Introduction

- **The spirit of the Filtration Plant**
- **Run II**
- **A few highlights from LHCb**

On behalf of the LHCb collaboration

03/11/2015 — Implications Workshop

Patrick Koppenburg

Fog

Welcome

Welcome to our theorist friends and LHCb colleagues
for this Vth edition of the LHCb Implications Workshop

On behalf of the organising committee

John Ellis, Tim Gershon, Gino Isidori, Patrick Koppenburg, Gilad Perez, Frederic Teubert, Vincenzo Vagnoni, Andreas Weiler

and the stream conveners (who did the actual work)

Marcin Chrzaszcz, Justine Serrano, Wolfgang Altmannshofer, Evelina Mihova Gersabeck, Stefano Perazzini, Joachim Brod, Xabier Cid Vidal, Stephen Farry, Emmanuel Stamou, Sascha Stahl, Gregory Ciezarek, Aoife Bharucha

And many thanks to everyone, speakers and attendees.
Let's make this an enjoyable experience.

Purpose of the Workshop

- Follow on from successful previous workshops, Nov.10-11, 2011, Apr.16-18, 2012, Oct. 14–16, 2013, Oct 15–17 2014.
- discuss latest results and more ideas of exploitation of Run I dataset
- Develop new ideas for future analysis
  - Ideas for Run II.
    - ➜ **2015 is a test/commissioning year (but with some great physics). There's Still time to add ideas for 2016.**
  - Ideas for Run III and the LHCb upgrade

Beyond the workshop

- We like a close collaboration with the theory community.
- If you have an idea, feel free to contact us to check its feasibility.
- And/or show it in one of our physics working group meetings.

The spirit of the Filtration Plant

We will show a few results for the first time

➜ The agenda is open to the world (except two talks). If you are uncomfortable with that let me know. We can protect some slides.

✗ The room is not open to everyone.

➜ We will be a bit more open about prospects than we would at EPS-HEP.

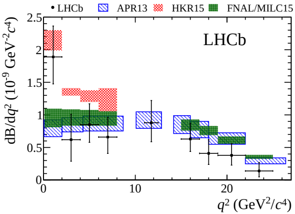
We want to discuss!

- Talks should be triggering fruitful discuss rather than transmit a lot of data

➜ Timing will have to be respected

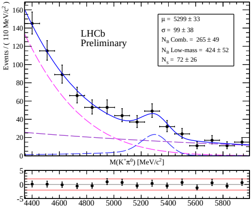
- I'll try to show the example by being shorter than my allocated time

LHCb Jargon



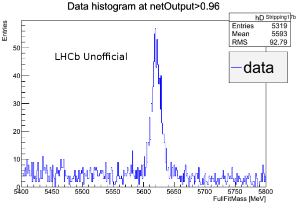
$B^+ \to \pi^+\mu^+\mu^-$

[arXiv:1509.00414]



$B^+ \to K^+\pi^0$

[LHCb-CONF-2015-001]



$\Lambda_b^0 \to J/\psi\, p\pi^-$ from my summer student

LHCb: Material from a paper submitted to arxiv

LHCb Preliminary: Preliminary material either from a conference note (on CDS) or from a paper about to be submitted

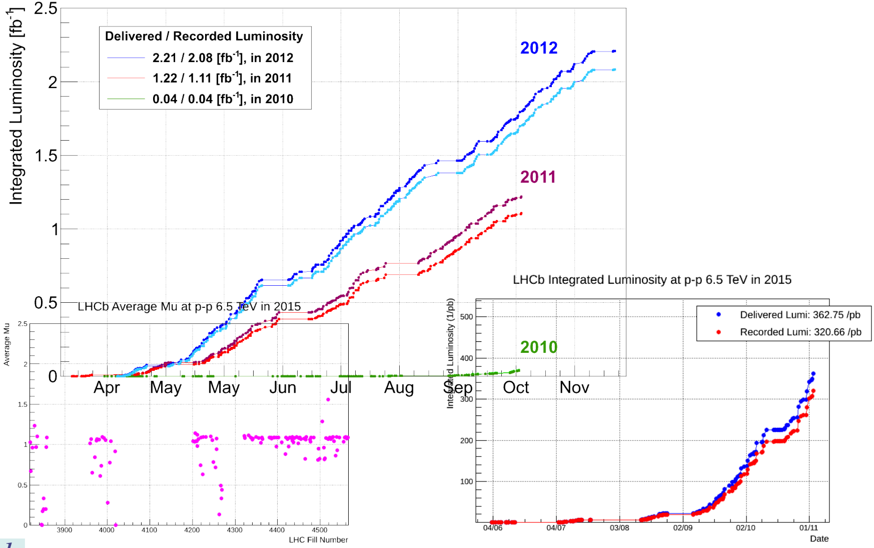
➜ Cite CONF or PAPER

LHCb Unofficial: Work in progress.

➜ Do not cite. Contact me in case of doubt.

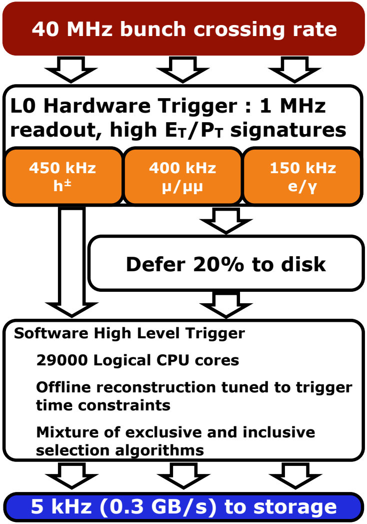
Run 2

Run 1 and Run 2

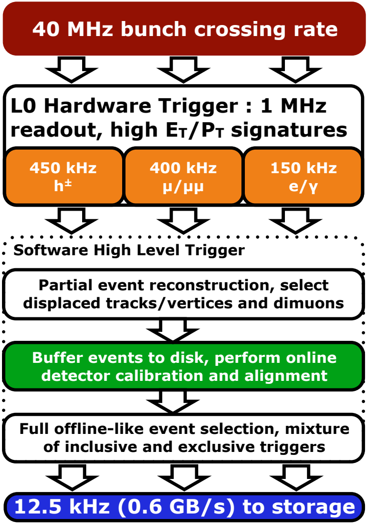


LHCb Trigger in Run II

LHCb 2012 Trigger Diagram

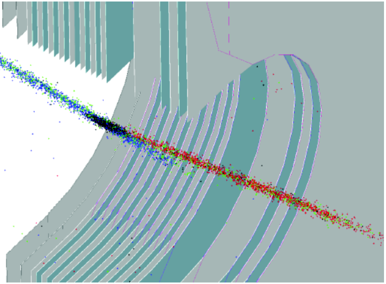


LHCb 2015 Trigger Diagram



13 TeV Luminosity

$$\mu^{\text{ref}} = \sigma^{\text{ref}} \times \overbrace{\underbrace{N_1 N_2}_{\text{Bunch intensity}} \times \text{Overlap}}^{\mathcal{L}}$$



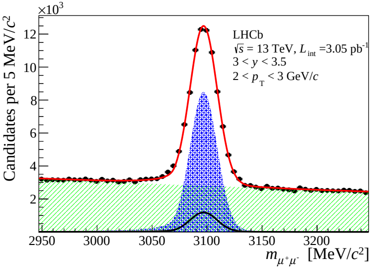
- μ^{ref} is the average number of interactions per crossing
- N_i are the bunch intensities from Direct Current Current Transformers (DCCT) and Fast Beam Current Transformer (FBCT)
- The Overlap is determined from beam gas imaging (BGI)

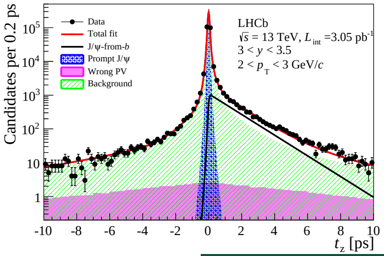
$$\sigma^{\text{ref}}_{13\ \text{TeV}} = 64.2 \pm 2.5\,\text{mb}\ (3.9\%)$$ [arXiv:1509.00771]

$$\sigma^{\text{ref}}_{8\ \text{TeV}} = 62.7 \pm 0.7\,\text{mb}\ (1.1\%)$$ [JINST 9 (2014) P12005]

The larger uncert

J/ψ cross section at $\sqrt{s} = 13$ TeV



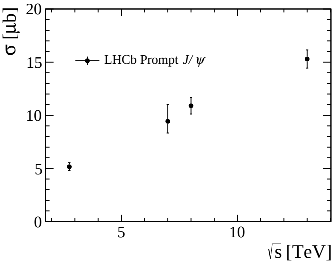


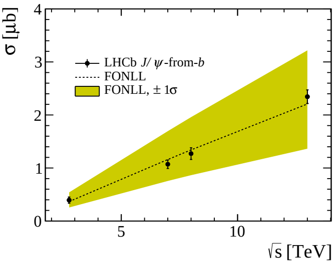
- The trigger found 10^6 $J/\psi \to \mu^+\mu^-$ in 3.02 ± 0.12 pb^{-1} with J/ψ $p_T < 14$ GeV$/c$ and $2 < y < 4.5$
- Analysis based on trigger candidates — No offline processing
  - Mass resolution of ~ 12 MeV$/c^2$, compatible with Run I data
- Data is binned in p_T and y and the pseudo decay time

$$t_z = \frac{(z_{J/\psi} - z_{PV}) M_{J/\psi}}{p_z}$$

is used to determine the fraction of J/ψ-from-b

J/ψ cross section at $\sqrt{s} = 13$ TeV





Double-differential cross-sections are determined in J/ψ $p_{\mathrm{T}} < 14$ GeV/c and $2 < y < 4.5$

Total cross-sections :

$$\sigma_{J/\psi}(\text{LHCb}) = 15.30 \pm 0.03 \pm 0.86\,\mu\text{b}$$

$$\sigma_{J/\psi/b}(\text{LHCb}) = 2.34 \pm 0.01 \pm 0.13\,\mu\text{b}$$

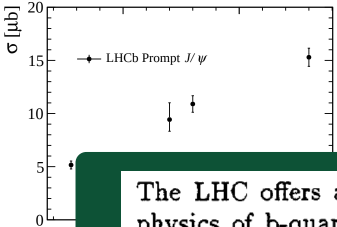
where the systematic uncertainty is dominated by the luminosity

Naively applying a factor 5.2 from Pythia:

$$\sigma_{b\bar{b}}(4\pi) = 515 \pm 2 \pm 53\,\mu\text{b}$$

where there's no uncertainty for the extrapolation

J/ψ cross section at $\sqrt{s} = 13$ TeV



Double-differential cross-sections are determined in J/ψ $p_{\mathrm{T}} < 14$ GeV/c and $2 < y < 4.5$

Total cross-sections :

.86 μb

.13 μb

s dom-

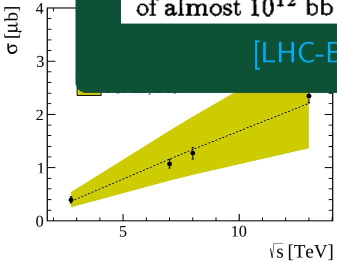
Pythia:

> The LHC offers a unique opportunity to study the physics of b-quarks. The expected $b\bar{b}$ production cross section of 500 μbarn leads to a production rate of almost 10^{12} $b\bar{b}$ per 10^7 second year already with a

[LHC-B Letter of Intent, 1995]

$$\sigma_{b\bar{b}}(4\pi) = 515 \pm 2 \pm 53\,\mu\mathrm{b}$$

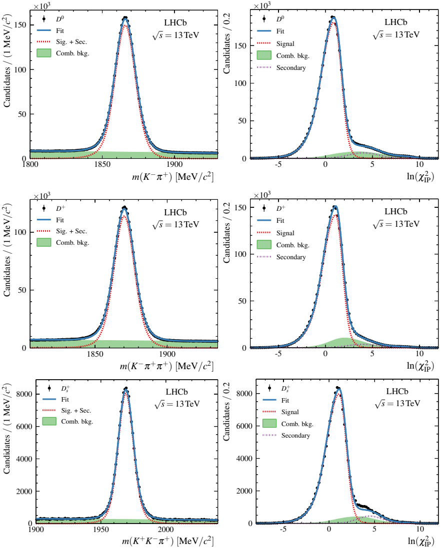
where there's no uncertainty for the extrapolation

