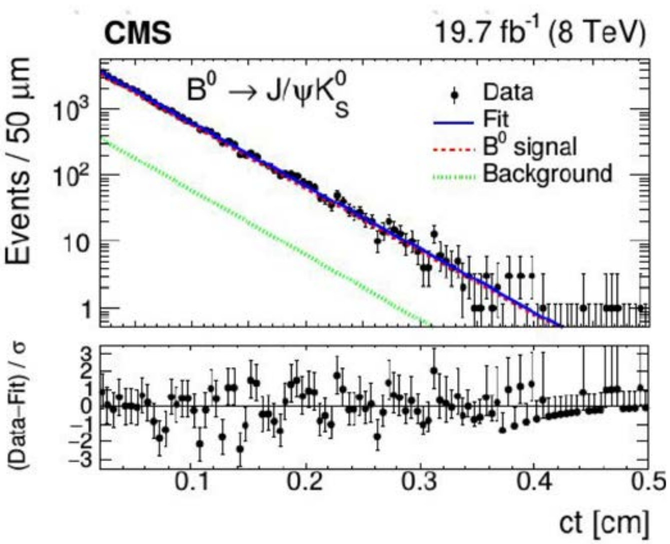
Very competitive *b*-hadron lifetimes from CMS

arXiv:1710.08949

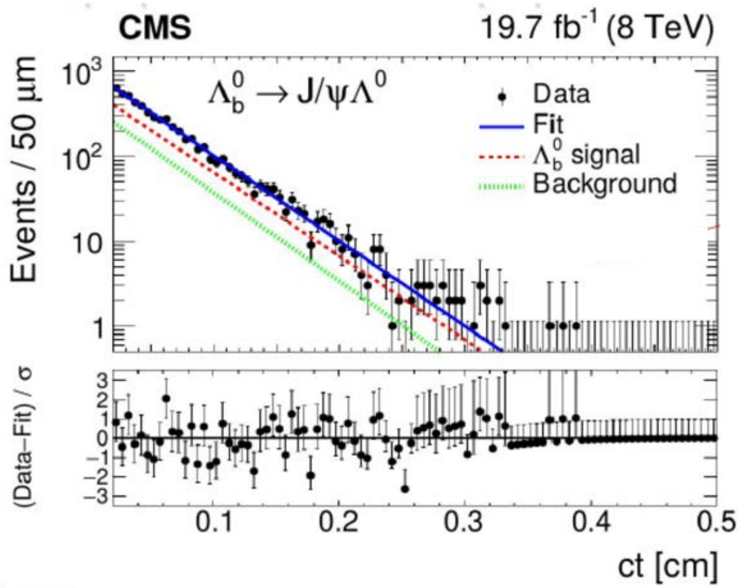
$c\tau_{B^0} = 453.0 \pm 1.6\,(\text{stat}) \pm 1.5\,(\text{syst})\ \mu\text{m}$



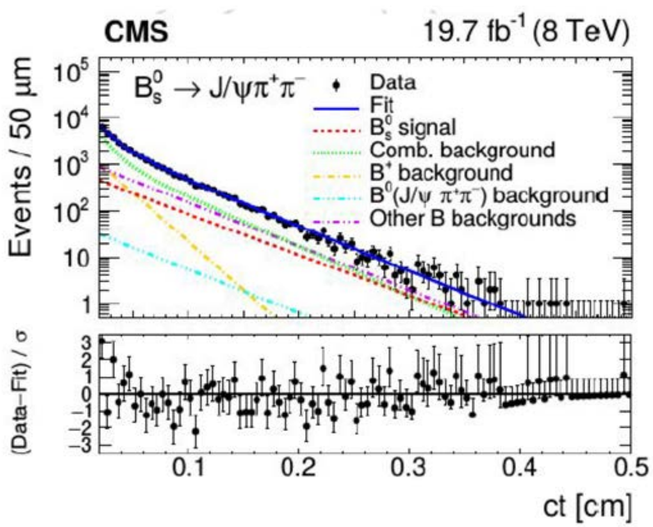
$c\tau_{B^0} = 457.8 \pm 2.7\,(\text{stat}) \pm 2.7\,(\text{syst})\ \mu\text{m}$



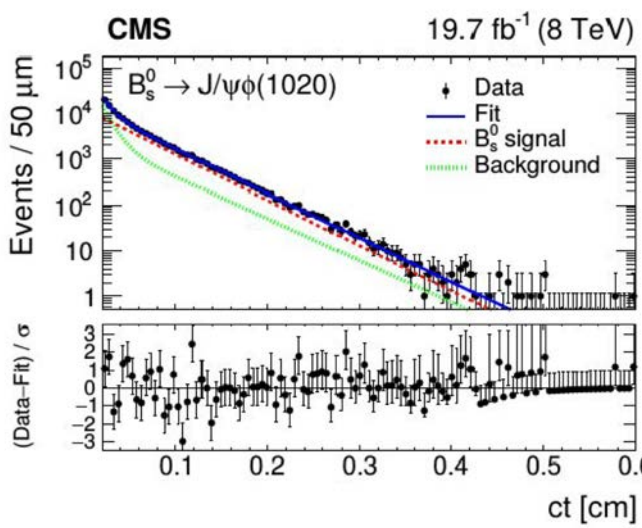
$c\tau_{\Lambda_b^0} = 442.9 \pm 8.2\,(\text{stat}) \pm 2.7\,(\text{syst})\ \mu\text{m}$



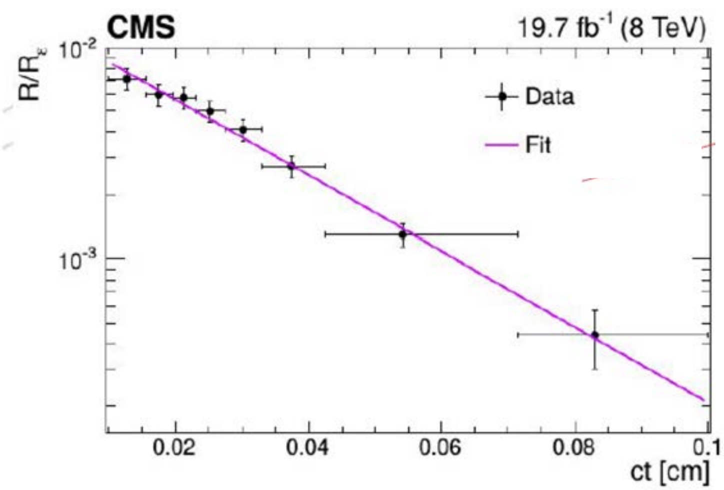
$c\tau_{B_s^0 \to J/\psi\pi^+\pi^-} = 502.7 \pm 10.2\,(\text{stat}) \pm 3.2\,(\text{syst})\ \mu\text{m}$



$c\tau_{B_s^0 \to J/\psi\phi(1020)} = 443.9 \pm 2.0\,(\text{stat}) \pm 1.2\,(\text{syst})\ \mu\text{m}$



$c\tau_{B_c^+} = 162.3 \pm 8.2\,(\text{stat}) \pm 4.7\,(\text{syst}) \pm 0.1\,(\tau_{B^+})\ \mu\text{m}$



J. Mejia

Spectroscopy

Social life of heavy quarks:

"Who with whom,

For how long ?

A "one-night stand",

"avventura di una notte"

Or "Till Death Us Do Part" ?

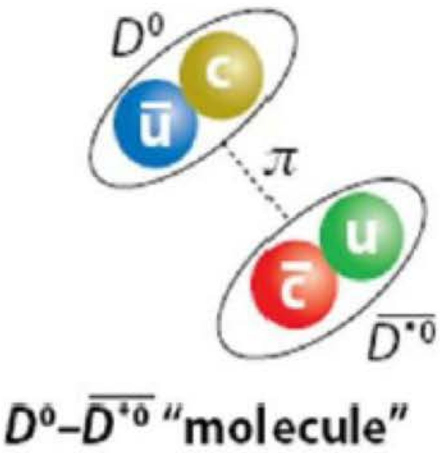
"finché morte non ci separi"

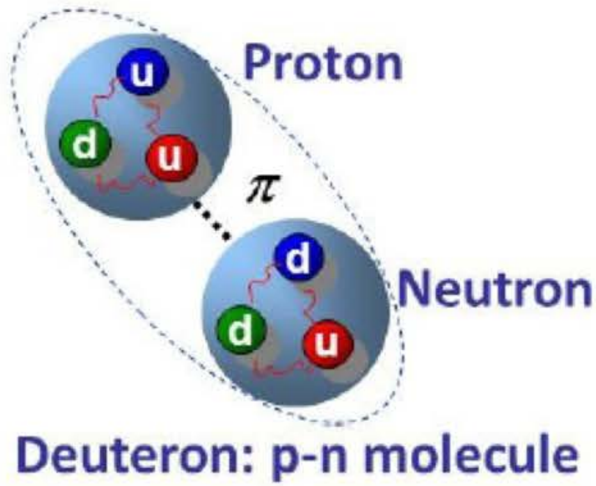
You'll never look at heavy quarks with the same eyes again

What is your favourite option?

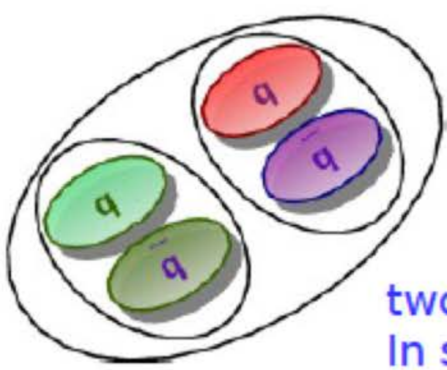
Hadronic molecules: deuteron-like

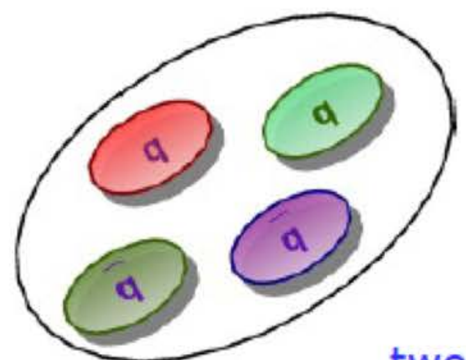
M. Karliner





Tetraquarks: same 4 quarks, but tightly bound:





The first of a long list

Thresholds for $Q\bar{Q}'$ molecular states

Channel	Minimum isospin	Minimal quark content[a,b]	Threshold (MeV)[c]	Example of decay mode
$D\bar{D}^*$	0	$c\bar{c}q\bar{q}$	3875.8	$J/\psi\,\pi\pi$
$D^*\bar{D}^*$	0	$c\bar{c}q\bar{q}$	4017.2	$J/\psi\,\pi\pi$
D^*B^*	0	$c\bar{b}q\bar{q}$	7333.8	$B_c^+\pi\pi$
$\bar{B}B^*$	0	$b\bar{b}q\bar{q}$	10604.6	$\Upsilon(nS)\pi\pi$
$\bar{B}^*B^*$	0	$b\bar{b}q\bar{q}$	10650.4	$\Upsilon(nS)\pi\pi$
$\Sigma_c\bar{D}^*$	1/2	$c\bar{c}qqq'$	4462.4	$J/\psi\,p$
Σ_cB^*	1/2	$c\bar{b}qqq'$	7779.5	B_c^+p
$\Sigma_b\bar{D}^*$	1/2	$b\bar{c}qqq'$	7823.0	B_c^-p
Σ_bB^*	1/2	$b\bar{b}qqq'$	11139.6	$\Upsilon(nS)p$
$\Sigma_c\bar{\Lambda}_c$	1	$c\bar{c}qq'\bar{u}\bar{d}$	4740.3	$J/\psi\,\pi$
$\Sigma_c\bar{\Sigma}_c$	0	$c\bar{c}qq'\bar{q}\bar{q}'$	4907.6	$J/\psi\,\pi\pi$
$\Sigma_c\bar{\Lambda}_b$	1	$c\bar{b}qq'\bar{u}\bar{d}$	8073.3[d]	$B_c^+\pi$
$\Sigma_b\bar{\Lambda}_c$	1	$b\bar{c}qq'\bar{u}\bar{d}$	8100.9[d]	$B_c^-\pi$
$\Sigma_b\bar{\Lambda}_b$	1	$b\bar{b}qq'\bar{u}\bar{d}$	11433.9	$\Upsilon(nS)\pi$
$\Sigma_b\bar{\Sigma}_b$	0	$b\bar{b}qq'\bar{q}\bar{q}'$	11628.8	$\Upsilon(nS)\pi\pi$

[a]Ignoring annihilation of quarks. [b]Plus other charge states when $I \neq 0$.
[c]Based on isospin–averaged masses. [d]Thresholds differ by 27.6 MeV.

M. Karliner

Mass and lifetime of doubly heavy baryons

State	Quark content	$M(J=1/2)$	$M(J=3/2)$
$\Xi_{cc}^{(*)}$	ccq	3627 ± 12	3690 ± 12
$\Xi_{bc}^{(*)}$	$b[cq]$	6914 ± 13	6969 ± 14
Ξ'_{bc}	$b(cq)$	6933 ± 12	$\cdots$
$\Xi_{bb}^{(*)}$	bbq	10162 ± 12	10184 ± 12

LHCb: 3621 ± 1

Baryon	This work	[28]	[51]	[71]	[72]
$\Xi_{cc}^{++} = ccu$	185	430 ± 100	460 ± 50	500	~ 200
$\Xi_{cc}^{+} = ccd$	53	120 ± 100	160 ± 50	150	~ 100
$\Xi_{bc}^{+} = bcu$	244	330 ± 80	300 ± 30	200	–
$\Xi_{bc}^{0} = bcd$	93	280 ± 70	270 ± 30	150	–
$\Xi_{bb}^{0} = bbu$	370	–	790 ± 20	–	–
$\Xi_{bb}^{-} = bbd$	370	–	800 ± 20	–	–

M. Karliner

The hunting season is open

The same theoretical toolbox

that led to the accurate Ξ_{cc} mass prediction

now predicts

a stable, deeply bound $bb\bar{u}\bar{d}$ tetraquark,

215 MeV below BB^* threshold

the first manifestly exotic stable hadron

The ugly duckling that became a swan!

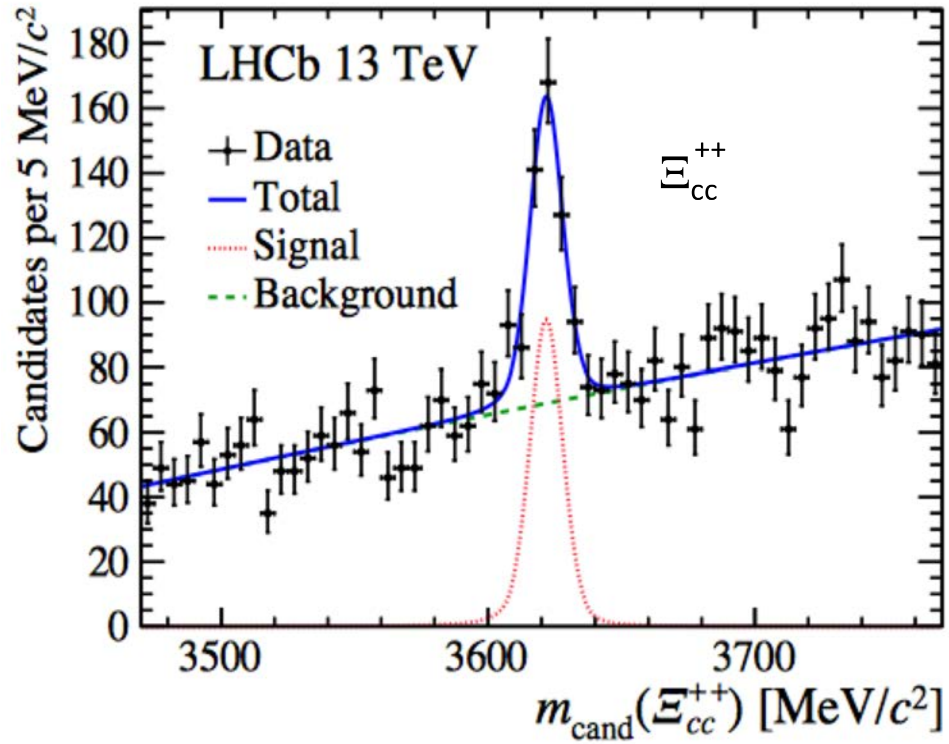
M. Karliner

From first observations straight to precision measurements

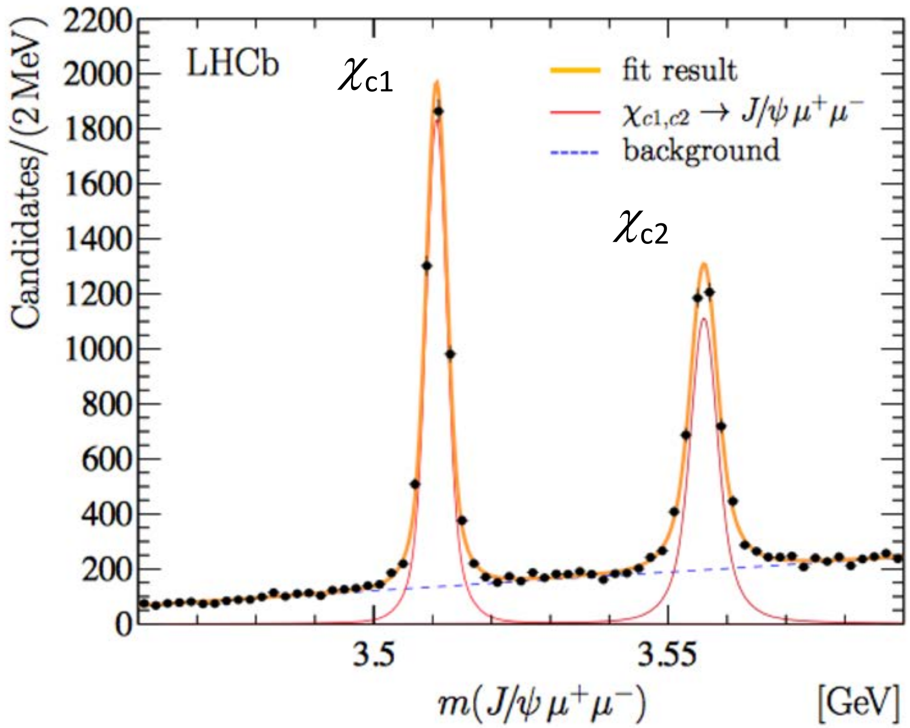
S. Stone

- First observation of a doubly-charmed baryon, the Ξ_{cc}^{++}
  - Now working on measuring properties and partners

PRL 119 (2017) 112001



PRL 119 (2017) 221801

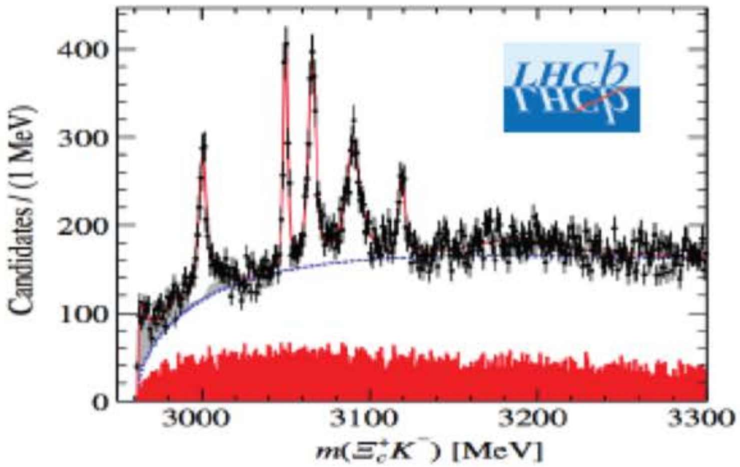


- Precision measurements of masses and widths of χ_{c1} and χ_{c2} mesons via the decay mode $\chi_{c2} \to J/\psi\mu\mu$
  - New avenues are opened, e.g. to study χ_{bJ} states

From first observations straight to precision measurements cont'd

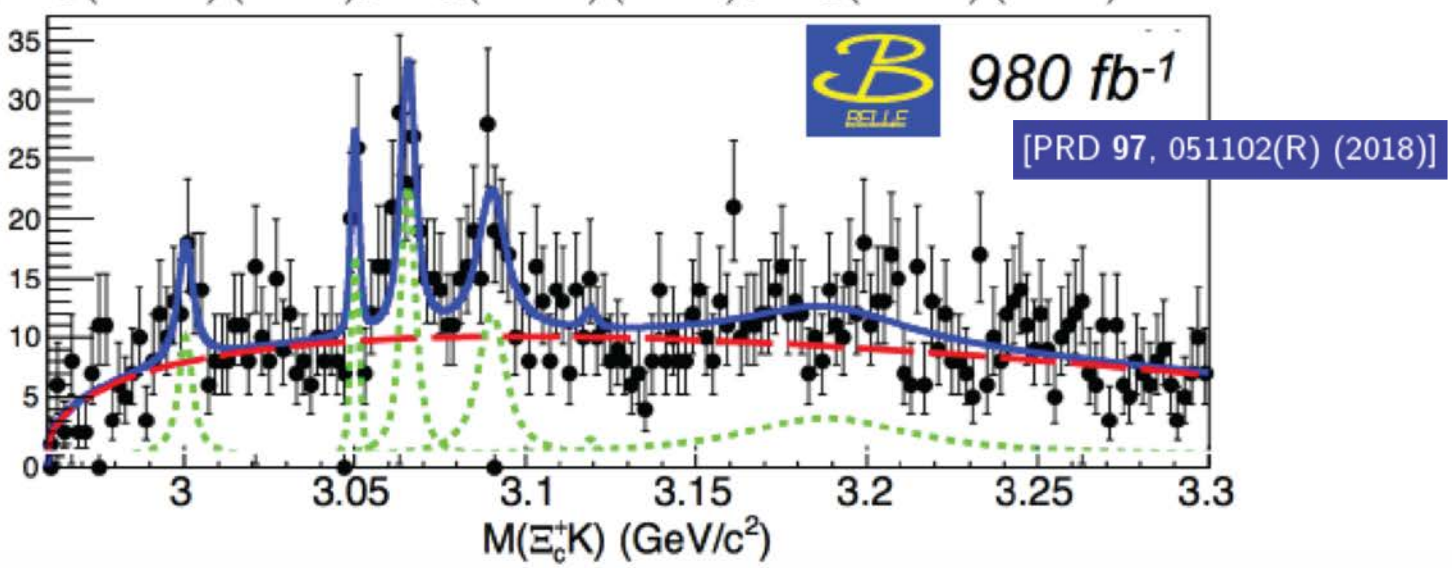
S. Stone

- LHCb: dramatic observation of five excited Ω_c based on 3.3 fb^{-1} [PRL 118, 182001 (2017)]
  - ► Reconstruct $\Xi_c^+ \to pK^-\pi^+$ (1.0×10^6), five peaks appear in $\Xi_c^+ K^-$:



Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$ <1.2 MeV, 95% C.L.	$970 \pm 60 \pm 20$	20.4
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$ <2.6 MeV, 95% C.L.	$480 \pm 70 \pm 30$	10.4
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	
$\Omega_c(3066)^0_{fd}$			$700 \pm 40 \pm 140$	
$\Omega_c(3090)^0_{fd}$			$220 \pm 60 \pm 90$	
$\Omega_c(3119)^0_{fd}$			$190 \pm 70 \pm 20$	

- Belle: using full data sets, confirm four of five narrow states reported by LHCb.
  - ► $\Omega_c(300)(3.9\sigma)$, $\Omega_c(3050)(4.6\sigma)$, $\Omega_c(3066)(7.2\sigma)$, $\Omega_c(3090)(5.7\sigma)$

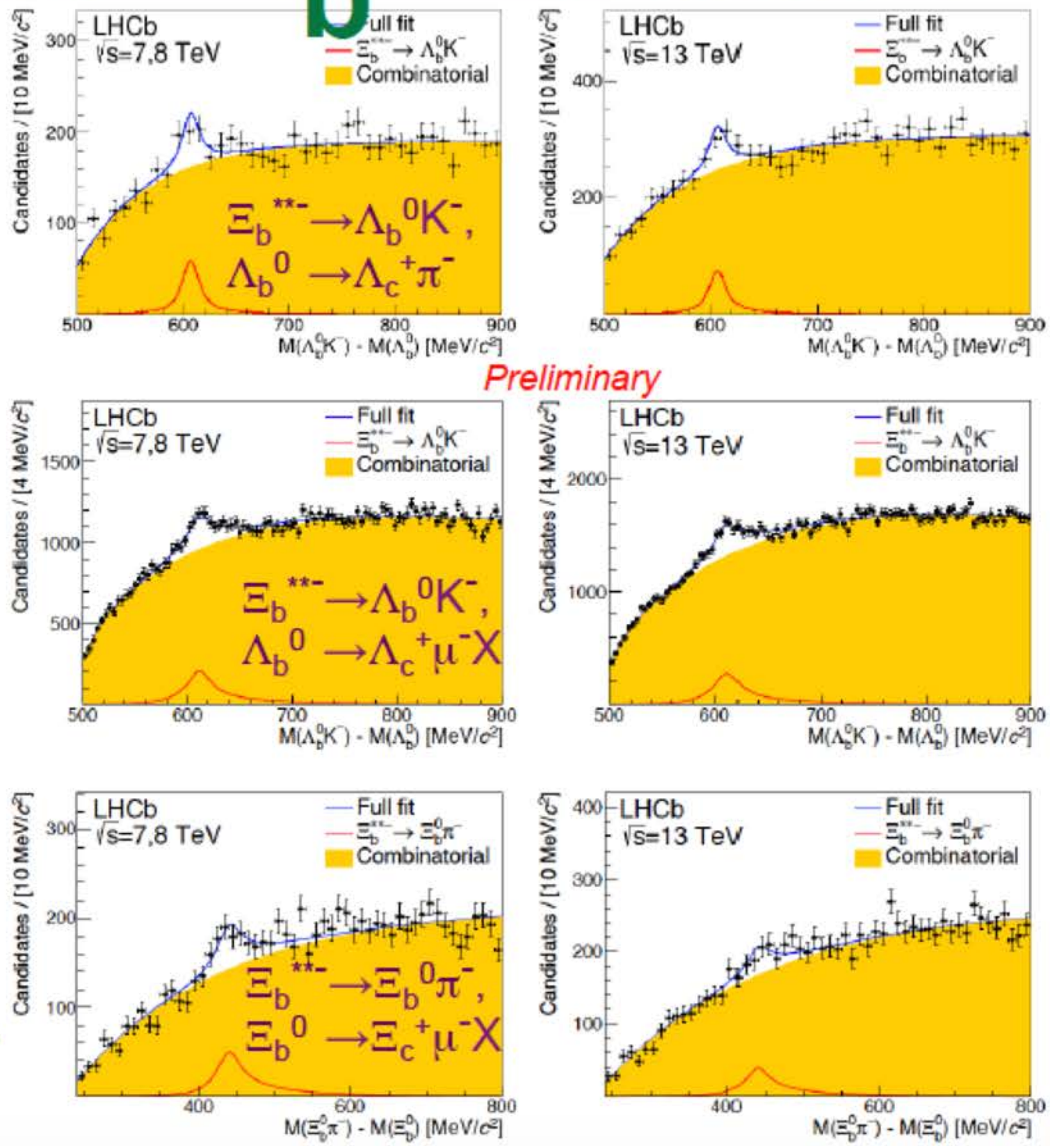


L. Li

New states popping out…

A new Ξ_b^{**-} state

- Seen in both fully hadronic decays & semileptonic decays
- Mass (MeV) =6226.9±2.0±0.3±0.2
- Γ=18.1±5.4±1.8 MeV
- J^P not yet measured



LHCb-PAPER-2018-013

S. Stone

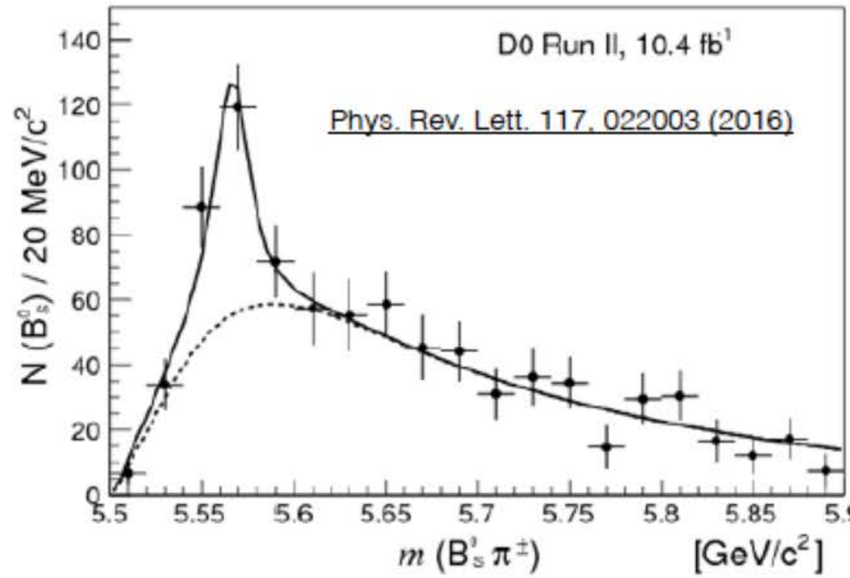
Some others...

