Status of LHCb:

Recent Physics results
&
Future Plans

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Acknowledgment

I am grateful to these colleagues for their help with this talk; Also benefitted and borrowed from their recent talks:

Pierluigi Campana – LHCb Spokesperson
Sheldon Stone (talk, Chicago Workshop on LHC)
Burkhard Schmidt (talk, HCP 2012)
Olivier Callot (talk, HCP 2012)

Outline

- LHCb detector
- Highlights of recent physics results
- Upgrade plans

Primary Goals of Flavor Physics in the LHC era

- If New Physics is found at LHC, determining its flavor structure will be amongst the next major goals of the field:

New CPV phases, right-handed currents, Lepton Flavor Violation,….

- ☐ A broad set of loop-dominated flavor processes are shown to be highly sensitive to the parameters of most NP scenarios.
- ☐ Current flavor data already severely constrains many NP models.

- If no New Physics is found at the TeV energy regime:

→ Flavor physics would provide a window for physics at higher scales

Some of the key experimental handles:

- FCNC processes
- Precision CKM parameters (aiming for O(1%) level)
- Lepton Flavor Violation

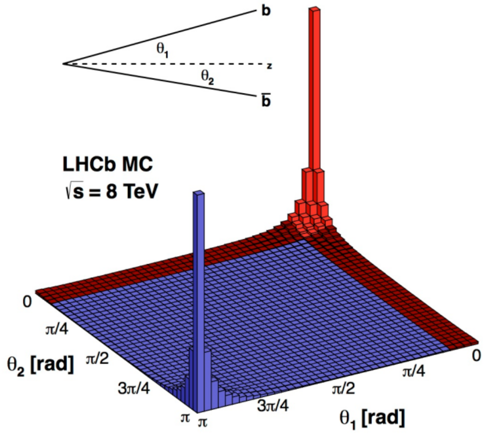
The LHCb Detector

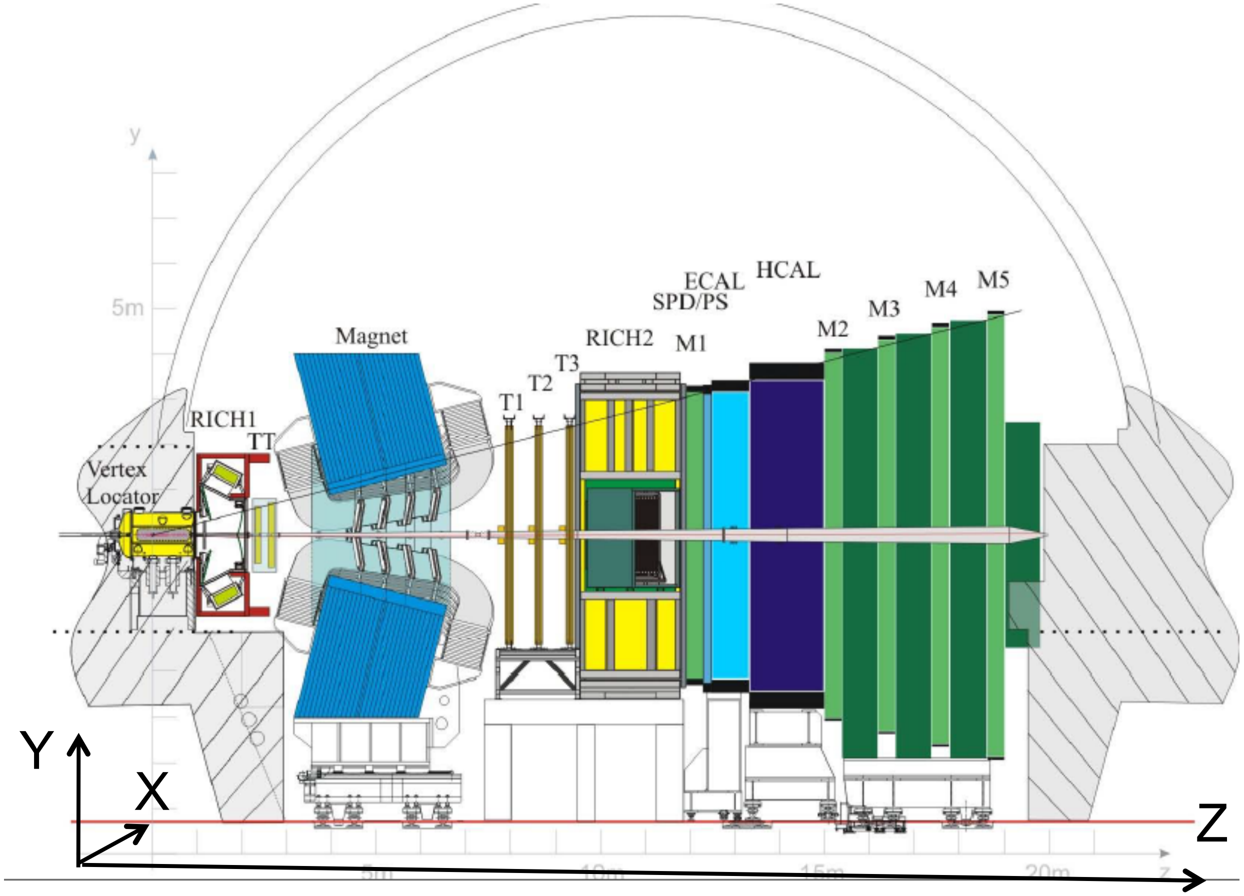
A Single Arm Spectrometer at LHC

Acceptance: $2 < \eta < 5$

σ_{inel}~70-80 mb
σ_{cc}~6 mb (7 TeV)
σ_{bb}~280 μb (7 TeV)
σ_{bb}~500 μb (14 TeV)

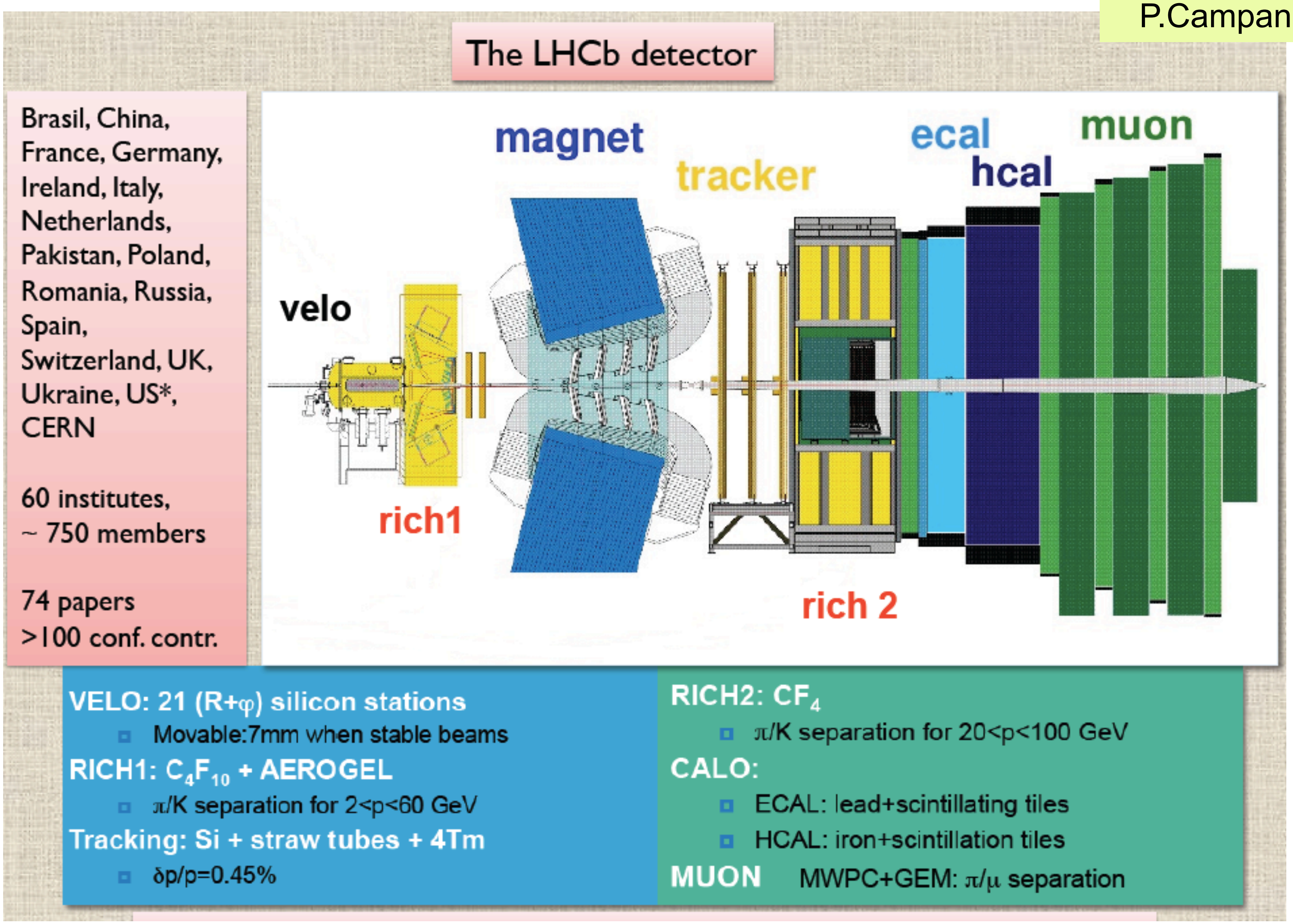
$b\overline{b}$ peaked forward or backward with ~25% in detector acceptance





Access to all species of B hadrons

P.Campana



The LHCb detector

Brasil, China, France, Germany, Ireland, Italy, Netherlands, Pakistan, Poland, Romania, Russia, Spain, Switzerland, UK, Ukraine, US*, CERN

60 institutes,
~ 750 members

74 papers
>100 conf. contr.

VELO: 21 (R+φ) silicon stations
- Movable:7mm when stable beams

RICH1: C_4F_{10} + AEROGEL
- π/K separation for 2<p<60 GeV

Tracking: Si + straw tubes + 4Tm
- $\delta p/p=0.45\%$

RICH2: CF_4
- π/K separation for 20<p<100 GeV

CALO:
- ECAL: lead+scintillating tiles
- HCAL: iron+scintillation tiles

MUON MWPC+GEM: π/μ separation

US Participation: Pioneered by Syracuse U. (since:2005);
Recently: U. Cincinnati (since 5/2012), U. Maryland (since 9/2012), MIT(since 11/2012)

Trigger

- L0 Hardware trigger:
  - Require High Pt μ, e, γ or hadron candidates: HCAL (>3.6 GeV), ECAL (>2.6 GeV), Pt muon (>1.4 GeV) or di-muons
  - Maximum allowed rate is limited to ~1MHz

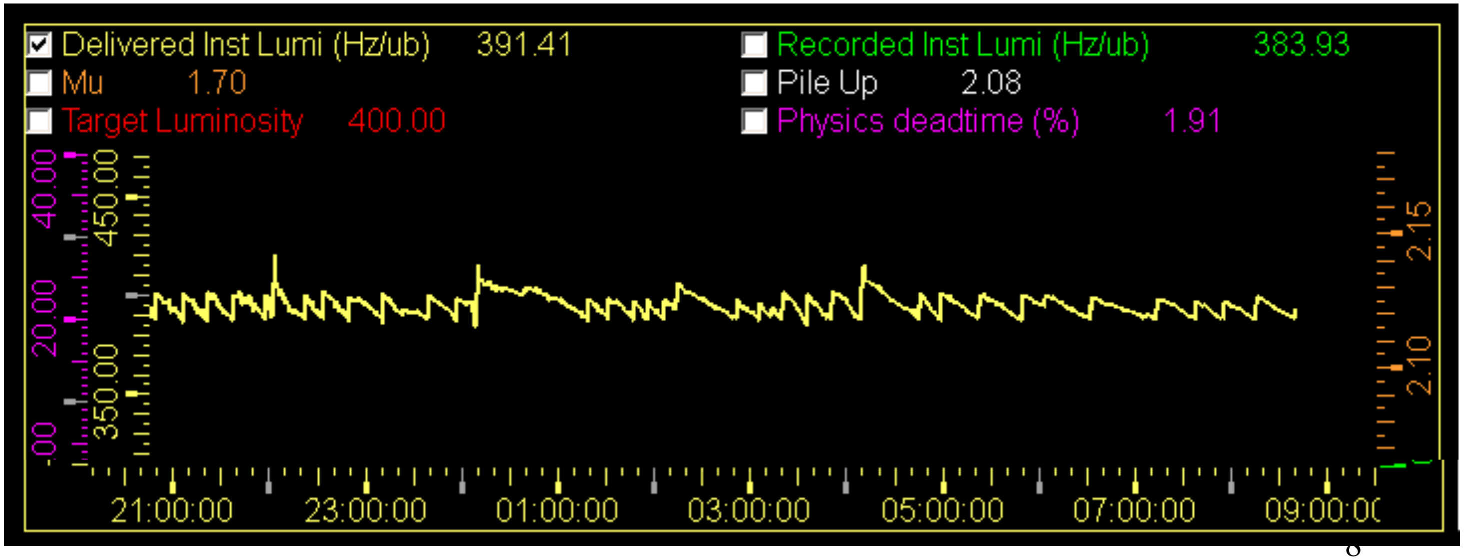
- High Level (software) Trigger (HLT):
  - HLT1: topological trigger & cuts on impact parameter (50 kHz)
  - HLT2: Select inclusive or exclusive channels using full track reconstruction.
  - Total rate ~5 kHz to permanent storage.
  - 25% of the input events are deferred; stored on disk and processed during inter-fills.

Operation

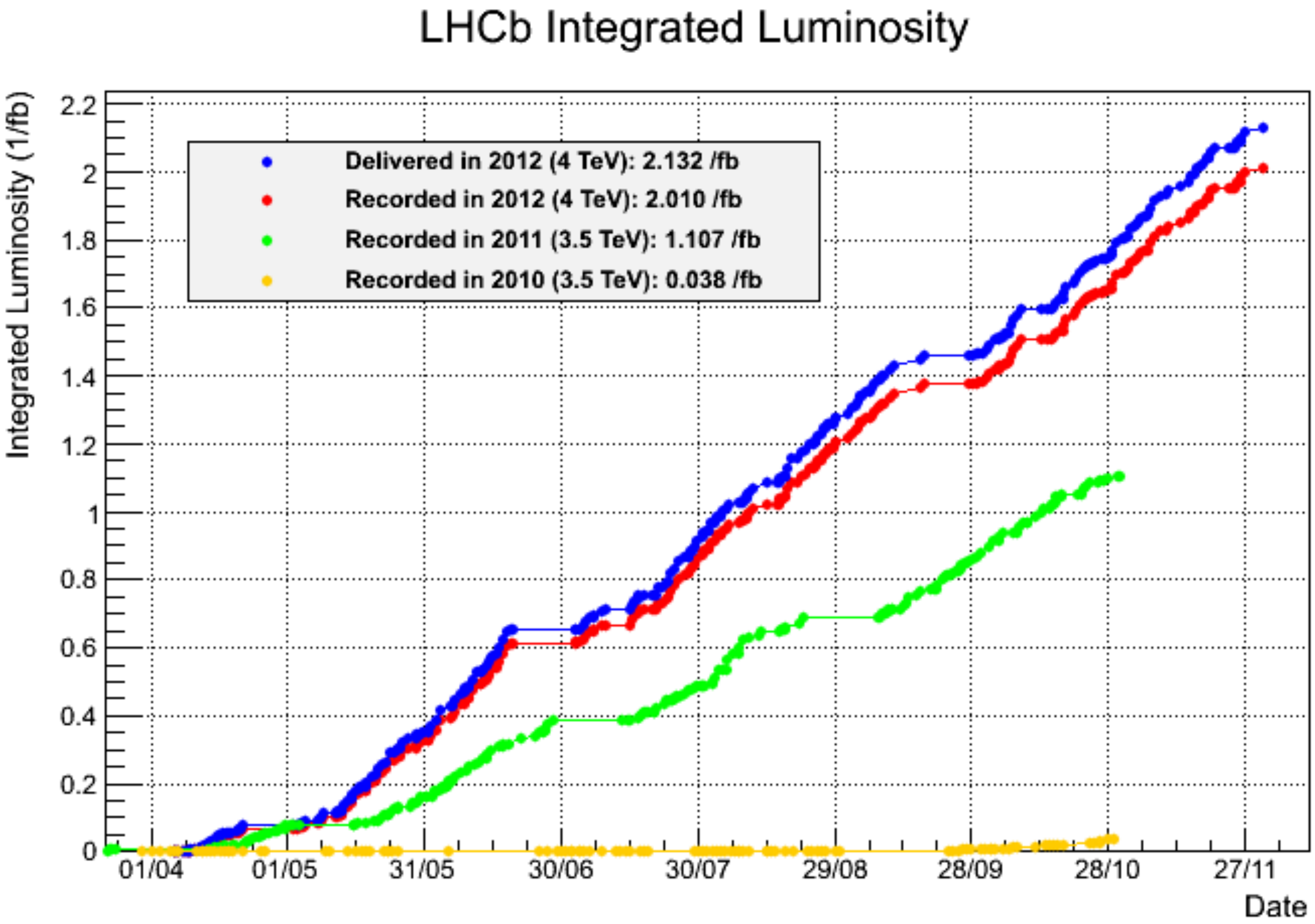
- In the latest run- has been running with **~4x10^{32} cm^{-2} s^{-1}** with 1262 colliding bunches with 50 ns bunch spacing (since end of 2011)
  - Was designed for peak luminosity 2x10 ^{32} cm^{-2} s^{-1} for ~2700 colliding bunches with 25 ns spacing.
  - The average number of visible collisions per crossing is ~1.8

- Luminosity levelling:
  - The beam separation is adjusted to maintain the luminosity constant.