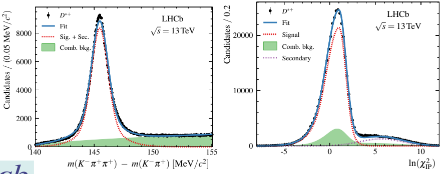


[LHCb, submitted to JHEP, arXiv:1510.01707]

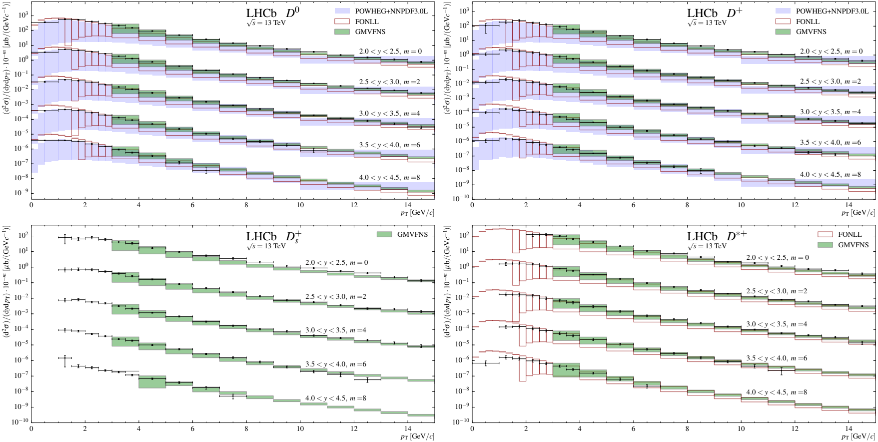
Prompt charm production at 13 TeV

- Using 5 pb^{-1} collected in July 2015 with minimum bias trigger (L0) and TURBO stream selection
- $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to \phi\pi^+$ and $D^{*+} \to D^0\pi^+$ used to measure cross-sections.
- $D^0 \to K^-\pi^+\pi^-\pi^+$, $D^+ \to K^-K^+\pi^+$ and $D_s^+ \to \overline{K}^{*0}K^+$ used as check.





Prompt charm production at 13 TeV



- Double-differential cross-sections determined and compared to theory [Gauld, Rojo, Rottoli, Talbert], [Cacciari, Mangano, Nason]. Generally, the data is on the high side of expectations

Prompt charm production at 13 TeV

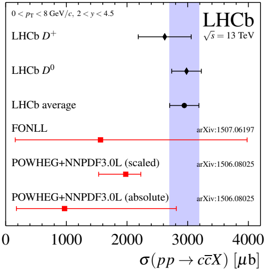
- Integrated cross-section are determined in fiducial range
- Hadronization fractions are used to determine the $c\bar{c}$ cross-section in $0 < p_{\mathrm{T}} < 8\ \mathrm{GeV}/c^2$ and $2 < y < 4.5$

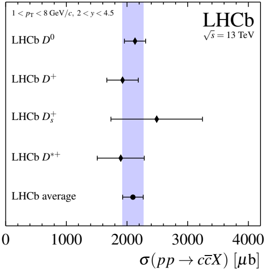
$$2.940 \pm 0.003 \pm 0.18 \pm 0.16\,\mathrm{mb}$$

where the last uncertainty is due to hadronization fractions.

- Value at 7 TeV: [Nucl. Phys. B871 (2013) 1]

$$1.419 \pm 0.012 \pm 0.116 \pm 0.065\,\mathrm{mb}$$





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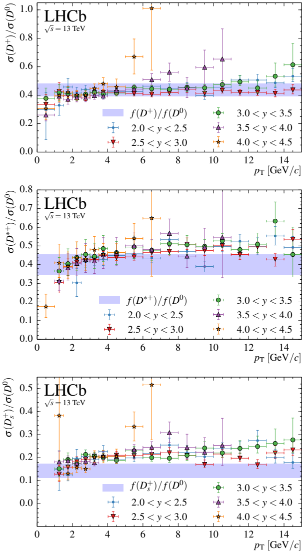
- Value at 7 TeV: [Nucl. Phys. B871 (2013) 1]

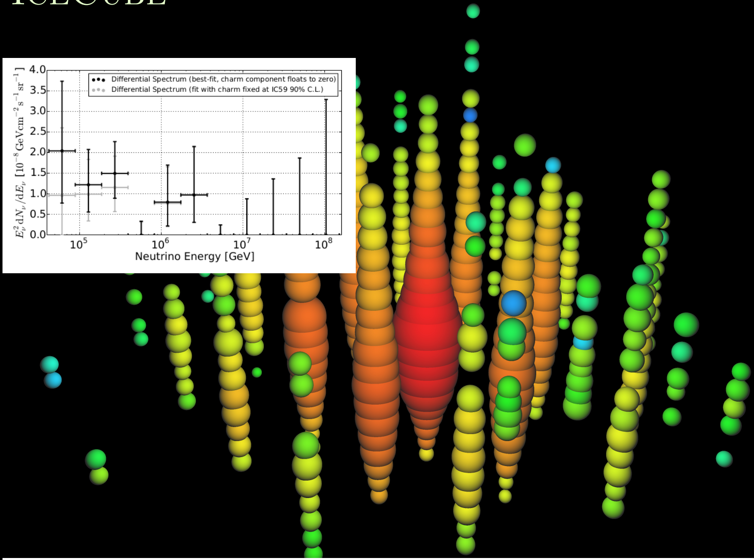
$$1.419 \pm 0.012 \pm 0.116 \pm 0.065\,\mathrm{mb}$$

- But the universality of hadronisation fractions is only an approximation



[Phys. Rev. Lett. 113, 101101 (2014)]

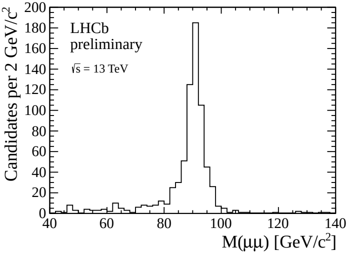
IceCube

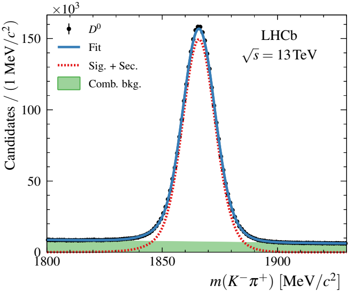


present measurements at $\sqrt{s} = 13\,\text{TeV}$ and these probe a new kinematic region, which corresponds to a primary cosmic ray energy of 90 PeV.

Run 2 yields

- The charm yields per pb^{-1} are considerably larger than in Run I
  - ➜ Largely thanks to the trigger
- The same applies for hadronic *b*-hadron decays
  - ➜ An improved Hlt2 compensates for tighter L0 cuts
- For *b*-hadron decays to dimuons we fully profit from the increased *b* production
- Prospects are even better for heavy objects, like Z, W, top, (Higgs?)





LHCb Trigger in Run III

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

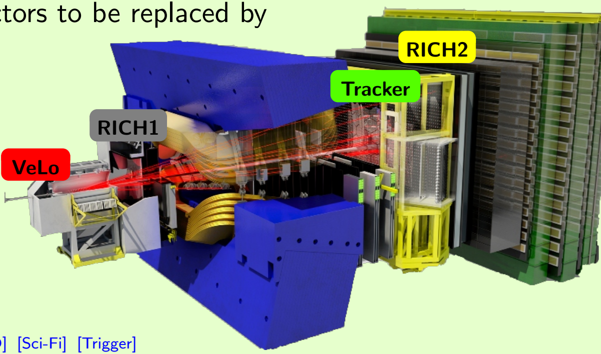
LHCb Upgrade

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

VELO: New pixel vertex detector

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

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

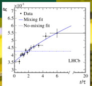


[Upgrade TDR] [Velo] [PID] [Sci-Fi] [Trigger]

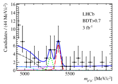
To be discussed this year

LHCb Physics Programme

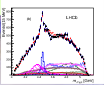
CKM and *CP* violation with *b* and *c* hadrons



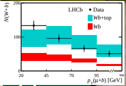
Rare decays of *b* hadrons and *c* hadrons



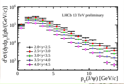
Spectroscopy in *pp* interactions and *B* decays



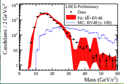
Celebrating 250 publications!



Electroweak and QCD measurements in the forward acceptance



Heavy quark production

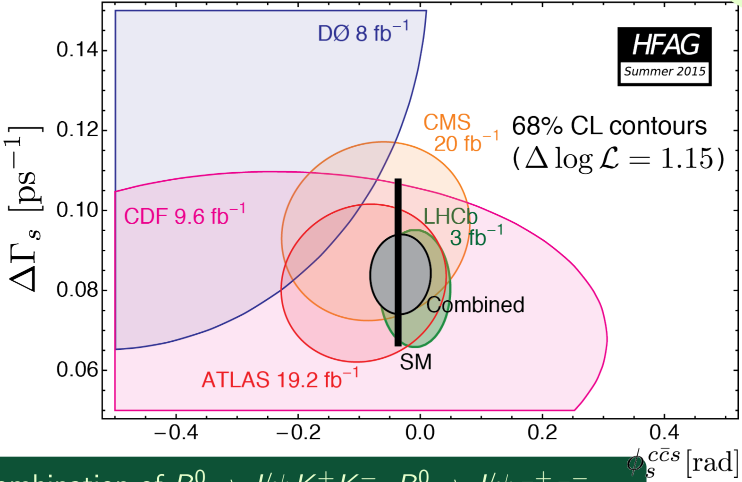


Exotica searches

[HFAG]

$\Delta\Gamma_s$ versus φ_s in Summer 2015

Simon Akar, Thursday



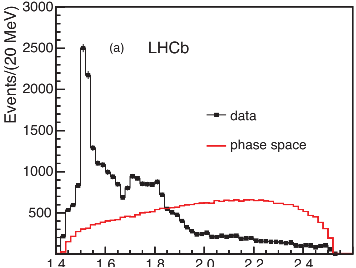
Combination of $B_s^0 \to J/\psi K^+K^-$, $B_s^0 \to J/\psi \pi^+\pi^-$ and $B_s^0 \to D_s^+D_s^-$: $\varphi_s = -0.034 \pm 0.033\,\mathrm{rad}$

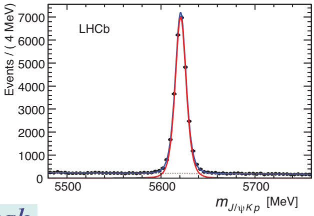
Observation of two pentaquarks

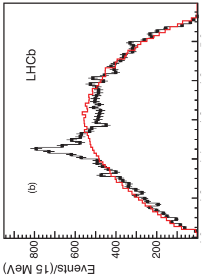
We knew here was something strange in $\Lambda_b^0 \to J/\psi\, pK^-$ [JHEP 07 (2014) 103][Phys. Lett. B734 (2014) 122][Phys. Rev. Lett. 111 (2013) 102003]

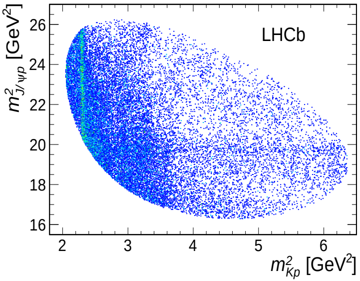
➜ Revisit this channel with a clean selection: 26000 ± 160 decays

- Reflections from B^0 and B_s^0 vetoed

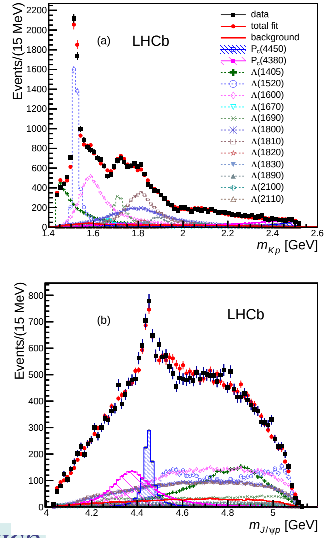






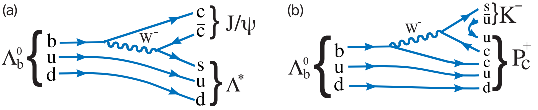


Observation of two pentaquarks

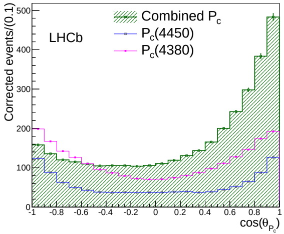


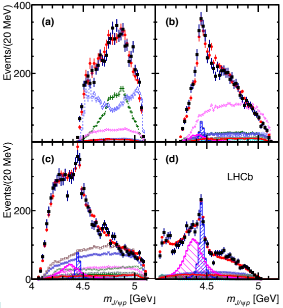
- There's an obvious peak at 4.45 GeV/c^2: Add one P_c^+ state with free J^P.
  - ✗ Unsatisfactory fit. $J^P = \frac{5}{2}^+$
- Add another P_c^+
  - ✔ Good fit

