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LHCb overview

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Motivation of flavour physics

- Interactions of the different flavours of the quark and lepton sector
  - Any physics model (SM or NP) has to deal with this
- In SM this is through the Yukawa couplings to the Higgs field and the weak force
  - Misalignment of these give rise to CKM matrix
    - Wide range: $m_u = O(10^{-5})\ m_t$, $|V_{ub}|=O(10^{-3})\ |V_{tb}|$ Why???
- Any NP model with new flavoured particles or flavour breaking interactions must “hide” behind SM interactions
  - NP mass scale VERY large (>~100 TeV)
    - or
  - NP mimics Yukawa couplings (minimal flavour violation)
- In all cases flavour physics will enlighten or constrain us

What can LHCb data do

- Understand the origin of mass
  - Provide evidence for an extended Higgs sector
- Provide a dark matter candidate
  - A SUSY neutralino discovered through loop diagrams of *B* decays
  - A massive Majorana neutrino
- Poke holes in the Standard Model
  - Find inconsistencies that are not (yet) explainable within the SM
- Enlighten us on *CP* violation in Universe
  - Reveal that the *CP* violation from the Yukawa coupling cannot explain observations

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

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

Like sign leptons

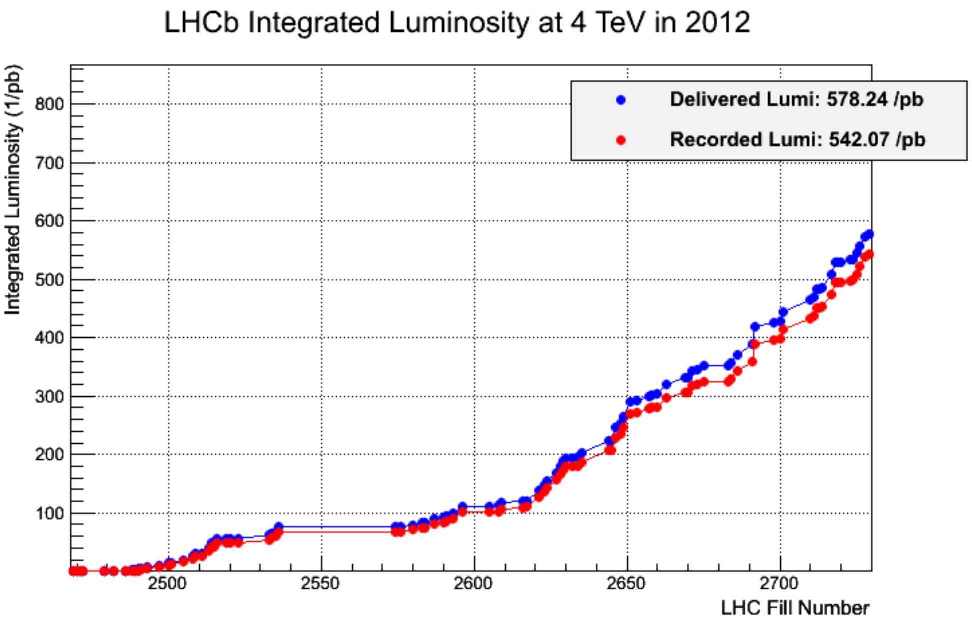
Isospin asymmetry

CPV in B^0_s decays

CPV in charm

Run conditions

- At $\sqrt{s}$=8 TeV 1/200 events contains a b quark
  - ... and we look for branching ratios to below 10^{-9}
- Stable conditions currently are
  - 1274 colliding bunches
  - ~2 interactions in every non-empty collision
  - Instantaneous luminosity 4.0×10^{32} $cm^{-2}s^{-1}$
    - 2 x design
  - Data taking efficiency 92%



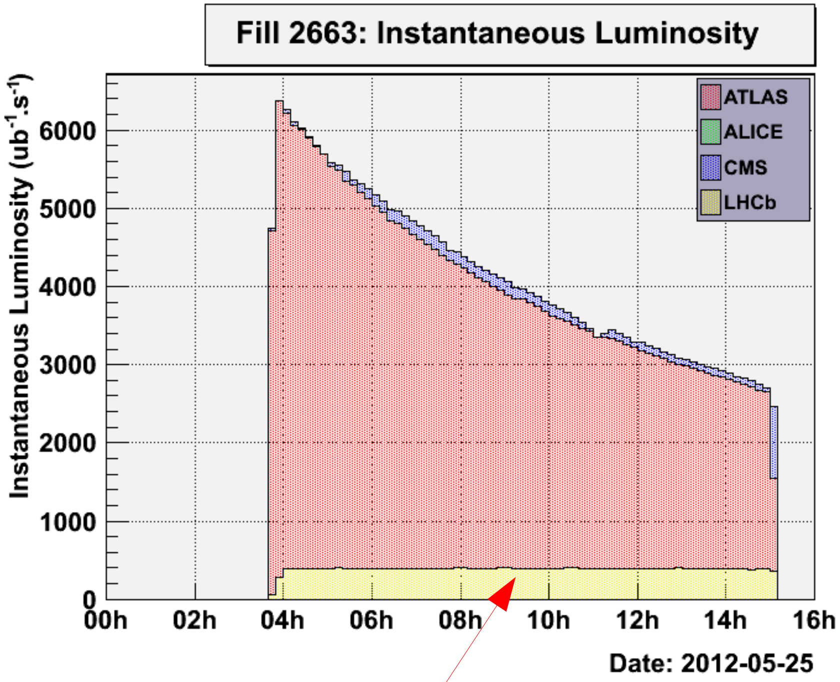
Run conditions

Luminosity levelling

- Continuously adjust beam overlaps in collision region
- Luminosity kept flat at optimal level

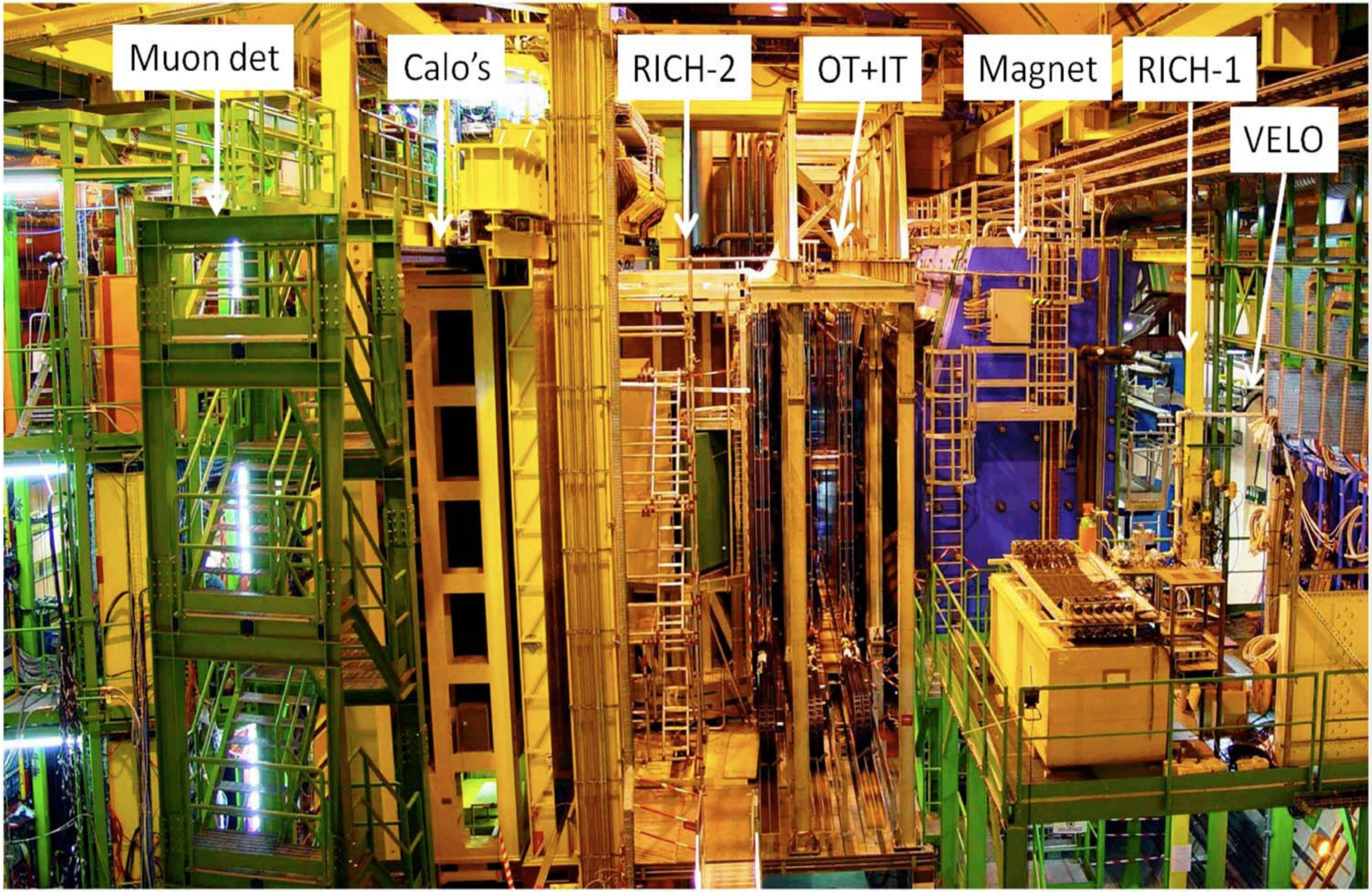
Triggered at two levels

- 14 MHz → 920 kHz in hardware
- 920 kHz → 4.4 kHz in software
  - 2 x design
- Shared equally between beauty and charm triggers