Luminosity is frequently adjusted (±3% around target value



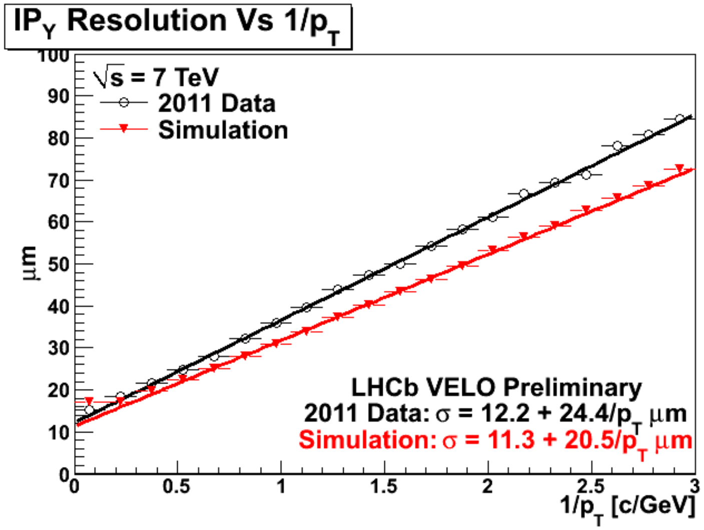
☑ Delivered Inst Lumi (Hz/ub) 391.41
☐ Mu 1.70
☐ Target Luminosity 400.00
☐ Recorded Inst Lumi (Hz/ub) 383.93
☐ Pile Up 2.08
☐ Physics deadtime (%) 1.91

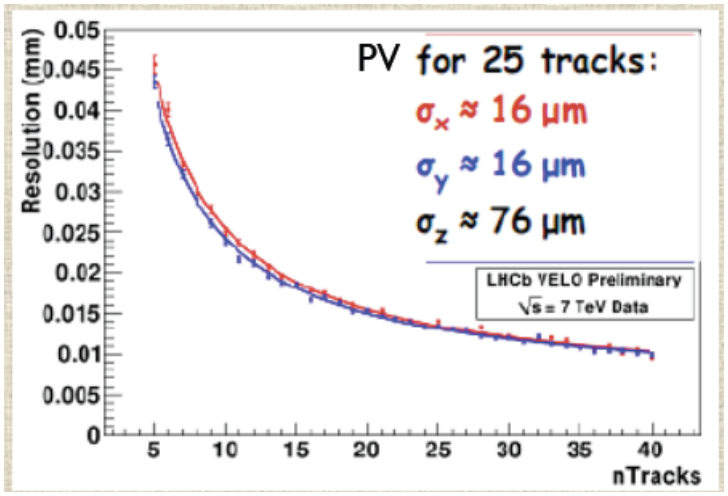


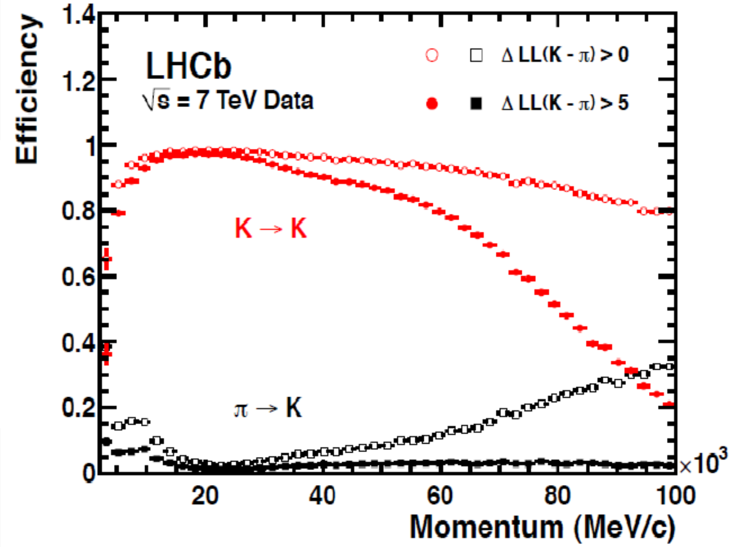
After the Long Shutdown 1 (LS1) will restart in 2015 at 13 TeV, with 25 ns bunch spacing (nominal)
Expect to reach a total of ~7/fb by 2018

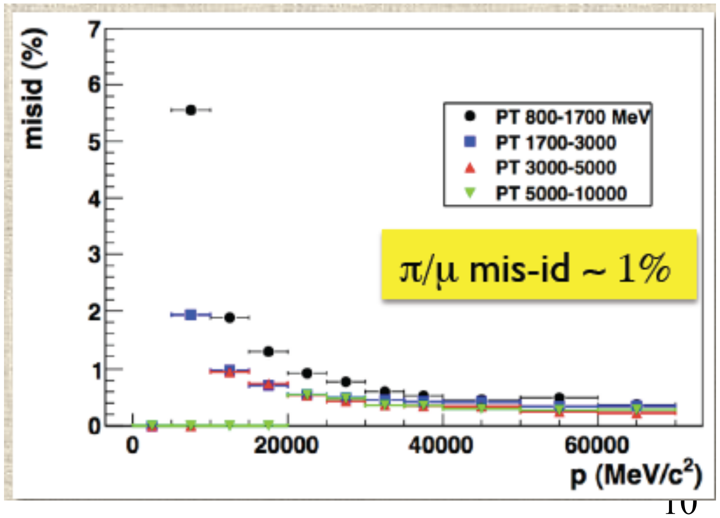
Detector & Reconstruction Performance (1)

- Detector & reconstruction Performance has been excellent- at about the design level in essentially all important aspects.





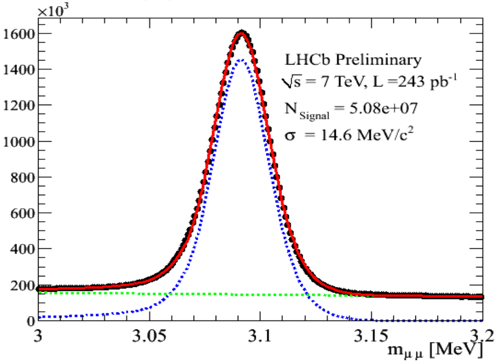




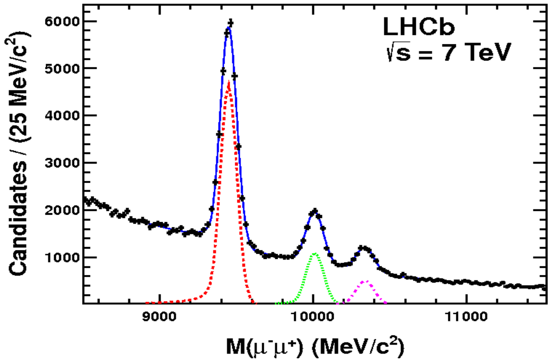
π/μ mis-id ~ 1%

Detector & Reconstruction performance(2)

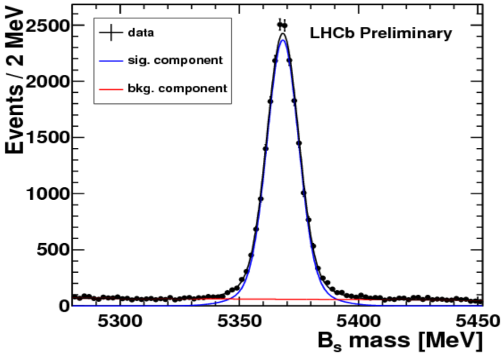
J/Ψ → μμ : σ ≈ 15 MeV/c²



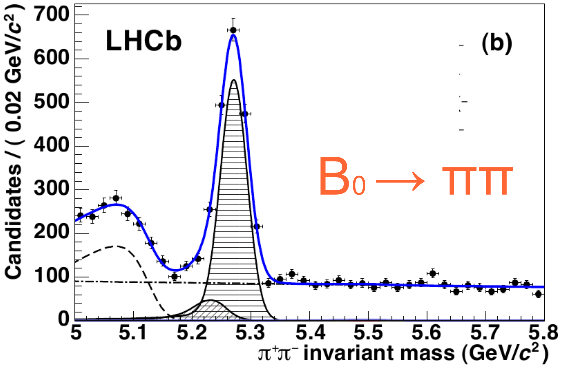
Y(1S) → μμ : σ ≈ 54 MeV/c²

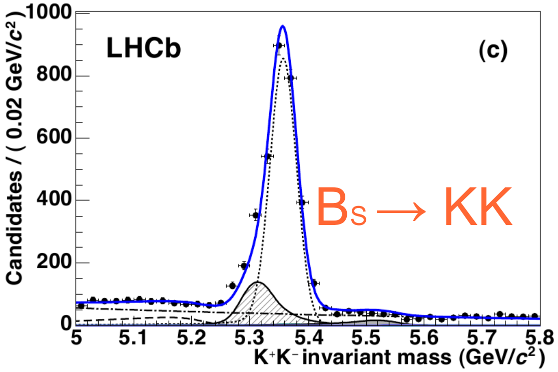


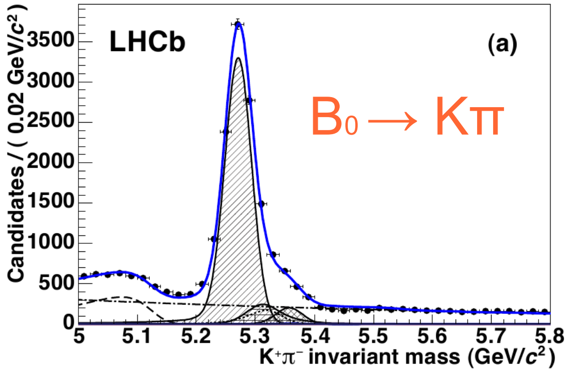
B_S→J/ΨΦ : σ ≈ 8 MeV/c²

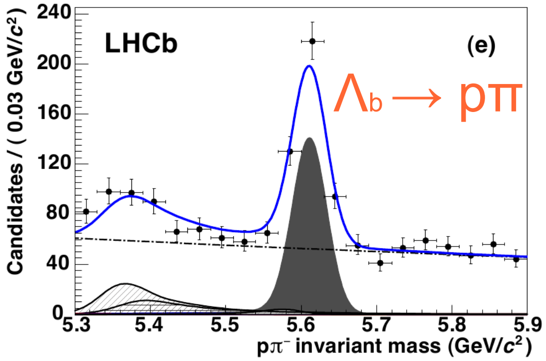


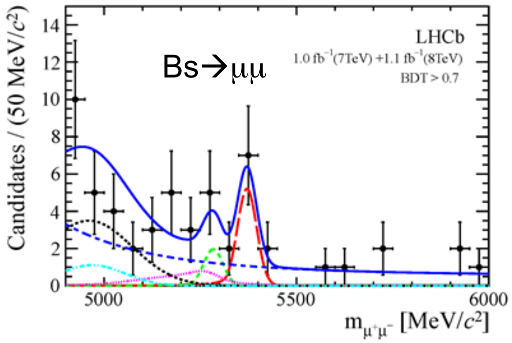
Excellent PID performance - as shown in separation of various 2-body charmless decays

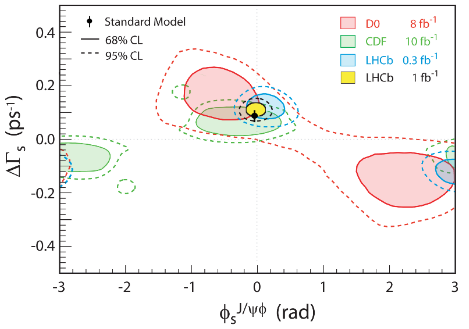


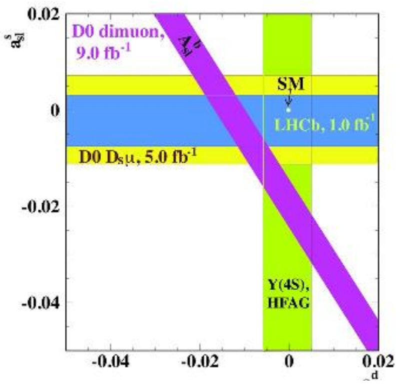


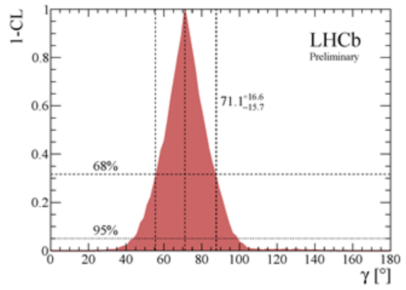


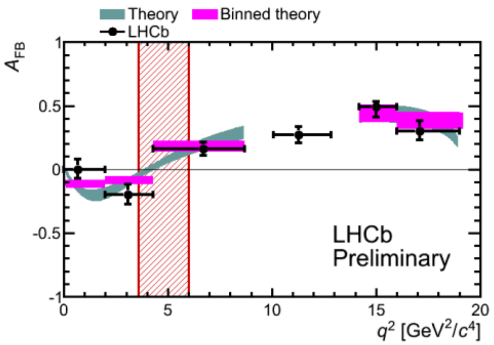


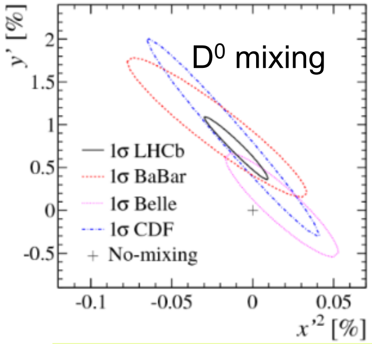


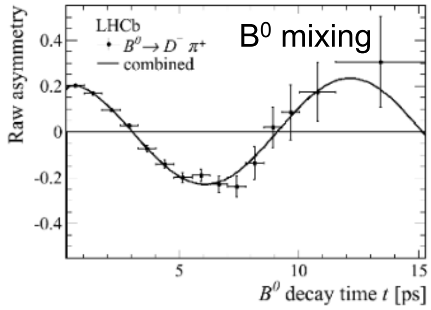


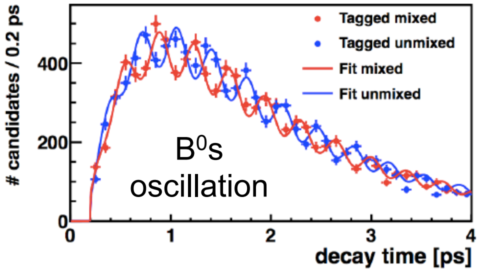


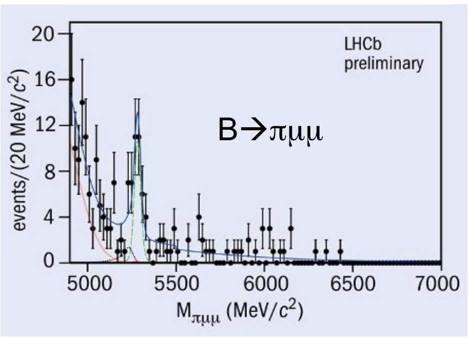




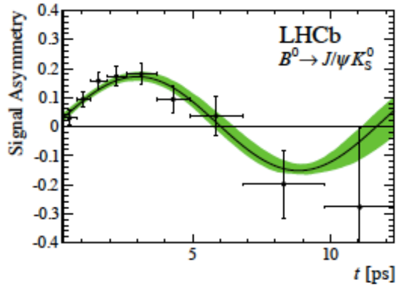


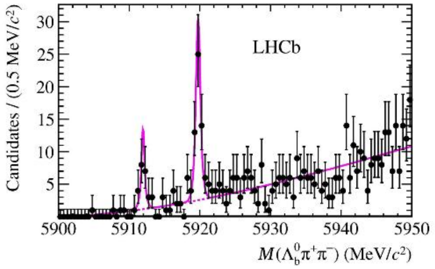


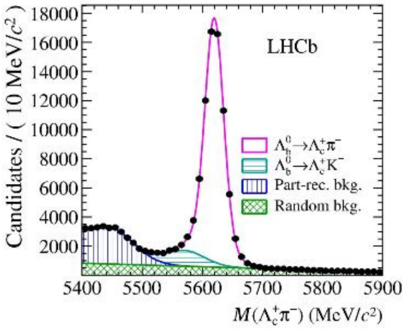


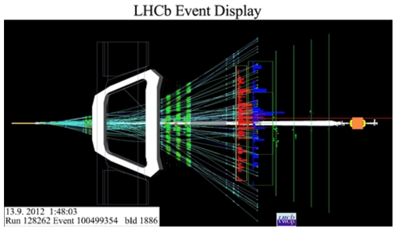


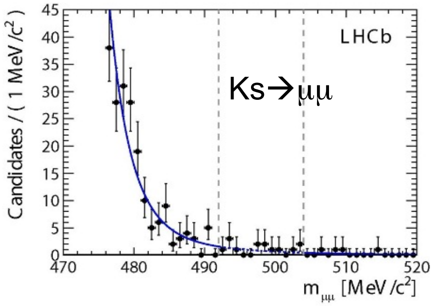
LHCb Physics Covers a very broad spectrum from Flavor to EW, QCD, pA…