	$P_c(4380)^+$	$P_c(4450)^+$
J^P	$\frac{3}{2}^-$	$\frac{5}{2}^+$
Mass $[\mathrm{MeV}/c^2]$	$4380 \pm 8 \pm 29$	$4449.8 \pm 1.7 \pm 2.5$
Width $[\mathrm{MeV}]$	$205 \pm 18 \pm 86$	$39 \pm 5 \pm 19$
Significance	9σ	12σ



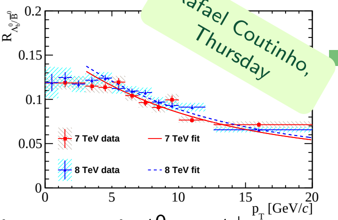
Observation of two pentaquarks





- The angular distributions are well reproduced
  - Other acceptable solutions are $(\frac{3}{2}^+, \frac{5}{2}^-)$ or $(\frac{5}{2}^+, \frac{3}{2}^-)$
  - ➜ In any case opposite parities
- Interference pattern confrms this:
  - At $\cos\theta_{P_c^+} \sim +1$, low m_{Kp}: positive interference.
  - At $\cos\theta_{P_c^+} \sim -1$, high m_{Kp}: negative interference.

Λ_b^0 PRODUCTION AT THE LHC



The ratio of Λ_b^0 to B^0 is

$$R(p_\mathrm{T}) = \frac{f_{\Lambda_b^0}}{f_d}(p_\mathrm{T})\frac{\mathcal{B}(\Lambda_b^0)}{\mathcal{B}(B^0)}$$

We measured $f_{\Lambda_b^0}/f_d(p_\mathrm{T})$ using semileptonic decays and $\Lambda_b^0 \to \Lambda_c^+\pi$ [Phys. Rev. D85 (2012) 032008] [JHEP 08 (2014) 143]. We determine the ratio of BFs and thus

$$\mathcal{B}(\Lambda_b^0 \to J/\psi\, pK^-) = \left(3.04 \pm 0.04 \pm 0.06 \pm 0.33(\mathcal{B})\,^{+0.43}_{-0.27}(\frac{f_{\Lambda_b^0}}{f_d})\right) \times 10^{-4}$$

from which we get [JHEP 07 (2014) 103]

$$\mathcal{B}(\Lambda_b^0 \to J/\psi\, p\pi^-) = \left(2.51 \pm 0.04 \pm 0.08 \pm 0.13\,^{+0.45}_{-0.35}\right) \times 10^{-5}$$

and [Phys. Rev. Lett. 115 (2015) 07201]

$$\mathcal{B}(\Lambda_b^0 \to P_c^+(4380)K^-)\mathcal{B}(P_c^+ \to J/\psi\, p) = \left(2.56 \pm 0.22 \pm 1.28\,^{+0.46}_{-0.36}\right) \times 10^{-5}$$

$$\mathcal{B}(\Lambda_b^0 \to P_c^+(4450)K^-)\mathcal{B}(P_c^+ \to J/\psi\, p) = \left(1.25 \pm 0.15 \pm 0.33\,^{+0.22}_{-0.18}\right) \times 10^{-5}$$

→ LHCb can do absolute Λ_b^0 BF and A_{CP} measurements!

[LHCb, LHCb-CONF-2015-002]

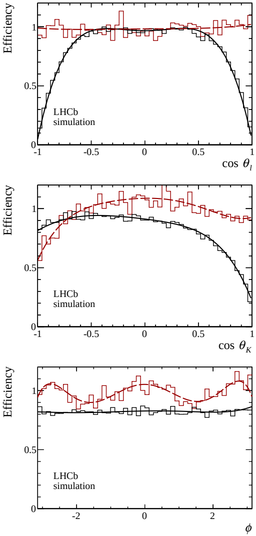
Angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay

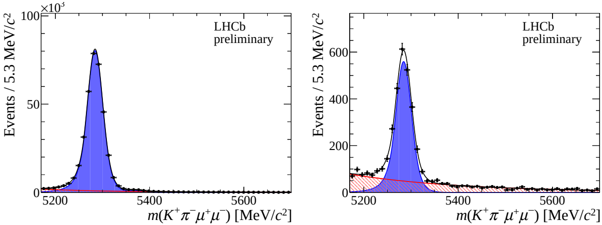
Sam Cunliffe, Today

Update of [LHCb, JHEP 08 (2013) 131, arXiv:1304.6325] and [LHCb, Phys. Rev. Lett. 111 (2013) 191801, arXiv:1308.1707] to 3 fb^{-1}.

Now S-wave is taken into account, we have finer bins, and no φ folding is needed.

- Angular acceptance obtained from MC and validated on $B^0 \to J/\psi K^*$ decays.





[LHCb, LHCb-CONF-2015-002]

Angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay

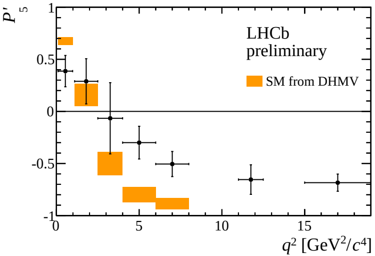
Sam Cunliffe, Today

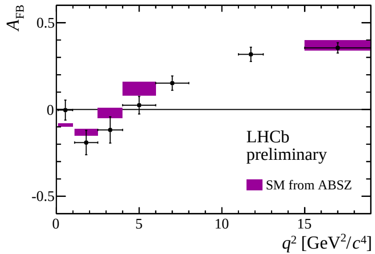
Update of [LHCb, JHEP 08 (2013) 131, arXiv:1304.6325] and [LHCb, Phys. Rev. Lett. 111 (2013) 191801, arXiv:1308.1707] to 3 fb^{-1}. Now S-wave is taken into account, we have finer bins, and no φ folding is needed.

- Observables consistent with SM, except S_5
- $P'_5 = S_5/\sqrt{F_L(1-F_L)}$ has a local discrepancy in two bins of 3.7σ
- $A_{\rm FB}$ seems to show a trend, but is consistent with SM

More analyses will feature in the paper

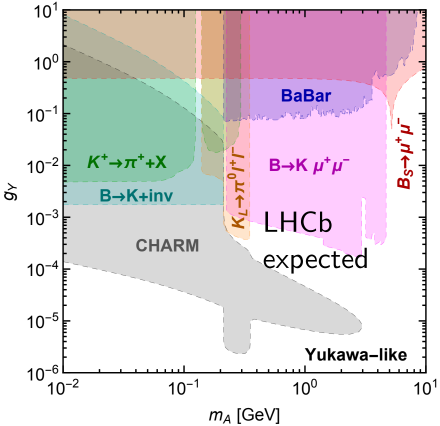
Results to be shown for the first time in the next talk





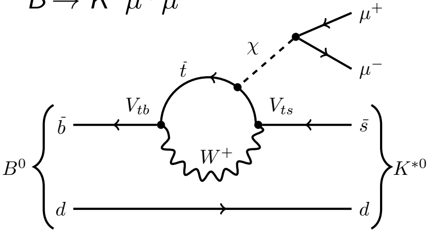
Dark Bosons in $B^0 \to \chi(\mu^+\mu^-)K^*$

Mitesh Patel, Wednesday



Coupling vs mass [Dolan et al., JHEP 03 (2015) 171]

- A lot of interest for models with dark matter interacting feebly with the SM, via a portal particle
  - LHCb has sensitivity for $\mathcal{O}(\text{GeV})$ particles and low couplings
- Looking for such a particle χ decaying to muons and interfering with the Z or γ in $B \to K^*\mu^+\mu^-$

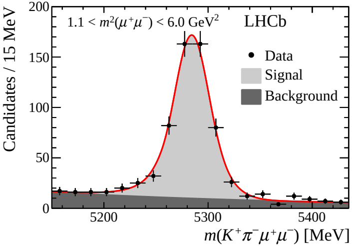


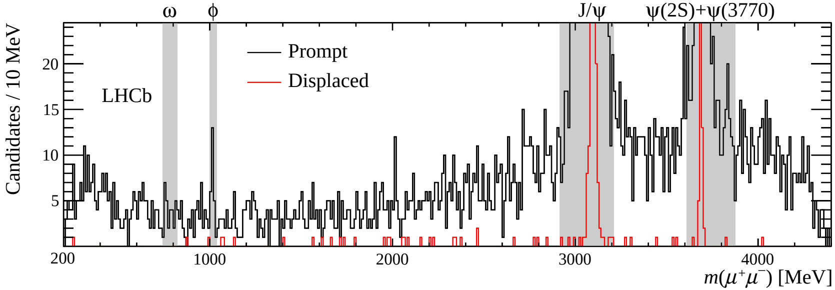
[LHCb, to appear in Phys.Rev.Lett., arXiv:1508.04094]

Dark Bosons in $B^0 \to \chi(\mu^+\mu^-)K^*$

Mitesh Patel, Wednesday

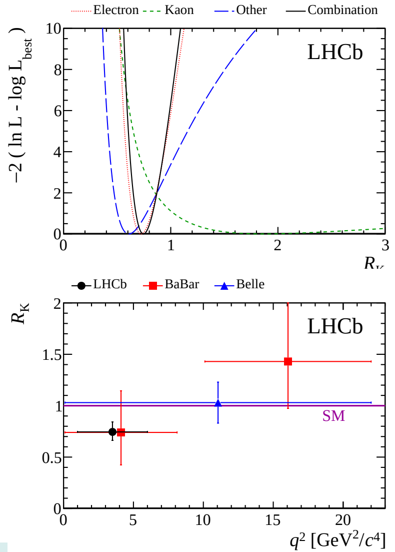
- Selection very similar to other $B \to K^*\mu^+\mu^-$ analyses [LHCb, LHCb-CONF-2015-002]
- Except for χ lifetime cut
  - ➜ Allows for displaced $\mu^+\mu^-$
- Mass spectrum consistent with no-χ expectation





Lepton universality with $B^+ \to K^+\ell\ell$

Jon Harrison, Wednesday



- Measure ratio R_K of $B^+ \to K^+\mu\mu$ to $B^+ \to K^+ee$ in $1 < q^2 < 6\ \mathrm{GeV}^2$
  - ✔ Signal clearly visible in $K^+\mu^-\mu^+$
- Separate K^+ee by electron, hadron and other L0 triggers
  - Use different mass pdf depending on the number of bremsstrahlung photons
- Build a double ratio $R_K =$