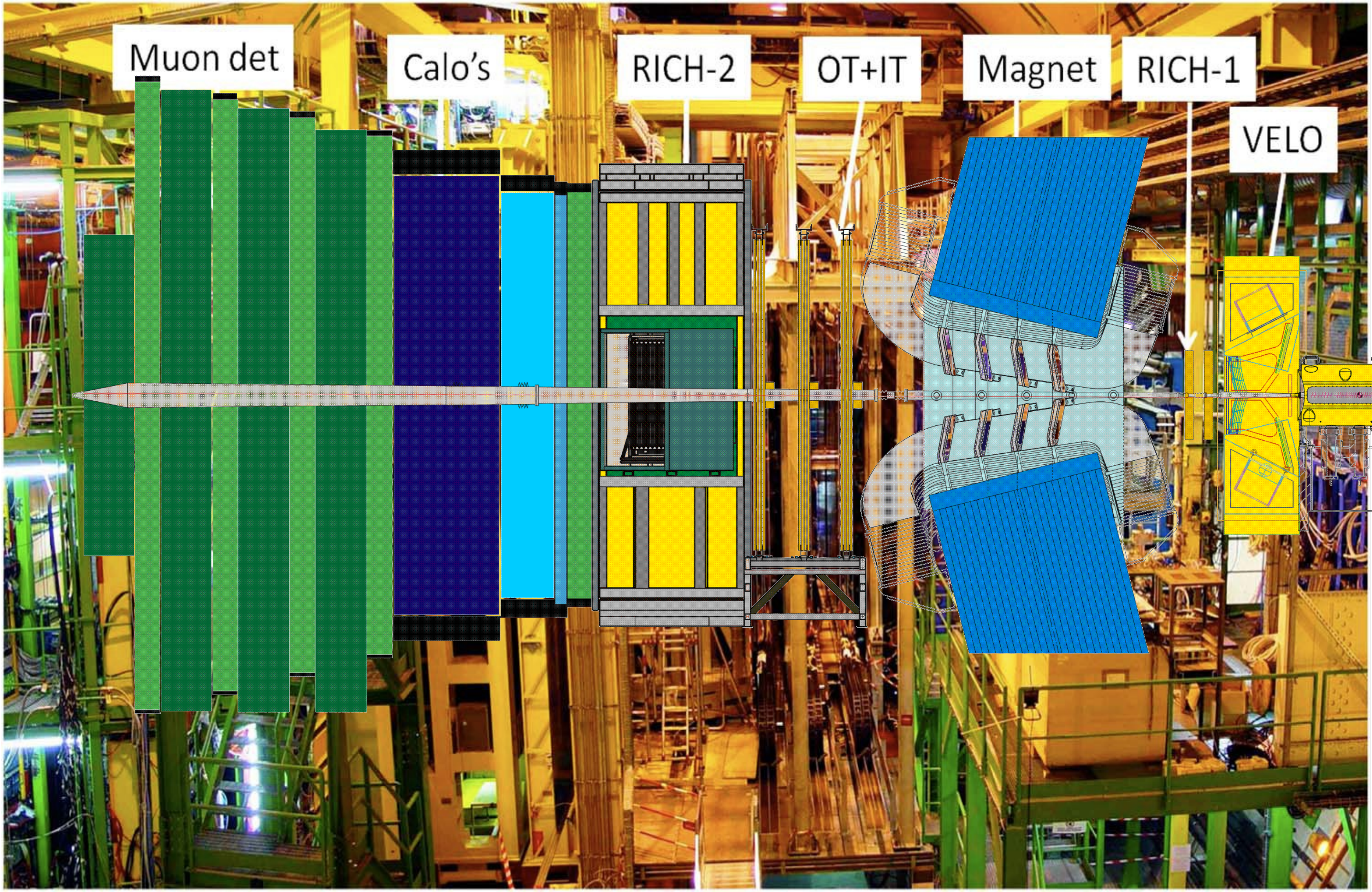


LHCb $\mathcal{L}$ is flat for 9 hours

LHCb layout



LHCb layout



Rare decays

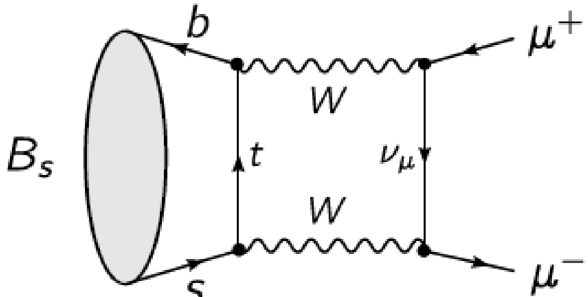
Search for $B^0_s \rightarrow \mu^+\mu^-$

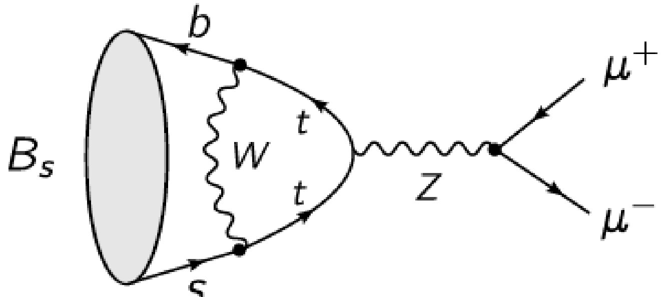
Decay a very sensitive probe for Higgs sector of any New Physics model