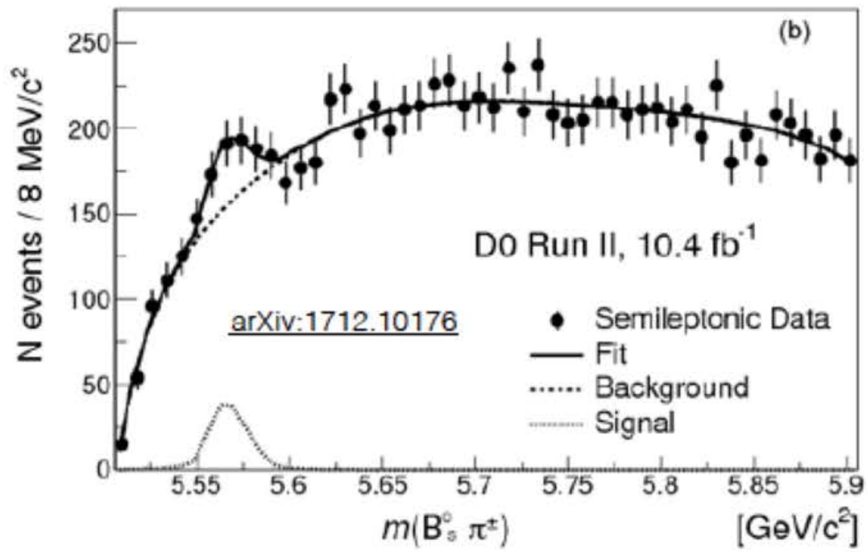
Search for a structure in $B^0_s\ \pi^{\pm}$ spectrum

- D0 published evidence of X(5568) state in the $B^0_s\ \pi^{\pm}$ spectrum via:
  - B^0_s to J/Ψ (μ μ) ϕ(K K)
  - B^0_s to $\mu^+ D_s^-$ (ϕ[KK]π^-) X
    - X = neutrino

- $m = 5567.8 \pm 2.9_{stat}\ ^{+0.9}_{-1.9}$ MeV
- $\Gamma = 21.9 \pm 6.4_{stat}\ ^{+5.0}_{-2.5}$ MeV
- significance 5.1sigma

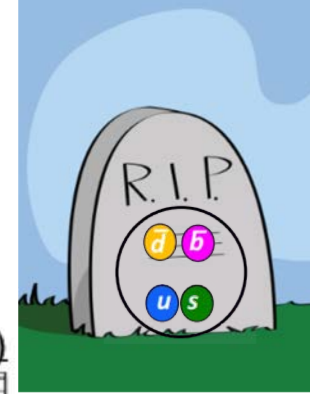
- interpreted as a tetraquark made of 4 different quarks (b, s, u, d)

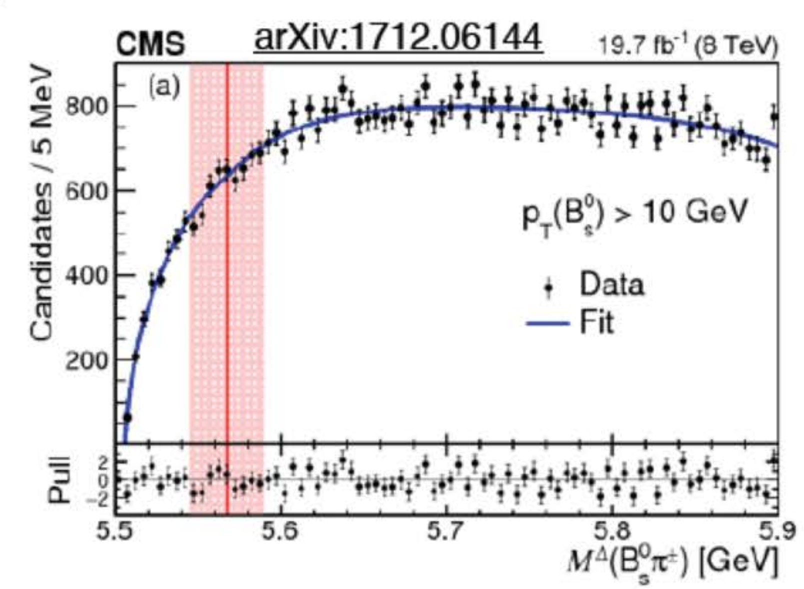


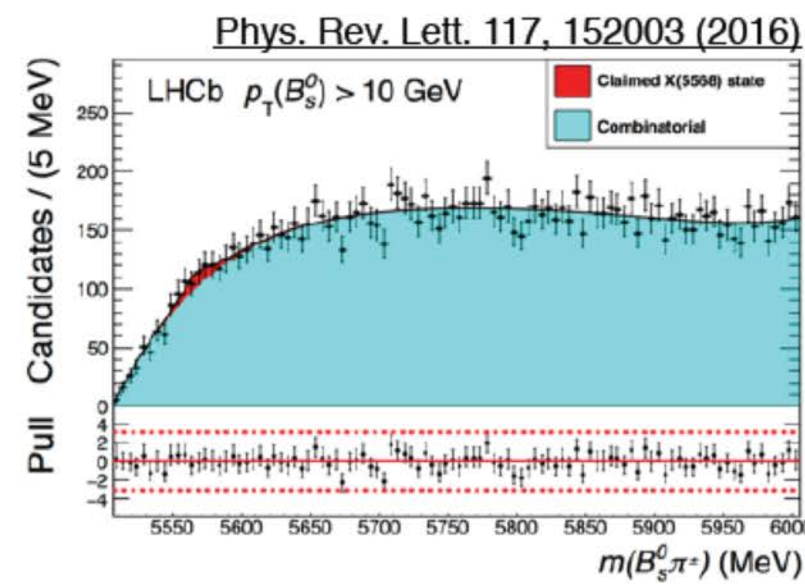


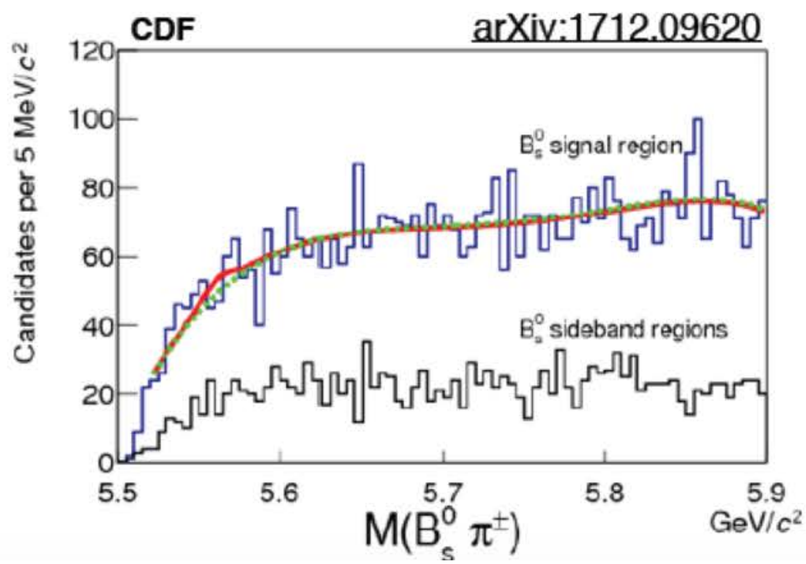
F. Tresoldi

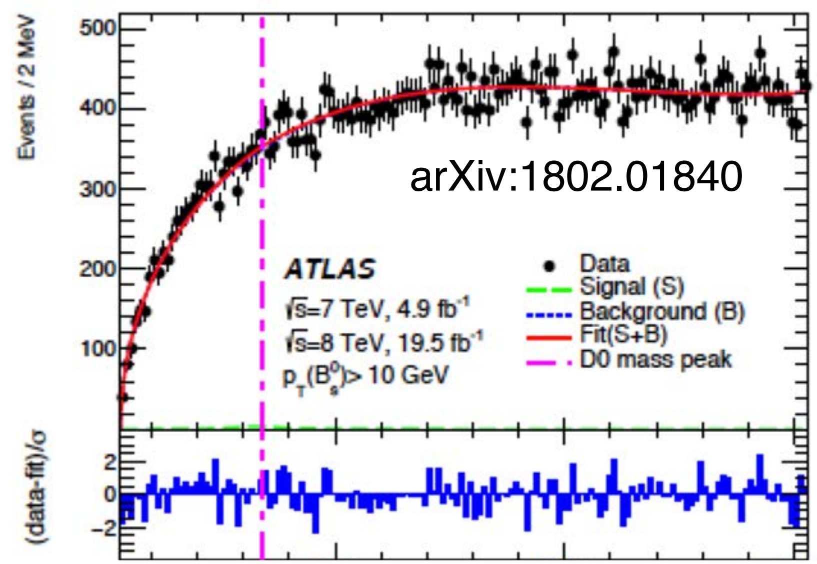
...disappearing







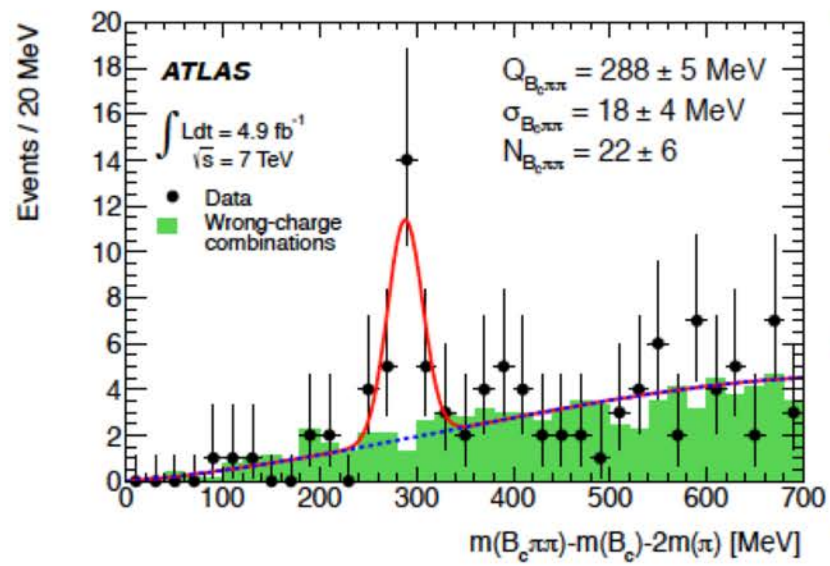


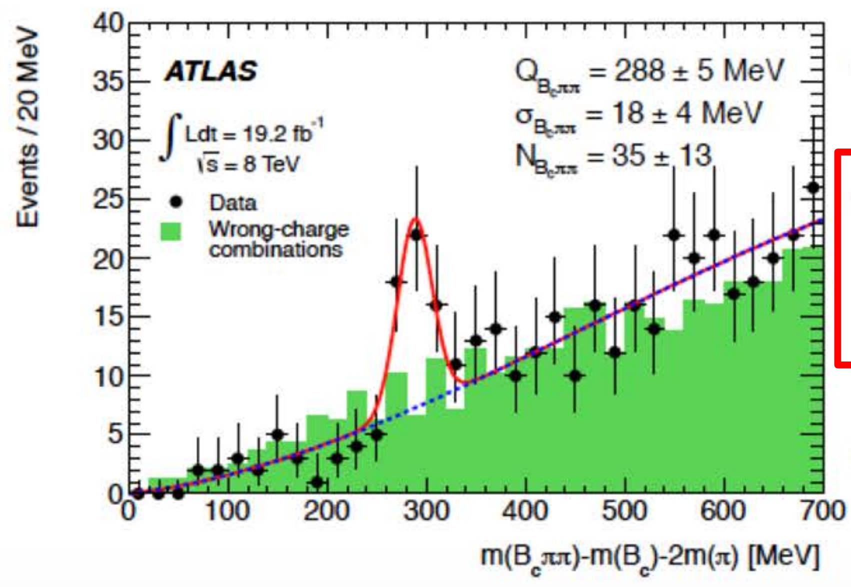


F. Tresoldi

But not always things are so clear (not yet a sad case: ATLAS update? CMS?)

B_c(2S) observation at ATLAS



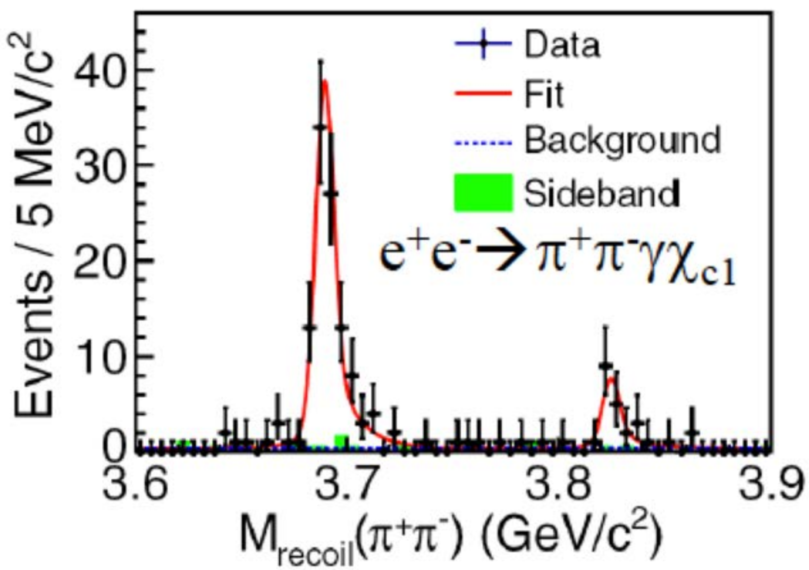


- peak at $Q = 288.3 \pm 3.5_{stat} \pm 4.1_{syst}$ MeV
- corresponds to mass $m(B_c(2S)) = 6842 \pm 4_{stat} \pm 5_{syst}$ MeV
  - no $B_c^*(2S)$ hypothesis
- consistent with theory [6835,6917] MeV
- significance:
  - 5.2 sigma combining 7 and 8 TeV
- first observation of B_c excited state
- similar analysis recently performed by LHCb (arXiv:1712.04094)
  - no evidence found
- further studies underway

F. Tresoldi, M. Dorigo

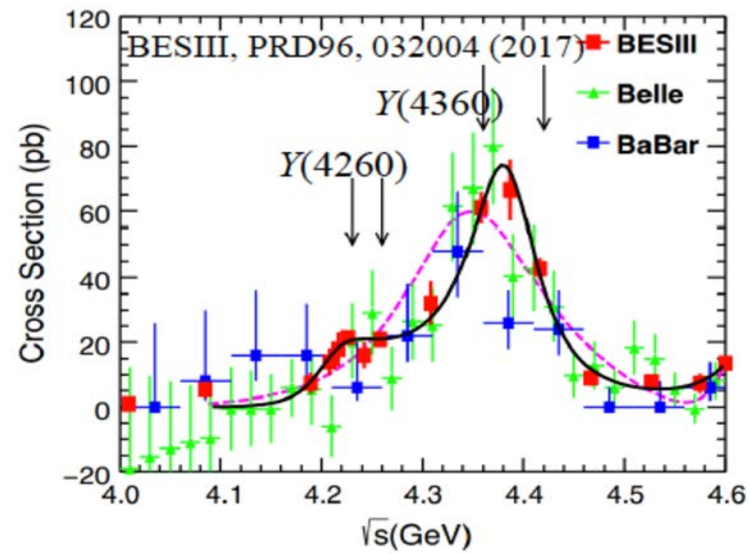
Breaking news: Spectroscopy gold mine discovered in China!

- $X(3872)$
- $X(3823)$
- $X(4140)$
- $Y(4260)$
- $Y(4360)$
- $Y(4660)$
- $Z_c(3900)$
- $Z_c(4020)$



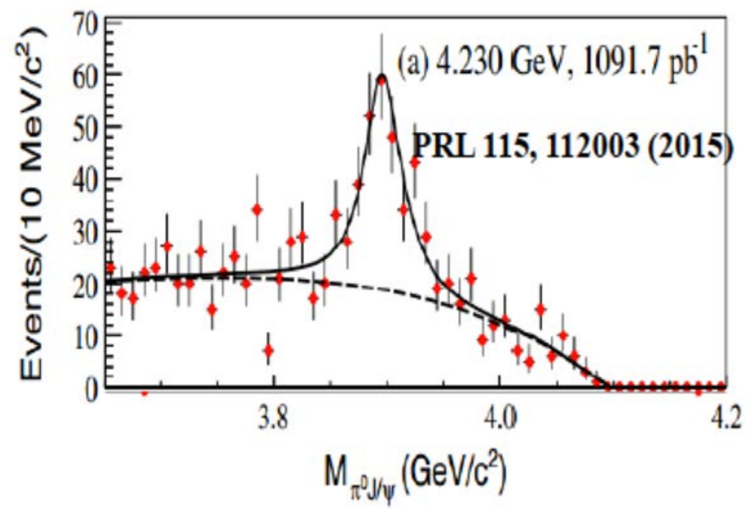
$M = 3821.7 \pm 1.3 \pm 0.7$ MeV

$e^+e^- \to \pi^+\pi^-\psi(3686)$



- BEPCII/BESIII is a *Y*-factory, and more data taking is under consideration for XYZ studies

$Z_c(3900)^0 : e^+e^- \to \pi^0\pi^0 J/\psi$

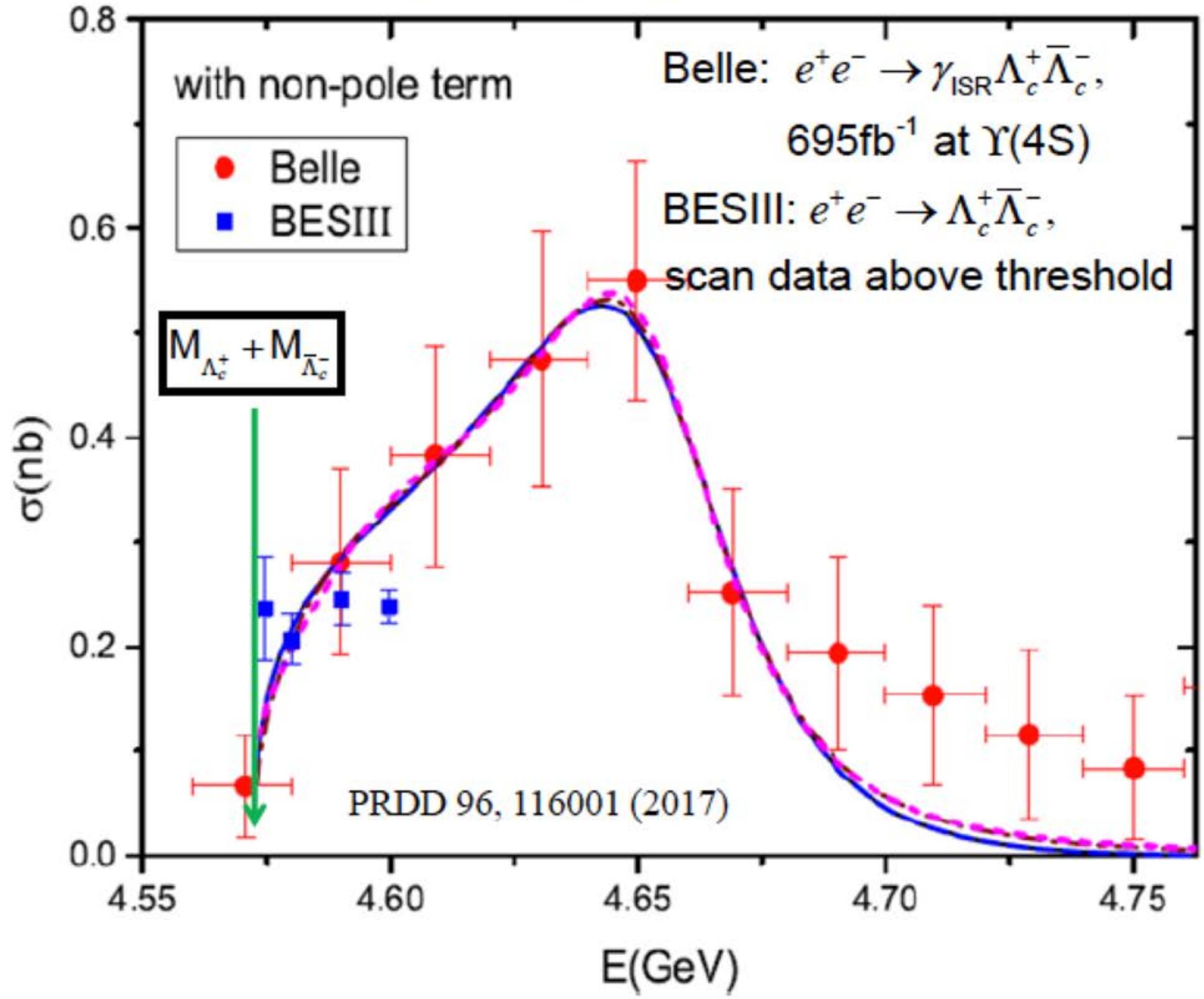


P. Ronggang

$e^+e^- \rightarrow \Lambda_c \Lambda_c$ cross-section near threshold

Belle G. Pakhlova *et al.* [Belle Collaboration], Phys. Rev. Lett. 101, 172001 (2008).