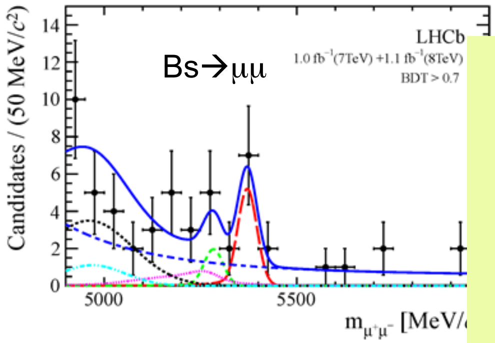


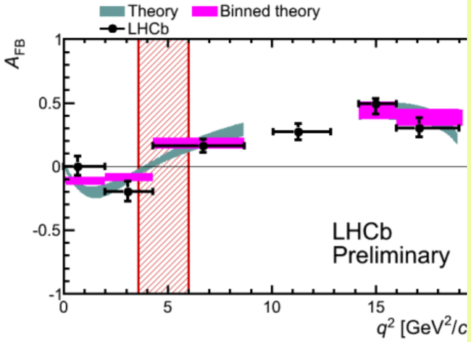
A small Selection of LHCb physics results Sensitive to New Physics Effects

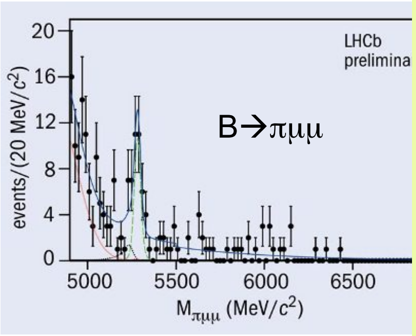
- ➢NP Search in B mixing
  Φ_s & a^s_{sl}

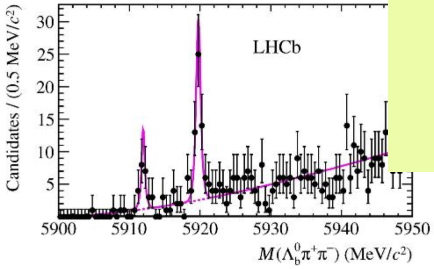
- ➢NP search in FCNC processes:
  - •Evidence for B→$\mu^+\mu^-$
  <u>(A major milestone in Flavor Physics)</u>
  - •Angular Analysis of B→$K^{(*)}\mu^+\mu^-$

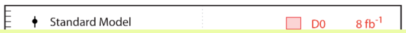
- ➢(& if I have time)
  CKM phase γ
  Prospects for photon helicity in b→sγ
  Direct CPV

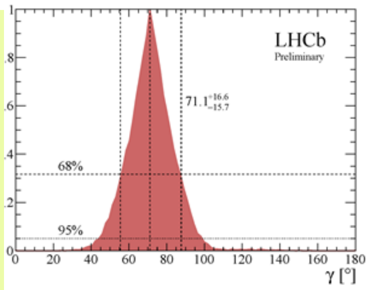


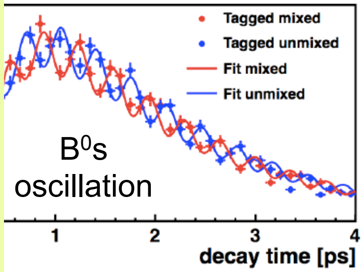


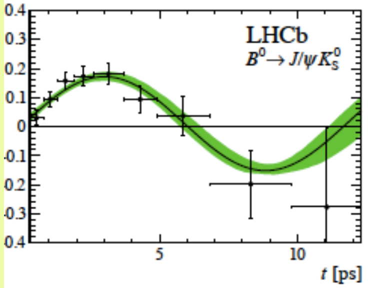


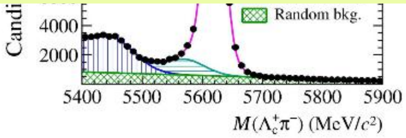


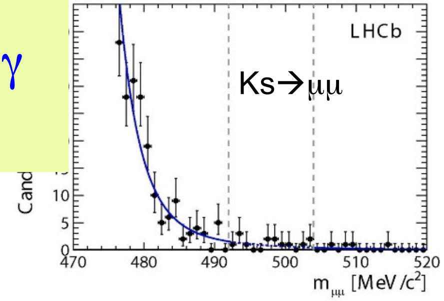




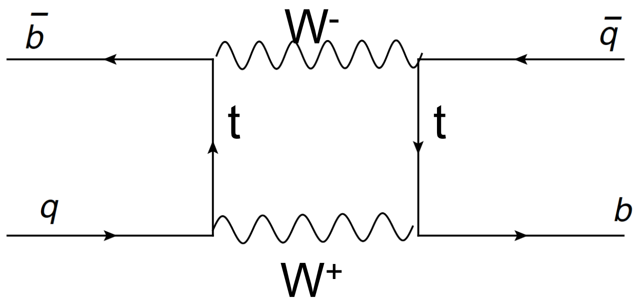




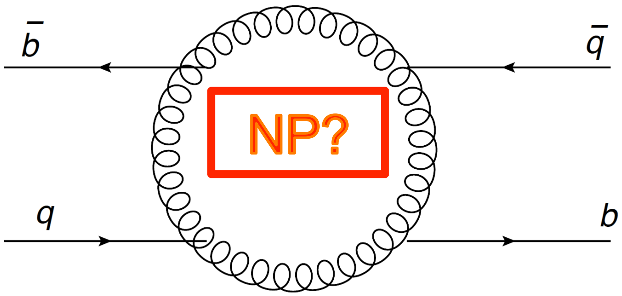




B^0 mixing as a probe of New Physics



$$\propto \frac{|V_{tq}|^2}{M_W^2}$$



$$\propto \frac{|C|^2}{\Lambda_{NP}^2}$$

Described by 2x2 mass matrix

$$i\frac{d}{dt}\begin{pmatrix} B \\ \bar{B} \end{pmatrix} = \begin{pmatrix} M_{11} - \Gamma_{11} & M_{12} - \Gamma_{12} \\ M_{21} - \Gamma_{21} & M_{22} - \Gamma_{22} \end{pmatrix} \begin{pmatrix} B \\ \bar{B} \end{pmatrix}$$

$$B_L = p|B^0> + q|\bar{B}^0>$$

$$B_H = p|B^0> - q|\bar{B}^0>$$

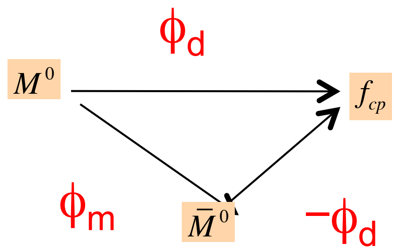
- Parameters: $\phi_{12}=\arg(-M_{12}/\Gamma_{12})$ $\Delta m = m_H - m_L = 2|M_{12}|$ $\Delta\Gamma = \Gamma_H - \Gamma_\Lambda = 2|\Gamma_{12}|\cos(\phi_M)$ are highly constrained within SM for the B_d and B_s systems.

- New Physics contribution can manifest in sizeable CP violations effects & alter these parameters from SM values- in particular in the B_s system.

Key CPV observables in B^0_s system

ϕ_s: Relative phase of mixing and decay amplitude in CP eigenstates

Extract from Time-dependent CPV



$$\phi_s = \phi_m - 2\phi_d$$

$$A_{cp}(t) \simeq \eta_{cp} \sin\phi_s \sin \Delta m t$$

$$\varphi_s^{J/\psi\phi} = -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \approx 0.04(SM)$$

a^s_{sl}: Semileptonic Asymmetry

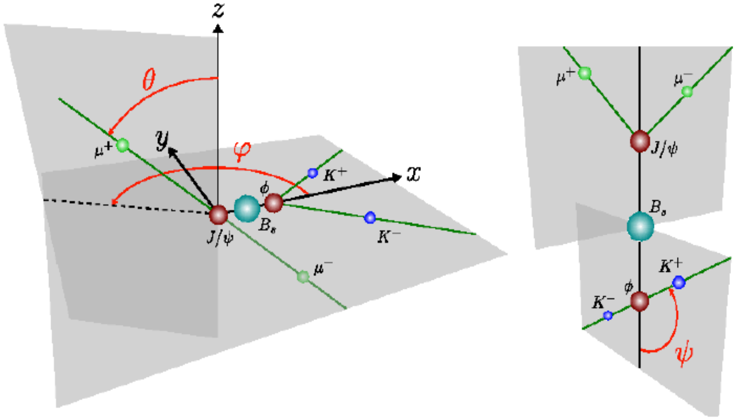
$$a_{sl}^s = \frac{\Gamma(B_s^0 \to l^+\nu_l X) - \Gamma(\bar{B}_s^0 \to l^-\bar{\nu}_l X)}{\Gamma(B_s^0 \to l^+\nu_l X) - \Gamma(\bar{B}_s^0 \to l^-\bar{\nu}_l X)} = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_{12} = (2.06 \pm 0.57)\times 10^{-5}(SM)$$

Both parameters are small & with well defined SM predictions

Thus, highly sensitive probes of NP

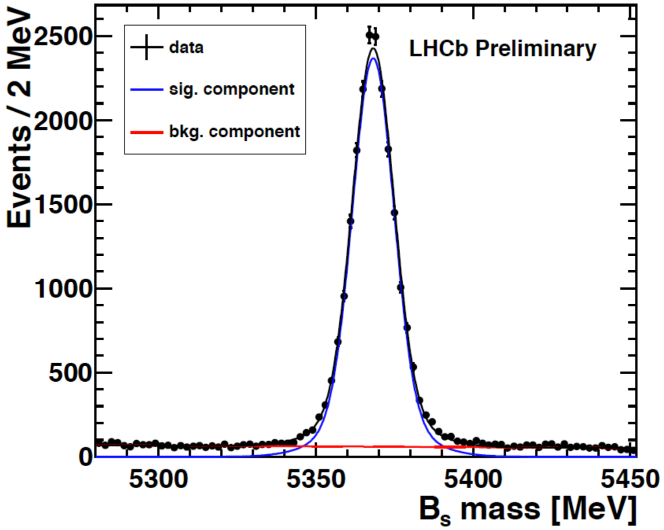
ϕ_s measurement

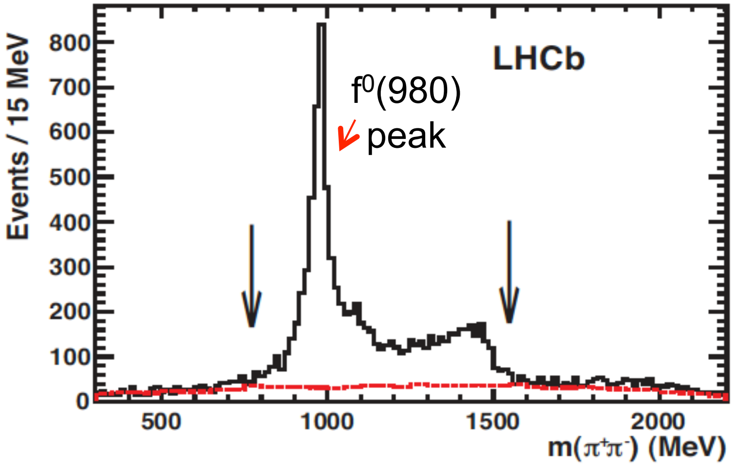
- From Time-dependent CPV in Bs→J/ψφ:
- Mixture of CP odd & CP even states Angular analysis required to extract CPV info.



- From Bs→J/ψπ⁺π⁻ : The (π⁺π⁻) system in $f_0(980)$ region and the nearby is dominated by CP-odd state (97.7%).

$$A_{cp}(t) \sim 2\sin\phi_s \sin\left(\Delta M t\right)$$





ϕ_s results

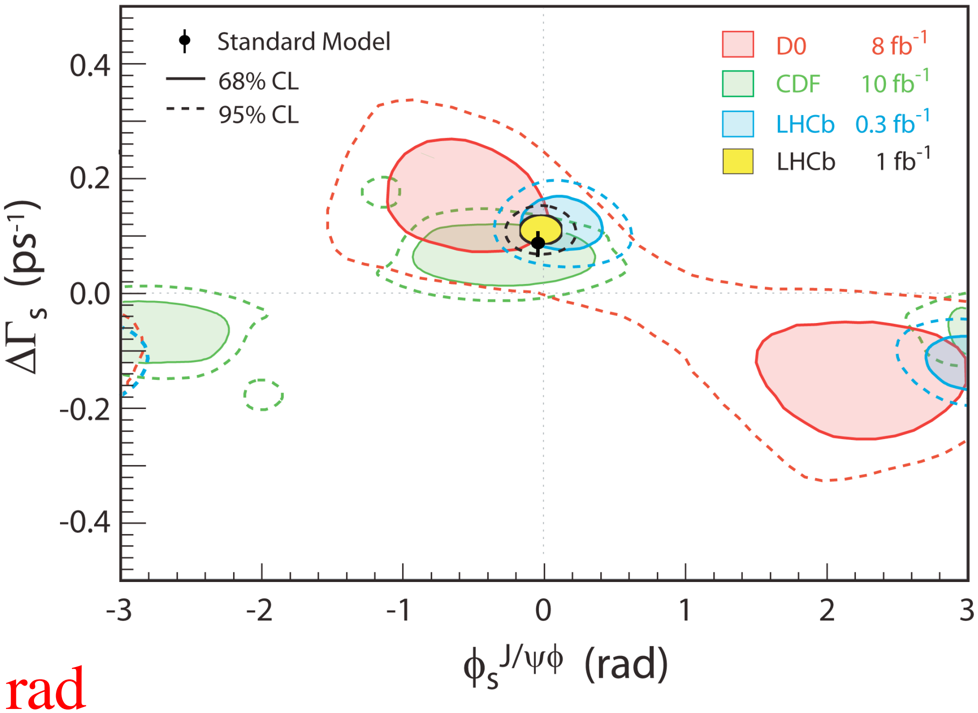
LHCb: From $J/\psi\phi$

$\phi_s = 0.001 \pm 0.10 \pm 0.027$ (rad)

$\Gamma = 0.6580 \pm 0.0054 \pm 0.0066\ (ps^{-1})$

$\Delta\Gamma = 0.116 \pm 0.018 \pm 0.006\ (ps^{-1})$

Ambiguity removed using interference with K^+K^- S-wave



$$\phi_s(J/\psi\pi^+\pi^-) = -0.019^{+0.173+0.004}_{-0.174-0.003}\ \text{rad}$$

Combining LHCb results:

$\phi_s = -0.002 \pm 0.083 \pm 0.027$ rad

Future:

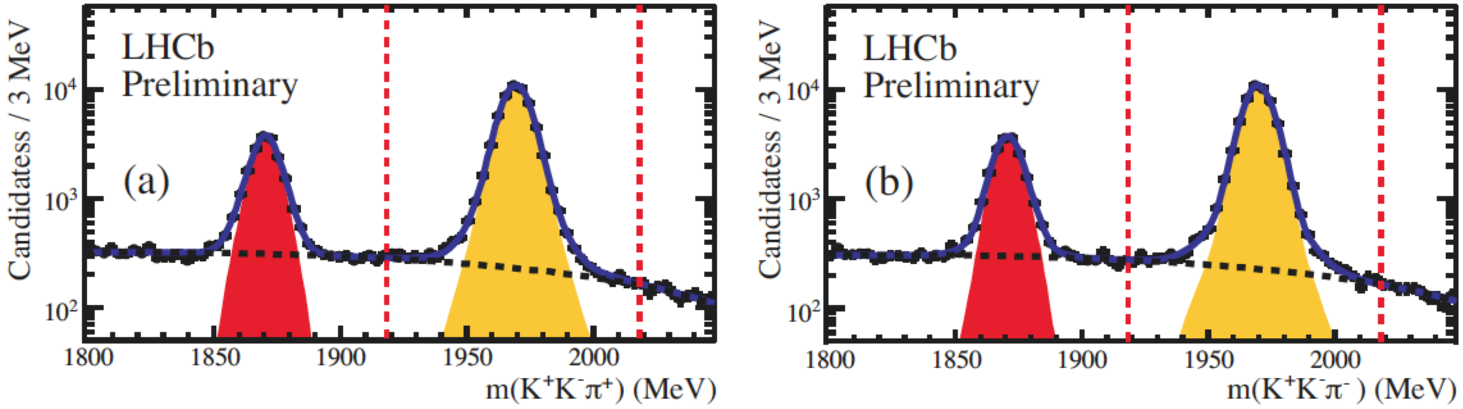
expected accuracy with 5/fb: $\phi_s^{J/\Psi\phi} \sim \pm 0.025$ (rad)