SM BR predicted to 10% precision at $3.2 \pm 0.2 \; 10^{-9}$ *

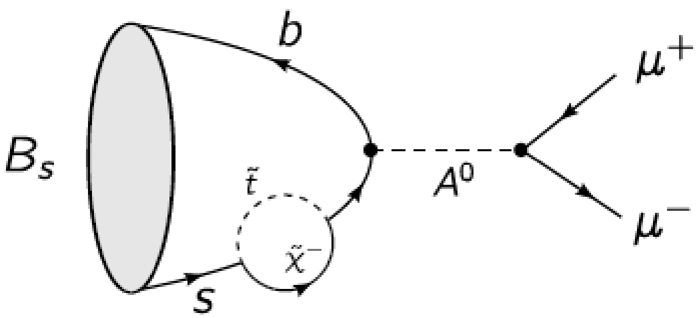
arXiv:1007.5291, arXiv:1204.1735

Small due to $|V_{ts}|$ and helicity suppression





In SUSY there can be a dramatic enhancement

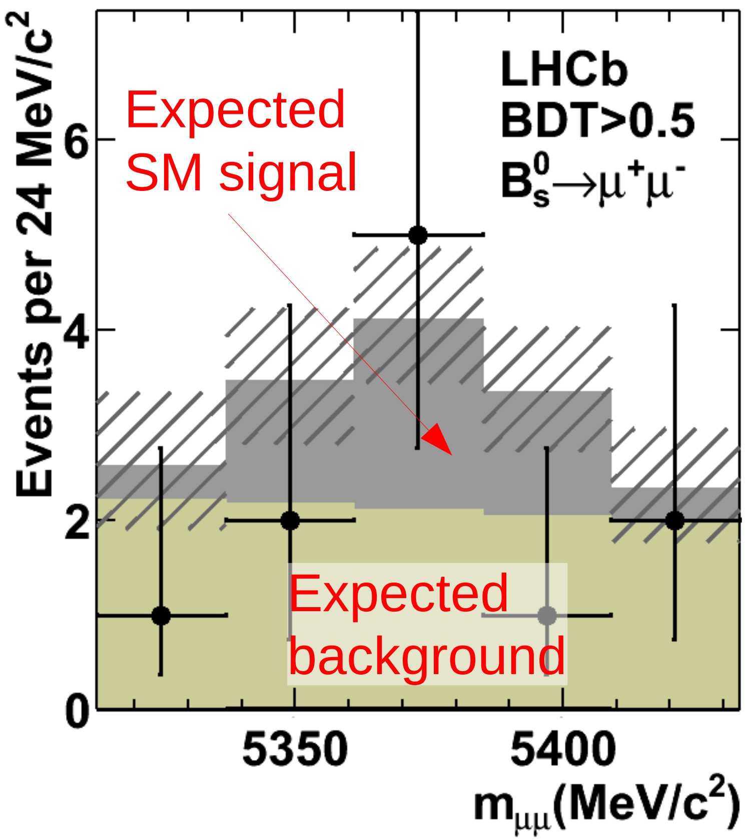


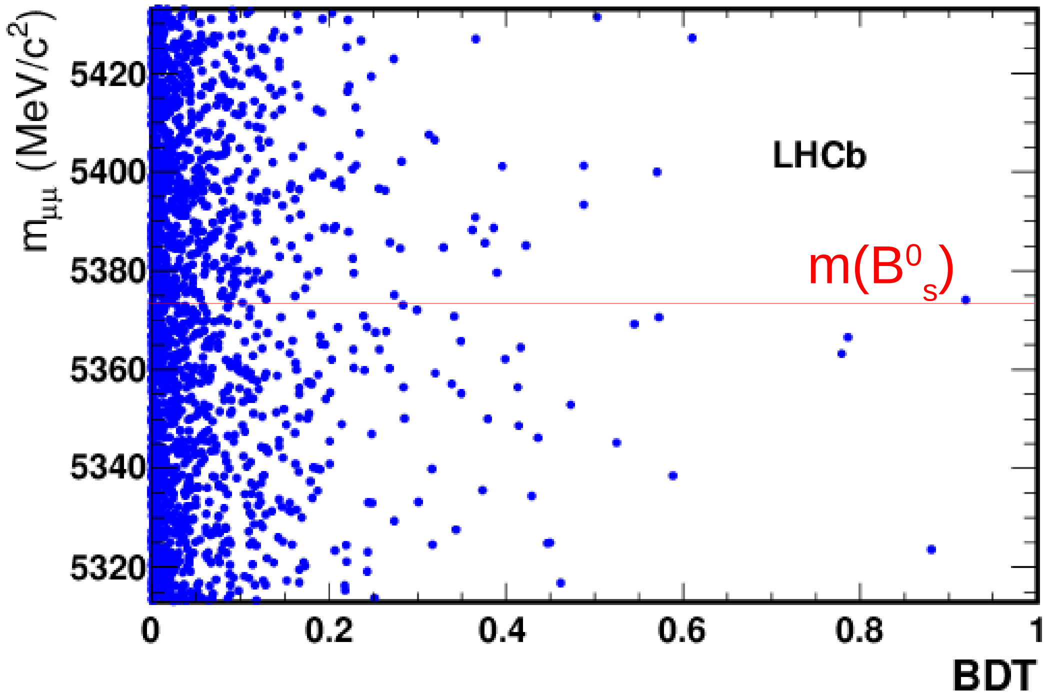
* 3.2 at *t*=0; becomes 3.5 time integrated

Search for $B^0_s \to \mu^+\mu^-$

Search carried out with full 2011 data

Signal classified according to output of multivariate classifier and invariant mass



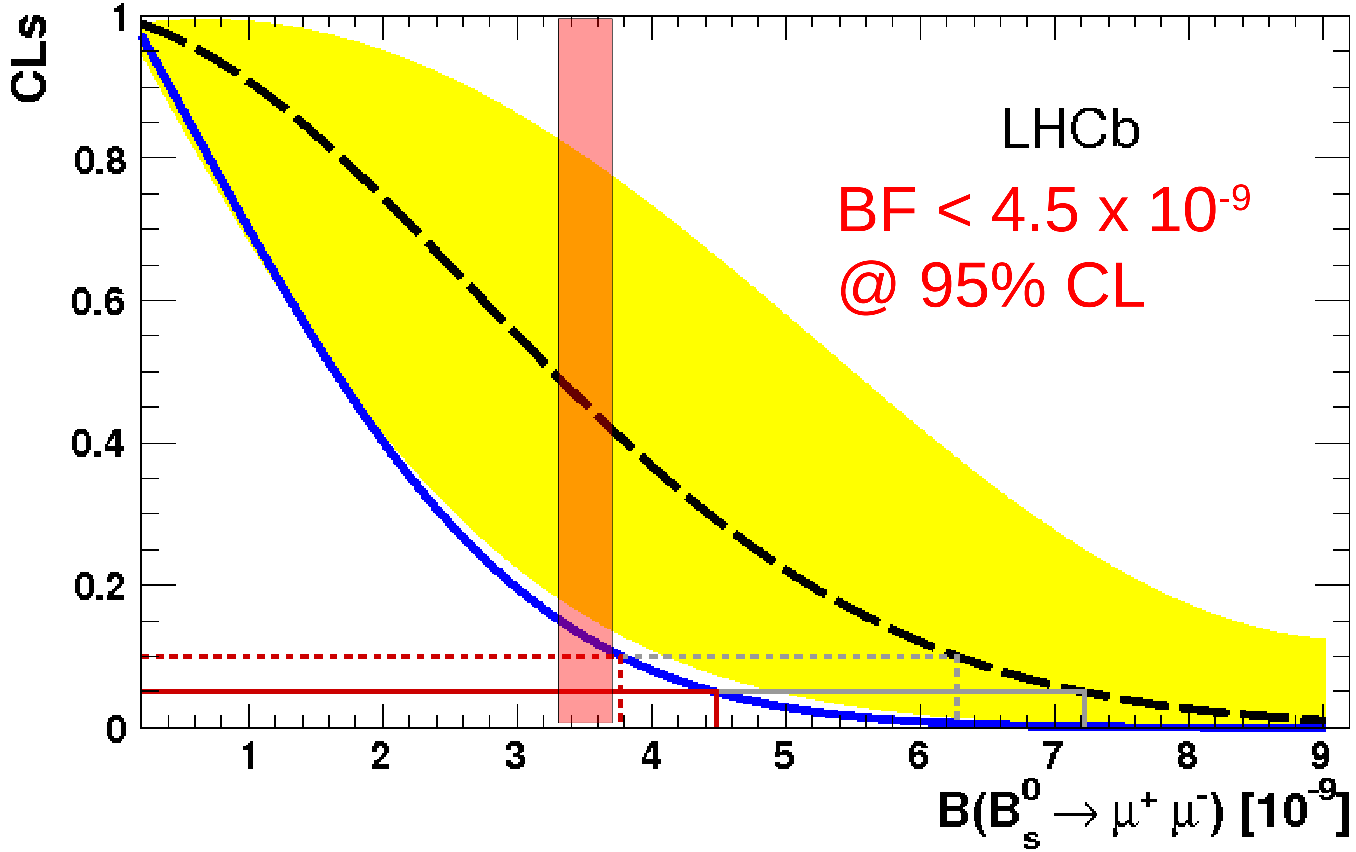


$B^0_s \to \mu^+\mu^-$ branching fraction limit

arXiv:1203.4493

- Upper limit found on number of signal events
  - Translated into limit on branching fraction via control channels

Time integrated SM prediction



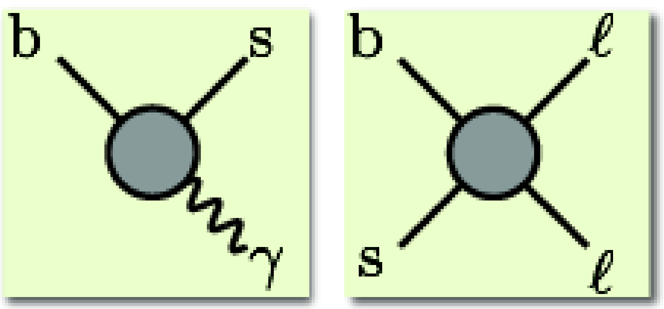
The penguin laboratory

The decay $B^0 \to K^{*0}\mu^+\mu^-$, $K^{*0} \to K^-\pi^+$ is in the SM only possible at loop level

- This means that SM and NP processes are put on equal footing.