BESIII Ablikim *et al.*, **PRL 120, 132001 (2018)**



Ecms will be upgraded to 4.6~4.9 GeV in 2018-2019 21

P. Ronggang

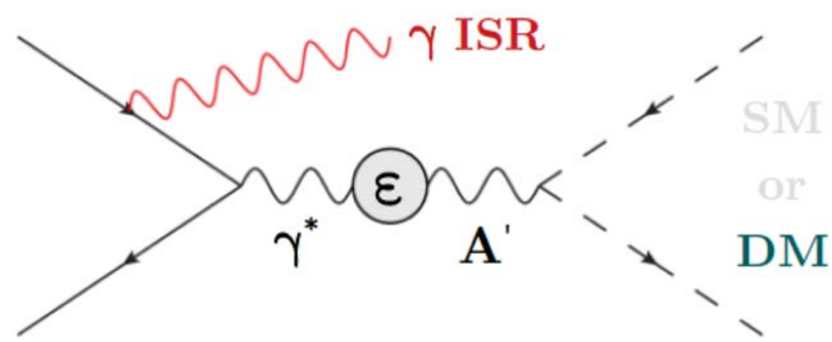
Dark and rare

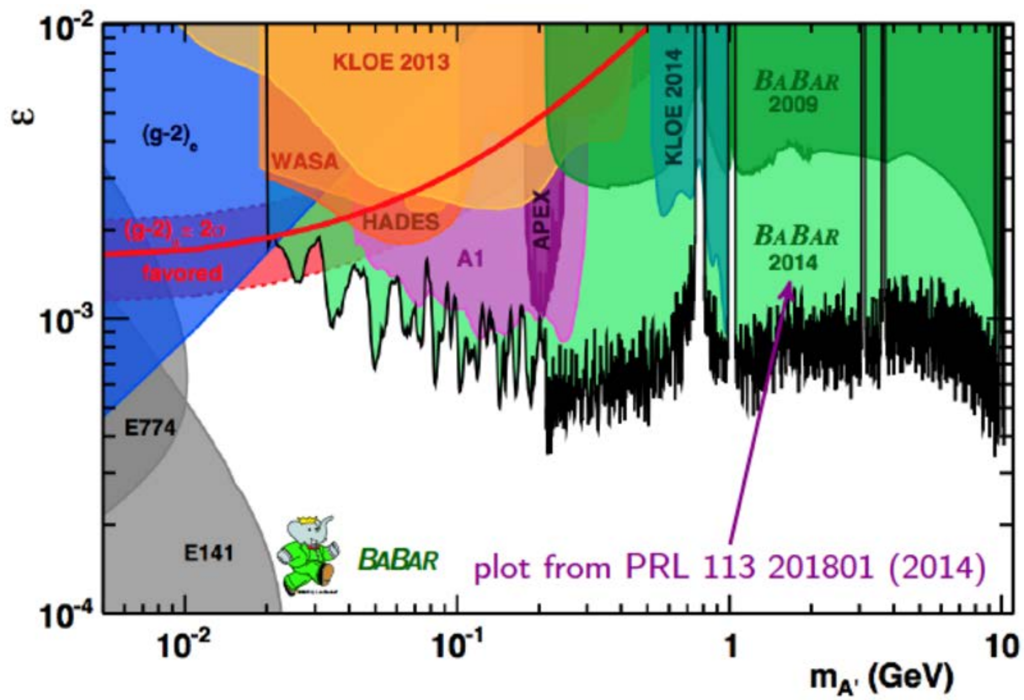
Dark photons at BaBar

- A massive dark photon A' can mix with SM with coupling strength ε
- Depending on DM mass, a dark photon decays as

SM (if $m_{DM} > \frac{1}{2} m_{A'}$)

→ **visible decay**





Dark Photon: visible decay

A. Lusiani

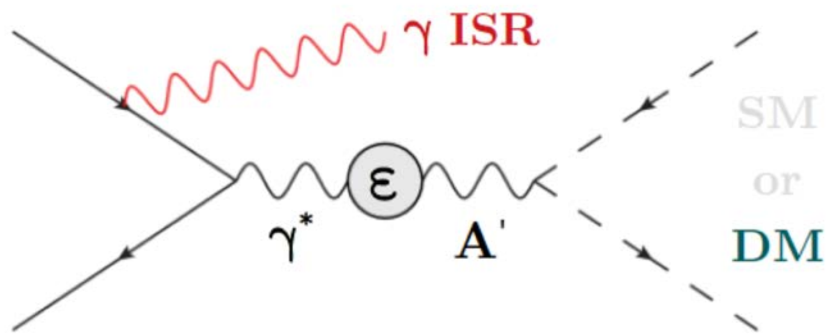
Dark photons at BaBar

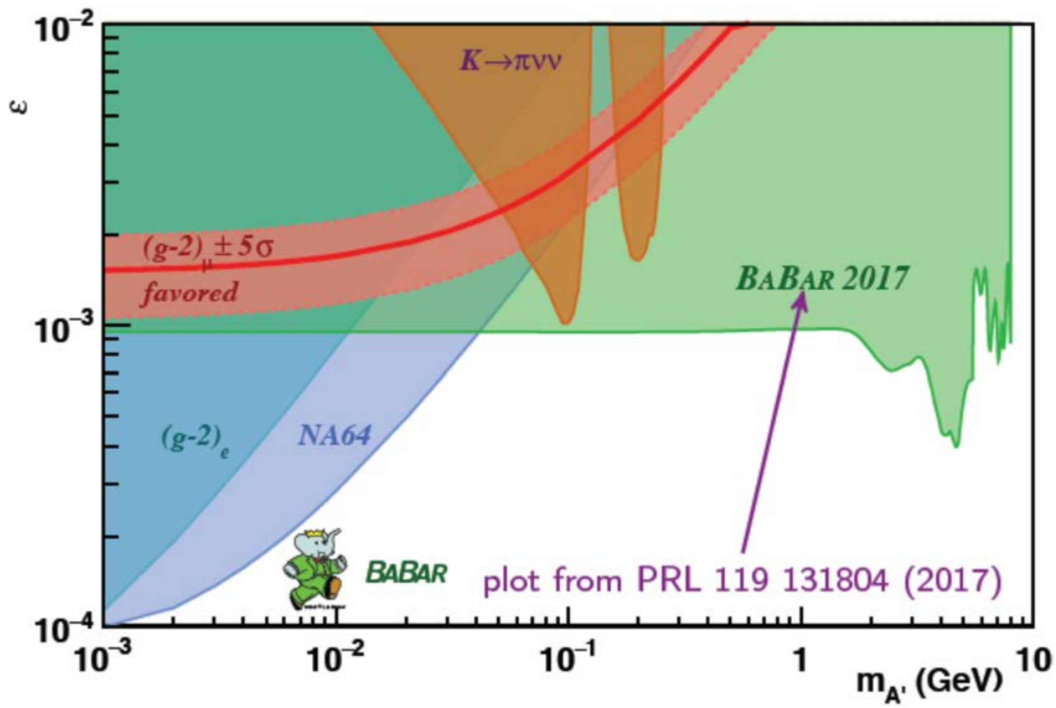
cont'd

- A massive dark photon A' can mix with SM with coupling strength ε
- Depending on DM mass, a dark photon decays as

DM (if $m_{DM} < ½ m_{A'}$)

→ **invisible decay**



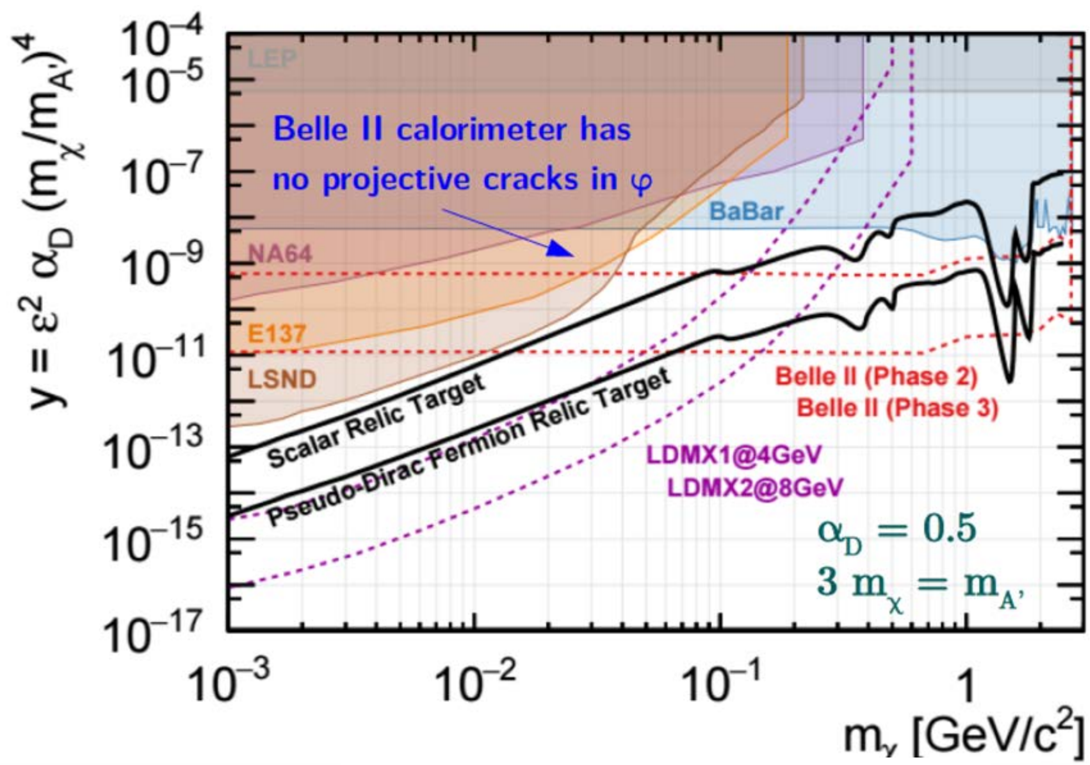


Dark Photon: invisible decay

A. Lusiani

Dark photons at Belle II

- Dedicated triggers for dark sector searches at Belle II ready for 2018 run
- Already a small dataset (~20 fb^{-1}) will give world leading sensitivity for invisible dark photon decays at Belle II
- Promising results expected during Phase 2 also in the ALPs sector

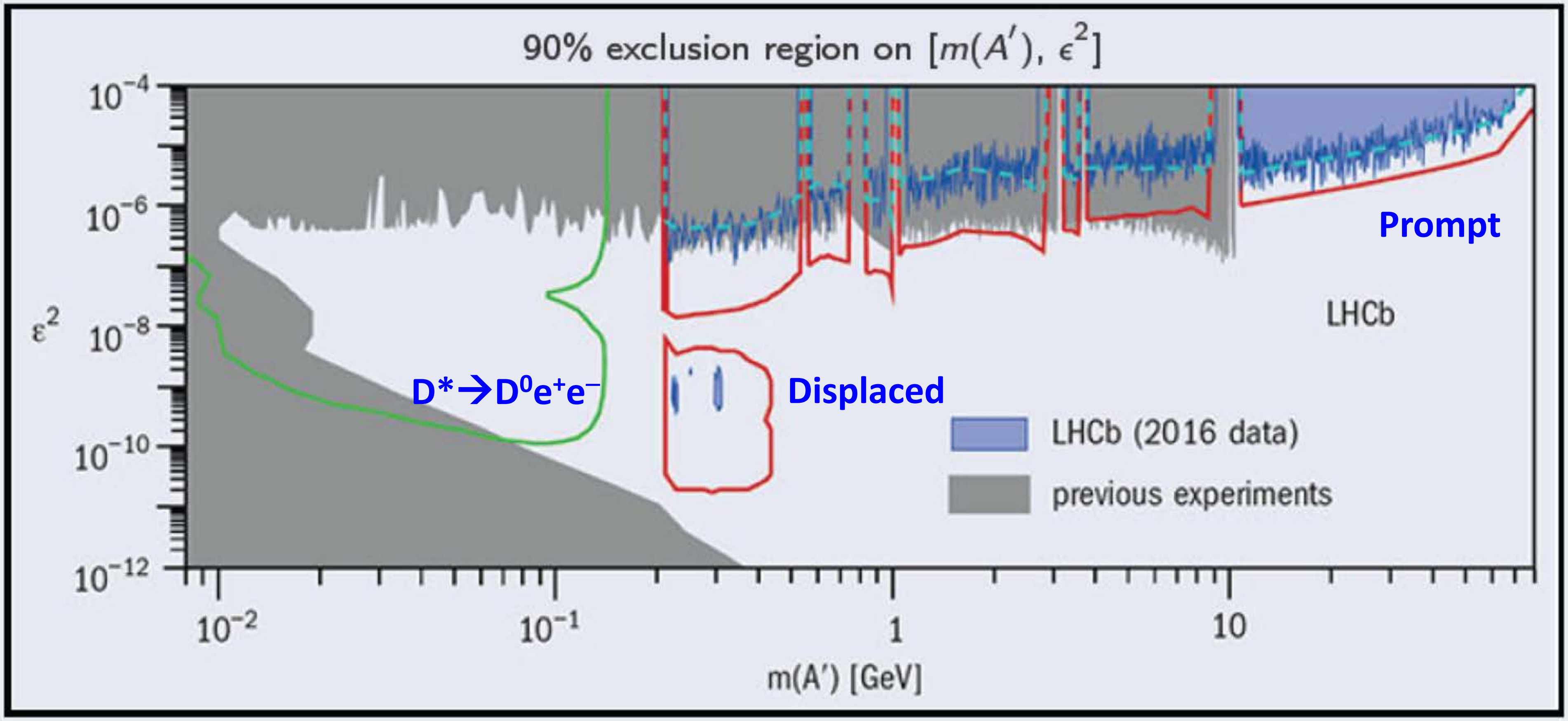


Dark Photon: invisible decay

First citation ever of the CERN Courier at Beauty!

Many present and future facilities other than *B*-factories effective on Dark Photon searches, e.g., LHCb, SHiP, . . .

LHCb on CERN Courier Jan 15, 2018, see also PRL 116 251803 (2016)



Red and green are expectations for LHC Run 3.

Dashed cyan curve is expectation rescaled to 2016 LHCb data sample.

Dark Photon: visible decay ($A' \to \mu\mu$)

A. Lusiani

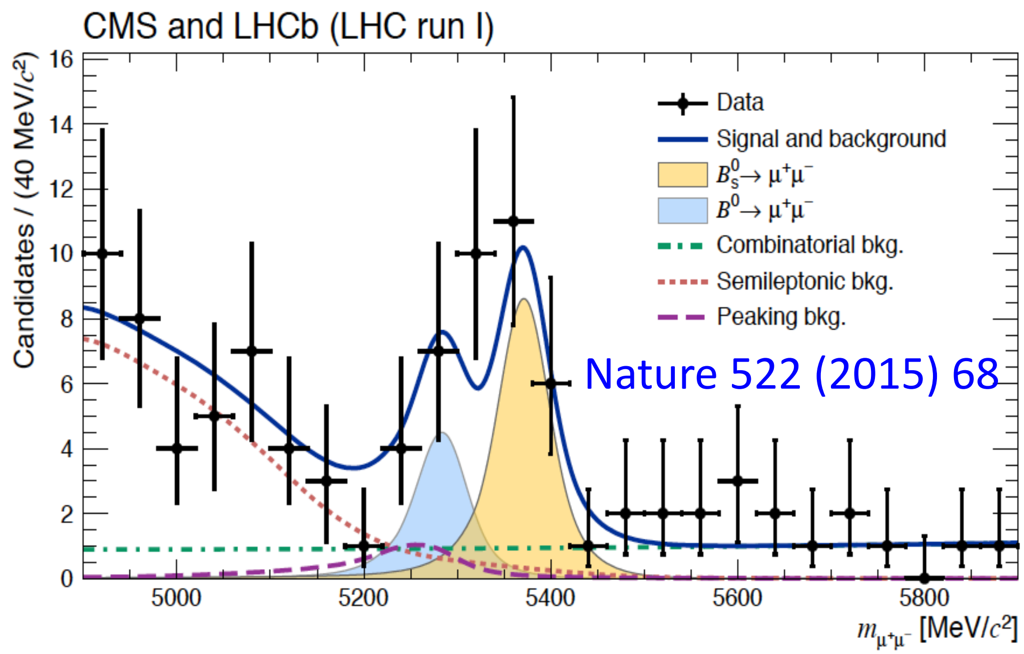
$B^0 \rightarrow \mu^+\mu^-$ and $B_s \rightarrow \mu^+\mu^-$

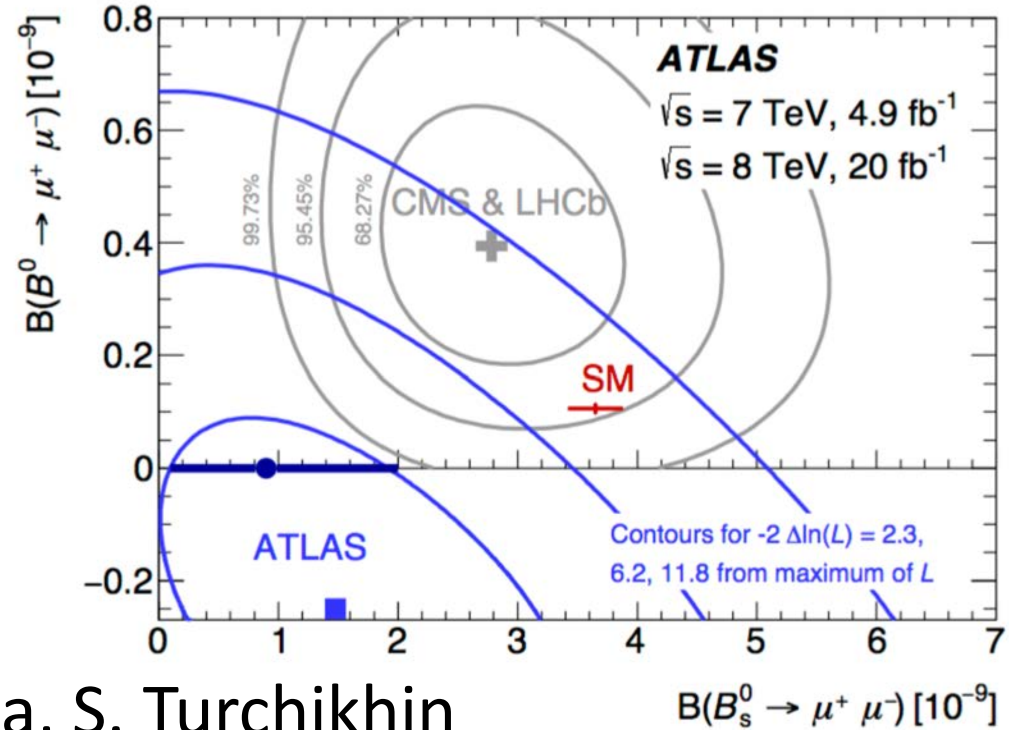
- CMS and LHCb have performed a combined fit to their full Run-1 data sets

$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$$

- $B_s \rightarrow \mu\mu$ 6.2σ significance was first observation
  - Compatibility with the SM at 1.2σ
- Excess of events at the 3σ level for $B^0 \rightarrow \mu\mu$
  - Compatible with SM at 2.2σ
- More recently, also ATLAS published a measurement with Run-1 data EPJC 76 (2016) 513





G. Fedi, M. Rama, S. Turchikhin

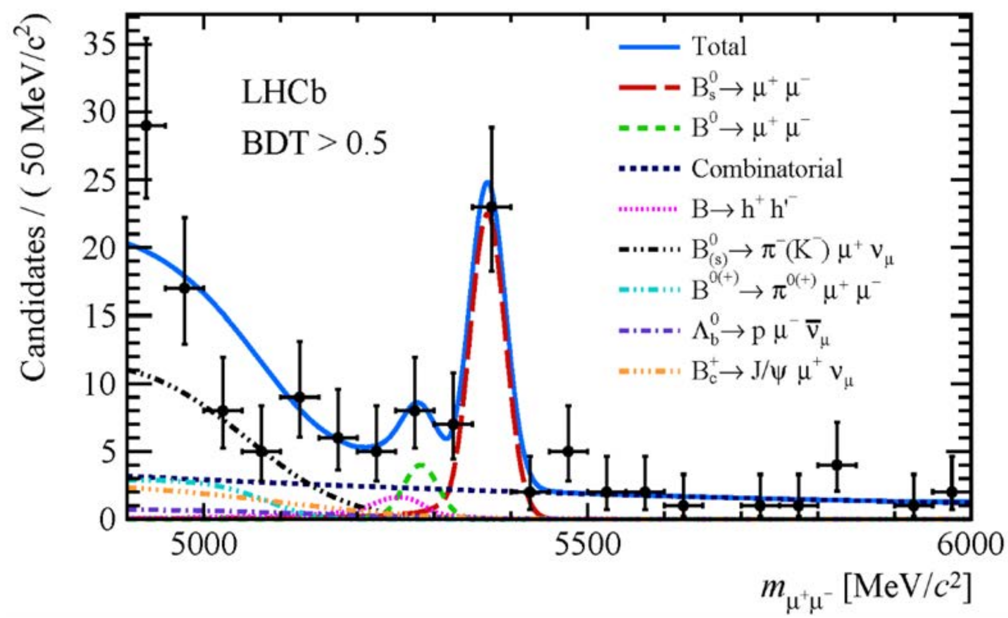
Update on $B_s \to \mu^+\mu^-$ by LHCb with Run-2 data

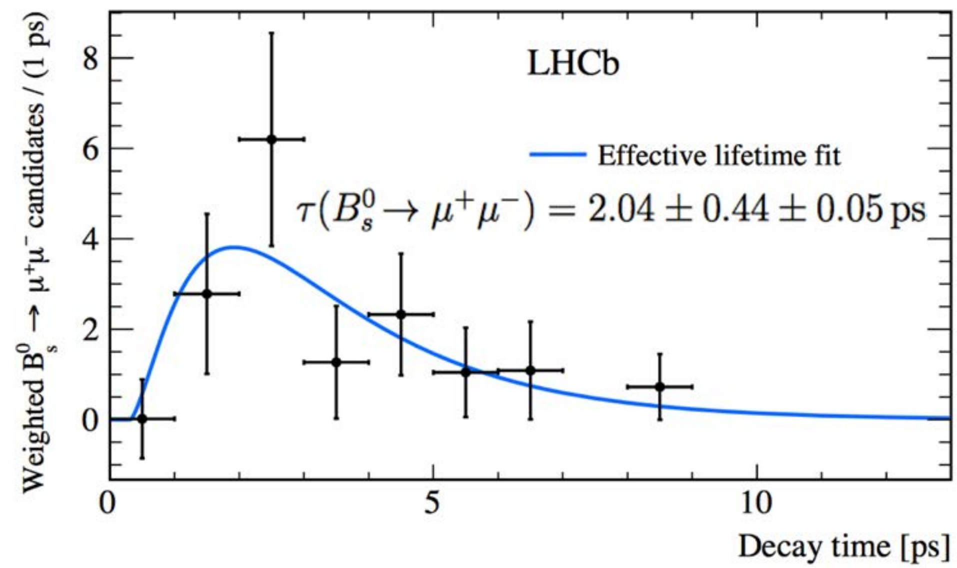
- New measurement from LHCb using Run-2 data has led last year to the first observation of the $B_s \to \mu\mu$ decay from a single experiment

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

- Moreover, it starts to be possible to measure other properties, such as the effective lifetime
  - Experimental precision not yet in the interesting range, but important proof of concept

Phys. Rev. Lett. 118, 191801 (2017)





M. Rama

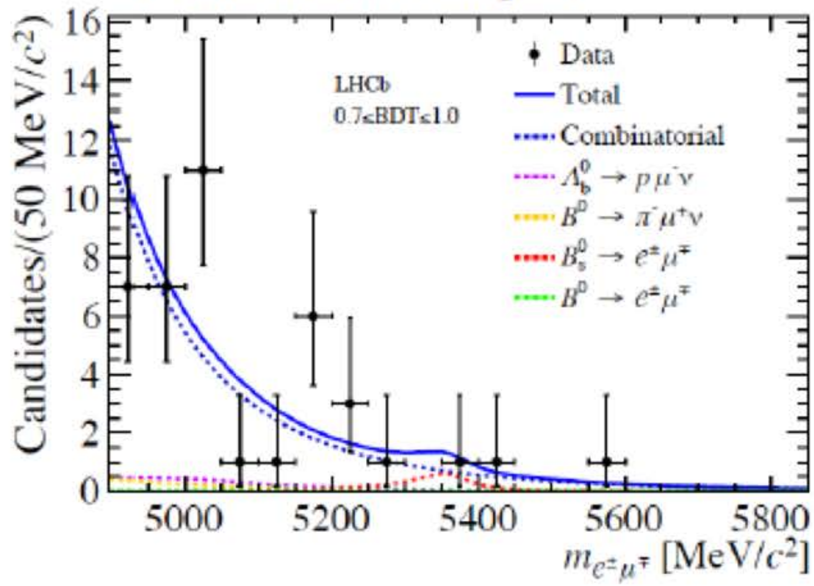
Updated search for $B^0_{(s)} \rightarrow e\mu$ decays

[JHEP 1803 (2018) 078]

$$i = B^0 \to K^+\pi^-, B^+ \to J/\psi K^+$$

$$\mathcal{B}(B^0_{(s)} \to e^\pm\mu^\mp) = \sum_i w^i \frac{\mathcal{B}^i_{\rm norm}}{N^i_{\rm norm}} \frac{\varepsilon^i_{\rm norm}}{\varepsilon_{\rm sig}} \frac{f_q}{f_{d(s)}} \times N_{B^0_{(s)} \to e^\pm\mu^\mp} = \alpha_{B^0_{(s)}} \times N_{B^0_{(s)} \to e^\pm\mu^\mp},$$

events summed over the 3 most sensitive BDT bins and the 2 brem. categories



- No signal found. Events in signal region consistent with the expected background
- Upper limit on $BF(B^0_{(s)} \to e^\pm\mu^\mp)$ evaluated with the CLs method:

$$BF(B^0_s \to e^\pm\mu^\mp) < 5.4(6.3)\ 10^{-9} \text{ @ } 90(95)\% \text{ CL}$$
$$BF(B^0 \to e^\pm\mu^\mp) < 1.0(1.3)\ 10^{-9} \text{ @ } 90(95)\% \text{ CL}$$

Best UL to date, improved by factor 2-3 since previous LHCb measurement

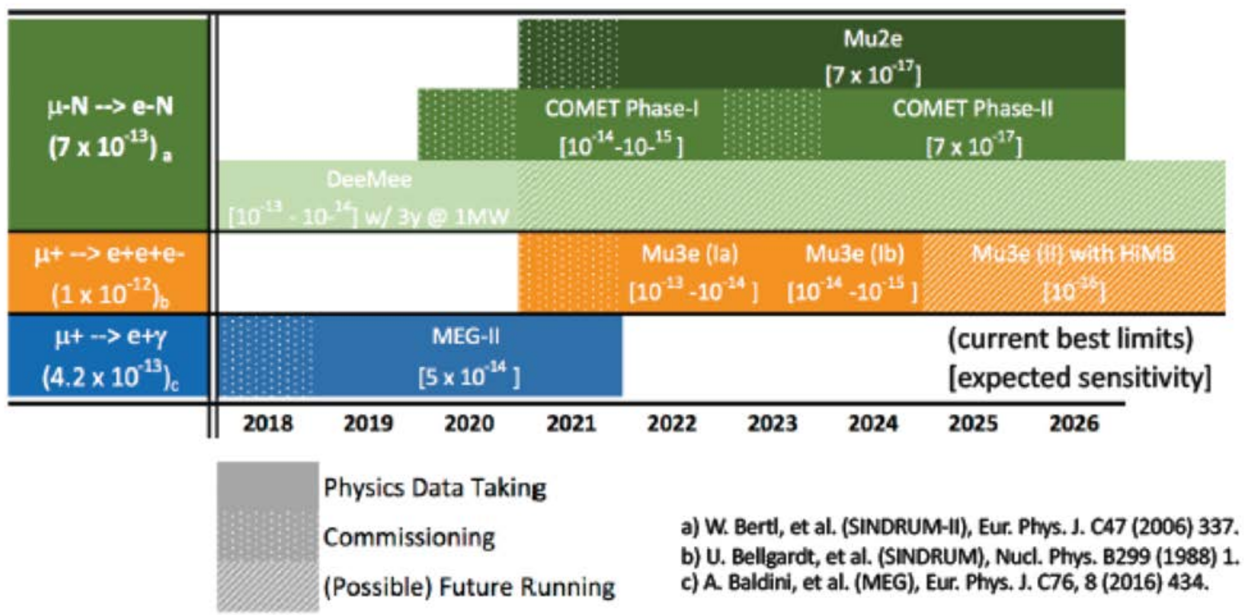
Searches for CLFV

- Quarks mix, ν mix… what about l^{+}?
  - CLFV : neutrino-less transitions of the type $\mu \to e$, $\tau \to e$, $\tau \to \mu$
- There is no known Global Symmetry that requires LF conservation
- Many extensions to the Standard Model predict large CLFV effects
- CLFV offers opportunity to probe $\Lambda_{NP} \sim O(10^3 - 10^4)$ TeV >> TeV

Process	Current Limit	Next Generation exp
$\tau \to \mu\eta$	BR < 6.5 E-8	
$\tau \to \mu\gamma$	BR < 6.8 E-8	10^{-9} - 10^{-10} (Belle II, LHCb)
$\tau \to \mu\mu\mu$	BR < 3.2 E-8	
$\tau \to eee$	BR < 3.6 E-8	
$K_L \to e\mu$	BR < 4.7 E-12	NA62
$K^+ \to \pi^+ e^- \mu^+$	BR < 1.3 E-11	
$B^0 \to e\mu$	BR < 7.8 E-8	LHCb, Belle II
$B^+ \to K^+ e\mu$	BR < 9.1 E-8	
$\mu^+ \to e^+\gamma$	BR < 4.2 E-13	10^{-14} (MEG)
$\mu^+ \to e^+e^+e^-$	BR < 1.0 E-12	10^{-16} (PSI)
$\mu^- N \to e^- N$	$R_{\mu e}$ < 7.0 E-13	10^{-17} (Mu2e, COMET)

(current limits from the PDG)