Measurement of Semileptonic Asymmtery (a^s_{sl})

- Use exclusive channel: Bs→$D_s\mu^-\nu$, ($D^\pm_s \to \phi\pi^\pm$)

$$\frac{\Gamma(D_s^-\mu^+)-\Gamma(D_s^+\mu^-)}{\Gamma(D_s^-\mu^+)+\Gamma(D_s^+\mu^-)} \approx \frac{a^s_{sl}}{2}$$

For magnet polarity down



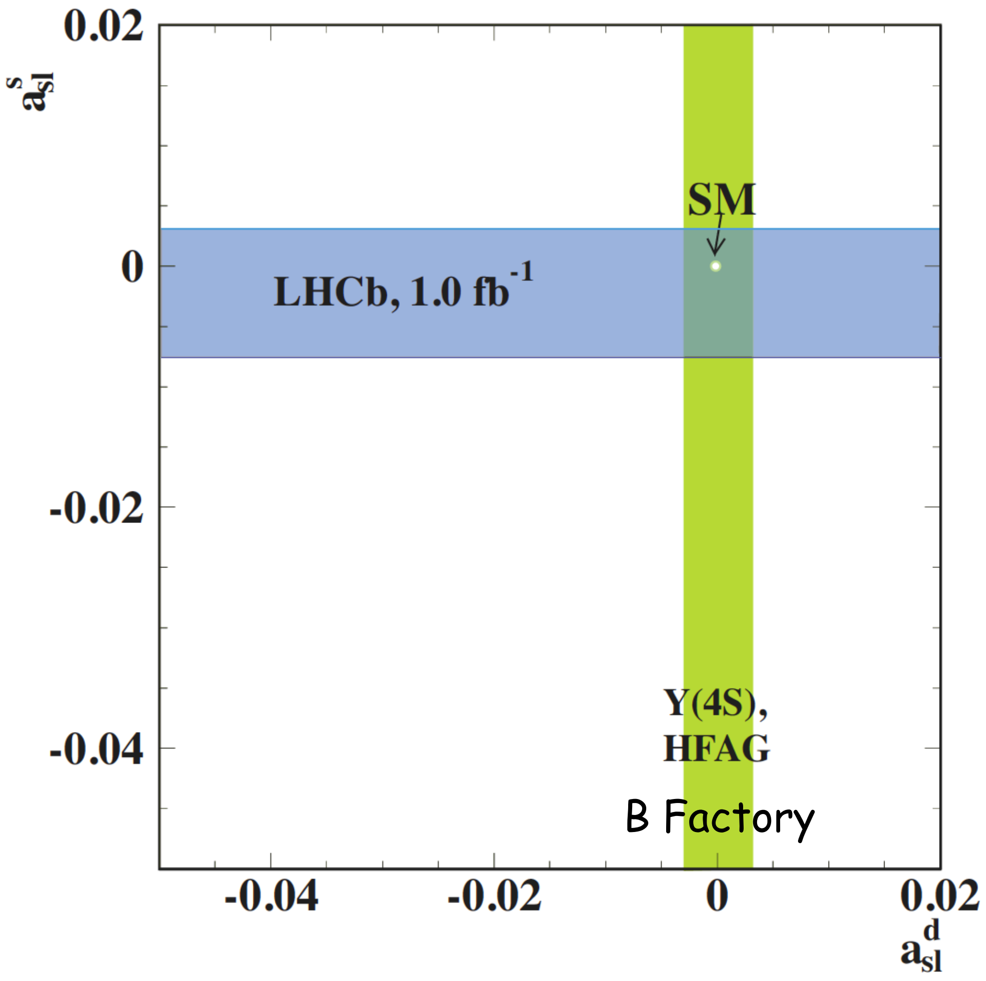
- Control samples used to correct for detector induced asymmetries
  - *Magnet is periodically reversed.*
- Rapid mixing oscillations reduce production asym (~1%) to negligible level (0.2%)

LHCb measurment of a^s_{sl}

- LHCb finds

$$a^s_{sl} = \left(-0.24 \pm 0.54 \pm 0.33\right)\%$$

In good agreement with SM



LHCb measurment of a^s_{sl}

- LHCb finds

$$a^s_{sl} = (-0.24 \pm 0.54 \pm 0.33)\%$$

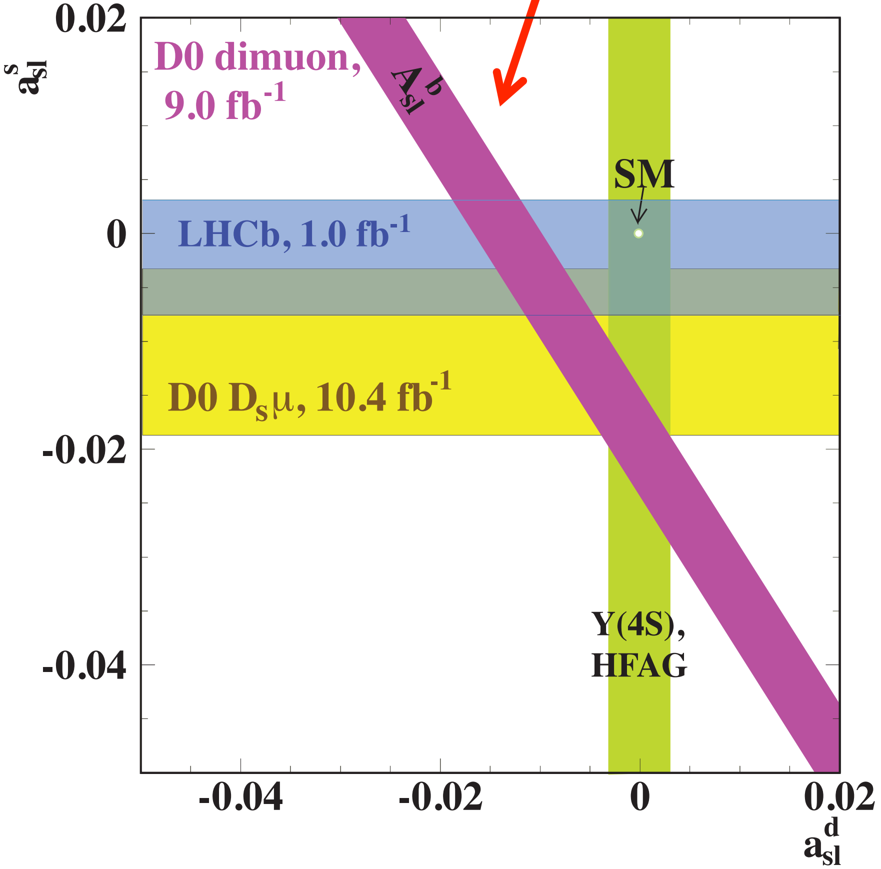
In good agreement with SM

- Combined D0 measurement with di-muons & $D_s l$:

$a^s_{sl} = (-1.70 \pm 0.56)\%$

~3σ from SM

$$A^b_{sl}(D0) = C_d a^d_{sl} + C_s a^s_{sl}$$



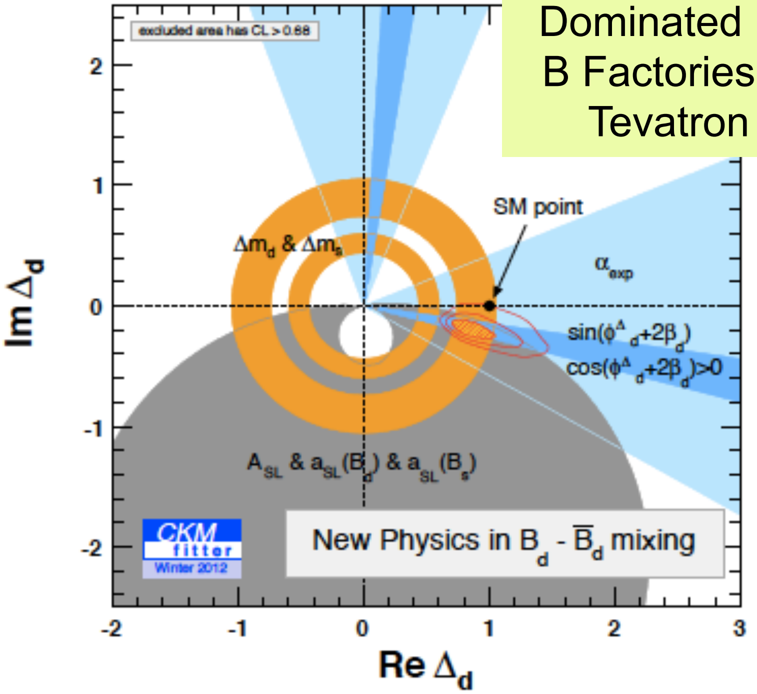
B Factories: $a^d_{sl} = (-0.02 \pm 0.31)\%$

Combined D0: $a^d_{sl} = (0.10 \pm 0.30)\%$

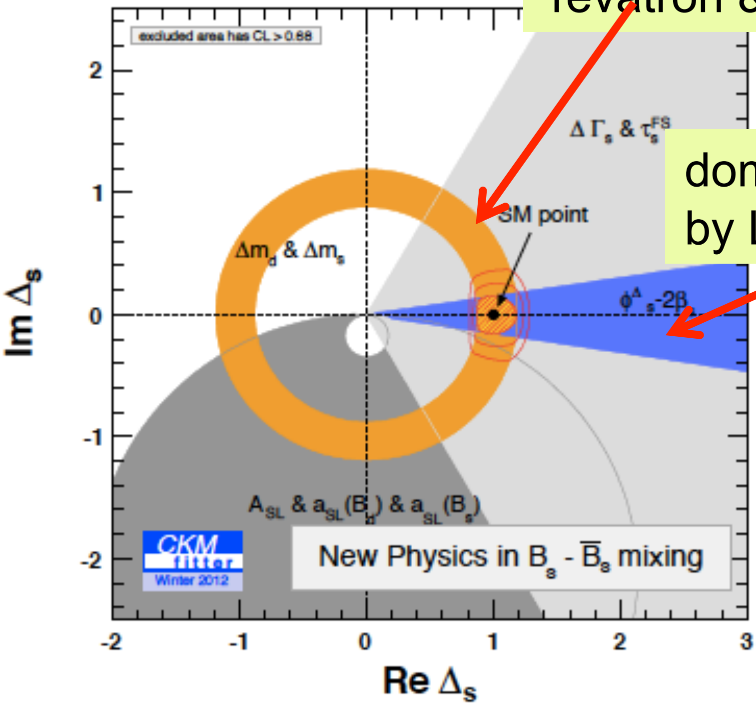
Implication for New Physics in Mixing

Analysis by A. Lenz, U. Niereste with J. Chales et al (CKMfitter)

$$M_{12}^q \equiv M_{12}^{\mathrm{SM},q} \cdot \Delta_q \,, \qquad \Delta_q \equiv |\Delta_q| e^{i\phi_q^\Delta} \,, \qquad q = d, s,$$



Dominated by B Factories & Tevatron



Tevatron & LHCb

dominated by LHCb ϕ_s

The test with B_s system is now nearly as precise as that in B_d ; The B_s system is consistent with SM; There is still room for NP in both systems.

$\mathrm{Re}(\Delta_s)$	$0.965^{+0.133}_{-0.078}$
$\mathrm{Im}(\Delta_s)$	$-0.00^{+0.10}_{-0.10}$

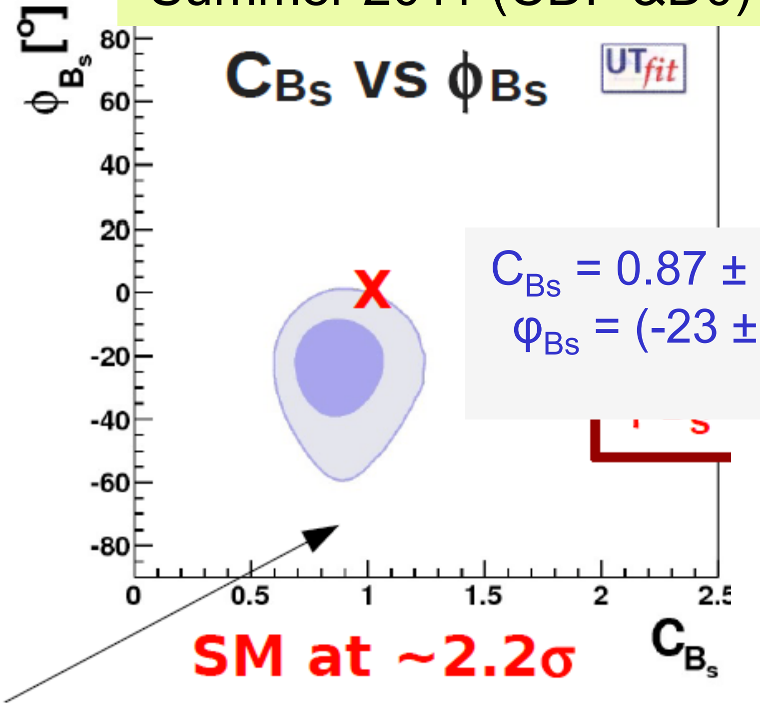
Implication for New Physics in Mixing (Utfit analysis)

Model independent approach   NP
through mixing amplitude (Utfit group)

$$C_{B_q} e^{2i\varphi_{B_q}} = \frac{< B_q \,|\, H_{eff}^{Full} \,|\, \bar{B}_q >}{< B_q \,|\, H_{eff}^{SM} \,|\, \bar{B}_q >}$$

$SM : C_{B_q} = 1 \qquad \varphi_{B_q} = 0$

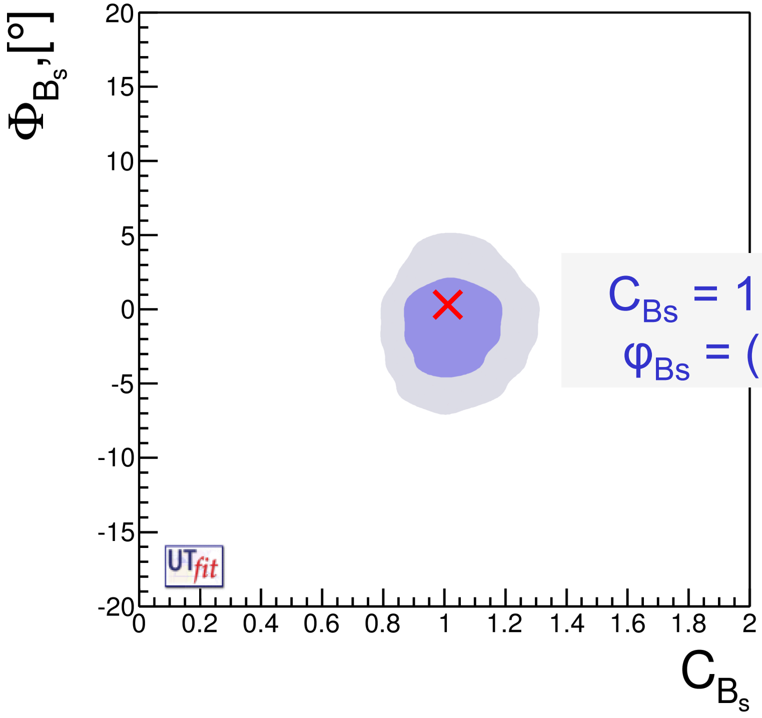
Summer 2011 (CDF &D0)



C_{Bs} = 0.87 ± 0.12
φ_{Bs} = (-23 ± 10)°

SM at ~2.2σ

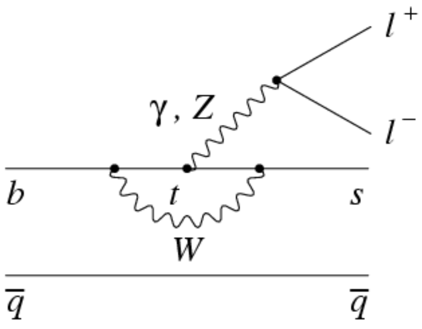
2012 (Now includes LHCb results)

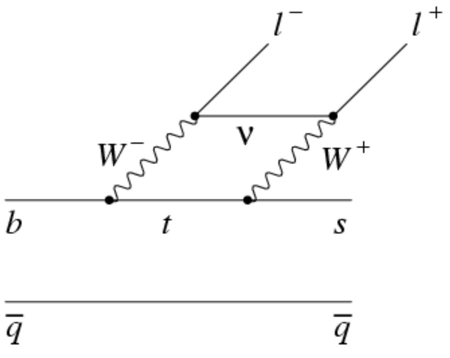


C_{Bs} = 1.02 ± 0.1
φ_{Bs} = (-1.1 ± 2)°

LHCb Measurements of FCNC Processes

$B \to K^{(*)}\ell^+\ell^-$

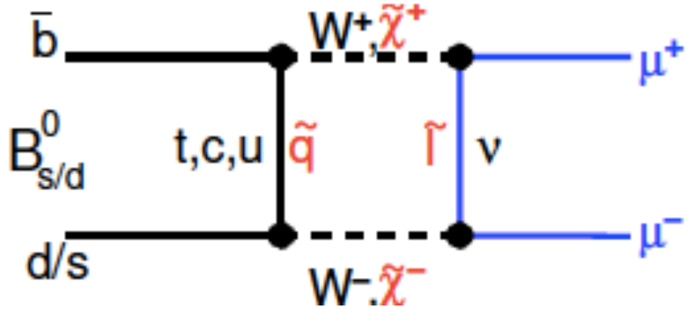


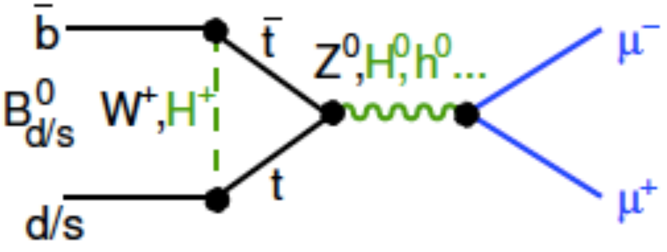


b→s processes are highly sensitive to parameters of most NP scenarios & are key to obtaining generic constraints on NP through wilson coefficients.