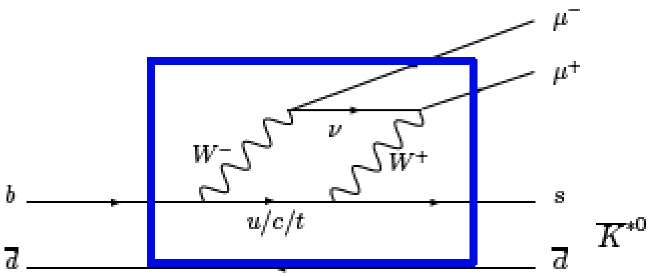
Angular analysis of 4-body $K^-\pi^+\mu^+\mu^-$ final state brings large number of observables

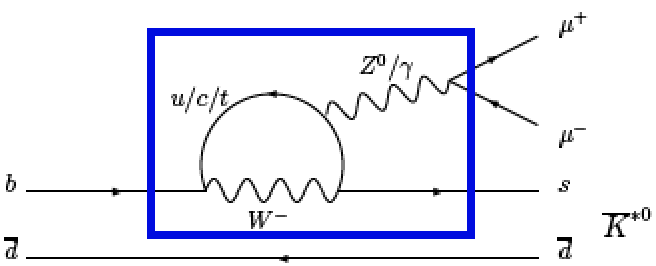
Interference between these



$O_{7\gamma}$ $O_{9,10}$

... and their right-handed counterpart



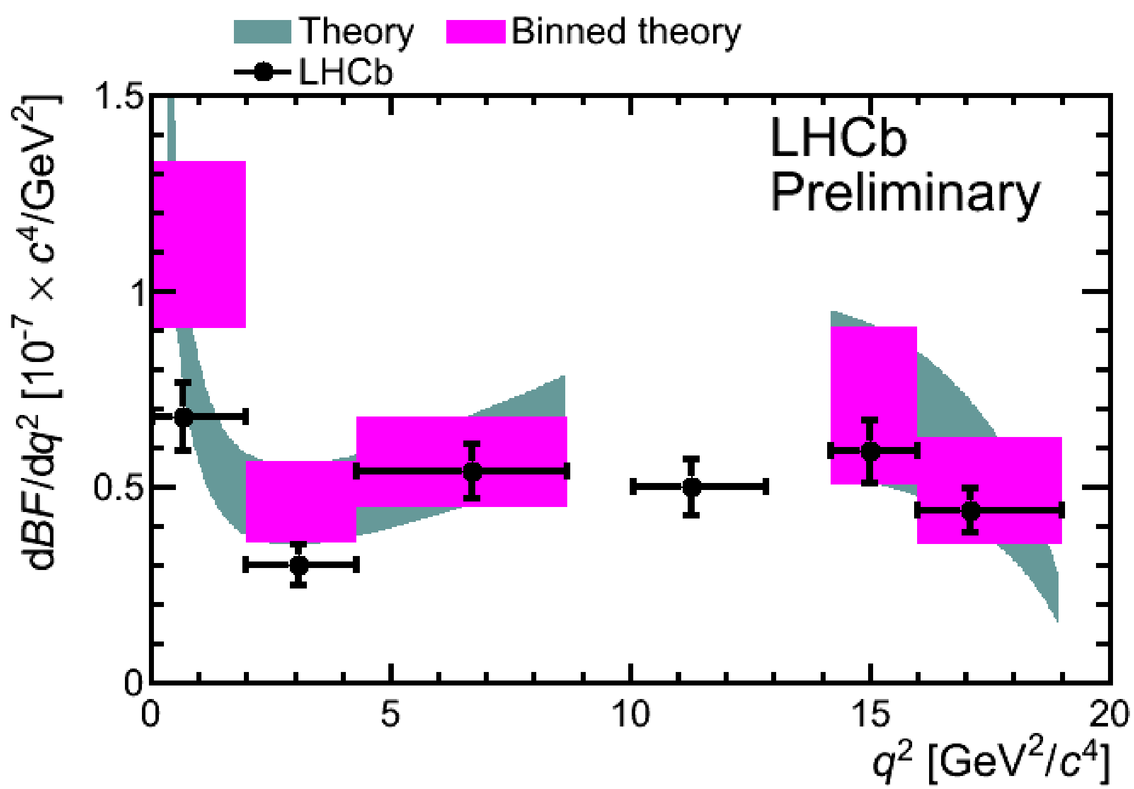


Differential branching fraction

LHCb-CONF-2012-008

Measure BF as a function of dimuon mass squared (q^2)

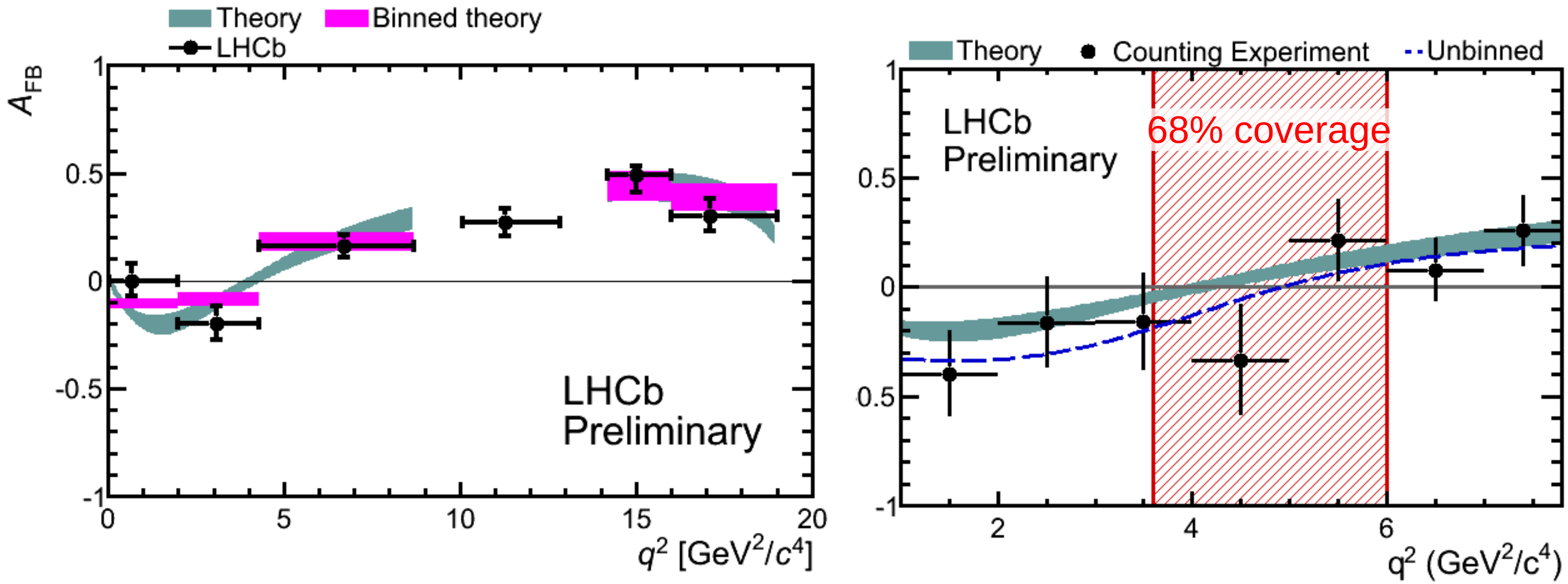
- Based on full 2011 data
- Use veto on the tree level $B^0 \rightarrow J/\psi K^{*0}$, $\psi(2S)K^{*0}$ decays
- Compare to theory from arXiv:1105.0376



Forward backward asymmetry

LHCb-CONF-2012-008

- Now measure the forward-backward asymmetry of the muons
  - Depends on interference between O_7 and O_9
  - Zero crossing point well predicted in SM and sensitive to new physics
    - Theory errors still much smaller than experimental errors



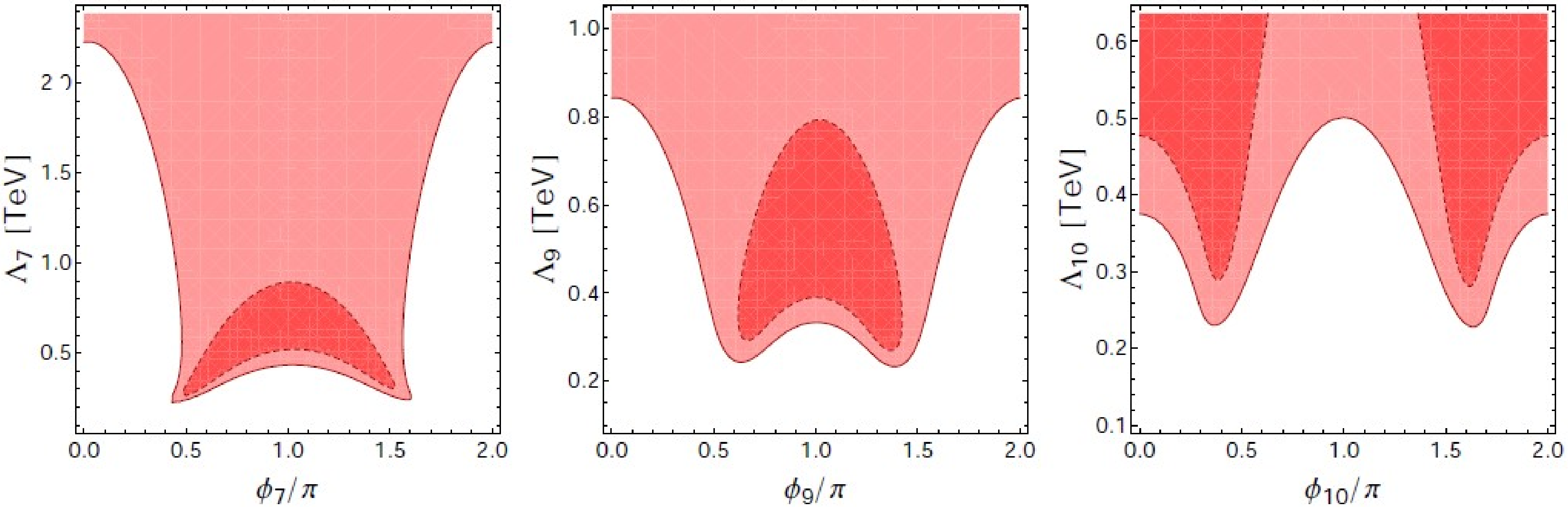
Constraints on new physics

Measurements of $B \to \mu\mu$, $B \to K^*\mu\mu$, $B \to X_s ll$, $b \to s\gamma$ sets limits on the mass scale of non-SM contributions