Experiments using muons among the most sensitive



D. Glenzinski

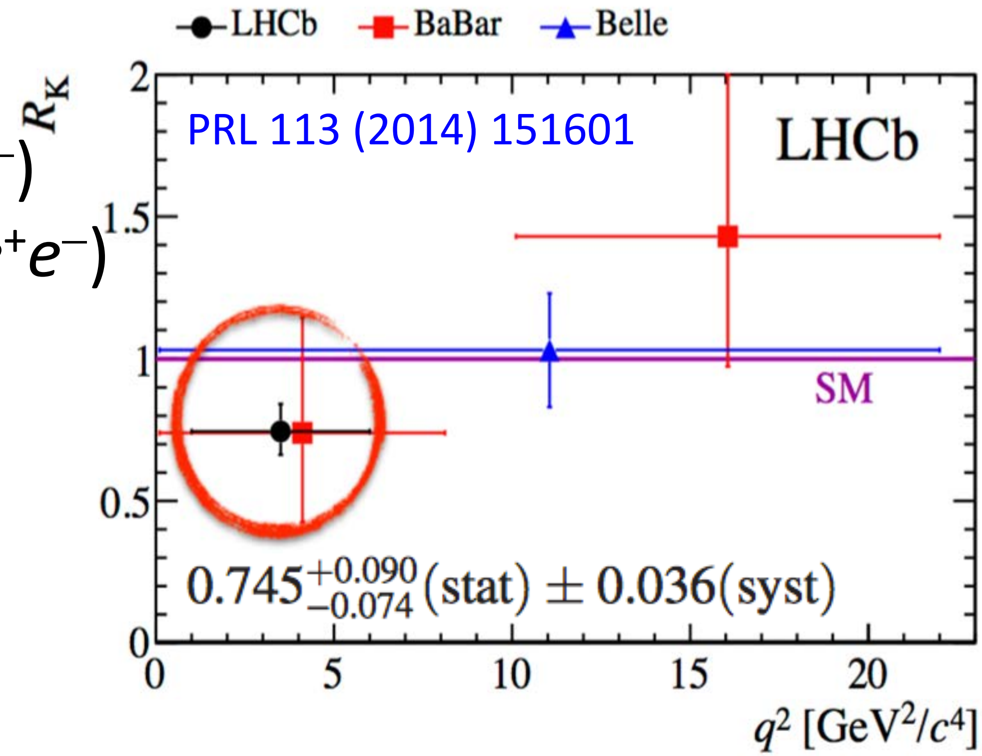
- Significant progress in all three μ channels in next 5-7 years

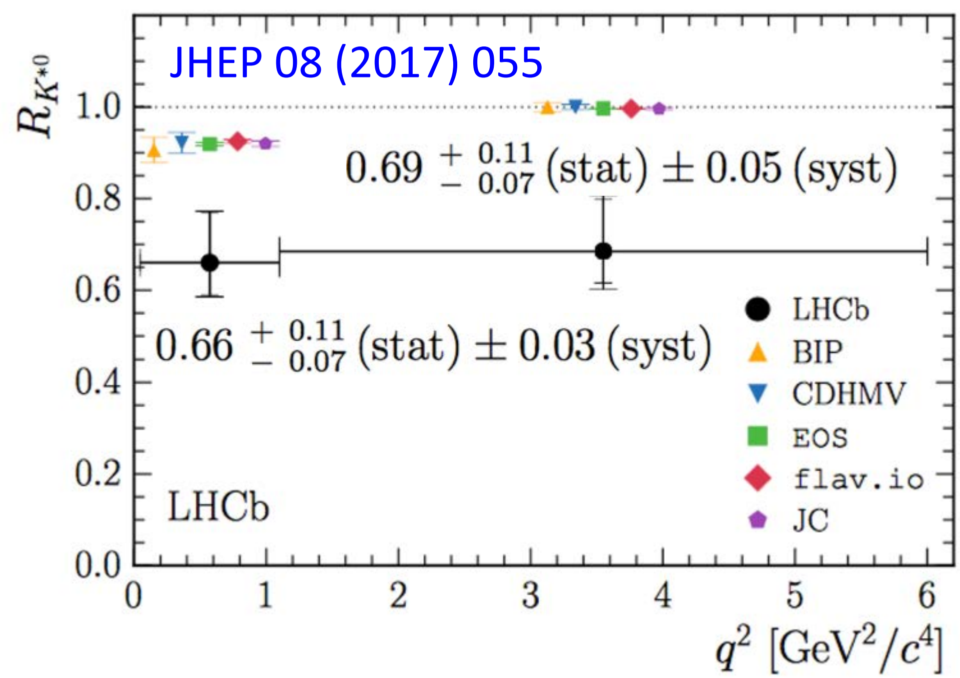
LFU tests in $b \to s\ell^+\ell^-$ transitions

- Measure ratios

  $R_K = BF(B^+ \to K^+\mu^+\mu^-) / BF(B^+ \to K^+e^+e^-)$

  $R_{K^*} = BF(B^0 \to K^{*0}\mu^+\mu^-) / BF(B^0 \to K^{*0}e^+e^-)$
- Theoretically very clean
  - Observation of non-LFU would be a clear sign of new physics
- For the moment at the 3σ-ish level from the SM
- Updates with Run-2 as well as other new measurements with different decay modes eagerly awaited from LHCb

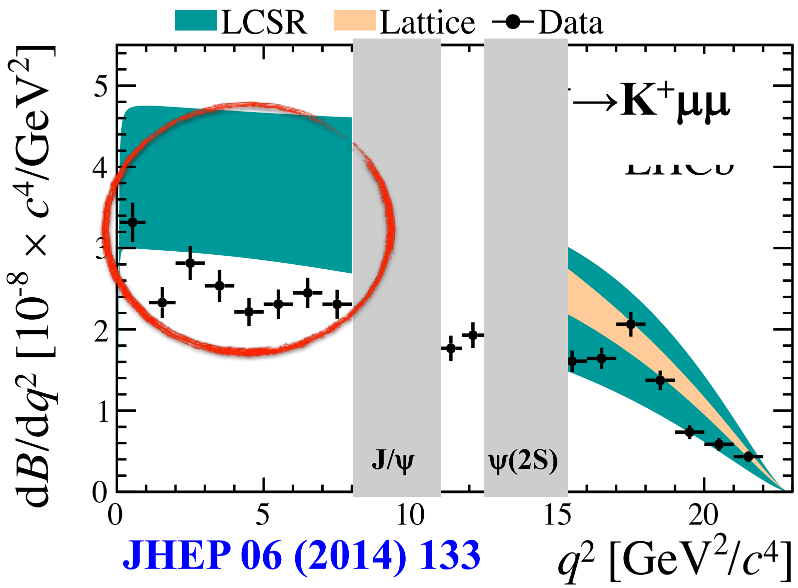




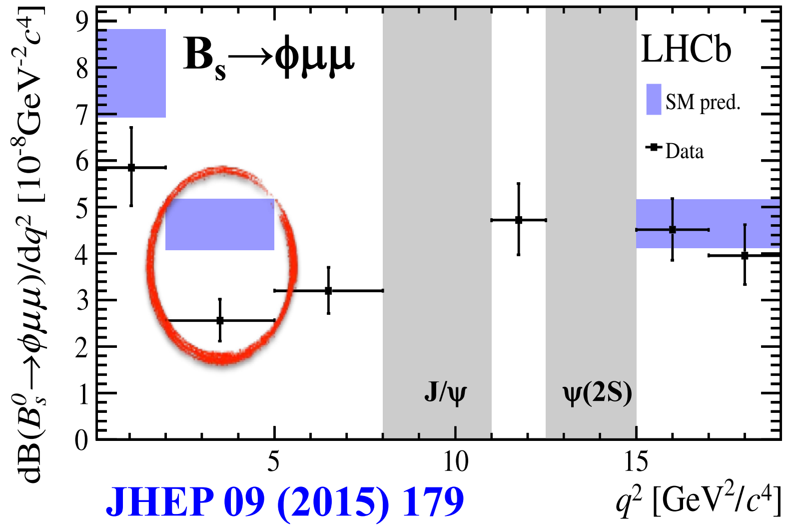
A. Puig

Anomalous BFs in the $b \rightarrow s\ell^+\ell^-$ sector

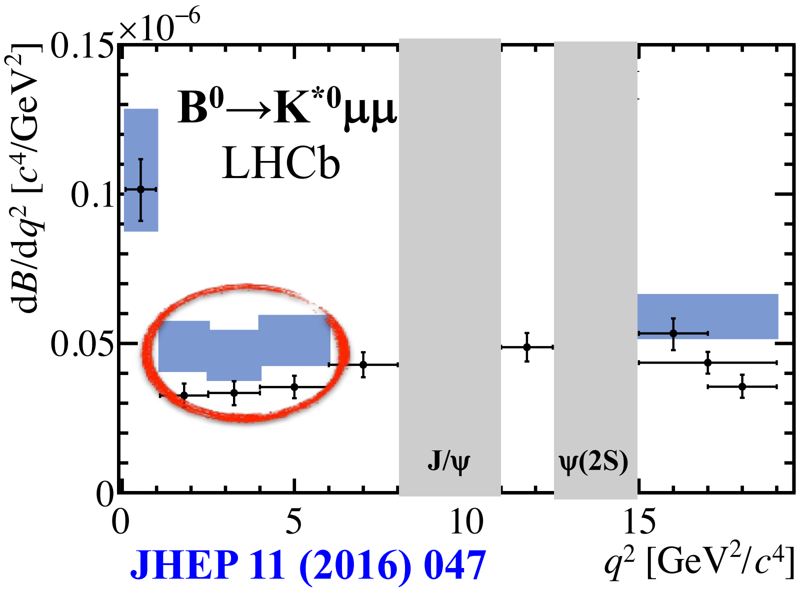
- Differential BFs consistently lower than SM expectations, although uncertainties in the predictions are matter of lively debates



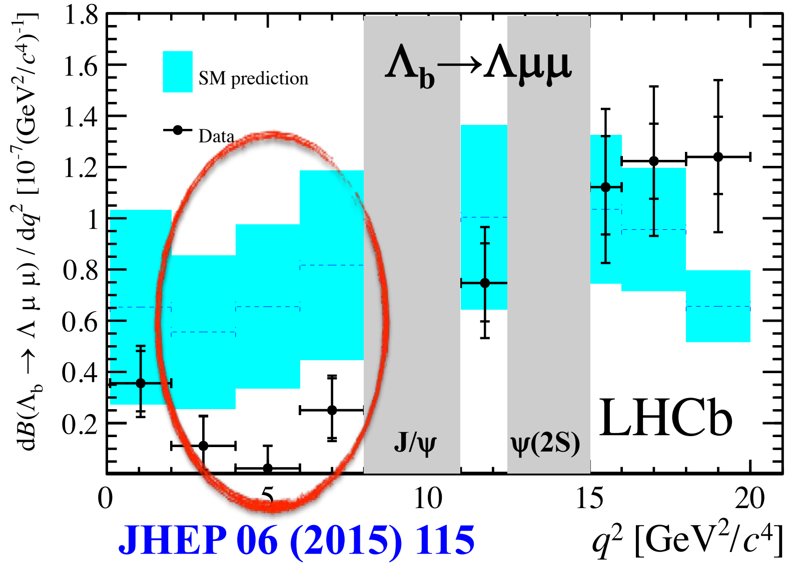
JHEP 06 (2014) 133



JHEP 09 (2015) 179



JHEP 11 (2016) 047
JHEP 04 (2017) 142

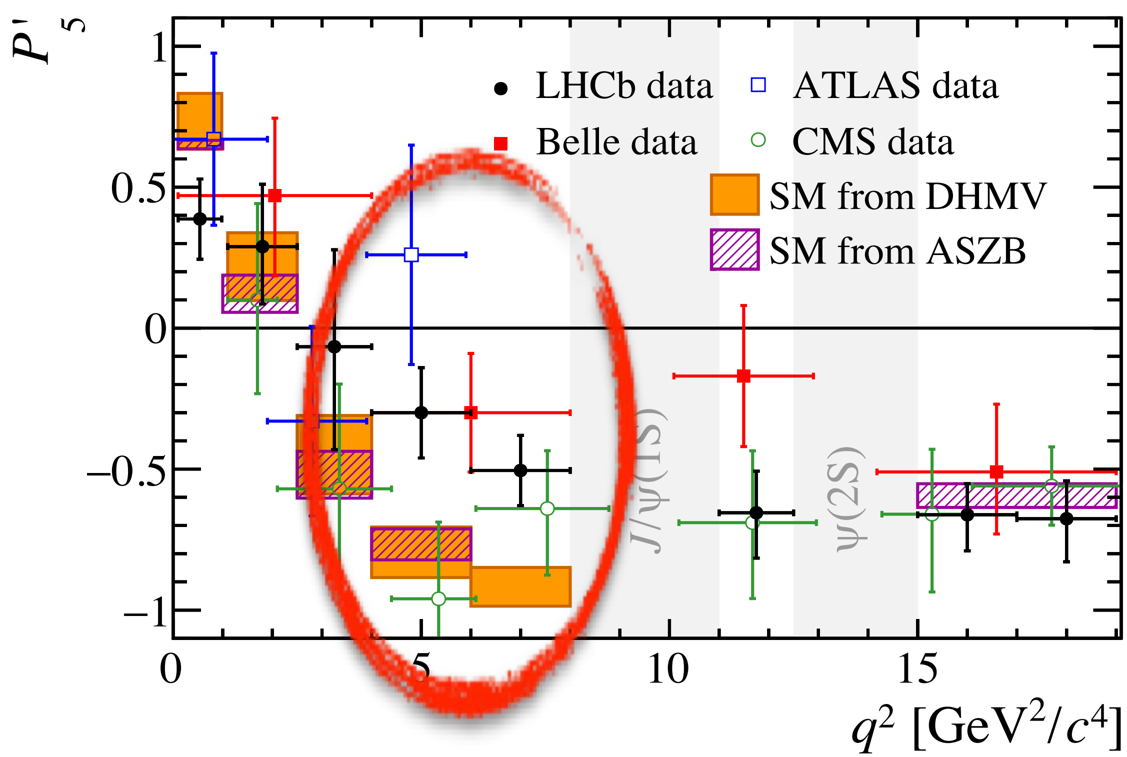


JHEP 06 (2015) 115

E. Smith

Angular anomaly in $B^0 \rightarrow K^{*0}\mu\mu$

- Angular analysis of $B^0 \rightarrow K^{*0}\mu\mu$
- Can construct less form-factor dependent ratios of observables, like P_5'



- JHEP 02 (2016) 104
- PRL 118 (2017) 111801
- arXiv:1805.04000 ← This morning!
- arXiv:1710.02846

- It is important to remark that global fits by several theory groups take into account a plethora of observables from various experiments, notably including $B \rightarrow \mu\mu$ and $b \rightarrow s\ell^+\ell^-$ transitions, and nicely get a consistent overall picture

N. Mahmoudi

S. Sandilya, E. Smith, S. Turchikhin, D. Wang

Global WC fits

- The full LHCb Run 1 results still show some tensions with the SM predictions
- Significance of the anomalies depends on the assumptions on the power corrections

- Model independent fits point to about 25% reduction in C_9, and new physics in muonic C_9^μ is preferred
- We compared the fits for NP and hadronic parameters through the Wilk's test
- At the moment adding the hadronic parameters does not improve the fit compared to the new physics fit, but the situation is inconclusive
- The LHCb upgrade will have enough precision to distinguish between NP and power corrections

N. Mahmoudi

And attempts for model building

- simultaneous explanation of $R_{K^{(*)}}$ and $R_{D^{(*)}}$ anomalies appealing
  it calls for a "low" New Physics scale $\Lambda \approx 1$ TeV, at least in simplest scheme

F. Feruglio

But how to tame the monster?

Charm loop: dangerous or  harmless?

A clear-cut non-perturbative calculation is not available yet

Combinations of QCDF, LCSR, analiticity and unitarity point to a moderate effect with a flat q^2 dependence in the region of interest.

Yet their ability to fully describe c-loop rescattering is questionable

Future data could be able to pin down hadronic contributions with no short-distance counterparts (all but ΔC_7 and ΔC_9)

LFUV signals are not affected, but their interpretation may be

M. Ciuchini

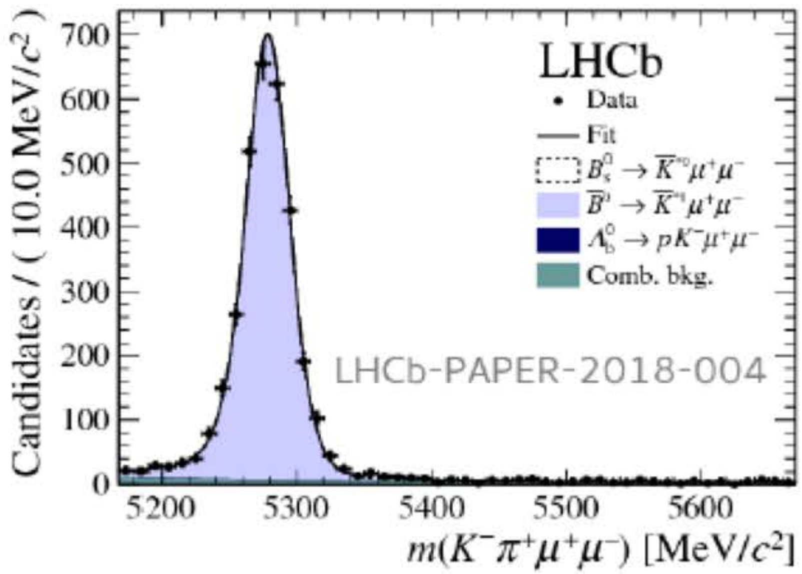
Next frontier: $b \to d\ell^+\ell^-$ transitions

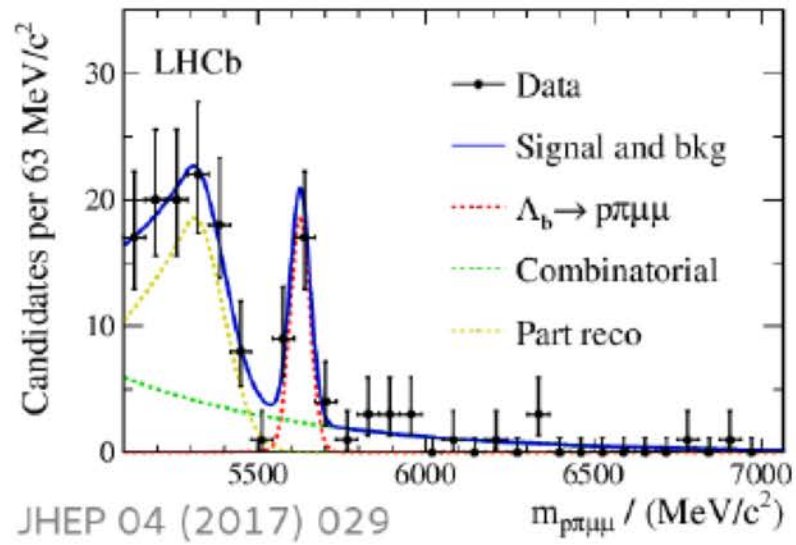
$\mathcal{B}(B_s^0 \to \overline{K^{*0}}\mu^+\mu^-)$ = $(2.9 \pm 1.0 \pm 0.2 \pm 0.3) \times 10^{-8}$

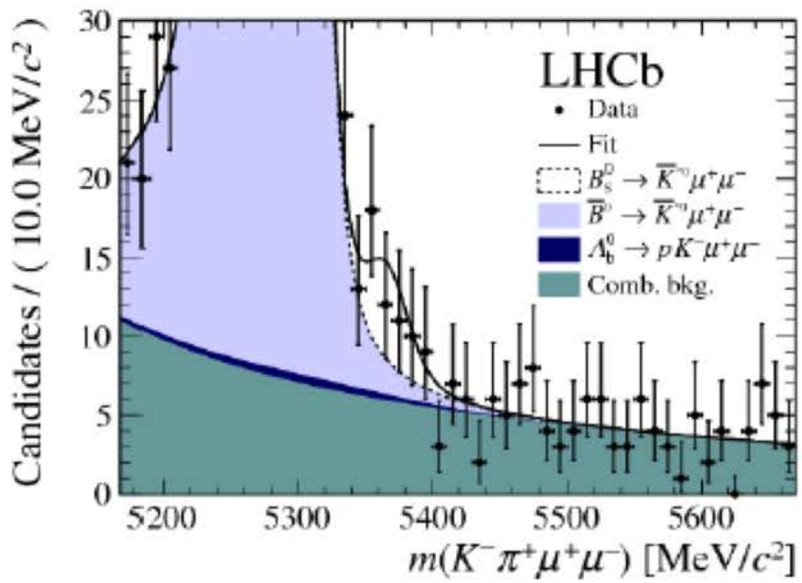
$B^0 \to K^{*0}\mu^+\mu^-$ equivilent

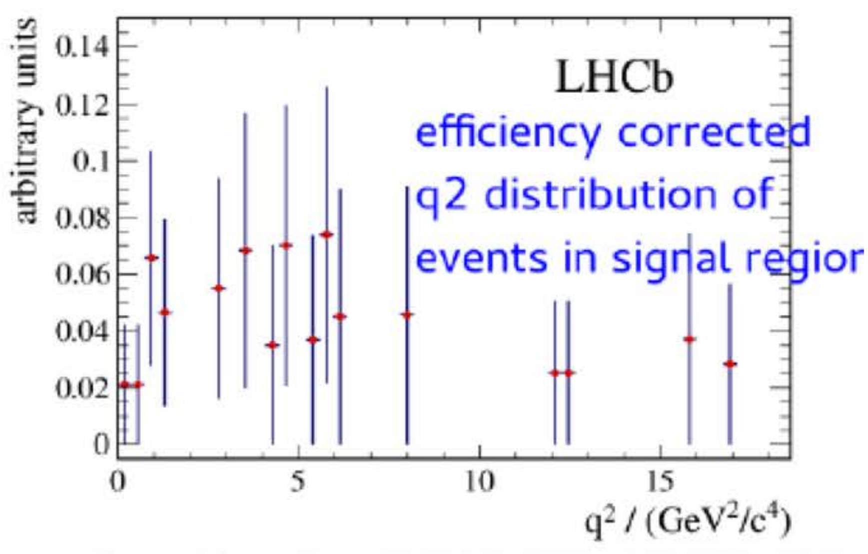
$\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)$ = $(6.9 \pm 1.9 \pm 1.1^{+1.3}_{-1.0}) \times 10^{-8}$

$\Lambda_b^0 \to pK^-\mu^+\mu^-$ equivilent









E. Smith

Charm

From Beauty to Charm

- From Elba island to Novosibirsk: ~ 6.000 km, two weeks
- Experimentally, b-machines are also charm-machines
- The structure of charm flavor-changing-neutral-current transitions allows to uniquely probe the SM and BSM physics with many decays and observables - despite branching ratios being dominated by long-distance effects.
- Not to forget: Rare charm decays may help to improve our understanding of QCD/check theoretical frameworks.
- The little sister of beauty is growing up: Rare charm decays at the level of rare b-decays back twenty years.
- Many experiments, *e.g.*, Belle (II), BESIII, LHCb and theoretical works ongoing, *e.g.*, [SdB, Hiller: $D \to PP\ell\ell$, to appear].

S. De Boer

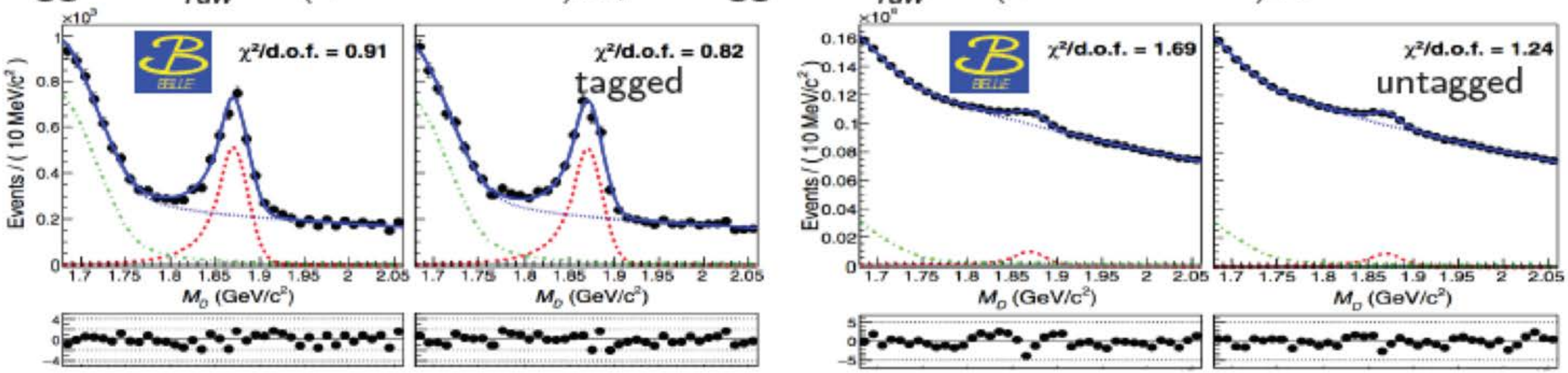
CP violation in $D^+ \rightarrow \pi^+\pi^0$

[PRD **97**, 011101(R) (2018)]

- Singly Cabibbo-suppressed decay: excellent candidates to probe CPV in charm sector.
- Any *CP* asymmetry found in these channels point to New Physics [PRD 85,114036(2012)]
- Based on 921 fb^{-1}, *CP* asymmetries are measured from a simultaneous fit to M_D:

$$A^{\pi\pi}_{raw} = \frac{N(D^+ \to \pi^+\pi^0) - N(D^- \to \pi^-\pi^0)}{N(D^+ \to \pi^+\pi^0) - N(D^- \to \pi^-\pi^0)} = A_{CP} + A_{FB} + A^{\pi^\pm}_{\epsilon}$$

- tagged: $A^{\pi\pi}_{raw} = (+0.52 \pm 1.92)\%$; untagged: $A^{\pi\pi}_{raw} = (+3.77 \pm 1.60)\%$.



- normalization $D^+ \to K^0_S\pi^+$ with $A^{K\pi}_{CP} = (-0.363 \pm 0.094 \pm 0.067)\%$[PRL **109**, 021601 (2012)]
  $A^{K\pi}_{raw} = (-0.29 \pm 0.44)\%$ (tagged); $A^{K\pi}_{raw} = (-0.25 \pm 0.17)\%$.
- A combination: $A_{raw} = (+2.67 \pm 1.24 \pm 0.20)\%$ [EPJC75,453(2015)]
- Leads to $A^{\pi\pi}_{CP} = A^{K\pi}_{CP} + \Delta A_{raw}$, thus $A_{CP}(D^+ \to \pi^+\pi^0) = (+2.31 \pm 1.24 \pm 0.23)\%$.