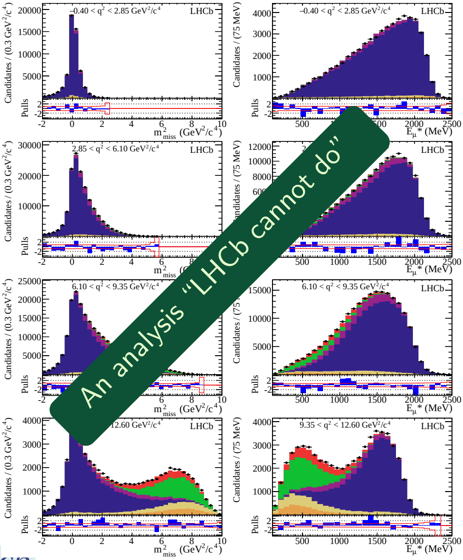
$$\left(\frac{\mathcal{N}_{K^+\mu^+\mu^-}}{\mathcal{N}_{K^+e^+e^-}}\right)\left(\frac{\mathcal{N}_{J/\psi\,K^+e^+e^-}}{\mathcal{N}_{J/\psi\,K^+\mu^+\mu^-}}\right)$$

$$= 0.745\,^{+\,0.090}_{-\,0.074} \pm 0.036$$

2.6σ from unity

$\overline{B}^0 \rightarrow D^* \tau \nu$ at LHCb

Basem Khanji, Wednesday

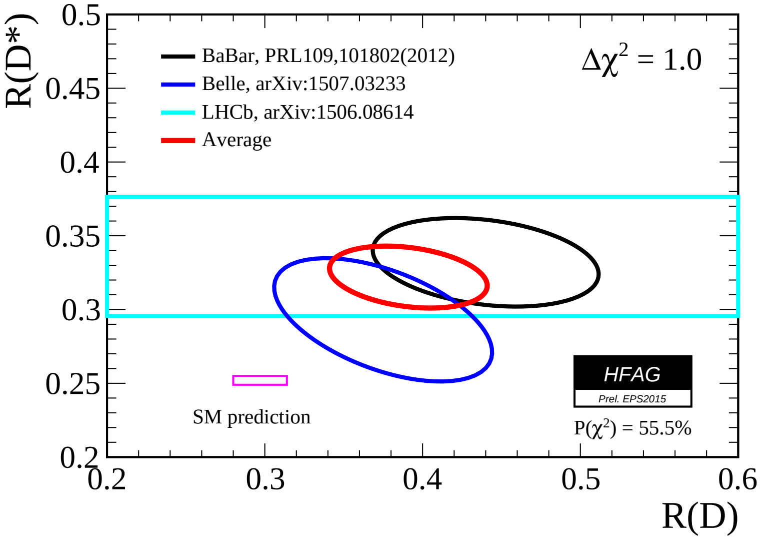


- $B^0 \rightarrow D^{*+}\tau^-\overline{\nu}$ with $\tau^- \rightarrow \mu^-\nu\overline{\nu}$ and $B^0 \rightarrow D^{*+}\mu^-\overline{\nu}$ have same final state.
- Disentangled by kinematical variables : q^2, E^*_μ, m^2_{miss}.
- A template fit in q^2 bins determines signal yields
- Get 36300 ± 1600 $B \rightarrow D^{*+}\mu^-\overline{\nu}$ decays and $R_{D^*} = 0.336 \pm 0.027 \pm 0.030$
  - Dominant systematics are MC stats and mis-ID μ shapes

[HFAG]

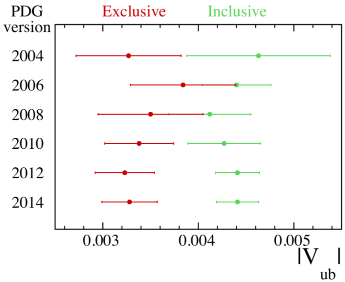
$\bar{B}^0 \to D^* \tau \nu$ after FPCP

Basem Khanji, Wednesday



V_{ub} HISTORY

- There has been a long standing discrepancy between the value of $|V_{ub}|$ determined from exclusive $B \to \pi\ell\nu$ and inclusive $b \to u\ell\nu$ decays.
- PDG 2014 reports

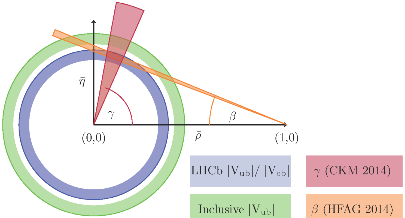


$$\text{Inclusive}: (4.41 \pm 0.15\,^{+0.15}_{-0.10}) \times 10^{-3}$$

$$\text{Exclusive}: (3.28 \pm 0.29) \times 10^{-3}$$

$$\text{Average}: (4.13 \pm 0.49) \times 10^{-3}$$

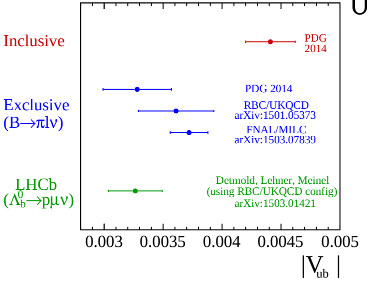
- CKMFitter uses $3.55\,^{+0.17}_{-0.15} \times 10^{-3}$,
- UTFit $3.75 \pm 0.46 \times 10^{-3}$

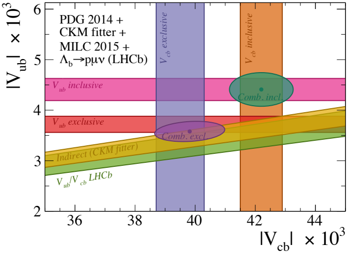


[LHCb, Nature Physics 11 (2015) 743, arXiv:1504.01568]

$|V_{ub}|/|V_{cb}|$ FROM $\Lambda_b^0 \to p\mu^-\bar{\nu}$

Patrick Owen, Wednesday





Using 2 fb^{-1} (2012) we measure

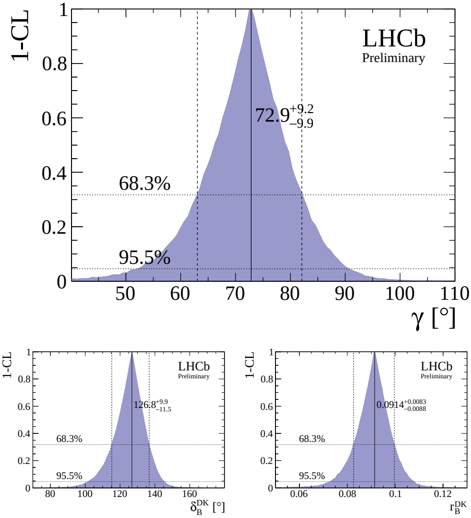
$$\frac{\mathcal{B}(\Lambda_b^0 \to p\mu\nu)_{q^2>15\ \mathrm{GeV}/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu\nu)_{q^2>7\ \mathrm{GeV}/c^2}} = (1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$$

- The result is $|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-5}$ where the uncertainties are statistical, experimental and from lattice.
  - We measure $|V_{ub}|/|V_{cb}|$, while the B factories measure $|V_{ub}|$ and $|V_{cb}|$ separately

➜ The puzzle is still alive

γ combination for CKM

Giulia Tellarini, Thursday



- Using only $B \to DK$ gets $\gamma = (73\,^{+\,9}_{-\,10})^\circ$
  - ➜ **More precise than B factory combination**

New results sensitive to γ came out in the meantime $B^+ \to D(h^\pm h^\mp \pi^0)h^+$ [Phys. Rev. D91 (2015) 112014] $B^+ \to Dh^+\pi^+\pi^-$ [arXiv:1505.07044] and more will come soon.

[LHCb, Phys. Rev. Lett. 115 (2015) 031601, arXiv:1503.07089]

$\sin 2\beta$ WITH $B^0 \to J/\psi K^0_S$

Simon Akar, Thursday

Golden mode for CP violation in B^0

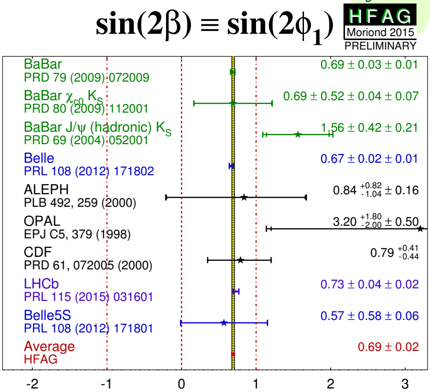
- World average
  $\sin 2\beta^{\text{exp}} = 0.682 \pm 0.019.$
- Expectation from global fits
  $\sin 2\beta^{\text{SM}} = 0.771\, ^{+\,0.017}_{-\,0.041}.$

  [CKMFitter, arXiv:1501.05013]
- Systematic uncertainties mostly from data ➜ will improve

$$S = 0.731 \pm 0.035 \pm 0.020$$

$$S^{\text{Belle}}_{J/\psi K^0_S} = 0.670 \pm 0.029 \pm 0.013$$

$$S^{\text{BaBar}}_{J/\psi K^0_S} = 0.662 \pm 0.039 \pm 0.012$$

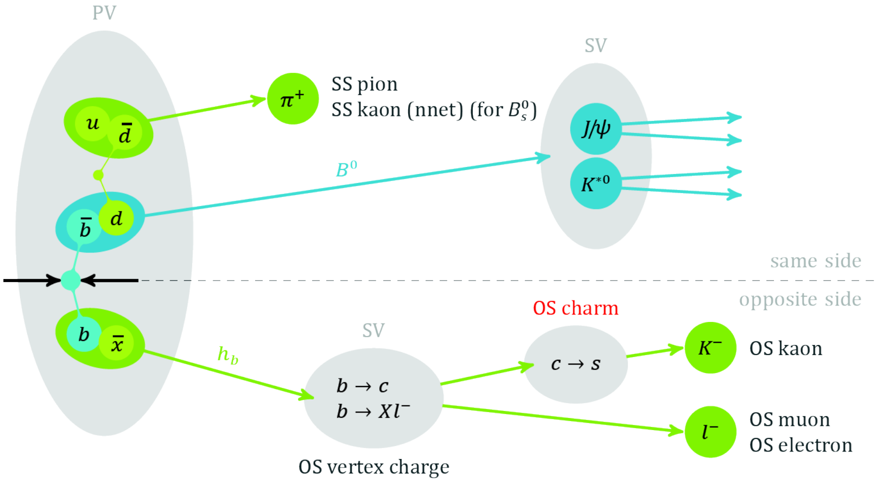


Now competitive with B factories!

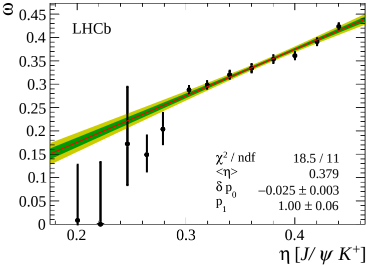
[Belle, Phys. Rev. Lett. 108, 171802 (2012), arXiv:1201.4643]

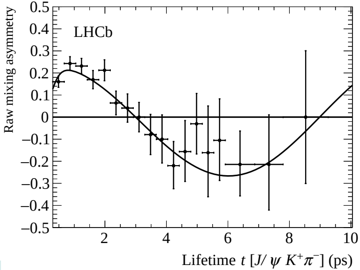
[Babar, Phys. Rev. D79 072009 (2009), arXiv:0902.1708]

B Flavour Tagging at the LHC



Opposite-side Charm Tagger





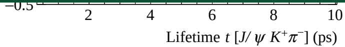
- New opposite-side flavour tagging algorithm using exclusively reconstructed D decays from b hadrons.
- Complementary to vertex charge (no PID) and to OS kaon (hard K, but no requirements on other tracks)
- Low-ish $\epsilon_{\text{tag}} = 3$–$4\%$, good $\omega \sim 35\%$ ➜ $\epsilon_{\text{eff}} = 0.3$–$0.4\%$ depending on mode

Opposite-side Charm Tagger

- New opposite-side flavour tagging

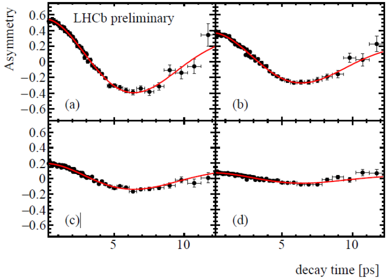
Channel	ϵ_{eff} [%] 2011	Run I	Imprvt	Reference
$B_s^0 \to \phi\phi$	3.29	5.38	+64%	[Phys. Rev. D90 (2014) 052011]
$B_s^0 \to D_s^+ D_s^+$		5.33		[Phys. Rev. Lett. 113 (2014) 211801]
$B_s^0 \to D_s^+ K^-$	5.07			[JHEP 11 (2014) 060]
$B_s^0 \to J/\psi K^+ K^-$	3.13	3.73	+19%	[Phys. Rev. Lett. 114 (2015) 041801]
$B_s^0 \to J/\psi \pi^+ \pi^-$	2.43	3.89	+60%	[Phys. Lett. B736 (2014) 186]
$B^0 \to J/\psi K_S^0$	2.38	3.03	+27%	[Phys. Rev. Lett. 115 (2015) 031601]
$B_s^0 \to J/\psi \phi$	1.45	1.49	+3%	Preliminary
$B_s^0 \to J/\psi \phi$	0.97	1.31	+35%	[arXiv:1507.07527]