Altmannshofer, Paradisi , Straub: JHEP 04 (2012) 008 + updates

$$\mathscr{L} = \mathscr{L}_{\text{SM}} - \sum_{j=7,9,10} \frac{V_{tb}V_{ts}^*}{16\pi^2} \frac{e^{i\phi_j}}{\Lambda_j^2} \mathcal{O}_j$$

~loop level CKM-like flavour violation



Nothing with SM type flavour couplings below O(400 GeV)

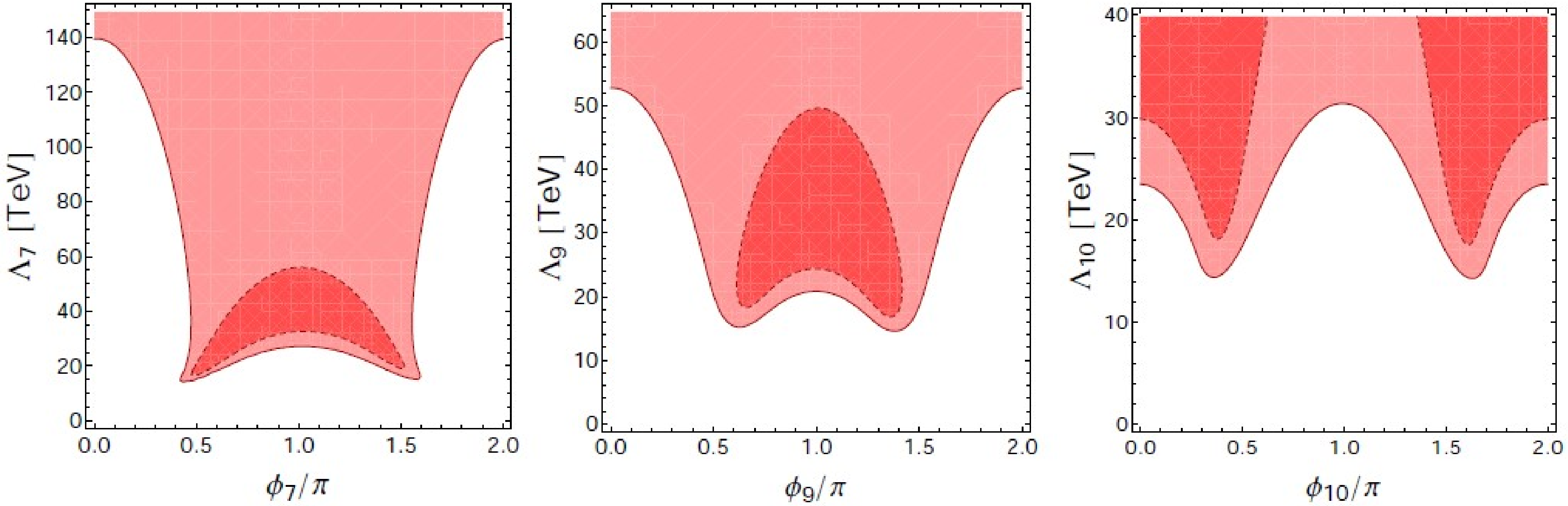
Constraints on new physics

If on the other hand considering tree level processes with O(1) couplings

Limits on this are in excess of 15 TeV!

$$\mathscr{L} = \mathscr{L}_{\mathrm{SM}} + \sum_{j=7,9,10} \frac{e^{i\phi_j}}{\Lambda_j^2} \mathcal{O}_j$$

~tree level generic flavour violation

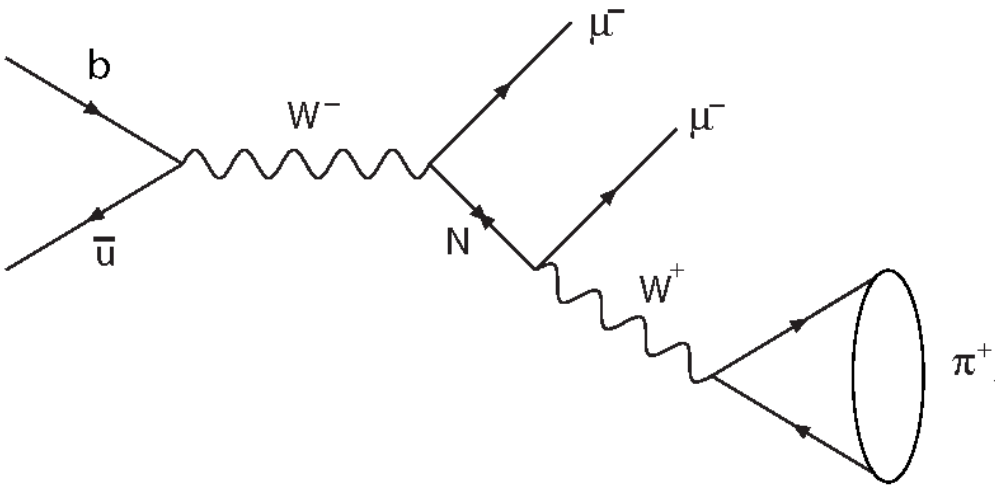


Majorana neutrinos

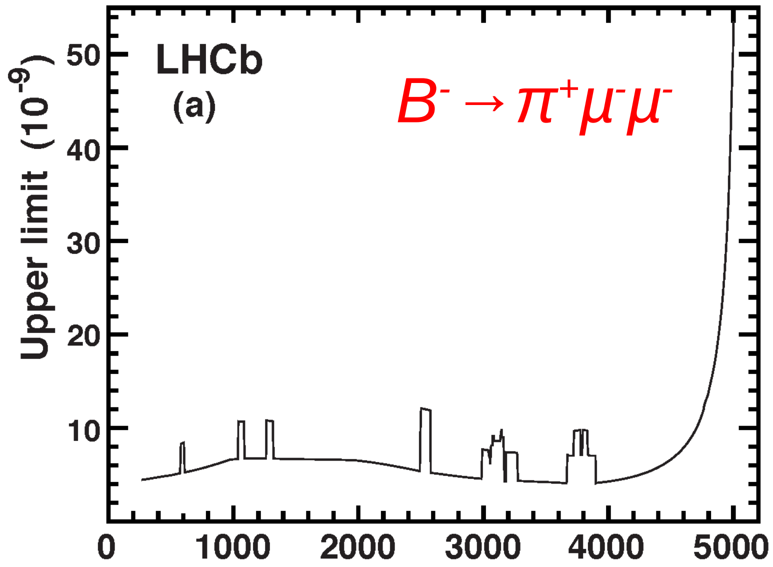
Phys. Rev. D 85 (2012) 112004

Phys. Rev. Lett. 108 (2012) 101601

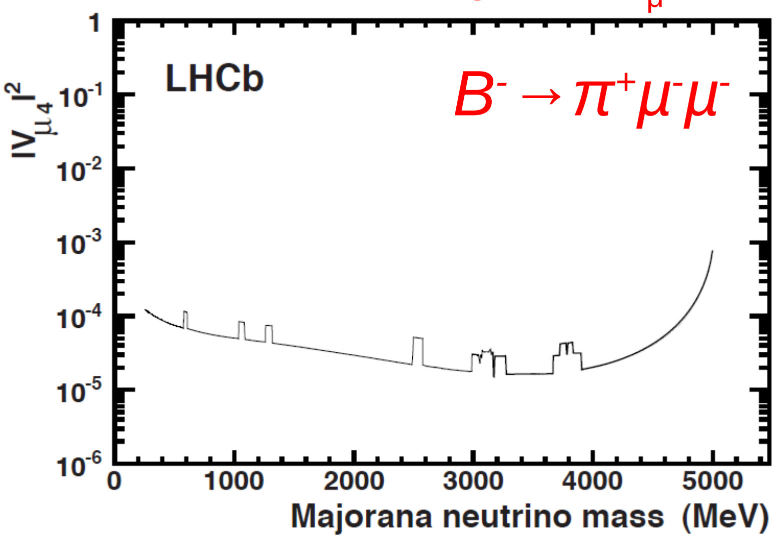
- Like sign leptons could be sign of GeV mass Majorana neutrino
  - Searches performed in 2010 and early 2011 data