L. Li

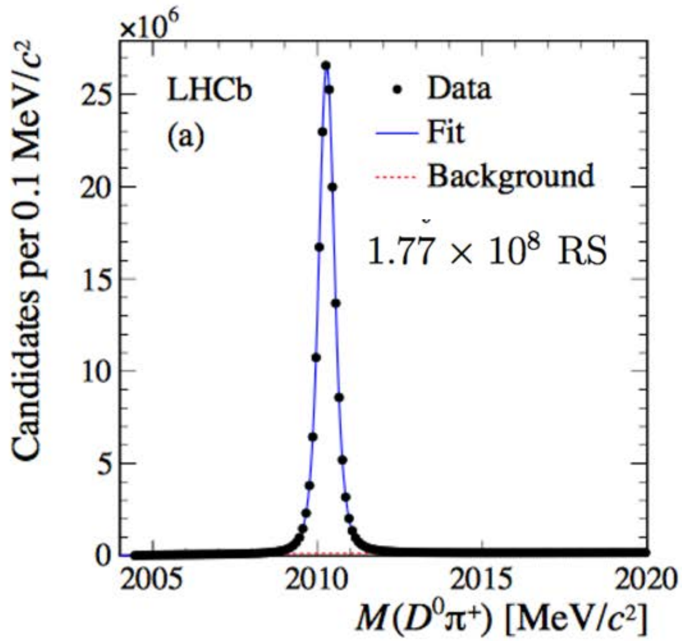
Updated determination of neutral *D*-meson mixing parameters and search for *CP* violation

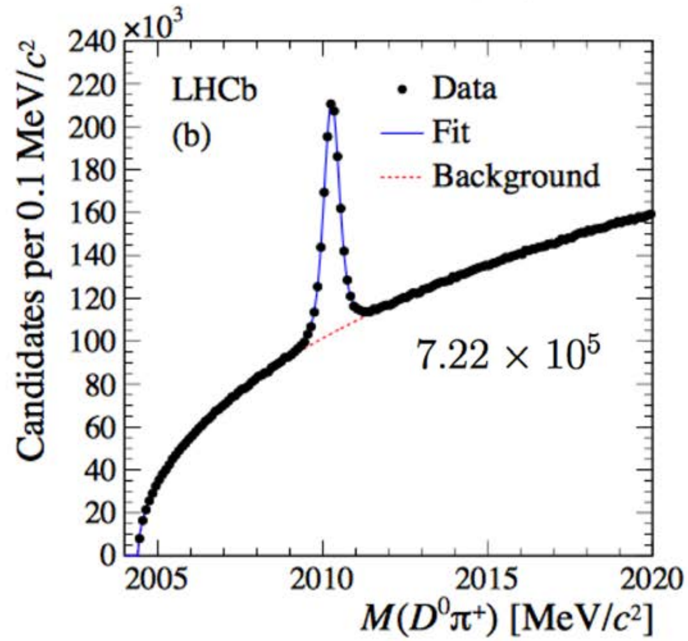
- Recent publication on charm mixing and search for *CP* violation using Run-1 + Run-2 data   PRD 97 (2018) 031101
- Measure time-dependent ratio of wrong-sign to right-sign $D^0 \rightarrow K\pi$ decays

$$R(t) = \frac{N(D^0 \to K^+\pi^-)}{N(D^0 \to K^-\pi^+)}$$

$$R(t) \approx R_D + \sqrt{R_D}\, y' \frac{t}{\tau} + \frac{x'^2 + y'^2}{4} \left(\frac{t}{\tau}\right)^2$$

- By far the largest sample of such decays ever





M. Williams

Updated determination of neutral *D*-meson mixing parameters and search for *CP* violation

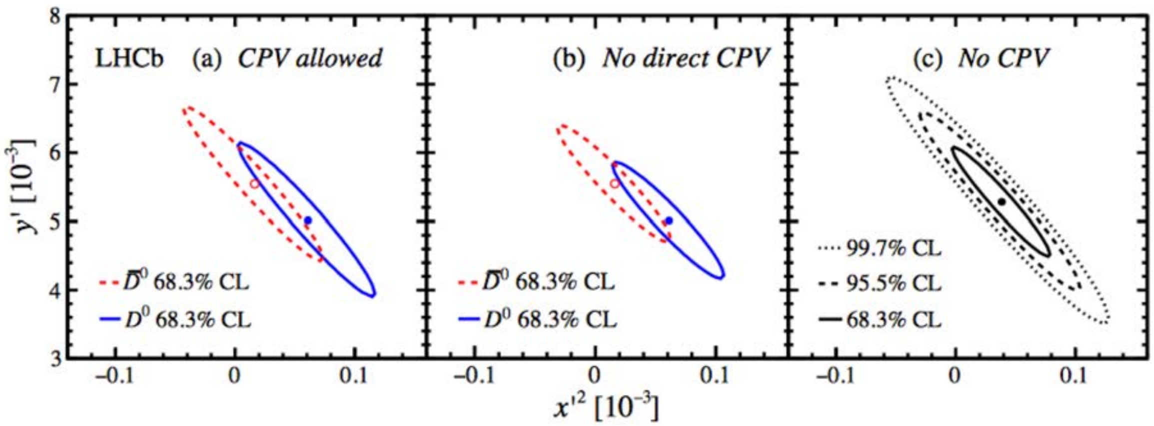
arXiv:1712.03220

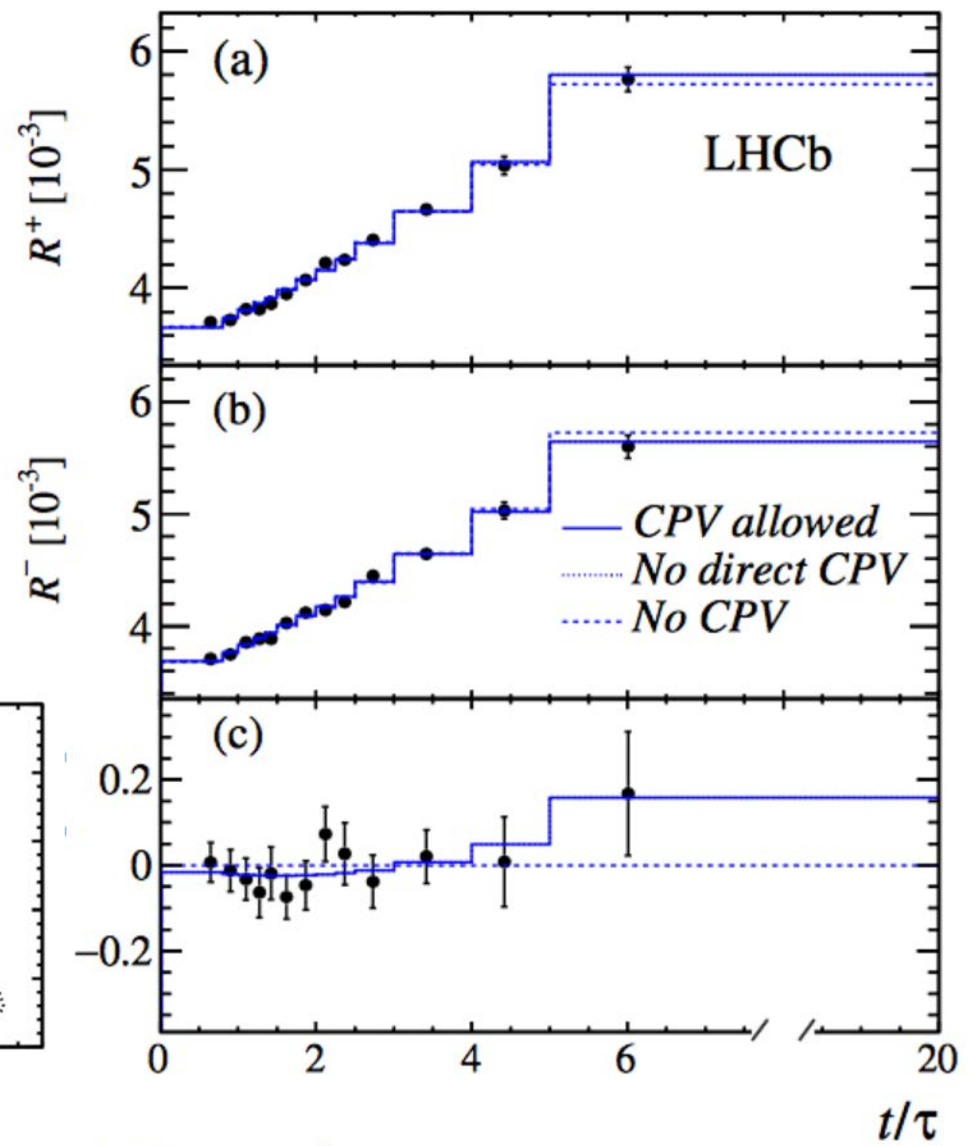
$$x'^2 = (3.9 \pm 2.7) \times 10^{-5}$$

$$y' = (5.28 \pm 0.52) \times 10^{-3}$$

$$R_D = (3.454 \pm 0.031) \times 10^{-3}$$

- The results are twice as precise as previous LHCb results (but no CPV yet)

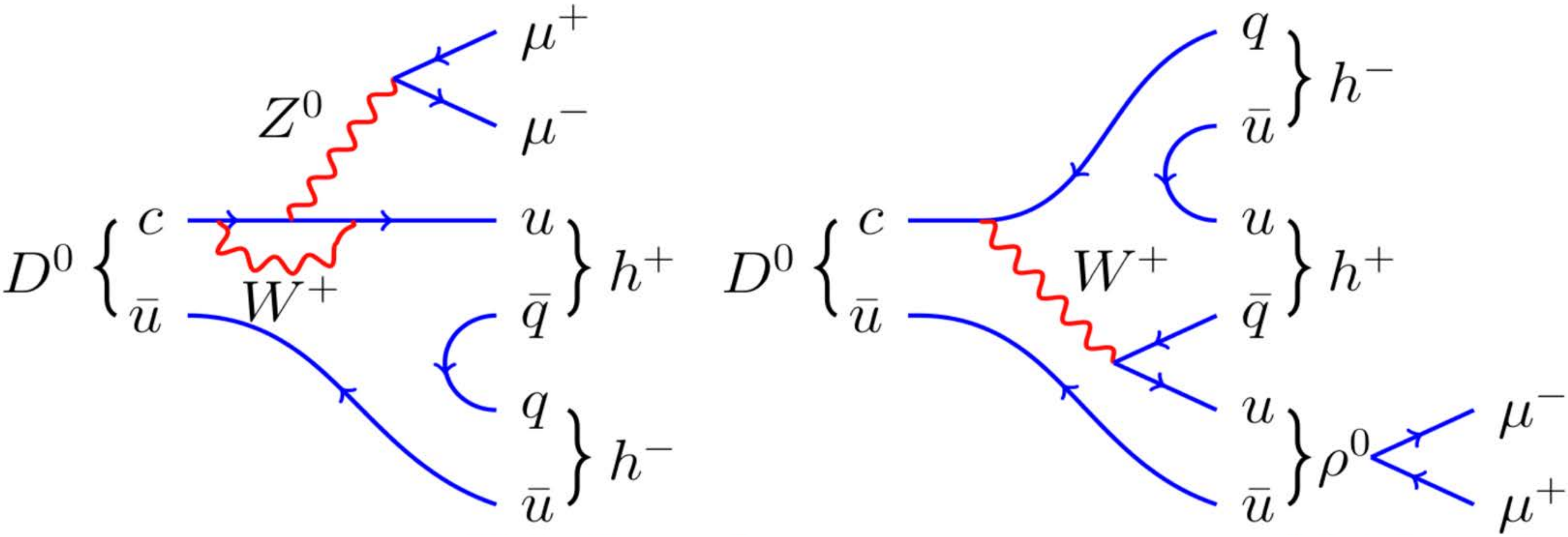




$$A_D \equiv (R_D^+ - R_D^-)/(R_D^+ + R_D^-) = (-0.1 \pm 8.1 \pm 4.2) \times 10^{-3}$$

M. Williams

$D^0 \to h^+h^-\mu^+\mu^-$ decays at LHCb



- Rarest charm-hadron decays ever observed:

[PRL 119 (2017) 181805]

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$

$$\mathcal{B}(D^0 \to K^+K^-\mu^+\mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}$$

where the uncertainties are statistical, systematic and due to the BF of the normalisation

- Branching fractions in broad agreement with SM predictions [JHEP 04 (2013) 135]

Now looking for *CP* asymmetries!

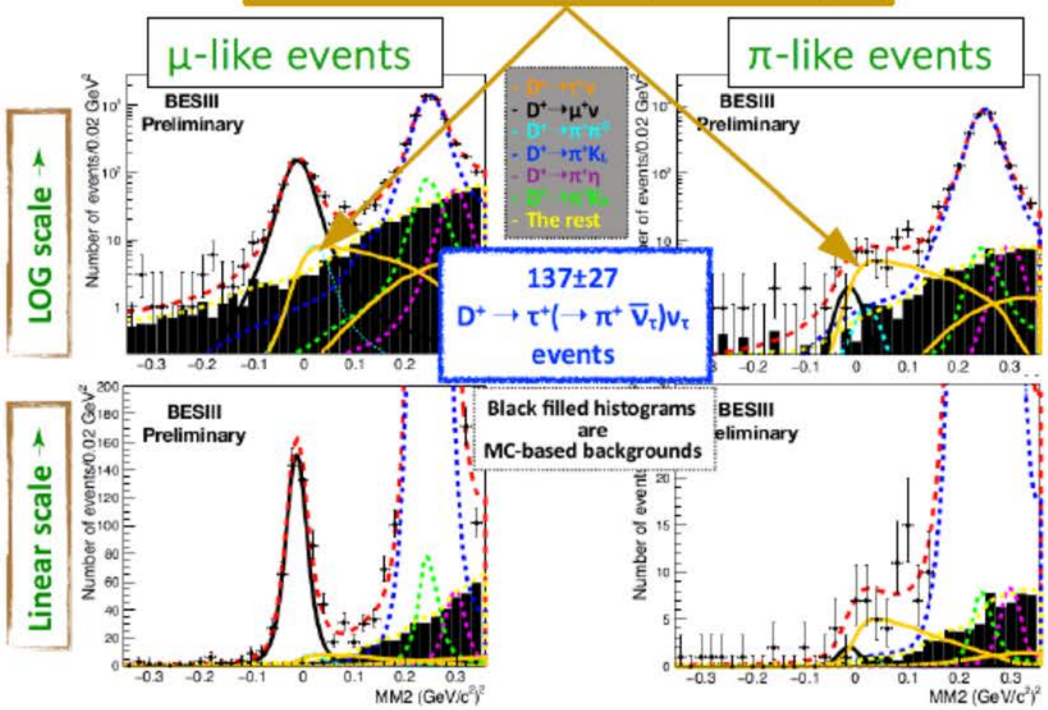
LFU tests also in charm!

Leptonic $D^+ \to \tau^+ \nu_\tau$ (preliminary)

Search for pure leptonic decay of D meson (never observed before) and possible test of *lepton universality*.

$$R \equiv \frac{\Gamma(D^+ \to \tau^+\nu)}{\Gamma(D^+ \to \mu^+\nu)} = \frac{m_{\tau^+}^2 \left(1 - \frac{m_{\tau^+}^2}{M_{D^+}^2}\right)^2}{m_{\mu^+}^2 \left(1 - \frac{m_{\mu^+}^2}{M_{D^+}^2}\right)^2}$$

Signal: $D^+ \to \tau^+ \nu_\tau$, $\tau^+ \to \pi^+ \bar{\nu}_\tau$



Two signal regions:

- μ-like (E_{EMC} < 300 MeV);
- π-like (E_{EMC} > 300 MeV)

Simultaneous Fit to the missing-mass-squared

$$M_{\rm miss}^2 = (E_{\rm beam} - E_{\mu^+})^2 - (-\vec{p}_{D^-_{\rm tag}} - \vec{p}_\mu)^2$$

Preliminary Results

$BF(D^+ \to \tau^+\nu_\tau) = (1.20 \pm 0.24)\ 10^{-4}$

$R = 3.21 \pm 0.64$,
consistent with SM prediction ($R = 2.66 \pm 0.01$) at 0.9σ level

And...

$D^{+(0)} \to \pi^{0(-)} \mu^+ \nu_\mu$

$$R^0_{LU} = 0.905 \pm 0.027 \pm 0.023$$

Theoretically: $R^{0(+)} = 0.97$

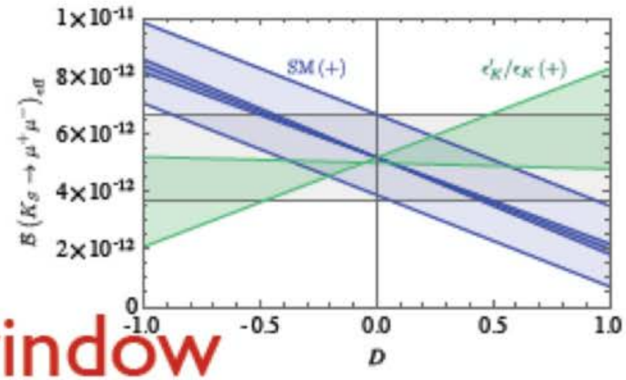
Agreement at 1.9σ and 0.6σ level

G. Mezzadri

Strange, isn’t it?

Rare is not only heavy!

- Flavour anomalies: interplay with K->π***νν*** but 10% measurement needed!



- LHCB: K_S->μμ extraordinary result: interference effect!!!Short distance window

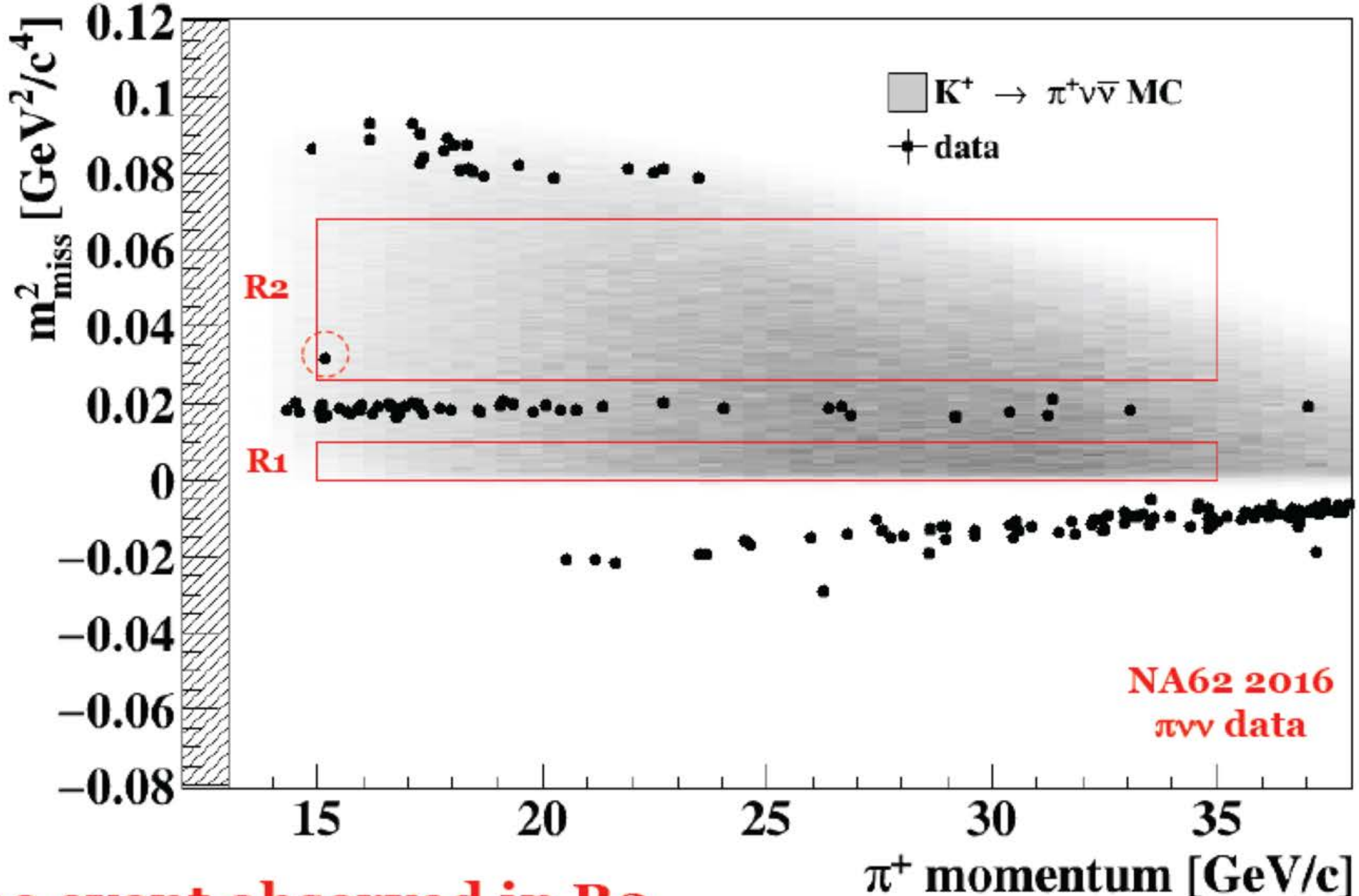
- weak chiral lagrangian

- LFUV in Kaons very useful

- Rich rare kaon program

G. D'Ambrosio

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Results



One event observed in R2

A. Romano

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Results

- One event observed in signal region R2
- Full exploitation of the CLs method in progress
- The results are compatible with the Standard Model

$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 11 \times 10^{-10} \text{ @ } 90\% \; CL$$

$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 14 \times 10^{-10} \text{ @ } 95\% \; CL$$

- Analysis of data collected in 2017 started
  - data sample x 20 larger than presented statistics
  - expect improvements on signal acceptance, efficiency and S/B ratio
- Data taking is ongoing (April-November 2018)
- Expect ~20 SM events before LS2
- Data taking after 2018 to be approved

A. Romano

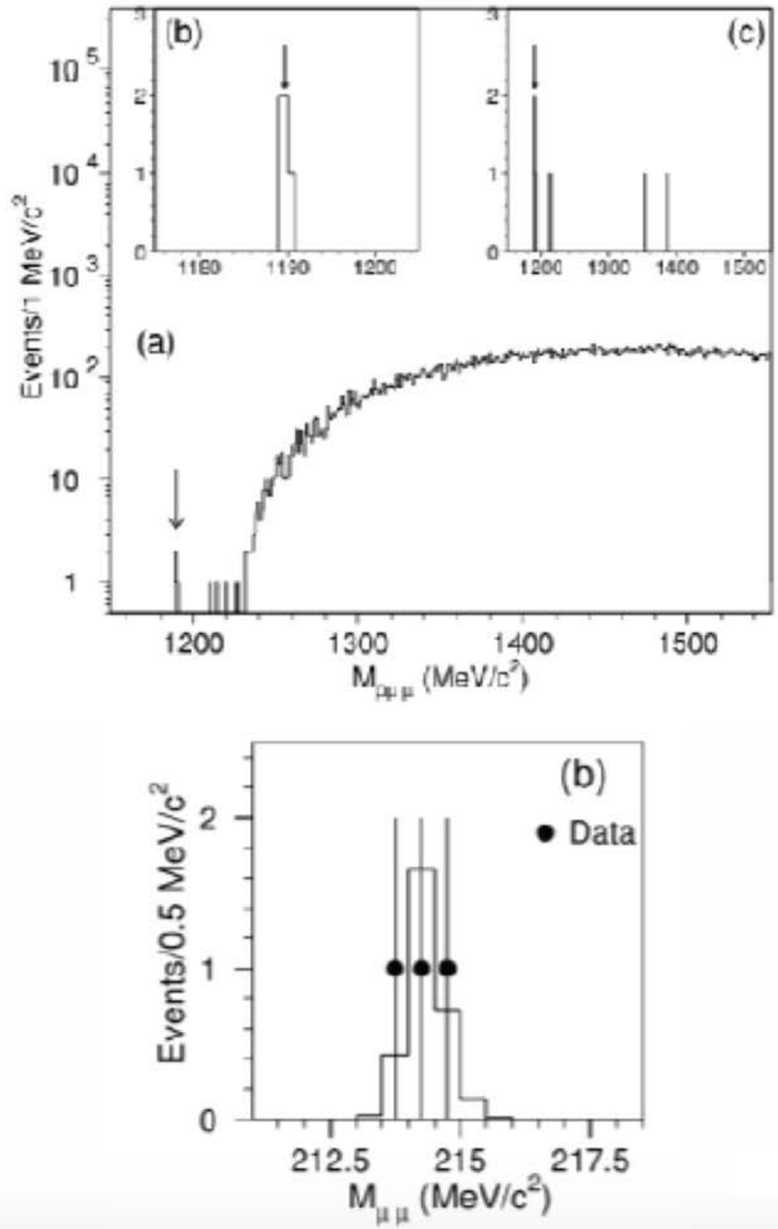
The HyperCP anomaly in $\Sigma^+ \to p\mu^+\mu^-$

- Short-distance SM branching fraction is at $O(10^{-12})$, long-distance contribution up to 10^{-7}
- First evidence reported by HyperCP with 3 events in absence of background

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4} \pm 5.5) \times 10^{-8}$$

- All events clustered at the same dimuon mass of (214.3 ± 0.5) MeV/c^2, indicating the existence of a new particle $P^0 \to \mu^+\mu^-$
- P^0 searched for and not found by several experiments using dimuons from different decays

[PRL 94 (2005) 021801]



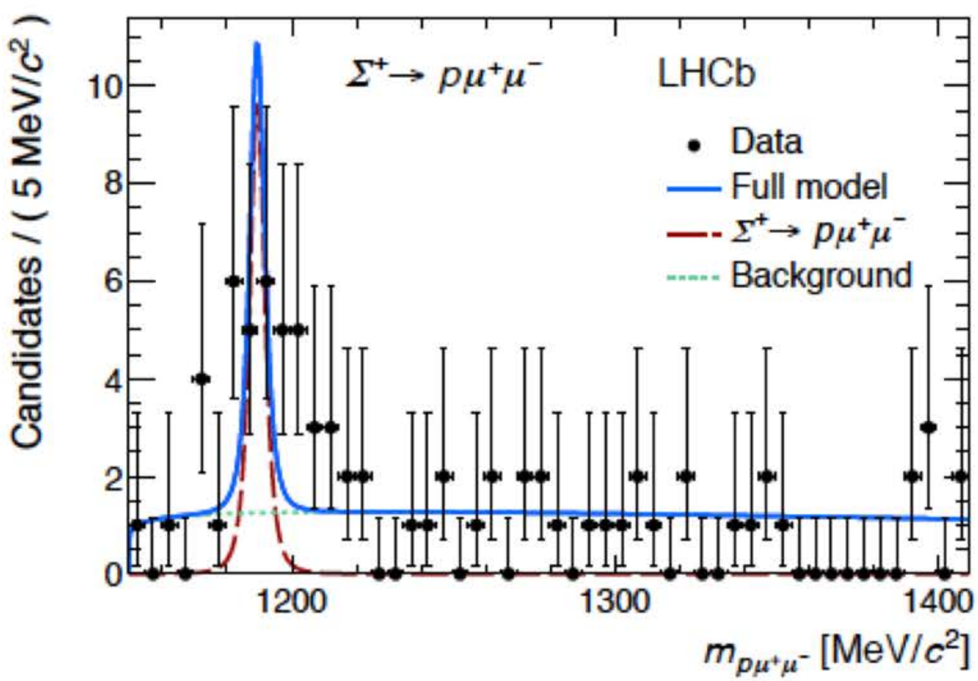
A. Di Canto

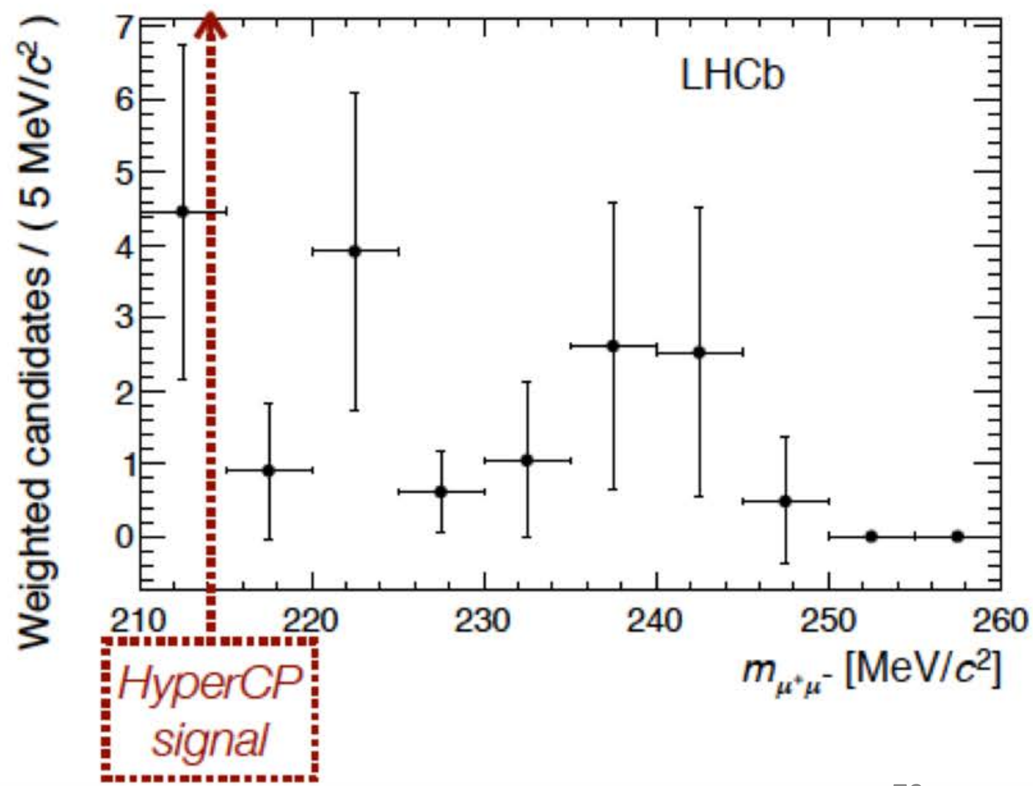
Search for $\Sigma^+ \to p\mu^+\mu^-$ at LHCb