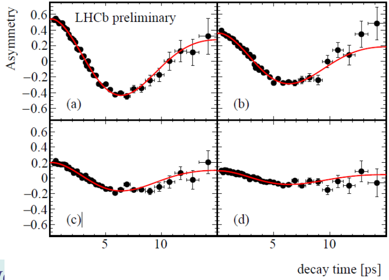
Impressive improvements in tagging performance in the last 3 years



Δm_d WITH SEMILEPTONIC B^0 DECAYS

Lucia Grillo, Today





- Use $B^0 \to D^{(*)-}\mu^+\nu_\mu X$ with 2.2×10^6 $D^- \to K^+\pi^+\pi^+$ and 8.2×10^5 $D^{*-} \to \overline{D}^0(K^+\pi^-)\pi^-$
- Tagging power 2.32–2.55% depending on mode and year

Preliminary result:

$$\Delta m_d = (503.6 \pm 2.0 \pm 1.3)\ \mathrm{ns}^{-1}$$

We are still working on the systematics
➜ expect them to decrease

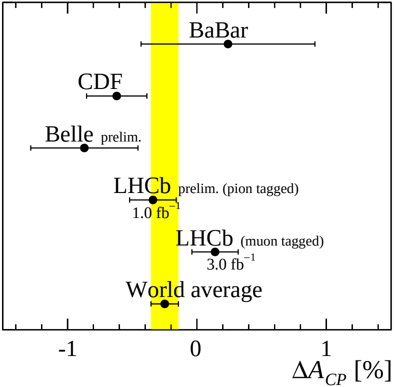
World average [HFAG]

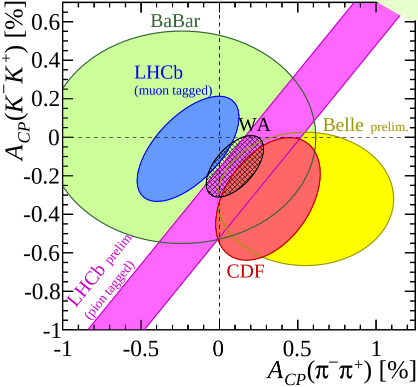
$$\Delta m_d = (510 \pm 3)\ \mathrm{ns}^{-1} \text{ (without this)}$$

$$\Delta m_d = (505.5 \pm 2.0)\ \mathrm{ns}^{-1} \text{ (with this)}$$

ΔA_{CP} of $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$

Stefanie Reichert, Today

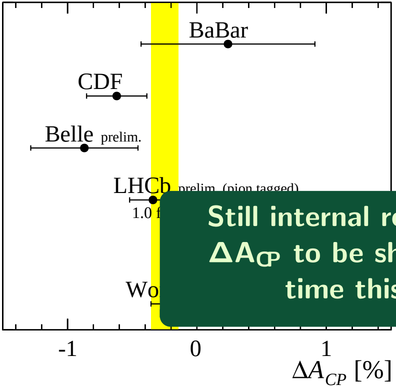


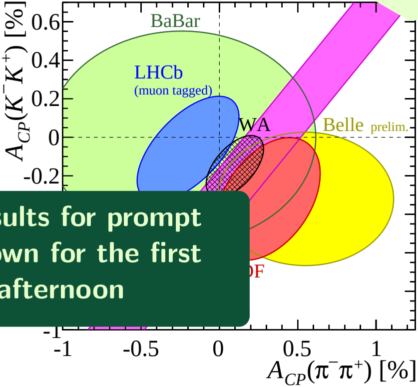


$$A_{CP}(K^+K^-) = (-0.016 \pm 0.012)\%$$
$$A_{CP}(\pi^+\pi^-) = (-0.05 \pm 0.15)\%$$
$$\Delta A_{CP} = (-0.253 \pm 0.104)\%$$ [HFAG 2/15]

ΔA_{CP} of $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$

Stefanie Reichert, Today





Still internal results for prompt ΔA_{CP} to be shown for the first time this afternoon

$$A_{CP}(K^+K^-) = (-0.016 \pm 0.012)\%$$
$$A_{CP}(\pi^+\pi^-) = (-0.05 \pm 0.15)\%$$
$$\Delta A_{CP} = (-0.253 \pm 0.104)\%$$ [HFAG 2/15]

[LHCb, Phys. Rev. Lett. 115 (2015) 112001, arXiv:1506.00903]

Top observation in the forward dir...n

Victor Coco, Today

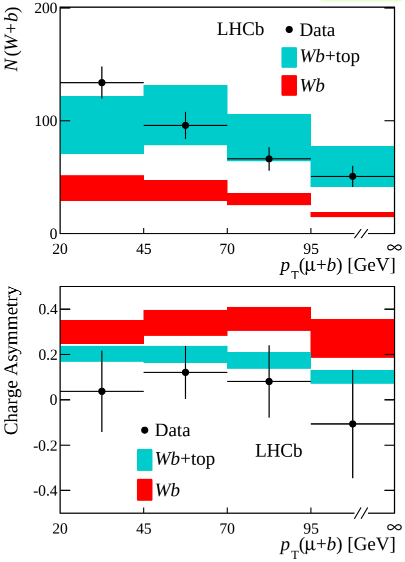
Strategy: First measure W+jet yields and then obtain $W+b$ from fraction of b-tagged jets

- The 2D BDT response is fitted in bins of $p_{\mathrm{T}}(\mu)/p_{\mathrm{T}}(j_\mu)$ and $p_{\mathrm{T}}(\mu+j)$
  - ➜ $W+c$ and $W+b$ yields
  - ✔ $W+c$ agrees with SM
- For b-tags, $p_{\mathrm{T}}(\mu)/p_{\mathrm{T}}(j_\mu) > 0.9$ is dominated by W

➜ Yields of $W+b$, and asymmetry inconsistent with no top hypothesis at 5.4σ level.

$$\sigma(t, 7\ \text{TeV}) = 239 \pm 53 \pm 38\ \text{fb}$$

$$\sigma(t, 8\ \text{TeV}) = 289 \pm 43 \pm 46\ \text{fb}$$



Ronan Wallace, Today

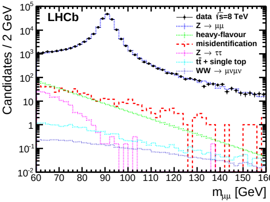
$\sin^2\theta_{\mathrm{W}}^{\mathrm{EFF}}$ FROM $Z \to \mu^+\mu^-$ A_{FB}

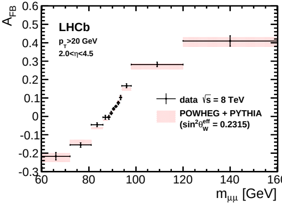
In the SM the Z boson couples differently to left- and right-handed fermions, leading to A_{FB} depending on $\sin^2\theta_{\mathrm{W}}^{\mathrm{eff}}$

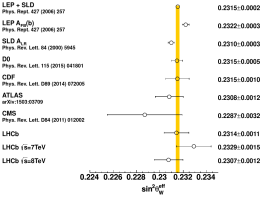
$$\sin^2\theta_{\mathrm{W}}^{\mathrm{eff}} = 0.23142 \pm 0.00073 \pm 0.00052 \pm 0.00056$$

where last uncertainty is theoretical: PDFs (dominant), normalisation and factorisation scales, α_s and FSR.

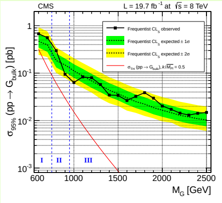
- ➜ **Most precise value at the LHC**, statistically limited.
- ✔ Will improve with 13 TeV data: double-differential in $m_{\mu\mu}$ and y.



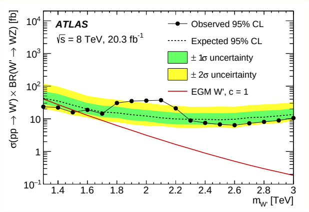




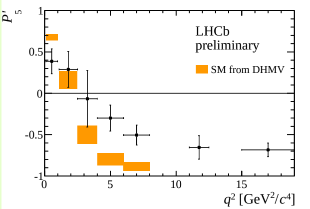
Are we already seeing New Physics?



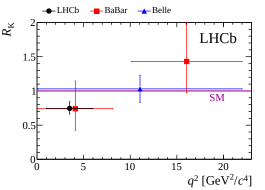
Excess at 2 TeV [CMS, JHEP 08 (2014) 174]



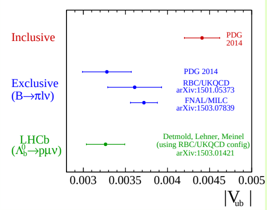
Excess at 2 TeV [Atlas, arXiv:1506.00962]



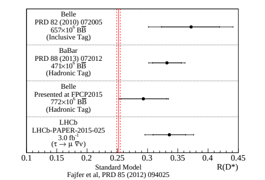
P'_5 in $B \to K^* \mu^+ \mu^-$ [LHCb-CONF-2015-002]



Lepton universality [Phys. Rev. Lett. 113 (2014) 151601]



V_{ub} puzzle [Nature Physics 11 (2015) 743]



$B \to D^* \tau \nu$ [Phys. Rev. D92 (2015) 011102(R)]

There's a handful of intruiguing 3–4σ anomalies


DIRKJAN
Meer DirkJan? Kijk op
veronicamagazine.nl
Mark Retera
TOK
KLEI
KLAP
KLAP
KLAP

Conclusion

- Many results need interpretation from theory
- ... and need more data

✔ LHCb had a very good start in Run II

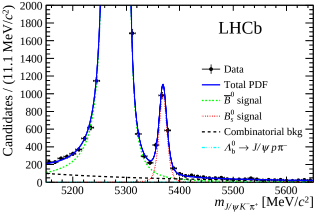
Looking forward to interesting discussions

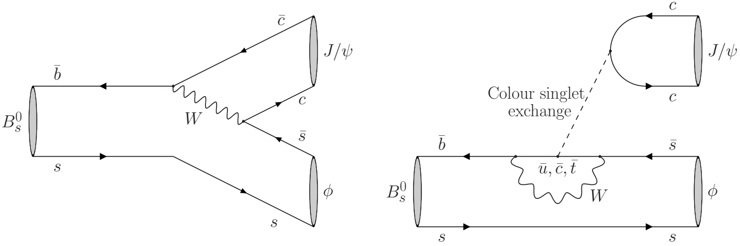
Backup

ANGULAR ANALYSIS OF $B_s^0 \to J/\psi \bar{K}^{*0}$

The predictions of φ_s and $\sin 2\beta$ assume these are measured in $b \to c\bar{c}s$ transitions.

- Size of penguin topologies?
  - ✗ Effects ≃ exp. sensitivity
- ➜ Measure it in decays where these are enhanced relative to the tree





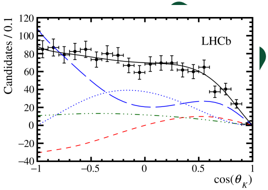
(a) (b)

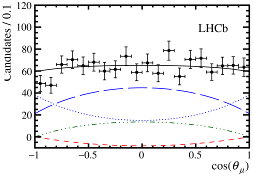
Following [De Bruyn, Fleischer, JHEP 1503 (2015) 145], [Faller et al., PRD79 014005]. See [backup]

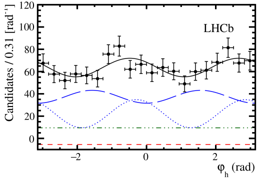
Angular analysis of $B_s^0 \to J/\psi \overline{K}^{*0}$

Angular analysis in helicity frame

- 208700 ± 500 B^0 and 1800 ± 60 B_s^0 decays
- Correction for production and detection asymmetries [Phys. Rev. Lett. 114 (2015) 041601] [Phys. Lett. B739 (2014) 218] [JHEP 07 (2014) 041]



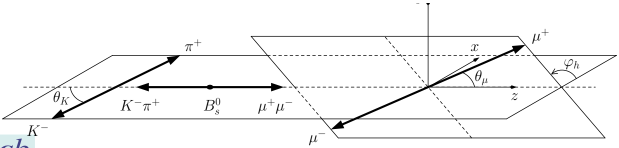




Results:

$$\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0}) = \left(4.13 \pm 0.16(\text{stat}) \pm 0.25(\text{syst}) \pm 0.24(f_d/f_s)\right) \times 10^{-5}$$

$$\begin{aligned}
f_0 &= 0.497 \pm 0.025\ (\text{stat}) \pm 0.025\ (\text{syst}) \\
f_{\|} &= 0.179 \pm 0.027\ (\text{stat}) \pm 0.013\ (\text{syst}) \\
A_0^{CP}(B_s^0 \to J/\psi \overline{K}^{*0}) &= -0.048 \pm 0.057\ (\text{stat}) \pm 0.020\ (\text{syst}) \\
A_{\|}^{CP}(B_s^0 \to J/\psi \overline{K}^{*0}) &= 0.171 \pm 0.152\ (\text{stat}) \pm 0.028\ (\text{syst}) \\
A_{\perp}^{CP}(B_s^0 \to J/\psi \overline{K}^{*0}) &= -0.049 \pm 0.096\ (\text{stat}) \pm 0.025\ (\text{syst})
\end{aligned}$$