BF limit as function of m_υ



Limit on mixing with υ_μ



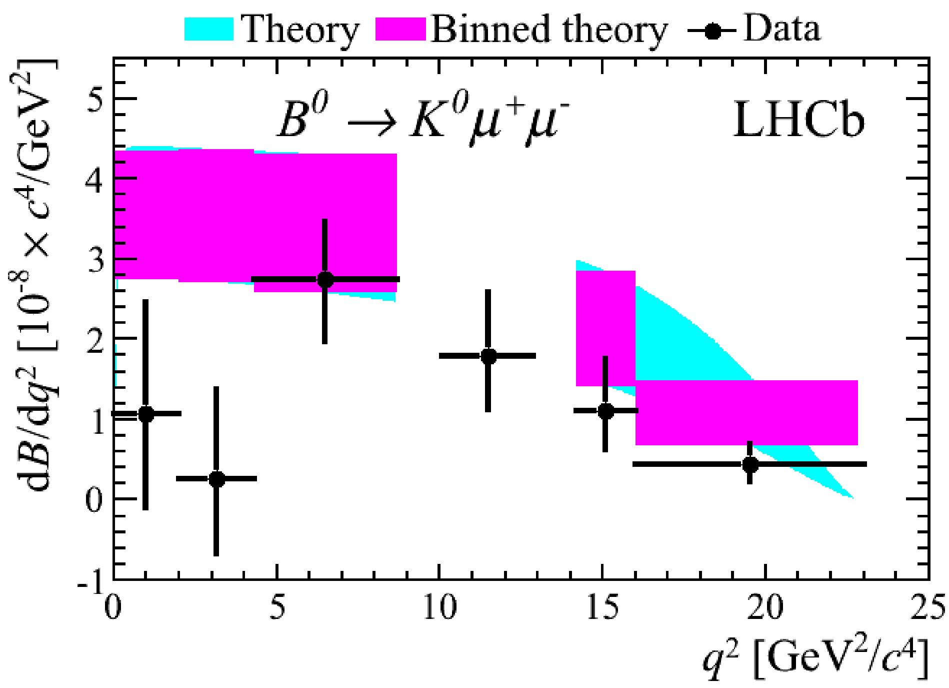
$B \to K^{(*)}\mu^+\mu^-$ isospin analysis

arXiv:1205.3422

Can look at the isospin asymmetry in rare decays

$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

In full 2011 data, measure individual differential branching fractions



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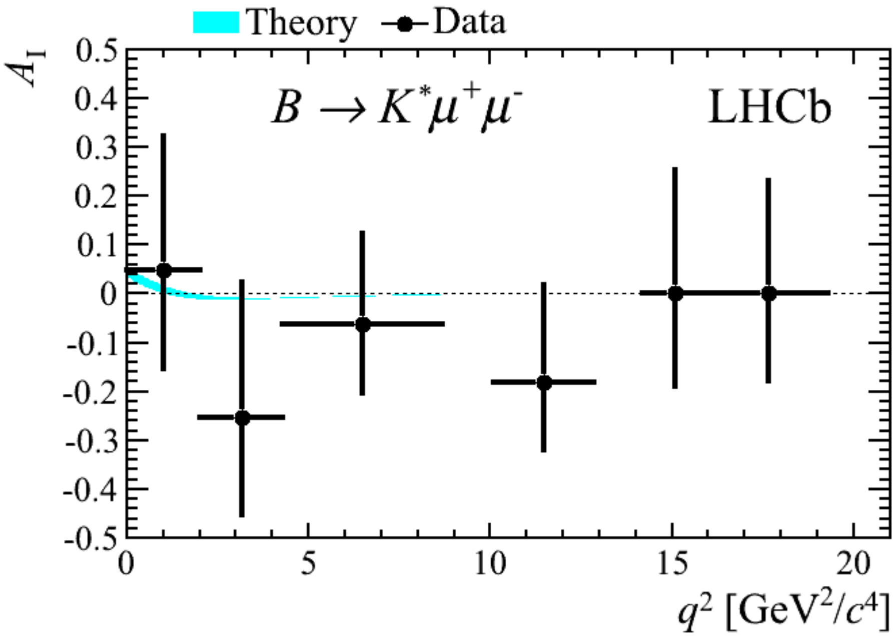
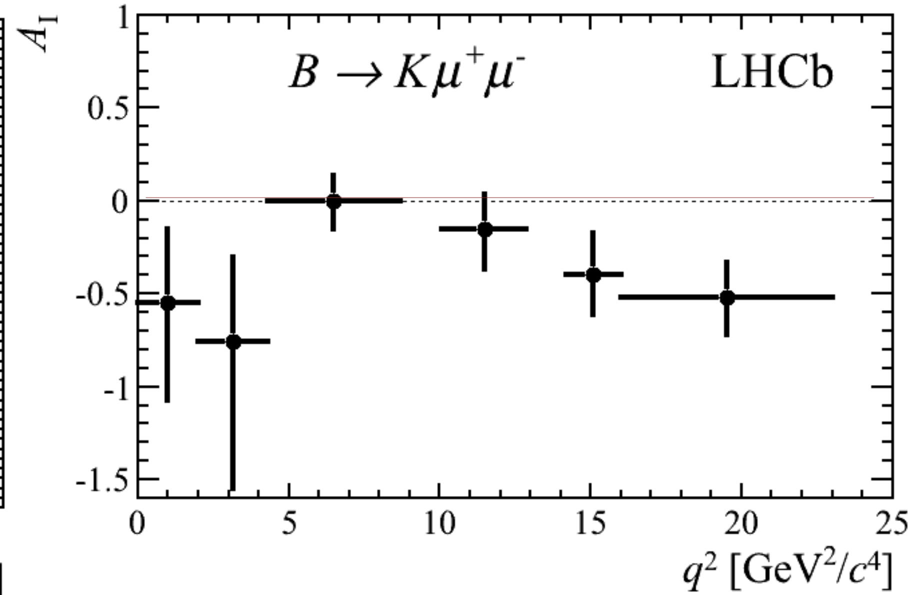
Then form ratios





Result for $B \to K^*\mu^+\mu^-$ in agreement with SM theory

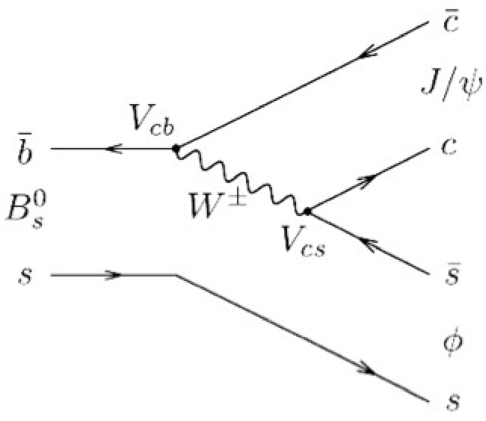
But $B \to K\mu^+\mu^-$ differs from naive zero expectation of above 4σ

No theory explanation of this yet, neither in or outside SM

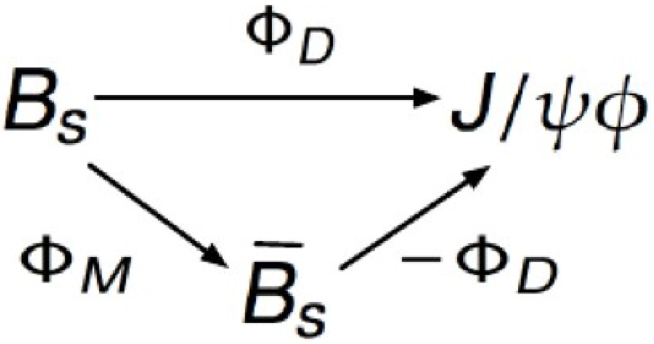
CP violation

CP violation in $B^0_s \to J/\psi\ \varphi$

- Decay is is SM dominated by tree level diagram
  - Small *CPV* in SM arises from phase of B^0_s oscillations
- New physics phases in box diagram could dominate over SM contribution



- Measurement combines
  - Flavour tagging
  - Fast B^0_s oscillation measurement
  - Angular analysis