LHCb measurements of some exclusive channels have already significantly exceeded the sensitivities of previous measurements.

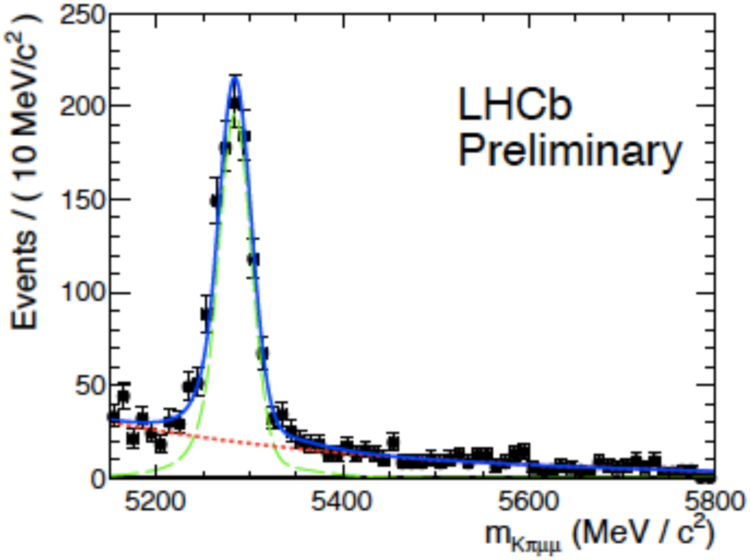
$B_{s/d} \to \mu^+\mu^-$





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

- Provides several observables- through angular analysis- Br, dBr/dq^2, $A_{FB}(q^2)$, $F_L(q^2)$, CP asymmetry- highly sensitive to NP- constraining C'_7, C'_9, C'_{10}
- LHCb has the largest sample of events -> the combined past expt's



$$\frac{1}{\Gamma}\frac{d^4\Gamma}{d\cos\theta_\ell \, d\cos\theta_K \, d\hat{\phi} \, dq^2} = \frac{9}{16\pi}\Big[F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) \; +$$

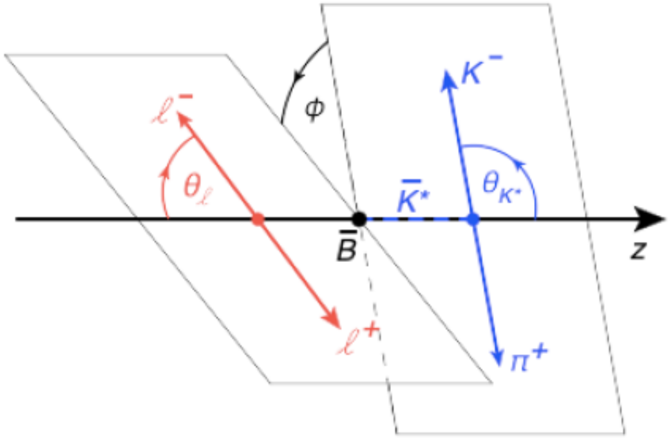
$$F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) \; +$$

$$\frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) \; +$$

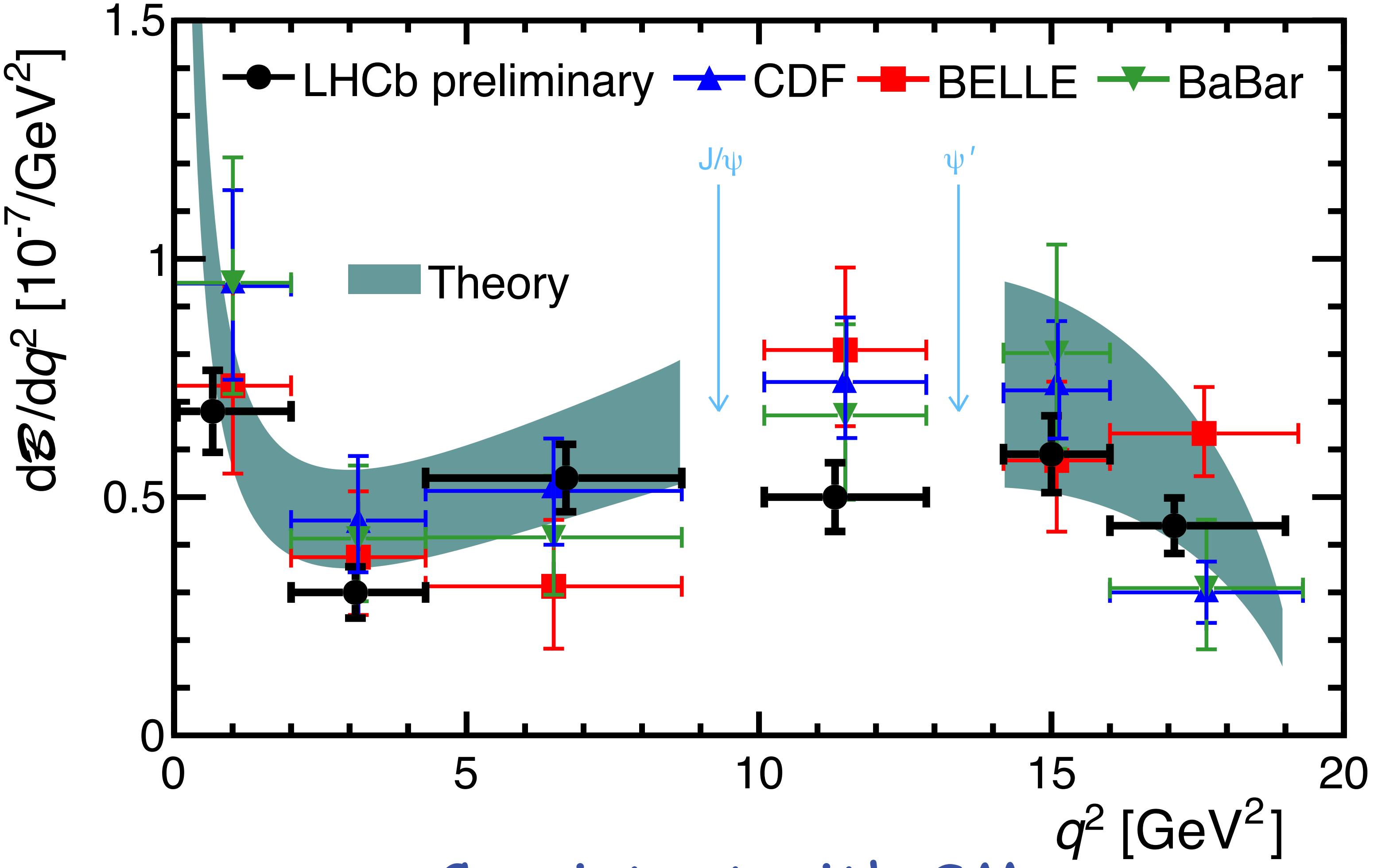
$$S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \; +$$

$$\frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell \; +$$

$$A_{Im}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \Big]$$

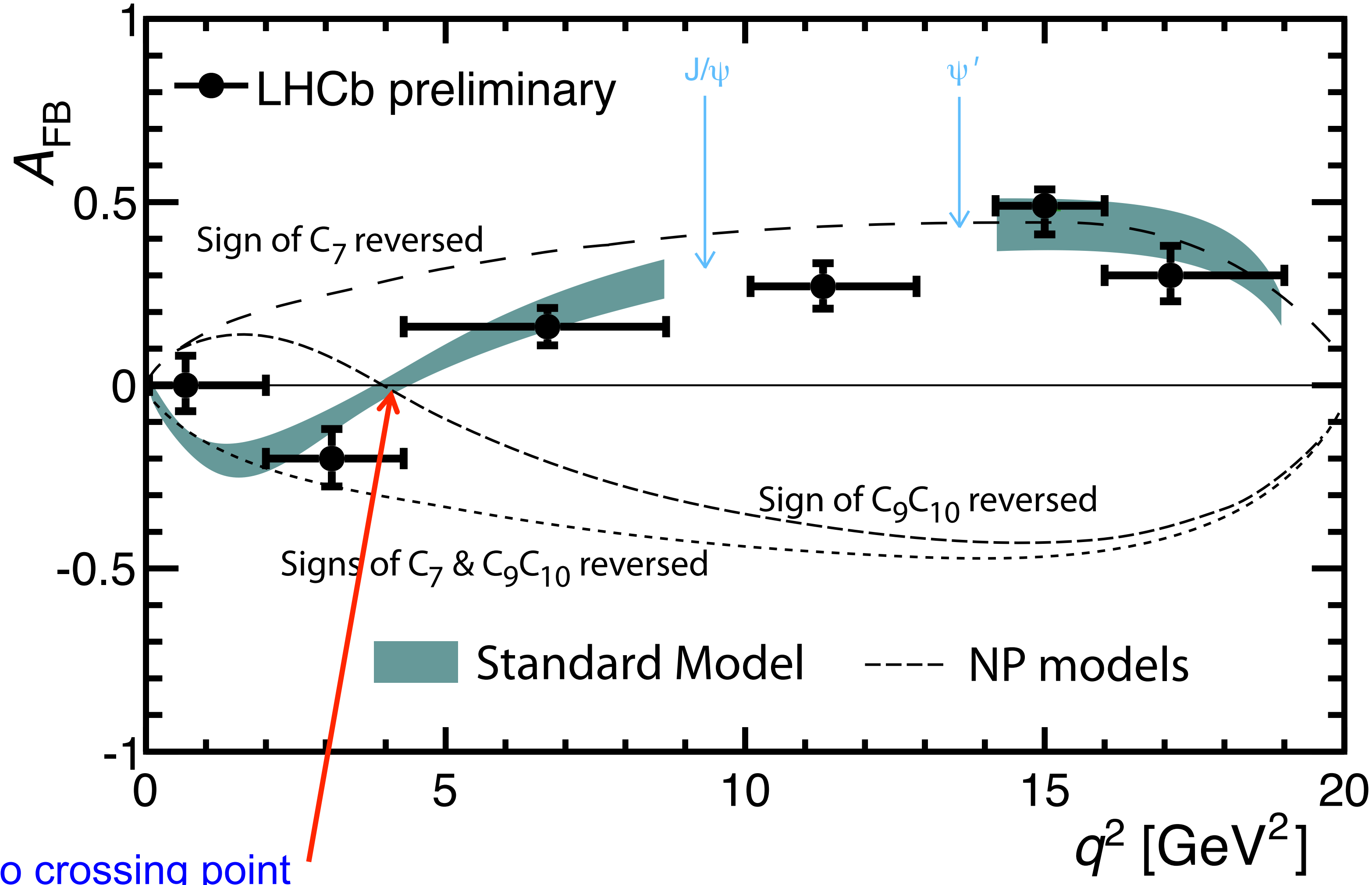


Differetial Rate: $B^o \to K^{*o}\mu^+\mu^-$



Consistent with SM

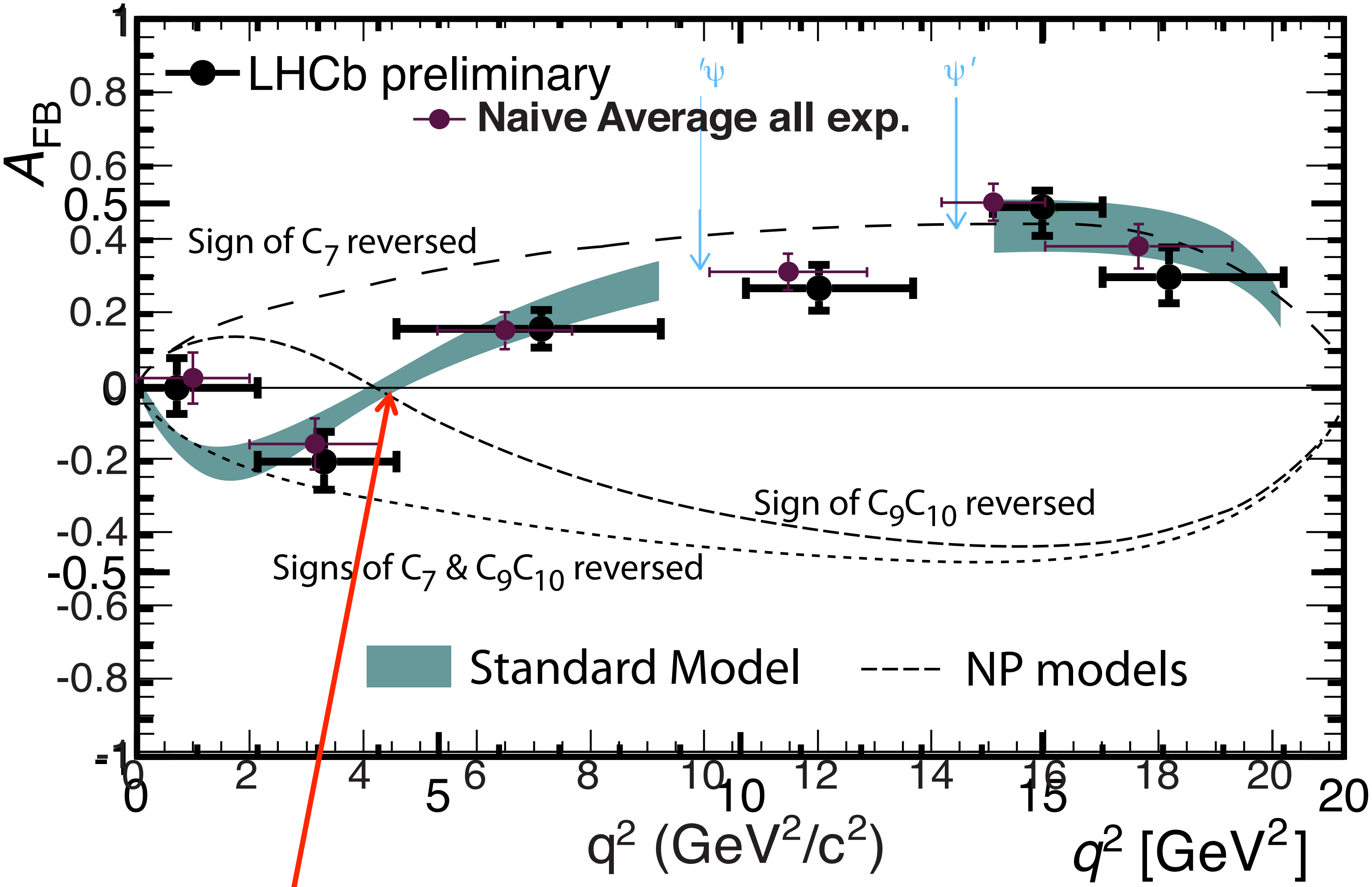
Forward-Backward asymmetry



Zero crossing point
Measured: $q_0^2 = 4.9^{+1.1}_{-1.3}\ GeV^2$
Consistent with SM

Consistent with SM

Forward-Backward asymmetry



Zero crossing point measured: $q_0^2 = 4.9^{+1.1}_{-1.3}\ GeV^2$
Consistent with SM

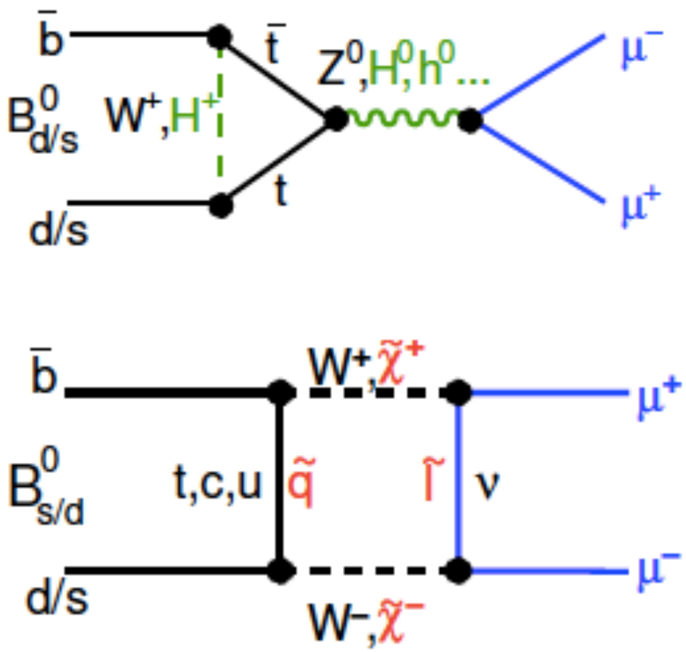
Consistent with SM

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

- SM branching ratio is $(3.2\pm0.2)\times10^{-9}$

[Buras arXiv:1012.1447]