- Searched in 3/fb of Run 1 data
- Evidence for the decay at 4σ, no structure observed in $m(\mu^+\mu^-)$

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (2.1^{+1.6}_{-1.2}) \times 10^{-8}$$

arxiv:1712.08606





A. Di Canto

The (not so far) future

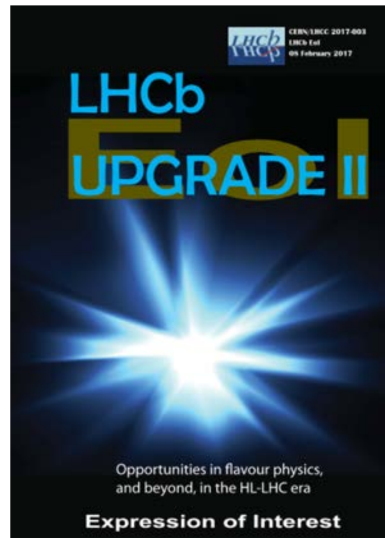
Upgrades at the LHC

P. Collins, S. Fiorendi, N. Neri, W. Walkowiak

	LHC era			HL-LHC era	
	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-24)	Run 4 (2027-30)	Run 5+ (2031+)
ATLAS, CMS	25 fb^{-1}	150 fb^{-1}	300 fb^{-1}	⟶	3000 fb^{-1}
LHCb	3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	*300 fb^{-1}

* assumes a future LHCb upgrade to raise the instantaneous luminosity to $2\text{x}10^{34}$ $cm^{-2}s^{-1}$

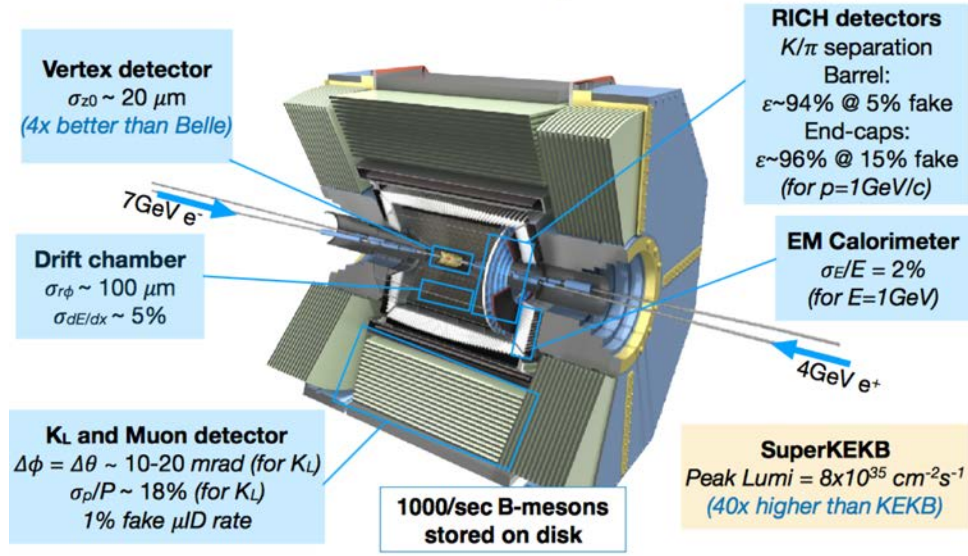
- A first LHCb upgrade comes already in LS2 (to raise the instantaneous luminosity to $2\text{x}10^{33}$ $cm^{-2}s^{-1}$), whereas the HL ATLAS and CMS upgrades come in LS3
- LHCb has submitted at the beginning of 2017 an Expression of Interest for a further upgrade during LS4 to reach $2\text{x}10^{34}$ $cm^{-2}s^{-1}$

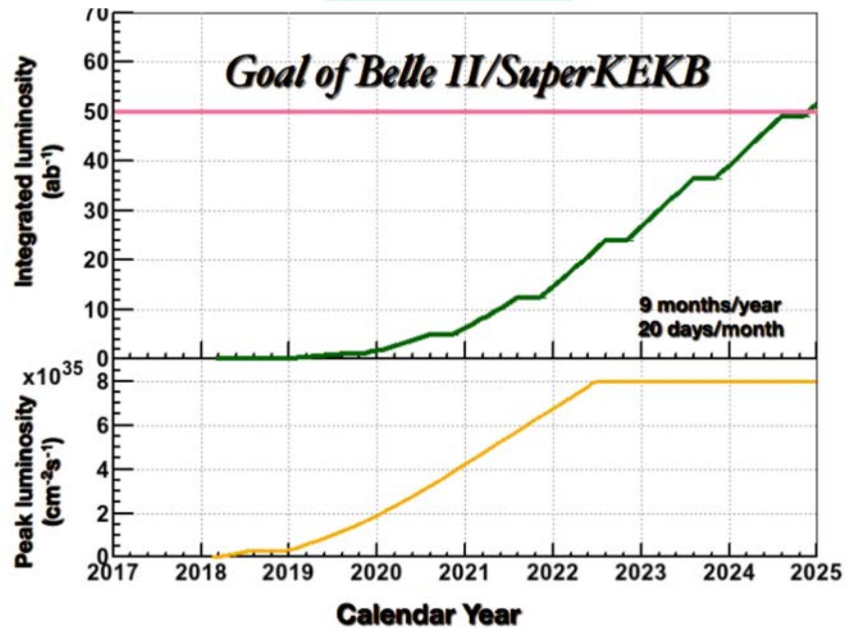


CERN-LHCC-2017-003 https://cds.cern.ch/record/2244311

Belle-II takes off!

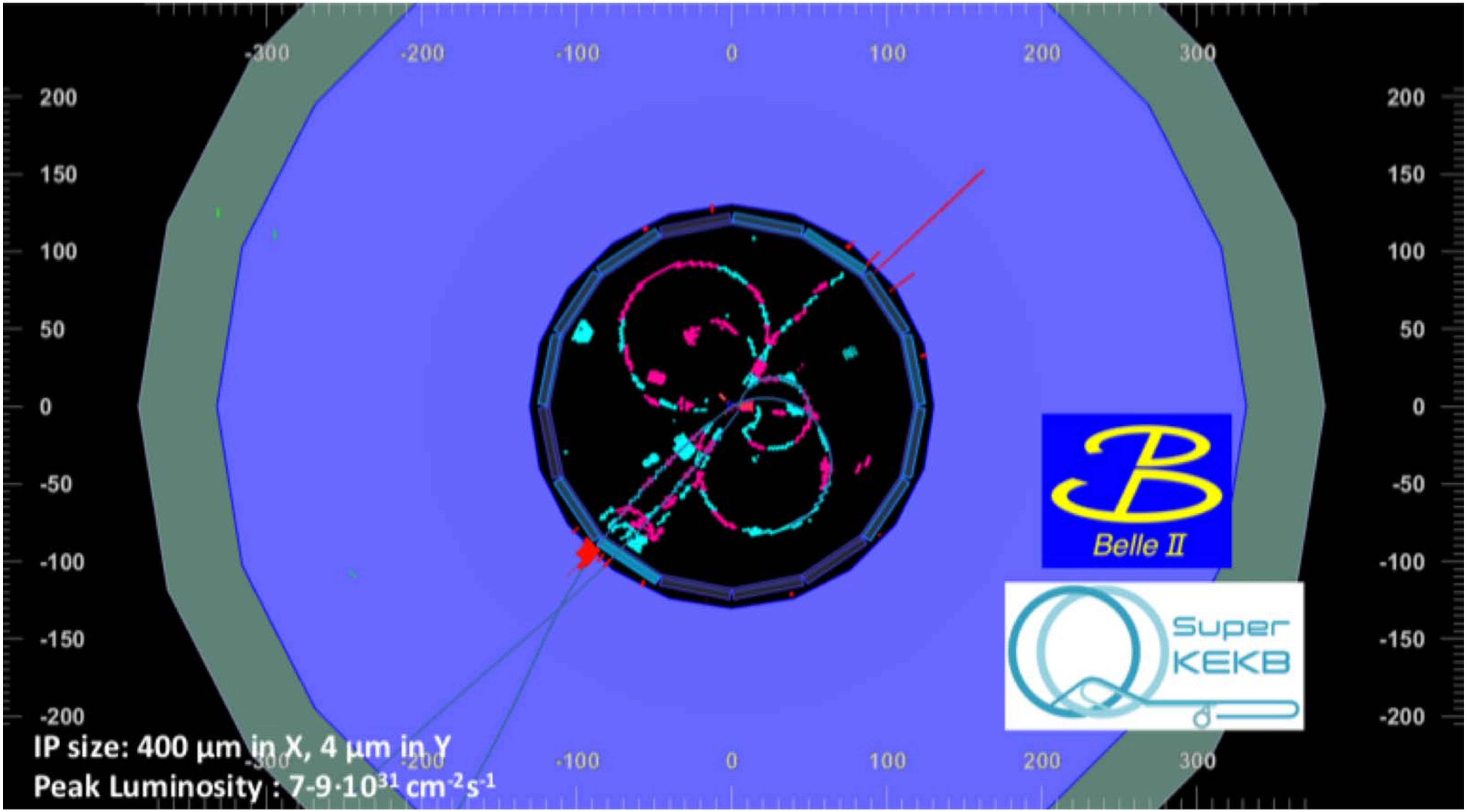
- Exciting prospects from the SuperKEKB machine and Belle-II detector
- An integrated luminosity of 5 ab^{-1} will be collected by 2021, and 50 ab^{-1} by 2025
- By around 2021, enough luminosity will be available to perform very competitive measurements
- There are important areas, especially with neutrals and missing energy modes, where Belle-II will provide crucial complementary measurements to LHC experiments in the flavour sector





C. Marinas

First collisions at Belle II (26 April)



C. Marinas

And then?

Concluding remarks

- In the current state with fundamental physics, it is necessary to have a programme as diversified as possible
- If anomalies will consolidate, it will be of paramount importance to seek confirmation from multiple experiments
- Furthermore, new physics should affect different modes coherently
  - Maintaining the broadest possible physics programme in the long term will be crucial
- Don’t forget: this has been, is and will remain a combined effort between theory and experiments!

Long live Beauty!

Now let's enjoy the approximate symmetry of the island

A. Strumia

Extended material

All scales probed so far appear to be rather large…

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda_W}\,\mathcal{O}_W^{(D=5)} + \sum_{i=1}^{\text{many}} \frac{1}{\Lambda_i^2}\,\mathcal{O}_i^{(D=6)} + \dots$$

SM without neutrino masses

Neutrino masses and oscillations

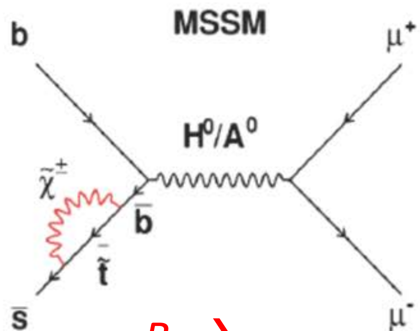
Generic new-physics phenomena

Order	Observable	New-physics scale for g=O(1)
D=5	Neutrino oscillations	$\Lambda \sim 10^9$ TeV
D=6	Proton decay	$\Lambda > 10^{12}$ TeV
D=6	Flavor physics	$\Lambda > 1$–10^5 TeV
D=6	EWPT	$\Lambda > 1$ TeV
D=6	Higgs couplings	$\Lambda > 0.5$–1 TeV

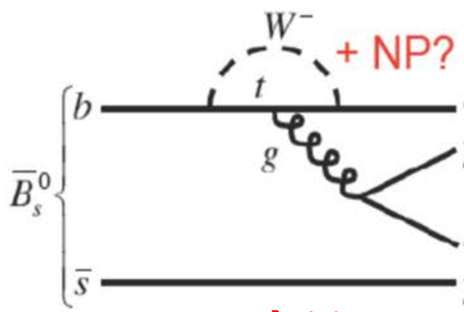
M. Neubert

New physics searches in the flavour sector

- Instead of searching for new particles directly produced, look for their indirect effects to low energy processes (e.g. *b*-hadron decays)

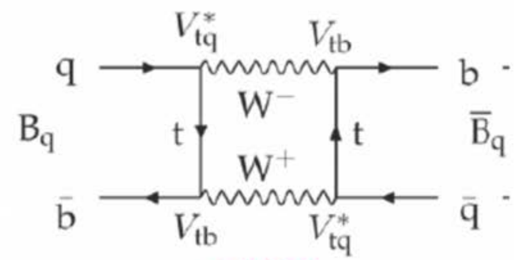


$B_s \to \mu\mu$



$B_s \to \phi\phi$

B-$\bar{B}$ mixing



+ NP?

- General amplitude decomposition in terms of couplings and scales

$$A = A_0 \left[c_{SM} \frac{1}{M_W^{\,2}} + c_{NP} \frac{1}{\Lambda^2} \right]$$

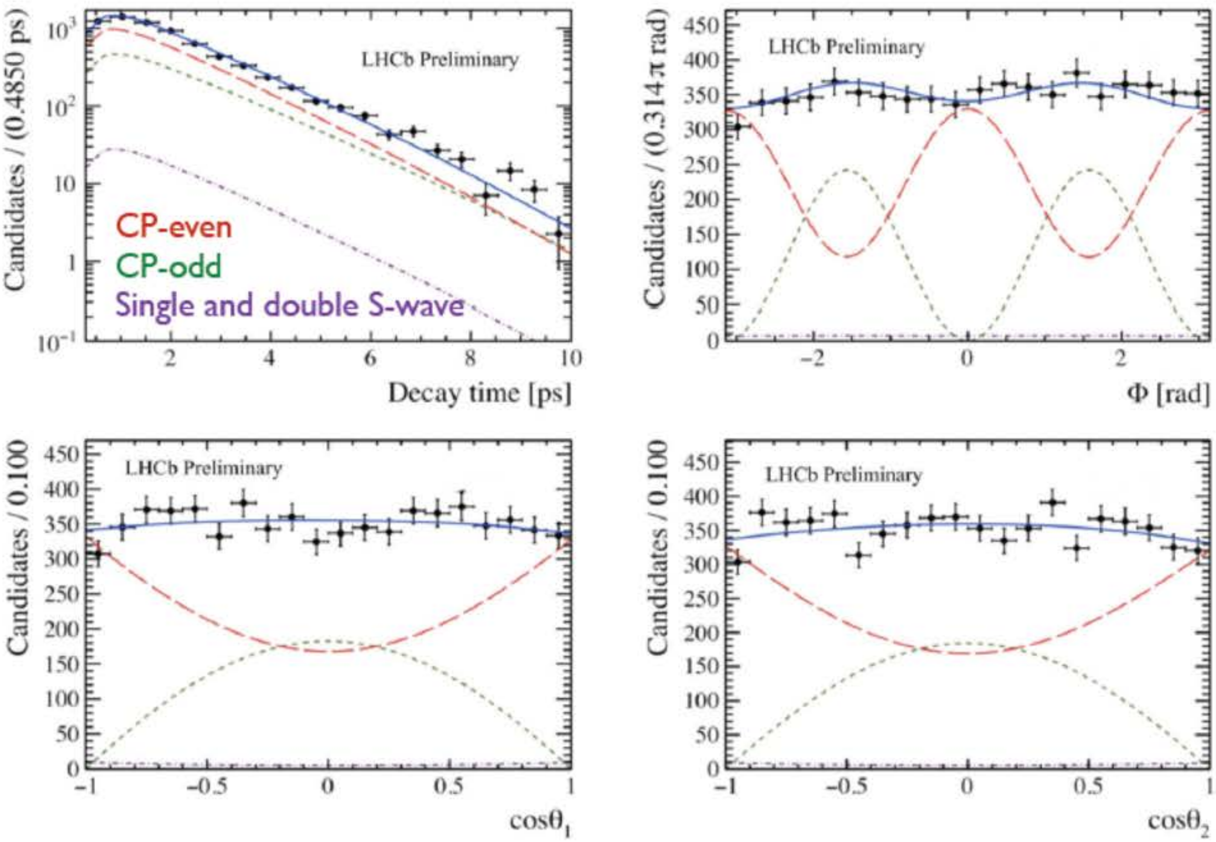
- Fundamental tasks
  - Identify new symmetries (and their breaking) beyond the SM
  - Probe mass scales not accessible directly at a collider like LHC

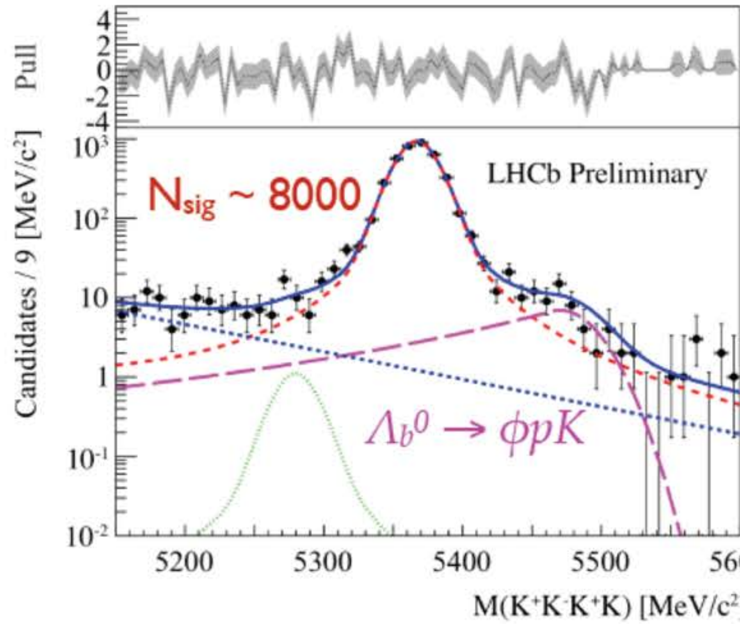
Other ϕ_s's cont'd

$\phi_s^{s\bar{s}}$ from $B_s^0 \to \phi\phi \to (K^+K^-)(K^+K^-)$

[LHCb-CONF-2018-001]

2011-2016 dataset





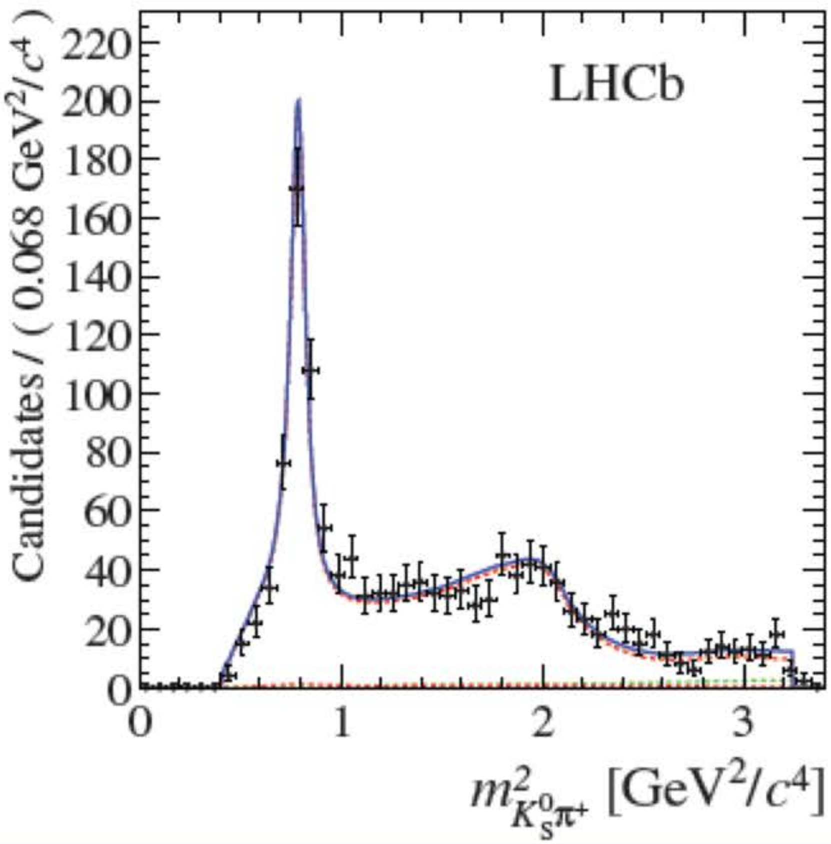
$$\phi_s^{s\bar{s}} = -0.07 \pm 0.13 \pm 0.03 \text{ rad}$$
$$|\lambda| = +1.02 \pm 0.05 \pm 0.03$$

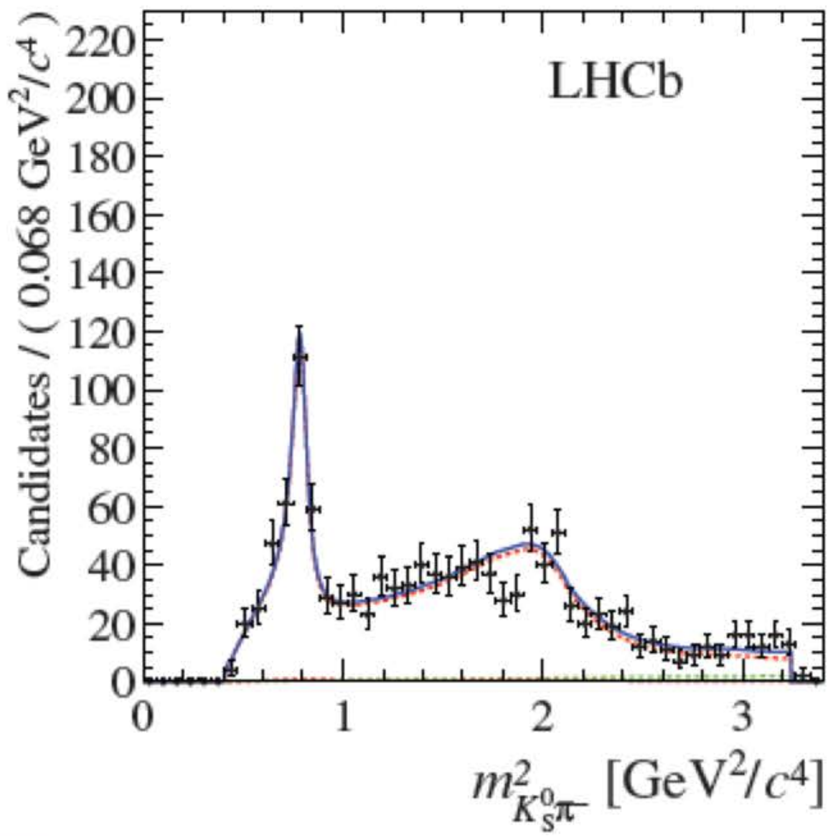
Dominant uncertainty from knowledge mass shape and angular/time efficiency from simulation/control samples

TPAs
$$A_U = 0.000 \pm 0.012\,(\text{stat}) \pm 0.004\,(\text{syst})$$
$$A_V = -0.003 \pm 0.012\,(\text{stat}) \pm 0.004\,(\text{syst})$$

Dalitz analysis of $B^0 \rightarrow K_S\pi^+\pi^-$

arXiv:1712.09320, LHCb-PAPER-2017-033, submitted to PRL





$\mathcal{A}_{CP}(K^*(892)^-\pi^+) = -0.308 \pm 0.060 \pm 0.011 \pm 0.012$

$\mathcal{A}_{CP}((K\pi)_0^-\pi^+) = -0.032 \pm 0.047 \pm 0.016 \pm 0.027$

$\mathcal{A}_{CP}(K_2^*(1430)^-\pi^+) = -0.29 \pm 0.22 \pm 0.09 \pm 0.03$

$\mathcal{A}_{CP}(K^*(1680)^-\pi^+) = -0.07 \pm 0.13 \pm 0.02 \pm 0.03$

$\mathcal{A}_{CP}(f_0(980)K_S^0) = 0.28 \pm 0.27 \pm 0.05 \pm 0.14$

First observation of *CP* violation in $B^0 \rightarrow K^*(892)\pi$ with ~ 6 sigma