Angular analysis of $B_s^0 \to J/\psi \overline{K}^{*0}$

$$A(B_s^0 \to J/\psi \overline{K}^{*0}) = -\lambda \mathcal{A}_i \left[1 - a_i e^{i\theta_i} e^{i\gamma}\right], i = 0, \parallel, \perp$$

$$A(B_s^0 \to J/\psi \phi) = \left(1 - \frac{\lambda^2}{2}\right) \mathcal{A}'_i \left[1 - \epsilon a'_i e^{i\theta'_i} e^{i\gamma}\right]$$

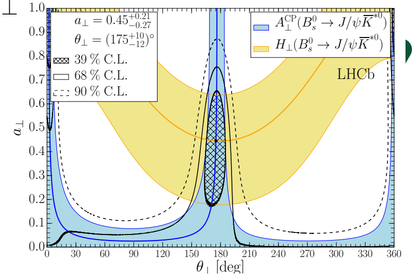
with $\epsilon = 0.054$, $\gamma = 74 \pm 7^\circ$ (CKM) and $a_i = a'_i$, $\theta_i = \theta'_i$ (SU(3)) ➜

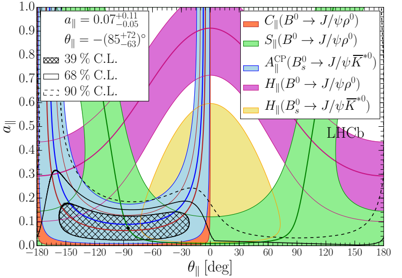
$$a_0 = 0.03^{+0.97}_{-0.03}, \quad \theta_0 = (64^{+116}_{-244})^\circ,$$
$$a_\parallel = 0.32^{+0.58}_{-0.32}, \quad \theta_\parallel = -(15^{+150}_{-14})^\circ,$$
$$a_\perp = 0.45^{+0.21}_{-0.27}, \quad \theta_\perp = (175 \pm 10)^\circ,$$

Combine with $B^0 \to J/\psi \rho^0$ [Phys. Lett. B742 (2015) 38]

$$\frac{\mathcal{A}'_i}{\mathcal{A}_i} \equiv \left|\frac{\mathcal{A}'_i(B_s^0 \to J/\psi \phi)}{\mathcal{A}_i(B_s^0 \to J/\psi \overline{K}^{*0})}\right| = \left|\frac{\mathcal{A}'_i(B_s^0 \to J/\psi \phi)}{\mathcal{A}_i(B^0 \to J/\psi \rho^0)}\right|$$

$$\Delta\phi_{s,0}^{J/\psi\phi} = 0.000^{+0.009}_{-0.011}\,(\text{stat})^{+0.004}_{-0.009}\,(\text{syst}),$$
$$\Delta\phi_{s,\parallel}^{J/\psi\phi} = 0.001^{+0.010}_{-0.014}\,(\text{stat})^{+0.007}_{-0.008}\,(\text{syst}),$$
$$\Delta\phi_{s,\perp}^{J/\psi\phi} = 0.003^{+0.010}_{-0.014}\,(\text{stat})^{+0.007}_{-0.008}\,(\text{syst}).$$





➜ **Penguin pollution is small wrt ± 0.039 rad**

Interplay of CKM and rare decays

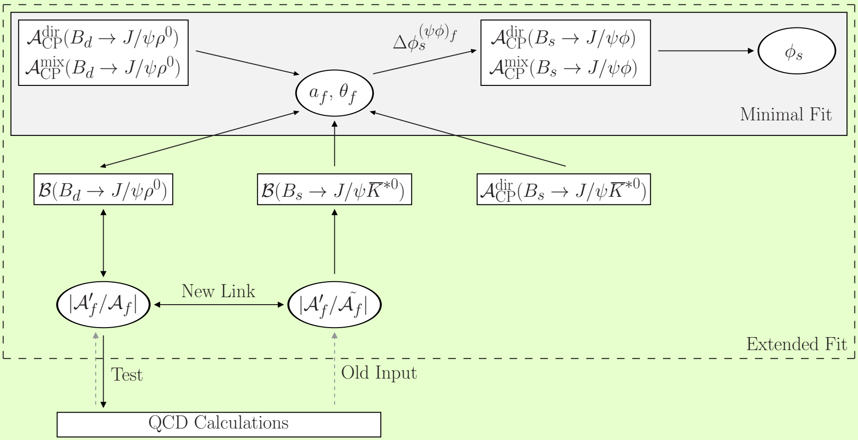
CKM matrix elements uncertainties dominate in many "clean" measurements

- SM BF uncertainties on $K^0_{\mathrm{L}} \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ dominated by CKM uncertainties
- Wilson coefficient extraction from $b \to s\ell\ell$ affected by form factors and CKM elements.
- $B^0 \to \mu^+\mu^-$: 6.9 of 8.5% theory uncertainty comes from CKM elements

We are entering a regime where an improved knowledge of the CKM matrix will help constraining new physics in rare decays.

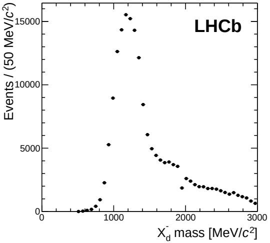
[De Bruyn, Fleischer, JHEP 1503 (2015) 145]

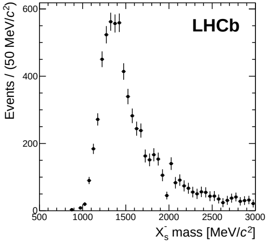
Penguins Roadmap



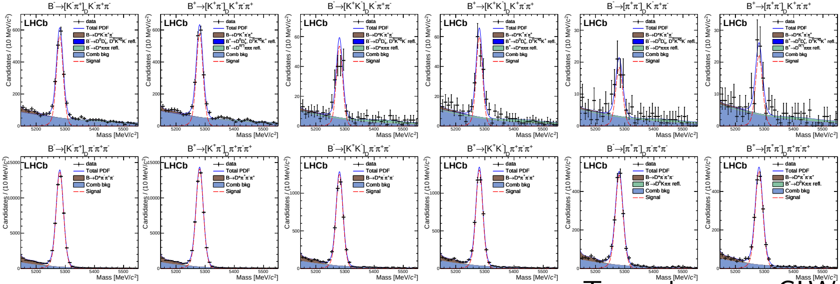
γ WITH $B^- \to DK^-\pi^+\pi^-$ AND $B^- \to D\pi^-\pi^+\pi^-$

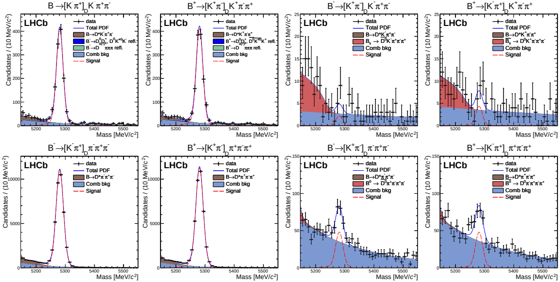
- The CKM angle γ is the least constrained angle of the unitarity triangle, $\gamma = (73\,^{+\,9}_{-\,10})^\circ$ [LHCb, LHCb-CONF-2014-004]
  - $B^\pm \to D(hh\pi^0)h^\pm$ [Phys. Rev. D91 (2015) 112014], $B^0 \to DK^*$ [Phys. Rev. D90 (2014) 112002], $B^0_s \to D_s^\mp K^\pm$ [JHEP 11 (2014) 060], $B^\pm \to D(K^0_S\pi^+\pi^-)h^\pm$ [JHEP 10 (2014) 097], [Nucl. Phys. B888 (2014) 169], $B^\pm \to D(K^0_S K\pi)h^\pm$ [Phys. Lett. B733 (2014) 36] ...
- But it can de determined in tree decays to unlimited precision [Brod, Zupan, JHEP 1401 (2014) 051]
- Here look for $B^- \to DK^-\pi^+\pi^-$ and $B^- \to D\pi^-\pi^+\pi^-$ with $D \to K^\mp\pi^\pm$ (ADS) and $D \to h^+h^-$ $h = \pi, K$ (GLW)





γ WITH $B^- \to DK^-\pi^+\pi^-$ AND $B^- \to D\pi^-\pi^+\pi^-$





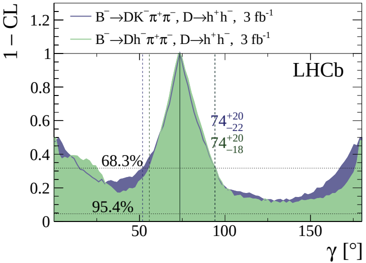
Top to bottom: GLW X_s and X_d modes, ADS X_s and X_d modes

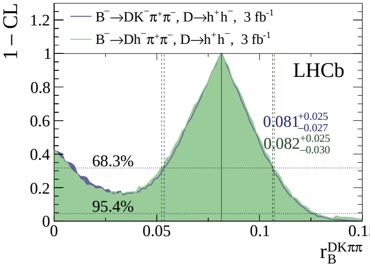
Between 90k (favoured $B^- \to D\pi^-\pi^+\pi^-$) and 20 (DCS $B^- \to DK^-\pi^+\pi^-$, 3σ) decays seen

γ WITH $B^- \to DK^-\pi^+\pi^-$ AND $B^- \to D\pi^-\pi^+\pi^-$

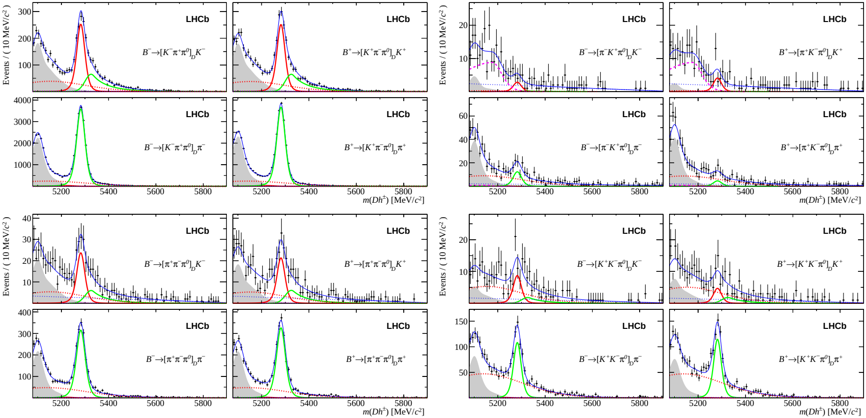
A combined fit to all *CP* observables gets $\gamma = (74\,^{+\,20}_{-\,18})^\circ$ and $r_B^{DX_s} = 0.08 \pm 0.03$ at 68% CL. At 95% there are no constraints yet.

$$
\begin{aligned}
R_{CP+}^{K^+K^-} &= 1.043 \pm 0.069 \pm 0.034,\\
R_{CP+}^{\pi^+\pi^-} &= 1.035 \pm 0.108 \pm 0.038,\\
\mathcal{A}_{X_d}^{K^+K^-} &= -0.019 \pm 0.011 \pm 0.010,\\
\mathcal{A}_{X_d}^{\pi^+\pi^-} &= -0.013 \pm 0.016 \pm 0.010,\\
\mathcal{A}_{X_d}^{K^-\pi^+} &= -0.002 \pm 0.003 \pm 0.011,\\
R^{X_d^+} &= (42.8 \pm 5.3 \pm 2.1) \times 10^{-4},\\
R^{X_d^-} &= (42.5 \pm 5.3 \pm 2.1) \times 10^{-4},\\
\mathcal{A}_{X_s}^{K^+K^-} &= -0.045 \pm 0.064 \pm 0.011,\\
\mathcal{A}_{X_s}^{\pi^+\pi^-} &= -0.054 \pm 0.101 \pm 0.011,\\
\mathcal{A}_{X_s}^{K^-\pi^+} &= 0.013 \pm 0.019 \pm 0.013,\\
R^{X_s^+} &= (105^{+60}_{-44} \pm 11) \times 10^{-4} \quad [\ < 0.018 \text{ at } 95\% \text{ CL }],\\
R^{X_s^-} &= (54^{+45}_{-42} \pm 6) \times 10^{-4} \quad [\ < 0.012 \text{ at } 95\% \text{ CL }].
\end{aligned}
$$





γ WITH $B^+ \to D(h^+h^-\pi^0)K^+$ (ADS/GLW)



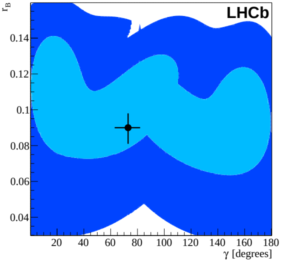
$B^- \to D(h^\pm h^\mp \pi^0)h^-$ with π^0 in the final state:
37k $D(K^-\pi^+\pi^0)\pi^-$, 3k $D(K^-\pi^+\pi^0)K^-$, 88 ± 20 $D(K^+\pi^-\pi^0)\pi^-$ (FO), 40 ± 13 $D(K^+\pi^-\pi^0)K^-$, 3k $D(\pi^-\pi^+\pi^0)\pi^-$, 164 ± 27 $D(\pi^-\pi^+\pi^0)K^-$, 1k $D(K^+K^-\pi^0)\pi^-$, 76 ± 17 $D(K^+K^-\pi^0)\pi^-$ (FO).