- Sensitive to new scalar sectors, extended Higgs.. in MSSM to high tanβ



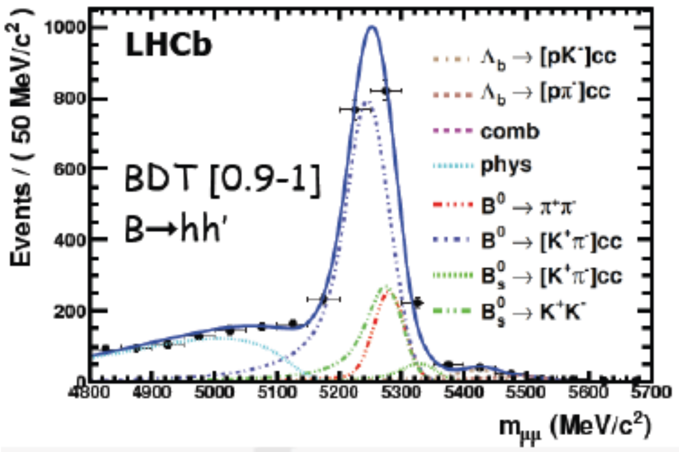
$$\mathcal{B}(B_q^0\to\mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_q}^2\tau_{B_q}m_{B_q}^3|V_{tb}V_{tq}^*|^2\sqrt{1-\frac{4m_\mu^2}{m_{B_q}^2}}$$

$$\times\left\{\left(1-\frac{4m_\mu^2}{m_{B_q}^2}\right)|C_S-C_S'|^2+\left|(C_P-C_P')+2\frac{m_\mu}{m_{B_q}}(C_{10}-C'_{10})\right|^2\right\}$$

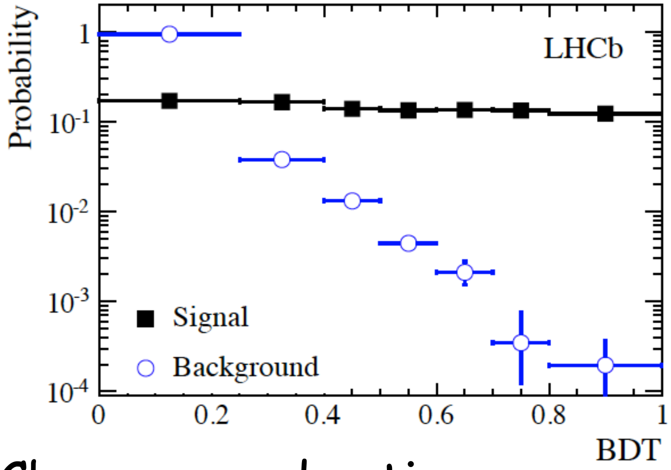
The only SM term

Evidence for $B_s \to \mu^+\mu^-$ (1)

- Events mainly triggered by di-muon L0 trigger



- Use $B \to h^+h^-$ to tune cuts for a multivariate analysis (Boosted Decision Tree). Main variables:
  - B impact parameter, B lifetime, B p_T, B isolation, muon isolation, minimum impact parameter of muons, ...

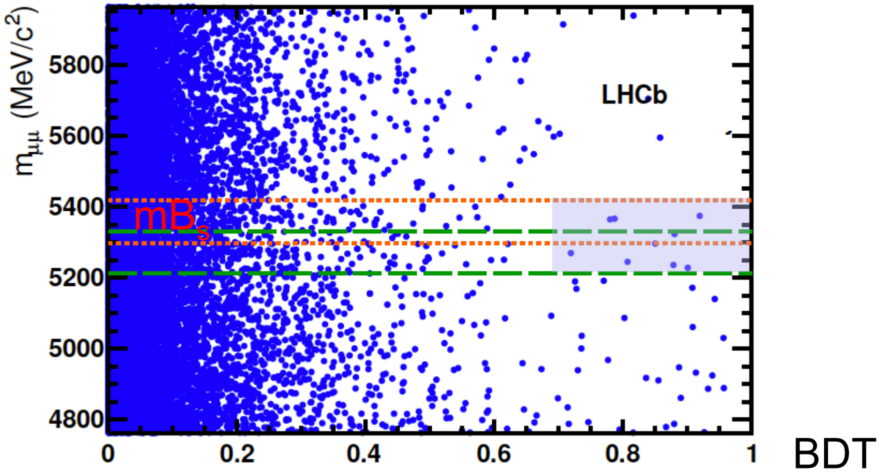


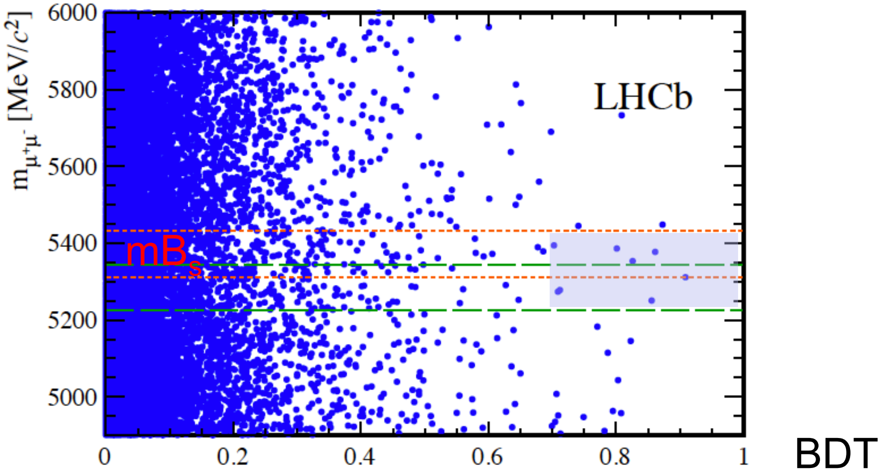
- Simultaneously measure $B^+ \to J/\psi K^+$, and $B \to K^+\pi^-$ as normalization.

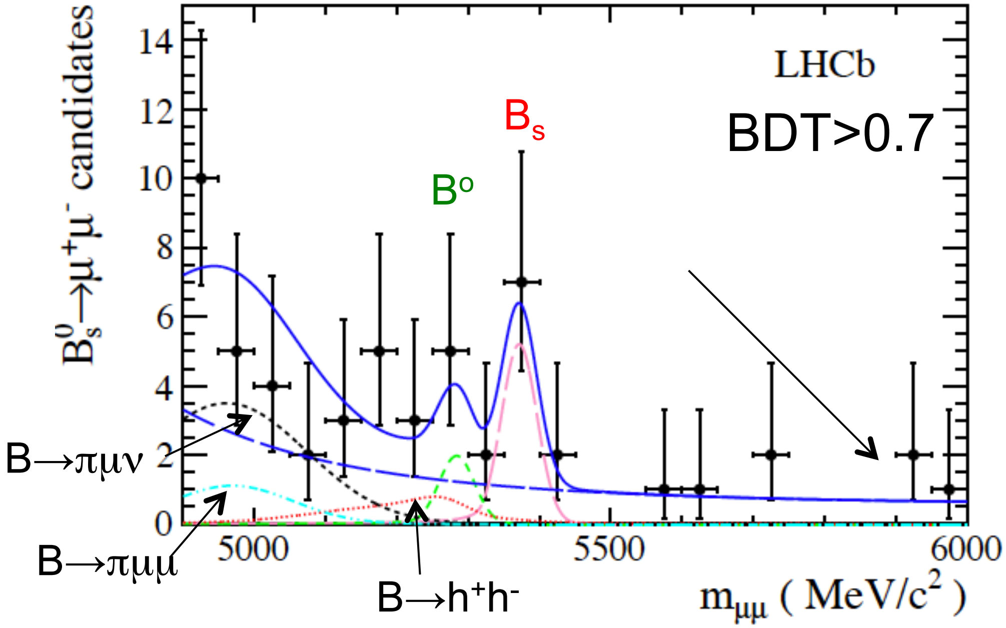
- B_s production is measured by using the LHCb measured ratio f_s/f_d. New value of 0.256 ± 0.020

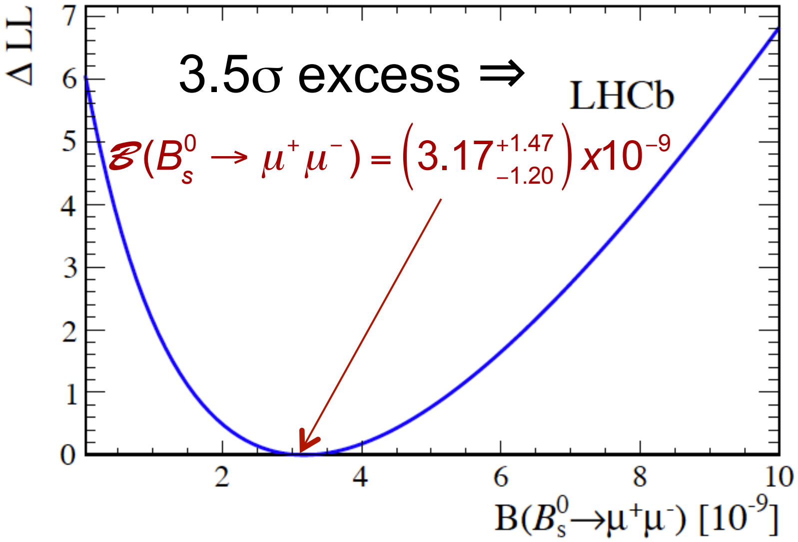
Evidence for $B_s \to \mu^+\mu^-$ (2)

- LHCb 1.0 fb^{-1} (2011) + 1.1 fb^{-1} (2012)









3.5σ excess ⇒

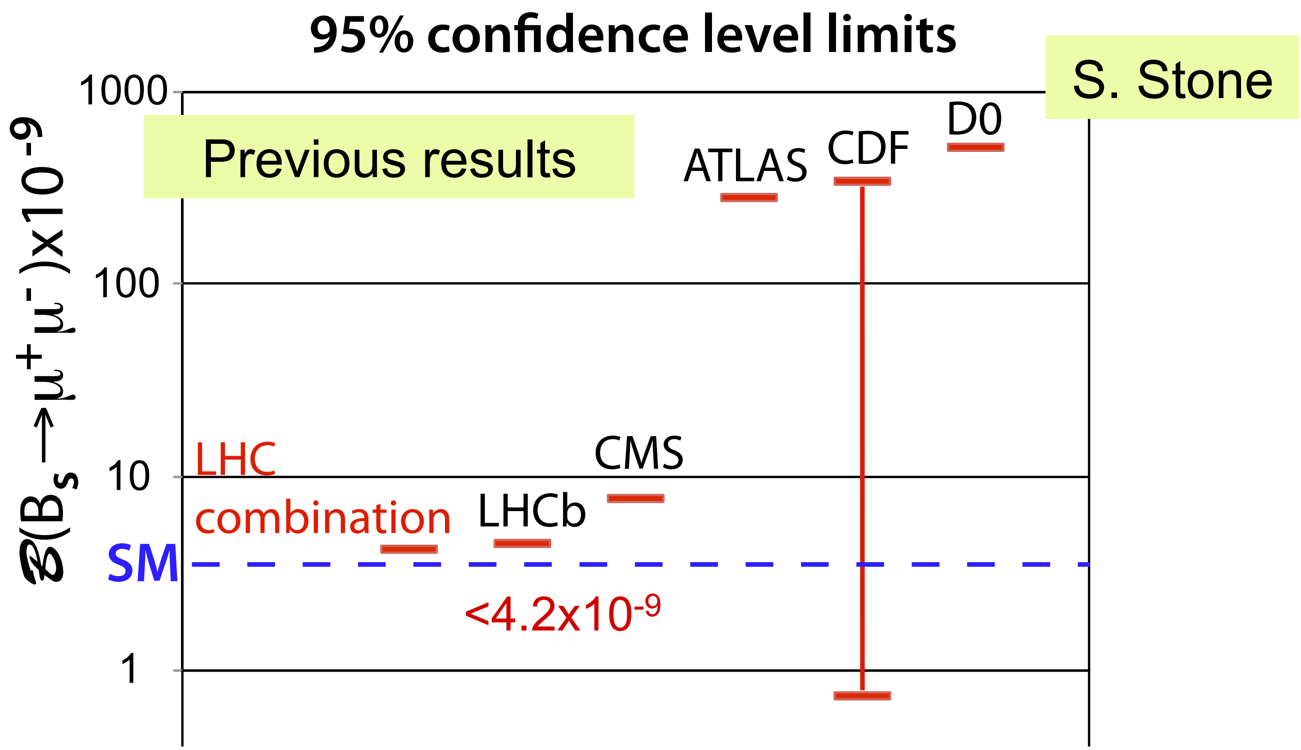
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.17^{+1.47}_{-1.20}\right) x10^{-9}$$

Branching ratio for $B_s \to \mu^+\mu^-$

LHCb results:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.2^{+1.4}_{-1.2}(stat)^{+0.5}_{-0.3}(syst)\right) x10^{-9}$$

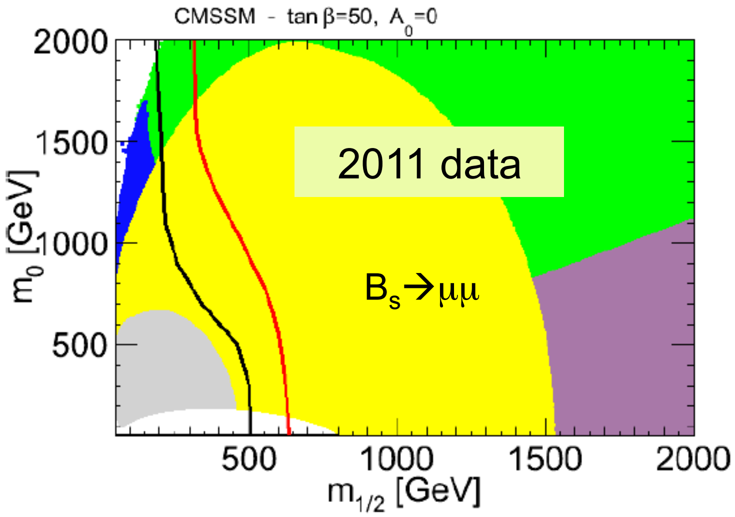
$\mathcal{B}(B_d \to \mu^+\mu^-) < 9.4x10^{-10}$ @95% c.l.