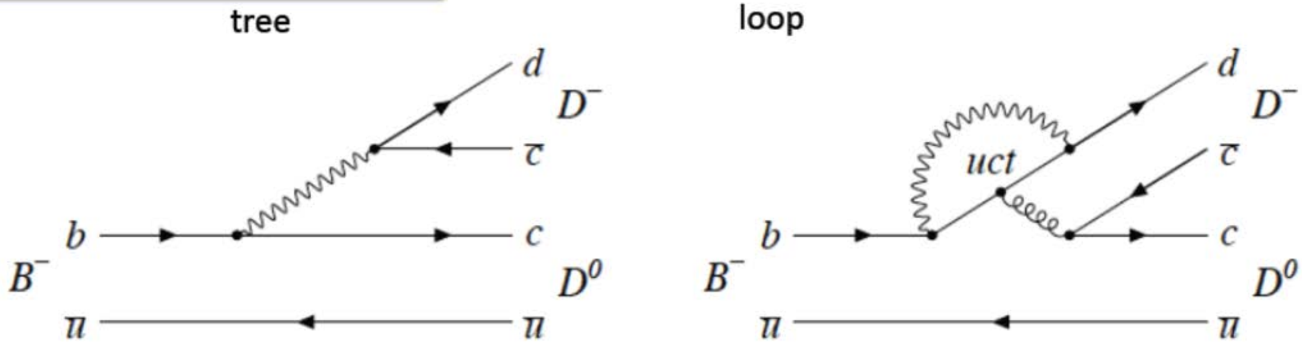
Previous world average

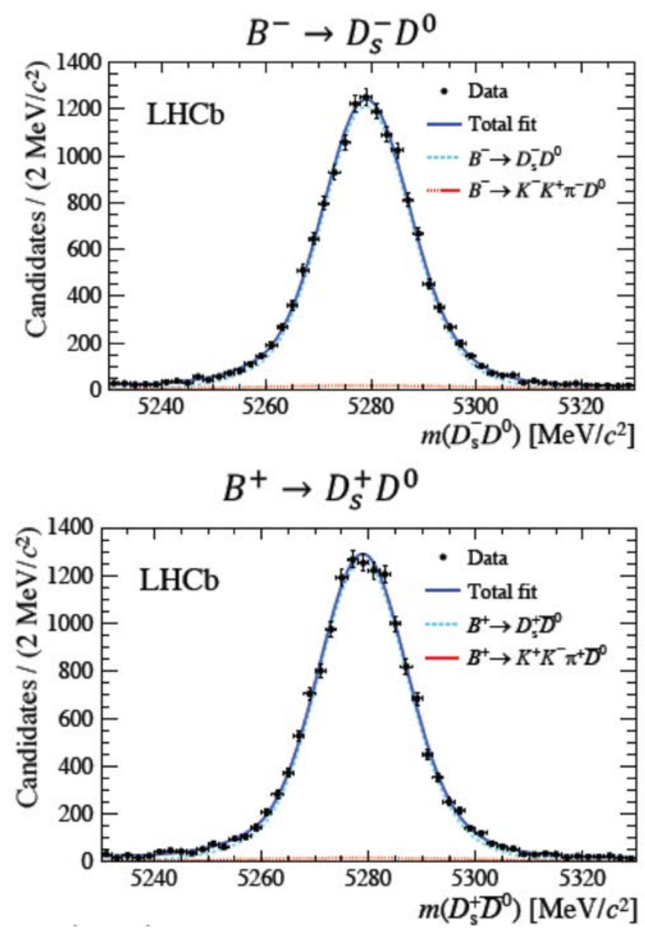
$\mathcal{A}(K^*(892)\pi) = -0.23 \pm 0.06$

R. Coutinho

B decays to two charm mesons

LHCb-PAPER-2018-007
Run I – $\mathcal{L}$=3fb^{-1}





- Loop level diagram expected to be suppressed
- Isospin symmetry relates $\bar{B}^0 \to D^+ D^-$, $\bar{B}^0 \to D^0 \bar{D}^0$, and $B^- \to D^- D^0$

$$\mathcal{A}^{CP}(B^- \to D_s^- D^0) = (-0.4 \pm 0.5 \pm 0.5)\%$$

First measurement ever

$$\mathcal{A}^{CP}(B^- \to D^- D^0) = (\ \ 2.3 \pm 2.7 \pm 0.4)\%$$

M. Artuso

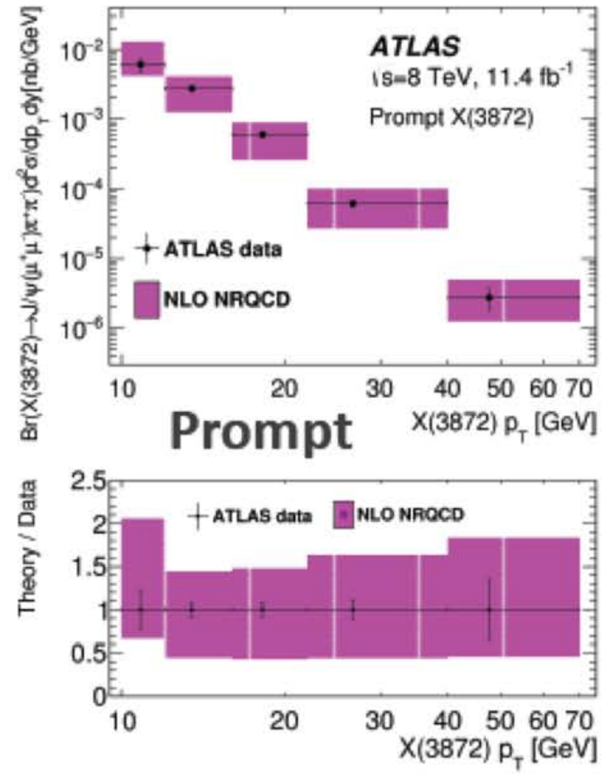
X(3872) cross sections

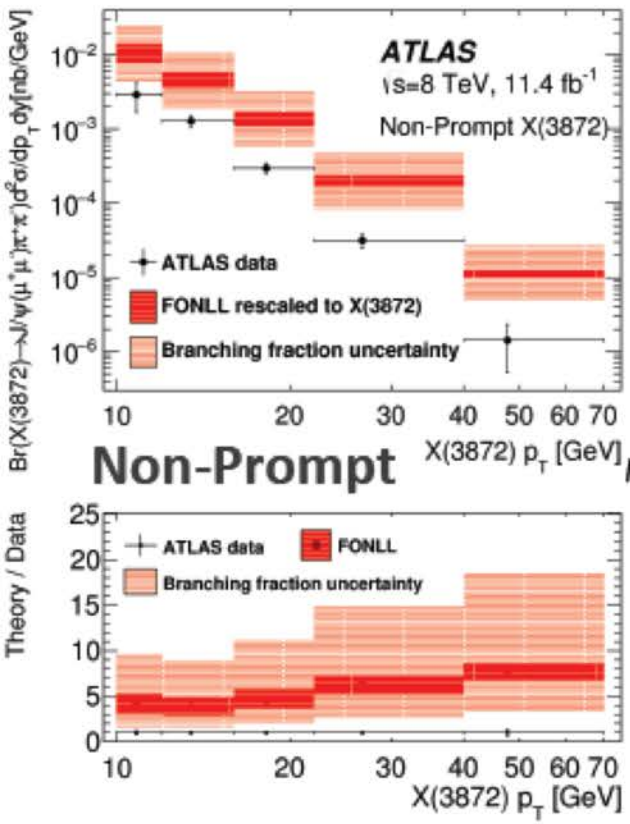
Prompt: **Described well by NLO NRQCD**

assumes X(3872) is a mix $\chi_{c1}(2P)$ - ($D^0 D^{0*}$)

$\chi_{c1}(2P)$ dominant using production parameters fitted to CMS data

not surprising, CMS and ATLAS consistent





Non prompt:

use the fitted kinematic template to recalculate from FONLL $\psi(2S)$ prediction

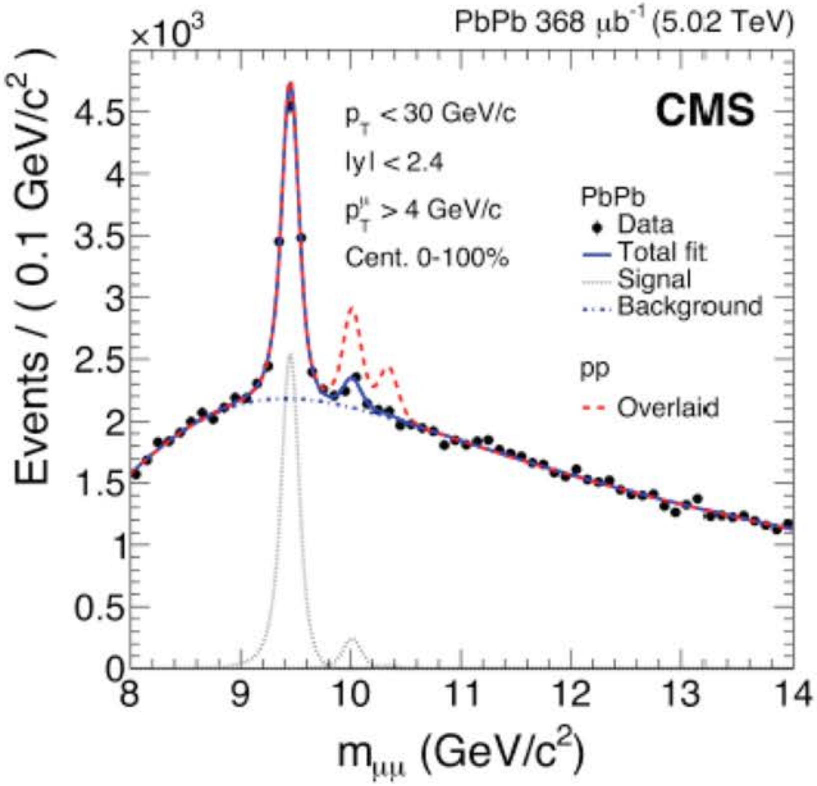
BR not measured – used estimate from Artoisenet, Braaten based on Tevatron data [hep-ph:0911.2016]

$$R_B = \frac{Br(B \to X(3872))Br(X(3872) \to J/\psi\pi^+\pi^-)}{Br(B \to \psi(2S))Br(\psi(2S) \to J/\psi\pi^+\pi^-)} = 18 \pm 8\,\%$$

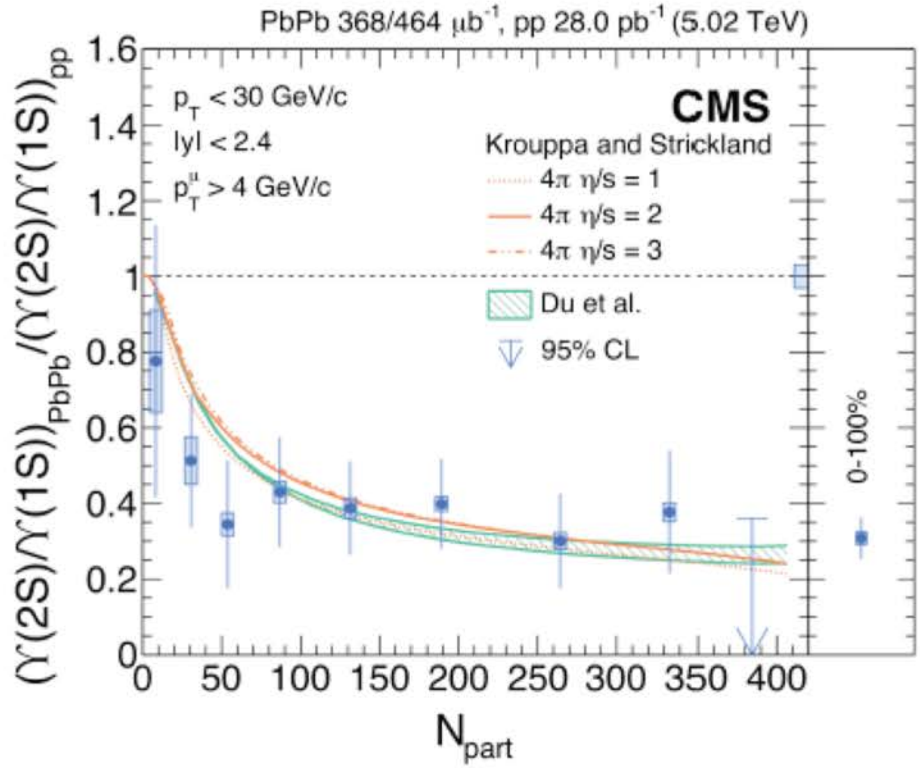
Clearly overshoots the data: factor of 4 to 8, increasing with pT

R. Jones

Upsilon sequential dissociation



PRL 120 (2018) 142301



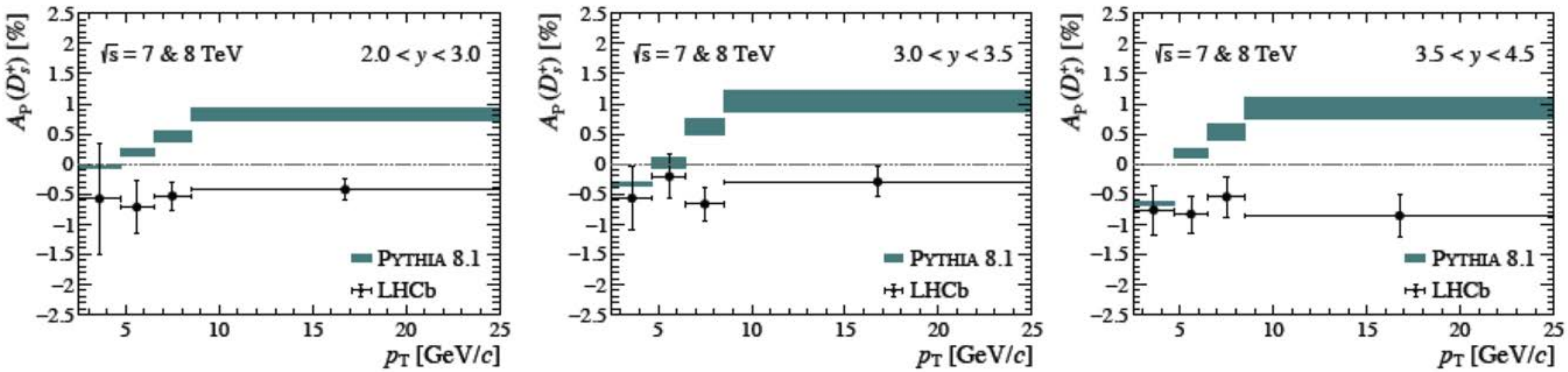
- double ratio measured to be less than 0.26 at 95% CL for the Υ(3S)
- no p_T dependence for the Υ(2S) double ratio

G. Bruno

Production asymmetry of D_s mesons

- Pythia simulation shows a strong dependence on both p_T and y, that is not observed in data

LHCb-PAPER-2018-010



- Results obtained in this analysis can be used to tune production models for various event generators
- Averaging in the range $2.5 < p_T(\mathrm{GeV}/c) < 25$ and $2.0 < y < 4.5$ the D_s^+ production asymmetry is found to be

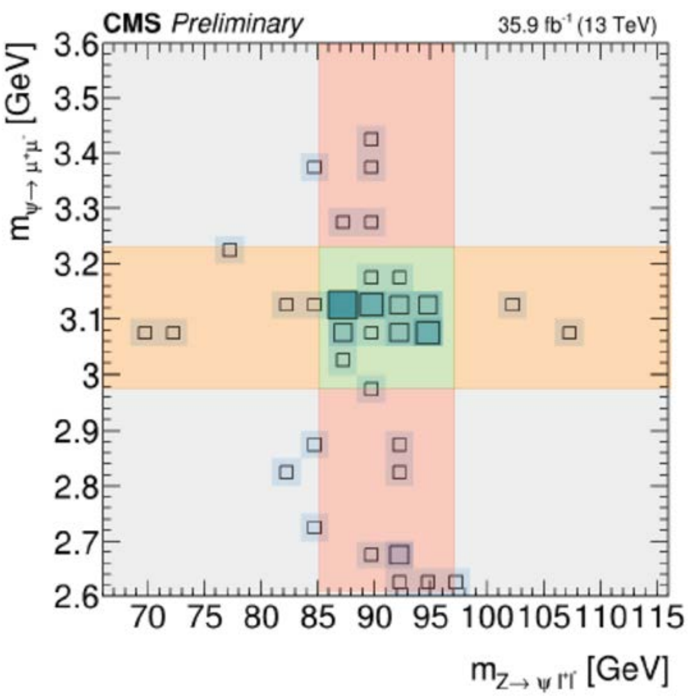
$$A_P(D_s^+) = \big(-0.52 \pm 0.13\ (\mathrm{stat}) \pm 0.10(\mathrm{syst})\big)\%$$

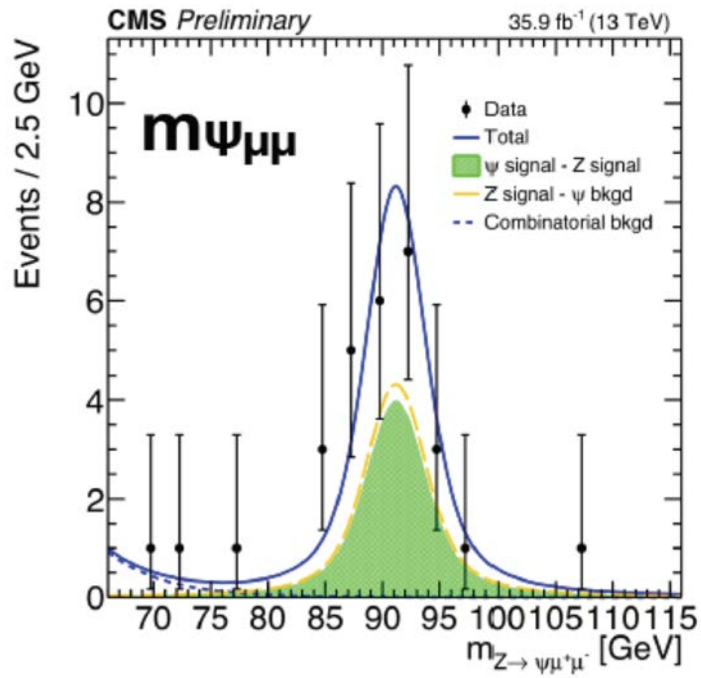
- Evidence for nonzero asymmetry at 3.3σ level
- No dependence on kinematics observed

F. Ferrari

Rare Z decays

- CMS reports the first observation of the rare $Z \to J/\Psi \ell\ell$ decay with 5.7σ significance
- $B[Z \to J/\Psi \ell\ell]/B[Z \to \mu\mu\mu\mu] = 0.70 \pm 0.18 \pm 0.05$
  - In agreement with theory





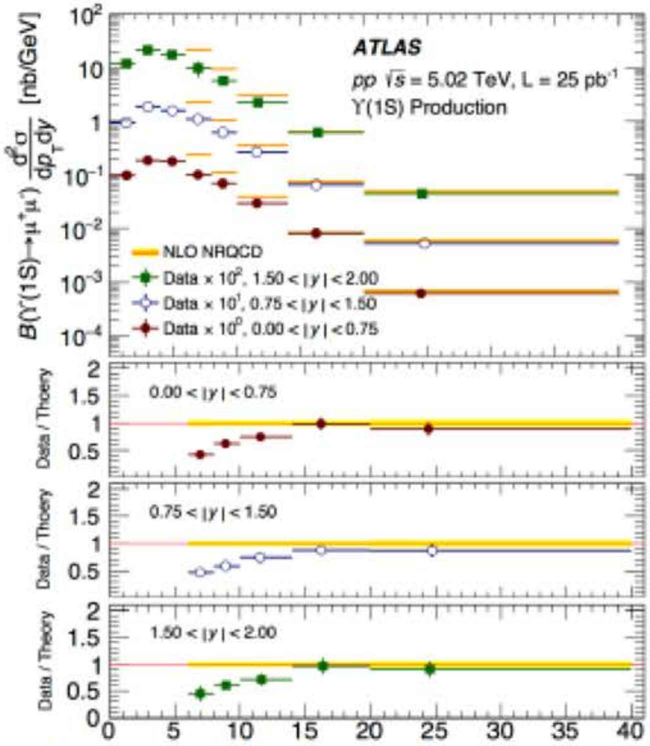
R. Manzoni

$B(Z \to J/\Psi \ell\ell) \approx 8 \cdot 10^{-7}$ assuming $B(Z \to \mu\mu\mu\mu)$ from PDG

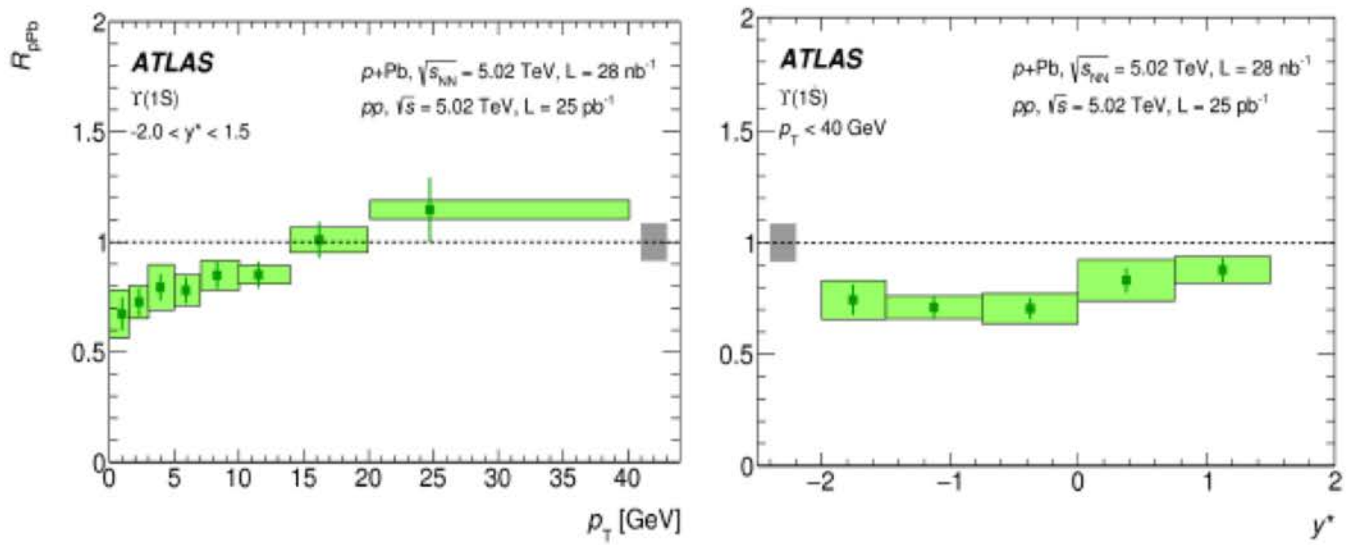
Quarkonium Production in p+Pb: Results

EPJC 78 (2018) 171

- Prompt charmonium production in p_T 8-40 GeV x-section compatible with NRQCD, bottomonium only at $p_T > 15$ GeV
- Non-prompt charmonium consistent with FONLL calculations
- R-factors of prompt and non-prompt J/ψ consistent with unity (no p_T and y* dependence)
  - Weak modification of J/ψ production due to CNM effects
- R-factors of ϒ(1S) below 1 at $p_T < 15$ GeV, compatible with 1 above; no y* dependence
  - Nuclear parton distribution functions modified relative to of nucleon (nPDF shadowing)



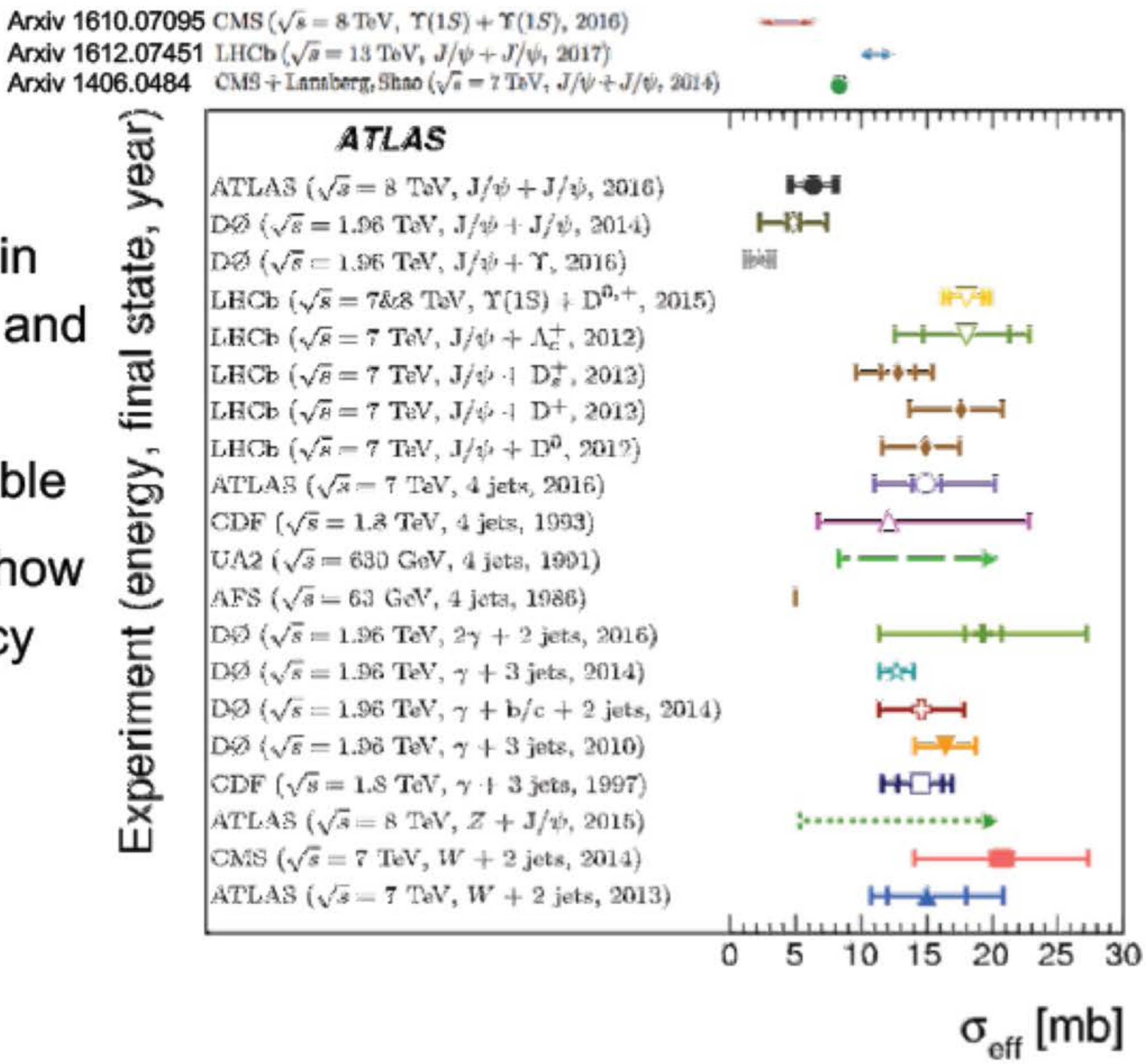
probes smaller Bjorken-x region



P. Řezníček

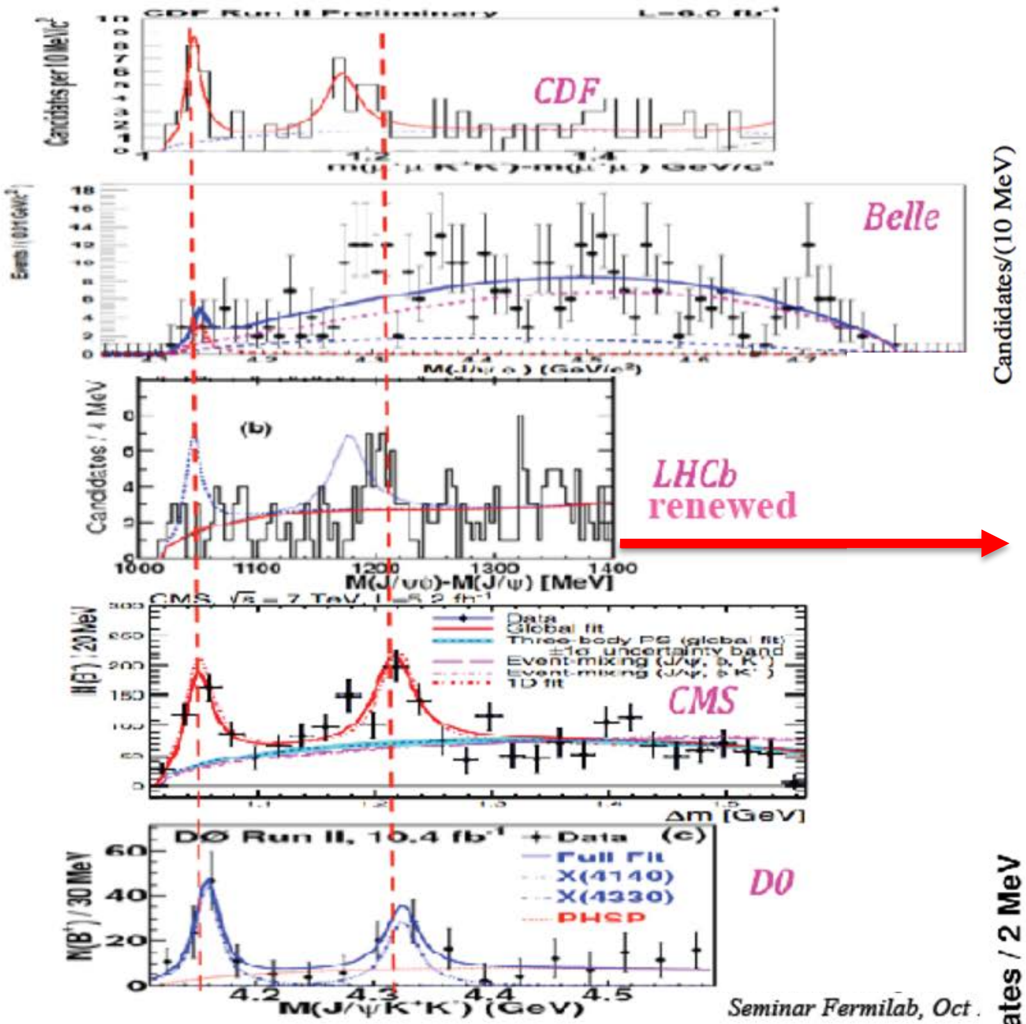
Associated production in ATLAS

- LHC fertile ground for associated production measurements
- ATLAS measures effects in Wjj, jjjj, Z and W plus J/ψ and di-J/ψ
- DPS visible and measurable
- σ_{eff} measurements may show some process dependency
- More measurements to come:
    - Run 2 data for W+J/ψ
    - DPS in ZZ