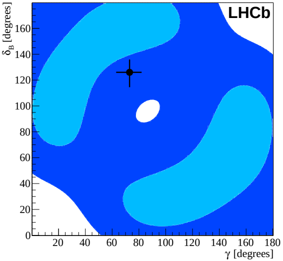
γ WITH $B^+ \to D(h^+h^-\pi^0)K^+$ (ADS/GLW)

- Ratios R of suppressed to favoured modes and asymmetries A of B^- and B^+ are determined following ADS [PRD63 036005] and GLW prescriptions [PLB265 172].
  - $h^+h^-\pi^0$ is almost a CP eigenstate (quasi-GLW).
  - Systematics dominated by mass PDF and instrumental ymmetry for kaons

➜ Bounds on γ, r_B and δ_B. Consistent with average [LHCb-CONF-2014-001].

$$A^{K\pi\pi^0}_{\mathrm{ADS}(K)} = -0.20 \pm 0.27 \pm 0.04$$
$$A^{K\pi\pi^0}_{\mathrm{ADS}(\pi)} = 0.438 \pm 0.190 \pm 0.011$$
$$A^{KK\pi^0}_{\mathrm{qGLW}(K)} = 0.30 \pm 0.20 \pm 0.02$$
$$A^{\pi\pi\pi^0}_{\mathrm{qGLW}(K)} = 0.054 \pm 0.091 \pm 0.011$$
$$A^{KK\pi^0}_{\mathrm{qGLW}(\pi)} = -0.030 \pm 0.040 \pm 0.005$$
$$A^{\pi\pi\pi^0}_{\mathrm{qGLW}(\pi)} = -0.016 \pm 0.020 \pm 0.004$$
$$A^{K\pi\pi^0}_{K} = 0.010 \pm 0.026 \pm 0.005$$
$$R^{K\pi\pi^0}_{\mathrm{ADS}(K)} = 0.0140 \pm 0.0047 \pm 0.0021$$
$$R^{K\pi\pi^0}_{\mathrm{ADS}(\pi)} = 0.00235 \pm 0.00049 \pm 0.00006$$
$$R^{KK\pi^0}_{\mathrm{qGLW}} = 0.95 \pm 0.22 \pm 0.05$$
$$R^{\pi\pi\pi^0}_{\mathrm{qGLW}} = 0.98 \pm 0.11 \pm 0.05$$

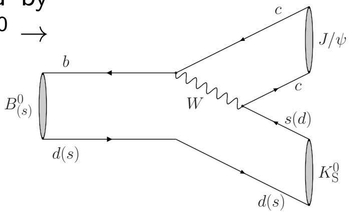




CPV IN $B_s^0 \to J/\psi K_S^0$

In $B_s^0 \to J/\psi K_S^0$ the penguin is enhanced by a factor 20 wrt the tree, compared to $B^0 \to J/\psi K_S^0$

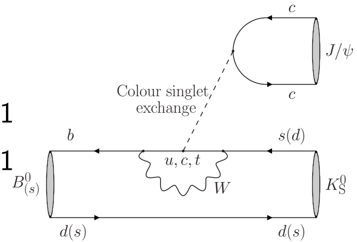
- ➜ Penguin control for $B^0 \to J/\psi K_S^0$
- ✗ Cabibbo-suppressed



$$\Gamma \equiv \mathcal{N}_f e^{it/\tau_{B_s^0}} \left[\cosh(\Delta\Gamma_s t/2) + \mathcal{A}_{\Delta\Gamma}\sinh(\Delta\Gamma_s t/2) - S_{\text{mix}}\sin(\Delta m_s t) + C_{\text{dir}}\cos(\Delta m_s t)\right] ,$$

SM predictions: [De Bruyn et al., arXiv:1412.6834]

$$\mathcal{A}_{\Delta\Gamma}(B_s^0 \to J/\psi K_S^0) = 0.957 \pm 0.061$$
$$C_{\text{dir}}(B_s^0 \to J/\psi K_S^0) = 0.003 \pm 0.021$$
$$S_{\text{mix}}(B_s^0 \to J/\psi K_S^0) = 0.29 \pm 0.20$$



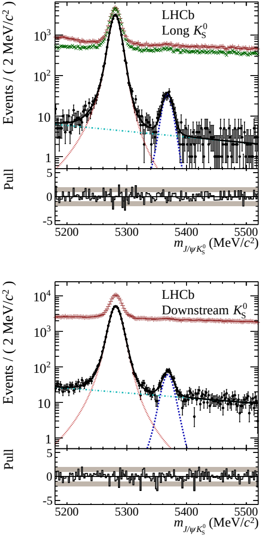
CPV IN $B_s^0 \to J/\psi K_S^0$

In $B_s^0 \to J/\psi K_S^0$ the penguin is enhanced by a factor 20 wrt the tree, compared to $B^0 \to J/\psi K_S^0$

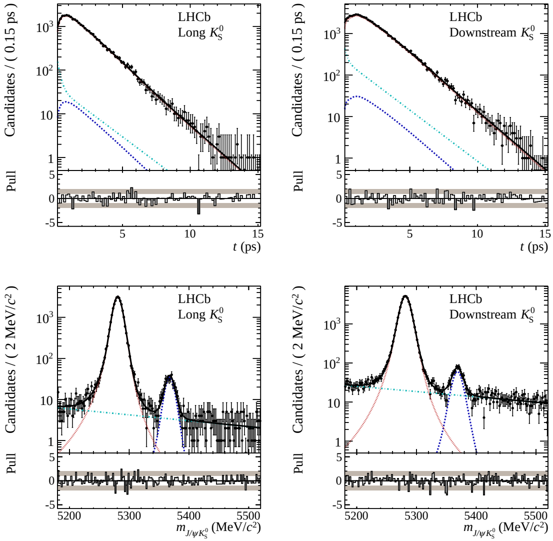
➜ Penguin control for $B^0 \to J/\psi K_S^0$

✗ Cabibbo-suppressed

- Selection in three steps:
  1. Preselection, identical to $B^0 \to J/\psi K_S^0$
  2. NN to suppress $B^0 \to J/\psi K^*$ background (LL)
  3. NN to suppress background

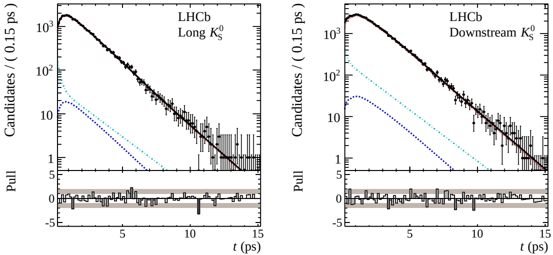


CPV IN $B_s^0 \to J/\psi K_S^0$



- Time-dependent tagged fit
- Identical to $B^0 \to J/\psi K_S^0$, except for same-side kaon
  - That has some efficiency on the B^0, when its decision is reversed

CPV in $B_s^0 \to J/\psi K_S^0$

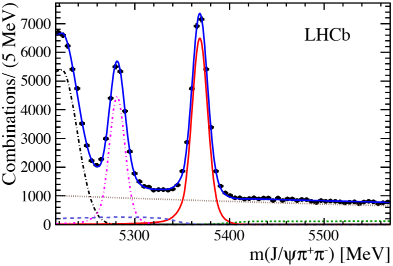


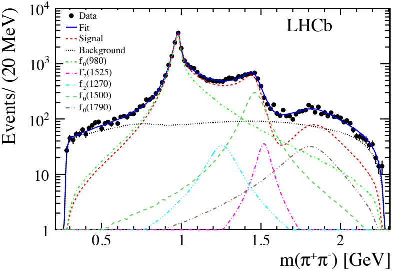
With 3 fb^{-1} we can make a measurement but are not sensitive to penguins yet

$$\mathcal{A}_{\Delta\Gamma}\left(B_s^0 \to J/\psi K_S^0\right) = 0.49\ {}^{+0.77}_{-0.65}\,(\text{stat}) \pm 0.06\,(\text{syst})\,,$$
$$C_{\text{dir}}\left(B_s^0 \to J/\psi K_S^0\right) = -0.28 \pm 0.41\,(\text{stat}) \pm 0.08\,(\text{syst})\,,$$
$$S_{\text{mix}}\left(B_s^0 \to J/\psi K_S^0\right) = -0.08 \pm 0.40\,(\text{stat}) \pm 0.08\,(\text{syst})\,.$$

$$\frac{\mathcal{B}(B_s^0 \to J/\psi K_S^0)}{\mathcal{B}(B^0 \to J/\psi K_S^0)} = 0.0431 \pm 0.0017\,(\text{stat}) \pm 0.0012\,(\text{syst}) \pm 0.0025\,(f_s/f_d)$$

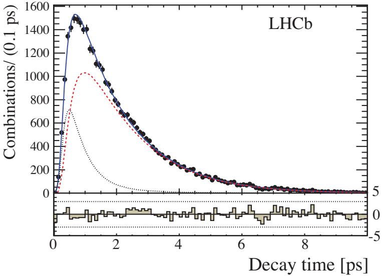
ϕ_s IN $B_s^0 \to J/\psi\,\pi^-\pi^+$

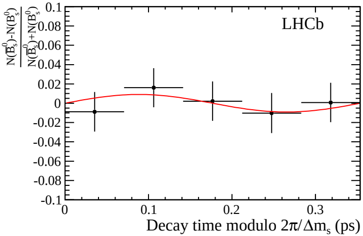




- Follow-up of *CP*-components in $B_s^0 \to J/\psi\,\pi^-\pi^+$ [Phys. Rev. D89 (2014) 092006, arXiv:1402.6248] ➜ $> 97\%$ *CP*-odd
- Tagged time-dependent angular analysis
  - Use opposite and same-side taggers
  - Effective power $3.89 \pm 0.25\%$

ϕ_s IN $B_s^0 \to J/\psi\,\pi^-\pi^+$





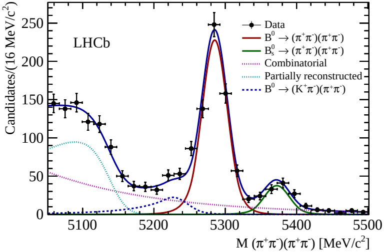
- Follow-up of *CP*-components in $B_s^0 \to J/\psi\,\pi^-\pi^+$ [Phys. Rev. D89 (2014) 092006, arXiv:1402.6248] ➜ $> 97\%$ *CP*-odd
- Tagged time-dependent angular analysis
  - Use opposite and same-side taggers
  - Effective power $3.89 \pm 0.25\%$
- Result: $\phi_s = 75 \pm 67 \pm 8$ mrad
  - $\phi_s = 70 \pm 68 \pm 8$ mrad and $|\lambda| = \left|\frac{q}{p}\frac{\bar{\mathcal{A}}}{\mathcal{A}}\right| = 0.89 \pm 0.05 \pm 0.01$ if *CPV* allowed
- Consistent with SM $\phi_s = -36.3 \pm 1.6$ mrad and $B_s^0 \to J/\psi\,KK$: $\phi_s = 70 \pm 90 \pm 10$

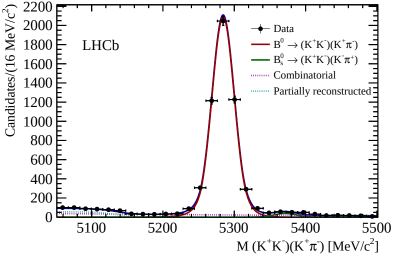
[Phys. Rev. D 87, 112010 (2013), arXiv:1304.2600]

Amplitude analysis of $B^0 \to \rho^0\rho^0$

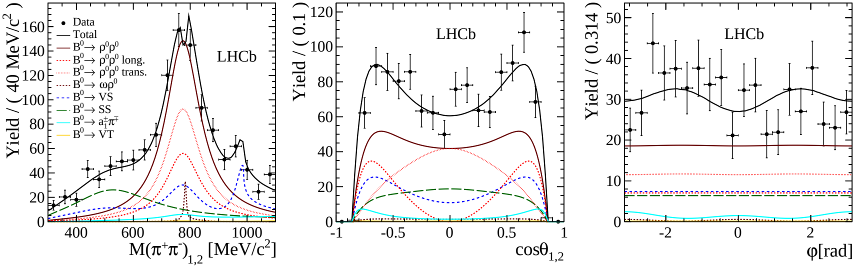
$B \to \rho\rho$ sensitive to α but size of penguin must be determined via isospin analysis of charged and neutral modes.