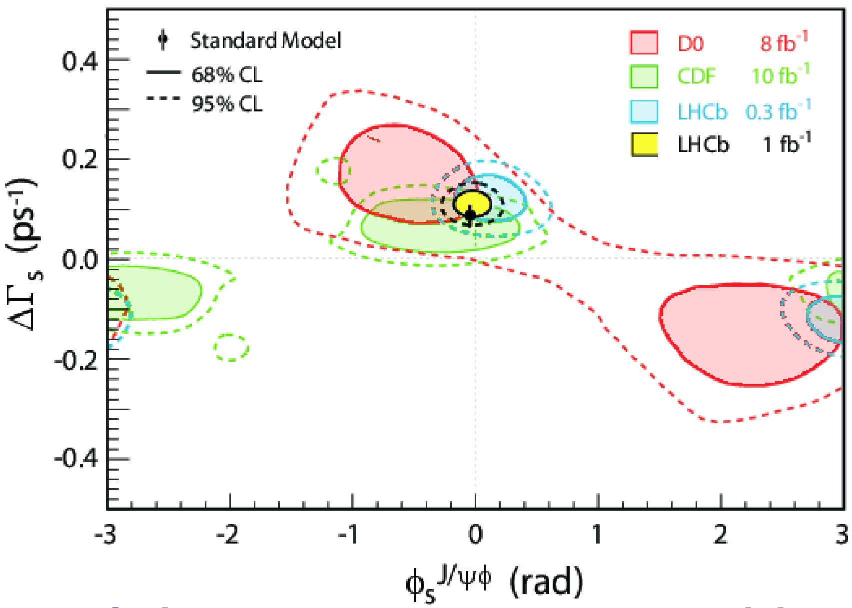


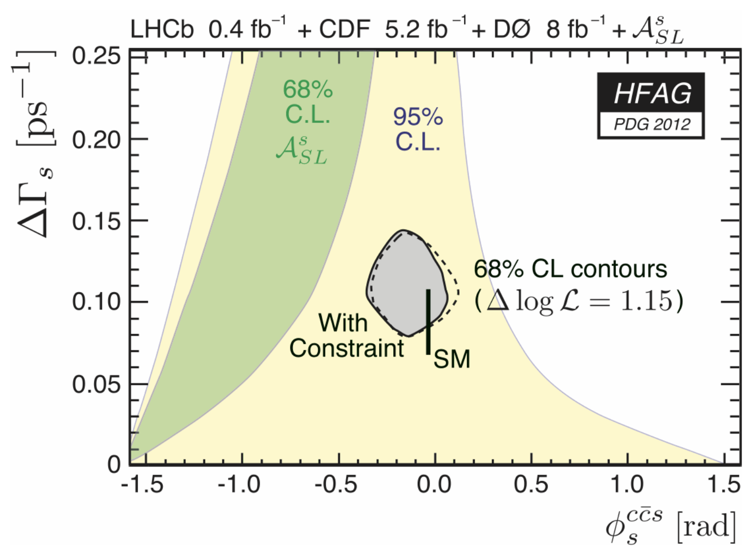
CP violation in B^0_s oscillations

LHCb-CONF-2012-002
PRL 108 (2012) 241801

Measurement with 2011 data confirms that CPV is small in B^0_s oscillations

- Exploiting interference with K^+K^- S-wave system selects SM solution of ambiguity





Result in poor agreement with semileptonic CP asymmetry result from D0

CP violation in Charm

PRL 108, 111602 (2012)

Tag the D^0 flavour through the charge of the pion in the $D^{*+} \rightarrow D^0\pi^+$ decay

Form the *CP* asymmetry

$$A_{CP}(f;t) \equiv \frac{\Gamma(D^0(t) \to f) - \Gamma(\bar{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\bar{D}^0(t) \to f)}$$

Look at singly Cabibbo suppressed decays $D^0 \rightarrow \pi^+\pi^-$ and $D^0 \rightarrow K^+K^-$

Looking at their difference

$$\Delta A_{CP} \equiv A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+)$$

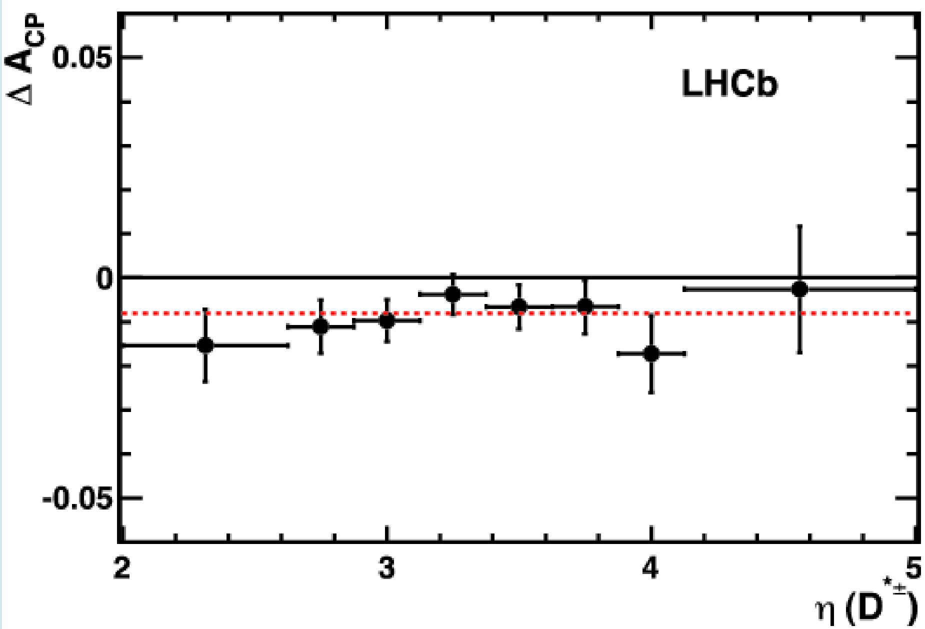
Makes the unknown D^{*+}/D^{*-} production asymmetry cancel

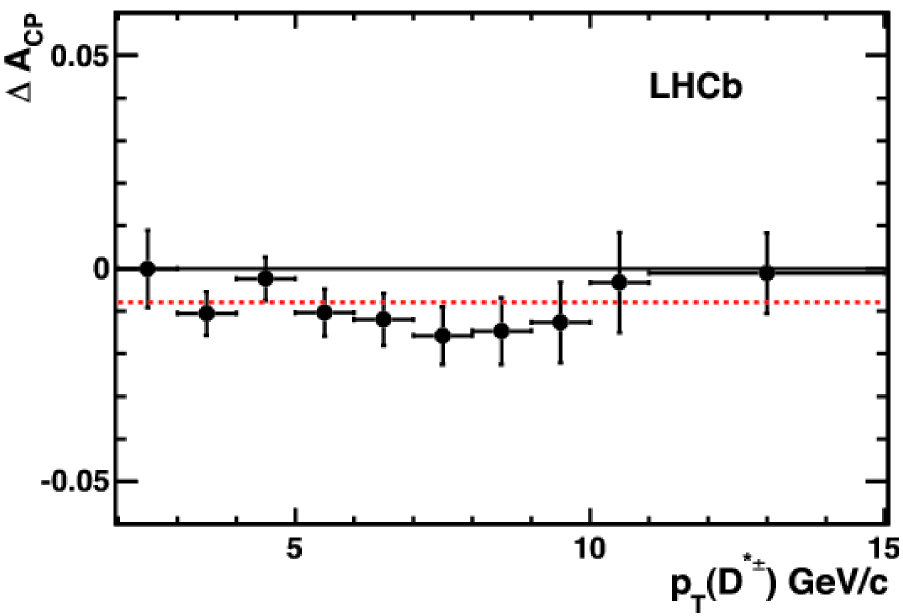
Analysing data with both magnet polarities makes detector asymmetries cancel

CP violation in Charm

PRL 108, 111602 (2012)

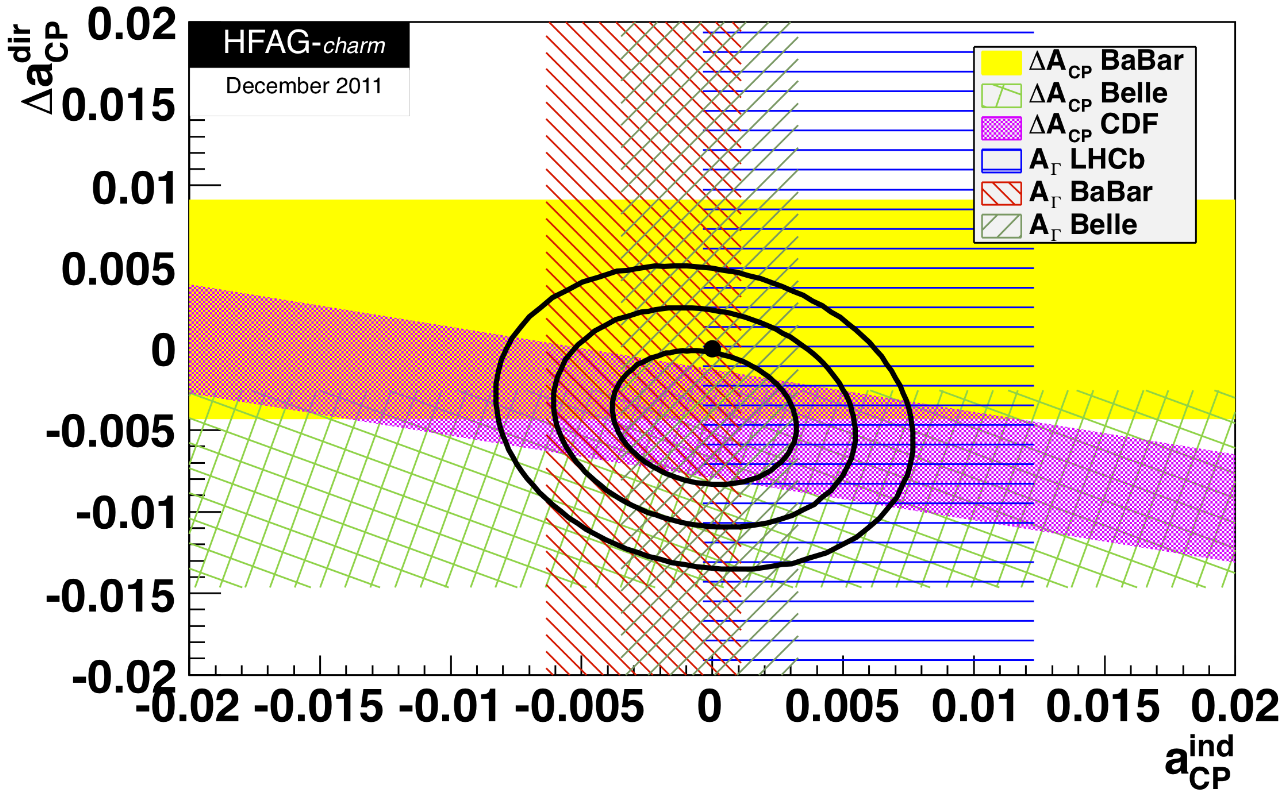
- From analysing 2/3 of 2011 data we determine
  - ΔA_{CP} = [-0.82 ± 0.21(stat) ± 0.11(syst)]%
  - Differs from *CP* conserving hypothesis at 3.5σ
- Cross checks
  - Value should not vary with kinematics of the D^{*+}