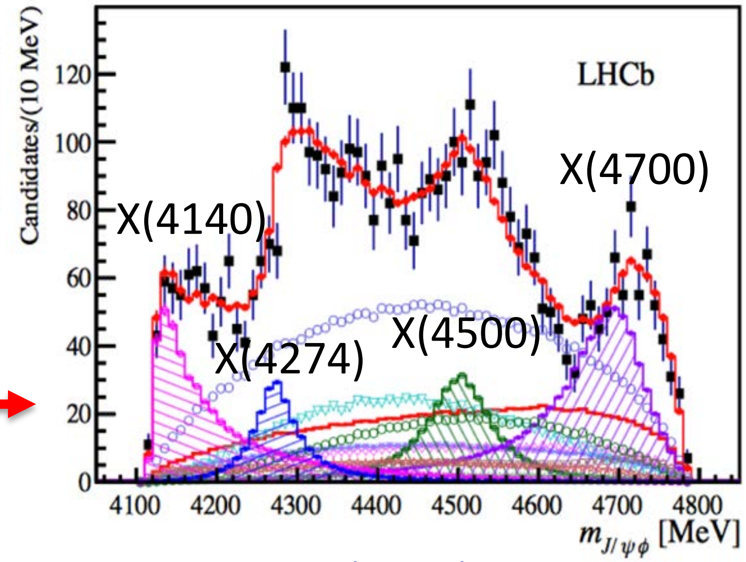


A. Cerri

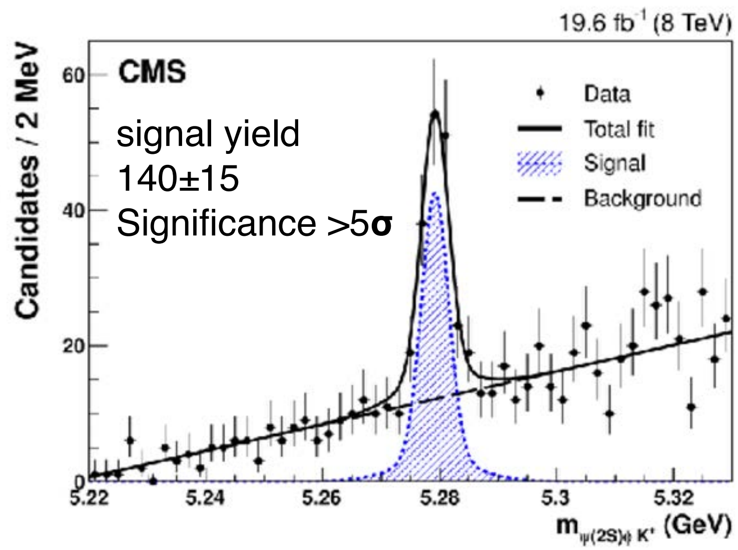
Observation of $B^+ \to \psi(2S)\phi K^+$



First amplitude analysis from LHCb confirms the particle(s)



PRL 118 (2017) 022003



PLB 764 (2017) 66

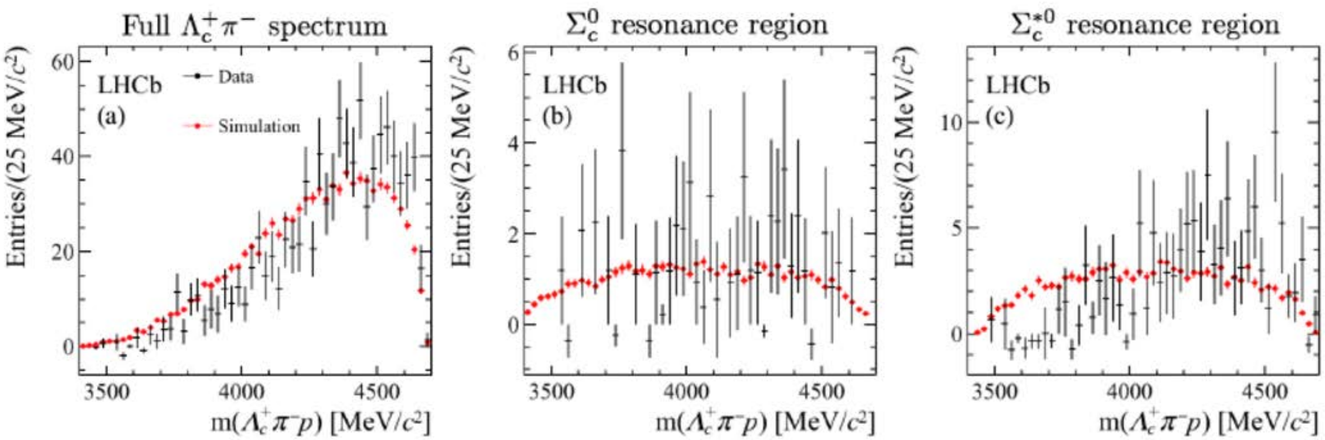
- Although, there is no resonance search (yet) in the ψ(2S)ϕ mass scale, the observation of B+ → ψ(2S)ϕK+ offers future opportunities in searches for resonances in the ψ(2S)ϕ mass spectrum.

O. Ozludil

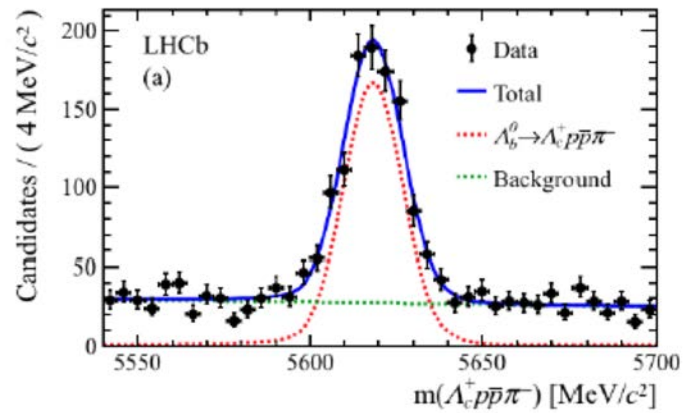
Search for dibaryons

Observation of $\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-$ decays

[arXiv:1804.09617]

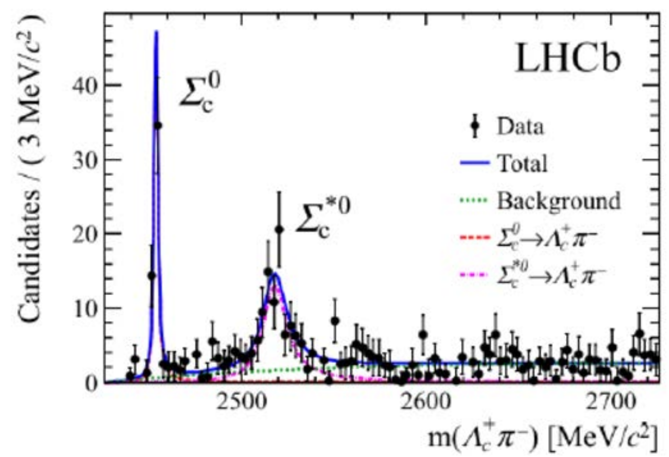


$N_{\Lambda_b^0 \to \Lambda_c^+ p\bar{p}\pi^-} = 926 \pm 43$



Resonance structures in $\Lambda_c^+\pi^-$

$N_{\Lambda_b^0 \to \Sigma_c^0 p\bar{p}} = 59 \pm 10$, $N_{\Lambda_b^0 \to \Sigma_c^{*0} p\bar{p}} = 104 \pm 17$

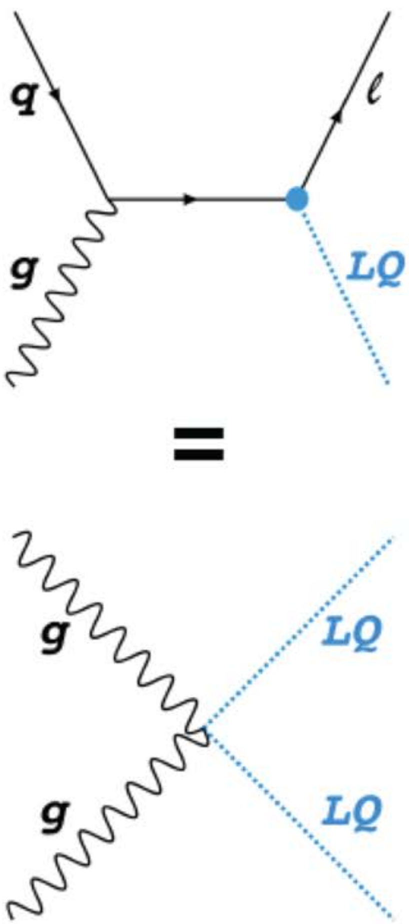


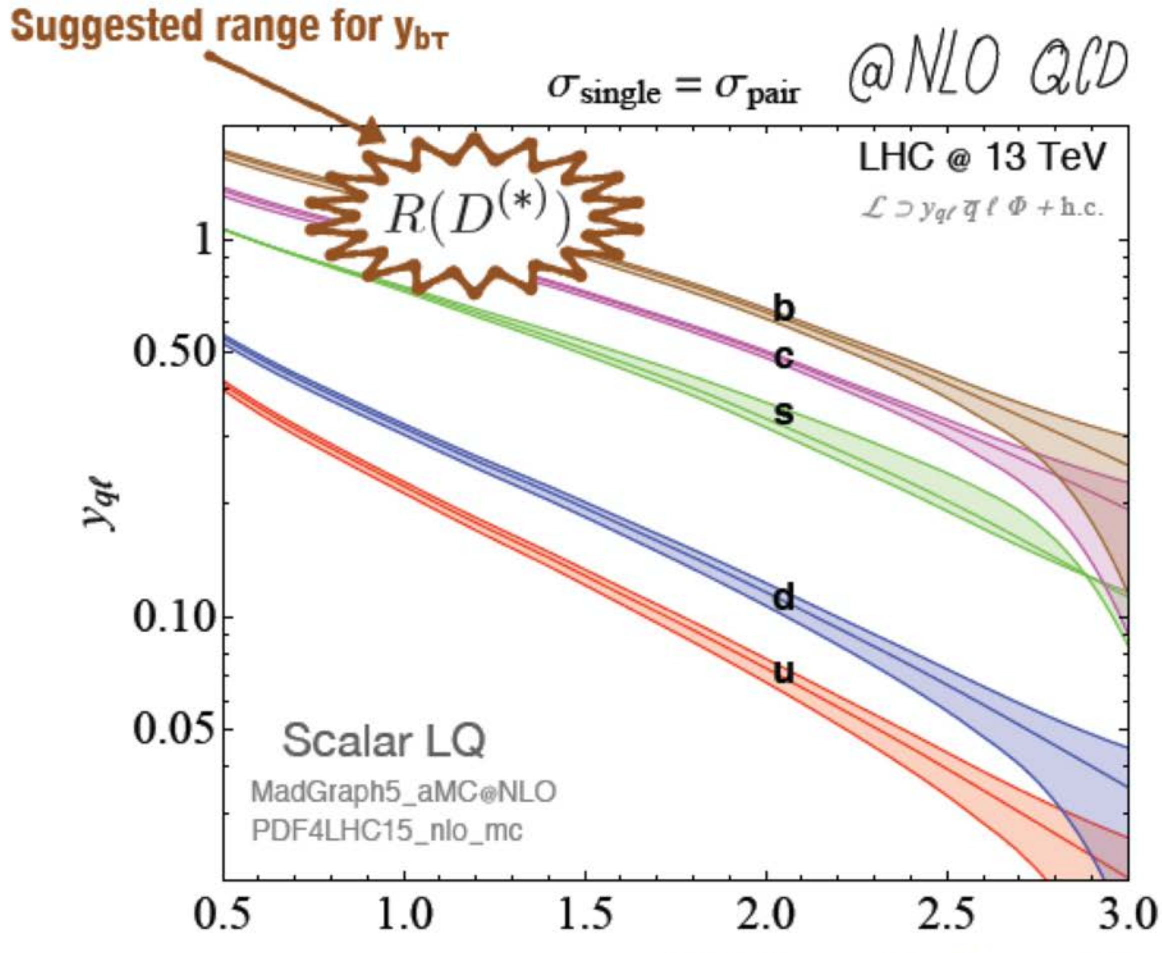
- background-subtracted data using the sPlot technique
- **no peak structures are observed**
- the two dimensional distribution of $m_{\Lambda_c^+\pi^- p}$ versus $m_{\Lambda_c^+\pi^-}$ does not exhibit any clear structure

G. Cavallero

Flavour at high p_T

LQ toolbox





[Doršner, AG] 1801.07641

LQ MC tool at NLO QCD:
http://lqnlo.hepforge.org

A. Greljo

Fundamental Composite Higgs

Theorists avoid fundamental scalars. Then flavour becomes tasteless: composite Higgs studied in effective theories that don't tell what H is made of.

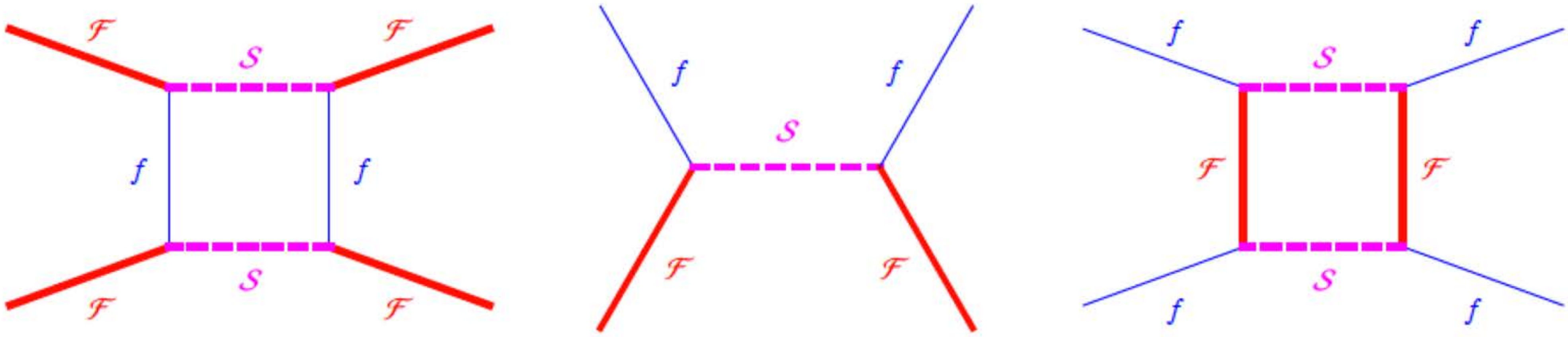
Here: fundamental theory written adding fundamental techni-scalars. Theory:

$$(\text{SM without } H) +$$

$$+ \,(\text{extra } G_{\text{TC}} = \text{SU}(N) \text{ or } \text{SO}(N) \text{ or } \text{Sp}(N) \text{ strong at } \Lambda_{\text{TC}}) +$$

+ (vector-like TCfermions $\mathcal{F}$) + (TCscalars $\mathcal{S}$) + Yukawa couplings such that

(each SM fermion $f = L, E, Q, U, D$)×(some TC scalar $\mathcal{S}$)×(some TC fermion $\mathcal{F}$)



Higgs potential
$\mathcal{F}^4 \sim H^2$

SM fermion masses
$ff\mathcal{F}\mathcal{F} \sim ffH$

Flavour violations
f^4

A. Strumia

$B \to \ell^+\ell^-$ decays

- Rare decays $B_s^0 \to \ell^+\ell^-$ for $\ell = \mu, \tau, e$:

  Theoretically very clean, QCD information only in f_q with $\mathcal{O}(2\%)$ precision.

  Ideal to search for NP effects from scalar and pseudo-scalar particles.

  Also sensitive to vector-like particles Z', ...

- $\overline{\mathcal{B}}(B_s^0 \to e^+e^-)$ forgotten by the High Energy Physics community.

  In the SM $\overline{\mathcal{B}}(B_s^0 \to e^+e^-) \propto m_e^2$ extremely suppressed (helicity suppression).

  Helicity suppression can be lifted by NP scalar and pseudoscalar particles.

- $\overline{\mathcal{B}}(B_s^0 \to \mu^+\mu^-)$ has been measured by LHCb and CMS.

- $B_s^0 \Leftrightarrow \bar{B}_s^0$ mixing gives access to the observable $\mathcal{A}_{\Delta\Gamma_s}^{\mu\mu}$.

- First pioneering determination of $\mathcal{A}_{\Delta\Gamma_s}^{\mu\mu}$ by LHCb.

G. Tetlalmatzi

$B \to \ell^+\ell^-$ decays

- Using the Universal New Physics Scenario (lepton flavour independent) we have mapped out NP bounds from $\overline{\mathcal{B}}(B_s^0 \to \mu^+\mu^-)$ on

  $B_d \to \mu^+\mu^-$ $\Rightarrow$ small suppression in $\mathcal{B}(B_d \to \mu^+\mu^-)$ respect to the SM.

  $B_{s,d} \to \tau^+\tau^-$ $\Rightarrow$ NP effects are suppressed by m_μ/m_τ in $\mathcal{B}(B_{s,d} \to \tau^+\tau^-)$.

  $B_{s,d} \to e^+e^-$ $\Rightarrow$ potential enhancement of NP effects due to m_μ/m_e in $\mathcal{B}(B_{s,d} \to e^+e^-)$.

  $\Longrightarrow$ Search for $B_{s,d} \to e^+e^-$ at the LHC, a measurement would imply NP!

- Processes $B_{s,d} \to \ell^+\ell^-$ can unveil the presence of NP sources of CP violation.

  This entails the interplay of the CP asymmetries: $\mathcal{A}^{\mu\mu}_{\Delta\Gamma_s}$, $\mathcal{S}_{\mu\mu}$ and $\mathcal{C}_{\mu\mu}$.

  $\Longrightarrow$ Improve the measurement of $\mathcal{A}^{\mu\mu}_{\Delta\Gamma_s}$, paramount in the search for NP phases.

Missing energy *B* decays at Belle II

- Unique capabilities of Belle II to study **B decays with missing energy in the final state**

- Within the first **two years of data taking** Belle II will collect **5 to 10 ab^{-1}** and will be able to
  - address the Lepton Flavour Universality Violation by precisely measuring **R(D) / R(D*)**
  - address the **$|V_{ub}|$ puzzle** from inclusive and exclusive semileptonic decays

- Discovery potential also in rare processes suppressed in the SM ($B \to \tau\nu$, $B \to l\nu\gamma$, $B \to K^{(*)}\nu\nu$, $B \to \mu\nu$, $B \to \nu\nu$)

M. Merola

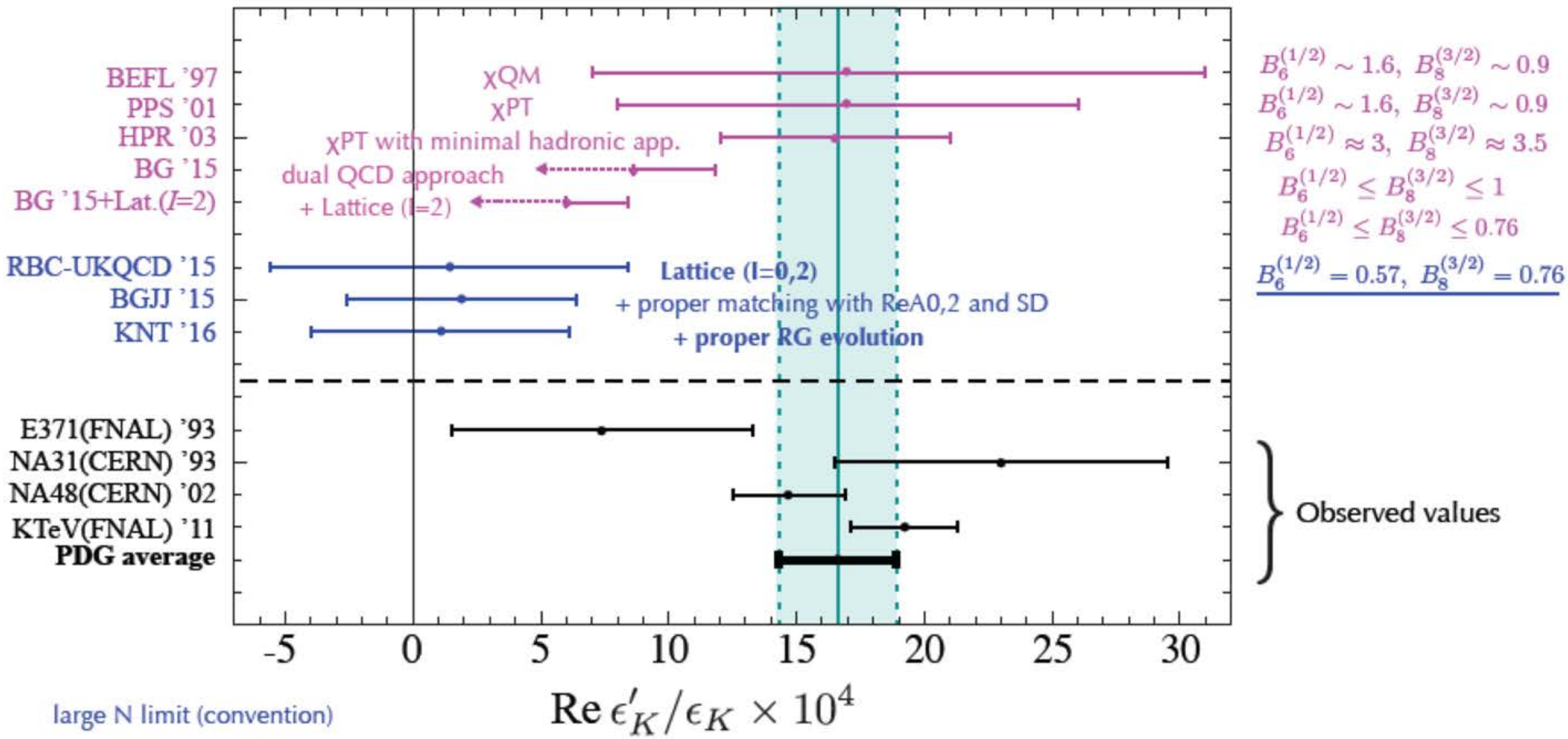
LHCb charm harvest

	Direct CPV	Mixing + indirect CPV
Two-body	**$\Delta A_{CP}(D^0 \to hh)$ and $A_{CP}(hh)$:** PRL 108 (2012) 111602 PLB 723 (2013) 33 JHEP 07 (2014) 041 PRL 116 (2016) 191601 PLB 767 (2017) 177 **$D_{(s)}^+ \to \eta' \pi^+$** PLB 771 (2017) 21 **$D^0 \to K_S^0 K_S^0$** JHEP 10 (2015) 055 **$D_{(s)}^+ \to K_S^0 h^+$** JHEP 06 (2013) 112 JHEP 10 (2014) 025	**$A_\Gamma(D^0 \to hh)$:** JHEP 1204 (2012) 129 (KK), **+y_{CP}** PRL 112 (2014) 041801 JHEP 04 (2015) 043 PRL 118 (2017) 261803 **WS $D^0 \to K^+\pi^-$:** PRL 110 (2013) 101802 – 1st SE Obs PRL 111 (2013) 251801 PRD 95 (2017) 052004 PRD 97 (2018) 031101
Multibody	**$D^0 \to \pi^+\pi^-\pi^0$** PLB 740 (2015) 158 **$D^+ \to K^-K^+\pi^+$** PRD 84 (2011) 112008 JHEP 06 (2013) 112 **$D^0 \to K^-K^+\pi^-\pi^+, \pi^-\pi^+\pi^-\pi^+$:** PLB 726 (2013) 623 ($S_{CP}$) JHEP 10 (2014) 005 (T-odd) PLB 769 (2017) 345 (energy test) **$D^+ \to \pi^+\pi^-\pi^+$:** PLB 728 (2014) 585 **$\Lambda_c^+ \to p h^+ h^-$** JHEP 03 (2018) 182	**$D^0 \to K_S^0\pi^+\pi^-$** JHEP 04 (2016) 033 (model-indep) **$D^0 \to K^-\pi^+\pi^-\pi^+$** PRL 116 (2016) 241801 https://lhcbproject.web.cern.ch/lhcbproject/Publications/p/LHCb-PAPER-2015-057.html

M. Williams

Another anomaly popping up from the kaon sector?

Current situation of $\epsilon'_K/\epsilon_K \propto \mathrm{Im}A_0 - \left(\frac{\mathrm{Re}A_0}{\mathrm{Re}A_2}\right)\mathrm{Im}A_2$



large N limit (convention)

$$B_6^{(1/2)} = B_8^{(3/2)} = 1$$

dual QCD prediction

$$B_6^{(1/2)} \leq B_8^{(3/2)} < 1,\ B_8^{(3/2)} = 0.8$$

	Exp.	χPT	dual QCD	Lattice (I=0,2)
$\left(\frac{\mathrm{Re}A_0}{\mathrm{Re}A_2}\right)$	22.45 ± 0.05	~ 14	16.0 ± 1.5	31.0 ± 11.1

G. D'Ambrosio