- Discrepancy in polarisation of $B^0 \to \rho^0\rho^0$: $f_L = 0.12\,^{+0.22}_{-0.26}$ at Belle [PRD89, 072008, arXiv:1212.4015] and $f_L = 0.75\,^{+0.12}_{-0.15}$ at BaBar [PRD78, 071104, arXiv:0807.4977]
- Select $B^0 \to (\pi^+\pi^-)(\pi^+\pi^-)$ with $300 < m_{\pi^+\pi^-} < 1100\ \mathrm{MeV}/c^2$ (no charge ambiguities)
  - ➜ 634 ± 29 decays
  - $B^0 \to \phi K^*$ used as normalisation channel





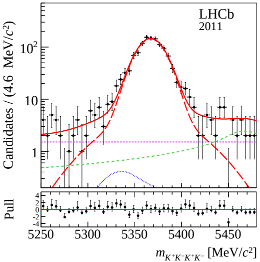
Amplitude analysis of $B^0 \to \rho^0\rho^0$

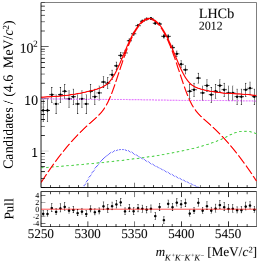


- Amplitude analysis used to determined the VV ($\rho^0\rho^0$ and $\rho^0\omega$), VS ($\rho^0 f_0$ and $\rho^0\pi^+\pi^-$) and VT ($\rho^0 f_2(1270)$).
- $F_L = 0.745\,^{+\,0.048}_{-\,0.058} \pm 0.034$ (same as BaBar, more precise)
- BFs normalised to $B^0 \to \phi K^*$:
  $\mathcal{B}(B^0 \to \rho^0\rho^0) = (0.94 \pm 0.17 \pm 0.09 \pm 0.06) \times 10^{-6}$ and
  $\mathcal{B}(B^0 \to \rho^0 f_0(980)) \times \mathcal{B}(f_0 \to \pi^+\pi^-) < 0.82 \times 10^{-6}$

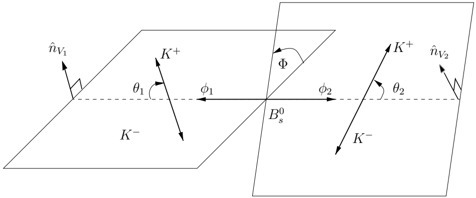
[LHCb, Phys. Rev. D90 (2014) 052011, arXiv:1407.2222]

CP violation in $B^0_s \to \phi\phi$

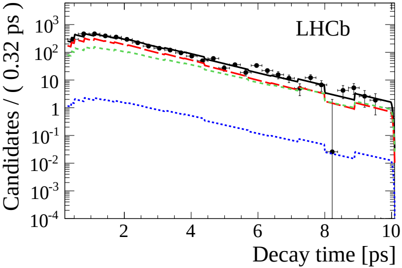


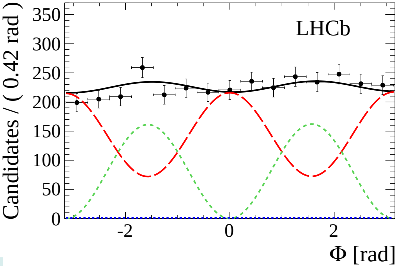


- $B^0_s \to \phi\phi$ is a QCD penguin induced decay. Allows to measure the phase of interference of mixing and decay. SM prediction is $\phi_s = 0$.
- Select almost 4000 decays and do a time-dependent tagged angular analysis
  - ➜ $\epsilon\mathcal{D}^2 \simeq 3.1\%$

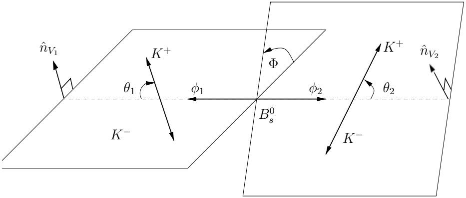


CP violation in $B_s^0 \to \phi\phi$





- $B_s^0 \to \phi\phi$ is a QCD penguin induced decay. Allows to measure the phase of interference of mixing and decay. SM prediction is $\phi_s = 0$.
- Select almost 4000 decays and do a time-dependent tagged angular analysis
  - ➜ $\epsilon\mathcal{D}^2 \simeq 3.1\%$



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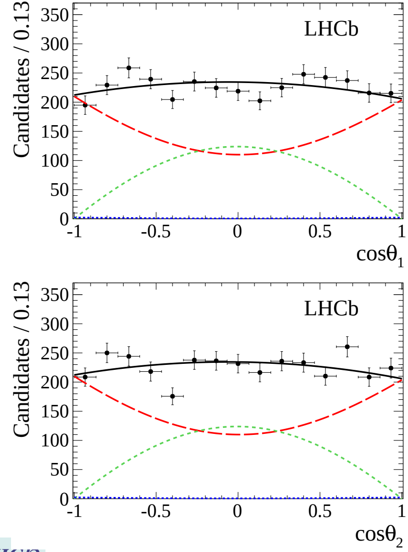

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- Select almost 4000 decays and do a time-dependent tagged angular analysis
  - ➜ $\epsilon\mathcal{D}^2 \simeq 3.1\%$
- $\phi_s = -0.17 \pm 0.15 \pm 0.03$ ($\lambda = 1.04 \pm 0.07 \pm 0.03$)
- T-odd triple product asymmetries:

$$A_U = -0.003 \pm 0.017 \pm 0.006$$
$$A_V = -0.017 \pm 0.017 \pm 0.006$$

$D^0 \to hh$ A_Γ with semileptonics

Measurement of time-dependent CP violation

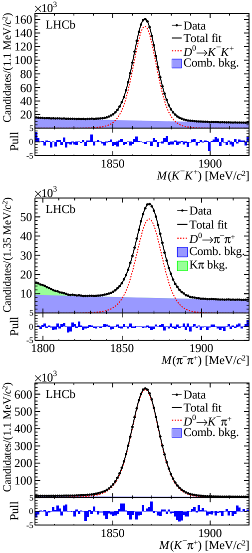
$$A_{CP}(t) \simeq A_{CP}^{\text{dir}} - A_\Gamma \frac{t}{\tau}$$

where A_Γ is the asymmetry of effective limetimes of D^0 and $\overline{D}^0$.

In terms of mixing parameters x and y:

$$A_\Gamma \simeq \left(\frac{1}{2}A_{CP}^{\text{mix}} - A_{CP}^{\text{dir}}\right) y \cos\phi - x \sin\phi$$

- This is measured for $D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$ and $D^0 \to K^-\pi^+$ in semileptonic B decays



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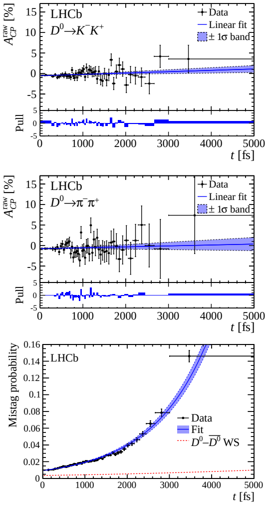
- This is measured for $D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$ and $D^0 \to K^-\pi^+$ in semileptonic B decays
- Lifetime obtained from $D^0\mu$ to $D^0 \to hh$ vertices
- Mistag asymmetry is the largest systematic uncertainty
  - ➜ Mistag larger for larger lifetimes. Checked with $D^0 \to K^-\pi^+$



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In terms of mixing parameters x and y:

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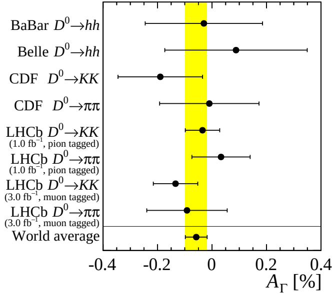
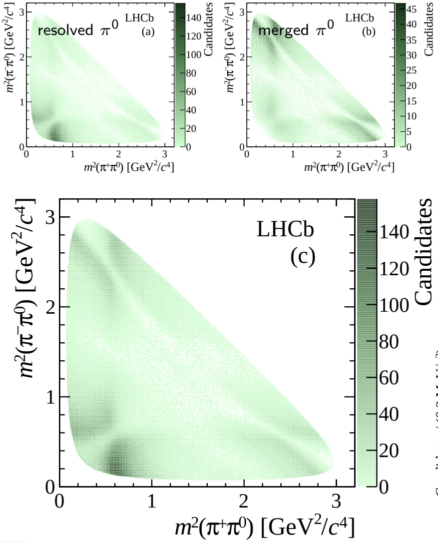
We measure:

$$A_\Gamma(K^+K^-) = (-0.134 \pm 0.077 \,^{+0.026}_{-0.034})\%,$$
$$A_\Gamma(\pi^+\pi^-) = (-0.092 \pm 0.145 \,^{+0.025}_{-0.033})\%$$

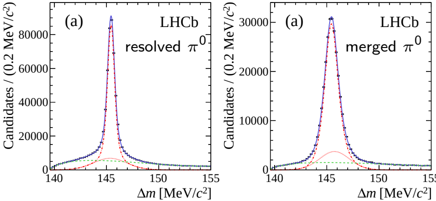


3 fb^{-1} Prompt still to come

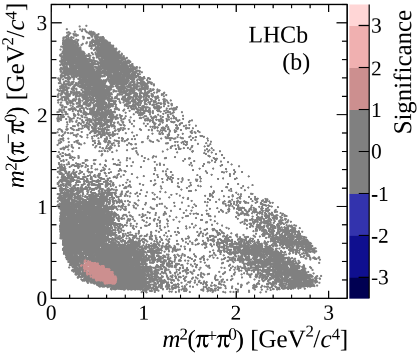
CPV IN $D^0 \to \pi^+\pi^-\pi^0$ WITH ENERGY TEST

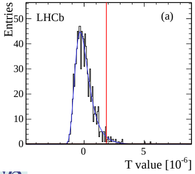


- Model-independent search for local *CP* asymmetry in tagged $D^0 \to \pi^+\pi^-\pi^0$ decays.
  - Use resolved (both γ seen) and merged π^0
  - 2 fb^{-1} at 8 TeV



CPV in $D^0 \to \pi^+\pi^-\pi^0$ with energy test





- Model-independent search for local *CP* asymmetry in tagged $D^0 \to \pi^+\pi^-\pi^0$ decays.
  - Use resolved (both γ seen) and merged π^0
  - 2 fb^{-1} at 8 TeV
- Energy test: Unbinned test of compatibility between D^0 and $\overline{D}^0$ Dalitz distributions
  - Based on distance in phase-space of events
- The data are found to be consistent with the hypothesis of *CP* symmetry with a p-value of (2.6 ± 0.5).