CP violation in Charm

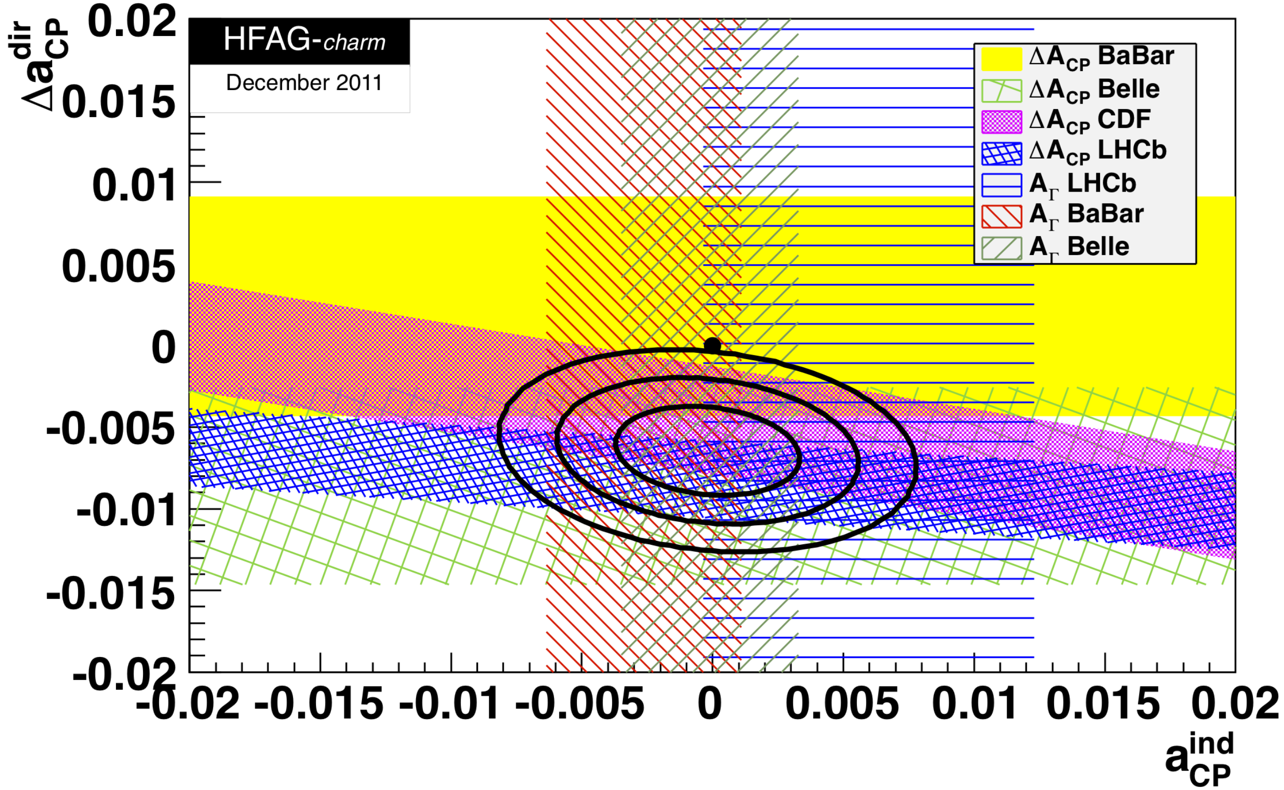
Results from CS Charm decays before LHCb measurement



Plots compiled by HFAG charm group

CP violation in Charm

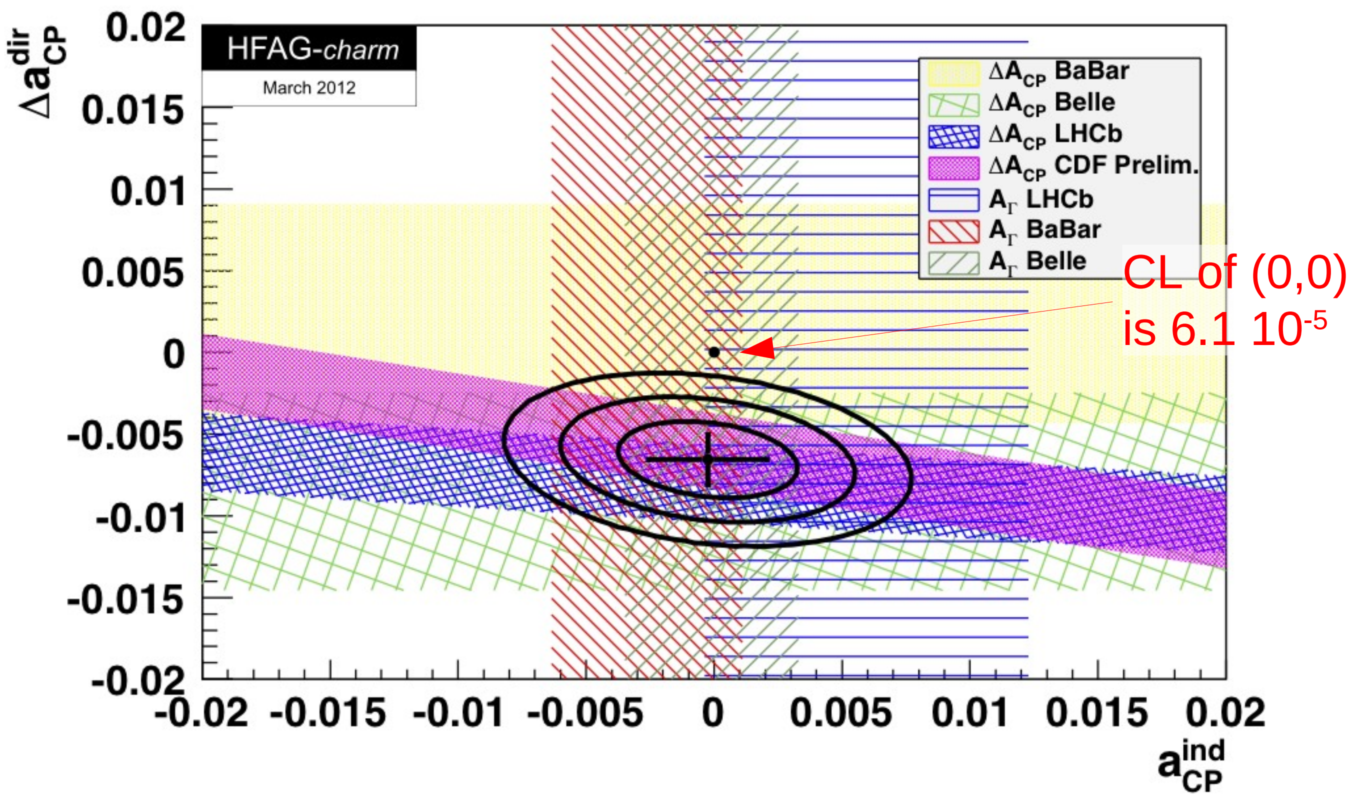
... with LHCb measurement



Much active theory work on explanations inside and outside the SM

CP violation in Charm

... and further confirmed by updated CDF measurement



Much active theory work on explanations inside and outside the SM

Conclusion

- The LHCb experiment is working very well
- Results in all areas of flavour physics
  - Putting strong constraints on NP models
  - Isospin and charm CPV results await theoretical interpretation
- Other LHCb talks
  - Plamen Hopchev: LHCb upgrade
  - Aurelien Martens: Charmless B decays
  - Barbara Sciascia: Rare B decays as a probe for new physics
  - Andrea Contu: Production and spectroscopy at LHCb
- All LHCb results
  - Submitted papers http://cern.ch/go/S7fh
  - Preliminary results http://cern.ch/go/zMg7