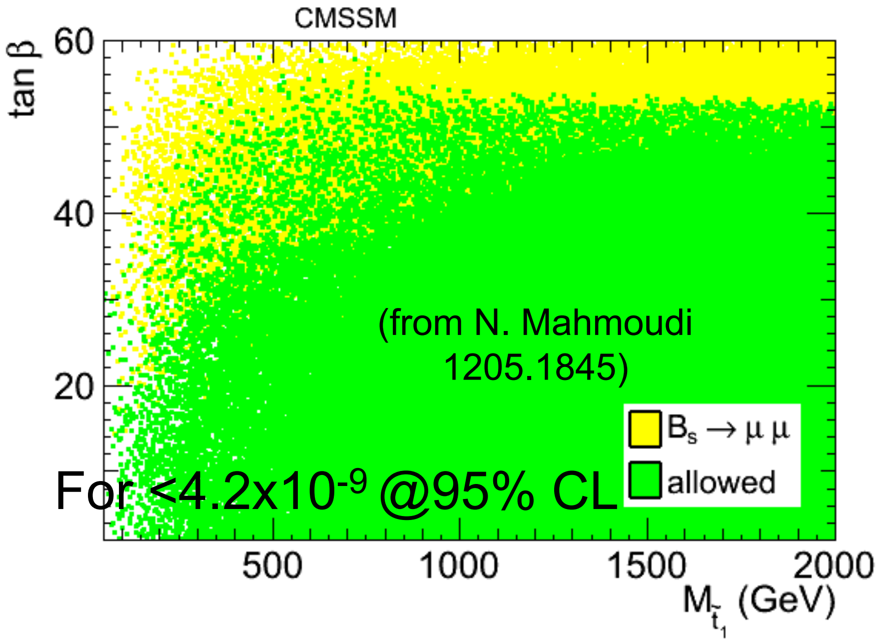
Implications of $B_s \rightarrow \mu^+\mu^-$ constraints

Analysis based on previous results (2011)

$B_{s/d} \rightarrow \mu^+\mu^-$ very effective at constraining large $\tan\beta$ region in SUSY models

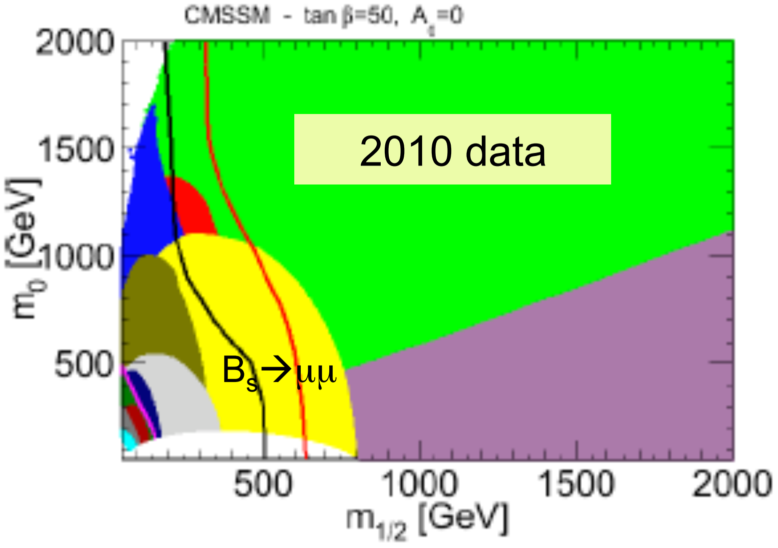


2011 data

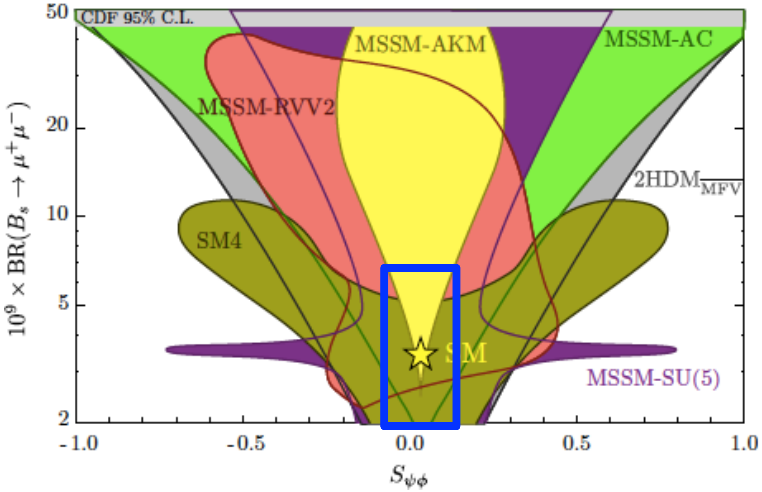


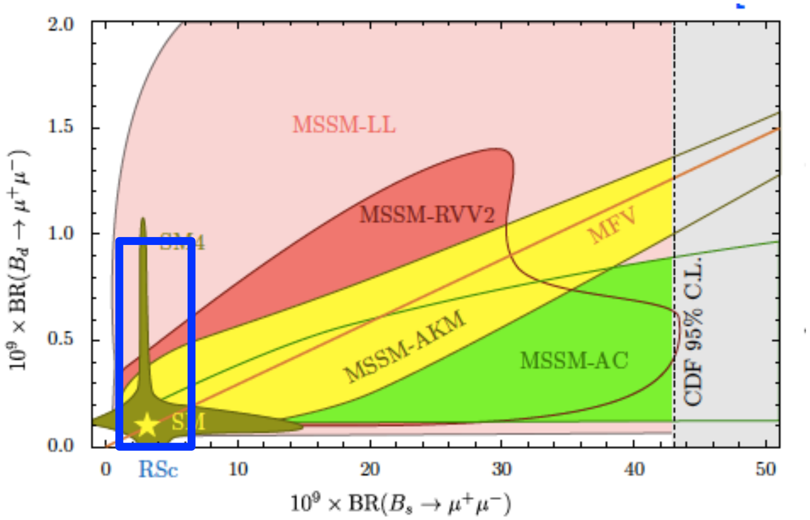
(from N. Mahmoudi 1205.1845)

For $<4.2\times10^{-9}$ @95% CL

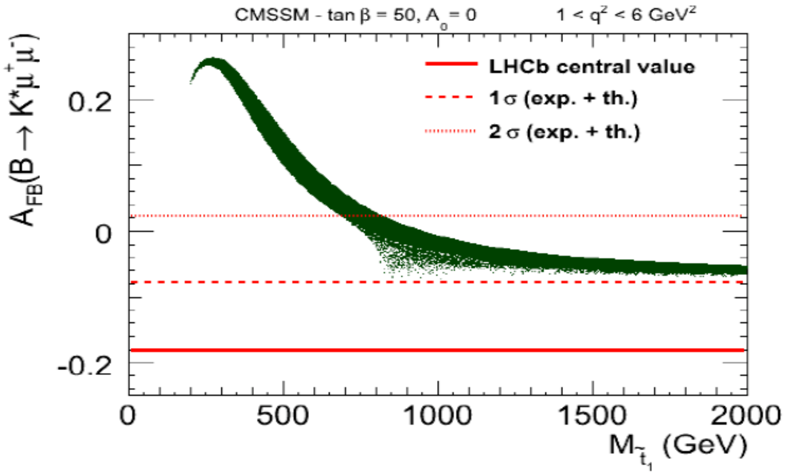


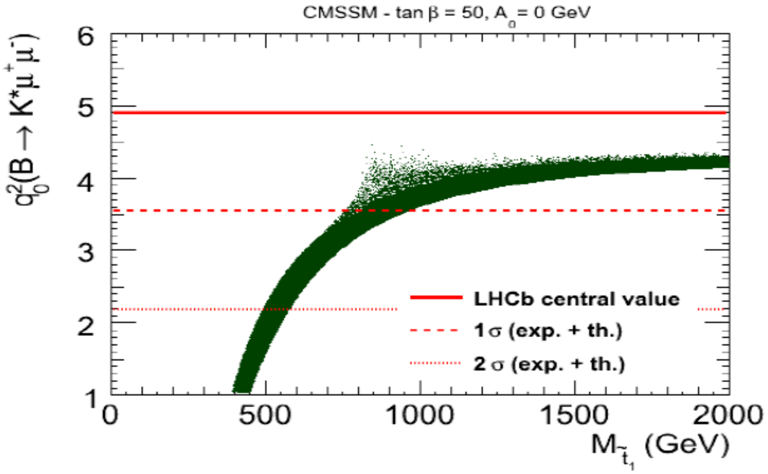
2010 data





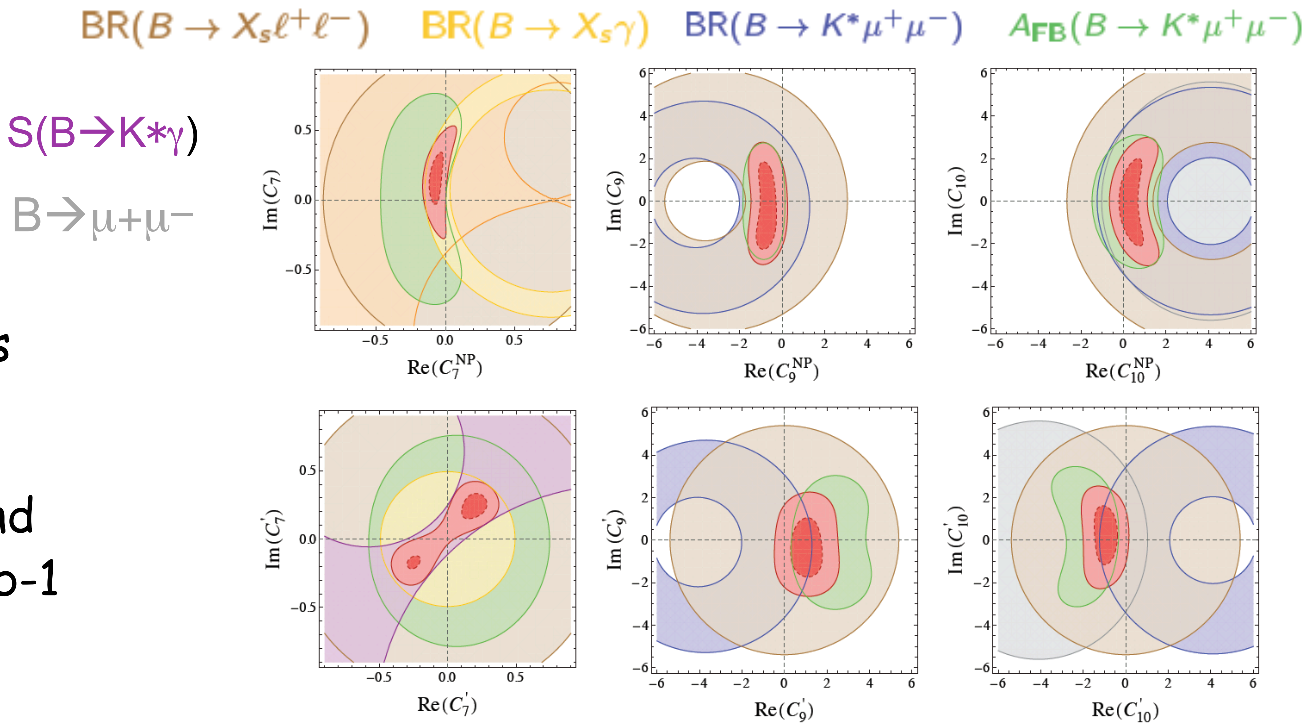
Hurth & Mahmoudi
arXiv:1211.6453





Model independent- generic- limits on NP through Wilson coeff's arXiv:1111.1257v2

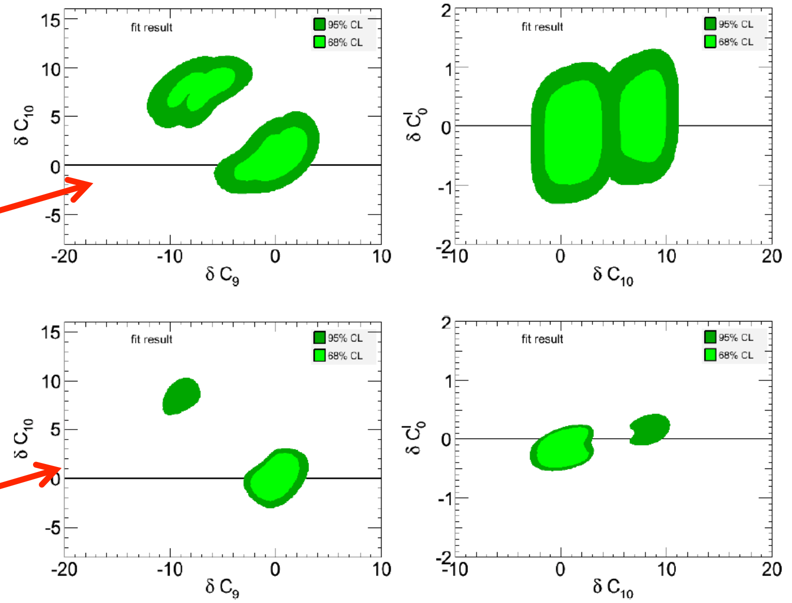
B factory, Tevatron and LHCb results w 0.37 fb-1



Hurth & Mahmoudi
arXiv:1211.6453
Global Fit to MFV

Pre- LHCb

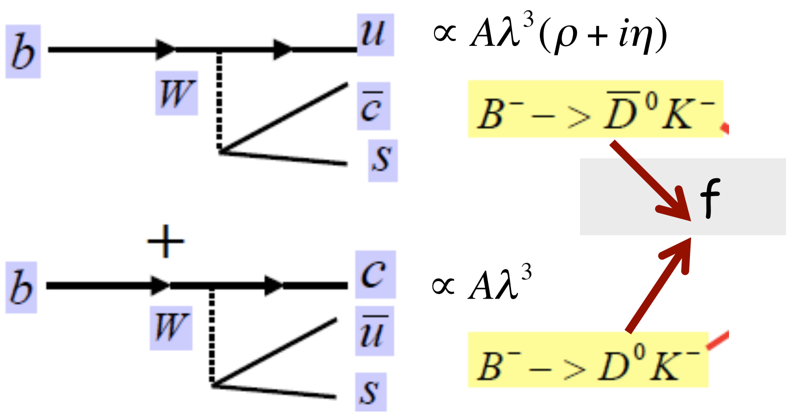
With LHCb data



Other Promising Channels in Flavor Physics

Measurement of CKM phase γ

γ is still relatively poorly measured
Critical to constraining NP through CKM parameters- measured with tree level processes

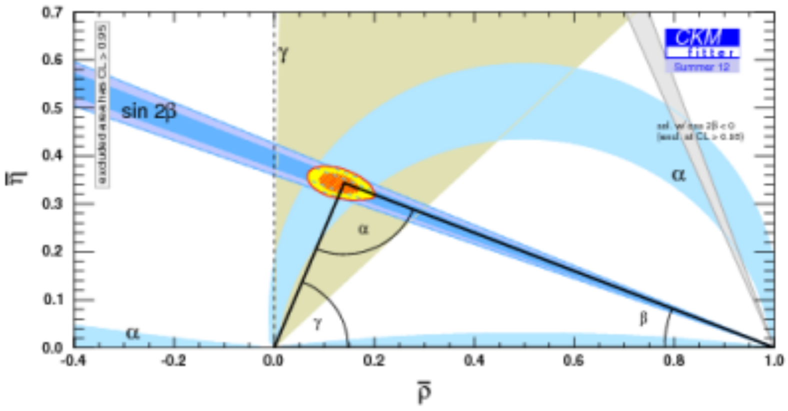


$\propto A\lambda^3(\rho + i\eta)$

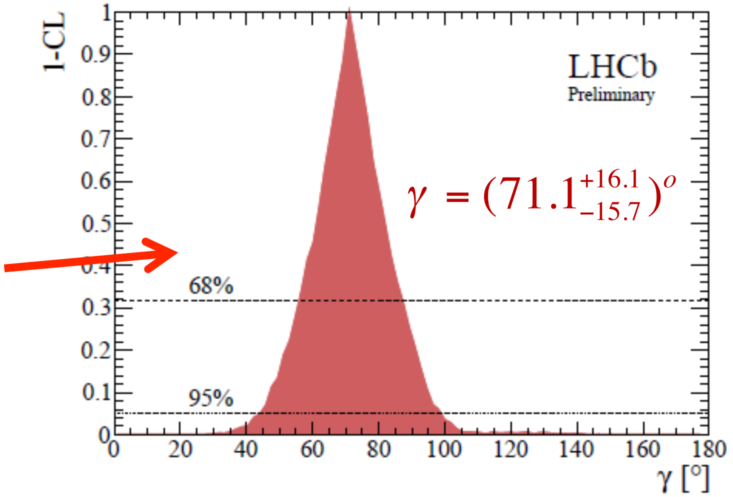
$B^- -> \overline{D}^0 K^-$

$\propto A\lambda^3$

$B^- -> D^0 K^-$



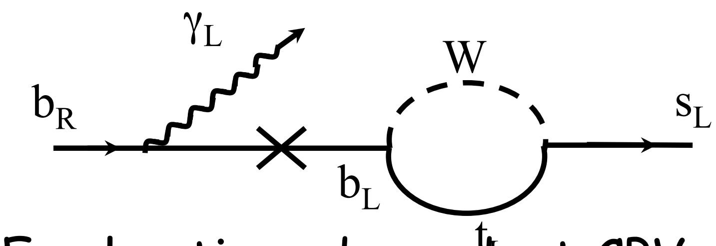
With 1/fb and combination of Methods (ADS, GLW, GGZK): LHCb finds:



- ➢Comparable to individual results of Babar and Belle
- ➢World average: γ = (66 ±12)°

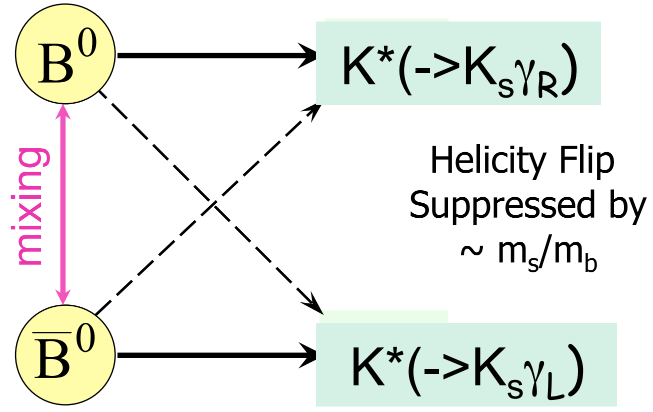
Future uncertainty with ~5/fb:
~4° (with B→DK) & ~11° (with B→DsK)

Probing right-handed currents with B→K*γ



γ polarization (left-handed in SM) serves as a probe of right-handed currents due to NP

Employ time-dependent CPV as a measure of photon helicity (Atoowd, Gronau, & Soni (1997)



Helicity Flip Suppressed by ~ m_s/m_b

$$A_{cp}(t)=\frac{\Gamma(\bar{B}^0(t)\to f_{cp}\gamma)-\Gamma(B^0(t)\to f_{cp}\gamma)}{\Gamma(\bar{B}^0(t)\to f_{cp}\gamma)+\Gamma(B^0(t)\to f_{cp}\gamma)}$$

$$= S_{f_{cp}\gamma}\sin\Delta m t - C_{f_{cp}\gamma}\cos\Delta m t$$

$$S_{K^*\gamma}\simeq\frac{2}{|C_7|^2+|C_7'|^2}\mathrm{Im}\left(e^{-2i\beta}C_7C_7'\right)$$

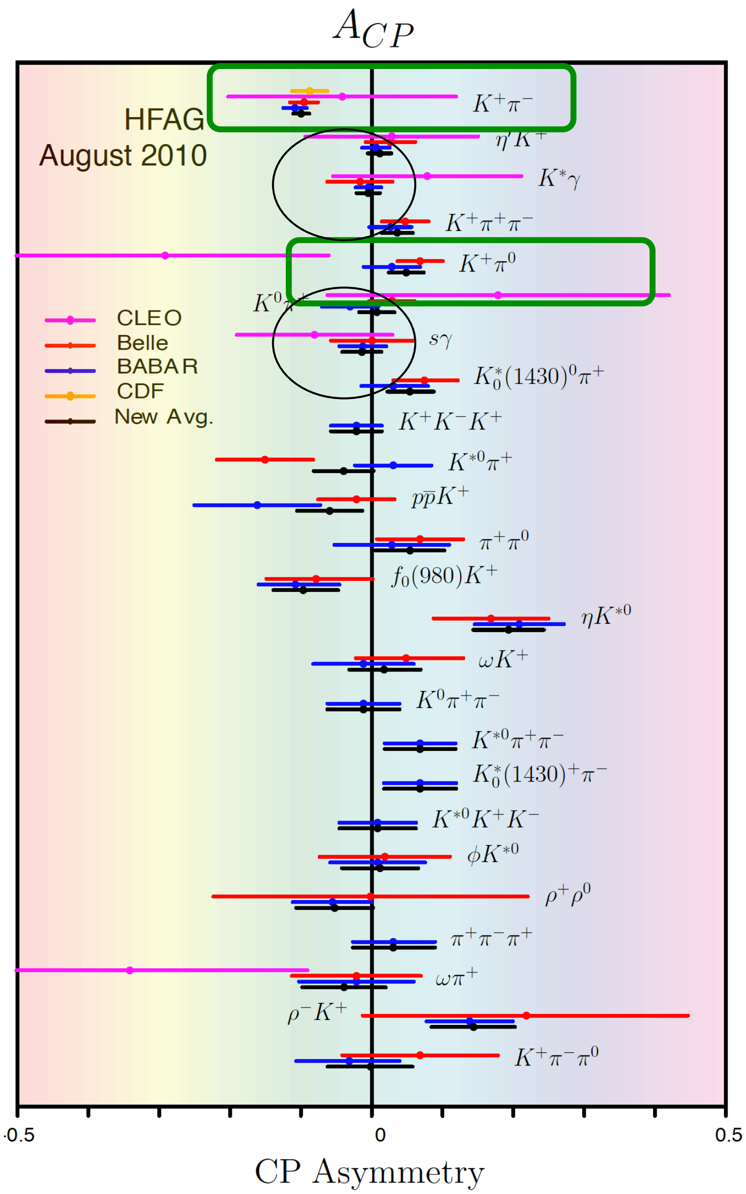
In SM: $\mathbf{S}_{\mathbf{K^*\gamma}}$ ~0.04

BaBar & Belle: $\mathbf{S}_{\mathbf{K^*\gamma}} = -0.16 \pm 0.22$

LHCb can also measure this effect in the B^0_s sector via: $B^0_s\to\phi\gamma$:
Signal detected; Expected sensitivity: ~ 0.09 (5/fb) & 0.02 (50/fb)
Other channels & approaches are also under study

Direct CP Violation in B decays

$$A_{CP} = \frac{\Gamma(B \to f) - \Gamma(\bar{B} \to \bar{f})}{\Gamma(B \to f) + \Gamma(\bar{B} \to \bar{f})}$$



LHCb confirmed some elements of the "B→Kpi puzzle": with 320/pb

$$A_{cp}(B^0 \to K^+\pi^-) = -0.085 \pm 0.011 \pm 0.008$$

$$A_{cp}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.08 \pm 0.02$$

With 320/pb at about the level of precision of previous results

World average

$$A_{cp}(B^0(\bar{b}d) \to K^+\pi^-) = -0.085 \pm 0.010$$

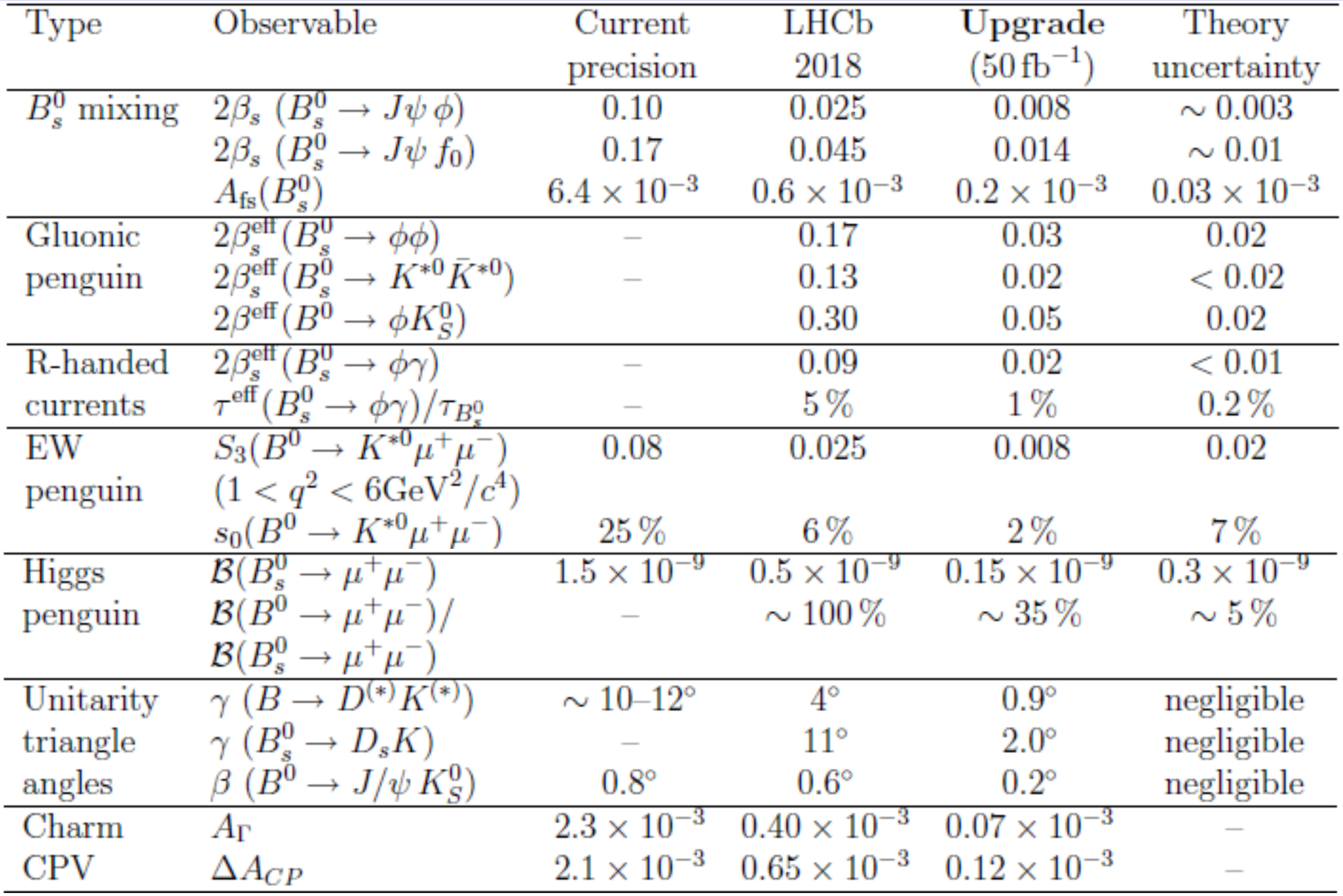
$$A_{CP}(B^+(\bar{b}u) \to K^+\pi^0) = +0.038 \pm 0.018$$

The "Kπ puzzle": changing the spectator quark leads to a drastic change in CPV asymmetry!

Also observed large CPV in 3-body B→hhh decays

Future of LHCb program

LHCb sensitivity to key flavour channels



Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J\psi\,\phi)$	0.10	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J\psi\, f_0)$	0.17	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3}	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$		0.30	0.05	0.02
R-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
EW penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-)$ $(1 < q^2 < 6\mathrm{GeV}^2/c^4)$	0.08	0.025	0.008	0.02
	$s_0(B^0 \to K^{*0}\mu^+\mu^-)$	25 %	6 %	2 %	7 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9}	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim$ 10–12°	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\, K_S^0)$	0.8°	0.6°	0.2°	negligible
Charm CPV	A_Γ	2.3×10^{-3}	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3}	0.65×10^{-3}	0.12×10^{-3}	–

- Unique potential B_s / b baryon sector

[LHCb-PUB-2012-009]

- Charged particle final states far in excess of other facilities

The LHCb upgrade

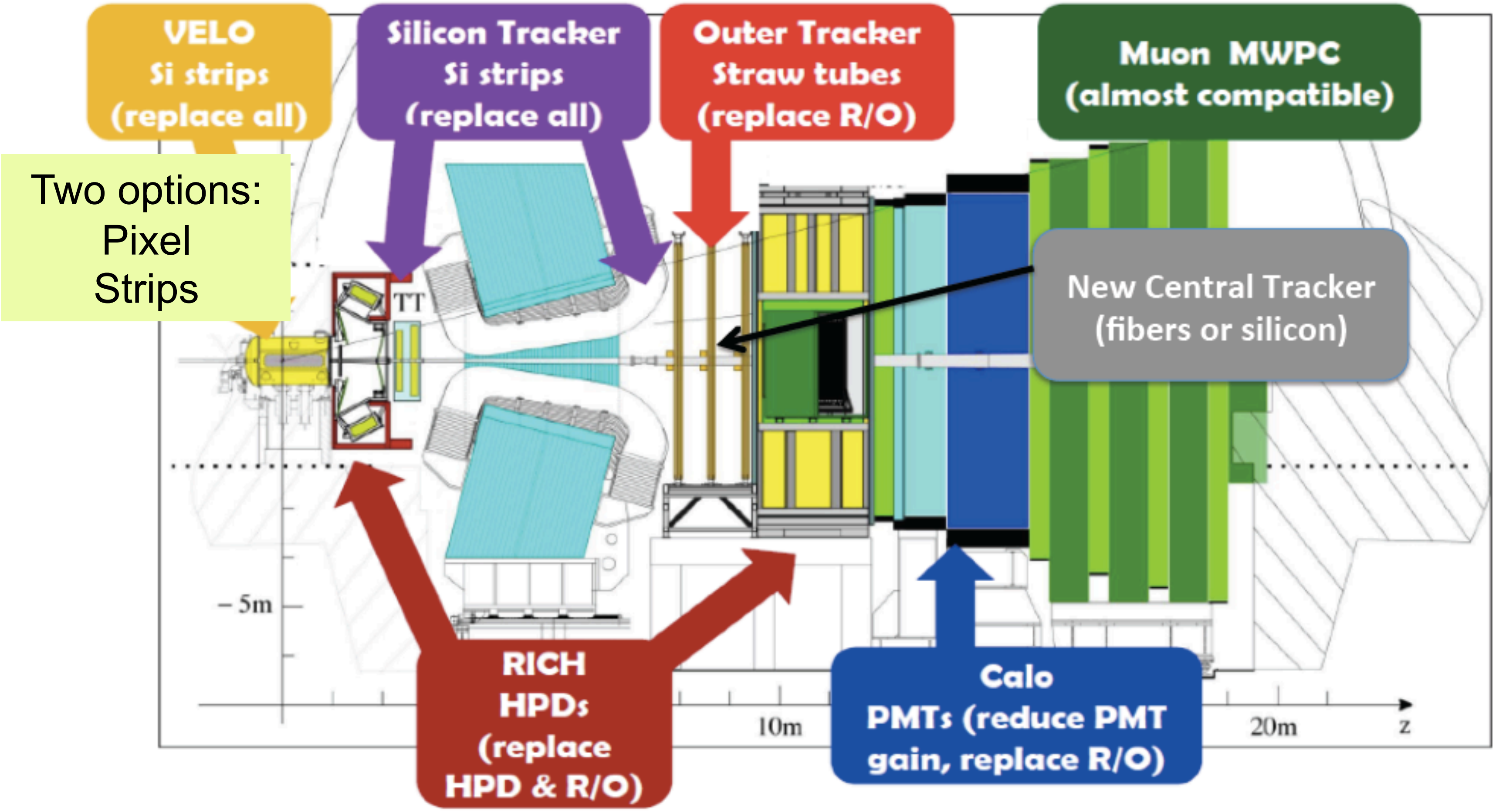
- Precision Flavor physics remains a major element of the quest for New Physics in the coming decades.
  - The LHCb sensitivity at 50 fb-1 will provide strong constraints on NP with the potential to reveal evidence for it.
  - The LHCb program with its unique capability in the B^0_s sector and and extremely high statistical power in key exclusive decays will remain complementary to future e+e- facilities.

- To reach the LHCb goal of 50 fb-1 in a reasonable time scale, the experiment must run at higher luminosity- aiming for 2×10^{33} $cm^{-2}s^{-1}$. This requires removing the current L0 trigger limit of 1 MHz, imposed by the front-end electronics.

  - ➢ Readout the detector at the 40 MHz LHC clock rate & implement a software trigger (HLT) running on reconstructed events.

  - ➢ This also provides significant flexibility; a gain of x10 for hadronic channels at 2×10^{33} $cm^{-2}s^{-1}$

LHCb detector modifications for the upgrade



VELO
Si strips
(replace all)

Two options:
Pixel
Strips

Silicon Tracker
Si strips
(replace all)

Outer Tracker
Straw tubes
(replace R/O)

Muon MWPC
(almost compatible)

New Central Tracker
(fibers or silicon)

RICH
HPDs
(replace HPD & R/O)

Calo
PMTs (reduce PMT gain, replace R/O)

All front-end electronics must be rebuilt to upgrade the output rate; chips imbedded in detectors & use of optical links to transfer the data.

Summary of major elements of LHCb Upgrade

- Replace Front-End Electronics & DAQ in most sub-detectors (Except Muon System)
- Replace Vertex Locator (VELO):
  - Improve occupancy & impact Parameter resolution, reduce ghost rate
  - Options: Pixel or Si-Strips
- Trackers:
  - Upstream Trigger Tracker (TT): Key to trigger, and ghost reduction
    - New Geometry, and thinner Si sensors
  - Downstream Tracker: reduce occupancy in inner region
  - Two options:
    - Replace Inner Si Tracker with increased area and lower mass
    - Or Sci-Fiber tracker
- Particle ID:RICH1 & RICH2
  - Replace HPD's with MaPMT & new readout
  - Other alternatives are also being considered.

P.Campana

The schedule of the LHCb upgrade

2013-14 Long Shutd. 1 / LHCb maintenance, first infrastructures for upgrade
2015-17 LHCb data taking (13-14 TeV) / 40 MHz protos in test
2018-19 Long Shutd. 2 / LHCb upgrade installation [Atlas/CMS upgrades phase 1]
≥ 2019 Upgraded LHCb in data taking (14 TeV)

- LHCb Upgrade preparation

2012-13 R&D, technological choices, preparation of subsystems TDRs
2014 Funding/Procurements
2015-19 Construction & installation

"Framework TDR for the Upgrade" submitted to LHCC and F. Agencies in June 2012

Two documents prepared for the European Strategy Group for Particle Physics:

- LHCb collab. – The LHCb Upgrade – LHCb-PUB-2012-008
- LHCb collab. & 40 theorists – Implications of LHCb measurements and future prospects - LHCb-PUB-2012-009

→ Very positive outcome for the LHCb Upgrade from ESPG Krakow meeting
→ The Upgrade has been endorsed (for approval) by the LHCC in September meeting

Summary

- LHCb has been running successfully at the LHC:
  - It operates at 4xdesign luminosity and higher interaction/crossing, with excellent detector performance- at about the design level.

- The current physics output has already left a major mark on the search for New Physics through rare flavor processes:
  - Obtained first evidence for $B^0_s \rightarrow \mu^+\mu^-$ - a major milestone in flavor physics
  - Has significantly constrained the parameter space of many NP scenarios.

- The LHCb- including the upgrade program- will remain a central element of the overall LHC program for NP search. (A message that has emerged from many studies, including last year's intensity frontier workshop).
  - Planning for LHCb upgrade is progressing well- now in R&D and design stage & funding planning.

- The US effort (mainly Syracuse, till recently) has had major impact on the program thus far. The recently strengthened group (4 institutions) is well placed, given their past experience, to continue significant participation in both the current program and its upgrade.